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QUARTERMASTER RESEARCH & ENGINEERING COMMAND

U S ARMY

TECHNICAL REPORT

EP-101

A DEVICE AND METHOD FOR ANALYZING LINE OF SIGHT

QUARTERMASTER RESEARCH & ENGINEERING CENTER

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

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ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-101

A DEVICE AND METHOD FOR ANALYZING LINE OF SIGHT

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ENVIRONMENTAL ANALYSIS BRANCH

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Foreword

Line-of-sight analysis is an important aspect of many geographic problems, particularly those relating to tactical military planning. The standard procedure for solving such problems requires drawing earth profiles. Although it produces accurate results, this method takes a great deal of time. A device has been developed which will produce equally accurate results in considerably less time. When the underlying principle and the procedure for operating the device are clearly understood, it is a simple matter to make the necessary adjustments to solve a variety of problems.

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A DEVICE AND METHOD FOR ANALYZING LINE OF SIGHT

1. Introduction

An important aspect of many geographic investigations is line-of-sight analysis. Heretofore, most problems involving line of sight have been solved by drawing earth profiles, i.e., vertical cross sections of the surface along a traverse. Although this produces satisfactory results, it is a laborious procedure.

The inefficiency of this method became acutely evident during a relief study which sought to determine the effectiveness of terrain for shielding troops from thermal radiation of nuclear or other weapons. As a consequence, a simple device was invented to eliminate the actual and repeated drawing of profiles and thus to minimize the time required to study line-of-sight situations.

This report serves as an instruction manual to accompany the new device. It is anticipated that people with varying degrees of knowledge and ability will make use of the instrument. Thus, the author has written the text and designed illustrative material with this assumption in mind.

The meaning of the term "line of sight" is reviewed in this report. The new device, and procedure for operating it, are described. Applications of line of sight to specific problems, by means of the device, are discussed. A person unfamiliar with the subject will find it necessary to study the entire report. A well-versed person need refer only to the description of the device and procedure for operating it. With a little practice, an individual should be able to use his own ingenuity to adapt the basic principle of the device to suit his own needs.

2. Line of sight

a. Definition

Line of sight is a term which denotes a straight line representing a line of vision, or the line along which light and other electro-magnetic waves travel from a point of origin. An infinite number of lines of sight may originate from any point. These lines radiate outward in all directions along azimuths and elevations. Such waves continue to travel in a straight line until they are refracted by the medium through which they pass, or meet an obstacle high enough or dense enough to obstruct their course. Figure 1 illustrates the line-of-sight principle.

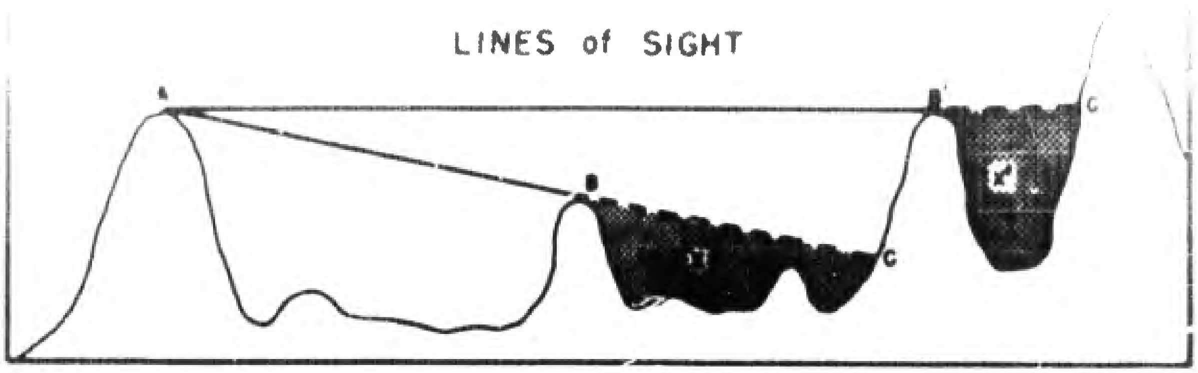


Figure 1. Lines of sight

Lines of sight (A C and A C') originate at A. These lines radiate outward until encountering objects at C and C'. The respective lines of sight touch B and B' in transit. B obscures the surface below the line of sight between B and C (shaded area X). Similarly, B' obscures the surface between B' and C' (shaded area X').

b. Applications

There are many occasions or purposes for which it is desirable to determine the line of sight between or beyond two points. Any problem demanding precise knowledge of interference or lack of interference by objects to a straight line makes use of this principle. How much of an area can be kept in one's field of vision without being obstructed by higher land? Will certain terrain features interfere with radio waves? The answers to these and similar questions may be vital in such diverse areas as military operations and the television industry. A quick method for analyzing such situations is necessary.

c. Method of analysis

Solving line-of-sight problems requires knowledge of the heights of the objects which determine the line, the distance between these points, and the configuration of the surface over which the line travels. Aside from actual field observations, line-of-sight problems are most practically worked out in conjunction with contour maps, since actual values for heights can be read from them, and distances can be measured directly from these maps. Surface configuration can be most accurately reproduced with profiles on which lines of sight can be superposed. The technique for drawing profiles is illustrated in Figure 2. A detailed description of this process can be found in FM 21-26, Map Reading,[2] or any standard introductory geography text.

