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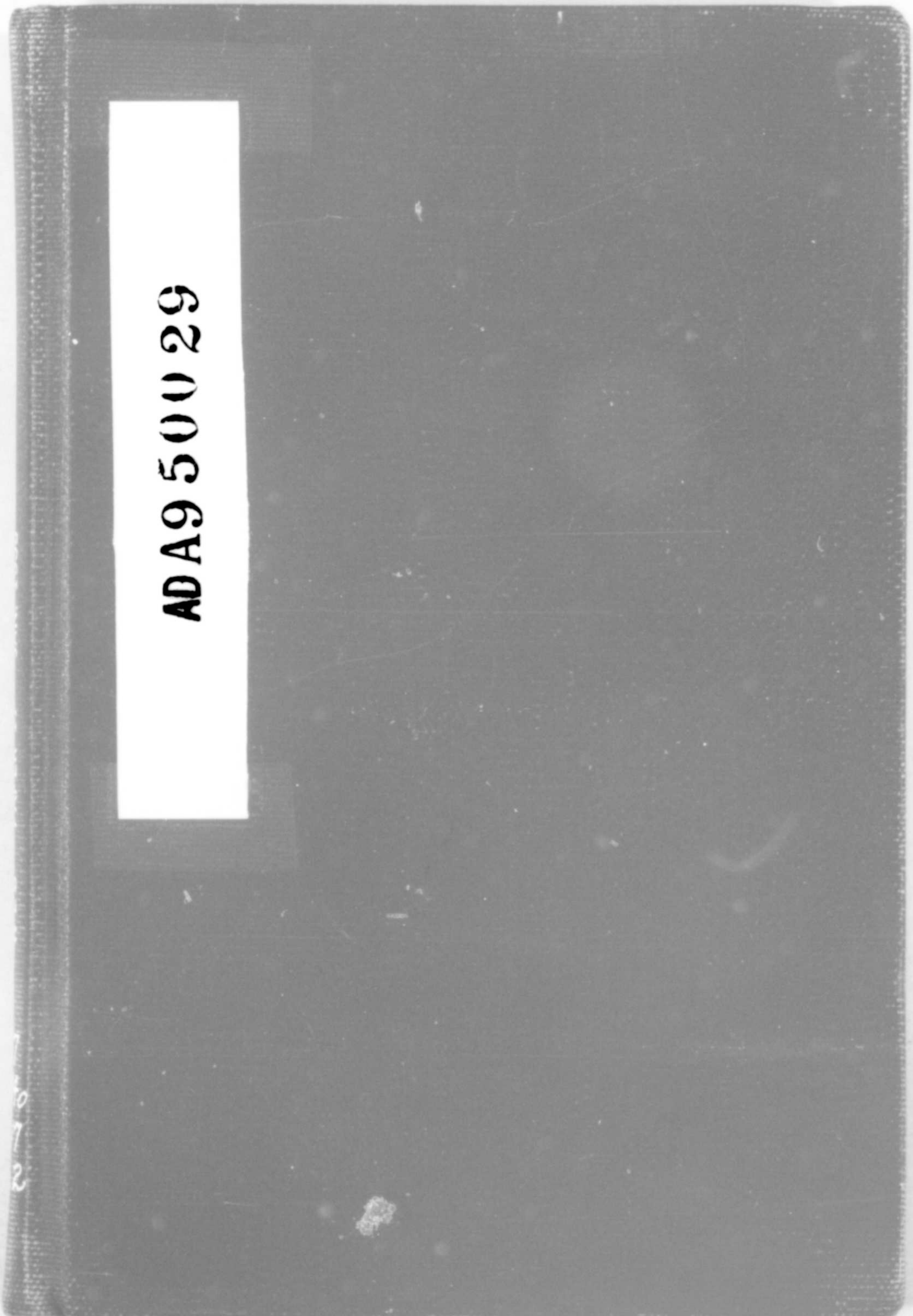
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WAR DEPARTMENT
CORPS OF ENGINEERS, U. S. ARMY

STUDIES OF RIVER BED MATERIALS AND THEIR MOVEMENT, WITH SPECIAL REFERENCE TO THE LOWER MISSISSIPPI RIVER

PAPER 17
OF THE
U. S. WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

JANUARY, 1935

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PREFACE

This paper presents the results of two closely related investigations which have been actively carried on by the U. S. Waterways Experiment Station since the summer of 1932. In August of that year, the Chief of Engineers, U. S. Army, directed that studies be undertaken to determine the force of flowing water required to move materials composing the bed of the Lower Mississippi River. In complying with this directive it was realized that much information was needed, not only concerning the tractive force required to move particles of different sizes and physical characteristics, but also concerning the actual composition of the bed of the Mississippi River from Cairo, Illinois to the Gulf of Mexico. Without accurate knowledge of the nature of the material composing the bed, it would be impossible to evaluate the forces required to move it. Consequently, the problem divided naturally into two phases.

Part I of this report contains a resume' of results obtained from flume tests of materials moved by hydraulic traction. This work was begun under the immediate supervision of Lieutenant P. W. Thompson, C. E., designer of the special flume used throughout the investigation. At a later date this work was taken over by J. B. Tiffany, Jr., Junior Engineer, upon whom fell the task of correlating data, analyzing the results, and preparing the subsequent report. C. E. Bentzel, Junior Engineer, who performed most of the actual tests and who assisted in the study of the data, performed a great service to the Station through the development of the velocity meter which bears his name. The Bentzel Velocity Tube, which is described in the main body of this report, has largely supplanted other types of velocity-measuring devices in the hydraulic model studies at the U. S. Waterways Experiment Station.

Part II of this report consists of a tabulation and discussion of data relative to the characteristics of the materials composing the bed of the Lower Mississippi River. Mr. Charles W. Schweizer, Engineer, of the Mississippi River Commission, in 1932 made a trip over the Lower Mississippi and several of its tributaries and procured about 750 small samples of bed material, which were analyzed in the soil mechanics laboratory at this Station, under the direction of Spencer J. Buchanan, Soils Engineer.

Special credit is due to Lieutenant Herbert D. Vogel, C. E., former Director of the U. S. Waterways Experiment Station, who planned the scope of these investigations, and under whose direction most of the actual work was performed. Lieutenant K. D. Nichols, C. E., rendered valuable service in interpreting data and checking results.

Acknowledgment is here made of the service and suggestions of Capt. Hans Kramer, C. E., whose work in Germany proved helpful as a basis for undertaking the study. Gratitude is also expressed to Prof. K. C. Reynolds and Mr. C. H. MacDougall of the Massachusetts Institute of Technology for their helpful cooperation, and to Profs. Henry V. Howe and R. Dana Russell of the Department of Geology of the Louisiana State University for their work in the petrographic analysis of the samples of bed materials.

It is desired to emphasize that the investigations conducted thus far by the U. S. Waterways Experiment Station cover a very limited field in the research on critical tractive force and rates of river bed materials. However, it is believed that this report will add much to the general fund of knowledge. For a complete bibliography on this subject, the reader is referred to "Sand Mixtures and Sand Movement in Fluvial Models", by Hans Kramer, Proceedings, Am. Soc. C. E., April, 1934, or to "Bibliography on the Subject of Transportation of Solids by Flowing Water in Open Channels", published by the United States Department of the Interior, Bureau of Reclamation, Denver, Colorado. Additional references are given throughout this report.

FRANCIS H. FALKNER

1st Lieut., Corps of Engineers
Director, U. S. Waterways
Experiment Station

STUDIES OF RIVER BED MATERIALS AND THEIR MOVEMENT, WITH SPECIAL REFERENCE TO THE LOWER MISSISSIPPI RIVER

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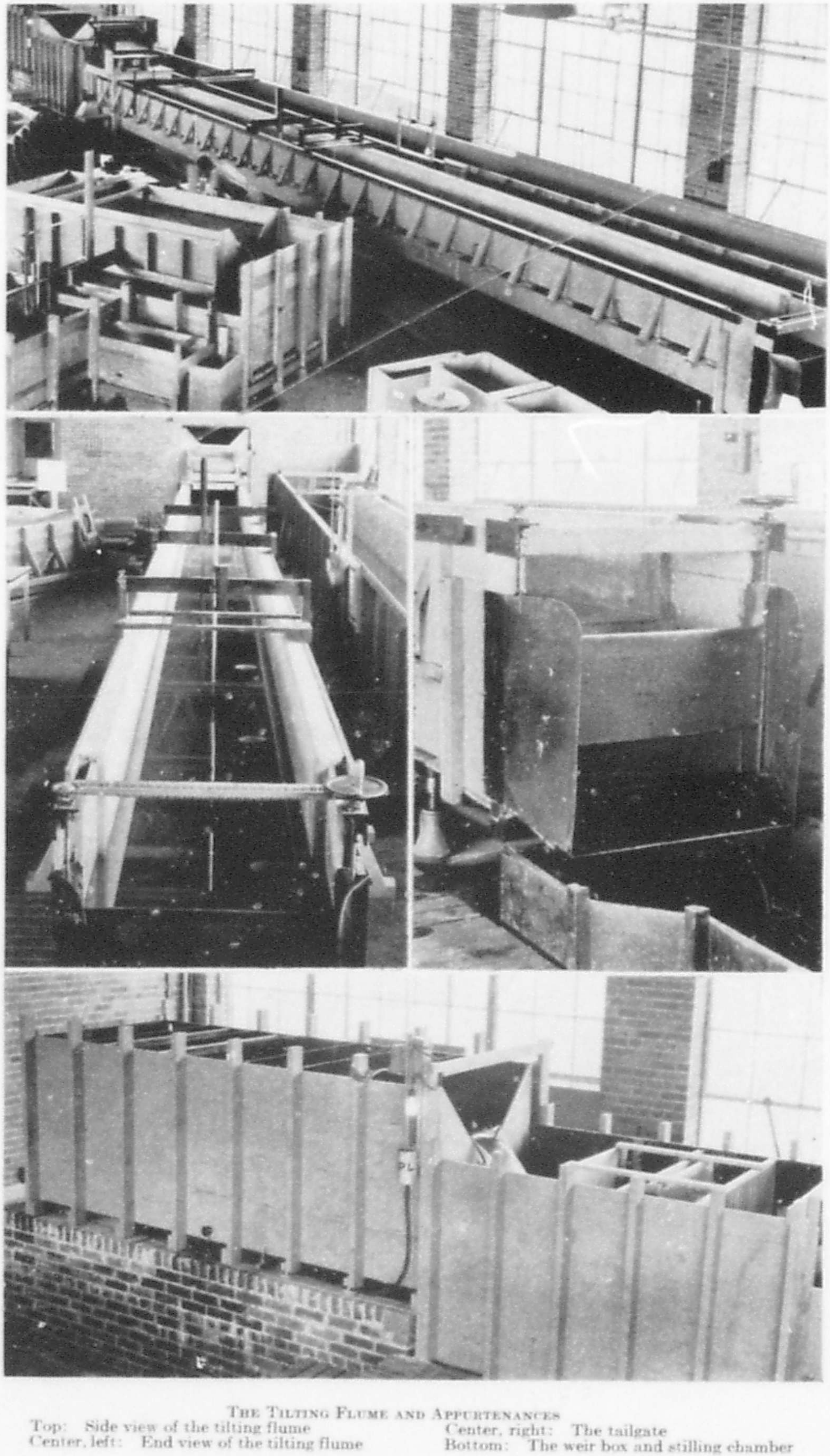


THE TILTING FLUME AND APPURTENANCES

Top: Side view of the tilting flume
Center, left: End view of the tilting flume
Center, right: The tailgate
Bottom: The weir box and stilling chamber

STUDIES OF RIVER BED MATERIALS AND THEIR MOVEMENT, WITH SPECIAL REFERENCE TO THE LOWER MISSISSIPPI RIVER

PART I

FLUME STUDIES OF MOVEMENT OF RIVER BED MATERIALS

PRELIMINARY CONSIDERATIONS, APPARATUS, AND PROCEDURE

The ultimate purpose of the flume studies of bed-load movement described herein was to discover and evaluate laws to the end that the river hydraulician might be able to calculate the action of a given bed material under given conditions. Inasmuch as this has been the subject of a great amount of research by both American and European experimenters during the past generation, the purpose as conceived is both far-reaching and ambitious. It was thought, however, that advances might be made on the problem, and that even failing to attain a complete answer to the baffling problem of bed-load movement, many data contributing toward the final solution might be observed and recorded.

The original expectation was that, from the study of the distribution of materials in the river samples, in combination with the knowledge gained from the tests in the tilting flume, an accurate determination could be made of the tractive force required to move the material at any point in the lower Mississippi River. From this it was hoped to ascertain the stage necessary to produce the critical force in any reach of the river. It now seems certain, however, that the present state of knowledge precludes the immediate possibility of making any such sweeping conclusions. Much more research will be necessary before any satisfactory equations can be set up, to express the movement of Mississippi River bed material throughout an entire range of depth, slope, sizes of material, curvature of bends, bed configuration, etc.

The more immediate purpose of the flume tests, which was satisfactorily achieved, was the discovery of many of the basic laws underlying the subject of bed-load movement. In particular, emphasis was given to the study of the rates of movement of bed materials of various sizes, and of the tractive forces necessary for the commencement of their movement. Information was also obtained on riffle formations, values of bed roughness, turbulence, velocity variations, etc. All the data are presented for reference in tabular form at the end of Part I of this report.

Authority for the Bed-Load Studies

Authority to undertake a study of the bed-load of the Lower Mississippi River was contained in a letter from the Chief of Engineers, dated August 13, 1932, addressed to the President, Mississippi River Commission. This authority was transmitted to the Director, U. S. Waterways Experiment Station, in August, 1932.

Program of Experiments

Ten series of experiments were conducted in the tilting flume in the laboratory building, nine of them with sand or gravel mixtures, and one with a neat cement surface on both bottom and sides of the flume. Each material was tested at three slopes; viz, 0.0010, 0.0015, and 0.0020, except in the case of a small gravel, where slopes of 0.0030 0.0040, and 0.0045 were employed. During the course of the individual tests the depth of water flowing was varied by small increments to a maximum of about 0.55 foot. The three main variables, then, of the study were:

(1) Sand or gravel mixture.
(2) Slope of the bed and water surface.
(3) Depth of the water in the flume.

Description of Materials Tested

All of the materials tested during the course of this study were natural mixtures (see Plates 1 and 2) found either in the bed of the Mississippi River, or in deposits near Vicksburg, Mississippi. The mean grain diameter (see page 5) of the mixtures ranged from a minimum of 0.2053 mm in the case of Sand No. 8, to 4.0769 mm in the case of the gravel mixture. The uniformity modulus (see page 5)*, expressing the distribution of sizes within the samples, ranged from 0.2796 to 0.6428, and the specific gravity of each of the materials was very close to 2.65. All the materials were composed of quartz and feldspar particles, with minute quantities of other minerals, the shape of the particles ranging mostly from sub-angular to sub-rounded, with some angular and some rounded particles. The following table summarizes the physical characteristics of the mixtures:

TABLE 1

PHYSICAL CHARACTERISTICS OF MIXTURES TESTED

Sand No.	Mean Grain Size d_g mm	Mean Grain Size d_g in.	Uniformity Modulus M	Shape of Grains	Color	Source of Material
1	0.5861	0.0230	0.2796	Sub-angular to sub-rounded	Brown	Mississippi River, Mile 190.
2	0.5409	0.0213	0.4388	Sub-angular to sub-rounded	White	Creek bed near Vicksburg, Miss.
3	0.5246	0.0207	0.5385	Sub-rounded to rounded	Light Brown	Mississippi River, Mile 467½.
4	0.5056	0.0199	0.4063	Angular to sub-rounded	White	Creek bed near Myles, Miss.
5	0.4828	0.0190	0.4384	Sub-angular to angular	White	Pearl River, near Jackson, Miss.
6	0.3470	0.0137	0.6428	Sub-rounded to sub-angular	Brown	Mississippi River, Mile 303½.
7	0.3104	0.0122	0.5246	Sub-rounded to sub-angular	Light Brown	Hills adjacent to Okay Creek, near Vicksburg, Miss.
8	0.2053	0.0081	0.5597	Sub-angular to angular	White	National Military Park, Vicksburg, Mississippi.
9	4.0769	0.1605	0.5661	Sub-rounded to sub-angular	Brown	Creek bed near Vicksburg, Miss.

* Developed by Capt. Hans Kramer, Corps of Engineers, U. S. Army, "Modellgeschiebe und Schleppkraft", Preussische Versuchsanstalt fur Wasserbau und Shiffbau, Berlin, Germany, 1932; also, "Proceedings", Am. Soc. C. E., April, 1934.

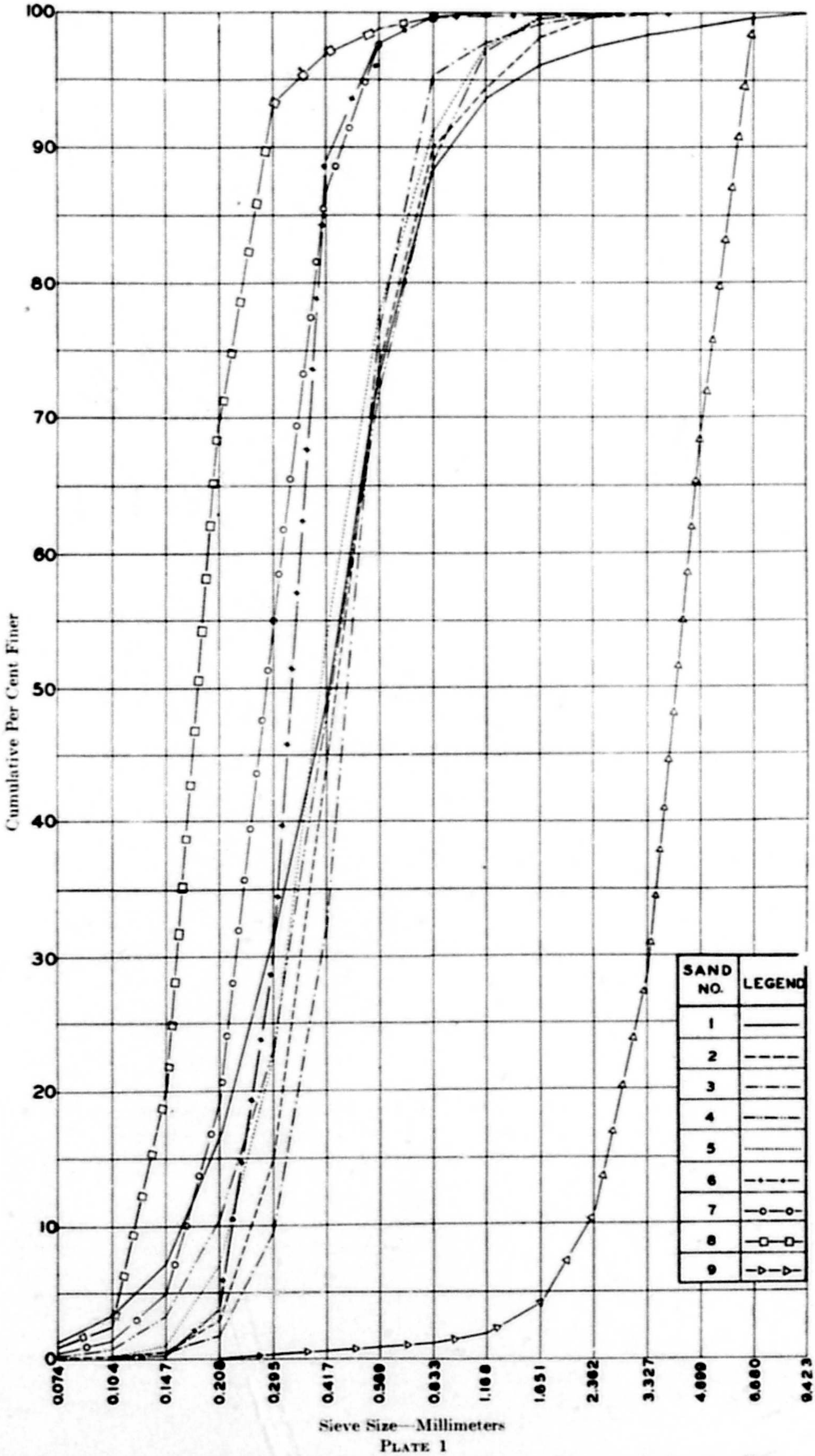


PLATE 1

GRAIN SIZE DISTRIBUTION OF ORIGINAL MATERIALS BEFORE TESTING—CUMULATIVE PLOT

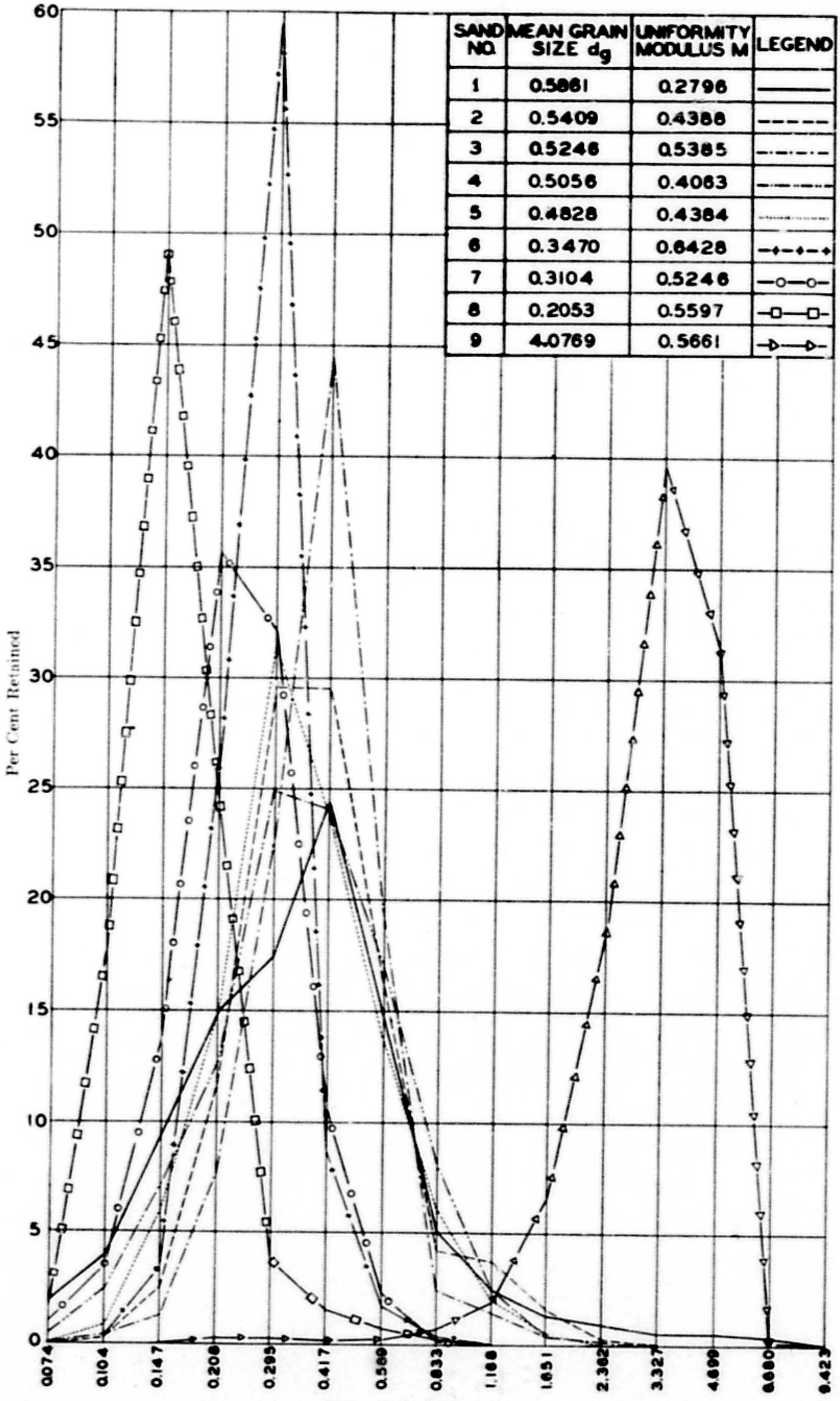


PLATE 2

GRAIN SIZE DISTRIBUTION OF ORIGINAL MATERIALS BEFORE TESTING

The mean grain diameter, d_g, is a value often used by Krey in his experiments concerning bed-load movement, and was adopted later by Kramer, in his study of critical tractive force. Referring to Plate 3, which shows the grain sizes plotted as abscissa and the cumulative per cent passing as ordinates, d_g is simply the mean abscissa of the curve, and represents a weighted average size of particle.

The uniformity modulus, M, has been proposed by Kramer as a convenient expression for the distribution of sizes of the particles in a sand mixture. Expanding upon a scheme devised by Hummel to express the strength of concrete from the gradation curve of the aggregate, Kramer divided the area between the gradation curve

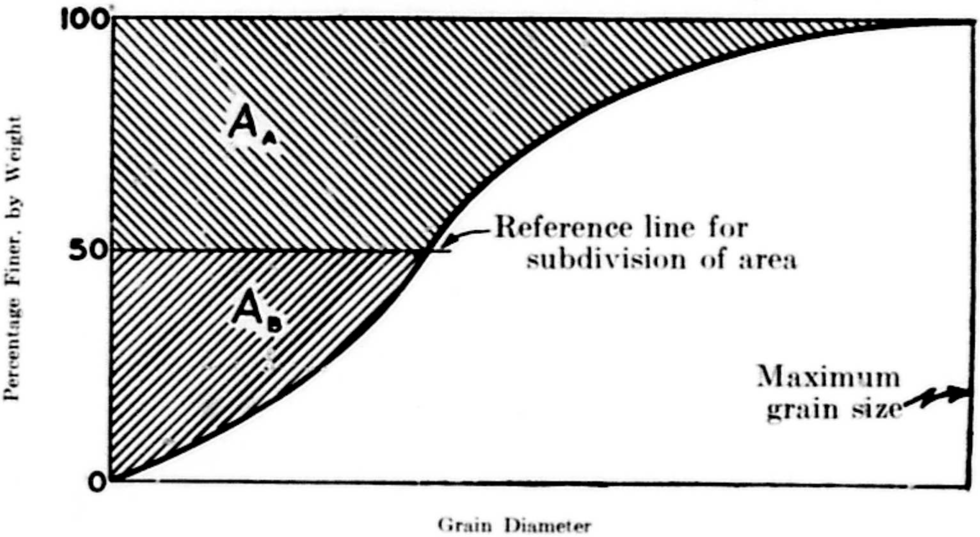


PLATE 3

HYPOTHETICAL SAND ANALYSIS CURVE

(see Plate 3) and the vertical axis into two parts, above and below the 50-per cent line. The uniformity modulus, M, is the ratio of the area below this line to the area above the line. This value, which has been found convenient when it is necessary to evaluate the distribution of particles within a mixture, has the following characteristics:

(1) For a uniform grain size, its value is 1.0.
(2) For a uniform distribution, its value is 1/3.
(3) The addition of fine or coarse materials to a given mixture tends to reduce its value.
(4) It therefore is a measure of the voids ratio. For a uniform material, which has the largest possible percentage of voids, its value is the maximum of 1.0. With the addition of finer or coarser materials, the voids ratio decreases, as does the value of M.

The value of M can be determined from the plotted sieve analysis curve, or it can be computed directly from the sieve analysis data.

The shapes of grains are classified according to a chart prepared by Dr. R. Dana Russell, Assistant Professor of Geology at the Louisiana State University. This chart, composed of micro-photographs of sand grains of various shapes, with the designation assigned to these shapes by Dr. Russell, is reproduced in Plate 4. It should be understood that the designations "angular, sub-angular", etc., are entirely arbitrary. The use of these terms has been extremely loose, with no very definite agreement among experimenters as to their exact limits. Dr. Russell's chart makes it possible, however, by means of a comparison between the microscopic view of sand grains and the chart, to give a definite classification for all grains, with most of the element of personal opinion removed. Dr. Russell's descriptions of the shape classification follows:

(1) Angular (A)—showing very little or no evidence of wear. Edges and corners are sharp.

(2) Sub-angular (SA)—showing definite effect of wear. The grains still have their original form and the faces are practically untouched, but the edges and the corners have been rounded off somewhat, though the angles between faces may still be sharp.

(3) Sub-rounded (SR)—showing considerable wear. The edges and corners are rounded off to smooth curves and the area of the original faces is considerably reduced. The original shape of the grain is still distinct, however.

(4) Rounded (R)—original faces almost completely destroyed but some comparatively flat surfaces may be present. There may be broad reentrant angles between remnant faces. All original edges and corners have been smoothed off to rather broad curves.

(5) Well-rounded (WR)—No original faces, edges or corners left. The entire surface consists of broad curves; flat areas are absent. The original shape of the grain may be suggested by its present form, however.

Collection of Samples:

The three samples from the bed of the Mississippi River were collected by field parties of the U. S. Engineer Department, placed in sacks or drums, and transported to the Experiment Station. Most of the other samples, from creek beds and hill deposits, were obtained from commercial sand pits within 50 miles of Vicksburg.

Analysis of Samples:

Before being tested in the flume, small representative samples of the materials were submitted to the soils laboratory at the Experiment Station for analysis. In addition to a complete mechanical analysis, conducted in the Ro-Tap testing sieve shaker, each sample was subjected to a specific gravity test and to a close microscopic examination, to determine the shape of grain and mineralogic composition of the material. In addition to this original analysis of the materials, made in each case before the testing was begun, other analyses were made periodically of the grains entrapped at the lower end of the flume, and a comparison was made between the original material and that which had been moved by the flowing water in the flume.

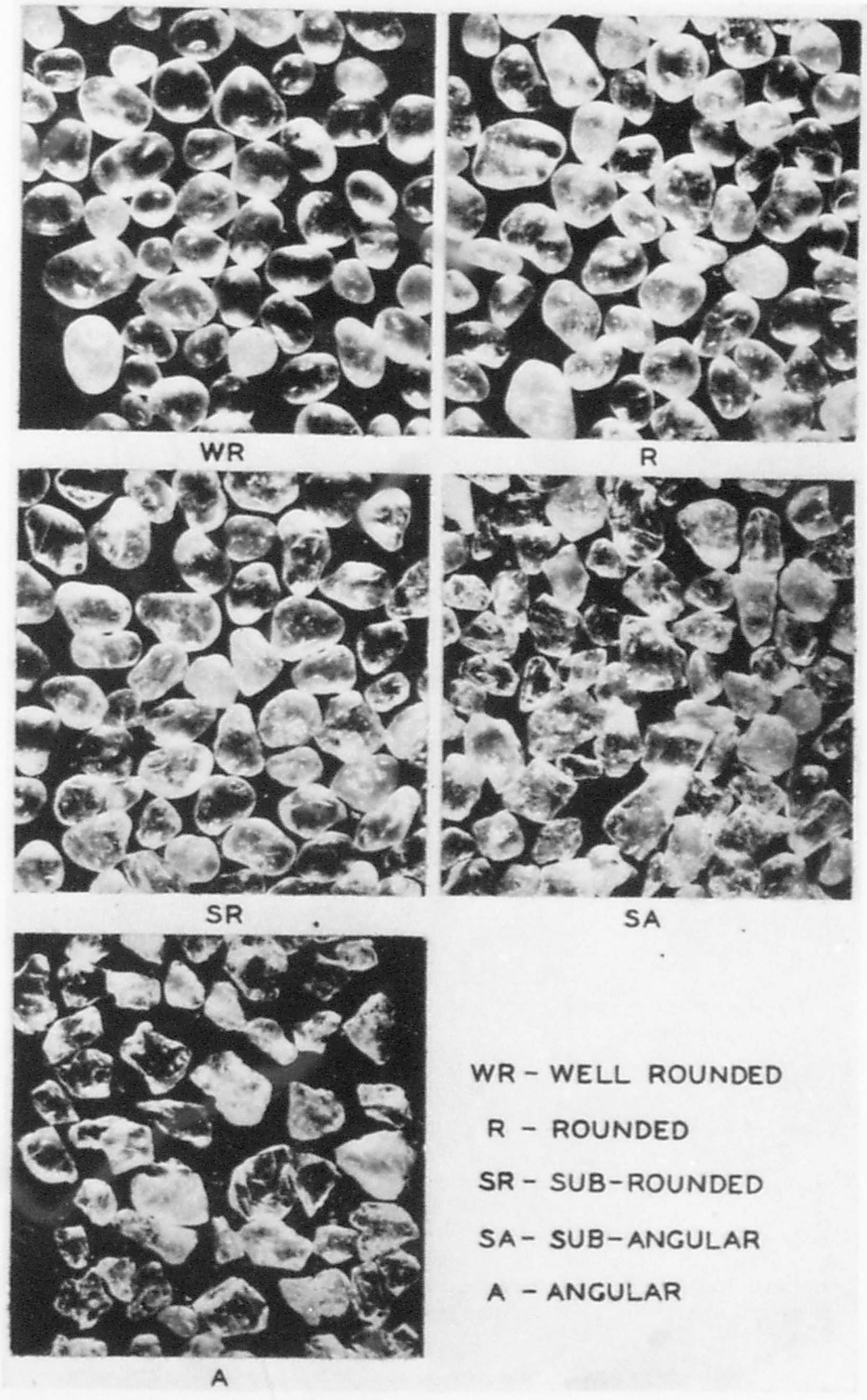


PLATE 4
MICROPHOTOGRAPHS OF SAND GRAIN SHAPES
Magnified 13.1 diameters

Set-up for Experiments, and Measuring Devices

All the bed-load tests were conducted in a tilting flume, which is located on the main floor of the laboratory building. The water was supplied from a circulating system, composed of an underground storage sump*, two centrifugal pumps for elevating the water to a constant-head tank on the second floor of the building, piping connections to the entrance of the weir box, weir box with measuring weir, stilling chamber, the flume itself, and the return channel.

The Tilting Flume:

The flume itself, illustrated pictorially in the frontispiece, and diagrammatically in Plate 5, is a wooden structure, lined with concrete trowelled to a smooth surface, and supported by two 12-inch I-beams. Rectangular in cross-section, its approximate inside dimensions are: length, 48 feet; width, 2.3 feet; depth, 1.3 feet. The I-beams are supported at the upper end on horizontal pins, and at the mid-point and lower end on jack screws, through the proper manipulation of which it is possible to set the flume to any desired slope, up to a maximum of 0.015. At the top of the flume, as shown in Plate 6, are two adjustable wooden straight edges, one on each side, which can be set to any slope desired. In actual operation, these rails have the same slope as the water surface and the bottom of the flume, and are used as a base for the various sliding measuring devices.

The Weir Box and Weir Plate:

The water was admitted through an 8-inch pipe, controlled by a valve, from the constant-head tank into the weir box; the latter is a wooden structure 10 feet long, 4 feet wide, and 3½ feet deep (see frontispiece). This box is equipped with baffles which effectively stilled the flow before the water discharged over the weir plate, and with a stilling well and hook gage, which were used to measure the head over the weir. The weir itself, of the 90° V-notch type, is made of a ⅜-inch steel plate, with a 60° bevel on the downstream face and a 1/16-inch flat edge; it was carefully calibrated for all heads by means of a volumetric measuring tank. The rating curve for the plate was found to check very closely the curve of King's equation $Q = 2.52\ H^{2.47}$; all discharge quantities, however, were taken from the experimental rating curve.

The Stilling Chamber:

From the weir box, the water was discharged into a stilling chamber (also shown in frontispiece), 4 feet wide, 6 feet long, and about 1½ feet deeper than the flume. This chamber contains a system of baffles of various types, which served to quiet the water and allowed it to enter the flume in a smooth flow, free from waves and surges.

The Approach Flume:

The approach flume is simply a wooden trough which connects the stilling chamber with the upper end of the flume proper. It is supported on stationary foundations, and cannot be tilted with the flume.

* The first three series of tests, with Sands Nos. 2, 6, and 7, were conducted with water from the lake which supplies the outdoor models at the Station. This water was wasted into the creek bed after leaving the flume.

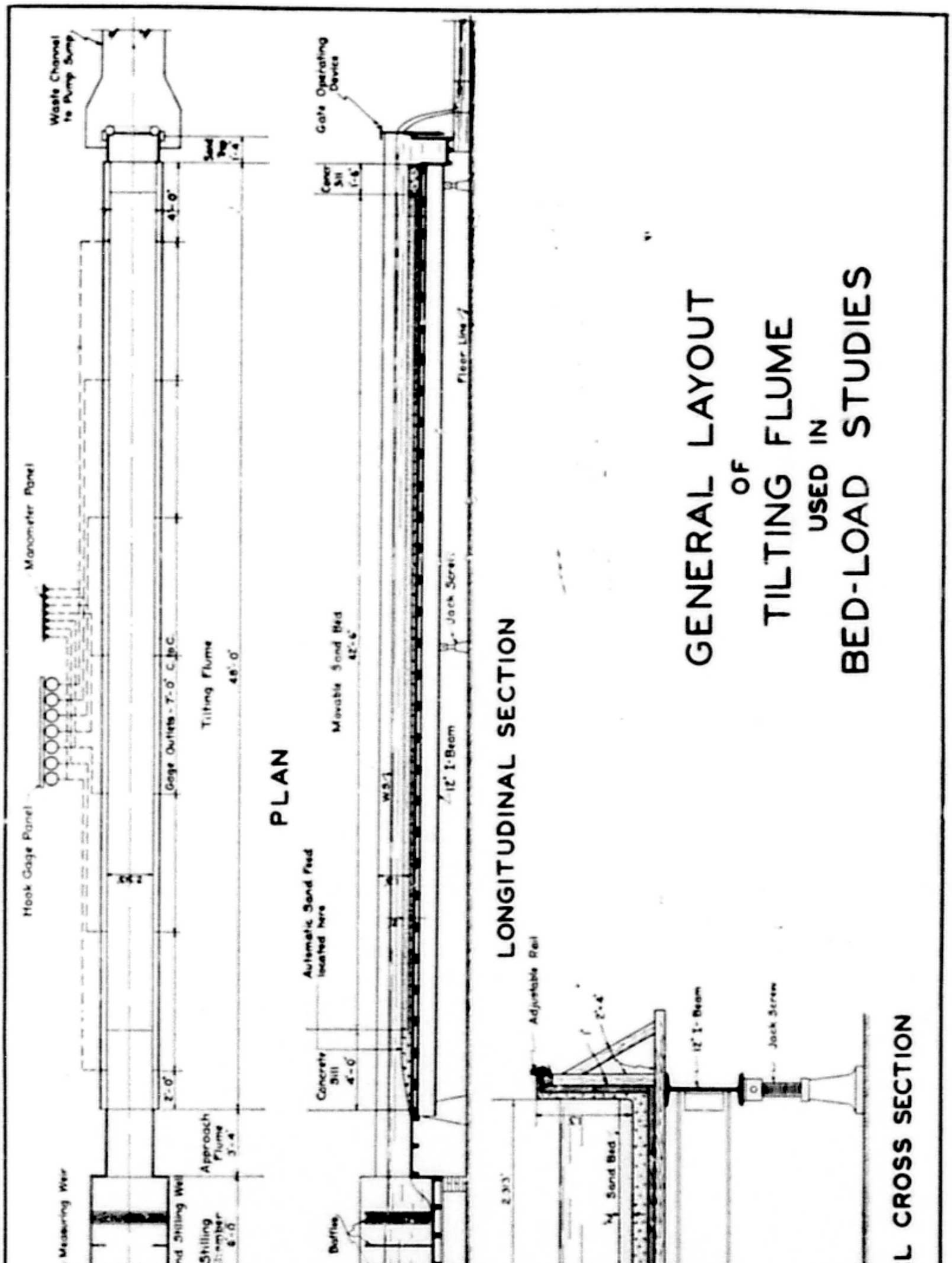

GENERAL LAYOUT OF TILTING FLUME USED IN BED-LOAD STUDIES
PLAN
LONGITUDINAL SECTION
TYPICAL CROSS SECTION
Waste Channel to Pump Sump
Manometer Panel
Hook Gage Panel
Gage Outlets - 7'-0" C. to C.
Tilting Flume
48'-0"
Approach Flume
Stilling Chamber
Weir Box
10'-0"
Measuring Weir
Gage and Stilling Well
From Constant-Head Tank
8" Pipe Line
Regulating Valve
Gate Operating Device
Automatic Sand Feed located here
Movable Sand Bed
Floor Line
Jack Screw
12" I-Beam
Concrete Sill
4'-0"
Baffles
Adjustable Rail
Sand Bed
2'-4"

PLATE 5

The Sandtrap:

The measurement of the rate of movement of the sand under test was made possible by the sandtrap at the downstream end of the flume. This trap, shown in Plate 6, consists of a suddenly enlarged section about 1½ feet deeper than the flume itself. The sudden decrease in the velocity of the flowing water caused the sand in transportation to drop into this trap. To facilitate the removal and measurement of the sand, a wooden box lined with sheet metal was designed to fit closely into the trap. This box, equipped with handles, has rubber gaskets on all sides to insure that all the sand is caught.

This trap was found to be too small to catch the fine materials in sand No. 8. Hence, a supplementary trap with a much more enlarged section was installed for temporary use while this sand was being tested. In addition, water samples were taken from the overflow below the second trap, and the rate of suspended load movement was calculated from their turbidity measurements.

The Tailgate:

The elevation of the water surface at the lower end of the flume was controlled by the manipulation of a vertical, sliding tailgate. This gate, illustrated in the frontispiece, consists of a vertical, ⅜-inch steel plate, which can be raised or lowered by two bolts which are turned by a sprocket-and-chain arrangement. Leakage around the plate was prevented by rubber seals.

Pumps, Constant-head Tank, Return Channel:

After being discharged over the tailgate, the water passed into a return channel under the floor of the laboratory building. This channel carried it to an underground, concrete-lined sump, from which it was lifted by means of centrifugal pumps to the constant-head tank. The latter served to provide a non-changing head on the measuring weir, and made it possible to secure uniform flow. The maximum capacity of the system, controlled by the pipe connecting the overhead tank with the weir box, is approximately 2¼ c. f. s.

Gages:

The elevation of the water surface, as well as the profile of the bed, was determined by means of a needle-gage (illustrated in Plate 6), which was so mounted as to slide along the rails on the side of the flume. Since the rails themselves were made parallel to the bottom of the molded bed and to the water surface, the datum plane of the gage was also parallel to the bed; consequently, readings of the gage could immediately be converted to depths regardless of the location of the gage along the flume.

Flow Indicator:

The existence of laminar or turbulent flow in the flume was determined by means of the injection of a stream of potassium permanganate solution into the water, and observation of the course taken by the colored stream. The solution was inserted into the water from an injector which worked as a syphon; this apparatus consisted of a glass tube drawn to a fine point at one end, a 3-foot length of rubber tubing, and a bottle containing the solution. The photograph at the left in Plate 7 shows this apparatus in use, and that at the right shows the typical straight, parallel stream lines existing in laminar flow. (These colored lines have their origin in small

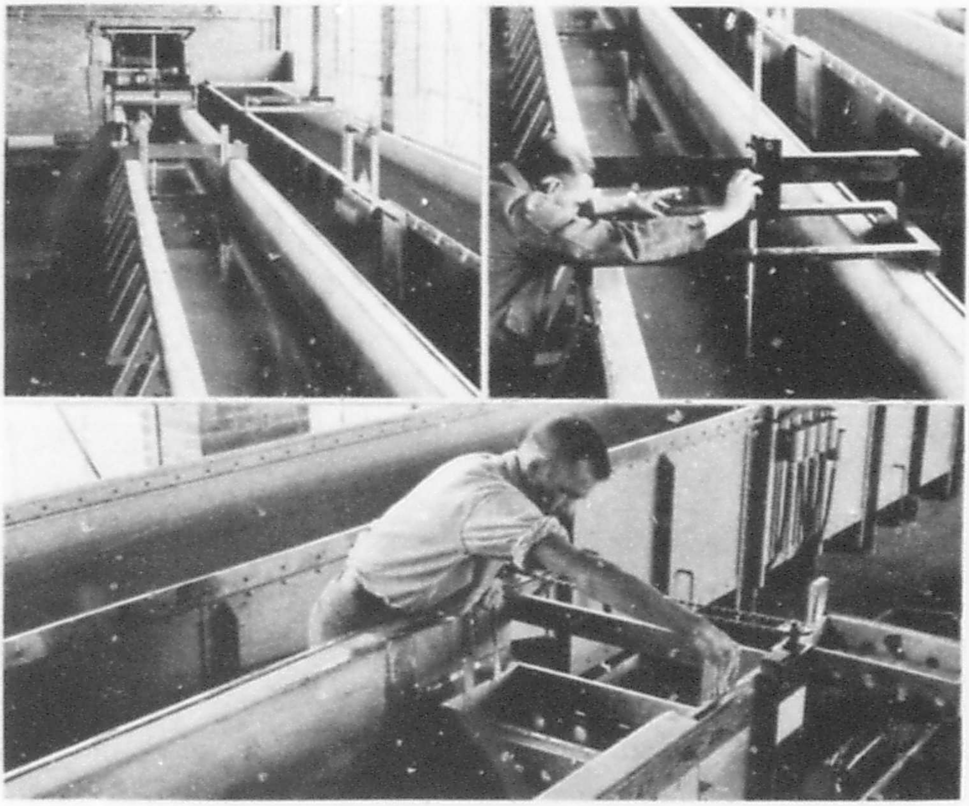


PLATE 6

USE OF TILTING FLUME APPURTENANCES

Top, left: Molding the sand bed with the sliding template
Top, right: Measuring an elevation with the sliding needle gage
Bottom: Removing the sand box from the sandtrap

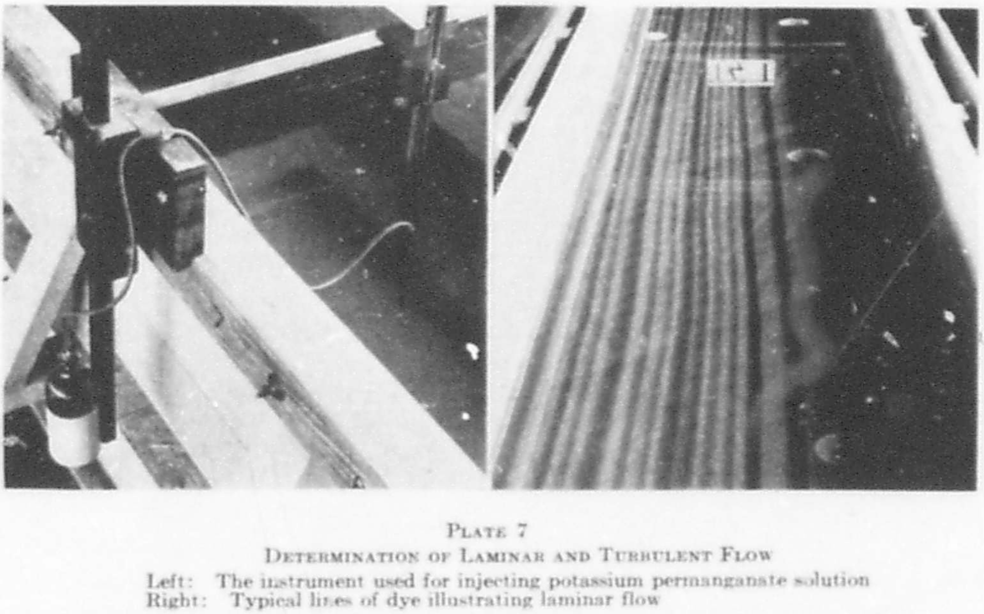


PLATE 7

DETERMINATION OF LAMINAR AND TURBULENT FLOW

Left: The instrument used for injecting potassium permanganate solution
Right: Typical lines of dye illustrating laminar flow

crystals of potassium permanganate which were placed on the bed of the flume; the injector was not used for this photograph.)

The rate of discharge of the solution was controlled by changes in the elevation of the bottle containing the liquid. It was necessary to regulate the flow so as to obtain the same velocity as that of the flowing water. With this set-up, thread-like lines of dye as long as 10 feet were frequently obtained.

Automatic Sandfeed:

One of the necessary conditions in an experiment involving the movement of bed-load is that there be no progressive change in the elevation or slope of the bed during the course of a test. In order to insure that this condition exists, it is necessary to secure a balance

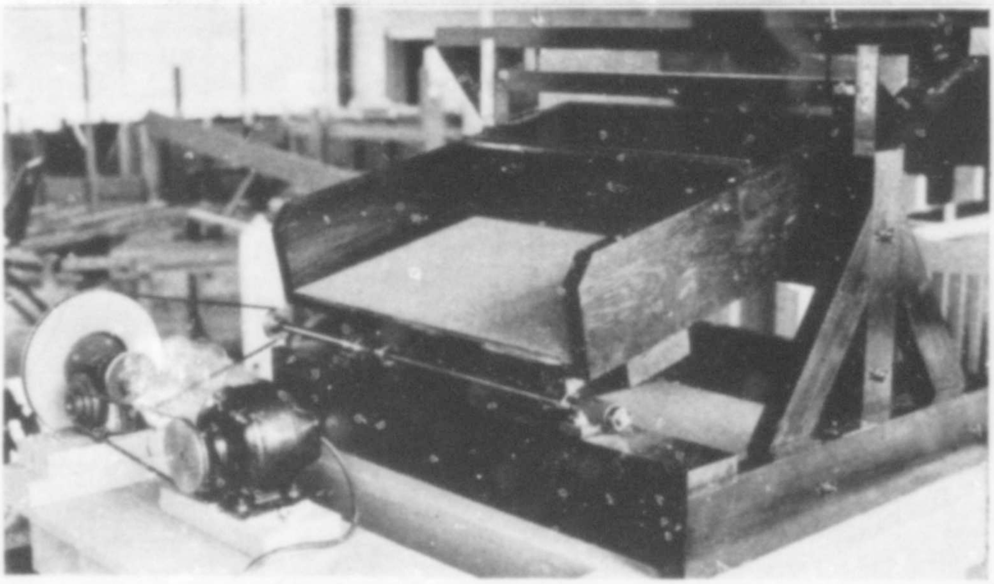


PLATE 8
THE AUTOMATIC SANDFEED

between the amount of sand which is in movement, and which is consequently being carried out at the lower end of the flume, and the amount which is being added at the upper end. Any attempt to attain this balance by the occasional manual addition of material is likely to result in a disturbed condition at the head of the flume which will create a progressive riffle formation and may render the test valueless. Consequently, it is desirable to install some kind of automatic sandfeed which can be adjusted to discharge sand into the flume at approximately the same rate at which it is being extruded at the lower end.

It was first attempted to devise a machine following the principles suggested by Gilbert*, and later used with success by MacDougall**. It was found after some experimentation with various designs, however, that the machine illustrated in Plate 8 gave acceptable results, and was much simpler in its operation and adjustment than the rotating-drum arrangement of Gilbert's. This device consisted fundamentally of a square box, 6 inches deep, divided into two

* Gilbert, "The Transportation of Debris by Running Water", U. S. G. S. Professional Paper 86, 1914.

** MacDougall, "An Experimental Investigation of Bed Sediment Transportation".

compartments which were separated by a vertical sliding partition. The box was pivoted about the center of the smaller compartment, which was used for the storage of sand, and was shaken at the open end by means of a pair of cams operating against a pair of rollers at approximately 165 r. p. m. The cams had an eccentricity of ¼ inch; a bumper was constructed on a solid block under the open end of the box, and caused a sharp blow to be delivered to the box. In operation, the box was set at a predetermined angle, dry sand was placed in the small compartment, and the sliding partition was set to an opening corresponding to the largest grain size existing in the sand under test; the rapid shaking of the box caused the sand to move in an evenly distributed layer down the slope and to drop through the slot in the base into the flume below. A piece of smooth plate glass on the bottom of the box insured a plane surface at all times.

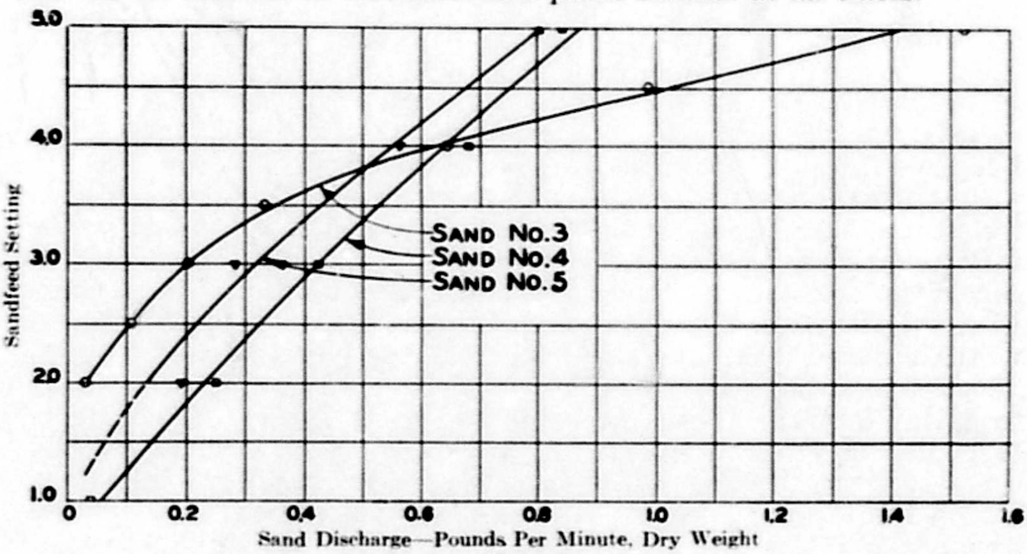


PLATE 9

SANDFEED RATING CURVES

The rate of feeding was varied by an adjustment of the slope of the bottom of the box. As can be seen in Plate 8, the shaft on which the box was pivoted had a vertical range of movement of about 6 inches. A scale was installed on the vertical adjustment to facilitate the duplication of setting. In order to keep the rollers directly over the cams on which they ran, a horizontal movement of the entire box was provided.

The sandfeed was calibrated for each sand mixture for which it was used (see page 22) before the mixture was tested, and a curve was drawn showing the variation of the rate of feed with the vertical scale setting. Three of these curves are shown in Plate 9. During the course of the test, the machine was set after each run to the position corresponding to the rate of movement found for that run. Hence there was a lag of one run in the adjustment of the quantities. Since the water discharge through the flume was increased in very small increments, however, and since the upper 22 feet of the flume were used as an entrance channel, with observations confined to the lower portion, this lag was considered to be of no importance. Furthermore, bed profiles were taken periodically, to insure that no progressive alterations were occurring in the slope of the bed.

*Bentzel Velocity Tube**:

One of the most valuable incidental results of this bed-load investigation was the development of a suitable instrument for measuring low velocities of flowing water. This instrument has been constructed to measure a range in velocities from about 0.10 feet per second to as much as 4 or 5 feet per second. It has been found to be ideally suited for velocity measurements at the Station, where it has entirely superseded the use of the Pitot tube and other current-measuring devices. The principle on which the meter works is as follows (see Plate 10):

The water flowing into the upstream leg of the tube causes a velocity head to be created; the velocity head on the downstream leg, on the other hand, is negative. This difference in head causes the circulation through the tube of a small quantity of water, the amount depending upon the velocity of the water flowing through the flume. In the downstream leg of the tube, which has an even taper inside, is a small float, made of a piece of capillary glass tubing, closed at both ends, and so constructed that it has a very slight buoyancy.

When there is no flow through the tube, this float rises until it rests against a wire stop in the top of the tapered tube. When water is flowing through the tube, however, the impact of the flowing water causes the float to be pushed down the tapered tube. At some point within the length of the tapered section, the unit impact force of the water, reduced by the enlarged section, exactly balances the buoyancy force of the float, which then comes to rest. It has been found that this instrument can be calibrated very closely by towing it through still water, and that for every velocity of flow, within the range of the instrument, there is a corresponding position of the float within the tapered section, which will not vary in successive trials by more than 1 or 2 per cent. By the use of floats of various specific gravities, and tapered tubes of varying inside dimensions, almost any velocity can be measured with the tube. Necessarily the effect of temperature on the viscosity and the density of the water must be considered, although a variation in temperature of only a few degrees has only a small effect. In Plate 11 are shown the calibrations for two of the floats used in the conduct of the bed-load tests.

Definitions and Symbols

Classification of Materials in Transportation:

There exists no universally accepted set of nomenclature for the materials involved in the transportation of debris by floating water. The following definitions have been adopted for use at the U. S. Waterways Experiment Station, and will be followed throughout this paper:

Stream load: All material, either mineral or organic, which is being transported by the stream, whether in solution or by hydraulic traction, hydraulic suspension, colloidal suspension, or flotation.

* Invented by Carl E. Bentzel, Research Assistant, U. S. Waterways Experiment Station. Patent pending.

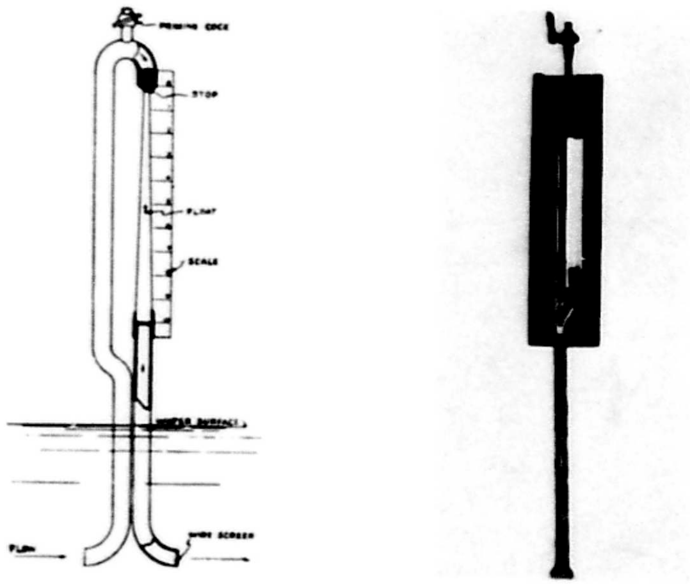


PLATE 10
THE BENTZEL VELOCITY TUBE

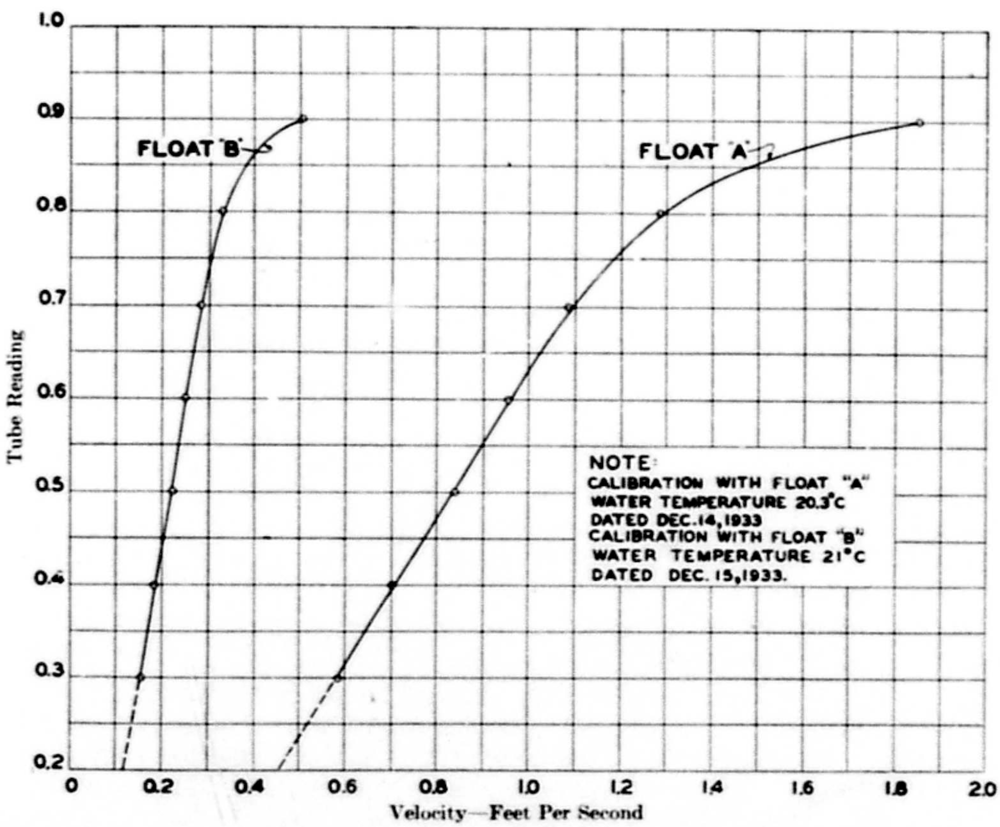


PLATE 11
RATING CURVES, BENTZEL VELOCITY TUBE

Floating load: That portion of the stream load which is being transported by flotation (e. g., trees and drift).

Quasi-sedimentary load: That portion of the stream load which is being transported by colloidal suspension or in solution.

Sedimentary load: That portion of the stream load which is being transported by hydraulic traction or hydraulic suspension (e. g., clay not in colloidal suspension, silt, sand, gravel, boulders, organic material).

Suspended load: That portion of the sedimentary load which is not in contact with the bed of the stream.

Bed-load: That portion of the sedimentary load which is in contact with the bed of the stream.

Saltation: Movement by "jumping"; particles in saltation or particles moving intermittently as suspended load and as bed-load. (No sharp dividing line is intended for this type of movement).

Stream bed: The non-moving (not necessarily non-movable) material underlying the stream.

Sediment: Fragmental material deposited by water. In general, both that which has been deposited and that which is still being transported. Specifically, that which has been deposited.

Consolidated material: Material which cannot be transported without first being disintegrated (e. g., masonry linings, beds of rock).

Bed-load Movement:

The definitions suggested by Kramer were tentatively adopted for use at the Experiment Station, and throughout the experiments each stage of movement was classified according to his definitions. The difficulties encountered by Kramer and other investigators in attempting an accurate classification of movement by visual observation, however, were found to be so pronounced in the early tests that additional definitions were essential. The use of actual measured quantities of material moved was found practicable, since the tilting flume was equipped with a sandtrap which efficiently caught all the material extruded at the lower end of the flume. All the rates of movement, therefore, have been computed in terms of pounds per foot width of flume per hour, dry weight, and this unit is used throughout all the tests.

For purposes of reference, Kramer's definitions of rates of bed-load movement are quoted below:

"1. 'None' refers to that condition in which absolutely no geschiebe* particles are in motion.

"2. 'Weak' movement indicates that a few or several of the smallest sand particles are in motion, in isolated spots, and in countable numbers. By countable is meant that by confining the field of observation to, say 1 cm^2, the particles in motion can be counted by the observer.

* The word "geschiebe" is the concise German word corresponding to "bed-load"; literally, "that which is being shoved".

"3. 'Medium' movement is used for that condition in which grains of medium size are in motion in numbers too large to be countable. Such movement is no longer local in character. It is not yet strong enough to affect bed configuration and does not result in transportation of an appreciable amount of geschiebe.

"4. 'General' means that condition in which sand grains up to and including the largest are in motion. Since in these experiments, as in general laboratory practice, sand grains above a certain size have been sifted out, this designation has a definite significance. This movement is also not local but general. It is sufficiently vigorous to change the bed configuration, although at lower stages this action takes place only slowly. There is an appreciable amount of material transported with this condition of movement. This condition is termed in this paper the lower limit of usefulness of the sand.

"No higher stages of movement are designated, although increasing intensity might be based upon the quantity of geschiebe movement. Intermediate stages are denoted by (+) plus or (—) minus signs."

Critical Tractive Force:

Critical tractive force is that tractive force which brings about general movement of the bed-load mixture.

Riffles:

Local riffles are those riffles which appear first in isolated sections.

General riffles are approximately uniform in height and length, and are distributed throughout the entire area of the flume.

No attempt will be made to designate riffle stages by size. Kramer bases his riffle classification on the height of riffle as compared with the depth of water which forms it, and classifies as excessive any riffle which is more than 8 per cent of the depth of the water. It has been found at the Experiment Station, however, that all sands of mean grain diameter about 0.5 mm or less have a strong tendency to riffle greatly in excess of this 8-per cent limit. In fact, for some of the finer sands, very little downstream movement of the particles was obtained until the formation of riffles was as high as 20 to 25 per cent of the water depth.

It should be noted, however, that frequent profiles of the bed were taken throughout these experiments, and are shown in Plates 39 to 44. From these plates the size of riffles at any time can be found.

Symbols and Units:

With the exception of the size of sand grain, which is expressed in millimeters, the English system of units was used throughout these experiments. The use of millimeters for the grain size resulted from the fact that the openings in the sieves used in the analyses of the sands are commonly expressed in these units at the Laboratory. Equivalent sizes, in inches, are given throughout this report, however.

The selection of a suitable system of notation for a study of this type was extremely difficult. Each experimenter who has worked on the subject of bed-load movement has developed his own set of nomenclature, and difficulties naturally arise when an effort is made to correlate the results from several investigators, because of a lack of uniformity in their systems. The system of nomenclature in Table 2 has been used in these experiments. Occasional deviations will be necessary, when reference is made to previous investigations and will be noted.

TABLE 2

NOMENCLATURE AND UNITS

Symbol	General Meaning	Units
Q	Discharge	c. f. s.
q	Unit discharge	c. f. s. per ft. width
D	Depth	Ft.
A	Cross-sectional area	Sq. ft.
V	Velocity	Ft. per sec.
V_m	Mean velocity	"
V_s	Surface velocity	"
S	Slope	Non-dimensional
R	Hydraulic radius	Ft.
T	Tractive force	Lb. per sq. ft.
T_c	Critical tractive force	Lb. per sq. ft.
D_k	Depth at general movement, visual criterion	Ft.
D_c	Depth at general movement, "model" criterion	Ft.
D_o	Depth corresponding to tractive force at zero movement as taken from rate-of-movement curves	Ft.
t	Time	Sec.
R	Reynolds' number for open channels	Non-dimensional
ν	Coefficient of kinematic viscosity	Sq. ft. per sec.
C	Coefficient in Chezy formula	$Ft.^{1/2}/sec.$
n	Roughness coefficient in Manning formula	$Ft.^{1/6}$
λ	Roughness coefficient	Non-dimensional
g	Acceleration of gravity	Ft. per sec. per sec.
W	Rate of bed-load movement	Lb. per ft. width per hr.
ρ_1	Absolute unit weight of sand	Lb. per cu. ft.
ρ	Unit weight of water	"
d	Grain size	mm. or in.
d_g	Mean grain size	"
Z	Grain volume	cu. mm. or cu. in.
M	Uniformity modulus, grain distribution	Non-dimensional
k, k_1—	Constants	
o (subscript)	Critical or initial value	

Procedure of Experimentation

Before placement in the flume, each of the materials (with the exception of Sand No. 1, which was used in its natural state) was thoroughly washed, to remove all traces of silt, clay, and other extraneous material, and screened through a 4-mesh sieve, to remove the particles larger than 4.699 mm in size. In the case of the tests on the small gravel, the particles ranged in size from 0.208 mm to 6.680 mm, with about 98 per cent larger than 1.168 mm.

Setting the Slope of the Flume:

The flume was adjusted to the desired slope by regulation of the jack screws on which it is supported. After the main structure itself had been set to the proper slope, the adjustable rails on the sides of the flume were set very accurately to this same slope. In this operation, shots were taken with a level at 2-foot intervals along the rails, to insure that no humps or hollows existed; an accuracy of about 0.002 foot was obtained.

Molding the Bed:

The sand or gravel surface was molded to the exact slope by means of a vertical template so constructed as to slide along the adjustable rails. The material was first thoroughly mixed, to insure a uniform distribution of the particles, then was placed in the flume to a depth of about 2 inches. At the upper and lower end of the flume cement sills had previously been constructed to this same depth, the upper one arranged to provide a smooth transition section from the approach flume. These sills are shown in the longitudinal section of the flume, Plate 5.

The bottom edge of the sliding template was adjusted to the elevation of the cement sills, and then was worked back and forth over the material (all molding was done under water) until a smooth surface of uniform slope was obtained. Care was taken that no ridges or furrows, or isolated large particles, remained on the surface, since they would start the formation of riffles at an unnaturally early stage in the test. A series of photographs showing such unnatural development is presented in Plate 12. The process of molding is illustrated pictorially in Plate 6.

Other Preliminary Steps:

At this stage in the procedure, small samples of material were taken from three locations in the flume, and submitted to the soil mechanics laboratory for mechanical and microscopic analysis*, and for a specific gravity test. The average of these analyses was used as the original on which all tractive force and rate-of-movement calculations were based.

After the holes from which these samples had been taken were filled in and the surface again made smooth, a longitudinal profile of the bed was taken, to provide a check on the molding of the bed and to measure the bottom elevation. These original profiles are shown in Plates 39 to 44, along with the profiles taken later after the formation of riffles. It should be noted that in these plates the original slope of the bed is plotted as a straight, horizontal line.

* The methods of analyzing the materials are described in detail in Part II, page 122.

The Test Proper:

To start the test, the flume was flooded slowly from the lower end, after which the inlet valve above the weir box was opened slightly, and a small quantity of water began to flow through the stilling chamber and into the flume. The tailgate was then manipulated until it was found that uniform flow prevailed throughout the length of the flume. This condition was attained when the needle gage readings on the water surface were the same at all points. After equilibrium of flow conditions had been reached and held for several minutes, a complete set of observations was made and recorded. A discussion of these observations will follow, under the heading "Observations".

At the conclusion of the first run, after all necessary data had been recorded, the discharge was increased slightly by an adjustment of the inlet valve, the tailgate was again manipulated until uniform flow was obtained, as evidenced by like readings of the sliding needle gage at all points, and another complete set of data was recorded. This procedure was repeated, the discharge being increased in successive small increments, until the maximum capacity of the supply pipe was reached. After the conclusion of the test, the flume was set to another slope, the bed was remolded to that same slope, and another independent test was made in a similar manner.

The first run in each test, and several subsequent runs, were with laminar flow in the flume. During this period in which laminar flow was obtained, the discharge in the flume was increased in very small increments, in order to provide complete data on the transition stage between laminar and turbulent flow. The type of flow, whether laminar or turbulent, was determined by observation of the course taken by the solution of potassium permanganate which was injected into the water with the instrument described on page 10. After the flow had passed well into the turbulent range, no further observations were made with the permanganate solution. Typical stream lines indicating laminar flow are shown in Plate 7.

During the first several runs of each test, the sand bed remained smooth, practically as it had been molded at the commencement of the test. After the first ten or so runs, however, the number depending upon the type of sand, slope of bed, etc., small riffles invariably began to appear at isolated points in the flume, and gradually spread over the entire sand bed. It was preferred to have these riffles start at the upper end of the flume and work themselves downstream. The riffles frequently appeared simultaneously at several points, however, and developed in all directions. The general practice was not to interfere with or attempt to control their development, but to let the riffles develop themselves. It was impossible to secure uniform conditions of flow while these riffles were developing, for the reason that the gradually increasing roughness of the bed caused the same discharge to be carried at gradually increasing depths. Hence, no attempts were made to record simultaneous readings of depth, velocity, etc., until this riffling period had been finished. In most of the tests this development required from two to four hours, during which the discharge was kept constant and the tailgate was manipulated as often as was necessary to maintain the slope of the water surface parallel to the original slope.

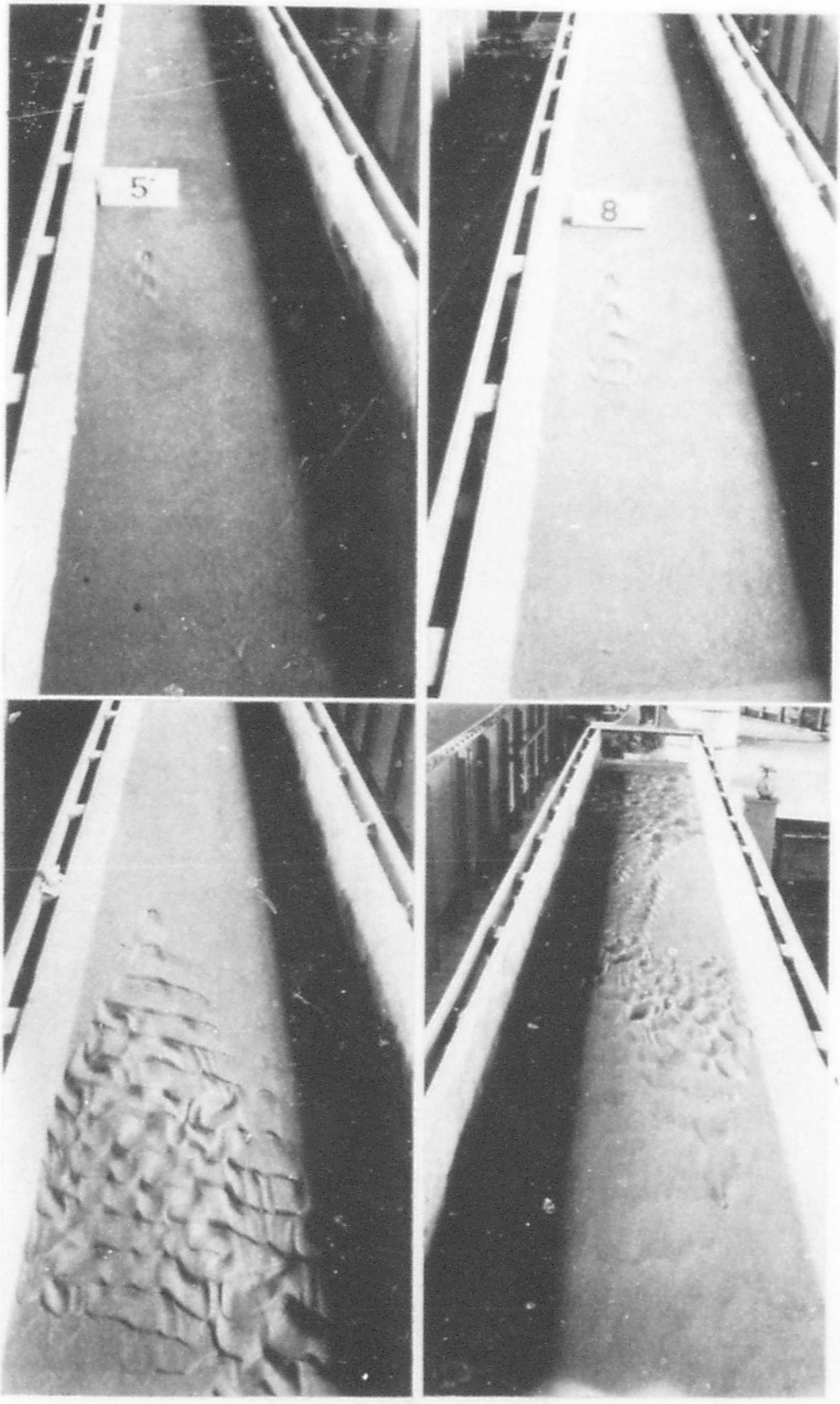


Plate 12
Progressive Development of Riffles, Caused By Obstruction on Bed

After the riffles had spread uniformly over the flume, and had reached a height where they maintained an equilibrium of flow conditions, as evidenced by a constant depth of flow at the original slope, another complete set of observations was taken and recorded, after which the flow was again increased slightly. More time was required to reach an equilibrium for each run after the formation of the riffles, because of the constant change in their size and the resulting slowness of the depth in reaching a constant value. In general, no data were recorded for a run until an absolute equilibrium had been reached.

A check was maintained on the riffle development by the frequent taking of longitudinal profiles of the bed formation. In general, a profile was always taken after the first run following the riffle-developing period, after every third or fourth run thereafter, and again after the last run of the test. These profiles were plotted over the original profile, to provide a check on whether there was any progressive change in the slope of the sand bed. Plates 39 to 44 contain all of these plotted profiles for all the tests except those of Sand No. 6, during which no observations of this nature were made. It should be noted that the data from several runs were rejected because of the fact that the sand bed showed a progressive change of slope, usually a flattening, induced by a scour at the upper end of the flume and a fill at the lower end.

Shortly before the commencement of riffle formation, isolated sand grains were noticed to be moving, and as the depth of water was increased, this movement increased in intensity. When this movement became appreciable, the sandtrap box, described on page 10, was lowered into the sandtrap, and the sand discharge was determined during a measured time interval. The length of time of collection of the sand varied from about 10 minutes to 1 hour, depending upon the intensity of movement. In general, the longer time intervals were devoted to the lesser movements.

At the end of the run, the sand box was lifted from the trap (see photograph, Plate 6), the water drained off, and the wet sand weighed. A representative sample of the wet material was then placed in an air-tight bottle, and sent to the soil mechanics laboratory for a complete mechanical analysis*. Before the analysis was begun, the weight of the wet sample was obtained, after which the sand was thoroughly dried, then weighed again. The ratio between the dry weight and the wet weight was used in computing the total dry weight of the material caught in the trap.

Sands Nos. 1, 2, 6, and 7 were tested before the construction of the sandfeed machine. Hence it was impossible in these tests to feed sand at a uniform rate at the upper end of the flume; sand was added manually, however, whenever a scour was started at the upper end. In the tests on the other sands the sandfeed was in operation, and it was endeavored to maintain the rate of feeding the same as the rate at which the sand was being caught in the trap. At the higher flows the rate of sand movement was sometimes greater than the maximum capacity of the sand feed; the practice was then to keep a

* No mechanical analyses were made of the trapped material in the tests on Sand No. 6, the first that was tested. In the case of Sands Nos. 1, 2, and 7, samples were analyzed only after every third or fourth run. With Sands Nos. 3, 4, 5, 8, and 9, however (the last to be tested), a sample was analyzed after each run during which there was appreciable movement. The method of analysis was the same as that described in Part II, page 122

constant check on the bed development by means of the profiles, and to end the test whenever it was seen that any appreciable change had taken place.

Observations

Head on Weir:

The head on the weir was derived from a hook-gage reading on the water surface in a manometer cup, which was attached to an opening in the weir box by rubber tubing. The corresponding discharge for this head was determined from the weir rating curve.

Water-Surface Elevation:

The elevation of the water surface was read with the sliding point gage previously described. Before the reading was taken, the tailgate was manipulated to a position where the slope of the water surface was the same as that of the bed; hence, the gage reading of the water-surface elevation was the same at all points in the flume. From the water-surface elevation, the mean elevation of the bed was subtracted to determine the depth of flow.

Temperature of Water:

In the last five series of tests, the temperature of the water was read for each run, from a Centigrade thermometer suspended in the water just above the approach flume. The temperatures in the other tests, those on Sands Nos. 1, 2, 6, and 7, were estimated later from a study of air temperature records of the U. S. Weather Bureau at Vicksburg, and a few temperature records of the reservoir at the Experiment Station. Inasmuch as these sands were tested during the summer of 1933, when the air temperature remained fairly consistently between 80° and 95° F, no serious errors entered the results from the assumption that the air and water temperatures were the same.

