INVESTIGATION OF FLOW
THROUGH STANDARD AND EXPERIMENTAL GRATE INLETS FOR STREET GUTTERS

by

St. Anthony Falls Hydraulic Laboratory
University of Minnesota

Project Report No. 3

Submitted by
Lorenz G. Straub
Director

Prepared by
Curtis L. Larson

October, 1947

Prepared for the
Minnesota Highway Department
St. Paul, Minnesota

C O N T E N T S

INVESTIGATION OF FLOW

THROUGH STANDARD AND EXPERIMENTAL GRATE INLETS FOR STREET GUTTERS

I. INTRODUCTION

This report presents the results of an investigation of the flow of water and entrained debris through standard and experimental gutter inlets of the grate type. The investigation was requested by the Minnesota Highway Department in connection with the proposed construction of a length of highway at 6 per cent grade. Under the sponsorship of the Highway Department, the experiments were conducted at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota.

In designing surface drainage facilities for streets and highways, the highway engineer has been handicapped by the general lack of data on the capacity of grate inlets. Clogging of inlets with paper, leaves, and other debris is often a serious maintenance problem. The purposes of this investigation were therefore as follows:

1. To determine the capacity of grate inlets now in use, and to ascertain the ability of these inlets to pass debris.
2. To develop an inlet with better self-cleaning qualities, and with higher capacity than existing inlets.

Among the standard inlets tested were those of the Minnesota Highway Department and of the City of Minneapolis Street Department, which were mounted full-scale in a simulated gutter in the Laboratory. Tests were then conducted at several slopes and over a wide range of discharges. A procedure for tests with simulated debris was also adopted.

In tests conducted at the North Carolina Engineering Experiment Station, it was found that deflecting slots in a gutter are self-cleaning when set at an angle of 45° with the direction of flow. With this in mind, Mr. A. W. Verharen, Assistant Administrative Engineer of the Minnesota Highway Department, proposed an experimental inlet with its bars and openings set at this angle. It was hoped that this inlet would be self-cleaning and would also have a high capacity. To determine these characteristics, the proposed experimental inlet was constructed full-scale, and was tested in the same manner as the standard inlets. Similar tests were made with other experimental inlets.

The tests revealed that the original experimental inlet has a capacity somewhat greater than standard inlets, mainly as a result of its greater width. It was also found that the capacity of this inlet can be increased substantially by a simple improvement in the form of its bars, which is applicable to any inlet with transverse bars. In addition, the tests showed that the capacity of any inlet can be increased greatly by permitting a small portion of the gutter flow to pass over or around the inlet. The debris tests indicated that only inlets with openings parallel or nearly parallel to the flow are self-cleaning.

II. APPARATUS

The general arrangement of the apparatus used in the investigation is shown in Fig. 1. The various full-size inlets were mounted in a cantilever frame or cradle which was attached to the outlet end of the 36-in. tilting channel of the Laboratory. Around each inlet was placed a masonite floor with a transverse slope of 20.6 to 1, corresponding to the crown slope of the proposed highway. This floor extended 16 ft upstream of the test section, providing a total of approximatoly 21 ft of uniform gutter section. A simulated curb of the dimensions shown in Fig. 1 was fabricated and installed. Adjacent to the inlet, an opening in the curb was constructed, in which could be placed either a masonite blank or a simulated curb opening of any shape. By means of the tilting mechanism of the channel, this entire assembly could then be set at any slope from zero to six per cent.

The orifice meters permanently installed in the supply line of the channel were suitable for metering the total inflow. A previous calibration of these meters was checked at several points by discharging through the waste channel into the Laboratory weighing tanks.

For measuring the cross section of flow in the test gutter, a movable point gage was mounted on a track extending across the channel at the head of the test section. This arrangement made it possible to take readings of the water surface elevation at any point in that section. The gage was set to read zero at the lowest point in the section, that is, adjacent to the curb. Measurements of the bottom elevation were then taken every 0.2 ft across the section, and were recorded. These readings were checked several times during the progress of the tests, and were found to remain within 0.001 ft of the original values.

The location of the test section permitted discharge through the grate inlets directly into the waste channel. The water passing over and around the inlets, arbitrarily termed "carryover,"flowed through an overflow chute into a weir tank 10 ft long and $39\frac{1}{4}$ in. wide. This flow was metered by a rectangular weir. Heads on the weir were read with an electric point gage, which was installed in a $2\frac{1}{2}$-in. stilling well open to the weir tank at a point near the bottom. In order to calibrate the weir with the orifice meters, the grate inlet openings were covered temporarily to permit the entire flow to pass directly into the weir tank. Since the weir is relatively long, it was found necessary to provide a separate means of measuring carryover discharges of less than 0.15 cu ft per sec. The weir tank was therefore calibrated volumetrically over a range of several tenths of a foot on the weir gage. Low carryover discharges could then be determined accurately by timing the rise of water in the weir tank from one elevation to another.

III. METHOD AND SCOPE OF INVESTIGATION

Although this investigation was initiated to provide data for a specific installation, the general need for design criteria made it desirable to secure results which could be applied to the range of conditions likely to be encountered in actual practice. Accordingly, tests were conducted with each inlet setup at several slopes.

In planning these tests, it was reasoned that where inlets are placed in series in a long uniform gutter, some carryover of water from inlet to inlet may be permissible or even desirable, if it causes each inlet to operate at a higher capacity. In order to evaluate this possibility, it was decided to conduct a series of tests at each slope using several discharges. These discharges were selected to produce a variation in carryover from zero to a relatively large amount.

For each capacity test, the variables to be determined, in addition to the depth of flow, included the discharge in the gutter, the carryover, and the flow intercepted by the inlet. The test apparatus provided means for the direct measurement of the gutter discharge and the carryover. The difference between these two quantities is, of course, the flow passing through the test inlet, referred to in this report as the "inlet capacity."

Measurements of the depth of flow in the test gutter were made with each test run of the A series, as shown in Fig. 2. Since the water surface was found to be somewhat irregular, readings of the water surface elevation were taken with the movable point gage at 0.5-ft intervals across the section, beginning at the curb line. (The curb line was taken as the intersection of the curb plane with the channel bottom.) Inasmuch as the flow was found to be supercritical in the range of test slopes used, the depth of flow at the point gage section could not be affected by either backwater or drawdown from the inlet, even though the readings were taken near the inlet. The depth-discharge data obtained in the A series of tests was therefore applicable to tests of other inlets, and depth of flow measurements were omitted for the rest of the tests.

In order to compare the self-cleaning qualities of the standard and experimental inlets, a quantitative basis for comparison was needed. Since leaves are the most common type of debris found in gutters, it was decided to simulate leaves in some manner which could be readily duplicated. For this purpose, an arbitrary procedure for debris tests was adopted, using newsprint paper cut into rectangular pieces, one by two inches in size. For each trial, 50 of these pieces were introduced into the flow at the head of the gutter section. Each piece was held under water until soaked, and was then released individually. Soaking permitted the pieces to mix with the flow, and also eliminated the variable of partial soaking. When all the pieces had reached the inlet, the pieces lodged on the bars were removed and counted. Since decreasing the discharge caused some of the pieces to wash off, the discharge was maintained constant during the counting. Three trials were made at test slopes of 0.5 and 2.0 per cent for each inlet. The average of the three results was computed in each case. Of all the debris tests made, none of the trials varied more than five pieces above or below their corresponding averages, and few varied more than three pieces from the average.

The nine inlet setups investigated are described below. In each case, the first demension is the width of the inlet, which was measured normal to the flow from the curb line.

A. Experimental inlet, width $23\frac{1}{4}$ in., length 24 in., Fig. 3, dropped $\frac{1}{2}$ in. at curb, with standard 6-in. curb opening.

B. Experimental inlet, $23\frac{1}{4}$ x 24 in., dropped $\frac{1}{2}$ in. at curb, with no curb opening.

C. Experimental inlet, $23\frac{1}{4}$ x 24 in., dropped $1\frac{1}{2}$ in. at curb, and 1 in. on street side, with standard 6-in. curb opening.

D. Improved experimental inlet, $23\frac{1}{4}$ x 24 in., altered as shown in Fig. 4, dropped $\frac{1}{2}$ in. at curb, with standard 6-in. curb opening.

E. Improved experimental inlet with upstream half covered, $23\frac{1}{4}$ x 13 in., dropped $\frac{1}{2}$ in. at curb, with 6- x 12-in. curb opening.

F. Improved experimental inlet, $23\frac{1}{4}$ x 24 in., set flush with roadway, with standard 6-in. curb opening.

G. Minnesota Highway Department standard inlet, $16\frac{1}{4}$ x $25\frac{1}{2}$ in., Fig. 5, set flush with roadway, with standard 6-in. curb opening.

H. City of Minneapolis standard inlet, 19 x 23 5/8 in., Fig. 6, set flush with roadway, with standard City curb opening.

J. Experimental baffle inlet, 24 x 19 in., Fig. 7, set flush with roadway, no curb opening.

To permit easy identification of all test runs, a numbering system was adopted, using the letters designated above to distinguish the various inlet setups. For example, test number C 301 indicates the first of a series of tests of inlet setup C at 3 per cent slope. For tests at $\frac{1}{2}$ per cent slope, 9 was used as the first digit of the test number.

IV. CRITERION FOR APPLICATION OF TEST RESULTS

From the nature of the occurrence and from previous tests, it is evident that variations in the characteristics of the approach flow affect the capacity of grate inlets. Therefore, if the test results for a certain inlet are to be applicable to the same inlet in an actual gutter, one must take into consideration the effects of the difference between the flow conditions in the test gutter and those in an actual gutter. Either these effects must be evaluated and applied as corrections to the test results, or the test results must be applied to gutters in which the flow conditions will be identical to those in the test gutter. In planning these tests and in presenting the results, the latter procedure was followed.

By this method, the results of a certain test may be transferred directly from the test gutter to an equivalent gutter, that is, to one in which the mean velocity and depth of flow are equal to those in the test gutter for the same discharge. In other words, the depth-discharge relation of the equivalent gutter must be identical to that of the test gutter. The factors involved are related by the Manning formula, $V = 1.486 \sqrt{s}/n \; R^{2/3}$, in which V is the mean velocity, n the roughness coefficient, s the slope, and R the hydraulic radius. This formula shows that the roughness can be varied directly as the square root of the slope without affecting the other variables in the equation. Thus, in addition to being of the same shape, the equivalent gutter must have a factor $\sqrt{s}/n$ which is numerically equal to that of the test gutter. Since this factor is proportional to the velocity for a given channel and a certain depth of flow, it will be referred to in this report as the "velocity index."

In using this method of transferring the test results, it is assumed that uniform flow prevails just above the inlet in the actual gutter, as well as in the test gutter. In an actual gutter, the flow is not exactly uniform, since a thin sheet of runoff is being contributed all along the gutter. In mixing with the gutter flow, this inflow is accelerated, thereby causing a decrease in the resulting gutter velocity in accordance with the laws of momentum. In applications such as lateral spillways, where the side inflow is relatively large, the influence of lateral flow is quite important, as shown by several investigators. In a street gutter, however, the side inflow is distributed over several hundred feet, making the inflow per foot of gutter only a fraction of one per cent of the final gutter flow. The effects of this inflow, if significant for a gutter, would be reflected mainly in the velocity index scale, rather than in the capacities obtained for the various inlets. In application, the velocity index itself is subject to considerable error in the estimate of a roughness coefficient for the gutter. This error is of perhaps greater magnitude than the error which would result from the effects of side inflow. For this reason, and because time did not permit, no tests were made using side inflow as an additional variable.

In order to obtain results with the greatest range of application, test slopes were selected to cover the variation in velocity index likely to occur in practice. Using an estimated value of roughness for the masonite test channel, test slopes of $\frac{1}{2}$, 1, 2, and 3 per cent were chosen. The actual velocity indexes for the test gutter at these test slopes were then evaluated experimentally from the depth of flow data taken with the A series of tests.

These data are presented in Tables 1 through 4; the computations for the velocity indexes are summarized in Tables 5 through 8. In making these computations, areas of the flow cross section A and values of $AR^{2/3}$ are taken from the corresponding curves in Fig. 8, which are based on the actual bottom configuration of the test gutter section as plotted in the same figure. Values of the velocity index and the roughness coefficient for each test run are then computed by application of Manning's formula. Although both factors show some variation with discharge, it is believed that the averages of the results obtained at each slope are sufficiently accurate for the purposes intended. It may be noted that the average roughness coefficients computed for each slope agree quite consistently, indicating in some measure the reliability of this group of data. In applying the results of tests at slopes of $\frac{1}{2}$, 1, 2, and 3 per cent, the values of the velocity index to be used will therefore be 6.6, 9.8, 14.0, and 17.2, respectively. As an example, test results obtained with an inlet at 2 per cent slope may be transferred directly to the same inlet in any gutter of similar shape having a combination of slope and roughness corresponding to a velocity index of 14.0.

V. TREATMENT OF DATA

Presented in Tables 9 through 40 are the results of the 181 capacity tests conducted. For depths of flow greater than approximately 0.14 ft in the test gutter, the flow was restrained by the right wall of the tilting channel at a point 2.86 ft from the curb line, necessitating corrections equal to the discharges which would flow to the right of that point in a gutter of unlimited width. For various depths of flow in the test gutter, these corrections were computed by regarding the small incremental area as a separate channel of slope and roughness equal to the test gutter. The resulting corrections and gutter discharges for corresponding depths of flow are plotted as coordinates in Fig. 9. These curves permit direct application of the correction without reference to the depth of flow. Both observed and corrected values of the gutter discharge are included in the tables. Also included are inlet capacities, which are correct as observed.

Visual observations during the tests indicated that the measurements of gutter discharge, inlet capacity, and carryover do not fully explain the differences in behavior between the various inlets. For instance, with some inlets the carryover includes mainly water passing over the inlet, while with others the carryover is composed largely or entirely of water passing around the inlet. To supplement the data, therefore, numerous photographs were taken throughout the tests. A number of these are included in this report as Figs. 10 through 17.

Figs. 18 through 21 present the data of Tables 9 through 40 in the form of rating curves, which serve as a basis for comparing the performance of the various inlets. For any point on these curves, the carryover is determined by reading downward to the horizontal scale. The gutter discharge is obtained by following the sloping dotted lines to the same scale. Each of these figures contains all the test data obtained at one of the four test slopes, and is therefore applicable only for one particular velocity index. Capacities at intermediate velocity indexes can be obtained by interpolation between figures. Such interpolation, however, may give inaccurate results because of the irregular manner in which inlet capacity varies with velocity index. To permit easier and more accurate determination of the capacity of Inlets A, D, G, and H at intermediate velocity indexes, Figs. 22 through 26 were prepared by selecting capacities from the rating curves corresponding to carryovers of 0, 0.05, 0.10, 0.15, and 0.20 cu ft per sec. If capacities for other carryovers in this range are desired, they can be obtained quite accurately by interpolation from these figures. If desired, the data can be replotted once more to provide rating curves for any velocity index within the range of the tests.

Presented in Tables 41 and 42 are the data obtained in the debris tests at test slopes of 2.0 and 0.5 per cent, respectively. In the last column of these tables is given the average percentage of debris passing the inlet during three trials. Comparison of the self-cleaning qualities of the various inlets may be made directly from this table.

VI. DISCUSSION OF RESULTS

A. Capacity Tests

Perhaps the most important fact established by this investigation is that the capacity of a grate inlet can be greatly increased by permitting a small amount of carryover. This fact appears to apply to all grate inlets. The rating curves show that carryovers as small as 0.10 to 0.20 cu ft per sec double the capacities of most of the inlets tested. For example, if the gutter flow is increased to produce a change in carryover from zero to 0.10 cu ft per sec in a gutter having a velocity index of 14.0, as shown in Fig. 19, the capacity of Inlet A would be increased from 0.53 to 1.01 cu ft per sec. Where inlets are in series, a carryover of this small magnitude produces no ill effects, since carryover is not cumulative. Thus, for inlets of a given type in series, it is possible to double the spacing that would be needed for operation with no carryover.

In comparing the capacities of the various inlets, it is seen that the capacity of a grate inlet is affected both by the characteristics of the inlet and by the characteristics of the approach flow. Furthermore, variations in the nature of the approach flow produce varying and sometimes opposite effects, depending on the characteristics of the inlet. As indicated by the data and by visual observations, the inlet characteristics which are of primary importance in determining inlet capacity are: the width of the inlet, and the efficiency of the inlet openings.

The width of an inlet, measured normal to the direction of flow, is an influential factor in that the carryover in almost every case is either partly or wholly composed of water which passes around the inlet. In other words, no inlet can be expected to intercept a large portion of the flow unless it extends well into the path of the flow. The importance of width can be seen from an inspection of the rating curves and photographs of Inlets D, G, and J, all of which take water readily. Inlets D and J, being approximately 24 in. in width, have high rating curves, while Inlet G, which is $16\frac{1}{4}$ in. wide, has a low rating. Thus it appears worthwhile to make grate inlets at least 24 in. wide for a gutter of this shape, and perhaps wider for highways with flatter crown slopes. In such cases, a grate inlet could be widened in effect by providing transverse slots in the roadway leading to the inlet.

The efficiency of grate inlet openings was found to depend mainly on the effective length of the individual openings, which is in all cases measured in the direction of flow. For inlets with transverse bars, only a thin sheet of water was diverted downward at the face of each bar. Theoretically, the thickness of this sheet of water varies as the square of the length of opening, for a flow of a given velocity, if the path of the water crossing the opening is assumed to be that of a freely falling body. For this reason it would appear highly desirable to increase the effective length of opening in any way possible.

The importance of length of opening is well demonstrated in a general way by the results of the tests, although no attempt was made to measure the capacity of individual openings. Fig. 15 shows that an appreciable portion of the flow passes over Inlet H, which has 1 3/16-in. transverse openings. The $1\frac{1}{4}$-in. openings of Inlet A are set at an angle of 45° from the direction of flow, and increase the effective length of opening to approximately 1 3/4 in. Fig. 10 shows that this inlet also permits some water to flow over it, but not in as large proportion as does Inlet H. In Inlet G, $1\frac{1}{4}$- by 11-in. openings are placed parallel to the flow, making their effective length 11 in. As seen from Fig. 14, these openings readily intercept the flow. Thus, the simplest and most efficient openings are conventional openings with their long dimension parallel or nearly parallel to the direction of flow.

In Test Series D, the surface of each bar was rounded, in an attempt to increase the effective length of opening. This method was carried out on the experimental inlet of Series A, as shown in Fig. 4, and was found to be very effective. Since the rounding of the surface approximated a free overfall from the leading edge, the effective length of opening was almost doubled. Such an improvement theoretically quadruples the capacity of each opening, and, as seen from a comparison of Figs. 10 and 12, causes almost the entire flow to be intercepted by the first two openings, whereas in the original setup of Inlet A, six openings failed to do as well. Fig. 17 shows Inlet D with a gutter discharge of 1.50 cu ft per sec, still not operating to capacity. Test Series E was run to demonstrate that only half as many openings can be used with the improved grate bar without seriously lowering the rating curves in the ordinary range. Although this improvement was tested with 45° bars and openings, it is evident that the same relative benefits would be obtained by using a similar form for bars set perpendicular to the flow.

Whether the overall length of the inlet affects its capacity depends on the efficiency of its openings. For example, an increase in length may effect a capacity increase for Inlets A and H, which have inefficient openings. On the other hand, efficient inlets, such as D and G, could be shortened considerably without noticeably changing the rating curves, as seen from the photographs of these inlets in operation, and as demonstrated by the results of Test Series E.

The characteristics of the approach flow were also found to have a pronounced effect on the capacity of grate inlets. The tests showed that high velocities tend to decrease the capacity of an inlet by increasing the tendency for water to flow or spray over it. On the other hand, high velocities tend to increase the capacity of an inlet by concentrating a greater flow in a given width of gutter. It was found that either of these opposing tendencies may be predominant, depending on the width of the inlet and the efficiency of the inlet openings. The net results are shown in Figs. 22 through 26, for Inlets A, D, G, and H. Within the range of the tests, Inlets D and G, which have efficient openings, operate with increasing capacity as the velocity is increased. Inlets A and H, which have less efficient openings, increase in capacity with increased velocity indexes up to approximately 14, but decrease in capacity for higher velocity indexes.

Other factors which may affect the capacity of an inlet somewhat are the use of or omission of a curb opening and the setting of the inlet with respect to the surface of the roadway. The B series of tests were conducted with the same inlet and setting as the A series, except that the curb opening was replaced by a blank. Comparison of the rating curves shows that only a small percentage of the inlet capacity, less than 5 per cent, can be credited to the curb opening. For inlets with efficient openings, which permit no water to flow over the inlet bars, it is evident that a curb opening provides no increase in capacity. Lowering the inefficient inlets below the surface of the roadway, as in Setup C, was found to increase their capacity, but would probably result in a traffic hazard if carried out to an appreciable degree. The improved inlet, however, operated just as effectively when set flush with the roadway surface in Series F2 as when it was lowered $\frac{1}{2}$ in. at the curb line for the D series of tests.

B. Debris Tests

Since no attempt was made to duplicate actual gutter debris, the results of the debris tests were not intended to indicate the percentage of actual debris that would pass any of the inlets. Nevertheless, it is believed that the data serve as a basis for comparing the relative abilities of the several inlets to pass debris similar to the test debris.

Inlet A was found to pass only 20 to 30 per cent of the debris, and would therefore probably clog quite easily. Rounding its bars to form Inlet D, however, permitted approximately 70 per cent of the test debris to pass through the inlet. It was hoped that the experimental inlet, in which the bars are placed 45° from the direction of flow, would be self-cleaning as a result of the component of the flow along the axis of each bar. Although this component was not strong enough to move the pieces of wet paper, which seem to cling tenaciously when caught, it is possible that this inlet would be more effective with other types of debris, which may not adhere as strongly as the water-soaked paper.

Because its openings are parallel to the direction of flow, Inlet G handled the test debris as easily as it did water, having an efficiency of about 95 per cent. However, it should be noted that if the debris should include longer and stiffer material such as twigs or straw, or even large, dry floating leaves, this inlet might clog as quickly as any other. Inlet H, which is a rough casting with bars normal to the flow, passed a smaller percentage of debris than any of the others tested. The debris tests of Inlets A through H, therefore, demonstrated that improving the hydraulic efficiency of inlet openings increases their ability to take debris.

During the tests, it was observed that the debris was caught on the upstream corners of the grate bars where the flow divides. Once caught there, the pieces were pulled in opposite directions by the frictional drag of the water passing over the bar and the drag of the water passing downward along the face of the bar. The static pressure on the top of the bar and the dynamic pressure on the face of the bar resulted in friction between bar and debris, which was apparently greater than the difference between the two opposing forces tending to remove the debris. It was also noted that if the pressure on either the top or face of the bar is relieved artificially, the drag force is usually sufficient to carry off the debris.

With this phenomenon in mind, a baffle type of inlet, Inlet J, was devised as shown in Fig. 7. It was hoped that the arrangement of its baffle blocks would incite enough turbulence to relieve the pressure on either top or front faces of the inlet bars, causing debris to wash off. However, a definite pattern of flow formed over and around the blocks, particularly where the depth of flow was still appreciable, and caused debris to lodge on the blocks in the same manner as it had on the bars of the other inlets. It appeared doubtful that any change in the arrangement of baffle blocks or openings could be expected to result in any great improvement. Tests of this type of inlet were therefore discontinued, even though the inlet was found to be highly efficient from the standpoint of capacity.

In summary it can be said that, of the inlets investigated, only Inlet G, which has openings parallel to the flow, can be considered highly efficient in passing this type of debris.

