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UNITED STATES DEPARTMENT OF THE INTERIOR

# INVESTIGATIONS OF METHODS AND EQUIPMENT USED IN STREAM GAGING

## PART 1. PERFORMANCE OF CURRENT METERS IN WATER OF SHALLOW DEPTH

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 868-A

UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

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W. C. Mendenhall, Director

Water-Supply Paper 868-A

# INVESTIGATIONS OF METHODS AND EQUIPMENT USED IN STREAM GAGING

## PART 1. PERFORMANCE OF CURRENT METERS IN WATER OF SHALLOW DEPTH

BY

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Prepared in collaboration with the
HYDRAULIC LABORATORY COMMITTEE
OF THE GEOLOGICAL SURVEY
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# INVESTIGATIONS OF METHODS AND EQUIPMENT USED IN STREAM GAGING

## PART 1. PERFORMANCE OF CURRENT METERS IN WATER OF SHALLOW DEPTH

By C. H. Pierce


### ABSTRACT

The investigation of the performance of current meters in measuring the velocity of water in shallow depths, recently made by the Geological Survey at the National Hydraulic Laboratory, National Bureau of Standards, Washington, D. C., was arranged primarily for the purpose of determining coefficients to be applied as correction factors to velocities obtained by current meters when used under the adverse conditions of very shallow water. The scope of the investigation covered measurements of discharge in the 12-foot flume with standard-size current meters and with cup-type pygmy current meters that have a bucket wheel 2 inches in diameter. The investigation was limited to water between a minimum depth of 0.2 foot and a maximum depth of 1.5 feet. The velocity ranged from 0.1 foot to 1.5 feet per second. Coefficients for the 0.6-depth method and for the 0.2- and 0.8-depth method, where standard-size current meters were used, were determined for the entire range of velocities. For the 0.5-depth method where standard-size current meters were used and for all methods where pygmy meters were used coefficients were determined for the entire range of velocities except for those below 0.2 foot per second. The depths of water in which measurements were made by the various methods are shown by the depths for which coefficients are given in the diagrams.

The depth of water in the flume was regulated by needle gates a short distance below the place of measurement, the needle gates being adjusted so as to obtain the desired depth and velocity for a given discharge. An 8-inch or a 4-inch venturi meter calibrated in place was used for determining discharges less than 3.5 second-feet. Discharges greater than 3.5 second-feet were measured by a sharp-crested weir calibrated in place. The discharge as measured by the current meter was compared with the weir or venturi-meter discharge measurement to obtain the correction factor for the current-meter measurement. Conditions of beds of smooth concrete, ¾-inch gravel, and coarse gravel were investigated. The coarse gravel was run-of-bank gravel, all retained on a 1-inch screen but passing through a 5-inch screen.

Other phases of the investigation, such as studies of pulsations, vertical velocity curves, distribution of velocities near the side walls of the flume, and performance of current meters when used near the water surface and near the flume walls, were incidental to the main purpose of the investigation. The information obtained from these studies was used in analyzing and interpreting the results of the discharge measurements.

## INTRODUCTION

Current meters used in measuring river discharge must be operated under a great variety of conditions. The depth of water at the place of measurement may be from 50 to 100 feet in large rivers and less than 1 foot in small streams. Some measurements are made where the velocity is 15 feet per second or more; others, where the velocity is as low as 0.1 foot per second. Not only are large differences in depth and velocity encountered in measuring rivers and streams in widely separated regions, but also large variations between flood stages and minimum low water in the same river. Measurements are made from cableways, bridges, and boats; by wading; and through ice cover. Structures from which current-meter measurements are made may be designed and built for that particular purpose and may be placed at a selected reach of the stream where, for ordinary stages, the conditions are favorable for accurate measurements of velocity with a current meter. It has often been found, however, that the conditions at low water are not so favorable for current-meter measurements as the conditions at the same place at stages of medium and high water. It may be desirable at low water to select a place where measurements can be made by wading at a section other than at the cableway or bridge used for the measurements made at higher stages.

In selecting a section for a wading measurement particular consideration is given to the distribution of velocities as indicated by the appearance of the water surface. Sections containing cross-currents, eddies, or pools of extremely low velocity are avoided if possible. At times of low water the most favorable conditions with respect to distribution of velocity are generally found at sections of comparatively shallow depth, possibly 1 foot or less. Depths greater than 1 foot but not exceeding about 2.5 feet for wading measurements are desirable for the use of the 0.2- and 0.8-depth method, if the velocities at those depths are not too low. Velocities as low as 0.1 foot per second can be measured with the current meter, but the precision of the measurements is generally better for velocities of 0.5 foot per second and higher than it is for extremely low velocities.

In wading measurements the current meter is usually held in position by means of a rod and a double-ended sliding support that can be readily adjusted to the desired position for the depth of observation. (See pl. 1.) Measurements of small canals and ditches and of low-water flow in small streams where the width is not too great may be made from a small footbridge or similar structure with the same equipment that is used in wading measurements. This procedure eliminates the necessity of standing in the water in the near vicinity of the meter. In current-meter measurements in shallow depths care should be used in placing the meter at the selected position in the vertical, as small errors in placement of the meter may have considerable effect on the accuracy of the results.

Current meters are ordinarily rated in a still-water rating flume by drawing the meter through the water at a known rate of travel and holding it far enough below the surface of the water and from the side walls of the flume so that the performance of the meter is not affected by proximity to either the water surface or the side walls. Under those conditions, the static water pressure being about the same on all sides of the current meter, the rating that is obtained may be assumed to correspond to a condition where the meter is held in a fixed position in water moving steadily in straight lines of uniform velocity on all sides.

It has been found by experiments that when a vertical-axis cup-type current meter is used in water of very shallow depth in positions where the current-meter cups are in the vicinity of the water surface the action of the meter is retarded, and it is said to "underregister." Likewise, when the meter is placed very close to the stream bed its action may be affected by its proximity to the bed and by irregularities in the boundary surface.

For flow in open channels it has been demonstrated by many experiments that the distribution of velocities in a vertical section may be represented by a segment of a parabolic curve, in which the axis of the parabola is parallel to the water surface. With such a distribution the average of the velocities at 0.2- and 0.8-depth is very nearly the mean velocity in the vertical. It has been found also, that the velocity at 0.6-depth is likewise very near the average velocity for the vertical. Discharge measurements that are made by observations of velocities at 0.2- and 0.8-depth below the water surface are said to be made by the "0.2- and 0.8-depth" method; those made by observations at 0.6-depth below the water surface are said to be made by the "0.6-depth" method. Most discharge measurements are made by one or the other of these methods if the depths and velocities are such as to permit measurements of velocities at those points. The 0.2- and 0.8-depth method is generally preferred because of its greater reliability. Unusual or abnormal conditions in the movements of the water have a less serious effect on the accuracy of the measurement if the observations are taken at the two points at 0.2- and 0.8-depth instead of only at 0.6-depth.

In very shallow water it is not always practicable to use the current meter at the 0.2- and 0.8-depth positions because of the proximity of those positions to the water surface or the stream bed, and under those circumstances the 0.6-depth method may be preferable. In streams where the water may be so shallow that the 0.6-depth method is not practicable, the current meter must be placed at middepth, where the velocity is ordinarily somewhat greater than the average in the vertical.

Coefficients other than unity may be necessary for current-meter measurements of velocity in very shallow depths for two reasons. First, the distribution of velocity in a vertical may be such that the actual velocity at the point of observation—for instance, at 0.5 depth—is not the mean for the vertical; second, the registration of the current meter may be affected by its proximity to the water surface or the stream bed. Under some conditions the errors from these two sources may have opposite effects and therefore be compensating; under other conditions both errors may be in the same direction and therefore not of a compensating nature.

Because of the lack of definite information in regard to the performance of current meters under the adverse conditions of very shallow water and in order to obtain information as to coefficients that should be applied to measurements made under those conditions, arrangements were made to investigate this problem in the National Hydraulic Laboratory, National Bureau of Standards, Washington, D. C.

## ADMINISTRATION AND PERSONNEL

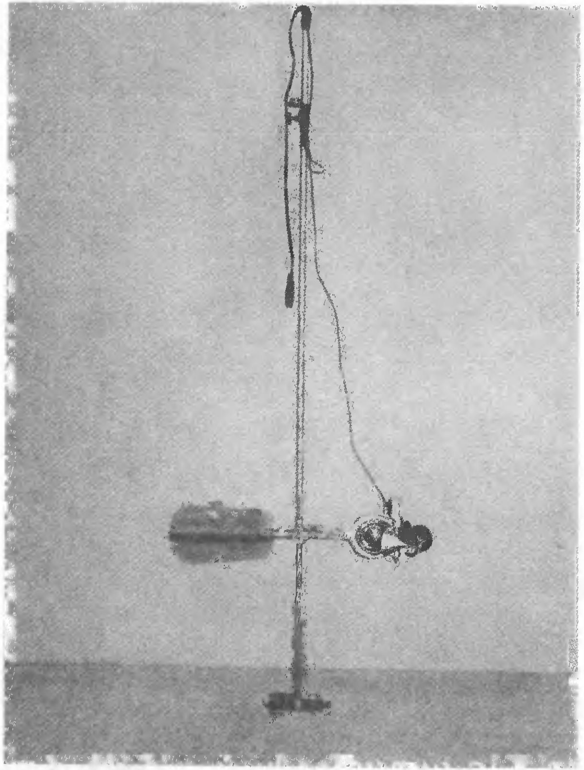
The methods and procedure used in conducting the investigation were arranged by the hydraulic laboratory committee of the water-resources branch of the Geological Survey, consisting of Lasley Lee, C. H. Pierce, and O. W. Hartwell under the administrative direction of N. C. Grover, chief hydraulic engineer, and C. G. Paulsen, chief of the division of surface water. The instrumental observations and current-meter measurements were made by W. S. Eisenlohr, Jr., A. H. Frazier, H. E. Cox, and A. D. Ash. The analyses of data and the computations of coefficients were made by C. H. Pierce, assisted by Mr. Eisenlohr, Mr. Ash, and H. C. Woster.

## COOPERATION AND ACKNOWLEDGMENTS

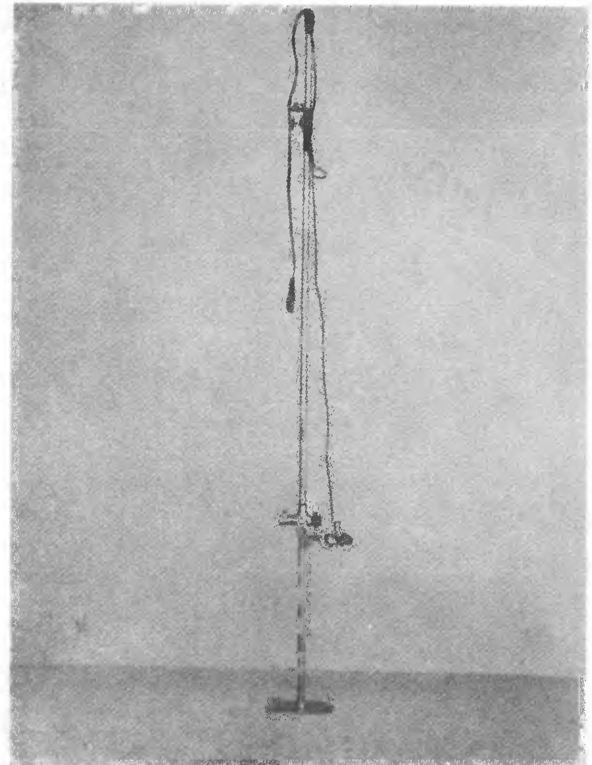
The facilities of the National Hydraulic Laboratory were provided by the National Bureau of Standards. The laboratory staff, under the direction of H. N. Eaton, assisted in the conduct of the work and furnished the pitot static tube that was used for comparisons with the current-meter observations. The various current meters used in the investigation were rated several times during the progress of the work by the section of engineering instruments and mechanical appliances, division of mechanics and sound, National Bureau of Standards. The Ott Xb-type meter was loaned by that section.

## PURPOSE AND SCOPE OF THE INVESTIGATION

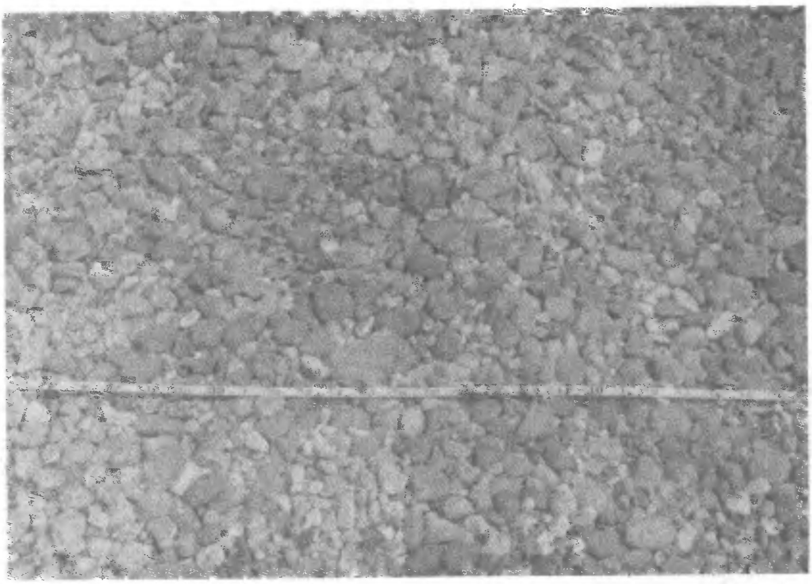
The investigation was made primarily for the purpose of determining coefficients for use as correction factors to velocities obtained in



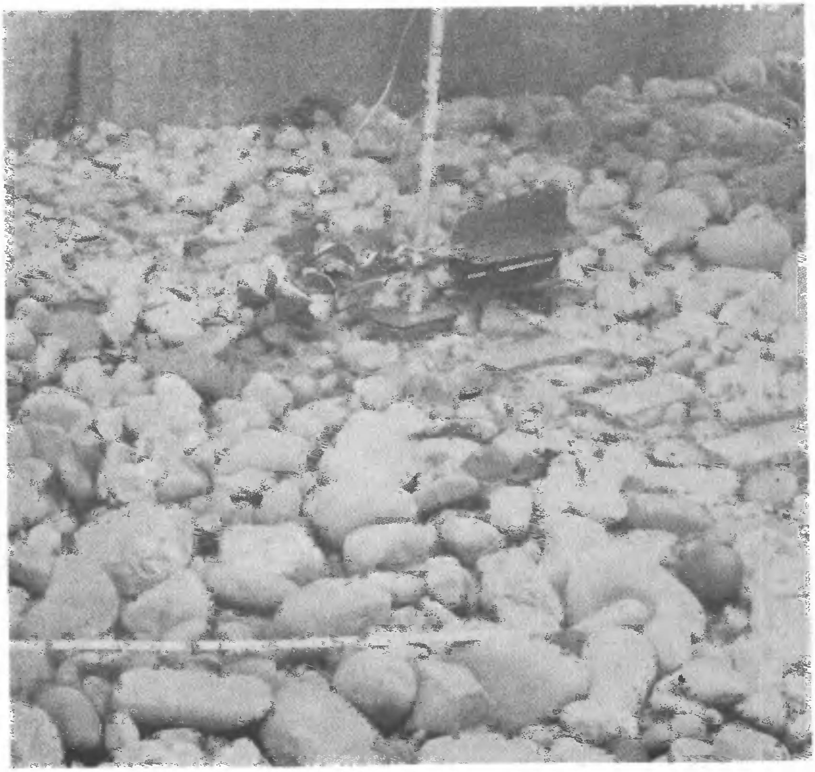
*A*. TYPE A SMALL PRICE CURRENT METER.



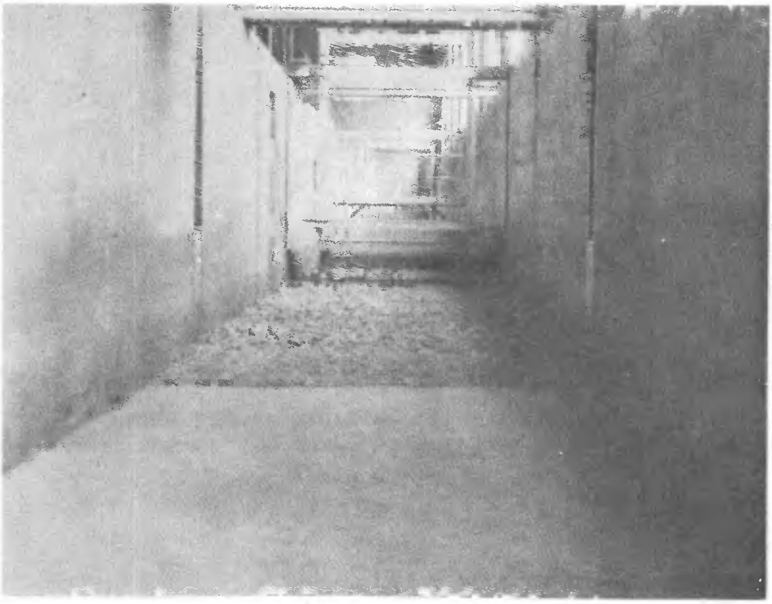
*B*. CUP-TYPE PYGMY CURRENT METER.



*A.* FLUME WITH BED OF ¾-INCH GRAVEL.



*B.* FLUME WITH BED OF COARSE GRAVEL.



*A*. SECTION OF 12-FOOT FLUME AND PLATFORM FROM WHICH MEASUREMENTS WERE MADE.

*B*. PART OF THE MEASUREMENT SECTION AND GAGE.

measurements of streams of shallow depths by small Price current meters such as are generally used by engineers of the Geological Survey. A Geological Survey type A small Price current meter, which was used in this investigation, is shown in plate 1, *A*. Descriptions of the individual current meters are given on pages 15–18.

Measurements of discharge in the flume were made under the different conditions of smooth bed, bed of ¾-inch gravel, and bed of coarse gravel in order to obtain information regarding the extent to which the performance of the current meter was affected by the roughness of the bed.

The pygmy current meters, designed and constructed by the Geological Survey, were in an experimental stage and therefore not in general use in stream-gaging work at the time of this investigation, but they were included for the purpose of obtaining information respecting their performance in measurements of velocity in shallow depths and for determining coefficients that would be applicable to measurements made with such meters. One of the pygmy meters used in this investigation is shown in plate 1, *B*. These meters are described on page 18.

Other phases of the investigation, such as studies of pulsations, vertical velocity curves, distribution of velocities near the side walls of the flume, and performance of the current meters when used near the water surface and near the flume walls, were incidental to the main purpose of the investigation. The information obtained from these studies was used in analyzing and interpreting the results of the discharge measurements.

The scope of the investigation covered measurements of discharge in the 12-foot flume with standard-size current meters and with cup-type pygmy current meters that have a bucket wheel 2 inches in diameter for the determination of coefficients applicable to the current-meter measurements by comparison with the discharge as measured by other methods. The depth of water for this investigation was limited to a minimum of 0.2 foot and a maximum of 1.5 feet. The velocity was limited to a range of 0.1 foot to 1.5 feet per second. Coefficients for the 0.6-depth method and for the 0.2- and 0.8-depth method, were determined for the entire range of velocities, using standard-size small Price-type current meters. For the 0.5-depth method where standard-size current meters were used and for all methods where pygmy meters were used coefficients were determined for the entire range of velocities except for those below 0.2 foot per second. The depths of water in which measurements were made by the various methods are shown by the depths for which coefficients are given in the diagrams (pls. 7–13).

## METHODS OF MEASUREMENT

The depth of water in the flume was regulated by needle gates a short distance below the place of measurement, the needle gates being adjusted so as to obtain the desired depth and velocity for a given discharge. An 8-inch or a 4-inch venturi meter calibrated in place was used for determining discharges less than 3.5 second-feet. Discharges greater than 3.5 second-feet were measured by a sharp-crested weir calibrated in place. The discharge as measured by the current meter was compared with the weir or venturi-meter discharge measurement to obtain the correction factor for the current-meter measurement. The concrete bed of the flume was assumed to represent a smooth stream bed, and measurements made on it were used in determining the relations for a smooth bed. A layer of ¾-inch gravel was then placed in the flume, as shown in plate 2, *A*, and a series of measurements was made for this condition. The third condition investigated was that of coarse gravel, as shown in plate 2, *B*. The coarse gravel was run-of-bank gravel, all retained on a 1-inch screen but passing a 5-inch screen.

Measurements were made with several different type A small Price current meters, such as are shown in plate 1, *A*. One current meter of the so-called combination type or 623 type, formerly in general use by the Geological Survey (see description on p. 18), was used in the investigation. Measurements were made also with cup-type pygmy meters having bucket wheels 2 inches in diameter (see pl. 1, *B*). The meters were held on a ½-inch round rod with a base plate by means of a double-ended sliding support inserted between the yoke and the tailpiece and were operated from a platform above the water. The section of the flume and the platform from which the measurements were made are shown in plate 3, *A*. An Ott Xb-type meter, a pitot static tube, and propeller-type pygmy meter were used for purposes of comparison. Observations were also made with a Bentzel velocity tube. Observations of velocity were made at 0.6-depth, at 0.2- and 0.8-depth, at middepth, and at other points in the vertical at intervals of 0.5 foot across the flume and at 0.25 foot from the flume walls. In special studies in which the pitot static tube and the pygmy meters were used, determinations of velocity were made as close as 0.1 foot to the flume wall.

The depths of water at the points where observations of velocity were made were taken from a standard cross section that was developed from numerous soundings and by use of an engineer's level, the standard cross section being referred to a gage at the measurement section (see pl. 3, *B*). Except as noted elsewhere for the condition of 0.2-foot depth of water on the concrete bed, the current meters were placed in the vertical to the nearest 0.01 foot of the correct position. The period of time for each observation of velocity by the current meter was generally between 50 and 90 seconds, with most of the periods longer than 60 seconds. In studies of the effects of pulsations, the observations extended over periods of several minutes in order to obtain information regarding the effects of pulsations on the velocity measurements. The results of the individual current-meter measurements of discharge are listed in the tables, pages 20–32.

## POSITION OF THE CURRENT METER

The current-meter measurements of velocity were made with the current meter supported on a rod at definite, predetermined distances below the surface of the water. The positions of the current meter were those ordinarily used in the 0.5-depth, the 0.6-depth, and the 0.2- and 0.8-depth methods of measurement. The minimum depth of water for which the 0.2- and 0.8-depth method was investigated was 1.0 foot. The minimum depth of water for the investigation of the 0.6-depth method was 0.4 foot for standard-size current meters and 0.2 foot for pygmy meters. For the 0.5-depth method the minimum depth of water was 0.2 foot. Other positions of the current meter for measurements of velocity in shallow depths, such as the 0.4-depth method and a modified form of the 0.2- and 0.8-depth method, were investigated to some extent but were found to give results no better than those obtained by the use of the more generally accepted methods.

The current-meter cups could not be placed exactly at middepth when the depth of water was 0.2 foot on the concrete bottom of the flume. For this condition, when the bottom of the meter yoke rested on the concrete the center of the meter cups was at a depth of 0.07 foot below the water surface, and the top edges of the cups were out of the water. With the current meter in this position the indicated mean velocities were too large for velocities less than 0.7 foot per second (coefficients less than unity) and too small for mean velocities greater than 0.7 foot per second (coefficients greater than unity), the range of coefficients for this condition being from 0.882 at a velocity of 0.2 foot per second to 1.49 at a velocity of 1.5 feet per second. (See pl. 7.)

With 0.2-foot depth of water on the bed of ¾-inch gravel, the current-meter cups were placed at middepth by forcing the bottom of the meter yoke into the gravel until the tops of the meter cups were just submerged (practically at the water surface). This position of the current meter permitted observations to be made at middepth, the diameter of the meter cups being slightly less than the depth of water. The indicated mean velocities of measurements made under this condition were too small, and therefore the coefficients to be applied to the indicated velocities were greater than unity, increasing from

1.01 at a velocity of 0.2 foot per second to 1.52 at a velocity of 1.4 feet per second. (See pl. 8.)

In water 0.3 foot deep the center of the current-meter cups was placed at middepth, and in this position the bottoms of the meter cups were about 0.07 foot above the bed, and the tops of the cups were the same distance below the surface of the water. The coefficients for individual current-meter measurements made in the 0.3-foot

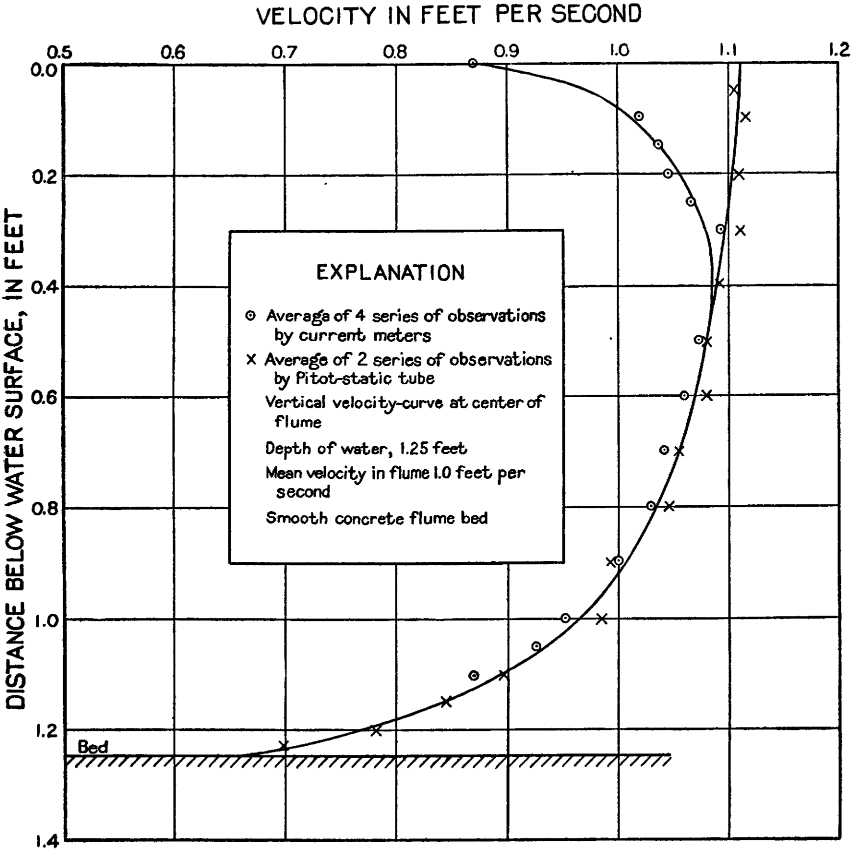



FIGURE 1.—Underregistration of current meters near the water surface.

depth of water showed large variations, not only for the different conditions of beds of smooth concrete and ¾-inch gravel but also for the same conditions of bed. No current-meter measurements were made in water 0.2 or 0.3 foot in depth on the coarse-gravel bed.

The cup-type current meter has a tendency to underregister if the position of the meter is such that the tops of the cups are at or just below the surface of the water. Under those circumstances a vertical velocity curve plotted from current-meter observations of velocity may indicate velocities at the upper end of the curve that are less than the true velocities. This condition is shown in figure 1, where a vertical velocity curve plotted from the average of four series of observations made with current meters is shown in comparison with the average of two series of observations made with the pitot static tube. In some measurements of velocity errors due to underregistration of the current meter near the water surface may be compensated by the effects of other conditions; but the effect of proximity of the current meter to the surface in water of shallow depth is one of the principal reasons for the use of coefficients to measurements made under such conditions.

## DISTRIBUTION OF VELOCITIES IN THE 12-FOOT FLUME

The horizontal distribution of velocity was fairly uniform across the 12-foot flume between distances of about 1 foot from each wall, except for the ordinary variations in velocity between the water surface and the flume bed. Within distances of about 1 foot from each wall the velocity decreased with increasing nearness to the wall until at a distance of 0.1 foot from the wall it was from 40 to 80 percent of the average velocity in the flume. This relation varied somewhat with the depth of water and the discharge in the flume.

The distribution of velocities in the flume was studied by means of measurements made with the pitot static tube and the current meters. Figure 2 shows the horizontal distribution of velocities for half the width of the flume, based on observations at 0.2 depth and 0.8 depth. The averages of the velocities at equal distances from the side walls on the two sides of the flume were used in preparing this diagram. Although distributed fairly uniformly across the flume between distances of about 1 foot from each wall, the velocities were slightly greater on the left side than on the right. This irregularity of flow, which was caused by conditions upstream from the measuring section, was smoothed out to some extent by taking averages of the velocities at equal distances from the two side walls, although the plotted points still show some minor variations. The diagram in figure 2 corresponds to a depth of water of 1.25 feet and a discharge of 7.51 second-feet flowing on a bed of ¾-inch gravel, the average velocity in the flume being 0.50 foot per second, and is typical of the conditions that existed for other depths and velocities. The results of observations made with the pitot static tube and those made with a current meter are indicated by different symbols.

## VERTICAL VELOCITY CURVES

The vertical velocity curves in plate 4 show the distribution of velocity in vertical sections near the side walls and at the center of the flume. The velocity measurements were made with the pitot static tube under the same conditions as those described above. The individual curves for sections on the two sides of the flume shown in plate 4 indicate slightly higher velocities for the sections on the left side of the flume than for those on the right.

