PROFESSIONAL PAPERS, No. 29

CORPS OF ENGINEERS, U. S. ARMY

Third (Revised) Edition

ENGINEER FIELD MANUAL

PARTS I-VI

I RECONNAISSANCE
II BRIDGES
III ROADS
IV RAILROADS
V FIELD FORTIFICATION
VI ANIMAL TRANSPORTATION

PREPARED UNDER THE DIRECTION OF THE

CHIEF OF ENGINEERS, U. S. ARMY

My Dear Karl—

I am sending you herewith, my copy of the Engineers Field Manuel, U S Army. There is a good deal in this book which you will not need in your job there but there are some things which cover some of the work you are on.

For instance under the subject of "Reconnaissance"

It teaches about the compass

Traversing — Page 42

The transit — Page 80

The Level — Page 84

Bridges — Page 147

Roads — " 249

I have another book which I will send to you as soon as I find it. I think it is a little more in detail on roads.

I am sending you $15.00 Karl.

I dont know whether you and Mary appreciate it but you are both spending more than we can afford. To give you an idea of what you are costing here is a statement of money I have giving and spent on you this month:

May 31 —— 25.00
June 18 —— 50.00
This check —— 15.–
$90.00

I cannot stand the pressure Karl. Not so far back, ~~you we~~ not so very long ago you were careful of your money but you have changed and are demanding more and more and spending with less regard to income than formerly. My income has not increased, I am saving nothing, but am spending more than my income. I have borrowed on my life insurance policies in order to get cash to pay my bills and meet the demands of yourself and Mary. When that money is spent I ~~to~~ will then have to discontinue ~~discontinue~~ carrying life insurance. I dont know whether you realize what ~~that~~ means and it occurs to me ~~th~~ at times that you and Mary dont care. If that is your attitude I will soon know and then will be obliged to change my policy.

I am asking you to be careful of your money save for the rainy day coming for I assure you it is coming fast

Please be careful of the ~~bo~~ books I send you I want them back

Lovingly

Guy.

PROFESSIONAL PAPERS OF THE CORPS OF ENGINEERS, U. S. ARMY

No. 29

ENGINEER FIELD MANUAL

PARTS I–VI

I. RECONNAISSANCE
II. BRIDGES
III. ROADS
IV. RAILROADS
V. FIELD FORTIFICATION
VI. ANIMAL TRANSPORTATION

PREPARED UNDER THE
DIRECTION OF THE CHIEF OF ENGINEERS, U. S. ARMY

THIRD (REVISED) EDITION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

WAR DEPARTMENT.

Document No. 355.

Office of the Chief of Engineers.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF STAFF,
Washington, November 19, 1909.

The Engineer Field Manual, United States Army, prepared under the direction of the Chief of Engineers, U. S. Army, is published for the information and guidance of all concerned; it will not be modified except by specific authority given in each case.

Any changes or suggestions that may occur to officers or others using the manual will be submitted to the Chief of Engineers for consideration in connection with the publication of future editions.

By order of the Secretary of War:

J. FRANKLIN BELL,
Major General,
Chief of Staff.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, March 12, 1907.

The Adjutant General.

SIR: 1. By authority of the Secretary of War, six parts of the Engineer Field Manual, compiled under the direction of this office by Lieut. Col. Smith S. Leach, Corps of Engineers and General Staff, have been published in five separate volumes. These parts are: Part I, Reconnaissance; Part II, Bridges; Part III, Roads; Part IV, Railroads, and Part V, Field Fortification (in one volume); and Part VI, Animal Transportation. Each of these six parts received the approval of the Chief of Staff before its publication.

2. It is now desired to publish under a single cover these six parts, revised and corrected, for issue to the service when ready for distribution.

3. In addition to the correction of such errors as have been discovered in the original editions, it is proposed to add some new matter to bring the work up to date. The most important addition is a description of the new types of instruments adopted in 1906. It is also desired to add, in Part I, a brief description of the new military survey of Cuba; some additional topographical signs and symbols recently prescribed by the General Staff, and a brief account of the new system of angular measurement in *mils* adopted for position finding by the Field Artillery; to incorporate, in Part II, a very useful table of dimensions of floor systems for stated loads and spans, and to incorporate, in Part V, a plate and description of the Fort Riley redoubt, which presents several excellent features of design. It is proposed to add the new matter at convenient places as nearly in its topical relation as possible, but under a caption "Addenda, 1907."

4. The mechanical work involved in the preparation and publication of this revised edition would be, roughly, as follows: Drawing and engraving of four or five plates; making of a consolidated index; composition of the equivalent of about three or four pages of text; composition of consolidated index (about 48 pages); electrotyping of new plates, new pages of text, and new index; repaging of Parts II to VI, both inclusive, and printing and binding of 1,000 copies of the complete work, the cover to have a pocket, a pencil tube, and a broad flap folding over the back. The manuscript of a proposed introduction and list of authorities is inclosed.

5. The matter in the six parts as now published is electrotyped; the electrotype plates are at the Government Printing Office. The expense of drawing and engraving the new plates, of preparing the new matter, and of making the consolidated index would be chargeable to the appropriation carried by the army appropriation act approved June 12, 1906, "For pontoon material, tools, instruments, and supplies required for use in the engineer equipment of troops, including the purchase and preparation of engineer manuals," of which there is an available balance sufficient for the purpose; the expense of composition, electrotyping, repaging existing electrotype plates, and of printing and binding to be borne by the appropriation for public printing and binding. The paper for the work is on hand in this office.

6. I have the honor to recommend that 1,000 copies of the revised edition of the six parts of the Engineer Field Manual, as hereinbefore described, and their accompanying plates be printed at the Government Printing Office and furnished for the use of this office on the usual requisition, the cost to be paid as stated in the preceding paragraph.

7. A copy of each of the parts as published is submitted herewith.

Very respectfully,

A. MACKENZIE,
Brig. Gen., Chief of Engineers,
U. S. Army.

ENGINEER FIELD MANUAL.

INTRODUCTION.

In April, 1899, the Chief of Engineers directed the Commandant of the Engineer School to enter upon the preparation of an Engineer Field Manual. At the same time all officers of the Engineer Corps who had been in the field during the Spanish war were invited to contribute data and suggestions, and many of them did so. At the Engineer School the work of compilation was committed to the instructor in civil engineering, then Capt. Henry Jervey, and under his control, and mostly by his own hand, a general plan of a manual was worked out, manuscript and plates prepared on the subjects of reconnaissance and bridges, and more or less complete notes on roads and railroads.

The instructions of the Chief of Engineers required a topical division and publication by parts, as completed. The part on reconnaissance was published in tentative form and distributed to officers of Engineers and other arms and to a few civil engineers, for comment and criticism. The parts on bridges and roads were sent in manuscript to certain Engineer officers for like criticism. As a result, the method of treatment of subject-matter and the mechanical features of the book were definitely determined and it was decided to revise the work already done to conform it to the modified plan and to republish Part I.

At this stage, 1903, the pressure of work at the Engineer School made it necessary to place this duty in other hands and it was devolved upon the commanding officer of the First Battalion of Engineers, and shortly thereafter the relation of that officer to the preparation of the manual was made personal, instead of ex-officio, and all subsequent work has been by the same hand.

By July 1, 1906, six parts had been published—reconnaissance, bridges, roads, railroads, field fortification, and animal transportation. These parts are now collected in a single cover, with corrections of errors which crept into the first edition and some additions of new matter which has become available since the first publication. The most important of these additions, made by direction of the Chief of Staff, is the incorporation of the signs, etc., for finished maps, published by authority of the Secretary of War in 1904. A few minor changes which have been approved, will be noted.

The opportunity now first offers to make acknowledgment of sources from which material has been drawn and of assistance rendered by persons in the preparation and publication of the manual.

As to authorities, a list is appended of works which have been consulted and from which facts or suggestions have been derived. Other works have been consulted, but nothing having been taken from or suggested by them, they are not mentioned. The titles in the list which appear in full-face type have been relied upon, more or less, as standard and as guides to topics and arrangement. But a single work seems to deserve further mention, and that is the incomparable Trautwine, the indebtedness to which is too obvious to require mention, but too important to permit it to be dispensed with. Substantially no matter from any source is quoted. The exigency of space required everything used to be rewritten with a view to condensation. In addition to the works cited, much valuable information, especially as to railroads and field fortifications, was obtained from the reports of military observers with the Japanese and Russian armies and from fugitive publications as to the war in Manchuria. Of the latter, the Journal of the Royal Engineers of Great Britain deserves special mention.

Personal assistance in the preparation of text has come exclusively from brother officers of the Corps of Engineers, with the single exception of "Landscape Sketching," paragraph 85, and plates 39 and 40, "Reconnaissance," which was abstracted from material furnished by Professor C. W. Larned of the Military Academy. In verifying, criticising, and correcting the work of the compiler, many officers have rendered assistance in greater or less degree, and none who have had opportunity to assist have refused. But a few have given so much of time and labor as to make

mention by name an act of simple justice. Lieutenant Colonel Abbot, who has handled the manual in the office of the Chief of Engineers during the entire period of preparation and publication, has contributed never-failing enthusiasm, encouragement, and counsel, which have been of the greatest possible assistance. Major Rees read critically the parts on reconnaissance, bridges, and roads. Major Sibert and Lieutenants Johnston and Spalding did the same for railroads. Captain Connor read the same part and forwarded a paper of his own on the subject, from which some suggestions were taken. Major Gaillard read the parts on field fortification and animal transportation and made valuable suggestions from personal experience with pack trains. Captain Cheney read the part on animal transportation and made valuable suggestions. This part was also read by Dr. Hunter, V. S., Sixth Cavalry, and Mr. Daly, chief packer, upon whose approval much of its value rests. The original drawings for Parts I and II were made by enlisted men of the Second Battalion of Engineers, under the supervision of Major Judson, instructor of military engineering at the Engineer School. The names of these men, unfortunately, have not been made of record. These drawings were revised and those for Parts III and VI made by Sergeant Pihlgrem, of the First Battalion of Engineers, assisted for a short time by Corporal Flugel of the same organization. The drawings for Parts IV and V and the Addenda were made by Mr. S. P. Hollingsworth, of Washington, D. C. The indexing, partial and consolidated, was done by Mr. G. T. Ritchie of the Library of Congress. Mr. Pickering Dodge, chief clerk, U. S. Engineer Office, Washington, D. C., contributed valuable assistance in final proof reading.

LIST OF BOOKS CONSULTED.

Theory and Practice of Surveying. Johnson.
Military Topography and Sketching. Root.
Tables and Formulæ. Lee.
Higher Surveying. Gillespie.
Roads and Railroads. Gillespie.
Engineer's Pocketbook Trautwine.
U. S. Bridge Equipage and Ponton Drill.
Military Bridges. Haupt.
Roads and Pavements. Baker.
Masonry Construction. Baker.
Highway Construction. Byrne.
Economic Railroad Location. Wellington.
Railroad Construction. Webb.
Notes on Track. Camp.
Railroad Curves. Allen.
The Railroad Spiral. Searles.
The Roadmaster's Assistant. Railroad Gazette.
Locomotive Breakdowns. Emergencies, and their Remedies. Fowler.
Text-book on Locomotives. International Correspondence Schools.
Train Rules and Train Dispatching. Dalby.
Block Signal Operation. Derr.
Letters of an Old Railway Official. Hine.
Manual of Field Engineering. Beach.
Field Fortification. Fieheger.
Manual of Military Engineering. Ernst.
Attack of Fortified Places. Mercur.
Royal Engineers Aide Memoire.
Handbook of Modern Explosives. Eissler.
Woolwich Text-book, Parts I and II.
Chatham Text-book, Parts II and III.
Text-book of Field Engineering. Phillips.
Field Fortification. Hutchinson.
British Manual of Field Engineering. 1903.
Destruction of Obstacles in Campaign. Bornecque, Tr. Burr.
U. S. Field Service Regulations.
Manual of the Quartermaster's Department, U. S. Army.
Horses, Saddles, and Bridles. Carter.
Packer's Manual. Daly.
Treatise on Feeding and Training of Mules. Riley.
Military Transport. Furse.

PART I.

RECONNAISSANCE.

PART I—RECONNAISSANCE.

1. **Topographical reconnaissance,** as here treated, includes suitable means for obtaining and recording all needful information of a terrain in the shortest possible time, and within the limits of accuracy required for the operations of troops in the field.

Also, the interpretation of a record when made, to determine from it the favorable or unfavorable effect of the terrain, for the purpose of directing military operations with reference thereto.

2. The information to be obtained in a topographical reconnaissance may be grouped under the headings of **time, cover, resources,** and **nomenclature.** The map should permit a determination of the time which a column will require to pass between any two given points by showing the distance between them and the condition of the road or country which must be traversed, as regards its effect on the rate of march; the accidents of ground which will afford cover to the army or to the enemy; the location, quantity, and quality of water, fuel, grass, etc., and should give to each feature its local name. The last requirement is of great importance and is the one most often neglected.

3. **The fundamental topographical operation** is the determination of the direction and distance of one point from another point.

The direction of one point from another is composed of two elements: First, the angle made by the line joining the two points, with a *vertical* plane passing through one of them. This angle is measured in a horizontal plane and is called the **azimuth;** second, the angle made by the line joining the two points, with a *horizontal* plane passing through one of them. This angle is measured in a vertical plane passing through both points, and for convenience will be called the **gradient.**

4. **Azimuths.**—As an infinite number of vertical planes may pass through a given point, it is necessary to select one as the origin of azimuths. In topographical reconnaissance the plane selected is that of the magnetic meridian at the point. Its direction *in a horizontal plane* is the line of rest of a freely suspended and balanced magnetic needle, and this line is the origin of azimuths.

From this origin azimuths are measured in degrees of arc from 0 to 360, passing from the north point through the east, south, and west to north again. Azimuths of 0° to 90° are in the northeast or first quadrant, fig. 1; those of 90° to 180° are in the southeast or second quadrant; those from 180° to 270° in the southwest or third quadrant, and those from 270° to 360° in the northwest or fourth quadrant.

Azimuths are bearings between stations taken in the direction of progress of the reconnaissance. Bearings taken in the other direction are called **back azimuths.** If the stations are numbered in the order they are occupied, a bearing from a lower to a higher numbered station is an azimuth, and a bearing from a higher to a lower numbered station is a back azimuth.

The method of stating azimuths described above is that commonly used in surveying when direction is maintained by **carrying an azimuth.** It is the simplest to understand and use, and permits the angle between any two lines to be read at a glance.

There are other ways of expressing azimuths, adapted to special conditions or circumstances. In astronomical work and tables the azimuth is reckoned from the **south,** through W., N., and E., 360° to south again. Any astronomical azimuth differs from the corresponding survey azimuth by 180°.

In navigation azimuths are reckoned from the **mariner's compass,** and are called **bearings.** The dial is divided into 32 **points** and each point into **quarter points.** The names of the points and their relation to survey azimuths are shown in fig. 1.

Land surveyors reckon bearings in both directions from N. and S. Their compasses are graduated 90° in each direction from the N. and S. points and a bearing is stated by giving the angle and direction from N. or S., whichever may be nearest, as N. 46° W., S. 29° E.

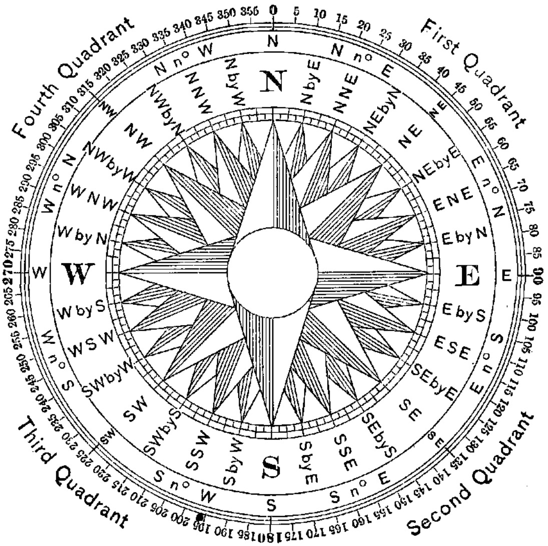


Fig. 1.

A Case
B Needle
C Card
D Pivot
E Stop

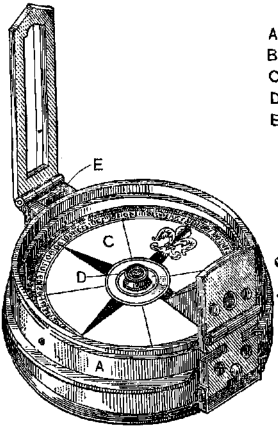


Fig. 3.

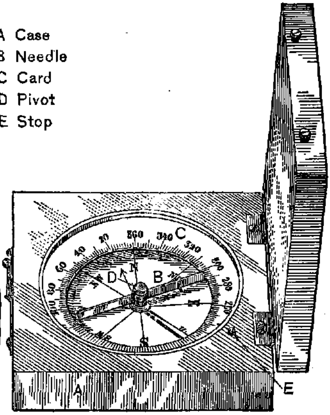


Fig. 2.

Formerly such bearings were reckoned from the nearest cardinal point, N., S., E., or W., as W. 44° N., which corresponds to N. 46° W. This method is very convenient for giving directions in orders and reports. It is shown in the middle circle of fig. 1. See par. 4a, p. 15.

5. The **compass** is the standard instrument for the determination of azimuths in topographical reconnaissance. It consists of *case*, *needle*, *card*, *pivot*, and *stop*, figs. 2 and 3.

The **card** may be **fixed** to the case or **movable**, attached to the needle and revolving with it. The stop raises the needle from the pivot and clamps it against the glass cover. A good compass must have a needle sufficiently magnetized to settle accurately and a pivot free from rust and roughness. If the needle becomes too weak, it may be remagnetized by rubbing gently from pivot to point on a permanent or electro magnet, each end of the needle to be rubbed on the pole which attracts it. In returning the needle for another stroke, carry it a foot or more from the magnet. The pivot may be polished with Putz pomade or similar substances on a soft stick.

If possible, however, turn in the defective compass and get a good one in place of it.

A needle loses part of its magnetism if kept for a long time out of the plane of the magnetic meridian. In storing a compass, care should be taken to place it in the case or on the shelf with the N. end of its needle pointing north.

6. **Dip.**—The earth's magnetic poles are beneath the surface, and the end of a symmetrical needle is drawn downward out of the horizontal plane so as to point to the nearest pole. This displacement from the horizontal plane is called **dip,** and is measured in degrees of arc. The dip increases generally with the latitude. Immediately over a magnetic pole the needle stands vertical, or has a dip of 90°. Near the equator, where north and south poles exert an equal influence, the needle may be horizontal, or the dip 0.

For reading azimuths the needle must be kept in a horizontal plane, which is done by a small movable counterweight. For considerable changes in latitude, as in passing from the United States to the Philippine Islands, the counterweight will require adjustment to keep the needle horizontal, and in passing from the northern to the southern hemisphere, the counterweight must be changed to the opposite side of the pivot.

7. There are **two adopted forms** of compass for topographical reconnaissance, one of the fixed and one of the movable card type.

The **box compass** is shown in fig. 2. The card is fixed and graduated counter-clockwise from N. 360° to N. again. The E. and W. points, if marked, are reversed. The stop is operated by opening and closing the lid. The lid is hinged parallel to the north and south line, and when open its upper edge forms a convenient line of sight. The needle when stationary can be read to the nearest degree by the eye, and to half a degree with a reading glass.

Another pattern which has been issued has the lid on an E. and W. side, and the sighting line is a fine line drawn across the lid.

Some of the box compasses in use are graduated **clockwise.** Care must be taken in using these. The true azimuth is 360° **minus** the reading of the needle. The actual reading of such a compass should never be recorded; the corresponding azimuth only should be set down. It will be safer to add a rough graduation in the proper direction.

8. The **prismatic compass** is shown in fig. 3. It is of the movable-card type. It is read through a reflecting inverting magnifying prism. The prism revolves on an axis and is over the circumference of the card for reading, and against the edge of the case for carrying. It slides up and down in the support which attaches it to the case, which motion permits it to be focussed on the scale. The focus for each observer should be determined when the compass is resting on a level surface, and not thereafter varied. If, when so adjusted, the scale is out of focus when the sight is taken, it shows that the card is not horizontal, and the case must be tilted until the scale comes into focus. The needle may be compensated for dip by a bit of sealing wax stuck on the underside of the card. The leaf sight folds down for carrying, and in so doing stops the needle.

In the pattern illustrated, the metal cover goes on outside the leaf sight when folded down. When the compass is used, the cover is removed and placed for convenience on the bottom of the case, where it fits closely. In another pattern, the metal cover has a window in it opposite the prism, and is not removed when sighting. The leaf sight folds down outside the cover and is not protected. See par. 8*a*, p. 15.

9. **Compass errors.**—The magnetic and true meridians generally do not coincide. The angle which the needle makes with the true north at any place is called the **declination of the needle,** or **magnetic declination** at that place. For latitudes of 60° and less the declination ordinarily varies between limits of 20° east and 20° west. For high latitudes the declination is greater and more irregular.

There are daily and secular variations of declination at every place, but they are too small to have any bearing on the class of work now under consideration, and for purposes of topographical reconnaissance the declination at any place may be considered constant for the period of the survey.

A close watch must be kept for the change in declination from place to place, and for local disturbances of the needle due to the proximity of magnetized substances, natural or artificial.

Change of declination or *normal* direction of the needle should be checked frequently. If a change is observed, it is certain to have taken place gradually, and, if desired, may be distributed among the courses run, though the change will seldom be great enough in a single day's work to make its distribution practicable.

Abnormal deflections of the needle, due to local disturbances, are sudden and erratic and should not be distributed among all the courses, but only among those in which there is reason to believe the disturbance occurs.

A simple way to detect—not measure—such disturbances is to take frequent back azimuths. If the position of the needle is normal at both stations, the azimuth and back azimuth will differ by 180°. If there is local attraction on the course, it will usually be stronger or cause a greater deflection at one station than at the other, and the azimuth and back azimuth will not differ by 180°.

Another way is, when taking the bearing to a station, to select a well-defined point beyond and on the same course. On arriving at the new station, take a bearing from there to the selected point ahead. If it is the same as the first bearing to that point, there probably is no local disturbance. If the two bearings to the same point differ, there probably is local disturbance.

A course in which local attraction is detected or suspected should be noted, and if, on closing, an azimuth correction is necessary, it should be applied to the suspected courses.

10. **Gradients.**—There can be but one horizontal plane through a given point, and it may be determined by the spirit level or plumb line without serious error. Gradients are measured by taking the angle of the line of direction with a horizontal line through the point.

11. Gradients are commonly called *grades* or *slopes* and are expressed in degrees, as 1°, 2°, 3½°, 6¼° slope, etc.

Each angle corresponds to two slopes, one up and one down from the initial point. Rising grades may be recorded with a + before, or an R after the number of degrees; falling grades with — before, or F after. On a map, general slopes are indicated by an arrow pointing in the direction of the drainage, with the gradient written beside it, thus $\xrightarrow{\quad 4^\circ \quad}$. Road grades are indicated by an arrowhead at top and bottom of the grade, the one at top pointing toward the road and the one at bottom away from it, thus ↓——— 4° ———↓.

Gradients are also expressed by the relation between the change of elevation—rise or fall—and the corresponding horizontal distance. This relation is stated in various ways.

By the rise in ft. per 100 ft. hor. or the ft. rise as a percentage, as "the slope is 4 in 100, or 4 per cent."

By the ft. rise for 1 mile of hor. distance; as "the grade is 50 ft.," or "a 50 ft. grade." This method and the preceding are commonly used for R. R. track grades.

By the number of ft. hor. corresponding to 1 ft. rise; as 3 **to** 1, 10 **to** 1. This method is commonly used for slopes of embankments and excavations when less than 45°.

By the ft. rise corresponding to 1 ft. hor.; as, 1 **on** 1, 6 **on** 1. This method is commonly used for slopes of embankments and excavations, etc., from 45 to 75 degrees.

By the number of inches hor. corresponding to 1 ft. rise; as, 3 ins. to the ft., 1 inch in the ft. This method is commonly used for gradients of 70 degrees and over, and is called *batter*.

ADDENDA, 1907.

4*a*. A special method of azimuth measurement has been adopted for use in the fire control of field artillery. The unit, called a **mil**, is the arc whose length is one one-thousandth of the radius. By computation this arc is 3′.437+. This length is not commensurate with the length of the circle being contained in it 6,283.24 times. For convenience of graduation, the circle is divided into 6,400 equal parts, assumed to be mils, the angular value of each of which is 3′.375, differing from the computed value by nearly 2 %, which error enters into all determinations and is neglected.

Each change of 1 mil in az. corresponds to a change in position in a direction perpendicular to the line of sight of one one-thousandth of the range. This method reduces all elements of fire control to functions of the range.

8*a*. The prismatic compass, model 1906, is shown in fig. 67c, p. 93. It differs from the types described in par. 8 in having the protective cover and leaf sight combined as shown in the figure. The inner glass cover of the full size of the case protects the card. The middle cover is hinged and the front sight is provided by a slit in the cover, in the middle of which is a thin metal strip. Holes and screws are provided to permit the convenient attachment of a wire or thread in case the sighting strip is broken.

13*a*. The clinometer level, model 1906, fig. 67b, differs from the type shown in fig. 4, in having a tangent screw, *A*, a reading glass, *B*, and in having supporting brackets in the angle between the top of the sight tube and the graduated arc to prevent the latter from being bent.

14*a*. The **gravity clinometer** adopted in 1906 is shown in fig. 67d. It consists of a circular case in which is a graduated circle controlled by a pendulum. The line of sight is through the peep *L* and a glass-covered opening at *M*. The zero line is engraved on the glass. A mirror near the center reflects the scale back to the peep. Looking through the instrument the object is seen on the zero line, and at one end of the latter a graduation of the scale is visible. The graduations are from zero at the horizontal each way to 45°, the graduations and numbers for elevation being in red and those for depression in black.

A sliding bar at *H* unlocks the spring-controlled stop, which, when pressed, frees the pendulum and graduated circle, and when released stops them again.

To use, move the locking bar *F* to free the stop *H*; hold the instrument in the left hand with the forefinger on the stop; depress stop; bring line of sight on object and read.

TABLE I.

12. **Comparison** of the **different methods** of expressing **gradients:**

In this table the different methods of expressing gradients have their values given for the usual range and to the customary degree of accuracy of their use.

Angle.	Ft. per 100 ft. hor., or %.	Ft. to the mile, hor.	1 vertical **on** or **in**—	1 horizontal **to**—	Batter **ins.** to the **foot.**
Degrees.			*Horizontal.*	*Vertical.*	
¼	0.44	23	229		
½	.87	46.1	115		
¾	1.31	69.1	76		
1	1.74	92.2	57		
1¼	2.18	115.1	46		
1½	2.62	138.3	38		
1¾	3.06	161.2	33		
2	3.49	184.4	29		
2½	4.37	230.5	23		
3	5.24	276.7	19		
3½	6.12	322.9	16		
4	6.99	369.2	14		
4½	7.87	415.5	13		
5	8.75	461.9	11.4		
6	10.51	555	9.5		
7	12.28		8.1		
8	14.05		7.1		
9	15.84		6.3		
10	17.63		5.7		
15			3.7		
20			2.7		
25			2.1		
30			1.7		
40			1.2		
45			1	1	
50				1.2	
60				1.7	
65				2.1	
70				2.7	
75				3.7	3¼
80				5.7	2⅛
81				6.3	1⅞
82				7.1	1¾
83				8.1	1⅜
84				9.5	1¼
85				11.4	1
85½				13	⅞
86				14	
86½				16	¾
87				19	⅝
87½				23	½
88				29	
88¼				33	⅜
88½				38	
88¾				46	¼
89				57	
89¼				76	
89½				115	⅛
89¾				229	

13. The **clinometer** is the instrument adopted for measuring gradients, with the horizontal plane indicated by a spirit level. It consists, fig. 4, of a sight-tube, *A*, with a graduated vertical arc, *B*, fastened to it, and a level-tube, *C*, with attached index arm, *D*, revolving about a horizontal axis through the center of the vertical arm. The base of the sight-tube is a plane parallel to the line of sight. Under the center of the level-tube is an opening in the sight-tube, inside of which is a mirror occupying one-half the width of the sight-tube and facing the eye end at an angle of 45° with the line of sight. A horizontal wire extends across the middle of the sight-tube in front of the mirror. When the bubble is brought to the center, its reflected image seen from the eye end appears to be bisected by the wire.

The central position of the bubble indicates that the level-tube is horizontal, and the reading of the index arm upon the arc is the angle between the axis of the level-tube and the line of sight. This reading should be 0° when these lines are parallel. The vertical arc is graduated each way from 0° at its middle point. The index arm has a double vernier whose smallest reading is 10′ of arc. Gradients of more than 15° are difficult to measure on account of the foreshortening of the level-tube as reflected in the mirror. See par. 13*a*, p. 15.

When the vernier is set at 0°, the instrument may be used as a hand level to locate points at the same elevation as the eye. The graduation on the inner edge of the vertical limb corresponds to the ordinary fractional method of indicating slopes, as 1 on 2, 1 on 10, etc. This scale should be read on the forward edge of the index arm, or in some forms on a special index mark on a shorter part of the arm.

The **level-tube is made parallel to the sight-tube** by the adjusting screws *E*, fig. 4. To test and correct the adjustment, place the instrument on a smooth surface, the more nearly horizontal the better, and mark carefully the position of one side and one end of the sight-tube. Center the bubble by moving the index arm, and read the vernier. Reverse the instrument, bringing the other side and end of the sight-tube to the marks. Center the bubble by moving the index arm, and read again. Note and record for each reading its direction from 0°, whether toward or away from the eye end of the sight-tube. Note and record also the location of the eye end in each position with respect to some fixed object, so that the instrument can be replaced in the first position or second position at will.

If the first and second readings are the same, the adjustment is correct. If they differ, take the mean of the two and set the vernier at that reading on the side corresponding to the first reading. Place the instrument in the first position and bring the bubble to the center by means of the adjusting screws *E*. For a check, set the same reading on the side corresponding to the second reading and place the instrument in the second position. The bubble should come to the middle.

14. The **determination of gradients by the plumb line** is quicker and simpler, but less precise than with the clinometer, though exact enough for ordinary purposes. If a line of sight be taken along the edge of a board and a line be drawn on the board perpendicular to the sighting edge, this line, when the board is held in a vertical plane, will make the same angle with the plumb line that the sighting edge makes with the horizontal, or, in other words, will indicate the gradient, fig. 5.

Such a construction is called a **slope board** and is readily improvised. The scale may be constructed by sweeping an arc of a circle *AB*, fig. 5, from the point *C*, at the intersection of the perpendicular and the sighting edge. From the perpendicular at *D* lay off each way on the arc chords equal in length to the radius *CD* divided by 57.3. It is convenient to take a radius of 5.73 ins., or $5\frac{3}{4}$ ins. scant, when the chords will be $\frac{1}{10}$ in., or a radius of $7\frac{3}{16}$ ins., when the chords will be $\frac{1}{8}$ in., accordingly as the scale used is graduated to 10ths or 8ths.

Short radial lines drawn at the ends of the chords form a graduation in degrees. The scale may be drawn on the lower edge of the board by prolonging the radial lines as indicated in the figure. The plumb line is suspended from the point *C*.

In use, the board is held so that the plumb line swings free but very close to the board. The sighting edge is directed to the object and when the line is steady the board is quickly tilted so that the line draws across the edge. The board is then turned to a horizontal position or nearly so, and the reading taken; or, when the line is steady, it may be pressed against the board with the finger and held in place until the reading is taken. With a straight scale and for steep grades, the latter method is better. See par. 14*a*, p. 15.

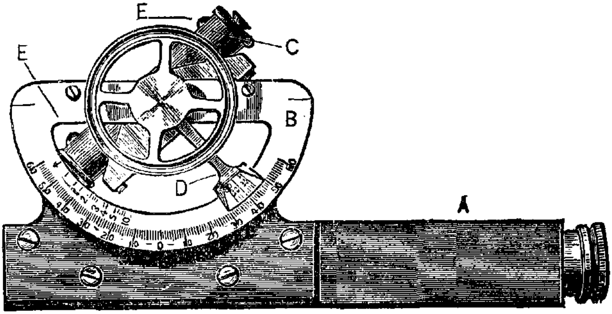


Fig. 4.

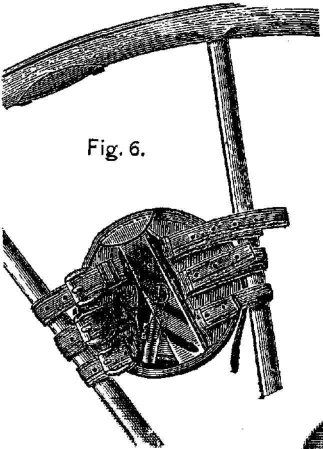


Fig. 6.

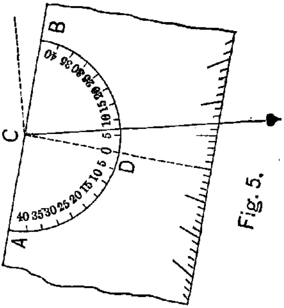


Fig. 5.

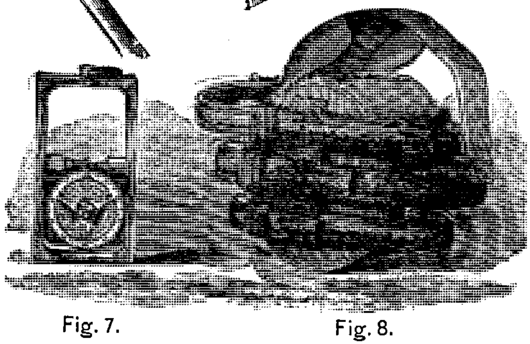


Fig. 7. Fig. 8.

15. **Elevations.**—From the **slope** and **distance** the elevation of a point above an assumed plane of reference may be derived. The **difference of height** of any two points is known by comparing their elevations above a common plane, called the **plane of reference**, or **datum.**

The plane of reference is taken low enough so that no point of the area to be covered by the reconnaissance will be below it. This makes all elevations positive. Knowing the height of a point above this plane of reference, the elevation of any other point may be obtained by taking the gradient and distance to that point, deriving from them the difference of height between the two points, and adding this difference to the elevation of the first point if the gradient is rising, or subtracting it if the gradient is falling.

The elevation for a given gradient and distance depends upon whether the distance is measured *along the gradient* or *along the horizontal.* Distances paced are along the gradient. Those measured with a chain will also usually be on the slope, though sometimes care is taken to hold the chain horizontal, in which case the table for horizontal distances is to be used. Those determined by intersections or scaled from a map are along the horizontal.

The differences of elevation corresponding to various gradients and any distances may be taken from the following tables.

TABLE II.

16. **Differences of elevation** for gradients of 0° to 30°, and horizontal distances.

Gradient in degrees.	Difference of elevation for horizontal distances of—								
	1.	2.	3.	4.	5.	6.	7.	8.	9.
½	00087	00174	00261	00348	00435	00522	00609	00696	00783
1	00174	00340	00523	00698	00872	01047	01221	01396	01570
1½	00262	00524	00786	01048	01310	01572	01834	02096	02358
2	00349	00698	01047	01396	01745	02094	02443	02792	03141
2½	00436	00872	01308	01744	02180	02616	03052	03488	03924
3	00524	01048	01572	02096	02620	03144	03668	04192	04716
4	00699	01398	02097	02797	03496	04195	04894	05594	06293
5	00875	01750	02625	03500	04375	05250	06125	07000	07875
6	01051	02102	03153	04204	05255	06306	07357	08408	09459
7	01228	02456	03684	04912	06140	07368	08596	09824	11052
8	01405	02810	04216	05621	07027	08432	09837	11243	12648
9	01584	03168	04752	06336	07920	09504	11088	12672	14256
10	01763	03526	05289	07053	08816	10579	12343	14106	15869
12	02125	04251	06376	08502	10628	12753	14879	17004	19130
14	02493	04986	07479	09973	12466	14059	17453	19946	22439
16	02867	05734	08602	11469	14337	17204	20071	22939	25806
18	03249	06498	09747	12996	16245	19494	22743	25992	29241
20	03639	07279	10919	14558	18198	21838	25477	29117	32757
22	04040	08080	12120	16161	20201	24241	28282	32322	36362
24	04452	08904	13356	17809	22261	26713	31166	35618	40070
26	04877	09754	14631	19509	24386	29263	34141	39018	43895
28	05317	10634	15951	21268	26585	31902	37219	42536	47853
30	05773	11547	17320	23094	28867	34641	40414	46188	51961

The diff. of elevation for *any* gradient and *any* hor. distance may be obtained by multiplying the dist. by the **tang.** of the angle or gradient, Table XIV.

TABLE III.

17. **Differences of elevation** for gradients of 0° to 30°, and distances measured on the slope.

Gradient in degrees.	Difference of elevation for sloping distances of—								
	1.	2.	3.	4.	5.	6.	7.	8.	9.
½	00087	00174	00262	00349	00436	00523	00611	00698	00785
1	00174	00349	00523	00698	00873	01047	01222	01396	01571
1½	00262	00523	00785	01047	01309	01571	01832	02094	02356
2	00349	00698	01047	01396	01745	02094	02443	02792	03141
2½	00436	00872	01308	01745	02181	02617	03053	03489	03926
3	00523	01047	01570	02093	02617	03140	03663	04187	04710
4	00697	01395	02093	02790	03488	04185	04883	05580	06278
5	00871	01743	02615	03486	04358	05229	06101	06972	07844
6	01045	02090	03136	04181	05226	06272	07317	08362	09407
7	01219	02437	03656	04875	06093	07312	08531	09749	10968
8	01392	02783	04175	05567	06959	08350	09742	11134	12525
9	01564	03129	04693	06257	07822	09386	10950	12515	14079
10	01736	03473	05209	06946	08682	10419	12155	13892	15628
12	02079	04158	06237	08316	10395	12475	14554	16633	18712
14	02419	04838	07258	09677	12096	14515	16934	19354	21773
16	02756	05513	08269	11025	13782	16538	19294	22051	24807
18	03090	06180	09270	12361	15451	18541	21631	24721	27811
20	03420	06840	10261	13681	17101	20521	23941	27362	30782
22	03746	07492	11238	14984	18730	22476	26222	29968	33714
24	04067	08135	12202	16269	20337	24404	28471	32539	36606
26	04384	08767	13151	17535	21918	26302	30686	35070	39453
28	04695	09389	14084	18779	23473	28168	32863	37558	42252
30	05000	10000	15000	20000	25000	30000	35000	40000	45000

The diff. of elevation for *any* sloping distance and *any* angle or gradient may be found by multiplying the dist. by the **sine** of the angle, Table XIV.

Explanation of use of Tables II and III:

Rule.—From the line of the given gradient, take out the tabular numbers corresponding to each of the figures of the given distance, *beginning* at the *right*, and set them down; each one place to the left of the one above it. Retain the ciphers at the beginning of the last tabular number taken out, if any. Other left-hand ciphers may be dropped.

Add the tabular numbers, and point off from the *left* the number of places equal to that of the left-hand figure of the distance, *counting any left-hand ciphers*. The result is the difference of elevation, in the same unit as the distance.

Examples.—For the diff. of elevation corresponding to a gradient of 3° and a distance of 6,273 ft., on the slope—

From Table III—

For 3 opp. 3° and under 3,	1570	
For 7 opp. 3° and under 7,	3663	
For 2 opp. 3° and under 2,	1047	
For 6 opp. 3° and under 6,	03140	retain leading cipher.
As 6 is in 4th place, point off 4,	0328.2900	
Diff. of elevation =	328.29 ft.	

2d. What diff. of elevation for gradient of 5°, and horizontal distance of 7,180.56 yds.?

From Table II—

Opp. 5° and under 6,	5250	
Opp. 5° and under 5,	4375	
Opp. 5° and under 8,	7000	
Opp. 5° and under 1,	875	
Opp. 5° and under 7,	06125	retain leading cipher.
7 is in 4th place, point off 4,	0628.299000	
Diff. of elevation =	628.299	yds.

18. **Barometric leveling.**—The weight of the atmosphere at sea level is 14.703 lbs. per sq. in., equal to the weight of a column of mercury 29.92 in. high, or a column of fresh water 34.7 ft. high.

The **aneroid barometer** records the pressure of the atmosphere in inches, the same as a mercurial barometer, the reading being taken from a pointer moving on a circular scale. It must be carefully handled as it is sensitive to shocks. A screw head will be seen through a hole in the back of the outer case by which the needle may be brought to any desired reading, and the instrument corrected whenever it can be compared with a standard. With the aneroid, corrections for instrumental temperature can not be made, and for this reason small pocket instruments are preferable, as carried in the pocket they are not exposed to so great changes in this respect.

The **pressure of the atmosphere varies** with the altitude above sea level, and it also varies with the moisture, temperature, and latitude, which do not depend upon the altitude.

In measuring altitudes with the barometer these other causes of variation must be eliminated so far as possible. It is best done by simultaneous observation at both stations. If the stations are not far apart all disturbing conditions will be substantially the same at each and therefore eliminated, except temperature, which, with considerable difference of altitude, will always be less at the upper than at the lower station.

If *simultaneous* observations *can not* be made, the stations should be occupied with as *little interval of time* between as possible, and better results will be obtained if the time of observation can be so chosen as to take advantage of calm, bright, dry weather.

When the hygrometric conditions are very uniform an aneroid read at intervals on a day's march over a rough country will give a fairly good idea of the profile.

TABLE IV.

19. **Table of elevations** above sea level from barometer readings (United States Coast and Geodetic Survey), for mean hygrometric conditions and mean temperature of 50° F.:

Barometer reading.	Altitude above sea level.	Diff. for 0.01″.	Barometer reading.	Altitude above sea level.	Diff. for 0.01″.	Barometer reading.	Altitude above sea level.	Diff. for 0.01″.
Inches.	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Feet.*
18.0	13,918	−15.1	22.2	8,204	−12.2	26.4	3,483	−10.3
.1	13,767	15.0	.3	8,082	12.2	.5	3,380	10.3
.2	13,617	14.9	.4	7,960	12.2	.6	3,277	10.2
.3	13,468	14.9	.5	7,838	12.1	.7	3,175	10.2
.4	13,319	14.7	.6	7,717	12.0	.8	3,073	10.1
.5	13,172	14.7	.7	7,597	12.0	.9	2,972	10.1
.6	13,025	14.6	.8	7,477	11.9	27.0	2,871	10.1
.7	12,879	14.6	.9	7,358	11.9	.1	2,770	10.0
.8	12,733	14.4	23.0	7,239	11.8	.2	2,670	10.0
.9	12,589	14.4	.1	7,121	11.7	.3	2,570	10.0
19.0	12,445	14.3	.2	7,004	11.7	.4	2,470	9.9
.1	12,302	14.2	.3	6,887	11.7	.5	2,371	9.9
.2	12,160	14.2	.4	6,770	11.6	.6	2,272	9.9
.3	12,018	14.1	.5	6,654	11.6	.7	2,173	9.9
.4	11,877	14.0	.6	6,538	11.5	.8	2,075	9.8
.5	11,737	13.9	.7	6,423	11.5	.9	1,977	9.8
.6	11,598	13.9	.8	6,308	11.4	28.0	1,880	9.7
.7	11,459	13.8	.9	6,194	11.4	.1	1,783	9.7
.8	11,321	13.7	24.0	6,080	11.3	.2	1,686	9.7
.9	11,184	13.7	.1	5,967	11.3	.3	1,589	9.7
20.0	11,047	13.6	.2	5,854	11.3	.4	1,493	9.6
.1	10,911	13.5	.3	5,741	11.2	.5	1,397	9.6
.2	10,776	13.4	.4	5,629	11.1	.6	1,302	9.5
.3	10,642	13.4	.5	5,518	11.1	.7	1,207	9.5
.4	10,508	13.3	.6	5,407	11.1	.8	1,112	9.5
.5	10,375	13.3	.7	5,296	11.0	.9	1,018	9.4
.6	10,242	13.2	.8	5,186	10.9	29.0	924	9.4
.7	10,110	13.1	.9	5,077	10.9	.1	830	9.4
.8	9,979	13.1	25.0	4,968	10.9	.2	736	9.3
.9	9,848	13.0	.1	4,859	10.8	.3	643	9.3
21.0	9,718	12.9	.2	4,751	10.8	.4	550	9.2
.1	9,589	12.9	.3	4,643	10.8	.5	458	9.2
.2	9,460	12.8	.4	4,535	10.7	.6	366	9.2
.3	9,332	12.8	.5	4,428	10.7	.7	274	9.2
.4	9,204	12.7	.6	4,321	10.6	.8	182	9.1
.5	9,077	12.6	.7	4,215	10.6	.9	91	9.1
.6	8,951	12.6	.8	4,109	10.5	30.0	00	9.1
.7	8,825	12.5	.9	4,004	10.5	.1	− 91	9.0
.8	8,700	12.5	26.0	3,899	10.5	.2	−181	9.0
.9	8,575	12.4	.1	3,794	10.4	.3	−271	9.0
22.0	8,451	12.4	.2	3,690	10.4	.4	−361	9.0
.1	8,327	12.3	.3	3,586	10.3	.5	−451	8.9

TABLE V.

20. **Coefficients for temperature correction.**—Argument $(t+t')$ = Sum of temperatures at the two stations:

$t+t'$.	Coefficient C.	$t+t'$.	Coefficient C.	$t+t'$.	Coefficient C.
°		°		°	
0	−0.1024	60	−0.0380	120	+0.0262
10	−0.0915	70	−0.0273	130	+0.0368
20	−0.0806	80	−0.0166	140	+0.0472
30	−0.0698	90	−0.0058	150	+0.0575
40	−0.0592	100	+0.0049	160	+0.0677
50	−0.0486	110	+0.0156	170	+0.0779
60	−0.0380	120	+0.0262	180	+0.0879

Examples:

Station.	Barometer.	Temperature.
	Inches.	°*F.*
Sacramento	30.014	59.9
Summit	23.288	42.1

From table of elevations .... Sacramento = −12.7
Summit = 6,901.0

Diff. = 6,913.7

$t+t' = 102°$
$\therefore C = +0.0070$
$\therefore$ Temperature correction, 6,913.7 × 0.007 = +48.4

H = 6,962.1 feet.

Station.	Barometer.	Temperature.
	Inches.	°*F.*
Lower	28.075	57.3
Upper	22.476	38.5

From table of elevations .... Lower = 7,867.0
Upper = 1,807.0

Diff. = 6,060.0

$t+t' = 95°.08$
$\therefore C = +0.0004$
. . Temperature correction, 6,060 × 0.0004 = +2.4

H = 6,062.4 feet.

21. **Use of compasses.**—A good needle requires time to settle even when the case is firmly supported, and the user should cultivate the knack of catching it at the middle of its swing, which is the desired reading. If the compass can be supported, it is always better to do so. Then the sight can be carefully taken and the position of the eye changed to read the needle. Wait till the swing gets down to 4° or 5°, which it will usually do in a few seconds. Then catch the highest and the lowest readings on the same swing and take their mean for the true reading. If the first swings are very large, catch the needle with the stop near the middle of the swing and release it quickly. This will suddenly check the swings and shorten the time in which the reading can be taken.

In using the box compass without a support, hold it sufficiently below the eye so that the swing of the needle can be seen. Point the edge of the lid in the required direction, catch the needle with the stop in the middle of a swing and hold it stopped until the reading is taken. Stop readings are less accurate than sight readings, as the needle may be displaced slightly when off the pivot. When the stop is used press it quickly and firmly. Always sight a *fixed-card* compass from the south end of the card and read the north end of the needle.

With the prismatic compass the stop is not used except to check the swings. Utilize a support if practicable. The prism having been adjusted for focus, as already explained, par. 8, adjust the case so as to bring the scale into focus, and when the swings become small, read the extremes and take the mean.

Compasses for night marching are on the market, but are not very reliable. They have the dial rendered luminous by a paint. After exposure to the sun or strong daylight, they give off light, at first rather strong, but rapidly diminishing in intensity. After a few hours they are not bright enough to be of much use.

The surest preparation for night marching is a provision for illuminating the compass by ordinary means without allowing the light to be seen.

22. **To determine the declination of the compass:**

1st method; from the sun.—Prick a small hole in a piece of tin or opaque paper and fix securely over the south edge of a table or other surface perfectly level, so that the sunlight coming through the hole will fall on a convenient place on the surface, fig. 9. The hole may be 2 ft. above the table for long days and 18 ins. for short ones. Half an hour before to half an hour after noon, mark the position of the spot of sunlight on the horizontal surface at equal time intervals of about 10 min. Draw a curve as *bd*, fig. 9, through the points marked, and from point *c* in the horizontal surface and in a vertical line with the hole *a* sweep an arc *ef* intersecting *bd* in two points. The line *cg*, drawn from *c* through a point on the arc midway between the intersections, is the true meridian. The line *bd* illustrates the method merely. Its form varies with the sun's declination.

2d method; from the sun or a star.—Observe the magnetic bearing of the sun, a planet, or a bright star at rising and setting on the same day, or at setting on one day and at rising on the next. Take the difference between the sum of the rising and setting azimuths and 360°. One-half of this difference is the declination of the compass or variation of the needle, *east* if the sum of the azimuths is *less* than 360°; *west*, if it is *greater*. **In using this method**, the observations are better taken when the object is just above the true horizon, or at a gradient of zero. This can usually be done if a high point is chosen for the observations. **If it can not be done,** be careful to take both observations with the object at the same gradient. **This is most important with the sun.** Under the least favorable conditions, an inequality of 1° in the gradients at the times of observation on the sun may introduce an error of ½° in the result. If using a star, choose one which rises nearly east from the point of observation, and the inequality of a degree in gradients will not be material.

The change in declination of the sun between observations can not affect the result more than ⅛°.

Both observations need not be made at the same point, but should not be more than 10 miles apart in east and west, or north and south directions.

The *two foregoing methods* are applicable in the *northern* or *southern* hemisphere.

3d method; from Polaris.—The true north pole is about 1° 12′ distant from Polaris on a line joining that star with one in the handle of the dipper, and another in Cas-

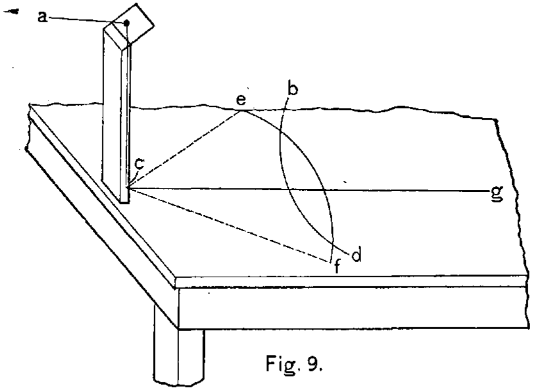


Fig. 9.

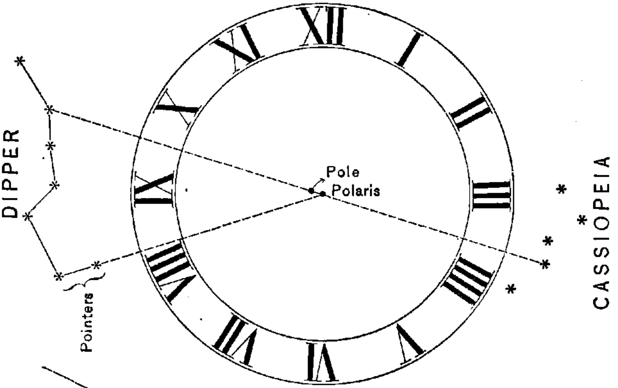


Fig. 10.

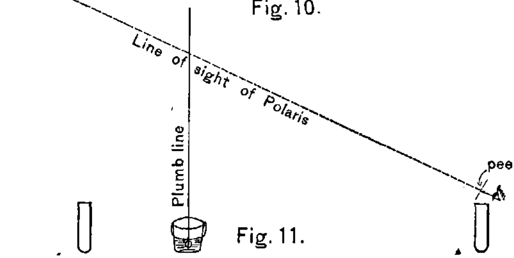


Fig. 11.

siopeia's Chair, fig. 10. One of these stars can be seen whenever Polaris is visible. The polar distance of Polaris is decreasing at the rate of 19″ a year. It also varies during the year by as much as 1′. The latter variation may be neglected, and the former also for a series of years.

Imagine Polaris to be the center of a clock dial, with the line joining 12 and 6 o'clock vertical and with the position of one of the lines described considered as the hour hand of the clock. The distance in azimuth of Polaris from the true north may be taken from the following table:

TABLE VI.

23. **Table showing the azimuths of Polaris** in different positions with respect to the pole. Epoch 1911; polar distance 70′. Latitude 0° to 18° north. This table may be used until 1930.

Clock reading of—		Azimuth of Polaris.	Clock reading of—		Azimuth of Polaris.	Clock reading of—		Azimuth of Polaris.
δ Cass.	Z Ursae Maj.		δ Cass.	Z Ursae Maj.		δ Cass.	Z Ursae Maj.	
		′			° ′			° ′
XII:30	VI:30	18	IIII:30	X:30	49	VIII	II	358 59
I	VII	35	V	XI	35	IX	III	358 50
I:30	VII:30	49	V:30	XI:30	18	X	IIII	358 59
II	VIII	61	VI:30	XII:30	359 42	X:30	IIII:30	359 11
III	IX	70	VII	I	359 25	XI	V	359 25
IIII	X	61	VII:30	I:30	359 11	XI:30	V:30	359 42

For higher latitudes add to the small azimuths or subtract from the large ones, as follows:

Lat. 19°—30°, $\frac{1}{10}$.
Lat. 31°—37°, $\frac{2}{10}$.
Lat. 38°—42°, $\frac{3}{10}$.
Lat. 43°—46°, $\frac{4}{10}$.
Lat. 47°—50°, $\frac{5}{10}$.
Lat. 51°—53°, $\frac{6}{10}$.
Lat. 56°—57°, $\frac{7}{10}$.
Lat. 58°—59°, $\frac{8}{10}$.
Lat. 60°—61°, $\frac{9}{10}$.

It is well to keep track of the position of Polaris by noting it frequently and taking the corresponding clock time. Then if on a cloudy night a glimpse of Polaris is had, the observation may be taken even though the other stars can not be seen.

24. **For practical details of the observation,** the following may serve as a guide: Select a clear space of level ground not too near buildings or any object which might cause local disturbance of the needle. Drive a picket, leaving its top smooth and level, about 18 ins. above the ground. Six feet north of the picket suspend a plumb line from a point high enough so that Polaris, seen from the top of the picket, will be near the top of the line, fig. 11. The line should be hard and smooth, about $\frac{1}{10}$ in. diam. The weight at the bottom of the line should hang in a vessel of water or in a hole dug in the ground to lessen its vibration. Drive a second picket in range with the first one and the plumb line, a short distance north of the latter. Make a peep sight by punching a hole about $\frac{1}{10}$ in. diam. in a piece of paper and hold it on the top of the first picket; adjust it so that the star is behind the plumb line when looking through the peep. Note the position of one of the stars on the imaginary clock face at the moment the observation is taken. Mark the position of the peep on the top of the first picket, and lay a straightedge or stretch a line from that point touching the plumb line to the second picket. Place the north-and-south edge of the compass box against the line or straightedge, and read the needle. Find the azimuth of the star at the time of observation from Table VI.

If the **az. of Polaris** (Table VI) and the **reading of the needle** are **both less** or **both greater** than 180°, their **diff.** is the **declination; east** if the **needle** reading is **less, west** if it is **greater.** If one of these quantities is **less** and the other **greater** than 180°, add 360° to the lesser and take the diff. which is the declination; **east** if after the addition is made the **needle** reading is **less, west** if it is **greater** than the tabulated az.

This method will give results true to within ¼°.

25. **Distances** passed over are ordinarily measured by the stride of a man or a horse, or by the revolutions of a wheel. Distances not passed over are determined by intersection, or are estimated.

Pacing on foot.—The length of a man's pace at a natural walk is about 30 ins., varying somewhat above and below. Each sketcher must determine his own length of pace by walking several times over a known distance. An unnatural stride should never be taken. Knowing the length of a pace or step, the measurement of a distance is only a matter of counting steps. The counting may be done mentally, and with practice becomes a subconscious operation, leaving the attention free to take note of surrounding objects and conditions. The greatest danger is of dropping one hundred paces. It is better to keep a tally of the hundreds. See par. 25*a*, below.

On level ground, careful pacing will give distances correct to 3% or less. The normal length of pace decreases on slopes. The decrease varies with the slope and with the direction, whether ascending or descending. The following table gives the length of pace on slopes of 5° to 30°, corresponding to a normal pace on a level of 30.4 ins.

TABLE VII.

Slopes.	0°	5°	10°	15°	20°	25°	30°
Length of step ascending	30.4	27.6	24.4	22.1	19.7	17.8	15.0
Length of step descending	30.4	29.2	28.3	27.6	26.4	23.6	19.7

For the same person, the length of step usually decreases with fatigue. Sketchers should test their pace when fresh and when tired, and if there is an appreciable difference, use one length for the morning and the other length for the afternoon work.

26. A distance on a slope measured by foot pacing may be reduced to the correct horizontal distance for plotting on the map by the following table, which takes account of the decrease in length of pace, Table VII, and also of the reduction to the horizontal, Table XII. This table can be used only when the length of pace has been determined on level ground, which should usually be done. When a considerable stretch of road is found with fairly uniform slopes, a special average rating may be made over a distance involving a fairly representative range of slopes and this *average rating* may be used without reduction.

ADDENDA, 1907.

25*a*. A pace tally is issued for use when desired. It is the size and shape of an ordinary watch.

28*a*. The most convenient timer for mounted pacing is the type known as the football watch. It has a stop and start arrangement independent of the fly back and gives a cumulative record of the times in motion.

TABLE VIII.

27. **Reduction to horizontal** of distances paced on different slopes, ascending and descending:

Number of paces measured on the slope.	Equivalent number of paces on horizontal, for slopes of—											
	5°		10°		15°		20°		25°		30°	
	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.
100	090.4	095.6	078.7	091.5	069.3	087.4	058.8	080.8	049.1	068.2	035.8	051.4
110	099.4	105.0	086.6	101.0	076.2	096.1	064.7	088.9	054.0	075.0	039.4	056.5
120	108.4	114.7	094.4	109.8	083.2	104.9	070.6	097.0	058.9	081.8	043.0	061.7
130	117.5	124.3	102.3	119.0	090.1	113.6	076.4	105.0	063.8	088.7	046.5	066.8
140	126.6	133.8	110.2	128.1	097.0	122.4	082.3	113.1	068.7	095.5	050.1	072.0
150	135.6	143.4	118.1	137.3	104.0	131.1	088.2	121.2	073.7	102.3	053.7	077.1
160	144.6	153.0	125.9	146.4	110.9	139.8	094.1	129.3	078.6	109.1	057.3	082.2
170	153.7	162.5	133.8	155.6	117.8	148.6	100.0	137.4	083.5	115.9	060.9	087.4
180	162.7	172.1	141.7	164.7	124.7	157.3	105.8	145.4	088.4	122.8	064.4	092.5
190	171.8	181.6	149.5	173.9	131.7	166.1	111.7	153.5	093.3	129.6	068.0	097.7
200	180.8	191.2	157.4	183.0	138.6	174.8	117.6	161.6	098.2	136.4	071.6	102.8
300	271.2	286.8	236.1	274.5	207.9	262.2	176.4	242.4	147.3	204.6	107.4	154.2
400	361.6	382.4	314.8	366.0	277.2	349.6	235.2	323.2	196.4	272.8	143.2	205.6
500	452.0	478.0	394.5	457.5	346.5	437.0	294.0	404.0	245.5	341.0	179.0	257.0
600	542.4	573.6	472.2	549.0	415.8	524.4	352.8	484.8	294.6	409.2	214.8	308.4
700	632.8	669.2	550.9	640.5	485.1	611.8	411.6	565.6	343.7	477.4	250.6	359.8
800	723.2	764.8	629.6	732.0	554.4	699.2	470.4	646.4	392.8	545.6	286.4	411.2
900	813.6	860.4	708.3	823.5	623.7	786.6	529.2	727.2	441.9	613.8	322.2	462.6

Table VIII gives directly the horizontal equivalents of the distances usually occurring in foot pacing. If desired, other distances may be obtained by combinations.

From 1 to 9, take the first figure, left-hand cipher included, of 100 to 900 for the whole number and the second figure for the tenths.

From 10 to 90, take the first two figures, left-hand ciphers included, of 100 to 900 for the whole number and the third figure for tenths.

For 290 take 100 + 190; for 440 take 140 + 300, etc.

Example: For the horizontal equivalent of 738 paces on a 5° rising slope,

$$700 + 30 + 8 = 632.8 + 27.1 + 7.2 = 667.1.$$

28. **Pacing mounted.**—The *average walk* of a horse is a mile in 16 mins., or 3¾ miles per hour, making 120 steps, covering 110 yds. per min., the step being 0.916 of a yd., or 33 ins.

The *average trot* is a mile in 8 mins., or 7½ miles an hour, making 180 steps, covering 220 yds. per min., the length of step being 1.22 yds. or 44 ins.

It will **generally be found more convenient** in pacing, both on foot and mounted, to count the steps of one foot only, and multiply the number counted by the stride of one foot, which is twice the length of step given above. In this case, the number counted is doubled for use with the tables and scales given herein.

Timing.—Counting the steps of a horse diverts the attention more than is desirable, and it is better to determine distances in mounted reconnaissance from the times occupied by the horse in passing over them. The rating is done by ascertaining the time required to pass over a known distance. Time and step ratings should be taken together by counting and timing at once. Ratings should be taken before the reconnaissance, if possible, but for short stretches of hasty work, the averages given above may be used without serious error. See par. 28*a*, p. 27.

Horses travel better in pairs, and two men should be sent out together, one to do the sketching and the other to give his entire attention to taking the time and keeping his horse at a regular gait. It is better to rate the pairs together. If it has not been done, take the rate of the timer's horse.

When a sketcher is traveling with a party and must keep their gait, an occasional count of his horse's steps for a minute or two will give a special scale for use in plotting.

29. The **speed** of a horse over road grades, even in moderately hilly countries, is not affected by the slope sufficiently to make an allowance necessary. Distances up and down grades measured by timing in mounted reconnaissance will require no correction except that to the horizontal, Table XII, which may be applied if the slopes exceed 5° or 6°. This statement **does not apply** to distances measured by mounted pacing or counting the steps of a horse.

30. **The walk is the normal gait for reconnaissance.**—If greater speed is necessary, the timer may go on while the sketcher is taking angles and plotting; the latter taking the trot or the gallop and overtaking the timer just before he reaches the next station. This method should be used only when the required distance can not be covered at a walk.

If circumstances require short distances to be covered at a trot or gallop, the times may be reduced to walking time by multiplying by 2 for the trot and 3 for the gallop.

31. The **odometer** is an instrument for recording the number of revolutions of a wheel. The adopted form is in a leather case, 4½ ins. in diameter by 2½ ins. thick, figs. 6, 7, and 8. It is attached by straps to the front wheel of a wagon, fig. 6. To read, the case is opened, the registering train, fig. 7, withdrawn, and the number of revolutions read from the scale. Multiply the diameter of the wheel by 3.1416 for the circumference; multiply the circumference by the number of revolutions for the distance traveled by the wagon.

The bearings of the odometer must be kept free from grit and may be oiled with fine oil used sparingly; gummy oils or grease must not be used. If good oil is not to be had, rub the bearings with a soft lead pencil.

Odometer readings are valuable as a rough check on a day's march. They are not accurate, but are free from large errors. Two instruments on the same wagon will not always agree. On heavy roads, mud or sand, there is a slip, sometimes positive and sometimes negative.

TABLE IX.

32. **Number of revolutions** per mile, of **odometers** attached to wheels 36 ins. to 48 ins. diam.:

Diam. of wheel:	Revolutions.
36 inches	560.2
37 inches	545.1
38 inches	530.7
39 inches	517.1
40 inches	504.2
41 inches	491.1
42 inches	480.2
43 inches	469.0
44 inches	458.4
45 inches	448.2
46 inches	438.4
47 inches	429.1
48 inches	420.2

Sizes of wheels of some military wagons: Ambulance, $36\frac{1}{2}$ ins.; ponton (light) tool and chess, $42\frac{5}{8}$ ins.; escort, $44\frac{3}{4}$ ins.; ponton (heavy) 45 ins.; army six, $47\frac{1}{8}$ ins.

33. **Estimation of distances** is a knack which may be cultivated by practice to a degree of accuracy far beyond that which is at first attainable, and quite sufficient for the location of many objects off the traverse line. Short distances are more closely estimated than longer ones; those on a level, than those up or down hill. When the intermediate ground can be seen, the estimation will be closer than when it can not.

A *rough estimate* of distance may be made from the velocity of sound, as by knowing the time that elapses between seeing and hearing the discharge of a gun, or the fall of an ax. Note the time in seconds and multiply by 400 for the distance in yds.

Distances across water are usually underestimated. The distance of the visible horizon on water in *miles* is $1.225\sqrt{H}$; H being the height of the observer above the water surface in feet.

A cartridge or other small heavy object fastened to a string 10 ins. long and allowed to swing through a small angle or arc will beat half seconds approximately.

34. **The location of a point by intersection** is done by taking azimuths to it from two known points. As each of these azimuths when plotted must pass through the unknown point, it must be at their intersection.

An observer at an unknown point may locate himself from two visible known points by taking an azimuth to each. From the known points plot the corresponding *back azimuths* and they will intersect at the point of observation. This process is called **resection.** It is subject to errors of local attraction. (Par. 9.)

The accuracy of a location by intersection is affected by the relation of the azimuths and of the distances. The greatest accuracy results when the azimuths differ by 90° or 270° and the distances are equal; in which case the two azimuths and the base form a right-angled triangle. A difference of azimuths of less than 30° or more than 330° should be avoided.

Errors in length of the base, or distance between the known points, affect the distances in the same proportion. If the base is 5 or 10% in error, both the distances will be in error in the same direction by the same percentage.

Distances are most easily determined from intersections by plotting the points and scaling. The distances are horizontal. If gradients are taken at the same points as the azimuths or at one of them, the elevation of the unknown point may be determined after the distance has been scaled.

35. **Tape-chains** are adapted for the accurate measurement of considerable distances. The tape-chain is a steel tape detachable from the reel on which it is carried, and with a handle at each end. It is graduated in feet, the last foot to tenths and the last tenth to hundredths.

Metallic tapes are of linen with wires woven in longitudinally. They are graduated in the same way as tape-chains, and also in feet, inches, and eighths. Metallic tapes are used for the exact measurement of short distances, as dimensions of buildings, lengths of bridges, etc. They stretch slightly, but not enough to introduce appreciable error.

In **using tapes note carefully** whether the small divisions are inches or tenths of feet. See that the **first graduation** is the **proper distance** from the end, and if the tape has been spliced note whether the graduations on either side of the splice are the right distance apart.

Rules are used for measuring short distances and dimensions and are usually graduated in feet, inches, and sixteenths, fig. 45.

Rules approximately correct may be improvised in several ways. If a rule or rod graduated to feet be grasped in both hands, palms down, with the outside edges of the hands at consecutive foot marks and the thumbs extended toward each other along the rule, the tips of the thumbs will meet or pass, and by carefully noting their relative positions a foot may be approximately reproduced at any time by grasping a stick in the hands, placing the thumbs in the proper position, and marking the outside of the hands. A length may be measured in feet by passing along it hand over hand, placing first the edges of the hands together and then the thumbs as described.

Every military topographer should know the length of his shoe, his exact height, and the length of his forefinger. A copper cent is $\frac{3}{4}$ in. in diameter.

It is impracticable to adopt and adhere to one system of graduation. The decimal system is most convenient for computation. For field measurements an observer will make fewer mistakes with the system he is familiar with and should be allowed to use it.

The following table will convert units of one system into those of the other:

TABLE X.

36. **Table for conversion** of **inches** and **sixteenths** into decimals of a foot and the reverse. The quantities in the table are thousandths of a foot. The decimal point is omitted.

Ins.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
0	000	005	010	016	021	026	031	036	042	047	052	057	062	068	073	078
1	083	089	094	099	104	109	115	120	125	130	135	141	146	151	156	162
2	167	172	177	182	188	193	198	203	208	214	219	224	229	234	240	245
3	250	255	260	265	271	276	281	286	292	297	302	307	313	318	323	328
4	333	339	344	349	354	359	365	370	375	380	385	391	396	401	406	412
5	417	422	427	432	438	443	448	453	458	464	469	474	479	484	490	495
6	500	505	510	516	521	526	531	536	542	547	552	557	562	568	573	578
7	583	589	594	599	604	609	615	620	625	630	635	641	646	651	656	662
8	667	672	677	682	688	693	698	703	708	714	719	724	729	734	740	745
9	750	755	760	766	771	776	781	787	792	797	802	807	813	818	823	828
10	833	839	844	849	854	859	865	870	875	880	885	891	896	901	906	912
11	917	922	927	932	938	943	948	953	958	964	969	974	979	984	990	995

TABLE XI.

37. **16ths of an inch in decimals of an inch:**

$\frac{1}{16}$	$\frac{2}{16}$	$\frac{3}{16}$	$\frac{4}{16}$	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$
063	125	188	250	313	375	438	500	563	625	688	750	813	875	938

38. **Reduction to the horizontal.**—Distances measured along a slope may require a correction before plotting them on a map, as all map distances are, or are supposed to be, measured in a horizontal plane. Such corrections, when made, are called **reduction to the horizontal.** The following table gives horizontal distances corresponding to sloping distances for gradients up to 30°. This table is to be used in the same way as Tables II and III. The correction for slopes of 6° and less is too small to be plotted on the customary scales and is nsually neglected. In flat or ordinary rolling country, the correction will rarely be necessary.

TABLE XII.

39. **Horizontal distances** for gradients of 0° to 30° corresponding to distances on the slope:

Gradient in degrees.	Horizontal distances for sloping distances of—								
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1	09998	19997	29995	39994	49992	59991	69989	79988	89986
2	09994	19988	29982	39976	49969	59963	69957	79951	89945
3	09986	19972	29959	39945	49931	59918	69904	79890	89877
4	09976	19951	29927	39902	49878	59854	69829	79805	89781
5	09962	19924	29886	39848	49810	59772	69733	79695	89657
6	09945	19890	29836	39781	49726	59671	69616	79562	89507
7	09925	19851	29776	39702	49627	59553	69478	79404	89329
8	09903	19805	29708	39611	49513	59416	69319	79221	89124
9	09877	19754	29631	39507	49384	59261	69138	79015	88892
10	09848	19696	29544	39392	49240	59088	68936	78785	88633
12	09781	19563	29344	39126	48907	58689	68470	78252	88033
14	09703	19406	29108	38812	48515	58218	67921	77624	87326
16	09613	19225	28838	38450	48063	57676	67288	76901	86513
18	09510	19021	28532	38042	47553	57063	66574	76084	85595
20	09397	18794	28191	37588	46985	56381	65778	75175	84572
22	09272	18544	27815	37087	46359	55631	64903	74175	83446
24	09135	18271	27406	36542	45677	54813	63948	73084	82219
25	09063	18126	27189	36252	45315	54378	63441	72505	81568
26	08988	17976	26964	35952	44940	53928	62915	71903	80891
27	08910	17820	26730	35640	44550	53460	62370	71280	80190
28	08829	17659	26488	35318	44147	52977	61806	70636	79465
29	08746	17492	26238	34985	43731	52477	61223	69969	78716
30	08660	17320	25981	34641	43301	51961	60622	69282	77942

The hor. dist. corresponding to *any* sloping dist., and *any* angle or gradient may be found by multiplying the sloping distance by the **cosine** of the angle, Table XIV.

40. The **protractor** is an angular scale of equal parts used for plotting azimuths. That adopted for reconnaissance is the rectangular form, figs. 12 and 13. It is

graduated on one face, which will be called the A face, fig. 12, from 0° to 180°, and on the other, or B face, fig. 13, from 180° to 360°. The graduation is clockwise on both faces. It has a scale of inches and tenths along one edge. The protractor may be used as ruler, scale, triangle, and parallel ruler.

To plot a given azimuth from a given point, draw a meridian through the point. If the azimuth is less than 180°, lay the protractor down A face up with the center at the point and the edge on the meridian, 0° to the north. Make a pencil dot on the paper at the proper graduation on the edge of the protractor. Move the protractor so that one of its edges passes through the two points and draw a line, which will be the desired azimuth.

If the azimuth is more than 180°, lay the protractor down B face up, 360° to the north, and proceed as before. The moving of the protractor after setting off the angle and before drawing the line may be avoided by adding a **counter-clockwise** graduation to the protractor. The sum of the two graduations at any point will be 180°. Place the center of the protractor and the given azimuth, read on the **counter-clockwise** graduation, on a meridian, and slide the protractor up or down, keeping the two points on the meridian until one of the long edges passes through the given point, when the azimuth may be drawn along that edge.

A semicircular protractor is shown in fig. 14. It is usually double graduated, in opposite directions from 0° to 180°. With this form an azimuth may be laid off and the line drawn along the diameter without moving the protractor. Lay the protractor down with the center on a meridian. If the azimuth is less than 180°, place its number of degrees on the **counter-clockwise** scale on the meridian north of the center, fig. 15. If it is greater than 180°, subtract its number of degrees from 360 and place the difference on the **clockwise** scale over the N. end of the meridian, fig. 16. In either case slide the protractor up or down, keeping the center and the graduation on the meridian until the diam. passes through the point, when the az. may be drawn along the diameter of the protractor. Fig. 17 shows a triangle graduated for use as a protractor.

41. **Improvised protractors.**—If a rule is at hand, a protractor may be made as described for slope board in par. 14 by extending the 1° graduations around a half or whole circle. **If without compasses,** measure off the radius on a piece of paper, stick a pin through one extremity for a center and a fine pencil point through the other extremity and sweep the circle.

If without a rule, fold a piece of paper carefully through the middle. The folded edge should be straight. Place the ends of the folded edge together and fold again. The two edges now make an angle of 90°. Fold again through the middle and the angle will be 45°. Now fold in three parts and the angle is 15°. Spread the paper out flat and the creases will represent radii of 15° intervals. These may be divided into three equal parts by the eye, and the protractor will then read to 5°.

The hour graduations of a watch are 30° apart, and the minutes 6°.

42. **The scale of a map** is the ratio between *dimensions on the map* and the corresponding *dimensions on the ground.* If the lengths on map and ground were expressed in the same unit, the scale ratio would always be expressed by the number of ground units corresponding to tho map unit. If 1 in. (map) corresponds to 120,000 ins. (ground), the *ratio*, or *scale*, is plainly 1 ÷ 120,000, or as usually described, 1 to 120,000. This fraction is called the **representative fraction,** and designated R. F. But ground distances are so much greater than map distances that they are ordinarily expressed in a larger unit, which makes the scale ratio less apparent. If 1 in. (map) equals 10,000 ft. (ground), the scale is still 1 to 120,000 because 10,000 ft. equal 120,000 ins. **The map unit is almost always inches.** Hence, a good rule for obtaining the scale ratio is to reduce the given number of ground units to inches, which will indicate the ratio.

Another method of stating scales, much employed in military map making, is to take ratios which will give ½, 1, 2, 3, 6, 12, or 15 ins. on the map to 1 mile on the ground, and call the scales ½, 1, 2, 3, 6, 12, or 15 ins. *to the mile.* Such scales can be put into terms which express the ratio by dividing 63,360, the number of ins. in 1 mile, by the number of ins. given in the scale. Thus, 1 in. to 1 mile equals 1 ÷ 63,360; 2 ins. to 1 mile equals 1 ÷ 31,680; 3 ins. to 1 mile equals 1 ÷ 21,120, etc.

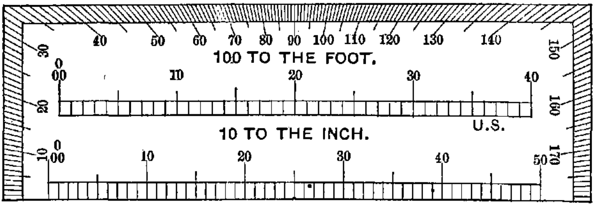


Fig. 12. A. Face.

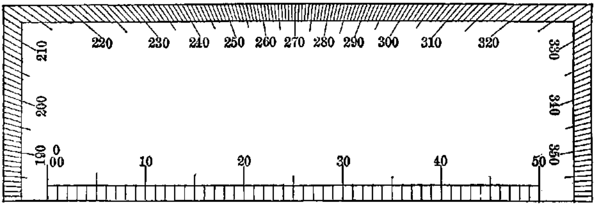


Fig. 13. B Face.

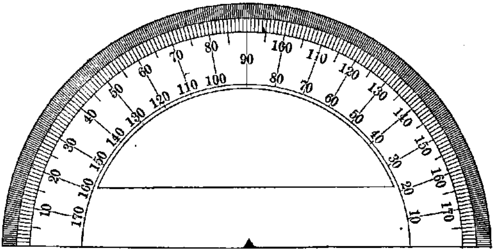


Fig. 14.

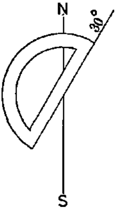


Fig. 15.

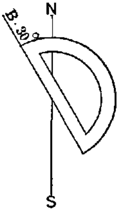


Fig. 16.

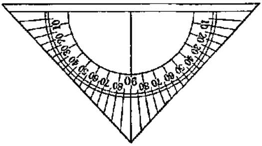


Fig. 17.

The scale ratio is true for all units. If a scale ratio is 1 ÷ 9,600, 1 in. (map) = 9,600 ins. (ground); 1 ft. (map) = 9,600 ft. (ground); 1 meter (map) = 9,600 meters (ground), etc.

When the scale of a map is changed, as by reduction or enlargement, the R. F. changes too, and hence the ratio should not be given on maps which are to be reproduced. **A linear scale should be drawn on every map.** This will be enlarged or reduced with the map and will always be true. Such a scale is also very convenient for taking distances from the map. It consists of a straight line divided into equal parts which are numbered with reference to the relation between distances on the ground and distances on the map. The numbers relate to distances on the ground and the graduations, or lengths set off on the line, relate to distances on the map. A distance on the map equal to that from the zero of the scale to any graduation corresponds to the distance on the ground represented by the number of that graduation. Scales are designated by the unit of their parts, as **scales of miles, scales of feet, scales of meters,** etc.

A scale might be constructed by drawing a scale of inches on the map and placing opposite the divisions the numbers expressing the equivalent ground distances. It is customary, however, because more convenient, to take the numbers at intervals of 10, 100, or 1,000, or multiples of them, and make the divisions of the line correspond. A scale should be divided into a convenient number of equal parts called **primary divisions.** The zero should be between the first and second primary divisions, counting from the left. The primary divisions are numbered from the zero to the right. The primary division on the left of the zero is subdivided into smaller parts, called **secondary divisions,** and these are numbered from the zero to the left. The secondary are usually $\frac{1}{5}$ or $\frac{1}{10}$ of the primary divisions.

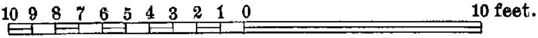
To take off any distance from such a scale, put one leg of the dividers on the primary division next below the distance sought, and the other leg on the secondary division corresponding to the remaining figures.

Figs. 18 and 19 give scales for the usual range of topographic maps, which may be taken off on the edge of a strip of paper and transferred to a map. Fig. 20 gives scales for plotting distances measured by pacing on foot, and fig. 21 for those by pacing mounted.

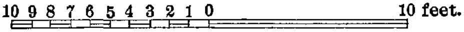
Scales may be constructed on strips of paper, wood, celluloid, or metal instead of on the map, and are then called **plotting scales.** The scales given in figs. 18–21 are plotting scales. A distance may be taken between dividers from any map and read by applying the dividers to the proper one of these scales.

These scales are not engraved and can not be relied upon within 1%. They are sufficiently exact for reconnaissance and, in fact, for most topographical drawing and scaling.

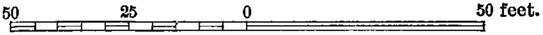
1° R. F. $= \frac{1}{100} = 8'.33$ to $1'' = 633''.6$ to 1 mile.



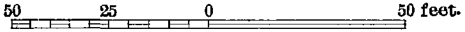
2° R. F. $= \frac{1}{120} = 10'$ to $1'' = 528''$ to 1 mile.



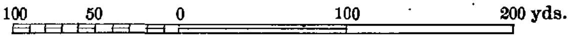
3° R. F. $= \frac{1}{500} = 41'.66$ to $1'' = 126''.7$ to 1 mile.



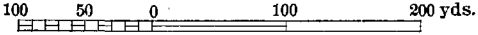
4° R. F. $= \frac{1}{600} = 50'$ to $1'' = 105''.6$ to 1 mile.



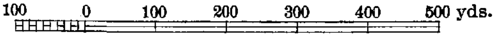
5° R. F. $= \frac{1}{4224} = 352'$ to $1'' = 15''$ to 1 mile.



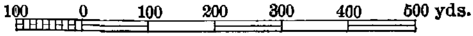
6° R. F. $= \frac{1}{5280} = 440'$ to $1'' = 12''$ to 1 mile.



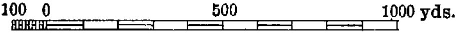
7° R. F. $= \frac{1}{10000} = 833'.3$ to $1'' = 6''.34$ to 1 mile.



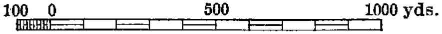
8° R. F. $= \frac{1}{10560} = 880'$ to $1'' = 6''$ to 1 mile.



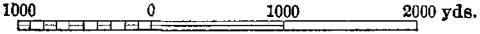
9° R. F $= \frac{1}{20000} = 1666'.7$ to $1'' = 3''.17$ to 1 mile.



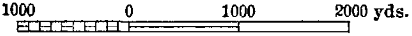
10° R. F $= \frac{1}{21120} = 1760'$ to $1'' = 3''.00$ to 1 mile.



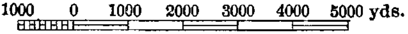
11° R. F $= \frac{1}{52800} = 4400'$ to $1'' = 1''.2$ to 1 mile.



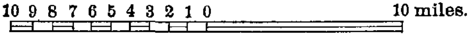
12° R. F $= \frac{1}{63360} = 5280'$ to $1'' = 1''.00$ to 1 mile.



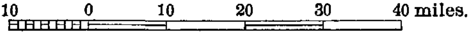
13° R. F $= \frac{1}{126720} = 10560'$ to $1'' = 0''.50$ to 1 mile.

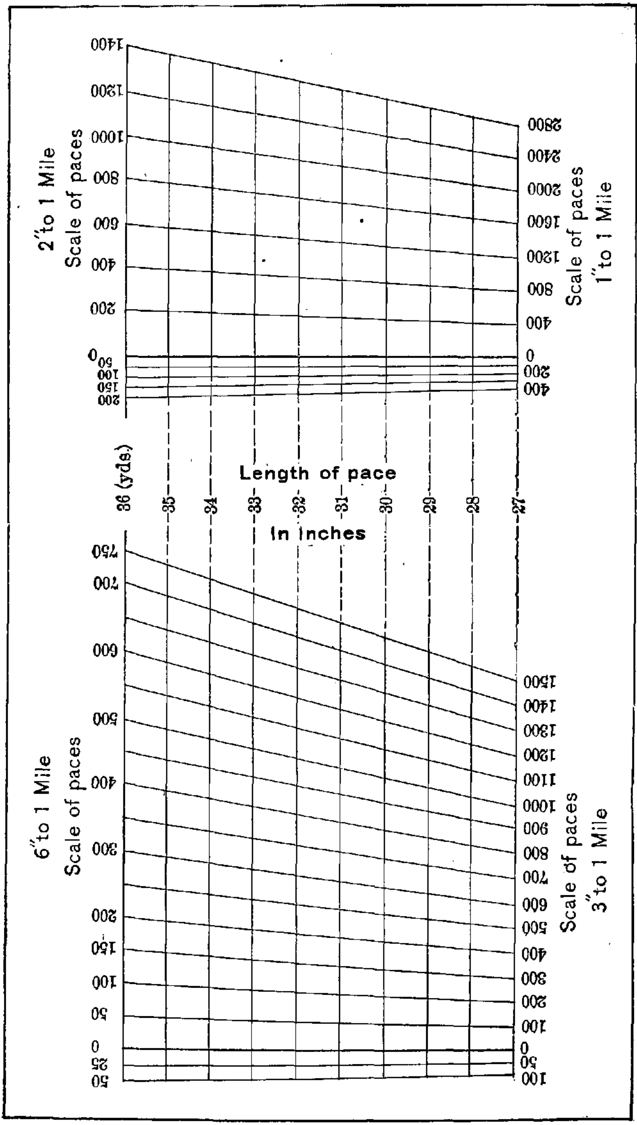


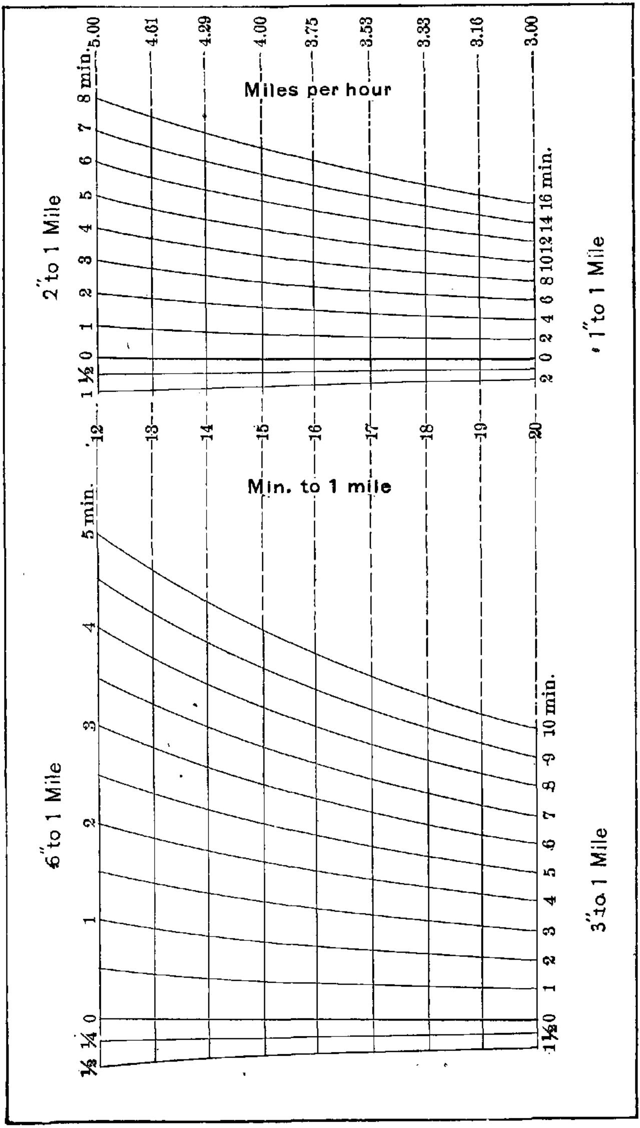
14° R. F $= \frac{1}{633600} = 52800'$ to $1'' = 10$ miles to $1''$.



15° R. F $= \frac{1}{1584000} = 132000'$ to $1'' = 25$ miles to $1''$.




2" to 1 Mile
Scale of paces
Scale of paces
1" to 1 Mile
Length of pace
36 (yds.)
35
34
33
32
31
30
29
28
27
in inches
6" to 1 Mile
Scale of paces
Scale of paces
3" to 1 Mile


Miles per hour
5.00
4.61
4.29
4.00
3.75
3.53
3.33
3.16
3.00
Min. to 1 mile
12
13
14
15
16
17
18
19
20
2" to 1 Mile
8 min.
1" to 1 Mile
16 min.
6" to 1 Mile
5 min.
3" to 1 Mile
10 min.

43. A series of points connected by azimuths and distances is called a **traverse,** and the operation of determining the azimuths and distances is called **traversing.** The latter term is usually extended to include all azimuths, distances and elevations taken while running such a line.

A traverse line with elevations along it may also be called a **profile,** and when the traverse is run for the express purpose of taking the elevations, the operation is called **profiling;** and the line on the ground and the plot of it on paper, are called **profiles.**

Distances in topography are so much greater than elevations that both can not conveniently be represented on the same scale. It is usual to take a scale for elevations called the **vertical scale,** much larger than the scale of distances, or **horizontal scale.** The ratio of the two scales is called the **distortion** or **exaggeration.** Ten or 20 ft. to the in. is a common scale for elevations. If the horizontal scale is 3 ins. to the mile, the resulting distortions are 176 and 88 times. Both scales should always be written below every profile.

Angles on a distorted profile are also distorted, and gradients can not be plotted or read with an ordinary protractor.

Angles can be plotted or read on a profile by any of the other methods of expressing gradients, par. 11 and Table I. The horizontal distance is plotted to the horizontal scale and the corresponding vertical distance to the vertical scale. A special protractor may be made for any given distortion and used to plot and read angles directly on a profile having that distortion. To make such a protractor, lay off a distance of 100 to the horizontal scale. At one end of it erect a perpendicular, and lay off on this, from the intersection, distances corresponding to 1°, 2°, 3°, etc., Table I, col. 2. These distances must be laid off to the vertical scale. Draw lines through the points on the perpendicular and the other end of the horizontal line. These lines represent the angles **on the profile** corresponding to the **slopes on the ground.**

44. **Fieldwork.**—Measurements and additional notes may be recorded and afterwards plotted on a map, or may be plotted on a map as taken, or the two operations may be combined, as circumstances demand. A written report also will often be reqnired.

45. **A road sketch** consists of a map of the road with a narrow belt of country on either side. If roads, parallel and intersecting, are not too far apart, the road sketches may be combined into a fairly good map of the entire area.

The **road itself** will, if practicable, be traversed with the degree of precision already indicated as required for topographical reconnaissance. If the country is open, so that long sights are possible, a trained observer will get better work by the use of the prismatic compass and clinometer. For shorter courses, when the object is of sufficient importance to use a chain for distances, the prismatic compass and clinometer should also be used and the readings taken with the greatest care.

Usually, however, the box compass will be used for azimuths and the slope board for gradients, or else the sketching case, to be described later, par. 54.

Side features will, if important, be located by intersection; otherwise by estimation. A convenient method is to estimate the distance of an object when it bears at right angles to the course, and plot it from that point. In such case the azimuth will be denoted by R or L. Thus, *house 300 R* would mean a house at a distance of 300 units to the right, on a line at right angles to the course through the point where the observation was taken.

46. **Traversing with compass and notebook.**—Rule a column ¾ of an inch wide down the center of each left-hand page of the notebook. Select for the starting point some object or point which can be identified by description. Standing at this point, sight with the compass toward some object—tree, stump, telegraph pole, or stone—that will serve as the second station of the traverse line. Note the reading of the compass and record it in the center column of the notebook, at the bottom of the first left-hand page, making also the symbol for ⊙ 1. Observe and record also the azimuths of any other objects which are to be located from ⊙ 1. All the observations taken at this station are written in order in the central column from the bottom upward and are bracketed together with the station symbol. The name of

each object is written on the same horizontal line with its azimuth, on the right side of the page if on the right of the traverse, and on the left side of the page if on the left of the traverse. If elevations are to be obtained, observe the gradients from ⊙ 1 to the several objects and place each in the notebook next to the corresponding azimuth.

Proceed toward ⊙ 2, counting paces. Halt when necessary to sketch and measure offsets to objects on either side of the course, to take bearings of intersecting roads, paths, streams, etc. When a halt is made, a mark is scored on the ground, the distance in paces from the last ⊙ recorded in the central column and the desired notes made. Distances along the main line, azimuths, and gradient angles only are recorded in the central column. All descriptive matter relative to side objects is placed outside of that column on the side corresponding to that where the objects lie. Return to the scored mark and resume the pacing, beginning with the number recorded at the halt, so that the total count of paces at any point shall be the number taken since leaving the last ⊙.

The center column of the page is taken to represent the line actually paced and to be without width, so that offsets in the side sketches are shown measured from the sides of the column and not from its center.

On reaching the second ⊙, record its distance from ⊙ 1; draw a horizontal line across the page; write ⊙ 2 in the center column above the line, and continue as before to ⊙ 3.

It is well at ⊙ 2 to take a back azimuth on ⊙ 1. This should differ from the azimuth of ⊙ 2 from ⊙ 1 by exactly 180°. A marked discrepancy indicates error in observation or the effect of local attraction on the needle, and should be investigated before proceeding. If a back azimnth is taken, it should be the first observation made and recorded.

When opportunity offers, take bearings on distant bends of the road, spires, towers, hilltops, tall trees, etc., and enter the angles in the center column with the name of each object written beside its bearing. Endeavor to get bearings of the same distant object from several stations or from two stations at some distance apart. These, when plotted, should intersect at a common point if the observed bearings are correct and the compass has not suffered local disturbance. It is not to be expected in work of this grade that an exact intersection of more than two bearings can be obtained except by accident.

When a sketcher at any point of the traverse finds himself in prolongation of a line that defines or bounds a feature of the country, such as a fence, the edge of a wood, a reach of shore line of river or lake, a gully, canyon, or ridge, a face of a building, or a stretch of road or railroad, its bearing should be taken. The same rule should be observed when important features come into range with each other from a point on the traverse. A valuable check on the relative positions of such features is thus obtained.

If a traverse line is interrupted by any obstacle that interferes with the measurement of distance, its width should be estimated and the pacing resnmed on the other side; or, for greater exactness, make an offset, perpendicular to the traverse line if possible, long enough to clear the obstacle, continue the traverse parallel to the original course and return to the latter after passing the obstacle by a second offset parallel and equal to the first and in the opposite direction; or, locate points on the farther side by intersections.

47. **The unit of measure should be clearly stated in the notes.** Ordinarily distances along the course are in paces, while estimated offsets may be in paces, feet, yards, or fractions of a mile, according to their distances, and also according to the unit in which the sketcher finds he can make the closest estimate.

On the usual recounaissance scales, the dimensions of buildings, widths of roads, bridges, etc., can not be plotted to scale. They are shown exaggerated, and the true dimensions, if important, must be given in figures.

48. **The best method of plotting** is to plot the traverse lines and the check bearings first. Then any error discovered by means of the latter, or by closure on the initial or other known point, can be more readily corrected. When the traverse line has been adjusted, the details on either side are plotted in and do not have to be changed.

The outfit desirable for the method of traversing with compass and notebook is the following: Notebook or sheets of paper ruled as described, prismatic or pocket compass, pencil of medium hardness, rubber eraser, pocket knife, 25 ft. tape, a piece of twine 100 ft. long. The absolute necessities are the paper, the compass, pocket knife or pencil sharpener, and rubber-tipped pencil. The tape measure is to be used for making small measurements of distance or dimensions. The cord is useful for measuring depths of water, heights of structures, etc. It should be graduated to yards by knots.

49. **The topographic field notebook** is designed to facilitate the foregoing method of traversing. In addition to the central column, it has columns on either side in which to record the offset distances, each of which is put down on the proper side of the central column, avoiding the necessity of using the letters R and L, and eliminating the liability of mistakes in confusion of the direction.

The opposite right-hand page is ruled in 1 in. squares, and has a full-circle protractor graduated to degrees printed on it. This page facilitates a hasty plot of the traverse with respect to which many details can be sketched in more clearly and certainly than they could be recorded in writing. At the bottom of the page are scales of tenths and eighths of inches. The alternate pairs of pages are plain ruled for notes and memoranda. Figs. 22 and 23 show the arrangement and illustrate the use of the book described.

50. **Traversing with compass and drawing board.**—The observations are taken as in traversing with a notebook and compass, but the traverse line and such offsets as come within the limits of the sketch are plotted at once; that is, the map is drawn as the observer proceeds over the ground. A great advantage of this method is that any large error in measurement is likely to be detected by the eye, as the map is compared with the ground, and errors can be corrected on the spot. The plotting scale of equal parts should be prepared beforehand to suit the scale of the map. If this scale can be pasted or drawn on the edge of the protractor opposite the angular graduation, it is a convenience.

The sides of the sheet of paper should be lettered N, E, S, and W to correspond with the points of the compass. If the paper is ruled or water-lined, the lines are taken parallel to the magnetic meridian.

Having observed the azimuth at ⊙ 1, draw through the point designating that station a line having the observed azimuth. Azimuth lines are erased finally as a rule, and hence should be lightly drawn and with a fairly hard pencil. Prolong this line in the direction of ⊙ 2 far enough to surely reach that ⊙. If other azimuths are taken at ⊙ 1, plot them also, and note on each the object to which it bears. If the distance to the object is estimated, it may be laid off on the azimuth and the position of the object plotted at once.

Proceeding toward ⊙ 2 to take any desired side shot, halt abreast of the object, plot the distance from ⊙ 1 on the course, estimate the distance to the object, and plot it in at that distance opposite the point plotted on the course and on the proper side.

Arrived at ⊙ 2, lay off the entire distance from ⊙ 1, and plot and mark ⊙ 2. Erase the azimuth line beyond ⊙ 2; take and plot any other desired azimuths. If any of them are to points previously sighted to, make the intersections and plot and mark the points. In plotting azimuths to side objects, it is better to draw only a short part of the line near the object to avoid confusion of lines on the sketch and especially near the station.

51. **The following outfit is desirable** for traversing by this method: A thin, smooth board 12 x 15 ins. to which the paper is attached by thumbtacks or rubber bands, prismatic or pocket compass, clinometer or slope board, a rectangular protractor, a plotting scale, lead pencil, No. 3 or 4, rubber eraser, 25 ft. tape, 100 ft. of twine, watch, pocket knife, canvas cover for board and paper, notebook. A field glass is also very useful. Good work can be done with a less elaborate outfit, or with improvised arrangements for some of those mentioned. The drawing board may be utilized as a slope board.

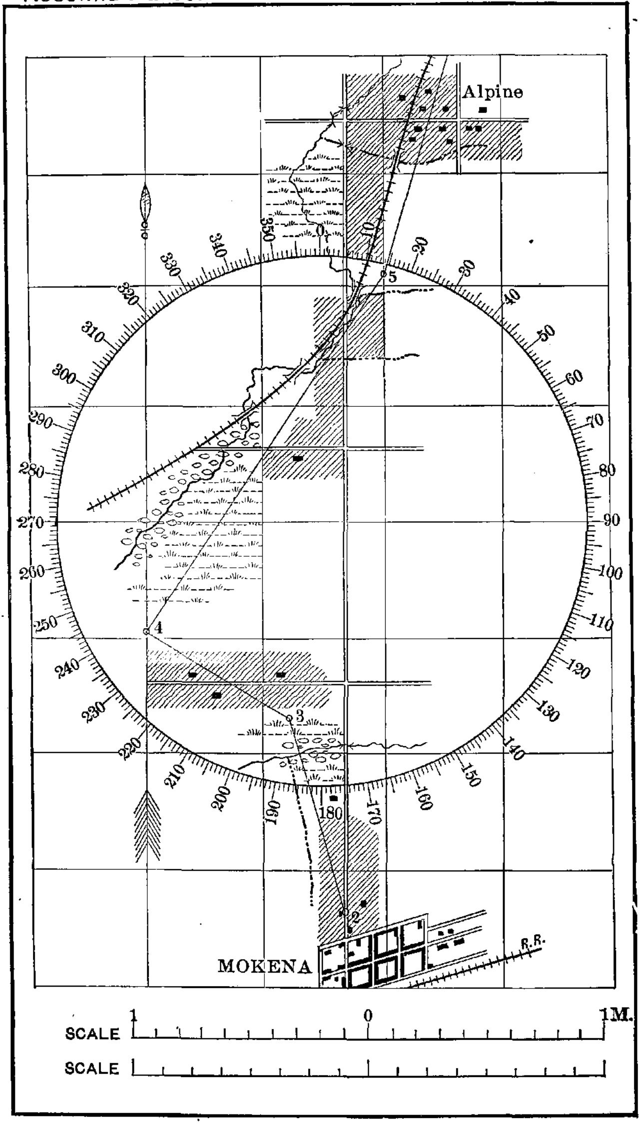
52. A road sketch will be long and narrow, and two or more stretches should be got on a board if possible. In this way a board of the size indicated will hold a fair day's work. When a section runs off the paper mark it with a letter, as *A*, and make a note, *Continued at B.* Mark the beginning of the next section *B* and write *Continued from A.*

Remarks Left.	Offsets Left.	Courses & Distances	Offsets Right.	Remarks Right.
Crossed wagon road		1230	230	Road running N.&S.
running E.& W.		4° R.		through Alpine
Crossed dry Cr.		880		village.
Cr.	12	100	230	Farm H.
Cult.		18°00'		
		$\odot$5		
		3256		
		$7^h 41^m$		
R.R.Br.	100	4000		
Cr.	25	3080		Crossed dry Cr.
		2765		Crossed wagon road
Cr.	2	2465		Crossed dry Cr.
R. R. Br.	100	2300		
R. R Br.	250	1760		
		1660	200	Farm H.
		1650		Crossed Wagon road
				running E. & W.
Creek 30 wide.	440	620		
Woods along Cr.				
		34°00'		
Rolling Prairie		$\odot$4		Pasture.
Pasture		1230		
		$7^h 4^m$		
Farm H.	110	800		
Farm H.	150	600		
		450		Crossed wagon road.
		230	160	Farm H.
		1.5°R.		
		303°00'		
Corn & Wheat		$\odot$3		Corn & Wheat
		1530		
		$6^h 50^m$		
		1230		Crossed Cr. 15 wide.
Creek, dry run	130	880	175	Farm H.
		3° F.		
		343°00'		
		$\odot$2	50	Farm H.
Left wagon road		230		Cult.
Cult.		$6^h 33^m$		
Farm H.	25	200		Level Country
		100	10	Farm H.
Left Mokena $6^h 30^m$ A.M.		0°00'		Following wagon road.

Sept. 4th. 1900. $6^h 30^m$

$\odot$1 All distances in Yds.

Beginning


Alpine
MOKENA
R.R.
SCALE
1
0
1M.
SCALE

Wherever else a road runs off the map, make a marginal note "To ———, ——— miles," giving the name and distance of nearest settlement or conspicuous topographical feature. If the road crosses one parallel to the main route, write also "To crossing, ——— miles."

53. **Traversing with oriented drawing board.**—A drawing is said to be oriented when so placed that its true meridian is parallel to the true meridian on the ground. When using magnetic azimuths, making the magnetic meridians—map and ground—parallel, may be accepted as a proper orientation. When a map is oriented, with any given point vertically over the corresponding point on the ground, a ruler held on the point or station on the map, and pointed in the direction of any object gives the azimuth of that object on the map. No angular measurements need be made. A compass is not necessary, but it is very convenient as it affords the quickest means of orienting the map.

To run a traverse by this method, assume on the map the initial point and the magnetic meridian, selecting them so that the general direction of the traverse will coincide with the longest dimension of the paper. Place the board over the first station; lay the compass on it with the north-and-south line parallel to the assumed meridian, and turn the board until the needle reads north. The board is then oriented, and must be in this position whenever a sight is taken. It should also be level, as nearly as can be determined by the eye.

Place a ruler on the station point of the map and sight it in the direction of any object which it is desired to plot. Draw a line along the edge of the ruler and on it lay off to the adopted scale the distance of the object if known or assumed. When all the desired azimuths have been taken from the station, sight the ruler to the second station and draw its azimuth, and then proceed to that station, pacing the distance. Arrived at the forward station, plot the paced distance, orient the board over the station, and proceed as before. If any of the objects taken at the first station can be seen from the second, new azimuths may be taken to them which will locate them by intersection, fig. 24. If no compass is at hand, orient the board arbitrarily at the first station, and at the second station orient it by placing the ruler on the line between the two, and sighting back to the station just left. Fig. 25 shows the relative positions of board and ground at four successive stations.

54. **Traversing with sketching case.**—The sketching case is a compact device for traversing by the oriented-map method. The simplest form issued to the service, usually called the cavalry sketching case, is shown in fig. 26. The compass is set into the board, and a movable index is provided which can be revolved to place it parallel to the assumed meridian on the map. When the needle is brought parallel to the wire the board is oriented. The needle may be parallel to the index wires, but end for end, or 180° out of its true position, in which case the sketcher is turned completely around. Such a mistake is so great and so obvious that it needs no preventive, but a sketcher may note at the outset whether the *N* or *S* end of the needle is toward the stud which moves the wires and keep it in this position.

The ruler *A* is pivoted to a slide, moving in a slot in the radial arm *B*, pivoted in turn to the board near the compass. The screw *C* clamps the ruler and slide with respect to the arm, and the screw *D* clamps the arm on the board. The combination permits the ruler to be set on any point of the board and on any direction through that point and clamped there.

To facilitate road sketching rollers *KK* are provided, on which 30 or 40 ins. of paper may be placed. The paper should roll on and off the undersides of the rollers. If the traverse runs off either edge of the paper draw a meridian through the last station, roll back the paper until that station is off the board, plot the same station in a new assumed position with a new meridian through it, and continue the sketch. When the paper is cut and one position of the station placed over the other with the two meridians coinciding, the two parts of the sketch are in their true relative positions.

By clamping the ruler with the stud *F* engaged in the notch *G*, loosening the screw *D* and holding the board in a vertical plane, the case may be used as a slope board. The tops of the roller screws *HH* form a sighting line, and the angle is read from the left edge of the arm, on the scale across the bottom of the board. See par. 54*a*, p. 92.

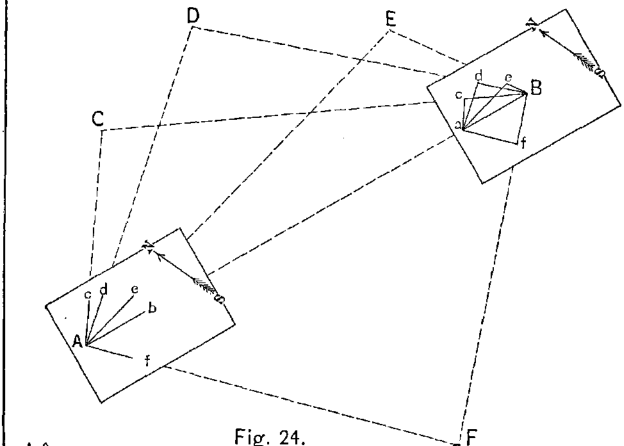


Fig. 24.

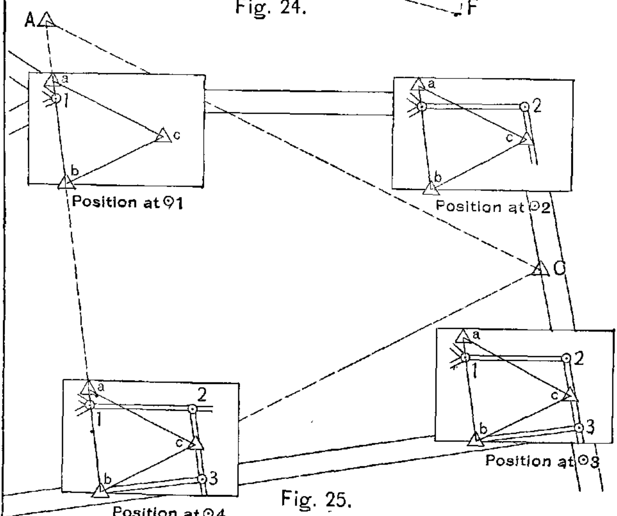


Fig. 25.

Traversing by plane table and Resection

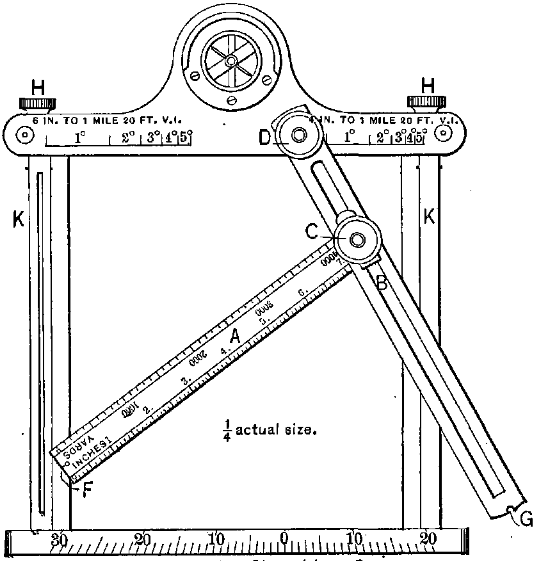


Fig. 26. Cavalry Sketching Case

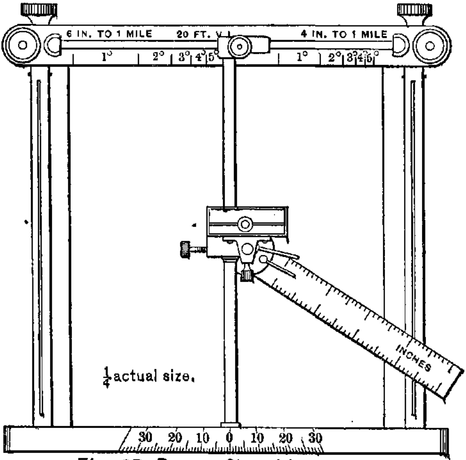


Fig. 27. Bower Sketching Case

55. Another form of sketching case is shown in fig. 27. The radial arm of the cavalry case is replaced by two sliding motions at right angles to each other, which permit the compass to be placed over the pivot end of the ruler and bring it directly under the eye when aligning the ruler. Several minor details are worked out to promote convenience and accuracy of use. These advantages are secured at some sacrifice of simplicity and compactness, and this form of case will not stand as much rough usage as the cavalry case.

56. **Improvised instruments.**—By the oriented-map method a very good sketch may be made with improvised instruments. Any smooth surface on which lines will show will answer for the board and paper. The edge of a book, an envelope, or a piece of paper carefully folded makes the ruler. A narrow strip of paper folded double several times makes a scale of equal parts. See par. 56*a*, p. 69.

57. **A road reconnaissance should procure data on the following subjects:**

The road.—Gradients, especially the steepest; width of roadway; if paved, width, kind, and condition of paving; width and depth of side ditches, and whether wet or dry; if not paved, character of soil, sand, clay, or gravel; kind of fences and width between them. The sketch should also show where the road is in embankment or cutting; where wagons can not double or pass, and where foot troops can not march along the side between the wagon track and the fences.

Bridges.—Material of piers and abutments; type and material of superstructure, as girder, truss, arch, suspension, wood, steel, stone, etc.; width of roadway, and clear headroom; safe load (see Bridges). Of bridges over the road, clear width and height; over streams, the nearest bridges above and below and whatever information can be obtained about them.

The country.—Character of cultivation or natural vegetation; areas and density of timber, underbrush, vines, especially poisonous ones; marshes and fords, kinds of fences, nature of soil; general configuration of surface, especially high hills, long ridges or valleys, bluffs or slopes too steep to scale, and practicable routes to their crests.

Streams crossed.—Name, width, depth, and surface velocity in swiftest current; velocity noted as sluggish, moderate, quick, or swift; elevation of high-water marks in relation to the road; which bank is the higher at crossing and above and below, and how much; accessibility of water for stock; fords at or near crossing; length, depth, and steepness of approaches; levees or embankments, height, and thickness on top; if navigable, to what distance above and below and for what class of vessels—steamers, flatboats, rowboats.

Towns and villages passed through.—Name, location on map, and population. Names of streets to be traversed. Material, as stone, brick, frame, log; size, 1, 2, 3 stories, and distribution, close or scattered, of the houses in those streets; gradients of intersecting streets; location of railway depots, post, telegraph, and telephone offices; of drinking fountains and watering troughs; of elevators, storehouses, or other accumulations of food or forage; of blacksmith, wagon, and machine shops.

When ordered to make a complete examination of a town or village, note besides the foregoing, location and size of principal buildings, halls, court and school houses, churches, banks, jails, and their ownership; sources, maximum quantity and distribution of water supply; sanitary conditions and disposal of wastes; location of railroads, depots, freight houses, sidings, etc.; for all roads entering from the surrounding country the same information as scheduled above for streets; location and extent of open spaces, and of large substantial buildings standing apart; location and extent of high ground within range, especially that from which streets can be enfiladed.

Railroads crossed.—Name, gauge, single or double track, sidings and loading platforms at point of crossing; crossing at grade, over or under; distance and name of nearest station each way; direction and distance of nearest roundhouse, shops, etc.

58. **River reconnaissance.**—Designate the banks as right or left, the right bank being that on the right hand when looking down the stream. If, when standing on the bank facing across the stream, the current flows from left to right, the observer is on the right bank; if from right to left, he is on the left bank.

If the stream is navigated, pilots and residents will know distances by channel between landings with sufficient accuracy for the purposes of a field reconnaissance. In making a traverse along the banks of the river, it may be desirable to cross from one side to the other to save distance or avoid obstacles. When a crossing is to be made, at two or three stations from the point of crossing select a point on the other side and take an azimuth to it. From the last station take another azimuth to the selected point, locating it by intersection. If the conditions prevent an intersection, take an azimuth from the last station to the point on the opposite bank and estimate the distance.

The valley.—General configuration, heights of limiting ranges, and positions of passes or roads crossing them; commanding ground from which a stretch of the channel of considerable length can be enfiladed by artillery; forest growth on or near banks; soil and cultivation of the valley; roads parallel to river, and means of access to them from the river.

The stream.—Its width, depth, and velocity; navigability, as for steamboats, flatboats, rowboats, rafts, and head of navigation for each; nature of obstructions to navigation and possibility of removing or avoiding them; season of high and low water; average rise and fall; rapidity of rise and fall and causes; amount of drift; character of banks and relative command. Quality of water; amount and kind of sediment borne; usual period and thickness of ice.

Tributaries and canals.—Width, depth, navigability, and means of crossing. Nature and purpose of canals; dimensions and lifts of locks; time for lockages; means of destroying locks and effect of destruction; floating plant found.

Bridges and fords.—As in road report. Also for bridges note position of the channel and navigable width between piers; height of arches and lower chords above the water at different stages; dimensions and operation of draw spans. Note the exact position of fords and the marks on both banks by which they may be found; length, width, and nature of bottom; velocity of current; position of deep holes; aids to crossing. Fords should not be more than 4 ft. 4 ins. for cavalry, 3½ ft. for infantry, and 2 ft. 4 ins. for guns and ammunition. Note nature of approaches to bridges and fords; width of roadway, slopes, soil, effect of weather and traffic. Note especially the defensibility of bridges and fords.

Ferries, boats, and other means of crossing.—Position of ferries; approaches and practicability for horses and loaded wagons; sizes, number, and kinds of boats; method of propulsion; sites for military bridges or ferries; character of site for construction, use, and defense; proximity of islands and tributary streams; approaches and slope of banks; width of river and maximum surface velocity of current; materials for the construction or repair of boats, bridges, or ferries.

Inundations.—Places suitable for inundations by damming or obstructing a narrow bridge span, or by cutting a levee or dike. Note raised roads on ground liable to natural or artificial inundations and the safest route to follow by known landmarks when the road is overflowed. An extensive inundation 2 ft. deep on level ground is a serious obstacle unless the roads are very sound and marked by trees, posts, etc. Even when so marked a dip in the roadbed of 3 or 4 ft. may render the road impassable. A railroad bed is soon washed out even by a slight overflow.

59. **Reconnaissance of a railroad.—The line.** Local name; terminal points and distances between stations and other points; gauge; single or double track; condition of roadbed, ties, and rails; drainage and liability to overflows or washouts; facilities for repair; condition of right of way for marching troops along the line.

Tunnels and bridges.—Number and location; dimensions; strength of bridges; means of destroying and repairing; of blocking traffic.

Rolling stock.—Number and nature of engines and cars available; capacity for transporting troops between given points; facilities for constructing armored trains, as spare rails, old boilers, etc.; location and capacity of shops and store yards.

Stations.—Name and location; facilities for entraining and detraining troops with wagons and horses; platforms on through line and sidings; ramps; side tracks, number and capacity; turntables; water tanks; fuel supply; storage facilities; derricks or cranes; cross-overs for teams and pedestrians. Facilities at hand for hospitals, camps, depots; for feeding men, heating coffee, watering horses during temporary halts.

87625—09——4

Other communications.—Telegraph lines; number and location of stations; number of wires; connections; parallel highways, roads, rivers, or canals; means of access from same to railroad; junctions and crossings of other lines; relative elevation; facilities for laying temporary switches and sidings at stations or between crossing lines.

Defensibility.—Heights commanding line of road; defense of stations; defense of road and telegraph lines against raiding parties; structures exposed to demolition; defense and attack of same; defiles and river crossings.

60. **Reconnaissance of a wood or forest.**—Note all roads and paths, and all hills, ravines, and streams within the wood or skirting the edges; kinds of trees, density and growth; underbrush, prevalence of poisonous shrubs and vines; marshy or large open spaces; practicability of forming new roads by cutting; creation of obstacles by felling trees; if there are no roads traverse the shortest practicable path between the point of entrance and point of exit, and mark boulders or blaze trees, set stakes, or otherwise indicate this path, and also give compass bearings of the route to be followed. Note the exterior forms of the woods, whether parts of the edge flank other parts; connection with neighboring pieces of wood by scattered trees or clearings; undulations of the ground that would give cover to attacking force or to defenders.

61. **Reconnaissance of mountains.**—Note the number and positions of passes through the mountains, of roads and trails leading to these passes, their condition, practicability and means of repair; steepness of slopes on the sides of roads; means of constructing additional roads; water courses, their direction, nature, and time of floods; means of crossing. Note ravines and open glades on mountain sides, lookout points, and good signal stations; note time and duration of snowdrifts on roads or passes; depth of drifts and possibility of removing them or of traveling on the surface of the snow. Note extent and nature of forest growth.

62. **Reconnaissance for a camp or winter quarters—Site.**—Location, elevation, and area; sanitary features, such as drainage, dryness, and general character of top soil; proximity of swampy ground or stagnant ponds.

Communications.—Sufficiency of existing roads and paths, maximum grades, probable condition under heavy traffic and in bad weather, location and kind of materials available for improvement or repair, railroad or water communication and terminal facilities of same.

Water and fuel.—Location, kind, and quantity of fuel at hand; quality and quantity of water; facilities for filling water carts, for watering animals and for washing and bathing; nature of supply, as wells, springs, running streams, and its reliability.

Shelter and conveniences.—Proximity of trees, brush, wood, hay, and straw for huts and bedding; of markets; of towns and villages.

Defensibility.—Location of outposts and guards; location and character of defensive positions in or near the camp; force required to hold positions which may command the camp.

63. **Reconnaissance of a position.**—This problem usually includes the selection of the position, and is therefore tactical as well as topographical. Certain relations and conditions must be observed in the selection, and the extent and degree in which they are found must be clearly shown on the map or in the report.

The length of the position, or its development along the firing line, should be proportional to the force available for its occupation. Exact rules can not be given, but 5,000 infantry per mile or 3 men per yard is the usual estimate.

The **flanks must be secure.** Impassable natural features, a river, mountain, or stream form the best flank. Lacking these, a wood, a deep ravine, a cliff, or a high hill will serve. Even with these features absent a flank may be strengthened by the construction of a strong earthwork, but the general rule obtains that natural weakness of the flanks must be made up by a greater number of men, or by the substitution of cavalry for infantry in case the ground favors the movements of mounted troops.

If the **flanks are naturally strong** the line should be withdrawn to make the entire position reentrant; if the **flanks are naturally weak** the connecting line should be held straight or advanced so as to make the position straight or salient, The **depth of the position**, or its extent in rear of the firing line, should afford natural cover for supports, reserves, and trains, which may require a total depth of 800 to 2,400 yds.; but a short position may be relatively shallower than a long one. Three or four parallel ridges, 300 to 600 yds. apart, with the intervening ground practicable, form an excellent position. If the first ridge is somewhat higher than the rest, so much the better. Whatever cover there may be for the component parts of the force, whether natural or artificial, fences, ditches, trees, etc., should be shown or described. If digging is necessary, its amount and the character of the soil should be stated.

Strong points in front of the line, which may be occupied as outposts, should be shown.

Communication should be free in every direction, concealed so far as possible from the enemy's view.

Artillery positions are required when that arm is represented in the occupying force, as will usually be the case. They should permit the guns to sweep all ground in front of the position over which the enemy can advance, to the limit of effective range. Every point in front of the position and within range which commands any part of it, is an element of weakness.

Ranges at which the enemy can be seen and reached by artillery fire; the points beyond rifle range covered by such fire and its relative command of adverse artillery positions should be shown or described.

If possible, similar information should be obtained of the ground likely to be occupied by the enemy in forming for attack, or in taking up a counter position.

64. A **position occupied by an enemy** must be reconnoitered from a distance, and few details can actually be seen. Valuable inferences may be drawn by remembering that the enemy has probably chosen his position in accordance with the principles above given.

Especial attention should be given to the flanks and the feasibility of turning one of them.

65. A **position sketch** will usually be on a scale of 6 ins. or 12 ins. to the mile. It will be found most convenient and expeditious to make it by the compass and drawing-board method, par. 50, or the method with oriented board alone, par. 53. The traverse will include the fewest points from which the entire area can be seen, often only two, and all other features will be located by intersections from these points. Elevations may be taken by slope board or clinometer, the height of the first point occupied being arbitrarily assumed if not known.

If two points can be found which overlook the area in front of them and which are also visible from each other, **the compass may be dispensed with** except for a meridian. Measure the distance between the two points. Assume the position of one of the points and of the line joining them, so as to bring the desired area on the paper. From the first point lay off on the line the distance between the two points to the adopted scale and plot the second point. The line joining the two is called the **base,** and will be near one edge of the board, if all the area to be mapped is on one side of the line, or toward the middle if it is on both sides.

Place the board over the first point; lay the ruler along the base and turn the board until the ruler points to the second point. Keep the board in this position and point the ruler successively to the objects to be located, drawing the lines as explained in par. 53. Gradients are written along the corresponding azimuths. One gradient should be taken to each point determined.

Proceed to the second point Lay the ruler along the base and point it to the first point. Point the ruler to the objects to be located, marking where it crosses the line to the same object drawn from the first point.

66. **Contouring** is a method of exhibiting relief of ground by means of lines so drawn on a map as to indicate points of equal elevation. The lines so drawn on a map and the corresponding lines on the ground are called *contours*. The word *contouring* is applied to the field work directed especially to obtaining data for drawing contours.

The difference of elevation of points in adjacent contours is called the **contour interval,** and is usually constant for all the contours on the same map. The horizontal distance between contours, measured in a radial direction with reference to the curvature of the contours will be referred to as **contour distance.**

The theory of contouring is that no inadmissible error will be made by supposing the slope of the ground from a point in one contour to the corresponding point in the next, or along the contour distance, to be a straight line. The less the contour interval, the less error will be made. If in fig. 28 the curved line *AB* represents the actual surface of the ground, and points 1, 3, 5, the elevation of successive contours, the broken line 1, 3, 5, will represent the assumed ground surface, and its departure from the line *AB* is the error introduced. If now the points 2, 4, and 6 are also determined, or the contour intervals be reduced one-half, the assumed slope is 1, 2, 3, 4, 5, 6, which differs less from the line *AB* than the line 1, 3, 5, and hence introduces less error. With points determined at very short intervals the error is practically eliminated.

If contour distances **decrease** with **elevation,** or the contours become closer as they go higher, the **slope** is **concave,** and points between contours are lower than the straight line joining corresponding contour points. If the contours become closer as the ground falls, the ground is **convex,** or lies above the straight line joining corresponding contour points. A **point of inflection,** or change from convex to concave, is at the point where the contour distance is less or greater than those on either side of it. **Equal** contour distances correspond to uniform slope.

67. One contour does not necessarily join all the points of the same elevation on the map but only those which have a continuous series of points of the same elevation joining them. It may require several contours to take in all the points of a given elevation on the map. Parts of the same contour will appear as separate when the ground over which they could be connected is not on the map. The selection of the points to connect in one contour is the difficult part of the process and can not be done correctly without thorough knowledge of the principles of the method and a good idea of the general shape of the ground to be contoured. In military reconnaissance only enough elevations can usually be taken in the field to guide one who has seen and studied the ground in drawing the contours. No one who has not seen and studied the ground should be expected or permitted to draw contours from such data. Erroneous information may be worse than none at all.

68. For equal contour intervals the map contours are closer together as the slope is steeper. It follows that for steep slopes the map contours will approach each other very closely, and for a vertical wall or cliff they will coincide.

Ground contours can not cross, but map contours may cross in the very unusual case of a cave or a bluff overhanging by an amount which can be shown on the horizontal scale. This is so rare that it is usual to say that map contours can not cross.

Every contour must close upon itself in a loop or else must extend unbroken from one point on the margin on the map to some other point on the margin. An exception is made in the case of large streams, the contour on each bank being carried upstream until it cuts the water surface when it is dropped. The two ends must be directly opposite, fig. 29. In a small stream or dry bed, the contour crosses at the point where the elevation of the bed is that of the contour, fig. 30.

Maximum ridge and **minimum** valley contours go in pairs. A single lower contour can not lie between two higher ones, or a single higher between two lower. When two **adjacent contours** have the **same elevation,** the ground between them will be **still lower** if they are valley, or **still higher** if ridge contours.

69. Contours are designated by their heights above a datum plane. The height is expressed in feet, except when the metric scale is used, when contour intervals are in meters.

The elevation of each contour should be shown in figures at points close enough together to allow the eye to run from one to the other with ease. It is best to break the contours and write the numbers between the ends. If written alongside, the numbers should always be on the higher side of the contour, figs. 31 and 32.

70. Straight contours are very rare. They may be determined by locating any two points, or by locating one point and observing the azimuth of the line.

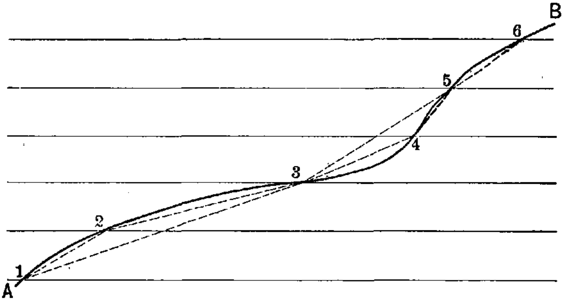


Fig. 28.

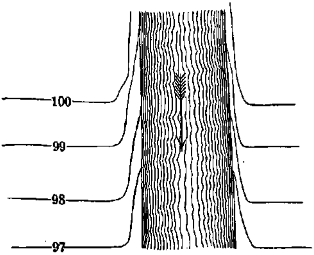


Fig. 29.

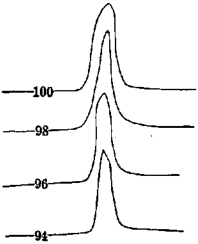


Fig. 30.

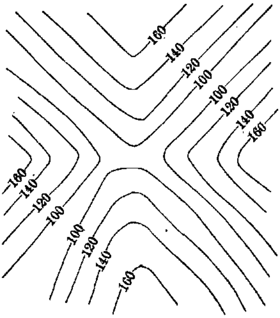


Fig. 31.

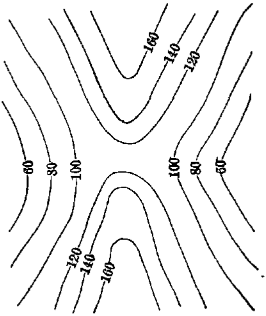


Fig. 32.

Simple curved contours are more frequent than straight ones, but are not often found of any considerable length. They may be determined by fixing 3 points; or by 2 points with the radius estimated; or by 1 point with the center assumed.

The **typical contour** is a **wavy** line, alternately salient and reentrant, and may be determined with the precision needful for hasty reconnaissance by fixing the extreme points of the convex and concave portions.

71. Looking at contours from the higher side, the salient parts, or those concave to the observer, correspond to the ridges, and the reentrant parts, or those convex to the observer, to the valleys. The valleys are also lines of drainage. Hence, half of the points necessary to determine a wavy contour will lie on drainage lines, as indicated by rivers, creeks, brooks, and rivulets, and by ravines, or other depressions dry at most seasons.

The slope of a drainage line grows less in the direction of flow. Tributaries, or branches, are usually steeper than the main stream at their junction, and also increase in slope toward their sources. Generally, in a limited area, the sources will be at nearly the same elevation. To apply this principle in increasing the amount of topographical relief that may legitimately be drawn from a given number of known elevations, let fig. 33 represent the drainage lines of an area taken from a civil map. Suppose the ground to have been studied and elevations to have been determined at 2 points, *A* and *B*. How much topography can be drawn?

The 110 ft. contour will be above the 105 ft. and by a distance somewhat less than the length *AB*, because the slope becomes steeper and the contour distance less in going upstream. The succeeding contours at 10 ft. intervals will cross the tributary at gradually decreasing distances, as indicated, and for the same reason. The source is found to be about 130 ft. Take the other sources to be also 130 ft., and draw the contour at that level, remembering that it is concave where it crosses the streams, and that the part between the streams is convex and advanced. Lay off the contour points on the other stream lines, keeping in mind the law of slopes, and draw the other contours, following the same rule as for the first.

72. If enough elevations were taken on stream lines the concave parts of the contours would be fairly well determined, but the convex points would still be in part uncertain. It is known that they are convex and salient, but not how much. This information is supplied by elevations taken along the ridges, crests, or divides which lie between adjacent drainage lines. The typical profile of a crest is a reversed curve, flat and convex between the sources of streams, flat and concave near the junctions of streams, and steepest in the middle, with the inflection at the steepest point. The form of crests is not so regular as that of valleys, and less use can be made of it. It should be kept in mind as a basis of comparison, so that actual forms can be more readily remembered.

73. **The field work of contouring** an area which has a sufficient relief to exhibit drainage lines clearly may begin by traversing these lines, with gradients taken by clinometer or slope board. It is most convenient to begin where collected drainage leaves the area to be mapped, and follow each valley to its source.

If the valley is open and the flanks of the ridges on each side can be seen, time may be saved by taking level sights from some of the contour points on the drainage line to points on the ridges as far advanced as possible, usually where the line of sight is tangent to the hill. This gives two points, *a a*, fig. 33, near the apex of the salient from which the contour may be drawn often as well as by a point at the apex. If this can be generally done, it may not be necessary to run out the ridges. Notes should be made of the apparent shape of the contours near the drainage line, whether sharp or blunt, or whether the valley is narrow or wide. The general shape of the sky line of the ridge or its projection against higher ground should be noted whenever a lateral view of it can be had.

If hill points can not be taken from the valley traverse, the ridge lines must be run out. They must be connected in plan (distance and azimuth) and in elevation with the drainage lines. When drainage and ridge lines are plotted on the map, the contour points, if not actually observed, may be interpolated and the contours drawn.

The symmetry of adjacent contours is obvious from the inspection of any contoured map, and this relation may be utilized where one contour has been well determined,

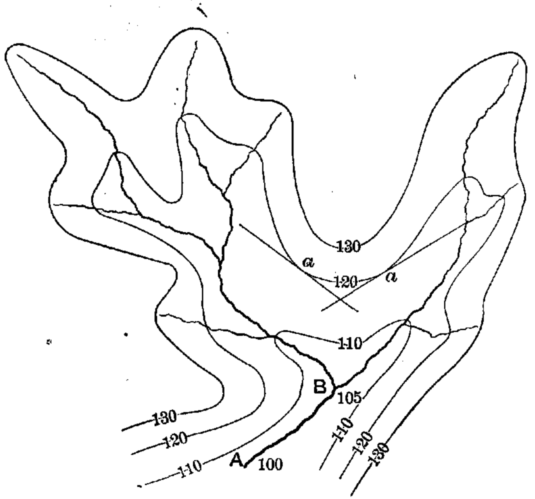

130
a
120
a
110
B
105
130
120
110
A
100
110
120
130

Fig. 33

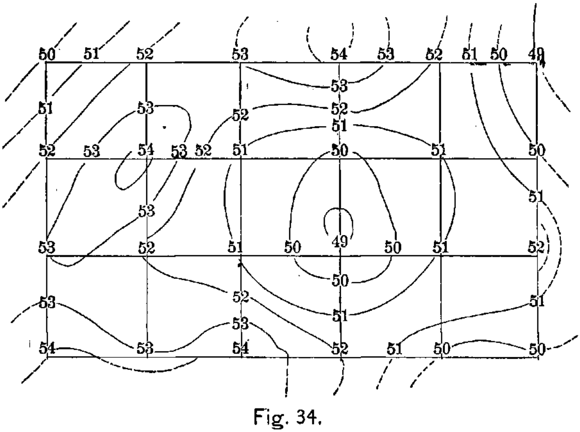

50
51
52
53
54
53
52
51
50
49
53
52
51
53
52
51
52
53
54
53
52
51
50
51
50
53
51
53
52
51
50
49
50
51
52
50
52
51
53
51
53
53
54
53
54
52
51
50
50

Fig. 34.

to draw the one on either side of it from a very few points, often but one. If the contours are wavy, they will generally be a little farther apart at the concave and convex points than at the reversion points between them. If the contours are not wavy, they are generally parallel.

74. If the **relief** of the ground is so **slight** that the drainage and ridge lines are uncertain, the field work of contouring is best done by taking elevations at points arbitrarily selected Such points will usually be in straight lines running in the general direction of the steepest slope. The points are plotted on the map, the corresponding elevations written near them, and the contours are interpolated as indicated in fig. 34, assuming that the surface of the ground between observed points is a straight line. The closer the points are together, the less error is involved in this assumption.

If the country is comparatively flat and unbroken, profiles may be run along roads and paths, and contours sketched in on each side so far as they can be seen. Then by going over the intervening ground and observing its shape, the portions drawn can be joined with the eye with sufficient accuracy.

In towns and villages profiles along intersecting streets and the study of the intervening space furnish data for approximate contours.

75. **Slope equivalents.**—Actual distances between contours on a map depend on the contour interval, the scale of the map, and the gradient. For any given map the contour interval and scale are constant and the distances between contours depend on the slope alone. On any map with contours at equal intervals each gradient has its corresponding contour distance, which is called its **equivalent.** A line subdivided to show the equivalents of various gradients on any map is called a **scale of slope equivalents** for that map, or simply the **scale of slopes,** and by applying such a scale to the distance between two successive contours the slope of the ground between them may be read off.

For different maps slope equivalents vary with the ratio between the contour interval and the scale. A scale of slope equivalents may be constructed for a given ratio and will be true for all maps having that ratio, no matter how much the scales may vary. The ratio may be taken as the fraction of an inch on the scale of the map corresponding to the contour interval. If the scale of the map is 500 ft. to the inch and the contour interval 1 ft., the ratio is $\frac{1}{500}$ or 0.002, which is the fraction of an inch corresponding to 1 ft. on a scale of 500 ft. to the inch. If the scale is 1,000, 5,000, 10,000, or 50,000 ft. to the inch, and the corresponding contour interval is 2, 10, 20, or 100 ft., the ratio in each case is $\frac{1}{500}$ and the contour interval corresponds to 0.002 in. on the scale of the map and a scale of slope equivalents corresponding to the ratio applies.

Fig. 35 contains scales of slope equivalents for ratios of $\frac{1}{500}$ to $\frac{1}{5000}$, which will cover the usual range.

To get any desired scale of slope equivalents from the figure, divide the number of feet in the contour interval by the number of feet per inch of the scale, or divide the number of *inches* in the contour interval by the denominator of the R. F. The result is the **ratio.** Place the straight edge of a piece of paper horizontally on the diagram and passing through the corresponding point on the ratio scale on the left of the figure, and prick off the scale.

Slope equivalents afford a convenient and rapid method of determining contour points on any line of a map the gradient of which is known.

Any fraction of the equivalent for any slope corresponds to the same fraction of the contour interval. If an end of the line is on a contour, the slope equivalent may be stepped off along the line and each point so determined will be a contour point. If the end of the line is between contours, measure off on the line the part of the slope equivalent corresponding to the rise or fall to the next contour point. From this step off the slope equivalent as before. If a fractional distance remains at the end of the line, find what part of the slope equivalent it is, and add to or subtract from the last contour elevation the corresponding part of the contour interval for the elevation of the end of the line. To illustrate: If in fig. 36 elevation at a of the line ab is 103, gradient $+2°$, the contour interval 10 ft. and the slope equivalent cd, then the rise to the next contour is $110-103=7$ ft. or $\frac{7}{10}$ of the contour interval. Seven-tenths of $cd=ae$, and hence e is the position of the 110 ft. contour point. Lay off

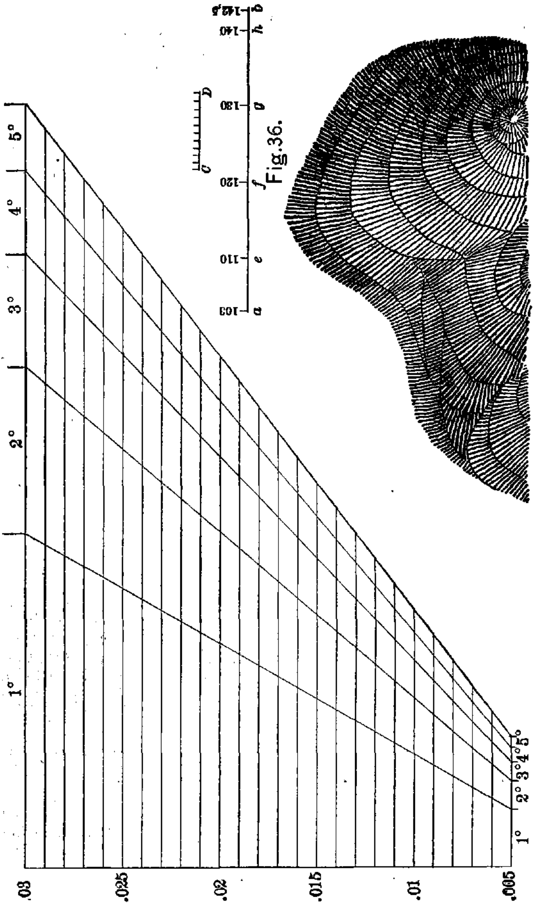


Fig. 35.

Fig.36.

Fig.37.

ef, *fg*, and *gh* = *cd* and locate the 120 ft., 130 ft., and 140 ft. contour points. The remaining distance *hb* = ¼ of *cd*, hence the rise beyond *h* = 2½ ft. and the elevation of *b* = 142.5.

76. In the absence of contours relief may be indicated by **hachures,** which are short parallel or slightly divergent lines running in the direction of the steepest slope. Hachures should be used only to indicate areas which present slopes steep enough to offer cover or become obstacles. The use of hachnres is illustrated in fig. 37.

77. The **reconnaissance with a moving column** will require the simultaneous work of a number of sketchers and must be so organized that each sketcher shall do his full share in the time allowed; that the sketches and reports shall be turned in about the same hour, and that the assigned ground shall be thoroughly covered without unnecessary duplication.

A good sketcher on foot can take about 10 miles of road in a day, or can keep up with a slowly advancing column. A good sketcher mounted can cover 15 miles a day steadily, or in an emergency 20 or 25, and can keep up with infantry on a forced march or with cavalry marching at ordinary rate.

The reconnaissance for a column should include besides the road traveled the nearest parallel road on each side and all connecting roads between them. Each mile traversed by the column on the main road will thus involve 2½ to 5 miles of sketching.

If a reconnaissance is to be made when a force is not in motion, the area to be covered will usually be so large and the time allowed so short as to make it necessary to combine the work of a number of sketchers.

78. ***If any map is available,*** the area to be reconnoitered should be outlined on it and snbdivided into as many parts as there are sketchers, the parts to be made equal, not in size necessarily, but in amount of work aud time reqnired, the important point being that all the parts shall be finished at the same hour.

Each of these parts is assigned to a sketcher, with full instrnctions as to the amount and class of work to be done, the scale to be used—which should be the same for all —and the place and hour at which the sketch must be turned in. If practicable, each sketcher should be given a tracing or copy of enough of the map to show the boundaries of his own task and the adjacent features of those next to his.

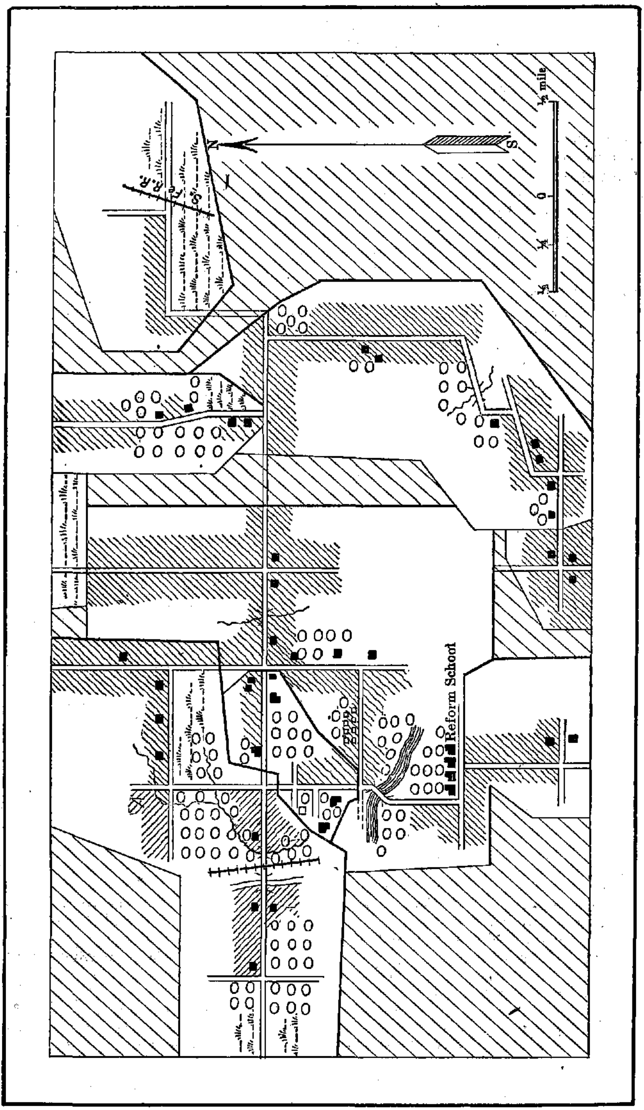
If there is **no map,** the area may be indicated by landmarks, but it will be usually necessary, and always desirable, to go over the ground and point out his task to each sketcher. When boundaries are definite, there need be very little overlapping. The amount of reduplication must increase as boundaries become more vague.

79. The area to be mapped may be divided np in any convenient way, but it is best to use roads, fences, streams, or other well-defined lines as much as possible. Lacking these, compass courses passing through well-defined points will answer.

In a road sketch one man should be assigned to the main road or that on which the column is marching. Others will be assigned to such parallel and intersecting roads as it may be necessary to map. So far as practicable, side parties should leave the main road by an intersecting road, traverse a short stretch of parallel road, and return to the main road by another cross road.

80. **Compilation.**—The sketches when turned in are consolidated, usually by pasting them in their proper relative positions on a large sheet of paper, or else by pasting them together at their edges so that corresponding features will join. If one of them does not exactly fit, as will often happen, the adjustment is best made by cutting the sketch into two or more pieces and moving them with respect to each other so as to absorb the discrepancy. Thus, if a piece of road is half an inch too short, cut it at three or four places on lines perpendicular to the road and separate the pieces by a sixth or eighth of an inch. If too long, overlap the pieces instead of separating them. If a road or other feature is out of azimuth, make a cut through one of its ends and swing it into place. These operations may be combined. The adjustment is rapid and sufficiently exact. If a sketch is too much out to be adjusted by this process, it will usually be of little value and time will be saved by leaving it out of the compilation and filling in the gap freehand, using the sketch as a guide.

Fig. 38 illustrates this method of adjustment.


N
S
½ mile
0
¼
½
R. R.
Reform School

81. **Reproduction.**—As many copies of the map will be made as circumstances may require. The first step is to divide the map into sections of convenient and usually equal size, and make a tracing of each. The size of the sections will usually be determined by the method of reproduction to be used and the size of the apparatus at hand. Time will be saved if there are not more sections than there are men available to trace, supposing that all the tracers are of approximately the same speed. If one of them can work two or three times as fast as the average, two or more sections should be reserved for him, the idea being that the work will be done in the shortest time if so arranged that all finish at once.

With fairly expert sketchers, it will be possible to have each ink his work before turning it in. A useful expedient in case of great haste is to make the sketches themselves transparent by oiling and fasten them together for use instead of a tracing.

82. The tracing made, further processes depend upon the time available and whether the work can be done in daylight or must be done at night.

Of processes requiring sunlight, the most reliable, simplest, and quickest is the **blueprint process.**

The prepared paper may be purchased in rolls of 10 or 50 yds. It should be put up in tin foil and each 6 or 8 rolls should be in a sealed tin case; it will then keep in good condition for a long time. If necessary to sensitize the paper in the field the following solutions must be prepared:

		Ounces.
Stock solution A	Citrate of iron and ammonia	2
	Water	8
Stock solution B	Red prussiate of potash	2
	Water	8

For use mix 4 parts of **A** with 3 parts of **B.**

Unprepared paper may be purchased in 50-yard rolls. To sensitize the paper a sheet of the desired size is cut from the roll and placed on a flat surface; the mixed solution is applied with a sponge to the upper surface in a smooth, even coat, care being taken not to wet through to the back of the paper. The sheet is hung up in a dark room until dry, when it is ready for use. Only enough paper for a day's use is sensitized at one time, for it does not keep well.

The exposure takes from four to eight minutes in bright sunlight, varying with the intensity of the light and the transparency of the tracing Under other conditions than sunlight a much longer exposure is required; sometimes an hour or more. Care must be taken that the paper is not taken from the frame before it has been sufficiently exposed. When the margin protruding from under the tracing has a greenish-bronze color, open one part of the back of the frame and observe the print. The lines should stand out sharp and distinct on a gray hackground. Take the print from the frame and place it in a tray containing water sufficient to fully cover the print. Rinse it until the lines stand out in clear white, then hang up to dry. It is to be remembered that the fresher the paper is the slower it will print and the quicker it will wash out; the older the paper is the quicker it will print but the slower it will wash.

Additions and alterations may be made to blueprints with a 10% solution of oxalate of potash used as an ink. If it shows a tendency to run, add a very little mucilage. Common soda may be used, but the lines have a yellowish cast instead of the pure white which the potash gives. Additions and alterations of a drawing are conveniently made by inking the lines of a blueprint with waterproof liquid india ink and removing all the blue color by the potash or soda solutions. The black lines then remain on a white ground. They take well in photographing, and by treating the paper with oil, it becomes transparent enough for contact printing, being used in place of a tracing and in the same way.

Brown prints.—Next in point of simplicity for daylight use is the **brown-print process.** It is in many respects the most satisfactory of the copying processes. The paper is purchased prepared.

After exposure for about two minutes in bright sunlight, the margin protruding from under the tracing turns from its original light yellow to a reddish-brown color. The print is then taken from the frame, immersed in water, and thoroughly rinsed on both sides, when the lines come out in perfect white on a sepia-brown ground. It is then immersed in a fixing bath made from the salt which accompanies each roll of the paper (2 ounces of fixing salt to 1 gallon of water); this makes the print permanent and also darkens the sepia-brown color, the lines remaining white. After fixing, the print must be thoroughly washed for twenty to thirty minutes and then hung up to dry.

The brown color being impervious to light makes this paper very valuable for negatives which may be used to produce positive copies, either with the blue or brown print papers, yielding an exact reproduction of the original in either blue or brown lines on a white background. In making the positive prints from the brown-paper negatives the time of exposure is somewhat longer, since the brown-process paper is not as transparent as tracing cloth or tracing paper. Even very fine lines of the original are reproduced with surprising distinctness, due to the fact that in both manipulations the original is in direct contact with the sensitive side of the paper, so that no light can enter sideways under the lines.

By making several negatives and printing from them simultaneously, the rate of reproduction may be largely increased.

83. **For printing by artificial light** bromide papers are used. A contact print from the tracing has clear white lines on a very dark brown ground. The contrast is clear and agreeable. Alterations may be made with a sharp red pencil, which makes a legible line, or by scratching through the emulsion, which makes a white line. A print can be obtained quickly from the light of three candles at 12 ins. distance.

To **develope bromide prints** make a stock solution of hydrochinon, 150 gr.; sodium sulphite, 360 gr.; water, 12 oz.

For use, to 1 oz. of stock solution add 1 dr. rodinal and 8 oz. water; or, make stock solution of metol, 150 gr.; sodium sulphite crystals, 2½ oz.; sodium carbonate crystals, 3½ oz.; bromide potash, 8 gr.; water, 20 oz. For use, add 1 oz. stock solution to 4 oz. water.

Acetic acid is used to clear bromide prints after development and to stop the action of the developer, 16 oz. water to 1 dr. acetic acid.

For **fixing bromide prints** use hyposulphite of soda, 1 oz.; water, 6 oz. A little alum added to the fixing bath in hot weather hardens the film.

A bromide print may be made transparent by oil and used for contact printing by artificial light. It will be better, though not essential, to secure a paper for negatives thinner than that usually supplied for prints.

The **cycle of operations** for quick reproduction by the bromide process is as follows:

From a tracing or transparent drawing make, say, 3 to 5 negatives. Make them transparent and start printing from all of them. If the sketchers are in by 5.30 p. m. the negatives can be ready for printing by 7 p. m., and after that prints can be turned out at the rate of 15 per hour from each negative. It should not be difficult to have all that are needed for the next day done by 9 p. m.

84. **Transfer processes.**—With the **hectograph** the drawing is made in a special ink and pressed face down on the surface of a gelatin compound in a metal pan. When the paper is pulled off the drawing appears reversed on the gelatin surface. A piece of blank paper pressed on the surface and then withdrawn shows the drawing direct in purplish lines. Fifty to 100 impressions may be taken. Each print is covered with a thin film of the compound and is sticky, curly, and very stubborn. The process is at best only a makeshift, but it is the easiest of all to improvise, and the simplest to operate. For quick work several pans should be provided, as each must be washed after use and should not be used again until well dried.

The hectograph compound is made of—	*Parts.*
Glue or gelatin	100
Glycerin	400
Water	400

Kaolin, 50 parts, or some fine inert light-colored powder, may be added with advantage. The ingredients require prolonged mixing at 200° F., which is best obtained in a salt-water bath, 2 oz. salt to 1 pt. water.

The ink is made of—	*Parts.*
Nigrosine black	1
Glycerin	4
Water	14

Writing or drawing is done with a fresh, clean steel pen. The surface of the compound is moistened lightly with a brush or sponge and allowed to **nearly dry**, when the copy is laid smoothly on face down and rubbed to a good contact throughout, eliminating all air bubbles. The paper is allowed to remain two or three minutes and then removed by starting one corner and pulling parallel to the surface. The sheets for impressions are put on and removed in the same way, except that they are left on but a few seconds.

With the **black autocopyist** the drawing is made in a special ink and transferred to a parchment sheet held in a special frame. This process is free from some of the objections to the hectograph, but it is more difficult to work. The copies are in printer's ink, are permanent, and very satisfactory.

85. **Landscape sketching.**—Free-hand sketching can not take the place of topography, but it is a valuable adjunct and should be practiced by every soldier who has any aptitude for pictorial drawing.

A sketch differs from a photograph only in that it shows in sharp outline a limited number of the larger and characteristic features easily seen and understood, while the photograph shows all details, many of them so minute that they are lost in a mass of confused forms, with the form lines, other than the sky line, relatively inconspicuous. All the lines of a perfect sketch exist in a photograph, but close scrutiny is often necessary to find them. If sought out and traced, however, a perfect sketch results. Tracing from photographs is excellent practice.

The outfit for field sketching should be as simple as possible. A sketchbook with a canvas cover, carried in a water-tight case, together with a few lead pencils B, F, and H, and pieces of soft and hard rubber are the essentials for satisfactory work. For active field work the book should be no wider than can be carried in the pocket of a service blouse, and relatively long, say 5 by 9 ins.

The **point of view** should as a rule be high enough to give a comprehensive grasp of all that is important—a rock, a knoll, a hill, a peak—depending upon the conditions. Face toward the middle of the field of view which is determined upon. Hold the board or sketchbook vertically before the eye and move it backward or forward until the sheet just fills the field. Lower the board until the sky line of the hills can be seen above its top edge, and with a pencil mark on that edge the points corresponding to the principal salients and reentrants of the hill forms. If desirable the board can be moved sideways far enough to enable the principal heights and depressions to be marked on the vertical edge. By intersecting references the locations can then be easily established on the sheet. From these points the forms can be sketched in with much greater accuracy.

Proceed next to draw the hills in outline, but faintly, with attention to the larger curves or humps at first. Go over them again with more care, bringing out the small irregularities. If any part of the horizon is visible, draw in lightly, and then complete the general mass of hills by drawing the water or base lines. Seek now for the surface character of the hills by tracing the ravine lines. The knobs and foothills are brought out by tracing the tree meanders that show form. All changes in form or breaks in the ground produce corresponding breaks in the foliage of the tree masses, which show in the distance as irregular lines. If the more important of these are sought and drawn, the general character of the hill will result. Add now the foreground crest, and the skeleton of the sketch is complete.

The road and railroad meanders should follow as a rule, and the fences of the fields. Cultivated land is rendered by parallel irregularly broken lines. Houses, fortifications, trenches, etc., will be drawn more or less in detail according to distance and importance. Enemy's lines or trenches even at a great distance should be strongly marked by simple black lines. The indication of forests and trees is the most difficult feature for students. The indications given in the accompanying sketches will show the treatment in outline work.

Figs. 39 and 40 show a variety of forms sufficient for most localities.