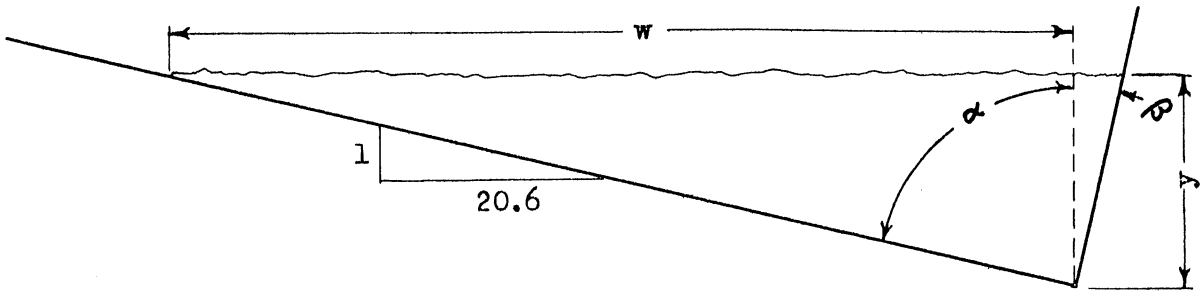
VII. ANALYSIS OF GUTTER CAPACITY

If a grate inlet can be so constructed that its capacity is greater than the capacity of the gutter in which it is set, the gutter capacity may become the limiting design condition. The depth of flow may never be excessive, at least in a gutter of this shape, but it may be necessary to limit the width of flow to an amount which will not constitute a serious traffic hazard, even though that flow occurs only rarely. For this reason, the relation between gutter discharge and width of flow must be known. This relation can be obtained by establishing the depth-discharge relation for a gutter, since depth determines width, and vice versa.

Inasmuch as the hydraulic radius, R, of the gutter section can be given by a single expression in terms of depth, the depth-discharge relation of this gutter may be obtained by application of the Manning formula, in the form:

$$Q = 1.486/n \; AR^{2/3} \; s^{1/2}. \qquad (1)$$

The hydraulic radius, R, is defined as the ratio of the area of flow, A, to the wetted perimeter, P. Expressions for A, P, and R are derived from the following sketch, which shows a cross section of the gutter, with a depth of flow at the curb equal to y.



$$A = \frac{y^2}{2}\tan\alpha + \frac{y^2}{2}\tan\beta = \frac{y^2}{2}(\tan\alpha + \tan\beta).$$

$$P = \frac{y}{\cos\alpha} + \frac{y}{\cos\beta} = y\,\frac{(\cos\alpha + \cos\beta)}{\cos\alpha\cos\beta}.$$

$$R = \frac{A}{P} = \frac{y}{2}\,\frac{(\tan\alpha + \tan\beta)\cos\alpha\cos\beta}{\cos\alpha + \cos\beta}.$$

Substituting these expressions for A and R in Manning's formula,

$$Q = \frac{1.486}{n}\left(\frac{\tan\alpha + \tan\beta}{2}\right)^{5/3}\left(\frac{\cos\alpha\cos\beta}{\cos\alpha + \cos\beta}\right)^{2/3} s^{1/2}\, y^{8/3}.$$

Since the crown slope of this gutter is 1 3/4 in. in 3 ft, and the curb slope 6 1/2 in. in 1 3/4 in., the angles α and β are 87° and 13.9°, respectively. Substituting these values in the above expression and simplifying, a depth-discharge relation is obtained for the test gutter and gutters of the same shape, as follows:

$$Q = 9.5\,\sqrt{s}/n\; y^{8/3}. \qquad (1)$$

The above formula can be used to compute the discharge for any depth of flow, or vice versa, if the velocity index, $\sqrt{s}/n$, is known. Fig. 27 gives solutions of this formula for even-numbered values of the index from 6 to 18. Solutions for intermediate values of the velocity index can be obtained by interpolation or by substitution in the formula.

Since the gutter is of triangular shape, the width of flow from the curb line at any discharge is equal to a constant times the depth of flow, in this case 20.6 y. For convenience, a scale of width of flow was superimposed on the depth scale in Fig. 27, making it possible to observe directly the width of flow corresponding to any depth or to any discharge.

To obtain an empirical formula for the gutter discharge, an analysis was also made of the experimental data on the depth of flow in the test gutter. The data of Table 1 was plotted on logarithmic paper, using as coordinates the average water surface elevations and corrected gutter discharges. The data for each test slope yielded a straight line, the equation of which was therefore of the form $Q_G = K\,y^m$. The lines, which were very close to parallel, were drawn parallel with a slope of 2.45, which is therefore the exponent m. The values of the constant, K, obtained for each test slope were then plotted on logarithmic paper, and were found to vary as the square root of the slope, as is true for flow in any open channel. Thus, $K = K' s^{1/2}$, and, since this logarithmic plot also showed that K' has a value of 710, the empirical formula for the discharge of the test gutter is:

$$Q_G = 710\, s^{1/2}\, y^{2.45}. \qquad (2)$$

This formula can be compared to the theoretical formula by converting either to the form of the other. Since the roughness coefficient n for the test gutter was found to be 0.0103, the empirical formula for any gutter of the same shape becomes:

$$Q_G = 7.3\, \sqrt{s}/n\, y^{2.45}. \qquad (3)$$

If the empirical curves are drawn with an arbitrary slope of 8/3, the formula obtained is:

$$Q_G = 10.8\, \sqrt{s}/n\, y^{8/3}. \qquad (4)$$

Thus it is seen that in this range of depths the constant is very sensitive to small variations in the exponent of y. In either form the empirical formula gives gutter discharges up to 5 per cent higher than those obtained with the theoretical formula. This discrepancy may be due to differences between the shape of the test gutter section and that of the theoretical gutter. From an inspection of the bottom configuration in Fig. 8, it can be seen that the bottom of the test gutter did not conform exactly to a 20.6 to 1 cross slope, but sagged a significant amount. This sagging caused an increase in the area of flow up to almost 5 per cent for some of the discharges used. For this reason, it was decided that the theoretical formula, $Q_G = 9.5\ \sqrt{s}/n\ y^{8/3}$, more accurately represents the flow in an actual gutter of this shape.

VIII. APPLICATION OF RESULTS TO DESIGN

The results of this investigation can be used to determine the required spacing for inlets of any of the types tested, for a given set of design conditions. Moreover, the data enable one to predict the operating capacity of any individual inlet, either under the design conditions or under other circumstances, such as rainfall intensities higher or lower than the design intensity, or clogging of one or more inlets in a series.

In the design of a surface drainage system for any particular roadway, the design conditions which will ordinarily be known are as follows:

s - highway grade or slope,
n - Manning's roughness coefficient,
I - rainfall intensity, in. per hour,
b - width of highway drained, ft.

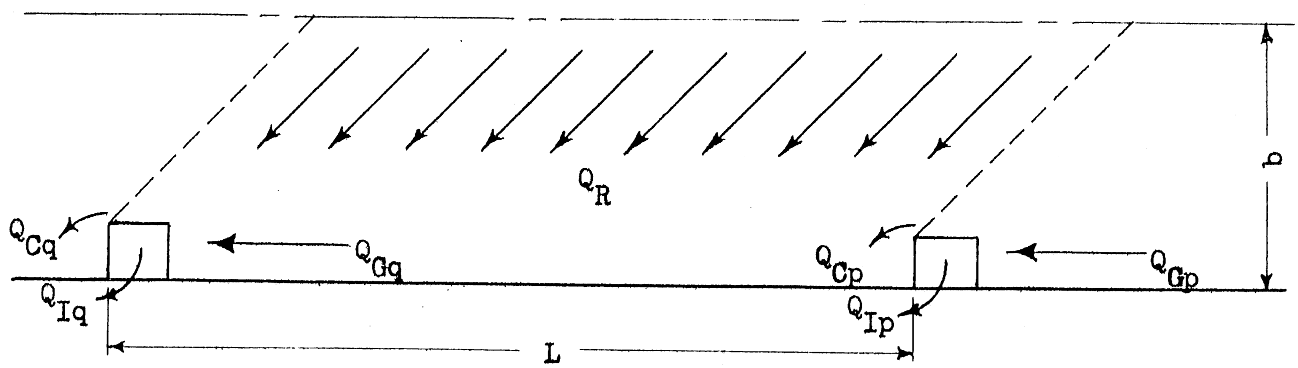
Knowing the above elements, one may select a value for one of the following three variables as a limiting factor and compute the other two from the data of this report:

Q_C - carryover discharge, cu ft per sec,
w - maximum width of flow in gutter, ft,
L - inlet spacing, ft.

In making these computations, one will also determine the following variables, which are dependent on those above:

Q_G - gutter discharge, cu ft per sec,
Q_I - inlet capacity, cu ft per sec,
Q_R - runoff per inlet, cu ft per sec.

The relationship of variables may be seen from the following sketch which shows the portion of roadway drained by Inlet q, one of a series of grate inlets.



The area drained by Inlet q is bL sq ft. During a rainfall of I in. per hour, the rate of runoff from this area will therefore be bIL/12 cu ft per hour, or

$$Q_R = \frac{bIL}{43{,}200} \text{ cu ft per sec.} \qquad (5)$$

The flow approaching Inlet q will be the sum of the runoff and the carryover from Inlet p.

$$Q_{Gq} = Q_R + Q_{Cp} .$$

For any inlet

$$Q_G = Q_I + Q_C . \qquad (6)$$

Therefore

$$Q_{Gq} = Q_{Iq} + Q_{Cq} .$$

Combining the two equations for Q_{Gq},

$$Q_{Gq} = Q_{Iq} + Q_{Cq} = Q_R + Q_{Cp} .$$

From this equation it can be seen that as Q_{Cq} approaches Q_{Cp} in magnitude, Q_{Iq} approaches Q_R, and if $Q_{Cq} = Q_{Cp}$, $Q_{Iq} = Q_R$. In other words, in a series of evenly spaced inlets where each inlet has the same carryover as adjacent inlets, the capacity of each inlet is equal to the runoff per inlet. Therefore for a series of inlets,

$$Q_I = Q_R = \frac{bIL}{43{,}200} \text{ cu ft per sec.}$$

and the spacing which will result in this inlet capacity is:

$$L = \frac{43,200\ Q_I}{bI}\ \text{ft.} \qquad (7)$$

A typical design problem might be to determine the maximum spacing of inlets on a long uniform grade. As an example, a series of inlets of Type G is to drain a 24-ft width of highway of 6 per cent grade and gutter roughness corresponding to $n = 0.016$, during a rainfall of 4 in. per hour, with a carryover of 0.15 cu ft per sec or less. The velocity index can be computed or taken directly from Table 43. For $s = 6$ per cent and $n = 0.016$, the velocity index is 15.3. For $\sqrt{s}/n = 15.3$, and a carryover of 0.15 cu ft per sec, Fig. 25 shows the capacity of Inlet G to be 0.76 cu ft per sec. The maximum spacing for this carryover can then be computed by the use of Equation (7).

$$L = \frac{43,200\ Q_I}{bI} = \frac{43,200 \times 0.76}{24 \times 4} = 342\ \text{ft.}$$

If the width of flow in the gutter is desired,

$$Q_G = Q_I + Q_C = 0.76 + 0.15 = 0.91\ \text{cu ft per sec.}$$

and the depth-discharge curves, Fig. 27, show that for $Q_G = 0.91$ and $\sqrt{s}/n = 15.3$,

$$w = 3.1\ \text{ft.}$$

Similar computations can be made using the width of flow as a limiting factor. For instance, inlets of Type D are to drain the roadway of the previous example with a maximum width of flow of 3.5 ft in the gutter. From the depth-discharge curves, for a velocity index of 15.3, the gutter flow corresponding to $w = 3.5$ ft is seen to be 1.28 cu ft per sec. In this case, it is necessary to interpolate between Figs. 24 and 25 to determine the correct carryover and inlet capacity. From Fig. 24, for $Q_C = 0.10$, $Q_I = 1.14$. From Fig. 25, for $Q_C = 0.15$, $Q_I = 1.29$. By interpolation, for $Q_C = 0.11$, $Q_I = 1.17$, and $Q_G = 1.28$. Then:

$$L = \frac{43,200 \times 1.17}{24 \times 4} = 526\ \text{ft.}$$

If the spacing of the inlets is determined by some other consideration, such as the spacing of intersecting streets, the same computations may be made in reverse to determine whether or not a given inlet is adequate. It should be noted here that in cases where backwater is produced by intersecting streets, the capacity of an inlet may be greater than that obtained in the tests. Returning to the example, and using the same gutter and rainfall intensity, but with an arbitrary inlet spacing of 440 ft, it is found that:

$$Q_I = Q_R = \frac{24 \times 4 \times 440}{43,200} = 0.98 \text{ cu ft per sec.}$$

If inlets of Type A are to be used, the approximate operating point of the inlets can be found from Fig. 25, which shows that for a velocity index of 15.3 and a carryover of 0.15 cu ft per sec, Inlet A has a capacity of 1.00 cu ft per sec, which is slightly greater than the required capacity.

An interesting feature of a series arrangement of grate inlets is the inherent safety factor; that is, the ability of the inlets to adjust to a rainfall of higher intensity than that for which the series was designed. A rain of higher intensity automatically causes each inlet to operate with higher capacity, as a result of the increase in gutter discharge and carryover. This valuable attribute can be illustrated by extending the second example, in which it was found that inlets of Type D, with a spacing of 526 ft, will handle a rainfall of a 4-in.-per-hour intensity, with 0.11 cu ft per sec carryover. If an intensity of 5 in. per hour occurs during a rare storm, the runoff per inlet will increase to 1.42 cu ft per sec, causing each inlet to operate at that capacity. The carryover will then be 0.21 cu ft per sec, still a relatively small amount. The gutter flow above each inlet will be 1.42 + 0.21 = 1.63 cu ft per sec, increasing the width of flow from 3.5 to 3.8 ft. Thus, the only adverse result of this excessive rainfall is a slight increase in the width of flow. One might utilize this ability of inlets in series by designing for a fairly frequent storm, such as a yearly storm, allowing the design conditions to be exceeded in this manner by less frequent storms.

The flexibility of inlets in series may be utilized in other ways. For instance, one might select as a design condition an average rainfall intensity for an arbitrary length of time, such as 5 or 6 minutes, rather than the rainfall corresponding to the time of concentration, which for a grate inlet will ordinarily be only a few minutes. According to Meyer's rainfall formulas and curves, the expected rainfall intensity for a period of 3 or 4 minutes is not considerably greater than that for a period of 5 or 6 minutes. Since inlets in series adjust to changes in the rate of runoff, the use of a rainfall intensity corresponding to an arbitrary period somewhat longer than the time of concentration appears to be a justifiable approximation in the design of a series of inlets. The design calculations are thus shortened, and the only undesirable result is that the design width of flow in the gutter is slightly exceeded for a period of a few minutes once in several years.

To demonstrate that all inlets of a series tend to operate at the same capacity, another example will be used. The "normal" capacity for the series can be determined by the methods previously outlined. However, if for any reason the gutter flow approaching any individual inlet becomes either more or less than the normal amount for the series, the flow intercepted by succeeding inlets will increase or decrease, as the case may be, until the normal inlet capacity is reached at some inlet. Inlets further downstream will operate at normal capacity, unless they are affected by some other unusual circumstance.

Gutter flows other than normal for the series occur at the beginning of the series, and may also be produced by clogging of one or more inlets in the series. Both possibilities are illustrated in the following example. In a gutter having a velocity index of 14.0, ten inlets of Type D are spaced to receive 1.00 cu ft per sec runoff per inlet, which results in a normal carryover of 0.07 cu ft per sec. By some unusual circumstance, Inlet No. 5 becomes completely clogged. The discharge intercepted by each of the other inlets can then be determined by use of the appropriate rating curve for the inlet, as shown in the following table.

Inlet Number	Runoff	Condition	Q_G	Q_I	Q_C
1	1.00	Clean	1.00	0.94	0.06
2	"	"	1.06	0.99	0.07
3	"	"	1.07	1.00	0.07
4	"	"	1.07	1.00	0.07
5	"	Clogged	1.07	0	1.07
6	"	Clean	2.07	1.71	0.36
7	"	"	1.36	1.23	0.13
8	"	"	1.13	1.05	0.08
9	"	"	1.08	1.01	0.07
10	"	"	1.07	1.00	0.07

In this example, the normal inlet capacity is reached at the third inlet of the series. Clogging of Inlet No. 5 does not cause any of the runoff to be lost, unless the increased gutter flow overtops the curb. Actually, the increase in gutter flow is of substantial magnitude only between the clogged inlet and the following one, as shown by this computation. Normal inlet capacity is again reached at Inlet No. 9. Unless the last inlet is affected by backwater, 0.07 cu ft per sec of carryover will be lost at the end of the series. This loss can be prevented by shortening the distance between Inlets 9 and 10, so that the runoff from this area plus the carryover from Inlet 9 will be equal to or less than the no-carryover capacity of Inlet 10, which in this example is 0.58 cu ft per sec.

In making similar computations for other inlets, it will be observed that inlets with the highest rating curves readjust to normal capacity in the shortest distance. Furthermore, the lower the design carryover, the quicker this readjustment takes place.

IX. CONCLUSIONS

The results of this investigation lead to the following conclusions. Although all of these tests were made in a gutter with a crown slope of 20.6 to 1, it is probable that many similar conclusions would be obtained from tests in a gutter of different transverse slope.

1. The capacity of a grate inlet can be approximately doubled by permitting a small portion of the water to pass over or around the inlet.

2. The characteristics of grate inlets which are most influential in determining capacity are the width of the inlet normal to the direction of flow, and the efficiency of the inlet openings.

3. The efficiency of grate inlet openings depends mainly on the effective length of the openings in the direction of flow.

4. The capacity of inlets with transverse bars and openings can be increased substantially by rounding the surface of each bar.

5. In the normal range of application, inlets with efficient openings operate with increased capacity as the velocity is increased.

6. Inlets with inefficient openings attain maximum capacity at a velocity index of 12 to 16.

7. In a continuous gutter with supercritical flow, a curb opening only slightly increases the capacity of an inefficient inlet, and has no effect upon the capacity of an efficient inlet.

8. Improving the hydraulic efficiency of inlet openings apparently increases the ability of the inlet to pass debris.

9. For the debris used in the tests, grate bars oriented 45° from the direction of flow are not self-cleaning.

10. In a long series of inlets, the capacity of each inlet is normally equal to the runoff per inlet, except for the first few of the series.

11. In a given series of inlets, a change in the runoff per inlet causes the capacity of each inlet to make a corresponding change, remaining equal to the runoff, unless the gutter capacity is exceeded.

12. If the gutter flow at any one inlet in a series is caused to be more or less than the normal amount for the series, natural adjustments in the capacity of succeeding inlets will restore the series to normal capacity at a point several inlets downstream.

X. RECOMMENDATIONS

On the basis of these conclusions, the following recommendations are offered:

1. If an economy can be so effected, the use of curb openings with grate inlets should be discontinued, except where capacity is provided by ponding over the inlet.

2. For a gutter of cross section similar to that used in the tests, a series of inlets should be designed to operate with a carryover of about 0.10 to 0.20 cu ft per sec, whenever possible.

3. For a continuous gutter of velocity index within the range of these tests, the following three inlet designs are recommended as most nearly satisfying the requirements of capacity, self-cleaning ability and economy.

a. A modification of the standard Minnesota Highway Department inlet.

b. A rectangular inlet with rounded transverse bars, and, for the purpose of economy, rectangular in shape.

c. The Minnesota Highway Department inlet without modification.

4. If the standard Minnesota Highway Department inlet is to be modified for use in a continuous gutter, the form and orientation of openings should be retained, but the width of the inlet normal to the flow should be increased to at least 24 in. As an economy measure, the length of the inlet can be decreased to 16 in. without sacrificing any capacity in the normal range of operation.

5. If an inlet with transverse openings is to be used in a continuous gutter, it should have overall dimensions similar to the above, and should have bars with surface profiles (in a section parallel to the flow) which are arcs of about $4\frac{1}{2}$- to 6-in. radius, tangent to the surface of the bar at the leading edge.

APPENDIX I. - FIGURES

Figure | Page

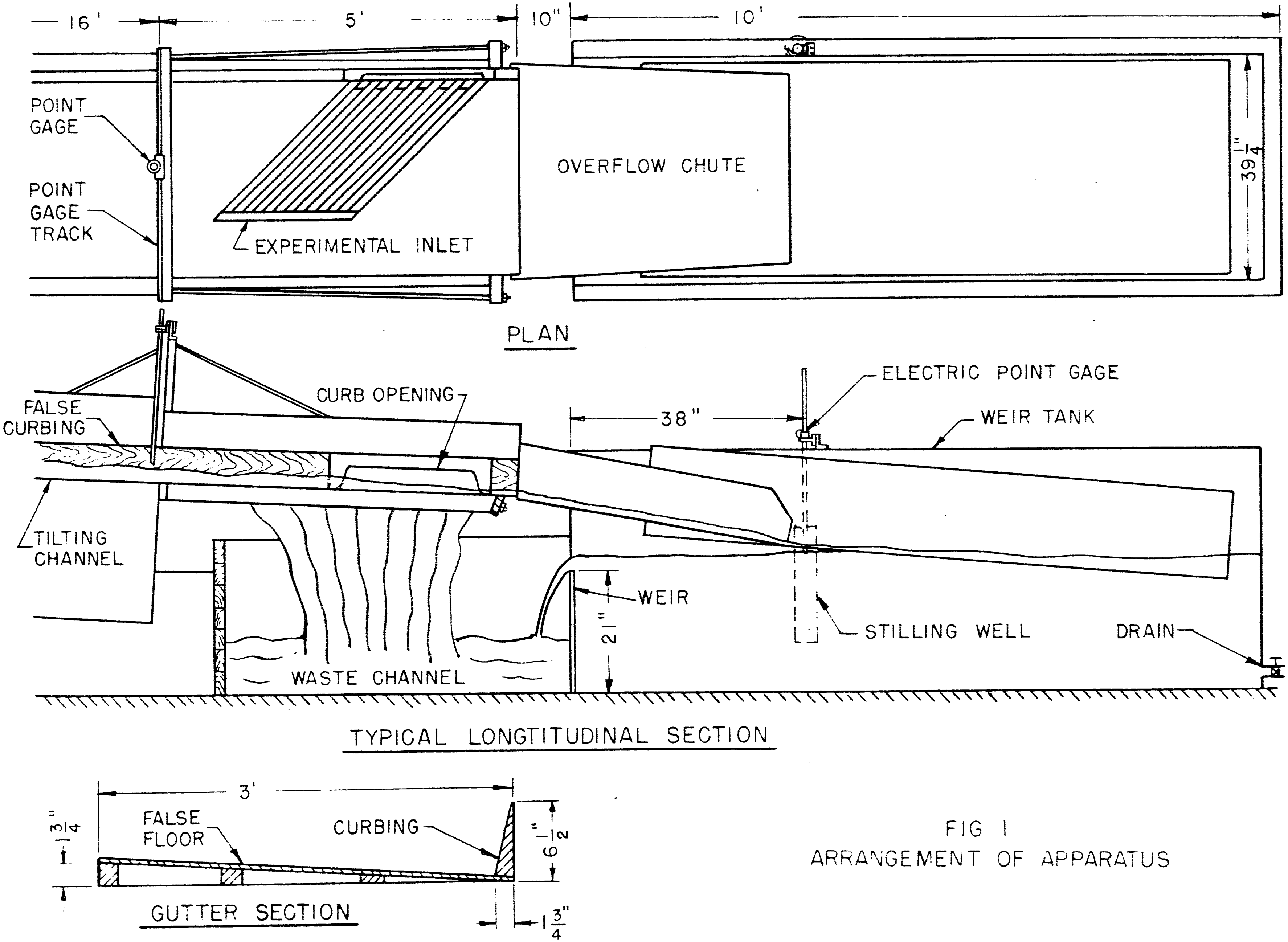


FIG 1
ARRANGEMENT OF APPARATUS

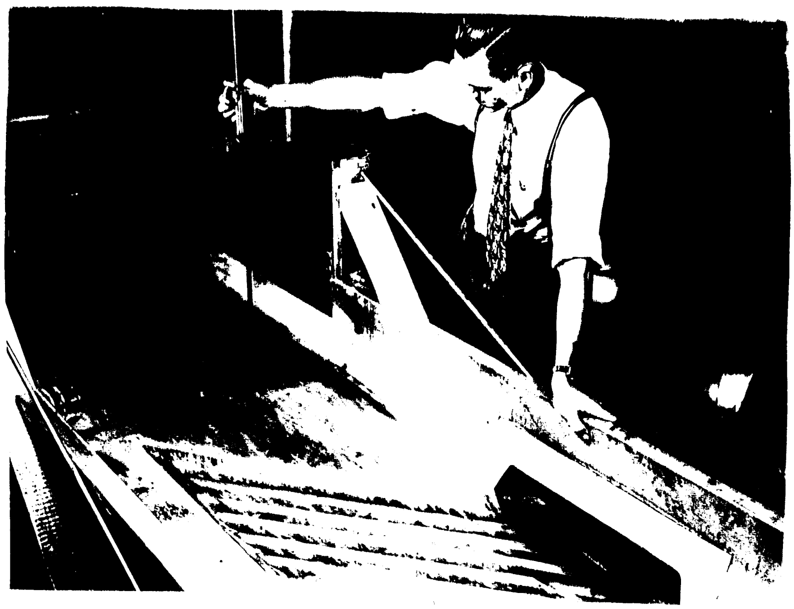


Fig.2. Method of Observing Depth of Flow in Gutter.