**EFFECTS OF NONUNIFORM VELOCITIES NEAR THE FLUME WALLS**

In this investigation it was found that vertical-axis cup-type current meters, if used near the sides of the flume where the velocity was not uniformly distributed across the width of section in front of

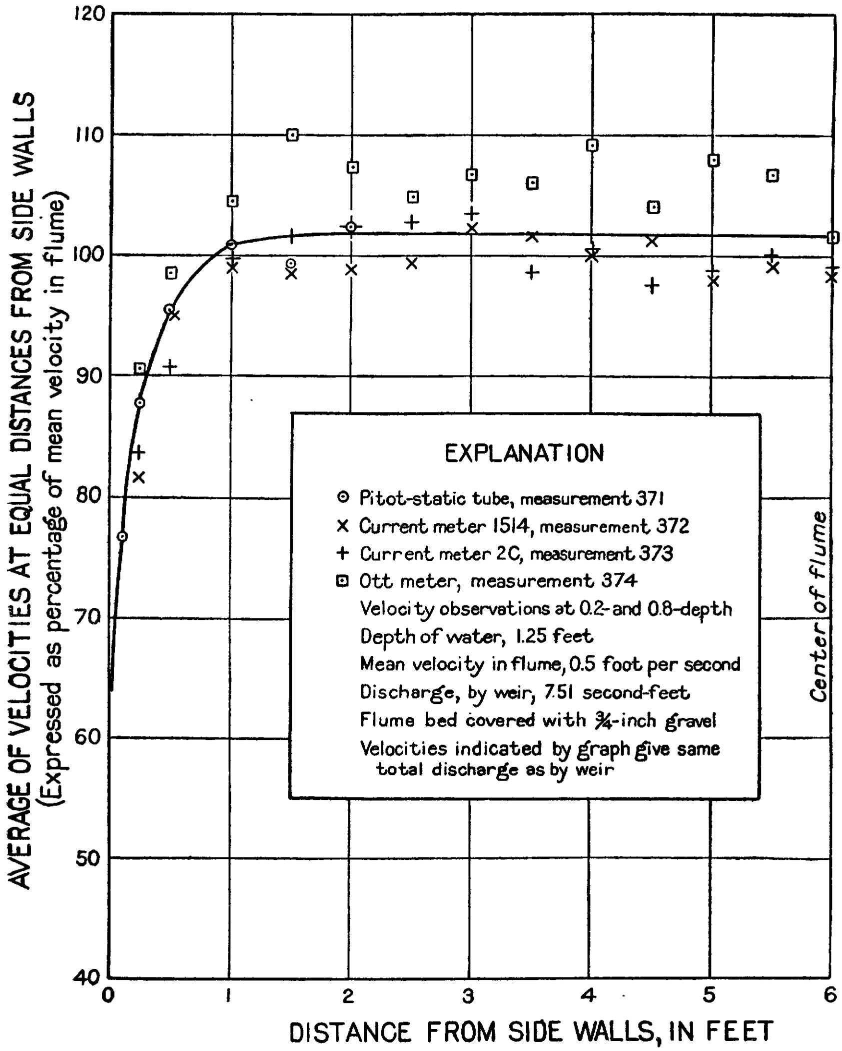



FIGURE 2.—Horizontal distribution of velocities.

the meter (see fig. 2), generally indicated velocities in excess of the true velocities on that side of the flume where the position of the resultant of the nonuniform velocities acting on the meter fell on the side of the axis toward which the cups were turning. Similarly, the current meter indicated velocities less than the true velocities on that side of the flume where the resultant of the nonuniform velocities acting on the meter fell on the side of the axis from which the cups were turning.

A study of the effects of underregistration and overregistration of the current meter when used near the flume walls, where the velocity distribution was not uniform, was made by comparisons of measurements made with various instruments. These comparisons showed that, for the conditions of depth and velocity at which the measurements were made, the underregistration near one wall of the flume and the overregistration near the opposite wall were so nearly equal that no consistent effects either of uncompensated underregistration or of uncompensated overregistration could be detected. It is recognized that if the rate of change in the velocity distribution had been materially greater on one side of the flume than on the other, there might have been some uncompensated underregistration or overregistration.

In studying the possibility of any uncompensated underregistration or overregistration of the current meter because of the nonuniform velocities in the vicinity of the flume walls, the writer compared the discharge as measured by the current meter in the two 2-foot widths adjacent to the walls and the discharge as measured by the current meter in the 8-foot width between the two 2-foot widths, and determined the ratios of the discharge in each of these parts to the total discharge in the flume as measured by the current meter. These ratios, which are shown in the tables on page 12, are in close agreement with ratios obtained in a similar manner from measurements made by other types of current meters and by the pitot static tube under similar conditions of depth and velocity.

In the comparisons of measurements of discharge in the two 2-foot widths and of the discharge in the central 8-foot width, several different current meters were used. One of these, meter 2C, was arranged with the bucket wheel in reverse position, so that the cups revolved in a clockwise direction when viewed from above instead of in the usual counterclockwise direction. The change in position of the bucket wheel caused no change in the rating of the meter, but its performance with respect to underregistration and overregistration near the side walls was the opposite from that of the cup-type meters using bucket wheels that rotated in the counterclockwise direction. The preceding statement in regard to the effect of nonuniform distribution of velocities and the position of the resultant of the nonuniform velocities acting on the current-meter cups with respect to the axis of the meter is applicable irrespective of the direction of rotation of the meter cups. A pygmy current meter 2 inches in diameter, an Ott propeller-type meter, and a pitot static tube were also used in these comparisons. The comparisons showed no consistent differences in the percentage of discharge in the two 2-foot widths and in the central 8-foot width that could be attributed to uncompensated underregistration or overregistration of the current meters in the vicinity of the flume walls.

*Comparison of measurements by different current meters and the pitot static tube*

| Measurement No. | Meter [1] | Depth of water (feet) | Method of measurement (fractional depth below surface) | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement | Meter discharge (second-feet) | | Percentage of total meter discharge | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | | In two 2-foot widths | In one 8-foot width | In two 2-foot widths | In one 8-foot width |
| | | | | **Flume bed covered with ¾-inch gravel** | | | | | | | |
| 132 | 1175 | 1.25 | 0.6 | 0.50 | 7.53 | 7.38 | 1.020 | 2.44 | 4.94 | 33.06 | 66.94 |
| 371 | Pitot | 1.25 | 0.6 | .50 | 7.51 | 7.32 | 1.026 | 2.42 | 4.90 | 33.06 | 66.94 |
| 375 | 1514 | 1.25 | 0.6 | .50 | 7.51 | 7.54 | .996 | 2.45 | 5.09 | 32.49 | 67.51 |
| 376 | 2C | 1.25 | 0.6 | .50 | 7.51 | 7.56 | .993 | 2.49 | 5.07 | 32.94 | 67.06 |
| 377 | Ott Xb | 1.25 | 0.6 | .50 | 7.51 | 7.81 | .962 | 2.60 | 5.21 | 33.29 | 66.71 |
| 378 | A3 | 1.25 | 0.6 | .50 | 7.51 | 7.64 | .983 | 2.54 | 5.10 | 33.25 | 66.75 |
| 132 | 1175 | 1.25 | 0.2 and 0.8 | .50 | 7.53 | 7.31 | 1.030 | 2.32 | 4.99 | 31.74 | 68.26 |
| 372 | 1514 | 1.25 | 0.2 and 0.8 | .50 | 7.51 | 7.34 | 1.023 | 2.34 | 5.00 | 31.88 | 68.12 |
| 373 | 2C | 1.25 | 0.2 and 0.8 | .50 | 7.51 | 7.39 | 1.016 | 2.37 | 5.02 | 32.07 | 67.93 |
| 374 | Ott Xb | 1.25 | 0.2 and 0.8 | .50 | 7.51 | 7.85 | .957 | 2.54 | 5.31 | 32.36 | 67.64 |
| 378 | A3 | 1.25 | 0.2 and 0.8 | .50 | 7.51 | 7.50 | 1.001 | 2.42 | 5.08 | 32.27 | 67.73 |
| 77 | 1196 | .50 | 0.6 | 1.00 | 6.03 | 5.86 | 1.029 | 1.92 | 3.94 | 32.76 | 67.24 |
| 363 | 1514 | .50 | 0.6 | 1.00 | 6.01 | 5.67 | 1.060 | 1.83 | 3.84 | 32.28 | 67.72 |
| 364 | Ott Xb | .504 | 0.6 | .995 | 6.01 | 6.08 | .988 | 1.95 | 4.13 | 32.07 | 67.93 |
| 365 | 2C | .50 | 0.6 | 1.00 | 6.01 | 5.72 | 1.051 | 1.86 | 3.86 | 32.52 | 67.48 |
| 370 | Pitot | .50 | 0.6 | 1.00 | 6.01 | 6.08 | .988 | 1.98 | 4.10 | 32.57 | 67.43 |
| 379 | A3 | .50 | 0.6 | 1.00 | 6.01 | 6.01 | 1.000 | 1.96 | 4.05 | 32.61 | 67.39 |
| | | | | **Smooth concrete flume bed** | | | | | | | |
| 308 | 1514 | 1.25 | 0.6 | 1.01 | 15.13 | 15.13 | 1.000 | 4.99 | 10.14 | 32.98 | 67.02 |
| 309 | 2C | 1.25 | 0.6 | 1.01 | 15.13 | 15.56 | .972 | 5.14 | 10.42 | 33.03 | 66.97 |
| 314 | 1175 | 1.25 | 0.6 | 1.00 | 15.06 | 14.97 | 1.006 | 4.92 | 10.05 | 32.87 | 67.13 |
| 315 | 2C | 1.25 | 0.6 | 1.00 | 15.06 | 15.25 | .988 | 4.92 | 10.33 | 32.26 | 67.74 |
| 330 | 1514 | 1.25 | 0.6 | 1.00 | 15.00 | 15.01 | .999 | 4.90 | 10.11 | 32.64 | 67.36 |
| 331 | 2C | 1.25 | 0.6 | 1.00 | 15.00 | 15.33 | .978 | 4.94 | 10.39 | 32.22 | 67.78 |
| 332 | Ott Xb | 1.25 | 0.6 | 1.00 | 15.00 | 15.34 | .978 | 4.92 | 10.42 | 32.07 | 67.93 |
| 333 | A3 | 1.25 | 0.6 | 1.00 | 15.00 | 15.03 | .998 | 4.91 | 10.12 | 32.67 | 67.33 |
| 354 | Pitot | 1.25 | 0.6 | 1.00 | 14.98 | 15.25 | .982 | 4.94 | 10.31 | 32.39 | 67.61 |
| 308a | 1514 | 1.25 | 0.2 and 0.8 | 1.01 | 15.13 | 14.95 | 1.012 | 4.84 | 10.11 | 32.37 | 67.63 |
| 309a | 2C | 1.25 | 0.2 and 0.8 | 1.01 | 15.13 | 15.11 | 1.001 | 4.83 | 10.28 | 31.96 | 68.04 |
| 334 | 1514 | 1.25 | 0.2 and 0.8 | 1.00 | 15.02 | 14.78 | 1.016 | 4.78 | 10.00 | 32.34 | 67.66 |
| 335 | 2C | 1.25 | 0.2 and 0.8 | 1.00 | 15.02 | 15.01 | 1.001 | 4.84 | 10.17 | 32.24 | 67.76 |
| 336 | Ott Xb | 1.25 | 0.2 and 0.8 | 1.00 | 15.02 | 15.19 | .989 | 4.90 | 10.29 | 32.26 | 67.74 |
| 337 | A3 | 1.25 | 0.2 and 0.8 | 1.00 | 15.02 | 14.81 | 1.014 | 4.74 | 10.07 | 32.01 | 67.99 |

[1] See descriptions of current meters, pp. 15–18.

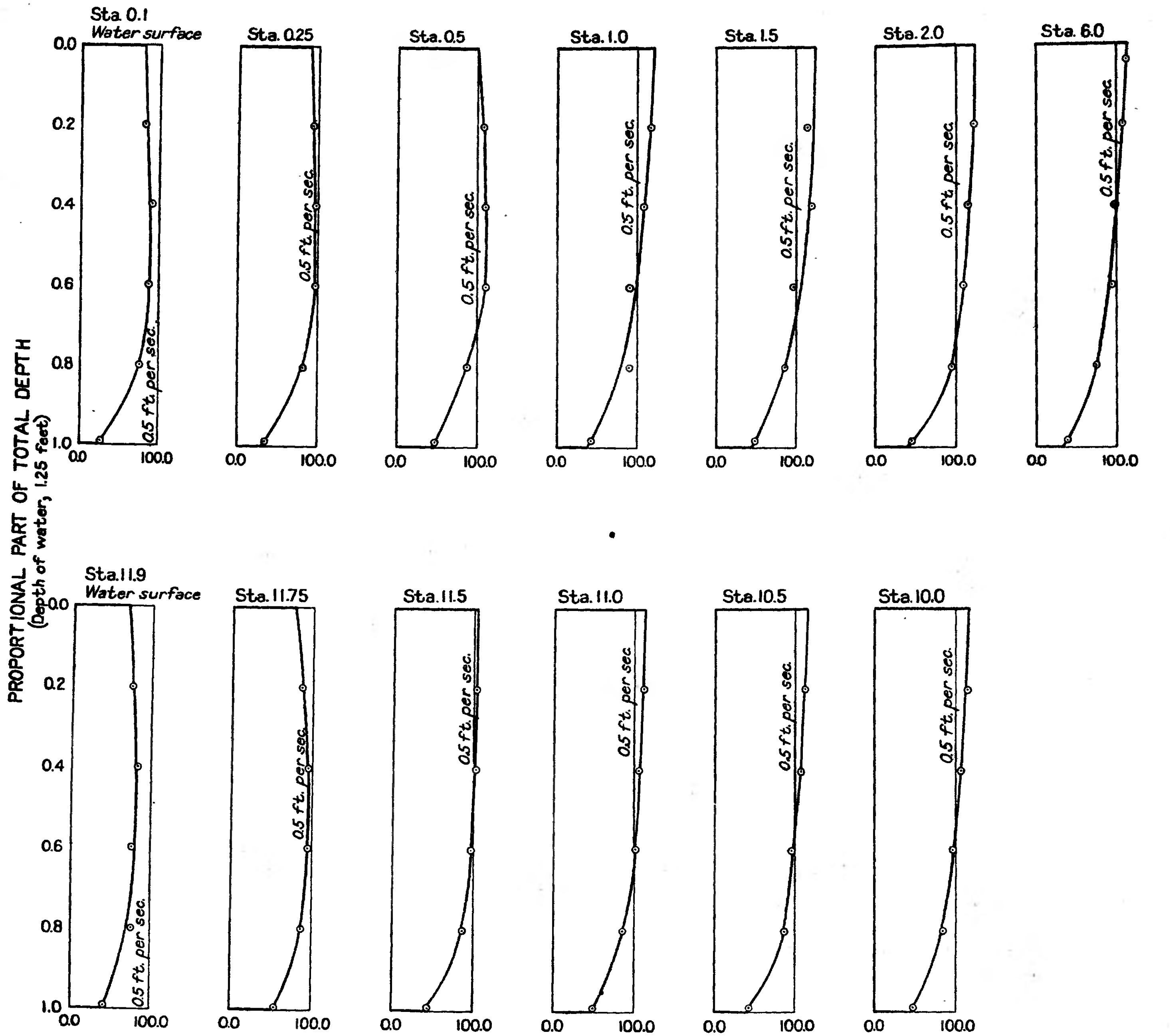
NOTE.—Comparison of measurements for other conditions of depths and velocity showed equally consistent relations of the discharge in the two 2-foot widths at the sides of the flume and the discharge in the 8-foot width as measured by different types of current meters, although the proportional parts of the total discharge carried by the two 2-foot widths and the 8-foot width were somewhat different for the other conditions of depth and velocity.

## PULSATIONS

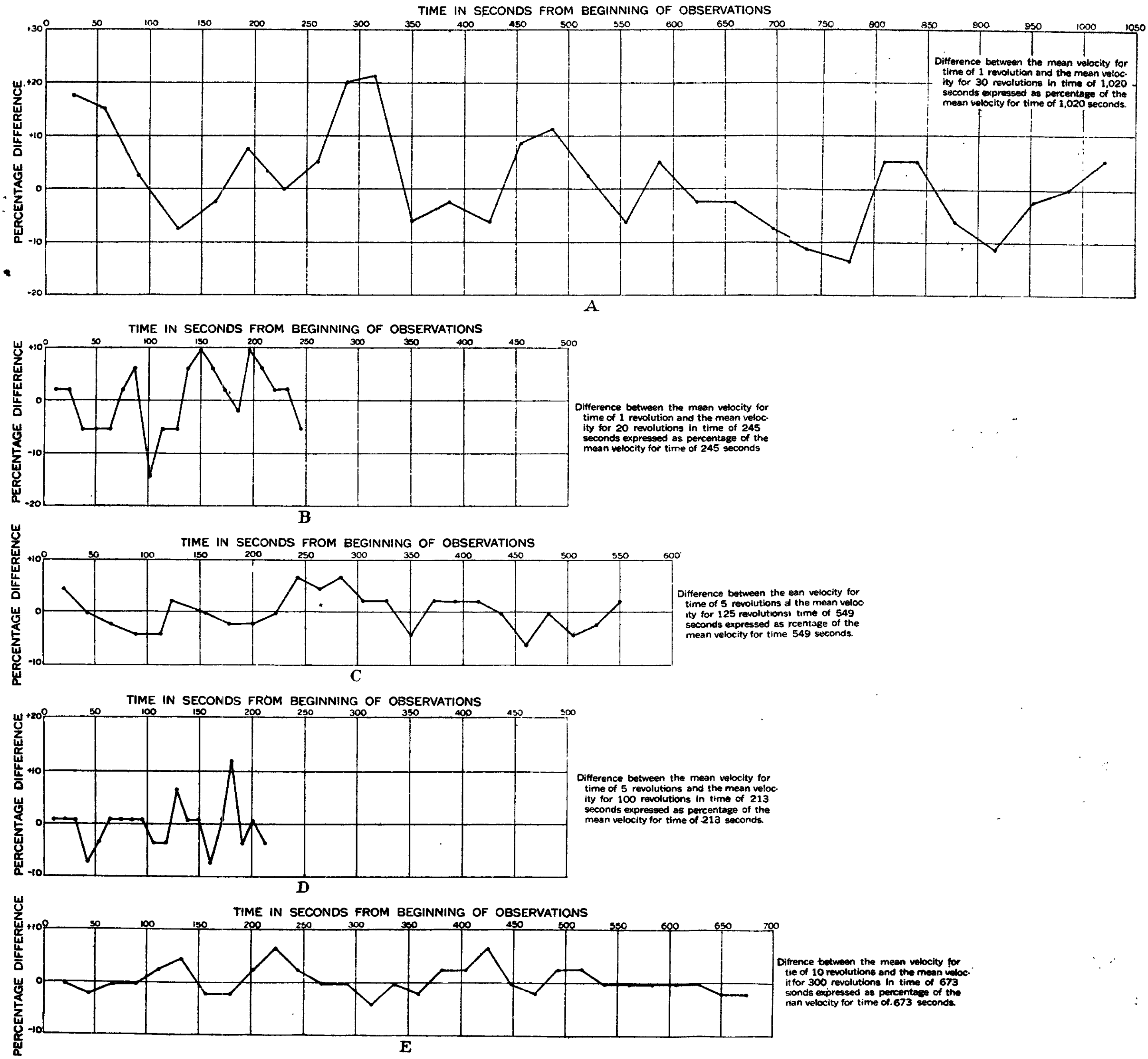
Because of the possibility that the results obtained in the investigations of current-meter performance might have been affected by pulsations, studies were made to obtain information for comparisons of pulsations in different velocities and the effects of pulsations on the observations of velocities for different periods.

Fluctuations in the velocity of flowing water have been observed and commented on by many writers [1] and may readily be perceived

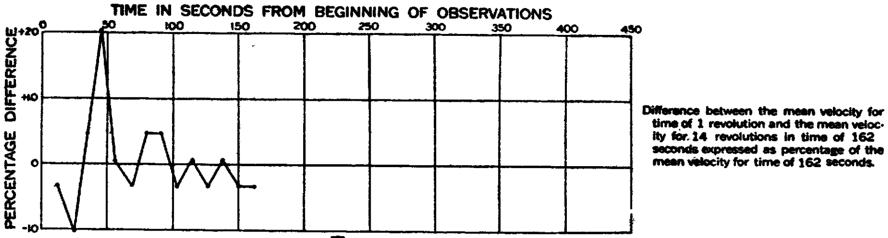
[1] See U. S. Geol. Survey Water-Supply Paper 95, pp. 28–32, 1904.



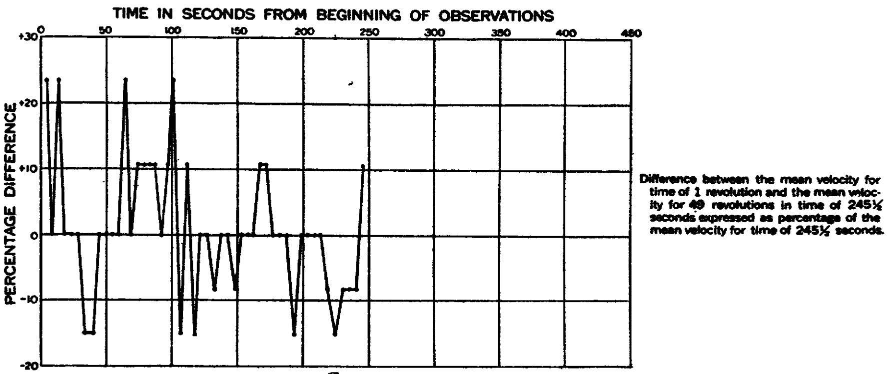

VERTICAL VELOCITY CURVES.




COMPARISONS OF PULSATIONS IN DIFFERENT VELOCITES.




F

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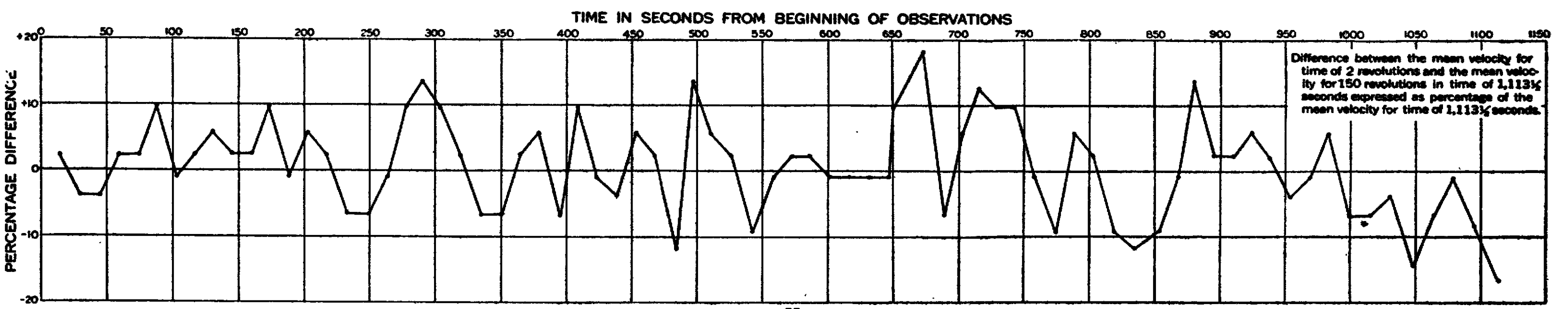


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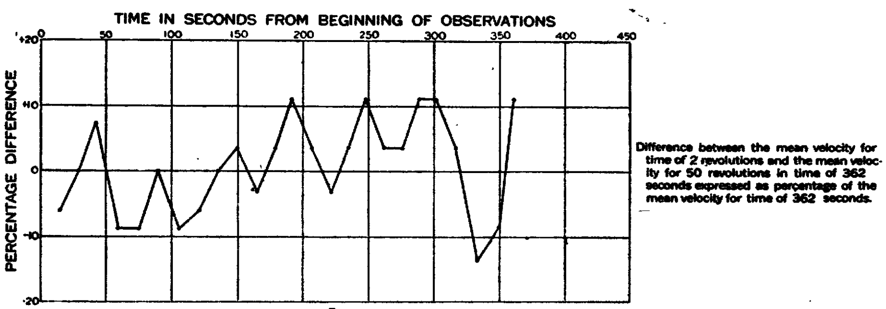


I

COMPARISONS OF PULSATIONS IN DIFFERENT PERIODS OF OBSERVATION.

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by noting the intervals of time between the revolutions of a current meter held in a fixed position in a stream. In addition to the short-period fluctuations, or pulsations that are characteristic of turbulent flow, such as is generally found in natural streams and in artificial channels where the depths and velocities are comparable with those of natural streams, water flowing in open channels nearly always exhibits longer-period variations in velocity, which are commonly called surges. Pulsations and surges in the flow of water in the 12-foot flume in the laboratory were indicative of turbulent flow. The results obtained by the investigation may be considered better applicable, therefore, to measurements of natural streams than they could have been if laminar flow had prevailed.

The condition of flow generally referred to as "turbulent," as differentiated from either "laminar" or "shooting" flow, is characterized by erratic movements of the individual particles of water wherein any particle may move in any direction with respect to any other particle.

As stated by O'Brien and Hickox:[2]

In most of the problems in the motion of air and water the flow is turbulent in the sense that there occur erratic variations in direction and velocity. Color injected into a turbulent flow quickly diffuses through it, and the motion of light particles is highly irregular, Direct measurements of these fluctuations show that they do not exhibit a regular period.

Owing, apparently, to the predominance of the dynamic characteristics over the viscous characteristics of turbulent flow as generally found in open channels, the velocity of water at a given point in an open channel is continually changing with respect to its component of motion in the direction of flow. For fully developed turbulence, the loss of head caused by frictional resistance is about proportional to the second power of the velocity, and the potential gradient will be governed by the mass acceleration.

The range in depth, velocity, and viscosity of the water in which current-meter measurements of natural streams are ordinarily made is generally within those limits in which the flow is turbulent in distinction from laminar or shooting flow, although the condition of turbulence may not always be complete, as judged by the usual criteria.[3] According to Vogel,[4]

"Expressed mathematically, the criterion for turbulent flow is $Z=VD>0.02$, $D$ being expressed in feet and $V$ in feet per second." As stated by Thompson,[5] "Turbulence is a comparative phenomenon—that is, there are degrees of turbulence. Thus, in a regimen in which the value of $Z$ is, say, 0.06, the effects of the

[2] O'Brien, M. P., and Hickox, G. H., Applied fluid mechanics, p. 25, 1937.

[3] See Vogel, H. D., Practical river laboratory hydraulics, and discussions by P. W. Thompson and others: Am. Soc. Civil Eng. Trans., vol. 100, 1935.

[4] Idem, p. 136.

[5] Idem, p. 151.

forces of internal friction will be more nearly negligible than in a regimen in which $Z$ has a value less than 0.06."

At the National Hydraulic Laboratory the flow in the 12-foot flume used in investigating current-meter performance in measurements of the velocity of water in shallow depths was turbulent, as shown by the Reynolds' number criterion $Vr$, which gave values between 2,000 and 186,000, and the criterion $Z$ used by Vogel, which had a value of 0.04 or more. At the lower velocities and minimum depths at which measurements were made the Reynolds' number was between 2,000 and 3,000, and thus it is possible that the condition of turbulence may not have been fully developed. Special precautions were taken, by the use of surface floats, to eliminate surface disturbance and wave action.

The variations in the velocity of the water at a given point in the cross section of the 12-foot flume at the National Hydraulic Laboratory were investigated by observing the times of individual revolutions of the current meter, or the times of every 2, 5, or 10 revolutions, during periods of several minutes—sometimes the periods of observation were as long as 17 or 18 minutes. For each set of observations in the study of the effects of pulsations, the mean velocity indicated by the current meter during successive short periods of observation corresponding to 1, 2, 5, or 10 revolutions of the meter was compared with the average velocity corresponding to the total number of revolutions of the meter during the entire period, and the amount by which the mean velocity for each short period differed from the average for the entire period was expressed in percentage of the mean velocity for the entire period and plotted as the ordinate of a point, the abscissa of which was the total elapsed time from the beginning of the series of observations to the end of the individual observation for which the point was plotted. Diagrams showing these variations in velocity corresponding to several series of observations are shown in plates 5 and 6. Several other series of observations were obtained for different depths and velocities for both smooth bed and bed of ¾-inch gravel. Diagrams A, B, C, D, and E in plate 5 show the manner in which pulsations in the same depth of water varied with different velocities and with different lengths of individual observations corresponding to 1, 5, or 10 revolutions of the current meter. Diagrams F, G, H, and I, in plate 6 show comparisons of pulsations for different conditions of smooth bed and ¾-inch gravel and for different depths and velocities of water, as well as for differences in periods of observation corresponding to 1 and 2 revolutions of the current meter. Results obtained by use of the pygmy current meter are shown in plate 6, diagram G.

It is, of course, impossible to obtain an instantaneous observation of velocity by means of the current meter, for the principle of the instrument is such that the number of complete revolutions in a measured interval of time corresponds to the average velocity of the water during that interval. The longer the period of time of an observation, therefore, the smaller will be the variation of the mean velocity during the observation period from the average velocity for a long-time period. A comparison of diagrams D and E in plate 5 shows that the variations in the mean velocity for periods corresponding to 5 revolutions of the current meter are much more pronounced and more erratic than the variations in the mean velocity for periods corresponding to 10 revolutions.

It is evident from these diagrams that a period of several minutes would have been required to eliminate entirely the effects of the pulsations in the flume that caused these variations of velocity. However, the comparatively large number of individual observations that make up a complete measurement of discharge in the 12-foot flume—the observation points being taken at 0.5-foot intervals across the 12-foot width, with additional observations at 0.25 foot from each side wall—gave a total period of observation of such length that the plus and minus differences in velocity caused by pulsations during periods of 1 minute or thereabouts were largely compensated.

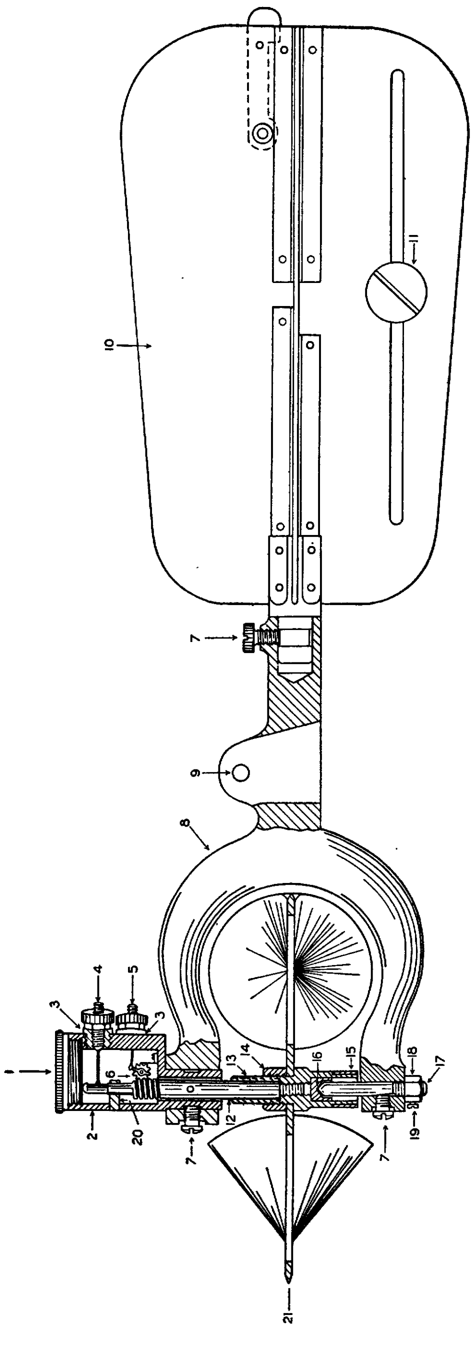
## CURRENT METERS AND OTHER EQUIPMENT USED IN MEASURING DISCHARGE IN THE 12-FOOT FLUME

The investigation of the performance of current meters in measuring velocities in shallow depths necessarily was based on comparisons of discharge measurements by current meters and measurements of the same discharge by other methods. The current meters and other equipment that were used for measuring the discharge in the 12-foot flume are described in the following pages.