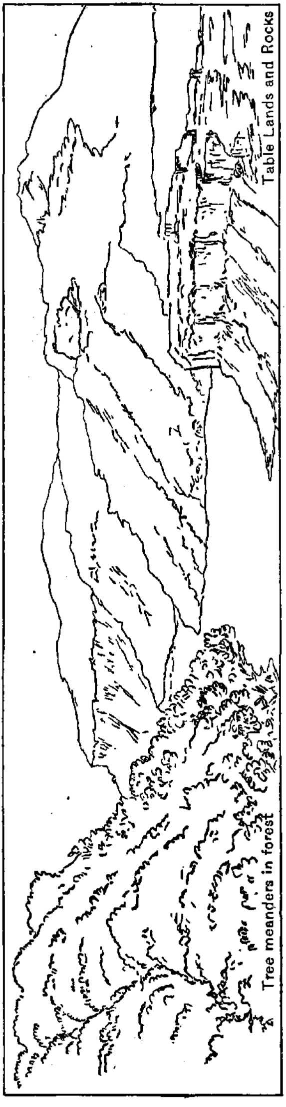
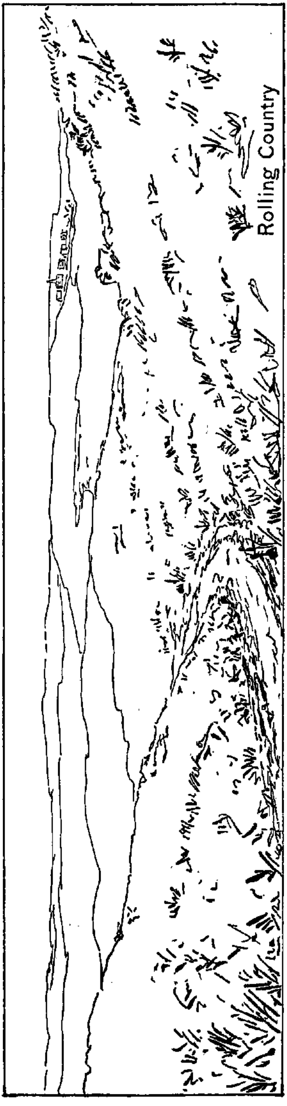
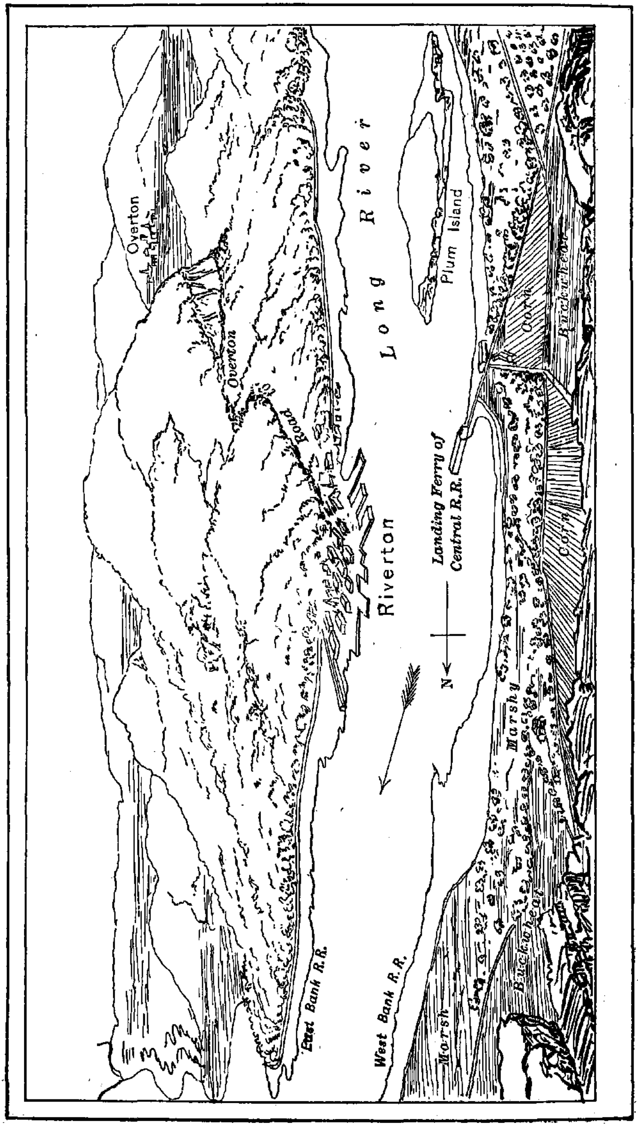


Table Lands and Rocks
Tree meanders in forest


Rolling Country


Overton
Overton
Road
Long River
Plum Island
Riverton
Landing Ferry of
Central R.R.
N
Marshy
Corn
Buckwheat
Corn
Buckwheat
East Bank R.R.
West Bank R.R.
Marsh

86. **Hydrography.**—Depth of water and character of bottom are determined by sounding with a pole or with a lead and line. **The sounding pole** may be improvised, or of permanent form. A convenient one is 10 ft. long, octagonal in section, tapering slightly from middle to ends, divided into feet which are painted alternately white, and black or red. There should be an iron shoe at the bottom, heavy enough to make the rod stand erect when free in deep water. Such a rod is convenient to use in water 9 ft. or less in depth.

If a sounding lead is not furnished, any compact weight may be used. The **sounding line** should be of braided hemp or cotton, $\frac{3}{8}$ to $\frac{1}{2}$ in. in diam., and tagged with cloth or leather. The tagging will depend on the depth to be measured, and degree of precision required. Cloth of different colors may be used for different units, and leather tags may be distinguished by cutting notches or punching holes in them. The line should be thoroughly wet, stretched, and allowed to dry. It should then be wet again and tagged while wet. The zero of the graduation is at the bottom of the lead or weight. A lead and line are best connected by a rawhide thong passing through an eye in the lead and an eye made in the end of the line.

Soundings are usually referred to a plane parallel to the water surface, horizontal except in flowing streams. The plane usually selected is the water surface itself if stationary, or one of its positions if variable, so that soundings will indicate approximately the actual depths of water. The elevation of the water surface in the position selected is called the **datum level.** If the surface elevation varies, a gauge rod must be set near the water's edge, and read often enough to plot a continuous curve of water level. The time of beginning and ending a particular group of soundings is noted. The mean elevation of the water surface during that interval is taken from the curve, and the soundings are corrected by the difference between the actual level and the datum level. If the correction to be applied is less than half a foot, it is usually neglected.

The material of the bottom, as rock, gravel, sand, or mud, can usually be told from the feeling of the rod or lead when it strikes. A specimen of the bottom can be brought up by smearing the end of the lead with tallow.

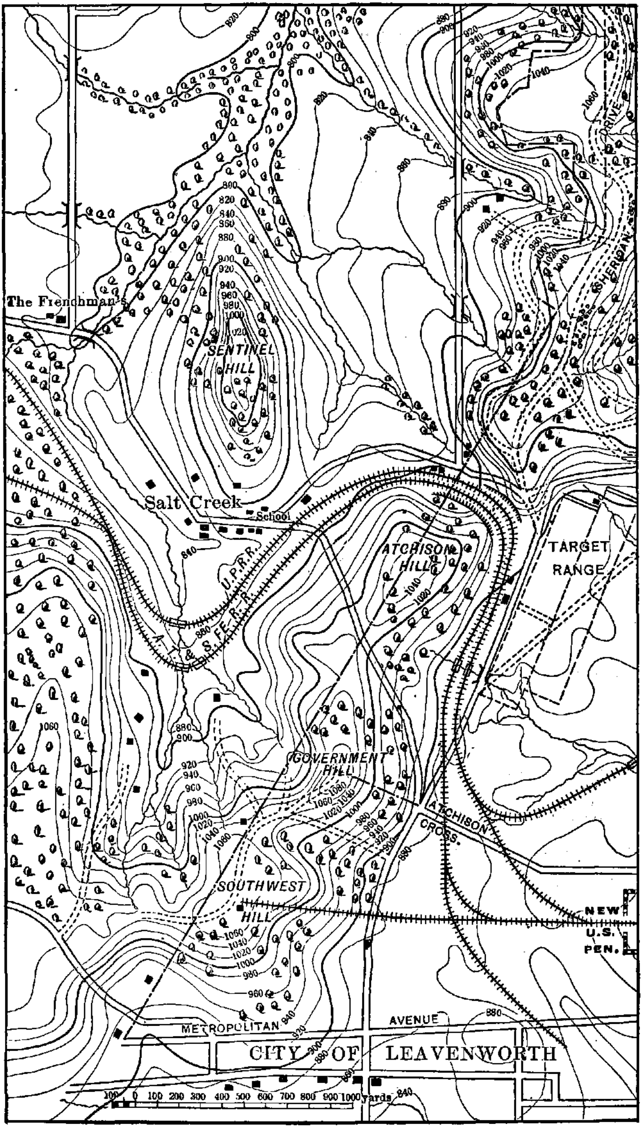
A correct sounding is obtained only when the line or rod is plumb and straight and its length correct, or its error known and applied. Except for blunders in reading the line, only one source of error operates to make the soundings too small, and that is a line which has stretched since it was tagged or is too long. All other sources of error make the soundings too large, and hence they are apt to be so, and actual depths slightly less than those recorded will usually be found.

To get a plumb sounding from a boat moving through the water, the lead is thrown out or the pole inclined in the direction of motion far enough to allow it to reach bottom by the time the boat is directly over the spot where it strikes. Soundings taken with a line from a moving boat will always be too large.

The most accurate soundings with lead and line in running water are taken from a boat floating with the current, with line allowed to hang and move with the water. It is raised only a foot or so between soundings, just enough to clear the bottom.

87. **Location of soundings.**—The simplest method is by two simultaneous azimuths from known points on shore. If the soundings are taken on a line passing through one of the points, all azimuths from that point will be constant, and one measurement will suffice. This line is plainly marked by range flags and the boat's crew instructed to keep the flags in range. Only one instrument and observer are required. This is the usual method for streams and is best for all work where the soundings can be taken in straight lines. **Locations** may be made **from the boat** by two observers taking simultaneous compass bearings to two known points on shore—see resection—or by two simultaneous sextant angles. The latter is less convenient, as a special protractor is required for rapid plotting.

88. The following notation or its equivalent should be made on a map or chart containing soundings: "Soundings are in feet (or meters) and are referred to the stage of water at (location of gauge) at —— o'clock, on the —— day of ——. The elevation of this datum level is —— ft. (or meters)." If the reference plane is inclined, add: "and its inclination is —— in a —— direction." The first blank is filled with the rate of fall expressed in any recognized way, and the second with a compass bearing.


The Frenchman's
SENTINEL HILL
Salt Creek
School
U.P.R.R.
A. T. & S. FE. R. R.
ATCHISON HILL
TARGET RANGE
SHERIDAN DRIVE
GOVERNMENT HILL
ATCHISON CROSS.
SOUTHWEST HILL
NEW U.S. PEN.
METROPOLITAN AVENUE
CITY OF LEAVENWORTH
100 0 100 200 300 400 500 600 700 800 900 1000 yards

89. **Map reading** is essentially the reverse of map making. In the latter process ground is measured and studied with a view of forming a mental picture of how a map of it will look. In the former—map reading—a map is measured and studied for the purpose of forming a mental picture of how the ground itself looks. All rules and principles heretofore stated as to relations between ground and map are to be used in studying the relations of map to ground.

The following suggestions will aid the beginner:

Note the meridian on the map and associate it in the mind with the local meridian. This may be done by turning the map so that the meridian will point to the north, using the compass as a guide if necessary. If there is no meridian on the map, look for indications of direction in local names, or for some road, stream, ridge, or other feature the general direction of which is known.

Note the scale of the map. Estimate certain distances, as the total width or total length or distance between prominent points and test these estimates by scaling. If there is no scale, look for some indications of distance. It may possibly be found in local names, as Three Mile Creek, Two Mile House, etc.; roads uniformly spaced, as the U. S. land surveys; city blocks, which are usually about 100 yds. on the shorter side; railroad stations or sidings, the distance of which may be taken from time tables. If the map has parallels of latitude a good scale may be drawn by assuming 69 miles to each degree, or 1.15 miles to each minute. If the ground is accessible, take two convenient points shown on the map and measure the distance between them.

If the map is contoured, **note the contour intervals** and the scale of slope equivalents. If the contours are not numbered, decide which are the high and which the low ones. Closed contours are much more likely to be elevations than depressions, especially if several are concentric. A single closed contour may be uncertain. Look for indications of marsh or water inside of it. If the contour interval is not given, it will be difficult to get any clue to it unless isolated elevations appear on the map. If the ground is accessible the contour interval may be determined by actual measurement of a gradient.

Note all topographical and cultural signs, and associate them in mind with their advantages or disadvantages for military operations.

90. A problem frequently arising in map reading is that of determining **what points are visible from a given point.** A point is visible when the gradient to it, if rising, is greater, and if falling, is smaller than the gradient to any intermediate point.

For this comparison gradients are conveniently represented by the quotient of distance in ft. divided by the difference of elevation in ft. The point will be visible when this quotient is smaller, if rising, and larger if falling, than the quotient for the intermediate point. Thus, to determine whether the bridge near the Frenchman's, fig. 41, is visible from Atchison Hill or is concealed by intermediate ground, assume the highest point of Atchison Hill to be in the center of the 1,040 contour and to have an elevation of 1,050. The distance from this point to the bridge is 5,610 ft., fall 250 ft., quotient 22.4. The line of sight from this point to the bridge crosses the 960 ft. contour on the flank of Sentinel Hill at 3,060 ft. distance, fall 90 ft., quotient 34, hence bridge is not visible from Atchison Hill, since the gradient is falling, and the nearer point has the larger quotient.

Working from the bridge the quotient for the whole distance is 22.4, as before, but the gradient is rising. The distance from the bridge to the high point is 2,550 ft., rising; difference of elevation 160 ft., quotient 16, hence, as before, the top of Atchison Hill is not visible from the bridge, since the gradient is rising, and the nearer point has the smaller quotient.

If one gradient is rising and the other falling, no computation is necessary. A point of rising gradient will hide a farther point of falling gradient, but will not be hidden by a nearer one. See par. 90*a*, p. 78.

91. **Drawing.**—The essential requirements of a good topographical drawing are *accuracy* and *clearness*. By accuracy is meant a faithful exhibit of measurements and observations made in the field, or of data taken from other maps. Clearness involves absence of confusion or crowding, and neatness in execution. **Beauty** and **pictorial effect** are obtainable by skilled draftsmen only, and while always desirable, are

rarely necessary. Persons who are not skilled draftsmen should not attempt pictorial effect, as it will detract from accuracy and clearness without substituting anything of equal value.

Avoid unnecessary haste in plotting and drawing. If possible, take time to check carefully all azimuths and distances plotted and be sure they are exact. There should be no approximation on the drawing board. Although an observer may have simply guessed a distance to be 550 yds. in the absence of other information, the plotter should be careful to lay it down at exactly 550 yds.

Start with clean paper and keep it as clean as possible In the office, wipe off the instruments before using, especially rulers, scales, and triangles. Dust the drawing carefully before beginning work. Dust again when stopping and cover with a cloth or paper. If necessary, dust the drawing and wash the hands occasionally while at work.

Make all ink lines firm and very black. A drawing to be made in ink is usually drawn first in pencil, and in such cases a very hard pencil (4H or 6H) is best. If the pencil drawing is to be traced, a softer and blacker pencil should be used, but must be kept well pointed.

India ink in stick form gives the best results, but the time required for proper grinding precludes its extensive use in military field work. The prepared india inks in liquid form are ready for use and are satisfactory. They must be kept well corked when not actually filling a pen. If the ink gets thick in the bottle so that it will not run freely from a fresh-filled pen, add a little water.

The **ruling, or right-line pen,** figs. 42 and 43, is best for making lines of uniform thickness. The points must be kept clean, and when worn must be ground on a very fine stone to the form shown and to exactly equal length. The points may be closed and the ends shaped together, which will make them identical. Then open the points and grind each on the outside to a proper edge. Right-line pens are set to make lines of different thicknesses by the screw *D*, but the range for any one pen is limited, and different sizes of pens are made. A very fine line can not be made with a coarse pen, and it is difficult to make a very broad line with a fine one. The points should never touch. If a line made with the points slightly separated is too coarse, take a smaller pen. These pens are graded by the length over all. Five inches is a medium and useful size.

Right-line pens may be filled by dipping an ordinary pen in the ink and inserting it between the points. A strip of paper closely folded may be used in the same way. In the bottles of prepared ink the cork carries a small quill for filling. Take only as much ink as can be used in two or three minutes. As soon as the flow becomes the least sluggish, the pen should be emptied and refilled. To empty or clean the pen, pass a piece of paper (the corner of a blotter is excellent) between the points.

The adjusting screw should not be disturbed while working on lines of the same thickness. When changing from one thickness to another, open the pen and clean more thoroughly. To reset for a given thickness, draw a short length on a scrap of paper and lay it alongside of a line of the desired thickness, previously drawn. The difference will be seen, the pen can be changed and another trial made, and so on until the lines are matched.

For ruled lines the ruler or curve is laid in the proper position and the pen drawn along the edge, lightly pressing against it. The pen should be held with the plane of its points perpendicular to the plane of the paper and in the direction of motion. The handle should be slightly inclined in the same direction. For free-hand lines, as contours, hold the pen in the same way and move the hand so as to cause the points to follow the line.

In ruling with a writing pen, choose one of a size which will make a line of the required thickness without pressing on the paper. Dip the point only in the ink. If the ruler has a beveled edge place it with the top projecting. A curve or a ruler not beveled should be raised slightly from the paper. The pen should not be inked above the point which touches the ruler. It is held as described for the ruling pen. Parallel lines close together may be drawn with one setting of the ruler by inclining the pen slightly.

Writing pens are best for stream lines. When it can be done, vary the size of the pen to suit the thickness of line. When using a writing pen free-hand do as much of the work as possible by drawing the pen toward the body in about the direction of the down stroke in writing.

For lettering, signs, and all free-hand work with the writing pen, keep the pen clean and freshly inked and the ink free from dust and of proper consistency to flow freely without dripping from the pen in blots.

In using a circular pen, fig. 43, set the legs of the compasses so that they will span the right distance and the pen point will be vertical. The lead of a pencil point should be sharpened to the shape of the ruling-pen points with the flat side toward the pivot leg of the compasses. When using compasses with pen or pencil, incline them slightly in the direction of motion and rotate the head between the thumb and forefinger. Very slight pressure only should be necessary beyond the weight of the instrument.

Fig. 46 represents the most convenient instrument for measuring the length of curved or broken lines on a map. The small wheel is run over the line and its length in the unit of the instrument is read from the dial. This length is converted into actual length by the scale of the map.

92. **Papers.**—Manila paper of cream or buff tint, usually called **detail paper**, is suitable for sketches and drawings which are to be traced or used in the field. Only the better grade stands erasing and that imperfectly. This paper comes in rolls 36, 42, and 54 ins. wide. It may be ordered by the pound or yard.

White drawing paper may be had in rolls or sheets mounted on muslin or unmounted. Whatman's cold-pressed fine-grain is most generally useful. It comes in sheets of names and sizes as follows: Royal, 19 x 24 ins.; Imperial, 22 x 30 ins.; Double Elephant, 27 x 40 ins.; Antiquarian, 31 x 53 ins. Roll papers are 27 to 63 ins. wide.

Sheet papers unmounted and kept flat are best for field topographical use.

93. If a blot drops on the drawing take a piece of blotting paper, tear a corner or edge to expose a fresh surface, and hold it in the blot without touching the drawing until the surplus ink is absorbed. Then press a dry blotter firmly on the spot and let it dry thoroughly before attempting to erase. A piece of newspaper may be used instead of blotting paper, but should be slightly moistened to hasten the absorption. For a large blot several pieces may be required.

94. **Erasers** for ink are of steel or rubber. A steel eraser or penknife must be very sharp to give good results. An eraser of gritty rubber is most generally used. It is best to use an erasing shield of thin metal or celluloid, fig. 44, which exposes the area to be erased through one of the openings and protects the rest.

95. **Tracing linen** is usually *dull back*, having one side glazed and the other dull. Erasing can be done on the glazed side only. The glazed side is used for ink and the dull side for pencil work. The glazed side requires preparation before use to remove excess of paraffin, which prevents ink from running well and clogs the pen. Rubbing hard with fresh blotting paper is the simplest method.

Tracing paper is alike on both sides. It will not erase. Most varieties are less transparent than tracing cloth.

In tracing it is helpful to use a dull-pointed instrument in the left hand—a stylus or top of a penholder—to press the linen against the drawing at the point where the pen is resting.

ADDENDUM, 1907.

56*a*. A handy device, easily improvised, for attaching a compass to a book or other object to orient it for use as a plane table, has been proposed by Lieut. E. K. Massee, Seventh Infantry. It is shown in fig. 60*a*. The material used should be non-magnetic.

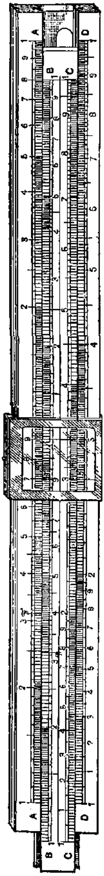


Fig. 47

Fig. 45

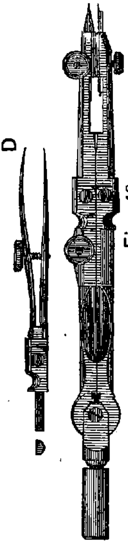


Fig. 43

Fig. 42

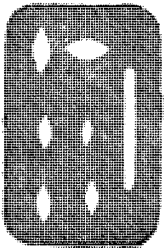


Fig. 44

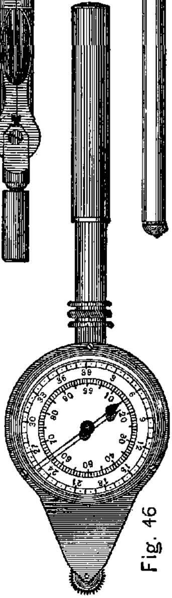


Fig. 46

96. **Conventional signs.**—The symbols or signs used to represent topographical features are designed to be rapidly made and readily understood, and to resemble or suggest the actual features they represent. Multiplicity of signs is not desirable, and a verbal designation or description of the features is often more intelligible and more quickly recorded. For instance, it is better to write the names of the growing crops of a district, as tobacco, corn, or cane, than to cover the entire area with a symbol. Another method of expediting mapping is to surround an area with a narrow border of the proper sign and leave the middle blank.

The commonly used signs are given in figs. 48 and 49. See also par. 96*a*, p. 128.

97. **Titles, notes, etc.**—Every finished drawing should have a descriptive title, consisting of—

(1) The designation of the organization under whose auspices it is made, as **Engineer Department; Bureau of Insular Affairs, War Department; Division of the Philippines; 1st Division, 2d Corps.**

(2) Its kind, as **map, sketch, plot, plan, profile, section**, or **elevation**. If more than one kind of drawing appears on the sheet, each should be mentioned in the title, as **Plan and sections of battery; Plan, section**, and **elevations of guardhouse**, etc.

(3) Its subject, if it relates to a particular object, feature, or purpose.

(4) Its locality. This and the preceding may be interchanged in position.

(5) Its sources, as **Compiled from, etc.; Reduced from, etc.; From a survey, etc.**

(6) Its authorship. If the work has been done by one person, acting nnder the instructions of another, both should be named, as *under the direction of Colonel* **John Doe,** *General Staff*, by *Captain* **William Roe,** *1st U. S. Infantry.*

(7) Its date.

(8) Its linear scale; its contour interval; its scale of slope eqnivalents.

Titles should be adapted in size and boldness to the size and importance of the sheet. They should be divided into lines, following mainly the divisions just stated. The middle letter of each line should fall on a line drawn vertically through the middle of the space allotted to the title. Lines should be alternately long and short, and if the long lines are symmetrically disposed, the effect is better.

To prepare a title, write down the matter under the various heads, with proper connecting words, and divide it up into lines. Then block out the title, observing the division of lines decided upon, and make such alterations as seem desirable. Finally, letter the title on the map. The following is an example:

Division of the Philippines. | Sketch map | of a tract of land northeast of | Zamboanga, | Island of Mindanao, | showing the proposed location of a | cantonment of U. S. troops. | From a reconnaissance by | Capt. A____ B____, | Chief Engr., Department of Mindanao, | Jan. 15, 1904. | Scale | Contour interval, 20 ft.

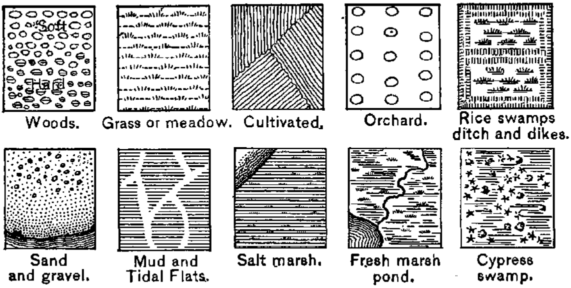
Notes.—Besides the title, such information as will help to a proper understanding of the meaning and value of the map should be given in the form of notes. These usually relate to methods used in the survey, datum points, etc.

Fig. 50 shows the title corresponding to the above example, with notes.

Meridian.—The magnetic meridian should be shown, and the true meridian also if the declination is known. The true meridian may be a line, of 3 ins. or upward in length, with a star at its north and the feather of an arrow at its south end. The magnetic meridian may be an arrow crossing the former at the middle point and making with it an angle equivalent to the declination.

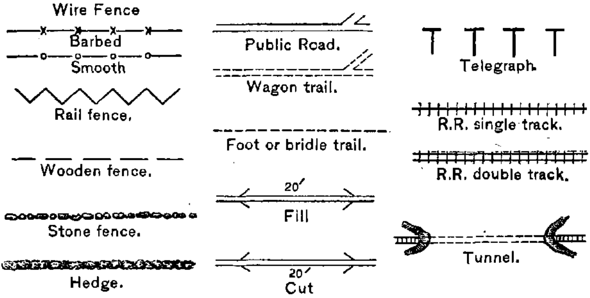
Border.—The drawing should be inclosed in a rectangle, preferably with its sides N. and S. and E. and W. The border consists of two parallel lines, the inner one medium fine, the outer one medium heavy, with a space between them equal to the width of the outer. For geographical maps a double border is used, with space between sufficient to contain the numbers of meridians and parallels.

Soil and Cultivation.

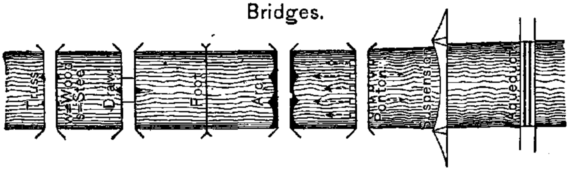


Enclosures.

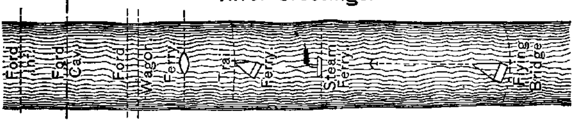
Communications.



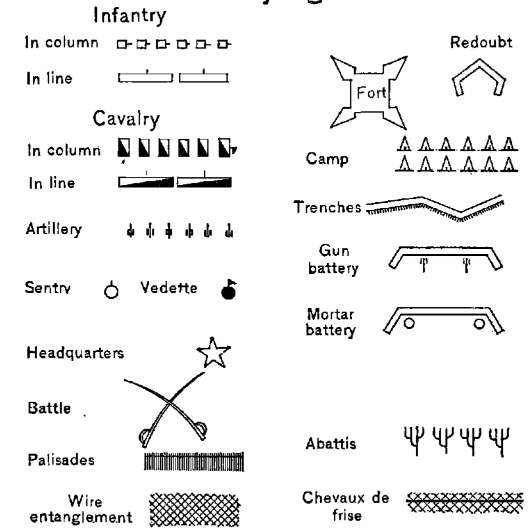
Bridges.



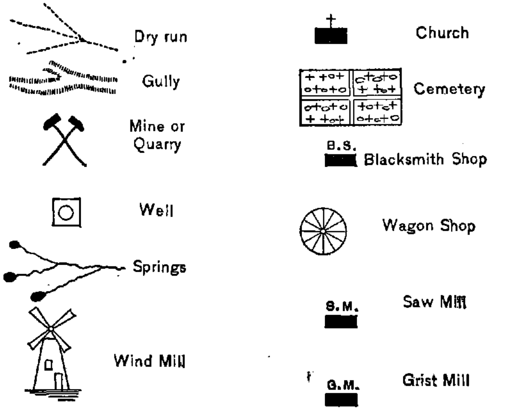
River Crossings.



Military Signs.



Miscellaneous.



For additional symbols see figs. 72 to 84.

DIVISION OF THE PHILIPPINES.

SKETCH MAP

OF A TRACT OF LAND NORTHEAST OF

ZAMBOANGA, ISLAND OF MINDANAO.

Showing the proposed location of a

CANTONMENT OF U.S. TROOPS.

FROM A RECONNAISSANCE BY

CAPTAIN A____ B____

CHIEF ENG'R. DEP'T. OF MINDANAO.

JAN. 15, 1904.

SCALE:

100 0 500 1000 Yds.

Contour Interval 20'

1° 2° 3° 4° 5°

NOTE:—Elevations are above mean l.w. at Q.M. wharf in Zamboanga.

Lettering.—Names and figures relating to points on the map should be made parallel to one side. Names and figures relating to extended features or large areas are disposed along the feature or across the area in straight or curved lines.

Ornamental lettering should be avoided. A plain unshaded letter is best. All needful variety of effect and prominence may be obtained by the size, spacing, weight, and inclination of such letters and the larger initials for important words. Fig. 51 shows the style of letter described, upright and inclined—usually called italic—with normal, condensed, and extended spacing. Fig. 51 A is a scale for spacing letters and determining the length of a given line. This scale gives equal space to all letters, which is not strictly correct, but is simple and does well enough for present purposes. It is the method necessarily employed in typewriters and the eye is accustomed to it.

For ordinary or normal lettering the height of letters is the width of the letter space in the second line below that adopted for the widths of the letters, fig. 51 A.

For condensed lettering take for the height the space in the third or fourth line below; and for extended letters make the height equal to the width or take it from the first line below.

A very good effect may be obtained by the exclusive use of capitals. The small letters require one-half the space of capitals in the same line. They are not so easy to make well as the capitals, but can be made more rapidly and look better on the face of the map. A very good general rule is to use inclined letters for all names and words on the face of the map which relate to water and upright letters for those which do not.

98. **Enlargement and reduction.**—The simplest method is by squares. Divide the original into squares of 2 ins. or less by lines drawn parallel to the borders, fig. 52. Divide the paper on which the copy is to be made into squares with sides corresponding to the same distance on the scale of the copy that the side of a square on the original itself does to the scale of the original, fig. 53. If a plotting scale of the original be placed on the side of a square on the original and the plotting scale of the copy on the side of a square of the copy, the readings should be the same. The square on the copy will be larger if the drawing is to be enlarged and smaller if it is to be reduced. The ratio between the sides of the squares on the original and the copy is the ratio of reduction or enlargement. This ratio must not be confused with the ratio of areas of the two maps, which is different and not important.

Select a square of the original and reproduce its contents in the corresponding square of the copy; or take a feature of the original, as a road or stream, and trace its course through several squares.

Usually the position of a point in a square or on one of the sides can be *estimated* with sufficient accuracy. Important points may be located by measurement of distances from the nearest sides of the squares, using the scale of the map and the scale of the copy respectively.

Instead of drawing the squares on the original, they may be drawn on tracing linen or paper laid over it, or fine threads may be stretched to form the squares. Every drawing board should have a scale of inches on each edge marked with fine saw-cuts or with small tacks to facilitate the drawing of squares.

99. **To measure an irregular area.**—Lay over the area a piece of cross-section tracing paper, fig. 54. Count the full squares inside the area and to their number add the sum of the estimated fractional ones. In the figure the fractional squares to be added are shaded. Multiply the equivalent number of full squares in the area by the area of one square to the scale of the figure. If the scale is 500 ft. to the inch=250,000 sq. ft. to the sq. in., and the squares $\frac{1}{12}$ of an inch on one side, then the area of one square is $\frac{1}{144}$ of a sq. in., and its value to the scale of 500 ft. to 1 in.=2,500 sq. ins.=17.36 sq. ft. The number of squares counted, multiplied by 17.36, is the number of square feet in the area.

If the scale is distorted, the area per sq. in. of the drawing is found by multiplying the scales together. Thus, in a profile plotted to a hor. scale of 500 ft. to 1 in. and a vert. scale of 10 ft. to 1 in., the area of a sq. in. of the drawing is $500 \times 10 = 5{,}000$ sq. ins. On such a profile a square of $\frac{1}{10}$ in. on a side, or $\frac{1}{100}$ in. area, corresponds to 50 sq. ins.

Upright 123456789

ABCDEFGHIJKLMN

OPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz

Inclined 123456789

ABCDEFGHIJKLMNOPQRST

abcdefghijklmnopqrstuvwxyz

Condensed PLAN AND

Extended ELEVATION

Inclined shows errors less.

DIAGRAM DIAGRAM

Prominence obtained by weight of letters.

CHANNELS.

SHOALS.

SPINDLES.

COMPASS.

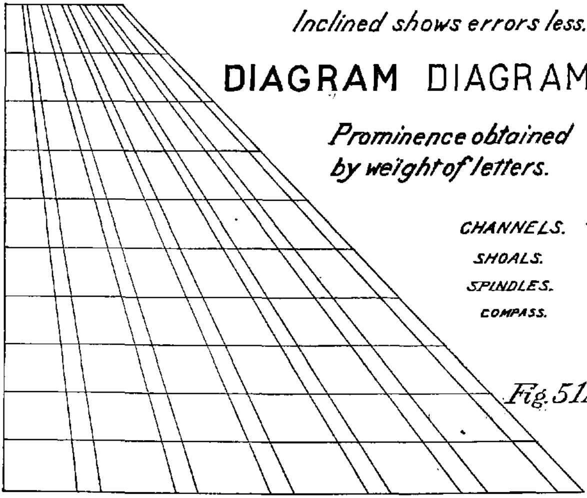


Fig. 51A.

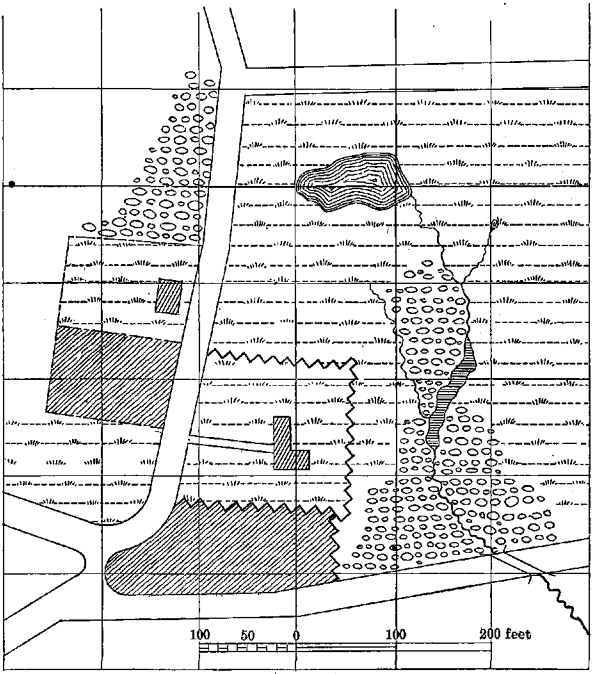


Fig. 52

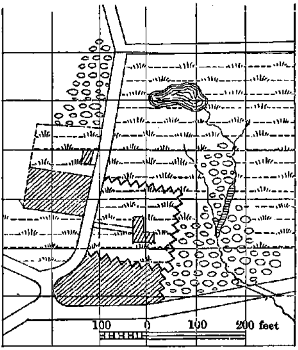


Fig. 53

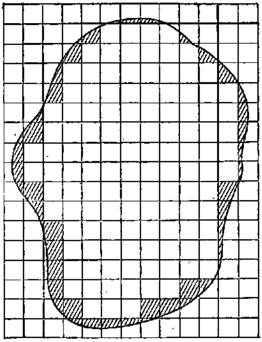


Fig. 54

100. **Verniers.**—A vernier is an auxiliary scale by means of which the principal scale can be read more closely than can be shown by actual subdivision.

Consider *AB*, fig. 55, as part of a scale of equal parts. Construct the auxiliary scale or vernier *CD*, the total length of which is equal to 9 of the smallest divisions of the principal scale, but divided into 10 equal parts instead of 9, which makes each division of the vernier $\frac{9}{10}$ the length of the division of the scale.

When the zero division of the vernier, indicated by an arrow, is coincident with a division, as 31, of the scale, the reading is 31 and it is obvious that the first division of the vernier is to the left of 32 in the scale by $\frac{1}{10}$ of the distance between 31 and 32. Similarly, the second, third, etc., division of the vernier is 2, 3, etc., tenths to the left of the 33, 34, etc., division of the scale. To make any division of the vernier, as 2d, 3d, 5th, or 8th, coincide with the division of the scale next ahead of it, the vernier must be moved to the right 2, 3, 5, or 8 tenths of the length of one division of the scale, and the arrow will then be opposite a point on the scale 2, 3, 5, or 8 tenths of the distance from 31 to 32; or at 31.2, 31.3, 31.5, or 31.8. The quantity obtained by dividing the value of one division of the scale by the number of divisions of the vernier is called the **least count of the vernier.** But one intermediate vernier division can coincide with a scale division at the same time and the number of the coincident vernier division, counting from the arrowhead, is the number of times the least connt must be added to the last scale division passed by the arrow to get the true reading.

To read any vernier, note the value of the last scale division passed by the zero of the vernier and to it add the least count multiplied by the number of the coincident vernier division.

A vernier constructed as described is always read ahead of the zero, or in the direction in which the scale graduations increase, and is called a **direct vernier.** Verniers may also be constructed by dividing the length of a certain number of divisions of the scale, as 11, into eqnal parts one less in number, as 10. The principles of operation and method of reading are the same, except that the coincident line is to be found behind the zero of the vernier, or in the direction in which scale graduations decrease. This form is called **retrograde.** It is but little used.

If the scale is graduated in both directions, as is often the case, the vernier is donbled, the zero in the middle and each side forming a direct vernier for the graduations increasing in the same direction. This form is called **double direct,** fig. 56. The most compact form is that shown in fig. 57, called the **folded vernier,** in which the graduations are numbered from the middle to one end and continue from the other end to the middle. This is read as a direct vernier in either direction. If the coincident line is *ahead* of the middle or in the direction of *increasing graduation*, take its number from the middle as zero. If it is *behind* the middle, or in the direction of *decreasing graduation*, take its number from the nearest end, counting the end line as numbered on the vernier.

Verniers are also constructed on cylindrical surfaces, fig. 58, and on conical surfaces, fig. 59. The principles and method of reading are the same for all.

ADDENDUM, 1907.

90*a*. A quick rough test as to whether an intermediate point obscures the view between two other points may be made by setting up at three points on the map pencils or other suitable objects having the corresponding elevations marked on them on a convenient assumed scale. Sight, or stretch a thread, along the pencils. If the middle mark is above the line joining the other two, each of the two extreme points is invisible from the other. If the middle point is below the line, each extreme point is visible from the other.

ADDENDUM, 1909.

91*a*. The statement in paragraph 91 of former editions that vinegar may be used to thin prepared india ink is erroneous. The effect of vinegar is to precipitate the coloring matter. Water may be used with satisfactory results, or spirits of ammonia if quickness of drying is important. Glycerin is recommended, but its use is likely to delay drying.

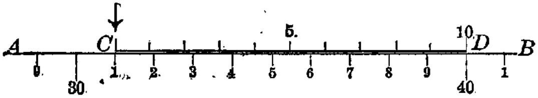


Fig. 55.

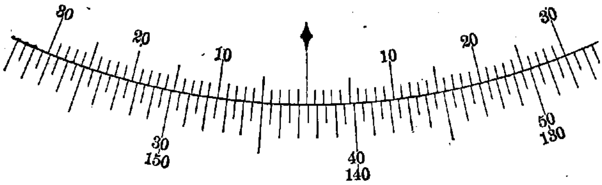


Fig 56.

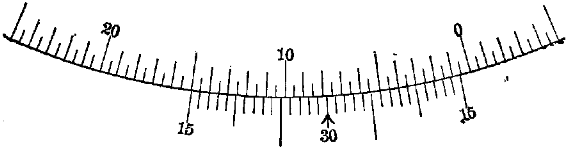


Fig. 57.

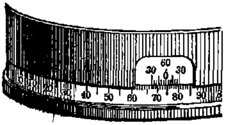


Fig. 58.

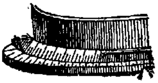


Fig. 59

101. **The engineer's transit.**—This instrument is shown, and the names of its parts indicated in fig. 60. To use the transit, set up the tripod, the legs extending far enough to give a stable base and so as to make the top surface of the head horizontal or nearly so. On level ground the legs will be equally extended. On inclined ground, the leg on the lower side will be straighter and the others more inclined. Remove the cap from the tripod and screw on the instrument in its place. Hang the plumb line on the hook depending through the tripod head, and adjust its length to bring the point of the plumb bob as close as possible to the setting point. Unclamp the vernier and turn the transit so that one of the plate levels is parallel to one pair of leveling screws. The other plate level will be parallel to the other pair. Bring the bubbles of the levels to the center in succession by means of the leveling screws. Always turn one of a pair down as the opposite one is turned up and avoid more pressure of the screws against the plate than is necessary for a firm bearing. If a screw turns hard at any time it is either sprung or has been set up too tight. In turning a pair of leveling screws always move the thumbs toward each other or away from each other. The bubble will follow the motion of the left thumb.

With the level bubbles in the centers of their tubes, the plate will be level if the bubbles are in adjustment. Turn the transit slowly in azimuth and watch the bubbles. If they remain in the centers, the plate is level and the levels are also correct. If either bubble leaves the center, the amount of its motion indicates the amount by which it is out of adjustment. If the amount is small it may be neglected; if large, the adjustment should be made as hereafter described. For short lines the level error may be neglected if the entire bubble remains in sight during the entire revolution. Adjust the leveling screws in this case so that the travel of the bubble will be equal on both sides of the center.

Having leveled the plate, draw out the eyepiece until the cross hairs are clearly defined. The instrument is now ready for use or adjustment. Adjustments should be invariably made in the order in which they are described.

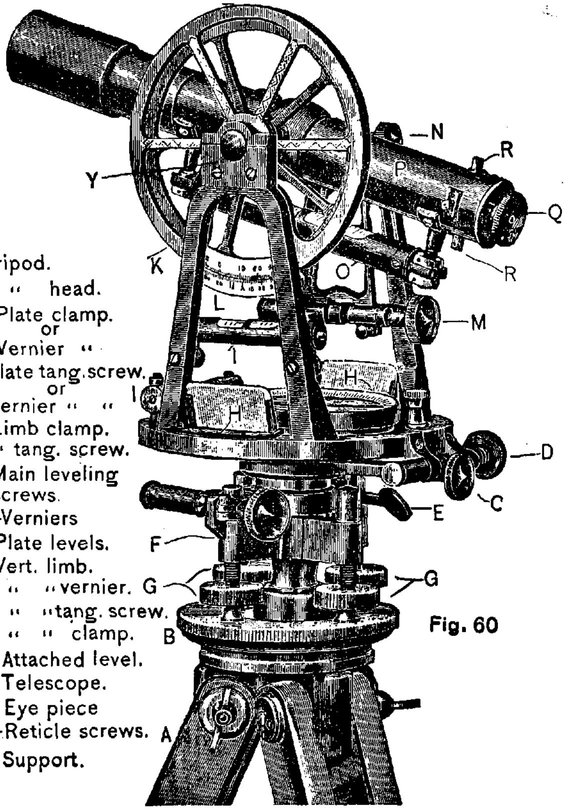
1st adjustment.—To make the axes of the plate levels perpendicular to the axis of the instrument and therefore parallel to the plate:

Having set up and leveled, clamp the limb and revolve the plate 180°. If either bubble recedes from the middle of its tube, bring it back by raising the lower, or depressing the higher end, one-half by the main leveling screws, and one-half by the small screws which fasten the level to the plate. Again revolve the plate 180° and if the bubble still recedes from the middle, correct the error as before and repeat the operation until the bubble does remain in the middle in both positions of the plate. When the adjustment is complete, both bubbles will remain in the center with the plate in any position.

2d adjustment.—To place the intersection of the cross wires in the straight line through the optical center of the object glass and perpendicular to the horizontal axis of the telescope:

The first adjustment completed, direct the telescope to some small, well-defined, and distant object. With the screw which moves the object-glass slide adjust the latter so that the distant object is as distinct as possible. Both cross wires and object should now be clearly seen. Note whether the image appears to move with reference to the wires when the eye is moved from side to side across the opening of the eyepiece. Such displacement is called **parallax**, and indicates that the image is not exactly in the plane of the cross wires. Move the object glass by its thumbscrew until the parallax ceases. **This must be done every time the transit is used** to read an angle, as well as when adjusting it.

Unclamp the plate and lay the intersection of the wires upon the middle of a pin 200 or 300 ft. distant; clamp the plate; plunge the telescope, that is, revolve it about its horizontal axis, and have a pin driven at the same distance from the transit so that its middle shall be seen exactly at the intersection of the cross wires. Revolve the plate 180°; clamp and lay exactly upon the middle of the first pin. Again plunge the telescope and look at the second pin. If the intersection again strikes the pin the adjustment is correct, but if the pin appears to one side of the intersection, bring it back one-quarter of the way by the side reticle screws, turning one in as the other is turned out. If the instrument is *erecting* (most transits are) loosen the reticle screw on the side toward which the wire should move in the field and tighten the other one. If *inverting*, turn the other way. Repeat the process until the pins are cut exactly in the middle without reference to position of transit or telescope. The adjustment will then be correct.



A—Tripod.
B— " head.
C { Plate clamp. or Vernier "
D { Plate tang. screw. or Vernier " "
E— Limb clamp.
F— " tang. screw.
G—Main leveling screws.
H-H—Verniers
I-I—Plate levels.
K— Vert. limb.
L— " " vernier.
M— " " tang. screw.
N— " " clamp.
O— Attached level.
P— Telescope.
Q— Eye piece
R-R-Reticle screws.
Y— Support.

Fig. 60

Addendum, 1907

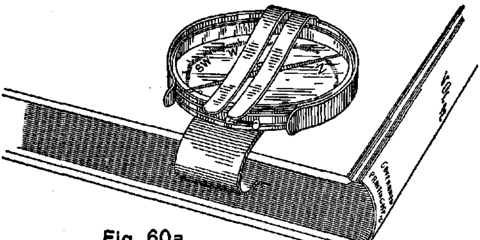


Fig. 60a

3d adjustment.—To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument:

The instrument leveled, lay the telescope on a point at the top of a nearly vertical line, such as the corner of a building or a steady plumb line. Clamp the plate and depress the telescope until the horizontal wire is near the lower end of the vertical line, and note the position of the intersection of the wires with respect to the selected vertical, whether to right or left of it, and how much. Revolve the plate 180°; plunge the telescope, and again bring the intersection of the cross wires on the top point of the selected vertical; again depress the telescope and bring the horizontal wire to the bottom of the vertical. If the intersection of the wires is again on the same side and at the same distance from the selected vertical the adjustment is correct. If it is not so, raise or lower the movable support by the proper adjusting screws so as to correct half the difference, and repeat the operation. If the instrument is erecting, raising the support will move the intersection away from it; or lowering the support will move the intersection toward it. If inverting, the reverse.

4th adjustment.—To make the vertical wire perpendicular to the horizontal axis:

Level carefully and lay the top of the wire on a definite point. Elevate the telescope slowly and note whether the point remains on the wire. If not, loosen two *adjacent* reticle screws and tap the head of one very gently until the point will travel on the wire from end to end. Then tighten the screws. If gently tapping on a screw head does not move the wire, tap on the opposite side of the opposite screw.

For a transit without vertical limb or attached level, known in the trade as a **plain transit,** the adjustments are now complete, If the transit has an attached level, its axis is made parallel to the line of sight by the—

5th adjustment.—Set up midway between two stakes, which have their tops at about the same elevation, and with the bubble of the attached level in the center, read a rod on each stake. The difference in the readings is the true difference in level of the tops of the stakes. Move the instrument toward one of the stakes, and set it up so that the eyepiece is about over the center of the stake. Place the rod on the stake near the eyepiece, and set the target in the middle of the field as seen through the *object glass.* Set up the rod on the far stake with a target set at the reading just taken through the object glass, plus or minus the difference of level between stakes—plus if lower, minns if higher. Bisect the target with the horizontal cross wire. The line of sight must now be horizontal, and keeping the vertical motion clamped so as to retain the pointing, adjust the bubble of the attached level to the center by means of the small screws at the movable end of its tube. Botb line of sight and axis of bubble are now horizontal and therefore parallel.

Note that the position of the horizontal wire in the field is a matter of convenience mainly. It is best to have it near the middle of the field and it can be placed there by inspection with all needful precision.

6th adjustment.—If the transit has a vertical limb in addition to the attached level, the line of sight and axis of the attached level made parallel to each other by the preceding adjustment should also be so adjusted that the vertical scale will read zero, when they are horizontal. If the vernier of the vertical limb is adjustable, bring the bubble of the attached level to the center and then adjust the vernier to read zero. If the vernier is fixed, the reading, when the attached level is horizontal, may be taken as an index error and applied to all readings, or the line of sight may be adjusted to the vernier. To do this, establish a horizontal line from the center of the level to the target, as explained in the preceding adjustment. Set the vertical limb so that the vernier reads zero, and bring the intersection of the wires on to the target by the top and bottom reticle screws. Then keeping the intersection on the target, bring the bubble of the attached level to the center by its adjusting screws. The line of sight and the axis of the attached level are now parallel, and are horizontal when the vertical limb is at zero, which completes the adjustment.

102. **Use of the transit.**—To measure a horizontal angle, set up over the vertex of the angle to be measured, and direct the telescope along one of the sides of the angle. Clamp limb and plate—if the latter is set at zero it is more convenient—and with the tangent screw of the limb bring the intersection of the cross hairs on a

definite point of the line. Read each of the two verniers and record, calling one vernier **A** and one **B**. Unclamp the plate—not the limb—and direct the telescope along the other line. Clamp and bring the cross hairs to a definite point with the vernier tangent screw. Read and record as before. Take the differences of the two readings **A** and **B**, respectively. If these differences are the same, it is the value of the angle. If not, take the mean of the differences as the value. **For greater accuracy,** the method of **repetition** is used. After the first measurement is made, unclamp the limb—not the plate—and resight on the first point by means of the limb tangent screw, and proceed as before. The reading of the vernier is now twice the angle. Continue the repetitions until the desired number are made. The last reading divided by the number of measurements is the value of the angle. To guard against errors, it is well to read and record after each measurement.

To measure a vertical angle.—Point the instrument; clamp the horizontal motions and make the readings on the vertical limb. For greater accuracy when there is a complete vertical circle, revolve the instrument through 180°, plunge the telescope, and take new readings. If the results differ, use the mean.

To run out a straight line.—Set up accurately over the initial point. Point the telescope in the required direction, and establish a second point. These two determine the line which is to be run out. Set up over the forward, or second point; lay the telescope on the initial point; clamp limb and plate; plunge telescope and set a point forward. If the adjustments are good, this third point will be in line with the first and second and the line may be prolonged by repeating the steps taken at the second point.

If the adjustments are not good, set a third point as before. Then unclamp the limb and turn 180° in azimuth and lay on the initial point. Clamp and plunge again and set another third point beside the first one. Take the middle point between the two for the true third point. This method eliminates errors of adjustment, except those of the plate levels. These are so easily observed and corrected that they should never exist when close work is required.

103. **Traversing.**—The transit must be set at each station with the 0–180° line of the azimuth circle parallel to its position at preceding stations. This is called **carrying an azimuth.** The direction chosen for the 0–180° line is usually the true N. and S., or as near it as data at hand will permit.

Having observed the second station from the first, proceed to the second, set up, and set one of the verniers at its reading from the first to the second station, plus 180°, or at the **back azimuth.** Point at the first station and clamp the limb. The line 0–180° is now in a position parallel to that at the first station. Unclamp the plate, direct the telescope to the third station and proceed as before.

104. **Stadia surveying,** or **stadia work,** is in theory the determination of the distance of an object along the line of sight from the size of its image in a telescope. In usual practice, it is the determination of the distance from the size of the object at that distance which is required to produce an image of a fixed size in the telescope. The sizes of objects required to produce an image of fixed size are directly proportional to their distances from the point over which the telescope is set. This hypothesis is not rigidly correct, but the theoretical error is small and the practical errors negligible.

The **limits** of the **image** in the telescope are fixed by two horizontal wires in the reticle, called **stadia wires,** one above and one below, the middle wire, and at nearly equal distances from it. The **object** most convenient to use is a **graduated rod** held vertically. Special graduations are used, presenting a variety of forms, so that different units may be recognized as far as the rod can be seen, and so also that small readings may be taken by estimating the position of the wire on a diagonal line. Very many different forms of stadia graduations have been proposed, and most experienced stadia workers have special forms which they consider better than any other. Fig. 63 shows a form which has received wide approval, and may safely be accepted as one of the best.

Wires can not be placed in reticles exactly at predetermined distances, even though the places for them are accurately marked by the maker. They must be placed as accurately as possible, and their actual distances determined afterwards. Hence stadia rods are not in the market as level rods are, but must be made for each instrument. To minimize error of refraction, the upper wire should be placed on the primary division nearest the top of the rod and the graduations counted downward. Rods should be of light, straight-grained, well-seasoned wood, 12 to 14 ft. long, 5 ins. wide, and ⅞ in. thick, dressed smooth all around, and covered with two coats of white paint.

To graduate the rod, set the transit up over a point, and from the point measure off a distance in round hundreds of feet so that at that distance somewhat more than half of the rod falls between the stadia wires. Set the top wire near the top of the rod, and have the point where each wire cuts the rod carefully marked. Measure the distance between the extreme marks and divide it by the number of hundreds of feet in the distance of the rod from the transit point. The result is the length on the rod corresponding to 100 ft. Lay this distance off on the rod, beginning near the top and repeating to the bottom. Divide each 100 ft. space according to the style chosen, and mark the graduations. All distances read on this rod, except the one at which the length of graduation was found, will be slightly in error; those less, too small; and those greater, too large.

A rod may be so graduated as to be practically free from error. Mark the zero near the top of the rod. Set the rod up at say 100 ft., bring the top wire to the zero, and mark the bottom one. Carry the rod to 200 ft., and repeat the operation. Continue at intervals of 100 ft. until the full length of the rod falls between the wires. Each of the marks corresponds to the distance at which it was made, and the space between it and the next, to the corresponding 100 ft. interval. The 100 ft. divisions are not exactly of equal length, and each must be divided into equal parts and marked. In using this rod, the top wire must be always at the top of the rod, and the same end of the rod always up, or error will be introduced. For long distances the reading from the top to the middle wire may be taken and multiplied by the ratio of the full to the partial interval. This ratio should be determined with care and may be utilized to secure a reading when all the rod can not be seen and which would otherwise be lost.

The stadia is used in connection with a transit with vertical limb, or a plane table. By reading a stadia rod through either instrument and noting the gradient and azimuth at the same time, a point may be completely determined both in position and elevation at a single observation. The distance measured is along the gradient, and may be reduced to the horizontal if desired, by Table XII. The elevation is obtained from Table III. Before reading the vertical circle, depress the telescope until the middle wire is on a rod graduation at the same distance from the bottom that the telescope is above the station or the ground.

These instructions will introduce some error if the rod is always held vertical. It amounts to 1% of the distance for a gradient of 8°; 2% for 11°, and 3% for 14°. In rough country, giving important sights at gradients of more than 5°, it will be better to attach a short pointer to the rod perpendicular to its face and at about the height of the rod-holder's eye. If the rod holder aims this pointer at the instrument when the sight is taken, the rod will always be perpendicular to the line of sight, and the method of reduction explained will give results free from this error.

A scale of equal parts, as a **level rod,** may be used instead of a specially graduated stadia. Take two careful readings, at say 100 and 200 ft. Their difference is the true reading for 100 ft. Divide 100 by the reading. The quotient is a factor, by which any other reading may be multiplied, and the product will be the corresponding distance. Example: If the readings on a level rod are 1.15 ft. for 100 ft., 2.29 ft. for 200 ft. then $2.29-1.15=1.14$ ft. the true reading for 100 ft. $100\div1.14=88+$, which is the reduction factor. Any reading on a scale of equal parts with this telescope, multiplied by 88+ is the distance of the scale from the instrument in the unit of the scale.

105. **Engineer's level.**—This instrument is shown and its parts indicated in fig. 65. To use it, set up and focus as described for the transit, except that, as there is but one level, the telescope must be turned in the direction of one pair of leveling screws and leveled, and then turned in the direction of the other pair and leveled again. The second leveling may disturb the first, which should be retested.

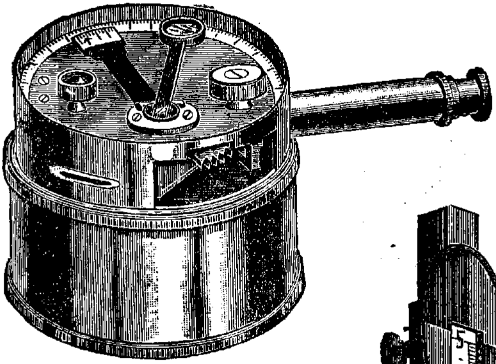
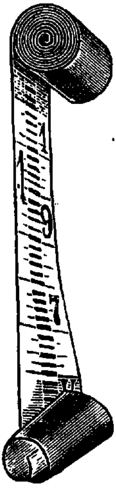


Fig. 61.



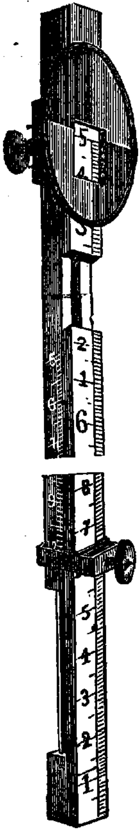


Fig. 62. Fig. 63. Fig. 64.

1st adjustment.—To fix the intersection of the cross wires in the axis of the telescope:

Lay the telescope exactly on some definite point. Revolve it in the wyes until the attached level is on top. If the horizontal wire now appears above or below the point, move it over half the space between its position and the point by the top and bottom reticle screws, and the other half by the main leveling screws of the instrument. Revolve the telescope in the wyes till it is again in the first position, and repeat the operation till the horizontal wire neither ascends nor descends when the telescope is revolved in the wyes. A similar process adjusts the vertical wire.

2d adjustment.—To make the axis of the attached level parallel to the axis of the telescope:

Clamp the level; turn the telescope in the wyes until it comes against the stop, and with the main leveling screws bring the bubble to the middle of the tube. Open the loops, lift out the telescope, put it back with ends reversed, and turn it in the wyes till it comes against the stop again. If the bubble settles away from the middle of the tube, bring it back by raising the lower end, or depressing the higher end, one-half by the vertical adjusting screw at the end of the attached level, and one-half by the main leveling screws. Repeat all the operations until the bubble remains in the middle of the tube without reference to the way the telescope is placed in the wyes. The axes of the telescope and of the level are now horizontal but not necessarily parallel. Turn the telescope slowly in the wyes through a small angle. If the bubble does not remain at the middle point of its tube, bring it back by the *horizontal* adjusting screws of the attached level. If both parts of the adjustment are perfect, the bubble should now remain at the middle of its tube whether the latter is directly under the telescope or a little to one side. In practice it will be found difficult to complete the first part of the adjustment in a satisfactory manner independently of the second part. The best sequence is to make the first part roughly; then the second part carefully; then the first part again more carefully, and so on till the desired permanency of bubble position is attained.

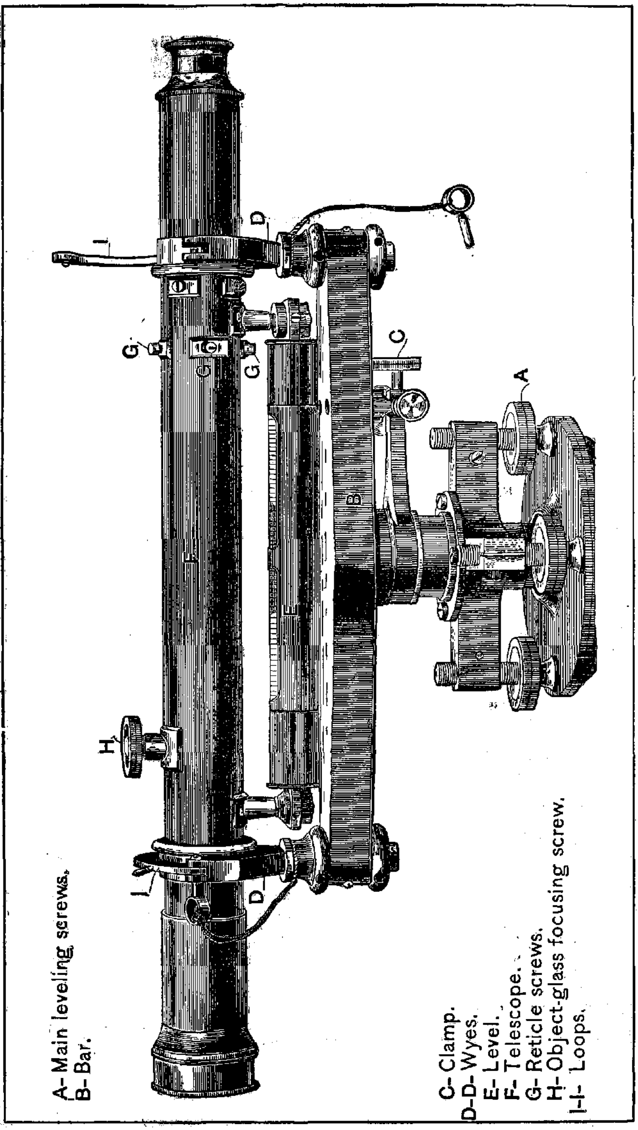
3d adjustment.—To make the axis of the wyes perpendicular to the vertical axis of the instrument:

This adjustment is not essential, but it is a convenience, as it permits the telescope to be revolved about the vertical axis without releveling before a reading is made. Level the instrument in any position; revolve it 180° about the vertical axis and correct one-half the movement of the bubble by adjusting the movable wye. Repeat for a check. As a final check, level the instrument when the telescope is over one set of leveling screws. Revolve 90° and again level. The bubble should now remain in the middle of its tube while the instrument is slowly revolved about the vertical axis. To do accurate leveling it is necessary to check the adjustments frequently and make all observations with the greatest care.

Level rods are of two kinds, **target** and **self-reading** or **speaking.** The target rod is finely graduated and has a metal target sliding on it, which is graduated as a vernier. The levelman signals to the rodman, who moves the target up or down until it is in the right position, when the reading is taken by the rodman, or else the rod is carried to the levelman to be read. The ordinary form is the New York rod, fig. 64. The rod proper is in two parts, which slide on each other. For readings up to 6½ feet the target is moved on the rod and read from the graduation on the front part by a vernier on the target. For greater readings the target is clamped at 6½ feet and the back part of the rod slid up on the front part, the reading being taken from a scale on the *side* of the back part by a vernier on the *side* of the front part. The rod is graduated to 100ths of feet and the verniers read to 1000ths.

For convenience of field use flexible rods are made, which roll up for carrying, and are stretched on a board for use. They may even be held in the hand. A common form is shown in fig. 62. There is also a form consisting of a series of aluminum plates 1 ft. long, graduated, which may be fastened, end to end, on a board to form a level rod.

106. **Use of the level.**—The first sight to any point is the **fore sight** (F. S.), and a later sight to the same point from a new position of the instrument is a **back sight** (B. S.). All the elevations observed at any station depend upon the B. S. at that station. A **bench mark** (B. M.) is a point especially selected or prepared with a view to definiteness and permanency. A **turning point** (T. P.) is a temporary


A- Main leveling screws.
B- Bar.
C- Clamp.
D-D- Wyes.
E- Level.
F- Telescope.
G- Reticle screws.
H- Object-glass focusing screw.
I-I- Loops.
A
B
C
D
D
E
F
G
G
G
H
I
I

point used for a B. S. The plane of reference for each instrument station is the horizontal plane through the line of sight of the telescope, called **height of instrument**, (H. I.). A B. S. is a sight taken to a point of known elevation to determine H. I. A F. S. is taken from a known H. I. to determine the elevation of the point sighted on. The rod readings are the distances of points below the plane of reference, and for the same station their differences are the differences of level of the points themselves. For the difference of elevation of points observed from different stations the H. I. must be considered, and hence it must be worked out for each station and the rod readings subtracted from it.

Fore sights and back sights on the same point should be as nearly as possible of equal length.

107. **Notes.**—The clearest way of recording level notes is in the following form:

B. S. +	H. I.	F. S. −	El.	Station.	Remarks.
8.75	108.75	-------	100.00	B. M. 21	NE. cor. Main and 12th streets.
------	--------	6.41	102.34	----------	Stake 132.
------	--------	3.28	105.41	----------	Center of 12th street at top of grade.
------	--------	5.37	103.38	----------	Center of 12th street at bottom of grade.
------	--------	9.74	99.01	T. P.	
7.60	106.61	-------	99.01	T. P.	

Add the B. S. to the elevation of the B. M. or T. P. for the H. I. Subtract the F. S. from the H. I. for the elevation of a point. As a check, the H. I. at any B. M. or T. P. plus the F. S. to that point, minus the B. S. from that point, equals the last preceding H. I.

108. **The sextant.**—This instrument is shown and its parts indicated in figs. 61 and 66. The former is a very compact form, called the **pocket sextant,** and is the one in most general use in the military service. The larger form, fig. 66, has telescopes of different powers and also a telescope tube without lenses, which is used for reconnaissance work at short ranges. The pocket sextant has a telescope for use in astronomical and long-range terrestrial work. For ordinary reconnaissance and surveying, the pocket sextant is used without the telescope, the sight being taken through a small hole in the slide which closes the telescope opening.

The adjustments are as follows: For the index glass, place the vernier at about 30° of the limb and examine the arc and its image in the index glass. If the arc and image appear continuous, the glass is in adjustment. If the image appears above the arc, the mirror leans forward; if below, it leans backward. Adjust with screws if provided, or with slips of paper inserted between the mirror and its frame.

For the horizon glass.—Set at zero and observe a well-defined distant point, using the telescope. If the direct and reflected images coincide, the horizon glass is in adjustment. If not, adjust it until they do, or if that can not be conveniently done, move the arm a short distance from zero until coincidence occurs. Read the vernier and apply that reading with its proper sign to all angles measured. Such a reading applied as a correction is called the **index error.** If the index error is **off the arc,** that is, between zero and the end, it is additive. If **on the arc,** subtractive.

In the pocket form the horizon glass only is adjustable. **To adjust the pocket sextant,** select a distant object with a clearly defined straight outline. Set the vernier carefully at the zero of the arc and look at the object through the peephole and the lower portion of the horizon glass. Turn the sextant about the line of sight as an axis until the straight line appears to be perpendicular to the straight bottom edge of the horizon glass. If the instrument is not perfectly adjusted for this position, the straight line of the observed object will appear broken, in which case unscrew the smaller milled head of the top plate, and using its small end as a key, turn the single adjusting screw in the cylindrical surface while looking at the object through the peep. The part of the image seen in the mirror will appear to move, and by turning the key in the proper direction the two parts may be brought together. Next turn the sextant about 60° about the line of sight, and if the straight line again appears broken, use the key to slightly loosen one of the two adjusting screws in the top plate while looking through the instrument. If this brings the two parts nearer in line, the proper screw has been selected; if not, try the other one. Then turn the two adjusting screws in the top plate by corresponding amounts and in opposite directions and continue turning them alternately till the straight line becomes continuous. The two screws are opposed to each other, and care must be taken to use no considerable force and to always unscrew one before screwing up the other. When the adjustment is complete, the line should remain continuous and straight while the sextant is slowly revolved about the line of sight. If the index arm is then moved back and forth by turning the large milled head, the reflection of any object may be made to pass exactly over that object as seen through the clear glass.

For adjusting at night, screw the telescope in place. Pull its inner tube well out. Remove the sunglass from the eyepiece. Focus the telescope on a bright star by pushing in the tube till the image of the star is clear. Then, by turning the large milled head, make the star's reflected image pass through the field of view. If it does not pass exactly over the stationary image of the star, adjust the horizon glass with the two screws in the top plate till one image will pass exactly over the other. Next set the vernier accurately to the zero of the arc, and with the single adjusting screw in the cylindrical surface make the two images appear as one. The instrument is then completely adjusted. The daylight method is most convenient, but it is well to test the adjustment by the star method before attempting to do any astronomical work.

In the cylindrical surface just below the zero degree end of the arc are two projecting levers which move colored glasses to be used in looking at the sun. At other times these glasses should be depressed through the opening in the bottom plate by first sliding the brass stud in the plate and then pushing the two levers. The telescope also has a colored sunglass secured on the eye end which must be removed when observing any other object.

109. **The plane table.**—The instrument is shown and its parts indicated in fig. 67.

The adjustments are analogous to those of the transit, the table corresponding to the limb and the ruler to the plate. In revolving the plate for level adjustment, care must be taken to have it cover the same part of the table in both positions by marking two corners on the paper. The figure shows a device for plumbing any point on the table over a given point on the ground. Except for very close work on a very large scale, this refinement is unnecessary. For all probable uses in the military service it is enough to place the corresponding part of the drawing over the station by the eye.

110. **The logarithm of a number** is the exponent of the power to which a certain other number, called the base, must be raised to produce the given number. The base of the system most used, called **common logarithms,** is 10.

In any system—

The log. of a product equals the sum of the logs. of the factors.

The log. of a quotient equals the log. of the dividend minus the log. of the divisor; or the log. of a common fraction equals the log. of the numerator minus the log. of the denominator.

The log. of 1 is 0; since the log. $1 =$ the log. $\frac{1}{1} =$ the log. $1 -$ log. $1 = 0$. The log. of a power of a number equals the log. of the number multiplied by the exponent of the power. The log. of a root of a number equals the log. of the number divided by the index of the root.

The first property above is utilized in the construction of the tables. Each log. is the sum of the logs. of two factors of which its number is composed, and the factors may be so chosen that the log. of one is a whole number, called the **characteristic,** and the log. of the other is a decimal fraction, called the **mantissa.** Any number may be resolved into two factors one of which is the number itself with the

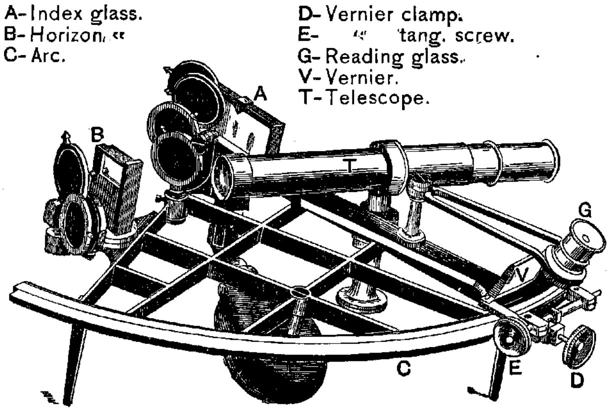

A-Index glass.
B-Horizon "
C-Arc.
D-Vernier clamp.
E- " tang. screw.
G-Reading glass.
V-Vernier.
T-Telescope.
A
B
T
G
V
C
E
D

Fig. 66.

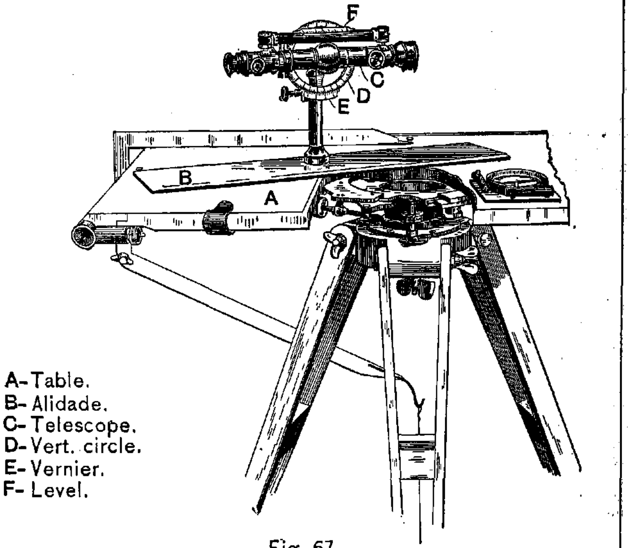

F
C
D
E
B
A
A-Table.
B-Alidade.
C-Telescope.
D-Vert. circle.
E-Vernier.
F-Level.

Fig. 67.

decimal point after the first significant figure, and the other the figure 1, alone, or followed or preceded by one or more ciphers.

Thus:

$$\begin{array}{rll} 3760 = 3.76 \times 1000 & \log. = 3.57518 \\ 376 = 3.76 \times 100 & \log. = 2.57518 \\ 37.6 = 3.76 \times 10 & \log. = 1.57518 \\ 3.76 = 3.76 \times 1 & \log. = 0.57518 \\ 0.376 = 3.76 \times 0.1 & \log. = \bar{1}.57518 \\ 0.0376 = 3.76 \times 0.01 & \log. = \bar{2}.57518 \\ 0.00376 = 3.76 \times 0.001 & \log. = \bar{3}.57518 \end{array}$$

The log. of the constant factor, 3.76 in the above example, is always a positive decimal fraction, and is called the **mantissa.** The log. of the variable factor in the third column above, is a whole number, and may be positive or negative. It is called the **characteristic.** The logs. of all numbers presenting the same combination of significant figures have the same mantissa regardless of the position of the decimal point. **Logarithmic tables contain mantissas only,** since the characteristics may be written by inspection and mental calculation. To this rule tables of logarithmic circular functions are an exception, as will be explained later. If the number is **whole or mixed**, the characteristic of its log. is positive, and **one less** than the number of places of figures in the integral part, or on the **left of the decimal point.** If the number is a decimal fraction, the characteristic of its log. is **negative,** and **one greater** than the number of ciphers **immediately following the decimal point.** See example preceding. **If the characteristic is positive,** the log. is a mixed number, and may be treated as such in addition, subtraction, multiplication, and division.

If the characteristic is negative, the log. is not a true mixed number, and special treatment is necessary. A negative characteristic may be considered as composed of two numbers, one negative and the other positive. The positive number, prefixed to the mantissa, forms a mixed number for arithmetical operations. The positive and negative parts may be simultaneously increased numerically by the same number without altering the value of the log.

Thus:

$$\begin{aligned} \bar{3}.4281 &= \bar{3} + 0.4281 \\ &= \bar{4} + 1.4281 \\ &= \bar{5} + 2.4281, \text{ etc.} \end{aligned}$$

For example, to multiply $\bar{4}.7265$ by 4.

$$\begin{array}{r} \bar{4} + 0.7265 \\ 4 \\ \hline \bar{16} + 2.9060 \end{array} = \bar{14}.9060, \text{ which is the required result.}$$

To subtract $\bar{1}.8432$ from $\bar{3}.1329 = \bar{4} + 1.1329$.

$$\begin{array}{r} \bar{4} + 1.1329 \\ \bar{1} + 0.8432 \\ \hline \bar{3} + 0.2897 \end{array} = \bar{3}.2897.$$

To divide $\bar{2}.2368$ by 7. $\bar{2}.2368 = \bar{7} + 5.2368$.

$$\frac{\bar{7} + 5.2368}{7} = \bar{1} + 0.7481 = \bar{1}.7481$$

In this case the number added to the minus characteristic should be just enough to make it *exactly divisible* by the divisor.

In the logs. of circular functions a characteristic is given in the tables which is larger by 10 than the true characteristic. These logs. may be used by the above rule by prefixing $\bar{10}$ to each. Thus the log. sine of 21 min. as given in the table = 7.78594. The true log. is $\bar{10} + 7.78594$, or $\bar{3}.78594$. Those who are familiar with the use of these logs. perform the operation on the $\bar{10}$ mentally. The inexperienced will do well to write them out in full.

111. **Explanation of the table.**—Table XIII gives to five decimal places the common logs. of numbers from 0 to 999, directly, and by interpolation from 0 to 9999. If the log. of a number larger than 10000 is desired, factor it and take the sum of the logs. of the factors. Thus, log. 99225 = log. of 75000, plus the log. of 1.323 = 4.87506 + 0.12156 = 4.99662. Or, convert the number into a mixed number less than 1000 and find its log. Thus, log. 992.25 = 992 + ¼ diff. between 992 and 993 = 99662, which is the mantissa for 99225.

In the table the logs. of 2 to 9 inclusive are found at the tops of the columns. For numbers above 10, the first two figures are in the first column, the 3d at the tops of the columns, and the 4th is interpolated. The right-hand column contains the average difference in each line between logs. in successive columns. For the 4th place multiply $\frac{1}{10}$ of the difference on the same line by the 4th figure, and add the product to the log. of the first three figures. Thus:

To find the log. of 4827, look for 48 in the left-hand column; follow the line to the column headed 2, and take out the mantissa .68304 for the number 482. In the right-hand column on the same line is the difference 90, $\frac{1}{10}$ of which, 9, multiplied by the 4th figure 7, = 63, to be added to the log. of 482, making the mantissa of 4827 = .68367. The characteristic is 3 or 1 less than the number of places of integral figures in the number, hence the complete log. of 4827 is 3.68367.

When the difference exceeds 200, if close results are desired, use the difference obtained by subtracting the number found for the third figure from that in the column for the next higher figure.

The number corresponding to any log. may be obtained from the table by the inverse process. If the given log. is found in the table, the corresponding number consists of the two figures on the left of the line, followed by the one at the top of the column. If the exact log. is not in the table, find the next one below and take out the three figures for that. Take the difference between the given log. and the one found in the table next below it and divide this diff. by $\frac{1}{10}$ the tabulated diff. on the line. Write down the quotient for the 4th figure of the required number.

Thus, to find the number corresponding to $\bar{1}.49638$. This is not in the table and the next below is 49554. The two figures on the left of the line are 31 and the figure at top of column is 3. Hence 313 is the number corresponding to 49554. The difference between 49638 and 49554 is 74, which divided by 14 or $\frac{1}{10}$ of the tabulated diff. 138 on the right of the line gives a quotient of 5 + to be set down as the 4th figure. Hence the number required is 0.3135, since the characteristic is $\bar{1}$ and therefore the significant figures are immediately after the decimal point.

ADDENDUM, 1907.

54*a*. The Engineer sketching case, model 1906, is shown in fig. 67a, p. 93. It differs from the type shown in fig. 26 in the form of the slide, which embraces the radial bar *B* instead of lying in the slot only and in the two concentric clamping screws *C* and *C′*; the former clamps the ruler to the slide, and the latter the slide to the radial bar *B*. With both screws loose, the ruler can move in az. or along the bar. By setting screw *C*, the ruler is clamped in az., but may still be moved along the bar. By setting screw *C′* also, the ruler is fixed in position, it being understood that the clamping screw *D*, which holds the radial bar in az., is also clamped.

The new form has graduations around the edge of the compass so that its stability may be tested at any time, and it may quickly be reset if disturbed. Cases for pencils are also provided in this new type.

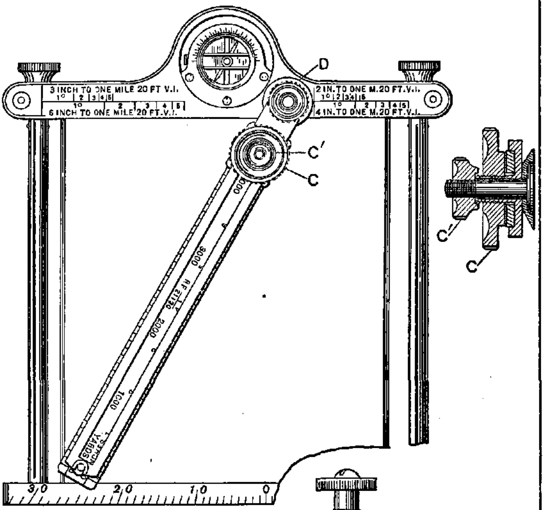


Fig. 67a

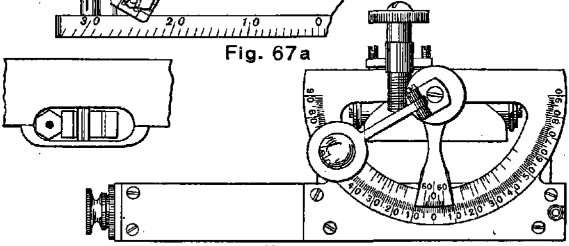


Fig. 67b

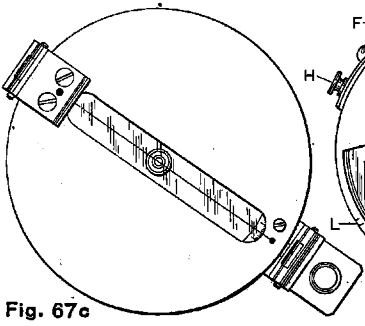


Fig. 67c

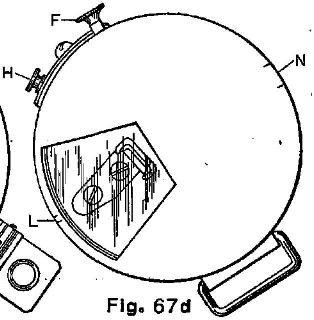


Fig. 67d

TABLE XIII.

112. **Common logarithms,** 1 to 999:

No.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	Diff.
		00000	30103	47712	60206	69897	77815	84510	90309	95424	
10	00000	00432	00860	01283	01703	02118	02530	02938	03342	03742	415
11	04139	04532	04921	05307	05690	06069	06445	06818	07188	07554	379
12	07918	08278	08636	08990	09342	09691	10037	10380	10721	11059	349
13	11394	11727	12057	12385	12710	13033	13353	13672	13987	14301	323
14	14613	14921	15228	15533	15836	16136	16435	16731	17026	17318	300
15	17609	17897	18184	18469	18752	19033	19312	19590	19865	20139	281
16	20412	20682	20951	21218	21484	21748	22010	22271	22530	22788	264
17	23045	23299	23552	23804	24054	24303	24551	24797	25042	25285	249
18	25527	25767	26007	26245	26481	26717	26951	27184	27415	27646	236
19	27875	28103	28330	28555	28780	29003	29225	29446	29666	29885	223
20	30103	30319	30535	30749	30963	31175	31386	31597	31806	32014	212
21	32222	32428	32633	32838	33041	33243	33445	33646	33845	34044	202
22	34242	34439	34635	34830	35024	35218	35410	35602	35793	35983	194
23	36173	36361	36548	36735	36921	37106	37291	37474	37657	37839	185
24	38021	38201	38381	38560	38739	38916	39093	39269	39445	39619	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	171
26	41497	41664	41830	41995	42160	42324	42488	42651	42813	42975	164
27	43136	43296	43456	43616	43775	43933	44090	44248	44404	44560	158
28	44716	44870	45024	45178	45331	45484	45636	45788	45939	46089	153
29	46240	46389	46538	46686	46834	46982	47129	47275	47421	47567	148
30	47712	47856	48000	48144	48287	48430	48572	48713	48855	48995	143
31	49136	49276	49415	49554	49693	49831	49968	50105	50242	50379	138
32	50515	50650	50785	50920	51054	51188	51321	51454	51587	51719	134
33	51851	51982	52113	52244	52374	52504	52633	52763	52891	53020	130
34	53148	53275	53402	53529	53655	53781	53907	54033	54157	54282	126
35	54407	54530	54654	54777	54900	55022	55145	55266	55388	55509	122
36	55630	55750	55870	55990	56110	56229	56348	56466	56584	56702	119
37	56820	56937	57054	57170	57287	57403	57518	57634	57749	57863	116
38	57978	58092	58206	58319	58433	58546	58658	58771	58883	58995	113
39	59106	59217	59328	59439	59549	59659	59769	59879	59988	60097	110
40	60206	60314	60422	60530	60638	60745	60852	60959	61066	61172	107
41	61278	61384	61489	61595	61700	61804	61909	62013	62118	62221	104
42	62325	62428	62531	62634	62736	62838	62941	63042	63144	63245	102
43	63347	63447	63548	63648	63749	63848	63948	64048	64147	64246	99
44	64345	64443	64542	64640	64738	64836	64933	65030	65127	65224	98
45	65321	65417	65513	65609	65705	65801	65896	65991	66086	66181	96
46	66276	66370	66464	66558	66651	66745	66838	66931	67024	67117	94
47	67210	67302	67394	67486	67577	67669	67760	67851	67942	68033	92
48	68124	68214	68304	68394	68484	68574	68663	68752	68842	68930	90
49	69020	69108	69196	69284	69372	69460	69548	69635	69722	69810	88
50	69897	69983	70070	70156	70243	70329	70415	70500	70586	70671	86
51	70757	70842	70927	71011	71096	71180	71265	71349	71433	71516	84
52	71600	71683	71767	71850	71933	72015	72098	72181	72263	72345	82
53	72428	72509	72591	72672	72754	72835	72916	72997	73078	73158	81
54	73239	73319	73399	73480	73559	73639	73719	73798	73878	73957	80
55	74036	74115	74193	74272	74351	74429	74507	74585	74663	74741	78
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511	77
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267	75
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011	74
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742	73
60	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461	72

TABLE XIII—*Continued.*

No.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	Diff.
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169	71
62	79239	79309	79379	79448	79518	79588	79657	79726	79796	79865	70
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550	69
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224	68
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888	67
66	81954	82020	82085	82151	82216	82282	82347	82412	82477	82542	66
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187	65
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83821	64
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447	63
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064	62
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672	61
72	85733	85793	85853	85913	85973	86033	86093	86153	86213	86272	60
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864	59
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448	58
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024	57
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592	56
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153	56
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707	55
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254	54
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794	54
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855	53
83	91907	91960	92012	92064	92116	92168	92220	92272	92324	92376	52
84	92427	92479	92531	92582	92634	92685	92737	92788	92839	92890	51
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399	51
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902	50
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398	49
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376	48
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856	48
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331	48
92	96378	96426	96473	96520	96567	96614	96661	96708	96754	96801	47
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266	47
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726	46
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181	46
96	98227	98272	98317	98362	98407	98452	98497	98542	98587	98632	45
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078	45
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519	44
99	99563	99607	99651	99694	99738	99782	99825	99869	99913	99956	44

113. Table XIV—**Common logarithms of circular functions:**

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
0	00	Inf. neg.	-------	10.00000	-----	Inf. neg.	-------	Inf. pos.	90	00
	01	6.46373	-------	10.00000	-----	6.46373	-------	13.53627		59
	02	.76476	30103	10.00000	-----	.76476	30103	.23524		58
	03	6.94085	17609	10.00000	-----	6.94085	17609	13.05915		57
	04	7.06579	12494	10.00000	-----	7.06579	12494	12.93421		56
	05	.16270	9691	10.00000	-----	.16270	9691	.83730		55
	06	.24188	7918	9.99999	-----	.24188	7918	.75812		54
	07	.30882	6694	.99999	-----	.30882	6694	.69117		53
	08	.36682	5800	.99999	-----	.36682	5800	.63318		52
	09	.41797	5115	.99999	-----	.41797	5115	.58203		51
	10	.46373	4576	.99999	-----	.46373	4576	.53627		50
	11	7.50512	4139	9.99999	-----	7.50512	4139	12.49488		49
	12	.54291	3779	.99999	-----	.54291	3779	.45709		48
	13	.57767	3476	.99999	-----	.57767	3476	.42233		47
	14	.60985	3218	.99999	-----	.60986	3219	.39014		46
	15	.63982	2996	.99999	-----	.63982	2996	.36018		45
	16	.66784	2803	.99999	-----	.66785	2803	.33215		44
	17	.69417	2633	.99999	-----	.69418	2633	.30582		43
	18	.71900	2482	.99999	-----	.71900	2482	.28100		42
	19	.74248	2348	.99999	-----	.74248	2348	.25752		41
	20	.76475	2227	.99999	-----	.76476	2228	.23524		40
	21	7.78594	2119	9.99999	-----	7.78595	2119	12.21405		39
	22	.80615	2020	.99999	-----	.80615	2020	.19384		38
	23	.82545	1930	.99999	-----	.82546	1931	.17454		37
	24	.84393	1848	.99999	-----	.84394	1848	.15606		36
	25	.86166	1773	.99999	-----	.86167	1773	.13833		35
	26	.87869	1703	.99999	-----	.87871	1704	.12129		34
	27	.89508	1639	.99999	-----	.89510	1639	.10490		33
	28	.91088	1580	.99999	-----	.91089	1579	.08911		32
	29	.92612	1524	.99998	-----	.92613	1524	.07387		31
	30	.94084	1472	.99998	-----	.94086	1473	.05914		30
	31	7.95508	1424	9.99998	-----	7.95510	1424	12.04490		29
	32	.96887	1379	.99998	-----	.96889	1379	.03111		28
	33	.98223	1336	.99998	-----	.98225	1336	.01775		27
	34	7.99520	1297	.99998	-----	7.99522	1297	12.00478		26
	35	8.00779	1259	.99998	-----	8.00781	1259	11.99219		25
	36	.02002	1223	.99998	-----	.02004	1223	.97996		24
	37	.03192	1190	.99997	-----	.03194	1190	.96805		23
	38	.04350	1158	.99997	-----	.04353	1158	.95647		22
	39	.05478	1128	.99997	-----	.05481	1128	.94519		21
	40	.06578	1100	.99997	-----	.06581	1100	.93419		20
	41	8.07650	1072	9.99997	-----	8.07653	1072	11.92347		19
	42	.08696	1046	.99997	-----	.08700	1047	.91300		18
	43	.09718	1022	.99997	-----	.09722	1022	.90278		17
	44	.10717	998	.99996	-----	.10720	999	.89280		16
	45	.11693	976	.99996	-----	.11696	976	.88304		15
	46	.12647	954	.99996	-----	.12651	955	.87349		14
	47	.13581	934	.99996	-----	.13585	934	.86415		13
	48	.14495	914	.99996	-----	.14500	915	.85500		12
	49	.15391	895	.99996	-----	.15395	895	.84605		11
	50	.16268	877	.99995	-----	.16273	878	.83727		10
	51	8.17128	860	9.99995	-----	8.17133	860	11.82867		9
	52	.17971	843	.99995	-----	.17976	843	.82024		8
	53	.18798	827	.99995	-----	.18804	828	.81196		7
	54	.19610	812	.99995	-----	.19616	812	.80384		6
	55	.20407	797	.99994	-----	.20413	797	.79587		5
	56	.21189	782	.99994	-----	.21195	782	.78805		4
	57	.21958	769	.99994	-----	.21964	769	.78036		3
	58	.22713	755	.99994	-----	.22719	755	.77280		2
	59	.23456	743	.99994	-----	.23462	743	.76538		1
	60	8.24185	729	9.99993	-----	8.24192	730	11.75808	89	0
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
1	00	8.24185	729	9.99993	-----	8.24192	730	11.75808		60
	01	.24903	718	.99993	-----	.24910	718	.75090		59
	02	.25609	706	.99993	-----	.25616	706	.74383		58
	03	.26304	695	.99993	-----	.26311	695	.73688		57
	04	.26988	684	.99992	-----	.26996	685	.73004		56
	05	.27661	673	.99992	-----	.27669	673	.72331		55
	06	.28324	663	.99992	-----	.28332	663	.71668		54
	07	.28977	653	.99992	-----	.28986	654	.71014		53
	08	.29621	644	.99991	-----	.29629	643	.70371		52
	09	.30255	634	.99991	-----	.30263	634	.69737		51
	10	.30879	624	.99991	-----	.30888	625	.69112		50
	11	8.31495	616	9.99991	-----	8.31505	617	11.68495		49
	12	.32103	608	.99990	-----	.32112	607	.67888		48
	13	.32702	599	.99990	-----	.32711	599	.67289		47
	14	.33292	590	.99990	-----	.33302	591	.66697		46
	15	.33875	583	.99990	-----	.33886	584	.66114		45
	16	.34450	575	.99989	-----	.34461	575	.65539		44
	17	.35018	568	.99989	-----	.35029	568	.64971		43
	18	.35578	560	.99989	-----	.35589	560	.64410		42
	19	.36131	553	.99988	-----	.36143	554	.63857		41
	20	.36678	547	.99988	-----	.36689	546	.63310		40
	21	8.37217	539	9.99988	-----	8.37229	540	11.62771		39
	22	.37750	533	.99988	-----	.37762	533	.62238		38
	23	.38276	526	.99987	-----	.38289	527	.61711		37
	24	.38796	520	.99987	-----	.38809	520	.61191		36
	25	.39310	514	.99987	-----	.39323	514	.60677		35
	26	.39818	508	.99986	-----	.39831	508	.60168		34
	27	.40320	502	.99986	-----	.40334	503	.59666		33
	28	.40816	496	.99986	-----	.40830	496	.59170		32
	29	.41307	491	.99985	-----	.41321	491	.58679		31
	30	.41792	485	.99985	-----	.41807	486	.58193		30
	31	8.42272	480	9.99985	-----	8.42287	480	11.57713		29
	32	.42746	474	.99984	-----	.42762	475	.57238		28
	33	.43216	470	.99984	-----	.43231	469	.56768		27
	34	.43680	464	.99984	-----	.43696	465	.56304		26
	35	.44139	459	.99983	-----	.44156	460	.55844		25
	36	.44594	455	.99983	-----	.44611	455	.55389		24
	37	.45044	450	.99983	-----	.45061	450	.54939		23
	38	.45489	445	.99982	-----	.45507	446	.54493		22
	39	.45930	441	.99982	-----	.45948	441	.54052		21
	40	.46366	436	.99982	-----	.46385	437	.53615		20
	41	8.46798	432	9.99981	-----	8.46817	432	11.53183		19
	42	.47226	428	.99981	-----	.47245	428	.52755		18
	43	.47650	424	.99980	-----	.47669	424	.52331		17
	44	.48069	419	.99980	-----	.48089	420	.51911		16
	45	.48485	416	.99980	-----	.48505	416	.51495		15
	46	.48896	411	.99979	-----	.48917	412	.51083		14
	47	.49304	408	.99979	-----	.49325	408	.50675		13
	48	.49708	404	.99979	-----	.49729	404	.50271		12
	49	.50108	400	.99978	-----	.50130	401	.49870		11
	50	.50504	396	.99978	-----	.50527	397	.49473		10
	51	8.50897	393	9.99977	-----	8.50920	393	11.49080		9
	52	.51287	390	.99977	-----	.51310	390	.48690		8
	53	.51673	386	.99976	-----	.51696	386	.48304		7
	54	.52055	382	.99976	-----	.52079	383	.47921		6
	55	.52434	379	.99976	-----	.52459	380	.47541		5
	56	.52810	376	.99975	-----	.52835	376	.47165		4
	57	.53183	373	.99975	-----	.53208	373	.46792		3
	58	.53552	369	.99974	-----	.53578	370	.46422		2
	59	.53919	367	.99974	-----	.53945	367	.46055		1
	60	8.54282	363	9.99973	-----	8.54308	363	11.45692	88	0
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

87625—09——7

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc. °	Arc. ′	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	°	′
2	00	8.54282	363	9.99973	-----	8.54308	363	11.45692		60
	01	.54642	360	.99973	-----	.54669	361	.45331		59
	02	.54999	357	.99973	-----	.55027	358	.44973		58
	03	.55354	355	.99972	-----	.55382	355	.44618		57
	04	.55705	351	.99972	-----	.55734	352	.44266		56
	05	.56054	349	.99971	-----	.56083	349	.43917		55
	06	.56400	346	.99971	-----	.56429	346	.43571		54
	07	.56743	343	.99970	-----	.56773	344	.43227		53
	08	.57084	341	.99970	-----	.57114	341	.42886		52
	09	.57421	337	.99969	-----	.57452	338	.42548		51
	10	.57757	336	.99969	-----	.57788	336	.42212		50
	11	8.58089	332	9.99968	-----	8.58121	333	11.41879		49
	12	.58419	330	.99968	-----	.58451	330	.41549		48
	13	.58747	328	.99967	-----	.58779	328	.41220		47
	14	.59072	325	.99967	-----	.59105	326	.40895		46
	15	.59395	323	.99966	-----	.59428	323	.40572		45
	16	.59715	320	.99966	-----	.59749	321	.40251		44
	17	.60033	318	.99965	-----	.60068	319	.39932		43
	18	.60349	316	.99965	-----	.60384	316	.39316		42
	19	.60662	313	.99964	-----	.60698	314	.39302		41
	20	.60973	311	.99964	-----	.61009	311	.38991		40
	21	8.61282	309	9.99963	-----	8.61319	310	11.38681		39
	22	.61589	307	.99963	-----	.61626	307	.38374		38
	23	.61894	305	.99962	-----	.61931	305	.38069		37
	24	.62196	302	.99962	-----	.62234	303	.37766		36
	25	.62496	300	.99961	-----	.62535	301	.37465		35
	26	.62795	299	.99961	-----	.62834	299	.37166		34
	27	.63091	296	.99960	-----	.63131	297	.36869		33
	28	.63385	294	.99960	-----	.63426	295	.36574		32
	29	.63678	293	.99959	-----	.63718	292	.36282		31
	30	.63968	290	.99959	-----	.64009	291	.35991		30
	31	8.64256	288	9.99958	-----	8.64298	289	11.35702		29
	32	.64543	287	.99957	-----	.64585	287	.35415		28
	33	.64827	284	.99957	-----	.64870	285	.35130		27
	34	.65110	283	.99956	-----	.65154	284	.34846		26
	35	.65391	281	.99956	-----	.65435	281	.34565		25
	36	.65670	279	.99955	-----	.65715	280	.34285		24
	37	.65947	277	.99955	-----	.65993	278	.34007		23
	38	.66223	276	.99954	-----	.66269	276	.33731		22
	39	.66497	274	.99953	-----	.66543	274	.33457		21
	40	.66769	272	.99953	-----	.66816	273	.33184		20
	41	8.67039	270	9.99952	-----	8.67087	271	11.32913		19
	42	.67308	269	.99952	-----	.67356	269	.32644		18
	43	.67575	267	.99951	-----	.67624	268	.32376		17
	44	.67840	265	.99951	-----	.67890	266	.32110		16
	45	.68104	264	.99950	-----	.68154	264	.31846		15
	46	.68366	262	.99949	-----	.68417	263	.31583		14
	47	.68627	261	.99949	-----	.68678	261	.31322		13
	48	.68886	259	.99948	-----	.68938	260	.31062		12
	49	.69144	258	.99947	-----	.69196	258	.30804		11
	50	.69400	256	.99947	-----	.69453	257	.30547		10
	51	8.69654	254	9.99946	-----	8.69708	255	11.30292		9
	52	.69907	253	.99946	-----	.69962	254	.30038		8
	53	.70159	252	.99945	-----	.70214	252	.29786		7
	54	.70409	250	.99944	-----	.70465	251	.29535		6
	55	.70658	249	.99944	-----	.70714	249	.29286		5
	56	.70905	247	.99943	-----	.70962	248	.29038		4
	57	.71151	246	.99942	-----	.71208	246	.28792		3
	58	.71395	244	.99942	-----	.71453	245	.28547		2
	59	.71638	243	.99941	-----	.71697	244	.28303		1
	60	8.71880	242	9.99940	-----	8.71940	243	11.28060	87	0
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc.		Sine.	Diff.	Cosine.	Diff	Tang.	Diff.	Cotang.		
°	′								°	′
3	00	8.71880	242	9.99940	-----	8.71940	243	11.28060		60
	01	.72120	240	.99940	-----	.72181	241	.27819		59
	02	.72359	239	.99939	-----	.72420	239	.27579		58
	03	.72597	238	.99938	-----	.72659	239	.27341		57
	04	.72834	237	.99938	-----	.72896	237	.27104		56
	05	.73069	235	.99937	-----	.73132	236	.26869		55
	06	.73303	234	.99936	-----	.73366	234	.26634		54
	07	.73535	232	.99936	-----	.73600	234	.26400		53
	08	.73767	232	.99935	-----	.73832	232	.26168		52
	09	.73997	230	.99934	-----	.74063	231	.25937		51
	10	.74226	229	.99934	-----	.74292	229	.25708		50
	11	8.74454	228	9.99933	-----	8.74521	229	11.25479		49
	12	.74680	226	.99932	-----	.74748	227	.25252		48
	13	.74905	225	.99931	-----	.74974	226	.25026		47
	14	.75130	225	.99931	-----	.75199	225	.24801		46
	15	.75353	223	.99930	-----	.75423	224	.24577		45
	16	.75575	222	.99929	-----	.75645	222	.24355		44
	17	.75795	220	.99929	-----	.75867	222	.24133		43
	18	.76015	220	.99928	-----	.76087	220	.23913		42
	19	.76234	219	.99927	-----	.76306	219	.23693		41
	20	.76451	217	.99926	-----	.76525	219	.23475		40
	21	8.76667	216	9.99926	-----	8.76742	217	11.23258		39
	22	.76883	216	.99926	-----	.76958	216	.23042		38
	23	.77097	214	.99924	-----	.77173	215	.22827		37
	24	.77310	213	.99923	-----	.77387	214	.22613		36
	25	.77522	212	.99923	-----	.77599	212	.22400		35
	26	.77733	211	.99922	-----	.77811	212	.22189		34
	27	.77943	210	.99921	-----	.78022	211	.21978		33
	28	.78152	209	.99920	-----	.78232	210	.21768		32
	29	.78360	208	.99920	-----	.78441	209	.21559		31
	30	.78567	207	.99919	-----	.78649	208	.21351		30
	31	8.78774	207	9.99918	-----	8.78855	206	11.21145		29
	32	.78979	205	.99917	-----	.79061	206	.20939		28
	33	.79183	204	.99917	-----	.79266	205	.20734		27
	34	.79386	203	.99916	-----	.79470	204	.20530		26
	35	.79588	202	.99915	-----	.79673	203	.20327		25
	36	.79789	201	.99914	-----	.79875	202	.20125		24
	37	.79990	201	.99913	-----	.80076	201	.19924		23
	38	.80189	199	.99913	-----	.80276	200	.19723		22
	39	.80388	199	.99912	-----	.80476	200	.19524		21
	40	.80585	197	.99911	-----	.80674	198	.19326		20
	41	8.80782	197	9.99910	-----	8.80872	198	11.19128		19
	42	.80978	196	.99909	-----	.81068	196	.18932		18
	43	.81173	195	.99909	-----	.81264	196	.18736		17
	44	.81367	194	.99908	-----	.81459	195	.18541		16
	45	.81560	193	.99907	-----	.81653	194	.18347		15
	46	.81752	192	.99906	-----	.81846	193	.18154		14
	47	.81944	192	.99905	-----	.82038	192	.17962		13
	48	.82134	190	.99904	-----	.82230	192	.17770		12
	49	.82324	190	.99904	-----	.82420	190	.17579		11
	50	.82513	189	.99903	-----	.82610	190	.17390		10
	51	8.82701	188	9.99902	-----	8.82799	189	11.17201		9
	52	.82888	187	.99901	-----	.82987	188	.17013		8
	53	.83075	187	.99900	-----	.83175	188	.16825		7
	54	.83261	186	.99899	-----	.83361	186	.16639		6
	55	.83446	185	.99898	-----	.83547	186	.16453		5
	56	.83630	184	.99898	-----	.83732	185	.16268		4
	57	.83813	183	.99897	-----	.83916	184	.16084		3
	58	.83996	183	.99896	-----	.84100	184	.15900		2
	59	.84177	181	.99895	-----	.84282	182	.15717		1
	60	8.84358	181	9.99894	-----	8.84464	182	11.15536	86	0
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc. °	Arc. ′	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	°	′
4	00	8.84358	181	9.99894	1	8.84464	182	11.15536	86	00
	10	.86128	1770	.99885	9	.86243	1779	.13757		50
	20	.87828	1700	.99876	9	.87953	1710	.12047		40
	30	.89464	1636	.99866	10	.89598	1645	.10402		30
	40	.91040	1576	.99856	10	.91185	1587	.08815		20
	50	.92561	1521	.99845	11	.92716	1531	.07284		10
5	00	8.94030	1469	9.99834	11	8.94195	1479	11.05805	85	00
	10	.95450	1420	.99823	11	.95627	1432	.04373		50
	20	.96825	1375	.99812	11	.97013	1386	.02987		40
	30	.98157	1332	.99800	12	.98358	1345	.01642		30
	40	.99450	1293	.99787	13	.99662	1304	.00338		20
	50	9.00704	1254	.99774	13	9.00930	1268	10.99070		10
6	00	9.01923	1219	9.99761	13	9.02162	1232	10.97838	84	00
	10	.03109	1186	.99748	13	.03361	1199	.96639		50
	20	.04262	1153	.99734	14	.04528	1167	.95472		40
	30	.05386	1124	.99720	14	.05666	1138	.94334		30
	40	.06481	1095	.99705	15	.06775	1109	.93225		20
	50	.07548	1067	.99690	15	.07858	1083	.92142		10
7	00	9.08589	1041	9.99675	15	9.08914	1056	10.91086	83	00
	10	.09606	1017	.99659	16	.09947	1033	.90053		50
	20	.10599	993	.99643	16	.10956	1009	.89044		40
	30	.11570	971	.99627	16	.11943	987	.88057		30
	40	.12519	949	.99610	17	.12909	966	.87091		20
	50	.13447	928	.99593	17	.13854	945	.86146		10
8	00	9.14355	908	9.99575	18	9.14780	926	10.85220	82	00
	10	.15245	890	.99557	18	.15688	908	.84312		50
	20	.16116	871	.99539	18	.16577	889	.83423		40
	30	.16970	854	.99520	19	.17450	873	.82550		30
	40	.17807	837	.99501	19	.18306	856	.81694		20
	50	.18628	821	.99482	19	.19146	840	.80854		10
9	00	9.19433	805	9.99462	20	9.19971	825	10.80029	81	00
	10	.20223	790	.99442	20	.20782	811	.79218		50
	20	.20999	776	.99421	21	.21578	796	.78422		40
	30	.21761	762	.99400	21	.22361	783	.77639		30
	40	.22509	748	.99379	21	.23130	769	.76870		20
	50	.23244	735	.99357	22	.23887	757	.76113		10
10	00	9.23967	723	9.99335	22	9.24632	745	10.75368	80	00
	10	.24677	710	.99313	22	.25365	733	.74635		50
	20	.25376	699	.99290	23	.26086	721	.73914		40
	30	.26063	687	.99267	23	.26797	711	.73203		30
	40	.26739	676	.99243	24	.27496	699	.72504		20
	50	.27405	636	.99219	24	.28186	690	.71814		10
11	00	9.28060	655	9.99195	24	9.28865	679	10.71135	79	00
	10	.28705	645	.99170	25	.29535	670	.70465		50
	20	.29340	635	.99145	25	.30195	660	.69805		40
	30	.29965	625	.90119	26	.30846	651	.69154		30
	40	.30582	617	.99093	26	.31488	642	.68511		20
	50	.31189	607	.99067	26	.32122	634	.67878		10
12	00	9.31788	599	9.99040	27	9.32747	625	10.67252	78	00
	10	.32378	590	.99013	27	.33365	618	.66635		50
	20	.32960	582	.98986	27	.33974	609	.66026		40
	30	.33534	574	.98958	28	.34575	601	.65424		30
	40	.34100	566	.98930	28	.35170	595	.64830		20
	50	.34658	558	.98901	29	.35757	587	.64243		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc. °	′	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	°	′
13	00	9.35209	551	9.98872	29	9.36336	579	10.63664	77	00
	10	.35752	543	.98843	29	.36909	573	.63091		50
	20	.36289	537	.98813	30	.37476	567	.62524		40
	30	.36818	528	.98783	30	.38035	559	.61965		30
	40	.37341	523	.98753	30	.38589	554	.61411		20
	50	.37858	517	.98722	31	.39136	547	.60864		10
14	00	9.38367	509	9.98690	32	9.39677	541	10.60323	76	00
	10	.38871	504	.98659	31	.40212	535	.59788		50
	20	.39368	497	.98627	32	.40742	530	.59258		40
	30	.39860	492	.98594	33	.41266	524	.58734		30
	40	.40345	485	.98561	33	.41784	518	.58216		20
	50	.40825	480	.98528	33	.42297	513	.57703		10
15	00	9.41300	475	9.98494	34	9.42805	508	10.57195	75	00
	10	.41768	468	.98460	34	.43308	503	.56692		50
	20	.42232	464	.98426	34	.43806	498	.56194		40
	30	.42690	458	.98391	35	.44299	493	.55701		30
	40	.43143	453	.98356	35	.44787	488	.55213		20
	50	.43591	448	.98320	36	.45271	484	.54729		10
16	00	9.44034	443	9.98284	36	9.45750	479	10.54250	74	00
	10	.44472	438	.98248	36	.46224	474	.53776		50
	20	.44905	433	.98211	37	.46694	470	.53306		40
	30	.45334	429	.98174	37	.47160	466	.52839		30
	40	.45758	424	.98136	38	.47622	462	.52378		20
	50	.46178	420	.98098	38	.48080	458	.51920		10
17	00	9.46593	415	9.98060	38	9.48534	454	10.51466	73	00
	10	.47005	412	.98021	39	.48984	450	.51016		50
	20	.47411	406	.97982	39	.49430	446	.50570		40
	30	.47814	403	.97942	40	.49872	442	.50128		30
	40	.48213	399	.97902	40	.50311	439	.49689		20
	50	.48607	394	.97861	41	.50746	435	.49254		10
18	00	9.48998	391	9.97821	40	9.51178	432	10.48822	72	00
	10	.49385	387	.97779	42	.51606	428	.48394		50
	20	.49768	383	.97738	41	.52030	424	.47969		40
	30	.50148	380	.97696	42	.52452	422	.47548		30
	40	.50523	375	.97653	43	.52870	418	.47130		20
	50	.50896	373	.97610	43	.53285	415	.46715		10
19	00	9.51264	368	9.97567	43	9.53697	412	10.46303	71	00
	10	.51629	365	.97523	44	.54106	409	.45894		50
	20	.51991	362	.97479	44	.54512	406	.45488		40
	30	.52349	358	.97435	44	.54915	403	.45085		30
	40	.52705	356	.97390	45	.55315	400	.44685		20
	50	.53056	351	.97344	46	.55712	397	.44288		10
20	00	9.53405	349	9.97299	45	9.56107	395	10.43893	70	00
	10	.53751	346	.97252	47	.56498	391	.43502		50
	20	.54093	342	.97206	46	.56887	389	.43113		40
	30	.54432	339	.97159	47	.57274	387	.42726		30
	40	.54769	337	.97111	48	.57658	384	.42342		20
	50	.55102	333	.97063	48	.58039	381	.41961		10
21	00	9.55433	331	9.97015	48	9.58418	379	10.41582	69	00
	10	.55761	328	.96966	49	.58794	376	.41206		50
	20	.56085	324	.96917	49	.59168	374	.40832		40
	30	.56407	322	.96868	49	.59540	372	.40460		30
	40	.56727	320	.96818	50	.59909	369	.40091		20
	50	.57043	316	.96767	51	.60276	367	.39724		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
22	00	9.57357	314	9.96717	50	9.60641	365	10.39359	68	00
	10	.57669	312	.96665	52	.61004	363	.38996		50
	20	.57978	309	.96614	51	.61364	360	.38636		40
	30	.58284	306	.96561	53	.61722	358	.38278		30
	40	.58588	304	.96509	52	.62079	357	.37921		20
	50	.58889	301	.96456	53	.62433	354	.37567		10
23	00	9.59188	299	9.96403	53	9.62785	352	10.37215	67	00
	10	.59484	296	.96349	54	.63135	350	.36864		50
	20	.59778	294	.96294	55	.63484	349	.36516		40
	30	.60070	292	.96240	54	.63830	346	.36170		30
	40	.60359	289	.96185	55	.64175	345	.35825		20
	50	.60646	287	.96129	56	.64517	342	.35483		10
24	00	9.60931	285	9.96073	56	9.64858	341	10.35142	66	00
	10	.61214	283	.96016	57	.65197	339	.34803		50
	20	.61494	280	.95960	56	.65535	338	.34465		40
	30	.61773	279	.95902	58	.65870	335	.34130		30
	40	.62049	276	.95844	58	.66204	334	.33796		20
	50	.62323	274	.95786	58	.66537	333	.33463		10
25	00	9.62595	272	9.95728	58	9.66867	330	10.33133	65	00
	10	.62865	270	.95668	60	.67196	329	.32804		50
	20	.63133	268	.95609	59	.67524	328	.32476		40
	30	.63398	265	.95549	60	.67850	326	.32150		30
	40	.63662	264	.95488	61	.68174	324	.31826		20
	50	.63924	262	.95427	61	.68497	323	.31503		10
26	00	9.64184	260	9.95366	60	9.68818	321	10.31182	64	00
	10	.64442	258	.95304	62	.69138	320	.30862		50
	20	.64698	256	.95242	62	.69457	319	.30543		40
	30	.64953	255	.95179	63	.69774	317	.30226		30
	40	.65205	252	.95116	63	.70089	315	.29911		20
	50	.65456	251	.95052	64	.70404	315	.29596		10
27	00	9.65705	249	9.94988	64	9.70717	313	10.29283	63	00
	10	.65952	247	.94923	65	.71028	311	.28972		50
	20	.66197	245	.94858	65	.71339	311	.28661		40
	30	.66441	244	.94793	65	.71648	309	.28352		30
	40	.66682	241	.94727	66	.71955	307	.28044		20
	50	.66922	240	.94660	67	.72262	307	.27738		10
28	00	9.67161	239	9.94593	67	9.72567	305	10.27433	62	00
	10	.67398	237	.94526	67	.72872	305	.27128		50
	20	.67633	235	.94458	68	.73175	303	.26825		40
	30	.67866	233	.94390	68	.73476	301	.26524		30
	40	.68098	232	.94321	69	.73777	301	.26223		20
	50	.68328	230	.94252	69	.74077	300	.25923		10
29	00	9.68557	229	9.94182	70	9.74375	298	10.25625	61	00
	10	.68784	227	.94112	70	.74673	298	.25327		50
	20	.69010	226	.94041	71	.74969	296	.25031		40
	30	.69234	224	.93970	71	.75264	295	.24736		30
	40	.69456	222	.93898	72	.75558	294	.24441		20
	50	.69677	221	.93826	72	.75852	294	.24148		10
30	00	9.69897	220	9.93753	73	9.76144	292	10.23856	60	00
	10	.70115	218	.93680	73	.76435	291	.23565		50
	20	.70332	217	.93606	74	.76725	290	.23274		40
	30	.70547	215	.93532	74	.77015	290	.22985		30
	40	.70761	214	.93457	75	.77303	288	.22697		20
	50	.70973	212	.93382	75	.77591	288	.22409		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc. °	′	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	°	′
31	00	9.71184	211	9.93307	75	9.77877	286	10.22123	59	00
	10	.71393	209	.93230	77	.78163	286	.21837		50
	20	.71602	209	.93154	76	.78448	285	.21552		40
	30	.71808	206	.93077	77	.78732	284	.21268		30
	40	.72014	206	.92999	78	.79015	283	.20985		20
	50	.72218	204	.92921	78	.79297	282	.20703		10
32	00	9.72421	203	9.92842	79	9.79579	282	10.20421	58	00
	10	.72622	201	.92763	79	.79860	281	.20140		50
	20	.72823	201	.92683	80	.80140	280	.19860		40
	30	.73022	199	.92603	80	.80419	279	.19581		30
	40	.73219	197	.92522	81	.80697	278	.19303		20
	50	.73416	197	.92441	81	.80975	278	.19025		10
33	00	9.73611	195	9.92359	82	9.81252	277	10.18748	57	00
	10	.73805	194	.92277	82	.81528	276	.18472		50
	20	.73997	192	.92194	83	.81803	275	.18196		40
	30	.74189	192	.92111	83	.82078	275	.17922		30
	40	.74379	190	.92027	84	.82352	274	.17648		20
	50	.74568	189	.91942	85	.82626	274	.17374		10
34	00	9.74756	188	9.91857	85	9.82899	273	10.17101	56	00
	10	.74943	187	.91772	85	.83171	272	.16829		50
	20	.75128	185	.91686	86	.83442	271	.16557		40
	30	.75313	185	.91599	87	.83713	271	.16287		30
	40	.75496	183	.91512	87	.83984	271	.16016		20
	50	.75678	182	.91425	87	.84253	269	.15746		10
35	00	9.75859	181	9.91336	89	9.84523	270	10.15477	55	00
	10	.76039	180	.91248	88	.84791	268	.15209		50
	20	.76218	179	.91158	90	.85059	268	.14941		40
	30	.76395	177	.91069	89	.85327	268	.14673		30
	40	.76572	177	.90978	91	.85594	267	.14406		20
	50	.76747	175	.90887	91	.85860	266	.14140		10
36	00	9.76922	175	9.90796	91	9.86126	266	10.13874	54	00
	10	.77095	173	.90704	92	.86391	265	.13608		50
	20	.77267	172	.90611	93	.86656	265	.13344		40
	30	.77439	172	.90518	93	.86921	265	.13079		30
	40	.77609	170	.90424	94	.87185	264	.12815		20
	50	.77778	169	.90330	94	.87448	263	.12552		10
37	00	9.77946	168	9.90235	95	9.87711	263	10.12289	53	00
	10	.78113	167	.90139	96	.87974	263	.12026		50
	20	.78280	167	.90043	96	.88236	262	.11764		40
	30	.78445	165	.89947	96	.88498	262	.11502		30
	40	.78609	164	.89849	98	.88759	261	.11241		20
	50	.78772	163	.89752	97	.89020	261	.10980		10
38	00	9.78934	162	9.89653	99	9.89281	261	10.10719	52	00
	10	.79095	161	.89554	99	.89541	260	.10459		50
	20	.79256	161	.89455	99	.89801	260	.10199		40
	30	.79415	159	.89354	101	.90060	259	.09939		30
	40	.79573	158	.89254	100	.90320	260	.09680		20
	50	.79731	158	.89152	102	.90578	258	.09421		10
39	00	9.79887	156	9.89050	102	9.90837	259	10.09163	51	00
	10	.80043	156	.88948	102	.91095	258	.08905		50
	20	.80197	154	.88844	104	.91353	258	.08647		40
	30	.80351	154	.88741	103	.91610	257	.08390		30
	40	.80504	153	.88636	105	.91868	258	.08132		20
	50	.80656	152	.88531	105	.92125	257	.07875		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—*Continued.*

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
40	00	9.80807	151	9.88425	106	9.92381	256	10.07618	50	00
	10	.80957	150	.88319	106	.92638	257	.07362		50
	20	.81106	149	.88212	107	.92894	256	.07106		40
	30	.81254	148	.88105	107	.93150	256	.06850		30
	40	.81402	148	.87996	109	.93406	256	.06594		20
	50	.81548	146	.87887	109	.93661	255	.06339		10
41	00	9.81694	146	9.87778	109	9.93916	255	10.06084	49	00
	10	.81839	145	.87668	110	.94171	255	.05829		50
	20	.81983	144	.87557	111	.94426	255	.05574		40
	30	.82126	143	.87446	111	.94681	255	.05319		30
	40	.82269	143	.87333	113	.94935	254	.05065		20
	50	.82410	141	.87221	112	.95190	255	.04810		10
42	00	9.82551	141	9.87107	114	9.95444	254	10.04556	48	00
	10	.82691	140	.86993	114	.95698	254	.04302		50
	20	.82830	139	.86878	115	.95952	254	.04048		40
	30	.82968	138	.86763	115	.96205	253	.03795		30
	40	.83106	138	.86647	116	.96459	254	.03541		20
	50	.83242	136	.86530	117	.96712	253	.03288		10
43	00	9.83378	136	9.86413	117	9.96966	254	10.03034	47	00
	10	.83513	135	.86295	118	.97219	253	.02781		50
	20	.83648	135	.86176	119	.97472	253	.02528		40
	30	.83781	133	.86056	120	.97725	253	.02275		30
	40	.83914	133	.85936	120	.97978	253	.02022		20
	50	.84046	132	.85815	121	.98231	253	.01769		10
44	00	9.84177	131	9.85693	122	9.98484	253	10.01516	46	00
	10	.84308	131	.85571	122	.98736	252	.01263		50
	20	.84437	129	.85448	123	.98989	253	.01011		40
	30	.84566	129	.85324	124	.99242	253	.00758		30
	40	.84694	128	.85200	124	.99495	253	.00505		20
	50	.84822	128	.85074	126	.99747	252	.00253		10
45	00	9.84948	126	9.84948	126	10.00000	253	10.00000	45	00
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

114. **The slide rule** is a contrivance for using logs. mechanically. It consists, fig. 47, of a rule, in the middle of which is a slide. The edges of the groove and the edges of the slide are graduated, forming 4 scales called A, B, C, and D. An indicator, which can be set at any point, guides the eye in selecting opposite numbers. The slide rule deals with **mantissas** only. Characteristics must be obtained by inspection.

To multiply.—Move the slide to the *right* until 1 on scale B is opposite the smaller of the 2 numbers on A; the number on A opposite the larger of the 2 numbers on B is the product.

To divide.—Move the slide to the *left* until the *divisor* on B is under 1 on A. The number on A opposite the *dividend* on B is the quotient desired. **To multiply and divide simultaneously**, or to **solve a proportion**, set the divisor on B opposite one of the other numbers on A. The number on A opposite the 3d number on B is the result desired.

To find the square of a number.—Take the number on A opposite the given number on D.

To find the square root.—Take the number on D opposite the given number on A. In taking square roots use only the *left half* of A, for an odd number of figures in front of the decimal point, and the *right half* only for *even* number.

To find a cube.—Set 1 on B opposite the given number on D. The number on A opposite the given number on B is the cube desired.

To find a cube root.—Take the root approximately by inspection. Set this number on B opposite the given number on A. Note whether 1 on C is opposite the approximate root on D. If so, the approximate root is the correct one; if not, move the slide slightly one way or the other until the number on B opposite the given number, and the number on D opposite the one on C are the same. This number is the desired cube root.

Occasional users of the slide rule will do well to adhere to the simple operations above described. Regular users will study the theory and scope of the rule from one of the several treatises on the subject.

TABLE XV.

115. **Table of squares, cubes, square roots, and cube roots** of numbers from 1 to 1,000:

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
1	1	1	1.	1.	51	2601	132651	7.1414	3.7084
2	4	8	1.4142	1.2599	52	2704	140608	7.2111	3.7325
3	9	27	1.7321	1.4422	53	2809	148877	7.2801	3.7563
4	16	64	2.0000	1.5874	54	2916	157464	7.3485	3.7798
5	25	125	2.2361	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.4495	1.8171	56	3136	175616	7.4833	3.8259
7	49	343	2.6458	1.9129	57	3249	185193	7.5498	3.8485
8	64	512	2.8284	2.0000	58	3364	195112	7.6158	3.8709
9	81	729	3.0000	2.0801	59	3481	205379	7.6811	3.8930
10	100	1000	3.1623	2.1544	60	3600	216000	7.7460	3.9149
11	121	1331	3.3166	2.2240	61	3721	226981	7.8102	3.9365
12	144	1728	3.4641	2.2894	62	3844	238328	7.8740	3.9579
13	169	2197	3.6056	2.3513	63	3969	250047	7.9373	3.9791
14	196	2744	3.7417	2.4101	64	4096	262144	8.	4.
15	225	3375	3.8730	2.4662	65	4225	274625	8.0623	4.0207
16	256	4096	4.	2.5198	66	4356	287496	8.1240	4.0412
17	289	4913	4.1231	2.5713	67	4489	300763	8.1854	4.0615
18	324	5832	4.2426	2.6207	68	4624	314432	8.2462	4.0817
19	361	6859	4.3589	2.6684	69	4761	328509	8.3066	4.1016
20	400	8000	4.4721	2.7144	70	4900	343000	8.3666	4.1213
21	441	9261	4.5826	2.7589	71	5041	357911	8.4261	4.1408
22	484	10648	4.6904	2.8020	72	5184	373248	8.4853	4.1602
23	529	12167	4.7958	2.8439	73	5329	389017	8.5440	4.1793
24	576	13824	4.8990	2.8845	74	5476	405224	8.6023	4.1983
25	625	15625	5.	2.9240	75	5625	421875	8.6603	4.2172
26	676	17576	5.0990	2.9625	76	5776	438976	8.7178	4.2358
27	729	19683	5.1962	3.0000	77	5929	456533	8.7750	4.2545
28	784	21952	5.2915	3.0366	78	6084	474552	8.8318	4.2727
29	841	24389	5.3852	3.0723	79	6241	493039	8.8882	4.2908
30	900	27000	5.4772	3.1072	80	6400	512000	8.9443	4.3089
31	961	29791	5.5678	3.1414	81	6561	531441	9.	4.3267
32	1024	32768	5.6569	3.1748	82	6724	551368	9.0554	4.3445
33	1089	35937	5.7446	3.2075	83	6889	571787	9.1104	4.3621
34	1156	39304	5.8310	3.2396	84	7056	592704	9.1652	4.3795
35	1225	42875	5.9161	3.2711	85	7225	614125	9.2195	4.3968
36	1296	46656	6.	3.3019	86	7396	636056	9.2736	4.4140
37	1369	50653	6.0828	3.3322	87	7569	658503	9.3274	4.4310
38	1444	54872	6.1644	3.3620	88	7744	681472	9.3808	4.4480
39	1521	59319	6.2450	3.3912	89	7921	704969	9.4340	4.4647
40	1600	64000	6.3246	3.4200	90	8100	729000	9.4868	4.4814
41	1681	68921	6.4031	3.4482	91	8281	753571	9.5394	4.4979
42	1764	74088	6.4807	3.4760	92	8464	778688	9.5917	4.5144
43	1849	79507	6.5574	3.5034	93	8649	804357	9.6437	4.5307
44	1936	85184	6.6332	3.5303	94	8836	830584	9.6954	4.5468
45	2025	91125	6.7082	3.5569	95	9025	857375	9.7468	4.5629
46	2116	97336	6.7823	3.5830	96	9216	884736	9.7980	4.5789
47	2209	103823	6.8557	3.6088	97	9409	912673	9.8489	4.5947
48	2304	110592	6.9282	3.6342	98	9604	941192	9.8995	4.6104
49	2401	117649	7.	3.6593	99	9801	970299	9.9499	4.6261
50	2500	125000	7.0711	3.6840	100	10000	1000000	10.	4.6416

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
101	10201	1030301	10.0499	4.6570	151	22801	3442951	12.2882	5.3251
102	10404	1061208	10.0995	4.6723	152	23104	3511808	12.3288	5.3368
103	10609	1092727	10.1489	4.6875	153	23409	3581577	12.3693	5.3485
104	10816	1124864	10.1980	4.7027	154	23716	3652264	12.4097	5.3601
105	11025	1157625	10.2470	4.7177	155	24025	3723875	12.4499	5.3717
106	11236	1191016	10.2956	4.7326	156	24336	3796416	12.4900	5.3832
107	11449	1225043	10.3441	4.7475	157	24649	3869893	12.5300	5.3947
108	11664	1259712	10.3923	4.7622	158	24964	3944312	12.5698	5.4061
109	11881	1295029	10.4403	4.7769	159	25281	4019679	12.6095	5.4175
110	12100	1331000	10.4881	4.7914	160	25600	4096000	12.6491	5.4288
111	12321	1367631	10.5357	4.8059	161	25921	4173281	12.6886	5.4401
112	12544	1404928	10.5830	4.8203	162	26244	4251528	12.7279	5.4514
113	12769	1442897	10.6301	4.8346	163	26569	4330747	12.7671	5.4626
114	12996	1481544	10.6771	4.8488	164	26896	4410944	12.8062	5.4737
115	13225	1520875	10.7238	4.8629	165	27225	4492125	12.8452	5.4848
116	13456	1560896	10.7703	4.8770	166	27556	4574296	12.8841	5.4959
117	13689	1601613	10.8167	4.8910	167	27889	4657463	12.9228	5.5069
118	13924	1643032	10.8628	4.9049	168	28224	4741632	12.9615	5.5178
119	14161	1685159	10.9087	4.9187	169	28561	4826809	13.	5.5288
120	14400	1728000	10.9545	4.9324	170	28900	4913000	13.0384	5.5397
121	14641	1771561	11.0000	4.9461	171	29241	5000211	13.0767	5.5505
122	14884	1815848	11.0454	4.9597	172	29584	5088448	13.1149	5.5613
123	15129	1860867	11.0905	4.9732	173	29929	5177717	13.1529	5.5721
124	15376	1906624	11.1355	4.9866	174	30276	5268024	13.1909	5.5828
125	15625	1953125	11.1803	5.	175	30625	5359375	13.2288	5.5934
126	15876	2000376	11.2250	5.0133	176	30976	5451776	13.2665	5.6041
127	16129	2048383	11.2694	5.0265	177	31329	5545233	13.3041	5.6147
128	16384	2097152	11.3137	5.0397	178	31684	5639752	13.3417	5.6252
129	16641	2146689	11.3578	5.0528	179	32041	5735339	13.3791	5.6357
130	16900	2197000	11.4018	5.0658	180	32400	5832000	13.4164	5.6462
131	17161	2248091	11.4455	5.0788	181	32761	5929741	13.4536	5.6567
132	17424	2299968	11.4891	5 0916	182	33124	6028568	13.4907	5.6671
133	17689	2352637	11.5326	5.1045	183	33489	6128487	13.5277	5.6774
134	17956	2406104	11.5758	5.1172	184	33856	6229504	13.5647	5.6877
135	18225	2460375	11.6190	5.1299	185	34225	6331625	13.6015	5.6980
136	18496	2515456	11.6619	5.1426	186	34596	6434856	13.6382	5.7083
137	18769	2571353	11.7047	5.1551	187	34969	6539203	13.6748	5.7185
138	19044	2628072	11.7473	5.1676	188	35344	6644672	13.7113	5.7287
139	19321	2685619	11.7898	5.1801	189	35721	6751269	13.7477	5.7388
140	19600	2744000	11.8322	5.1925	190	36100	6859000	13.7840	5.7489
141	19881	2803221	11.8743	5.2048	191	36481	6967871	13.8203	5.7590
142	20164	2863288	11.9164	5.2171	192	36864	7077888	13.8564	5.7690
143	20449	2924207	11.9583	5.2293	193	37249	7189057	13.8924	5.7790
144	20736	2985984	12.	5.2415	194	37636	7301384	13.9284	5.7890
145	21025	3048625	12.0416	5.2536	195	38025	7414875	13.9642	5.7989
146	21316	3112136	12.0830	5.2656	196	38416	7529536	14.	5.8088
147	21609	3176523	12.1244	5.2776	197	38809	7645373	14.0357	5.8186
148	21904	3241792	12.1655	5.2896	198	39204	7762392	14.0712	5.8285
149	22201	3307949	12.2066	5.3015	199	39601	7880599	14.1067	5.8383
150	22500	3375000	12.2474	5.3133	200	40000	8000000	14.1421	5.8480

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
201	40401	8120601	14.1774	5.8578	251	63001	15813251	15.8430	6.3080
202	40804	8242408	14.2127	5.8675	252	63504	16003008	15.8745	6.3164
203	41209	8365427	14.2478	5.8771	253	64009	16194277	15.9060	6.3247
204	41616	8489664	14.2829	5.8868	254	64516	16387064	15.9374	6.3330
205	42025	8615125	14.3178	5.8964	255	65025	16581375	15.9687	6.3413
206	42436	8741816	14.3527	5.9059	256	65536	16777216	16.	6.3496
207	42849	8869743	14.3875	5.9155	257	66049	16974593	16.0312	6.3579
208	43264	8998912	14.4222	5.9250	258	66564	17173512	16.0624	6.3661
209	43681	9129329	14.4568	5.9345	259	67081	17373979	16.0935	6.3743
210	44100	9261000	14.4914	5.9439	260	67600	17576000	16.1245	6.3825
211	44521	9393931	14.5258	5.9533	261	68121	17779581	16.1555	6.3907
212	44944	9528128	14.5602	5.9627	262	68644	17984728	16.1864	6.3988
213	45369	9663597	14.5945	5.9721	263	69169	18191447	16.2173	6.4070
214	45796	9800344	14.6287	5.9814	264	69696	18399744	16.2481	6.4151
215	46225	9938375	14.6629	5.9907	265	70225	18609625	16.2788	6.4232
216	46656	10077696	14.6969	6.	266	70756	18821096	16.3095	6.4312
217	47089	10218313	14.7309	6.0092	267	71289	19034163	16.3401	6.4393
218	47524	10360232	14.7648	6.0185	268	71824	19248832	16.3707	6.4473
219	47961	10503459	14.7986	6.0277	269	72361	19465109	16.4012	6.4553
220	48400	10648000	14.8324	6.0368	270	72900	19683000	16.4317	6.4633
221	48841	10793861	14.8661	6.0459	271	73441	19902511	16.4621	6.4713
222	49284	10941048	14.8997	6.0550	272	73984	20123648	16.4924	6.4792
223	49729	11089567	14.9332	6.0641	273	74529	20346417	16.5227	6.4872
224	50176	11239424	14.9666	6.0732	274	75076	20570824	16.5529	6.4951
225	50625	11390625	15.	6.0822	275	75625	20796875	16.5831	6.5030
226	51076	11543176	15.0333	6.0912	276	76176	21024576	16.6132	6.5108
227	51529	11697083	15.0665	6.1002	277	76729	21253933	16.6433	6.5187
228	51984	11852352	15.0997	6.1091	278	77284	21484952	16.6733	6.5265
229	52441	12008989	15.1327	6.1180	279	77841	21717639	16.7033	6.5343
230	52900	12167000	15.1658	6.1269	280	78400	21952000	16.7332	6.5421
231	53361	12326391	15.1987	6.1358	281	78961	22188041	16.7631	6.5499
232	53824	12487168	15.2315	6.1446	282	79524	22425768	16.7929	6.5577
233	54289	12649337	15.2643	6.1534	283	80089	22665187	16.8226	6.5654
234	54756	12812904	15.2971	6.1622	284	80656	22906304	16.8523	6.5731
235	55225	12977875	15.3297	6.1710	285	81225	23149125	16.8819	6.5808
236	55696	13144256	15.3623	6.1797	286	81796	23393656	16.9115	6.5885
237	56169	13312053	15.3948	6.1885	287	82369	23639903	16.9411	6.5962
238	56644	13481272	15.4272	6.1972	288	82944	23887872	16.9706	6.6039
239	57121	13651919	15.4596	6.2058	289	83521	24137569	17.	6.6115
240	57600	13824000	15.4919	6.2145	290	84100	24389000	17.0294	6.6191
241	58081	13997521	15.5242	6.2231	291	84681	24642171	17.0587	6.6267
242	58564	14172488	15.5563	6.2317	292	85264	24897088	17.0880	6.6343
243	59049	14348907	15.5885	6.2403	293	85849	25153757	17.1172	6.6419
244	59536	14526784	15.6205	6.2488	294	86436	25412184	17.1464	6.6494
245	60025	14706125	15.6525	6.2573	295	87025	25672375	17.1756	6.6569
246	60516	14886936	15.6844	6.2658	296	87616	25934336	17.2047	6.6644
247	61009	15069223	15.7162	6.2743	297	88209	26198073	17.2337	6.6719
248	61504	15252992	15.7480	6.2828	298	88804	26463592	17.2627	6.6794
249	62001	15438249	15.7797	6.2912	299	89401	26730899	17.2916	6.6869
250	62500	15625000	15.8114	6.2996	300	90000	27000000	17.3205	6.6943

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
301	90601	27270901	17.3494	6.7018	351	123201	43243551	18.7350	7.0540
302	91204	27543608	17.3781	6.7092	352	123904	43614208	18.7617	7.0607
303	91809	27818127	17.4069	6.7166	353	124609	43986977	18.7883	7.0674
304	92416	28094464	17.4356	6.7240	354	125316	44361864	18.8149	7.0740
305	93025	28372625	17.4642	6.7313	355	126025	44738875	18.8414	7.0807
306	93636	28652616	17.4929	6.7387	356	126736	45118016	18.8680	7.0873
307	94249	28934443	17.5214	6.7460	357	127449	45499293	18.8944	7.0940
308	94864	29218112	17.5499	6.7533	358	128164	45882712	18.9209	7.1006
309	95481	29503629	17.5784	6.7606	359	128881	46268279	18.9473	7.1072
310	96100	29791000	17.6068	6.7679	360	129600	46656000	18.9737	7.1138
311	96721	30080231	17.6352	6.7752	361	130321	47045881	19.	7.1204
312	97344	30371328	17.6635	6.7824	362	131044	47437928	19.0263	7.1269
313	97969	30664297	17.6918	6.7897	363	131769	47832147	19.0526	7.1335
314	98596	30959144	17.7200	6.7969	364	132496	48228544	19.0788	7.1400
315	99225	31255875	17.7482	6.8041	365	133225	48627125	19.1050	7.1466
316	99856	31554496	17.7764	6.8113	366	133956	49027896	19.1311	7.1531
317	100489	31855013	17.8045	6.8185	367	134689	49430863	19.1572	7.1596
318	101124	32157432	17.8326	6.8256	368	135424	49836032	19.1833	7.1661
319	101761	32461759	17.8606	6.8328	369	136161	50243409	19.2094	7.1726
320	102400	32768000	17.8885	6.8399	370	136900	50653000	19.2354	7.1791
321	103041	33076161	17.9165	6.8470	371	137641	51064811	19.2614	7.1855
322	103684	33386248	17.9444	6.8541	372	138384	51478848	19.2873	7.1920
323	104329	33698267	17.9722	6.8612	373	139129	51895117	19.3132	7.1984
324	104976	34012224	18.	6.8683	374	139876	52313624	19.3391	7.2048
325	105625	34328125	18.0278	6.8753	375	140625	52734375	19.3649	7.2112
326	106276	34645976	18.0555	6.8824	376	141376	53157376	19.3907	7.2177
327	106929	34965783	18.0831	6.8894	377	142129	53582633	19.4165	7.2240
328	107584	35287552	18.1108	6.8964	378	142884	54010152	19.4422	7.2304
329	108241	35611289	18.1384	6.9034	379	143641	54439939	19.4679	7.2368
330	108900	35937000	18.1659	6.9104	380	144400	54872000	19.4936	7.2432
331	109561	36264691	18.1934	6.9174	381	145161	55306341	19.5192	7.2495
332	110224	36594368	18.2209	6.9244	382	145924	55742968	19.5448	7.2558
333	110889	36926037	18.2483	6.9313	383	146689	56181887	19.5704	7.2622
334	111556	37259704	18.2757	6.9382	384	147456	56623104	19.5959	7.2685
335	112225	37595375	18.3030	6.9451	385	148225	57066625	19.6214	7.2748
336	112896	37933056	18.3303	6.9521	386	148996	57512456	19.6469	7.2811
337	113569	38272753	18.3576	6.9589	387	149769	57960603	19.6723	7.2874
338	114244	38614472	18.3848	6.9658	388	150544	58411072	19.6977	7.2936
339	114921	38958219	18.4120	6.9727	389	151321	58863869	19.7231	7.2999
340	115600	39304000	18.4391	6.9795	390	152100	59319000	19.7484	7.3061
341	116281	39651821	18.4662	6.9864	391	152881	59776471	19.7737	7.3124
342	116964	40001688	18.4932	6.9932	392	153664	60236288	19.7990	7.3186
343	117649	40353607	18.5203	7.	393	154449	60698457	19.8242	7.3248
344	118336	40707584	18.5472	7.0068	394	155236	61162984	19.8494	7.3310
345	119025	41063625	18.5742	7.0136	395	156025	61629875	19.8746	7.3372
346	119716	41421736	18.6011	7.0203	396	156816	62099136	19.8997	7.3434
347	120409	41781923	18.6279	7.0271	397	157609	62570773	19.9249	7.3496
348	121104	42144192	18.6548	7.0338	398	158404	63044792	19.9499	7.3558
349	121801	42508549	18.6815	7.0406	399	159201	63521199	19.9750	7.3619
350	122500	42875000	18.7083	7.0473	400	160000	64000000	20.	7.3681

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
401	160801	64481201	20.0250	7.3742	451	203401	91733851	21.2368	7.6688
402	161604	64964808	20.0499	7.3803	452	204304	92345408	21.2603	7.6744
403	162409	65450827	20.0749	7.3864	453	205209	92959677	21.2838	7.6801
404	163216	65939264	20.0998	7.3925	454	206116	93576664	21.3073	7.6857
405	164025	66430125	20.1246	7.3986	455	207025	94196375	21.3307	7.6914
406	164836	66923416	20.1494	7.4047	456	207936	94818816	21.3542	7.6970
407	165649	67419143	20.1742	7.4108	457	208849	95443993	21.3776	7.7026
408	166464	67917312	20.1990	7.4169	458	209764	96071912	21.4009	7.7082
409	167281	68417929	20.2237	7.4229	459	210681	96702579	21.4243	7.7138
410	168100	68921000	20.2485	7.4290	460	211600	97336000	21.4476	7.7194
411	168921	69426531	20.2731	7.4350	461	212521	97972181	21.4709	7.7250
412	169744	69934528	20.2978	7.4410	462	213444	98611128	21.4942	7.7306
413	170569	70444997	20.3224	7.4470	463	214369	99252847	21.5174	7.7362
414	171396	70957944	20.3470	7.4530	464	215296	99897344	21.5407	7.7418
415	172225	71473375	20.3715	7.4590	465	216225	100544625	21.5639	7.7473
416	173056	71991296	20.3961	7.4650	466	217156	101194696	21.5870	7.7529
417	173889	72511713	20.4206	7.4710	467	218089	101847563	21.6102	7.7584
418	174724	73034632	20.4450	7.4770	468	219024	102503232	21.6333	7.7639
419	175561	73560059	20.4695	7.4829	469	219961	103161709	21.6564	7.7695
420	176400	74088000	20.4939	7.4889	470	220900	103823000	21.6795	7.7750
421	177241	74618461	20.5183	7.4948	471	221841	104487111	21.7025	7.7805
422	178084	75151448	20.5426	7.5007	472	222784	105154048	21.7256	7.7860
423	178929	75686967	20.5670	7.5067	473	223729	105823817	21.7486	7.7915
424	179776	76225024	20.5913	7.5126	474	224676	106496424	21.7715	7.7970
425	180625	76765625	20.6155	7.5185	475	225625	107171875	21.7945	7.8025
426	181476	77308776	20.6398	7.5244	476	226576	107850176	21.8174	7.8079
427	182329	77854483	20.6640	7.5302	477	227529	108531333	21.8403	7.8134
428	183184	78402752	20.6882	7.5361	478	228484	109215352	21.8632	7.8188
429	184041	78953589	20.7123	7.5420	479	229441	109902239	21.8861	7.8243
430	184900	79507000	20.7364	7.5478	480	230400	110592000	21.9089	7.8297
431	185761	80062991	20.7605	7.5537	481	231361	111284641	21.9317	7.8352
432	186624	80621568	20.7846	7.5595	482	232324	111980168	21.9545	7.8406
433	187489	81182737	20.8087	7.5654	483	233289	112678587	21.9773	7.8460
434	188356	81746504	20.8327	7.5712	484	234256	113379904	22.	7.8514
435	189225	82312875	20.8567	7.5770	485	235225	114084125	22.0227	7.8568
436	190096	82881856	20.8806	7.5828	486	236196	114791256	22.0454	7.8622
437	190969	83453453	20.9045	7.5886	487	237169	115501303	22.0681	7.8676
438	191844	84027672	20.9284	7.5944	488	238144	116214272	22.0907	7.8730
439	192721	84604519	20.9523	7.6001	489	239121	116930169	22.1133	7.8784
440	193600	85184000	20.9762	7.6059	490	240100	117649000	22.1359	7.8837
441	194481	85766121	21.	7.6117	491	241081	118370771	22.1585	7.8891
442	195364	86350888	21.0238	7.6174	492	242064	119095488	22.1811	7.8944
443	196249	86938307	21.0476	7.6232	493	243049	119823157	22.2036	7.8998
444	197136	87528384	21.0713	7.6289	494	244036	120553784	22.2261	7.9051
445	198025	88121125	21.0950	7.6346	495	245025	121287375	22.2486	7.9105
446	198916	88716536	21.1187	7.6403	496	246016	122023936	22.2711	7.9158
447	199809	89314623	21.1424	7.6460	497	247009	122763473	22.2935	7.9211
448	200704	89915392	21.1660	7.6517	498	248004	123505992	22.3159	7.9264
449	201601	90518849	21.1896	7.6574	499	249001	124251499	22.3383	7.9317
450	202500	91125000	21.2132	7.6631	500	250000	125000000	22.3607	7.9370

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
501	251001	125751501	22.3830	7.9423	551	303601	167284151	23.4734	8.1982
502	252004	126506008	22.4054	7.9476	552	304704	168196608	23.4947	8.2031
503	253009	127263527	22.4277	7.9528	553	305809	169112377	23.5160	8.2081
504	254016	128024064	22.4499	7.9581	554	306916	170031464	23.5372	8.2130
505	255025	128787625	22.4722	7.9634	555	308025	170953875	23.5584	8.2180
506	256036	129554216	22.4944	7.9686	556	309136	171879616	23.5797	8.2229
507	257049	130323843	22.5167	7.9739	557	310249	172808693	23.6008	8.2278
508	258064	131096512	22.5389	7.9791	558	311364	173741112	23.6220	8.2327
509	259081	131872229	22.5610	7.9843	559	312481	174676879	23.6432	8.2377
510	260100	132651000	22.5832	7.9896	560	313600	175616000	23.6643	8.2426
511	261121	133432831	22.6053	7.9948	561	314721	176558481	23.6854	8.2475
512	262144	134217728	22.6274	8.	562	315844	177504328	23.7065	8.2524
513	263169	135005697	22.6495	8.0052	563	316969	178453547	23.7276	8.2573
514	264196	135796744	22.6716	8.0104	564	318096	179406144	23.7487	8.2621
515	265225	136590875	22.6936	8.0156	565	319225	180362125	23.7697	8.2670
516	266256	137388096	22.7156	8.0208	566	320356	181321496	23.7908	8.2719
517	267289	138188413	22.7376	8.0260	567	321489	182284263	23.8118	8.2768
518	268324	138991832	22.7596	8.0311	568	322624	183250432	23.8328	8.2816
519	269361	139798359	22.7816	8.0363	569	323761	184220009	23.8537	8.2865
520	270400	140608000	22.8035	8.0415	570	324900	185193000	23.8747	8.2913
521	271441	141420761	22.8254	8.0466	571	326041	186169411	23.8956	8.2962
522	272484	142236648	22.8473	8.0517	572	327184	187149248	23.9165	8.3010
523	273529	143055667	22.8692	8.0569	573	328329	188132517	23.9374	8.3059
524	274576	143877824	22.8910	8.0620	574	329476	189119224	23.9583	8.3107
525	275625	144703125	22.9129	8.0671	575	330625	190109375	23.9792	8.3155
526	276676	145531576	22.9347	8.0723	576	331776	191102976	24.	8.3203
527	277729	146363183	22.9565	8.0774	577	332929	192100033	24.0208	8.3251
528	278784	147197952	22.9783	8.0825	578	334084	193100552	24.0416	8.3300
529	279841	148035889	23.	8.0876	579	335241	194104539	24.0624	8.3348
530	280900	148877000	23.0217	8.0927	580	336400	195112000	24.0832	8.3396
531	281961	149721291	23.0434	8.0978	581	337561	196122941	24.1039	8.3443
532	283024	150568768	23.0651	8.1028	582	338724	197137368	24.1247	8.3491
533	284089	151419437	23.0868	8.1079	583	339889	198155287	24.1454	8.3539
534	285156	152273304	23.1084	8.1130	584	341056	199176704	24.1661	8.3587
535	286225	153130375	23.1301	8.1180	585	342225	200201625	24.1868	8.3634
536	287296	153990656	23.1517	8.1231	586	343396	201230056	24.2074	8.3682
537	288369	154854153	23.1733	8.1281	587	344569	202262003	24.2281	8.3730
538	289444	155720872	23.1948	8.1332	588	345744	203297472	24.2487	8.3777
539	290521	156590819	23.2164	8.1382	589	346921	204336469	24.2693	8.3825
540	291600	157464000	23.2379	8.1433	590	348100	205379000	24.2899	8.3872
541	292681	158340421	23.2594	8.1483	591	349281	206425071	24.3105	8.3919
542	293764	159220088	23.2809	8.1533	592	350464	207474688	24.3311	8.3967
543	294849	160103007	23.3024	8.1583	593	351649	208527857	24.3516	8.4014
544	295936	160989184	23.3238	8.1633	594	352836	209584584	24.3721	8.4061
545	297025	161878625	23.3452	8.1683	595	354025	210644875	24.3926	8.4108
546	298116	162771336	23.3666	8.1733	596	355216	211708736	24.4131	8.4155
547	299209	163667323	23.3880	8.1783	597	356409	212776173	24.4336	8.4202
548	300304	164566592	23.4094	8.1833	598	357604	213847192	24.4540	8.4249
549	301401	165469149	23.4307	8.1882	599	358801	214921799	24.4745	8.4296
550	302500	166375000	23.4521	8.1932	600	360000	216000000	24.4949	8.4343

TABLE XV—*Continued.*

No.	Square	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
601	361201	217081801	24.5153	8.4390	651	423801	275894451	25.5147	8.6668
602	362404	218167208	24.5357	8.4437	652	425104	277167808	25.5343	8.6713
603	363609	219256227	24.5561	8.4484	653	426409	278445077	25.5539	8.6757
604	364816	220348864	24.5764	8.4530	654	427716	279726264	25.5734	8.6801
605	366025	221445125	24.5967	8.4577	655	429025	281011375	25.5930	8.6845
606	367236	222545016	24.6171	8.4623	656	430336	282300416	25.6125	8.6890
607	368449	223648543	24.6374	8.4670	657	431649	283593393	25.6320	8.6934
608	369664	224755712	24.6577	8.4716	658	432964	284890312	25.6515	8.6978
609	370881	225866529	24.6779	8.4763	659	434281	286191179	25.6710	8.7022
610	372100	226981000	24.6982	8.4809	660	435600	287496000	25.6905	8.7066
611	373321	228099131	24.7184	8.4856	661	436921	288804781	25.7099	8.7110
612	374544	229220928	24.7386	8.4902	662	438244	290117528	25.7294	8.7154
613	375769	230346397	24.7588	8.4948	663	439569	291434247	25.7488	8.7198
614	376996	231475544	24.7790	8.4994	664	440896	292754944	25.7682	8.7241
615	378225	232608375	24.7992	8.5040	665	442225	294079625	25.7876	8.7285
616	379456	233744896	24.8193	8.5086	666	443556	295408296	25.8070	8.7329
617	380689	234885113	24.8395	8.5132	667	444889	296740963	25.8263	8.7373
618	381924	236029032	24.8596	8.5178	668	446224	298077632	25.8457	8.7416
619	383161	237176659	24.8797	8.5224	669	447761	299418309	25.8650	8.7460
620	384400	238328000	24.8998	8.5270	670	448900	300763000	25.8844	8.7503
621	385641	239483061	24.9199	8.5316	671	450241	302111711	25.9037	8.7547
622	386884	240641848	24.9399	8.5362	672	451584	303464448	25.9230	8.7590
623	388129	241804367	24.9600	8.5408	673	452929	304821217	25.9422	8.7634
624	389376	242970624	24.9800	8.5453	674	454276	306182024	25.9615	8.7677
625	390625	244140625	25.	8.5499	675	455625	307546875	25.9808	8.7721
626	391876	245314376	25.0200	8.5544	676	456976	308915776	26.	8.7764
627	393129	246491883	25.0400	8.5590	677	458329	310288733	26.0192	8.7807
628	394384	247673152	25.0599	8.5635	678	459684	311665752	26.0384	8.7850
629	395641	248858189	25.0799	8.5681	679	461041	313046839	26.0576	8.7893
630	396900	250047000	25.0998	8.5726	680	462400	314432000	26.0768	8.7937
631	398161	251239591	25.1197	8.5772	681	463761	315821241	26.0960	8.7980
632	399424	252435968	25.1396	8.5817	682	465124	317214568	26.1151	8.8023
633	400689	253636137	25.1595	8.5862	683	466489	318611987	26.1343	8.8066
634	401956	254840104	25.1794	8.5907	684	467856	320013504	26.1534	8.8109
635	403225	256047875	25.1992	8.5952	685	469225	321419125	26.1725	8.8152
636	404496	257259456	25.2190	8.5997	686	470596	322828856	26.1916	8.8194
637	405769	258474853	25.2389	8.6043	687	471969	324242703	26.2107	8.8237
638	407044	259694072	25.2587	8.6088	688	473344	325660672	26.2298	8.8280
639	408321	260917119	25.2784	8.6132	689	474721	327082769	26.2488	8.8323
640	409600	262144000	25.2982	8.6177	690	476100	328509000	26.2679	8.8366
641	410881	263374721	25.3180	8.6222	691	477481	329939371	26.2869	8.8408
642	412164	264609288	25.3377	8.6267	692	478864	331373888	26.3059	8.8451
643	413449	265847707	25.3574	8.6312	693	480249	332812557	26.3249	8.8493
644	414736	267089984	25.3772	8.6357	694	481636	334255384	26.3439	8.8536
645	416025	268336125	25.3969	8.6401	695	483025	335702375	26.3629	8.8578
646	417316	269586136	25.4165	8.6446	696	484416	337153536	26.3818	8.8621
647	418609	270840023	25.4362	8.6490	697	485809	338608873	26.4008	8.8663
648	419904	272097792	25.4558	8.6535	698	487204	340068392	26.4197	8.8706
649	421201	273359449	25.4755	8.6579	699	488601	341532099	26.4386	8.8748
650	422500	274625000	25.4951	8.6624	700	490000	343000000	26.4575	8.8790

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
701	491401	344472101	26.4764	8.8833	751	564001	423564751	27.4044	9.0896
702	492804	345948408	26.4953	8.8875	752	565504	425259008	27.4226	9.0937
703	494209	347428927	26.5141	8.8917	753	567009	426957777	27.4408	9.0977
704	495616	348913664	26.5330	8.8959	754	568516	428661064	27.4591	9.1017
705	497025	350402625	26.5518	8.9001	755	570025	430368875	27.4773	9.1057
706	498436	351895816	26.5707	8.9043	756	571536	432081216	27.4955	9.1098
707	499849	353393243	26.5895	8.9085	757	573049	433798093	27.5136	9.1138
708	501264	354894912	26.6083	8.9127	758	574564	435519512	27.5318	9.1178
709	502681	356400829	26.6271	8.9169	759	576081	437245479	27.5500	9.1218
710	504100	357911000	26.6458	8.9211	760	577600	438976000	27.5681	9.1258
711	505521	359425431	26.6646	8.9253	761	579121	440711081	27.5862	9.1298
712	506944	360944128	26.6833	8.9295	762	580644	442450728	27.6043	9.1338
713	508369	362467097	26.7021	8.9337	763	582169	444194947	27.6225	9.1378
714	509796	363994344	26.7208	8.9378	764	583696	445943744	27.6405	9.1418
715	511225	365525875	26.7395	8.9420	765	585225	447697125	27.6586	9.1458
716	512656	367061696	26.7582	8.9462	766	586756	449455096	27.6767	9.1498
717	514089	368601813	26.7769	8.9503	767	588289	451217663	27.6948	9.1537
718	515524	370146232	26.7955	8.9545	768	589824	452984832	27.7128	9.1577
719	516961	371694959	26.8142	8.9587	769	591361	454756609	27.7308	9.1617
720	518400	373248000	26.8328	8.9628	770	592900	456533000	27.7489	9.1657
721	519841	374805361	26.8514	8.9670	771	594441	458314011	27.7669	9.1696
722	521284	376367048	26.8701	8.9711	772	595984	460099648	27.7849	9.1736
723	522729	377933067	26.8887	8.9752	773	597529	461889917	27.8029	9.1775
724	524176	379503424	26.9072	8.9794	774	599076	463684824	27.8209	9.1815
725	525625	381078125	26.9258	8.9835	775	600625	465484375	27.8388	9.1855
726	527076	382657176	26.9444	8.9876	776	602176	467288576	27.8568	9.1894
727	528529	384240583	26.9629	8.9918	777	603729	469097433	27.8747	9.1933
728	529984	385828352	26.9815	8.9959	778	605284	470910952	27.8927	9.1973
729	531441	387420489	27.	9.	779	606841	472729139	27.9106	9.2012
730	532900	389017000	27.0185	9.0041	780	608400	474552000	27.9285	9.2052
731	534361	390617891	27.0370	9.0082	781	609961	476379541	27.9464	9.2091
732	535824	392223168	27.0555	9.0123	782	611524	478211768	27.9643	9.2130
733	537289	393832837	27.0740	9.0164	783	613089	480048687	27.9821	9.2170
734	538756	395446904	27.0924	9.0205	784	614656	481890304	28.	9.2209
735	540225	397065375	27.1109	9.0246	785	616225	483736625	28.0179	9.2248
736	541696	398688256	27.1293	9.0287	786	617796	485587656	28.0357	9.2287
737	543169	400315553	27.1477	9.0328	787	619369	487443403	28.0535	9.2326
738	544644	401947272	27.1662	9.0369	788	620944	489303872	28.0713	9.2365
739	546121	403583419	27.1846	9.0410	789	622521	491169069	28.0891	9.2404
740	547600	405224000	27.2029	9.0450	790	624100	493039000	28.1069	9.2443
741	549081	406869021	27.2213	9.0491	791	625681	494913671	28.1247	9.2482
742	550564	408518488	27.2397	9.0532	792	627264	496793088	28.1425	9.2521
743	552049	410172407	27.2580	9.0572	793	628849	498677257	28.1603	9.2560
744	553536	411830784	27.2764	9.0613	794	630436	500566184	28.1780	9.2599
745	555025	413493625	27.2947	9.0654	795	632025	502459875	28.1957	9.2638
746	556516	415160936	27.3130	9.0694	796	633616	504358336	28.2135	9.2677
747	558009	416832723	27.3313	9.0735	797	635209	506261573	28.2312	9.2716
748	559504	418508992	27.3496	9.0775	798	636804	508169592	28.2489	9.2754
749	561001	420189749	27.3679	9.0816	799	638401	510082399	28.2666	9.2793
750	562500	421875000	27.3861	9.0856	800	640000	512000000	28.2843	9.2832

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
801	641601	513922401	28.3019	9.2870	851	724201	616295051	29.1719	9.4764
802	643204	515849608	28.3196	9.2909	852	725904	618470208	29.1890	9.4801
803	644809	517781627	28.3373	9.2948	853	727609	620650477	29.2062	9.4838
804	646416	519718464	28.3549	9.2986	854	729316	622835864	29.2233	9.4875
805	648025	521660125	28.3725	9.3025	855	731025	625026375	29.2404	9.4912
806	649636	523606616	28.3901	9.3063	856	732736	627222016	29.2575	9.4949
807	651249	525557943	28.4077	9.3102	857	734449	629422793	29.2746	9.4986
808	652864	527514112	28.4253	9.3140	858	736164	631628712	29.2916	9.5023
809	654481	529475129	28.4429	9.3179	859	737881	633839779	29.3087	9.5060
810	656100	531441000	28.4605	9.3217	860	739600	636056000	29.3258	9.5097
811	657721	533411731	28.4781	9.3255	861	741321	638277381	29.3428	9.5134
812	659344	535387328	28.4956	9.3294	862	743044	640503928	29.3598	9.5171
813	660969	537367797	28.5132	9.3332	863	744769	642735647	29.3769	9.5207
814	662596	539353144	28.5307	9.3370	864	746496	644972544	29.3939	9.5244
815	664225	541343375	28.5482	9.3408	865	748225	647214625	29.4109	9.5281
816	665856	543338496	28.5657	9.3447	866	749956	649461896	29.4279	9.5317
817	667489	545338513	28.5832	9.3485	867	751689	651714363	29.4449	9.5354
818	669124	547343432	28.6007	9.3523	868	753424	653972032	29.4618	9.5391
819	670761	549353259	28.6182	9.3561	869	755161	656234909	29.4788	9.5427
820	672400	551368000	28.6356	9.3599	870	756900	658503000	29.4958	9.5464
821	674041	553387661	28.6531	9.3637	871	758641	660776311	29.5127	9.5501
822	675684	555412248	28.6705	9.3675	872	760384	663054848	29.5296	9.5537
823	677329	557441767	28.6880	9.3713	873	762129	665338617	29.5466	9.5574
824	678976	559476224	28.7054	9.3751	874	763876	667627624	29.5635	9.5610
825	680625	561515625	28.7228	9.3789	875	765625	669921875	29.5804	9.5647
826	682276	563559976	28.7402	9.3827	876	767376	672221376	29.5973	9.5683
827	683929	565609283	28.7576	9.3865	877	769129	674526133	29.6142	9.5719
828	685584	567663552	28.7750	9.3902	878	770884	676836152	29.6311	9.5756
829	687241	569722789	28.7924	9.3940	879	772641	679151439	29.6479	9.5792
830	688900	571787000	28.8097	9.3978	880	774400	681472000	29.6648	9.5828
831	690561	573856191	28.8271	9.4016	881	776161	683797841	29.6816	9.5865
832	692224	575930368	28.8444	9.4053	882	777924	686128968	29.6985	9.5901
833	693889	578009537	28.8617	9.4091	883	779689	688465387	29.7153	9.5937
834	695556	580093704	28.8791	9.4129	884	781456	690807104	29.7321	9.5973
835	697225	582182875	28.8964	9.4166	885	783225	693154125	29.7489	9.6010
836	698896	584277056	28.9137	9.4204	886	784996	695506456	29.7658	9.6046
837	700569	586376253	28.9310	9.4241	887	786769	697864103	29.7825	9.6082
838	702244	588480472	28.9482	9.4279	888	788544	700227072	29.7993	9.6118
839	703921	590589719	28.9655	9.4316	889	790321	702595369	29.8161	9.6154
840	705600	592704000	28.9828	9.4354	890	792100	704969000	29.8329	9.6190
841	707281	594823321	29.	9.4391	891	793881	707347971	29.8496	9.6226
842	708964	596947688	29.0172	9.4429	892	795664	709732288	29.8664	9.6262
843	710649	599077107	29.0345	9.4466	893	797449	712121957	29.8831	9.6298
844	712336	601211584	29.0517	9.4503	894	799236	714516984	29.8998	9.6334
845	714025	603351125	29.0689	9.4541	895	801025	716917375	29.9166	9.6370
846	715716	605495736	29.0861	9.4578	896	802816	719323136	29.9333	9.6406
847	717409	607645423	29.1033	9.4615	897	804609	721734273	29.9500	9.6442
848	719104	609800192	29.1204	9.4652	898	806404	724150792	29.9666	9.6477
849	720801	611960049	29.1376	9.4690	899	808201	726572699	29.9833	9.6513
850	722500	614125000	29.1548	9.4727	900	810000	729000000	30.	9.6549

TABLE XV—*Continued.*

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
901	811801	731432701	30.0167	9.6585	951	904401	860085351	30.8383	9.8339
902	813604	733870808	30.0333	9.6620	952	906304	862801408	30.8545	9.8374
903	815409	736314327	30.0500	9.6656	953	908209	865523177	30.8707	9.8408
904	817216	738763264	30.0666	9.6692	954	910116	868250664	30.8869	9.8443
905	819025	741217625	30.0832	9.6727	955	912025	870983875	30.9031	9.8477
906	820836	743677416	30.0998	9.6763	956	913936	873722816	30.9192	9.8511
907	822649	746142643	30.1164	9.6799	957	915849	876467493	30.9354	9.8546
908	824464	748613312	30.1330	9.6834	958	917764	879217912	30.9516	9.8580
909	826281	751089429	30.1496	9.6870	959	919681	881974079	30.9677	9.8614
910	828100	753571000	30.1662	9.6905	960	921600	884736000	30.9839	9.8648
911	829921	756058031	30.1828	9.6941	961	923521	887503681	31.	9.8683
912	831744	758550528	30.1993	9.6976	962	925444	890277128	31.0161	9.8717
913	833569	761048497	30.2159	9.7012	963	927369	893056347	31.0322	9.8751
914	835396	763551944	30.2324	9.7047	964	929296	895841344	31.0483	9.8785
915	837225	766060875	30.2490	9.7082	965	931225	898632125	31.0644	9.8819
916	839056	768575296	30.2655	9.7118	966	933156	901428696	31.0805	9.8854
917	840889	771095213	30.2820	9.7153	967	935089	904231063	31.0966	9.8888
918	842724	773620632	30.2985	9.7188	968	937024	907039232	31.1127	9.8922
919	844561	776151559	30.3150	9.7224	969	938961	909853209	31.1288	9.8956
920	846400	778688000	30.3315	9.7259	970	940900	912673000	31.1448	9.8990
921	848241	781229961	30.3480	9.7294	971	942841	915498611	31.1609	9.9024
922	850084	783777448	30.3645	9.7329	972	944784	918330048	31.1769	9.9058
923	851929	786330467	30.3809	9.7364	973	946729	921167317	31.1929	9.9092
924	853776	788889024	30.3974	9.7400	974	948676	924010424	31.2090	9.9126
925	855625	791453125	30.4138	9.7435	975	950625	926859375	31.2250	9.9160
926	857476	794022776	30.4302	9.7470	976	952576	929714176	31.2410	9.9194
927	859329	796597983	30.4467	9.7505	977	954529	932574833	31.2570	9.9227
928	861184	799178752	30.4631	9.7540	978	956484	935441352	31.2730	9.9261
929	863041	801765089	30.4795	9.7575	979	958441	938313739	31.2890	9.9295
930	864900	804357000	30.4959	9.7610	980	960400	941192000	31.3050	9.9329
931	866761	806954491	30.5123	9.7645	981	962361	944076141	31.3209	9.9363
932	868624	809557568	30.5287	9.7680	982	964324	946966168	31.3369	9.9396
933	870489	812166237	30.5450	9.7715	983	966289	949862087	31.3528	9.9430
934	872356	814780504	30.5614	9.7750	984	968256	952763904	31.3688	9.9464
935	874225	817400375	30.5778	9.7785	985	970225	955671625	31.3847	9.9497
936	876096	820025856	30.5941	9.7819	986	972196	958585256	31.4006	9.9531
937	877969	822656953	30.6105	9.7854	987	974169	961504803	31.4166	9.9565
938	879844	825293672	30.6268	9.7889	988	976144	964430272	31.4325	9.9598
939	881721	827936019	30.6431	9.7924	989	978121	967361669	31.4484	9.9632
940	883600	830584000	30.6594	9.7959	990	980100	970299000	31.4643	9.9666
941	885481	833237621	30.6757	9.7993	991	982081	973242271	31.4802	9.9699
942	887364	835896888	30.6920	9.8028	992	984064	976191488	31.4960	9.9733
943	889249	838561807	30.7083	9.8063	993	986049	979146657	31.5119	9.9766
944	891136	841232384	30.7246	9.8097	994	988036	982107784	31.5278	9.9800
945	893025	843908625	30.7409	9.8132	995	990025	985074875	31.5436	9.9833
946	894916	846590536	30.7571	9.8167	996	992016	988047936	31.5595	9.9866
947	896809	849278123	30.7734	9.8201	997	994009	991026973	31.5753	9.9900
948	898704	851971392	30.7896	9.8236	998	996004	994011992	31.5911	9.9933
949	900601	854670349	30.8058	9.8270	999	998001	997002999	31.6070	9.9967
950	902500	857375000	30.8221	9.8305	1000	1000000	1000000000	31.6228	10.