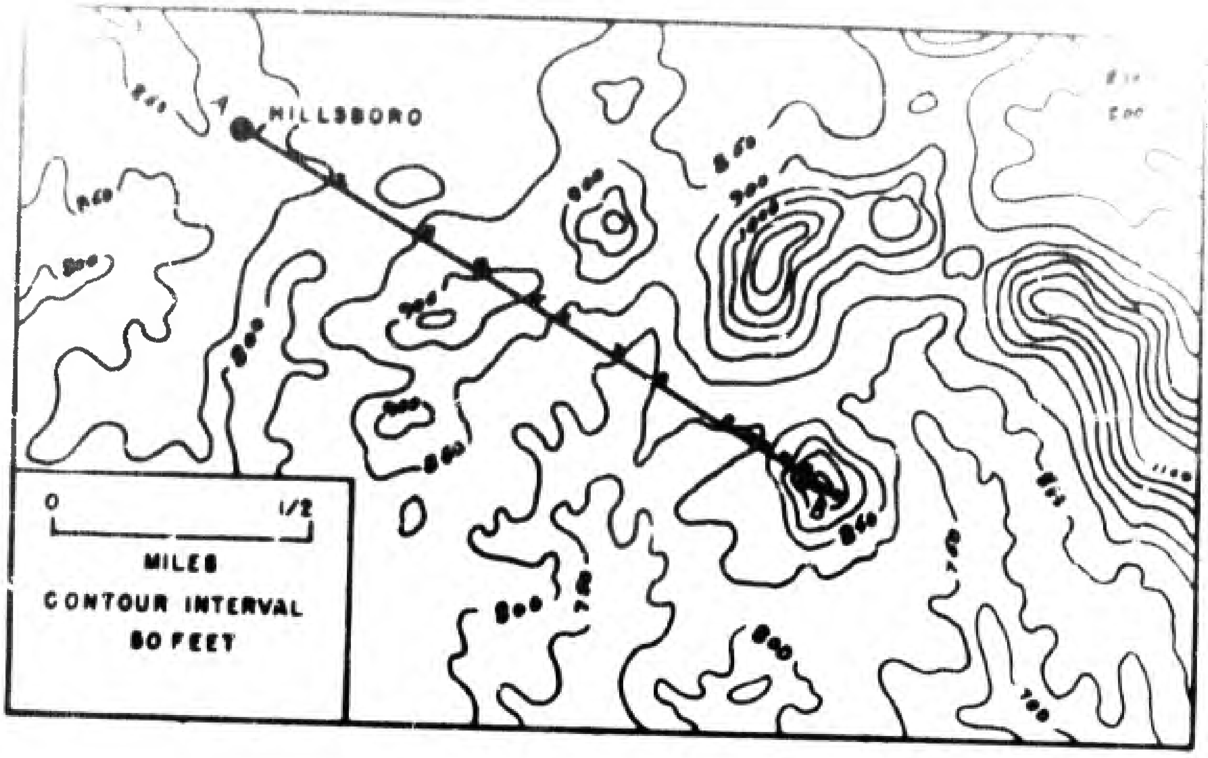


Figure 2a. Section of a topographic map (7)

A profile is to be constructed along line A B.

3. New device

a. Purpose

Accurate determinations regarding interference and shadow areas along any line of sight can be observed from earth profiles. These profiles, as described in Section 2, must be drawn carefully in order to reach the correct solution to a problem. Each time a new line of sight is to be examined, a new profile must be drawn. Thus, the solution of line-of-sight problems becomes a lengthy task when numerous lines of sight and corresponding profiles are required.

To facilitate this procedure, a simple device has been developed which will quickly and accurately aid in the solution of problems concerning the line of sight between or beyond two points.

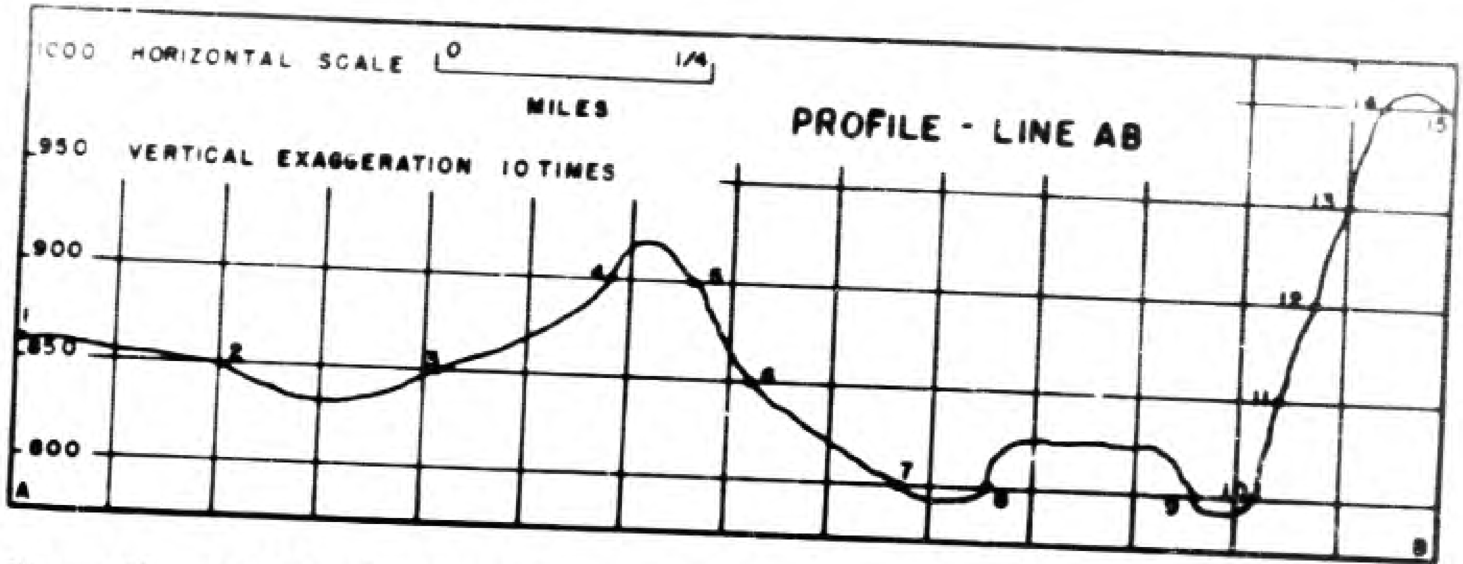


Figure 2b. Profile along line A B constructed on graph paper

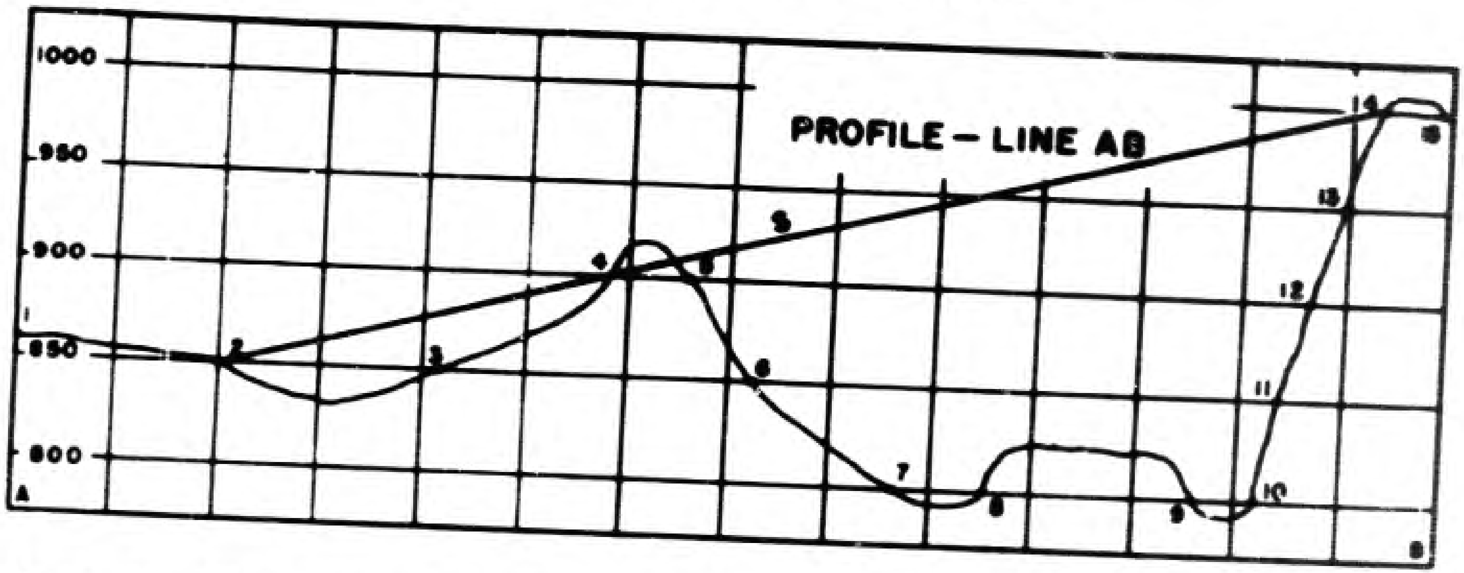


Figure 2c. Line of sight (S) superposed on profile

Is point 2 visible from point 14? A straight line to represent line of sight is drawn on the profile connecting points 2 and 14. The height of land between points 4 and 5 intercepts this line. Thus, that height of land obscures point 2 from point 14.