### CURRENT METERS

The current meters that were used in this investigation consisted of seven Geological Survey standard-size small Price-type current meters, two Geological Survey cup-type pygmy current meters, one propeller-type pygmy meter, and one propeller-type Ott current meter.

The Geological Survey standard-size current meters were all of the same general type with respect to size and essential features of design (see pl. 1, *A*) and were selected as being representative of current meters generally used by engineers of the Geological Survey in measuring river discharge. Minor differences in design or construction of the current meters are mentioned in descriptions of the individual meters, but those minor differences had no distinguishable effects on the results of the measurements of the total discharge in the flume. The assembly of a Geological Survey type A small Price current meter, which is illustrative of the current meters referred to under that designation, is shown in figure 3.




EXPLANATION

1 Cap for contact chamber
2 Contact chamber
3 Insulating bushing for contact binding post
4 Single-contact binding post (upper)
5 Penta-contact binding post (lower)
6 Penta gear
7 Set screws
8 Yoke
9 Hole for hanger screw
10 Tailpiece
11 Balance weight
12 Shaft
13 Bucket-wheel hub
14 Bucket-wheel hub nut
15 Raising nut
16 Pivot bearing
17 Pivot
18 Pivot adjusting nut
19 Keeper screw for pivot adjusting nut
20 Bearing lug
21 Bucket wheel

FIGURE 3.—Assembly of Geological Survey type A small Price current meter.

All the current meters were rated at the meter-rating station of the National Bureau of Standards. Diagrams showing the results of individual runs in the rating flume, plotted with revolutions per second as ordinates and velocity in feet per second as abscissas, together with the graphic presentation of the ratings for the range of velocities covered by the runs made in the rating flume, were furnished by that Bureau. The ratings were for velocities from 0.10 foot to 2.5 feet per second. Rating tables deduced from equations corresponding to the graphic presentation of the ratings were prepared by engineers of the Geological Survey. The current meters were rerated at frequent intervals, the intervals between ratings depending on the extent of use of the meters. The current meters used in this investigation were not used in other work during the period of investigation.

Current meter 1175, shown in plate 1, *A*, is a standard type A meter equipped with both single and penta contacts. Before its use in this investigation it had been used on routine stream-gaging work in the field and was one of the group of current meters first equipped with type A pivots and bearings. This meter was used for 160 discharge measurements in the 12-foot flume.

Current meter 1196 is similar to standard type A current meters in all respects except that it does not have the penta contact, and the point of the pivot is ground to a sharper angle. This meter was one of a group of meters intended for measuring low velocities in the field, and prior to its use in this investigation it had been in field service. This meter was used for 83 discharge measurements in the 12-foot flume.

Current meter 1217, a standard type A meter, had been used for experimental work at the meter-rating station of the National Bureau of Standards in 1932. This meter was used for 91 discharge measurements in the 12-foot flume.

Current meter 1310 is similar to standard type A meters except that it has the contact chamber built into the yoke about half an inch below the usual position. It was originally constructed as an experimental meter and as such was used in the field by several Survey engineers prior to this investigation. Because of its unusual construction with respect to the position of the contact chamber, meter 1310 was used only to a small extent. Only three of the discharge measurements in the 12-foot flume were made with this meter.

Current meter 1514 is a new type A meter that had not been used before this investigation. It was used in making 112 discharge measurements in the 12-foot flume.

Current meter 2C, a new meter, is of standard type A design except that the bucket wheel is reversed in position so that its direction of rotation is opposite to that of standard meters. This change in the bucket wheel was made in connection with the study of the distribution of velocity near the side walls of the flume. (See pp. 10–12.) Meter 2C was used in making 17 discharge measurements in the 12-foot flume.

Current meter 730 is a "combination" or 623 type meter having interchangeable single-contact and penta heads. The single-contact head was used with this meter in making 14 discharge measurements in the 12-foot flume.

Pygmy meters A3 and A7, constructed by the Geological Survey, are vertical-axis cup-type meters similar to type A current meters but only two-fifths of their size. (See pl. 1, *B*.) The pygmy meters are provided with single contact only, and because of their greater number of revolutions for a foot of travel of the water, the intervals between the contacts at each revolution of the bucket wheel are much shorter than the intervals between the contacts made by the standard-size meters for the same velocities of the water. Although more sensitive to changes in velocity because of the lesser moment of inertia of the bucket wheel, the pygmy meters did not materially differ from the standard-size meters with respect to the precision of their ratings at the velocities for which they were used in this investigation.

Discharge measurements that were made by use of the pygmy meters are listed in the tables on pages 28–31 and include 173 measurements made with meter A3 and 22 measurements made with meter A7. Besides these measurements, the pygmy meters were used also in studying the distribution of velocities near flume walls and the variation of velocities in verticals.

Pygmy meter A2 is a horizontal-axis propeller-type meter having four blades of 20° pitch and a diameter of rotor of 0.75 inch. This meter was used for purposes of comparison with the vertical-axis cup-type current meters in studying the distribution of velocities in the flume and in making six discharge measurements listed on page 32.

The Ott Xb meter is a horizontal-axis propeller-type meter having three blades protected by a band 3 inches in diameter. Comparisons of measurements by this meter and by other meters and the pitot static tube are shown in the table on page 12. The results of 10 discharge measurements made with the Ott Xb meter are listed on page 32.

## PITOT STATIC TUBE

The pitot static tube was used principally for investigating the distribution of velocities near the side walls and in verticals at various points across the width of the flume. Vertical velocity curves plotted from velocity measurements made with the pitot tube are shown in plate 4.

This instrument consists essentially of two concentric tubes: The inner tube, of ⅛-inch outside diameter, is open at the upstream end; the outer tube, of 5/16-inch outside diameter, is beveled at the upper end to the diameter of the inner tube. The space between the two tubes is filled by a jacket extending back 1 7/16 inches from the end. The length of the tube from the upstream end to the center of the two riser tubes is 5½ inches. The static water pressure is communicated to the outer tube through 15 holes, each hole 1 mm. in diameter, arranged in three rows of five holes in each row. The first row of holes is 1⅝ inches from the end of the tube; the other rows of holes are 3/16 inch and ⅜ inch, respectively, from the first row. The impulse tube and the static tube were connected to vertical riser tubes 2 feet in length. Flexible connections are carried from the end of each riser tube to inclined manometer gages. The riser tubes are supported by a traveler operating on a frame spanning the flume, and after the instrument is adjusted to the desired position in the water it is clamped in place so that the attention of the operator can be directed to readings of the manometer gages. These gages are inclined at a slope of 1 on 5. A calibration of the pitot static tube showed that the instrument constant was 1.000. The velocity of the water was computed from the formula $V=\sqrt{2g(h_1-h_2)}$, in which $h_1$ and $h_2$ were obtained from readings of the manometer gages. Those gages were calibrated in the inclined position in which they were used, so that effects of possible differences in the slopes of the two gages or irregularities in their bore were eliminated.

Point measurements of velocities by means of the pitot static tube were obtained as close as 0.01 foot to the side walls and bottom of the flume and within 0.01 foot from the water surface. Variations in pressure caused by pulsations of the water made instantaneous readings somewhat uncertain; therefore the variations in $h_1$ and $h_2$ were averaged by inspection over an interval of several minutes before making determinations of height. Several measurements of discharge in the flume were made by means of the pitot static tube. Comparisons of three of those measurements with measurements of the same discharge by current meters are given in the table on page 12.

## SHARP-CRESTED WEIR

The sharp-crested weir that was accepted as the standard of comparison for the current-meter measurements of discharge was at the lower end of the 12-foot flume, about 99 feet from the section of the flume where the measurements were made. The weir had a level crest 7.99 feet wide. The contractions at the ends of the weir were cut off by vertical approach walls that began 3 feet upstream from the weir and reached a width of 22 inches at a point 3 inches upstream from the crest, leaving a contraction of 2 inches at each end of the weir. The top of the steel crest was 5 inches above the bottom of the flume, and it had a width of 1/16-inch with a downstream bevel of 45°. The thickness of the steel plate below the bevel was a quarter of an inch. The intake to the gage well led from the bottom of the flume, 5.62 feet from the weir crest. A hook gage was used in measuring the head on the weir. The weir was calibrated by means of an 8-inch venturi meter that had been calibrated previously by the weighing tanks. The weir was also calibrated volumetrically by observing heights of water in the tumble bay. The weir rating that was used in the computations of discharge was based on the laboratory calibrations by the above-described methods and was accepted as the standard of comparison for the current-meter measurements except for discharges less than 3.5 second-feet.

## VENTURI METERS

The two venturi meters that were used in measurements of discharge below 3.5 second-feet were inserted in 8-inch and 4-inch supply pipes and had throat diameters of 4 inches and 2 inches, respectively. Both meters were calibrated by means of the weighing tanks, and the following equations of discharge were determined from plottings of the calibration curves: For the 8-inch venturi meter, $Q=0.144\sqrt{h}$, and for the 4-inch venturi meter, $Q=0.0234\sqrt{h}$, where $h$ is the difference, in millimeters, of heads at the entrance and the throat of the meter.

The 8-inch venturi meter was used as the standard of measurement for discharges between 0.5 second-foot and 3.5 second-feet. The 4-inch venturi meter was used as the standard for measurements of 0.5 second-foot or less.

## DISCHARGE MEASUREMENTS

*Discharge measurements made with standard-size small Price-type current meters*

**Smooth concrete flume bed**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 260 | 1514 | 0.20 | 0.35d | 0.50 | [1] 1.205 | 1.327 | 0.908 |
| 261 | 730 | .20 | .35d | .50 | [1] 1.205 | 1.332 | .905 |
| 262 | 1514 | .20 | .35d | 1.00 | [1] 2.400 | 2.026 | 1.185 |
| 263 | 1514 | .20 | .35d | 1.26 | [1] 3.014 | 2.257 | 1.335 |
| 264 | 1514 | .20 | .35d | 1.52 | 3.653 | 2.454 | 1.489 |
| 266 | 1514 | .20 | .35d | .80 | [1] 1.916 | 1.812 | 1.057 |
| 267 | 1514 | .20 | .35d | .40 | [1] .966 | 1.087 | .889 |
| 270 | 1514 | .20 | .35d | .20 | [1] .478 | .516 | .926 |
| 272 | 1514 | .20 | .35d | .30 | [1] .734 | .829 | .885 |
| 297 | 1514 | .20 | .35d | .20 | [1] .478 | .552 | .866 |

[1] By 8-inch venturi meter.

NOTE.—For the condition of 0.2-foot depth of water on the concrete bottom of the flume, the current-meter cups could not be placed exactly at middepth. For this condition the center of the meter cups was at a depth of 0.07 foot below the water surface when the bottom of the meter yoke rested on the concrete, and the top edges of the cups were out of the water. For descriptions of the individual current meters see pages 15-18.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Smooth concrete flume bed—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 244 | 1217 | 0.30 | 0.5d | 1.51 | 5.55 | 4.41 | 1.236 |
| 245 | 1217 | .30 | .5d | 1.26 | 4.54 | 4.09 | 1.110 |
| 246 | 1217 | .30 | .5d | 1.02 | 3.66 | 3.58 | 1.022 |
| 247 | 1514 | .30 | .5d | .30 | [1] 1.087 | 1.089 | .998 |
| 250 | 1514 | .30 | .5d | .80 | [1] 2.891 | 2.846 | 1.016 |
| 255 | 1514 | .30 | .5d | .50 | [1] 1.799 | 1.787 | 1.007 |
| 256 | 730 | .30 | .5d | .50 | [1] 1.799 | 1,763 | 1.020 |
| 269 | 1514 | .30 | .5d | .40 | [1] 1.440 | 1,350 | 1.067 |
| 273 | 1514 | .30 | .5d | .20 | [1] .734 | .667 | 1.100 |
| 296 | 1514 | .30 | .5d | .40 | [1] 1.440 | 1.391 | 1.035 |
| 298 | 1514 | .30 | .5d | .20 | [1] .727 | .680 | 1.069 |
| 299 | 1514 | .30 | .5d | .30 | [1] 1.087 | 1.032 | 1.053 |
| 236 | 1217 | .40 | .5d | 1.52 | 7.28 | 6.86 | 1.061 |
| 238 | 1217 | .40 | .5d | 1.26 | 6.06 | 5.83 | 1.039 |
| 241 | 1514 | .40 | .5d | 1.01 | 4.85 | 4.86 | .998 |
| 243 | 1514 | .40 | .5d | .80 | 3.86 | 3.76 | 1.027 |
| 249 | 1514 | .40 | .5d | .50 | [1] 2.405 | 2.340 | 1.028 |
| 265 | 1514 | .40 | .5d | .40 | [1] 1,916 | 1.889 | 1.014 |
| 268 | 1514 | .40 | .5d | .30 | [1] 1.440 | 1.410 | 1.021 |
| 271 | 1514 | .40 | .5d | .20 | [1] .966 | .925 | 1.044 |
| 236a | 1217 | .40 | .6d | 1.52 | 7.28 | 6.80 | 1.071 |
| 238a | 1217 | .40 | .6d | 1.26 | 6.06 | 5.65 | 1.073 |
| 241a | 1514 | .40 | .6d | 1.01 | 4.85 | 4.71 | 1.030 |
| 243a | 1514 | .40 | .6d | .80 | 3.86 | 3.69 | 1.046 |
| 249a | 1514 | .40 | .6d | .50 | [1] 2.405 | 2.260 | 1.064 |
| 265a | 1514 | .40 | .6d | .40 | [1] 1.916 | 1.732 | 1.106 |
| 268a | 1514 | .40 | .6d | .30 | [1] 1.440 | 1.318 | 1.093 |
| 271a | 1514 | .40 | .6d | .20 | [1] .966 | .874 | 1.105 |
| 224 | 1514 | .52 | .5d | 1.20 | 7.56 | 7.80 | .969 |
| 232 | 1217 | .50 | .5d | 1.51 | 9.07 | 9.11 | .996 |
| 237 | 1217 | .50 | .5d | 1.00 | 6.03 | 6.16 | .979 |
| 240 | 1514 | .50 | 5d | .81 | 4.85 | 4.95 | .980 |
| 248 | 1514 | .50 | .5d | .40 | [1] 2.405 | 2.449 | .982 |
| 252 | 1514 | .50 | .5d | .50 | [1] 3.014 | 3.049 | .989 |
| 254 | 1514 | .50 | .5d | .30 | [1] 1.799 | 1.719 | 1.047 |
| 259 | 1514 | .50 | .5d | .20 | [1] 1.205 | 1.179 | 1.022 |
| 293 | 1514 | .50 | .5d | 1.26 | 7.56 | 7.68 | .984 |
| 294 | 1514 | .50 | .5d | .30 | [1] 1.799 | 1.811 | .993 |
| 224a | 1514 | .52 | .6d | 1.20 | 7.56 | 7.63 | .991 |
| 232a | 1217 | .50 | .6d | 1.51 | 9.07 | 8.87 | 1.023 |
| 237a | 1217 | .50 | .6d | 1.00 | 6.03 | 6.02 | 1.002 |
| 240a | 1514 | .50 | .6d | .81 | 4.85 | 4.85 | 1.000 |
| 248a | 1514 | .50 | .6d | .40 | [1] 2.405 | 2.328 | 1.033 |
| 252a | 1514 | .50 | .6d | .50 | [1] 3.014 | 2.898 | 1.040 |
| 254a | 1514 | .50 | .6d | .30 | [1] 1.799 | 1.637 | 1.099 |
| 259a | 1514 | .50 | .6d | .20 | [1] 1.205 | 1.128 | 1.068 |
| 293a | 1514 | .50 | .6d | 1.26 | 7.56 | 7.45 | 1.015 |
| 294a | 1514 | .50 | .6d | .30 | [1] 1.799 | 1.717 | 1.048 |
| 306 | 1514 | .50 | .6d | 1.01 | 6.06 | 5.94 | 1.020 |
| 307 | 2C | .50 | .6d | 1.01 | 6.06 | 6.03 | 1.005 |
| 310 | 1514 | .50 | .6d | .50 | [1] 3.000 | 2.928 | 1.025 |
| 311 | 2C | .50 | .6d | .50 | [1] 3.000 | 2.976 | 1.008 |
| 346 | 1514 | .50 | .6d | .50 | [1] 3.000 | 2.947 | 1.018 |
| 347 | 2C | .50 | .6d | .50 | [1] 3.000 | 3.030 | .990 |
| 350 | 2C | .50 | .6d | 1.00 | 6.01 | 6.02 | .998 |
| 351 | 1514 | .50 | .6d | 1.00 | 6.01 | 5.90 | 1.019 |
| 7 | 1196 | .60 | .5d | .19 | 1.376 | 1.431 | .962 |
| 45 | 1196 | .60 | .5d | .10 | [1] .720 | .726 | .992 |
| 65 | 730 | .60 | .5d | .20 | [1] 1.440 | 1.447 | .995 |
| 222 | 1217 | .61 | .5d | 1.49 | 10.94 | 11.10 | .986 |
| 233 | 1217 | .60 | .5d | 1.26 | 9.07 | 9.20 | .986 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Smooth concrete flume bed—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 235 | 1217 | 0.60 | 0.5d | 1.01 | 7.28 | 7.52 | 0.968 |
| 239 | 1175 | .60 | .5d | .81 | 5.80 | 6.04 | .960 |
| 242 | 1514 | .60 | .5d | .50 | 3.62 | 3.71 | .976 |
| 251 | 1514 | .60 | .5d | .40 | [1] 2.891 | 3.010 | .960 |
| 253 | 1514 | .60 | .5d | .30 | [1] 2.156 | 2.171 | .993 |
| 384 | 1514 | .60 | .5d | .30 | [1] 2.160 | 2.176 | .993 |
| 7a | 1196 | .60 | .6d | .19 | 1.376 | 1.355 | 1.015 |
| 39 | 1196 | .60 | .6d | .09 | .649 | .603 | 1.076 |
| 40 | 1175 | .60 | .6d | .09 | .649 | .660 | .983 |
| 45a | 1196 | .60 | .6d | .10 | [1] .720 | .691 | 1.042 |
| 65a | 730 | .60 | .6d | .20 | [1] 1.440 | 1.392 | 1.034 |
| 222a | 1217 | .61 | .6d | 1.49 | 10.94 | 10.91 | 1.003 |
| 233a | 1217 | .60 | .6d | 1.26 | 9.07 | 8.91 | 1.018 |
| 234 | 1514 | .60 | .6d | 1.01 | 7.28 | 7.24 | 1.006 |
| 239a | 1175 | .60 | .6d | .81 | 5.80 | 5.81 | .998 |
| 242a | 1514 | .60 | .6d | .50 | 3.62 | 3.55 | 1.020 |
| 251a | 1514 | .60 | .6d | .40 | [1] 2.891 | 2.772 | 1.043 |
| 253a | 1514 | .60 | .6d | .30 | [1] 2.156 | 2.030 | 1.062 |
| 357 | 1175 | .60 | .6d | .20 | [1] 1.436 | 1.375 | 1.044 |
| 384a | 1514 | .60 | .6d | .30 | [1] 2.160 | 1.990 | 1.085 |
| 3a | 1175 | .79 | .5d | .50 | 4.70 | 5.00 | .940 |
| 16a | 1196 | .80 | .5d | .19 | 1.844 | 1.903 | .969 |
| 26a | 1196 | .80 | .5d | .40 | 3.80 | 3.93 | .967 |
| 27a | 1196 | .80 | .5d | .30 | 2.842 | 2.969 | .957 |
| 42a | 1175 | .80 | .5d | .10 | [1] .966 | 1.017 | .950 |
| 47a | 1196 | .80 | .5d | .20 | [1] 1.921 | 1.933 | .994 |
| 56a | 1196 | .80 | .5d | .20 | [1] 1.916 | 1.895 | 1.011 |
| 61a | 730 | .80 | .5d | .50 | [1] 4.77 | 4.97 | .960 |
| 213a | 1217 | .81 | .5d | .99 | 9.68 | 10.14 | .955 |
| 221a | 1217 | .80 | .5d | 1.50 | 14.47 | 14.88 | .972 |
| 3b | 1175 | .79 | .6d | .50 | 4.70 | 4.71 | .998 |
| 16b | 1196 | .80 | .6d | .19 | 1.844 | 1.823 | 1.012 |
| 26b | 1196 | .80 | .6d | .40 | 3.80 | 3.69 | 1.030 |
| 27b | 1196 | .80 | .6d | .30 | 2.842 | 2.858 | .994 |
| 42b | 1175 | .80 | .6d | .10 | [1] .966 | .947 | 1.020 |
| 47b | 1196 | .80 | .6d | .20 | [1] 1.921 | 1.902 | 1.010 |
| 50 | 1217 | .80 | .6d | .51 | 4.85 | 4.89 | .992 |
| 56b | 1196 | .80 | .6d | .20 | [1] 1.916 | 1.825 | 1.050 |
| 58 | 1196 | .80 | .6d | .40 | 3.84 | 3.76 | 1.021 |
| 61b | 730 | .80 | .6d | .50 | 4.77 | 4.76 | 1.002 |
| 213b | 1217 | .81 | .6d | 1.00 | 9.68 | 9.68 | 1.000 |
| 221b | 1217 | .80 | .6d | 1.50 | 14.47 | 14.33 | 1.010 |
| 358 | 1175 | .80 | .6d | .40 | 3.80 | 3.81 | .997 |
| 57 | 1196 | 1.00 | .5d | .20 | 2.405 | 2.300 | 1.046 |
| 214 | 1175 | 1.01 | .5d | .50 | 6.11 | 6.42 | .952 |
| 218 | 1217 | 1.00 | .5d | 1.50 | 18.10 | 18.39 | .984 |
| 219 | 1217 | 1.00 | .5d | 1.00 | 12.09 | 12.57 | .962 |
| 227 | 1514 | 1.01 | .5d | .20 | 2.405 | 2.274 | 1.058 |
| 230 | 1175 | 1.00 | .5d | .30 | 3.62 | 3.71 | .976 |
| 1a | 1175 | 1.00 | .6d | .79 | 9.49 | 9.57 | .992 |
| 4a | 1175 | 1.00 | .6d | .49 | 5.88 | 5.94 | .990 |
| 6a | 1196 | 1.00 | .6d | .20 | 2.438 | 2.403 | 1.015 |
| 8a | 1175 | 1.00 | .6d | .61 | 7.28 | 7.44 | .978 |
| 9a | 1175 | 1.04 | .6d | .96 | 12.03 | 12.31 | .977 |
| 18a | 1196 | 1.00 | .6d | .30 | 3.55 | 3.64 | .975 |
| 19a | 1196 | 1.00 | .6d | .40 | 4.75 | 4.84 | .981 |
| 25 | 1196 | .98 | .6d | .10 | 1.159 | 1.204 | .963 |
| 37 | 1196 | 1.00 | .6d | .10 | 1.138 | 1.059 | 1.075 |
| 46a | 1196 | 1.02 | .6d | .09 | [1] 1.106 | 1.047 | 1.056 |
| 48 | 1217 | 1.00 | .6d | .80 | 9.61 | 9.80 | .981 |
| 48a | 1217 | 1.00 | .6d | .80 | 9.61 | 9.69 | .992 |
| 49a | 1217 | 1.04 | .6d | .96 | 11.96 | 12.17 | .983 |
| 51a | 1217 | 1.00 | .6d | .49 | 5.93 | 5.94 | .998 |
| 52a | 1217 | 1.00 | .6d | .60 | 7.20 | 7.36 | .978 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Smooth concrete flume bed—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 53a | 1217 | 1.00 | 0.6d | 0.40 | 4.80 | 4.90 | 0.980 |
| 54 | 1196 | 1.00 | .6d | .10 | [1] 1.205 | 1.068 | 1.128 |
| 57a | 1196 | 1.00 | .6d | .20 | [1] 2.405 | 2.260 | 1.064 |
| 59a | 730 | 1.04 | .6d | .96 | 11.99 | 12.06 | .994 |
| 60a | 730 | 1.00 | .6d | .50 | 6.01 | 6.02 | .998 |
| 218a | 1217 | 1.00 | .6d | 1.50 | 18.10 | 17.85 | 1.014 |
| 300a | 1514 | 1.00 | .6d | .20 | [1] 2.401 | 2.329 | 1.031 |
| 302a | 1217 | 1.00 | .6d | 1.52 | 18.18 | 18.12 | 1.003 |
| 305a | 1514 | 1.00 | .6d | .81 | 9.71 | 9.78 | .993 |
| 360 | 1175 | 1.00 | .6d | .50 | 5.99 | 5.94 | 1.008 |
| 1b | 1175 | 1.00 | .2d, .8d | .79 | 9.49 | 9.00 | 1.054 |
| 4d | 1175 | 1.00 | .2d, .8d | .49 | 5.88 | 5.63 | 1.044 |
| 6b | 1196 | 1.00 | .2d, .8d | .20 | 2.438 | 2.297 | 1.061 |
| 8b | 1175 | 1.00 | .2d, .8d | .61 | 7.28 | 6.97 | 1.044 |
| 9b | 1175 | 1.04 | .2d, .8d | .96 | 12.03 | 11.58 | 1.039 |
| 18b | 1196 | 1.00 | .2d, .8d | .30 | 3.55 | 3.41 | 1.041 |
| 19b | 1196 | 1.00 | .2d, .8d | .40 | 4.75 | 4.61 | 1.030 |
| 46b | 1196 | 1.02 | .2d, .8d | .09 | [1] 1.106 | 1.023 | 1.081 |
| 48b | 1217 | 1.00 | .2d, .8d | .80 | 9.61 | 9.25 | 1.039 |
| 49b | 1217 | 1.04 | .2d, .8d | .96 | 11.96 | 11.58 | 1.033 |
| 51b | 1217 | 1.00 | .2d, .8d | .49 | 5.93 | 5.76 | 1.030 |
| 52b | 1217 | 1.00 | .2d, .8d | .60 | 7.20 | 7.24 | .994 |
| 53b | 1217 | 1.00 | .2d, .8d | .40 | 4.80 | 4.70 | 1.021 |
| 55 | 1196 | 1.00 | .2d, .8d | .10 | [1] 1.205 | 1.101 | 1.094 |
| 57b | 1196 | 1.00 | .2d, .8d | .20 | [1] 2.405 | 2.189 | 1.099 |
| 59b | 730 | 1.04 | .2d, .8d | .96 | 11.99 | 11.66 | 1.028 |
| 60b | 730 | 1.00 | .2d, .8d | .50 | 6.01 | 5.91 | 1.017 |
| 218b | 1217 | 1.00 | .2d, .8d | 1.50 | 18.10 | 17.05 | 1.062 |
| 300b | 1514 | 1.00 | .2d, .8d | .20 | [1] 2.401 | 2.303 | 1.043 |
| 302b | 1514 | 1.00 | .2d, .8d | 1.52 | 18.18 | 17.36 | 1.047 |
| 305b | 1514 | 1.00 | .2d, .8d | .81 | 9.71 | 9.36 | 1.037 |
| 360 | 1175 | 1.00 | .2d, .8d | .50 | 5.99 | 5.70 | 1.051 |
| 216 | 1217 | 1.26 | .5d | 1.49 | 22.66 | 23.10 | .981 |
| 220 | 1217 | 1.25 | .5d | 1.00 | 15.11 | 15.50 | .975 |
| 223a | 1175 | 1.25 | .5d | .50 | 7.56 | 7.90 | .957 |
| 226a | 1175 | 1.26 | .5d | .30 | 4.54 | 4.77 | .952 |
| 231 | 1514 | 1.26 | .5d | .20 | [1] 3.017 | 2.802 | 1.077 |
| 5a | 1175 | 1.25 | .6d | 1.25 | 18.69 | 19.12 | .978 |
| 11a | 1196 | 1.25 | .6d | .49 | 7.39 | 7.56 | .978 |
| 12a | 1175 | 1.24 | .6d | 1.01 | 15.04 | 15.30 | .983 |
| 14a | 1175 | 1.24 | .6d | .81 | 12.08 | 12.52 | .965 |
| 15a | 1196 | 1.25 | .6d | .20 | 2.950 | 2.938 | 1.004 |
| 22a | 1196 | 1.25 | .6d | .30 | 4.46 | 4.51 | .989 |
| 24a | 1196 | 1.25 | .6d | .30 | 4.43 | 4.53 | .978 |
| 28a | 1217 | 1.24 | .6d | .60 | 8.95 | 9.08 | .986 |
| 29a | 1175 | 1.24 | .6d | .40 | 5.92 | 5.94 | .997 |
| 43a | 1175 | 1.24 | .6d | .10 | [1] 1.503 | 1.555 | .967 |
| 62a | 1217 | 1.24 | .6d | .61 | 9.04 | 9.12 | .991 |
| 216a | 1217 | 1.26 | .6d | 1.50 | 22.66 | 22.70 | .998 |
| 308a | 1514 | 1.25 | .6d | 1.01 | 15.13 | 15.13 | 1.000 |
| 309a | 2C | 1.25 | .6d | 1.01 | 15.13 | 15.56 | .972 |
| 312a | 1514 | 1.25 | .6d | .51 | 7.59 | 7.75 | .979 |
| 313a | 2C | 1.25 | .6d | .51 | 7.59 | 7.86 | .966 |
| 314 | 1175 | 1.25 | .6d | 1.00 | 15.06 | 14.97 | 1.006 |
| 315 | 2C | 1.25 | .6d | 1.00 | 15.06 | 15.25 | .988 |
| 330 | 1514 | 1.25 | .6d | 1.00 | 15.00 | 15.01 | .999 |
| 331 | 2C | 1.25 | .6d | 1.00 | 15.00 | 15.33 | .978 |
| 338 | 1514 | 1.25 | .6d | .50 | 7.51 | 7.70 | .975 |
| 339 | 2C | 1.25 | .6d | .50 | 7.51 | 7.75 | .969 |
| 361a | 1175 | 1.25 | .6d | .50 | 7.51 | 7.57 | .992 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Smooth concrete flume bed—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 5b | 1175 | 1.25 | 0.2d, 0.8d | 1.25 | 18.69 | 18.33 | 1.020 |
| 11b | 1196 | 1.25 | .2d, .8d | .49 | 7.39 | 7.24 | 1.021 |
| 12b | 1175 | 1.24 | .2d, .8d | 1.01 | 15.04 | 14.84 | 1.013 |
| 14b | 1175 | 1.24 | .2d, .8d | .81 | 12.08 | 11.89 | 1.016 |
| 15b | 1196 | 1.25 | .2d, .8d | .20 | 2.950 | 2.893 | 1.020 |
| 22b | 1196 | 1.25 | .2d, .8d | .30 | 4.46 | 4.43 | 1.007 |
| 24b | 1196 | 1.25 | .2d, .8d | .30 | 4.43 | 4.34 | 1.021 |
| 28b | 1217 | 1.24 | .2d, .8d | .60 | 8.95 | 8.91 | 1.004 |
| 29b | 1175 | 1.24 | .2d, .8d | .40 | 5.92 | 5.85 | 1.012 |
| 43b | 1175 | 1.24 | .2d, .8d | .10 | [1] 1.503 | 1.504 | .999 |
| 62b | 1175 | 1.24 | .2d, .8d | .61 | 9.04 | 8.89 | 1.017 |
| 216b | 1217 | 1.26 | .2d, .8d | 1.50 | 22.66 | 21.91 | 1.034 |
| 223b | 1175 | 1.25 | .2d, .8d | .50 | 7.56 | 7.45 | 1.015 |
| 226b | 1175 | 1.26 | .2d, .8d | .30 | 4.54 | 4.43 | 1.025 |
| 308b | 1514 | 1.25 | .2d, .8d | 1.01 | 15.13 | 14.95 | 1.012 |
| 309b | 2C | 1.25 | .2d, .8d | 1.01 | 15.13 | 15.11 | 1.001 |
| 312b | 1514 | 1.25 | .2d, .8d | .51 | 7.59 | 7.67 | .990 |
| 313b | 2C | 1.25 | .2d, .8d | .51 | 7.59 | 7.62 | .996 |
| 334 | 1514 | 1.25 | .2d, .8d | 1.00 | 15.02 | 14.78 | 1.016 |
| 335 | 2C | 1.25 | .2d, .8d | 1.00 | 15.02 | 15.01 | 1.001 |
| 344 | 1514 | 1.25 | .2d, .8d | .50 | 7.51 | 7.41 | 1.013 |
| 345 | 2C | 1.25 | .2d, .8d | .50 | 7.51 | 7.51 | 1.000 |
| 361b | 1175 | 1.25 | .2d, .8d | .50 | 7.51 | 7.32 | 1.026 |
| 212 | 1175 | 1.49 | .5d | .50 | 9.07 | 9.49 | .956 |
| 215 | 1217 | 1.52 | .5d | 1.49 | 27.33 | 27.87 | .981 |
| 217 | 1217 | 1.49 | .5d | 1.01 | 18.14 | 18.63 | .974 |
| 225 | 1514 | 1.53 | .5d | .30 | 5.48 | 5.60 | .979 |
| 229 | 1175 | 1.52 | .5d | .20 | 3.62 | 3.59 | 1.008 |
| 2a | 1175 | 1.50 | .6d | .50 | 9.03 | 9.06 | .997 |
| 13a | 1175 | 1.50 | .6d | 1.00 | 18.01 | 18.39 | .979 |
| 17a | 1196 | 1.51 | .6d | .20 | 3.55 | 3.50 | 1.014 |
| 20a | 1175 | 1.50 | .6d | 1.25 | 22.51 | 22.54 | .999 |
| 21a | 1217 | 1.53 | .6d | 1.46 | 26.97 | 27.53 | .980 |
| 23a | 1217 | 1.50 | .6d | 1.25 | 22.58 | 22.61 | .999 |
| 30a | 1217 | 1.50 | .6d | .80 | 14.42 | 14.69 | .982 |
| 31a | 1217 | 1.50 | .6d | .60 | 10.75 | 10.76 | .999 |
| 32a | 1196 | 1.50 | .6d | .40 | 7.17 | 6.87 | 1.044 |
| 33a | 1196 | 1.51 | .6d | .30 | 5.34 | 5.47 | .976 |
| 34a | 1196 | 1.50 | .6d | .40 | 7.14 | 7.38 | .967 |
| 41a | 1175 | 1.50 | .6d | .40 | 7.20 | 7.15 | 1.007 |
| 44a | 1196 | 1.52 | .6d | .10 | [1] 1.799 | 1.697 | 1.060 |
| 63a | 730 | 1.50 | .6d | .50 | 8.98 | 9.15 | .981 |
| 64a | 730 | 1.50 | .6d | 1.00 | 18.03 | 18.00 | 1.002 |
| 225a | 1514 | 1.53 | .6d | .30 | 5.48 | 5.37 | 1.020 |
| 228 | 1514 | 1.52 | .6d | .20 | 3.62 | 3.41 | 1.062 |
| 301a | 1217 | 1.50 | .6d | 1.26 | 22.66 | 22.99 | .986 |
| 303a | 1514 | 1.50 | .6d | .20 | 3.64 | 3.70 | .984 |
| 304a | 1514 | 1.50 | .6d | .81 | 14.51 | 14.93 | .972 |
| 362a | 1175 | 1.50 | .6d | .50 | 8.98 | 9.14 | .982 |
| 2b | 1175 | 1.50 | .2d, .8d | .50 | 9.03 | 8.83 | 1.023 |
| 13b | 1175 | 1.50 | .2d, .8d | 1.00 | 18.01 | 17.71 | 1.017 |
| 17b | 1196 | 1.51 | .2d, .8d | .20 | 3.55 | 3.45 | 1.029 |
| 20b | 1175 | 1.50 | .2d, .8d | 1.25 | 22.51 | 22.36 | 1.007 |
| 21b | 1217 | 1.53 | .2d, .8d | 1.46 | 26.97 | 26.68 | 1.011 |
| 23b | 1217 | 1.50 | .2d, .8d | 1.25 | 22.58 | 22.34 | 1.011 |
| 30b | 1217 | 1.50 | .2d, .8d | .80 | 14.42 | 14.35 | 1.005 |
| 31b | 1217 | 1.50 | .2d, .8d | .60 | 10.75 | 10.60 | 1.014 |
| 32b | 1196 | 1.50 | .2d, .8d | .40 | 7.17 | 7.07 | 1.014 |
| 33b | 1196 | 1.51 | .2d, .8d | .30 | 5.34 | 5.28 | 1.011 |
| 34b | 1196 | 1.51 | .2d, .8d | .39 | 7.14 | 7.34 | .973 |
| 41b | 1175 | 1.50 | .2d, .8d | .40 | 7.20 | 7.45 | .966 |
| 44b | 1196 | 1.52 | .2d, .8d | .10 | [1] 1.799 | 1.761 | 1.022 |
| 63b | 730 | 1.50 | .2d, .8d | .50 | 8.98 | 9.03 | .994 |
| 64b | 730 | 1.50 | .2d, .8d | 1.00 | 18.03 | 17.57 | 1.026 |
| 301b | 1217 | 1.50 | .2d, .8d | 1.26 | 22.66 | 22.58 | 1.004 |
| 303b | 1514 | 1.50 | .2d, .8d | .20 | 3.64 | 3.57 | 1.020 |
| 304b | 1514 | 1.50 | .2d, .8d | .81 | 14.51 | 14.62 | .992 |
| 362b | 1175 | 1.50 | .2d, .8d | .50 | 8.98 | 8.76 | 1.025 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Flume bed covered with ¾-inch gravel**