116. To find the **square root** of a **decimal fraction** or **mixed number** from the foregoing table, multiply by 100 or by 10,000 and find the product in the column of squares. The corresponding number in the first column, with the decimal point one or two places to the left, is the desired root.

For the cube root of a similar number, multiply by 1,000 or by 1,000,000, and find the nearest number in column of cubes. The corresponding number in the first column, with the decimal point one or two places to the left, is the desired root.

Examples: Required the square root of 5.246.

Multiply by 100; the result is 524, which found in column of squares is opposite 23 in the column of numbers. Moving the decimal point one place to the left to correspond with the multiplication by 100, gives 2.3 for the desired square root, to the first place of decimals and hence approximate only. Second: Multiply by 10,000; the result is 52,460, which found in the column of squares is opposite 229 in the column of numbers. Moving the decimal point two places to the left to correspond to the multiplication by 10,000, the result is 2.29, which is the desired root to the second place of decimals.

Required the cube root of 5.246. Multiply by 1,000, giving 5,246, which found in the column of cubes is opposite the number 17 in the first column. Moving the decimal point one place to the left to correspond to the multiplication by 1,000, gives 1.7, which is the required cube root to one decimal place. Again, multiplying by 1,000,000 gives 5,246,000, which found in the column of cubes is opposite the number 174 in the column of numbers. Moving the decimal point two places to the left to correspond with the multiplication by 1,000,000, gives the number 1.74, which is the desired cube root correct to two places of decimals.

To **find** the **square root** or **cube root** of a **number greater** than 1,000, find the nearest number in the column of squares or cubes and take the corresponding number in the first column, which will be correct for the number of figures it contains.

For the **fourth root,** take the square root of the square root. For the **sixth root,** the square root of the cube root, or the cube root of the square root. **Higher roots,** the indices of which can be factored in 3's and 2's, may be taken in the same way.

117. **Circular functions.**—Those most used are shown graphically in fig. 68. They bear a definite relation to the radius of a circle in which they are drawn. When the radius is unity, functions are called **natural,** as nat. sine, nat. tangent, etc. Their values are given in Table XVI for each 10′ of arc. The tabulated values are ratios of the several functions to the radius, and if any length, expressed in any unit, considered as a radius, be multiplied by a tabular number, the result will be the corresponding function of the circle of the given radius. The table gives values from 0 to 90°. For greater angles, use the following relations: Subtract the given angle from 180° or 360°, or subtract 180° from the angle, as may be required, to leave a remainder of 90° or less. Take out the required function of the remainder, which is also that of the given angle.

Interpolation for values not in the table may be done approximately by taking the proportional amount of the difference between two consecutive values. Thus, for the sine of 28° 43′ take the sine of 28° 40′ plus $\frac{3}{10}$ of the difference between sine 28° 40′ and sine 28° 50′.

TABLE XVI.

118. **Natural sines and tangents** to a radius 1:

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
0	00	.0000000	.000000	Infinite.	1.0000000	90	00
	10	.0029089	.002908	343.7737	.9999958		50
	20	.0058177	.005817	171.8854	.9999831		40
	30	.0087265	.008726	114.5886	.9999619		30
	40	.0116353	.011636	85.93979	.9999323		20
	50	.0145439	.014545	68.75008	.9998942		10
1	00	.0174524	.017455	57.28996	.9998477	89	00
	10	.0203608	.020365	49.10388	.9997927		50
	20	.0232690	.023275	42.96407	.9997292		40
	30	.0261769	.026185	38.18845	.9996573		30
	40	.0290847	.029097	34.36777	.9995770		20
	50	.0319922	.032008	31.24157	.9994881		10
2	00	.0348995	.034920	28.63625	.9993908	88	00
	10	.0378065	.037833	26.43160	.9992851		50
	20	.0407131	.040746	24.54175	.9991709		40
	30	.0436194	.043660	22.90376	.9990482		30
	40	.0465253	.046575	21.47040	.9989171		20
	50	.0494308	.049491	20.20555	.9987775		10
3	00	.0523360	.052407	19.08113	.9986295	87	00
	10	.0552406	.055325	18.07497	.9984731		50
	20	.0581448	.058243	17.16933	.9983082		40
	30	.0610485	.061162	16.34985	.9981348		30
	40	.0639517	.064082	15.60478	.9979530		20
	50	.0668544	.067004	14.92441	.9977627		10
4	00	.0697565	.069926	14.30066	.9975641	86	00
	10	.0726580	.072850	13.72673	.9973569		50
	20	.0755589	.075775	13.19688	.9971413		40
	30	.0784591	.078701	12.70620	.9969173		30
	40	.0813587	.081629	12.25050	.9966849		20
	50	.0842576	.084558	11.82616	.9964440		10
5	00	.0871557	.087488	11.43005	.9961947	85	00
	10	.0900532	.090420	11.05943	.9959370		50
	20	.0929499	.093354	10.71191	.9956708		40
	30	.0958458	.096289	10.38539	.9953962		30
	40	.0987408	.099225	10.07803	.9951132		20
	50	.1016351	.102164	9 788173	.9948217		10
6	00	.1045285	.105104	9.514364	.9945219	84	00
	10	.1074210	.108046	9.255303	.9942136		50
	20	.1103126	.110989	9.009826	.9938969		40
	30	.1132032	.113935	8.776887	.9935719		30
	40	.1160929	.116883	8.555546	.9932384		20
	50	.1189816	.119832	8.344955	.9928965		10
7	00	.1218693	.122784	8.144346	.9925462	83	00
	10	.1247560	.125738	7.953022	.9921874		50
	20	.1276416	.128694	7.770350	.9918204		40
	30	.1305262	.131652	7.595754	.9914449		30
	40	.1334096	.134612	7.428706	.9910610		20
	50	.1362919	.137575	7.268725	.9906687		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI—**Natural sines and tangents**—*Continued.*

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
8	00	.1391731	.140540	7.115369	.9902681	82	00
	10	.1420531	.143508	6.968233	.9898590		50
	20	.1449319	.146478	6.826943	.9894416		40
	30	.1478094	.149451	6.691156	.9890159		30
	40	.1506857	.152426	6.560553	.9885817		20
	50	.1535607	.155404	6.434842	.9881392		10
9	00	.1564345	.158384	6.313751	.9876883	81	00
	10	.1593069	.161367	6.197027	.9872291		50
	20	.1621779	.164353	6.084438	.9867615		40
	30	.1650476	.167342	5.975764	.9862856		30
	40	.1679159	.170334	5.870804	.9858013		20
	50	.1707828	.173329	5.769368	.9853087		10
10	00	.1736482	.176327	5.671281	.9848078	80	00
	10	.1765121	.179327	5.576378	.9842985		50
	20	.1793746	.182331	5.484505	.9837808		40
	30	.1822355	.185339	5.395517	.9832549		30
	40	.1850949	.188349	5.309279	.9827206		20
	50	.1879528	.191363	5.225664	.9821781		10
11	00	.1908090	.194380	5.144554	.9816272	79	00
	10	.1936636	.197400	5.065835	.9810680		50
	20	.1965166	.200424	4.989402	.9805005		40
	30	.1993679	.203452	4.915157	.9799247		30
	40	.2022176	.206483	4.843004	.9793406		20
	50	.2050655	.209518	4.772856	.9787483		10
12	00	.2079117	.212556	4.704630	.9781476	78	00
	10	.2107561	.215598	4.638245	.9775386		50
	20	.2135988	.218644	4.573628	.9769215		40
	30	.2164396	.221694	4.510708	.9762960		30
	40	.2192786	.224748	4.449418	.9756623		20
	50	.2221158	.227806	4.389694	.9750203		10
13	00	.2249511	.230868	4.331475	.9743701	77	00
	10	.2277844	.233934	4.274706	.9737116		50
	20	.2306159	.237004	4.219331	.9730449		40
	30	.2334454	.240078	4.165299	.9723699		30
	40	.2362729	.243157	4.112561	.9716867		20
	50	.2390984	.246240	4.061070	.9709953		10
14	00	.2419219	.249328	4.010780	.9702957	76	00
	10	.2447433	.252420	3.961651	.9695879		50
	20	.2475627	.255516	3.913642	.9688719		40
	30	.2503800	.258617	3.866713	.9681476		30
	40	.2531952	.261723	3.820828	.9674152		20
	50	.2560082	.264833	3.775951	.9666746		10
15	00	.2588190	.267949	3.732050	.9659258	75	00
	10	.2616277	.271069	3.689092	.9651689		50
	20	.2644342	.274194	3.647046	.9644037		40
	30	.2672384	.277324	3.605883	.9636305		30
	40	.2700403	.280459	3.565574	.9628490		20
	50	.2728400	.283599	3.526093	.9620594		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI—Natural sines and tangents—*Continued.*

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
16	00	.2756374	.286745	3.487414	.9612617	74	00
	10	.2784324	.289896	3.449512	.9604558		50
	20	.2812251	.293052	3.412362	.9596418		40
	30	.2840153	.296213	3.375943	.9588197		30
	40	.2868032	.299380	3.340232	.9579895		20
	50	.2895887	.302552	3.305209	.9571512		10
17	00	.2923717	.305730	3.270852	.9563048	73	00
	10	.2951522	.308914	3.237143	.9554502		50
	20	.2979303	.312103	3.204063	.9545876		40
	30	.3007058	.315298	3.171594	.9537170		30
	40	.3034788	.318499	3.139719	.9528382		20
	50	.3062492	.321706	3.108421	.9519514		10
18	00	.3090170	.324919	3.077683	.9510565	72	00
	10	.3117822	.328138	3.047491	.9501536		50
	20	.3145448	.331363	3.017830	.9492426		40
	30	.3173047	.334595	2.988685	.9483237		30
	40	.3200619	.337833	2.960042	.9473966		20
	50	.3228164	.341077	2.931888	.9464616		10
19	00	.3255682	.344327	2.904210	.9455186	71	00
	10	.3283172	.347584	2.876997	.9445675		50
	20	.3310634	.350848	2.850234	.9436085		40
	30	.3338069	.354118	2.823912	.9426415		30
	40	.3365475	.357395	2.798019	.9416665		20
	50	.3392852	.360679	2.772544	.9406835		10
20	00	.3420201	.363970	2.747477	.9396926	70	00
	10	.3447521	.367268	2.722807	.9386938		50
	20	.3474812	.370572	2.698525	.9376869		40
	30	.3502074	.373884	2.674621	.9366722		30
	40	.3529306	.377203	2.651086	.9356495		20
	50	.3556508	.380530	2.627912	.9346189		10
21	00	.3583679	.383864	2.605089	.9335804	69	00
	10	.3610821	.387205	2.582609	.9325340		50
	20	.3637932	.390554	2.560464	.9314797		40
	30	.3665012	.393910	2.538647	.9304176		30
	40	.3692061	.397274	2.517150	.9293475		20
	50	.3719079	.400646	2.495966	.9282696		10
22	00	.3746066	.404026	2.475086	.9271839	68	00
	10	.3773021	.407413	2.454506	.9260902		50
	20	.3799944	.410809	2.434217	.9249888		40
	30	.3826834	.414213	2.414213	.9238795		30
	40	.3853693	.417625	2.394488	.9227624		20
	50	.3880518	.421046	2.375037	.9216375		10
23	00	.3907311	.424474	2.355852	.9205049	67	00
	10	.3934071	.427912	2.336928	.9193644		50
	20	.3960798	.431357	2.318260	.9182161		40
	30	.3987491	.434812	2.299842	.9170601		30
	40	.4014150	.438275	2.281669	.9158963		20
	50	.4040775	.441747	2.263735	.9147247		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

Table XVI—**Natural sines and tangents**—*Continued.*

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
24	00	.4067366	.445228	2.246036	.9135455	66	00
	10	.4093923	.448718	2.228567	.9123584		50
	20	.4120445	.452217	2.211323	.9111637		40
	30	.4146932	.455726	2.194299	.9099613		30
	40	.4173385	.459243	2.177492	.9087511		20
	50	.4199801	.462771	2.160895	.9075333		10
25	00	.4226183	.466307	2.144506	.9063078	65	00
	10	.4252528	.469853	2.128321	.9050746		50
	20	.4278838	.473409	2.112334	.9038338		40
	30	.4305111	.476975	2.096543	.9025853		30
	40	.4331348	.480551	2.080943	.9013292		20
	50	.4357548	.484136	2.065531	.9000654		10
26	00	.4383711	.487732	2.050303	.8987940	64	00
	10	.4409838	.491338	2.035256	.8975151		50
	20	.4435927	.494954	2.020386	.8962285		40
	30	.4461978	.498581	2.005689	.8949344		30
	40	.4487992	.502218	1.991163	.8936326		20
	50	.4513967	.505866	1.976805	.8923234		10
27	00	.4539905	.509525	1.962610	.8910065	63	00
	10	.4565804	.513195	1.948577	.8896822		50
	20	.4591665	.516875	1.934702	.8883503		40
	30	.4617486	.520567	1.920982	.8870108		30
	40	.4643269	.524269	1.907414	.8856639		20
	50	.4669012	.527983	1.893997	.8843095		10
28	00	.4694716	.531709	1.880726	.8829476	62	00
	10	.4720380	.535446	1.867600	.8815782		50
	20	.4746004	.539195	1.854615	.8802014		40
	30	.4771588	.542955	1.841770	.8788171		30
	40	.4797131	.546728	1.829062	.8774254		20
	50	.4822634	.550512	1.816489	.8760263		10
29	00	.4848096	.554309	1.804047	.8746197	61	00
	10	.4873517	.558117	1.791736	.8732058		50
	20	.4898897	.561939	1.779552	.8717844		40
	30	.4924236	.565772	1.767494	.8703557		30
	40	.4949532	.569619	1.755559	.8689196		20
	50	.4974787	.573478	1.743745	.8674762		10
30	00	.5000000	.577350	1.732050	.8660254	60	00
	10	.5025170	.581235	1.720473	.8645673		50
	20	.5050298	.585133	1.709011	.8631019		40
	30	.5075384	.589045	1.697663	.8616292		30
	40	.5100426	.592969	1.686426	.8601491		20
	50	.5125425	.596908	1.675298	.8586619		10
31	00	.5150381	.600860	1.664279	.8571673	59	00
	10	.5175293	.604826	1.653366	.8556655		50
	20	.5200161	.608806	1.642557	.8541564		40
	30	.5224986	.612800	1.631851	.8526402		30
	40	.5249766	.616809	1.621246	.8511167		20
	50	.5274502	.620832	1.610741	.8495860		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

Table XVI—Natural sines and tangents—*Continued.*

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
32	00	.5299193	.624869	1.600334	.8480481	58	00
	10	.5323839	.628921	1.590023	.8465030		50
	20	.5348440	.632988	1.579807	.8449508		40
	30	.5372996	.637070	1.569685	.8433914		30
	40	.5397507	.641167	1.559655	.8418249		20
	50	.5421971	.645279	1.549715	.8402513		10
33	00	.5446390	.649407	1.539865	.8386706	77	00
	10	.5470763	.653551	1.530102	.8370827		50
	20	.5495090	.657710	1.520426	.8354878		40
	30	.5519370	.661885	1.510835	.8338858		30
	40	.5543603	.666076	1.501328	.8322768		20
	50	.5567790	.670284	1.491903	.8306607		10
34	00	.5591929	.674508	1.482561	.8290376	56	00
	10	.5616021	.678749	1.473298	.8274074		50
	20	.5640066	.683006	1.464114	.8257703		40
	30	.5664062	.687281	1.455009	.8241262		30
	40	.5688011	.691572	1.445980	.8224751		20
	50	.5711912	.695881	1.437026	.8208170		10
35	00	.5735764	.700207	1.428148	.8191520	55	00
	10	.5759568	.704551	1.419342	.8174801		50
	20	.5783323	.708913	1.410609	.8158013		40
	30	.5807030	.713293	1.401948	.8141155		30
	40	.5830687	.717691	1.393357	.8124229		20
	50	.5854294	.722107	1.384835	.8107234		10
36	00	.5877853	.726542	1.376381	.8090170	54	00
	10	.5901361	.730996	1.367995	.8073038		50
	20	.5924819	.735469	1.359676	.8055837		40
	30	.5948228	.739961	1.351422	.8038569		30
	40	.5971586	.744472	1.343233	.8021232		20
	50	.5994893	.749003	1.335107	.8003827		10
37	00	.6018150	.753554	1.327044	.7986355	53	00
	10	.6041356	.758124	1.319044	.7968815		50
	20	.6064511	.762715	1.311104	.7951208		40
	30	.6087614	.767327	1.303225	.7933533		30
	40	.6110666	.771958	1.295405	.7915792		20
	50	.6133666	.776611	1.287644	.7897983		10
38	00	.6156615	.781285	1.279941	.7880108	52	00
	10	.6179511	.785980	1.272295	.7862165		50
	20	.6202355	.790697	1.264706	.7844157		40
	30	.6225146	.795435	1.257172	.7826082		30
	40	.6247885	.800196	1.249693	.7807940		20
	50	.6270571	.804979	1.242268	.7789733		10
39	00	.6293204	.809784	1.234897	.7771460	51	00
	10	.6315784	.814611	1.227578	.7753121		50
	20	.6338310	.819462	1.220312	.7734716		40
	30	.6360782	.824336	1.213097	.7716246		30
	40	.6383201	.829233	1.205932	.7697710		20
	50	.6405566	.834154	1.198818	.7679110		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI—**Natural sines and tangents**—*Continued.*

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
40	00	.6427876	.839099	1.191753	.7660444	50	00
	10	.6450132	.844068	1.184737	.7641714		50
	20	.6472334	.849062	1.177769	.7622919		40
	30	.6494480	.854080	1.170849	.7604060		30
	40	.6516572	.859124	1.163976	.7585136		20
	50	.6538609	.864192	1.157149	.7566148		10
41	00	.6560590	.869286	1.150368	.7547096	49	00
	10	.6582516	.874406	1.143632	.7527980		50
	20	.6604386	.879552	1.136941	.7508800		40
	30	.6626200	.884725	1.130294	.7489557		30
	40	.6647959	.889924	1.123690	.7470251		20
	50	.6669661	.895150	1.117130	.7450881		10
42	00	.6691306	.900404	1.110612	.7431448	48	00
	10	.6712895	.905685	1.104136	.7411953		50
	20	.6734427	.910994	1.097702	.7392394		40
	30	.6755902	.916331	1.091308	.7372773		30
	40	.6777320	.921696	1.084955	.7353090		20
	50	.6798681	.927091	1.078642	.7333345		10
43	00	.6819984	.932515	1.072368	.7313537	47	00
	10	.6841229	.937968	1.066134	.7293668		50
	20	.6862416	.943451	1.059938	.7273736		40
	30	.6883546	.948964	1.053780	.7253744		30
	40	.6904617	.954508	1.047659	.7233690		20
	50	.6925630	.960082	1.041576	.7213574		10
44	00	.6946584	.965688	1.035530	.7193398	46	00
	10	.6967479	.971326	1.029520	.7173161		50
	20	.6988315	.976995	1.023546	.7152863		40
	30	.7009093	.982697	1.017607	.7132504		30
	40	.7029811	.988431	1.011703	.7112086		20
	50	.7050469	.994199	1.005834	.7091607		10
45	00	.7071068	1.000000	1.000000	.7071068	45	00
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

119. **Properties of circles.**—The ratio of the diameter to the circumference is represented in mathematics by π called **Pi.** Its value can not be exactly expressed. To 5 decimal places it it 3.14159, which equals $^{22}/_{7}$ nearly. Log. π equals 0.4971499.

Diam. $\times$ 3.14159 = circ.
Diam. $\times$ 0.886277 = side of square of equal area.
Diam. $\times$ 0.7071 = side of inscribed square.
$\frac{1}{4}\pi D^2 = 0.7854 \times D^2$ = Area of the circle.
$\pi r^2 = 3.1416 \times r^2$ = Area of the circle.
The length of an arc of $n^\circ = rn \times 0.017453$.

Example: If the radius is 542 ft., the length of an arc of 18° 20′ = 18°.33 $\times$ 542 $\times$ 0.017453 = 165.5 ft.

120. **Properties of some plane figures.**—Triangles are classed as equilateral when the 3 sides are of equal length; isoceles, when two sides only are equal; acute-angled, when each of its angles is less than 90°; obtuse-angled, when one angle is greater than 90°.

The sum of the angles of any triangle is 180°. The sides are directly proportional to the sines of the opposite angles, the greatest and least sides opposite the greatest and least angles.

Formulas for the solution of plane triangles. Fig. 69.

Given 2 sides, as a and b, and an angle opposite to one of them, as B.

$$\text{Sin. } A = \frac{a \text{ sin. } B}{b}; \quad C = 180^\circ - (A + B); \quad c = \frac{a \text{ sin. } C}{\text{sin. } A}.$$

Given 2 angles as A and B and the included side c, the most common case.

$$C = 180^\circ - (A + B); \quad a = \frac{c \text{ sin. } A}{\text{sin. } C}; \quad b = \frac{a \text{ sin. } B}{\text{sin. } A}.$$

Given 2 sides at a and b, and the included angle C.

$$180^\circ - C = A + B$$

$$\text{Tan. } \frac{A - B}{2} = \frac{(a - b)\, \frac{(A + B)}{2}}{a + b}$$

$$A = \frac{A + B}{2} + \frac{A - B}{2}; \quad B = \frac{A + B}{2} - \frac{A - B}{2}; \quad C = \frac{a \text{ sin. } C}{\text{sin. } A}.$$

Given the 3 sides—

$$\frac{a + b + c}{2} = S; \quad \text{sin. } \frac{A}{2} = \sqrt{\frac{(S - b)(S - c)}{bc}};$$

$$\text{sin. } \frac{B}{2} = \sqrt{\frac{(S - a)(S - c)}{ac}}; \quad \text{sin. } \frac{C}{2} = \sqrt{\frac{(S - a)(S - b)}{ab}}.$$

For every **right-angled** triangle the sine of the right angle is 1 and the following relations result: The side opposite the right angle is called the **hypothenuse.** Fig. 69.

$$\text{Hypothenuse} = a = c \div \text{sin. } C = c \times \text{sec. } B = \frac{b}{\text{Cos. } C}.$$
$$= b \times \text{sec. } C = \sqrt{b^2 + c^2};$$
$$b = a \times \text{sin. } B = a \times \text{cos. } C = c \times \text{cotang. } C = c \times \text{tang. } B;$$
$$c = a \times \text{sin. } C = a \times \text{cos. } B = b \times \text{tang. } C;$$
$$\text{sin. } B = \frac{b}{a} \text{ cos. } C; \quad \text{sin. } C = \frac{c}{a} = \text{cos. } B;$$
$$\text{tang. } B = \frac{b}{c} = \text{cotang. } C; \quad \text{tang. } C = \frac{c}{b} = \text{cotang. } B.$$

The area of a triangle equals any side multiplied by ½ the perpendicular distance from that side to the opposite angle. If the perpendicular from the angle does not intersect the opposite side, prolong the side, but do not include the prolongation in its length for computing the area. All triangles which have a common side and their opposite angles in a straight line parallel to the common side, are equal in area.

A line bisecting one angle divides the opposite side into parts proportional to the adjacent sides. In fig. 70, *ab* bisects the angle at *a* and *bc* : *ac* : : *bd* : *ad*.

Lines drawn from each angle to the middle of the opposite side intersect in a common point, which is the center of gravity of the triangle. The shorter part of each line is ½ the longer, fig. 71.

A line joining the middle points of two sides is parallel to the third side and ½ its length. In fig. 71 the line *ef*, joining the middle points of *ab* and *bc*, is parallel to *ac*, and ½ its length. Lines joining *eg* and *fg* would be parallel to *ab* and *bc*, and half their length, respectively.

Similar triangles are those which have the same angles and differ only in length of sides. The ratio between corresponding sides of all similar triangles is the same, since it is the ratio of the same function of the same angles. Hence, if two sides of a triangle and one of the corresponding sides of a similar triangle are known, the other corresponding side may be determined. The simplest test of similar triangles is that their corresponding sides are parallel or perpendicular. The principle of similar triangles is of great utility in field geometry.

The side of a square equals the diam. of an inscribed circle; or the diam. of a circumscribed circle × 0.7071. The diagonal of a square equals one side × 1.4142.

The area of a trapezoid, fig. 72, equals ½ the sum of the parallel sides *ab* and *cd* multiplied by the distance between them, *ef*.

The area of a trapezium—no two sides parallel—fig. 73, equals ½ the diagonal *ac* multiplied by the sum of the perpendiculars, *bf* and *de*.

The side of a hexagon equals the radius of a circumscribed circle. The area equals the square of 1 side × 2.598. The side of an octagon equals the radius of a circumscribed circle × 0.7633. The area equals the square of one side × 4.8289.

To draw an octagon in a square (fig. 74).—From each corner with a radius equal to ½ the diagonal describe arcs as shown. Join the points at which they cut the sides. If a square stick be scribed at a distance from each corner equal to 0.3 the side of the square and the corners chamfered to the marks, the resulting section will be nearly a true octagon.

121. **Geometrical constructions.**—To divide a straight line into any number of equal parts. From one end of the line draw another, making any convenient angle with it, as 10° or 20°. On this auxiliary line lay off any assumed distance as many times as the number of equal parts desired. Join the last point so determined with the end of the first line. Through each of the points marked on the auxiliary line draw a line parallel to the line joining the ends. These lines will divide the given line into the desired number of equal parts.

To draw a perpendicular from a given point on a line: Mark 2 points equidistant from the given point, fig. 75, and with them as centers and a radius greater than their distance from the given point describe arcs on each side of the line. Connect one intersection with the given point by a straight line, which is the perpendicular required. As a check on accuracy, note whether the line passes through the other intersection.

If the given point is at one end of the line, from a convenient point *c* outside the line describe a semicircle passing through the given point, and cutting the line again as at *b*, fig. 78. Draw a straight line *bc* through the center to the arc on the other side as at *d*. The line *da* is the perpendicular required.

From a given point to let fall a perpendicular to a given line. From the given point, fig. 77, describe an arc cutting the line twice. With these two points proceed as in erecting a perpendicular at a given point, fig. 75, or bisect the portion of the line between the intersections, as at *d*, and draw the line *ad*, which is the perpendicular required.

To describe a circle passing through 3 given points: Join the points by 2 lines, as *ab* and *bc*, fig. 76, and construct a bisecting perpendicular on each. The perpendiculars intersect at the center of the required circle.

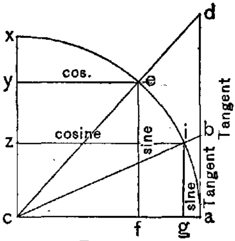


Fig. 68.

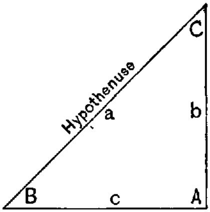


Fig. 69.

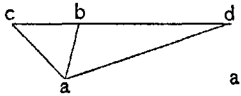


Fig. 70.

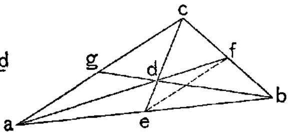


Fig. 71.

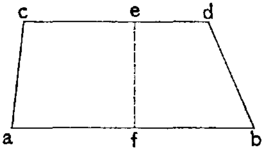


Fig. 72.

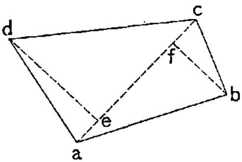


Fig. 73.

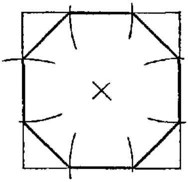


Fig. 74.

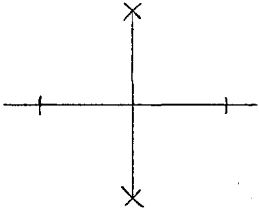


Fig 75.

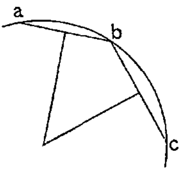


Fig. 76.

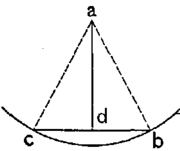


Fig. 77.

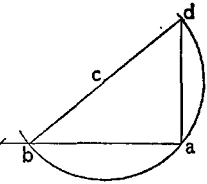


Fig. 78.

122. **Areas** are to each other as the squares of similar lines; similar triangles as the squares of corresponding sides, or of perpendiculars from corresponding angles to opposite sides, etc.

Squares are to each other as the squares of the sides or diagonals.

Other regular polygons are to each other as the squares of the sides or of the radii of inscribed or circumscribed circles.

Circles are to each other as the squares of diams., or radii, or chords of equal arcs.

123. **Spheres and cubes.**—The surface of a sphere $= 4\pi r^2 = 12.5664 r^2 = 3.1416 d^2 = 0.3183$ circ. squared $= 4 \times$ area of a great circle $=$ diam. $\times$ circ. $=$ the curved surface of circumscribed cylinder.

The surfaces of two spheres are to each other as the squares of corresponding lines.

The volume of a sphere $= \frac{4}{3}\pi r^3 = 4.1888 r^3 = 0.5236 d^3 = 0.01689$ circ.$^3 = \frac{2}{3}$ diam. $\times$ area of great circle $= \frac{2}{3}$ vol. of circumscribed cylinder $= 0.5326$ vol. of circumscribed cube.

The volumes of spheres and cubes are to each other as the *cubes* of their corresponding *lines*, or the *squares* of corresponding *surfaces;* for a sphere, the radius, the diam., the area of a great circle, or of any circle subtending equal angles at the center; for a cube, an edge, a diagonal of a side, or a diagonal of the cube. The diagonal of a cube $=$ the edge $\times$ 1.7321.

124. **Gravitation.**—The earth's attraction is measured by the increase in the velocity of a falling body which that attraction produces in a second of time. This quantity is represented by g, and its value at the surface of the earth on the equator is 32.092 ft. This means that if any body is falling freely its velocity at the end of any second of time is 32.092 ft. per second greater than at the beginning of that second. If the body starts from rest, its velocity at the beginning is 0, and at the end of the first second is g. The velocity of any falling body at any instant equals g multiplied by the number of seconds the body has been falling. This relation is strictly true for a vacuum only, but for moderate heights is nearly correct in air.

The value of **g** varies slightly with the latitude as shown in the following table:

TABLE XVII.

125. **Values of g** at surface of earth in different latitudes:

Latitude.	Value of g in feet.	Latitude.	Value of g in feet.
Equator	32.09	52° 15′	32.19
20° 40′	32.11	60°	32.21
30°	32.13	69° 15′	32.23
37° 10′	32.15	90° pole	32.25
45°	32.17		

126. The value of **g** varies also with the distance from the center of the earth; or the distance above or below the surface, diminishing in both cases. This diminution is approximately 0.016 ft. for each mile above the surface and 0.008 ft. for each mile below.

127. The fundamental law of motion of falling bodies is $v^2 = 2gh$, in which $v =$ the velocity at any point in feet per second; h, the distance through which the body has fallen from rest to the given instant.

As $v = gt$, $h = \frac{1}{2}gt^2 = 16t^2$. These relations are strictly true only in vacuo, but for small, smooth, dense objects are approximately correct for motion in air up to 5 seconds.

128. **Centrifugal force.**—If $w =$ the weight of a revolving body and n the number of revolutions per minute, $r =$ the radius of revolution or the distance of center of gravity of the body from center of motion, and $c =$ the centrifugal force or pull on the radius in lbs., then $c = 0.00034wrn^2$.

ADDENDA, 1907.

129. **Military reconnaissance of Cuba.**—In October, 1906, Gen. J. Franklin Bell, commanding the Army of Cuban Pacification, ordered a military reconnaissance of the Island of Cuba. This work, though done under conditions somewhat different from those assumed in the foregoing pages, and covering territory much larger than is likely to be reconnoitered by a marching army, is such a valuable practical exemplification of the principles upon which all military reconnaissance must be based that a succinct description of it is given.

130. The reconnaissance was organized and conducted as prescribed in Field Service Regulations through the agency of the Chief of Staff and the Chief Engineer of the Army of Cuban Pacification The subjoined description is condensed from the instructions issued and information supplied by the Chief Engineer.

131. A military map of Cuba prepared, largely by compilation, after the close of the Spanish war, was used as a base. Its scale was 1 : 250,000. This map was divided into 87 rectangles of 30′ of latitude by 30′ of longitude. These rectangles were enlarged to 1 : 62,500 by pantograph, and blueprints made of the enlargements. The prints were reversed, showing blue lines on white ground. Each rectangle was then divided into 35 subrectangles or sections arranged and numbered according to the following scheme:

N.

	1	6	11	16	21	26	31	
	2	7	12	17	22	27	32	
W.	3	8	13	18	23	28	33	E.
	4	9	14	19	24	29	34	
	5	10	15	20	25	30	35	

S.

These sections were about 5 by 7 ins., and two copies of each large rectangle were cut up into sections and the smaller parts pasted on heavy cardboard. Each such card was numbered on the back to correspond with its place on the full sheet. When a full sheet extended beyond the land area the sections falling entirely on the water were omitted, but the number of a section corresponding to its place on the full sheet was never changed. Two sets of these cards were sent to each officer charged with the area covered by them, and in addition two or more uncut sheets or rectangles.

132. When several parties worked from the same station a coordinating reconnaissance officer was appointed to supervise the work of all, allotting cards to the various parties, preventing duplication, and seeing that the work was well done and checked. For convenience, plotting was authorized to be done on a scale of 1 in. to 1 mile. The work was done by officers assisted by enlisted men.

The method of procedure was as follows:

Each party took into the field one or more of the cardboard sections and actually traversed all roads, railways, public and private (plantation), and important trails. Inaccuracies of the base map were corrected to show in true location all roads, buildings, bridges, large culverts, fords, telegraph and telephone lines, fortifications, and other features of military importance. Lines of communication not shown on the base map were followed and drawn in. Features shown on the map but not found on the ground were crossed off and marked "OUT."

Contouring was not attempted on flat or ordinary rolling country, but hill forms, prominent ridges, and accessible mountains were shown by contours at 50-ft. intervals.

Swamps, woods, cultivated land, etc., were shown by conventional signs. Villages and towns were shown in true plan when practicable, with their names correctly spelled. If a true plan could not be shown on the scale of the map, a sketch of the village on a larger scale was included in the notebook of descriptive matter, which was very complete. The rule, however, was to put on the map everything that could be shown there without confusion. Matter which could not be so shown was entered in the notebooks which were sent in with the completed sheets.

The work of each day was transferred in ink to the large sheet in the evening. If parties were to be out more than one day and there was no copy of the large sheet available to carry with them, each day's work was gone over with ink on the cards themselves in the evening. Care was taken to have continuing features, as roads and streams crossing the dividing lines between cards, checked by comparison with adjacent cards before sending in results. When this could not be done on account of the adjacent territory not having been covered by field parties, such features were continued far enough beyond the border of the card to be checked with well-defined points on the other cards, a special description of the checking point being made and attached to the card when necessary.

Distances were measured by pacing, foot or mounted, and by odometer and cyclometer. Directions were by compass, with sufficient attention to the variation to permit the deduction of true bearings.

The large sheets were sent in to the office of the Chief Engineer as soon as completed. The card sections were sent in as opportunity offered as soon as practicable after work on them was completed and transferred.

The base map was found so defective in many parts that practically everything on it was marked "OUT" and the cards were used as though they had nothing on them. In some cases the cards were entirely discarded, and to avoid accumulative errors, the following method was adopted: Road reconnaissances, showing all road and stream crossings, were first made so as to form large loops of 20 to 60 miles in perimeter, the several loops covering the entire rectangle. Each of these loops was made to close on itself and adjusted so as to properly connect with the adjacent loops. The crossroads, etc., were then run in and adjusted to fit the crossings as already determined, the adjusted loops taking in some degree the place of a triangulation system. This method was found to give good results.

133. The total area covered by the survey was 40,000 square miles, and the field work was completed between the middle of October and the middle of April. More than 90 per cent, however, was completed in five of these six months. A battalion of engineers completed 14,000 square miles in four and one-half months. Three companies of another battalion of engineers completed 4,800 square miles in about two months. Five officers of marines with detachments from that corps completed 1,200 square miles. The remainder, 20,000 square miles, was assigned to infantry and cavalry commanders at twenty different stations throughout the island.

96*a*. By direction of the Chief of Staff, the conventional signs adopted in 1904 and published to the Army in pamphlet form as War Department Document No. 238, Office of Chief of Staff, are included in the revised edition of the Engineer Field Manual. These signs are shown in figs. 79–91, inclusive. Except for the lettering, which has been reengraved, the original plates, slightly modified, have been used, with some changes in spacing and disposition of matter to suit the form and size of the Manual page. The modifications alluded to, which have been approved by the Chief of Staff, are in the classification of wagon roads (fig. 79), and of streams (fig. 85), and in the sign for a canal (fig. 80). Other changes are additional and explanatory.

96*b*. The adaptation of conventional signs to the size and scale of the map is accomplished in part by varying the boldness of the pen or brush strokes and in part by wider spacing of them. The strokes must never be so small as to render the sign illegible and never larger than can be easily made with a medium pen. The object is to produce a result which, while distinct as to conventional meaning, shall not be so heavy in general tone as to catch the eye, or, what is especially important in military maps, to obscure any additions which may be made. Topographical signs should be perfectly clear when looked for, but not obtrusive.

As a rough guide, it may be stated that the signs shown in the plates are about right for continuous areas of 3 sq. ins. or less in maps of scales of 2 or 3 ins. to the mile. If the map areas are larger or the scale smaller, the signs should be lightened some, but not much, by making the strokes smaller and by spacing them wider. Some examples of good maps show the meadow sign, for example, with 2 or 3 elements to the sq. in. For very large scale maps and for field sketches the strokes may be made heavier and the spacing in them close. These remarks apply only to cultural signs, and a few others the significance of which is independent of size and shape. All natural or artificial features in which size and form are in any way material should be drawn with as much regard to the scale as practicable. This becomes more important as the scale is larger.

It may, therefore, happen that the same feature will be differently shown on maps of different scales. This is well illustrated in the case of streams. Fig. 85 shows three signs for streams. On a large-scale map, say 1 : 1,000, a rivulet a few feet wide would be shown by the third sign, or probably the second, while on a scale of 1 : 1,000,000 a stream 1 mile wide would be shown by the first sign.

96*c*. There should always be a certain correspondence between the refinement of the map drawing and the accuracy and elaborateness of the field measurements and observations on which the map is based. The general appearance of a map suggests the class of fieldwork from which it should be derived, and if this suggestion is not in accordance with fact the map is deceptive. A broad simple drawing corresponds to rough and rapid fieldwork. A finely drawn and highly finished map corresponds to a deliberate and exact survey. If rough fieldwork is represented by a highly finished work, it is given more value than it deserves, and more confidonce in its details may lead to disaster. If, on the contrary, high-class fieldwork is crudely drawn, its apparent is less than its true value and time may be wasted in needless verification. The former contingency is much more serious than the latter. The conventional signs or lettering shown in figs. 48–51, inclusive, are suitable for the rough and hasty work of field sketches and maps for temporary use. Those shown in figs. 79–91, inclusive, are suitable for finished permanent maps representing accurate surveys. Between these two extremes there is a wide range to be covered by field signs more finely drawn, or by the finished map signs more boldly drawn, or by combinations of the two methods.

96*d*. On civil maps explanatory matter is usually confined to notes. On military maps much use should be made of explanatory matter in the body of the map relating to single features. The design, material, and dimensions of bridges may be indicated; the height and width of channels and dimensions of locks and canals may be given; the width, depth, and character of streams may be indicated, and other data of tactical value may be set forth. This method of expression will be more freely used as the maps or sketches are of less permanency or more historical in character. For maps designed for permanent use, or for use at an indefinite future time, this method must be employed with caution, in view of the fact that most of such data is of changeable type and may become obsolete, when its presence on the map will do more harm than good.

The following abbreviations of words of frequent recurrence have been adopted by the War Department for use on all military maps and sketches. It is not required that an abbreviation shall be used when space and time permit the full word to be written, but it is required that when any of the following words is used it must be written in full or abbreviated as shown, and none of the abbreviations given may be used for any other word than the one for which it stands in the table. Words not given in the table should not be abbreviated if it can be avoided.

96*e*. Authorized abbreviations.

A.	Arroyo.	gir.	Girder.	q. p.	Queen-post.
abut.	Abutment.	G. M.	Gristmill.	R.	River.
Ar.	Arch.	i.	Iron.	R. H.	Roundhouse.
b.	Brick.	I.	Island.	R. R.	Railroad.
B. S.	Blacksmith shop.	Jc.	Junction.	S.	South.
bot.	Bottom.	k. p.	King-post.	s.	Steel.
Br.	Branch.	L.	Lake.	S. H.	Schoolhouse.
br.	Bridge.	Lat.	Latitude.	S. M.	Sawmill.
C.	Cape.	Ldg.	Landing.	Sta.	Station.
cem.	Cemetery.	L. S. S.	Life-saving station.	st.	Stone.
con.	Concrete.	L. H.	Lighthouse.	str.	Stream.
cov.	Covered.	Long.	Longitude.	T. G.	Tollgate.
Cr.	Creek.	Mt.	Mountain.	tres.	Trestle.
cul.	Culvert.	Mts.	Mountains.	tr.	Truss.
D. S.	Drug store.	N.	North.	W. T.	Water tank.
E.	East	n. f.	Not fordable.	W. W.	Waterworks.
Est.	Estuary.	p.	Pier.	W.	West.
f.	Fordable.	pk.	Plank.	w.	Wood.
Ft.	Fort.	P. O.	Post office.		
G. S.	General store.	Pt.	Point.		

ADDENDUM, 1908.

96*f*. A method of conventionally indicating topographical data on maps and sketches in greater completeness, and in much smaller compass than by any other known system, and which promises excellent results, has just been proposed by Capt. Consuelo A. Seoane, Philippine Scouts. It is based on the decimal system of library classification, substituting for the various subjects incorporated in the library catalogue the names of topographical features and other important qualities and characteristics.

Any number of digits may be employed, but Captain Seoane has found eight (that is, four on each side of the decimal point) to cover any one subject fully. If, for example, it be required that the map shall show the military significance of a road, and in the classification index roads are assigned under the general heading 6000, by employing eight digits, the information may be conveyed that the feature described is a road, and seven facts pertaining to the road may be clearly stated. The kind or class of road may be placed in the hundreds place, or the third digit from the decimal point; and it may appear that while 6000 is a road, 6100 is a macadam road, 6200 is a paved road, 6300 is a dirt road, 6400 a trail, and so on up to 9, if there be so many kinds of roads.

Practicability for military uses, the next important classification after the kind of road, may be assigned to the tens place, and as to practicability 6010 may represent a road passable for artillery, 6020 for wagons, 6030 for cavalry, 6040 for foot troops, and so on to as many places as may be necessary to cover all the varieties of troops and trains in the column.

Taking the character of the soil next, its classification may appear in the units place; and we might have 6001, a sand road; 6002, a clay road; 6003, a gravel road, and so on.

Width, as relating to military use, being an important item, it may be placed in the tenths place; and we may have 6000.1, wide enough for wagons to pass; 6000.2, wide enough for troops to pass wagons; 6000.3, wide enough for troops to pass each other by breaking into column of twos; 6000.4, wide enough for troops to march in file and pass each other, but with difficulty, and so on.

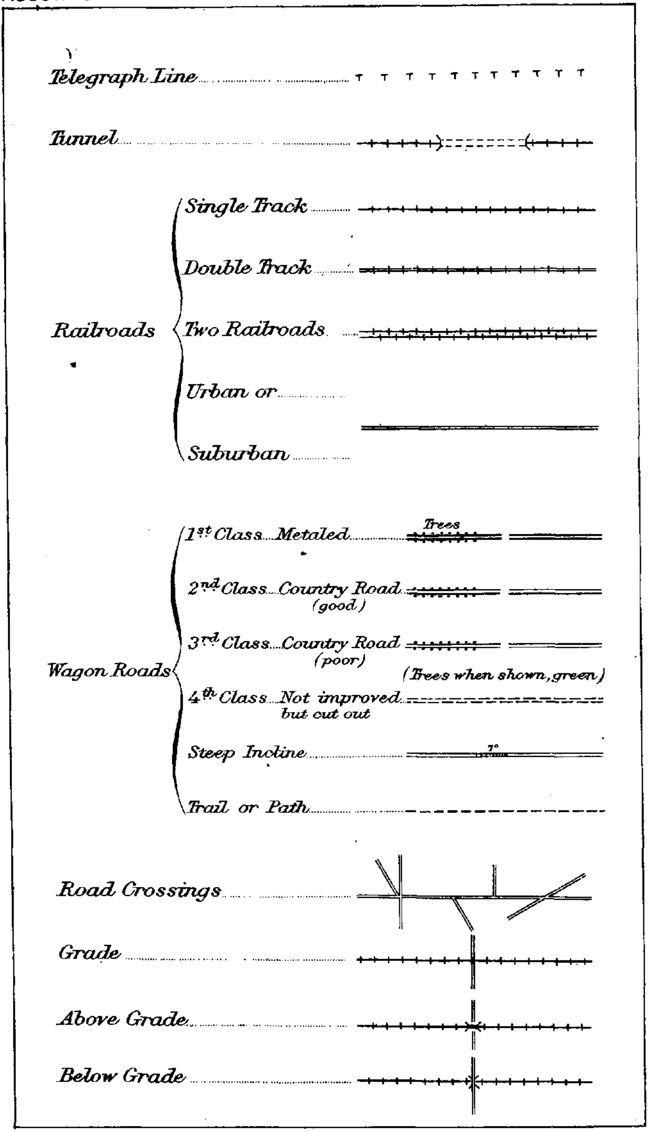
This may be followed by drainage in the hundredths place; as 6000.01, well drained; 6000.02, poorly drained; 6000.03, flooded in the rainy season.

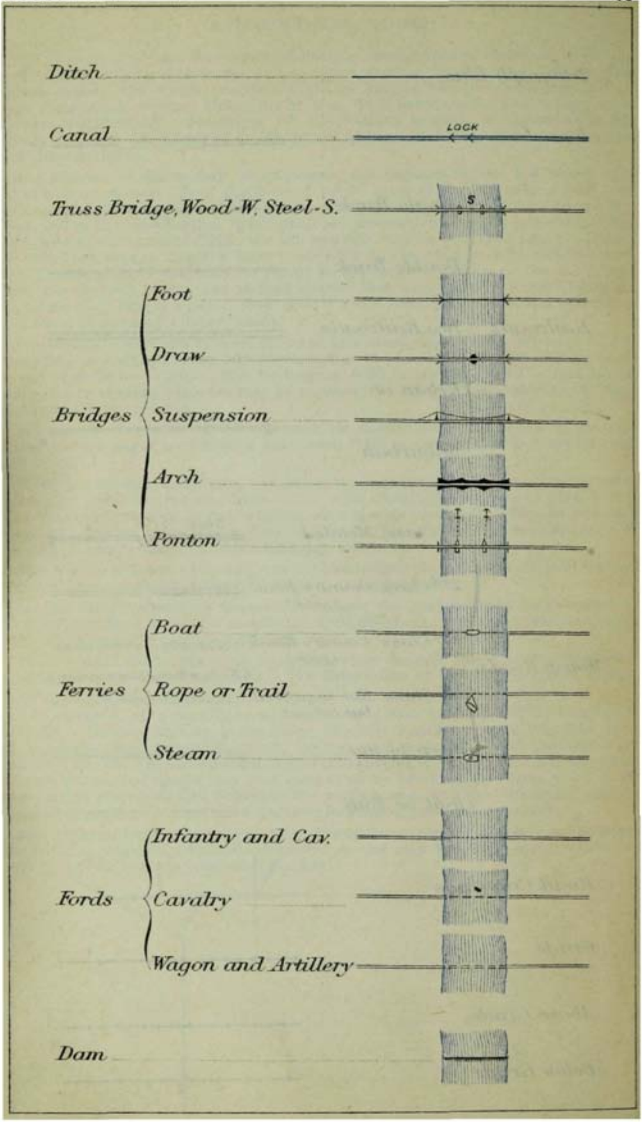
In the third decimal, or thousandths place, the gradient may be described, as 6000.001, less than 2 degrees maximum; 6000.002, from 2 to 5 degrees maximum; 6000.003, from 5 to 8 degrees maximum, etc.

There remain the fourth or as many following decimal places as are required to accommodate the desired subheads. The description of the ordinary road is fully given on the headings indicated above.

For example, let a map have written along a road between towns a number, as 6113.331. Looking this up in the index, the first number, 6, means a road; the 1 in hundreds place means macadam, the second 1 shows the road practicable for artillery, and the 3 in units place indicates that the soil is gravelly; the 3 in the tenths column shows that troops may pass each other by breaking into twos, the 3 in the hundredths place indicates flooded in the rainy season, and the following 1 that the maximum gradient is less than 2 degrees, indicating quite a flat country.

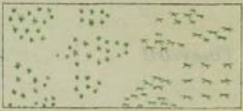
One important advantage claimed for this system is that by properly safeguarding the index the topographical data displayed on the map become a secret which can only be known to those possessing the key.


Telegraph Line
Tunnel
Railroads
Single Track
Double Track
Two Railroads
Urban or
Suburban
Wagon Roads
1st Class Metaled
Trees
2nd Class Country Road (good)
3rd Class Country Road (poor)
(Trees when shown, green)
4th Class Not improved but cut out
Steep Incline
7°
Trail or Path
Road Crossings
Grade
Above Grade
Below Grade


Ditch
Canal
LOCK
Truss Bridge, Wood-W. Steel-S.
S
Bridges
Foot
Draw
Suspension
Arch
Ponton
Ferries
Boat
Rope or Trail
Steam
Fords
Infantry and Cav.
Cavalry
Wagon and Artillery
Dam

Deciduous Trees, Isolated groups

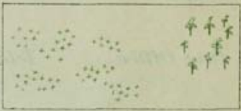
Evergreens *Palms*



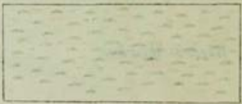
Outline of Forest

Cactus *Spanish Bayonet*

Bamboo *Banana*



Meadow Land



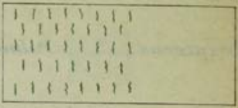
Ploughed Land

Sugar Cane *Corn*

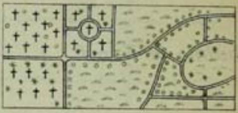
Cotton *Rice with Dikes*

Tobacco

Vineyard



Cemetery *Park*



Electric Power Plant

Church

Hospital

Post Office *Telegraph Office* P.O.

Factory (state character)

Water Works W.W.

Forage Station

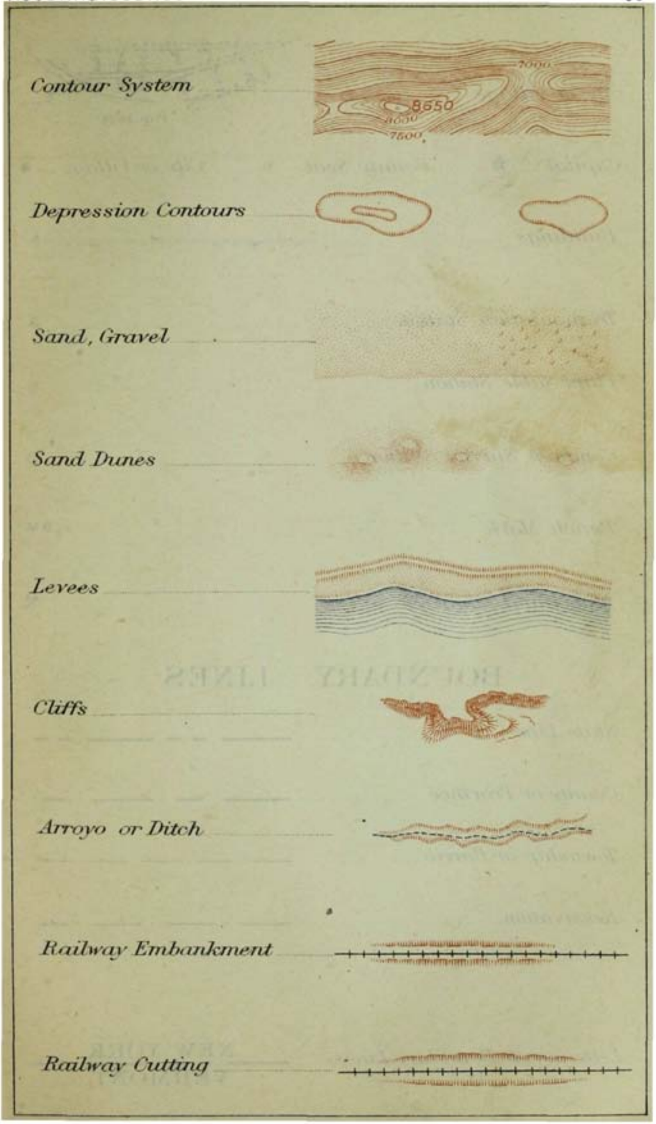
Hedge

Stone Fence

Worm Fence

Wire Fence *Barbed* x—x—x—x—x—x *Smooth* o—o—o—o—o—o

Board Fence


Contour System
7000
8650
7500
Depression Contours
Sand, Gravel
Sand Dunes
Levees
Cliffs
Arroyo or Ditch
Railway Embankment
Railway Cutting

City or Village

Capital .... ⊛ *County Seat* .... ⊙ *City or Village* .... ●

Buildings ....

Triangulation Station .... △

Plane-table Station .... ⊡

Common Survey Station .... ⊙

Bench Mark .... × BM 1362

Mines and Quarries .... ⚒

BOUNDARY LINES

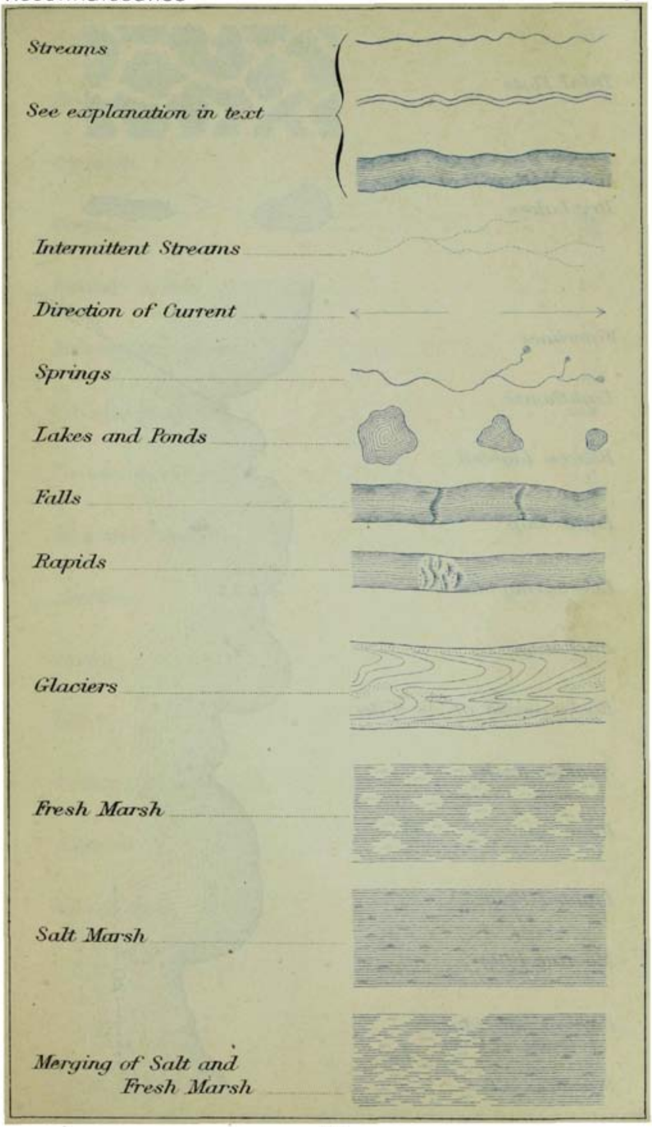
State Line ....

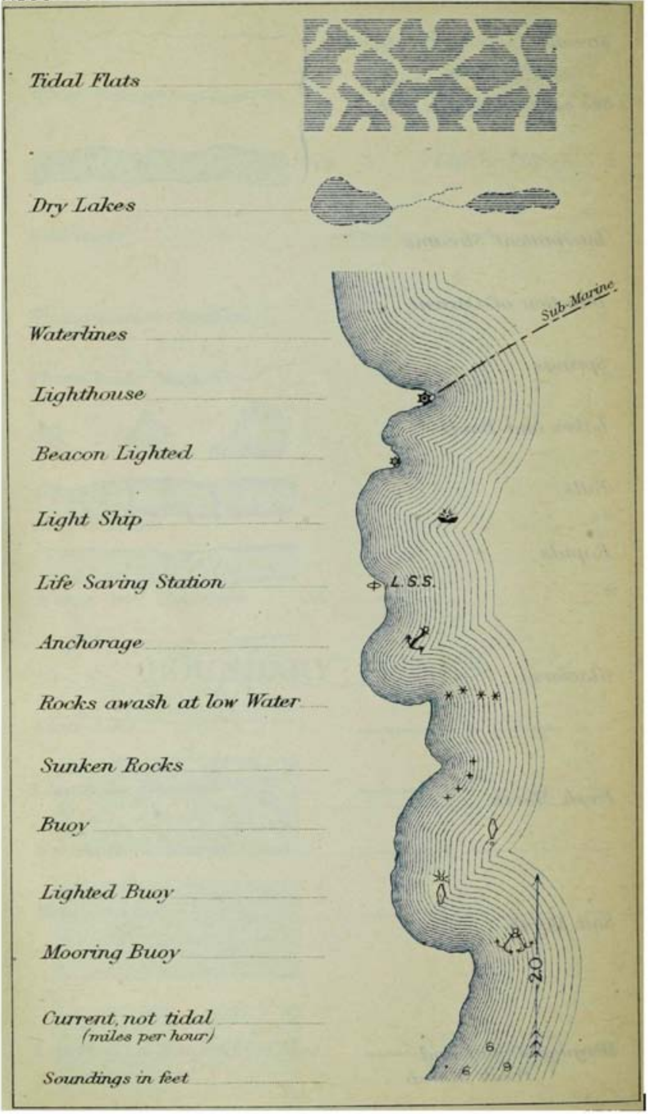
County or Province ....

Township or Barrio ....

Reservation ....

Lettering on Boundary Lines .... NEW YORK VERMONT


Streams
See explanation in text
Intermittent Streams
Direction of Current
Springs
Lakes and Ponds
Falls
Rapids
Glaciers
Fresh Marsh
Salt Marsh
Merging of Salt and Fresh Marsh


Tidal Flats
Dry Lakes
Sub-Marine
Waterlines
Lighthouse
Beacon Lighted
Light Ship
Life Saving Station
L.S.S.
Anchorage
Rocks awash at low Water
Sunken Rocks
Buoy
Lighted Buoy
Mooring Buoy
2.0
Current, not tidal
(miles per hour)
6
6
9
Soundings in feet

Regimental Headquarters	23 I
Brigade "	2B 4D★3C
Division "	5D★3C
Corps "	8 C
Infantry in line	
Infantry in column	
Cavalry in line	
Cavalry in column	
Mounted Infantry	
Artillery	
Sentry	
Vidette	
Picket, Cav. and Infty.	
Support " " "	
Wagon train	
Adjutant General	
Quarter-master	
Commissary	

Medical Corps

Ordnance

Signal Corps

Engineer Corps

Gun Battery

Mortar Battery

Fort ⎧ *True plan to be* ⎫

Redoubt ⎩ *shown if known* ⎭

Camp

Battle

Trench

OBSTACLES

NOTE: When color is used execute these in red

Abattis

Wire entanglement

Palisades

Contact Mines

Controlled Mines

Demolitions

CIVIL DIVISIONS

States, Counties, Townships, Capitals and Principal Cities (all capital letters)

ABCDEFGHIJ
KLMNOPQRST
UVWXYZ

Towns and Villages (with Cap. initials)

abcdefghijklmnopqrstuvwxyz

HYDROGRAPHY

Lakes, Rivers and Bays (all capital letters)

ABCDEFGHIJ
KLMNOPQRST
UVWXYZ

Creeks, Brooks, Springs, small Lakes, Ponds, Marshes and Glaciers (with Cap. initials)

abcdefghijklmnopqrstuvwxyzz

HYPSOGRAPHY

Mountains, Plateaus, Lines of Cliffs and Canyons (all capital letters)

A B C D E F G H I J K L M N O P Q R S T U
V W X Y Z

Peaks, small Valleys, Islands and Points (with Cap. initials)

abcdefghijklmnopqrstuvwxyz

PUBLIC WORKS

Railroads, Tunnels, Bridges, Ferries, Wagon-roads, Trails, Fords and Dams (capitals only)

ABCDEFGHIJKLMNOPQRSTUVWXYZ

CONTOUR NUMBERS

Heavy contours *1234567890*

Light contours *1234567890*

MARGINAL LETTERING

ABCDEFGHIJKLMNOPQRSTU
VWXYZ

(with Cap. initials)

abcdefghijklmnopqrstuvwxyz
1234567890

Gage of Letters
(in Decimillimeters)

5	Lone Tree
6	*Silver Lake*
7	Drawn by
8	Plum Pt.
9	*LONG BRIDGE*
10	Newton
12	*Itasca L.*
13	Edition of
14	Pilot Knob
15	NEWBURG
18	*Lake George*
20	SHEET NO. 1
22	ROCKY MTS.
25	ALBANY
30	*POTOMAC R.*
35	DISTRICT
40	CALVERT
45	*ONTARIO*
50	VIRGINIA
55	*PACIFIC*
60	OHIO

Thickness of letter $\frac{1}{7}$ of height.
Slope of letter 3 parts of base to 8 of height.

FIRE CONTROL; COAST ARTILLERY.

	Abbreviation.	Sign.
Battle Commander's Station	C	C
Primary Station of a Fire Command	F′	F′
Secondary " " " " "	F″	$\boxed{F''}$
Supplementary " " " " "	F‴	$\boxed{F'''}$
Primary Station of a Battery	B′	B′
Secondary " " " "	B″	$\boxed{B''}$
Supplementary " " " "	B‴	$\boxed{B'''}$
Primary Station of a Mine Command	M′	M′
Secondary " " " " "	M″	$\boxed{M''}$
Supplementary " " " " "	M‴	$\boxed{M'''}$
Double Primary " " " " "	M′ M′	M′ M′
" Secondary " " " " "	M″ M″	$\boxed{M''}\boxed{M''}$
Separate Observing Room	O	O
" Plotting "	P	P
Battery Commander's Station	B.C.	BC
Meteorological Station	Met.	$\boxed{M}$
Tide Station	T	$\boxed{T}$
Searchlight	S	S
Illuminating Light	I	I
Post Telephone Switchboard	P.S.B.	$\boxtimes$

PART II.

BRIDGES.

87625—09——10

PART II—BRIDGES.

1. The **kind** of **bridge** to be built depends upon the *load*, the nature of the *obstacle*, and the *materials* available. Time is of prime importance in the construction of bridges for troops in campaign, and the proper distribution of men and material to do the work quickly must be made.

2. **Loads.**—Loads are classified as *dead* or stationary and *live* or moving. Generally speaking, the former is the weight of the bridge itself and the latter the weight of the traffic over it. Loads are usually stated in lbs. per sq. ft. for highway and per lin. ft. for military and railway bridges. Some loads of military bridges are as follows, all in lbs. per lin. ft.: Infantry, single file, 140; infantry, column of twos, 280; infantry, column of fours, 560; cavalry in single file, 196; cavalry in column of twos, 392. Infantry in heavy marching order average 200 lbs. per man; when unarmed, 160 lbs. When crowded in a mass they may weigh 133 lbs. per sq. ft. of standing room.

TABLE I.

3. Weights of guns and military carriages, fully loaded for traveling:

	Weight on the wheels.		Distance between axles, c. to c.	Width of wheel track, c. to c.
	Front.	Hind.		
	Lbs.	*Lbs.*	*Ft. Ins.*	*Ft.*
3.2-in. B. L. F. gun	1,735	2,070	8 7	5
3.6-in. B. L. F. gun	1,870	2,415	8 9	5
3.2-in. caisson	1,775	2,805	8 5¾	5
3.6-in. caisson	1,930	3,070	8 6	5
Battery and forge wagon	1,130	2,130	8 6	5
5-in. siege rifle	2,530	6,425	8 1¼	5
7-in. siege howitzer	2,510	6,920	8 1¼	5
Maxim automatic	1,950	1,230	7 0	5
Gatling	754	1,075	7 0	5
Army escort wagon (4 mules)	2,500	2,500	5 9½	5
Army wagon (6 mules)	3,500	3,500	6 1½	5

4. **Bridges for general road traffic.**—The *dead load* is the weight of the superstructure. Estimate quantities of the different materials and multiply by unit weights from the tables following.

The *live load* is *assumed* at 100 lbs. per sq. ft. of floor, or 5 tons concentrated on two axles 5 ft. long and 8 ft. c. to c.

Bridges for a special purpose exclusively may be proportioned for the corresponding load.

5. **Railroad bridges.**—The *dead load* is computed as before. To save time the floor, consisting of rails, ties, and guard timbers only, may be taken at 400 lbs. per lin. ft. of **track.**

The *live load* on *each* track, supposed to be moving in either direction, may be assumed at 6,000 lbs. per lin. ft. of track, or 50,000 lbs. on each of two pairs of driving wheels 7½ ft. c. to c.

6. **Site.**—Favorable conditions are narrowness of stream; stable banks of equal height; hard but penetrable bottom; moderate depth and current; permanent water level, and absence of navigation.

7. **Measurement of width** will be done directly by use of tape, wire, or line, if practicable. Boats or floats may be used to support a long line. Otherwise, by intersections (see Topographical reconnaissance).

8. **Strength of wooden beams.**—For crushing, tensile, and shearing strength, multiply the cross section in sq. ins. by the unit stresses in Table II. The result will be the ultimate tensile strength in lbs. This divided by the adopted factor of safety gives the safe tensile load in lbs. From this the crushing and shearing strengths are derived by applying the percentages given in the table.

For *transverse strength*.—Multiply breadth of cross section by sq. of depth; divide by ¾ of the length between supports, all in ins.; multiply by factor in column 2, Table II. The result will be the *breaking* load in lbs. applied uniformly, or *twice* the breaking load applied at *center* of span. The *safe* load is ¼ to ⅙ of the above, depending upon the importance of the structure, its temporary or permanent character, and the amount of vibration probably caused by the live load. The ratio of breaking load to maximum actual load is the *factor of safety*. It should be 4 to 6 as above.

The *breadth* of a rectangular cross section is the face to which a load is applied. The *depth* is the face at right angles to the breadth.

A round beam has $\frac{6}{10}$ the transverse strength of a square beam with breadth and depth equal to its middle diameter.

TABLE II.

9. **Constants of strength** and **weight** of a number of species of wood when dry; principal authority, Trautwine:

Species.	R.	Tensile str.	Wt. per cu. ft.
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs.*
Ash, American white	7,800	16,500	38
Ash, swamp	4,800		
Ash, black	7,200		47
Beech, American	10,200		43
Birch, American black	6,600	7,000	
Birch, American yellow	10,200	15,000	
Cedar, American white	3,000		
Chestnut	5,400	13,000	41
Elm, American white	7,800	6,000	36
Hemlock	6,000		25
Hickory	9,600	11,000	53
Locust	8,400	18,000	
Larch	4,800		32
Mahogany	9,000		35
Mangrove, white	7,800	10,000	
Mangrove, black	6,600		
Maple, soft	9,000	10,000	32
Maple, black	9,000	10,000	49
Oak, red	10,200	10,000	32–45
Oak, live	7,200	10,000	59.3
Oak, American white	7,200	10,000	48
Poplar	6,600	7,000	24
Spruce	5,400	10,000	
Pine, American white	5,400	7,000	25
Pine, American yellow	6,000	9,000	34
Pine, American pitch	6,600	9,000	45
Pine, American Georgia	10,200	12,000	65
Pine, long leaf	7,750		
Sycamore	6,000	12,000	37
Teak	9,000	15,000	61
Walnut	6,600	8,000	38
Willow	4,200		

The *crushing* strength may be taken at 40% of the tensile strength in the *direction* of the grain and 5% *across* the grain, except oak, which is 10% across the grain. The *shearing* strength may be taken at ⅔ of the *crushing* strength *across* the grain. These ratios are approximate only, but sufficiently exact for field designing.

10. A rapidly moving load produces about double the stress of an equal quiescent load. A concentrated moving load must be considered as applied at the point where the greatest strains are produced, usually midway between the supports.

11. A beam *safe* against breaking may *bend* too much under the desired load. The maximum allowable deflection in permanent structures is $\frac{1}{250}$ of the span. In military bridges for temporary use, and especially in bridges with floating supports, a greater deflection is permissible. The factor of safety will generally give enough stiffness.

12. **Safe loads.**—The formula is,

$$S = \frac{\frac{bd^2}{l} \times \frac{4\,R}{3}}{f.\,s.} \qquad \text{(A)}$$

in which

S = safe load in lbs., uniformly distributed.
b = breadth, d = depth, l = length — of beam, all in ins.
R = coefficient of resistance for the timber used, Table II, column 2.
$f.\,s.$ = factor of safety.

Or,

$$S = C \times b \times \frac{R_1}{R} \qquad \text{(B)}$$

in which

S = safe uniformly distributed load with factor of safety of 5, if timber is seasoned, or 4 if timber is green.
b = breadth of beam in ins.
C = coefficient from Table III, corresponding to length and depth of beam.
R = coefficient of resistance of long leaf pine, Table II, column 2.
R_1 = coefficient of resistance of timber used, Table II, column 2.

For *concentrated middle* load take *one-half* of S. The quantity bd^2 for any beam will be called its *index*. The ratio of strength of any beams is the ratio of their indexes.

13. **Examples.**—Determine the safe uniform load on a horizontal beam of long-leaf pine 3 ins. thick, 12 ins. deep, and 20 ft. clear span, factor of safety 5. From Formula (A), uniformly distributed safe load S equals $3 \times 12 \times 12 \div 240$, multiplied by $\frac{4}{3}$ of 7,750 divided by 5, equals 3,720 lbs. Safe center load = $3,720 \div 2 = 1,860$ lbs.

By Formula (B), uniform safe load S equals $1,240 \times 3 \times 7,750 \div 7,750 = 3,720$, as before. Or, for a different wood, as white oak, $S = 1,240 \times 3 \times 7,200 \div 7,750 = 3,469$.

If various sizes of materials are available, the *inverse problem* may be used to select the size which will give requisite strength with least weight. The *ratio* of *breadth* and *depth* must be assumed.

Example: Determine the size of beam to carry a safe load of 3,750 lbs., uniformly distributed over a clear span of 20 ft.; factor of safety, 5; breadth, ¼ of depth; material, yellow pine, seasoned.

From Formula (A),

$$3,750 = \frac{\frac{\frac{1}{4}\,d \times d^2}{240} \times 10,333}{5}$$

whence

$$d^3 = 1,728\,; \quad d = 12\,; \quad b = \tfrac{1}{4}\,d = 3.$$

The beam should be 3 by 12 ins.

TABLE III.

14. **Safe loads** in lbs. for **long-leaf pine beams, uniformly loaded,** and 1 in. in width; factor of safety 5; being values of *C* in Formula (B); authority, U. S. Dept. of Agriculture:

Length of beam.	Depth of beam in ins. (width equals 1 in.).								
	4.	5.	6.	8.	10.	12.	14.	16.	18.
Ft.									
4	689	1,076	1,550	------	------	------	------	------	------
5	551	861	1,240	------	------	------	------	------	------
6	459	718	1,033	1,837	------	------	------	------	------
7	394	615	885	1,574	2,460	------	------	------	------
8	344	538	775	1,376	2,150	3,100	------	------	------
9	306	478	688	1,224	1,914	2,755	------	------	------
10	276	431	620	1,101	1,720	2,480	3,370	------	------
11	251	391	562	1,000	1,564	2,253	3,068	4,010	------
12	230	359	517	917	1,434	2,067	2,812	3,673	4,650
13	212	331	477	847	1,322	1,906	2,595	3,390	4,285
14	197	308	442	787	1,230	1,770	2,408	3,145	3,980
15	184	287	413	733	1,147	1,653	2,250	2,940	3,720
16	172	269	386	688	1,074	1,550	2,109	2,753	3,485
17	162	253	364	647	1,013	1,459	1,984	2,590	3,280
18	153	239	343	612	956	1,379	1,878	2,450	3,100
19	145	227	327	580	905	1,305	1,777	2,320	2,933
20	138	215	310	550	860	1,240	1,689	2,206	2,790
21	131	205	296	525	820	1,181	1,609	2,100	2,656
22	126	196	281	500	783	1,129	1,536	2,005	2,535

15. The effect of seasoning is to increase the strength of timber. Green timber has about 20% less strength than that shown in the usual tables, and the factor of safety may be increased accordingly. Table III, used for green timber, gives the factor of safety 4 instead of 5, which will usually be sufficient.

TABLE IV.

16. **Working load** in lbs. of **pillars** of half-seasoned white or common yellow pine, firmly fixed and equally loaded; based on formula of C. Shaler Smith, C. E., with f. s. of 5:

Length.	Side of square pillar in inches.							
	3.	4.	5.	6.	7.	8.	10.	12.
Ft.								
5	3,461	8,419	15,865	25,711	37,867	52,237	87,420	130,896
6	2,903	6,970	13,670	22,846	34,437	48,333	82,860	125,885
7	2,176	5,789	11,740	20,182	31,095	44,403	78,000	120,413
8	1,766	4,838	10,100	17,784	27,969	40,614	73,040	114,653
9	1,456	4,083	8,725	15,682	25,108	37,018	68,180	108,749
10	1,217	3,478	7,565	13,846	22,520	33,677	63,460	102,845
12	880	2,589	5,845	10,894	18,336	27,878	54,680	91,382
14	664	1,987	4,530	8,705	15,387	23,155	46,960	80,720
16	518	1,565	3,625	7,063	12,221	19,366	40,400	71,136
18	425	1,264	2,945	5,825	10,182	16,333	34,900	62,726
20	372	1,034	2,445	4,867	8,560	13,914	30,260	55,382
22	--------	867	2,060	4,118	7,311	11,982	26,400	49,046
24	--------	736	1,750	3,521	6,361	10,355	23,380	43,574
26	--------	630	1,510	3,046	5,390	8,960	20,440	38,880
28	--------	--------	1,310	2,647	4,596	7,949	18,120	34,819
30	--------	--------	1,150	2,340	4,224	7,040	16,180	31,306
32	--------	--------	1,015	2,074	3,753	6,259	14,500	28,253
34	--------	--------	905	1,850	3,391	5,619	13,060	25,603
36	--------	--------	--------	1,656	3,009	5,094	11,620	23,270
38	--------	--------	--------	1,490	2,725	4,582	10,740	21,254
40	--------	--------	--------	1,354	2,470	4,160	9,780	19,469

When a wooden beam is to bear compression in the direction of the fibers, no matter whether vertical, horizontal, or inclined, its safe load is that given in this table.

The *factor* of *safety* of timber against *crushing* should be 6 to 8 for important structures, and 4 to 6 for temporary ones.

17. A horizontal beam should have a part of its length equal to its width firmly bearing on the support at each end, and more if possible. A pillar can not have a greater bearing surface than its end section. Crushing effect may be reduced by interposing a hard-wood plank or sheet of iron between the end of the beam and its support.

TABLE V.

18. **Properties of steel I beams;** authority, manufacturers' handbooks.

Depth of beam.	Weight per ft.	Area of section, min.	C = coeff. of strength; max. fiber strain of 12,500 per sq. in.	Depth of beam.
Ins.	*Lbs.*	*Sq. ins.*	*Lbs.*	*Ins.*
15	80.00	23.54	799,200	15
15	60.00	17.64	598,400	15
15	42.00	12.25	490,500	15
12	40.00	11.76	341,500	12
12	31.50	9.26	299,000	12
10	40.00	11.75	264,500	10
10	25.00	7.34	203,000	10
9	35.00	10.29	207,000	9
9	21.00	6.17	157,200	9
8	25.50	7.43	142,700	8
8	18.00	5.22	118,500	8
7	20.00	5.88	100,400	7
7	15.00	4.42	86,200	7
6	17.25	5.07	72,700	6
6	12.25	3.60	60,500	6
5	14.75	4.34	50,500	5
5	9.75	2.87	40,300	5
4	10.50	3.08	29,800	4
4	7.50	2.20	24,900	4
3	7.50	2.20	16,200	3
3	5.50	1.62	13,800	3

The coefficient of strength in column 4 is the safe load for a span of 1 ft., allowing an extreme fiber stress of 12,500 lbs. per sq. in. as is done in bridge work. For any other span l, divide C by l in ft. The quotient $W = \frac{C}{l}$, equals the safe load in lbs. uniformly distributed.

In long beams without lateral support, the safe load must be reduced as follows: For a span 30 times the width of flange, reduction of 10%; 40 times, 20%; 50 times, 30%; 60 times, 40%; 70 times, 50%.

TABLE VI.

19. **Properties of steel channels**; authority, manufacturers' handbooks:

Depth of channel.	Weight per ft.	Area of section.	C = coeff. for safe load; fiber stress of 12,500 lbs. per sq. in.
Ins.	*Lbs.*	*Sq. ins.*	*Lbs.*
15	55.00	16.17	482,100
15	33.00	9.69	345,800
12	40.00	4.76	273,500
12	20.50	6 02	177,900
10	35.00	10.29	193,200
10	15.00	4.41	111,500
9	25.00	7.35	130,800
9	13.25	8.89	87,600
8	21.25	6.25	100,000
8	11.25	3.31	67,300
7	19.75	5.79	78,800
7	9.75	2.85	50,200
6	15.50	4.56	54,500
6	8.00	2.35	36,100
5	11.50	3.38	34,800
5	6.50	1.91	24,600
4	7.25	2.13	19,000
4	5.25	1.54	15,600
3	6.00	1.76	11,400
3	4.00	1.18	8,900

The safe uniform load in lbs. is the quantity in last col. divided by the length of span in ft.

ADDENDUM, 1907.

TABLE VIA.

19*a*. **Properties of steel Z bars**; authority, manufacturers' handbooks.

Depth of Z bar.	Weight per ft.	Area of section.	C = coeff. for safe load; fiber stress of 12,000 lbs. per sq. in.
Ins.	*Lbs.*	*Sq. ins.*	*Lbs.*
6	15.0	4.59	67,500
6	22.7	6.68	92,400
6	29.3	8.63	112,300
5	11.6	3.40	42,700
5	17 8	5.25	61,400
5	23.7	6.96	75,800
4	8.2	2.41	25,100
4	13.8	4.05	38,600
4	18.9	5.55	48,400
3	6.7	1.97	15,400
3	9.7	2.86	20,600
3	12.5	3.69	24,500

TABLE VII.

20. **Dimensions** and **widths** of **angles** of equal legs:

Size.	Thickness.	Weight per ft.
Ins.	*In.*	*Lbs.*
6 x 6	3/8	14.8
6 1/4 x 6 1/4	15/16	35.9
5 x 5	3/8	12.3
5 1/4 x 5 1/4	15/16	29.4
4 x 4	5/16	8.2
4 1/4 x 4 1/4	3/4	18.6
3 1/2 x 3 1/2	5/16	7.1
3 5/8 x 3 5/8	5/8	13.7
3 x 3	1/2	8.6
2 3/4 x 2 3/4	1/4	4.5
2 1/2 x 2 1/2	3/16	3.1
2 5/8 x 2 5/8	1/2	7.8
2 1/4 x 2 1/4	3/16	2.7
2 7/16 x 2 7/16	3/8	5.4
2 x 2	3/16	2.5
2 3/16 x 2 3/16	3/8	4.8
1 3/4 x 1 3/4	3/16	2.1
1 15/16 x 1 15/16	3/8	4.1
1 1/2 x 1 1/2	1/8	1.2
1 3/4 x 1 3/4	3/8	3.5
1 1/4 x 1 1/4	1/8	1.0
1 3/8 x 1 3/8	1/4	2.0
1 1/8 x 1 1/8	1/4	1.5
1 x 1	1/8	0.8

21. Average ultimate tensile strength in lbs. per sq. in. of various metals:

Brass wire, unannealed or hard	80,000
Brass wire, annealed	63,000
Copper bolts	33,000
Copper wire, hard or unannealed	60,000
Copper wire, annealed	32,000
Cast iron, ordinary pig	14,500
Iron, wrought	45,000
Iron wire, annealed	45,000
Iron wire, unannealed or hard	75,000
Iron-wire rope, per sq. in. of section of rope	38,000
Phosphor-bronze wire, hard	150,000
Phosphor-bronze wire, annealed	63,000
Steel wire, soft	68,000
Steel wire, medium	76,000
Steel wire, hard	85,000
Steel, rivet	55,000
Steel, cast	60,000

FASTENING MATERIALS.

22. **Rope and wire.**—Much confusion is caused by two methods in common use to denote the size of rope. In marine use it is indicated by the circumference in ins.; on land the practice is not uniform, but the use of the diam. in ins. is prevalent. The former method is used by manufacturers and is correct as a matter of fact. The same rope is called 3-in. or 1-in. by the two systems. It is practically 3 ins. in circ., but only approximately 1 in. in diam. It is better to state which dimension is used.

The strength of hemp and jute rope varies; pieces from the same coil differ as much as 25%. Rope made from manila hemp is the best. Other hemp, sisal, and jute ropes are very unreliable in strength. Tarring rope increases its weight and lessens its strength, but adds to its durability. Use and exposure weaken rope 20% to 50% in a few months. Ropes shorten when wet and lengthen when dry.

TABLE VIII.

23. **Dimensions, weight,** and **strength** of **Manila rope:**

Diam.	Circ.	Weight in lbs. per 100 ft.	Breaking load.	Proper working load depending upon age and condition.
Ins.	*Ins.*		*Lbs.*	*Lbs.*
0.32	1	3.3	780	120—390
0.48	1½	7.4	1,600	250—800
0.64	2	13.2	2,730	350—1,300
0.80	2½	20.6	4,300	600—2,000
0.96	3	29.7	6,100	900—2,800
1.11	3½	40.4	8,500	1,100—4,000
1.27	4	52.8	11,600	1,500—5,000
1.43	4½	66.8	15,000	2,000—6,500
1.59	5	82.5	18,400	2,600—8,000
1.75	5½	99.8	22,000	3,000—10,000
1.91	6	119	25,500	3,500—11,500
2.07	6½	139	29,100	4,000—13,000
2.23	7	162	32,700	4,600—15,000
2.39	7½	186	36,300	5,000—16,000

Up to 5 ins. circ. rope is made in coils of 1,200 ft. each.

24. Ordinary *wire rope* is composed of 6 strands, each containing 7 or 19 wires, laid up about a hemp or wire strand center. Rope with hemp center is more flexible than that with a wire center. The 19-wire rope with hemp center is better adapted to power transmission; the 7-wire rope is used for standing rigging, as derrick guys and other purposes where frequent bending is not involved.

The *safe load* on wire ropes is from $\frac{1}{5}$ to $\frac{1}{7}$ of the breaking load.

TABLE IX.

25. **Dimensions, weight,** and **strength** of **hoisting rope,** hemp center, 6 strands, of 19 wires each:

Diam.	Circ.	Wt. per 100 ft.	Strength.				Circ. of new manila rope of equal strength.	
			Cast steel.		Iron.		To steel.	To iron.
			Brkg. load.	Wrkg. load.	Brkg. load.	Wrkg. load.		
Ins.	*Ins.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Ins.*	*Ins.*
3/8	1 1/4	23	9,000	1,750	5,000	750	3 3/4	2 3/4
1/2	1 1/2	39	15,000	3,000	6,960	1,250	4 1/2	3 1/4
5/8	2	60	28,000	5,000	10,260	2,500	6 1/2	4
3/4	2 3/8	88	36,000	7,000	17,280	3,500	7 1/2	5
7/8	2 3/4	120	50,000	10,000	23,000	5,000	9 1/2	5 1/2
1	3 1/8	158	66,000	12,000	32,000	6,000	11 1/2	7
1 1/4	4	250	104,000	20,000	54,000	11,000	--------	10
1 1/2	4 3/4	365	154,000	30,000	78,000	16,000	--------	13 1/2
1 3/4	5 1/2	525	212,000	42,000	108,000	22,000	--------	-------
2	6 1/4	630	250,000	50,000	130,000	26,000	--------	-------

TABLE X.

26. **Dimensions, weight,** and **strength** of **transmission or standing rope,** hemp center, 6 strands, of 7 wires each; authority, manufacturers' handbooks:

Diam.	Circ.	Wt. per 100 ft.	Strength.				Circ. of new manila rope of equal strength.	
			Cast steel.		Iron.		To steel.	To iron.
			Brkg. stress.	Wrkg. stress.	Brkg. stress.	Wrkg. stress.		
Ins.	*Ins.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Ins.*	*Ins.*
9/32	7/8	12	5,500	1,250	2,060	333	2 3/4	1 3/4
5/16	1	16	6,000	1,500	2,760	500	3	2
3/8	1 3/16	21	8,000	1,750	3,300	667	3 1/2	2 1/4
1/2	1 1/2	31	12,000	2,500	5,660	1,500	4	2 3/4
5/8	2	57	22,000	4,000	11,600	3,000	5 1/2	4
3/4	2 3/8	92	34,000	7,000	18,000	4,500	7 1/2	5
7/8	2 3/4	112	44,000	9,000	24,600	6,000	9	6
1	3 1/8	150	60,000	12,000	32,000	8,000	11	7
1 1/4	4	228	88,000	18,000	50,000	12,500	--------	9 1/2
1 1/2	4 3/4	337	124,000	26,000	72,000	18,000	--------	13

To preserve wire rope, cover it thoroughly with raw linseed oil, or a paint of equal parts of linseed oil and lampblack.

Galvanized-wire rope as commonly sold is a cheaper grade of rope, laid up in 6 strands of 7 or 12 wires each. Its breaking strength is slightly less than that of iron rope given in the table.

27. **Wire-rope fittings.**—There are two methods of making attachments to wire rope, by use of the *thimble*, figs. 1 and 2, and the *socket*, figs. 3, 4, 5, and 6. Cables are secured in three ways.

(*a*) Bend the rope around the thimble and fasten it with clips, fig. 1.

(*b*) Unlay the wire for a short distance at the end of the rope; bend the rope around the thimble; lay the straightened wires snugly about the main portion of the rope and serve with annealed wire, bending back the ends of the wires projecting beyond the wrappings, fig. 2.

(*c*) Interlock the strands in a splice and serve with wire (not illustrated).

Of these three methods the first is most used on engineering constructions; but is not adapted to field use, as a great many clips must be used for security, and they are heavy. The third method requires an expert rigger who may not be available. The second method will be found more generally useful. In emergencies where the value of the rope is negligible, wire rope of 1½ ins. diameter, or less, can be knotted very much like manila rope. The part used for such fastenings can not be used again.

Sockets are used for ropes too large to be bent around a thimble. For smaller rope they present a neat appearance and are convenient to handle. The end of the rope is passed through the neck of the socket; and the wires are then opened out for a distance at the ends equal to about twice the length of the neck, the rope having first been served at the point to which the unlaying extends, fig. 5. Some of the wires are trimmed off to shorter length, and all of them bent back upon themselves hook fashion, so that the resulting bunch will conform as nearly as possible to the conical shape of the socket, fig. 5. The bunch is then drawn back into the socket, a conical plug driven into the center spreading out the wires tightly against the sides of the socket, and the whole cemented with Babbitt metal or solder, fig. 6. For ropes made with large stiff wire, the ends are simply straightened out and the interstices filled with narrow tapering pins or wedges. Socket fastenings can not be securely made in the field and should not be relied upon without testing Their weight is also an objection for field use.

28. **Wire.**—Is put up in coils of 80 to 100 lbs. each. *Galvanized* wire is coated with zinc, which retards oxidation, but is in every other respect objectionable. It increases weight, while reducing strength. Wire not galvanized is known commercially as *black*.

An important distinction is between annealed and unannealed wire, also known as *hard* and *soft*. The advantages of annealing are increase in flexibility and ductility. The disadvantage is a decrease of 20 to 25% in strength. Unannealed wire is very difficult to handle, and if allowed to kink, all the advantage of strength, and more, too, is lost. For general indeterminate use, annealed wire is best.

TABLE XI.

29. **Size, weight, and strength** of black charcoal **iron wire**; authority, Trenton Iron Company; the sizes of corresponding numbers are those of the Trenton Iron Company, and are almost identical with the "new British W. gauge":

No.	Diam.	Lin. ft. to the lb.	Approximate tensile strength.
	In.		*Lbs.*
6	0.1900	10.453	2,476
7	0.1750	12.322	2,136
8	0.1600	14.736	1,813
9	0.1450	17.950	1,507
10	0.1300	22.333	1,233
11	0.1175	27.340	1,010
12	0.1050	34.219	810

If the quality of the wire is not known, the t. s. in the table should be reduced 15%. For soft Bessemer steel wire, they may be increased 10%.

Wire should always be taken from the *outside* of the coil, by placing the coil on an axle or rod and walking away with the end, or by holding the outer end and rolling the coil along the ground.

30. **Chains** are designated by the diameter of the rod from which the links are made, as ½ in., 1 in., etc.

Also by the form of the link, as *close link*, in which one link is just large enough to inclose the two adjacent ones, fig. 8; *open link*, in which the link is larger than in close link, fig. 7; *bar chain*, which consists of open links with a bar across the middle of each; and *twisted link*, fig. 9, in which each link is twisted through a certain angle, usually 90°, and *straight* or *flat link*, figs. 7 and 8, which is not so twisted.

Chain is also *galvanized* or *black*, the latter most used.

TABLE XII.

31. **Size, weight,** and **strength** of iron **chains;** authority, Trantwine; strength taken at 1.4 that of the rod of which the links are made.

Size of chain.	*Wt. per ft.	Breaking strain.	Size of chain.	*Wt. per ft.	Breaking strain.
In.	*Lbs.*	*Lbs.*	*Ins.*	*Lbs.*	*Lbs.*
¼	0.8	3,069	⅞	8.0	37,632
⅜	1.7	6,922	1	10.7	49,280
½	2.5	12,320	1⅛	12.5	59.226
⅝	4.3	19,219	1¼	16.0	73,114
¾	5.8	27,687	1½	21.7	105,280

*Weights given are for close link. Open link will weigh less.

32. **Serving.**—On wire or manila rope and with wire or marlin, serving is best done as indicated in fig. 17. Provide a bar, *A*, 18 ins. to 24 ins. long, smooth and rounded, with cross pins *bb* near one end, the outer one removable, to form a reel for the coil of serving wire *C*.

Lay the free end of the wire along the rope from the point *B*, where the serving is to end, to the point *C*, where it is to begin; make a short bend at the latter and pass the wire twice around the rope over the straight part, half around the bar, around the rope in the opposite direction, and place the coil between the pins, as shown. Rotate the bar around the rope, keeping the following turns close together and the leading turn as taut as may be necessary to get the proper tension. When the following turn has reached *B*, cut off the wire and twist its end with the end of the straight wire, coming out from under the turns.

33. *Driftbolts*, *spikes*, *nails*, and wooden *pins* or *treenails* are used for fastening together parts of wooden frames or structures. For driftbolts and treenails, a hole is first bored of slightly less diameter than the bolt or pin. Fastenings of this sort depend upon friction to hold together the parts that are joined. Design joints to avoid as far as possible a heavy shearing stress on the fastenings.

Driftbolts are iron bars of square or circular cross section, headed more or less at one end and bluntly pointed at the other. The head is often omitted, as a small one is made in driving. All bolts, spikes, and nails should be of such length that when driven the point will rest in solid wood.

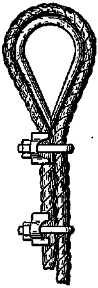


Fig.1

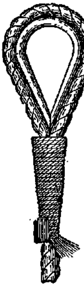


Fig.2

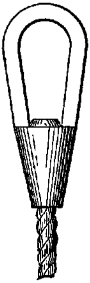


Fig.3

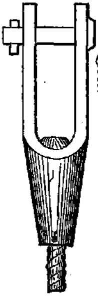


Fig.4


Fig.5

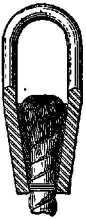


Fig.6


Fig.7


Fig.8


Fig.9

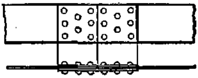


Fig.10

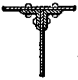


Fig.11

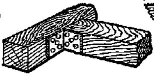


Fig.12

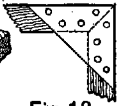


Fig.13

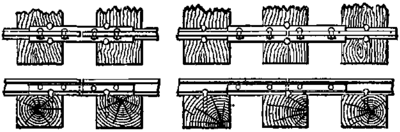


Fig.14


Fig.15

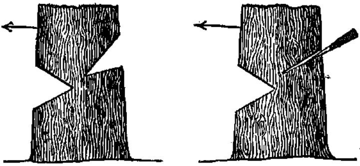


Fig.16

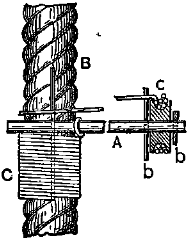


Fig.17

TABLE XIII.

34. **Dimensions** and **weights** of **driftbolts:**

Length.	Square section, side.		Round section, diam.	
	¾ in.	1 in.	¾ in.	1 in.
Ins.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
18	2.9	5.1	2.3	4.0
20	3.2	5.7	2.5	4.4
22	3.5	6.2	2.8	4.9
24	3.8	6.8	3.0	5.4
26	4.1	7.3	3.3	5.8

35. Wood joints may also be secured with screw bolts or lag screws.

Screw bolts are of round iron with square heads forged at one end and standard screw threads cut on the other. Nuts should be square, with a thickness equal to the diam. of the bolt and a side equal to twice the diam. Cast-iron washers should be placed under the nut, and under the head also if the timber is soft.

Lag screws are large gimlet-pointed wood screws with sq. heads to be turned with a wrench instead of a screw-driver. The timber next to the head should be bored the full size of the shank; the rest of the hole should be smaller, and its total length somewhat less than that of the screw. Wrought-iron washers should be placed under the head.

TABLE XIV.

36. **Dimensions** and approximate **weights** of **screw bolts** in pounds, including sq. head and nut:

Length under head.	Diameter.				
	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.
Ins.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
6	0.59	1.01	----------	----------	----------
7	0.64	1.10	----------	----------	----------
8	0.70	1.19	----------	----------	----------
9	0.75	1.27	----------	----------	----------
10	0.81	1.36	2.10	3.05	4.23
11	0.86	1.44	2.22	3.22	4.45
12	0.92	1.53	2.35	3.39	4.67
13	0.97	1.62	2.47	3.55	4.89
14	1.03	1.70	2.59	3.72	5.11
15	1.08	1.79	2.72	3.89	5.34
16	----------	1.87	2.84	4.06	5.56
17	----------	1.96	2.97	4.23	5.78
18	----------	2.05	3.09	4.40	6.00
19	----------	----------	3.21	4.57	6.22
20	----------	----------	3.34	4.74	6.44
21	----------	----------	3.46	4.90	6.66
22	----------	----------	3.59	5.07	6.88
23	----------	----------	3.71	5.24	7.10
24	----------	----------	3.83	5.41	7.32

TABLE XV.

37. **Dimensions** and **weights** of wrought-iron **washers:**

Diam. of lag screw.	Diam. of washer.	Diam. of hole.	Thickness, wire gauge.	No. in 150 lbs.	Weight of one.
In.	*Ins.*	*In.*			*Lb.*
½	1⅜	$\frac{9}{16}$	No. 12	4,500	0.0333
⅝	1¾	$\frac{11}{16}$	No. 10	2,500	0.0600
¾	2	$\frac{13}{16}$	No. 10	1,600	0.0938

TABLE XVI.

38. **Dimensions** of **steel-wire nails** and approximate **number** per **pound**, etc.:

Sizes.	Common. Diam. B. W. G.	Common. Diam. In.	Number per pound. Common.	Fencing.	Box.	Flooring.	Shingle.	Length.
								Ins.
2*d*.	15	0.072	900	------	1,000	------	------	1
3*d*.	14	0.083	615	------	660	------	380	1¼
4*d*.	12½	0.102	322	------	550	------	256	1½
5*d*.	12½	0.102	250	127	366	------	226	1¾
6*d*.	11½	0.115	200	114	250	151	200	2
7*d*.	11½	0.115	154	88	236	136	130	2¼
8*d*.	10¼	0.124	106	74	157	98	120	2½
9*d*.	10¼	0.124	85	58	145	86	115	2¾
10*d*.	9	0.148	74	42	107	66	79	3
12*d*.	9	0.148	57	36	98	51	------	3¼
16*d*.	8	0.165	46	28	65	40	------	3½
20*d*.	6	0.203	29	22	45	29	------	4
30*d*.	5	0.220	23	------	40	------	------	4½
40*d*.	4	0.238	17	------	30	------	------	5
50*d*.	3	0.259	13½	------	------	------	------	5½
60*d*.	2	0.284	10½	------	------	------	------	6

TABLE XVII.

39. **Dimensions** of miscellaneous **steel-wire nails** and approximate **number** per **pound.**

B. W. G.	Diam.	Lengths, inches.															
		2.	2¼.	2½.	2¾.	3.	3½.	4.	4½.	5.	6.	7.	8.	9.	10.	11.	12.
	In.																
00	0.380	20	18	16	15	14	12	10	9	8	7	6	5	4	4	3	3
3/8	0.375	20	18	16	15	14	12	10	9	8	7	6	5	4	4	3	3
0	0.340	21	19	17	16	15	13	11	10	9	8	7	5	5	4	4	3
5/16	0.313	28	25	23	21	19	16	14	13	11	10	8	7	6	6	5	4
2	0.284	32	29	26	24	22	19	16	14	13	11	9	8	7	6	6	5
3	0.259	38	34	30	28	25	22	19	17	15	13	11	10	8	7	---	---
4	0.238	45	40	36	33	30	26	23	20	18	15	13	11	10	9	---	---
5	0.220	53	47	42	39	35	30	26	24	21	18	15	---	---	---	---	---
6	0.203	62	55	50	45	41	35	31	28	25	21	18	---	---	---	---	---
7	0.180	75	67	60	54	50	43	37	33	30	25	---	---	---	---	---	---
8	0.165	86	76	69	62	57	49	43	39	35	29	---	---	---	---	---	---
9	0.148	103	92	82	75	69	59	52	46	41	---	---	---	---	---	---	---
10	0.134	124	110	99	90	83	71	62	55	50	---	---	---	---	---	---	---
11	0.120	157	139	125	114	105	90	79	70	---	---	---	---	---	---	---	---
12	0.109	204	182	164	149	137	117	103	---	---	---	---	---	---	---	---	---
13	0.095	268	238	214	195	178	153	---	---	---	---	---	---	---	---	---	---
14	0.083	350	315	284	258	236	---	---	---	---	---	---	---	---	---	---	---
15	0.072	438	389	350	---	---	---	---	---	---	---	---	---	---	---	---	---

TABLE XVIII.

40. **Dimensions** of sq. **boat spikes** and approximate **number** in a **keg** of 200 lbs.:

Size.	Length of spike, inches.											
	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	14.	16.
In.												
1/4	3,000	2,375	2,050	1,825	---	---	---	---	---	---	---	---
5/16	1,660	1,360	1,230	1,175	990	880	---	---	---	---	---	---
3/8	1,320	1,140	940	800	650	600	525	475	---	---	---	---
7/16	---	---	---	600	590	510	440	360	320	218	---	---
1/2	---	---	---	450	375	335	300	275	260	240	---	---
5/8	---	---	---	---	---	260	240	220	205	190	175	160

TABLE XIX.

41. **Dimensions** of **railroad spikes:**

Size measured under head.	Average number per keg 200 lbs.	Quantity of spikes per mile of single track. Ties 2 ft. c. to c., 4 spikes per tie.		Rail used, weight per yard.
Ins.		*Lbs.*	*Kgs.*	*Lbs.*
$5\frac{1}{2}$ x $\frac{5}{8}$	300	7,040	$35\frac{1}{3}$	75—100
$5\frac{1}{2}$ x $\frac{9}{16}$	375	5,870	$29\frac{1}{3}$	45— 75
5 x $\frac{9}{16}$	400	5,170	26	40— 56
5 x $\frac{1}{2}$	450	4,660	$23\frac{1}{3}$	35— 40
$4\frac{1}{2}$ x $\frac{1}{2}$	530	3,960	20	30— 35
4 x $\frac{1}{2}$	600	3,520	$17\frac{2}{3}$	25— 35
$4\frac{1}{2}$ x $\frac{7}{16}$	680	3,110	$15\frac{1}{2}$	20— 30
4 x $\frac{7}{16}$	720	2,910	$14\frac{3}{4}$	20— 30
$3\frac{1}{2}$ x $\frac{7}{16}$	900	2,350	11	16— 25
4 x $\frac{3}{8}$	1,000	2,090	$10\frac{1}{2}$	16— 25
$3\frac{1}{2}$ x $\frac{3}{8}$	1,190	1,780	9	16— 20
3 x $\frac{3}{8}$	1,240	1,710	$8\frac{1}{2}$	16— 20
$2\frac{1}{2}$ x $\frac{3}{8}$	1,342	1,575	$7\frac{7}{8}$	8— 16

42. **Joints in metal** are made with screw bolts already described, or with rivets. With bolts the holes should come fair when the pieces are assembled and the bolt should fit snugly in the hole; abutting surfaces should be well painted before assembling to exclude moisture. In riveted joints it is equally important that the holes come fair, but the rivet should fit loosely in the hole. Bolted joints are much more conveniently made, especially in the field, but they have less strength than the riveted ones.

Joints in metal are most frequently made by the use of auxiliary pieces such as *butt straps*, *angle plates*, *gusset plates*, *angle irons*, etc. Some common forms are shown in figs. 10 to 15.

43. **Felling trees.**—If convenient, arrange for the tree to fall in the direction of its natural inclination. If it be necessary to fell in another direction, use ropes to pull the tree partly over before the cutting is finished. Commence cutting with the axe on the side toward which the tree is to fall; cut as far as the center of the tree or a little beyond, as in fig. 16; then change to the opposite side and commence cutting slightly above the former cut, continuing until the tree falls. If experienced axmen be lacking, better results can be obtained with crosscut saws. Cut from the falling side until the saw begins to jamb, then cut from the other side until the tree falls. Both saw and ax may be used.

44. **Framing.**—The following methods are applicable to joining the sills and caps to the posts of wooden trestles:

By *driftbolts*, fig. 33, two through the foot of each post into the sill, and one through the cap into the post.

By using *split caps* and *sills*, figs. 31 and 32. Instead of a single stick of timber, two pieces of half the width are used. For example, a 12 by 12 in. cap or sill is replaced by two 6 by 12 in. sticks. A tenon 3 to 6 in. thick and the full width of the post is made on its top. One of the cap or sill pieces is placed on each side of the tenon and held in place by bolts at each post.

By *fish plates* and *bolts*, as in fig. 37.

Figs. 18 to 30 show various useful forms of joints.

KNOTS.

45. The following knots are most useful in bridging:

Overhand knot, fig. 38*a*, used at the end of a rope to prevent unreeving or to prevent the end of the rope from slipping through a block.

Figure-of-eight knot, fig. 38*b*, used for purposes similar to above.

Square or *reef knot*, fig. 38, commonly used for joining two ropes of the same size. The standing and running parts of each rope must pass through the loop of the other in the same direction, i. e., from above downward or vice versa; otherwise a *granny*, fig. 39, is made, which is a useless knot that will not hold. The reef knot can be upset by taking one end of the rope and its standing part and pulling them in opposite directions. With dry rope a reef knot is as strong as the rope; with wet rope it slips before the rope breaks, while a double sheet bend is found to hold.

The *thief knot*, fig. 40, commonly mistaken for a reef knot, should be avoided as it will not hold. The figure shows that the end of each rope turns around the standing part instead of around the end of the other, as in a reef knot.

Single sheet bend, *weaver's knot*, fig. 41, used for joining ropes together, especially when unequal in size. It is more secure than the reef knot but more difficult to untie.

Double sheet bend, fig. 42, used also for fastening ropes of unequal sizes, especially wet ones, and is more secure than the single sheet bend.

Two half hitches, fig. 43, especially useful for belaying, or making fast the end of a rope round its own standing part. The end may be lashed down or seized to the standing part with a piece of spun yarn; this adds to its security and prevents slipping.

This knot should never be used for hoisting a spar.

Round turn and *two half hitches*, fig. 44, like the preceding except that a turn is first taken round the spar or post.

Fisherman's bend or *anchor knot*, fig. 45, used for fastening a rope to a ring or anchor. Take two turns round the iron, then a half hitch round the standing part and between the rings and the turns, lastly a half hitch round the standing part.

Clove hitch, fig. 46, generally used for fastening a rope at right angles to a spar or at the commencement of a lashing. If the end of the spar is free, the hitch is made by first forming two loops, as in fig. 47, placing the right-hand loop over the other one and slipping the double loop (fig. 48) over the end of the spar. If this can not be done, pass the end of the rope round the spar, bring it up to the right of the standing part, cross over the latter, make another turn round the spar, and bring up the end between the spar, the last turn, and the standing part, fig. 49. When used for securing guys to sheer legs, etc., the knot should be made with a long end, which is formed into two half hitches round the standing part and secured to it with spun yarn.

Timber hitch, fig. 50, used for hauling and lifting spars. It can easily be loosed when the strain is taken off, but will not slip under a pull. When used for hauling spars, a half hitch is added near the end of the spar, fig. 51.

Telegraph hitch, fig. 52, used for hoisting or hauling a spar.

Hawser bend, fig. 53, used for joining two large cables. Each end is seized to its own standing part.

Bowline, fig. 54, forms a loop that will not slip. Make loop with the standing part of the rope underneath, pass the end from below through the loop, over the part round the standing part of the rope, and then down through the loop *c*. The length of bight depends upon the purpose for which the knot is required.

Bowline on a bight, fig. 55. The first part is made like the above, with the double part of a rope; then the bight *a* is pulled through sufficiently to allow it to be bent past *d* and come up in the position shown. It makes a more comfortable sling for a man than a single bight.

Running bowline, fig. 56.

To sling a barrel or box horizontally, fig. 57, make a bowline with a long bight and apply it as shown.

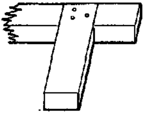


Fig. 18.

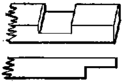


Fig. 19.

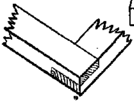


Fig. 20.

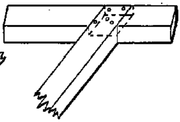


Fig. 21.

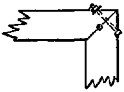


Fig. 22.

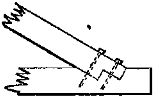


Fig. 23.

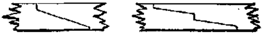


Fig. 24.

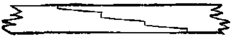


Fig. 25.

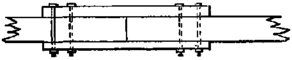


Fig. 26.

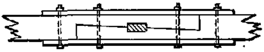


Fig. 27.

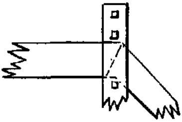


Fig. 28.

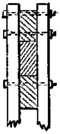


Fig. 29.

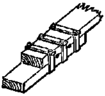


Fig. 30.

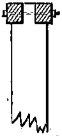


Fig. 31.

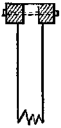


Fig. 32.

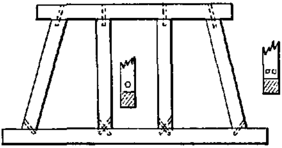


Fig. 33.

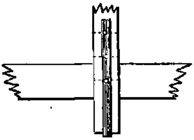


Fig. 34.

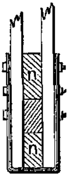


Fig. 35.

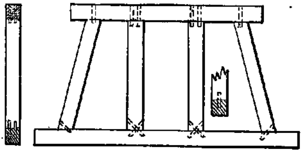


Fig. 36.

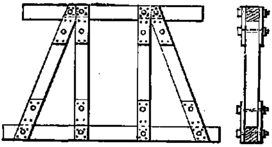


Fig. 37.

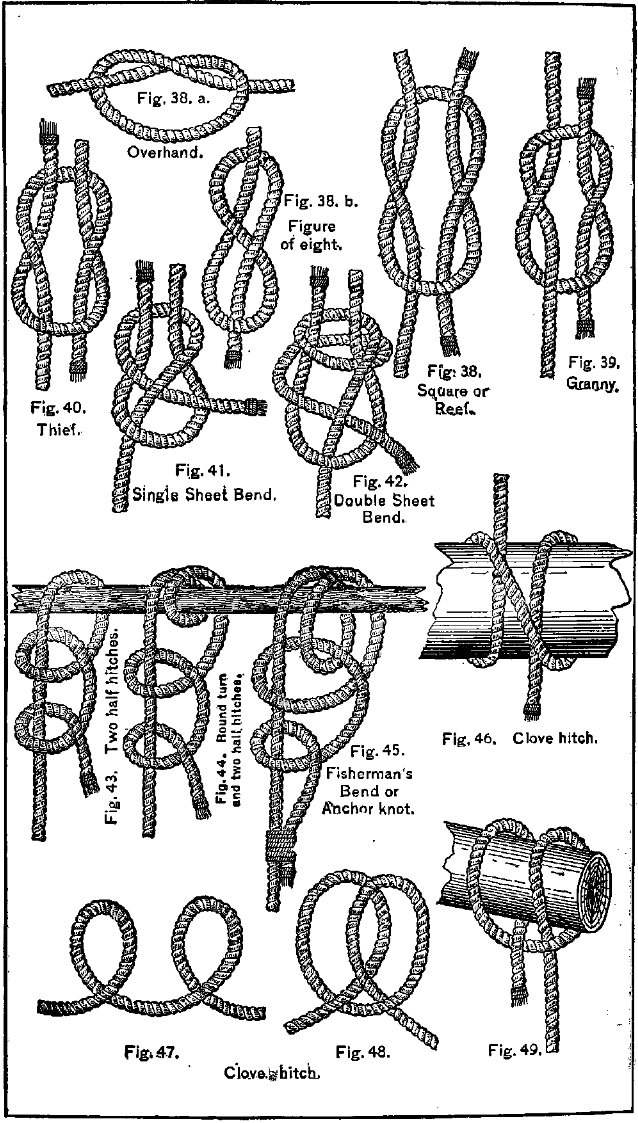


Fig. 38. a.
Overhand.
Fig. 38. b.
Figure of eight.
Fig. 38.
Square or Reef.
Fig. 39.
Granny.
Fig. 40.
Thief.
Fig. 41.
Single Sheet Bend.
Fig. 42.
Double Sheet Bend.
Fig. 43. Two half hitches.
Fig. 44. Round turn and two half hitches.
Fig. 45.
Fisherman's Bend or Anchor knot.
Fig. 46. Clove hitch.
Fig. 47.
Fig. 48.
Fig. 49.
Clove hitch.

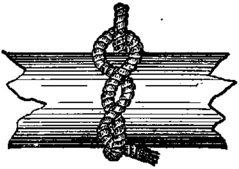


Fig. 50. Timber hitch.

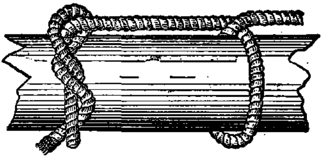


Fig. 51. Timber hitch and Half hitch.

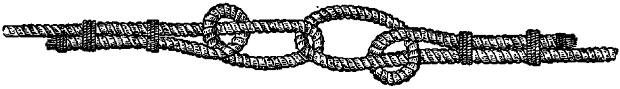


Fig. 53. Hawser Bend.

Fig. 52. Telegraph hitch.

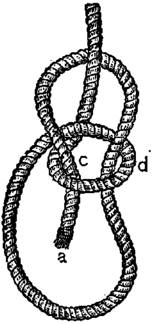


Fig. 54. Bowline.

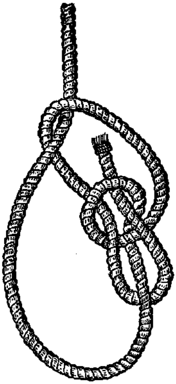


Fig. 56. Running Bowline.

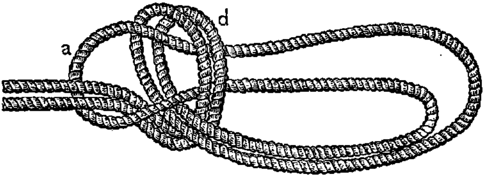


Fig. 55. Bowline on a Bight.

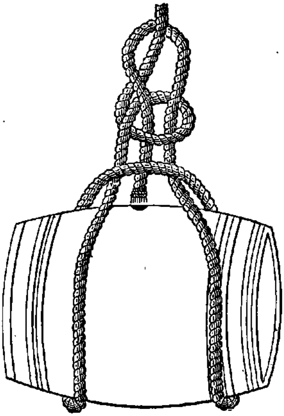


Fig. 57. Sling for barrel horizontal.

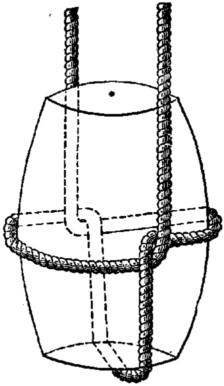


Fig. 58. Sling for barrel vertical.

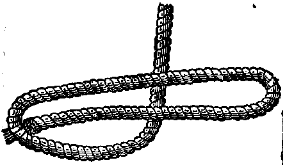


Fig. 59. Cat's Paw. a.

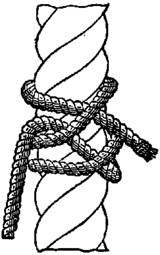


Fig. 62. Rolling Hitch.

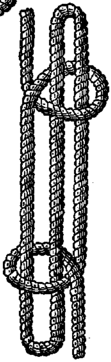


Fig. 61. Sheepshank.

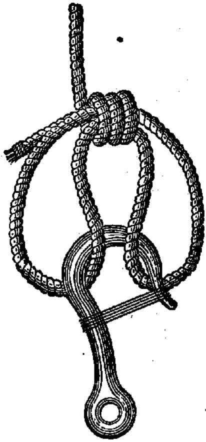


Fig. 60. Cat's Paw. *b*.

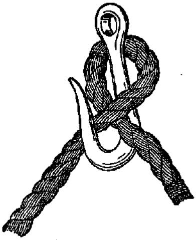


Fig. 63. Blackwall Hitch.

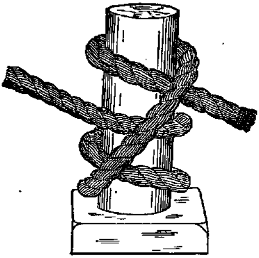


Fig. 64. Mooring Knot.

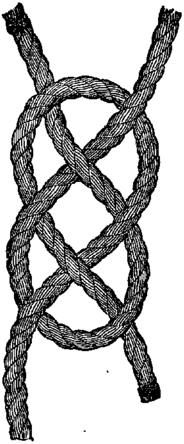


Fig. 65.
Carrick Bend.

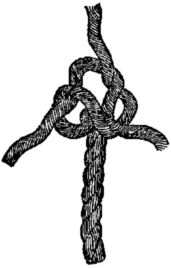


Fig. 66. Wall Knot.

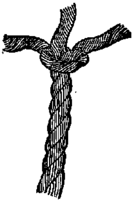


Fig. 67. Wall Knot.

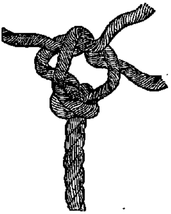


Fig. 68.

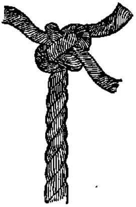


Fig. 69.

Crown on Wall.

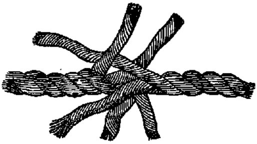


Fig. 70. Short Splice.

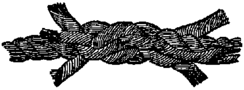


Fig. 71. Short Splice.

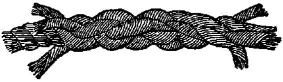


Fig. 72. Short Splice.

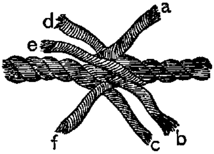


Fig. 73. Long Splice.

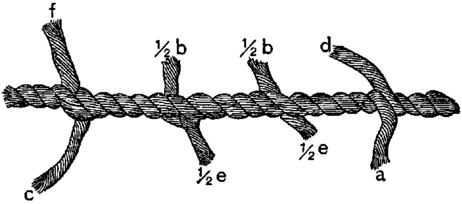


Fig. 74. Long Splice.

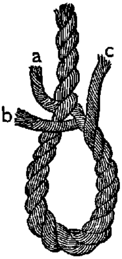


Fig. 75.

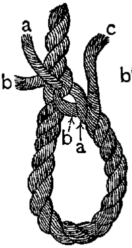


Fig. 75a.

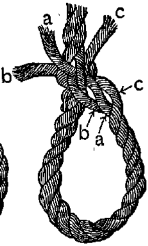


Fig. 76.

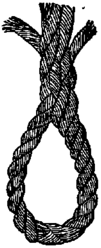


Fig. 76a.

To sling a barrel vertically, fig. 58, make an overhand knot on top of the two parts of the rope; open out the knot and slip each half of it down the sides of the cask; secure with a bowline.

Cat's-paw, figs. 59 and 60. Form two equal bights, as in fig. 59; take one in each hand and roll them along the standing part till surrounded by three turns of the standing part; then bring both loops (or bights) together and pass over the hook of a block, as in fig. 60, where the hook is shown moused with yarn.

Sheep shank, fig. 61, used for shortening a rope or to pass by a weak spot; a half hitch is taken with the standing parts around the bights.

Rolling hitch, fig. 62, used for hauling a larger rope or cable. Two turns are taken round the large rope in the direction in which it is to be hauled and one half hitch on the other side of the hauling part. A useful knot and quickly made.

For armored cable, or wet manila rope, the hitch must be made with a strap of rope yarn, fig. 86. Rope will not hold.

Blackwall hitch, fig. 63, used for attaching a single rope to a hook of a block for hoisting.

Mooring knot, fig. 64. Take two turns round the mooring or snubbing post, pass the free end of the rope under the standing part; take a third turn above the other and pass the free end between the two upper turns.

Carrick bend, fig. 65, much used for hawsers and to fasten guys to derricks.

Wall knot, figs. 66 and 67, and

Crown on wall, figs. 68 and 69; both used for finishing off the ends of ropes to prevent unstranding.

To make a *short splice*, figs. 70, 71, and 72, unlay the strands of each rope for a convenient length. Bring the rope ends together so that each strand of one rope lies between the two consecutive strands of the other rope. Draw the strands of the first rope along the second and grasp with one hand. Then work a free strand of the second rope over the nearest strand of the first rope and under the second strand, working in a direction opposite to the twist of the rope. The same operation applied to all the strands will give the result shown by fig. 71. The splicing may be continued in the same manner to any extent (fig. 72) and the free ends of the strands may be cut off when desired. The splice may be neatly tapered by cutting out a few fibers from each strand each time it is passed through the rope. Rolling under a board or the foot will make the splice compact.

Long splice (figs. 73, 74).—Unlay the strands of each rope for a convenient length and bring together as for a short splice. Unlay to any desired length a strand, *d*, of one rope, laying in its place the nearest strand, *a*, of the other rope. Repeat the operation in the opposite direction with two other strands, *c* and *f*. Fig. 74 shows strands *c* and *f* secured by tying together. Strands *b* and *e* are shown secured by unlaying half of each for a suitable length and laying half of the other in place of the unlayed portions, the loose ends being passed through the rope. This splice is used when the rope is to run through a block. The diameter of the rope is not enlarged at the splice. The ends of the strands should not be trimmed off close until the splice has been thoroughly stretched by work.

Eye splice (figs. 75, 75*a*, 76, 76*a*).—Unlay a convenient length of rope. Pass one loose strand, *a*, under one strand of the rope, as shown in fig. 75, forming an eye of the proper size. Pass a second loose strand, *b*, under the strand of the rope next to the strand which secures *a*, fig. 75*a*. Pass the third strand, *c*, under the strand next to that which secures *b*, fig. 76. Draw all taut and continue and complete as for a short splice.

LASHINGS.

46. *To lash a transom to an upright spar*, fig. 77, transom in front of upright.—A clove hitch is made round the upright a few inches below the transom. The lashing is brought under the transom, up in front of it, horizontally behind the upright, down in front of the transom, and back behind the upright at the level of the bottom of the transom and above the clove hitch. The following turns are kept outside the previous ones on one spar and inside on the other, not riding over the turns already made. Four turns or more are required. A couple of frapping turns are then taken between the spars, around the lashing, and the lashing is finished off either round

one of the spars or any part of the lashing through which the rope can be passed. The final clove hitch should never be made around the spar on the side toward which the stress is to come, as it may jam and be difficult to remove. The lashing must be well beaten with handspike or pick handle to tighten it up. This is called a square lashing.

47. *Lashing for a pair of shears*, fig. 78.—The two spars for the shears are laid alongside of each other with their butts on the ground, the points below where the lashing is to be resting on a skid. A clove hitch is made round one spar and the lashing taken loosely eight or nine times about the two spars above it without riding. A couple of frapping turns are then taken between the spars and the lashing is finished off with a clove hitch above the turns on one of the spars. The butts of the spars are then opened out and a sling passed over the fork, to which the block is hooked or lashed, and fore and back guys are made fast with clove hitches to the bottom and top spars, respectively, just above the fork, fig. 79.

48. *To lash three spars together as for a gin or tripod.*—Mark on each spar the distance from the butt to the center of the lashing. Lay two of the spars parallel to each other with an interval a little greater than the diameter. Rest their tips on a skid and lay the third spar between them with its butt in the opposite direction so that the marks on the three spars will be in line. Make a clove hitch on one of the outer spars below the lashing and take eight or nine loose turns around the three, as shown in fig. 80. Take a couple of frapping turns between each pair of spars in succession and finish with a clove hitch on the central spar above the lashing. Pass a sling over the lashing and the tripod is ready for raising.

49. **Holdfasts.**—To prepare a fastening in the ground for the attachment of guys or purchases, stout pickets are driven into the ground one behind the other, in the line of pull. The head of each picket except the last is secured by a lashing to the foot of the picket next behind, fig. 81. The lashings are tightened by rack sticks, the points of which are driven into the ground to hold them in position. The distance between the stakes should be several times the height of the stake above the gronnd.

Another form requiring more labor but having much greater strength is called a "*deadman*," and consists of a log laid in a transverse trench with an inclined trench intersecting it at its middle point. The cable is passed down the inclined trench, takes several round turns on the log, and is fastened to it by half hitches and marlin stopping, figs. 82, 83, and 84. If the cable is to lead horizontally or inclined downward, it should pass over a log at the outlet of the inclined trench, fig. 83. If the cable is to lead upward, this log is not necessary, but the anchor log must be buried deeper.

BLOCKS AND TACKLES.

50. The parts of a block are the *shell* or *frame*, the *sheave* or *wheel* upon which the rope runs, and the *pin* npon which the wheel turns in the shell. A *strap* of iron or rope passes around the shell and forms attachments for a *hook* at one end and an *eye* at the other; see figs. 85, 86, 87, and 88.

Blocks are also made entirely of metal, in which the strap is replaced by bolts, fig. 89.

Blocks are designated by the length of the shell in inches and by the number of their sheaves. Those with one, two, three, and four sheaves are called *single*, *double*, *triple*, and *quadruple*. The largest rope a wooden block will take has a circumference equal to one-third the length of the shell. Self-lubricating blocks may be obtained and are to be preferred.

A *snatch block* is a single block with the shell and strap open at one side to admit a rope without passing the end through, fig. 90.

A *running block* is attached to the object to be moved; a *standing block* is fixed to some permanent support, figs. 94, 95, and 96. A *simple tackle* consists of one or more blocks rove with a single rope or fall. The end of the fall fixed in the tackle is called the standing end; the other is the running end. Each part of the fall between the two blocks, or between either end and the block, is called a *return*.

To *overhaul* is to separate the blocks; to *round in*, to bring them closer together. When the blocks are in contact the fall is said to be *chockablock*.

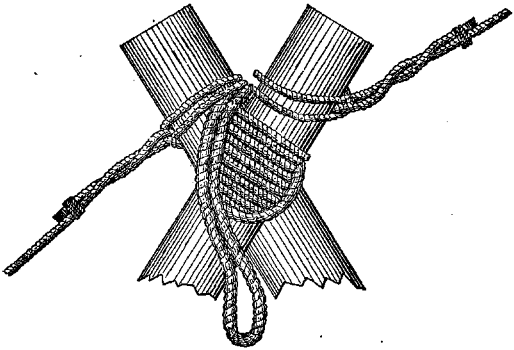


Fig. 79

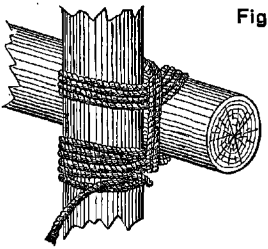


Fig. 77

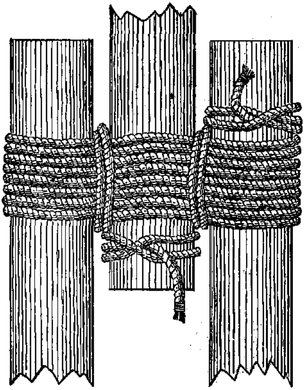


Fig. 80

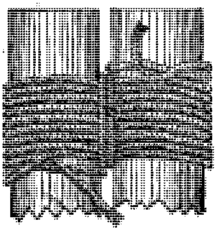


Fig. 78

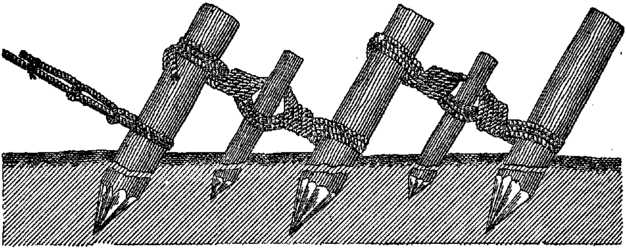


Fig. 81

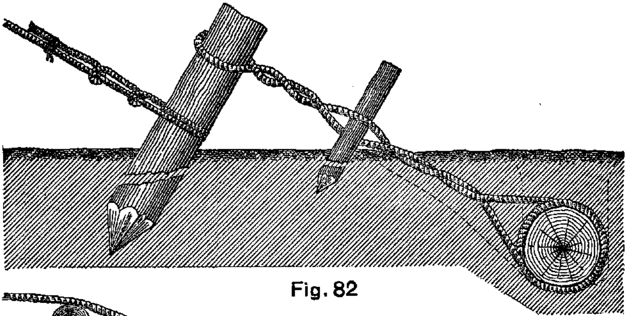


Fig. 82

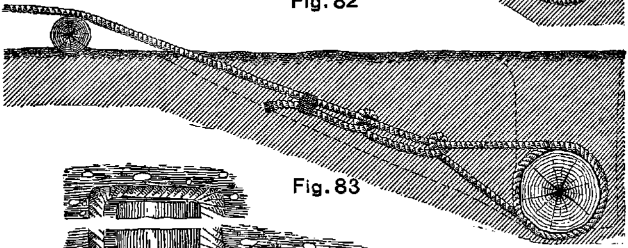


Fig. 83

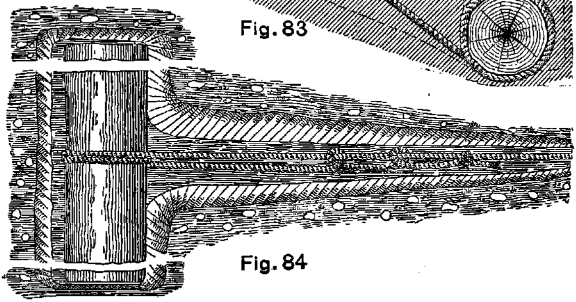


Fig. 84

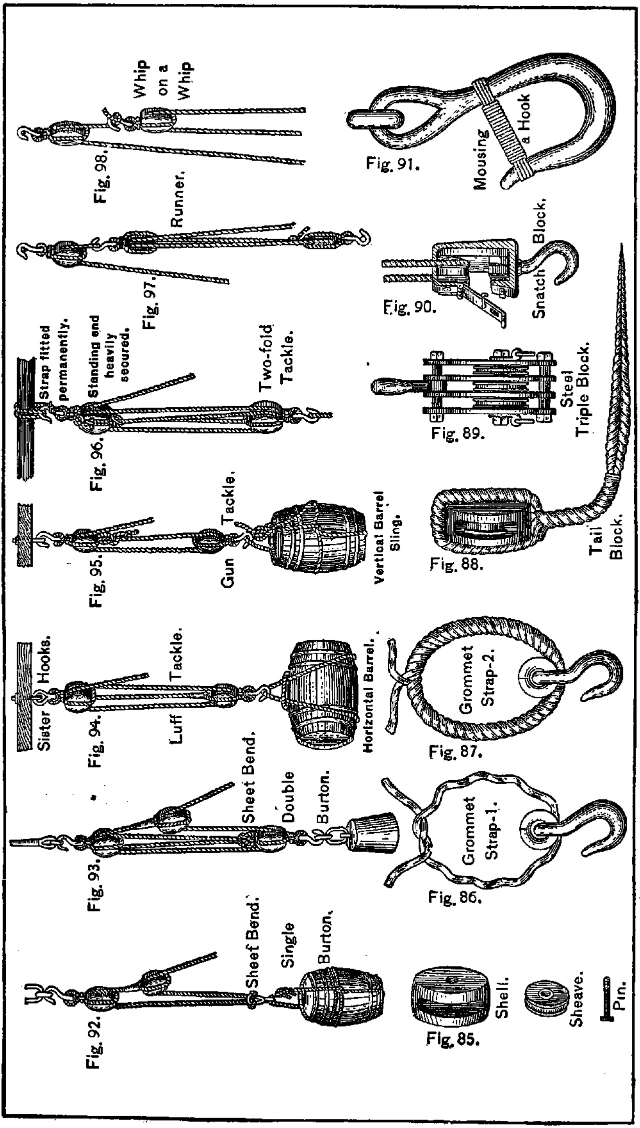


Fig. 92.
Sheet Bend.
Single
Burton.
Fig. 93.
Sheet Bend.
Double
Burton.
Fig. 94.
Sister Hooks.
Luff Tackle.
Horizontal Barrel.
Fig. 95.
Gun Tackle.
Vertical Barrel Sling.
Fig. 96.
Strap fitted permanently.
Standing end heavily secured.
Two-fold Tackle.
Fig. 97.
Runner.
Fig. 98.
Whip on a Whip
Fig. 85.
Shell.
Sheave.
Pin.
Fig. 86.
Grommet Strap-1.
Fig. 87.
Grommet Strap-2.
Fig. 88.
Tail Block.
Fig. 89.
Steel Triple Block.
Fig. 90.
Snatch Block.
Fig. 91.
Mousing a Hook

A *whip* is a single fixed block and fall; it gives no increase of power. A whip on a whip, fig. 98, doubles its power.

A *luff tackle* consists of a single and a double block, either fixed or movable, fig. 94.

A *gun tackle* consists of a double and a single block, the standing end attached to the fixed block, fig. 95.

GENERAL NOTES ON BRIDGE DESIGN.

51. When frequent supports can be obtained, the floor system, consisting of longitudinal beams and cross planking, or their equivalents, rests directly on piers. This method of construction should be adopted whenever practicable. If long spans are necessary, the floor system must be sustained by *cantilevers*, *trusses*, *arches*, or *cables* resting on the supports and forming cantilever, truss, arched, or suspension bridges.

52. A roadway 9 ft. wide in the clear should be provided to pass infantry in fours, cavalry two abreast, and military wagons in one direction; a width of 6 ft. will suffice for infantry in column of twos, cavalry in single file, and field guns passed over by hand.

The *clear width* of roadway of an ordinary highway bridge should not be less than 12 ft. for single track, or 20 ft. for double track.

The *clear head room* in ordinary military bridges should not be less than 9 ft. for wagons and cavalry; for highway bridges not less than 14 ft.

Ramps at the ends of a bridge, if intended for artillery, should not be steeper than 1 on 7. For animals, slopes steeper than 1 on 10 are inconvenient.

If the bridges are high, hand rails should be provided. A single rope may suffice, or it may have brush placed upon it to form a screen.

A guard rail should be provided along each side of the roadway, near the ends of the flooring planks. In hasty bridges it may be secured by a lashing or lashings through the planking to the stringer underneath. Otherwise it may be fastened with spikes or bolts.

53. Examples of **improvised short-span** military bridges:

Trussed ladder bridge.—A ladder may be used as a bridge by placing it on its edge, thus forming a kind of trussed beam. A portable bridge of this kind was used in China in 1860 for crossing canals. Two beams 24 ft. long were formed out of four scaling ladders, each 12 ft. long, by lashing them in pairs end to end, with planks 3 ft. long covering the junctions. The beams so made were laid across the canal, set on edge in grooves cut into the bank. Planks 4 ft. long were laid across from beam to beam to form the roadway, fig. 99.

This bridge, 24 ft. long, was laid and crossed in a quarter of an hour. Its total weight was 750 lbs., or 31 lbs. per ft. It was crossed by half a company of infantry, two abreast, files well closed and in step.

The ladder beam may be greatly strengthened by trussing with a rope, as shown in fig. 100.

In shallow streams intermediate supports may be quickly obtained by moving wagons into the water.

54. **Spar bridges.**—This name is applied to bridges built of round timbers lashed together. Intermediate points of support are provided by inclined frames acting as struts to transmit weight from the middle of the bridge to the banks. The single-lock and double-lock bridges with two and three spans of 15 ft., respectively, are the ones of most utility.

The first step in constructing a spar bridge is to measure the gap to be bridged and select the position of the footings on either bank. Determine the distance from each footing to the middle point of the roadway if a single-lock, or the two corresponding points of a double-lock bridge. Next determine and mark on each spar except the diagonals the places where other spars cross it. The marking may be done with chalk, or with an ax. If possible a convenient notation should be adopted. As, for example, in marking with chalk, a ring around the spar where the edge of the crossing spar will come, and a diagonal cross on the part which will be hidden by the crossing spar.

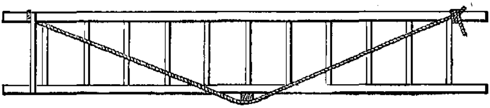


Fig. 100.

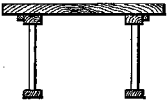


Fig. 99.

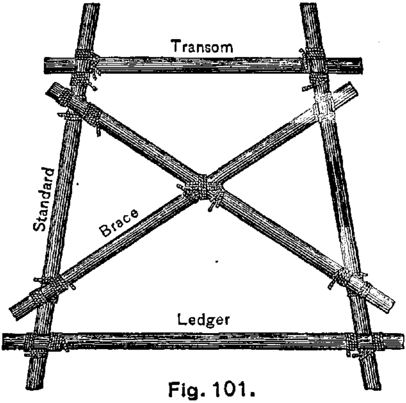


Fig. 101.

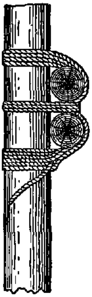


Fig. 103.

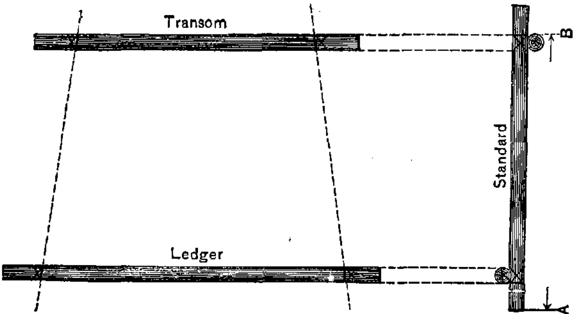


Fig. 102.

87625—09——12

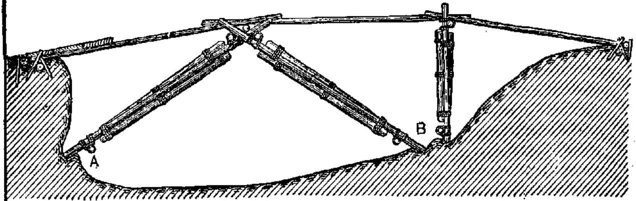


Fig. 104

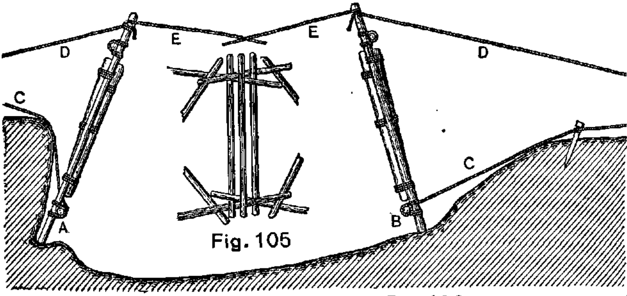


Fig. 105

Fig. 106

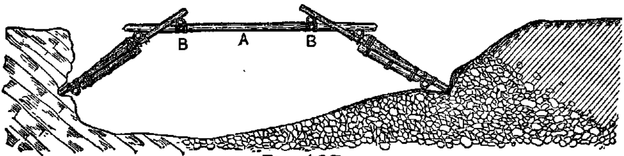


Fig. 107


Fig. 108

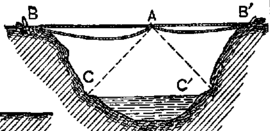


Fig. 109

Fig. 110

A simple way to determine the length of spars is the following: Take two small lines somewhat longer than the width of the gap, double each and lash the bights together. Stretch them tightly across the gap so that the lashing comes at the middle, as at A, fig. 109. Release one end of each and stretch it to the footing on the same side as indicated by the dotted lines. Mark each line at the footing C or C', and at the position chosen for the abutment sill, B or B'. Cut the lashing and take each piece of rope to its own side. The distances AB and AB' are the lengths between the transoms, and with 2 ft. added give the length of road bearers required. The distances AC and AC' are the lengths of struts from butt to top of transom, and with 3 ft. added, give the total length of spars required.

For a double-lock bridge, a piece of rope of a length equal to the length of the middle bay replaces the lashing. If the banks are not parallel, a measurement should be taken on each side of the bridge.

If desired, a section of the gap may be laid down on the ground in full size and the lengths of spars determined by laying them in place. This method, though given as standard by all authorities, requires more time and more handling of material than the other and gives no better results.

The construction of a frame is shown in fig. 101, and the system of marking in fig. 102. The arrangement of frames to form a single-lock bridge is shown in figs. 104 and 105, and a double-lock bridge in fig. 107.

55. *Construction of single-lock bridges*, figs. 104, 105, and 106.—Suitable for spans of 30 ft. or less. The two frames lock together at the center of the span; their slope must not be more than 4 on 7. The bridge can be erected by two or three noncommissioned officers and 20 men, one-half on each side of the gap. Heavy spars require more men.

The footings at A and B must be firm, horizontal if possible, and at right angles to the axis of the bridge. In a masonry pier they may be cut out. In firm soil a simple trench will suffice. In yielding soil a plank or sill must be laid in the trench. The frames are made of such length as to give a slight camber to the bridge, which may be increased to allow for probable settlement of the footings. The inside dimension of one frame is made slightly greater than the outside dimension of the other, so that one frame may fall inside of the other when hauled into position. For a 9 ft. roadway the standards of the narrow (inside) frame should be 9 ft. 6 ins. apart at the transom and 10 ft. 6 ins. at the ledger, in the clear, and the other (outside) frame 1 ft. 6 ins. wider throughout.

A frame is constructed on each bank. The standards are laid on the ground in prolongation of the bridge, butts toward the bank. The ledgers are lashed on *above* and the transoms *beneath* the standards at the positions marked. The diagonal braces are lashed to the standards, two butts and one tip above the latter, and to each other. Before the braces are lashed the frame must be squared by checking the measurements of the diagonals.

If necessary, pickets for the foot and guy ropes are driven, the former about 2 paces from the bank and 4 paces on each side of the axis of the bridge; the latter about 20 paces from the bank and 10 paces on each side of the axis. The foot ropes, CC, fig. 106, are secured by timber hitches to the butts of the standards and the back and fore guys, DD and EE, to the tips; the fore guys are passed across to the opposite bank. The guys of the *narrow* frame should be *inside* the guys and standards of the wide frame.

The frames are put into position one after the other, or simultaneously if there are enough men. A man is told off to each foot rope and one to each back guy to slack off as required, two turns being taken with each of these ropes aronnd their respective pickets. The other men raise the frame and launch it forward, assisted by the men at the fore guys, until the frame is balanced on the edge of the bank. The frame is then tilted until the butts rest on the footing, by slacking off the foot ropes and hauling on the fore guys, fig. 106. After the head of the frame has been hauled over beyond the perpendicular, it is lowered nearly into its final position by slacking off the back guys. When the two frames are in this position opposite each other, the narrow frame is further lowered until its standards rest upon the transom of the other. The wider (outer) frame is then lowered until the two lock into each other, the standards of each resting upon the transom of the other.

The center or fork transom, figs. 104 and 105, is then passed from shore and placed in the fork between the two frames. This forms the central support to receive a floor system of two bays, built as already described.

The estimated time for construction of such a bridge is about one hour if the material is available and in position on both sides of the stream. The construction of the roadway requires about twenty minutes; forming footings in masonry about one hour.

56. *Construction of double-lock bridge*, fig. 107.—Suitable for spans not exceeding 45 ft., and consisting of two inclined frames which lock into a connecting horizontal frame of two or more distance pieces, with cross transoms, dividing the gap to be bridged into three equal bays of about 15 ft. The force required is two or three noncommissoned officers and 25 to 50 men; the time for construction, except roadway, about two and one-half hours; extra time to be allowed for difficult footings.

The width of gap is measured, the position of footings determined, and the length of standards from butt to transom determined and marked as before.

The inclined frames in this case are built of equal widths, launched as before, and held by guys just above their final position. Two stringers are launched out from each bank to the main transom. The distance pieces, fig. 107, are put into position inside the standards, using tackle if necessary, and the road transoms are placed and lashed to the distance pieces at the places marked. Both frames are now lowered until they jam.

TABLE XX.