Velocities:

The water-surface velocity was obtained from the measurement of the time necessary for a small float to travel a distance of 20 feet in the flume. In every case, this velocity was taken as the average of about five trials. It must be noted that surface velocities were not observed in the tests on Sands Nos. 1, 2, 6 and 7.

Mean velocities were computed from the discharge and cross-sectional area.

In the test on Sands Nos. 3, 4, 5, 8, and 9, a complete set of velocity observations was made with the Bentzel tube. Most of these observations were made with the tube directly over the downstream cement sill, an inch or two below the end of the sand section. The use of the tube over the sand itself was found to be impracticable because of the scour which immediately resulted when the tube approached the sand bottom. Velocity measurements were made at the bottom, and at one to three other depths, depending upon the total depth of flow.

Character of Flow—Laminar or Turbulent:

The type of flow, whether laminar, turbulent, or in the transition stage between these general classifications was determined from the course taken by lines of potassium permanganate dye injected into the water.

Sand Movement:

In addition to an attempt to classify the intensity of sand movement according to the visual method, samples of the sand in movement were actually trapped at the lower end of the flume, and the quantity caught during a measured time interval was weighed. In the tests on Sand No. 8, several samples of water were taken from the overflow below the sandtraps, and their parts-per-million content determined. These data were used in a computation of the rate of suspended load movement.

Riffles:

Riffles were classified as local or general, with occasional references to "large" riffles or "sand waves", whose exact meanings would be extremely difficult to define. The principal source of data on the subject of riffles is the series of plates, Nos. 39 to 44, which show the profiles of the bed at frequent intervals in each test.

Profiles:

As previously explained, longitudinal profiles of the bed were taken after the first run following the development of the riffles, and at frequent intervals thereafter. The procedure was to measure with the sliding point gage the elevation of the crest and trough of each riffle along the center line of the flume, and to record each measurement with the corresponding longitudinal location.

Presentation of Data from Experiments

A complete tabulation of the observed data in all these experiments, along with certain corresponding calculated data, such as roughness coefficients, values of Reynolds' number, rates of sand movement, etc., is presented in Tables 8 to 37, pages 57 to 86. In addition, on Plates 24 to 38 will be found a complete graphical presentation of some of these same data, with such information as velocity, rate of sand movement, roughness value, grain size, etc., plotted simultaneously against the depth. A discussion of the interrelationship of these various factors will be found below under "Results". It is believed that the care with which these data were obtained justifies their presentation in full, and that they can be used with confidence by hydraulicians in calculations involving either open-channel flow or sand movement.

Explanation of Tables:

Several of the colums in the tables need some explanation, although most of the headings are self-explanatory. The water temperature, in Column (6), was actually observed in the tests on Sands Nos. 3, 4, 5, 8, and 9, and for the tests on Sands Nos. 1, 2, 6, and 7, was estimated from weather bureau records. The mean velocity, in

Column (7), was computed from the discharge and the area of cross-section; the surface velocity, in Column (8), was computed from the measured time interval required for a small float to traverse a 20-foot course; and the bottom velocity, in Column (9), was read from the rating curve for the velocity tube, the argument being the scale reading of the tube when in its lowest position. The velocity measured at this lowest point was actually that at a distance of 0.02 foot above the bottom, this distance being half the diameter of the glass tubing of which the instrument was constructed.

The value of Manning's n, in Column (10), was computed from the formula $V = \frac{1.486}{n} R^{2/3}S^{1/2}$, V and R being taken from Columns (7) and (5), and S being the slope used throughout the test. Reynolds' number for open channels, in Column (12), is equal to $\frac{VR}{\nu}$, where ν is the coefficient of kinematic viscosity. The value of ν was taken from a viscosity curve, the water temperature being used as argument. It must be noted again that these values for Reynolds' number are accurate for the tests on Sands Nos. 3, 4, 5, 8, and 9, in which the water temperature was measured, but that the values for the other tests are accurate only so far as the estimate of water temperature was correct.

The wave velocity, in Column (13), corresponding to the velocity at which flow changes from streaming to shooting, was computed from the acceleration of gravity and the depth. In the tabulations for Sand No. 8, the rates of suspended load movement, as determined from the turbidity analyses, are listed, in addition to the usual bed-load rates. The mean size of the trapped sand, and the uniformity modulus, in Columns (16) and (17), were computed in the manner described on page 5. The tractive force, in Column (18), is the product of the depth, slope, and unit weight of water. The nature of flow, in Column (19), was based on observation of the behavior of the dye injected into the water, and the nature of sand movement, in Column (20), is the visual description of the movement, in conformity with Kramer's rate classification.

It will be noted that in Tables 8 to 10, presenting the results of the flow experiments conducted on the cement bottom, all of the columns concerning the movement of sand have been omitted, but that the column numbers have been made consistent with those in the other tables.

Explanation of Curves Showing Basic Data:

The complete history of developments of the tests is presented in the curves on Plates 24 to 38. On these plates are shown the calculated values of mean velocity, the roughness coefficient n from Manning's formula, the mean size of the grains in motion, and the rate of movement of the sand particles, all plotted against simultaneous values of the depth. (In Plates 35 and 36, the rate of suspended load movement is also shown.) At the top of each plate is the visual history of the test, showing the development of the riffles, and the points at which the flow changed from laminar to turbulent, through the transition stage in which the flow was partly laminar and partly turbulent. The depths at which general movement was observed, according to both the visual criterion and the newly developed "model" criterion (see page 33), are designated as D_k and D_c respectively. The value D_o corresponds to an initial value of tractive force at which the rate-of-movement curve touches the horizontal axis (see page 38).

The development of the riffles is further illustrated in Plates Nos. 39 to 44, in which are shown the plotted longitudinal profiles taken at intervals throughout the tests. Each profile is superimposed upon the line representing the original elevation of the sand bed, and the elevation of the water surface is shown in order that a comparison can be made between riffle height and depth of flow. The slope of bed and water surface is indicated in the dimension at the right, as is the number of the sand in the case of two plates in which the profiles for two sands have been combined.

The results of the analyses of the sand caught in the trap at the lower end of the flume are shown in Plates 45 to 52. The analysis of the material in movement before the development of riffles is indicated by the short dashed lines, while the dash-dot symbol is used for the analysis of the material caught after the development of the riffles. The heavy solid line represents the original material which was placed in the flume, and the table at the top of each division of the plate summarizes the variation of the mean grain size and uniformity modulus.

DU BOYS' EXPRESSION FOR TRACTIVE FORCE

The Waterways Experiment Station has adopted as the basis for these studies involving sand movement the convenient du Boys expression involving the slope and depth of flow. This procedure is in close conformity with the methods used by most European investigators, and has also been widely used in this country during the last few years.

Other possible bases for the formulation of sand movement involve such hydraulic factors as mean velocity, bottom velocity, discharge, discharge per unit width, turbulence, etc. Gilbert, in his extensive investigations of this subject, attempted to correlate sand movement with velocity, and until recently his lead has been followed quite generally in this country. Although the use of velocity as the basis for studies of traction has a sound theoretical foundation, inasmuch as the square of velocity is a parameter of the energy of the flowing water, the measurement of either mean or bottom velocity entails certain practical difficulties which lessen their value as criteria for the movement of bottom materials. In the first place, it has been found that the placing of any velocity-measuring device near the bottom of the flowing stream immediately creates a scour hole in the bed, which in turn changes the velocity and may result in a premature riffle progression throughout the entire length of the flume. Further, while most investigators believe that the bottom velocity is the real controlling factor in the subject of bed movement, no unanimity of opinion has prevailed as to just where this velocity is to be measured. While the actual velocity of the water at the bottom is close to zero, its rate of change with distance from the bottom is very rapid; consequently, any slight error in the vertical location of a measured bottom velocity might result in a quite appreciable error in its value. The use of mean velocity is subject to these same limitations, except in the case of uniform flow through a flume of known cross-section, where it can be computed from the discharge and area of cross-section. An additional limitation is that the mean velocity does not bear a constant relationship to the bottom velocity, the probable controlling factor in bed-load transportation.

MacDougall* has adopted the unit discharge as the basis for his work. The use of this hydraulic factor results from the development of an expression for tractive power, which can easily be shown to be consistent with du Boys' expression for tractive force.

Inasmuch as it has been found at this Station that the du Boys expression is consistent with experimental results, and since the slope and depth are the hydraulic elements most easily measured in the laboratory, this expression has been adopted. It can be developed in the following manner:

Consider a uniform flow of water of depth D down an incline of slope S. If no resistance were offered to its flow, the increase in kinetic energy of a prism of water 1 foot square and D feet deep, in a short time dt (neglecting differentials of a higher order), would be

$$dE = \frac{m}{2}\left\{(v + dv)^2 - v^2\right\} = mvdv$$

Since $\frac{dv}{dt} = gS$,

$$dE = mgSvdt, \qquad (1)$$

where m is the mass of the prism of water.

Since it is presumed that uniform flow prevails, hence that there is no increase in the kinetic energy, this increase must be prevented by the action of a force T, acting through the distance v dt. Dividing (1) by v dt, the force is

$$T = mg\,S$$

Substituting $\rho\,\frac{D}{g}$ for m, this force is seen to be

$$T = \rho DS \qquad (2)$$

Equation (2), is the familiar du Boys expression for tractive force, expanded by du Boys after observations on the Rhone River, following the theory advocated earlier by du Buat.

The use of this expression as a basis for the formulation of the movement of bed materials has frequently been criticized on the basis that the users of the expression assign the entire value T to the movement of the bed-load. It is fully realized on the contrary that the energy dissipated by a flowing stream is utilized in the following manners:

1. Internal friction and turbulence.
2. Friction of the bed.
3. Friction of the air.
4. Movement of the bed-load.

* "An Experimental Investigation of Bed Sediment Transportation", by C. H. MacDougall.

While it does not appear reasonable to assign the entire value of the tractive force to the last of these four, it does seem reasonable to assume that with a given bed material, its movement will be in some manner proportional to the value of the tractive force, which then can be used as a measure of the bed movement. As will be pointed out later in this report, it has been demonstrated in these experiments that there is a definite relationship between the tractive force and the bed movement. Furthermore, the assumption of this relationship is as reasonable as any attempt to correlate bed movement with velocity or unit discharge, where it must also be assumed that the movement is in some way proportional to the value of these hydraulic elements.

RESULTS OF EXPERIMENTS

General

The primary purpose of these experiments, as originally outlined, was to discover and evaluate, if possible, the laws controlling the movement of bed materials in flowing streams. The two principal problems which grew out of this original purpose were:

1. Determination of the value of the tractive force at which movement of a given bed material starts—i. e., "critical tractive force".
2. Determination of the rate of movement of a given material at all values of tractive force within the range of values which can be reached in the experiment flume.

Obviously, these two problems are quite intimately related, and in all studies pertaining to either, it was necessary to keep constantly in mind the importance of the other. Also, the assumption was necessarily made that the existing tractive force value was the factor controlling the movement of the bed—that is, that for a given value of tractive force acting on a given bed material, there was a resultant type and intensity of movement, which, after the completion of the studies, could then be predicted with fair accuracy from the value of the tractive force. It will be shown below that this assumption was verified, at least within the range of the values of slope, depth, and width-depth ratios which were used in these experiments. At the present time, however, no attempt will be made to extrapolate these results beyond this range, and it must remain for further studies to determine whether the same verifications can be made for tractive forces equivalent to those found in full-scale rivers and for flumes of different width-depth ratios. Moreover, it must be kept constantly in mind that these experiments were conducted under nearly ideal conditions of uniform flow in a straight channel, and that their results are not necessarily directly applicable to curved channels of varying cross-section.

The discussion of the results will be divided into three general sections: (1) Critical tractive force; (2) rate of movement; (3) miscellaneous incidental results. Included in the latter discussion, will be:

1. Variation of Manning's roughness coefficient (n).
2. Riffle development.
3. Velocities.
4. Turbulence criteria.

Critical Tractive Force

Definition:

Critical tractive force is that tractive force which brings about general movement of the bed-load mixture; general movement is that condition in which sand grains up to and including the largest are in motion.

Resume' of Previous Investigations:

Since MacDougall* has presented a thorough summary of the work done by earlier investigators on the subject of sand movement, it is not deemed necessary to include here a duplication of his discussion. It will be sufficient to say that, while investigations of critical tractive force have been made by Krey, Schoklitsch, Eisner, Schaffernak, Kramer, and others, only the latter has developed a practical formula for critical conditions in terms of the sand size and distribution. Most of the formulas developed by the other experimenters contain certain constants, whose determination is almost impossible without first conducting a test on the individual sand in question.

Kramer's experiments, made in Berlin in 1931-32, included tests on three sand mixtures, his general procedure being closely similar to that used at this Station. After analyzing the results of his experiments to determine the general behavior of the mixtures, and verifying the "law of constant critical force" (according to this law, the critical tractive force for a given sand mixture is a constant, not a function alone of either depth or slope), he developed the following formula for critical tractive force in terms of the physical characteristics of the sand:

$$T_c = \frac{100}{6} \frac{d_g}{M} (\rho_1 - \rho), \qquad (3)$$

in which T_c is in grams per square meter, d_g in millimeters, and ρ_1 and ρ are in grams per cubic centimeter. In English units this equation reduces to the form,

$$T_c = 0.00138 \frac{d_g}{M} (\rho_1 - \rho) \qquad (4)$$

in which T_c is in pounds per square foot, d_g is in inches, and ρ_1 and ρ are in pounds per cubic foot. His method of evaluating d_g and M is explained on page 5, this paper.

Critical Tractive Force Curve:

On Plate 13 are shown the values of the critical tractive forces of Sands Nos. 1 to 8, plotted against the computed values of the expression $\frac{d_g}{M} (\rho_1 - \rho)$. On the same plate are shown Kramer's curve for critical tractive force and the plotted data from which his curve was drawn. In order to follow more closely the plotted points†, the parabolic curve marked "Modified Curve" has been drawn, and

* "An Experimental Investigation of Bed Sediment Transportation", by C. H. MacDougall.
† Kramer considers only points A, M, N, P, Q, as comparable with his own values.

it is suggested in preference to the straight-line expression for the variation of critical tractive force with the characteristics of the sand mixture. The equation for this curve, in English units, is

$$T_c = 0.0038 \sqrt{\frac{d_g}{M}(\rho_1 - \rho)} \qquad (5)$$

or, in metric units,

$$T_c = 29 \sqrt{\frac{d_g}{M}(\rho_1 - \rho)} \qquad (6)$$

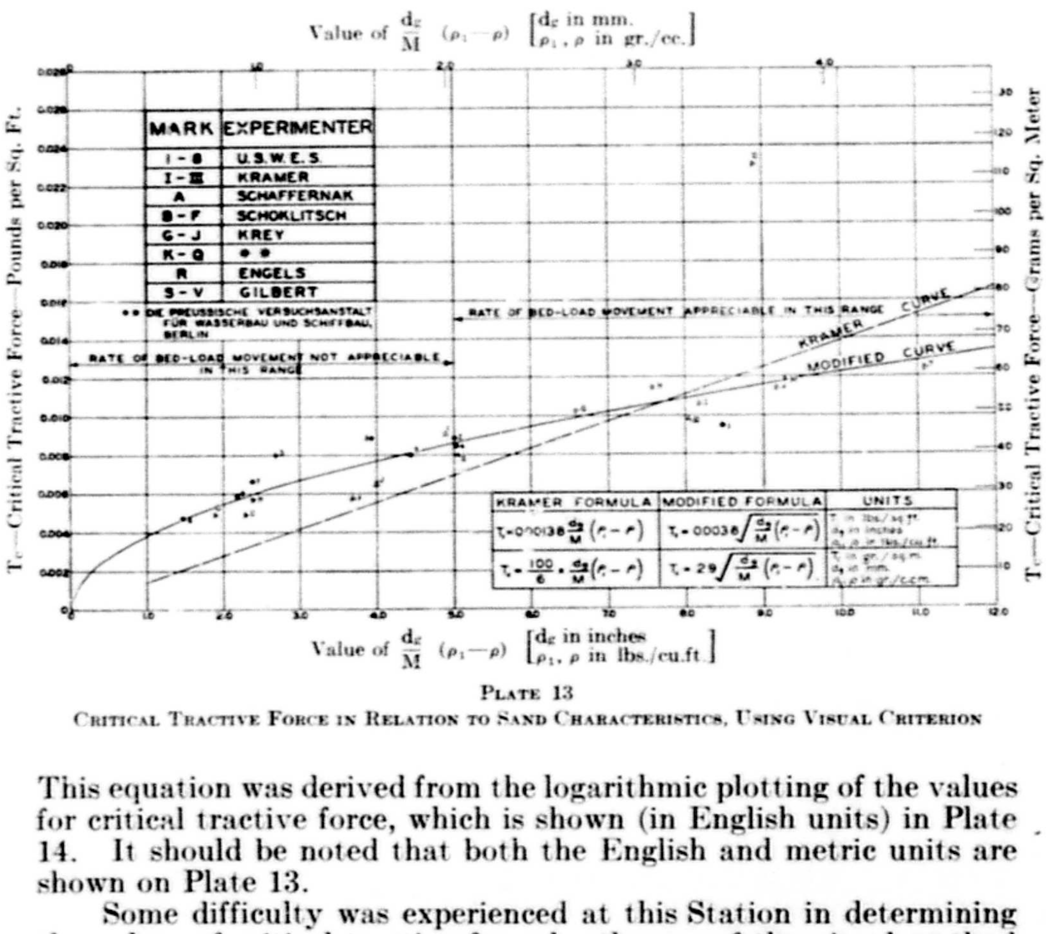


PLATE 13

CRITICAL TRACTIVE FORCE IN RELATION TO SAND CHARACTERISTICS, USING VISUAL CRITERION

This equation was derived from the logarithmic plotting of the values for critical tractive force, which is shown (in English units) in Plate 14. It should be noted that both the English and metric units are shown on Plate 13.

Some difficulty was experienced at this Station in determining the values of critical tractive force by the use of the visual method of spotting general movement. This difficulty was especially serious in the tests of Sands Nos. 2, 6, and 7, during which it was necessary to use somewhat turbid lake water. Even after the flume had been connected with the clear water circulating system, however, consistent results were not obtained by the various assistants in charge of the tests. In determining the values of critical tractive force which are plotted on Plate 13, therefore, the tabulated data were studied carefully, and due weight was given to the value of Manning's *n*, the measured rate of bed-load movement, the designation of the intensity of movement according to Kramer's classification, and the stage of riffle development. A careful analysis of Kramer's data revealed the fact that his tractive force values were all close to the point at which the first riffles appeared on the sand bed (of his twelve points, one was selected after weak riffles had formed, four were selected between the last smooth-bed run and the first run with riffles, and the remaining seven were selected within the last two or three runs with smooth bed); this fact was used as a guide to the selection of the point of general movement in tests where a visual determination produced unusually inconsistent results.

The point at which the critical tractive force was chosen, according to this method of spotting general movement, is noted in each of the tabulations of observed and computed data, Tables 11 to 37. The corresponding depth D_K is noted on the composite graphs, Plates 24 to 38, and the critical tractive force values are summarized in Table 3.

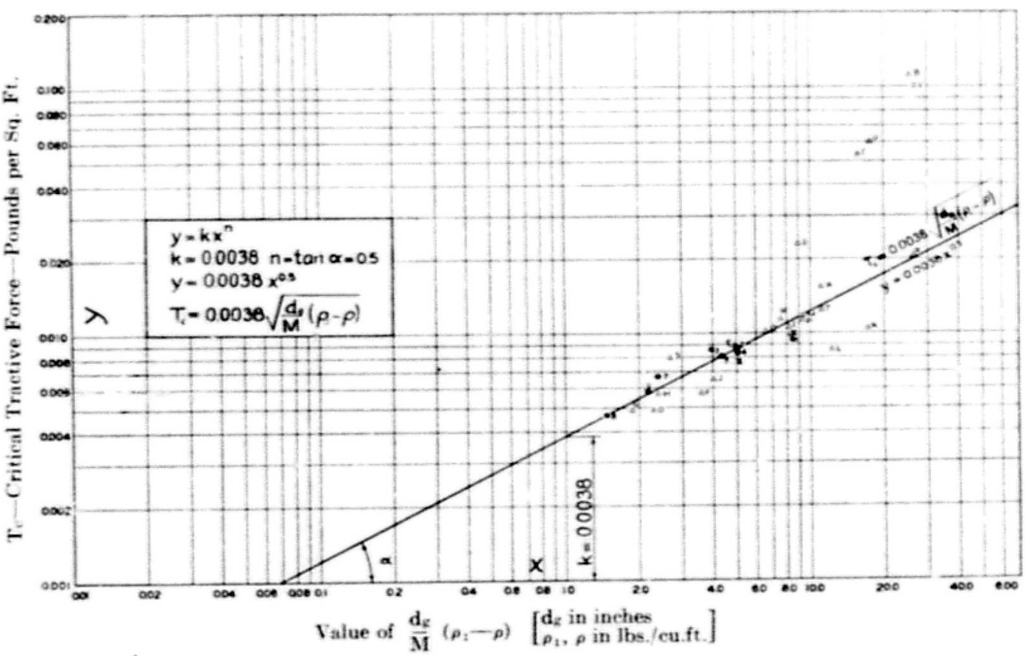


PLATE 14

CRITICAL TRACTIVE FORCE IN RELATION TO SAND CHARACTERISTICS, USING VISUAL CRITERION—LOGARITHMIC PLOT

Need for New Definition for General Movement, for Use in Models:

In attempting to apply to model design the critical tractive force values for fine sands found in the study described above, several obstacles were encountered which made it apparent that a lower limit should be placed on the sand sizes to which the visual method of general movement determination should apply. Studies of the data available from these experiments indicate that this lower limit may tentatively be placed at a mean grain size of about 0.6 mm. The following data tend to support this belief, and lead to the conclusion that a new criterion for general movement may be advisable for finer materials, if they are to be used in movable bed hydraulic models:

1. With sands of grain size less than this limiting value, the rate of movement at the point of "general movement" is too small to be appreciable.

2. With some fine sands, even though the rate of movement at the point of "general movement" is appreciable, riffle formations at tractive forces greater than this "critical" value so increase the roughness of the bottom and retard the velocity that there is a sudden decrease in the rate of movement. In the case of the finest sands tested, the rate of movement frequently became zero at tractive forces above "critical". This point, as well as the first one, is brought out in Table 3, column (20), and on the graphs on Plates 24 to 38, where it can be seen that the rate-of-movement curve drops suddenly when the riffles begin to form.

3. In the case of all the sands except Nos. 1 and 9, the sand mixture in movement at the point of "general movement" was not representative of the material of which the bed was molded. The mean size of the sand in motion was much larger than that of the original sand. The exception in the case of Sand No. 1 may be explained by the clay content in the mixture; Sand No. 9, the small gravel, is probably above the range where this condition obtains. This fact is evidenced by the curves showing the analyses of the trapped materials, Plates 45 to 52, where it can be seen that it was not until after a uniform riffling condition had been reached that the analysis of the trapped sand approached that of the original. The progressive change in the mean grain size, and its relation to the riffling stage, are shown on the graphs on Plates 24 to 38. In other words, it would appear that at the point at which, according to the visual method, general movement of the bed material was obtained, actually the material in motion was not representative of the mixture of which the bed was originally molded.

This somewhat paradoxical condition, in which the material first moved by the flowing water was larger in size than the original material, was confirmed in every test of Sands Nos. 2 to 8 by visual observation of the individual particles in motion. In every instance it was noticed that the first particles to begin moving were the larger ones, and that as the depth was increased, more of the smaller began to be moved. It is believed that the explanation for this phenomenon lies in the fact that the larger particles, which protrude a small distance above the general level of the bed, are acted upon by greater velocities than are the finer particles, which fill the interstices between the larger particles. While this vertical distance is very small, the change in velocity at the bottom of the flume is very rapid, and a small difference in vertical location causes a relatively great difference in velocity. At greater depths, however, the increased velocity at the bottom, aided by the increased condition of turbulence, is sufficient to reach and remove the finer particles. Hence, it may be concluded that movement of a fine sand on a smooth bed is a sorting process, and that only after the formation of riffles does the movement become general in the sense that all the particles are moved in about the proportion of their occurence in the mixture.

This condition, as stated above, was not observed in the tests on the small gravel, in which at the very commencement of movement the mean size of the material in motion was approximately equal to the mean size of the original material. The reason for this probably lies in the fact that a particle's resistance to motion varies as the cube of its diameter, while the distance the particle protrudes above the bed, and the velocity acting on the particle, vary as a much smaller power, probably less than unity. Hence, there must be some limiting size of particle at which the larger sizes no longer move first, and above which the finer materials are the first to be placed in motion. While no data were recorded in these experiments which would tend to locate this limiting size, it is believed that its value is in the vicinity of 0.6 mm.

Suggested New Definition for General Movement:

To answer the need for an evaluation of critical tractive force which can be used in model design, and which has a real meaning through the range of sand sizes smaller than 0.6 mm, the following tentative new definition for general movement has been worked out at this Station.

General movement is obtained when both the following conditions are attained:

1. The material in transportation is reasonably similar in composition to the material composing the original bed.
2. The rate of movement is equal to or exceeds one pound (dry weight) per foot width of channel per hour.

The critical tractive force is still defined as that value of tractive force existing at the time of the commencement of general movement.

It is desired to emphasize the fact that this definition of general movement is intended solely for use in connection with hydraulic models, where sands of mean grain size less than about 0.6 mm are used. In no case is it meant to be extended to include bed-load movement in full-scale streams, or sands larger than the limit stated. It is fully realized that the two specifications do not define a condition of movement which is exactly the same for a sand of mean grain size of, say 0.3 mm, as for another of mean grain size of, say 0.5 mm. It is believed, however, that within the assigned limitations it defines a condition which is nearly uniform, and which will prove useful in hydraulic model design. Further studies will be made of this subject, and it is hoped that a better definition for general movement, which will satisfy strict theoretical as well as practical considerations, can be developed.

It is understood that this definition can not be applied to a gravel or small stone mixture because of the fact that the movement of only a few isolated large particles might be sufficient to satisfy the 1-pound requirement, even though the movement was not at all general. Through the range of sizes with which this Station is usually concerned, however, it is believed that this condition leads to a usable definition for critical tractive force. The value of 1 pound was derived from experience records at the Laboratory, where it has been found that in a 12-hour cycle of operation of a model of the Mississippi River, which averages about 4 feet wide, a minimum of about 50 pounds of sand must be moved to secure satisfactory development of the model bed.

The fulfillment of the first condition—that the moving material must be similar to the material composing the bed—insures that the value chosen for the critical tractive force is greater than that necessary to produce riffles, and consequently, that there is no retardation in the rate of movement at tractive forces greater than critical. This point is evident from an inspection of the upper curve on the composite drawings, Plates 24 to 38, where it can be seen that the curve for mean grain size of the material in motion approaches that of the original grain size at the point of full development of the riffles.

Evaluation of Critical Tractive Force:

With this definition for general movement (designated the "model" criterion") as a basis, a study was made of the data tabulation in Tables 11 to 37, and the point at which movement became general was selected. The locations of these points are indicated in the tables, and also on the graphs, Plates 24 to 38, by the designation "D_c". The corresponding values of tractive force were then computed and recorded in Table 3, columns (7) to (9), averaged in column (10), and the rates of movement at critical tractive force and the least rate at tractive forces above critical were recorded in columns (11) and (12). The average values from column (10) were then plotted against the corresponding values of $\frac{d_g}{M}(\rho_1 - \rho)$, and the result is shown in Plate 15, on which are also shown the curve representing Kramer's equation and the revised curve suggested by this Station, using Kramer's criterion for general movement.

Again it is apparent that the product of depth and slope is a usable measure for critical conditions, inasmuch as the values determined from the three slopes were nearly the same for every sand.

The data from which the curve is drawn, representing the apparent trend of these points, are too few to locate the line closely, especially for values of $\frac{d_g}{M}(\rho_1 - \rho)$ of more than 5. The evidence seems to point out, however, that there is a minimum value of critical tractive force near this value, corresponding to a mean grain size of about 0.6 mm, and that both above and below this size, there is an increase in critical tractive force. This optimum size of particle corresponds very closely to that size below which riffles become appreciable in height.

It will be noticed that the rate of sand movement at the time of commencement of general movement of Sand No. 2 was about 6.0 pounds per foot width per hour, while that of the other sands was about 1 pound. The explanation of this is that the size-of-moving-grains specification was the controlling factor in the determination of general movement of this sand, while in all the others the 1-pound limit controlled its location. In general, the finer the sand, the smaller was the tractive force at the time of riffling, hence at the time when the particles in motion became similar in composition to the molded bed. For the finer sands, then, the 1-pound specification was the last to be satisfied and became the controlling factor in the determination of the value of critical tractive force. With increasing sand size, the appearance of riffles was delayed to higher values of tractive force, and the 1-pound limit was the first to be met. In the case of Sand No. 1, this limit again became the controlling factor, in spite of the general trend just described; it is believed, however, that the clay content of this material served as a binder which held back the larger particles, thereby causing the mean size of the moving particles to approach the size of the original material before the appearance of riffles.

The increase in the critical tractive force values for the finer sands, according to this criterion for general movement, is the exact reverse of the trend indicated by the Kramer formula, which was derived from tests of sands larger than those tested at this Station. It is believed that the explanation for this phenomenon lies in the matter of the riffle development. As can be seen from the profiles, Plates 39 to 44, the finer the sand, the greater was the height of riffles in comparison with the depth of water forming them, and, consequently, the greater the roughness of the bed. At a given depth, the velocity of the water, then, was less for the fine materials than for the coarse, and the movement of the particles was correspondingly less brisk. The value of tractive force at which the 1-pound limit was satisfied increased therefore with decreasing grain size, and since the 1-pound limit was the controlling factor locating the value of critical tractive force for the finer sands, the critical value also increaseed in this manner.

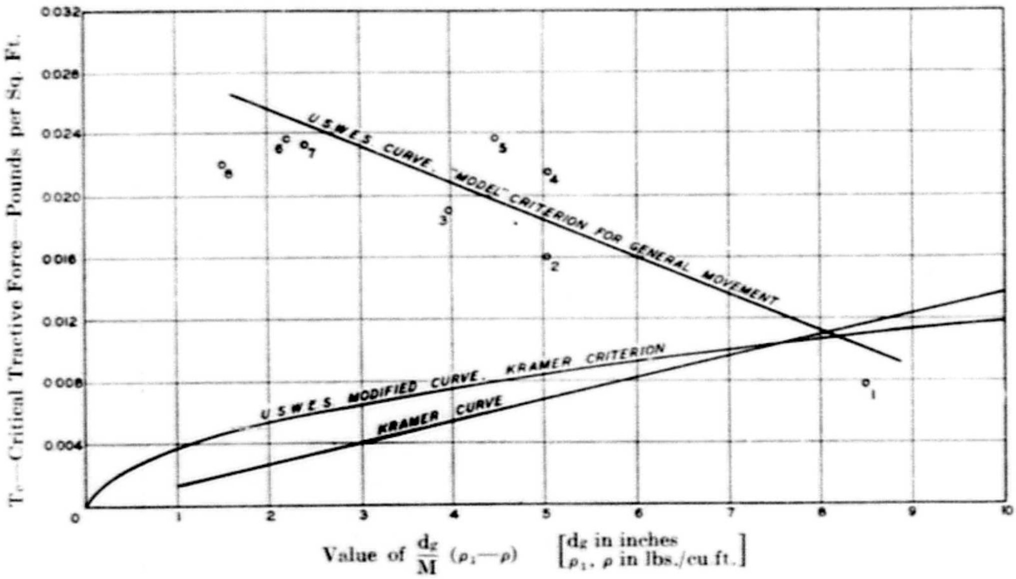


Plate 15

Critical Tractive Force in Relation to Sand Characteristics, Using Visual and "Model" Criteria

The scattering of the points on the curve of Plate 15 is not considered to decrease the usefulness of this evaluation, for these reasons: Sands Nos. 4 and 5, which have higher critical values than seem consistent with the curve, were composed of grains which were much more angular than those composing the other sands, and it is believed that the interlocking effect of the angular grains caused a retardation in their movement. The low value of Sand No. 8, which was also angular, or rather, the high values of Sands Nos. 6 and 7, can be attributed to the probability that some of the moving material in the tests on the latter sands was lost over the tailgate, and that the tractive force corresponding to a 1-pound rate was higher than its true value. This argument is borne out by the fact that the enlarged sandtrap used in the tests on Sand No. 8 caught, at all stages of movement, an appreciable quantity of the sand, which passed over the trap used in the other tests. The possibility is suggested that this portion of the critical tractive force relationship should be represented by two or three nearly parallel curves, each curve joining the

TABLE 3.

Critical Tractive Force.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
						By "Model" Criterion						By Visual Criterion							
						Critical Tractive Force** Lb. per sq. ft.				Rate of Movement Lb/ft. width/hour		Critical Tractive Force** Lb. per sq. ft.						Rate of Movement Lb/ft. width/hour	
Sand No.	Mean Grain Size mm	Mean Grain Size in.	Uniformity Modulus M	Shape of Grain*	Value of $\frac{d_z}{M}(\rho_1-\rho)$ (d_z in in., ρ_1, ρ in lb. per cu. ft.)	Slope 0.0010	Slope 0.0015	Slope 0.0020	Average	At Critical Tractive Force	Least at Tractive Forces above Critical	Slope 0.0010	Slope 0.0015	Slope 0.0020	Average	Value from Kramer Curve	Value from U. S. W. E. S. Curve	At Critical Tractive Force	Least at Tractive Forces above Critical
U. S. W. E. S.																			
1	0.586	0.0230	0.280	SA to SR	8.50	0.0077	0.0072	0.0081	0.0077	1.0	1.0	0.0084	0.0092	0.0107	0.0094	0.0117	0.0112	2.5†	1.5
2	0.541	0.0213	0.439	SA to SR	5.04	0.0130	0.0180	0.0170	0.0160	6.0†	6.0†	0.0080	0.0090	0.0095	0.0088	0.0069	0.0086	1.0†	1.0†
3	0.525	0.0207	0.539	SR to R	3.98	0.0198	0.0215	0.0160	0.0191	1.0†	1.0	0.0085	0.0090	0.0090	0.0088	0.0055	0.0076	1.0†	1.5
4	0.506	0.0199	0.406	A to SR	5.04	0.0213	0.0219	0.0222	0.0215	1.0	1.0	0.0080	0.0083	0.0090	0.0084	0.0070	0.0086	1.0†	0.04
5	0.483	0.0190	0.438	SA to A	4.49	0.0234	0.0230	0.0248	0.0237	1.0	1.0	0.0080	0.0075	0.0085	0.0080	0.0062	0.0080	1.0†	0.10
6	0.347	0.0137	0.643	SR to SA	2.20	0.0236	0.0252	0.0223	0.0237	1.0	1.0	0.0060	0.0060	0.0060	0.0060	0.0030	0.0057	0.02†	0.0
7	0.310	0.0122	0.525	SR to SA	2.40	0.0228	0.0227	0.0246	0.0234	1.0	1.0	0.0070	0.0058	0.0070	0.0066	0.0034	0.0060	0.10†	0.03
8	0.205	0.0081	0.560	SA to A	1.50	0.0210	0.0210	0.0244	0.0221	1.0	1.0	0.0051	0.0048	0.0042	0.0047	0.0021	0.0047	0.04†	0.0
9	4.077	0.1605	0.586	SR to SA	29.20	(Slope 0.0030) 0.0570	(Slope 0.0040) 0.0570	(Slope 0.0045) 0.0600	0.0580	1.0	1.0	(Slope 0.0030) 0.0570	(Slope 0.0040) 0.0570	(Slope 0.0045) 0.0600	0.0580	0.0404	0.0205	1.0	1.0
Kramer																			
I	0.705	0.0278	0.358		8.27										0.0106	0.0114	0.0110		
II	0.558	0.0220	0.461		5.06										0.0080	0.0070	0.0086		
III	0.800	0.0315	0.414		8.06										0.0698	0.0112	0.0109		

* See Plate 4 and pages 5-6.
** Computed from du Boys' expression.
† Approximate value.

points corresponding to sands of the same angularity of grains. Although the data from these experiments are not numerous enough to establish this theory, future studies may serve to prove or disprove its merits.

Rate of Bed-Load Transportation

A knowledge of the rate of transportation of bed-load is as important in calculations concerning changes in the configuration of stream beds as is the knowledge of the stage at which bed movement begins. In the operation of hydraulic models with movable beds, for instance, it is essential that the material composing the bed of the model be moved at all stages corresponding to those during which there is movement in nature, and it is likewise important that the movement in the model be quantitatively in some known proportion to the rate of movement in the full-scale stream. Hence, some knowledge of the laws governing the rates of movement of both the model stream bed and the natural stream bed is essential to the proper interpretation of model results. Likewise, in the design of regulatory works for rivers, the subject of sedimentary load transportation sometimes is as important as the hydraulics of the problem.

Resume' of Previous Investigations:

Several investigators, including du Boys, Schoklitsch, Gilbert, Eisner, and MacDougall have contributed to the knowledge of the subject of the rate of bed-load movement, but none has as yet succeeded in so formulating the movement of sand that a mechanical and physical analysis of the material is sufficient to predict accurately its behavior when acted upon by a flowing stream.

MacDougall* has contributed the latest information on the subject, as a result of his experiments at the Massachusetts Institute of Technology, and has arrived at an approximate method for predicting the movement of bed-load from an analysis of the material. His conclusions are based on observations of only three sand mixtures, however, and his final curves are drawn from only three points.

Basis for Formulation of Rate of Movement:

There is a noticeable similarity in the general form of the equations derived by various experimenters to express the rate of movement of bed-load in terms of the hydraulic elements. Almost all of them attempt to relate the rate to some function of slope and excess discharge or excess depth, with an experimental constant to take care of the variation in the sand mixtures. Gilbert has attempted to show the individual effect of each of the factors, velocity, slope, and discharge, by keeping the other factors constant, and has presented several expressions which show these relationships. Eisner has included in his formula a factor to express the friction on the bed. MacDougall has derived three similar equations in terms of discharge, one for each of his sands, and has then attempted to evaluate his constants in terms of the physical characteristics of the materials.

U. S. Waterways Experiment Station Formulation of Rate Movement:

After a thorough study of the rate-of-movement data accumulated in the experiments, it was found that the following empirical

* "An Experimental Investigation of Bed Sediment Transportation", by C. H. MacDougall.

equation expressed the relationship existing between the hydraulic factors and the rate of bed-load movement after the formation of riffles:

$$W = \frac{1}{n}\left(\frac{DS - D_oS_o}{k_1}\right)^m \qquad (7)$$

In equation (7), W is the rate of bed-load movement for a given sand mixture resulting from a given set of hydraulic conditions, DS is the corresponding product of depth and slope, n is Manning's roughness value as computed for the given conditions, and k_1 and m are parameters whose values are dependent upon the physical characteristics of the bed-load material (see Table 2, page 18, for explanation of units). D_oS_o is the value of the depth-slope product for the given sand mixture at the time of commencement of movement, as determined from the linear plot of Wn against DS (see Plate 16).

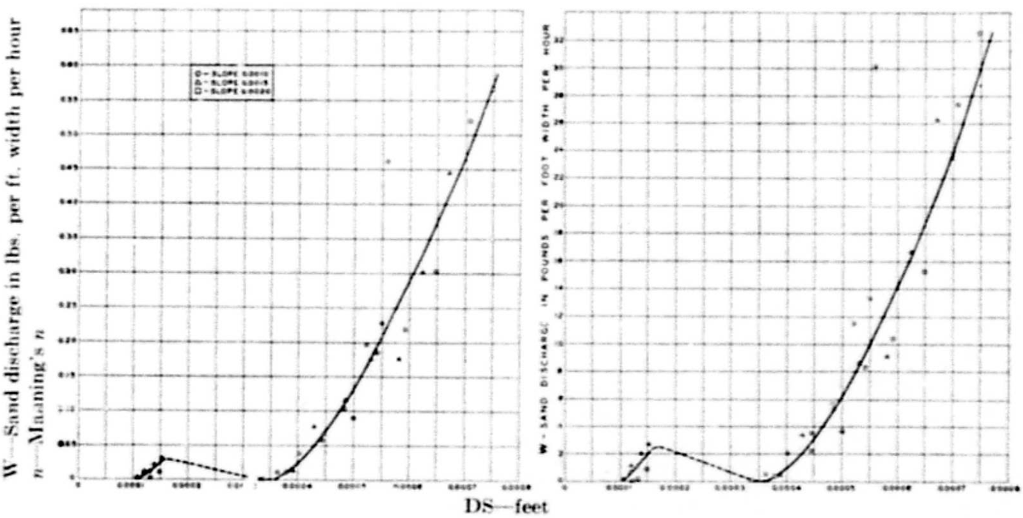


PLATE 16

EFFECT OF INTRODUCING MANNING'S n IN RATE-OF-MOVEMENT EVALUATION

Sand No. 5

As stated above, equation (7) is an empirical expression derived from the study of over 275 sets of observations of bed-load movement rates made after the formation of riffles, in addition to about 500 observations made before and during their formation. While the empirical nature of the derivation of the equation makes it necessary to limit its application to the range of values of slope, depth, and bed-load characteristics used in these experiments, the mass of data and the consistency of the results seem to verify the validity of the expression within the proper limitations.

The general form of the equation is seen to conform with the du Boys theory of tractive force, in which the bed-load movement is shown to be dependent upon the product of depth, slope, and the density of the water. The inclusion of the roughness value n serves to relate the tractive force value with the velocity. This factor was necessary because of the greater relative bed-load movements at the higher values of slope x depth, where the riffles became smoothed out and the movement of the sand particles became uniformly distributed over the bed. This factor serves to bridge the gap between movement in dunes and the next stage of transportation, that of uniformly distributed movement.

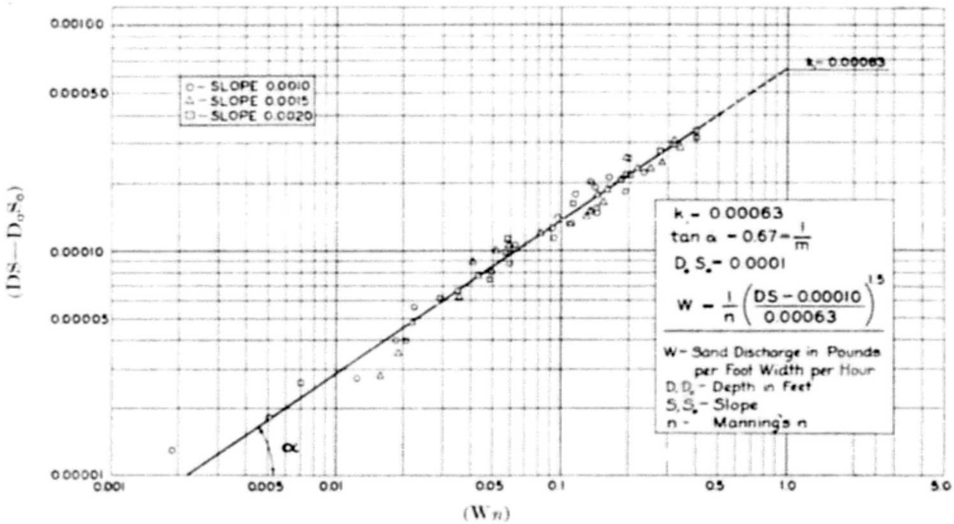
As will be shown below, the value of the parameter m is very nearly constant. The parameter k_1 which varies within narrow limits, is of extremely complex dimensions, embodying the composite effects on bed-load rate of such factors as mean grain size, distribution of grain sizes, voids ratio, angularity of grains, specific gravity of material, density of liquid, viscosity of liquid, degree of turbulence, width-depth ratio of flume, etc.

The nine logarithmic plottings of Wn against $(DS - D_oS_o)$, from which equation (7) was derived, are reproduced in Plates 17a to 19c, and the range of values of parameters k_1 and m, as well as those of n and D_oS_o, are summarizeed in Table 4. The nine curves are shown together for comparison on Plate 20.

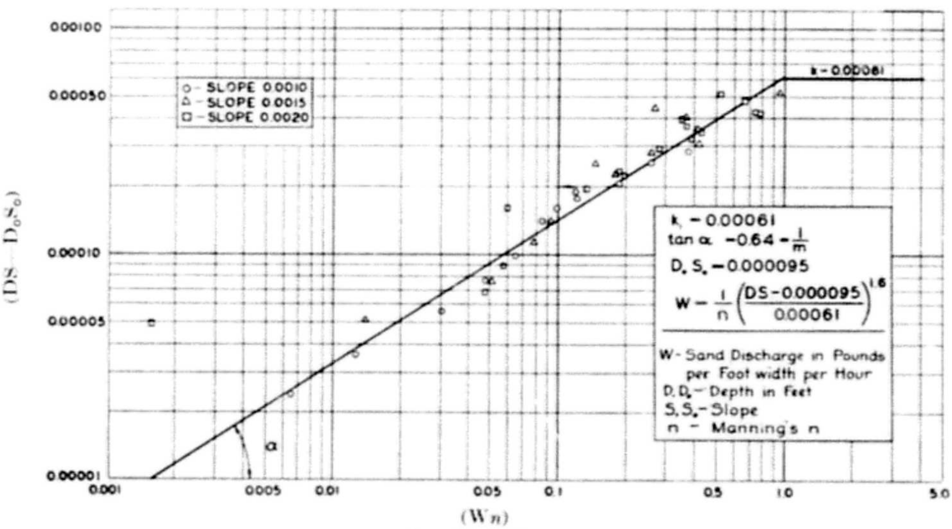
TABLE 4

VALUE OF CONSTANTS IN EXPRESSION $W = \frac{1}{n}\left(\frac{DS - D_oS_o}{k_1}\right)^m$

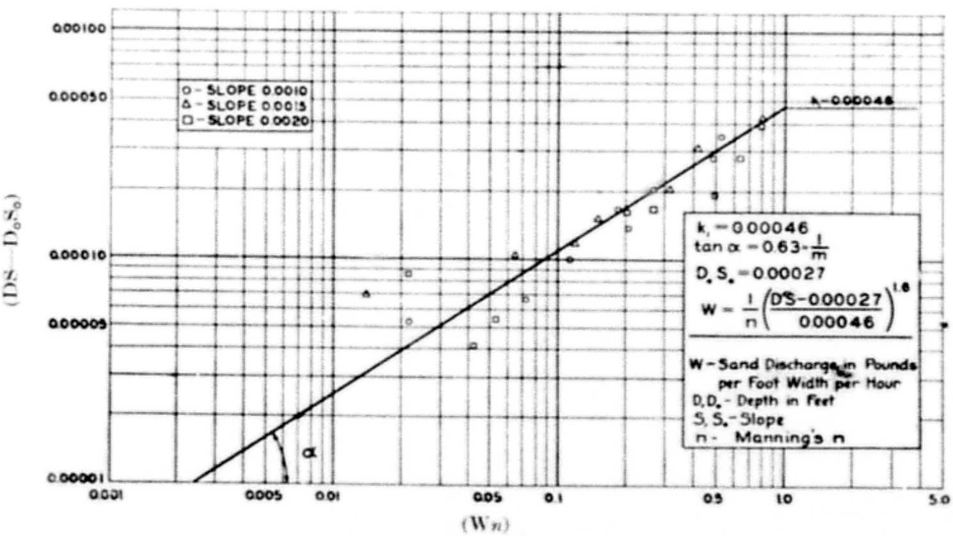
Sand No.	d_g mm	M	Slope	Range of values of n	D_oS_o	k_1	m
1	0.586	0.280	0.0010 0.0015 0.0020	.0112 to .0118 .0116 to .0124 .0118 to .0128	0.000100	0.00063	1.5
2	0.541	0.439	0.0010 0.0015 0.0020	.0120 to .0132 .0124 to .0143 .0132 to .0144	0.000095	0.00061	1.6
3	0.525	0.539	0.0010 0.0015 0.0020	.0146 to .0193 .0165 to .0232 .0132 to .0188	0.000270	0.00046	1.6
4	0.506	0.406	0.0010 0.0015 0.0020	.0152 to .0188 .0184 to .0248 .0140 to .0260	0.000300	0.00049	1.7
5	0.483	0.438	0.0010 0.0015 0.0020	.0166 to .0194 .0170 to .0260 .0178 to .0260	0.000350	0.00058	1.5
6	0.347	0.643	0.0010 0.0015 0.0020	.0195 to .0212 .0190 to .0242 .0184 to .0250	0.000280	0.00100	1.8
7	0.310	0.525	0.0010 0.0015 0.0020	.0214 to .0238 .0218 to .0252 .0206 to .0272	0.000250	0.00110	1.7
8	0.205	0.560	0.0010 0.0015 0.0020	.0176 to .0296 .0236 to .0276 .0180 to .0292	0.000260	0.00066	1.6
9	4.077	0.566	0.0030 0.0040 0.0045	.0164 to .0172 .0162 to .0165 .0164 to .0193	0.000940	0.00060	1.6



a. Sand No. 1



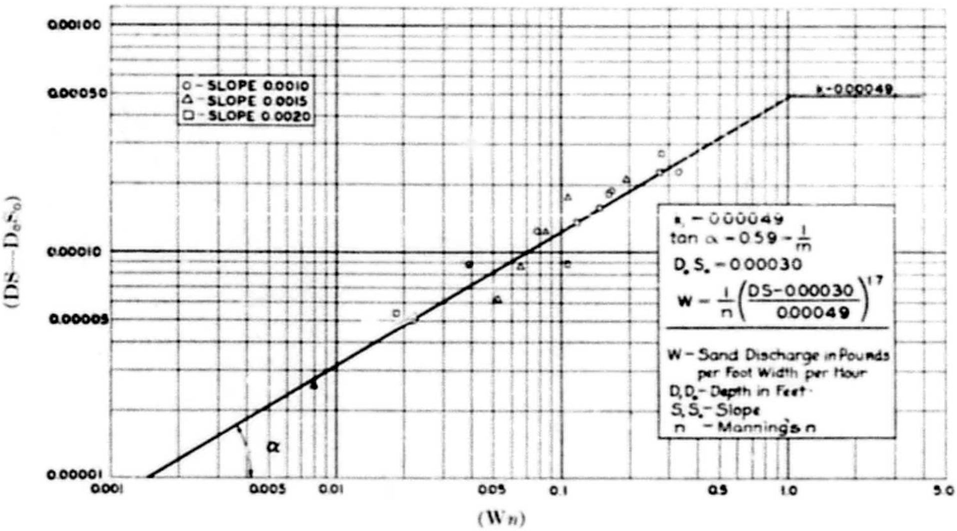
b. Sand No. 2



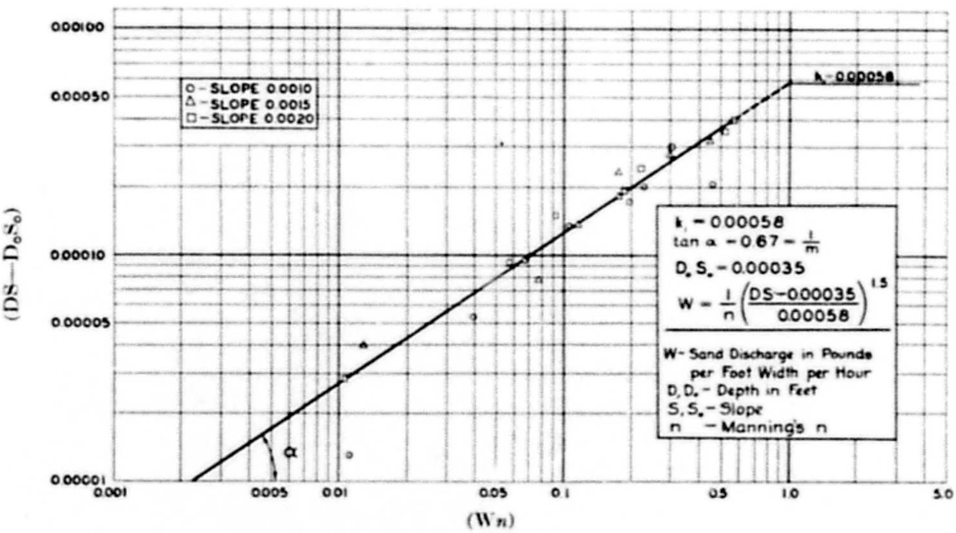
c. Sand No. 3

PLATE 17

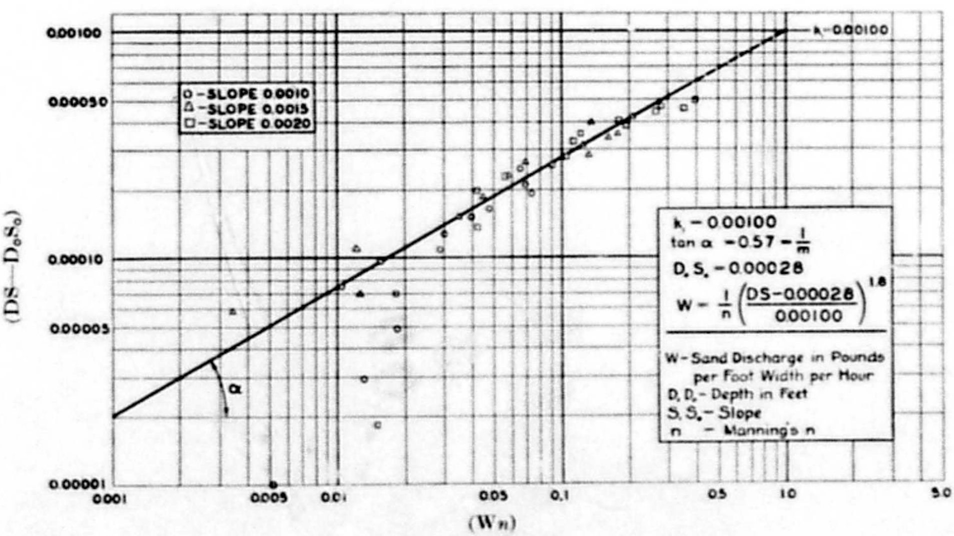
RELATION OF RATE OF SAND MOVEMENT TO DEPTH, SLOPE, AND ROUGHNESS



a. Sand No. 4



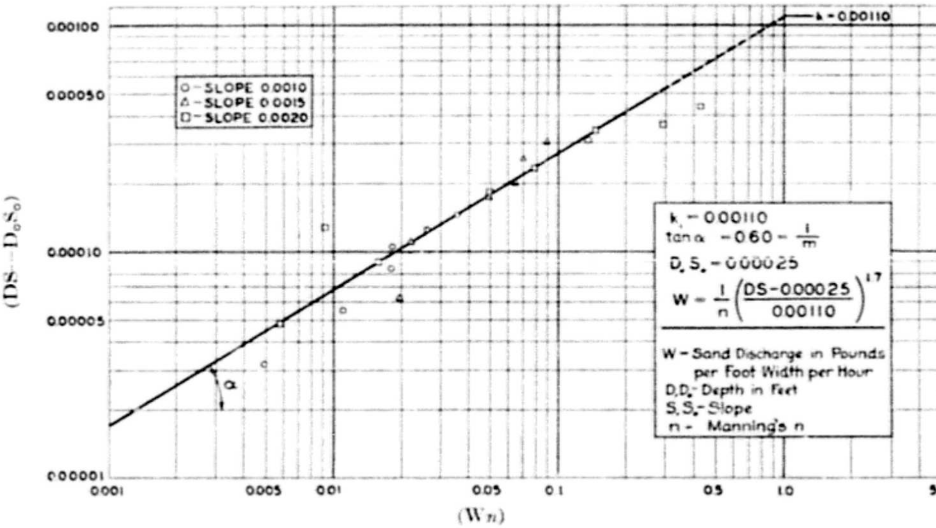
b. Sand No. 5



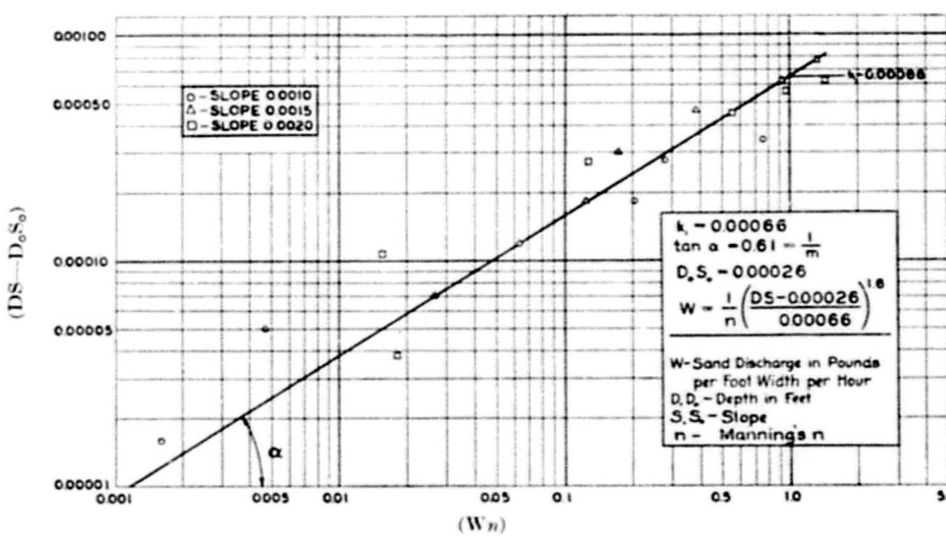
c. Sand No. 6

PLATE 18

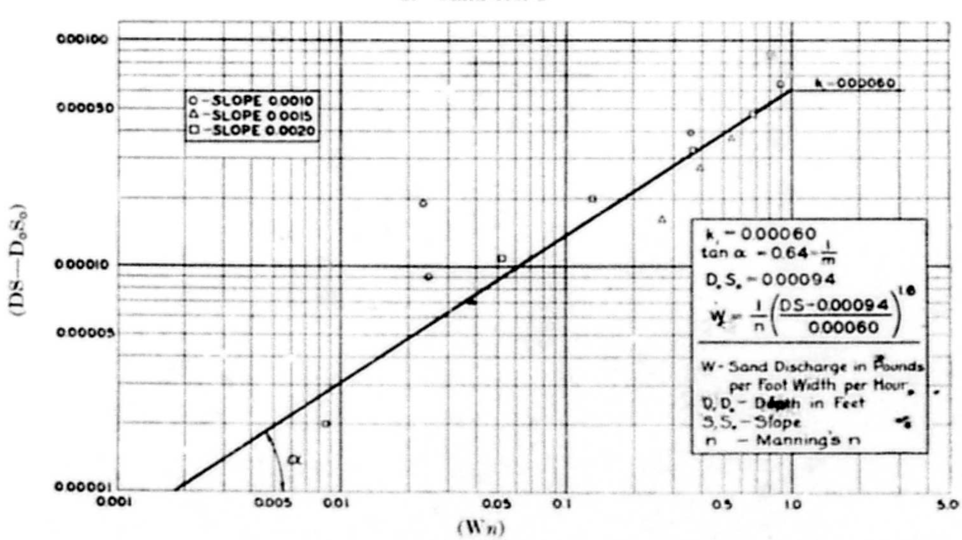
RELATION OF RATE OF SAND MOVEMENT TO DEPTH, SLOPE, AND ROUGHNESS



a. Sand No. 7



b. Sand No. 8



c. Sand No. 9

PLATE 19

RELATION OF RATE OF SAND MOVEMENT TO DEPTH, SLOPE, AND ROUGHNESS

Critique of Equation (7):

It will be noticed from Table 4 that the values of the exponent m are confined to a narrow range, from 1.5 to 1.8, and this same fact is evidenced in the composite logarithmic plot (Plate 20), where it can be seen that all nine of the lines are very nearly parallel. Furthermore, the values of k_1 fall within the small range from 0.00046 to 0.00110, and with the omission of Sands Nos. 6 and 7, fall between 0.00046 and 0.00066. It is believed possible that the same explanation may be offered for these high values of k_1 for the two sands that was offered for the high values of critical tractive force for the same sands—i. e., that not all of the sand was caught in the trap, and that actual values of W should be somewhat larger than their recorded values. It will be seen that an increase in each W-value, with its corresponding effect on W*n*, would serve to move the logarithmic curve down and to the right, and would reduce the value of k_1.

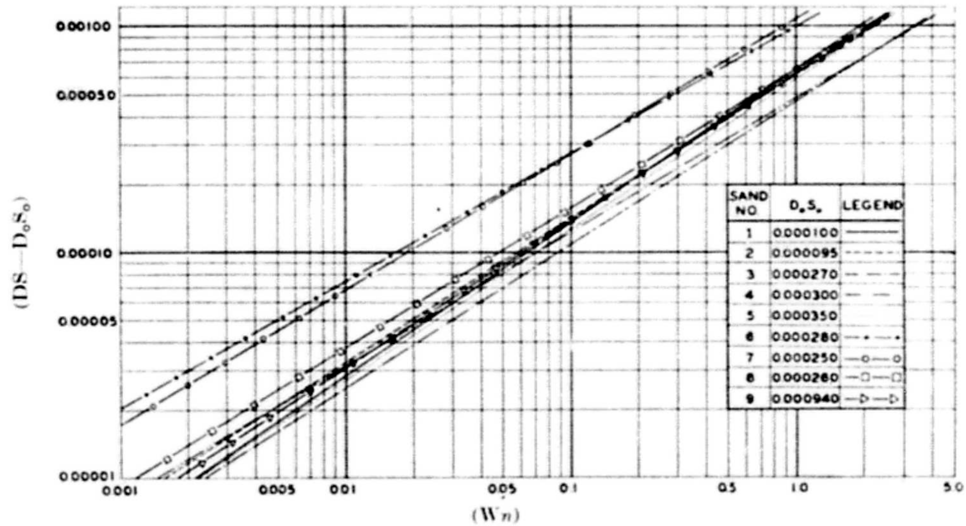


PLATE 20

COMPARISON OF RATES OF MOVEMENT OF SANDS TESTED—LOGARITHMIC PLOT

Whether the effect on k_1 would be large enough to bring the values for Sands Nos. 6 and 7 into the range of values for the other sands cannot be said, but it can be said that the effect would be in the proper direction. Hence, it may be found possible, with further study, to express the rate of movement for all sands by an equation similar to (7), in which the values of m and k_1 will be constant, and the only variables will be the values of D_oS_o and *n*.

Little consistency has been found in the manner of variation of the D_oS_o-values. An attempt was made to plot the values against corresponding values of $\frac{d_g}{M}(\rho_1 - \rho)$, a procedure parallel to that used in the study of critical tractive force, but no more than a general trend could be discovered from the somewhat scattered positions of the plotted points. It must be realized, however, that these values have little real meaning, and are only the points determined from the extension of the rate curves to the horizontal axis. Their primary use is in the equation, and it is not intended to mean that their values correspond to the actual commencement of movement of the bed-load. Actually there is a rather wide scattering of the plotted points at the low values of rate of movement, and the value of D_oS_o can be chosen from a range having a variation of as much as 15 per cent.

It is believed, however, that there is a definite relationship between the values of D_oS_o and the physical properties of the sand mixture, and that later studies will disclose it. The preliminary plot discussed in the preceding paragraph showed a close similarity in its general form to the curve (Plate 15) for critical tractive force according to the "model" criterion for general movement. It seems reasonable that there should be such a similarity, since there is a close relation between the 1-pound limit for general movement and the value of D_oS_o. Probably the main reason for the discrepancy between these two curves is that the critical tractive force values were chosen from the tabulated rate values, which tend to disperse at the bottom of the curves, while the D_oS_o values were taken from the curves themselves.

Equation (7) can be expressed in the following form, which includes the results from the eight sands and the small gravel:

$$W = \frac{1}{n}\left(\frac{DS - [0.000095 \text{ to } 0.000940]}{[0.00046 \text{ to } 0.00110]}\right)^{1.5 \text{ to } 1.8} \qquad (8)$$

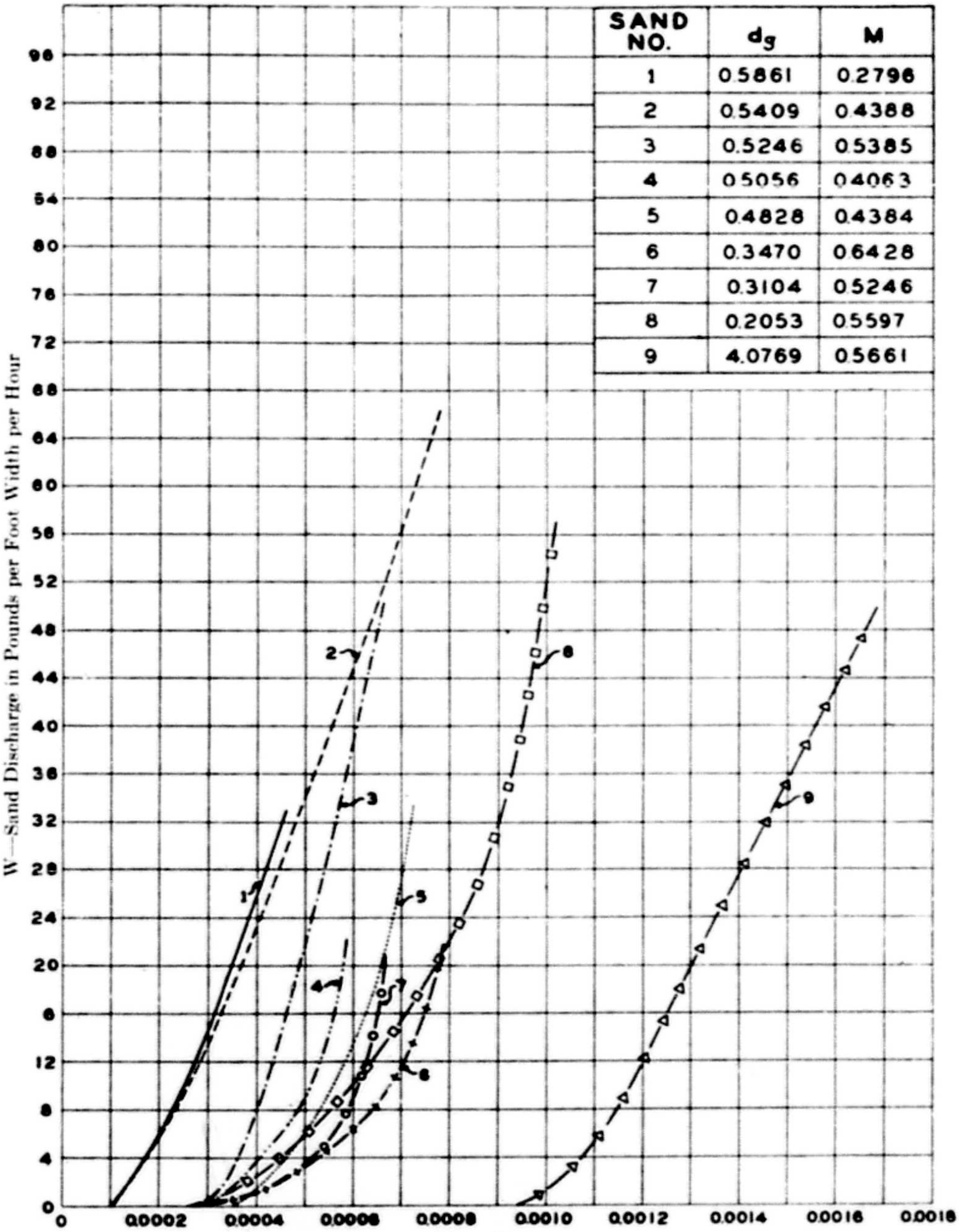
With the omission of the results from the small gravel, equation (8) becomes:

$$W = \frac{1}{n}\left(\frac{DS - [0.000095 \text{ to } 0.000350]}{[0.00046 \text{ to } 0.00110]}\right)^{1.5 \text{ to } 1.8} \qquad (9)$$

The rate-of-movement curves on the composite graphs, Plates 24 to 38, have been drawn to conform with the logarithmic plots on Plates 17a to 19c. The value of Wn corresponding to each selected value of DS, as read from the logarithmic curve, was divided by the n-value corresponding to that value of DS, as read from the composite graph, and the resulting value of W was used in determining the location of the curve on the latter sheet. From an inspection of these curves, it will be seen that they follow the points very closely. The test of Sand No. 2 at slope 0.002 presents the only inconsistent results in the entire series, in that the value of D_c is less than that of D_o, and the curve does not closely follow the plotted points. The first discrepancy is explained by the fact that D_c was chosen from the individual rate points, while D_o was determined from the average curve for all three slopes. The probable explanation for the second inconsistency is that the experiment was conducted too rapidly, and that a real equilibrium between riffle conditions and discharge was not reached.

Method of Using Equation (7):

In order to demonstrate the method suggested for using the equation for the rate of movement, a hypothetical example will be worked out. Suppose that it is desired to determine the rate of movement of Sand No. 4 at a slope of 0.0012 and a depth of 0.417 feet. The product D and S is thus 0.0005. From Plate 29, the roughness value of 0.5 depth, corresponding at slope 0.001 to a DS-product of 0.0005 is 0.0155. From Table 4, m is seen to be 1.7, D_oS_o is 0.0003, and k_1 is 0.00049. Substituting these values in the general form of equation (7),



SAND NO.	d_g	M
1	0.5861	0.2796
2	0.5409	0.4388
3	0.5246	0.5385
4	0.5056	0.4063
5	0.4828	0.4384
6	0.3470	0.6428
7	0.3104	0.5246
8	0.2053	0.5597
9	4.0769	0.5661

PLATE 21

COMPARISON OF RATES OF MOVEMENT OF SANDS TESTED

Average curves drawn from plotted values secured after the formation of riffles

$$W = \frac{1}{0.0155}\left(\frac{0.0065 - 0.0003}{0.00049}\right)^{1.7}$$

or, W = 14.1 lbs. per foot width per hour.

The experimental values for the three slopes, at corresponding DS-values, are 14.6, 11.3, and 11.2 lbs. per foot width per hour, respectively. Thus it is evident that the formula gives results which are accurate to within about 25% for all three slopes. The n values for the two higher slopes were 0.0186 and 0.0210, respectively, and had they been used in the computation instead of the lower value for the slope of 0.001, the computed rate would have been closer to the lower experimental value.

If it is desired to determine the rate of movement of a sand different from those tested, the results will depend on the accuracy with which the values for m, n, k_1, and D_oS_o are estimated. It is believed, however, that if the sand is within the range covered by these experiments, these constants can be evaluated from a study of Table 4, and the results will be reasonably accurate.

Limitations of Equation (7):

It is not intended to submit equation (7) as the final solution to the problem of bed-load movement, and it is suggested that it be used with caution. Its use must be limited, of course, to sand mixtures which are within the range of sizes covered by the materials used in these experiments, and to slopes not greatly different from the range between 0.001 and 0.002. Further, the highest values of slope-times-depth which were obtained were about 0.0008, and it is not recommended that the results be extrapolated beyond that value.

The use of this equation, then, for computations involving full-scale river flows, is hardly possible. In a river like the Mississippi, the slope is much flatter than the lowest slope used in the experiments, but the average depth is sufficiently great to produce a depth-slope product of a least double the value of 0.0008. Further, while this product served as a good measure of bed-load movement through the narrow range of slopes used in the experiments, it remains to be proved that its use with extremely flat or extremely steep slopes is also possible. Lastly, it must be remembered that these results were obtained with uniform flow in a straight flume, and that the relationship between bed-load movement under these ideal conditions and that under the usual conditions of curved channels of varying cross-sections has not yet been established.

Variation of Rate with Grain Size:

Comparative curves showing the rates of movement of all the sands after the development of riffles are shown in Plate 21. It will be noticed that the rate of movement is greater with the larger sands, except in the case of Sand No. 9, the small gravel.

The explanation for this condition again lies in the riffle development. The fine sands, through the range of tractive force values when the riffles were of appreciable height, were retarded in their movement, while the coarser materials, retarded to a lesser extent, were moved at greater rates.

After the smoothing out of the riffles, however, the increase in the rates of the fine sands was much more rapid, and at high values of tractive force the curves for the fine materials tended to cross those for the coarse mixtures, showing greater rates of movement at given values of tractive force.

Variation of Manning's Roughness Coefficient (n)

The value of Manning's roughness coefficient n, as computed from the Manning formula for open channel flow, has been recorded for each run in Tables 8 to 37, and all the values have been plotted against depth on the composite graphs, Plates 24 to 38.

Applicability of the Manning Formula:

The fact that the Manning formula can be used to advantage in these studies is well demonstrated from the shape of the Manning's n curves on Plates 24 to 38, and especially those on Plate 24, wherein are presented data from the flume both with sand bottom and with cement bottom. On the latter plates it can be seen that the computed value of n remains at a nearly constant value very close to 0.01, throughout the complete range of depths which were used. For the sand bottom, on the other hand, n remained nearly constant so long as the bottom remained smooth, at a slightly higher value than the 0.01 found for the cement bottom.

Some caution must be applied to the use of the actual values of n computed in these experiments, for the reason that the side roughness was not the same as the bottom roughness. The sides of the flume had a smooth surface of neat cement, exactly like the bottom in the tests made without sand in the flume, and it was not believed practicable to roughen the sides to conform to the roughness of the sand bed. This equal roughness would have been especially hard to achieve after the formation of riffles. While the usual conception of Manning's n is that it represents the roughness of the bed, actually it is a resistance factor which must include such other factors in addition to roughness as curvatures, eddies, and changes in bed configuration. In these computations, therefore, it must be considered that the n-values represent the resistance to flow of a channel with a smooth side surface and a bottom of variable roughness.

It must also be noted that the Manning formula applies only to turbulent flow. The values of n have been computed for the laminar flow range, and have been plotted, to illustrate the point that they are meaningless in this range. A dashed line is drawn through these points, to distinguish them from the points computed from turbulent conditions.

Variation in Values of n:

The range of n-values encountered in these experiments is summarized in Table 5. The average value for the cement bottom, 0.0097, checks very closely the value of 0.010 given by King* for a neat cement surface under best conditions. The average value for all the sands for a smooth bottom is 0.0107, close to the value of 0.011 given by King for a neat cement surface under good conditions. The value of 0.016 for the small gravel is nearly the same as the value King gives for a cement-rubble surface.

With a riffled bottom, the n-values show a great variation, from a minimum of 0.0112 in the case of Sand No. 1 to a maximum of 0.0287 for Sand No. 8. It is evident, however, that the n-values

* King, "Handbook of Hydraulics".

have the same general trend followed by the riffle sizes—i. e., the finer the sand, or the larger the percentage of fines in the sand, the larger will be the *n*-values. In the case of Sands Nos. 1 and 2, where the riffles were very small, the *n*-values on the riffled bed were only about 0.001 higher than on the smooth bed. With the finer materials, however, the *n*-value for the riffled bed frequently was more than double its magnitude for the smooth bed.

Relation of Manning's n and Rate of Sand Movement:

The rate of movement of the sand is very closely related to the value of Manning's *n*, which is determined principally by the size and shape of the riffles. This fact was brought out in the discussion of Rate of Bed-load Transportation, where it was shown that the inclusion of *n* in the rate formulation tended to reconcile the rates at high discharges to those at lower discharges. In general, the rate of movement varies inversely with the value of *n*. Lacking enough information to determine what power of *n* should be used, it was assumed that the first power sufficiently covered the effect of the roughness of the flume.

TABLE 5

SUMMARY OF COMPUTED VALUES OF MANNING'S *n*

Sand No.	d_g mm	Manning's *n*		Maximum Change in *n*
		Average for Smooth Bottom	Maximum for Riffled Bottom	
1	0.586	0.0102	0.0112	0.0010
2	0.541	0.0115	0.0120	0.0005
3	0.525	0.0117	0.0207	0.0090
4	0.506	0.0110	0.0270	0.0170
5	0.483	0.0110	0.0243	0.0133
6	0.347	0.0099	0.0233	0.0134
7	0.310	0.0100	0.0254	0.0154
8	0.205	0.0103	0.0287	0.0184
9	4.077	0.0160	0.0173	0.0013
Cement bottom		0.0097		

Riffle Development

The several manners in which sand is transported by traction have been described in detail by Gilbert*, who has conducted the most comprehensive investigation of the subject, and by MacDougall**. Briefly summarized, these modes of transportation are:

(1) Movement on a smooth bed. This movement begins at a definite stage when the tractive force reaches a certain value, dependent on the characteristics of the bed material.

* "Transportation of Debris by Running Water", by Grove Karl Gilbert, U. S. G. S. Professional Paper 86, 1914.

** "An Experimental Investigation of Bed Sediment Transportation", by C. H. MacDougall.

(2) Movement in "dunes", or riffles which progress downstream. With this type of movement, the individual particles are moved up the upstream face of the dune, are rolled over its crest, and are deposited at the foot of the slope, resulting in the typical downstream movement of the riffle. With increasing depth, these riffles increase in size, until the beginning of the next stage of movement.

(3) Uniformly distributed movement, in which the riffles formed in the preceding state are smoothed out, and the bed becomes approximately plane, although somewhat irregular in appearance. This stage is reached at a point close to that at which the flow changes from streaming to shooting.

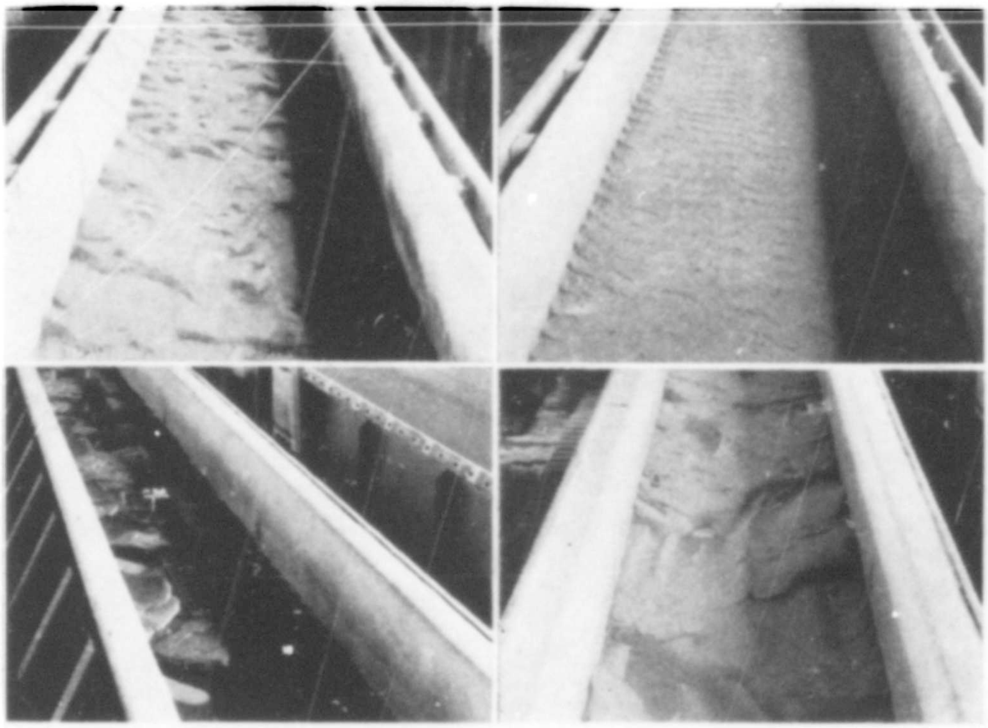


PLATE 22
TYPICAL RIFFLE FORMATIONS
Upstream Views
Top, left: Sand No. 2, after run 7, slope 0.0010
Top, right: Sand No. 1, after run 17, slope 0.0020
Bottom, left: Sand No. 3, after run 30, slope 0.0025
Bottom, right: Sand No. 4, after run 32, slope 0.0020

(4) Movement in "anti-dunes", in which, as the term implies, there is an upstream progression of riffles. In this stage of movement, there is a scouring on the gentle downstream slope of the riffle, and a deposit on the steeper upstream face of the next riffle. This anti-dune stage occurs only with shooting flow, and is seldom observed in nature.