| Measure-ment No. | Meter No. | Depth of water (feet) | Method of measure-ment | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measure-ment |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 108 | 1175 | 0.20 | 0.5d | 0.30 | [1] 0.720 | 0.706 | 1.020 |
| 109 | 1175 | .21 | .5d | .47 | [1] 1.205 | 1.159 | 1.040 |
| 110 | 1175 | .21 | .5d | .94 | [1] 2.400 | 1.867 | 1.285 |
| 113 | 1217 | .21 | .5d | 1.18 | [1] 3.021 | 2.145 | 1.408 |
| 114 | 1217 | .21 | .5d | 1.18 | [1] 3.021 | 2.155 | 1.402 |
| 117 | 1196 | .20 | .5d | .20 | [2] .482 | .475 | 1.015 |
| 129 | 1217 | .23 | .5d | 1.28 | 3.554 | 2.633 | 1.350 |
| 168 | 1175 | .21 | .5d | .57 | [1] 1.440 | 1.344 | 1.071 |
| 178 | 1175 | .21 | .5d | .76 | [1] 1.916 | 1.645 | 1.165 |
| 181 | 1175 | .20 | .5d | .40 | [1] .966 | .935 | 1.033 |
| 185 | 1175 | .21 | .5d | .76 | [1] 1.916 | 1.658 | 1.156 |
| 381 | 1514 | .20 | .5d | .50 | [1] 1.207 | 1.280 | .943 |
| 383 | 1514 | .20 | .5d | 1.25 | [1] 3.000 | 2.191 | 1.369 |
| 66 | 1175 | .32 | .5d | 1.41 | 5.38 | 4.44 | 1.212 |
| 67 | 1175 | .27 | .43d | 1.12 | 3.60 | 3.02 | 1.192 |
| 71 | 1196 | .30 | .5d | 1.25 | 4.52 | 3.88 | 1.165 |
| 76 | 1196 | .31 | .5d | .77 | [1] 2.887 | 2.713 | 1.064 |
| 80 | 1196 | .31 | .5d | .48 | 1.777 | 1.622 | 1.096 |
| 84 | 1175 | .30 | .5d | 1.47 | 5.38 | 4.23 | 1.272 |
| 87 | 1310 | .30 | .5d | 1.48 | 5.40 | 4.33 | 1.247 |
| 97 | 1196 | .30 | .5d | .30 | [1] 1.087 | 1.063 | 1.023 |
| 107 | 1196 | .30 | .5d | .99 | 3.58 | 3.31 | 1.082 |
| 145 | 1175 | .31 | .5d | .48 | [1] 1.799 | 1.725 | 1.043 |
| 157 | 1175 | .30 | .5d | 1.25 | 4.52 | 3.76 | 1.202 |
| 166 | 1175 | .32 | .5d | .19 | [1] .727 | .628 | 1.158 |
| 167 | 1175 | .29 | .5d | .41 | [1] 1.440 | 1.404 | 1.026 |
| 171 | 1175 | .30 | .5d | .80 | [1] 2.891 | 2.560 | 1.129 |
| 177 | 1175 | .30 | .5d | .60 | [1] 2.160 | 2.044 | 1.057 |
| 382 | 1514 | .30 | .5d | .50 | [1] 1.799 | 1.619 | 1.111 |
| 68 | 1175 | .41 | .5d | 1.46 | 7.23 | 6.85 | 1.055 |
| 70 | 1175 | .39 | .5d | 1.03 | 4.80 | 4.69 | 1.023 |
| 72 | 1196 | .40 | .5d | 1.25 | 6.03 | 6.01 | 1.003 |
| 81 | 1196 | .40 | .5d | .79 | 3.82 | 3.65 | 1.047 |
| 90 | 1175 | .40 | .5d | 1.49 | 7.17 | 6.75 | 1.062 |
| 91 | 1310 | .40 | .5d | 1.49 | 7.17 | 6.85 | 1.047 |
| 96 | 1217 | .43 | .5d | 1.85 | 9.58 | 9.09 | 1.054 |
| 98 | 1196 | .40 | .5d | .30 | [1] 1.440 | 1.462 | .985 |
| 101 | 1175 | .41 | .5d | .49 | [1] 2.405 | 2.487 | .967 |
| 116 | 1196 | .40 | .5d | .10 | [2] .480 | .443 | 1.084 |
| 120 | 1175 | .40 | .5d | .20 | [1] .966 | .949 | 1.018 |
| 163 | 1217 | .40 | .5d | 1.25 | 6.06 | 5.86 | 1.034 |
| 170 | 1175 | .40 | .5d | .60 | [1] 2.891 | 2.831 | 1.021 |
| 176 | 1175 | .40 | .5d | .80 | 3.84 | 3.71 | 1.035 |
| 179 | 1175 | .40 | .5d | .40 | [1] 1.916 | 1.927 | .994 |
| 186 | 1175 | .40 | .5d | .50 | [1] 2.405 | 2.433 | .988 |
| 386 | 1514 | .40 | .5d | .50 | [1] 2.401 | 2.375 | 1.011 |
| 68a | 1175 | .41 | .6d | 1.46 | 7.23 | 6.49 | 1.114 |
| 70a | 1175 | .39 | .6d | 1.03 | 4.80 | 4.47 | 1.074 |
| 72a | 1196 | .40 | .6d | 1.25 | 6.03 | 5.62 | 1.073 |
| 81a | 1196 | .40 | .6d | .79 | 3.82 | 3.40 | 1.124 |
| 90a | 1175 | .40 | .6d | 1.49 | 7.17 | 6.45 | 1.112 |
| 91a | 1310 | .40 | .6d | 1.49 | 7.17 | 6.37 | 1.126 |
| 96a | 1217 | .43 | .6d | 1.85 | 9.58 | 8.99 | 1.066 |
| 98a | 1196 | .40 | .6d | .30 | [1] 1.440 | 1.329 | 1.084 |
| 101a | 1175 | .41 | .6d | .49 | [1] 2.405 | 2.346 | 1.025 |
| 116a | 1196 | .40 | .6d | .10 | [2] .480 | .395 | 1.215 |
| 120a | 1175 | .40 | .6d | .20 | [1] .966 | .885 | 1.092 |
| 186a | 1175 | .40 | .6d | .50 | [1] 2.405 | 2.226 | 1.080 |

[1] By 8-inch venturi meter. [2] By 4-inch venturi meter.

NOTE.—For the condition of 0.2-foot depth of water on the bed covered with ¾-inch gravel, the tailpiece was removed from the meter, and the bottom of the meter yoke was forced into the gravel bed until the tops of the meter cups were submerged. This position of the current meter permitted the observations to be made at middepth, as the diameter of the meter cups, which was 2 inches, was slightly less than the depth of water.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Flume bed covered with ¾-inch gravel—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 75 | 1196 | 0.52 | 0.5d | 1.44 | 9.01 | 9.24 | 0.975 |
| 77 | 1196 | .50 | .5d | 1.00 | 6.03 | 6.19 | .974 |
| 79 | 1175 | .50 | .5d | 1.25 | 7.51 | 7.81 | .962 |
| 83 | 1196 | .47 | .5d | .53 | [1] 3.014 | 3.061 | .985 |
| 99 | 1196 | .50 | .5d | .30 | [1] 1.799 | 1.836 | .980 |
| 153 | 1175 | .51 | .5d | .60 | 3.69 | 3.76 | .981 |
| 155 | 1175 | .51 | .5d | .79 | 4.87 | 5.05 | .964 |
| 182 | 1175 | .50 | .5d | .40 | [1] 2.401 | 2.524 | .951 |
| 183 | 1175 | .52 | .5d | .19 | [1] 1.205 | 1.220 | .988 |
| 187 | 1175 | .50 | .5d | .40 | [1] 2.401 | 2.474 | .970 |
| 75a | 1196 | .52 | .6d | 1.44 | 9.01 | 8.86 | 1.017 |
| 77a | 1196 | .50 | .6d | 1.00 | 6.03 | 5.86 | 1.029 |
| 79a | 1175 | .50 | .6d | 1.25 | 7.51 | 7.50 | 1.001 |
| 83a | 1196 | .47 | .6d | .53 | [1] 3.014 | 2.930 | 1.029 |
| 99a | 1196 | .50 | .6d | .30 | [1] 1.799 | 1.750 | 1.028 |
| 187a | 1175 | .50 | .6d | .40 | [1] 2.401 | 2.311 | 1.039 |
| 190 | 1175 | .51 | .6d | .79 | 4.87 | 5.01 | .972 |
| 191 | 1175 | .49 | .6d | .20 | [1] 1.205 | 1.138 | 1.059 |
| 200 | 1175 | .51 | .6d | .79 | 4.87 | 4.80 | 1.015 |
| 363 | 1514 | .50 | .6d | 1.00 | 6.01 | 5.67 | 1.060 |
| 365 | 2C | .50 | .6d | .99 | 6.01 | 5.72 | 1.051 |
| 366 | 1514 | .50 | .6d | .50 | [1] 3.003 | 2.853 | 1.053 |
| 368 | 2C | .50 | .6d | .50 | [1] 3.003 | 2.939 | 1.022 |
| 69 | 1175 | .59 | .5d | 1.53 | 10.80 | 11.44 | .944 |
| 73 | 1196 | .60 | .5d | 1.25 | 8.98 | 9.53 | .942 |
| 78 | 1175 | .60 | .5d | 1.05 | 7.51 | 7.90 | .951 |
| 89 | 1175 | .60 | .5d | .97 | 6.98 | 7.47 | .934 |
| 104 | 1175 | .60 | .5d | .29 | 2.116 | 2.229 | .949 |
| 106 | 1196 | .60 | .5d | .50 | 3.58 | 3.75 | .955 |
| 123 | 1196 | .60 | .5d | .20 | 1.440 | 1.481 | .972 |
| 158 | 1175 | .60 | .5d | .61 | 4.40 | 4.72 | .932 |
| 160 | 1217 | .60 | .5d | 1.25 | 9.04 | 9.26 | .976 |
| 169 | 1175 | .60 | .5d | .40 | [1] 2.891 | 3.042 | .950 |
| 173 | 1217 | .61 | .5d | .79 | 5.78 | 5.97 | .968 |
| 184 | 1175 | .60 | .5d | .97 | 7.01 | 7.38 | .950 |
| 384 | 1514 | .60 | .5d | .30 | [1] 2.160 | 2.176 | .993 |
| 69a | 1175 | .59 | .6d | 1.53 | 10.80 | 11.02 | .980 |
| 73a | 1196 | .60 | .6d | 1.25 | 8.98 | 9.16 | .980 |
| 78a | 1175 | .60 | .6d | 1.05 | 7.51 | 7.51 | 1.000 |
| 89a | 1175 | .60 | .6d | .97 | 6.98 | 7.14 | .978 |
| 104a | 1175 | .60 | .6d | .29 | 2.116 | 2.106 | 1.005 |
| 106a | 1196 | .60 | .6d | .50 | 3.58 | 3.62 | .989 |
| 123a | 1196 | .60 | .6d | .20 | 1.440 | 1.372 | 1.050 |
| 184a | 1175 | .60 | .6d | .97 | 7.01 | 7.09 | .989 |
| 188 | 1217 | .61 | .6d | .80 | 5.85 | 5.66 | 1.034 |
| 189 | 1175 | .59 | .6d | .62 | 4.40 | 4.35 | 1.011 |
| 192 | 1175 | .60 | .6d | .40 | [1] 2.891 | 2.876 | 1.005 |
| 384a | 1514 | .60 | .6d | .30 | [1] 2.160 | 1.990 | 1.085 |
| 93 | 1175 | .80 | .5d | 1.51 | 14.51 | 15.23 | .953 |
| 102 | 1217 | .80 | .5d | 1.00 | 9.58 | 10.06 | .952 |
| 103 | 1175 | .80 | .5d | .30 | 2.87 | 3.03 | .947 |
| 105 | 1196 | .80 | .5d | .50 | 4.80 | 5.05 | .950 |
| 142 | 1217 | .80 | .5d | 1.25 | 12.03 | 12.66 | .950 |
| 172 | 1217 | .80 | .5d | .80 | 7.67 | 8.03 | .955 |
| 174 | 1175 | .81 | .5d | .59 | 5.78 | 6.00 | .963 |
| 175 | 1175 | .79 | .5d | .40 | 3.84 | 4.06 | .946 |
| 180 | 1175 | .81 | .5d | .20 | [1] 1.916 | 1.866 | 1.027 |
| 93a | 1175 | .80 | .6d | 1.51 | 14.51 | 14.48 | 1.002 |
| 102a | 1217 | .80 | .6d | 1.00 | 9.58 | 9.50 | 1.008 |
| 103a | 1175 | .80 | .6d | .30 | 2.87 | 2.89 | .993 |
| 105a | 1196 | .80 | .6d | .50 | 4.80 | 4.83 | .994 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Flume bed covered with ¾-inch gravel—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) Weir | Total discharge (second-feet) Meter | Coefficient for meter for meter measurement |
|---|---|---|---|---|---|---|---|
| 74 | 1175 | 0.99 | 0.5d | 1.01 | 12.03 | 12.43 | 0.968 |
| 82 | 1175 | 1.00 | .5d | 1.50 | 18.06 | 19.22 | .940 |
| 88 | 1175 | .99 | .5d | .50 | 5.98 | 6.25 | .957 |
| 100 | 1175 | 1.00 | .5d | .30 | 3.55 | 3.69 | .962 |
| 115 | 1196 | 1.04 | .5d | .19 | [1] 2.410 | 2.434 | .990 |
| 148 | 1217 | .99 | .5d | 1.27 | 15.11 | 15.54 | .972 |
| 154 | 1175 | .99 | .5d | .41 | 4.85 | 5.03 | .964 |
| 161 | 1217 | 1.00 | .5d | .81 | 9.68 | 10.27 | .943 |
| 165 | 1175 | 1.01 | .5d | .59 | 7.20 | 7.36 | .978 |
| 74a | 1175 | .99 | .6d | 1.01 | 12.03 | 12.01 | 1.002 |
| 82a | 1175 | 1.00 | .6d | 1.50 | 18.06 | 18.36 | .984 |
| 88a | 1175 | .99 | .6d | .50 | 5.98 | 6.00 | .997 |
| 100a | 1175 | 1.00 | .6d | .30 | 3.55 | 3.47 | 1.023 |
| 115a | 1196 | 1.04 | .6d | .19 | [1] 2.410 | 2.271 | 1.061 |
| 218a | 1217 | 1.00 | .6d | 1.50 | 18.10 | 17.85 | 1.014 |
| 385 | 1514 | 1.00 | .6d | .20 | [1] 2.401 | 2.303 | 1.043 |
| 387 | 1514 | 1.00 | .6d | .80 | 9.61 | 9.56 | 1.005 |
| 74b | 1175 | .99 | .2d, .8d | 1.01 | 12.03 | 11.33 | 1.062 |
| 82b | 1175 | 1.00 | .2d, .8d | 1.50 | 18.06 | 17.02 | 1.061 |
| 88b | 1175 | .99 | .2d, .8d | .50 | 5.98 | 5.71 | 1.047 |
| 100b | 1175 | 1.00 | .2d, .8d | .30 | 3.55 | 3.35 | 1.060 |
| 218b | 1217 | 1.00 | .2d, .8d | 1.50 | 18.10 | 17.05 | 1.062 |
| 132 | 1175 | 1.25 | .5d | .50 | 7.53 | 7.96 | .946 |
| 143 | 1175 | 1.24 | .5d | 1.52 | 22.66 | 23.77 | .953 |
| 144 | 1175 | 1.28 | .5d | .99 | 15.20 | 16.21 | .938 |
| 147 | 1217 | 1.25 | .5d | 1.25 | 18.88 | 19.94 | .947 |
| 150 | 1217 | 1.25 | .5d | .80 | 11.99 | 12.27 | .977 |
| 156 | 1175 | 1.24 | .5d | .20 | [1] 3.017 | 3.077 | .981 |
| 159 | 1175 | 1.25 | .5d | .60 | 9.04 | 9.60 | .942 |
| 162 | 1175 | 1.26 | .5d | .40 | 6.01 | 6.34 | .948 |
| 130a | 1196 | 1.25 | .6d | .30 | 4.49 | 4.46 | 1.007 |
| 131 | 1175 | 1.26 | .6d | .30 | 4.49 | 4.44 | 1.011 |
| 132a | 1175 | 1.25 | .6d | .50 | 7.53 | 7.38 | 1.020 |
| 143a | 1175 | 1.24 | .6d | 1.52 | 22.66 | 22.67 | 1.000 |
| 144a | 1175 | 1.28 | .6d | .99 | 15.20 | 15.36 | .990 |
| 375 | 1514 | 1.25 | .6d | .50 | 7.51 | 7.54 | .996 |
| 376 | 2C | 1.25 | .6d | .50 | 7.51 | 7.56 | .993 |
| 378 | 1514 | 1.25 | .6d | .50 | 7.51 | 7.64 | .983 |
| 388 | 1514 | 1.25 | .6d | 1.00 | 14.98 | 14.78 | 1.014 |
| 130b | 1196 | 1.25 | .2d, .8d | .30 | 4.49 | 4.36 | 1.030 |
| 132b | 1175 | 1.25 | .2d, .8d | .50 | 7.53 | 7.31 | 1.030 |
| 143b | 1175 | 1.24 | .2d, .8d | 1.52 | 22.66 | 22.01 | 1.030 |
| 144b | 1175 | 1.28 | .2d, .8d | .99 | 15.20 | 15.22 | .999 |
| 372 | 1514 | 1.25 | .2d, .8d | .50 | 7.51 | 7.34 | 1.023 |
| 373 | 2C | 1.25 | .2d, .8d | .50 | 7.51 | 7.39 | 1.016 |
| 388 | 1514 | 1.25 | .2d, .8d | 1.00 | 14.98 | 14.62 | 1.025 |
| 133 | 1175 | 1.52 | .5d | .50 | 9.07 | 9.50 | .955 |
| 134 | 1175 | 1.50 | .5d | 1.50 | 26.97 | 28.60 | .943 |
| 136 | 1175 | 1.52 | .5d | .30 | 5.42 | 5.69 | .953 |
| 138 | 1175 | 1.52 | .5d | 1.00 | 18.14 | 19.24 | .943 |
| 146 | 1217 | 1.53 | .5d | 1.22 | 22.49 | 23.31 | .965 |
| 149 | 1217 | 1.50 | .5d | .80 | 14.47 | 15.21 | .951 |
| 151 | 1217 | 1.51 | .5d | .60 | 10.85 | 11.41 | .951 |
| 152 | 1175 | 1.50 | .5d | .21 | 3.82 | 3.99 | .957 |
| 164 | 1175 | 1.50 | .5d | .40 | 7.20 | 7.60 | .947 |
| 133a | 1175 | 1.52 | .6d | .50 | 9.07 | 9.09 | .998 |
| 135a | 1217 | 1.50 | .6d | 1.50 | 26.97 | 27.06 | .997 |
| 136a | 1175 | 1.52 | .6d | .30 | 5.42 | 5.34 | 1.015 |
| 139a | 1217 | 1.52 | .6d | 1.00 | 18.14 | 17.94 | 1.011 |
| 133b | 1175 | 1.52 | .2d, .8d | .50 | 9.07 | 8.94 | 1.015 |
| 135b | 1217 | 1.50 | .2d, .8d | 1.50 | 26.97 | 26.84 | 1.005 |
| 136b | 1175 | 1.52 | .2d, .8d | .30 | 5.42 | 5.43 | .998 |
| 139b | 1217 | 1.52 | .2d, .8d | 1.00 | 18.14 | 18.00 | 1.008 |

[1] By 8-inch venturi meter.

*Discharge measurements made with standard-size small Price-type current meters*—Continued

**Flume bed covered with coarse gravel**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 417 | 1175 | 0.40 | 0.5d | 0.20 | [1] 0.961 | 0.978 | 0.983 |
| 418 | 1175 | .40 | .5d | .40 | [1] 1.919 | 1.989 | .965 |
| 421 | 1175 | .40 | .5d | .60 | [1] 2.880 | 2.833 | 1.017 |
| 425 | 1217 | .40 | .5d | 1.49 | 7.17 | 6.52 | 1.100 |
| 440 | 1514 | .40 | .5d | .99 | 4.77 | 4.70 | 1.015 |
| 419 | 1514 | .60 | .5d | .20 | [1] 1.440 | 1.474 | .977 |
| 424 | 1217 | .60 | .5d | 1.49 | 10.75 | 11.21 | .959 |
| 426 | 1217 | .60 | .5d | 1.00 | 7.17 | 7.71 | .930 |
| 429 | 1175 | .60 | .5d | .40 | [1] 2.880 | 3.065 | .940 |
| 439 | 1514 | .60 | .5d | .59 | 4.26 | 4.54 | .938 |
| 419a | 1514 | .60 | .6d | .20 | [1] 1.440 | 1.385 | 1.010 |
| 424a | 1217 | .60 | .6d | 1.49 | 10.75 | 10.35 | 1.039 |
| 426a | 1217 | .60 | .6d | 1.00 | 7.17 | 6.98 | 1.027 |
| 429a | 1175 | .60 | .6d | .40 | [1] 2.880 | 2.772 | 1.039 |
| 439a | 1514 | .60 | .6d | .59 | 4.26 | 4.18 | 1.019 |
| 414 | 1514 | 1.00 | .6d | 1.50 | 17.95 | 17.76 | 1.011 |
| 420a | 1175 | 1.00 | .6d | .20 | [1] 2.400 | 2.286 | 1.050 |
| 422a | 1217 | 1.00 | .6d | 1.00 | 11.99 | 11.84 | 1.013 |
| 427a | 1514 | 1.00 | .6d | .60 | 7.17 | 7.17 | 1.000 |
| 441a | 1514 | 1.00 | .6d | .40 | 4.77 | 4.76 | 1.002 |
| 415 | 1514 | 1.00 | .2d, .8d | 1.50 | 17.95 | 16.76 | 1.071 |
| 420b | 1175 | 1.00 | .2d, .8d | .20 | [1] 2.400 | 2.254 | 1.065 |
| 422b | 1217 | 1.00 | .2d, .8d | 1.00 | 11.99 | 11.39 | 1.053 |
| 427b | 1514 | 1.00 | .2d, .8d | .60 | 7.17 | 6.84 | 1.048 |
| 441b | 1514 | 1.00 | .2d, .8d | .40 | 4.77 | 4.58 | 1.041 |
| 416a | 1514 | 1.25 | .6d | 1.50 | 22.47 | 22.40 | 1.003 |
| 423a | 1217 | 1.25 | .6d | 1.00 | 14.98 | 15.24 | .983 |
| 428a | 1175 | 1.25 | .6d | .20 | [1] 3.000 | 2.827 | 1.061 |
| 430a | 1514 | 1.25 | .6d | .60 | 8.95 | 9.13 | .980 |
| 438a | 1514 | 1.25 | .6d | .40 | 5.95 | 5.99 | .993 |
| 416b | 1514 | 1.25 | .2d, .8d | 1.50 | 22.47 | 21.56 | 1.042 |
| 423b | 1217 | 1.25 | .2d, .8d | 1.00 | 14.98 | 14.54 | 1.030 |
| 428b | 1175 | 1.25 | .2d, .8d | .20 | [1] 3.000 | 2.811 | 1.067 |
| 430b | 1514 | 1.25 | .2d, .8d | .60 | 8.95 | 8.78 | 1.019 |
| 428b | 1514 | 1.25 | .2d, .8d | .40 | 5.95 | 5.83 | 1.021 |

[1] By 8-inch venturi meter.