57. **Round timber** required for **spar bridges**:

Kind of bridge.	Spars.	Length.	Diameter. At tip.	Diameter. Throughout or mean.	Purpose.
	No.	*Ft.*	*Ins.*	*Ins.*	
Single lock, 30 ft. span	4	22	7	----------	Standards.
	2	15	----------	6	Transoms.
	4	15	----------	4 to 6	Ledgers and shore trans.
	4	20	----------	3	Diag. braces.
	1	15	----------	10	Fork trans.
	10	20	----------	6	Balk.
	4	20	----------	3 to 6	Side rails.
Double lock, 45 ft. span	4	20	7	----------	Standards.
	2	15	----------	6	Main trans.
	4	15	----------	4 to 6	Ledgers and shore trans.
	2	25	----------	8	Distance pcs.
	2	15	----------	10	Road trans.
	4	20	----------	3	Braces.
	15	20	----------	6	Balk.
	4	20	----------	4 to 6	Side rails.

TABLE XXI.

58. **Rope** required for **spar bridges:**

Description and size of ropes.	Single lock.			Double lock.		
	Ropes.	Total length.	Max. wt.	Ropes.	Total length.	Max. wt.
	No.	*Ft.*	*Lbs.*	*No.*	*Ft.*	*Lbs.*
Foot ropes, 3 in. circ., 40 to 60 ft	4	240	71	4	240	71
Guys, 3 in. circ., 120 to 150 ft	8	1,200	356	8	1,200	356
2 in. circ., 108 ft	2	216	29	2	216	29
$1\frac{1}{2}$ in. circ., 54 ft., for transom lashings	4	216	29	8	512	68
$1\frac{1}{2}$ in. circ., 36 ft., for ledger and brace lashings	10	360	27	14	504	37
1 in circ., 21 ft., for road bearers	10	210	7	10	210	7
Spun yarn			7			7
Aggregate length and weight of rope required		2,442	526		2,882	575

Miscellaneous materials: 2 pieces chalk; 8 pickets, 5 ft. long; 4 pickets, 3 ft. long; tracing pickets; plank for chess ($1\frac{1}{2}$ by 12 ins. by 10 ft.) (according to span); rack sticks and lashings (at 4 ft. intervals) (according to span); 2 tracing tapes, 150 ft. each.

59. **Roadway** of **spar bridge.**—For infantry in fours crowded the transoms should have a diam. of not less than 9 ins. for a span of 15 ft. Five stringers 2 ft. 3 ins. c. to c., and 6 ins. diam. at the tip will suffice. If the sticks vary in size, the larger ones should be notched down on the transom so as to bring the tops in the same plane. The stringers should be long enough to overlap the transoms, and should be lashed together at each tip. The floor is held down by side rails over the outside stringers and lashed to them. If lumber can not be obtained, a floor may be made of small spars, the interstices filled with brush, and the whole covered with loam or clay; figs. 108 and 110.

60. **Trestle bridges.**—Applicable to shallow rivers with firm bottoms and not subject to sudden change in water level. Improvised structures are seldom satisfactory. On a rocky bottom they are difficult to fit; on a muddy bottom they sink, and on a sandy bottom they undermine. *Portable trestles* require but little timber and can easily be transported. The parts are fitted together and numbered to facilitate assembling. A trestle bridge is not limited as to length. The bays are of convenient length, usually 12 to 15 ft., depending upon the traffic and the available material.

Accurate soundings across the stream along both sides of the bridge are required where the bottom is irregular, to determine the length of legs and the height of the cap of each trestle above the bottom.

61. **Trestles** of **spars** and **lashings** are applicable to rocky ravines, or when circumstances make it difficult to drive piles. They may be two, three, or four legged.

The two-legged form is similar to a frame for a single-lock bridge (par. 55), the only difference being that the trestle standards have a greater slope. Four men should make the trestle in forty-five minutes. If the timber be weak, both ledger and transom may be doubled, as in fig. 103. Light material may be used for the diagonal braces, as little strain is brought upon them. Two-legged trestles are maintained in upright positions by lashing the stringers to the transoms and by longitudinal bracing of adjacent trestles. The trestles next the shore must be rigidly braced by spars lashed to the standards and to stout stakes driven in the bank. This *end bracing* is *very important.*

Three-legged trestles, fig. 111, have the advantage of utilizing light material. They will stand without bracing and admit of more ready adjustment than the other forms.

To make a tripod, the lashing of the tips may be done as described in par. 48, or as shown in fig. 112, the latter method permitting a transom to be placed in the fork. In the latter method the tips of the two legs are lashed together with a shear lashing, par. 47, and the third leg or tripod is then added. The tripod is then raised, the feet placed on the angles of an equilateral triangle with sides about half the height of the tripod, and secured by lashing three light ledgers, as shown in the figure.

Three-legged trestles of bamboo fitted with three transoms lashed at different heights for varying depths of water were used near Manila for a portable bridge 150 ft. long. The floor was made of bamboo frames covered with bamboo mats. The floor for each bay was carried entire and was designed to be hung by ropes from the transoms. The entire bridge could be carried by 120 men, but was rather heavy for them.

A four-legged trestle made of spars and lashings is shown in fig. 113. It consists of two frames similar to two-legged trestles, locked together at the transoms and connected by short ledgers at the feet. The breadth of the base on which the trestle stands should not be less than one-half the height. Fig. 114 shows a four-legged trestle for same use as that shown in fig. 113. It presents slightly different arrangements of the parts and of the lashings. Four-legged trestles are not convenient for use on uneven bottom.

If trestles are placed in considerable depth of water it may be necessary to ballast them temporarily until the weight of the roadway can be put on. Pieces of rock or sacks of gravel may be used for ballast, or any articles of the equipment in compact form and of considerable weight may be lashed to the trestle when it is set and removed to the next when no longer needed.

In setting trestles of all forms on dry foundations they may be made with legs of uniform length as prescribed in the text, set up in place, and fitted to the ground by lashing suitable extension pieces to the feet.

TABLE XXII.

62. **Spars** and **lashings** for **trestles:**

Kind of trestle.	No. of spars or lashings.	Length.	Diam. of spars or circ. of rope.	Purpose.
		Ft.	*Ins.*	
Two-legged	2	----------	4½ to 6	Legs.
	1	10 to 14	5¾ to 7	Transom.
	2	----------	3½ to 4½	Diagonals.
	1	----------	3 to 6	Ledger.
	6	30	1½	Lashings.
	3	15	1½	Lashings.
Three-legged	6	----------	3 to 5	Legs.
	1	14	7 to 8	Transom.
	4	4 to 6	3 to 3½	Cross bearers.
	6	6	1¾ to 2½	Ledgers.
	4	2	2	Stakes.
	12	30	1½	Lashings.
	6	15	1½	Lashings.
Four-legged	4	----------	3¼ to 4¾	Legs.
	2	10 to 14	5 to 6	Transom.
	4	----------	3 to 3½	Diagonals.
	4	----------	2½ to 3	Ledgers.
	12	30	1½	Lashings.
	6	15	1½	Lashings.

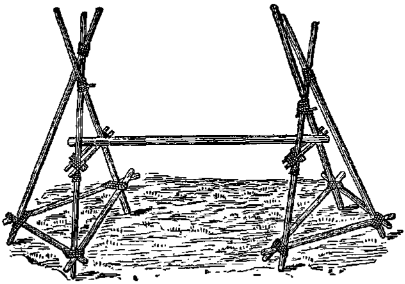


Fig. 111.

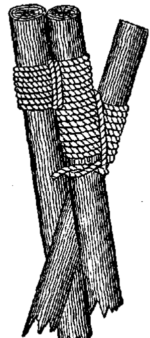


Fig. 112.

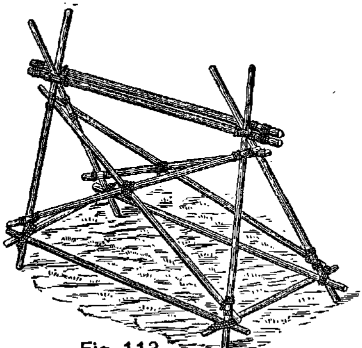


Fig. 113.

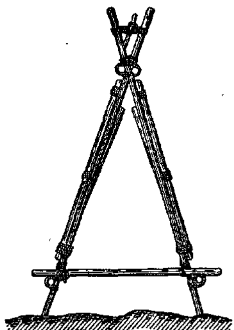


Fig. 114.

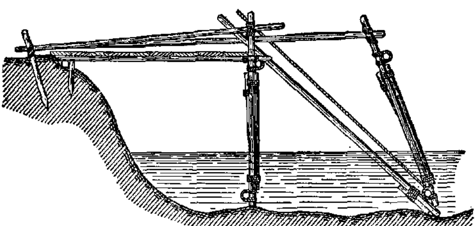


Fig. 115.

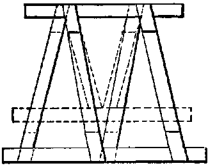


Fig.116

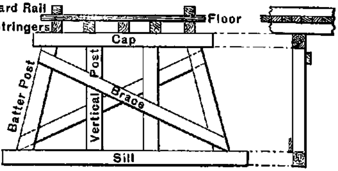


Fig.117

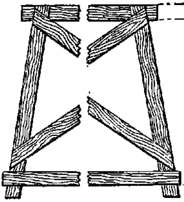


Fig.118

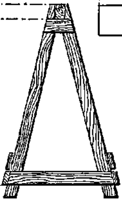


Fig.119

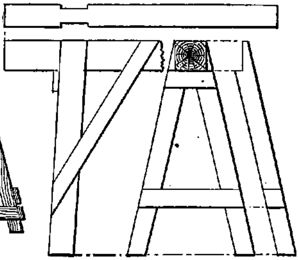


Fig.120

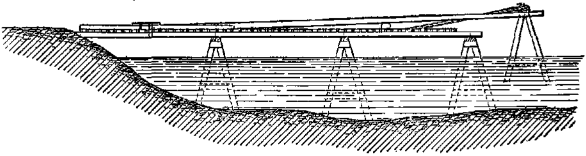


Fig.121

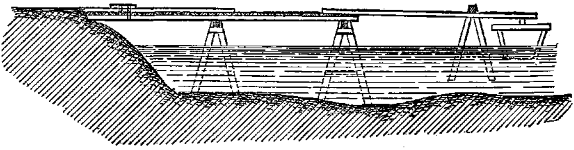


Fig.122

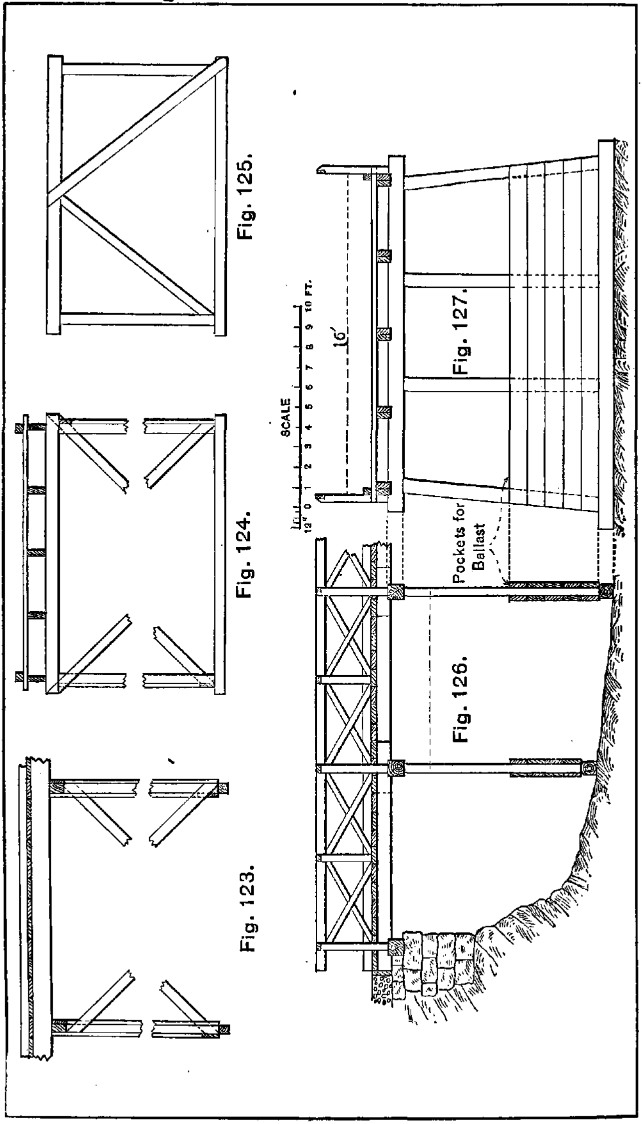


Fig. 123.

Fig. 124.

Fig. 125.

Fig. 126.

Fig. 127.

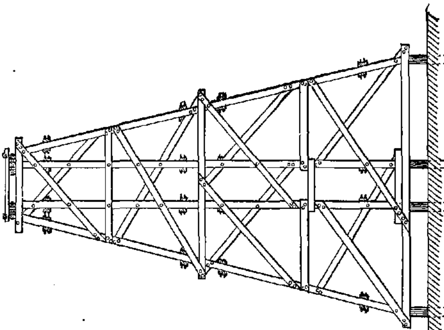


Fig. 130.

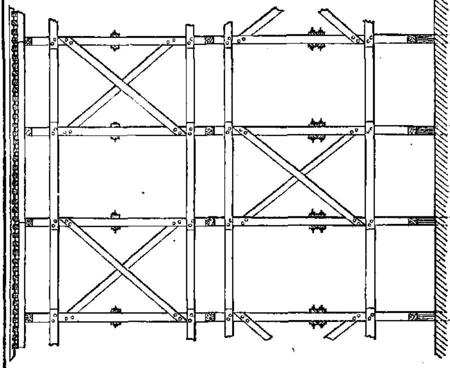


Fig. 129.

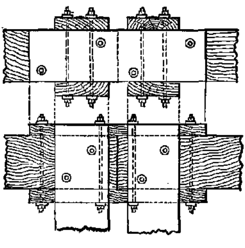


Fig. 128.

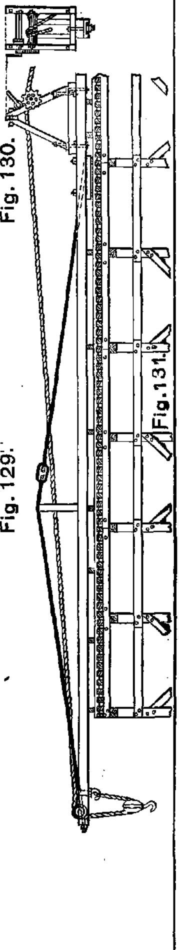


Fig. 131.

Fig. 132

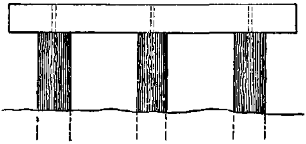


Fig. 133

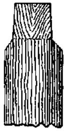
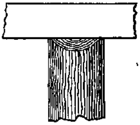


Fig. 134



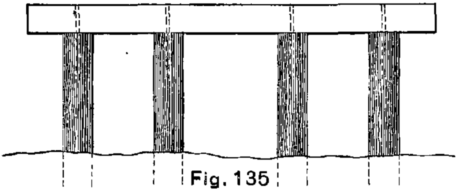


Fig. 135

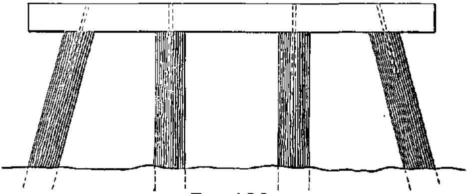


Fig. 136

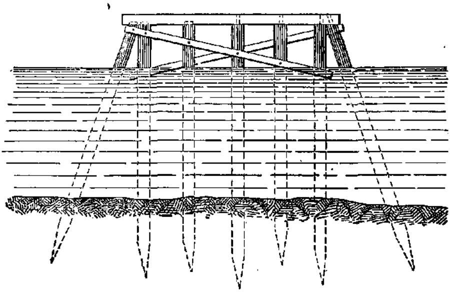


Fig. 137

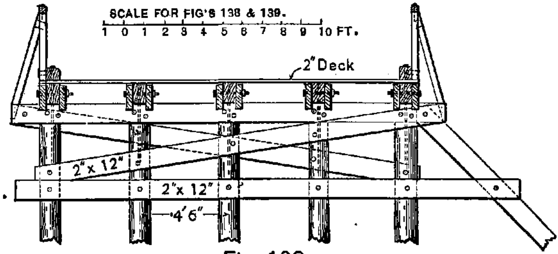


Fig. 138

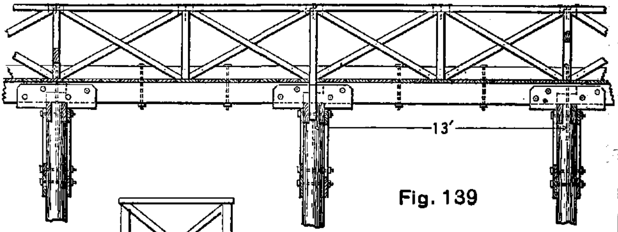


Fig. 139

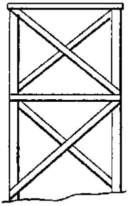


Fig. 142

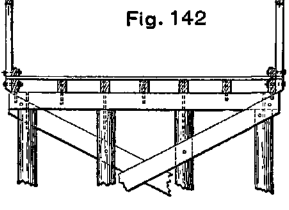


Fig. 140

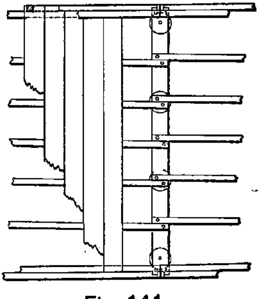


Fig. 141

63. **Erecting trestle bridges.**—Trestles may be placed in position by hand in dry situations, and also in shallow streams of moderate current when the weather will permit men to work in the water. This method facilitates rapid construction, as several trestles can be placed simultaneously. Alternative methods are slower of execution, since but one trestle can be placed at a time if the bridge be built from one end, or two if work is prosecuted from both ends. One of these methods is shown in fig. 115. Inclined timbers are run out from the end of the bridge, their lower ends resting on the bottom at the point where the next trestle is to stand. Slide the trestle down these ways until it strikes the bottom. Lash stringers to the cap and push the bent into an erect position. Lay the remaining stringers and complete the roadway over the new bay, and place another trestle as before.

Another method is shown in fig. 121, involving the use of beams, roller, and rope. The beams used must be about twice the length of the bay.

Fig. 122 illustrates a method of placing trestles when a boat or raft is available.

High trestles are usually erected by the use of a balance beam, fig. 131, rolled forward as the floor advances, and projecting beyond the last bent completed.

64. **Framed trestles.**—The trestle is also one of the most useful methods of utilizing dimension timbers for bridge supports. In framed trestle bents, figs. 116 and 117, the posts rest on a sill placed on the ground or supported by footings of some kind. The names of the principal parts of a trestle bent are indicated in fig. 117. In varying the height of the trestle the cap remains of the same length and the batter posts have the same inclination. The length of the sill varies, as indicated in dotted lines, fig. 116.

The simplest framed trestle is the sawhorse. The relative dimensions and arrangement of its parts are as shown in figs. 118, 119, and 120. The figures and proportions given are to be regarded as typical only with the widest latitude of adaptation to materials available.

65. Figs. 123 and 124 illustrate a trestle bridge designed to carry the loaded escort wagon with a factor of safety of 3. If the height of the trestle is not greater than its width, the bracing shown in fig. 125 may be used. It has the advantage of giving a middle support to the transom. Figs. 126 and 127 show a hasty trestle bridge thrown across Conemaugh River at Johnstown, Pa., by a detachment of engineers, June, 1889. The piers are *stiffened laterally* by planking the uprights on both sides for some distance above the bottom, and are made *self-anchoring* by filling the 6-inch space between the planks with scrap iron or other heavy material.

Trestles of considerable height may be made in two or more tiers, the cap of each forming the sill of the one next above and resting upon it, or the posts may be continuous, figs. 128, 129, and 130.

When trestle sills are supported on footings or piles, the points of support must be under the posts.

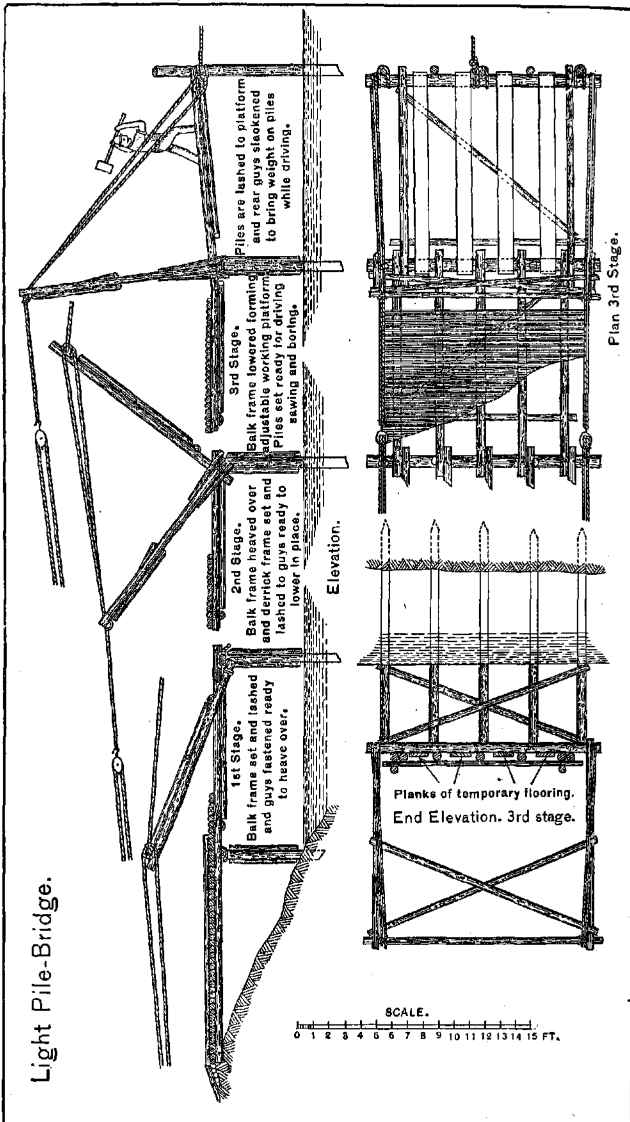
66. **Pile bents** are similar in construction to trestle bents. The sill is omitted, the posts are driven into the ground, and usually are all vertical. Pile bents are to be preferred on soft ground and in rapid streams. Piles should be from 8 to 12 ins. in diameter at the butt for highway traffic, and must be approximately straight, or they can not be driven. Dimension timbers, the nearer square the better, make excellent piles.

Types of arrangement of piling for railroad work are shown in figs. 132 to 136.

For bents more than 10 ft. high, the outside piles may be driven with a batter. Bents 10 to 20 ft. in height have one set of *sway braces*. Crossed diagonals of 3 by 10 in. plank, one on each side of the bent, suffice, fig. 140. Heights of more than 20 ft. should have additional sets of crossed diagonals, with horizontal sticks between them, fig. 142.

Except in streams subject to floods, *longitudinal bracing* also is required. It may be in one or more tiers, as described for sway bracing, or as is shown in fig. 129.

A pile bent for water 10 ft. deep is shown in fig. 137. Figs. 138 and 139 show a bridge built across the Portuges River, Porto Rico, and designed to allow *floods to pass over* it without other injury than carrying away the hand rail, which is lightly constructed with that end in view. Figs. 140 and 141 show a type of pile bridge of which several were built in the Philippines.


Light Pile-Bridge.
Piles are lashed to platform and rear guys slackened to bring weight on piles while driving.
3rd Stage. Balk frame lowered forming adjustable working platform. Piles set ready for driving sawing and boring.
2nd Stage. Balk frame heaved over and derrick frame set and lashed to guys ready to lower in place.
1st Stage. Balk frame set and lashed and guys fastened ready to heave over.
Elevation.
Plan 3rd Stage.
Planks of temporary flooring.
End Elevation. 3rd stage.
SCALE.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 FT.

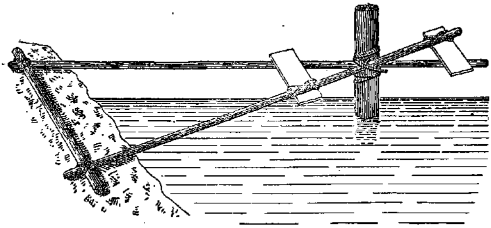


Fig. 143

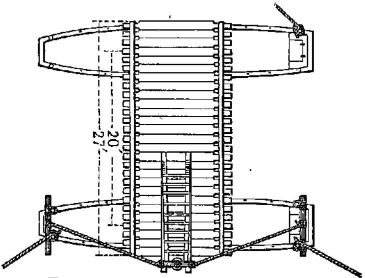


Fig. 144

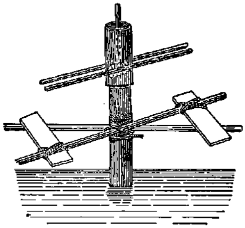


Fig. 143A

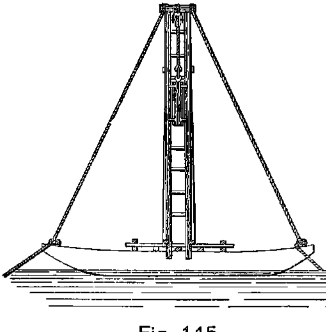


Fig. 145

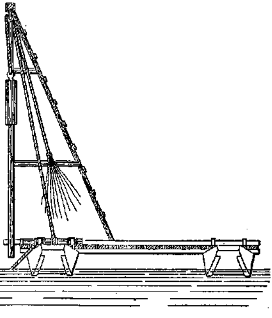


Fig. 146

Improvised Hand-Power Pile-Driver.

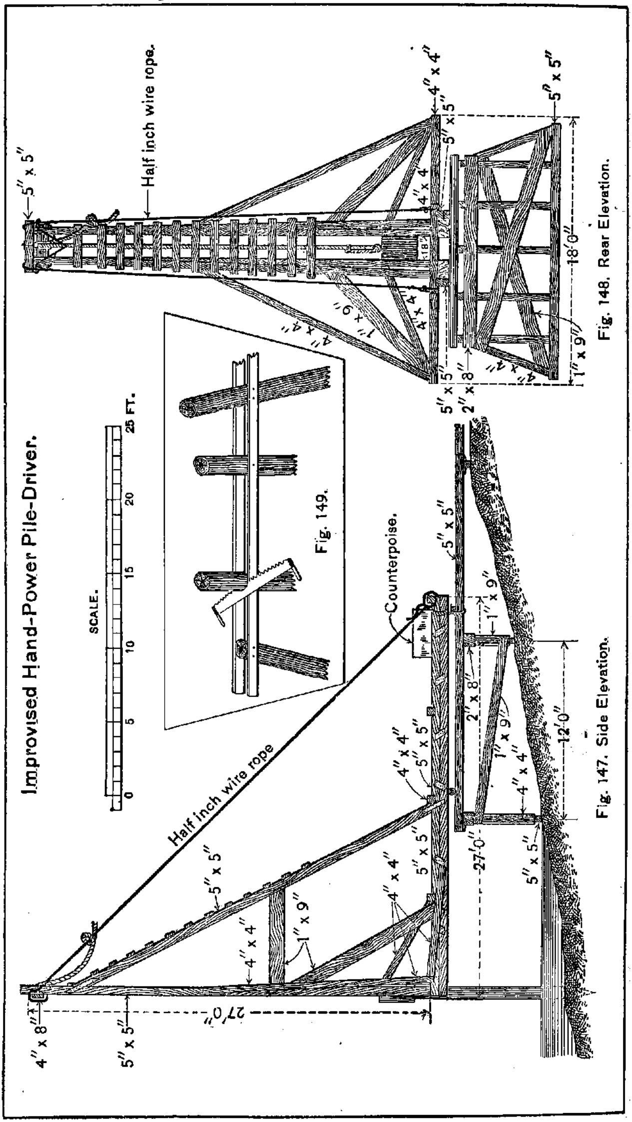


Fig. 147. Side Elevation.

Fig. 148. Rear Elevation.

Fig. 149.

67. **Pile-driving.**—Piles may be driven with a hammer in mud or any loose soil except sand. In still water or moderate currents, and to the penetration usually sufficient for light work, piles may be driven with sledges or mauls. It is best done from a platform attached to the pile and going down with it, as shown in fig. 143. The weights of drivers balance, and after the pile is well fixed in place the shore ends of the spars may be held shoulder high and lowered as the pile goes down, so as to keep the platform horizontal for the hard driving.

Heavier blows can be struck by the device shown in fig. 143*a*. For four men the hammer may weigh 250 to 300 lbs.

For sand, a force pump and water jet are required, and these will often facilitate driving in other soils. For driving with the jet, a length of hose and a piece of wrought-iron pipe, long enough to reach from the point of the pile to a point above the water level when driven, are required. After the pile is hoisted into the leads, attach the pipe to one side, its lower end opposite the point, which should not be sharpened, using two or three wrought-iron spikes driven a short distance into the wood and bent over the pipe. Place the pile in position, lower the hammer onto the head, couple the hose to the pipe and start the pump. If the pile does not settle under the weight of the hammer, tap it lightly. Heavy blows are to be avoided, as they will dislodge the pipe.

In the Philippine streams piles are often placed by setting them up in position and working the tops back and forth by guy lines or twisting them by levers. On a tributary of Camilleis River between Bayambang and Camilleis, 12-in. piles were sunk in the river to 10 or 12 ft. penetration. The peculiar softness of bottom and the great weight of native woods contribute to the success of this method.

When the piles of a bridge are to be driven by hand, the following method, which utilizes the floor of the bridge as a working platform, has been found to work admirably. It was devised by Captain Rees, instructor of engineering in the General Service and Staff College, Fort Leavenworth, Kans., and used by him in the instruction of his classes.

The first bent is driven at the water's edge, and connected with the shore by a bay of roadway. A derrick frame is prepared as shown in fig. 142*a*. The feet of the standards are forked to embrace the trestle cap. The floor frame is formed by lashing two stringers to a trestle cap and placing a diagonal. This frame is laid on the floor of the last bay with the free ends of the stringers under the last cap and lashed to it, the lashings passing up on the rear side and down on the front side of the caps, fig. 142*a* (first stage). The new cap and the diagonal are on top of the stringers in this position. The frame is raised at first by hand and later by the fore guys and rotates about the cap to which the stringers are lashed. As the frame passes the vertical, it is held by the back guys and lowered to a slightly inclined position (second stage). The derrick frame is then placed with its claws embracing the cap outside of the stringers, raised by hand, and the back guys made fast at the tops of its posts (second stage). The two frames are then revolved about the cap by slacking the back guys until the floor frame is nearly horizontal (third stage). It then forms a working platform for driving the piles of the next bent. By lashing the cap to the piles and slacking the guys (fourth stage), the weight of the platform and men may be thrown onto the piles to assist in sinking them.

68. **Designs** for **pile drivers.**—If two service pontons with balk and chess are available a floating hand pile driver, shown in figs. 144, 145, and 146, may be improvised. The construction is obvious from the drawings. The hammer is a log of heavy wood 16 in. in diam. and 4 or 5 ft. long, flattened on opposite sides to fit loosely between the leads. Pairs of pins are inserted near the top and bottom of the block on both sides, to serve as guides.

Another form of field pile driver is shown in figs. 147 and 148. It can be constructed from balk, chess, and 2-in. plank by six men in about six hours. It is rolled forward on the bridge as built.

The form of driver shown in figs. 150, 151, and 152 also rolls forward on the trestles, projecting beyond the last one driven far enough to drive the one ahead. For two or four pile bents the double leads, shown in this construction, are an advantage, as they reduce the lateral shifting, besides doubling the rate of driving.

The *tops of the piles* must be cut accurately to the plane of the bottom of the cap to give firm bearings. If cut by hand, nail a straight strip of wood on each side of

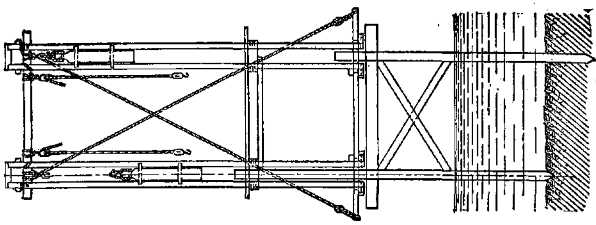


Fig. 152.

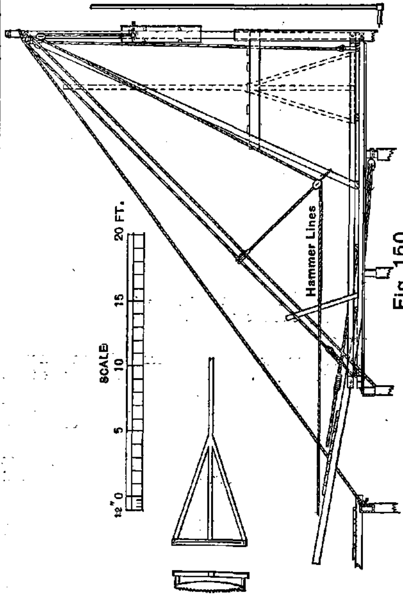


Fig. 150.

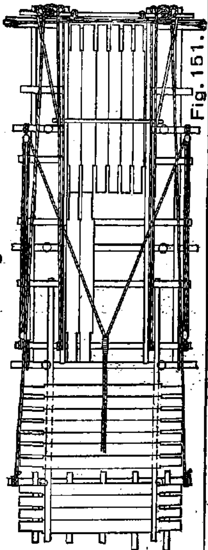


Fig. 151.

the pile with its upper edge in the desired plane, and run the saw on top of these strips, fig. 149.

In the field pile driver shown in figs. 150 and 151, a swinging saw frame is indicated. When in use it is hung from a pivot attached to the hammer. In starting the cut, the sag of the saw must be lifted until its middle is on line with its ends and held so until engaged in the cut.

69. **Operating field driver**, figs. 150, 151, and 152.—A bent just completed, overhaul the shifting tackles and attach them by straps to the last cap; fasten blocks to the caps on the outside of the sills of the machine to serve as guides; slush or soap the runners, and haul away on the shifting tackles to advance the machine the proper distance. Lash the heel of the machine to the trestle cap. As soon as the leads clear the last cap the hammers may be lowered into the water to take off their weight. When made fast in the new position, haul hammers to the top of leads; hook onto piles with the hoisting tackles and swing them in place; pass lashings to hold them and lower the hammers to rest on their tops. Hoist and drop the hammers until the piles are driven to the required penetration or resistance. Hoist the hammers, hang the saw frame, and adjust to proper height. While sawing off, hook onto a cap with hoisting tackles, sling it horizontally into position, and onto the piles as soon as sawed. Bore through the cap into piles and drive driftbolts or treenails. Spike on the longitudinal braces that stay this bent against the pull of the shifting tackles and advance to the next bent. Other bracing may be placed after the pile driver has passed.

Above applies to bents with two piles. For driving four-pile bents the machine is shifted laterally on cross skids with tackle or with handspikes. When mules are available they may replace the men on the hammer lines to great advantage.

70. The **supporting power** of **piles** is not of paramount importance in military bridges of hasty or temporary character, since a slight settlement is usually of no especial consequence.

It may be said in general that the bearing power of piles will vary from 5 to 70 tons according to the size of the stick, its penetration, and the character of the soil into which it is driven. A frictional resistance per sq. ft. of the surface of the pile in contact with the soil may have working limits of 200 to 800 lbs. The smaller should not be exceeded in alluvial and soft soil nor the greater in firmer material such as stiff clay, sand and gravel, or mixed material.

If it is necessary to insure against settlement, the following formula, known as the "Engineering News Formula," may be used:

$$L = \frac{2\,wh}{S+1}$$

in which

L = safe load in lbs.
w = weight of hammer in lbs.
h = fall of hammer in ft. (average of last few blows).
S = penetration per blow in ins. (average of last few blows).

This formula includes a factor of safety of 6, or is based on the assumption that $\frac{12\,wh}{S+1}$ = the ultimate supporting capacity of the pile.

No pile formula yet proposed is absolutely reliable. The above is one of the latest and simplest, and probably among the best.

CRIB CONSTRUCTION.

71. In *dry situations* the cribs are built on the site and no fastenings are required. The ground is prepared to receive the bottom timbers, level and bearing firmly toward the ends and but lightly in the middle. The sticks of the next course are laid across their ends, noting that they rest fair and do not rock. If logs are used, the ends are flattened sufficiently to give bearing surfaces. With dimension timbers each piece which does not lay fair must be given a solid bearing by shims or wedges before the next one is put on. These small pieces must be fastened so that they can not jar out. The construction of a dry crib is shown in fig. 153.

The part of a crib that is to stand *in water* must be tied together and adapted to form a cage for the ballast. Enough of the ballast to overcome the flotation of the wood should be so confined that it can not escape. For the rest, it is better to leave the ballast free to run out through the floor of the crib and fill any cavities in the bottom which may exist or be formed by the scour of the current. A crib may be given a level bearing on a rough or sloping bottom by holding it in the desired position and throwing in ballast which runs through.

A large crib may be made in compartments or pockets, the interior ones floored to take the sinking ballast and the others open at the bottom to allow ballast to run through, figs. 154 and 155. A small crib made in one pocket may have extra logs in the second course on which a large rock can be laid to sink the crib, after which smaller ballast may be thrown in around it, fig. 156.

72. Cribs are built on shore usually on inclined ways, and when up to a sufficient height to form a substantial raft may be launched. They are built up to a little more than the depth of the water in which they are to stand and are floated to their places. The sinking ballast is then placed in the closed compartments or on the floor prepared to receive it, until the crib is well grounded. By means of spars set at the corners with tackle attached, the lower corners may be raised until the crib is level, and the rest of the ballast thrown in.

The construction of the *sides* of a crib must be *adapted* to the *ballast* to be used. If large stones are available, the full interval may be left between sticks as described for dry cribs. If the ballast is small, the timbers must be gained together to make the spaces smaller, and it may even be necessary to plank the sides of the crib.

73. To resist the *outward thrust* of the *ballast* the logs may project in full size a foot or two at each end, so that each one rests in a notch cut in the one below. A log may be split into quarters and one of these placed in each outside corner, nailed or pinned to each timber. For light cribs in shoal water the projection may be small and a pole substituted for the quarter log. Both of these methods are shown in figs. 155 and 156. For cribs of squared timbers, two planks nailed or pinned in the outside corner, as shown in fig. 157, are best.

74. On a bottom of *soft mud* it may be necessary to *distribute* the *weight* of the pier over a greater area than its own bottom. For this purpose riprap stone is commonly used if easily procurable. A quantity is thrown in on the site of the crib and allowed to find its bed. When the bottom is well covered and no further settlement appears, the top is roughly leveled and the pier sunk on top of the mound.

If stone can not be had, a raft of logs may be sunk on the bottom and the pier built on that. The logs should run parallel to the short side of the crib or pier, figs. 162 and 163.

75. A pier placed in *running water* increases the tendency to *scour* in its vicinity, and if the bottom is erosible may be undermined. To prevent this, a flexible construction of brush, called a mattress, may be used. Its construction and use are illustrated in figs. 158–161.

A grillage of poles is made on the ground or on skids, and at every intersection a stake is set somewhat longer than the desired thickness of mattress. A double lashing is attached to the grillage at each stake, brought to the top of the stake, and loosely fastened with plenty of end.

Brush is now laid on in one or more tiers until the desired thickness is obtained. A second grillage is laid on the top with its intersections at the stakes. The lashings are removed from the stakes, passed around the upper grillage, and set up with levers and rack sticks, fig. 160. Such mattresses are usually built 1 to 2 ft. in thickness.

The mattress is launched and floated to its place, where it is sunk on the bottom by throwing on rock or other ballast. When in place the crib or pier is built on top of it.

The effect of a mattress is shown in fig. 161. As the current scours under its outer edge the mattress bends downward, following the bottom until the scour ceases. The mattress must be large enough so that this action at the edges will not disturb the middle.

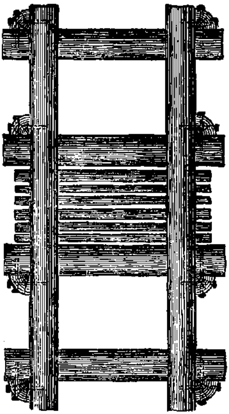


Fig. 155

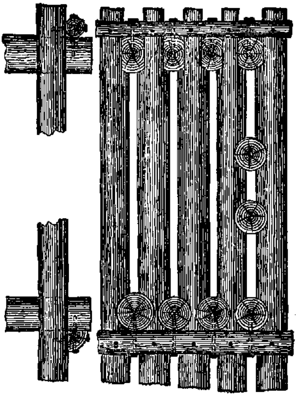


Fig. 156

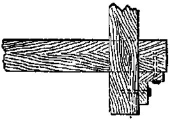


Fig. 157

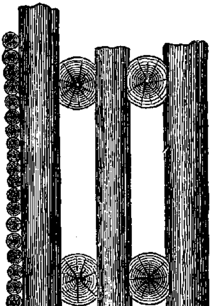


Fig. 153

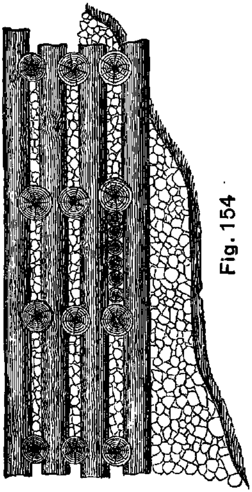


Fig. 154

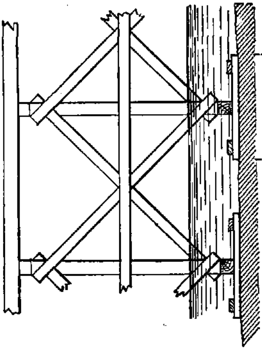
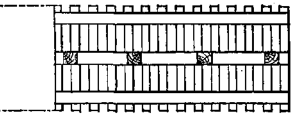



Fig. 163.

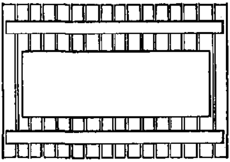


Fig. 162.

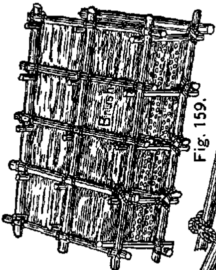


Fig. 159.

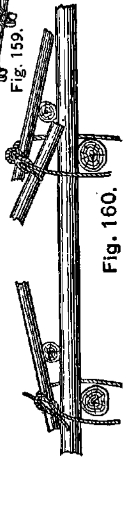


Fig. 160.

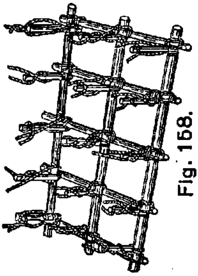


Fig. 158.

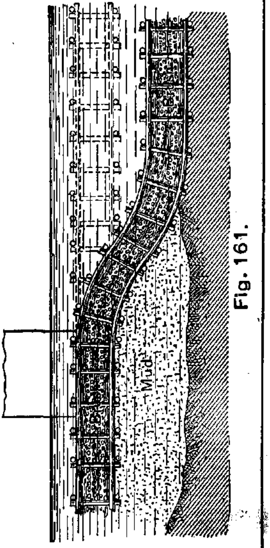


Fig. 161.

LANDING PIERS.

76. The dispositions described for pile and crib bridges are those usually adopted for temporary piers, wharves, or docks for loading or discharging vessels. The chief difference is in the provision made against *lateral thrusts*, which are much greater than in the case of bridges. Vessels warping in and out and even striking the pier, which can not be avoided, cause excessive lateral strains which call for special features in addition to much heavier construction throughout.

Lighters can be discharged at a properly constructed dock in considerable seaway. Transports can also be discharged in a moderate seaway by providing adequate mooring devices at bow, stern, and on the outside, so that the vessel can be held alongside of the pier, but not touching it. Only in perfectly protected situations can a large ship lie directly against a pier.

77. The **best mooring** is a massive structure of piles driven close together and connected near their tops by a cable, or by bolts, or both. Such a construction is often called a *dolphin*. It yields readily to the first impact and develops resistance steadily but rapidly. Fig. 164 shows the usual construction, and fig. 165 the method of binding with wire rope. The end of the rope is stapled to a pile and the rope drawn around the dolphin until it bears on the next one. A strain is then put on with a tackle and a staple or spike driven in the second pile and so on. At least three or four complete turns should be taken. Wire rope is best; chain next.

78. Such dolphins require heavy plant for their construction. If materials are abundant, a crib mooring may be made with ordinary tools. The crib should be square, with a side not less than the depth of water at low tide. It should be exceptionally well fastened. It should be constructed with a middle pocket, to be kept free from ballast until the crib is sunk and a cluster of piles has been put down through the pocket and driven into the bottom as far as possible. The tops of the piles should be arranged like the dolphin. Ballast, preferably of moderate size, will now be thrown into the middle pocket and packed closely around the piles to support them. Such a mooring is less elastic than the dolphin and will be more destructive of lines and of fastenings on the ship, but it can be made when a dolphin of sufficient strength can not.

79. Figs. 167 to 170 illustrate points which must receive especial attention in building pile docks. These are the arrangement of fender piles and chocks so that vessels may ride up and down against the dock without catching, the inclined or spur piles driven to resist lateral thrusts, and the arrangement of fastenings on the dock to take heavy strains.

FLOATING BRIDGES.

80. Bridges of this class have several disadvantages, due to change in grade of roadway with change of water level and with change of load, and to their limited capacity, which can not exceed the flotation of the supports. As a rule, such bridges will be resorted to only when the materials for them are plentiful and the materials for other kinds scarce.

This rule finds an important exception in the organized bridge equipage prepared in advance to be carried with an army. Such a bridge possesses a great advantage in the paramount element of time, since it can be laid, crossed, and taken up in less time than any other form of bridge can be built, and its component parts can be used as water transportation for several important purposes which no other kind of bridge can subserve.

81. The bridge equipage adopted for the United States service is of two forms, *heavy* and *light*. The heavy equipage is sufficient in capacity for all requirements of an army on the march, and is mobile enough to be carried at the ordinary rate of marching. In the light equipage, capacity is somewhat sacrificed for the sake of further mobility to enable a bridge to be carried with a rapidly moving column.

Both heavy and light equipage are organized into *trains* and in each the train is composed of four *divisions* each complete in itself, with the necessary materials and tools for repairs and the requisite wagon transportation for land carriage. With one train four short bridges can be built, or two twice the length in the same

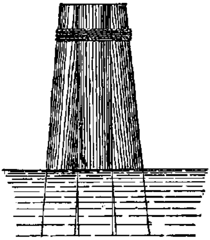


Fig. 164

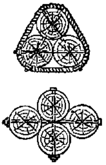


Fig. 166

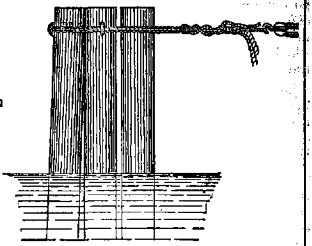


Fig. 165

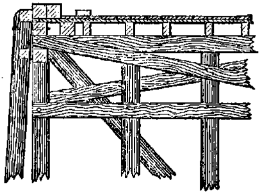


Fig. 167

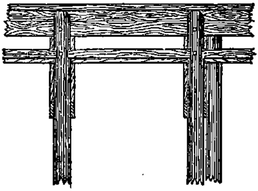


Fig. 168

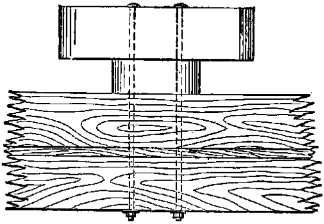


Fig. 169

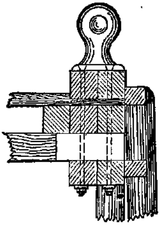


Fig. 170

or different localities, or three four-thirds the length or one of four times the length in the same locality, with obvious intermediate combinations.

The principal parts in both forms of bridge are *pontons* or boats; the longitudinal bearers or stringers joining them called *balks;* the cross planks, called *chess*, and the beams which hold the chess in position, called *side rails*, fig. 181.

82. In the heavy train each division will construct a bridge of 11 bays, or 225 ft. in length, and is divided into four *sections*, two of which are called *ponton sections* and the other two *abutment sections.* The two abutment or end sections suffice for any length of bridge. Increase in length is accomplished by adding one or more ponton or interior sections. The ponton section is never divided, as it can not be done without breaking wagon loads. This equipage weighs, wagons included, 315 lbs. per ft. of bridge, or without wagons 169 lbs.

A division of light equipage will construct 186 ft. of bridge. It is not divided into sections, as each ponton wagon carries the material for a complete bay and the bridge may be lengthened by adding one or more ponton wagons. This equipage weighs, including wagons, 275 lbs. per ft. of bridge, or without wagons 128 lbs.

83. **Heavy equipage.**—A division is loaded on 16 wagons. Eight of them are called *ponton wagons* and carry each a ponton, 7 long balks, anchor, cable, 5 oars, 2 boat hooks, 20 lashings, 6 rack sticks, 2 scoops, ax, hatchet, bucket, and 20 lbs. spun yarn. Four of the wagons carry chess or floor planks only, 60 each, or enough for 3 bays, and are called *chess wagons.* Two wagons carry each a complete trestle, 7 long balks, 7 trestle balks, 2 abutment sills, and 2 coils of rope. The *tool wagon* carries axes, shovels, picks, tools and materials for carpentry, saddlery, calking and painting, and spare cordage. The *forge wagon* carries a forge, smithing tools, iron and other materials. Each wagon is drawn by 6 mules with one driver.

84. **Supporting power** of **boats.**—The boats of the heavy train are of wood, of about 9½ tons displacement, and weigh 1,600 lbs. Each can carry 40 infantrymen armed and fully equipped besides its crew, a total of about 9,300 lbs. This load crowds the boat and should be used only in favorable conditions. In rough water or swift currents 20 men and the crew make a suitable load. The ponton is cranky, and uneven loading and shifting of loads must be avoided.

The light or canvas ponton is of 6 tons capacity and weighs 510 lbs. Its normal load is 20 men and crew, which should be reduced for unfavorable conditions.

85. The **supporting power** of the **bridge** is determined by that of the roadway, purposely made less than that of the pontons. With a factor of safety of 4, the safe uniform load of the standard heavy bridge of 5 balks is 9,500 lbs. on the 14 ft. 4 ins. between the supports, or 660 lbs. per lin. ft. This is more than the weight of infantry armed and equipped in column of fours, but less than the weight of such a column if crowded by a check. The corresponding concentrated center load is 4,750 lbs., which is about that on one axle of a wagon of 5 tons gross weight. It is more than the field gun and carriage and 1,675 lbs. less than the siege gun. Each additional balk above 5 adds 165 lbs. per ft. to the safe uniform load, or 1,280 lbs. to safe concentrated load. Seven balks will carry the siege gun with a factor of safety of nearly 4.

Six extra balks, or 11 in all, will carry as much concentrated load as the boats will support. Extra balks when used should be added in pairs and concentrated under the wheel tracks.

When either end of a bay is supported at one point only, as on an abutment or saddle sill, 30% more balks must be used for the same load and span. If both ends are so supported, 50% more balks will be required for the same load and span.

The above loadings should not be exceeded except under unusual circumstances and with great caution. With new and perfectly sound material in an emergency of actual service an officer in charge of a bridge would be justified in doubling the loads given, or, in other words, reducing the factor of safety to 2.

Heavy loads on wheels may be partially distributed by track planks or by skidding the wagons over on shoes or runners. For long continued use a false floor of common lumber should be laid to take the wear off the chess. Such a floor serves also to partially distribute the load. A covering of hay or straw is advantageous.

The *floor system* of the *light train* has $\frac{9}{10}$ the strength of the heavy, with equal number of balks for concentrated loads and equal capacity per lin. ft. for uniform loads, as the bays are shorter. The standard floor of 5 balks will carry as much as the boats will safely support.

TABLE XXIII.

86. **Names** and **dimensions** of the principal **parts** of the **light** and **heavy trains:**

Name of part.	Light train.	Heavy train.
Ponton, $9\frac{1}{2}$ tons		31 ft. by 5 ft. 8 ins. by 2 ft. 7 ins.
Canvas ponton, 6 tons	21 ft. by 5 ft. 4 ins by 2 ft. 4 ins.	
Balks and side rails	22 ft. by $4\frac{1}{2}$ by $4\frac{1}{2}$ ins	27 ft. by 5 by 5 ins.
Trestle balks		21 ft. 8 ins. by 5 by 5 ins.
Chess	11 ft. by 12 by $1\frac{1}{2}$ ins	13 ft. by 12 by $1\frac{1}{2}$ ins.
Abutment sills		14 ft. by 8 by 6 ins.
Trestle caps, 2 planks, each		20 ft. by 12 by 2 ins.
Trestle legs		15 ft. by 7 by $3\frac{1}{2}$ ins.
Trestle shoe		
Suspension chains		$\frac{1}{2}$ in. by 8 ft.
Paddles	8 ft	
Oars		18 ft.
Boat hooks	8 ft., blunted points	10 ft.
Rack sticks	$1\frac{1}{4}$ ins. diam., 2 ft. long	$1\frac{1}{4}$ ins. diam., 2 ft. long.
Anchor	75 lbs	150 lbs.
Anchor cable	3 ins. circ., 180 ft. long	3 ins. circ., 240 ft. long.
Lashings	1 in. circ., 18 ft. long	1 in. circ., 18 ft. long.
Canvas-ponton cover	No. 0000 cotton duck	
Ponton chest	8 ft. long, 2 ft. 4 ins. wide, 18 ins. deep.	

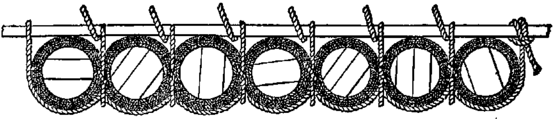
TABLE XXIV.

87. **Weights** of **wagons** and their **loads:**

Kind of wagon.	Light train.			Heavy train.		
	Wagon.	Load.	Total.	Wagon.	Load.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Ponton	1,750	1,985	3,735	2,200	2,900	5,100
Chess	1,750	1,856	3,606	1,750	2,280	4,030
Trestle	1,750	2,060	3,810	2,200	2,635	4,835
Tool	1,700	1,938	3,638	1,700	2,100	3,800
Battery and forge	2,081	600	2,681	2,081	600	2,681

88. **Boat bridges.**—When it becomes necessary to use boats found on the stream or elsewhere, select those as nearly of one size as possible. Of these, use the largest for the shore ends and for the swiftest currents. Estimate their supporting power roughly by comparing their size with the ponton boat, heavy or light, or compute as in par. 100. Support the balks on saddle sills and transoms blocked up from the frames of the boats. If boats differing very much in displacement are used, make the bays supported by the small boats shorter than those supported by the larger ones. Avoid getting a very large and a very small boat adjacent. The floor system may

Fig. 171



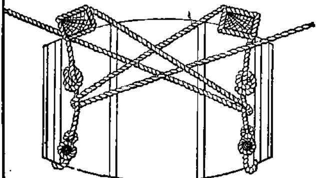


Fig. 172

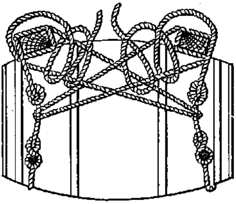


Fig. 173

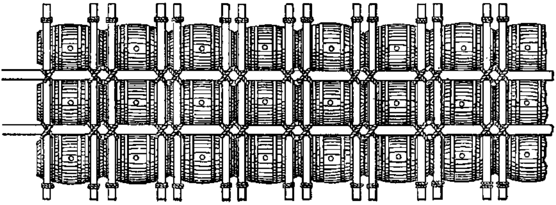


Fig. 174

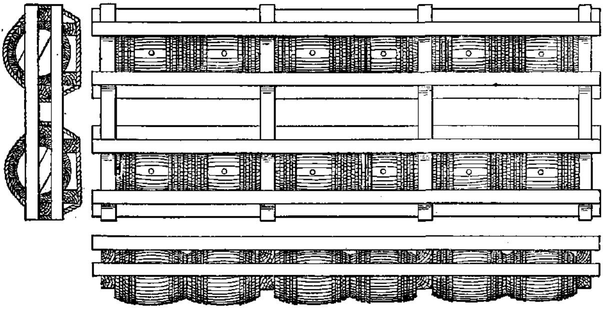


Fig. 175

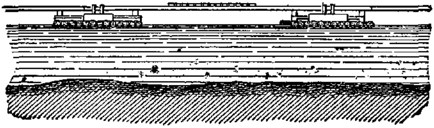


Fig. 179

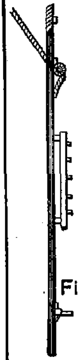


Fig 178

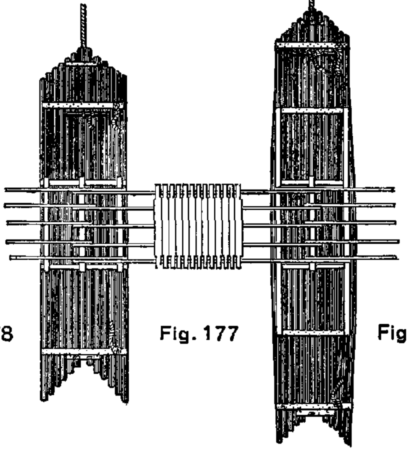


Fig. 177

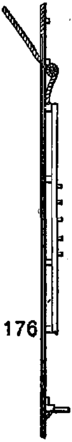


Fig. 176

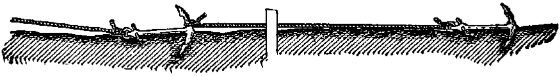


Fig. 180

be designed as in par. 59 for spar bridge. With scow-built barges, which will usually have excess of supporting power, a serviceable bridge is readily built. If the boats are large and well decked, they may be placed endwise in the bridge, separated by 20 ft. or more, the intervals spanned by bays of roadway and the decks used for roadway on the boats themselves. With boats of different shapes and sizes, such a bridge should be attempted with great caution, and only under exceptional circumstances.

89. **Barrel piers.**—When barrels are available, floating piers can be made by assembling a sufficient number of them by means of timbers or lashings, or both combined. An ordinary 50-gallon barrel has a buoyancy of about 400 lbs. when completely submerged; those of other sizes in proportion to their capacity. The supporting power of any barrel or keg can be determined with sufficient accuracy by weighing it when full of water and again when empty; the difference will be the supporting power.

The number of barrels required for a pier is obtained by dividing the total load to be borne by the supporting power of one barrel. A margin of 20% or 25% should be allowed, as the barrels of a pier must not be completely submerged.

In forming the piers the barrels are laid out in line with the bungs uppermost. The gunwale timbers are placed over and the rope slings under the ends, the slings secured to the gunwales at each end of the line. Between each pair of barrels on each side a brace is secured to the sling and then led around the gunwale on its own side, round the opposite brace rope and back again to its own gunwale, where it is made fast, figs. 171, 172, and 173. Care must be taken in launching to avoid injuring the ropes by chafing on the ground.

The rafts so formed may be united into larger ones as indicated in fig. 174.

Where timber is available the best method of forming a barrel pier is to make an inverted box crib of lumber or timbers nailed, bolted, or lashed together. If the crib is as strong as it should be, it may be inverted over the barrels, which will require no other fastenings. Fig. 175 shows this method.

90. **Raft piers.**—Rafts of timber may be used for floating piers when other materials are not at hand. They are durable if not disturbed and secure against being sunk by hostile fire. Their defects are, small and decreasing buoyancy, great weight, and bulk; figs. 176 to 179.

The buoyancy of each stick used may be obtained from the following rule: Find the girth or circ. at middle point in ft., multiply it by itself, multiply this product by the factor 0.08, and multiply again by the length of the stick in ft. The result will be the volume of the stick in cu. ft., which, multiplied by the difference between $62\frac{1}{2}$ and the weight of a cu. ft. of the timber, gives the supporting power in lbs. when fully submerged.

Example: Find the net buoyancy of a pine log with a middle girth of 6 ft. and a length of 35 ft., and which weighs 40 lbs. to the cu. ft.

Volume in cu. ft. $= 6 \times 6 \times 0.08 \times 35 = 100.80$ cu. ft.

Buoyancy $= 100.80 \times (62\frac{1}{2} - 40) = 2{,}268$ lbs.

Allowing $\frac{4}{5}$ of this as available buoyancy, a bridge of 7 such logs in each pier, with 20 ft. bays, will carry the maximum infantry loads calculated in paragraph 85 for the heavy bridge.

91. **Construction** of the **rafts** is done in the water if possible. Arrange the logs side by side to form a point upstream, fig. 177. The upstream ends should be beveled on the lower side, fig. 176. The logs are held together by cross timbers pinned or spiked over the tops. Where the logs are of small size additional sticks may be placed in the intervals between the others, or two or more courses may be built up, the logs of each layer at right angles to those below. The latter method has been found advantageous in constructing rafts of bamboo.

92. **Anchorage** of **floating bridges.**—The anchorage of the piers of a floating bridge is of the greatest importance. The piers should be so constructed and placed as to present the least obstruction to the current. In nontidal streams all the bows are placed upstream; in tidal estuaries they should alternate up and down stream.

The piers near the shore should be secured by strong cables to rocks, trees, or deadmen on the shore above and below.

Abutment.					Up. str. anchors.					Down str. anchors.					Balk carriers.						Balk lashers.					Chess.												Side rails.					Cable.
	1	2	3	4	X	1	2	3	4	X	1	2	3	4		1	2	3	4	5	X	1	2	3	4		1	2	3	4	5	6	7	8	9	10	11		1	2	3	4	1
X	1	2	3	4	X	1	2	3	4	X	1	2	3	4	X	1	2	3	4	5	X	1	2	3	4	X	1	2	3	4	5	6	7	8	9	10	11	X	1	2	3	4	1

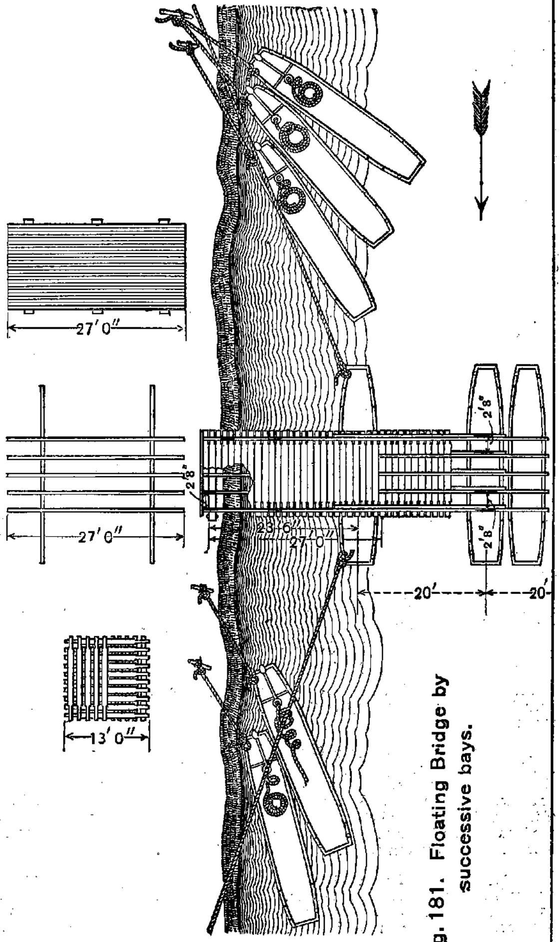


Fig. 181. Floating Bridge by successive bays.

For the heavy and light bridge equipage the anchors provided are sufficient, and in moderate currents it will answer to anchor alternate boats upstream and every fourth one downstream; the downstream anchors always on boats which have upstream anchors also. In swift currents it may be necessary to anchor every boat upstream. Even in slack water every second or third boat should be anchored both up and down stream to reduce oscillation.

For any other kind of floating bridge every pier must be securely anchored. Ordinary anchors can be relied upon in good holding ground only; when it is poor or the current unusually swift two anchors may be used, one backing up the other, fig. 180. Or, the following devices may be used:

A line of schooners or large barges may be anchored above the bridge and the piers moored to them, or,

A hawser may be stretched across the stream, buoyed on intermediate floats if necessary, and the anchor cables carried to it, or,

Long guys may be carried direct from each pier to the shore and secured as before indicated.

The *length of cable between anchor* and *pier* should be at least *ten times* the *depth* of the stream. Otherwise the anchor is likely to drag and a downward pull is brought on the upstream end of the pier. The anchor must be cast as nearly as possible directly upstream from the position which the pier is to occupy, so that the pier in the bridge will have the same position that it would assume if riding at anchor.

Improvised anchors may be made of any heavy materials on hand, as railway iron, pieces of machinery, or large stones. Such anchors must be of considerable weight, as dependence is placed on their mass rather than their attachment to the bottom.

93. **Construction of floating bridges.**—The regular bridge equipage is designed for unloading, construction, removal, and reloading in the shortest possible time, and its systematic drill is given in a separate manual. This elaborate drill is necessary only for troops handling the equipage habitually. The descriptions given of the methods of construction recommended involve the principles of the Ponton Manual and are illustrated for the heavy equipage but are adapted in language to all kinds of floating bridges, the ponton equipage being here considered simply as one kind of bridge of that class. The method selected will depend upon the character of the stream, the kind and location of materials, the force available, and the proximity of the enemy. It may be desirable to combine two or more of the methods described.

A *tug* or *power launch* is of the greatest assistance and no effort should be spared to obtain one.

The three methods available are: (1) By successive bays, (2) by parts, (3) by rafts.

94. *By successive bays*, fig. 181.—In a trench 1 ft. deep and wide lay the abutment sill horizontal and at right angles to the axis of the bridge. Secure it by four large pickets, two in front and two in rear, near the ends. A support or pier, be it boat, barrels, or raft, is brought close to the bank opposite the abutment sill. The free ends of cables, previously fastened on the bank 30 or more paces above and below, are passed onto the pier. A set of balks are brought up, the outer ends placed on the saddle sill of the pier and lightly secured. The pier is pushed off until the inner ends of the balks can be placed on the abutment sill, when all fastenings are completed. The floor is then laid on the balks placed, and the second pier is brought alongside of the first, its anchor having been previously cast. A second set of balks are brought up and the operation is repeated until the other shore is reached, where an abutment sill is laid as before described and the shore bay completed. Unless the supports are manageable boats, all anchors should be dropped from a special boat and the cables passed onto the piers.

95. *Construction by parts*, fig. 182.—For long bridges the method by successive bays requires materials to be transported considerable distances. These may be reduced by constructing the bridge in parts along the shore above. Each part may conveniently consist of three bays. To construct the parts a pier is moored close to the shore and gangways are temporarily laid to it from the bank. The other two piers are brought up outside the first and two bays are constructed successively, as above described, except that the outer bay is constructed first and shoved out into

the stream by the balks of the inner bay. Enough of the floor is omitted from each end of the part to permit fastenings to be made. The materials for the floor of one bay are loaded on the part thus formed, which is then pushed off and conducted to the line of upstream anchors, where it casts its anchors and drops down to its place in the bridge. If not easily manageable, the part may be swung out into the stream on an anchor previously laid.

An abutment will have been formed and one or more floating bays constructed during the construction of the part, a few planks being omitted from the outer end. The first part is brought into position opposite the shore end and connected to it by constructing one bay of roadway from the material loaded on the part. The other parts are joined in the same way until the opposite shore is reached, when an abutment bay is formed, as before described.

96. *Construction by rafts*, fig. 183.—Rafts differ from parts only in having the roadway completed. Rafts are assembled in the bridge with the outer piers of adjacent rafts in contact. The roadway is made continuous by connecting or false balks laid on top of the floor over the outer balks and connected to them to form a splice. For the heavy train, devices called rack collars are provided for clamping the false balks, fig. 184.

This method is not often employed, as it requires more piers for the same length of bridge and distributes the support unequally, throwing the roadway into humps when loaded.

97. *Draw spans in floating bridges*, fig. 185.—To form a draw a raft is introduced into the bridge over the channel of navigation. The attachments of the false balks are adapted to convenient removal and replacement. To open the draw the raft is disconnected from the bridge, the upstream cables slacked off, the raft dropped out of the opening, made fast at one end to the bridge and allowed to swing around. If the current does not suffice, the raft must be moved by hauling on the downstream cables and on a swinging cable laid for the purpose. A wide draw in a strong current may be made of two rafts, one swinging on each end of the bridge.

The draw is closed by hauling the raft around until parallel to the bridge and just below it, and then hauling it into the gap.

98. *Care must be taken* to provide a free hinging motion between abutment or trestle bays and those next to them. In case of a staunch boat with straight sides, the balks may join on one gunwale, one set only extending across. The hinge should be on the side toward the abutment or trestle, fig. 186. A saddle sill on the first pier to receive the balks will answer, figs. 187, 189. In fact, with the exception of the heavy bridge train, balks will usually be supported on saddle sills.

The *abutment sill* should be placed as low as possible without danger of being washed out. The abutment bay will usually be nearly horizontal when the bridge is light. When the bottom is of mud or sand, and shoals gradually, the sill may be placed about 2 ft. above high-water mark, and the part of the bridge near the shore built at high water by successive bays. As the water falls, the piers ground successively, forming a gentle ramp from the abutment to the floating part of the bridge. Ordinary boats can not be so used, as they will not support the weight when grounded. If the banks are high, ramps must be dug, reaching the proper level for the abutment sill, and long enough to give a practicable slope for the traffic using the bridge, fig. 189.

A bridge may be laid with extended intervals to cover a greater length by placing the balks as in fig. 188. Proper allowance must be made in loading.

99. Figs. 190, 191, 192, and 193 illustrate the assembling and placing of the *Birago trestle*, which forms part of the ponton bridge equipage. Two methods are shown, one by means of a raft of two boats, and the other by a single boat. In either method the trestle assembled and in a vertical position is brought up to the end of the bridge, the trestle balks placed on the cap and lashed, and the boat or raft then pushed out until the inner ends of the balks fall in place. The trestle legs are then let go, and when the shoes are on the bottom, the false legs are set and the boat or raft removed.

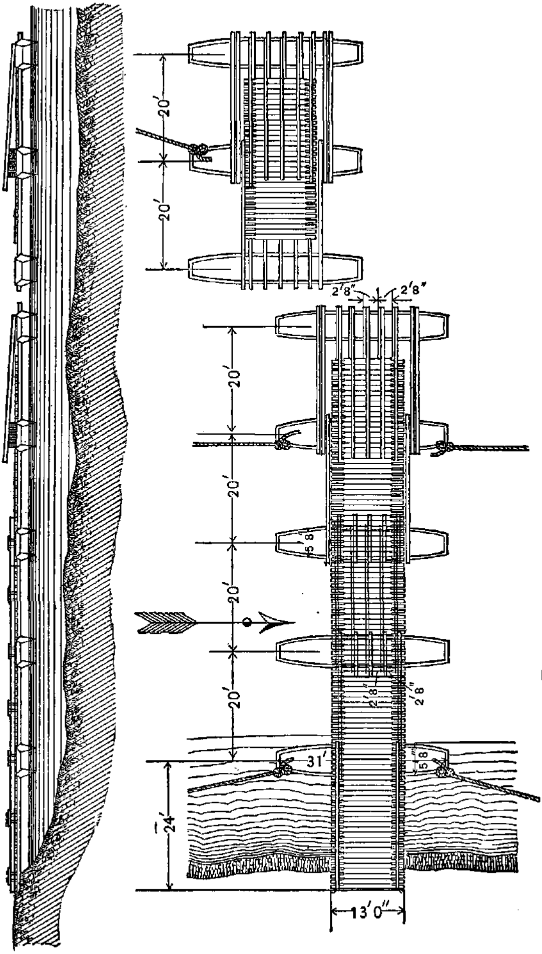


Fig. 182. Floating Bridge by parts.

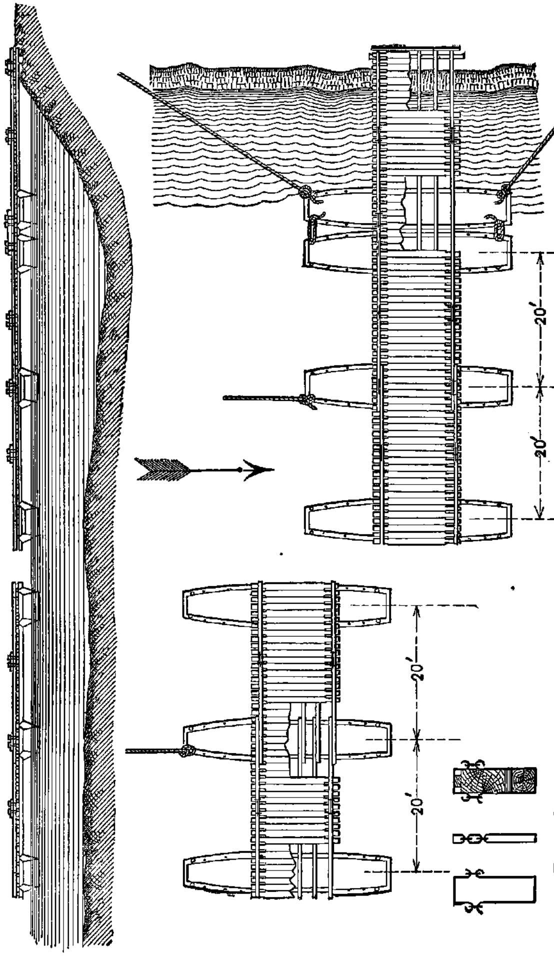


Fig. 183. Floating Bridge by Rafts.

Fig. 184.

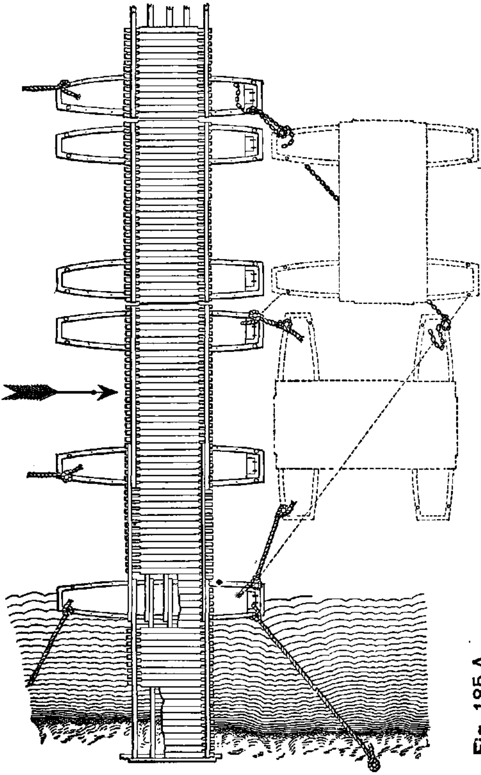


Fig. 185

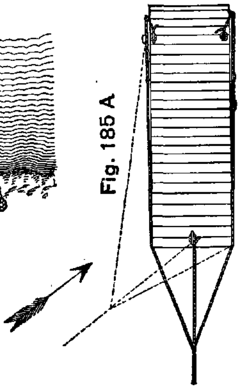


Fig. 185 A

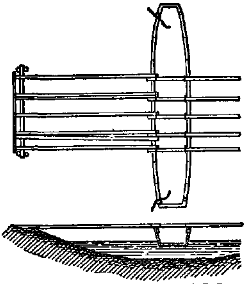


Fig. 186.

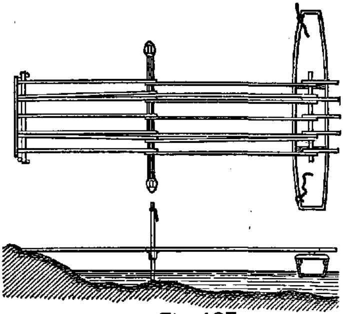


Fig. 187.

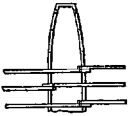


Fig. 188.

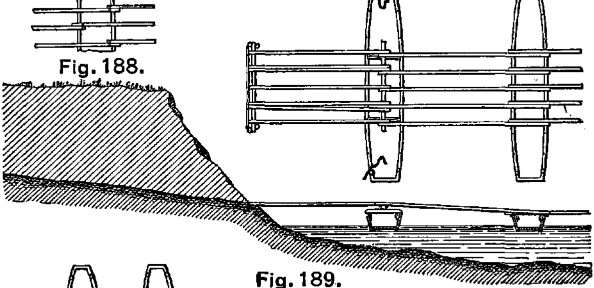


Fig. 189.

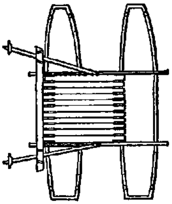


Fig. 190.

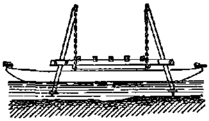


Fig. 193.

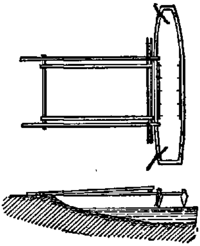


Fig. 191.

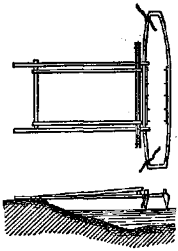


Fig. 192.

100. **Examples** of calculations for floating bridges:

To find length of bay: Piers of flat-bottomed boats with vertical sides, 5 ft. wide, 3 ft. deep, allowed immersion $2\frac{1}{2}$ ft. Mean length of part immersed 16 ft. Weight of boat = 1,000 lbs. Dead load, 80 lbs. per lin. ft.; live load, 560 lbs. per lin. ft.

Maximum displacement, 16 by 5 by $2\frac{1}{2}$ ft. = 200 cu. ft.
Weight of water displaced, 12,500 lbs.
Weight of boat deducted, 1,000 lbs.

Available buoyancy of one boat, 11,500 lbs.

Maximum length of bay $= \frac{11500}{560 + 80} = 18$ ft. nearly.

To find capacity of bridge with barrel piers: Pier of 70 barrels, buoyancy per barrel, $112\frac{1}{2}$ lbs.; length of bay, 10 ft.; dead load, 105 lbs. per lin. ft.

Required the maximum live load:

Available buoyancy of one pier $112\frac{1}{2} \times 70 \times .8 = 6{,}300$ lbs. Deduct weight of superstructure, 10×105 lbs. $= 1{,}050$ lbs.

Available buoyancy per bay, 5,250 lbs.

Maximum live load per lin. ft., $\frac{5250}{10} = 525$ lbs., or, length of bay for any assumed live load, say 400 lbs. per lin. ft., $\frac{5250}{400} = 13$ ft. +

To find capacity of bridge with raft piers: Piers of 7 logs each; length of logs 45 ft.; mean girth, $4\frac{1}{2}$ ft.; weight of timber, 35 lbs. per cu. ft.; dead load, 150 lbs. per lin. ft. of roadway; intervals between centers of piers, 19 ft.

Required the maximum live load: Volume of log, par. 90, $4.5 \times 4.5 \times 0.08 \times 45 = 72.5$ cu. ft. Volume of 7 such logs, 507.5 cu. ft. Supporting power of pier, $507.5 \times (62.5 - 35) \times 0.8 = 11{,}160$ lbs. Deduct dead load, $150 \times 19 = 2{,}850$ lbs. Net buoyancy per bay, 8,310 lbs. Maximum live load for 19-ft. span, $\frac{8310}{19} = 437$ lbs per lin. ft., or, length of bay for any assumed live load, say 500 lbs. per lin. ft., $\frac{8310}{500} = 16.6$ ft.

101. **Precautions in passing floating bridges.**—Infantry must break step and music cease; distances must be maintained or extended; riders and drivers must dismount and all horses must be led. Halting on a bridge should be avoided. If it is absolutely necessary to halt on a floating bridge, concentrated loads, such as the wheels of wagons and guns, should rest between piers. Interruptions of the column of march and alternations of direction should be made as few as possible. The greatest strains on the bridge occur when part of it is empty and the rest loaded. The column should also be so arranged as to make the alternations among the different classes of loads, as troops, artillery, and trains, as infrequent as possible.

If a bridge begins to sway or oscillate considerably the column must be halted and not allowed to resume its march until the swaying has ceased.

102. **Protection of floating bridges.**—The bridge must be kept clear of drift and other floating objects, especial attention being given to the anchor cables. If the objects are not too large or too numerous they may be passed under the bridge by men working with pike poles from the piers and roadway. Large trees may be disposed of in this way by sawing them up into logs of manageable length. Floating objects may be prevented from striking the bridge by a guard upstream, or by a draw span in the bridge, or by a floating boom crossing the stream obliquely.

A guard, if used, is placed about 1,000 yards above the bridge. It is stationed in boats at different points across the stream and is provided with cables, grapnels, anchors, dogs, hammers, saws, etc. The business of this guard is to anchor or tow ashore dangerous drifting bodies.

The floating boom is constructed of trees united by chains and forms a continuous barrier to surface drift. Its general direction should form an angle of about 20° with the current, giving it a length about $2\frac{3}{4}$ times the width of the river. A boom is not a very reliable protection.

A guard should always be posted at a floating bridge with a sentry at each end, and if the bridge is long, at intermediate points. Sentries turn out the guard whenever the bridge is in danger from any cause. The body of the guard should be stationed near one end of the bridge.

The guard will regulate the traffic over the bridge and enforce orders as to right of way of vehicles desiring to cross in opposite directions. They will see that loads greater than those prescribed for the particular bridge do not enter.

The officer in charge of a floating bridge must frequently inspect the cables to see that they are not chafing and that the anchors do not drag. He will cause rack lashings to be tightened up when they work loose and see that boats are bailed or pumped when they leak or ship water. A suitable depot of spare balks, floor planks, cordage, etc., should be established on shore near one end of the bridge. The guard will be stationed at the same end.

Ice, if thin or rotten, is a serious obstacle to crossing a stream; if thick and sound, it is a very good bridge itself. Boats used in ice must be protected with chafing pieces, especially near the water line at the bows. Heavy ice, rapidly moving, makes a crossing impracticable.

With sound ice, infantry may pass on 3 ins. thickness and cavalry on 4, but with large intervals. Fieldpieces are safe on 6 ins., and ice 10 ins. thick will carry any load that an army is likely to have.

Loads may be carried on lesser thicknesses or on unsound ice by distributing the weights. Infantry may cross on lines of planks. The wheels of wagons may be skidded on planks. Wagon boxes may be placed on boards and used as sleds to cross supplies. Animals may be hauled across on platforms.

In shallow lakes, springs are apt to cause weak spots. A path should be carefully examined by chopping through the ice at frequent intervals to determine its thickness and quality, and when a safe track is found it should be marked on both sides by bushes stuck in holes in the ice.

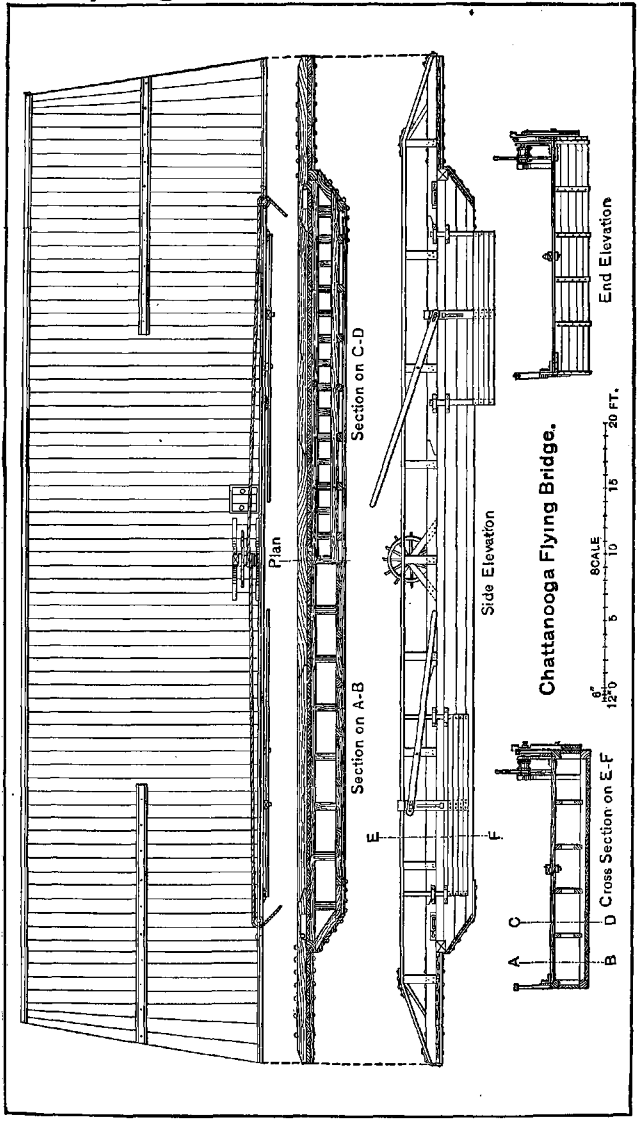
BARGES.

103. A few types of barges of simple, quick construction are shown in the plates. They are useful in towing and lightering, are easy to manage, and are staunch in rough weather. Fig. 194 shows a barge or flying bridge used at Chattanooga during the civil war for crossing men and wagons over the Tennessee River. It will carry four 6-mule teams and wagons besides infantry and cavalry. The cable was attached to an island above and was supported upon three floats. The connection with the boat was made by a rope with both ends fastened to the end of the cable, passing through snatch blocks at the bow and stern of the boat on the upstream side and around a windlass at the middle. The velocity was controlled by turning the windlass to give the hull the proper direction with respect to the current. Leeboards near bow and stern were used to catch the current and increase its force.

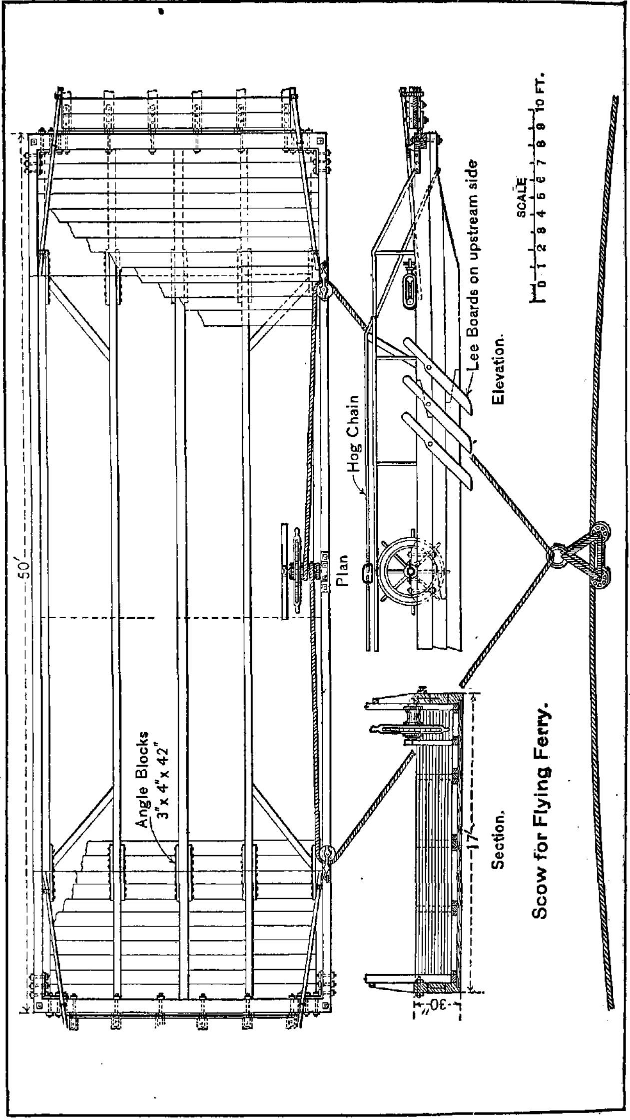
In swift currents the scow can not be held broadside to the stream. The roadway must then be made across instead of along the deck. To make the bridles, attach the end of the main cable at the middle of the bow. Stop the bight of a line to the cable 50 to 75 ft. above the scow and lead its ends to tackles on the starboard and port sides. By slacking the port tackle and holding the starboard a bridle is formed to the right, and by the reverse process a bridle is formed to the left, fig. 185*a*. If it be desired to stop quickly, as on landing or avoiding floating objects, let both tackles go and the scow rides at ease on the main cable.

Fig. 195 shows a smaller barge than the preceding. It is operated by the force of the current, but by means of a traveler or trolley running on a cable stretched across the stream. It will carry two field pieces, with four horses each, side by side. It differs from the former one in having the flooring on the bottom of the boat instead of being decked. For temporary use, loose planks called *dunnage* can be laid on the bottom frames.

Figs. 196 to 199 show a type of barge easily built by ordinary carpenters. It is best built bottom side up. Place skids or ways on or near the ground parallel to each other and about 10 ft. apart, with their upper sides in a plane, horizontal or slightly inclined. Get out the gunwales complete, with timberheads attached, and place them on the ways in their relative positions, but upside down. Build the intermediate frames in their relative positions, also upside down. Plank the bottom, making close joints on the inside and beveling the plank at the edges so as to have a $\frac{1}{8}$ to $\frac{1}{4}$ in. open seam on the outside. This is called *outgauge* and facilitates calking. Put on the head blocks and the corner irons. Then calk, and stay the gunwales by spiking a few deck planks on. Slide the barge into the water, still bottom side up.



Chattanooga Flying Bridge.



Scow for Flying Ferry.

Calking is done with oakum or cotton, which is driven into the seam with the calking tool and calking mallet. Oakum comes in bales and must be picked and spun before use. Picking is the process of loosening up the compressed fibers of the oakum by pulling and beating. The loose oakum is spun by rolling it into a rope or strand usually under one hand across the knee, feeding the material from the loose pile with the other hand. The spun oakum is ½ to 1 in. diam., according to the thickness of planks and size of seams.

Calking cotton comes in a strand wound into balls and is ready for driving.

Seams should be well filled with material driven hard.

In recalking, the old work should be *horsed up*, which is done by driving it in with the large tool and a sledge.

The seam is finished by a *paying* with paint or pitch.

Certain marine animals destroy calking by eating the oakum. This may be prevented by laying a strand of hard-twisted rope, called *ratline*, on the top of the seam, secured to the planks by staples. If the seams are wide, wide strips of wood may be used.

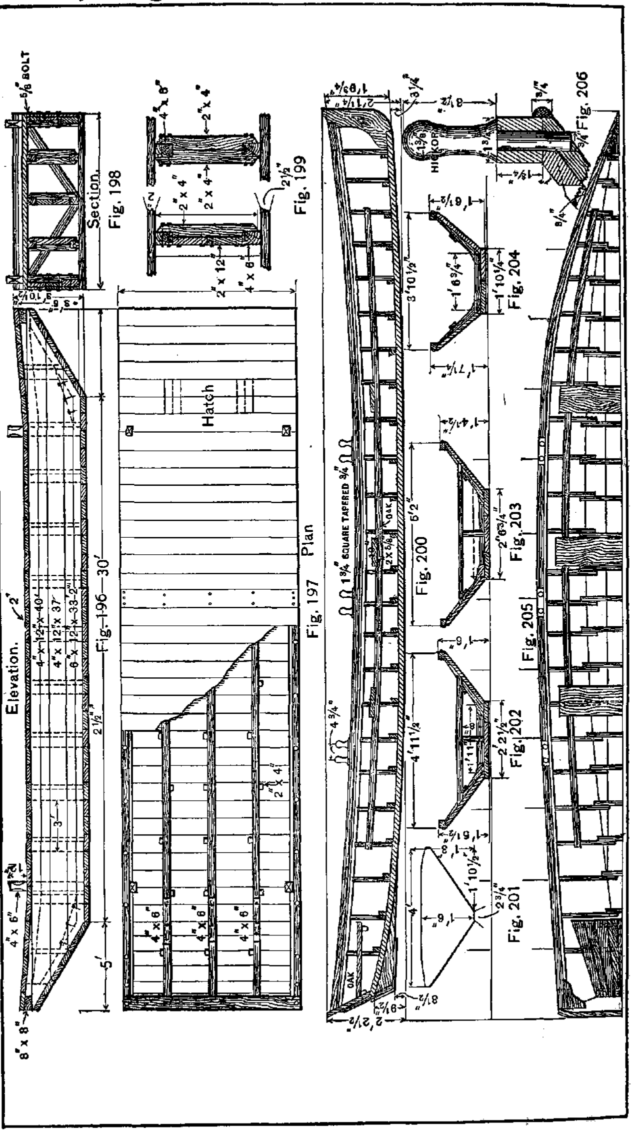
To turn the barge over lay her along the bank. Fasten two lines to the outside gunwales, pass them under the boat, and lead well upstream. Shovel earth on the outer edge of the bottom till it is partially submerged, then slack off the upper line, allowing the upper end to swing out into the stream until the barge lies with one end to the bank instead of the side. Hold fast both lines and the current will right the boat. A depth of water of somewhat more than half the width of the boat and a current of 1½ miles per hour are necessary to the success of this operation. It is most conveniently done at the shore, but may be done in the stream or in slack water if a tug or other means be available to set a strain on the lines.

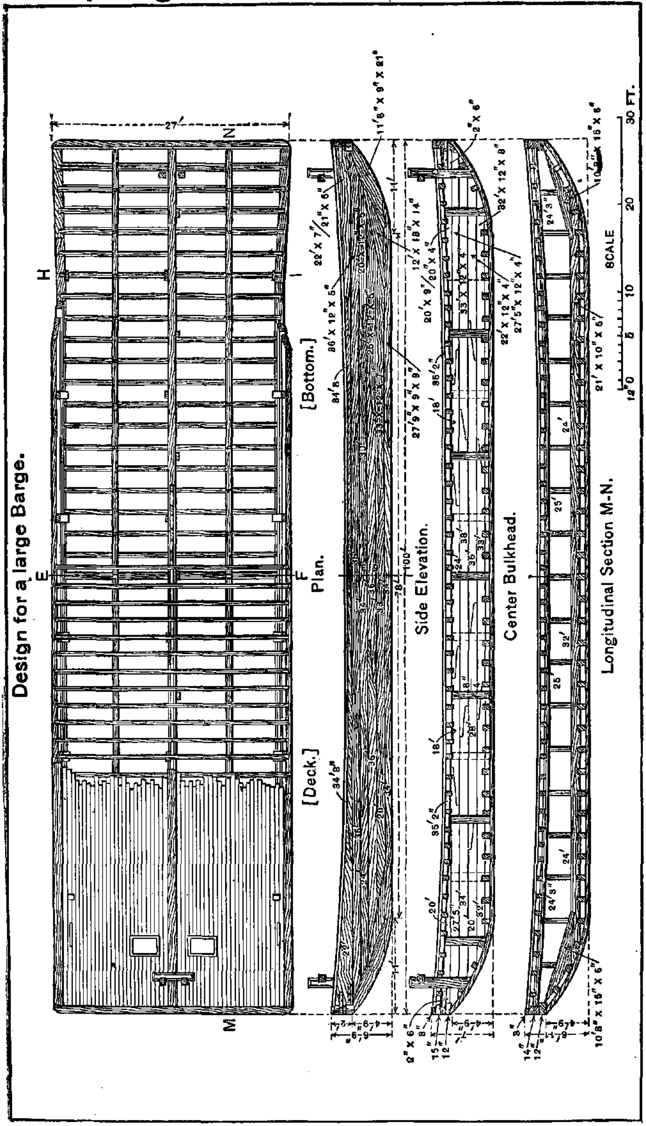
104. Bill of materials:

Gunwales, 2 pieces, 4 by 12 ins. by 40 ft.
Gunwales, 2 pieces, 4 by 12 ins. by 37 ft.
Gunwales, 2 pieces, 6 by 12 ins. by 33 ft. 2 ins.
Head blocks, 2 pieces, 8 by 8 ins. by 10 ft.
Knees, 6 pieces, 4 by 6 ins. by 3 ft.
Struts, 42 pieces, 2 by 4 ins. by 2 ft. 10 ins.
Braces, 4 pieces, 2 by 4 ins. by 7 ft.
Timberheads, 4 pieces, 4 by 6 ins. by 4 ft., oak.
Deck stringers, 3 pieces, 4 by 6 ins. by 40 ft.
Floor stringers, 3 pieces, 4 by 6 ins. by 33 ft.
Rake stringers, 6 pieces, 4 by 6 ins. by 6 ft.
Bottom planks, 45 pieces, 2½ by 12 ins. by 10 ft.
Deck planks, 43 pieces, 2 by 12 ins. by 10 ft.
Driftbolts, 20, ⅝ in. by 3 ft. 10 ins.
Driftbolts, 4, ⅝ in. by 2 ft. 6 ins.
Driftbolts, 4, ⅝ by 12 ins.
Driftbolts, 4, ⅝ by 8 ins.
Carriage bolts, 20, ⅝ by 9 ins.
Carriage bolts, 12, ⅝ by 12 ins.
Spikes, 6-in., 150 lbs.
Spikes, 5-in., 250 lbs.
Corner bands, 4, $\frac{3}{16}$ by 4 ins. by 4 ft.
Countersunk-head spikes, 40, ¼ by 4 ins.
Oakum, 30 lbs.
Pitch or seam paint, 5 gals.

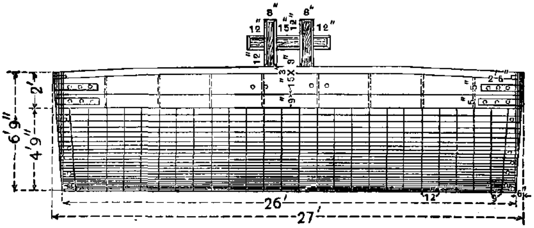
Figs. 200 to 206 show a skiff easily constructed and valuable for a number of purposes. It may be 18 to 26 ft. long, with parts proportioned as in the drawings.

Figs. 207 and 208 show a design for a 100-ft. barge. This barge is of greater dimensions than any of the preceding and somewhat more elaborate in construction. It was designed specially for carrying stone and would be useful in heavy water transportation generally. The construction is shown in detail and to scale, and is within the limits of ordinary rough carpentry. It should be built on ways, top side up, and planked from below.

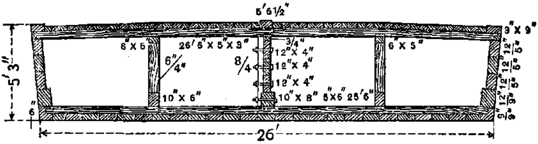

Elevation.
Fig. 196—30′
Plan
Fig. 197
Hatch
Section.
Fig. 198
Fig. 199
Fig. 200
Fig. 201
Fig. 202
Fig. 203
Fig. 204
Fig. 205
Fig. 206
OAK
HICKORY
1¾″ SQUARE TAPERED ¾″
⅝″ BOLT



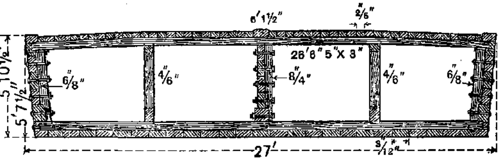
Design for a large Barge.



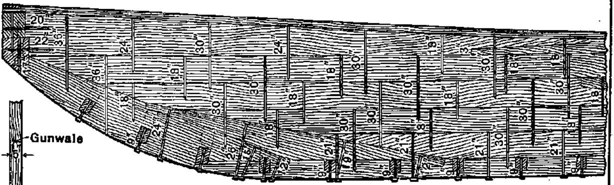
End Elevation.



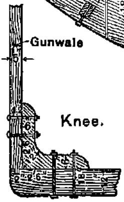
Section E-F.



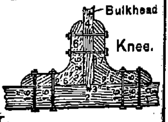
Section H-I.



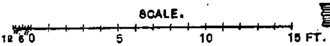
Section through Gunwale Rake.
Showing Bolts.



Knee.



Knee.



CANTILEVERS.

105. A **cantilever** is a projecting or overhanging support, transmitting all of its load to one of its ends.

The cantilever principle may be utilized in military field bridges for short spans and moderate loads. Some typical forms are shown in figs. 209 to 212. The main points to be observed are that the maximum pressure on the abutment is greater than the heaviest load, live and dead, on the projecting part of the cantilever; that any settlement of the abutment causes a greater disturbance of the bridge; and that the weight or resistance of the anchor multiplied by its distance from the abutment must be greater than the greatest concentrated load multiplied by the length of the projecting part, or the greatest uniform load multiplied by half that length.

If the anchorage is beneath the beams as in figs. 209 and 210, the roadway may be laid directly upon them. If the anchorage is above the beams, separate road bearers must be provided resting on transoms carried by the cantilevers, and high enough at the inner end to pass over the anchorage; or the cantilevers may be at the sides only, as in figs. 211 and 212.

Bear in mind that the *safe load* of a cantilever, concentrated or uniform, is $\frac{1}{4}$ of the corresponding safe load of the same beam supported at both ends with the same span, and that the *deflection* of the cantilever under any load less than the safe load will be 10 to 16 times greater than the deflection of the same beam under the same load when supported at both ends. Much greater vibrations must be expected than in girder or truss bridges.

If the two cantilevers meet at the middle of the bridge they must be fastened together. This doubles the safe concentrated load for the bridge, making it equal to one-half the safe uniform load of both cantilevers instead of one, or one-half the safe concentrated load on a beam of the size and length of one cantilever supported at both ends.

When separate road bearers are used, the transoms are better arranged so that there will be a middle bay resting one end on each cantilever, figs. 211 and 212.

If the cantilevers do not meet, the gap is filled by a girder or truss supported by the ends of the cantilevers. This arrangement may be useful in case timbers too short to span the gap have to be used. To get the maximum strength for timbers of a given size, the cantilevers should be $\frac{1}{7}$ and the girder $\frac{5}{7}$ of the span.

106. When objects of sufficient mass and stability are available. the counterbalance is not necessary and the cantilevers take the form of brackets, fig. 213. If the opposite brackets meet and are well connected the structure becomes of the spar-bridge type, and there is no overturning moment on the abutments. Abutments which will sustain the weight of the cantilevers themselves and the working parties before they are connected will permit the construction of such a bridge. The two brackets on the same side should be connected by diagonals.

107. The horizontal and inclined members of a bracket are single sticks, or built up as may be most convenient. They are connected by fish plates. The vertical member is best made in two pieces. The parts should be accurately assembled on the ground and bored for the bolts. The fish plates are bolted to the strut. Place the strut between the verticals and connect them at the lower ends by a single bolt. Launch the three over the edge of the wall or bank, and lower until the tops of the ties are at the proper height, and make fast by an auxiliary piece bolted or lashed to the ties on the outside, leaving the strut free to rotate about the bolt at its foot. Then raise the end of the beam to the top of the strut and connect by one bolt. Launch out the beam until its inner end falls in place between the ties. Then set all the bolts and tighten up.

TRUSS BRIDGES.

108. A **truss** is a compound beam the parts of which are so disposed as to form one or more triangles in the same plane. The triangle is the only closed figure which is rigid. Four given sides may be formed into an infinite number of quadrilaterals, and similarly for a greater number of sides. It is only the resistance of the joints to bending which prevents the distortion of any of these figures, or its complete collapse. But a given three sides can be formed into one triangle and only one; hence, if the joints do not separate no side of a triangle can leave the position in which it is placed for another in the same plane.

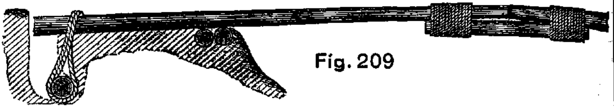


Fig. 209

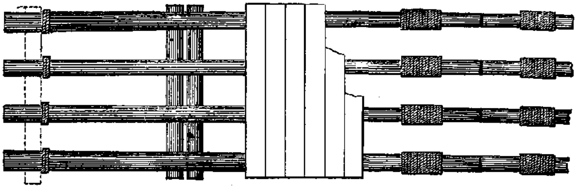


Fig. 210

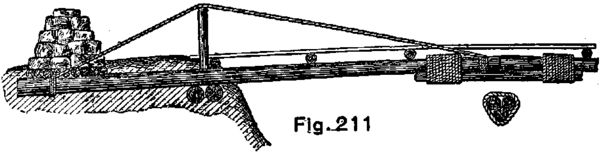


Fig. 211

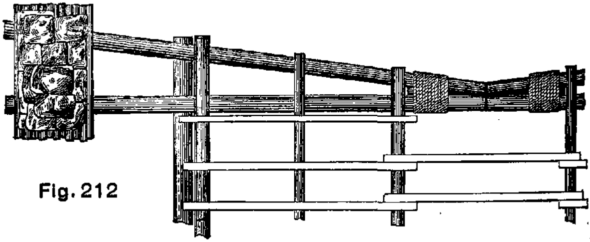


Fig. 212

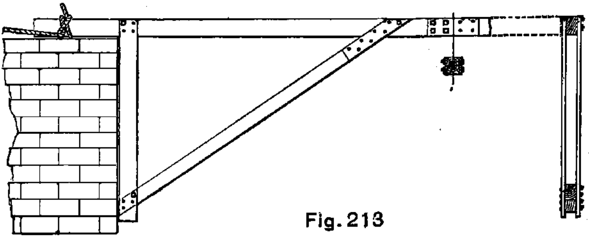


Fig. 213

Except in some of the simplest forms, the parts of a truss are subjected to tension and compression only, transverse strains being practically eliminated. For this reason parts can be combined into a truss of much greater length and supporting power than a possible single beam.

109. The simplest form is the *trussed beam*, in which a part of the load is taken up at an intermediate point and transferred directly to the ends, figs. 218 and 219.

In the *king-post* truss, fig. 214, the upright member is in tension and carries ½ the gross load on the truss, or ¼ the gross load on the bridge. One-half of this, or ⅛ the gross load on the bridge, is transmitted in compression by the inclined struts from the apex A to the ends of the beam at B and C, causing stresses, as shown in Table XXV.

In the *queen-post* truss, fig. 215, two points of the beam are supported, forming three equal bays. The counter braces in the middle panel are frequently omitted, and the resulting combination of two triangles and a parallelogram is not rigid and is not a true truss. As half of the bridge is loaded the other half tends to rise, permitting the loaded half to sink, the beam taking the form of an S. If the beam be stiff enough to withstand this double bending effect the bridge will be safe, but no stronger than if the beam were divided into two bays instead of three. In this form each post carries ⅛ of the total load, dead and live, on the bridge, all of which is transmitted down the corresponding strut.

110. The *stresses* in king and queen post trusses depend upon the *load* and the *inclination* of the struts. The load may be stated in tons or lbs. for the entire bridge. The inclination of the struts is represented by the ratio between the height of posts and the length of bay.

Besides the stresses on rods and struts there is a *tension* on the *beam*. It varies in the same way as the other stresses, and sufficient cross section must be given the beam to withstand it, in addition to that figured for the transverse strength. In the queen-post truss the upper horizontal member or straining beam takes this same stress, but in compression.

TABLE XXV.

111. **Stresses** on members of **king** and **queen post trusses** in terms of *total load* on bridge, for various inclinations of struts:

Ratio of height of post to length of bay.		King-post.		Queen-post.	
		Stress on each strut.	Stress on each beam.	Stress on each strut.	Stress on each beam.
1.		2.	3.	4.	5.
Customary range for inverted truss.	0.05	2.50	2.49	3.33	3.33
	0.10	1.25	1.24	1.66	1.66
	0.15	0.84	0.83	1.12	1.11
	0.20	0.64	0.62	0.85	0.83
	0.25	0.52	0.50	0.69	0.66
	0.30	0.42	0.40	0.58	0.55
	0.40	0.34	0.31	0.45	0.42
Customary range for erect truss.	0.50	0.28	0.25	0.37	0.33
	0.60	0.25	0.21	0.32	0.28
	0.70	0.22	0.18	0.29	0.24
	0.80	0.20	0.16	0.27	0.21
	0.90	0.19	0.14	0.25	0.18
	1.00	0.18	0.12	0.23	0.17

Fig. 214

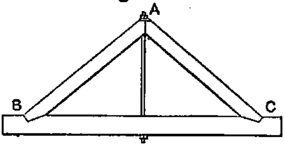
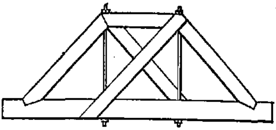


Fig. 215



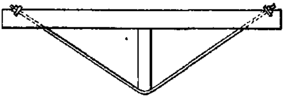


Fig. 216

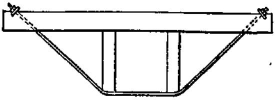


Fig. 217

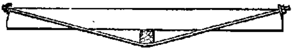


Fig. 218

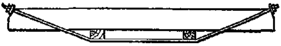


Fig. 219

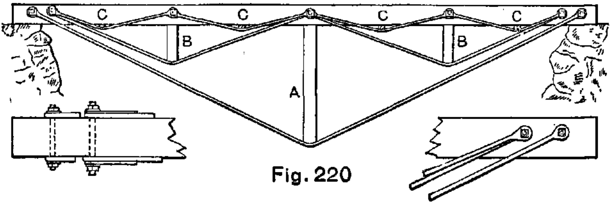


Fig. 220

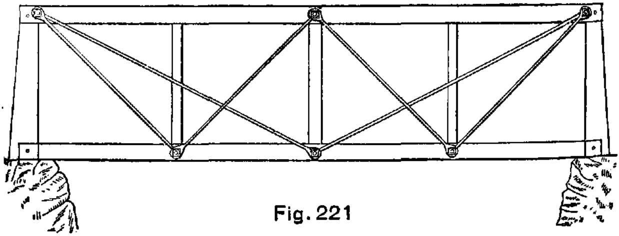


Fig. 221

TABLE XXVI.

112. **Sizes** and **tensile strengths** of **iron rods,** standard threaded, with assumed elastic limit of 30,000 lbs. per sq. in., strength computed for area inside threads:

Diam. of rod.	Tensile strength.	Diam. of rod.	Tensile strength.	Diam. of rod.	Tensile strength.
In.	*Lbs.*	*Ins.*	*Lbs.*	*Ins.*	*Lbs.*
1/8	294	1 1/8	23,857	2 1/8	85,119
1/4	1,178	1 1/4	29,453	2 1/4	95,426
3/8	2,650	1 3/8	35,638	2 3/8	106,322
1/2	4,712	1 1/2	42,412	2 1/2	117,809
5/8	7,363	1 5/8	48,774	2 5/8	129,886
3/4	10,603	1 3/4	57,727	2 3/4	142,552
7/8	14,432	1 7/8	66,269	2 7/8	155,803
1	18,850	2	75,399	3	169,646

113. **To design such a truss,** determine the span and gross load per lin. ft., and from them the total load on the bridge. Take from Table XXVI the size of the rod corresponding to the load. This size gives a factor of safety of 4 for king-post and 6 for queen-post. If timber is used, divide the load by the tensile strength of the wood, Table II, column 4. The result will be the required cross section in ins. of each post, with the same factors of safety as before.

To determine the size of struts, divide the length of post by length of bay, and with the quotient enter Table XXV and take out the factor from column 2 for king-post or column 4 for queen-post truss. Multiply the load by the factor. The result will be the maximum stress on the strut. With the length of strut enter Table IV and take out the size corresponding to a load next above the strain just found. Sticks of this size will give a factor of safety of 5.

Multiply the load by the factor in column 3 or 5, Table XXV, corresponding to the inclination of the strut already found, and the result will be the stress (tension) *on the beams.* Divide this stress by the tensile strength of the material, Table II, column 4. The result, multiplied by 5, will be the sq. in. of cross section to be allowed for this stress, with a factor of safety of 5. Unless the posts are short, this strain may be neglected.

Consider 1/4 the load applied uniformly to 1/2 the beam for king-post and 1/6 the load to 1/3 the beam for queen-post, and determine, as in paragraph 13, the size of beam of sufficient transverse strength. Add the cross section found above for the tensile strain. The sum will be the entire cross section of the beam.

114. **Example.**—To design a queen-post truss for a span of 45 ft., a dead load of 150 lbs., and a live load of 850 lbs. per lin. ft., or 1,000 lbs. gross. Total load, 45,000 lbs. Assume height of posts at 10 ft.

Size of rod, Table XXVI, 1 5/8 ins. diam.; or, if wood be used, then—

Size of posts (yellow pine), $\frac{45,000}{9,000}$, Table II, column 4 = 5 sq. in. area of cross section. A larger post with excess of strength would be used to give better joints.

Size of struts.—Height of the post, 10 ft. ÷ by length of bay, 15 ft., = 0.67. From Table XXV, column 4, opposite 0.70 in column 1, take factor 0.22. 45,000 multiplied by 0.22 = 9,900 lbs. = maximum stress on each strut. Length of struts = $\sqrt[2]{15^2 + 10^2}$ = 18 ft. In Table IV, opposite 18 ft. in column 1, the load 10,182 lbs. corresponds to a post 7 by 7 ins., which is the minimum size for struts.

Longitudinal stress on beam.—Multiply 45,000 by the factor 0.24 in column 5, Table XXV, corresponding to 0.70 in column 1. The result, 10,800 lbs., is the longitudinal stress on the beam. This divided by the tensile strength, 9,000, gives 1.2 sq. ins., which multiplied by a f. s. of 5 gives 6 sq. ins. to be added to the cross section of beam on account of this stress.

For transverse strength of beam.—One-sixth of load, 7,500 lbs. uniformly distributed over a clear span of 15 ft., breadth $\frac{2}{3}$ of depth, requires, by Formula A, paragraph 13, a beam 6.2 by 9.3 ins. = 57.66 sq. ins. Add the area to resist tensile strain on the beam, 6 sq. ins., as found above, and there results a total cross-sectional area of 63.66 sq. ins., or, in practice, a beam 7 by 10 ins.

The compression on the upper chord or straining beam is the same as the tension on the lower beam, 10,800 lbs. Its length is 15 ft., and from Table IV a 7 by 7 in. stick is found to be amply strong.

Each truss will then consist of a beam of 45 ft. clear span, not less than 7 by 10 ins. in cross section; two struts 18 ft. long, not less than 7 by 7 ins. in cross section; one straining beam, 15 ft. long, not less than 7 by 7 ins. in cross section; and two rods $1\frac{5}{8}$ ins. diam., or wooden posts of not less than 5 sq. ins. in cross section. In framed wooden structures it is desirable to have one dimension the same in all the pieces that meet at a point, and a considerable excess of material in the structure often results. In this case it will be convenient to take the beam 7 by 10 ins., struts 7 by 7 ins., straining beams 7 by 7 ins., and posts, if of wood, double, each half 3 by 7 ins.; or else beams 6 by 11 ins., struts 6 by 8 ins., straining beams 6 by 8 ins., and posts 3 by 7 ins., double.

Fig. 232 shows arrangement of a 30 ft. queen-post truss for a highway bridge, having about the dimensions above computed.

115. For a light *railroad bridge* of 30 ft. span and 10 ft. high, the following dimensions may be used for a king-post truss: Chord 10 by 18 ins., struts 10 by 10 ins., and rods $2\frac{3}{4}$ ins. diam. or better, two rods at each post, each $1\frac{7}{8}$ ins. diam., and several inches apart transversely of the bridge.

116. **Inverted forms.**—Both king and queen post trusses may be inverted, figs. 216 and 217. All stresses of tension and compression are then reversed. The principles of design are not affected by the change, but wood must be used for posts, and iron is much better for the inclined members and for the lower chords of queen-post trusses. The rods are best made double, one on each side of the beam, and fastened to bolts through the beam at the middle point of its depth. Three or more inverted trusses may be placed beneath a single-track roadway. Of the erect type but two can be used. Double-track bridges are often built with three erect trusses.

117. **Erection of small trusses.**—With a single beam long enough to span the opening the truss may be built in place. The same may be done with a spliced beam, provided it is stiff enough to support its own weight plus that of the men and materials necessary to complete the truss.

The simplest way to get a beam across an opening is to attach a rope to one end and pass it over to the other side; then launch the beam out and haul the front end up with the rope, fig. 222.

Two methods, in which the further bank need not be occupied, are illustrated in figs. 223 to 225. In one case an auxiliary beam, and wheels and axle from an ordinary wagon or cart, are used as indicated to place the beam on its abutments. No support between banks is needed. In the other case, two spars are stepped on the bottom as indicated, and their tops lashed together to form a fork, into which the beam is placed. The beam is then pushed across, the spars revolving on their lower ends. The spars must be long enough to reach the higher of the two banks.

Complete trusses may be sprung across by similar means. The application of the second method to an erect king-post truss is illustrated in fig. 224. Inverted trusses may be kept upside down until on the abutments and then turned over, provided the chord has sufficient lateral stiffness.

118. **Completion of the bridge.**—The trusses being in position, vertical and parallel to each other and secured, lay floor joists from truss to truss 18 to 30 ins., c. to c., and on them lay a double course of diagonal planking, the upper course at right angles to the lower. Or, lay floor transoms at intervals of about 5 ft., and on them stringers, the latter carrying a single course of cross plank, or two diagonal courses crossed. Planks should be at least $1\frac{1}{2}$ ins. thick; if less, lay more courses.

Assuming a live load of 100 lbs. per sq. ft. for highway bridges, 3 by 10 in. floor joists spaced 30 ins., c. to c., will be safe up to 12 ft. clear width between trusses, or 3 by 12 ins. up to 16 ft. For the same load, floor transoms 5 by 10 ins., 5 ft. apart, will be safe up to 13 ft. clear distance between trusses, or 6 by 12 ins. up to 17 ft.

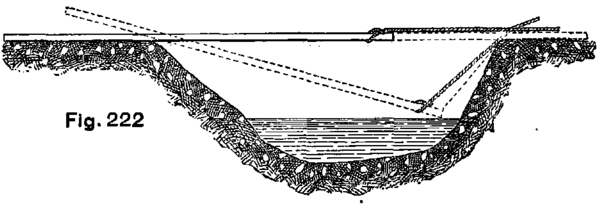


Fig. 222

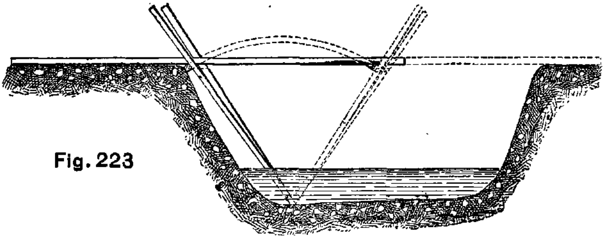


Fig. 223

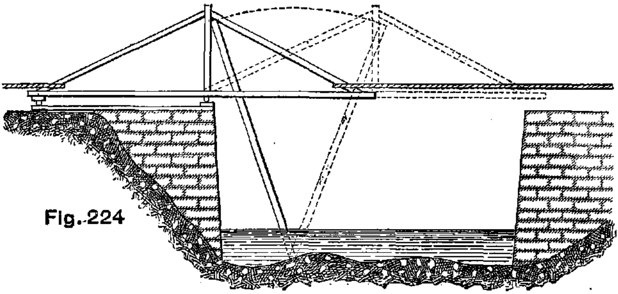


Fig. 224

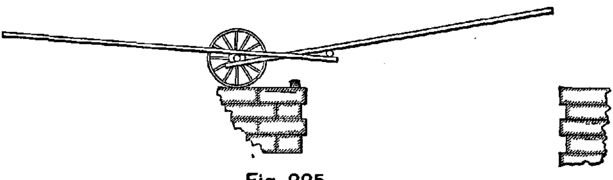


Fig. 225

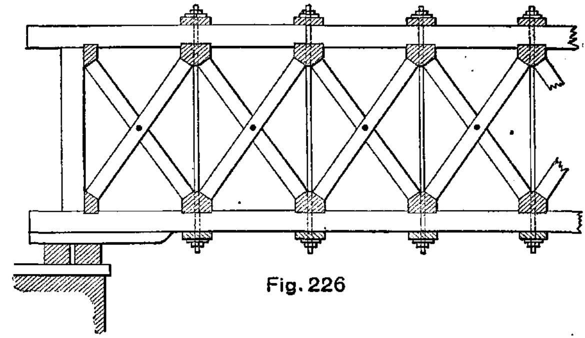


Fig. 226

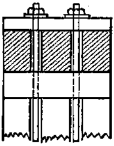


Fig. 227

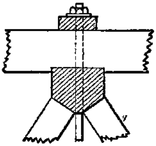


Fig. 228

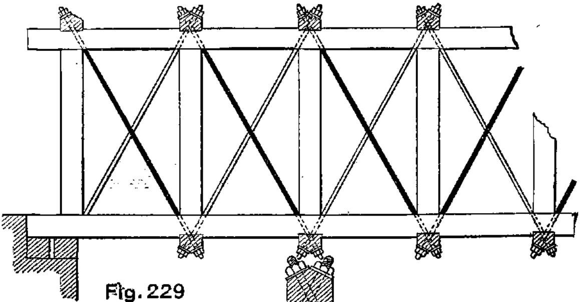


Fig. 229

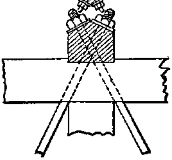


Fig. 230

On these transoms stringers should be 4 by 6 ins., spaced 18 ins., c. to c., for single, and 30 ins., c. to c., for double planking. See par. 118*a*, p. 243.

If the beam of the truss has not been designed to take transverse strains, the floor transoms must be placed at the panel points on the beam, or hung below them, as in fig. 232. Such a transom must be strong enough to take the load on one span of the bridge. The stringers, spaced as above, must be increased in size for their increased length. If a queen-post truss, it will be necessary to introduce the diagonal counter braces which may be smaller than the struts. One must run through and the other be made in two pieces so that both counters may be in the same plane, fig. 232.

119. **The Fink truss,** figs. 220 and 221, is a superposition of king-post trusses. It is practicable in the inverted form only, but may be elevated on posts as shown in fig. 221. In this case all the posts are best made of equal length to form the supports of the roadway. A primary post supports the middle, which becomes a central support for two secondary trusses, and the two points supported by the secondary posts *BB*, become in turn supports for four tertiary trusses *CC*, and so on. The stresses in the primary truss are worked out as in paragraph 113. The stresses for secondary and tertiary trusses are worked out in the same way, taking ½ the load on the bridge for the secondaries and ¼ for the tertiaries. The details of fastenings are shown in fig. 220.

120. **The Howe truss,** fig. 226.—This useful form consists of two parallel chords, usually continuous built-up beams, divided by posts in tension into equal panels, each of which has diagonals in compression. The upper chord is in compression, the lower in tension. Each chord is made up of three or more parallel timbers of uniform size, with lengths adapted to properly distribute the splices. The timbers are separated by the diameter of the largest rods so that the latter may pass through the spaces. The main braces are one less in number than the pieces in the chord and abut, top and bottom, against angle blocks of metal or hard wood, triangular in section and extending entirely across the chord. Against these blocks the counter braces, one less in number than the main braces, also abut. The vertical rods of each post are equal in number to the main braces. The relative positions of members at the panel points are shown in figs. 227 and 228. In permanent structures a cast-iron angle block is generally used. The ends of struts abut squarely against the ends of the block and are kept in place by tightening up the nuts on the rods. Iron angle blocks are formed to hold the braces in place even if slightly loose. When wooden blocks are used, cleats should be nailed on or dowels inserted in the ends of the braces for the same purpose. The timbers of the Howe truss are all square-sawed and have no mortises or tenons.

121. The **stresses** in a *chord* of a Howe truss are a maximum at the center and when the truss is loaded throughout its length. This maximum stress = the total load on the bridge × span in ft. ÷ 16 times height of truss in ft.

The chord stress in the *end panels* will not exceed ¼ the load on the bridge unless the length of the panel is greater than its height, which should never be the case. Between these lower and higher limits the chord stresses vary, but not by equal increments. The change is more rapid near the ends and less so toward the middle. For wooden trusses, convenience in framing requires that all chord pieces have one dimension the same, and it is not customary to make more than one change in the aggregate chord sections. This is done by bolting extra timbers on each side of the lower chord over its *middle third.*

122. The *stresses* in the *braces* are greatest at the ends and least in the middle. The maximum stress in the *end brace* is ¼ the load on the bridge divided by the length of the post and multiplied by the length of the brace. It will not exceed ⅓ of the total load on the bridge, unless the panel height is less than the panel length, which should never be permitted. The maximum stress in the *middle brace* will not exceed ½ the total load on *one panel* of the bridge, divided by the length of the post and multiplied by the length of the brace. Between these limits the stresses in the braces vary uniformly.

123. The stresses in *verticals* are greatest at the ends and least in the middle. The maximum stress in an *end rod* will not exceed ¼ of the total load on the bridge. The maximum stress in a *middle rod* will not exceed ¾ of the total load on *one panel.* Between these limits the stresses in verticals vary uniformly.

The stresses in *counter braces*, commonly called *counters*, depend upon the ratio of live to dead load per unit of length, and the distribution of the live load on the bridge. With the live load uniformly distributed over the entire length, there are no stresses in the counters. For the bridge partially loaded, the maximum stresses in counters are in the center panels and diminish rapidly toward the ends.

The assumption that the maximum uniformly distributed live load will not exceed the maximum uniformly distributed dead load per unit of length is safe for military truss bridges of 75 to 100 ft., or 6, 8, and 10 panels in length. Under this assumption, the 6-panel truss needs no counters.

The 8-panel truss requires counters in the panels adjacent to the center of ¼ the strength of the main diagonals in the same panels. No other counters are required.

The 10-panel truss requires counters in the same panels of ½ the strength of the main diagonals. No other counters are required.

For a ratio of live to dead loads of 2 to 1 the 6-panel truss requires counters in the middle panels of ⅓ the strength of the corresponding main diagonals; the 8-panel truss requires counters in the same panels of ⅔ the strength of the main diagonals, and the 10-panel truss requires counters in the same panels of equal strength with the main diagonals.

For ratios greater than 2 to 1, and especially for rapidly moving live loads, the center counters should be equal to the main diagonals, and counters of half the size should be placed in the next panels toward the ends.

These rules apply principally to trusses in which the inclined members are of metal and for which the areas can be conveniently varied. In the Howe truss convenience of framing has made it the usual practice to put counters of uniform size in all panels.

TABLE XXVII.

124. **Dimensions** for each of two **Howe trusses** of a single-track **railroad bridge.** Authority, Trautwine. Working stress of timber, 800 lbs. per sq. in. Working stress of iron, 12,500 lbs. per sq. in. The *middle third* of each *lower chord* must be *reenforced* by ⅙ of the cross section given in the table.

Clear span.	Rise.	Number of panels.	Upper chord.		Lower chord.		End brace.		Center brace.		Counter.		End rod.		Center rod.	
			No. pcs.	Size.	No. pcs.	Size.	No. pcs.	Size.	No. pcs.	Size.	No. pcs.	Size.	No. pcs.	Size.	No. pcs.	Size.
Ft.	*Ft.*			*Ins.*		*Ins.*		*Ins.*		*Ins.*		*Ins.*		*Ins.*		*Ins.*
25	6	8	3	5 x 6	3	5 x 12	2	5 x 8	2	5 x 6	1	5 x 6	2	1¾	2	1⅛
50	9	9	3	6 x 9	3	6 x 14	2	6 x 9	2	5 x 8	1	5 x 8	2	2	2	1⅜
75	12	10	3	6 x 12	3	6 x 14	2	6 x 11	2	6 x 8	1	6 x 8	2	2⅜	2	1½
100	15	11	3	6 x 14	3	6 x 16	2	8 x 12	2	6 x 10	1	6 x 10	2	2¾	2	1¾
125	18	12	4	6 x 14	4	6 x 16	2	9 x 14	2	6 x 12	1	6 x 12	2	3¼	2	2
150	21	13	4	8 x 14	4	8 x 18	3	8 x 14	3	6 x 10	2	6 x 10	3	3	3	1½
175	24	14	4	10 x 16	4	10 x 20	3	8 x 15	3	8 x 10	2	8 x 10	3	3¼	3	1¾
200	27	15	4	12 x 16	4	12 x 20	3	9 x 16	3	8 x 14	2	8 x 14	3	3¾	3	2

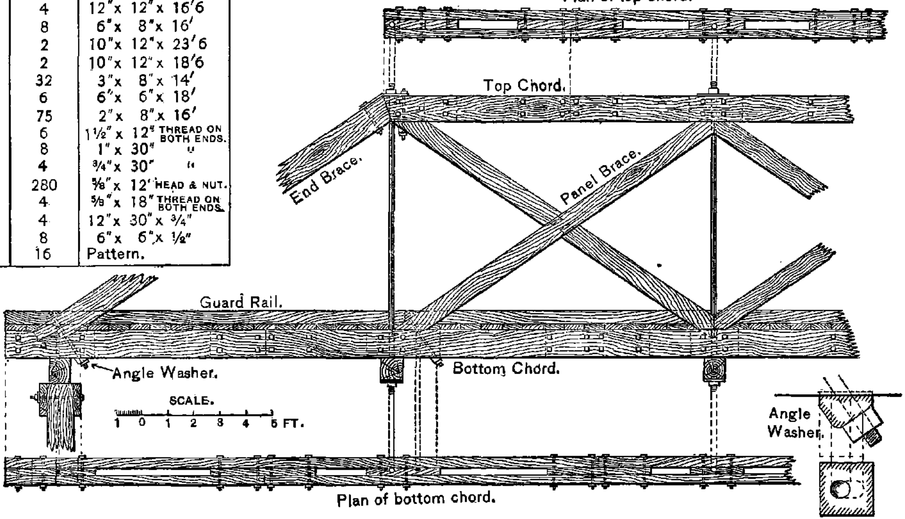
The above dimensions will be safe for a double-track highway bridge of the same span, or for a single-track highway bridge of 1½ times the span, the number of panels being increased one-half. Spans greater than 150 ft. should not be attempted in the field unless the difficulty of obtaining an intermediate support is very great.

The end posts and the upper chords and counters of the end panels of the Howe truss are not necessary and are frequently omitted. Fig. 231 shows the details of a 50-ft. truss so designed.

125. The *safety* of *existing bridges* may be tested by the rules for maximum stresses given above. Thus:

50′ Truss Bridge.

Section Similar to 30′ Truss. Fig. 232.



BILL OF MATERIALS		
Parts.	No. Pcs.	Size.
Bottom Chords.	10	4″ x 12″ x 23′
Top "	10	4″ x 12″ x 18′6
End Braces.	4	12″ x 12″ x 16′6
Panel "	8	6″ x 8″ x 16′
Transoms.	2	10″ x 12″ x 23′6
Wall Plates.	2	10″ x 12″ x 18′6
Floor Joists.	32	3″ x 8″ x 14′
Guard Rail.	6	6″ x 6″ x 18′
Floor Planks.	75	2″ x 8″ x 16′
Iron Rods	6	1½″ x 12′ THREAD ON BOTH ENDS.
" Bolts.	8	1″ x 30″ "
" "	4	¾″ x 30″ "
" "	280	⅝″ x 12′ HEAD & NUT.
" "	4	⅝″ x 18″ THREAD ON BOTH ENDS.
" Plates.	4	12″ x 30″ x ¾″
" Washers.	8	6″ x 6″ x ½″
Angle "	16	Pattern.

30 Ft. Truss Bridge

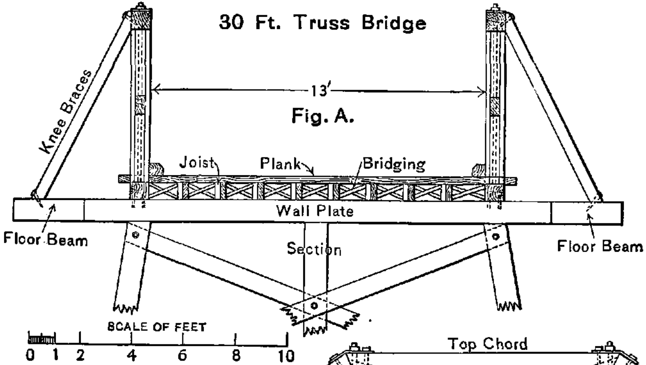


Fig. A.

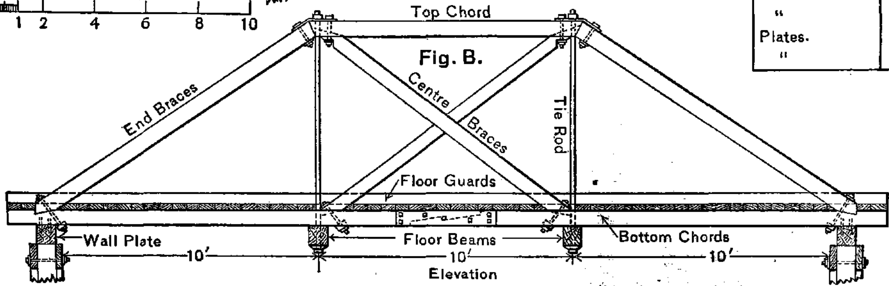


Fig. B.

BILL OF MATERIALS.		
Parts.	No.Pcs.	Size.
Bottom Chord.	4	8″ x 8″ x 17′
End Braces.	4	8″ x 8″ x 13′4″
Top Chord.	2	8″ x 8″ x 10′9″
Center Braces.	4	4″ x 6″ x 12′
Floor Beams.	2	8″ x 10″ x 23′6″
" Joist.	24	3″ x 8″ x 12′
" Planks.	51	2″ x 8″ x 16′
" Guards.	4	6″ x 6″ x 17′
Knee Braces.	4	6″ x 6″ x 8′
Wall Plate.	2	8″ x 10″ x 18′
Bridging.	9	2″ x 4″ x 16′
Rods.	4	1⅜″ x 9′6″
Bolts.	8	⅞″ x 21″
"	4	⅞″ x 12″
"	4	⅞″ x 10″
Plates.	4	8″ x ½″ x 48″
"	4	8″ x ¾″ x 12″

To determine the safe load on a bridge of two trusses of the dimensions given in the table for 100-ft. span.

Maximum chord stress = load × span ÷ 16 times height of truss.

Cross section of chord at middle = 288 sq. ins. At 800 lbs. per sq. in., the total working stress = 115 tons. Hence, $115 = \frac{\text{load} \times 100}{16 \times 15}$, or load = 276 tons, which divided by the span gives 2.76 tons load, live and dead, per lin. ft.

For an end brace, two 8 × 12, or two 10 × 10, $17\frac{1}{2}$ ft. long, working load, Table IV, 35 tons, divided by length of post, 15 ft. = 2.33 × length of brace, $17\frac{1}{2}$ ft. = 44 tons × 4 = 176 tons total load, or 1.76 tons per lin. ft.

For the verticals: The area of two rods $2\frac{3}{4}$ ins. diam. = 11.88 sq. ins. At 12,500 lbs. per sq. in., the total working stress = 74 tons × 4 = 296 tons total gross load, or 2.96 tons per lin. ft. For a middle post, the area of two rods $1\frac{1}{2}$ ins. diam. = 3.53 sq. ins. at 12,500 lbs. = 22.1 tons ÷ $\frac{3}{4}$ = 28 tons panel load × 11 = 308 tons total load on 11 panels, or 3.08 tons per lin. ft.

The value 1.76 tons for the end brace is the least and is the safe load of the bridge. Compute the dead load per ft. and subtract it from 1.76 tons; the remainder will be the safe live load. In this case the safe live load is about 1 ton per lin. ft.

126. **Pratt truss**, figs. 229 and 230.—The form and the distribution of stresses are the same as the Howe. The disposition of materials in web members is reversed, the verticals being of wood and in compression and the diagonals of metal and in tension. The arrangement at panel points is modified accordingly. The chords are the same as for a Howe truss of the same span, height, and load.

The Pratt truss is frequently modified by giving its end panels the same form as shown in the 50-ft. truss, fig. 231, the end posts, upper chords, and rods of the end panels being suppressed and a brace run from the end of the lower chord to the end of the upper one.

In both Howe and Pratt trusses care must be taken not to introduce unnecessary initial strain by setting up the rods too tight. The upper chord should be $1\frac{1}{2}$ ins. longer than the lower one for each 100 ft. of span; the excess to be divided equally among the panels. This prevents the upper chord becoming shorter than the lower when it is compressed and the lower one stretched by the load. The effect when the bridge is light is to give the truss a slight crown or camber.

127. **Erection of trusses.**—A scaffolding or false work must first be erected to sustain the parts of the truss until they are assembled. The false work will be ordinarily some form of trestle construction. The bottom chords are first laid with their ends in place on the abutments, and leveled. The top chords are then raised on temporary supports, footing on the false work, to positions a few inches above their final ones, so that the web members may be slipped into place. The top chord is then lowered until its weight comes on the braces in the Howe, or the posts in the Pratt truss. The nuts are then tightened, working uniformly along the entire truss, until the camber is developed and the middle of the truss rises, leaving its weight wholly on the abutments.

128. **Completion of the truss.**—The floor transoms are placed at the panel points. In the Howe truss they may hang by the rods below the lower chord, if a through bridge, or rest on the upper chord if a deck bridge.

For the Pratt truss the transoms may be doubled, resting on the bottom or top chords on either side of the panel point and as near together as possible. The floor system is completed by stringers and planking, as in paragraph 118.

129. Truss bridges require *lateral bracing* to withstand wind pressure and reduce vibration. It consists of a horizontal truss connecting the top chords and another connecting the bottom chords. The truss between the loaded chords should be proportioned by the foregoing rules for a load of 300 lbs. per lin. ft. if a highway or 450 lbs. if a railroad bridge. The truss between the other chords should be proportioned for a load of 150 lbs. per lin. ft. for all bridges.

The *lateral trusses* may be of the Howe or Pratt type. If the Howe, the braces must be in the same plane, one solid and the other framed into it, like the counters of the queen-post truss. The ends of the braces must be held in place by cleats spiked or bolted to the chords, or if iron angle blocks be used, by flanges cast on their bottom edges.

If the Pratt type be adopted, the ends of the posts must be similarly secured. For the loaded chords the road transoms serve as posts of a Pratt truss, which may be completed by adding the iron ties and without boring the chords. The ends of the transoms are shaped as angle blocks.

Generally the Pratt type will be best for the loaded chords and the Howe for the other lateral.

Unless the main truss is higher than the required head room on the bridge, the roadway must be placed on the upper chords, or else the trusses must be steadied by braces from the floor transoms, made longer and extending outside the trusses for that purpose; fig. 232.

SPECIAL FORMS.

130. Figs. 233 to 235 show a **double bowstring truss** which can be constructed of common boards and nails, or even with boards and pins. It does not possess advantages warranting its adoption when materials for standard trusses can be procured with equal convenience.

Lay out the truss by drawing on the ground two arcs of circles corresponding to the inner surfaces of the chords with a radius $2\frac{1}{2}$ times the length of the truss. Along these arcs drive stakes, around which bend the boards and nail securely to each other but not to the stakes. The boards are 1 by 12 ins.; the upper chord has 5 layers, the lower 6. The boards break butts and are nailed about every 4 ins. with 10*d*. nails; bolts or 6-in. spikes should also be driven through the lower chord at intervals of 6 to 12 ins. Bolts $\frac{1}{2}$ in. diam., set up tight, are the best.

The truss is divided into 10 panels by posts of 2 by 12 in. plank and tie-rods of $1\frac{1}{4}$ in. iron at each panel point. Main and counter braces of 2 by 12 in. plank are used in all the panels except at the ends, which are filled solid for about $4\frac{1}{2}$ ft. The chords are nailed to the blocks and the whole bolted through from top to bottom with 5 or 6 bolts at each end.

It will be found advantageous to cover the boards with a mixture of pitch and tar before they are nailed together to increase friction between them.

TABLE XXVIII.

131. **Bill of materials** required for **two double bowstring plank trusses** for each foot of span:

Lumber, 1 by 12 ins., 30 ft. B. M.
Lumber, 2 by 12 ins., 12 ft. B. M.
Lumber, 2 by 8 ins., 9 ft. B. M.
Nails, 10*d*., 2.5 lbs.
Nails, 20*d*., 1 lb.
Spikes, 6 in., 1 lb.
Iron rods, $1\frac{1}{4}$ ins. diam., 10 lbs.
Iron bolts, $\frac{1}{2}$ by 6 ins., 3 lbs.

The above quantities are approximate only, but suffice as a basis of estimate. The truss built as described will carry a live load of 500 lbs per ft. on a span of 60 ft., and proportionally more for shorter spans.

The roadway can best be carried on the top chord. The transoms should be at the posts. The middle one and the two on each side of it may rest directly on the chord. Those at 3, 4, and 5 tenths of the span from the middle on each side should be blocked up from the chord, 0.005, 0.010, and 0.018 of the span, respectively. This arrangement gives a camber of $\frac{1}{35}$ of the span. With the roadway on top, the trusses must be cross-braced with 2-in. plank as indicated in fig. 235.

If it is necessary to keep the trusses up, as for example to get above high water, the roadway may be carried between or below them. If between, bolt the transoms to the posts and extend them beyond the trusses far enough to receive steadying braces, fig. 232. The end transoms may rest on the abutments and the next ones to them on the lower chord. Stretch a line between the tops of the two which rest on the chord, raise this line at the middle post by the amount of camber desired, and mark on each intermediate post the point where the line crosses it, which will be the top of the transom on that post.

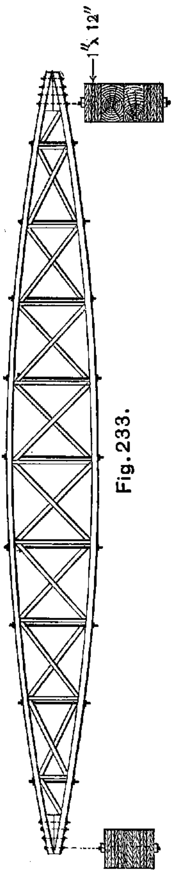


Fig. 233.

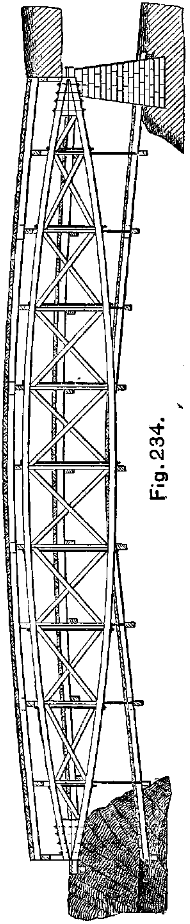


Fig. 234.

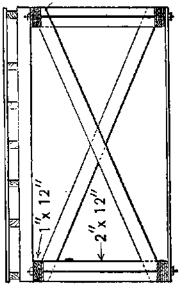


Fig. 235.

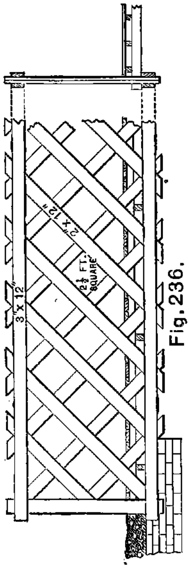
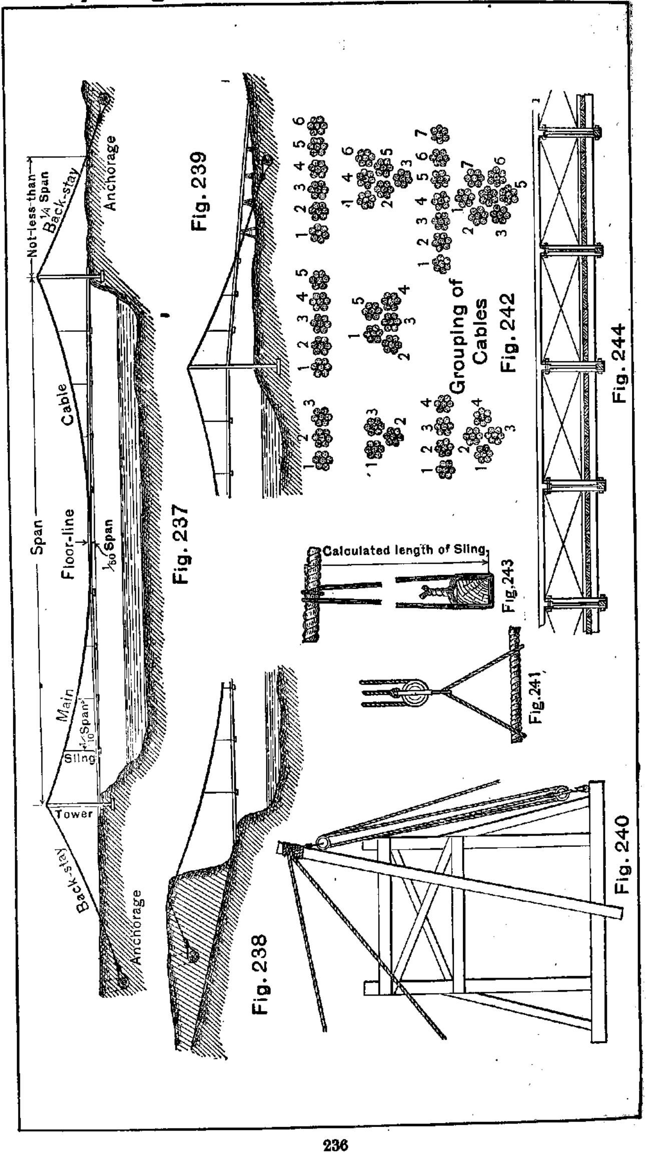


Fig. 236.


Span
Not-less-than 1/4 Span
Back-stay
Anchorage
Cable
Main
Floor-line
1/60 Span
1/10 Span
Sling
Tower
Back-stay
Anchorage
Fig. 237
Fig. 238
Fig. 239
Fig. 240
Fig. 241
Grouping of Cables
Fig. 242
Calculated length of Sling
Fig. 243
Fig. 244

By supporting the ends of the truss on posts or piers, the roadway may be carried at or below the bottom. The middle transom should be held firmly against the bottom of the chord. The next one on each side will be bolted to the chord through a block 0.006 of the span in thickness. These three transoms should extend beyond the trusses to receive steady braces. The second, third, and fourth transoms on each side of the middle will be hung below the chord by bolts or lashings, with clear intervals between bottom of chord and top of transom of 0.016, 0.038, and 0.062 of the span, respectively; this arrangement gives a camber of $\frac{1}{35}$ of the span.

The three floor systems described are shown in fig. 234. If dimension timbers can not be had for transoms, they may be made by nailing inch boards together. If such timbers are used they must be set with the boards on edge and stayed against lateral bending.

132. The **lattice truss,** fig. 236, may be built entirely of 2 or 3 in. planks and wooden pins. The latter will not be used if bolts can be had.

The disposition of material is clearly shown in the drawing. If there are three sets of planks the pairs must be in the position of braces and the single planks of counter braces. The planks are 2 or 3 ins. thick and 9 to 12 ins. wide, according to the span. They are placed about 2½ ft. apart, measured along the edges. Two to four pins or bolts, depending on width of plank, are placed at each intersection. The chords are formed of planks or timbers, with an aggregate cross section determined by the general rule for trusses, paragraph 121, and are pinned or bolted to the upper and lower edges of the lattice as indicated.

If the roadway be on the lower chord, its upper edge must be so placed that the transom can pass through the lattice and rest on it.

The *lateral bracing* may be as described for other trusses, paragraph 129, and is *very important*, as a chief defect of the lattice truss is its lack of lateral stiffness.

The lattice truss may be used for highway bridges up to 150 ft. span with depth of ⅙ the span.

SUSPENSION BRIDGES.

133. In this type of bridge the roadway is hung to two or more cables stretched from bank to bank, with their ends attached to fastenings called *anchorages*. The cables are allowed to sag; the greater the sag the less the tension, but the more the vibration. A sag of $\frac{1}{7}$ to $\frac{1}{12}$ the span is the best for field bridges. This fraction will be referred to as the ratio of deflection. The cables are usually passed over elevated supports called *towers*, to keep their lowest point above the roadway. The parts of the cables between the towers and the anchorages are called *backstays*. The connection between cables and roadway is by rods called *suspenders*, *ties*, or *slings*. The latter designation will be used. There is a sling at each end of each transom.

The principal features of a suspension bridge are indicated in fig. 237.

134. In military field operations the suspension bridge is best adapted to light loads or long spans or the two combined. The construction of a suspension bridge for heavy traffic will usually be impracticable with field equipment. When materials for non-floating bridge must be carried with a column, the suspension type is best because it is lightest for a given capacity and its materials are divisible into small portions for transportation.

TABLE XXIX.

135. **Data** for calculating **main cables** for **suspension bridges**; authority, Trautwine:

Deflection in parts of the chord.	Length of main cable between towers in parts of chord.	Tension on all the main cables at either tower in parts of entire suspended weight of bridge and its load.	Tension at the center of all main cables in parts of entire weight.	Angle of direction of cables at piers = A = angle made by cable with horizontal.	Radius = deflection multiplied by—
1.	2.	3.	4.	5.	6.
$\frac{1}{15}$	1.012	1.94	1.870	14° 55′	28.625
$\frac{1}{14}$	1.013	1.82	1.740	15° 57′	25.000
$\frac{1}{13}$	1.016	1.70	1.620	17° 6′	21.625
$\frac{1}{12}$	1.018	1.57	1.490	18° 33′	18.500
$\frac{1}{11}$	1.022	1.46	1.370	19° 59′	15.625
$\frac{1}{10}$	1.026	1.35	1.250	21° 48′	13.000
$\frac{1}{9}$	1.033	1.23	1.120	23° 58′	10.625
$\frac{1}{8}$	1.041	1.12	1.000	26° 33′	8.500
$\frac{1}{7}$	1.053	1.01	0.881	29° 45′	6.625
$\frac{1}{6}$	1.070	0.90	0.750	33° 41′	5.000
$\frac{1}{5}$	1.098	0.80	0.625	38° 40′	3.625

The above table is based on the assumption that the curve of the main cables is a parabola, which is not strictly correct, though near enough for all practical purposes. For ratios of deflection in the table, the curve is practically the segment of a circle, the radius of which may be taken from the 6th column of the table.

136. Having the *span* and total *live load* on the bridge, to determine the total area of the cables, compute the dead load as in paragraph 4; add the live load to it and multiply the sum by the factor in column 3 of the table corresponding to the adopted ratio of deflection. Multiply this result by the factor of safety. The product will be the ultimate strength which all the cables together should have. This divided by the number of cables to be used gives the ultimate tensile strength of each one, and its size and composition may be determined from Tables IX, X, or XXX. A lower factor of safety is admissible for wire than for most other materials, as it is very homogeneous in structure.

TABLE XXX.

137. **Composition** of **main cables** of **suspension bridges**; factor of safety $2\frac{1}{2}$; live load 200 lbs. per lin. ft.; dead load 100 lbs. per lin. ft.; ratio of deflection $\frac{1}{7}$:

Span.	No. of strands of $\frac{3}{4}$-in. wire rope in main cables.		Number of parallel steel wires in main cables.						
	Iron.	Steel.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.
Ft.									
45	4	2	14	16	20	24	28	34	42
60	4	2	18	22	24	30	36	46	56
75	4	2	22	26	32	38	44	56	70
90	4	2	28	32	38	44	54	70	84
105	4	4	32	38	44	52	64	80	98
120	6	4	36	42	50	60	72	90	112
135	6	4	40	48	56	68	80	100	122
150	8	4	46	54	62	74	90	112	140
165	8	4	50	58	68	82	100	124	154
180	8	4	54	64	76	90	110	136	170
195	10	6	58	70	80	98	118	146	182

For any other ratio of deflection, less than $\frac{1}{7}$, increase the tabular numbers by $\frac{1}{3}$ for each unit of the denominator above 7. For other loads, greater or less, increase or decrease the tabular numbers pro rata.

Example: How many No. 8 steel wires are required for the main cables of a bridge of 105 ft. span, ratio of deflection $\frac{1}{10}$, and a gross load, live and dead, of 600 lbs. per lin. ft.?

From the table, 105 ft. span, No. 8 steel wire, take 44. Add for change of ratio of deflection from $\frac{1}{7}$ to $\frac{1}{10}$, $\frac{3}{9}$ or $\frac{1}{3}$, making $58\frac{2}{3}$. For change from 300 to 600 lbs. load multiply by 2, making $117\frac{1}{3}$. Take next even number above, 118, which is the number required. If two cables are used, make each of 59 wires.

138. **Tension** on **backstays.**—If the cables are free to move on the tops of the towers, the tension on the backstays will always be the same as that on the cables. In this case the towers are stationary and should be massive.

If the cables are fixed to the tops of the towers, the tension on the backstays will be equal to, less than, or greater than the tension on the cable, accordingly as the slope of the backstay at the top of the tower is equal to, less than, or greater than the slope of the cable. It is usually best to make these slopes equal.

139. **Stresses** on the **towers.**—When the slopes of cables and backstays are equal, the stresses on each tower will be vertical and equal to the entire weight and load of the clear span.

When these slopes are unequal the pressure on the towers will be oblique. If the slope of the backstay is *less* than that of the cable the tower will tend to revolve or slide *toward* the anchorage, and the pressure on each tower will be less than the weight and load of clear span. If the slope of the backstay is *greater* than that of the cable the towers will tend to revolve or slide *toward each other*, and the stresses in each will be *greater* than the weight and load of clear span.

When possible, the horizontal distance from the foot of a tower to the corresponding backstay should be $\frac{1}{4}$ of the clear span or greater. In such case the tension on the backstay will not exceed that on the cable, and the pressure on the tower will not exceed the total weight and load of the clear span.

140. **Making cables.**—Three-quarter in. wire rope weighing 92 lbs. to the 100 ft. can usually be carried in lengths sufficient for practicable suspension spans, and will be the most convenient form.

If ordinary wire must be used, cables can be made by stretching wires, seven is a good number, close together and under equal strain, and binding them together at intervals of a ft. with marline or wire. If short cables are required, time may be saved by making one of two or more times the length and cutting it in pieces.

141. **Anchorages.**—These are of prime importance and must be secure and as rigid as possible. Their character will often be determined by accidents of the site. When the stumps of large trees are available they will usually be chosen. Ledge rock or large bowlders are the best, but require care and some skill in making the fastenings. Heavy staples leaded or wedged into holes drilled into the rock will usually be most convenient. If Portland cement can be had a grouting will hold the iron firmly after it is set. See also description of *deadman*, paragraph 49.

142. **Towers.**—Large trees will be used if available; otherwise trestles of timber; see paragraph 64. With high banks it may be feasible to start the cables from the surface of the ground or a short distance above it and provide approaches to a depressed roadway as indicated in fig. 238. For low banks the roadway must be kept above the grade as in fig. 239, the backstay carrying it beyond the tower.

The towers must be high enough to bring the supports of the cables called *saddles* above the level of the roadway at the tower by the desired deflection plus $\frac{1}{50}$ of the span, see paragraph 131.