b. Description

The device is constructed from a clear plastic and comprises three parts: the base and two movable pieces, the pivot and the slide. The base and pivot are held together with a bolt. The slide is attached to the base in a groove. A series of parallel lines and a perpendicular line are inscribed on the base; a single line is inscribed on the pivot and one on the slide. Figure 3 shows the device assembled and ready for operation. Figure 4 shows the device unassembled and the various parts identified.

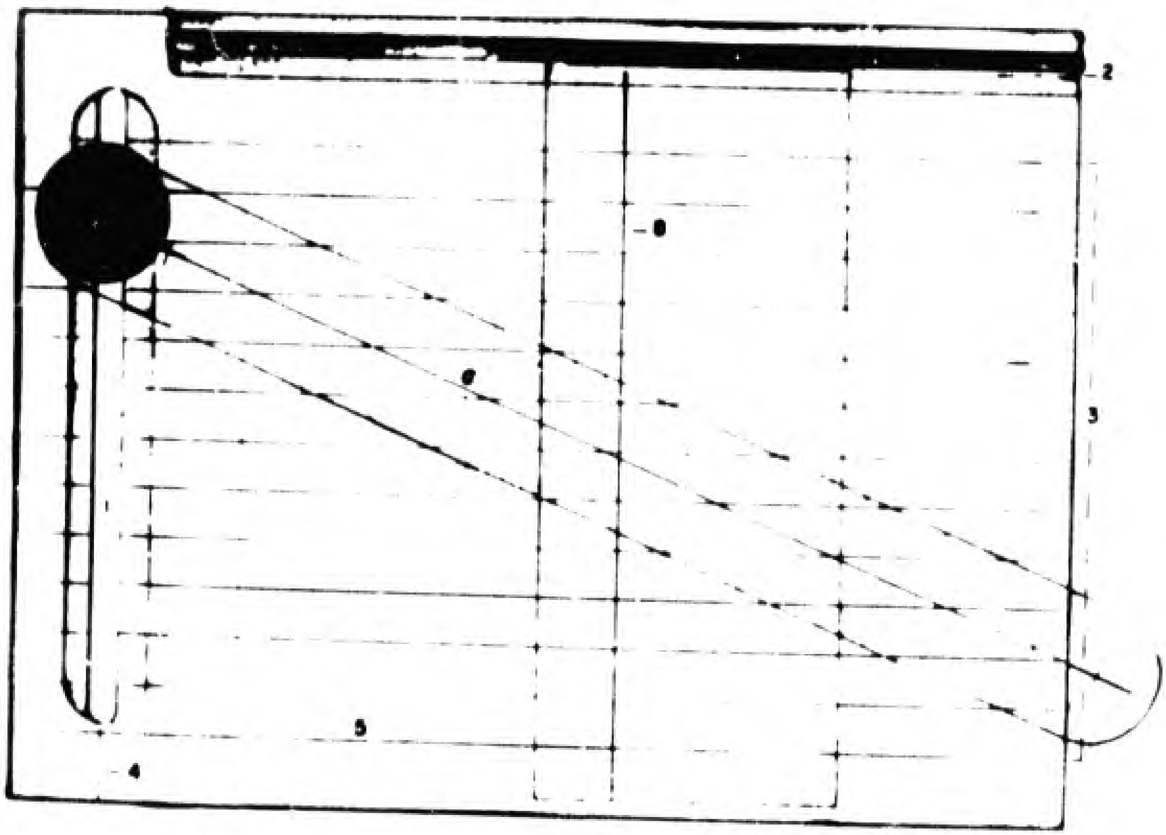


Figure 3. Device assembled

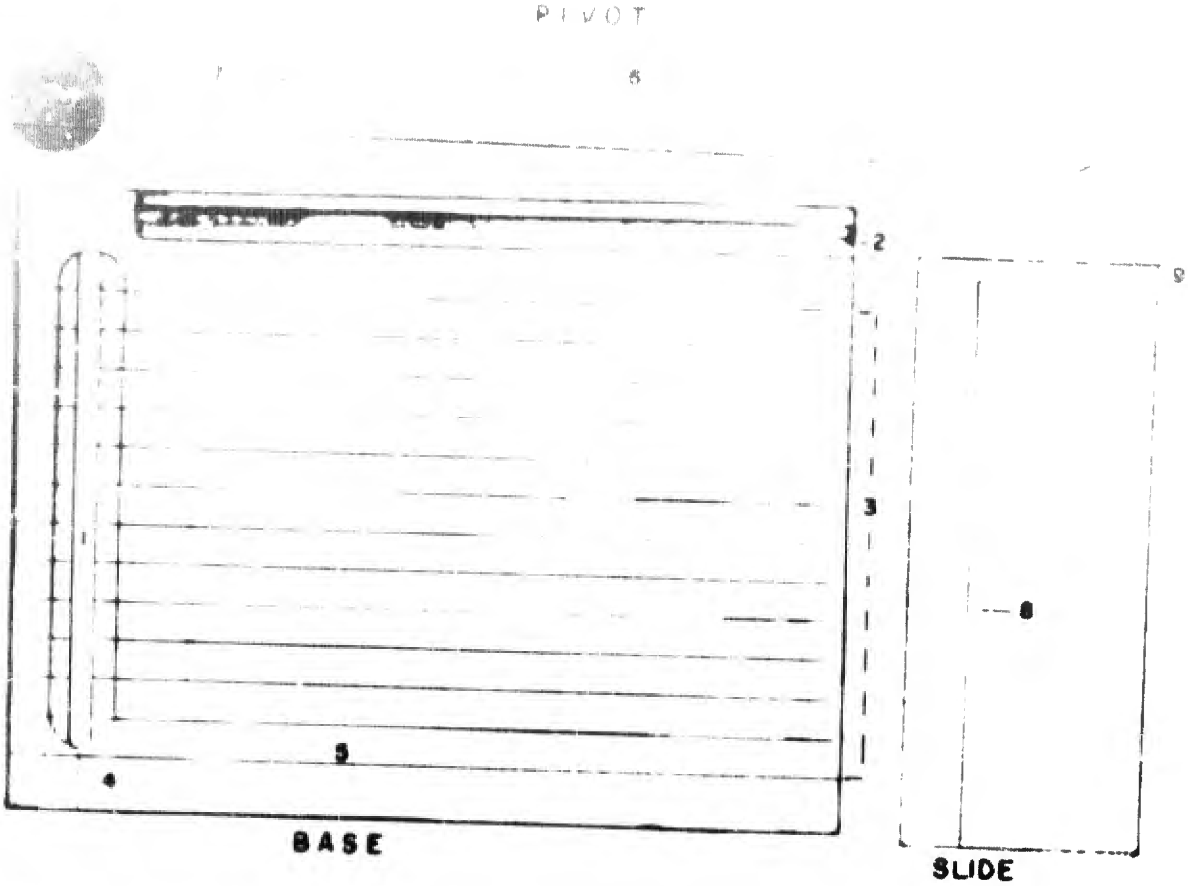


Figure 4. Device unassembled

The device consists of three parts: the base, slide, and pivot. A bolt connects the pivot with the base.