*Discharge measurements made with cup-type pygmy current meters*

**Smooth concrete flume bed**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 275 | A3 | 0.20 | 0.5d | 0.20 | [1] 0.478 | 0.438 | 1.091 |
| 276 | A3 | .20 | .5d | 1.52 | 3.64 | 3.36 | 1.083 |
| 284 | A3 | .20 | .5d | .60 | [1] 1.440 | 1.377 | 1.046 |
| 287 | A3 | .20 | .5d | 1.00 | [1] 2.405 | 2.320 | 1.037 |
| 288 | A3 | .20 | .5d | 1.25 | [1] 3.014 | 2.788 | 1.081 |
| 275a | A3 | .20 | .6d | .20 | [1] .478 | .410 | 1.166 |
| 276a | A3 | .20 | .6d | 1.52 | 3.64 | 3.20 | 1.138 |
| 284a | A3 | .20 | .6d | .60 | [1] 1.440 | 1.313 | 1.097 |
| 287a | A3 | .20 | .6d | 1.00 | [1] 2.405 | 2.201 | 1.093 |
| 288a | A3 | .20 | .6d | 1.25 | [1] 3.014 | 2.673 | 1.128 |
| 274 | A3 | .30 | .5d | .20 | [1] .720 | .706 | 1.020 |
| 277 | A3 | .30 | .5d | 1.02 | 3.66 | 3.69 | .992 |
| 281 | A3 | .30 | .5d | 1.51 | 5.45 | 5.26 | 1.036 |
| 285 | A3 | .30 | .5d | .60 | [1] 2.160 | 2.123 | 1.017 |
| 289 | A3 | .30 | .5d | 1.26 | 4.54 | 4.63 | .981 |

[1] By 8-inch venturi meter.

*Discharge measurements made with cup-type pygmy current meters*—Continued

**Smooth concrete flume bed—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 274a | A3 | 0.30 | 0.6d | 0.20 | [1] 0.720 | 0.652 | 1.104 |
| 277a | A3 | .30 | .6d | 1.02 | 3.66 | 3.51 | 1.043 |
| 281a | A3 | .30 | .6d | 1.51 | 5.45 | 5.00 | 1.090 |
| 285a | A3 | .30 | .6d | .60 | [1] 2.160 | 2.057 | 1.050 |
| 289a | A3 | .30 | .6d | 1.26 | 4.54 | 4.36 | 1.041 |
| 279 | A3 | .40 | .5d | 1.52 | 7.28 | 7.39 | .985 |
| 282 | A3 | .40 | .5d | .20 | [1] .966 | .949 | 1.018 |
| 286 | A3 | .40 | .5d | .60 | [1] 2.891 | 2.976 | .971 |
| 290 | A3 | .40 | .5d | 1.01 | 4.87 | 4.92 | .990 |
| 279a | A3 | .40 | .6d | 1.52 | 7.28 | 7.06 | 1.031 |
| 282a | A3 | .40 | .6d | .20 | [1] .966 | .911 | 1.060 |
| 286a | A3 | .40 | .6d | .60 | [1] 2.891 | 2.843 | 1.017 |
| 290a | [illegible] | .40 | .6d | 1.01 | 4.87 | 4.77 | 1.021 |
| 257 | A3 | .50 | .5d | 1.51 | 9.04 | 9.22 | .980 |
| 402 | A3 | .50 | .5d | .20 | [1] 1.203 | 1.204 | .999 |
| 404 | A3 | .50 | .5d | 1.50 | 8.98 | 9.50 | .945 |
| 406 | A3 | .50 | .5d | .60 | 3.58 | 3.80 | .942 |
| 409 | A3 | .50 | .5d | 1.00 | 5.98 | 6.19 | .966 |
| 257a | A3 | .50 | .6d | 1.51 | 9.04 | 8.88 | 1.018 |
| 349 | A3 | .50 | .6d | .50 | [1] 3.000 | 2.972 | 1.009 |
| 352 | A3 | .50 | .6d | 1.00 | 6.01 | 5.99 | 1.003 |
| 402a | A3 | .50 | .6d | .20 | [1] 1.203 | 1.150 | 1.046 |
| 404a | A3 | .50 | .6d | 1.50 | 8.98 | 9.11 | .986 |
| 406a | A3 | .50 | .6d | .60 | 3.58 | 3.64 | .984 |
| 409a | A3 | .50 | .6d | 1.00 | 5.98 | 5.93 | 1.008 |
| 258 | A3 | .60 | .5d | .20 | [1] 1.440 | 1.387 | 1.038 |
| 278 | A3 | .60 | .5d | 1.00 | 7.28 | 7.63 | .954 |
| 280 | A3 | .60 | .5d | 1.50 | 10.91 | 11.11 | .982 |
| 283 | A3 | .60 | .5d | .20 | [1] 1.440 | 1.379 | 1.044 |
| 291 | A3 | .60 | .5d | .60 | 4.36 | 4.48 | .973 |
| 292 | A3 | .60 | .5d | .30 | [1] 2.152 | 2.150 | 1.001 |
| 295 | A3 | .60 | .5d | .40 | [1] 2.891 | 2.894 | .999 |
| 38 | A3 | .60 | .6d | .09 | .649 | .593 | 1.094 |
| 278a | A3 | .60 | .6d | 1.00 | 7.28 | 7.35 | .990 |
| 280a | A3 | .60 | .6d | 1.50 | 10.91 | 10.77 | 1.013 |
| 283a | A3 | .60 | .6d | .20 | [1] 1.440 | 1.357 | 1.061 |
| 291a | A3 | .60 | .6d | .60 | 4.36 | 4.30 | 1.014 |
| 292a | A3 | .60 | .6d | .30 | [1] 2.152 | 2.060 | 1.045 |
| 295a | A3 | .60 | .6d | .40 | [1] 2.891 | 2.807 | 1.030 |
| 403 | A3 | 1.00 | .5d | .20 | [1] 2.397 | 2.304 | 1.040 |
| 405 | A3 | 1.00 | .5d | 1.00 | 11.96 | 12.50 | .957 |
| 408 | A3 | 1.00 | .5d | .60 | 7.14 | 7.36 | .970 |
| 410 | A3 | 1.00 | .5d | 1.50 | 17.95 | 18.92 | .949 |
| 35a | A3 | .99 | .6d | .20 | 2.348 | 2.311 | 1.016 |
| 36 | A3 | 1.00 | .6d | .095 | 1.138 | 1.049 | 1.085 |
| 403a | A3 | 1.00 | .6d | .20 | [1] 2.397 | 2.234 | 1.073 |
| 405a | A3 | 1.00 | .6d | 1.00 | 11.96 | 12.38 | .966 |
| 408a | A3 | 1.00 | .6d | .60 | 7.14 | 7.26 | .983 |
| 410a | A3 | 1.00 | .6d | 1.50 | 17.95 | 18.42 | .974 |
| 35b | A3 | .99 | .2d, .8d | .20 | 2.348 | 2.299 | 1.021 |
| 403b | A3 | 1.00 | .2d, .8d | .20 | [1] 2.397 | 2.198 | 1.091 |
| 405b | A3 | 1.00 | .2d, .8d | 1.00 | 11.96 | 12.09 | .989 |
| 408b | A3 | 1.00 | .2d, .8d | .60 | 7.14 | 7.15 | .999 |
| 410b | A3 | 1.00 | .2d, .8d | 1.50 | 17.95 | 18.02 | .996 |
| 333 | A3 | 1.25 | .6d | 1.00 | 15.00 | 15.03 | .998 |
| 340 | A3 | 1.25 | .6d | .50 | 7.51 | 7.66 | .980 |
| 337 | A3 | 1.25 | .2d, .8d | 1.00 | 15.02 | 14.81 | 1.014 |
| 343 | A3 | 1.25 | .2d, .8d | .50 | 7.51 | 7.45 | 1.008 |
| 407a | A3 | 1.50 | .6d | .20 | 3.58 | 3.60 | .994 |
| 411a | A3 | 1.50 | .6d | 1.00 | 17.95 | 18.40 | .976 |
| 412a | A3 | 1.50 | .6d | .60 | 10.78 | 10.85 | .994 |
| 413a | A3 | 1.50 | .6d | 1.50 | 26.97 | 27.86 | .968 |
| 407b | A3 | 1.50 | .2d, .8d | .20 | 3.58 | 3.42 | 1.047 |
| 411b | A3 | 1.50 | .2d, .8d | 1.00 | 17.95 | 18.09 | .992 |
| 412b | A3 | 1.50 | .2d, .8d | .60 | 10.78 | 10.71 | 1.007 |
| 413b | A3 | 1.50 | .2d, .8d | 1.50 | 26.97 | 27.19 | .992 |

[1] By 8-inch venturi meter.

949294 O—51——3

*Discharge measurements made with cup-type pygmy current meters*—Continued

**Flume bed covered with ¾-inch gravel**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 111 | A3 | 0.21 | 0.5d | 0.94 | [1] 2.401 | 2.466 | 0.974 |
| 112 | A3 | .21 | .5d | 1.18 | [1] 3.015 | 3.015 | 1.000 |
| 118 | A3 | .20 | .5d | .20 | [1] .480 | .525 | .914 |
| 128 | A7 | .22 | .5d | 1.35 | 3.554 | 3.650 | .974 |
| 198 | A3 | .21 | .5d | .57 | [1] 1.440 | 1.404 | 1.026 |
| 391 | A3 | .20 | .5d | .59 | [1] 1.439 | 1.381 | 1.042 |
| 128a | A7 | .22 | .6d | 1.35 | 3.554 | 3.380 | 1.051 |
| 391a | A3 | .20 | .6d | .59 | [1] 1.439 | 1.254 | 1.148 |
| 85 | A3 | .30 | .5d | 1.47 | 5.38 | 5.93 | .907 |
| 194 | A3 | .30 | .5d | 1.25 | 4.54 | 4.64 | .978 |
| 195 | A3 | .30 | .5d | 1.01 | 3.64 | 3.84 | .948 |
| 196 | A3 | .30 | .5d | .60 | [1] 2.160 | 2.226 | .970 |
| 210 | A7 | .30 | .5d | .20 | [1] .720 | .743 | .969 |
| 211 | A3 | .30 | .5d | .20 | [1] .720 | .702 | 1.026 |
| 392 | A3 | .30 | .5d | .59 | [1] 2.160 | 2.229 | .969 |
| 393 | A3 | .30 | .5d | 1.48 | 5.35 | 5.67 | .944 |
| 392a | A3 | .30 | .6d | .59 | [1] 2.160 | 2.034 | 1.062 |
| 393a | A3 | .30 | .6d | 1.48 | 5.35 | 5.19 | 1.031 |
| 92 | A3 | .40 | .5d | 1.49 | 7.17 | 7.58 | .946 |
| 119 | A3 | .40 | .5d | .20 | [1] .966 | 1.024 | .943 |
| 125 | A7 | .40 | .5d | .99 | 4.77 | 5.18 | .921 |
| 193 | A3 | .40 | .5d | .60 | [1] 2.891 | 3.028 | .955 |
| 92a | A3 | .40 | .6d | 1.49 | 7.17 | 7.22 | .993 |
| 119a | A3 | .40 | .6d | .20 | [1] .966 | .962 | 1.004 |
| 125a | A7 | .40 | .6d | .99 | 4.77 | 4.89 | .975 |
| 193a | A3 | .40 | .6d | .60 | [1] 2.891 | 2.894 | .999 |
| 94 | A3 | .50 | .5d | 1.49 | 8.98 | 9.41 | .954 |
| 390 | A3 | .50 | .5d | .20 | [1] 1.203 | 1.207 | .997 |
| 94a | A3 | .50 | .6d | 1.49 | 8.98 | 9.26 | .970 |
| 379 | A3 | .50 | .6d | .99 | 6.01 | 6.01 | 1.000 |
| 380 | A3 | .50 | .6d | .50 | [1] 3.000 | 2.835 | 1.058 |
| 390a | A3 | .50 | .6d | .20 | [1] 1.203 | 1.092 | 1.102 |
| 124 | A7 | .60 | .5d | .20 | [1] 1.440 | 1.529 | .942 |
| 126 | A7 | .60 | .5d | 1.00 | 7.20 | 7.68 | .938 |
| 127 | A7 | .60 | .5d | 1.50 | 10.78 | 11.40 | .946 |
| 199 | A3 | .59 | .5d | .20 | [1] 1.440 | 1.257 | 1.146 |
| 201 | A3 | .60 | .5d | .20 | [1] 1.440 | 1.471 | .979 |
| 202 | A3 | .60 | .5d | .20 | [1] 1.440 | 1.450 | .993 |
| 203 | A3 | .59 | .5d | .20 | [1] 1.440 | 1.423 | 1.012 |
| 204 | A7 | .59 | .5d | .20 | [1] 1.440 | 1.489 | .967 |
| 205 | A3 | .59 | .5d | .20 | [1] 1.440 | 1.475 | .976 |
| 206 | A7 | .59 | .5d | .20 | [1] 1.440 | 1.505 | .957 |
| 207 | A3 | .59 | .5d | .20 | [1] 1.440 | 1.480 | .973 |
| 208 | A7 | .59 | .5d | .20 | [1] 1.440 | 1.496 | .963 |
| 209 | A3 | .59 | .5d | .20 | [1] 1.440 | 1.475 | .976 |
| 394 | A3 | .60 | .5d | .50 | 3.60 | 3.86 | .933 |
| 122 | A3 | .60 | .6d | .20 | [1] 1.440 | 1.360 | 1.059 |
| 124a | A7 | .60 | .6d | .20 | [1] 1.440 | 1.501 | .959 |
| 126a | A7 | .60 | .6d | 1.00 | 7.20 | 7.44 | .968 |
| 127a | A7 | .60 | .6d | 1.50 | 10.78 | 11.03 | .977 |
| 394a | A3 | .60 | .6d | .50 | 3.60 | 3.66 | .984 |
| 121 | A3 | 1.00 | .5d | .20 | [1] 2.405 | 2.448 | .982 |
| 140 | A7 | 1.00 | .5d | 1.51 | 18.14 | 18.73 | .968 |
| 141 | A7 | 1.00 | .5d | 1.00 | 12.03 | 12.51 | .962 |
| 389 | A3 | 1.00 | .5d | .50 | 5.98 | 6.26 | .955 |
| 121a | A3 | 1.00 | .6d | .20 | [1] 2.405 | 2.360 | 1.019 |
| 140a | A7 | 1.00 | .6d | 1.51 | 18.14 | 18.31 | .991 |
| 141a | A7 | 1.00 | .6d | 1.00 | 12.03 | 12.11 | .993 |
| 389a | A3 | 1.00 | .6d | .50 | 5.98 | 5.96 | 1.003 |
| 121b | A3 | 1.00 | .2d, .8d | .20 | [1] 2.405 | 2.277 | 1.056 |
| 140b | A7 | 1.00 | .2d, .8d | 1.51 | 18.14 | 17.96 | 1.010 |
| 141b | A7 | 1.00 | .2d, .8d | 1.00 | 12.03 | 11.87 | 1.013 |
| 389b | A3 | 1.00 | .2d, .8d | .50 | 5.98 | 5.85 | 1.022 |

[1] By 8-inch venturi meter.

*Discharge measurements made with cup-type pygmy current meters*—Continued

**Flume bed covered with ¾-inch gravel—Continued**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| | | | | | Weir | Meter | |
| 378a | A3 | 1.25 | 0.6d | 0.50 | 7.51 | 7.64 | 0.983 |
| 398a | A3 | 1.25 | .6d | 1.00 | 14.96 | 15.30 | .978 |
| 401a | A3 | 1.25 | .6d | 1.50 | 22.45 | 23.36 | .961 |
| 378b | A3 | 1.25 | .2d, .8d | .50 | 7.51 | 7.50 | 1.001 |
| 398b | A3 | 1.25 | .2d, .8d | 1.00 | 14.96 | 15.01 | .997 |
| 401b | A3 | 1.25 | .2d, .8d | 1.50 | 22.45 | 22.30 | 1.007 |
| 137 | A7 | 1.52 | .6d | .30 | 5.42 | 5.51 | .984 |
| 137a | A7 | 1.52 | .6d | .30 | 5.42 | 5.42 | 1.000 |
| 395a | A3 | 1.50 | .6d | 1.50 | 26.92 | 27.79 | .969 |
| 397a | A3 | 1.50 | .6d | 1.00 | 17.95 | 18.27 | .982 |
| 399a | A3 | 1.50 | .6d | .50 | 8.98 | 9.03 | .994 |
| 400a | A3 | 1.50 | .6d | 1.50 | 26.97 | 27.89 | .967 |
| 395b | A3 | 1.50 | .2d, .8d | 1.50 | 26.92 | 27.27 | .987 |
| 397b | A3 | 1.50 | .2d, .8d | 1.00 | 17.95 | 17.81 | 1.008 |
| 399b | A3 | 1.50 | .2d, .8d | .50 | 8.98 | 8.93 | 1.006 |
| 400b | A3 | 1.50 | .2d, .8d | 1.50 | 26.97 | 27.16 | .993 |

**Flume bed covered with coarse gravel**

| Measurement No. | Meter No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Weir | Meter | Coefficient for meter measurement |
|---|---|---|---|---|---|---|---|
| 431 | A3 | 0.40 | 0.5d | 0.60 | [1] 2.880 | 3.188 | 0.903 |
| 433 | A3 | .40 | .5d | .40 | [1] 1.918 | 2.067 | .928 |
| 434 | A3 | .41 | .5d | .20 | [1] .961 | .985 | .976 |
| 443 | A3 | .40 | .5d | .99 | 4.75 | 5.11 | .930 |
| 444 | A3 | .40 | .5d | 1.49 | 7.14 | 7.61 | .938 |
| 432 | A3 | .60 | .5d | .40 | [1] 2.880 | 3.082 | .934 |
| 436 | A3 | .60 | .5d | .20 | [1] 1.440 | 1.502 | .959 |
| 446 | A3 | .60 | .5d | .99 | 7.14 | 7.68 | .930 |
| 447 | A3 | .60 | .5d | .59 | 4.28 | 4.72 | .907 |
| 450 | A3 | .60 | .5d | 1.50 | 10.78 | 11.63 | .927 |
| 432a | A3 | .60 | .6d | .40 | [1] 2.880 | 2.852 | 1.010 |
| 436a | A3 | .60 | .6d | .20 | [1] 1.440 | 1.368 | 1.053 |
| 446a | A3 | .60 | .6d | .99 | 7.14 | 7.32 | .975 |
| 447a | A3 | .60 | .6d | .59 | 4.28 | 4.38 | .977 |
| 450a | A3 | .60 | .6d | 1.50 | 10.78 | 10.99 | .981 |
| 435a | A3 | 1.00 | .6d | .20 | [1] 2.399 | 2.282 | 1.051 |
| 442a | A3 | 1.00 | .6d | .40 | 4.77 | 4.82 | .990 |
| 445a | A3 | 1.00 | .6d | .60 | 7.14 | 7.26 | .983 |
| 451a | A3 | 1.00 | .6d | 1.49 | 17.91 | 18.22 | .983 |
| 452a | A3 | 1.00 | .6d | 1.00 | 11.94 | 12.10 | .987 |
| 435b | A3 | 1.00 | .2d, .8d | .20 | [1] 2.399 | 2.252 | 1.065 |
| 442b | A3 | 1.00 | .2d, .8d | .40 | 4.77 | 4.68 | 1.019 |
| 445b | A3 | 1.00 | .2d, .8d | .60 | 7.14 | 7.24 | .986 |
| 451b | A3 | 1.00 | .2d, .8d | 1.49 | 17.91 | 17.90 | 1.001 |
| 452b | A3 | 1.00 | .2d, .8d | 1.00 | 11.94 | 12.05 | .991 |
| 437a | A3 | 1.25 | .6d | .20 | [1] 3.000 | 2.854 | 1.051 |
| 448a | A3 | 1.25 | .6d | .40 | 5.98 | 5.99 | .998 |
| 449a | A3 | 1.25 | .6d | .59 | 8.92 | 9.19 | .971 |
| 453a | A3 | 1.25 | .6d | 1.00 | 14.94 | 15.34 | .974 |
| 454a | A3 | 1.25 | .6d | 1.50 | 22.45 | 23.14 | .970 |
| 437b | A3 | 1.25 | .2d, .8d | .20 | 3.000 | 2.782 | 1.078 |
| 448b | A3 | 1.25 | .2d, .8d | .40 | 5.98 | 5.84 | 1.024 |
| 449b | A3 | 1.25 | .2d, .8d | .59 | 8.92 | 9.05 | .986 |
| 453b | A3 | 1.25 | .2d, .8d | 1.00 | 14.94 | 15.09 | .990 |
| 454b | A3 | 1.25 | .2d, .8d | 1.50 | 22.45 | 22.76 | .986 |

[1] By 8-inch venturi meter.

*Discharge measurements made with Ott propeller-type current meter*

| Measurement No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement | Flume bed |
|---|---|---|---|---|---|---|---|
| | | | | Weir | Meter | | |
| 348 | 0.50 | 0.6d | 0.50 | [1] 3.000 | 3.132 | 0.958 | Smooth concrete. |
| 353 | .50 | .6d | 1.00 | 6.01 | .612 | .982 | Do. |
| 364 | .50 | .6d | 1.00 | 6.01 | .608 | .988 | ¾-inch gravel. |
| 367 | .50 | .6d | .50 | [1] 3.005 | 3.148 | .955 | Do. |
| 332 | 1.25 | .6d | 1.00 | 15.00 | 15.35 | .977 | Smooth concrete. |
| 341 | 1.25 | .6d | .50 | 7.51 | 7.89 | .952 | Do. |
| 377 | 1.25 | .6d | .50 | 7.51 | 7.81 | .962 | ¾-inch gravel. |
| 336 | 1.25 | .2d, .8d | 1.00 | 15.02 | 15.19 | .989 | Smooth concrete. |
| 342 | 1.25 | .2d, .8d | .50 | 7.51 | 7.65 | .982 | Do. |
| 374 | 1.25 | .2d, .8d | .50 | 7.51 | 7.85 | .957 | ¾-inch gravel. |

[1] By 8-inch venturi meter.

*Discharge measurements made with propeller-type pygmy current meter*

| Measurement No. | Depth of water (feet) | Method of measurement | Average velocity in flume (feet per second) | Total discharge (second-feet) | | Coefficient for meter measurement | Flume bed |
|---|---|---|---|---|---|---|---|
| | | | | Weir | Meter | | |
| 86 | 0.30 | 0.5d | 1.48 | 5.40 | 6.08 | 0.888 | ¾-inch gravel. |
| 95 | .50 | .5d | 1.49 | 8.95 | 10.08 | .888 | Do. |
| 10 | 1.04 | .6d | .96 | 12.0 | 12.2 | .984 | Smooth concrete. |
| 23a | 1.50 | .6d | 1.26 | 22.6 | 23.2 | .974 | Do. |
| 95a | .50 | .6d | 1.49 | 8.95 | 9.70 | .923 | ¾-inch gravel. |
| 10a | 1.04 | .2d, .8d | .96 | 12.0 | 11.6 | 1.034 | Smooth concrete. |

## RESULTS OF THE INVESTIGATION

The principal results of the investigation of the performance of current meters in water of shallow depth at the National Hydraulic Laboratory consist of a determination of coefficients to be applied as correction factors to current-meter measurements of velocities within the range of depths and velocities included in the scope of the investigation. Some conclusions also may be reached in regard to methods most suitable for use in current-meter measurements of velocity in shallow depths. Separate analyses have been made of data for the standard-size current meters and for the pygmy meters. The coefficients for use with standard-size current meters are shown by the diagrams in plates 7 to 10; those for pygmy meters, by the diagrams in plates 11 to 13.

### STANDARD-SIZE CURRENT METERS

The coefficients for use with the standard-size small Price-type current meters that are shown in plates 7 to 10 apply to the methods commonly used in measurements of velocities in shallow depths where the meter is placed at middepth, at 0.6-depth, or at 0.2- and 0.8-

depth. Other methods that were investigated did not appear to give better or more consistent results than those.

As mentioned elsewhere in this report, there were some variations in the coefficients for individual measurements and some scattering of points when the coefficients were plotted. Two sets of curves were prepared preliminary to each diagram shown in plates 7 to 13. Velocities and coefficients were used as coordinates for one set of curves, and a separate curve was prepared for each depth at which measurements were made. The plotting of the points corresponding to the coefficients for the individual measurements under the different conditions of bed and by the different methods of measurement when plotted to show variations in coeffieients with change in velocity are shown in plates 14, 16, 18, and 20. Depths and coefficients were used as coordinates for the other set of curves, and a separate curve was prepared for each velocity at which measurements were made. These curves plotted to show variations in coefficients with change in depth are shown in plates 15, 17, 19, and 21. The curves were drawn to average the results of the individual measurements so far as possible, and the two sets of curves necessarily were made consistent with each other. These curves were used as the bases of the diagrams shown in plates 7 to 13, one set of curves corresponding to horizontal sections through the diagram and the other set corresponding to vertical sections.

It may be seen from the curves in plates 14 and 16 that for the 0.5-depth method in depths of 0.2 and 0.3 foot, the coefficients for a bed covered with ¾-inch gravel are considerably larger than the coefficients for a smooth concrete bed for the same velocities. This difference in coefficients for the 0.2-foot depth may possibly be due to a difference in the position of the current meter, as explained on page 7. Because of some variations in the coefficients obtained from different measurements made at the same depths and velocities and with the same conditions of bed, it is uncertain to what extent the different conditions of bed may have contributed to the small differences in coefficients, and to what extent the results may have been affected by minor differences in the position of the current meter, especially for those small depths where the current-meter cups were not completely submerged. Analyses of the data obtained from measurements made with standard-size current meters by the 0.5-depth method indicate, however, that when the 0.5-depth method is used the coefficients for use with smooth bed and with gravel bed should be different. The two sets of coefficients for the different conditions of smooth bed and ¾-inch gravel bed are shown in plates 7 and 8.

For measurements made by the 0.6-depth and the 0.2- and 0.8-depth methods, there was no consistent difference in the results obtained with the different conditions of flume bed for which the measurements were made, the variations in coefficients for measurements made under the same conditions being as much as or more than the variations in the results obtained for the different beds. No consistent differences were found in the coefficients for the two conditions of gravel bed that were investigated.

Although some inconsistencies exist in the results of individual measurements,[6] the methods used in the analyses and interpretation of the data were such that the results of the investigation presented in the accompanying diagrams of coefficients should be representative of average relations between the actual discharge and the discharge as measured by current meters by the methods indicated. It is probable that the conditions of flow in the 12-foot flume in the laboratory were more favorable for current-meter measurements than the conditions that may be found in most natural channels of similar depths and comparable velocities.

### PYGMY CURRENT METERS

The coefficients for measurements made with pygmy current meters by the 0.5-depth method shown in plate 11 are average values for the three conditions of bed, as also are those for the 0.6-depth and the 0.2- and 0.8-depth methods shown in plates 12 and 13. It is possible that a larger number of measurements with the pygmy meters might indicate some differences in the coefficients for the 0.5-depth method with the different conditions of bed so that separate curves might be developed that would agree with the observational data somewhat more closely than the average values that have been used. The plotting of the points corresponding to the coefficients for the individual measurements made with the pygmy current meters under the different conditions of bed and by the different methods of measurement are shown in plates 22 to 27.

Measurements made with the pygmy current meters were much fewer than those made with the standard-size current meters, for the pygmy meters were included within the scope of this investigation in order to obtain general information regarding their operation under the adverse conditions of very shallow water.