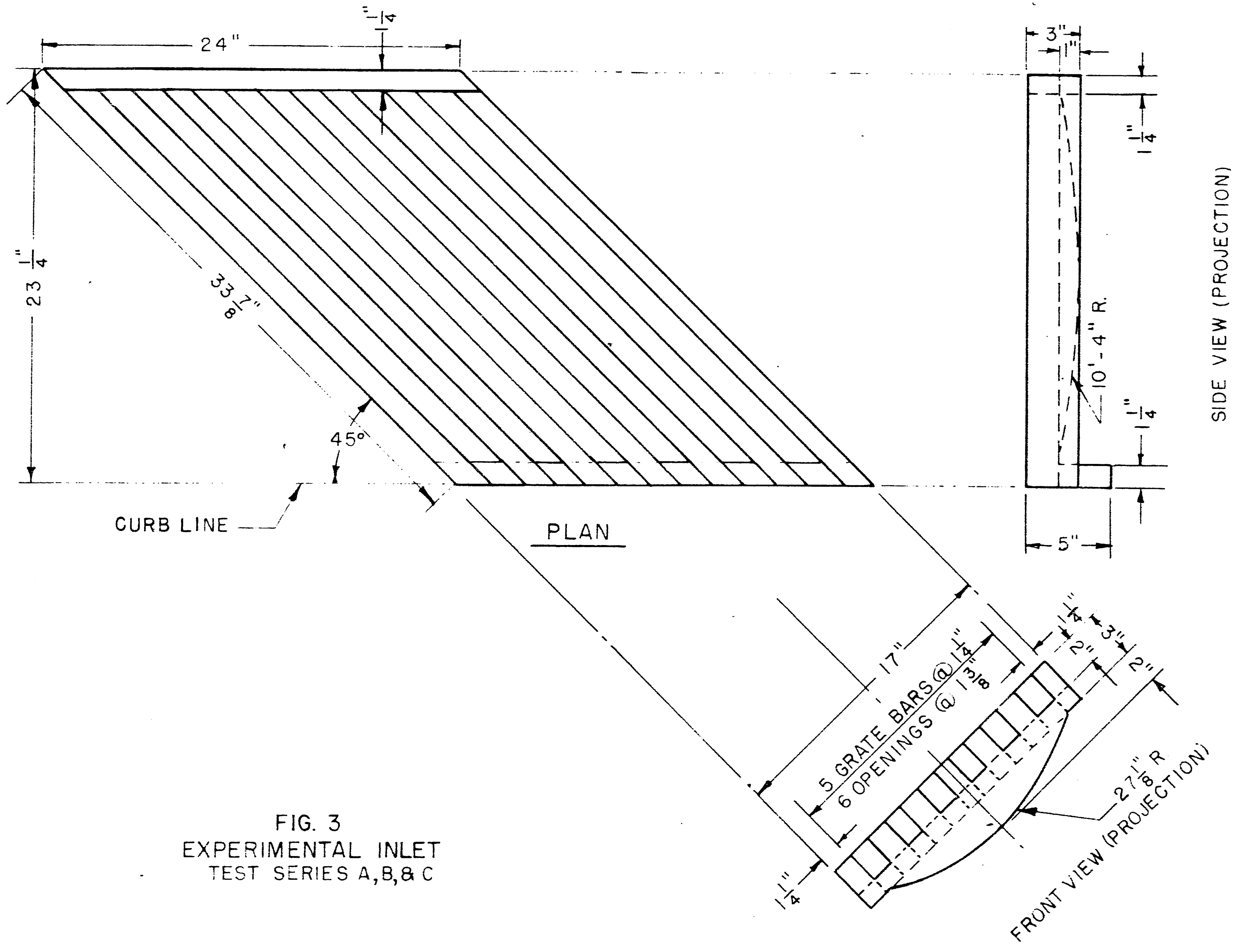


FIG. 3
EXPERIMENTAL INLET
TEST SERIES A, B, & C

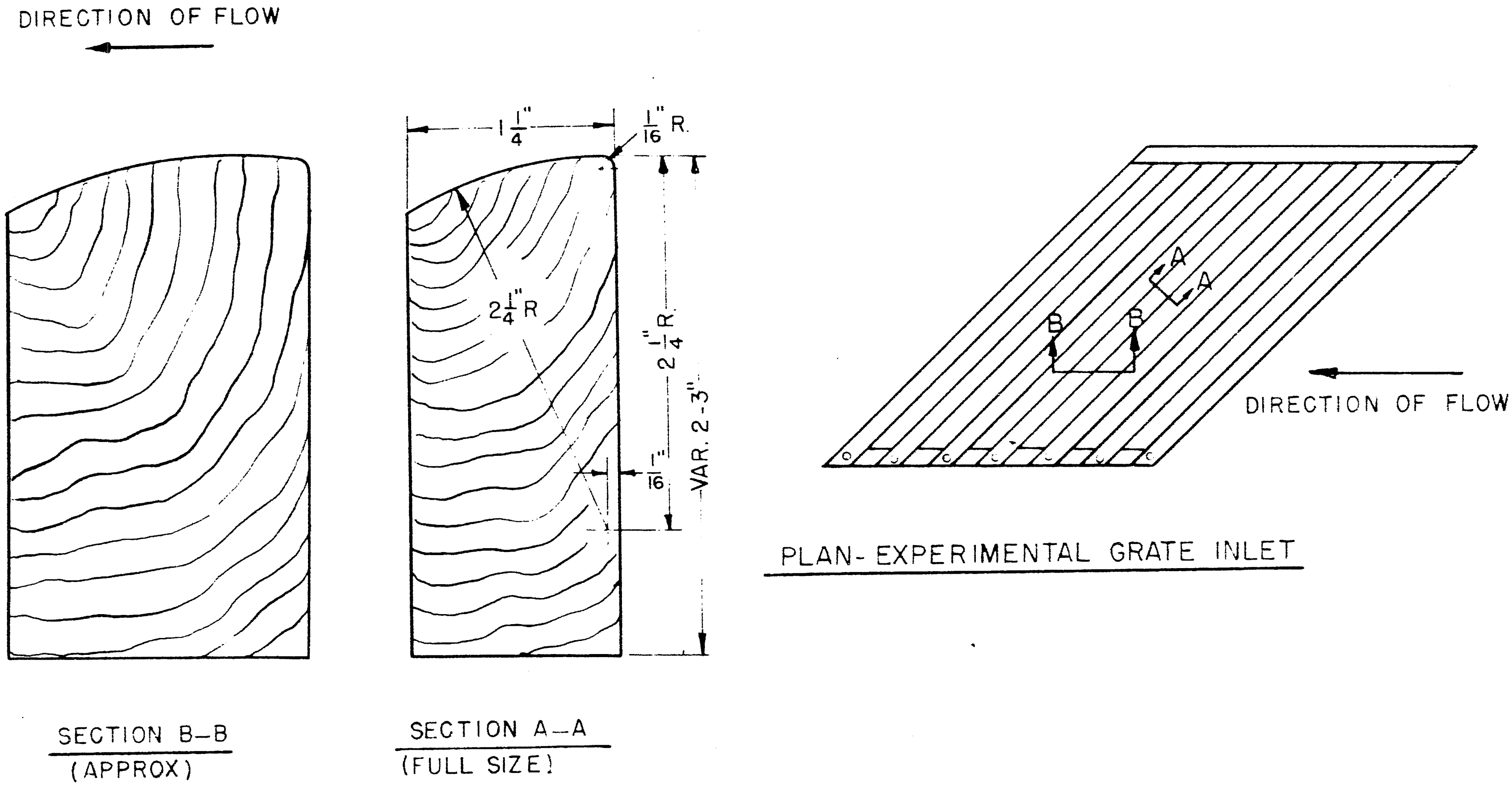


FIG. 4
IMPROVED EXPERIMENTAL INLET
TEST SERIES D, E, & F

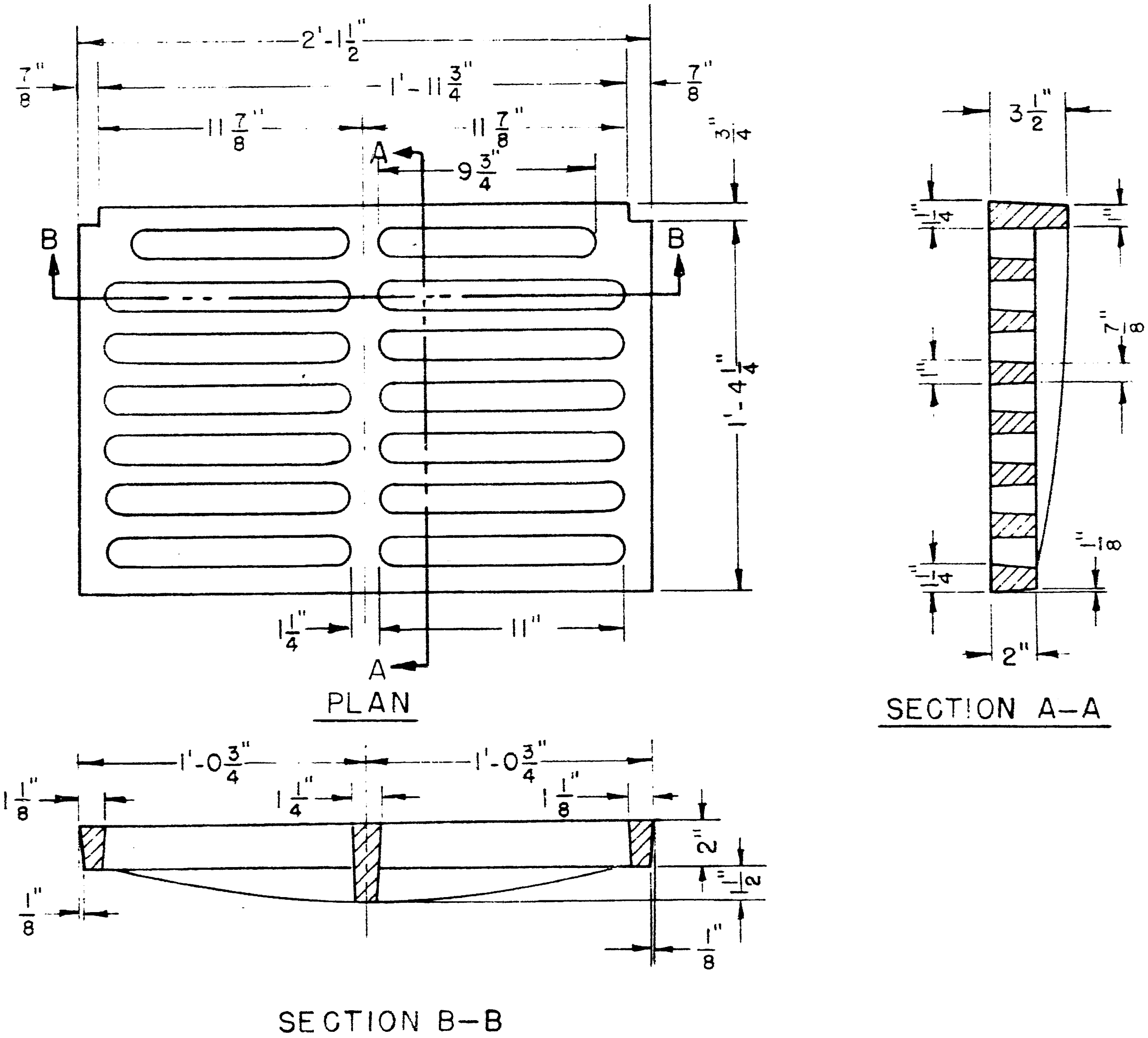


FIG. 5
MINNESOTA HIGHWAY DEPARTMENT INLET
TEST SERIES G

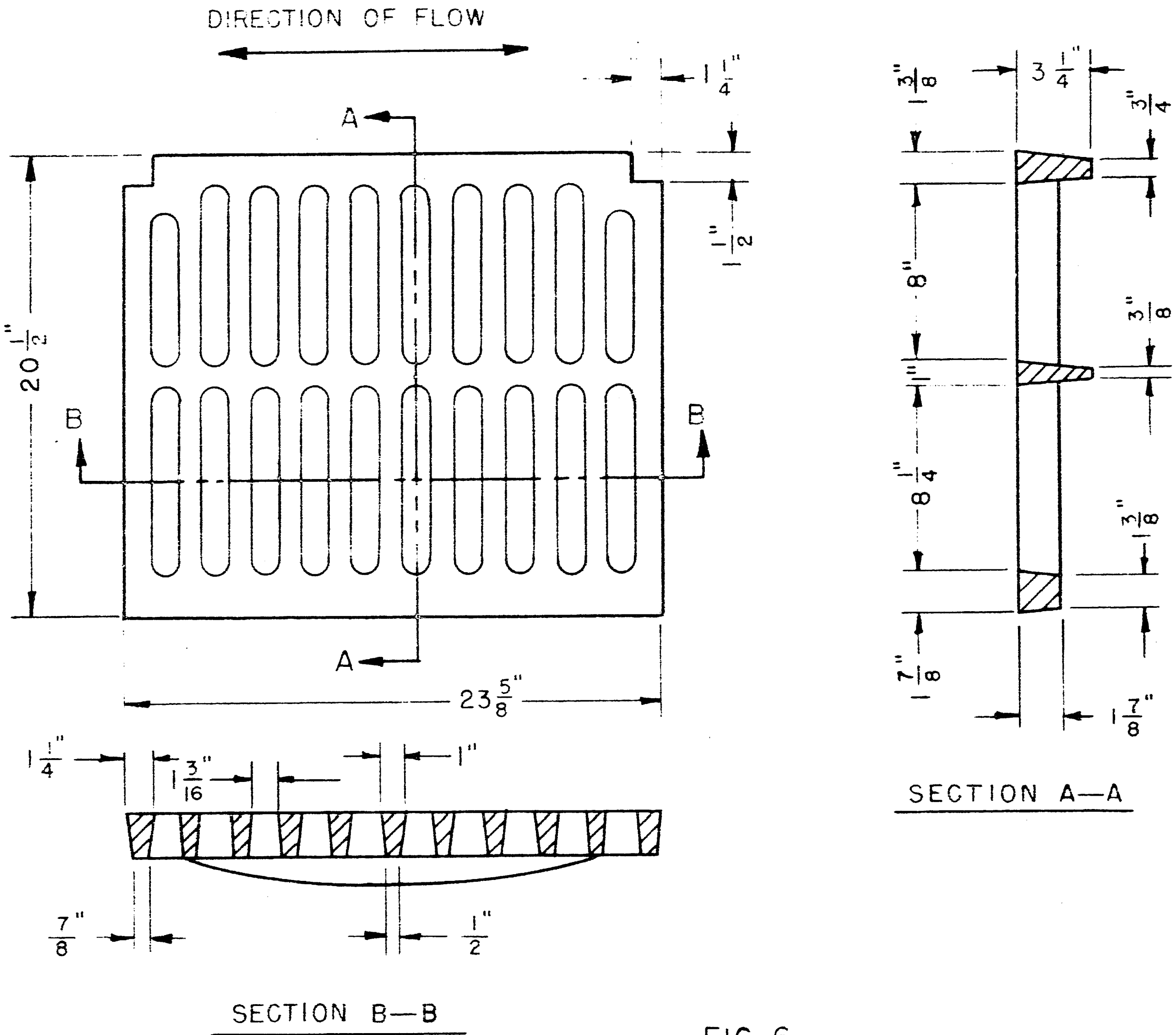


FIG. 6
CITY OF MINNEAPOLIS INLET
TEST SERIES H

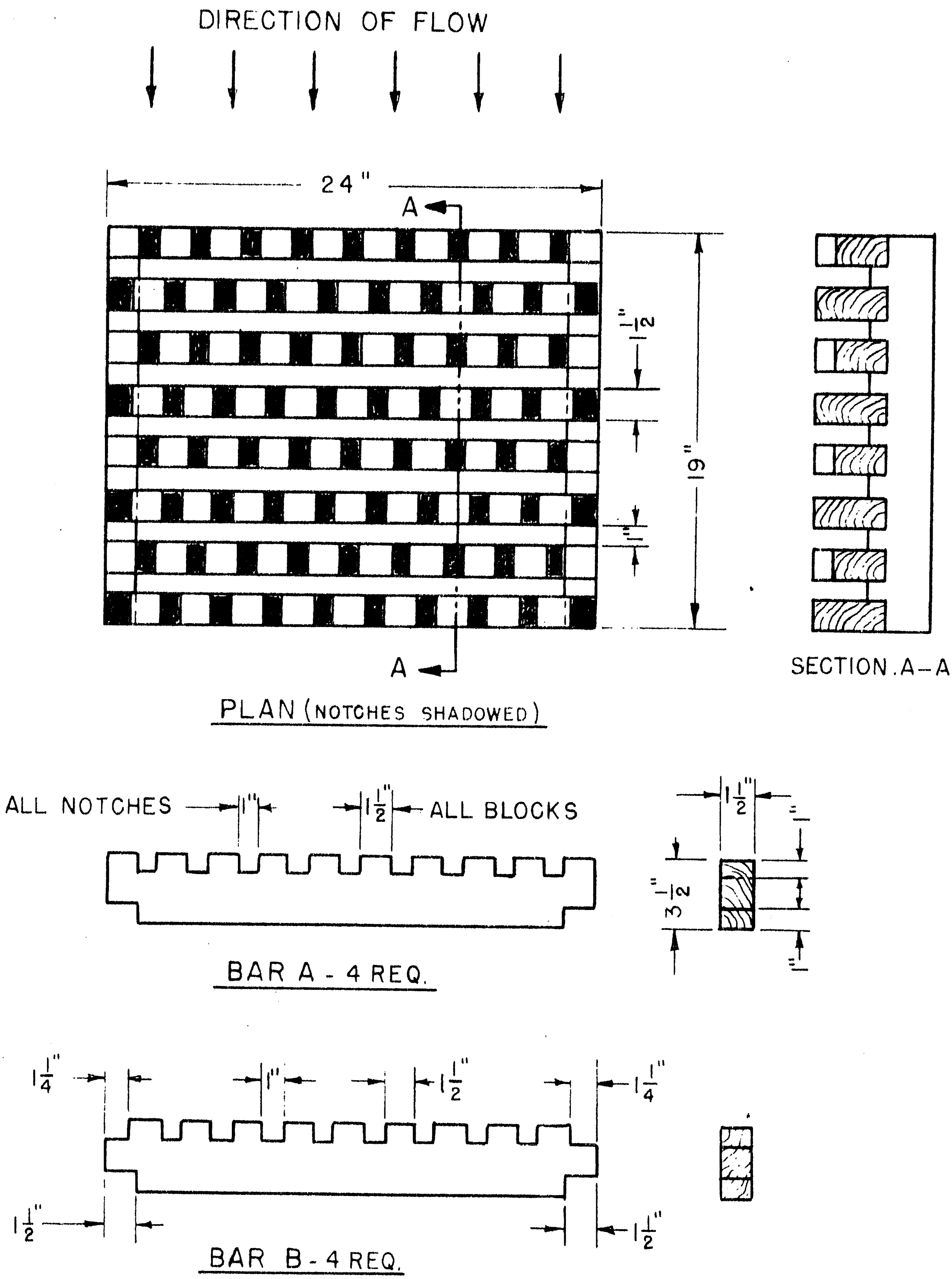


FIG. 7
EXPERIMENTAL BAFFLE INLET
TEST SERIES J

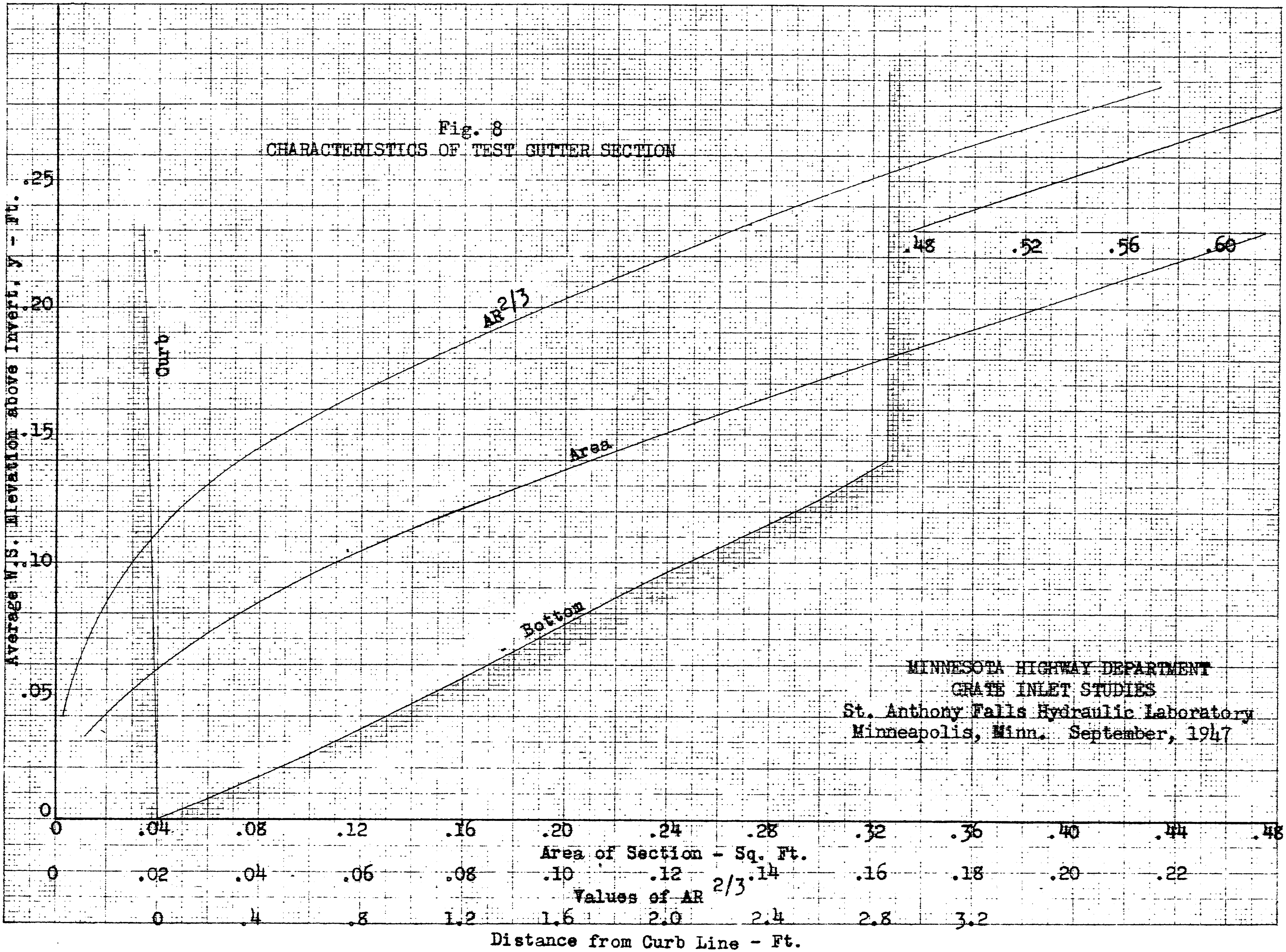


Fig. 8
CHARACTERISTICS OF TEST GUTTER SECTION

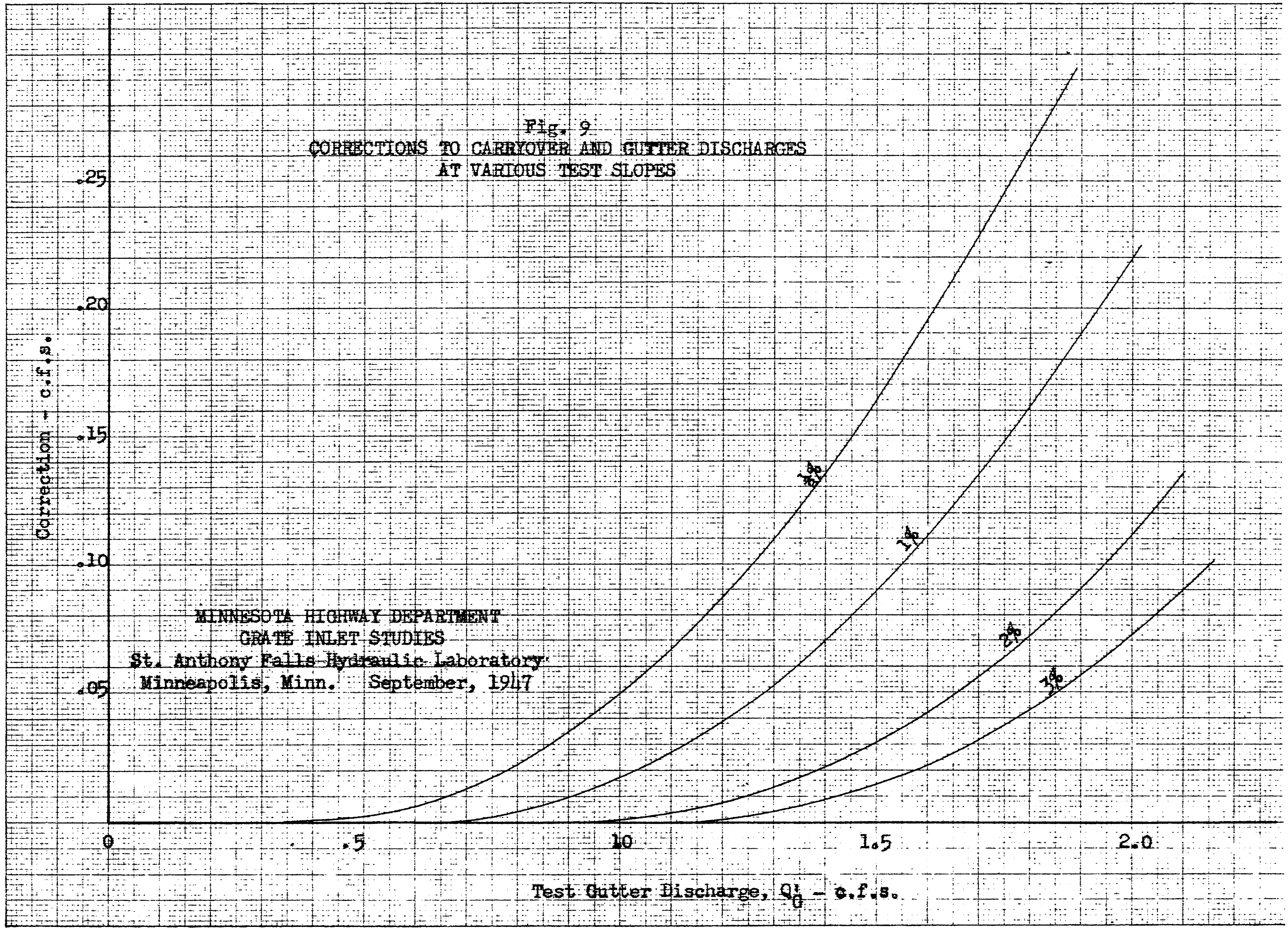


Fig. 9
CORRECTIONS TO CARRYOVER AND GUTTER DISCHARGES
AT VARIOUS TEST SLOPES

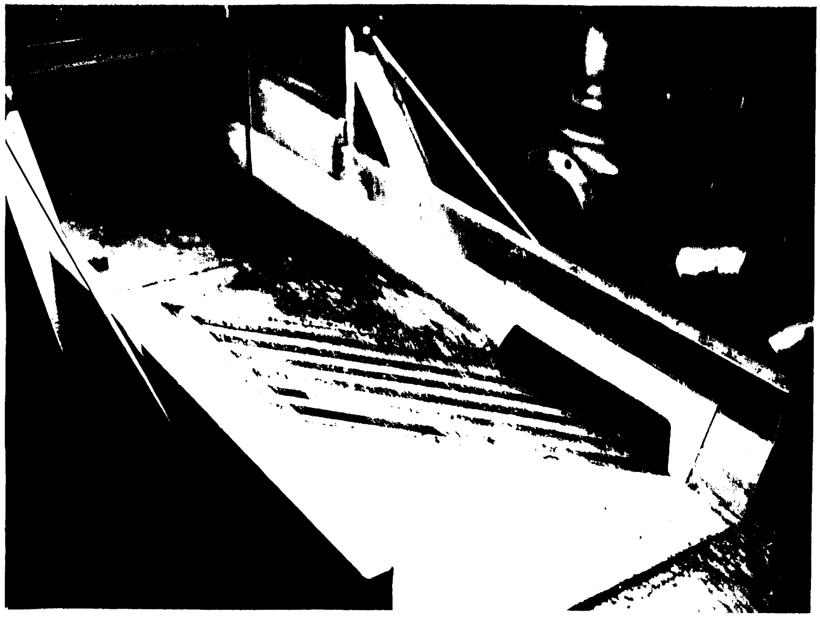


Fig. 10. Experimental inlet, Series A, $\sqrt{s}/n = 14.0$. $Q_G = 1.02$, $Q_I = 0.92$, $Q_C = 0.10$ cu ft per sec.

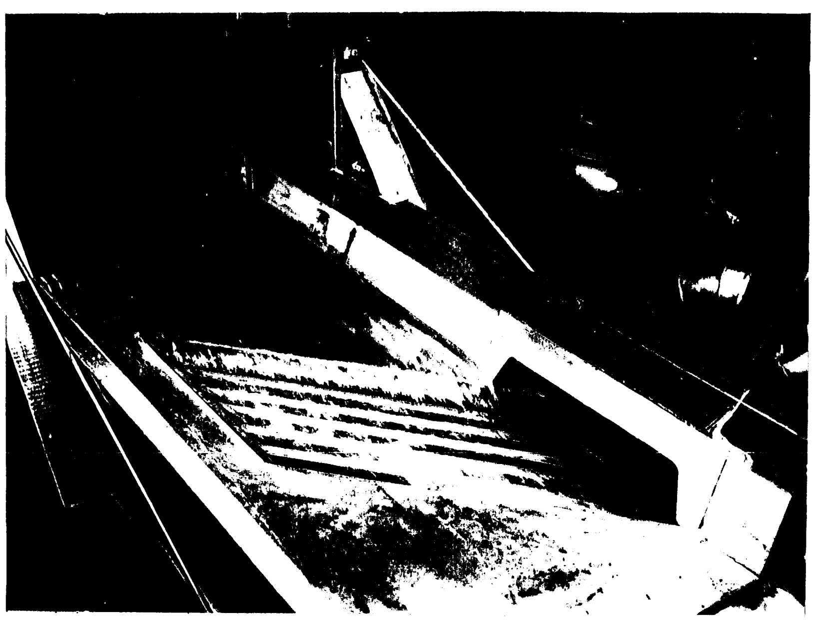


Fig. 11. Experimental inlet, Series C, $\sqrt{s}/n = 14.0$. $Q_G = 1.02$, $Q_I = 0.97$, $Q_C = 0.05$ cu ft per sec.