(1) - slideway to mount the pivot for both sliding and angular movement

(2) - groove to mount the slide and to guide movement of the slide

(3) - grid consisting of a number of uniformly-spaced parallel lines; (3) is parallel to (2) and perpendicular to (1)

(4) - continuation of (1); (1) and (4) together form a perpendicular line and are a line of reference with respect to (3)

(5) - baseline of the grid and a line of reference

(6) - straight line used to represent line of sight

(7) - aperture through which the bolt connects the pivot to the base

(8) - straight line parallel to (1) and perpendicular to (3) at all positions of slidable adjustment

(9) - head of slide which fits in (2) and maintains slide in parallel relationship to (1)

This apparatus serves as an aid to visualize a profile of the surface along a line of sight. It should be kept in mind that the various parts of the device are substitutes for graph paper and that the device is used directly on a contour map so that no profile is actually drawn.

The parallel lines on the base (3) are analogous to the horizontal lines on a sheet of graph paper and hence are a scale for measuring heights. The two perpendicular lines (4) and (8) are used to locate the position of objects along the line of sight. The moving perpendicular line (8) is a substitute for the vertical lines on a sheet of graph paper. Line (6), on the pivot, represents the line of sight connecting two points. All these parts, working in proper relationship, will establish the profile under consideration. However, some skill must be developed to use the device properly.

c. <u>Method of operation</u>

The fundamental operation of the device will be explained in detail through a hypothetical situation. This basic procedure, when clearly understood, can be easily adapted to solve similar problems.

Suppose that Hillsboro, Kentucky, is a major supply depot. It is necessary to place an observation post in the area from which to watch the traffic moving into and out of town. About 1½ miles east of Hillsboro is a hill 1200 feet high which is considered a suitable site for the post. However, there are several nearby hills, some of which might obscure the road from this site. To quickly determine whether or not these hills seriously interfere with the view of the road, a line-of-sight situation is established and, with the aid of the device, is examined.

The first step towards solving this problem is to locate the points under consideration at their representative positions on the topographic map of the area. Figure 5 is a portion of the Hillsboro, Kentucky, topographic sheet (7) with the necessary information recorded. The proposed observation site is found and suitably marked, A. The hills that might cause interference, five in number, are selected and marked (B1, B2, B3, B4, B5). Lines representing lines of sight (A C1, A C2, A C3, A C4, A C5) are drawn from A passing across each of the five hills, to the road beyond (C1, C2, C3, C4, C5). During the following description, the reader is advised to consult Figure 5 along with Figures 3 and 4. (Numbers in parentheses refer to the appropriate parts of the device as noted in Figures 3 and 4.)

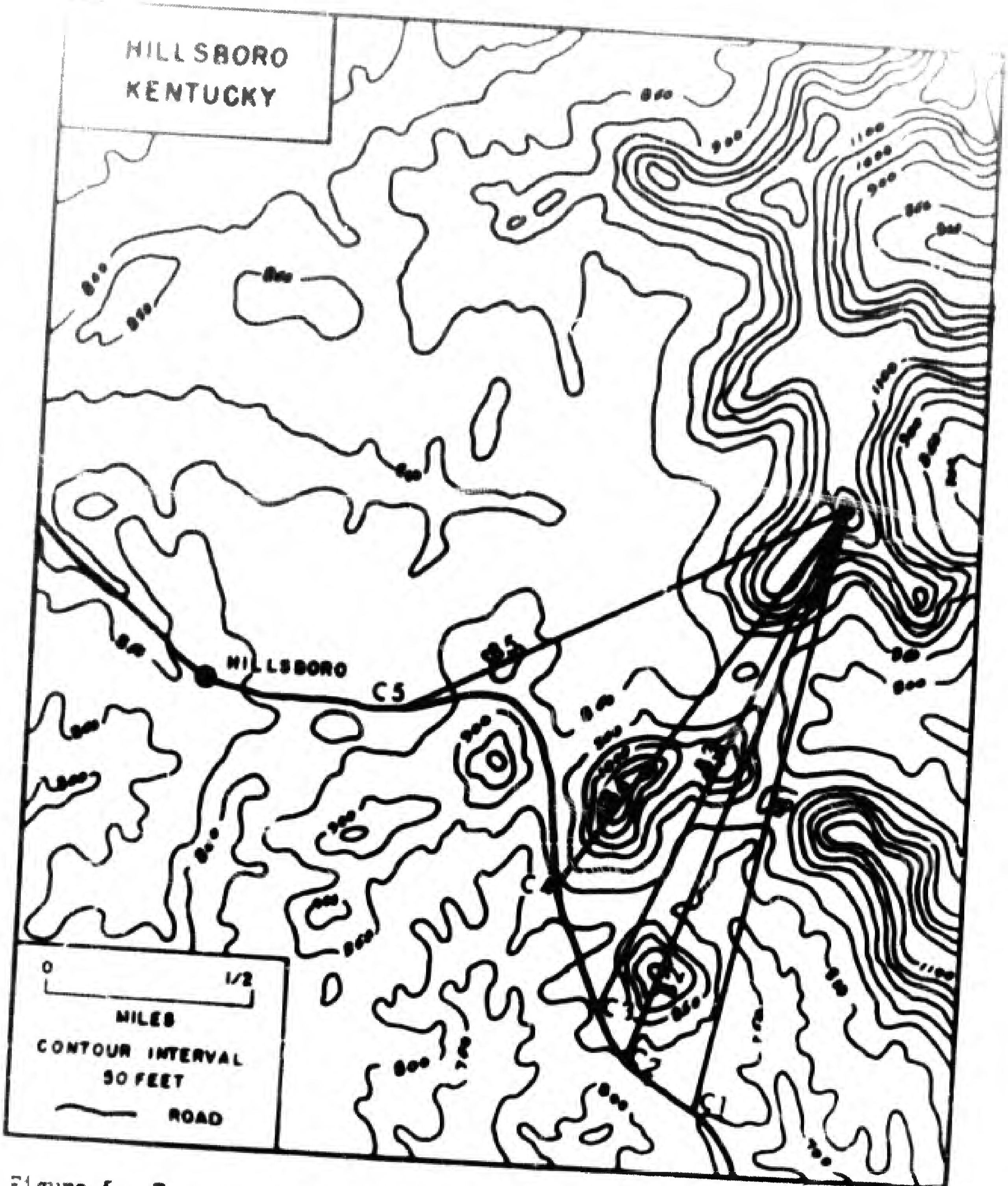


Figure 5. Topographic map of Hillsboro, Kentucky[7] (contour interval changed from 20 feet to 50 feet)