### APPLICATION OF COEFFICIENTS

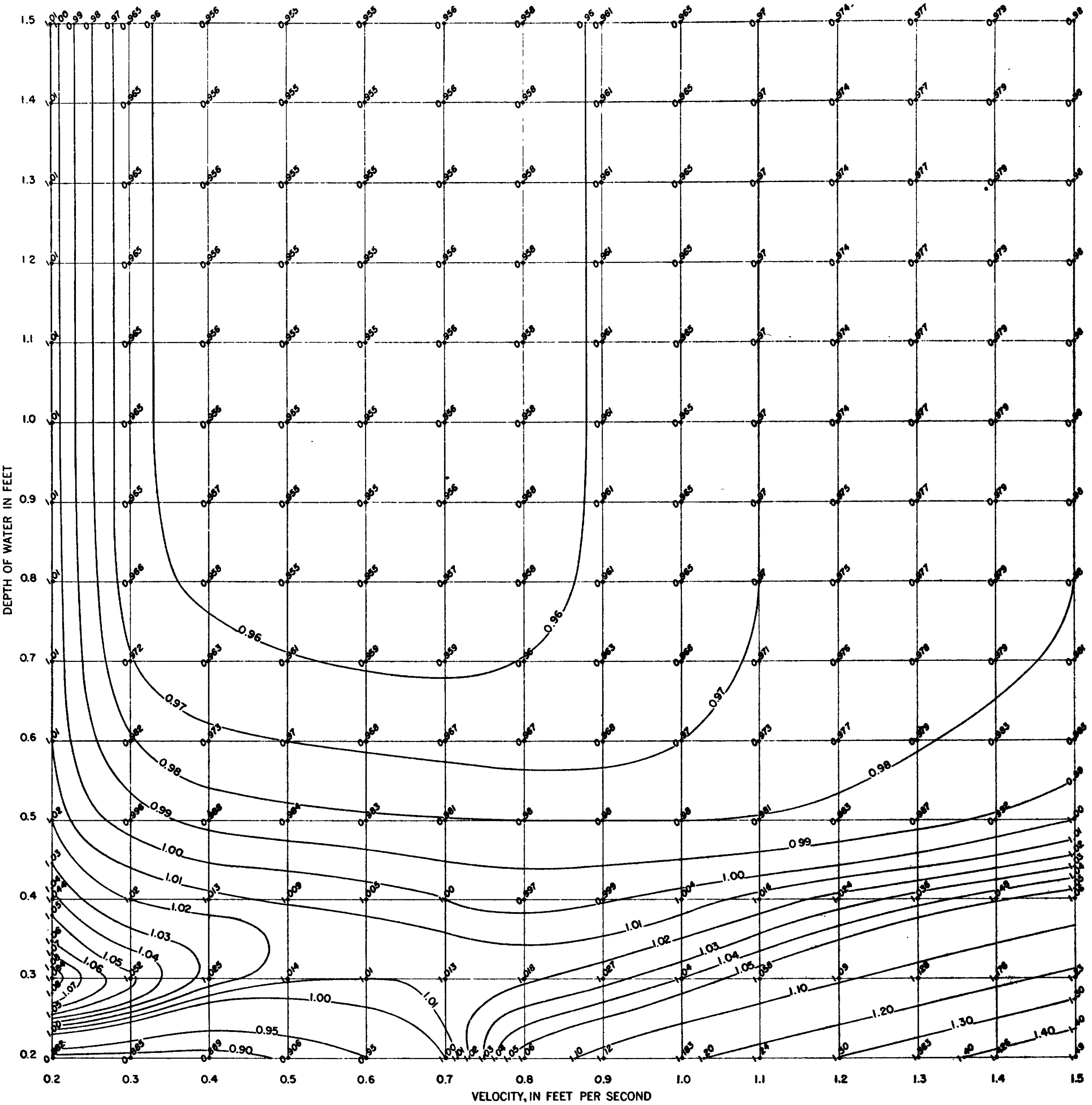
The coefficients shown in the diagrams, plates 7 to 13, apply to those methods commonly used in current-meter measurements of velocity of water in shallow depths. It is generally considered desirable to select a method of measurement in which the current meter

[6] Subsequent to the completion of this investigation a water-stage recorder with a time scale of 3.6 inches=1 hour and a height scale of 1 inch=0.2 foot was temporarily installed on the flume. The records obtained by this instrument indicated considerable variation in the flow of water at the measuring section.

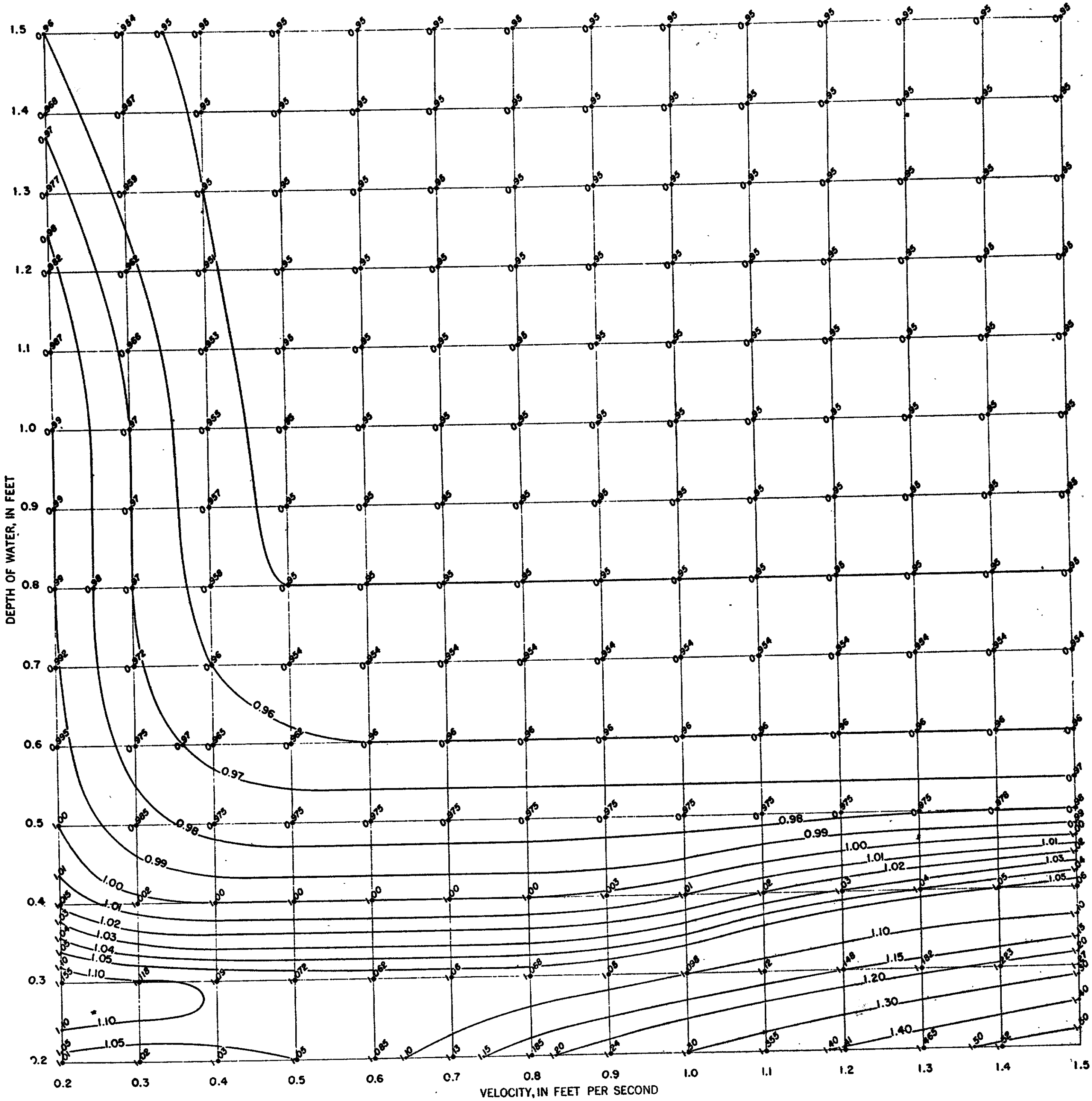
is placed in a position or positions in the vertical where the velocity indicated by the meter in the method used for the measurement is the same as the mean velocity in the vertical, or as nearly the same as may be obtained. In other words, it is desirable to keep the coefficient as near unity as possible by selection of the most suitable method, if that method is equally reliable in other respects.

The diagrams indicate that for depths between 0.5 foot and 1.5 feet the coefficients are nearer unity for the 0.6-depth method than for either of the other methods, and that for depths less than 0.5 foot the coefficients are nearer unity for the 0.5-depth method. The greater reliability of the 0.2- and 0.8-depth method in natural streams where the conditions of bed and the distribution of velocities are more variable than those found in the laboratory, however, might warrant the use of that method for depths between 1.0 foot and 1.5 feet, as well as for greater depths, even though the coefficients to be used with the 0.2- and 0.8-depth method are not so near unity as those for the 0.6-depth method.

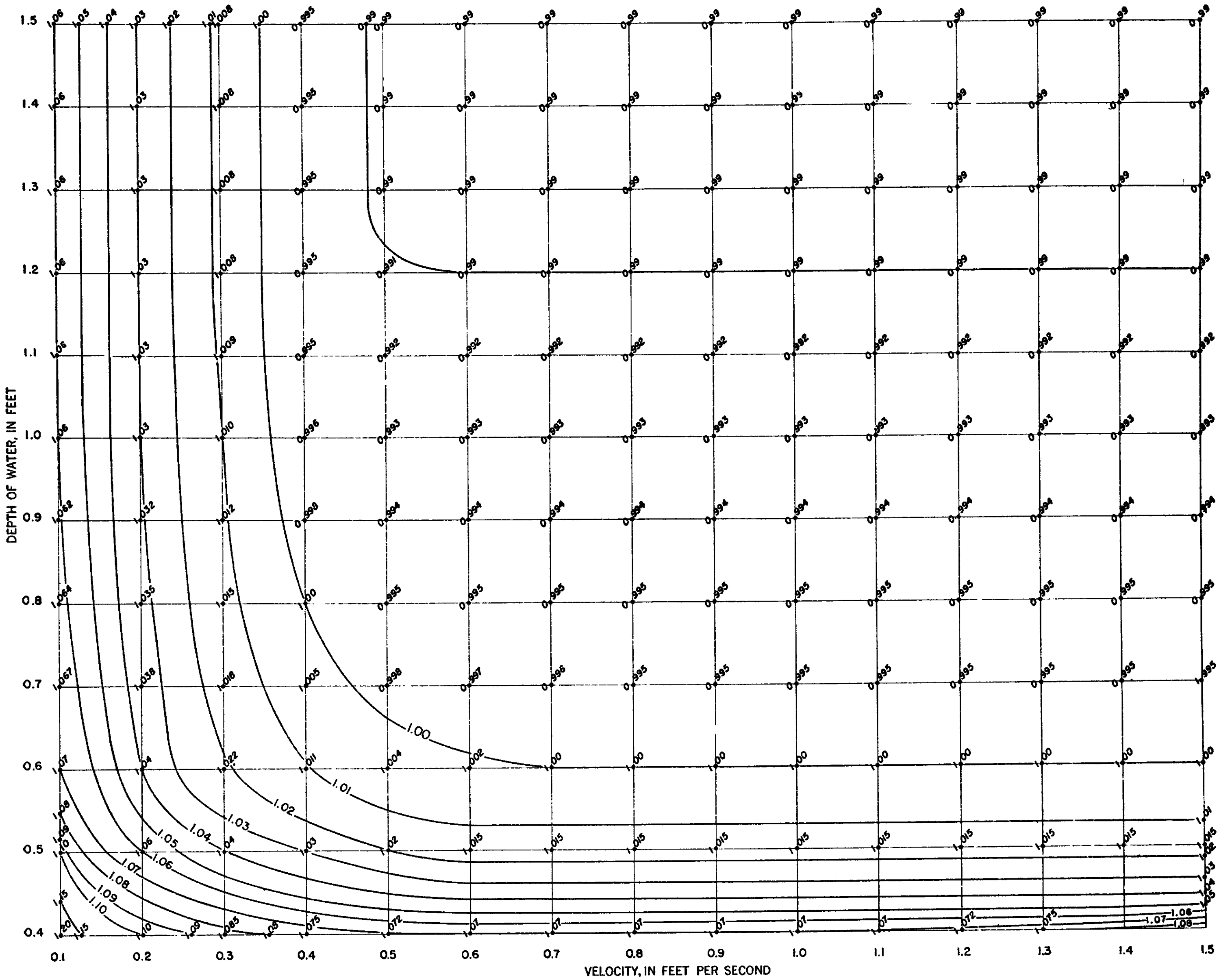
It is desirable, so far as possible, to select measuring sections where the velocity is not less than 0.4 foot per second. If the variations in the depth at a measuring station are not too great, the use of the same method for the entire section may be preferable. The coefficient to be applied to the velocity observation at each measuring point should be selected in accordance with the method of measurement and the depth and velocity at the point of observation.



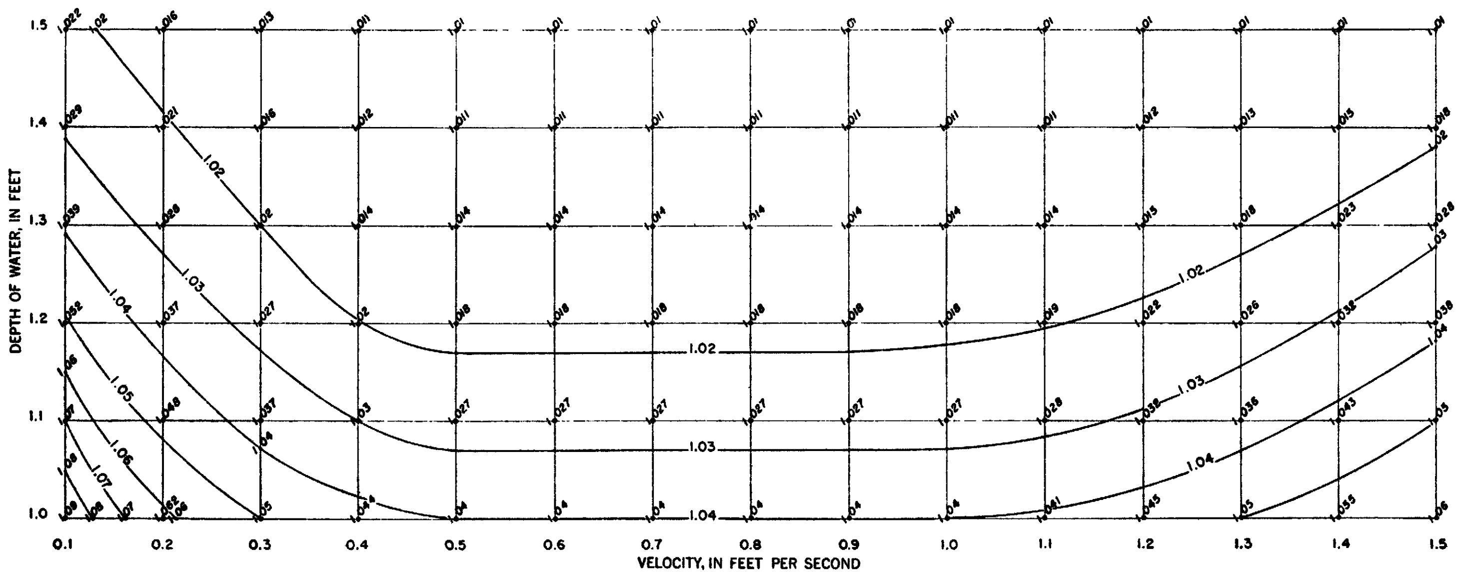

**COEFFICIENTS FOR USE WITH 0.5-DEPTH METHOD, STANDARD-SIZE CURRENT METERS, SMOOTH BED.**



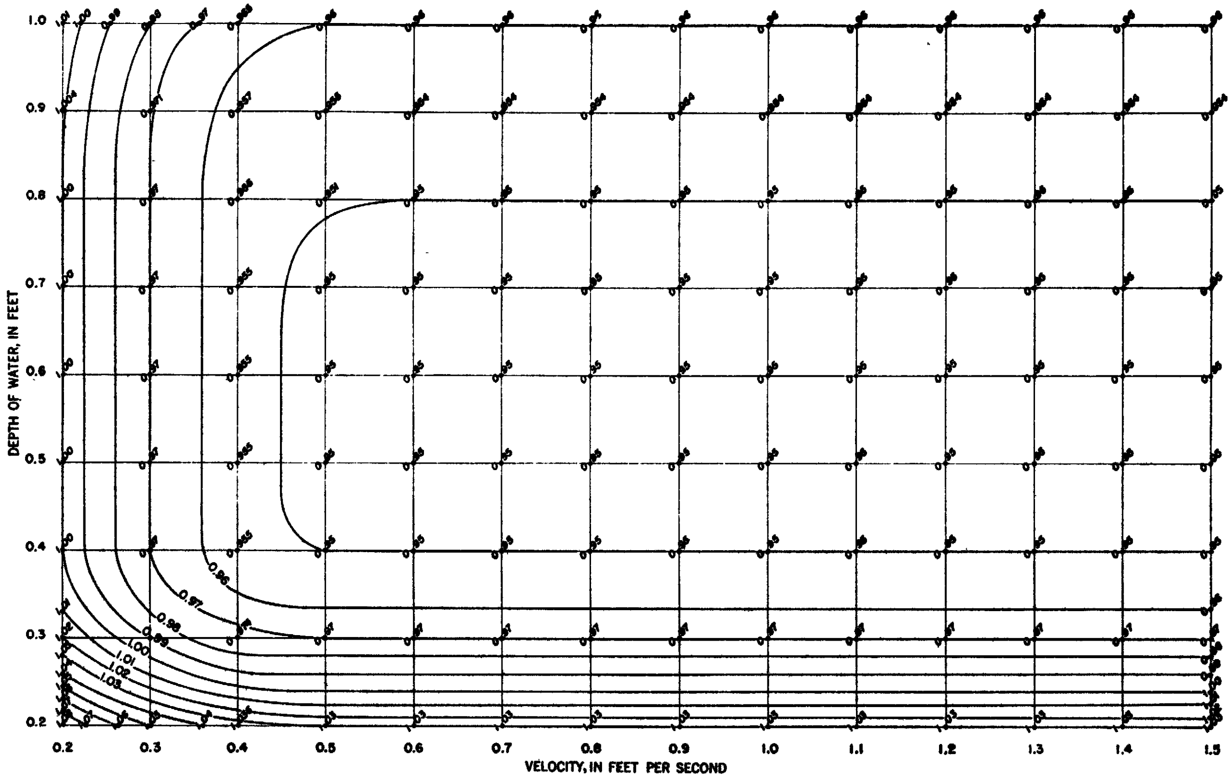

COEFFICIENTS FOR USE WITH 0.5-DEPTH METHOD, STANDARD-SIZE CURRENT METERS, BED OF ¾-INCH GRAVEL.



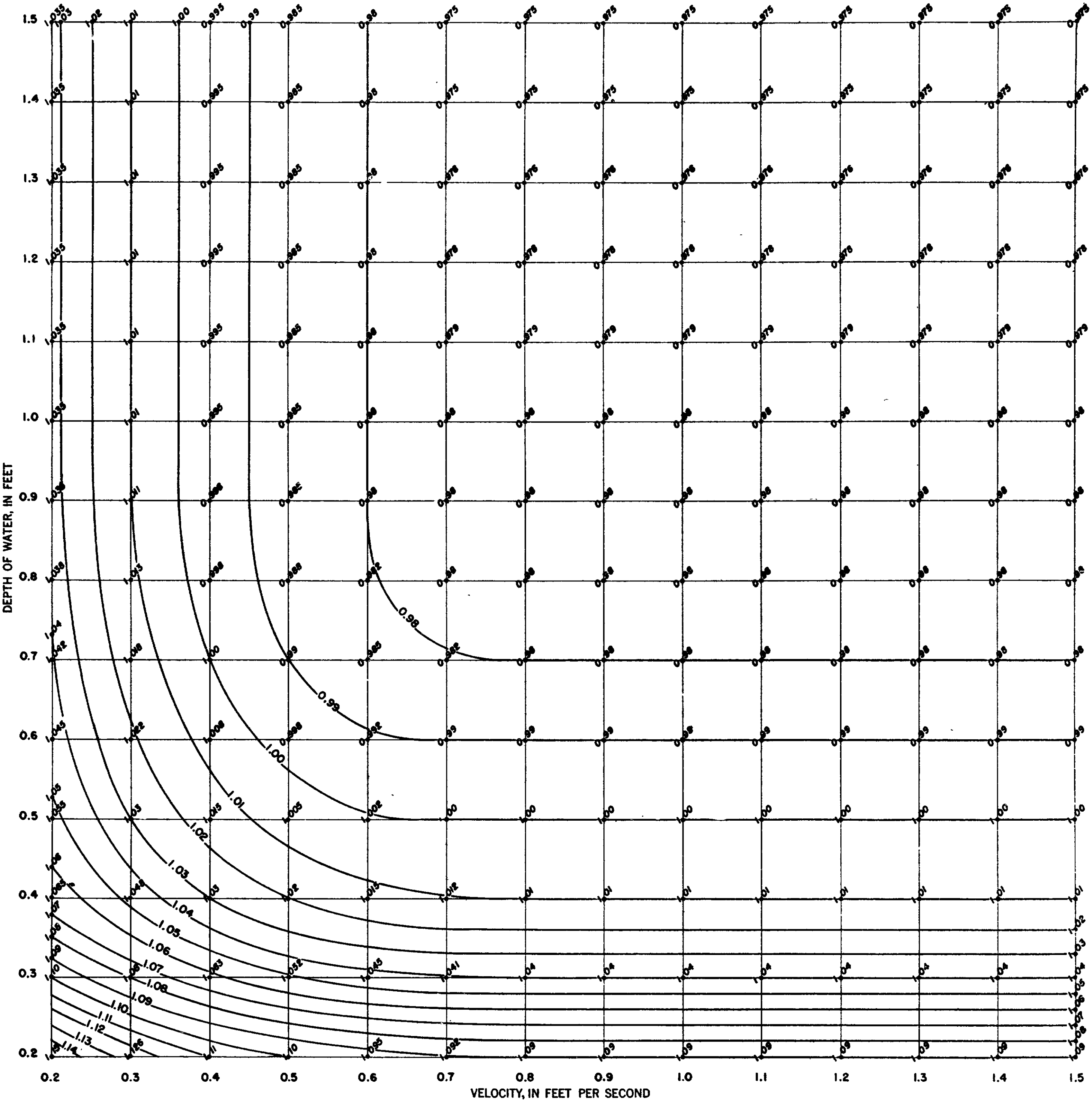

**COEFFICIENTS FOR USE WITH 0.6-DEPTH METHOD, STANDARD-SIZE CURRENT METERS.**




COEFFICIENTS FOR USE WITH 0.2- AND 0.8-DEPTH METHOD, STANDARD-SIZE CURRENT METERS.




COEFFICIENTS FOR USE WITH 0.5-DEPTH METHOD, PYGMY CURRENT METERS.

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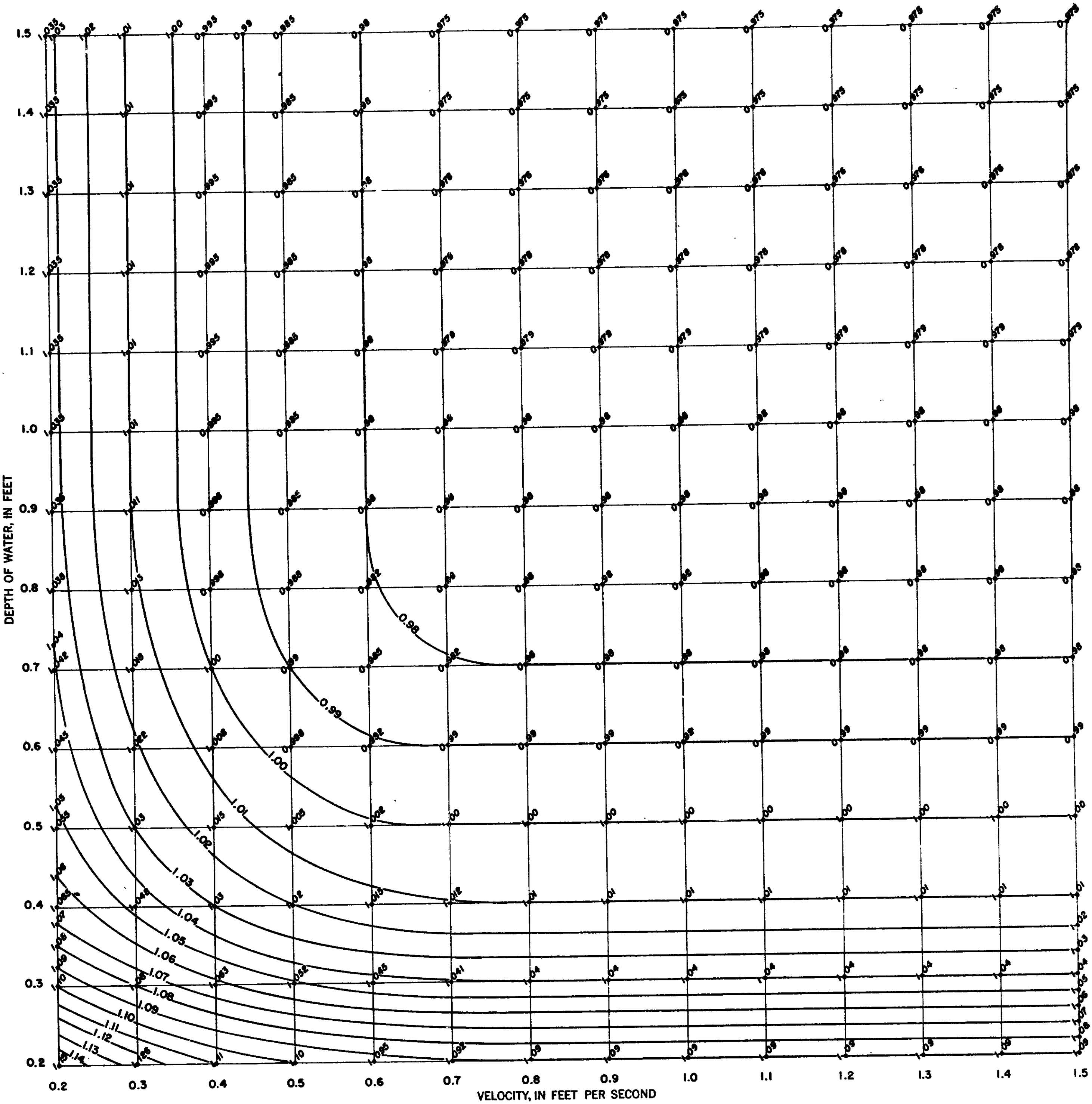
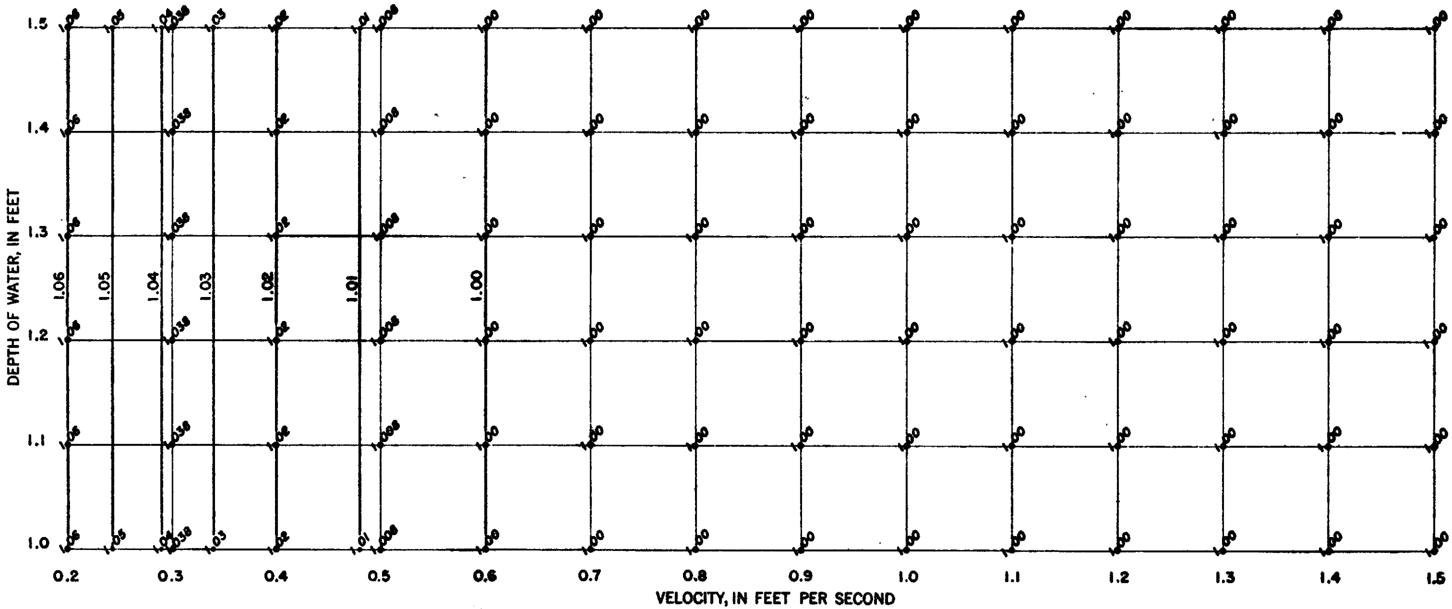
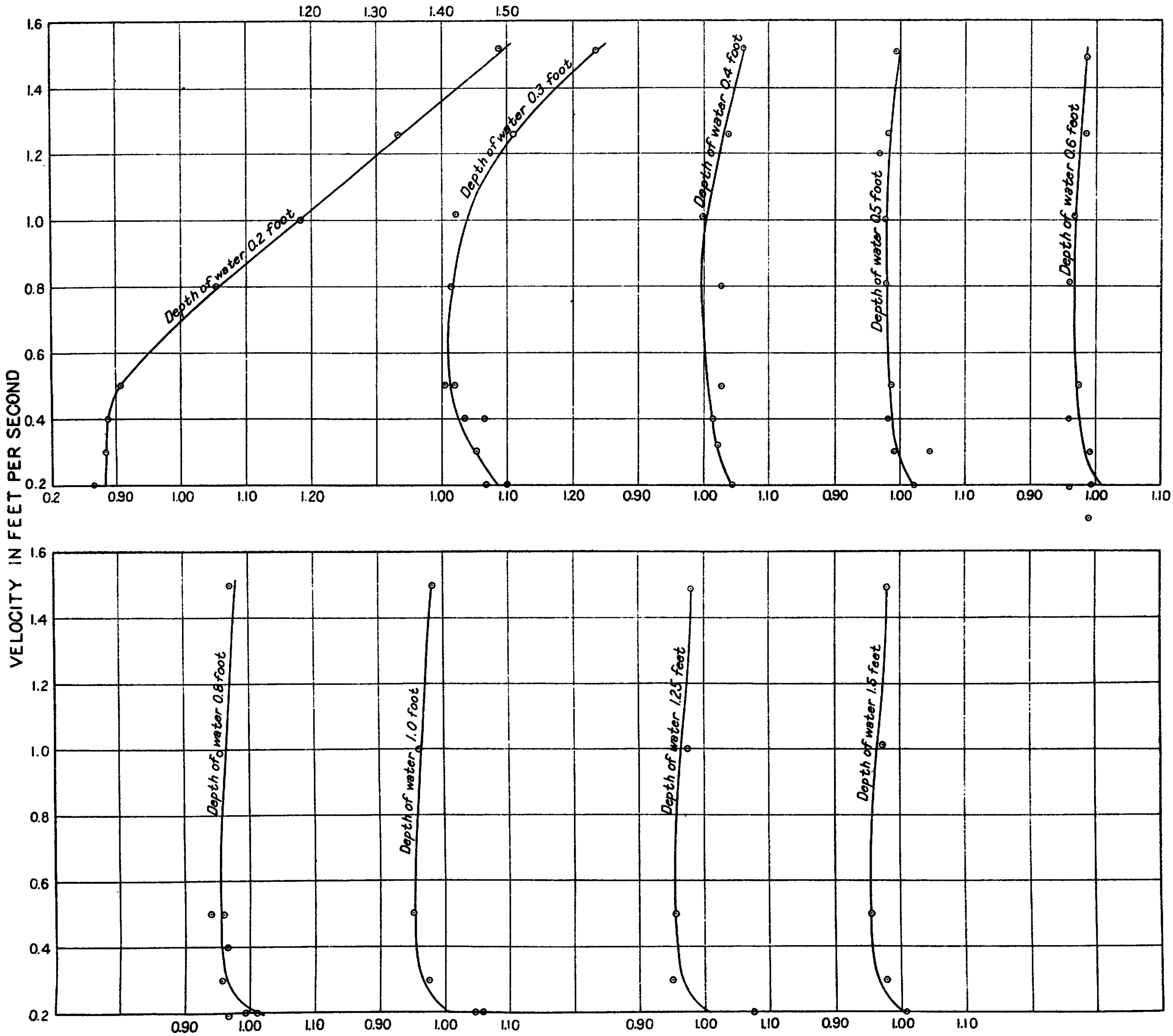


