UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 854

Contribution from the Bureau of Public Roads
THOS. H. MACDONALD, Chief

Washington, D. C. PROFESSIONAL PAPER August 26, 1920

THE FLOW OF WATER IN DRAIN TILE

By

D. L. YARNELL, Senior Drainage Engineer, and SHERMAN M. WOODWARD, Professor of Mechanics and Hydraulics
State University of Iowa

CONTENTS

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CONTENTS.

INTRODUCTION.

The discharging capacity of tile drains has become a matter of considerable importance in recent years, on account of the heavy investments being made in this kind of agricultural improvement. Drain tile in small sizes have been used for a long time, but recently much larger sizes, 2 feet and more in diameter, have come into rather common use in some States. Where tile 24 to 48 inches in diameter and larger are to be installed, at a cost of $8,000 and upward per mile, reducing the diameter 2 or 3 inches may mean saving $500 to $1,500 per mile.

Planning the best tile-drainage system for any situation is a complicated problem of balancing many diverse and uncertain factors of benefit and cost. The point of largest rate of return upon the investment can not be determined exactly. Obviously, a point may easily be reached where additional expenditure, although securing an enhanced degree of drainage, would not yield additional benefit in proportion to the increase in cost, and might not be justified. On the other hand, an inadequate installation might be so ineffective as not to justify even the small expenditure it would require. It is the engineer's high duty, therefore, in planning the general scheme of improvement for any drainage undertaking, to determine just what expenditure will yield a satisfactory return, and to so proportion the details as to secure the maximum benefit from the investment. A deficiency at one point may reduce the effectiveness of the whole system, while the elaboration of one part out of proportion to the others might add materially to the expense without obtaining any benefit.

The formulæ in general use for computing the velocity of flow in tile drains were proposed years ago, when all drain tile were small as compared with the larger sizes used to-day. Under the earlier conditions, when other considerations had relatively large weight in determining the size of tile to be used, accuracy in computing carrying capacity was relatively unimportant; but nowadays drains 12 to 48 inches in diameter are common, and accurate knowledge of the capacity is essential for economical design.

Although many experiments have been made upon flow of water in iron, steel, concrete, and wood-stave pipes, the results are not directly applicable to tile drains. The tile usually are not nearly so regular in size and shape as are the other pipes mentioned, and specially noteworthy is the number and nature of the joints. While the other conduits are either of continuous construction or in 10 to 20 foot lengths, drain tile are in lengths of only 1 to 3 feet. Furthermore, with clay tile the nature of the materials used and the methods of manufacture are the causes of some distortion in cross section; this is particularly noticeable where two lengths abut. The considerable unevenness at the joints, when multiplied by the greater number of joints, so greatly disturbs the flow of water as to make formulæ devised for other kinds of conduit inapplicable to tile drains.

Realizing the need for accurate knowledge regarding the flow of water in tile drains, plans for investigating this subject were made by the drainage division of the Bureau of Public Roads, early in 1915. The experiments so far made concern only the smaller sizes of tile, and this report therefore should be considered as a progress report of the investigation of the whole subject.

SCOPE OF THE INVESTIGATION.

Drain tile installed for agricultural improvement serve two somewhat distinct purposes—as collectors of excess water and as conduits to convey the water to some more or less distant outlet, but usually both purposes are served coincidentally. The investigation herein reported, however, deals only with the discharge or carrying capacity of tile drains as conduits. No tests were made on sizes smaller than 4 inches in inside diameter, as the use of smaller sizes now is considered generally inadvisable, the small bore greatly increasing the danger of obstruction by sediment or by displacement.

Laboratory methods are essential for securing definite results in such an investigation, in order that each factor influencing the flow may be varied through a considerable range, yet always subject to control, while the other factors are maintained constant. Only in this manner can each influence be measured separately. The factors influencing the velocity of flow in a tile drain are: the inside diameter of the pipe, the depth of the water flowing, the slope or grade of the water surface (which ordinarily is that of the tile line), and the roughness and irregularity of the interior surface and of the joints. On tile lines installed for actual use in land drainage the grade of each line is fixed; most of the time they are empty or carry but little water; the amount of flow depends upon weather and seasons and can not be regulated for investigation; and when the flow is considerable the weather is likely to be bad, the roads practically impassable, and the ground surface covered with water—conditions that make it impossible to secure satisfactorily precise measurements in tile several feet under ground.

The principal feature of the equipment for making the experiments was a wooden flume about 570 feet long, in which the tile were laid in earth exactly as drains are installed in the ground. The flume was adjustable to any grade up to 1.50 per cent ($s = 0.015$), without disturbing the tile. The depths of flow were observed by piezometer tubes hung on the side of the flume. Care was taken to make the tile lines truly representative of drains ordinarily well laid under field conditions.

Experiments were made with all the usual commercial sizes of tile, both of clay and of concrete, from 4 to 12 inches inside diameter. Nine grades were used, from 0.05 to 1.50 per cent, for each size and kind of tile. For each size, kind, and grade it was desired to test depths of flow of one-fourth, three-eighths, and one-half the internal diameter of the tile, and other depths ranging from half full to full by successive increases of 5 per cent of the diameter. However, because of the practical difficulty of securing exactly any given depth of flow, the number of tests was considerably less than anticipated in the smaller sizes of tile. Also, the capacity of the pumping plant was not sufficient to fill the largest tile at the maximum grade. Tests were run, also, with the tile under slight internal pressure. In all, 824 separate tests were made, and from these a new formula has been devised for computing the flow in drain tile.

For comparison, 69 tests were made on 10 and 12 inch tile, so laid as closely to approximate poorly laid drains as found in the field, to show the results of using unskilled workmen in laying drains without proper supervision. Nine experiments were made upon the loss of head in catch-basins, using 8-inch clay tile. Grades of 0.20, 0.75, and 1.50 per cent were tested, with drops in the catch-basin of 0.10, 0.20, and 0.30 foot for each grade.

The investigations were made at Arlington, Va., in 1916 and 1917. The experimental plant was designed and constructed by S. W. Frescoln, drainage engineer, and the tests were made by D. L. Yarnell, senior drainage engineer, under the direction of S. H. McCrory, chief of drainage investigations. S. M. Woodward acted as consulting engineer for the investigation, making suggestions in the conduct of the experiments and collaborating in the preparation of the data and report.

This report upon the investigation of flow in drain tile includes a detailed description of the equipment and methods used and the tabulated data from the experimental work. The results deduced from the data are shown graphically, the method of developing the curves being explained. The formulæ now in general use for computing velocity in tile are discussed and comparison is made with the new formula presented. A diagram is given showing discharge capacities based upon this formula, covering sizes from 4 to 48 inch tile, and grades from 0.04 to 3.00 per cent.

So far as the writers have been able to learn, only one other similar investigation of this subject has ever been made. This was by Messrs. J. F. Rightmire and M. E. Chappel and was quite limited in extent (see Vol. IV, No. 4, Bulletin of the Iowa State College Engineering Experimental Station).

CONCLUSIONS.

The following general conclusions have been drawn after a detailed study of all of the experimental data:

(1) That the value of the coefficient of roughness, n, in the Kutter formula, as obtained by experiments in a drain or pipe at any depth of flow less than full, does not necessarily apply to that drain or pipe when flowing full.

(2) That the exponent of the slope, s, is practically 0.5. In other words, the loss of head is in proportion to the 2.0 power of the velocity and not the 1.8 power, as given by many authorities.

(3) That the exponent of the mean hydraulic radius, R, is 2/3.

(4) The Chezy formula gives the same velocity of flow in a pipe flowing one-half full as in one flowing full, with the grade constant. The experimental data obtained seem to disprove this commonly accepted theory.

DESCRIPTION OF EXPERIMENTAL PLANT.

PUMPING PLANT.

A complete pumping plant was installed to supply the water necessary to carry on the tests. The pump used was an 8-inch side-suction centrifugal pump. Its economical capacity was 1,800 gallons per minute. The suction pipe, 10 inches in diameter and approximately 40 feet long, was laid sloping from the pump to the intake ditch or sump. The discharge pipe, 8 inches in diameter, was so arranged that the entire capacity of the pump could be delivered to the supply tank with the least frictional losses.

The pump was run by a 30 h. p. engine rated at 200 r. p. m. It was equipped with an oscillating-type magneto with the make-and-break spark. It was started on gasoline, and after becoming warm operated on kerosene. The engine was connected to the pump by a 10-inch, double thickness, endless leather belt.

SUPPLY TANKS.

In order to maintain a constant flow through the tile line, a supply tank 7 feet 9 inches by 7 feet 9 inches by 10 feet 9 inches deep (*A*, Pl. I) was built to receive the pump discharge. On the side of this tank opposite the entrance of the pump discharge pipe, a measuring weir and a hook gage were installed. A baffle board extending from the top of the tank to within 2 feet of the bottom was constructed. Thus the movement of the water from the discharge of the pump was quieted sufficiently to obtain a quiet surface on the water at the hook gage and weir.

Since the entire discharge of the pump was not required for all the experiments, an overflow tank (*B*, Pl. I) was built. Its size was 9 feet 6 inches by 9 feet 6 inches by 5 feet 6 inches deep. A trough from this tank carried the overflow water back to the intake ditch.

For regulating the flow into the supply tank, an 8-inch gate valve was inserted in the pump discharge pipe. This valve is shown in Plate I, between tank *B* and the pump house. The water not required for the experiment passed through another 8-inch gate valve into the overflow tank. When the entire discharge from the pump was used in the tile, the gate valve in the overflow tank was closed.

Another tank containing baffle board, hook gage, and weir was used at the lower end of the tile line to measure the discharge from the tile as a check on the amount of water entering the tile. However, the measurements from this tank, as will be explained later, were not used in the final computations.

Both weir tanks were covered with boards to prevent any surface movement on the water being set up by winds.

WEIRS.

For use in measuring the water entering into and discharging from the tile line, brass, triangular-notch weirs were used, the notch angle being 90 degrees (Pl. II, fig. 1, and Pl. III, figs. 1 and 3). For tile over 4 inches in diameter, weirs with $\frac{1}{8}$-inch lips were used; while for the 4-inch tile, knife-edged weirs were deemed the most accurate. The weir plates, both of which were set level, were so placed that the nappe of each weir cut free and was fully aerated.

To determine the discharge over the weirs, V. M. Cone's formula,

$$Q = 2.487 H^{2.4805}$$

was used in all computations. In this formula, Q = discharge in cubic feet per second and H = head in feet on weir notch.

HOOK GAGES.

Boyden hook gages were used to determine the head on the weirs. On both gages the vernier plates were securely fastened and bradded to the gage, so as to eliminate any error due to possible charge of position of the plates. Each gage was set at a distance of over 2 H to the side of the weir so as to record the correct head on the weir.

FLUME.

In order to test the carrying capacity of the tile bedded in earth as in actual practice, a continuous wooden flume (Pl. IV) 570 feet long, 2 feet wide, and 2 feet deep was constructed of 2-inch plank. All joints and seams were calked with oakum and covered with pine pitch to make the flume water-tight. This continuous channel or flume was supported on yoke blocks suspended by $\frac{3}{4}$-inch steel rods (*A*, Pl. V) from 6 by 6 inch caps (*B*, Pl. V) which rested on 4 by 4 inch vertical posts (*C*, Pl. V). Two vertical posts with their yoke block formed a bent; the bents were spaced 8 feet apart. In all, 72 bents were erected. Each bent was braced by 4 by 4 inch posts (*D*, Pl. V).

METHOD OF CHANGING GRADE.

The upper 6 feet of the steel rods were threaded with 10 threads to the inch. For support on the caps, bearing plates with ogee washers and 2-inch hexagonal nuts were used. To raise the flume an inch at any bent it was necessary to turn the nuts just 10 revolutions. Ordinary wrenches were cumbersome and slow for turning these nuts, consequently specially-constructed socket wrenches (Pl. VI, fig. 1) were used, consisting of hollow pipes so shaped as to fit over the nuts and with circular disk handles. This type of wrench greatly facilitated the work of changing grade.

[1] Journal of Agricultural Research, U. S. Department of Agriculture, Vol. V, No. 23, p. 1083.

To decrease the amount of work necessary to adjust the grade of this continuous channel, the flume was rotated about its longitudinal center. Thus, when changing grade, one half of the flume would be lowered while the other half would be raised. The flume could be set to any grade up to 1.50 feet in 100 feet.

To enable the workmen to determine whether the flume was at the proper grade, graduated wooden strips (*A*, Pl. VI, fig. 1) 2 inches wide, 0.5 inch thick, and several feet long were placed on each side of the flume at each bent. The difference of elevation between various grades at each bent had been previously computed, and these differences were marked on the gage strips with the corresponding grade number. Thus, when the proper mark appeared at the cross board through which the gage strip ran, the workmen knew that part of the flume to be at the desired grade. At points where the required change of elevation was considerable, the flume was not raised or lowered the entire amount at one time, but was changed by successive increments of only a few inches. Thus the amount of stress on the flume was lessened, and the liability of leakage through the possible springing of the planks was eliminated.

The grade of the flume was checked with an engineer's level immediately before each experiment, to eliminate all possible errors from inaccurate adjustment or from settlement of the vertical posts.

LAYING THE TILE.

The tile were laid on earth in the flume as in actual practice. This earth in the bottom of the flume was about 7 inches deep. It was placed in layers, 2 inches at a time, and each layer was thoroughly tamped so that the bed on which the tile rested would not settle. At first a line was stretched along the flume immediately over its center and about 3 feet above the grade, and this line was used to grade the bed for the tile. It was soon found, however, that the gage line was in the way of the workmen, and another method for grading the tile bed was adopted. The material for this method consisted of a 30-inch strip, 2 inches wide and 0.75 inch thick, and a gage stick of the same size but $17\frac{1}{4}$ inches long. The workman laid the strip across the top of the flume and, holding the top of this gage stick flush with the top of the cross arm, determined whether the invert of each tile was at grade (P. VI, fig. 2).

COVERING THE TILE.

While blinding the tile, an engineer was constantly in the flume to oversee the work and prevent any tile from being pushed out of line. Fine earth, free from large clods, was used for blinding, the inspector tamping the earth on each side of the tile with his feet. Thus any appreciable movement or current of water through the earth on either side of the tile in the flume was prevented. After the tile were covered, the remaining space in the flume was filled with earth.

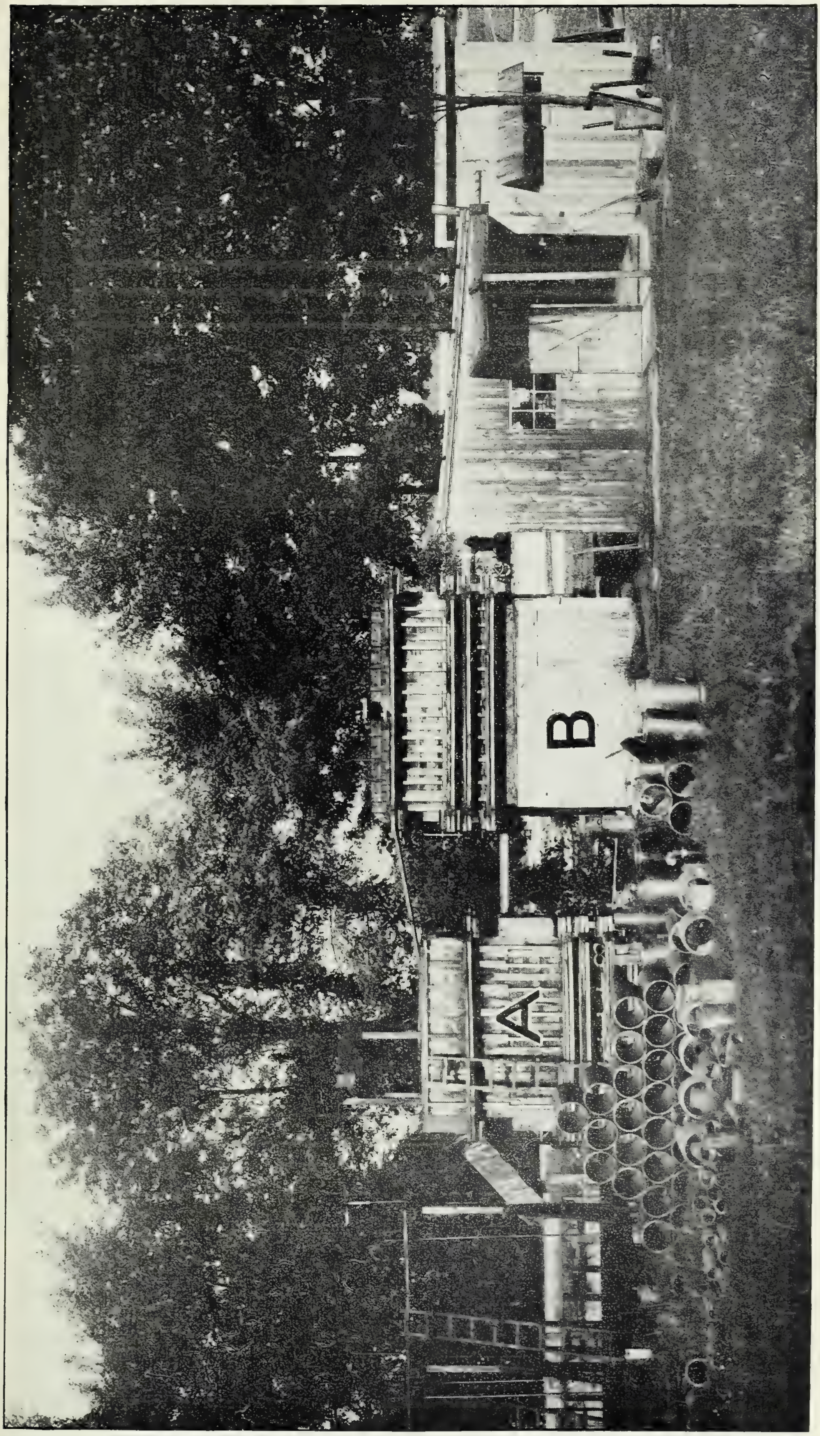
PIEZOMETERS AND PIEZOMETER TILES.

In order to measure the depth of flow in the tile drain, piezometer tubes of graduated glass were placed on the side of the flume and connected to the lower part of the tile line. Twelve tiles of uniform shape, for each size and kind, were selected, and a small hole was drilled through the wall of each. In each hole a ¼-inch iron pipe, 2 inches long, was inserted, care being taken that the tube did not project inside the tile bore. This tube was set in cement (Pl. II, fig. 2), and any unevenness on the inside wall of the tile at the entrance of the tube was removed by coating the surface with a little cement. This method of inserting the tube was deemed the best as determined by Hiram F. Mills from a study of the results of some 6,000 observations on various piezometer connections (see Trans. Amer. Academy of Science, 1878). Mills found that with an orifice whose edges are in the plane of the side of the conduit and with the bore of the tube normal to the plane of the wall, the piezometer column indicates the true height of the water surface in any open conduit, or the pressure in a closed conduit.

At first these piezometer tile were so turned as to have the tube on the bottom of the tile in the flume. Much trouble was experienced from the tube openings filling up, so the piezometer tile were then laid with the tube leading toward the side of the flume but turned slightly downward. The connection was made by rubber tubing to a steel nipple inserted through the wall of the flume (Pl. VII). On the side of the flume at each piezometer tile, a frame holding the glass tube was set. This glass tube (Pl. VII) was graduated in tenths and hundredths of a foot. Its zero was set at a definite distance below the top of the flume. A rubber tube connected the piezometer glass to the nipple in the wall of the flume.

The zero of each piezometer gage was 17½ inches below the top of the flume. The invert of the tile in the flume was always laid 16½ inches below the top of the flume. The capillarity of the glass tubes used was found to be 0.01 foot. Thus, with water just entering the tile drain, the piezometer tube read 0.09 foot. In other words, in order to obtain the true depth of flow in the drain, 0.09 foot was subtracted from each piezometer reading.

With the exception of the two piezometers near the tile entrance, which were only 8 feet apart, these tubes were distributed along the flume approximately 55 feet apart, the last piezometer being within a few feet of the outlet of the tile drain.



B. P. R. D-698

OVERFLOW AND SUPPLY TANKS.

Note arrangement of piping to the tanks. Engine house at right.

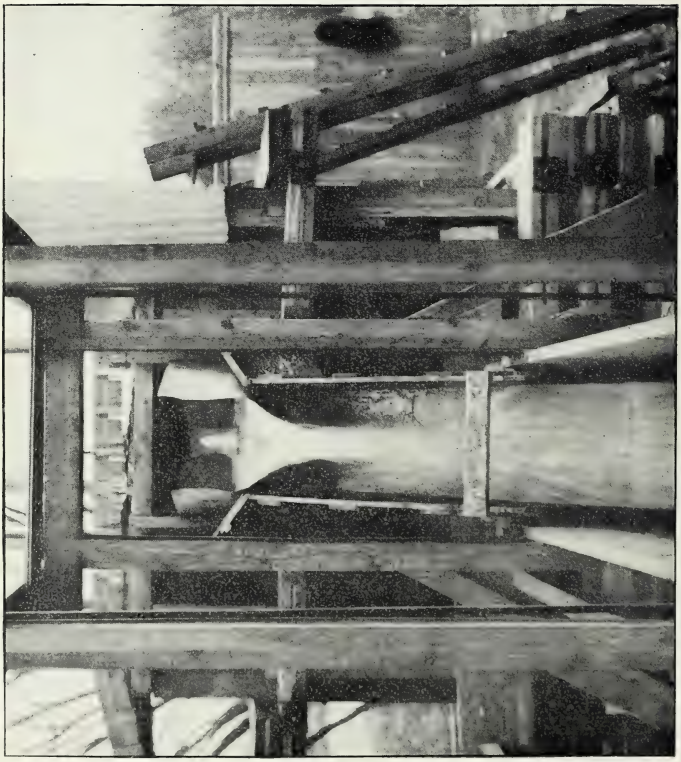


FIG. 1.—WEIR WITH 90-DEGREE NOTCH.

Note free fall of discharge from supply tank.

B. P. R. D-693

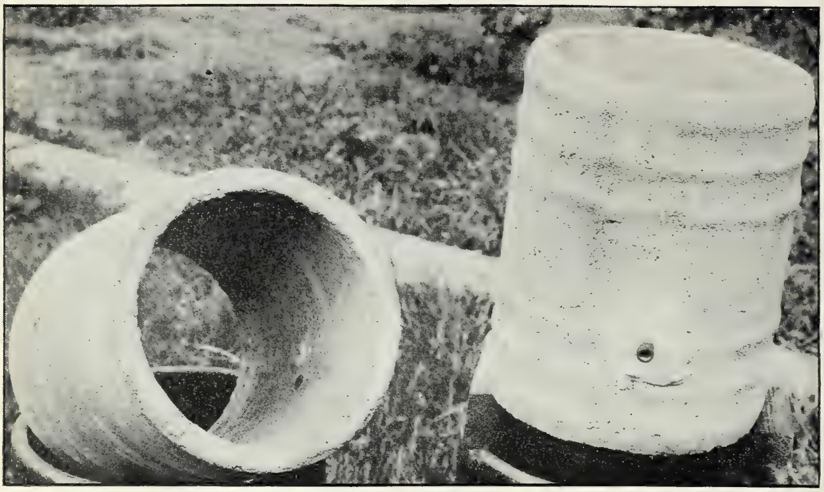
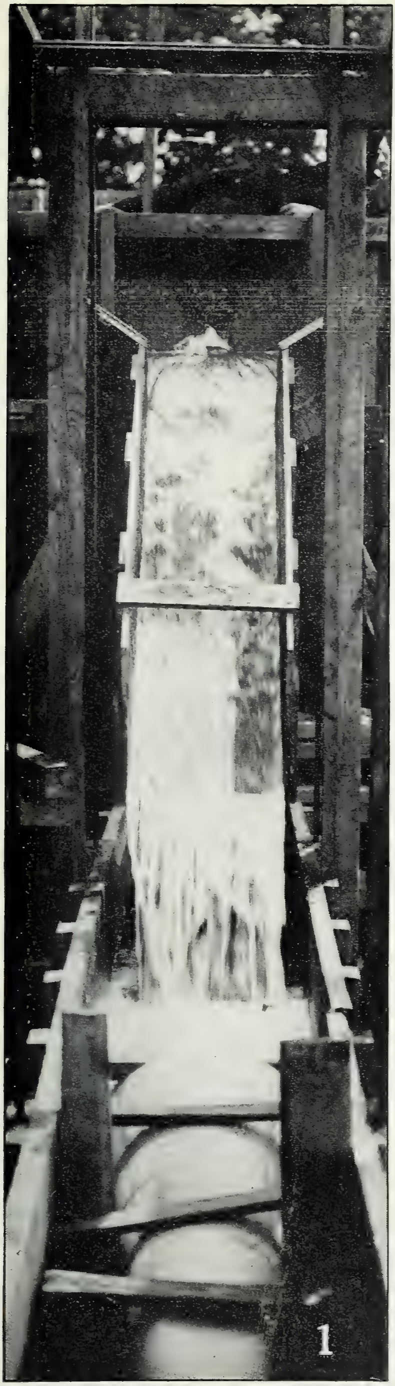


FIG. 2.—PIEZOMETER TILE.

Note tube set flush with inside wall of tile.

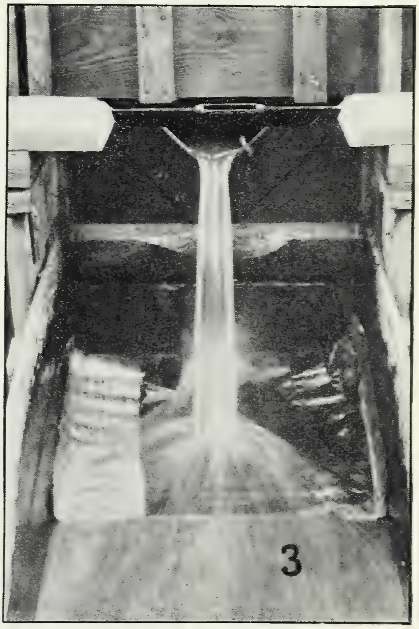


B. P. R. D-537

FIG. 1.—CONICAL ENTRANCE USED TO INCREASE ENTRANCE VELOCITY INTO TILE.