Most of the movement in these experiments fell in the first two classifications, with a tendency at the highest stages toward the third classification, (see Plate 43, Sand No. 8). None of the tests extended into the anti-dune stage of transportation.

Variation in Riffle Size with Type of Bed Material:

In general, it was found that the size of the riffles increased as the percentage of fine material in the mixture increased. Sands Nos.

1 and 2, for instance, the two coarsest sand mixtures tested, developed very low riffles, and their effect on the roughness of the bed was hardly noticeable. This fact can be verified from an inspection of Plates 25 to 27, where the values of Manning's *n* increase very little as the riffles develop. The actual size of the riffles can be measured from the profiles plotted on Plates 39 and 40. Sands Nos. 6, 7, and 8 (the finest mixtures), on the other hand, developed riffles which were sometimes as high as 30 per cent of the depth of water forming them, and which more than doubled the roughness value of the bed.

Typical riffle formations for four of the mixtures are pictured in Plate 22, and the exact profiles for all the mixtures are plotted on Plates 39 to 44.

Tractive Force Value at Appearance of Riffles:

In Table 6 the average tractive force value existing on the last smooth bed run, immediately before the appearance of riffles, has been listed for each of the sands. Each of these values is the average for the three slopes, but it was found that the individual values were never greatly different from the average. According to the table, the coarsest sand, No. 1 (excluding the small gravel), was the slowest to riffle, the finest sand, No. 8, was the quickest, and between these extremes the general tendency was for a more rapid riffle development as the grain size decreased. This fact was verified in every case by visual observations, from which the conclusion was made, by the laboratory assistants in charge of tests, that the fine sands riffle more easily then the coarse.

TABLE 6

VALUE OF TRACTIVE FORCE AT APPEARANCES OF RIFFLES

Average of Values for Three Slopes

Sand No.	1	2	3	4	5	6	7	8	9
Mean Grain Size, mm.	0.586	0.541	0.523	0.506	0.483	0.347	0.310	0.205	4.077
Tractive Force at Last Smooth Bed Run (Lb. per Sq. Ft.)	0.0104	0.0105	0.0095	0.0098	0.0084	0.0058	0.0060	0.0047	0.0270

Velocities

A very comprehensive series of velocity observations, including mean, surface, and bottom values, and velocities at various depths, was taken during the course of these experiments, and the data are presented in tabular form in Tables 8 to 37. The mean velocities have been plotted against the corresponding depths on Plates 24 to 38, and a number of the vertical velocity distributions are shown in Plate 23.

Mean Velocities:

The variations in mean velocities are best illustrated in the curves on the composite graphs, Plates 24 to 38, in which they have been plotted against depths. On each one of these curves it will be observed that a straight-line relationship exists between velocity and

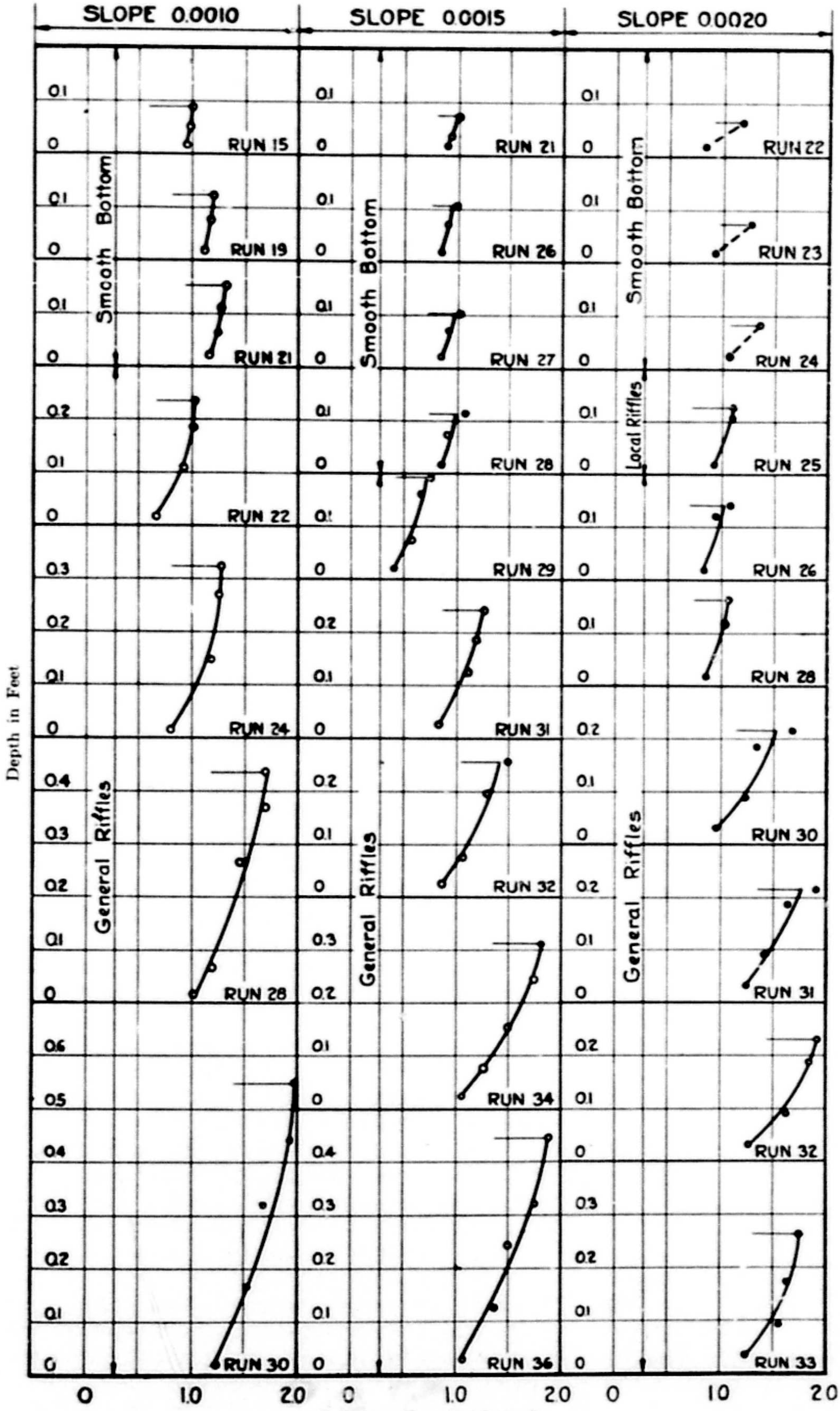


PLATE 23

VERTICAL VELOCITY CURVES
(Sand No. 3 in flume)

depth through the laminar flow range, while at the beginning of turbulent flow the curve assumes a parabolic shape, which it retains until the commencement of riffle formations. This break in the curve between the straight line and the parabolic section very closely checks the observed transition between laminar and turbulent flow.

The next break in the velocity curve occurs at the point where the riffles commenced to form. At this time the roughness of the bed was very suddenly increased, the velocity retarded, and the depth increased for the same discharge through the flume. In most of the tests, including those on the finer materials, the velocity was actually decreased at this point, owing to the size of the riffles which were formed. In the tests on Sands Nos. 1, 2, and 9, however, there was no actual decrease in the velocity, only a retardation in the rate of increase of the velocity with depth. The severity of the break at this point necessarily conforms closely to the change which occurs in the curve of Manning's n values, and is a function of the size of the grains in the sand mixture.

A third change in the shape of the velocity curve occurs at the point when the riffles become smoothed out, at high flows nearing the shooting flow range. At this point the velocity begins to increase at a greater rate, owing to the reduced roughness of the bed.

Bottom Velocities:

In the tests on Sands Nos. 3, 4, 5, 8, and 9, the last to be performed, it was attempted to secure measurements of bottom velocities (using the Bentzel velocity tube), for the purpose of correlating if possible, these readings with the rate of bed-load movement. Several practical difficulties arose, however, and while it is believed that the values of the readings themselves are nearly correct, it is not certain that they are representative or consistent readings which could be duplicated in repeat tests.

In the first place, as pointed out earlier in the report, the placing of a measuring device close to a sand bed which is moving or on the verge of moving invariably results in a scouring below the instrument. This scouring may result in the development of a progressive riffle formation, and is certain to change the velocity distributions at the bottom, thereby making the reading itself no longer representative of normal conditions.

Secondly, if riffles have already formed, the velocity at the bottom is extremely variable, due to the existence of rollers and eddies. If the measurement is made at the crest of the riffle, the velocity will have a maximum value, but if the instrument is placed in one of the troughs, the reading will be much less, and may even be negative. In order to reduce this effect, and to eliminate the forming of scour holes, the velocity tube was usually placed over the concrete sill at the lower end of the flume, about an inch downstream from the sand bed, and an average of several readings across the flume was taken as the most practical value for the bottom velocity.

As previously indicated, there was little success in the attempt to correlate bottom velocity and sand movement. The values which were obtained from the experiments are recorded in full in Tables 8 to 37, however, where they are available for reference.

Surface Velocities:

Measurements were made of surface velocities, in addition to bottom velocities, in the tests on Sands Nos. 3, 4, 5, 8, and 9. These values were all plotted against simultaneous values of mean velocity, and it was discovered that a straight line could be drawn through the points, for all the tests on smooth sand beds or cement bottom. The equation of this line was approximately $V_m = 0.90V_s$. After the formation of riffles, the relationship was not so definite, although an equation of the form $V_m = 0.85V_s$ would satisfy most of the points, within a reasonable percentage of error.

Vertical Distribution of Velocities:

In Plate 23, a series of vertical velocity distribution curves is given for Sand No. 3, with points selected from several runs both before and after the formation of riffles. The general shape of all the curves is the same, with a nearly uniform increase in the velocity from bottom to top. At the time of riffle formation, the same phenomenon is observed for the velocities at all depths—a marked decrease occurs, followed by a gradual increase as the depth becomes increased.

Turbulence Criteria

In each of the tests except those with Sands Nos. 1 and 6, observations were made of the type of flow, whether laminar or turbulent, and special attention was paid to the transition stage between these two types. As explained in detail under Procedure of Experimentation, these determinations were made from observations of the path taken by a stream of potassium permanganate solution which was injected into the water.

The values of Reynolds' number for open channel flow and of the VR-criterion for turbulence (the latter value is similar to the Reynolds' number, lacking only the factor for change of viscosity with temperature, and is conveniently used when the temperature is nearly constant), defining the transition from laminar to turbulent flow, are given in Table 7. The values given in the table were taken from the last run in which the flow was partly laminar. It was found impracticable to use the values for the first turbulent run, since they sometimes were too far into the turbulent range to define its lower limit.

The maximum value of Reynold's number for open channels at which some laminar flow was observed was 1970, and the corresponding value of VR was 0.024. From these observations it may tentatively be concluded that turbulence will exist in a flume if the value of Reynolds' number is about 2500 or more, or if the corresponding VR-value is about 0.030 (assuming the coefficient of kinematic viscosity at an average value of 1.2×10^{-5}).

As previously stated by this Station, turbulence in a hydraulic model is insured if the product of depth and velocity is greater than 0.02. The criterion of depth and velocity is very similar to that of hydraulic radius and velocity, inasmuch as the hydraulic radius is almost equal to the depth. The two values, 0.02 for the VD-product in a model, and 0.03 for the VR-product in a flume, are not inconsistent, however, since the model, with its bends, irregular cross-section, and greater roughness, will produce turbulence at lower values than will the comparatively smooth flume. The fact that the roughness, or resistance to flow, tends to hasten the turbulent condition is indicated by the results on Sand No. 9, the small gravel. According to the table, the VR-product at the last run in these tests which was partly laminar was 0.003, only one-tenth the value suggested in the preceding paragraph as a safe value to insure turbulence. This material had a Manning's *n* value of about 0.016 before the appearance of riffles, as compared with the usual values of about 0.011 for the other sands.

TABLE 7

VALUES OF REYNOLDS' NUMBER AND VR-TURBULENCE CRITERION AT CHANGE FROM LAMINAR TO TURBULENT FLOW

Sand No.	Reynolds' Number at Last Flow Partly Laminar*				VR – Value at Last Flow Partly Laminar*			
	Slope 0.0010	Slope 0.0015	Slope 0.0020	Maximum	Slope 0.0010	Slope 0.0015	Slope 0.0020	Maximum
1	†	......	......	......	......	......	......	......
2	......	1180	860	1180	......	0.011	0.008	0.011
3	990	960	880	990	0.012	0.011	0.010	0.012
4	1380	1380	1970	1970	0.016	0.016	0.024	0.024
5	1300	940	850	1300	0.016	0.011	0.010	0.016
6	†	......	......	......	......	......	......	......
7	1880	1610	1000	1880	0.017	0.015	0.009	0.017
8	1810	1160	1200	1810	0.021	0.014	0.014	0.021
9	{Slope 0.0030} 310	{Slope 0.0040} 290	{Slope 0.0045} 180	310	{Slope 0.0030} 0.003	{Slope 0.0040} 0.003	{Slope 0.0045} 0.002	0.003
Cement Bed	{Slope 0.0005} 1080	{Slope 0.0010} 1050	{Slope 0.0015} 1170	1170	{Slope 0.0005} 0.012	{Slope 0.0010} 0.012	{Slope 0.0015} 0.013	0.013

* Values taken from last run in which flow was partly laminar. The next run in each case was entirely turbulent.
† No observations.

PROBABLE FUTURE STUDIES OF BED-LOAD MOVEMENT

Emphasis must be placed on the fact that these studies are not intended to be the final answer to the problem of bed-load movement. Accordingly, plans are being made at the Waterways Experiment Station for a continuation of these experiments, with the hope that more information will be obtained and made available to hydraulic engineers who are concerned with this subject.

The staff members at the Station are of the opinion that the rate of movement of bed-load is as important a factor in these studies as the critical tractive force, especially so far as it concerns the design and operation of hydraulic models, and the interpretation of their results. In most rivers, such as the Mississippi, there is movement of the bed at all stages, including the lowest; hence, the determination of the critical tractive force of the material composing the bed is not so important as a knowledge of its rate of movement at all stages. An exception to this condition may occur in some instances, however, and the critical tractive force may become the important factor. An example of this is found in certain upper reaches of the Savannah River, in which there is little or no movement of the bed at low stages. At higher stages, however, the movement is appreciable, and the determination of the stage at which the movement begins is essential.

One of the aims of the future studies will be the elimination, or partial elimination, of riffles in movable bed models. While the formation of riffles in the sands in use in models at the Station has been troublesome at times, it is not believed that they have been so severe as to vitiate the results of the studies. Nevertheless, the elimination of large riffles will make for easier operation of the models, and will to some extent reduce the element of judgment necessary in the interpretation of the results. The present studies have indicated that there is little riffle formation with sands of about 0.6 mm mean grain size, and that the critical tractive force, using the "model" criterion for general movement, is a minimum at about this same grain size. Hence, the first efforts will be be to mix a sand of about this size, having a very small percentage of fine grains.

Another step that must be taken is the study of the relation between the flume results and the results under corresponding conditions in a model having the complicating factors of bends, changing cross-sections, etc. Until such a time as this step is taken, flume results must be taken as indications only, comparable only within themselves, and applicable only with careful judgment to hydraulic models.

The final logical problem to be faced is that of the determination of rates of movement and critical tractive forces for materials composing the beds of full-scale rivers, and the relation between these full-scale phenomena and the results of flume observations. Some work has been done on this subject, by the Mississippi River Commission and various others in this country, and by several observers in Europe, but no measuring devices have yet been perfected with which quantitative results can be obtained. A strong impetus will be given to the study of bed-load movement whenever a satisfactory method is devised for measuring its rate and determining its critical tractive force in natural rivers.

SUMMARY OF RESULTS

Nine sand mixtures, ranging in mean grain size from 0.205 mm (0.008 in.) to 4.077 mm (0.161 in.) were tested in a tilting flume at the U. S. Waterways Experiment Station, to determine their critical tractive forces and their rates of movement corresponding to all values of tractive force within the range obtainable in the flume. Each sand was tested at three different slopes, 0.0010, 0.0015, and 0.0020, with the exception of the coarsest mixture, which was tested at slopes of 0.0030, 0.0040, and 0.0045.

The basic data derived from the experiments, along with corresponding calculated data, are tabulated in Tables 8 to 37, and are shown graphically on Plates 24 to 38. The du Boys expression for tractive force, involving the slope, depth, and unit weight of water, was adopted as the basis for the study of the results.

Critical tractive force data were obtained which checked Kramer's formula within a reasonable percentage of error. A slight modification of his curve was suggested, in order that the plotted points might be followed somewhat more closely, and it was suggested that a lower limit of applicability (for model use) be placed on his formula, corresponding to a mean grain size of sand mixture of about 0.6 mm. For sands of mean grain size smaller than 0.6, a new criterion for general movement (the "model" criterion) was proposed; i. e., that general movement be said to obtain when, (1) the sand in motion as bed-load is reasonably similar in composition to the original material of which the bed was formed, and when, (2) the rate of movement equals or exceeds 1 pound per foot width per hour, dry weight.

The following equation was derived empirically for the rate of sand movement of the nine mixtures.

$$W = \frac{1}{n}\left(\frac{DS - D_o S_o}{k_1}\right)^m$$

in which W is the rate of movement in pounds per foot width per hour (dry weight), n is the Manning roughness coefficient, DS is the product of the depth in feet and the slope, $D_o S_o$ is the depth-slope product at which the linear plot of W against DS meets the DS-axis, and m and k_1 are dimensional constants obtained from a logarithmic plot of the data. The range of values of each of these factors is summarized in Table 4.

A study was made of the values of Manning's n encountered in the experiments, and it was found that for flow on a smooth sand bed, before the formation of riffles, the values differed very little from an average of 0.0107. After the formation of riffles, however, there was a great variation in the values, the maximum being 0.0287. In general, the finer the sand mixture, the larger was the riffle size, and consequently the higher the value of n.

It was also discovered that the finer sands commenced to riffle at smaller values of tractive force than the value at which the coarser materials riffled. The tractive force values at which riffles appeared are summarized in Table 6, and actual bed profiles are shown on Plates 39 to 44.

Mean, bottom, and surface velocities were observed, and are recorded in Tables 8 to 37. While they were not used as a basis for the studies of bed movement, significant changes in their variation with depth were found at points corresponding to the change from laminar to turbulent flow conditions and the change from smooth to riffled sand bed.

From a study of the turbulence conditions in the experiments, it was concluded that turbulent flow in a straight flume was assured if the value of Reynolds' number for open channels was 2500 or more.

Emphasis is placed on the fact that only a limited field was covered in the research reported in this paper. An extension of the original series of experiments is now under way at the Experiment Station.

TABLE 8[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Flow on Cement Bottom. Test No. 0-0.0005. Slope 0.0005. December 9-12, 1933.

(1) Run No.	(2) Discharge. Q c. f. s.	(3) Depth. D Ft.	(4) Area[3] Cross-section. A Sq. Ft.	(5) Hydraulic Radius. R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity, Ft. per Sec. Mean	(8) Velocity, Ft. per Sec. Surface	(9) Velocity, Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number **R** Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(19) Nature of Flow
1	0.005	0.018	0.042	0.018	16.5	0.11	0.18		0.0209	0.002	160	0.76	Laminar
2	0.005	0.019	0.044	0.019	16.5	0.11	0.20		0.0206	0.002	180	0.78	"
3	0.009	0.022	0.051	0.022	16.7	0.18	0.30		0.0145	0.004	340	0.84	"
4	0.014	0.026	0.060	0.025	16.7	0.23	0.38		0.0125	0.006	500	0.92	"
5	0.017	0.027	0.063	0.026	17.0	0.27	0.41		0.0107	0.007	610	0.93	"
6	0.021	0.029	0.067	0.028	17.0	0.31	0.44		0.0098	0.009	760	0.97	Lam. and Turb.
7	0.022	0.032	0.074	0.031	16.8	0.30	0.43		0.0111	0.009	790	1.01	"
8	0.024	0.035	0.081	0.034	16.5	0.30	0.43		0.0117	0.010	860	1.06	"
9	0.026	0.036	0.083	0.035	16.[illegible]	0.31	0.42		0.0116	0.011	920	1.08	"
10	0.029	0.042	0.097	0.041	18.6	0.30	0.42		0.0132	0.012	1080	1.16	"
11	0.032	0.043	0.100	0.041	17.4	0.32	0.43		0.0122	0.013	1150	1.18	Turbulent
12	0.034	0.044	0.102	0.042	18.0	0.33	0.44		0.0119	0.014	1230	1.19	"
13	0.052	0.054	0.125	0.052	18.0	0.42	0.53		0.0112	0.022	1900	1.32	"
14	0.069	0.065	0.151	0.062	18.0	0.46	0.57		0.0113	0.028	2470	1.45	"
15	0.100	0.075	0.174	0.071	18.0	0.58	0.69	0.55	0.0099	0.041	3580	1.55	"
16	0.140	0.093	0.215	0.086	18.0	0.65	0.78	0.61	0.0100	0.056	4900	1.73	"
17	0.175	0.107	0.248	0.098	18.0	0.71	0.84	0.70	0.0099	0.069	6080	1.85	"
18	0.235	0.128	0.296	0.115	18.0	0.79	0.98	0.72	0.0098	0.091	8000	2.03	"
19	0.300	0.171	0.395	0.149	18.0	0.76	1.03	0.82	0.0123	0.113	9940	2.34	"
20	0.360	0.173	0.400	0.151	18.0	0.90	1.08	0.86	0.0104	0.136	11900	2.36	"
21	0.428	0.194	0.448	0.166	18.0	0.96	1.15	0.87	0.0104	0.159	13900	2.50	"
22	0.514	0.214	0.495	0.181	18.0	1.04	1.26	0.92	0.0102	0.188	16500	2.62	"
23	0.670	0.245	0.567	0.202	18.0	1.18	1.40	1.06	0.0096	0.239	21000	2.83	"
24	0.890	0.288	0.666	0.231	18.0	1.34	1.53	1.16	0.0094	0.309	27100	3.05	"
25	1.102	0.339	0.789	0.263	18.0	1.40	1.64	1.23	0.0097	0.368	32300	3.30	"
26	1.340	0.378	0.875	0.285	18.0	1.53	1.73	1.27	0.0094	0.437	38300	3.59	"
27	1.520	0.414	0.958	0.304	18.0	1.59	1.77	1.36	0.0094	0.483	42400	3.64	"
28	1.750	0.454	1.050	0.327	18.0	1.67	1.89	1.40	0.0095	0.543	47600	3.82	"
29	1.900	0.487	1.125	0.342	18.0	1.69	1.96		0.0096	0.578	50800	3.96	"
30	2.057	0.519	1.200	0.358	18.2	1.71	1.98		0.0097	0.612	54100	4.08	"
31	2.163	0.549	1.270	0.373	18.2	1.71	2.00		0.0101	0.636	56300	4.20	"
32	2.238	0.559	1.292	0.378	18.2	1.73	2.02		0.0101	0.654	57700	4.24	"
33	2.290	0.580	1.341	0.386	18.2	1.71	2.00		0.0103	0.658	58200	4.32	"

[1] See Plate 24. [2] All values in English units. [3] Width of flume 2.313 ft.

TABLE 9 [1]

Observed Data and Computed Results [2]

Flow on Cement Bottom. Test No. 0-0.0010. Slope 0.0010. December 5-8, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(19)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area [3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity, Ft. per Sec. Mean	Surface	Bottom	Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Nature of Flow
1	0.008	0.016	0.037	0.016	19.2	0.22	0.37	....	0.0137	0.003	310	0.72	Laminar
2	0.010	0.018	0.042	0.018	19.2	0.24	0.45	....	0.0136	0.004	390	0.76	"
3	0.012	0.019	0.044	0.019	19.2	0.27	0.51	....	0.0122	0.005	470	0.78	"
4	0.017	0.021	0.049	0.021	19.0	0.35	0.60	....	0.0102	0.007	660	0.82	"
5	0.023	0.024	0.055	0.023	19.0	0.42	0.61	....	0.0091	0.010	870	0.88	Lam. and Turb
6	0.028	0.028	0.065	0.027	19.5	0.43	0.55	....	0.0098	0.012	1050	0.95	"
7	0.032	0.032	0.074	0.031	19.3	0.43	0.57	....	0.0107	0.013	1220	1.01	Turbulent
8	0.038	0.035	0.081	0.034	19.3	0.47	0.60	....	0.0105	0.016	1450	1.06	"
9	0.050	0.041	0.095	0.040	19.3	0.53	0.67	....	0.0104	0.021	1920	1.15	"
10	0.065	0.048	0.111	0.046	19.2	0.59	0.74	....	0.0103	0.027	2430	1.24	"
11	0.090	0.058	0.134	0.055	19.3	0.67	0.84	....	0.0101	0.037	3360	1.36	"
12	0.120	0.069	0.160	0.065	19.2	0.75	0.95	....	0.0101	0.049	4400	1.49	"
13	0.168	0.084	0.194	0.078	19.2	0.87	1.08	....	0.0099	0.068	6080	1.65	"
14	0.228	0.101	0.234	0.093	19.2	0.98	1.24	....	0.0099	0.091	8170	1.82	"
15	0.291	0.116	0.268	0.105	19.2	1.09	1.35	....	0.0096	0.114	10300	1.93	"
16	0.397	0.139	0.322	0.124	19.2	1.23	1.49	....	0.0095	0.153	13800	2.11	"
17	0.505	0.162	0.374	0.142	19.2	1.35	1.67	....	0.0095	0.192	17300	2.28	"
18	0.597	0.183	0.423	0.158	19.2	1.41	1.70	....	0.0097	0.223	20100	2.42	"
19	0.670	0.195	0.451	0.167	19.2	1.49	1.79	....	0.0095	0.248	22400	2.51	"
20	0.692	0.198	0.458	0.169	18.0	1.51	1.87	....	0.0095	0.255	22400	2.52	"
21	0.763	0.217	0.502	0.183	18.0	1.52	1.91	....	0.0099	0.278	24400	2.64	"
22	0.840	0.242	0.560	0.200	18.0	1.50	1.89	....	0.0107	0.300	26300	2.78	"
23	0.889	0.244	0.565	0.202	17.0	1.57	1.93	1.45	0.0103	0.318	27200	2.80	"
24	0.960	0.256	0.592	0.209	17.0	1.62	1.96	1.47	0.0101	0.339	29000	2.87	"
25	1.040	0.274	0.635	0.222	17.0	1.64	2.00	1.47	0.0105	0.364	31100	2.96	"
26	1.250	0.294	0.680	0.234	17.0	1.84	2.13	1.54	0.0096	0.430	36800	3.07	"
27	1.420	0.314	0.726	0.247	17.0	1.96	2.18	1.54	0.0095	0.483	41300	3.17	"
28	1.610	0.341	0.789	0.264	17.0	2.04	2.36	1.70	0.0095	0.538	46000	3.31	"
29	1.770	0.364	0.842	0.276	17.2	2.10	2.42	1.72	0.0094	0.580	49600	3.42	"
30	1.960	0.388	0.897	0.291	17.2	2.19	2.50	1.84	0.0094	0.636	54400	3.53	"
31	2.174	0.414	0.957	0.304	17.2	2.27	2.60	1.92	0.0094	0.690	59000	3.64	"
32	2.255	0.434	1.002	0.315	17.8	2.25	2.71	2.05	0.0097	0.708	60600	3.73	"

[1] See Plate 24. [2] All values in English units. [3] Width of flume 2.313 ft.

TABLE 10[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Flow on Cement Bottom. Test No. 0-0.0015. Slope 0.0015. December 12-14, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(19)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity, Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number $\mathbf{R}$ Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Nature of Flow
						Mean	Surface	Bottom					
1	0.007	0.014	0.032	0.014	17.6	0.20	0.33	....	0.0159	0.003	240	0.67	Laminar
2	0.008	0.015	0.035	0.015	17.6	0.22	0.37	....	0.0155	0.003	280	0.70	"
3	0.010	0.016	0.037	0.016	17.6	0.26	0.40	....	0.0136	0.004	360	0.72	"
4	0.011	0.017	0.039	0.017	17.6	0.29	0.46	....	0.0128	0.005	420	0.74	"
5	0.016	0.019	0.044	0.019	18.9	0.36	0.57	....	0.0112	0.007	610	0.78	Lam. and Turb.
6	0.020	0.021	0.049	0.021	18.9	0.41	0.61	....	0.0108	0.008	750	0.82	"
7	0.022	0.022	0.051	0.022	17.9	0.43	0.62	....	0.0103	0.009	830	0.84	"
8	0.026	0.025	0.058	0.024	18.0	0.45	0.64	....	0.0109	0.011	970	0.90	"
9	0.031	0.028	0.065	0.027	18.2	0.48	0.65	....	0.0109	0.013	1170	0.95	"
10	0.035	0.030	0.069	0.029	18.4	0.50	0.67	....	0.0109	0.015	1320	0.98	Turbulent
11	0.048	0.036	0.083	0.035	18.4	0.57	0.75	....	0.0109	0.020	1780	1.08	"
12	0.090	0.050	0.116	0.048	18.4	0.78	0.94	....	0.0099	0.037	3330	1.27	"
13	0.139	0.065	0.150	0.062	18.5	0.92	1.13	0.98	0.0097	0.057	5060	1.45	"
14	0.190	0.077	0.179	0.072	18.6	1.07	1.28	1.13	0.0094	0.077	6920	1.58	"
15	0.260	0.094	0.218	0.087	18.6	1.20	1.46	1.27	0.0094	0.104	9350	1.74	"
16	0.385	0.118	0.273	0.107	18.6	1.41	1.71	1.47	0.0091	0.151	13700	1.95	"
17	0.605	0.152	0.352	0.135	18.6	1.72	2.02	1.57	0.0087	0.232	20800	2.21	"
18	0.815	0.188	0.435	0.162	18.6	1.87	2.25	1.69	0.0091	0.315	28400	2.46	"
19	1.020	0.219	0.507	0.184	18.7	2.02	2.41	....	0.0092	0.370	33200	2.66	"
20	1.210	0.244	0.565	0.202	18.7	2.14	2.50	....	0.0092	0.432	38800	2.80	"
21	1.320	0.259	0.600	0.212	18.7	2.20	2.54	....	0.0093	0.467	42000	2.89	"
22	1.470	0.279	0.645	0.225	18.7	2.28	2.63	....	0.0093	0.513	46300	2.98	"
23	1.660	0.304	0.704	0.241	18.8	2.36	2.78	....	0.0094	0.568	51200	3.13	"
24	1.930	0.334	0.772	0.259	18.8	2.50	2.94	....	0.0093	0.647	58300	3.28	"
25	2.112	0.359	0.831	0.274	18.8	2.54	3.03	....	0.0096	0.696	62700	3.40	"
26	2.267	0.369	0.854	0.280	18.8	2.66	3.18	....	0.0093	0.742	66800	3.45	"

[1] See Plate 24. [2] All values in English units. [3] Width of flume 2.313 ft.

TABLE 11[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 1. Mean Grain Size 0.5861 mm. Uniformity Modulus 0.2796. Test No. 1-0.0010. Slope 0.0010. June 19, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.006	0.015	0.036	0.015	27.0	0.17	No Observations	No Observations	0.0169	0.003	270	0.69					0.0009	No Observations	None	Smooth	
2	0.012	0.017	0.042	0.017	27.0	0.29			0.0107	0.005	530	0.74					0.0011		"	"	
3	0.029	0.027	0.066	0.026	27.0	0.44			0.0094	0.011	1240	0.93					0.0017		"	"	
4	0.053	0.039	0.095	0.038	27.0	0.56			0.0096	0.021	2310	1.20					0.0024		"	"	
5	0.083	0.054	0.131	0.051	27.0	0.63			0.0103	0.032	3510	1.32					0.0034		"	"	
6	0.109	0.062	0.149	0.059	27.0	0.73			0.0097	0.043	4700	1.41					0.0039		"	"	
7	0.131	0.070	0.169	0.066	27.0	0.78			0.0100	0.051	5560	1.50					0.0044		"	"	
8	0.168	0.080	0.194	0.075	27.0	0.87			0.0097	0.065	7050	1.60					0.0050		"	"	
9	0.196	0.090	0.218	0.084	27.0	0.90			0.0100	0.076	8200	1.70					0.0056		Weak	"	
10	0.227	0.096	0.232	0.089	27.0	0.98			0.0095	0.087	9450	1.75					0.0060		"	"	
11	0.256	0.106	0.256	0.097	27.0	1.00			0.0099	0.097	10500	1.85					0.0066		"	"	
12	0.287	0.113	0.273	0.103	27.0	1.05			0.0098	0.108	11800	1.90	61	0.2	0.568	0.600	0.0071		"	"	
13	0.308	0.118	0.286	0.107	27.0	1.08			0.0098	0.115	12500	1.95	45	0.5			0.0074		"	"	
14	0.348	0.127	0.307	0.115	27.0	1.13			0.0098	0.130	14200	2.02	22	1.3			0.0079		Medium	"	$T_c = 0.0077$ ("Model")
15	0.392	0.140	0.338	0.126	27.0	1.16			0.0101	0.146	15900	2.12	20	1.8	0.530	0.480	0.0087		General	"	$T_c = 0.0084$ (Visual)
16	0.435	0.156	0.377	0.138	27.0	1.15			0.0108	0.159	17300	2.24	15	2.1			0.0097		"	"	
17	0.490	0.166	0.401	0.146	27.0	1.22			0.0106	0.178	19400	2.31	14	3.3			0.0104		"	"	
18	0.534	0.180	0.436	0.158	27.0	1.22			0.0112	0.193	21000	2.40	15	4.4			0.0112		"	"	
19	0.595	0.187	0.452	0.163	27.0	1.32			0.0107	0.215	23400	2.45	12	5.6	0.598	0.410	0.0117		"	"	
20	0.651	0.206	0.498	0.176	27.0	1.31			0.0113	0.230	25000	2.57	12	5.5	0.558	0.388	0.0129		"	Local riffles	
21	0.720	0.214	0.517	0.182	27.0	1.39			0.0108	0.254	27500	2.62	12	8.7			0.0134		"	"	
22	0.762	0.227	0.549	0.191	27.0	1.39			0.0112	0.266	28800	2.70	11	8.2			0.0142		"	"	
23	0.825	0.240	0.580	0.200	27.0	1.42			0.0113	0.284	30900	2.77	10	8.6			0.0150		"	"	
24	0.935	0.252	0.608	0.208	27.0	1.54			0.0107	0.320	34800	2.84	10	13.4	0.555	0.349	0.0157		"	General riffles	
25	1.000	0.276	0.667	0.225	27.0	1.50			0.0116	0.337	36600	2.98	12	9.9			0.0172		"	"	
26	1.050	0.291	0.704	0.235	27.0	1.49			0.0119	0.350	38100	3.06	10	11.9			0.0182		"	"	
27	1.115	0.302	0.730	0.242	27.0	1.53			0.0119	0.370	40100	3.11	10	11.4			0.0189		"	"	
28	1.160	0.310	0.750	0.247	27.0	1.55			0.0120	0.382	41500	3.15	10	13.7			0.0194		"	"	
29	1.260	0.322	0.778	0.254	27.0	1.62			0.0116	0.401	44600	3.21	10	20.1			0.0201		"	"	

[1] See Plate 25.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 feet.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 12[1]

Observed Data and Computed Results[2]

Sand No. 1. Mean Grain Size 0.5861 mm. Uniformity Modulus 0.2796. Test No. 1-0.0015. Slope 0.0015. May 25, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	[5]Water Temperature, Degrees Centigrade	Velocity Ft. per Sec. Mean	Velocity Ft. per Sec. Surface	Velocity Ft. per Sec. Bottom	Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
1	0.009	0.017	0.041	0.017	27.0	0.22	No Observations	No Observations	0.0170	0.004	410	0.74	......	......	......	......	0.0016	No Observations	None	Smooth	
2	0.017	0.020	0.048	0.020	27.0	0.35			0.0120	0.007	770	0.80	......	......	......	......	0.0019		"	"	
3	0.035	0.030	0.073	0.029	27.0	0.48			0.0114	0.014	1520	0.98	......	......	......	......	0.0028		"	"	
4	0.066	0.042	0.102	0.041	27.0	0.65			0.0107	0.027	2890	1.16	......	......	......	......	0.0039		"	"	
5	0.101	0.054	0.131	0.052	27.0	0.77			0.0103	0.040	4370	1.32	......	......	......	......	0.0051		Weak	"	
6	0.134	0.062	0.150	0.059	27.0	0.89			0.0098	0.053	5730	1.41	60	0.1	0.507	0.274	0.0058		"	"	
7	0.169	0.071	0.172	0.067	27.0	0.98			0.0097	0.066	7160	1.51	42	0.5	......	......	0.0067		Medium	"	
8	0.217	0.085	0.206	0.080	27.0	1.65			0.0101	0.084	9150	1.65	20	1.6	......	......	0.0080		General	"	$\Gamma_c = 0.0072$ ("Model")
9	0.241	0.090	0.218	0.084	27.0	1.10			0.0100	0.093	10100	1.70	25	1.9	0.607	0.509	0.0084		"	"	
10	0.267	0.099	0.239	0.091	27.0	1.12			0.0105	0.102	11100	1.78	18	2.1	......	......	0.0093		"	"	$T_c = 0.0092$ (Visual)
11	0.314	0.108	0.261	0.099	27.0	1.20			0.0102	0.119	12900	1.86	21	3.5	......	......	0.0101		"	Local riffles	
12	0.338	0.118	0.286	0.108	27.0	1.18			0.0110	0.128	13900	1.95	20	3.9	0.532	0.440	0.0111		"	"	
13	0.365	0.125	0.303	0.113	27.0	1.20			0.0111	0.136	14800	2.00	17	3.8	......	......	0.0117		"	"	
14	0.390	0.133	0.321	0.120	27.0	1.21			0.0115	0.146	15800	2.07	20	4.5	......	......	0.0125		"	"	
15	0.416	0.137	0.331	0.123	27.0	1.25			0.0113	0.154	16800	2.10	20	5.3	0.714	0.411	0.0128		"	"	
16	0.462	0.147	0.355	0.131	27.0	1.30			0.0114	0.170	18500	2.17	17	7.3	......	......	0.0138		"	"	
17	0.490	0.153	0.370	0.136	27.0	1.32			0.0115	0.180	19600	2.22	17	9.6	......	......	0.0143		"	"	
18	0.526	0.159	0.384	0.141	27.0	1.37			0.0114	0.193	20900	2.26	16	11.4	0.537	0.384	0.0149		"	"	
19	0.562	0.165	0.400	0.145	27.0	1.41			0.0113	0.235	25500	2.30	14	12.2	......	......	0.0155		"	"	
20	0.607	0.175	0.423	0.153	27.0	1.44			0.0114	0.220	23900	2.37	16	13.5	......	......	0.0164		"	"	
21	0.648	0.183	0.442	0.159	27.0	1.47			0.0115	0.232	25400	2.42	14	12.7	......	......	0.0171		"	"	
22	0.681	0.190	0.459	0.165	27.0	1.49			0.0117	0.245	26600	2.47	16	13.7	0.529	0.383	0.0178		"	General riffles	
23	0.747	0.204	0.493	0.175	27.0	1.52			0.0119	0.265	28800	2.56	15	15.5	......	......	0.0191		"	"	
24	0.783	0.211	0.510	0.180	27.0	1.54			0.0120	0.277	30100	2.60	12	16.9	......	......	0.0198		"	"	
25	0.814	0.217	0.524	0.184	27.0	1.55			0.0120	0.286	31100	2.64	13	18.4	0.515	0.394	0.0203		"	"	
26	0.835	0.218	0.527	0.185	27.0	1.58			0.0118	0.293	31900	2.65	12	21.4	......	......	0.0204		"	"	
27	0.880	0.227	0.549	0.191	27.0	1.60			0.0119	0.306	33300	2.70	12	23.7	......	......	0.0213		"	"	
28	0.902	0.238	0.574	0.199	27.0	1.57			0.0125	0.313	34000	2.76	12	15.7	0.534	0.415	0.0223		"	"	
29	1.066	0.257	0.621	0.212	27.0	1.72			0.0120	0.364	39600	2.87	10	28.6	......	......	0.0241		"	"	
30	1.105	0.270	0.652	0.221	27.0	1.69			0.0124	0.374	40700	2.94	10	25.7	......	......	0.0253		"	"	

1 See Plate 25.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 13[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 1. Mean Grain Size 0.5861 mm. Uniformity Modulus 0.2796. Test No. 1-0.0020. Slope 0.0020. May 17, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius R Ft.	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.010	0.015	0.036	0.015	27.0	0.28	No Observations	No Observations	0.0144	0.004	450	0.69	----	----	----	----	0.0019	No Observations	None	Smooth	
2	0.019	0.017	0.041	0.017	27.0	0.46			0.0095	0.008	860	0.74	----	----	----	----	0.0021		"	"	
3	0.033	0.026	0.063	0.025	27.0	0.52			0.0110	0.013	1430	0.91	----	----	----	----	0.0032		"	"	
4	0.076	0.042	0.101	0.040	27.0	0.75			0.0104	0.030	3280	1.16	----	----	----	----	0.0052		Weak	"	
5	0.116	0.053	0.128	0.051	27.0	0.91			0.0102	0.046	5010	1.30	110	0.1	----	----	0.0066		"	"	
6	0.152	0.063	0.152	0.060	27.0	1.00			0.0102	0.060	6520	1.42	84	0.7	0.679	0.522	0.0079		Medium	"	$T_c = 0.0081$ ("Model")
7	0.184	0.070	0.169	0.066	27.0	1.09			0.0100	0.072	7800	1.50	30	2.1	----	----	0.0087		General	"	
8	0.222	0.081	0.196	0.076	27.0	1.13			0.0105	0.086	9330	1.61	30	2.8	----	----	0.0101		"	"	$T_c = 0.0107$ (Visual)
9	0.258	0.087	0.210	0.081	27.0	1.23			0.0102	0.100	10800	1.67	30	4.8	----	----	0.0109		"	Local riffles	
10	0.297	0.099	0.239	0.092	27.0	1.24			0.0110	0.114	12400	1.78	32	5.2	0.459	0.370	0.0124		"	"	
11	0.332	0.108	0.262	0.099	27.0	1.27			0.0113	0.125	13600	1.86	35	5.2	----	----	0.0135		"	"	
12	0.363	0.116	0.280	0.106	27.0	1.30			0.0114	0.137	14900	1.93	24	9.7	----	----	0.0145		"	"	
13	0.400	0.124	0.300	0.112	27.0	1.33			0.0116	0.150	16300	1.99	29	12.5	----	----	0.0155		"	"	
14	0.418	0.131	0.316	0.119	27.0	1.32			0.0122	0.158	17200	2.05	29	9.3	0.514	0.413	0.0164		"	General riffles	
15	0.505	0.141	0.341	0.127	27.0	1.48			0.0114	0.188	20400	2.13	29	17.0	----	----	0.0176		"	"	
16	0.573	0.158	0.382	0.140	27.0	1.50			0.0119	0.210	22800	2.25	20	16.4	----	----	0.0197		"	"	
17	0.648	0.178	0.430	0.155	27.0	1.51			0.0128	0.234	25400	2.39	26	15.5	----	----	0.0222		"	"	
18	0.735	0.188	0.454	0.163	27.0	1.62			0.0122	0.264	28700	2.46	23	22.4	----	----	0.0235		"	"	
19	0.785	0.198	0.478	0.170	27.0	1.64			0.0125	0.279	30400	2.52	17	25.7	0.545	0.340	0.0247		"	"	
20	0.860	0.209	0.505	0.178	27.0	1.70			0.0124	0.304	33000	2.59	10	32.4	----	----	0.0261		"	"	
21	0.957	0.220	0.531	0.186	27.0	1.80			0.0121	0.335	36400	2.66	13	32.8	0.545	0.376	0.0275		"	"	

1 See Plate 26.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 14 [1]

OBSERVED DATA AND COMPUTED RESULTS [2]

Sand No. 2. Mean Grain Size 0.5409 mm. Uniformity Modulus 0.4388. Test No. 2-0.0010. Slope 0.0010. September 5, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area [3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement [4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.014	0.034	0.014	27.0	0.15	No Observations	No Observations	0.0185	0.002	220	0.67	......	......	......	......	0.0009	No Observations	None	Smooth	
2	0.015	0.018	0.044	0.018	27.0	0.34			0.0094	0.006	670	0.76	......	......	......	......	0.0011		"	"	
3	0.029	0.031	0.075	0.033	27.0	0.39			0.0125	0.013	1390	1.00	......	......	......	......	0.0019		"	"	
4	0.062	0.047	0.113	0.045	27.0	0.55			0.0109	0.025	2680	1.23	......	......	......	......	0.0029		"	"	
5	0.100	0.063	0.152	0.060	27.0	0.66			0.0109	0.040	4290	1.43	......	......	......	......	0.0039		"	"	
6	0.127	0.074	0.179	0.070	27.0	0.71			0.0113	0.050	5400	1.54	......	......	......	......	0.0046		"	"	
7	0.157	0.087	0.210	0.081	27.0	0.75			0.0119	0.061	6580	1.67	......	......	......	......	0.0054		"	"	
8	0.193	0.096	0.232	0.089	27.0	0.83			0.0113	0.074	8060	1.76	......	......	......	......	0.0060		"	"	
9	0.267	0.119	0.288	0.108	27.0	0.93			0.0114	0.100	10900	1.96	45	0.6	0.742	0.533	0.0074		Weak	"	
10	0.315	0.131	0.317	0.118	27.0	0.99			0.0114	0.117	12700	2.05	40	1.1	......	......	0.0082		"	"	$T_c = 0.0080$ (Visual)
11	0.390	0.151	0.365	0.134	27.0	1.07			0.0114	0.144	15600	2.20	25	2.7	0.714	0.487	0.0094		Medium	"	
12	0.470	0.172	0.416	0.151	27.0	1.13			0.0117	0.171	18500	2.35	26	4.0	......	......	0.0107		"	"	
13	0.560	0.193	0.466	0.166	27.0	1.20			0.0118	0.200	21700	2.49	33	5.5	0.571	0.465	0.0120		General	"	
14	0.743	0.237	0.572	0.197	27.0	1.30			0.0123	0.256	27800	2.76	28	7.0	0.502	0.518	0.0148		"	General riffles	$T_c = 0.0130$ ("Model")
15	0.834	0.255	0.616	0.210	27.0	1.35			0.0123	0.284	30900	2.86	25	8.0	0.481	0.496	0.0159		"	"	
16	0.900	0.270	0.652	0.221	27.0	1.38			0.0125	0.305	33200	2.95	20	9.7	......	......	0.0169		"	"	
17	0.995	0.286	0.691	0.232	27.0	1.44			0.0123	0.334	36300	3.04	20	9.7	0.510	0.475	0.0179		"	"	
18	1.087	0.304	0.735	0.243	27.0	1.48			0.0124	0.359	39000	3.12	20	15.1	......	......	0.0190		"	"	
19	1.180	0.321	0.775	0.254	27.0	1.52			0.0124	0.387	42100	3.21	15	15.8	0.552	0.455	0.0200		"	"	
20	1.300	0.351	0.848	0.272	27.0	1.53			0.0129	0.417	45300	3.36	12	20.0	......	......	0.0219		"	"	
21	1.430	0.383	0.925	0.291	27.0	1.55			0.0133	0.450	48900	3.50	10	28.4	......	......	0.0239		"	"	

[1] See Plate 26.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 ft.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 15[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 2. Mean Grain Size 0.5409 mm. Uniformity Modulus 0.4388. Test No. 2-0.0015. Slope 0.0015. August 25, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.002	0.010	0.024	0.010	27.0	0.07	No Observations	No Observations	0.0361	0.001	70	0.57	......	......	......	......	0.0009	Laminar	None	Smooth	
2	0.006	0.011	0.026	0.011	27.0	0.25			0.0112	0.003	300	0.59	......	......	......	......	0.0010	"	"	"	
3	0.008	0.012	0.029	0.012	27.0	0.27			0.0113	0.003	350	0.62	......	......	......	......	0.0011	"	"	"	
4	0.010	0.013	0.032	0.013	27.0	0.31			0.0102	0.004	430	0.65	......	......	......	......	0.0012	"	"	"	
5	0.012	0.014	0.034	0.014	27.0	0.37			0.0088	0.005	560	0.67	......	......	......	......	0.0013	"	"	"	
6	0.015	0.016	0.039	0.016	27.0	0.39			0.0093	0.006	670	0.72	......	......	......	......	0.0015	"	"	"	
7	0.018	0.019	0.046	0.019	27.0	0.39			0.0107	0.007	800	0.78	......	......	......	......	0.0018	"	"	"	
8	0.019	0.024	0.058	0.023	27.0	0.34			0.0139	0.008	840	0.88	......	......	......	......	0.0022	Lam. & Turb.	"	"	
9	0.022	0.027	0.066	0.027	27.0	0.34			0.0153	0.009	990	0.93	......	......	......	......	0.0025	"	"	"	
10	0.027	0.031	0.075	0.030	27.0	0.36			0.0154	0.011	1180	1.00	......	......	......	......	0.0029	"	"	"	
11	0.106	0.062	0.150	0.059	27.0	0.71			0.0123	0.042	4540	1.41	......	......	......	......	0.0058	Turbulent	Weak	"	
12	0.161	0.080	0.194	0.075	27.0	0.83			0.0123	0.062	6760	1.60	......	......	......	......	0.0075	"	"	"	$T_c = 0.0090$ (Visual)
13	0.227	0.097	0.234	0.090	27.0	0.97			0.0119	0.088	9510	1.76	21	1.2	0.784	0.438	0.0091	"	"	"	
14	0.297	0.114	0.276	0.104	27.0	1.08			0.0117	0.112	12200	1.91	8	4.4	0.831	0.460	0.0107	"	Medium	"	
15	0.412	0.140	0.338	0.125	27.0	1.22			0.0118	0.153	16600	2.12	8	6.6	0.791	0.404	0.0131	"	General	Local riffles	
16	0.476	0.157	0.380	0.139	27.0	1.25			0.0123	0.174	19000	2.24	19	7.6	......	......	0.0147	"	"	General riffles	$T_c = 0.0180$ ("Model")
17	0.760	0.218	0.527	0.187	27.0	1.44			0.0130	0.270	29400	2.65	10	14.0	......	......	0.0204	"	"	"	
18	0.836	0.234	0.565	0.199	27.0	1.48			0.0132	0.295	32100	2.74	15	11.0	0.494	0.508	0.0219	"	"	"	
19	0.923	0.251	0.608	0.208	27.0	1.52			0.0133	0.316	34400	2.84	9	19.2	......	......	0.0235	"	"	"	
20	1.040	0.271	0.655	0.222	27.0	1.59			0.0133	0.352	38300	2.94	10	31.6	......	......	0.0254	"	"	"	
21	1.226	0.308	0.745	0.246	27.0	1.65			0.0137	0.405	44000	3.14	10	30.2	......	......	0.0288	"	"	"	
22	1.390	0.335	0.810	0.262	27.0	1.72			0.0137	0.450	48800	3.28	10	26.6	0.534	0.482	0.0313	"	"	"	
23	1.460	0.361	0.872	0.278	27.0	1.67			0.0146	0.465	50600	3.40	10	18.4	......	......	0.0338	"	"	"	
24	1.816	0.413	0.997	0.307	27.0	1.82			0.0144	0.558	60800	3.64	7	66.3	0.554	0.463	0.0387	"	"	"	

[1] See Plate 27.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 ft.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 16 [1]

OBSERVED DATA AND COMPUTED RESULTS [2]

Sand No. 2. Mean Grain Size 0.5409 mm. Uniformity Modulus 0.4388. Test No. 2-0.0020. Slope 0.0020. August 15, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area [3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5] Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement [4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.007	0.012	0.029	0.012	27.0	0.24	No Observations	No Observations	0.0143	0.003	310	0.62	.....	.....	.....	.....	0.0015	Laminar	None	Smooth	
2	0.010	0.013	0.031	0.013	27.0	0.32			0.0111	0.004	460	0.65	.....	.....	.....	.....	0.0016	"	"	"	
3	0.015	0.017	0.041	0.017	27.0	0.37			0.0118	0.006	680	0.74	.....	.....	.....	.....	0.0021	Lam. & Turb	"	"	
4	0.019	0.020	0.048	0.020	27.0	0.40			0.0124	0.008	860	0.80	.....	.....	.....	.....	0.0025	"	"	"	
5	0.024	0.025	0.060	0.024	27.0	0.40			0.0138	0.010	1040	0.90	.....	.....	.....	.....	0.0031	Turbulent	"	"	
6	0.037	0.032	0.077	0.031	27.0	0.48			0.0138	0.015	1620	1.01	.....	.....	.....	.....	0.0040	"	"	"	
7	0.099	0.054	0.130	0.052	27.0	0.76			0.0121	0.040	4300	1.32	.....	.....	.....	.....	0.0067	"	Weak	"	
8	0.125	0.064	0.155	0.061	27.0	0.81			0.0128	0.049	5350	1.43	.....	.....	.....	.....	0.0080	"	"	"	
9	0.150	0.072	0.174	0.068	27.0	0.86			0.0128	0.059	6370	1.52	31	0.1	0.739	0.396	0.0090	"	"	"	
10	0.187	0.082	0.198	0.077	27.0	0.94			0.0127	0.073	7880	1.62	10	3.7	0.783	0.491	0.0102	"	General	"	$T_c = 0.0095$ (Visual)
11	0.241	0.092	0.222	0.085	27.0	1.09			0.0118	0.092	10000	1.72	8	4.8	0.796	0.434	0.0115	"	"	Local riffles	
12	0.287	0.103	0.249	0.095	27.0	1.15			0.0120	0.109	11900	1.82	7	6.5	0.632	0.457	0.0129	"	"	"	
13	0.379	0.128	0.309	0.116	27.0	1.23			0.0128	0.142	15400	2.03	8	4.7	.....	.....	0.0160	"	"	General riffles	$T_c = 0.0170$ ("Model")
14	0.456	0.146	0.353	0.130	27.0	1.29			0.0132	0.168	18300	2.16	22	10.1	.....	.....	0.0182	"	"	"	
15	0.550	0.165	0.399	0.145	27.0	1.38			0.0132	0.200	21700	2.30	10	14.0	0.525	0.507	0.0206	"	"	"	
16	0.660	0.193	0.466	0.167	27.0	1.42			0.0142	0.236	25700	2.49	10	19.8	.....	.....	0.0241	"	"	"	
17	0.750	0.210	0.508	0.179	27.0	1.48			0.0143	0.264	28700	2.60	10	27.4	0.493	0.446	0.0262	"	"	"	
18	0.820	0.223	0.539	0.188	27.0	1.53			0.0143	0.287	31200	2.68	8	30.1	.....	.....	0.0278	"	"	"	
19	0.924	0.235	0.568	0.197	27.0	1.63			0.0138	0.321	34800	2.75	7	26.8	0.511	0.517	0.0294	"	"	"	
20	0.998	0.248	0.600	0.206	27.0	1.66			0.0140	0.343	37200	2.82	8	25.4	.....	.....	0.0310	"	"	"	
21	1.080	0.264	0.638	0.217	27.0	1.69			0.0142	0.368	39900	2.91	7	52.3	.....	.....	0.0330	"	"	"	
23	1.238	0.287	0.693	0.232	27.0	1.79			0.0140	0.415	45100	3.03	5	47.4	.....	.....	0.0358	"	"	"	Run No. 22 discarded. Non-uniform flow.
24	1.298	0.302	0.730	0.242	27.0	1.78			0.0145	0.431	46800	3.11	5	35.8	0.612	0.432	0.0377	"	"	"	

[1] See Plate 27.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 ft.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 17 [1]

Observed Data and Computed Results [2]

Sand No. 3. Mean Grain Size 0.5246 mm. Uniformity Modulus 0.5385. Test No. 3-0.0010. Slope 0.0010. January 15, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area [3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement [4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.004	0.013	0.031	0.013	15.0	0.11	0.15		0.0227	0.002	120	0.65					0.0008	Laminar	None	Smooth	
2	0.009	0.018	0.042	0.018	14.5	0.22	0.27		0.0140	0.004	310	0.76					0.0011	..	..	..	
3	0.015	0.021	0.049	0.021	14.5	0.30	0.41		0.0120	0.006	500	0.82					0.0013	..	..	..	
4	0.020	0.024	0.056	0.023	15.0	0.37	0.49		0.0105	0.009	700	0.88					0.0015	Lam. & Turb.	..	..	
5	0.029	0.032	0.074	0.031	15.3	0.39	0.51		0.0120	0.012	990	1.02					0.0020	..	..	..	
6	0.038	0.038	0.088	0.037	15.4	0.43	0.55		0.0122	0.016	1290	1.11					0.0024	Turbulent	..	..	
7	0.049	0.044	0.102	0.042	16.2	0.48	0.60		0.0120	0.020	1700	1.19					0.0027	..	..	..	
8	0.060	0.049	0.113	0.047	16.2	0.53	0.65		0.0117	0.025	2090	1.26					0.0031	..	..	..	
9	0.074	0.057	0.132	0.054	16.2	0.56	0.70		0.0121	0.031	2560	1.35					0.0036	..	..	..	
10	0.090	0.062	0.143	0.059	16.2	0.63	0.75		0.0113	0.037	3110	1.41					0.0039	..	..	..	
11	0.105	0.067	0.155	0.063	16.3	0.68	0.82	0.74	0.0110	0.043	3620	1.47					0.0042	..	..	..	
12	0.129	0.075	0.174	0.070	16.5	0.74	0.87	0.80	0.0108	0.052	4440	1.56					0.0047	..	..	..	
13	0.145	0.082	0.190	0.077	16.5	0.77	0.91	0.82	0.0111	0.059	4970	1.63					0.0051	..	..	..	
14	0.163	0.088	0.204	0.082	16.5	0.80	0.96	0.86	0.0111	0.066	5550	1.69					0.0055	..	..	..	
15	0.186	0.095	0.220	0.088	17.5	0.82	1.05	0.97	0.0109	0.074	6450	1.75	60	0.05	0.675	0.564	0.0059	..	Very weak	..	
16	0.207	0.100	0.231	0.092	16.0	0.90	1.11	1.05	0.0107	0.082	6860	1.80	79	0.03	0.687	0.549	0.0062	..	Weak	..	
17	0.235	0.108	0.250	0.099	16.2	0.94	1.13	1.03	0.0107	0.093	7810	1.87	56	0.2	0.694	0.571	0.0067	..	..	..	
18	0.260	0.117	0.271	0.106	16.4	0.96	1.17	1.05	0.0110	0.102	8630	1.94	60	0.2	0.690	0.557	0.0073	..	Medium	..	
19	0.299	0.126	0.292	0.114	16.4	1.00	1.24	1.14	0.0107	0.116	9820	2.02	64	0.5	0.643	0.554	0.0079	..	..	..	$T_c = 0.0085$
20	0.331	0.136	0.315	0.122	16.5	1.03	1.28	1.15	0.0110	0.128	10800	2.10	50	1.0	0.604	0.638	0.0085	..	General	..	(Visual)
21	0.399	0.154	0.356	0.136	16.8	1.10	1.36	1.19	0.0111	0.153	13000	2.22	36	2.0	0.639	0.583	0.0096	..	..	Local riffles	
22	0.470	0.239	0.553	0.198	17.0	0.85	1.04	0.68	0.0188	0.138	14400	2.77					0.0149	..	..	General riffles	
23	0.587	0.279	0.646	0.225	17.0	0.90	1.16	0.73	0.0192	0.204	17500	2.99	64	0.3	0.484	0.656	0.0174	..	..	..	$T_c = 0.0198$
24	0.729	0.323	0.748	0.253	17.0	0.98	1.27	0.83	0.0193	0.247	21200	3.22	54	1.1	0.510	0.590	0.0202	..	..	..	("Model")
25	0.870	0.336	0.777	0.260	16.8	1.12	1.46	0.95	0.0171	0.291	24900	3.30	69	4.2	0.489	0.565	0.0210	..	..	..	
26	1.050	0.370	0.856	0.281	17.0	1.21	1.56	1.06	0.0164	0.345	29600	3.46	61	6.9	0.536	0.566	0.0231	..	..	..	
27	1.260	0.408	0.944	0.302	17.0	1.32	1.61	1.19	0.0159	0.404	34700	3.62	60	12.9	0.493	0.599	0.0255	..	..	..	
28	1.450	0.438	1.012	0.318	17.0	1.43	1.69	1.02	0.0153	0.454	38900	3.76	45	12.0	0.533	0.554	0.0273	..	..	..	
29	1.721	0.476	1.101	0.337	17.0	1.56	1.89	0.92	0.0146	0.527	45300	3.92	50	18.3	0.520	0.534	0.0297	..	..	..	
30	1.975	0.551	1.276	0.374	17.0	1.55	1.96	1.23	0.0158	0.579	49700	4.22	40	30.5	0.481	0.584	0.0344	..	..	..	
31	2.267	0.623	1.441	0.406	17.0	1.57	2.10	1.46	0.0165	0.639	54800	4.49	30	31.9	0.538	0.545	0.0389	..	..	..	

[1] See Plate 28.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.313 ft.
[4] Dry weight.

TABLE 18 [1]

OBSERVED DATA AND COMPUTED RESULTS [2]

Sand No. 3. Mean Grain Size 0.5246 mm. Uniformity Modulus 0.5385. Test No. 3-0.0015. Slope 0.0015. December 19, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area [3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity Ft. per Sec. Mean	Surface	Bottom	Manning's n	Turbulence Criterion VR	Reynolds' Number $\mathbf{R}$ Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement [4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
1	0.006	0.016	0.057	0.016	18.0	0.16	0.34	......	0.0217	0.003	230	0.72	......	......	......	......	0.0015	Laminar	None	Smooth	
2	0.007	0.017	0.039	0.017	18.0	0.17	0.36	......	0.0224	0.003	240	0.74	......	......	......	......	0.0016	"	"	"	
3	0.008	0.018	0.042	0.018	18.0	0.19	0.41	......	0.0203	0.003	290	0.76	......	......	......	......	0.0017	"	"	"	
4	0.011	0.019	0.044	0.019	18.0	0.24	0.45	......	0.0169	0.004	400	0.78	......	......	......	......	0.0018	"	"	"	
5	0.014	0.021	0.049	0.021	18.0	0.29	0.54	......	0.0152	0.006	530	0.82	......	......	......	......	0.0020	"	"	"	
6	0.018	0.023	0.053	0.023	18.8	0.34	0.60	......	0.0136	0.008	690	0.86	......	......	......	......	0.0022	Lam. & Turb.	"	"	
7	0.021	0.025	0.058	0.024	18.8	0.35	0.58	......	0.0137	0.009	780	0.90	......	......	......	......	0.0023	"	"	"	
8	0.025	0.028	0.065	0.027	19.0	0.39	0.57	......	0.0136	0.011	960	0.95	......	......	......	......	0.0026	"	"	"	
9	0.030	0.031	0.072	0.030	19.0	0.41	0.59	......	0.0137	0.012	1130	1.00	......	......	......	......	0.0029	Turbulent	"	"	
10	0.038	0.035	0.081	0.034	19.0	0.46	0.64	......	0.0132	0.016	1430	1.06	......	......	......	......	0.0033	"	"	"	
11	0.045	0.040	0.093	0.039	19.2	0.49	0.70	......	0.0135	0.019	1710	1.13	......	......	......	......	0.0037	"	"	"	
12	0.058	0.045	0.104	0.043	19.2	0.56	0.75	......	0.0128	0.024	2200	1.27	......	......	......	......	0.0042	"	"	"	
13	0.077	0.052	0.121	0.050	19.4	0.64	0.84	......	0.0122	0.032	2900	1.29	......	......	......	......	0.0049	"	"	"	
14	0.085	0.054	0.125	0.052	19.4	0.68	0.86	......	0.0118	0.035	3210	1.32	......	......	......	......	0.0051	"	"	"	
15	0.080	0.055	0.127	0.053	18.1	0.63	0.82	0.84	0.0129	0.033	2920	1.33	......	......	......	......	0.0051	"	"	"	
16	0.088	0.058	0.134	0.055	19.0	0.66	0.85	0.84	0.0128	0.036	3280	1.37	......	......	......	......	0.0054	"	"	"	
17	0.095	0.060	0.139	0.057	19.0	0.69	0.86	0.84	0.0124	0.039	3540	1.39	......	......	......	......	0.0056	"	Very weak	"	
18	0.105	0.064	0.148	0.061	19.0	0.71	0.90	0.85	0.0125	0.043	3880	1.43	......	......	......	......	0.0060	"	"	"	
19	0.115	0.067	0.155	0.063	19.0	0.74	0.93	0.85	0.0122	0.047	4250	1.47	......	......	......	......	0.0063	"	"	"	
20	0.130	0.072	0.167	0.068	19.0	0.78	0.99	0.89	0.0122	0.053	4800	1.52	......	......	......	......	0.0067	"	Weak	"	
21	0.140	0.076	0.176	0.071	19.0	0.80	1.03	0.91	0.0124	0.057	5150	1.56	......	......	......	......	0.0071	"	"	"	
22	0.160	0.081	0.187	0.076	19.0	0.85	1.09	0.92	0.0121	0.065	5850	1.61	......	......	......	......	0.0076	"	"	"	
23	0.176	0.087	0.201	0.081	19.0	0.87	1.14	0.93	0.0125	0.071	6400	1.67	61	0.1	0.769	0.536	0.0081	"	Medium	"	
24	0.195	0.092	0.213	0.085	19.2	0.92	1.17	0.94	0.0123	0.077	7020	1.72	60	0.3	0.741	0.569	0.0086	"	"	"	
25	0.210	0.099	0.229	0.091	19.4	0.92	1.22	1.09	0.0128	0.084	7640	1.79	40	1.2	0.641	0.572	0.0093	"	"	"	$T_c = 0.0090$ (Visual)
26	0.240	0.105	0.243	0.096	19.5	0.99	1.25	1.10	0.0123	0.095	8700	1.84	30	1.7	0.632	0.563	0.0098	"	General	"	
27	0.250	0.109	0.252	0.100	19.0	0.99	1.28	1.10	0.0124	0.099	8930	1.87	30	1.6	0.665	0.539	0.0102	"	"	"	
28	0.275	0.116	0.269	0.106	19.0	1.02	1.34	1.11	0.0126	0.108	9770	1.93	30	2.6	0.530	0.599	0.0109	"	"	Local riffles	
29	0.345	0.194	0.449	0.166	19.0	0.77	1.02	......	0.0226	0.127	11500	2.50	61	0.5	0.515	0.577	0.0182	"	"	General riffles	
30	0.450	0.227	0.525	0.190	19.0	0.86	1.07	0.78	0.0222	0.163	14700	2.70	73	0.6	0.517	0.566	0.0213	"	"	"	
31	0.580	0.249	0.576	0.205	18.5	1.01	1.27	0.83	0.0199	0.206	18400	2.83	62	3.3	0.488	0.588	0.0233	"	"	"	$T_c = 0.0215$ ("Model")
32	0.720	0.260	0.602	0.213	18.5	1.20	1.49	0.88	0.0171	0.255	22800	2.89	77	7.0	0.532	0.547	0.0244	"	"	Large riffles	
33	0.860	0.281	0.650	0.226	19.0	1.32	1.68	1.03	0.0162	0.301	27300	3.00	63	9.4	0.497	0.580	0.0263	"	"	"	
34	1.030	0.316	0.730	0.248	18.5	1.41	1.84	1.07	0.0162	0.350	31200	3.18	70	19.5	0.542	0.524	0.0296	"	"	"	
35	1.225	0.388	0.897	0.291	18.5	1.37	1.91	0.94	0.0189	0.391	34900	3.53	58	22.2	0.560	0.500	0.0363	"	"	"	
36	1.475	0.441	1.020	0.320	18.5	1.45	1.89	1.07	0.0187	0.462	41200	3.76	46	41.8	0.559	0.520	0.0413	"	"	Sand waves	

[1] See Plate 28. [2] All values in English units except grain size in millimeters. [3] Width of flume 2.313 ft. [4] Dry weight.

TABLE 19[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 3. Mean Grain Size 0.5246 mm. Uniformity Modulus 0.5385. Test No. 3-0.0020. Slope 0.0020. January 26-31, 1934.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity Ft. per Sec. Mean	Velocity Ft. per Sec. Surface	Velocity Ft. per Sec. Bottom	Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
1	0.005	0.012	0.028	0.012	16.0	0.18	0.27		0.0187	0.002	180	0.62					0.0015	Laminar	None	Smooth	
2	0.007	0.013	0.030	0.013	16.0	0.23	0.35		0.0157	0.003	240	0.65					0.0016	"	"	"	
3	0.009	0.014	0.032	0.014	16.0	0.27	0.41		0.0136	0.004	320	0.67					0.0017	"	"	"	
4	0.011	0.015	0.035	0.015	16.0	0.32	0.51		0.0126	0.005	390	0.70					0.0019	"	"	"	
5	0.013	0.016	0.037	0.016	16.0	0.36	0.56		0.0114	0.006	470	0.72					0.0020	"	"	"	
6	0.014	0.017	0.039	0.017	16.5	0.36	0.58		0.0121	0.006	510	0.74					0.0021	Lam. & Turb.	"	"	
7	0.016	0.018	0.042	0.018	16.5	0.37	0.64		0.0119	0.007	560	0.76					0.0022	"	"	"	
8	0.019	0.019	0.044	0.019	16.0	0.42	0.68		0.0116	0.008	660	0.78					0.0024	"	"	"	
9	0.021	0.021	0.049	0.021	16.4	0.43	0.66		0.0117	0.009	750	0.82					0.0026	"	"	"	
10	0.025	0.024	0.056	0.023	16.3	0.45	0.65		0.0120	0.010	880	0.88					0.0030	"	"	"	
11	0.029	0.026	0.060	0.025	16.4	0.48	0.69		0.0118	0.012	1040	0.92					0.0032	Turbulent	"	"	
12	0.036	0.030	0.069	0.029	16.1	0.51	0.70		0.0125	0.015	1250	0.98					0.0037		"	"	
13	0.036	0.029	0.067	0.028	16.3	0.54	0.71		0.0116	0.015	1270	0.97					0.0036	"	"	"	
14	0.042	0.032	0.074	0.031	16.3	0.56	0.76		0.0117	0.017	1460	1.02					0.0040	"	"	"	
15	0.047	0.035	0.081	0.034	16.3	0.58	0.77		0.0120	0.020	1660	1.06					0.0044	"	"	"	
16	0.054	0.036	0.083	0.035	16.3	0.65	0.83		0.0110	0.023	1900	1.08					0.0045	"	"	"	
17	0.060	0.041	0.095	0.040	16.5	0.63	0.84		0.0124	0.025	2110	1.15					0.0051	"	"	"	
18	0.075	0.046	0.106	0.044	16.6	0.70	0.91		0.0119	0.031	2630	1.22					0.0057	"	"	"	
19	0.093	0.051	0.118	0.049	16.7	0.79	1.00		0.0113	0.039	3280	1.28					0.0064	"	Weak	"	
20	0.111	0.056	0.130	0.053	16.7	0.86	1.09		0.0111	0.046	3880	1.34	71	0.03	0.784	0.478	0.0070	"	"	"	
21	0.130	0.061	0.141	0.058	16.7	0.92	1.12	0.83	0.0109	0.053	4540	1.40	63	0.1	0.776	0.428	0.0076	"	"	"	
22	0.150	0.066	0.153	0.062	16.8	0.98	1.20	0.84	0.0106	0.061	5240	1.46	46	0.3	0.721	0.458	0.0082	"	Medium	"	$T_c=0.0090$ (Visual)
23	0.185	0.078	0.180	0.073	16.8	1.03	1.28	0.93	0.0113	0.075	6400	1.59	40	2.4	0.656	0.576	0.0097	"	General	"	
24	0.206	0.088	0.204	0.082	16.2	1.01	1.36	1.07	0.0123	0.083	6950	1.68	38	3.9	0.629	0.560	0.0110	"	"	Local riffles	
25	0.251	0.127	0.294	0.115	16.2	0.85	1.12	0.93	0.0184	0.098	8250	2.02	60	2.6	0.501	0.609	0.0159	"	"	General riffles	$T_c=0.0160$ ("Model")
26	0.281	0.142	0.329	0.127	16.0	0.86	1.10	0.86	0.0196	0.109	9040	2.14	30	2.7	0.488	0.598	0.0177	"	"	"	
27	0.318	0.156	0.361	0.137	16.1	0.88	1.14	0.86	0.0201	0.121	10100	2.24	31	2.1	0.505	0.578	0.0195	"	"	"	
28	0.325	0.162	0.375	0.142	10.8	0.87	1.08	0.86	0.0209	0.123	8950	2.28	30	2.6	0.514	0.582	0.0202	"	"	"	
29	0.410	0.178	0.412	0.154	16.1	1.00	1.20	0.68	0.0193	0.154	12800	2.39	30	1.1	0.511	0.604	0.0222	"	"	"	
30	0.631	0.215	0.498	0.181	16.0	1.27	1.67	0.97	0.0168	0.231	19200	2.63	40	12.0	0.509	0.589	0.0269	"	"	"	
31	0.770	0.219	0.506	0.184	15.8	1.52	1.92	1.23	0.0142	0.280	23300	2.65	30	18.6			0.0274	"	"	"	
32	0.930	0.231	0.534	0.193	16.0	1.74	1.94	1.26	0.0128	0.336	28000	2.72	51	38.4	0.503	0.606	0.0289	"	"	"	
33	1.130	0.278	0.643	0.224	16.0	1.76	2.04	1.33	0.0139	0.394	32800	2.99	30	45.8	0.448	0.633	0.0347	"	"	"	
34	1.351	0.329	0.761	0.256	16.0	1.78	2.13		0.0155	0.455	37900	3.25	30	50.2	0.449	0.622	0.0411	"	"	"	

1 See Plate 29.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 20[1]

Observed Data and Computed Results[2]

Sand No. 4. Mean Grain Size 0.5056 mm. Uniformity Modulus 0.4063. Test No. 4-0.0010. Slope 0.0010. March 13, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number **R** Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.013	0.030	0.013	16.9	0.17	0.24	.....	0.0152	0.002	180	0.65	....	....	......	....	0.0008	Laminar	None	Smooth	
2	0.006	0.014	0.032	0.014	17.0	0.19	0.29	.....	0.0141	0.003	220	0.67	....	....	......	....	0.0009	..	..	..	
3	0.007	0.015	0.035	0.015	16.8	0.21	0.33	.....	0.0136	0.003	270	0.70	....	....	......	....	0.0009	..	..	..	
4	0.010	0.017	0.039	0.017	17.0	0.24	0.41	.....	0.0124	0.004	350	0.74	....	....	......	....	0.0011	..	..	..	
5	0.013	0.018	0.042	0.018	17.0	0.30	0.43	.....	0.0106	0.005	460	0.76	....	....	......	....	0.0011	..	..	..	
6	0.016	0.019	0.044	0.019	17.0	0.36	0.51	.....	0.0089	0.007	590	0.78	....	....	......	....	0.0012	..	..	..	
7	0.019	0.020	0.046	0.020	17.0	0.42	0.57	.....	0.0081	0.008	710	0.80	....	....	......	....	0.0012	..	..	..	
8	0.022	0.025	0.058	0.024	16.4	0.38	0.55	.....	0.0106	0.009	770	0.90	....	....	......	....	0.0016	..	..	..	
9	0.026	0.028	0.065	0.027	16.7	0.39	0.55	.....	0.0108	0.011	910	0.95	....	....	......	....	0.0017	Lam. & Turb.	..	..	
10	0.033	0.032	0.074	0.031	16.8	0.44	0.57	.....	0.0106	0.014	1180	1.02	....	....	......	....	0.0020	..	..	..	
11	0.039	0.036	0.083	0.035	16.8	0.46	0.59	.....	0.0109	0.016	1380	1.08	....	....	......	....	0.0022	..	..	..	
12	0.050	0.041	0.095	0.040	16.8	0.52	0.64	.....	0.0104	0.021	1770	1.15	....	....	......	....	0.0026	..	..	..	
13	0.066	0.049	0.113	0.047	16.8	0.59	0.73	.....	0.0104	0.027	2340	1.26	....	....	......	....	0.0031	..	..	..	
14	0.085	0.055	0.127	0.052	16.8	0.67	0.80	0.80	0.0098	0.035	2990	1.33	....	....	......	....	0.0035	Turbulent	..	..	
15	0.106	0.065	0.150	0.062	16.9	0.71	0.87	0.75	0.0104	0.044	3720	1.45	....	....	......	....	0.0041	..	..	..	
16	0.128	0.072	0.166	0.068	16.9	0.77	0.91	0.85	0.0108	0.049	4160	1.52	....	....	......	....	0.0045	..	..	..	
17	0.166	0.083	0.192	0.078	16.9	0.87	0.97	0.85	0.0099	0.067	5730	1.64	....	....	......	....	0.0052	..	..	..	
18	0.200	0.097	0.224	0.089	16.9	0.89	1.06	0.94	0.0106	0.080	6830	1.77	....	....	......	....	0.0061	..	..	..	
19	0.223	0.106	0.245	0.097	16.9	0.91	1.13	0.88	0.0109	0.088	7550	1.85	47	0.1	0.661	0.420	0.0066	..	Weak	..	
20	0.250	0.113	0.261	0.103	16.6	0.96	1.17	1.14	0.0107	0.099	8340	1.91	60	0.4	0.727	0.487	0.0071	..	..	..	
21	0.317	0.132	0.305	0.118	16.5	1.04	1.28	1.18	0.0109	0.129	10900	2.06	50	1.8	0.697	0.483	0.0083	..	..	..	$T_c = 0.0080$
22	0.380	0.147	0.340	0.131	16.5	1.12	1.37	1.18	0.0108	0.146	12400	2.18	30	2.5	0.688	0.449	0.0092	..	Medium	..	(Visual)
23	0.445	0.167	0.386	0.146	16.5	1.15	1.41	1.23	0.0114	0.169	14300	2.32	20	2.7	0.693	0.424	0.0104	..	General	..	
24	0.516	0.255	0.589	0.209	16.5	0.88	1.12	0.94	0.0190	0.186	15700	2.87	60	0.9	0.481	0.431	0.0159	..	..	..	
25	0.570	0.277	0.640	0.223	16.9	0.89	1.19	0.85	0.0194	0.199	17000	2.99	60	0.8	0.478	0.442	0.0173	..	..	General riffles	
26	0.635	0.306	0.706	0.234	17.0	0.90	1.20	0.88	0.0198	0.210	18100	3.14	60	0.7	0.483	0.450	0.0191	..	..	..	
27	0.781	0.351	0.811	0.269	17.0	0.96	1.30	0.91	0.0203	0.259	22300	3.36	60	1.1	0.480	0.464	0.0219	..	..	..	$T_c = 0.0213$
28	0.970	0.388	0.896	0.290	17.0	1.08	1.40	0.98	0.0190	0.314	27100	3.54	47	2.1	0.443	0.447	0.0242	..	..	..	("Model")
29	1.200	0.424	0.980	0.310	17.5	1.22	1.56	1.14	0.0176	0.379	32900	3.69	43	4.4	0.473	0.447	0.0265	..	..	..	
30	1.485	0.458	1.060	0.326	17.5	1.40	1.63	1.32	0.0159	0.456	39600	3.84	30	9.3	0.512	0.462	0.0286	..	..	..	
31	1.680	0.487	1.125	0.342	17.8	1.49	1.77	1.42	0.0154	0.511	44800	3.96	30	10.9	0.505	0.464	0.0304	..	..	..	
32	1.960	0.527	1.219	0.362	17.9	1.61	1.92	.....	0.0148	0.583	51100	4.12	30	22.2	0.531	0.412	0.0329	..	..	..	