A - hill, 1200 feet, point of origin for lines of sight
B1, B2, B3, B4, B5 - hills which may cause interference
C1, C2, C3, C4, C5 - points on road which hills may shadow
Lines A C1, A C2, A C3, A C4, A C5 - lines of sight from hill A to road passing through interfering hills; these lines also serve as baselines for profiles.

he contour map, with the various points marked for identification is laid on a flat surface and the device is introduced. Numerical values are assigned to the grid (3) to form a scale representing height above sea level. To facilitate the operation, these values could be marked on the device with a grease pencil. The values assigned will depend on the operator's preference, the scale of map, and the accuracy required for each particular problem. For this example, a 50-foot interval will be maintained and baseline (5) will be given the value of 750 feet.

Line of sight A C5, as now drawn on the map, is to be examined first. The device is placed on the map so that (5) coincides with line of sight A C5. The intersection of (5) and (4) superposes point A. The map and device are held in this relationship during the rest of the operation.

The pivot is moved vertically along (1) to bring (6) in conjunction with the grid line representing the elevation of point A, 1200 feet. In accordance with the values assigned for this problem, (6) is adjusted to the tenth line of the grid. The pivot is then locked against lengthwise sliding movement by tightening the bolt.

The slide is moved horizontally along (2) to bring (8) into alinement with point C5. Thus (8) forms a perpendicular to (5) at the position of point C5. The grid line which represents the elevation of point C5 is located. In this case, the elevation of point C5, approximately 840 feet, lies slightly below the third grid line which has been assigned the value of 850 feet. While the slide is held over point C5 in the position described, the pivot is moved so that (6) coincides with the intersection of (8) and the grid line representing the elevation of point C5. This intersection is slightly below the third grid line. At this position, (6) represents the simulated line of sight between points A and C5.

To determine whether or not C5 will be visible from A, the pivot is maintained in the position of adjustment described above. The slide is moved so that (8) overlies hill B5 and forms a perpendicular to (5) at this point. The elevation of B5, 900 feet, is located on the scale and is found to correspond with the fourth grid line. The intersection of (8) with the fourth grid line lies below (6), hence hill B5 does not intercept the line of sight between A and C5. Thus the road is clearly visible from point A.

When the elevations of two points on the map have been transposed to the grid, and the line inscribed on the pivot has established a line of sight between them, it can be determined whether any points along the baseline will interfere with that line of sight. By transposing the elevation of any point along the baseline to the grid, one can see that any elevation which lies below the line on the pivot will not interfere with the line of sight; any elevation which lies above the line on the pivot will interfere.

The next consideration is hill B4. For this, the device is shifted so (5) coincides with line A C4 on the map, the intersection of (5) and (4) overlies point A, and the process described above is repeated. The slide and pivot are adjusted in accordance with the differing elevations and positions of points A, C4, and B4. The line of sight is established between points A and C4 by (6); the elevation and position of hill B4 are located on the grid. Since the elevation of hill B4, as read on the grid, lies above (6) it is evident that this hill will obscure the road at C4 from an observer at A.

The other lines are treated in the same manner as lines A C5 and A C4. For each line, the device is shifted so (5) coincides with the appropriate line of sight drawn on the map and adjustments are made with the slide and pivot for the elevations and positions of the different points. The results show that two places on the road, points C2 and C4, will be obscured from hill A. On the basis of this study, a decision can be made regarding the effectiveness of this site as an observation post.

It is sometimes difficult to grasp the concept of visualizing the three-dimensional aspect of the earth's surface by placing the representative elevations of certain key points on a grid, as the device does. Careful scrutiny of Figures 6 and 7 will help to achieve an understanding that an accurate profile can be described without a drawing.

d. <u>Adaptations</u>

It may be necessary to vary the procedure described above to fit individual problems. In all instances, the essential elements will be the locations and elevations of two points with which to establish a line of sight. Once this line has been determined, any number of points at any position along this line can be analyzed in relation to the line.

There are two fundamental arrangements for line-of-sight analysis. The example which has been shown in Section 3c makes use of one of these, to discover whether or not a position is shadowed by any object in regard to a line of sight originating from a particular point (Figure 8a). Referring to line A C5 in Section 3c, a line of sight was drawn from point of origin A to the position in question, C5. Then point B5, the highest elevation lying between A and C5 along the line of sight, was examined to see if it shadowed position C5.

The other fundamental arrangement is to determine the extent of shadow from an object in regard to a line of sight originating at a particular point (Figure 8b). In this type of problem, a line of sight can be established from the point of origin to the object causing shadow. The area lying beyond this object, along the continued line of sight, would then be studied to ascertain the places shadowed by this object.