Fig. 12. Improved experimental inlet, Series D, $\sqrt{s}/n=14.0$. $Q_G = 1.05$, $Q_I = 0.98$, $Q_C = 0.07$ cu ft per sec.

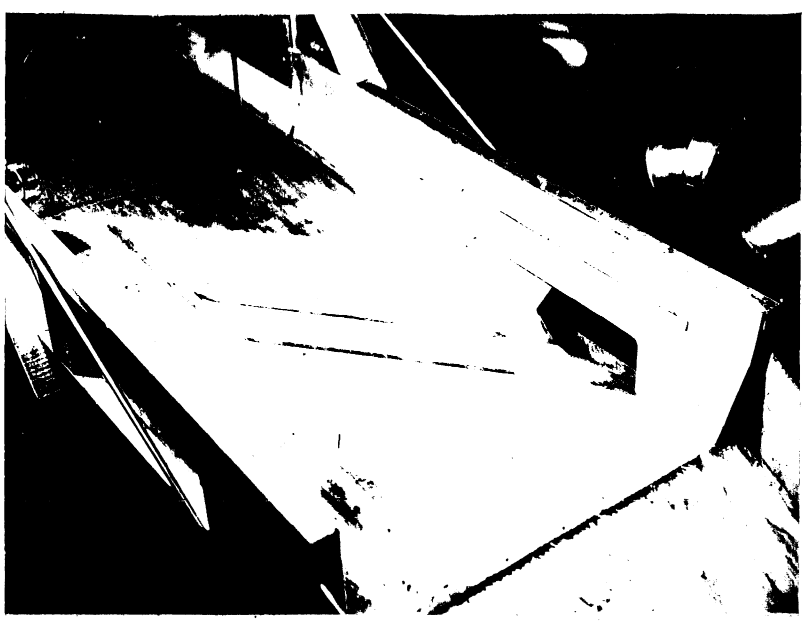


Fig. 13. Improved experimental inlet, Series E, $\sqrt{s}/n=14.0$. $Q_G = 1.10$, $Q_I = 1.00$, $Q_C = 0.10$ cu ft per sec.

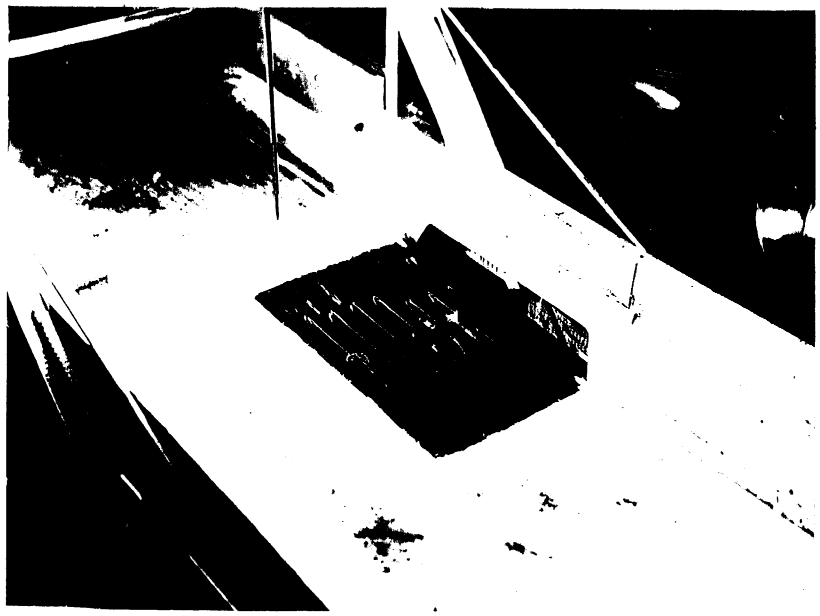


Fig. 14. Highway Department inlet, Series G, $\sqrt{s}/n = 14.0$.
$Q_G = 1.00$, $Q_I = 0.81$, $Q_C = 0.19$ cu ft per sec.

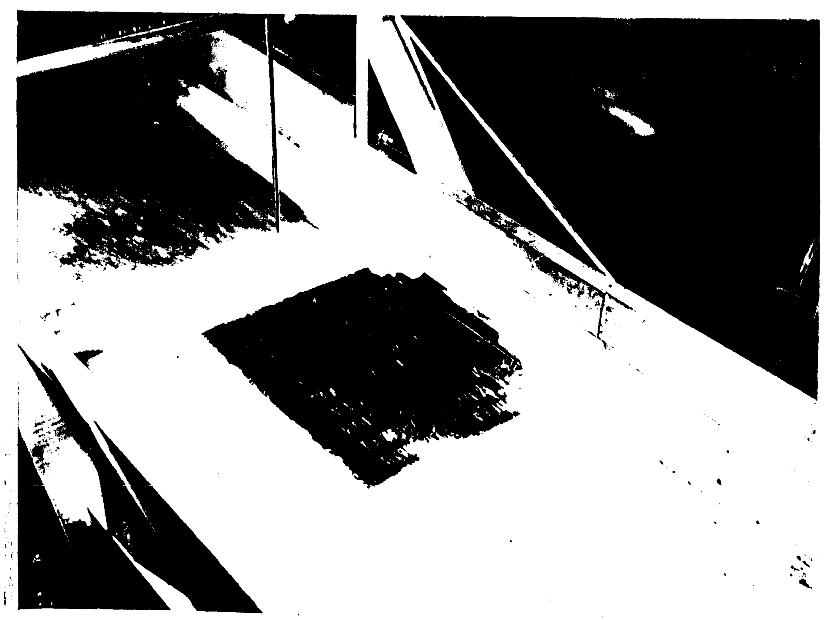


Fig. 15. City of Minneapolis inlet, Series H, $\sqrt{s}/n = 14.0$.
$Q_G = 1.00$, $Q_I = 0.77$, $Q_C = 0.23$ cu ft per sec.

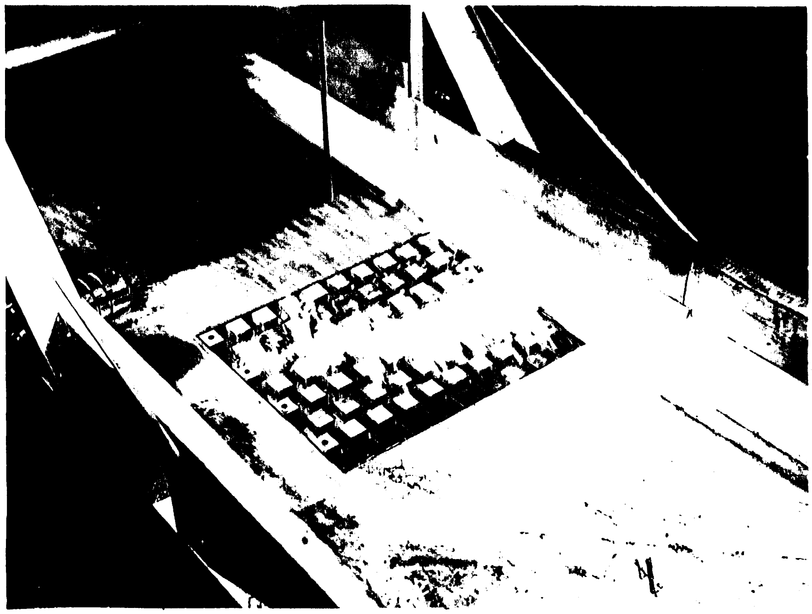


Fig. 16. Experimental baffle inlet, Series J, $\Upsilon s/h = 14.0$. $Q_G = 1.00$, $Q_I = 0.96$, $Q_C = 0.04$ cu ft per sec.

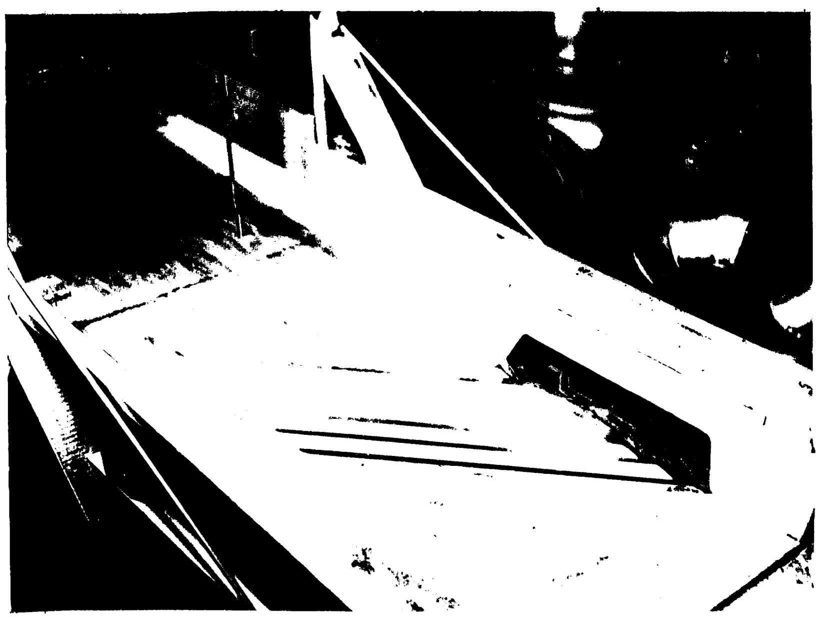


Fig. 17. Improved experimental inlet, Series D, $\Upsilon s/h = 14.0$. $Q_G = 1.50$, $Q_I = 1.33$, $Q_C = 0.17$ cu ft per sec.