[1] See Plate 29. [2] All values in English units except grain size in millimeters. [3] Width of flume 2.313 ft. [4] Dry weight.

TABLE 21[1]

Observed Data and Computed Results[2]

Sand No. 4. Mean Grain Size 0.5056 mm Uniformity Modulus 0.4063. Test No. 4-0.0015. Slope 0.0015. March 12, 1934.

(1) Run No.	(2) Discharge, Q c.f.s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.006	0.012	0.028	0.012	17.4	0.21	0.33	....	0.0139	0.002	210	0.62	....	....	....	....	0.0011	Laminar	None	Smooth	
2	0.007	0.013	0.031	0.013	17.4	0.22	0.36	....	0.0144	0.003	240	0.65	....	....	....	....	0.0012	..	..	..	
3	0.008	0.014	0.032	0.014	17.3	0.23	0.40	....	0.0139	0.003	280	0.67	....	....	....	....	0.0013	..	..	..	
4	0.010	0.015	0.035	0.015	17.3	0.27	0.45	....	0.0124	0.004	350	0.70	....	....	....	....	0.0014	..	..	..	
5	0.012	0.016	0.037	0.016	17.0	0.32	0.50	....	0.0110	0.005	430	0.72	....	....	....	....	0.0015	..	..	..	
6	0.015	0.017	0.039	0.017	17.0	0.37	0.57	....	0.0098	0.006	540	0.74	....	....	....	....	0.0016	Lam. & Turb.	..	..	
7	0.018	0.018	0.042	0.018	17.0	0.42	0.64	....	0.0089	0.008	640	0.76	....	....	....	....	0.0017	..	..	..	
8	0.023	0.022	0.051	0.022	17.0	0.45	0.60	....	0.0099	0.010	840	0.84	....	....	....	....	0.0021	..	..	..	
9	0.026	0.025	0.058	0.025	17.0	0.44	0.60	....	0.0111	0.011	920	0.90	....	....	....	....	0.0023	..	..	..	
10	0.030	0.027	0.063	0.026	17.1	0.48	0.62	....	0.0107	0.013	1100	0.93	....	....	....	....	0.0025	..	..	..	
11	0.038	0.032	0.074	0.031	17.2	0.51	0.67	....	0.0111	0.016	1380	1.02	....	....	....	....	0.0030	..	..	..	
12	0.048	0.037	0.086	0.036	17.2	0.56	0.72	0.51	0.0111	0.020	1730	1.09	....	....	....	....	0.0035	Turbulent	..	..	
13	0.061	0.042	0.097	0.041	17.3	0.63	0.78	0.58	0.0108	0.025	2190	1.16	....	....	....	....	0.0039	..	..	..	
14	0.070	0.045	0.105	0.044	17.3	0.67	0.82	0.60	0.0107	0.029	2510	1.21	....	....	....	....	0.0042	..	..	..	
15	0.093	0.053	0.123	0.051	17.3	0.76	0.89	1.01	0.0105	0.038	3310	1.31	....	....	....	....	0.0050	..	..	..	
16	0.111	0.060	0.140	0.058	17.3	0.79	0.97	1.05	0.0108	0.046	3930	1.39	....	....	....	....	0.0056	..	..	..	
17	0.130	0.066	0.153	0.063	17.3	0.85	1.03	1.23	0.0106	0.053	4580	1.46	60	0.5	0.658	0.446	0.0062	..	Weak	..	
18	0.179	0.081	0.187	0.076	17.2	0.96	1.18	1.18	0.0107	0.073	6250	1.62	30	0.5	0.759	0.462	0.0076	..	Medium	..	Tc=0.0083
19	0.205	0.088	0.203	0.082	17.2	1.01	1.23	1.27	0.0108	0.083	7120	1.69	60	1.0	0.717	0.476	0.0083	..	General	..	(Visual)
20	0.253	0.098	0.226	0.090	17.2	1.12	1.27	1.37	0.0104	0.101	8710	1.78	60	2.1	0.678	0.506	0.0092	..	..	..	
21	0.280	0.112	0.257	0.101	17.1	1.09	1.39	1.47	0.0105	0.110	9480	1.90	30	4.0	0.630	0.489	0.0105	..	..	Local riffles	
22	0.320	0.192	0.443	0.165	17.0	0.72	0.93	0.73	0.0239	0.119	10200	2.49	60	0.1	0.499	0.361	0.0180	..	..	General riffles	
23	0.380	0.217	0.501	0.182	17.0	0.76	0.98	0.75	0.0244	0.138	11800	2.64	50	0.3	0.468	0.414	0.0204	..	..	..	
24	0.430	0.233	0.538	0.194	17.0	0.80	1.05	0.75	0.0241	0.155	13200	2.74	45	0.9	0.502	0.427	0.0218	..	..	..	$T_c=0.0219$
25	0.487	0.241	0.556	0.199	16.8	0.88	1.11	0.80	0.0224	0.174	14900	2.79	50	2.3	0.481	0.442	0.0226	..	..	..	("Model")
26	0.580	0.257	0.593	0.210	16.8	0.98	1.28	0.94	0.0207	0.205	17500	2.88	48	3.2	0.475	0.456	0.0241	..	..	..	Results from
27	0.680	0.282	0.651	0.226	16.0	1.04	1.33	1.05	0.0183	0.236	19700	3.02	30	4.6	0.470	0.398	0.0264	..	..	..	Runs 30 and
28	0.825	0.316	0.730	0.248	16.0	1.13	1.47	1.09	0.0201	0.280	23400	3.19	30	5.3	0.456	0.395	0.0297	..	..	..	31 discarded
29	1.000	0.341	0.788	0.263	16.1	1.27	1.67	1.23	0.0186	0.334	28100	3.32	30	10.4	0.473	0.460	0.0320	..	..	..	because of
30	1.240	0.359	0.829	0.274	16.2	1.50	1.91	1.48	0.0162	0.410	34400	3.40	30	30.0	0.438	0.501	0.0336	..	..	Large riffles	non-uniform
31	1.457	0.375	0.866	0.383	16.4	1.68	2.00	1.59	0.0181	0.644	54600	3.47	30	30.7	0.434	0.475	0.0351	..	..	..	flow.

[1] See Plate 30.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.313 ft.
[4] Dry weight.

TABLE 22[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 4. Mean Grain Size 0.5056 mm. Uniformity Modulus 0.4063. Test No. 4-0.0020. Slope 0.0020. February 12-15, 1934.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand. M. Dimensionless	Tractive Force Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.006	0.013	0.030	0.013	14.0	0.21	0.34		0.0174	0.003	210	0.65					0.0016	Laminar	None	Smooth	
2	0.008	0.014	0.032	0.014	13.9	0.23	0.36		0.0161	0.003	250	0.67					0.0017	..	..	..	
3	0.009	0.015	0.035	0.015	13.2	0.26	0.42		0.0151	0.004	310	0.69					0.0019	..	..	..	
4	0.011	0.016	0.037	0.016	14.3	0.29	0.45		0.0139	0.005	370	0.72					0.0020	..	..	..	
5	0.014	0.017	0.039	0.017	14.4	0.35	0.52		0.0121	0.006	470	0.74					0.0021	..	..	..	
6	0.016	0.018	0.042	0.018	14.8	0.39	0.58		0.0114	0.007	560	0.76					0.0022	..	..	..	
7	0.020	0.019	0.043	0.018	15.0	0.46	0.67		0.0101	0.008	680	0.77					0.0023	Lam. & Turb.	..	..	
8	0.024	0.022	0.051	0.022	14.0	0.46	0.67		0.0111	0.010	790	0.84					0.0027	..	..	..	
9	0.027	0.024	0.055	0.023	14.0	0.49	0.67		0.0111	0.011	910	0.88					0.0030	..	..	..	
10	0.032	0.027	0.062	0.026	14.5	0.51	0.67		0.0115	0.014	1080	0.93					0.0034	..	..	..	
11	0.039	0.030	0.069	0.029	15.0	0.56	0.72		0.0112	0.016	1340	0.98					0.0037	..	..	..	
12	0.045	0.033	0.076	0.032	15.1	0.59	0.76		0.0114	0.019	1550	1.03					0.0041	Turbulent	..	..	
13	0.057	0.038	0.088	0.037	15.2	0.65	0.83		0.0112	0.024	1970	1.11					0.0047	..	..	..	
14	0.068	0.042	0.097	0.041	15.3	0.70	0.88		0.0111	0.028	2330	1.16					0.0052	..	..	..	
15	0.081	0.046	0.106	0.044	15.3	0.76	0.94		0.0110	0.034	2760	1.22					0.0057	..	..	..	
16	0.095	0.052	0.120	0.050	15.3	0.79	1.01		0.0114	0.039	3220	1.29					0.0065	..	..	..	
17	0.110	0.055	0.127	0.052	15.3	0.87	1.05		0.0108	0.045	3720	1.33					0.0069	..	..	..	
18	0.126	0.061	0.141	0.058	15.3	0.89	1.09		0.0111	0.052	4240	1.40					0.0076	..	Weak	..	
19	0.145	0.066	0.153	0.062	15.3	0.95	1.14		0.0110	0.059	4840	1.46	60	0.2	0.820	0.490	0.0083	..	..	..	$T_c = 0.0090$ (Visual)
20	0.170	0.073	0.169	0.069	15.3	1.01	1.25		0.0111	0.069	5670	1.53	53	1.3	0.765	0.508	0.0091	..	..	..	
21	0.186	0.078	0.180	0.073	15.3	1.03	1.28	1.10	0.0113	0.075	6170	1.58	35	2.1	0.736	0.509	0.0097	..	Medium	..	
22	0.226	0.089	0.206	0.083	15.3	1.10	1.37	1.23	0.0115	0.091	7450	1.69	20	4.3	0.673	0.445	0.0111	..	..	Local riffles	
23	0.226	0.148	0.342	0.131	15.3	0.66	0.85	0.55	0.0259	0.086	7090	2.18	60	0.0			0.0185	..	Weak	General riffles	
24	0.320	0.177	0.409	0.153	15.3	0.78	0.94	0.61	0.0242	0.120	9840	2.39	60	0.8	0.386	0.393	0.0221	..	..	..	$T_c = 0.0222$ ("Model")
25	0.360	0.194	0.448	0.166	15.4	0.80	1.05	0.75	0.0251	0.133	11000	2.50	35	4.3	0.459	0.421	0.0242	..	Medium	..	
26	0.467	0.218	0.504	0.183	15.6	0.93	1.16	0.72	0.0232	0.170	14100	2.65	30	5.0	0.469	0.429	0.0272	..	General	..	
27	0.595	0.241	0.556	0.199	15.6	1.07	1.35	0.81	0.0211	0.213	17600	2.79	30	7.7	0.441	0.424	0.0301	..	..	..	Results from Runs 30, 31, and 32 discarded because of non-uniform flow
28	0.717	C.263	0.607	0.214	15.6	1.18	1.50	0.89	0.0201	0.253	20900	2.91	30	13.6	0.448	0.466	0.0328	..	..	..	
29	0.850	0.287	0.663	0.230	15.6	1.28	1.70	0.93	0.0194	0.294	24300	3.04	30	14.3	0.490	0.418	0.0358	..	..	..	
30	1.051	0.299	0.690	0.231	15.7	1.53	2.06	1.05	0.0164	0.352	29200	3.11	31	49.6	0.404	0.520	0.0373	..	..	..	
31	1.250	0.305	0.704	0.241	16.0	1.78	2.22	1.19	0.0144	0.429	35700	3.14	20	58.8	0.458	0.483	0.0381	..	..	..	
32	1.470	0.344	0.794	0.265	16.0	1.85	2.33	1.74	0.0148	0.489	40800	3.33	16	81.5	0.437	0.473	0.0429	..	..	..	

1 See Plate 30.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 23 [1]

OBSERVED DATA AND COMPUTED RESULTS [2]

Sand No. 5. Mean Grain Size 0.4828 mm. Uniformity Modulus 0.4384. Test No. 5-0.0010. Slope 0.0010. February 23, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area [3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Surface	(9) Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number $\mathbf{R}$ Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement [4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.006	0.015	0.035	0.015	14.5	0.16	0.27		0.0172	0.002	200	0.70					0.0009	Laminar	None	Smooth	
2	0.008	0.017	0.039	0.017	14.8	0.20	0.35		0.0156	0.003	260	0.74					0.0011	"	"	"	
3	0.010	0.018	0.042	0.018	15.0	0.23	0.38		0.0138	0.004	330	0.76					0.0011	"	"	"	
4	0.012	0.020	0.046	0.020	14.3	0.26	0.41		0.0132	0.005	410	0.80					0.0012	"	"	"	
5	0.015	0.021	0.049	0.021	15.0	0.31	0.45		0.0114	0.006	520	0.82					0.0013	"	"	"	
6	0.018	0.022	0.051	0.022	15.1	0.36	0.50		0.0103	0.008	630	0.84					0.0014	"	"	"	
7	0.022	0.025	0.058	0.024	15.2	0.38	0.52		0.0105	0.009	760	0.90					0.0016	"	"	"	
8	0.027	0.029	0.067	0.028	15.2	0.41	0.53		0.0108	0.012	940	0.97					0.0018	Lam. & Turb.	"	"	
9	0.033	0.033	0.076	0.032	14.2	0.43	0.57		0.0111	0.014	1100	1.03					0.0021	"	"	"	
10	0.038	0.036	0.083	0.035	15.0	0.46	0.59		0.0110	0.016	1300	1.08					0.0022	"	"	"	
11	0.047	0.040	0.093	0.039	15.2	0.51	0.62		0.0107	0.020	1600	1.14					0.0025	Turbulent	"	"	
12	0.054	0.045	0.104	0.043	15.3	0.52	0.67		0.0112	0.022	1840	1.20					0.0028	"	"	"	
13	0.065	0.050	0.116	0.048	15.5	0.56	0.70		0.0110	0.027	2210	1.27					0.0031	"	"	"	
14	0.081	0.057	0.132	0.054	15.5	0.61	0.77		0.0110	0.033	2740	1.35					0.0036	"	"	"	
15	0.099	0.062	0.143	0.059	15.5	0.69	0.83		0.0103	0.041	3340	1.41					0.0039	"	"	"	
16	0.125	0.072	0.167	0.068	15.5	0.75	0.91		0.0104	0.051	4190	1.52					0.0045	"	"	"	
17	0.143	0.082	0.190	0.077	15.7	0.76	0.94	0.87	0.0112	0.058	4780	1.63					0.0051	"	"	"	
18	0.169	0.090	0.208	0.084	15.8	0.81	1.00	0.93	0.0111	0.068	5630	1.70					0.0056	"	"	"	
19	0.192	0.098	0.227	0.090	15.8	0.85	1.06	1.08	0.0112	0.076	6330	1.78					0.0061	"	Weak	"	
20	0.213	0.104	0.241	0.095	15.8	0.89	1.08	1.16	0.0111	0.084	6990	1.83					0.0065	"	"	"	
21	0.243	0.112	0.260	0.102	15.9	0.94	1.18	1.16	0.0109	0.096	7990	1.90	88				0.0070	"	"	"	
22	0.279	0.120	0.278	0.109	15.9	1.00	1.23	1.23	0.0107	0.109	9130	1.97	45	0.7	0.680	0.467	0.0075	"	Medium	"	$T_c = 0.0080$
23	0.319	0.131	0.303	0.118	16.0	1.05	1.28	1.23	0.0107	0.124	10300	2.05	40	1.1	0.676	0.662	0.0082	"	"	Local riffles	(Visual)
24	0.389	0.215	0.497	0.181	16.0	0.78	0.99	0.87	0.0192	0.141	11800	2.63					0.0134	"	General	General riffles	
25	0.431	0.231	0.534	0.192	16.0	0.81	1.02	0.79	0.0194	0.155	13000	2.73					0.0144	"	"	"	
26	0.495	0.261	0.604	0.213	16.0	0.82	1.12	0.85	0.0204	0.175	14600	2.90					0.0163	"	"	"	
27	0.561	0.288	0.666	0.231	16.0	0.84	1.15	0.85	0.0209	0.194	16200	3.04					0.0180	"	"	"	
28	0.658	0.317	0.733	0.249	16.0	0.90	1.24	0.89	0.0207	0.224	18600	3.19					0.0198	"	"	"	
29	0.730	0.337	0.779	0.261	16.0	0.94	1.27	0.87	0.0205	0.245	20400	3.30	60	0.1	0.475	0.445	0.0210	"	"	"	
30	0.830	0.363	0.840	0.276	16.1	0.99	1.39	0.91	0.0202	0.273	22800	3.42	30	0.5	0.430	0.492	0.0226	"	"	"	
31	1.009	0.403	0.933	0.299	16.1	1.08	1.47	0.99	0.0194	0.324	27100	3.60	60	2.0	0.430	0.467	0.0252	"	"	"	$T_c = 0.0234$
32	1.225	0.446	1.032	0.322	16.2	1.19	1.54	1.10	0.0187	0.383	32200	3.79	30	3.6	0.451	0.488	0.0278	"	"	"	("Model")
33	1.400	0.484	1.119	0.341	16.2	1.25	1.63	1.03	0.0183	0.427	35900	3.94	25	5.7	0.442	0.520	0.0302	"	"	"	
34	1.675	0.522	1.208	0.360	16.0	1.39	1.73	1.28	0.0172	0.500	41600	4.10	30	11.5	0.546	0.461	0.0326	"	"	"	
35	1.817	0.550	1.271	0.373	16.0	1.43	1.82	1.40	0.0171	0.532	44400	4.21	30	13.4	0.470	0.474	0.0343	"	"	"	
36	2.079	0.559	1.292	0.377	16.0	1.61	2.02	1.46	0.0153	0.606	50500	4.24	20	30.2	0.548	0.339	0.0349	"	"	"	

1 See Plate 31.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 24 [1]

Observed Data and Computed Results [2]

Sand No. 5. Mean Grain Size 0.4828 mm. Uniformity Modulus 0.4384. Test No. 5-0.0015. Slope 0.0015. February 17, 1934.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area [3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number **R** Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement [4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.012	0.019	0.043	0.018	15.0	0.28	0.48	.....	0.0144	0.005	410	0.77	.....	.....	.....	.....	0.0017	Laminar	None	Smooth	
2	0.016	0.020	0.045	0.019	15.0	0.36	0.55	.....	0.0101	0.006	500	0.79	.....	.....	.....	.....	0.0018	"	"	"	
3	0.018	0.020	0.046	0.020	15.2	0.39	0.58	.....	0.0107	0.008	630	0.80	.....	.....	.....	.....	0.0019	"	"	"	
4	0.020	0.021	0.049	0.021	15.4	0.40	0.60	.....	0.0109	0.008	680	0.82	.....	.....	.....	.....	0.0020	Lam. & Turb.	"	"	
5	0.022	0.024	0.056	0.024	15.6	0.40	0.60	.....	0.0119	0.009	770	0.88	.....	.....	.....	.....	0.0022	"	"	"	
6	0.027	0.027	0.062	0.026	15.6	0.43	0.61	.....	0.0117	0.011	940	0.93	.....	.....	.....	.....	0.0025	"	"	"	
7	0.033	0.031	0.072	0.030	15.0	0.46	0.64	.....	0.0123	0.014	1130	1.00	.....	.....	.....	.....	0.0029	Turbulent	"	"	
8	0.039	0.035	0.081	0.034	15.5	0.48	0.67	.....	0.0127	0.016	1340	1.06	.....	.....	.....	.....	0.0033	"	"	"	
9	0.044	0.037	0.086	0.036	15.8	0.51	0.70	.....	0.0121	0.018	1520	1.09	.....	.....	.....	.....	0.0035	"	"	"	
10	0.048	0.039	0.090	0.038	16.0	0.53	0.72	.....	0.0121	0.020	1680	1.12	.....	.....	.....	.....	0.0037	"	"	"	
11	0.060	0.043	0.099	0.041	16.0	0.60	0.75	.....	0.0115	0.025	2080	1.18	.....	.....	.....	.....	0.0040	"	"	"	
12	0.072	0.048	0.111	0.046	15.8	0.65	0.84	.....	0.0115	0.030	2470	1.24	.....	.....	.....	.....	0.0045	"	"	"	
13	0.093	0.056	0.130	0.053	15.8	0.72	0.91	.....	0.0114	0.038	3170	1.34	.....	.....	.....	.....	0.0052	"	"	"	
14	0.124	0.062	0.143	0.059	15.8	0.87	1.01	.....	0.0101	0.051	4200	1.41	.....	.....	.....	.....	0.0058	"	Weak	"	
15	0.141	0.071	0.164	0.067	15.8	0.86	1.11	.....	0.0111	0.057	4740	1.51	60	0.3	0.634	0.467	0.0066	"	"	"	
16	0.178	0.080	0.185	0.075	15.8	0.96	1.18	.....	0.0106	0.072	5950	1.61	30	1.2	0.682	0.482	0.0075	"	Medium	"	$T_c = 0.0075$
17	0.218	0.092	0.213	0.085	15.8	1.02	1.27	.....	0.0109	0.087	7230	1.72	30	2.0	0.675	0.488	0.0086	"	"	"	(Visual)
18	0.248	0.101	0.234	0.093	15.8	1.06	1.32	.....	0.0111	0.099	8160	1.80	30	2.8	0.603	0.453	0.0095	"	General	Local riffles	
19	0.313	0.194	0.448	0.166	15.4	0.70	0.95	0.73	0.0249	0.116	9490	2.50	.....	.....	.....	.....	0.0182	"	"	General riffles	
20	0.357	0.213	0.493	0.180	15.4	0.73	1.03	0.69	0.0253	0.131	10700	2.62	.....	.....	.....	.....	0.0199	"	"	"	
21	0.416	0.229	0.529	0.191	15.5	0.79	1.07	0.78	0.0243	0.150	12400	2.71	.....	.....	.....	.....	0.0214	"	"	"	$T_c = 0.0230$
22	0.536	0.260	0.601	0.212	15.5	0.89	1.19	0.87	0.0229	0.190	15700	2.89	60	1.6	0.391	0.465	0.0244	"	"	"	("Model")
23	0.636	0.286	0.662	0.230	15.5	0.96	1.24	1.10	0.0225	0.221	18200	3.04	45	3.5	0.446	0.475	0.0268	"	"	"	
24	0.800	0.323	0.747	0.253	15.5	1.07	1.43	1.10	0.0215	0.271	22400	3.22	30	5.4	0.451	0.480	0.0302	"	"	"	
25	0.970	0.354	0.819	0.271	15.5	1.18	1.54	1.13	0.0204	0.321	26500	3.38	30	8.7	0.496	0.438	0.0332	"	"	"	
26	1.175	0.388	0.897	0.290	15.5	1.31	1.67	1.10	0.0192	0.380	31400	3.53	30	9.2	0.437	0.437	0.0364	"	"	"	
27	1.390	0.416	0.962	0.306	15.6	1.45	1.82	1.19	0.0181	0.442	36600	3.66	30	16.7	0.500	0.459	0.0390	"	"	"	
28	1.650	0.446	1.031	0.322	15.8	1.60	1.98	1.41	0.0169	0.515	42600	3.79	30	26.3	0.517	0.416	0.0418	"	"	"	

1 See Plate 31.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 25[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 5. Mean Grain Size 0.4828 mm. Uniformity Modulus 0.4384. Test No. 5-0.0020. Slope 0.0020. March 1, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.011	0.025	0.011	14.8	0.21	0.32	----	0.0155	0.002	180	0.59	----	----	----	----	0.0014	Laminar	None	Smooth	
2	0.006	0.012	0.028	0.012	14.8	0.22	0.36	----	0.0147	0.003	220	0.62	----	----	----	----	0.0015	"	"	"	
3	0.007	0.013	0.030	0.013	14.8	0.24	0.38	----	0.0147	0.003	250	0.65	----	----	----	----	0.0016	"	"	"	
4	0.009	0.014	0.032	0.014	15.0	0.28	0.46	----	0.0133	0.004	310	0.67	----	----	----	----	0.0018	"	"	"	
5	0.012	0.015	0.035	0.015	15.0	0.34	0.52	----	0.0116	0.005	410	0.69	----	----	----	----	0.0019	"	"	"	
6	0.014	0.016	0.037	0.016	15.0	0.37	0.59	----	0.0110	0.006	470	0.72	----	----	----	----	0.0020	Lam. & Turb.	"	"	
7	0.017	0.017	0.039	0.017	15.1	0.42	0.67	----	0.0102	0.007	580	0.74	----	----	----	----	0.0021	"	"	"	
8	0.021	0.020	0.046	0.020	15.2	0.44	0.66	----	0.0107	0.009	720	0.80	----	----	----	----	0.0025	"	"	"	
9	0.024	0.023	0.053	0.023	15.3	0.45	0.65	----	0.0115	0.010	850	0.86	----	----	----	----	0.0029	Turbulent	"	"	
10	0.029	0.025	0.058	0.024	15.4	0.50	0.66	----	0.0112	0.012	1000	0.90	----	----	----	----	0.0031	"	"	"	
11	0.033	0.027	0.062	0.026	15.6	0.53	0.68	----	0.0112	0.014	1150	0.93	----	----	----	----	0.0034	"	"	"	
12	0.042	0.031	0.072	0.030	15.8	0.58	0.72	----	0.0112	0.017	1460	1.00	----	----	----	----	0.0039	"	"	"	
13	0.055	0.038	0.088	0.037	15.8	0.63	0.81	0.95	0.0117	0.023	1930	1.11	----	----	----	----	0.0047	"	Weak	"	
14	0.068	0.043	0.099	0.042	15.8	0.69	0.88	1.03	0.0116	0.028	2370	1.18	----	----	----	----	0.0054	"	"	"	
15	0.090	0.050	0.116	0.048	15.8	0.78	0.96	1.13	0.0113	0.037	3110	1.27	----	----	----	----	0.0062	"	"	"	
16	0.105	0.055	0.127	0.052	15.5	0.83	1.05	1.28	0.0112	0.043	3570	1.33	----	----	----	----	0.0069	"	"	"	
17	0.128	0.061	0.141	0.058	15.6	0.91	1.11	1.28	0.0108	0.053	4340	1.40	60	0.1	0.584	0.336	0.0076	"	Medium	"	$T_c = 0.0085$
18	0.149	0.066	0.153	0.063	15.6	0.97	1.18	1.35	0.0107	0.061	5030	1.46	70	0.3	0.773	0.437	0.0082	"	"	"	(Visual)
19	0.172	0.074	0.171	0.070	15.8	1.01	1.24	1.45	0.0111	0.070	5820	1.55	60	1.0	0.747	0.482	0.0092	"	General	General riffles	
20	0.212	0.146	0.337	0.129	15.8	0.63	0.86	0.72	0.0267	0.081	6760	2.17	----	----	----	----	0.0182	"	"	"	
21	0.345	0.189	0.436	0.162	16.0	0.79	1.11	0.85	0.0248	0.128	10700	2.47	58	0.4	0.430	0.432	0.0236	"	"	"	$T_c = 0.0218$
22	0.452	0.222	0.514	0.187	16.0	0.88	1.23	1.05	0.0246	0.165	13700	2.68	66	2.3	0.478	0.447	0.0278	"	"	"	("Model")
23	0.545	0.250	0.577	0.205	16.1	0.95	1.29	1.28	0.0243	0.194	16300	2.84	30	3.8	0.477	0.441	0.0312	"	"	"	
24	0.680	0.271	0.626	0.220	16.2	1.09	1.47	1.06	0.0221	0.239	20100	2.96	36	8.4	0.515	0.426	0.0338	"	"	"	
25	0.820	0.296	0.684	0.235	16.3	1.20	1.59	1.46	0.0210	0.282	23700	3.09	30	10.4	0.509	0.422	0.0370	"	"	"	
26	0.990	0.324	0.748	0.252	16.4	1.32	1.80	1.51	0.0198	0.333	28200	3.23	30	15.3	0.458	0.439	0.0404	"	"	"	
27	1.169	0.354	0.818	0.271	16.5	1.45	1.94	1.51	0.0190	0.394	33400	3.38	30	27.4	0.500	0.449	0.0442	"	"	"	
28	1.410	0.374	0.864	0.282	16.6	1.63	2.00	----	0.0174	0.460	39000	3.47	20	32.6	0.514	0.411	0.0467	"	"	"	

1 See Plate 32.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 26[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 6. Mean Grain Size 0.3470 mm. Uniformity Modulus 0.6428. Test No. 6-0.0010. Slope 0.0010. April 7-10, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	[5]Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.019	0.020	0.048	0.019	18.0	0.40	No Observations	No Observations	0.0086	0.008	660	0.80	----	----	Trapped Sand Not Analyzed	Trapped Sand Not Analyzed	0.0012	No Observations	None	Smooth	
2	0.033	0.066	0.160	0.062	18.0	0.21			0.0356	0.013	1120	1.46	----	----			0.0041		"	"	
3	0.203	0.091	0.219	0.085	18.0	0.93			0.0098	0.079	6900	1.71	----	----			0.0057		Weak	"	
4	0.314	0.148	0.358	0.132	18.0	0.88			0.0138	0.116	10200	2.18	----	----			0.0092		"	Local riffles	$T_c = 0.0060$ (Visual)
5	0.407	0.233	0.563	0.196	18.0	0.72			0.0219	0.142	12500	2.74	60	0.3			0.0145		"	"	
6	0.504	0.245	0.594	0.204	18.0	0.85			0.0192	0.173	15200	2.80	60	0.6			0.0153		"	General riffles	
7	0.564	0.281	0.679	0.228	18.0	0.83			0.0211	0.189	16600	3.00	60	0.2			0.0175		"	"	
8	0.653	0.309	0.747	0.246	18.0	0.87			0.0210	0.215	18900	3.14	63	0.6			0.0193		"	"	
9	0.738	0.328	0.793	0.258	18.0	0.93			0.0205	0.240	21100	3.24	36	0.9			0.0205		"	"	
10	0.833	0.354	0.854	0.274	18.0	0.98			0.0203	0.267	23400	3.37	44	0.5			0.0221		"	"	
11	0.937	0.376	0.908	0.286	18.0	1.03			0.0198	0.296	26000	3.47	30	0.8			0.0235		"	"	$T_c = 0.0236$ ("Model")
12	1.046	0.391	0.944	0.295	18.0	1.11			0.0188	0.327	28700	3.54	30	1.5			0.0244		"	"	
13	1.125	0.408	0.986	0.304	18.0	1.14			0.0186	0.347	30500	3.62	30	1.6			0.0255		"	"	
14	1.217	0.430	1.038	0.317	18.0	1.17			0.0186	0.372	32700	3.71	30	2.1			0.0268		"	"	
15	1.310	0.444	1.072	0.325	18.0	1.22			0.0182	0.396	34800	3.77	30	2.6			0.0277		"	"	
16	1.371	0.472	1.140	0.339	18.0	1.20			0.0190	0.408	35900	3.89	30	3.8			0.0295		"	"	
17	1.481	0.491	1.185	0.350	18.0	1.25			0.0187	0.438	38500	3.96	30	3.7			0.0306		"	"	
18	1.565	0.525	1.268	0.365	18.0	1.23			0.0194	0.450	39500	4.09	30	3.4			0.0328		"	"	

1 See Plate 32.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 27 [1]

Observed Data and Computed Results [2]

Sand No. 6. Mean Grain Size 0.3470 mm. Uniformity Modulus 0.6428. Test No. 6-0.0015. Slope 0.0015. April 26-29, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area [3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5] Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement [4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand, d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.012	0.013	0.032	0.013	20.0	0.38	No Observations	No Observations	0.0083	0.005	450	0.65	----	----	Trapped Sand Not Analyzed	Trapped Sand Not Analyzed	0.0012	No Observations	None	Smooth	Run 2 discarded
3	0.046	0.029	0.070	0.028	20.0	0.66			0.0081	0.018	1710	0.97	----	----			0.0027		"	"	
4	0.096	0.049	0.119	0.047	20.0	0.81			0.0092	0.038	3530	1.25	----	----			0.0046		Weak	"	
5	0.157	0.061	0.148	0.058	20.0	1.06			0.0081	0.062	5710	1.40	----	----			0.0057		Medium	"	$T_c=0.0060$
6	0.157	0.105	0.254	0.096	20.0	0.62			0.0195	0.059	5490	1.87	----	----			0.0098		Weak	Local riffles	(Visual)
7	0.230	0.131	0.317	0.118	20.0	0.73			0.0190	0.086	7930	2.05	----	----			0.0123		None	"	
8	0.327	0.188	0.454	0.163	20.0	0.72			0.0238	0.117	10900	2.46	59	0.2			0.0176		Weak	General riffles	
9	0.354	0.204	0.493	0.175	20.0	0.72			0.0251	0.126	11700	2.56	47	0.2			0.0191		"	"	
10	0.420	0.225	0.544	0.190	20.0	0.77			0.0246	0.147	13600	2.69	75	0.1			0.0211		"	"	
11	0.467	0.233	0.563	0.195	20.9	0.83			0.0233	0.162	15000	2.74	51	0.5			0.0218		Medium	"	
12	0.565	0.259	0.626	0.214	20.0	0.90			0.0227	0.193	17900	2.88	65	0.5			0.0242		"	"	$T_c=0.0252$
13	0.673	0.286	0.691	0.232	20.0	0.97			0.0223	0.226	20900	3.03	40	1.5			0.0268		General	"	('Model")
14	0.803	0.311	0.752	0.247	20.0	1.07			0.0212	0.264	24400	3.16	44	2.1			0.0291		"	"	
15	0.940	0.336	0.812	0.263	20.0	1.16			0.0204	0.304	28200	3.28	27	2.8			0.0314		"	"	
16	1.070	0.365	0.882	0.280	20.0	1.21			0.0203	0.340	31500	3.42	34	3.4			0.0341		"	"	
17	1.180	0.376	0.908	0.286	20.0	1.30			0.0192	0.372	34500	3.47	34	6.8			0.0352		"	"	
18	1.263	0.399	0.964	0.300	20.0	1.31			0.0197	0.393	36400	3.58	52	6.3			0.0373		"	"	
19	1.348	0.413	0.998	0.307	20.0	1.35			0.0191	0.414	38400	3.64	27	8.5			0.0386		"	"	
20	1.400	0.426	1.030	0.315	20.0	1.36			0.0196	0.428	39700	3.70	34	9.1			0.0399		"	"	
21	1.500	0.446	1.077	0.326	20.0	1.39			0.0196	0.455	42200	3.78	38	6.9			0.0417		"	"	
22	1.645	0.466	1.122	0.336	20.0	1.47			0.0190	0.493	45600	3.87	40	10.8			0.0436		"	"	

1 See Plate 33.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 28[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 6. Mean Grain Size 0.3470 mm. Uniformity Modulus 0.6428. Test No. 6-0.0020. Slope 0.0020. May 7-10, 1933

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft	Hydraulic Radius, R Ft.	[5]Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.019	0.020	0.048	0.020	23.0	0.40	No Observations	No Observations	0.0125	0.008	790	0.80	----	----	Trapped Sand Not Analyzed	Trapped Sand Not Analyzed	0.0025	No Observations	None	Smooth	
2	0.021	0.022	0.052	0.021	23.0	0.40			0.0127	0.009	850	0.84	----	----			0.0027		"	"	
3	0.059	0.036	0.087	0.035	23.0	0.68			0.0105	0.024	2370	1.08	----	----			0.0045		"	"	
4	0.101	0.048	0.116	0.046	23.0	0.87			0.0098	0.040	4000	1.24	75	----			0.0060		Weak	"	$T_c = 0.0060$ (Visual)
5	0.154	0.090	0.218	0.084	23.0	0.71			0.0180	0.059	5930	1.70	30	----			0.0112		None	Local riffles	
6	0.210	0.120	0.291	0.109	23.0	0.72			0.0210	0.072	7220	1.96	30	0.8			0.0150		Medium	General riffles	
7	0.278	0.149	0.361	0.133	23.0	0.77			0.0224	0.103	10300	2.19	39	0.7			0.0186		"	"	
8	0.338	0.175	0.423	0.153	23.0	0.80			0.0238	0.122	12200	2.37	36	0.8			0.0218		"	"	
9	0.420	0.207	0.500	0.177	23.0	0.84			0.0250	0.149	14900	2.58	34	1.7			0.0258		General	"	$T_c = 0.0223$ ("Model")
10	0.510	0.239	0.577	0.200	23.0	0.88			0.0257	0.177	17700	2.77	33	1.6			0.0298		"	"	
11	0.576	0.254	0.613	0.210	23.0	0.94			0.0249	0.198	19800	2.86	30	2.3			0.0317		"	"	
12	0.661	0.267	0.645	0.219	23.0	1.02			0.0235	0.225	22500	2.93	30	3.8			0.0333		"	"	
13	0.742	0.279	0.675	0.227	23.0	1.10			0.0225	0.249	24900	2.99	30	4.6			0.0348		"	"	
14	0.838	0.303	0.733	0.243	23.0	1.14			0.0226	0.278	27800	3.12	30	4.9			0.0378		"	"	
15	0.927	0.318	0.769	0.252	23.0	1.21			0.0219	0.304	30400	3.20	31	5.5			0.0397		"	"	
16	1.000	0.331	0.801	0.260	23.0	1.25			0.0216	0.324	32400	3.26	30	9.0			0.0413		"	"	
17	1.115	0.343	0.829	0.267	23.0	1.35			0.0205	0.360	36000	3.32	30	8.8			0.0428		"	"	
18	1.223	0.357	0.863	0.276	23.0	1.42			0.0198	0.392	39200	3.38	30	13.3			0.0445		"	"	
19	1.310	0.367	0.887	0.281	23.0	1.48			0.0193	0.415	41500	3.43	30	18.2			0.0458		"	"	
20	1.367	0.373	0.901	0.285	23.0	1.51			0.0190	0.432	43200	3.46	30	14.7			0.0465		"	"	
21	1.452	0.385	0.930	0.292	23.0	1.56			0.0187	0.457	45700	3.52	30	21.1			0.0480		"	"	

[1] See Plate 33.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 ft.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 29[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 7. Mean Grain Size 0.3104 mm. Uniformity Modulus 0.5246. Test No. 7-0.0010. Slope 0.0010. July 7-14, 1933.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area[3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	[5]Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement[4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M, Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.003	0.012	0.029	0.012	27.0	0.10	No Observations	No Observations	0.0228	0.001	130	0.62					0.0008	Laminar	None	Smooth	
2	0.020	0.021	0.051	0.021	27.0	0.39			0.0088	0.008	900	0.82					0.0013	"	"	"	
3	0.043	0.034	0.082	0.033	27.0	0.52			0.0092	0.017	1880	1.05					0.0021	Lam. & Turb.	"	"	
4	0.062	0.044	0.107	0.042	27.0	0.58			0.0098	0.024	2640	1.19					0.0028	Turbulent	"	"	
5	0.094	0.058	0.141	0.055	27.0	0.67			0.0102	0.037	3990	1.37					0.0036	"	"	"	
6	0.134	0.073	0.177	0.069	27.0	0.76			0.0104	0.052	5680	1.53					0.0046	"	"	"	
7	0.169	0.084	0.204	0.079	27.0	0.83			0.0105	0.065	7100	1.64					0.0053	"	Weak	"	
8	0.206	0.095	0.230	0.088	27.0	0.90			0.0104	0.079	8570	1.75	60	0.1	0.396	0.617	0.0059	"	"	"	
9	0.235	0.108	0.261	0.099	27.0	0.90			0.0113	0.089	9690	1.86					0.0068	"	Medium	"	
10	0.252	0.111	0.269	0.101	27.0	0.94			0.0109	0.095	10300	1.89	18	0.6	0.391	0.598	0.0069	"	"	"	$T_c = 0.0070$
11	0.284	0.121	0.293	0.110	27.0	0.97			0.0111	0.107	11600	1.97					0.0076	"	"	Local riffles	(Visual)
12	0.286	0.190	0.459	0.165	27.0	0.62			0.0227	0.103	11200	2.47					0.0119	"	None	General riffles	
13	0.323	0.204	0.493	0.175	27.0	0.66			0.0225	0.115	12500	2.56	83	0.0			0.0128	"	Weak	"	
14	0.363	0.223	0.539	0.188	27.0	0.67			0.0229	0.127	13800	2.67	85	0.1	0.321	0.551	0.0139	"	"	"	
15	0.400	0.239	0.577	0.199	27.0	0.69			0.0231	0.138	15000	2.77	85	0.2			0.0149	"	"	"	
16	0.416	0.248	0.599	0.206	27.0	0.70			0.0236	0.143	15600	2.82	75	0.3			0.0155	"	"	"	
17	0.473	0.282	0.681	0.229	27.0	0.69			0.0253	0.159	17300	3.00	75	0.2	0.328	0.549	0.0176	"	"	"	
18	0.596	0.305	0.738	0.244	27.0	0.80			0.0229	0.195	21200	3.12	65	0.5			0.0191	"	"	"	
19	0.672	0.334	0.808	0.262	27.0	0.83			0.0231	0.218	23700	3.27	30	0.8			0.0209	"	"	"	
20	0.755	0.356	0.860	0.275	27.0	0.88			0.0227	0.242	26300	3.38	32	0.8	0.325	0.565	0.0222	"	"	"	
21	0.852	0.376	0.908	0.287	27.0	0.94			0.0218	0.269	29200	3.47	31	1.2			0.0235	"	"	"	$T_c = 0.0228$
22	0.947	0.397	0.959	0.299	27.0	0.99			0.0212	0.296	32100	3.57	28	1.7	0.314	0.606	0.0248	"	"	"	("Model")

1 See Plate 34.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 30[1]

Observed Data and Computed Results[2]

Sand No. 7. Mean Grain Size 0.3104 mm. Uniformity Modulus 0.5246. Test No. 7-0.0015. Slope 0.0015. July 14, 1933.

(1) Run No.	(2) Discharge, Q c.f.s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Foot	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number $\mathbf{R}$ Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.004	0.009	0.022	0.009	27.0	0.18	No Observations	No Observations	0.0133	0.002	180	0.47					0.0008	Laminar	None	Smooth	
2	0.008	0.012	0.029	0.012	27.0	0.28			0.0106	0.003	360	0.62					0.0011	"	"	"	
3	0.013	0.015	0.036	0.015	27.0	0.36			0.0096	0.005	590	0.69					0.0014	"	"	"	
4	0.016	0.017	0.041	0.017	27.0	0.39			0.0097	0.007	720	0.74					0.0016	"	"	"	
5	0.020	0.020	0.048	0.020	27.0	0.42			0.0102	0.008	910	0.80					0.0019	"	"	"	
6	0.024	0.021	0.051	0.021	27.0	0.47			0.0093	0.010	1080	0.82					0.0020	"	"	"	
7	0.025	0.022	0.053	0.022	27.0	0.47			0.0096	0.010	1130	0.84					0.0021	Lam. & Turb.	"	"	
8	0.027	0.023	0.056	0.023	27.0	0.48			0.0097	0.011	1210	0.86					0.0022	"	"	"	
9	0.037	0.027	0.065	0.026	27.0	0.57			0.0089	0.015	1610	0.93					0.0025	"	"	"	
10	0.059	0.036	0.087	0.035	27.0	0.68			0.0091	0.024	2590	1.07					0.0034	Turbulent	"	"	
11	0.081	0.043	0.104	0.042	27.0	0.78			0.0089	0.033	3550	1.17					0.0040	"	"	"	
12	0.099	0.050	0.121	0.048	27.0	0.82			0.0093	0.039	4270	1.27					0.0047	"	Weak	"	
13	0.113	0.054	0.130	0.051	27.0	0.87			0.0091	0.044	4830	1.32	86	0.0	0.455	0.462	0.0051	"	"	"	
14	0.130	0.058	0.140	0.055	27.0	0.93			0.0090	0.051	5540	1.36	50	0.1	0.479	0.523	0.0054	"	"	Local riffles	
15	0.131	0.110	0.266	0.101	27.0	0.49			0.0252	0.050	5400	1.88	56	0.1	0.357	0.548	0.0103	"	"	"	$T_c = 0.0058$ (Visual)
16	0.189	0.140	0.338	0.125	27.0	0.56			0.0257	0.070	7620	2.12	90	0.0			0.0131	"	"	General riffles	
17	0.263	0.165	0.399	0.145	27.0	0.66			0.0241	0.096	10400	2.30	65	0.3			0.0154	"	"	"	
18	0.376	0.208	0.502	0.178	27.0	0.75			0.0243	0.134	14600	2.58	33	0.8	0.318	0.604	0.0195	"	"	"	
19	0.505	0.241	0.581	0.201	27.0	0.87			0.0227	0.175	19000	2.78	30	1.0			0.0226	"	"	"	
20	0.625	0.283	0.683	0.229	27.0	0.92			0.0235	0.210	22800	3.01	30	2.1			0.0265	"	"	"	$T_c = 0.0227$ ("Model")
21	0.743	0.300	0.725	0.241	27.0	1.02			0.0218	0.247	26800	3.10	32	2.9	0.301	0.588	0.0280	"	"	"	
22	0.897	0.340	0.822	0.266	27.0	1.09			0.0218	0.291	31600	3.30	30	3.2			0.0318	"	"	"	
23	1.024	0.368	0.890	0.282	27.0	1.15			0.0215	0.325	35300	3.44	30	4.1	0.299	0.567	0.0344	"	"	"	

1 See Plate 34.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.416 ft.
4 Dry weight.
5 Estimated from weather bureau records.

TABLE 31[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 7. Mean Grain Size 0.3104 mm. Uniformity Modulus 0.5246. Test No. 7-0.0020. Slope 0.0020. July 26, 1933.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) [5]Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M. Dimensionless	(18) Tractive Force T Lb. per Sq. Ft	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.012	0.013	0.031	0.013	27.0	0.39	No Observations	No Observations	0.0093	0.005	550	0.65					0.0016	Laminar	None	Smooth	
2	0.013	0.014	0.034	0.014	27.0	0.38			0.0099	0.005	580	0.67					0.0017	"	"	"	
3	0.014	0.014	0.034	0.014	27.0	0.41			0.0092	0.006	630	0.67					0.0017	"	"	"	
4	0.015	0.015	0.036	0.015	27.0	0.42			0.0096	0.006	680	0.70					0.0019	"	"	"	
5	0.016	0.015	0.036	0.015	27.0	0.45			0.0090	0.007	730	0.70					0.0019	"	"	"	
6	0.017	0.016	0.039	0.016	27.0	0.44			0.0095	0.007	760	0.72					0.0020	Lam. & Turb.	"	"	
7	0.020	0.018	0.044	0.018	27.0	0.46			0.0101	0.008	890	0.76					0.0022	"	"	"	
8	0.022	0.020	0.048	0.020	27.0	0.46			0.0107	0.009	1000	0.80					0.0025	"	"	"	
9	0.024	0.022	0.053	0.022	27.0	0.45			0.0114	0.010	1080	0.84					0.0027	"	"	"	
10	0.030	0.025	0.060	0.024	27.0	0.50			0.0110	0.012	1310	0.90					0.0031	Turbulent	"	"	
11	0.063	0.038	0.092	0.037	27.0	0.69			0.0109	0.025	2750	1.11	42	0.0			0.0047	"	Weak	"	
12	0.098	0.049	0.118	0.047	27.0	0.83			0.0105	0.039	4240	1.26	8	0.8	0.509	0.571	0.0061	"	"	"	
13	0.134	0.061	0.147	0.058	27.0	0.91			0.0107	0.053	5750	1.40	10	0.8			0.0076	"	"	Local riffles	$T_c = 0.0070$ (Visual)
14	0.186	0.075	0.181	0.071	27.0	1.03			0.0111	0.073	7920	1.55					0.0094	"	"	"	
15	0.186	0.123	0.298	0.111	27.0	0.63			0.0246	0.069	7530	1.99	38	0.1	0.340	0.517	0.0154	"	"	General riffles	
16	0.232	0.149	0.360	0.133	27.0	0.64			0.0269	0.086	9310	2.19	53	0.2			0.0186	"	"	"	
17	0.285	0.170	0.411	0.149	27.0	0.69			0.0270	0.103	11200	2.34	25	0.6	0.343	0.562	0.0212	"	Medium	"	
18	0.330	0.189	0.457	0.164	27.0	0.72			0.0275	0.119	12900	2.47	40	0.3			0.0236	"	"	"	
19	0.442	0.216	0.524	0.184	27.0	0.84			0.0255	0.155	16800	2.64	38	2.0			0.0270	"	General	"	$T_c = 0.0246$ ("Model")
20	0.558	0.243	0.586	0.202	27.0	0.95			0.0242	0.193	20900	2.80	34	3.2	0.314	0.555	0.0304	"	"	"	
21	0.676	0.280	0.675	0.228	27.0	1.00			0.0248	0.228	24800	3.00	25	5.4			0.0350	"	"	"	
22	0.818	0.295	0.712	0.238	27.0	1.15			0.0222	0.274	29700	3.08	24	6.5	0.331	0.556	0.0368	"	"	"	
23	0.953	0.309	0.746	0.248	27.0	1.28			0.0207	0.317	34400	3.15	17	14.1			0.0386	"	"	"	
24	1.146	0.346	0.836	0.270	27.0	1.36			0.0205	0.368	40000	3.34	15	20.7			0.0432	"	"	"	

[1] See Plate 35.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.416 ft.
[4] Dry weight.
[5] Estimated from weather bureau records.

TABLE 32[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 8. Mean Grain Size 0.2053 mm. Uniformity Modulus 0.5597. Test No. 8-0.0010. Slope 0.0010. March 20, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15a) Rate Sand Movement[4] Lb./Ft Width/Hour Bed-load	(15b) Rate Sand Movement[4] Lb./Ft Width/Hour Suspended Load	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.013	0.030	0.013	15.0	0.18	0.26	....	0.0141	0.002	190	0.65	....	....	....	....	....	0.0008	Laminar	None	Smooth	
2	0.007	0.014	0.032	0.014	15.1	0.20	0.29	....	0.0132	0.003	220	0.67	....	....	....	....	....	0.0009	"	"	"	
3	0.008	0.016	0.037	0.016	15.8	0.22	0.37	....	0.0128	0.004	300	0.72	....	....	....	....	....	0.0010	"	"	"	
4	0.010	0.017	0.039	0.017	16.2	0.26	0.41	....	0.0118	0.004	360	0.74	....	....	....	....	....	0.0011	"	"	"	
5	0.014	0.019	0.044	0.019	16.4	0.31	0.45	....	0.0105	0.006	490	0.78	....	....	....	....	....	0.0012	"	"	"	
6	0.018	0.020	0.046	0.020	16.5	0.38	0.54	....	0.0089	0.007	630	0.80	....	....	....	....	....	0.0012	"	"	"	
7	0.024	0.022	0.051	0.022	16.7	0.47	0.62	....	0.0078	0.010	870	0.84	....	....	....	....	....	0.0014	"	"	"	
8	0.029	0.024	0.056	0.023	16.7	0.53	0.72	....	0.0072	0.012	1040	0.88	....	....	....	....	....	0.0015	"	"	"	
9	0.040	0.034	0.079	0.033	16.8	0.51	0.60	....	0.0095	0.017	1440	1.05	....	....	....	....	....	0.0021	Lam. & Turb.	"	"	
10	0.051	0.041	0.095	0.040	16.8	0.53	0.63	....	0.0102	0.021	1810	1.15	....	....	....	....	....	0.0026	"	"	"	
11	0.064	0.050	0.116	0.048	16.0	0.55	0.72	0.57	0.0112	0.027	2210	1.27	....	....	....	....	....	0.0031	Turbulent	Weak	"	
12	0.082	0.056	0.129	0.053	16.7	0.64	0.77	0.66	0.0105	0.034	2880	1.34	....	....	....	....	....	0.0035	"	"	"	
13	0.095	0.061	0.141	0.058	16.9	0.67	0.82	0.67	0.0104	0.039	3330	1.40	....	....	....	....	....	0.0038	"	"	"	
14	0.118	0.068	0.157	0.064	16.9	0.75	0.90	0.73	0.0100	0.048	4100	1.48	....	....	....	....	....	0.0042	"	"	"	
15	0.140	0.075	0.173	0.070	16.9	0.81	0.96	0.77	0.0099	0.057	4840	1.56	60	0.1	....	0.343	0.374	0.0047	"	Medium	"	
16	0.165	0.082	0.189	0.076	17.0	0.87	1.03	0.85	0.0097	0.067	5750	1.63	60	0.1	....	0.277	0.420	0.0051	"	"	"	T_c = 0.0051
17	0.250	0.217	0.502	0.183	18.0	0.50	0.71	0.42	0.0304	0.091	8080	2.64	....	....	....	....	....	0.0135	"	General	General riffles	(Visual)
18	0.305	0.234	0.540	0.194	18.1	0.57	0.80	0.48	0.0279	0.110	9740	2.74	....	....	....	....	....	0.0146	"	"	"	
19	0.362	0.255	0.589	0.209	18.1	0.62	0.85	0.49	0.0269	0.129	11400	2.87	....	....	....	....	....	0.0159	"	"	"	
20	0.425	0.276	0.637	0.222	18.0	0.67	0.91	0.49	0.0258	0.148	13100	2.98	60	0.1	....	0.168	0.501	0.0172	"	"	"	
21	0.505	0.310	0.716	0.244	18.0	0.71	0.97	0.61	0.0260	0.172	15200	3.16	60	0.2	....	0.152	0.569	0.0194	"	"	"	
22	0.800	0.382	0.883	0.288	18.0	0.91	1.21	0.66	0.0226	0.261	23100	3.51	90	2.8	....	0.156	0.632	0.0238	"	"	"	T_c = 0.0210
23	1.155	0.445	1.028	0.321	18.0	1.12	1.43	0.85	0.0196	0.361	31900	3.78	60	10.4	....	0.171	0.621	0.0278	"	"	"	("Model")
24	1.525	0.540	1.250	0.368	18.2	1.22	1.63	0.91	0.0197	0.449	39800	4.17	56	14.3	10.7	0.172	0.638	0.0337	"	"	"	
25	2.197	0.603	1.391	0.396	18.0	1.58	2.00	1.01	0.0161	0.624	55200	4.41	60	47.2	35.6	0.178	0.655	0.0376	"	"	"	

[1] See Plate 35.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.313 ft.
[4] Dry weight.

TABLE 33[1]

Observed Data and Computed Results[2]

Sand No. 8. Mean Grain Size 0.2053 mm. Uniformity Modulus 0.5597. Test No. 8-0.0015. Slope 0.0015. March 28, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec.	(8)	(9)	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Ft. per Sec.	(14) Length of Run Minutes	(15a) Rate Sand Movement[4] Lb./Ft. Width/Hour	(15b)	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
						Mean	Surface	Bottom						Bed-load	Suspended Load							
1	0.005	0.013	0.030	0.013	16.2	0.17	0.24	......	0.0182	0.002	180	0.65	....	......	......	......	......	0.0012	Laminar	None	Smooth	
2	0.009	0.015	0.035	0.015	16.2	0.25	0.39	......	0.0134	0.004	310	0.70	....	......	......	......	......	0.0014	..	..	..	
3	0.021	0.019	0.044	0.019	16.0	0.47	0.65	......	0.0086	0.009	730	0.78	....	......	......	......	......	0.0018	..	..	..	
4	0.033	0.029	0.067	0.028	16.0	0.49	0.65	......	0.0109	0.014	1160	0.97	....	......	......	......	......	0.0027	Lam. & Turb.	..	..	
5	0.045	0.033	0.077	0.032	16.0	0.59	0.73	......	0.0100	0.019	1580	1.03	....	......	......	......	......	0.0031	Turbulent	..	..	
6	0.067	0.043	0.100	0.042	16.0	0.67	0.84	......	0.0103	0.028	2320	1.18	....	......	......	......	......	0.0040	..	Weak	..	
7	0.090	0.051	0.118	0.049	16.0	0.76	0.93	0.75	0.0102	0.037	3100	1.28	....	......	......	......	......	0.0048	..	..	..	$T_c=0.0048$
8	0.140	0.125	0.289	0.113	16.0	0.48	0.65	0.41	0.0277	0.055	4550	2.01	....	......	......	......	......	0.0117	..	General	General riffles	(Visual)
9	0.179	0.146	0.357	0.129	16.0	0.53	0.72	0.47	0.0276	0.069	5720	2.17	....	......	......	......	......	0.0137	..	..	..	
10	0.233	0.165	0.381	0.144	16.4	0.61	0.81	0.48	0.0258	0.088	7400	2.31	....	......	......	......	......	0.0154	..	..	..	
11	0.298	0.193	0.446	0.165	16.5	0.67	0.92	0.66	0.0260	0.110	9270	2.50	....	......	......	......	......	0.0181	..	..	..	
12	0.386	0.220	0.508	0.185	16.5	0.76	1.01	0.61	0.0246	0.141	11900	2.66	60	1.1	......	0.164	0.605	0.0206	..	..	..	$T_c=0.0210$
13	0.635	0.296	0.684	0.235	16.8	0.93	1.25	0.77	0.0235	0.218	18600	3.09	60	5.3	......	0.170	0.594	0.0277	..	..	..	("Model")
14	0.900	0.373	0.862	0.282	16.8	1.04	1.39	0.88	0.0237	0.295	25200	3.46	60	7.4	......	0.177	0.618	0.0349	..	..	..	
15	1.255	0.480	1.110	0.339	16.9	1.13	1.58	0.85	0.0247	0.383	32700	3.93	60	15.7	3.2	0.167	0.658	0.0449	..	..	..	
16	1.735	0.592	1.368	0.392	16.9	1.27	1.87	0.82	0.0243	0.497	42400	4.37	45	37.9	16.7	0.183	0.644	0.0554	..	..	..	
17	2.238	0.684	1.580	0.429	17.0	1.42	2.18	1.18	0.0231	0.607	52300	4.69	30	57.3	26.5	0.197	0.629	0.0640	..	..	Sand waves	

1 See Plate 36.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

TABLE 34[1]

Observed Data and Computed Results[2]

Sand No. 8. Mean Grain Size 0.2053 mm. Uniformity Modulus 0.5597. Test No. 8-0.0020. Slope 0.0020. March 31, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number ■ Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Lb. per Sq. Ft.	(14) Length of Run Minutes	(15a) Rate Sand Movement[4] Lb./Ft. Width/Hour Bed-load	(15b) Rate Sand Movement[4] Lb./Ft. Width/Hour Suspended Load	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.010	0.023	0.010	15.8	0.22	0.29	-----	0.0132	0.002	180	0.57	----	-----	-----	-----	-----	0.0012	Laminar	None	Smooth	
2	0.014	0.015	0.035	0.015	16.0	0.39	0.59	-----	0.0099	0.006	480	0.70	----	-----	-----	-----	-----	0.0019	"	"	"	
3	0.034	0.026	0.060	0.025	16.0	0.57	0.76	-----	0.0101	0.014	1200	0.92	----	-----	-----	-----	-----	0.0032	Lam. & Turb.	"	"	
4	0.051	0.034	0.079	0.033	16.2	0.64	0.84	-----	0.0107	0.021	1780	1.05	----	-----	-----	-----	-----	0.0042	Turbulent	Weak	"	$T_c = 0.0042$
5	0.100	0.096	0.222	0.088	17.0	0.45	0.65	0.44	0.0293	0.040	3430	1.76	----	-----	-----	-----	-----	0.0120	"	General	General riffles	(Visual)
6	0.128	0.111	0.256	0.101	17.5	0.50	0.73	0.46	0.0289	0.051	4390	1.89	----	-----	-----	-----	-----	0.0139	"	"	"	
7	0.160	0.128	0.296	0.115	17.5	0.54	0.80	-----	0.0290	0.062	5400	2.03	60	0.4	-----	0.181	0.633	0.0160	"	"	"	
8	0.203	0.149	0.344	0.132	17.5	0.59	0.91	-----	0.0291	0.078	6780	2.19	85	0.6	-----	0.202	0.618	0.0186	"	"	"	
9	0.283	0.184	0.425	0.158	17.6	0.67	0.91	0.47	0.0291	0.105	9220	2.43	60	0.5	-----	0.194	0.591	0.0230	"	"	"	$T_c = 0.0244$
10	0.465	0.268	0.620	0.218	17.8	0.75	1.19	0.51	0.0318	0.164	14400	2.94	60	4.0	-----	0.178	0.653	0.0335	"	"	"	("Model")
11	0.810	0.355	0.820	0.271	18.0	0.99	1.52	0.73	0.0282	0.268	23700	3.48	45	19.7	0.7	0.187	0.632	0.0443	"	"	"	
12	1.130	0.408	0.943	0.301	18.2	1.20	1.72	0.88	0.0248	0.362	32100	3.62	30	39.0	3.0	0.180	0.555	0.0509	"	"	"	Run No. 14 discarded.
13	1.758	0.445	1.029	0.321	18.2	1.71	2.11	0.94	0.0182	0.548	48500	3.78	20	79.3	21.0	0.170	0.628	0.0555	"	"	Sand waves	Non-uniform
14	2.220	0.425	0.982	0.310	18.5	2.26	2.56	1.42	0.0135	0.701	62500	3.70	15	143.2	36.4	0.192	0.652	0.0530	"	"	Almost smooth	flow.

[1] See Plate 36.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.313 ft.
[4] Dry weight.

TABLE 35[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 9. Mean Grain Size 4.0769 mm. Uniformity Modulus 0.5661. Test No. 9-0.0030. Slope 0.0030. April 9, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Lb. per Sq. Ft.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand, M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.012	0.028	0.012	18.4	0.17	0.35	.....	0.0245	0.002	180	0.62	.....	.....	.....	.....	0.0023	Lam. & Turb.	None	Smooth	
2	0.008	0.016	0.037	0.016	18.5	0.22	0.49	.....	0.0223	0.003	310	0.72	.....	.....	.....	.....	0.0030	"	"	"	
3	0.018	0.024	0.055	0.023	18.7	0.33	0.51	.....	0.0196	0.008	700	0.88	.....	.....	.....	.....	0.0045	Turbulent	"	"	
4	0.036	0.034	0.079	0.033	18.8	0.46	0.65	.....	0.0183	0.015	1360	1.05	.....	.....	.....	.....	0.0064	"	"	"	
5	0.060	0.044	0.102	0.043	19.0	0.59	0.79	.....	0.0169	0.025	2270	1.19	.....	.....	.....	.....	0.0082	"	"	"	
6	0.095	0.058	0.134	0.055	19.0	0.71	0.91	.....	0.0167	0.039	3560	1.37	.....	.....	.....	.....	0.0108	"	"	"	
7	0.132	0.069	0.160	0.065	19.1	0.83	1.07	.....	0.0160	0.054	4900	1.49	.....	.....	.....	.....	0.0129	"	"	"	
8	0.199	0.089	0.206	0.083	19.2	0.97	1.27	.....	0.0160	0.080	7260	1.69	.....	.....	.....	.....	0.0167	"	"	"	
9	0.272	0.107	0.247	0.098	19.2	1.10	1.44	1.26	0.0158	0.108	9790	1.86	.....	.....	.....	.....	0.0200	"	"	"	
10	0.350	0.124	0.287	0.112	19.2	1.22	1.59	1.44	0.0155	0.137	12500	1.99	.....	.....	.....	.....	0.0232	"	"	"	
11	0.455	0.143	0.331	0.127	19.2	1.37	1.72	1.70	0.0149	0.175	15900	2.14	.....	.....	.....	.....	0.0268	"	"	"	
12	0.580	0.166	0.384	0.145	19.2	1.51	1.90	1.72	0.0148	0.219	19900	2.31	.....	.....	.....	.....	0.0311	"	"	"	
13	0.695	0.189	0.437	0.162	19.2	1.59	2.04	1.77	0.0152	0.258	23500	2.47	.....	.....	.....	.....	0.0354	"	"	"	
14	0.850	0.215	0.496	0.181	19.2	1.71	2.22	2.15	0.0152	0.310	28200	2.63	.....	.....	.....	.....	0.0403	"	"	"	
15	1.040	0.242	0.559	0.200	19.2	1.86	2.38	2.08	0.0149	0.372	33800	2.79	60	0.1	3.602	0.608	0.0453	"	Weak	"	
16	1.240	0.270	0.624	0.219	19.4	1.99	2.44	2.49	0.0149	0.436	40000	2.95	60	0.6	3.693	0.603	0.0505	"	"	"	
17	1.440	0.305	0.705	0.241	19.6	2.04	2.60	1.96	0.0154	0.492	45100	3.13	60	1.0	3.479	0.566	0.0571	"	Medium	"	$T_c = 0.057$ (Visual and "Model")
18	1.695	0.342	0.790	0.264	19.8	2.15	2.67	2.14	0.0156	0.567	52500	3.32	45	1.6	3.643	0.520	0.0640	"	General	"	
19	1.943	0.378	0.873	0.284	19.9	2.23	2.82	1.92	0.0158	0.634	58600	3.49	45	1.5	3.914	0.558	0.0707	"	"	"	
20	2.220	0.444	1.025	0.320	19.8	2.17	2.94	1.86	0.0176	0.693	64200	3.78	45	20.3	3.512	0.553	0.0832	"	"	Small scours	

[1] See Plate 37.
[2] All values in English units except grain size in millimeters.
[3] Width of flume 2.313 ft.
[4] Dry weight.

TABLE 36[1]

OBSERVED DATA AND COMPUTED RESULTS[2]

Sand No. 9. Mean Grain Size 4.0769 mm. Uniformity Modulus 0.5661. Test No. 9-0.0040. Slope 0.0040. April 12, 1934.

(1) Run No.	(2) Discharge, Q c. f. s.	(3) Depth, D Ft.	(4) Area[3] Cross-section, A Sq. Ft.	(5) Hydraulic Radius, R Ft.	(6) Water Temperature, Degrees Centigrade	(7) Velocity Ft. per Sec. Mean	(8) Velocity Ft. per Sec. Surface	(9) Velocity Ft. per Sec. Bottom	(10) Manning's n	(11) Turbulence Criterion VR	(12) Reynolds' Number R Dimensionless	(13) Wave Velocity $\sqrt{gD}$ Lb. per Sq. Ft.	(14) Length of Run Minutes	(15) Rate Sand Movement[4] Lb./Ft. Width/Hour	(16) Mean Size of Trapped Sand d_g, mm.	(17) Uniformity Modulus of Trapped Sand M, Dimensionless	(18) Tractive Force T Lb. per Sq. Ft.	(19) Nature of Flow	(20) Nature of Sand Movement	(21) Condition of Bed	(22) Remarks
1	0.005	0.016	0.037	0.016	18.5	0.14	0.35	......	0.0416	0.002	190	0.72	......	......	......	......	0.0040	Lam. & Turb.	None	Smooth	
2	0.008	0.020	0.046	0.020	18.4	0.17	0.44	......	0.0406	0.003	290	0.80	......	......	......	......	0.0050	"	"	"	
3	0.014	0.024	0.055	0.023	18.2	0.25	0.49	......	0.0304	0.006	530	0.88	......	......	......	......	0.0060	Turbulent	"	"	
4	0.026	0.031	0.072	0.030	18.2	0.36	0.61	......	0.0253	0.011	970	1.00	......	......	......	......	0.0077	"	"	"	
5	0.045	0.042	0.097	0.041	18.8	0.47	0.75	......	0.0237	0.019	1700	1.16	......	......	......	......	0.0105	"	"	"	
6	0.071	0.052	0.120	0.050	19.0	0.59	0.92	......	0.0216	0.029	2680	1.29	......	......	......	......	0.0130	"	"	"	
7	0.106	0.062	0.143	0.059	19.1	0.74	1.08	......	0.0193	0.044	3960	1.41	......	......	......	......	0.0152	"	"	"	
8	0.153	0.076	0.176	0.071	19.1	0.87	1.24	......	0.0184	0.062	5640	1.57	......	......	......	......	0.0190	"	"	"	
9	0.215	0.092	0.213	0.085	19.0	1.01	1.45	2.08	0.0180	0.086	7830	1.72	......	......	......	......	0.0230	"	"	"	
10	0.292	0.109	0.252	0.100	19.0	1.16	1.59	1.78	0.0174	0.115	10500	1.87	......	......	......	......	0.0272	"	"	"	
11	0.385	0.126	0.291	0.114	19.0	1.32	1.79	2.25	0.0166	0.150	13700	2.02	......	......	......	......	0.0315	"	"	"	
12	0.505	0.148	0.342	0.131	19.0	1.48	2.02	2.33	0.0163	0.193	17600	2.18	......	......	......	......	0.0370	"	"	"	
13	0.642	0.170	0.393	0.148	19.0	1.64	2.15	2.33	0.0160	0.242	22000	2.34	......	......	......	......	0.0424	"	"	"	
14	0.765	0.191	0.441	0.164	19.0	1.74	2.30	2.60	0.0162	0.284	25800	2.48	......	......	......	......	0.0477	"	Weak	"	
15	0.960	0.224	0.517	0.187	18.5	1.86	2.41	2.89	0.0166	0.347	31000	2.68	60	0.8	3.880	0.627	0.0559	"	"	"	
16	1.165	0.252	0.582	0.207	18.2	2.00	2.60	1.85	0.0165	0.414	36700	2.85	60	2.3	4.254	0.649	0.0629	"	"	"	
17	1.350	0.275	0.635	0.222	18.1	2.13	2.71	1.78	0.0162	0.471	41700	2.98	60	16.5	3.619	0.589	0.0687	"	Medium	"	Tc = 0.057 (Visual and "Model")
18	1.550	0.302	0.697	0.239	18.2	2.22	2.94	1.93	0.0163	0.530	46900	3.12	40	24.1	4.071	0.607	0.0754	"	General	"	
19	1.705	0.327	0.755	0.255	18.3	2.26	3.03	1.86	0.0167	0.575	50900	3.24	30	32.6	3.831	0.564	0.0816	"	"	Scours	

1 See Plate 37.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.

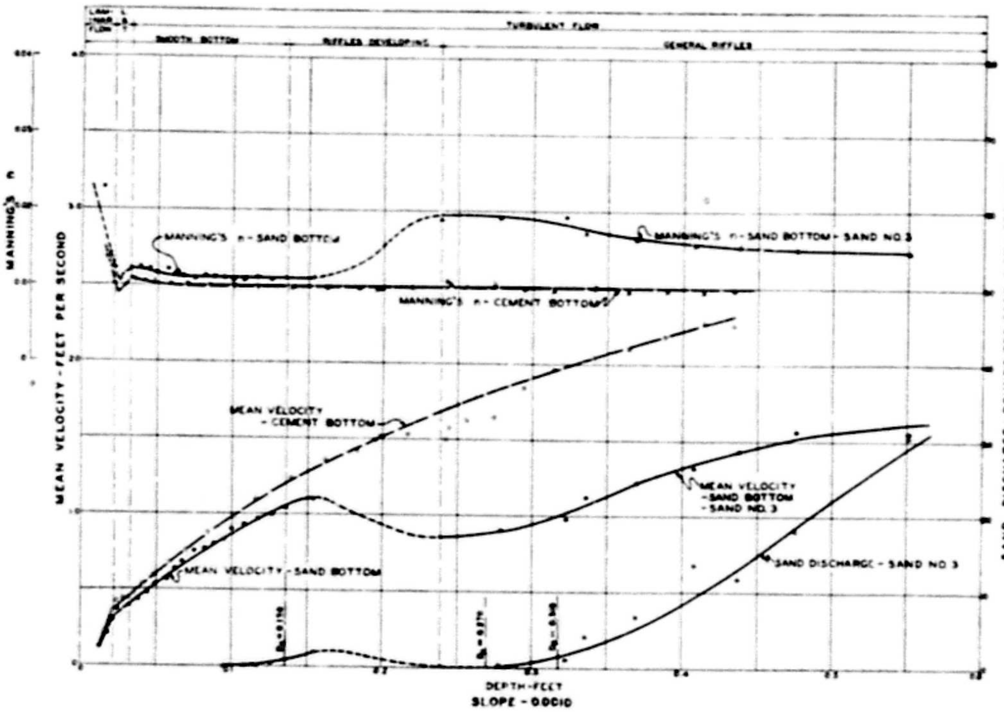
TABLE 37 [1]

Observed Data and Computed Results [2]

Sand No. 9. Mean Grain Size 4.0769 mm. Uniformity Modulus 0.5661. Test No. 9-0.0045. Slope 0.0045. April 16, 1934.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Run No.	Discharge, Q c. f. s.	Depth, D Ft.	Area [3] Cross-section, A Sq. Ft.	Hydraulic Radius, R Ft.	Water Temperature, Degrees Centigrade	Velocity Ft. per Sec.			Manning's n	Turbulence Criterion VR	Reynolds' Number R Dimensionless	Wave Velocity $\sqrt{gD}$ Ft. per Sec.	Length of Run Minutes	Rate Sand Movement [4] Lb./Ft. Width/Hour	Mean Size of Trapped Sand d_g, mm.	Uniformity Modulus of Trapped Sand, M Dimensionless	Tractive Force T Lb. per Sq. Ft.	Nature of Flow	Nature of Sand Movement	Condition of Bed	Remarks
						Mean	Surface	Bottom													
1	0.005	0.011	0.025	0.011	18.5	0.19	0.38	-----	0.0258	0.002	180	0.60	----	-----	-----	-----	0.0031	Lam. &Turb.	None	Smooth	
2	0.007	0.013	0.030	0.013	18.5	0.24	0.51	-----	0.0220	0.003	280	0.65	----	-----	-----	-----	0.0036	Turbulent	..	..	
3	0.015	0.020	0.046	0.020	18.5	0.33	0.56	-----	0.0214	0.007	590	0.80	----	-----	-----	-----	0.0056	..	..	..	
4	0.035	0.030	0.069	0.029	18.8	0.50	0.71	-----	0.0188	0.015	1320	0.98	----	-----	-----	-----	0.0084	..	..	..	
5	0.066	0.043	0.099	0.041	19.0	0.67	0.93	-----	0.0178	0.028	2480	1.18	----	-----	-----	-----	0.0121	..	..	..	
6	0.107	0.056	0.129	0.053	19.0	0.83	1.14	-----	0.0170	0.044	3960	1.35	----	-----	-----	-----	0.0157	..	..	..	
7	0.155	0.069	0.160	0.065	19.0	0.97	1.29	1.05	0.0166	0.063	5690	1.49	----	-----	-----	-----	0.0194	..	..	..	
8	0.219	0.085	0.197	0.079	19.0	1.12	1.48	1.32	0.0165	0.088	7930	1.66	----	-----	-----	-----	0.0239	..	..	..	
9	0.290	0.099	0.229	0.091	19.1	1.27	1.67	1.42	0.0159	0.115	10500	1.79	----	-----	-----	-----	0.0278	..	..	..	
10	0.397	0.120	0.277	0.109	19.2	1.43	1.84	-----	0.0157	0.156	14200	1.97	----	-----	-----	-----	0.0337	..	..	..	
11	0.492	0.137	0.316	0.122	19.2	1.56	2.00	1.78	0.0157	0.191	17300	2.10	----	-----	-----	-----	0.0385	..	..	..	
12	0.625	0.158	0.365	0.139	19.2	1.71	2.18	1.78	0.0156	0.238	21600	2.26	----	-----	-----	-----	0.0443	..	..	..	
13	0.693	0.168	0.388	0.147	19.2	1.79	2.28	1.86	0.0154	0.262	23800	2.33	----	-----	-----	-----	0.0472	..	Weak	..	
14	0.800	0.180	0.436	0.162	19.2	1.83	2.38	1.86	0.0161	0.297	27000	2.47	----	-----	-----	-----	0.0530	..	..	..	
15	0.945	0.212	0.489	0.179	19.2	1.93	2.60	2.09	0.0164	0.346	31400	2.62	60	0.5	4.398	0.654	0.0595	..	..	..	
16	1.110	0.232	0.535	0.193	19.5	2.08	2.67	1.93	0.0160	0.400	36700	2.74	60	3.3	3.963	0.617	0.0651	..	..	..	$T_c = 0.0600$ (Visual and "Model")
17	1.220	0.253	0.584	0.207	19.6	2.09	2.86	1.79	0.0167	0.433	39700	2.86	60	7.9	4.132	0.617	0.0710	..	Medium	..	
18	1.430	0.282	0.651	0.227	20.0	2.20	2.94	1.86	0.0168	0.498	46100	3.02	30	21.9	3.910	0.604	0.0791	..	..	..	
19	1.670	0.314	0.725	0.246	20.0	2.31	3.03	2.24	0.0170	0.567	52500	3.18	30	39.8	3.602	0.565	0.0881	..	General	Scours	
20	1.948	0.351	0.811	0.269	20.0	2.40	3.18	2.33	0.0172	0.645	59700	3.36	22	52.2	3.715	0.579	0.0985	..	..	..	
21	2.226	0.400	0.925	0.297	20.0	2.41	3.33	2.50	0.0184	0.716	66200	3.59	20	43.6	3.492	0.555	0.1121	..	..	..	