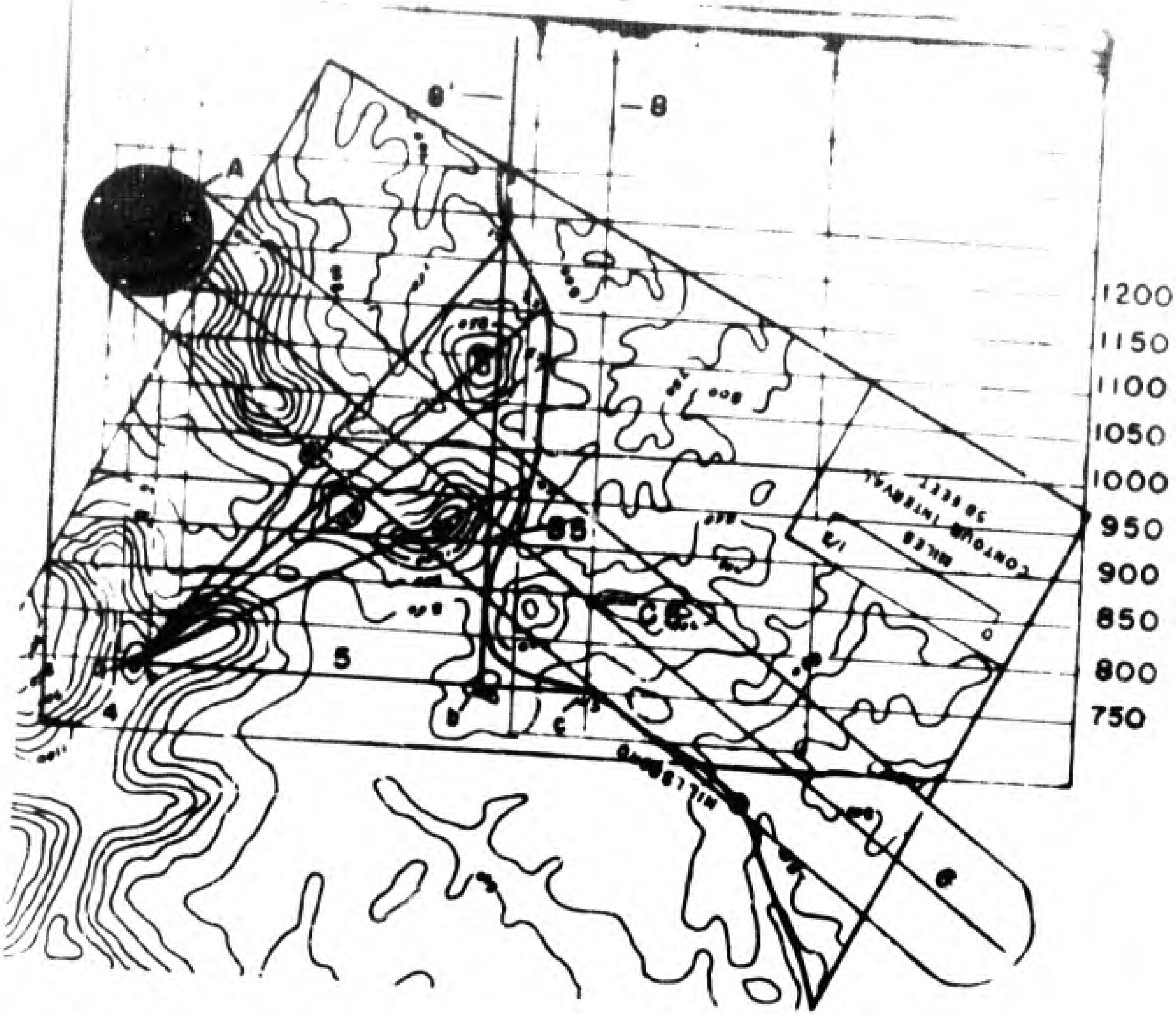


Figure 6. Device in operation

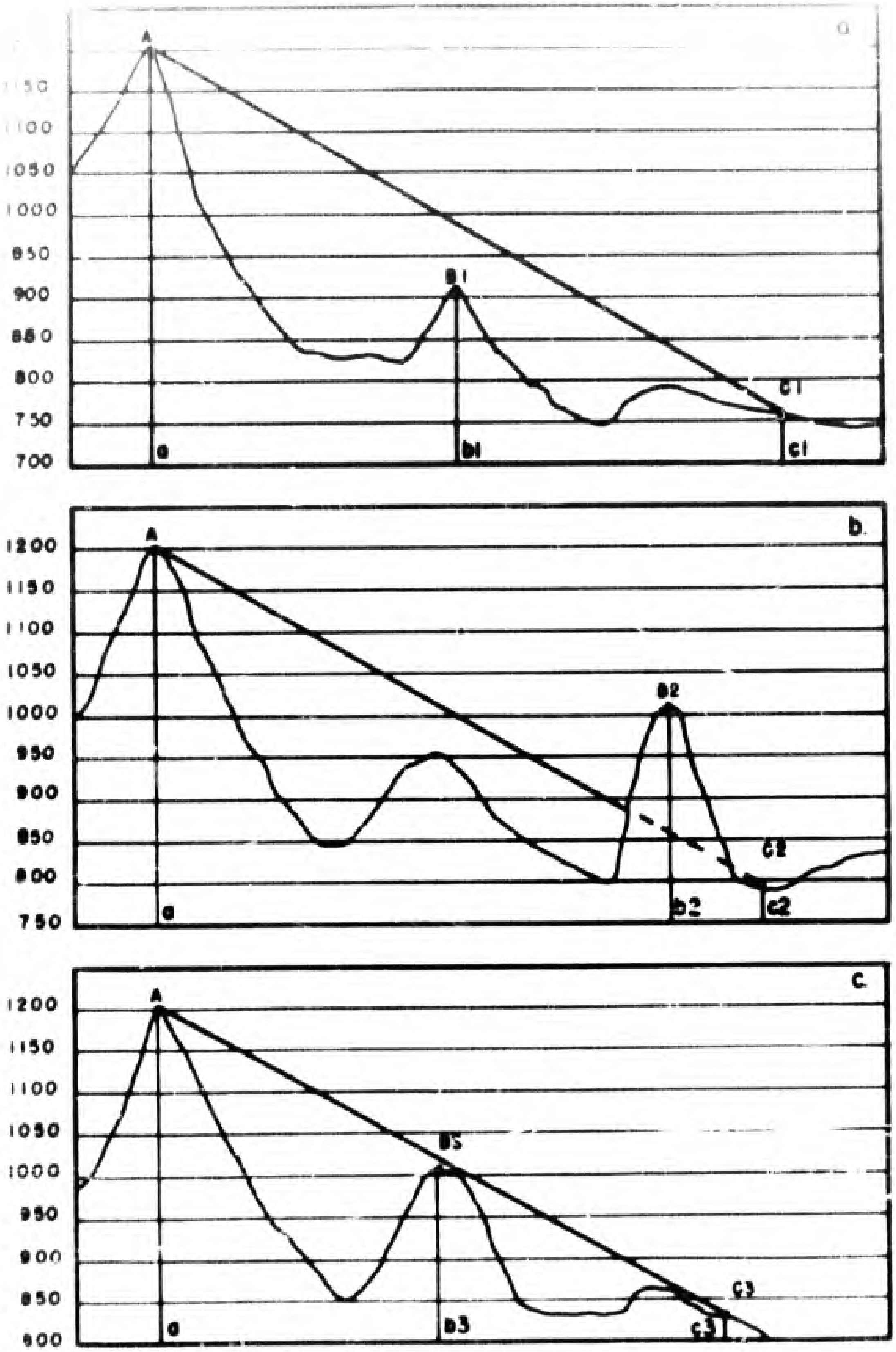
Values for height above sea level are assigned to the grid at 50-foot intervals.

Line (5) on the device superposes line of sight A C5 on the map. (a) is the intersection of (4) and (5) overlying hill A. The bolt end of (6) is fastened on the tenth grid line (A), representing the elevation of A, 1200 feet.

The slide is moved so that the intersection of (8) with (5) overlies C5 on the map (c). (6) is adjusted to the intersection of (8) and a point slightly below the third grid line which corresponds to the elevation of C5, approximately 840 feet (C5). (6) now represents the line of sight connecting points A and C5.

(8') indicates the position of (8) when the slide is moved so that the intersection of (8) and (5) will overlie B5 on the map (b).