B. P. R. D-534

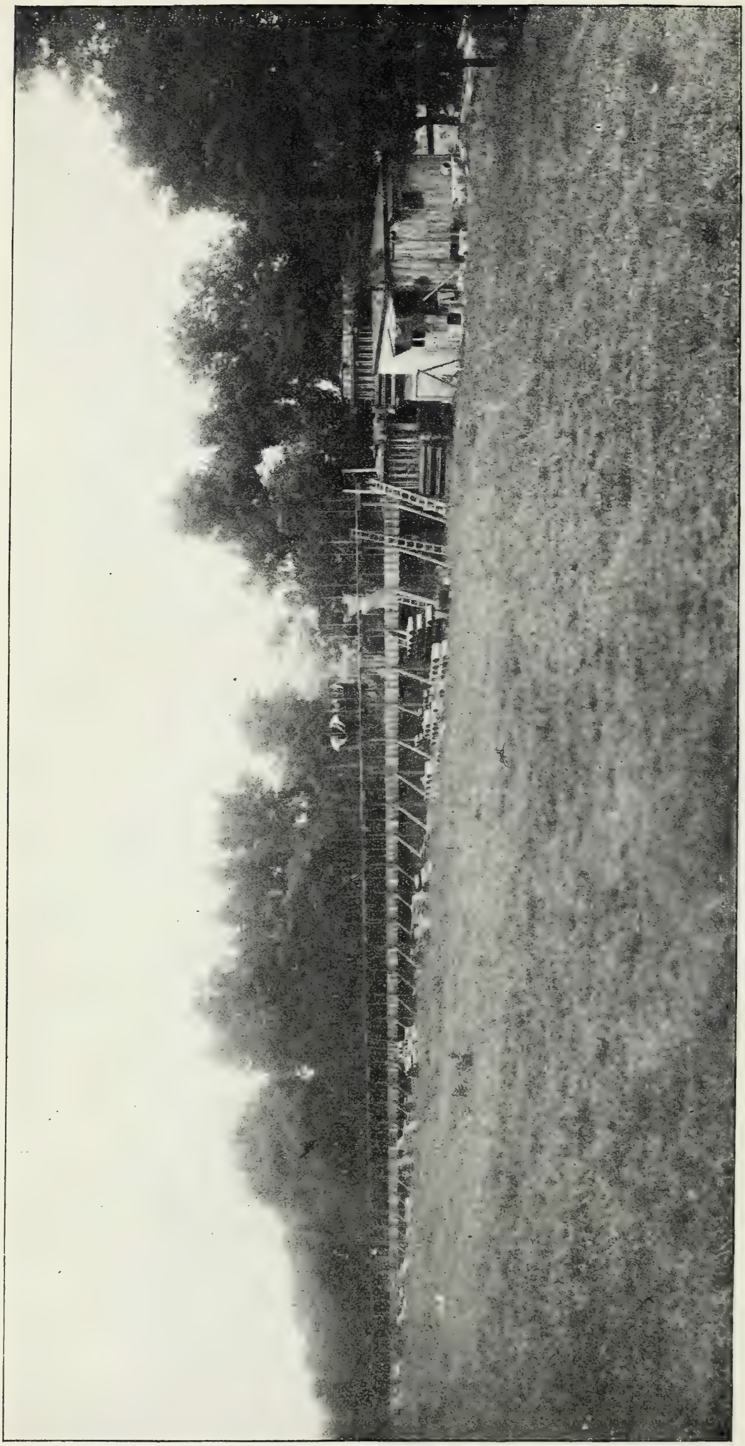
FIG. 2.—CONICAL ENTRANCE USED TO INCREASE ENTRANCE VELOCITY INTO TILE.



B. P. R. D-691

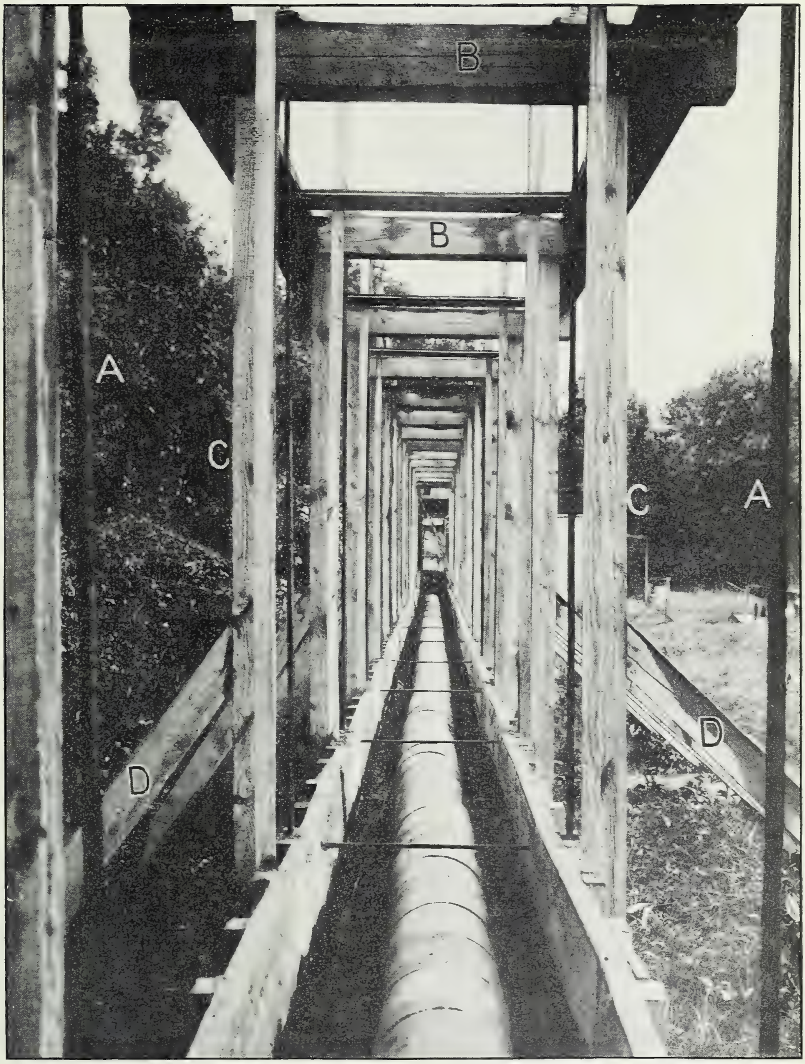
FIG. 3.—WEIR WITH 90-DEGREE NOTCH.

Note free fall from discharge tank.



B. P. R. D-524

GENERAL VIEW OF UPPER END OF FLUME, SHOWING ENGINE HOUSE AND OVERFLOW AND SUPPLY TANKS.



B. P. R. D-700

UPPER END OF FLUME, SHOWING 10-INCH CONCRETE TILE LAID READY FOR BLINDING.

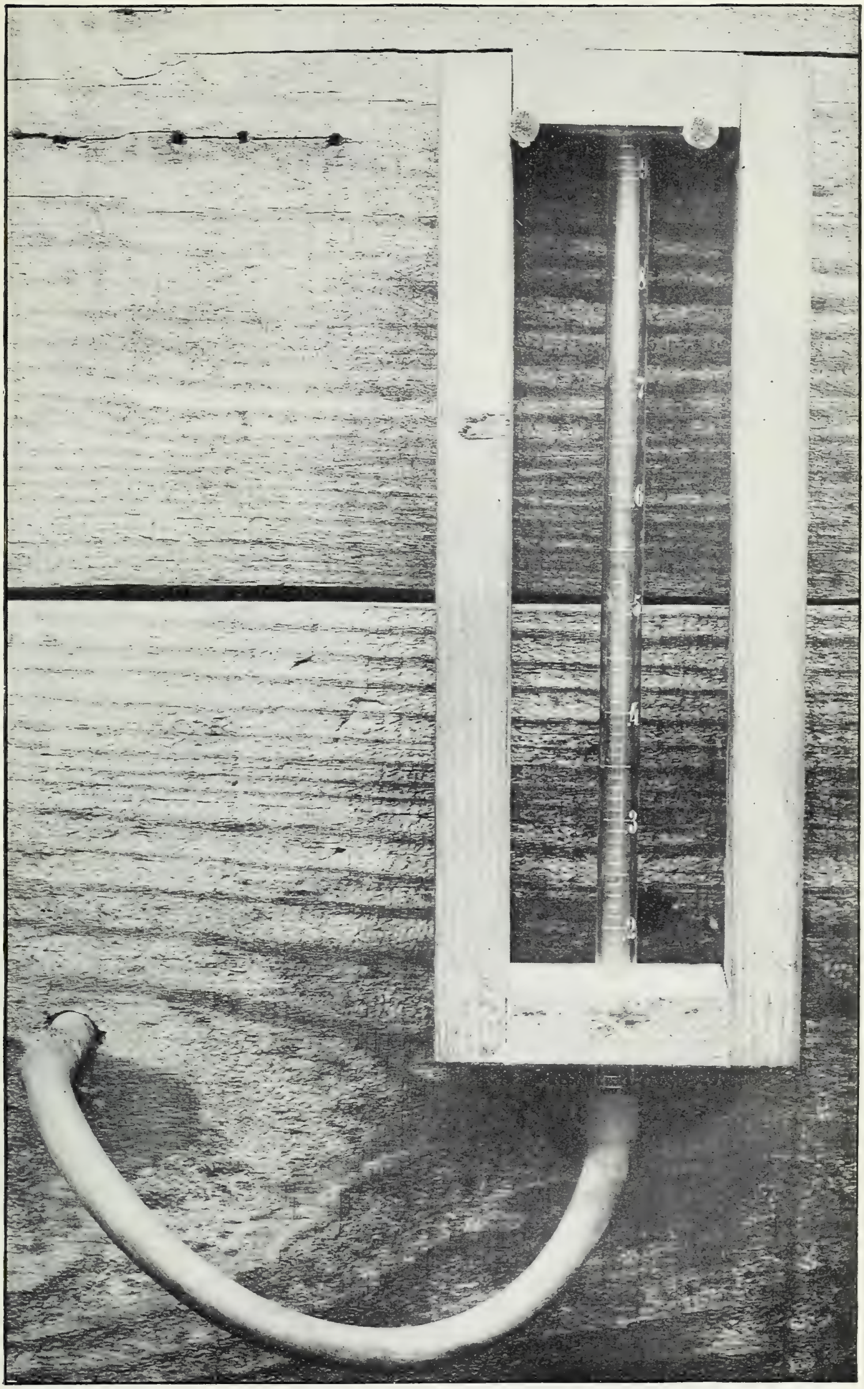
B. P. R. D-528

FIG. 1.—CHANGING THE GRADE OF THE FLUME.

Note 12-inch plank laid along top of flume for men to work on while changing grade.

B. P. R. D-699

FIG. 2.—LAYING 10-INCH CONCRETE TILE IN THE FLUME.



B. P. R. D-522

GRADUATED PIEZOMETER GLASS, FRAME, AND RUBBER TUBE CONNECTION TO PIEZOMETER TILE INSIDE OF FLUME.

NOMENCLATURE.

The following symbols are used throughout this report:

d=mean depth of flow in the drain, in feet.
D=mean inside diameter of the tile, in feet.
r=mean inside radius of the tile, in feet=$\frac{1}{2}D$.
Q=mean discharge of the tile during the test, in second-feet.
A=mean area of the tile bore, in square feet=πr^2.
a=average area of flow in the tile, in square feet.
V=mean velocity of the water during the test in feet per second=$\frac{Q}{a}$.
P=wetted perimeter in the tile, in feet.
R=mean hydraulic radius=$\frac{a}{P}$; in a tile drain running full $R=\frac{D}{4}$.
s=hydraulic grade or slope.
n=coefficient of roughness in Kutter's formula.
C=coefficient in Chezy's velocity formula.
C_w=coefficient in the Williams-Hazen velocity formula.
h=total difference in elevation between ends of a main drain, in feet.
l=length of the drain tested, in feet.
b=summation of the amounts of excess head in the submains, in feet.
T=number of submains.
U=depth of the soil over the main drain at its head, in feet; used only when main drains are 1,000 feet or more in length.
$s=mv^z$ is the general equation for the flow of water in drain tile, in which z is always constant and m varies only with the size of tile.
$m=eD^x$ is the equation for the variation of m for a series of drain tile of various sizes but of the same material; e and x are constants.
m'=the special values of m found for each series of tile.

Whenever a test is numbered, the reference is to the corresponding numbers in Tables 3 and 4 and to Plates X and XI.

Throughout this discussion the term "concrete tile" is used instead of "cement tile." The American Society for Testing Materials, in its standard specifications for drain tile, defines concrete tile as tile made of "a suitable mixture of Portland cement, mineral aggregates, and water, hardened by hydraulic chemical reaction."

FORMULÆ FOR FLOW OF WATER IN DRAIN TILE.

It is common knowledge that the water enters drains at the joints and not through the walls of the tile. Since there is a joint either every foot or every 2 feet in the length of the drain, water enters the tile drain throughout its entire length. In tile of small sizes, this leads to an appreciable variation in the amount of water carried at different points in the tile; but in the larger sizes the amount entering is so small a proportion of the amount carried as to be unimportant in considering carrying capacity.

The water in any tile drain is caused to flow and velocity is set up by two forces, one due to the grade of the tile line, and the other created when there is a variation in areas of water cross-section.

One authority includes a third force caused by the head due to height of the water table in the soil.

It is interesting to note the variations between the different formulæ recommended for tile drainage. Some formulæ take into account only the grade or slope of the tile drain, while others include the additional head caused by the weight of the water in the soil above the drain. Few formulæ distinguish between the retardation influences in concrete and those in clay drain tile, while many treat both kinds of tile the same.

One formula used by drainage engineers is the well-known Chezy formula,

$$V = C\sqrt{Rs} = CR^{0.5}s^{0.5} \qquad (1)$$

This was introduced by Chezy, a French engineer, in 1775. In this formulæ, C is a coefficient, originally considered a constant but since discovered to vary with the retardation factors as well as with the mean hydraulic radius and the slope.

The Kutter modification of the Chezy formula,

$$V = \left\{ \frac{\frac{1.811}{n} + 41.66 + \frac{0.00281}{s}}{1 + \left(41.66 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{R}}} \right\} \sqrt{Rs} \qquad (2)$$

is the equation probably most widely used by drainage engineers. To obtain this formula, the coefficient C has been replaced by an expression involving the hydraulic grade or slope and the mean hydraulic radius, as well as a quantity, n, to represent the influence of the roughness of the walls of the channel or conduit.

The Poncelet, Hawkesley,[1] or Eytelwein [2] formula

$$V = 48\sqrt{\frac{Dh}{l + 54D}} \qquad (3)$$

applies to drains in which the velocity is due only to the hydraulic grade or slope of the drain. It has been used to a great extent for small tile systems in close soil and for determining the size of outlet drains.

According to Wollender, Wage, and John,[3] the mean velocity in drain tile is

$$V = 44.2\sqrt{\frac{Dh}{l + 46.5D}} \qquad (4)$$

The Vincent formula is

$$V = 45.95\ K\sqrt{\frac{Dh}{l + 50\ D}} \qquad (5)$$

---

[1] Sullivan's New Hydraulics, p. 9.

[2] Hamilton Smith's Hydraulics, p. 272.

[3] L. Faure, Drainage et Assainissement Agricole des Terres, Paris, 1903, p. 90.

in which Vincent gives values for the variable coefficient, K, ranging from 0.75 for 2-inch tile to 0.875 for 6-inch tile.

Friedrich[1] states that Professor Gieseler's formula,

$$V=36.22\sqrt{Ds} \tag{6}$$

is the best in practice as well as the simplest.

Formula 6 is said by Professor Luedecke to have been deduced as early as 1852 by the agricultural engineer Stocken, at Schweidnitz, from Prony's formula, which is

$$V=47.63\sqrt{Ds} \tag{7}$$

Beardmore's, sometimes called Leslie's, formula,

$$V=100\sqrt{Rs} \tag{8}$$

is similar to Chezy's, the coefficient C being taken as a constant, 100.

The Williams-Hazen general formula for all kinds of pipes is

$$V=C_wR^{0.63}s^{0.54}0.001^{-0.04} \tag{9}$$

This formula is of special importance in this discussion, since careful comparison of it with the Chezy-Kutter formula has been made.

C. G. Elliott, a widely known drainage authority, has modified the Poncelet or Hawkesley formula as follows:[2]

$$V=48\sqrt{\frac{Dh+\frac{1}{2}U}{l+54\ D}} \tag{10}$$

for use on systems where the soil is open;

$$V=48\sqrt{\frac{D\left(h+\frac{b}{T}\right)}{l+54\ D}} \tag{11}$$

for use on large systems in close soil;

$$V=48\sqrt{\frac{D\left(h+\frac{b}{T}\right)+\frac{1}{2}\ U}{l+54\ D}} \tag{12}$$

for use on large systems in open soil.

The last term in the numerator under the radical in formulæ 10 and 12 has been added to allow for the water pressure in the soil above the tile drain. This additional head, however, is constantly varying, being greatest when the earth is completely saturated. It is doubtful whether it should be used in computing the discharge of a drain, and if so, then only in open, porous soils.

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[1] Friedrich, Kulturtechnischer Wasserbau, vol. 1, Berlin, 1912, p. 343.

[2] C. G. Elliott, Engineering for Land Drainage, New York, 2d ed., 1912, p. 93.

A new formula based on tests actually made on drain tile, derived as hereinafter explained, is tentatively offered for tile flowing full. This formula is

$$V = 138\, R^{\frac{2}{3}} s^{\frac{1}{2}} \qquad (13)$$

It may seem that the exponential type of formula is inconvenient because logarithms must be used to calculate results from it. However, it is comparatively simple in the case of such a formula to prepare a diagram or chart, composed of parallel, straight lines if on logarithmic scale, from which the required velocity or the required discharge for any size of tile at any grade can be obtained at a glance, the accuracy of the reading depending entirely upon the scale of the diagram. Plate XIII is a diagram prepared by using the formula as derived from the actual tests made, but applied to commercial or nominal sizes of tile.

It should be noted that Elliott's modifications of Poncelet's or Hawkesley's formula are the only ones which take into consideration the head caused by the water table in the soil, while the Chezy-Kutter formula is the only one in which the different retardation influences in clay and concrete drain tile may be considered.

NECESSARY DATA FOR COMPARING VELOCITY FORMULÆ.

In order to test the relative accuracy of the various formulæ which have been recommended for use in determining the discharge of tile drains, the effect of each hydraulic element involved in the formulæ must be determined by experiment. However, in the tests made at the experimental plant it was impossible to determine the effect of the additional head caused by the water table in the soil. The elements to be determined are as follows: (1) the mean velocity of the water in the tile drain; (2) the grade or slope of the drain, or the water slope if it is different from that of the drain; (3) the internal size of the tile; (4) the actual depth of flow in the tile drain.

MEAN VELOCITY.

The mean velocity of the water flowing in the drain can be determined by various methods. However, only the following two methods were used: (1) by actually measuring the quantity of water entering or discharging from the tile drain per second, and then solving the equation $V=\frac{Q}{a}$; (2) by timing a given volume of water through a previously measured distance.

HYDRAULIC GRADE OR SLOPE.

The slope of the line of tile tested at the experimental plant was always known, since the tile were laid in an adjustable flume which could be changed to the desired grade, the grade always being checked by a level.

INTERNAL SIZE OF DRAIN TILES.

It is generally known that drain tile are not exactly of the dimensions corresponding to the nominal size. All of the concrete tile used in these experiments were under the nominal size, while the clay tile generally were larger than the nominal size. However, the concrete tile more nearly averaged the nominal size than did the clay tile.

Although in actual practice the nominal or commercial size of tile is invariably used in computing the discharge, yet to determine accurately the retardation factors it is essential to know the correct average diameter of the drain tile being tested. To determine the average diameter of all the tile tested at the experimental plant, two measurements were made at right angles to each other at each end of every tile. This task required the recording and averaging of 1,160 measurements when tile in 2-foot lengths were used, and twice this number when tile in 1-foot lengths were used.

Table 1 gives the dimensions and cross-sectional areas of each kind of tile tested at the experimental plant. From a study of this table several points are revealed. In the first place, considerable error would have been introduced into the final results had the nominal or commercial diameter—instead of the actual, measured, average diameter—been used in the computations. For example, the mean velocity for the 6-inch clay tile at a grade of 0.50 foot in 100 feet, with a depth of flow of 0.498 foot and discharging 0.554 second-foot, is, when computed from the measured average diameter, 2.659 feet per second; with the nominal or commercial diameter the velocity is 2.823 feet per second. As a rule the mean of the areas of the tile computed from the diameters varying most above and below the measured average diameter, with their companion diameters, varies little from the area computed from the measured average diameter.

TABLE 1.—*Comparison of dimensions and areas of various kinds of tile used.*

1	2	3	4	5	6	7	8	9	10	11	12	13
Kind of tile.	Commercial size of tile.	Commercial or nominal diameter.	Actual measured average diameter.	Area computed on col. 3.	Area computed on col. 4.	Variation in area between cols. 5 and 6.	Smallest measured diameter.	Diameter normal to diameter in col. 8.	Area[1] using diameters in cols. 8 and 9.	Largest measured diameter.	Diameter normal to diameter in col. 11.	Area[1] using diameters in cols. 11 and 12.
	In.	*Feet.*	*Feet.*	*Sq.ft.*	*Sq.ft.*	*P. ct.*	*Feet.*	*Feet.*	*Sq.ft.*	*Feet.*	*Feet.*	*Sq.ft.*
Concrete	4	0.3333	0.3280	0.0873	0.0845	+3.2	0.3100	0.3300	0.0804	0.3380	0.3320	0.0881
Hard-burned clay	4	.3333	.3398	.0873	.0907	−3.9	.3150	.3380	.0837	.3520	.3500	.0968
Concrete	5	.4167	.4127	.1364	.1338	+1.9	.3950	.4100	.1272	.4220	.4180	.1385
Hard-burned clay	5	.4167	.4193	.1364	.1381	−1.2	.3780	.4510	.1349	.4350	.4310	.1473
Concrete	6	.5000	.4970	.1964	.1940	+1.2	.4850	.4850	.1847	.5130	.4950	.1995
Soft-burned clay	6	.5000	.5184	.1964	.2111	−7.4	.4760	.5260	.1971	.5350	.5300	.2227
Concrete	8	.6667	.6585	.3491	.3406	+2.4	.6400	.6450	.3242	.6770	.6620	.3520
Hard-burned clay	8	.6667	.6850	.3491	.3685	−5.5	.6700	.6720	.3536	.7360	.7030	.4066
Concrete	10	.8333	.8274	.5454	.5377	+1.4	.8080	.8110	.5147	.8420	.8410	.5562
Vitrified[2]	10	.8333	.8360	.5454	.5489	−0.6	.7950	.8300	.5185	.8650	.8400	.5708
Concrete	12	1.0000	.9915	.7854	.7721	+1.7	.9630	.9780	.7398	1.0100	1.0000	.7933
Vitrified[2]	12	1.0000	.9857	.7854	.7631	+2.8	.9700	.9760	.7436	1.0200	.9980	.7996

[1] Computed as an ellipse.

[2] These tile were in 2-foot lengths; all others in 1-foot lengths.

ACTUAL DEPTH OF FLOW.

The depths of flow in the tile lines tested were measured by means of the 12 piezometer tubes distributed along the flume, as previously described.

As first laid, the tile at the lower end of the experimental line discharged into the open air with a free drop of several inches. This produced a backwater curve of the drop-off type which extended back for a considerable distance into the tile line, decreasing the depth of the water near the lower end. For the steeper slopes this effect was much extended, and, indeed, in extreme cases reached throughout the length of the experimental line. Such a condition was objectionable for two reasons: first, the hydraulic gradient under such circumstances would be represented by the slope of the water surface, which was then somewhat greater than the grade of the tile; second, since the condition was not one of uniform flow, it would become necessary to take account of the change of velocity at different points in the tile, with the corresponding changes in velocity head, in determining the head consumed in overcoming friction. Since these additional complications were unnecessary and objectionable, the drop-off curve was eliminated by installing a low, movable dam (shown in Pl. VIII, fig. 1) just below the lower end of the tile line. By adjusting the height of this dam, the water surface at the outlet could be maintained in close agreement with any desired depth throughout the experimental line.

The water entered the upper end of the tile through a conical entrance pipe (Pl. III, figs. 1 and 2) designed to give an entrance velocity approximating that of the steady, uniform flow in the tile line. But it was found impracticable to adjust the entrance velocity exactly to that of the line, with the result that the upper 50 feet of tile were required to bring the velocity to the condition of uniform flow, and the piezometers at the upper end would not always agree with the others along the tile. With this exception, the readings of depth in the various piezometers along the tile line could generally be brought into satisfactory agreement.

With the tile only partly full, there were occasional quite erratic readings on some piezometers. These indicated unusual disturbances within the tile line. When through the warped or elliptical shape of the tile the joints do not fit closely, a portion of one tile at the joint may project inward in such a way as to present a square obstruction against the edge of the moving stream of water. Violent impact of the water against such an obstruction produces a marked disturbance of the stream, and is indicated by extensive ripples and foam on the water surface which may persist for several feet downstream. Several such cases were carefully examined by uncovering the tile and inspecting the water surface within, as well as by measuring the height of the water surface outside of the tile at the joint. In some cases the water level outside the tile would remain steadily 0.1 or 0.2 foot higher on one side of the tile than on the other, and the surface inside the tile would be very turbulent and would seem to bear no relation to the elevation of the water surface outside the tile joint. Such phenomena were most conspicuous when the depth of flow was between half and full depth, and with the high velocities due to the steeper slopes. The phenomena seemed to depend upon the presence of air in the tile, as they disappeared largely when the tile were completely filled, so that all air was excluded.

METHODS OF CONDUCTING TESTS.

A test was always begun at the least depth of flow. Six men were needed to conduct a complete experiment at one grade, which required from 3 to 6 hours, depending upon the number of depths of flow tested. One man cared for the pump and engine, one read the upper hook gage, a third was stationed midway the length of the flume at a piezometer tube, another was stationed at the outlet to adjust the height of the movable dam, and a fifth man read the lower hook gage. The engineer in charge usually operated the valve controlling the supply of water to the upper weir tank, and watched the upper piezometer tubes.

The engineer announced the depth of flow he desired to obtain to the man stationed at the dam. The gate valve in the supply pipe was partly opened and the piezometer readings noted. The dam was then raised or lowered to secure the correct depth of flow at the piezometer tube near the outlet, special care being taken not to get a greater depth than desired there. The observer at the upper hook gage called out the various gage heights at short intervals, that the water supply might be regulated properly, and when the desired depth in the tile was obtained, sufficient time was allowed to determine that the depth over the weir was constant. The observations at the upper, middle, and lower piezometers indicated when the flow was steady throughout the tile line. When the flow was steady at the proper depth, the signal was given and each of the two hook-gage readers made record of the readings at his station every 30 seconds. Meanwhile, the engineer in charge passed along the flume, recording the readings of all piezometers in succession; the observer at the lower end of the flume went to the upper end and then recorded the piezometer readings in order, following just 2 minutes behind the engineer's readings; the observer at the middle of the flume watched the piezometer there to report if any considerable fluctuation indicated that the test should be run again. If the depth over the upper weir remained constant throughout the test, the engineer proceeded to obtain the next depth of flow; if the weir readings varied, the test for the same depth of flow was run again. About 20 minutes were required to obtain the data for each depth of flow, the amount of time depending upon the grade of the flume.

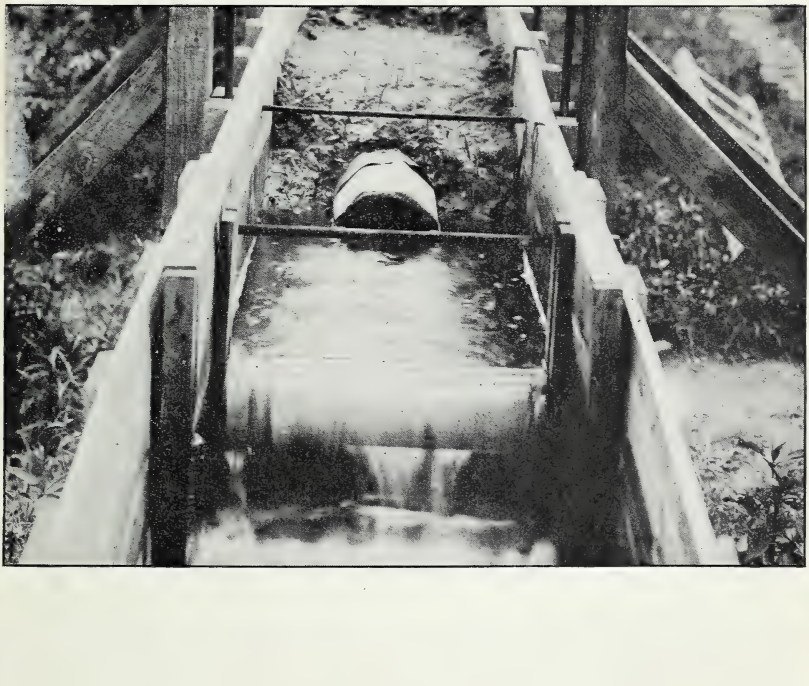
The readings for the first two and the last piezometers were not included to obtain the depth of flow in the drain. It should be remembered that water as it enters the drain has not the velocity it will acquire after traveling some distance; therefore the first two piezometers usually recorded a depth slightly different from that of the piezometer 60 feet from the tile entrance or those of the succeeding piezometers. Even with a gradual, conical entrance to the tile drain (Pl. III, figs. 1 and 2), the entrance velocity could not be easily regulated to be the same as the uniform velocity through the main portion of the tile. The average of the readings of the intermediate nine piezometers, less 0.09 foot, usually was taken as the true depth of flow, although at times very erratic individual piezometer readings were obtained which were not used in obtaining the average.