1 See Plate 38.
2 All values in English units except grain size in millimeters.
3 Width of flume 2.313 ft.
4 Dry weight.



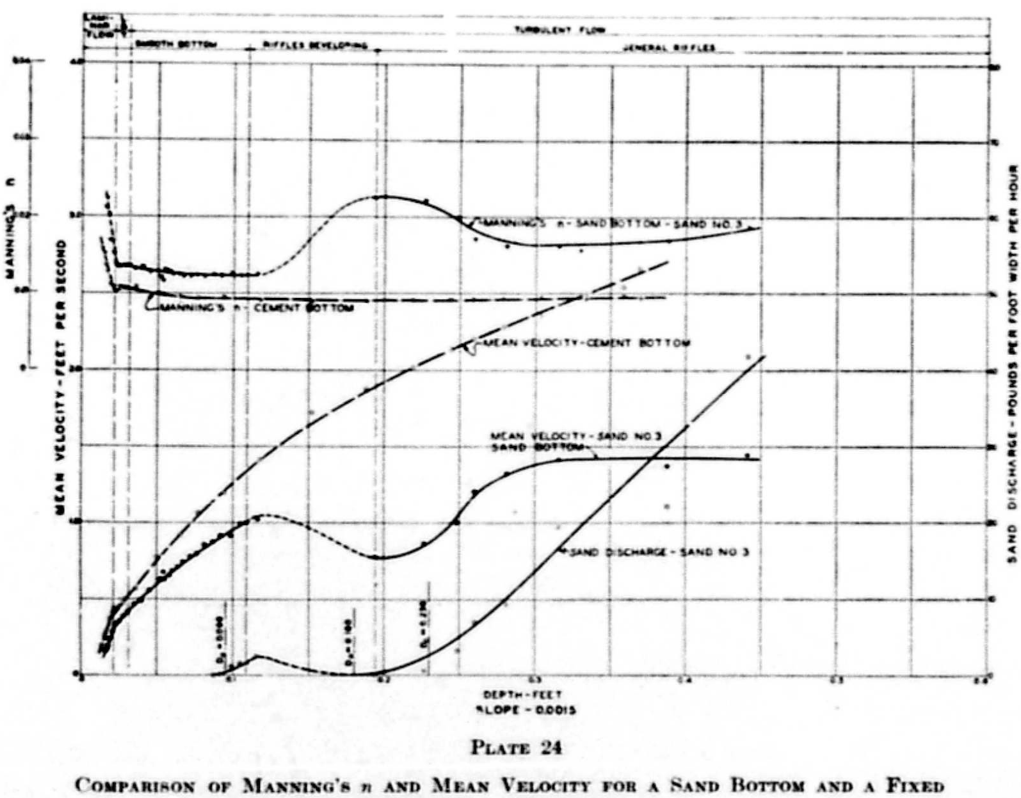
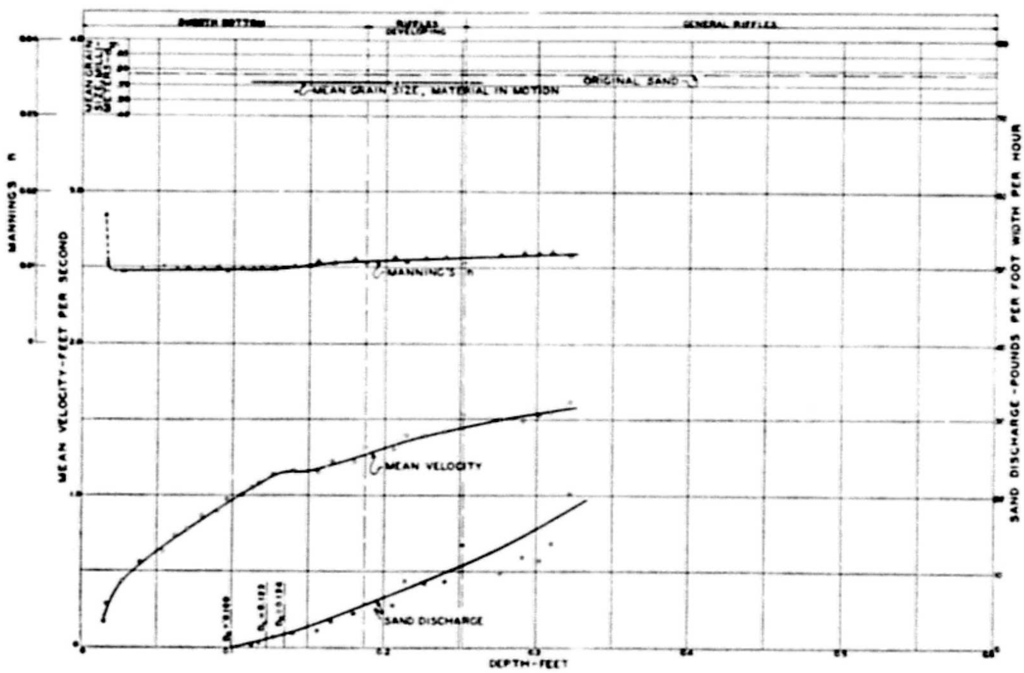
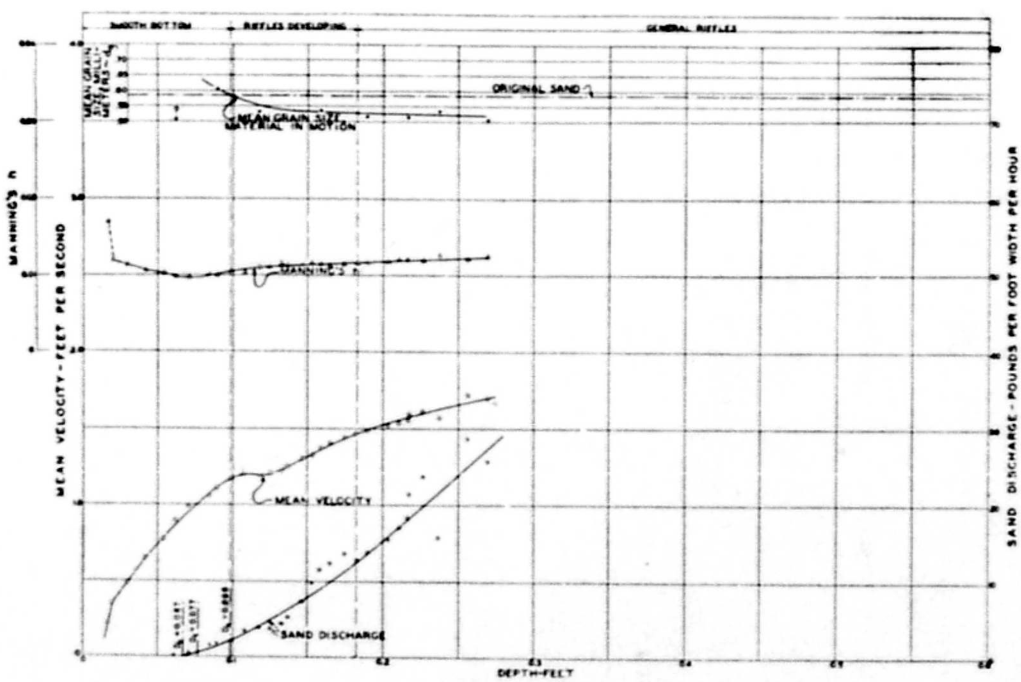


PLATE 24

COMPARISON OF MANNING'S n AND MEAN VELOCITY FOR A SAND BOTTOM AND A FIXED BOTTOM OF NEAT CEMENT



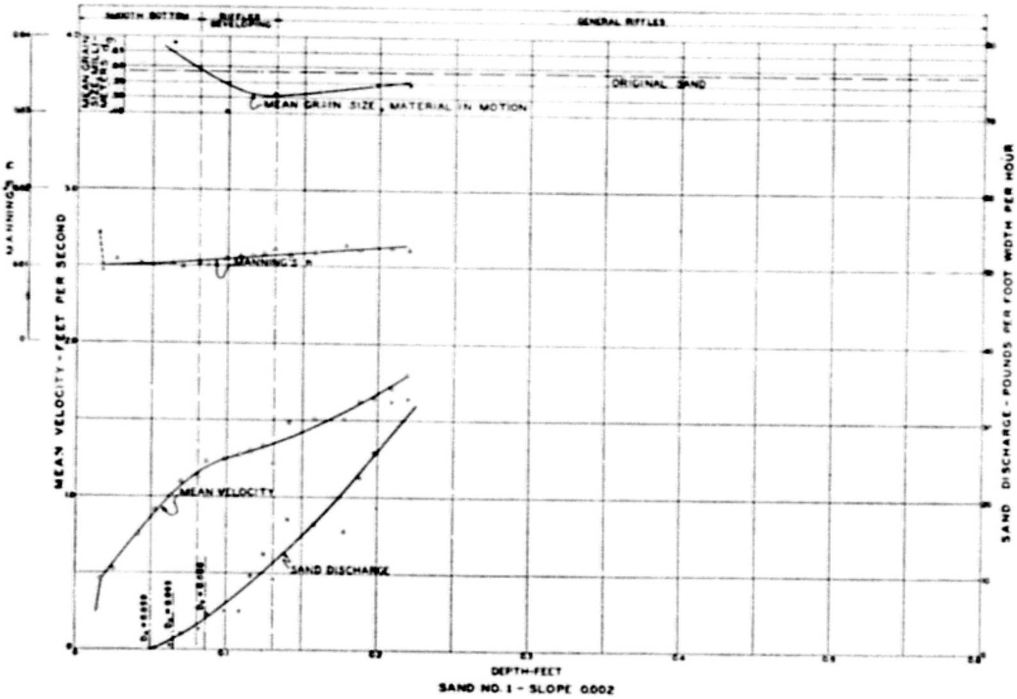
SAND NO. 1 - SLOPE 0.001



SAND NO. 1 - SLOPE 0.0015

PLATE 25

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S *n*, AND MEAN GRAIN SIZE WITH DEPTH



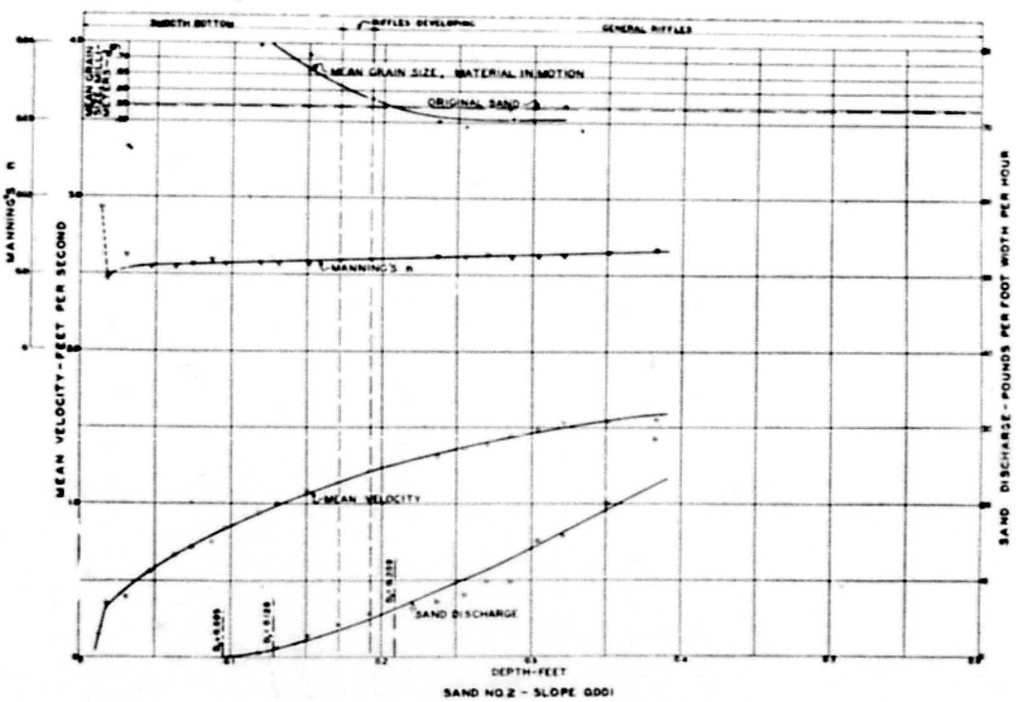
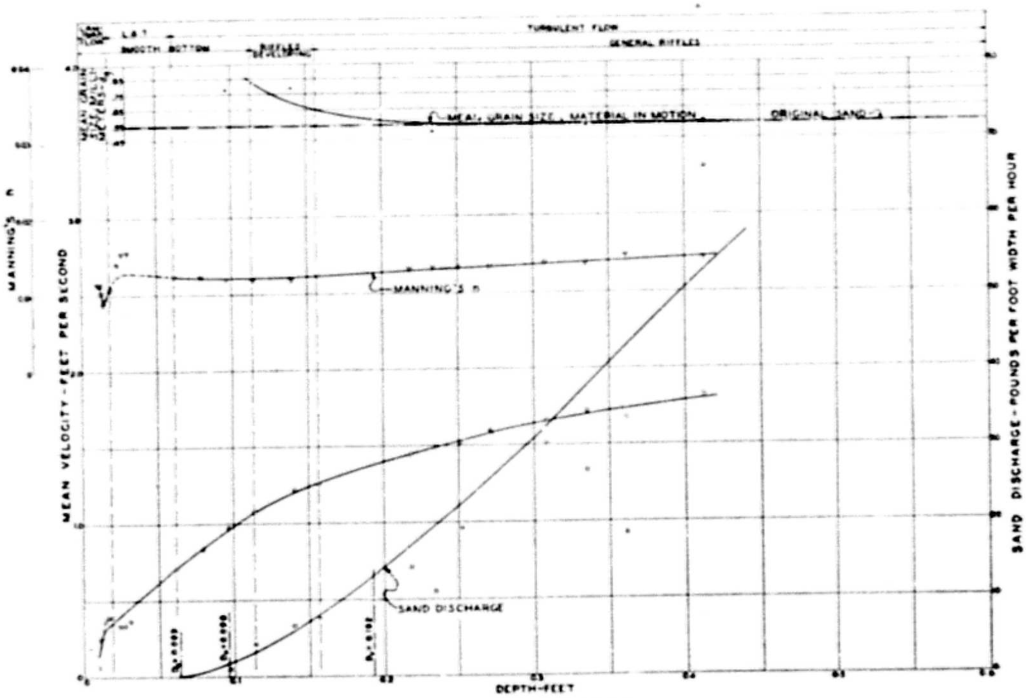
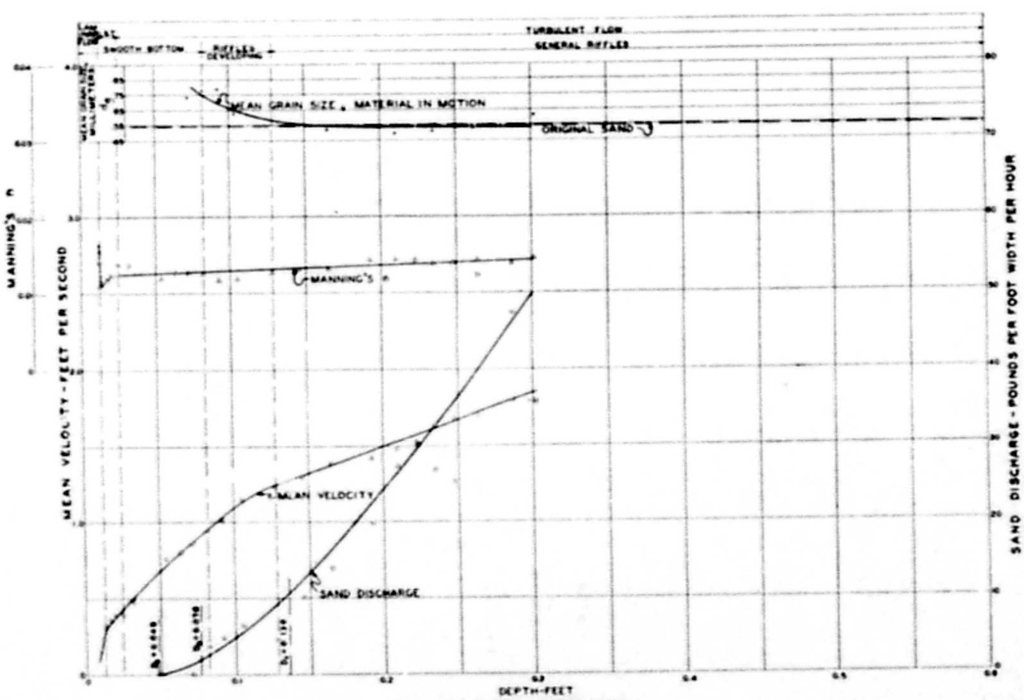


PLATE 26

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



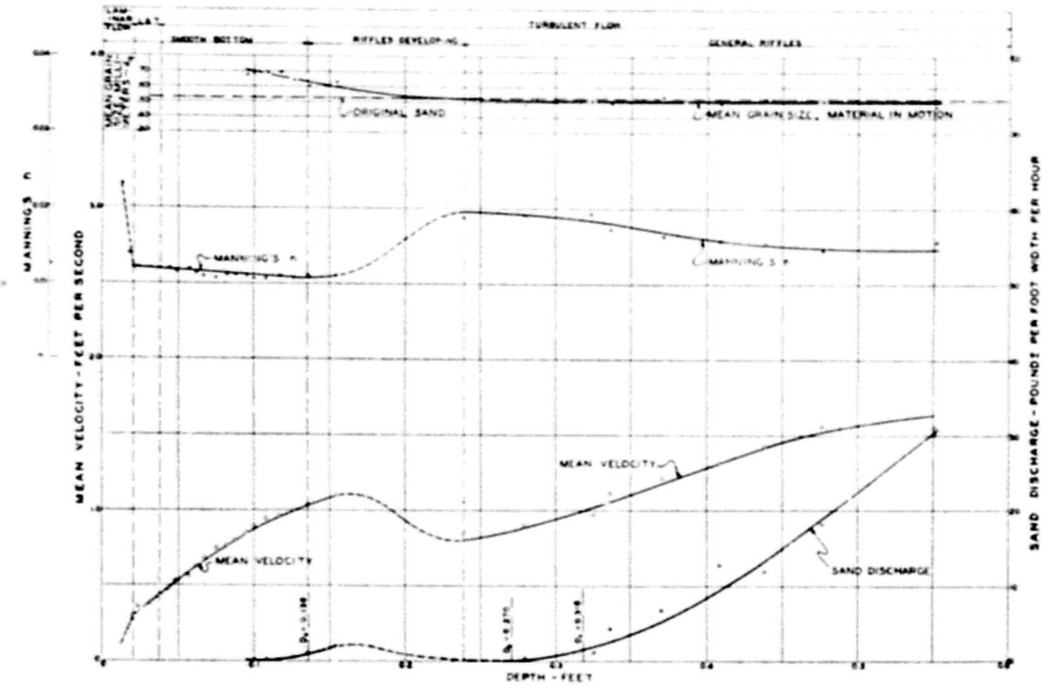
SAND NO 2 - SLOPE 0.0015



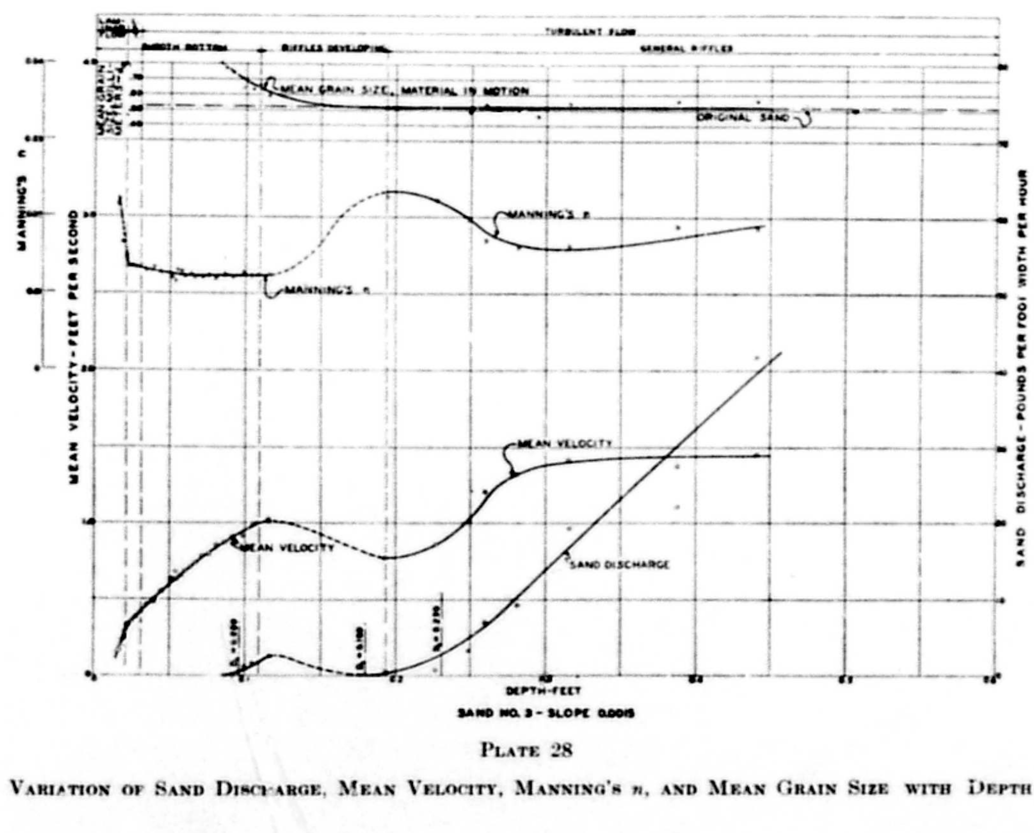
SAND NO. 2 - SLOPE 0.002

PLATE 27

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S *n*, AND MEAN GRAIN SIZE WITH DEPTH



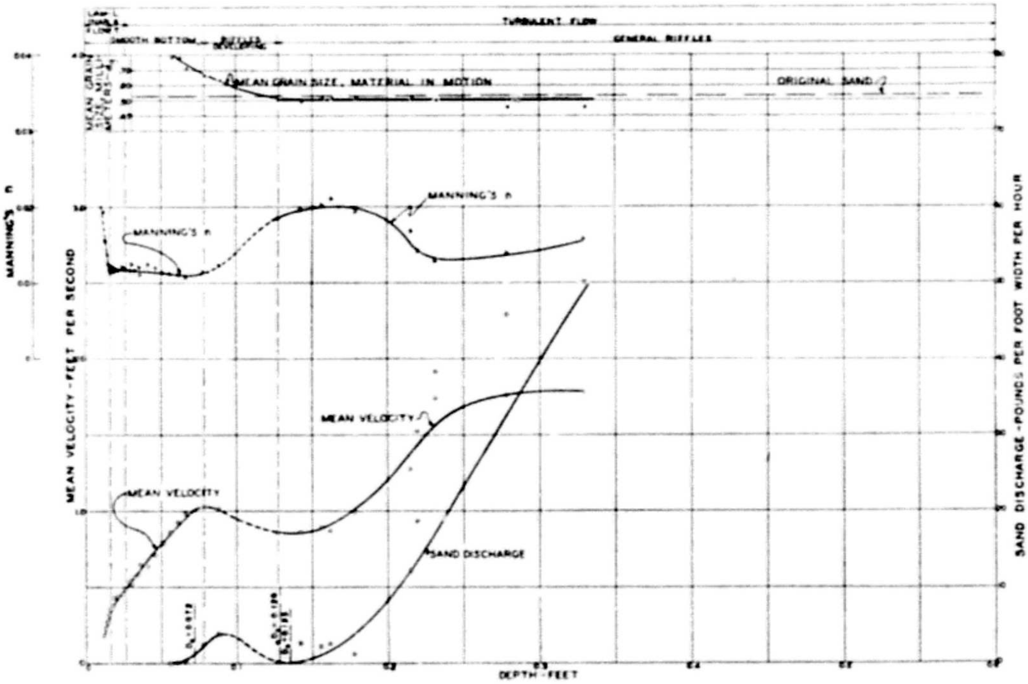
SAND NO. 3 - SLOPE 0.001



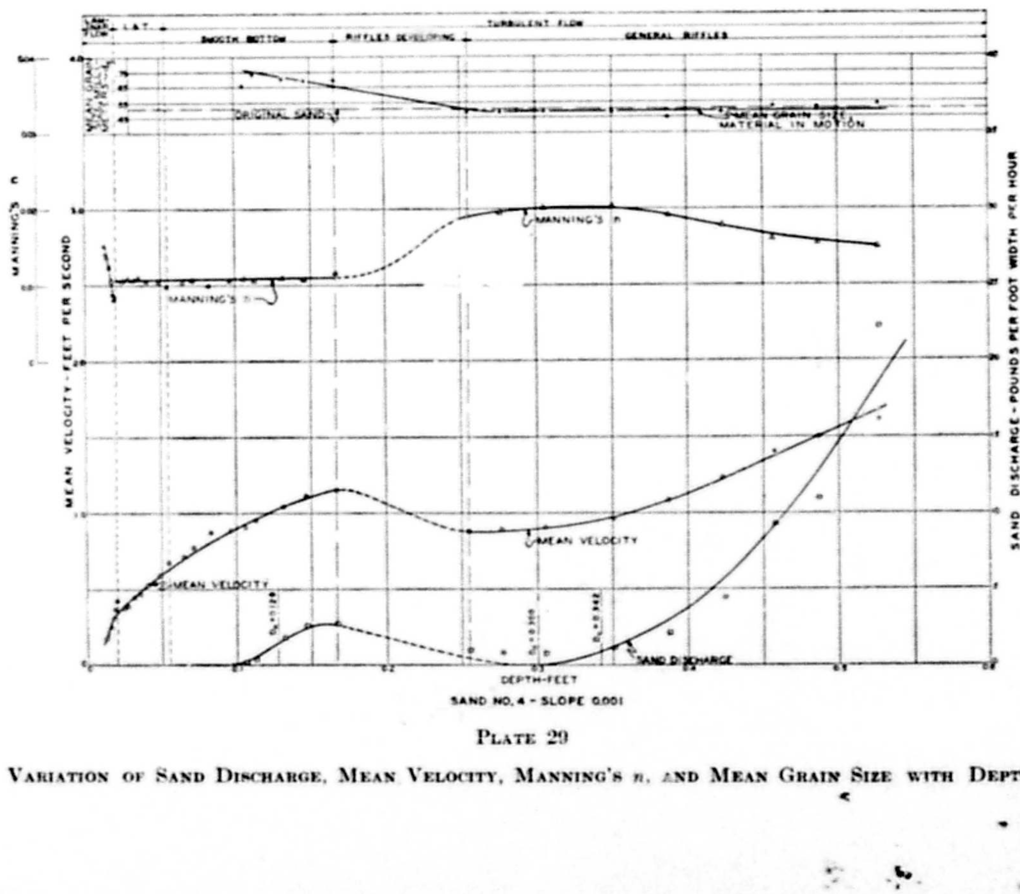
SAND NO. 3 - SLOPE 0.0015

PLATE 28

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



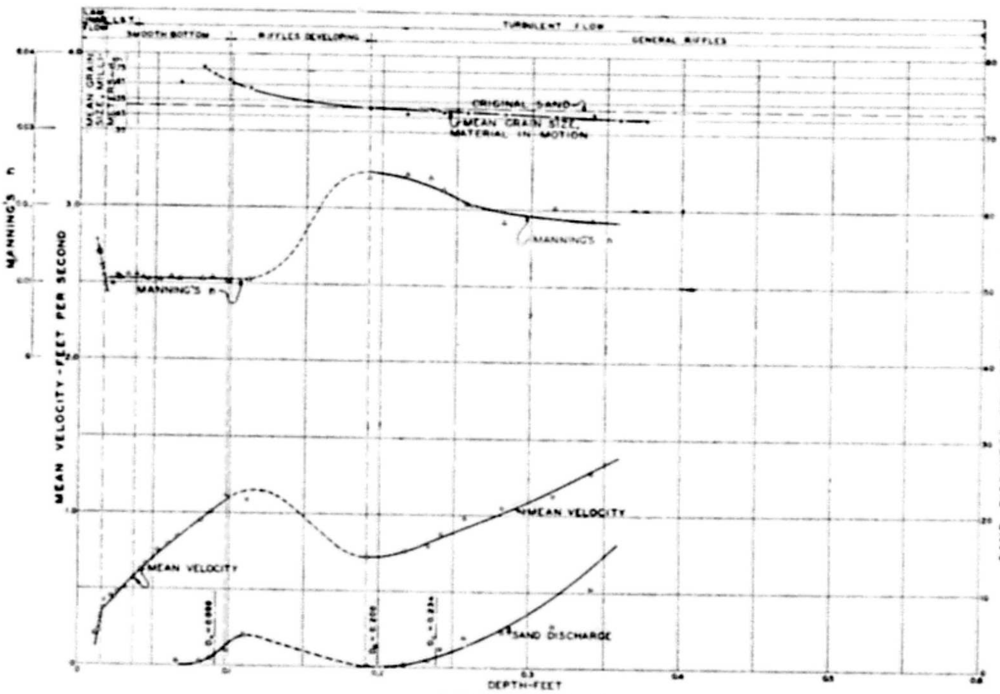
SAND NO. 3 - SLOPE 0.002



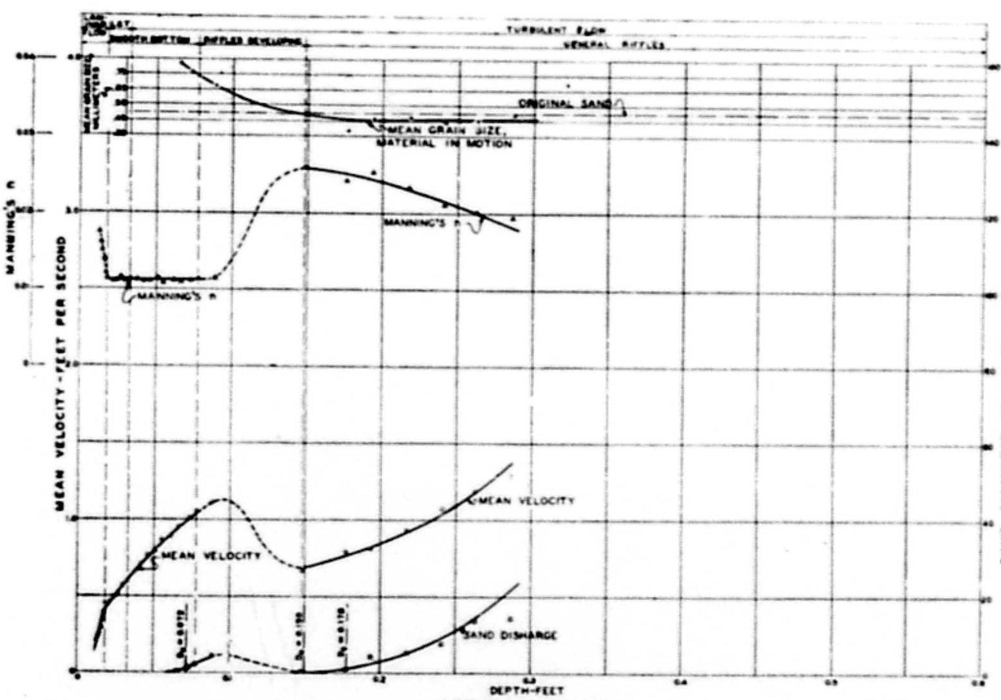
SAND NO. 4 - SLOPE 0.001

PLATE 29

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



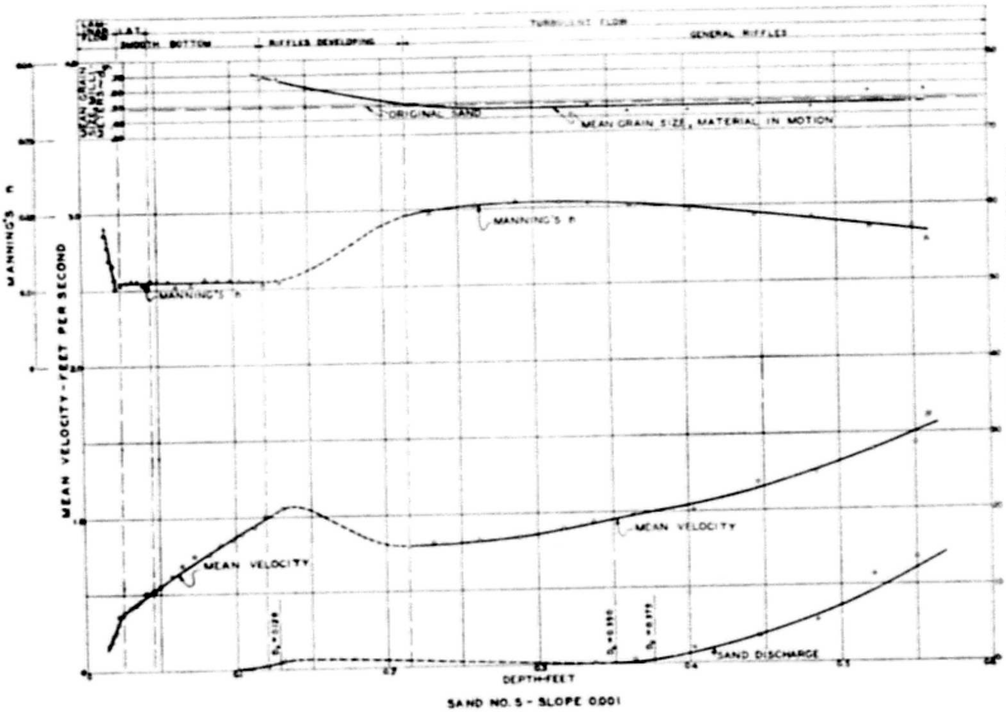
SAND NO. 4 – SLOPE 0.0015



SAND NO. 4 - SLOPE 0.002

PLATE 30

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



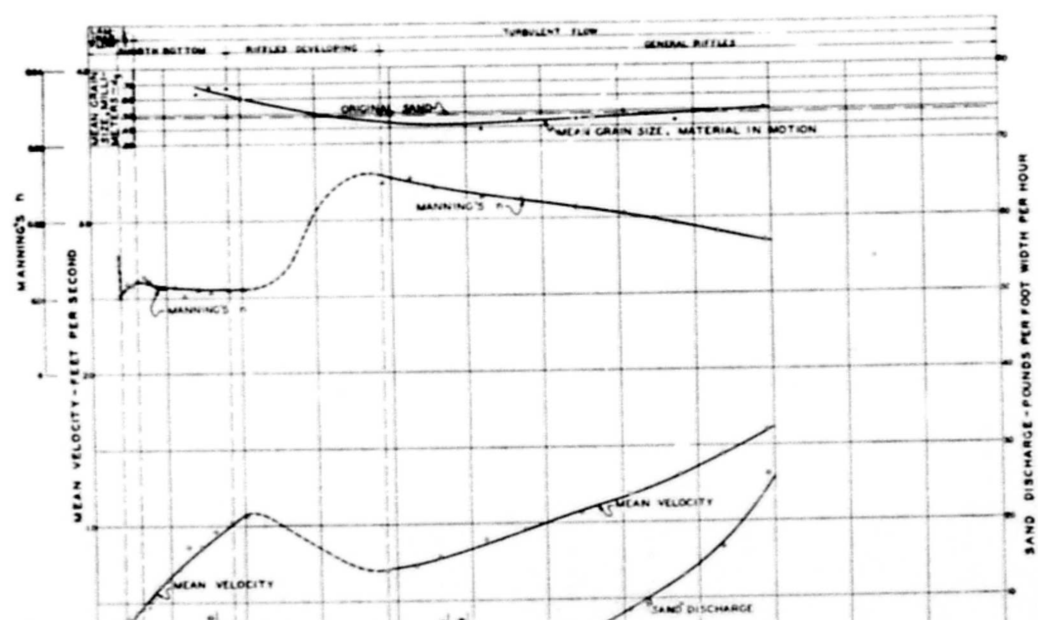
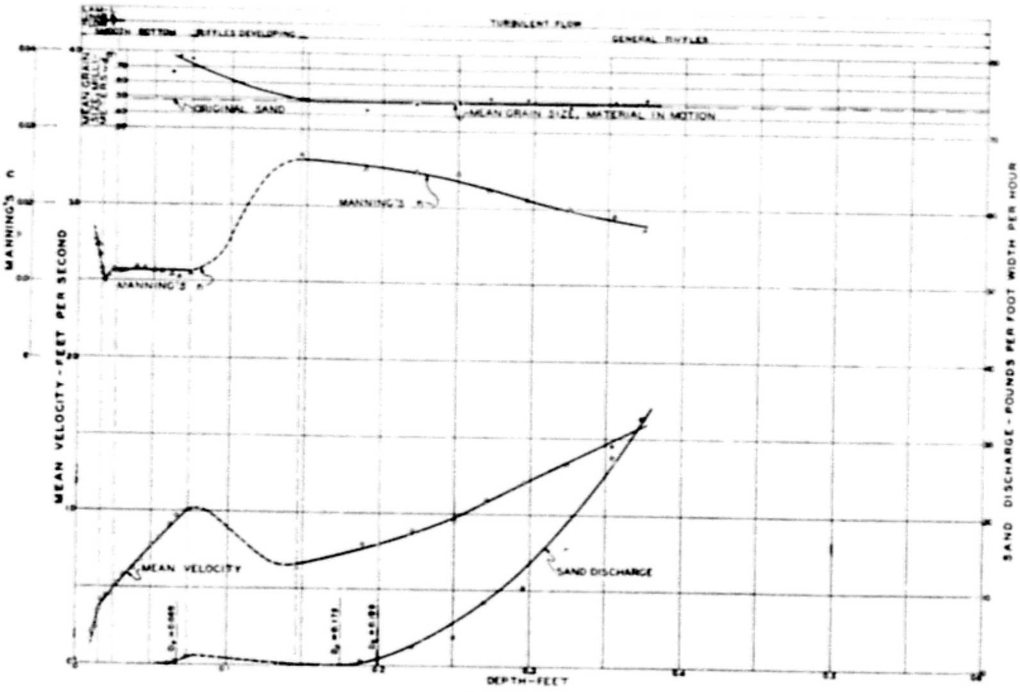
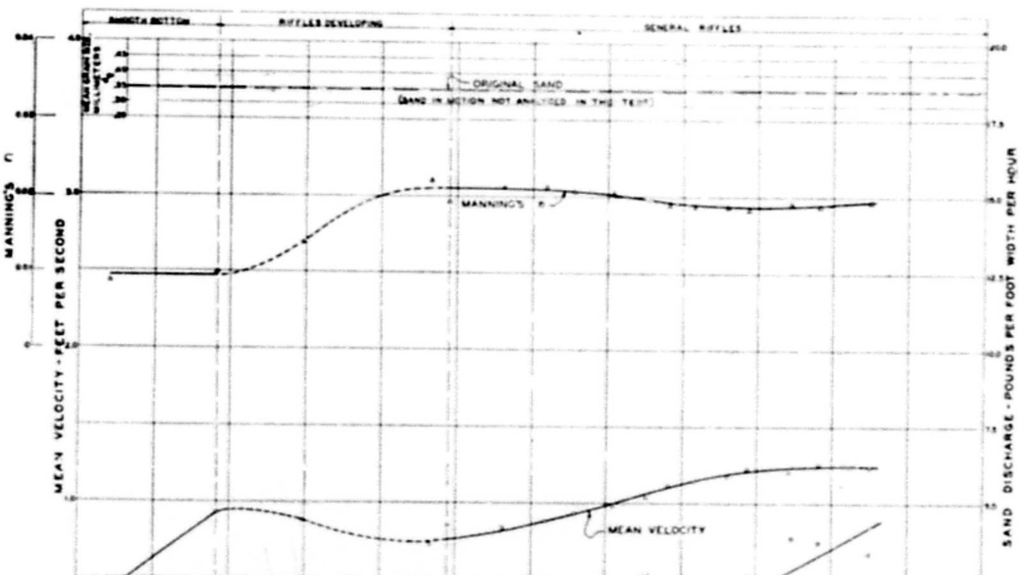


PLATE 31

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



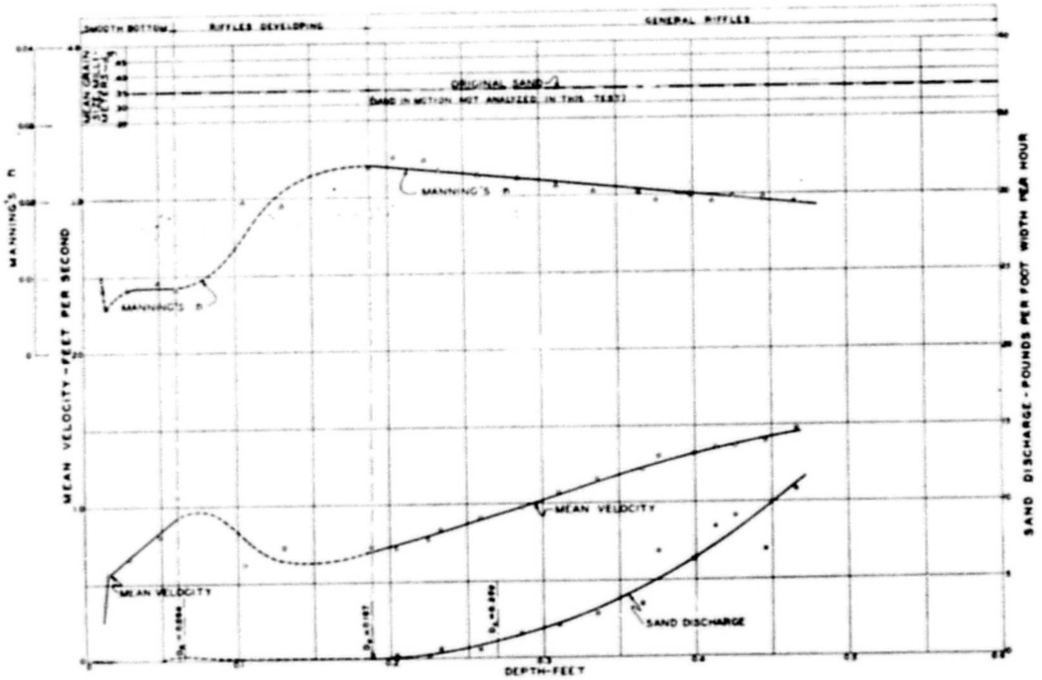
SAND NO. 5 - SLOPE 0.002



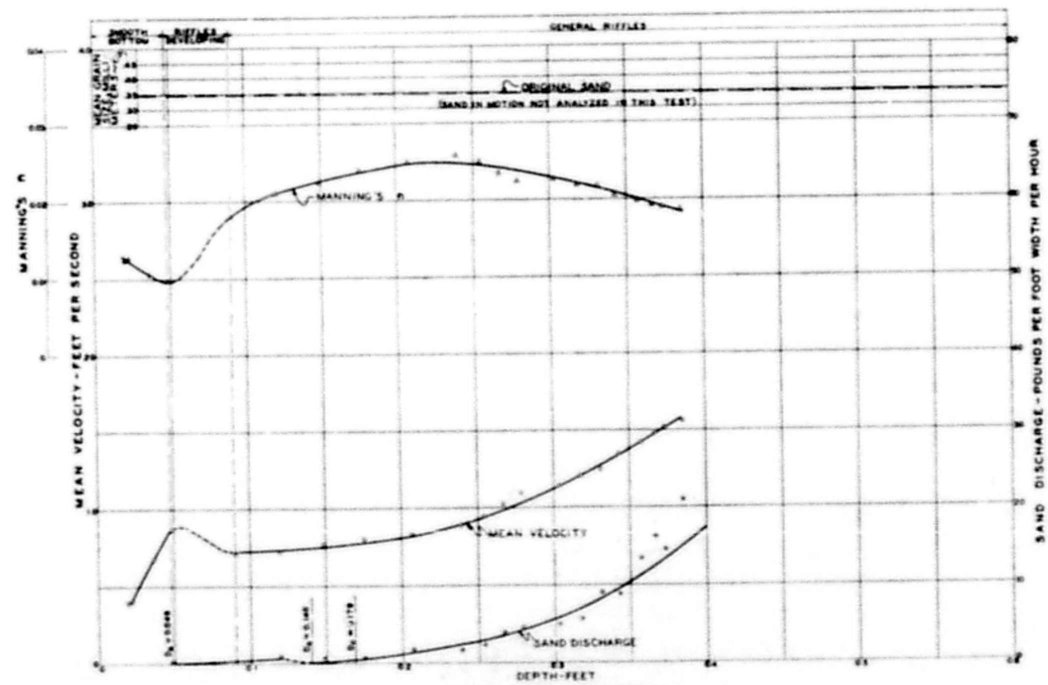
SAND NO. 6 - SLOPE 0.001

PLATE 32

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S *n*, AND MEAN GRAIN SIZE WITH DEPTH



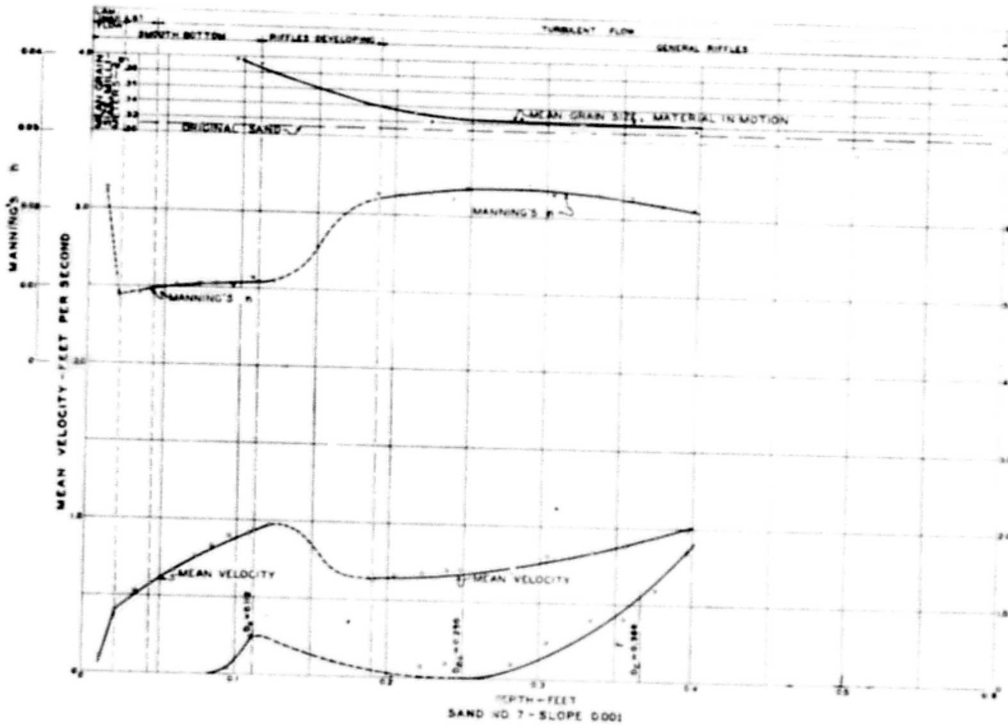
SAND NO. 6 - SLOPE 0.0015



SAND NO. 6 - SLOPE 0.002

PLATE 33

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S *n*, AND MEAN GRAIN SIZE WITH DEPTH



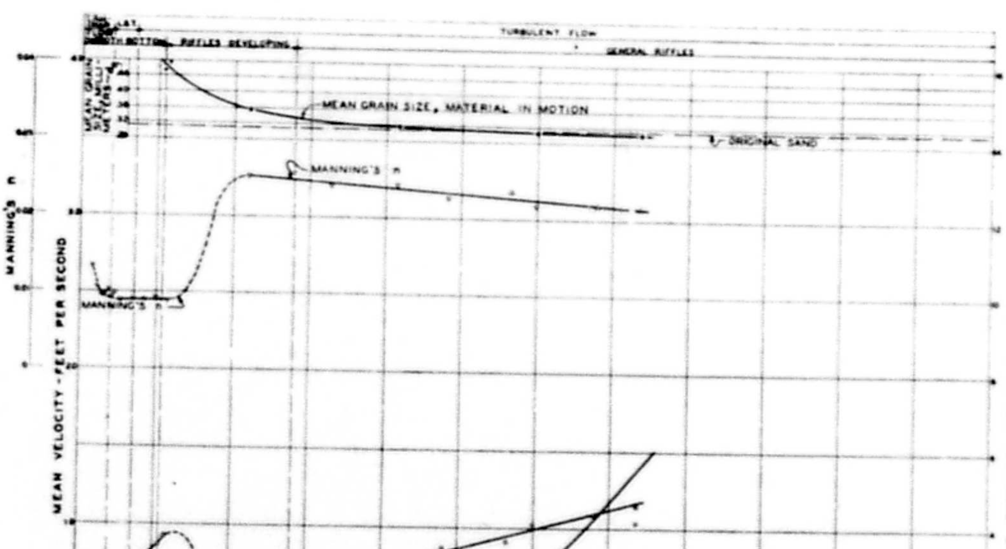
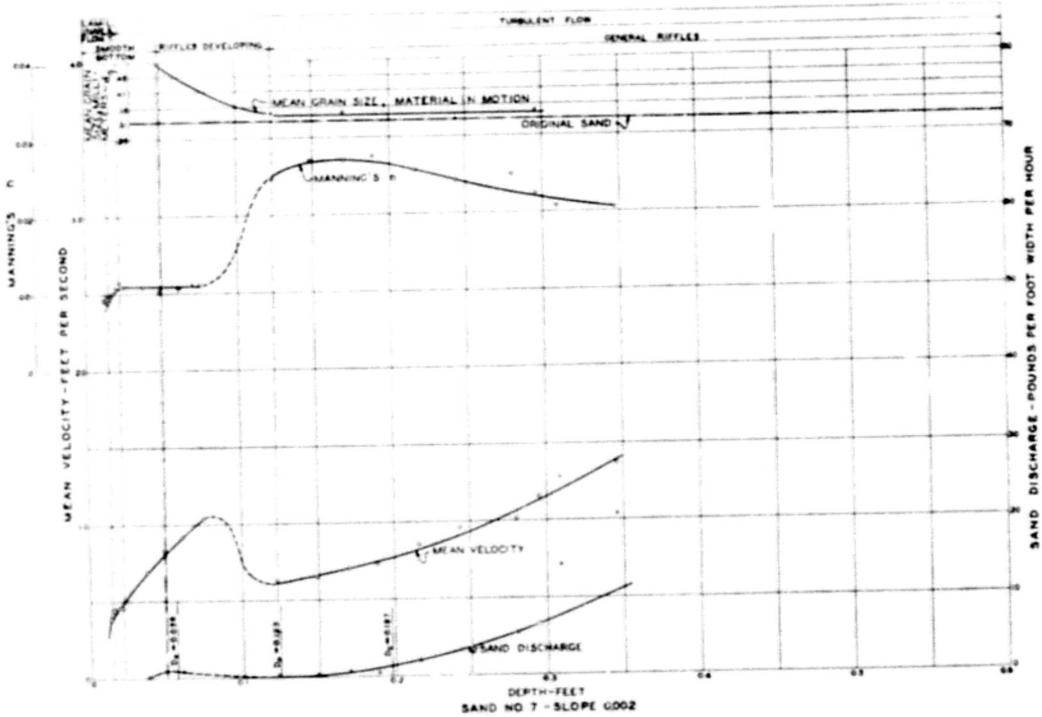
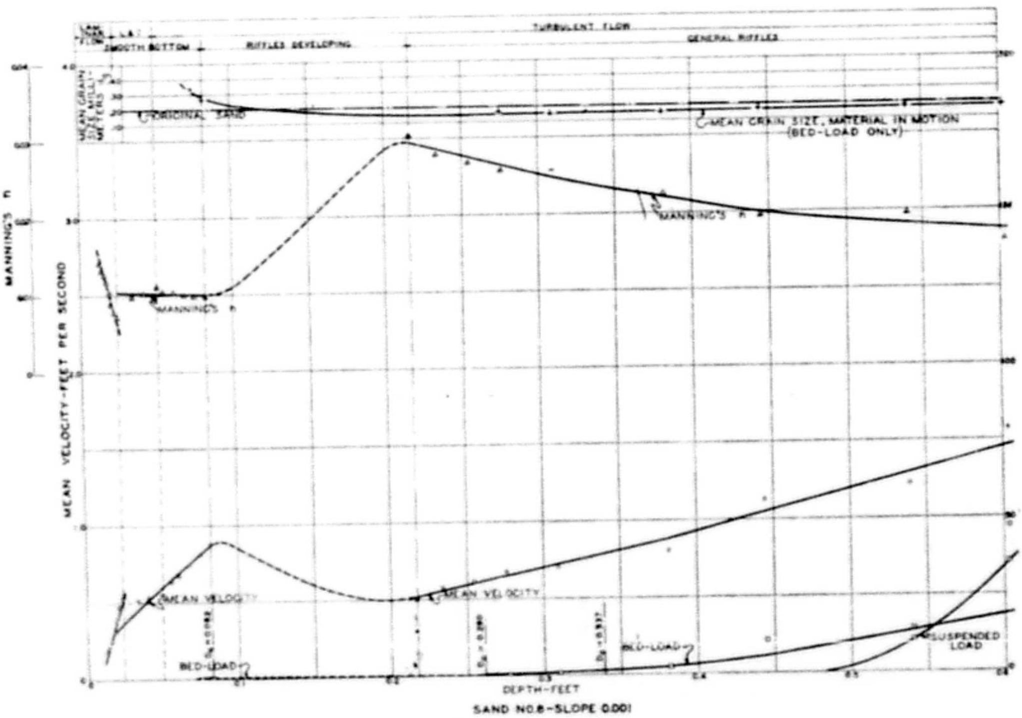


PLATE 34

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH

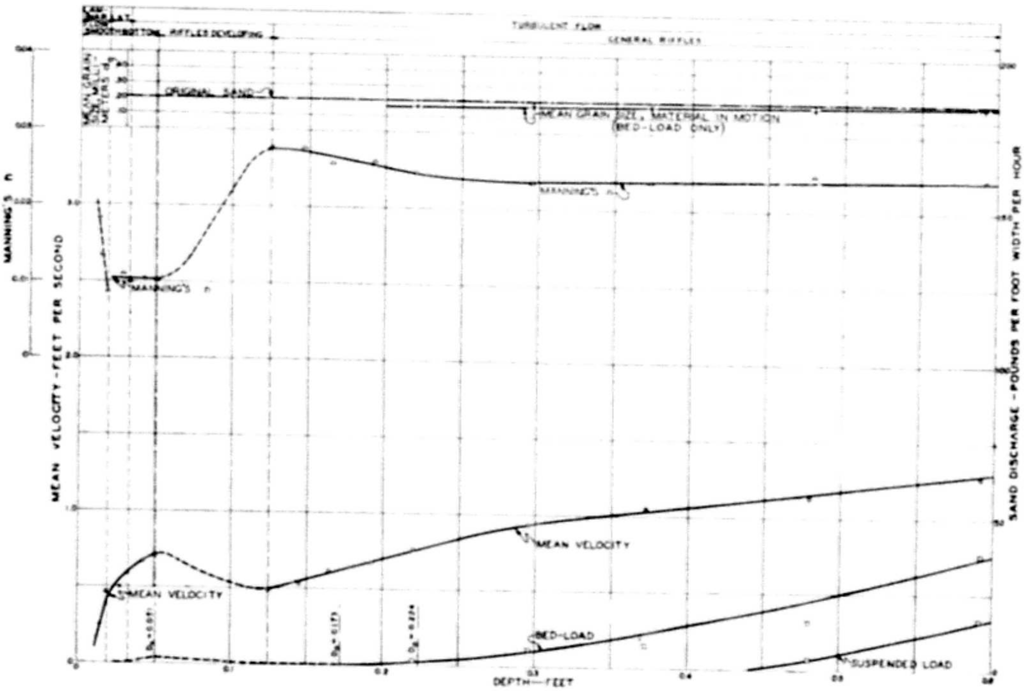




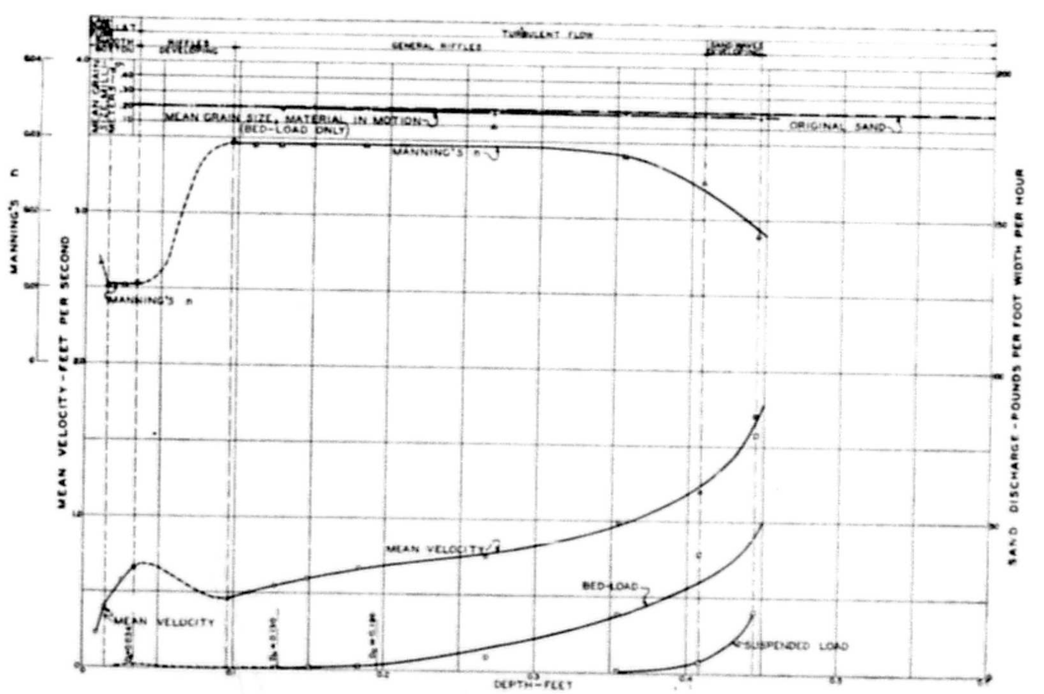
Note—The bed-load rate is greater than the suspended load rate throughout the range of this test. The curves cross because the bed-load curve, drawn from Plate 19 b, is the average derived from data from three slopes, while the suspended load curve follows the individual points.

PLATE 35

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n AND MEAN GRAIN SIZE WITH DEPTH



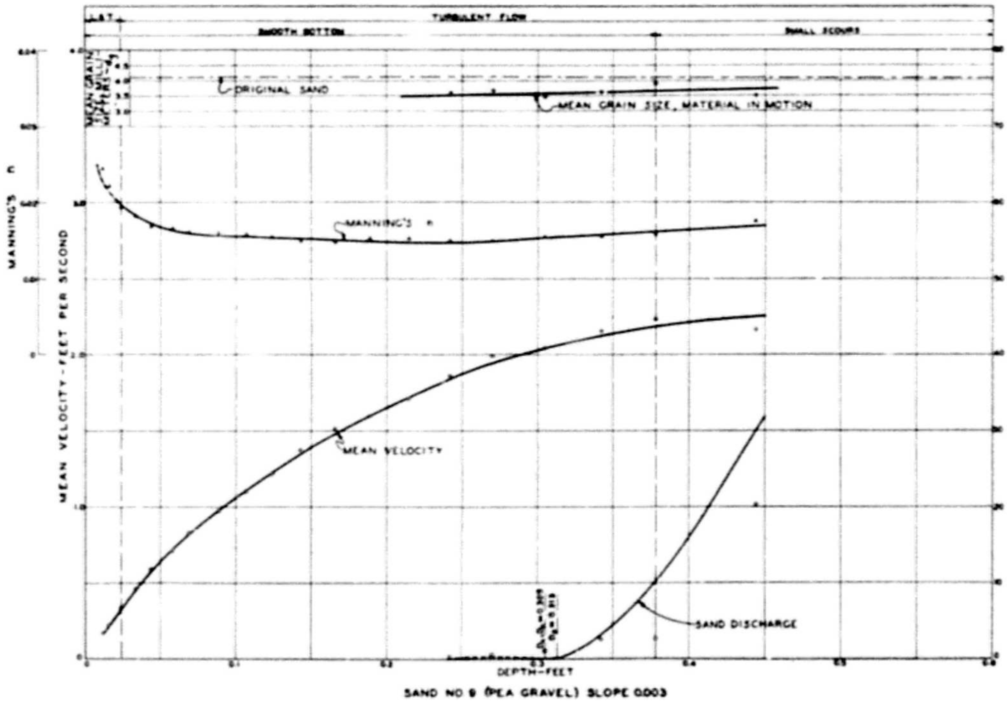
SAND NO 8 - SLOPE 0.0015



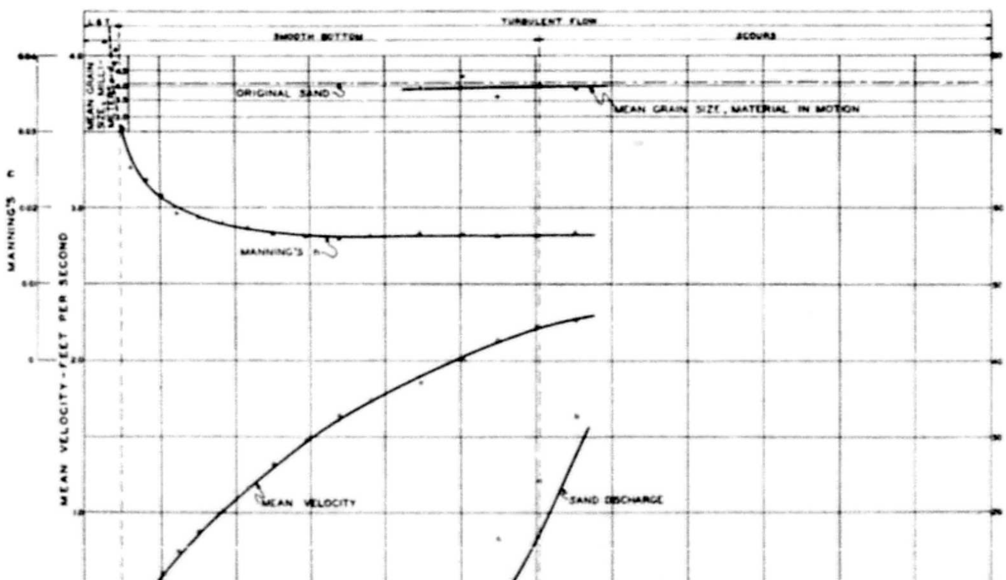
SAND NO 8 - SLOPE 0.002

PLATE 36

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH



SAND NO 9 (PEA GRAVEL) SLOPE 0.003



SAND NO 9 (PEA GRAVEL) SLOPE 0.004

PLATE 37

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH

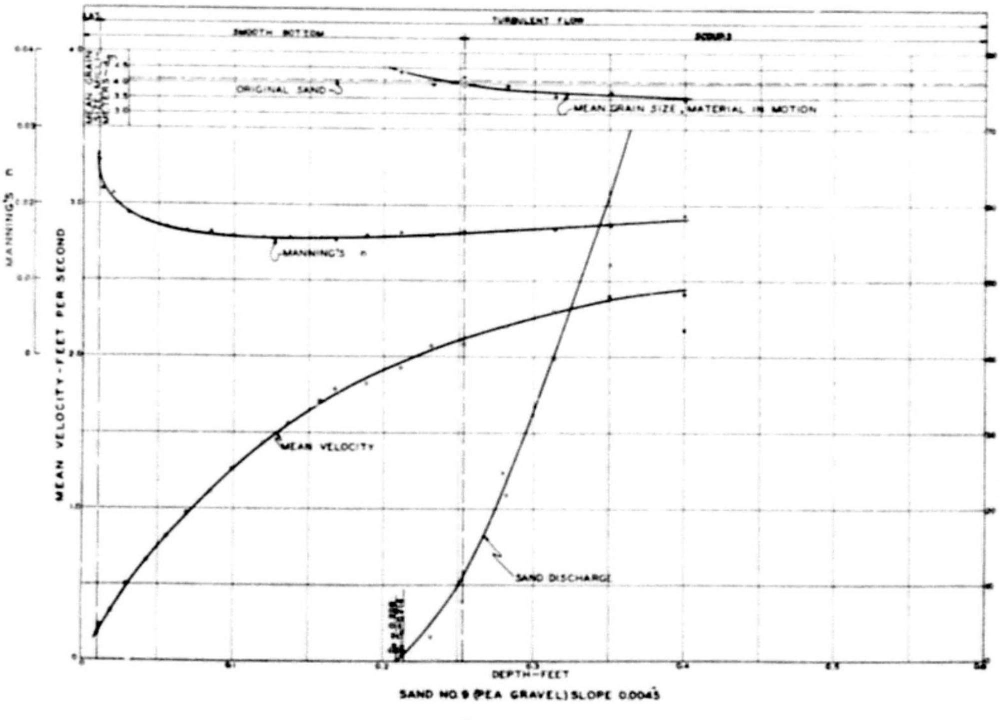


PLATE 38

VARIATION OF SAND DISCHARGE, MEAN VELOCITY, MANNING'S n, AND MEAN GRAIN SIZE WITH DEPTH

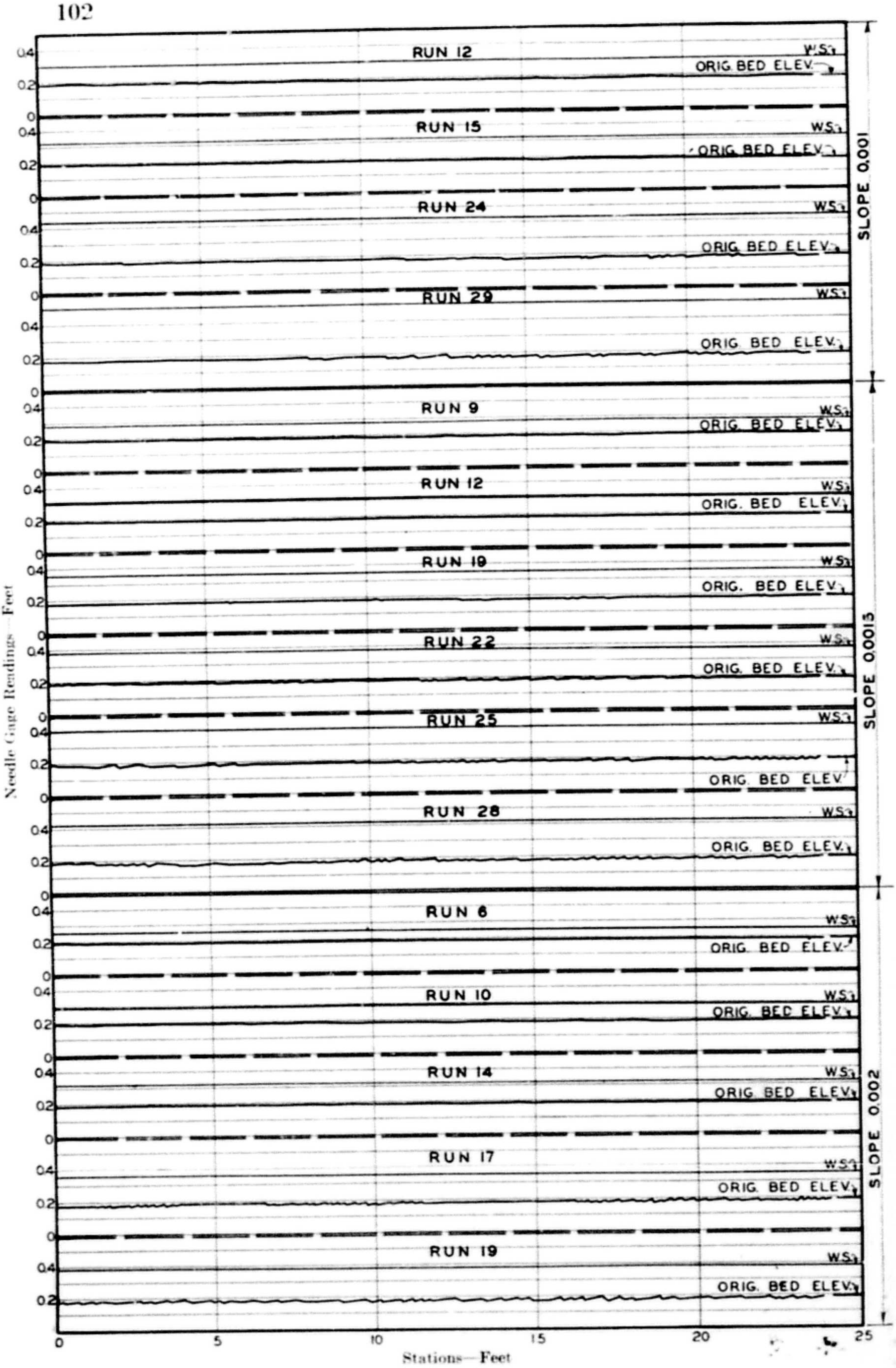


PLATE 39

LONGITUDINAL PROFILES OF SAND BED
Sand No. 1

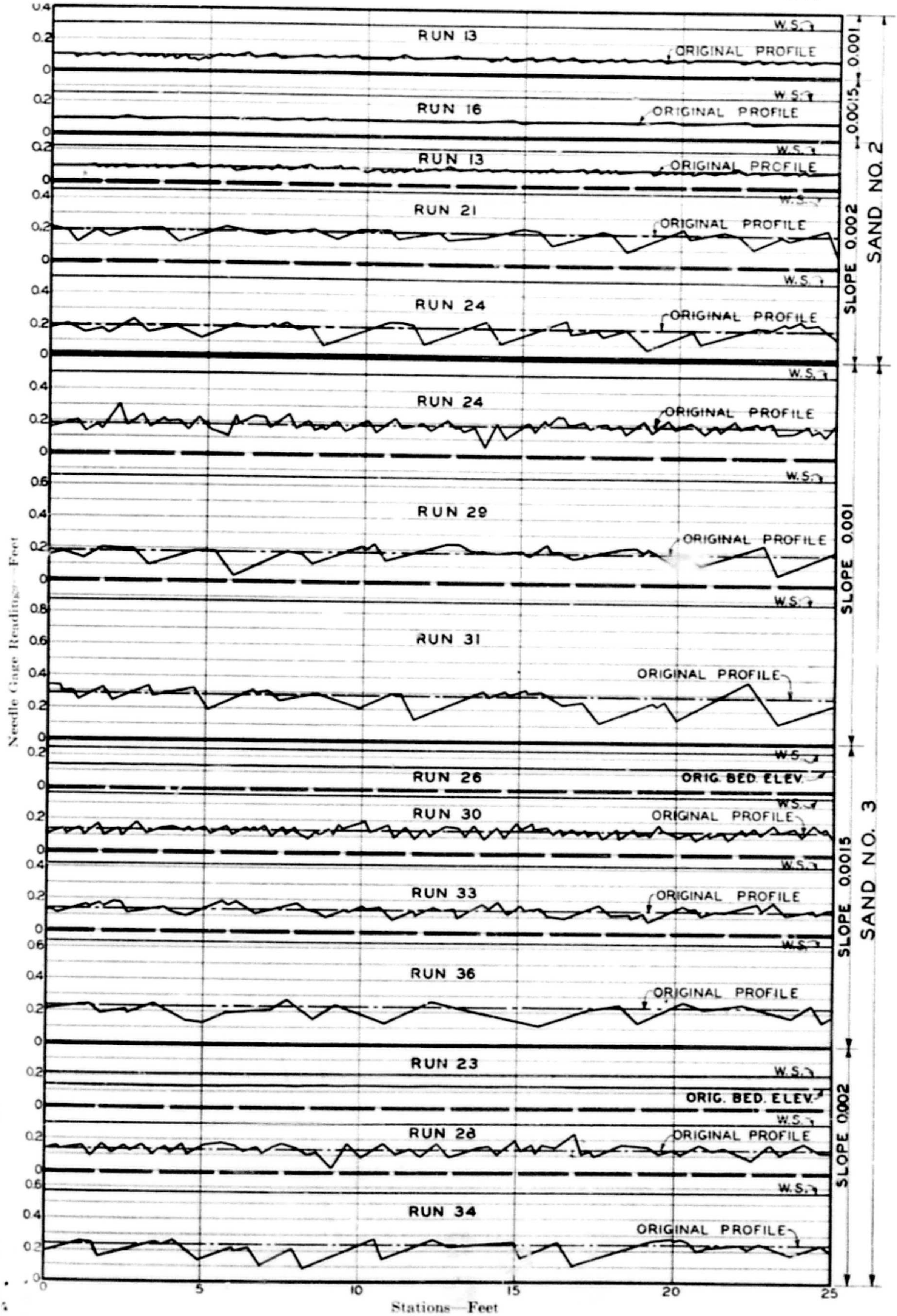


PLATE 40

LONGITUDINAL PROFILES OF SAND BED

Sands Nos. 2 and 3

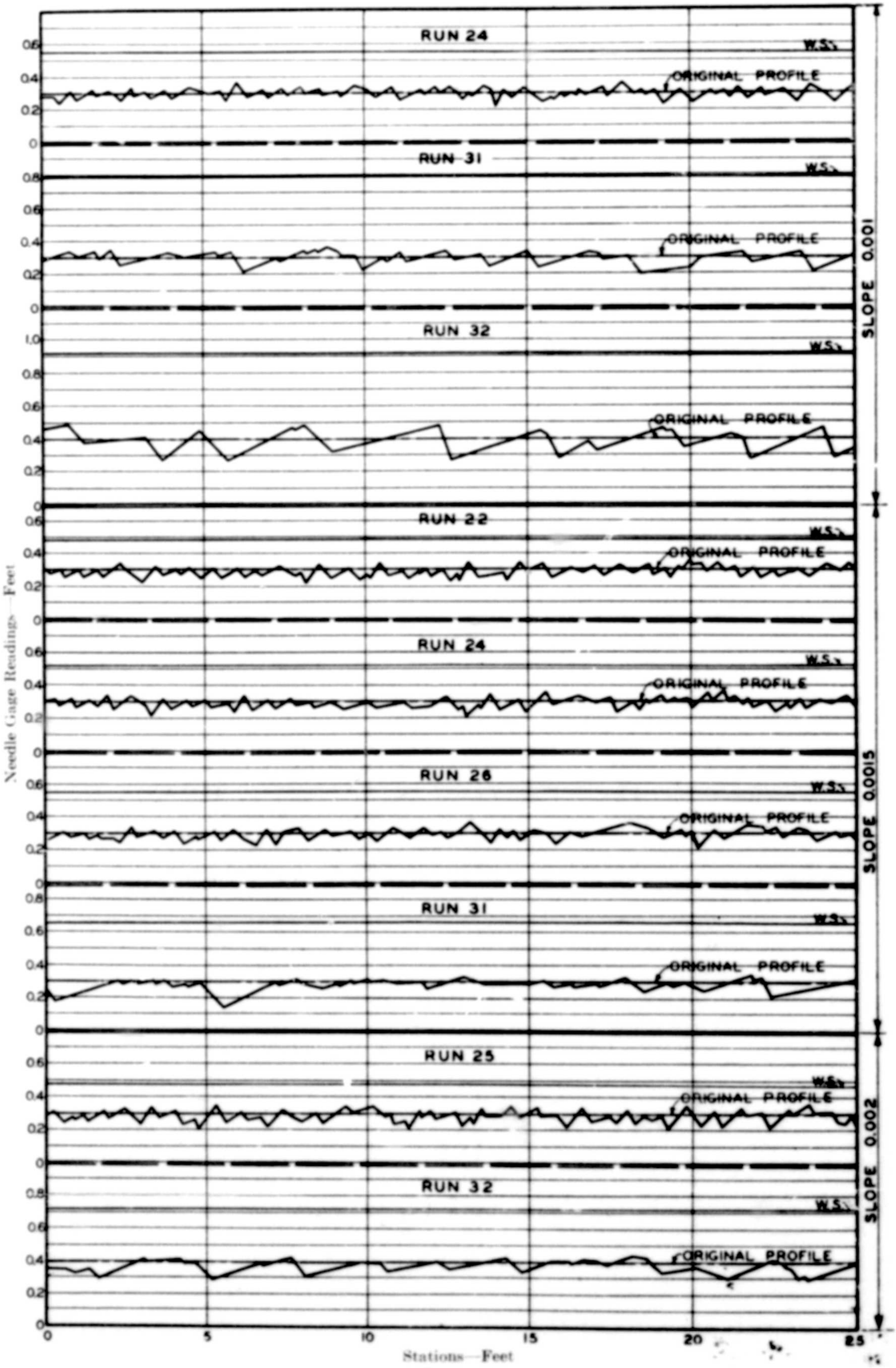
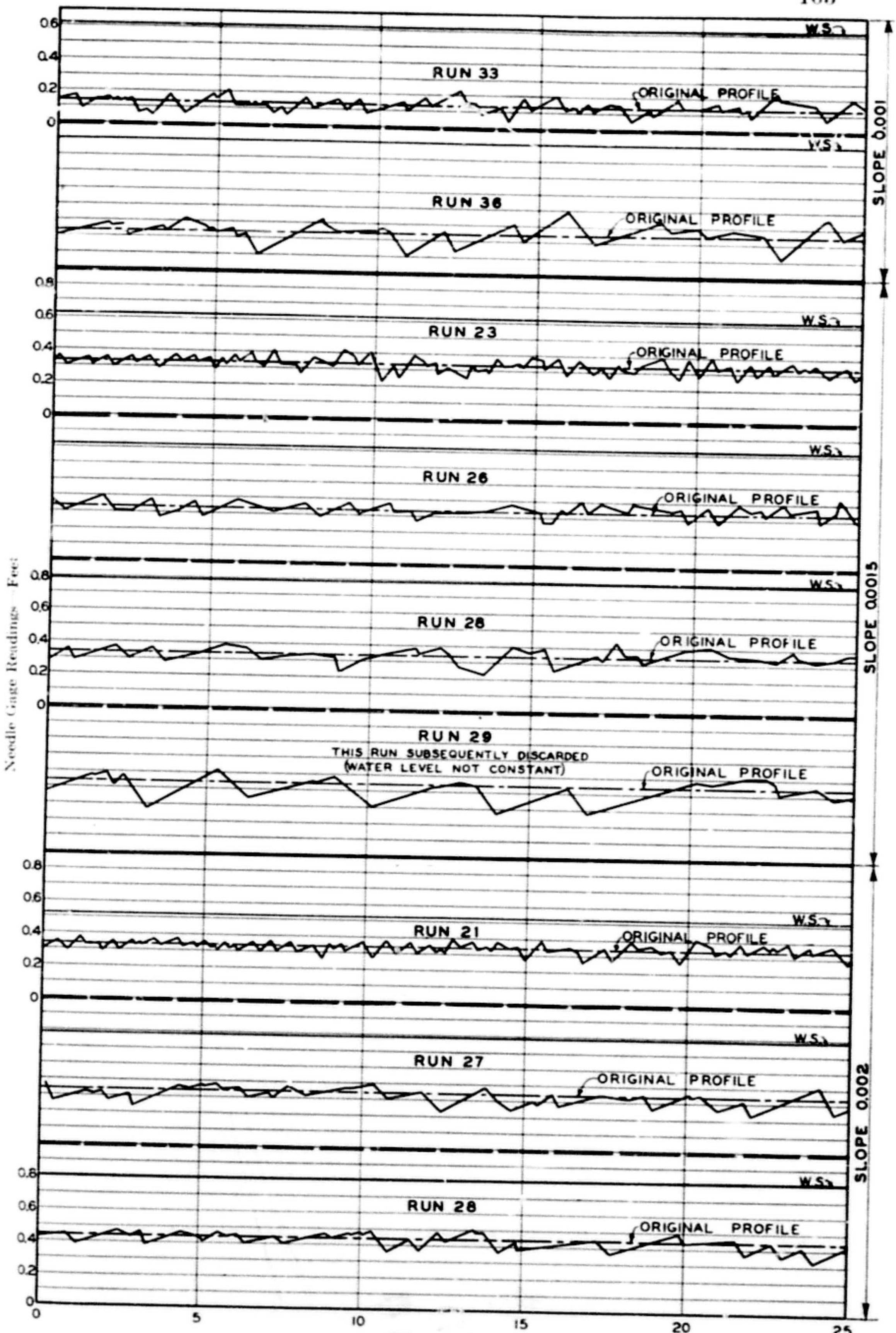