The elevation of B5, 900 feet, will be located on the scale along (8') at the fourth grid line (B5). This point will lie below (6) and will indicate that hill B5 does not obstruct the view of C5 from A. A graphic illustration of this situation will be found in Figure 7e.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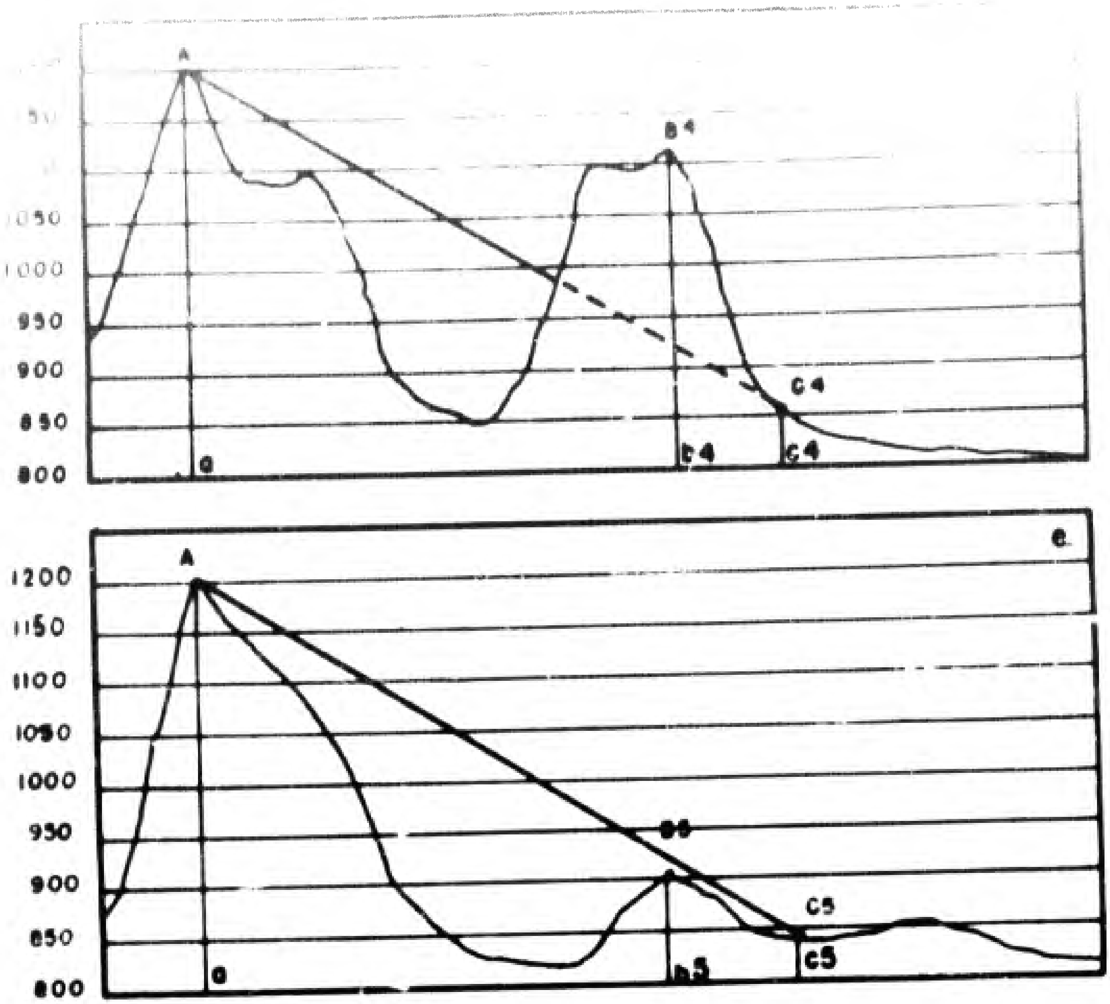

Figure 7. Profiles along lines of sight; Hillsboro, Kentucky[7]

7e reconstructs line-of-sight conditions for line A C5.

The horizontal lines on the diagram represent the grid on the device. Elevation values are assigned to this scale at 50-foot intervals with baseline (5) value of 800 feet.

Vertical line A a represents (1) and (4) on the device. a is the intersection of (4) with (5), overlying hill A on the map. A is the position of the bolt end of (6) affixed to the scale at the elevation of hill A (1200 feet).

Vertical line C5 c5 represents (8) positioned over point C5 on the map. c5 indicates the intersection of (8) and (5). C5 is the place at which the elevation of point C5 (approximately 840 feet) is read on the scale.

Line A C5 represents the adjustment of (6) to establish the line of sight between hill A and point C5.

Vertical line B5 b5 represents (8) when it is moved to overlie hill B5 on the map. b5 indicates the intersection of (8) and (5) over hill B5. B5 is the point at which the elevation of hill B5 (900 feet) is measured on the scale.

The four additional diagrams are reconstructions of the other lines of sight discussed in the hypothetical problem. Variations in elevations and placement of points have been made in accordance with the different lines.