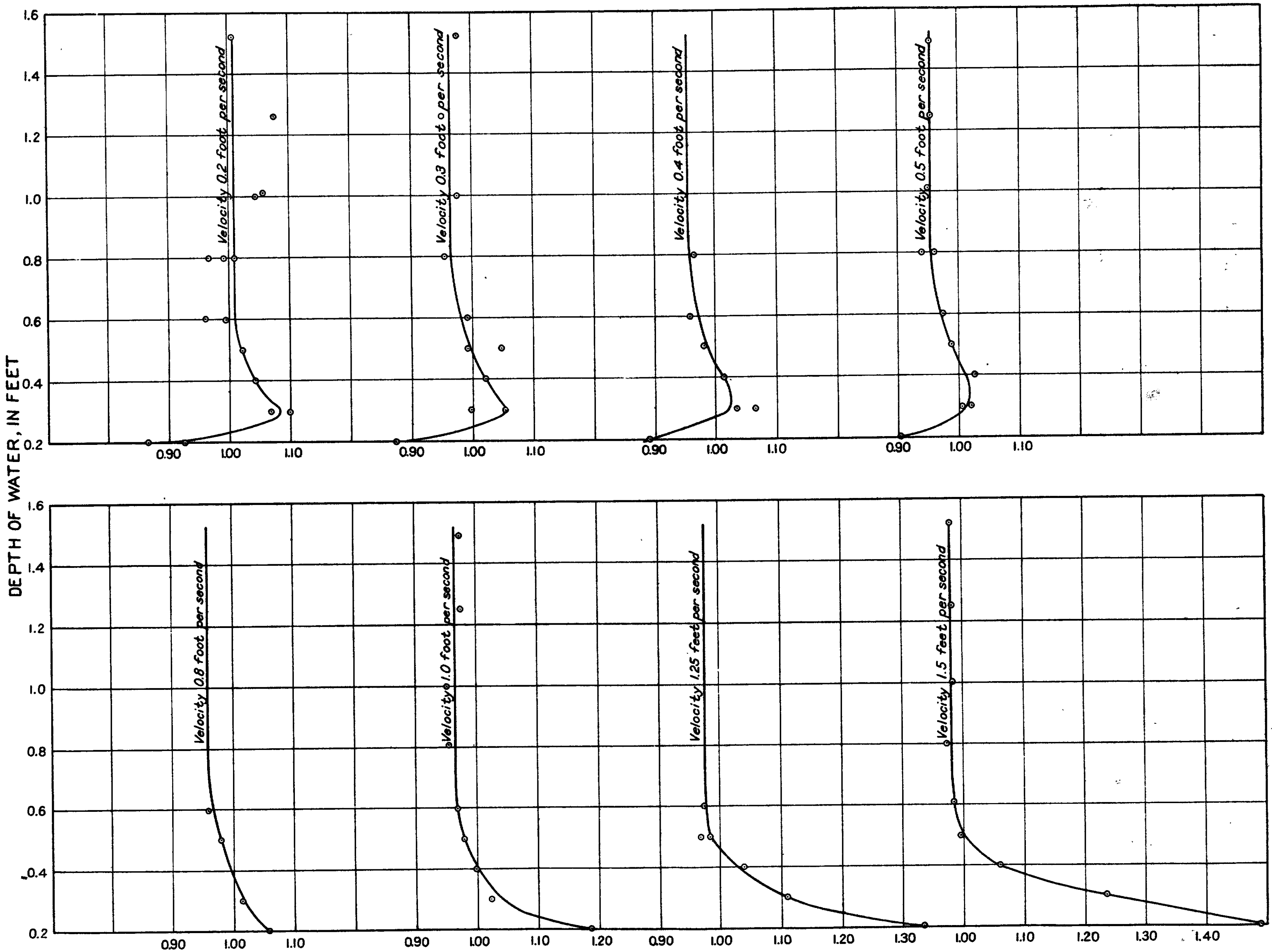

COEFFICIENTS FOR USE WITH 0.6-DEPTH METHOD, PYGMY CURRENT METERS.



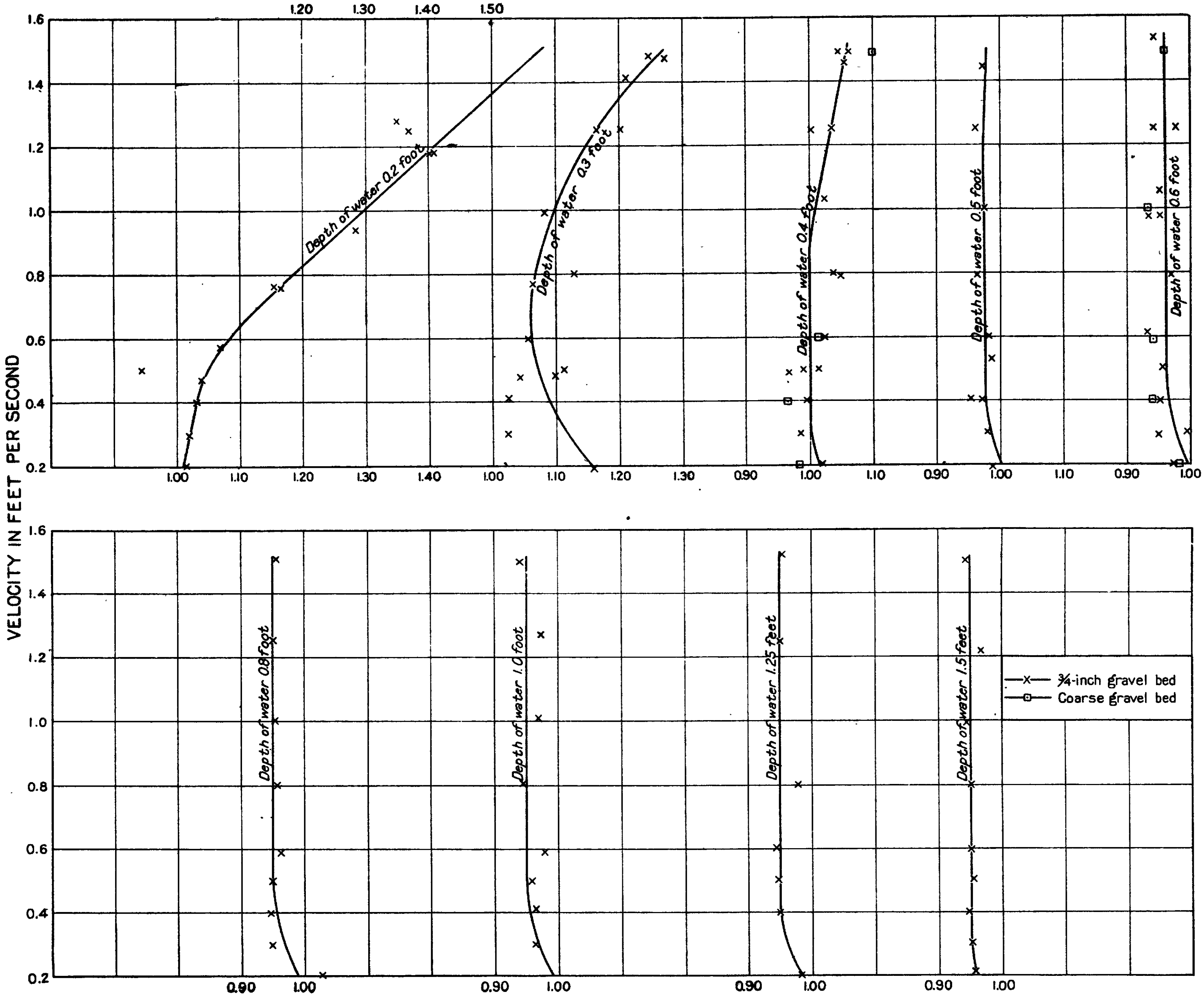

COEFFICIENTS FOR USE WITH 0.2- AND 0.8-DEPTH METHOD, PYGMY CURRENT METERS.




VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, SMOOTH BED, 0.5-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.




VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, SMOOTH BED, 0.5-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.




VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, GRAVEL BED, 0.5-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

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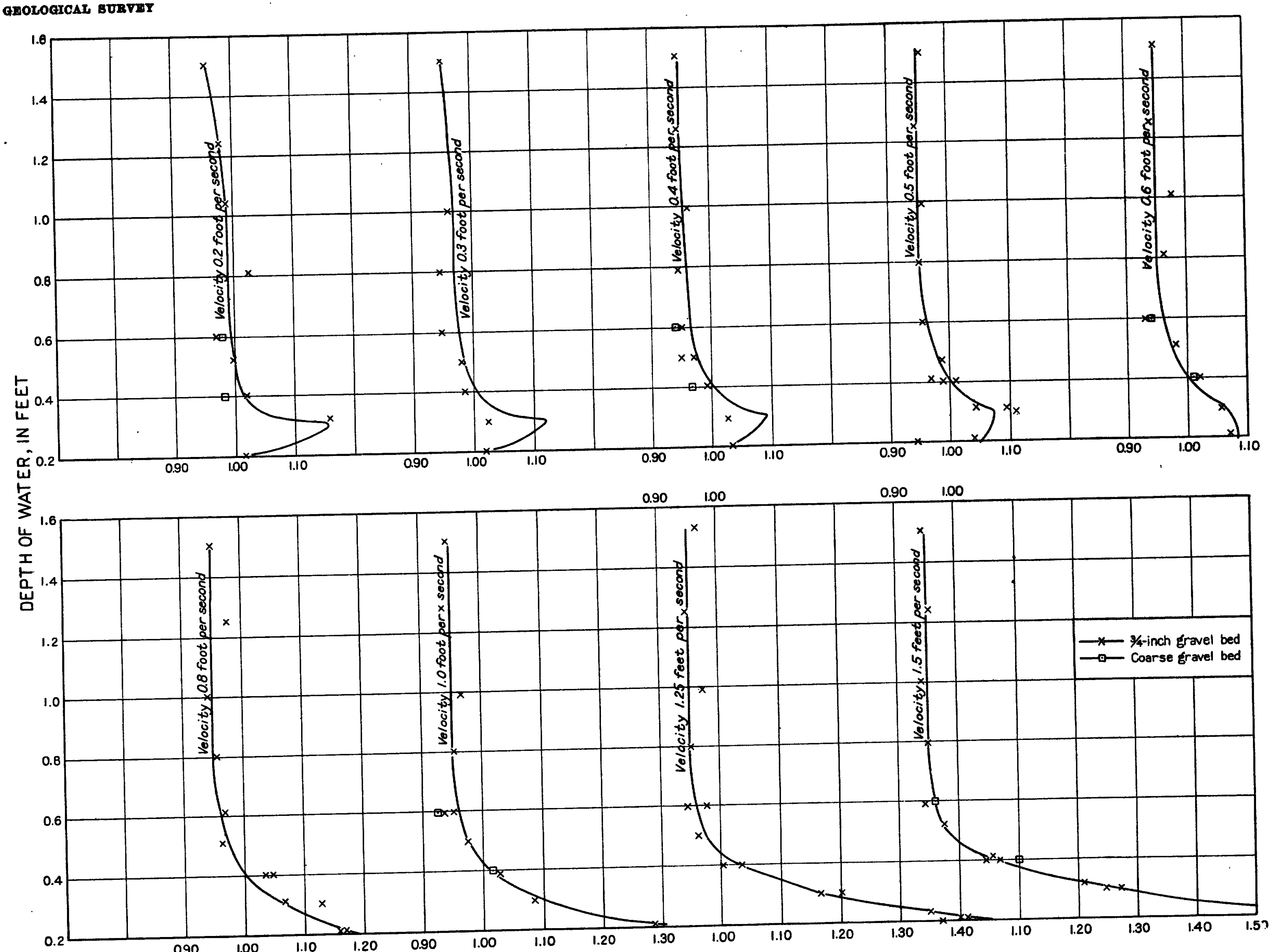
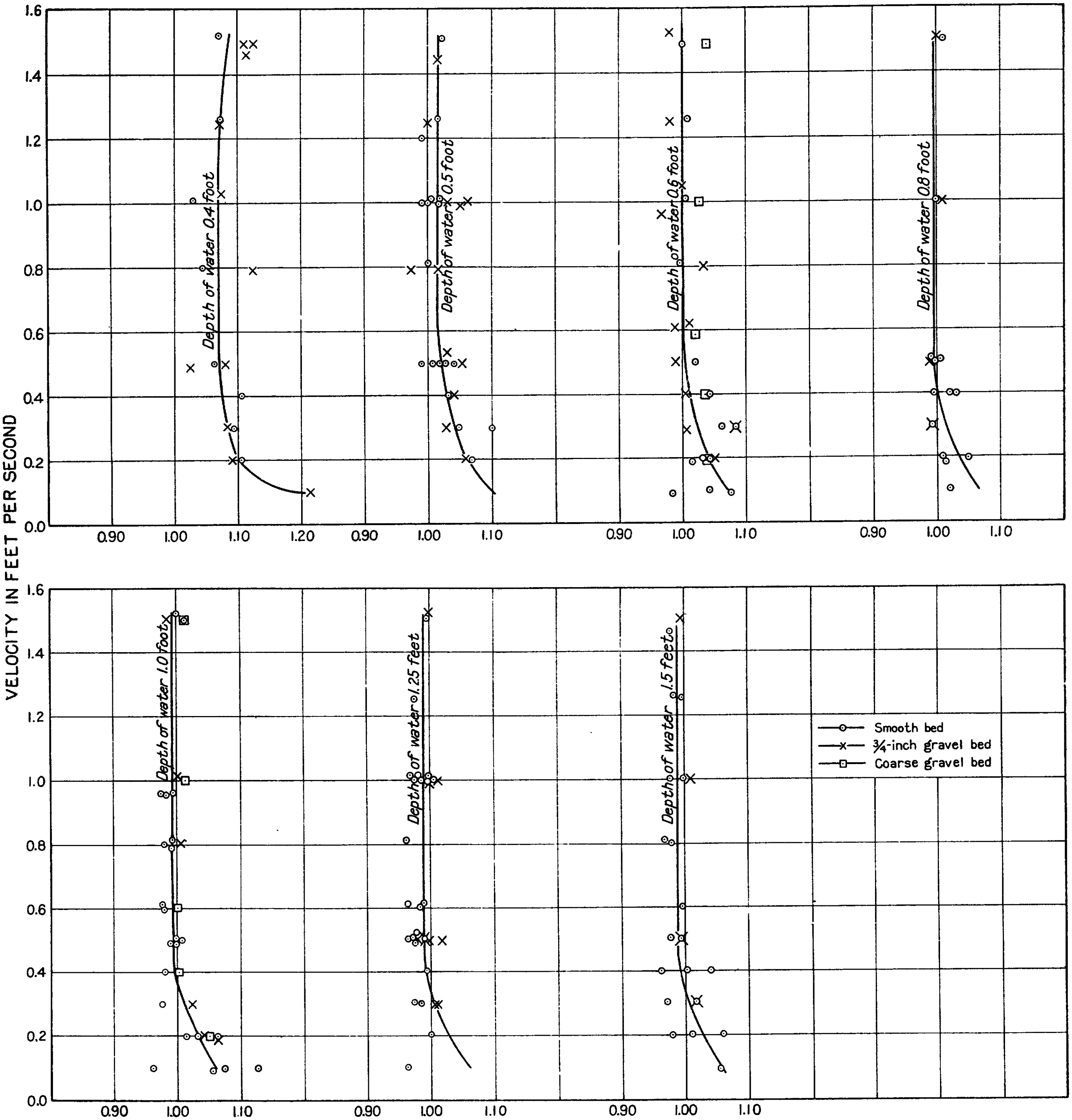
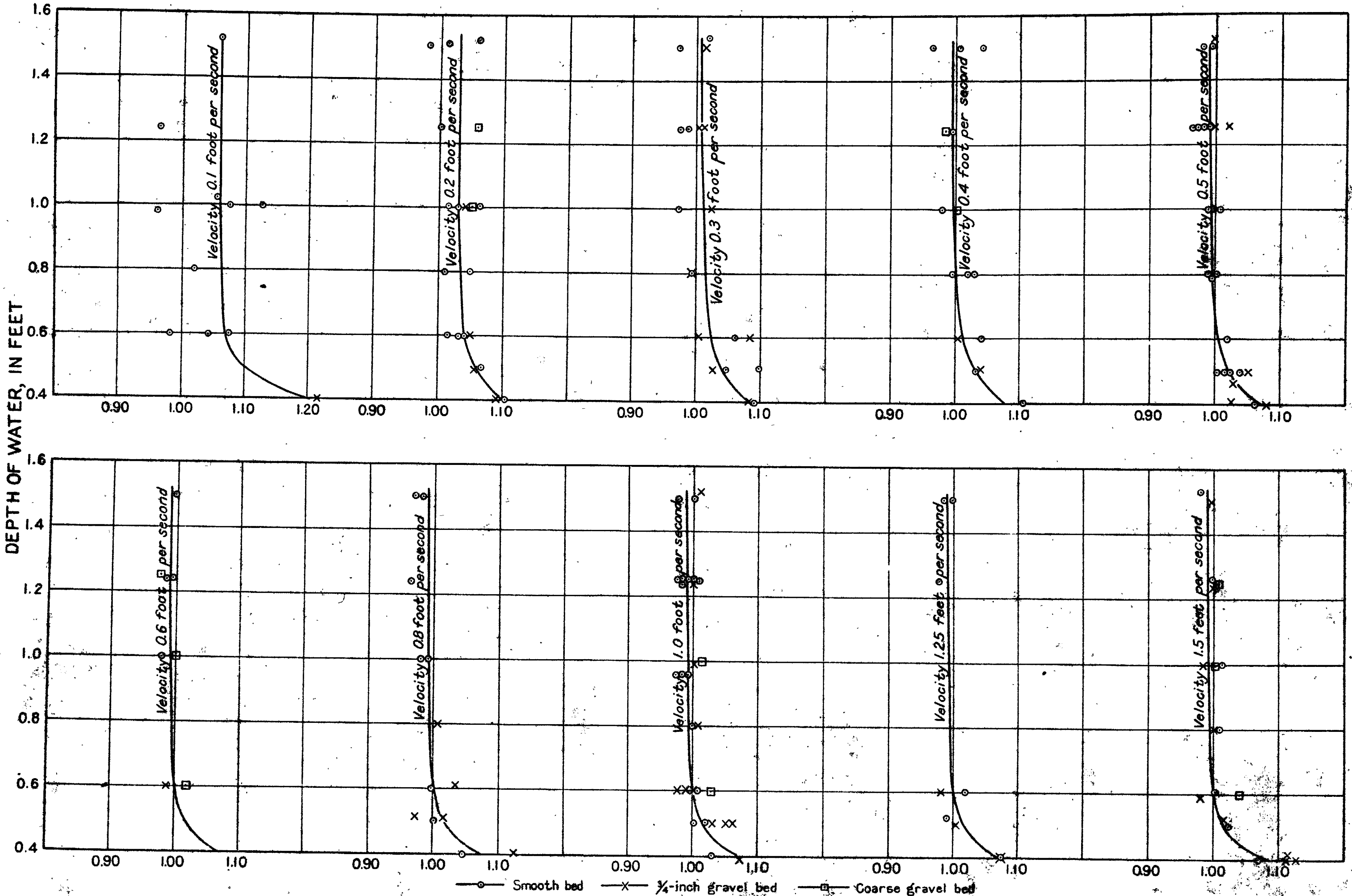


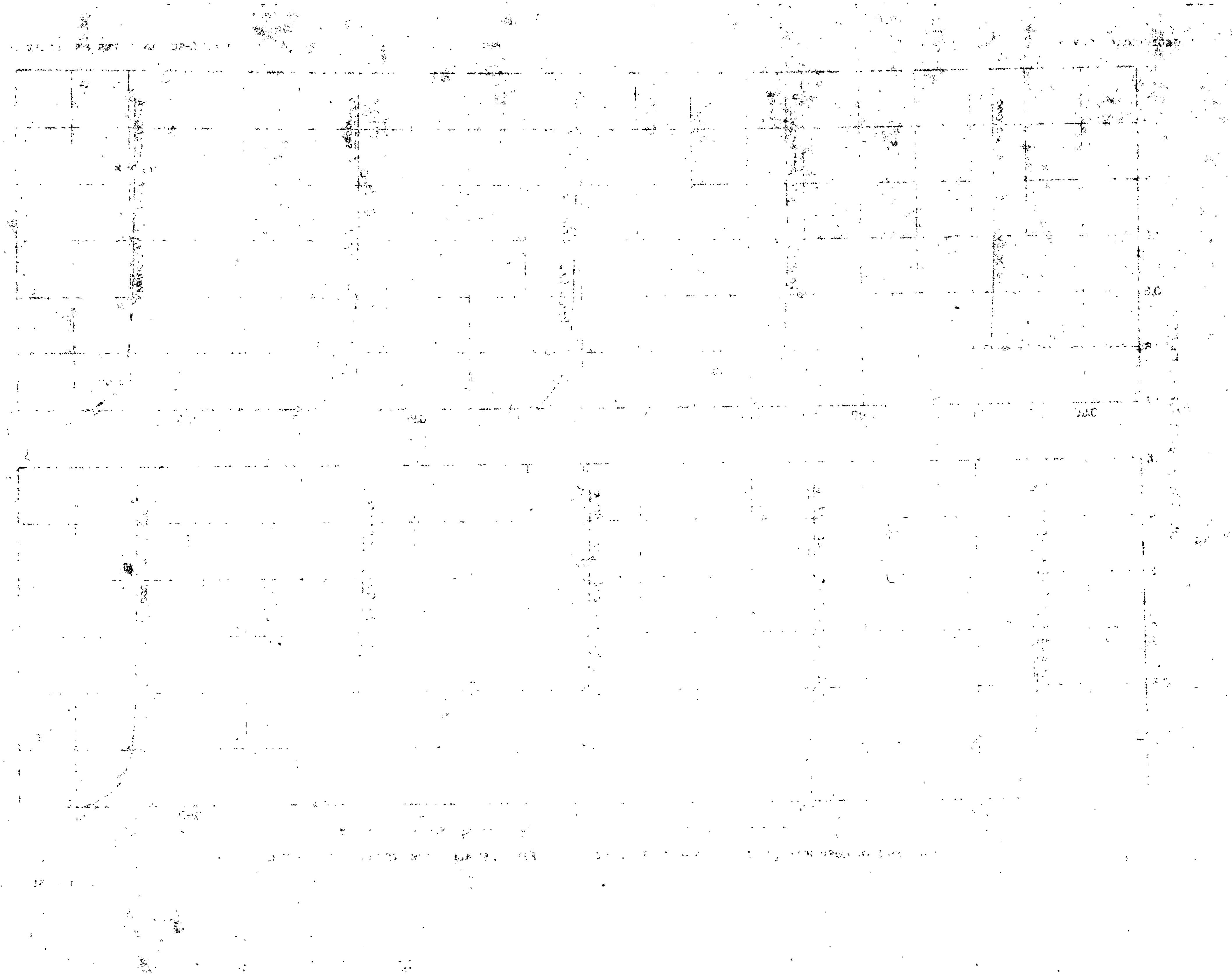

VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, GRAVEL BED, 0.5-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

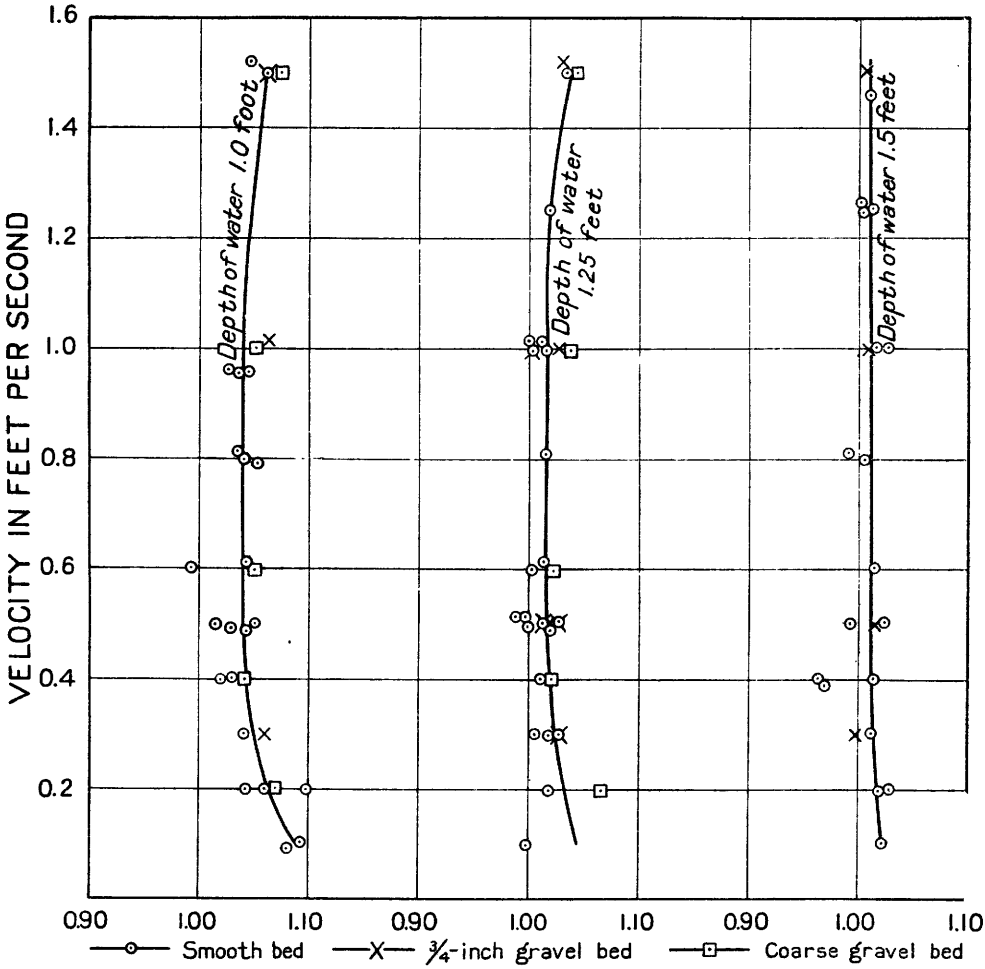



VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, 0.6-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

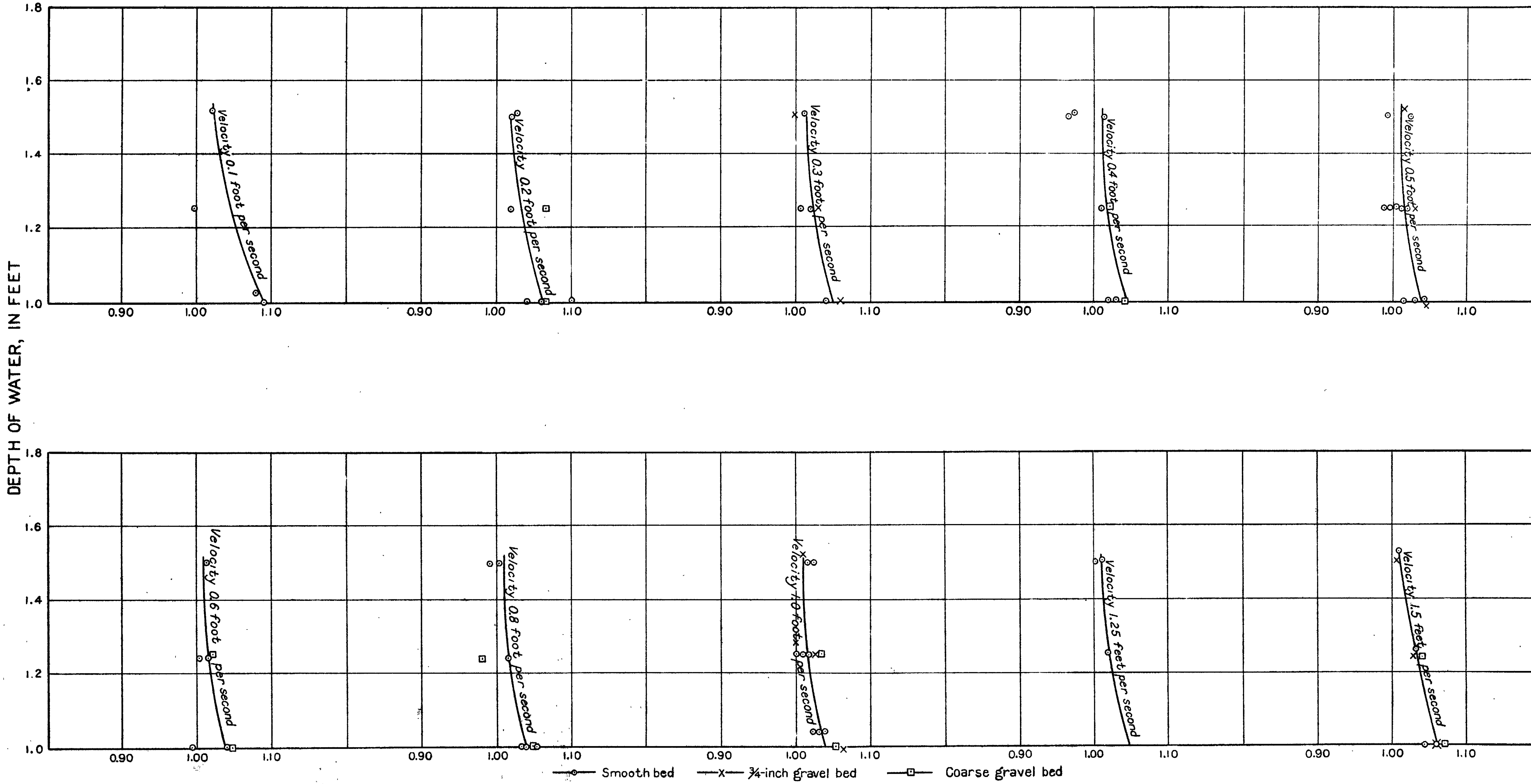



VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, 0.6-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