PLATE 41

LONGITUDINAL PROFILES OF SAND BED

Sand No. 4



Stations—Feet

PLATE 42

LONGITUDINAL PROFILES OF SAND BED

Sand No. 5

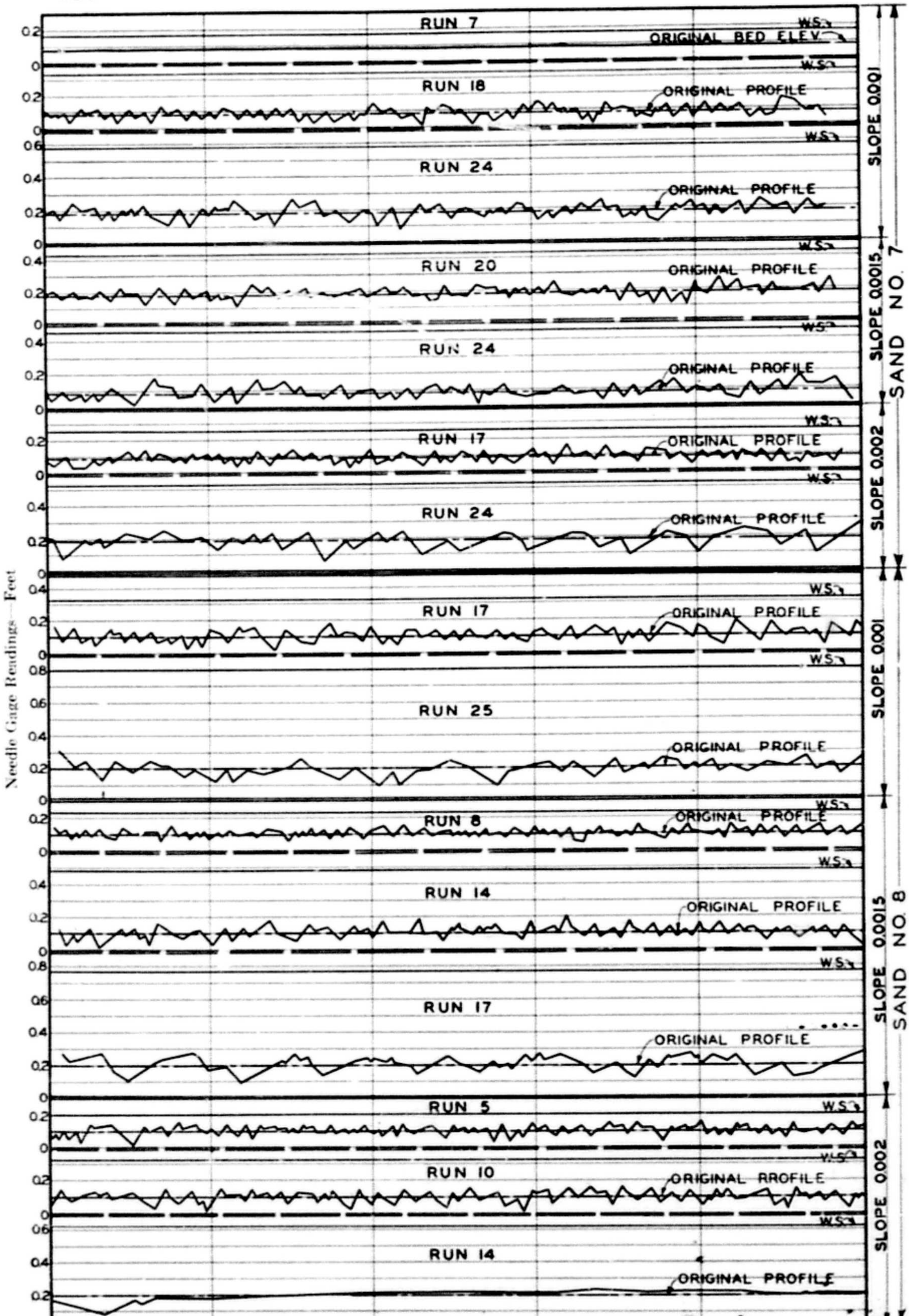


PLATE 43

LONGITUDINAL PROFILES OF SAND BED

Sands Nos. 7 and 8

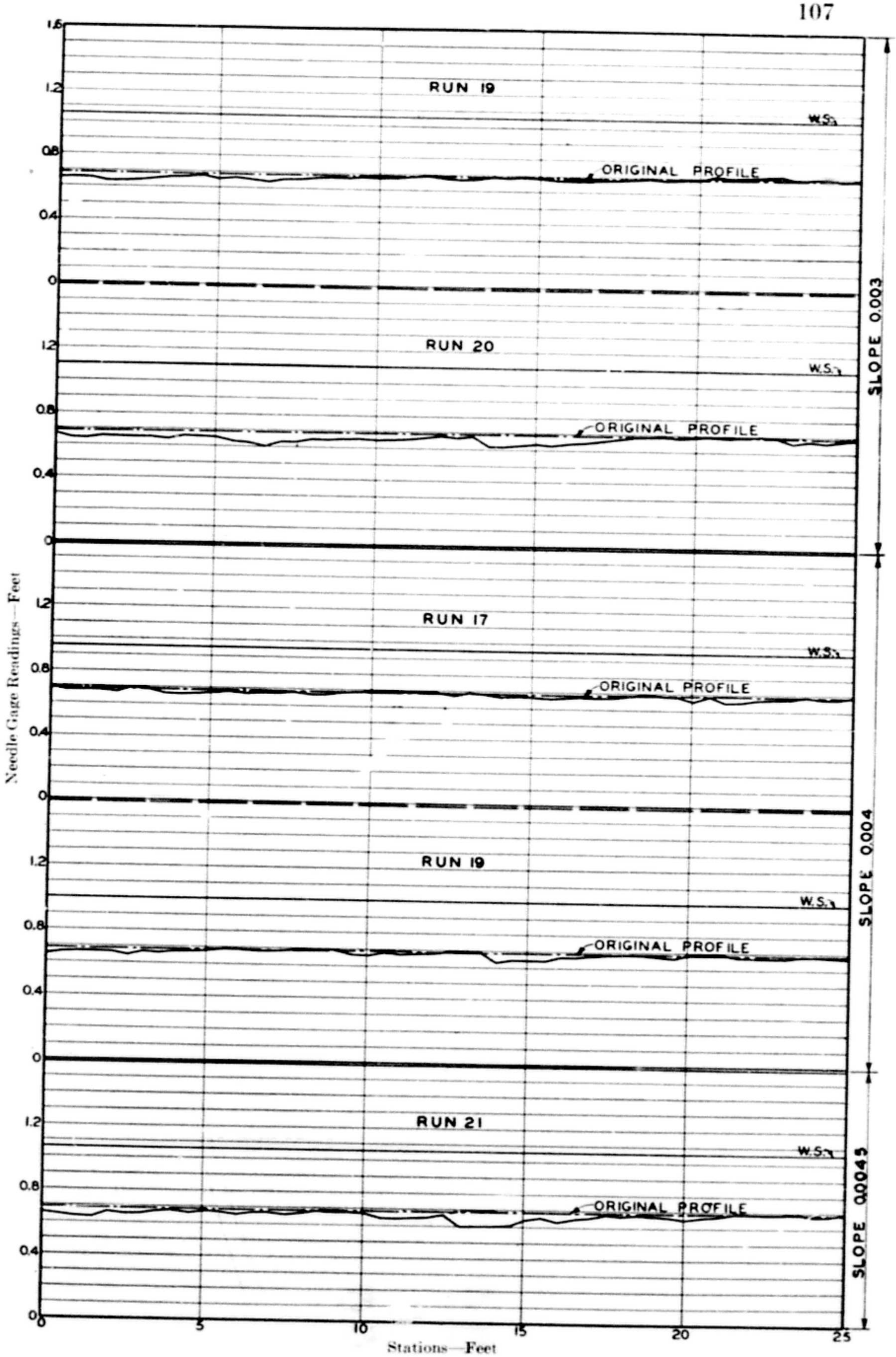
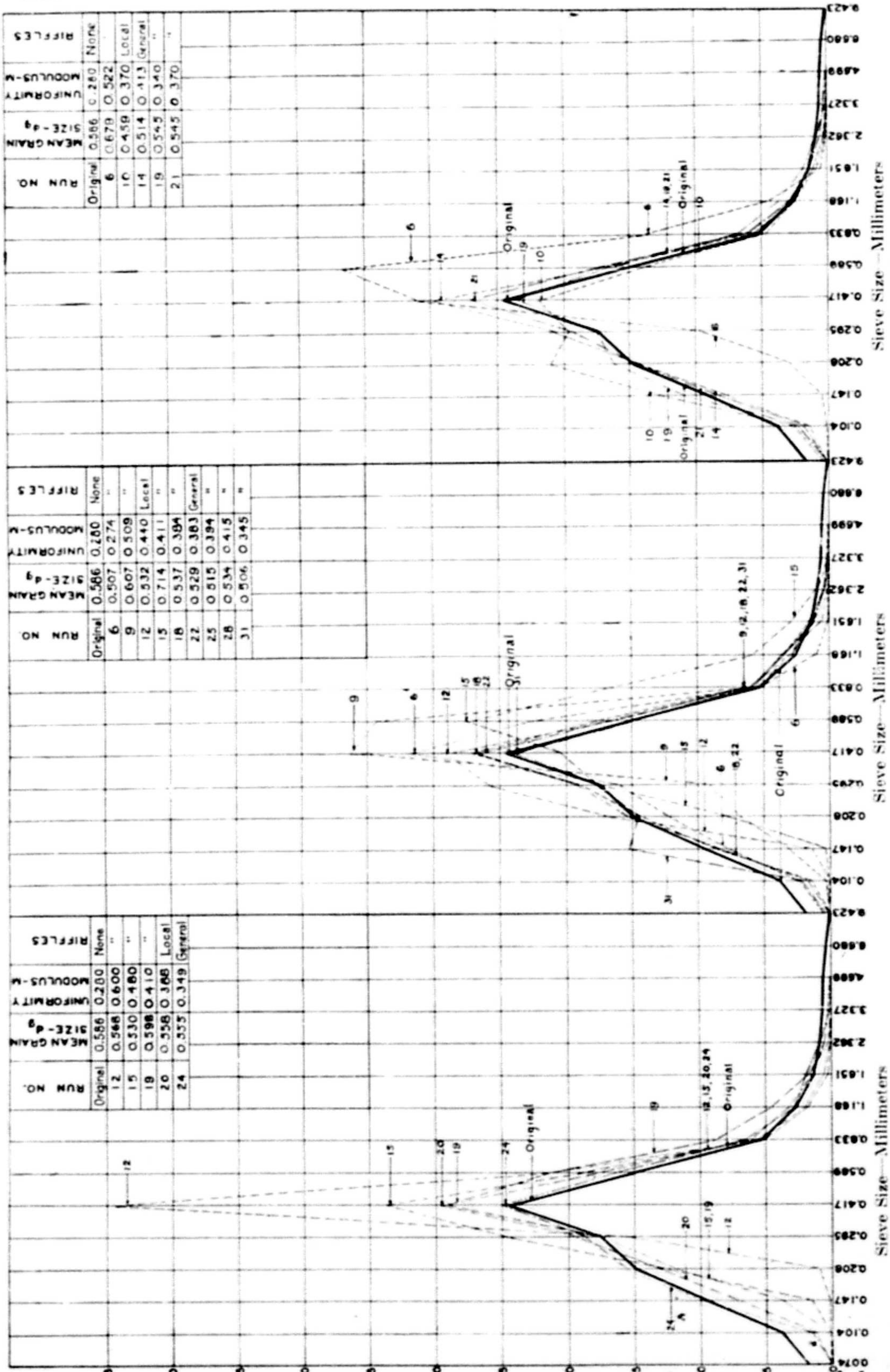


Plate 44

Longitudinal Profiles of Sand Bed

Sand No. 9



RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.586	0.280	None
12	0.568	0.600	"
15	0.530	0.480	"
19	0.598	0.410	"
20	0.558	0.388	Local
24	0.555	0.349	General

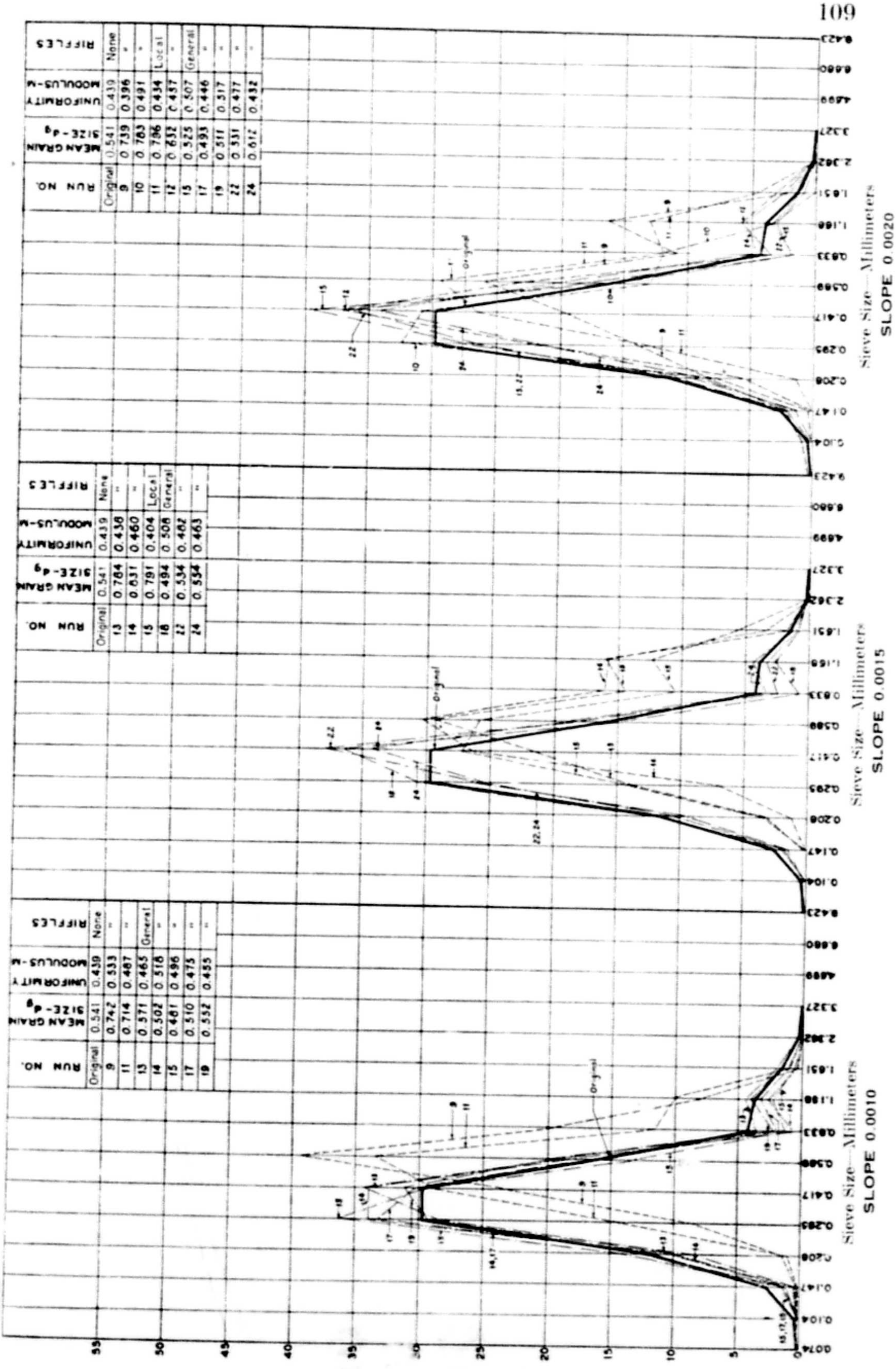
RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.586	0.280	None
6	0.507	0.274	"
9	0.607	0.509	"
12	0.532	0.440	Local
15	0.714	0.411	"
18	0.537	0.384	"
22	0.529	0.383	General
25	0.515	0.394	"
28	0.534	0.415	"
31	0.506	0.345	"

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.586	0.280	None
6	0.679	0.522	
10	0.459	0.370	Local
14	0.514	0.413	General
19	0.545	0.340	"
21	0.545	0.370	"

PLATE 45

PROGRESSIVE VARIATION OF SIZE AND DISTRIBUTION OF GRAINS IN MOVEMENT

Sand No. 1



Slope 0.0010

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.541	0.439	None
9	0.742	0.533	"
11	0.714	0.487	"
13	0.571	0.465	General
14	0.502	0.518	"
15	0.481	0.496	"
17	0.510	0.475	"
19	0.552	0.455	"

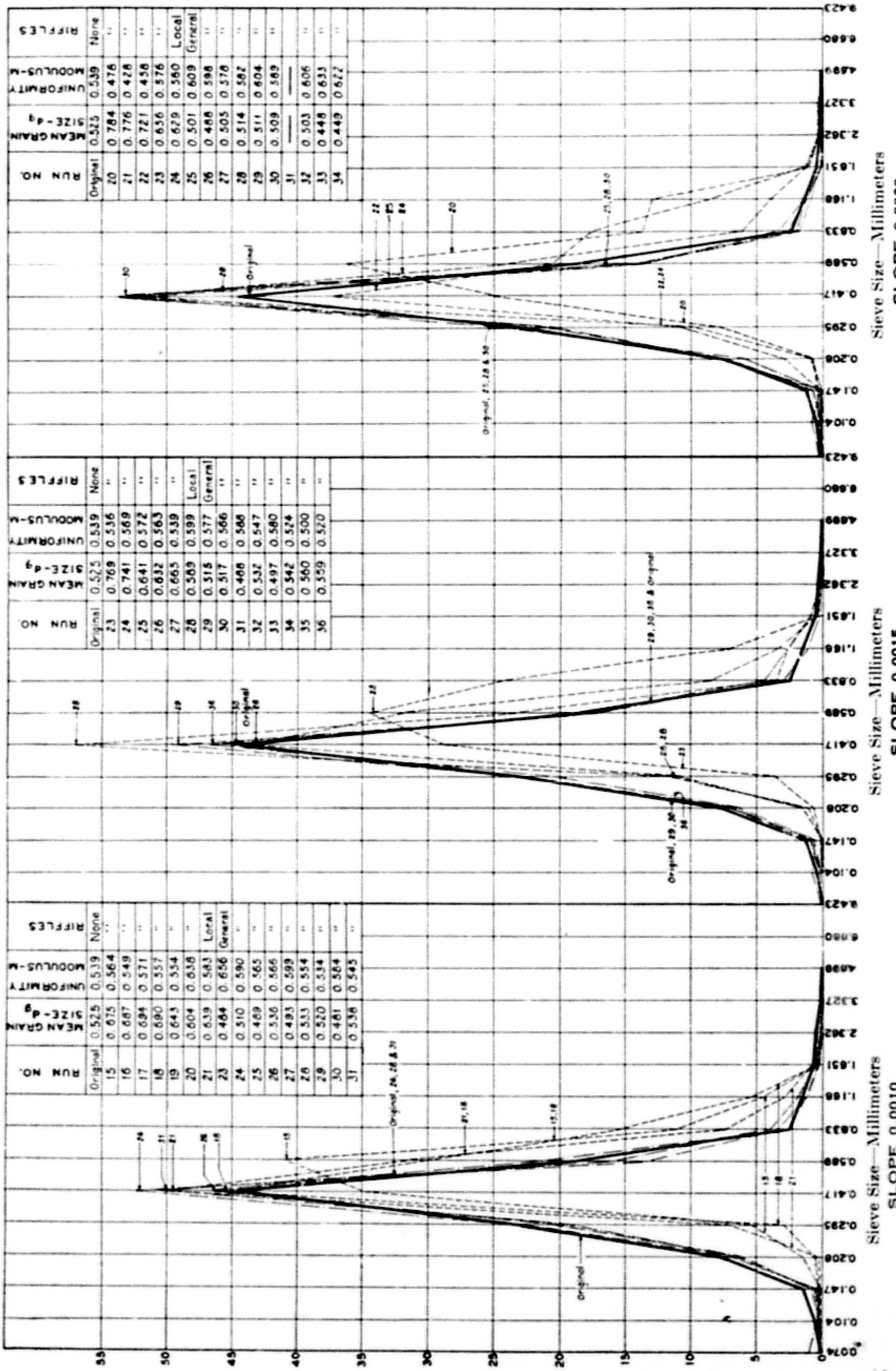
Slope 0.0015

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.541	0.439	None
13	0.784	0.436	"
14	0.631	0.460	"
15	0.791	0.404	Local
18	0.494	0.508	General
22	0.534	0.482	"
24	0.534	0.463	"

Slope 0.0020

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.541	0.439	None
9	0.739	0.396	"
10	0.783	0.491	"
11	0.786	0.434	Local
12	0.632	0.457	"
15	0.525	0.507	General
17	0.493	0.446	"
19	0.511	0.517	"
22	0.531	0.477	"
24	0.612	0.432	"

PLATE 46
PROGRESSIVE VARIATION OF SIZE AND DISTRIBUTION OF GRAINS IN MOVEMENT
Sand No. 2



Slope 0.0010

Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Original	0.525	0.539	None
15	0.675	0.564	"
16	0.687	0.549	"
17	0.694	0.571	"
18	0.690	0.557	"
19	0.643	0.554	"
20	0.604	0.638	"
21	0.639	0.583	Local
23	0.484	0.656	General
24	0.510	0.590	"
25	0.489	0.565	"
26	0.536	0.566	"
27	0.493	0.599	"
28	0.533	0.554	"
29	0.520	0.534	"
30	0.481	0.584	"
31	0.538	0.545	"

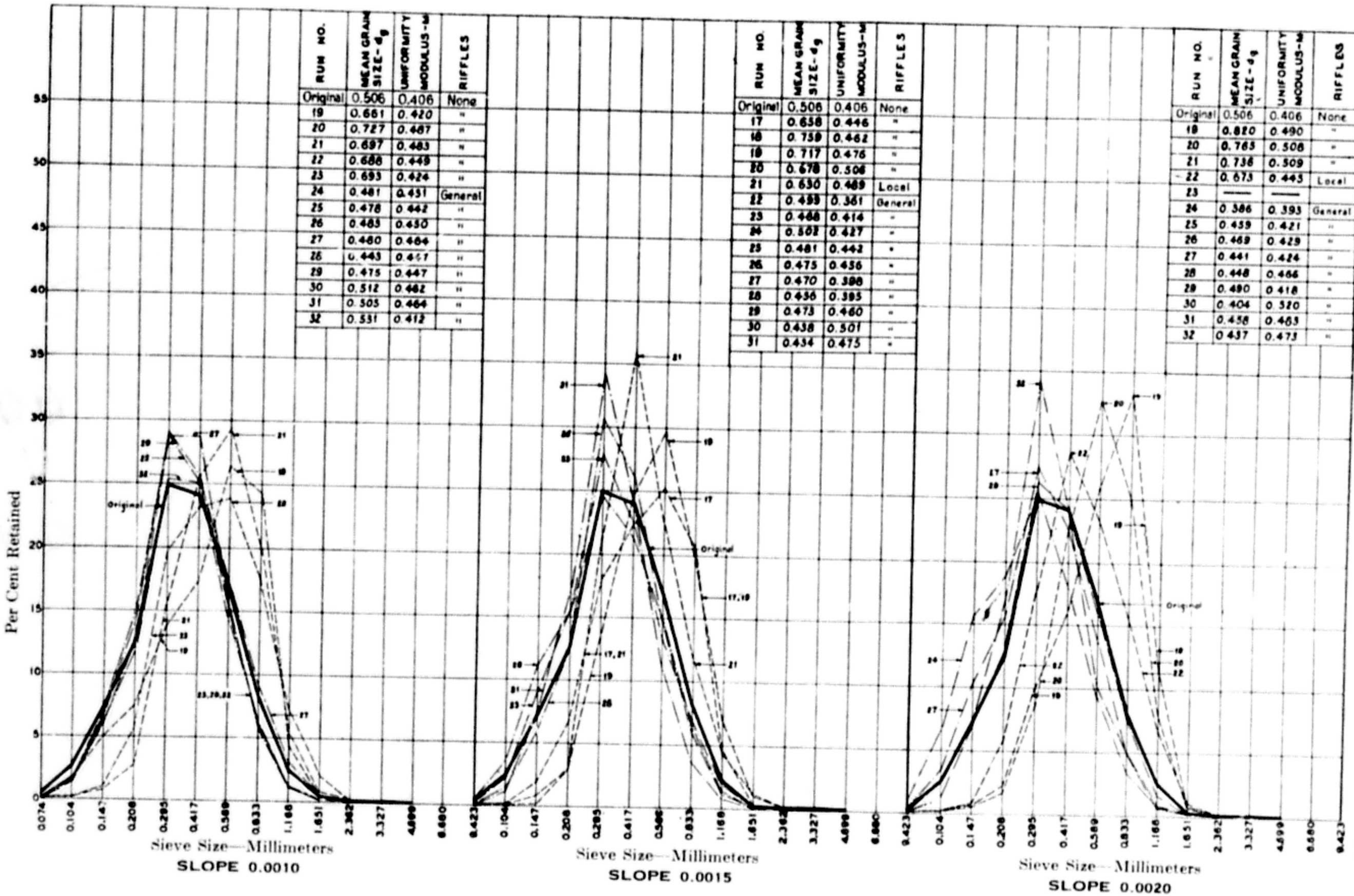
Slope 0.0015

Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Original	0.525	0.539	None
23	0.769	0.536	"
24	0.741	0.569	"
25	0.641	0.572	"
26	0.632	0.563	"
27	0.665	0.539	"
28	0.589	0.599	Local
29	0.515	0.577	General
30	0.517	0.566	"
31	0.468	0.568	"
32	0.532	0.547	"
33	0.497	0.580	"
34	0.542	0.524	"
35	0.560	0.500	"
36	0.559	0.520	"

Slope 0.0020

Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Original	0.525	0.539	None
20	0.784	0.476	"
21	0.776	0.428	"
22	0.721	0.458	"
23	0.656	0.576	"
24	0.629	0.560	Local
25	0.501	0.609	General
26	0.488	0.598	"
27	0.505	0.578	"
28	0.514	0.582	"
29	0.511	0.604	"
30	0.509	0.589	"
31	—	—	
32	0.503	0.606	"
33	0.448	0.633	"
34	0.449	0.622	"

Plate 47
Progressive Variation of Size and Distribution of Grains in Movement
Sand No. 3



Slope 0.0010

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.506	0.406	None
19	0.661	0.420	"
20	0.727	0.467	"
21	0.697	0.463	"
22	0.688	0.449	"
23	0.693	0.424	"
24	0.481	0.451	General
25	0.478	0.442	"
26	0.483	0.450	"
27	0.460	0.464	"
28	0.443	0.447	"
29	0.475	0.447	"
30	0.512	0.462	"
31	0.505	0.464	"
32	0.531	0.412	"

Slope 0.0015

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.506	0.406	None
17	0.658	0.446	"
18	0.759	0.462	"
19	0.717	0.476	"
20	0.678	0.508	"
21	0.630	0.489	Local
22	0.459	0.361	General
23	0.468	0.414	"
24	0.502	0.427	"
25	0.481	0.442	"
26	0.475	0.456	"
27	0.470	0.398	"
28	0.456	0.395	"
29	0.473	0.460	"
30	0.438	0.501	"
31	0.434	0.475	"

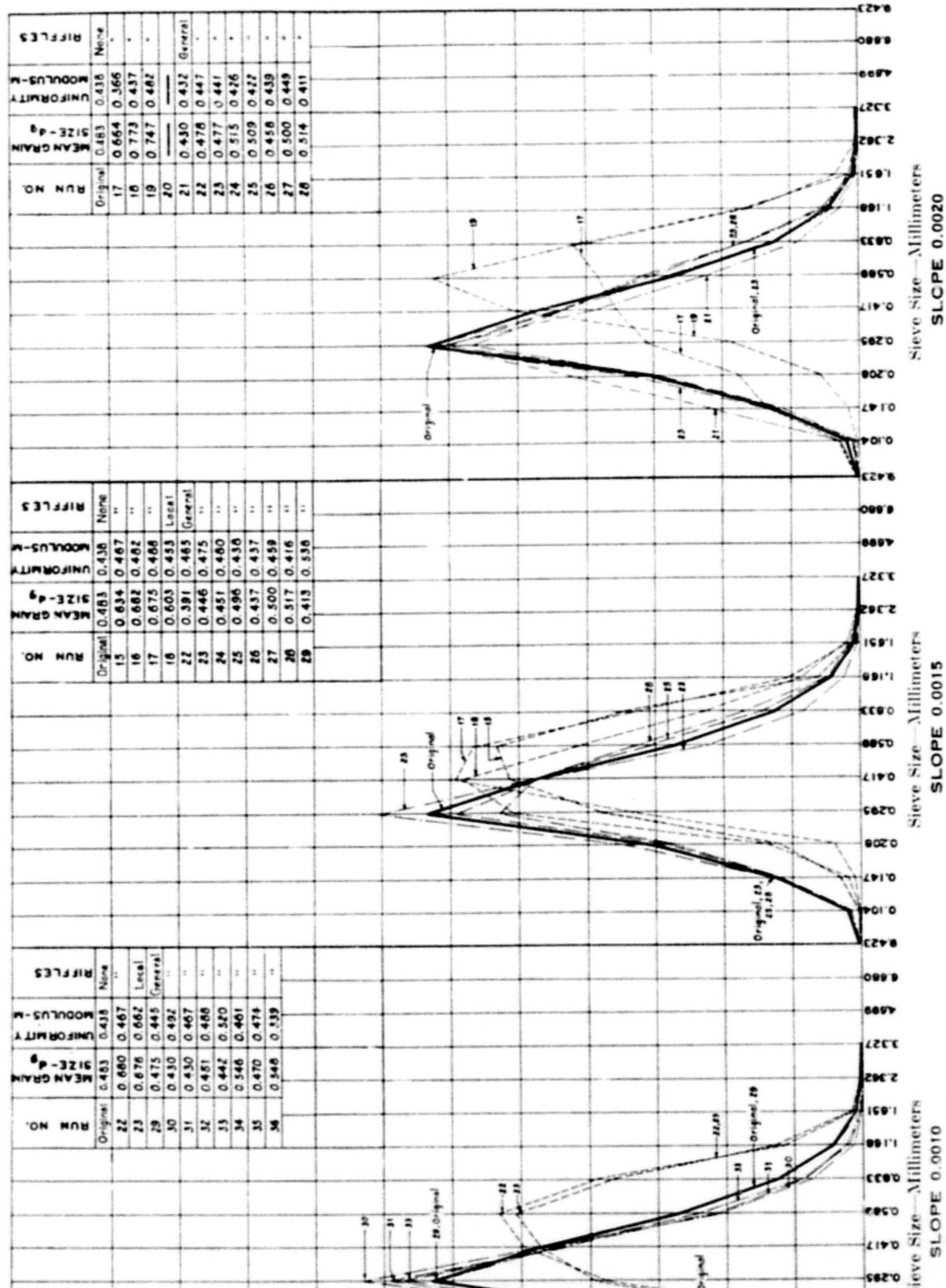
Slope 0.0020

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.506	0.406	None
19	0.820	0.490	"
20	0.765	0.508	"
21	0.738	0.509	"
22	0.673	0.445	Local
23	——	——	
24	0.386	0.393	General
25	0.459	0.421	"
26	0.469	0.429	"
27	0.441	0.424	"
28	0.448	0.466	"
29	0.490	0.418	"
30	0.404	0.320	"
31	0.458	0.463	"
32	0.437	0.473	"

PLATE 48

PROGRESSIVE VARIATION OF SIZE AND DISTRIBUTION OF GRAINS IN MOVEMENT

Sand No. 4



SLOPE 0.0010

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.483	0.438	None
22	0.680	0.467	"
23	0.676	0.662	Local
29	0.475	0.445	General
30	0.430	0.492	"
31	0.430	0.467	"
32	0.451	0.488	"
33	0.442	0.520	"
34	0.546	0.461	"
35	0.470	0.474	"
36	0.548	0.339	"

SLOPE 0.0015

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.483	0.438	None
15	0.634	0.467	"
16	0.682	0.482	"
17	0.675	0.488	"
18	0.603	0.453	Local
22	0.391	0.465	General
23	0.446	0.475	"
24	0.451	0.480	"
25	0.496	0.438	"
26	0.437	0.437	"
27	0.500	0.459	"
28	0.517	0.416	"
29	0.413	0.538	"

SLOPE 0.0020

RUN NO.	MEAN GRAIN SIZE-d_g	UNIFORMITY MODULUS-M	RIFFLES
Original	0.483	0.438	None
17	0.664	0.366	"
18	0.773	0.437	"
19	0.747	0.482	"
20	——	——	
21	0.430	0.432	General
22	0.478	0.447	"
23	0.477	0.441	"
24	0.515	0.426	"
25	0.509	0.422	"
26	0.458	0.439	"
27	0.500	0.449	"
28	0.514	0.411	"

PLATE 49

PROGRESSIVE VARIATION OF SIZE AND DISTRIBUTION OF GRAINS IN MOVEMENT

Sand No. 5

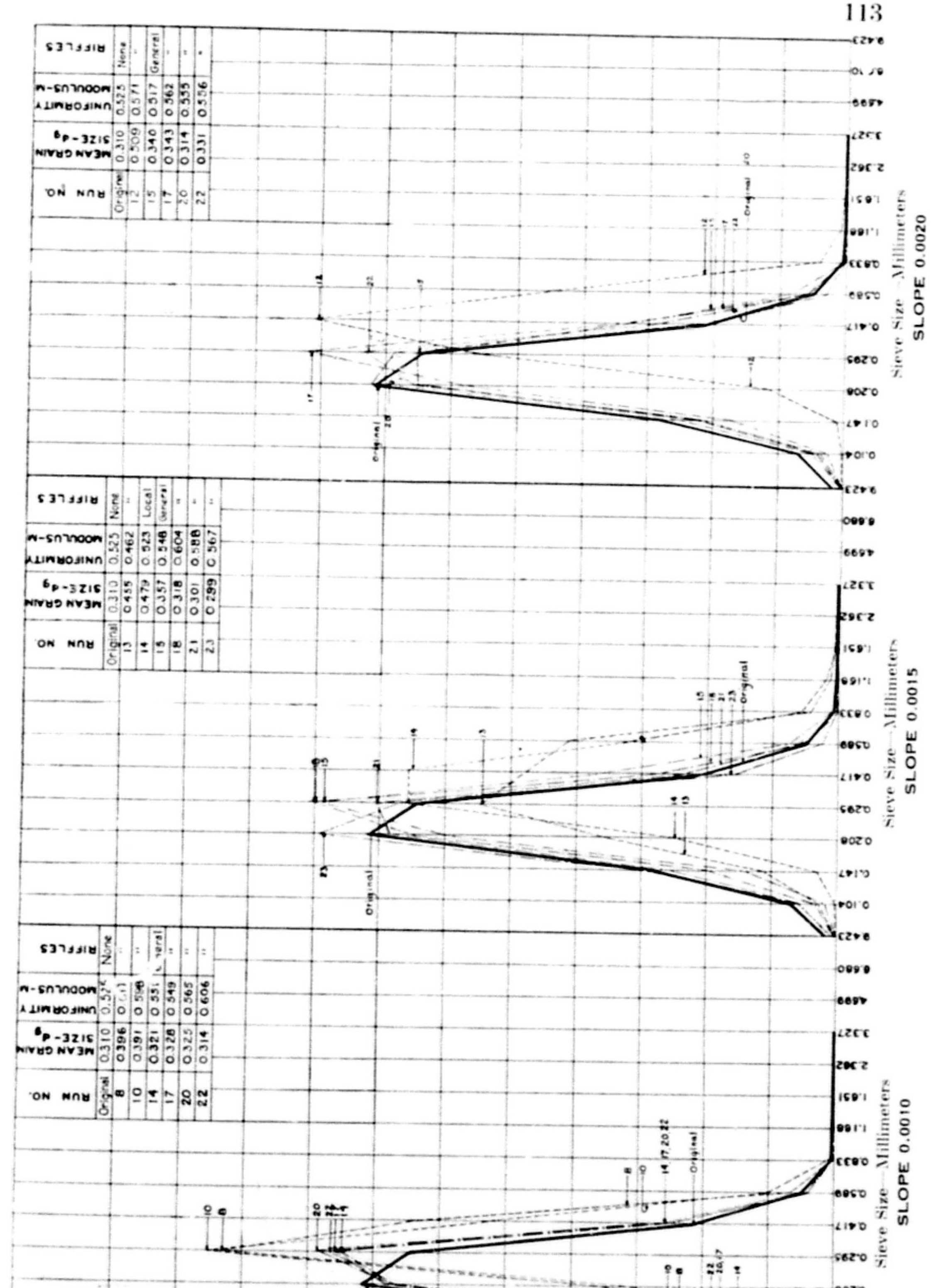
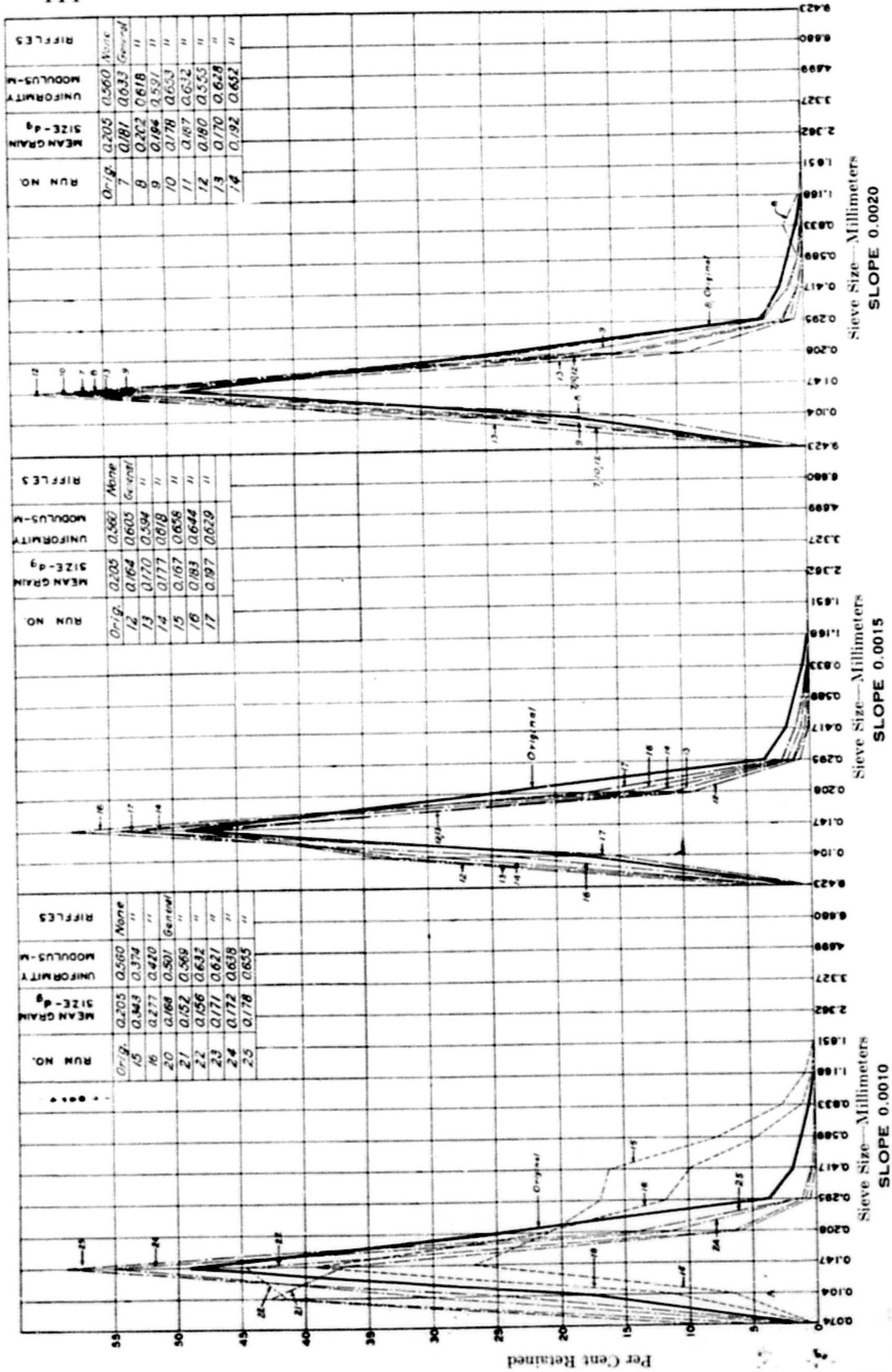


Plate 50

Progressive Variation of Size and Distribution of Grains in Movement

Sand No. 7



Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Orig.	0.205	0.560	None
7	0.181	0.633	General
8	0.202	0.618	"
9	0.194	0.591	"
10	0.178	0.653	"
11	0.187	0.632	"
12	0.180	0.555	"
13	0.170	0.628	"
14	0.192	0.652	"

Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Orig.	0.205	0.560	None
12	0.164	0.605	General
13	0.170	0.594	"
14	0.177	0.618	"
15	0.167	0.658	"
16	0.183	0.644	"
17	0.197	0.629	"

Run No.	Mean Grain Size-d_g	Uniformity Modulus-M	Riffles
Orig.	0.205	0.560	None
15	0.343	0.374	"
16	0.277	0.420	"
20	0.168	0.501	General
21	0.152	0.569	"
22	0.156	0.632	"
23	0.171	0.621	"
24	0.172	0.638	"
25	0.178	0.655	"

PLATE 51

PROGRESSIVE VARIATION OF SIZE AND DISTRIBUTION OF GRAINS IN MOVEMENT

Sand No. 8

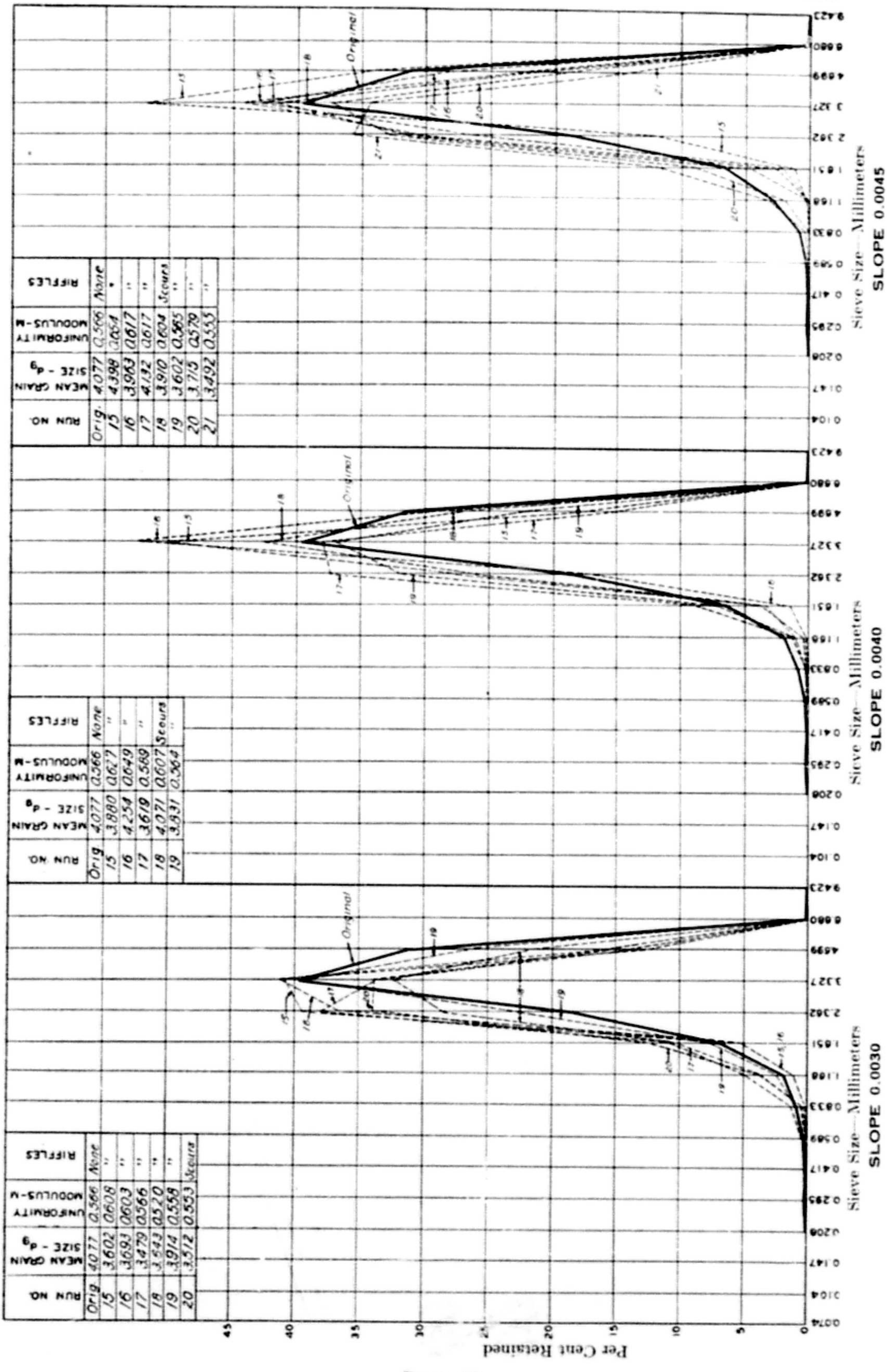


Plate 52

Progressive Variation of Size and Distribution of Grains in Movement

Sand No. 9

PART II

STUDIES OF COMPOSITION OF BED MATERIALS IN MISSISSIPPI RIVER SYSTEM

SCOPE AND PROCEDURE

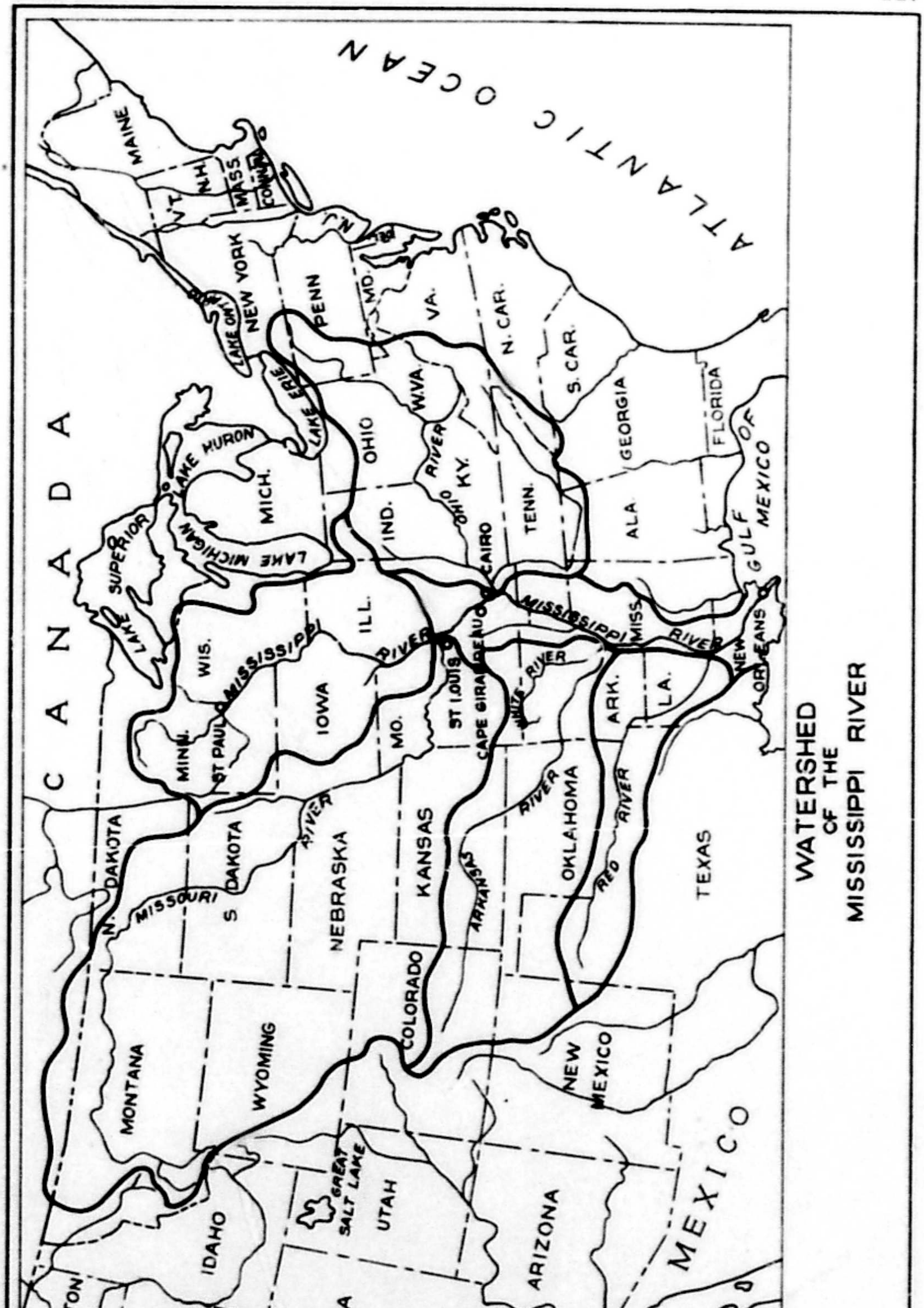
For many years engineers working on the Mississippi River have been restricted by a paucity of data regarding the type of material making up the bed of the stream. In spite of the fact that scattered observations had been made from time to time, no thorough, comprehensive survey had ever been undertaken to determine the distribution of the various materials throughout the length of the Lower Mississippi. Thus, although the theory has been held by most river hydraulicians that there is a progressive downstream decrease in the size of the particles composing the bed of the lower Mississippi, there have not been sufficient data to prove or disprove this theory.

During the fall of 1932, a survey of bed materials of the Mississippi River was conducted, under the supervision of Mr. Charles W. Schweizer, Engineer, of the Mississippi River Commission. Between Cairo, Illinois, and New Orleans, Louisiana, 531 samples were taken from the talweg of the Mississippi. In addition 143 samples were taken from the beds of the Ohio, Atchafalaya, Old, Black, and Red Rivers. In May, 1934, further information being desired as to the material in the river bed below New Orleans, another series of talweg samples was taken between that point and the Gulf of Mexico. Eighty-four samples were obtained from the Mississippi, including material from all the principal passes and several of the minor outlets to the Gulf.

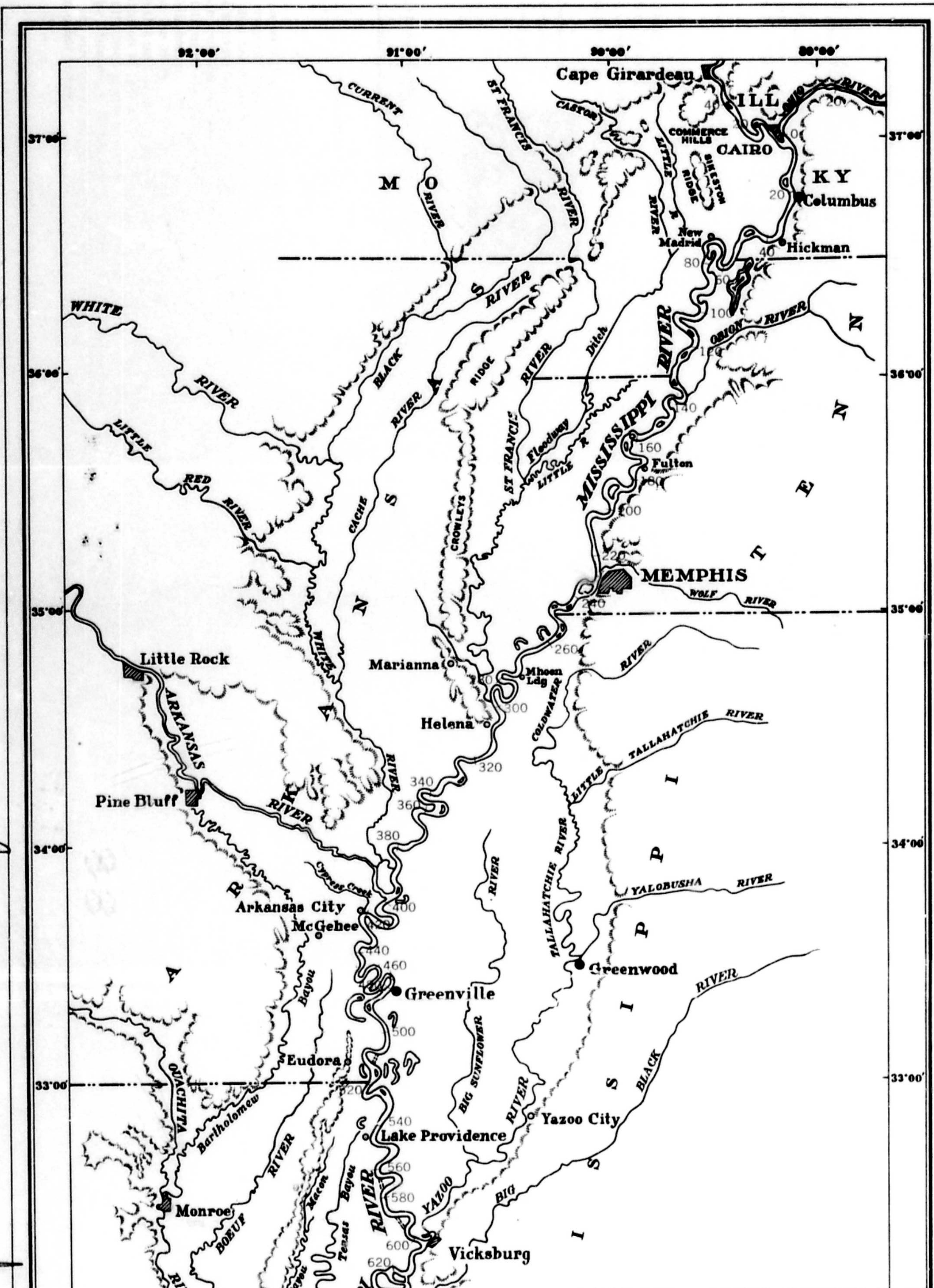
The samples were sent to the U. S. Waterways Experiment Station, where they were split into two parts; one was retained at the Station and the other was sent to the Geology Department of the Louisiana State University. Each portion retained at this Station was subjected to a close analysis to determine its physical properties and, from these, the factors influencing its rate of movement. That sent to the University is being used in a comprehensive petrographic study of the Mississippi River system.

After the completion of the analyses, a small quantity of material from each sample was sealed in a thin cardboard box with celophane face. Such pertinent data as location, mile number, mean grain size, uniformity modulus, etc., appear on the face, in the manner shown in Plate 55, which pictures one of the boxes. These will be kept in a permanent file at the office of the Mississippi River Commission at Vicksburg.

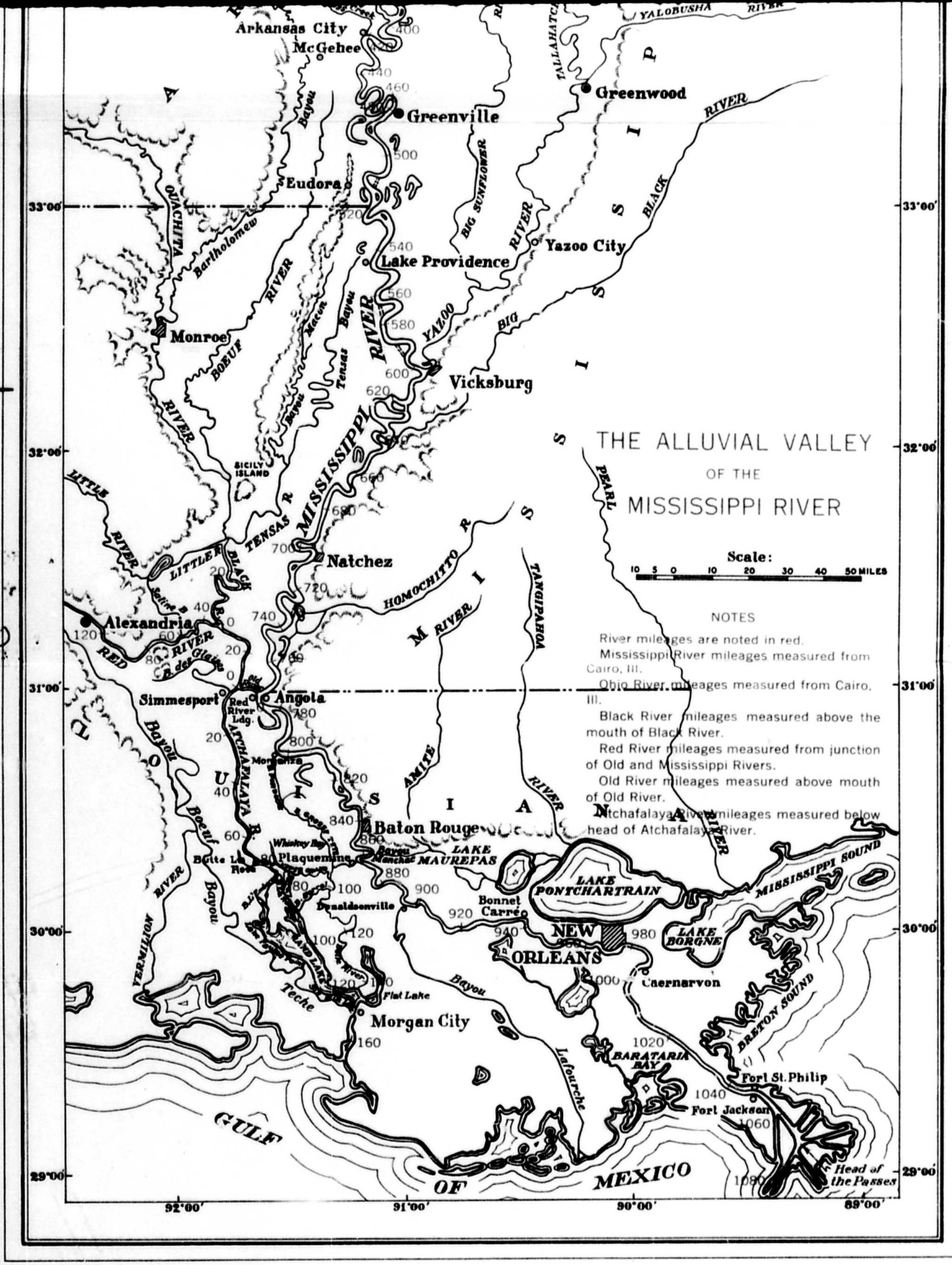
The results of the physical and mechanical analyses are presented in Tables 39 to 42, herein, followed by such conclusions as have been made to date. The petrographic survey has been started only recently; consequently, no results have been included in this report. The reader is referred to "The Improvement of the Lower Mississippi River for Flood Control and Navigation", printed in 1932, by the U. S. Waterways Experment Station, for a complete report on the history of the Mississippi River and its tributaries, its



WATERSHED OF THE MISSISSIPPI RIVER



THE ALLUVIAL VALLEY



THE ALLUVIAL VALLEY
OF THE
MISSISSIPPI RIVER
Scale:
10 5 0 10 20 30 40 50 MILES
NOTES
River mileages are noted in red.
Mississippi River mileages measured from Cairo, Ill.
Ohio River mileages measured from Cairo, Ill.
Black River mileages measured above the mouth of Black River.
Red River mileages measured from junction of Old and Mississippi Rivers.
Old River mileages measured above mouth of Old River.
Atchafalaya River mileages measured below head of Atchafalaya River.
Arkansas City
McGehee
Greenville
Greenwood
Eudora
Lake Providence
Yazoo City
Monroe
Vicksburg
Natchez
Alexandria
Simmesport
Angola
Red River Ldg.
Baton Rouge
Plaquemine
Donaldsonville
Bonnet Carré
NEW ORLEANS
Caernarvon
Morgan City
Fort St. Philip
Fort Jackson
Head of the Passes
MISSISSIPPI RIVER
YAZOO RIVER
BIG SUNFLOWER RIVER
BIG BLACK RIVER
YALOBUSHA RIVER
OUACHITA RIVER
BOEUF RIVER
TENSAS R
LITTLE RIVER
BLACK
RED RIVER
ATCHAFALAYA R.
HOMOCHITTO R
AMITE RIVER
TANGIPAHOA RIVER
PEARL RIVER
VERMILION RIVER
Bayou Teche
Bayou Lafourche
LAKE MAUREPAS
LAKE PONTCHARTRAIN
LAKE BORGNE
MISSISSIPPI SOUND
BRETON SOUND
BARATARIA BAY
GULF OF MEXICO
33°00′
32°00′
31°00′
30°00′
29°00′
92°00′
91°00′
90°00′
89°00′

physical characteristics, hydraulics, methods of transporting sediment, etc.; and to "Sedimentation in the Mississippi River Between Davenport, Iowa, and Cairo, Illinois", by Alvin L. Lugn, published in 1927 by the Augustana College and Theological Seminary, Rock Island, Illinois. This latter publication presents the results of the investigation of sediment and bed material made by Mr. Lugn in 1925. Reference is also made to Papers H and U of the Station, in which are presented the results of studies made prior to 1932 to determine the quantity and distribution of sediment in suspension in the Mississippi and several tributaries. The results of a similar sediment investigation, made during the Spring high water of 1932, will be printed in a later paper of the Waterways Experiment Station.

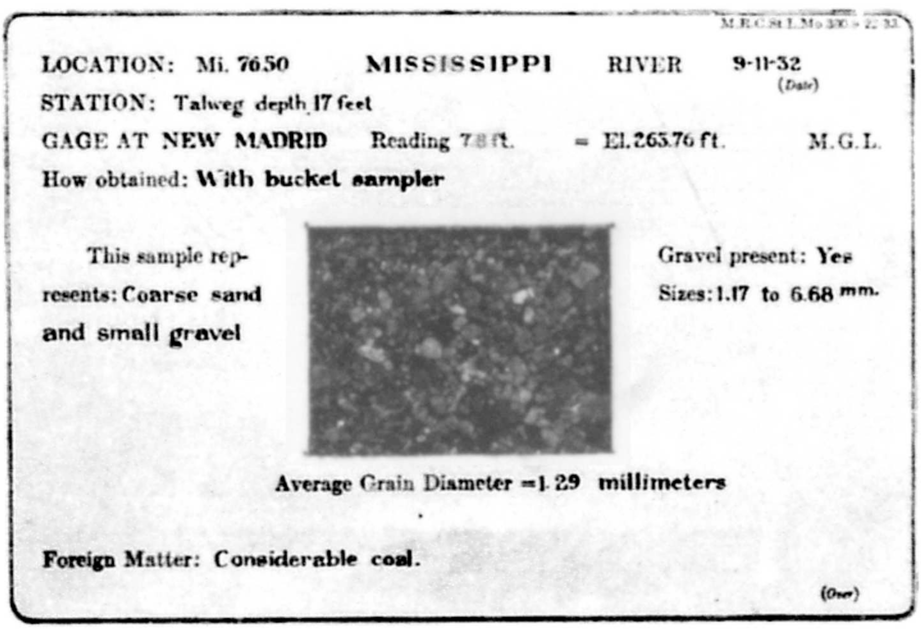


Plate 55

Permanent Container for River Bed Sample

Purpose

As stated in Part I, the purpose of the entire series of investigations of river bed materials was "to discover and evaluate laws to the end that the river hydraulician might be able to calculate the action of a given bed material under given conditions." The more immediate purpose of this portion of the investigation, however, was to determine the composition of the material in the bed of the Lower Mississippi, and its progressive variation throughout the course of the river. The information presented in the tables and curves in this part of the report may be considered as one step toward the realization of this goal. It should be noted here that authority has recently been given for a further investigation of the bed material of the Mississippi River and its tributaries, which is planned to include such streams as the Missouri, Illinois, Ohio, Arkansas, White, Red, and other rivers.

Procuring the Samples

The bed samples were taken by a field party on specially scheduled trips of Engineer Department towboats. In general, each District was responsible for supplying the floating equipment necessary to procure the samples within the part of the river in its jurisdiction. Table 38 shows the dates when the various portions of the river were traversed, along with the number of samples secured in the various Districts, and Plate 54, a map of the Lower Mississippi Valley, shows the mileages, to which the samples are referred. Plate 53, showing the watershed of the Mississippi, is included for general reference.

TABLE 38

SAMPLES OF BED MATERIAL OF MISSISSIPPI RIVER AND TRIBUTARIES

River	Engineer District	Mile	Number of Samples	Date
Mississippi	Memphis	0-400 below Cairo	209	Sept. 10-17, 1932
Mississippi	Vicksburg	400-610 below Cairo	217	Oct. 20-25, 1932
Mississippi	2nd New Orleans	610-977 below Cairo	105	Aug. 23-30, 1932
Mississippi	1st New Orleans*	977-Gulf	84	May 1-5, 1934
Ohio	Louisville	0-1 above Cairo	2	Sept. 10, 1932
Atchafalaya	2nd New Orleans	0-148 below head	110	Nov. 9-17, 1932
Old	Vicksburg	0-7 above Miss. River	12	Nov. 9-17, 1932
Black	Vicksburg	0-4 above mouth	5	Nov. 9-17, 1932
Red	Vicksburg	7-37 above Miss. River	14	Nov. 9-17, 1932
		Total......	758	

* Samples collected by 2nd New Orleans District.

The Sampler:

After several years of experimentation with various types of samplers, the device pictured in Plate 56 has been developed, and has proved quite successful. It is designed to pick up samples of material from the bed of the river, and is expected to produce only qualitative (not quantitative) results. The sampler consists simply of a steel pipe 4 inches in inside diameter and 4 feet long, closed at one end, and flaring at the other end to a diameter of about 8 inches. The device is attached by means of a bail to a 1¼-inch rope, with which it is controlled from the boat.

Use of the Sampler:

Practice has shown that the sampler operates best when it is dragged along the bottom in a downstream direction, as indicated in the sketch of Plate 57. The reason for this is that when it is dragged upstream, the force of the current tends to belly the rope in

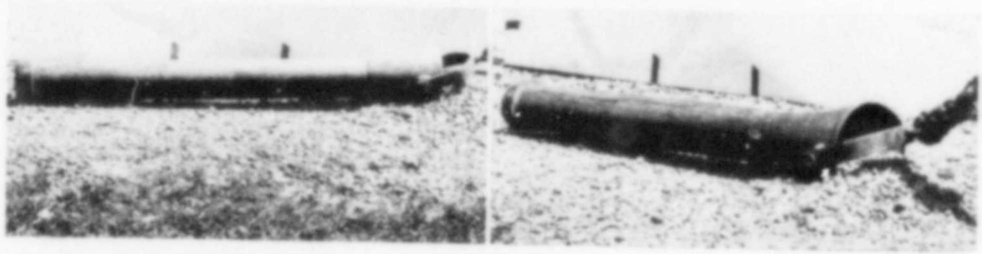


PLATE 56

SAMPLER USED FOR PROCURING RIVER BED MATERIAL

such a manner as to pull the mouth of the sampler off the bottom of the stream. When it is dragged downstream, on the other hand, the sag of the rope keeps the mouth in contact with the bed. When a sample is being taken, the speed of the boat is reduced until there is practically no motion with respect to the current. The sampler is then dropped overboard, and several hundred feet of line are paid

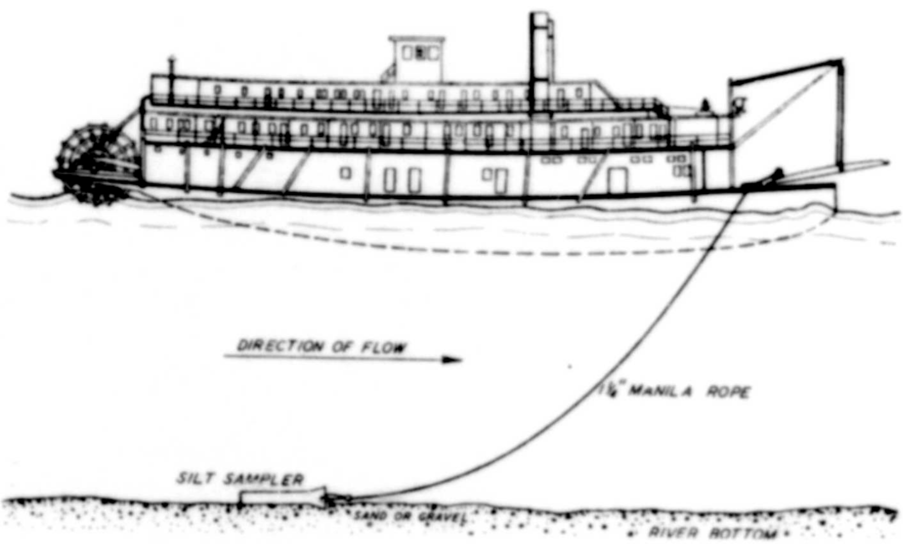


PLATE 57

METHOD OF USING THE SILT SAMPLER

out, to allow the device to remain on the bottom, after which it is pulled along at the approximate speed of the current by the drifting boat, until a sufficient quantity of material has been obtained. The pipe is then pulled in, the contents emptied by dropping the open end of the pipe on a board, and a sample of the material is placed in a properly marked can.

Analysis of Samples

The samples of the bed material retained at the U. S. Waterways Experiment Station were analyzed in the soil mechanics laboratory, to determine the percentages of the various sized grains, the absolute specific gravity, the shape of the grains, and the presence of such material as mica, lignite, and iron oxide.

Mechanical Analysis:

The mechanical analysis has yielded most of the basic information on the physical properties of the soils, when studied as a bed-load material. The samples were all prepared for testing by being dried for 5 hours in an electric oven, which maintained a constant temperature of 105° C. They were then allowed to cool to room temperature, and were reduced with a sample splitter until a representative sample of approximately 200 grams was obtained. The samples of cohesionless material (grain size larger than 0.074 mm) were subjected to a sieve analysis. A set of standard Tyler sieves and a Ro-Tap machine were used, the latter equipped with a Stop-Rite time switch to insure uniform shaking of all samples for the same period of time (20 minutes). The remaining details of this analysis are standardized and used universally; hence no further description is deemed necessary. The samples of cohesive material were analyzed by the hydrometer method. For this test a density hydrometer was used, having a range of 0.995 to 1.040, and reading to 0.002±. The procedure and details of this test as described in "The Hydrometer Method of Mechanical Analysis of Soils and other Granular Materials"* were followed.

Absolute Specific Gravity:

The pycnometer method of determining the specific gravity of soil was used because of its reliability and simplicity. The values determined for the sand samples were found to be fairly constant, about 2.65, but those for the clay and silt varied from this to a maximum of about 2.80. The air in the voids of the soil was released by boiling the mixture of soil and water in the pycnometer bottle.

*Petrographic Analysis***:

The purpose of the petrographic study of bed samples from the Mississippi River is the determination of the mineralogical composition of the material and of changes in the material effected by transportation by the river. The procedure which is being followed in the investigation is as follows:

First, samples differing in grain size, but collected from closely adjacent points where there is no possibility of addition of new material between the samples, are being studied in detail to determine the distribution of minerals and of rounded grains in different grade sizes. In addition, detailed studies are being made of several repre-

* Prepared by Mr. Arthur Casagrande for the U. S. Bureau of Soils at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

** Written by Dr. R. Dana Russell, Assistant Professor of Geology at the Louisiana State University, who is conducting the petrographic study.

sentative samples taken from the river between Cairo and New Orleans. This phase of the study includes percentage determination of minerals, and of rounding in every grade size, as far as possible, with the expectation that a legitimate basis of comparison for all the samples will be discovered. The procedure used in this detailed study consists of the separation of the whole sample into grade sizes, the further separation of each grade into a light and heavy fraction by means of bromoform, and a percentage determination, by count, of the minerals in both the light and heavy fractions of each grade size. The percentage of well-rounded, rounded, sub-rounded, sub-angular, and angular quartz grains in each grade size is also determined by count, using photographs of type grains for comparison (see Plate 4, page 7).

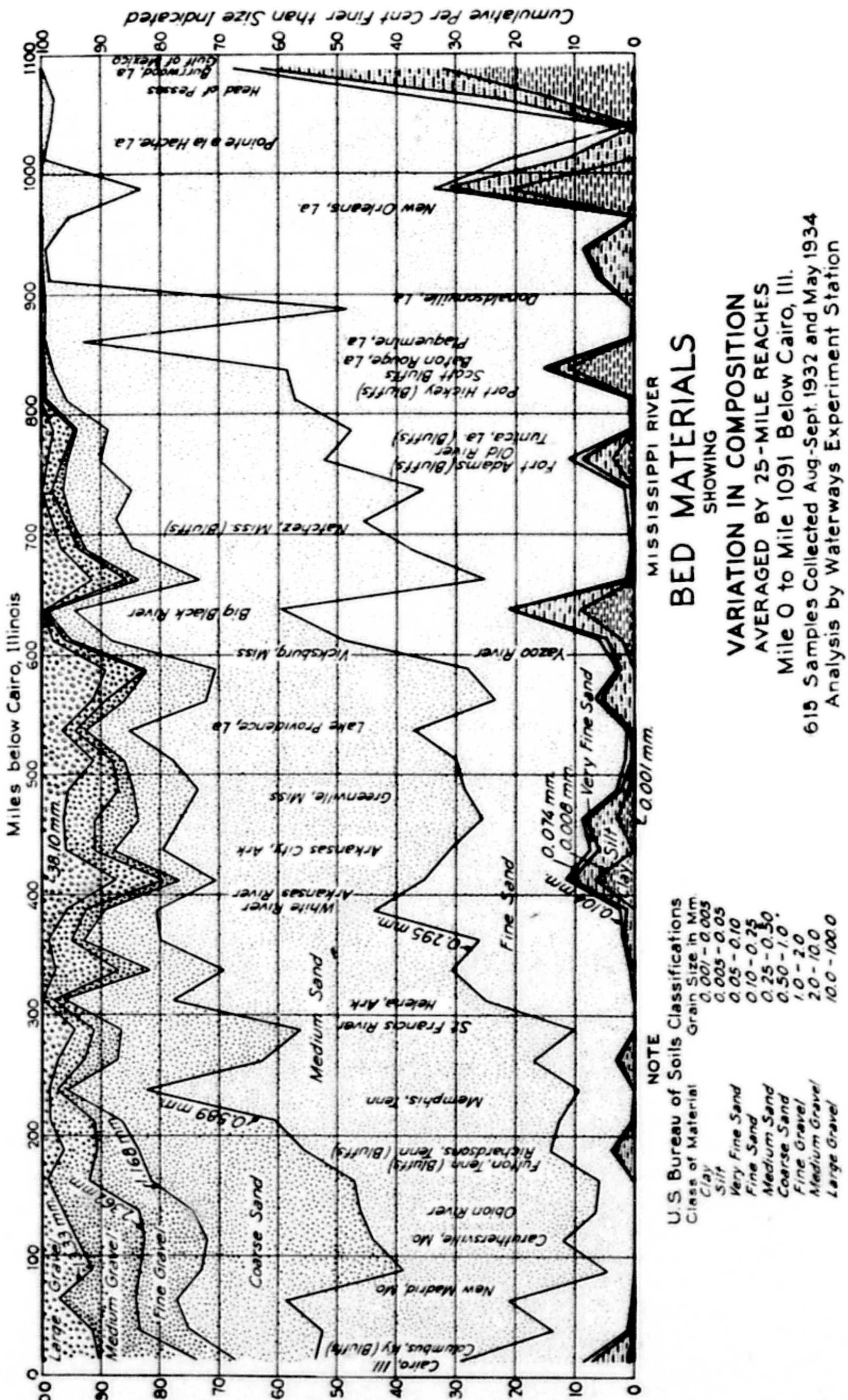
Second, with a legitimate basis of comparison established by the detailed work outlined above, the majority of the samples will then be studied in a similar fashion, with the exception that only one or two representative grade sizes will be separated from each sample for comparison.