Only the upper weir readings were used in the final computations. It was found in the earlier experiments that after waiting some time for the lower weir box to fill to a steady height, the lower weir would read practically the same as the upper weir, proving that there was no measurable loss of flow in passing through the tile line. Hence, to save time in performing the experiments, it was decided not to wait for the lower weir to reach a steady reading. It may appear that, in using only the upper weir readings to obtain the carrying capacity of the drain, too great a quantity of water was recorded due to seepage into the earth adjacent to the drain, which would credit the tile with carrying more water than it actually did carry. However observation of the condition of the soil indicated clearly that the soil became sufficiently saturated by the time steady flow was obtained in the tile, that there was no such loss, at least not in quantity that could have affected the results of this investigation.

The use of the dam at the tile outlet did not affect the carrying capacity of the drain, for special care was taken not to allow any piezometer readings at the lower end of the flume to exceed the readings near the upper end. The dam merely assisted in obtaining a uniform depth of flow throughout the length of the drain. Thus the necessity of corrections for changing velocity heads due to decrease in the water cross-sectional area at succeeding piezometers near the outlet was eliminated. Without the dam and with a constant flow over the upper weir, the successive piezometers showed a continuous decrease in depth, and therefore increase in velocity, toward the outlet of the tile line. In other words, the hydraulic gradient or water slope was greater than the grade of the tile. With no change in the amount of water passing over the weir, the height of the dam could be raised until the piezometer near the outlet re-

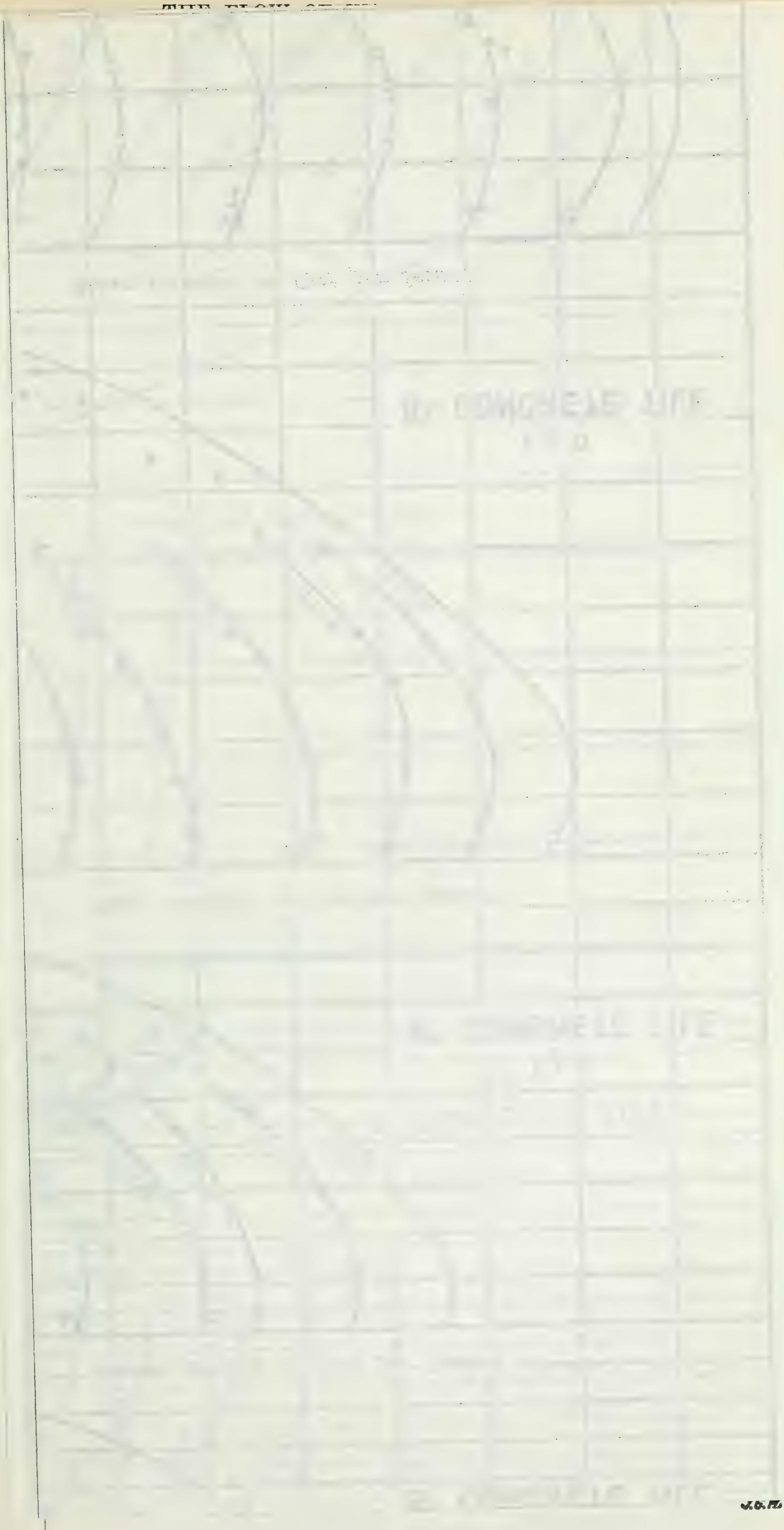
B. P. R. D–3508

FIG. 2.—12-INCH CLAY TILE AS LAID TO DETERMINE THE EFFECT OF IRREGULAR JOINTS ON THE COEFFICIENT OF ROUGHNESS.

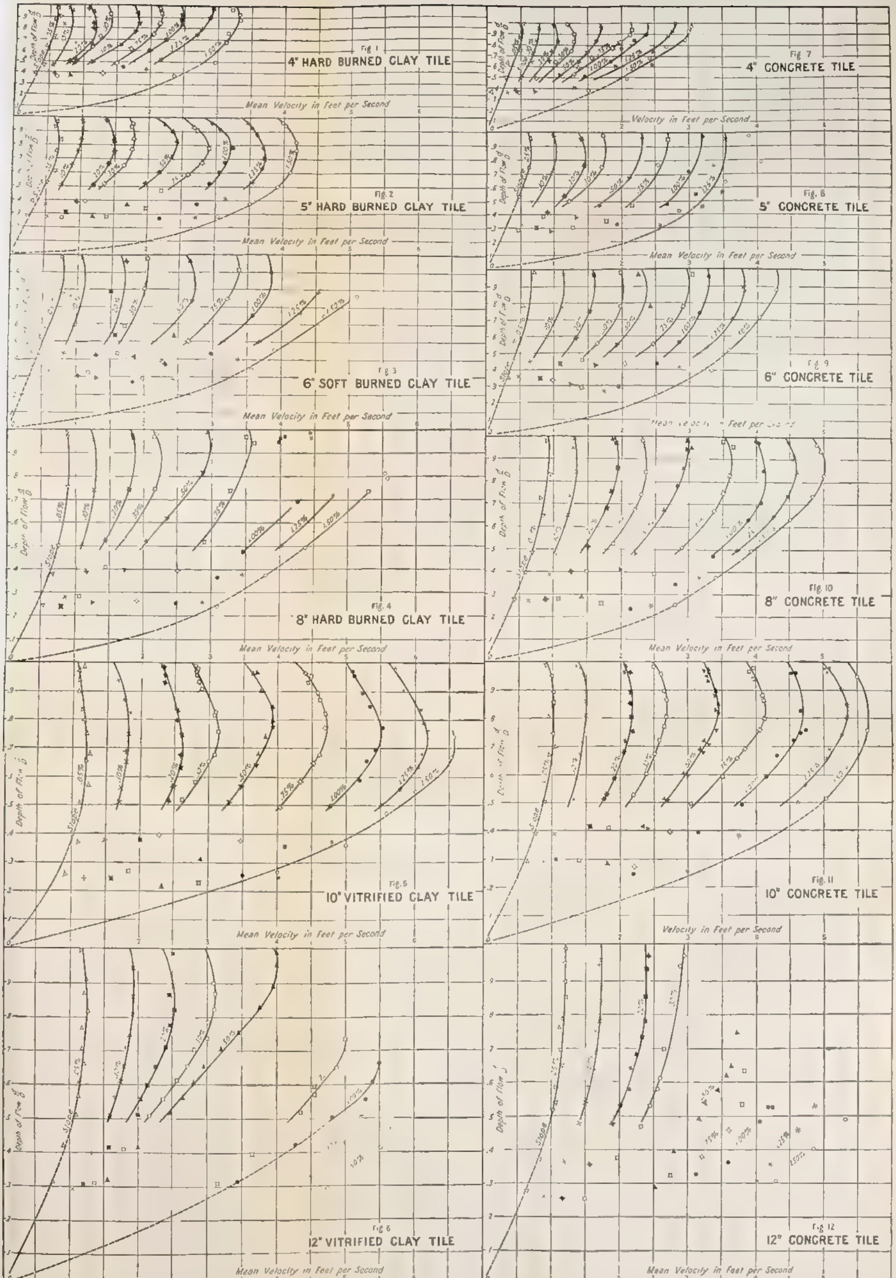


B. P. R. D–533

FIG. 1.—DAM USED IN EXPERIMENTS TO OBTAIN UNIFORM DEPTH OF FLOW IN TILE.



J.C.R.



CURVES SHOWING RELATION BETWEEN DEPTH OF FLOW, VELOCITY, AND SLOPE.

corded the same depth as that shown by the piezometer 60 feet from the tile entrance, without affecting the latter piezometer but causing the intermediate piezometers to register the same depth.

MEASUREMENT OF MEAN VELOCITY.

As stated before, the mean velocities obtained during the experiments were determined by dividing the quantity of water passing over the upper weir by the average cross-sectional area of the water in the tile. For checking these results, velocities were determined also by coloring matter and by the use of a voltmeter. Both potassium permanganate and dyes were used. For injecting the colored solution into the tile, the use of a large hard-rubber syringe proved a satisfactory method. The voltmeter was of the portable Weston type (model 45) with a range of scale from zero to 1½ volts; carbon and zinc electrodes were used. To complete the circuit, a saturated salt solution was inserted by the method employed in the color tests. When the water saturated with salt passed the point where the electrodes were placed in the tile, a current was set up whose intensity was indicated by the voltmeter. When the volume of saturated water had all passed, the needle of the voltmeter would return to its original position.

An observer noted the time the color was injected and also obtained the times when the first and the last color passed the outlet. The time the color spent in the tile was taken as from the instant of injection to the mean between the first and the last of the appearance at the outlet. This same method was used in the voltmeter tests, the time being taken as from the instant of injection of the salt solution to the mean between the time the needle of the voltmeter began to register and the time when it returned to its original position. Table 2 shows part of the results obtained in comparing the values of the mean velocity as found by the weir, with those determined by color and voltmeter.

TABLE 2.—*Comparison of mean velocities as determined by various methods.*

Tile diameter.	Velocity by weir (V).	Velocity by color (V_c).	Velocity by voltmeter (V_v).	$\frac{V-V_c}{V}$	$\frac{V-V_v}{V}$
Inches.	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Per cent.*	*Per cent.*
4	2.168	2.227	....	−2.7	....
4	2.133	2.167	....	−1.6	....
4	1.866	1.898	....	−1.7	....
12	1.236	1.293	....	−4.6	....
12	1.124	1.211	....	−7.7	....
12	4.551	4.782	....	−5.1	....
12	3.711	3.691	....	+0.5	....
12	2.251	2.320	2.291	−3.1	−1.8
12	2.493	2.656	2.500	−6.5	−0.3
12	2.769	2.723	2.764	+1.7	+0.2
12	2.104	2.272	2.235	−8.0	−6.2

For determining the velocity, coloring matter can be used successfully only in clear water. Potassium permanganate as well as dyes of all colors were tried in muddy water having a large velocity and it was found practically impossible to detect the colors. However, the voltmeter method may be used equally well in muddy and in clear water for determining the velocity. It is believed that velocities obtained by the use of either color or voltmeter will be quite accurate if the mean of several readings is taken.

RESULTS OF OBSERVATIONS.

Tables 3, 4, and 5 give the results of the tests. The various series are arranged in ascending sizes of tile and ascending grades. Table 3 gives the results of observations on clay tile; Table 4, the results of observations on concrete tile; and Table 5, the results of observations on clay tile poorly laid. The Kutter coefficient of roughness, *n*, given in column 10, was determined from a large diagram specially drawn for this investigation. The variation and irregularity of the joints of the tile in the lines poorly laid can be seen in Plate VIII, figure 2.

The tests summarized in Tables 3 and 4 were plotted on coordinate paper, with velocities as abscissæ and depths of flow as ordinates. Mean curves were drawn for each grade through the points representing the tests for each size and kind of tile. These curves are shown on Plate IX. A study of the curves reveals some interesting facts. For the flatter slopes the curves more nearly approximate a straight line; as the slopes increase the lines become more curved, until at the steepest grade there is considerable bulge to the curve. The velocity at any depth of flow over half full is shown at a glance. It will be noted that the velocities at half full and at full are seldom the same, as they would be according to the Chezy formula. The greatest velocity seems to be approximately at the 0.8 depth. The curves were not extended below the half-full point on account of the insufficiency of data. In the largest sizes of tile, where symbols are shown but no curves have been drawn, incompleteness of data has prevented the development of accurate curves through these points. It will be seen that with some of the curves the points lie practically on the lines, while with other curves some points vary greatly, showing probable error in the experiments.

TABLE 3.—*Elements of experiments for clay tile.*

4-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (d)	$\frac{d}{D}$	Area of flow. (a)	$\frac{a}{A}$	Hydraulic radius. (R)	Discharge. (Q)	Velocity. (V)	Slope. (s)	Kutter coefficient. (n)	Chezy coefficient. (C)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
1[1]	0.332	0.98	0.0901	0.99	0.0935	0.0547	0.607	0.0005	0.0101	88.8
2[1]	.309	.91	.0866	.96	.1007	.0562	.649	.0005	.0100	91.4
3	.298	.88	.0843	.93	.1023	.0487	.578	.0005	.0110	80.8
4	.248	.73	.0709	.78	.1018	.0404	.570	.0005	.0111	79.9
5	.214	.63	.0602	.66	.0965	.0274	.456	.0005	.0126	65.6
6	.159	.47	.0416	.46	.0813	.0177	.424	.0005	.0120	66.5
7	.131	.39	.0322	.36	.0708	.0098	.304	.0005	.0139	51.1
8[1]	.331	.97	.0900	.99	.0940	.0703	.780	.0010	.0110	80.5
9[1]	.327	.96	.0896	.99	.0958	.0744	.831	.0010	.0106	84.9
10	.285	.84	.0812	.89	.1032	.0580	.714	.0010	.0123	70.3
11	.228	.67	.0647	.71	.0992	.0568	.878	.0010	.0104	88.2
12	.160	.47	.0420	.46	.0817	.0235	.560	.0010	.0128	62.0
13	.136	.40	.0339	.37	.0728	.0166	.490	.0010	.0131	57.4
14[1]	.329	.97	.0898	.99	.0950	.0969	1.079	.0020	.0113	78.3
15	.321	.95	.0887	.98	.0979	.1019	1.148	.0020	.0111	82.1
16	.283	.83	.0807	.89	.1033	.0940	1.165	.0020	.0113	81.0
17	.271	.80	.0775	.86	.1034	.0904	1.166	.0020	.0112	81.1
18	.223	.66	.0631	.70	.0983	.0710	1.125	.0020	.0113	80.2
19	.173	.51	.0464	.51	.0859	.0414	.892	.0020	.0122	68.1
20	.129	.38	.0316	.35	.0700	.0187	.592	.0020	.0145	50.0
21[1]	.313	.92	.0874	.96	.1000	.1230	1.408	.0030	.0112	81.3
22	.244	.72	.0697	.77	.1013	.0864	1.240	.0030	.0123	71.1
23	.213	.63	.0598	.66	.0963	.0685	1.145	.0030	.0127	67.4
24	.166	.49	.0440	.49	.0837	.0361	.820	.0030	.0148	51.8
25	.123	.36	.0296	.33	.0675	.0180	.608	.0030	.0161	42.7
26[1]	.317	.93	.0881	.97	.0990	.1578	1.792	.0050	.0113	80.5
27	.287	.84	.0817	.90	.1032	.1494	1.829	.0050	.0114	80.5
28	.263	.77	.0753	.83	.1031	.1327	1.762	.0050	.0117	77.6
29	.223	.66	.0631	.70	.0983	.0978	1.550	.0050	.0125	69.9
30	.170	.50	.0454	.50	.0850	.0517	1.139	.0050	.0142	55.3
31	.128	.38	.0313	.35	.0696	.0256	.819	.0050	.0159	43.9
32[1]	.332	.98	.0901	.99	.0935	.1931	2.142	.0075	.0111	80.9
33[1]	.320	.94	.0886	.98	.0982	.1905	2.151	.0075	.0114	79.3
34	.288	.85	.0819	.90	.1031	.1756	2.143	.0075	.0118	77.1
35	.253	.74	.0724	.80	.1023	.1482	2.047	.0075	.0121	73.9
36	.209	.62	.0585	.65	.0954	.0996	1.702	.0075	.0133	63.6
37	.164	.48	.0434	.48	.0830	.0654	1.508	.0075	.0133	60.4
38	.134	.39	.0332	.37	.0720	.0425	1.279	.0075	.0137	55.0
39[1]	.312	.92	.0872	.96	.1002	.2159	2.477	.0100	.0116	78.3
40	.298	.88	.0843	.93	.1023	.2068	2.453	.0100	.0118	76.7
41	.283	.83	.0807	.89	.1033	.1984	2.459	.0100	.0118	76.5
42	.233	.69	.0663	.73	.1000	.1476	2.227	.0100	.0125	70.4
43	.205	.60	.0572	.63	.0946	.1140	1.994	.0100	.0131	64.8
44	.151	.44	.0389	.43	.0785	.0615	1.579	.0100	.0138	56.4
45[1]	.331	.97	.0900	99	.0940	.2640	2.932	.0125	.0107	85.5
46	.304	.90	.0856	.94	.1016	.2472	2.888	.0125	.0113	81.1
47	.270	.80	.0773	.85	.1033	.2124	2.749	.0125	.0120	76.5
48	.254	.75	.0727	.80	.1024	.1951	2.683	.0125	.0120	75.0
49	.177	.52	.0478	.53	.0871	.1032	2.161	.0125	.0127	65.5
50	.148	.44	.0379	.42	.0774	.0736	1.941	.0125	.0128	62.4
51[1]	.329	.97	.0898	.99	.0950	.2890	3.218	.0150	.0108	85.3
52[1]	.313	.92	.0874	.96	.1000	.2907	3.328	.0150	.0108	85.9
53	.298	.88	.0843	.93	.1023	.2814	3.338	.0150	.0110	85.2
54	.257	.76	.0736	.81	.1027	.2318	3.150	.0150	.0114	80.2
55	.228	.67	.0647	.71	.0992	.2026	3.132	.0150	.0113	81.2
56	.168	.49	.0447	.49	.0843	.1322	2.957	.0150	.0107	83.1
57	.126	.37	.0306	.34	.0688	.0720	2.353	.0150	.0111	73.3

5-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
58[1]	0.404	0.96	0.1364	0.99	0.1180	0.0868	0.636	0.0005	0.0111	82.8
59[1]	.390	.93	.1338	.97	.1225	.0848	.634	.0005	.0114	81.0
60	.350	.83	.1231	.89	.1275	.0832	.676	.0005	.0112	84.6

[1] These tests used in deriving formulæ 27 and 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

5-INCH TILE—Continued.

1 Test No.	2 Depth of flow. (*d*) *Feet.*	3 $\frac{d}{D}$	4 Area of flow. (*a*) *Sq. ft.*	5 $\frac{a}{A}$	6 Hydraulic radius. (*R*) *Feet.*	7 Discharge. (*Q*) *Cu. ft. per sec.*	8 Velocity. (*V*) *Feet per sec.*	9 Slope. (*s*)	10 Kutter coefficient. (*n*)	11 Chezy coefficient. (*C*)
61	0.314	0.75	0.1109	0.80	0.1265	0.0699	0.630	0.0005	0.0116	79.3
62	.255	.61	.0879	.64	.1171	.0547	.623	.0005	.0113	81.3
63	.221	.53	.0738	.54	.1083	.0386	.523	.0005	.0122	71.1
64	.162	.39	.0492	.36	.0875	.0150	.305	.0005	.0157	46.2
65	.119	.28	.0323	.23	.0684	.0074	.231	.0005	.0165	39.4
66 [1]	.406	.97	.1368	.99	.1172	.1415	1.035	.0010	.0102	95.6
67 [1]	.402	.96	.1361	.99	.1189	.1366	1.003	.0010	.0105	92.0
68	.350	.83	.1231	.89	.1275	.1230	.999	.0010	.0110	88.5
69	.314	.75	.1109	.80	.1264	.1065	.960	.0010	.0112	85.4
70	.273	.65	.0952	.69	.1209	.0824	.866	.0010	.0118	78.7
71	.215	.51	.0713	.52	.1065	.0532	.746	.0010	.0122	72.3
72	.155	.37	.0464	.34	.0847	.0231	.497	.0010	.0142	54.0
73	.116	.28	.0311	.23	.0670	.0165	.531	.0010	.0119	64.9
74 [1]	.411	.98	.1374	.99	.1146	.1905	1.386	.0020	.0105	91.6
75 [1]	.410	.98	.1373	.99	.1152	.1892	1.378	.0020	.0106	90.8
76	.348	.83	.1225	.89	.1275	.1827	1.491	.0020	.0106	93.4
77	.315	.75	.1113	.81	.1265	.1686	1.515	.0020	.0105	95.3
78	.279	.67	.0976	.71	.1220	.1371	1.405	.0020	.0108	90.0
79	.212	.51	.0700	.51	.1056	.0840	1.200	.0020	.0112	82.6
80	.164	.39	.0501	.36	.0883	.0481	.961	.0020	.0118	72.3
81	.129	.31	.0361	.26	.0732	.0291	.807	.0020	.0120	66.7
82 [1]	.399	.95	.1356	.98	.1199	.2408	1.775	.0030	.0105	93.6
83 [1]	.392	.94	.1343	.97	.1220	.2370	1.765	.0030	.0106	92.3
84	.352	.84	.1238	.90	.1274	.2208	1.784	.0030	.0108	91.3
85	.321	.77	.1134	.82	.1270	.1998	1.761	.0030	.0109	90.3
86	.273	.65	.0952	.69	.1209	.1566	1.645	.0030	.0111	86.4
87	.219	.52	.0730	.53	.1077	.0987	1.368	.0030	.0119	76.4
88	.165	.39	.0505	.37	.0887	.0544	1.078	.0030	.0126	66.1
89	.115	.27	.0308	.22	.0665	.0231	.751	.0030	.0137	53.1
90 [1]	.397	.95	.1352	.98	.1205	.3026	2.237	.0050	.0107	91.1
91	.377	.90	.1308	.95	.1250	.3096	2.367	.0050	.0106	94.7
92	.347	.83	.1222	.89	.1275	.2958	2.421	.0050	.0105	95.9
93	.298	.71	.1050	.76	.1247	.2464	2.347	.0050	.0106	94.0
94	.254	.61	.0875	.63	.1169	.1892	2.162	.0050	.0109	89.4
95	.220	.52	.0734	.53	.1080	.1448	1.973	.0050	.0111	84.9
96	.154	.37	.0460	.33	.0842	.0784	1.705	.0050	.0107	83.1
97	.118	.28	.0319	.23	.0680	.0381	1.194	.0050	.0121	64.8
98 [1]	.387	.92	.1332	.97	.1232	.3573	2.682	.0075	.0111	88.2
99 [1]	.383	.91	.1323	.96	.1240	.3582	2.708	.0075	.0110	88.8
100	.325	.78	.1148	.83	.1272	.3326	2.896	.0075	.0107	93.7
101	.281	.67	.0984	.71	.1223	.2746	2.790	.0075	.0107	92.1
102	.249	.59	.0855	.62	.1158	.2215	2.592	.0075	.0110	88.0
103	.197	.47	.0637	.46	.1006	.1404	2.203	.0075	.0114	80.2
104	.142	.34	.0412	.30	.0791	.0816	1.981	.0075	.0108	81.4
105	.118	.28	.0319	.23	.0680	.0445	1.396	.0075	.0126	61.8
106 [1]	.402	.96	.1361	.99	.1189	.4009	2.945	.0100	.0113	85.4
107 [1]	.383	.91	.1323	.96	.1240	.4051	3.063	.0100	.0112	87.0
108	.326	.78	.1152	.83	.1273	.3740	3.247	.0100	.0109	91 0
109	.282	.67	.0988	.72	.1225	.3096	3.135	.0100	.0110	89.6
110	.252	.60	.0867	.63	.1165	.2648	3.055	.0100	.0109	89.5
111	.216	.52	.0717	.52	.1068	.2096	2.923	.0100	.0107	89.4
112	.154	.37	.0460	.33	.0842	.1255	2.730	.0100	.0098	94.1
113	.111	.26	.0293	.21	.0646	.0640	2.185	.0100	.0098	86.0
114 [1]	.402	.96	.1361	.99	.1189	.4749	3.488	.0125	.0108	90.5
115 [1]	.386	.92	.1330	.96	.1234	.4703	3.537	.0125	.0109	90.1
116	.327	.78	.1155	.84	.1273	.4272	3.698	.0125	.0107	92.7
117	.294	.70	.1034	.75	.1242	.3862	3.734	.0125	.0105	94.7
118	.264	.63	.0916	.66	.1190	.3392	3.704	.0125	.0103	96.0
119	.221	.53	.0738	.53	.1083	.2624	3.556	.0125	.0101	96.7
120	.173	.41	.0538	.39	.0919	.1698	3.158	.0125	.0100	93.2
121	.115	.27	.0308	.22	.0665	.0836	2.718	.0125	.0092	94.3
122 [1]	.399	.95	.1356	.98	.1199	.5415	3.993	.0150	.0105	94.2
123 [1]	.394	.94	.1347	.98	.1215	.5428	4.030	.0150	.0105	94.4
124	.343	.82	.1209	.88	.1276	.5066	4.190	.0150	.0105	95.8
125	.319	.76	.1127	.82	.1269	.4738	4.203	.0150	.0104	96.4
126	.253	.60	.0871	.63	.1167	.3582	4.113	.0150	.0102	98.3
127	.209	.50	.0688	.50	.1046	.2704	3.932	.0150	.0099	99.3
128	.158	.38	.0476	.35	.0859	.1674	3.516	.0150	.0095	98.0
129	.118	.28	.0319	.23	.0680	.0969	3.041	.0150	.0093	95.2

[1] These tests used in deriving formulæ 27 an d 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

6-INCH TILE.