143. **Placing cables** may be done by hauling across tops of towers, or by laying out cable from one anchorage to the other and raising the bights to the tops of the towers by shear poles, fig. 240. The cable should hang in a bridle, fig. 241. In the former case the cable will usually have to be slushed, which is an inconvenience in the subsequent operations.

The saddle should be a smooth, firm bearing, sufficient to take all the cables side by side. In binding the small cables together to form a larger one, adopt the most compact arrangement, the outside strands as they lie side by side on the saddle generally going into the upper half and the central ones into the lower half of the complete cable; and note carefully that the arrangement is identical at all points, so that the strands do not ride or cross each other anywhere. The bunching should include the backstays, but need not be carried across the towers, leaving the strands flat on the saddles. Several groupings are illustrated in fig. 242.

In either method of placing, the cables should be permanently fastened at one end and be connected with the anchorage at the other end by a luff tackle, to be used in adjusting the length. When the adjustment is finished, this end is made permanently fast and the tackle removed.

144. In clear weather the *dip of the cables* may be determined by direct observation. Fix the elevation of the bottom of the transom at each tower, and above it, a distance equal to $\frac{1}{50}$ of the span, fasten a batten or stretch a line horizontally. Adjust the cable so that its lowest point ranges between the battens or lines.

If wind, fog, or darkness prevents this operation, lay the cables out side by side before they are hoisted up, and put them under as uniform strain as possible. Mark each with a few turns of soft wire, as near the point where it will rest on the saddles as can be computed. The distance between marks on all the cables must be exactly the same. When the cables are in place, adjust them so that these marks coincide, and the deflections will be sufficiently uniform to develop the combined strength of the strands.

145. **Lengths of slings** depend upon the curve of the main cables and the camber of the roadway. The latter must be liberal in field suspension bridges. The cables will stretch, especially those made of wire rope, and the anchorages and tower footings will give more or less. One-fiftieth of the span will usually be enough.

The lengths of slings are reckoned from the cable to the lower side of the transoms in a vertical line, fig. 243. They must be determined in advance and adhered to during construction, regardless of the appearance of the bridge when partially done. When the roadway is completed the distortion will disappear.

From the following table the lengths of slings at intervals of $\frac{1}{20}$ of the span, starting from the middle, may be readily determined.

TABLE XXXI.

146. From the line corresponding to the ratio of deflection take out the successive factors and multiply each by the span in ft. The results will be the lengths of slings in ft. at the corresponding points on *each side* of the middle.

As the length of the middle sling is 0, the middle transom will rest directly on the cable. If transoms are not of same depth allowance must be made for the difference.

Note especially that these tabular lengths do not include any fastenings. Be sure to add enough for that purpose, but when the fastenings are made see to it that the distance from cable to bottom of transom is precisely the corresponding tabular distance.

In this table allowance is made for a camber of $\frac{1}{80}$ of the span in two straight lines from the ends to the middle.

Ratio of deflection.	Distance of sling from center in parts of span.								
	0.05.	0.1.	0.15	0.2.	0.25.	0.3.	0.35.	0.4.	0.45.
$\frac{1}{6}$	0.0036	0.0107	0.0209	0.0346	0.0516	0.0720	0.0953	0.1267	0.1529
$\frac{1}{7}$	0.0034	0.0097	0.0188	0.0308	0.0456	0.0634	0.0840	0.1074	0.1336
$\frac{1}{8}$	0.0032	0.0090	0.0172	0.0280	0.0412	0.0570	0.0752	0.0960	0.1192
$\frac{1}{9}$	0.0032	0.0084	0.0160	0.0258	0.0377	0.0519	0.0684	0.0871	0.1080
$\frac{1}{10}$	0.0030	0.0080	0.0150	0.0240	0.0350	0.0480	0.0630	0.0800	0.0990
$\frac{1}{11}$	0.0029	0.0076	0.0142	0.0226	0.0327	0.0447	0.0585	0.0742	0.0916
$\frac{1}{12}$	0.0028	0.0073	0.0135	0.0214	0.0308	0.0420	0.0548	0.0693	0.0855
$\frac{1}{13}$	0.0028	0.0071	0.0129	0.0203	0.0292	0.0397	0.0517	0.0652	0.0803
$\frac{1}{14}$	0.0027	0.0069	0.0124	0.0194	0.0278	0.0377	0.0490	0.0617	0.0759
$\frac{1}{15}$	0.0027	0.0067	0.0120	0.0187	0.0267	0.0360	0.0467	0.0587	0.0720

147. **Form** and **strength** of **slings.**—Wire will usually be the material used. The load on each sling may be taken as the total load, live and dead, divided by the number of slings. It is really somewhat less. Knowing the size of wire on hand, divide the number of wires of that size which are used or would be required for the main cables, Table XXX, by the number of slings. The quotient will be the number of wires of that size which should be in each sling.

The slings may be made single and fastened at top and bottom by loops around cable and transom, or, more conveniently, made of half size and double length, taking a round turn on the cable at the middle, bringing the two ends around the transom in opposite directions and twisting them together on top of it, fig. 243.

A very useful attachment of wire to wood is made by means of a nail or spike partly driven beside the wire and the head bent over so as to embrace the wire like a staple. A staple, if available, is of course better.

148. **Construction** of the **roadway.**—A transom will hang in each pair of slings. On the transoms lay longitudinal stringers of number and size determined by the load, length of bay, and materials available, see paragraph 8. The stringers should be long and should lap 3 ft. or more and be firmly lashed or spiked together; the lap need not be on a transom, but is better near one. On the stringers the planks are placed and spiked down or held by side rails.

Place the first pair of slings on the cables, taking the turns loosely so that they will slide. Sling the first transom so that its bottom shall be the calculated distance from the cable measured along the sling. Fasten two stringers to it and push it out, the slings sliding on the cables, until the transom is in its proper position and the slings vertical. Crimp the turns at the top and place the second pair of slings and transom in the same way. Follow up with stringers and planks.

149. A **hand rail** should be provided, and a screen on each side of brush or other light materials will be useful.

150. Suspension bridges change their shape vertically and laterally from the live load and from wind pressure. Vertical distortions are referred to as *undulations* and lateral ones as *oscillations*. Undulations result principally from changes in the moving load and to a less extent from the vertical component of wind pressure. Oscillations are caused principally by horizontal wind pressures and in a lesser degree by the moving load. Both must be kept within small limits. Undulations may be reduced by making the hand rail or balustrade fairly high and trussing it lightly, fig. 244. Also by using deep stringers well lapped and fastened so as to be practically continuous.

Oscillations may be reduced by placing the cables farther apart at the towers and drawing them in at the center. This will affect the length of slings but not seriously. Also by a lateral truss under the roadway using the transoms for posts, and adding diagonal ties or braces. See paragraph 129.

Both undulations and oscillations may be controlled by guys attached to the roadway and carried inshore and up and down stream to secure fastenings.

151. **Railway bridges.**—With proper assumptions as to loads (see paragraph 5) the foregoing rules for designing and proportioning the several types of bridges will give safe structures for railway traffic. See also paragraphs 42, 66, and 115, and Tables XIX and XXVII.

A railroad bridge should not be built on an incline if it can be avoided. The approaches at each end should be straight and nearly level for a distance equal to at least twice the maximum train length.

Foundations must be especially unyielding as settlement is more troublesome than in other bridges.

For a single-track standard-gauge railway bridge the clear width between trusses or girders should be 14 ft. In double-track bridges the distance from c. to c. of tracks must not be less than 13 ft. No part of the truss may be less than 7 ft. from the c. of the nearest track at a height exceeding 1 ft. above the rail.

The clear head room must be 21 ft. above the base of the rail for a width of 6 ft. over each track.

Stringers are put under the rails and are best made in two or more pieces long enough to span two bays and breaking joints. The pieces are separated about 2 inches by blocks and well bolted together. Ties are placed 18 to 24 ins. c. to c., and every third or fourth one should be spiked to the stringers. A guard rail should be placed along the ends of the ties, and it is better to place under the tie a lighter stringer and bolt the guard rails to it.

ADDENDA, 1907.

TABLE K (XXXII).

118*a*. **Distance in feet,** center to center, between stringers or beams to carry a distributed load of 100 lbs. per sq. ft. of roadway, including its own weight. For other loads divide the tabular number by the assumed load per sq. ft. and multiply by 100.

Round.	Rectangular.	Span in ft.											
D	*b* x *d*	9	10	11	12	13	14	15	16	18	20	22	24
Ins.	*Ins.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
5	2 x 6	1.2	1.0										
6	8	2.1	1.7	1.4	1.2	1.0							
7	10	3.3	2.7	2.2	1.8	1.5	1.3	1.1	1.0				
	12	4.7	3.8	3.1	2.6	2.2	1.9	1.7	1.5	1.2	1.0		
	3 x 6	1.7	1.4	1.2	1.0								
	8	3.1	2.5	2.1	1.8	1.5	1.3	1.1	1.0				
8	10	4.9	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0		
9	12	7.1	5.7	4.7	4.0	3.4	3.0	2.5	2.2	1.7	1.4	1.2	1.0
	4 x 6	2.3	1.9	1.5	1.3	1.1	1.0						
	8	4.2	3.4	2.8	2.4	2.0	1.7	1.5	1.3	1.0			
	10	6.6	5.4	4.4	3.6	3.0	2.6	2.2	2.0	1.6	1.3	1.1	1.0
	12	9.4	7.6	6.2	5.2	4.4	3.8	3.4	3.0	2.4	1.9	1.5	1.3
	6 x 6	3.4	2.8	2.4	2.0	1.7	1.4	1.2	1.1				
	8	6.2	5.0	4.2	3.6	3.0	2.6	2.2	2.0	1.6	1.2	1.0	
10	10	9.8	8.0	6.6	5.6	4.6	4.0	3.5	3.1	2.4	2.0	1.6	1.3
	12	14.2	11.4	9.4	8.0	6.8	6.0	5.0	4.4	3.4	2.6	2.4	2.0
	8 x 8	8.4	6.8	5.6	4.8	4.0	3.4	3.0	2.6	2.0	1.7	1.4	1.1
11	10	13.2	10.6	8.8	7.2	6.0	5.2	4.4	4.0	3.2	2.6	2.2	2.0
	12	18.8	15.2	12.4	10.4	8.8	7.6	6.6	6.0	4.8	3.8	3.0	2.6
	10 x 10	16.4	13.3	11.0	9.2	7.9	6.8	5.9	5.2	4.1	3.3	2.7	2.3
	12	23.7	19.2	15.8	13.3	11.3	9.8	8.5	7.5	5.9	4.6	4.0	3.3
12		17.0	13.8	11.4	9.6	8.1	7.0	6.1	5.4	4.2	3.4	2.8	2.4

EXAMPLES.

(1) The span between roadway bearers of a bridge is 16 ft. and the timber available for balks is 4 x 12 ins. How many balks will be required in each bay for a 12-ft. roadway? The table under span 16 and opposite size 4 x 12 gives a spacing, center to center, of 3 ft. between balks, therefore there will be 4 spaces and 5 balks in each bay. If 11-in. round timbers were available, the spacing would be 4 ft. and there would be 3 spaces and 4 balks in each bay.

(2) The bays of a bridge are to have a span of 12 ft. and the balks are to be spaced 4 ft. center to center. What sizes of balks may be used?

Answer. Either 9-*in*. round timbers or 3 by 12 *in*. rectangular beams.

(3) The cap of a pile bent is supported on two piles, 10 ft. center to center, and the bents are spaced 15 ft. center to center. What size of cap is required? Opposite "15.2 ft." in column "10 ft." is found the required size, 8 x 12 ins., for the cap. Intermediate sizes, spans, and spaces may be found by simple interpolation.

118*b*. Wagons and artillery carriages bring concentrated wheel loads on the bridge, and for such loads the foregoing table is not applicable.

The following assumptions simplify the problem, give safe results, and are in accord with the usual conditions. The balks are assumed to be so spaced that the load of any one wheel is transmitted by the flooring to at least 2 balks.

When the span of the balks is less than twice the length of wheel base of the carriage the greatest strain occurs when the heaviest wheel loads are at the middle of the span. When the span of the balks is more than twice the length of wheel base of the carriage each wheel is supposed to have a load equal to the greatest wheel load of the carriage, and the strain is greatest when the center of the carriage is at the middle of the span.

For light artillery and army wagons the heaviest wheel load is 1,750 lbs. Add one-half the weight of the flooring carried by 2 balks, and 2,000 lbs. may be taken as the concentrated load on 2 balks, giving 1,000 lbs. on 1 balk, applied at the middle point if the span is less than twice the wheel base, and applied at two points, 6 ft. apart and equidistant from the middle point if the span is more than twice the wheel base. In the same way 2,000 lbs. may be taken as the concentrated load on 1 balk for siege artillery applied in like manner with a wheel base of 8 ft.

Table XXXIII.

118c. Sizes of round and rectangular balks and maximum safe spans in feet for wagons and artillery.

Round.	Rectangular.	Maximum safe spans in feet for 4 or more balks.	
D	*b* x *d*	Wagons and light artillery.	Siege artillery.
Ins.	*Ins.*		
5	2 x 6	4.8	----------
6	8	11.2	5.6
7	10	12.6	6.6
	12	15.6	9.6
	3 x 6	7.2	3.6
8	8	12.6	6.4
	10	16.0	10.0
9	12	20.4	14.4
	4 x 6	9.6	4.8
	8	14.5	8.5
	10	19.3	13.3
	12	25.2	17.6
	6 x 6	13.2	7.2
	8	18.8	12.8
10	10	26.0	18.0
	12	34.8	22.4
	8 x 8	23.0	16.5
11	10	32.5	21.2
	12	44.4	27.2
12	10 x 10	39.3	24.6
	12	52.0	32.0

118*d*. The flooring must be strong enough to transmit its load to the balks, and its thickness will depend on the load and on the spacing of the balks. Concentrated wheel loads will cause the greatest stresses, and these may be taken as 1,600 lbs. on one wheel for wagons and light artillery and 3,200 lbs. on one wheel for siege artillery.

TABLE XXXIV.

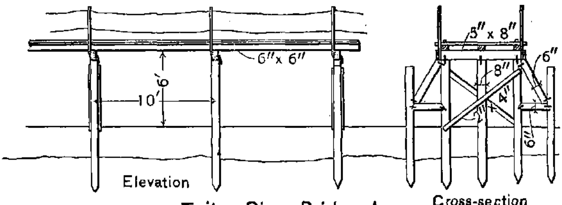
118*e*. Thickness of flooring in inches to carry wagons and artillery for varying distances between balks.

Distance between balks (*s*, in feet).	Thickness of flooring.			
	Wagons and light artillery.		Siege artillery.	
	Plank. *d*	Poles. *D*	Plank. *d'*	Poles. *D'*
	Ins.	*Ins.*	*Ins.*	*Ins.*
1.0	1.4	2.3	2.0	3.5
1.5	1.7	3.2	2.4	4.0
2.0	2.0	3.5	2.8	4.4
2.5	2.2	3.8	3.2	4.8
3.0	2.4	4.0	3.6	5.1
3.5	2.6	4.3	3.7	5.4
4.0	2.8	4.5	4.0	5.6

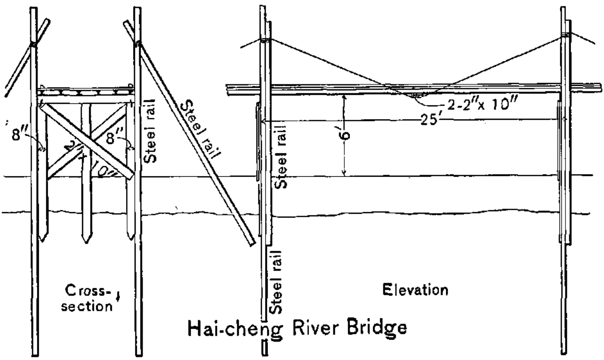
For a footbridge, the thickness of flooring in inches may be safely taken as one half the span between balks in feet, or $d = \frac{1}{2} s$.

118*f*. Figs. 245–247, reproduced by permission from Plate III, War Department Document No. 273, 1906, show interesting features of field bridges built by the Japanese during the Manchurian war. The use of railroad iron and the very general employment of iron dogs for fastenings are noticeable.

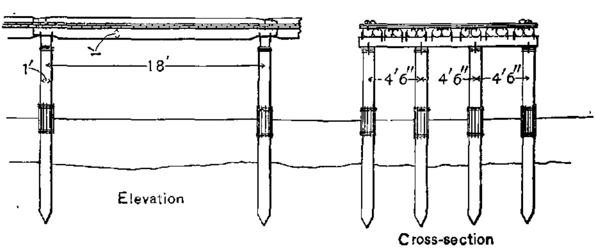
Japanese Field Bridges



Taitzu River Bridge A.
Fig. 245.



Hai-cheng River Bridge
Fig. 246.



Taitzu River Bridge B.
Fig. 247.

JOSEPH E. KUHN,
MAJOR OF ENGINEERS.

PART III.

ROADS.

PART III—ROADS.

1. **Military road making** will, in most cases, be a question of repairing existing roads to make them temporarily passable, the work to be done in the shortest possible time. Labor is likely to be plentiful, though not the most efficient. Machinery and transportation will be scarce. Materials actually on the line or very near it must be used. To decide upon the best plan under such circumstances, and to carry it out most successfully, it will be helpful to have a general knowledge of the conditions which make good roads and those which make bad ones, and of the best methods of converting the latter into the former, or, in other words, of the principles of road construction. These principles are the same for all roads, though the practice resulting from their application may differ in military roads from that considered best for civil roads.

2. **The supporting power** of cohesive compacted earth, moist but not wet, is sufficient to bear without objectionable indentation the weights on hoofs and wheels which result from ordinary highway traffic. The supporting power of the same earth when thoroughly wet is only about $\frac{1}{30}$ as much, and is not sufficient to carry the weights on hoofs and wheels until the wagons have sunk to their axles and the animals to their bellies, when traffic becomes impossible. Between these extremes lie many gradations of good and bad roads.

3. Civil roads are also rated as bad when the surface, though hard, is rough, as when there are projecting bowlders or ledges of rock crossing the road, or stumps or roots in the way; and also when any of the grades exceed the limit at which a team can pull its own load.

As to roughness, its principal effect is to increase the wear and tear of vehicles and the discomfort of passengers, and to prevent a faster gait than a walk; hence it is of secondary importance for military traffic. As to gradients, it is to be remembered that army transportation is always in trains, so that teams can be doubled when necessary, and also that there is usually an ample supply of labor in reach so that loads can be broken. Within the limits of possible wheel transportation, steep gradients alone may delay military traffic, but can not stop it.

Extensive work for reduction of grades will rarely be worth while so long as the prevailing natural grades do not exceed 3°, and the maximum are short and not steeper than 6°. Rolling country, classed as decidedly rough, will be found within these limits.

For long grades, as in mountain roads, considerable work may be profitably expended in keeping prevailing grades within 2°, with a maximum of not more than 4° on short ones.

4. The **paramount question** to be dealt with will be the supporting power of the roadbed as affected by water. This supporting power will be a maximum when the soil is sufficiently damp to compact well and yet not wet enough to yield considerably under the pressure. It is not desirable to remove all the moisture from the soil, because if this is done it loses its compacting power, and any particles dislodged from cohesion to adjacent ones remain on the surface in a friable condition, refusing to reunite under pressure until moisture is supplied.

The **supporting power of wet earth** may be increased in two ways: first, by removing the surplus water and keeping it out, and, second, by introducing rigid material, or a combination of materials, which will afford a proper bearing surface and so distribute the pressures as to reduce them below the supporting power of the wet soil. The application of methods involving one or both of these principles will constitute the bulk of military road work, whether of construction or repairs.

5. **Drainage.**—The water to be disposed of in connection with any road is: that which flows toward the road from adjacent slopes; that which falls on the surface of the roadbed, and that which finds its way beneath the surface, commonly called *ground water*.

6. **Side ditches.**—Surface water flowing toward the road is intercepted and carried off by ditches along one or both sides of the road, according to the direction from which the surface water comes. If on one side only, the water is carried under the road—across it in some cases—and discharges down the slope, preferably in a gully or natural drainage line.

7. **Drainage of the road surface** takes care of the water which falls on the roadbed itself, and is effected by making the surface of the roadbed smooth and compact and giving it regular slopes longitudinally or in the direction of the road and laterally or toward the sides. The longitudinal slope is the **grade,** and the lateral slope is called the **crown.** The compacting or consolidation of the road surface reduces the rate of absorption of water, and the smooth regular slopes cause the rainfall to run off promptly. Compacted earth absorbs water slowly if the surface is not disturbed. By digging in a beaten road or footpath it will be found, even after a hard rain, that the ground is wet for a slight depth only. The surface stratum when wet seems to form an impervious coating which keeps the rest dry. If the surface is disturbed during the rain, as by traffic, the protection of the surface stratum is lost, and the water penetrates deeper. An earth road in constant use in wet weather will become muddy no matter how much attention is paid to drainage, but with proper drainage a road will not become muddy so soon, nor stay muddy so long, nor will the mud get so deep.

To maintain a road in good condition under traffic in wet weather it must be given a surface the supporting power of which is not diminished by moisture, so that the wetted surface is not disturbed by the traffic. Various kinds of such surfaces are formed artificially, and are called *pavements.* In addition to their qualities just described they also act in an important way in distributing the pressures from the wheels to the earth foundation. It has been noted that all binding materials lose their efficiency when absolutely free from moisture. As the distributed pressure on the ground surface can be borne by earth carrying more moisture, and as such earth underneath the pavement has a tendency to prevent the latter from becoming too dry, it is readily seen that where a road is covered with pavement it is possible to do harm rather than good by too much underdrainage.

8. The **crown** of an **earth road** should be 6 in. for a road of ordinary width. Theoretically the crown should increase with the grade, but this is an unnecessary refinement in practice. The convenience in construction of a fixed crown outweighs any advantages of a variable crown. If the grade is so steep that water flows too far along the road, causing scour in the wheel ruts, it is better to build low ridges across the road at intervals to turn the water to the side than to attempt to produce the same effect by a greater crown. The ridges may be wide and flat, amounting, in fact, to a reversed grade for a few feet, perfectly effective, and yet so gentle as not to materially disturb traffic.

The **best distribution** of the **crown** is to give 5/8 of it to the outside quarters and 3/8 to the inside quarters of the road. The resulting crown is nearly an arc of a circle. With inexperienced men it may be necessary to use a form for a crown. Fig. 1 shows its construction. The upright forms a convenient handle, and may be provided with a plummet to level the gauge across the road.

9. **Subdrainage** is resorted to when it is desirable to lower the surface of the ground water. By the ground-water level, at any point, is meant the depth at which the soil becomes fully saturated. It is the depth at which water will stand in a well or pit. If it is 4 ft. or more below the surface, it will not affect the condition of a road in good soil. Ground water rises in wet and falls in dry weather. It probably rises when the ground is frozen, regardless of the rainfall.

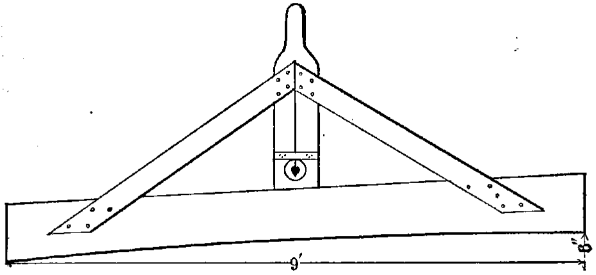


Fig. 1

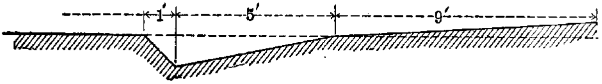


Fig. 2

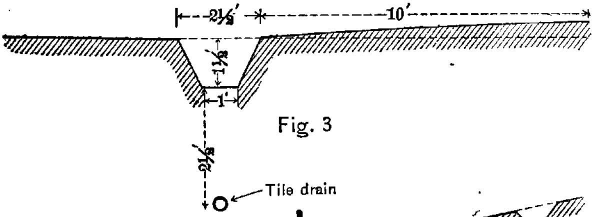


Fig. 3

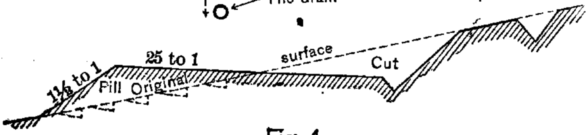


Fig. 4

If the ground water comes nearer the surface than 4 ft. its effect may be bad or not, depending upon the character of the soil and the elevation of the road. Generally, however, high ground-water level and poor soil for road making go together.

10. **Subdrainage** will not often be a feature of military road work; but when it is done it is best accomplished by a tile drain laid on one or both sides of the road under the side ditches, fig. 3. The tile should be of the bell-and-spigot pattern, laid with open joints, the bell upgrade. As water flows along the outside of the pipe as well as on the inside, it should be surrounded by porous, nonerosible material, such as broken stone or gravel.

On military roads substitutes for the tile must often be used. The essential is a continuous conduit into which water may percolate through the sides and along which it may flow with a relatively high velocity. Broken stone, plank, or layers of fascines or brush will do much good. Any form except a pipe or box tends to quickly choke up with fine silt washed into the interstices. This may be partly prevented by interposing a layer of filtering material such as straw, turf, grain sacks, etc., between the material of the drain and the surrounding earth, especially on the top. If turf is used, put the grass side toward the drain.

Side ditches act as subdrains to the extent of their depth. A free outlet is necessary for the efficient operation of subdrains and side ditches.

11. **Importance of side ditches.**—It is obvious that the side ditches contribute to the improvement of a road in so many ways that they must be of great importance. They assist in every class of drainage and also offer the most convenient source for material to crown and raise the roadbed. Ample side ditching is the consideration of first importance in every road project, except in arid climates or very sandy soil.

12. **Form of side ditches.**—The best form of side ditch is shown in fig. 2. Its advantages are that it is favorable for a variable flow of water at relatively uniform velocity; that it does not fill up by caving or from the wash of earth from the road; that if a wagon is run into it accidently or in an emergency no especial trouble follows, and that it furnishes earth enough to crown the road. This form is suited to a road which has ample width and is on good ground. If these conditions are reversed, the road narrow, and the ground wet, a ditch of the form shown in fig. 3 will be better. It takes less space and is deeper. It will fill up more rapidly and require more work to keep it open. The form in fig. 2 can be opened with scrapers. The form in fig. 3 must be dug with shovels.

13. The **slope of side ditches** will usually be that of the road, though if the latter is less than 1 in 125, the slope of the bottom of the ditch should be increased by making it shallower at the upper and deeper at the lower end. A **long ditch** on a steady grade will do its work better if made **gradually larger** from the upper to the lower end. In all cases, the bottom should have a uniform or increasing grade to the outlet to prevent the formation of pools. Large springs near the road should be tapped below the surface and led into the side ditches.

On very steep hills roads are often badly damaged by the scour of water flowing in the side ditches. To prevent this, the ditches may be roughly paved or may have weirs of logs and brush or stone built across them at intervals. These dams should not be tight enough to hold any water permanently. Or, the ditch may be stepped, paving the steps at top and bottom, to prevent scour by the overfalls.

14. **Embankments.**—Raising the surface of a road or carrying it on an embankment produces the same relative effect, so far as saturation of the soil is concerned, as lowering the ground water. Roads may also be carried on embankments to reduce grades. This is especially advantageous when a cut is made at the top of a hill and the material can be placed in the roadbed at the bottom so as to raise it materially. The haul is short and down hill, and the movement of the earth accomplishes a double benefit in reducing the grade by lowering the road at the top and raising it at the bottom.

When there is no near-by cutting, the material for embankments must be dug on areas outside of the line. Excavations made for this purpose are called **borrow**

pits. If the material along the roadbed is fit for use, the borrow pits are enlargements of the side ditches. The superior convenience of this arrangement determines its use in many cases when the material is poor. It is indeed seldom that the material from side ditches cast up on an unimproved road and properly surfaced and compacted will not make the road temporarily better than it was before.

Embankments should have a top or crown at least 5 ft. wider than the proposed roadway, and should have side slopes not steeper than $1\frac{1}{2}$ to 1, unless the material stands naturally at a steeper slope. An **allowance for settlement** should be made of about $\frac{1}{10}$ the height. If the embankment is put up in such a way as to be compacted by traffic during its construction, this allowance for shrinkage may be considerably reduced.

15. **Cuttings.**—Excavations on the line of the road may be made either to reduce extreme elevations and grades or to give a level surface for the roadway. In the former case they are usually called **cuts**, and in the latter **side cuttings**, or sometimes **cuts and fills**, since the material excavated is usually used to make an embankment to carry part of the road, fig. 4.

Cuts will have a bottom width sufficient for the roadbed and narrow side ditches. The top width will depend on the depth of the cut and slopes of the sides. Side slopes in earth will usually be $1\frac{1}{2}$ to 1. In rock they may be steeper; in sand and in some clays they must be flatter. In northern latitudes cuts are sometimes made with very flat slopes to prevent them from drifting full of snow.

For side cuttings the same remarks apply so far as the upper side is concerned. The embankment may be made, as indicated in fig. 4, to prevent the mass from sliding bodily down the hill. Stepping of the slopes under the fill is a good rule for heavy embankments where there is likely to be a good deal of drainage against them from above. On ordinary sidehill slopes and with ordinary embankments stepping is not necessary. On very steep and unstable sidehills it will be better not to cut at all, but to make the fill on the natural surface with earth brought from a distance. As the embankment in a cut and fill will settle, it is best to make it higher at the start than the floor of the cut, and to arrange for all the drainage to go into the side ditch on the uphill side, fig. 4. If the face of the cut presents two materials, a pervious one above and an impervious below, as sand and clay, it may be necessary to cut a drain in the slope at the junction of the two.

16. **Retaining walls.**—This term is here applied only to walls which are designed to support made ground, and will include all devices for giving a vertical face to such ground whether of masonry or not. For military fieldwork, the easiest and quickest will usually be preferred to the best.

A **crib of logs or timbers** (see Bridges) may be made and filled with earth or stone and filling deposited against it. Such a crib should be half as wide as it is high. For stiff soils the rear wall of the crib may be omitted and the front one held in place by logs running back into the bank, fig. 5. These logs may be replaced by cables made fast to posts. This construction can best be applied when the cables can be carried back to solid ground, fig. 6.

Vertical posts with their feet let well into the ground and the tops anchored by either of the above methods may support horizontal planks, which in turn support the fill, fig. 6. Constructions in timber for this purpose are usually called *bulkheads*.

Masonry retaining walls should have an average thickness of $\frac{4}{10}$ to $\frac{5}{10}$ their height above the ground, the former for good rubble laid in cement mortar, the latter for dry rubble. The thickness may be the same from top to bottom, or it may be greater at the bottom and less at the top, the average remaining the same. If the wall is high, the latter section should be adopted, as it requires less material for a given height and strength. Dry rubble must be of large stones fairly well fitted together. Whether with or without mortar, it is desirable to avoid through horizontal joints. Some stones should be so placed as to lie partly in two adjacent courses, acting as dowels to prevent the upper part of the wall from sliding along the joint between the two courses. Walls should be built with a batter on the front from $\frac{1}{2}$ to 1 in. to the foot, as they will always move out a little at the top, and if originally built plumb, will then overhang and look unsafe.

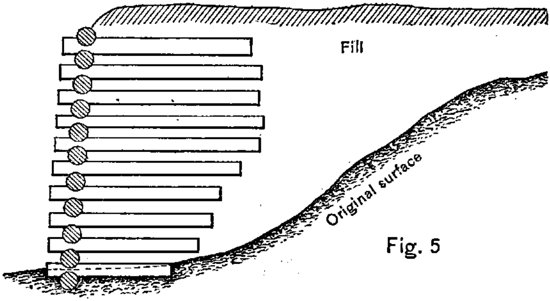


Fig. 5

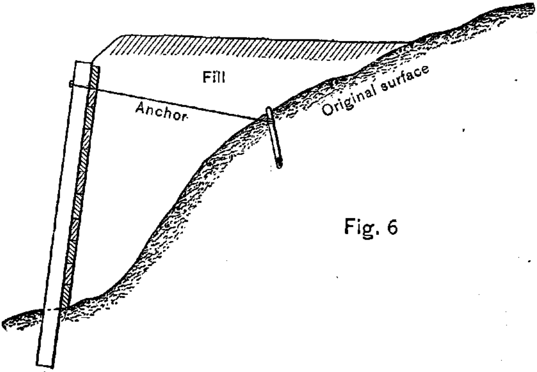


Fig. 6

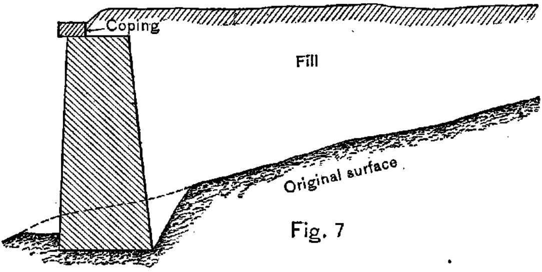


Fig. 7

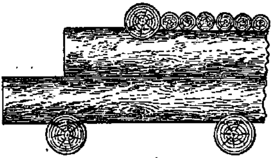


Fig. 8

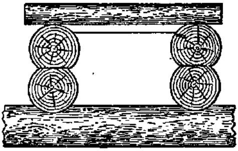


Fig. 9

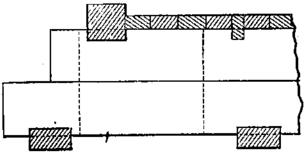


Fig. 10

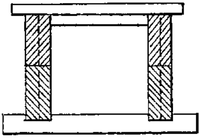


Fig. 11

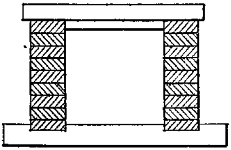


Fig. 12

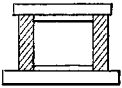


Fig. 13

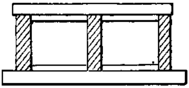


Fig. 14

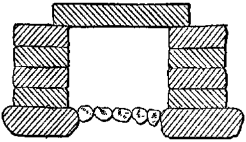


Fig. 15

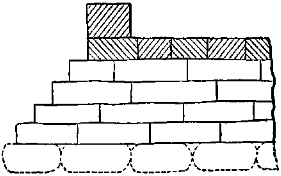


Fig. 16

Especial attention must be given to the **character** of the **foundation at the foot** of the front face. A trench must be excavated deep enough to get to a firm bea ing at this point. The front of this trench should be kept as solid as possible to form a support to the wall against sliding on its base, fig. 7. If the wall yields to the pressure against it, it will most probably revolve around the toe, and its entire weight will come on the front edge of the foundation trench, which must be able to support the weight or the wall will overturn.

17. **Culverts.**—An inclosed conduit for passing drainage under a road is called a **culvert.** The distinction between bridges and culverts is vague. Some small bridges are often called culverts, and some large culverts have been called bridges. If the traffic is borne directly on the top or roof of the conduit, it must be designed as a bridge, and may be called a bridge, no matter what its length or height. If a considerable thickness of the roadbed passes over the conduit so that water may stand above it at one end and pass through under pressure, the structure may properly be called a culvert.

18. The **area of waterway** required can not be determined by any rule. It depends upon the maximum rate of rainfall, the kind of soil, whether rocky, sandy, clayey, etc., and the slope of the surface and its condition, whether cultivated or not, timbered or not, frozen or not, etc.

If the culvert conveys the flow of a side ditch under the road, its capacity should be equal to that of the ditch. The discharging capacities of channels of different forms are to each other as the squares of their areas divided by their surface widths; thus, the area of the side ditch in fig. 3 is $3\frac{1}{2}$ sq. ft. The area squared $= 12.25$. The surface width is $2\frac{1}{2}$ ft.; hence the area squared divided by the width $= 12.25 \div 2\frac{1}{2} = 4.9$. To find the dimensions of a rectangular conduit of equal capacity, assume the width $1\frac{1}{2}$ ft. Then the area squared divided by $1\frac{1}{2} = 4.9$; hence, the area squared $= 7.3$, or the area $= 2.7$; the depth equals the area divided by the width $= 2.7 \div 1.5 = 1.8$; hence a conduit of equivalent section will be 1.5 by 1.8 ft.

Required, the size of a circular conduit equivalent to the side ditch. Divide the equivalent number 4.9 by 0.616, and take the cube root of the quotient, which will be the diameter of the circle; thus, $4.9 \div 0.616 = 8$; the cube root of $8 = 2$, which is the diameter of the equivalent circular conduit.

These relations are true only when the water has a good approach to the culvert and free discharge from it, and when the fall of water surface from the upper to the lower end of the culvert is not less than the fall of the ditch in the same length. These conditions can ordinarily be secured in construction. In fact a considerably greater fall can usually be obtained through the culvert than exists in the side ditch, so that areas computed by the rule will usually be in excess.

When the drainage to be handled is that of a natural drainage line, estimate as well as can be done the area and surface width of the maximum cross section of flow and convert it into the equivalent regular section by the rule. If the conversion gives a size larger than can conveniently be constructed, consider the possibility of giving a greater fall through the culvert. The area of the culvert may be reduced as the square of the slope increases. If twice the fall of the natural flow can be obtained, one-fourth the culvert area will answer.

19. **As to their design,** culverts are classed as **box,** or **rectangular, arched,** and **pipe.** The box culvert may be of wood or stone, or of the two combined. The **arch culvert** is usually of masonry. The **pipe culvert** may be of clay, iron, concrete, or wooden-stave pipe. In the latter material it is sometimes called **barrel culvert.**

20. **Wooden culverts.**—Figs. 8 to 14 represent type forms in logs, squared timbers, and lumber. The principles are the same for all. The inside should be smooth to facilitate the flow of water and the passage of floating substances. The outside should be a broken surface to offer more resistance to the flow of water between the wood and earth, which, if continued, will wash the culvert out. If logs are used, those in the walls should be flattened on two sides to give a good bearing and leave no opening greater than 2 ins. If there is time to square the timbers, it is much better. All timbers should be drift-bolted together. (For drift-bolting, see Part II, Bridges.)

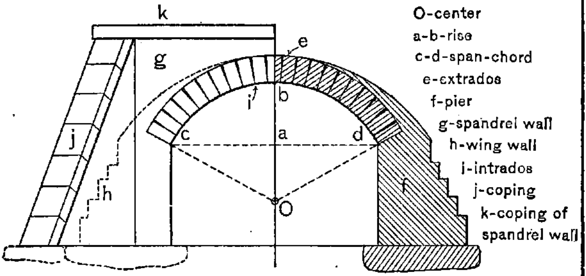


Fig. 17

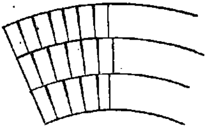


Fig. 18

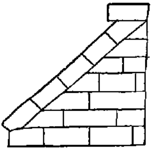


Fig. 19

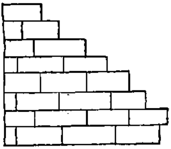


Fig. 20

Fig. 23

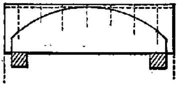


Fig. 21

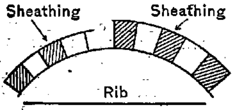


Fig. 22

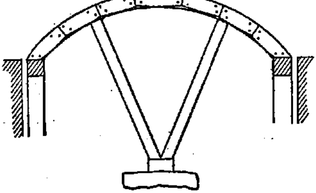


Fig. 24

Stone culverts.—Figs. 15 to 17 show type forms. The stone box culvert, fig. 15, is a convenient form when suitable stone can be had. It will usually be laid up without mortar. If necessary to economize large stone, the side walls may be built of rubble in mortar or of concrete. Concrete blocks may also be used for the top. For the class of stone usually found in such shapes, the top slabs should be 2 ins. thick for each foot of span. For well-made concrete of Portland cement, the same thicknesses will do. Concrete blocks should not be loaded within 7 days after they are made.

The **side walls** should have a thickness of $\frac{1}{2}$ their height, or better $\frac{1}{3}$ the height at the top and $\frac{2}{3}$ at bottom. They should be well footed in trenches not less than a foot deep, and deeper if the bearing is not firm. The backs of the walls are better rough so that the earth can get a good grip on them, and pains should be taken to make them so.

Arch culverts.—The lines and surfaces of the arch and their names are shown in fig. 17.

The best form of arch for culverts is the segmental, which is an arc of a circle. The rise should be $\frac{1}{4}$ the span, making the radius of the intrados $\frac{5}{8}$ of the span.

For all masonry except concrete the arch is usually of uniform thickness. To determine the proper thickness, add 50 to the span in feet and divide the sum by 50. The quotient is the thickness of the arch ring in feet; or, add $\frac{1}{50}$ of the span in feet to 1 ft. This rule is given in view of the inferior masonry likely to be built under service conditions. A ring of the thickness so determined should be built of selected materials laid with all face joints in radial planes. The faces are better perfectly true, but if cement mortar is used they need be only approximately so. Stratified rocks which break out in fairly uniform thickness may be used without dressing. Three-quarters of the stone at least should go through from intrados to extrados. Care should be taken to leave no open joints on the intrados, nor any of more than $\frac{3}{4}$ in. of mortar alone. Greater spaces between stones should be filled with shims or spalls coated with mortar and well driven in. All joints should be completely filled with mortar.

If brick are used, they are laid as indicated in fig. 18. The concentric circles are called rings, and the thickness of brick arches is sometimes given as 3, 4, etc., rings. Under the rule given above, a brick arch will have at least 3 rings. Particular attention should be paid to the surfaces between rings, which must be separated by a film of mortar in good contact with both surfaces and monolithic, so far as possible, with the mortar in the radial joints.

Spandrel filling.—The stability of the arch requires that it be permanently loaded on its haunches. This may be done by depositing any heavy material, but in small arches is commonly done by continuing the masonry from the outside of the arch ring to a line or curve swept from the crown to the outer edge of the top of the abutment. For culverts, the embankment supplies the necessary weight, and the main function of the spandrel filling is to give a smooth and regular slope to the top of the structure to promote the run off of water.

Spandrel walls.—At each end of the arch a wall is built up to the level of the crown and in length from out to out of the abutments. It acts to stiffen the arch and also as a retaining wall for the embankment over it. For wide or very long arches there may be interior spandrel walls of similar dimensions, and in small arches the masonry may be built up to these lines all along.

Wing walls.—These are built from the ends of the spandrel walls with a splay of about 30°, and act as buttresses for the spandrel walls and also as retaining walls for part of the embankment left unsupported by the cut made to give access to the culvert. The tops of the wing walls are not horizontal, but slope with the earth of the embankment.

The thickness of wing walls may be slightly less than that of retaining walls. The bond with the spandrel wall gives support to the highest part, and the slope of the embankment affords relief against great pressure. For brick or fair rubble in cement mortar the thickness should be $\frac{1}{6}$ of the height throughout, or $\frac{1}{12}$ at the top and $\frac{1}{3}$ at bottom, the top, however, to be not less than 18 ins. for rubble and 13 ins. for brick. As the height varies, the thickness does also. Determine the thickness at the spandrel wall and at the toe of the embankment and vary it uniformly from one to the other. The coping may be inclined, fig. 19, or in steps, fig. 20. In the former case the stones must be well anchored to the wall to prevent sliding. The step form is much better. For a high wall the coping will be of uniform width and will form a low parapet on the front edge of the top surface, fig. 7. Except as above noted, all the requirements of retaining walls apply to wing walls.

Concrete arches, on account of their great homogeneity and the ability of the material to take tensile as well as compressive strains, may be of reduced dimensions, and the spandrel filling is most conveniently combined with the arch ring in a monolith. For thickness of crown add 25 to the span in feet and divide by 5. The result will be the thickness at the crown in inches. The extrados is a cylinder passing through the crown and the outer top edges of the side walls. Its radius will be about equal to the span, and may be so taken. Side, spandrel, and wing walls of concrete culverts have the same proportions as for other masonry.

21. **Centers.**—All arches must be supported during construction and until the mortar has set sufficiently to bear the pressure. Supports are commonly built of wood and are called **centers. Great rigidity** is **necessary,** and all principal pieces must be so proportioned that they will take their stresses without appreciable deflection. Long pieces must have a radial direction so as to be in compression only. Short pieces which can be made very deep relatively may be used as beams. The foundations of centers must be made with great care so as to be unyielding. In addition to precautions in the construction of centers it is also necessary to build the arch simultaneously from both sides and at the same rate so that the two sides of the centers shall always be equally loaded.

The **principal parts** of **centers** are the **ribs** and the **sheathing.** The **ribs** are segments of the proper circle, solid or framed, and the **sheathing** is a covering of the ribs to produce the necessary supporting surface. The ribs are proportioned to support the weight of the arch and are the same for all kinds of arches. The sheathing may differ for different kinds of arches. For concrete it must be with tight joints which will not allow thin mortar to flow through. For brick it may be more open, with gaps small enough only to prevent a brick from sliding through. For stone the sheathing may be still more open.

For small culverts, centers may be built as shown in fig. 21. For larger arches, fig. 24 shows a convenient construction. The radial supports will vary in number according to the size of the arch. The points supported on the ribs need not be less than 3 or 4 ft. apart. The distances between ribs will be 2 to 3 ft., depending on the thickness of the sheathing.

22. **Laying out centers.**—For small arches lay down the material of the ribs and strike the curves of the centers with a radius. When this method is not convenient, make a template or pattern. On the edge of a board or along a straight line drawn near the edge lay off in each direction from the middle, spaces of 6 ins. each. At each of the points so determined draw a perpendicular to the edge or line, and on these perpendiculars lay off the ordinates given in the following table for the span adopted. The ordinates in the top lines are to be used unless the bottom of the plank is to be the chord of the arch, in which case the bottom lines will do equally well. The points so laid off are on the curve of the arch, which should be drawn through them by a flexible rule or spline bent to touch them all at the same time, fig. 21. Shape the edge of the board to the curve, and using it as a pattern scribe the others. Planks 2 x 12 ins. are very convenient material for ribs. From the table it will be seen that such a plank will cut the whole rib for a 3-ft. arch, and by adding a 3-in. strip on the top edge, it will give a rib for a 4-ft. arch. For larger arches, build up the ribs by putting segments end to end with a close bearing and fasten them with other segments put on as fish plates, fig. 23. The end bearings should not be less than 3 ins.

TABLE I.

23. **Middle and side ordinates for segmental arches** with rises = ¼ span. Ordinates in top lines measured from the tangent; ordinates in bottom lines measured from the chord.

Span.	Radius.	Rise or middle ordinates.	Ordinates in feet at distances from middle of—									
			0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
3	1.87	0.75	0.06 0.69	0.36 0.39	0.75 0.00							
4	2.50	1.00	0.05 0.95	0.21 0.79	0.50 0.50	1.00 0.00						
5	3.12	1.25	0.04 1.21	0.17 1.08	0.42 0.83	0.78 0.47	1.25 0.00					
6	3.75	1.50	0.03 1.47	0.14 1.36	0.31 1.19	0.49 1.01	0.95 0.55	1.50 0.00				
8	5.00	2.00	0.03 1.97	0.10 1.90	0.23 1.77	0.42 1.58	0.67 1.33	1.00 1.00	1.50 0.50	2.00 0.00		
10	6.25	2.50	0.02 2.48	0.08 2.42	0.18 2.32	0.33 2.17	0.52 1.98	0.77 1.73	1.18 1.32	1.45 1.05	2.15 0.35	2.50 0.00
12	7.50	3.00	0.02 2.98	0.07 2.93	0.15 2.85	0.27 2.73	0.43 2.57	0.62 2.38	0.87 2.13	1.16 1.84	1.50 1.50	1.91 1.09
14	8.75	3.50	0.01 3.49	0.07 3.43	0.13 3.37	0.23 3.27	0.36 3.14	0.53 2.97	0.73 2.77	0.97 2.53	1.37 2.13	1.57 1.93
16	10.00	4.00	0.01 3.99	0.05 3.95	0.11 3.89	0.20 3.80	0.32 3.68	0.46 3.54	0.63 3.37	0.83 3.17	1.07 2.93	1.34 2.66
18	11.25	4.50	0.01 4.49	0.05 4.45	0.10 4.40	0.19 4.31	0.28 4.22	0.42 4.08	0.55 3.95	0.75 3.75	0.95 3.55	1.15 3.35
20	12.50	5.00	0.01 4.99	0.04 4.96	0.09 4.91	0.16 4.84	0.25 4.75	0.36 4.64	0.50 4.50	0.67 4.33	0.84 4.16	1.05 3.95

24. **Pipe culverts.**—Vitrified clay, concrete, and cast-iron pipe culverts should, if possible, be laid on a carefully prepared foundation of broken stone, gravel, or concrete, shaped to the curve of the lower part of the pipe, which should rest evenly and solidly on the foundation from end to end. The earth filling should be thoroughly compacted around the lower part of the pipe, using water if practicable, but should be left loose around the upper part. It has been demonstrated that thorough under-tamping trebles the strength of concrete pipe. The top surface of earthenware pipes should be not less than 18 ins. below the surface of the roadbed. It is better to have the joints tight. Clay, or cement mortar may be used for packing. Care should be taken in laying to have the spigots enter the bells to the full length. Oakum, rope, grass, or any available material may be put in first and rammed to the bottom to prevent the packing material from running through into the pipe. Pipe culverts should run dry when the flow ceases. They should have an average fall of not less than 1 in 72 for vitrified and 1 in 225 for cast-iron pipe. The fall

should not be uniform, but should increase slightly from the upper to the lower side, giving the pipe a camber which will prevent the formation of pockets by settlement.

The ends of pipe culverts should be protected by head walls. These may be of rubble or brick masonry, or for temporary purposes of wood, figs. 25 and 26.

Vitrified pipe is made in 2 and 3 ft. lengths; the former is the standard market length. Up to 2 ft. in diameter it usually comes in bell-and-spigot form. Larger sizes are ordinarily in cylindrical form with rings of the same material to cover the joints. The trade designation of vitrified and cast-iron pipe is the **inside diameter.**

Cast-iron pipe is made in 12 ft. lengths, and is bell and spigot for all sizes.

Concrete pipe, if used, will be made on the site. The thickness should be 1 in. for all up to 12 ins. diam. Above 12 ins., a thickness of $\frac{1}{12}$ the diameter.

25. **Surfacing.**—It is of great importance to keep the surface of earth roads smooth and free from ruts as far as possible. During continuous rainy weather it is usually not practicable to do this, but as soon as the road has dried out enough to permit it, the surface should be gone over and the ruts and other depressions filled up. If this is done, the mud from the next rain will be very much less, and by attention to this simple expedient a road that would be constantly bad with intermittent rains, can be kept good most of the time. An excellent opportunity for such work arises when a badly cut road is lightly frozen, and especially just as the frost is beginning to come out of the ground.

The work may be done by men with picks and shovels, or by the use of harrows and scrapers drawn by animals. A good farm harrow gives excellent results. A scraper may be improvised by putting a tongue on a piece of heavy plank, and a steel shoe on its lower edge, fig. 27. A railroad rail is said to make an excellent scraper. A team is hitched to each end. For soft mud a drag which will do much good is made by splitting a 12-in log in halves, placing them round sides down on the ground 2½ ft. apart, and nailing cleats across their flat sides. See par. 25*a*, p. 267.

The **scraping grader** is a scraper mounted on wheels and adjustable as to height. It hangs obliquely over the road, the onter end in advance, so that the surplus earth is pushed toward the center. With such a machine on hand, the manner of using it will be obvious. One may be improvised by hanging the heavy plank and steel shoe shown in fig. 27 under the bed of an ordinary wagon.

26. The **quality of the earth** has a great influence upon its behavior in a road. Clay compacts well but will not drain. Sand drains well but usually will not pack. There are some exceptions to this rule, notably among the volcanic sands of the Philippine Islands, which are sharply angular in grain and do pack well enough to make a fairly good road metal. It is also to be observed that sand packs under pressure when damp, and that sandy roads are usually better in wet than in dry weather, for which reason nothing is done to promote drainage of very sandy roads. A road which is too sandy may be improved by an admixture of clay, and conversely. Gravel, with a certain proportion of clay, makes an excellent road. The combination is similar to that which produces the hardpan, sometimes found in excavations.

27. A **road good in all conditions of weather** can be obtained only by the introduction of materials other than earth. These materials must be of such character that they will offer a bearing surface not affected by moisture, and of such thickness as will distribute the load so that the soil below can bear it without compression. It is also requisite that the surface be smooth enough for easy traction and rough enough to give a footing for animals. Such constructions range from the simplest expedients of road making to the highest class of street pavements.

Corduroying is done by laying logs crosswise of the road and touching each other. The result will be better if the logs are nearly of the same size. The butts and tips should alternate. If the logs are large the spaces may be filled with smaller poles. The bottom tier of logs should be evenly bedded and should have a firm bearing at the ends and not ride on the middle. The filling poles, if used, should be cut and trimmed to lie close, packing them about the ends if necessary. If the soil is only moderately soft the logs need be no longer than the width of the road. In soft marsh it may be necessary to make them longer.

The logs may be utilized as the wearing surface. In fact this is usually the case. They make a rough surface, uncomfortable for passengers and hard on wagons and

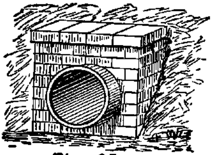


Fig. 25

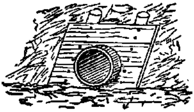


Fig. 26

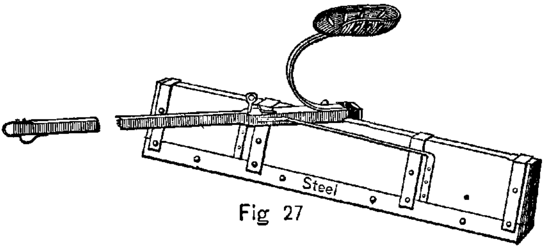


Fig 27

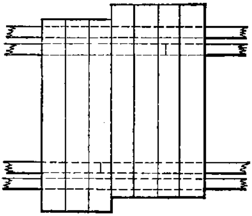


Fig. 28

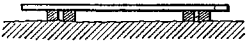


Fig. 29

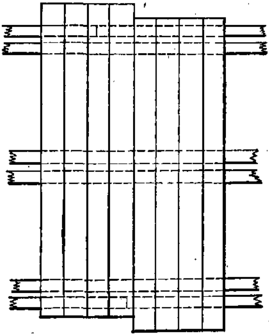


Fig. 30

Fig. 31

loads, but the resistance to traction is much less than would be expected, and the roughness and slightly yielding surface make excellent footing for animals. Surface corduroy is perishable and can last but a short time. In marshes, where the logs can be placed below the ground-water level, they are preserved from decay, and, if any suitable material can be found, to put a thin embankment over them, a good permanent road may be made.

Any tough, fibrous material may be used to temporarily harden the surface of a road. Hay or straw, tall weeds, corn and cane stalks have been used to good advantage. Such materials should be laid with the fibers crosswise of the road, and covered with a thin layer of earth, thrown on from the sides; except in sand, when it is better to dig a shallow trench across the road, fill it with the material and then dig another trench just in front of and in contact with the first and throw the sand from it back onto the material in the first trench, etc.

28. **Plank roads** are built by laying lines of sleepers about 4 ft. apart, well bedded and breaking joints, and nailing to them cross planks 2 or 3 ins. thick and 9 to 12 ins. wide, figs. 28 and 29. Each line of sleepers should be doubled and composed of pieces 4 x 6 ins. laid flatwise and 2 or 3 ins. apart, breaking joints. The planks should have 2 spikes in each end and should be laid ¼ in. apart if dry. If wet, they may be laid lightly touching. The length of plank will depend upon the amount and condition of traffic. If all one way, or if return traffic is mainly of empties, 2 lines of sleepers and 8 ft. plank will answer. If loaded traffic is heavy in both directions, there should be 4 lines of sleepers and planks 14 ft. long, fig. 30. The interior sleepers need not be double. Planks should be offset in blocks of about 20 to facilitate getting back a wheel which has run off the road.

When suitable timber is plentiful and sawmills are at hand, a good road for all conditions of weather can be made easily and quickly as above described. It is neither muddy nor dusty, and is easy on loads, wagons, and animals.

29. **Charcoal roads** have been built through swampy forests by piling logs longitudinally on the line of road and burning them into charcoal, which is raked down to 2 ft. thickness in the middle and 1 ft. at the edges. The logs may be 12 to 24 ft. long, in piles 5 or 6 ft. high, 9 ft. wide at the bottom, and 2 ft. wide at the top. The piles are covered with straw and earth and burned with a restricted air supply. Good draft should be permitted until the pile is well ignited, when all air openings at the bottom should be closed.

30. **Gravel,** to form a good road covering or metal, must have enough binding material to cause the pebbles to pack and remain in place under traffic. The material from ordinary deposits or pits of gravel will usually make a fair road. That from beaches and streams will not, unless binding material is supplied. If there is a considerable proportion of stones larger than 4 ins. diameter they should be broken up or excluded. For gravel and for all other metal roads, the roadbed is first brought to the shape and condition described for an earth road, but at a grade lower than the proposed surface of the road by the thickness of the metal. This lower grade is called the **subgrade.** In excavated roads and those formed by crowning on the natural surface, the subgrade is formed at the first operation. For roads on embankments, it is better to bring the fill up to the final grade, and then, just before putting on the metal, excavate to subgrade, forming a **trough** or **box** in which to deposit the metal.

The first or bottom course of gravel should be about 4 ins. thick and should be well compacted by travel or by rolling before the next layer is deposited. The following courses should be of the same thickness, each compacted as laid. The net thickness of 3 such layers will be about 10 ins. and will make a good road of the class.

31. **Broken stone** and **crushed stone** are terms applied to angular fragments of stone made by breaking up larger pieces either by hand hammers or by power crushers. The stone should be hard and tough and not very absorbent. Trap is the best; granite is good at first, but disintegrates rapidly; sandstone is deficient in binding qualities. Limestone has excellent binding properties, but is generally soft and wears rapidly; it is, however, the material most used in stone roads because more plentiful than stone of better quality.

Broken stone is **classed** according to the **largest dimension** in ins. of its largest pieces. The test of size is that the largest piece shall pass freely, in any position, through a ring of a certain diameter. The largest size commonly used in road making is $2\frac{1}{2}$ ins., meaning that the largest piece can not fail to pass through a ring of $2\frac{1}{2}$ ins. diameter. The smallest usual size is $\frac{1}{2}$ in. Sometimes double limits are imposed, as that all shall pass through a $2\frac{1}{2}$-in. ring and none through a $1\frac{1}{2}$-in. ring. The **run of the crusher** means all material which comes from the crusher not exceeding the specified size. Stone broken by hand can not be graded in sizes. It is considered by some that hand-broken stone is superior on account of the more nearly cubical shape of the fragments and the less quantity of small pieces. The advantage, if any, is not enough to outweigh the greater rapidity and economy of machine breaking. Hand breaking will be used only when there are no crushers and plenty of labor.

For breaking stone by hand the best hammers are of steel in the form of a circular disk, of 2 to 3 lbs. weight, with rather long handles.

Broken stone is measured by the ton or by the cubic yard; by the ton, when it can be passed over scales or measured by displacement of vessels; otherwise by the yard. For a rude comparison, the cubic yard and the long ton may be taken as equivalent.

32. **Macadam roads** are made of broken stone deposited on the natural surface, or preferably on a properly prepared subgrade and compacted by traffic or by rolling. For military roads, compacting by traffic will be the rule, and by rolling the exception. Better results will be obtained if the stone is put on in two layers, the lower one compacted before the upper one is spread. If graded stone is to be bad, use $2\frac{1}{2}$-in. for the lower course and $1\frac{1}{2}$ or 2 in. for the upper. When compacted by traffic, the thickness of the lower course, when first spread, must be enough to prevent the wheels cutting through it. If the foundation is dry and hard, 4 ins. will be right. If the foundation is yielding, a greater thickness will be necessary, and it may happen that all will have to be put on at once to carry the traffic while compacting. On a 4-in. bottom layer, a 3-in. top course may be spread.

The **width** to be **stoned** or **metaled** will depend upon the conditions of the moment. Ten ft. will do for a single line of wagons, or 16 ft. for a double line. If the traffic in one direction is light, the width may be increased with the same amount of stone by limiting the bottom layer to the middle and extending the top layer out on the sides. Such extensions are called **wings.** This disposition requires that the earth of the roadbed shall be of excellent quality.

If the traffic can be distributed over the entire surface of the stone, it will be much better. If the wagons track and quickly wear down 2 ruts, they should be filled up by raking in stones from the sides.

33. If time, materials, and appliances are available, a **high-class macadam road** may be built as follows: Prepare the subgrade and compact it thoroughly by rolling. Lay a bottom course 6 ins. thick of $2\frac{1}{4}$-in. to $2\frac{1}{2}$-in. stone and roll it down to 5 ins. or less, leaving it smooth, even, and true to grade.

Lay a top course 4 ins. thick of $\frac{1}{2}$-in. to $1\frac{1}{4}$-in. stone and roll it down to 3 ins. and leave the surface as before.

Spread a layer of screenings from the same stone just thick enough to cover the projections of the top course, water and roll until to grade and so compact that no material can be picked up.

34. **Telford roads** are made by covering the subgrade with a layer of medium-size stones laid by hand, larger face down and in close contact, and filling the interstices with chips snugly set with a small hammer. On this foundation a layer of broken stone is laid and compacted as described for macadam, fig. 31. Well-made telford will probably stand on ground too soft and wet to carry macadam of reasonable thickness. It may also be preferred if the large stones are easily obtained and hand breaking is necessary.

In all work with broken stone, the compacting is more rapid and effective when the stone is wet. When roads are compacted with rollers it is worth while to arrange for a thorough sprinkling just in advance of the machine.

In using a roller it is best to roll the sides first so that the compacted sides may offer lateral resistance to prevent the material in the center spreading out when the roller passes over it. For efficient service, the roller should be not less than 4 ft. diam. nor weigh less than 1 ton to the foot of length.

35. Other kinds of pavement, wood or stone block, brick, and asphalt are constructed on the same principles but require special materials, machinery and appliances, skilled labor, and expert superintendence.

36. **Noninterruption of traffic.**—The methods, and to a certain extent the plans, will be affected by the necessity of keeping the road open for use during the work of repair or reconstruction. Generally, the system will be adopted of doing one side at a time. Sometimes a new road may be built alongside the old one, or a temporary road may be opened for use while the old one is repairing. The result, in any case, will be to discourage changes of grade, and to cause cuts and embankments to be made in horizontal layers along the whole length and not to the full height or depth at once as would otherwise be done; to cause side cuttings in wet weather to be all cut and no fill, and to encourage preparation and distribution of materials along the road ready to be put on quickly.

37. **Location.**—Much military road work, especially of repairs, will be done under conditions which will make instrumental location impossible. When it can be done, it will be advantageous to mark the center line with stakes at intervals of 100 ft., or less if the ground is irregular, and to mark the grade on each stake. If levels are not run the grade can be marked by the eye. From the center stakes side stakes may be set to mark the outer edges of the side ditches. Lines stretched on the center and side stakes will be of assistance in getting the true lines and grades quickly. If the side lines are stretched parallel to the grade, they will be at a uniform distance above the bottom of the side ditches, and can be used as guides in finishing the latter.

In the **location of a new road** more instrumental work is desirable. The general line will be laid down on a map. This line will be run out on the ground, correcting obvious difficulties, marked by stakes 50 or 100 ft. apart, and the height of ground at each stake determined. The slope of the ground at right angles to the line will be noted at every stake, as also the distance of any obstacles on either side which would make it difficult to shift the line. The character of the soil will be carefully noted.

From these notes a **profile of the ground** will be made with suitable horizontal and vertical scales (see Reconnaissance). On this ground profile, a profile of the road will be laid down. This profile will follow the natural surface so long as no heavy grades result. When the grades are too steep, the notes will be consulted to see if grades can be reduced by shifting the line to one side. If this can not be done, the road profile will be so drawn as to make the cuts and fills equal in volume. The locations of bridges and culverts will be noted on the profile, as also the lengths requiring especial treatment, as corduroying, etc.

Having fixed the lines and grades, determine the cuts or fills at the stakes and the lateral deviations of the line, if any are decided upon, and go over the ground again, staking out the changes in the line and marking on each stake the cut or fill in feet below or above its top. The usual method is to write **cut** or **fill**, or **C** for cut and **F** for fill, with the figures indicating its amount immediately below.

38. **Side stakes** are those used to mark the intersections of the side slopes of cuts or embankments with the natural ground surface. They are set on each side of the center stakes on lines at right angles with the traverse. Their distances from the center stake, called **side distances,** d_r and d_l, fig. 32, depend on the depth of cut or height of fill, width of bottom or top, slope of sides, and the transverse gradient of ground surface.

The **vertical distances** from the ground surface at the side stakes to the level of top of embankment or bottom of cut are called **side heights,** h_r and h_l, fig. 32.

If the ground is level, the side distances are the same and are equal to $\frac{1}{2}w+cs$, in which $w=$ the width of top of embankment or bottom of cut; $c=$the center cut or fill, and $s=$the number of units horizontal to 1 unit vertical in the side slopes.

If the ground slopes from the center to the side stakes, the determination of side distances and heights can not be directly made by any formula simple enough to be of practical use. The relation is $d_r=\frac{1}{2}w+h_rs$, which is not determinate, because d_r and h_r are not independent of each other. The method of trial and error must be used by applying the following rule: Estimate the side height and work out the side distance by the formula $d_r = \frac{1}{2}w + h_r s$, or $d_l = \frac{1}{2}w + d_l s$. Measure off the resulting distance to right or left of the center stake and take the ground level at the point found. If it is the same as the estimated level, it is correct and the stake may be driven. If the **measured** elevation is **greater** than the **estimated,** multiply the difference by the slope ratio and add the product to the trial side distance. If the **measured** elevation is **less** than the **estimated,** multiply as before and subtract the product from the trial side distance. Lay off the new distance for the second trial side distance and repeat the operation. A little practice will enable a sufficiently correct result to be got at the first trial. Side staking will not often be necessary for military roads.

39. In **metaling** a road, much more attention to lines and grades is necessary. After the grading is finished, center and side stakes should be set and marked with grade and subgrade instrumentally determined.

40. **Curvature.**—Horizontal curves for changes of direction can be put in by the eye with sufficient accuracy. Run out the 2 tangents to points beyond where the curve will leave them. Select on each a point where the curve is to begin and set stakes at these points. Lay a line loosely between the stakes and with small pickets 5 ft. apart throw the line into a curve and shift the pickets until the curve is fair and on the desired ground, letting out or taking up the length of the line accordingly as it proves to be too short or too long. If the curve can be made level, it is better to do it; if not, the roadway must be widened to permit long teams to straighten out and pull, fig. 33. This is important for mountain roads, which combine steep grades and short turns. If the width of the road **outside of the center line** is made equal to 1,600 divided by the **radius of curvature** in feet, it will be wide enough for an 8-mule team. If the radius of curvature exceeds 200 feet no widening is required.

To find the radius of a curve which has been staked out, stretch a string from any stake to the 3d, 5th, or 7th stake in either direction and measure the distance from the string to the stake opposite its middle point. This distance is called a **middle ordinate.** The **radius of curvature** in feet is the length of the string in feet squared, divided by 8 times the middle ordinate in feet. The stakes must be equidistant.

41. **Intersections of rising grades** should be flattened so that the rise on either side shall not exceed 2 ft. in the last 100 ft. All abrupt changes of grade should be softened. This can be done well enough by the eye. If not done in construction, it will soon be done by the weather and traffic.

42. **Estimates for earthwork.**—The calculation of quantities in excavations and embankments will usually be for balancing cuts and fills, and for making requisitions for men, teams, and tools. For these purposes a simple rapid method giving approximate results is best.

Volumes are derived from the **areas** of **cross sections** of the cut or embankment and the **distances** between them. The distances can be directly measured, and to any desired accuracy. The uncertainty in the volume resides entirely in the determination of the cross-sectional areas. The cross section to be multiplied by any distance to deduce a volume is assumed to be the average cross section for that distance. The more uniform the ground the easier will be the measurement of any section and the fewer sections will be necessary in a given distance to get a fair average. Experience has shown that for **ordinary ground** the **average** section for 100 ft. in length is very nearly one-half the sum of the **actual** sections at the ends of the same 100 ft. The difference is so small that it may be neglected when the end areas do not differ widely in size and the ground between changes regularly from one to the other.

43. When the ground has no transverse slope the sections are called **level sections.** For these the area depends upon the center cut or fill, the bottom or top width, and the slope of the sides. Volumes per 100 ft. of line for level sections, with center cuts or fills of 1 to 24 ft. and widths of 16, 18, 20, 22, and 24 ft. and side slopes of 1 to 1, 1½ to 1, and 2 to 1 are given in Table II. To use this table it is only necessary to know the center cut or fill, the width, and the side slopes, and of these only the first requires a measurement on the ground. For preliminary estimates, the average cut or fill for the entire length of a cutting or embankment may be used, and the resulting volume per 100 ft. taken from the table may be multiplied by the number of hundreds of feet in the entire distance for the total volume.

TABLE II.

44. **Volumes** in cubic yards of sections 100 ft. long of cuts or embankments on level ground with side slopes of 1 to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14.	16.	18.	20.	22.	24.
1	56	63	70	78	85	92
2	119	133	148	163	178	192
3	189	211	233	256	278	300
4	267	296	326	356	385	415
5	352	389	426	463	500	537
6	444	489	533	578	622	667
7	544	596	648	700	752	803
8	652	711	770	830	889	948
9	767	833	900	967	1,033	1,100
10	889	963	1,037	1,111	1,185	1,259
11	1,019	1,100	1,181	1,263	1,344	1,426
12	1,156	1,244	1,333	1,422	1,511	1,600
13	1,300	1,396	1,493	1,589	1,685	1,781
14	1,452	1,556	1,659	1,763	1,867	1,970
15	1,611	1,722	1,833	1,944	2,055	2,166
16	1,778	1,896	2,015	2,133	2,251	2,370
17	1,952	2,078	2,204	2,330	2,456	2,581
18	2,133	2,267	2,400	2,533	2,666	2,800
19	2,322	2,463	2,604	2,744	2,885	3,025
20	2,519	2,667	2,815	2,963	3,111	3,259
21	2,722	2,878	3,033	3,189	3,344	3,500
22	2,933	3,096	3,259	3,422	3,585	3,748
23	3,152	3,322	3,493	3,663	3,833	4,003
24	3,378	3,556	3,733	3,911	4,089	4,266
25	3,611	3,796	3,981	4,167	4,352	4,537

ADDENDUM, 1907.

25*a*. If the material is friable, the halves of the log may be placed on edge, flat sides forward and 2 or 3 ft. apart, connected by crosspieces.

TABLE II—Continued.

Volumes in cubic yards of sections 100 ft. long of cuts or embankments on level ground with side slopes of $1\frac{1}{2}$ to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14.	16.	18.	20.	22.	24.
1	57	65	72	80	87	94
2	126	141	156	170	185	200
3	206	228	250	272	294	316
4	296	326	356	385	415	444
5	398	435	472	509	546	583
6	511	556	600	644	688	733
7	635	687	739	791	843	894
8	770	830	889	948	1,007	1,066
9	917	983	1,050	1,116	1,183	1,249
10	1,074	1,148	1,222	1,296	1,370	1,444
11	1,243	1,324	1,406	1,487	1,568	1,650
12	1,422	1,511	1,600	1,689	1,778	1,866
13	1,613	1,709	1,806	1,902	1,998	2,094
14	1,815	1,919	2,022	2,126	2,230	2,334
15	2,028	2,139	2,250	2,361	2,472	2,583
16	2,252	2,370	2,489	2,607	2,725	2,844
17	2,487	2,613	2,739	2,865	2,991	3,117
18	2,733	2,867	3,000	3,133	3,266	3,400
19	2,991	3,131	3,272	3,413	3,554	3,694
20	3,259	3,407	3,556	3,704	3,852	4,000
21	3,539	3,694	3,850	4,005	4,161	4,316
22	3,830	3,993	4,156	4,318	4,481	4,644
23	4,131	4,302	4,472	4,642	4,812	4,983
24	4,444	4,622	4,800	4,978	5,156	5,333
25	4,769	4,954	5,139	5,324	5,509	5,694

TABLE II—Continued.

Volumes in cubic yards of sections 100 ft. long of cuts or embankments on level ground with side slopes of 2 to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14.	16.	18.	20.	22.	24.
1	59	67	74	81	88	96
2	133	148	163	178	193	207
3	222	244	267	289	311	333
4	326	356	385	415	444	474
5	444	481	519	556	593	630
6	578	622	667	711	755	800
7	726	778	830	881	933	985
8	889	948	1,007	1,067	1,126	1,185
9	1,067	1,133	1,200	1,267	1,333	1,400
10	1,259	1,333	1,407	1,481	1,555	1,629
11	1,467	1,548	1,630	1,711	1,792	1,874
12	1,689	1,778	1,867	1,956	2,045	2,133
13	1,926	2,022	2,119	2,215	2,311	2,407
14	2,178	2,281	2,385	2,489	2,593	2,696
15	2,444	2,556	2,667	2,778	2,889	3,000
16	2,726	2,844	2,963	3,081	3,200	3,318
17	3,022	3,148	3,274	3,400	3,526	3,652
18	3,333	3,467	3,600	3,733	3,866	4,000
19	3,659	3,800	3,941	4,081	4,222	4,362
20	4,000	4,148	4,296	4,444	4,592	4,740
21	4,356	4,511	4,667	4,822	4,977	5,133
22	4,730	4,889	5,052	5,215	5,378	5,541
23	5,111	5,281	5,452	5,622	5,792	5,963
24	5,511	5,689	5,867	6,044	6,222	6,400
25	5,926	6,111	6,296	6,481	6,666	6,851

45. For **ground which has a lateral slope** another variable must be introduced, for with a given depth, width, and side slopes the area will not be the same for different ground slopes. For every such section there is a level section of the same area, and having the same bottom width and side slopes. This is called the **equivalent level section.** If the ratios between the depths of oblique sections and their equivalent level sections are known, the areas of the oblique sections can be taken from the foregoing table.

The **ratios** between **center cuts** or **fills** of oblique sections and the **center cuts or fills** of the equivalent level sections are given in the following table in percentages, by which the **actual center cut** or **fill** of the oblique section must be **increased** to produce the **center cut** or **fill** of the **equivalent level** section. The table gives values for transverse gradients of 15 to 1 to 5 to 1, and for side slopes of 1 to 1, $1\frac{1}{2}$ to 1, and 2 to 1.

To use the table, take from the line corresponding to the gradient and the column corresponding to the side slope, the percentage factor, and increase the center cut or fill by this percentage. The result will be the depth of the equivalent level section. With this increased depth enter the table of level sections and take out the volume for a length of 100 ft. This method will give results correct to $\frac{1}{2}$%, corresponding to an accuracy in the levels of $\frac{1}{10}$ ft. in 20 ft.

TABLE III.

46. **Percentages to be added to center heights** of sidehill embankments and cuttings to obtain the center height of the level section of equal area.

Transverse gradient of ground surface.	Side slopes of cut or embankment.		
	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.
15 to 1	0.02	0.03	0.04
14 to 1	.03	.03	.04
13 to 1	.03	.04	.05
12 to 1	.03	.04	.06
11 to 1	.04	.05	.08
10 to 1	.05	.07	.09
9 to 1	.06	.08	.12
8 to 1	.07	.11	.14
7 to 1	.09	.14	.19
6 to 1	.13	.19	.27
5 to 1	.18	.27	.41

47. To **balance** the **cut** and **fill** in a **side cutting** the center line should be run so that there will be a slight cut along it. This will give a small excess of volume of cut over volume of fill, which is desirable.

48. **Handling earth.**—The excavation of a mass of earth and its formation into an embankment may be classified into **loosening, loading, hauling,** and **spreading.**

Loosening with a plow will require 2 horses, 2 men, and a plow for each 40 yds. per hour. If very hard, 4 horses will be required for the plow. With picks, 1 man for each 40 yds. per day, or 10 men equal 1 plow.

Loading material into carts or wagons will require 1 man for each 2 yds. per hour. All other loading is included as a part of the hauling.

The **haul** or **lead** is the distance to be traveled from the point of loading to the point of dumping. The **mean haul** is the quantity usually considered, and is the distance from the center of gravity of the cut or excavation to the center of gravity of the fill.

The following table gives the yardage made on various leads for wagons, carts, wheel and drag scrapers, wheelbarrows and boxes, or other improvised facilities. The load units assumed are 1 yd. for wagons, $\frac{1}{2}$ yd. for carts and wheel scrapers, $\frac{1}{4}$ yd. for drag scrapers, $\frac{1}{14}$ yd. for wheelbarrows, and $\frac{1}{20}$ yd. as a load for 2 men, carried in a box or otherwise.

TABLE IV.

49. **Yardage of earth** which can be handled **per hour** in different conveyances:

Length of haul in feet.	Yardage per hour per conveyance for hauling in—				
	Wagons.	Carts or wheel scrapers.	Drag scrapers.	Wheel-barrows.	In tubs or boxes.
40 or less			22.0	2.5	2.0
50			14.0	2.2	1.8
75			10.0	1.9	1.6
100	12.0	6.0	8.0	1.7	1.4
200	10.0	5.0	4.2	1.2	0.9
300	8.6	4.3		0.9	
400	7.5	3.7		0.7	
500	6.7	3.3		0.6	
600	6.0	3.0			
700	5.5	2.7			
800	5.0	2.5			
900	4.6	2.3			
1,000	4.3	2.1			

A wagon should be loaded in 4 mins. or less and a cart in 2 mins. or less. There should be at least 6 shovelers for each wagon at each loading point, and at least 3 for each cart. One gang of shovelers should not be required to load more than 10 wagons or carts per hour.

Wagons for hauling earth should have the ordinary box replaced by a bed formed of side boards, front and tail gates, and a bottom of scantling about 3 x 4 ins. not fastened together. The side boards should have cleats on the outside to take the standards of the bolsters, and other cleats on the inside to receive the head and tail gates. The pieces of the bottom should have cleats on the underside to take the rear bolster. To dump a load from such a wagon the ends are first removed, then one side board is raised and dropped down on the hubs outside the bolster. Beginning on this side, the bottom pieces are pulled up one at a time, allowing the dirt to sift through. For dumping wagons there should be 2 men at each dumping point, and, if provided with shovels, they should be able to take care of the spreading.

Carts and **scrapers** are dumped by the driver and deposit the entire contents in one pile. For this kind of hauling, spreaders should be provided at the rate of 1 man for each 10 yds. per hour.

Example.—Having a cut to make 400 ft. long with an average center depth of 10 ft. and a bottom width of 18 ft., side slopes of 2 to 1, and a transverse ground slope of 10 to 1; the material to be placed in an embankment 600 ft. long adjacent to one end of the cut; the work to be done in 24 hours; material to be handled, a light loam. What requisitions should be made?

From Table III take the coefficient corresponding to 2 to 1 and 10 to 1 slopes, 0.09, and add this percentage to the actual depth 10 ft., giving 10.9 ft. or say 11 ft., depth of equivalent level section. From Table II for level section of 11 ft. cut, 18 ft. wide, and 2 to 1 slopes, take the quantity 1,630, which is the yardage in 100 ft. of the cut, giving $1,630 \times 4 = 6,520$ for the total yardage to be handled.

Loosening will require 2 horses, 1 plow, and 2 men for each 40 yds. per hour, or $6,520 \div 40 = 163$ hours for the whole, which will require $163 \div 24 = 7$ plows to do the work in 24 hours. If 7 plows can not be had, substitute 10 men with picks for each plow short. If no plows are to be had, 70 men with picks will be needed.

The mean haul will be $400 + 600 \div 2 = 500$ ft. Table IV shows that this can best be done with wagons, and that each wagon will take care of 6.7 yds. per hour at that distance, or 160 yds. in 24 hours; hence $6,520 \div 160 = 41$ wagons. A wagon and a half will haul 10 loads per hour, and hence there should be a loading gang for each wagon and a half, or 27 gangs of 6 men each equal 162 men, with shovels for loading.

Dumping and spreading will require 10 men with shovels. The total force working continuously will be:

Kind of work.	Number of men.	Number of tools.	Number of animals.
Loosening	14	7 plows	14
or if without plows	70	70 picks	
Loading	162	162 shovels	
Hauling	41	41 wagons	82
Spreading	10	10 shovels	

Total, 227 men and 96 animals if plows are used; or 283 men and 82 animals if picks are used.

To supply this force for continuous work for 24 hours, there should be at least 1,000 men and 200 animals.

50. **Estimating rock.**—The principles are the same as for earth, but the surfaces are likely to be less regular, and greater accuracy is desirable on account of the labor of excavation. On the other hand, the side slopes, which in rock may be nearly vertical, introduce much less difficulty in computation than the flatter earth slopes. It is best to give the side slopes in rock a slight batter. Cross sections should be measured at distances of 25 ft. or less. If irregular, it will be best to plot the cross sections on paper and measure the area by squares. (See Reconnaissance.)

If cuts and fills are to be made in rock, it must be remembered that the broken rock in the fill will occupy 75% more volume than the same rock did in place in the cut, but the slopes of the rock fill will be flatter than the walls of the cut and the crown may be wider. It is safe to assume that the rock taken from a cut will make an embankment of the same average width and height and 50% longer.

51. In handling rock much depends on its hardness and stratification. Some rock can be pried out with crowbars, but as a rule blasting and wedging will be necessary. The frequency, depth, and direction of drill holes, and the sizes of charges will depend on the nature of the rock. For all that relates to the use and handling of explosives for this purpose, see Demolitions. As a rough rule for estimating, allow $\frac{3}{4}$ lb. of explosive to 1 cu. yd. of solid rock.

52. **Drilling for blasting** is best done with a jumper. This is a drill of proper length to be held by a man and struck on top alternately by 2 other men with 8 to 12 lb. sledges. The holder turns the drill slightly after each blow. If the hole is deep it may be started with a drill of convenient length and finished with a longer one. The form of the cutting edge or bit is shown in figs. 34, 35, and 36. Drills are commonly made of hexagonal or octagonal steel. The form of the bit is the same for both. Fig. 34 shows a point made on an hexagonal bar, and fig. 36 the point made on an octagonal bar. Drills are sharpened by grinding, and when necessary by reforging and tempering. At frequent intervals the holder removes the drill and scoops out the dirt from the bottom of the hole with a spoon.

Drill holes are usually from $\frac{1}{2}$ in. to 2 in. diam., according to the form of the cartridges to be used. The number and depth will depend on the character of the rock. If the rock is to be loaded into wagons, it is best to use enough powder to break it at once into **1-man** and **2-man** stone, which names apply to pieces of about 50 and 100 lbs. weight, which can be thrown into a wagon by 1 and 2 men, respectively. Stones too large to be handled may sometimes be broken by sledges, or they can be split by wedging. For this purpose holes about $\frac{7}{8}$ in. diam. and 4 in. deep are drilled on a line, with their axes lying in the **plane of cleavage,** called by quarrymen, the **grain.** One man does the drilling and striking, using a small

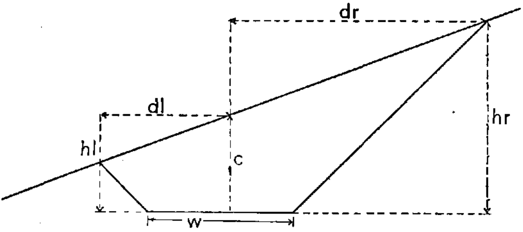


Fig. 32

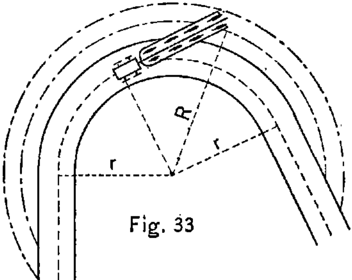


Fig. 33

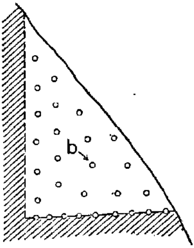


Fig. 39

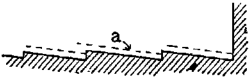


Fig. 38

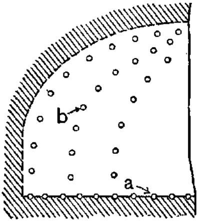
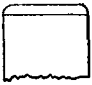


Fig. 40



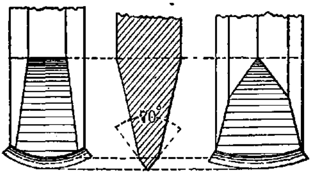


Fig. 34 Fig. 35 Fig. 36

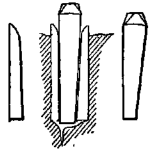


Fig. 37

drill the size of a cold chisel and a hand hammer of 2 to 5 lbs. weight. When the holes are drilled, **plugs** and **feathers** are inserted. These are wedges of steel and frustums of cones of malleable iron, fig. 37. The feathers are placed in the hole, large ends down, and the plugs are inserted between them and struck in rotation until the stone splits. This method is used for breaking out pieces for culverts, coping, etc.

The rate of progress in drilling depends on the character of the rock and the skill of the drillers and tool sharpeners. For average conditions of military road work, estimate 8 in. per drill per hour.

53. When it is desired to make a side cutting in rock too steep to permit working on its face, operations may be carried on from one or both ends. Figs. 38–40 show a good method. A line of drill holes should be made at the floor level as shown at *a* and other holes *b* drilled in the working face to break up the rock over the area to be removed. The holes *a* are not loaded; their purpose is to produce a fairly uniform surface of fracture to form the roadbed. It is necessary to drill them on a slant as shown in fig. 38, which will leave the floor in a saw-toothed surface. This and other asperities left in the floor must be sledged off, and the cavities filled with small broken stone and stone dust to give a proper wheel-bearing surface, The holes *b* are overcharged sufficiently to break up the rock and throw as much of it as possible over the bank. If the cliff is vertical or nearly so, the cutting takes the form of a half tunnel, fig. 40.

The roadbed should slope inward for greater security of traffic. This will throw the drainage to the wall. There will not be much of it as a rule, and there will usually be crevices in the rock sufficient to take care of it. Otherwise it must run to the ends of the cut or be collected at a low point and a channel made through the floor of the cut, with slopes sufficient to run the water over the cliff. This channel can be filled up to the road level with broken stone. Vertical holes should be drilled a few feet apart near the outer edge of the roadway and bars of iron set in them with eyes in the top through which a chain or rope may be passed to form a guard rail.

54. In **clearing a line through woods,** the work may be reduced to a minimum by curving the road gently to avoid as many large trees as possible. If there is undergrowth of any kind, a first party should cut and remove it to a distance of 20 ft. on each side of the road. If needed for use elsewhere, the same party should prepare it for such use. If not needed, it should be burned. The second party should fell trees, cut them up into manageable lengths and remove them from the roadway, and this party should be so adjusted that the cutting up and removal will keep pace with the felling. Care should be taken to avoid felling a tree across another one already down.

Trees in the actual roadway or near its edges are best felled by digging around them and cutting off the principal roots at 3 or 4 ft. from the trunk and then pulling the tree over, stump and all. If stumps of trees already cut are to be removed, it may be done by blasting. The charge should be put low down in the stump, digging if necessary.

55. **Cost.**—The factors entering into the cost of roads are so many and so complex that a safe estimate can not be made without a knowledge of the conditions to be met in the particular case.

The following data are designed to guide the judgment in forming conclusions as to the probable limits of cost of different classes of roads, so that the first survey and estimate may be made for a road which can be built with the resources at hand.

56. **Clearing** may be taken at $10 to $50 per acre, or $20 to $400 per mile for timber varying from scattering to dense and widths of 16 ft. to 60 ft.

57. **Earthwork.**—In a flat or gently rolling country where the road will mainly follow the natural surface with level cross sections, the side ditching and crowning may be taken at $350 per mile. In mountainous or rough country, with the road mainly in side cuttings, the grading and ditching may be taken at $350 to $700 per mile, the former for a lateral gradient or 15 to 1, and the latter for 5 to 1. For steeper lateral gradients, the cost will be greater.

58. **For embankments and cuttings in earth,** compute the volume of earth to be moved from tables II or III and take the cost at 20 cents per yard plus $\frac{1}{2}$ cent for each 100 ft. of haul.

Cuttings and embankments in rock vary so widely in cost that any figure given as standard would be misleading in a majority of cases. Extensive rock excavations will rarely be undertaken in military road work.

59. **Metaling.**—For gravel, take \$400 and for macadam \$500 per mile for each inch of thickness.

60. Bridges and culverts must be estimated separately.

61. For a dirt road following the natural surface in level cutting, the limit of cost may range from \$500 to \$2,000 per mile, depending on the character of soil, amount of clearing, and the number of bridges and culverts.

For a dirt road in side cutting, the limits of cost may vary from \$500 to \$3,000 per mile, depending on the character of the soil, amount of clearing, number of bridges and culverts, and the lateral gradients.

Two thousand dollars per mile is used in estimating the cost of standard roads under average conditions in the Yellowstone National Park.

Macadam roads, usually called *stone roads*, have been built extensively in various states of the Union, at costs ranging from \$2,500 to \$3,000 per mile. The figures here given as to metaling are based on a maximum width of 18 ft.

PART IV.

RAILROADS.

PART IV—RAILROADS.

1. The subject of military railroads as here treated will include the location, construction, operation, and maintenance of railroads in the theater of war under military auspices and for military purposes; that is, with a personnel consisting of officers, enlisted men, and civilian employees, and for the main purpose of facilitating the movements and supply of the army.

2. The difference between war and peace conditions will cause a wide departure of military from civil railroad practice. Some of the conditions of military railroad service are:

(*a*) Quick results for a short period are of the first consideration.

(*b*) The mechanical possibilities of the property can not be fully developed by reason of an untrained personnel.

(*c*) Speed requirements are moderate and practically uniform for all traffic.

(*d*) The roadbed and equipment are subject to damage not resulting from the operation of the road, or from the elements, or from decay. A civil road is operated on the presumption that the track is safe; a military road must be operated on the presumption that the track is unsafe.

(*e*) The property will usually be in fair but unequal condition, often hastily restored after partial demolition. The operation of the whole will depend on the condition of the worst parts.

(*f*) A military road is best operated with an ample supply of motive power and rolling stock, and a moderate speed; whereas on a civil road the tendency is to increase speed to economize rolling stock, and to increase train loads to economize motive power. The known ratios of equipment and mileage on civil roads can not be taken as sufficient for military roads.

3. Military railroads, as to **general location**, will usually follow the line over which the army has advanced from its base. In case of a change of base, the line will be the most direct from its advanced position to the new base.

Detailed location will be done with a view to rapid construction with a minimum of labor and materials. Sharper curves and steeper grades may be adopted than would be tolerated on commercial roads. Some features, such as roadbed and track, may be very primitive as compared with modern standard properties. They will have the advantage, however, of some modern matériel, especially the track and equipment, and of standard methods and rules of construction and especially of operation, the results of accumulated experience. For these reasons military roads should be more efficient than the primitive ones which they outwardly resemble.

4. The maintenance and operation of existing lines of high-class construction, and possibly their restoration or partial reconstruction, will require a knowledge of the fundamental principles of such construction.

In all that relates to location, construction, and maintenance, the foregoing conditions will be kept in view, and an attempt will be made to introduce everything which they require and to exclude everything which they do not require.

5. **Gage.**—The word **gage** is used with various meanings in railroading, but its most frequent and most important use is to indicate the distance between the inner edges of the heads of the rails when newly laid. The **standard gage** in the United States and most foreign countries is 4 ft. 8½ ins. to 4 ft. 9 ins., being adapted to running standard-gage equipment. The **actual gage** of any track exceeds the **nominal gage** by the amount of wear on the inner faces of the two rails since they were laid, and by any outward movement of either rail due to traffic.

Some **side play** between flanges and rails is necessary to safe running. Standard-gage equipment is designed to allow $\frac{3}{8}$ in. side play with a 4 ft. $8\frac{1}{2}$-in. gage. This is not enough for military roads, which should be laid with a 4 ft. 9-in. gage, giving $\frac{7}{8}$ in. side play on new rails, which may increase to $1\frac{3}{4}$ ins., by wear, permitting a wear of $\frac{7}{16}$ in. on each rail.

Side play on curves must be greater than on straight track, and if a 4 ft. $8\frac{1}{2}$-in. gage is used on tangents it is usually necessary to widen it to 4 ft. 9 ins. on curves. If a 4 ft. 9-in. gage is adopted, no widening on curves is required except in case of unusually sharp curvature. Trains will run less steadily, but with less tractive resistance. The latter fact is most important on military roads as grades will often be heavy.

Fig. 1 shows the **standard terms** and **points** for gage of wheels and track.

6. **Alignment.**—A railroad consists in plan of curves and tangents and in elevation of grades. Exactness and regularity of all these features are necessary for a good track. The curves must be true or smooth, the tangents straight, and the grades easy and regular. Alignment, which is of secondary consideration in common roads, is of first importance in railroads.

7. **Notation of curves.**—Suppose T, T', fig. 2, to be the tangents which are to be connected by a curve, prolonged to their intersection at V, called the **vertex.** Let C be the center of the adopted curve, CA, CB, the limiting radii. The angle between them, which is also the angle between the tangents, or the difference of their azimuths, is the **central** or Δ angle, often called the **external angle.** The direction of the survey being from A toward B, the beginning of the curve at A is called the **point of curvature,** *PC*. The end of the curve at B is called the **point of tangency,** *PT*. The straight lines AG and GB, 100 ft. long, joining points of the curve are called **chords.** The line AB, joining *PC* and *PT*, is called the **long chord.** The distance HG, from the middle of the long chord to the middle of the arc, is called the **middle ordinate.** The distance GV, from the arc to the vertex, is called the **external distance.** AV and BV are called the **tangent distances.**

8. The **rate of curvature** of railroad track is designated by the arc corresponding to a chord of 100 ft., and in U. S. railroad surveying the word *chord* is restricted to one of 100 ft. A shorter chord is called **a subchord** and a longer one, except the *long chord*, par. 7, **a secant.** In the following pages the terms chord, subchord, and secant will always be used in the sense indicated. The rate of curvature is also the deflection, or change of azimuth, in passing from one end of a chord to the other, or the angle made by the tangents to the curve at the ends of the chord.

If, in fig. 3, the line AB is 100 ft. in length and from a center, C, an arc is drawn passing from A to B, the rate of curvature of the arc is designated by the number of degrees in the angle ACB. Similarly, if arcs are drawn from the centers, C_1, C_2, C_3, etc., their rates of curvature are designated by the number of degrees in the angles AC_1B, AC_2B, etc. If the angle, ACB is 30°, then the arc ACB is called a 30° curve, etc. In the abstract, the rate of curvature is designated by the letter D, which will not be used herein for any other purpose, except in illustrations.

The less the rate of curve, or the flatter the curve, the longer is the radius and the greater the length of curve between given tangents. The radius of a 1° curve is 5,730 ft., nearly, and the radius of any curve may be determined approximately by dividing 5,730 by the degree of curvature. Thus, the radius of a 3° curve $= \frac{5730}{3} =$ 1,910 ft. The radius of a 10° 20′ curve $= \frac{5730}{10.33} = 554.7$ ft.; and the radius of a $\frac{1}{2}$° curve $= \frac{5730}{.5} = 11{,}460$ ft. Conversely, D for any curve is found by dividing 5,730 by its radius.

Curves of less than 50 ft. radius can not be expressed by this method, because a chord 100 ft. in length can not be drawn in them. Such curves are designated by the length of radius. **In foreign countries** all curves are designated by length of radius. In England the radius is expressed in chains of 66 ft. A curve of 20 chains on an English road is the same as an American curve of 1,320 ft. radius, or $\frac{5730}{1320} = 4°.34 = 4° 20′ 24″$. A 1,000-meter curve is the same as a curve of 3,280 ft. radius $= \frac{5730}{3280} = 1°.747 = 1° 44′ 49″$.

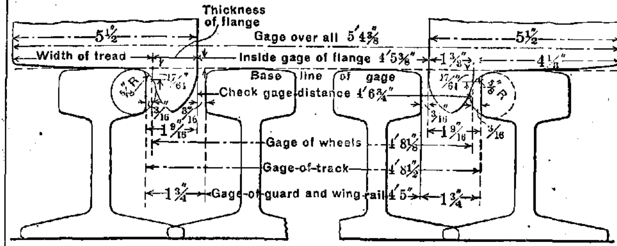


Fig. 1

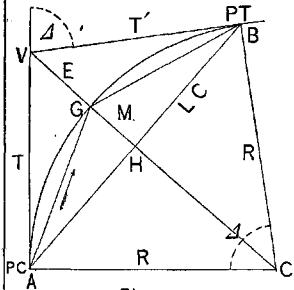


Fig. 2

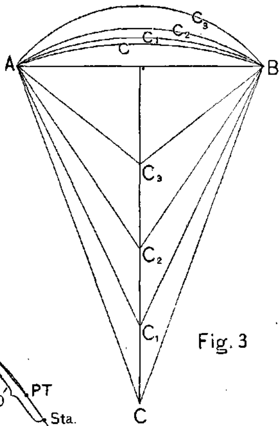


Fig. 3

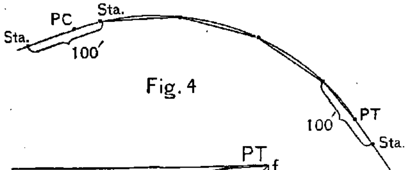


Fig. 4

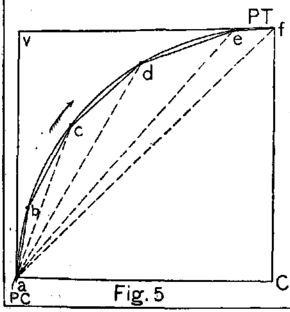


Fig. 5

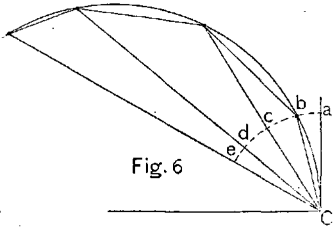


Fig. 6

Within the range of curvature used in railroad construction the elements of the curve are approximately inversely proportional to D, and having the elements for the curvature of 1°, those for any other curvature may be obtained by dividing the quantity for 1° by the desired value of D. Table I gives elements for a curvature of 1°. To obtain the elements for any other curvature, take out the quantities from Table I for same central angle and divide them by D.

9. It is the custom to state curvature in degrees, minutes, and seconds, and all tables are so constructed. In railroad work the curvature appears so often as a multiplier or divisor, that it will be found much more convenient to express it in degrees and hundredths, which give the arc to the nearest 36 seconds. If greater refinement is desired, extend the fraction to thousandths, which give the arc to 3″.6, which is closer than it can be measured with ordinary instruments.

Table II gives the minutes and seconds of arc corresponding to decimals of a degree. The conversion into minutes and seconds need be made only when the angle is to be laid off with an instrument.

10. **The amount of curvature** in any curve is the total deflection of the line affected by the curve and it is designated by the number of degrees of the arc included between its ends. It is found by multiplying D by the number of 100-ft. chords or stations on the curve. Thus, a 3° curve of 10 stations will deflect the line 30°. This is the angle between the end radii, called the **central angle**, and denoted by the symbol Δ, which will not be used for any other purpose. The chord of Δ is the *long chord*, par. 7. It is also the **external angle** of the tangents which the curve is to connect, also denoted by Δ, or the **difference of their azimuths.**

The sum of the central angles of all the curves on any line is the **total curvature** of the line. This, divided by the length in miles, gives the **curvature per mile,** a quantity which is of importance in considering the tractive force necessary to operate trains over the line; also in connection with questions of speed and maintenance.

11. **Relation between lengths of chords and arcs.**—The length of the arc of a chord is slightly greater than 100 ft.; 0.0013 ft. for a 1° curve and increasing as the square of D. For all usual railway curves it is negligible.

A curve may not, and generally does not, contain a whole number of chords. The remainder of the curve is spanned by **subchords.**

The relations of length between subchords and the corresponding arcs are not precisely the same as those between chords and their arcs. Neglecting the difference, or supposing the ratio of length of chord and length of corresponding arc to be the same for chords and subchords, the expression for the length of a subchord is $100\frac{d}{D}$; in which d is the arc of the subchord in degrees. This is called the **nominal length** of the subchord. The **excess** of the **real length** over the nominal length is a maximum for a subchord of 57 ft., nearly, and for a 10° curve is 0.05 ft., or $\frac{6}{10}$ in. As 10° is a rather sharp curve for railroad work and the average is much flatter, this excess is also neglected, subchords are treated as fractions of the chord, and the length of an arc in ft. is assumed to be the aggregate length of its chords and subchords. This length expressed in **stations** or units of 100 ft. may be obtained by substituting the values of D and Δ for the given curve in the expression $\frac{\Delta}{D}$; multiplying by 100 gives the length in ft.

12. **Examples.**—The length of a 4° curve with a central angle of $41° = \frac{41}{4} = 10.25$ stations $= 1{,}025$ ft. The length of a 2° 20′ curve having a central angle of $9° 45' = \frac{9.75}{2.33} = 4.18$ stations $= 418$ ft.

13. **Distribution of chords and subchords.**—It is desirable to have the number of the station at any point indicate the total length of the line to that point, and hence in passing from curve to tangent, or from tangent to curve, there should be 100 ft. between the last station on the one and the first station on the other. If the *PC* is at a fractional station on a tangent—called a **plus**—the curve should begin with a subchord equal to the difference between 100 ft. and the plus. If the *PT* is

at a plus, or the curve ends with a subchord, the first station on the tangent will be at a distance from PT equal to 100 ft. less the length of the subchord, fig. 4. A curve should be run in without subchords only in the rare case in which the PC falls on a station of the tangent and the curve is a round number of hundreds of feet in length.

14. **Curves are classified as simple, compound, and transition.**—A **simple curve** is the arc of a circle. A **compound curve** is composed of arcs of circles of different radii turning in the same direction, tangent to each other and to the straight track at each end. **Transition curves,** often called **spiral** or **easement** curves, are those in which a circular central part is connected with the tangents at either end by a curve of variable radius progressively increasing from that of the central curve at the ends of the latter, to infinity at PC and PT.

The point of tangency of curves of different radii turning in the same direction, is called the **point of compound curvature,** PCC.

Curves turning in opposite direction and less than a train length apart are called **reverse curves.**

15. **Simple curves.**—Curves are located on the ground partly by running out the chords and subchords and partly by offsets or ordinates from them.

The angle between a chord or subchord and a tangent to the circle at one of its ends is measured by **one-half of the arc** corresponding to the chord or subchord. The angle between a chord or subchord and a secant, or the angle between two secants, intersecting on an arc, is measured by **one-half the difference** of the arcs subtended by the chords or secants. Thus, in fig. 5, the angle between the tangent av and the subchord ab is measured by one-half the arc ab; the angle between av and ac is one-half the arc ac, etc.

But with equal chords of 100 ft., as in railroad practice, the arc corresponding to a chord is D, the degree of curvature; and the difference of the arcs corresponding to a chord or subchord and the secant to the first station beyond it, as bc, or between the secants to adjacent stations, as cd or de, is also D. Hence the angle between tangent and chord, or between chord and the secant to the next station beyond it, or between secants to adjacent stations, is $\frac{1}{2}D$. This is called the **deflection angle**, and is very important in curve location.

Generally, for *simple curves* the angle at any station between any other two in the same direction is $\frac{1}{2}D \times (n' - n)$; in which n' is the serial number of the farther and n of the nearer station. For example, the angle at station 12 between station 17 and $22 = \frac{1}{2}D \times (22 - 17) = 2\frac{1}{2}D$.

Under the assumption already made as to the length of subchords (par. 11) the **deflection angle for any subchord** is proportional to the length of the subchord, or is $\frac{1}{2}D\frac{l}{100}$; in which l is the length of the subchord in ft.; and generally the angle at any point of the curve between any two other points in the same direction is $\frac{1}{2}D \times \frac{L}{100}$; in which L is the aggregate length of chords and subchords in ft. between the two points. The **deflection angle** of the **long chord** is $\frac{1}{2}\Delta$, which relation is **valuable as a check** and should always be so used.

If at the PC, fig. 5, an angle of $\frac{1}{2}D\frac{l}{100}$ is measured from the tangent in the direction of curvature, the line of sight passes through the station b, and if the length l is measured on this line from PC, the station b is determined. If, now, another or additional angle of $\frac{1}{2}D$ is measured, the line of sight passes through station c, and if a 100-ft. tape is stretched from b and its forward end swung until it is on the line ac, the point so determined is station c. Similarly, any station may be located from a and the one next preceding.

The above-described method of determining the chords and subchords of a simple curve is called **location** by **deflections.** It is the **usual method** and is always employed for curves of 2 or more stations, unless there is something to prevent.

16. **Practical location of a curve.**—The general case will be that in which two tangents already located are to be connected by a curve.

1st step.—Run the tangents out to their intersection, if it has not already been done, and measure the external angle or difference of azimuth, which is Δ.

2d step.—Chain or pace over the ground on which it is desired to locate the curve, determine its approximate length in ft., and point off two places from the right, which gives the length in stations. If a map is available, this distance may be scaled. Divide Δ by this number and the quotient will be D. If it is not a convenient angle to use, take the nearest one above or below it and divide it into Δ for the corrected length in stations.

3d step.—Take from Table I the tangent distance T corresponding to Δ; divide it by D, which gives the tangent distance of the curve, or the distance of PC and PT from V.

Locate PC and PT on their respective tangents. Measure from PC back to the next preceding station to determine the *plus*. Begin the curve with a subchord equal to the difference between 100 ft. and the *plus*.

4th step.—Compute and tabulate all the deflections from PC thus:

For the 1st subchord, $\frac{1}{2} D \frac{l}{100}$

For the 1st chord, $\frac{1}{2} D \frac{l}{100} + \frac{1}{2} D$

For the 2d chord, $\frac{1}{2} D \frac{l}{100} + D$

For the 3d chord, $\frac{1}{2} D \frac{l}{100} + 1 \frac{1}{2} D$

For the 4th chord, $\frac{1}{2} D \frac{l}{100} + 2 D$

For last subchord, $\frac{1}{2} D \frac{l}{100} + \frac{n}{2} D + \frac{1}{2} D \frac{l'}{100} = \frac{1}{2} \Delta$

In the above tabulation l and l' represent the lengths of the first and last subchords in ft., and n the number of chords in the curve.

5th step.—Set up the transit on PC, put the 0°–180° line on the tangent and turn off in the proper direction the first tabulated angle. Measure on this line the length of the first subchord and locate the first station of the curve. Turn off, from the tangent also, the second tabulated angle and locate the second station by swinging a 100-ft. tape from the first station as described in par. 15. Continue as long as the stations can be seen clearly from PC. If all can not be seen, shift the transit forward and set on a station which has been determined, and orient by the following rule:

Set the vernier at the reading in the table corresponding to any convenient preceding station, point to that station and clamp the limb. Plunge the telescope and locate forward stations by using the tabulated deflections originally computed for those stations, precisely as if still working from PC. In using this rule remember that the deflection corresponding to PC is the azimuth of the back tangent from which the deflections were started.

Usually the forward tangent will not have been run out much beyond PT. Measure off on it from PT a distance equal to 100 ft. minus the last subchord of the curve, and locate the station next to the curve on the tangent. From this run out the tangent, setting stations 100 ft. apart nntil another curve is reached.

17. **Example.**—Given two tangents intersecting in a Δ of 20°, the vertex being at station 291 + 48 of the back tangent, to connect them by a simple curve approximately 740 ft. = 7.4 stations in length. $\frac{20^\circ}{7.4} = 2^\circ.7027 = 2^\circ\ 42'\ 9''.7 = D$.

As this is not a convenient value to use, assume $D = 2^\circ\ 42' = 2^\circ.7$, and $\frac{20^\circ}{2.7} = 7.408$ stations = 740.8 ft. = corrected length of cnrve.

From Table I for $\Delta = 20°$, $T = 1010.29 \div 2.7 = 374.2$ ft. $= 3.74$ stations $=$ the tangent distance. This measured back on the tangent locates *PC* at $(291 + 48) - (3 + 74) = 287 + 74$.

The curve will begin with a subchord of $100 - 74 = 26$ ft. The remaining length, $740.8 - 26 = 714.8$, will consist of 7 chords and a closing subchord of 14.8 ft.

The deflections from *PC*, assuming the azimuth of the tangent to be 0°, will be as follows:

For the opening subchord of 26 ft.; $\frac{1}{2} D \frac{l}{100} = 1°.35 \times 26/100 = 0° 21'$. $\frac{1}{2} D = 1° 21'$.

For the 1st chord, $0° 21' + 1° 21' = 1° 42'$.
For the 2d chord, $1° 42' + 1° 21' = 3° 03'$.
For the 3d chord, $3° 03' + 1° 21' = 4° 24'$.
For the 4th chord, $4° 24' + 1° 21' = 5° 45'$.
For the 5th chord, $5° 45' + 1° 21' = 7° 06'$.
For the 6th chord, $7° 06' + 1° 21' = 8° 27'$.
For the 7th chord, $8° 27' + 1° 21' = 9° 48'$.

For the last subchord of 14.8 ft., $0° 21' + 7\,(1° 21') + \left(\frac{14.8}{100} \times 1° 21'\right) = 9° 48' + 12' = 10° = \frac{1}{2}\Delta$.

If an azimuth is carried, that of the back tangent is to be added to all the deflections. Thus, if the az. of the back tangent is 100°, the table of deflections will read 100° 21'; 101° 42'; 103° 03', etc.

Having located say three stations from *PC* as above described, suppose it is not convenient to work from that point any longer. Shift the transit forward to station 3, set the vernier at 0°, point to the *PC*, and clamp the limb. Then plunge the telescope, set the vernier at 5° 45', and locate the 4th station, etc.

To get on the forward tangent set up on *PT* and orient by the rule, par. 16. Set the vernier at the deflection corresponding to *PT*. Plunge the telescope and it will point along the forward tangent.

As the last subchord is 14.8 ft. the first station on the forward tangent will be $100 - 14.8 = 85.2$ ft. from the *PT*.

18. This method may be used **without a transit** at some sacrifice of accuracy by substituting a geometrical construction for the angle measurements. A good way is to take a distance, $l = Ca$, fig. 6, as a radius with a center at *PC*, and set stakes on the arc of a circle, the first on the tangent, the next at a distance of $0.000087 \times D \times l^2$, and the others, one for each chord of the curve, at equal distances of $0.87 \times D$. If there is an opening subchord, it will be taken as the radius; if there is not an opening subchord, the radius will be 100 ft. If there is an opening subchord of insufficient length for a good radius, use it as a radius for setting the first stake off the tangent, then prolong the line from *PC* through this point to 100 ft. and set the remaining stakes on the arc of that radius.

19. Chords and subchords may also be located by traversing, Recon. 103. If short sights are necessary, this method is to be preferred. Without an instrument this method is known as location by **tangent offsets and chord deflections**, or, **offsets from chords produced.**

Lay off on the tangent from *PC*, fig. 7, the length of the subchord and with the end of the tape held at *PC*, swing the forward end in the direction of curvature until the distance $bc = 0.000087 \times D \times l^2$. This locates the forward end of the subchord. Prolong the subchord and from c lay off 100 ft. to d and swing as before a distance of $0.0174 \times D \times \frac{(100 + l)}{2}$, locating the forward end of the first chord at e. For the remaining chords, the expression is $1.74 \times D$, since $l = 100$. For the closing subchord, the expression is the same as for the first chord, *de* of the fig. The above constants will give sufficiently accurate results up to 20°. The first is used when one of the lines is a tangent; the second and third when both are chords or subchords.

A convenient method of laying down curves of very short radius when the arc can not be swept from the center is called the **method of offsets from the tangents.**

If from *PC* or *PT* distances be laid off along the tangent and at each point so determined a corresponding distance be laid off normal to the tangent and in the direction of curvature, the ends of the offset distances will be points of the curve. It is most convenient to take equal distances on the tangent.

Table III gives the tangent offsets in ft. for curves of 10 to 100 ft. radius at each tenth of the radius from *PC*. Values for intermediate radii may be obtained by interpolation. It will not often be necessary to do this, as the difference between any desired curve and the nearest one in the table will rarely be of importance.

20. **Compound curves** are principally used when the rate of curvature is controlled by accidents of the ground, as in passing through ravines and around the flanks of hills. It is not desirable to introduce short tangents between curves if it can be avoided, nor to make very abrupt changes of curvature.

Some of the relations of length, etc., of simple curves can be worked out for compound curves, but they are too complex for use except by experts. If a map is available, the parts of the curve can be laid down and all questions of curvature and length determined in advance. Otherwise run out each curve separately as described for simple curves, determining the common tangent as an initial direction for the new deflections. If the first curve ends with a subchord, the second one should begin with a subchord, the sum of the lengths being 100 ft., as in passing from curve to tangent.

21. By using the **azimuth method**—instrument on each station—a curve may be run out haphazard to fit the ground, each station being located from the next preceding one according to the requirements of the ground, and the deflection angles determined from the transit. In such work it is important to utilize all the leeway which the ground affords to secure as few and as small changes of curvature as possible and to avoid reverse curves.

22. **Filling in the curve.**—The chords and subchords located and marked, the **intermediate points** are found by ordinates from these lines. Those at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of the length of a chord or subchord are most convenient. That at $\frac{1}{2}$ distance is called the middle ordinate and the others are called side ordinates. Points 50 ft. apart are usually sufficiently close to lay the rails by.

The middle ordinate for a chord $= .218$ ft. $\times$ D, with sufficient accuracy for all practical purposes. The **side ordinates** at 25 and 75 ft. are approximately $\frac{3}{4}$ of the middle ordinate or .163 ft. $\times$ D. Ordinates for other lengths of chord or subchord vary as the square of the length. Table III gives ordinates for subchords varying by 1 ft., and indicates the method of obtaining ordinates for lengths greater than 100 ft.

As a check, a line may be stretched on a secant of two stations and the ordinate at the middle station measured. It should be 4 times the middle ordinate for one station.

The final location by ordinates is usually done at the time of laying track. **It is especially to be noted** that all that has been given as to location refers to the **center line** of the track. The rails are placed by measuring one-half of the gage each way from this line.

23. **Superelevation of outer rail.**—When a train runs on a curve there are two forces acting to crowd the wheel flanges against the outer rail—centrifugal force and the tendency of the stiff trucks to run straight. The former varies as the square of the speed; the latter is constant for all speeds. If the train is stretched, i. e., a tension on all drawbars, the pull of the locomotive works against these two forces and tends to draw the trucks to the inner rail, but this effect is small, variable, and negligible.

To reduce pressure on the outer rail, it is elevated above the inner rail by a certain amount. A safe rule for standard gage is to elevate $\frac{3}{4}$ in. per degree of curvature up to a maximum of 6 ins., which should not be exceeded. This rule is modified, or not applied, on curves in special situations where all traffic must run at low speed, as at important stations, crossings, in yards, etc. It can not be applied to reverse curves, which is a strong objection to their use. Neither is it used on switches and yard tracks which are adapted to low speed only.

24. **Length of run-off.**—The curvature may begin suddenly at a single point, but the outer rail must be elevated gradually, so that the elevation must begin on the tangent and increase gradually to *PC*, where it has its proper value for the curvature. This gradual elevation of the rail along the tangent is called the **run-off** and its length is usually 40 ft. per degree of curvature, although some roads use a constant run-off of 120 ft.

25. **Transition curves.**—To avoid the run-off or superelevation of one rail on straight track is the principal purpose of transition curves. In these, the curvature begins very small and increases gradually, so that the superelevation may begin at *PC* and, increasing gradually, bear everywhere a proper relation to the curvature.

The theoretical form of a transition curve is a spiral, but its practical location reduces to that of a multi-compound curve, consisting of several short arcs of equal subchords and uniformly increasing curvature connecting each tangent to the main curve. In curving the rails and laying them to meet the points so determined, a very close approach to a true spiral is produced. Such curves find no place in military railroad construction and it is only necessary to give such data as will enable them to be recognized and classified when found in existing track. If the run-off begins at *PC* and ends at *PT*, the curve is some kind of spiral or easement. If the full run-off appears to be on the tangents, the curve is probably simple.

26. **To determine the curvature of existing track** roughly, a rule of thumb is to stretch a string 62 ft. long knotted in the middle with its ends against the concave side of the head of one of the rails. The distance in ins. from the middle knot to the rail is the curvature in degrees. A curve may be tested at several points by this method to find out whether it is simple, compound, or spiral. If simple, or originally so, the curvature can be determined accurately by dividing Δ by the length of the center line in stations.

27. **Vertical curves** are used to ease off changes of grade to avoid strain on couplings and breaking trains in two. A safe average rule is to give them a length of 170 ft. for each 1% of change of grade. On some roads a uniform length of 400 ft. is used.

The exact length is not important and may be varied to suit conditions and convenience. Vertical curves increase fills and cuts, and if an embankment is already high or a cut deep, an increase means much time and labor. In such case the length of a vertical curve may be shortened until the extra cut or fill is reduced to a manageable quantity.

Assume a convenient length for the curve, giving preference to an even number of stations, and determine the elevations of the intersection *B* and the points of tangency, *A* and *C*, fig. 8. Set temporary stakes to the grades *AB* and *BC* at *B* and at distances on each side of *B* of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{3}{8}$ of *AC*. Take the difference between elevation at *B* and half the sum of elevations at *A* and *C*. Call the difference *M* and apply it as a correction to the elevation *B* for the elevation *D* of the corresponding point of the vertical curve. Apply a correction of $\frac{9}{16}$ *M* at the point nearest *B*, $\frac{1}{4}$ *M* at the next points on each side, and $\frac{1}{16}$ *M* at the points nearest *A* and *C*.

All these corrections are **negative** or **subtractive** if the 1st grade prolonged passes **above** the 2d grade, in which case the curve lies **below** the grade lines and is **convex** upward. The corrections are all **positive** or **additive,** when the 1st grade prolonged passes **below** the 2d grade, in which case the curve lies **above** the grade lines and is **concave** upward.

If a standard length of 400 ft. is taken for *AC* and the grades are expressed in percentages (Recon. 12), then $\frac{1}{2}$ the **change of grade** is the middle correction in ft. The **change of grade** is the **sum** of the percentages if one is up and the other down. It is the difference of the percentages if both grades are up or both down, reckoned in the same direction.

Example.—Assume an up grade of 1.12%, followed by a down grade of 1.5%, to be connected by a vertical curve 400 ft. long, the initial point of which is at elevation 92.5 ft. above the datum of the survey.

The intersection of grades, *B*, is higher than the initial point by 1.12% of 200 ft. = 2.24 ft., making its elevation 92.5 + 2.24 = 94.74 ft. The terminal point is lower

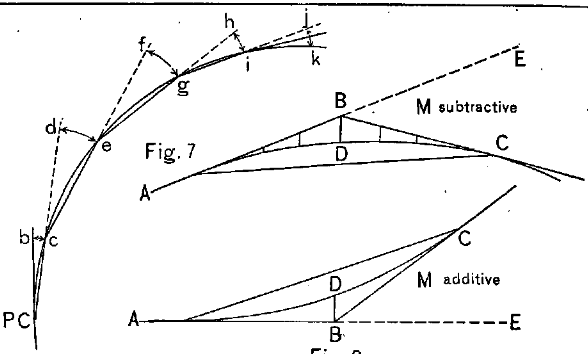


Fig. 7

Fig. 8

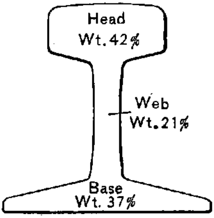


Fig. 9

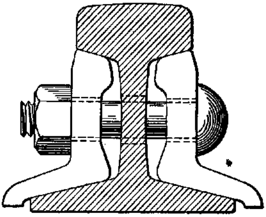


Fig. 10

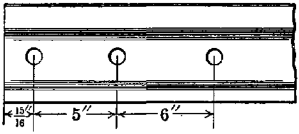


Fig. 11

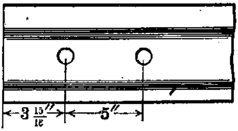


Fig. 12

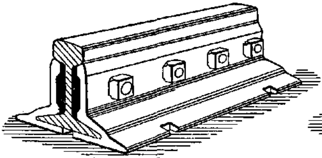


Fig. 13

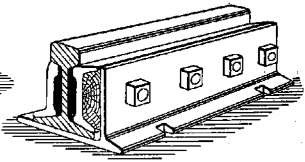


Fig. 14

than the intersection by 1.5% of 200 ft.=3 ft., making its elevation 94.74−3=91.74 ft. The correction M is $\frac{1}{2}\left(\frac{92.5+91.74}{2}-94.74\right)=-1.31$ ft., and the middle point of the curve will be 1.31 ft. lower than the intersection, or at elevation 94.74−1.31 =93.43 ft. The other corrections are $\frac{9}{16}$ (1.31)=0.74 ft. at 50 ft. each way from D, $\frac{1}{4}$ (1.31)=0.33 ft. at 100 ft. each way from D, and $\frac{1}{16}$ (1.31)=0.082 ft. at 150 ft. each way from D. All the corrections are subtractive, because the 1st grade prolonged passes above the 2d grade.

Or, change of grade=1.12+1.5=2.62%. $\frac{2.62}{2}=1.31$ ft., the middle correction as above. The other corrections are derived as before. This method applies only when a curve is 400 ft. long. The first method is general.

28. **Surveys.**—The instrumental location of a military railroad does not differ in scope from that prescribed for a new wagon road (pars. 37 and 38, Roads), but greater accuracy is desirable and a much more careful adjustment of curves, and especially of grades, is indispensable. As with common roads, the grade will mainly follow the natural surface, but the line must be so located as to keep these grades within the adopted limit, which will usually be 2%, though, in exceptional cases and for short grades, 4% is allowable. It will be noted that this restriction of grades will, in rough country, cause the road to be longer between given points than a wagon road would be (see Recon., fig. 41).

Drainage lines (Recon. 48) present the most regular and easiest gradients, and in a broad sense it may be said that every railroad location follows lines of drainage. When the head or source of one drainage line is reached, the location crosses the divide to the next. With few exceptions, drainage lines have slopes not exceeding those permissible for railroad location. The first requisite in considering a railroad location is to get the lines of drainage clearly in the mind. This done, start the exploration from the initial point on a straight line for the objective. Keep on this line as long as it can be done within the prescribed limits of grade and curvature. Leave the line only when forced away from it. Do not go away from it farther than is absolutely necessary and get back to it as soon as possible.

Curvature is not so strictly limited in amount. Its requirements are mainly accuracy of location. It will seldom be found necessary to put in a curve which can not easily be run under military conditions. 10° to 12° is the maximum adopted by some roads traversing fairly rough country.

29. Each determined point of the survey should be marked by a stake with a smooth, flat top, having a nail or tack driven in the top to mark the exact point. As a rule, lengths should be computed and measured to the nearest tenth of a foot for long distances—chords, secants, tangents—and to the nearest hundredth for short ones—ordinates, subchords, etc.

If closing errors are large, the line should be run over again. If they are reasonably small, they may be distributed in proportion to the distance. On curves, closing errors and distributed parts of them must be measured on a radius.

30. **Compensation for curvature.**—To equalize the resistance of traction, it is customary when a curve comes on a heavy grade to reduce the grade over the curve in proportion to the curvature. The usual rule is to reduce the steepest grades $\frac{1}{20}$ of 1% for each degree of curvature. Minor grades need not be compensated.

31. **The roadbed** is the support prepared for the track. It generally consists of the **foundation** and the **ballast.** The latter should be a material the consistency of which is not affected by water and especially which does not become slippery when wet. Sand will do if nothing else can be had; gravel is better, and broken stone is the best of all. Cinders, shells, burnt clay, and other materials are also used. The surface of the foundation on which the ballast rests is called the **subgrade.**

Unless the natural ground is very unfavorable, it will not be necessary to use a separate material for ballast and the subgrade really disappears. Even then, the earth between and immediately under the ties which is dug into in surfacing the track is called ballast. Such roads, usually called **mud roads,** will be the rule in military practice.

The preparation of the earth foundation for railroad track is called **graduation** and is done as indicated for roads (see Part III). **Drainage** is quite as **important** as for wagon roads. The operation of placing the ballast is called **ballasting.**

32. **Cross sections.**—For single track, **cuts** should be 20 ft. wide at the bottom, from toe to toe of slopes. **Fills** should be 18 ft. wide at subgrade elevation. For double track add 12 ft.

Ballast should be 6 to 9 ins. deep under the ties, 10 ft. wide on the subgrade for single track, and 8 ft. wide at top. The drainage qualities of different ballast materials are recognized in cross sections made with them.

33. **The track** consists of the **ties**, the **rails**, and the attachments of the latter to the former and to each other.

Ties for military roads will be made of the most accessible wood, and should be 8 ft. long, 6 to 7 ins. thick, and 8 to 10 ins. face, top and bottom, if hewed, and 9 ins. if sawed. They should be spaced 24 ins. c. to c., as a rule, but if the ties are broad it may be necessary to space them wider as clear room between of 12 ins. is needed for tamping. It is usual to allot a certain number of ties (14 to 16) to a 30-ft. rail, and space them equal clear distances rather than equal center distances.

Where the rail joints fall, the ties are spaced so that the joint comes midway between two ties, giving what is called a **suspended joint.** The best ties, largest and truest, should be selected for these positions.

34. **Rails** are of soft steel 30 ft. in standard length with the cross section shown in fig. 9. The names of the various parts of the section are given in the fig. The size of rails is reckoned by the weight per yard in lbs. and varies from 20 to 110 lbs., the former used for industrial and construction roads and the latter on a few of the highest class trunk lines. Rails for military roads will probably run from 60 to 80 lbs. The name of the mill and the weight per yard are rolled in raised letters on the web of each rail at short intervals.

35. **Joints.**—The connection most used for the ends of rails is called the **angle-bar** or **splice-bar** joint and consists of two specially formed bars which fit the rail on each side and are bolted through. Fig. 10 shows a cross section of the joint and figs. 11 and 12 the bolt spacing. The standard joint has four bolts. **For extra-heavy rail** some roads use **six** bolts. Joints are also classed as **suspended**, par. 33, and **supported,** in which there is a tie under the middle of the joint. The **suspended** joint is **generally preferred.** Figs. 13 and 14 show two forms of joints lately proposed for very heavy tracks. Splice bars are made of mild steel.

The joints of the opposite rails may be placed on or between the same ties, or the joint of each rail may be placed opposite the middle of the one on the other side. Both methods are in use. For a high-class road with good ballast, the latter method gives good results; for a poor foundation, such as military roads will usually be built upon, opposite joints are necessary.

36. **Track bolts** are $\frac{3}{4}$ to 1 in. diameter according to weight of rail, proportioned as shown in fig. 15. The length varies from $3\frac{1}{4}$ ins. for 60-lb. to 5 ins. for 100-lb. rail. Except on heavy rails the **nut** must be placed on the **outside.**

Nut locks are used to prevent the nuts of track bolts coming off under the vibration of traffic. Several common forms are shown in fig. 16. The bolt is prevented from turning by making it oval near the head and lengthening the holes in the splice bar to fit.

37. **Spikes** are used to fasten the rails to the ties. The standard form is shown in fig. 17. Fig. 18 shows the Goldie spike. Spikes have none too much holding power at the best and careful driving is required to develop what they have. Each blow of the maul should be true and fair in the axis of the spike. Otherwise the spike wabbles in driving and the hole is made too large. The spikes in one end of the tie should not be directly opposite, but should be staggered, the two inner ones on one side of the tie and the two outer ones on the other, fig. 19.

Spikes gradually pull up under the vibration of traffic and may be set down once or twice, but after that they should be pulled and redriven in another place. Redriven spikes hold better if the old holes are plugged.

38. **Auxiliary tracks.—A siding** or **side track** is a piece of track usually parallel to the main track and connected with it at each end so that trains may run through it or not, as may be desired. Main sidings should be not less than 1,000 ft. long, and longer if practicable.

A spur track or **spur** is a lateral track often not parallel to the main track, and connected with it at one end only.

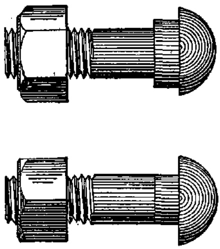


Fig. 15

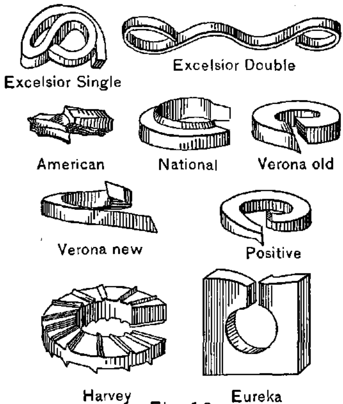


Fig. 16

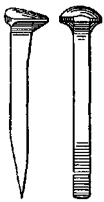


Fig. 17

Fig. 18

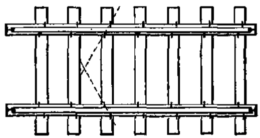


Fig. 19

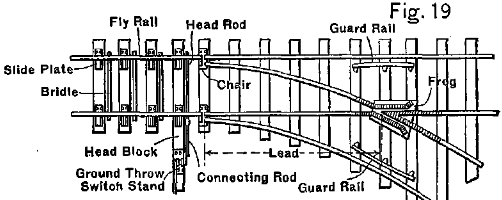


Fig. 20

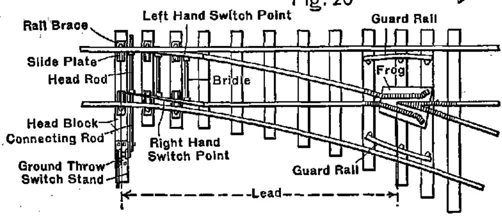


Fig. 21

A **cross over** is a track connecting two other tracks, usually parallel or nearly so, enabling cars or trains to pass from each to the other.

A **Y**, fig. 22, is often used for turning locomotives, cars, and trains end for end. A curved connecting track at a crossing is often called a Y. Two such tracks in adjacent angles of the crossing are usually provided, and trains on either track can be turned by running over them.

39. **Switches.**—A device for connecting auxiliary tracks to main tracks or to each other is called a **switch**. It consists of several parts, which are shown and named in figs. 20 and 21.

There are three general classes of switches:

(*a*) **Stub switches**, in which both main-line rails are cut.

(*b*) **Split** or **point switches**, in which but one main-line rail is cut.

(*c*) **Special switches**, in which neither main-line rail is cut.

40. **The stub switch**, fig. 20, is the oldest and simplest form, but has disadvantages, especially for high-speed traffic, which have caused its virtual exclusion from main-line tracks. A train **trailing** the switch—approaching from the direction of the frog—must be derailed if the switch is misplaced, while trains from the other direction are likely to be derailed if the switch is not fair for either the main line or siding. This form of switch is less objectionable under the conditions of military roads and will be much used.

The switch rails have one end spiked to the ties for a short distance and are straight when in the main line. When the switch is thrown these rails take a curve which assists in the change of direction. The deflected part is not spiked and has no support except what it receives from the spiked ends and from the **tie-rods**, fig. 23, of which there are usually four.

41. **The split switch**, fig. 21, has one rail of each track continuous and spiked. The moving rails when in position for use rest against and are supported by the continuous rails. If the rail section is heavy and the lead rails short, they are usually jointed at the point where spiking ends.

Point switches become trailing if so arranged that the switch rails can move under a lateral pressure so that the trailing train must take or keep the main line.

42. **Special forms** which leave both main rails unbroken have the lead rails elevated above the main rails at the point of crossing, enough to permit the wheels to pass over the latter without striking their flanges. Parts of the lead rails move laterally so as to join over the main rail or clear it entirely. The Wharton is the best-known switch of this type.

43. **Switch details.**—The **frog**, fig. 24, is the controlling feature of switch dimensions. Frogs are designated by numbers ranging from 4 to 12 for the sizes in customary use. These numbers are the ratios of length to width. Measure the distance between the gage sides of main and side points perpendicular to the axis of the frog, *ab*, and the distance along the axis from this line to the theoretical point, *cd*. The quotient of the latter by the former is the frog number. The frog number may be found without a rule. Take a lead pencil or stick of suitable length and mark on the frog near one end the point where the opening equals the length of the measure, step the measure off between this point and the theoretical point *C* of the switch, and the number of lengths counted will be the frog number. Table V gives the angles corresponding to usual frog numbers.

Frogs are classed as **rigid**, in which no parts can move, and **springrail**, in which one of the wings is movable laterally. In its normal position the springrail closes the gap in the main rail and is pushed aside by the flanges of the wheels to open the gap in the lead rail.

44. **Frog construction.**—Frogs for light rail are usually cast in a single piece, but for all weights likely to be used in railroad construction they are made up of pieces of the track rail bent to proper angles and fastened together.

The kinds in most common use are the **keyed**, fig. 25, and the **bolted** frog, fig. 26. In each the spaces between the webs are occupied by cast fillers.

In ordering frogs the frog **number** and **gage** of the track, the **section** of the rail and its **drilling** must be given, and if for renewal, the total **length** of the frog should also be stated. If the springrail is desired state whether **right** or **left**

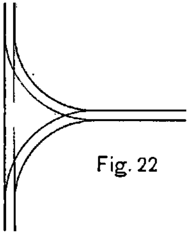


Fig. 22

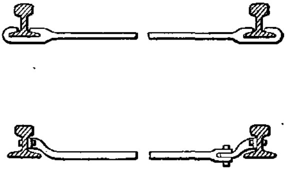


Fig. 23

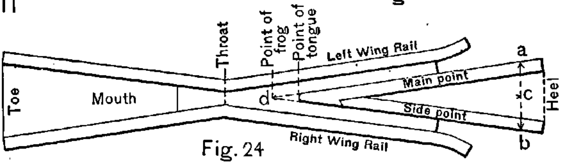


Fig. 24

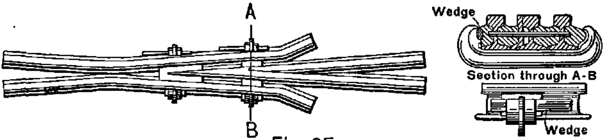


Fig. 25

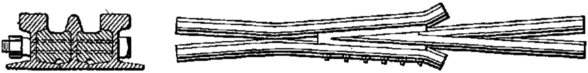

Section

Fig. 26

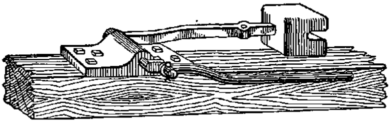


Fig. 27

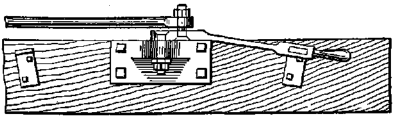


Fig. 28

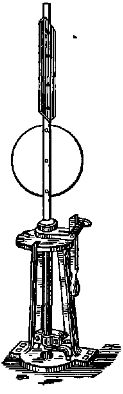


Fig. 29

hand, accordingly as the springrail should be on the right or left side of the frog looking from the point of the switch. Of the pair of springrail frogs required for any siding, one must be right and the other left hand.

45. **Operating devices.**—The switch rails are moved by applying leverage to the end of the **head bar**, which is a name given to the first tiebar. The leverage device is called the **switch stand,** and is connected to the head bar by the **connecting rod,** figs. 20 and 21. The simplest form is the **jackknife** or **ground lever** pattern, figs. 27 and 28, which may be used in unimportant points. Generally the switch stand is adapted to carry a signal to show whether the switch is open or closed, a color board always and a lamp at night, and this purpose has an important bearing on many of the designs. A good stand must have an accurate throw, and in the best forms the throw is adjustable. It must also lock securely when open or closed and must display its position clearly hy means of a signal fixed to some of its moving parts. **All these points** should receive attention in putting in and operating switches.

The commonest form of switch stand consists of a support carrying a vertical rod with the crank lever at bottom connected to the head rod; an operating handle at convenient height, with stops and locking devices to control its movement, and a target at top showing the **danger** color when the switch is **set for the siding,** or **open,** and the **safety** color when **set for the main line,** or **closed.** The top has a socket to receive the lamp, showing the danger and safety colors in the same positions as the targets. Fig. 29 shows the features of such a stand.

46. **Minor features.**—For stub switches a **head shoe** or **slide plate** is used, figs. 30 and 31, adapted to engage the ends of main and lead rails and provide a surface across them for the end of the switch rail to slide upon, with stops to limit its motion. They may be cast or wrought metal.

Rail braces, fig. 32, are used to steady the part of the continuous rail of a point switch opposite the switch rail, and for this use are combined with a bearing plate for the latter. Rail braces are also used for supporting the outside rails on curves and for guard rails, although for this purpose they are rapidly being replaced by tie plates. Fig 33 shows typical forms, cast and wrought.

Two guard rails are laid at each switch, both opposite the frog, figs. 20 and 21. A good arrangement of them is shown in the figures, but they are often straight, with the ends bent away from the rail. Care is necessary in placing guard rails. The minimum space between guard and main rails is opposite the point of the frog and is 2 ins. for 4 ft. 9-in. gage and $1\frac{3}{4}$ ins. for 4 ft. $8\frac{1}{2}$-in. gage. Guard rails are spiked and usually supported by braces. They are sometimes bolted to the rails with fillers, as described for frogs.

47. **Layout of switches and sidings.**—The outside lead rail is a simple curve tangent to the switch rail when set for the siding, and to the frog. It is customary to keep the length of the switch rail and lead in some definite relation to the frog number.

The frog makes a certain angle with the main rail corresponding to its number. The switch rail when set for the siding makes a certain angle with the main rail, depending on its length and the throw. The difference of these angles is Δ for the lead rail curve. Its length in stations divided into Δ gives D, which known, a line may be stretched between the two points named and the middle and side ordinates for the length and curvature D, par. 8, may be laid off.

All the quantities required for the solution are tabulated in Table V for frog numbers 4 to 12, inclusive, except the ordinates, which may be taken from Table IV for the length of rail, and multiplied by the curvature in degrees. The curvature D and the length and ordinates of the lead curve are computed on the assumption that the straight frog is 10 ft. long. If the actual length of frog used differs much from 10 ft., the curvature and ordinates may be recomputed for the actual length. **Note** that the lead is measured to the moving end of the switch rail. The length of the switch rail is included in the lead of split switches and not included in that of stub switches. There is no good reason for this, but it is the practice. On some good roads split switches are put into stub switch measurements.

48. **The curved ends** of the siding outside the main track are called **connecting curves.** The inner rail is tangent to the frog and to the straight rail of the siding. The frog angle is Δ. The length, sufficiently exact for the purpose, will be twice the clear distance between the main line and the siding multiplied by the frog number. The distance between centers of main and side tracks should not be

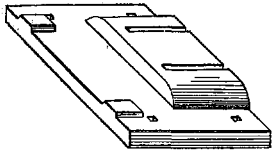


Fig. 30

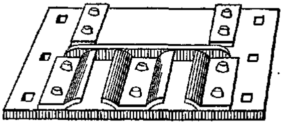


Fig. 31

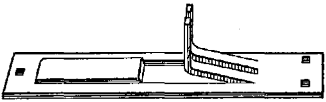


Fig. 32

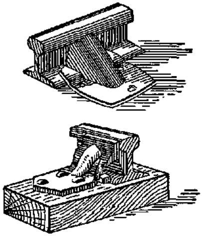


Fig. 33

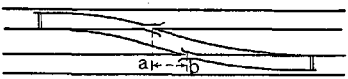


Fig. 34

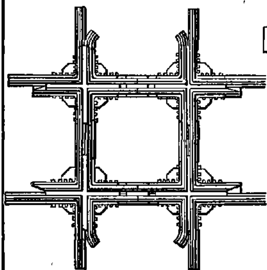


Fig. 35

Fig. 36

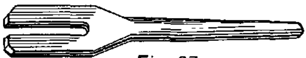


Fig. 37

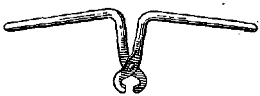


Fig. 38

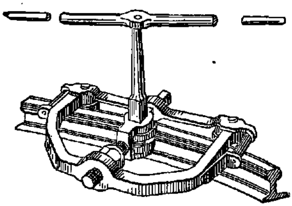


Fig. 40

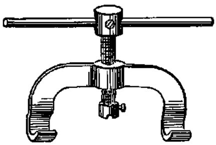


Fig. 39

less than 13 ft. and need not be more than 15 ft., unless a road is desired between the tracks, for which allowance must be made.

If this rule gives the length of connecting curve too great to suit local conditions, run the frog tangent out part way and connect with the siding by a shorter curve.

49. **Sidings should be located** on straight track if possible. If not, add the curvature of track to the curvature of the leads and connecting curve if the siding leaves the curve on the outside, and subtract if the siding leaves the curve on the inside.

50. **Ties of extra dimensions** will be required for each switch, as shown in Table VI. Each switch requires, in addition to the pieces given in the table, one **head block** 8 x 12 ins. x 16 ft.

51. **A cross over** is a double switch connecting two parallel tracks, fig. 34. The distance between frogs *a–b*, measured along the rail, may be taken from Table VII. The switches may be located separately and run toward each other until they can be connected by straight rail tangent to both. If the tracks are straight, it is important that the frogs should be of the same number. If the tracks are curved, the inside frog should be wider than the outside one by 2 *D*.

52. **Crossings.**—In crossing one track over another at grade, 4 frogs are employed similar in design and construction to switch frogs, but usually of much wider angles. Crossings are designated by the angle which the two tracks make with each other. If the angle is 90°, all the frogs are identical. Otherwise, they are in pairs, two less and two greater than 90°. Fig. 35 shows the arrangement of a 90° crossing.

The foundations of crossings require special attention, beginning with the subdrainage. An extra depth of ballast should be used. Switch ties are best and should be laid parallel to the shortest diagonal of the crossing if each track is much used. If one track is but little used, the ties may be laid square with the other one.

Crossings in curved track are complicated in design and are very objectionable for other reasons. They should not be permitted, if avoidable, and never on main track.

53. The crossing of a highway or common road over the track at grade is prepared by laying planks on the ties parallel to the rails, as shown in fig. 36.

54. **Track laying.**—Track is laid progressively and usually on the subgrade or the surface of the foundation. The ties are carried or hauled forward, but the rest of the material is transferred on the rails to its place in the track. The ties are spaced and fairly aligned, the rails spiked carefully to gage, the track surfaced roughly by tamping any ties that are off the ground, and the track is then used to distribute the ballast. The final alignment is made by raising and straightening the track, at the same time placing the ballast under and around the ties.

55. **Placing ties.**—This operation usually controls the speed of track laying. If the ties are cut along the line they should be placed beside the roadbed in wagonload piles at the proper distance to get the desired spacing.

If brought from a distance, it will be on cars run over the track to a point near the ends of the rails. Here they are unloaded and taken forward, either by carrying or hauling, and placed on the roadbed. If teams and wagons are available and the ground alongside the track permits, it will be better to use teams. Otherwise details of men must carry the ties forward. Ten teams can haul out the ties for 500 ft. of track per hour.

For lining ties stretch a line along stakes, set ½ the standard-length from the center stakes. Put the longest corner of the tie to the line. Place the wide face of the tie down, and on curves the broad end outside.

It is very convenient to have the distance from the end of the tie to the flange of the rail gaged on each tie ahead of the spikers.

56. **Placing rails.**—The rails will always be brought up to the head of the track from some point in the rear. They should be on flat cars provided with rollers at the corners. The rails are rolled forward and loaded on the **rail car,** a low stout push car with extra-wide wheel faces to enable it to run on the rails before they are brought to gage. This car should also have rollers to carry the rail forward. The car is stopped with its front end over the last rail end. A rail on each side is rolled ahead and dropped on the ties and hastily placed in approximate position, and the car is run ahead on them a rail length. The rail car carries 50 ordinary rails, enough to lay 750 ft. of track. Two rail cars may be used by tipping the empty one on edge outside the rails while the loaded one passes it.

In handling rails, the **rail fork,** fig. 37, and the **rail tongs,** fig. 38, are used.

57. When it is necessary **to curve rails** before laying, the tool used is called a **rail bender,** in its simplest form, known popularly as a **jim=crow,** fig. 39. Fig. 40 shows a traveling rail bender which runs from one end to the other, leaving the rail curved behind it.

For new work rails are best bent at the supply yard. The quantity required is readily determined from the lengtbs of the curves. Ordinarily, both rails of a curve may be bent alike. Curved rails must be handled with extra care in shipment. In bending a rail, adjust the bender until the rail when uniformly bent will have the middle ordinate, Table IV, corresponding to the curvature. If the jim-crow is used, set at equal distances and turn up the screw the same amount at each set. If the curve is too flat, set closer, or turn up more, or both. If too sharp, the reverse. The jim-crow is not a convenient tool for making smooth bends. Its best use is to bend rails at an angle. If a rail is not evenly bent, the irregularity is easily seen by sighting along it. Mark the point with chalk on the side toward which the bend should be made. It is important to carry the curve quite to the ends of the rail. This is frequently neglected.

A large proportion of rails are bent while laying by drawing them to the required curve as they are spiked. The ease of doing this depends on the rate of curvature and the length and weight of rail. A straight 30 ft. rail of average weight may be drawn to a 7° curve while spiking if the ties are sound. For greater curvature, or shorter or heavier rail, it will be better to use the bender.

Drilling rails will frequently be necessary. The most convenient tool is the ratchet **track drill,** fig. 41, but any improvised arrangement which will hold a drill at the proper point may be made to answer.

Rail cutting is best done with a **rail saw,** but may be done with an ordinary hack saw, or by notching a groove around with a chisel and breaking the rail in two.

58. **Expansion of rails.**—A 30 ft. rail expands $\frac{1}{16}$ in. for a rise in temperature of 25° F. The highest temperature in the sun likely to be encountered in the locality should be ascertained and the ends of the rails separated in laying by $\frac{1}{16}$ in. for each 25° of difference between the actual temperature and the assumed highest. Shims of different thickness are inserted between the ends of the rails while splicing. They should be of metal. Shims of $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{1}{4}$ in. thickness, used singly or in combination, will be sufficient. Buckets or boxes containing shims should be attached to the front end of the rail car. As each rail is dropped off the car, one man holds the shim against the end of the last rail and the new one is set back against it to hold it in place.

59. **Splicing.**—The splicers follow the rail car, but not too closely. They work in two parties, the leading one, or **head strappers,** removing the shims, placing the splice bars and inserting a bolt to hold them in position. **The back strappers** follow and complete the joint. After the bolts are first tightened the splice bars should be struck a sharp blow with a sledge in each interval and on the ends. Each bolt should also be lightly tapped. The bolts will then be found loose and must be tightened by a good pull on an 18-in. wrench. Fig. 43 shows a track wrench for square nuts.

60. **Spiking.**—Two men work together, driving the spikes in the end of the same tie at the same time, striking alternately. They usually stand near the rail. If both are right or left handed, they will face each other, one ahead of, and the other behind the driving point. If one is right and the other left handed, they will both stand behind the driving point and face ahead.

The tie is held firmly against the rail while driving, by a man called the **nipper,** who is provided with a pinch bar, fig. 44—a crowbar or lining bar, fig. 45, is not so good—and a hard-wood block 2 x 4 x 12 ins., with a spike driven in it for a handle. The nipper sets his block outside the end of the tie, lays his bar across it, engaging the point under the middle of the end of the tie, and throws his weight on the bar.

The two spikers start their spikes at the same time. The point must be held against the rail and the spike must be kept plumb while driving. This is not so easy as to drive them at a slight angle, and the spikers must be watched, and occasionally cautioned, or the work will not be well done. After the head of the spike is against the rail, which can be told from the sound, one moderate blow only should be given. This will draw the rail tight, without danger of cracking the head of the spike. If rail braces are not used, the outer rail of curves may be double-spiked on the outside. If this is done, both spikers strike on the extra spikes.

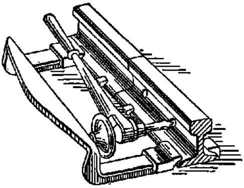


Fig. 41

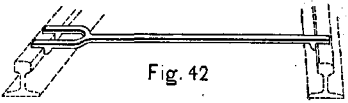


Fig. 42

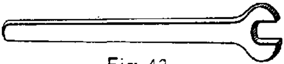


Fig. 43

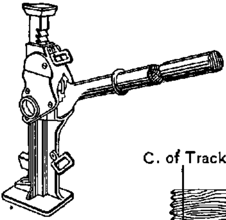


Fig. 46


Fig. 44


Fig. 45

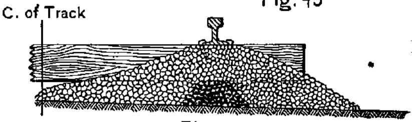


Fig. 47

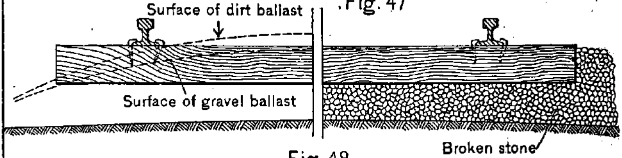


Fig. 48


Fig. 49


Fig. 50


Fig. 52


Fig. 53

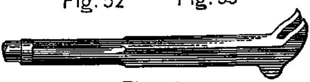


Fig. 51

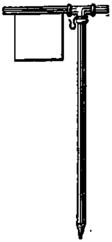


Fig. 54

The line side is spiked first, the nipper and spikers seeing that the rail crosses each tie at the proper distance from the end. If the ties have been gaged, they are brought to the mark; if not, the distance is measured by a notch on the handle of one of the mauls. In spiking the gage side, the **track gage,** fig. 42, should be laid over every third tie at least. The best spikers should be put on this side. If, after the spikes are started, the rail is found slightly out of gage, it can be drawn a very little in either direction by bending the opposite spike toward the rail. It is much better, however, to use a maul or bar for shifting the rail, as drawing with the spike weakens its hold in the tie. If the gage is tight, the inside spike is started first. If loose, the outside one.

Gaging should be **accurately done.** The gage should be tested by the foreman each morning. When one end is down on the rail, the other should just go to place without catching, the points of the gage rubbing the rail head lightly as they pass np or down.

On curves the inside rail gains on the outside one about an inch per 100 ft. per degree of curvature. When one rail is 3 ins. ahead, a rail 6 ins. shorter than the standard should be put down on the inside.

Track-laying gang.—With fairly experienced men, 3 foremen, 56 laborers, and 11 teams should lay a mile of track in 10 hours. The division is as follows: 11 men driving teams (10 hauling ties and one hauling rail car), 4 men loading ties on wagons, 6 men unloading and placing ties, 8 men handling rails, 2 head strappers, 4 back strappers, 12 spikers, 6 nippers, 3 men miscellaneous. With untrained men a larger gang will be required to make the same rate of progress, but the proportional distribution will not vary greatly from the above.

There are several forms of machine for track laying in use which deliver the track material ahead of them and follow on the track as it is laid. With them track laying can be done rapidly with few men. Machines can not be used to advantage unless the bridges are in.

61. **The depot of materials.**—The materials for several miles of track should be collected at the initial point before track laying begins. A well-arranged **storage yard** is essential to rapid work. The first requisites are plenty of room and plenty of temporary tracks. They may be laid on the ground surface, roughly graded, 10 or 12 ties to the rail, half spiked and half bolted. No material should be unloaded on ground much below track level.

Definite portions of track should be assigned to ties, rails, etc., keeping materials of the same kind together. Part of the temporary tracks should have switches at each end. Spur tracks should have the switch at the rear or home end. On sidings, rails should be nearest the forward switch, bolts, spikes, splice bars, etc., frequently referred to as **trimmings,** next, and ties last or nearest the home switch. On spur tracks the ties should be nearest the switch, the small parts next, and the rails last.

Rails should be **piled lengthwise** of the track, on three or more ties to keep them off the ground. The piles should be at a distance from tbe track such as to permit the rails to be nnloaded and reloaded with rails used as skids. The skid rails will work better if they have the base and web cut away at one end, and the heads bent down to form hooks, which may be dropped into the stake sockets on the side of the car. The kegs of spikes, bolts, etc., should be on skids or platforms made of ties or lumber. **The ties** should be **piled at right angles** to the track and in not more than two ranks on the side.

62. **The construction train.**—If a permanent gang is orgauized, cars should be fitted up for cooking, eating, and sleeping. There should also be a car for office aud stores, one for fuel, and a tank car, if water must be carried. These cars should be run on a siding, temporary if necessary, and kept near enough to the head so that the work train can make the distance in 30 minutes or less. When the camp cars are near the head the men may take their meals on the siding, the work train running them back and forth. When the distance is greater the men's dinners may be sent out or the locomotive may run the kitchen and dining cars up to the head at noon. All box cars used in this train should have end openings.

The work train consists of a locomotive, and flat cars loaded with materials. All materials should arrive at the front on flat cars. If any arrive at the yard in box cars, they should be reloaded. It is best to break through the ends of box cars and run them on a siding, alternating with empty flats, transferring the loads from one to the other across the ends. **A mile of average track** requires **8 cars** of ties, **5 cars** of rails, and **1 car** of fastenings, or **trimmings.** The work train should leave the rail head each evening with all empties and should arrive next morning from the base with materials enough for the day's work. The rail cars are ahead, the trimmings next, and the ties last.

If all or part of the labor is drawn by details of troops, the organizations may be camped near the line and the camp moved forward as necessary.

63. **Ballasting** may be kept within a short distance of the track laying, using a separate work train and gang. Ballast is hauled on flat cars. There are several quick unloading devices, one of which, a double plow hauled by the locomotive, might be used, but it is probable that in military railroading men and shovels will be the main reliance.

The quantity of ballast required per 100 ft. of track is 16 cu. yds. from the bottom of the ties up, and 4 cu. yds. for each inch of ballast below the ties. For ties on 6 ins. of ballast the quantity is $16 + (4 \times 6) = 40$ cu. yds. for each 100 ft. of single track, or 2,112 cu. yds. per mile. This quantity is ample and track can be ballasted with somewhat less.

Ballast is first deposited on both sides of the track outside the ties at the rate of about ½ the total quantity required. This is used to tamp the ends of the ties, the middles being left for a subsequent operation.

64. **In raising track** to grade, **track jacks,** fig. 46, are used. If jacks are not at hand, bars or levers must be used, but they are slower and less satisfactory. The jacks are best worked in pairs and are first used at the grade stakes, where the rails are brought to proper grade, level or not as may be required. Next the joints are brought up, the jacks being set 2 or 3 ft. away from the joint, and last the centers of rails. Jacks should be run up until the rail is a little above grade, as it will always settle a little when the jack is slacked off. The amount depends on the ballast and the tamping. It will soon be determined by observation.