RESULTS OF ANALYSES

Presentation of Data

The data from all these samples are summarized in Tables 39 to 42. In Tables 39 and 40 is given the complete size distribution of each sample of material. The samples are designated by mile number in the first column (see Plate 54), and each of the successive figures in the rows across the page represents the percentage of the sample which is finer than the arbitrary size heading the column. It will be noted that the U. S. Bureau of Soils classification of materials has been bracketed above the sieve sizes, in such a manner that the percentage of the samples falling within the clay, silt, sand, or gravel range can easily be calculated. It must be understood that the exact points of division between the Bureau of Soils designations are not obtainable from this table, owing to the fact that the sizes heading the columns correspond to the sizes of the openings in the sieves which were used in the analyses. The Bureau of Soils classification follows: Clay—up to 0.005 mm; silt—0.005 to 0.05 mm; very fine sand—0.05 to 0.1 mm; fine sand—0.1 to 0.25 mm; medium sand—0.25 to 0.50 mm; coarse sand—0.50 to 1.0 mm; fine gravel—1.0 to 2.0 mm; medium gravel—2.0 to 10.0 mm; large gravel—10.0 to 100.0 mm.

It should be noted that the values in the silt and clay range are interpolated; the arbitrary sizes heading the columns in these ranges were chosen close to the sizes dividing the classes. This interpolation was made necessary by the fact that the hydrometer method of analysis does not lead to the sorting of the particles into definite size classifications, as does the sieve analysis. Rather, the tabulation of a hydrometer analysis leads to a series of simultaneous values, size, and percentage finer than that size, with no regularity between any two samples as to the sizes shown. Hence, in order to simplify the tabulation of a large number of samples, it became necessary to interpolate each sample into the percentages finer than the chosen sizes.


MISSISSIPPI RIVER
BED MATERIALS
SHOWING
VARIATION IN COMPOSITION
AVERAGED BY 25-MILE REACHES
Mile 0 to Mile 1091 Below Cairo, Ill.
615 Samples Collected Aug.-Sept. 1932 and May 1934
Analysis by Waterways Experiment Station
Miles below Cairo, Illinois
Cumulative Per Cent Finer than Size Indicated
NOTE
U.S. Bureau of Soils Classifications
Class of Material | Grain Size in Mm.
Clay 0.001 - 0.005
Silt 0.005 - 0.05
Very Fine Sand 0.05 - 0.10
Fine Sand 0.10 - 0.25
Medium Sand 0.25 - 0.50
Coarse Sand 0.50 - 1.0
Fine Gravel 1.0 - 2.0
Medium Gravel 2.0 - 10.0
Large Gravel 10.0 - 100.0
Large Gravel
Medium Gravel
Fine Gravel
Coarse Sand
Medium Sand
Fine Sand
Very Fine Sand
Silt
Clay
38.10 mm.
1.168 mm.
0.589 mm.
0.295 mm.
0.104 mm.
0.074 mm.
0.008 mm.
0.001 mm.
Cairo, Ill.
Columbus, Ky (Bluffs)
New Madrid, Mo.
Caruthersville, Mo.
Obion River
Fulton, Tenn. (Bluffs)
Richardsons, Tenn. (Bluffs)
Memphis, Tenn.
St. Francis River
Helena, Ark.
White River
Arkansas River
Arkansas City, Ark.
Greenville, Miss.
Lake Providence, La.
Vicksburg, Miss.
Yazoo River
Big Black River
Natchez, Miss. (Bluffs)
Fort Adams (Bluffs)
Old River
Tunica, La. (Bluffs)
Port Hickey (Bluffs)
Scott Bluffs
Baton Rouge, La.
Plaquemine, La.
Donaldsonville, La.
New Orleans, La.
Pointe a la Hache, La.
Head of Passes
Burrwood, La.
Gulf of Mexico

Tables 41 and 42 contain the physical data for the same samples, with the river mileage again the distinguishing designation. The method used in computing the mean grain size, median grain size, and uniformity modulus are discussed on page 5 of this report. In the "locality" column are given the geographical locations from which the samples were taken.

In addition to the complete presentation of data in Tables 39 to 42, Plates 58, 59, and 60 are included, showing the results of the studies which have been made to date of the systematic variation in the composition of the materials in the Mississippi River. The manner in which these plates were prepared is explained in the following paragraphs:

Plate 58:

This illustration shows the steady decrease in the percentage of large materials in the samples, and the corresponding increase in the percentage of fine sands and silts. In calculating the data for this diagram, the sieve sizes nearest to those dividing the U. S. Bureau of Soils classes were selected for study. For the values plotted at Mile 12½, for instance, all the samples between Miles 0 and 25 were included in the computation, and the average percentage passing each of the arbitrary sizes was determined. The same averages were determined for the samples between Miles 25 and 50, and the values plotted at Mile 37½; this procedure was followed for each 25-mile reach from Cairo to the Gulf, following Southwest Pass below the Head of Passes.

To interpret the curve, the vertical distance between adjacent jagged lines represents the percentage of the material falling in the class noted between the lines. At Mile 500, for example, the percentage of coarse sand is about 76 minus 29, or 47 per cent, that of fine sand is 29 minus 3, or 26 per cent, etc. At Cairo it is evident that nearly 50 per cent of the material is coarse sand or gravel, and that there is only a small percentage of silt and clay. At New Orleans, on the other hand, the material is almost all fine sand, silt, or clay. Between these points there is a steady, though irregular, increase in the proportion of fine particles, while below New Orleans there is a rapid increase in the percentage of silt and clay.

Plate 59:

The mean grain diameters have been averaged by 25-mile reaches and plotted on this diagram. The extremely high peaks in the dashed line are due to the occasional occurrence of large gravel samples, and their influence is seen in the solid line, presenting the average for all the samples. The dash-dot line was drawn to show the general variation of the materials other than the extremely large gravels, and fits in consistently with the trend noticed in Plate 58, showing a definite downstream decrease in the size of the materials.

Plate 60:

It was desired to determine the variation in the size of the sand portion of the samples, eliminating from consideration the portion of each sample outside this classification. Accordingly, the average size of the sand portion of each of the samples was computed in the manner described in Part I, page 5, and these means were averaged by 25- and 10-mile reaches. The same downward trend in size is evident from the curves, with fewer and less violent irregularities appearing in the 25-mile averages.

DISCUSSION

The principal geographic locations have been noted on each of these plates in their proper positions. Care should be taken that no hasty conclusions are drawn from the coincidence of certain of these locations with irregularities in the curves. In Plate 59, for instance, a peak in the mean grain size appears at about Mile 410, just below the mouths of the Arkansas and White Rivers. The hasty conclusion might be made that this sudden increase in size is caused by the

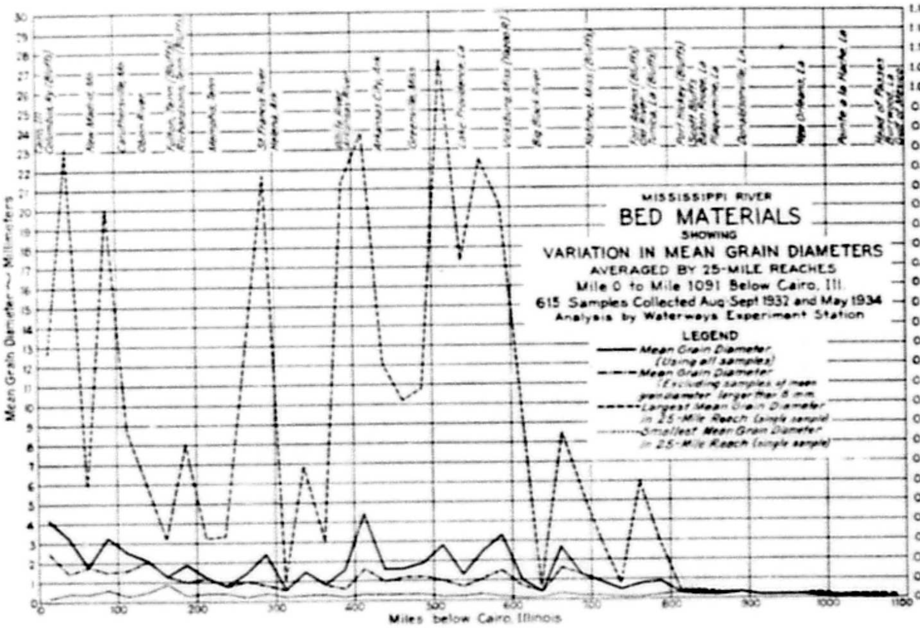


PLATE 59

influx of large materials from these tributary rivers. Actually, this peak is caused by the appearance of three large samples, one from a gravel bar about 4 miles below the mouth of White River, and two from a gravel bar about 3 miles below the mouth of the Arkansas. Whether these bars were built up from materials discharged by the tributary rivers is a question that cannot be determined from this study.

Since the peak near the mouth of the St. Francis River is caused by one sample about 5 miles above the mouth, the possible conclusion that it is caused from the discharge of large material by the St. Francis is clearly fallacious. Similarly, care should be taken, in interpreting all these curves, to study the data in the tables before drawing any conclusions as to the cause of the irregularities.

It should also be remembered that these samples were all taken from the talweg of the river, and do not necessarily represent the material which was in transportation, since they were scooped off the bottom itself. Further, they were all taken at low stages of the

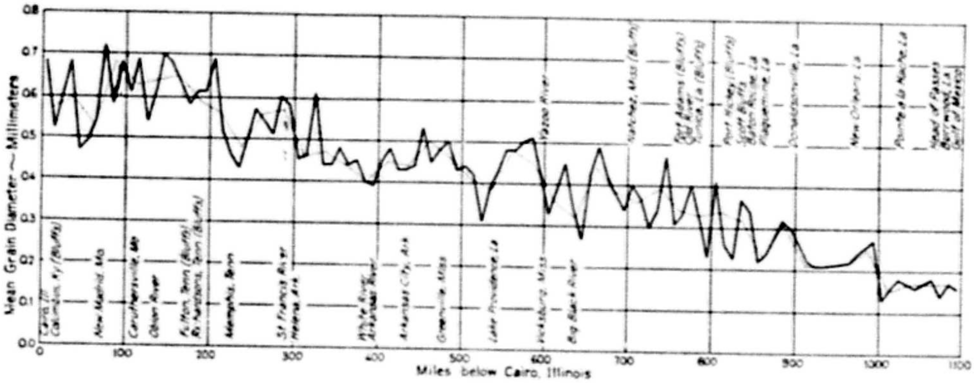


PLATE 60

VARIATION IN MEAN GRAIN SIZE OF SAND ONLY

(0.074-1.168 mm)

Averaged by Reaches

Other Materials in Samples Eliminated from Calculations

LEGEND

10-Mile Reach Averages ————

25-Mile Reach Averages ....

river, and the material found may be different from that which would be taken at other stages.

These studies, then, while they represent a long step forward in the accumulation of knowledge of the materials composing the beds of streams, can be considered only preliminary in nature. The scope of the investigation should eventually be enlarged to include the taking of samples from all points in many representative transverse sections of the river, at stages varying from the extremely low to the extremely high. Also, instruments must be perfected with which samples of the moving materials can be taken, from which quantitative as well as qualitative results can be obtained.

TABLE 39

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
2		100.0	91.9	74.8	66.9	58.1	49.1	40.0	27.2	12.3	5.0	1.0	0.1	0.1				
6												100.0	77.0	55.2	36.5	17.2		
7			100.0	99.9	99.8	99.8	99.6	99.1	96.5	88.5	27.2	1.6	0.2	0.1				
10		100.0	97.0	92.6	88.9	84.8	79.1	71.0	55.0	39.8	22.6	3.0	0.2	0.1				
12†	81.1	72.9	68.2	63.8	60.3	55.2	48.5	40.7	31.2	24.3	20.1	5.9	0.2	0.1				
13	100.0	94.0	92.2	91.9	91.7	91.1	89.3	82.2	57.8	21.3	5.2	1.8	0.1	0.0				
13A	100.0	76.2	64.9	58.0	55.6	53.7	52.1	50.4	43.7	20.7	6.1	1.8	0.1	0.0				
14						100.0	99.9	99.9	99.7	99.5	99.3	56.8	0.4	0.1				
16½	100.0	66.3	58.5	54.1	52.7	51.6	50.6	49.6	48.5	47.5	46.9	46.0	43.3	43.0				
19¼		100.0	90.9	82.1	77.2	70.2	62.9	54.3	37.8	16.5	4.8	0.8	0.1	0.1				
19½	100.0	98.3	91.8	86.1	84.2	81.3	77.1	70.5	56.8	41.0	20.4	3.6	0.1	0.0				
21			100.0	99.7	99.0	97.7	95.8	92.8	85.4	73.3	53.3	36.7	4.4	0.8				
22½	100.0	59.4	44.3	33.6	29.4	25.9	22.4	19.2	14.1	8.4	4.6	2.9	0.6	0.3				
23½	100.0	87.8	81.4	78.3	77.0	75.3	72.3	66.1	44.0	16.1	5.7	1.9	0.4	0.3				
25	100.0	99.2	93.3	79.1	71.7	65.5	60.3	55.8	50.4	44.0	33.9	16.1	0.5	0.3				
27	100.0	93.2	87.3	72.2	62.6	51.5	39.6	27.7	15.6	7.2	2.7	0.8	0.1	0.1				
29½		100.0	99.7	99.3	99.1	98.7	96.6	84.7	39.1	7.8	2.4	1.3	0.2	0.0				
31		100.0	99.2	96.3	93.3	87.6	77.1	58.2	22.7	5.8	1.8	0.6	0.1	0.0				
32		100.0	98.5	97.3	96.0	93.6	89.4	82.7	67.3	37.3	10.6	2.3	0.1	0.0				
35		100.0	98.8	98.1	97.3	96.2	93.9	89.8	78.6	55.9	40.5	22.6	0.9	0.2				
37½	100.0	82.9	79.8	71.5	64.5	53.4	39.9	27.3	18.5	16.1	15.2	13.4	4.0	1.7				
38½†	83.8	24.5	12.5	6.9	5.7	4.6	3.7	2.8	1.4	0.7	0.4	0.3	0.1	0.1				
41	100.0	97.9	96.9	94.5	92.3	88.8	82.5	72.6	49.8	20.1	6.6	1.1	0.1	0.0				
43		100.0	99.2	95.1	91.3	87.4	83.4	79.6	61.9	20.5	13.3	10.0	4.9	3.5				
44					100.0	99.9	99.9	99.7	98.0	85.5	21.7	5.5	0.3	0.1				
44¼			100.0	99.3	98.7	98.3	98.0	97.6	95.5	76.4	14.0	2.5	0.1	0.0				
48½			100.0	99.8	99.6	99.2	97.2	91.7	80.3	64.6	33.3	11.8	2.1	0.7				
51		100.0	99.6	98.7	97.6	94.9	90.2	80.3	55.2	23.8	11.8	7.3	1.1	0.2				
55½		100.0	98.1	96.7	95.9	94.5	92.1	87.1	69.9	34.7	10.3	1.0	0.1	0.0				
56			100.0	99.4	99.1	98.1	96.7	93.6	89.0	77.7	55.9	27.8	0.1	0.0				
56¼			100.0	99.6	99.4	99.3	99.2	98.5	92.8	71.4	35.1	12.1	0.2	0.1				
60	100.0	98.6	86.3	73.7	67.6	62.6	57.0	50.7	38.5	22.1	11.3	4.5	0.6	0.1				
61		100.0	98.7	96.2	95.9	95.6	95.3	94.9	93.6	89.0	68.9	18.3	0.4	0.1				
65	100.0	94.2	77.3	59.3	51.2	43.8	37.3	31.1	21.4	8.9	2.6	0.4	0.1	0.1				
70		100.0	98.8	96.2	93.9	90.3	84.2	24.4	51.4	20.3	5.2	1.1	0.1	0.0				
71	100.0	80.5	66.2	57.9	54.2	50.3	46.1	40.5	28.2	12.1	4.1	0.9	0.1	0.0				
72½	100.0	97.3	94.1	89.9	86.3	80.8	73.2	63.1	46.2	23.8	6.6	1.3	0.1	0.0				
76½		100.0	99.1	95.0	89.7	80.2	65.4	46.0	20.0	3.8	0.7	0.2	0.1	0.0				

*See also Table 41.
†100% finer than 50.8 mm.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
78		100.0	98.8	96.2	94.0	90.6	84.7	73.9	49.1	12.5	1.6	0.3	0.1	0.0				
80		100.0	97.8	91.9	87.5	80.5	68.1	46.6	22.6	9.8	5.9	3.4	0.2	0.0				
81		100.0	98.5	97.9	97.0	94.8	90.4	81.7	60.8	26.9	4.3	0.3	0.1	0.0				
87			100.0	99.3	98.6	97.6	95.0	89.6	75.2	38.5	8.6	1.5	0.1	0.0				
88½		100.0	99.7	97.7	96.1	93.0	87.5	77.6	50.2	20.6	10.2	5.4	0.1	0.0				
91	100.0	82.2	69.7	62.6	59.3	54.0	47.9	40.5	25.8	9.6	3.4	1.1	0.1	0.0				
92		100.0	99.6	98.8	97.6	94.1	90.2	73.2	35.3	8.4	2.0	0.4	0.1	0.0				
94		100.0	99.8	97.7	96.2	92.8	85.6	70.8	37.9	9.3	3.3	0.9	0.0					
98	100.0	33.8	23.4	18.6	17.6	16.2	14.5	12.6	9.9	6.8	4.5	1.8	0.2	0.1				
100½				100.0	99.9	99.8	99.6	99.4	98.6	92.0	40.0	6.4	0.1	0.1				
102	100.0	86.3	83.9	77.0	72.2	65.7	56.1	43.4	27.3	16.4	13.2	5.1	0.1	0.0				
106	100.0	96.6	95.0	91.7	89.8	87.1	80.7	67.7	41.3	15.1	3.4	0.5	0.1	0.0				
106½		100.0	97.2	87.8	82.6	75.8	67.9	58.2	43.7	29.1	11.5	2.1	0.1	0.1				
108		100.0	98.6	96.3	93.7	89.5	81.6	67.9	37.9	9.3	1.9	0.4	0.1	0.0				
113		100.0	90.1	84.5	80.2	72.3	60.8	43.7	15.8	1.8	0.1	0.0						
115½	100.0	70.8	55.8	48.4	46.3	44.4	42.0	38.1	30.7	21.7	7.5	1.3	0.0					
124		100.0	99.1	98.2	96.6	94.4	86.9	75.2	56.2	39.9	19.0	4.4	0.1	0.0				
128			100.0	99.5	99.1	98.2	96.2	92.1	76.1	37.0	14.9	2.8	0.1	0.0				
131½		100.0	99.6	98.7	98.2	97.1	94.8	89.2	67.3	24.8	5.3	0.6	0.1	0.0				
137	100.0	83.0	60.2	57.0	53.6	49.8	45.0	38.4	26.3	12.8	5.8	1.2	0.1	0.1				
138		100.0	99.4	98.1	96.8	94.4	89.5	80.3	55.2	18.5	3.5	0.5	0.1	0.0				
141½	100.0	92.9	86.6	79.5	74.9	67.8	57.1	41.0	21.9	6.3	3.2	1.7	0.1	0.0				
142	100.0	98.2	93.9	91.8	89.6	85.2	76.5	62.1	34.0	8.9	2.4	0.8	0.1	0.0				
144	100.0	98.2	84.7	66.8	57.3	47.0	38.2	31.7	24.9	17.9	11.7	5.3	0.3	0.1				
146			100.0	99.8	99.5	98.9	97.0	90.6	61.2	18.8	5.3	2.2	0.2	0.1				
150½		100.0	99.4	96.9	94.3	90.0	82.0	68.4	43.3	20.1	6.7	1.0	0.2	0.1				
155¼	100.0	91.1	84.8	80.5	78.3	74.6	67.6	55.1	35.7	22.1	8.7	2.3	0.2	0.1				
159½		100.0	99.2	95.0	90.7	83.6	73.1	59.3	38.7	20.9	7.0	1.2	0.1	0.1				
160½		100.0	98.3	95.9	94.1	90.5	83.4	71.0	46.2	13.9	4.7	1.8	0.2	0.1				
161½		100.0	99.5	96.2	93.5	88.4	80.5	69.8	53.0	22.5	6.1	2.1	0.1	0.0				
163¾		100.0	95.3	94.7	94.1	92.9	89.9	82.7	57.3	20.3	4.4	0.6	0.1	0.0				
170¾		100.0	97.6	96.4	95.5	93.8	90.1	82.0	58.3	25.4	6.0	0.8	0.0					
172½		100.0	99.4	97.6	95.7	90.7	85.0	70.0	43.0	20.0	4.1	0.8	0.1	0.0				
176						100.0	99.9	99.8	98.9	83.7	33.4	7.0	0.1	0.0				
178½	100.0	97.9	94.6	93.0	91.3	87.9	80.9	67.2	35.9	8.1	1.5	0.2	0.0					
181¾		100.0	96.5	86.5	80.4	73.0	63.5	49.6	26.7	10.5	4.9	2.0	0.1	0.0				
182¾			100.0	98.7	97.1	94.7	90.8	83.6	65.9	46.0	36.9	32.7	29.6	29.0				
186½†	93.5	73.8	71.5	69.7	69.2	68.8	68.2	67.2	60.2	26.1	11.0	2.5	0.1	0.0				
194	100.0	98.5	96.1	93.9	92.4	89.8	84.2	71.2	32.9	5.4	1.2	0.5	0.1	0.0				

*See also Table 41.
†100% finer than 50.8 mm.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER *

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
195		100.0	98.9	97.5	95.7	92.8	87.1	76.2	49.3	21.5	3.4	0.3	0.0					
200			100.0	99.3	98.5	97.1	94.4	89.6	75.1	47.3	21.2	5.5	0.1	0.1				
201½	100.0	94.0	84.4	80.6	79.1	76.3	70.2	59.0	31.0	6.3	1.7	0.4	0.1	0.0				
205		100.0	99.1	97.2	95.1	91.8	85.3	72.7	36.1	7.1	1.1	0.3	0.1	0.0				
209	100.0	95.8	82.7	71.2	65.8	60.9	56.1	50.1	33.0	10.5	4.1	2.2	0.4	0.1				
210¾			100.0	99.7	99.4	99.0	97.7	93.0	64.1	15.9	3.6	1.2	0.1	0.0				
215½		100.0	99.0	98.6	98.0	97.0	94.7	87.1	55.6	20.1	6.5	1.4	0.2	0.1				
219¼						100.0	99.9	99.7	98.6	74.3	20.9	3.7	0.1	0.0				
221½	100.0	99.5	98.5	94.7	93.8	92.4	90.0	85.6	73.6	58.2	49.5	32.0	0.7	0.0				
225			100.0	99.6	99.3	98.8	97.7	95.2	91.3	33.0	12.9	3.9	0.2	0.0				
229						100.0	99.7	99.2	95.3	54.1	8.9	1.5	0.1	0.0				
230	100.0	88.0	84.2	82.9	82.6	82.1	80.5	76.4	61.1	20.9	4.4	1.0	0.1	0.0				
231			100.0	99.9	99.8	99.7	99.4	97.8	87.9	32.5	5.0	0.4	0.0					
236¾							100.0	99.9	99.2	75.7	15.1	2.1	0.1	0.0				
241			100.0	99.5	99.1	98.4	96.9	93.9	81.8	30.4	5.2	1.0	0.1	0.0				
243		100.0	98.4	97.6	97.2	96.3	94.2	89.0	69.5	31.0	15.2	2.2	0.1	0.0				
244			100.0	99.1	98.3	96.5	92.9	85.4	62.3	24.7	5.8	1.0	0.0					
247½			100.0	99.8	99.7	99.2	98.1	95.9	83.5	34.0	6.8	0.7	0.0					
249¾						100.0	99.9	99.8	99.2	56.8	19.0	3.6	0.2	0.0				
250½						100.0	99.9	99.6	96.4	75.1	26.8	4.0	0.1	0.0				
251			100.0	99.5	98.7	96.9	93.0	85.7	70.4	44.8	20.6	5.0	0.1	0.0				
251¾	100.0	53.0	47.3	44.0	42.0	39.7	36.3	31.5	23.8	15.3	9.0	3.1	0.0					
252¼		100.0	97.5	95.1	93.1	90.2	85.1	75.0	47.3	13.4	2.0	0.2	0.0					
252½		100.0	96.6	93.1	91.2	88.5	83.6	73.2	43.0	11.9	2.2	0.3	0.0					
253¼			100.0	99.9	99.8	99.6	99.4	98.7	94.9	64.7	21.4	1.2	0.0					
254							100.0	99.9	98.9	77.2	30.1	2.3	0.0					
254⅛		100.0	99.0	97.4	96.1	93.5	87.6	76.9	52.5	28.9	16.7	2.6	0.1	0.0				
254¼	100.0	93.6	87.8	80.0	75.1	68.7	60.8	50.6	36.6	24.9	10.6	2.0	0.1	0.0				
254½	100.0	93.0	91.5	88.4	86.2	83.0	78.2	70.9	56.1	40.6	32.0	13.4	0.5	0.1				
254¾A		100.0	98.0	93.6	89.5	81.2	66.0	42.5	14.9	3.9	2.6	0.7	0.0					
254¾B		100.0	99.0	97.6	96.7	94.9	91.6	85.4	68.6	46.3	25.3	4.3	0.1	0.0				
255	100.0	96.4	94.4	93.7	93.1	92.1	88.9	79.9	51.1	17.4	6.2	1.0	0.1	0.0				
255½		100.0	99.0	98.4	98.1	97.2	94.5	87.3	63.8	28.3	5.8	1.3	0.0					
255¾A			100.0	99.7	99.5	99.1	98.3	95.3	76.8	30.0	8.4	2.3	0.1	0.0				
255¾B	100.0	96.5	92.5	88.7	85.9	81.7	75.6	64.2	34.2	6.5	1.5	0.2	0.0					
256¼	100.0	96.8	94.2	93.4	92.9	91.8	88.9	82.9	64.9	31.2	10.2	1.9	0.0					
256½			100.0	99.4	99.0	97.8	87.1	57.2	26.9	13.7	8.4	2.0	0.0					
258		100.0	98.9	98.8	98.7	98.6	98.2	94.7	67.8	27.8	10.3	3.0	0.1	0.1				
259		100.0	97.5	96.0	94.6	92.5	88.9	81.8	67.8	36.9	11.4	4.5	2.2	2.1				
260¼				100.0	99.4	98.4	95.9	88.9	63.9	29.7	17.7	3.2	0.1	0.0				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
261½		100.0	99.4	98.8	98.6	98.4	97.9	96.8	91.3	59.7	31.8	6.2	0.5	0.1				
263¼			100.0	98.6	96.8	93.8	88.9	80.1	57.9	17.7	6.6	0.2	0.0					
264½		100.0	98.5	97.1	96.5	95.0	91.7	84.6	63.8	37.6	19.5	5.8	0.1	0.0				
266	100.0	93.7	87.5	84.0	82.9	81.7	79.6	74.7	55.4	22.7	8.7	1.4	0.1	0.0				
266½		100.0	97.4	94.7	92.6	89.0	82.4	71.3	45.7	16.1	5.7	0.3	0.0					
267	100.0	94.8	91.5	89.4	87.8	85.5	81.8	74.8	58.6	43.2	38.4	33.7	32.4	32.2				
269½				100.0	99.9	99.8	99.3	97.7	90.5	65.2	26.8	2.7	0.1	0.0				
270½			100.0	99.8	99.7	99.3	97.9	93.1	72.1	23.6	12.2	1.1	0.0					
271½	100.0	98.3	97.7	96.2	95.5	93.7	90.0	82.7	60.0	21.5	6.6	0.8	0.0					
272½		100.0	99.8	99.1	99.0	98.8	98.3	97.3	94.8	78.2	26.1	7.9	0.1	0.0				
272¾	100.0	97.7	94.6	93.8	93.5	93.0	91.8	87.9	67.2	17.5	4.5	0.4	0.0					
273						100.0	99.8	99.3	96.5	88.2	71.8	42.6	22.8	22.0				
273A		100.0	98.6	95.3	92.1	87.8	82.7	75.5	57.2	25.3	8.4	1.2	0.0					
273¾	100.0	96.4	89.6	84.5	82.2	79.3	75.4	69.9	58.5	48.6	44.7	43.3	42.1	42.0				
277½			100.0	99.7	99.6	99.2	98.4	96.2	85.5	54.4	27.2	3.7	0.1	0.1				
280¾		100.0	99.7	97.7	95.3	90.1	81.5	68.0	45.2	21.4	9.0	1.7	0.3	0.1				
281½		100.0	97.6	95.8	94.6	92.9	89.8	84.9	69.0	22.1	7.5	0.5	0.1	0.0				
283½		100.0	99.8	99.4	98.9	98.1	96.9	92.2	62.7	27.9	8.4	3.5	0.1	0.0				
286¾			100.0	99.1	98.3	96.8	91.3	54.6	11.7	3.9	0.8	0.4	0.0					
287¼		100.0	99.6	99.5	99.5	99.4	99.1	97.7	81.3	33.8	7.4	0.8	0.1	0.0				
289¼			100.0	99.6	99.5	99.2	98.4	95.8	83.1	39.5	8.5	2.3	0.0					
292½			100.0	99.8	99.2	97.3	94.1	87.2	55.6	15.8	4.0	1.0	0.1	0.0				
293†	83.3	32.7	28.6	27.1	26.7	26.3	25.5	24.2	18.5	8.6	3.0	1.3	0.1	0.0				
293¾	100.0	92.7	88.7	81.7	78.9	75.4	71.0	63.9	42.6	14.6	3.8	0.6	0.1	0.0				
296			100.0	99.8	99.6	99.0	96.9	91.7	75.9	56.4	42.8	25.1	0.3	0.1				
298½		100.0	98.9	97.9	97.4	96.1	93.1	85.8	65.8	31.5	9.0	2.7	0.1	0.0				
300			100.0	99.5	98.4	95.7	89.6	75.0	37.6	6.1	1.1	0.4	0.1	0.0				
300¾		100.0	98.7	97.0	96.0	94.5	90.9	83.2	59.6	21.2	2.6	0.3	0.1	0.0				
301½		100.0	97.5	95.8	94.6	92.5	88.2	80.1	59.0	29.6	9.5	3.4	0.3	0.1				
302¾			100.0	99.8	99.7	99.5	99.2	97.6	82.9	31.0	7.7	1.0	0.1	0.0				
303¼			100.0	99.8	99.8	99.8	99.7	99.5	97.1	76.3	17.6	1.5	0.1	0.0				
303½				100.0	99.9	99.9	99.8	99.5	97.7	89.0	29.8	3.7	0.1	0.0				
303⅝	100.0	99.0	97.9	96.6	95.9	94.7	92.1	85.5	57.3	14.7	3.7	0.3	0.0					
304					100.0	99.9	99.9	99.8	99.6	99.2	98.6	58.2	1.0	0.1				
306¾						100.0	99.9	98.5	71.4	7.2	2.7	1.5	0.1	0.0				
310		100.0	99.3	99.0	98.9	98.9	98.7	98.2	94.7	88.9	63.6	14.1	0.1	0.1				
310¾		100.0	97.2	94.9	93.7	91.9	89.0	82.6	60.5	23.7	2.7	0.2	0.0					
313¾			100.0	99.8	99.7	99.3	98.6	96.6	86.6	56.3	20.4	3.8	0.1	0.0				
314¼					100.0	99.9	99.8	99.7	98.9	85.0	28.8	3.5	0.1	0.0				

*See also Table 41.
†100% finer than 50.8 mm.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
316¼		100.0	98.8	98.4	98.3	98.2	97.7	93.8	60.3	11.6	4.0	3.2	0.5	0.1				
317½		100.0	98.7	98.4	98.3	98.0	97.5	96.2	91.1	69.0	23.3	2.7	0.1	0.0				
321½			100.0	99.6	99.4	98.8	97.3	91.7	64.9	28.5	10.1	2.5	0.1	0.0				
324½		100.0	98.4	97.2	96.4	94.5	90.1	81.0	62.2	38.7	15.8	4.4	0.1	0.0				
329½	100.0	85.1	53.4	34.2	28.1	22.8	18.4	15.2	10.4	4.3	1.7	0.6	0.1	0.0				
330					100.0	99.9	99.6	97.5	63.4	7.3	1.3	0.3	0.0					
331				100.0	99.9	99.9	99.7	99.3	91.2	32.0	3.2	0.2	0.0					
332			100.0	99.9	99.9	99.8	99.7	98.8	94.9	83.0	50.9	7.6	0.1	0.0				
333½			100.0	99.4	98.4	97.2	94.7	89.9	70.9	35.1	25.2	20.2	3.3	0.5				
337		100.0	99.3	96.1	93.8	89.8	83.7	70.4	30.8	4.4	1.0	0.4	0.1	0.1				
338¾			100.0	99.9	99.8	99.6	99.2	98.4	97.0	94.3	87.5	13.9	0.2	0.0				
339½			100.0	99.8	99.6	99.5	99.4	98.9	97.0	90.1	45.2	3.5	0.1	0.0				
342¾				100.0	99.9	99.9	99.8	99.5	98.1	82.6	44.8	12.2	0.1	0.0				
344				100.0	99.9	99.9	99.8	99.7	99.6	98.2	88.0	14.7	0.2	0.1				
348		100.0	97.1	89.7	80.8	68.5	55.3	44.5	34.3	21.8	11.6	5.4	1.1	0.4				
349			100.0	99.2	98.1	96.3	94.3	92.2	88.4	68.3	31.3	7.3	0.5	0.2				
350	100.0	87.0	51.9	37.2	33.7	31.2	29.5	27.9	24.1	15.6	6.6	1.4	0.1	0.1				
351				100.0	99.9	99.8	99.6	99.3	97.1	62.4	9.9	0.7	0.1	0.0				
352¼			100.0	98.6	98.1	97.2	95.9	92.7	74.0	14.2	1.6	0.3	0.1	0.1				
352½						100.0	99.9	99.8	99.2	91.0	45.0	3.4	0.1	0.0				
353			100.0	99.3	99.1	98.7	97.7	95.3	84.6	49.1	11.1	0.9	0.1	0.0				
356		100.0	97.7	96.6	96.2	95.4	92.7	82.6	43.3	9.0	3.4	2.2	0.3	0.1				
357½	100.0	97.3	91.3	85.1	82.8	79.8	75.5	67.6	45.5	14.1	2.5	0.2	0.0					
359		100.0	99.0	98.9	98.8	98.7	98.6	98.3	95.5	83.5	57.6	8.4	0.2	0.0				
360¾	100.0	94.9	85.1	72.9	63.4	61.6	55.7	48.9	37.2	23.5	16.0	6.9	0.2	0.1				
362½			100.0	99.6	99.3	98.8	97.8	94.8	79.2	42.3	16.4	3.1	0.1	0.0				
363¼						100.0	99.9	99.7	97.8	85.6	66.2	16.7	0.1	0.1				
366½		100.0	99.8	99.7	99.7	99.6	99.5	99.4	97.5	76.3	24.1	4.5	0.1	0.0				
371¾			100.0	99.2	98.9	98.4	97.7	95.7	81.4	42.3	20.6	6.2	0.1	0.1				
372				100.0	99.9	99.9	99.8	99.6	98.3	85.7	64.3	45.3	1.4	0.5				
372¾		100.0	97.8	97.4	97.2	96.9	96.4	95.5	90.1	64.8	36.6	28.2	23.4	22.7				
375	100.0	94.7	92.8	91.8	91.4	90.9	90.2	88.4	77.3	44.6	26.2	16.2	0.4	0.0				
376¾		100.0	98.5	89.5	83.6	76.6	69.4	63.4	55.6	42.6	26.9	8.4	1.1	0.7				
378½				100.0	99.9	99.9	99.8	99.4	98.4	95.0	60.9	21.0	0.7	0.2				
381		100.0	99.1	95.1	92.3	89.5	86.7	81.7	64.9	37.3	16.8	5.6	2.7	2.1				
382						100.0	99.9	99.6	98.1	90.9	71.7	35.9	2.3	0.5				
390½		100.0	99.6	99.3	99.2	99.0	98.8	98.2	95.5	90.7	86.5	55.8	1.2	0.1				
391¼				100.0	99.9	99.9	99.8	99.7	98.8	92.4	78.4	52.4	1.3	0.2				
393					100.0	99.9	99.8	99.6	98.1	91.8	75.5	28.7	6.6	3.3				
394	100.0	98.7	94.2	80.1	71.3	61.2	52.6	44.9	29.7	15.0	11.4	9.7	4.1	1.4				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
395			100.0	99.9	99.6	99.2	98.2	95.5	81.4	35.6	10.2	7.1	2.7	0.9				
396				100.0	99.9	99.6	98.[illegible]	95.6	79.4	35.2	11.0	7.6	3.9	1.5				
396¼	100.0	97.4	92.3	86.1	82.0	76.7	69.7	58.0	32.1	10.2	3.6	1.9	0.7	0.2				
397	100.0	27.2	26.2	25.6	25.4	25.3	25.2	25.0	24.1	18.6	5.7	0.5	0.0					
397¼			100.0	99.8	99.6	99.4	99.2	98.8	98.1	96.4	94.2	75.7	1.0	0.1				
397½							100.0	99.9	99.6	91.6	51.7	11.2	0.1	0.0				
397½A		100.0	98.5	98.0	97.1	96.3	95.3	93.4	85.8	50.9	10.2	0.7	0.1	0.0				
398		100.0	99.4	98.7	98.5	98.3	97.9	96.5	81.2	19.0	3.7	0.7	0.1	0.1				
398¼					100.0	99.9	99.7	99.0	96.2	86.1	70.4	43.8	19.1	13.8				
398½					100.0	99.9	99.7	99.2	94.8	57.5	9.8	1.2	0.1	0.1				
399			100.0	99.8	99.8	99.7	99.6	99.5	99.2	97.1	86.1	30.2	0.6	0.1				
399¾				100.0	99.9	99.9	99.8	99.7	99.3	98.2	95.1	39.0	0.5	0.1				
401			100.0	99.5	98.7	97.7	96.2	93.6	83.6	68.3	61.6	43.7	2.1	0.3				
401½	100.0	40.9	29.6	24.3	22.9	21.8	20.9	20.1	18.4	13.8	9.0	5.6	1.1	0.4				
402	100.0	76.1	52.4	33.9	27.5	22.3	18.3	14.9	10.2	5.4	2.0	0.7	0.0					
403	100.0	20.2	12.6	8.7	7.3	6.2	5.4	4.5	3.0	1.2	0.4	0.1	0.0					
404	100.0	98.7	96.4	94.9	93.7	92.2	89.7	85.4	71.7	37.1	5.5	0.6	0.1	0.0				
404½					100.0	99.9	99.9	99.8	99.7	96.7	35.8	2.6	0.2	0.1				
406					100.0	99.9	99.8	99.7	99.5	95.9	80.4	29.0	1.0	0.1				
407½												100.0	97.1	90.8	85.4	65.0		
410			100.0	99.9	99.9	99.8	99.8	99.6	99.3	97.6	69.2	6.1	0.1	0.0				
411½	100.0	71.1	58.9	53.6	51.7	50.3	49.0	47.6	43.2	18.1	5.4	2.0	0.3	0.1				
412½	100.0	81.0	77.8	68.0	60.5	51.4	42.7	34.3	23.0	9.5	2.1	0.3	0.1	0.1				
413½		100.0	99.6	96.2	94.0	91.3	87.6	83.0	70.8	47.1	26.0	5.8	0.2	0.1				
416			100.0	99.7	99.6	99.4	98.9	97.8	90.8	37.0	7.4	1.0	0.1	0.0				
419		100.0	99.5	98.3	98.2	98.0	97.7	97.0	94.4	77.0	29.4	7.7	0.1	0.0				
420					100.0	99.9	99.7	99.5	95.8	61.3	15.7	2.2	0.1	0.0				
423			100.0	[illegible].5	99.2	98.7	98.3	97.3	93.1	74.1	48.9	17.0	0.2	0.0				
424½												100.0	94.1	88.1	74.2	50.2		
425½	100.0	88.6	75.7	[illegible].5	69.9	68.1	65.7	61.7	45.7	15.9	8.0	3.2	0.8	0.3				
426½												100.0	79.0	73.3	64.3	36.1		
428			100.0	99.9	99.8	99.7	99.6	99.2	95.3	49.2	12.1	7.0	2.2	1.1				
429½			100.0	99.3	99.0	98.2	97.1	94.9	86.1	28.9	11.3	2.9	0.7	0.3				
429¾		100.0	99.7	99.4	99.3	99.1	99.0	98.7	97.4	88.0	40.5	9.8	0.6	0.2				
430½	100.0	56.0	23.9	12.6	9.1	7.0	5.8	5.0	3.8	1.7	0.3	0.1	0.0					
431½		100.0	99.7	97.5	96.1	93.9	89.4	80.2	50.5	12.2	3.8	0.2	0.1	0.1				
433A					100.0	99.9	99.9	99.8	99.4	93.5	52.0	24.6	0.5	0.1				
433B	100.0	87.8	86.2	85.7	84.8	83.6	81.9	79.1	69.9	31.3	4.8	0.4	0.1	0.1				
433½		100.0	94.8	89.6	87.6	85.5	82.4	77.6	65.4	39.8	12.5	2.1	0.1	0.1				
435½			100.0	99.9	99.9	99.8	99.6	99.2	97.1	82.4	38.6	12.1	7.2	7.1				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
436¾						100.0	99.9	99.9	99.8	96.4	72.1	38.7	1.1	0.1				
438½			100.0	99.4	99.3	99.1	98.9	98.6	96.8	85.1	48.8	22.2	0.6	0.1				
439½			100.0	99.9	99.9	99.8	99.5	99.0	96.8	84.4	52.7	31.4	17.3	16.4				
441	100.0	97.8	96.0	95.6	95.5	95.4	95.1	94.3	91.1	80.4	61.8	49.4	34.0	20.1				
441½			100.0	99.7	99.0	97.8	96.0	92.4	78.7	38.3	10.0	4.2	1.7	0.6				
442½					100.0	99.9	99.7	99.6	98.3	64.0	4.6	0.4	0.2	0.1				
443½					100.0	99.9	99.9	99.8	99.7	96.4	38.1	1.8	0.1	0.1				
447½	100.0	94.3	90.3	87.2	82.8	75.5	65.3	52.5	30.6	12.3	9.2	7.8	0.4	0.1				
449			100.0	99.3	99.2	98.9	98.0	96.0	89.5	73.1	42.9	11.9	0.6	0.1				
451½													100.0	94.8	90.8	70.8	62.4	
452½				100.0	99.9	99.9	99.8	99.7	96.7	41.8	3.1	0.7	0.4	0.2				
454												100.0	99.2	93.4	90.1	70.5	52.1	
454½	100.0	85.6	56.0	37.6	32.3	27.5	23.6	19.6	12.5	4.9	1.2	0.2	0.1	0.1				
455½				100.0	99.9	99.9	99.7	99.3	96.0	53.3	6.0	0.1	0.1	0.1				
456½			100.0	99.6	99.4	99.3	99.1	98.6	95.4	69.3	23.9	2.7	0.1	0.1				
457½		100.0	98.7	96.7	95.2	92.8	87.2	77.7	58.8	27.5	5.8	0.4	0.1	0.1				
459	100.0	56.2	50.4	49.6	49.0	48.1	45.8	40.7	26.7	7.7	1.7	0.5	0.1	0.1				
459¼		100.0	99.4	96.4	95.0	92.9	89.2	82.5	68.4	49.3	32.1	18.8	2.5	0.8				
460½			100.0	99.2	97.1	94.3	88.7	77.7	52.6	33.9	21.8	4.4	0.3	0.1				
461½				100.0	99.9	99.9	99.8	99.2	84.0	30.1	13.0	3.7	0.3	0.1				
462	100.0	76.1	62.6	55.9	53.0	50.6	48.5	43.5	37.2	13.3	5.1	0.9	0.1	0.0				
464			100.0	97.7	97.0	96.0	94.3	89.9	75.6	27.5	3.2	0.5	0.1	0.1				
464¼			100.0	99.7	99.5	99.2	98.7	97.8	92.3	74.0	26.6	2.1	0.2	0.1				
465½		100.0	99.0	96.9	96.2	95.4	94.4	92.6	86.0	66.0	29.4	4.4	0.1	0.1				
466						100.0	99.9	99.9	99.3	95.2	53.2	5.8	0.1	0.1				
466½			100.0	99.6	99.5	99.4	99.3	98.9	97.7	93.4	66.8	17.9	0.1	0.1				
468			100.0	99.1	98.3	96.9	94.5	89.2	73.2	51.4	41.6	29.2	0.2	0.1				
469½			100.0	94.2	86.3	75.9	64.4	52.4	42.6	39.3	38.7	37.2	1.2	0.2				
470½		100.0	98.5	96.5	96.3	96.2	95.4	94.6	81.2	13.0	2.2	1.6	0.1	0.1				
472½			100.0	99.4	98.6	94.7	92.7	60.5	18.7	3.0	0.3	0.2	0.1	0.1				
474				100.0	99.9	99.8	99.5	97.4	84.2	25.3	3.6	0.5	0.1	0.1				
475					100.0	99.9	99.9	99.8	94.2	42.9	7.1	0.6	0.1	0.1				
475¾	100.0	90.5	89.8	89.5	89.3	89.2	89.1	89.0	88.6	73.7	14.4	0.7	0.1	0.1				
476¼			100.0	99.9	99.9	99.8	99.7	99.6	98.8	74.5	9.1	0.4	0.1	0.1				
477½			100.0	98.2	98.0	97.9	97.6	96.0	85.4	71.3	55.5	11.7	0.1	0.1				
479¾		100.0	98.4	98.1	98.0	97.9	97.6	96.2	90.4	59.8	17.3	5.9	0.2	0.1				
481						100.0	99.9	99.9	99.7	97.8	65.1	15.3	2.7	0.6				
481¼	100.0	70.1	53.6	46.9	44.8	43.5	42.3	39.8	31.8	19.5	7.3	1.7	0.1	0.1				
481¾	100.0	78.7	75.3	73.1	72.3	71.0	68.6	64.4	53.4	31.3	21.1	2.6	0.2	0.1				
482						100.0	99.9	99.9	99.8	98.1	57.8	5.2	0.2	0.1				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
483						100.0	99.9	99.6	95.9	68.6	23.4	2.9	0.1	0.1				
484					100.0	99.9	99.9	99.5	94.9	57.0	16.0	4.4	0.1	0.1				
484¼	100.0	80.2	13.1	0.7	0.2	0.1	0.1	0.0										
484¾		100.0	90.2	78.5	67.0	52.5	36.6	21.6	8.1	2.8	0.8	0.2	0.1	0.1				
485¼A			100.0	99.9	99.9	99.2	98.2	94.5	73.1	22.0	3.6	0.6	0.1	0.1				
485¼B	100.0	85.9	41.8	26.6	20.6	15.7	11.7	8.4	5.1	3.1	1.3	0.1	0.0					
486			100.0	99.6	99.5	99.4	99.2	97.9	84.9	38.6	14.6	2.2	0.1	0.1				
487			100.0	97.7	97.6	97.1	95.8	89.9	63.6	30.5	21.7	17.8	1.1	0.2				
488½A						100.0	99.9	99.8	99.7	97.5	50.2	7.3	0.2	0.1				
488½B			100.0	99.9	99.7	99.1	97.3	93.2	71.7	26.3	5.5	0.9	0.1	0.1				
489			100.0	99.3	99.2	99.0	98.4	97.3	92.3	67.3	23.0	2.9	0.2	0.1				
489¼												100.0	92.0	80.6	59.2	34.9	27.3	
489½			100.0	99.7	99.6	99.6	99.5	99.4	98.7	93.7	56.0	4.7	0.1	0.1				
489¾	100.0	92.5	39.5	88.2	87.2	86.4	85.2	83.2	72.3	36.5	7.0	0.4	0.1	0.1				
490						100.0	99.9	99.8	99.7	98.0	66.3	7.3	0.1	0.1				
490½A						100.0	99.9	99.9	99.3	79.3	36.6	3.5	0.1	0.1				
490½B	100.0	98.4	97.0	95.3	94.4	92.9	90.8	88.0	80.9	47.4	10.4	0.5	0.1	0.0				
491			100.0	99.8	99.7	99.6	99.3	99.0	98.3	93.2	43.8	3.9	0.1	0.1				
491¼			100.0	99.9	99.8	99.8	99.7	99.7	99.4	93.5	44.6	3.9	0.0					
492½				100.0	99.8	99.2	98.3	97.0	93.8	86.8	77.3	52.3	1.4	0.4				
493½	100.0	80.8	65.4	51.1	44.3	38.4	32.8	26.1	14.2	5.8	3.2	1.1	0.1	0.1				
494	100.0	72.9	56.6	50.8	48.1	45.3	42.6	38.3	24.8	8.8	4.3	2.0	0.2	0.0				
494½		100.0	96.4	96.1	96.1	96.0	95.9	95.5	91.1	44.1	5.9	0.6	0.1	0.0				
496				100.0	99.9	99.9	99.7	99.6	98.9	89.8	30.7	6.4	0.2	0.1				
497			100.0	98.6	97.0	95.0	91.7	86.1	73.8	58.5	29.0	10.4	0.4	0.1				
498¾				100.0	99.9	99.7	99.4	99.0	97.2	91.0	78.5	32.4	3.7	0.4				
500			100.0	96.5	94.1	91.1	86.7	80.0	61.8	21.1	3.0	0.5	0.1	0.1				
501½	100.0	68.1	58.6	48.9	45.0	42.2	40.2	38.0	33.6	20.4	9.1	3.9	0.3	0.1				
502			100.0	99.8	99.6	99.2	98.4	96.3	80.4	34.6	8.1	0.8	0.1	0.1				
503½			100.0	99.7	99.1	98.4	97.2	95.4	87.6	57.1	24.3	2.9	0.1	0.1				
505½			100.0	92.9	91.3	90.0	88.4	86.3	80.1	61.9	36.2	12.9	1.9	1.0				
507						100.0	99.9	99.9	98.8	80.0	42.7	7.6	0.7	0.2				
508¾			100.0	99.4	98.9	98.2	96.4	91.6	71.5	32.4	11.2	2.5	0.2	0.1				
510½			100.0	99.4	99.0	98.7	98.4	97.7	93.7	58.0	9.5	2.0	0.1	0.1				
512¼						100.0	99.9	99.9	99.1	90.9	66.8	31.9	4.1	1.1				
513					100.0	99.9	99.8	99.7	99.6	98.7	82.1	24.6	9.9	0.9				
514	100.0	1.5	1.1	1.0	1.0	1.0	0.9	0.8	0.7	0.5	0.3	0.2	0.1	0.0				
514½	100.0	68.2	68.1	67.6	67.5	67.3	67.1	66.8	65.2	53.5	17.7	2.0	0.1	0.1				
515			100.0	98.6	98.1	97.3	96.2	94.4	88.6	72.1	22.9	1.5	0.1	0.1				
517		100.0	93.9	92.5	92.1	91.7	91.1	89.7	83.5	65.4	52.6	23.8	1.2	0.1				
518		100.0	96.5	93.4	91.7	89.5	85.0	76.9	54.2	24.1	7.8	2.9	0.1	0.1				

*See also Table 41

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
519½	100.0	97.3	92.9	89.1	86.7	83.0	78.0	71.2	53.5	24.9	6.6	1.8	0.1	0.1				
520½					100.0	99.9	99.9	99.8	98.5	73.6	26.2	3.3	0.1	0.1				
521¾			100.0	99.6	99.5	99.2	98.9	98.3	96.7	93.2	57.9	5.0	0.1	0.1				
522½			100.0	99.9	99.8	99.7	99.5	98.6	94.0	63.3	22.8	5.0	0.1	0.1				
523½				100.0	99.9	99.5	99.0	98.5	96.9	88.3	67.9	62.0	14.0	3.7				
526			100.0	99.0	98.4	97.9	97.3	96.3	92.6	71.5	28.2	15.5	1.4	0.3				
526¾			100.0	99.9	99.8	99.7	99.6	99.1	97.9	94.4	83.6	15.3	0.2	0.1				
527¼					100.0	99.9	99.9	99.8	99.6	98.7	89.1	15.4	0.1	0.1				
528			100.0	99.9	99.8	99.7	99.6	99.3	98.5	96.2	80.3	9.4	0.1	0.1				
530							100.0	99.9	99.7	92.8	49.7	3.9	0.1	0.1				
530½						100.0	99.9	99.9	99.4	91.8	70.4	20.6	0.1	0.1				
532					100.0	99.9	99.9	99.8	99.8	98.5	91.8	24.1	0.2	0.1				
533½			100.0	99.4	99.3	99.1	98.5	97.5	93.8	77.7	49.7	11.8	0.1	0.1				
536			100.0	99.5	99.2	98.4	96.6	92.5	77.4	40.7	12.9	3.7	0.2	0.1				
537	100.0	84.1	81.4	78.1	75.6	72.6	68.3	62.3	48.8	27.6	14.8	5.1	0.1	0.0				
537½			100.0	99.9	99.7	99.5	99.2	97.3	85.7	37.1	9.5	1.7	0.1	0.1				
538½			100.0	98.8	98.1	97.0	95.4	92.7	82.3	42.2	13.0	3.4	0.1	0.1				
538¾	100.0	93.8	92.8	92.1	91.7	91.1	89.4	85.8	73.7	34.2	6.4	1.0	0.1	0.1				
539A		100.0	98.8	97.4	96.5	95.2	92.8	88.5	74.1	35.4	6.3	0.9	0.1	0.1				
539B				100.0	99.9	99.9	99.8	99.7	99.2	94.6	65.0	16.5	0.2	0.1				
539¼					100.0	99.9	99.8	99.8	99.5	94.7	59.2	16.4	0.1	0.1				
539¾			100.0	99.9	99.6	99.3	99.2	99.1	98.7	97.2	93.0	78.1	2.2	0.4				
540			100.0	99.9	99.8	99.5	98.8	97.1	88.9	46.2	9.3	2.0	0.2	0.1				
540¼	100.0	97.9	89.9	88.1	87.2	86.4	84.9	81.9	70.2	30.7	5.3	0.5	0.1	0.1				
540¼A		100.0	98.6	96.9	95.5	93.8	90.7	83.6	59.3	17.4	2.2	0.4	0.1	0.1				
541¼					100.0	99.9	99.9	99.8	99.8	99.4	87.6	19.8	0.2	0.1				
541½					100.0	99.9	99.9	99.8	99.6	97.9	81.1	31.5	10.3	10.0				
543¾					100.0	99.9	99.9	99.8	98.1	59.8	14.9	1.9	0.1	0.1				
546¼					100.0	99.9	99.8	99.8	98.8	60.5	9.4	0.5	0.1	0.1				
548		100.0	98.3	94.6	93.0	91.9	90.3	87.6	79.1	60.2	37.0	7.0	0.3	0.1				
548½	100.0	34.4	27.2	22.2	20.1	18.1	16.1	13.9	9.9	5.3	2.3	0.5	0.1	0.0				
549	100.0	97.2	93.9	90.8	88.5	86.1	83.1	78.3	65.8	41.3	11.0	1.0	0.1	0.1				
549½								100.0	99.3	87.4	30.7	7.4	0.2	0.1				
551	100.0	98.5	94.5	89.5	86.2	81.7	75.3	65.9	46.0	15.8	3.5	0.9	0.1	0.0				
554			100.0	99.8	99.7	99.6	99.3	97.2	76.1	17.8	6.5	3.7	0.6	0.2				
555	100.0	84.2	83.0	82.5	81.9	80.3	77.1	69.4	38.5	5.8	2.4	1.4	0.1	0.0				
556			100.0	99.7	99.5	99.4	99.1	97.9	92.8	79.5	59.3	22.7	0.3	0.0				
558½			100.0	99.5	99.4	99.2	98.8	97.4	90.5	66.7	33.2	16.8	0.9	0.1				
560			100.0	99.8	99.6	99.3	98.8	97.5	91.9	74.6	48.2	7.4	0.1	0.0				
560½		100.0	99.8	98.9	98.8	98.5	98.1	97.2	92.8	75.7	37.3	5.1	0.1	0.0				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
563½			100.0	99.8	99.7	99.2	97.3	92.7	75.6	35.2	14.2	4.6	0.4	0.1				
565	100.0	97.5	94.5	92.5	91.2	88.9	85.2	78.5	57.0	17.3	2.1	0.2	0.1	0.1				
566½			100.0	99.4	99.4	99.1	98.7	98.0	94.0	60.7	12.5	1.0	0.1	0.1				
568		100.0	98.6	94.1	90.4	85.1	77.8	68.0	51.0	26.4	4.6	0.4	0.1	0.1				
569½		100.0	97.8	97.4	97.3	97.1	96.9	96.4	94.7	86.9	30.6	2.3	0.1	0.1				
570¾													100.0	90.3	64.3	34.0	27.1	
572½					100.0	99.9	99.9	99.7	95.1	54.1	18.8	9.0	1.4	0.3				
573½	100.0	95.5	86.2	82.7	81.6	80.3	78.4	74.7	57.8	19.3	3.6	1.0	0.1	0.1				
575	100.0	5.4	0.4	0.0														
575½	100.0	32.5	27.4	23.7	22.1	20.6	18.7	16.4	11.0	3.5	0.6	0.2	0.1	0.0				
577		100.0	95.5	92.5	90.7	88.3	84.6	77.6	53.8	17.4	2.2	0.3	0.1	0.1				
578			100.0	99.9	99.9	99.8	99.8	99.2	94.0	61.9	24.1	4.0	0.1	0.1				
579			100.0	99.1	98.9	98.6	98.1	96.9	89.5	66.8	32.5	4.2	0.1	0.1				
580			100.0	99.0	98.7	98.5	98.2	97.5	89.3	37.5	14.8	8.9	0.3	0.1				
581	100.0	55.9	41.5	34.7	32.0	30.0	28.2	26.2	20.8	9.9	5.4	3.9	0.2	0.1				
581¾				100.0	99.9	99.7	99.2	96.1	71.9	25.5	12.2	8.4	0.6	0.1				
583	100.0	74.6	69.9	65.8	63.7	62.1	59.9	54.9	36.6	10.0	1.9	0.6	0.1	0.0				
583½	100.0	89.3	86.5	85.4	84.9	84.2	81.8	75.6	49.9	13.3	1.7	0.3	0.1	0.1				
586¼	100.0	98.2	94.5	93.4	92.8	92.3	91.1	88.6	78.9	45.0	10.2	3.1	0.2	0.1				
586¾		100.0	99.0	96.6	95.6	94.4	91.6	86.7	69.8	29.7	6.9	2.5	2.0	2.0				
588	100.0	69.5	62.1	58.1	57.3	56.3	55.0	51.6	35.2	11.3	4.1	2.4	0.1	0.0				
589				100.0	99.8	99.8	99.6	99.2	95.7	59.9	14.7	1.4	0.1	0.1				
590												100.0	99.2	93.6	80.5	39.4	31.3	
591			100.0	98.4	98.1	97.8	97.2	96.2	90.5	65.0	22.7	3.0	0.7	0.6				
593			100.0	99.8	99.7	99.3	98.3	96.9	91.8	72.0	44.5	5.4	0.2	0.1				
595			100.0	98.3	96.9	94.5	90.8	85.9	73.6	31.5	11.7	7.3	0.5	0.2				
595¼	100.0	97.7	92.6	90.8	90.4	90.3	90.2	90.1	89.3	83.2	46.4	15.3	1.0	0.2				
595½	100.0	74.8	71.8	68.0	65.3	62.0	56.5	48.7	32.1	10.3	2.9	1.6	0.1	0.0				
595½A							100.0	99.9	99.9	99.6	97.3	56.3	2.6	1.0				
595¾	100.0	28.4	23.0	21.0	20.4	20.0	19.6	19.1	16.7	8.9	2.6	0.5	0.1	0.0				
595¾A				100.0	99.9	99.9	99.8	99.8	99.7	99.6	98.9	83.7	5.3	1.2				
596¼	100.0	74.1	62.0	60.1	58.6	57.7	56.9	55.8	49.0	24.4	6.1	0.9	0.1	0.1				
596½	100.0	8.6	0.0															
596½A			100.0	99.3	98.4	96.7	93.5	87.6	67.6	22.7	3.4	1.8	0.1	0.1				
596¾					100.0	99.9	99.9	99.6	97.6	85.4	32.8	3.0	0.1	0.1				
597	100.0	72.9	68.3	65.9	64.5	63.3	61.4	58.9	54.5	47.9	33.8	6.8	0.1	0.1				
597A						100.0	99.9	99.9	99.8	99.7	99.5	80.1	1.7	0.2				
597½		100.0	99.2	93.9	90.4	84.7	75.2	60.7	30.1	4.8	1.0	0.3	0.1	0.1				
597½A					100.0	99.9	99.9	99.8	97.3	79.2	31.0	3.3	0.1	0.1				
598				100.0	99.9	99.9	99.8	99.8	99.5	96.1	84.3	34.3	0.1	0.1				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
598¼	100.0	88.9	85.0	80.2	77.7	74.2	69.5	61.4	36.6	8.6	1.8	0.4	0.1	0.1				
598½	100.0	95.8	93.2	92.8	92.6	92.2	91.1	88.0	72.8	24.5	2.4	0.3	0.1	0.0				
598½A					100.0	99.9	99.9	99.8	99.5	96.2	82.6	49.1	0.3	0.1				
599	100.0	97.6	92.1	90.4	89.9	89.1	87.7	84.7	73.0	49.4	16.3	1.4	0.1	0.1				
599A					100.0	99.9	99.9	99.8	99.4	97.9	95.9	63.5	0.4	0.1				
599½			100.0	96.6	93.5	89.7	84.0	75.8	51.8	13.7	2.7	0.4	0.1	0.1				
599½A					100.0	99.9	99.9	99.4	93.6	59.7	21.4	8.2	0.1	0.1				
599¾			100.0	99.9	99.8	99.4	98.5	96.7	88.5	61.3	45.9	41.9	5.6	1.9				
600			100.0	99.9	99.8	99.6	99.2	98.1	90.9	56.8	13.2	1.2	0.1	0.1				
600A			100.0	99.8	99.7	99.6	99.5	99.1	93.1	52.7	12.5	2.2	0.1	0.1				
600½						100.0	99.9	99.9	99.5	95.4	73.0	13.6	0.1	0.1				
601 3/5						100.0	99.9	99.9	99.5	97.1	82.8	15.9	0.2	0.0				
601¾					100.0	99.9	99.8	99.7	97.9	89.5	65.6	12.5	0.1	0.1				
602½				100.0	99.9	99.9	99.6	98.9	98.4	98.0	96.9	84.6	3.3	0.7				
603	100.0	67.9	62.4	61.3	60.9	60.5	59.9	58.8	55.4	47.9	40.5	28.6	4.1	2.9				
604¾			100.0	99.1	99.0	98.7	98.1	95.4	72.4	26.3	8.5	3.5	0.2	0.1				
605¾					100.0	99.9	99.9	99.8	99.7	98.7	85.0	16.2	0.2	0.1				
606A						100.0	99.9	99.9	99.8	99.7	97.5	28.6	0.2	0.1				
606				100.0	99.9	99.9	99.8	98.5	77.7	18.3	4.7	1.2	0.1	0.0				
606½						100.0	99.9	99.9	99.8	99.3	90.8	19.2	0.2	0.1				
606¾						100.0	99.9	99.8	97.8	73.1	19.1	2.1	0.1	0.1				
607½					100.0	99.9	99.9	99.8	99.7	98.5	94.0	58.3	0.9	0.1				
608			100.0	99.6	99.3	98.8	98.1	96.6	90.0	71.7	34.8	4.5	0.2	0.1				
608¼			100.0	99.6	99.1	98.6	97.7	96.6	91.6	64.7	21.6	3.5	0.1	0.1				
608½						100.0	99.9	99.9	97.7	75.3	47.4	26.6	0.9	0.1				
609							100.0	99.9	99.9	97.5	74.4	17.8	0.2	0.1				
609½	100.0	93.5	89.8	86.5	85.0	83.2	81.0	77.1	66.1	43.3	16.2	2.9	0.1	0.0				
610			100.0	99.3	99.2	99.1	98.9	98.1	92.4	69.2	28.9	3.3	0.1	0.1				
611				100.0	99.8	99.7	99.6	99.4	97.3	78.7	19.7	1.7	0.1	0.1				
612		100.0	95.9	93.2	91.9	90.2	88.2	83.8	61.1	20.1	7.0	4.8	0.9	0.2				
612¼			100.0	99.6	99.6	99.5	99.4	99.1	97.0	77.9	37.3	8.7	0.6	0.2				
613				100.0	99.9	99.9	99.8	99.3	99.3	56.0	13.7	2.5	0.1	0.1				
614					100.0	99.9	99.9	99.9	99.8	99.8	99.4	27.3	4.5	1.5				
614A							100.0	99.8	99.5	98.4	90.1	69.8	52.1	48.8				
615				100.0	99.9	99.9	99.8	99.4	94.4	60.3	22.1	6.1	0.8	0.6				
617			100.0	99.8	99.5	99.4	99.0	97.6	89.6	56.4	23.5	7.7	0.3	0.1				
619	100.0	83.6	67.8	64.5	63.0	62.0	60.8	59.2	51.0	30.1	19.5	15.2	11.2	10.7				
620												100.0	93.8	71.5	63.9	42.8	30.2	
625		100.0	94.1	89.9	87.1	83.4	77.1	65.5	38.1	13.5	4.4	0.5	0.1	0.1				
628						100.0	99.9	99.8	99.3	97.0	95.8	94.1	10.0	1.6				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel		Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
630		100.0	98.4	97.2	96.7	96.0	94.6	90.8	72.6	39.2	10.5	3.3	0.4	0.2				
631					100.0	99.9	99.9	99.9	98.7	88.7	50.3	7.0	0.4	0.1				
631A				100.0	99.9	99.9	99.7	99.1	94.7	60.5	12.6	1.1	0.1	0.1				
633			100.0	99.4	99.3	99.1	98.8	98.3	93.2	81.5	73.3	57.7	3.2	0.4				
633A		100.0	99.3	98.3	97.5	96.7	95.4	91.9	73.5	23.0	4.6	0.9	0.1	0.1				
635				100.0	99.9	99.9	99.8	99.7	96.4	55.7	9.8	2.1	0.1	0.1				
638													100.0	95.4	90.4	42.5	28.7	
639					100.0	99.9	99.9	99.8	96.1	74.6	43.0	20.3	0.9	0.1				
640						100.0	99.9	99.9	99.7	99.5	99.0	98.5	69.5	28.2				
642						100.0	99.9	99.9	99.7	99.1	98.3	97.4	36.5	12.1				
643												100.0	93.8	91.3	81.7	49.9		
647												100.0	95.5	88.5	77.9	47.7	32.4	
648			100.0	99.9	99.9	99.8	99.7	99.1	93.8	59.0	15.3	2.9	0.5	0.2				
650			100.0	99.9	99.9	99.8	99.8	99.6	98.4	91.6	73.8	35.4	1.5	0.3				
657	100.0	73.4	56.1	52.2	50.8	49.6	48.0	44.3	29.3	14.3	4.6	1.2	0.4	0.2				
659				100.0	99.9	99.7	99.5	99.1	95.5	83.7	64.4	8.5	0.2	0.1				
659A			100.0	99.9	99.9	99.8	99.6	99.0	92.9	62.2	23.9	3.0	0.3	0.1				
662			100.0	97.1	94.4	92.1	89.8	86.6	74.5	50.0	27.3	12.5	6.9	6.3				
666		100.0	98.6	98.2	97.3	96.5	95.3	92.7	78.7	37.1	9.4	1.4	0.1	0.1				
670	100.0	67.2	60.1	57.2	55.9	54.8	53.6	51.8	44.8	20.8	6.0	1.4	0.3	0.1				
671			100.0	99.7	99.6	99.4	99.3	98.9	97.4	88.3	38.4	4.1	0.1	0.1				
676	100.0	78.7	71.5	67.5	66.4	65.8	64.6	62.4	51.3	25.5	10.0	3.8	0.4	0.1				
683		100.0	99.2	97.3	95.4	93.7	90.5	85.0	65.8	35.9	15.7	6.1	0.4	0.2				
687			100.0	99.9	99.9	99.8	99.8	99.7	96.3	74.8	32.9	4.4	0.1	0.1				
689					100.0	99.9	99.9	99.8	98.6	92.1	84.5	51.4	1.8	0.4				
693			100.0	99.9	99.7	99.4	99.0	98.2	94.7	75.7	42.4	11.5	0.2	0.1				
696					100.0	99.9	99.9	99.8	99.4	91.4	40.0	3.3	0.2	0.1				
701		100.0	98.9	96.4	96.0	95.4	94.3	90.7	57.2	6.9	1.9	0.6	0.1	0.1				
708½		100.0	97.4	96.3	96.2	95.7	95.0	93.1	71.3	29.6	11.9	1.6	0.1	0.1				
709						100.0	99.9	99.9	99.7	97.7	77.4	12.0	0.4	0.1				
710					100.0	99.9	99.9	99.8	99.7	98.9	92.1	42.9	0.8	0.2				
710¾	100.0	90.7	86.6	80.6	77.9	75.9	72.1	66.8	51.9	15.1	2.8	0.3	0.1	0.0				
711					100.0	99.9	99.8	99.7	99.4	97.7	83.7	31.4	0.6	0.1				
712¼	100.0	91.5	85.6	84.1	83.7	83.5	83.2	82.4	75.8	40.1	6.8	0.6	0.1	0.0				
713					100.0	99.9	99.9	99.7	98.1	86.0	38.4	4.1	0.1	0.1				
713A						100.0	99.9	99.9	99.8	99.6	95.3	37.7	1.1	0.2				
715¾					100.0	99.8	99.7	99.5	98.1	88.9	69.8	28.0	0.7	0.1				
716¼	100.0	91.1	85.4	82.9	82.3	81.5	80.7	79.6	73.5	46.7	16.8	6.4	0.3	0.1				
718½					100.0	99.9	99.9	99.6	97.0	86.2	48.5	6.1	0.1	0.1				
720		100.0	99.1	98.4	98.4	98.1	97.8	97.0	91.3	65.4	22.6	5.2	0.1	0.1				
722				100.0	99.9	99.8	99.7	99.6	97.5	74.7	32.7	8.0	0.2	0.1				

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
723½					100.0	99.9	99.9	99.8	99.3	95.0	84.9	68.5	9.2	1.0				
725½		100.0	99.5	98.6	97.9	97.2	96.0	93.7	81.1	31.3	6.3	1.3	0.2	0.1				
728½						100.0	99.9	99.9	99.7	99.4	99.0	97.5	11.2	2.3				
733		100.0	99.5	98.3	97.7	97.2	96.1	94.3	87.0	72.6	35.3	10.9	0.4	0.1				
736						100.0	99.9	99.9	99.6	93.8	51.1	12.9	0.6	0.2				
740			100.0	99.1	98.8	98.6	98.1	97.5	95.2	84.8	39.6	5.2	0.5	0.1				
742		100.0	99.7	97.0	95.3	92.9	88.5	82.3	56.5	15.9	5.6	2.3	0.3	0.1				
745					100.0	99.9	99.8	99.7	99.6	95.8	46.0	11.0	0.2	0.1				
749		100.0	99.1	97.2	95.8	94.6	91.0	84.5	59.6	15.5	2.4	0.7	0.1	0.1				
752						100.0	99.9	99.9	99.8	99.7	99.6	85.5	1.5	0.3				
756½					100.0	99.9	99.5	98.8	95.9	88.8	82.8	78.9	62.8	55.9				
757															100.0	74.3		
758½			100.0	99.9	99.2	98.2	96.6	95.1	88.9	22.4	15.4	12.6	6.0	3.8				
759½						100.0	99.9	99.9	99.8	99.1	76.4	12.2	0.1	0.1				
760						100.0	99.9	99.9	99.8	92.8	27.6	3.4	0.3	0.1				
760¼						100.0	99.9	99.9	99.8	99.8	99.3	66.2	0.8	0.1				
760½			100.0	99.8	99.8	99.7	99.5	99.2	95.7	61.7	18.6	1.5	0.1	0.0				
760¾		100.0	91.9	88.7	87.7	86.6	85.2	82.6	60.8	14.8	3.4	0.8	0.1	0.1				
761½				100.0	99.9	99.9	99.8	99.7	99.4	98.7	97.4	89.5	2.6	0.5				
763			100.0	99.9	99.9	99.8	99.8	99.7	99.6	99.4	99.4	98.6	15.6	4.0				
766		100.0	95.7	95.2	95.2	95.1	95.0	93.6	74.3	23.0	6.8	3.6	0.7	0.2				
767								100.0	99.7	88.1	46.7	7.0	0.5	0.1				
767½	100.0	79.8	68.5	67.2	66.9	66.6	66.4	65.6	54.9	23.4	7.9	1.2	0.1	0.1				
768							100.0	99.9	99.9	99.8	99.6	98.2	15.9	6.9				
770		100.0	95.4	92.9	92.4	91.9	91.0	90.2	84.9	63.2	29.7	11.3	1.1	0.5				
770½		100.0	98.3	96.9	96.3	95.7	94.9	93.0	84.4	41.5	10.5	3.9	0.2	0.1				
771		100.0	99.3	98.7	98.6	98.6	98.4	97.9	94.8	43.7	12.0	4.8	0.2	0.2				
771½		100.0	97.4	90.2	86.8	84.1	81.5	79.0	70.2	43.5	23.0	9.8	0.4	0.2				
773½			100.0	99.9	99.9	99.8	99.8	99.7	99.1	95.7	89.3	82.6	13.6	1.1				
777½	100.0	90.2	84.3	79.8	78.5	77.6	76.7	75.8	67.5	30.7	9.6	4.8	0.3	0.0				
785¾			100.0	98.8	98.6	98.5	98.3	97.6	90.0	66.8	35.6	14.3	0.5	0.1				
786¾		100.0	98.9	98.7	98.7	98.6	98.5	98.3	96.7	89.6	68.3	22.8	0.7	0.1				
787		100.0	97.9	97.0	96.8	96.7	96.1	95.3	90.0	62.8	26.6	6.1	0.1	0.1				
800								100.0	99.9	99.4	98.9	35.2	0.3	0.1				
807			100.0	99.7	99.4	99.2	98.8	97.9	91.6	52.7	22.5	11.5	1.3	0.2				
814						100.0	99.9	99.8	99.5	95.8	91.9	13.5	0.2	0.1				
826½						100.0	99.9	99.9	99.8	99.7	99.2	29.4	0.5	0.1				
835½				100.0	99.9	99.8	99.6	99.5	96.9	63.3	35.3	7.8	0.2	0.1				
838												100.0	89.2	86.7	81.0	66.0		
840½						100.0	99.9	99.8	99.7	94.7	55.9	6.1	0.4	0.2				
842			100.0	99.9	99.8	99.7	99.3	98.3	92.8	59.4	17.4	2.8	0.4	0.1				

*See also Table 41.

TABLE 39—Continued.

Mechanical Analyses of Material from Bed of Mississippi River.*

Accumulative Per Cent Finer

Miles Below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
847½					100.0	99.9	99.8	99.7	99.4	97.2	42.3	6.4	0.2	0.1				
860					100.0	99.9	99.9	99.8	99.7	99.5	99.4	42.4	0.7	0.2				
861						100.0	99.9	99.9	99.8	99.5	80.4	11.2	0.1	0.1				
867½				100.0	99.9	99.9	99.8	99.8	99.7	99.7	98.5	56.8	1.1	0.4				
882½				100.0	99.9	99.9	99.8	99.8	99.4	91.5	43.2	6.3	0.2	0.1				
896					100.0	99.9	99.9	99.8	99.7	97.9	53.8	6.5	0.4	0.3				
911						100.0	99.9	99.9	99.8	99.8	98.7	59.7	16.5	15.2				
917							100.0	99.9	99.9	99.8	98.5	48.1	0.9	0.3				
924					100.0	99.9	99.9	99.8	99.7	99.7	99.3	53.0	0.6	0.1				
937							100.0	99.9	99.9	99.8	99.3	59.9	8.7	8.2				
967½								100.0	99.9	99.6	95.6	49.0	0.2	0.1				
968½										100.0	99.9	95.0	2.5	0.5	0.0			
972¼									100.0	98.4	32.2	7.7	0.1	0.0				
977										100.0	99.5	99.1	98.2	97.9	96.3	82.9	75.5	49.2
979½									100.0	99.6	85.1	31.1	0.9	0.6	0.0			
983									100.0	99.9	96.4	27.4	0.2	0.1	0.0			
986¾							100.0	99.9	99.7	98.9	89.3	55.8	30.9	30.6	29.8	24.9	20.8	13.7
990¼								100.0	99.9	99.4	65.1	21.3	0.2	0.1	0.0			
992¾									100.0	98.4	97.6	96.6	95.8	95.5	95.1	80.0	69.6	46.5
994½									100.0	99.9	97.0	42.6	0.8	0.2	0.0			
997¾									100.0	99.4	98.8	97.9	95.1	92.4	88.8	63.3	51.1	29.9
999½								100.0	99.6	99.2	98.2	86.4	3.5	1.6	0.0			
1001½													100.0	98.4	97.8	87.1	76.1	42.8
1004¼									100.0	99.8	98.7	53.5	0.4	0.1	0.0			
1007									100.0	99.6	94.5	82.3	1.9	1.3	0.0			
1010									100.0	99.9	99.7	99.3	39.3	22.4	0.0			
1014¼										100.0	98.9	82.5	1.6	0.3	0.0			
1017¼									100.0	99.8	99.4	90.1	1.8	0.4	0.0			
1019										100.0	99.9	99.3	3.3	0.5	0.0			
1021¼									100.0	99.9	98.0	53.8	1.4	0.5	0.0			
1023½									100.0	99.9	97.4	71.9	1.5	0.2	0.0			
1027¼										100.0	98.2	82.1	16.9	15.1	0.0			
1030									100.0	99.8	97.3	84.1	1.3	0.4	0.0			
1033									100.0	99.8	96.1	29.9	0.8	0.5	0.0			
1037								100.0	99.9	99.5	94.2	83.7	74.5	70.4	67.7	60.0	51.2	33.0
1040¾										100.0	99.5	83.1	1.3	0.7	0.0			
1044								100.0	99.8	99.5	98.8	71.9	0.9	0.6	0.0			
1047½								100.0	99.9	99.6	92.6	76.7	2.0	0.4	0.0			
1050										100.0	99.3	95.3	5.1	0.7	0.0			
1052½								100.0	99.9	99.7	99.5	97.3	4.5	1.6	0.0			
1057								100.0	99.9	99.4	99.0	98.8	55.1	42.6	37.8	27.7	23.2	14.9
1058¼												100.0	99.9	98.1	96.7	75.1	63.4	41.4

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles below Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
1060													100.0	99.6	98.7	87.1	76.4	45.2
1062¼								100.0	99.9	99.8	97.5	83.0	2.4	0.5	0.0			
1064									100.0	99.8	99.4	95.2	78.2	75.3	73.4	52.9	43.3	27.2
1065½									100.0	99.9	99.3	97.4	3.5	0.5	0.0			
1066										100.0	99.9	99.7	3.9	0.7	0.0			
1066¾								100.0	99.9	99.7	99.1	96.2	78.2	74.4	68.1	29.3	23.4	15.5
1067¾									100.0	99.8	98.1	94.3	82.9	79.4	77.9	57.1	44.8	21.1
1069												100.0	99.9	99.8	99.3	90.5	81.6	50.8
1069½								100.0	99.9	99.9	94.5	65.8	6.5	2.1	0.0			
South Pass																		
1070¾												100.0	99.9	99.5	99.0	94.5	84.7	52.4
1071								100.0	99.9	99.8	99.7	99.2	92.9	88.0	85.3	79.3	70.6	46.2
1072							100.0	99.9	99.9	99.6	99.3	98.8	16.4	7.4	0.0			
1072¾								100.0	99.8	99.3	96.7	79.7	45.6	44.0	43.2	40.1	35.5	24.4
1075½										100.0	99.6	93.7	3.6	0.6	0.0			
1077										100.0	99.5	98.1	94.5	92.1	89.1	71.2	59.2	38.2
1079									100.0	99.9	99.6	99.3	12.1	3.6	0.0			
1080½								100.0	99.8	99.5	99.1	98.3	10.4	2.8	0.0			
1082										100.0	99.4	97.4	91.5	89.5	85.1	55.3	45.0	
1083¼												100.0	97.7	93.1	73.9	27.0	23.0	17.5
1084¼						100.0	99.7	98.8	98.0	96.6	95.7	94.0	90.0	87.1	76.4	51.6	42.6	20.6
1085									100.0	99.6	98.8	98.0	96.4	96.0	88.2	61.4	52.8	34.2
South Pass Bar																		
1083½								100.0	99.9	99.8	99.4	98.2	16.9	7.7				
1083¾									100.0	99.9	99.9	99.7	20.6	3.9				
Southwest Pass																		
1069½						100.0	99.9	99.9	99.8	99.6	98.6	87.6	6.9	1.2				
1070¼									100.0	99.9	99.8	99.4	84.0	75.6	70.4	55.0	48.2	29.1
1070¾										100.0	99.8	98.0	23.3	13.5				
1073								100.0	98.9	97.2	94.8	92.0	88.6	88.2	87.2	76.4	64.9	39.7
1076¾													100.0	99.2	98.4	92.0	84.8	42.3
1082									100.0	99.9	99.7	94.0	2.9	0.7				
1083½								100.0	99.7	99.3	99.0	76.1	24.2	13.9	12.1	11.4	10.6	6.9
1085								100.0	99.9	99.9	99.9	99.7	50.0	39.6	37.1	26.1	21.6	13.3
1085¾							100.0	99.9	98.0	97.2	95.1	91.4	85.7	83.7	79.8	59.8	49.7	30.4
1088½							100.0	99.6	98.0	96.6	95.4	93.8	90.2	88.5	86.0	63.0	49.8	23.9
1090			100.0	99.9	99.8	99.7	99.5	99.4	99.1	98.8	98.4	97.4	33.0	9.2				
1091								100.0	99.9	99.9	99.8	99.7	97.5	92.2	40.9	26.6	22.5	16.6
1091¾									100.0	99.1	97.2	93.9	83.0	75.1	61.5	33.9	26.5	11.5
Southwest Pass Bar																		
1090½									100.0	99.4	97.0	92.0	69.4	54.0	38.1	13.6		

*See also Table 41.