1 Test No.	2 Depth of flow. (*d*)	3 $\frac{d}{D}$	4 Area of flow. (*a*)	5 $\frac{a}{A}$	6 Hydraulic radius. (*R*)	7 Discharge. (*Q*)	8 Velocity. (*V*)	9 Slope. (*s*)	10 Kutter coefficient. (*n*)	11 Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
130 [1]	0.517	1.00	0.2110	1.00	0.1319	0.1614	0.765	0.0005	0.0103	94.2
131	.402	.78	.1756	.83	.1573	.1404	.800	.0005	.0111	90.1
132	.300	.58	.1266	.60	.1412	.0724	.572	.0005	.0134	68.0
133	.223	.43	.0868	.41	.1170	.0397	.457	.0005	.0141	59.7
134	.188	.36	.0692	.33	.1031	.0225	.325	.0005	.0165	45.3
135 [1]	.510	.98	.2103	.99	.1404	.2229	1.060	.0010	.0111	89.5
136	.396	.76	.1730	.82	.1569	.1578	.912	.0010	.0132	72.8
137	.304	.59	.1286	.61	.1422	.1255	.976	.0010	.0119	81.8
138	.221	.43	.0858	.41	.1163	.0706	.823	.0010	.0120	76.3
139	.171	.33	.0607	.29	.0958	.0372	.613	.0010	.0132	62.6
140 [1]	.498	.96	.2083	.99	.1465	.3563	1.710	.0020	.0104	99.9
141	.409	.79	.1786	.85	.1576	.2680	1.500	.0020	.0119	84.5
142	.277	.53	.1148	.54	.1350	.1801	1.569	.0020	.0105	95.5
143	.216	.42	.0832	.39	.1144	.1090	1.310	.0020	.0110	86.6
144	.157	.30	.0540	.26	.0893	.0559	1.036	.0020	.0112	77.5
145 [1]	.508	.98	.2100	.99	.1418	.4282	2.039	.0030	.0104	98.8
146	.414	.80	.1807	.86	.1577	.3620	2.003	.0030	.0112	92.1
147	.302	.58	.1276	.61	.1417	.2194	1.719	.0030	.0118	83.4
148	.222	.43	.0863	.41	.1167	.1382	1.601	.0030	.0112	85.6
149	.167	.32	.0588	.28	.0939	.0685	1.165	.0030	.0123	69.4
150 [1]	.498	.96	.2083	.99	.1465	.5540	2.659	.0050	.0106	98.2
151	.378	.73	.1649	.78	.1552	.4440	2.692	.0050	.0108	96.6
152	.276	.53	.1143	.54	.1347	.2771	2.425	.0050	.0108	93.5
153	.213	.41	.0817	.39	.1133	.1512	1.850	.0050	.0119	77.7
154	.152	.29	.0516	.24	.0870	.0664	1.287	.0050	.0131	61.7
155 [1]	.473	.91	.2020	.96	.1534	.6804	3.368	.0075	.0106	99.3
156	.385	.74	.1681	.80	.1560	.5390	3.206	.0075	.0111	93.7
157	.258	.50	.1049	.50	.1292	.2771	2.641	.0075	.0115	84.9
158	.199	.38	.0746	.35	.1077	.1692	2.268	.0075	.0116	79.8
159	.147	.28	.0493	.23	.0846	.0969	1.967	.0075	.0112	78.1
160	.461	.89	.1983	.94	.1554	.7630	3.847	.0100	.0107	97.6
161	.336	.65	.1448	.69	.1491	.5174	3.575	.0100	.0111	92.6
162	.222	.43	.0863	.41	.1167	.2560	2.966	.0100	.0111	86.8
163	.191	.37	.0706	.33	.1044	.1608	2.278	.0100	.0126	70.5
164	.141	.27	.0465	.22	.0817	.0864	1.860	.0100	.0126	65.1
165	.405	.78	.1769	.84	.1574	.8028	4.538	.0125	.0104	102.3
166	.343	.66	.1482	.70	.1505	.6346	4.281	.0125	.0106	98.7
167	.260	.50	.1060	.50	.1299	.3894	3.674	.0125	.0109	91.2
168	.204	.39	.0771	.37	.1097	.2600	3.371	.0125	.0105	91.0
169	.147	.28	.0492	.23	.0846	.1185	2.409	.0125	.0116	74.1
170	.392	.76	.1712	.81	.1567	.8771	5.122	.0150	.0102	105.7
171	.333	.64	.1433	.68	.1485	.6650	4.641	.0150	.0106	98.3
172	.233	.45	.0920	.44	.1207	.3592	3.904	.0150	.0107	91.7
173	.175	.34	.0627	.30	.0975	.2243	3.579	.0150	.0101	93.6
174	.140	.27	.0460	.22	.0812	.0872	1.896	.0150	.0142	54.3
8-INCH TILE.										
175 [1]	0.673	0.98	0.3670	0.99	0.1862	0.3240	0.883	0.0005	0.0114	91.5
176 [1]	.664	.97	.3652	.99	.1911	.3260	.893	.0005	.0115	91.3
177	.515	.75	.2972	.81	.2067	.2540	.885	.0005	.0122	84.1
178	.342	.50	.1839	.50	.1711	.1370	.745	.0005	.0123	80.6
179	.259	.38	.1277	.35	.1406	.0840	.658	.0005	.0120	78.5
180	.166	.24	.0689	.19	.0978	.0363	.527	.0005	.0114	75.4
181 [1]	.656	.96	.3631	.99	.1944	.4570	1.259	.0010	.0118	90.3
182 [1]	.656	.96	.3631	.99	.1944	.4670	1.286	.0010	.0116	92.2
183	.509	.74	.2936	.80	.2061	.3740	1.274	.0010	.0121	88.7
184	.348	.51	.1881	.51	.1730	.2060	1.095	.0010	.0122	83.3
185	.271	.40	.1357	.37	.1456	.1380	1.017	.0010	.0118	84.4
186	.192	.28	.0846	.23	.1106	.0720	.851	.0010	.0114	80.9

[1] These tests used in deriving formulæ 27 and 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

8-INCH TILE—Continued.

1 Test No.	2 Depth of flow. (*d*)	3 $\frac{d}{D}$	4 Area of flow. (*a*)	5 $\frac{a}{A}$	6 Hydraulic radius. (*R*)	7 Discharge. (*Q*)	8 Velocity. (*V*)	9 Slope. (*s*)	10 Kutter coefficient. (*n*)	11 Chezy coefficient. (*C*)
	Feet.		*Sq.ft.*		*Feet.*	*Cu.ft. per sec.*	*Feet per sec.*			
187[1]	0.669	0.98	0.3663	0.99	0.1885	0.6750	1.842	0.0020	0.0113	94.9
188[1]	.661	.96	.3644	.99	.1924	.6720	1.844	.0020	.0115	94.0
189	.509	.74	.2936	.80	.2061	.5220	1.778	.0020	.0123	87.6
190	.358	.52	.1949	.53	.1760	.2805	1.439	.0020	.0130	76.8
191	.267	.39	.1329	.36	.1439	.1540	1.159	.0020	.0138	68.4
192	.165	.24	.0684	.19	.0973	.0540	.790	.0020	.0144	56.6
193[1]	.670	.98	.3664	.99	.1880	.7996	2.182	.0030	.0117	91.9
194	.663	.97	.3649	.99	.1915	.7870	2.157	.0030	.0119	90.1
195	.510	.74	.2942	.80	.2062	.6390	2.172	.0030	.0122	87.5
196	.364	.53	.1990	.54	.1778	.3392	1.705	.0030	.0136	73.8
197	.280	.41	.1417	.39	.1490	.2054	1.449	.0030	.0139	68.7
198	.196	.29	.0871	.24	.1126	.0920	1.057	.0030	.0149	57.6
199[1]	.676	.99	.3675	.99	.1840	1.0800	2.939	.0050	.0112	96.9
200	.558	.82	.3215	.87	.2085	.9210	2.870	.0050	.0121	88.9
201	.427	.62	.2415	.66	.1935	.5660	2.344	.0050	.0137	75.4
202	.358	.52	.1949	.53	.1760	.3950	2.030	.0050	.0143	68.4
203	.272	.40	.1363	.37	.1459	.2360	1.730	.0050	.0145	64.0
204	.177	.26	.0755	.21	.1033	.0946	1.250	.0050	.0149	55.0
205[1]	.662	.97	.3647	.99	.1919	1.2840	3.522	.0075	.0117	92.8
206[1]	.642	.94	.3588	.97	.1989	1.3000	3.623	.0075	.0117	93.8
207	.503	.73	.2900	.79	.2055	.9480	3.270	.0075	.0129	83.3
208	.356	.52	.1935	.53	.1754	.5590	2.889	.0075	.0128	79.7
209	.270	.39	.1350	.37	.1451	.3392	2.513	.0075	.0127	76.2
210	.180	.26	.0773	.21	.1048	.1481	1.915	.0075	.0129	68.3
211[1]	.667	.97	.3658	.99	.1886	1.4920	4.079	.010	.0116	93.7
212[1]	.661	.96	.3644	.99	.1924	1.4650	4.021	.010	.0118	91.7
213[1]	.657	.96	.3635	.99	.1940	1.4475	3.982	.010	.0120	90.4
214	.473	.69	.2714	.74	.2021	1.1580	4.267	.010	.0116	94.9
215	.325	.47	.1723	.47	.1654	.5980	3.471	.010	.0120	85.4
216	.250	.37	.1217	.33	.1369	.3760	3.089	.010	.0118	83.5
217	.173	.25	.0731	.20	.1013	.1814	2.483	.010	.0116	78.0
218[1]	.673	.98	.3670	.99	.1861	1.6200	4.414	.0125	.0118	91.5
219[1]	.669	.98	.3663	.99	.1885	1.6200	4.423	.0125	.0118	91.1
220	.490	.72	.2821	.77	.2040	1.3475	4.778	.0125	.0117	94.6
221	.346	.51	.1867	.51	.1723	.7525	4.031	.0125	.0120	86.9
222	.260	.38	.1283	.35	.1410	.4430	3.453	.0125	.0120	82.3
223	.173	.25	.0731	.20	.1013	.2096	2.869	.0125	.0113	80.6
224	.553	.81	.3187	.87	.2085	1.7675	5.546	.0150	.0112	99.2
225	.540	.79	.3116	.85	.2082	1.7375	5.576	.0150	.0111	99.8
226	.501	.73	.2888	.78	.2053	1.5350	5.316	.0150	.0114	95.8
227	.338	.49	.1812	.49	.1698	.7932	4.378	.0150	.0119	86.7
228	.256	.37	.1257	.34	.1394	.4772	3.798	.0150	.0119	83.1
229	.166	.24	.0689	.19	.0978	.2138	3.102	.0150	.0112	81.0

10-INCH TILE.

230[1]	0.821	0.98	0.5467	0.99	0.2275	0.6386	1.168	0.0005	0.0104	109.5
231[1]	.812	.97	.5444	.99	.2324	.5874	1.079	.0005	.0112	100.1
232[1]	.783	.94	.5343	.97	.2429	.5770	1.080	.0005	.0114	98.0
233	.749	.90	.5186	.95	.2497	.5640	1.088	.0005	.0116	97.3
234	.697	.83	.4890	.89	.2541	.5578	1.141	.0005	.0112	101.2
235	.666	.80	.4689	.85	.2542	.5503	1.174	.0005	.0110	104.1
236	.626	.75	.4408	.80	.2521	.5366	1.217	.0005	.0107	108.4
237	.567	.68	.3963	.72	.2451	.4982	1.257	.0005	.0102	113.6
238	.546	.65	.3798	.69	.2413	.4611	1.214	.0005	.0104	110.8
239	.473	.57	.3203	.58	.2250	.3967	1.239	.0005	.0098	116.5
240	.421	.50	.2770	.50	.2099	.3078	1.111	.0005	.0103	108.4
241	.310	.37	.1852	.34	.1692	.1998	1.079	.0005	.0093	117.3
242	.214	.26	.1110	.20	.1251	.1005	.906	.0005	.0089	114.5

[1] These tests used in deriving formulæ 27 and 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

10-INCH TILE—Continued.

1 Test No.	2 Depth of flow. (d)	3 $\frac{d}{D}$	4 Area of flow. (a)	5 $\frac{a}{A}$	6 Hydraulic radius. (R)	7 Discharge. (Q)	8 Velocity. (V)	9 Slope. (s)	10 Kutter coefficient. (n)	11 Chezy coefficient. (C)
	Feet.		*Sq.ft.*		*Feet.*	*Cu.ft. per sec.*	*Feet per sec.*			
243 [1]	0.782	0.94	0.5339	0.97	0.2431	0.8870	1.661	0.0010	0.0109	106.6
244	.723	.87	.5045	.92	.2526	.8837	1.752	.0010	.0107	110.2
245	.681	.82	.4788	.87	.2544	.8722	1.822	.0010	.0104	114.2
246	.625	.75	.4401	.80	.2520	.7996	1.817	.0010	.0103	114.5
247	.572	.68	.4002	.73	.2459	.7120	1.780	.0010	.0104	113.5
248	.542	.65	.3766	.69	.2406	.6748	1.792	.0010	.0102	115.6
249	.466	.56	.3145	.57	.2231	.5378	1.710	.0010	.0101	114.5
250	.425	.51	.2803	.51	.2112	.4726	1.686	.0010	.0099	116.1
251	.313	.37	.1876	.34	.1704	.2788	1.486	.0010	.0097	113.8
252	.205	.25	.1044	.19	.1206	.1240	1.188	.0010	.0094	108.2
253 [1]	.823	.99	.5471	.99	.2260	1.2680	2.318	.0020	.0106	109.0
254 [1]	.797	.95	.5397	.98	.2385	1.2680	2.350	.0020	.0108	107.6
255 [1]	.778	.93	.5322	.97	.2441	1.2520	2.353	.0020	.0110	106.5
256	.694	.83	.4871	.89	.2542	1.2300	2.525	.0020	.0106	112.0
257	.667	.80	.4696	.86	.2543	1.1840	2.521	.0020	.0106	111.8
258	.623	.75	.4386	.80	.2518	1.1380	2.595	.0020	.0104	115.6
259	.563	.67	.3932	.72	.2444	1.0090	2.566	.0020	.0102	116.1
260	.525	.63	.3629	.66	.2370	.9380	2.585	.0020	.0100	118.8
261	.472	.56	.3195	.58	.2248	.7964	2.493	.0020	.0100	117.6
262	.428	.51	.2828	.52	.2121	.6832	2.416	.0020	.0099	117.3
263	.318	.38	.1917	.35	.1724	.3841	2.004	.0020	.0101	107.9
264	.203	.24	.1030	.19	.1196	.1614	1.567	.0020	.0099	101.4
265 [1]	.827	.99	.5479	.99	.2232	1.5300	2.793	.0030	.0107	107.9
266 [1]	.814	.97	.5449	.99	.2314	1.5350	2.817	.0030	.0109	106.9
267	.810	.97	.5438	.99	.2334	1.5350	2.823	.0030	.0109	106.7
268 [1]	.804	.96	.5421	.99	.2360	1.5250	2.813	.0030	.0110	105.8
269 [1]	.796	.95	.5393	.98	.2388	1.5180	2.815	.0030	.0111	105.2
270	.777	.93	.5318	.97	.2444	1.5140	2.847	.0030	.0111	105.1
271	.756	.90	.5221	.95	.2485	1.5020	2.877	.0030	.0112	105.4
272	.689	.82	.4840	.88	.2543	1.4960	3.091	.0030	.0107	111.9
273	.684	.82	.4808	.88	.2544	1.4800	3.078	.0030	.0107	111.4
274	.631	.76	.4444	.81	.2525	1.3960	3.141	.0030	.0105	114.1
275	.563	.57	.3932	.72	.2444	1.2100	3.077	.0030	.0104	113.7
276	.542	.65	.3766	.69	.2406	1.1240	2.985	.0030	.0106	111.1
277	.484	.58	.3294	.60	.2278	.9227	2.801	.0030	.0108	107.2
278	.431	.52	.2853	.52	.2130	.7450	2.611	.0030	.0110	103.3
279	.328	.39	.1998	.36	.1765	.4542	2.274	.0030	.0109	98.8
280	.224	.27	.1183	.22	.1301	.2173	1.836	.0030	.0107	93.0
281 [1]	.801	.96	.5410	.99	.2371	1.9900	3.678	.0050	.0110	106.8
282 [1]	.801	.96	.5410	.99	.2371	1.9700	3.641	.0050	.0110	105.8
283	.751	.90	.5197	.95	.2494	1.9575	3.767	.0050	.0110	106.7
284	.701	.84	.4915	.90	.2540	1.9300	3.927	.0050	.0108	110.2
285	.665	.80	.4682	.85	.2542	1.8400	3.930	.0050	.0108	110.2
286	.647	.77	.4558	.83	.2536	1.7975	3.944	.0050	.0107	110.7
287	.618	.74	.4350	.79	.2512	1.6575	3.811	.0050	.0110	107.5
288	.565	.68	.3948	.72	.2448	1.4700	3.724	.0050	.0110	106.5
289	.534	.64	.3701	.67	.2389	1.3625	3.681	.0050	.0110	106.5
290	.470	.56	.3178	.58	.2242	1.0980	3.455	.0050	.0111	103.2
291	.426	.51	.2811	.51	.2115	.9261	3.294	.0050	.0112	101.3
292	.307	.37	.1828	.33	.1679	.5306	2.903	.0050	.0107	108.2
293	.213	.25	.1102	.20	.1246	.2568	2.330	.0050	.0106	93.3
294 [1]	.801	.96	.5410	.99	.2371	2.3850	4.409	.0075	.0111	104.5
295 [1]	.796	.95	.5393	.98	.2388	2.4120	4.473	.0075	.0110	105.7
296	.782	.94	.5339	.97	.2431	2.3760	4.450	.0075	.0112	104.2
297	.748	.90	.5181	.94	.2498	2.3760	4.586	.0075	.0111	106.0
298	.726	.87	.5063	.92	.2524	2.3400	4.623	.0075	.0111	106.3
299	.684	.82	.4808	.88	.2544	2.2590	4.699	.0075	.0110	107.6
300	.646	.77	.4551	.83	.2536	2.1330	4.687	.0075	.0110	107.5
301	.564	.68	.3939	.72	.2446	1.8150	4.608	.0075	.0109	107.6
302	.540	.65	.3749	.68	.2401	1.6925	4.515	.0075	.0110	106.4
303	.487	.58	.3318	.61	.2286	1.4350	4.325	.0075	.0110	104.5
304	.409	.49	.2669	.49	.2060	1.0820	4.054	.0075	.0109	103.1
305	.311	.37	.1860	.34	.1696	.6440	3.462	.0075	.0110	97.9
306	.226	.27	.1198	.22	.1311	.3449	2.879	.0075	.0109	91.1

[1] These tests used in deriving formulæ 27 and 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

10-INCH TILE—Continued.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hydraulic radius. (*R*)	Discharge. (*Q*)	Velocity. (*V*)	Slope. (*s*)	Kutter coefficient. (*n*)	Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
307 [1]	.809	0.97	0.5435	0.99	0.2338	2.7715	5.099	0.0100	0.0110	105.5
308 [1]	.795	.95	.5389	.98	.2391	2.7645	5.130	.0075	.0111	105.0
309	.744	.89	.5161	.94	.2505	2.7070	5.245	.0100	.0112	104.8
310	.741	.89	.5145	.94	.2508	2.7505	5.347	.0100	.0111	106.8
311	.708	.85	.4957	.90	.2537	2.6695	5.385	.0100	.0111	106.9
312	.705	.84	.4939	.90	.2538	2.6485	5.363	.0100	.0111	106.4
313	.676	.81	.4755	.87	.2545	2.5980	5.464	.0100	.0110	108.3
314	.642	.77	.4523	.82	.2534	2.5050	5.538	.0100	.0108	110.0
315	.577	.69	.4041	.74	.2460	2.1960	5.435	.0100	.0108	109.5
316	.545	.65	.3790	.69	.2411	2.0075	5.297	.0100	.0109	107.9
317	.489	.59	.3335	.61	.2291	1.7325	5.196	.0100	.0107	108.6
318	.414	.50	.2711	.49	.2077	1.2920	4.766	.0100	.0108	104.6
319	.299	.36	.1764	.32	.1645	.7270	4.122	.0100	.0106	101.6
320	.212	.25	.1095	.20	.1241	.3831	3.498	.0100	.0102	99.3
321 [1]	.819	.98	.5462	.99	.2288	3.1220	5.717	.0125	.0109	106.9
322	.752	.90	.5202	.95	.2492	3.0380	5.841	.0125	.0112	104.7
323	.697	.83	.4890	.89	.2541	2.9750	6.085	.0125	.0110	107.9
324	.657	.79	.4628	.84	.2541	2.8430	6.144	.0125	.0109	109.0
325	.636	.76	.4480	.82	.2529	2.7715	6.187	.0125	.0109	110.0
326	.563	.67	.3932	.72	.2444	2.4030	6.112	.0125	.0107	110.6
327	.528	.63	.3653	.67	.2376	2.2080	6.045	.0125	.0106	110.9
328	.461	.55	.3104	.57	.2218	1.7950	5.784	.0125	.0106	109.8
329	.418	.50	.2745	.50	.2090	1.5120	5.509	.0125	.0106	107.8
330	.308	.37	.1836	.34	.1683	.8804	4.796	.0125	.0104	104.5
331	.208	.25	.1066	.19	.1221	.4303	4.038	.0125	.0099	103.4
332	.618	.74	.4350	.79	.2512	2.8580	6.569	.0150	.0110	107.0
333	.557	.67	.3885	.71	.2433	2.5380	6.533	.0150	.0109	108.1
334	.526	.63	.3637	.66	.2372	2.3670	6.509	.0150	.0108	109.1
335	.457	.55	.3070	.56	.2206	1.8480	6.018	.0150	.0110	104.6
336	.392	.47	.2527	.46	.2003	1.4120	5.587	.0150	.0110	101.9
337	.300	.36	.1772	.32	.1650	.8854	4.997	.0150	.0107	100.5
338	.215	.26	.1117	.20	.1256	.4462	3.995	.0150	.0108	92.0

12-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
339 [1]	0.986	1.00	0.7631	1.00	0.2464	0.8972	1.176	0.0005	0.0108	105.9
340 [1]	.896	.91	.7286	.96	.2922	.9006	1.236	.0005	.0115	102.3
341	.856	.87	.7037	.92	.2975	.8540	1.214	.0005	.0118	99.5
342	.803	.81	.6657	.87	.3000	.8380	1.259	.0005	.0115	102.8
343	.754	.76	.6263	.82	.2985	.7360	1.175	.0005	.0121	96.2
344	.694	.70	.5743	.75	.2924	.6762	1.178	.0005	.0120	97.4
345	.650	.66	.5338	.70	.2857	.6496	1.217	.0005	.0115	101.8
346	.592	.60	.4786	.63	.2738	.5390	1.126	.0005	.0119	96.3
347	.558	.57	.4456	.58	.2654	.5006	1.124	.0005	.0117	97.6
348	.502	.51	.3906	.51	.2493	.4261	1.091	.0005	.0115	97.7
349	.412	.42	.3022	.40	.2181	.2754	.911	.0005	.0122	87.3
350	.306	.31	.2019	.27	.1732	.1518	.752	.0005	.0124	80.8
351 [1]	.931	.95	.7464	.98	.2841	1.4350	1.923	.0010	.0107	114.1
352	.846	.86	.6970	.91	.2984	1.3430	1.927	.0010	.0109	111.5
353	.794	.81	.6587	.86	.2999	1.2660	1.922	.0010	.0110	111.0
354	.730	.74	.6060	.79	.2964	1.1320	1.868	.0010	.0111	108.5
355	.697	.71	.5769	.76	.2927	1.0500	1.820	.0010	.0113	106.4
356	.646	.66	.5300	.70	.2850	.9516	1.795	.0010	.0112	106.3
357	.601	.61	.4873	.64	.2756	.8508	1.746	.0010	.0112	105.1
358	.555	.56	.4427	.58	.2646	.7360	1.663	.0010	.0114	102.2
359	.501	.51	.3896	.51	.2490	.6170	1.584	.0010	.0115	100.4
360	.390	.40	.2809	.37	.2094	.3730	1.328	.0010	.0118	91.7
361	.296	.30	.1928	.25	.1686	.2026	1.051	.0010	.0124	80.9
362 [1]	.974	.99	.7614	.99	.2640	1.9080	2.506	.0020	.0109	109.1
363	.853	.87	.7017	.92	.2978	1.7200	2.451	.0020	.0120	100.4
364	.807	.82	.6687	.88	.3000	1.6900	2.527	.0020	.0117	103.2
365	.764	.78	.6346	.83	.2991	1.5550	2.450	.0020	.0120	100.2
366	.701	.71	.5805	.76	.2932	1.3900	2.394	.0020	.0121	98.9
367	.646	.66	.5300	.70	.2850	1.1960	2.256	.0020	.0124	94.5
368	.590	.60	.4767	.63	.2733	1.0160	2.133	.0020	.0127	91.2
369	.549	.56	.4368	.57	.2630	.8904	2.038	.0020	.0128	88.9
370	.504	.51	.3925	.51	.2499	.7450	1.898	.0020	.0131	84.9
371	.406	.41	.2964	.39	.2157	.4657	1.571	.0020	.0140	75.6
372	.298	.30	.1947	.26	.1695	.2340	1.202	.0020	.0148	5.36

[1] These tests used in deriving formulæ 27 and 29.

TABLE 3.—*Elements of experiments for clay tile*—Continued.

12-INCH TILE—Continued.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (d)	$\frac{d}{D}$	Area of flow. (a)	$\frac{a}{A}$	Hydraulic radius. (R)	Discharge. (Q)	Velocity. (V)	Slope. (s)	Kutter coefficient. (n)	Chezy coefficient. (C)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
373	0.887	0.90	0.7234	0.95	0.2938	2.2320	3.086	0.0030	0.0116	103.9
374	.853	.87	.7017	.92	.2978	2.1840	3.113	.0030	.0116	104.1
375	.809	.82	.6702	.88	.3000	2.0800	3.103	.0030	.0117	103.4
376	.773	.78	.6420	.84	.2995	1.9450	3.030	.0030	.0119	101.1
377	.724	.73	.6007	.79	.2957	1.7980	2.992	.0030	.0120	100.5
378	.693	.70	.5734	.75	.2923	1.6100	2.809	.0030	.0124	94.9
379	.646	.66	.5300	.70	.2850	1.4400	2.717	.0030	.0126	92.9
380	.603	.61	.4893	.64	.2761	1.2560	2.567	.0030	.0129	89.2
381	.547	.56	.4349	.57	.2624	1.0260	2.360	.0030	.0134	84.1
382	.500	.51	.3886	.51	.2487	.8440	2.173	.0030	.0138	79.6
383	.402	.41	.2925	.38	.2142	.5222	1.785	.0030	.0147	70.4
384	.303	.31	.1992	.26	.1718	.2737	1.374	.0030	.0158	60.5
385 [1]	.974	.99	.7614	.99	.2640	3.0380	3.990	.0050	.0109	109.8
386 [1]	.940	.95	.7504	.98	.2811	3.0030	4.002	.0050	.0113	106.8
387	.878	.89	.7179	.94	.2952	2.8400	3.956	.0050	.0117	103.0
388	.817	.83	.6763	.89	.2998	2.5440	3.762	.0050	.0124	97.2
389	.741	.75	.6154	.81	.2975	2.1300	3.461	.0050	.0131	89.7
390	.696	.71	.5760	.76	.2927	1.8400	3.195	.0050	.0138	83.5
391	.644	.65	.5282	.69	.2846	1.5650	2.963	.0050	.0144	78.6
392	.597	.61	.4835	.63	.2748	1.3550	2.803	.0050	.0147	75.6
393	.552	.56	.4398	.58	.2638	1.1660	2.651	.0050	.0150	73.0
394	.509	52	.3975	.52	.2514	.9838	2.475	.0050	.0154	69.8
395	.409	42	.2993	.39	.2169	.5981	1.998	.0050	.0165	60.7
396	.313	.32	.2083	.27	.1765	.3259	1.564	.0050	.0175	52.7
397	.723	.73	.5998	.79	.2956	2.9890	4.983	.0075	.0114	105.8
398	.638	.65	.5225	.69	.2834	2.5440	4.869	.0075	.0114	105.6
399	.584	.59	.4708	.62	.2719	2.1480	4.563	.0075	.0117	101.0
400	.563	.57	.4505	.59	.2667	2.0500	4.551	.0075	.0117	101.8
401	.512	.52	.4004	.53	.2523	1.7400	4.346	.0075	.0117	99.9
402	.388	.39	.2790	.37	.2086	1.0180	3.651	.0075	.0120	92.3
403	.302	.31	.1983	.26	.1714	.6250	3.153	.0075	.0119	87.9
404	.651	.66	.5347	.70	.2858	2.9400	5.498	.0100	.0117	102.8
405	.598	.61	.4844	.64	.2750	2.6170	5.403	.0100	.0116	103.0
406	.546	.55	.4339	.57	.2622	2.2980	5.297	.0100	.0114	103.5
407	.494	.50	.3827	.50	.2468	1.8400	4.809	.1000	.0119	96.8
408	.413	.42	.3031	.40	.2184	1.2960	4.276	.0100	.0121	91.5
409	.307	.31	.2028	.27	.1737	.6972	3.438	.0100	.1026	82.5
410	.496	.50	.3847	.50	.2474	2.0150	5.239	.0125	.0122	94.2
411	.419	.43	.3090	.41	.2207	1.5400	4.984	.0125	.0118	94.9
412	.321	.33	.2157	.28	.1801	.9694	4.495	.0125	.0114	94.7
413	.459	.47	.3482	.46	.2351	1.9600	5.630	.0150	.0120	94.8
414	.444	.45	.3335	.44	.2299	1.8575	5.570	.0150	.0119	94.9
415	.403	.41	.2935	.39	.2145	1.6150	5.525	.0150	.0116	97.0
416	.284	.29	.1820	.24	.1629	.8639	4.747	.0150	.0111	96.0

[1] These tests used in deriving formulæ 27 and 29.