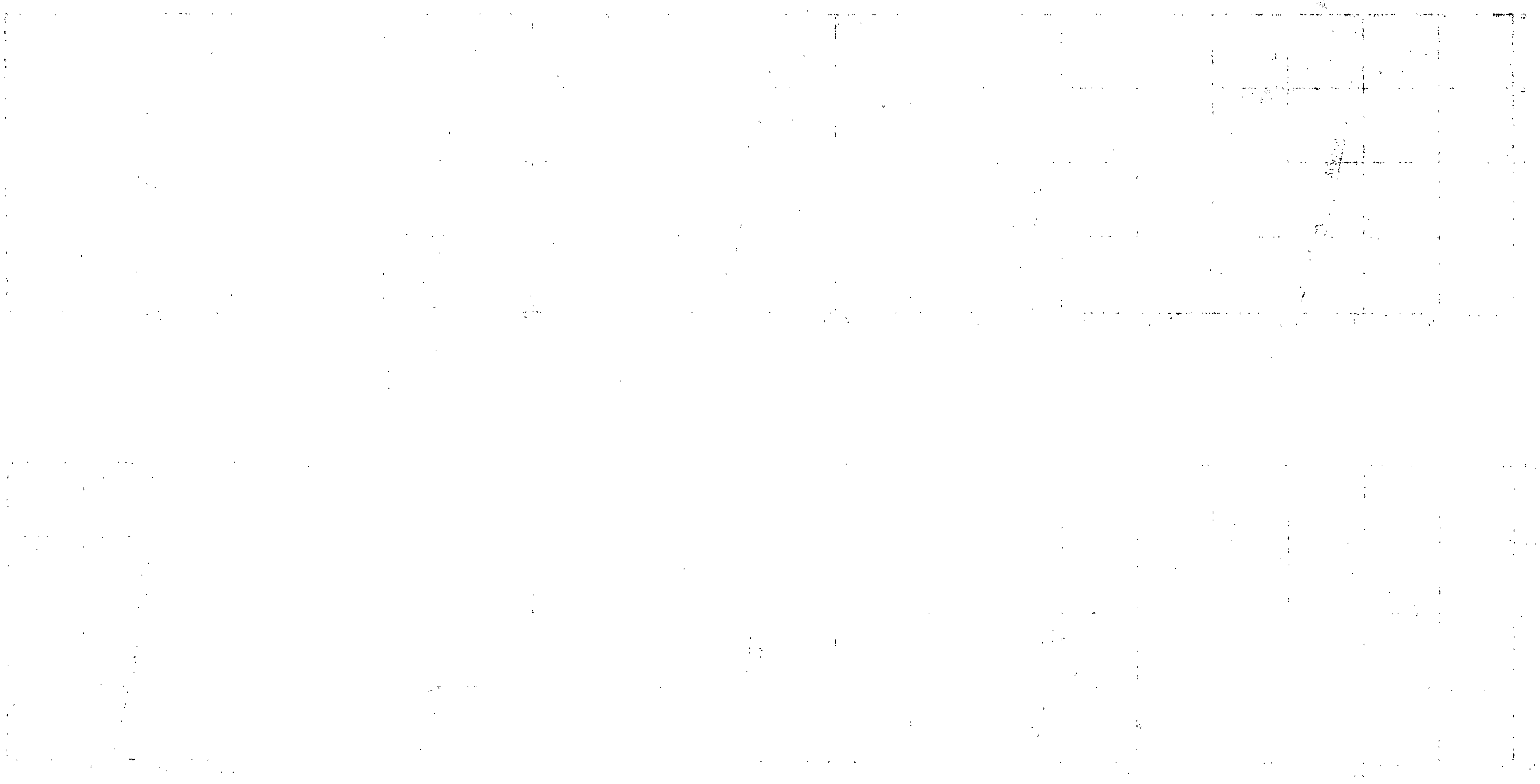


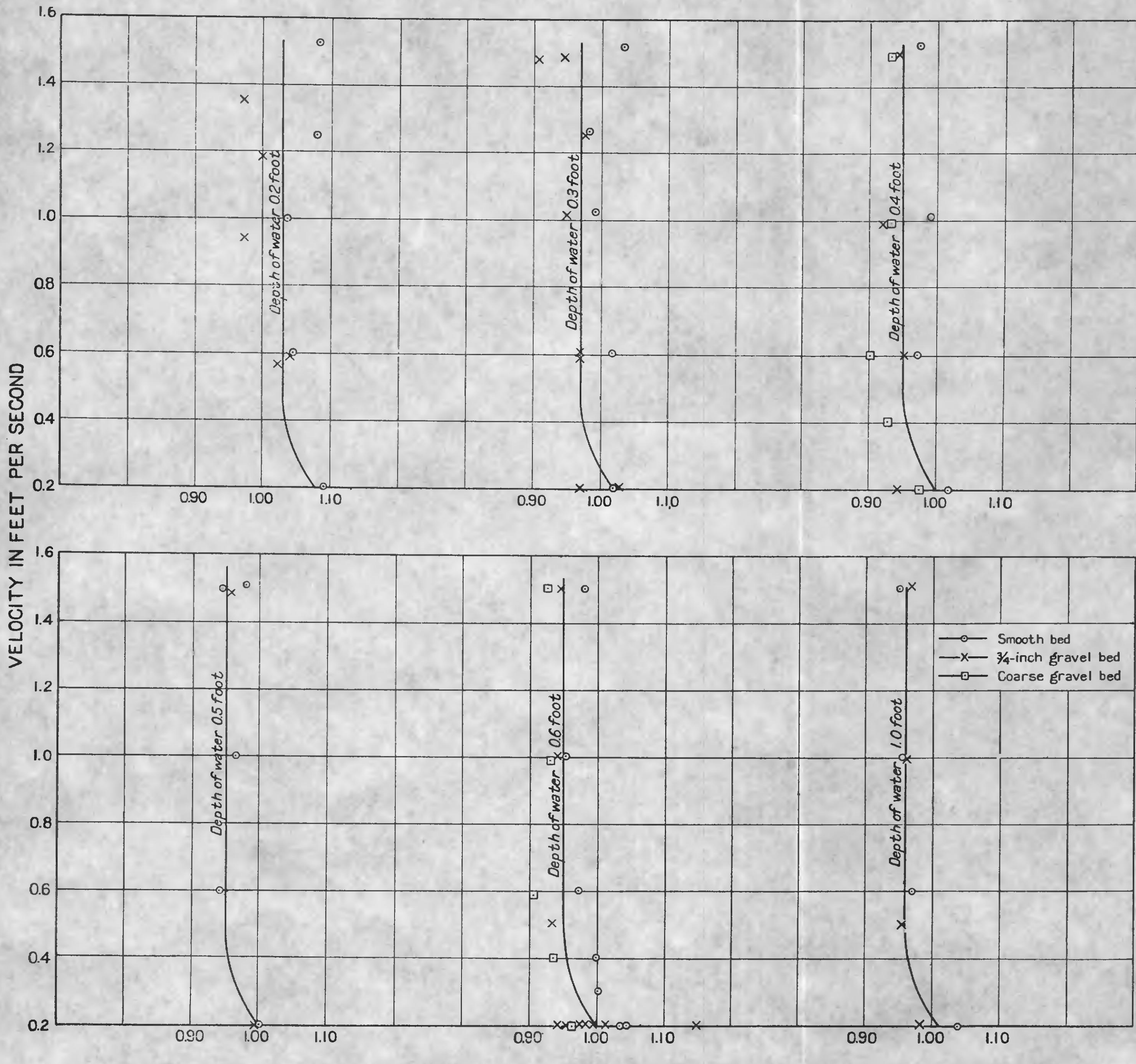



VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, 0.2- AND 0.8-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

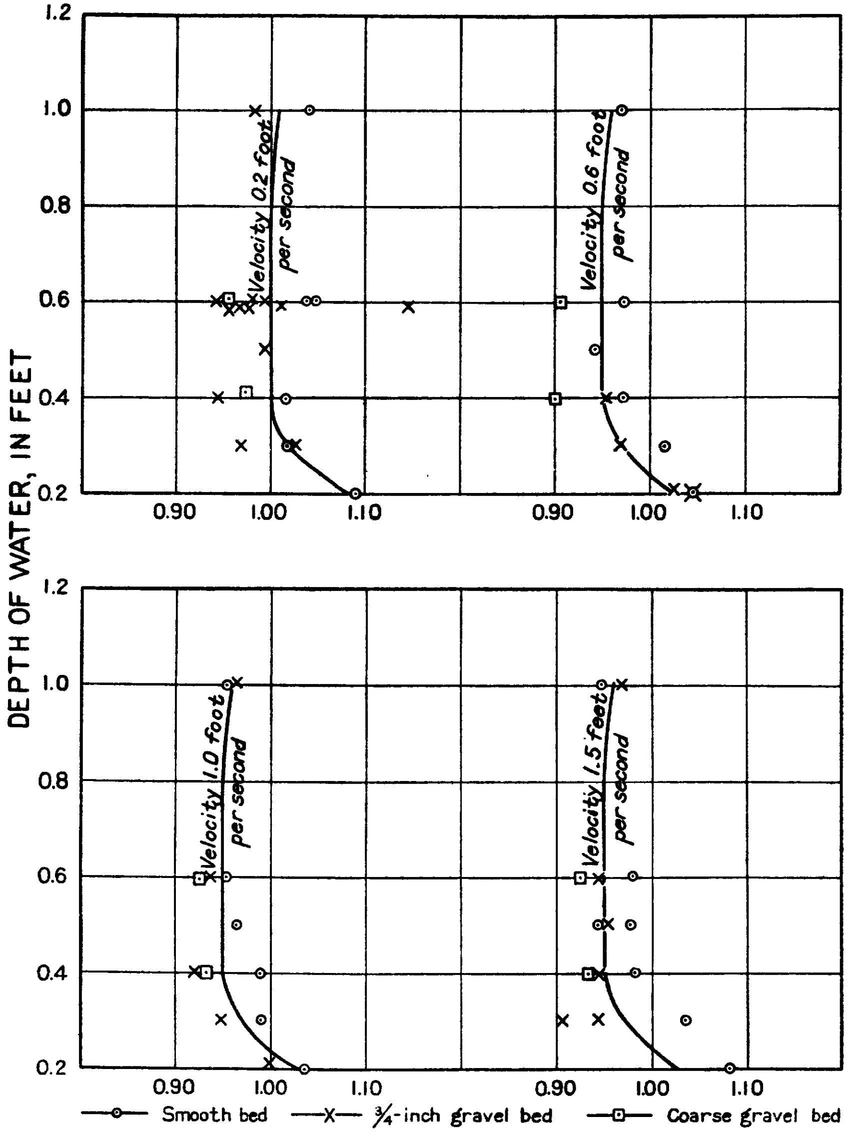



VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, 0.2- AND 0.8-DEPTH METHOD, SMALL PRICE-TYPE CURRENT METERS.

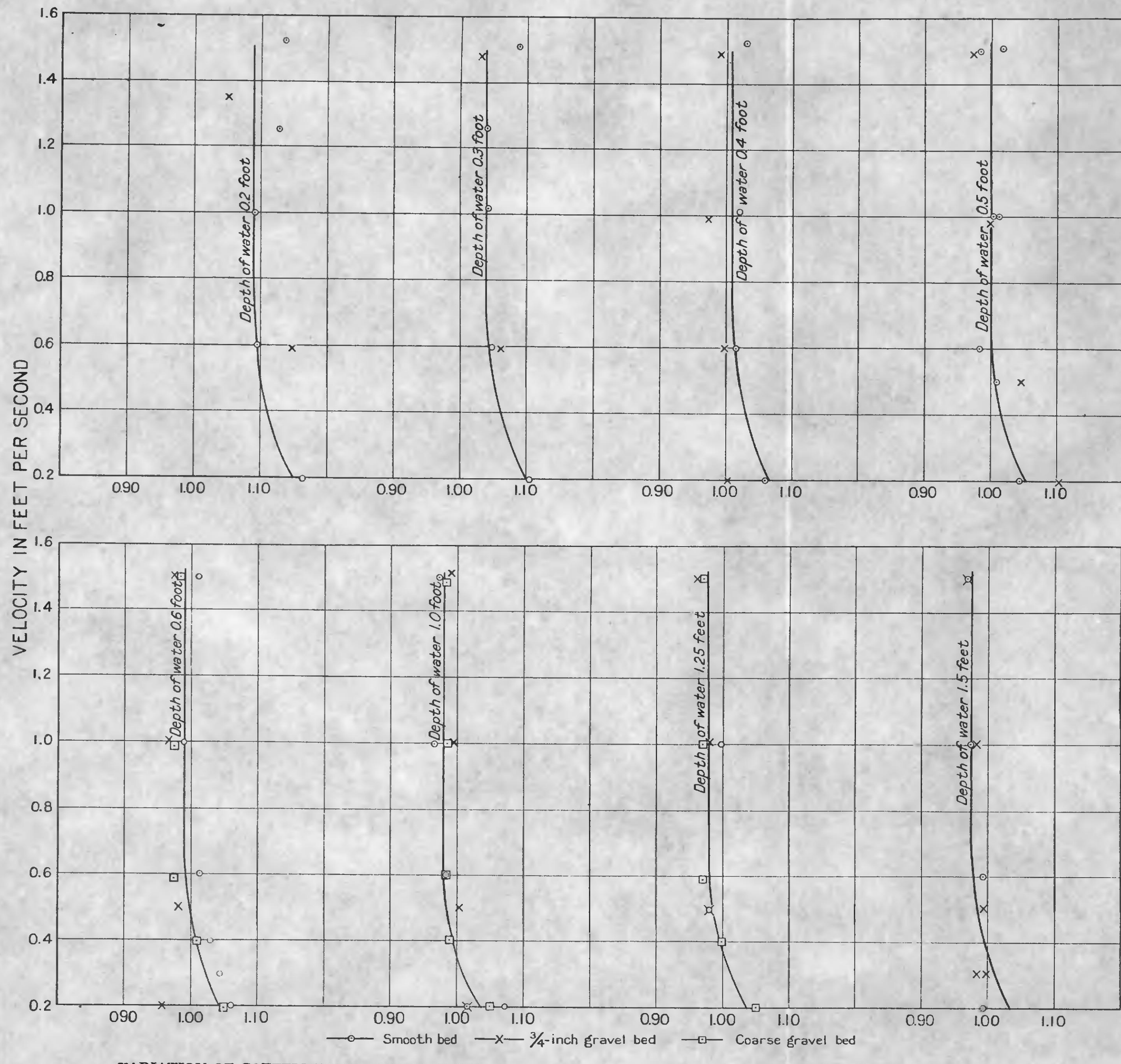




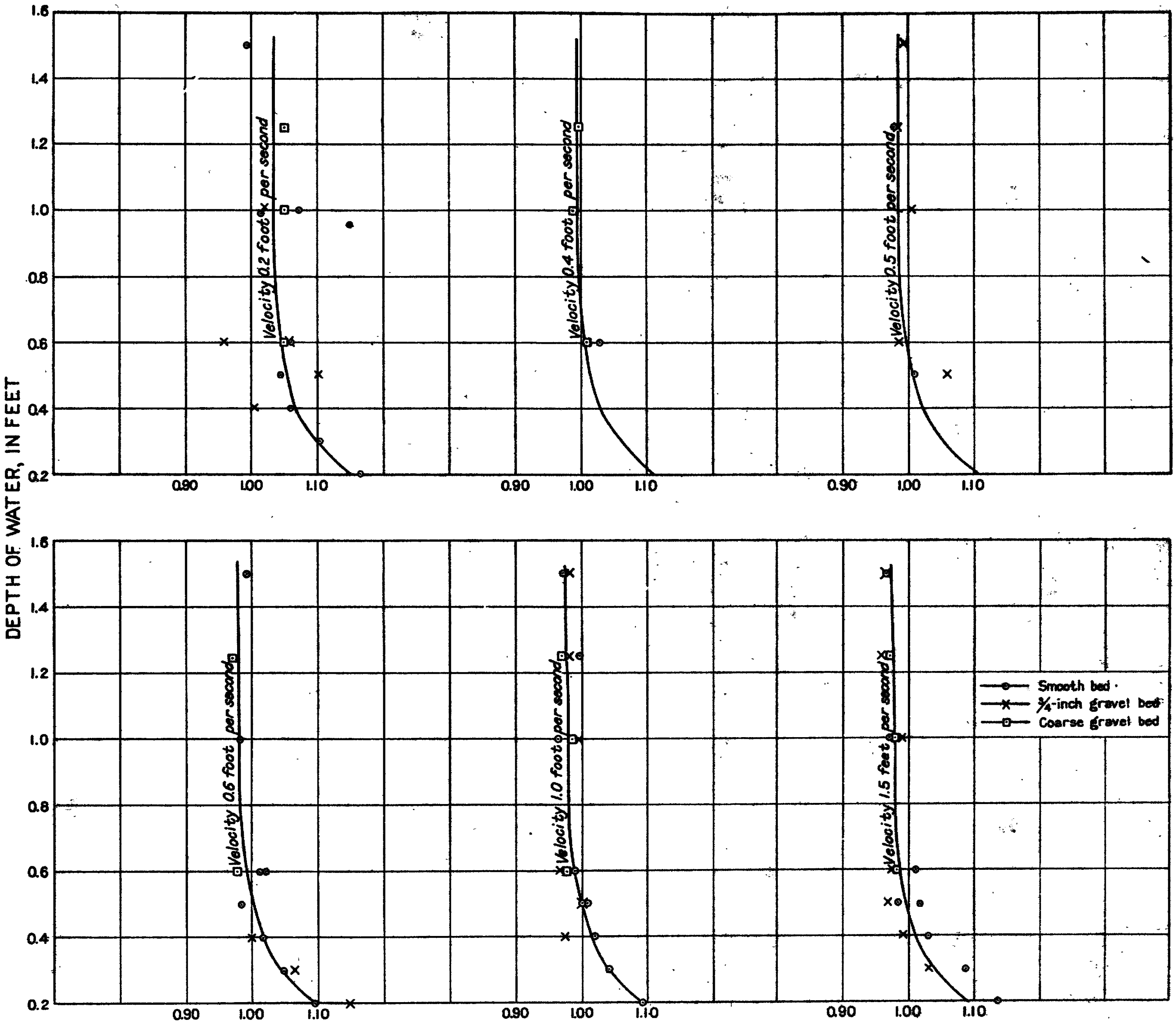

VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, 0.5-DEPTH METHOD, PYGMY CURRENT METERS.



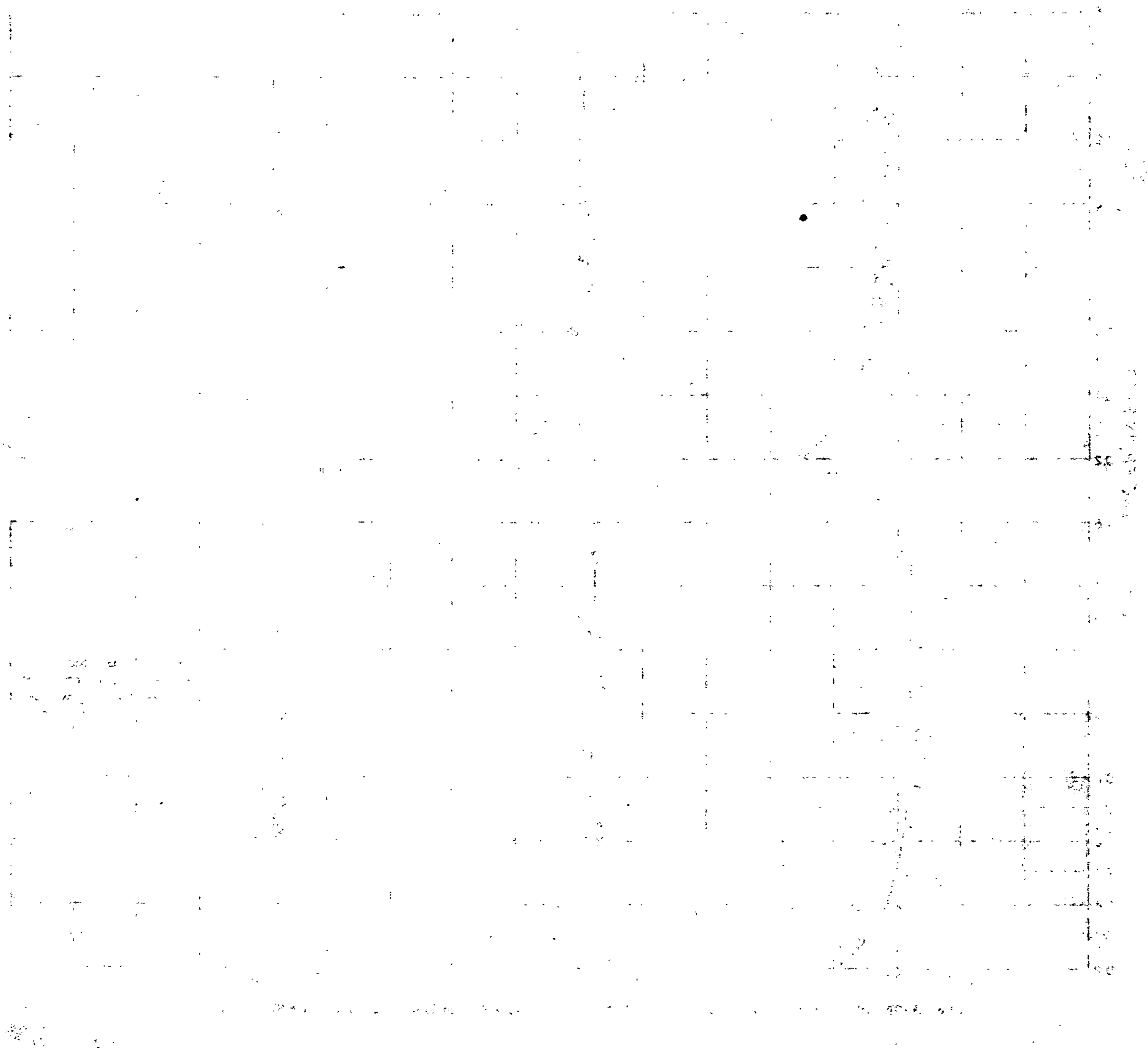

VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, 0.5-DEPTH METHOD, PYGMY CURRENT METERS.

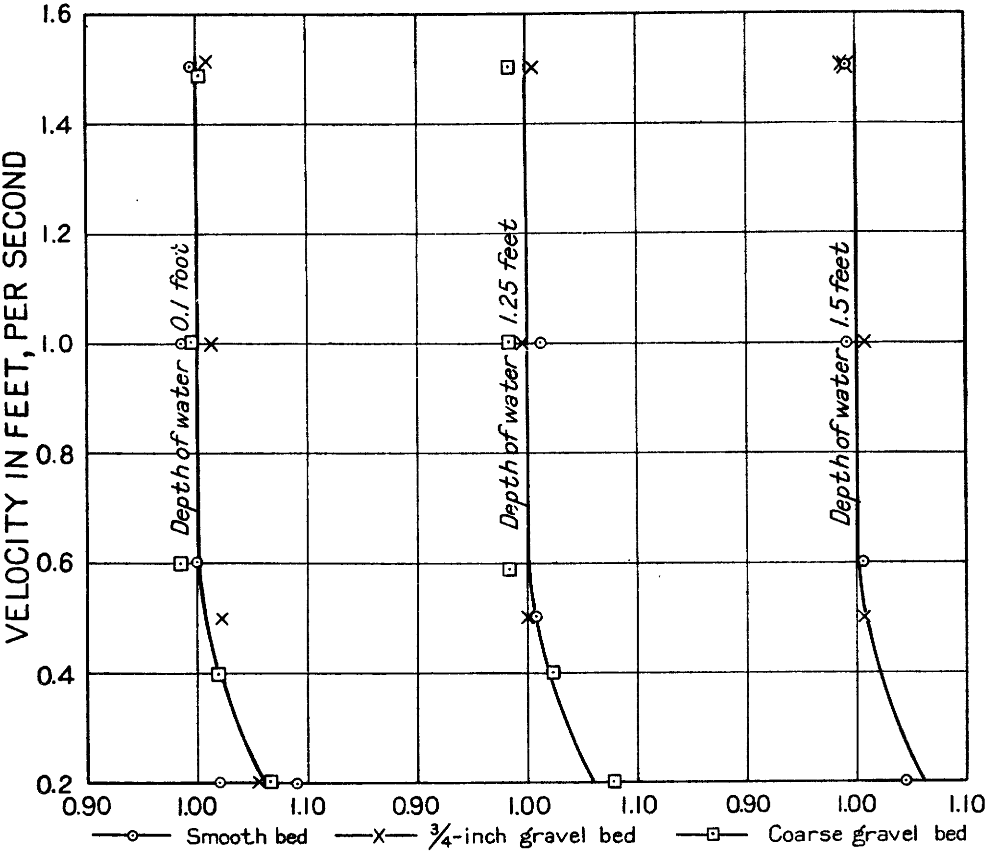



VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, 0.6-DEPTH METHOD, PYGMY CURRENT METERS.

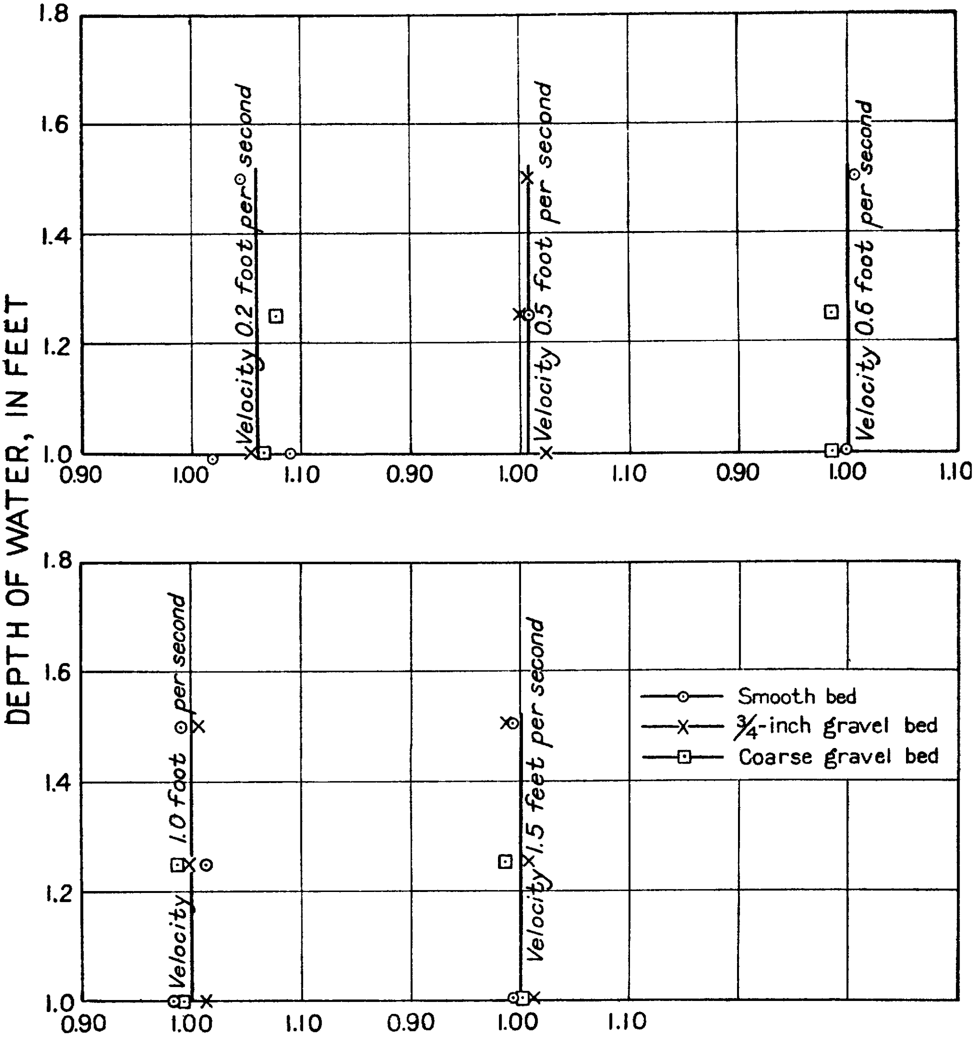



VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, 0.6-DEPTH METHOD, PYGMY CURRENT METERS.






VARIATION OF COEFFICIENTS WITH CHANGE IN VELOCITY, 0.2- AND 0.8-DEPTH METHOD, PYGMY CURRENT METERS.




VARIATION OF COEFFICIENTS WITH CHANGE IN DEPTH, 0.2- AND 0.8-DEPTH METHOD, PYGMY CURRENT METERS.

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