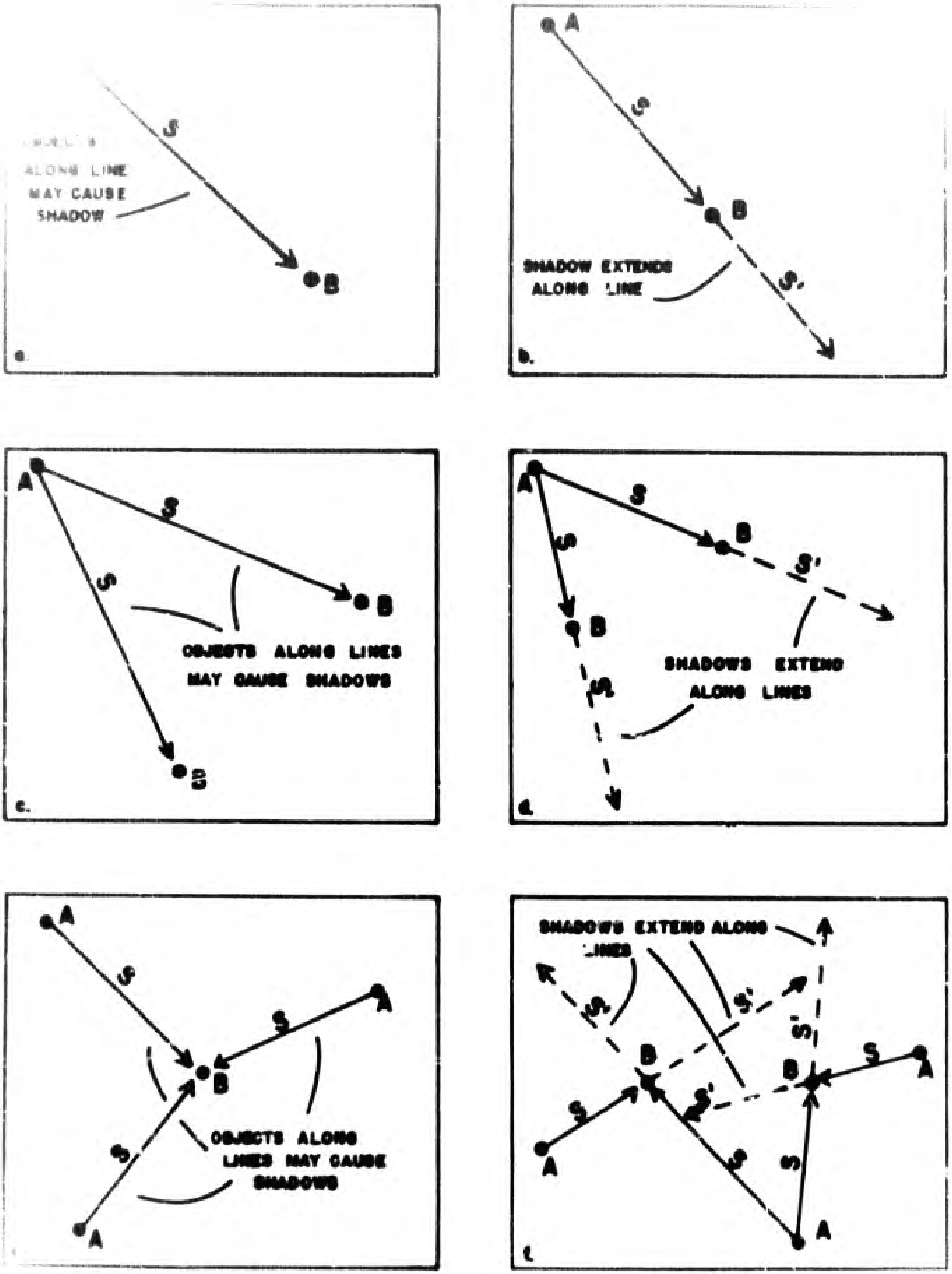

Figure 8. Arrangements for different line-of-sight situations

A - point of origin; B - position of object in question;
S - line of sight; S' - line of sight continued beyond object

Many problems can be solved by using multiple lines of sight in various combinations of these two arrangements. For instance, it can be determined whether or not a number of positions would be shadowed by any objects in regard to lines of sight originating from a particular point (Figure 8c). The example in Section 3c is a problem of this sort.

Another combination is to determine shadowed areas cast by various objects by several lines of sight from an origin (Figure 8d). Here numerous lines would radiate from one point towards numerous objects. Positions beyond these objects would be studied to delimit the extent of shadowed area. Military considerations of thermal effects from nuclear or other weapons exploded at a particular point exemplify this line-of-sight arrangement which would reveal areas sheltered by terrain.

The interference caused by surrounding objects to a particular position from lines of sight emanating from various origins can be disclosed by a number of lines of sight directed toward one position (Figure 8e). To place a television tower so that a town is best served, a number of possible sites could be selected on which to place the tower. Lines of sight would be drawn from these positions toward the town, and the terrain lying between the proposed sites and the receiving area examined to find that site which presents the least interference to reception.

One other combination of lines is to determine the interference caused by various elevations within an area from lines of sight emanating from various origins (Figure 8f). A meteorological study of the amount of sunshine an area receives would illustrate this situation. One series of points would represent the sun's position at different times of the day and another series, those elevations which would cause shadow. A number of lines of sight would be drawn connecting each point of origin with the appropriate elevations. The areas shaded, at different hours of the day, would be outlined.

e. Special considerations

Additional considerations may be necessary for certain problems. In some instances, such as placing of television towers or observation posts, the height of these objects should be added to the elevation of the surface before establishing the line of sight.

Although all the examples cited have dealt with topographic maps, the device is not necessarily limited to surface observations. Any contour map may be used and it is conceivable that application of the principles set forth could be used with subsurface contour maps.

If it is impractical to use actual values for elevations, angular heights may be used and proportional heights calculated for the various objects. For meteorological studies, where the height of the sun above the earth's surface is too great to be workable at this scale, some

...minary calculations are needed. A height representing the ... determined by the angle at which the sun's rays fall to earth. Computations of this sort can be determined from the Air Almanac,[8] published yearly by the U. S. Naval Observatory.

All the above described procedures will work satisfactorily and produce accurate results on any contour map regardless of map scale. Scale is not a limiting factor since one is dealing with relative, rather than absolute, values of distance and height. The parallel lines on the grid are evenly spaced and unnumbered; hence any value can be assigned. These values can vary from map to map and problem to problem.

These methods will work satisfactorily at relatively short distances where curvature of the earth is not a limiting factor, or where the slight earthward bend of high-frequency radio waves is not restricting (TM 11-673).[3] Beyond that distance, an operator would still be able to utilize the device but would have to compensate mentally for the apparent lessening of heights due to earth curvature. This can be accomplished with the aid of a table which shows the amount of apparent diminishing of heights at specific distances from point of origin. This amount is then subtracted from the actual height as presented on the map. Table I indicates the amount of apparent diminishing which occurs at various distances away from a point.

TABLE I

APPARENT LESSENING OF HEIGHT DUE TO EARTH CURVATURE*

Distance (miles)	Divergence (feet)	Distance (miles)	Divergence (feet)
5	14.4	30	516.4
10	57.4	35	703.0
15	129.1	40	918.1
20	229.5	45	1,162.0
25	358.6	50	1,434.6

*See Bibliography, number 6

If only one map scale were to be used, however, a base could be designed with curved, rather than horizontal, lines and so compensate for earth curvature without these calculations.

f. Areas of possible use

The examples cited to illustrate the operation of the device have indicated that its use is not limited to any one field of study. Actually wherever it is necessary to determine line of sight and shadows caused by irregularities of terrain, this device can be used effectively.

Military science is one of the major areas of study in which the device can find application. Problems of visibility (FM 21-26),[2] which heretofore were solved by drawing profiles, now can be worked out more quickly. Planning for operations, such as positioning of troops and supplies to receive maximum protection from the terrain, or locating areas of defilade and enfilade will be facilitated. Additional line-of-sight situations are discussed in A Survey of Map Skills Requirements (HumRRO Technical Report 43)[1] and the principle of the device also could be applied to these.

The device can be useful in the field of communications. High-frequency radio waves travel by line-of-sight transmission (Van Nostrand's Scientific Encyclopedia).[9] The device can be employed to determine suitable locations for VHF and UHF transmitter and receiver towers, and to indicate those regions where portable VHF and UHF transmitters can be used most favorably (TM 11-673).[3]

Other fields where the device could be an asset are: geology, to work out problems requiring knowledge of the location and extent of ore bodies, or the dip and strike of strata; civil engineering, as an aid when planning underground construction such as tunneling or excavating where it is necessary to determine the extent of hard and soft strata; and meteorology, for problems requiring precise knowledge of illumination including solar radiation, evaporation and precipitation studies.

4. Conclusion

The above-described device has proved a distinct aid to simplify the process of line-of-sight analysis. Its greatest advantage over previous methods, is that of a time-and labor-saving device. It is also flexible and movable so it can be easily adapted to suit a variety of problems. Its small, compact size renders it useful in both laboratory and field situations. The operation of the device is comparatively simple and, once understood, can be applied quickly to make accurate determinations for numerous problems.

Application for patent is on file at the U.S. Patent Office under serial number 694,686 dated 5 November 1957.

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