65. **Tamping.**—The short-handled square-pointed shovel is the best tool for filling and tamping new track. Ballast is shoveled between and beneath the ends of the ties and crowded under with the shovel by making the first part of the motion which would be used to dig it out. To get the best results, the fill between the ties should be an inch or so above their bottoms. **The first material** should be thrown under the tie **directly beneath where the rail crosses** it and that spot should be well tamped before access to it is obstructed by other material deposited.

A half cross section of the track when partly ballasted as described is shown in fig. 47.

66. **Lining.**—As the track is raised to grade, it is also lined. The best way is to make a center mark on the track gage and throw the track at each center-line stake until the center mark is brought over the tack in the stake when the gage is placed on the rails. On tangents, the rails between the stations are lined by sighting. On curves, if 25-ft. stakes are set, the rails are curved by the eye while spiking. If the rails have been accurately curved, the alignment between stakes will take care of itself.

Filling in.—The rest of the ballast is next distributed. It must be unloaded on the sides of the track as before, unless special ballast cars can be had, arranged for center dumping. It is shoveled in and under the ties and between them to their tops or sometimes above, as shown in the sections, fig. 48. Under the middle of the tie the filling is snug but not tamped.

67. **Track maintenance.**—Constant attention is necessary to keep track in good condition. **The principal points** to be attended to are to keep all ditches and drains clear, and to deepen them rather than to allow them to grow shallow; to keep spikes and bolts tight, rails in line and grade, and the ends of ties solidly tamped, and the removal of worn-out or broken rails and ties. For a military road the repair of the enemy's depredations will furnish a large percentage of maintenance work.

Tamping in maintenance is a slightly different operation from tamping new track, and other tools are used. The space to be tamped is that between the tie and a trough in the well-packed ballast. **A tamping bar,** fig. 49, is used for fine ballast and a **tamping pick,** fig. 50, for broken stone. The tie is **nipped up,** as in new work, and the tamping is tight under the rails and snug only at the middle. **Surfacing** will be required in the spring, if the track is on dirt or gravel ballast, and in any kind of ballast if the drainage is not good and the frost is deep. If there are especially bad spots on the section, they should be attended to first; otherwise, it is best to begin at one end and work continuously to the other. Send men ahead to set up bolts, nip up ties, and set spikes, and, if necessary, to gage the track, so that when the surfacing gang follows it has nothing to do but line and tamp. With tamping bars, two men should work on a tie opposite each other, striking simultaneously.

To renew a tie, draw the spikes with a claw bar, fig. 51, dig out under the tie until it drops clear of the rail, strike a pick in one end, and draw the tie out. Slip the new tie in its place, spike, and tamp.

To renew a rail, have the new one alongside of the old one, and see that it is of the right length. Draw or loosen the inside spikes, and when all is ready slip the old rail out of place and lift the new one in. Set part of the inner spikes as quickly as possible, and the rest before the first train passes, if possible. Be sure that the old rail is not disturbed until everything is ready.

Fig. 52 shows the usual form of spiking maul. Its average weight is 8 lbs. The handle should be 3 ft. long and in driving the hammer should be swung at the full length of the handle.

Fig. 53 shows a track chisel. Its average weight is 4 lbs. It is used with a short handle, which must not be tight in the eye. In frosty weather a chisel should be warmed before using. A little oil will make a chisel cut faster and last longer. In addition to keeping the cutting edge properly sharpened, the struck end should be cleaned up and trued whenever it becomes ragged or battered.

Fig. 54 shows a device for holding a flag or lamp for protecting the section gang when at any work which would interrupt the use of the track.

68. **Wrecking and reconstruction.**—On military roads it is very important to have the most complete facilities quickly available for removing wrecks and repairing extensive damage to bridges and track, such as would be the result of successful raiding expeditions. Civil roads keep wrecking trains prepared to start at short notice. They are manned by regular employees taken from shops and other places, the regular work being interrupted. For military roads, it is essential that the necessary working force be kept for this purpose alone. If they can, when things are quiet, be occupied in useful work around the shops and yards, it may be done, but their function as a wrecking and repairing gang should be of the first importance.

Wrecking and repair trains are, in part, identical, but they differ enough to make it advisable to have one of each made up, loaded and manned ready to start at a moment's notice. There should be one at each division terminus, but it should work half the length of a division in each direction. If the trouble is serious, a train may be sent from each side, but in any case a locomotive should be sent to the wreck from the side opposite the wrecking train. These trains should stand on a double Y, from which they can pull out on the main line, headed either way, without delay.

Both wrecking and repair trains should be made up, generally, like the construction train, par. 62. One engine should be kept under steam ready to couple on to either one. If one goes out, an engine should be stationed at a convenient point to couple on to the other. These engines may often be taken from those which are waiting their turn to go out on the line. Generally, the necessity for the wrecking or work train determines the fact that the next regular train or two will not go out.

The wrecking train consists of a derrick car, a tool car, and the necessary cars of blocking, trucks, and other car repairs and track supplies, and, if required, empties for loading the wreckage. **The derrick car** should be next to the engine, with its **derrick end ahead.** The tool car should contain an ample supply of jacks of different sizes and of tackle, a rail saw, track drill, and at least four pairs of car replacers, with a full complement of track tools, saws, axes, wedges, crowbars, and a telegraph outfit, with climbers, tools, and enough insulated wire to make a connection with the pole line. A limited quantity of explosives and accessories will often be a time saver.

The most convenient **size of rope** is 1¼ in. diam. for reeving tackle and 1½ in. diam. for slings and attachments to wreckage and holdfasts. There should be plenty of rope straps and chains with rings and hooks for slinging objects to be moved or lifted. There should be at least one whole coil of 1¼-in. rope, to be used in making a lead under the train to the engine for power. **Double blocks** and **plenty of snatch blocks** are best.

The track material should be a quantity of light rail, about 50-lb., for laying temporary tracks, and some standard rails, ties, joints, spikes, etc., for repairing the injured track. There should also be a carload of timbers and blocking. Ties may be used, but uniformity of size is inconvenient. Old car and bridge wreckage will supply plenty of good blocking. Sections 4 x 6, 6 x 6, 6 x 8, 8 x 8, and 10 x 10 ins., and lengths of 2, 4, 6, and 8 ft., are suitable. A few 12 x 12 in. timbers, 20 ft. or more in length, should also be carried.

A wrecking train should have a **surgeon** and **hospital detachment** on board with necessary equipment.

The wrecking operations are usually directed by the road master, acting under the orders of the superintendent or assistant superintendent, if either of them is present. The train master should be present to direct the transfer of freight and passengers and to arrange for passing trains by the wreck when it is possible to do so. The man in charge of the wrecking train should be a practical rigger and a competent foreman. A few of the wrecking crew should be machinists and car repairers, the former to strip the engine or get it in shape to run, and the latter to replace parts of cars and make quick repairs.

Wrecking operations are directed to the following objects, in the order named:

(*a*) To clear and repair the main track for the passage of trains.

(*b*) To get in running order and on the rails all rolling stock which can go in on its own wheels.

(*c*) To load all wreckage which is worth saving or which can not be destroyed.

(*d*) To destroy all remaining wreckage. Nothing should be left on the ground which the enemy could use for further obstructions to cause subsequent wrecks.

The emergency repair train will differ from the wrecking train mainly in the substitution of a pile driver for the derrick car, and of additional track, bridge, and trestle material for the tool and truck cars. **In addition to the train,** there should be stored as near to each important bridge, trestle, culvert, or other especially vulnerable point as can be safely done, a supply of construction material especially suited to repairs at that particular point.

In this kind of work the first effort must be to get a temporary track across the gap, on which trains can be passed at low speed, and next, to reconstruct the permanent track, or, if the two are on the same ground, to improve the temporary track and make it permanent without stopping traffic.

When a high-level bridge is cut, the quickest way to get a track over may be by means of a **deviation,** which is a track run down each bluff to the valley level and crossing the stream by a short, low bridge, involving much less and easier work than the repair of the high bridge.

69. When the reconstruction involves a large amount of common labor, as extensive excavation or embankment, clearing timber, etc., working details from line troops will be required, and it may be necessary to put on a construction force independent of the technical staff.

70. **Yards and terminals.—A yard** is a number of sidings and spurs, usually parallel to each other, although often not parallel to the main track. These auxiliary tracks must be sufficient in number to permit the convenient and rapid breaking up of trains, classification of cars by contents, destination, or otherwise, and making them up into new trains in accordance with the new requirements. Yard tracks are divided into groups, according to their purpose. A certain number near the main line at one end of the yard are called **receiving tracks,** and trains arriving pull in on them. In convenient proximity is a **caboose track,** where cabooses are stored when not in trains. A group of **repair tracks** are convenient to the shops, and the **engine track** leads to the engine house, near which should be the coaling and watering stations and the ash pit.

The train on the receiving track is broken up and its cars switched on to the **distribution tracks,** selected so that those on each of these tracks will belong in the same outgoing train. There should be enough distribution tracks to permit the convenient classification of freight cars according to their contents and destination, and of passenger cars according to character, as baggage, express, coaches, tourist and standard sleepers. In most cases, outgoing trains are completed on the distribution tracks and pulled from them on to the main track, when authorized by order to do so. It is better, when possible, to have a third group of tracks at the other end of the yard, which may be called the **departure tracks.** When a train is completed on a distribution track it may be pulled out on to a departure track, where a caboose and engine are added, the designated crew takes charge, and the train is ready, on the receipt of orders, to pull out on the main line without delay, and without crossing or interfering with any of the yard traffic. Departure tracks permit the distributing tracks to be fewer and somewhat shorter. If there are departure tracks, they and the

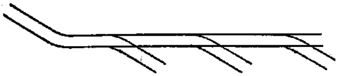


Fig. 55

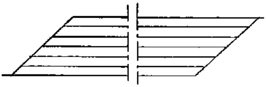


Fig. 56

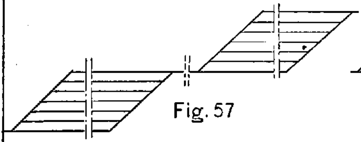


Fig. 57

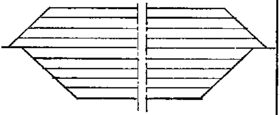


Fig. 58

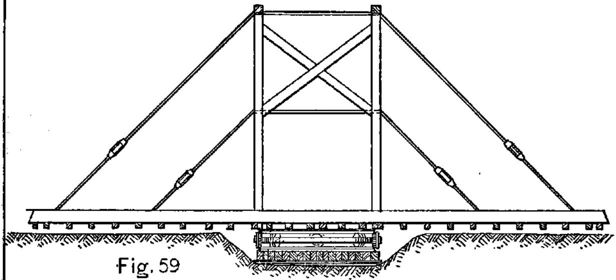


Fig. 59

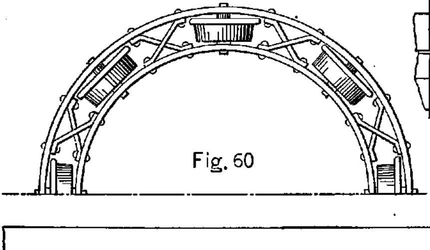


Fig. 60

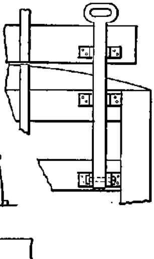


Fig. 63

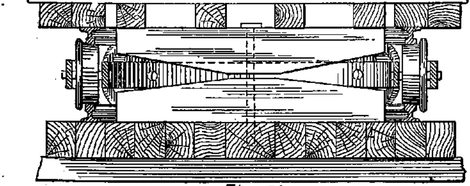


Fig. 61

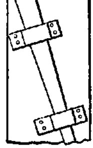


Fig. 62

receiving tracks should be divided into two groups designated for traffic in opposite directions. Trains which go through or return without change, go direct from the receiving tracks to a distribution or departure track, the returning trains through a loop or Y to turn them around.

All yard tracks, except repair and team tracks, should be open at both ends, so that all traffic over them may be in the same direction. This permits all traffic through the yard to be in one direction, which saves much confusion and delay. The standard method of arranging yard tracks for greatest convenience and compactness is by the use of **ladder tracks,** fig. 55, which are oblique tracks at the proper distance apart to accommodate the other tracks between them. Each receiving, distribution, and departure track connects with a ladder track at each end by the ordinary switch. The dead end of each spur track should be provided with an obstacle, to prevent cars running off. Fig. 97 shows a **bumper** which may be made in the field. There are several forms on the market, consisting of heavy castings adapted to be bolted to the ends of tbe rails, turned upward and inward to meet. A mass of cinders, or even of earth, 2 or 3 ft. deep and half a car length along the rails will serve. If the spur ends in a cut, the end breast will be left rather steep and the rails run up to it.

Receiving, distribution, and departure tracks should be 12 ft. c. to c. The ladder track at one end of the receiving tracks connects with the main line, as does also the ladder track at the opposite end of the distribution or departure tracks. These two connections at opposite ends of the yard should be the only ones between main line and yard.

The extent and shape of the yard will usually be controlling as to its layout. Figs. 56 to 58 show some of the ways in which the ladder tracks may be varied, to conform to differently shaped sites. If necessary to fit the ground available, the yard tracks may be curved, but it should be avoided if possible. The angle of any ladder track will be the nearest of the series of frog angles which will adapt the general plan to the requirements of the site. As a rule, the higher numbers will be wasteful of space. No. 7 is a good one, and if very crowded, No. 6, or even No. 5, may be used.

The main tracks should be on one side of the yard, unless, in case of **double track,** one can be carried along each edge, leaving the yard between them, which is most convenient. A yard on both sides of the main track is objectionable, as the main line must be frequently crossed in switching.

Track scales should be as near the main-line end of the receiving tracks as possible; in no case on the main line.

71. **A turntable** is the best means for turning an engine or car. It is almost universally used for switching engines on to the housing tracks, which are usually the radii of a circle, covered by a circular building called a **roundhouse.**

The required length will rarely be more than 60 ft. The track is supported on two girders or trusses, tied together, and rotating, sometimes on the pivot alone, and sometimes with part of the weight on circumferential wheels. In any case, the ends must be supported when a locomotive is running on or off. This is conveniently done by a step in the pit wall, over which the ends of the table project and from which they may be blocked up or otherwise snpported.

The main requirements are a good foundation, especially under the pivot, in tables of the first-named kind, and under the lining or wall of the pit in all kinds. A secure locking arrangement to hold the table at any track is necessary. Figs. 59–63 show the general features of a turntable, which may be improvised in the field. It consists mainly of timber and requires a very shallow pit. A table of this form must be 8 to 10 ft. wide, with the track carried on heavy ties. The central part should have a clear headway of 20 ft.

It will be difficult to improvise a pivot construction which will give satisfaction. It will be better to carry the table on a train of live rollers or wheels. Bend two rails to a circle of 6 to 8 ft. diam. and connect the ends by splice bars. Procure 6 or 8 small heavy wheels—push-car wheels will do very well—and mount them, **flanges outward,** on a frame as indicated in fig. 61, so that they will run easily on the circular rails. Spike one of the circles on a solid platform; place the wheel train on it; lay the other circle, head down, on the treads of the wheels, and build the table on top of and attach it to the base. On such a ring the engine can always be balanced so that the ends of the table will ride free. Fig. 62 shows a lever for rotating the table, and fig. 63 a locking bar to hold it in position opposite any track.

Ashes are dumped in **ash pits** provided at all engine yards. The ash pit is an excavation between the rails, usually lined with masonry. The rails are carried on

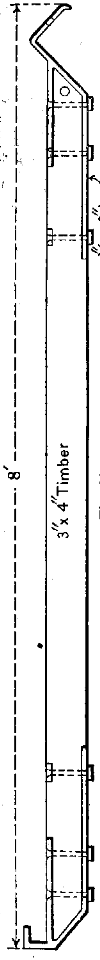


Fig. 63 a

Fig. 63 b

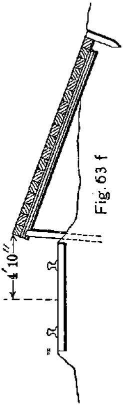


Fig. 63 f

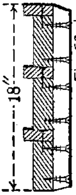


Fig. 63 d

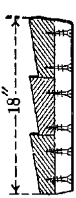


Fig. 63 c

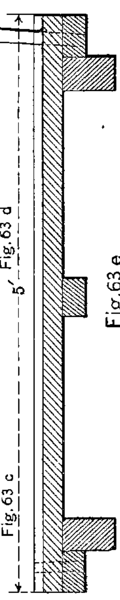


Fig. 63 e

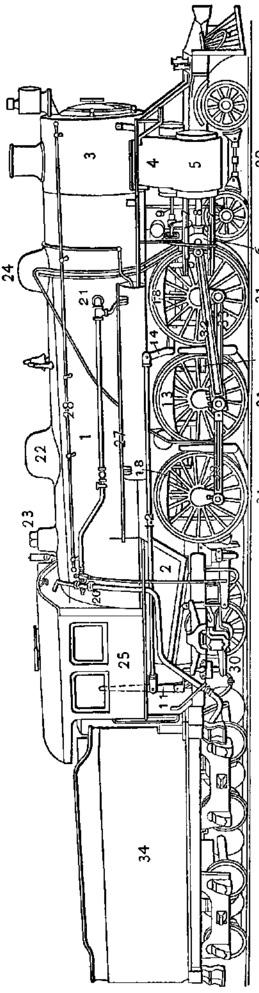


Fig. 64

Nomenclature of Parts of Locomotive indicated in Figs. 64 and 65.

1 Boiler
2 Fire box
3 Smoke box
4 Steam chest
5 Cylinder
6 Cross head
7 Guides
8 Piston rod
9 Valve stem
10 Link
11 Reverse lever
12 Reach rod
13 Tumbling shaft
14 Rocker arm
15 Eccentric rod
16 Frame
17 Equalizing bars
18 Springs
19 Pedestals
20 Injector
21 Boiler check
22 Steam drum
23 Filling funnel
24 Sand box
25 Cab
26 Air pump
27 Foot board
28 Hand rail
29 Pilot truck
30 Trailing truck
31 Drivers
32 Main rod
33 Side rods
34 Tender

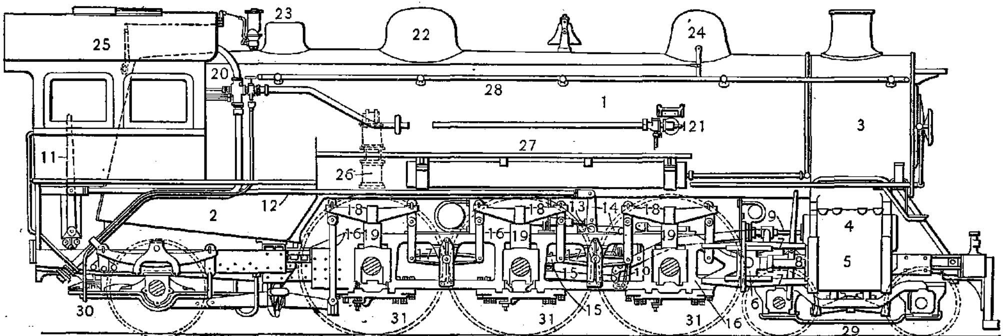


Fig. 65

stringers or on the tops of the side walls, as the case may be; the ties being omitted. Ashes may be dumped on well-ballasted track in emergencies, but **never on trestles or bridges.**

72. **A transfer table** is very convenient for shifting cars between parallel tracks. It is especially useful in the repair yard. It consists of a platform similar to a turn-table, but running laterally, parallel to itself on tracks perpendicular to its direction. It can be set in line with the ends of a number of tracks which run to the edges of the pit. A transfer table is easily improvised from car trucks and timbers.

73. **Permanent yards** seldom form a part of military construction. For **field terminals,** which are temporary, the arrangement of auxiliary tracks will be much less regular and more open. Sidings will be provided wherever it is necessary to unload cars. Stores consigned to organizations present will ordinarily not pass through storehouses, but will be unloaded from the trains on to the ground, or, so far as possible, directly into wagons.

Stores consigned to the supply departments will usually go into storehouses or into compact piles at designated points for temporary cover, pending issue. **Platforms** will be used to the degree to which time and materials at hand permit, but the **main reliance for discharging** cars will be **ramps** of suitable form to lead from the car floor to the ground, which should be provided in profusion and so distributed that it will be next to impossible to set out a car at a time or place where a ramp can not be procured within easy carrying distance.

Figs. 63a to 63e show a convenient form of ramp, which may be carried on the car or used otherwise. It consists of two skids or girders, figs. 63a and 63b, having a hook at the upper end to engage the floor of the car, and a hook at the lower end to hold the planking in place. The planks are made up in panels 18 ins. wide. The necessary roughness may be given by sawing the planks obliquely, fig. 63c, or by alternating battens on edge with the planks, fig. 63d. In each end of each panel a hole may be bored to receive a stanchion, supporting a side rail or line, fig. 63e.

A semi-permanent ramp may be formed of ties and rails, as indicated in fig. 63f.

Storehouses should be narrow and long enough to permit all the cars of a train to discharge simultaneously. If there are no houses, the ground occupied by the supply departments for storage should be of similar shape for the same purposes.

74. **Motive power.—The locomotive** is the most important and most difficult feature of railroad equipment. Its full capacity can be developed only by the most expert attendance. Every effort should be made to draw expert engineers and firemen by detail from the troops or by employment of civilians, and it will usually be possible to do so. If not, men familiar with other forms of steam engines and boilers may be utilized, or railroad firemen who have never had engines may be made engineers. It will be the rule in military railroading that more locomotives must be used to do the work than would be necessary in civil procedure, the efficiency of each being less.

The principal parts of the locomotive and their names are shown in figs. 64 and 65. Attention will be confined to parts the functions of which are peculiar to the locomotive and without the range of experience with other steam motors.

75. **The running gear** consists of the **frame** (*a*), the **equalizing bars** (*b*), the **springs** (*c*), and **pedestals** (*d*), the **journal boxes** (*e*), and the **wheels** (*f*), fig. 66.

The frame consists of two forged skeleton girders, one on each side, connected at the front end by the bumpers, at the cylinders by the cylinder plate and the boiler saddle, and at the rear end by the foot plate. **The main feature** of their design is a jaw for each **driver,** in which the **journal box may slide** snugly up and down. Its vertical motion is controlled by the equalizing levers acting through the springs and pedestal. The function of the equalizing lever is to keep the full share of weight always on each journal, which equalizes the wheel pressure on the rail, upon which in turn the tractive force depends, and also prevents any wheel from rising from the rail, which might permit the flange to ride over the rail and cause a derailment. When an irregularity in the track causes one driver to rise or drop, the entire frame on that side moves upward or downward by an amount equal to the change in one driver divided by the number of drivers and the pressure on the wheels is not changed.

Breaks or **weakness** of the equalizing gear may be temporarily overcome by blocking against or chaining to the frame, but in this condition the equalizing action ceases, and very careful running is necessary. If a spring breaks, block under the adjacent ends of the bars and between the journal box and the top of the jaw, as at

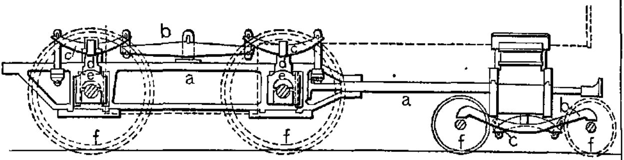


Fig. 66

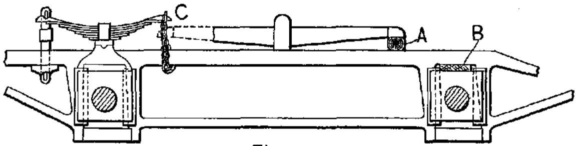


Fig. 67

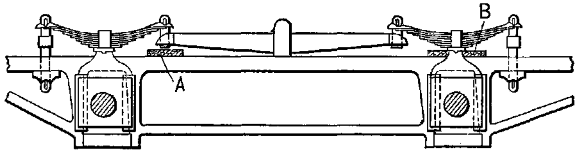


Fig. 68

American 4—4—0

Fig. 69

Columbia 2—4—2

Fig. 70

Atlantic 4—4—2

Fig. 71

Mogul 2—6—0

Fig. 72

Ten-Wheel 4—6—0

Fig. 73

Consolidated 2—8—0

Fig. 74

A and *B*, fig. 67. If one end of the bar or the hanger breaks, block up the other end of the bar and chain down the end of the spring *C*, fig. 67; or, if chaining is not practicable, block as at *B*. In case of a broken brass or any accident to the journal requiring a reduction of pressure on it, block between the frame and the spring, as at *B*, fig. 68. If a spring is weak but not broken, set a striking block under the end of the bar to limit the downward motion, as at *A*, fig. 68.

When the wheel has to be raised in any of these operations, put a wedge on the rail in front of it and run the engine forward until the wheel is on the wedge.

The wedges which regulate the clearance between the box and the jaw require close attention. If too loose, the journal will pound and heat. If too tight, the box may stick and cause a break in the equalizing gear. The left side usually requires more attention than the right. **To adjust these wedges** set the cranks near the upper quarter to bring the box against the forward wedges, which are usually the fixed ones. Then set up the moving wedges with a short-handled wrench to a snug fit, mark their positions, and slack them back 1/8 in.

76. **Locomotives are classed** by the numbers and disposition of their wheels. The most common types and the names by which they are known are illustrated in figs. 69 to 74, in which the larger circles represent drivers and the smaller ones truck wheels, the direction of forward motion being also indicated.

A better system, rapidly coming into use, is to describe the running gear by giving the number of wheels in the three following groups in the order named: (1) **Forward non-drivers,** (2) **drivers,** and (3) **rear non-drivers.** Thus an engine with 2 forward truck wheels, 4 drivers, and 2 rear truck wheels is indicated by 2—4—2, etc.

By this system the Atlantic type becomes 4—4—2; the Columbia, 2—4—2, etc.

Locomotives are also classed as passenger and freight, the former having large drivers and other proportions adapted to high speed.

77. **The boilers** of locomotives are restricted in size by the necessity of carrying their furnaces between the wheels. To make up for the deficient size they are designed to produce the highest possible rate of evaporation. This is partly done by increasing the heating surface as much as possible, but mainly by using a high forced draft induced by control of the exhaust, which enables a very large amount of coal to be burnt on each sq. ft. of grate. The most expert firing is also required, and care on the part of the engineer to favor the boiler whenever possible. It is only with all these conditions met that the locomotive can make as much steam as it can use.

The type of boiler which has grown out of these requirements, has come into very general use in stationary practice, and is known as the **locomotive boiler.** It is shown in section, in fig. 75. The boiler of a locomotive differs from the stationary boiler of the same type in the piping of the steam to the cylinders. The steam pipe leads from the dome down and forward just above the water level and through the smoke box to the steam chests. **The throttle** is at the bend of the pipe, inside the boiler, and its stem is prolonged through a stuffing box over the fire door.

The ash pit has two dampers, one at the forward and the other at the rear end. The fire door is farther above the grate than in stationary boilers. A rocking or shaking grate is used.

78. **The smoke box** or **front end** connects the flues with the stack, and its design is mainly determined by the requirements of forced draft and the necessity of intercepting sparks and cinders. Fig. 76 shows the principal parts in their relative positions.

The nozzle *N* delivers the exhaust steam through its contracted end in the axis of the stack and at high velocity. The height and orifice of the nozzle must be such that the jet of steam will just fill the stack at its bottom. The opening should not be smaller than necessary, as it causes back pressure on the pistons and reduces the power.

The gases flow in parallel lines, those from the rear end of the fire box passing through the upper flues and those from the front end through the lower ones. The tendency is for the upper flues to rob the lower, and this is corrected by the **diaphragm** *DD*, which also acts as a deflector to throw the cinders down, or the **petticoat pipe** *PP*. **The diaphragm** or **deflector plate** is used in modern smoke-box construction and the petticoat pipe in older forms. Sometimes they are combined as in the fig. Both are **adjustable,** the diaphragm by its movable lower edge and the petticoat pipe by raising and lowering. The necessity for adjustment is indicated by the condition of the tubes and the behavior of the fire. If the upper tubes are clogged with ashes, there is too much draft at the bottom, and the fire will burn brighter and faster—or **pull**, as it is termed—at the front end. The conditions will be reversed if the upper tubes are drawing too much. **Lowering** the **diaphragm** or **raising** the **petticoat pipe favors** the **lower** tubes. **The reverse** motion **favors** the **upper** ones.

The netting *S* intercepts the sparks and cinders which would otherwise be blown out of the stack. It is apt to become clogged, especially when too much oil is used in the cylinders, and will not allow the gases to pass freely. It may be cleaned by beating, or by building a light fire on top of it.

79. **Firing.**—In addition to the forced draft, a thin fire must be carried to get the requisite quantity of coal burned. Such a fire burns through very quickly, and when there is a hole in it cold air rushes through and a great amount of heating effect is lost. The best method of firing is that known as **spreading**, or a **"shovel at a time."** The coal is broken to suitable sizes, not exceeding a 3-in. cube, a shovel full is taken, the fire door quickly opened, the shovel of coal thrown on the brightest spot in the fire, and the door shut as quickly as possible. **Raking** and **slashing** the fire should be done as **little as possible.**

80. **Economizing heat.**—The feed water absorbs heat from the fire that otherwise might go to the production of steam. The engineer should regulate the feed so that it will be greatest when the demand for steam is least. If all steam is required, the feed may be reduced so much that the level of water in the boiler will run down slowly, or, for a short time, may be cut off entirely. If little steam is required the feed may be increased to bring the water level up. Great care must be taken that the water level is not carried too high, and especially not too low in this operation.

81. **Boiler troubles.—Foaming, priming, scaling, burning,** and **leaks** are the principal causes of boiler troubles.

Foaming and **priming** are the same thing in effect, but due to different causes. It is the passage of water with the steam through the cylinders and out with the exhaust. It is called **foaming** when it is due to impurities in the water, as oil, alkaline salts, or matters in suspension. It is called **priming** when the cause is the too rapid elimination of steam, and takes place when the boiler is forced, or the water is carried so high as to contract the steam space. **The remedy for priming** is to lower the water level and reduce the fire.

Foaming is more persistent and troublesome. If the water is impure at its source, its treatment becomes a feature of the water supply. If the trouble is temporary, the remedy is to open the cylinder cocks and work the surface blow if there is one. Start both injectors and shut off steam at frequent intervals to allow the water to settle and indicate its correct level. If it is found too high, open the boiler blow-off. At the next water station run the tender tank over freely and wash out any oil that may be in it.

Scaling is caused by the deposit of mineral salts and sediment on the interior surface of the boiler. It is due to continued and not temporary causes, and if its reduction is necessary it should be done by treatment of the water supply. In most cases the scale will be soft enough to be washed off with a jet of water under fair pressure. If too hard to be thus removed it may be necessary to send a man inside the boiler at intervals and clean off as much as possible by hammering and scraping. Unless the water is known to be nonscaling, scale may be suspected whenever the boiler steams hard. Very thin scale is not injurious. When it is $\frac{1}{16}$ of an inch or more in thickness it becomes wasteful and dangerous.

Burning is overheating the metal so that it loses its rigidity and yields under pressure. Its cause is the lack of water against the other side of the sheet to take the heat away from it. It may result from neglecting to carry the water at proper level or it may be due to one or more of the preceding causes. **Priming** and **foaming** may lift the water away from the metal long enough to let a hot fire burn it. **Scale** prevents the water from touching the metal and reduces the transfer of heat. When it becomes thick enough burning results.

Burning occurs only on the interior surface of the fire box and oftenest in the crown and tube sheets. It is disclosed by a bag or bulging of the sheet between the heads of the stay bolts. Unless very bad, the engine can be run temporarily, as to a station or repair shop, by using low steam and firing moderately.

Leaks do not demand instant attention so long as they do not quench the fire or waste steam faster than the boiler can replace it, but the pressure should always be reduced and the engine worked carefully until it can be turned in for repairs.

Sudden large leaks are most apt to occur in the tubes. By plugging the end next to the fire, the escaping steam and water are sent forward to the smoke box. Hard-wood plugs for the tubes are sometimes carried on the engine.

In case of a **large leak,** such as the blowing out of a hand-hole plate, which must empty the boiler, the **fire must be drawn or banked at once.** It is best to get it out if possible; otherwise damp earth may be shoveled on it. Water should not be used if it can be avoided.

82. **Fuel for locomotives** will in all probability be bituminous coal. The quantity required will depend on the quality, but for present purposes may be assumed to average 75 lbs. per train mile, or 4 tons per locomotive per day. The coal bunker on the tender carries more than a day's supply and should be filled before each trip, if possible.

Lacking better means, the coal may be shoveled and thrown into the tender by hand. If it is arriving daily, a coal car and an engine may be switched on to parallel tracks and the coal loaded direct from the car to the tender. If the coal is stored, it will usually be on the ground. If possible, a place should be selected where the track is in a shallow cut. A platform built out from the bank to the clearance line will facilitate the operation. Coal should be moved forward from the face of the pile to the edge of the platform so that it can be thrown in with the least possible delay.

If power is used, a convenient arrangement will be a small derrick and a supply of boxes or tubs. Enough tubs for one or more engines may be kept filled under the derrick.

Some form of coal pocket which is, in general, a structure in which coal is stored at an elevation above the level of the tender, from which it may run in by gravity, may be used if the materials are at hand and the length of time in which coaling is to be done at the particular point will justify the erection of such a structure.

83. **Boiler feeding.**—Water is supplied to the boiler through **injectors** or an equivalent device called an **inspirator.** There should be one on each side, each large enough to supply the boiler alone, thus duplicating the feed. A system should be followed to insure the regular use of both. If one is cut out of use for a long time it is very apt to refuse to work when the other one breaks down. The two may be used day or week about, or one may be used when running in one direction and the other when running in the opposite direction.

84. **The injector** is a steam siphon which operates on a very small differential pressure and requires good design, accurate workmanship, and to be in good order to make it successful. When in order its operation is simple, and when out of order the defect should be easy to find. Fig. 77 shows the typical form of the injector. Its essential parts are a **case,** containing the **nozzles** and **seats** for **steam, water,** and **overflow** valves. **The steam valve** is arranged so that a slight opening sends the steam through a small orifice and a full opening through a larger one. The former is called the **priming jet.** This jet, passing through the vacuum chamber, drags the air with it and lifts the water until it fills the vacuum chamber and passes forward to flow through the **overflow valve.** This valve normally opens to inside pressure and closes to outside pressure, the same as the check valve, but requiring less force.

When **water appears** at the **overflow valve** the injector is said to be **primed.** The overflow is usually brought into the cab, where the engineer can see it, by a tube connecting with the overflow chamber. More steam is now admitted, is condensed, and communicates its momentum to the stream of water until the latter acquires sufficient velocity to force the check valve open and enter the boiler.

85. For the injector to work properly, the following conditions are necessary:

(*a*) The interior parts must be solidly in place, fairly clean and not too much worn. If the tubes are taken out, see that they are screwed firmly home when replaced.

(*b*) The water supply connection from the tender to the injector must be unobstructed and sufficiently air-tight to hold the vacuum.

(*c*) The connection from the injector to the boiler must be unobstructed and the check valve must be free to work.

(*d*) The supply of steam and water must be in the proper proportion. If there is too much steam, the water will be too hot, which will reduce the vacuum. If too much water, the velocity of the combined jet will not be sufficient to lift the check.

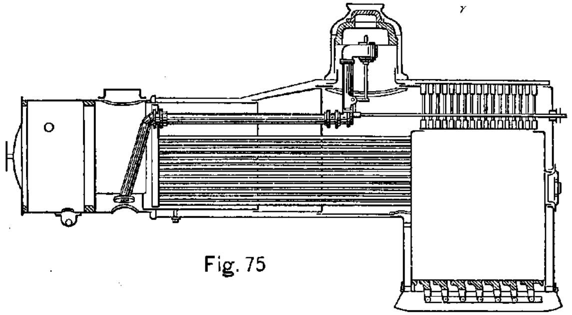


Fig. 75

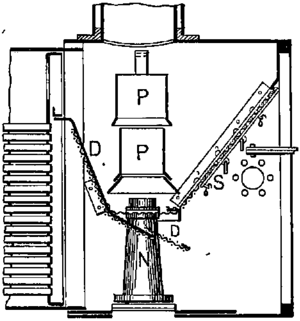


Fig. 76

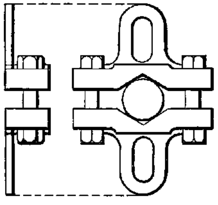


Fig. 78

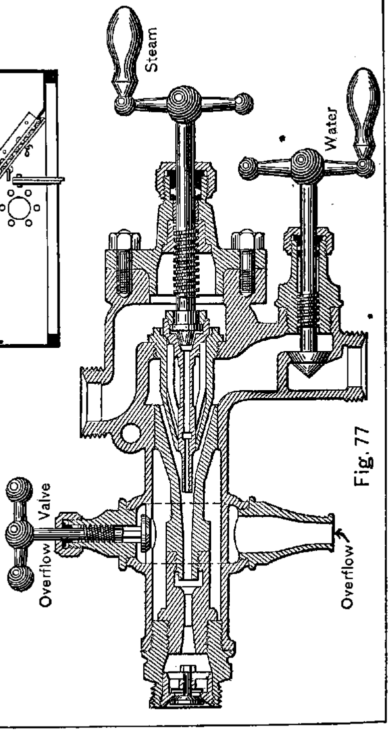


Fig. 77

The proper mixture is well indicated by the temperature of the water at the overflow.

In cold climates it may be necessary to warm the water in the tender to prevent freezing. This is sometimes done by passing live steam through a coil of pipe laid in the bottom of the tank. The injector may be used as a heater by closing the overflow and opening steam and water valves, when steam will blow back through the feed pipe to the tender.

86. **Injector troubles.**—If the injector **refuses to prime**, it is likely that the flow of water from the tender is obstructed or that the pipe is leaking air. **Look at the connections** carefully to see that the strainer is clear, pipes clean, and valves open; also that the hose is not kinked or its lining collapsed. The pipe may be cleared of slight obstruction and tested for leakage by blowing live steam into it as described above for the use of the injector as a heater; the tank valve in this case being closed sufficiently to put a slight pressure on the pipe. The escape of steam will show the leaks, which may be closed by wrapping, or if in a valve or joint, by packing.

If, after priming, the injector **will not feed**, examine the check valve and connections to the boiler. The check valve is likely to stick from an accumulation of scale. It may often be set working by tapping the case with a soft hammer or block of wood. If stuck open, keep the injector working as long as possible, and when it must be stopped, close overflow and water valves. If stuck shut, the check valve must be freed before injector can be used. If the check valve chatters, it is an indication of too much steam for the water or of an air leak in the suction.

Injectors work best with wet steam, and if one acts badly at high boiler pressure, it may sometimes be made to operate by reducing the pressure. On the contrary, too much water in the steam will stop the injector, so that great care is needed when the boiler is foaming to keep the injector going. It may be necessary to stop the engine to make them work, in which case both should be run so as to bring the water up as quickly as possible.

If steam leaks back through the injector, it may heat the water in the supply pipe so hot that a vacuum will not form and the injector will not prime. The remedy is to blow the hot water back to the tender, as described in testing for leaks and removing obstructions.

87. **Water supply.—The quantity required** will vary somewhat with the ruling gradient, but may safely be taken at an average of 4,000 gals. per day for each locomotive at work.

Tender tanks hold from 2,000 to 5,000 gals., generally proportionate to the rate of consumption, so that all locomotives can work over about equal distances on a tank full of water. It is not safe to allow a tank to run low, as the engine might be delayed before reaching the next water station and the boiler might suffer or the train be laid out for lack of water.

Water stations for military roads should not be more that 10 miles apart. They should be arranged so that water may be taken both from the main track and from the siding. If trains going north or east have the right of way, the station should be near the south or west end of the siding, as that is where the engine will be when the train is sidetracked.

The water should be pumped into tanks with their bottoms 12 ft. above the rail. In cold climates provision must be made against freezing by boxing in pipes, making double bottoms and tops, and by draining all pipes when water is not flowing through them.

The tanks should be of such size that the pumps need be in use in daytime only. If water is run direct from tank to tender, there should be two tanks, one on the main track and one on the siding, both connected to a single pump, unless the side track can be spaced far enough from the main track to give room for a tank between. If water cranes are available, they may be placed between the tracks to supply engines on both, and one tank only is required. If the activity of the enemy makes it impracticable to use an elevated tank, a cistern must be used and the water pumped into the tender. The quantity of water to be supplied at any station will depend on the distance to the adjacent one and the number of trains per day. As a rough guiding rule, a minimum will be 1,000 gals. per hour and the source of supply and pumping capacity should be for at least that quantity. If no water is to be had along the line, the only recourse is to provide tank cars and haul the necessary quantity in the train.

In emergencies, the use of the pulsometer or other form of pump not requiring a rigid foundation, may be held in view. If the water is fit for use and its source close by and not too far below track level, such a pump may be used to fill the tank, taking steam from the locomotive. This process will be slow.

88. **The quality of water** best suited to boiler use is that usually described as clear and soft. Waters which are hard or turbid, or both, will form scale. With most such waters the scale results from deposits of carbonate of lime or magnesia, and is soft enough to be blown or washed out, unless caked or hardened by blowing out the water while the boiler is hot, and attention to the operation of the boiler obviates the necessity of treating the water. Waters containing sulphate of lime or magnesia sometimes form scale so hard that it can only be removed with chisels. Feeding kerosene oil into the boiler at the rate of 3 pints a day, as regularly and as continuously as possible, will soften much scale of this kind so that it can be blown or washed out. Soda ash used in the tender tank will soften hard scale. No scale solvent should be used in excess of the quantity necessary to neutralize the scale-forming impurities, and all commercial softening compounds, usually denominated **boiler compounds,** should be **regarded with suspicion,** as most of them contain tannic or some other acid which will injure the metal of the boiler.

Some impurities **corrode the boiler,** and these, if present, **must be neutralized.** Acids, including those derived from grease, chloride and sulphate of magnesium, dissolved carbonic acid, and oxygen are corrosives. Slaked lime may be used with advantage for all such waters. If chemicals are applied in the tender, they should be stirred in with a stick or paddle to disseminate them as much as possible.

Frequent blowing-off of the boiler is essential when any scale solvents are used in the tender tank.

89. The water may be treated at the station, in which case the object is to remove the incrusting solids and prevent the formation of scale.

For this purpose lime is used to precipitate the solids which form soft scale and soda ash for those which form hard scale. The quantities depend upon the character of the water.

There are two general systems of water softening in use—the intermittent and the continuous. With proper apparatus, which can be obtained from manufacturers, the continuous system is the best. With apparatus extemporized in the field, the intermittent system only need be considered.

The reagents should be dissolved in water to saturated solutions in barrels or small tanks raised above duplicate water tanks and arranged for discharging into either. The water tanks should be provided with gates or valves in their bottoms to draw off the sludge. The solutions may be allowed to run slowly from their tanks and mix with the entering raw water, the rate of flow being so regulated that the proper amount will be delivered while the tank is filling. Or, the tank filled, the entire quantity of solution to be used may be run in at once and mixed with the water by a stirring device. The former method will be better if the flow of solution can be watched to see that it does not diminish by clogging the outlet. The tank of treated water is allowed to stand for as much of 24 hours as the tank capacity permits, when it is available for use. Care must be taken to draw from the tank at a level well above the top of the sludge. By treating and using the duplicate tanks alternately a continuous supply is maintained.

An analysis of the water, which may be obtained from the Medical Department, will show the weight of each mineral constituent, usually in grains per gallon. This divided by 7 gives the lbs. per 1,000 gals., which is a convenient unit to use.

The quantities of reagents required are:

For each 100 lbs. of carbonate of lime in the water, 56 lbs. of unslaked lime.

For each 100 lbs. of sulphate of lime in the water, 85 lbs. of soda ash.

Water requiring treatment will carry from 1 to 6 lbs. of total incrusting solids per 1,000 gals. The upper limit is not likely to be exceeded except in highly contaminated wells.

For purposes of estimate, the corresponding aggregate weight of soda ash and lime may be taken at ½ to 4 lbs. per 1,000 gals.

If an analysis can not be had, the kind and quantity of reagent required may be determined fairly well by examination of boilers which have been using the water. If the scale is lightish in color and soft, lime is needed, in quantities proportionate to the amount of scale. If the scale is light in color and very hard, soda ash is probably required. If the scale is light colored and medium hard, it is likely that both reagents should be used, more lime or more soda ash, according as the scale is softer or harder. If the scale is dark in color, the suspended matters in the water have formed part of it.

If the water is very turbid and not very hard, the proper quantities of reagents will not cause sufficient deposition of sediment and a **coagulant** may be required. Alum and copperas, in the ratio of 1 to 4, make a good coagulant, $\frac{3}{4}$ lb. of which per 1,000 gals. will settle a very turbid water. Great care must be taken to neutralize the coagulant by increasing the quantities of lime and soda or the treated water will be corrosive. One-half lb. of soda ash and $\frac{1}{4}$ lb. of lime should be added for each pound of coagulant in addition to the quantities necessary to remove the hardness.

90. **Troubles with steam distribution.**—These relate to the control of the flow of steam from the time it leaves the boiler until it reaches the atmosphere through the exhaust. They may result from breakage, or from the lack of adjustment of moving parts which should be steam-tight.

Breaks will always require instant attention. **Leaks,** often called **blows,** may or may not, according to their nature and amount. In most cases the trouble will be on one side only and the work to be done on the spot will consist of applying a remedy, if it can be done, or if not, of disconnecting the lame side and arranging all parts so that the engine can run in by use of the other cylinder or, as it is called, **on one side.**

91. **Location of the trouble.**—The simplest tests of steam distribution are the escape of steam from the cylinder cocks and the regularity of the exhaust. There are four blasts of the exhaust for each revolution of the drivers, and if things are right, the four puffs should be regular in interval and force. They rarely are so perfectly so that a quick ear can not detect some irregularity, but a difference indicating that something needs attention will be obvious to anyone. A considerable irregularity of exhaust will not require immediate attention if it continues. If the irregularity comes and goes, or changes in amount, something is wrong, and instant attention is required. It is very important for the engineer to know, and as far as practicable locate, every irregularity, no matter how slight, in order that he may report it at the end of the run and give the repair force all possible help in getting at the seat of trouble quickly. When one blast is too strong, the other on the same side is likely to be too weak. If one is too early, the other will probably be too late. Note which side is on the center at the time the unequal blasts occur. The trouble is on that side. In case of a sudden and variable bad exhaust, see that the valve is well lubricated, and examine the valve mechanism, rods, rockers, eccentrics, eccentric shafts, and link motion for looseness, bends, or breaks.

With all cylinder cocks open, steam should blow from the cocks away from which the piston is moving and not from the others. Any variation from this condition indicates that something is wrong and which side it is on. With the reverse lever at the center and the throttle open, no steam should escape from any of the cylinder cocks. Trouble indicated by the cylinder cocks is generally in the piston or valve seat.

92. **To shut off steam on one side.**—If the valve is in working order, set it at its middle point, determined by the rocker arm being vertical; or by no steam escaping from the cylinder cocks when throttle is slightly open. Place the valve clamp, fig. 78, on the stem and push it up firmly against the face of the gland with the slotted lugs on the gland studs. Tighten the clamp bolts and then set up the stud nuts against the lugs of the clamp. Now disconnect the valve rod from the stem and rocker.

If the **valve stem** is **broken** off too short to take the clamp, the steam-chest cover must be lifted and the valve blocked inside. Set the valve in the middle position, cut and fit wooden blocks between it and the ends of the steam chest, *AA*, fig. 79. If the valve is not balanced, it should also be blocked down by a piece filling the space between it and the cover *B*, fig. 79. If the stem is too short to reach through the opening in the gland, take out the yoke and stem and drive a plug in the hole from the inside. If the **valve only is broken,** take out the pieces and fit blocks under and inside the yoke, using the clamp as before described, fig. 80. If the stem is short enough to take out the yoke, a piece of plank the length of the inside of the steam chest and the width of the valve openings may be used, the hole in the stuffing box to be plugged as before.

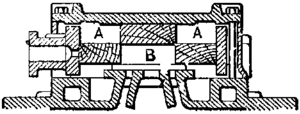


Fig. 79

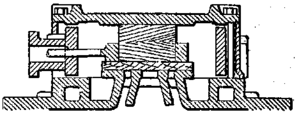


Fig. 80

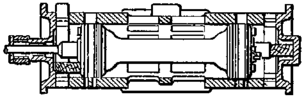


Fig. 81

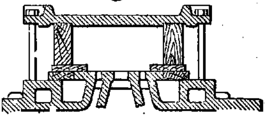


Fig. 82

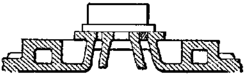


Fig. 83

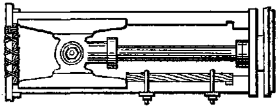


Fig. 84

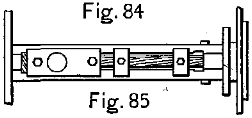


Fig. 85

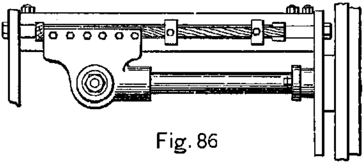


Fig. 86

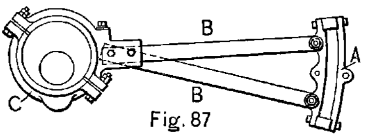


Fig. 87

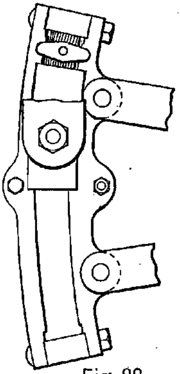


Fig. 88

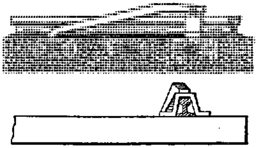


Fig. 89

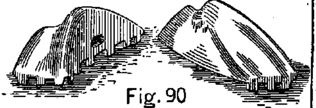


Fig. 90

For piston valves, the operation of clamping or blocking is the same in principle, but much easier, fig. 81.

There is no pressure tending to move a valve out of its position when blocked. The blocking should be designed and placed to resist displacement by vibration rather than by pressure.

If the **steam chest will not hold steam**, the blow must be blocked off at the ports which lead into the chest. If the cover is not broken, it may be used to hold the blocking, fig. 82. If the cover is broken, remove it and substitnte a piece of plank. The valve, yoke, and stem must be removed. The side casing of the chest mnst be removed if badly broken, otherwise it is not necessary.

If the **forward cylinder head** is broken, it may be possible to close the forward steam port by a block under the valve and use that side single-acting, fig. 83.

93. **To disconnect.**—When steam is cut off from one side, the piston and crosshead on that side **must not be allowed to move.** The exceptions to this rule are so few and unimportant that it is better to make it universal. The main rod is disconnected at both ends or *taken down.* The piston and crosshead are pushed to one end as far as they will go, and held there by blocking between the crosshead and the farther ends of the guides, kept in place by bolts, clamps, or lashing. Figs. 84, 85, and 86 show the application to different forms of crossheads.

94. **Accident to link motion.**—If a link is broken, the side is disabled. Remove the link *A*, eccentric rods *B*, and straps *C*, fig. 87, and **disconnect the side.** Note that when this phrase is nsed, it **always** includes **cutting off the steam**, par. 92, **blocking the crosshead**, par. 93, and **taking down main rod.** If a **backing eccentric** rod or strap is broken, take it down and set the link for full stroke forward. The engine can not be reversed nor the cut-off changed in this condition. If a **forward strap or rod** is broken, take it down and put the backing strap and rod in its place. If the rod is not broken, it may be put on the backing side and clamped to the forward rod to steady the link, fig. 87. The engine can not be reversed, though the reverse lever may be used on the forward motion, changing the cut-off on the good side, but the lame side will work at full stroke in all positions of the link. If a **backing eccentric** breaks, proceed as though the strap and rod were broken. If a **forward eccentric** breaks, it may be possible to shift the backing one into its place, although it will usually be better and quicker to disconnect the side.

If a **rocker arm**, upper or lower, is broken, remove the part and disconnect the side.

If an **upper rocker pin** is broken, an attempt should be made to replace it. If a bolt or pin smaller than the hole must be used, drive hard-wood wedges around it, or make a liner of a sheet of thin metal wrapped around the pin as many times as may be necessary to give a snug fit. If the pin can not be replaced, disconnect the side.

If a break occurs in the connection between the reverse lever and the link, the engine may be set to go ahead with a fixed cut-off on the lame side by blocking the link in the desired position. If the break affects one side only, a single block above the link block will do, fig. 88. In this case the good side may be worked at longer cut-off than the lame one, but not at shorter, and the engine can not be reversed.

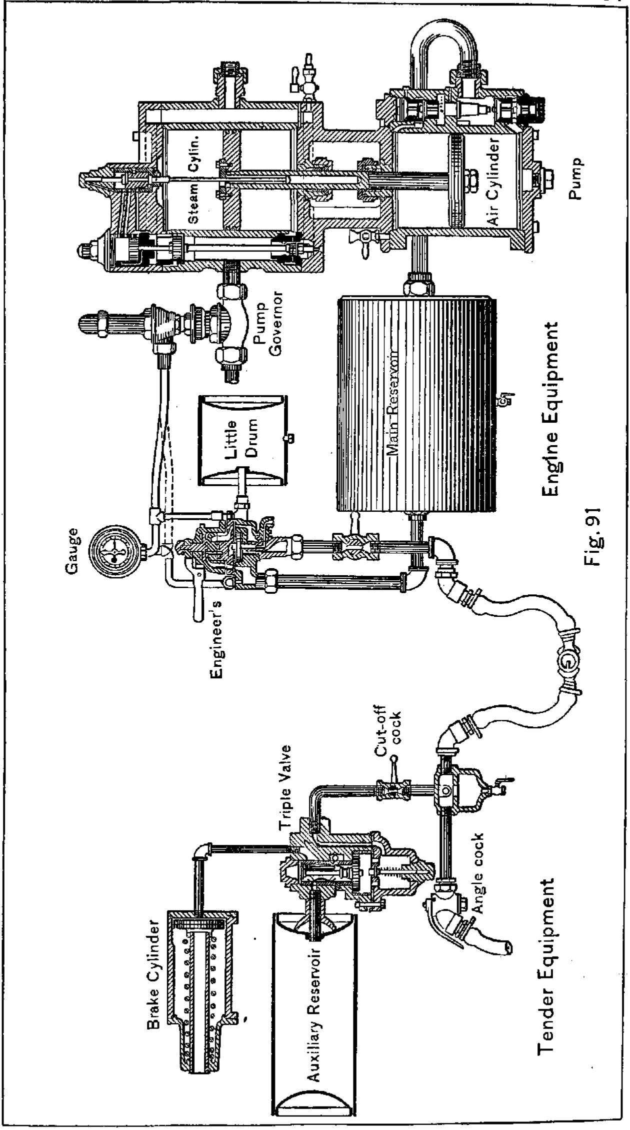
If the break affects both sides, take down the hangers and block both link blocks above and below at the point of forward cut-off which will haul the train. In this case no change can be made in cut-off and it is impossible to reverse.

If a **side rod** is broken or bent, it must be removed or *taken down;* and in all cases where a side rod is taken down on one side, the corresponding side rod must be taken down on the other side.

95. If the **throttle connection** breaks, the valve may remain open or it may remain shut. In the former case, the engine can be run with care by reducing the steam pressure, if necessary, so that the reverse lever can be worked, in which case steam can be shut off sufficiently for operation of the engine by placing the reverse lever on the center.

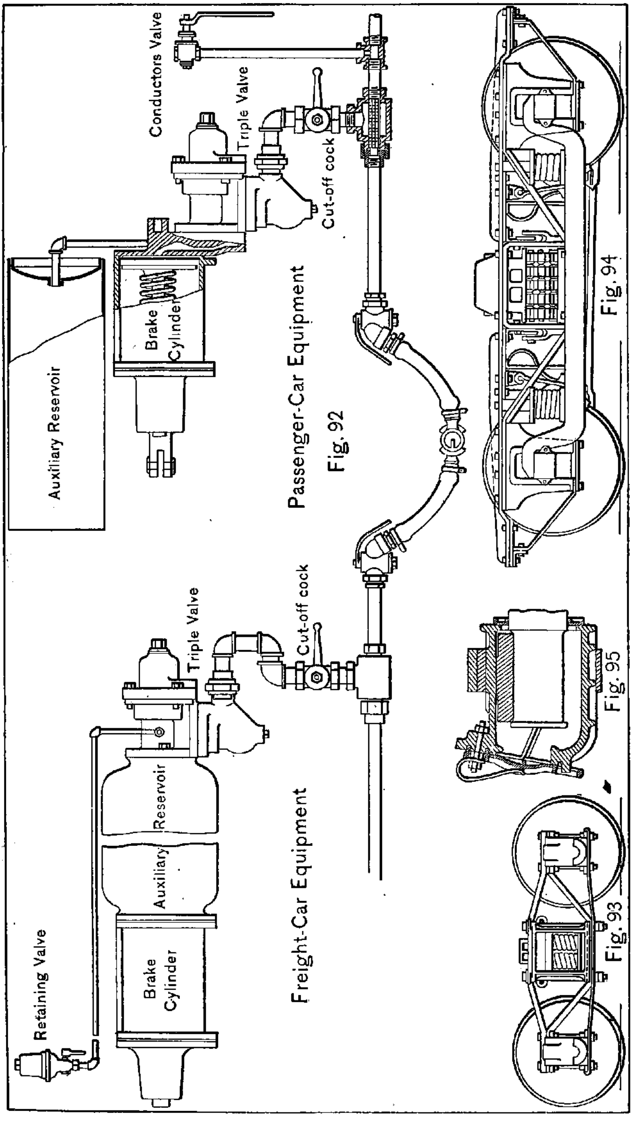
If the broken throttle is shut, nothing can be done until the steam is lowered, the cover of the dome removed, and the break repaired.

Drifting.—A locomotive running with steam shut off is said to be **drifting** or to **drift.** As the piston must move, the cylinder becomes a pump, and there is danger of injuring it by cinders or hot gases drawn in from the smoke box. When power



Steam Cylin.
Air Cylinder
Pump
Pump Governor
Little Drum
Main Reservoir
Engine Equipment
Gauge
Engineer's
Cut-off cock
Triple Valve
Angle cock
Brake Cylinder
Auxiliary Reservoir
Tender Equipment

Fig. 91



Passenger-Car Equipment
Fig. 92

Freight-Car Equipment

Fig. 93

Fig. 94

Fig. 95

is not required, set the reverse lever in the end notch, forward or back, as the case may be, and open the cylinder cocks and give a little steam—just enough to show at the cocks.

96. **Rerailing.**—An engine off the rails but not off the ties may often be put back without outside assistance, especially if, as is often the case, only the pilot truck is derailed.

Some form of rerailing frog, figs. 89 and 90, should be carried on the train. If there is not a frog for each wheel off, give preference to the wheels which are outside the rails and block up under the others.

As a rule, an engine will go back easiest over the route it followed in going off.

When anything happens to the engine during a run, there is always something for the engineer and train crew to do at once, either in making the necessary repairs to get in, or in preparing the machine to be towed in. If help is sent for, the engineer should try to have his engine ready to be moved by the time help arrives.

97. **The air brake.**—The fundamental parts of the quick-action automatic are shown diagrammatically in figs. 91 and 92. Fig. 91 contains the locomotive and tender equipments and fig. 92 those of passenger and freight service. They are the **pump,** which compresses the air; the **main reservoir,** in which it is stored; the **train pipe,** which runs from the engine to the rear of the train connected from car to car by **hose** with quick couplings; the **brake cylinder,** one beneath each car, which operates the brake mechanism; the **auxiliary reservoir,** one for each cylinder, which supplies air to the cylinder; the **triple valve,** which controls the flow of air from the train pipe to the auxiliary reservoir and brake cylinder, from the reservoir to the cylinder, and from the cylinder to the atmosphere; and the **engineer's valve** in the cab, which controls the flow of air to and from the train pipe and the pressure therein. Minor features are, a **cut-off valve** between the train pipe and the triple, by means of which any car can be cut out without affecting the rest of the train; the **angle valves,** one at each end of each car at the inner end of the connecting hose; the **bleeder cock** of the auxiliary reservoir, by which the pressure in it can be reduced, to compel the brake to release when stuck; the **conductor's valve,** used on passenger equipment, which may be operated from a car and opens the train pipe to the atmosphere, reducing the pressnre and setting the brakes; and the **gage** which indicates the pressure in the main reservoir and train pipe. Usually the gage is duplex, two hands moving in front of the same dial, the red hand indicating reservoir pressure and the white or black hand the train-pipe pressure. There is also a pressure-retaining valve, which, when placed on a car and cut into action, holds the cylinder pressure at 15 lbs. while the engineer's valve is set to release and the auxiliary reservoirs are recharged. It is not always used, but is added to freight equipment when long grades are encountered. The handle of the valve is in an accessible position at the end of the car and is worked by hand.

98. **The pump,** fig. 91, is a small air compressor mounted vertically on the engineer's side just in front of the cab. The proper speed is 45 to 60 strokes a minute. It may be run faster, but not for long, as it will get hot, due to the liberation of heat from the rapidly compressed air. If run too slow, it may also get hot from leakage past the air piston, causing the same air to be recompressed without the cooling effect of fresh outside air.

The **gland packing** between cylinders requires careful attention. The gland nuts should be no tighter than is absolutely necessary to prevent leakage of steam or air. The piston rod is kept well lubricated by a swab. Some oil passes into the air cylinder on the rod, probably enough, as little is required. No heavy or gummy oil should be used on the rod or in the air cylinder.

To start the pump, open the draincocks of the cylinder and valve chest and admit steam slowly to blow out water and warm up gradually. When there is a pressure of from 20 to 30 lbs. in the reservoir, the cocks may be closed and full steam given. The pump when started regulates automatically by means of a **pressure governor,** starting when the train-pipe pressure falls below the standard and stopping when it goes above it. The interior parts and surfaces of the air end are very likely to become gummy and stick and will require occasional cleaning with lye or soapsuds, followed by a thorough rinsing with clean hot water.

The **triple valve** is operated by the difference of pressure in train pipe and auxiliary reservoir. If the train-pipe pressure is equal to or greater than that in the auxiliary, the valve takes a position allowing air to pass from the train pipe to the reservoir, but through a contracted opening and not rapidly. This keeps the reservoir charged to full pressure at all times when the brake is not in action. If the train-pipe pressure falls below auxiliary pressure, the triple takes a position which cuts off the flow from the train pipe to the reservoir and permits a flow from the auxiliary to the brake cylinder, setting the brake. This is called the **service position.** If the reduction is large enough, the triple takes another position, which, in addition, allows air to pass direct from the train pipe to brake cylinder and increases the speed and force of the brake action. This is called the **emergency position.** When the train-pipe pressure is increased to somewhat more than the auxiliary pressure, the triple takes the position first described, called the **release position.**

The **engineer's valve** is a triple-ported rotary valve combined with a differential pressure valve. It regulates and controls the distribution of air and pressures between the main reservoir and the train pipe and between the train pipe and the atmosphere. It also maintains a pressure normally equal to train-pipe pressure in a small equalizing reservoir, usually called the **little drum.** The little-drum pressure and the train-pipe pressure act on opposite sides of the piston of the differential valve and control its movements. The white or black pointer, while nominally indicating the train-pipe pressure, is in reality connected to the little-drum, the pressure in which is, with momentary exceptions, the same as the train-pipe pressure.

The engineer's valve is mounted in the cab under the engineer's hand and connected to the duplex gage, the main reservoir, the train pipe, and the little drum. It also opens to the atmosphere. It performs all its functions by placing the handle of the rotary in different positions indicated by marks.

There are five such positions: **Running, service, lap, release,** and **emergency.**

In the **running position,** used when the train is in motion and the brakes off, air passes from the main reservoir to the train pipe and the little drum, but through small ports and also through a reducing valve, called the **excess pressure valve,** which reduces its pressure. In one form of engineer's valve the reduction is constant at 20 lbs. In another form it may be varied. When the latter form of valve is used the pump governor is connected with the main reservoir instead of the train pipe. In the running position a constant pressure is maintained in the train pipe, enough air passing from the reservoir to supply leakage.

In the **service position,** which is that of ordinary brake application, the rotary opens the little drum momentarily to the atmosphere, reducing its pressure below that of the train pipe, which moves the differential piston, opens the train pipe to the atmosphere, and sets the brake. When the train-pipe pressure reaches the reduced pressure in the little drum, or a little below, to allow for friction of parts, the piston moves back and closes the exhaust of the train pipe, holding its pressure at that point. The engineer's valve in such an application is set at service until the black pointer drops about 5 lbs., when it is quickly set at lap. The service reduction is not constant. For a long train, or with brakes in bad order, a greater reduction than 5 lbs. will have to be made. The rule should be to make the least reduction which will set the brakes promptly and surely.

In the **lap position,** all ports of the rotary are closed and there is no movement of air in any direction. In this position the black hand shows the pressure in the little drum, not in the train pipe. Leakage should be so small that all pressures will remain nearly constant in this position.

To throw off the brakes, the engineer's valve is set to the position of **release.** Air now passes direct, not through the reducing valve, from the main reservoir to the train pipe, raising its pressure and releasing the brakes through the action of the triple valve. The little-drum pressure is at the same time equalized with that of the train pipe.

There is also a **full release position,** differing from the above, in giving a larger passage from the reservoir to the train pipe, to bring its pressure up more rapidly and give a more positive working of the triple.

The standard pressure in train pipe, auxiliary reservoir, and little drum is 70 lbs. per sq. in., and is indicated, except in the lap position, by the **black hand.** The standard **main reservoir** pressure, indicated by the **red hand,** is 90 lbs. When these pressures are indicated, the pump should be running only fast enough to supply leakage. In the **running position,** the hands should always be 20 lbs. apart, or with the adjustable form of engineer's valve, should differ by the adopted excess pressure. When the black hand shows less than 70 lbs., the pump should be running. When the pump governor is connected to the train pipe, to get any excess pressure in the main reservoir, it is necessary to move the valve to running position before the black hand has reached 70 lbs.

87625—09——21

99. **Terminal test.**—As soon as an engine is coupled to a train with air brakes, the train-pipe pressure being preferably 70 lbs., but in no case less than 50 lbs., the engineer's valve should be put to lap and leakage in all parts of the system noted. If the train pipe leaks, the brakes will go on. If the reservoir or little drum leaks, the pointers will fall. If the leaks are large enough to interfere with operation, they must be found and corrected. A series of moderate reductions should then be made to give 20 lbs. reduction of train-pipe pressure, and the **brakes held on while all the cars are examined** to see if their brakes have set and are holding. When this is done, the engineer is signaled and he puts his valve to release, when the **inspection is repeated** to see if all the brakes have gone off. If these moderate reductions do not cause the brakes to act properly and promptly, try heavier reductions.

100. **A brake may refuse to set** or, having set, **may release prematurely,** or may **refuse to release** at all. If the brake **refuses to set,** look particularly to see that it is cut in. If it is cut in, try the bleeder of the auxiliary to see if that is charged. If it is not charged, the trouble is likely to be a stoppage in the feed groove of the triple. If the reservoir is charged, it is likely that the piston of the triple is stuck. It will sometimes let go if the case is jarred a little with a block of wood. If these means do not prevail, cut out that brake and mark the car for attention at the shop.

If the brake **goes on and releases immediately,** there is a leak from the auxiliary or the brake cylinder. If from the auxiliary, air will blow from the exhaust of the triple. If the leak can not be found and stopped, the brake must be cut out and the car marked as before.

If a brake, having set, **fails to release,** note whether air escapes from the exhaust port of the triple. If it does not, look at the retaining valve, if there is one on the car, and see if it is cut out and whether its exhaust port is free. See that the hand brake is quite off, and note whether the slack of the brake gear is right. If there is a **blow at the triple,** jar the case with a block of wood, make a heavy reduction, and release. If the brake does not go off, cut it out, discharge the auxiliary through the bleeder, and then cut the brake in suddenly. If the blow continues, cut the brake out for the rest of the run, marking the car as before.

The tightness of the piston in the triple is of great importance and may be tested when air is on and the brake set, by opening the bleeder of the auxiliary very slightly. If the brake releases promptly, the piston is tight. If not, open the bleeder a little more, and after 15 seconds or so, if the brake does not release, open it a little more, repeating the operation until the brake goes off. The leakage past the piston is a quantity somewhere between the discharge of the bleeder just before and after the brake releases.

A very frequent trouble is a brake going into **emergency action** when a service application is made. If one brake on a train does this the others will follow. The most frequent cause is a sticky triple which does not respond to a moderate reduction, and when a further reduction is made, lets go and jumps to emergency position. This reduces the train-pipe pressure suddenly in that vicinity and causes the nearest triple on each side to go into quick action, and so on throughout the train. **To locate a defective valve,** make a light service reduction and look for a brake that has not set. Cut it out and test to see if the rest are working properly.

The trouble may be due to a **weak or broken spring,** in which case it is more difficult to locate. A good way is to close an angle cock in the middle of the train and try the brakes. If the trouble occurs again, it is in the half nearest the engine. If it does not occur, the trouble is in the other half. This may be repeated until the defective triple is located in a cut of a few cars, which may be cut out one by one until the trouble is found. When found, cut out the brake and mark the car.

101. **Accidental applications.**—When the brakes go on suddenly without the use of the engineer's valve, the engineer should set his valve at lap to hold the main reservoir pressure, and as soon as the train has stopped, look for the cause of the application. It may be the opening of a conductor's valve, the bursting of a hose, or the parting of the train.

102. **Leaks in the train pipe** may usually be located by the noise of escaping air. A piece of hose, however, may leak considerably by porosity. Smear it with soapsuds and watch for the formation of bubbles. Other leaks are corrected by screwing up joints or putting in new gaskets.

A leak in the triple is indicated by a blow at the exhaust. If the brake sets when cut off from the train pipe, the leak is from the train pipe. If not, it is from the auxiliary. **The exhaust port** of a triple or retaining valve must **never be plugged up** to stop a blow.

103. **Piston travel.**—The proper working of the brakes in a train requires a fair uniformity in the travel of the pistons in the brake cylinders. The normal travel is 6 to 9 ins. It is regulated by devices called **slack adjusters,** generally on the brake beam, but sometimes provision is made for changing the length of some of the brake rods for this purpose. When adjusted, the travel should be about 6 ins. It will gradually increase as the brake shoes wear, and when it reaches 9 ins. it should be set back. When new brake shoes are put on, the travel must always be adjusted. Some of the latest passenger equipment has automatic slack adjusters.

104. **Hand braking.**—The air brake is the most difficult to work of all railroad appliances. Civil roads find it necessary to maintain a school of instruction and practice, to give the men the proper knowledge in its use. For military roads, it should be used if possible, but it should not be relied upon exclusively. All hand brakes should be kept in order, and engineers and brakemen should be trained in their use and in the signals for working them.

When air brakes are in use, the hand brakes on the same car must always be entirely off, and **when hand brakes are used** on any car the air brake on that car must be cut out.

Military trains will usually be mixed, i. e., will contain passenger and freight cars. The latter have a certain amount of slack in their couplings, the proper management of which is of great importance to smooth running. **In stopping or slackening** speed, the cars tend to run together, when the train is said to be **bunched,** but in starting the slack runs out and the train is said to be **stretched.** If the train is all air, which is not probable, the slack will not give much trouble. If the train is part air, as it is very likely to be, the speed should first be checked by shutting off the steam and allowing the engine to drift until the train is bunched, then a very light reduction should be made to take up the spring slack, followed by a sufficient reduction to bring the train to a stop at the desired point.

The order of cars in a military train is affected by some considerations other than the air braking, but so far as the other conditions permit, the air cars should be placed next to the engine and cut in, with the non-air cars in rear of them. All air brakes which will work should be used. If a fair proportion of the cars are air-braked, no hand brakes will be needed. If the air brakes in use will not control the train, hand brakes must be set in addition. Those nearest the air cars should be set first. When hand brakes are used on the same train with air brakes, the engineer must signal *brakes off* and wait for the hand brakes to be released before he releases the air brakes.

Smooth handling of trains is, if possible, more important for military than for civil roads, since the management of a military road has a vital interest in the nervous condition of its animate traffic when delivered at destination. Engineers can, if careful, handle trains without much shock and they should be required to do it.

105. **Sanding.**—From the sand box on the top of the boiler, sand is discharged through a pipe on each side and falls on top of the rails. Sand is used for two purposes: To increase the adhesion of the drivers and give the engine more tractive force, and to increase the adhesion of all wheels to augment the brake effect.

It is better not to apply sand to wheels that are slipping. If for increased traction, cut down the steam until the drivers roll on the rails, then sand and open the throttle. If for braking, let off the brakes to be sure that all wheels are rolling, then sand, and after the train has run its length, set the brakes. The object of this is to prevent flatting the wheels by sliding them on sanded rails, and this injury to the rolling stock is the main objection. For an emergency stop, it goes without saying that brakes will be set and sand applied without regard to the effect on the wheels.

Sand should not be run continuously, but intermittently, opening the sand valve for a few seconds at intervals of 100 or 200 feet. The tires will take the sand up and distribute it. When sanding for a stop, continue until the train comes to a standstill. When sand will not run on one side, it is better not to use it on the other.

106. **Rolling stock.**—In the **finances** of a road this term includes everything on wheels. In **operation** it is useful to class locomotives separately as **motive power** and to include cars of every description as rolling stock.

The parts of a car are the **truck,** the **body,** and the **draft** and **brake mechanisms.** American cars are principally of the 8-wheel type, moving on two 4-wheel

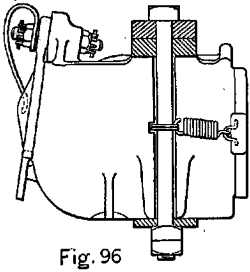


Fig. 96

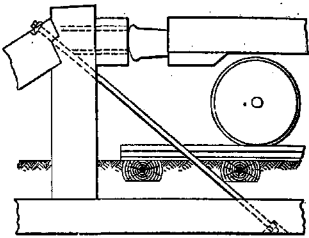


Fig. 97

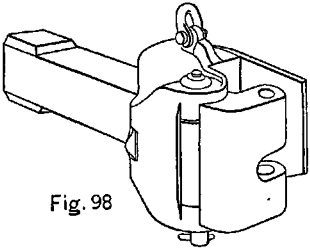


Fig. 98

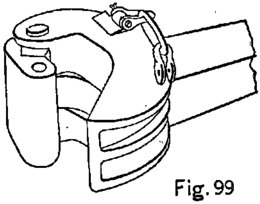


Fig. 99

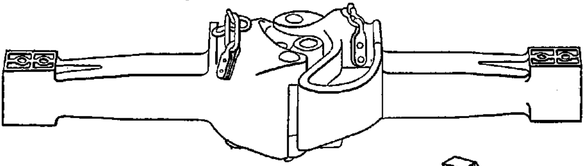


Fig. 100

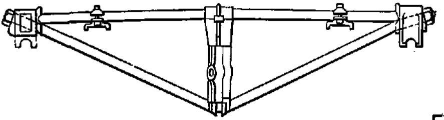


Fig. 101

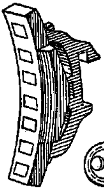


Fig. 102

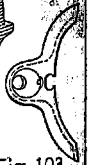


Fig. 103

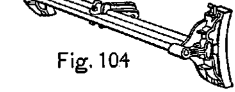


Fig. 104


Fig. 105

trucks. The only important exceptions are on coal roads, where many coal cars on four wheels are used, and heavy passenger cars which have six wheels to each truck.

107. **Trucks.**—The truck is a rigid frame holding the two axles parallel to each other. It presents jaws to receive the journal boxes as described for the locomotive. In these jaws the boxes move up and down, controlled by springs. Fig. 93 shows a side view of a typical freight truck, and fig. 94 of a passenger truck.

The truck is attached to the body by a kingbolt. Sometimes the kingbolt may be withdrawn through the floor of the car; if not, by picking up the end of the car the kingbolt will draw out and the truck may be removed and replaced by another. The car is steadied on the truck by side bearings on the bolster. Sometimes these are of roller type.

The principal characteristic of the truck is that the pressure is on the top of the bearing instead of on the bottom as in most stationary practice. A section of a car bearing is shown in fig. 95, and a side elevation in fig. 96. It consists of a **journal box** fitting into jaws in the truck frame. The top of the box receives the **brass** which rests on the journal. The lower part of the box is called the **cellar** and is designed to hold the lubricant. The back or inside of the box fits fairly close around the axle, fig. 95. The front is closed by the **lid,** sometimes called the **dust cover.** The cellar is filled with waste saturated with oil. The waste must be alive or springy so that it will press against the underside of the journal, which takes its oil by rubbing against the waste. If it mats down so as to leave the journal, no oil is supplied and heating results. Especial care is required to get the waste up to the journal at the back end.

108. **The draft gear** consists of the **coupler** and **drawbar, spring case,** and **spring.** Couplers are of two general classes, the **link and pin** and the **automatic,** figs. 98, 99, and 100. The link and pin type is almost obsolete in standard equipment. The automatic is of many forms, all depending on the working of a **knuckle.**

The drawbar is attached to the underside of the floor frame by means of timbers or plates or both, firmly bolted to the floor frame and forming a channel to receive the drawbar and the spring case. In some forms of attachment allowance is made for a slight spring-controlled side motion, to reduce lateral shocks. The variable distance between cars which a coupler permits is called **slack,** and that part of it which is caused by compression of springs is called **spring slack.** Passenger couplers lock very closely and are supplied with spring buffers, so that all their slack is spring slack. Freight couplers have considerable pin slack, the link and pin more than the automatic.

The brake gear, figs. 101–105, consists of a system of rods and levers connecting the piston or handwheel with the **brake beam,** which carries at each end opposite the tread of the wheel a **brake block,** in which is keyed a removable and sometimes reversible **brake shoe.** The beam is of wood or metal, the latter rapidly coming into use; the block of cast steel and the shoe most often of soft cast iron, though many forms of composite shoes, composed of hard and soft materials, are in use.

109. **Signals** are given by means of **targets, flags, lamps, fusees, whistles, bells, torpedoes, posts, and boards,** and with **hands** and **arms.** They may be **classified** in various ways.

First, into **permanent signals,** which may have several meanings, are continuously displayed in one or another of their meanings, their absence to be construed in their safest meaning; **temporary signals,** which have but one meaning, and the absence of which means nothing; and **train signals,** which are those carried on locomotives and rear cars to indicate the character of the train and its completeness, the direction of its motion, and whether it is followed by other trains.

Temporary signals, in addition to compliance, require to be **answered** as an indication that they are seen and understood. **Permanent signals,** as a rule, require **no acknowledgment,** but only compliance.

Switch, crossing, station, and block signals, bell and whistle posts, slow boards, etc., are permanent signals. Lanterns, flags, bells, fusees, and torpedoes are temporary signals. Train signals consist of flags and lamps.

Second, into **visual** and **audible** signals.

Third. Visual signals are also classed as **day** and **night. Night signals** are made by lanterns, lamps, and fusees. Usually day signals are displayed at night also, the night signals being added. Night signals are displayed from sunset to sunrise and during the day also in thick weather. Audible signals are equally effective day or night.

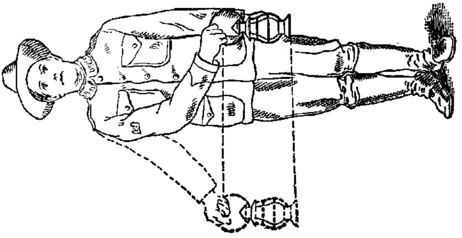


Fig. 106. Stop.

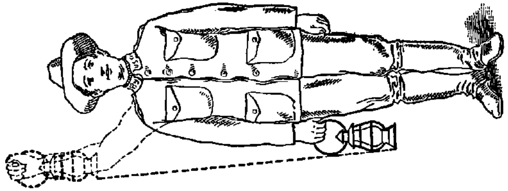


Fig. 107. Proceed.

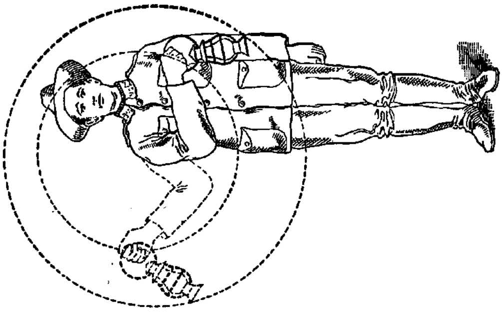


Fig. 108. Back.

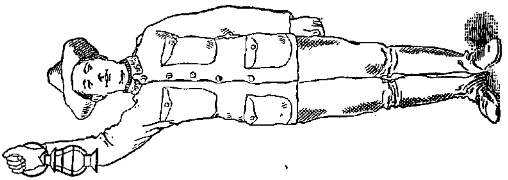


Fig. 111. Release Air Brakes

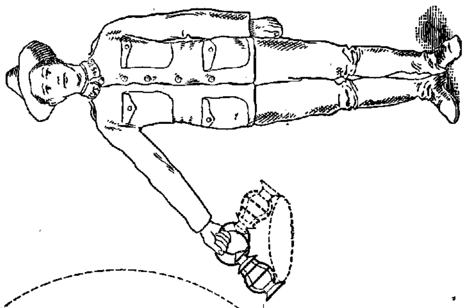


Fig. 110. Apply Air Brakes

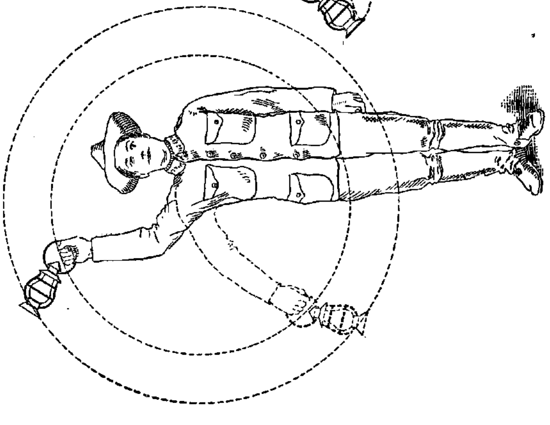


Fig. 109. Train has Parted

Visual signals give their indications by **color, position,** or **motion.** The standard signals adopted by the American Railway Association, and in general use on the roads in the United States, are as follows:

Color signals.—Red, stop, except on switch stands, where it means that the switch is set for the siding. A fusee burning red, on or beside the track, must not be passed *until it* goes out.

Green and white, to **stop;** used only at points designated on the time-table as flag stops for the train.

Green, safety or **proceed,** but may be given a different meaning by motion. A fusee burning green means proceed with caution.

Blue is used to indicate that men are working under or about the cars near which it is displayed.

White, not from a lantern or lamp, same as green. On an engine, indicates that the train is an extra.

Yellow is used on some roads as a cautionary color, and **red and green** on others. For military purposes, a cautionary signal is less necessary. Red and green should be used if a cautionary color is desired, as yellow has a special significance.

Position signals.—For a semaphore or movable arm, a **horizontal position** indicates **stop;** a **vertical position, proceed;** an **inclined position, caution.** At night the position may be indicated by lanterns at the ends of the arm, or the signal may be given by colors, the latter method generally employed, the movement of the arm causing screens of glass to come in front of the lamp, colored to correspond, by indication in color, with the position of the arm.

Motion signals are given by the **hands** and **arms,** or by lanterns held in the hand. They are shown in figs. 106 to 111.

Any object waved violently on or near the track, or any demonstration with the evident purpose of attracting the attention of the crew is, in civil practice, a stop signal. In military practice, it should be accepted as a signal to the engineer to bring his train under full control and proceed with great caution, whistling for the guard at the same time.

Steam whistle signals.—In the following schedule, o indicates a short blast of the whistle, — a long blast, in proportion to its length:

o	Stop. Apply brakes.
— —	Release brakes; train will move forward.
— — —	When running, train has parted. Engineer's answer to signal that train has parted.
— o o o	Flagman go back to protect rear of train.
— — — —	Flagman come in from west or south.
— — — — —	Flagman come in from east or north.
o o o	Train will back. Engineer's answer to signal to back.
— o o	To call attention to engine signals carried, or to ask for signals. For the former purpose, to be blown for every train met while carrying signals.
— — o o	Approaching highway crossings at grade.
———	Approaching stations, junctions, and railway crossings at grade.
o o	"I understand." Answer to any signal not otherwise provided for.
o o o o	Call for signals.
o o o o o o o, etc	Repeated short blasts, warning to persons or stock on track.
o — o — o —, etc	General alarm. Calls out all armed men on train.

Air whistle or **bell-cord** signals:

Two, when train is standing, start; when running, stop at once.

Three, when train is standing, back; when running, stop at next station.

Four, when train is standing, apply air brakes if off, or release if on; when running, reduce speed.

Five, when train is standing, call in flag; when running, increase speed.

The explosion of **one torpedo** is the signal to **stop; two in quick succession** are a signal to **reduce speed** and look out for a stop signal.

110. **Train signals.**—The locomotive **headlight** indicates the presence of the train. Yard engines carry headlights front and rear. If there is no headlight for the tender, display two white lanterns instead.

Markers are displayed on each side of the rear end of the rear car of every train or section, a green flag by day and a light showing green to front and side and red to the rear by night. If there are no cars attached to the engine, the markers are carried on the rear end of the tender. At night, when a train is standing on a siding, clear of the main track, the headlight should be concealed, and the markers turned to show green to the rear. This **must not be done,** however, until the train is **in to clear** and the switches **have been turned** for the main line **and locked.**

A green flag by day and in addition, a **green light** by night, carried on each side of the front of the engine, indicate that another section of the same train is following. Attachments are provided on the engine for carrying these signals. **White flags** and **lights** in these positions, instead of green, indicate that the train carrying them is an extra, but not that anything is following. Extra trains are not divided into sections. If flags or lamps are seen on one side only, they are to be construed as having the same meaning. It is the **duty of the engineer** when carrying these signals to **call attention** to them hy **whistle** whenever a train is met.

Coupling signals are made with hands or lanterns, and it is important that there should be a proper understanding between the engine crew and the brakemen or yard men, to prevent unnecessary shock in coupling cars. The coupling signal most generally used is made by extending one or both arms transversely to the track and moving the hands in circles, larger and slower when the cars are some distance apart, smaller and faster as they approach, and dropping quickly at the moment the couplers touch. The circles with the hands are so made that the hands in their upper positions move in the same direction with the car.

When any signal is imperfectly displayed or made, or when a permanent signal having more than one meaning is not displayed in any of its meanings, the train must stop.

The engine bell is rung when the engine is about to move and when approaching highway crossings at grade. The engineer also rings the bell at stops to indicate to the conductor that he is ready to move.

111. **Protecting** is a term used to cover the general requirement that every train or part of a train standing or running on the main line under exceptional circumstances must have suitable signals on the track, in rear or in front, or both, at such distance as will enable any approaching train to stop before collision. If the protected train is in motion, the head signals should be at a greater distance than the rear signals. If at rest, the head and rear signals may be at equal distances, except that in all cases greater distance must be given a train to stop on a down grade than on a level track.

Proper protection to trains is of **first importance** to safety. Nevertheless, it is so freqnently neglected or inadequately performed as to produce more collisions than any other one cause.

A running train can be protected in front only by a flagman walking on the track or a party ou a hand car a proper distance from the train with the signals displayed by hand. This is called **flagging ahead,** or **back,** or **through.** Rear protection of a moving train may be had by a flagman or hand car following, or, in some cases, by leaving a red fusee burning on the track at time intervals a little less than the time of burning, usually 5 or 10 minutes, and placing two torpedoes on the rail, two rail lengths apart, five telegraph poles behind each fusee.

It is assumed that stop signals for protecting trains will not be expected by an engineer, and hence **both audible and visual** signals should be employed to increase the chance that one or the other will be noticed by some of the train crew. Besides, if flag or lamp, it must actually be in the flagman's hand and must be **moved to indicate stop** in accordance with the code of motion signals. **A flagman's outfit** for protecting his train is a red flag or lamp, 12 torpedoes, and in thick weather 3 red fusees. The flagman or rear brakeman has the necessary signals in his possession, is supposed to know when he should go out, and is held responsible if he does not go when he ought to. For greater safety the **conductor** is charged to see that the flagman goes and to acquaint him with all extra stops which are ordered and their probable length. It is the duty of the **engineer** also to whistle out the flagman when he sees that an extra stop or unusual reduction in speed must be made. Often an engineer may whistle out the flag before the stop is reached and enable the flagman to drop off before the train stops. This increases security and saves time. A **stop between stations always** calls for protection. A station stop not in the schedule requires protection if longer than one minute. A train running past a siding at a meeting point, to back in, must protect in front.

The time of **greatest danger** is while the flag is going back and while returning to the train when it is called in. The latter risk is partly covered by leaving 2 torpedoes or a fusee where the stop signal was.

For ordinary conditions the **flagman should go back** ¼ of a mile from the end of his train and place one torpedo, then go ¼ of a mile farther and place 2 torpedoes, then return to the first torpedo and stand with flag or lamp in hand. **When called in** he should place a second torpedo two rail lengths from the first and rejoin his train, except that if he hears a **train coming** he must not go in, even if recalled, until he has signaled the approaching train and his signal has been answered.

A break in the track, a **wreck,** or a **work extra** must be similarly protected in *both directions.*

112. **Trains.**—The word train is used in railroad language with two meanings. **One or more engines, coupled, with or without cars and displaying markers** constitute a train, and, as a rule, no rolling stock has any right to be on the main track unless made up into such trains.

Several such trains running close together in the same direction may be **operated as one,** and in such case the **whole** is called the **train** and the parts, each a complete train under the first definition, and all, except the last, also carrying the required engine signals, par. 110, are called **sections.**

113. **Precedence.**—There must be an arrangement in advance as to which of two trains shall give way when their interests clash. The train which is not required to yield is said to have **precedence** over the other, or to be a **superior** train, and the train which is required to yield is called an **inferior** train.

A train may be made superior to other trains by **right; class,** or **direction.**

Right is conferred by **train order.** It is temporary and may give the train precedence over all other trains.

Superiority of class and direction are conferred by the **time-table** and are permanent, except as modified by train order. **Class** is superior to direction, a train of a higher class taking precedence over one of a lower class whatever the direction. Between trains of the same class **direction** gives superiority. Superiority of direction applies to single track only. When an inferior train meets a superior train on single track, the inferior train must take the siding and clear the time of the superior train not less than 5 mins. An inferior train must keep 5 mins. off the time of a superior train following. A train following another must keep not less than 5 mins. from it.

114. On military roads, precedence by direction is more important than on civil roads. The superior direction will be that toward the front of the army. Superiority by class will be much less important, since the fundamental characteristic of military operation is uniformity of speed for all trains, and it is mainly difference in speed which gives rise to superiority of class. Superiority by right or by train order will be minimized on military roads and should, as far as possible, be eliminated. The conditions under which important persons should be passed over the line are privacy and security. Equal privacy and greater security are obtainable by special cars on regular trains, or by special trains running at the regular schedule speed. Specials run at high speed involve danger to the train and its occupants and a general disturbance of the traffic on the line, causing a marked decrease of its capacity, which will rarely be large enough to stand any loss.

115. **A regular train** is one which runs on designated days and is due at any point on its run at the same time each day. Regular trains are designated by numbers, odd numbers running in one direction and even numbers in the other, usually the superior direction. **Sections** are also designated by numbers in connection with the train number, as 2nd section of No. 4, usually abbreviated, 2nd No. 4.

Any other train than a regular one as described is an **extra.** If it is a work train, it must be designated as a **work extra,** to give notice that it may run in either direction. Extras are designated by the word **extra** followed by the engine number and the direction, as, "*extra No. 461 west*" for an extra drawn by engine No. 461 and running west.

116. **Time=tables.**—A statement showing the number, class, and direction of any train, fixing its time of arrival and departure at all stops and otherwise prescribing its movements, is called a **schedule** of that train. **A time=table** is a single exhibit of the schedules of all regular trains.

In the standard time-tables the names of stations, junctions, crossings, and other points at which it is desired to indicate the time of arrival or departure of any train are placed in a column on the left side of the sheet. For large time-tables the column may be repeated on the right edge or in the middle. The second column usually contains the distance of the points from each other, or from the terminus, in miles and tenths. Then follow the train schedules, each in a column, beginning at the left with the first train leaving the terminus after midnight and continuing to the right in the order of their departure.

Each schedule is headed by the number of the train and a description of it sufficient to determine its class. If a stop of fixed duration is to be made at any point, the arriving and leaving time are both given. If one time only is given, it is the leaving time and the train is expected to arrive in time to leave at the hour and minute given. Time may be omitted from all points which are not stops. If times are given at all points, the regular stops are indicated by prefixing **s** to the time. Other customary references on time-tables are: **f**, flag stop; **m**, stop for meals; or, **B**, breakfast; **D**, dinner; **S**, supper; **arr.**, arrive; **lve.**, leave.

Schedule meeting or passing places must be indicated by **full=faced type** or by **underscoring.** If a meeting point has arrival and departure times, both are so distinguished.

Usually a time-table is in two parts, one for each direction. It is better to have numerical references at each meeting point in each schedule referring to footnotes, stating what trains are to be met at that time and place.

It is absolutely essential that all timepieces on which the running of trains depends should be kept together. First-rate clocks should be provided for dispatcher's offices, and the time should be sent along the line by telegraph every day. All operators, conductors, and engineers must be provided with reliable watches, which will not vary more than ½ minute in 24 hours, and all watches must be set every day by the telegraph time, or else be set with another watch which has been set by that time.

On consulting a watch, always look at the second hand first, and long enough to see that it is moving. Otherwise, time may be taken from a watch which has stopped.

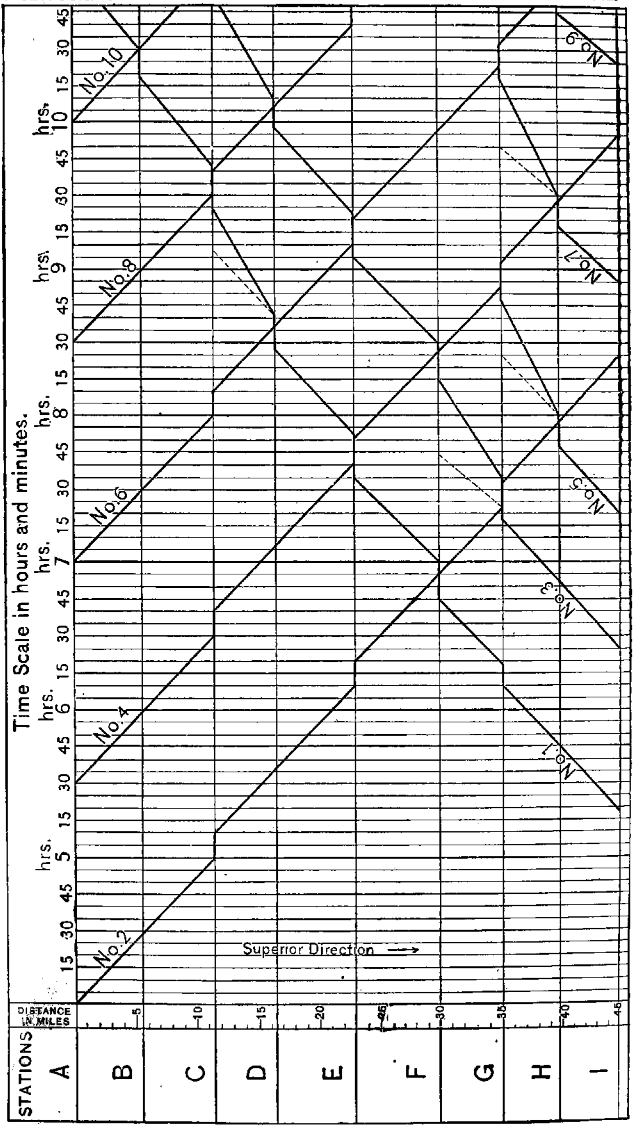
117. **Construction of time-tables.**—On civil roads great knowledge and skill are required to construct a time-table which shall provide for meeting trains in opposite directions and passing those of different speeds in the same direction, bearing in mind that superior trains must not be delayed by inferior ones, and that heavy trains can not make the same speed on all parts of the road and in all conditions of track and weather. On military roads the problem is very much simplified by the practical absence of class precedence, which eliminates the passing of trains in the same direction, and by the use of trains of moderate length running at moderate speed, so that in the absence of a breakdown or some unusual cause of delay, trains should always be able to make the schedule time on any part of the line. With the track well guarded, or the adjacent country thoroughly controlled, military trains should be habitually on time, and if they are not, the operation of the road is not up to the proper standard.

The first thing to be determined in making a time-table for military purposes is the **schedule speed** of trains, which should not be less than 10, but will rarely be more than 20 miles an hour, including stops. **The actual speed** which must be made between stops is somewhat greater than schedule speed and should be determined from the schedule speed when fixed by deducting the time estimated to be consumed in stops, and dividing the remainder or running time into the distance, for the actual or **running speed.**

If sidings are equidistant, all trains may be run at nearly average speed at all times. If the sidings are at unequal distances, the inferior trains may sometimes be given a quicker schedule to make the meeting points, but will usually be held there for the superior train to arrive.

The next question is to determine the number of trains to leave each terminus daily and to assign a leaving time to each.

The rest of the operation is best done graphically. Plot a scale of distances on the vertical edges of a sheet of cross-section paper and a scale of hours across the top


Time Scale in hours and minutes.
STATIONS
A B C D E F G H I
DISTANCE IN MILES
5 10 15 20 25 30 35 40 45
Superior Direction
No. 2
No. 4
No. 6
No. 8
No. 10
No. 1
No. 3
No. 5
No. 7
No. 9

and bottom. Plot the stations and meeting points on the scale of distances and at each draw a horizontal line across the sheet. Lines drawn obliquely across the sheet represent speeds. Determine the slope or angle of the line corresponding to the schedule running speed, including stops. **Beginning with the superior trains,** plot on the line corresponding to the terminus the point on the time scale at which a train is to leave. From this point draw a line at the **running-speed slope** to the next stop, and set off on the corresponding horizontal line a length equal to the time to be allowed the train at that point. The ends of this short horizontal line represent the arriving and departing time at that station or stop. Continue the operation until all the superior trains are plotted.

The inferior trains are next plotted, beginning at the bottom and plotting upward and to the right. All intersections of the two sets of lines are meeting places, and the inferior lines must be so adjusted that these meeting places will fall where there are sidings long enough to take the inferior train. At such points the inferior train must arrive before and leave after the superior train. **It will be found convenient** to take the speed scale so that the length on it of the number of miles to be run in an hour will be the same as the length of an hour on the time scale. The running-speed slope for superior trains will then be 45°.

If the sidings are equidistant, the inferior trains can be kept up to the schedule time adopted for the superior trains by giving them a little higher running speed to make up for more or longer stops. If the sidings are not equidistant, the inferior trains can not be put over the line in the same time as the superior ones, the difference depending on the inequality of distances.

118. The average distance between sidings and the speed determine the interval or headway between trains. Superior trains can not leave the initial point at intervals of less than twice the time required for a train to run the distance between sidings, supposing that distance to be uniform. If the sidings are not equidistant, the headway must be increased for the same running speed. If the running speed is so great that it can not be much exceeded, the headway must be twice the time over the longest distance between sidings.

It is obvious that in building a line sidings should be placed as nearly equidistant as possible, and in taking over an existing road for military purposes, the necessary additional sidings to eliminate long stretches should be put in at the earliest opportunity.

119. **Example.**—Fig. 112 shows the application of the graphical method described to a part of the case of a road 40 miles long with 7 sidings between termini, on which it is proposed to run trains at a schedule speed of 10 miles per hour. Estimating 30 minutes for stops of the superior trains, the 40 miles must be made in $3\frac{1}{2}$ hours running time and the resulting running speed is $11\frac{1}{2}$ miles per hour.

Considering it unsafe to require superior trains to run faster than will be necessary to make a schedule speed of 10 miles per hour and the maximum distance between sidings being $6\frac{1}{2}$ miles, the minimum headway is $\frac{6.5 \times 2}{10} = 1.3$ hours. Assume for safety a headway of $1\frac{1}{2}$ hours, which will delay the inferior trains a little, but will reduce the probability of delays to the superior trains. This headway permits 16 trains to be started each 24 hours. If fewer trains will suffice, they may be run at the same headway and during the most favorable hours only.

Suppose it is decided to start the first train of each day at 4 a. m. Plot this train from the terminus with a speed slope of $11\frac{1}{2}$ miles per hour, giving it such stops as local conditions require. In the fig. each superior train is given a stop of 10 minutes for water at alternate stations. Plot the remaining superior trains parallel to the first and $1\frac{1}{2}$ hours apart.

Inferior trains are next plotted, the requirements being that each shall leave the terminus at a designated time, shall run at not exceeding the running speed, shall reach the first meeting point with a superior train 5 mins. or more before the superior train is due to arrive there, shall leave that point after the superior train has passed, shall make its run to the meeting point with the next superior train under the same conditions, etc. It will be noted from the diagram that the average schedule speed of inferior trains is 8 miles an hour and that at no time is an inferior train required to run faster than $11\frac{1}{2}$ miles an hour.

At several points, indicated by dotted lines, the inferior train may be run on schedule time and wait at the meeting point for the superior train.

This diagram completed and adjusted, the times may be read off from the time schedule and used to fill in the schedule columns of the time-table.

A convenient practical method is to use pins, instead of plotted points, and strings stretched taut instead of lines drawn on the paper.

120. **Train dispatching** is the control of the movements of all traffic on the road, except regular trains on time. This control is exercised from a central point by the **train dispatcher,** who runs all trains, except regular trains on time, by means of **train orders** communicated by telegraph to the train crews.

The working force of the train dispatcher's office usually includes a **chief dispatcher** and **three assistants,** one on each of the three **tricks** into which the day is divided. All dispatchers should be skilled telegraph operators.

The work of the dispatcher is, in reality, the **making of temporary time-tables** by lightning calculation, and the sending of orders to trains which will run them in accordance therewith.

There should be in the dispatcher's office an operator charged specially with looking after all cars on the division. He is usually called a **car distributor.**

From each station there should be sent to the car distributor a daily telegraphic report of the number of cars at the station, showing:

- The number of all empties;
- The number, kind, contents, and destination of all cars loaded and ready to move;
- The number, kind, contents, and consignee of all cars awaiting discharge which have stood unloaded less than 24 hours;
- The same for all cars which have stood unloaded more than 24 and less than 48 hours;
- A special report for each car standing unloaded more than 48 hours, giving, in addition to the foregoing data, all known circumstances connected with the delay.

If a tabular form be constructed to contain the above reports and the lines of this form be lettered in sequence and its columns numbered, a code will result, so that the information can be readily sent by telegraph, a letter and a figure identifying the space in the table in which the data following is to be placed.

If two or more divisions are operated under one management, each car distributor consolidates his daily return and transmits it to the official at general headquarters, usually called a **car-service agent.** He also reports to his own superintendent any case of car detention requiring action.

121. **It is assumed** that the telegraph service will be performed by the Signal Corps. **The interest of the railroad** demands, however, that **one or more wires** and a set of operators be assigned **exclusively to railroad** service and that no non-railroad messages be put on these wires.

122. **Train orders** must be so worded that they can not be misunderstood, and should contain neither information nor instructions not essential to the movements of the trains affected. They are issued under the signature, or initials, of the division superintendent and should be initialed by the dispatcher on duty. They are numbered consecutively in each twenty-four hours, beginning with No. 1, which is the first one put out after midnight. A date and a number completely identify any order.

Train orders must be **addressed** to those who are to execute them, naming the place at which each is to receive his copy. Those for a train are addressed to its conductor and engineer (C. and E.), and also to the **pilot man** by name if there is one on board. The order must be given in identical words to all persons addressed. In practice, a single message is sent and manifolded by the receiving operators. If enough copies can not be made at one writing, a second lot must be made by **tracing from a copy** of the first lot. The order is addressed, first, to the operator at the point where it is to be executed; second, to the C. and E. of the superior train and then to the C. and E. of the inferior train, the last two at the first office at which they can be reached. Thus:

To the operator at C.
To C. and E. No. 2 at B.
To C. and E. No. 1 at D.

Each receiving operator takes his proper address only, followed by the body of the order and the signature. If separate messages are sent they must be in the order of the addresses given.

123. There are **two general classes** of train orders, those to receive which trains must stop, and those which may be delivered to trains while in motion. The **former** are known as **31** and the **latter** as **19** orders. The signal **31** or **19** sent over the wire notifies operators that a train order of the corresponding form is to follow. Some roads do not use the 19 form, in which case this signal need not be sent. The safe use of the 19 order requires a highly trained personnel, in view of which fact it is probable that that form of order will find no considerable use in military railroading.

124. **In sending a 31 order,** the dispatcher first calls the offices concerned in the order in which they will be addressed. After the last has answered, the order is sent and the operators immediately repeat it from the manifold copies, taking the wire for this purpose in the order of the addresses. Each operator must write the time of his own repetition on the order and should also observe whether the others repeat it as he has understood it. If the repetition discloses any error or misunderstanding, it is corrected by the dispatcher.

Those to whom the order is addressed, except engineers, must then sign it, and the operators in the same sequence as before send the following message to the dispatcher:

"Train order No. —, to train No. —, Signed by ———."

On receipt of this message from the last of the offices addressed, the dispatcher signals "**complete.**" Each operator writes "**complete**" and the **time** on the order, signs his last name in full, and delivers the copies to the proper persons. The order is now effective and its execution begins at once. At any **prior stage** it acts as a **hold order** and no train affected by it can move, except to clear the main track.

The conductor must show his copy of the order to the brakeman, and the engineer must show his to the fireman.

A train order remains in force until fulfilled, superseded, or annulled. An order giving space limits, as S. to E., etc., is fulfilled when the train reaches the second-named point, and the train can not pass that point without other orders, unless it is a regular train on time. An order giving time limits is fulfilled when the time limit has expired, and the train to which such an order has been given can not proceed, except as above.

125. **The following** of the **standard forms** prescribed by the **American Railway Association** for the body of an order are applicable to military conditions and should be **followed literally** whenever possible. Some modifications have been made to meet the special conditions of military operation.

Form A.—Meet order:

"No. 1 will meet No. 2 at D."

Several meeting points may be contained in **one order,** as:

"No. 1 will meet No. 2 at D, No. 4 at F, and Extra 28 North at G."

A meet order should not be made for a point where there is **no telegraph operator.** If a siding is so located as to be convenient for a meeting place, a telegraph office should be established there.

Form B.—Passing order:

"No. 1 will pass No. 3 at D," or
"No. 1 will pass No. 3 when overtaken."

Form C.—Giving superior right:

"No. 1 has right over No. 2, A to B," or
"Extra 394 East has right over No. 3, C to E."

If the trains meet *between* the designated points, the second named takes the siding, if the meeting is *at* either of the points, the first-named train takes the siding unless otherwise directed in the order.

If both trains are regular and the second named reaches the first-named point before the other arrives there, it may proceed, keeping clear of the opposing train by five minutes. If one is an extra, the regular must not pass the last-named point until the extra has arrived there. If the meeting is within or beyond the designated limits, the conductor of the second-named train must stop the other train and inform its conductor of his presence.

Form E.—Time orders:

"No. 1 will run twenty minutes late C to D," or
"No. 1 will wait at B until nine a. m. for No. 2."

On a **run-late order**, the time specified is **added** to all **schedule times** for the train, giving it a **new schedule** to which all other trains conform. The interval should be an easy one to add. Care must be taken that all other trains and operators interested in this change of schedule are informed of it.

Form F.—To carry signals:

"No. 1 will display signals D to F for Engine 90," or
"Engine 20 will display signal, and run as 2nd No. 1 A to C," or
"Engines 65, 105, and 138 will run as 1st, 2nd, and 3rd No. 4 A to F."

In this case **engine 138 last named does not** display signals. Each train or section affected must be furnished with a copy of the order.

Form G.—Extras:

"Engine 462 will run extra to D."

A train under this order is not required to protect itself against opposing extras, **unless the order so directs,** but must clear all regular trains or run inferior to them.

Unless otherwise explicitly stated in the order, an extra is supposed to leave the initial point immediately after the time its order is made complete, and to run at schedule speed.

"Engine 462 will run extra, leaving A on Thursday, February 15, as follows, with right over all trains:

Lve.	A	11.30 p. m.
	B	12.25 a. m.
	C	1.47 a. m.
Arr.	D	2.22 a. m."

A train-order schedule may be changed by a **run-late** order, Form E, the same as a time-table schedule. Thus:

"Extra 462 E will run one hour later than schedule in Order No. —, this date."

This order may be varied by describing the extra or specifying certain trains over which it shall have right. All trains over which this order gives right must **clear the time of the extra** by at least **5 minutes.**

Form H.—Work extras:

"Work extra 75 will work 7 a. m. to 6 p. m., between A and A Junction, protecting itself."

Both time and working limits should be made **short** and **changed frequently.** The words **protecting itself** require the work extra to keep stop or cautionary signals ahead and in rear at all times when not in motion. If the limits can be made short enough, it will be best to keep a flagman at each end. A work extra must run away from the siding behind another train and must return to the same siding ahead of the next opposing train. If necessary to run against an opposing train the work extra must flag through, par. 111.

Form J.—Holding order:

"Hold No. 1 at B," or
"Hold all south-bound trains at B."

Trains so held **must not leave** the designated point until the order is received: **"No. 1 may go," or "All trains held by order No. 10, this date, may go."**

Form K.—Annulling trains or sections:

"No. 1 is annulled from D," or
"2nd No. 6 is annulled from B."

If there are **sections behind** the one annulled, **add** the words **"Following sections will change numbers accordingly."**

Form L.—Annulling an order:

"Order No. 9 of ——— is annulled." (Date to be given in blank space.)

An order annulled **must not be reissued** under its **original number.** If it has **not been delivered** the annulling order is addressed to the operator, who destroys all copies of the order annulled, except one, and indorses on that **"Annulled by order No. —."** **In the address** of an annulling order the train to which right was given by the order annulled must be first named and the order must not be made complete for other trains until the first-named train has replied.

Form M.—Annulling an order in part:

"That part of order No. 18 reading: No. 1 will meet No. 2 at D, is annulled."

It will usually be better to annul the order completely and issue a new one in correct form.

Form P.—Superseding an order wholly or in part:

"No. 1 will meet No. 2 at D instead of at C."

The words "**instead of**" must be used and new reading must be capable of literal substitution for the old. An order which has been **superseded must not** be reissued under its original number, nor is it revived by the annulment of the superseding order.

Special Form Q.—While, as a rule, all military trains in the same direction will be of equal importance, emergencies may arise in which the necessity of getting a certain train through is far more urgent than can ever occur on civil roads. In this case a form of order such as the following may be used:

"To all operators: Hold all trains and clear main track for extra No. 219 South, leaving, etc.," as in Form G, second example.

From every point where a train is sidetracked under this form of order, a green flag should be sent out at least a mile in the direction from which the extra will approach, to notify it that the track is clear and prevent the necessity of slackening speed, except as may be necessary for safe running of switches.

126. **A train sheet** is kept in the dispatcher's office showing for each train on the line its number and that of the engine, names of conductor, engineer, and pilot (if there is one), the time of departure from the starting point, and the times of its arrival and departure at all stops. The train sheet should also show by a notation all train orders sent to the train and whether they are in force. A convenient form of train sheet is a time-table with the times omitted, and with additional columns for extra trains. A train order may be noted by writing its number in red opposite the station to which it was sent and the fulfillment, supersedence, or annulment of the order may be indicated by a blue check mark opposite the red number.

A glance at the train sheet should show the location of all trains on the line and whether they are under orders or not. Each trick dispatcher and operator going off duty should transfer to his successor a list of all train orders not completely executed.

127. **Blocking.—Dispatching** and **protection** of trains, as already described, should, if perfectly done, give complete immunity from collisions. Experience shows that neither is, nor can be, perfectly done and further safeguards are desirable.

The blocking system is essentially the maintaining of a **space between trains.** The line is divided into sections called **blocks,** of convenient length, and arrangements are made by signal, or otherwise, which prevent any train from entering the block at either end until the last train which entered has left it.

The operation of a standard block system depends on the transmission of signals given by a signalman, or automatically by the train itself, over considerable distance, by electrical or mechanical means. The equipment is complex and could not be kept in working order with reasonable certainty under military conditions. In bad order and with nonexpert service, it would do more harm than good.

The only safeguard of this class which is practicable for military railroads is the **pilot-man system.** The line is divided into **blocks,** which for single track extend from siding to siding. For each block there are two **pilot men** who divide the day between them. There is also, for each block, a properly marked **set of checks** or **tags,** and a **separate tag** which is a receipt for the set. No engine can enter the block at either end unless the pilot man on duty is in the cab, or the engineer has in his possession one of the set of checks for the block **handed him personally** by the **pilot man** in the **presence of the conductor.**

If a group of trains is to pass through the block in the same direction, the pilot man gives a check to each engineer except the last, bearing numbers in the order of their departure, and goes himself in the cab of the last engine. Arrived at the other end of the block the pilot man collects his checks and returns to the point from which he started, with a train or group of trains in the opposite direction. When a pilot man goes off duty he transfers the set of checks to his relief and takes the receipt tag in exchange.

128. **Technical organization.**—The units of organization are territorial and differ for the different departments of the road. For track maintenance the unit is the

section, a stretch of track 5 or 6 miles long, in charge of a section gang, consisting of a foreman and, roughly, one man for each mile of track, including sidings.

For the **motive-power department** the unit is the **engine district,** which, in military roads, will probably not exceed 75 miles. An engine is expected to haul a train from one end of a district to the other, and arrangements must be made at all engine-district terminals for quick repairs, turning, fueling, watering, and, if practicable, housing, as well as for the comfort and control of the engine crews.

For train movements the unit is the **division,** consisting usually of two engine districts. The division is the real administrative unit, as it is here that the threads of control are first collected into one pair of hands. **The division superintendent** is the ruling spirit. If the line is long enough to make two or more divisions a general control is exercised by a **general manager,** but this official is not in close touch with the details of daily work. He devotes his attention to harmonizing and unifying the work of the several divisions, to matters which affect all divisions alike, and to extensions of the line into new territory.

The concentration of authority in the division superintendent is the practice of some civil roads and is the method best suited to military conditions. Some civil roads adopt a system which may be called the department system, in which all lines of control do not converge until they reach a very high official, often a vice-president. A majority of civil roads are organized on a combination of the two systems, in which some lines of control converge at the division superintendent and others pass by him to higher authority.

129. **Under the division superintendent** several separate chiefs or heads are in charge of separate branches of work. A **division engineer** has charge of the construction and maintenance of track, bridges, and buildings, and any other work which may be assigned to the engineer department. He is assisted as to track work by **roadmasters,** one for each 30 or 40 miles of the division, who in turn supervise and control the section gangs and work trains. The division engineer attends to bridges, trestles, culverts, buildings, etc., through a **superintendent of bridges,** who controls and supervises the work of the various gangs of mechanics and laborers, each under its own foreman.

130. **A master mechanic** has charge of all motive power of a division and of all repairs to cars which become necessary while the car is on his division. He may be assisted by an **assistant master mechanic** for each engine district, who in turn directs the work of the repair shops, and **roundhouse foreman,** who regulates the assignment of engines and crews to duty and attends to the care of engines and some minor repairs.

Under the assistant master mechanic a **chief car repairer** supervises the work of car repairs.

The chief train dispatcher has charge of the making up of trains, as to tonnage, composition, and arrangement of cars, and of the assignment to duty, instruction, and regulation of all train crews. In this work he may be assisted by a **train master.** The chief dispatcher also assists the division superintendent in the arrangement of time-tables and supervises the work of the trick dispatchers and operators.

If no nonmilitary traffic is handled, the operators will also act as **station agents** at minor points, and their work in this capacity may be regulated by the chief dispatcher. If nonmilitary traffic is carried, which will almost always be the case to a greater or less extent, a division official will be required as **passenger and freight agent,** who will control the station agents and arrangements for the necessary accounting.

At each considerable terminal a **yard master** is required to direct the movement of cars while not made up in *trains*, par. 112.

The yard master is under the direction of the **train master,** but his work is so systematized that but little personal supervision is necessary. If the yard master is not all right that fact will soon be indicated by congestion in the yard and delay in forwarding trains.

131. **Assignment of troops.**—In a regiment of troops organized for railroad duty, the officers and noncommissioned officers would be selected with reference to their ability as railroad men, and the military and railroad precedence would be the same.

When officers and men are detailed from line troops, every possible effort must be made to make such selections as will permit each to be placed in the most responsible position for which his railroad experience qualifies him, without becoming subordinate to a junior or in authority over a senior in the military service.

132. **Traffic organization.**—A military railroad, like a civil road, receives traffic from shippers, forwards it with greatest possible dispatch, and delivers it at specific points to designated consignees.

In doing this the relations between the technical staff, representing the transportation, and the rest of the army, representing shippers and consignees, are the same as on civil roads and are covered in the Field Service Regulations, as are also matters relating to the make-up of trains, etc.

There are a multitude of shippers over civil roads, with diverse interests, the adjustment of which must be made by the technical staff of the road. For military traffic all shipping interests merge into one, and that single interest should be ascertained by a definite and plenary authority and communicated through authorized channels to the railroad staff.

The only safe guiding rule for the technical staff is that all traffic shall be forwarded in the order that it is presented for shipment. Any priority to be given one thing over another must be determined by an officer having such authority expressly delegated to him, and must be communicated explicitly to the railroad staff.

The receipt and delivery of traffic are on the carload basis; that is, the shipper loads and is responsible for proper loading, and the consignee unloads. The railroad furnishes, so far as possible, the necessary facilities for loading and unloading.

A military operated road should not be made responsible for goods in transit. When organizations are moved the officer responsible for property goes with them. When freight is shipped without troops the accountable officer should be represented on the train by a responsible agent, who will obtain the necessary receipts from the consignee and return them. Other conditions not preventing, shipments should be presented in such order as to facilitate this arrangement. One agent or supercargo may represent all the shippers by one train or by a group of trains. He is a trusted messenger only and should not be treated as having any connection with the railroad.

It is of the utmost importance to have the **contents** and **destination of every car** plainly indicated on the **outside of the car.**

It is the business of the railroad to move traffic; but perfection of track, completeness of equipment, and skill of operation will not make a road effective if the shippers and consignees do not do their share by loading promptly at the appointed times and places, and by unloading promptly on the arrival of trains. A complete and efficient organization for these purposes is as important as an organization for operating the road.

These two sets of officials, the one representing the necessity for transportation and the other its possibilities, should be in close touch through designated channels at all important points of the line, so that the former may be constantly advised what transportation can be furnished, and the latter may be advised as to what purposes it shall be applied.

This relation in nowise impairs the obligation of the technical railroad staff to provide all the transportation possible and increase its amount by every available means until all demands are met.

133. **Guarding.**—**Protection from the enemy** is work which, like the shipment and receipt of traffic, must be **done by the army** for the railroad staff and **not by the staff** itself. Tactical requirements insure the exclusion of the enemy from approach to the line, except as individuals, or small infrequent raiding parties may evade the vigilance of the protecting screen. Against them protection is had by stationing along the line or carrying on trains such troops as may permit the concentration of a superior force at any threatened point before extensive damage can be done there.

134. **Important points** must be occupied by garrisons proportioned in strength to their vulnerability. There should be an adequate force at each **bridge,** large **culvert, tunnel, water station,** or any other point where a hasty demolition would involve a large amount of reconstruction or a wreck would cause unusual delay and inconvenience to traffic. The technical staff will, when desired, indicate what points are determined by these conditions. **For bridges** the guard should be stationed at the end which presents the best defensive conditions. Unless very short, a small outpost should be stationed at the other end and a sentry should patrol the bridge.

The vulnerable points selected, **additional ones** should be chosen, if necessary, so that the adjacent stations of the cordon will be everywhere **within patrolling and supporting distance.** All these parties must be protected by **blockhouses** or other artificial defenses.

Important terminals should be converted into intrenched camps with ample garrisons.

Suitable regulations should be made for **train guards** when necessary and also for the conduct of all armed troops in transit over the line, with a view to utilizing their services in this capacity.

135. **Armored trains** form a part of the guarding force, and, in that sense, are out of the control of the technical staff; however, as the trains themselves form a part of the equipment of the road and when in motion form a part of its traffic, there is much concerning them which it is important for the technical staff to know.

There is but little American experience on the subject. The fullest development of construction, organization, and use of armored trains occurred in the South African war, and the following statements are condensed from the official reports of the railroad operations in that war, with some obvious modifications to suit American conditions and practice.

136. An armored train consists of a locomotive and sufficient cars to carry a 12-pounder quick-firing gun, or a similar piece, 2 machine guns, and 2 searchlights.

The cab, tender, and injector pipes of the locomotive are sheathed with ½-in. steel. There is also a curved hood over the roof of the cab hanging over the front end of the tender, to protect the engineer and fireman from reverse fire. The doors of the cab slide and there are sliding covers over the windows. If necessary, an armored tank car is placed next to the tender and connected by pipes with the tender tank.

A machine gun and a searchlight are on the same car, one of which is placed at each end of the train. The searchlights should have independent power on the cars with them. A 12-in. projector, hand-controlled, was found satisfactory.

For flat country a box car is sheathed on sides and ends from floor to roof only. At one end a slit is left across the end, and 5 ft. back on each side, through which the machine guns may fire. Above the machine gun the plating forms a protection to the searehlight operator, whose head projects through a hole in the roof, protected by a bonnet or by movable shields. The rest of the car is for infantry and is separated from the machine-gun space by two metal screens projecting from the sides of the car and overlapping each other with space between to allow men to pass. The infantry portion is loopholed for kneeling fire, the loopholes being provided with sliding covers and staggered on the two sides so there is not a clear view through.

For hilly country a ⅜-in. steel sloping roof is added and the plate of armor containing the loopholes is hinged at the bottom and can be hauled in to an angle of 45°, permitting guns to be fired through the slits at a higher angle.

The quick-firing gun is on a car with its ammunition, which is placed next to the machine gun and in the rear half of the train, if it is known which will be the rear. The gun is mounted on its pedestal in the middle of a flat car. The side plates, of ½-in. steel, are 2 ft. high at the ends, rising to 3 ft. at the points where they intersect a circle of 5 ft. radius from the gun center, and carried at that height around the arc of the circle, forming sponsons, projecting as much as may be necessary beyond the sides of the car. The projection must not be greater than the line clearance. From the ends of the car to the circle the sides are joined by a roof of ⅜-in. steel plates, lapped and riveted; beneath this is the ammunition space. A shield of usual form rotating with the gun protects the gun crew.

The necessary cars for quarters, subsistence, etc., are placed in front of the engine, and, with the machine-gun car, form the front half of the train. Cars for this purpose may be armored with steel plates as described, or improvised forms may be employed.

Two such forms were developed in South Africa—one by the use of **T** rails which are placed along the sides, supported between uprights. One rail is omitted at the proper height to provide a firing slit. The ends are closed by a bulkhead of ties with the rails butted against them.

The other form consisted of a double wall of corrugated iron with a 9-in. space between filled with 1-in. broken stone. The necessary openings for doors and loopholes were formed by metal frames extending from wall to wall. Cars so protected are suitable for use with infantry guards accompanying ordinary trains when such protection is necessary.

137. The engineer, boxed up in the middle of the train, can do nothing but handle the engine on signals made to him from the front car. As the train may run in either direction, the proper arrangements and connections should be made to enable the lookout at either end to communicate with the engineer, to apply the air brake, or signal for hand brakes. If the train pipe is not armored, arrangements must be made for cutting out the air brake on each car from within its armor, and the hand brake must also be arranged to be worked inside the car.

138. The personnel of an armored train includes the commanding officer and a second in command. The former, when in action, is in the front, and the latter in the rear car; they should never be together when the train is moving or engaged.

There is an artillery detachment to work the quick-firing gun, an engineer detachment to attend to small repairs of line and equipment, and a Signal Corps detachment for telegraphing. The infantry garrison should be as large as the accommodations permit.

The train crew should consist of the engineer and fireman and two or three intelligent brakemen familiar with the movements of trains and signals. The officer in command takes the position of conductor and must have a sufficient knowledge of railroading to do this, in addition to the sound judgment, quick perception, and fighting spirit which the position demands on its military side.

139. The administration of armored trains may be under an officer on the staff of the general in command, who, having access to all headquarters information, may best know where the trains are likely to be needed. Acting within the scope of his instructions from the general, this officer will control the selection, assignment, inspection, and training of the garrisons of all armored trains, and will determine their status and movements.

140. When an armored train is to be moved, orders will be transmitted to its commander informing him where he is to go, what he is to do, and what resistance he may expect. It will be much better if these orders are sent through the division superintendent, or duplicated to him at the time.

In passing over parts of the line where traffic is not disturbed, the armored train should run as any other extra. When ready to leave the terminus, the commander of the train should call up the dispatcher and ask for orders, and on receipt of them, move his train in accordance therewith. It is to be assumed that the dispatcher will understand the importance of getting this extra through and will act accordingly.

On arrival at or near his destination, the commander of the armored train is likely to find the track clear for his work so far as ordinary traffic is concerned. Here he will necessarily assume local control of the road. He would best exercise this control by asking for such orders as will enable him to do his work, leaving the dispatcher free to act in getting any traffic through which can be done without interfering with the armored train.

141. From a tactical standpoint, the work of armored trains may be grouped into:

Escort of work trains,
Escort of traffic trains,
Independent operations.

In escorting a work train, an armored train goes on alone to the break to reconnoiter and drive off the enemy. This done, it returns to the nearest siding, brings out the work train ahead of it, and remains on guard while the break is closed. A single one of the several armored trains employed in South Africa was present with construction trains on 61 different occasions.

In escorting single trains, the place for the armored train is behind. If the train is in sections, the armored train should be between the first and second sections. If the stretch of line threatened by the enemy is long, it will be best to run the trains in groups, convoyed by an armored train. If the dangerous stretch is short, it will be better to have the trains run on schedule and let the armored train escort them in each direction through the danger space, which will be treated as a block, the armored train corresponding to the pilot man, so far as operation is concerned.

Independent operations of armored trains divide themselves into:

Patrolling, day or night,
Reenforcing local guards,
Reconnoitering,
Supporting the advance,
Cutting the enemy's line of retreat.

Patrolling by day will usually be unnecessary on roads properly protected by blockhouses, but some movement of the trains will have the effect of confusing the enemy as to their whereabouts. Night patrolling is very important. If the enemy desires to cross the line, especially with artillery or trains, the attempt is certain to be made at night. When night patrolling is necessary, it will not be practicable to move traffic at night. The track should be cleared and divided into sections, so that each train can patrol its section without using lights or making signals. A train need not be constantly on the move. It is better to stop for an hour or so in a position favoring concealment and then run slowly to another such position. With proper precautions and slow running armored trains have been moved so quietly as to effect a complete surprise.

If mines are suspected, a flat car, heavily loaded with track material, should be pushed ahead of the train. The first train each morning on any section, whether armored or not, should push such a car ahead of it to explode any mines which may have been placed during the night. The train can usually be stopped in time to escape injury. The loss of the pilot car is relatively unimportant and its load of track material is available for repairs.

In reenforcing local guards it may be best to cut off the artillery car and the rear infantry and machine-gun car and leave them in a good working position for the gun and push the leading car up close to where the guard is engaged, to add its infantry and machine-gun fire to the defense; or, if the gun car is in the front half of the train, run up and drop the leading car and then run back to a suitable position from which to work the gun.

In reconnoitering toward a force supposed to be strong, care must be taken not to let the enemy get on the line behind the train. A cavalry force may be combined with the train to advantage, its duty being to see to it that the track is not broken behind the train. Parts of the line where the train can not use its armament to advantage, such as gorges, should be explored by scouts before the train advances.

An advance, when parallel to the line, may be supported by an armored train. It is better to have all the column on the same side of the line, so that the train may form a flank and be well advanced to prevent a turning movement on that side.

In general, when an armored train can be put within shooting distance of the enemy, with its retreat protected, it may be done with advantage, as the train is a moving fort and its small garrison a match for a much larger force fighting without protection.

142. **Field railways.**—Extensive use will be made of portable railways in rear of the line of encampment or bivouac, and in the zone of investment and in parallels in siege operations.

Portable track consists of tangent and curve sections riveted or bolted to metal ties, and of switches, crossings, turntables, etc., made up in single pieces.

In Manchuria, both Japanese and Russians used equipment of French manufacture. In the Japanese equipment the tangent sections are 6 ft. 6 ins. long, the rails bolted to 3 ties. Two splice bars are bolted to one end of each rail and the projecting ends are joined by a pin which engages in an oblique slot in the end of the adjoining rail. Each section must be ended up to engage it, and when lowered to a horizontal position the two are fairly locked. The gage is 23.6 ins.

The curve sections are similarly put together and are of different curvatures.

The Russian material differed somewhat from the above in form. The ordinary sections were 5 ft. long, the two rails joined by a $\frac{3}{4}$-in. iron tie-rod at one end and a stamped iron tie concave downward at the other. The rails weighed 25 lbs. and were $2\frac{1}{2}$ ins. high and $2\frac{1}{2}$ ins. base. The connecting device consisted of a hook riveted to the outside of the web of each rail at the rod end, engaging a pin in the tie end of the adjacent rail. The tie projected beyond the ends of the rails of its own section and supported the rod end of the adjacent section. The gage was 30 ins. In addition to the standard straight sections were other solid units for switches, curves, and crossings of different lengths, mostly longer than 5 ft. The ordinary freight cars consisted of bogie trucks with double-flanged wheels and platforms that were easily and quickly removable, upon which were built wooden structures and seats for passengers, kitchens and bunks for hospital use, bake ovens, etc. The flat car weighed 1,920 lbs., and its capacity was 4,400 lbs. These cars were all drawn by two ponies or mules, one on each side of the car, their paths being clear of the track and ties. Cars were run in trains on regular schedules, with points for passing and changing horses approximately 7 miles apart. With this arrangement the maximum capacity of these roads was about 600 tons of freight both ways per day. This could, of course, be largely increased by more sidings and by double tracking.

The track is laid on the ground, a suitable route being sought out. An old roadbed is admirably adapted, if it can be spared. All principles of grades, curvatures, etc., for standard track apply to this portable equipment, but the application is mainly in the design and manufacture, and in use is carried only so far as the special circumstances require.

The Russians used animal traction, mainly: two mules pulling the car or train, one on each side of the track. The Japanese used man traction, mainly. The speeds were low, according to railroad standards, though considerable compared with wagon traction, and the consequences of derailment not serious.

If mechanical traction were used, higher speed would be possible, but derailments would cause more delay, and hence the track would have to be better laid.

Double track should be laid, if possible, with frequent sidings and cross overs. If a single track is used, sidings should be put in every mile or so.

Beyond these general outlines the use of such equipment will depend on its design, and will be obvious to those who are supplied with it.

TABLE I.—**Elements of a circular curve** of 1° curvature, 5,730 ft. radius.

∆	Tang., T.	Ext. dist., E.	Long chord, L. C.	∆	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
1 00	50.00	0.218	100.00	9 00	450.93	17.717	899.09
10	58.34	0.297	116.67	10	459.32	18.381	915.70
20	66.67	0.388	133.33	20	467.71	19.058	932.31
30	75.01	0.491	150.00	30	476.10	19.746	948.92
40	83.34	0.606	166.66	40	484.49	20.447	965.53
50	91.68	0.733	183.33	50	492.88	21.161	982.14
2 00	100.01	0.873	199.99	10 00	501.28	21.886	998.74
10	108.35	1.024	216.66	10	509.68	22.624	1015.35
20	116.68	1.188	233.32	20	518.08	23.375	1031.95
30	125.02	1.364	249.98	30	526.48	24.138	1048.54
40	133.36	1.552	266.65	40	534.89	24.913	1065.14
50	141.70	1.752	283.31	50	543.29	25.700	1081.73
3 00	150.04	1.964	299.97	11 00	551.70	26.500	1098.3
10	158.38	2.188	316.63	10	560.11	27.313	1114.9
20	166.72	2.425	333.29	20	568.53	28.137	1131.5
30	175.06	2.674	349.95	30	576.95	28.974	1148.1
40	183.40	2.934	366.61	40	585.36	29.824	1164.7
50	191.74	3.207	383.27	50	593.79	30.686	1181.2
4 00	200.08	3.492	399.92	12 00	602.21	31.561	1197.8
10	208.43	3.790	416.58	10	610.64	32.447	1214.4
20	216.77	4.099	433.24	20	619.07	33.347	1231.0
30	225.12	4.421	449.89	30	627.50	34.259	1247.5
40	233.47	4.755	466.54	40	635.93	35.183	1264.1
50	241.81	5.100	483.20	50	644.37	36.120	1280.7
5 00	250.16	5.459	499.85	13 00	652.81	37.069	1297.2
10	258.51	5.829	516.50	10	661.25	38.031	1313.8
20	266.86	6.211	533.15	20	669.70	39.006	1330.3
30	275.21	6.606	549.80	30	678.15	39.993	1346.9
40	283.57	7.013	566.44	40	686.60	40.992	1363.4
50	291.92	7.432	583.09	50	695.06	42.004	1380.0
6 00	300.28	7.863	599.73	14 00	703.51	43.029	1396.5
10	308.64	8.307	616.38	10	711.97	44.066	1413.1
20	316.99	8.762	633.02	20	720.44	45.116	1429.6
30	325.35	9.230	649.66	30	728.90	46.178	1446.2
40	333.71	9.710	666.30	40	737.37	47.253	1462.7
50	342.08	10.202	682.94	50	745.85	48.341	1479.2
7 00	350.44	10.707	699.57	15 00	754.32	49.441	1495.7
10	358.81	11.224	716.21	10	762.80	50.554	1512.3
20	367.17	11.753	732.84	20	771.29	51.679	1528.8
30	375.54	12.294	749.47	30	779.77	52.818	1545.3
40	383.91	12.847	766.10	40	788.26	53.969	1561.8
50	392.28	13.413	782.73	50	796.75	55.132	1578.3
8 00	400.66	13.991	799.36	16 00	805.25	56.309	1594.8
10	409.03	14.582	815.99	10	813.75	57.498	1611.3
20	417.41	15.184	832.61	20	822.25	58.699	1627.8
30	425.79	15.799	849.23	30	830.76	59.914	1644.3
40	434.17	16.426	865.85	40	839.27	61.141	1660.8
50	442.55	17.066	882.47	50	847.78	62.381	1677.3

Table I—*Continued.*

Δ		Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ		Tang., T.	Ext. dist., E.	Long chord, L. C.
°	′				°	′			
17	00	856.30	63.634	1693.8	25	00	1270.2	139.11	2480.2
	10	864.82	64.900	1710.3		10	1279.0	141.01	2496.5
	20	873.35	66.178	1726.8		20	1287.7	142.93	2512.8
	30	881.88	67.470	1743.2		30	1296.5	144.85	2529.0
	40	890.41	68.774	1759.7		40	1305.3	146.79	2545.3
	50	898.95	70.091	1776.2		50	1314.0	148.75	2561.5
18	00	907.49	71.421	1792.6	26	00	1322.8	150.71	2577.8
	10	916.03	72.764	1809.1		10	1331.6	152.69	2594.0
	20	924.58	74.119	1825.5		20	1340.4	154.69	2610.3
	30	933.13	75.488	1842.0		30	1349.2	156.70	2626.5
	40	941.69	76.869	1858.4		40	1358.0	158.72	2642.7
	50	950.25	78.261	1874.9		50	1366.8	160.76	2658.9
19	00	958.81	79.671	1891.3	27	00	1375.6	162.81	2675.1
	10	967.38	81.092	1907.8		10	1384.4	164.87	2691.3
	20	975.96	82.525	1924.2		20	1393.2	166.95	2707.5
	30	984.53	83.972	1940.6		30	1402.0	169.04	2723.7
	40	993.12	85.431	1957.1		40	1410.9	171.15	2739.9
	50	1001.70	86.904	1973.5		50	1419.7	173.27	2756.1
20	00	1010.29	88.389	1989.9	28	00	1428.6	175.41	2772.3
	10	1018.89	89.888	2006.3		10	1437.4	177.55	2788.4
	20	1027.49	91.399	2022.7		20	1446.3	179.72	2804.6
	30	1036.09	92.924	2039.1		30	1455.1	181.89	2820.7
	40	1044.70	94.462	2055.5		40	1464.0	184.08	2836.9
	50	1053.31	96.013	2071.9		50	1472.9	186.29	2853.0
21	00	1061.9	97.58	2088.3	29	00	1481.8	188.51	2869.2
	10	1070.6	99.15	2104.7		10	1490.7	190.74	2885.3
	20	1079.2	100.75	2121.1		20	1499.6	192.99	2901.4
	30	1087.8	102.35	2137.4		30	1508.5	195.25	2917.6
	40	1096.4	103.97	2153.8		40	1517.4	197.53	2933.7
	50	1105.1	105.60	2170.2		50	1526.3	199.82	2949.8
22	00	1113.7	107.24	2186.5	30	00	1535.3	202.12	2965.9
	10	1122.4	108.90	2202.9		10	1544.2	204.44	2982.0
	20	1131.0	110.57	2219.2		20	1553.1	206.77	2998.1
	30	1139.7	112.25	2235.6		30	1562.1	209.12	3014.2
	40	1148.4	113.95	2251.9		40	1571.0	211.48	3030.2
	50	1157.0	115.66	2268.3		50	1580.0	213.86	3046.3
23	00	1165.7	117.38	2284.6	31	00	1589.0	216.25	3062.4
	10	1174.4	119.12	2301.0		10	1598.0	218.66	3078.4
	20	1183.1	120.87	2317.3		20	1606.9	221.08	3094.5
	30	1191.8	122.63	2333.6		30	1615.9	223.51	3110.5
	40	1200.5	124.41	2349.9		40	1624.9	225.96	3126.6
	50	1209.2	126.20	2366.2		50	1633.9	228.42	3142.6
24	00	1217.9	128.00	2382.5	32	00	1643.0	230.90	3158.6
	10	1226.6	129.82	2398.8		10	1652.0	233.39	3174.6
	20	1235.3	131.65	2415.1		20	1661.0	235.90	3190.6
	30	1244.0	133.50	2431.4		30	1670.0	238.43	3206.6
	40	1252.8	135.36	2447.7		40	1679.1	240.96	3222.6
	50	1261.5	137.23	2464.0		50	1688.1	243.52	3238.6

TABLE I—*Continued.*

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
33 00	1697.2	246.08	3254.6	41 00	2142.2	387.38	4013.1
10	1706.3	248.66	3270.6	10	2151.7	390.71	4028.7
20	1715.3	251.26	3286.6	20	2161.2	394.06	4044.3
30	1724.4	253.87	3302.5	30	2170.8	397.43	4059.9
40	1733.5	256.50	3318.5	40	2180.3	400.82	4075.5
50	1742.6	259.14	3334.4	50	2189.9	404.22	4091.1
34 00	1751.7	261.80	3350.4	42 00	2199.4	407.64	4106.6
10	1760.8	264.47	3366.3	10	2209.0	411.07	4122.2
20	1770.0	267.16	3382.2	20	2218.6	414.52	4137.7
30	1779.1	269.86	3398.2	30	2228.1	417.99	4153.3
40	1788.2	272.58	3414.1	40	2237.7	421.48	4168.8
50	1797.4	275.31	3430.0	50	2247.3	424.98	4184.3
35 00	1806.6	278.05	3445.9	43 00	2257.0	428.50	4199.8
10	1815.7	280.82	3461.8	10	2266.6	432.04	4215.3
20	1824.9	283.60	3477.7	20	2276.2	435.59	4230.8
30	1834.1	286.39	3493.5	30	2285.9	439.16	4246.3
40	1843.3	289.20	3509.4	40	2295.6	442.75	4261.8
50	1852.5	292.02	3525.3	50	2305.2	446.35	4277.3
36 00	1861.7	294.86	3541.1	44 00	2314.9	449.98	4292.7
10	1870.9	297.72	3557.0	10	2324.6	453.62	4308.2
20	1880.1	300.59	3572.8	20	2334.3	457.27	4323.6
30	1889.4	303.47	3588.6	30	2344.1	460.95	4339.0
40	1898.6	306.37	3604.5	40	2353.8	464.64	4354.5
50	1907.9	309.29	3620.3	50	2363.5	468.35	4369.9
37 00	1917.1	312.22	3636.1	45 00	2373.3	472.08	4385.3
10	1926.4	315.17	3651.9	10	2383.1	475.82	4400.7
20	1935.7	318.13	3667.7	20	2392.8	479.59	4416.1
30	1945.0	321.11	3683.5	30	2402.6	483.37	4431.4
40	1954.3	324.11	3699.3	40	2412.4	487.16	4446.8
50	1963.6	327.12	3715.0	50	2422.3	490.98	4462.2
38 00	1972.9	330.15	3730.8	46 00	2432.1	494.82	4477.5
10	1982.2	333.19	3746.6	10	2441.9	498.67	4492.8
20	1991.5	336.25	3762.3	20	2451.8	502.54	4508.2
30	2000.9	339.32	3778.0	30	2461.7	506.42	4523.5
40	2010.2	342.41	3793.8	40	2471.5	510.33	4538.8
50	2019.6	345.52	3809.5	50	2481.4	514.25	4554.1
39 00	2029.0	348.64	3825.2	47 00	2491.3	518.20	4569.4
10	2038.4	351.78	3840.9	10	2501.2	522.16	4584.7
20	2047.8	354.94	3856.6	20	2511.2	526.13	4599.9
30	2057.2	358.11	3872.3	30	2521.1	530.13	4615.2
40	2066.6	361.29	3888.0	40	2531.1	534.15	4630.4
50	2076.0	364.50	3903.6	50	2541.0	538.18	4645.7
40 00	2085.4	367.72	3919.3	48 00	2551.0	542.23	4660.9
10	2094.9	370.95	3935.0	10	2561.0	546.30	4676.1
20	2104.3	374.20	3950.6	20	2571.0	550.39	4691.3
30	2113.8	377.47	3966.3	30	2581.0	554.50	4706.5
40	2123.3	380.76	3981.9	40	2591.1	558.63	4721.7
50	2132.7	384.06	3997.5	50	2601.1	562.77	4736.9

TABLE I—*Continued.*

Δ °	′	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ °	′	Tang., T.	Ext. dist., E.	Long chord, L. C.
49	00	2611.2	566.94	4752.1	57	00	3110.9	790.08	5467.9
	10	2621.2	571.12	4767.3		10	3121.7	795.24	5482.5
	20	2631.3	575.32	4782.4		20	3132.6	800.42	5497.2
	30	2641.4	579.54	4797.5		30	3143.4	805.62	5511.8
	40	2651.5	583.78	4812.7		40	3154.2	810.85	5526.4
	50	2661.6	588.04	4827.8		50	3165.1	816.10	5541.0
50	00	2671.8	592.32	4842.9	58	00	3176.0	821.37	5555.6
	10	2681.9	596.62	4858.0		10	3186.9	826.66	5570.2
	20	2692.1	600.93	4873.1		20	3197.8	831.98	5584.7
	30	2702.3	605.27	4888.2		30	3208.8	837.31	5599.3
	40	2712.5	609.62	4903.2		40	3219.7	842.67	5613.8
	50	2722.7	614.00	4918.3		50	3230.7	848.06	5628.3
51	00	2732.9	618.39	4933.4	59	00	3241.7	853.46	5642.8
	10	2743.1	622.81	4948.4		10	3252.7	858.89	5657.3
	20	2753.4	627.24	4963.4		20	3263.7	864.34	5671.8
	30	2763.7	631.69	4978.4		30	3274.8	869.82	5686.3
	40	2773.9	636.16	4993.4		40	3285.8	875.32	5700.8
	50	2784.2	640.66	5008.4		50	3296.9	880.84	5715 2
52	00	2794.5	645.17	5023.4	60	00	3308.0	886.38	5729.7
	10	2804.9	649.70	5038.4		10	3319.1	891.95	5744.1
	20	2815.2	654.25	5053.4		20	3330.3	897.54	5758.5
	30	2825.6	658.83	5068.3		30	3341.4	903.15	5772.9
	40	2835.[illegible]	663.42	5083.3		40	3352.6	908.79	5787.3
	50	2846.3	668.03	5098.2		50	3363.8	914.45	5801.7
53	00	2856.7	672.66	5113.1	61	00	3375.0	920.14	5816.0
	10	2867.1	677.32	5128.0		10	3386.3	925.85	5830.4
	20	2877.5	681.99	5142.9		20	3397.5	931.58	5844.7
	30	2888.0	686.68	5157.8		30	3408.8	937.34	5859.1
	40	2898.4	691.40	5172.7		40	3420.1	943.12	5873.4
	50	2908.9	696.13	5187.6		50	3431.4	948.92	5887.7
54	00	2919.4	700.89	5202.4	62	00	3442.7	954.75	5902.0
	10	2929.9	705.66	5217.3		10	3454.1	960.60	5916.3
	20	2940.4	710.46	5232.1		20	3465.4	966.48	5930.5
	30	2951.0	715.28	5246.9		30	3476.8	972.39	5944.8
	40	2961.5	720.11	5261.7		40	3488.2	978.31	5959.0
	50	2972.1	724.97	5276.5		50	3499.7	984.27	5973.3
55	00	2982.7	729.85	5291.8	63	00	3511.1	990.24	5987.5
	10	2993.3	734 76	5306.1		10	3522.6	996.24	6001.7
	20	3003.9	739.68	5320.9		20	3534.1	1002.3	6015.9
	30	3014.5	744.62	5335.6		30	3545.6	1008.3	6030.0
	40	3025.2	749.59	5350.4		40	3557.2	1014.4	6044.2
	50	3035.8	754.57	5365.1		50	3568.7	1020.5	6058.4
56	00	3046.5	759.58	5379.8	64	00	3580.3	1026.6	6072.5
	10	3057.2	764.61	5394.5		10	3591.9	1032.8	6086.6
	20	3067.9	769.66	5409.2		20	3603.5	1039.0	6100.7
	30	3078.7	774.73	5423.9		30	3615.1	1045.2	6114.8
	40	3089.4	779.83	5438.6		40	3626.8	1051.4	6128.9
	50	3100.2	784.94	5453.3		50	3638.5	1057.7	6143.0

TABLE I—*Continued.*

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
65 00	3650.2	1063.9	6157.1	73 00	4239.7	1398.0	6816.3
10	3661.9	1070.2	6171.1	10	4252.6	1405.7	6829.6
20	3673.7	1076.6	6185.2	20	4265.6	1413.5	6843.0
30	3685.4	1082.9	6199.2	30	4278.5	1421.2	6856.4
40	3697.2	1089.3	6213.2	40	4291.5	1429.0	6869.7
50	3709.0	1095.7	6227.2	50	4304.6	1436.8	6883.1
66 00	3720.9	1102.2	6241.2	74 00	4317.6	1444.6	6896.4
10	3732.7	1108.6	6255.2	10	4330.7	1452.5	6909.7
20	3744.6	1115.1	6269.1	20	4343.8	1460.4	6923.0
30	3756.5	1121.7	6283.1	30	4356.9	1468.4	6936.2
40	3768.5	1128.2	6297.0	40	4370.1	1476.4	6949.5
50	3780.4	1134.8	6310.9	50	4383.3	1484.4	6962.8
67 00	3792.4	1141.4	6324.8	75 00	4396.5	1492.4	6976.0
10	3804.4	1148.0	6338.7	10	4409.8	1500.5	6989.2
20	3816.4	1154.7	6352.6	20	4423.1	1508.6	7002.4
30	3828.4	1161.3	6366.4	30	4436.4	1516.7	7015.6
40	3840.5	1168.1	6380.3	40	4449.7	1524.9	7028.8
50	3852.6	1174.8	6394.1	50	4463.1	1533.1	7041.9
68 00	3864.7	1181.6	6408.0	76 00	4476.5	1541.4	7055.0
10	3876.8	1188.4	6421.8	10	4489.9	1549.7	7068.2
20	3889.0	1195.2	6435.6	20	4503.4	1558.0	7081.3
30	3901.2	1202.0	6449.4	30	4516.9	1566.3	7094.4
40	3913.4	1208.9	6463.1	40	4530.4	1574.7	7107.5
50	3925.6	1215.8	6476.9	50	4544.0	1583.1	7120.5
69 00	3937.9	1222.7	6490.6	77 00	4557.6	1591.6	7133.6
10	3950.2	1229.7	6504.4	10	4571.2	1600.1	7146.6
20	3962.5	1236.7	6518.1	20	4584.8	1608.6	7159.6
30	3974.8	1243.7	6531.8	30	4598.5	1617.1	7172.6
70	3987.2	1250.8	6545.5	40	4612.2	1625.7	7185.6
50	3999.5	1257.9	6559.1	50	4626.0	1634.4	7198.6
70 00	4011.9	1265.0	6572.8	78 00	4639.8	1643.0	7211.6
10	4024.4	1272.1	6586.4	10	4653.6	1651.7	7224.5
20	4036.8	1279.3	6600.1	20	4667.4	1660.5	7237.4
30	4049.3	1286.5	6613.7	30	4681.3	1669.2	7250.4
40	4061.8	1293.7	6627.3	40	4695.2	1678.1	7263.3
50	4074.4	1300.9	6640.9	50	4709.2	1686.9	7276.1
71 00	4086.9	1308.2	6654.4	79 00	4723.2	1695.8	7289.0
10	4099.5	1315.5	6668.0	10	4737.2	1704.7	7301.9
20	4112.1	1322.9	6681.6	20	4751.2	1713.7	7314.7
30	4124.8	1330.3	6695.1	30	4765.3	1722.7	7327.5
40	4137.4	1337.7	6708.6	40	4779.4	1731.7	7340.3
50	4150.1	1345.1	6722.1	50	4793.6	1740.8	7353.1
72 00	4162.8	1352.6	6735.6	80 00	4808.7	1749.9	7365.9
10	4175.6	1360.1	6749.1	10	4822.0	1759.0	7378.7
20	4188.4	1367.6	6762.5	20	4836.2	1768.2	7391.4
30	4201.2	1375.2	6776.0	30	4850.5	1777.4	7404.1
40	4214.0	1382.8	6789.4	40	4864.8	1786.7	7416.8
50	4226.8	1390.4	6802.8	50	4879.2	1796.0	7429.5

TABLE I—*Concluded.*

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
81 00	4893.6	1805.3	7442.2	86 00	5343.0	2104.7	7815.2
10	4908.0	1814.7	7454.9	10	5358.6	2115.3	7827.4
20	4922.5	1824.1	7467.5	20	5374.2	2126.0	7839.6
30	4937.0	1833.6	7480.2	30	5389.9	2136.7	7851.7
40	4951.5	1843.1	7492.8	40	5405.6	2147.5	7863.8
50	4966.1	1852.6	7505.4	50	5421.4	2158.4	7876.0
82 00	4980.7	1862.2	7518.0	87 00	5437.2	2169.2	7888.1
10	4995.4	1871.8	7530.5	10	5453.1	2180.2	7900.1
20	5010.0	1881.5	7543.1	20	5469.0	2191.1	7912.2
30	5024.8	1891.2	7555.6	30	5484.9	2202.2	7924.3
40	5039.5	1900.9	7568.2	40	5500.9	2213.2	7936.3
50	5054.3	1910.7	7580.7	50	5517.0	2224.3	7948.3
83 00	5069.2	1920.5	7593.2	88 00	5533.1	2235.5	7960.3
10	5084.0	1930.4	7605.6	10	5549.2	2246.7	7972.3
20	5099.0	1940.3	7618.1	20	5565.4	2258.0	7984.2
30	5113.9	1950.3	7630.5	30	5581.6	2269.3	7996.2
40	5128.9	1960.2	7643.0	40	5597.8	2280.6	8008.1
50	5143.9	1970.3	7655.4	50	5614.2	2292.0	8020.0
84 00	5159.0	1980.4	7667.8	89 00	5630.5	2303.5	8031.9
10	5174.1	1990.5	7680.1	10	5646.9	2315.0	8043.8
20	5189.3	2000.6	7692.5	20	5663.4	2326.6	8055.7
30	5204.4	2010.8	7704.9	30	5679.9	2338.2	8067.5
40	5219.7	2021.1	7717.2	40	5696.4	2349.8	8079.3
50	5234.9	2031.4	7729.5	50	5713.0	2361.5	8091.2
85 00	5250.3	2041.7	7741.8	90 00	5729.7	2373.3	8103.0
10	5265.6	2052.1	7754.1	10	5746.3	2385.1	8114.7
20	5281.0	2062.5	7766.3	20	5763.1	2397.0	8126.5
30	5296.4	2073.0	7778.6	30	5779.9	2408.9	8138.2
40	5311.9	2083.5	7790.8	40	5796.7	2420.9	8150.0
50	5327.4	2094.1	7803.0	50	5813.6	2432.9	8161.7

Note.—If $\Delta \times D$ is less than 600, the error in **tang. dist.** of the above table is less than 0.4 ft. If $\Delta \times D$ is less than 400, the error in tang. dist. is less than 0.25 ft. If $\Delta \times D$ is less than 200, the error in tang. dist. is less than 0.1 ft.

TABLE II.—**Minutes and seconds in decimals of a degree.**

Min.	Deg.	Min.	Deg.	Min.	Deg.	Sec.	Deg.	Sec.	Deg.	Sec.	Deg.
1	0.017	21	0.350	41	0.683	1	0.000	21	0.006	41	0.011
2	.033	22	.367	42	.700	2	.001	22	.006	42	.012
3	.050	23	.383	43	.717	3	.001	23	.006	43	.012
4	.067	24	.400	44	.733	4	.001	24	.007	44	.012
5	.083	25	.417	45	.750	5	.001	25	.007	45	.012
6	.100	26	.433	46	.767	6	.002	26	.007	46	.013
7	.117	27	.450	47	.783	7	.002	27	.007	47	.013
8	.133	28	.467	48	.800	8	.002	28	.008	48	.013
9	.150	29	.483	49	.817	9	.002	29	.008	49	.014
10	.167	30	.500	50	.833	10	.003	30	.008	50	.014
11	.183	31	.517	51	.850	11	.003	31	.009	51	.014
12	.200	32	.533	52	.867	12	.003	32	.009	52	.014
13	.217	33	.550	53	.883	13	.004	33	.009	53	.015
14	.233	34	.567	54	.900	14	.004	34	.009	54	.015
15	.250	35	.583	55	.917	15	.004	35	.010	55	.015
16	.267	36	.600	56	.933	16	.004	36	.010	56	.016
17	.283	37	.617	57	.950	17	.005	37	.010	57	.016
18	.300	38	.633	58	.967	18	.005	38	.011	58	.016
19	.317	39	.650	59	.983	19	.005	39	.011	59	.016
20	.333	40	.667	60	1.000	20	.006	40	.011	60	.017

TABLE III.—**Tangent offsets in feet** for curves of small radius.