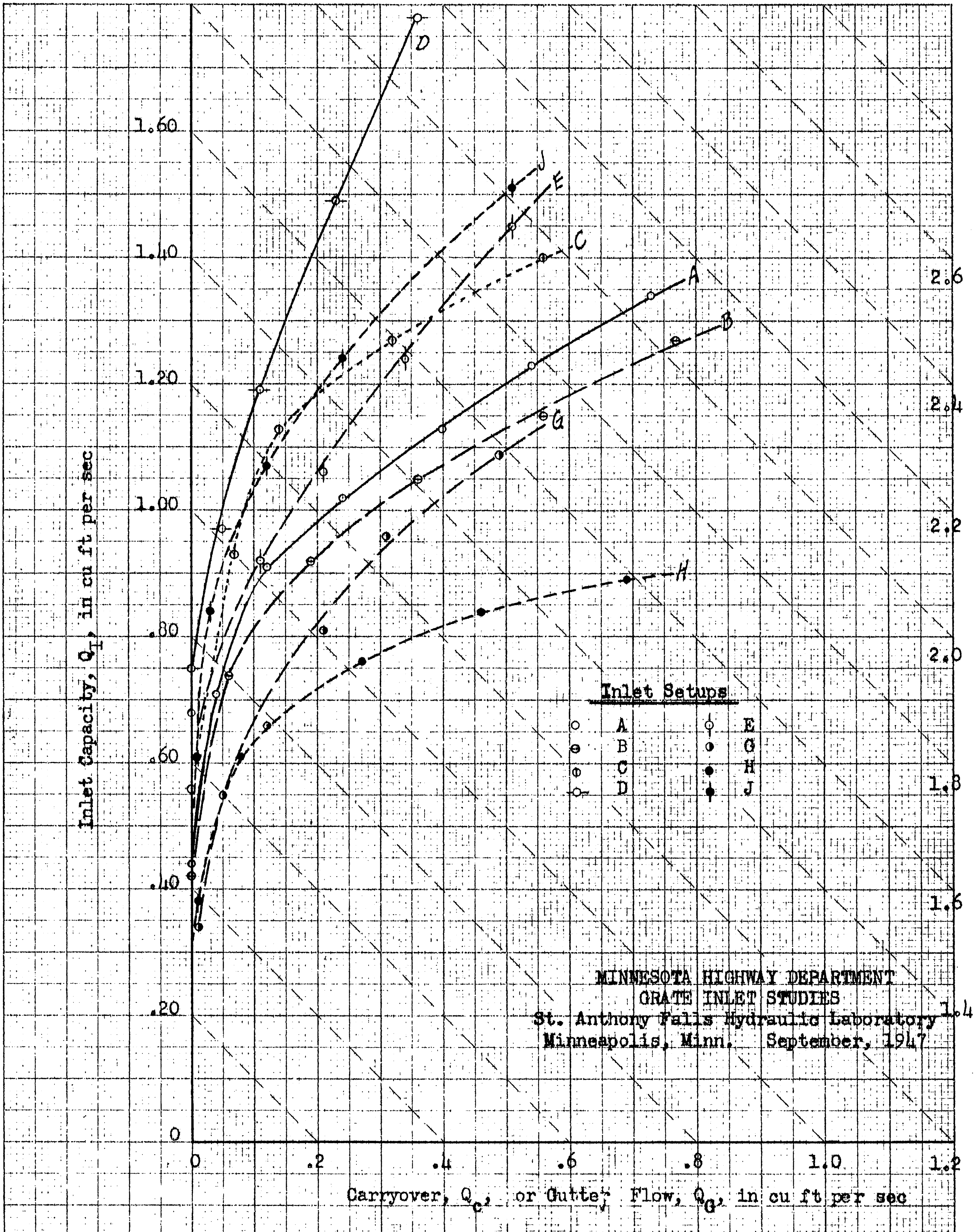


Fig. 18. RATING CURVES FOR VARIOUS INLET SETUPS AT TEST SLOPE OF 3.0%, $\sqrt{s}/n$ = 17.2

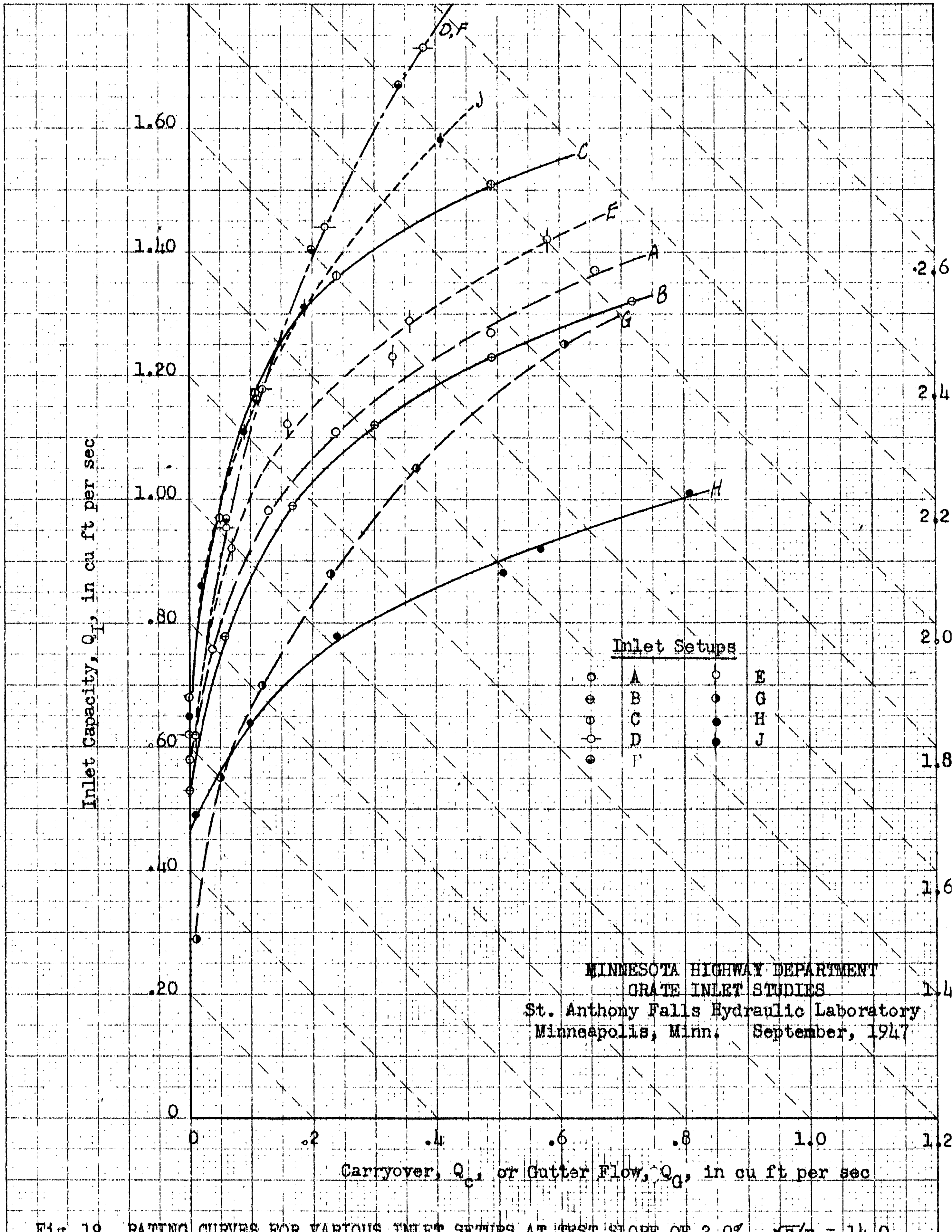


Fig. 19. RATING CURVES FOR VARIOUS INLET SETUPS AT TEST SLOPE OF 2.0%, $\sqrt{s}/n = 14.0$

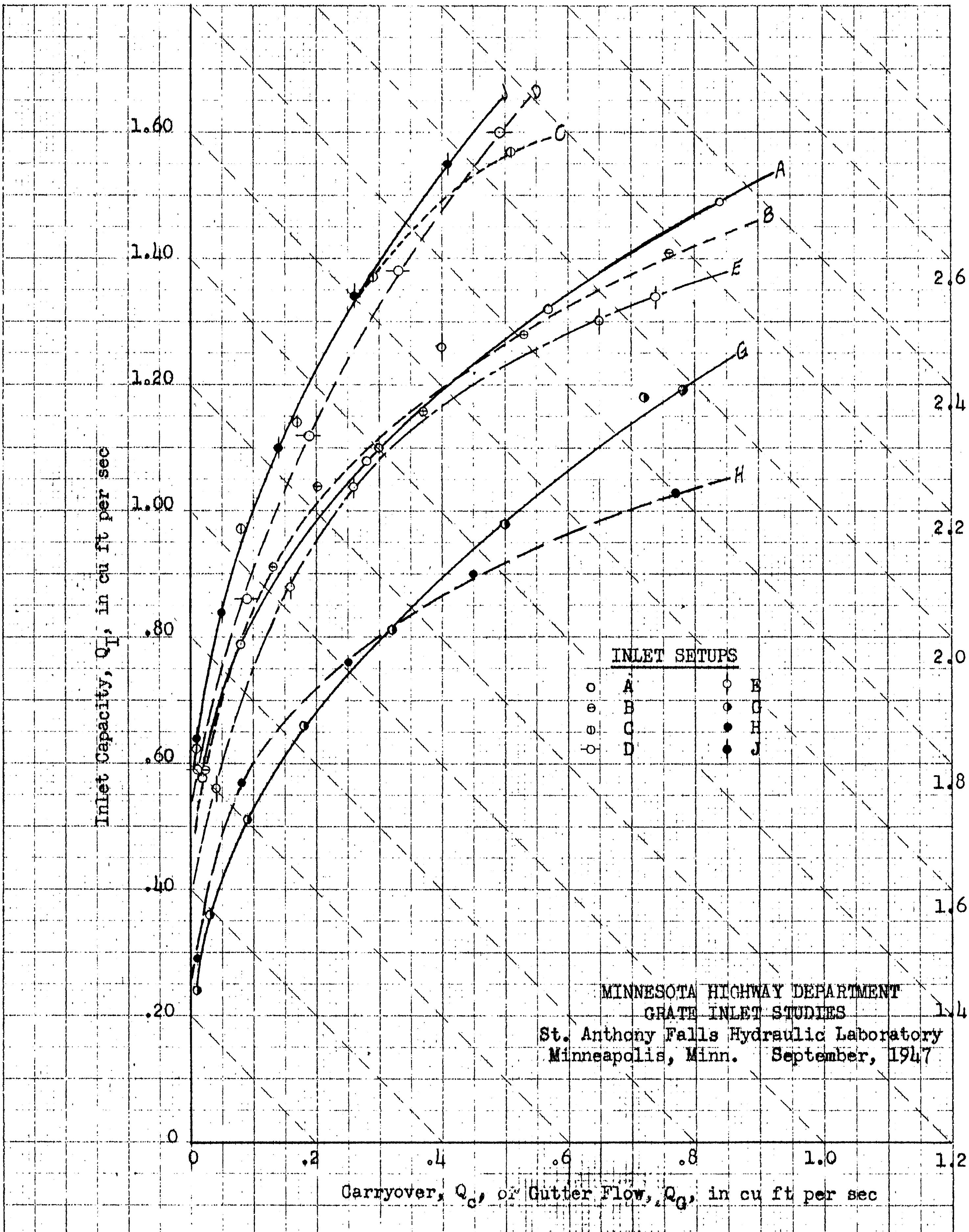


Fig. 20. RATING CURVES FOR VARIOUS INLET SETUPS AT TEST SLOPE OF 1.0%, $\sqrt{s}/n = 9.8$

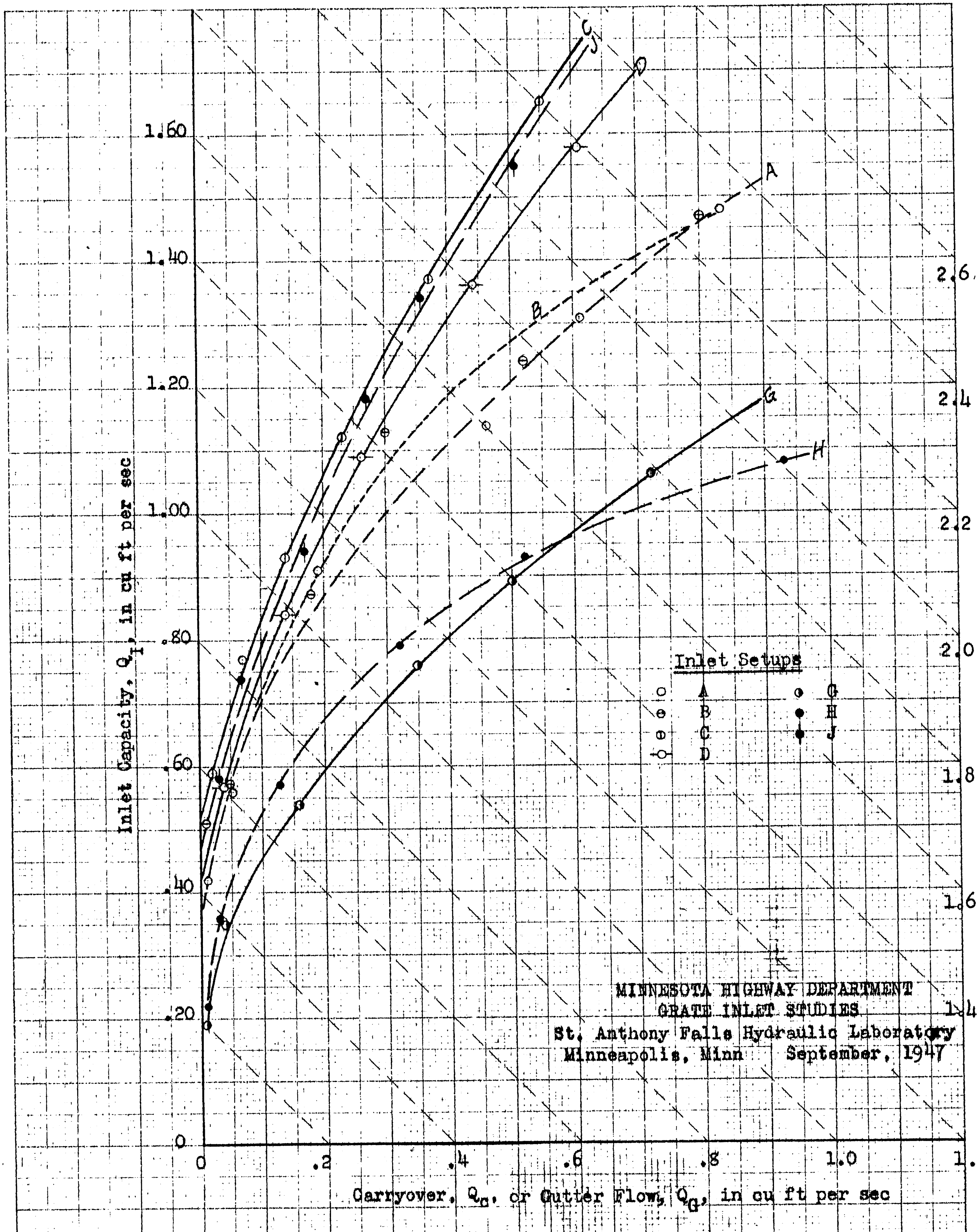
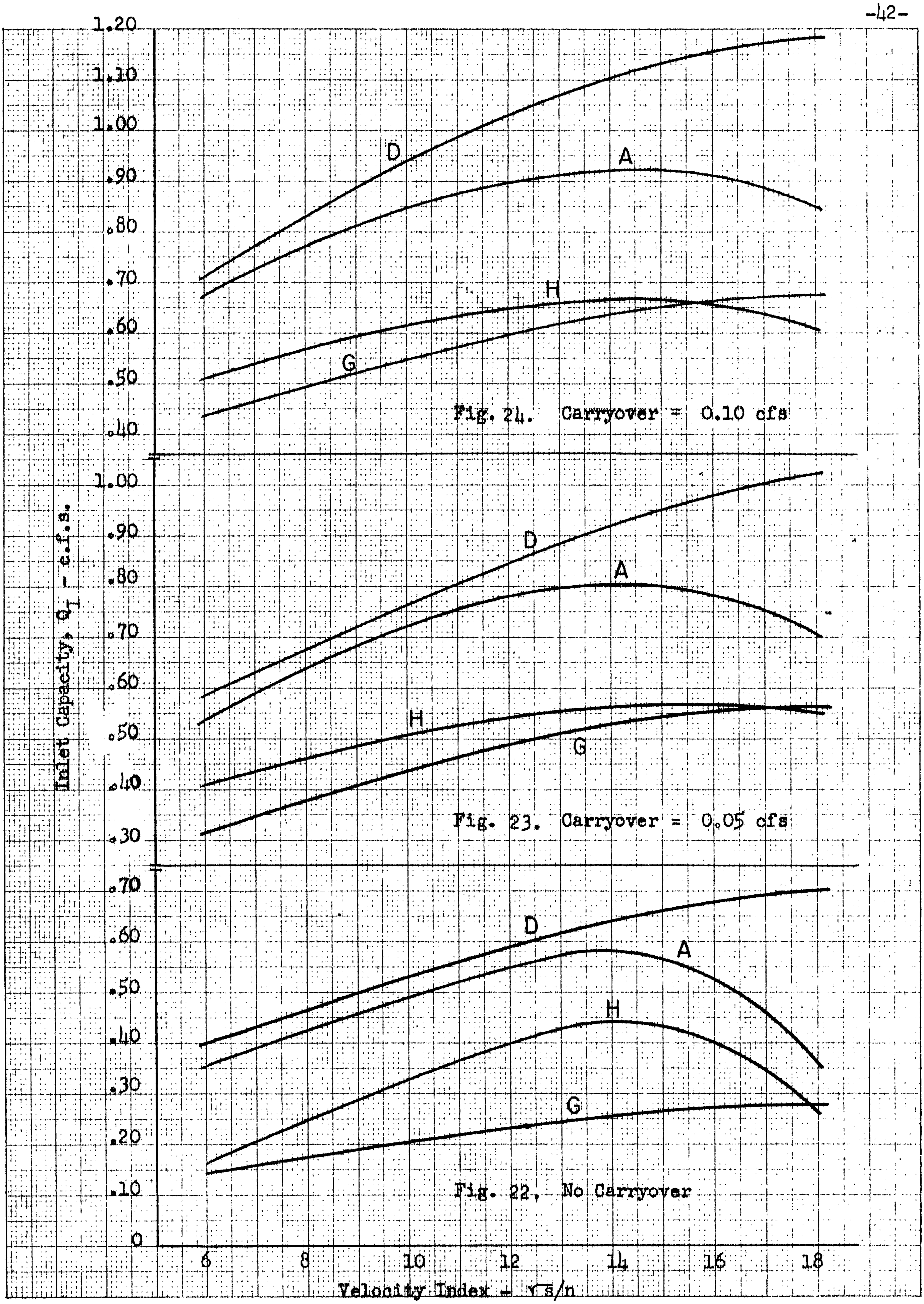
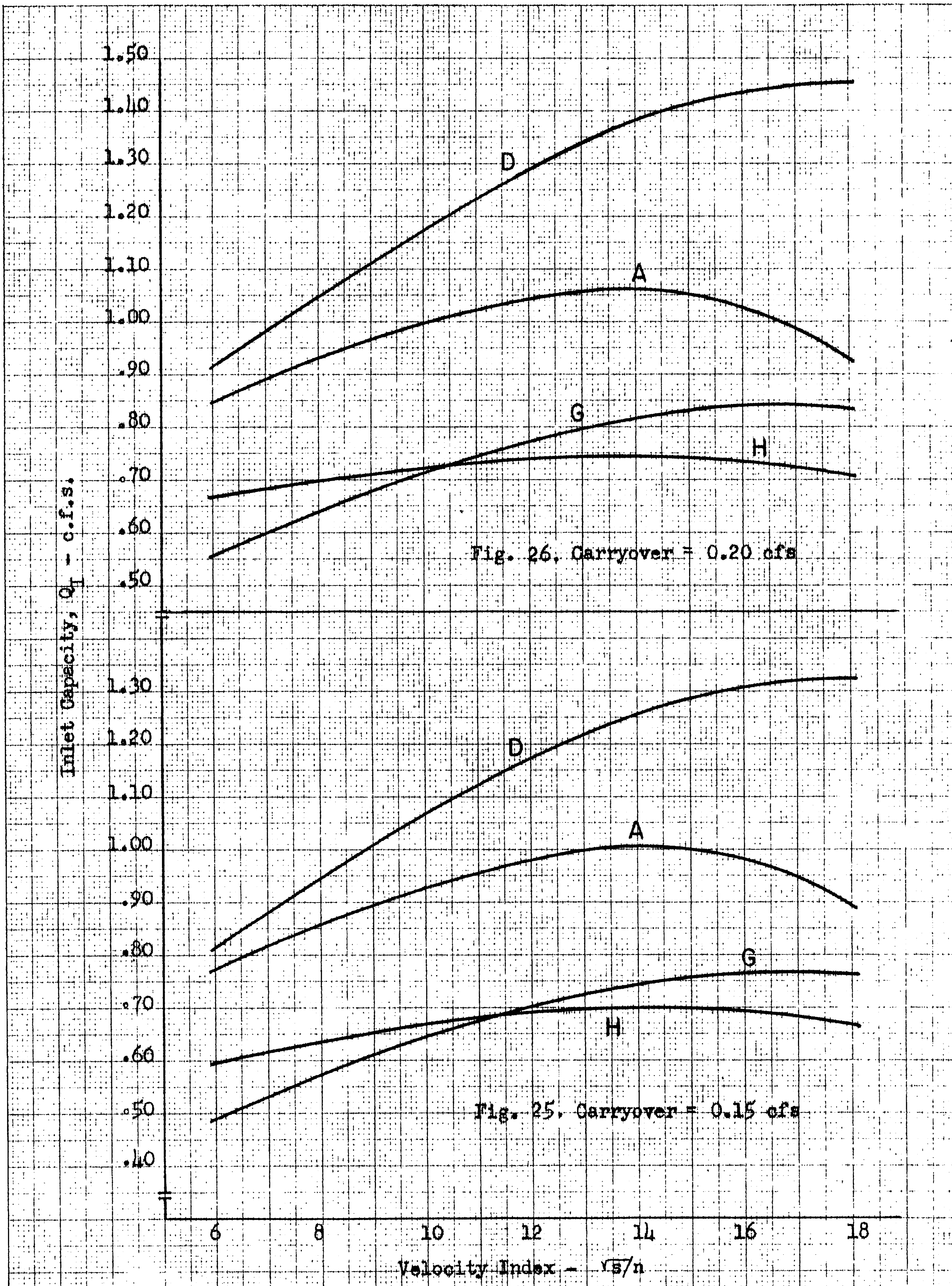


Fig. 21. RATING CURVES FOR VARIOUS INLET SETUPS AT TEST SLOPE OF 0.5%, $\sqrt{S}/n$ = 6.6



Figs. 22 - 24. CAPACITIES OF SEVERAL INLETS WITH VARIOUS CARRYOVER DISCHARGES



Figs. 25 - 26. CAPACITIES OF SEVERAL INLETS WITH VARIOUS CARRYOVER DISCHARGES

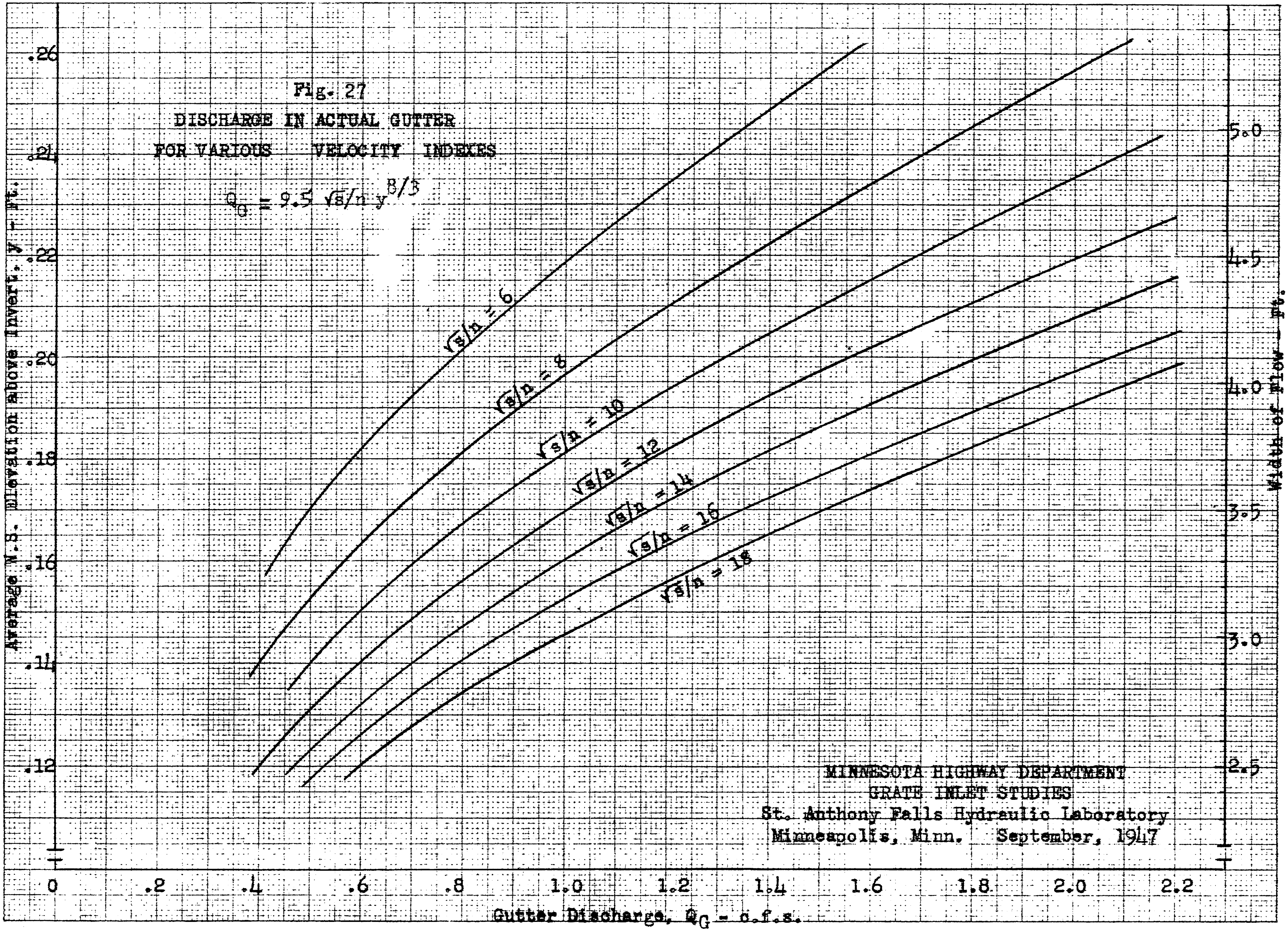


Fig. 27
DISCHARGE IN ACTUAL GUTTER
FOR VARIOUS VELOCITY INDEXES
$Q_G = 9.5\ \sqrt{s}/n\ y^{8/3}$
√s/n = 6
√s/n = 8
√s/n = 10
√s/n = 12
√s/n = 14
√s/n = 16
√s/n = 18
Average W.S. Elevation above Invert, y - Ft.
Width of Flow - Ft.
Gutter Discharge, Q_G - c.f.s.
.26
.24
.22
.20
.18
.16
.14
.12
5.0
4.5
4.0
3.5
3.0
2.5
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
MINNESOTA HIGHWAY DEPARTMENT
GRATE INLET STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. September, 1947

APPENDIX II. - TABLES

TABLES 1 - 4. OBSERVATIONS OF DEPTH OF FLOW IN TEST GUTTER

TABLE 1. Series A, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	W.S.Elevation y at Distance x from Curb Line, Ft						Average y	Observed Gutter Discharge
	x = 0	0.5	1.0	1.5	2.0	2.5		
A301	.199	.206	.187	.189	.190	.187	.193	2.00
A302	.197	.177	.171	.177	.179	.175	.179	1.73
A303	.176	.165	.165	.166	.169	.165	.168	1.51
A304	.160	.154	.155	.155	.158	.149	.155	1.25
A305	.144	.145	.142	.142	.145	.137	.143	1.03
A306	.133	.130	.122	.120	.127	.124	.126	0.75
A307	.101	.108	.100	.097	---	---	.101	0.44