TABLE 4.—*Elements of experiments for concrete tile.*

4-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hydraulic radius. (*R*)	Discharge. (*Q*)	Velocity. (*V*)	Slope. (*s*)	Kutter coefficient. (*n*)	Chezy coefficient. (*C*)
	Feet.		*Sq.ft.*		*Feet.*	*Cu.ft. per sec.*	*Feet per sec.*			
417[1]	0.328	1.00	0.0845	1.00	0.0820	0.0426	0.504	0.0005	0.0107	78.7
418	.282	.86	.0773	.92	.0993	.0386	.499	.0005	.0120	70.9
419	.247	.75	.0683	.81	.0990	.0335	.491	.0005	.0122	69.7
420	.206	.63	.0559	.66	.0930	.0196	.315	.0005	.0160	46.3
421	.167	.51	.0432	.51	.0829	.0120	.278	.0005	.0163	43.1
422	.118	.36	.0274	.32	.0649	[2] .0020	[2] .075	.0005	[2] .0352	[2] 13.1
423[1]	.311	.95	.0828	.98	.0941	.0650	.785	.0010	.0110	80.9
424	.274	.84	.0754	.89	.0997	.0550	.730	.0010	.0120	73.1
425	.239	.73	.0660	.78	.0982	.0450	.682	.0010	.0124	68.8
426	.210	.64	.0571	.68	.0938	.0375	.656	.0010	.0124	67.8
427	.163	.50	.0419	.50	.0817	.0218	.519	.0010	.0134	57.4
428	.118	.36	.0274	.32	.0649	.0083	.301	.0010	.0172	37.4
429[1]	.323	.99	.0842	.99	.0890	.0832	.988	.0020	.0116	74.1
430	.271	.83	.0747	.88	.0998	.0800	1.071	.0020	.0117	75.8
431	.243	.74	.0671	.79	.0986	.0650	.968	.0020	.0125	68.9
432	.215	.66	.0587	.70	.0948	.0544	.927	.0020	.0126	67.3
433	.162	.49	.0416	.49	.0814	.0280	.673	.0020	.0144	52.8
434	.124	.38	.0293	.35	.0674	.0127	.434	.0020	.0175	37.4
435[1]	.323	.99	.0842	.99	.0886	.1014	1.204	.0030	.0117	73.8
436	.295	.90	.0801	.95	.0978	.1041	1.300	.0030	.0117	75.9
437	.271	.83	.0747	.88	.0998	.0969	1.298	.0030	.0119	75.0
438	.243	.74	.0671	.79	.0986	.0848	1.263	.0030	.0120	73.4
439	.211	.64	.0575	.68	.0940	.0591	1.028	.0030	.0135	61.2
440	.160	.49	.0409	.48	.0807	.0298	.727	.0030	.0157	46.7
441	.118	.36	.0274	.32	.0649	.0130	.475	.0030	.0185	34.1
442[1]	.315	.96	.0834	.99	.0928	.1415	1.697	.0050	.0113	78.8
443	.276	.84	.0759	.90	.0996	.1235	1.627	.0050	.0121	72.9
444	.243	.74	.0671	.79	.0986	.0996	1.484	.0050	.0129	66.8
445	.212	.65	.0578	.68	.0943	.0788	1.364	.0050	.0133	62.8
446	.170	.52	.0442	.52	.0838	.0478	1.081	.0050	.0146	52.8
447	.121	.37	.0283	.34	.0661	.0200	.706	.0050	.0171	38.9
448[1]	.305	.93	.0819	.97	.0959	.1775	2.168	.0075	.0112	80.8
449	.290	.88	.0790	.94	.0985	.1686	2.133	.0075	.0116	78.5
450	.269	.82	.0742	.88	.0998	.1459	1.968	.0075	.0123	71.9
451	.252	.77	.0697	.83	.0994	.1299	1.866	.0075	.0127	68.3
452	.222	.68	.0609	.72	.0961	.0956	1.571	.0075	.0141	58.5
453	.191	.58	.0511	.61	.0897	.0696	1.362	.0075	.0150	52.5
454	.173	.53	.0452	.54	.0847	.0594	1.314	.0075	.0149	52.1
455	.296	.90	.0803	.95	.0976	.1931	2.406	.0100	.0117	77.0
456	.291	.89	.0792	.94	.0984	.1905	2.404	.0100	.0118	76.6
457	.278	.85	.0764	.90	.0995	.1686	2.208	.0100	.0125	70.0
458	.249	.76	.0688	.81	.0992	.1382	2.008	.0100	.0134	63.8
459	.209	.64	.0568	.67	.0936	.1046	1.840	.0100	.0138	60.1
460	.165	.50	.0426	.50	.0823	.0622	1.461	.0100	.0151	50.9
461[1]	.301	.92	.0812	.96	.0967	.2250	2.771	.0125	.0114	79.7
462	.287	.88	.0784	.93	.0988	.2124	2.709	.0125	.0117	77.1
463	.242	.74	.0668	.79	.0985	.1656	2.478	.0125	.0124	70.6
464	.204	.62	.0552	.65	.0926	.1377	2.492	.0125	.0120	73.3
465	.196	.60	.0396	.47	.0793	.0760	1.918	.0125	.0132	60.9
466	.133	.41	.0322	.38	.0710	.0416	1.293	.0125	.0163	43.4
467[1]	.314	.96	.0833	.99	.0931	.2544	3.056	.0150	.0111	81.8
468	.302	.92	.0814	.96	.0965	.2456	3.018	.0150	.0114	79.3
469	.274	.84	.0754	.89	.0997	.2236	2.965	.0150	.0118	76.7
470	.255	.78	.0705	.83	.0996	.1892	2.684	.0150	.0126	69.5
471	.224	.68	.0615	.73	.0964	.1506	2.449	.0150	.0128	66.3
472	.159	.49	.0406	.48	.0804	.0848	2.088	.0150	.0133	60.1
473	.123	.38	.0290	.34	.0669	.0438	1.511	.0150	.0150	47.7

[1] These tests used in deriving formulæ 26 and 28.
[2] Evidently an incorrect hook-gage reading.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

5-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (d)	$\frac{d}{D}$	Area of flow. (a)	$\frac{a}{A}$	Hydraulic radius. (R)	Discharge. (Q)	Velocity. (V)	Slope. (s)	Kutter coefficient. (n)	Chezy coefficient. (C)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
474[1]	0.396	0.96	0.1319	0.99	0.1169	0.0844	0.640	0.0005	0.0110	83.7
475	.308	.75	.1071	.80	.1243	.0671	.627	.0005	.0116	79.5
476	.221	.54	.0729	.55	.1076	.0346	.475	.0005	.0131	64.7
477[1]	.405	.98	.1332	.99	.1125	.1305	.980	.0010	.0103	92.4
478	.293	.71	.1016	.76	.1227	.0969	.954	.0010	.0111	86.1
479	.206	.50	.0667	.50	.1031	.0448	.671	.0010	.0130	66.1
480	.134	.32	.0377	.28	.0752	.0196	.521	.0010	.0130	60.1
481[1]	.393	.95	.1314	.98	.1179	.1840	1.400	.0020	.0106	91.2
482	.317	.77	.1102	.82	.1251	.1608	1.459	.0020	.0107	92.2
483	.223	.54	.0738	.55	.1082	.0848	1.150	.0020	.0117	78.2
484	.171	.41	.0524	.39	.0907	.0466	.890	.0020	.0127	66.1
485	.126	.31	.0346	.26	.0715	.0256	.740	.0020	.0126	61.9
486[1]	.404	.98	.1331	.99	.1131	.2303	1.730	.0030	.0104	93.9
487	.310	.75	.1078	.81	.1246	.1853	1.719	.0030	.0110	88.9
488	.209	.51	.0680	.51	.1040	.0828	1.218	.0030	.0127	69.0
489	.159	.38	.0475	.36	.0859	.0404	.851	.0030	.0146	53.0
490	.119	.29	.0319	.24	.0683	.0150	.470	.0030	.0191	32.9
491[1]	.398	.96	.1323	.99	.1160	.3052	2.307	.0050	.0103	95.8
492	.278	.67	.0959	.72	.1207	.2020	2.107	.0050	.0113	85.8
493	.193	.47	.0613	.46	.0987	.1023	1.668	.0050	.0119	75.1
494	.159	.38	.0475	.36	.0859	.0622	1.310	.0050	.0130	63.2
495	.114	.27	.0301	23	.0659	.0283	.940	.0050	.0139	52.2
496[1]	.393	.95	.1314	.98	.1179	.3563	2.711	.0075	.0107	91.2
497	.316	.77	.1099	.82	.1250	.2814	2.560	.0075	.0116	83.6
498	.196	.47	.0626	.47	.0997	.1349	2.154	.0075	.0115	78.8
499	.146	.35	.0423	.32	.0805	.0748	1.767	.0075	.0117	71.9
500	.126	.31	.0346	.26	.0715	.0439	1.270	.0075	.0138	54.8
501[1]	.404	.98	.1331	.99	.1131	.4282	3.218	.0100	.0103	95.7
502	.298	.72	.1034	.77	.1233	.3105	3.003	.0100	.0114	85.5
503	.224	.54	.0742	.56	.1085	.2318	3.124	.0100	.0102	94.9
504	.195	.47	.0614	.46	.0987	.1644	2.680	.0100	.0109	85.3
505	.135	.33	.0380	.28	.0757	.0736	1.935	.0100	.0117	70.3
506[1]	.396	.96	.1319	.99	.1169	.4669	3.538	.0125	.0106	92.6
507	.312	.76	.1085	.81	.1247	.3660	3.374	.0125	.0114	85.4
508	.231	.56	.0771	.58	.1104	.2688	3.489	.0125	.0104	93.9
509	.188	.46	.0593	.44	.0970	.1892	3.189	.0125	.0102	91.6
510	.129	.31	.0357	.27	.0729	.0920	2.574	.0125	.0101	85.3
511[1]	.401	.97	.1327	.99	.1147	.5162	3.891	.0150	.0104	93.8
512	.323	.78	.1123	.84	.1254	.4565	4.065	.0150	.0107	93.8
513	.261	.63	.0892	.67	.1174	.3150	3.533	.0150	.0114	84.2
514	.176	.43	.0544	.41	.0926	.1548	2.846	.0150	.0116	76.4

6-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
515[1]	0.492	0.99	0.1937	0.99	0.1325	0.1366	0.705	0.0005	0.0111	86.6
516	.391	.79	.1637	.84	.1510	.0888	.542	.0005	.0145	62.4
517	.282	.57	.1136	.59	.1340	.0463	.408	.0005	.0164	49.8
518	.225	.45	.0853	.44	.1163	.0343	.401	.0005	.0154	52.6
519	.173	.35	.0601	.31	.0958	.0206	.343	.0005	.0152	49.6
520[1]	.484	.97	.1926	.99	.1375	.2187	1.136	.0010	.0104	96.8
521	.384	.77	.1608	.83	.1508	.1795	1.116	.0010	.0110	90.9
522	.298	.60	.1214	.63	.1379	.1070	.881	.0010	.0126	75.0
523	.222	.45	.0838	.43	.1152	.0535	.638	.0010	.0142	59.5
524	.176	.35	.0615	.32	.0971	.0295	.480	.0010	.0159	48.7
525[1]	.481	.97	.1921	.99	.1390	.3026	1.575	.0020	.0107	94.5
526	.371	.75	.1553	.80	.1498	.2378	1.531	.0020	.0115	88.5
527	.293	.59	.1190	.61	.1368	.1578	1.326	.0020	.0121	80.2
528	.216	.43	.0809	.42	.1130	.0880	1.088	.0020	.0124	72.4
529	.170	.34	.0587	.30	.0944	.0459	.783	.0020	.0142	57.0

[1] These tests used in deriving formulæ 26 and 28.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

6-INCH TILE—Continued.

1 Test No.	2 Depth of flow (*d*)	3 $\frac{d}{D}$	4 Area of flow. (*a*)	5 $\frac{a}{A}$	6 Hydraulic radius. (*R*)	7 Discharge. (*Q*)	8 Velocity. (*V*)	9 Slope. (*s*)	10 Kutter coefficient. (*n*)	11 Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
530[1]	0.489	0.98	0.1933	0.99	0.1346	0.3831	1.983	0.0030	0.0103	98.7
531	.383	.77	.1604	.83	.1507	.3177	1.981	.0030	.0111	93.1
532	.273	.55	.1091	.56	.1315	.1795	1.644	.0030	.0117	82.8
533	.222	.45	.0839	.43	.1152	.1190	1.419	.0030	.0121	76.3
534	.164	.33	.0558	.29	.0919	.0550	.985	.0030	.0137	59.4
535[1]	.480	.97	.1919	.99	.1394	.4335	2.259	.0050	.0116	85.6
536	.385	.77	.1612	.83	.1508	.3915	2.428	.0050	.0115	88.4
537	.270	.54	.1077	.56	.1307	.2082	1.934	.0050	.0126	75.7
538	.210	.42	.0779	.40	.1108	.1250	1.604	.0050	.0129	68.2
539	.151	.30	.0498	.26	.0858	.0615	1.234	.0050	.0135	59.6
540[1]	.480	.97	.1919	.99	.1394	.5874	3.061	.0075	.0108	94.7
541	.384	.77	.1608	.83	.1508	.4691	2.917	.0075	.0117	86.8
542	.272	.55	.1087	.56	.1313	.2680	2.466	.0075	.0121	78.6
543	.212	.43	.0789	.41	.1115	.1602	2.030	.0075	.0126	70.2
544	.142	.29	.0457	.24	.0816	.0633	1.383	.0075	.0139	55.9
545[1]	.473	.95	.1905	.98	.1421	.6238	3.274	.0100	.0116	86.9
546	.365	.73	.1527	.79	.1491	.4807	3.148	.0100	.0123	81.5
547	.278	.56	.1116	.58	.1329	.3186	2.854	.0100	.0123	78.3
548	.212	.43	.0789	.41	.1115	.1991	2.523	.0100	.0122	75.5
549	.144	.29	.0466	.24	.0825	.0904	1.939	.0100	.0123	67.5
550	.440	.89	.1816	.94	.1492	.6874	3.785	.0125	.0116	87.7
551	.431	.87	.1787	.92	.1500	.6818	3.815	.0125	.0114	88.1
552	.350	.70	.1460	.75	.1474	.5306	3.635	.0125	.0118	84.7
553	.264	.53	.1047	.54	.1289	.3402	3.249	.0125	.0119	80.9
554	.202	.41	.0740	.38	.1077	.2096	2.832	.0125	.0119	77.2
555	.132	.27	.0413	.21	.0767	.0706	1.709	.0125	.0139	55.2
556	.435	.88	.1800	.93	.1497	.7705	4.280	.0150	.0113	90.3
557	.352	.71	.1469	.76	.1477	.5941	4.043	.0150	.0117	85.9
558	.258	.52	.1017	.52	.1271	.3630	3.569	.0150	.0118	81.7
559	.193	.39	.0696	.36	.1041	.2325	3.339	.0150	.0111	84.5
560	.123	.25	.0874	.19	.0723	.0936	2.504	.0150	.0110	76.1

8-INCH TILE

1	2	3	4	5	6	7	8	9	10	11
561[1]	0.645	0.98	0.3389	0.99	0.1803	0.3096	0.914	0.0005	0.0109	96.2
562[1]	.642	.98	.3383	.99	.1818	.3096	.915	.0005	.0109	96.0
563	.547	.83	.3024	.89	.2002	.2873	.950	.0005	.0113	94.9
564	.479	.73	.2654	.78	.1970	.2187	.824	.0005	.0124	83.0
565	.426	.65	.2331	.68	.1893	.1957	.840	.0005	.0120	86.3
566	.319	.48	.1635	.48	.1612	.1105	.676	.0005	.0128	75.3
567	.258	.39	.1237	.36	.1389	.0720	.582	.0005	.0134	69.8
568	.180	.27	.0755	.22	.1042	.0323	.428	.0005	.0137	59.3
569[1]	.654	.99	.3402	.99	.1720	.4440	1.305	.0010	.0107	99.5
570[1]	.625	.95	.3341	.98	.1888	.4261	1.276	.0010	.0116	92.9
571	.554	.84	.3058	.90	.2000	.4104	1.342	.0010	.0115	94.9
572	.481	.73	.2666	.78	.1972	.3278	1.227	.0010	.0121	87.6
573	.428	.65	.2343	.69	.1897	.2839	1.212	.0010	.0120	88.0
574	.311	.47	.1583	.47	.1585	.1638	1.036	.0010	.0121	82.3
575	.253	.38	.1205	.35	.1368	.1130	.937	.0010	.0120	80.1
576	.177	.27	.0737	.22	.1027	.0463	.628	.0010	.0136	62.0
577[1]	.648	.98	.3394	.99	.1782	.6373	1.882	.0020	.0109	99.7
578[1]	.640	.97	.3379	.99	.1828	.6496	1.923	.0020	.0108	100.5
579	.565	.86	.3110	.91	.1994	.6035	1.940	.0020	.0113	97.2
580	.496	.75	.2752	.81	.1988	.5090	1.850	.0020	.0117	92.4
581	.448	.68	.2467	.72	.1933	.4387	1.778	.0020	.0119	90.7
582	.335	.51	.1741	.51	.1664	.2616	1.503	.0020	.0124	82.4
583	.263	.40	.1270	.37	.1409	.1602	1.260	.0020	.0128	75.1
584	.180	.27	.0755	.22	.1042	.0664	.879	.0020	.0139	60.9

[1] These tests used in deriving formulæ 26 and 28.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

8-INCH TILE—Continued.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hydraulic radius. (*R*)	Discharge. (*Q*)	Velocity. *V*	Slope. (*s*)	Kutter coefficient. (*n*)	Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
585[1]	0.643	0.98	0.3385	0.99	0.1813	0.7870	02.325	0.0030	0.0109	99.7
586[1]	.623	.95	.3334	.98	.1894	.7750	2.324	.0030	.0112	97.5
587	.553	.84	.3053	.90	.2001	.7240	2.371	.0030	.0114	96.8
588	.489	.74	.2712	.80	.1981	.6224	2.295	.0030	.0116	94.1
589	.445	.68	.2449	.72	.1928	.5440	2.221	.0030	.0118	92.4
590	.341	.52	.1780	.52	.1682	.3354	1.884	.0030	.0123	83.9
591	.262	.40	.1263	.37	.1405	.1886	1.492	.0030	.0131	72.7
592	.182	.28	.0767	.23	.1051	.0824	1.075	.0030	.0140	60.5
593[1]	.647	.98	.3392	.99	.1789	1.0105	2.979	.0050	.0109	99.6
594[1]	.628	.95	.3349	.98	.1877	1.0164	3.035	.0050	.0110	99.1
595	.623	.95	.3334	.98	.1894	.9930	2.978	.0050	.0113	96.8
596	.566	.86	.3115	.92	.1993	.9108	2.924	.0050	.0117	92.7
597	.512	.78	.2841	.83	.1999	.8028	2.825	.0050	.0121	89.4
598	.443	.67	.2437	.72	.1924	.6440	2.642	.0050	.0124	85.2
599	.318	.48	.1629	.48	.1609	.3610	2.216	.0050	.0128	78.1
600	.270	.41	.1315	.39	.1436	.2608	1.983	.0050	.0130	74.0
601	.189	.29	.0808	.24	.1085	.1140	1.411	.0050	.0141	60.6
602[1]	.647	.98	.3392	.99	.1790	1.1900	3.508	.0075	.0112	95.8
603[1]	.633	.96	.3362	.99	.1860	1.2280	3.652	.0075	.0112	97.0
604	.546	.83	.3019	.89	.2003	1.0880	3.603	.0075	.0117	93.0
605	.495	.75	.2746	.81	.1988	.9658	3.517	.0075	.0118	91.1
606	.442	.67	.2431	.71	.1922	.8204	3.375	.0075	.0120	88.9
607	.335	.51	.1741	.51	.1664	.5042	2.896	.0075	.0122	82.0
608	.260	.39	.1250	.37	.1397	.3096	2.476	.0075	.0125	76.5
609	.170	.26	.0697	.21	.0992	.1215	1.743	.0075	.0132	63.9
610[1]	.645	.98	.3389	.99	.1803	1.3580	4.007	.0100	.0114	94.4
611[1]	.642	.98	.3383	.99	.1818	1.3630	4.030	.0100	.0114	94.5
612	.559	.85	.3082	.91	.1998	1.2680	4.114	.0100	.0117	92.1
613	.464	.71	.2565	.75	.1954	1.0470	4.082	.0100	.0117	92.3
614	.415	.63	.2261	.66	.1870	.8788	3.886	.0100	.0118	89.9
615	.309	.47	.1570	.46	.1579	.5318	3.388	.0100	.0119	85.3
616	.225	.34	.1028	.30	.1250	.2899	2.820	.0100	.0120	79.8
617	.153	.23	.0601	.18	.0906	.1283	2.136	.0100	.0120	71.0
618[1]	.642	.98	.3383	.99	.1818	1.5120	4.470	.0125	.0115	93.8
619[1]	.600	.91	.3257	.96	.1950	1.4880	4.569	.0125	.0118	92.5
620	.593	.90	.3229	.95	.1962	1.4700	4.553	.0125	.0118	91.9
621	.553	.84	.3054	.90	.2001	1.4080	4.611	.0125	.0118	92.2
622	.487	.74	.2701	.79	.1979	1.2040	4.459	.0125	.0120	89.6
623	.426	.65	.2331	.68	.1893	.9928	4.260	.0125	.0121	87.6
624	.324	.49	.1668	.49	.1629	.6224	3.731	.0125	.0122	82.7
625	.244	.37	.1148	.34	.1332	.3620	3.153	.0125	.0123	77.3
626	.163	.25	.0656	.19	.0957	.1602	2.441	.0125	.0122	70.6
627[1]	.634	.96	.3365	.99	.1856	1.6450	4.889	.0150	.0116	92.7
628[1]	.616	.94	.3313	.97	.1915	1.6425	4.959	.0150	.0115	92.5
629	.545	.83	.3015	.89	.2003	1.5060	4.996	.0150	.0118	91.1
630	.482	.73	.2671	.78	.1974	1.2900	4.829	.0150	.0120	88.7
631	.414	.63	.2255	.66	.1868	1.0140	4.500	.0150	.0122	85.0
632	.323	.49	.1662	.49	.1626	.6524	3.926	.0150	.0126	79.5
633	.245	.37	.1155	.34	.1336	.3925	3.399	.0150	.0123	75.9
634	.165	.25	.0668	.19	.0967	.1879	2.813	.0150	.0120	73.9

10-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
635[1]	0.818	0.99	0.5366	0.99	0.2213	0.4818	0.898	0.0005	0.0125	85.4
636[1]	.783	.95	.5265	.98	.2379	.5150	.978	.0005	.0122	89.7
637	.739	.89	.5068	.94	.2475	.5114	1.009	.0005	.0122	90.7
638	.706	.85	.4887	.91	.2508	.4910	1.005	.0005	.0123	89.7
639	.666	.81	.4638	.86	.2518	.4429	.955	.0005	.0128	85.1
640	.616	.75	.4293	.80	.2491	.4324	1.007	.0005	.0122	90.3
641	.579	.70	.4018	.75	.2451	.4188	1.042	.0005	.0118	94.1
642	.551	.67	.3803	.71	.2408	.3660	.962	.0005	.0124	87.7
643	.474	.57	.3186	.59	.2243	.2780	.873	.0005	.0129	82.4
644	.416	.50	.2708	.50	.2076	.2408	.889	.0005	.0122	87.3
645	.323	.39	.1944	.36	.1741	.1470	.756	.0005	.0123	81.1
646	.241	.29	.1302	.24	.1380	.0832	.639	.0005	.0122	77.0

[1] These tests used in deriving formulæ 26 and 28.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

10-INCH TILE—Continued.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hydraulic radius. (*R*)	Discharge. (*Q*)	Velocity. (*V*)	Slope. (*s*)	Kutter coefficient. (*n*)	Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
647[1]	0.814	0.98	0.5357	0.99	0.2241	0.7240	1.351	0.0010	0.0121	90.3
648[1]	.811	.98	.5351	.99	.2262	.7510	1.403	.0010	.0119	93.3
649[1]	.789	.95	.5286	.98	.2360	.7780	1.472	.0010	.0117	95.8
650	.739	.89	.5068	.94	.2475	.7615	1.503	.0010	.0119	95.5
651	.710	.86	.4910	.91	.2505	.7360	1.499	.0010	.0120	94.8
652	.670	.81	.4664	.87	.2519	.6930	1.486	.0010	.0121	93.6
653	.617	.75	.4300	.80	.2493	.6278	1.460	.0010	.0121	92.5
654	.593	.72	.4124	.77	.2466	.5954	1.444	.0010	.0122	91.9
655	.557	.67	.3850	.72	.2419	.5354	1.391	.0010	.0124	89.4
656	.486	.59	.3283	.61	.2273	.4462	1.359	.0010	.0122	90.1
657	.423	.51	.2766	.51	.2097	.3650	1.320	.0010	.0119	91.1
658	.322	.39	.1936	.36	.1736	.1998	1.032	.0010	.0128	78.3
659	.238	.29	.1280	.24	.1366	.1110	.868	.0010	.0126	74.3
660[1]	.813	.98	.5355	.99	.2248	1.1160	2.084	.0020	.0114	98.3
661[1]	.798	.97	.5316	.99	.2326	1.1020	2.073	.0020	.0117	96.1
662[1]	.797	.96	.5313	.99	.2330	1.1360	2.138	.0020	.0115	99.1
663	.738	.89	.5063	.94	.2476	1.0960	2.165	.0020	.0118	97.3
664	.708	.86	.4899	.91	.2506	1.0600	2.164	.0020	.0119	96.7
665	.667	.81	.4644	.86	.2518	1.0105	2.176	.0020	.0119	97.0
666	.621	.75	.4329	.81	.2497	.9448	2.183	.0020	.0118	97.7
667	.594	.72	.4132	.77	.2467	.8639	2.091	.0020	.0121	94.1
668	.561	.68	.3881	.72	.2425	.7996	2.060	.0020	.0121	93.6
669	.483	.58	.3259	.61	.2265	.6251	1.918	.0020	.0123	90.2
670	.439	.53	.2898	.54	.2145	.5186	1.790	.0020	.0125	86.4
671	.429	.52	.2815	.52	.2115	.4982	1.770	.0020	.0125	86.0
672	.343	.41	.2106	.39	.1819	.3250	1.543	.0020	.0127	80.9
673	.248	.30	.1355	.25	.1413	.1437	1.060	.0020	.0145	63.1
674[1]	.813	.98	.5356	.99	.2248	1.3400	2.502	.0030	.0117	96.3
675[1]	.810	.98	.5349	.99	.2267	1.3380	2.502	.0030	.0117	95.9
676[1]	.790	.95	.5290	.98	.2356	1.3800	2.609	.0030	.0116	98.1
677	.740	.89	.5073	.94	.2473	1.3450	2.651	.0030	.0118	97.3
678	.715	.86	.4939	.92	.2501	1.3280	2.689	.0030	.0117	98.2
679	.663	.80	.4619	.86	.2517	1.2360	2.676	.0030	.0118	97.4
680	.636	.77	.4435	.83	.2508	1.1800	2.661	.0030	.0119	97.0
681	.598	.72	.4161	.77	.2472	1.0760	2.584	.0030	.0120	95.0
682	.554	.67	.3827	.71	.2413	.9586	2.505	.0030	.0122	93.1
683	.498	.60	.3381	.63	.2300	.8092	2.393	.0030	.0123	91.1
684	.436	.53	.2873	.53	.2136	.6332	2.205	.0030	.0125	87.1
685	.339	.41	.2074	.39	.1804	.3791	1.828	.0030	.0130	78.6
686	.243	.29	.1317	.25	.1390	.1853	1.407	.0030	.0136	68.9
687[1]	.805	.97	.5336	.99	.2294	1.7650	3.308	.0050	.0116	97.7
688[1]	.804	.97	.5333	.99	.2299	1.7350	3.253	.0050	.0118	96.0
689[1]	.789	.95	.5287	.98	.2360	1.7350	3.282	.0050	.0119	95.6
690	.741	.90	.5078	.95	.2471	1.7300	3.407	.0050	.0119	96.9
691	.704	.85	.4875	.91	.2509	1.6825	3.451	.0050	.0119	97.5
692	.678	.82	.4716	.88	.2518	1.6250	3.446	.0050	.0119	97.2
693	.623	.75	.4343	.81	.2498	1.4800	3.408	.0050	.0120	96.4
694	.586	.71	.4072	.76	.2458	1.3450	3.303	.0050	.0121	94.2
695	.562	.68	.3889	.72	.2427	1.2480	3.209	.0050	.0123	92.1
696	.492	.60	.3332	.62	.2286	.9930	2.980	.0050	.0126	88.1
697	.420	.51	.2741	.51	.2088	.7345	2.680	.0050	.0129	82.9
698	.338	.41	.2066	.38	.1800	.4934	2.388	.0050	.0129	79.6
699	.231	.28	.1227	.23	.1332	.2222	1.810	.0050	.0133	70.2
700[1]	.793	.96	.5300	.99	.2346	1.7600	3.321	.0050	.0117	97.0
701[1]	.785	.95	.5272	.98	.2373	1.7400	3.300	.0050	.0119	95.8
702[1]	.772	.93	.5222	.97	.2411	1.7175	3.289	.0050	.0120	94.7
703	.729	.88	.5016	.93	.2488	1.7100	3.409	.0050	.0119	96.7
704	.686	.83	.4766	.89	.2516	1.6250	3.410	.0050	.0120	96.1
705	.621	.75	.4329	.81	.2497	1.4840	3.428	.0050	.0119	97.0
706	.593	.72	.4124	.77	.2466	1.3400	3.249	.0050	.0123	92.5
707	.566	.68	.3919	.73	.2434	1.2460	3.179	.0050	.0124	91.1
708	.499	.60	.3389	.63	.2302	.9949	2.936	.0050	.0128	86.5
709	.421	.51	.2749	.51	.2091	.7315	2.661	.0050	.0130	82.0
710	.341	.41	.2090	.39	.1812	.4887	2.338	.0050	.0132	77.7
711	.232	.28	.1235	.23	.1337	.2236	1.811	.0050	.0134	70.3

[1] These tests used in deriving formulæ 26 and 28.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

10-INCH TILE—Continued.