Radius in ft.	Distance in ft. along tangent from *PC* and *PT* in parts of radius.								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	0.05	0.20	0.46	0.84	1.34	2.00	2.86	4.00	5.64
15	.08	.30	.69	1.25	2.01	3.00	4.29	6.00	8.46
20	.10	.40	.92	1.67	2.68	4.00	5.72	8.00	11.28
25	.13	.51	1.15	2.09	3.35	5.00	7.15	10.00	14.10
30	.15	.61	1.38	2.50	4.02	6.00	8.58	12.00	16.92
40	.20	.81	1.84	3.34	5.36	8.00	11.43	16.00	22.56
50	.25	1.01	2.31	4.18	6.70	10.00	14.29	20.00	28.21
60	.30	1.22	2.77	5.01	8.04	12.00	17.15	24.00	33.85
70	.35	1.41	3.22	5.84	9.38	14.00	20.01	28.00	39.49
80	.40	1.61	3.69	6.68	10.72	16.00	22.87	32.00	45.13
90	.45	1.82	4.15	7.52	12.06	18.00	25.73	36.00	50.77
100	.50	2.02	4.61	8.35	13.40	20.00	28.59	40.00	56.41

Tabular numbers give lengths of offsets in feet at points on tangent whose distance from *PC* or *PT* in feet is equal to the proportional part of radius given at head of column.

TABLE IV.—**Middle** and **side ordinates** in thousandths of feet for subchords varying by 1 ft. for 1° of curvature.

Length of subchord.	Ordinates.		Length of subchord	Ordinates.		Length of subchord.	Ordinates.		Length of subchord.	Ordinates.	
	Middle.	Side.		Middle.	Side.		Middle.	Side.		Middle.	Side.
1	0.000	0.000	26	0.015	0.011	51	0.056	0.042	76	0.126	0.094
2	.000	.000	27	.016	.012	52	.058	.043	77	.129	.097
3	.000	.000	28	.017	.013	53	.060	.045	78	.132	.099
4	.000	.000	29	.018	.014	54	.063	.047	79	.136	.102
5	.000	.000	30	.020	.015	55	.065	.049	80	.139	.104
6	.000	.000	31	.021	.016	56	.068	.051	81	.143	.107
7	.001	.000	32	.022	.016	57	.071	.053	82	.146	.109
8	.001	.000	33	.624	.018	58	.073	.055	83	.150	.112
9	.002	.001	34	.025	.019	59	.076	.057	84	.154	.115
10	.002	.001	35	.027	.019	60	.078	.059	85	.158	.118
11	.003	.002	36	.028	.021	61	.081	.061	86	.162	.121
12	.003	.002	37	.030	.022	62	.084	.063	87	.166	.124
13	.004	.003	38	.031	.023	63	.087	.065	88	.170	.127
14	.004	.003	39	.033	.024	64	.090	.067	89	.173	.130
15	.005	.003	40	.035	.026	65	.092	.069	90	.177	.133
16	.006	.004	41	.037	.028	66	.095	.071	91	.181	.136
17	.006	.004	42	.038	.029	67	.098	.073	92	.184	.138
18	.007	.005	43	.040	.030	68	.101	.076	93	.188	.141
19	.008	.006	44	.042	.031	69	.104	.078	94	.192	.144
20	.009	.007	45	.044	.033	70	.107	.080	95	.197	.148
21	.010	.007	46	.046	.034	71	.110	.082	96	.201	.151
22	.011	.008	47	.048	.036	72	.113	.085	97	.205	.154
23	.012	.009	48	.050	.037	73	.116	.087	98	.210	.157
24	.013	.009	49	.052	.039	74	.119	.089	99	.214	.160
25	.014	.010	50	.054	.040	75	.123	.092	100	.218	.163

For distances greater than 100 ft., take from the table the ordinates for $\frac{1}{2}$; $\frac{1}{3}$, or $\frac{1}{4}$ the distance and multiply them by 4, 9, or 16.

For any other curvature multiply by its values in degrees.

TABLE V.—**Dimensions of split and stub switches** for frog numbers 4 to 12, inclusive.

Frog.		Length of lead.		Switch rail.				Δ		Lead rail.			
				Split.		Stub.				Split.		Stub.	
Number. (1)	Angle. (2)	Split. (3)	Stub. (4)	Length. (5)	Angle. (6)	Length. (7)	Angle. (8)	Split. (9)	Stub. (10)	Length. (11)	D. (12)	Length. (13)	D. (14)
	° ′	Ft.	Ft.	Ft.	° ′	Ft.	° ′	° ′	° ′	Ft.	° ′	Ft.	° ′
4	14 15	34.44	26.10	10	2 38	10.92	2 24	11 37	11 51	20.07	58 24	21.94	54 54
5	11 25	40.40	32.06	10	2 38	12.75	2 04	8 47	9 21	26.23	32 06	26.72	35 18
6	9 32	53.56	41.06	15	1 45	16.67	1 35	7 47	7 57	34.31	22 47	36.64	21 47
7	8 10	59.50	47.00	15	1 45	18.50	1 25	6 25	6 45	40.11	16 05	42.48	15 04
8	7 09	65.17	52.67	15	1 45	20.67	1 16	5 24	5 53	45.68	11 51	48.08	12 16
9	6 22	70.52	58.02	15	1 45	23.33	1 06	4 37	5 16	50.96	9 04	53.38	9 52
10	5 43	75.58	63.08	15	1 45	25.00	1 03	3 58	4 40	55.96	7 07	58.39	8 01
11	5 12	86.29	71.29	18	1 26	25.00	1 03	3 46	4 09	63.64	5 55	66.58	6 14
12	4 46	91.15	76.15	18	1 26	25.00	1 03	3 20	3 43	68.46	4 53	71.42	5 13

The above table is computed for 4′ 8½″ gage; 5½″ throw and 5′ of straight frog rail in the lead curve. For a straight frog rail of greater length than 5′ subtract the difference from the quantities in columns 11 and 13. For a straight frog rail less than 5′ add the difference.

For 4′ 9″ gage, add 1% to quantities in columns 11 and 13. Other quantities will do.

TABLE VI.—**Number of special ties** required for single switches.

Frog number		4	5	6	7	8	9	10	11	12
Ties, 7 x 9 ins. required for each switch.	Length.	Number.								
	Ft.									
Stub switch only	9	1	1	3	3	3	3	3	2	2
Split switch only	9	6	6	10	10	10	10	10	11	11
Stub or split switch	10	6	7	8	9	10	10	11	12	13
	11	3	4	6	6	7	9	9	11	11
	12	2	3	4	5	6	6	7	9	9
	13	2	3	3	4	5	6	7	7	8
	14	3	3	3	5	4	5	6	6	7
	15	2	3	4	4	5	5	6	6	8

TABLE VII.—**Distances in feet** measured along the main rail between the **frogs of cross overs**, for a gage of 4 ft. 9 ins.

Frog number.	Distance between centers of tracks in ft.						
	11	11.5	12	12.5	13	13.5	14
4	5.25	7.17	9.17	11.08	13.08	15.00	17.00
5	6.92	9.33	11.83	14.25	16.75	19.17	21.58
6	8.50	11.50	14.42	17.42	20.33	23.33	26.25
7	10.08	13.50	17.00	20.50	23.92	27.25	30.83
8	11.67	15.58	19.58	23.58	27.58	31.50	35.50
9	13.17	17.67	22.17	26.58	31.08	35.58	40.08
10	14.67	19.67	24.67	29.67	34.67	39.58	44.58
11	16.25	21.75	27.25	32.75	38.25	43.75	49.25
12	17.75	23.75	29.67	35.67	41.67	47.58	53.58

Note.—If the gage varies slightly from 4 ft. 9 ins. correct the tabular number by twice the difference x frog number. **Add** the correction if the gage is **less** that 4 ft. 9 ins.; **subtract** if it is **greater.**

87625—09——23

Table VIII.—Quantities of material per mile of single track.

Note.—These quantities are assembled in one table for convenience. There is a general, but not an exact, correspondence between those on the same horizontal line. The size of spike is influenced by the kind of tie, and the length of bolt by the kind of joint.

Rails.		Ties.		Spikes. (4 to each tie.)						Bolts. (4 to each joint.)					
Wt. per yard.	Long tons per mile.	Distance c. to c.	No. per mile.	Length under head.	Size.	No. per keg of 200 lbs.	No. of kegs per mile for ties— 21 ins. c. to c.	24 ins. c. to c.	27 ins. c. to c.	Length under head.	Size.	No. per keg of 200 lbs. sq. nuts.	No. of kegs per mile for rails of— 30 ft.	30 ft. 10% short.	33 ft.
Lbs.		*Ins.*		*Ins.*	*Ins.*					*Ins.*	*Ins.*				
100	158	18	3,520	5½	$\frac{9}{16}$	360	33.0	29.3	25.7	5	1	115	12.2	12.5	11.1
90	142	21	3,017	5	$\frac{9}{16}$	405	29.3	26.0	22.8	4½	1	120	11.7	12.0	10.7
80	126	24	2,640	4½	$\frac{9}{16}$	460	25.9	23.0	20.1	4	1	125	11.3	11.5	10.2
75	118	27	2,348	5	½	505	23.6	21.0	18.4	4½	⅞	162	8.7	8.9	7.9
70	110	30	2,113	4½	½	535	21.3	19.8	17.3	4	⅞	170	8.3	8.5	7.5
65	103	Joints.		4	½	605	19.8	17.5	15.3	3½	⅞	188	7.4	7.7	6.8
60	95	Length of rail.	No. per mile.	3½	½	670	17.5	15.9	14.3	4¼	¾	195	7.2	7.4	6.6
56	88			4½	$\frac{7}{16}$	690	17.5	15.5	13.5	4	¾	200	7.0	7.2	6.4
50	79	30 ft.	352	4	$\frac{7}{16}$	780	15.3	13.6	11.0	3¾	¾	208	6.8	7.0	6.2
45	71	30 ft. 10% short.	360	4½	⅜	780	15.3	13.6	11.0	3½	¾	216	6.5	6.7	6.0
40	63	33 ft.	320	4	⅜	1,025	11.5	10.2	9.0	3½	⅝	329	4.3	4.4	3.9

PART V.

FIELD FORTIFICATION

INCLUDING

MINING AND DEMOLITIONS.

PART V—FIELD FORTIFICATION, INCLUDING MINING AND DEMOLITIONS.

1. **Fortification** is the art of increasing by engineering devices the fighting power of troops occupying a position. These devices have for their object to increase the effect of the fire action of troops protected by the fortifications and their mobility on the field, or to diminish the effect of the fire action of the assailant and his mobility.

2. **Field fortification** deals with the preparation of such devices of a temporary character for immediate—not permanent—use, in a position which derives its tactical value from the incidents of a pending campaign and which may lose that value at or before the close of the campaign.

3. **The principal classes** of field fortification devices are:

Those which produce an **unobstructed field of fire** in front of the line of defense—clearings, demolitions, grading.

Shields or **shelters**, which protect the defender from the assailant's fire—trenches, galleries, redoubts, blockhouses, etc.

Masks, which conceal the defender from the assailant's view—plantations, embankments, screens, etc.

Obstacles, by which the advance of the assailant is retarded—abattis, slashings, entanglements, etc.

Facilities for communication for the defender—roads, bridges, telegraphs, etc.

Obstructions to communication of the assailant—destruction of bridges, obstruction of roads, obstacles, etc.

Many devices fall into more than one of the above categories.

4. Field fortification may be divided into **hasty intrenchments, deliberate intrenchments,** and **siege works. Hasty intrenchment** includes devices resorted to by troops upon a battlefield to increase or prolong their fighting power, usually constructed in the presence of the enemy and in haste. **Deliberate intrenchment** comprises works constructed by troops not in line of battle for the protection of depots, lines of communication, supply, or retreat, etc. As they are usually intended to enable a small force to resist a much larger one, they are more carefully designed than hasty intrenchments and have greater defensive strength. **Siege works** comprise devices used by besiegers and besieged in the attack and defense of strong fortifications, and especially those devices which enable troops to advance under continuous cover.

The lines of division of the three classes are **not definite.** Some devices may belong to more than one class, and a work begun in one class may be merged into and be completed in another.

5. **Cover.—Protection from fire or view** is usually called **cover.** Protection from fire is divided into **horizontal** and **overhead** cover. **Horizontal cover** gives protection against direct or horizontal fire. It usually takes the form of a shot-proof barrier, vertical or nearly so. **Overhead cover** gives protection against indirect or high-angle fire, and against the fragments of shells and shrapnel bursting overhead. It ordinarily takes the form of a shot-proof barrier, horizontal or nearly so. Overhead covers are often referred to as **bombproofs** or **splinter proofs**—the latter if they are light, but proof against rifle fire or fragments of shell or shrapnel, the

former if they are strong enough to resist the curved and vertical fire of siege guns and mortars. The term **splinter proof** is also applied to horizontal cover thick enough only to stop fragments of shell or shrapnel.

6. **Profiles.—A profile** is a section of any cover made by a vertical plane perpendicular to its general direction or practically parallel to the direction of fire against and over it. Fig. 1 is a typical profile on which the names of the component parts are indicated.

In dimensioning a profile the plane of site (supposed horizontal) is taken as the **plane of reference.** The distances of points of the profile from this plane are stated in feet and fractions—those above with the *plus sign* and those below with the *minus* sign. These quantities are inclosed in parentheses and are called **references.** Generally speaking, the plus quantities relate to embankments and the minus quantities to excavations. If the site is not horizontal the plane of reference is assumed to pass through a point of the site vertically below the middle point of the interior crest.

7. **Command** has reference to difference of elevation; a higher point **commanding** a lower one; the latter **commanded** by the former. "**The command,**" used without qualification, means the **height of parapet,** or the elevation of interior crest above plane of site. The degree of command of one point over another may be expressed by the difference of elevation in feet, or better, by the gradient of the line joining them.

The relief of a parapet is the elevation of the interior crest above the lowest surface immediately in front—the bottom of the ditch, if there is one. With no ditch and a level site the relief and the height of parapet or command become the same.

The clear height behind the parapet will be referred to as **vertical cover.** It is the elevation of the interior crest above the bottom of the trench, or above the natural surface if there is no trench.

By the **thickness** of a parapet is meant the horizontal distance between the tops of the interior and exterior slopes. It is used as a measure of the **amount** of horizontal cover.

8. **The principal conditions** which determine the form of a profile of horizontal cover are the following:

The interior slope or breast height should be nearly vertical, and its height must correspond to one of the adopted firing positions, i. e., lying, kneeling, or standing.

The thickness is regulated by the kind of fire against which protection is desired, as rifle, field, or siege artillery, and the range.

The superior slope should have an inclination such that fire over and parallel to it will sweep the ground in front. **One-sixth** has been adopted as **standard.**

The exterior slope and the sides of trench and ditch should be as steep as the material of which they consist will stand. **The banquette slope,** if long, should be cut into steps to facilitate movement over it.

The quantity of trench excavation and of **embankment** should be nearly equal to minimize labor. This applies only to small parapets in which all the excavation is in a trench. For heavy parapets, labor is saved by making the trench supply the inner part and taking the outer from a ditch.

The command should usually be kept as low as possible, for better concealment. For the same reason all sharp angles and hard lines should be avoided.

The thickness of ordinary earth required **to resist penetration** at usual battle ranges is 3 ft. for rifle fire, 4 to 6 ft. for field guns, and 15 to 20 ft. for siege guns. It should be remembered that any protection is better than none. **Mere concealment** from view by a screen wholly inadequate to resist penetration will, for rifle fire especially, greatly reduce the casualties since the enemy's fire will be less rapid and less accurate if he can not see his target.

Figs. 2 to 10 show profiles of horizontal cover from the skirmisher's trench to a redoubt to resist artillery.

9. **Profiles to resist rifle fire.—The skirmisher's trench,** fig. 3, gives cover to a man lying down. The height of parapet should not exceed 1 ft. A trench of this profile, 2½ ft. front, can be constructed in soft ground in 20 minutes or less. If under fire, the trench can be constructed by a man lying down. He can mask

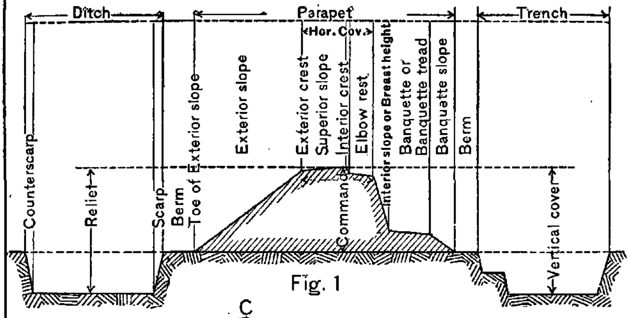


Fig. 1

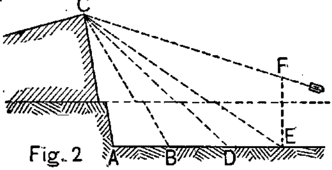


Fig. 2

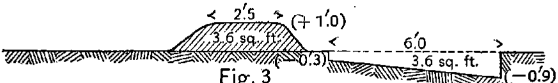


Fig. 3

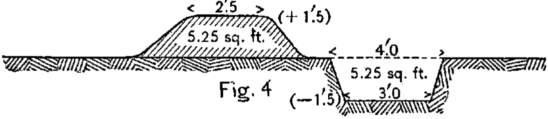


Fig. 4

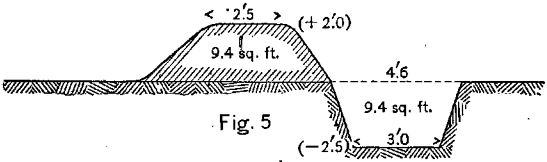


Fig. 5

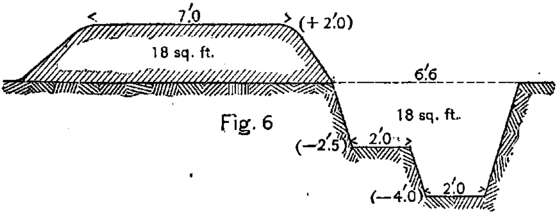


Fig. 6

himself from view in 10 or 12 minutes and can complete the trench in 40 to 45 minutes. A good method of working is to dig a trench 18 ins. wide back to the knees; roll into it and dig 12 ins. wide alongside of it and down to the feet; then roll into the second cut and extend the first one back.

For troops in the main line of resistance the **kneeling trench**, fig. 4, is the simplest. The width at bottom is not less than 2½ ft.—preferably 3 ft.—and the relief is 3 ft., the proper height for firing over in the kneeling position. This trench can be constructed in soft ground in 40 to 50 minutes.

The standing trench, fig. 5, has a bottom width of 3 to 3½ ft. and relief of 4½ ft. This is proper firing height for men of average stature. Short men may gouge out the superior slope a little or throw some earth under their feet. The standing trench can be excavated in soft ground in 2 to 2½ hours. The kneeling trench can be converted into the standing in about 1½ hours.

The standing trench does not give complete cover to men standing erect in it, and the next stage of development is a passageway executed in the rear of the trench not less than 6 ft. below the interior crest. This forms the **complete trench**, fig. 6, which can be constructed in soft ground in 4 to 4½ hours, placing all the material in the parapet. The height remaining the same, this extra material all goes to increased thickness, which, if rifle fire only is considered, becomes greater than is necessary. In this case some labor and time may be saved by wasting the excavation from the complete trench in the rear.

Fig. 7 shows the foregoing profiles superposed. Corresponding areas of embankment and excavation are similarly shaded. It is seen that work may proceed progressively from the first to the last, converting each into the next in order without handling any of the material twice.

10. **Profiles to resist field guns.**—The angle of fall of field artillery projectiles at 3,400 yds. range is 11°. The angle of dispersion of shrapnel is 14°, which makes the maximum angle of fall of the bullets 18° or 1 on 3. Bursting charges of high explosives will in the future greatly increase this angle, probably to a degree which will require continuous overhead cover.

A profile to resist shrapnel only is shown in fig. 8. The thickness is 4 ft. and the relief such that a shrapnel fragment grazing the interior crest with an angle of fall of 1 on 3 will clear the heads of men kneeling or sitting in the trench. This profile may be formed by enlarging the trench and parapet of fig. 6. It can be executed in soft soil in 4 to 4½ hours. The small area shown in broken shading must be handled a second time.

If liable to be exposed to a **prolonged attack of field guns** a parapet should be proof against their shells. This requires 9 ft. of ordinary earth, and a suitable profile is shown in fig. 9. The additional earth is taken from a ditch, and with working parties in ditch and trench this profile can also be executed in 4 to 4½ hours.

11. **Special profiles.—The advantages** of the normal profiles above described are that they produce a given cover with the least expenditure of time and labor, and that the first protection secured can be utilized as partial cover while enlarging and strengthening it. **The disadvantages** are that the effective cover is restricted to a narrow zone immediately in rear of the parapet, and that in wet ground or wet weather it is difficult to keep the trench reasonably dry. More complete concealment than is afforded by the normal profile is sometimes very desirable.

The normal profile may be modified in various ways to meet local conditions. **The cover** may be **all in embankment** and earth may be taken from a ditch or borrowed at a distance, fig. 10. In this form the command is equal to the relief and the protection extends to a greater distance in rear. It may be used when the conditions of the site call for more command or the character of the soil precludes a trench. A trench is not feasible in very wet soil, while a ditch, though more difficult to dig, is better when done for mud or water in the bottom.

The cover may be **all in excavation**, figs. 11 and 12. This form was used by the Boers, and by the Spanish in front of Santiago. The undercutting was peculiar to the Boer trench. This form may be made completely invisible. It is practicable only when the natural surface has sufficient command and when the ground to be swept is also a general concave; when the soil is stiff but workable, porous and dry to a considerable depth. If there are folds of ground, bushes, woods, or other means of concealing it, the excavated earth may be scattered on the ground; if not, it must be carried away, or thrown into irregular mounds on the rear side, concealed by making them resemble the foreground.

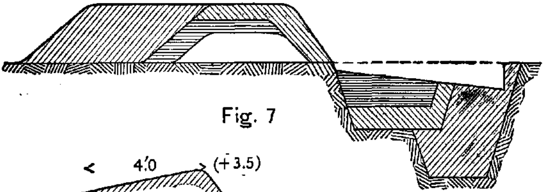


Fig. 7

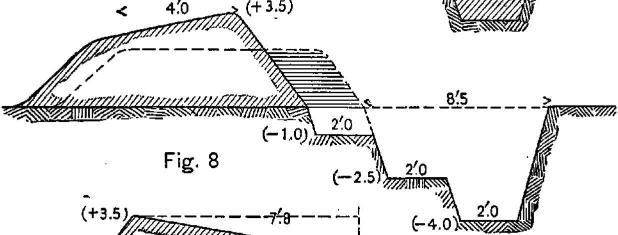


Fig. 8

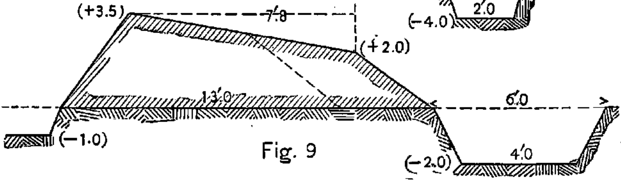


Fig. 9

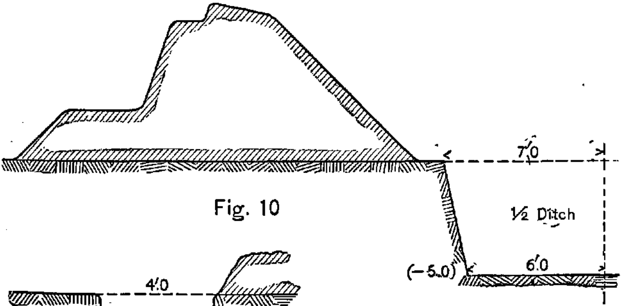


Fig. 10

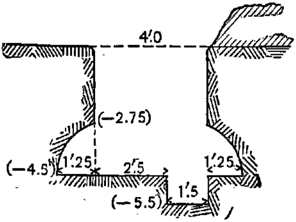


Fig. 11

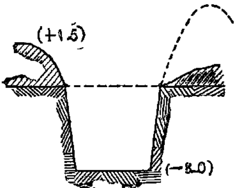


Fig. 12

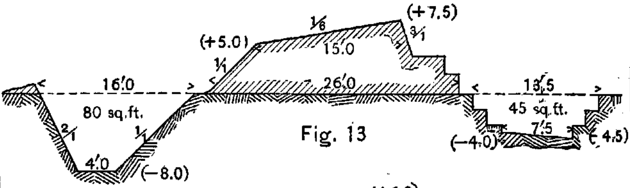


Fig. 13

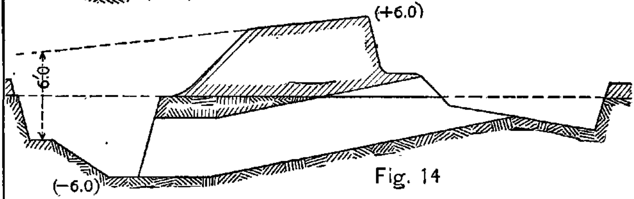


Fig. 14

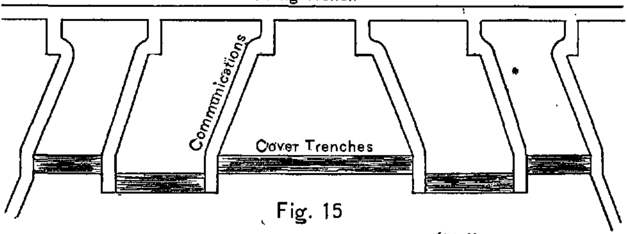


Fig. 15

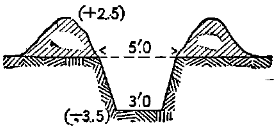


Fig. 16

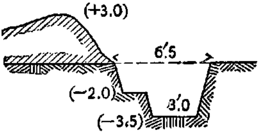


Fig. 17

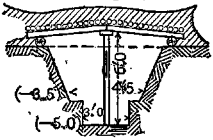


Fig. 18


Fig. 19


Fig. 20

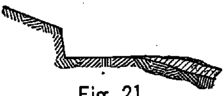


Fig. 21

In an inclosed or partially inclosed work for a stubborn defense of the ground, the parapet must be heavy enough to resist siege guns, the relief must be considerable to resist assault, and men on any part of the parade must be screened from view. A profile shown in fig. 13 results. **By preparing the counterscarp** as a firing crest a double tier of infantry fire is obtained. **Good communication,** but easily interrupted, must be provided **from the ditch through the parapet** to enable the front line to retreat when too hard pressed, fig. 14.

If the presence of water or hard material makes only shallow excavation practicable, the trench and ditch must be widened. The parapet must be higher by the difference between normal and actual depth of trench, so that more material must be handled and it must be moved farther.

For example, assume a parapet 6 ft. high with a sectional area of 60 sq. ft., to have a vertical cover of 10 ft. This might be dug from a trench 4 ft. deep and 15 ft. wide, or from a trench 10 ft. wide and a ditch 5 ft. wide by 4 ft. deep. In soil which can be dug to 2 ft. deep only, the parapet would have to be 8 ft. high to give 10 ft. vertical cover, and its area for the same horizontal cover would be 95 sq. ft., which would require excavating 2 ft. deep and 47½ ft. wide. The quantity of earth to be handled is greater by more than half and it must be carried, on an average, more than twice the distance.

12. **Trenches** are classified as **firing, communicating,** and **cover** trenches. The latter are used to shelter troops exposed to fire and not in action, as supports and reserves. They differ from firing trenches mainly in requiring no command. **Communicating trenches** connect firing and cover trenches and offer protected passage between them. Concealment from view is the principal requisite, as the enemy can not afford to sustain a fire on such trenches and the exposure in passing through them is to chance shots only. The important point in **cover trenches** is safety; it is very bad to have men hit in these trenches. They will be built with overhead cover, when necessary, to secure this condition.

Trenches are sometimes classified also as **offensive** and **defensive,** the former adapted to give exit over the parapet for the forward movement, and the latter not so adapted. Skirmisher's and kneeling trenches are offensive; standing and complete trenches are defensive, unless steps are made to facilitate mounting the parapet. Cover trenches will usually be of the same character as the firing trench. If exposed to artillery fire, cover trenches should be roofed if possible. Fig. 15 shows a plan of firing trench, cover trench, and communicating trenches, developed as a result of experience in South Africa. Fig. 16 is a section of a communicating trench. If the enemy's fire is all from one side, but one bank is needed, and all earth should be thrown on the exposed side. Fig. 17 is a section of an open cover trench and fig. 18 of a closed one. This section may also be used for communicating trenches. Fig. 19 indicates an arrangement suitable when the digging is easy and the ground permits the cover trench to be dug close in rear of the firing trench. Fig. 20 shows a disposition to permit the use of a natural depression as a cover trench. Fig. 21 shows a typical form of cover for reserves or supports on a reverse slope.

13. **Head cover** is the term applied to any horizontal cover which may be provided above the plane of fire. It is obtained by notching or loopholing the top of the parapet so that the bottoms of the notches or loopholes are in the desired plane of fire. The extra height of parapet may be 12 to 18 ins. and the loopholes may be 3 to 3½ ft. center to center.

Head cover is of limited utility. It increases the visibility of the parapet and restricts the field of fire. At close range the loopholes serve as aiming points to steady the enemy's fire and may do more harm than good at longer ranges. This is especially the case if the enemy can see any light through the loophole. He waits for the light to be obscured, when he fires, knowing there is a man's head behind the loophole. A background must be provided or a removable screen arranged so that there will be no difference in the appearance of the loophole whether a man is looking through it or not. Head cover is advantageous only when the conditions of the foreground are such that the enemy can not get close up.

Notches and **loopholes,** figs. 22-24, are alike in all respects, except that the latter have a roof or top and the former have not. The bottom, also called **floor** or **sole,** is a part of the original superior slope. The sides, sometimes called **cheeks,** are vertical or nearly so. The plan depends upon local conditions. There is always a narrow part, called the **throat,** which is just large enough to take the rifle and permit sighting. From the throat the sides diverge at an angle, called the **splay,** which depends upon the field of fire necessary.

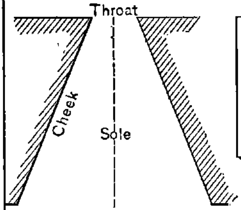


Fig. 22

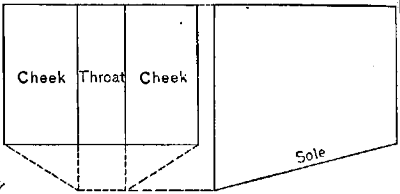


Fig. 23

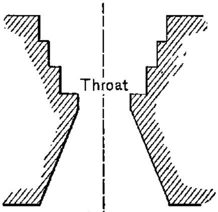


Fig. 24

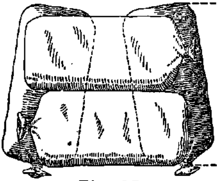


Fig. 25

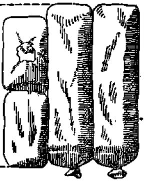


Fig. 26

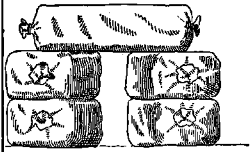


Fig. 27

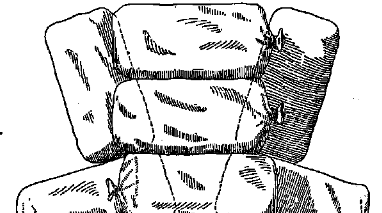


Fig. 28

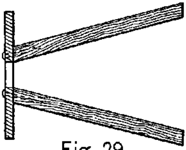


Fig. 29

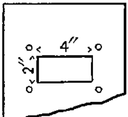


Fig. 30

Fig. 31

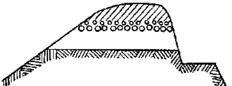


Fig. 32

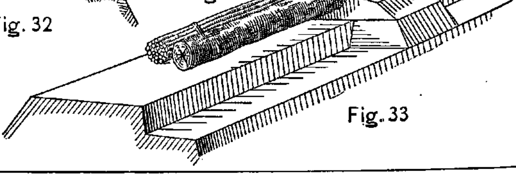


Fig. 33

The position of the throat may vary. If on the outside, it is less conspicuous but more easily obstructed by injury to the parapet and more difficult to use, since in changing aim laterally the man must move around a pivot in the plane of the throat. If the material of which the loophole is constructed presents hard surfaces, the throat should be outside, notwithstanding the disadvantages of that position, or else the sides must be stepped as in fig. 24. In some cases it may be best to adopt a compromise position and put the throat in the middle, fig. 24. Figs. 25 to 28 show details and dimensions of a loophole of sand bags.

A serviceable form of loophole consists of a pyramidal box of plank with a steel plate spiked across the small end and pierced for fire. Fig. 29 shows a section of such a construction. It is commonly known as the **hopper loophole.** The plate should be $3/8$ in. thick if of special steel; or $1/2$ in., if ordinary metal. Fig. 30 shows the opening used by the Japanese in Manchuria and fig. 31 that used by the Russians.

The construction of a notch requires only the introduction of some available rigid material to form the sides; by adding a cover the notch becomes a loophole. Various methods of supporting earth will be described under "Revetments." Where the fire involves a wide lateral and small vertical angle, loopholes may take the form of a long slit. Such a form will result from laying logs or fascines lengthwise on the parapet, supported at intervals by sods or other material, fig. 33, or small poles covered with earth may be used, fig. 32.

14. **Overhead cover.**—This usually consists of a raised platform of some kind covered with earth. It is frequently combined with horizontal cover in a single structure, which protects the top and exposed side. The supporting platform will almost always be of wood and may vary from brushwood or light poles to heavy timbers and plank. It is better, especially with brush or poles, to place a layer of sods, grass down, or straw, or grain sacks over the platform before putting on the earth, to prevent the latter from sifting through.

The thickness of overhead cover depends upon the class of fire against which protection is desired, and is sometimes limited by the vertical space available, since it must afford headroom beneath, and generally should not project above the nearest natural or artificial horizontal cover. For splinter proofs a layer of earth 6 to 8 ins. thick on a support of brush or poles strong enough to hold it up will suffice if the structure is horizontal. If the front is higher than the rear, less thickness is necessary; if the rear is higher than the front, more is required. For bombproofs a minimum thickness of 6 ins. of timber and 3 ft. of earth is necessary against field and siege guns, or 12. ins. timber and 6 ft. of earth against the howitzers and mortars of a heavy siege train.

In determining the **area of overhead cover** to be provided, allow 6 sq. ft. per man for occupancy while on duty only, or 12 sq. ft. per man for continuous occupancy not of long duration. For long occupation 18 to 20 sq. ft. per man should be provided.

Figs. 34 to 43 show a variety of the most usual types of overhead cover.

In a work of high command, especially if the earth is scarce or difficult to work and timber plentiful, it may be found that the construction of supports for overhead cover will involve less time and labor than the corresponding volume of embankment. In such cases bombproofs should be introduced at all possible points, regardless of the number of men to be sheltered.

15. **Trace.**—In field fortification the term **trace** usually designates the horizontal projection of the interior crest. If the interior crest were traversed (see Reconnaissance), and the traverse plotted on paper or on a map, the result would be the trace. As a general rule the trace of a parapet will follow the lines of best natural cover or those which determine the strongest natural position. In practice, it usually happens that the troops are located with a view to taking full advantage of the features of natural strength, and the fortifications are thrown up where they are to give them additional protection.

The interior crest should be horizontal, and hence the crest should, as a rule, follow a contour. Generally, a broken line will approach the contour near enough and will be easier to lay out and construct. If the contour curves sharply the trace should curve also. Angles must be rounded off to make them less conspicuous, and at the beginning and end of a trench its bottom should gradually rise and the parapet fall to nothing for better concealment.

The particular contour to be chosen depends upon local conditions. Fig. 44 is a section or profile of a ridge perpendicular to the general direction of its crest. The summit of the ridge *T* is called the **topographic crest.** The contour corresponding

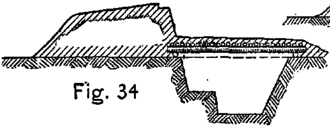


Fig. 34

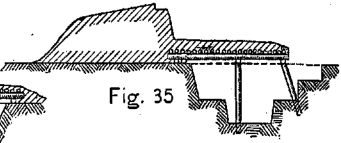


Fig. 35

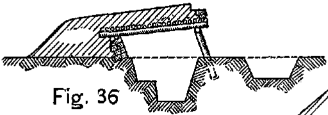


Fig. 36

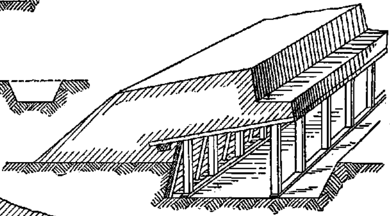


Fig. 37

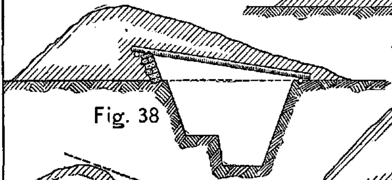


Fig. 38

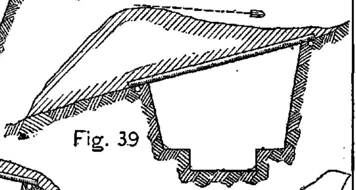


Fig. 39

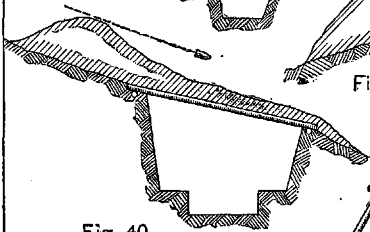


Fig. 40

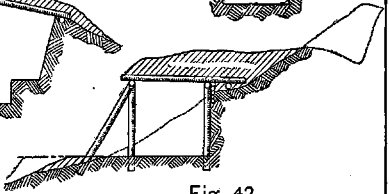


Fig. 42

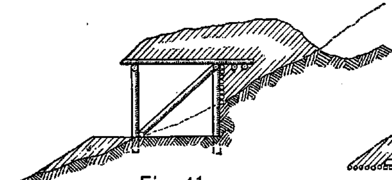


Fig. 41

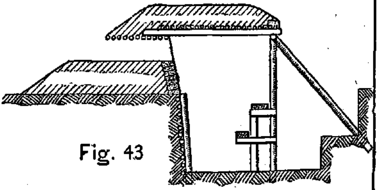


Fig. 43

to the point *M* is the one from which all the ground in front can be seen and reached by fire and is called the **military crest.** The sky line is variable in position. From the point *G* the sky line is at *D*. From *E* the sky line is at *F*.

In locating a line of trench, it is important—

(*a*) To avoid a sky line;

(*b*) To occupy the military crest or a line in advance of it, and

(*c*) To preserve communication under cover with the rear.

If the ridge is steep and is intersected by ravines or covered with growth through which men could move under cover, a position near the foot of the slope, as *G*, fig. 44, might be better, as a plunging fire, besides being more difficult to deliver, is not so effective as a fire parallel to the ground. Such a line would not be the main line of resistance and would not as a rule be reenforced. A reserve line should be constructed on the military crest and provision made for withdrawing the men from the front line under the best cover possible when it can no longer be held.

16. **Kinds of trace.**—Fieldworks are classified by the form of their trace into **open, half-closed,** and **closed works.** An **open work** is one affording cover on the side of the enemy's approach only, with no preparation to resist flank or rear attack. It may consist of a line or of lines disposed in a geometrical figure. A line of trench, like a line of men, depends upon adjacent parts of the line to protect its flanks. Ends of a line retired, as in fig. 45, give a fire in front of adjacent trenches for flanking support.

Lines of strong profile have a **dead space** in the ditch or close in front of the parapet which, if the work is to stand assault, must be swept by flank fire. Adjacent works may be made to bear on this ground, or a line may be made self-flanking by giving it the trace shown in fig. 46. The long lines may be 200 to 300 yds. long or even longer. The short lines should not be less than 12 yds. long and their crests should be held lower than the rest. Lines are always in the class of open works.

The dead space may be avoided by adopting a form of profile called the **triangular,** shown in fig. 47. The disadvantages of this profile are the additional labor of construction, the diminished thickness of the upper part of the parapet, and the comparatively slight obstacle to escalade presented by the flatter slope. A flanking fire will usually be preferred to the triangular profile.

17. **A redan** consists of two lines called **faces,** *ab* and *ac*, fig. 48, which make an angle of about 60°. This angle is called the **salient;** its bisecting line *ad* the **capital,** and the line *bc* the **gorge.** The redan is mainly used to secure a flanking fire along a line of parapet or a cross fire on important ground.

The exterior angle at *a* between the faces prolonged is dead space which must be denied to the enemy by obstacles or covered by fire from adjacent works, or the angle may be truncated, as shown by the full line in fig. 48. Such a disposition is a **pan coupé.** The pan coupé, if short, can deliver but a small volume of fire. The truncation may be made by a broken reentrant line, as shown dotted in the fig. This form is called a **priest cap.** A redan is usually open, but may be made a half-closed work by placing obstacles across the gorge.

18. **A lunette,** fig. 49, consists of four lines, two of them, *ab* and *ac*, called **faces,** and the other two, *bd* and *ce*, called **flanks.** The angles at *b* and *c* are called **shoulder angles.** The salient, capital, and gorge are as in the redan. The salient angle is at least 120°, which gives an effective fire on every part of the foreground and a good flanking fire as well.

The lunette is the simplest trace adapted for use in an isolated work. It may be open or half closed. In a half-closed work, either redan or lunette, the **gorge defense** may consist of obstacles or of a low trench, or of the two combined. In any case, a road must be left through it for communication. This road may be closed by a gate or removable barricade, or may be swept by fire from a short trench inside the gorge.

A gorge trench should have a double parapet, the front one serving as a parados to protect men in the trench from shots coming from the main line and also as a firing line to command the interior of the lunette in case the enemy gets in over the front. The gorge profile, fig. 50, is a type.

19. **Redoubts** are works entirely inclosed by defensible parapets, though the term **fort** is usually applied to such a work when it has unusual strength, either by reason of its trace or its armament. In the former case a word descriptive of the trace is often added, as **star** fort, fig. 51; **bastioned** fort, fig. 52.

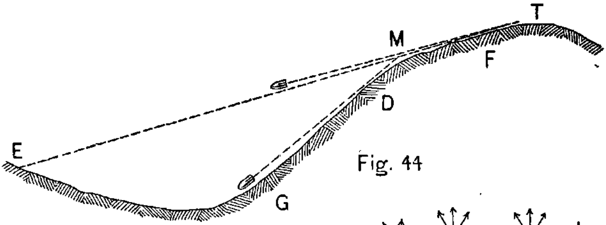


Fig. 44

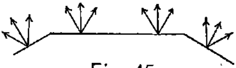


Fig. 45

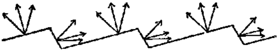


Fig. 46

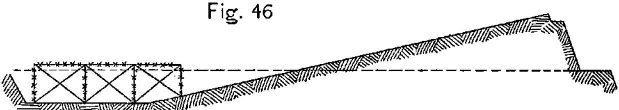


Fig. 47

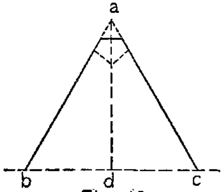


Fig. 48

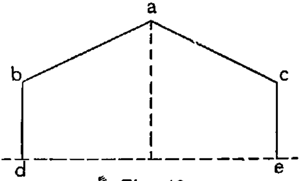


Fig. 49

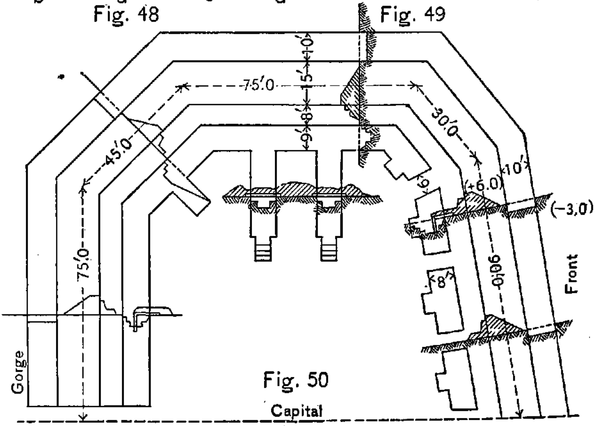


Fig. 50

The inclosed form and the restricted and usually crowded interior space, make redoubts excellent targets for artillery, and they can not be used in situations exposed to such fire unless they can be so arranged that they can not be recognized as redoubts from the enemy's artillery positions. A favorable site is one which commands the ground around it to effective rifle range and is not visible from artillery ranges.

In preparing a defensive position, if sites meeting the foregoing conditions can be found on which redoubts can be built to flank the adjacent trenches, they should by all means be built. Redoubts in good position **in rear of a line** form valuable supporting points. They also find important application for **isolated posts** on lines of communication or in other territory when the enemy can not operate in considerable force, and will probably not have artillery. Here invisibility is less necessary, the first requisite being security for the garrison. There must, however, be no higher ground within short range, and hence, in rolling country, such works will usually be placed on hills or ridges. As they are usually to be occupied for some time, care must be taken that a **supply of water** is available and proper **disposition of refuse** provided for.

20. **The trace** of a redoubt will depend upon the size of the garrison to be accommodated, the configuration of the ground, and the probable direction of attack.

The garrison should always consist of **one or more units** of command. No work should be designed for less than a company. If a larger force than one company is needed, then two companies, and so on. It is quite usual to indicate the size of a redoubt by its garrison, as a one, two or four company redoubt. The garrison assumed, the work should be large enough to give a **yard of parapet** for not more than **two men.** The length of parapet is determined first, as the siting of a small work may differ from that of a larger one on the same ground.

The adaptation to the ground consists mainly in the determination of a closed contour having the desired length. Such a contour, generalized by taking out small kinks, will usually be the best location for the parapet.

Men 5 to 10 yds. apart may stand on the contour and hold a tracing tape at the height of the interior crest. By looking over the tape all along, it will be seen whether each part of the parapet will command the ground in front of it. If not, the crest must be advanced or raised at that point until it does. If the command is greater than necessary, the crest may be lowered or retired. Note also whether the longest faces are on the sides of easiest approach. If not, the trace must be modified to produce that result. If possible, the tape should be viewed from a short distance all around the outside, and if it makes any sharp angles on the sky line, they should be softened.

As to details of trace, straight lines are to be preferred to curves as being easier to lay out and construct and giving a better guide to direction of fire. If curves must be introduced, they should have at least 20 yds. radius. All faces should be long enough to give effective volume of fire. Ten yds. will usually be a minimum. A quadrilateral with truncated corners is a good type. If two adjacent faces intersect at an angle of 30° or less, truncation is not necessary. The longest face should bear on the ground from which the strongest attack is to be expected and the entrance will usually be on the opposite side, though if attack from any direction is especially difficult, the entrance should be on that face.

21. **Profile.**—So far as regards the effectiveness of its fire, the command of a redoubt need not be greater than that of a trench on the same ground. A high command will better screen the interior space and offer greater resistance to assault, but will increase the visibility of the work and the labor of building it. The horizontal cover need not, as a rule, be as thick as the adjacent trenches, as the latter will certainly be exposed to deliberate artillery fire and the redoubt, as a rule, will have to resist unaimed and scattering artillery fire only. **A necessary feature** is a trench deep and wide enough to give complete shelter and free communication.

22. **Interior arrangements.**—The most important thing is the protection of the garrison from flank and reverse fire. When invisibility is not essential, a command of 6 or 7 ft. is the easiest method of giving interior protection. Extensive overhead cover will be necessary. It need not ordinarily be heavy. Six ins. of earth on brushwood stiff enough to support it will usually suffice. When long-range fire may be expected from the front only, the overhead cover will be developed along the front edge of the trench of the front face, in excavations perpendicular to the trench on the flanks, and along the edge of the trench opposite the parapet in the gorge.

87625—09——24

For a possible all-round long-range fire, short galleries should be run out to the rear of all trenches. This development of covered trenches may continue, if necessary, until the entire interior of the redoubt is converted into an underground camp. The parapet trenches and the shelters in them must be well traversed, the former by blocks of earth with oblique or crooked passages cut through them, and the latter by splinter-proof partitions of brush and earth.

Fig. 50 shows a typical plan, with sections, of a redoubt on level ground, where a command of 7 ft. is permissible. (See par. 22a, p. 422.)

23. **General considerations.**—The proper use of shelter trenches for the protection of firing lines is a matter of utmost importance to success. It may be accepted as a principle, established by experience, that a line of men can not remain stationary under fire without cover, natural or artificial. This is true in every phase of action, whether advancing, retreating, or standing on the defensive. Cover at all times is desirable; on the move it may be dispensed with, at a halt never. In some cases the cover will be partly natural and partly artificial, i. e., partial natural cover artificially improved. In a majority of cases, however, conditions of fire efficiency and concealment will require a line to be placed where it could not possibly live without artificial cover. Another principle which may be accepted is, that on the offensive the line must determine the general position of the cover and not the cover the position of the line. The position of the line at any moment of a battle depends on tactical considerations and the progress and incidents of the fight. To prepare trenches in advance, except for defensive occupation, is to attempt to predict the future. It follows that all troops not in a defensive attitude must prepare their own cover after occupying a line or after they are halted. The importance is paramount of having available for instant use on every firing line the appliances and training to enable the men to get sufficient cover in the shortest possible time. This involves not alone the training of the men to dig with the tools provided, but also the knowledge and skill of their own officers to locate the trenches to the best advantage. There is no time to wait for instructions or advice from the outside.

While the line will, as a rule, determine the general position of the cover, trench conditions will exercise a great influence on the detailed dispositions along the line. An inferior unit may be advanced or retired to get better command of its field of fire or to find easier digging. It must not be advanced far enough to interfere with the fire of adjacent troops on its flanks, nor be retired enough to allow them to interfere with its own fire. Trenches need not be continuous and should not be longer than suffices to contain the men on the firing line. Men should not be crowded together, neither should they be isolated. The best disposition is in self-sustaining groups, advantageously distributed. A trench should be long enough at least to take a squad; company or half-company lengths are, on the whole, the best. A straight line should be avoided.

In studying the command of the ground from a given line the eye should be placed at the adopted height of parapet, or if the line is adopted, then the necessary height of parapet must be determined in the same way. What can be seen 1 ft. from the ground will often be very different from what can be seen at 5 ft. When possible, proposed lines of trenches should be examined from the ground over which the enemy must approach, as suggested for redoubts, par. 20.

It will seldom happen that the entire field of fire to the limit of effective range can be completely swept from any position that can be selected. A position should be sought which reduces the dead spaces to a minimum in number and extent, and, if possible, advanced or auxiliary trenches should be located to sweep them. If the ground is open to 1,000 yards or more, the long or mid range is more important than the short range, for an effective fire on the enemy while he is advancing from 1,200 yds. to 200 yds. range will almost certainly put him out, or, if by any chance he arrives at 200 yds. in condition to keep on, little can be gained by holding him under fire from 200 yds. in, and a retirement is in order. In both cases, the disadvantage of dead space in the close foreground is more apparent than real and the main trenches should not sacrifice command of more distant ground within effective range in order to sweep the foreground. Such dead ground must be commanded at night or in thick weather by trenches detached or in flanking relation.

On the contrary, if an enemy can approach under cover to mid range or less, there will scarcely be time to stop him by fire alone and obstacles are desirable at close range, which must be commanded by fire. The trenches, in such cases, must be advanced to cover the close foreground, and if necessary, another line in a different position established to sweep the more distant ground.

In a rear-guard position, the object is to force the enemy to deploy and to delay him to a certain extent, and then retreat to another position before his advance to close range and before his fire becomes annoying. The command of the foreground is of no consequence, while a safe withdrawal is all-important, and the front slope of a ridge should be avoided. The forward edge of a plateau will do, or, if the plateau is long enough, the rear edge may be occupied. If there is timber on the plateau, its front edge should be the location of the line.

When concealment of the general position is not possible, as in case of a detached post guarding a well-defined and known objective, deception must take its place. The trenches actually occupied must be so arranged as to afford concealment of the individual man, and dummy trenches, purposely made easily visible, may be arranged to draw the enemy's fire. Dummy trenches should have head cover, not only to make them more conspicuous but also to make it more difficult to discover whether they are occupied or not. They are better above and behind the occupied trenches, if the lay of the ground permits. The enemy will observe that fire comes from the direction of the dummies and will conclude that it comes from them. Fire directed on the dummies will pass over the heads of the defenders, a condition preferable to shots falling short, which would be the result of dummies in front of the occupied trenches.

When an organization is designated to a particular part of a general line the duty devolves upon its commander to determine what is to be done in strengthening his position and get the work started without delay. He will direct what clearing is to be done or accidents utilized, and where and how the trenches are to be dug. All the working force available should be divided between preparation of field of fire, working progressively forward, and the construction of cover, working generally from the center of the position toward the ends, and giving first attention to points where the least work will secure the most and best cover. If work is interrupted by an attack, that which has been done will be of full use.

24. **Revetments.**—A revetment is a covering or facing placed upon an earth slope to enable it to stand at an inclination greater than its natural inclination. Steep interior slopes are easier to fire over, give better cover, and increase the horizontal space available. Some revetments also increase tenacity of slopes and diminish the injury from fire. Revetments are applied to the interior slopes or breast heigths of parapets for all of the above reasons and to traverses for all except the first.

The upper parts of revetments which may be struck by shots which have penetrated the cover of earth must not be made of materials of large units or which splinter when struck. The construction of the upper part of a revetment is often referred to as **crowning.**

25. **Sand-bag revetments.**—A sand bag is 33 ins. long and 14 ins. wide. In use it is loosely filled with earth or sand, requiring about ½ cub. ft. of earth, and having been placed in position is flattened with a shovel to roughly rectangular form, in which it fills a space about 20 x 13 x 5 ins. The bags weigh about 62 lbs. per 100, and when filled, about 65 lbs. each.

A sand-bag revetment is constructed by laying the filled bags as stretchers and headers, or as headers alone. The top row should always be headers. The tied ends of headers and the seams of stretchers should be in the parapet. Sand bags give no splinters and are conveniently used for the entire parapet when necessary. As they are more readily transported than corresponding quantities of any other revetting material, they are of great importance in field fortification. Their perishability is a disadvantage, though in many soils a surface revetted with bags will stand after the bags have lost their strength through decay. Sand bags are so valuable for crowning and repairs, however, that the stock on hand should not be exhausted in original construction if anything else can be had.

Fig. 53 indicates the appearance of a sand-bag revetment as seen from the front and from the end.

Rate of working.—A squad of 6 men, 2 shovels, 1 pick, 1 bag holder, and 2 tiers should, in fairly loose soil, fill 150 bags an hour.

Supposing the bags to be filled from the ditch or trench, with 10 additional men, 6 to carry and 4 to lay, or a squad of 16 men all told, 150 bags per hour can be taken care of, making 75 sq. ft. of revetment.

26. **Sod revetment.**—A convenient size to cut sods is 18 x 9 x 4½ ins. If tough, they may be cut larger, but the length should be twice the breadth. They are laid, grass down, in courses, alternately all headers and all stretchers, the latter double,

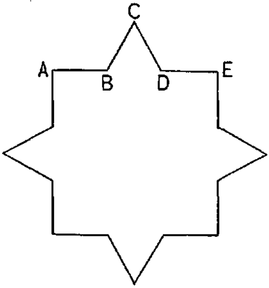


Fig. 51

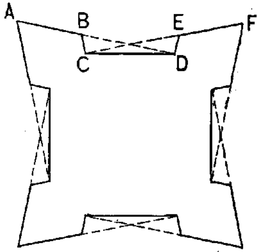


Fig. 52

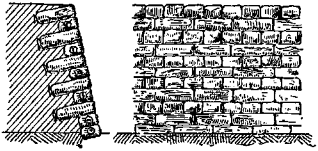


Fig. 53

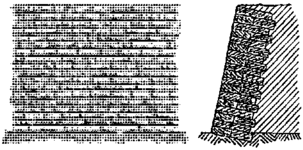


Fig. 54

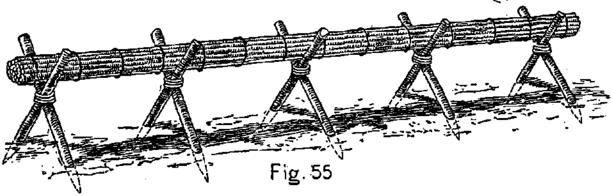


Fig. 55

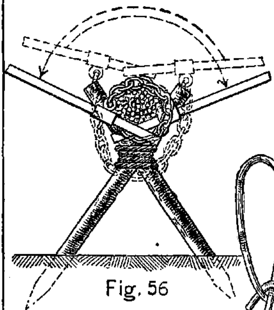


Fig. 56

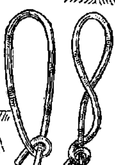


Fig. 57

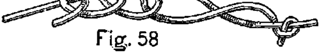


Fig. 58

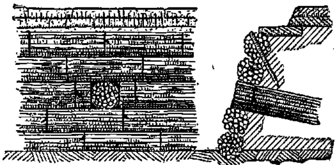


Fig. 59

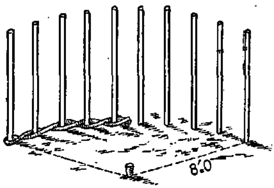


Fig. 60

with broken joints. A bed should be prepared at the proper inclination to receive the bottom course and give it the right pitch. The top course is laid grass up and all headers. If the sods show a tendency to slip, they may be pinned together with wooden pickets.

Sod revetments will not stand quite so steep as sand bags in the same soil. It is usual to allow a 3 to 1 slope for sods. The revetment should be built steeper if the soil is such that it will stand. Fig. 54 shows an elevation and section of a sod revetment.

Four sods, 18 x 9 x 4 ins., laid, make a sq. ft. of revetment, but as there is some wastage, 450 or more sods must be cut for each 100 sq. ft. of surface to be revetted. If the grass is long, it should be mowed before cutting sods.

One man should cut 30 sods per hour, or place the same number. A sod plow will cut as fast as 60 men.

If carrying is done by hand, multiply the number of sods to be moved per hour by the average length of carry in yds., and divide the product by 7,500 for the number of carriers. They should work in pairs, carrying 8 sods between them. If wagons are available, estimate as though moving earth (see Roads, 49), taking 72 sods to the cu. yd. Unloaders will be required, as the sods can not be dumped, say one man for 300 sods per hour. If ordinary sodding is to be done, for concealment or to prevent rain wash, use the same ratios for cutting, hauling, and laying, allowing 8 sods to the sq. yd. laid, or 9 cut.

27. **Brush work.**—Brush is used in many forms in revetting. Any kind will do, but the best is willow, birch, ash, hickory, or hazel. For weaving, it must be live, and is most pliable when not in leaf. Split bamboo of pliable dimensions, reeds, or similar vegetation, may be considered as a form of brush in all revetment constructions.

Brush for weaving should not be more than an inch in diameter at the butt. That to be used straight may be of larger size. In cutting, brush should be assorted in sizes for the various uses and made up in bundles of 40 to 60 lbs., the butts in one direction. The range of weights is given to convey a general idea of the size of bundles. The determining condition is that each bundle shall make a gabion, which will soon be determined after work begins. Poles of 2½ in. diam. at the butt or larger are not bundled but are piled together. They are used for posts, binders, grillage, and similar purposes.

The amount of labor required to cut brush will vary with its character, whether hard or soft, crooked or straight, thick or thin. A rough average may be taken at 6 bundles per man per hour. The men work in pairs, one cutting and one sorting, piling, and tying.

For carrying by hand, multiply the number of bundles by the carry in yards and divide by 2,200 for the number of men required. If transportation is by teams, assume 35 bundles to equal 1 yd. and figure as for earth.

28. **A fascine** is a cylindrical bundle of brush, closely bound. The usual length is 18 ft. and the diam. 9 ins. when compressed. Lengths of 9 and 6 ft., which are sometimes used, are most conveniently obtained by sawing a standard fascine into 2 or 3 pieces. The weight of a fascine of partially seasoned material will average 140 lbs.

Fascines are made in a **cradle** which consists of five trestles. A **trestle** is made of two sticks about 6½ ft. long and 3 ins. in diam., driven into the ground and lashed at the intersection as shown in fig. 55. In making a cradle, plant the end trestles 16 ft. apart and parallel. Stretch a line from one to the other over the intersection, place the others 4 ft. apart and lash them so that each intersection comes fairly to the line.

To build a fascine, straight pieces of brush, 1 or 2 ins. at the butt, are laid on, the butts projecting at the end 1 ft. beyond the trestle. Leaves should be stripped and unruly branches cut off, or partially cut through, so that they will lie close. The larger straighter brush should be laid on the outside, butts alternating in direction, and smaller stuff in the center. The general object is to so dispose the brush as to make the fascine of uniform size, strength, and stiffness from end to end.

When the cradle is nearly filled, the fascine is compressed or **choked** by the **fascine choker,** fig. 56, which consists of 2 bars 4 ft. long, joined at 18 ins. from the ends by a chain 4 ft. long. The chain is marked at 14 ins. each way from the middle by inserting a ring or special link. To use, two men standing on opposite sides pass the chain under the brush, place the short ends of the handles on top and pass the bars, short end first, across to each other. They then bear down on the long ends until the marks on the chain come together. Chokers may be improvised from sticks and rope or wire.

Binding will be done with a double turn of wire or tarred rope. It should be done in 12 places, 18 ins. apart, the end binders 3 ins. outside the end trestles. To bind a fascine will require 66 ft. of wire (see Bridges, 29).

Improvised binders may be made from rods of live brush; hickory or hazel is the best. Place the butt under the foot and twist the rod to partially separate the fibers and make it flexible. A rod so prepared is called a **withe.** To use a withe, make a half turn and twist at the smaller end, fig. 57; pass the withe around the brush and the large end through the eye. Draw taut and double the large end back, taking 2 half-hitches over its own standing part, fig. 58.

When the fascine is choked and bound, saw the ends off square, 9 ins. outside the end binders. After a cradle is made, 4 men can make 1 fascine per hour, with wire binding. Withes require 1 man more.

A fascine revetment is made by placing the fascines as shown in fig. 59. The use of headers and anchors is absolutely necessary in loose soils only, but they greatly strengthen the revetment in any case. A fascine revetment **must always be crowned** with sods or bags.

29. In all brush weaving the following terms have been adopted and are convenient to use:

Randing.—Weaving a single rod in and out between pickets.

Slewing.—Weaving two or more rods together in the same way.

Pairing.—Carrying two rods together, crossing each other in and out at each picket.

Wattling.—A general term applied to the woven part of brush construction.

30. **A hurdle** is a basket work made of brushwood. If made in pieces, the usual size is 2 ft. 9 ins. by 6 ft., though the width may be varied so that it will cover the desired height of slope.

A hurdle is made by describing on the ground an arc of a circle of 8 ft. radius and on the arc driving 10 pickets, 8 ins. apart, covering 6 ft. out to out, fig. 60. Brush is then woven in and out and well compacted. The concave side of a hurdle should be placed next the earth. It warps less than if made flat.

In weaving the hurdle, begin randing at the middle space at the bottom. Reaching the end, twist the rod as described for a withe, but at one point only, bend it around the end picket and work back. Start a second rod before the first one is quite out, slewing the two for a short distance. Hammer the wattling down snug on the pickets with a block of wood and continue until the top is reached. It improves the hurdle to finish the edges with two selected rods paired, fig. 61. A pairing may be introduced in the middle, if desired, to give the hurdle extra endurance if it is to be used as a pavement or floor. If the hurdle is not to be used at once, or if it is to be transported, it must be **sewed.** The sewing is done with wire, twine, or withes at each end and in the middle, with stitches about 6 ins. long, as shown in fig. 61. About 40 ft. of wire is required to sew one hurdle. No. 14 is about the right size, and a coil of 100 lbs. will sew 40 hurdles. Three men should make a hurdle in 2 hours, 2 wattling and the third preparing the rods.

31. **Continuous hurdle.**—If conditions permit the revetment to be built in place, the hurdle is made continuous for considerable lengths. The pickets may be larger; they are driven farther apart, 12 or 18 ins., and the brush may be heavier. The construction is more rapid. The pickets are driven with a little more slant than is intended and must be anchored to the parapet. A line of poles with wire attached at intervals of 2 or 3 pickets will answer. The wires should be made fast to the pickets after the wattling is done. They will interfere with the weaving if fastened sooner. Two men should make 4 yds. of continuous hurdle of ordinary height in one hour.

32. **Brush revetment.**—Pickets may be set as above described and the brush laid inside of them without weaving, being held in place by bringing the earth up with it. In this case the anchors must be fastened before the brush laying begins. The wires are not much in the way in this operation.

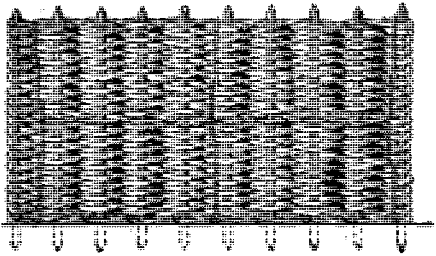


Fig. 61

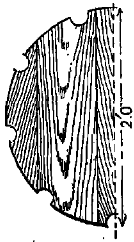


Fig. 62

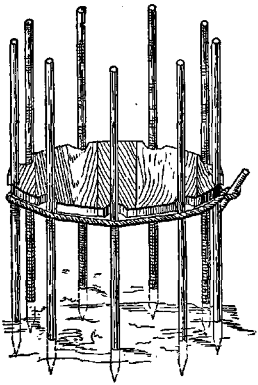


Fig. 63

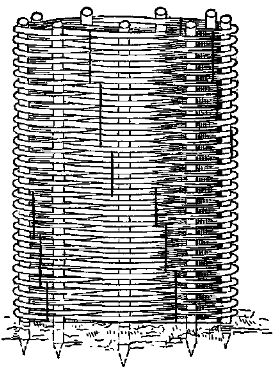


Fig. 64

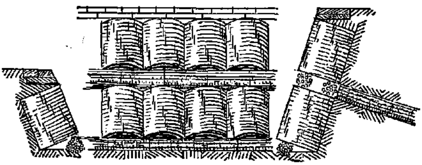


Fig. 65

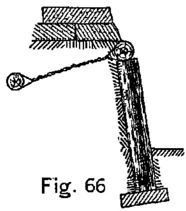


Fig. 66

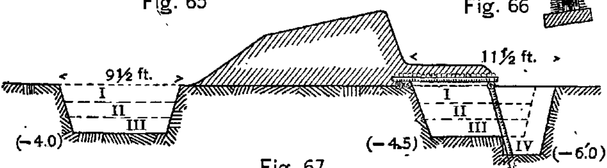


Fig. 67

33. **Gabion making.—A gabion** is a cylindrical basket with open ends, made of brush woven on pickets or stakes as described for hurdles. The usual size is 2 ft. outside diam. and 2 ft. 9 ins. height of wattling. On account of the sharp curvature somewhat better brush is required for gabions than will do for hurdles.

The gabion form, fig. 62, is of wood, 21 ins. diam., with equidistant notches around the circumference, equal in number to the number of pickets to be used, usually 8 to 14, less if the brush is large and stiff, more if it is small and pliable. The notches should be of such depth that the pickets will project to 1 in. outside the circle. The pickets should be 1¼ to 1¾ ins. diam., 3 ft. 6 ins. long and sharpened, half at the small and half at the large end.

To make a gabion, the form is placed on the ground, level or nearly so, and the pickets are driven vertically in the notches, large and small ends down, alternately. The form is then raised a foot and held by placing a lashing around outside the pickets, tightened with a rack stick, fig. 63. The wattling is randed or slewed from the form up. The form is then dropped down, the gabion inverted and the wattling completed. If the brush is small, uniform, and pliable, pairing will make a better wattling than randing. If not for immediate use, the gabion must be sewed as described for hurdles, the same quantity of wire being required.

The gabion, when wattled and sewed, is completed by cutting off the tops of the pickets 1 in. from the web, the bottom 3 ins., the latter sharpened after cutting, and driving a carrying picket through the middle of its length and a little on side of the axis. See that the middle of this picket is smooth. Three men should make a gabion in an hour.

Gabions may be made without the forms, but the work is slower and not so good. The circle is struck on the ground and the pickets driven at the proper points. The weaving is done from the ground up and the entire time of one man is required to keep the pickets in proper position.

If brush is scarce, gabions may be made with 6 ins. of wattling at each end, the middle left open. In filling, the open part may be lined with straw, grass, brush cuttings, or grain sacks, to keep the earth from running out.

34. **Gabion revetment.**—The use of gabions in revetments is illustrated in fig. 65. If more than two tiers are used, the separating fascines should be anchored back. Gabion revetments should be crowned with sods or bags.

The advantages of the gabion revetment are very great. It can be put in place without extra labor and faster and with less exposure than any other. It is self-supporting and gives cover from view and partial cover from fire quicker than any other form.

Several forms of gabions of other material than brush have been used. Sheet iron and iron and paper hoops are some of them. The iron splinters badly, is heavy, and has not given satisfaction. If any special materials are supplied the method of using them will, in view of the foregoing explanation, be obvious.

35. **Timber or pole revetment.**—Poles too large for use in any other way may be cut to length and stood on end to form a revetment. The lower ends should be in a small trench and have a waling piece in front of them. There must also be a waling piece or cap at or near the top, anchored back. Fig. 66 shows this form.

36. **Miscellaneous revetments.**—Any receptacles for earth which will make a stable, compact pile, as **boxes, baskets, oil or other cans,** may be used for a revetment. **Barrels** may be used for gabions. **Canvas** stretched behind pickets is well thought of in a foreign service. If the soil will make **adobe,** or sun-dried bricks, an excellent revetment may be made of them, but it will not stand wet weather.

37. **Execution of fieldworks.—Tracing** is the operation of marking on the ground the lines which determine the horizontal limits of cutting and embankment. **Profiling** is the operation of indicating the actual positions of such lines and slopes as are necessary to determine the proper sectional dimensions of trench, ditch, and parapet.

Tracing and profiling are not independent operations. The trace depends upon the profile and the profile upon the trace. They will be considered together under one title. For shelter trenches the profile is standardized, and the proper parapet results from the excavation of the necessary trench. The trace may be roughly determined as circumstances permit. The alignment of a line of skirmishers will do, if nothing better is possible. Heavy works will not often be built under fire, but if they are, the same rules must govern. For such works, executed deliberately, the following plan may be followed:

The first step is to mark on the ground the projection of the interior crest, sometimes called the **firing crest.** It may be marked continuously by stretching a line or by scratching the surface with a pick, or at intervals of a few feet by small pegs set to a line or ranged in.

The second step is to determine the **command** or height of the interior crest above the natural ground at as many points as the variation of the surface may make necessary. The thickness of the parapet having been assumed, the area of the parapet section and its ruling dimensions result.

The third step is to complete the profile by determining the depth and width of trench and of the ditch if there is to be one.

The fourth step is to mark on the ground, parallel to the interior crest and at proper distances from it, the edges of ditch and trench and the exterior crest. This marking is best done with pegs at 5 ft. interval or such other as may be allotted for each man's task.

The fifth step is to indicate the actual position of interior and exterior crests by setting up stakes of sufficient height to mark on each the height of the line.

The third of the foregoing steps is the only one which presents any difficulties. Table I gives areas of parapet sections for certain heights or commands, **h,** and thickness of parapet, **s,** on the supposition that the ground is level, the exterior slope and the interior or breast height slopes, each 1 on 1, and the superior slope 1 on 6. The assumed breast height slope gives a surplus of earth, increasing with the height. For low parapets it is not material; for high ones it supplies earth for a banquette. If the site slopes to the front, increase the area by the percentage for the corresponding slope at the right of the table. If the slope is to the rear, decrease the tabular area by the same percentages. Having the area of the parapet, the dimensions of the trench, or of the trench and ditch together, must be so taken as to give at least an equal area, and preferably, not much more.

If **h+s** is not more than 8 ft., the entire parapet can be built from a trench at a single cast. If **h+s** is greater than 8 ft. and not more than 16 ft., the entire parapet can he built from a trench and a ditch at one cast. If **h+s** is greater than 16 ft., some of the material must be transported or rehandled, no matter where it is obtained, though the labor in any case will be less if both trench and ditch are dug than if either one alone is relied upon. **Time also is saved** by working from both sides, not only because the labor is reduced, but principally because more men can be employed simultaneously.

38. **Working parties** should be made up, so far as possible, of entire organizations. A battalion should be ordered to send one, two, or three companies; a regiment, one or two battalions; and a brigade, one or more regiments.

The party is divided into two or more **reliefs,** and here also the principle of keeping organizations intact applies. If a regiment is to be used in three reliefs, each should consist of an entire battalion. This should be adhered to even if it makes reliefs of somewhat unequal strength. The total number of privates should be $\frac{1}{6}$ more than the number of men that are to be worked simultaneously.

Reliefs are regulated by work rather than by time. The amount of work to be done by each relief must be plainly indicated and the officers and noncommissioned officers of each organization are responsible that their men do the quantity of work assigned to them. As soon as any organization has completed its work, it should be dismissed.

39. **To place a relief on the work,** the organizations comprising it approach the tools in column of files, rifles slung, pass between the piles of tools, shovels on the right and picks on the left. Engineer soldiers at each pile hand tools to the men as they pass, each man taking a shovel in his right hand and a pick in his left. The corporal or squad leader places himself alongside the rear file of his squad and one of them takes a pick and the other a shovel.

Proceeding in suitable formation to one flank of the line and approaching it in column of files, the head of the column parallel to and about 3 yds. in rear of the rear cutting line, the column forms in line to the flank at 5 ft. intervals, the corporal and the rear file of each squad falling out and taking post in rear of the squad. The interval is most conveniently maintained by having the men extend the arms horizontally and touch hands. Each organization is assigned to a particular part of the line and goes to it and deploys independently of the rest. If the line is long, guides should be furnished to direct the head of each column to the point where its deployment is to begin. **At night guides must always be furnished.**

As the men are posted, each lays his shovel 5 ft. behind the cutting line, parallel to it, and drives his pick into the ground on the line at the left side of his task. Rifles and equipment are removed and placed three paces in the rear, butts of guns to the front. The corporal or squad leader and the last file of the squad take their places in rear of their respective squads and place their equipments in the line with the rest. The corporal acts as superintendent or foreman of the squad during the work and number 8 is a reserve to be put in when necessary to expedite the work of the squad or to take the place of a man who is obliged to fall out for any cause.

40. **Tasks.—The capacity of the average untrained man** for continuous digging does not much exceed 80 cu. ft. for easy soil; 60 cu. ft. for medium, and 40 cu. ft. for hard soil. He will do $3/8$ of this in the first hour, $5/8$ in the first two hours, and the other $3/8$ in another two hours, making an hourly average of $\frac{5}{16}$ of the task for the first, and $\frac{3}{16}$ for the second 2 hours. In addition to the fact that he works but a little over half as fast in the second 2 hours, four hours' work will leave him unfit for fighting or marching, while after two hours' work he should be able to do either. The quantity of work assigned to each relief should be that which can probably be done in 2 hours, and the relief is required to finish it and no more, whether it takes less or more time. For the first work, the soil is apt to be loose and the lift is less, so that a slightly greater task should be given to the first relief than to the second. Assuming men at 5 ft. intervals and neglecting fractions, the number of hours' work required to throw up a parapet is the section of the parapet in sq. ft. divided by 5 for easy; 4 for medium, and $2\frac{1}{2}$ for hard soil.

Determination of task.—The length over which each man works is settled when the intervals are assigned for the deployment. **The individual task** is the width and depth of excavation, which, carried over this length, will make the volume corresponding to 2 hours' fair average work. When either width or depth is determined, or assumed, the other results.

The task of the relief is defined when the width and depth of cut are stated or shown on a profile. As a rule, the lines dividing tasks should be horizontal or nearly so.

41. **Double gangs.**—When men are plenty, tools scarce, or time presses, a task may be completed in about $2/3$ of the ordinary time by detailing two men at each set of tools. In this case the organizations march to the tools in columns of twos, the right file taking shovels and the left file picks. The two gangs change off at frequent intervals and the men work as rapidly as possible.

42. **Changing reliefs.**—Each man of the first relief, as he completes his task, cleans the tools and lays them down as at first. The relief is then moved to the rear, the men resume their arms and equipments and are formed in column and march off. As soon as they are out of the cut the succeeding relief may enter at one end and form line to the flank, each man taking his place at the first set of tools he comes to.

43. **Example.**—Let it be required to design and construct 100 ft. of the front parapet of an inclosed work to resist siege guns at long range, sited on ground sloping 1 on 12 to the front, soil easy, materials procurable for revetting and cover, and 9 hours' time available.

Command.—Determine by trial the least height above the ground along the crest at which the foreground can be seen and swept by fire, par. 20. This is the *command* or *height of parapet*. Assume it for this case at 6 ft.

Thickness and relief of parapet.—As the severest fire is that of siege guns at long range, the minimum thickness for such guns will answer. Assume it at 10 ft. The long-range fire will have a high angle of fall, which calls for good interior relief or vertical cover and ample overhead cover.

The area of parapet for 6-ft. height, 10-ft. thickness, is, from Table I, 78 sq. ft. Add for 1 on 12 slope 8%, giving 85.1 sq. ft., or, for convenience, 85 sq. ft. This divided by 5, the factor for easy soil, gives 17 hours' work from one side; but as $\mathbf{h} + \mathbf{s} = 16$ ft., the work should be done from both sides, and $8\frac{1}{2}$ hours are required for a single relief, or a trifle under 6 hours for double reliefs. The time limit of 9 hours permits a single relief.

Overhead cover.—One hundred feet of parapet will be defended by 65 men, for whom 12 sq. ft. per man of overhead cover should be provided, or 7.8 sq. ft. per linear ft. of crest. This being too much, assume 6 sq. ft. per ft. of crest, giving cover for 50 men. This gives 6 ft. as the width of the cover. Cover for the remaining 15 men must be provided in rear of the trench. The cover along the parapet may be on the front edge of the ditch. As there will be a banquette $1\frac{1}{2}$ ft. above ground level, this may be continued to the rear to form the overhead cover. Allowing $1\frac{1}{2}$ ft. for thickness of earth and brush and $4\frac{1}{2}$ ft. headroom, the floor of the shelter will be at (-4.5) ft. and the bottom of the trench may be at $(-6$ ft.$)$, giving 12 ft. total vertical cover. The area of the profile under the cover will be $4\frac{1}{2} \times 6 = 27$ sq. ft. The part of the trench in rear of the cover should be 3 ft. wide at the bottom, or say 4 ft. wide at mid-depth. At 6 ft. depth its area will be 24 sq. ft., which, added to the 27 ft. deduced above, gives 51 sq. ft. total trench area, leaving 34 sq. ft. for the ditch, which may be assumed at $9\frac{1}{2}$ ft. top width and 4 ft. deep. The profile which results from these assumptions and deductions is shown in fig. 67.

Four reliefs should be provided. Thirty per cent of the digging may be assigned to the first relief, 25% each to the second and third, and 20% to the fourth, which will work in the trench only, and will have to build the overhead cover and rehandle its earth. Lines which apportion the tasks as indicated are shown on the profile. The first relief in the trench would be ordered to dig $9\frac{1}{2}$ ft. wide on top and $1\frac{1}{2}$ ft. deep. The first in the ditch $1\frac{1}{3}$ ft. deep, etc.

The revetment will be of gabions. If they have not been made beforehand they and the fascines should be on the ground within 3 hrs. and the brush and poles for splinter proofs should be on the ground within 5 hrs. after work begins. Fifty gabions and 6 fascines are required. Assume that they are made 600 yds. from the work and carried by hand. To make and deliver 50 of them in 3 hrs. would require 3 men to cut brush, 50 men to make, and $17 \times 600 \div 2{,}200 = 5$ men to carry, a total gabion party of 58 men. To make and deliver the 6 fascines in 3 hrs. will require 2 men to cut brush, 8 men to make, using 2 cradles, and 5 men to carry, a total of 13 men for the fascine party, or $58 + 13 = 71$ for the brush. The same party can cut and carry the brush for the overhead cover between the third and fifth hours. A company would likely be assigned to this work.

The total force required to construct the parapet in less than 9 hrs. will be—

Excavation and embankment, 4 reliefs of 40 men each	160 men.
Revetment and cover, 1 relief of	71 men.
Total	231 men.

44. **Traverses.**—The protected area in rear of a parapet as determined for a shot grazing and perpendicular to the crest, is reduced for a grazing shot with the same angle of fall coming at an angle to the crest. If a straight shot will clear a man's head at a certain distance back, oblique shots with the same angle of fall will clear a man at 90% of that distance for an angle of 26° with the perpendicular; 85% for 32°, and 80% for 37°. At 37° the distance is decreasing at the rate of 1% for each deg. For enfilade and reverse fire the parapet gives no cover at all.

To secure sufficient protection against very oblique, enfilade, or reverse fire, masks must be introduced to intercept such shots before they fall below the plane of desired protection. Such masks are called **traverses.** To those which are designed to intercept reverse fire, and which are mainly parallel to the parapet which they shelter, the name **parados** is given. The word **traverse** usually indicates a mask making an angle with the parapet which it protects and joined to it. Traverses may be of any available horizontal or overhead cover, but are usually topped with earth. They are revetted to make them take as little space along the parapet as possible, except that between guns there is sometimes room for earthen traverses with sloping sides. As the lower part can not be reached by fire, it need only form a support for the top and is often a good place to provide magazine or shelter space.

Distance between traverses.—The effective distance is the interval between the crest of one traverse and the adjacent face of the next. If the crests of the traverses are at the same elevation as the crest of the parapet, a distance between traverses of 0.43 of the width of protected area, for direct fire, preserves 90% of that width; 0.52, 85%, and 0.6, 80%.

If the crests of the traverses are **raised above** the crest of the parapet, the distance between traverses may be increased by the excess height multiplied by the assumed angle of fall, without reducing the width of the protected area, fig. 71. Fig. 72 shows a plan and side elevation of a raised traverse, with reference to its connection with the parapet. The full lines show relations when the crest of the traverse ends at the interior crest, and the broken lines indicate the arrangement when the crest of the traverse extends beyond the interior crest. Care must be taken that raised traverses do not make the position conspicuous. Traverses must be **at least as long** as the width of protection they are to give, and should be somewhat longer.

Profile of traverses.—The cross section of a traverse should be as nearly a rectangle as possible. The vertical sides give the maximum thickness with the minimum space, and the flat top gives a crest on each face and increases the interval by half the thickness, fig. 69. If exposed on one side only the profile in fig. 70 is suitable.

A traverse may be used as a firing parapet by providing a banquette or steps at the proper height.

Types of traverses.—A trench may be traversed by making an offset to the rear, as shown in fig. 73, and throwing up a bank of earth on the block left. Fig. 74 shows a form of double traversing. The long high traverses afford protection to men not firing, and the short traverses give increased protection to the more exposed space near the interior crest. For high traverses, the object should be to get a support up to the height where exposure to fire begins with the least time and labor. If the structure can be made hollow, so much the better. An elevated platform of planks, supporting a parapet of earth, revetted with sods or sand bags, will make a good traverse. If earth is the only material available, the entire traverse will be revetted, figs. 68 and 69. Below the plane of fire, any revetment may be used; above, only those which have been described for crowning a parapet revetment should be employed.

45. **Stockades.**—A stockade is an improvised bullet-proof wall or screen, usually adapted to defense by rifle fire. As compared with a parapet, the **advantages** of a stockade are that it combines obstacle and parapet, gives good cover and ample interior space, and the labor of construction increases less rapidly with the height. **The disadvantages** are the uncertainty of procurement of suitable material, the labor of construction, which is greater than for a parapet, except for considerable heights, and that most forms of stockades afford no cover, and the best of them only temporary cover, from artillery.

Construction.—The simplest form consists of a closed barricade of timbers loopholed and reenforced by earth, fig. 76. The inner embankment forms a banquette. The outer one fills the dead angle at the foot of the wall and is some protection against artillery fire. It makes a stockade easier to scale, but if the slope is steep and the tops of the timbers properly prepared by driving spikes or stringing barbed wire, the effect in that direction is small.

A single row of timbers affords too little protection unless they are squared or great pains taken to keep close joints. A double row, fig. 79, or if the logs are good size and workable, an arrangement of half timbers, fig. 80, gives the same cover with much less labor. Loopholes may be formed as indicated. They must be high enough so that the enemy can not fire through them when he comes to close quarters. Six feet above the ground is considered high enough.

A single row of timbers may be used as the front of two thin walls, the space between to be filled with earth or broken stone, fig. 75, or both walls may be alike, and of brush, plank, fascines, or sheet iron, fig. 78. Earth filling should be 2 ft. thick; stone filling 6 to 16 ins.

In all such constructions the two walls must be tied together at frequent intervals to resist the pressure of the filling. Wire is a very convenient material for such use. If T rails are available, an excellent stockade may be made as shown in fig. 81.

46. **A blockhouse** is a room or small building with bullet-proof walls, weather-proof and fireproof roof, loopholed for infantry, often for machine guns, and sometimes for light quick-firing guns. The walls may take any of the forms described for stockades, or may be of masonry. The roof will usually be of tin or sheet iron. If exposed to plunging fire, the roof may take the form of light overhead cover, and to promote the comfort of the garrison during long occupancy an ordinary roof may be placed over the earth, or it may be covered with canvas, or thatched, or made to turn water in any practicable manner. Figs. 82 to 85 and 89 show types of blockhouses. In fig. 85 the house provides 2 tiers of fire.

Extensive use was made of blockhouses by the British in South Africa. Some, at important points, were of masonry, presenting no unusual features. By far the greater number were of double skins of corrugated iron, filled between with broken stone. The first built were about 10 x 15 ft. in plan with the skins on separate frames or supports 2 ft. apart. Then an octagonal form was introduced with both skins on the same frame, leaving but a few inches between them. A difficulty experienced with this form was that a shot striking opposite a timber of the frame

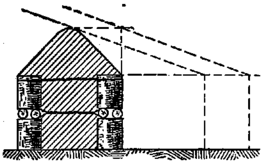


Fig. 68

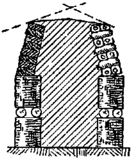


Fig. 69

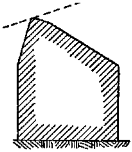


Fig. 70

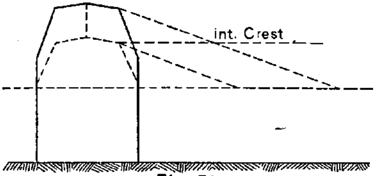


Fig. 71

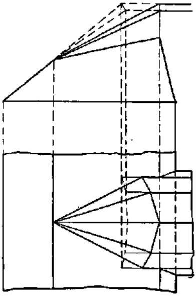


Fig. 72

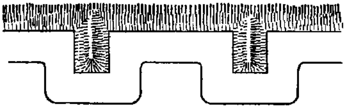


Fig. 73

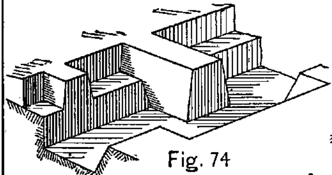


Fig. 74

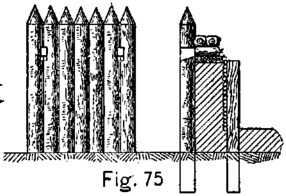


Fig. 75

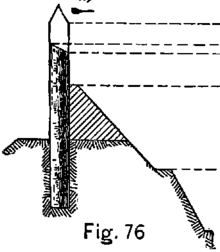


Fig. 76

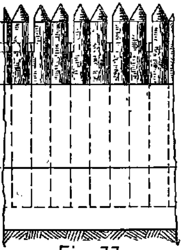


Fig. 77

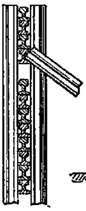


Fig. 81

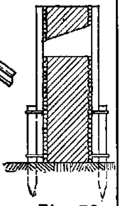


Fig. 78


Fig. 79


Fig. 80

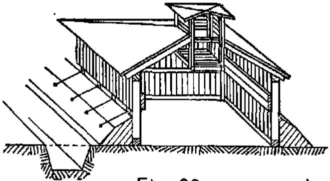


Fig. 82


Fig. 83

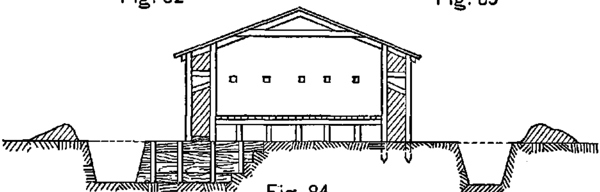


Fig. 84

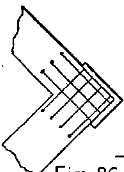


Fig. 86

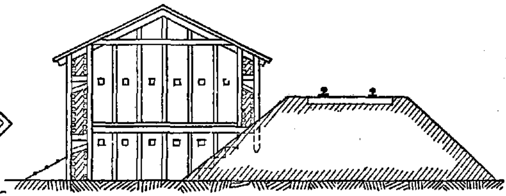


Fig. 85

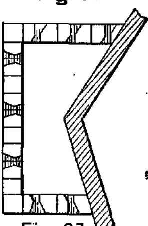


Fig. 87

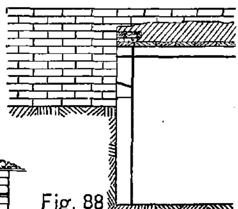


Fig. 88

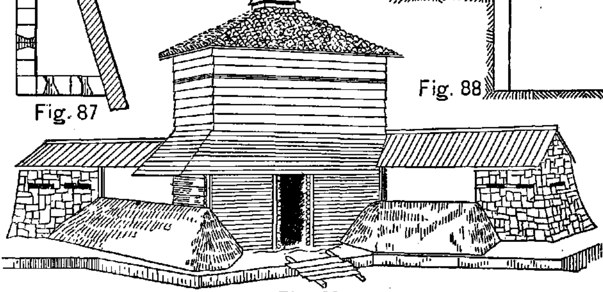


Fig. 89

would penetrate the entire structure, as it would encounter no stone. A construction permitting stone to be placed behind each timber in the path of a shot passing through it was introduced, but was complicated and difficult. The final and most satisfactory design was circular in plan. A corrugated-iron drum 13½ ft. in diam. and 3 ft. 11 ins. high was set on level ground and a parapet of stone, 3 ft. thick at bottom and 2 ft. at top, was built around it on the outside. On this parapet was placed a shield consisting of an inner drum of corrugated iron 15 ft. in diam. and an outer one 16 ft. in diam., each 2 ft. 3 ins. high, and kept at uniform distance by spacing blocks at the top.

The loopholes, 12 in number, of sheet iron of the double-hopper type, with throats 6 ins. high by 3 ins. wide, were placed in the shield, the bottoms 4 ft. 3 ins. from the floor. The space between the skins of the shield was filled with closely packed broken stone. It was found necessary to provide for adding stone under the loopholes to replace settlement. An octagonal frame rested on top of the shield and was bolted to the spacing blocks, its alternate sides extended to complete a square on which a pitch roof was built. A canvas roof, supported by a pole, like a conical tent was used in some cases.

A small opening on one side, large enough for a man to crawl through, was closed by an iron door under the outer drum of the shield. There was also a removable barrier of the same construction as the shield, which stood against the opening in the drum of the parapet.

A trench 4½ ft. deep was dug 2 to 5 yds. outside the blockhouse and a wire entanglement was constructed outside the trench. Such blockhouses were sometimes built at the rate of 6 a day by a party of 30 men. Nearly 400 of these were erected, most of them in a single month.

47. **Flanking defenses.**—Dead angles in front of a defensive structure may be swept longitudinally or parallel to the firing crest to prevent their being used as a rallying place by the assailants. Such fire is usually directed along the front from one of the flanks and is called **flanking fire.** The structures built for this purpose are called **flank defenses.**

A **caponiere** or **tambour** is a small, low, stockaded inclosure or blockhouse situated to fire along a dead angle. If it can be placed at the intersection of two dead angles, it may sweep both. At the foot of a wall a stockade open at the top may be used, if its floor must be at ground level, which will be the case on rock or marsh, though a weatherproof cover will generally be desirable, fig. 87. If the floor can be sunk below the ground level, a bullet-proof roof is necessary, fig. 88. In a ditch, the structure should be sunk so that the roof will be below ground level and the top should be of overhead cover. It must not extend entirely across the ditch, or if it does, or nearly so, it must be obstructed so that it can not be used as an approach.

There must be communication through and under the parapet or wall, so that the defenders in the tambour can escape into the interior at the last.

48. **A ditch** may also be flanked by a **counterscarp gallery,** which is a bombproof chamber formed behind or outside of the counterscarp at the salient of a parapet, fig. 86. The side toward the ditch is stockaded and loopholed for fire along the ditch. The entrance must be on the ditch side and protected from fire. The garrison of a counterscarp gallery will usually have no communication with the interior of the work.

49. **Obstacles** are designed to protect the works from surprise and to reduce the momentum of attack by breaking up the enemy's formation and holding him under the accurate fire of the defense. They should be **invisible** from the direction of approach, should be **difficult to destroy,** and should afford **no screen or cover** to the enemy.

Obstacles may be in front of or on the line of defense. In the former case they should be 50 to 100 yds. in front of the firing crest. If on the line, they are in the ditch, if there is one, or are employed to close intervals and are flanked or enfiladed by adjacent works.

50. **Abatis** consists of trees lying parallel to each other with the branches pointing in the general direction of approach and interlaced. All leaves and small twigs should be removed and the stiff ends of branches pointed.

Abatis on open ground is most conveniently made of branches about 15 ft. long, The branches are staked or tied down and the butts anchored by covering them with earth. Barbed wire may be interlaced among the branches. Successive rows are placed, the branches of one extending over the trunks of the one in front, so as

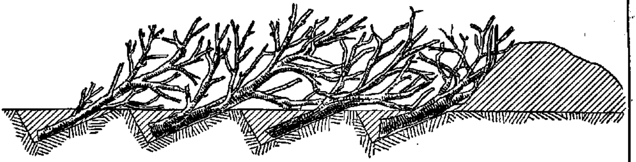


Fig. 90

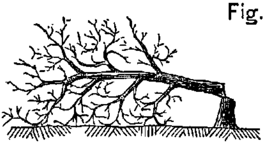


Fig. 91

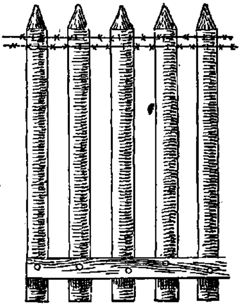


Fig. 92

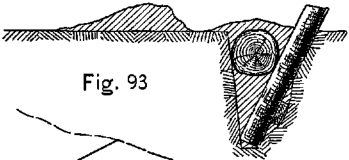


Fig. 93

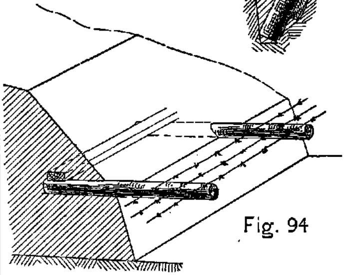


Fig. 94

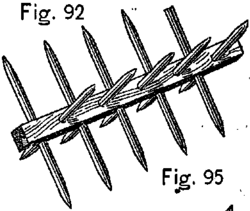


Fig. 95

Fig. 97

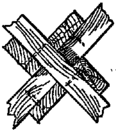


Fig. 96

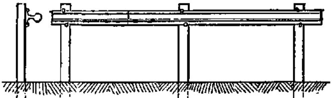


Fig. 98

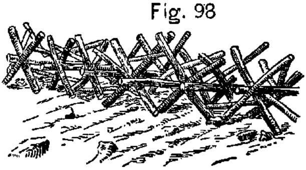


Fig. 99

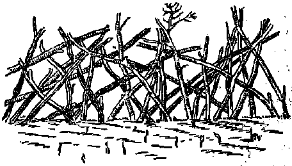


Fig. 100

to make the abatis 5 ft. high and as wide as desired It is better to place the abatis in a natural depression or a ditch, for concealment and protection from fire. If exposed to artillery, an abatis must be protected either as above or else by raising a glacis in front of it. Fig. 90 shows a typical form of abatis. An abatis formed by felling trees toward the enemy, leaving the butt hanging to the stump, the branches prepared as before, is called a **slashing,** fig. 91. It gives too much cover, and should be well flanked.

51. **A palisade** is a man-tight fence of posts. Round poles 4 to 6 ins. in diam. at the large end are best. If the sticks run 5 to 8 ins., they may be split. If defended from the rear, palisades give some shelter from fire and the openings should be made as large as possible without letting men through. If defended from the flank, they may be closer, say 3 to 4 ins. apart. The top should be pointed. A strand or two of barbed wire run along the top and stapled to each post is a valuable addition.

Palisading is best made up in panels of 6 or 8 ft. length, connected by a waling piece, preferably of plank, otherwise of split stuff. If the tops are free, two wales should be used, both underground. If the tops are connected by wires, one will do.

Palisades should be planted to incline slightly to the front. As little earth should be disturbed in digging as possible, and one side of the trench should be kept in the desired plane of the palisade. If stones can be had to fit between the posts and the top of the trench, they will increase the stiffness of the structure and save time in ramming, or a small log may be laid in the trench along the outside of the posts. Figs. 92 and 93 show the construction and placing of palisades.

52. **A fraise** is a palisade horizontal, or nearly so, projecting from the scarp or counterscarp. A modern and better form consists of supports at 3 or 4 ft. interval, connected by barbed wire, forming a horizontal wire fence, fig. 94.

53. **Cheveaux de frise** are obstacles of the form shown in fig. 95. They are usually made in sections of manageable length chained together at the ends. They are most useful in closing roads or other narrow passages, as they can be quickly opened for friendly troops. The lances may be of iron instead of wood and rectangular instead of round; the axial beam may be solid or composite. Figs. 96 and 97 show methods of constructing cheveaux de frise with dimension stuff.

54. **A formidable obstacle against cavalry** consists of railroad ties planted at intervals of 10 ft. with the tops 4½ ft. above the ground, and connected by a line of rails spiked securely to each, fig. 98. The rail ends should be connected by fish plates and bolted, with the ends of the bolts riveted down on the ends.

Figs. 99 and 100 show forms of heavy obstacles employed in Manchuria by the Russians and Japanese, respectively. The former is composed of timber trestles, made in rear and carried out at night. The latter appears to have been planted in place.

55. **A wire entanglement** is composed of stakes driven in the ground and connected by wire, barbed is the best, passing horizontally or diagonally, or both. The stakes are roughly in rectangular or quincunx order, but *slight irregularities*, both of position and height should be introduced.

In the **high entanglement** the stakes average 4 ft. from the ground, and the wiring is horizontal and diagonal, fig. 101.

The low wire entanglement has stakes averaging 18 ins. above the ground and the wire is horizontal only. This form is especially effective if concealed in high grass. In both kinds the wires should be wound around the stakes and stapled and passed loosely from one stake to the next. When two or more wires cross they should be tied together. Barbed wire is more difficult to string but better when done. The most practicable form results from the use of barbed wire for the horizontal strands and smooth wire for the rest.

This is the most generally useful of all obstacles because of the rapidity of construction, the difficulty of removal, the comparatively slight injury from artillery fire, and its independence of local material supplies.

Time and materials.—One man can make 10 sq. yds. of low and 3 sq. yds. of high entanglement per hour. The low form requires 10 ft. of wire per sq. yd. and the high 30 ft. No. 14 is a suitable size. The smooth wire runs 58.9 ft. to the lb. A 100-lb. coil will make 600 sq. yds. of low or 200 sq. yds. of high entanglement. If barbed wire is used, the weight will be about 2½ times as much.

56. **Wire fence.**—An ordinary barbed-wire fence is a considerable obstacle if well swept by fire. It becomes more formidable if a ditch is dug on one or both sides to

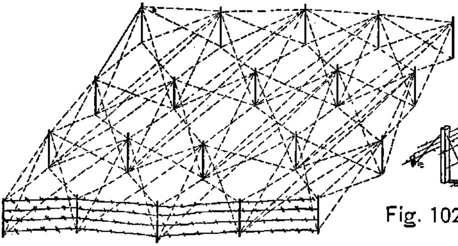


Fig. 101

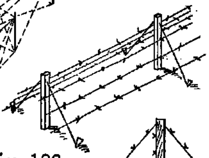


Fig. 102

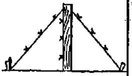
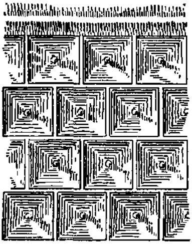


Fig. 103



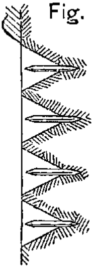


Fig. 104

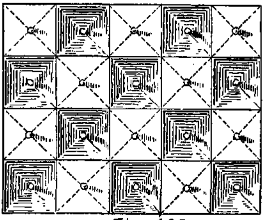


Fig. 105

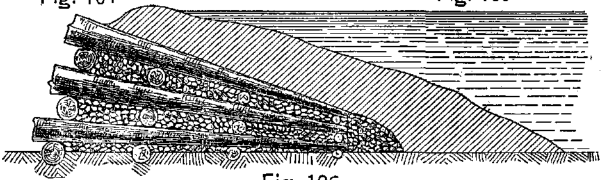


Fig. 106

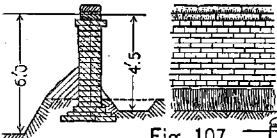


Fig. 107

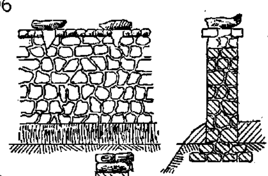


Fig. 108

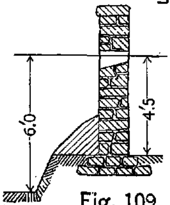


Fig. 109

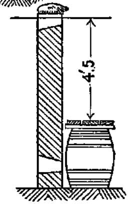


Fig. 110

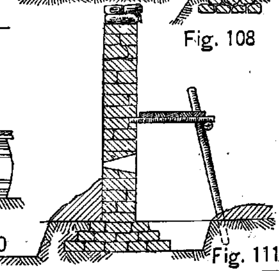


Fig. 111

obstruct the passage of wheels after the fence has been cut. The fence is much more difficult to get through if provided with an apron on one or both sides, inclined at an angle of about 45°, as indicated in figs. 102 and 103. This form was much used in South Africa for connecting lines between blockhouses. When used in this way the lines of fence may be 300 to 600 yds. long, in plan like a worm fence, with the blockhouses at the reentrant angles. Fixed rests for rifles, giving them the proper aim to enfilade the fence, were prepared at the blockhouses for use at night.

Such a fence may be arranged in many ways to give an automatic alarm either mechanically or electrically. The mechanical forms mostly depend on one or more single wires which are smooth, and are tightly stretched through staples on the posts which hold them loosely, permitting them to slip when cut and drop a counterweight at the blockhouse, which in falling explodes a cap or pulls the trigger of a rifle.

57. **Military pits** or **trous de loup** are excavations in the shape of an inverted cone or pyramid, with a pointed stake in the bottom. They should not be so deep as to afford cover to the skirmisher. Two and one-half feet or less is a suitable depth. Fig. 104 shows a plan and section of such pits.

They are usually dug in 3 or 5 rows and the earth thrown to the front to form a glacis. The rear row is dug first and then the next in front, and so on, so that no earth is cast over the finished pits.

An excellent arrangement is to dig the pits in a checkerboard plan, leaving alternate squares and placing a stake in each of them to form a wire entanglement, fig. 105. One man can make 5 pits on a 2-hour relief.

58. **Miscellaneous barricades.**—Anything rigid in form and movable may be used to give cover from view and fire and to obstruct the advance of an assailant. Boxes, bales and sacks of goods, furniture, books, etc., have been so used. The principles above stated for other obstacles should be followed, so far as the character of the materials will permit. The rest ingenuity must supply. Such devices are usually called **barricades** and are useful in blocking the streets of towns and cities.

59. **Inundations.**—Backing up the water of a stream so that it overflows a considerable area forms a good obstacle even though of fordable depth. If shallow, the difficulty of fording may be increased by irregular holes or ditches dug before the water comes up or by driving stakes or making entanglements. Fords have frequently been obstructed by ordinary harrows laid on the bottom with the teeth up.

The unusual natural conditions necessary to a successful inundation and the extent and character of the work required to construct the dams make this defense of exceptional use. It may be attempted with advantage when the drainage of a considerable flat area passes through a restricted opening, as a natural gorge, a culvert, or a bridge.

Open cribs filled with stones, or tighter ones filled with gravel or earth (see Bridges, 71), may form the basis of the obstruction to the flow of water. The usual method of tightening cracks or spaces between cribs is by throwing in earth or alternate layers of straw, hay, grass, earth, or sacks of clay. Unless the flow is enough to allow considerable leakage, the operation will not be practicable with field resources. A continuous construction, shown in section in fig. 106, is frequently employed. The ends of the dam must be carried well into the earth to prevent the water from cutting around them.

When the local conditions permit water to be run into the ditch of a parapet it should always be done.

60. **Accidental cover** includes accidents of the terrain not of natural origin, which can be used to advantage as cover from view and fire. Such are **walls** and other inclosures, **buildings, cuttings, embankments,** etc.

All these require preparation to better subserve their purpose. The application of the foregoing principles to such conditions is sufficiently indicated by the illustrations. The preparation has mainly to do with the defensive adaptation of the cover by providing for fire from it.

Fig. 107 shows the preparation of a wall less than 4 ft. high, for a single tier of fire. Fig. 108, the same for a wall 6 ft. high. Fig. 109, the same for a wall 7 ft. high. Fig. 110, a wall 9 ft. high for two tiers of fire, one standing and one lying. Fig. 111, the same for one tier standing and one kneeling.

Fig. 112 shows the treatment of a hedge which screens the parapet from view, holds the exterior slope at a steep pitch, and forms an excellent head cover.

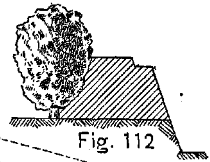


Fig. 112

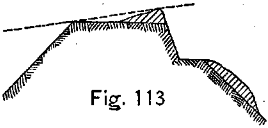


Fig. 113

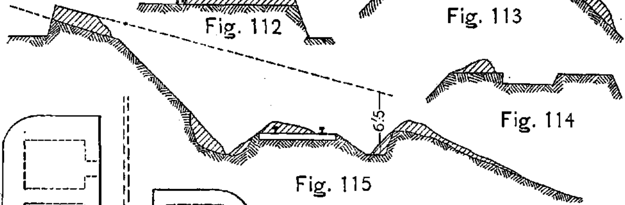


Fig. 114

Fig. 115

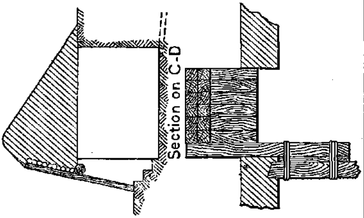


Fig. 116

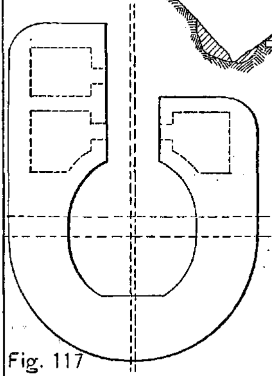


Fig. 117

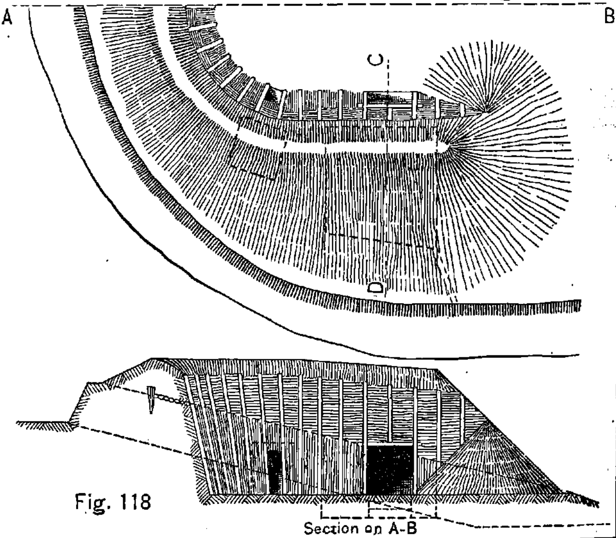


Fig. 118

Fig. 113 shows the best method of preparing a low embankment and fig. 114 a high one.

Fig. 115 shows three methods of treating a railroad cut; one by a tier of fire on the lower side, another by a tier of fire on the upper side, and the third by a firing crest on the track. Retreat from the first and advance from the second are obstructed by the cut itself. Both may be used, the fire of the rear line covering the retreat of the front one. Care must be taken that the rear line can not shoot into the forward one.

61. **Buildings** if exposed to artillery are untenable, but against rifle fire are made defensible by barricading all windows and doors, except one for ingress and egress on the most sheltered side, and providing loopholes.

Barricades for doors and windows may be of solid materials, such as timber, iron, brick, stone, of stockade construction, par. 45, or of hollow articles of any kind which will form receptacles to retain earth or other bullet-proof filling. Articles of furniture, trunks, baskets, and barrels may be mentioned (see also Revetments). Bags are useful here as everywhere.

A house of stone or brick will give some protection from fire. A wooden house gives protection from view only, unless time suffices to stockade the walls. Care must be taken not to exclude too much light. Openings in partitions should be enlarged and additional ones made to give the freest possible communication. Hatches should be cut through the floors and roof to give free escape of smoke and gases.

Loopholing is done as already explained, par. 13. The loopholes should not, as a rule, be less than 4 ft. apart in the same tier. They should be arranged to concentrate fire in front of doors or accessible windows. Doors should be fnrther strengthened by barricades across the spaces into which they open.

If **bay windows** or other projections are available, they may be utilized for **flanking fire.** The loopholes for them may well be near the ground so that a tier for other fire can be placed above them.

As soon as the barricades and necessary banquettes are finished all other combustible material should be removed and a supply of earth and water for fire fighting should be placed at convenient points. **Stores** and **ammunition** are also brought in and disposed of in suitable places. A space as secure as possible from fire should be set apart and prepared as a **hospital;** and **latrines** must also be arranged for.

The defensive preparation will depend much on whether the house is to stand an actual assault, or only to afford an advantageous cover for fire upon the enemy while approaching. Tbis should be determined and announced when the order to occupy the house is given. If the building is to be held to the last, a good flank defense must be arranged and the interior walls must be loopholed and arrangements made to quickly barricade interior openings, so that a fighting retreat may be made from room to room.

In addition to tambours and caponieres, par. 47, flanking by vertical fire may be accomplished, as shown in fig. 116. Such a construction is called a **machicoulis gallery.** Fire from such a gallery is not very effective and will usually not be worth the trouble of preparing for it. Hand grenades, small enough to be pushed through the loopholes, will be equally effective.

62. While the defensive preparation of the building is in progress the adjacent **ground must be cleared** of all obstructions to fire and such obstacles as are possible constructed. **Good obstacles** make flank defense much less necessary, except for houses to be held as long as possible regardless of losses.

63. **Groups of buildings,** such as villages, may be made the cover for a very stubborn defense. A number of them, sufficient to accommodate the desired garrison, of most substantial construction and so situated as to flank each other, are selected and treated as above described. The rest must be torn down or burnt to clear the ground.

64. **General considerations.**—The foregoing paragraphs involve the general supposition that the best is attainable. In actual service this will not often be the case. War does not usually permit sandpapering and polishing. The main thing is to get some substantial result and get it quickly. The military engineer, considering projects for field fortification, mnst reckon with four imperative limitations—lack of time, lack of men, lack of tools, and lack of materials. Each of these tends to defeat his object of doing the very best thing and compels him to work out a scheme which

goes as far in that direction as his limitations permit. The best is to be kept in view always to steady the aim even if it can not be reached.

The first move should be to take account of stock by finding out what time is allowed, what force is available, what tools are on hand, and what materials can be procured. The relative quantities and numbers hereinbefore given are to be considered as minima. Every effort should be made to get at least that number, and by all means get more if possible, especially of men. The more men the easier the work of each and the better condition all will be in when the work is finished. Manual labor for soldiers in the field is a necessary evil at best and should always be minimized.

Knowing from the time, force, tools, and materials to be had what can be done in the aggregate, lay out a scheme within the limits, following such of the preceding principles as are fundamental and slighting as much as may be necessary those which are secondary only. An incomplete or emergency scheme leaves some risk uncovered. Decide which is the least probable risk and economize time and labor in that direction.

65. **Sieges.**—The attack by regular approaches of a strongly fortified place involves mainly the principles and devices previously discussed, but their employment is under conditions so different from those resulting from the contact of two mobile forces as to require separate treatment. What follows is not a complete presentation of the subject of sieges, but only of such features as are concerned with engineering duties on the side of the attack.

The differences referred to are principally—

Guns of heavier caliber will be encountered.

The terrain being well known to the defense, all fire will be more accurate.

High-angle fire will be extensively employed, and angles of fall of 30° and greater must be expected.

Some trench work must be executed under close fire and must gain ground to the front. A variation either way from its proper direction will lose ground or else expose the trench to enfilade, so that accurate tracing is of great importance.

At the same time these conditions of sieges are more alike in different times and places than those of operations with mobile forces, and the best ways of doing some things can be stated for sieges with more confidence than in the case of ordinary fieldworks.

66. **The first step** toward the reduction of a fortress is to cut off communication of the occupants with the outside world. This is done by a rapid movement of a relatively small force followed by reenforcements sufficient to hold a line entirely around the place and beyond the range of its artillery, say 2½ to 3 miles from its main lines of defense. This line is called the **line of investment,** and the belt of territory immediately outside of it occupied by the investing force is called the **zone of investment.** Whether this line must be occupied continuously will depend upon its nature. As much must be actually occupied or commanded as could be used by the besieged for exit or entrance. The line of investment is divided into sections, preferably so chosen that a unit of command can be assigned to each.

67. **Troops assigned** to a section of the zone of investment begin at once to reconnoiter it and put it in the best possible state of defense. **Artificial or accidental features are prepared** and strengthened, **intrenchments** thrown up where required, **communications** made and improved through and between sections, and **telegraph** and **telephone** lines established around the zone and to headquarters. Every means must be utilized to gain knowledge of the ground inside the zone. The time which must elapse before the siege material can be brought up will permit a great deal of such work to be done.

68. **The real attack** or systematic approach is pushed inward from a few points only of the zone of investment, usually one or two. The side on which these approaches are to be made will be determined by the following conditions:

(1) The best communication with the base.

(2) The best terrain for battery positions and approaches under natural cover.

(3) The most favorable ground for construction and operation of siege railways.

(4) The easiest digging.

(5) The most important consequences of success.

The first condition will usually be controlling, unless one of the others is prohibitory. If the zone of investment is favorable and ample siege railway equipment is available, the attack may be conducted from points somewhat removed from the main terminus of the supply line.

69. **The main defensive** line of an important fortress will consist of a series of detached forts. To breach such a line one fort at least, more often two, must be taken, and during the operation the fire of the one on each side must be kept down. If two forts are to be reduced, the siege will consist of artillery work against four and trench work against the middle two of these.

When the front of attack is decided, the **main engineer park** is located, out of reach of the defenders' artillery, convenient to the front selected and to the main supply line, and connected with the latter by good communications. Here is assembled all the siege material pertaining to engineering operations as fast as it arrives, to be sorted and arranged in convenient shape for selection and forwarding to the front as required.

Sites for the main siege batteries are next selected, at moderately long range from the forts, 2,500 to 4,000 yds., and for **intermediate parks** near them to contain materials for the construction, repair, and supply of the batteries. These sites are connected by a belt railroad immediately in their rear, and the belt line is connected with the main park at one or more places.

70. **The complete investing force** must be heavily reenforced, ordinarily about doubled, before siege operations on any considerable scale are undertaken. The additional force will be concentrated along the front of attack, mainly toward its center. This and the investing force along the front of operations are sometimes called **siege troops,** and the remainder of the investing force distinguished as **investing troops.** The siege force should consist of infantry, engineers, and artillery in the proportion approximate of 83%, 5%, and 12%, respectively, with the proper contingent of the Signal and Hospital Corps, and supernumerary engineer and ordnance officers. The total attacking force will range from $2\frac{1}{2}$ to 4 times the strength of the garrison.

71. **The siege artillery** will probably be disposed in batteries of 4 pieces or less, dispersed as much as concentration of fire will permit, and sited when possible on the reverse slopes of ridges or hills, or behind timber, and will employ indirect fire almost exclusively.

Though batteries are invisible, the high-angle fire of the defense will reach them, as the enemy's artillery will systematically search all reverse slopes within range, and the effect of shells must be localized by artificial cover. An emplacement for each gun will be best. A light parapet across the front and on the sides will answer. A 4 to 1 slope is the most convenient inclination of ground. Fig. 118 shows a typical emplacement for such a slope. Ample bombproof cover for men and reserve ammunition should be provided, preferably on the flanks. Fig. 117 shows half plans of two types used by the Japanese.

On level ground the platforms may be laid on the natural surface, the guns surrounded by a splinter-proof wall, as fig. 78, in which case rooms of sufficient size may be walled off between the guns to form service magazines. The floors of the magazines may be depressed sufficiently to permit a weatherproof roof to be thrown over the ammunition, below the crest of the wall. The drainage of the roof must be intercepted before it runs into the pit.

72. **First parallel.**—When the siege batteries have brought the artillery fire of the defense under control the first attempt to gain ground to the front is made by opening a trench generally parallel to the line of investment and, if possible, within 1,200 yds. of the enemy's main line. During the day the outposts are advanced to or beyond the proposed line, to permit it to be reconnoitered and its bearings noted. At night the attack is pushed more strongly and the enemy driven in as far as possible for the greater safety of the working parties.

Tracing.—As soon as it is dark enough for concealment the tracing is begun. Each party consists of one engineer officer, one noncommissioned officer, and a private for each 50 yds. of line to be traced. The outfit consists of tracing tape, pegs, mallets, and measuring rods. The tracing tape is of white cotton, 50 yds. long, $\frac{3}{4}$ in. wide, and marked at 5-ft. intervals by weaving or printing. It is provided with a loop at each end to attach to a stake or to another tape. The officer must provide himself with a compass and means of reading it by artificial light (Reconnaissance, 21). There should be a tracing party for each 800 yds. of line, at least, and more will be better, as the time spent in tracing is lost for digging. It will be most advantageous if the tracing can be put through during the twilight, while it is still light enough to see the ground and read the compass, but too dark for the defenders to see the parties. The parties are paraded, outfitted, and moved up as close as possible before dark.

The officer, provided with a description of his initial point and the bearing or course of the line from it, proceeds to it, his party following in single file. Having identified the initial point, the officer stations a sapper there, faces him in the direction of the line, and taking the end of his tape, marches along the line to be traced, followed by the remainder of the party. When the tape is nearly run out the sapper checks it, and, as the end is reached, sets a stake between his heels and puts the loop of the tape over it The officer stations the second sapper at the front end of the first tape, facing in the direction of the line, and proceeds as before. When the second tape is run out the second sapper sets his peg and puts the loop of both tapes over it. The operation is continued until all the tapes are down. The officer returns to the rendezvous of the working party and conducts it to the line. Each sapper lies down at his peg, facing the initial point, and upon the arrival of the working party assists in the extension along his tape.

If the fire of the defense is not sufficiently under control, it will be necessary to have the outposts begin the first parallel by digging pits, or short lengths, which can afterwards be extended to a connection.

73. **Approaches** or zigzag trenches must be traced and dug on the same night with the first parallel, connecting it with cover in the rear. There should be at least three such approaches—at right, left, and center.

The typical trace of such an approach is shown in fig. 119. The **branches** or **legs** AB, BC, etc., must have a direction such that when prolonged they will pass outside of the extreme point on the corresponding flank from which the defense can bring fire to bear. A leg will usually be not more than 100 ft. in length.

The tracing of approaches for simultaneous digging differs in detail but little from that of the parallel already described. It is more difficult because the line is broken, and greater accuracy is required. Each tracing party is given an extra man for each angle. The tape is run continuously, and, as each angle is passed, the extra marker stationed there cuts the tape 9 ft. from the angle on the back course, makes the long end fast to a peg at the cut, and stretches the short end in prolongation of the forward course, fig. 120, to mark the direction of a return carried across the end of the back leg to protect it from enfilade. The return may be from 10 to 20 yds. long. It can be prolonged from this short end of tape without further tracing. Approaches so traced are dug simultaneously over their entire length the same as the parallel.

74. **The digging of approaches under fire** differs from ordinary trench work in that it is done progressively from one end and with the men reasonably protected from fire while doing it. Tracing is dispensed with. Approaches are usually called **saps**, the operation of digging them **sapping**, and the skilled men **sappers**. The end at which digging is in progress is called the **saphead**.

So long as the legs can be given the direction described in par. 73, cover is needed on the end and one side only. This form is called **single sap.** A single sap gaining ground to the left is called a **left-handed**, and to the right a **right-handed**, sap. The shovelers work right-handed in a left-handed sap, and the reverse.

When the saphead is very close to the enemy's line, such direction can not be given, and cover is required on the end and both sides. This form is called **double sap.**

Single sap.—A party of one noncommissioned officer and 8 sappers in two reliefs works at the saphead. The two leading sappers, Nos. 1 and 2, excavate a trench 4½ ft. deep and just wide enough to work in, throwing the earth to the front or exposed side. They are protected in front, or on the end of the trench, by a pile of half-filled sand bags, 50 or 60 in number, piled so as to make a parapet 2 ft. high. The sand bags should be smeared with mud so as to show the color of the soil. No. 1, kneeling or crouching, undercuts the end breast a few inches and brings down the earth. He steps back and No. 2 takes his place and shovels the loose earth out. No. 1 returns, throws forward as many sand bags as may be necessary to gain ground, using a fork or rolling them over with his hands. He then undercuts again and the operation is repeated. Nos. 3 and 4 widen the trench 2 ft. and raise the parapet, also forming a berm 12 to 13 ins. wide.

The rate of advance of a sap is only 2 to 4 ft. an hour. When half a yard has been gained, Nos. 1 and 2 exchange places and when a yard is gained the other

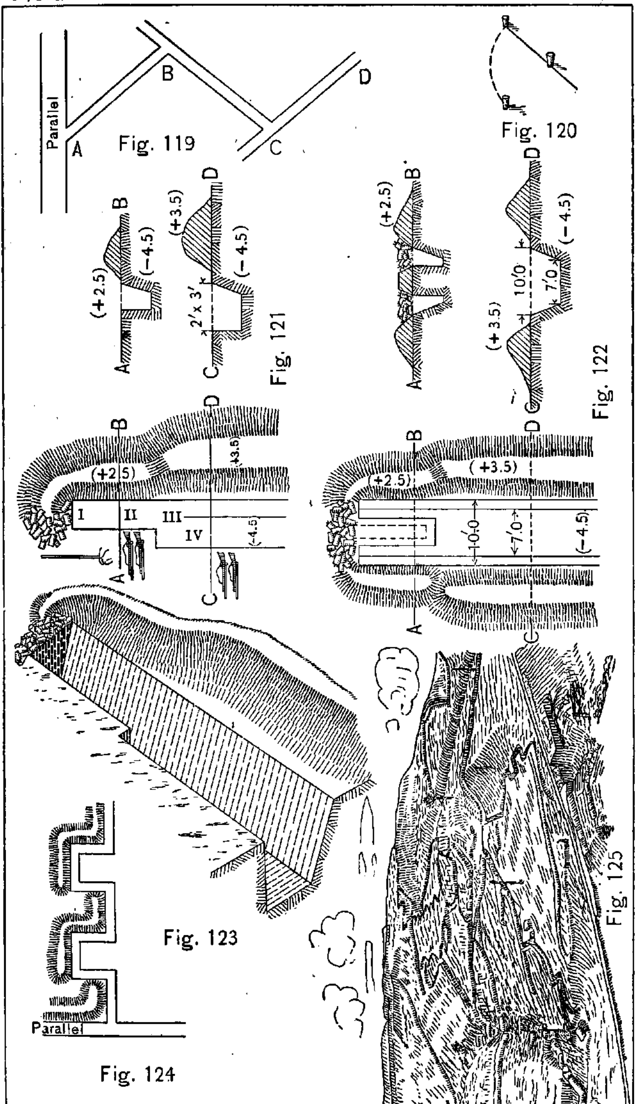


Fig. 119

Fig. 120

Fig. 121

Fig. 122

Fig. 123

Fig. 124

Fig. 125

relief comes in. At each change of reliefs the men who were Nos. 3 and 4 on the last tour take 1 and 2. Casualties are made up from the waiting relief. Generally, unless reduced to less than 4 men, the detachment must work without reenforcement until the regular change of trench reliefs.

A working party of infantry, 25 ft. in rear of the sappers, widens the trench to 10 ft. Fig. 121 shows a plan and sections of a single sap, and fig. 121 gives a perspective view of a left-handed single sap in progress.

Double sap.—Two parties work parallel to each other, Nos. 1 and 2 leaving a 4-ft. tongue between them, which is taken out by Nos. 3 and 4. No widening party is required. Fig. 122 shows a plan and sections of a double sap.

To prevent enfilade the direction of the trench is changed at right angles as soon as the plunging fire becomes too annoying. After going 25 to 30 ft. laterally, the trench turns again to the front, and after having advanced sufficiently to form a traverse, turns again to the right until it reaches the original line, when it resumes the main direction. Fig. 124 shows the plan of such a sap. It is called a **traversed sap.**

75. **Second parallel.**—The first infantry position established, a second one well advanced is the next objective. It is called the **second parallel** and should be 500 or 600 yds. from the enemy's works, or about midway in front of the first parallel. It will envelop only the work selected for attack and will thus be shorter than the first. The second parallel, and the approaches to it from the first, may be established in a night, like the first parallel and its approaches, though this will be the exception. With an alert defense the advance from first to second parallel must be by sap. When the heads of the saps are abreast of each other and on the desired line they may be turned toward each other and run to a connection, forming the second parallel, though, if possible, the work should be expedited by extending parties for simultaneous work.

76. **Third parallel.**—This will be about halfway from the second parallel to the enemy's works and will in most cases be the position of assault, though sometimes 4th and even 5th parallels have been found necessary. At this close range attention is necessary to guard the sapheads, which can be done by machine guns and rifle fire from the second parallel. As the saps advance the returns may be lengthened and turned so as to form demi-parallels. This will enable a stronger guarding force to be kept under shelter and well advanced to repulse sorties or to take the offensive if opportunity offers.

77. The foregoing description of siege works embodies principles but not complete practice; the latter is greatly affected by accidents of ground. Fig. 125 is a general view of the trenches actually constructed by the Japanese in the attack on Fort Kuropatkin. Especially interesting is the traversing of the ravine or gully on the left, which then became a good approach. Such ravines were characteristic of the terrain around Port Arthur, and much work of this kind was done by the besiegers. Sometimes the traverses were only planks laid across from bank to bank with sand bags on top, allowing passage under them. The distances between the traverses and the height of the sand-bag protection were so regulated that a shot grazing one could not pass under the next.

MINING.

78. **Military mining** will be here considered to include only the operations incident to forming communications or chambers completely underground; to placing in such chambers charges of explosives and to firing such charges.

Other uses of explosives in engineering operations are more commonly classed as **blasting** and will be considered under **demolitions.** Blasting also includes the use of explosives in forming the underground spaces in the process of mining.

Underground communications are classed according to their directions as **galleries,** which are horizontal or nearly so, and **shafts,** which are vertical or nearly so.

Galleries are classed according to their size as **great** or **grand galleries,** which are 6 ft. high by 7 ft. wide; **common galleries,** 6 ft. by 3½ ft.; **half galleries,** 4½ ft. by 3 ft.; **branches,** 3½ ft. by 2½ ft., and **small branches,** 2½ ft. by 2 ft. When the formation of the ground permits, earth augers may be used, forming **bores** or **drill holes.**

Shafts may be drill holes or wells, or may range in size from the smallest in which a man can work, say 3 by 3 ft., to any size which may be required, seldom more than 6 by 10 ft.

The dimensions of galleries and shafts are determined by the use to be made of them, their length, and the minimum space in which men can work. If troops or guns are to be passed through galleries they must be made large enough for that purpose. Grand and common galleries will usually meet these requirements. Galleries used only to reach the proper point to place the explosive are made of the size which is most rapidly driven and can be sufficiently ventilated. This is usually the half gallery in which men can work without too much constraint, through which the excavated earth can be transported by efficient methods, and in which reasonable ventilation can be maintained by simple means.

Branches or small branches may be used when near the objective points. They are rapidly driven for short distances, 20 ft. or so, but when longer the difficulties of digging, earth disposal, and ventilation become too great. When the soil permits the use of augers, bores will usually be employed for this purpose.

The quantity of explosive placed at any point is called a **charge.** The place prepared for the reception of the charge is called the **mine chamber** or simply the **chamber.**

79. **The primary requisites** of subterraneous excavations are **accuracy of direction, prevention of caving, ventilation, drainage,** and **lighting.**

The restricted space usually requires not only that men shall work in constrained positions, but also that special tools be provided of smaller size than those used for open earth work. A special tool called the **push pick,** shown in fig. 126, is very convenient in soft earth. Picks and shovels for mining are similar in form to standard tools, but are smaller, and have shorter handles.

80. **Accuracy of direction** may be secured in sufficient degree by refined application of methods described in Reconnaissance. The **principal characteristic** of underground surveying is the **absence of daylight.** All targets must be luminous, and readings of instruments may be made by artificial light. As a rule, the less light there is in the gallery, other than the target and reading lights, the better.

The best target is a light of medium strength behind a narrow slit, and is easily improvised. A convenient form is shown in fig. 127. The slit is V-shaped in form and adjustable by rotating the two sides about their pivots, so that the maximum width can be adjusted to the intercept of the wire at various distances, as shown in figs. 128 and 129. A sheet of white paper or cloth behind the light will enable the observer to work much faster.

In large galleries a transit may be used, and in smaller ones a plane table or prismatic compass. The box compass can not be sighted and read with sufficient accuracy for this work. Compass courses can not be relied upon, as the needle is subject to abnormal fluctuation when used underground. At each change of direction the back azimuth and azimuth must be carefully read and the angle between them used to determine the change. The light used for reading a compass should be nonmagnetic and nonelectric, or if not so, must be held in exactly the same position during both readings.

A ranging device may be improvised as shown in fig. 127. The edges of the box should be straight and parallel to each other and to the line of sight. The box resting on a smooth board or paper nearly level is pointed at the back and forward targets in succession, a pencil being drawn along one edge in each position. The angle between the pencil lines is measured with a protractor.

The slope of an inclined gallery is maintained by the use of a **field level.** Many forms may be improvised by the use of a level tube or plumb line. A convenient form is shown in fig. 130. The two pieces having been pivoted together, as shown, are given a series of suitable angles of inclination, and at each setting a small hole is bored through both pieces, forming two series of holes, as indicated. To reproduce any setting spread the pieces until the corresponding holes fall together and put a closely fitting pin through both. The longer piece is placed on the inclined line of the gallery, usually on two consecutive frames, for which its length is adapted. On the shorter piece may be placed an ordinary carpenter's or other level, or a level tube may be set in the piece itself if convenient.

The greatest accuracy need not be maintained during the construction of galleries though carelessness must be avoided. When the immediate vicinity of the chamber or other objective point is reached the entire line must be checked as accurately as possible, and the length and direction of the branch or drill hole necessary to reach the objective point must be determined. The digging having been substantially completed, the galleries may be kept clear of men to facilitate work when this final survey is made.

81. **The first step** in any mining operation will be to locate the objective point with respect to the point of departure by the best practicable measurements above the ground, preferably intersections with a transit from a carefully measured base. This position should be plotted on a good map. If no obstructions are suspected, a straight line from the point of departure to the objective should be adopted for the gallery and its length and azimuth determined. A profile of the ground along the line of the gallery permits determination of the proper slope or slopes.

The transfer of the azimuth underground will depend on whether the gallery starts from a shaft, fig. 134, from a reverse slope, fig. 131, or, if not very deep, from a level with a descending branch, fig. 132. In the second and third cases, which will be the rule in military mining, the azimuth may be established in the gallery by a transit or compass used in the ordinary way. In the case of a shaft, which will be the exception, the azimuth must be established across the top or mouth and transferred to the bottom by means of plumb lines, fig. 134. The plumb lines should be fine wires, the bobs true and heavy, suspended in water if necessary to steady them, and the marking should be done by scratches on the heads of nails or tacks. During construction the alignment may be kept by a line stretched along the gallery and the elevations by the field level.

Changes of direction, if necessary, are most conveniently measured in the gallery by means of a **bevel** made above ground to the proper angle, fig. 133. In checking, the angles should be determined by a careful geometrical construction in the gallery, or measured with an instrument.

In case an unexpected deviation is necessary, as to avoid an obstacle, it may be made to suit the conditions found and afterwards measured and plotted on the chart. The necessary change to be made after the obstacle is passed, in order to direct the gallery again on the objective, will be determined from the chart and the proper bevel made and sent into the gallery with instructions to make that change to right or left at a stated distance from the last angle.

82. **Gradients** are determined by the **field level.** Points at which changes of slopes are to be made must be determined from the chart and the necessary data sent in, showing the point where the change is to be made and designating both old and new slopes. In checking, gradients should be determined with clinometer or transit, sighting from one horizontal angle to the next, if it can be done, otherwise taking as few sights as possible.

83. **Prevention of caving** is accomplished by **linings.** In very firm soil it is sometimes practicable to drive small shafts and galleries short distances without lining them; but if they are to stand for any length of time there is always danger of their caving in, and especially so if the neighboring soil is shaken by the explosion of projectiles or mines. When it is considered safe to use them, unlined shafts should be elliptical in plan, and the roofs of the galleries should be pointed arches. **As a rule,** however, both shafts and galleries **should be lined.** Those which are permanent in their character, as the main galleries of the countermines of a permanent work, are lined with masonry. Galleries constructed during a siege are lined with wood. **Wooden linings** are of two general types, known as **cases,** and **frames and sheeting.**

Cases, fig. 135, are of plank, 6 to 9 ins. wide and not less than 1½ ins. thick, as a rule. They are formed as shown in the fig. The two pieces with tenons are called **stanchions** and are placed vertically. The top is called a **cap sill** and the bottom a **ground sill.**

In grand galleries the tenons at the top of the stanchions are usually shorter than the thickness of the cap sill, and those at the bottom, as well as the mortises in the ground sill, are omitted. The stanchions are kept from collapsing by blocks nailed to the ground sills. These blocks are 2 ins. thick and wide enough (about 9 ins.) to guide the wheels of a gun carriage and prevent the hub striking the stanchions, fig. 138.

In cases for smaller galleries also the tenons are sometimes omitted at the bottom of the stanchions, the mortises in the ground sills cut an inch or two deeper, and the stanchions kept from collapsing by keys driven in the mortises, fig. 137.

Frames and sheeting.—**Frames** are made of scantling, as shown in figs. 139 and 140 for shafts, and 141 for galleries. Pieces of the latter are named as for cases. **Sheeting** is of plank, sawed to the desired length and beveled at one end. Sheeting should ordinarily be 1 ft. longer than the distances c. to c. between frames. Frame distance is generally 4 ft. and the length of sheeting 5 ft. Round stuff may be used

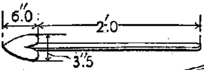


Fig. 126

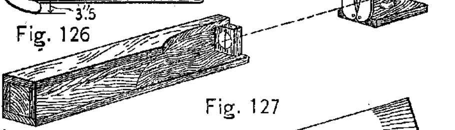


Fig. 127

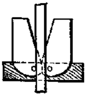


Fig. 128

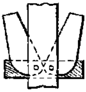


Fig. 129

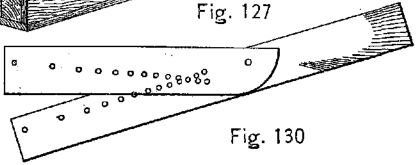


Fig. 130

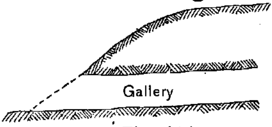


Fig. 131

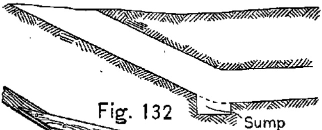


Fig. 132

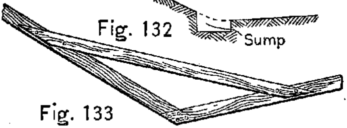


Fig. 133

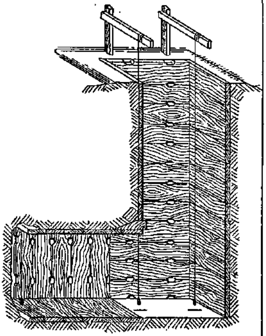


Fig. 134

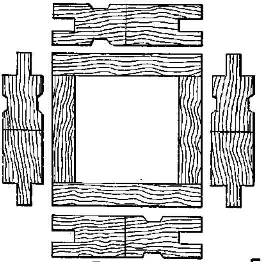


Fig. 135


Fig. 136

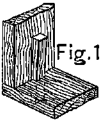


Fig. 137

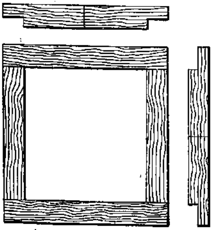


Fig. 139


Fig. 138

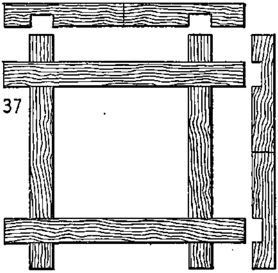


Fig. 140

for frames and also for sheeting, though the latter is not easy. The middle of each cap and ground sill, both in frames and cases, is marked by a saw cut or otherwise.

For galleries of moderate size, in good soil, lining with cases is more rapid and gives a smooth interior. Cases require uniform and fairly good lumber, which may not be obtainable. Frames and sheeting can be used for all sizes of galleries and in all soils and can be improvised from materials at hand.

The cases of branches and small branches are sometimes made very strong, with a view to resist rupture by the explosion of neighboring mines. Four-inch planks, or even thicker, have been used in certain circumstances.

84. The following table gives the **dimensions**, in inches, usually adopted for the pieces of **cases, frames**, and **sheeting**, for galleries of different sizes:

	Cases.			Frames and sheeting.			
	Ground sill.	Stanchion.	Cap sill.	Ground sill.	Stanchion.	Cap sill.	Sheeting.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Great galleries	3	4	5	6 x 4	6 x 6	6 x 9	2
Common galleries	2	2	2	6 x 3	6 x 6	6 x 8	$1\frac{1}{2}$
Half galleries	2	2	2	5 x 3	5 x 5	5 x 7	$1\frac{1}{2}$
Branches	$1\frac{1}{2}$ or 2	$1\frac{1}{2}$ or 2	$1\frac{1}{2}$ or 2	4 x 3	4 x 4	4 x 5	1 or $1\frac{1}{2}$
Small branches	1 to 2	1 to 2	1 to 2	3 x 3	3 x 3	3 x 4	1

85. **In sinking a shaft** with **frames** and **sheeting**, the size and position having been fixed, the **top frame**, distinguished from the others by projections at each end of each piece, fig. 140, is laid down and staked in place, with the scores on the end pieces accurately in the desired azimuth. The excavation of the shaft is then begun, making it enough larger than the top frame to take the sheeting all around. Usually the first interval can be dug without driving the sheeting. It is undercut so that at the level of the second frame it will be larger in each direction than at the top by twice the thickness of the sheeting. Gage rods cut to the length and width of the excavation and plainly marked at the middle points should be provided. The inconvenience of working under the top frame may be avoided by marking the sides carefully and digging the first interval before setting the top frame.

When the shaft is deep enough the second frame is put in place and nailed together; the notches in the ends of the side pieces turned upward and those of the end pieces downward. The top and second frame are connected by nailing to them four battens of proper length (two on each side), fig. 142, which suspend the second from the top frame at the established interval. The second frame is placed vertically below the top frame by using the plumb line and the scores in the frames.

The sheeting is inserted outside the top frame, beveled end first, bevel outside, and pushed down until its top is flush with the top frame. The lower end of the sheeting is held out from the lower frame by suitable wedges, and the excavation of the second interval is commenced.

In ordinary soil the sides of the shaft will now require support. Sheeting is therefore introduced and pushed down as the excavation proceeds, fig. 143, the wedges previously placed being driven down as the sheeting is inserted.

If the pressure of the earth becomes great enough to spring the sheeting planks inward, an **auxiliary frame** is introduced. This is a frame similar to the shaft frames, but from 4 to 6 ins. larger in outside dimensions, fig. 143a. The sheeting rests directly against the outside of this frame, and is thus held out far enough to allow the third frame to be placed and the wedges to be inserted as before. The auxiliary frame is then removed and used in the next interval.

Successive frames are placed in the same manner, fig. 142, until the one directly over the gallery is reached. Care is taken to place this frame at exactly the right height, and the shaft is then continued to the required depth. A frame is placed at the bottom with its top at the level of the floor of the gallery and the sheeting is allowed to rest directly against the outside of this frame. When the soil will allow

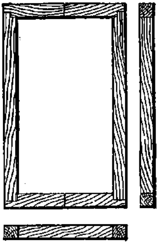


Fig. 141

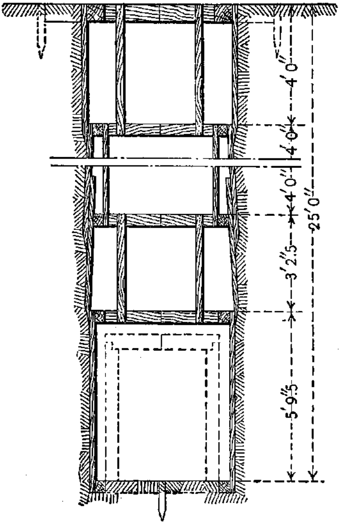


Fig. 142

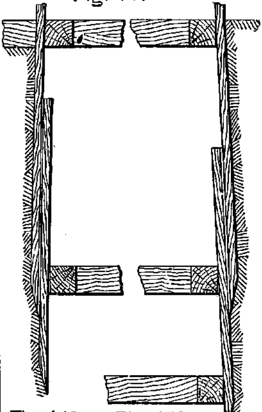


Fig. 143 Fig. 143a

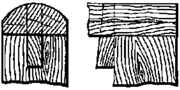


Fig. 145

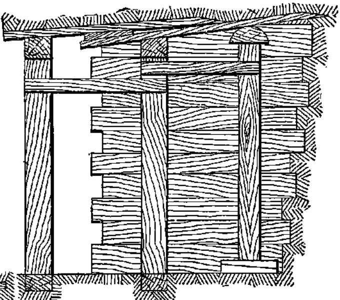


Fig. 144

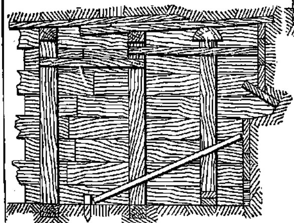


Fig. 146

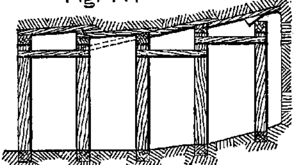


Fig. 147

it, the sheeting is omitted wholly or in part over the portion of the shaft which is to form the gallery entrance.

86. **Precautions.**—In sinking shafts especial care must be taken to make the excavation no larger than is required for placing the lining, since if a vacant space is left outside the lining the sides of the shaft may give way through its entire height and fall against the lining with a blow which will crush it in. *This has often been the cause of fatal accidents both in shafts and galleries.*

87. **Partly lined shafts,** i. e., those in which the sheeting planks are separated from each other by greater or less intervals, should only be used for small depths and when they are expected to stand for a very short time. They are a constant menace to the miners, owing to the danger of their caving in, and in a much greater degree to the probability of stones, etc., falling from the unprotected parts and seriously injuring or killing the men at the bottom.

88. **Driving a gallery with frames and sheeting.**—If from a shaft, the direction of the gallery has already been marked by the scores on the shaft frames; but it must be verified by plumb lines, and two small pickets driven on the line of its axis, which is located exactly by small nails, one driven in the head of each picket.

Two gage rods are prepared, giving the extreme height and breadth of the excavation, i. e., the height of the frame plus two thicknesses of top sheeting, and the breadth of the frame plus four thicknesses of side sheeting. The middle of each gage rod is also plainly marked.

A gallery frame is set up against the side of the shaft, fig. 142, its ground sill flush with the bottom frame of the shaft; or its stanchions may rest upon the shaft frame as a ground sill. This frame is carefully located and fastened in position with battens and braces. If the shaft sheeting on that side has been omitted, which can usually be done, the top gallery sheeting is started on top of the cap sill and driven until held in place by the earth. It is given the proper upward pitch by a scantling laid across the outer ends and held down by fastening to or under the shaft frame. The side sheeting is started in the same way against the outer faces of the stanchions and given an outward slant by bracing the outer ends slightly away from the sides of the shaft. Earth is now excavated and the sheeting advanced all around, keeping the front ends in solid earth far enough to hold them steady.

In this way the gallery is advanced one gallery interval, usually about 4 ft., when a second frame is placed. Its position is verified by the score marks; for direction, by a line; for grade, by a spirit, mason's, or field level, and for verticality, by a plumb line. It is then secured in place by nailing battens to it and the preceding frame. Wedges are inserted between the frame and the sheeting and the gallery is continued by the same methods. When the sheeting is advanced only by hard driving the frames are slightly inclined to the rear at first and are afterwards driven forward until vertical.

89. If, while advancing the sheeting, the pressure upon it becomes so great as to spring it, a **false frame,** fig. 144, must be used.

This consists of a cap sill, ground sill, and two stanchions, connected by mortises and tenons. The stanchions have tenons and the sills mortises at each end. The cap sill is usually rounded on top and, for facility in setting up and removing, its mortises are longer than the width of the tenons. The latter are held in place by wedges when the frame is in position, fig. 145. The false frame is usually made of the same height as the common frames and, when side sheeting is used, wider by twice the thickness of this sheeting. When side sheeting is not used, its outside width may be equal to the clear width of the gallery.

In using the frame, fig. 144, the ground sill is first placed accurately in position at a half interval in advance, the stanchions are set up, and the cap sill placed upon them and wedged. The whole frame is then raised about 2 inches by folding wedges placed under each end of the ground sill, and is secured by battens. The sheeting will now rest directly upon the cap sill and stanchions and have enough inclination to clear the next frame by its own thickness, as is required. The next frame is then set up, the wedges driven under the sheeting, and the false frame removed, which is easily done, owing to its construction.

If the gallery is not started from a shaft, a steep working face must be obtained and the first frame set up and braced, in correct position with respect to the center line marked on the ground. The subsequent operations are as above described, except that means must be provided to hold the rear ends of sheeting to give them the necessary upward and outward slant, or else a false frame used.

If it has been necessary in sinking the shaft to drive the sheeting on the side from which the gallery is to be broken out, the gallery frame is set as before and the sheeting behind it driven down until it barely engages the bottom edge of the cap sill of the gallery frame. The top gallery sheeting is then inserted and partly driven as before. The shaft sheeting outside the gallery stanchions is then cut away and the side gallery sheeting started. The middle plank of the shaft sheeting is prized down with a bar engaged nnder the cap sill until free at the top, when it is pulled outward and removed. Excavation proceeds through the gap thus made, and as the other planks come free they are removed. If the earth runs too free at any stage of the operation it can be checked by short horizontal stop plank, placed against or inside the sheeting or inside the gallery frame after all sheeting has been removed.

90. To continue the gallery in such soil a **shield,** fig. 146, may be used to prevent the earth in front and above from caving into the gallery. When the excavation at top of gallery has advanced as far as it is safe to go without causing the caving to extend beyond the top sheeting, a piece of plank a foot wide and in length equal to the width of the gallery is placed directly under the top sheeting and against the face of the excavation and is held in place by braces at its ends secured to the gallery lining. The earth is excavated until a second plank of the shield can be placed in the same way as before under the first one. This is continued until the entire face is covered. The top and side sheeting are then driven forward and the top plank of the shield is removed and replaced in advance, after which each plank is removed and replaced in succession, as above described.

91. **Partly lined galleries.**—In very firm soil side sheeting may be omitted entirely, and in that less firm the side planks need not be in contact. When the side sheeting is omitted the width of excavation may be reduced to the clear width of the gallery and the stanchions be let into the side wall flush with its surface. In this case the ground sills are frequently omitted, the stanchions resting upon wooden blocks, stones, or directly upon the earth.

To save material, the planks of the top sheeting are sometimes more or less separated also. This can only be recommended when rapid and temporary work is required with limited materials, and in these cases the earth between the planks should be supported by packing of sticks, brush, etc.

92. **Inclined galleries.**—If the gallery, instead of being horizontal, is **ascending,** fig. 147, or **descending,** fig. 148, the proper slope is obtained by the use of a field level or a mason's level properly marked or set for the slope.

Position of frames.—In driving **descending galleries** better progress will be made and less material used if the frames are set at right angles to the axis of the gallery, fig. 148, and this is the usual custom. In driving **ascending galleries** this is impracticable and the frames are set vertically, fig. 147. In all other respects inclined galleries are driven in the same manner as horizontal ones.

93. **Change of slope.**—To pass from a horizontal to an ascending gallery, fig. 147, it is only necessary to give the top sheeting the proper angle by holding down its back end with a piece of *scantling* placed across the gallery for that purpose; and, to give the side sheeting the proper inclination, cutting trenches in the bottom of the gallery for the lower pieces, if necessary.

In passing from a horizontal to a descending gallery, fig. 148, the roof may be carried forward horizontally, and the floor given the desired pitch by increasing the height of the consecutive frames, until enough headroom is obtained to allow the top sheeting for the descending gallery to be inserted at the proper height and in the new direction. The frame at this point is made with a cap sill (upon which the sheeting rests directly), and a second crosspiece below it, serving as a cap sill for the descending gallery. From this point forward the frames may be set perpendicular to the axis of the gallery, as previously stated.

If the descending gallery is very steep and the horizontal pressure of the soil great, it may be necessary to strengthen the stanchions of the last two or three vertical frames by crosspieces near their upper ends.

94. **In changing direction horizontally** with frames and sheeting, if the soil will stand for a distance of one frame interval, or even less, it is only necessary to place one or more frames at an angle until the necessary change is secured. The sheeting on the ontside is placed by running the forward end past the frame and then inserting the rear end behind the last bay of sheeting.

If the sides require constant support, the outer one may be continued in the old direction until the wedge left is thick enough to permit the sheeting to be driven in

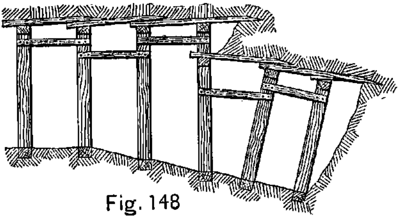


Fig. 148

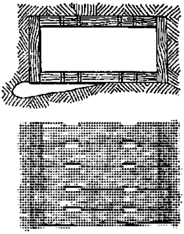


Fig. 149

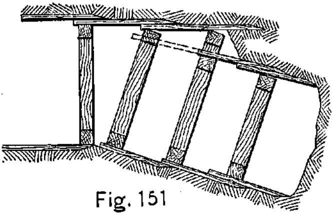


Fig. 151

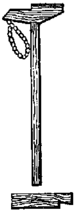


Fig. 153

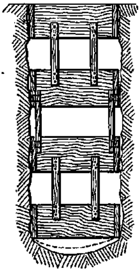


Fig. 150

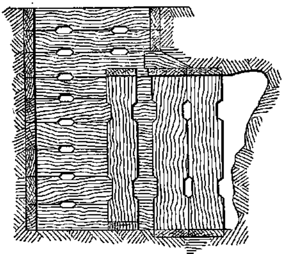


Fig. 152

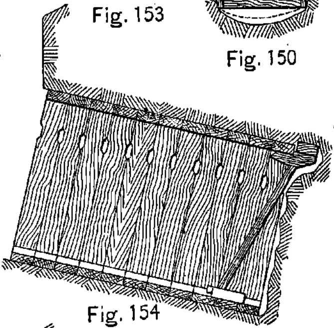


Fig. 154

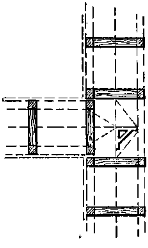


Fig. 155

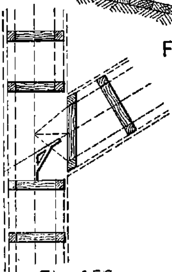


Fig. 156

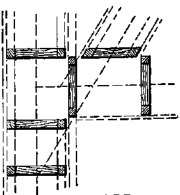


Fig. 157

the new direction. A short bay may be put in to reduce the amount of work to be done, fig. 151. Frames with extra-long caps and sills are required and the last one used is given an extra stanchion on the outside to take the sheeting in the new direction.

For abrupt changes of direction in large galleries it is customary to drive in the original direction entirely past the turning point and then break out a gallery in the new direction. A gallery starting out from the side of another is called a **return,** and is **rectangular** or **oblique,** according to the angle made by its **axis** with that of the original gallery, which is called the **gallery of departure.**

That the return may be broken out, the interval between the frames of the gallery of departure at this point must be such as to admit between the stanchions a frame and the side sheeting of the return, fig. 155. This part of the gallery of departure is called a **landing** and its floor is made horizontal.

If the return is oblique, fig. 156, its width measured along the gallery of departure will be determined by an oblique section, and may be so great that the strength of the lining of the gallery of departure will not allow the necessary length of landing. In this case a short rectangular return is first broken out from the side of the gallery of departure and the new gallery is broken out from the side of this return, fig. 157. The latter method diminishes the length of the landing when the change of direction is less than 45°.

The floor of a return is started at the level of the floor of its landing. In firm soils which will stand for a short time without support the first frame may be set up entirely outside the gallery of departure, figs. 156 and 157, and may be of the same height in clear as this gallery. When the soil is bad, however, and side sheeting is required in the gallery of departure, the first frame of the return must be set up against this sheeting in the interval between the stanchions of the landing, fig. 155. This makes the clear height of the return at this frame less than that of the gallery of departure by a little more than the thickness of the sheeting. When the first frame of the return is set against the sheeting of the gallery of departure it may be pulled or cut away to permit excavation, beginning in either case with the top plank.

The first frame of an oblique return should be so set that the sides of the stanchions will be parallel to the side walls of the return, thus giving a good bearing to the side sheeting.