TABLE 2. Series A, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

A201	.210	.217	.218	.205	.194	.200	.207	1.93
A202	.189	.198	.205	.182	.183	.185	.190	1.67
A203	.175	.179	.183	.164	.162	.170	.172	1.33
A204	.164	.167	.172	.150	.151	.155	.160	1.11
A205	.147	.147	.143	.128	.137	.139	.140	0.80
A206	.132	.125	.129	.113	.118	---	.123	0.58
B207	.109	.109	.117	.099	.104	---	.108	0.44

TABLE 3. Series A and B, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

A101	.249	.250	.258	.247	.235	.232	.245	2.09
A102	.241	.233	.235	.222	.215	.210	.226	1.74
A103	.211	.208	.213	.195	.192	.182	.200	1.31
A104	.172	.177	.170	.164	.155	.155	.165	0.86
A105	.139	.146	.152	.149	.134	.134	.142	0.60
B104	.201	.198	.201	.189	.182	.176	.191	1.20
B105	.176	.185	.185	.176	.166	.168	.176	1.02
B106	.140	.148	.153	.147	.134	.132	.142	0.61

TABLE 4. Series A, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

A901	.297	.275	.273	.281	.285	.253	.277	1.99
A902	.270	.257	.245	.256	.256	.239	.254	1.68
A903	.248	.247	.229	.236	.233	.215	.235	1.37
A904	.218	.213	.217	.205	.209	.187	.208	1.04
A905	.185	.178	.170	.166	.158	.151	.168	0.60
A906	.176	.186	.162	.149	.140	.139	.159	0.43
A907	.200	.204	.193	.186	.176	.176	.189	0.82

TABLES 5 - 8. COMPUTATIONS OF VELOCITY INDEX AND ROUGHNESS COEFFICIENT IN TEST GUTTER FOR VARIOUS TEST SLOPES

TABLE 5. Series A, Test Slope = 3.0%

Test Number	Observed Discharge	Avg. W.S. Elev.	Area of Section	Mean Velocity	$AR^{2/3}$	Velocity Index	Manning Coeff.
	Q'_G	$\bar{y}$	A	V		$\sqrt{s}/n$	n
A301	2.00	.193	.365	5.47	.0885	15.2	.0114
A302	1.73	.179	.322	5.37	.0730	15.9	.0109
A303	1.51	.168	.292	5.17	.0615	16.5	.0105
A304	1.25	.155	.254	4.93	.0485	17.3	.0100
A305	1.03	.143	.219	4.70	.0385	18.0	.0096
A306	0.75	.126	.171	4.39	.0270	18.7	.0093
A307	0.44	.101	.112	3.93	.0155	19.1	.0091
					Average -	17.2	.0101

TABLE 6. Series A, Test Slope = 2.0%

Test Number	Q'_G	$\bar{y}$	A	V	$AR^{2/3}$	$\sqrt{s}/n$	n
A201	1.93	.207	.407	4.74	.1045	12.4	.0114
A202	1.67	.190	.356	4.69	.0850	13.2	.0107
A203	1.33	.172	.306	4.38	.0655	13.7	.0103
A204	1.11	.160	.269	4.12	.0535	14.0	.0101
A205	0.80	.140	.210	3.81	.0355	15.2	.0093
A206	0.58	.123	.164	3.54	.0255	15.3	.0092
					Average -	14.0	.0102

TABLE 7. Series A and B, Test Slope = 1.0%

Test Number	Q'_G	$\bar{y}$	A	V	$AR^{2/3}$	$\sqrt{s}/n$	n
A101	2.09	.245	.517	4.04	.153	9.20	.0109
A102	1.74	.226	.461	3.77	.128	9.16	.0109
A103	1.31	.200	.385	3.41	.096	9.20	.0109
A104	0.86	.165	.284	3.03	.0585	9.89	.0101
A105	0.60	.142	.216	2.78	.0370	10.90	.0092
B104	1.20	.191	.360	3.34	.0860	9.41	.0106
B105	1.02	.176	.315	3.24	.0700	9.80	.0102
B106	0.61	.142	.216	2.82	.0370	11.10	.0090
					Average -	9.83	.0102

TABLE 8. Series A, Test Slope = 0.5%

Test Number	Q'_G	$\bar{y}$	A	V	$AR^{2/3}$	$\sqrt{s}/n$	n
A901	1.99	.277	.612	3.25	.200	6.70	.0106
A902	1.68	.254	.543	3.10	.166	6.81	.0104
A903	1.37	.235	.487	2.82	.139	6.63	.0107
A904	1.04	.208	.410	2.54	.106	6.60	.0107
A905	0.60	.168	.292	2.06	.0615	6.56	.0108
A906	0.43	.159*			.0525*	5.51*	.0128*
A907	0.82	.189	.352	2.33	.0840	6.57	.0108
					Average -	6.64	.0107

*Not included in computed averages

Average of all Slopes - .0103

TABLES 9 - 12. OBSERVED CAPACITIES OF INLET SETUP A AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 9. Inlet Setup A, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
A301	2.00	0.66	0.07	2.07	0.73	1.34
A302	1.73	0.50	0.04	1.77	0.54	1.23
A303	1.51	0.38	0.02	1.53	0.40	1.13
A304	1.25	0.23	0.01	1.26	0.24	1.02
A305	1.03	0.12	0.00	1.03	0.12	0.91
A306	0.75	0.04	0.00	0.75	0.04	0.71
A307	0.44	0.00	0.00	0.44	0.00	0.44

TABLE 10. Inlet Setup A, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

A201	1.93	0.56	0.10	2.03	0.66	1.37
A202	1.67	0.40	0.05	1.72	0.49	1.27
A203	1.33	0.22	0.02	1.35	0.24	1.11
A204	1.11	0.13	0.00	1.11	0.13	0.98
A205	0.80	0.04	0.00	0.80	0.04	0.76
A206	0.58	0.00	0.00	0.58	0.00	0.58

TABLE 11. Inlet Setup A, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

A101	2.09	0.60	0.24	2.33	0.84	1.49
A102	1.74	0.42	0.15	1.89	0.57	1.32
A103	1.31	0.23	0.05	1.36	0.28	1.08
A104	0.86	0.07	0.01	0.87	0.08	0.79
A105	0.60	0.02	0.00	0.60	0.02	0.58
A106	1.34	0.24	0.06	1.40	0.30	1.10

TABLE 12. Inlet Setup A, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

A901	1.99	0.51	0.32	2.31	0.83	1.48
A902	1.68	0.37	0.24	1.92	0.61	1.31
A903	1.37	0.23	0.13	1.50	0.46	1.14
A904	1.04	0.13	0.06	1.10	0.19	0.91
A905	0.60	0.04	0.01	0.61	0.05	0.56
A906	0.43	0.01	0.00	0.43	0.01	0.42
A907	0.82	0.05	0.02	0.84	0.07	0.77

TABLES 13 - 16. OBSERVED CAPACITIES OF INLET SETUP B AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 13. Inlet Setup B, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
B301	1.97	0.70	0.07	2.04	0.77	1.27
B302	1.68	0.53	0.03	1.71	0.56	1.15
B303	1.39	0.34	0.02	1.41	0.36	1.05
B304	1.11	0.19	0.00	1.11	0.19	0.92
B305	0.80	0.06	0.00	0.80	0.06	0.74
B306	0.42	0.00	0.00	0.42	0.00	0.42

TABLE 14. Inlet Setup B, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

B201	1.94	0.62	0.10	2.04	0.72	1.32
B202	1.67	0.44	0.05	1.72	0.49	1.23
B203	1.40	0.28	0.02	1.42	0.30	1.12
B204	1.15	0.16	0.01	1.16	0.17	0.99
B205	0.84	0.06	0.00	0.84	0.06	0.78
B206	0.53	0.00	0.00	0.53	0.00	0.53

TABLE 15. Inlet Setup B, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

B101	1.96	0.55	0.21	2.17	0.76	1.41
B102	1.68	0.40	0.13	1.81	0.53	1.28
B103	1.45	0.29	0.08	1.53	0.37	1.16
B104	1.20	0.16	0.04	1.24	0.20	1.04
B105	1.02	0.11	0.02	1.04	0.13	0.91
B106	0.60	0.02	0.00	0.60	0.02	0.59

TABLE 16. Inlet Setup B, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

B901	1.96	0.49	0.31	2.27	0.80	1.47
B902	1.57	0.33	0.19	1.76	0.52	1.24
B903	1.32	0.19	0.11	1.43	0.30	1.13
B904	1.00	0.13	0.05	1.05	0.18	0.87
B905	0.61	0.04	0.01	0.62	0.05	0.57
B906	0.52	0.01	0.00	0.52	0.01	0.51

TABLES 17-20. OBSERVED CAPACITIES OF INLET SETUP C AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 17. Inlet Setup C, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
C301	1.90	0.50	0.06	1.96	0.56	1.40
C302	1.00	0.07	0.00	1.00	0.07	0.93
C303	0.56	0.00	0.00	0.56	0.00	0.56
C304	1.57	0.30	0.02	1.59	0.32	1.27
C305	1.26	0.13	0.01	1.27	0.14	1.13

TABLE 18. Inlet Setup C, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

C201	1.91	0.40	0.09	2.00	0.49	1.51
C202	1.56	0.20	0.04	1.60	0.24	1.36
C203	1.27	0.10	0.01	1.28	0.11	1.17
C204	1.02	0.05	0.00	1.02	0.05	0.97
C205	0.68	0.00	0.00	0.68	0.00	0.68

TABLE 19. Inlet Setup C, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

C101	1.89	0.32	0.19	2.08	0.51	1.57
C102	1.56	0.19	0.10	1.66	0.29	1.37
C103	1.26	0.12	0.05	1.31	0.17	1.14
C104	1.03	0.06	0.02	1.05	0.08	0.97
C105	0.64	0.01	0.00	0.64	0.01	0.63

TABLE 20. Inlet Setup C, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

C901	1.90	0.25	0.30	2.20	0.55	1.65
C902	1.56	0.19	0.18	1.74	0.37	1.37
C903	1.25	0.13	0.10	1.35	0.23	1.12
C904	1.02	0.09	0.05	1.07	0.14	0.93
C905	0.60	0.01	0.01	0.61	0.02	0.59

TABLES 21 - 24. OBSERVED CAPACITIES OF INLET SETUP D
AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 21. Inlet Setup D, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
D301	2.06	0.28	0.08	2.14	0.36	1.78
D302	1.69	0.20	0.03	1.72	0.23	1.49
D303	1.30	0.11	0.00	1.30	0.11	1.19
D304	1.02	0.05	0.00	1.02	0.05	0.97
D305	0.70	0.00	0.00	0.70	0.00	0.70

TABLE 22. Inlet Setup D, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

D201	2.00	0.27	0.11	2.11	0.38	1.73
D202	1.62	0.18	0.04	1.66	0.22	1.44
D203	1.29	0.11	0.01	1.30	0.12	1.18
D204	1.02	0.06	0.00	1.02	0.06	0.96
D205	0.62	0.00	0.00	0.62	0.00	0.62

TABLE 23. Inlet Setup D, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

D101	1.90	0.30	0.19	2.09	0.49	1.60
D102	1.60	0.22	0.11	1.71	0.33	1.38
D103	1.26	0.14	0.05	1.31	0.19	1.12
D104	0.94	0.08	0.01	0.95	0.09	0.86
D105	0.60	0.01	0.00	0.60	0.01	0.59

TABLE 24. Inlet Setup D, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

D901	1.89	0.31	0.30	2.19	0.61	1.58
D902	1.60	0.24	0.20	1.80	0.44	1.36
D903	1.25	0.16	0.10	1.35	0.26	1.09
D904	0.94	0.10	0.04	0.98	0.14	0.84
D905	0.60	0.03	0.01	0.61	0.04	0.57

TABLES 25-28. OBSERVED CAPACITIES OF INLET SETUPS E AND F
AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 25. Inlet Setup E, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
E301	1.90	0.45	0.06	1.96	0.51	1.45
E302	1.56	0.32	0.02	1.58	0.34	1.24
E303	1.27	0.21	0.00	1.27	0.21	1.06
E304	1.03	0.11	0.00	1.03	0.11	0.92
E305	0.68	0.00	0.00	0.68	0.00	0.68

TABLE 26. Inlet Setup E, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

E201	1.91	0.49	0.09	2.00	0.58	1.42
E202	1.53	0.30	0.03	1.56	0.33	1.23
E203	1.27	0.15	0.01	1.28	0.16	1.12
E204	0.99	0.07	0.00	0.99	0.07	0.92
E205	0.63	0.01	0.00	0.63	0.01	0.62
E206	1.61	0.32	0.04	1.65	0.36	1.29

TABLE 27. Inlet Setup E, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

E101	1.89	0.55	0.19	2.08	0.74	1.34
E102	1.56	0.30	0.10	1.66	0.40	1.26
E103	1.25	0.21	0.05	1.30	0.26	1.04
E104	1.02	0.14	0.02	1.04	0.16	0.88
E105	0.60	0.04	0.00	0.60	0.04	0.56
E106	1.79	0.49	0.16	1.95	0.65	1.30

TABLE 28. Inlet Setup F, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

F201	1.92	0.25	0.09	2.01	0.34	1.67
F202	1.56	0.16	0.04	1.60	0.20	1.40
F203	1.26	0.10	0.01	1.27	0.11	1.16
F204	1.03	0.06	0.00	1.03	0.06	0.97
F205	0.64	0.00	0.00	0.64	0.00	0.64

TABLES 29 - 32. OBSERVED CAPACITIES OF INLET SETUP G AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 29. Inlet Setup G, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
G301	1.56	0.47	0.02	1.58	0.49	1.09
G302	1.27	0.31	0.00	1.27	0.31	0.96
G303	1.03	0.21	0.00	1.03	0.21	0.81
G304	0.78	0.12	0.00	0.78	0.12	0.66
G305	0.60	0.05	0.00	0.60	0.05	0.55
G306	0.35	0.01	0.00	0.35	0.01	0.34

TABLE 30. Inlet Setup G, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

G201	1.79	0.54	0.07	1.86	0.61	1.25
G202	1.40	0.35	0.02	1.42	0.37	1.05
G203	1.11	0.23	0.00	1.11	0.23	0.88
G204	0.82	0.12	0.00	0.82	0.12	0.70
G205	0.60	0.05	0.00	0.60	0.05	0.55
G206	0.30	0.01	0.00	0.30	0.01	0.29

TABLE 31. Inlet Setup G, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

G101	1.75	0.57	0.15	1.90	0.72	1.18
G102	1.41	0.43	0.07	1.48	0.50	0.98
G103	1.10	0.29	0.03	1.13	0.32	0.81
G104	0.83	0.17	0.01	0.84	0.18	0.66
G105	0.60	0.09	0.00	0.60	0.09	0.51
G106	1.81	0.62	0.16	1.97	0.78	1.19
G107	0.39	0.03	0.00	0.39	0.03	0.36
G108	0.25	0.01	0.00	0.25	0.01	0.24

TABLE 32. Inlet Setup G, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

G901	1.59	0.53	0.19	1.78	0.72	1.06
G902	1.28	0.39	0.11	1.39	0.50	0.89
G903	1.05	0.29	0.06	1.11	0.35	0.76
G904	0.69	0.15	0.01	0.70	0.16	0.54
G905	0.39	0.04	0.00	0.39	0.04	0.35
G906	0.20	0.01	0.00	0.20	0.01	0.19

TABLES 33 - 36. OBSERVED CAPACITIES OF INLET SETUP H AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 33. Inlet Setup H, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
H301	1.56	0.67	0.02	1.58	0.69	0.89
H302	1.30	0.46	0.00	1.30	0.46	0.84
H303	1.03	0.27	0.00	1.03	0.27	0.76
H304	0.69	0.08	0.00	0.69	0.08	0.61
H305	0.39	0.01	0.00	0.39	0.01	0.38

TABLE 34. Inlet Setup H, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

H201	1.76	0.75	0.06	1.82	0.81	1.01
H202	1.37	0.49	0.02	1.39	0.51	0.88
H203	1.02	0.24	0.00	1.02	0.24	0.78
H204	0.74	0.10	0.00	0.74	0.10	0.64
H205	1.46	0.54	0.03	1.49	0.57	0.92
H206	0.50	0.01	0.00	0.50	0.01	0.49

TABLE 35. Inlet Setup H, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

H101	1.67	0.64	0.13	1.80	0.77	1.03
H102	1.30	0.40	0.05	1.35	0.45	0.90
H103	0.99	0.23	0.02	1.01	0.25	0.76
H104	0.65	0.08	0.00	0.65	0.08	0.57
H105	0.30	0.01	0.00	0.30	0.01	0.29

TABLE 36. Inlet Setup H, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

H901	1.76	0.68	0.25	2.01	0.93	1.08
H902	1.33	0.40	0.12	1.45	0.52	0.93
H903	1.05	0.26	0.06	1.11	0.32	0.79
H904	0.69	0.12	0.01	0.70	0.13	0.57
H905	0.39	0.03	0.00	0.39	0.03	0.36
H906	0.23	0.01	0.00	0.23	0.01	0.22

TABLES 37-40. OBSERVED CAPACITIES OF INLET SETUP J AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 37. Inlet Setup J, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
J301	1.96	0.45	0.06	2.02	0.51	1.51
J302	1.47	0.23	0.01	1.48	0.24	1.24
J303	1.19	0.12	0.00	1.19	0.12	1.07
J304	0.87	0.03	0.00	0.87	0.03	0.84
J305	0.62	0.01	0.00	0.62	0.01	0.61

TABLE 38. Inlet Setup J, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

J201	1.90	0.32	0.09	1.99	0.41	1.58
J202	1.47	0.16	0.03	1.50	0.19	1.31
J203	1.19	0.08	0.01	1.20	0.09	1.11
J204	0.88	0.02	0.00	0.88	0.02	0.86
J205	0.65	0.00	0.00	0.65	0.00	0.65

TABLE 39. Inlet Setup J, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

J101	1.80	0.25	0.16	1.96	0.41	1.55
J102	1.51	0.17	0.09	1.60	0.26	1.34
J103	1.20	0.10	0.04	1.24	0.14	1.10
J104	0.88	0.04	0.01	0.89	0.05	0.84
J105	0.65	0.01	0.00	0.65	0.01	0.64

TABLE 40. Inlet Setup J, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

J901	1.80	0.25	0.26	2.06	0.51	1.55
J902	1.33	0.15	0.12	1.45	0.27	1.18
J903	1.53	0.19	0.17	1.70	0.36	1.34
J904	1.05	0.11	0.06	1.11	0.17	0.94
J905	0.79	0.05	0.02	0.81	0.07	0.74
J906	0.60	0.02	0.01	0.61	0.03	0.58

TABLE 41. DEBRIS TESTS OF VARIOUS INLETS AT A TEST SLOPE OF 2.0%, $\sqrt{s}/n$ = 14.0

Inlet Setup	Inlet Capacity	Observed Carryover	Corrected Carryover	Pcs. Debris Introduced	Avg. No. Pcs. Caught	Avg. % Passing
A	0.92	0.10	0.10	50	34.3	31.4
C	1.13	0.13	0.14	50	33.3	33.4
D	1.35	0.15	0.18	50	19.3	61.4
E	1.03	0.12	0.13	50	23.7	52.6
G	0.81	0.19	0.19	50	1.0	98.0
H	0.77	0.23	0.23	50	41.7	16.6
J	0.96	0.04	0.04	50	29.7	40.6

TABLE 42. DEBRIS TESTS OF VARIOUS INLETS AT A TEST SLOPE OF 0.5%, $\sqrt{s}/n$ = 6.6

A	0.83	0.09	0.12	50	39.0	22.0
C	0.95	0.10	0.16	50	21.0	58.0
D	0.89	0.11	0.16	50	13.3	73.4
G	0.73	0.27	0.32	50	3.0	94.0
H	0.76	0.24	0.29	50	42.0	16.0
J	0.91	0.09	0.14	50	28.0	44.0

TABLE 43. VELOCITY INDEXES FOR VARIOUS FIELD COMBINATIONS OF SLOPE AND ROUGHNESS

Gutter	Gutter Roughness - Manning's n						
Slope	0.012	0.013	0.014	0.015	0.016	0.017	0.018
0.6%	6.46	5.96					
0.8	7.46	6.88	6.39	5.96			
1.0	8.33	7.70	7.14	6.66	6.25	5.88	
1.5	10.2	9.43	8.76	8.17	7.66	7.22	6.82
2.0	11.8	10.9	10.1	9.43	8.85	8.32	7.86
2.5	13.2	12.2	11.3	10.5	9.88	9.30	8.78
3.0	14.4	13.3	12.4	11.6	10.8	10.2	9.63
3.5	15.6	14.4	13.4	12.5	11.7	11.0	10.4
4.0	16.7	15.4	14.3	13.3	12.5	11.8	11.1
4.5	17.7	16.3	15.2	14.1	13.3	12.5	11.8
5.0	18.6	17.2	16.0	14.9	14.0	13.2	12.4
5.5		18.0	16.7	15.6	14.7	13.8	13.0
6.0			17.5	16.3	15.3	14.4	13.6
6.5			18.2	17.0	16.0	15.0	14.2
7.0				17.6	16.5	15.6	14.7

INVESTIGATION OF FLOW THROUGH STANDARD AND EXPERIMENTAL GRATE INLETS FOR STREET GUTTERS

Project Report No. 3

Supplement I

by
St. Anthony Falls Hydraulic Laboratory
University of Minnesota

Submitted by
Lorenz G. Straub
Director

Prepared by
Curtis L. Larson

March, 1948

Prepared for the
Minnesota Highway Department
St. Paul, Minnesota

C O N T E N T S

INVESTIGATION OF FLOW

THROUGH STANDARD AND EXPERIMENTAL GRATE INLETS FOR STREET GUTTERS

SUPPLEMENT I

I. INTRODUCTION

Project Report No. 3, "Investigation of Flow Through Standard and Experimental Grate Inlets for Street Gutters," presented the results of tests performed to determine the capacity and self-cleaning ability of a number of grate inlets. These tests served to develop considerable evidence concerning the relative importance of various inlet characteristics, such as direction and form of inlet openings and over-all dimensions of the inlet. None of the inlets investigated, however, was found to combine the three desirable features: high capacity, self-cleaning ability, and economy. To develop an inlet possessing all three of these features, therefore, additional tests were made and the results are presented in this supplementary report.

II. DESCRIPTION OF ADDITIONAL TESTS

Description of Inlets

These tests were begun with several experimental inlets of rectangular shape, 24 in. wide (normal to the flow), and 16 in. long, dimensions which were recommended in the original project report. The first of these inlets, which had bars and openings parallel to the flow, is shown in Fig. 1. Another, shown in Fig. 2, had rounded bars normal to the flow. A third inlet, with rounded bars at a 45° angle to the direction of flow, is illustrated in Fig. 3. Tests of these three inlets constituted Series K, L, and M, respectively.

For Series N, the openings of Inlet M were extended into the curb opening, as shown in Fig. 3. Tests of Inlet N indicated that a modification of the over-all shape of such an inlet would result in further improvement, both in capacity and self-cleaning performance. For this reason, the inlet shown in Fig. 4 was designed and was tested in Series P, the last of the tests.

The following table summarizes the characteristics of the inlets investigated in this group of tests. Also included are Inlets D and the Highway Department standard inlet, Inlet G, both of which were studied in the original experiments.

TABLE 1.