1	1	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hy-draulic radius. (*R*)	Dis-charge. (*Q*)	Ve-locity. (*V*)	Slope. (*s*)	Kutter coeffi-cient- (*n*)	Chezy coeffi-cient. (*C*)
	Feet.		*Sq.ft.*		*Feet.*	*Cu.ft. per sec.*	*Feet per sec.*			
712[1]	0.806	0.97	0.5338	0.99	0.2288	2.1150	3.962	0.0075	0.0118	95.7
713[1]	.800	.97	.5322	.99	.2317	2.0900	3.927	.0075	.0120	94.2
714[1]	.779	.94	.5250	.98	.2392	2.0850	3.972	.0075	.0121	93.8
715	.726	.88	.5000	.93	.2491	2.0560	4.112	.0075	.0121	95.2
716	.718	.87	.4956	.92	.2498	2.0440	4.125	.0075	.0120	95.3
717	.659	.80	.4592	.85	.2616	1.8870	4.110	.0075	.0121	94.6
718	.627	.76	.4371	.81	.2501	1.7700	4.050	.0075	.0122	93.5
719	.570	.69	.3950	.74	.2440	1.5120	3.828	.0075	.0126	89.5
720	.541	.65	.3724	.69	.2389	1.3800	3.706	.0075	.0128	87.5
721	.487	.59	.3291	.61	.2275	1.1560	3.512	.0075	.0129	85.0
722	.408	.49	.2642	.49	.2050	.8044	3.045	.0075	.0136	77.7
723	.323	.39	.1944	.36	.1740	.5306	2.729	.0075	.0133	75.5
724	.224	.27	.1176	.22	.1299	.2600	2.211	.0075	.0131	70.9
725[1]	.792	.96	.5297	.99	.2349	2.4060	4.542	.0100	.0121	93.7
726[1]	.791	.96	.5294	.99	.2353	2.4210	4.574	.0100	.0120	94.3
727	.681	.82	.4735	.88	.2517	2.2080	4.663	.0100	.0123	92.9
728	.624	.75	.4350	.81	.2499	2.0560	4.727	.0100	.0122	94.6
729	.618	.75	.4307	.80	.2493	2.0050	4.655	.0100	.0123	93.2
730	.595	.72	.4139	.77	.2468	1.8840	4.552	.0100	.0124	91.6
731	.553	.67	.3819	.71	.2411	1.6450	4.308	.0100	.0128	87.7
732	.489	.59	.3308	.62	.2280	1.3750	4.157	.0100	.0127	87.1
733	.405	.49	.2616	.49	.2040	.9930	3.795	.0100	.0128	84.0
734	.327	.40	.1976	.37	.1756	.6238	3.156	.0100	.0134	75.3
735	.207	.25	.1052	.20	.1214	.2318	2.203	.0100	.0141	63.2
736[1]	.810	.98	.5349	.99	.2267	2.7040	5.055	.0125	.0119	95.0
737[1]	.809	.98	.5346	.99	.2273	2.7220	5.092	.0125	.0118	95.5
738[1]	.805	.97	.5336	.99	.2294	2.6890	5.040	.0125	.0120	94.1
739	.742	.90	.5083	.95	.2470	2.6800	5.272	.0125	.0121	94.9
740	.701	.85	.4857	.90	.2511	2.5920	5.336	.0125	.0121	95.2
741	.700	.85	.4852	.90	.2511	2.5920	5.343	.0125	.0121	95.4
742	.664	.80	.4625	.86	.2517	2.4660	5.332	.0125	.0121	95.1
743	.611	.74	.4257	.79	.2486	2.2410	5.265	.0125	.0122	94.5
744	.569	.69	.3942	.73	.2438	2.0000	5.073	.0125	.0124	91.9
745	.543	.66	.3740	.70	.2393	1.8840	5.037	.0125	.0123	92.1
746	.463	.56	.3096	.58	.2213	1.4620	4.725	.0125	.0123	89.8
747	.412	.50	.2674	.50	.2063	1.2360	4.622	.0125	.0120	91.0
748	.314	.38	.1872	.35	.1704	.7000	3.739	.0125	.0126	81.0
749	.213	.26	.1096	.20	.1244	.3260	2.983	.0125	.0124	75.6
750[1]	.781	.94	.5257	.98	.2386	2.8840	5.486	.0150	.0123	91.7
751	.624	.75	.4350	.81	.2499	2.4540	5.641	.0150	.0124	92.1
752	.421	.51	.2749	.51	.2091	1.3820	5.030	.0150	.0122	89.8

12-INCH TILE.

753[1]	0.985	0.99	0.7712	0.99	0.2587	0.9125	1.183	0.0005	0.0110	104.1
754	.943	.95	.7581	.98	.2836	.8938	1.179	.0005	.0117	99.0
755	.889	.90	.7299	.95	.2960	.8672	1.188	.0005	.0119	97.6
756	.845	.85	.7011	.91	.3006	.8492	1.211	.0005	.0118	98.8
757	.782	.79	.6532	.85	.3014	.7540	1.154	.0005	.0123	94.1
758	.756	.76	.6317	.82	.3001	.6986	1.106	.0005	.0127	90.3
759	.691	.70	.5745	.74	.2933	.6496	1.131	.0005	.0123	93.4
760	.643	.65	.5298	.69	.2854	.6062	1.144	.0005	.0120	95.8
761	.580	.59	.4692	.61	.2717	.4982	1.062	.0005	.0124	91.1
762	.534	.54	.4240	.55	.2594	.4485	1.058	.0005	.0120	92.9
763	.511	.52	.4012	.52	.2526	.4083	1.018	.0005	.0123	90.6
764	.364	.37	.2570	.33	.1991	.2152	.837	.0005	.0123	83.9
765	.275	.28	.1747	.23	.1588	.1120	.641	.0005	.0132	72.0

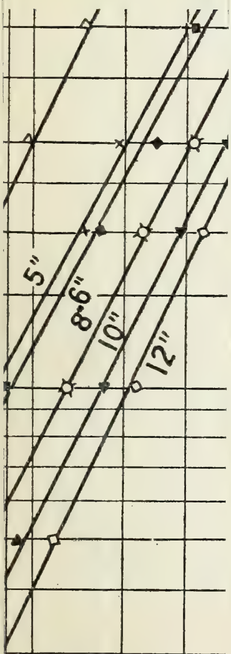
[1] These tests used in deriving formulæ 26 and 28.

TABLE 4.—*Elements of experiments for concrete tile*—Continued.

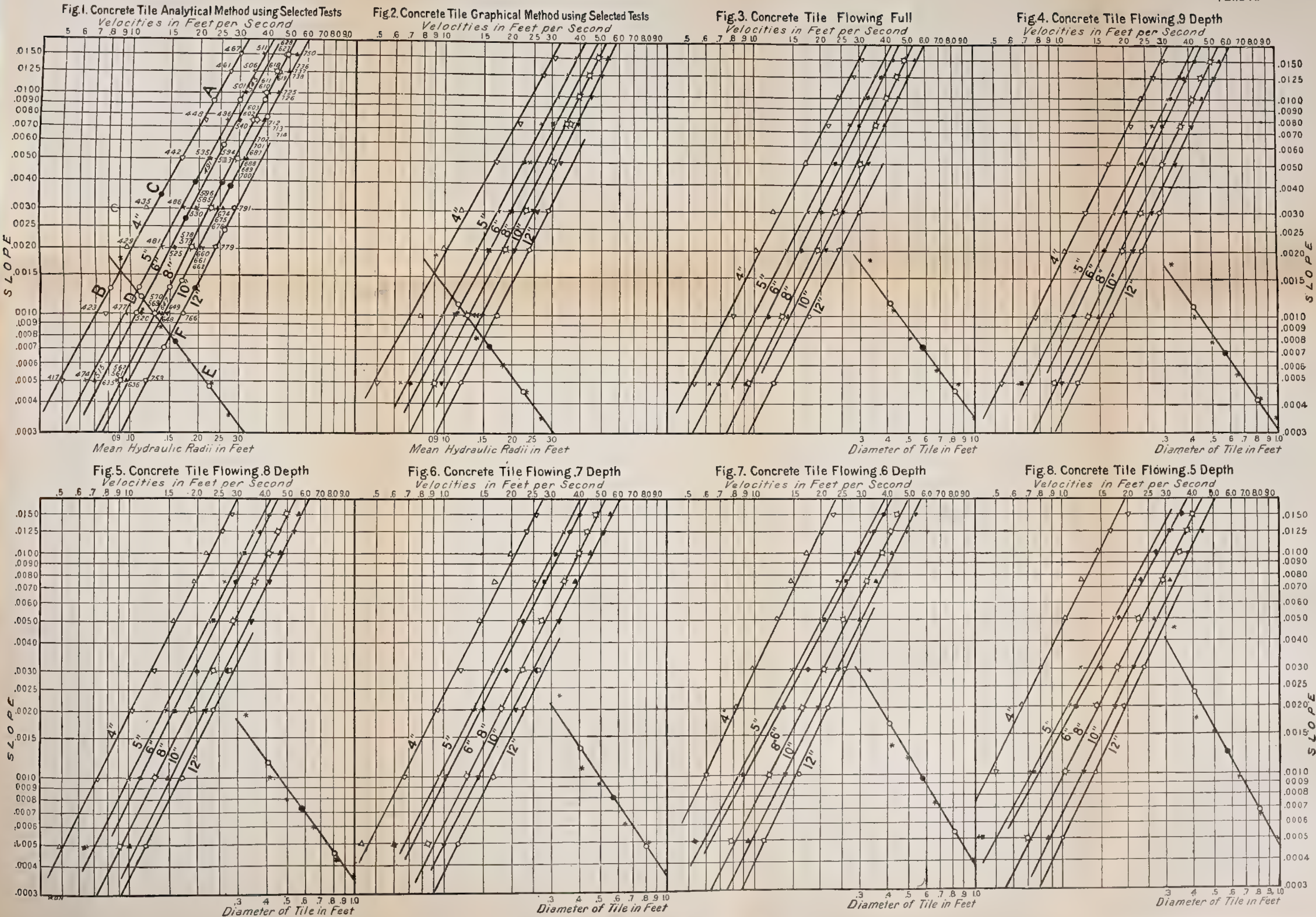
12-INCH TILE.

1 Test No.	2 Depth of flow. (*d*)	3 $\frac{d}{D}$	4 Area of flow. (*a*)	5 $\frac{a}{A}$	6 Hydraulic radius. (*R*)	7 Discharge. (*Q*)	8 Velocity. (*V*)	9 Slope. (*s*)	10 Kutter coefficient. (*n*)	11 Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
766 [1]	0.953	0.96	0.7623	9.99	0.2801	1.3180	1.729	0.0010	0.0115	103.3
767	.950	.96	.7610	.99	.2812	1.2980	1.706	.0010	.0116	101.7
768	.880	.89	.7244	.94	.2974	1.2460	1.720	.0010	.0119	99.8
769	.831	.84	.6910	.90	.3013	1.1900	1.722	.0010	.0120	99.2
770	.774	.78	.6467	.84	.3012	1.0920	1.689	.0010	.0122	97.3
771	.741	.75	.6189	.80	.2989	1.0164	1.642	.0100	.0124	95.0
772	.680	.69	.5645	.73	.2919	.9312	1.650	.0010	.0121	96.6
773	.631	.64	.5184	.67	.2828	.8492	1.638	.0010	.0120	97.4
774	.581	.59	.4701	.61	.2720	.7255	1.543	.0010	.0123	93.6
775	.531	.54	.4211	.55	.2585	.6278	1.491	.0010	.0122	92.7
776	.471	.47	.3616	.47	.2397	.5114	1.414	.0010	.0122	91.4
777	.360	.36	.2532	.33	.1974	.3018	1.192	.0010	.0124	84.8
778	.259	.26	.1606	.21	.1509	.1443	.898	.0010	.0131	73.1
779 [1]	.960	.97	.7647	.99	.2771	1.8400	2.406	.0020	.0116	102.2
780	.924	.93	.7492	.97	.2893	1.7525	2.339	.0020	.0121	97.3
781	.844	.85	.7003	.91	.3007	1.6575	2.367	.0020	.0123	96.5
782	.773	.78	.6459	.84	.3011	1.5350	2.377	.0020	.0123	96.9
783	.728	.73	.6077	.79	.2974	1.4160	2.331	.0020	.0124	95.6
784	.673	.68	.5580	.72	.2908	1.2520	2.244	.0020	.0126	93.1
785	.634	.64	.5213	.68	.2834	1.1300	2.168	.0020	.0128	91.1
786	.573	.58	.4623	.60	.2700	.9838	2.128	.0020	.0126	91.6
787	.527	.53	.4170	.54	.2574	.8364	2.006	.0020	.0129	88.4
788	.470	.47	.3606	.47	.2393	.6804	1.887	.0020	.0128	86.3
789	.352	.36	.2456	.32	.1940	.3820	1.556	.0020	.0132	79.0
790	.254	.26	.1563	.20	.1484	.1821	1.165	.0020	.0139	67.6
791 [1]	.963	.97	.7657	.99	.2757	2.2470	2.935	.0030	.0116	102.1
792	.932	.94	.7532	.98	.2872	2.1660	2.876	.0030	.0121	98.0
793	.690	.70	.5735	.74	.2932	1.5180	2.647	.0030	.0130	89.3
794	.606	.61	.4944	.64	.2776	1.2800	2.589	.0030	.0128	89.7
795	.573	.58	.4623	.60	.2700	1.1800	2.552	.0030	.0129	89.7
796	.526	.53	.4161	.54	.2571	1.0183	2.448	.0030	.0128	88.2
797	.463	.47	.3536	.46	.2370	.8172	2.311	.0030	.0128	86.7
798	.371	.37	.2637	.34	.2020	.5186	1.967	.0030	.0132	79.9
799	.254	.26	.1563	.20	.1484	.2333	1.493	.0030	.0134	70.8
800	.741	.75	.6189	.80	.2988	2.2920	3.704	.0050	.0124	95.8
801	.641	.65	.5279	.68	.2849	1.9170	3.631	.0050	.0122	96.2
802	.613	.62	.5012	.65	.2791	1.7800	3.552	.0050	.0124	95.1
803	.569	.57	.4584	.59	.2690	1.5760	3.438	.0050	.0124	93.8
804	.534	.54	.4240	.55	.2594	1.3750	3.243	.0050	.0127	90.1
805	.485	.49	.3754	.49	.2444	1.1880	3.165	.0050	.0124	90.5
806	.391	.39	.2830	.37	.2102	.7900	2.792	.0050	.0125	86.1
807	.284	.29	.1827	.24	.1631	.4600	2.518	.0050	.0117	88.2
808	.628	.63	.5156	.67	.2822	1.9700	3.821	.0075	.0138	83.1
809	.530	.53	.4200	.54	.2582	1.5900	3.786	.0075	.0131	86.0
810	.453	.46	.3437	.45	.2335	1.2320	3.585	.0075	.0129	85.7
811	.375	.38	.2675	.35	.2036	.8573	3.205	.0075	.0129	82.0
812	.322	.32	.2174	.28	.1808	.5954	2.739	.0075	.0136	74.1
813	.521	.53	.4111	.53	.2556	1.7150	4.172	.0100	.0136	82.5
814	.520	.52	.4101	.53	.2553	1.7425	4.249	.0100	.0134	84.1
815	.478	.48	.3685	.48	.2420	1.4960	4.060	.0100	.0134	82.5
816	.359	.36	.2523	.33	.1970	.9040	3.584	.0100	.0131	80.7
817	.324	.33	.2193	.28	.1817	.6846	3.123	.0100	.0138	73.3
818	.523	.53	.4131	.54	.2517	2.0080	4.860	.0125	.0130	86.6
819	.454	.46	.3447	.45	.2339	1.5900	4.613	.0125	.0130	85.3
820	.354	.36	.2475	.32	.1949	1.0420	4.211	.0125	.0125	85.3
821	.302	.30	.1990	.26	.1716	.8010	4.026	.0125	.0120	86.9
822	.482	.49	.3725	.48	.2433	1.9780	5.310	.0150	.0128	87.9
823	.399	.40	.2908	.38	.2133	1.4080	4.843	.0150	.0127	85.6
824	.301	.30	.1981	.26	.1711	.8510	4.295	.0150	.0122	84.8

[1] These tests used in deriving formulæ 26 and 28.



CONCRETE TILE.



Curves Used in the Derivation of Formulæ for Concrete Tile.

TABLE 5.—*Elements of experiments for clay tile poorly laid.*

10-INCH TILE.

1	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (*d*)	$\frac{d}{D}$	Area of flow. (*a*)	$\frac{a}{A}$	Hydraulic radius. (*R*)	Discharge. (*Q*)	Velocity. (*V*)	Slope. (*s*)	Kutter coefficient. (*n*)	Chezy coefficient. (*C*)
	Feet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
825	0.805	0.96	0.5423	0.99	0.2355	0.5342	0.985	0.0005	0.0120	90.8
826	.795	.95	.5389	.98	.2391	.5679	1.054	.0005	.0116	96.4
827	.708	.85	.4957	.90	.2537	.5465	1.103	.0005	.0116	97.9
828	.625	.75	.4401	.80	.2520	.4934	1.121	.0005	.0114	99.9
829	.524	.63	.3621	.66	.2368	.3780	1.044	.0005	.0116	96.0
830	.429	.51	.2837	.51	.2124	.2924	1.031	.0005	.0109	100.0
831	.313	.37	.1876	.34	.1704	.1602	.854	.0005	.0111	92.5
832	.214	.25	.1110	.20	.1251	.0744	.671	.0005	.0111	81.8
833	.836	1.00	.5489	1.00	.2090	.5102	.929	.0005	.0117	90.9
834	.791	.95	.5374	.98	.2405	.5390	1.003	.0005	.0120	91.5
835	.712	.85	.4981	.91	.2535	.5222	1.048	.0005	.0120	93.1
836	.620	.74	.4365	.80	.2514	.4772	1.093	.0005	.0116	97.5
837	.532	.64	.3685	.67	.2385	.4093	1.111	.0005	.0111	101.7
838	.417	.50	.2736	.50	.2087	.2737	1.000	.0005	.0111	97.9
839	.311	.37	.1860	.34	.1696	.1620	.871	.0005	.0109	94.6
840	.227	.27	.1206	.22	.1315	.0780	.647	.0005	.0117	79.8
841	.831	.99	.5484	.99	.2173	.7510	1.370	.0010	.0118	92.9
842	.799	.96	.5403	.98	.2378	.7964	1.474	.0010	.0118	95.6
843	.697	.83	.4890	.89	.2541	.7855	1.607	.0010	.0115	100.8
844	.628	.75	.4423	.81	.2523	.7180	1.624	.0010	.0113	102.2
845	.547	.65	.3806	.69	.2415	.6089	1.600	.0010	.0111	103.0
846	.422	.51	.2778	.51	.2103	.4114	1.481	.0010	.0109	102.1
847	.324	.39	.1966	.36	.1749	.2656	1.351	.0010	.0105	102.2
848	.234	.28	.1257	.23	.1349	.1393	1.108	.0010	.0105	95.4
849	.835	1.00	.5488	1.00	.2106	.7570	1.379	.0010	.0115	95.0
850	.786	.94	.5355	.98	.2421	.7720	1.442	.0010	.0121	92.7
851	.697	.83	.4890	.89	.2541	.7300	1.493	.0010	.0121	93.7
852	.619	.74	.4357	.79	.2513	.6720	1.542	.0010	.0117	97.3
853	.537	.64	.3726	.68	.2395	.5465	1.467	.0010	.0119	94.8
854	.433	.52	.2870	.52	.2136	.3720	1.296	.0010	.0122	88.7
855	.338	.40	.2080	.38	.1805	.2222	1.068	.0010	.0128	79.5
856	.221	.26	.1161	.21	.1285	.0768	.662	.0010	.0149	58.4

12-INCH TILE.

857	0.951	0.96	0.7546	0.99	0.2769	0.9193	1.218	0.0005	0.0112	103.5
858	.877	.89	.7173	.94	.2954	.8396	1.171	.0005	.0121	96.3
859	.731	.74	.6068	.80	.2965	.6468	1.066	.0005	.0130	87.6
860	.643	.65	.5272	.69	.2844	.5342	1.013	.0005	.0132	85.0
861	.559	.57	.4466	.59	.2657	.4335	.971	.0005	.0131	84.2
862	.463	.47	.3521	.46	.2365	.2814	.799	.0005	.0141	73.5
863	.373	.38	.2646	.35	.2025	.1512	.571	.0005	.0166	56.8
864	.916	.93	.7392	.97	.2882	1.2640	1.710	.0010	.0117	100.7
865	.789	.80	.6548	.86	.2999	1.0450	1.596	.0010	.0126	92.2
866	.691	.70	.5714	.75	.2921	.8492	1.486	.0010	.0132	87.0
867	.594	.60	.4806	.63	.2742	.6197	1.289	.0010	.0142	77.9
868	.483	.49	.3719	.49	.2432	.3760	1.011	.0010	.0159	64.8
869	.386	.39	.2771	.36	.2078	.2019	.729	.0010	.0186	50.6
870	.972	.99	.7609	.99	.2654	1.7125	2.251	.0020	.0119	97.7
871	.926	.94	.7442	.98	.2856	1.6750	2.251	.0020	.0124	94.2
872	.799	.81	.6626	.87	.3000	1.3940	2.104	.0020	.0135	85.9
873	.664	.67	.5469	.72	.2882	1.0125	1.851	.0020	.0147	77.1
874	.573	.58	.4602	.60	.2692	.7435	1.616	.0020	.0156	69.7
875	.470	.48	.3591	.47	.2389	.4634	1.291	.0020	.0171	59.1
876	.368	.37	.2599	.34	.2005	.2363	.909	.0020	.0200	45.4
877	.782	.79	.6493	.85	.2997	1.6475	2.538	.0030	.0136	84.6
878	.672	.68	.5542	.73	.2896	1.2700	2.293	.0030	.0145	77.8
879	.557	.57	.4447	.58	.2651	.8332	1.874	.0030	.0161	66.5
880	.457	.46	.3462	.45	.2344	.5174	1.495	.0030	.0177	56.4
881	.360	.37	.2522	.33	.1973	.2737	1.085	.0030	.0202	44.6

TABLE 5.—*Elements of experiments for clay tile poorly laid*—Continued.

12-INCH TILE—Continued.

2	2	3	4	5	6	7	8	9	10	11
Test No.	Depth of flow. (d)	$\frac{d}{D}$	Area of flow. (a)	$\frac{a}{A}$	Hydraulic radius. (E)	Discharge. (Q)	Velocity. (V)	Slope. (s)	Kutter coefficieno. (n)	Chezy coefficient. (C)
	Neet.		*Sq. ft.*		*Feet.*	*Cu. ft. per sec.*	*Feet per sec.*			
882	0.756	0.77	0.6280	0.82	0.2987	1.8025	2.870	0.0050	0.0152	74.3
883	.636	.65	.5207	.68	.2830	1.2980	2.493	.0050	.0164	66.3
884	.549	.56	.4368	.57	.2630	.9820	2.248	.0050	.0170	62.0
885	.450	.46	.3394	.45	.2320	.5887	1.735	.0050	.0191	50.9
886	.356	.36	.2485	.33	.1955	.3231	1.300	.0050		41.6
887	.929	.94	.7455	.98	.2847	2.8640	3.842	.0075	.0137	83.1
888	.849	.86	.6991	.92	.2982	2.5800	3.691	.0075	.0146	78.0
889	.709	.72	.5877	.77	.2941	2.1360	3.635	.0075	.0147	77.4
890	.700	.71	.5796	.76	.2931	2.0380	3.516	.0075	.0150	75.0
891	.638	.65	.5225	.69	.2834	1.7350	3.321	.0075	.0154	72.0
892	.519	.53	.4073	.53	.2544	1.0260	2.519	.0075	.0178	57.7
893	.428	.43	.3178	.42	.2240	.6265	1.972	.0075	.0198	48.1

NOTE: Nos. 825 to 832, inclusive, 841 to 848, inclusive, and 857 to 893, inclusive; grade of flume uniform. Nos. 833 to 840, inclusive, and 849 to 856, inclusive; grade of flume undulating.

DISCUSSION OF COMPUTATIONS.