In very bad soil the first few frames of a return must be firmly braced, to resist the backward thrust of the earth, by battens connecting them together and by struts across the gallery of departure. The latter are removed when the return is sufficiently advanced.

95. **In sinking a shaft with cases,** fig. 149, a case of the required size is put together and accurately placed upon the site of the shaft, whose dimensions are marked upon the ground outside it. The case is then removed and the earth excavated to the depth of the case, which is placed in the excavation with its top flush with the surface of the ground. Its position is carefully verified and it is secured in position by packing earth around it. The excavation is then continued for the depth of another case, which is put in place as follows:

One end piece is placed in position, the tenons of the two sides are inserted in the mortises at its ends, and the side pieces are pushed back into position; a pocket-shaped excavation is made with a push pick beyond the end of one of the side pieces and running back 3 or 4 ins. into the side wall; the remaining end piece is inserted in this cavity far enough to allow the mortise at its other end to slip over its corresponding tenon; it is then drawn back and the tenons at both ends fitted into their mortises. The notches cut in the sides of the pieces allow them to be easily handled.

The next case is placed in the same way, care being taken not to excavate two consecutive pockets at the same corner. It is well to fill up these pockets by stuffing in sods from below before placing the next case.

When the sides of the case are tenoned at one end only and secured by wedges at the other they are easily placed in position without cutting out behind them.

Upon reaching the level of the top of the gallery, the pieces on the gallery side of the shaft are omitted if the ground is firm, but if it needs support these pieces are put in place and secured by cleats or braces, but the tenons are not inserted in the mortises. In firm soil the cases may be placed at intervals, fig. 150.

96. **Driving a gallery with cases.**—This is practicable only when the soil is somewhat firm. In breaking out from a shaft, a frame is first placed inside the shaft to support the ends of the shaft cases resting against the pieces which are to be

removed. The latter pieces are then taken out and grooves are cut in the earth for the ground sill, stanchions, and cap sill of the gallery, and these are put in place in a manner entirely analogous to that described for sinking a shaft. This case is set flush with the inside of the shaft and supports the side pieces, whose tenons rest upon its stanchions. The projecting earth is then cut away and grooves are cut for the next case, which is placed in position and the excavation continued as before, fig. 152.

If the gallery is not started from a shaft, a vertical face is obtained and the cases are placed as above described.

When the earth shows a tendency to cave, which it frequently will in great galleries, the cap sill must be put in position and supported while the miner excavates the grooves for the ground sill and stanchions, for which purpose two **crutches** are used. **A crutch,** fig.153, consists of an upright piece of timber carrying a cross-piece, whose length is equal to the width of two cases. The upright piece rests upon the ground sill of the cases already placed and is raised to the proper height by wedges. The part of the crosspiece which projects in advance is made 2 ins. higher than the rear part, to support the cap sill somewhat above its final level, so as to allow the tenons of the stanchions to be easily inserted. The rear part of the cross-piece is attached to the upright by an iron rod or short chain. The use of the crutch is illustrated in fig. 154. When the case is set and adjusted to position the crutches are taken down by removing the wedges, and are replaced under the next cap sill.

In very firm soil shafts and galleries are frequently driven with cases not in juxtaposition, but separated by greater or less intervals. Pieces of planks (which may be parts of cases) placed vertically and resting against the sides and ends of the cases in shafts, or horizontally and resting upon the cap sills in galleries and somewhat separated from each other, may be used to support the earth between the cases. The same remarks apply to this construction as to the similar one sometimes used when mining with frames and sheeting.

97. **Change of direction in galleries lined with cases.**—Slight changes in direction in a horizontal plane can be easily and gradually made by setting each case a little obliquely to the one preceding it and separating the stanchions on one side while they touch on the other, supporting the roof in the wedge-shaped openings, if necessary, with pieces of wood, etc., fig. 158. For an abrupt change it is better to break out a rectangular return from the side of the gallery and pass from this into the required direction by gradual change.

If the return is to be of the same height as the gallery of departure, the cap sills of the latter, for a distance equal to the width of the return, are lifted off the tenons of the stanchions by struts and wedges, and the first case of the return is set as in breaking out from a shaft; the ground sill is, however, narrowed by the thickness of the stanchions of the gallery of departure so that the face of the case of the return is flush with the inside of the gallery of departure, and the ends of the cap sills of the latter rest upon the cap-sill of the first case of the return.

In passing from a horizontal to a descending gallery the change may be made gradually, in a manner similar to that described for a change in horizontal direction, fig. 158, and the cases remain normal to the axis of the gallery.

To pass to an ascending gallery by the method above described would require the earth at the face of the gallery to be undercut in order to introduce the case, and this undercutting would continue so long as the cases were normal to the axis of the gallery. This construction is, as a rule, impracticable. In ascending galleries, therefore, the cases are set with their stanchions vertical, while their cap and ground sills form steps in the slope of the roof and floor of the gallery or, for convenience in setting up, the ends of the stanchions may receive the proper bevel, fig. 136, while the sides of the tenons and mortises are made parallel to the sides of the stanchions.

98. **Rate of working.**—The following table gives an estimate of the men and tools required for shafts and galleries, with the probable rate of advance in good soil.

Kind of gallery, etc.	Men.		Tools.														
	N. C. officers.	Miners.	Picks.	Miner's picks.	Push picks.	Shovels.	Miner's shovels.	Miner's truck.	Field levels.	Measuring rod, 6'.	Tracing line.	Mauls or sledges.	Canvas buckets.	Rope ladder.	Wheelbarrows.	Miner's bellows.	Progress, ins. per hour.
Great gallery or blind gallery	1	*12	4	2	2	8	—	—	1	1	1	1	—	—	4	—	12
Common gallery	1	4	—	1	1	2	1	1	1	1	1	1	—	—	—	1	12
Half gallery	1	†4	—	1	1	2	1	1	1	1	1	1	—	—	—	1	16
Branch gallery	1	†4	—	1	1	2	1	1	1	1	1	1	—	—	—	1	24
Small branch	1	3	—	1	1	—	2	§1	‡	1	1	1	—	—	—	1	30 to 36
Shaft	1	‖4	—	1	1	2	1	—	1	1	1	1	1	1	—	—	18 24

*Four of these may be unskilled laborers.

†Number required at commencement of gallery. Beyond 4 ft. add one man, and one additional for every 20 ft. of gallery.

‡One mason's level.

§Instead of a truck a canvas bag may be used. A large hoe or drag may be used to draw back the earth from the face of the gallery.

‖These numbers are for small shafts of about 2 ft. by 4 ft.; large shafts require a larger force. They advance at about the same rate as galleries of equal cross section.

99. **Ventilation.**—A gallery can not be driven more than 60 ft. without artificial ventilation. The only possible way of ventilating a gallery with a single opening is to force fresh air into the working breast, which may be done through a duct of wood or metal, or through a canvas or other hose. **A pressure blower,** worked by hand or power, is among the essential items of a mining equipment. For excavations of moderate extent, a portable forge will form a convenient ventilating device. If a gallery passes under surface cover, a drill hole made through the roof and breaking the surface under protection of the cover may be used to promote ventilation.

In a **system of galleries,** having two or more outlets, air may be exhausted from one and drawn in through the other. Screens or doors may be arranged to compel the desired distribution of fresh air. Vacuum operation will never be so satisfactory as plenum. If there is considerable difference of level, as a shaft or rapidly ascending gallery, a fire built at or near the upper outlet will create a current throughout.

In urgent cases a man may enter and even work in a gallery which can not be ventilated, by providing him with a mask covering the nose and mouth and supplying fresh air through a hose or from a reservoir of compressed air carried with him.

100. **Drainage.**—Much water is not likely to be encountered in military mining, but what there is must be taken care of, or it will collect at the lowest point and flood the mine. If water shows itself or is suspected, dead-level galleries must be avoided and all slopes should fall toward a point or points where the water can be disposed of. If the mine has a level outlet, nothing is required except to so regulate the slopes that all water will run to the mouth. If the mine is entered by a shaft, a pit or sump must be formed at the bottom into which water can collect and from which it can be raised to the surface by pumping or bailing. A slope of 1% will

usually suffice for drainage if the floor of the gallery is sloped laterally and a fairly smooth gutter formed along one side.

If an interior low point can not be avoided, a sump must be made there and the water carried out in buckets or forced out with a pump. For low lifts, 20 ft. or less, a very efficient form of hand pump for drainage purposes is shown in fig. 159. A very good pump may be made as shown in fig. 160. The only materials required are wood, leather, cotton cord, rivets, tacks, and nails. This pump will lift several feet without difficulty in addition to the usual suction. It requires copious priming unless the sucker can be made to reach the water at the lowest point of its stroke. It is usually worked with a spring pole, fig. 161.

101. **The mine chamber** should be nearly cubical or a cylinder with length about equal to diameter. If it is to stand for some time before loading, or if of large size, its sides and top must be supported by a lining. The chamber is frequently no more than so much of the end of a gallery, branch, or drill hole as is necessary to contain the charge.

Figs. 164 and 165 show typical forms of earth augers; the former used by ramming and the latter by turning. Each must be withdrawn when full to dispose of the earth.

102. **Explosive.**—A satisfactory explosive for the purposes of military engineering must be—

(1) Stable as to its constitution and characteristics for a long period.

(2) Unaffected by ordinary variations of temperature and moisture.

(3) Insensitive to shocks of handling, transportation, projectiles, and neighboring explosions.

(4) Not too difficult of detonation.

(5) Quick enough to give good results when not confined and slow enough to give good results when confined.

(6) Convenient in form and consistency for packing and loading and for making up charges of different weights.

The third and fourth of the above requirements are antagonistic and must be compromised.

These conditions point to a high explosive of medium strength, of granular or plastic consistency, put up in waterproof cylindrical cartridges of standard size and length. A number of explosives meeting these requirements fairly well are on the market. No one of them is so distinctly superior as to warrant its adoption to the exclusion of the rest, and the one most easily procured at the time and place of need will probably be used.

Dynamites consist of a granular base, usually called *dope* in the trade, partly saturated with nitroglycerin. Dynamites are classed according to the percentage by weight of the nitroglycerin contained, as 75% dynamite, 60% dynamite, and so on. The grades No. 1, No. 2, and No. 3, often used, refer to 75, 50, and 25% dynamites, respectively. The *dope* may be an inert substance having no function except as a vehicle for the glycerin, or it may be, and usually is, a combustible substance contributing to the chemical reaction and improving the strength and character of the explosion. *Dopes* of this kind are usually nitrates of sodium or potassium. All American dynamites are of this class.

At extremes of temperature, high or low, an **exudation** of free nitroglycerin is likely to occur, making the dynamite **extremely sensitive** and **dangerous.** This danger increases with the degree of saturation. Dynamites higher than 60% will probably not be suitable for military purposes on this account. The tendency to exudation is greater when cartridges stand on end, and care should be taken to **keep them on the side** in storage and transportation. Dynamite freezes in moderately cold weather, and if no exudation has taken place becomes comparatively free from danger of explosion by concussion and is considered perfectly safe to handle. It is very difficult to explode when frozen, has less strength, and is not considered fit to use in that condition. In the frozen state dynamite is easily exploded by heat and the operation of thawing, if carelessly conducted, is one of great danger, a large majority of accidents with dynamite occurring from this cause. It should never be taken near a fire or very hot metal, but should be thawed in a mild, diffused heat, acting for considerable time. The cartridge must never be placed on end to thaw out. Packing in fresh manure, or inclosing in a chamber with cans of hot water are the safest methods of thawing dynamite. Plenty of time must be given. A cartridge

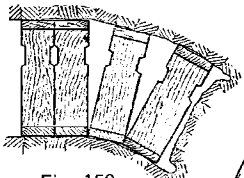


Fig. 158

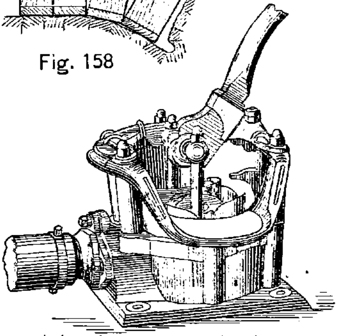


Fig. 159

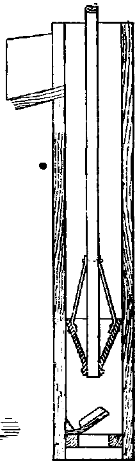


Fig. 160

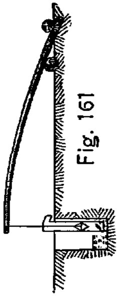


Fig. 161

Fig. 167a

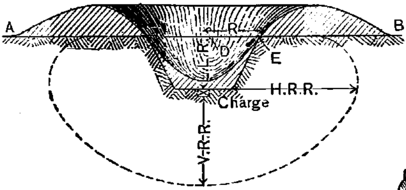


Fig. 162

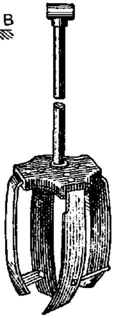


Fig. 165

Fig. 164

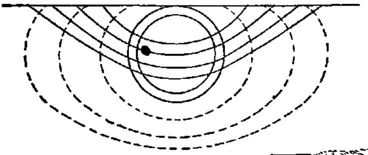


Fig. 163

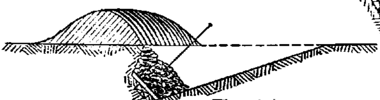


Fig. 166

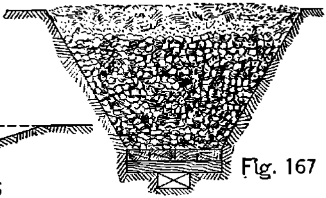


Fig. 167

soft on the outside may be frozen in the middle. None of the dynamites are fit for use as a military explosive in a cold climate.

Dynamite is a substance of the consistency of brown sugar. It should not be greasy to the touch, nor should there be any oily appearance of the packages. It is apt to cause a severe headache when touched with the hand. It is usually packed in paraffined paper cartridges, an inch or more in diameter and of varying lengths. A very common size is $1\frac{1}{4}$ ins. diam. by 8 ins. long, containing about $\frac{5}{16}$ of a pound.

Gelatins.—These compounds are formed by the action of nitroglycerin on gun cotton. They are unstable and become supersensitive and highly dangerous when frozen.

Picric powders.—These consist of pure picric acid, or that acid combined with a nonmetallic base. They are nonsensitive to shock, unaffected by heat and cold, and in some forms by water, can be produced in a granular form or fused into solid shapes. Their characteristic color is a yellowish, sulphur tinge, and if pulverized they have a strong tendency to escape from their packages and discolor everything around them, men included. Nevertheless, the most successful military explosives thus far introduced belong in this class; for example, the French melinite, the English lyddite, the Austrian ecrasite, the Japanese shimose, and others.

Combinations of picric acid with metallic bases, especially lead, iron, and potassium, or with oxides or nitrates of these metals, are dangerously sensitive. Premature explosions have resulted from handling iron shells loaded with picric acid. A special neutral coating is now used to prevent contact of the acid and the metal. Litharge is very apt to produce an explosion if it comes in contact with picric acid. Red or white lead must not be used in or around any receptacles of picric acid.

Jovite, an American powder of this class, seems to come as near meeting all military requirements as any explosive now known. It is unaffected by heat, cold, concussion, or water. The gases of explosion are less deleterious than those of dynamite and produce no headaches. A recent authority on explosives says:

"Jovite has been tested by the ablest explosive experts and has never proved unsafe or unreliable. It would seem to fulfill all the requirements of an ideal explosive."

Jovite may be had of strengths equal to 20, 40, and 60% dynamite.

Gun cotton has been extensively used in military operations and has some advantages. It is not considerably used commercially, and would probably have to be manufactured when wanted. When dry it is apt to deteriorate from the presence of free nitric acid, which it is very difficult to completely remove in manufacture. When wet, gun cotton is perfectly safe, but can be fired only by a primer of dry gun cotton or other high explosive. Attention is required to keep the wet stock saturated, and the additional weight of water has to be transported. The dry cotton must be kept perfectly dry and separate from the wet. It is difficult to fuse gun cotton unless holes are left in the cartridge to receive the cap.

Ammonal, an explosive recently introduced, is a mixture of ammonium nitrate and powdered metallic aluminum. It is one of the most powerful explosives known, and has, in a high degree, many of the most important requisites for military use. If produced commercially, and further experience with it does not develop objections now unknown, it promises to be one of the most satisfactory powders which can be found. **In priming ammonal especial care** is necessary to see that the paraffin coating of the cap is intact.

A class known as **Sprengle** explosives consists of separate constituents, each nonexplosive, which are combined at the moment of use. The most common is **rack-a-rock**, which consists of chlorate of potash, a dry crystalline substance, and nitrobenzol, a liquid. The chlorate is in linen tubes, which are dipped into the liquid when ready to be loaded. This explosive has been extensively used for military purposes in the Philippines and has given good satisfaction. The dipping requires but a few seconds, after which the excess liquid is allowed to drain back into the containing vessel, about 15 minutes being required for this part of the operation. The cartridges may be had of any length and diameter desired.

103. The following is a **list of well-known commercial powders** suitable, with the conditions and restrictions heretofore given, for use in military mining:

Dynamites.	*Per cent.*	*Dynamites.*	*Per cent.*
Ætna powders, No. 1	65	Giant powder, No. 1	75
" " No. 2XX	50	" " No. 2	40
" " No. 2	40	Hecla, IXX	75
Atlas " A	75	Hercules, IXX	75
" " B+	60	Rendrock	40
" " B	50		
" " C+	45	*Miscellaneous.*	
" " C	40	Jovite	60
Dualin	40	"	40
Forcite, No. 1	75	Rack-a-rock	40
" No. 2	50		

104. **Care and handling of high explosives.**—Such powders as have been described as suitable for use in military engineering operations are, when in sound condition, less liable to accidental explosion than gunpowder. It is the more disastrous result of a premature explosion, rather than the greater probability of its occurrence, that has caused high explosives to be regarded as especially dangerous. The following precautions should always be taken:

Gun cotton should be kept **saturated** with 30 per cent of its weight of water. If not hermetically sealed, the packages should be examined once a month or oftener and resaturated. The cotton required for **primers** must be **stored dry** and kept free from moisture. The cakes may be dipped in melted paraffin. The dry cotton must be **kept well apart** from any other explosives and from caps. If dry primers are not at hand, **wet cakes** must be dried at a temperature not exceeding 120° F.

All other powders should be stored in a cool, dry, shaded, and well ventilated space. The main supply must be well removed from the working points.

Avoid any unnecessary accumulation of powder at any other place than the magazine provided for it, and especially do not allow any powder to be stored near where caps are stored or where primers are made up.

Keep fire away from the powder and the **powder away from the fire.**

Do not use hard-metal tools in manipulating cartridges. Copper is the only metal that should be used. **Wood is better.**

Keep cartridges free from sand or other gritty substance.

Do not bend, strike, or **heat** a **cap** or **primer.** See that the **paraffin coating** of every cap is **free** from **cracks** or **holes.** The copper must be completely protected from contact with powder. **Redip if necessary,** keeping the paraffin in a water bath and only warm enough to flow freely.

Be careful not to allow a **pull** to come on the wires or fuses attached to a cap.

The exploder should not be connected to the leads, nor a **fuse lighted** until everything is ready for firing, warning has been given, and time allowed for everyone to get to a safe distance. As a rule, the exploder should be used or the fuse lighted under the personal supervision of the responsible officer.

105. **Firing devices.**—The powders which will be used are all of the class which can be fired by **detonation** only. The detonating compound in general use is **fulminate** of **murcury** and all methods of firing involve the explosion of a small quantity of fulminate inclosed in a cap or fuse and placed in the charge. **The fulminate** is easily ignited and very violent, which qualities have determined its use. It is unstable, corrosive, spoiled by moisture, and highly sensitive to shock and friction. Except strength, it possesses no characteristic which does not tend to unfit it for military purposes. It is used as a matter of necessity.

Caps and fuses must be **carefully handled,** must not be assembled in considerable quantities, and must be kept away from the explosive.

106. **Bickford** or **safety fuse** is used to ignite the fulminate when electricity is not available. It consists of a powder thread wrapped with a waterproof tape, a double wrapping or **double tape** preferred. This fuse may be used in wet holes, but for under-water use it should have a continuous rubber coating.

Time fuse burns at an average rate of 3 ft. per minute, but the rate is not regular, and when time is important the rate of burning should be tested.

Instantaneous fuse burns at a rate of 120 ft. per second. The taping of this fuse is in a different color from the time fuse and it is also covered with a netting of coarse thread, making it easily distinguishable by sight and touch, so that there can be no excuse for mistaking one fuse for the other, day or night.

When it is necessary **to splice** different **pieces of fuse** of either kind, the ends to be joined should be cut obliquely, as indicated in fig. 168. Care must be taken that the powder at the end of the cut does not fall out. The cut ends are placed carefully in juxtaposition, and before closing a few grains of powder should be dropped in and compressed between them. The splice is completed by wrapping with rubber tape if available, otherwise with any material at hand which will keep the ends in contact in their proper position. It is obvious that this splice must be completely protected from strain.

When a line of fuse is to be branched into two the same principles are followed, the double splice being connected, as indicated in fig. 169, and the same precautions taken in making up.

107. **For firing by electricity** a **magneto-electric** machine is used, the one most commonly employed being a **Laflin & Rand Exploder**, No. 3. Its exterior appearance is shown in fig. 170. The handle *A* is raised to its full height and depressed as forcibly as can be done with the hand. By a rack and pinion it gives rotation to an armature revolving in a magnetic field. At the end of the stroke, when the armature has its maximum velocity of rotation, the handle closes a contact which shunts the current through the leads connected at the binding points *b b*. The case is 13 x 8 x 5½ ins. and the weight 18 lbs. Its rated **capacity** is **12 fuses**, but not more than 6 should usually be connected. The lead wires should be insulated, though it is not absolutely necessary, as fuses have been fired through naked lead wires in fresh water. If short of insulated wire put all that there is into one of the leads and make the other entirely of bare wire. The wire should be of copper, not less than 18 gage for a distance of 500 ft. For firings through a greater distance, especially if more than one fuse is in the circuit, the leads should be larger or should be doubled for part of the way.

108. **Caps** or **detonators** are of two forms, adapted for firing with **powder fuse**, fig. 171, or by **electricity, fig.** 172. In both forms the fulminate, usually mixed with nitrate or chlorate of potassium to reduce its corrosive action, is contained in a copper capsule. In the first form it is held in place by a wad of shellac, collodion, or paper, and the end is left open for the insertion of the fuse. The latter is cut off square, care being taken that the powder at the end does not sift out, and the cut end is inserted in the cap and pressed down snugly on the fulminate. A twisting motion which might scrape the fulminate must be avoided. The case is then crimped around the fuse with a special tool and the cap is ready for use.

In the **electrical cap**, which is commonly called a **fuse**, the fulminate is held in place by a block of sulphur, or sometimes of wood, which fills the end of the case and also holds in place the terminals and the **bridge** of fine platinum wire which is embedded in the fulminate, the heating of which by the current causes the ignition. The lead wires are 30 ins. to several feet in length, as may be ordered. In quarrying, wires are usually made long enough to come out of the drill hole so that no joints are to be made in the hole. Also, in blasting under water, it is very desirable to have the fuse wires long enough to come above the water surface.

Caps are usually **rated** as follows:

Single strength,	X,	3 gr. fulminate;
Double strength,	XX,	6 gr. fulminate;
Triple strength,	XXX,	9 gr. fulminate;
Quadruple strength,	XXXX,	12 gr. fulminate,

and so on.

The strength of the cap makes a difference in the force of the explosion. This is greater for low-grade powders. For 40% dynamite, explosion by a 5 X cap is 15% stronger than by a 3 X. For 60% dynamite, the difference is only 6%. The same result follows from a loss of strength in the same cap. A 5 X cap may by deterioration become of the same strength as a 3 X and will then produce an explosion so much the less effective. It is **very important** to prevent deterioration of caps and also to know whether they have deteriorated or not. Caps stored in a damp place deteriorate rapidly. With less than 0.25% of moisture the caps will not explode

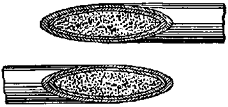


Fig. 168

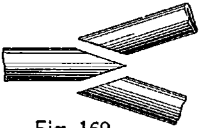


Fig. 169

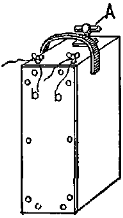


Fig. 170

Fig. 171

Fig. 172

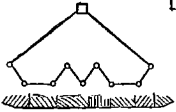


Fig. 174

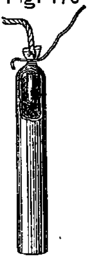


Fig. 176

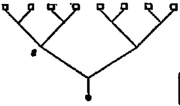


Fig. 173

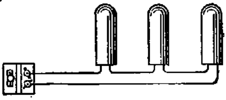


Fig. 175

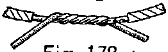


Fig. 178

Fig. 177

Fig. 179

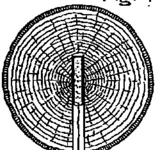


Fig. 180

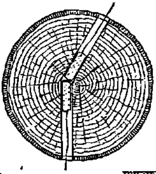


Fig. 181

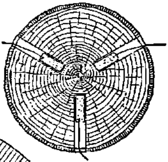


Fig. 182

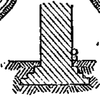


Fig. 183

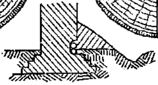


Fig. 184

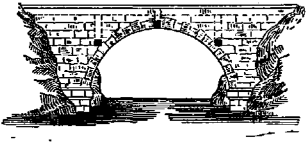


Fig. 185

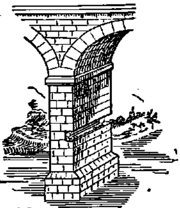


Fig. 186

dynamite, though they may still explode themselves. Single and double strength are best for mining. Triple and quadruple will give better results in demolitions.

Caps may be tested by exploding them in a confined space and noting the report and the effect on the shell. A cap in full strength will tear the copper shell into minute pieces, while a deteriorated cap will tear it into larger pieces.

109. **Simultaneous ignitions.**—When a total blast is divided into a number of charges, it is important that all should go at the same instant. This will not be easy with time fuse, and that method will not be used unless absolutely necessary. If it is used, certain precautions must be observed to avoid total failure. The fuse must be so laid that the total length from the firing point to each charge will be the same. It will be better to use time fuse to a common point near the charge, and instantaneous fuse from there on. Figs. 173 and 174 show typical arrangements. The fuse need not be in straight lines, but must be laid out so that sparks from the burning end can not reach any part in front of it. Though not absolutely necessary with instantaneous fuse, it is well worth while to make different lines as nearly equal in length as possible.

In simultaneous ignitions by electricity, the fuses are connected in **series**; that is to say, they are all placed in the same circuit, fig. 175. A lead from the firing apparatus is connected to one wire of a fuse on one flank. The other wire of this fuse is connected to a wire of the next fuse, and so on, until the last fuse is reached, the second wire of which is connected back by a lead to the firing point.

Figs. 178 and 179 show methods of jointing wires; the former, for temporary use, as a lead to a fuse wire; the latter, for more permanent use. The ends of the wires must always be brightened by scraping with a knife or otherwise. To insulate, wrap with rubber tape, lapping well onto the covering in both directions.

110. **Priming.**—The cap is inserted in a cartridge, usually called a **primer.** Whenever reference is made herein to use of explosives in or near water it is to be understood that under all circumstances the **cap and primer must be kept perfectly dry.** If but one primer is used, it should be placed near the center of the charge when the size and shape of the charge permit it to go in that position. If the cartridges are placed in a drill hole, as in rock blasting and some demolitions, the primer is put in last with the cap end down. The cap may be inserted as shown in figs. 176 and 177. Fig. 176 applies to caps fired by **train fuse** and **no other method** may be used with such caps. **The projection** of about 1/8 to 1/4 inch of the cap case above the surface of the powder is **to prevent** the latter from **taking fire** from the sparks of the fuse and burning partially before the fuse goes, which, should it occur, will reduce the force of the explosion, or may cause complete failure.

Primers must be prepared at a safe distance from the charge and from the store of caps and should be placed as short a time as possible before firing.

111. **Misfires.**—In case of a misfire there is risk in approaching the holes for several minutes, if electric firing is used, and for several hours in case of firing by fuse. Rules to this effect are laid down where safety to human life is a paramount consideration. They should be recognized in military operations to the extent which circumstances permit. There is also danger in attempting to reprime a charge, especially if tamping must be removed. The danger is reduced by care and by avoiding hard-metal tools and appliances; if possible, the tamping should be removed with wooden tools. In any case, leave a few inches of tamping above the charge undisturbed, then place several sticks of powder and a primer on top of the first charge and fire again. When conditions permit, it is better practice not to attempt repriming, but to place a new charge in a position to do all or a part of the work of the first charge.

The causes of misfires are various. With electricity, if none of the charges explode, the cause is probably due to overloading the machine, or a short circuit in the leads, or a complete break. An effectual, but less probable, cause is deterioration of all the primers. If part of the charges fire and others do not, the cause will probably be found to be either a defective cap, due to moisture or a broken bridge, or a short circuit in the fuse wires, which prevents current going through one fuse but not the others; or the sensitiveness of the caps may not be uniform, and there may be one or more so sensitive that they explode and break the circuit before the bridges of the others have become heated to the point of ignition.

112. **Loading.**—The charge should fill the chamber as nearly as practicable. If drill holes are used, they should be just large enough to permit a cartridge to slip down without jamming. In quarrying, cartridges are frequently slit open before

they are placed in the hole, so that with a slight pressure of the tamping rod, they spread and fill the hole completely. **When large charges** of free running powder are to be used, such as dynamite, jovite, and rack-a-rock, the cartridges may be opened and the contents put in bulk into another receptacle. As a rule, however, such charges will be made up by bunching *sticks* or *strings* of cartridges, par. 123, and tying them together. **The making up**, and **every possible detail** of preparation, should be done **above ground**, leaving as little to do in the mine as possible. Charges must not be made up into sizes or weights which can not be conveniently carried through the galleries and placed in the chamber.

The charging should be **personally directed** by the responsible officer, and if but one person can get at the charge at a time, he should place the powder himself. Such illumination as may be necessary must be provided by closed lights, with effective precautions against fire. When the primer is placed in the middle of a bulky charge, the wires or fuse must be led out through the powder. Only instantaneous fuse can be so used. If time fuse must be used, place the primer in the middle of one side of the charge so arranged that it must go before any sparks from the fuse can set fire to the powder.

When electric firing is used, the wires of each fuse should be twisted together at the ends to prevent the possibility of a chance current going through the fuse and for identification for connecting to each other and to the leads. Care must be taken that at no stage of the loading or tamping is a strain brought on any fuse or fuse wires, or any injury done to their coverings.

113 **Tamping** is less important for high explosives than for gunpowder, since the former do a fair proportion of their work without tamping, while the latter does practically none. *Light tamping* is desirable, however, and may consist of the excavated earth replaced in the communication next to the chamber to a distance of 6 to 10 ft. The use of high explosives facilitates tamping, because so many charges can be placed in drill holes, which are easily tamped.

For drill holes in rock which will hold it, water is the best possible tamping, otherwise sand or stone dust may be used. If the hole points upward, the top should be covered with a board or thick brush to stop the tamping which is blown out like a projectile. If neighboring ground can not be cleared for firing, the entire surface of the probable crater should be masked by brush or timbers piled upon it, and weighted down if necessary.

114. **Effects of explosion.**—It may be assumed as sufficiently exact for present purposes that charges of the same explosive develop total energies directly proportional to their weights. This energy is exerted in all directions in compression of the surrounding medium. The distance at which this disturbance remains sufficient to destroy galleries is called the **radius of rupture, R. R.** The surface joining the ends of these radii is called the **surface of rupture.** If the charge is large enough, further relief of pressure is afforded by the bodily displacement of a part of the surrounding medium on the side which presents the shortest distance from the charge to the surface. The relief of pressure on one side shortens all radii of rupture which have a component in that direction, but does not appreciably affect those which have no such component. Hence, when material is displaced the surface of rupture is ellipsoidal; when no material is displaced it is spherical. Fig. 163 illustrates in a very general way the supposed relations of craters and radii of rupture. It is not based on exact data.

The space left by this bodily displacement of material is called a **crater.** The determination of the crater which a particular charge in a particular place will produce, or of what charge must be put in that place to produce the given crater, or where a given charge must be placed to produce a desired crater, are problems constantly arising in military mining.

Fig. 162 shows a cross section of a typical crater in earth. The position of the charge is indicated; *AB* is the surface of the ground; *CD* is the **line of least resistance,** commonly designated L. L. R. or, in formulas, *l*; *DE* is the **crater radius,** and *CE* the **radius of explosion.** All the elements of the crater are reckoned with respect to the position of the charge and the opening of the original ground surface. This opening for level ground is circular in form and is approximately the intersection of the spheroid of rupture by the ground surface.

Craters are designated as **one-lined, two-lined,** etc., accordingly as the diam. is once, twice, or three times the L. L. R. A two-lined crater is also called a **common mine;** less than two-lined, **undercharged;** and more than two-lined, **overcharged.** A mine which does not break the surface is called a **camouflet.**

When a crater is formed, the part of the total work of the charge represented in crater effects is assumed to be proportional to the volume of earth actually moved. As a part is thrown vertically upward and falls back loosely into place, fig. 162, the hole actually left does not represent the earth moved. The total volume moved is assumed, from many experiments, to be represented by the frustum of a cone, shown in section in fig. 162, having the crater opening for its larger base, a circle of the diam. L. L. R. for its smaller base and L. L. R. for its height. For each cubic yard of volume of such a frustum a certain weight of explosive is allowed and it is thus that the corresponding weight of charge is ascertained. **The unit weight** is the quantity of powder required to **throw out one cubic yard.** It has been experimentally determined for gunpowder and is deduced for other explosives from their corresponding intensities.

The crater volume, or volume of the conical frustum, fig. 162, may, for any given ratio of height and crater radius, be expressed by the cube of the height, L. L. R., multiplied by a numerical constant and hence the weight of explosive required to produce a crater of corresponding proportions may also be expressed by t^3 multiplied by a constant. The constant varies with the character of the material, as well as with the proportions of crater.

115. Table II gives constants for various classes of materials and for craters from 1 to 6 line, the former practically a camouflet and the latter the largest that can be depended upon for results. The table also gives constants from which the R. R. may be determined.

The weight of charge may be determined from Table II. It is to be noted that the user of this table must exercise his judgment in classing the soil under the headings given, so that it can not be said that the table gives charges absolutely. If the mine is important, powder not scarce, and no information has been obtained from actual firings in the soil, the tabular charges should be increased 10% for large quan ties and 50% for small ones. It is to be remembered that while if more powder than necessary is used the excess may be said to be wasted, if less than the proper amount is used not only is the total quantity used wasted, but the time and labor spent in getting it into place are also wasted and the opportunity to gain advantage by successful firing is lost. In all uses of explosives in mining the maxim for the first charge should be, **do not spare the powder.** On the other hand, every charge fired should be carefully observed, and whenever it is obvious that more powder than necessary has been used advantage should be taken of the experience gained to economize powder in future firings. **The worst mistake** that can be made is having the **first charge too small.**

116. **Land mines.**—This term is applied to mines or groups of mines usually formed by excavation from the surface and designed to be exploded at the moment the enemy is over them. Such mines are usually employed in front of defensive positions and in connection with visible obstacles. It is **not permissible** to plant such mines in any ground which is **not obviously** prepared for defense. Any person who ventures on space so prepared does so at his peril, but if there is a road or path open to passage through such ground mines must not be placed therein, or in a place where the explosion would injure persons occupying the road. If any defensive works or recognized obstacles are thrown across the road, indicating that it is closed to traffic, the road may be mined to a reasonable distance in front of them.

The charges are placed deep enough only to avoid artillery projectiles. If no artillery fire is to be expected they may be placed just under the surface. If a bore hole is sufficient the charge is placed at the bottom and the hole well tamped. If an open pit is dug the mine chamber should be in firm ground at one side and the hole back-filled and well rammed.

The depth fixed, the charge may be adjusted to give a 2 or 3 line crater. The mines may be in one or more rows. Two rows, 30 to 40 yds. apart, are a good arrangement. The intervals between mines in a row should be such that the craters will nearly but not quite join. The positions of the mines should be concealed as completely as possible and further sophisticated by disturbing the ground slightly at points where there are no mines and so situated as to suggest a systematic arrangement.

A fougasse is a land mine in which the volume of the crater is artificially prepared to increase its range and effect. Fig. 166 shows the form which has been most used. The earth excavated must be piled around the pit, as shown, and well tamped, to prevent the charge blowing out behind the stones. It is not necessary to undercut the bank as shown in the section. If the soil will not stand it may be thrown out to its natural angle and back-filled and tamped against the stones. A charge of 25 lbs. should scatter a cu. yd. of stones over an area 200 x 100 yds.

This form is difficult to conceal and very easily destroyed by the enemy's fire. Another form, with the axis vertical, is shown in fig. 167. It is possible to conceal it by sprinkling earth over it, and an automatic firing device may be used with it, which is not practicable with the inclined form.

117. **The igniting means** may be instantaneous fuse or electricity. Fuses or wires should be laid in trenches 1 to 3 ft. deep. Mines are classed with respect to the method of firing as **judgment** and **automatic. Judgment** mines are controlled from a firing point and can be fired only at the will of the operator. **Automatic** mines are arranged to be fired by the disturbance of some apparatus in or near them. Automatic and judgment firing are often combined for the same mines. **If firing by cap,** the automatic firing device takes the form of a **mechanical trigger,** which may be operated by the pressure of feet on the ground over it, or by the pulling of a wire stretched along the line at such height as to be tripped by the feet. With electric firing this device is called a **circuit closer,** and the actuating force operates to close a contact which completes a metallic circuit from the battery to the fuse.

Planting and operation of land mines will ordinarily be the work of technical troops supplied with approved apparatus.

118. **Mine tactics.**—In siege operations mining is done at close quarters, and is, or should be, opposed by countermining by the enemy. There is then a double purpose in view; to reach the original objective by placing the charge where intended and firing it, and while so doing to detect and circumvent any attempt of the enemy to interfere, or to prosecute any enterprise of his own.

The only information of neighboring operations which is obtainable results from the **sound of working** carried through the earth. In compact soil an ordinary blow of a pick can be heard at a distance of 40 ft. and the most careful working is audible to a distance of 20 ft. Other sounds, such as rumbling of trucks and especially tamping, can be heard farther. These distances vary with the character of the soil and the skill of the listener. When more than one gallery is driven they should be parallel and not farther apart than twice the range of hearing, so that an enemy's gallery penetrating between them will be heard from one or both. Returns may be run out from the extreme galleries to detect the sound of working on the flanks. Such galleries are called **listeners.** They should not be large.

Efforts must be made to detect the enemy's working and to avoid, so far as possible, giving him like information. At occasional and irregular intervals all work should cease, all extraneous sounds be cut off, and men with quick and trained hearing should listen for sounds of working and estimate the distance and direction. A map of the galleries should be kept, and whenever two headings are approaching, listening should be done in them and the estimates made by the men compared with the measurements on the map as a check on the range of hearing. Accuracy of perception of the sounds may be tested by tapping messages across.

When hostile parties have approached within destructive range of each other the one who fires first is the winner, but the nearer he is, or the longer he holds his fire, the more complete the victory. Each party will be on the alert to discover when the other party is getting ready to fire, and hence the greatest care must be taken to sophisticate the sounds connected with loading. Digging should continue at some point near the end, and all movements of trucks or other operations which make a noise should be continued not less frequently and certainly not more frequently than during the digging. Especially should tamping be cautiously done. **The most probable mistake is premature firing,** and it should be impressed upon all concerned that it is **better to come into actual collision** with the enemy's miners than to fire prematurely.

Galleries are much more vulnerable to a side than an end attack. If the enemy's heading can be located, an attempt should be made to get a position on one side of his gallery. The best position is nearly abreast of the end, a little in rear, so that if he is still digging a considerable length of his gallery will be destroyed, or if he is loading or loaded his mine will be exploded.

For long galleries the difficulties of ventilation and earth disposal may make it advisable to take a new departure. The heads of galleries are brought on a line, or nearly so, branches run forward from each so as to end at intervals of 1½ times the depth below the surface, charged for common mines and fired simultaneously. An elongated crater is produced, which becomes a lodgment for new galleries as well as an advanced parallel in any system of surface approaches. The old galleries are reopened to form rear communications. It has frequently happened that entire underground operations have been directed to the single purpose of forming such an advanced trench in a position which could not be reached on the surface.

It will rarely be possible to get close enough to do serious damage with a camouflet, though in some cases it might be advantageons to avoid breaking ground at the surface. The maximum camouflet charge—$\frac{1}{5}$ to $\frac{1}{8}$ of common mines—gives an H. R. R. somewhat less than the L. R. R., which will usually be not more than 15 ft., while a 6-line crater has an H. R. R. of 5 times L. R. R. As countermining will usually result in a crater, consideration must be given to its situation with respect to the surface work, so that it will be an advantage if possible and certainly not a detriment.

DEMOLITIONS.

119. **Military demolitions** have for their purpose to destroy or make unserviceable any object in the theater of war the preservation of which would be unfavorable to the army or favorable to the enemy, excepting always objects neutralized by international convention or the laws of war.

The principal objects of demolition may be divided into **two general classes**, viz:

Natural or **artificial objects** having **no intrinsic** or **permanent value**, such as accidents of ground and structures of purely military character; and

Natural or **artificial objects** having intrinsic or permanent value, or **adapted to useful purposes** in time of peace, such as buildings and communications.

Demolition is permissible only under a **military necessity.** For the first class of objects above the military necessity is obvious, since the destruction is aimed directly and exclusively at the enemy's fighting efficiency.

For the second class, the destruction affects others besides the armed enemy, and for this class the existence of a military necessity justifying demolition can not be presumed but must be determined at the moment, and the amount and character of destruction or disablement explicitly ordered by competent authority.

Demolitions of a local character, which have no effect elsewhere, may be made on the order of the immediate commander, as may also demolitions of a more serious character, but which are necessary to the safety of a local force. For example, a small force in retreat may interrupt a bridge to avoid capture, but the destruction should go no farther than is necessary to produce the result immediately desired by detaining the pursuers long enough to enable the pursued to make their escape. Demolitions which are intended to, or in their ultimate consequences may, affect a larger force or a greater territory, must be ordered by the commanding general of an army or other force operating independently. In case of doubt, orders should be sought from the highest accessible commander. An officer upon whom work of demolition is devolved should, if not provided with proper orders, ask for them.

120. **Methods employed.**—Demolitions may be made by **fire,** by **mechanical means,** or by **explosives.** Fire is the only recourse when absolute destruction is necessary, as in case of food supplies, munitions of war, structural materials, etc. Soluble matter, as gunpowder, sugar, salt, etc., might be destroyed in water, but this method is laborious. Burning is equally effective and much easier. For quick results with slow-burning materials a quantity of highly combustible stuff must be collected. A small fire gains headway very slowly and much time is lost. Care must be taken that the fire does not spread to objects not intended to be destroyed.

121. Demolition by mechanical means is too simple to require, and too varied to permit, detailed description. Reference is made to a few cases in which the best method may not be obvious.

Abatis is difficult to destroy. If the trees are dry, time suffices, and concealment is not essential, fire is best; otherwise, if working from the front, cut up and carry away enough trees to make a passage through. If working from the rear, loosen the fastenings of the butts and haul away bodily with ropes.

Wire entanglements must be cut with nippers, the more and shorter the pieces the better. Wire may be cut with an ax or machete if a block of wood is held behind it as an anvil. **Trous de loup** are leveled by shoveling the walls into the pits, or bridged with planks, fascines, or other materials.

Palisades and **stockades** may be cut down with axes or saws, or the earth may be dug away from one side and the logs pulled over.

Railroads.—Operations may be directed against rolling stock, bridges, culverts, tunnels or track, or accessories, such as water stations, telegraphs.

Locomotives are temporarily disabled by removing valves or other small vital parts; permanently, by building a fire in a dry boiler or by detonating a charge of explosive in the boiler. In haste, piston or connecting rods, links, etc., may be destroyed by explosives, or a hole may be blown in the bottom of the tender tank. Cars may be burned or wrecked by collisions or derailment. The best places are in deep cuts or tunnels. A head-on collision in a tunnel will put it out of use for some time.

Wooden bridges may be burned or small ones may be pried off their seats by levers or dragged off with tackle.

Track may be destroyed by taking it up, burning the ties, heating the rails on the fires and twisting them with bars through the bolt holes, with a chain and lever, or a hook and lever, fig. 167a. Twisting is much better than bending, as twisted rails must be re-rolled before they can be used. The rail should be hot for the greater part of its length, so as to take a long twist. **A quick track demolition** requiring considerable time to repair, but not injuring the track material, may be made by loosening the ties over a stretch of track, taking off the end fish plates, putting a line of men along one side, two men to each tie, and turning the track over bodily. This plan works best on a high embankment.

Telegraph lines are temporarily disabled by **breaks,** in which the wires are cut, **grounds,** in which the wires are connected to the ground, and **crosses,** in which a metallic connection is made between the wires. **A ground** may be made by connecting a wire to the rail or to a bar or plate of metal in damp earth. Copper is best. A connection with water or gas pipe forms a ground. All faults should be carefully concealed from view, so as to prolong the time necessary to locate them. If a raid is made on a telegraph office, remove the instruments, bare and brighten the ends of all wires, and tie them together with a wrapping of brightened copper wire. Incoming and outgoing wires should be tied separately.

To destroy a telegraph line cut down and burn poles, cut and tangle wires, and break insulators.

122. **Demolition with explosives.**—Handling, priming, and firing explosives for demolition purposes are done as already described in pars. 104 to 113. Bickford fuse will be generally used in such work. Simultaneous ignition at long distances from the firing point should not be attempted unless a battery and electric fuses are available. In such cases the charges should be so arranged that the plan will not fail even though all charges do not go off at once. Proper charges and the best way to place them will be indicated for the most frequent and important uses.

123. **Weight of explosives.**—All calculations of weights of charges are based on the use of an explosive equal in strength to a 50% dynamite. **A stick** will be understood to mean a cylindrical cartridge 1¼ x 8 ins., which will weigh approximately 0.6 lb. **A chain** will be understood to mean a number of such sticks end to end, in close contact, and is taken at 1 lb. per running ft. The cartridges of a *string* will usually be attached to a rope or pole. When two or more strings of cartridges are to be used they may be lashed to the same support. In all the following formulas C represents the charge of 50% dynamite, or its equal in strength, in lbs.; d, the diam. in ft.; B, the breadth of the section to be ruptured, and T and t the thickness in ft. and ins., respectively.

124. **Timber.**—A charge of ½ lb. per sq. ft. of sectional area, placed in holes in the same cross section, will cut off trees and round or squared timbers of usual proportions. The holes should be tamped with clay behind the cartridges. One 2, 3, and 4 *sticks*, figs. 180 to 182, will cut off trees or poles 13, 19, 23, and 27 ins. diam., respectively. The center of the charge should be at the center of the section. If the holes meet, one primer at the middle will do. If they do not meet, as will usually happen in large trees, a fuse for each hole is required and simultaneous ignition. If firing must be done with time fuse, it may be well to charge and fire one hole, then bore another in the soundest part remaining, charge and fire it, and so on, until the tree falls.

A round timber not over 12 ins. diam. may be cut by a *chain* completely encircling it in the same plane. It must set snug against the wood and should be fired with primers on both sides.

Such a charge fired 3 ft. under water will cut any pile or trestle leg likely to be encountered. Close contact is not so necessary under water, and it is convenient to lash the charge to a wire ring or to a band or hoop and slip it down.

87625—09——27

For squared timbers the charge is placed in one or more holes parallel to one face. The direction will depend on the dimensions of the timber as compared with the length of a *stick*. The holes should not go entirely through and should be somewhat deeper than the *stick* is long to allow of tamping. Broadly speaking, the hole should be bored in the direction of the dimension which is nearest 12 ins. for whole *sticks* or in the direction which is nearest 8 ins. and charged with ½ *sticks*.

It may be necessary to cut bridge timbers when there is not time to bore. The charge required is 4 lbs. per sq. ft. of section, and may be placed as a *chain* around, if square or nearly so, or if the piece is thin as compared with its width, across one long side.

Stockades and **stockaded walls** or **palisades** are destroyed by *strings* of cartridges covering so much of their length as it may be necessary to break down. The cartridges can not be got close to the wood except in the case of square timbers, and more powder is required than the actual cross section of wood calls for. Besides, it may not be known what the construction of the stockade is or what strength it may have from braces or other reenforcement.

The charge is best placed along the foot of the wall and should be tamped, especially in the intervals between timbers. So far as its flexibility suffices, the *string* should be bent to fit the contour of the logs as snugly as possible.

If the demolition is deliberate and the structure can be examined, 1 or 2 *strings* well placed and tamped will throw down a single wall or one side of a double wall. If the work is to be done under fire, determine the minimum length of breach actually required and place and fire a charge of 4 *strings* tamped as well as conditions permit.

125. **Masonry.**—For ordinary walls, the charge per running foot varies with the square of the thickness, or $C=0.85\ T^2$. The charge should be laid in *chains* along the foot of the wall, fig. 183. If a tamping equal in thickness to the wall is placed, fig. 184, the charge may be reduced ⅓. If beside the tamping a groove is cut to hold the charge, fig. 184, the weight of the powder may be reduced ½.

The following table shows the **number of chains** required to throw down walls of usual thickness:

Thickness of wall.	Number of chains required.		
	Not tamped.	Tamped.	Grooved and tamped.
Ins.			
13	1	1	1
18	2	2	1
22	3	2	2
26	4	3	2

The walls of a house may be blown down with charges taken from the above table. It is sufficient to charge the walls between windows only, preferably inside and with tamping. In haste, one or more charges of 50 lbs. in a central position will demolish the house.

Retaining walls and **bridge abutments** should be charged at the back and low down. A trench is opened the full width of the back, or a shaft may be sunk and a gallery driven along the back. The charge is tamped with part of the excavated material. In case of a retaining wall it may be found easier to mine under it and place the charge from the front.

When a retaining wall supports a road both may be demolished by a common mine placed as indicated in fig. 187, L. L. R. being taken at ⅘ the width of roadway.

Locks should be attacked at the miter sills, the lower first. Start the gates open slightly and place a concentrated charge between them and the upper edge of the sill.

126. **Masonry bridges.**—A single arch (Roads, fig. 17) is best attacked by charging across the extrados at the haunches, or across the crown, fig. 185. The charge should be ½ more than for a wall of the same thickness. Both methods require digging, and if the spandrel filling is of masonry, the former is scarcely practicable.

Both methods also interrupt traffic on the bridge which it may be important to use until the last moment. A thin arch may be broken by a heavy charge exploded on the roadway at the crown. It should be tamped by throwing a mound of earth over it. The charge should be not less than T^2 lbs. per running ft., T reckoned from surface of roadway to soffit of arch.

The charge may be placed in a trough and suspended under the crown. The sides of the trough should make 60° angle. Planks 12 ins. wide will make a trough to hold 36 *chains* of 1¼ cartridges or 36 lbs, to the running ft. If the number to be used will not completely fill the trough, earth must be placed in the bottom so that the top tier of the cartridges will project slightly above the edges of the boards. The trough must not be allowed to sag away from the arch at the middle. If necessary, truss it up, figs. 216–219, Bridges.

Primers should be placed 3 or 4 ft. apart in the middle *chain* of the top tier and the wires or fuse led out through notches in the sides.

A bridge of **more than one arch** is usually most easily attacked at the piers. The destruction of one pier throws down two arches. The charge should be placed where the pier is the thinnest and should extend across one face. If possible, a groove should be cut in the pier, fig. 186, or irregular voids made by prizing out stones from the same course. This lessens T, partially tamps the charge, and furnishes a convenient support, which must otherwise be provided in the shape of a shelf, trough, or other device.

127. **Metals.**—As soft steel so greatly predominates in structural work, statements under this head will relate to that metal.

All charges will be external, as drilling or boring is not practicable. The standard formula is $C=2.5\ Bt^2$, in which $C=$ the charge in lbs., B the width of the section in ft., and t its thickness in ins. The charge must extend entirely across the plate or sheet.

The following table gives the charges necessary to cut through a plate 1 ft. wide and of the thickness given. It is computed from the above formula for 50% dynamite.

Thickness of plate.	Charge of 50% dynamite.	Thickness of plate.	Charge of 50% dynamite.
Ins.	*Lbs.*	*Ins.*	*Lbs.*
¼	0.16	1¼	3.90
½	0.62	1½	5.62
¾	1.40	2	10.00
1	2.5	3	23.50

A single *chain* will cut a plate up to ⅝ in. thick. Two, 3, and 4 *chains* will cut plates of ⅞, 1⅛, and 1¼ ins. thickness, respectively. The charge must be held snugly against the plate by a piece of plank, lashed or wedged, and whenever possible, must be tamped. **For structural shapes** figure the width as the sum of web and flange widths, and the thickness as the area of cross section in sq. ins., Bridges, 18–19, divided by this sum.

The charge should be in three parts—one on the web and one on each flange. For channels, angles, and Z bars, the entire charge may be on contiguous surfaces, figs. 188 to 190, and one primer will suffice. For I beams the flange charges should be on the outside and three primers are necessary, fig. 191.

As one *chain* will cut up to ⅝ in. thickness, and 2 *chains* up to ⅞ in., the choice will usually lie between the two, as few pieces of structural steel will be found with greater thickness than ⅞ in.

For lattice girders, diagonals, and **posts,** all the longitudinal members should be cut. For **plate girders,** fig. 192, the web and both flanges should be cut. If short of powder, cut the lower flange and lower part of the web. For a **box girder,** fig. 193, figure all four sides as plates. If powder is scarce, omit the top. For a **beam girder,** fig. 194, figure the flange charge for the combined thickness of beam—flange and plate.

128. **Cutting bridges.—Wooden trusses** are best cut near the middle of the lower chord. **Steel trusses** and **girders,** if a complete fall is desired, should have

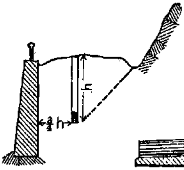


Fig. 187

Fig. 188

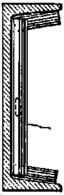


Fig. 189

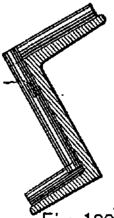


Fig. 190

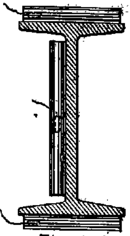


Fig. 191

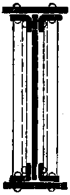


Fig. 192

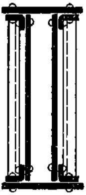


Fig. 193

Fig. 194

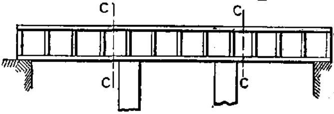


Fig. 195

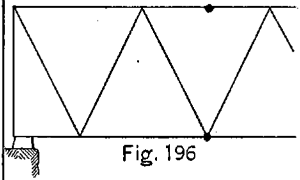


Fig. 196

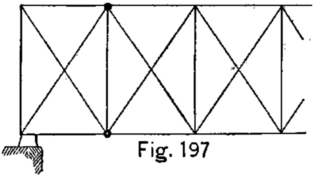


Fig. 197

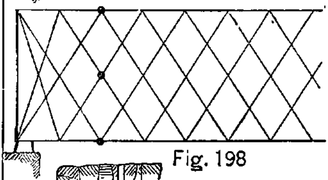


Fig. 198

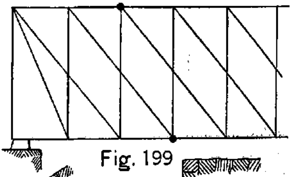


Fig. 199

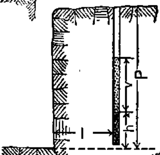


Fig. 200

Fig. 201

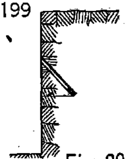


Fig. 202

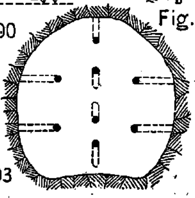


Fig. 203

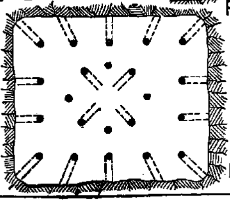


Fig. 204

every member cut on the same cross section. Continuous girders or trusses must be cut near the end of the shore spans opposite the abutment, as at *CC*, fig. 195.

Metal girders and **trusses** are better cut near the abutments, where the cross sections of chords and flanges are smaller. Where members meet or cross, as at panel points, etc., it is usually possible to place charges in a more or less acute angle and then tamp by throwing earth upon them. The effect of the charge in such a situation is always greater than if placed against the side of a single member, and, unless the panel points are of very massive construction and so complicated as to make the effect of the charge uncertain, it will be better to choose them as the location for cutting, remembering that a complete rupture of the entire cross section of the bridge is the object in view. **Panel points** and **intersections** will be selected so as to attain this object with the smallest number of charges. Figs. 196 to 199 show locations of charges for trusses of different form which meet this condition.

A cantalever bridge should be cut over the towers, with especial attention to the complete rupture of the top chords.

Wire cables of **suspension bridges** are difficult to cut. The best place to work is between the cable and the top of the tower, near the saddle. There are no reliable data as to charges required. A French formula gives $C = 0.42\,t^3$, in which t is the diameter of the cable in inches. Assuming the cable to be a plate with a thickness and width which is equal to d, the plate formula becomes $C = 0.21\,t^3$. Assuming the cable to be equivalent to a plate with a width equal to its circumference and thickness equal to its radius, the plate formula becomes $C = 0.16\,t^3$. It is probable that the last formula will give a charge which will weaken the cable at least, so that it will part under the dead load. For a cable of eyebars the charge is computed as for plates and placed between the bars.

129. **Railroads.**—To interrupt traffic rails may be cut and frogs and other parts of switches broken. A *stick* fastened against the web of a rail up to 70 lbs. will cut a gap in it about a foot long; if the charge is tamped, a heavier rail may be cut. Such a cut may be made to produce derailments, but for other purposes two charges should be fired on opposite sides and a few feet apart, which will blow out a piece and distort the ends.

A *stick* in the groove of a frog and covered with ballast will wreck the frog. A *stick* between two rails, as, for example, a track and a guard rail, or the main line and switch rail, will cut both. In such a situation tamping is easy and should always be done.

130. **Rock blasting.**—For maximum effect, it is desirable to get the axis of an elongated charge as nearly as possible at right angles to the L. L. R. This is easier done when the mass of rock presents two surfaces, as a top and side, fig. 200, when the holes can be drilled vertically from the top with the L. L. R. measured to the side face, called in quarrying the **breast.** When the mass of rock presents an inclined face, which is the most usual case, a vertical face is secured and maintained by successive rows of holes, increasing in length, fig. 201.

A wide range of conditions of hardness and stratification does not permit any fixed rules for number and location of charges. In stratified rock of medium hardness the depth of hole, d, fig. 200, may be $1\frac{1}{2}$ times the L. L. R., l, and the holes in the row may be at a distance, l, from each other. For hard granite rocks l must be $\frac{1}{2}\,d$ or even less. The depth of tamping, v, should not be less than $1\frac{1}{2}$ times the length of charge, h, and h should not be more than $\frac{3}{8}\,d$. If the length of charge—the weight of which may be taken from Table II—is more than $\frac{3}{8}\,d$, the holes should be closer together in the row, or the distance from the face diminished, or both.

When there is but one face, as in **tunnel work,** the holes should be drilled at an angle, fig. 202. The harder the rock the greater should this angle be, within the limits of convenience in drilling. Figs. 203 and 204 show a good disposition of drill holes in the face of elliptical and rectangular tunnels of small size. The black dots are the positions of the holes in the breast and the dotted lines show the direction and length. The central group should be fired first. These are called **breaking-in shots** and produce a concave breast which facilitates the throwing out of rock by the remaining shots.

Tunnel work is necessarily progressive. The first loading may be done according to the rules already given. The effect is to be carefully noted, and the number, direction, and depth of holes, and weight of charges so modified as to produce the desired results.

If the stratification is very pronounced, amounting to **fissures,** drill holes should be driven wholly in one layer, not lying in or crossing a fissure.

131. **Ice** can be removed by blasting if there is a current to carry the loosened blocks away and clear water near to receive them. The connection with the shore should first be broken. Small charges rather close together are necessary; on the surface covered with earth if the ice is thin, in drill holes if very thick. This work will be progressive, and charges, distances, etc., can be determined by trial better than from any rule.

TABLE I.—**Areas** in sq. ft. **of parapet sections** for certain heights and widths.

Height of parapet in feet $=h$.	Horizontal width of superior slope in feet$=s$.								
	2	2½	3	4	5	6	10	12	14
2	7.04	7.69	8.35	9.52	10.55	11.44	13.60		
3	13.70	14.78	15.84	17.84	19.70	21.62	26.90	28.88	30.14
4	22.36	23.86	25.33	28.16	30.85	33.40	42.20	45.84	48.76
4½	27.44	29.15	30.82	34.27	37.17	40.14	50.60	55.07	58.82
5	33.02	34.93	36.82	40.48	44.00	47.38	59.60	64.80	69.38
6	45.78	48.41	50.51	54.80	59.15	63.36	78.80	85.76	92.00
7					76.30	81.34	100.10	108.72	116.82
9					116.60	123.30	148.70	160.64	171.86
11							205.30	226.50	235.10
13							269.90	288.48	306.34

For inclined sites **add** if slope is to the **front**, or **subtract** if to the **rear:**

15 to 1, 7%.	9 to 1, 12%.
14 to 1, 7%.	8 to 1, 14%.
13 to 1, 8%.	7 to 1, 16%.
12 to 1, 8%.	6 to 1, 19%.
11 to 1, 9%.	5 to 1, 24%.
10 to 1, 11%.	

ADDENDUM, 1907.

22*a*. Figs. 205 and 206 show an infantry redoubt recently built at Fort Riley, Kans., for test purposes. It embodies some of the latest approved features of such works.

There is a tendency to limit the use of redoubts to the strengthening of key points. In other situations their depth must be restricted as much as possible, so that the redoubt resembles a trench of unusual strength. Overhead cover will always be an important feature.

TABLE II.—**Constants** for determining **charges** and **radius of rupture** of mines.

Kind of material.	Camouflet, 1-line.	Under-charged, 1½-line.	Common, 2-line.	Overcharged.				
				3-line.	4-line.	5-line.	6-line.	
Light earth	0.005	0.012	0.027	0.081	0.185	0.351	0.594	These numbers to be multiplied by l^3 for charges of 50% dynamite in lbs.
Common earth	0.006	0.015	0.033	0.094	0.229	0.433	0.733	
Hard sand	0.007	0.019	0.042	0.126	0.288	0.546	0.924	
Hardpan	0.008	0.023	0.050	0.150	0.343	0.650	1.100	
Ordinary brick masonry	0.010	0.026	0.057	0.161	0.391	0.741	1.254	
Medium rock or good *new* brickwork	0.013	0.034	0.075	0.225	0.514	0.975	1.650	
Best *old* brickwork	0.014	0.038	0.083	0.250	0.569	1.079	1.826	
Rad. rupture Hor	1.0	1.4	1.7	2.5	3.4	4.0	5.0	These numbers to be multiplied by l for radius in ft.
Rad. rupture Vert	1.0	1.0	1.1	1.2	1.7	2.0	2.5	

For gun cotton or 75% dynamite, reduce charges found from above table 40%. For ammonal, reduce 50%.

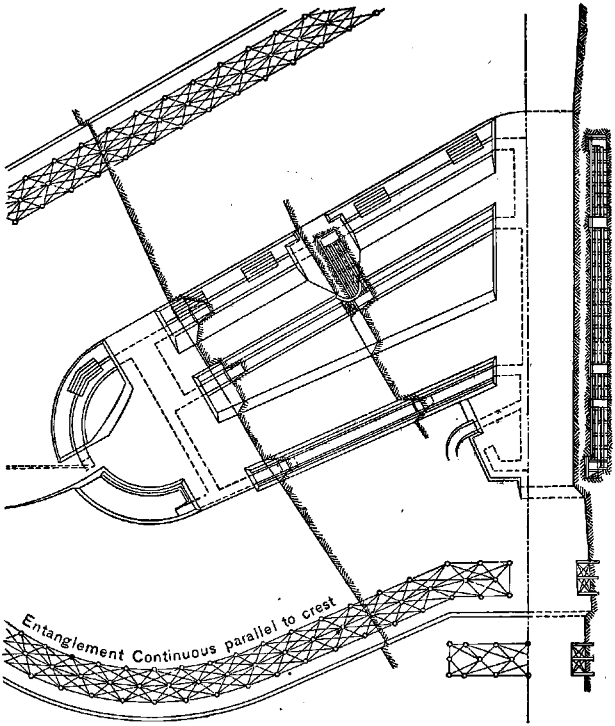


Fig. 205

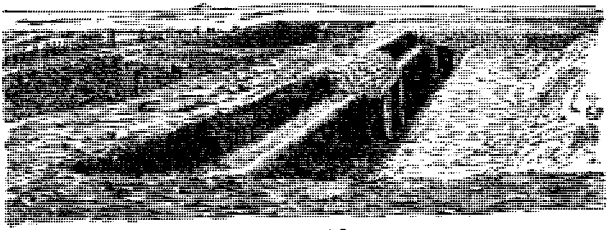


Fig. 206

9*a*. Certain changes in the consensus of military experts in the matter of **profiles** of **infantry trenches** must be noted. These changes rest upon principles which have been stated in former editions but have not heretofore been embodied in typical profiles.

Foremost among them is the **increasing weight** given to **concealment from view** and the sacrifices of other desirable conditions which are thought to be justified to secure or preserve such concealment. There is also to be considered the greater **depression angle** of lines of vision made possible by **balloon reconnaissance.**

Of the principal conditions set forth in paragraph 8, only the second, third, and fourth appear to require modification. When the parapet is not screened from view it can be seen more clearly and at greater distance if it presents marked difference in the inclination of its planes. For this reason it is now thought that the exterior slope, instead of being made "as steep as the material of which it consists will stand," would better be as **flat** as the **supply** of **material** and the **labor** of **placing** it will permit, and the superior and exterior slopes should either be **merged** or make a **small angle** with each other, and in the latter case should be **joined** by a **curve.**

As the new profiles are characterized by lower and wider parapets, the minimum **thickness** to resist penetration will **seldom** be a **controlling factor.**

An ample **elbow rest** is now considered very desirable. A **foot wide** and a **foot deep** are generally accepted dimensions, but when the trench is occupied each soldier may be allowed to adapt the elbow rest in front of him to his individual requirements.

9*b*. The importance of **overhead cover** is more generally **recognized** than formerly. In actual trench construction it is not so difficult as it would appear. The **lightest possible** cover is **better than none.** Among the **first thoughts** of an officer who becomes responsible for intrenching a line of troops should be the **kind** and **quantity** of **material** for overhead cover which is in reach and how it can best be utilized. Fig. 212 shows the general features of a design simpler than the forms heretofore proposed in this manual.

9*c*. It is noted by our observers of the Manchurian war that the **lying trench** was seldom if ever used. The lying trench still appears to be the **best way** to obtain slight **cover** under **hot fire** with a **minimum** of **casualties** not only because it involves less digging, but also because the men are less exposed while digging and are partially protected from the beginning of the work, and the use of the lying trench may yet be advisable for our Army. It is premature to relegate this form to oblivion. **Normally,** the **first** objective will be a simple **standing** trench. Lying and sitting forms will be used only when a standing trench is so difficult of construction as to be impracticable. However, the principles of the construction of the lighter forms and their conversion into stronger forms should not be lost sight of.

When a natural screen is available and the fire not too annoying, the profile shown in fig. 207 will give good cover in a short time. When no screen is available and the command is under fire, or likely to be so, fig. 208 is probably the best form.

9*d*. The **type profiles** shown are those which represent proper **solutions** of the **problem** under **average conditions.** If actual conditions are exceptional, the exceptions should be accounted for in the profile. Thus the existence of a screen of grass might determine a profile which is a compromise between figs. 207 and 208, the exact arrangement depending on the height of the grass, or a slight rise of ground in front calling for a higher command might result in the adoption of a profile based on fig. 209, but with a higher parapet and shallower trench, utilizing in the parapet part or all of the volume of earth marked "to be wasted" in fig. 211. Type, or average condition profiles having commands of 1 to 2½ feet, increasing by steps of one-half foot, are shown in figs. 208 to 214. Taking the earth from the entire width of trench and distributing it over the entire width of parapet in the easiest and most natural manner should produce nearly the desired profile. With the interior crest of proper height and the base of parapet of proper width, a general slope from the crest to the outer line of the base, a little full or convex upward in the rear or higher half and a little slack or concave upward in the front or lower half, will give an excellent profile. The elbow rest only requires especial attention. This may be formed as the parapet goes up or may be cut after the parapet is finished, according to conditions and the preference of the builders. The elbow rest, while most desirable, is not essential, and if under fire or if the earth does not stand well it may be omitted and an interior slope formed as in the older profiles.

12*a*. When the distance between firing and cover trenches is sufficient, the **communicating trench** may be given a zigzag trace somewhat as in fig. 119, but with the **returns** or extensions at the angles perpendicular to the general direction of the trench or approximately bisecting the angle between the adjacent legs. Counting from the firing trench, the first of these returns may be set apart as a rear, the second as a dressing station, and the third as a signal station.

20*a*. The **simplest redoubt** is an infantry trench inclosing the area selected, with communicating trenches, as described in 12*a*, ante, joining the front face which corresponds to the firing trench and the rear face or gorge which corresponds to the cover trench. All the instructions for siting in paragraph 20 apply except that it is not worth while to make any sacrifices to secure straight lines, and a **profile** giving **surplus earth** should be used, which surplus should be thrown to the rear to obtain some **cover** against **reverse fire;** this especially at the returns for dressing stations, etc., as in case of an attack from the rear the functions of the various parts are reversed; that is, the cover trench becomes the firing trench, the firing trench the cover trench, etc.

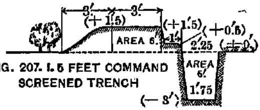


FIG. 207. 1.5 FEET COMMAND SCREENED TRENCH

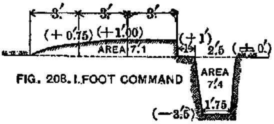


FIG. 208. 1.FOOT COMMAND

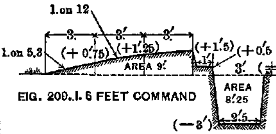


FIG. 209. 1.5 FEET COMMAND

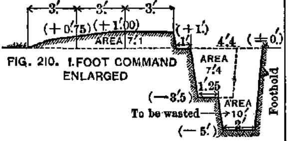


FIG. 210. 1.FOOT COMMAND ENLARGED

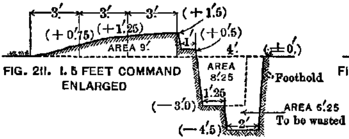


FIG. 211. 1.5 FEET COMMAND ENLARGED

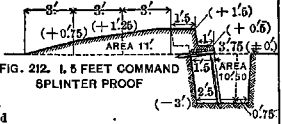


FIG. 212. 1.5 FEET COMMAND SPLINTER PROOF

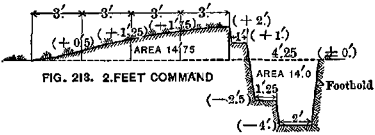


FIG. 213. 2.FEET COMMAND

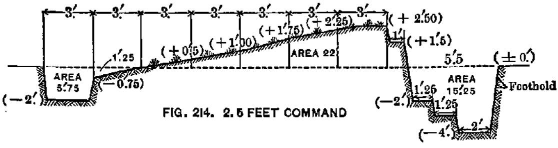


FIG. 214. 2.5 FEET COMMAND

PART VI.

ANIMAL TRANSPORTATION.

PART VI—ANIMAL TRANSPORTATION.

1. **Animal transportation** for the Engineer service is divided into **wheel** and **pack** transportation. In wheel transportation, the wagon is the unit, and each animal can haul, on a conservative estimate, 1,200 lbs. gross or 700 lbs. net load. In pack transportation, the animal is the unit, and each can carry, also on a conservative estimate, 300 lbs. gross or 225 lbs. net load. A given quantity of freight carried on packs will require three times as many animals as would be necessary to carry it on wheels. The larger number of animals means a proportionate increase of the forage to be provided and in the labor of feeding, shoeing, etc. If, however, the country and season are favorable for grazing, the pack mule will get on without any forage, while the draft mule can not. Other disadvantages of pack service are that packages must be limited in size and weight much more closely than for wagons; long articles, as tent poles, can not conveniently be carried except by special construction, and loading of pack cargoes is an expert service which must be performed by a few trained men, while loading of wagons is work in which all can participate.

The great **advantage** of **pack transportation** is its mobility, and this consideration is often paramount. A good pack train, well handled, can make 2 miles to 1 of the best wagon trains on good roads and more on bad ones, and can besides go where there are no roads at all and where the country is so rough that roads could hardly be made and wagons could not pass them if they were made.

Wagon transportation should be used unless the country is impracticable or the rate of march too rapid for wheels. The permanent pack trains should be limited to the probable requirements of rapidly moving columns, and in those the baggage, etc., should be kept down to an absolute minimum. When great difficulties of wagon transportation are foreseen, the draft mules should be broken to pack service and enough aparejos carried in the train so that in case the wagons must be abandoned, $\frac{1}{4}$ to $\frac{1}{3}$ of the loads may be placed on the mules and the march continued. The combination of harness and pack saddle which naturally suggests itself in this connection, is not practicable. Such a combination would make a very poor harness and a worse pack saddle.

Mules were used interchangeably for draft and pack service on the Mexican boundary survey, and pack mules were put into harness in the China campaign.

2. **The mule** is the standard draft and pack animal of the United States service. He can best be described and understood by noting his points of difference from the horse, which he resembles so closely that it has not been found necessary to devote books to him particularly. The points of difference in conformation are mainly larger, thicker head, longer ears and smaller feet, larger girth, shorter legs, and longer body. The relative disposition of bones and their angles are the same as for the horse. Fig. 1 shows the skeleton and the names of the bones most likely to be the seat of injuries or disease. Fig. 2 shows the mule's exterior conformation and the names of the regions into which it is divided.

Where extensive bogs are found, as in some parts of Alaska, horses are used for pack service, selection and breeding being conducted with a view to the maximum size of foot.

The mule is tougher and hardier than the horse, less subject to disease or to inflammation from slight injuries, and usually yields more readily to treatment. He is nearly exempt from some common diseases of the horse, and especially from colds. In the field, colic and kicks or other contusions, are his principal troubles. When injured he does not exhibit lameness as quickly as the horse, and on this account needs more careful watching.

3. **Selection of mules.**—The cross between a jack and a mare is that most used and is the best. Of these, experience seems to indicate that mules resembling the sire—that is, small or medium sized, with strong markings, large ears, and small feet—are hardier, while those resembling the mare, good-sized, smaller ears, larger feet, and no jack markings, are likely to show less endurance. Color does not seem to give any indication of constitution or disposition except as above noted. Good mules will be found in all colors. Mules for immediate use should not be taken under 4 years old. A mule sound and healthy at 4 years should, with proper care and treatment, last until he is 18. There need be no distinction as to sex. Some experienced men prefer mares. Female mules are said to stand sea voyages better than males. Very large mules are not desirable.

A mule should be judged as to his **age, strength, endurance,** and **disposition. Indications of age** are not very precise as to exact years, but are clear enough as to the question whether the mule is too young or too old for service. At 4 years, which should be the minimum age, 4 of the 6 incisors in each jaw are permanent, and the others, the end ones, are temporary or milk teeth. The difference is plain, as the milk teeth are white and smaller than the others and are smooth outside and grooved inside while the permanent teeth are grooved outside and smooth inside. In mules, the tushes also appear at this age, smooth, straight, and pointed, fig. 3. At 5 years, the remaining milk teeth are replaced by permanent ones, which latter, however, have no inside wall, fig. 4. At 6 years, these teeth have the inside wall. At 7 years, the ends of the incisors show wear and the tushes begin to appear blunted, fig. 5. From this stage on, the age is a matter of judgment, based on the amount of wear of incisors and tushes, and the angle of the incisors, which is obtuse in young animals and gradually changes to acute in very old ones, fig. 6. Other indications of age in the mule are the temples, full in the young and sunken in the old, and the wrinkles above the eyes, and gray hairs, both of which increase in number as the animal grows older.

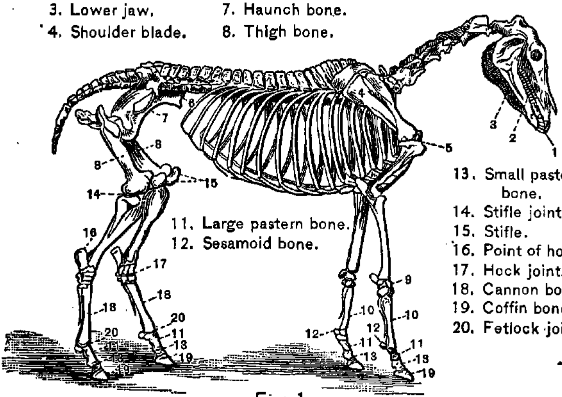
The **indications of strength** are, the size and build of the animal, especially of his legs. The fore legs should be set well apart at the shoulders and about equally wide at the feet and should appear straight when looked at from any direction. The hind legs should also set well apart and be parallel, and appear straight when looked at from behind. The angle of the pastern should be such that the middle line of the leg prolonged to the ground will just touch the heel when the animal is standing squarely and naturally on a smooth level surface.

The **indications of endurance** are principally the breadth and shape of the chest and the girth, both of which show the lung power on which endurance depends. The chest should be broad and muscular, and especially the breastbone should not be prominent. Looking at the animal from the side, the chest should appear to project distinctly in front of the fore legs. The girth, measured 6 to 9 ins. in rear of the fore legs, should not be less than $1\frac{1}{4}$ times the height of the animal.

For **indications of disposition** look to the head and eye; the latter is especially a good index. Avoid mules with extra long heads; also those with hollow or dish faces. The eyes should be set well apart and stand out prominently. Eyes close together or sunken show a mean disposition. A good mule has a soft kindly look in his eye which is difficult to describe but is easily recognized. The ears should be mobile, and in young animals constantly moving; one pointing forward and one back is a good sign; laying both ears clear back when approached is a bad sign; but animals at rest and undisturbed frequently lay the ears back.

4. **Feeding.**—The ration for the mule is 9 lbs. of oats or corn and 14 lbs. of hay, the latter the same as for the horse, the former $\frac{1}{4}$ less. Bran when issued is in lieu of grain, pound for pound. One hundred pounds of straw per month is allowed for bedding, or the same amount of hay if straw can not be had. The smaller grain ration is determined by the smaller average size of the mule and does not mean that he is a lighter eater than the horse or that he can do the same work with less nutrition. The ration is right for the *average* mule at *average* work. If he is extra large

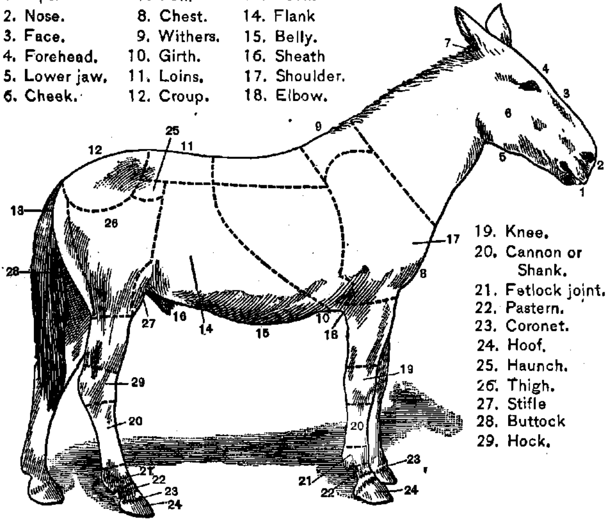
1. Incisor teeth.
2. Molar.
3. Lower jaw.
4. Shoulder blade.
5. Point of shoulder.
6. Haunch.
7. Haunch bone.
8. Thigh bone.
9. Knee bones.
10. Cannon bone.



11. Large pastern bone.
12. Sesamoid bone.
13. Small pastern bone.
14. Stifle joint.
15. Stifle.
16. Point of hock.
17. Hock joint.
18. Cannon bone.
19. Coffin bone.
20. Fetlock joint.

Fig. 1.

1. Lips.
2. Nose.
3. Face.
4. Forehead.
5. Lower jaw.
6. Cheek.
7. Poll.
8. Chest.
9. Withers.
10. Girth.
11. Loins.
12. Croup.
13. Dock.
14. Flank
15. Belly.
16. Sheath
17. Shoulder.
18. Elbow.



19. Knee.
20. Cannon or Shank.
21. Fetlock joint.
22. Pastern.
23. Coronet.
24. Hoof.
25. Haunch.
26. Thigh.
27. Stifle
28. Buttock
29. Hock.

Fig. 2.

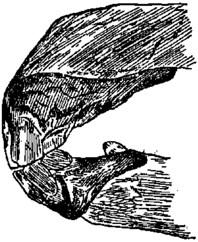


Fig. 3, 4 years

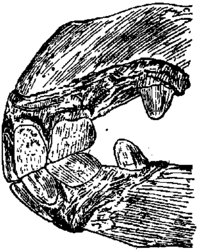


Fig. 4, 5 years.

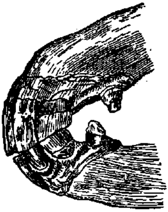


Fig. 5, 7 years.

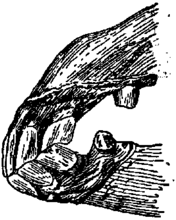


Fig. 6, very old.

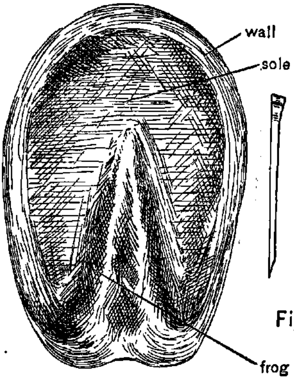


Fig. 7

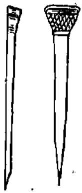


Fig. 9

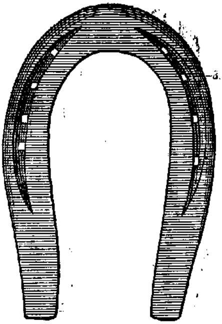


Fig. 8
Mule shoe, not fitted.

or is worked beyond this limit, he must have more grain or its equivalent in other food, or he will fall off in condition.

While the mule is less particular about his food than the horse, and will keep himself alive when a horse would starve, it is none the less important that his food should be clean and sound. He is particularly sensitive to sudden changes of diet even when the old food and the new is each good of its kind. Changes from grain to grass and the reverse, or from one kind of grain to another, should be made gradually. In addition to a proper quantity of food, the animal must have time to eat it. All of the hay and more than half of the grain should be fed at night, and the morning feed should be given at least an hour before hitching up. Pack mules frequently have the entire ration at night and are not fed at all in the morning. In the field, the mules can be fed at the picket line by putting a layer of hay along the line, making a hollow or nest in front of each mule and pouring the grain into it. When no hay is fed and the ground is not dry and clean, lay down sacks on which to place the grain. Animals must be watched while feeding to prevent stealing from each other and waste by scattering grain or trampling it into the dirt.

Mules which are nearly exhausted or *pumped out* after a hard march will sometimes refuse to eat. Their food should be taken away and offered to them later, after they are rested a little, when they will usually take it.

Bran moistened with water to the consistency of brown sugar should be given occasionally, and always if there are signs of constipation. It may be given alone or mixed with a part ration of grain. It must be freshly mixed to make sure that it is not in the least sour. This and a little fresh grass when it can be had are sufficient usually to keep the bowels right. Purgatives should not be given except under the advice of a veterinarian or when constipation persists in spite of the simple remedies suggested. An ounce of nitrate of potash, or, if this can not be had, about a pint of wood ashes mixed with the bran mash, will slightly increase its laxative effect. Common salt has the same effect.

5. **Salt.**—Mules require a certain amount of salt, of which they are the best judges. The allowance is 2 oz. per week for each animal, which may be increased to 12 oz. per month, in the discretion of the commanding officer. In a corral, lumps of rock salt may be kept in boxes from which the mules will lick as much as they need. If glanders should make its appearance anywhere in the vicinity, the use of these boxes should be discontinued and salt fed to the animals separately. This is best done in the bran mash. On the march salt must be fed in the same way. If the mules are found licking each other or the harness, or gnawing wagons or mangers, it is an indication of lack of salt.

6. If the mules are herded for grazing at night, there should be a **bell horse** to keep them from straggling. The bell horse should be hobbled but not picketed if it can be avoided. There should also be a herd guard on duty. Pack animals are habitually trained to follow a bell horse, but draft mules are not. Horses have a peculiar fascination for the mule, and if one is turned into a corral with a bunch of mules for 2 or 3 days, they will follow him anywhere and can not be induced to leave him. If a pack train is short of grain, the bell horse should have a full ration, since he can not graze along the line of march while the pack mules can and do.

In open country a white or gray bell horse will make it possible to locate the train at a much greater distance. This may or may not be desirable, according to circumstances. This remark applies also to white or gray mules.

7. **Water.**—A mule requires from 4 to 6 gallons of water a day, depending on the season and his work. In an arid climate 2 or 3 times as much may be required. In an emergency, he may be worked with what he will drink at one watering a day, but whenever possible he should be watered two or three times a day. In corrals there should be, except in freezing weather, a constant supply so that the animals can drink whenever they desire to do so. It is as important that the water be pure and wholesome as for any other animal. In fact, the mule is rather particular about his drinking water. In every herd, some animals will refuse water which others drink and which appears to be good. No pains should be spared to find water which these animals will drink.

If the mules have had enough water at night they often will not drink before starting in the morning. In such case **every effort must be made to get water**

at the end of the first hour's march. Especial attention is required on this joint, as the watering of draft mules on the road generally involves unhitching the seams or carrying the water in buckets, either of which operations causes trouble and delay and is likely to be neglected. In crossing a stream with soft bottom, if the mules are thirsty they should be watered before driving in; otherwise they may stop to drink and mire themselves or the wagon. A stream encountered at the end of a march should usually be crossed before going into camp.

8. **Diseases and treatment.**—The normal condition of a mule is indicated by a pulse of 34 to 38 per minute, and a temperature of 99 degrees. The pulse can best be taken inside the lower jaw or inside the fore leg just above the fetlock. Temperature is taken by a clinical thermometer inserted in the rectum for five minutes. Disease is almost always accompanied by an increase of temperature or pulse, or both. The pulse may run to 100 per minute or even more. A strong, full pulse of normal rate is a very good indication of freedom from disease or injury. The temperature in some diseases runs from 107 to 109 degrees. In taking either temperature or pulse, avoid exciting or worrying the animal. The normal rate of respiration when at rest is 12 per minute.

Apart from accidents, which will be frequent, and contagion, which will be infrequent, sick mules in the field will usually be the result of some neglect, as of feeding, watering, policing, or shoeing; or of abuse or overexertion. It is much easier and better to keep mules well by proper attention and treatment than to cure them when sick.

The diseases and injuries described below include those most likely to be encountered in field service, those in which effective treatment can be given by persons who are not skilled veterinarians, and those in which prompt action is necessary to prevent contagion.

Administration of medicines.—Liquid medicines are given as a drench. Put the liquid into a long-necked bottle without a shoulder, and see that there are no sharp edges or projections about the mouth or neck. Raise the animal's head until the mouth is higher than the throat. Insert the neck of the bottle in the side of the mouth between the incisors and the molars. Point it toward the throat and allow the medicine to run out slowly and with intermissions if necessary.

Powders without disagreeable taste or odor may be dissolved in water and sprinkled on the feed or put into the drinking water.

Balls to contain dry medicines may be made by the addition of honey, sirup, or soap, using oil meal if necessary for required consistency. They should be about 2 ins. long and ¾ in. in diameter, freshly made, and inclosed in tissue paper or gelatin capsules.

The mixture may be given a sticky consistency and placed on the tongue with a paddle or spoon. This form is called an **electuary.**

ADDENDUM, 1907.

8*a*. War Department Circular 9, series of 1907, provides that the mallein treatment as a preventive against generalized incipient glanders shall be administered quarterly in the United States and oftener in tropical countries.

The Quartermaster's Department supplies the mallein.

9. The following **table of veterinary supplies** is sufficient for ordinary requirements of field treatment:

Articles.	Designation.	Quantity for 100 animals.	Quantity for 200 animals.	Quantity for 300 animals.
Acid, boracic	oz	4	6	8
Acid, carbolic	oz	16	20	24
Aconite, fluid extract	oz	1	2	3
Alcohol, grain	gals	1	2	3
Aloes	oz	20	24	32
Alum	lbs	½	½	1
Camphor, gum	lbs	1	1½	2
Calomel	oz	2	4	6
Cosmoline	lbs	4	8	12
Creolin	lbs	2	4	6
Flaxseed meal	lbs	25	30	40
Ginger, powdered	lbs	1	2	3
Glycerin	lbs	1	2	3
Iodoform	oz	4	6	8
Iron, chloride, tinctnre	oz	8	12	16
Lead, acetate	lbs	1	2	3
Needles, surgeon's, asstd	doz	½	¾	1
Oil, linseed, raw	gals	2	3	4
Oil of turpentine	gals	1	1½	2
Opium, tincture	lbs	2	3	4
Potassium, nitrate	lbs	3	4	6
Sulphur, powdered	lbs	1	1	2
Sweet spirits of niter	lbs	4	8	12
Tar, pine	lbs	1	2	3
Witch-hazel, distilled	qts	2	4	6
Zinc, sulphate	lbs	1	2	3
Absorbent cotton	lbs	2	3	4
Antiseptic gauze	pkgs	2	2	3
Bandages, red flannel, 4 ins. wide, 4 yds. long.	doz	2	3	4
Bandages, white cotton, 4 ins. wide, 4 yds. long.	doz	4	6	8
Oakum	lbs	10	15	20
Plaster, adhesive, 2 ins. wide, 10 yds. long	rolls	1	1	2
Silk for ligatures, ordinary	oz	½	½	¾
Silk for ligatures, heavy-braided	oz	1	2	3
Soap, white castile	lbs	10	15	20
Sponges, surgeon's	lbs	1	2	3

10. **Standard veterinary prescriptions:**

One lb. fluid=16 oz.=1 pt.

One dram solid or fluid=⅛ oz.

A standard silver dollar weighs $\frac{88}{100}$ apothecary's oz., or $\frac{84}{100}$ avoirdupois oz. By giving liberal measure it may be used as an ounce weight.

A 5-cent nickel may be used for a dram weight. If well worn it will be nearly right; if new, take scant measure. A balance can always be improvised.

Antiseptic or sterilizing dressings for external use only (Nos. 2 and 3 may be used on eyes, nose, and mouth):

1. Creolin 1 part, water 40 parts.
2. Carbolic acid 1 part, water 40 parts.

3. Boracic acid 1 part, water 20 parts.

4. Iodoform, dry, necessary quantity sprinkled on wound.

5. Boracic acid, dry, necessary quantity sprinkled on wound.

6. Sulphate of zinc 1 oz., acetate of lead 1 oz., water 1 qt. This is the well-known **white lotion.** A dram of carbolic acid may be added if a strong antiseptic is needed.

Ointments.

7. Iodoform 1 part, cosmoline 6 parts.

8. Boracic acid 1 part, cosmoline 6 parts.

9. Carbolic acid 1 part, glycerin 6 parts.

10. Sulphur (if powdered) 2 drams, cosmoline 1 oz.

Liniments.

11. To relieve pain. Witch-hazel 2 oz., spirits of camphor 2 oz., laudanum 2 oz.

12. Stimulating. Turpentine 2 oz., spirits of ammonia 2 oz., linseed oil 4 oz.

13. Spirits of camphor 2 oz., spirits of ammonia 2 oz., turpentine 1½ oz., water 1 pt.

14. Soap liniment. Castile soap 6 oz., spirits of ammonia 6 oz., spirits of camphor 2 oz., alcohol and linseed oil each 1 pt.

Miscellaneous.

15. Purge. Aloes 6 drams, calomel ½ dram, ginger 2 drams.

16. To stimulate the kidneys. Sweet spirits of niter 1 oz, water 1 pt.

17. Founder powder. Nitrate of potash 4 oz., gentian, 4 drams.

18. Tonic. Gentian 2 drams, ginger 2 drams, flaxseed meal ½ dram.

19. Colic. Sweet spirits of niter 1 to 2 oz., laudanum 1 to 4 oz., ginger 2 drams.

20. To dress saddle and harness galls and to harden the skin. Alcohol 1 pt., water 1 pt. If the skin is abraded, mix with white of eggs to a paste and apply a thick coating.

Constipation.—Put the mule on a laxative diet, bran mashes, grass, or vegetables. Salt also has a slightly laxative effect.

Diarrhea.—Usually results from too laxative diet or exposure. Put the animal on dry feed without salt and keep dry and warm. Do not work more than necessary. In aggravated cases give ½ pint of raw linseed oil or 1 dram of powdered opium.

Spasmodic colic.—The animal appears to be in distress, looks around at its flanks, paws, kicks at its belly, attempts to evacuate the bowels and to pass urine. Pulse and respiration accelerated. The attacks are intermittent and between them the animal returns to apparently normal condition.

Give a drench of 1 pt. of raw linseed oil, and prescription No. 19. If the animal has not been overfed and the case is light, 1 dram of powdered ginger mixed in water will do. Give ample room to move about.

Flatulent colic.—More serious and less frequent than the former; pain apparently less severe but continuous; animal unsteady on its legs; extremities cold; excessive distention of abdomen.

Give No. 19 full strength, repeating at hour intervals until relieved. In severe cases it is necessary to puncture the animal to relieve the distention. The puncture is made in the right flank in the space bounded by the backbone, the hip bone, and the last rib, and at the point of greatest distention. The puncture is made with the trocar directed downward and inward. Leave the canula in the opening temporarily. This operation should be done by a veterinarian or farrier.

Poll evil.—An abcess on top of the head immediately behind the ears. Troublesome mainly from its unfavorable situation for treatment. Keep bowels open and reduce inflammation by applications of cold water. After pus has formed, open clear to the bottom so that pus can readily run out from the lowest part. Poultice and keep open until discharge of pus has entirely stopped. Use antiseptic dressings Nos. 1, 2, or 6.

Strangles.—An inflammation of the glands of the throat and neck, resulting in the formation of an abscess. Good care and soft food, varied as much as possible to stimulate the appetite, are all that is required until the tumor heads, when it should be freely opened and drained until it is free of pus.

Glanders.—A yellowish, sticky discharge from the nose, with ulcers inside the nostrils, at first distinct, then with ragged edges and finally confluent; enlargement and hardening of one or both glands below the jaws; staring coat; difficult respiration; extreme debility and profuse perspiration on the slightest exertion; fetid odor from nostrils in advanced cases. The disease is contagious and incurable. As soon as suspected, the animal must be isolated, and when the disease is recognized, he should be killed and burned or deeply buried. All grooming and other implements used about the animal should be destroyed and his surroundings thoroughly disinfected. Attendants should use great care to avoid contagion in handling suspected cases. The hands should be free from cracks or sores, and after touching the animal, should be well washed, with a little carbolic acid in the water. See p. 432.

Farcy.—A different and milder manifestation of the same poison as in glanders Ulcers appear on head, body, or legs; they are commonly called **farcy buds** or **buttons.** When the legs are affected, they swell, and the buds are usually below the knees or hocks, oftenest in a line down the front of the fore leg, beginning at top and running to the bottom. In the early stage, the buds are hard lumps beneath the skin. Later they enlarge and suppurate through the skin. Before this condition is reached, the animal should be killed.

Surra.—A disease resembling glanders, prevalent in the Philippine Islands. It is probably a wound disease, caused by contact of the infectious agent with a wounded surface, either skin or mucous membrane. At first loss of appetite, constipation, fever and thirst; later a dropsical swelling, usually beginning around the belly and immediately or quickly extending to legs and feet, with rapid and extreme emaciation. Sometimes the submaxillary glands are involved, with discharge from the nose resembling that of glanders. A very characteristic symptom is dragging the hind feet in walking. The disease runs from 3 to 4 weeks and sometimes longer. No remedy is as yet known. Isolate as soon as suspected, and, when the diagnosis is certain, destroy the animal and burn or bury the carcass.

Isolation hospitals and corrals should be half a mile from other corrals. No non-isolated animals should be allowed to approach them even to bring visitors or supplies, which should be conveyed by other means.

All animals should he carefully examined and all abrasions of skin or mucous membrane should be protected from biting insects by local applications.

Suspected and sick animals should be protected from biting insects, especially flies, by screens, smudges, or washes, and carcasses should be similarly protected until burned or buried.

All possible efforts should be made to exterminate biting insects and rats.

Where surra is or has been prevalent allow no grazing and avoid all green forage, especially from marshy or overflowed ground. The disease is more prevalent in wet places and wet weather.

Mange.—Small pustules form on the skin, usually beginning at the roots of mane and tail. The discharges form a crust under which the hair loosens and falls out. The disease is contagious and animals affected must be isolated and usual precautions taken. Cleanse the affected parts thoroughly with soap and water and dress with No. 2. If the skin is affected over a large surface, only a part of it should be gone over with the carbolic solution each day, to avoid carbolic-acid poisoning. It is better in such cases to substitute No. 1, which may be used with impunity.

Scratches.—An inflamed condition of the skin of the heel with crusts giving a watery discharge. Caused by exposure to wet and cold, sometimes by trimming the fetlocks. Keep the parts dry and clean. Wash, if at all, with warm water and castile soap and dry thoroughly after washing. If the skin is unbroken, use fresh lard and vaseline; dust with powdered alum twice a day. If the skin is cracked, use No. 10. A dry place for the animal to stand is necessary to a cure.

Thrush.—A disease of the frog, usually behind, accompanied by an offensive discharge. It results from uncleanliness. Keep the frog clean and dry; pare away ragged parts and open the cracks to facilitate discharge; dust with calomel and dress with iodoform or pine tar.

Laminitis or **founder.**—An acute inflammation of the processes which connect the wall of the hoof with the coffin bone. More common in the front feet; very painful and causes extreme lameness and stiffness with much heat in the foot. Over-exertion, indigestion, and *watering when heated* are most frequent causes. The animal can scarcely be induced to move and tries to take the weight off the toes by standing on the heels, or, if the fore feet only are affected, by drawing the hind feet forward under the body.

Give laxative diet and plenty of water, remove the shoes, and give the animal a soft footing which will throw as much weight as possible on the sole and frog. In the field a good plan is to make a slight depression in the ground, fill it with water and let the mule stand with his fore feet in the mud. Give No. 17.

Lockjaw.—Induced by pricking the foot with rusty iron, or by punctured wounds. The disease is caused by a microbe which thrives in rich soils, as of highly cultivated gardens and in the tropics. Common in the Philippine Islands as a result of punctured wounds.

There is difficulty in swallowing and rigidity of the limbs; ears erect and to the front; nostrils dilated; legs spread apart, and tail persistently held erect. General muscular rigidity; obstinate constipation and torpidity of the liver. The climax usually comes in 3 or 4 days.

Search for the exciting cause, and if found to be a wound of any kind, treat it. Give a strong purgative, and 2 to 3 drams solid extract of belladonna three times a day. Give liquid food—gruels—and have clean water in reach of the animal at all times. Give rest and quiet in a darkened stall. During convalescence give laxative nutritious food and tonics, as No. 18.

Rope burns.—Abrasion of the skin under the fetlock by rubbing against a rope. Very frequent, especially with mules not accustomed to being tethered or picketed. If not severe, cleanse with soap and apply ointments 7, 8, or 9, or tar, or any kind of clean grease. For severe cases, use the same treatment and bandage.

Pricking the foot.—This may result from picking up a nail or from one improperly driven in the shoe. If the point of injury can not be seen, locate it by pressure. The mule will flinch when the sore spot is touched. If suppuration has not set in, clean the part, treat it with antiseptic, and stop the orifice with a plug of sterilized material. If pus has formed, a free exit for it must be provided and maintained. It may be necessary to cut away a considerable amount of horn to do this.

A **puncture** of the **frog** is managed in a similar way.

Wounds and **bruises.**—The prime requisites of treatment are the arrest of hemorrhage (tinct. iron *hot* or *cold* water, pressure, if arterial); removal of foreign objects if possible; cleansing and sterilizing the wound (antiseptics 1, 2, or 6 may be used); replacement of parts in proper relative position by stitches or bandages, and a provision for the discharge of pus from the bottom of the wound. In some cases the greatest possible freedom from motion is desirable.

The healing of wounds in mules is almost always by suppuration. Before the tissues unite they assume a granular appearance. This **granulation** should begin at the deepest part and progress regularly outward. If granulation appears first near the outside, care must be taken to preserve a channel by which the pus may discharge freely from below. A tube, or a string of tow or other clean fibrous material dipped in melted wax or paraffin, will answer. This can be withdrawn when the wound is dressed, the accumulated pus pressed out, and the string replaced.

Spring tonic.—If mules are sluggish in early spring, lose their appetites, and are slow in shedding out, their condition may be improved by giving a small quantity of saltpeter in soft feed once a week for a month or so. If nothing else can be had, give a teaspoonful of powdered sulphur and a half pint of wood ashes.

11. **Shoeing.**—A mule's feet are designed to carry his weight partly on the lower edge of the outer wall and partly on the sole and frog, fig. 7. The pressure of the frog on the ground gives a better foothold and besides causes a lateral pressure on the inside of the wall which resists the natural tendency of the hoof to contract. The wall is constantly growing, and on a soft elastic footing it wears away at a rate.

equal to its growth and is always of the right length to take its share of the load. On a harder footing, such as is presented by most roads, the wall wears faster than it grows, and is constantly shortening, letting the sole down so that it carries too much of the load and lameness results. To prevent this, shoeing is resorted to. But when shoes are on, there is no wear of the walls, which grow longer and raise the sole and frog, removing the internal pressure from the wall and allowing it to contract and cause lameness. The art of good shoeing consists in providing a metal armor for the lower edge of the wall with the least possible interference with any other part of the foot, or with the natural relations of wall, sole, and frog. If the sole and frog have received proper daily care there will be no excuse for the shoer to touch either of them with any tool. If the bottom of the foot is foul, the shoer may clean it out, but always with a scraping, never with a cutting, tool. Cutting the sole and frog is the business of the veterinarian or farrier, not the shoer.

Mule shoes are supplied in several sizes. Numbers 2 to 5 will answer all ordinary requirements. The No. 2 shoe is $3\frac{3}{4}$ ins. wide by $5\frac{3}{8}$ ins. long, and the No. 5 is $4\frac{3}{4}$ ins. wide by 7 ins. long; all are $\frac{1}{2}$ in. thick, and are punched for 4 holes on a side. The top surface of the shoe is slightly beveled, the outside $\frac{1}{32}$ in. higher than the inside. The nail holes on each side are connected on the bottom of the shoe by a countersunk groove. The shoes are packed in kegs of 100 lbs. each. A keg of No. 2 contains 100 shoes; of No. 3, 85 shoes; of No. 4, 72 shoes, and of No. 5, 60 shoes, fig. 8.

The **nails** used with the above sizes of shoes are Nos. 5, 6, 7, and 8. No. 5 is 2 ins. long; No. 6, $2\frac{1}{8}$ ins.; No. 7, $2\frac{1}{4}$ ins., and No. 8, $2\frac{1}{2}$ ins. The heads and point bevels are formed on the outside; the inside of the nail is a plane surface. Nails are supplied in kegs of 100 lbs. No. 5 nails run 190 to the lb.; No. 6, 140; No. 7, 100, and No. 8, 80, fig. 9.

The old shoe should be carefully removed by cutting off the clinches and drawing the nails singly. Starting the shoe and prying it off, bringing all the nails with it, is dangerous. The bottom of the wall should then be cut down level with the sole at the toe and left a little longer at the heel. The heel wears a little under the shoe and will rarely require much cutting. The rasp is used to cross level the bottom of the wall, which should be accurately done, so that the mule will stand square on the shoe. The shoe is now to be fitted accurately, so that its outer edge will follow the circumference of the hoof all around. The fit must be made close enough so that no filing of the sides of the wall will be necessary to complete it. The shoe is then applied hot for a moment, and the high points indicated by burning are worked down. The shoe should then be applied hot long enough to slightly sear the lower surface of the wall, but no longer. It should then be cooled and nailed on. In nailing, begin with the front or toe nails and drive them in their order to the rear. After all are driven, cut off the points near the hoof, rasp the clinches thin enough to turn easily, but do not let the rasp cut the horn. Turn the clinches down snug, but do not try to drive them into the hoof, nor use a file on them to smooth up.

Management of vicious mules.—Ordinary cases can be handled by lifting the foot with a strap or rope. Take hold of the pastern and be sure that the rope can not slide so far as to cause a burn. For a hind foot, draw forward between the legs or to a collar; for a fore foot, bend sharply at the knee and strap the pastern to the upper leg. For bad cases in the field, throw the mule and shoe him while down. For the shop, construct a frame of stout timbers in which he can be tied in every direction by ropes, straps, or canvas bands. Twitches on the ears should never be used. If absolutely necessary to control the animal, put a twitch on the nose.

12. **Animal power.**—The capacity of an animal to exert a tractive effort decreases as speed and time increase. As a basis, it may be assumed that an average draft mule can pull on a level 80 lbs. at $2\frac{1}{2}$ miles an hour for 10 hours every day, or in other words, can pull 80 lbs. over 25 miles of average level roads every day. If a pull of 160 lbs. is required, it can be made over $12\frac{1}{2}$ miles a day only, the lesser distance being covered by a slower gait or longer rests, or as is usually the case, partly by each. An animal can exert $2\frac{1}{2}$ times the normal pull for a few minutes at a time, and 5 times for a few seconds, provided in each case the demand is not repeated too frequently.

The **load which can be hauled on any pull** depends mainly on the kind and condition of the road and a little on the wagon, especially as to width of tire and size of wheels. For the standard army wagon and on a level average dirt road in good condition, the load corresponding to 80 lbs. standard pull may be taken at 1,000 lbs. per animal. Of this, 300 lbs. will be wagon, leaving 700 lbs. net freight. Any reduction of this load to lessen the pull must come out of the 700 lbs. To reduce the pull to 40 lbs., 500 lbs. must be taken from the freight, leaving 200 lbs. only to be hauled. This 200 lbs. pulled over 25 miles would equal 5,000 lbs. pulled over 1 mile, while if the full load of 700 lbs. is hauled over $12\frac{1}{2}$ miles, which can be done with the same effort, the result equals $700 \times 12\frac{1}{2} = 8,750$ lbs. hauled 1 mile. If the length of the march is fixed, the animals can be relieved only by reducing the pull; otherwise it is better to relieve them by shortening the march.

On hilly roads there is no traction on the down grades and an increased gait is usually taken without appreciable extra exertion. This saves time which may be spent in rests, allowing greater effort on the up grades. Up to 8% grade, the load can be retained by reducing the distance. Up to 3% grade, the distance can be maintained by reducing the pull. Above 8%, both pull and distance must be reduced. The reduction of pull may be accomplished by removing part of the freight, by doubling up teams, or by putting men on dragropes.

The foregoing is based on the supposition that the animals have the full ration every day and remain in as good condition as when they started. In emergencies they can do more work than indicated, but will go off in condition and some will give out entirely. In campaign, animals are overworked as a rule, and finish in very poor condition. This is necessary because adequate transportation is rarely available and what there is must be worked at a killing rate. When marches are intermittent, mules may be pushed, since what they lose in 2 or 3 days' overwork can be made up by a week's rest with good care, and they will be fit when again required.

The following are the **weights and normal loads** of some army wagons:

	Weight.	Max. net load.	Gross load.
	Lbs.	*Lbs.*	*Lbs.*
Army six	1,950	4,000	5,950
Escort	1,500	3,000	4,500
Ambulance	1,450		
Dougherty	1,375		
Engineer tool wagon	2,200 to 2,600	2,500	4,700 to 5,100
Ponton tool wagon	1,700	2,100	3,800
Bridge train, light	1,750	1,856 to 2,060	3,606 to 3,810
Bridge train, heavy	1,750 to 2,200	2,280 to 2,900	4,030 to 5,100

Harness.—The harness supplied for heavy draft is of three kinds, known as **army wagon harness, 4-mule ambulance and wagon harness,** and **ambulance harness.** The first is distinguished by the absence of a saddle; by its breeching, which is of flat leather unstitched, and its traces, which are of chain throughout and pass through leather pipes to prevent chafing. The second is distinguished by its traces, which are of leather to the breeching, with chain extensions. The third has all leather traces. The second, or ambulance and wagon harness, is most suitable for Engineer transportation.

Most 6-mule teams are driven with a jerk line, the driver riding the near wheeler, fig. 10. Four-mule teams in the bridge train are driven in the same way. All other 4-mule teams are driven with lines from a seat on the wagon, fig. 11. The 6-mule harness includes a riding saddle, jerk line, check rein, jockey stick, and blacksnake

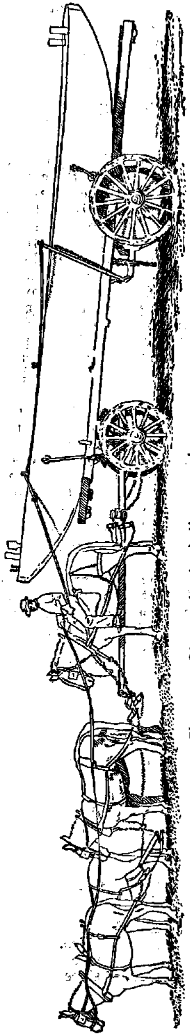


Fig. 10, Six-mule jerk-line and ponton wagon.

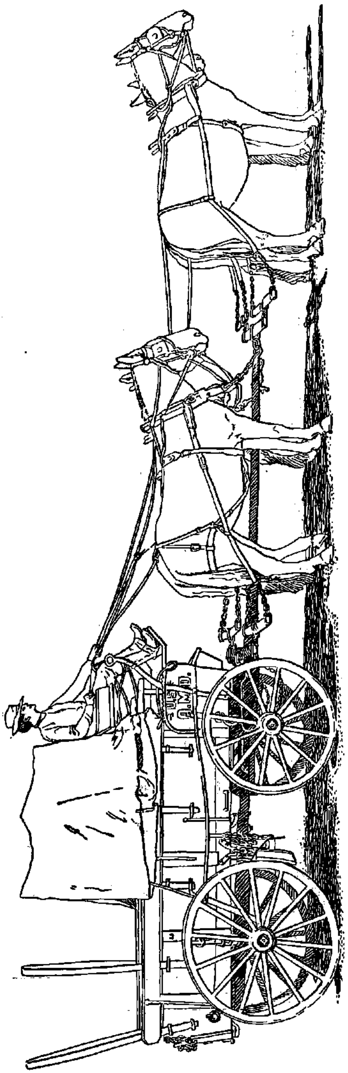


Fig. 11, Four-mule team and escort wagon.

whip. A set of 4-mule harness includes a pair of wheel lines, a pair of lead lines, a whipstock, and lash.

Proper **fitting of the harness** is very important. The bridle should be loosely fitted, the crownpiece and throatlatch not too tight; the brow band in the right place; the cheek pieces so adjusted that the bit will hang in the mouth just clear of the angle of the lips, not far from it and not touching it, especially not drawing it up into wrinkles. The bit should be of the right length for the width of the jaw. Less damage will be done, however, if the bit is too long than if too short. If the bit tends to irritate the mule's mouth at the ends, relief may be given by putting a large leather washer around the bit inside the ring. The blinds must be so adjusted as not to touch the eyelashes.

The fit of the collar requires close attention. If it is too small, it will cut off the wind; if too large, it is likely to make the shoulders sore. When the collar is on and adjusted, there should be room to insert the open hand between the bottom of the collar and the windpipe, and not much more. Collars should always be buckled when off the mules. A collar which is the right size but not the right shape, can be improved by soaking it in water and putting it on wet. A day's work in the rain will produce the same result. The under surface of the collar should be kept clean and soft. Do not scrape it but rub or wash it clean. The same remark applies to every part of the harness which touches the mule's skin. Cleaning the outside of a harness is good for the harness only; cleaning the inside is good for both mule and harness. The driver should be provided with two or more small pads of sheepskin with thongs attached. If the skin is abraded by the harness, two of these pads may be lashed to the underside, one on each side of the sore, and will afford relief until the march is over and regular treatment can be applied. The hames should be so adjusted to fit the collar closely without pinching it out of shape.

To clean harness, hang a set on a pole or line; wet a sponge in clean water, and rub gently over the harness until the dirt is softened. Rinse the sponge frequently and renew the water as often as necessary. Next rub the sponge on the harness soap until a good lather is formed. Give the harness a thorough coating of it and continue the rubbing until all dirt is removed. It may be necessary to use a thin piece of wood to get some spots clean. When the harness is clean, rub up a very thick lather and coat the leather evenly with it, allowing it to dry without rubbing. After the lather has been absorbed and the leather is dry, dip a small, clean sponge in harness dressing and touch the harness lightly, rubbing just enough to spread the dressing evenly.

If the leather is very hard, after cleaning as above, take a pint of neat's-foot oil and a teaspoonful of lampblack to each single set. Mix thoroughly until a black glossy appearance is produced and apply an even coat with a small sponge, rubbing it well in. In cold weather warm the oil enough to make it flow freely but do not let it get hot. After thoroughly dry, apply harness dressing as above described.

Harness should be looked over carefully every day. If stitches are broken, leather worn or cut, or any metal parts cracked or broken, have the defect remedied at once. If stitches are taken, be careful not to leave knots on the inner surface of the harness. Fasten at beginning and end by drop stitches. In the field, provide supports for the harness and keep it off the ground when not in use.

13. List of **materials** and **spare parts** required for repair of harness in the field, with quantities for 100 sets:

Bits, wagon bridle	6
Buckles, roller, japanned, ¾, ⅞, 1, 1¼, 1½ ins	1 doz. each.
Buckles, trace, 1¾ in	1 doz.
Chains, trace	1 doz.
Clips, hame	½ doz.
Ink, edge	1 pt.
Harness dressing	2 gals.
Hames, hook, high top, 19, 20, and 21 ins	2 prs. each.
Lampblack	¼ lb.
Leather, bridle	3 sides.
Leather, lace	1 side.
Leather, harness	6 sides.

Loops, halter, $1\frac{1}{4}$ ins	2 doz.
Open links, No. 2 iron, 10 per foot	50
Oil, neat's foot	10 gals.
Rings, No. 2, $1\frac{3}{4}$ and 2 ins	2 doz. each.
Rings, breeching, No. 3, $3\frac{1}{2}$ and 4 ins	2 doz. each.
Rings, D, $1\frac{1}{2}$ ins	1 doz.
Rings, line, $1\frac{3}{4}$ ins	2 doz.
Rivets and burrs, copper, No. 12, $\frac{1}{4}$ and $\frac{3}{8}$ in., No. 8, $\frac{1}{2}$ and $\frac{5}{8}$ in	1 lb. each.
Slides, breast, $1\frac{1}{2}$ ins	1 doz.
Snaps, harness, $\frac{7}{8}$ and 1 in	2 doz. each.
Snaps, harness, $1\frac{1}{4}$ and $1\frac{1}{2}$ ins	1 doz. each.
Soap, harness	100 lbs.
Sponges, coarse	5 lbs.
Squares, halter, $1\frac{1}{2}$ x $1\frac{1}{4}$ ins	3 doz.
Tacks, 4, 8, and 12 oz	$\frac{1}{2}$ doz. papers each.
Thread, shoe, Barbour's Nos. 3 and 10, white	1 lb. each.
Toggles, trace	6 doz.
Wax, saddler's, black, spring, summer, or winter	1 lb.

14. **Wagons.**—For general freighting, the wagons in use in the United States service are the **army six**, weighing 1,950 lbs., and carrying 4,000 lbs., with a 6-mule jerk-line team, and the **escort**, fig. 11, weighing 1,500 lbs , and carrying 3,000 lbs., with a 4-line team. The **army wagon complete** includes a fifth-chain with stretcher, 6 wagon bows, ridgepole, wagon cover, doubletree, and 2 singletrees, an extra kingbolt and 2 extra singletrees, feed box, and brake. An **escort wagon complete** includes a feed box, 6 wagon bows, ridgepole, 1 double and 2 singletrees, axle wrench, tar pot, extra kingbolt, 2 extra nuts for axle, a lead bar with stretcher chains and singletrees attached, and a brake.

The bridge equipage is carried on two types of wagons, the **ponton wagon,** fig. 10, weighing 2,200 lbs., and carrying 2,900 lbs , and the **chess wagon,** weighing 1,750 lbs., and carrying 2,300 to 2,700 lbs. The ponton wagon is used for the wooden ponton. The chess wagon is used for all other bridge loads.

To **keep a wagon in order** it is only necessary to keep all nuts tightened, the wheels greased, and to wash the mud off when opportunity offers. Four to 6 lbs. of axle grease per wagon per month will be ample. In dry sand, wagons in constant service should be greased daily. On hard roads they should be greased every 40 to 50 miles. Always clean off the old grease before putting on the new. In washing, use as much water and as little rubbing as possible.

The following spare parts and extras should be carried on each army six and escort wagon:

1 ax.	2 cans axle grease.
2 extra axle nuts.	1 lantern.
1 galvanized-iron bucket.	3 open links.
1 horse brush.	1 pole, extra.
1 currycomb.	1 reach, extra.
1 pick.	2 singletrees.
150 ft. rope, $\frac{1}{2}$ in. or $\frac{3}{4}$ in.	1 wrench.
1 doubletree.	Coil of stove wire.

A similar list should be carried for the bridge wagons, but preferably in supply wagons not on the wagons themselves. For the latter, spare wheels should also be carried.

15. **Pack saddles.**—The adopted pack saddle is of the Spanish type, and is commonly called by its Spanish name **aparejo,** fig. 12. Its principal parts are the **body,** the **cover,** the **cincha,** and the **crupper.** These parts have subdivisions, which are less important. The accessories added to the above to make the **aparejo complete,** are the **corona,** the **blanket,** the **lash rope** with its **cincha,** the **sling ropes,** the **lair ropes,** and the **mantas** or pack covers.

The body of the aparejo consists of 2 pieces of heavy leather 24 ins. wide by 58, 60, or 62 ins. long, sewed together at the edges and across the middle of the length, forming 2 pouches, into which moss or hay is stuffed to form pads fitting the contour

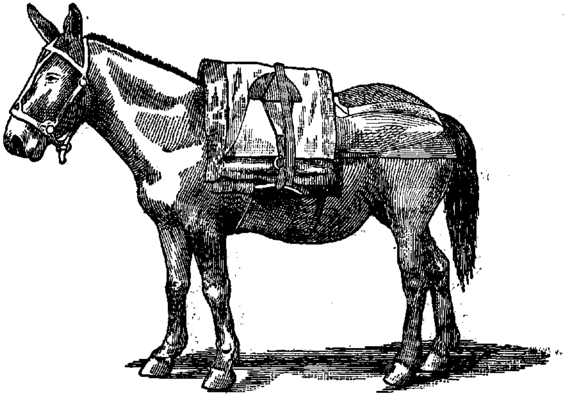


Fig. 12, Aparejo.

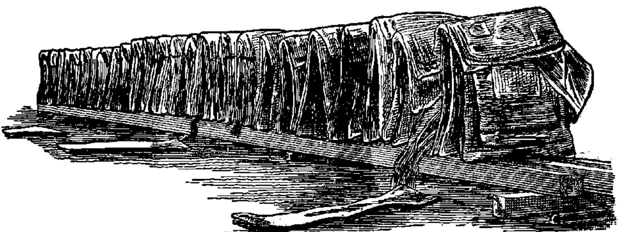


Fig. 13, Rigging.

of the animal on either side of the backbone. In the American form, the pads are given a peculiar elastic stiffness by means of ribs of wood or metal extending from a saddle piece at the top of each pouch to a boot piece at the bottom. These ribs are stiffer at the front and more flexible at the back, varying uniformly between. They convert each pad into an elastic lever, by which the pull of the cincha on the bottom acts to raise the aparejo and its load from the backbone, while the stuffing distributes the load uniformly over a large space on the ribs. The stuffing is introduced through a hand-hole in the middle of the underside of each pad, through which it is always accessible, and the finest art of the packer consists in fitting the pads to the shape of the particular animal which is to carry the aparejo, and keeping them so regardless of changes in the animal's condition by shifting, removing, or renewing the stuffing. If a bunch rises on the animal, it can be worked down by taking out stuffing immediately over it so as to take off the pressure at that point. Determine the proper point by wetting the top of the bunch and laying the aparejo on the mule. Aparejos and mules are numbered and the same pack is always on the same mule.

The **function of the crupper** is not what would naturally be expected. If the aparejo is properly set up and fitted there will be no tendency to move back or forward. The crupper is in reality a steadying lever to keep the aparejo from rocking fore and aft as the mule travels. For this purpose, the dock piece is large, smooth, and soft, and the crupper is wide, stiff, and firmly laced to the body. The crupper is adjustable in length, and must be accurately fitted so that when the aparejo is in its proper place the dock piece will ride between tail and dock without pressing on either.

The **cover** is permanently attached to the body and may be considered a part of it.

The **cincha** is of heavy canvas, doubled, and 10 ins. wide. It is long enough to reach from the near boot under the mule and around the aparejo to a little beyond the middle. The ends are connected by the **latigo, or cincha strap.**

The **corona** is a pad usually of several thicknesses of blanket, with a number or design which identifies the pack. It is important that the corona shall not be separated from its aparejo.

Off the mules, the aparejos are placed in a row on the ground or on skids, standing on their boots, fig. 13. The cincha, folded with the latigo inside, rests on the aparejo. The crupper is turned so that the dock piece rests on the cincha. The corona is placed on top of all. Canvas covers are stretched over the line of aparejos and tied down. The line of aparejos so arranged is usually referred to as **the rigging.**

Each packer is provided with a **blind.** The mules are trained to stand perfectly still when blinded, and if it is necessary to move a mule even by a step, the blind should be lifted.

To place the aparejo on the mule the corona is first put smoothly on, followed by the blanket folded to 6 thicknesses. The aparejo is then put on slightly in rear of its place. The crupper is turned, the dock piece adjusted, the aparejo settled to its place, and the cincha unfolded, placed, and tightened. Never put on or adjust a pack with the mule's head uphill.

16. **Loads** are divided into **side packs** and **top packs.** Side packs should be of approximately equal weight and size. A keg of paint on one side and an equal weight of oakum on the other do not make a proper load. Side packs should not be longer than 30 ins., wider than 20 ins., nor deeper than 12 ins. If the side packs do not fill out a load, the rest is placed between them as a top pack. Articles which by their size or shape are not suitable for side packs are carried on top. The center of gravity of the entire load should be below the top of the saddle, and the lower the better. For miscellaneous cargoes, the freight is made up into side and top packs, each wrapped in a **manta,** or canvas cover, and tied, or **laired up** with **lair ropes.** If a pack contains articles of different weights, place the heaviest at the bottom. The side packs are slung across the aparejo by the **sling ropes** and lashed on with the **lash rope** and **cincha** in the form of the **diamond hitch.** Such a load must remain unbroken until the end of the march.

Engineer tools, materials, and supplies, which may be needed for use during the march, are carried in leather pouches, figs. 14, 16, or pairs of wooden boxes, figs. 15, 17, 18, and 19. These are secured to the aparejo without lashing, and may be opened and the required articles taken out and replaced without disturbing the load.

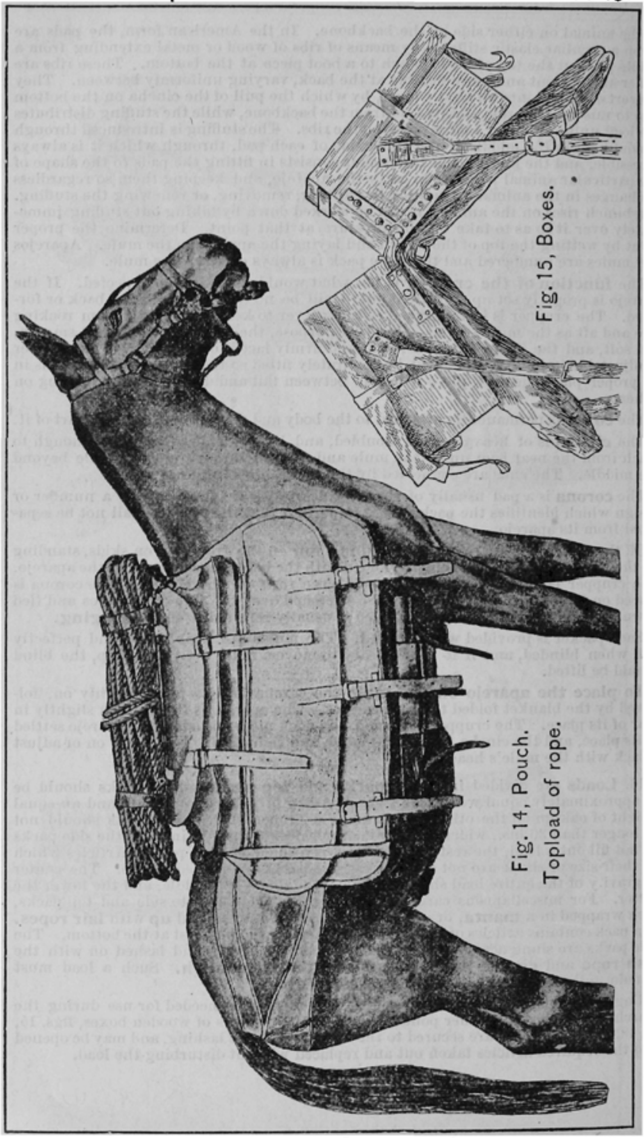


Fig. 14, Pouch.
Topload of rope.

Fig. 15, Boxes.

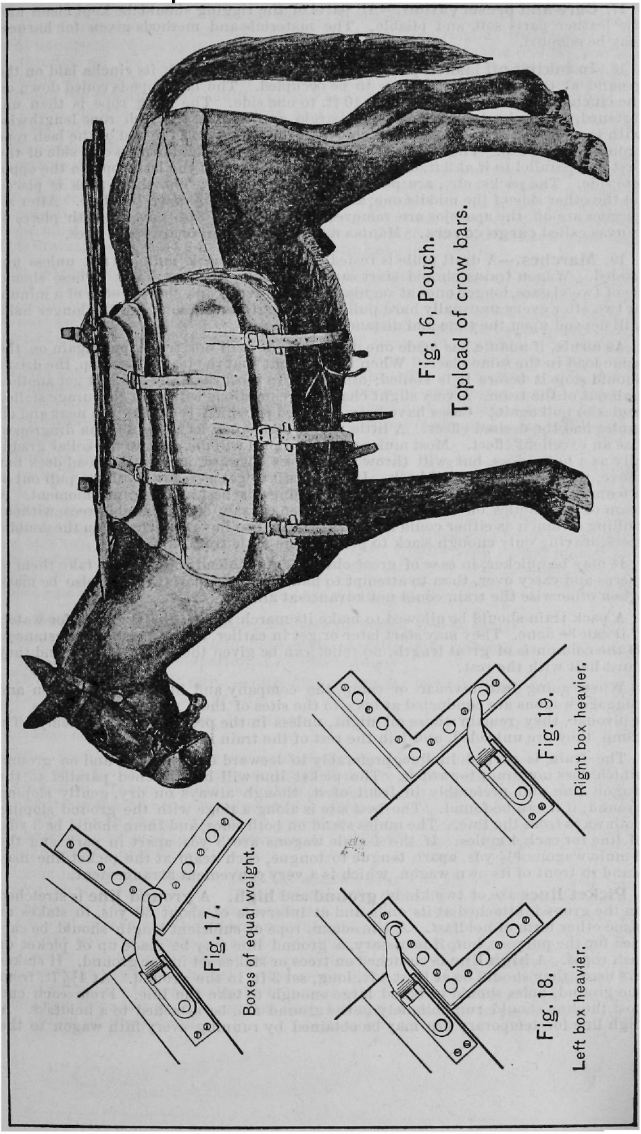


Fig. 16, Pouch.
Topload of crow bars.

Fig. 17.
Boxes of equal weight.

Fig. 18.
Left box heavier.

Fig. 19.
Right box heavier.

17. **Care and preservation.**—All parts of the rigging should be kept clean and the leather parts soft and pliable. The materials and methods given for harness may be adapted.

18. In **taking off lashed packs,** the lash rope is removed; its cincha laid on the ground at the middle of the line to be occupied. The lash rope is coiled down on the cincha and its end stretched out 10 ft. to one side. The sling rope is then unfastened, the packs dropped from the aparejo and laid on the lash rope lengthwise with the cincha. The sling rope is coiled on the packs, and the end of the lash rope brought up on top. The cincha of the second pack is laid down on one side of the first and parallel to it at 2 ft. distance, but with the end of the lash rope on the opposite side. The packs, etc., are placed on it as described. The third pack is placed on the other side of the middle one, and so on until all are down in a line. After all cargoes are off, the aparejos are removed. Cargoes are also covered with pieces of canvas called **cargo covers.** Mantas may be used if there are spare ones.

19. **Marches.**—A draft mule is rested by a halt; a pack mule is not unless unloaded. Wagon trains should start early and make frequent halts. These should be of two classes, longer ones at regular time intervals, and shorter ones of a minute or two after every unusually hard pull. The length and interval of the longer halts will depend upon the time and distance to be made.

As a rule, if a mule has made one dead pull, he will not try to pull again on the same load in the same place. When it is evident that the team must stop, the driver should stop it before it is stalled; otherwise, in most cases, he can not get another pull out of the team. A very slight change of conditions will often encourage stalled mules to pull again. Cases have been reported in which reversing the near and off mules had the desired effect. A little visible assistance, as a few men on dragropes, has an excellent effect. Most mules on a hard pull will not go into the collar gradually as a horse does, but will throw themselves forward, and if the load does not move, will immediately fall back. It is difficult to get a steady lay-down pull out of a team of mules in which every animal is doing his best at the same moment. A team of two mules on a hard pull will often seesaw on the doubletrees without pulling as much as either could alone. It is better to have stop chains on the doubletrees, leaving only enough slack to prevent one mule from shirking.

It may be quicker, in case of great obstacles, to unload wagons and take them to pieces and carry over, than to attempt to haul over. A portage may also be made when otherwise the train could not advance at all.

A pack train should be allowed to make its march without halts except for water, if it can be done. They may start later or get in earlier, according to circumstances. If the column is of great length, no relief can be given them in this way, and they must halt with the rest.

When going into bivouac or camp, the company and headquarters ration and baggage wagons are conducted at once to the sites of their respective kitchens. If a bivouac, they remain there all night, unless in the presence of the enemy; if a camp, they are unloaded, and join the rest of the train in park.

The train is parked in line, preferably to leeward of the camp, and on ground which does not drain toward it. The picket line will be stretched parallel to the wagon line and preferably in front of it, though always on dry, gently sloping ground, if it can be found. The best site is along a ridge with the ground sloping both ways from the line. The mules stand on both sides, and there should be 3 yds. of line for each 4 mules. If the 4-mule wagons are 3 yds. apart in park and the 6-mule wagons 4½ yds. apart, tongue to tongue, each team at the picket line may stand in front of its own wagon, which is a very convenient arrangement.

Picket lines are of two kinds, **ground** and **high.** A **ground line** is stretched on the ground, attached at its ends and at intervals of about 30 yds. to stakes or some other form of holdfast. A 1-in.-diam. rope of sufficient length should be carried for the purpose, but, if necessary, a ground line may be made up of picket or lash ropes. A **high line** is stretched on trees or stakes set in the ground. If stakes are used, they should be at least 8 ft. long, set 3 ft. in the ground. At 4½ ft. from the ground, holes should be bored large enough to take the line. From each end post the line should run obliquely to the ground and be attached to a holdfast. A high line for temporary use may be obtained by running every fifth wagon to the front and stretching the line across them. The end wagons should be loaded ones, and all must have the brakes set. Picket lines will be stretched with tackle if any is at hand; otherwise, by the following method: Attach the rope at one end and lead it through all the supports or fastenings; about 15 ft. from the other end make a bowline in the rope, pass the end around or through the end fastening and back through the bowline. By hauling on the end of the rope the necessary strain may be set on the line, the bowline acting as a single block. The end stakes of a high line should incline outward slightly.

The **picket line should be ditched** if it is to be used for some time, and if rain threatens it should be ditched even for a bivouac. The only exception is when the line is on a ridge and the ground slopes from it in both directions. Open a ditch on the high side about 3 yds. from the line. If the ground slopes along the line, the ditch will be parallel to it, and will have an outlet at the lower end; otherwise, the ditch must be farther uphill at the middle, and will have an outlet at each end. This drainage should be kept in mind in locating the line.

20. **Stable duties.**—The prime requisites in stabling mules are free circulation of air without drafts, equable temperature, dryness, and cleanliness. Grain is fed at reveille by the stable orderlies. When the animals have finished eating, those to be used are harnessed and hitched up. The rest are turned into the corral or tied at the picket line. The stable police then fork all clean and dry bedding to the head of the stall and work the rest of the manure into piles ready for loading. The manure wagon is driven down the aisle and loaded. The hay is then distributed to the mangers and the additional bedding is procured and spread. The aisle may then be washed with hose and brooms if the air is dry; if damp, do not wash, but sweep up with stable brooms. The evening feed is put in the mangers at **afternoon stables.**

Mules of the same team should stand together, and their harness should be hung on racks in rear of their stalls. It is much better to have harness covers to keep off dust.

Grooming is quite as important to the mule as to the horse, but he does not get so much of it, and in the nature of things he can not. He should be groomed every day, if it can possibly be done. When coming in from a long muddy march, the wet mud should be wiped off with a wisp of straw before it dries and hardens. If the animal will not stand, tie up a hind foot as described in *shoeing*. Always tie up the foot on the side opposite to that which is to be groomed.

21. **Shipping mules by rail.**—The cars furnished may be either:

The **palace stock car**, length 36 to 40 ft., capacity 16 to 20 head; each animal in a separate stall, with a compartment for attendants, or

The **improved stock car,** length 36 ft.; capacity 20 to 24 head, with facilities for feeding and watering in car, or

The **ordinary stock car,** length 30 to 34 ft., capacity 16 to 20 head, with no appliances of any kind.

Before loading, examine the car carefully to see that the floors are not rotten or broken; that the sides are secure, and that there are no projecting nails or splinters on the inside. The car should be cleaned and the floor covered with sand or sawdust. Hay or straw should never be allowed in a stock car on account of the danger from fire. The man in charge should be provided with a lantern, bucket, and hatchet. The latter is to be used to cut away part of a board in case an animal gets his hoof through the side of the car.

Except in very hot weather, pack the animals snugly in the car, as they will ride better than if loosely packed. If an animal falls down in the car it will be almost impossible for it to get up without assistance. The attendant should enter the car at the end and crawl along the side nearest the animal's head until he is reached. Take him by the halter and raise his head. With this assistance he will probably get up. For loading, use the railroad platform or the loading ramp found at railroad stations, or make a ramp well supported, with strong sides, and with cleats on the floor to prevent slipping. Lanyards should be attached to each side of the floor near the middle and made fast to truss rods or door fittings of the car to prevent the ramp from sliding off the doorsill.

If lumber is not at hand, a ramp may be made of poles and brush, supported on trestles and floored like a bridge (see Bridges). As a last resort, throw up a ramp of earth, reaching as near as possible to the side of the car, and bridge the gap with the car door.

For loading with improvised facilities, always try to get the car into a shallow cut.

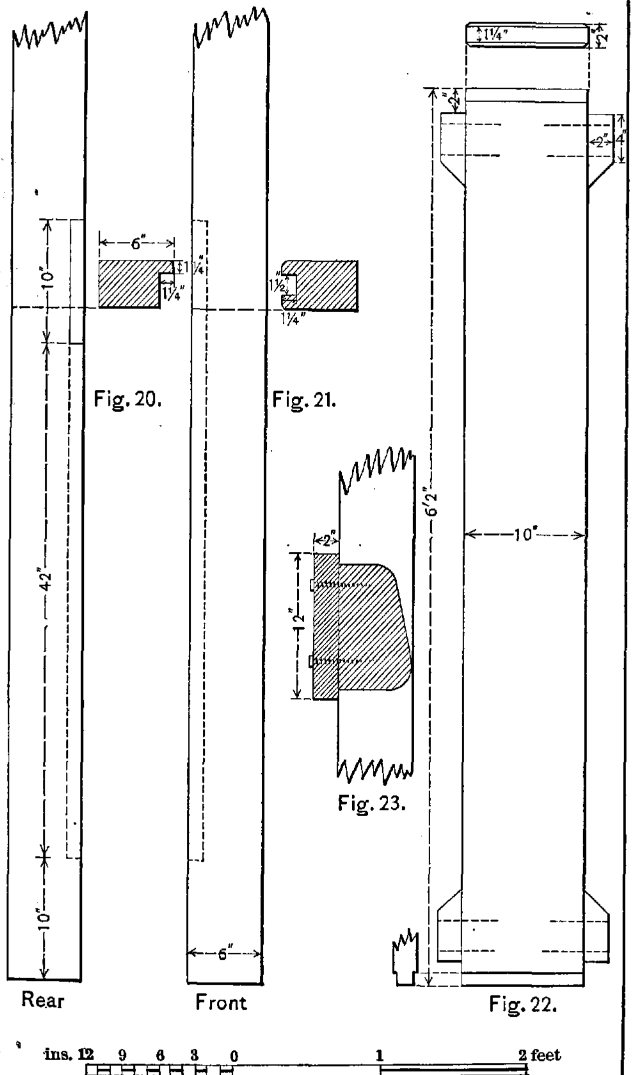
Lead the animals up the ramp and into the car and take off the halter straps, but not the halters. If the mules are shy of the ramp, a little hay thrown on it will make them less timid. Very obstinate cases can be handled by passing a rope around the haunches and having a few men pull on each end. The first animal is led to one end of the car and the second to the other end, leaving the middle for the last ones loaded. The animals face opposite sides of the car alternately. Each one led in must be held until the next one is in place. Load quietly and avoid exciting the animals either by haste or by unnecessary delay. It may occasionally be necessary to blindfold an animal before he can be led in. Animals in transit should be fed and watered once a day at least, or twice if opportunity offers. If closely packed in ordinary cars, they should be unloaded and exercised once in 48 hours and given 6 hours' rest.

22. **Shipping animals by sea.**—Ships must be especially fitted up and equipped for this service. Free ventilation and cleanliness are of the utmost importance. Air ports should be large and numerous and wind sails must be set up in every hatch to each deck. If there are dead spaces, special air shafts must be built to supply them. If there is machinery on board, forced ventilation should be employed. Animals do best on deck except in very heavy weather, and should never be put below the water line. Stalls are built in double rows lengthwise of the ship, facing each other, with a 4-ft. aisle between. There should be a passageway athwartships at each end of each compartment, and if the vessel is wide enough, the outside rows of stalls should be 3 ft. from the sides of the ship.

Stanchions 6 x 6 ins. are set up, 30 ins. c. to c. lengthwise, and 6 ft. 6 ins. c. to c. athwartships between the posts of the same stall. The stanchions are well secured at top and lightly to the deck. Before setting up, the stanchions are mortised for the side boards as shown in figs. 20 and 21. The stanchions should be further stayed near the tops by ties in both directions, fastened to or firmly butting against the framework of the vessel. The ties should run straight, disregarding the curve and sheer of decks. A false floor of 2-in. plank, 8 to 12 ins. wide, is spiked or bolted to the deck, the planks running lengthwise of the stalls, with ¾ in. space between them. If the ship is to be used for this purpose for a considerable time, the floor should be double, with tar paper between the courses. The floor is cut closely around the feet of the stanchions. Hard-wood cleats are placed across the stall and fastened to the false floor with screws. In spiking down the false floor, the nails should be so driven that their heads will be covered by these cleats. Larger cleats are laid lengthwise, from foot to rear posts. The stall partitions are of 2-in. plank, smoothly planed, fig. 22, inserted in the mortises in the stanchions, and the rear ends are closed by haunch pieces. These are shaped as shown in section in fig. 23, and are fastened by lag screws to a plank bolted to the rear posts. The haunch piece is adjustable in height, fig. 24, and should be placed so that its bottom edge will catch the mule 2 ins. above the hock. The front is best closed by a heavy canvas band 8 ins. wide, with reenforced edges, a spreading stick at each end and a grommet in each corner for lashing it to the front posts. A light strap over the neck will keep this band in place like a breast collar and the lashings may be left slack enough to permit the mule to sway and ride easier. Projecting nails must be avoided, edges and corners smoothed and rounded, knot holes trimmed out and splinters removed, and all parts which the mule can reach with his teeth should be sheathed with metal or wrapped with wire.

For deck stalls the posts are capped to form supports for a roof of 2-in. stuff, which should be covered with tar paper. The stalls must also be strongly cross-braced. This is best done by inserting diagonals between the posts of every fifth or sixth partition. The entire structure must be thoroughly strapped or tied down to the deck.

Under no circumstances should any stock be loaded until the ship is ready to sail, completely equipped, supplied, and manned.



Rear

Front

Fig. 20.

Fig. 21.

Fig. 22.

Fig. 23.

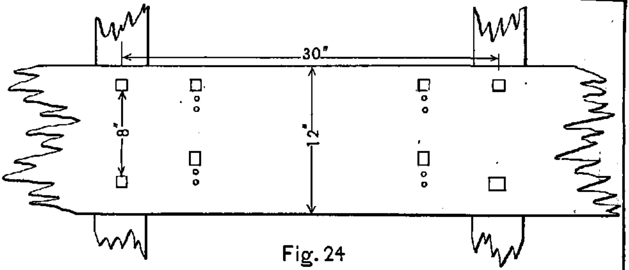


Fig. 24

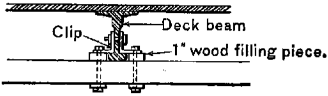
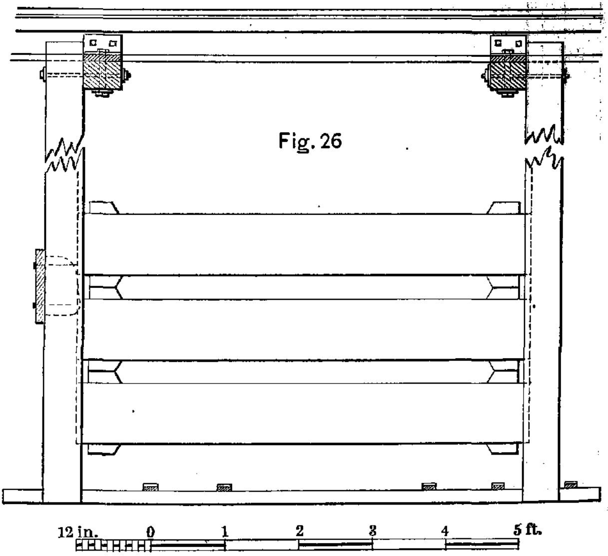


Fig. 25

Fig. 26



Watering is easily done by buckets filled from a hose, the nozzle of which is carried along the aisle. The nozzle should have a cock to enable the flow to be controlled at the end. The supply should not be less than 10 gals. per mule per day. If condensers are used, there should be several days' supply in fresh-water tanks to provide against a breakdown of the machinery or the use of water not thoroughly cooled.

Feeding is best done on the false floor in front of the stalls. Cleats may be nailed down to form shallow boxes to hold the grain in place. In heavy weather it may be better to use nosebags. Grain should be fed early in the morning. None should be given the first day out. The second day a half ration should be fed and increased by small quantities if found necessary to keep the animals in condition. Bran mashes with salt should be fed once a week. After feeding the deck should be thoroughly cleaned and such disinfectants as are to be used should be applied. Then the hay should be fed.

It is better to leave one vacant stall in each tier. Remove the side boards and shift the next animal into the vacant stall. Clean his stall thoroughly and shift the second animal into it and so on.

In **loading** and **unloading** the animals should be led up and down ramps and gangways if possible. If they are to be transferred to or from lighters, or dropped into the water to swim ashore, a sling or a flying stall must be used. After landing, animals should be corraled with the shortest possible march and should be allowed to rest 3 or 4 days under conditions which permit gradual increase of activity.

The **sling** should be 5 ft. long and 2 ft. wide, of heavy canvas, reenforced at the edges by a 2-in. binding of the same. A hem is made at each end to take a 2-in spreader. A loop of $1\frac{1}{4}$-in. rope is attached to each end, around the sticks, one 9 ins. long and the other 3 ft. long, measured from the middle of the sticks to the middle of the loop when stretched. The long loop has a heavy iron ring, 3 ins. inside diam. fixed at its middle point. Breast and haunch ropes $\frac{3}{4}$ in. diam. are sewed across the canvas 3 ins. from the sticks and on the outside of the sling. They should be 9 ft. long each way from the center of the sling. The sling is placed under the mule's barrel, the end of the long loop passed through the short one and the hook of the hoisting block engaged in the ring. The small ropes are passed around the shoulders and haunches and tied. The animal should be lifted from his feet quickly and set down gradually.

The **flying stall** is a stoutly framed box open at the top and high enough to prevent the mule jumping out. The inside should be smooth, 6 ft. 6 in. long and 30 ins. wide. The ends should be hinged at the bottom to open outward, with heavy latches at top arranged to be operated by lines from a distance. The floor should have several cleats running from side to side. At each corner a $\frac{1}{2}$-in. rod should run from bottom to top, terminating in a heavy eye or ring. To the rings slings should be fastened converging to the center where they are joined together to take the hook of the fall. The slings should be kept apart by spreaders high enough to clear the mule's head to prevent a cross strain on the sides. Guys should be provided to control the stall in raising and lowering to prevent its striking the edges of hatches.

For a short voyage and work immediately on landing, animals may be shipped with shoes on. In this case shoes should be recently set. For long voyages, shoes should be removed.

Animals should not be shipped in high condition. If not worked up to the time of embarking, give exercise and reduce feed.

23. **Accountability for public animals.**—A descriptive book of public animals will be kept with the records of every officer responsible for such animals. It will contain a description of every animal received and transferred, showing the kind, name, age, size, color, marks, brands, or other peculiarities of each; how and when acquired, and, if disposed of, in what manner; the name of his rider and driver, and the use to which applied.

A complete descriptive list of each animal will be made at the time of purchase and will accompany him wherever he may be transferred.

When public animals are issued or transferred, the person in charge will be provided with full and accurate descriptive lists, which he will deliver to the receiving officer, by whom they will be entered in his descriptive book of public animals.

Public animals shall, on the day received, be branded with the letters "U S" on the left fore shoulder, the letters to be 2 ins. in height.

Public animals will be assigned to their riders or drivers, who will not exchange or surrender them to the use of any other person without the permission of the company commander, quartermaster, or other officer responsible.

ADDENDUM, 1907.

24. Figs. 27–34 represent forms of Engineer packs for various purposes, recently devised and tested.

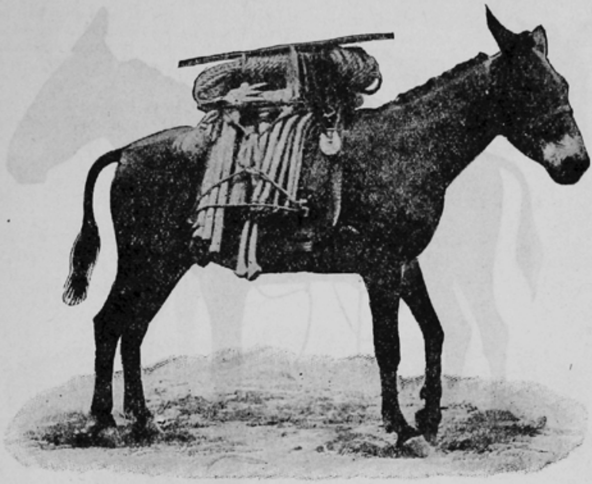


Fig. 27. Pioneer Pack, off side.

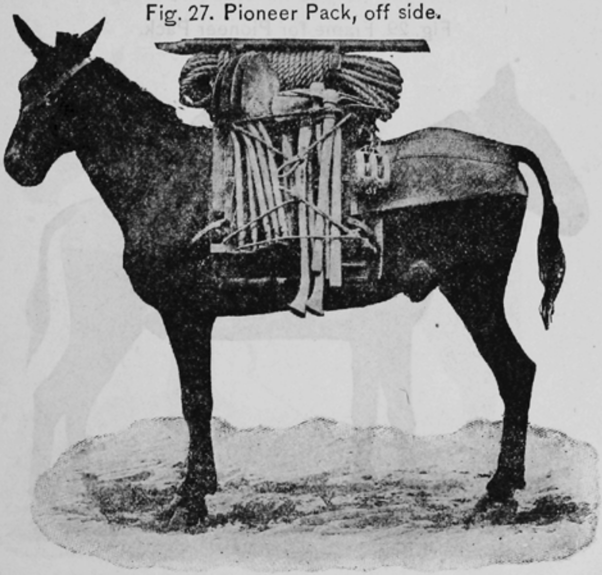


Fig. 28. Pioneer Pack, near side.

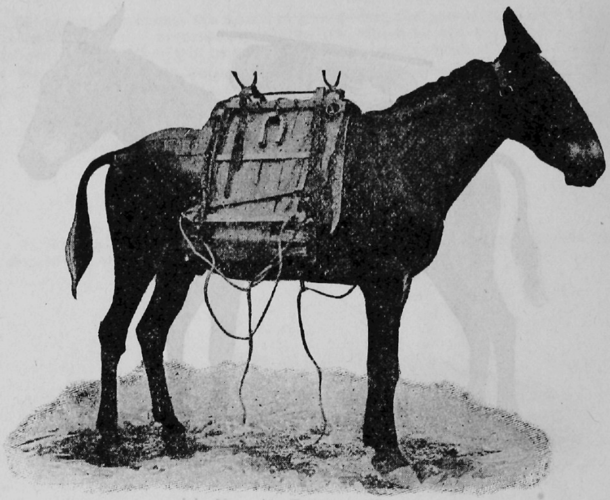


Fig. 29. Frame for Pioneer Pack.

Fig. 30. Supply Pack.

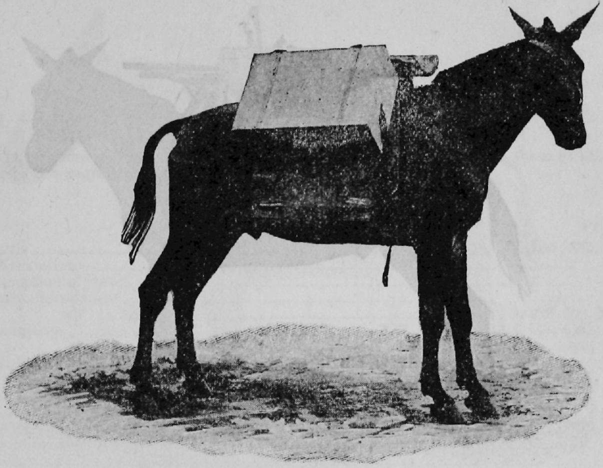


Fig. 31. Carpenter's Pack, off side, closed.

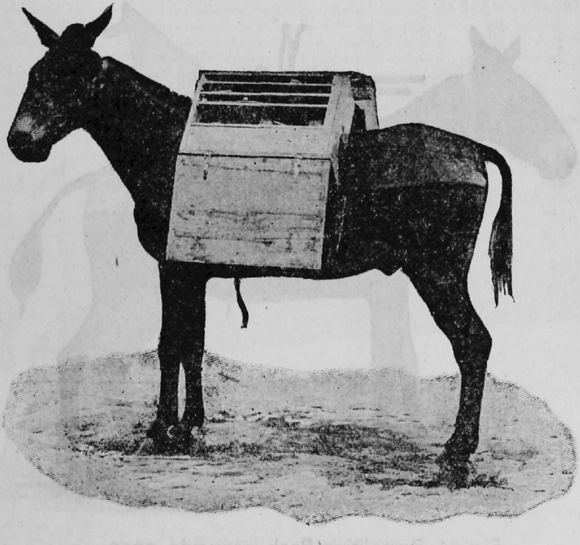


Fig. 32. Carpenter's Pack, near side, open.

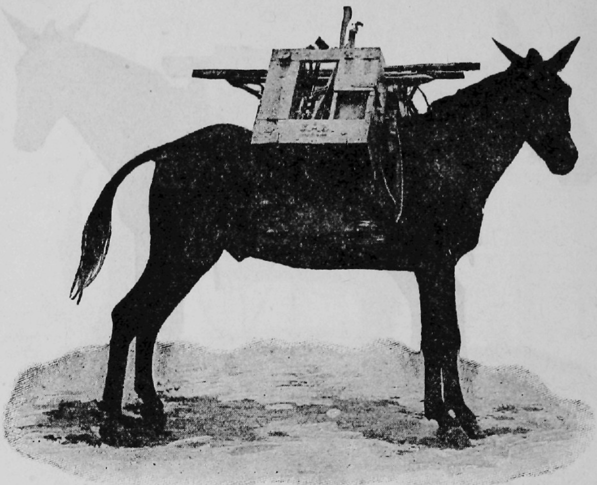


Fig. 33. Demolition Pack, off side.

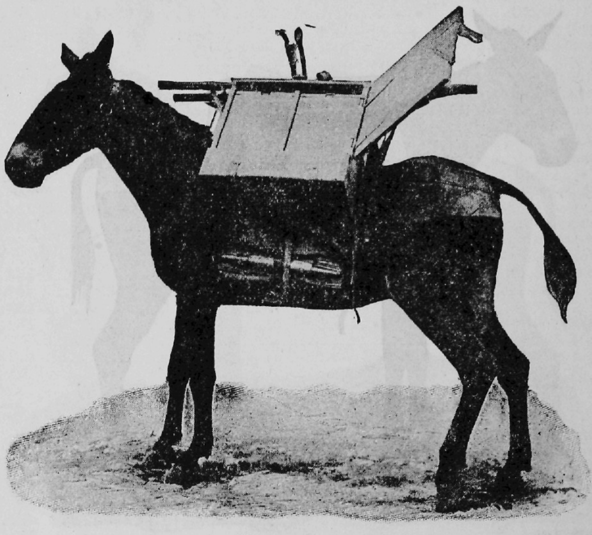


Fig. 34. Demolition Pack, near side, open.

INDEX.

(The figures in light-face type refer to the pages of the text, and those in black-face to the pages containing illustrations.)

A.

B.

C.

H.

M.

P.

Q.

R.

Y.

Z.