CHARACTERISTICS OF INLETS

Exp. Inlet	Figure No.	Direction of Openings	Type of Bars	Width from Curb	Maximum Length	Area in Plan
				in.	in.	sq. in.
D	4*	45°, toward curb	Rounded	24	48	576
G	5*	Parallel to flow	Square-cornered	17	25½	446
K	1	Parallel to flow	Square-cornered	24	16	384
L	2	Normal to flow	Rounded	24	16	384
M	3	45°, toward curb	Rounded	24	16	384
N	3	45°, toward curb	Rounded	24	16	384
P	4	45°, toward curb	Rounded	24	24	390

*Project Report No. 3

Apparatus and Procedure

Each of the inlets listed above was set flush with the gutter surface for all tests. A curb opening 6 in. high was used in each test. The length of the curb opening was made to correspond to the length of the inlet at the curb line. The rest of the test apparatus and the procedure used in this group of tests were the same as that used in the original experiments, with the exception of the debris tests.

The debris tests were modified and extended somewhat as compared to the debris tests of Inlets A through J in the original experiments. Instead of using 1- by 2-in. pieces of newsprint paper, the supplementary tests utilized a heavier unsized paper, approximately 0.004 in. thick, in pieces 1½ by 2½ in. In addition, dried leaves and grass were added to the gutter flow to test the performance of each inlet with natural debris. The leaves used were mostly poplar leaves, which are small to medium in size. The data showed a definite correlation between the test results with paper and the results with actual leaves. As expected, however, the leaves passed through the inlet openings somewhat easier than did the pieces of paper, and when lodged on the grate bars, the leaves were washed off more readily.

Preparation of Data

The data were prepared in the same manner as in the original report. The results of the capacity tests are presented in Tables 2 - 21, Appendix II. Rating curves for the various inlets, including the standard inlet, are given in Figs. 5, 6, 7, and 8, for velocity indexes of 17.2, 14.0, 9.8, and 6.6, respectively. In Figs. 9, 10, 11, and 12, inlet capacities are plotted against velocity indexes, for carryovers of 0, 0.10, 0.20, and 0.30 cu ft per sec. Figure 13 illustrates that the data can be replotted to obtain rating curves for any velocity index within the range of the tests. The rating curves in this figure are for Inlet P only.

The results of the debris tests are presented in Table 22. All debris tests were made at a test slope of 2 per cent.

As in the previous tests, photographs were taken of each inlet in operation. Figure 14 shows the various inlets investigated in these tests, with Inlet P in place and Inlets K, L, and N in proper orientation in the gutter. In Figs. 15 through 18, each of the inlets is pictured receiving a gutter flow of approximately 1.05 cu ft per sec. Figure 19 is an upstream view of Inlet P.

III. DISCUSSION OF RESULTS

Experimental Inlet K

Compared to the present standard inlet of the Highway Department, Inlet K was found to provide a substantial improvement in capacity, and proved to be one of the best of the inlets tested in the supplementary series. This inlet, shown in Fig. 1, has openings which are parallel to the flow and are very similar to the openings of the present standard inlet. The main difference between the two inlets is in over-all dimensions. Inlet K is 24 in. wide and 16 in. long, while the standard inlet extends into the gutter approximately 17 in., and is $25\frac{1}{2}$ in. long.

The additional seven inches of width undoubtedly account for the higher capacity of Inlet K. Decreasing the length of this inlet from $25\frac{1}{2}$ to 16 in. had no effect on its capacity, but reduced its size considerably, making it somewhat smaller than the standard inlet.

The longitudinal bars of Inlets G and K constitute a disadvantage in that there is a tendency for a small trickle of water to flow along the surface of each bar. This phenomenon is evident at all discharges. Although inconsequential at most discharges, this small flow is sufficient to lower considerably the capacity of Inlet K in the region of no carryover. The rating curve of Inlet K therefore tends to be asymptotic to the "no-carryover" line, making its no-carryover capacity quite indefinite and very low.

In the debris tests, approximately 90 per cent of the paper debris passed without difficulty through the openings of Inlet K. Leaves also passed readily through the inlet. A small percentage of the floating grass or hay tended to straddle the bars, "ride" to the downstream ends, and remain lodged there.

<u>Experimental Inlet L</u>

Inlet L, which was designed with rounded bars set normal to the direction of flow, fell short of the other experimental inlets both in capacity and in debris performance, particularly at the higher slopes. Its relatively low capacity at velocity indexes above 10 resulted from a heavy spray formation, which is evident in the photograph, Fig. 16. This relatively large amount of spray was not expected with Inlet L, since Inlet D, which also had rounded bars, was not affected appreciably by spray. Inlet D, however, had diagonal bars and openings.

In the debris tests of Inlet L, only 24 per cent of the paper debris passed through the openings. The performance of this inlet with dried leaves and grass was also quite poor.

<u>Experimental Inlets M and N</u>

Inlet M and particularly Inlet N (a modification of Inlet M) demonstrated good characteristics both in the capacity and in the debris tests. Inlet M was designed with the same over-all dimensions as Inlets K and L

(24 by 16 in.), but its bars were set at an angle of 45° with the direction of flow. For Series N, the openings of Inlet M were extended into the curb opening. Figure 3 shows both the original and modified design of this inlet.

In tests of Inlet M, a noticeable quantity of water flowed along the longitudinal frame-member next to the curb opening. This flow was intercepted by extending the openings in constructing Inlet N. The result of this change was a capacity increase of 5 to 10 per cent over the original design. In both inlets some spray was evident, as shown in the photograph, Fig. 17. This spray was deflected by the 45° bars, and was directed toward the curb, part of it going over the inlet and increasing the carryover. This behavior suggested that changing the shape of the inlet would be advantageous. This was done in Series P.

Approximately 68 per cent of the test debris passed through the openings of Inlet M. In Series N, extension of the openings permitted some of the debris to be carried along the bars into the curb opening, increasing the debris efficiency to 74 per cent. This self-cleaning action was more evident when actual leaves were used, and much more so when grass or other stringy material was used.

Experimental Inlet P

Inlet P was designed with rounded diagonal bars and an over-all shape adjusted to the spray pattern. This inlet, which is shown in Fig. 4, performed very well in all respects. When this shape of inlet is used, the spray from the diagonal bars is directed toward the downstream portion of the grating, and either passes through the openings nearer the curb, or passes directly into the curb opening. Thus, when the curb opening is favorably located, it is quite useful in increasing the capacity of this inlet. Figure 18 shows that no spray passes over the inlet when the gutter discharge is 1.05 cu ft per sec. It was found that the gutter discharge can be increased to about 1.40 cu ft per sec before spray begins to pass over this inlet.

Inlet P was found to have an efficiency of 84 per cent when tested with paper debris. In tests with leaves and grass, approximately 90 per cent of the leaves and all of the grass either passed through the grate openings or was carried along the bars to the curb opening. The curb opening therefore facilitates the self-cleaning of this inlet. However, pieces of grass longer than 4 or 5 in. tend to catch at the curb line where each bar is supported.

This inlet was designed for both right and left hand use, eliminating the need for two separate designs. Alternate positions of the curb line are shown in Fig. 4. The same curb opening could be used in either position, and it may be possible to design a support casting which would also serve in either position.

Comparison of Experimental Inlets

A comparison of Figs. 9 through 12, or the rating curves, Figs. 5 through 8, shows that Inlet P has the best "all-around" capacity characteristics, although under certain conditions its capacity is exceeded by either Inlet K or Inlet N. The following table indicates the conditions at which each of the inlets excells. For each combination of velocity index and carryover, the table lists the inlet having the highest capacity. Where two inlets have capacities that are equally high or within 0.01 cu ft per sec of each other, both are given. Inlet D of the original test series is not included.

TABLE 23

INLETS WITH HIGHEST CAPACITIES UNDER VARIOUS CONDITIONS

Carryover Q_C	Inlet Having Highest Capacity at Velocity Index of:						
	7	9	11	13	15	17	Av. $\sqrt{s}/n$
0	P	P	P	P	P	P	P
0.10	P N	N	N P	P	P	P	P
0.20	N	N	N P	P	P K	K	P
0.30	N	N	P	P K	K	K	K
Av. Q_C	N	N	P	P	P	P	P

This chart shows that Inlet N excells for low slopes and moderate carryovers, while Inlet K is most efficient at high slopes and moderate carryovers. Both of these inlets, however, decrease in effectiveness under other conditions. On the other hand, Inlet P has either the highest or next highest capacity throughout almost the entire range. The "all-around" superiority of

Inlet P can be substantiated by averaging the capacities of each inlet for all of the combinations of velocity index and carryover listed in Table 23. The "average" capacities thus obtained for each inlet are:

Inlet P	0.960 cu ft per sec
Inlet N	0.915 cu ft per sec
Inlet K	0.852 cu ft per sec
Inlet G	0.602 cu ft per sec

Within this range of conditions the capacity of Inlet P is thus found to average approximately 5 per cent greater than that of Inlet N, and about 13 per cent greater than the capacity of Inlet K. Inlets P, K, and N all provide a substantial improvement over the present standard inlet, Inlet G.

In self-cleaning ability, Inlet K proved to be superior in passing paper debris and leaves, although Inlet P demonstrated some advantage with grassy material. In general, Inlet K should be rated highest in debris performance, while Inlet P is slightly lower in efficiency.

Using grate area (Table 1) as a very rough basis for an economy comparison, it is found that the experimental inlets K, N, and P appear to be about equal in cost. Inlet K may have some advantage in its simplicity. Inlet N would require both a left hand and right hand design, resulting in some additional cost and inconvenience. Inlet P and Inlet K, which is similar to the present inlet, can be used in either position.

IV. CONCLUSIONS

The results of these additional tests are used as a basis for the following conclusions, which are applicable to a continuous gutter having a cross-slope of approximately 20 to 1, and a velocity index within the range of the tests.

1. Conclusions 1 through 5 of Project Report No. 3 are further substantiated.

2. When placed normal to the flow, rounded grate bars, as well as the conventional type, cause heavy spray action and have a tendency to clog with debris. For these reasons, they are considered unsatisfactory in this position.

3. When actual leaves are used as debris, diagonal, rounded grate bars tend to be self-cleaning, but are not fully so.

4. When grassy material is used as debris, diagonal, rounded bars demonstrate positive self-cleaning action.

5. If a curb opening is located so as to intercept spray, it may materially increase the capacity of an inlet with diagonal, rounded bars.

6. The tests have developed three inlet designs, which, for a gutter of 20 to 1 cross-slope, combine the features of high capacity, self-cleaning ability, and economy.