All of the formulæ derived herein are of the exponential type since this seems to be the only form capable of representing the data. It seemed most natural to determine first the relation of velocity to slope, other elements being unchanged. In using for this purpose the same line of tile without disturbing the joints, the most uncertain element in tile observations was removed. The chief remaining difficulty lay in the observations of depth of flow, to secure a constant value for comparison at different slopes. When, for a given size of tile and constant depth of flow, slopes are plotted logarithmically as ordinates against their corresponding velocities as abscissæ, the resulting points are approximately on a straight line. The equation of such a line is of the form,

$$s = mV^z \tag{14}$$

which in logarithmic terms may be written,

$$\log s = \log m + z \log V \tag{15}$$

where m is the intercept on the unity vertical axis, and z is the slope of the line, i. e., the tangent of the angle which it makes with the axis of V.

For several different sizes of tile of the same material, the values of m follow the equation,

$$m = eD^x \tag{16}$$

Substituting in formula 14,

$$s = eD^x V^z \tag{17}$$

This expressed in logarithmic terms is

$$\log s = \log e + x \log D + z \log V \tag{18}$$

FORMULÆ FOR TILE FLOWING FULL.

In deriving the various formulæ, both analytical and graphical methods were used in order to insure accuracy. Figure 1 of Plate X shows the results obtained by the analytical method for the concrete tile. This diagram was obtained by plotting the velocities of all the selected experiments in Table 4[1] against their respective slopes. The centers of gravity of the various points for each size of tile were plotted, after being calculated as outlined below. Straight lines were drawn through these centers of gravity for each size. Thus a series of approximately parallel lines was obtained. It should be noted that in using the analytical method, equal weight is given to the least velocity and the greatest velocity. The slopes and intercepts of each of the lines on this diagram were determined analytically.

The following description gives the methods of derivation. Taking the experiments in which the tile were approximately full, shown in Table 4,[1] the center of gravity of all the points belonging to any one size of tile was determined as follows: The antilogarithm of the mean value of the logarithms of the various velocities gave the velocity coordinate of the center of gravity; the slope coordinate of the center of gravity was found in a similar manner. This point, C, shown by a solid circle (Pl. X, fig. 1), divides the plotted points into two groups. The center of gravity of the two groups separated by the principal center of gravity must also be found. These points, A and B, are shown by open circles. Having these two points, the equation of the line for that particular size of tile and depth of flow can be readily determined, as shown by the following sample calculation for 4-inch concrete tile:

Let C = center of gravity of the whole group.
A = center of gravity of the part of the group above C.
B = center of gravity of the part of the group below C.

[1] The serial numbers of these selected experiments are indicated in Tables 3 and 4.

Let C_v, A_v, B_v, and C_s, A_s, B_s, be the V and s coordinates, respectively, of the above centers of gravity. The calculations for these coordinates are as follows:

No.	V.	s.	Log V.		Log s.	
417	0.5041	0.0005	9.702517	Sum=39.672744	6.698970	Sum=28.477121
423	.7847	.0010	9.894704	Mean=9.918186= B_v	7.000000	Mean=7.119280= B_s
429	.9884	.0020	9.994933	Antilog B_v=0.8283	7.301030	Antilog B_s=0.0013181
435	1.204	.0030	10.080590		7.477121	
442	1.697	.005	10.229682	Sum=41.493438	7.698970	Sum=31.847032
448	2.1676	.0075	10.335979	Mean=10.373359= A_v	7.875061	Mean=7.961758= A_s
461	2.7711	.0125	10.442652	Antilog A_v=2.3624	8.096910	Antilog A_s=0.0091571
467	3.0558	.0150	10.485125		8.176091	
			Sum=81.166182 Mean=10.1457727= C_v Antilog C_v=1.39885		Sum=60.324153 Mean=7.540519= Cs Antilog Cs=0.0034715	

$$A_v - C_v = 10.373359 - 10.1457727 = 0.227586$$
$$C_v - B_v = 10.1457727 - 9.918186 = .227587$$
$$A_s - C_s = 7.961758 - 7.540519 = .421239$$
$$C_s - B_s = 7.540519 - 7.119280 = .421239$$

Since

$$\frac{A_v - C_v}{C_v - B_v} = \frac{A_s - C_s}{C_s - B_s}$$

the three points, A, C, and B are in a straight line, which checks the accuracy of the work (see American Civil Engineers' Pocketbook, second edition, p. 848).

The exponent, z, of V in formula 14, is the inclination of the line ACB, and is equal to the tangent of the angle formed by the line and the unity axis of V.

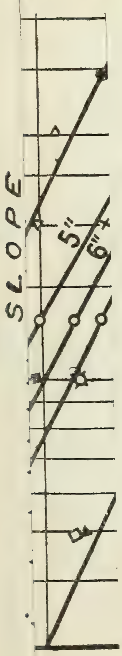
$$\frac{A_s - B_s}{A_v - B_v} = \frac{0.842478}{0.455173} = 1.8509 = z$$

The intercept, m, is determined as follows from equation 15, using the coordinates of the center of gravity, C:

$$\text{Log } m = \log s - z \log V \qquad (19)$$
$$= C_s - z\, C_v$$
$$= 7.540519 - 1.8509 \times 10.1457727 = 7.270709$$

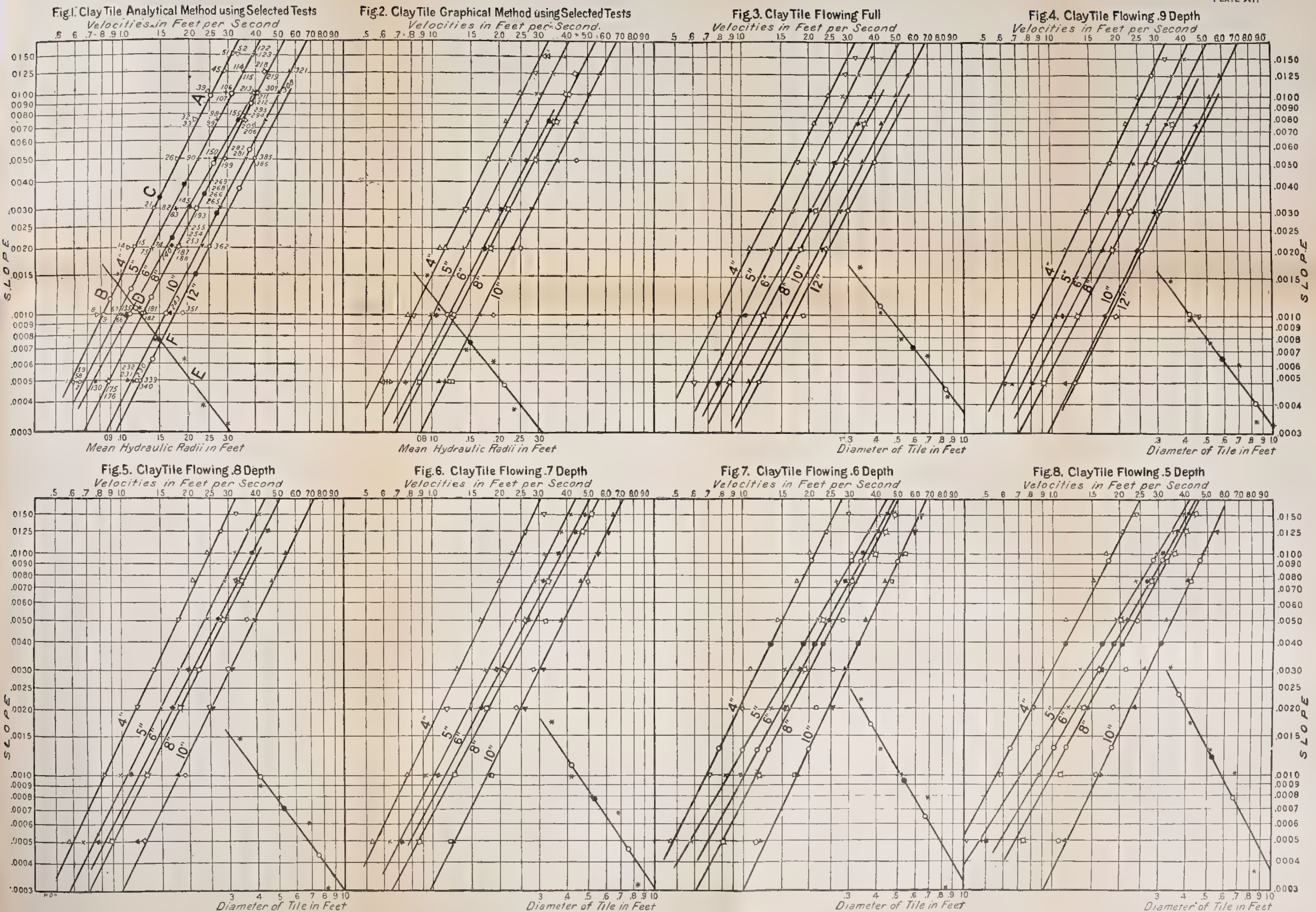
and $m = 0.0018651$.

The exponent of V and the value of m are found in the same manner for the other sizes of both concrete and clay tile, running nearly full. These values are shown in column 7 of Table 6. This table gives the formula derived as explained above for each size of tile as well as the range of velocities used in the derivation.



FOR CLAY

PLATE XI.



CURVES USED IN THE DERIVATION OF FORMULÆ FOR CLAY TILE.

TABLE 6.—*Individual tile formulæ and revised intercept values.*

1	2	3	4	5	6	7	8
Tile.				Velocity.	Number of observations.	Formulæ derived separately for each tile size.	Revised intercept values m'.
Kind.	Nominal size.	Actual average diameter.	Area of bore.				
	Inches.	*Feet.*	*Sq. feet.*	*Feet per second.*			
Hard-burned clay	4	0.3398	0.0907	0.607 to 3.328	14	$s=0.0014797\ V^{2.0326}$	0.0015185
Do	5	.4193	.1381	.634 to 4.030	17	$s=.0010494\ V^{1.9729}$	.0010524
Soft-burned clay	6	.5184	.2111	.765 to 3.368	6	$s=.000819\ V^{1.8321}$	.000761
Hard-burned clay	8	.685	.3685	.893 to 4.423	15	$s=.000617\ V^{1.9914}$	.0006297
Vitrified	10	.836	.5489	1.168 to 5.717	18	$s=.000384\ V^{1.9918}$	.0003927
Do	12	.9857	.7631	1.176 to 4.002	6	$s=.0003185\ V^{1.9907}$	.0003241
Concrete	4	.3280	.0845	.504 to 3.056	8	$s=.0018651\ V^{1.8509}$	.0017954
Do	5	.4127	.1338	.640 to 3.891	9	$s=.001077\ V^{1.9183}$	.0010444
Do	6	.4970	.1940	.705 to 3.274	7	$s=.000856\ V^{2.0104}$	.0008791
Do	8	.6585	.3406	.914 to 4.959	18	$s=.0005674\ V^{2.0373}$	.0006079
Do	10	.8274	.5377	.898 to 5.486	26	$s=.0005003\ V^{1.9632}$	.0004997
Do	12	.9915	.7721	1.183 to 2.935	4	$s=.0003449\ V^{2.0059}$	.0003546

Since for the same kind of tile the exponents V vary for the different sizes, the mean of the exponents has been taken as correct; thus,

For clay tile, $z=1.96859$.
For concrete tile, $z=1.96433$.

Using these mean values of z instead of the values derived for each separate size of tile, new values, m', were computed for the intercepts on the unity vertical axis, as follows:

$$\text{For clay tile, } \log m' = \log s - 1.96859 \log V \tag{20}$$

$$\text{For concrete tile, } \log m' = \log s - 1.96433 \log V \tag{21}$$

These values of m' are given in column 8 of Table 6.

To introduce the mean hydraulic radius into the formulæ, the relation of the values of m' to the hydraulic radii for the different sizes of concrete tile is represented by the formula,

$$m' = e\, R^x \tag{22}$$

in which e and x are determined analytically, by a method similar to that previously explained, as follows:

Tile size.	Mean hydraulic radius R.	Intercept values m'.	log R.		log m'.	
Inches.	*Feet.*					
4	0.0915	0.0017954	8.96142	Sum=27.16319	7.254171	Sum=21.217044
5	.1154	.0010444	9.06221	Mean=9.05439= D_r	7.018853	Mean=7.072348= $D_{m'}$
6	.1379	.0008791	9.13956	Antilog D_r=0.1133	6.944020	Antilog $D_{m'}$=0.0011813
8	.1840	.0006079	9.26482	Sum=28.0655	6.783850	Sum=20.032332
10	.2316	.0004997	9.36474	Mean=9.35519= E_r	6.698711	Mean=6.677444= $E_{m'}$
12	.2729	.0003546	9.43600	Antilog E_r=0.2265	6.549771	Antilog $E_{m'}$=.00047582
			Sum=55.22875 Mean= 9.20479= F_r Antilog F_r= 0.1602		Sum=41.249376 Mean= 6.874896= $F_{m'}$ Antilog $F_{m'}$= 0.00074971	

The line representing equation 22 is shown in figure 1 of Plate X. The mean hydraulic radii in the above computations were obtained by averaging the hydraulic radii for the selected tests in Table 4 for each size of tile, and not by using $\frac{D}{4}$, because these radii are for tests varying from 95 per cent full to full. The mean hydraulic radii have been plotted as abscissæ with their respective revised intercept values as ordinates. These points are designated in the figure by stars. The centers of gravity as computed above have also been plotted, and a line drawn through them. Substituting in equation 22, transposing, and using the center of gravity just computed,

$$\begin{aligned} \text{Log } e &= \log m' - (-1.3128) \log R \\ &= 6.874896 + 1.3128 \times 9.20479 \\ \text{and } e &= 0.00006775 \end{aligned} \tag{23}$$

Thus

$$m' = 0.00006775\ R^{-1.3128} \tag{24}$$

where 0.00006775 is the intercept on the line $R=1$, and -1.3128 is the inclination of the line to the horizontal axis. The logarithmic diagram showing the development of the line for equation 24 is shown in figure 1 of Plate X. A similar line for clay tile is shown in figure 1 of Plate XI.

Substituting equation 24 and the mean value of z (p. 40) in the general formula 17, this general equation is now obtained for concrete tile:

$$\begin{aligned} s &= 0.00006775\ R^{-1.3128}\ V^{1.96433} \\ &= \frac{0.00006775\ V^{1.96433}}{R^{1.3128}} \end{aligned} \tag{25}$$

From this, solving for V, we get

$$V = 132.5\ R^{0.668}\ s^{0.509} \tag{26}$$

which is the formula derived analytically, using the mean hydraulic radii for the selected experiments for each size of concrete tile in Table 4.

In a like manner, the formula as derived analytically for clay tile was found to be

$$V = 134.7\ R^{0.669}\ s^{0.508} \tag{27}$$

The data used in deriving equation 27 for clay tile are shown on figure 1 of Plate XI. This diagram has been prepared similarly to the diagram in figure 1 of Plate X, except that the values used are from the selected tests in Table 3, for clay tile.

Formulæ 26 and 27 were derived by the analytical method, using only experiments with the tile flowing from 95 per cent full to full, but not under pressure. In order to derive a formula graphically, using the same data as those from which equation 26 was derived analytically, a separate diagram was necessary. This diagram (Pl. X, fig. 2) was obtained by plotting the velocities used in figure 1 of Plate X as abscissæ, against their respective slopes as ordinates, just as in figure 1. Straight lines were drawn through each set of symbols, averaging the points by eye. Although these lines were not intentionally drawn parallel, it will be seen that they are practically so. The slopes of these lines were determined by scale, and the intercepts of the various lines with the unity vertical axis were read from the diagram. The inclination and location of the line involving the mean hydraulic radii and the intercepts were determined analytically. The formula as derived graphically for concrete tile is

$$V = 138.5\, R^{0.680}\, s^{0.510} \tag{28}$$

It should be noted that the exponents of s are the same in equations 26 and 28, while the exponents of R and the coefficients preceding R vary slightly.

In a similar manner, the formula for the flow of water in clay tile was derived graphically from the selected experiments in Table 3, this diagram being shown in figure 2 of Plate XI. In this case the inclination and location of the line involving the mean hydraulic radii and the intercepts were also determined analytically. The formula as derived for clay tile is

$$V = 121.4\, R^{0.635}\, s^{0.5} \tag{29}$$

Comparing this formula with equation 27, it will be noted that the exponents of s are practically the same, while the exponents of R as well as the coefficients preceding R vary somewhat. This difference is probably due to the fact that the observations on the 6-inch tile are slightly inconsistent with those on the other sizes, and this discrepancy is treated somewhat differently in the analytical and graphical methods. In the latter method, greater weight was given to the higher velocities than to the lower ones. The diagrams (Pl. XI, figs. 1 and 2) show the variation in the inclination of the lines for the 6-inch tile.

It will be noted that the formula for flow in clay tile, equation 27, was derived analytically. In order to determine the variation in the coefficient, the velocities for the selected experiments (column 8, Table 3), together with their respective hydraulic radii and slopes, were substituted in equation 27 and new coefficients computed. The mean of the coefficients obtained for clay tile was 137.6. Thus the formula for clay tile, using the same exponents for R and s as in equation 27, was found to be

$$V = 137.6\, R^{0.669}\, s^{0.508} \tag{30}$$

In a like manner, the data for the experimental velocities for the selected experiments (Table 4) were substituted in equation 26, and the formula for concrete tile became

$$V = 131\ R^{0.668}\ s^{0.509} \tag{31}$$

Noting how close the exponents of R and s were to $\frac{2}{3}$ and $\frac{1}{2}$, it was deemed advisable to determine what the coefficient would be when using these latter values. For the clay tile, using all the various sizes and lengths of tile, the formula became;

$$V = 136\ R^{\frac{2}{3}}\ s^{\frac{1}{2}} \tag{32}$$

In the case of concrete tile, the data for the 4-inch size show that greater resistance to flow is offered in this size than in the larger sizes. This is clearly shown in the diagram in Plate X as well as in column 10 of Table 4. Therefore, it was decided to eliminate the 4-inch size and use the remainder of the sizes in the derivation of the formula. The formula for concrete tile, then, is

$$V = 138.2\ R^{\frac{2}{3}}\ s^{\frac{1}{2}} \tag{33}$$

None of the previous formulæ were derived from the combined data for both clay and concrete tile. Therefore, it was decided to derive a formula by using the velocities for both clay and concrete tile flowing full as obtained from Plate IX. These velocities were plotted as abscissæ against their respective slopes as ordinates (Pl. XII). The formula derived graphically for both clay and concrete tile is

$$V = 137.96\ R^{0.67}\ s^{0.5} \tag{34}$$

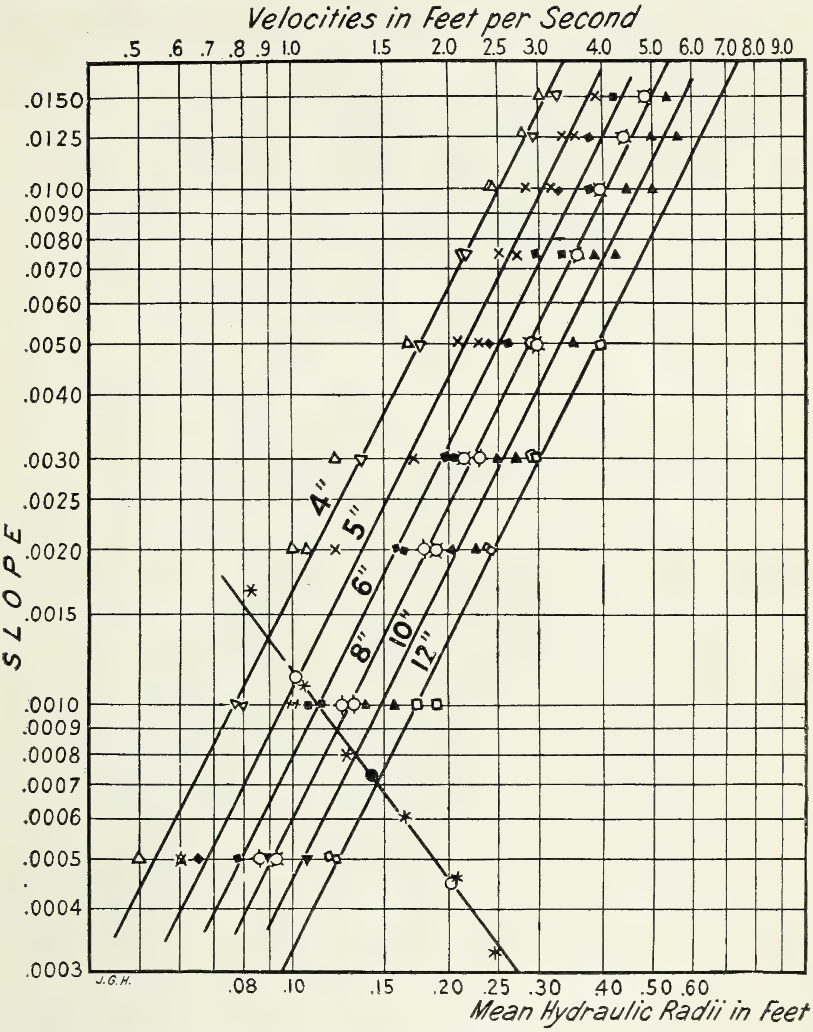
This formula is practically the same as that derived for concrete tile as given in equation 33. Since it was derived from the data for both clay and concrete tile, equation 34 is recommended as the general formula for computing the capacity of tile, merely eliminating the decimal in the coefficient and making the exponents $\frac{2}{3}$ and $\frac{1}{2}$, respectively, thus,

$$V = 138\ R^{\frac{2}{3}}\ s^{\frac{1}{2}} \tag{13}$$

FORMULÆ FOR TILE FLOWING PARTLY FULL

A great many experiments were made at other depths of flow as shown in Tables 3 and 4. These have been plotted and mean curves drawn through the points (see Pl. IX, figs. 1 to 12). The velocities at 0.5, 0.6, 0.7, 0.8, and 0.9 depths and for the tile flowing full were read from these curves and plotted on logarithmic charts as abscissæ, against their respective slopes as ordinates, to determine the equations for flow at these different depths.

Figures 3 to 8, Plate XI, show the studies made of clay tile at various depths of flow. With the exception of the 0.5 and 0.6 depths of flow (figs. 7 and 8), the lines were drawn through the various points by eye, the centers of gravity not being determined analytically.



CURVES USED IN THE DERIVATION OF A FORMULA APPLYING TO BOTH CLAY AND CONCRETE TILE.

However, for the 0.5 and 0.6 depths of flow the exponents of s were found to be rather high; so for these two depths the centers of gravity of the various sizes of tile were computed analytically, and the exponents of s were found to be the same as the values determined graphically. It should be noted that the diameter of the tile and not the mean hydraulic radius was used in the formulæ derived for various depths of flow. In determining the equation of the line showing the relation of m and the diameter D (equation 16), the centers of gravity were computed lest appreciable error should be introduced in attempting to draw these lines by eye. However, after the lines were drawn through the computed centers of gravity, the slopes of these lines were determined by scale and the intercept was read direct from the diagram.

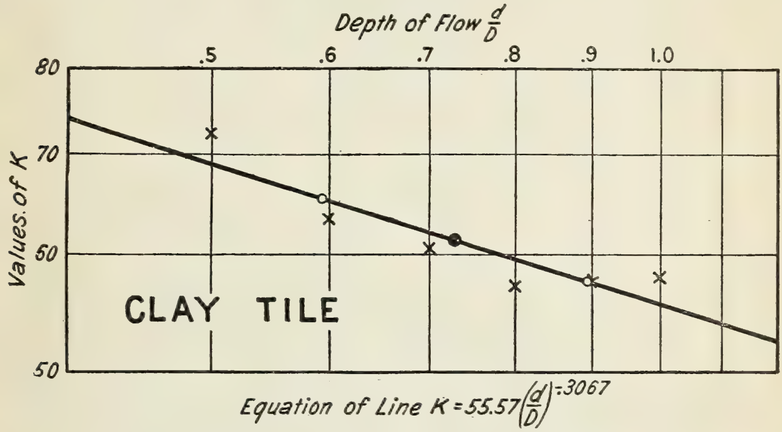


FIG. 1.—Relation of coefficient K to depth of flow in formulae 35–40.

The formulæ for clay tile as derived from figures 3 to 8, Plate XI, are as follows:

For tile flowing full,	$V=57.8\ D^{0.662}\ s^{0.512}$	(35)
For tile flowing 0.9 depth,	$V=57.5\ D^{0.678}\ s^{0.502}$	(36)
For tile flowing 0.8 depth,	$V=57.1\ D^{0.682}\ s^{0.498}$	(37)
For tile flowing 0.7 depth,	$V=60.5\ D^{0.756}\ s^{0.507}$	(38)
For tile flowing 0.6 depth,	$V=63.4\ D^{0.881}\ s^{0.518}$	(39)
For tile flowing 0.5 depth,	$V=72.2\ D^{1.01}\ s^{0.541}$	(40)

These equations furnish sufficient basis for determining next a general formula to cover every depth of flow. Since in this group of formulæ the exponent of s is about 0.5, each equation is of the form

$$V = K\,D^{\alpha} s^{0.5} \qquad (41)$$

Plotting the values of the coefficient K in formulæ 35 to 40 as ordinates, against their respective depths of flow as abscissæ, an equation involving K and $\frac{d}{D}$ is determined (see text-fig. 1). This equation is found to be

$$K=55.57\left(\frac{d}{D}\right)^{-0.3067} \qquad (42)$$

In a like manner, plotting values of the exponent of D as ordinates against their respective depths of flow as abscissæ, the equation for the exponent of D for any depth of flow was found to be (see text-fig. 2)

$$\alpha=0.6284\left(\frac{d}{D}\right)^{-0.639} \qquad (43)$$

Then writing the equation to cover every depth of flow in clay tile, we have

$$V=\frac{55.57}{\left(\frac{d}{D}\right)^{0.3067}}\left[D\right]^{\frac{0.6284}{\left(\frac{d}{D}\right)^{0.639}}} s^{0.5} \qquad (44)$$

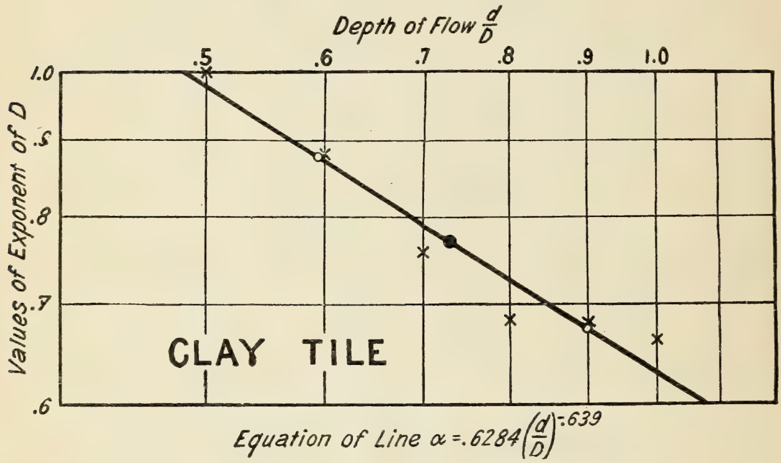


FIG. 2.—Relation of exponent of D to depth of flow in formulæ 35–40.