TABLE 39—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF MISSISSIPPI RIVER.*

Accumulative Per Cent Finer

Miles below Cairo	Locality	Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
		Size of opening in mm.															
		6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
	Pass A L'Outre																
1069½	½ mile below head							100.0	99.9	99.6	96.4	14.9	3.6				
1069½	1 mile below head							100.0	99.8	96.7	81.2	11.5	3.0				
1069½	1¾ miles below head						100.0	99.9	99.8	93.6	65.6	10.4	3.4				
	Cubits Gap																
1066¼	¼ mile east of east bank (upper side)						100.0	99.5	98.8	98.1	97.2	94.6	93.4	90.7	76.4	68.0	49.0
1066½	Head of Main Pass							100.0	99.6	99.3	98.7	98.2	98.0	97.2	81.1	67.1	44.3
1066½	Head of Octave Pass						100.0	99.8	99.5	98.9	97.5	83.6	70.7	62.6	42.4	33.7	20.9
1066½	Head of Island between Octave and Brant Passes						100.0	99.8	99.1	98.6	97.1	93.6	89.9	75.0	28.1	22.6	14.3
1066¾	Head of Brant Pass						100.0	99.8	99.6	99.4	98.8	17.4	8.7				
1066¾	Head of Raphael Pass							100.0	99.9	99.9	99.8	24.5	13.1				
1066¾	¼ mile east of light (lower side of Gap)							100.0	98.8	97.2	95.5	91.5	89.0	83.0	59.6	50.6	31.3
1066½	½ mile east of east bank of Mississippi River (center of Gap)								100.0	99.2	97.0	17.5	10.2				
	The Jump																
1059¼	¼ mile below head										100.0	95.5	88.9	68.4	35.0	30.5	20.4
1059¼	¾ mile below head						100.0	99.2	97.7	95.6	92.6	86.0	82.1	74.6	60.8	51.8	29.8
	Baptiste Collette Canal																
1058¼	At head			100.0	99.9	99.9	99.8	99.8	99.5	99.0	98.1	96.1	93.8	82.9	41.8	33.5	22.9
1058¼	½ mile east of head										100.0	99.5	97.9	94.2	74.7	66.9	49.0

*See also Table 41.

TABLE 40.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles From Cairo	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Ohio River.																		
+1 (Above Cairo)	100.0	56.5	29.0	19.4	16.7	14.9	13.5	12.1	9.2	6.5	5.8	3.9	3.3	3.3				
−1 (Below Cairo)	100.0	95.3	78.4	41.9	30.3	23.2	18.9	15.6	12.2	10.1	9.2	8.6	7.6	7.5				

Miles above Mouth of Black River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size in opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Black River.																		
½													95.4	90.9	72.8	34.4		
1													95.2	92.0	76.4	19.6		
2													99.5	98.0	91.4	29.5	22.4	16.0
3						100.0	99.9	99.8	99.7	99.6	99.4	91.4	58.7	56.7				
4														97.8	95.0	75.1		

Miles above Junction of Old and Miss. Rivers	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Red River.																		
9												99.0	74.5	63.0	55.3	32.0	26.2	18.8
10														98.0	96.5	13.9		
12													97.1	96.0	94.3	71.5		
15½														97.2	93.0	59.4		

*See also Table 42.

TABLE 40—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles above Junction of Old and Miss. Rivers	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Red River.—Continued.																		
20													95.8	94.0	91.5	73.4		
23														97.3	95.4	56.3		
23A													73.3	63.7	45.3	19.3		
25½							100.0	99.9	99.8	99.2	98.5	97.6	88.7	80.4				
29													97.1	94.3	78.8	40.3		
30½									100.0	99.9	95.8	52.5	42.5	40.6				
33½								100.0	99.9	99.9	99.8	99.7	99.0	57.5				
34½						100.0	99.9	99.9	99.8	99.8	99.7	99.4	44.3	11.1				
35						100.0	99.9	99.9	99.8	99.7	99.5	89.0	11.9	1.3				
35½						100.0	99.9	99.8	99.7	99.5	99.3	97.2	48.3	12.7				
36			100.0	99.9	99.8	99.7	99.6	99.3	97.7	90.2	73.0	23.9	4.2	0.6				
36½								100.0	99.9	99.9	99.9	99.8	51.7	27.0				

Miles above Mouth of Old River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	C.208	0.104	0.074	0.040	0.008	6.004	0.001
Old River.																		
¼		100.0	97.0	95.9	95.3	94.9	94.3	93.7	89.7	61.5	15.1	2.6	0.1	0.0				
½			100.0	99.9	99.9	99.8	99.8	99.5	94.2	39.8	5.0	0.7	0.2	0.1				
1														87.9	81.4	55.7	45.5	
1¼						100.0	99.9	99.9	99.0	77.0	16.7	1.5	0.1	0.1				
1½			100.0	99.8	99.7	99.6	99.5	99.3	98.0	88.6	50.0	5.2	0.2	0.1				
1¾						100.0	99.9	99.9	99.5	94.9	75.4	26.4	0.2	0.2				
3			100.0	99.3	98.5	97.0	94.9	92.6	83.5	64.6	37.8	17.8	6.0	5.9				
4			100.0	99.6	98.7	98.0	96.7	94.7	78.4	28.9	13.6	9.5	7.2	6.9				
5					100.0	99.9	99.8	99.7	99.6	99.1	95.4	75.4	29.1	27.5				
6					100.0	99.9	99.9	99.8	99.7	98.7	87.7	56.3	1.5	0.3				
7														93.5	81.7	54.8	43.0	
7½								100.0	99.9	99.8	97.4	24.1	1.3	0.6				

*See also Table 42.

TABLE 40—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles below Head of Atchafalaya River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Atchafalaya River.																		
½		100.0	98.2	98.0	97.9	97.9	97.8	97.7	94.5	63.8	24.4	6.9	0.7	0.2				
2												99.0	60.4	42.1	24.3	10.8	7.9	
3														86.9	69.1	19.5	13.7	
3½				100.0	99.9	99.9	99.8	99.8	99.4	94.2	67.6	40.8	25.9	21.2				
5½		100.0	98.2	94.3	92.2	90.5	88.1	86.8	79.5	72.1	66.7	56.3	37.1	32.2				
6½					100.0	99.9	99.9	99.8	99.5	97.2	80.3	54.3	26.1	21.4				
8			100.0	99.9	99.9	99.6	99.4	99.3	97.6	88.5	55.9	22.1	9.1	7.8				
9½			100.0	99.8	99.6	99.1	97.8	96.1	84.7	61.3	40.9	24.0	14.7	11.6				
10				100.0	99.9	99.9	99.8	99.8	96.2	61.4	23.9	14.7	8.8	7.9				
12¾												99.6	42.0	31.4	23.6	11.4	7.7	
13					100.0	99.9	99.9	99.8	99.6	92.5	49.4	19.5	1.4	0.4				
15½					100.0	99.9	99.9	99.1	83.3	56.8	42.8	31.6	19.0	10.2				
16¾														93.0	86.9	56.2	35.9	
17½														95.4	90.9	64.4	50.0	
18¾					100.0	99.9	99.9	99.8	99.3	90.8	49.1	15.4	3.8	3.2				
20¾												99.7	77.4	52.6	44.0	22.1	16.8	
22¾													80.2	68.0	33.0			
23														95.5	88.5	76.7	63.7	
24½	100.0	72.7	51.5	44.1	41.3	39.1	36.8	35.6	31.0	21.6	11.6	4.9	1.1	0.9				
24¾			100.0	99.9	99.7	99.3	97.8	95.9	83.4	42.0	13.5	4.5	0.2	0.1				
27½				100.0	99.9	99.8	98.6	94.4	76.9	54.5	34.0	21.5	16.4	16.0				
29														91.8	85.3	72.9	56,5	
32¼											99.9	99.1	50.6	36.9	27.1	13.9	11.1	
32¼A			100.0	98.9	97.9	96.8	95.8	95.2	91.5	76.5	60.6	48.2	36.7	35.3				
33														92.8	90.7	81.0	63.9	
33½		100.0	99.3	96.2	90.0	77.6	61.4	48.7	31.8	23.9	22.6	22.1	21.2	20.7				
36½			100.0	99.8	99.7	99.7	99.3	98.4	88.5	62.9	48.3	34.7	19.4	14.3				
37														98.5	93.9	73.5	50.6	
39			100.0	99.9	99.9	99.8	99.5	99.4	98.4	79.2	52.1	45.4	44.7	44.7				
39½														81.7	66.2	40.8	29.5	
41												96.5	66.1	50.7	34.5	13.2	9.2	
42¾														99.0	95.6	86.6	67.8	
45														88.9	85.4	76.8	64.2	23.9
48¾														96.0	88.1	71.8	57.7	
50½			100.0	99.9	99.8	99.8	99.7	99.6	98.3	88.6	56.4	36.3	32.3	31.5				
53½														92.1	85.3	71.4	56.8	25.3
56						100.0	99.9	99.9	99.5	88.7	53.4	17.2	2.8	2.5				

*See also Table 42.

TABLE 40—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles below Head of Atchafalaya River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Atchafalaya River.—Continued.																		
58½														97.9	92.6	86.2	67.4	
60¾											99.0	90.5	34.2	29.8	26.9	21.3	13.2	
63¼			100.0	99.9	98.3	97.2	95.1	93.1	68.6	38.4	26.7	21.1	18.5	18.0				
64¼				100.0	99.8	99.5	98.0	95.5	64.9	32.3	29.2	27.6	13.3	4.8				
65				100.0	99.9	99.9	99.5	98.9	86.9	30.7	3.5	1.6	1.1	0.4				
66¼														93.2	89.8	84.9	76.4	
67½											99.1	96.0	50.5	49.0	47.8	45.3	38.0	
Little Atchafalaya River.																		
68														80.0	69.4	60.9	53.7	
69														77.1	71.5	61.4	50.7	
70½					100.0	99.9	99.7	99.3	84.7	33.8	10.6	6.1	4.6	4.5				
Upper Grand River.																		
68¾														90.5	88.1	78.1	66.0	
69¼						100.0	99.9	99.9	99.4	92.4	71.9	17.3	0.4	0.2				
70¼	100.0	95.8	95.1	94.5	94.1	93.9	92.9	90.4	60.6	11.4	4.4	2.3	0.9	0.8				
72														87.8	79.8	75.8	63.1	
73				100.0	99.9	99.9	99.8	99.8	99.7	97.6	55.5	10.1	0.1	0.1				
73¾						100.0	99.9	99.9	99.7	94.9	47.9	14.1	0.5	0.2				
76¼					100.0	99.9	99.9	99.8	99.8	99.6	97.2	31.1	1.2	0.4				
79								100.0	99.9	99.8	98.1	71.4	2.6	0.6				
82								100.0	99.9	99.9	99.8	98.3	8.2	1.3				
85						100.0	99.9	99.9	99.8	99.5	97.6	91.4	35.6	30.2				
88½								100.0	99.9	99.9	99.8	98.9	4.9	0.6				
91														91.6	85.9	62.9	44.8	
93½														94.4	84.6	43.5	30.7	
94														91.0	77.8	43.8	28.9	
Lower Grand River.																		
98									100.0	99.9	99.0	64.5	46.1	40.2				
104												100.0	89.5	74.2	63.6	22.8		

*See also Table 42.

TABLE 40—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles below Head of Atchafalaya River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Atchafalaya Basin.																		
(Lower Grand River Route.)																		
111												100.0	91.7	88.0	74.8	35.7		
118												100.0	98.9	98.0	94.6	69.5		
132½												99.5	92.9	91.3	87.5	73.0	58.2	32.7
139½													100.0	93.4	86.3	66.1		
141												100.0	91.4	82.6	75.6	60.7		
143												100.0	96.7	94.9	88.9	69.0		
147½														100.0	97.9	82.2		
(Bayou La Rompe, Lake Chicot, and Grand Lake Route.)																		
71			100.0	99.7	99.6	99.6	99.4	99.3	95.9	78.5	40.9	16.6	1.6	0.5				
72			100.0	99.9	99.9	99.8	99.8	99.7	98.0	78.6	35.1	6.3	0.1	0.1				
72½	100.0	97.3	96.9	96.7	96.5	96.2	95.5	94.2	84.0	51.1	18.3	3.0	0.1	0.1				
73¾			100.0	99.8	99.7	99.6	99.5	99.0	94.7	62.6	17.7	2.9	0.4	0.4				
74½							100.0	99.9	95.7	63.7	18.4	3.4	0.1	0.1				
76						100.0	99.9	99.9	98.0	70.6	19.3	2.2	0.1	0.1				
76½					100.0	99.9	99.9	99.8	97.9	63.8	23.0	1.7	0.1	0.0				
78							100.0	99.9	99.8	97.9	80.1	22.7	0.3	0.1				
79½							100.0	99.9	99.9	98.9	63.4	11.4	0.1	0.1				
79¾							100.0	99.9	99.7	95.8	81.6	23.7	1.4	0.2				
82							100.0	99.9	99.9	99.5	75.1	18.1	1.2	0.2				
86						100.0	99.9	99.9	99.8	99.7	98.9	45.9	0.9	0.3				
88														87.4	83.1	68.8	61.2	
89												100.0	98.1	96.9	95.1	92.6		
90¾												100.0	93.6	86.1	71.7	39.2		
92¾												100.0	94.3	92.9	88.0	77.3		
95												100.0	93.6	90.8	81.6	51.5		
98														74.5	65.2	51.2	46.0	
99½														100.0	99.6	66.5		
104													89.1	84.8	79.4	50.5		
107½														100.0	97.8	87.0		
110½														100.0	97.6	92.8		
114													100.0	97.1	94.5	56.4		
119														100.0	97.7	86.8		

*See also Table 42.

TABLE 40—Continued.

MECHANICAL ANALYSES OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS.*

Accumulative Per Cent Finer

Miles below Head of Atchafalaya River	Large Gravel		Medium Gravel			Fine Gravel (U. S. Bureau of Soils Classification)		Coarse Sand		Medium Sand		Fine Sand		Very Fine Sand	Silt		Clay	
	Size of opening in mm.																	
	38.10	13.33	6.680	3.327	2.362	1.651	1.168	0.833	0.589	0.417	0.295	0.208	0.104	0.074	0.040	0.008	0.004	0.001
Atchafalaya Basin.—Continued. (Bayou L'Embarras, Lake Fausse Point, and Grand Lake Route.)																		
75½					100.0	99.9	99.9	99.7	94.4	46.8	9.8	1.8	0.6	0.6				
76							100.0	99.8	97.8	63.6	12.3	1.2	0.1	0.0				
82						100.0	99.9	99.9	99.9	96.7	49.1	9.2	0.4	0.1				
83													100.0	92.4	80.8	54.8		
84½			100.0	99.9	99.8	99.8	99.7	99.6	99.5	98.8	88.8	24.2	0.4	0.1				
86												100.0	81.7	78.2	76.4	65.6		
87½												100.0	95.1	92.1	89.8	80.8		
90							100.0	99.9	99.8	99.6	99.3	95.0	36.1	30.6				
93½						100.0	99.9	99.9	99.9	99.8	99.7	88.2	16.6	13.1				
95½														100.0	98.5	75.7		
98													100.0	98.7	94.3	74.8		
99													100.0	96.1	92.6	70.2		
103												100.0	98.8	97.5	91.5	33.4		
105½													100.0	98.8	97.4	82.6		
107															100.0	83.0		

*See also Table 42.

TABLE 41

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
2	Cairo Point	2.66	2.384	[illegible].218	0.1470
6	Port Jefferson	2.66	†	†	†
7	Norfolk Landing	2.73	0.358	0.340	0.6364
10	Foot Tow Head Island No. 1	2.63	1.136	0.533	0.[illegible]688
12	Campbell's Landing	2.60	11.845	1.277	0.0224
13	Head of Islands Nos. 3 and 4	2.63	1.703	0.552	0.1390
13A	Chute Islands Nos. 3 and 4	2.63	8.793	0.818	0.0264
14	Bryan Landing	2.73	0.209	0.200	0.6679
16½	Crosno, Mo.	2.65	7.765	0.965	0.0054
19¼	Foot of Islands Nos. 3 and 4	2.66	2.098	0.769	0.1310
19½	Chute of Islands Nos. 3 and 4 below dredge cut	2.63	1.776	0.515	0.1016
21	Columbus, Ky.	2.65	0.393	0.278	0.2706
22½	Head of Wolf Island No. 5	2.47††	12.732	9.897	0.1202
23½	Chalk Bluff	2.62	3.539	0.655	0.0685
25	1 mile below Chalk Bluff	2.66	2.013	0.580	0.0735
27	3 miles below Chalk Bluff	2.62	3.552	1.591	0.1316
29½	Medley Landing	2.65	0.712	0.647	0.5371
31	Medley Crossing	2.63	1.093	0.776	0.3604
32	Lower end of Medley Crossing	2.65	0.804	0.490	0.2829
35	1 mile above Hickman, Ky.	2.65	0.576	0.370	0.2430
37½	1 mile below Hickman, Ky.	2.62	6.484	1.531	0.0592
38½	3 miles below Hickman, Ky.	2.58††	23.16	22.49	0.3857
41	Henderson Point Landing	2.63	1.236	0.59	0.2096
43	Head of Island No. 8	2.65	0.921	0.540	0.2528
44	James Bayou Crossing	2.65	0.356	0.349	0.6545
44¼	Three States Landing	2.65	0.428	0.365	0.5507
48½	1½ miles above foot of Island No. 8	2.65	0.449	0.360	0.3906
51	½ mile below foot of Island No. 8	2.65	0.726	0.561	0.3605
55½	Lester Landing	2.65	0.785	0.492	0.3008
56	Donaldson Crossing	2.65	0.389	0.277	0.3487
56¼	Donaldson Point	2.65	0.388	0.345	0.4795
60	Slough Landing	2.66	2.697	0.818	0.0914
61	Cates, Tennessee	2.65	0.586	0.263	0.2193
65	La Forge Landing	2.60	4.137	2.246	0.1175
70	Morrison Tow Head	2.65	0.933	0.581	0.2980
71	1 mile above New Madrid, Mo.	2.58	5.878	1.616	0.0569
72½	1 mile below New Madrid, Mo.	2.63	1.691	0.644	0.1438
76½	Head of Island No. 11	2.63	1.286	0.902	0.3226
78	Toneys Tow Head	2.65	0.960	0.598	0.3184
80	Foot of Toneys Tow Head	2.63	1.406	0.886	0.2594
81	Point Pleasant Crossing	2.65	0.802	0.534	0.3340
87	Foot of Bixby Tow Head	2.65	0.579	0.471	0.4436
88½	1 mile below Burrus Landing	2.65	0.805	0.588	0.3438
91	Cherokee Landing	2.58	5.693	1.332	0.0586
92	Stewart Bar Crossing	2.65	0.829	0.683	0.447
94	Head of Joe Eckles Tow Head	2.65	0.884	0.679	0.3936
98	Head of Island No. 14	2.66	20.027	22.683	0.2741
100½	Reelfoot, Tennessee	2.65	0.328	0.318	0.6234
102	1 mile above Fritz Landing	[illegible].60	4.132	1.008	0.0700
106	Sandy Hook Crossing	[illegible].63	1.628	0.669	0.1696
106½	Sandy Hook Crossing	2.63	1.469	0.695	0.1611
108	1 mile below Gayoso, Mo.	2.63	1.041	0.687	0.3192
113	Caruthersville, Mo.	2.66	2.146	0.956	0.1827
115½	2 miles below Caruthersville, Mo.	2.64	8.705	4.096	0.0477
124	Cottonwood Point	2.65	0.785	0.523	0.2685
128	2 miles above head of Island No. 21	2.65	0.548	0.474	0.4560
131½	Huffman, Ark.	2.65	0.651	0.519	0.4441
137	Hales Point Landing	2.62	6.047	1.683	0.0575
138	Tamm Landing	2.65	0.781	0.565	0.3832
141½	Barr Landing	2.62	3.156	1.019	0.1110
142	Barfield Crossing	2.63	1.606	0.728	0.1933
144	2 miles above Barfield Point, Ark.	2.62	3.306	1.858	0.1266
146	Barfield Point, Ark.	2.65	0.601	0.544	0.5331
150½	Head of Forked Deer Island No. 26	2.65	0.936	0.654	0.3107
155¼	Ashport, Tenn.	2.70	3.212	0.768	0.0782
159½	Gold Dust Landing	2.63	1.115	0.723	0.2594
160½	1 mile above Keyes Point Landing	2.63	1.005	0.626	0.2944
161½	Keyes Point Landing	2.65	0.946	0.572	0.2817
163¾	Head of Island No. 30	2.63	1.142	0.555	0.2272
170¾	Head of Yankee Bar	2.65	0.919	0.546	0.2813
172½	Flour Island Bar	2.65	0.890	0.652	0.3384
176	1 mile below Fulton, Tenn.	2.65	0.343	0.335	0.6164

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.
††Sandstone, porous chert, and poor shale.

TABLE 41—Continued

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
178½	Lookout Landing	2.63	1.483	0.699	0.2101
181¾	Randolph Landing	2.63	1.647	0.843	0.2033
182¾	Randolph, Tenn.	2.65	0.558	0.452	0.1593
186½	Head of Island No. 35	2.64	8.086	0.537	0.0245
194	2 miles above Foot of Island No. 35	2.63	1.312	0.698	0.2542
195	1 mile above Foot of Island No. 35	2.65	0.880	0.595	0.3266
200	Dean Island Landing	2.65	0.550	0.434	0.3864
201½	Walts Landing	2.62	2.779	0.754	0.1085
205	Happy Valley Crossing	2.65	0.943	0.682	0.3767
209	Mouth of Old River Landing	2.62	3.207	0.831	0.0899
210¾	Island 39 Landing	2.65	0.594	0.539	0.5660
215½	Island 40 Landing	2.65	0.733	0.562	0.4005
219¼	Head of Redman Point Bar	2.65	0.373	0.362	0.6358
221½	5½ miles above Memphis, Tenn.	2.65	0.805	0.302	0.1391
225	2 miles above Memphis, Tenn.	2.65	0.497	0.467	0.5473
229	1 mile below bridge at Memphis, Tenn.	2.65	0.426	0.406	0.6329
230	Head of President's Island	2.62	3.325	0.541	0.0669
231	Head of Bauxippi Revetment	2.65	0.488	0.471	0.6258
236¾	Foot of President's Island	2.65	0.376	0.365	0.673
241	Josie Harry Tow Head Crossing	2.65	0.543	0.482	0.5379
243	Armstrong Crossing	2.65	0.723	0.502	0.3315
244	Head of Island No. 48	2.65	0.662	0.533	0.4367
247½	96 Landing	2.65	0.508	0.473	0.5701
249¾	Pinckney, Ark.	2.65	0.399	0.395	0.6133
250½	Pinckney Landing	2.65	0.371	0.354	0.6030
251	Rock Point Landing	2.65	0.578	0.452	0.3711
251¾	Opposite head of Cat Island	2.61	12.964	10.416	0.0690
252¼	Harklerodes Landing	2.63	1.062	0.613	0.2800
252½	Head of Cat Island Tow Head	2.63	1.192	0.646	0.2515
253¼	Below head of Cat Island Tow Head	2.65	0.406	0.376	0.5782
254	Opposite center of Cat Island Tow Head	2.65	0.359	0.347	0.6226
254⅛	Opposite center of Cat Island Tow Head	2.65	0.814	0.571	0.2999
254¼	Opposite foot of Cat Island	2.63	2.675	0.823	0.0938
254½	Star Landing	2.62	2.205	0.521	0.0697
254¾A	New Channel, opposite foot of Cat Island	2.62	1.363	0.940	0.3177
254¾B	Opposite foot of Cat Island Tow Head	2.65	0.689	0.446	0.2805
255	Just below Star Landing	2.63	1.420	0.584	0.1811
255½	New Channel, just below foot of Cat Island Tow Head	2.65	0.685	0.522	0.3994
255¾A	New Channel, ½ mile below foot of Cat Island Tow Head	2.65	0.530	0.490	0.5440
255¾B	½ mile below foot of Cat Island Tow Head	2.63	1.875	0.718	0.1638
256¼	New Channel, opposite Finley Tow Head	2.63	1.354	0.513	0.1597
256½	1½ miles above Seyppel Landing	2.65	0.838	0.775	0.4558
258	Seyppel Landing	2.65	0.649	0.513	0.4096
259	Bruins Landing	2.65	0.896	9.490	0.2383
260¼	Bruins, Ark.	2.65	0.577	0.519	0.4522
261½	2 miles below Bruins Landing	2.65	0.482	0.375	0.3902
263¼	1 mile above Commerce Landing	2.65	0.743	0.555	0.4014
264½	Commerce, Miss.	2.65	0.775	0.499	0.2714
266	2 miles below Commerce, Miss.	2.67	2.535	0.561	0.0875
266½	Mac Tow Head Crossing	2.63	1.085	0.630	0.2635
267	Mac Tow Head	2.63	1.725	0.493	0.0449
269½	Head of Peter's Tow Head	2.65	0.409	0.369	0.5341
270½	Peters Tow Head	2.65	0.552	0.511	0.5367
271½	½ mile below Lady Lee Landing	2.66	1.008	0.544	0.2569
272½	Ashley Point Landing	2.65	0.422	0.351	0.4774
272¾	¼ mile above Mhoon Landing	2.64	1.247	0.529	0.2037
273	Mhoon Landing	2.65	0.242	0.230	0.3036
273-A	Mhoon Landing	2.65	0.963	0.550	0.2616
273¾	1 mile below Mhoon Landing	2.63	1.916	0.441	0.0218
277½	Whitehall Landing	2.65	0.451	0.397	0.4706
280¾	1 mile above Walnut Bend Landing	2.65	0.893	0.640	0.316
281½	Walnut Bend Landing	2.65	0.915	0.519	0.2816
283½	3 miles above Hardin Point Landing	2.65	0.602	0.526	0.4682
286¾	Hardin Point Landing	2.65	0.900	0.807	0.5499
287¼	1 mile below Hardin Point Landing	2.65	0.523	0.476	0.5425
289¼	O. K. Bend Crossing	2.65	0.507	0.458	0.5315
292½	1 mile below Harbert Landing	2.65	0.655	0.565	0.5018
293	St. Francis Island Landing	2.65	21.662	23.483	0.2375
293¾	Shoo Fly Bar	2.62	2.790	0.674	0.0919
296	Tate Landing	2.63	0.444	0.359	0.3314
298½	Mouth of St. Francis River	2.63	0.705	0.511	0.3592
300	2 miles below mouth of St. Francis River	2.65	0.785	0.670	0.4855
300¾	Prairie Point	2.65	0.810	0.546	0.3527

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.

TABLE 41—Continued

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
301½	Head of Prairie Point Tow Head	2.65	0.936	0.536	0.2536
302¾	Nash Landing	2.65	0.503	0.480	0.5906
303¼	1 mile above Trotter Landing	2.65	0.385	0.362	0.6349
303½	½ mile above Trotter Landing	2.65	0.347	0.337	0.6428
303¾	½ mile above Trotter Landing	2.65	0.956	0.559	0.2994
304	Trotter Landing	2.65	0.209	0.198	0.6452
306¾	Helena, Ark.	2.65	0.553	0.532	0.6850
310	Head of Montezuma Bar	2.65	0.375	0.271	0.4155
310¾	Williamson Landing	2.65	0.950	0.540	0.2792
313¾	1 mile above Stokes Landing	2.65	0.448	0.395	0.5035
314¼	Stokes Landing	2.65	0.350	0.341	0.6444
316¼	Delta Landing	2.65	0.681	0.553	0.4763
317½	½ mile above Friar Point, Miss.	2.65	0.545	0.366	0.3618
321½	Kangaroo Point Landing	2.65	0.575	0.519	0.4908
324½	Miller Point	2.65	0.770	0.500	0.2816
329½	Head of Island No. 63	2.62	6.948	6.112	0.2094
330	Island 63 Crossing	2.65	0.577	0.548	0.6652
331	Opposite middle Island No 63	2.65	0.476	0.469	0.6661
332	Foot of Island No. 63	2.65	0.341	0.293	0.5399
333½	Modoc Landing	2.65	0.553	0.489	0.3553
337	1 mile below Fair Landing	2.62	1.005	0.707	0.3697
338¾	½ mile below Rescue Landing	2.65	0.282	0.251	0.6113
339½	1½ miles below Rescue Landing	2.65	0.341	0.308	0.5821
342¾	Dawson Landing	2.65	0.334	0.312	0.5534
344	1 mile below Dawson Landing	2.65	0.259	0.250	0.6934
348	½ mile below Offutt Landing	2.63	1.617	1.004	0.1791
349	1½ miles below Offutt Landing	2.65	0.486	0.357	0.3785
350	Cheek Landing	2.62	6.713	6.789	0.1614
351	Head of Island No. 66	2.65	0.411	0.388	0.646
352¼	1½ miles above Sunflower Landing	2.65	0.621	0.520	0.5337
352½	1¼ miles above Sunflower Landing	2.65	0.322	0.308	0.6380
353	1 mile above Sunflower Landing	2.65	0.502	0.422	0.4949
356	Malone Landing	2.65	0.927	0.631	0.3478
357½	Anderson Landing	2.63	1.941	0.639	0.1364
359	1 mile below Lake Charles Landing	2.65	0.432	0.282	0.3671
360¾	Ludlow Landing	2.66	2.976	0.885	0.0809
362½	Foot of Zenor Tow Head	2.65	0.510	0.453	0.4763
363¼	Island No. 68	2.65	0.301	0.267	0.5570
366½	Beith Landing	2.65	0.386	0.356	0.5761
371¾	Island No. 69	2.65	0.508	0.451	0.4499
372	1 mile above Mason Landing	2.65	0.277	0.230	0.4414
372¾	Mason Landing	2.65	0.568	0.353	0.1600
375	Laconia Landing	2.63	1.721	0.446	0.0889
376¾	1½ miles below Laconia Landing	2.63	1.290	0.545	0.1314
378½	Island No. 70 Landing	2.65	0.290	0.271	0.5650
381	Opposite Henrico, Ark.	2.65	0.858	0.496	0.2384
382	½ mile above Scrubgrass Tow Head	2.65	0.268	0.242	0.5005
390½	1 mile above mouth of White River	2.65	0.291	0.200	0.3836
391½	Mouth of White River	2.65	0.247	0.205	0.4994
393	½ mile below Mouth of White River Landing	2.65	0.264	0.248	0.5127
394	1½ miles below White River gage	2.66	2.141	1.052	0.1370
395	1½ miles above Rosedale Landing	2.65	0.499	0.471	0.5208
396	Rosedale Landing	2.65	0.493	0.475	0.5229
396¼	Rosedale Landing	2.63	1.958	0.757	0.1536
397	1 mile below Rosedale, Miss.	2.65	21.415	27.032	0.3152
397¼	1 mile below Rosedale Landing	2.65	0.219	0.183	0.5405
397½	Head of Island No. 73	2.65	0.307	0.291	0.6104
397½A	Head of Island No. 73	2.65	0.647	0.414	0.3454
398	Foot of Island No. 73	2.65	0.603	0.503	0.5170
398¼	Foot of Island No. 73	2.65	0.256	0.228	0.3313
398½	Foot of Island No. 73	2.65	0.422	0.398	0.6279
399	½ mile above mouth of Arkansas River	2.65	0.257	0.239	0.6059
399¾	Mouth of Arkansas River	2.65	0.232	0.225	0.6360
401	Prentiss Landing	2.65	0.396	0.239	0.2657
401½	½ mile below Prentiss Landing	2.60	16.668	16.795	0.2130
402	Ozark Landing	2.62	8.420	6.209	0.1676
403	½ mile below Ozark Landing	2.69	23.773	27.100	0.4585
404	1 mile above Indian Point Landing	2.63	1.049	0.481	0.2122
404½	½ mile above Indian Point Landing	2.65	0.323	0.324	0.6887
406	Monterey Landing	2.65	0.256	0.244	0.5867
407½	Caulk Neck	2.62	†	†	†
410	1 mile below Holly Ridge Landing	2.65	0.289	0.269	0.6330
411½	½ mile above Niblett Landing	2.63	7.858	1.541	0.032
412½	Head of Island No. 76	2.62	6.536	1.573	0.0589
413½	Island No. 76	2.65	0.748	0.438	0.2469

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 41—Continued

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
416	Kentucky Landing	2.65	0.480	0.459	0.6005
419	Catfish Tow Head	2.65	0.459	0.348	0.412
420	Foot of Catfish Tow Head	2.65	0.407	0.387	0.6120
423	Island No. 77	2.65	0.384	0.300	0.4141
424½	Lucca Landing	2.64	†	†	†
425½	De Soto Landing	2.60	4.204	0.655	0.0555
426½	Chicora Landing	2.70	†	†	†
428	1 mile below Chicora Landing	2.65	0.428	0.420	0.5801
429½	Chicot Landing	2.65	0.533	0.481	0.5192
429¾	Chicot Landing	2.65	0.371	0.319	0.4907
430½	Eutaw Landing	2.65	12.190	12.237	0.3692
431½	Head of Choctaw Bar	2.65	0.809	0.587	0.3947
433A	Mound Crevasse	2.65	0.291	0.289	0.5410
433B	Mound Landing	2.62	3.282	0.500	0.0620
433½	½ mile below Mound Crevasse	2.63	1.292	0.486	0.1544
435½	2 miles above Arkansas City	2.65	0.336	0.327	0.5080
436¾	Arkansas City, Ark.	2.65	0.250	0.237	0.523
438½	1½ miles below Arkansas City, Ark.	2.65	0.339	0.299	0.4510
439½	2½ miles below Arkansas City, Ark.	2.65	0.288	0.284	0.3504
441	Eunice Landing	2.65	0.790	0.212	0.0582
441½	½ mile below Eunice Landing	2.65	0.539	0.467	0.4688
442½	Georgetown Crossing	2.65	0.410	0.388	0.6824
443½	Georgetown Tow Head	2.65	0.322	0.320	0.6859
447½	Ashbrook Point Landing	2.66	2.479	0.805	0.1140
449	Gaines Landing	2.65	0.402	0.324	0.4202
451½	Panther Forest Landing	2.69	†	†	†
452½	Linwood Neck	2.65	0.447	0.443	0.6742
454	Point Comfort Landing	2.78	†	†	†
454½	½ mile below Point Comfort Landing	2.62	6.622	5.508	0.1755
455½	1½ miles below Point Comfort Landing	2.65	0.431	0.409	0.6485
456½	Moss Lake Landing	2.65	0.405	0.365	0.5520
457½	Shadyside Landing	2.65	0.845	0.540	0.3080
459	3 miles above Tarpley Landing	2.60	10.247	5.097	0.0359
459¼	2 miles above Tarpley Landing	2.65	0.697	0.423	0.2201
460½	1½ miles above Tarpley Landing	2.65	0.703	0.565	0.3257
461½	½ mile above Tarpley Landing	2.65	0.479	0.480	0.5992
462	Tarpley Landing	2.62	6.356	1.520	0.0455
464	½ mile above Carter Point Landing	2.65	0.650	0.497	0.435
464¼	Carter Point Landing	2.65	0.404	0.355	0.5391
465½	Linwood Landing	2.65	0.601	0.364	0.2990
466	1½ miles above Luna Landing	2.65	0.305	0.289	0.648
466½	1 mile above Luna Landing	2.65	0.306	0.265	0.5371
468	1 mile below Luna, Ark.	2.65	0.513	0.400	0.2751
469½	1 mile above Upper Leland Landing	2.63	1.101	0.772	0.1382
470½	Upper Leland Landing	2.65	0.742	0.510	0.4053
472½	Leland Neck Cut-off	2.65	0.902	0.772	0.5030
474	Point Chicot Landing	2.65	0.506	0.489	0.6417
475	1 mile below Point Chicot Landing	2.65	0.445	0.441	0.6479
475¾	Lower side of Tarpley Neck	2.66	2.283	0.368	0.0721
476¼	Upper Side Point Chicot	2.65	0.391	0.371	0.683
477½	2½ miles above Greenville, Miss.	2.65	0.433	0.284	0.3591
479¾	Greenville, Miss.	2.65	0.599	0.389	0.3348
481	Lower end of Greenville, Miss.	2.65	0.277	0.269	0.6182
481¼	Lower end of Greenville, Miss.	2.66	8.782	5.083	0.0526
481¾	Lower end of Greenville, Miss.	2.63	5.547	0.563	0.0353
482	2 miles below Greenville, Miss.	2.65	0.295	0.282	0.6729
483	½ mile above Leland Neck Cut-off	2.65	0.385	0.367	0.6010
484	Leland Neck Cut-off	2.65	0.412	0.396	0.5985
484¼	Foot of Lagrange Tow Head	2.66	10.794	10.720	0.5833
484¾	Chute, back of Warfield Tow Head	2.66	2.642	1.575	0.214
485¼A	Warfield Tow Head	2.65	0.552	0.511	0.5867
485¼B	Chute, lower end of Warfield Tow Head	2.64	8.429	8.850	0.2732
486	Warfield Point	2.65	0.483	0.459	0.5449
487	Leland Bar	2.65	0.604	0.519	0.3596
488½A	Bend, Upper end of Vaucluse Bar	2.65	0.303	0.295	0.653
488½B	Upper end of Vaucluse Bar	2.65	0.556	0.507	0.5470
489	Head of Vaucluse Bar	2.65	0.429	0.369	0.5113
489¼	Vaucluse Landing	2.68	†	†	†
489½	Vaucluse Landing	2.65	0.319	0.285	0.5995
489¾	Vaucluse Bar	2.63	1.991	0.482	0.1011
490	Back of Vaucluse Bar	2.65	0.285	0.271	0.6747
490½A	Foot of Vaucluse Bar	2.65	0.347	0.333	0.6081
490½B	Foot of Vaucluse Bar	2.65	0.971	0.430	0.2098
491	Sunnyside Landing	2.65	0.334	0.310	0.6038
491¼	Sunnyside Landing	2.65	0.323	0.308	0.6354

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 41—Continued

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
492½	½ mile above Refuge Landing	2.65	0.287	0.205	0.4119
493½	½ mile below Refuge Landing	2.62	6.472	3.174	0.0957
494	1 mile below Refuge Landing	2.62	6.816	3.032	0.0606
494½	1½ miles below Refuge Landing	2.65	0.830	0.439	0.2682
496	2 miles above Lakeport Landing	2.65	0.339	0.335	0.6423
497	1½ miles above Lakeport Landing	2.65	0.577	0.382	0.3044
498¾	Lakeport Landing	2.65	0.268	0.241	0.4845
500	1 mile below Seven Oaks Landing	2.65	0.803	0.539	0.3531
501½	1½ miles above Longwood Landing	2.60	8.797	3.652	0.0492
502	½ mile above Longwood Landing	2.65	0.511	0.475	0.5554
503½	Stella Landing	2.65	0.463	0.391	0.4654
505½	Fanny Bullitt Tow Head	2.65	0.449	0.361	0.3784
507	Point Moore Landing	2.65	0.337	0.319	0.5739
508¾	Mosswood Landing	2.65	0.566	0.494	0.4727
510½	Worthington Point	2.65	0.455	0.397	0.5533
512¼	1 mile below Grand Lake Landing	2.65	0.271	0.253	0.5063
513	1 mile above Head of Cracraft Tow Head	2.65	0.253	0.246	0.6295
514	Head of Cracraft Tow Head	2.61	27.601	27.806	0.6752
514½	Leota Landing	2.66	7.192	0.405	0.0222
515	Princeton Landing	2.65	0.476	0.362	0.4395
517	Foot of Cracraft Tow Head	2.63	1.018	0.287	0.1142
518	Carolina Landing	2.63	1.181	0.565	0.2068
519½	1½ miles below Carolina Landing	2.63	1.763	0.568	0.1307
520½	2 miles above Pilcher Landing	2.65	0.369	0.356	0.6160
521¾	Foot of Ashton Bar	2.65	0.331	0.282	0.5600
522½	Foot of Ashton Tow Head	2.65	0.404	0.377	0.5544
523½	Pittman Island Landing	2.65	0.246	0.173	0.3128
526	Foot of Pittman Island	2.65	0.429	0.357	0.4212
526¾	Chute of Duncansby Tow Head	2.65	0.278	0.252	0.6212
527¼	Head of Duncansby Tow Head	2.65	0.255	0.249	0.7099
528	Valewood Landing	2.65	0.281	0.258	0.6525
530	Foot of Duncansby Tow Head	2.65	0.312	0.296	0.6477
530½	Wild Cat Tow Head	2.65	0.280	0.259	0.594
532	Wilson Point Landing	2.65	0.245	0.241	0.6870
533½	Head of Island No. 93	2.65	0.380	0.296	0.4440
536	1 mile above Baleshed Tow Head	2.65	0.531	0.461	0.4681
537	Head of Baleshed Tow Head	2.67	5.635	0.610	0.0354
537½	½ mile below Baleshed Tow Head	2.65	0.484	0.463	0.5786
538½	Old Channel, back of Baleshed Tow Head	2.65	0.564	0.451	0.4230
538¾	Old Channel, back of Baleshed Tow Head	2.63	1.616	0.486	0.1297
539A	Baleshed Landing	2.65	0.705	0.482	0.3541
539B	Old Channel, opposite foot of Baleshed Tow Head	2.65	0.287	0.268	0.6052
539¼	Old Channel, foot of Baleshed Tow Head	2.65	0.292	0.276	0.6043
539¾	Old Channel, head of Stack Island	2.65	0.212	0.180	0.5433
540	Old Channel	2.65	0.465	0.432	0.5711
540¼	Head of Stack Island	2.63	1.733	0.501	0.1245
540¼A	Old Channel, ½ mile above Ben Lomond Landing	2.65	0.853	0.551	0.3410
541¼	Old Channel, ½ mile above Ben Lomond Landing	2.65	0.252	0.247	0.6936
541½	Ben Lomond Landing	2.65	0.238	0.241	0.5276
543¾	2 miles below Lake Providence, La.	2.65	0.403	0.390	0.6320
546¼	Head of Ajax Bar	2.65	0.408	0.392	0.6620
548	Foot of Ajax Bar	2.65	0.768	0.364	0.2039
548½	Foot of Ajax Bar	2.65	17.253	20.465	0.3041
549	Fitler Bend Crossing	2.63	1.473	0.478	0.1336
549½	Opposite Point Lookout Landing	2.65	0.338	0.337	0.6419
551	Fitler, Miss.	2.63	1.589	0.638	0.1676
554	Hay Landing	2.65	0.534	0.512	0.6092
555	Head of Cottonwood Bar	2.60	4.979	0.680	0.0538
556	Shiloh Landing	2.65	0.341	0.273	0.4376
558½	Cottonwood Landing	2.65	0.408	0.356	0.4321
560	1½ miles above Goodrich Landing	2.65	0.376	0.303	0.4728
560½	1 mile above Goodrich Landing	2.65	0.429	0.335	0.4346
563½	Dogtail Landing	2.65	0.524	0.480	0.4907
565	Salem Landing	2.63	1.400	0.559	0.1849
566½	Upper side of Willow Point	2.65	0.441	0.390	0.5645
568	Willow Point Landing	2.63	1.066	0.582	0.2401
569½	1 mile above Chotard Landing	2.65	0.600	0.337	0.2945
570¾	Chotard Landing	2.71	†	†	†
572½	Bellevue, Miss.	2.65	0.406	0.463	0.5655
573½	1 mile above Brunswick Landing	2.62	2.300	0.554	0.1021
575	Brunswick Landing	2.69	22.533	22.639	0.7264
575½	½ mile below Brunswick Landing	2.66	17.832	20.484	0.2832

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 41—Continued

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF MISSISSIPPI RIVER*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
577	2 miles below Brunswick Landing	2.63	1.230	0.571	0.2182
578	1 mile above Omega, La.	2.65	0.402	0.379	0.5623
579	Omega, La.	2.65	0.444	0.357	0.4387
580	Foot of Island No. 102	2.65	0.493	0.458	0.5023
581	Omega Landing	2.61	12.406	11.081	0.1273
581¾	Morancy Landing	2.65	0.519	0.508	0.5423
583	Millikens Bend Landing	2.62	6.685	0.767	0.0401
583½	½ mile below Millikens Bend Landing	2.62	3.164	0.590	0.0784
586¼	½ mile above Cabin Teele Landing	2.63	1.149	0.443	0.1714
586¾	Cabin Teele Landing	2.65	0.752	0.504	0.3314
588	Foot of Forest Home Tow Head	2.62	7.614	0.810	0.0350
589	1 mile above Halpino Landing	2.65	0.414	0.390	0.6090
590	Halpino Landing	2.60	†	†	†
591	Paw Paw Landing	2.65	0.470	0.374	0.4467
593	Browns Point Landing	2.65	0.388	0.320	0.4718
595	Nebraska Landing	2.65	0.649	0.493	0.3769
595¼	Lower side of Browns Point	2.63	1.273	0.307	0.0984
595½	Youngs Point Landing	2.63	8.612	0.890	0.0325
595½A	Opposite Youngs Point Landing	2.66	2.072	0.200	0.0405
595¾	Youngs Point Landing	2.64	20.140	23.011	0.3303
595¾A	Opposite Youngs Point Landing	2.65	0.179	0.173	0.6265
596¼	½ mile below Youngs Point Landing	2.62	6.291	0.625	0.0344
596½	¾ miles below Youngs Point Landing	2.62	18.493	18.010	0.6722
596½A	2 miles above Kings Point Landing	2.65	0.636	0.522	0.4714
596¾	1¾ miles above Kings Point Landing	2.65	0.348	0.335	0.6294
597	1½ miles below Youngs Point Landing	2.62	6.127	0.472	0.0233
597A	1½ miles above Kings Point Landing	2.65	0.186	0.181	0.6887
597½	2 miles below Youngs Point Landing	2.63	1.168	9.748	0.3095
597½A	1 mile above Kings Point Landing	2.65	0.359	0.343	0.6105
598	½ mile above Kings Point Landing	2.65	0.250	0.235	0.6056
598¼	2 miles above Delta Landing	2.62	3.659	0.721	0.0755
598½	1¾ miles above Delta Landing	2.63	1.452	0.508	0.1619
598½A	Kings Point Landing	2.65	0.239	0.210	0.5664
599	1 mile above Delta Landing	2.63	1.478	0.422	0.1215
599A	½ below Kings Point Landing	2.65	0.211	0.194	0.6388
599½	½ mile above Delta Landing	2.65	0.896	0.581	0.3385
599½A	1 mile below Kings Point Landing	2.65	0.402	0.386	0.5622
599¾	1¼ miles below Kings Point Landing	2.65	0.368	0.328	0.2993
600	Delta Landing	2.65	0.438	0.398	0.5743
600A	Opposite Delta Landing	2.65	0.436	0.409	0.5883
600½	½ mile below Delta Landing	2.65	0.277	0.261	0.6469
601⅔	½ mile above mouth of Yazoo River	2.65	0.263	0.252	0.6719
601¾	Vicksburg, Miss.	2.65	0.299	0.269	0.5907
602½	½ mile above Vicksburg bridge	2.65	0.190	0.173	0.5841
603	Vicksburg bridge	2.62	10.060	0.466	0.0108
604¾	1½ miles below Vicksburg bridge	2.65	0.565	0.505	0.5113
605¾	½ mile above head of Racetrack Tow Head	2.65	0.258	0.251	0.6897
606A	Head of Racetrack Tow Head	2.65	0.233	0.235	0.7116
606	Head of Racetrack Tow Head	2.63	0.524	0.509	0.6486
606½	Head of Reid-Bedford Bend	2.65	0.248	0.246	0.711
606¾	Racetrack Tow Head Chute	2.65	0.379	0.365	0.6420
607½	Middle of Reid-Bedford Bend	2.65	0.213	0.198	0.6138
608	Racetrack Tow Head Chute	2.65	0.414	0.345	0.4705
608¼	Racetrack Tow Head Chute	2.65	0.440	0.376	0.4997
608½	Foot of Reid-Bedford Bend	2.65	0.324	0.307	0.4674
609	Back of foot of Racetrack Tow Head	2.65	0.268	0.258	0.6482
609½	Foot of Racetrack Tow Head	2.66	2.062	0.467	0.0866
610	½ mile below foot of Racetrack Tow Head	2.65	0.423	0.359	0.4889
611	Taylor Landing	2.65	0.377	0.358	0.6385
612	1 mile below Taylor Landing	2.63	1.059	0.543	0.2352
612¼	1½ miles above Diamond Point Cut-off	2.65	0.365	0.333	0.5285
613	Oak Bend Landing	2.65	0.422	0.400	0.6011
614	Dredge-Cut, Diamond Point Cut-off	2.65	0.226	0.235	0.6728
614A	Upper side of Dredge Cut, Diamond Point Cut-off	2.65	0.139	0.085	0.1587
615	½ mile below head of Diamond Point Cut-off	2.65	0.401	0.384	0.5633
617	1½ miles above Hodge Landing	2.65	0.432	0.393	0.4977
619	Upper side of Diamond Point	2.67	5.309	0.581	0.0308
620	Diamond Point	2.69	†	†	†
625	Palmyra Lake	2.63	1.537	0.695	0.1879
628	Newtown Bend	2.65	0.164	0.152	0.5628
630	Togo Landing	2.65	0.687	0.473	0.3373
631	Ursino Landing	2.65	0.318	0.295	0.6022
631A	1 mile above Burns Landing, Palmyra Lake	2.65	0.416	0.390	0.6171
633	Point Pleasant	2.65	0.299	0.194	0.3218

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 41—Continued

Physical Data and Various Constants of Material from Bed of Mississippi River*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
633A	Point Pleasant, Palmyra Lake	2.65	0.658	0.509	0.4409
635	Buckridge Landing	2.65	0.419	0.402	0.6360
638	Mouth of Big Black River	2.71	†	†	†
639	Yucatan Bend	2.65	0.339	0.322	0.4848
640	Yucatan Landing	2.69	0.092	0.090	0.4409
642	Ship Bayou Landing	2.65	0.123	0.118	0.5018
643	1 mile below Ship Bayou Landing	2.70	†	†	†
647	1 mile below Hard Times Landing	2.68	†	†	†
648	Lower end of Yucatan Cut-off	2.65	0.417	0.392	0.5901
650	Grand Gulf Landing	2.65	0.268	0.241	0.5098
657	Head of Bondurant Tow Head	2.66	7.966	1.900	0.0382
659	Bruinsburg Landing	2.65	0.322	0.273	0.5510
659A	Bondurant Chute	2.65	0.406	0.378	0.5569
662	St. Joseph Upper Landing	2.65	0.644	0.417	0.2535
666	Rodney Island	2.65	0.642	0.471	0.3844
670	Upper end of Gilliam Chute	2.65	8.483	0.769	0.0269
671	Bieller Landing	2.65	0.352	0.323	0.5895
676	Ashland Landing	2.64	5.556	0.580	0.0372
683	1½ miles below L'Argent Landing	2.65	0.729	0.498	0.3038
687	1 mile below Lake St. John Landing	2.65	0.367	0.345	0.5728
689	½ mile above Giles Bend Cut-off	2.65	0.240	0.206	0.5269
693	Cowpen Point Landing	2.65	0.365	0.323	0.4949
696	Back of Giles Middle Ground Island	2.65	0.327	0.319	0.6488
701	Lower side of Cowpen Point	2.65	0.808	0.564	0.4062
708½	3 miles below Natchez, Miss.	2.65	0.831	0.501	0.2868
709	Whitehall Landing	2.65	0.270	0.259	0.6777
710	Carthage Point	2.65	0.229	0.221	0.6335
710¾	Head of Natchez Island Tow Head	2.66	2.997	0.580	0.0809
711	Natchez Island Tow Head Chute	2.65	0.249	0.239	0.6074
712¼	Natchez Island Tow Head	2.66	2.439	0.465	0.0790
713	Foot of Natchez Island Chute	2.66	0.339	0.325	0.6174
713A	Natchez Island Chute	2.66	0.225	0.227	0.6485
715¾	Warnicott Landing	2.65	0.284	0.254	0.5277
716¼	Warnicott Landing	2.66	2.836	0.438	0.059
718½	Destruction Landing	2.65	0.329	0.300	0.5863
720	Esperance Landing	2.65	0.500	0.373	0.4045
722	Hutchins Landing	2.65	0.362	0.345	0.5685
723½	½ mile below upper end of Glasscock Cut-off	2.65	0.199	0.160	0.4338
725½	½ mile below Briar Landing	2.65	0.596	0.482	0.4587
728½	Deerpark, La.	2.65	0.148	0.141	0.6149
733	2 miles above Fairview Landing	2.65	0.492	0.343	0.3465
736	Corena Landing	2.65	0.302	0.293	0.6086
740	1 mile below Gaines Landing	2.65	0.392	0.323	0.4784
742	Eureka Landing	2.65	0.796	0.562	0.3704
745	Bougere Landing	2.65	0.308	0.305	0.6280
749	Union Point Landing	2.65	0.794	0.552	0.3809
752	Artonish Landing	2.65	0.184	0.179	0.7224
756½	1½ miles below Black Hawk Landing	2.65	0.152	0.066	0.1218
757	2 miles below Black Hawk Landing	2.69	†	†	†
758½	1½ miles above Stamps Landing	2.65	0.505	0.489	0.5076
759½	1 mile above Stamps Landing	2.65	0.269	0.259	0.6877
760	Stamps Landing	2.65	0.336	0.337	0.6915
760¼	Stamps Landing	2.65	0.200	0.191	0.6757
760½	Knox Landing	2.65	0.411	0.384	0.5880
760¾	Knox Landing	2.62	1.442	0.549	0.1783
761½	1 mile above Point Breeze	2.65	0.182	0.173	0.6529
763	Fort Adams Landing	2.65	0.144	0.134	0.5782
766	1 mile above Tarbert Landing	2.65	0.918	0.508	0.2704
767	Tarbert Landing	2.65	0.320	0.305	0.6128
767½	Tarbert Landing	2.65	5.984	0.562	0.0354
768	1 mile below Tarbert Landing	2.65	0.148	0.154	0.5903
770	1½ miles above mouth of Old River	2.65	0.983	0.369	0.1536
770½	1 mile above mouth of Old River	2.65	0.675	0.451	0.3370
771	½ mile above mouth of Old River	2.65	0.516	0.438	0.4720
771½	Angola Landing	2.63	1.107	0.459	0.1575
773½	2 miles below mouth of Old River	2.65	0.181	0.144	0.4540
777½	Tucker Landing	2.66	2.834	0.507	0.0694
785¾	Head of Tunica Island	2.65	0.437	0.351	0.3954
786¾	1 mile below head of Tunica Island	2.65	0.379	0.260	0.3671
787	1½ miles below head of Tunica Island	2.65	0.662	0.374	0.2687
800	Boles Point	2.65	0.226	0.228	0.7016
807	Bayou Sara, La.	2.65	0.433	0.406	0.4871
814	1 mile above Grand Bay Landing	2.65	0.257	0.249	0.7077
826½	Foot of Profit Island Chute	2.65	0.230	0.234	0.7081
835½	Mulatto Bend Landing	2.65	0.3[illegible]	0.359	0.5271
838	1 mile below Scott Bluff, La.	2.69	†	†	†

*These data concern the same samples of bed material listed in Table 39.

**See page 5 for discussion of these values.

†Not computed for silt and clay samples. See Tabie 39 for size distribution.

TABLE 41—Continued

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF MISSISSIPPI RIVER*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
840½	2 miles above Baton Rouge, La.	2.65	0.302	0.285	0.6430
842	Baton Rouge, La.	2.65	0.422	0.390	0.5655
847½	Brushly Landing	2.65	0.314	0.312	0.6556
860	3 miles above Plaquemine, La.	2.65	0.222	0.220	0.6752
861	2 miles above Plaquemine, La.	2.65	0.265	0.257	0.7064
867½	Granada Landing	2.65	0.209	0.199	0.6441
882½	Claiborae Landing	2.65	0.322	0.312	0.6271
896	Donaldsonville, La.	2.65	0.299	0.288	0.6546
911	2 miles above College Point	2.65	0.184	0.192	0.4941
917	2 miles below College Point	2.65	0.215	0.211	0.6667
924	Gramercy, La.	2.65	0.213	0.204	0.6665
937	Bonnet Carre' Point	2.65	0.194	0.195	0.5861
967½	New Orleans, La.	2.65	0.219	0.210	0.6653
968½	Opposite Westwego, La.	2.65	0.169	0.171	0.7273
972¼	New Orleans Harbor, opposite Harvey, La.	2.66	0.318	0.328	0.6872
977	Just above Industrial Canal	2.63	0.009	0.001	†
979½	Just above Quarantine Station	2.66	0.241	0.238	0.6394
983	Meraux, La.	2.63	0.234	0.237	0.7153
986¾	Just below Lake Borgne Canal	2.66	0.168	0.188	†
990¼	Braithwaite, La.	2.64	0.271	0.265	0.6156
992¾	Shingle Point	2.73	0.019	0.001	†
994½	Belle Chasse, La.	2.65	0.220	0.220	0.6645
997¾	1½ miles below Concession, La.	2.63	0.022	0.004	†
999½	Bertrandville, La.	2.64	0.179	0.174	0.6563
1001½	Lower end, Jesuits Bend	2.69	0.005	0.001	†
1004¼	Belair, La.	2.65	0.211	0.204	0.6729
1007	2 miles below Belair, La.	2.64	0.188	0.179	0.6576
1010	Poverty Point	2.65	0.110	0.115	0.4665
1014¼	Deer Range, La.	2.65	0.182	0.178	0.6888
1017¼	Pointe Celeste	2.64	0.173	0.171	0.6938
1019	Woodland, La.	2.66	0.155	0.156	0.6939
1021¼	Pointe a la Hache, La.	2.66	0.206	0.202	0.6328
1023½	Bohemia, La.	2.65	0.193	0.185	0.6551
1027¼	Happy Jack, La.	2.62	0.164	0.171	0.5187
1030	Freeport Sulphur Company dock	2.67	0.182	0.176	0.6741
1033	1 mile below Home Place, La.	2.66	0.228	0.234	0.6752
1037	Bayou Lamoque	2.71	0.070	0.004	†
1040¾	Empire, La.	2.65	0.182	0.179	0.7038
1044	Buras, La.	2.64	0.196	0.187	0.6813
1047½	Triumph, La.	2.62	0.190	0.177	0.6017
1050	Fort Jackson, La.	2.70	0.156	0.152	0.6541
1052½	Boothville, La.	2.64	0.158	0.158	0.6680
1057	1½ miles above Venice, La.	2.72	0.086	0.093	†
1058¼	Venice, La.	2.69	0.008	0.002	†
1060	Just below The Jump	2.66	0.004	0.001	†
1062¼	3½ miles above Cubits Gap	2.66	0.179	0.173	0.6439
1064	2¼ miles above Cubits Gap	2.69	0.047	0.006	†
1065½	1 mile above Cubits Gap	2.67	0.160	0.161	0.6860
1066	Upper side Cubits Gap	2.64	0.161	0.165	0.7182
1066¾	Lower side Cubits Gap	2.63	0.052	0.021	†
1067¾	Pilottown, La.	2.68	0.043	0.005	†
1069	¾ mile above Head of Passes	2.66	0.003	0.001	†
1069½	Head of Passes	2.66	0.182	0.160	0.4995
	South Pass				
1070¾	1 mile below Head of Passes	2.63	0.003	0.001	†
1071	1¼ miles below Head of Passes	2.72	0.020	0.001	†
1072	2¼ miles below Head of Passes	2.66	0.137	0.134	0.5900
1072¾	3 miles below Head of Passes	2.69	0.112	0.117	†
1075½	5½ miles above Port Eads, La.	2.66	0.162	0.162	0.6703
1077	4 miles above Port Eads, La.	2.72	0.018	0.002	†
1079	2 miles above Port Eads, La.	2.66	0.128	0.126	0.6986
1080½	½ mile above Port Eads, La.	2.65	0.135	0.129	0.6683
1082	1 mile below Port Eads, La.	2.67	0.027	0.006	†
1083¾	Gulf of Mexico, ½ mile from jetties	2.69	0.030	0.024	†
1084¼	Gulf of Mexico, 1 mile from jetties	2.76	0.054	0.007	†
1085	Gulf of Mexico, at whistle buoy, 1¾ miles from jetties	2.68	0.020	0.003	†
	South Pass Bar				
1083½	In Gulf on bar, ½ mile southwest of jetties	2.67	0.133	0.131	0.599
1083¾	In Gulf on bar, ¼ mile west of jetties	2.67	0.119	0.121	0.715

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 41—Continued

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF MISSISSIPPI RIVER*

Miles Below Cairo	Locality	Specific Gravity	Mean Grain Diameter mm **	Median Grain Diameter mm **	Uniformity Modulus M **
	Southwest Pass				
1069½	Head of Passes	2.65	0.166	0.160	0.604
1070¼	½ mile below Head of Passes	2.63	0.040	0.006	†
1070¾	1 mile below Head of Passes	2.68	0.122	0.124	0.566
1073	3 miles below Head of Passes	2.78	0.041	0.002	†
1076½	2½ miles below Joseph Bayou	2.67	0.004	0.001	†
1082	3 miles above Burrwood, La.	2.65	0.171	0.172	0.721
1083½	1½ miles above Burrwood, La.	2.69	0.157	0.163	†
1085	Burrwood, La.	2.71	0.093	0.104	†
1085¾	¾ mile below Burrwood, La.	2.72	0.052	0.004	†
1088½	1½ miles above end of jetties	2.74	0.045	0.004	†
1090	Mouth of river at end of jetties	2.60	0.129	0.117	0.505
1091	In Gulf of Mexico, 1 mile from jetties	2.73	0.038	0.041	†
1091¾	In Gulf, near whistle buoy, 1¾ miles from jetties	2.64	0.057	0.024	†
	Southwest Pass Bar				
1090½	In Gulf on bar, ½ mile southwest of jetties	2.68	0.086	0.068	†
	Pass a L'Outre				
1069½	½ mile below head	2.64	0.135	0.130	0.635
1069½	1 mile below head	2.67	0.168	0.160	0.547
1069½	1¾ miles below head	2.65	0.188	0.180	0.517
	Cubits Gap				
1066¼	¼ mile east of east bank, Mississippi River	2.59	0.022	0.001	†
1066½	Head of Main Pass	2.67	0.010	0.002	†
1066½	Head of Octave Pass	2.67	0.048	0.014	†
1066½	From head of island between Octave & Brant Passes	2.64	0.038	0.024	†
1066¾	Head of Brant Pass	2.65	0.134	0.131	0.586
1066¾	Head of Raphael Pass	2.64	0.130	0.134	0.533
1066¾	¼ mile east of light (lower side of gap)	2.62	0.033	0.004	†
1066½	½ mile east of east bank, Mississippi River (center of gap)	2.66	0.141	0.142	0.556
	The Jump				
1059¼	¼ mile below head	2.65	0.317	0.025	†
1059¼	¾ mile below head	2.71	0.049	0.004	†
	Baptiste Collette Canal				
1058¼	At head	2.62	0.028	0.010	†
1058¼	½ mile east of head	2.48	0.009	0.001	†

*These data concern the same samples of bed material listed in Table 39.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 39 for size distribution.

TABLE 42

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS*

Miles from Cairo	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Ohio River.				
+1	Above Cairo	2.62	12.328	11.788	0.2693
−1	Below Cairo	2.60	4.634	3.957	0.2427

Miles above Mouth of Black River	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Black River.				
½	Delhoste Landing	2.69	†	†	†
1	Acme, La.	2.67	†	†	†
2	Acme Landing	2.72	†	†	†
3	1 mile above Acme Landing	2.68	0.102	0.065	0.1913
4	1 mile below Palmetto Landing	2.69	†	†	†

Miles above Junction of Old and Miss. Rivers	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Red River.				
9	Naples, La.	2.77	†	†	†
10	Mouth Upper Old River	2.69	†	†	†
12	2 miles above Upper Old River	2.69	†	†	†
15½	3 miles below Natchitoches Bayou	2.70	†	†	†
20	1 mile above Natchitoches Bayou	2.68	†	†	†
23	Bayou Cocodrie (East Bank Red River)	2.69	†	†	†
23A	Bayou Cocodrie	2.70	†	†	†
25½	2½ miles above Bayou Cocodrie	2.66	0.059	0.046	0.2404
29	1 mile below Five Mile Bayou	2.69	†	†	†
30½	½ mile above Five Mile Bayou	2.65	0.154	0.192	0.1875
33½	Two Mile Bayou	2.66	0.061	0.065	0.3727
34½	1 mile below mouth of Black River	2.66	0.107	0.109	0.5858
35	½ mile below mouth of Black River	2.65	0.174	0.168	0.5836
35½	Mouth of Black River	2.65	0.120	0.107	0.4913
36	½ mile above mouth of Black River	2.65	0.284	0.254	0.5196
36½	1 mile above mouth of Black River	2.65	0.094	0.102	0.4708

Miles above Mouth of Old River	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Old River.				
¼	Opposite Angola Landing	2.65	0.757	0.387	0.2571
½	Opposite Angola Landing	2.65	0.456	0.449	0.6525
1	¾ mile east of Sugar House Chute	2.78	†	†	†
1¼	½ mile east of Sugar House Chute	2.63	0.374	0.362	0.6717
1½	¼ mile east of Sugar House Chute	2.65	0.332	0.295	0.5781
1¾	Sugar House Chute	2.65	0.266	0.250	0.6001
3	½ mile west of T. & P. Railroad bridge	2.65	0.462	0.351	0.3198
4	1½ miles west of T. & P. Railroad bridge	2.65	0.530	0.490	0.4600
5	2½ miles east of Barbre Landing	2.65	0.159	0.164	0.3433
6	1½ miles east of Barbre Landing	2.65	0.218	0.199	0.5655
7	½ mile east of Barbre Landing	2.70	†	†	†
7½	Barbre Landing and Junction with Atchafalaya River	2.65	0.232	0.239	0.7014

*These data concern the same samples of bed material listed in Table 40.
**See page 5 for discussion of these values.
†Not computed for silt and clay samples. See Table 40 for size distribution.

TABLE 42—Continued

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS*

Miles below head of Atchafalaya River	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Atchafalaya River.				
½	½ mile below Barbre Landing	2.65	0.576	0.374	0.3215
2	2 miles below Barbre Landing	2.77	†	†	†
3	2 miles above Simmesport, La.	2.71	†	†	†
3½	1½ miles above Simmesport, La.	2.65	0.232	0.238	0.321
5½	Simmesport, La.	2.65	0.685	0.181	0.0545
6½	1 mile below Simmesport, La.	2.65	0.201	0.196	0.3287
8	1½ miles above Odenburg, La.	2.65	0.298	0.280	0.4590
9½	Odenburg, La.	2.65	0.395	0.350	0.3136
10	½ mile below Odenburg, La.	2.65	0.374	0.380	0.4977
12¾	McCrea Landing	2.69	†	†	†
13	McCrea Landing	2.65	0.299	0.297	0.5645
15½	Woodside, La.	2.65	0.364	0.358	0.2901
16¾	Burlong Landing	2.68	†	†	†
17½	1 mile above Hicks Landing	2.69	†	†	†
18¾	Hicks Landing	2.65	0.304	0.298	0.5589
20¾	Bayou Current	2.72	†	†	†
22¾	1½ miles above Baberton Landing	2.69	†	†	†
23	1¼ miles above Baberton Landing	2.78	†	†	†
24½	Baberton Landing	2.65	7.773	6.072	0.0824
24¾	Baberton Landing	2.65	0.486	0.450	0.5203
27½	1½ miles below Elba, La	2.65	0.419	0.390	0.3170
29	1 mile above Melville, La.	2.76	†	†	†
32¼	2 miles below Melville, La.	2.69	†	†	†
32¼A	2 miles below Melville, La.	2.65	0.338	0.221	0.1255
33	2½ miles below Melville, La.	2.69	†	†	†
33½	3 miles below Melville, La.	2.65	1.159	0.868	0.1914
36½	5½ miles above Krotz Springs, La.	2.65	0.348	0.309	0.2654
37	5 miles above Krotz Springs, La.	2.72	†	†	†
39	3 miles above Krotz Springs, La.	2.55	0.247	0.268	0.1315
39½	2½ miles above Krotz Springs, La.	2.72	†	†	†
41	½ mile above highway bridge	2.69	†	†	†
42¾	½ mile below Krotz Springs, La.	2.70	†	†	†
45	3 miles below Krotz Springs, La.	2.71	†	†	†
48¾	1 mile above Bayou Courtableau	2.71	†	†	†
50½	Bayou Courtableau	2.65	0.251	0.267	0.2596
53½	3 miles below Bayou Courtableau	2.69	†	†	†
56	1 mile above Alabama Bayou	2.65	0.301	0.287	0.5522
58½	3 miles above Atchafalaya, La.	2.70	†	†	†
60¾	½ mile above Atchafalaya, La.	2.71	†	†	†
63¼	2 miles below Atchafalaya, La.	2.65	0.525	0.483	0.2944
64¼	½ mile below head Butte La Rose Cut	2.65	0.484	0.511	0.3546
65	2 miles above Butte La Rose, La.	2.65	0.485	0.476	0.6394
66¼	1 mile above Butte La Rose, La.	2.69	†	†	†
67½	½ mile below Butte La Rose, La.	2.70	†	†	†
	Little Atchafalaya River.				
68	¼ mile below head Little Atchafalaya River.	2.70	†	†	†
69	1 mile below head Little Atchafalaya River.	2.68	†	†	†
70½	¾ mile above lower end Little Atchafalaya River.	2.65	0.467	0.472	0.5729
	Upper Grand River.				
68¾	¾ mile above lower end Butte La Rose Cut.	2.69	†	†	†
69¼	¼ mile above lower end of Butte La Rose Cut	2.65	0.279	0.259	0.6140
70¼	¾ mile below lower end of Butte La Rose Cut	2.65	1.519	0.552	0.1694
72	¼ mile below Bayou La Rompe	2.70	†	†	†
73	1½ miles below Bayou La Rompe	2.65	0.297	0.285	0.6397
73¾	2 miles below Bayou La Rompe	2.65	0.302	0.300	0.6100
76¼	½ mile above Big Tensas Bayou	2.65	0.230	0.233	0.6813
79	½ mile above Little Tensas Bayou	2.65	0.192	0.185	0.6498
82	2½ miles below Little Tensas Bayou	2.65	0.155	0.158	0.6648
85	1 mile above Bayou Maringouin	2.65	0.127	0.127	0.3470
88½	2½ miles below Bayou Maringouin	2.66	0.155	0.156	0.6816
91	3½ miles above Bayou Plaquemine	2.67	†	†	†
93½	1 mile above Bayou Plaquemine	2.67	†	†	†
94	½ mile above Bayou Plaquemine	2.70	†	†	†

*These data concern the same samples of bed material listed in Table 40.
**See page 5 for discussion of values.
†Not computed for silt and clay samples. See Table 40 for size distribution.

TABLE 42—Continued

PHYSICAL DATA AND VARIOUS CONSTANTS OF MATERIAL FROM BED OF TRIBUTARY AND OUTLET RIVERS*

Miles below head of Atchafalaya River	Locality	Specific Gravity	Mean Grain Diameter mm**	Median Grain Diameter mm**	Uniformity Modulus M**
	Lower Grand River.				
98	2 miles above Bayou Sorrel	2.65	0.142	0.151	0.2167
104	4 miles below Bayou Sorrel	2.68	†	†	†
	Atchafalaya River.				
	(Lower Grand River Route)				
111	Chopin Chute	2.71	†	†	†
118	Bay Natchez	2.67	†	†	†
132½	Belle River	2.73	†	†	†
139½	Bayou Long	2.42††	†	†	†
141	Bayou Long	2.65	†	†	†
143	Flat Lake	2.60	†	†	†
147½	Berwick Bay	2.68	†	†	†
	(Bayou La Rompe, Lake Chicot, and Grand Lake Route)				
71	¼ mile below head of Bayou La Rompe	2.65	0.354	0.325	0.4851
72	Bayou La Rompe, ½ mile above Rycade	2.65	0.354	0.337	0.5832
72½	Rycade	2.65	1.083	0.413	0.1680
73¾	Bayou La Rompe, 1 mile above Lake Long	2.65	0.413	0.383	0.5771
74½	Bayou La Rompe, ½ mile above L'Embarras	2.65	0.397	0.380	0.6088
76	Bayou La Rompe, 1 mile below L'Embarras	2.65	0.382	0.368	0.6363
76½	Bayou La Rompe, ½ mile above Big Tensas Bayou	2.65	0.389	0.376	0.6072
78	Bayou La Rompe at Logan Chute	2.65	0.258	0.249	0.6493
79½	Bayou La Rompe, foot of Nigger Chute	2.65	0.283	0.273	0.6604
79¾	Bayou La Rompe, foot of Splice Island Cut-off Chute	2.65	0.256	0.248	0.6157
82	Lake Mongoulois, 1 mile above Bayou Chene	2.65	0.262	0.257	0.6489
86	Big Bayou Chene	2.65	0.217	0.215	0.6739
88	Upper end of Lake Chicot	2.71	†	†	†
89	Middle of Lake Chicot	2.44††	†	†	†
90¾	Lake Chicot, 1 mile above Hog Island	2.61††	†	†	†
92¾	Keel Boat Pass	2.62††	†	†	†
95	Grand Lake, 1½ miles below Keel Boat Pass	2.70	†	†	†
98	Grand Lake at Pigeon Point	2.69	†	†	†
99½	Grand Lake, 1½ miles above Big Pigeon Bayou	2.70	†	†	†
104	Grand Lake, 3 miles below Big Pigeon Bayou	2.64	†	†	†
107½	Grand Lake, opposite Blue Point	2.57††	†	†	†
110½	Grand Lake, ½ mile above Cypress Island	2.69	†	†	†
114	Six Mile Lake	2.68	†	†	†
119	Six Mile Lake at lower end Riverside Pass	2.71	†	†	†
	(Bayou L'Embarras, Lake Fausse Point, and Grand Lake Route)				
75½	Bayou L'Embarras, ½ mile below Bayou La Rompe	2.65	0.435	0.429	0.6278
76	Bayou L'Embarras, 1 mile below Bayou La Rompe	2.65	0.401	0.385	0.6509
82	Lake Rond at Bayou Crocodile	2.65	0.302	0.297	0.6437
83	Lake Rond at Bayou Grand Gueule	2.69	†	†	†
84½	Lake Rond, 2 miles above Lake Fausse Point	2.65	0.253	0.243	0.6528
86	Grand Bayou, ½ mile above Lake Fausse Point	2.62††	†	†	†
87½	Lake Fausse Point at Head	2.62††	†	†	†
90	Lake Fausse Point at Head of Bird Island Chute	2.66	0.131	0.153	0.3647
93½	Lake Fausse Point, ½ mile below foot of Bird Island Chute	2.65	0.158	0.166	0.5413
95½	Lake Fausse Point, 3½ miles above Fisher Island	2.72	†	†	†
98	Lake Fausse Point, 1 mile above Little Pass	2.48††	†	†	†
99	In Little Pass	2.69	†	†	†
103	Grand Lake, opposite Taylor Point	2.62††	†	†	†
105½	Grand Lake, 1 mile above Myette Point	2.64	†	†	†
107	Grand Lake, 1 mile east of Myette Point	2.51	†	†	†

*These data concern the same samples of bed material listed in Table 40.
**See page 5 for discussion of values.
†Not computed for silt and clay samples. See Table 40 for size distribution.
††Considerable organic content.