When $\frac{d}{D}$ equals 1—in other words when the tile is flowing full—and assuming the exponent of s to be 0.5 for all depths of flow,

$$V=55.57\ D^{0.6284}\ s^{0.5} \qquad (45)$$

A study of figures 3 to 8, Plate X, shows that the 4-inch concrete tile appears to have a greater coefficient of roughness than do the larger sizes. This is also indicated in Table 4. Therefore it was decided to eliminate the 4-inch tile and consider only the remaining sizes in deriving a new formula. The formulæ for the concrete tile for the 5, 6, 8, 10, and 12 inch sizes for all depths of flow then become:

For tile flowing full, $V=51.15\ D^{0.590}\ s^{0.496}$ (46)
for tile flowing 0.9 depth, $V=50.80\ D^{0.589}\ s^{0.491}$ (47)
for tile flowing 0.8 depth, $V=51.49\ D^{0.582}\ s^{0.496}$ (48)
for tile flowing 0.7 depth, $V=51.93\ D^{0.625}\ s^{0.501}$ (49)
for tile flowing 0.6 depth, $V=51.37\ D^{0.723}\ s^{0.504}$ (50)
for tile flowing 0.5 depth, $V=49.22\ D^{0.789}\ s^{0.510}$ (51)

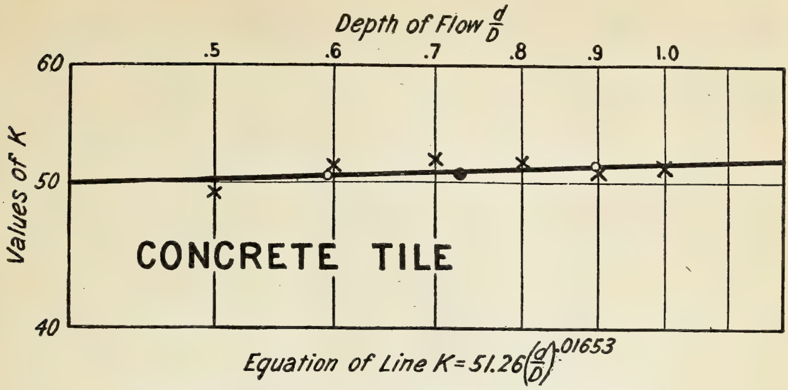


FIG. 3.—Relation of coefficient K to depth of flow in formulæ 46–51.

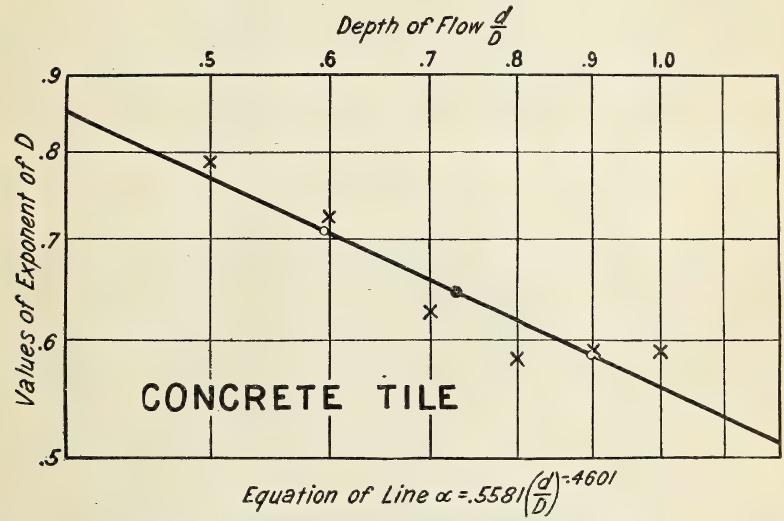


FIG. 4.—Relation of exponent of D to depth of flow in formulæ 46–51.

The exponent of s in all cases is very nearly 0.5, while the constant K also varies but little. Following the same method as before (see text-figs. 3 and 4) to obtain the formula for any depth of flow,

$$K=51.26\left(\frac{d}{D}\right)^{0.01653} \qquad (52)$$

and

$$\alpha=0.5581\left(\frac{d}{D}\right)^{-0.4601} \qquad (53)$$

Thus, the equation for any depth of flow in concrete tile is

$$V=51.26\left(\frac{d}{D}\right)^{0.01653}\left[D\right]^{\frac{0.5581}{\left(\frac{d}{D}\right)^{0.4601}}} s^{0.5} \qquad (54)$$

When $\frac{d}{D}$ equals 1 (when the tile is flowing full) and assuming the exponent of s to be 0.5 for all depths of flow,

$$V = 51.26\ D^{0.5581}\ s^{0.5} \tag{55}$$

The similarlity of this formula to Prony's formula in equation 7 should be noted.

A formula for the clay tile using only the data on the 5, 6, and 8 inch sizes (1-foot lengths) was derived, as well as a formula for the 10 and 12 inch clay tile (2-foot lengths). These, however, were not deemed of great importance as indicating the effect of joints in the tile line, since an insufficient number of tile sizes were available for consideration.

From a study of the data on the flow in tile running partly full, it will be seen that the velocity does not vary in accordance with the variation of the hydraulic radius. This fact suggested an attempt to derive a formula that does not involve the hydraulic radius, but is of the type,

$$V = \left(\frac{A^{\alpha}}{P^{\beta}}\right) s^{0.5} \tag{56}$$

That is, instead of the hydraulic radius, or the area divided by the wetted perimeter, it was recognized that the area might have one exponent and the perimeter a different exponent. A careful study of this type of formula revealed the fact that it would be impracticable.

Another type of formula which was considered was of the form

$$V = k\left(\frac{A}{P + C}\right)^{x} s^{0.5} \tag{57}$$

where k, x, and C are unknown constants. This type was also considered inadvisable.

Still another formula considered was of the type

$$V = \left(\frac{A}{P + FB}\right)^{\beta} s^{0.5} \tag{58}$$

where F and β are constants and B is the breadth of the water surface in the tile exposed to the air. This type was investigated quite carefully with the data relating to the concrete tile, but was not considered applicable to the conditions.

From a study of the velocity-depth of flow curves it will be seen that the greatest velocity in a pipe is approximately at 0.8 depth. Theoretically it would be at 0.81 depth. Below this the velocity decreases rapidly with the depth of flow. Observations on the flow in the tile during the experiments indicated that there is additional resistance to the flow caused by the action of the air on the water surface in tile flowing partly full, to which may be due the decided decrease in the velocity at the partial depths. Therefore it was decided to vary the formula for concrete tile,

$$V = 51\, D^{0.56}\, s^{0.5} \tag{59}$$

by substituting $\frac{A}{fP}$ for D, thus,

$$V = 51\left(\frac{A}{fP}\right)^{0.56} s^{0.5} \tag{60}$$

and to determine the proper values of f for the various depths of flow. In the formula 60, the values of V, s, A, and P from the experiments (V from Plate IX, the others from Table 4) were used, and the values of f were found to be as follows:

Tile flowing full	1.00
Tile flowing 0.9 depth	1.15
Tile flowing 0.8 depth	1.20
Tile flowing 0.7 depth	1.25
Tile flowing 0.6 depth	1.35
Tile flowing 0.5 depth	1.50

The above discussion is given merely as a method of making allowance for air resistance to flow. Further experiments are considered necessary to establish the necessity of making such allowance.

A comparison of the various formulæ which have here been derived may be made from Table 7. The formulæ have been arranged systematically, so that variations may be noted at a glance. They have been so classified that all involving the hydraulic radius are in one column, while those involving the diameter are in another column. The number opposite each formula refers to the corresponding equation in the text.

TABLE 7.—*Summary of formulæ derived.*

	In terms of R.	In terms of D.
Clay tile flowing full.		
Derived analytically, using mean hydraulic radii for selected experiments shown in table 3	$V=134.7R^{0.669}s^{0.508}$ (27).	
Derived graphically, using mean hydraulic radii for selected experiments shown in table 3	$V=121.4R^{0.635}s^{0.5}$ (29).	
Derived using experimental velocities in column 8, table 3, and working for mean coefficient	$V=137.6\ R^{0.669}\ s^{0.508}$ (30).	
Derived using velocities from figures 1 to 6, Plate IX, $R^{2/3}$, $s^{1/2}$, and working for mean coefficient	$V=136\ R^{2/3}\ s^{1/2}$ (32).	
Derived graphically, using velocities from figures 1 to 6, Plate IX		$V=57.8\ D^{0.662}\ s^{0.512}$ (35).
Clay tile flowing partly full.		
Derived graphically, for tile flowing 0.9 full, using velocities from figures 1 to 6, Plate IX		$V=57.5\ D^{0.678}\ s^{0.502}$ (36).
Derived graphically, for tile flowing 0.8 full, using velocities from figures 1 to 6, Plate IX		$V=57.1\ D^{0.682}\ s^{0.498}$ (37).
Derived graphically, for tile flowing 0.7 full, using velocities from figures 1 to 6, Plate IX		$V=60.5\ D^{0.756}\ s^{0.507}$ (38).
Derived graphically, for tile flowing 0.6 full, using velocities from figures 1 to 6, Plate IX		$V=63.4\ D^{0.881}\ s^{0.518}$ (39).
Derived graphically, for tile flowing 0.5 full, using velocities from figures 1 to 6, Plate IX		$V=72.2\ D^{1.01}\ s^{0.541}$ (40).
Concrete tile flowing full.		
Derived analytically, using mean hydraulic radii for selected experiments in table 4	$V=132.5\ R^{0.668}\ s^{0.509}$ (26).	
Derived graphically, using mean hydraulic radii for selected experiments in table 4	$V=138.5\ R^{0.680}\ s^{0.510}$ (28).	
Derived using experimental velocities in column 8, table 4, and working for mean coefficient	$V=131\ R^{0.668}\ s^{0.509}$ (31).	
Derived using velocities from figures 7 to 12, Plate IX, $R^{2/3}$, $s^{1/2}$, omitting 4-inch size, and working for mean coefficient.	$V=138.2\ R^{2/3}\ s^{1/2}$ (33).	
Derived graphically, using velocities from figures 7 to 12, Plate IX		$V=51.2\ D^{0.590}\ s^{0.496}$ (46).
Concrete tile flowing partly full.		
Derived graphically for tile flowing 0.9 full, using velocities from figures 7 to 12, Plate IX		$V=50.8\ D^{0.589}\ s^{0.491}$ (47).
Derived graphically for tile flowing 0.8 full, using velocities from figures 7 to 12, Plate IX		$V=51.5\ D^{0.582}\ s^{0.496}$ (48).
Derived graphically for tile flowing 0.7 full, using velocities from figures 7 to 12, Plate IX		$V=51.9\ D^{0.625}\ s^{0.501}$ (49).
Derived graphically for tile flowing 0.6 full, using velocities from figures 7 to 12, Plate IX		$V=51.4\ D^{0.723}\ s^{0.504}$ (50).
Derived graphically for tile flowing 0.5 full, using velocities from figures 7 to 12, Plate IX		$V=49.2\ D^{0.789}\ s^{0.510}$ (51).
Derived graphically using data for both clay and concrete tile flowing full, using velocities from Plate IX	$V=138\ R^{2/3}\ s^{1/2}$ (13).	

COMPARISON OF VARIOUS FORMULÆ.

Since from a practical standpoint we are interested only in the tile flowing full, velocities as computed by formula 34 are compared with velocities as taken from figures 1 to 12, Plate IX, for the tile flowing full. These results are shown in Tables 8 and 9. The difference is shown, rather than the ratio, between each two determinations of velocity, in order that the variations in the low velocities shall be given only equal weight with equal variations in the high velocities. To get the average differences given in Tables 8 and 9, the arithmetical sum of the differences is divided by the number of items.

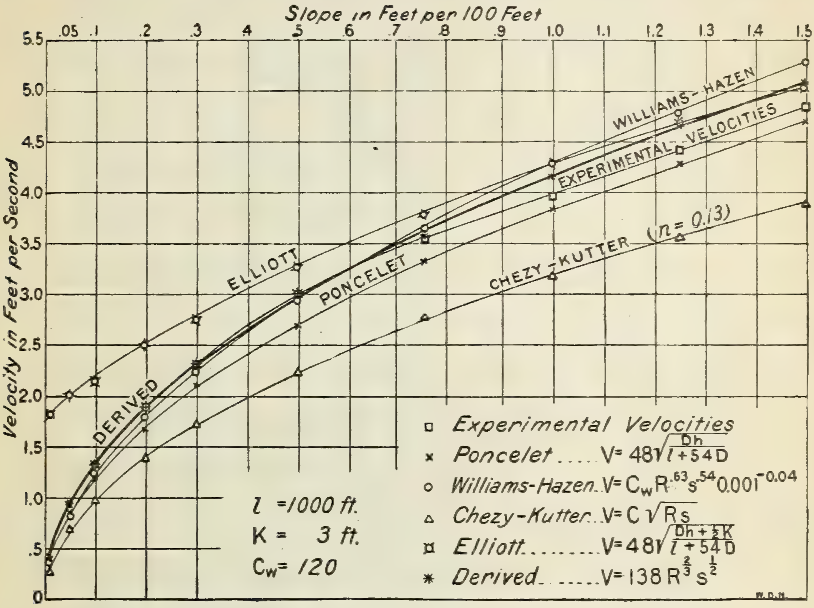


FIG. 5.—Comparison of velocities computed by various formulæ.

Both the Poncelet and the Beardmore formulæ gave greater differences when applied to the experimental data than does the tentative formula, No. 13. The velocities from the curves in Plate IX were substituted in the Williams-Hazen formula, and the average value of C_w, was found to be approximately 120. Using this value in the Williams-Hazen formula, recomputing the velocities, and comparing them with the velocities from the curves in Plate IX, it was found that the average differences were practically the same as the average differences stated at the bottom of Tables 8 and 9.

A comparison of the velocities computed by the various formulæ for one size of tile may be obtained from text-figure 5. This figure shows the velocities for 8-inch tile as computed by the Poncelet, the Williams-Hazen, the Chezy-Kutter (with the coefficient of roughness, n, taken equal to 0.013), the Elliott, and formula 13 herein derived from the experimental data. The observed experimental velocities are also shown.

TABLE 8.—*Comparison of velocities for clay tile flowing full.*

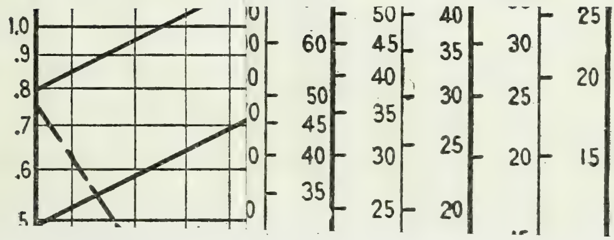
1 Size of tile.	2 Grade.	3 Velocity from curves in Plate IX.	4 Velocity by formula 34.	5 Difference between column 3 and column 4.	1 Size of tile.	2 Grade.	3 Velocity from curves in Plate IX.	4 Velocity by formula 34.	5 Difference between column 3 and column 4.
Inches.	*Per cent.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Inches.*	*Per cent.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*
4	0.05	0.60	0.59	−0.01	6	0.75	3.33	3.04	−0.29
	.10	.77	.84	+ .07		1.00	3.78	3.51	− .27
	.20	1.08	1.18	+ .10					
	.30	1.36	1.45	+ .09	8	.05	.87	.95	+ .08
	.50	1.76	1.87	+ .11		.10	1.23	1.34	+ .11
	.75	2.12	2.29	+ .17		.20	1.82	1.89	+ .07
	1.00	2.44	2.64	+ .20		.30	2.13	2.32	+ .19
	1.25	2.93	2.96	+ .03		.50	2.92	2.99	+ .07
	1.50	3.27	3.24	− .03		.75	3.53	3.66	+ .13
5	.05	.60	.68	+ .08	10	.05	1.06	1.08	+ .02
	.10	1.02	.96	− .06		.10	1.57	1.52	− .05
	.20	1.35	1.36	+ .01		.20	2.27	2.16	− .11
	.30	1.70	1.67	− .03		.30	2.74	2.65	− .09
	.50	2.11	2.15	+ .04		.50	3.50	3.42	− .08
	.75	2.52	2.64	+ .12		.75	4.23	4.19	− .04
	1.00	2.83	3.04	+ .21		1.00	4.98	4.84	− .14
	1.25	3.39	3.40	+ .01		1.25	5.63	5.40	− .23
	1.50	3.90	3.73	− .17					
					12	.05	1.17	1.21	+ .04
6	.05	.77	.79	+ .02		.10	1.86	1.71	− .15
	.10	1.04	1.11	+ .07		.20	2.35	2.41	+ .06
	.20	1.63	1.56	− .07		.30	2.95	2.96	+ .01
	.30	2.03	1.92	− .11		.50	3.94	3.82	− .12
	.50	2.59	2.48	− .11					

Total plus difference .... +2.11
Total minus difference .... −2.16
Number of items 44
Average difference .... foot per second .. .097

TABLE 9.—*Comparison of velocities for concrete tile flowing full.*

1 Size of tile.	2 Grade.	3 Velocity from curves in Plate IX.	4 Velocity by formula 34.	5 Difference between column 3 and column 4.	1 Size of tile.	2 Grade.	3 Velocity from curves in Plate IX.	4 Velocity by formula 34.	5 Difference between column 3 and column 4.
Inches.	*Per cent.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Inches.*	*Per cent.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*
4	0.05	0.52	0.58	+0.06	8	0.05	0.92	0.90	−0.02
	.10	.78	.82	+ .04		.10	1.31	1.30	− .01
	.20	.99	1.16	+ .17		.20	1.89	1.84	− .05
	.30	1.18	1.41	+ .23		.30	2.30	2.26	− .04
	.50	1.69	1.83	+ .14		.50	2.99	2.91	− .08
	.75	2.15	2.24	+ .09		.75	3.53	3.57	+ .04
	1.00	2.39	2.58	+ .19		1.00	3.98	4.11	+ .13
	1.25	2.82	2.89	+ .07		1.25	4.42	4.61	+ .19
	1.50	3.06	3.16	+ .10		1.50	4.83	5.04	+ .21
5	.05	.61	.67	+ .06	10	.05	.90	1.07	+ .17
	.10	.97	.95	− .02		.10	1.38	1.52	+ .14
	.20	1.36	1.32	− .04		.20	2.06	2.15	+ .09
	.30	1.71	1.65	− .06		.30	2.47	2.63	+ .16
	.50	2.30	2.13	− .17		.50	3.23	3.39	+ .16
	.75	2.69	2.61	− .08		.75	3.87	4.16	+ .29
	1.00	3.19	3.01	− .18		1.00	4.49	4.80	+ .31
	1.25	3.53	3.37	− .16		1.25	4.99	5.37	+ .38
						1.50	5.37	5.88	+ .51
6	.05	.67	.76	+ .09					
	.10	1.13	1.08	− .05	12	.05	1.20	1.21	+ .01
	.20	1.58	1.53	− .05		.10	1.72	1.71	− .01
	.30	1.97	1.87	− .10		.20	2.37	2.42	+ .05
	.50	2.30	2.41	+ .11		.30	2.93	2.97	+ .04
	.75	2.95	2.95	+ .00					
	1.00	3.26	3.41	+ .15					
	1.25	3.77	3.81	+ .04					
	1.50	4.28	4.18	− .10					

Total plus difference .... +4.42
Total minus difference .... −1.22
Number of items 48
Average difference .... foot per second .. .117


1.0
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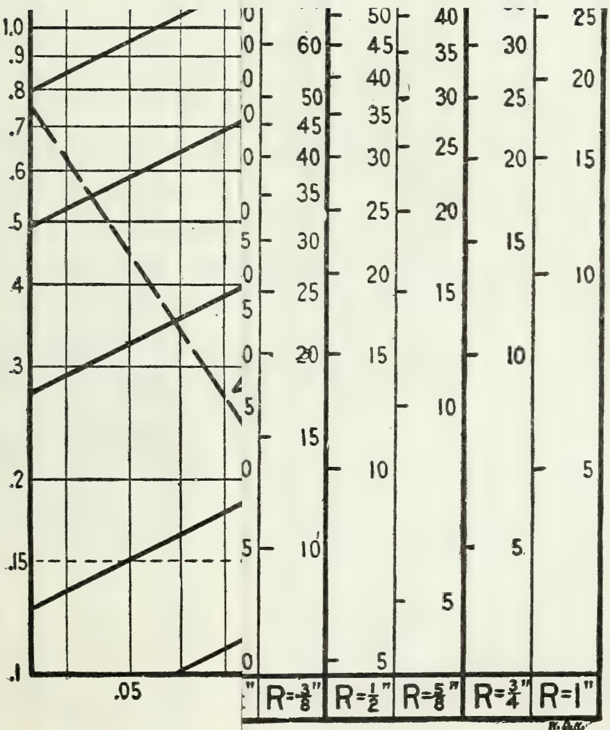
15

CORRECTION

In Bulletin 854 of the United States Department of Agriculture, entitled "The Flow of Water in Drain Tile," the formula given in the legend at the bottom of Plate XIII (facing page 48) should read:

$$V = 138 R^{\frac{2}{3}} S^{\frac{1}{2}}$$



1.0
.9
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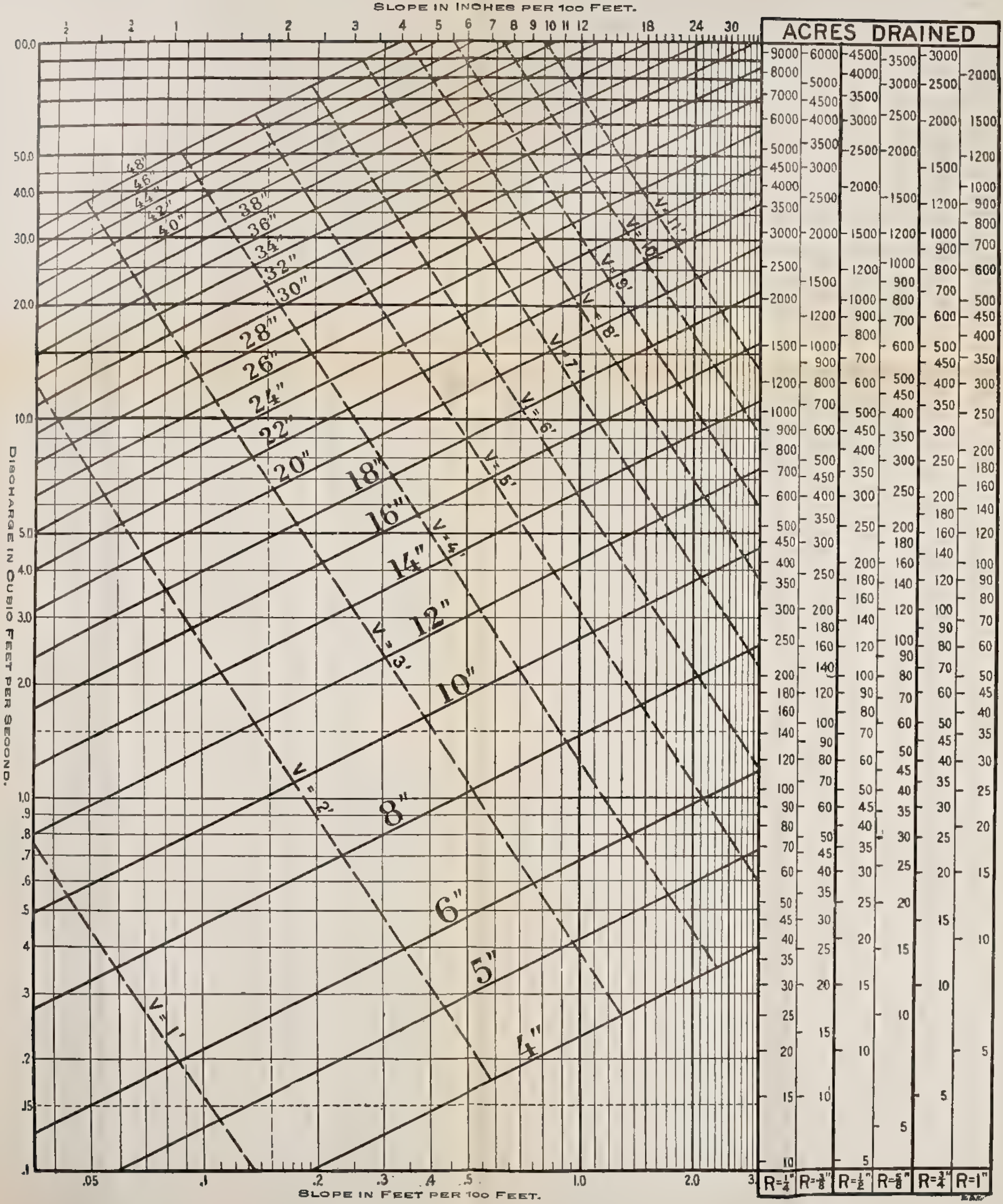
R=3/8"
R=1/2"
R=5/8"
R=3/4"
R=1"



Discharge Curves for Drain-Tile Based on Formula $V = 136\ S^{\frac{1}{2}} R^{\frac{2}{3}}$.

Equation 13 is tentatively offered for use in computing the capacity of tile drains, though with full recognition of the fact that further experiments are necessary to determine its applicability to tile of sizes larger than those used in these experiments. Additional data also are desirable to determine whether the variation in length of the individual tiles is an important item to consider in the derivation of a formula.

For convenience in quickly determining the number of acres drained, for each size of tile and for various rates of run-off, Plate XIII has been prepared from formula 13. Several velocity curves are also shown for use in determining approximately the velocity of flow.

LOSS OF HEAD IN CATCH-BASINS.

To actually determine the loss of head resulting from the installation of a surface inlet or catch-basin in a tile line, experiments were made on 8-inch clay tile at three different grades, 0.2, 0.75, and 1.50 feet in 100 feet, with differences of 0.1, 0.2, and 0.3 foot between the elevations of the inlet and the outlet tiles.

The catch-basin was made by inserting in the flume two wooden bulkheads 4 feet apart. The space between the bulkheads was cleared of tile and earth and thus formed a basin 2 feet wide by 4 feet long. The inlet and outlet tiles extended through the respective bulkheads. A piezometer was installed at the outlet of the catch-basin, another at a point 2 feet below the outlet, and a third at a point 2 feet below the second. Tests were made with and without the use of a 12 to 8 inch reducer at the outlet of the catch-basin. This reducer actually consisted of two sewer-pipe reducers (12 to 10 inch and 10 to 8 inch), each 2 feet long. When the reducer was used the middle piezometer was omitted.

TABLE 10.—*Effect of reducers on the loss of head at outlets of catch-basins.*

Drop in catch-basin.	Grade of tile.	Elevation of water surface without reducers.				Elevation of water surface with reducers.			Head saved by use of reducers.
		In catch-basin.	2 feet below catch-basin.	4 feet below catch-basin.	Loss of head.	In catch-basin.	4 feet below catch-basin.	Loss of head.	
Foot.	*Per cent.*	*Foot.*	*Foot.*	*Foot.*	*Foot.*	*Foot.*	*Foot.*	*Foot.*	*Foot.*
0.3	0.20	0.46	0.44	0.41	0.05	0.45	0.41	0.04	0.01
		.84	.79	.77	.07	.74	.73	.01	.06
	.75	.58	.57	.45	.13	.56	.52	.04	.09
		.97	.83	.83	.14	.81	.80	.01	.13
	1.50	.65	.53	.49	.16	.64	.53	.11	.05
		.78	.66	.64	.14	.76	.76	.00	.14
.2	.20	.46	.46	.45	.01	.44	.43	.01	.00
		.83	.79	.78	.05	.75	.74	.01	.04
	.75	.53	.53	.52	.01	.53	.52	.01	.00
		.76	.74	.74	.02	.74	.74	.00	.02
	1.50	.67	.65	.53	.14	.60	.56	.04	.10
		1.15	1.02	.80	.35	.82	.77	.05	.30
.1	.20	.44	.43	.43	.01	.45	.43	.02	....
		.79	.73	.73	.06	.76	.73	.03	.03
	.75	.56	.48	.43	.13	.54	.45	.09	.04
		.89	.68	.66	.23	.80	.70	.10	.13
	1.50	.68	.60	.56	.12	.65	.56	.09	.03
		1.11	.80	.78	.33	.88	.76	.12	.21

The results of these observations are shown in Table 10. The data indicate that the use of reducers with tile flowing approximately full reduces the loss of head to practically nothing, while with tile flowing half full some loss of head occurs. Without reducers, the loss of head decreases with the decrease in slope. The variation in drop in the catch-basin did not materially affect the loss of head, which seems to be about equal to the grade through 15 feet length of drain.

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