APPENDIX I. - FIGURES

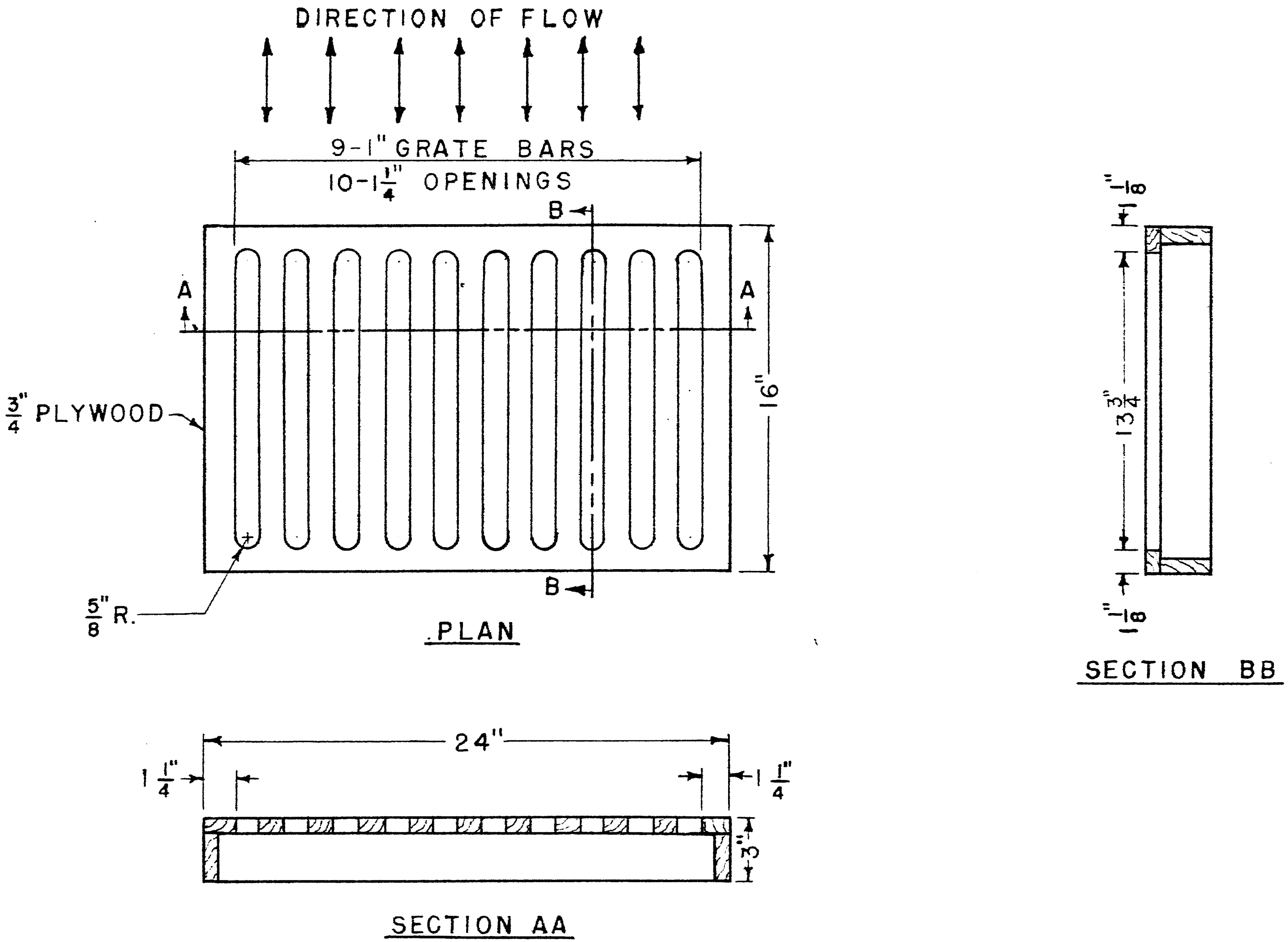


FIG. I
EXPERIMENTAL INLET K

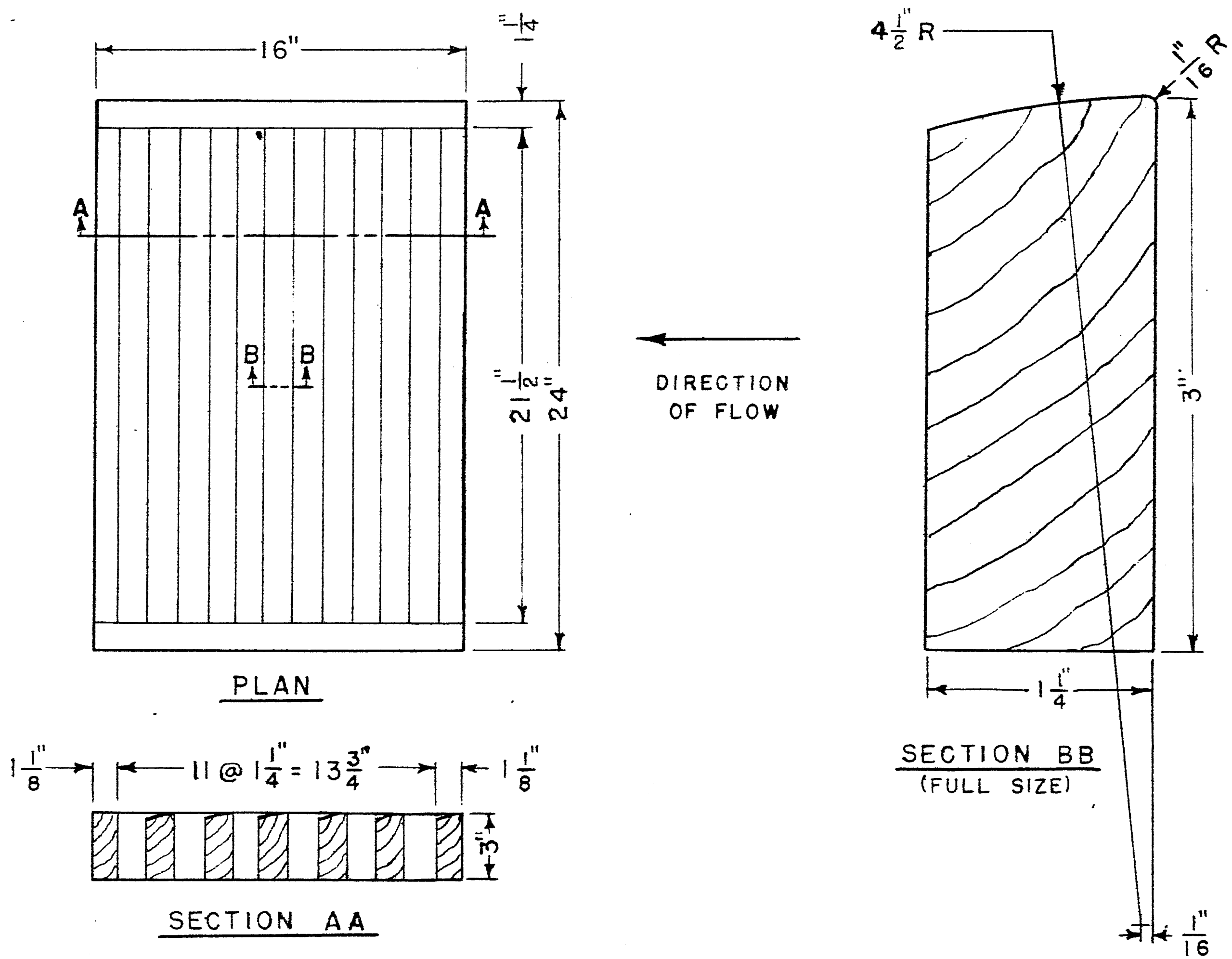


FIG. 2
EXPERIMENTAL INLET L

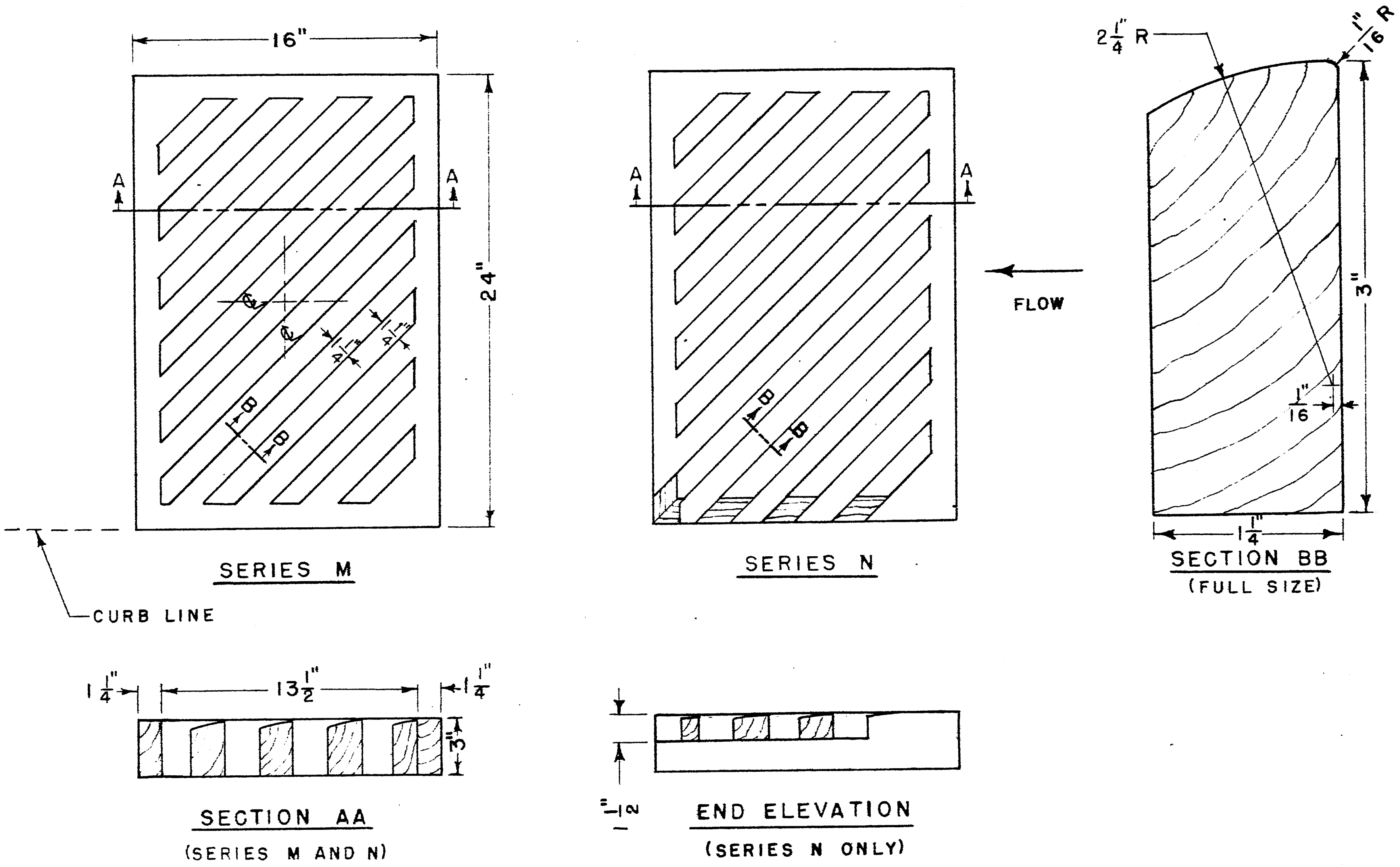


FIG. 3
EXPERIMENTAL INLETS M & N

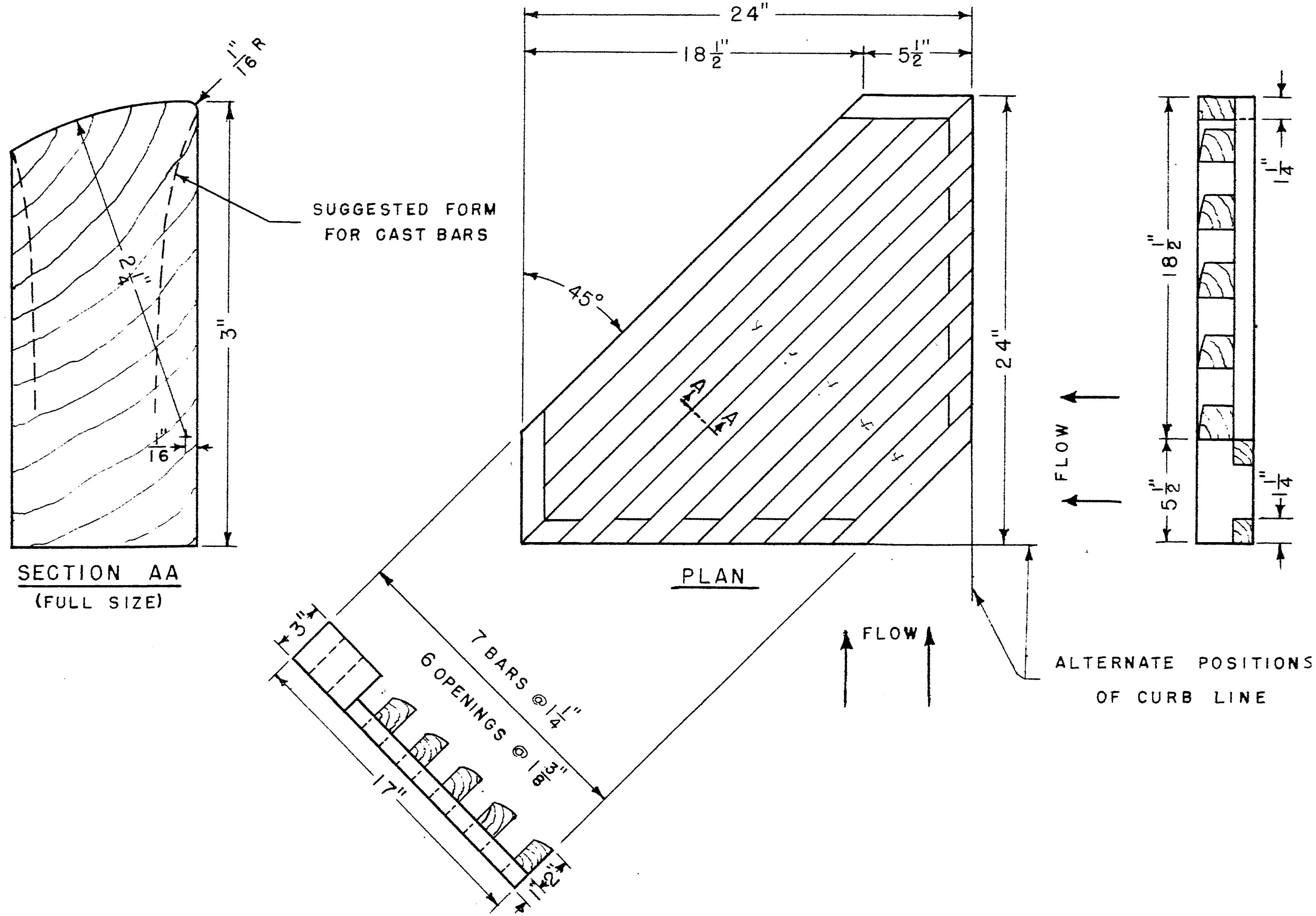


FIG. 4
EXPERIMENTAL INLET P

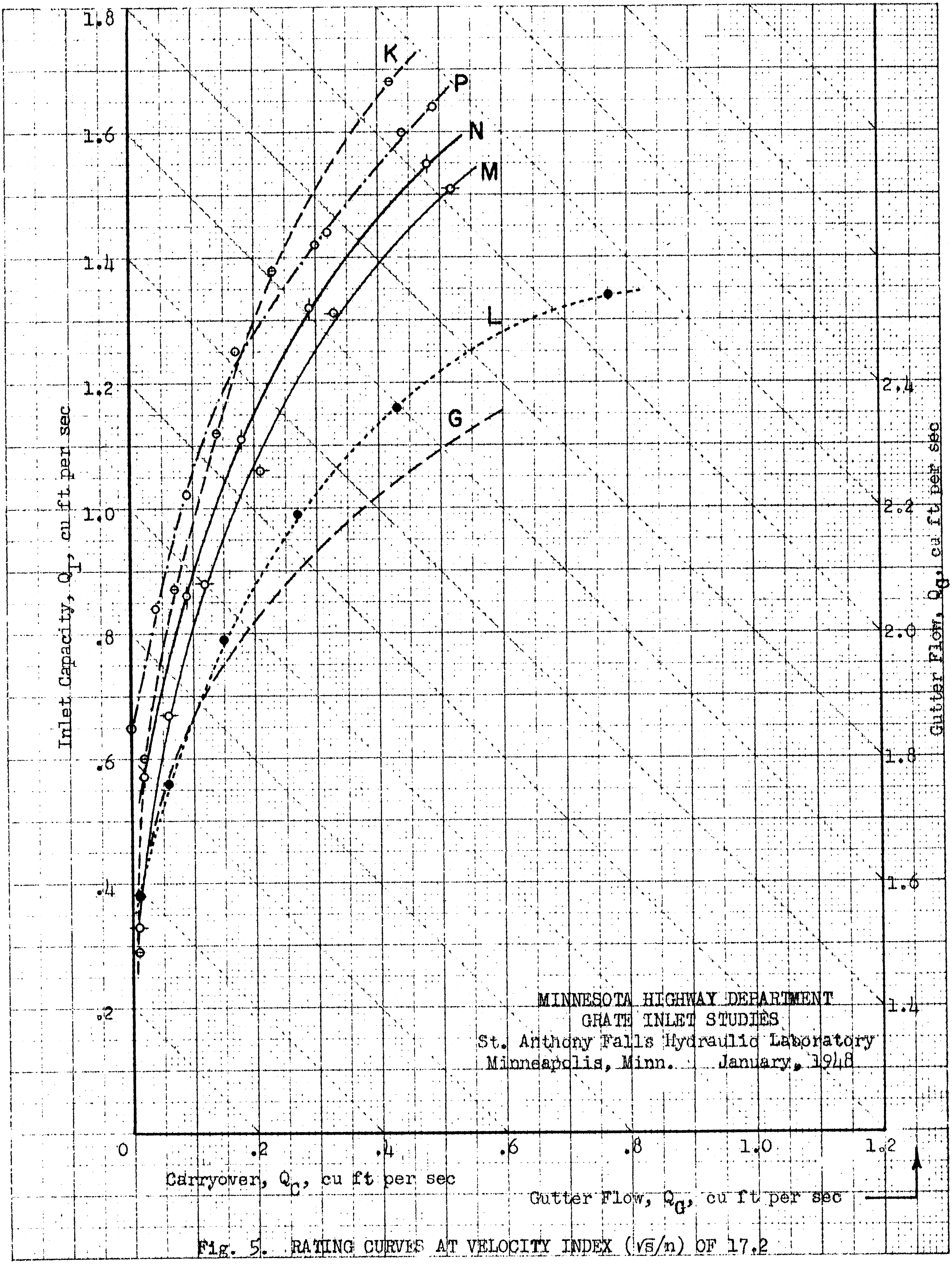


Fig. 5. RATING CURVES AT VELOCITY INDEX ($\sqrt{s}/n$) OF 17.2

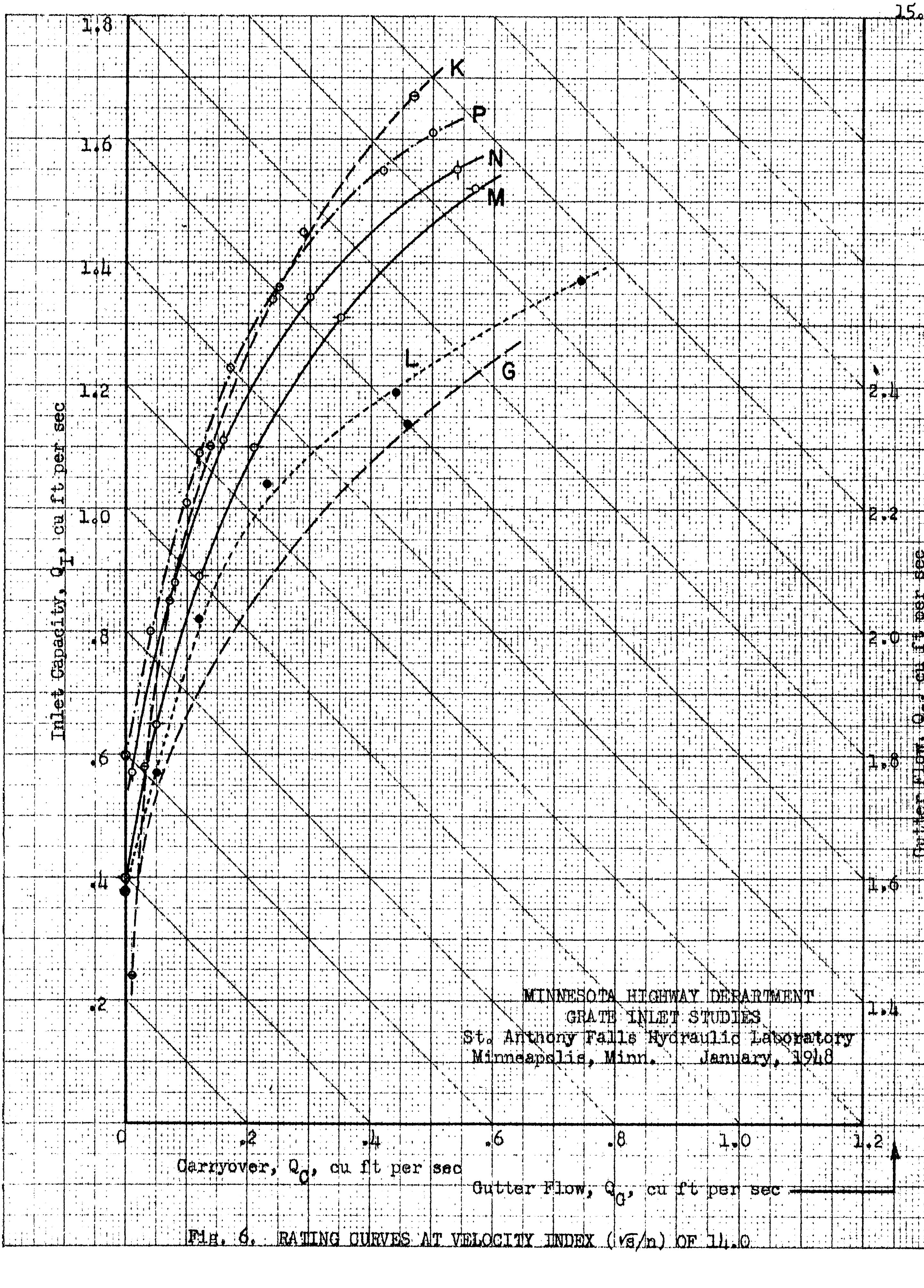


Fig. 6. RATING CURVES AT VELOCITY INDEX ($\sqrt{s}/n$) OF 14.0

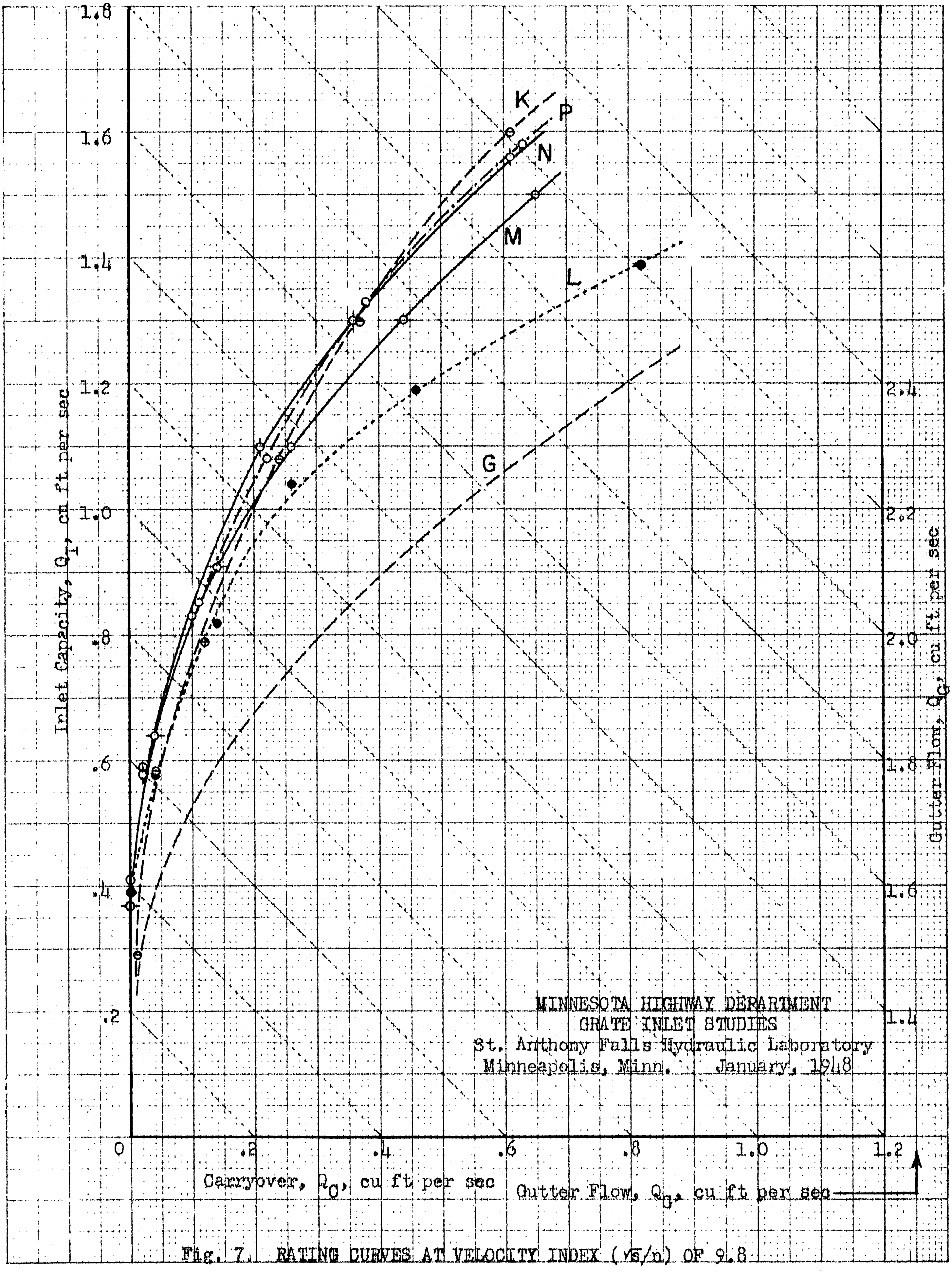


Fig. 7. RATING CURVES AT VELOCITY INDEX ($\sqrt{s}/n$) OF 9.8

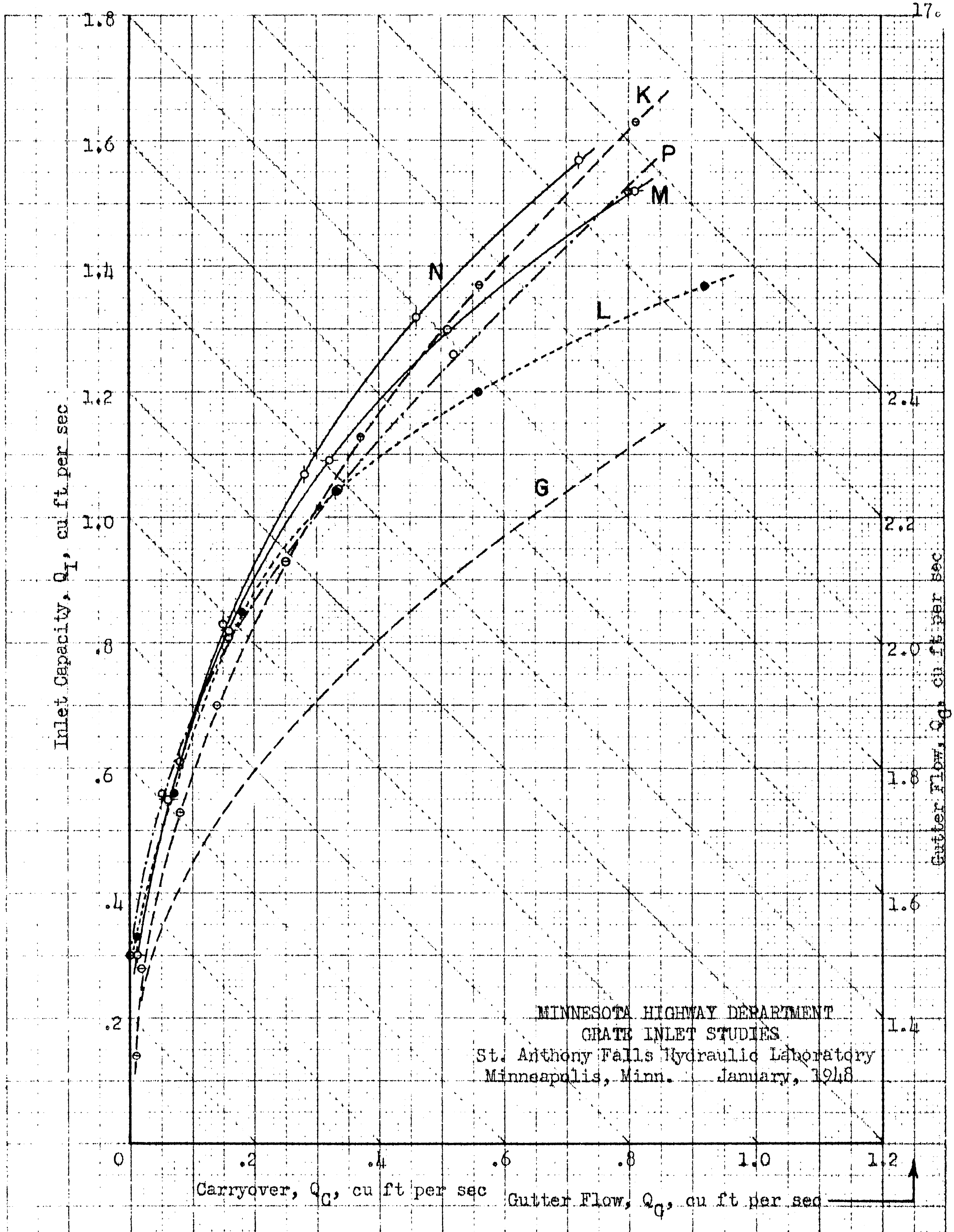


Fig. 8. RATING CURVES AT VELOCITY INDEX ($\sqrt{s}/n$) OF 6.6

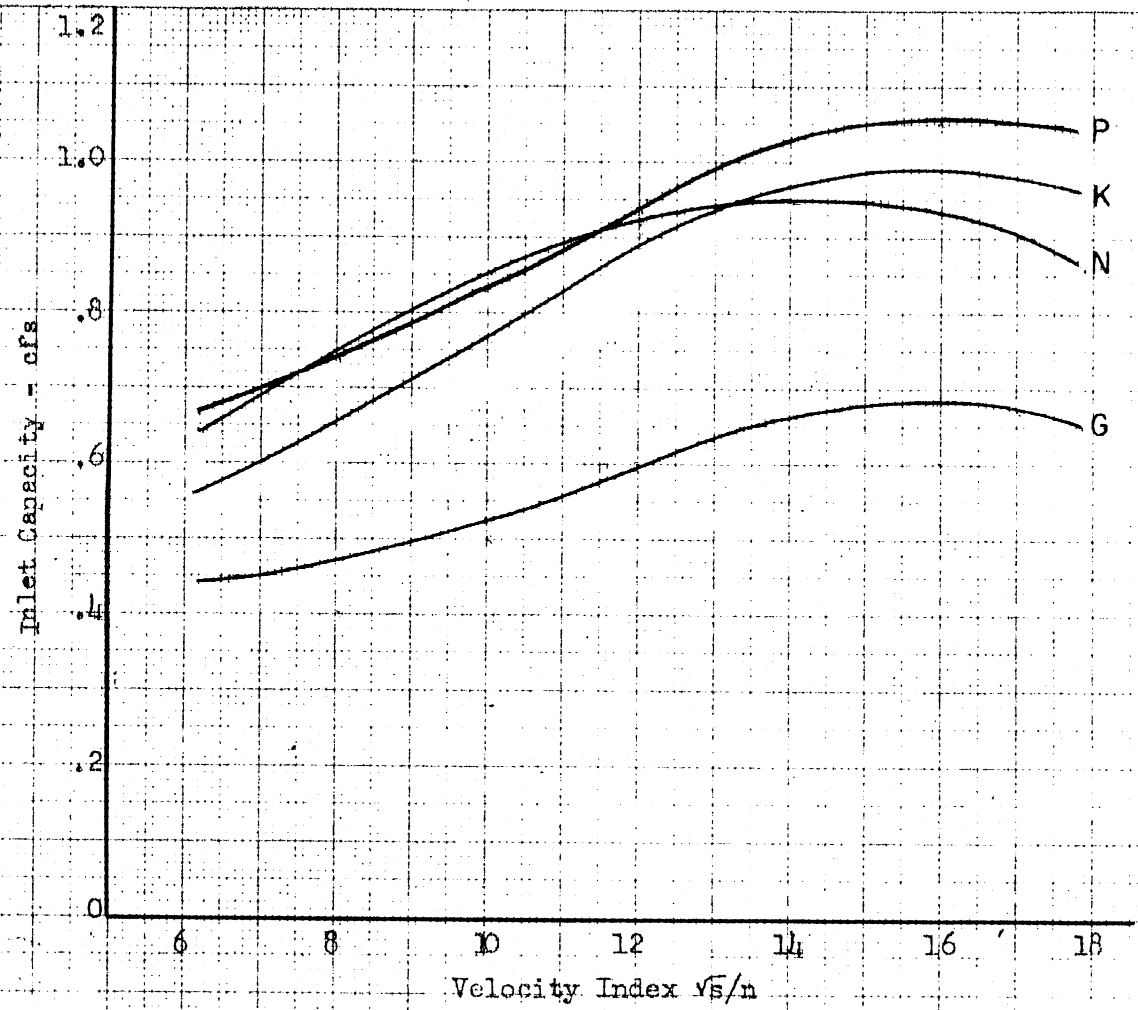


Fig. 10. INLET CAPACITIES CORRESPONDING TO CARRYOVER OF 0.10 CFS

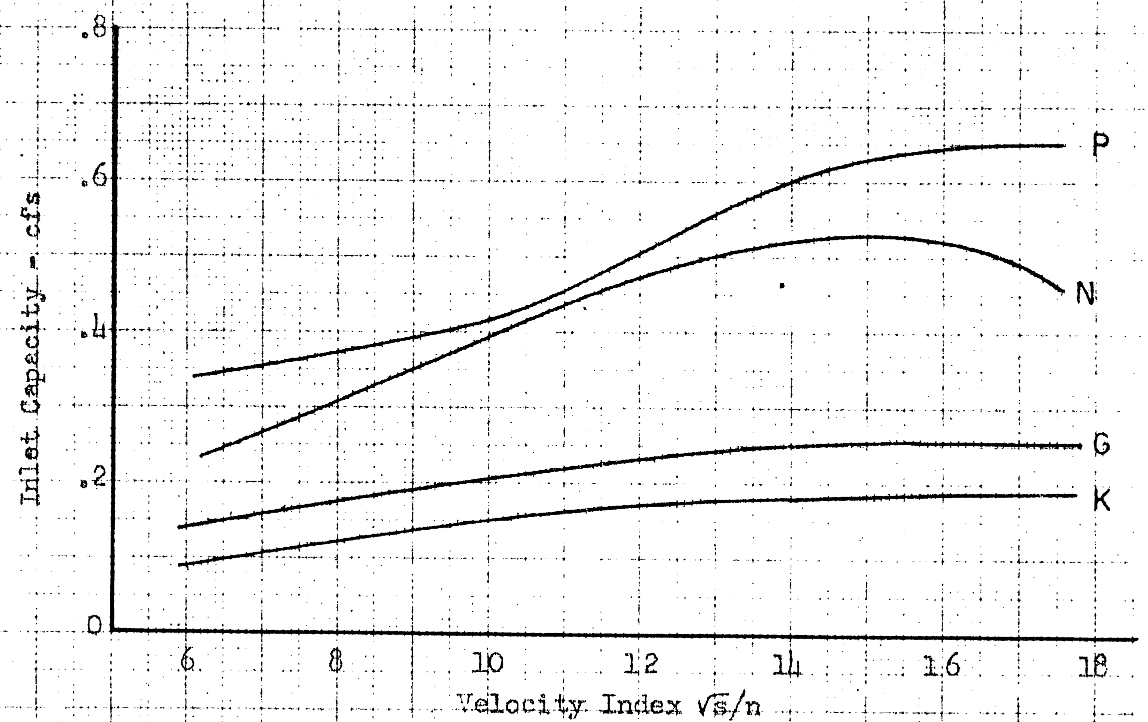


Fig. 9. INLET CAPACITIES CORRESPONDING TO NO CARRYOVER

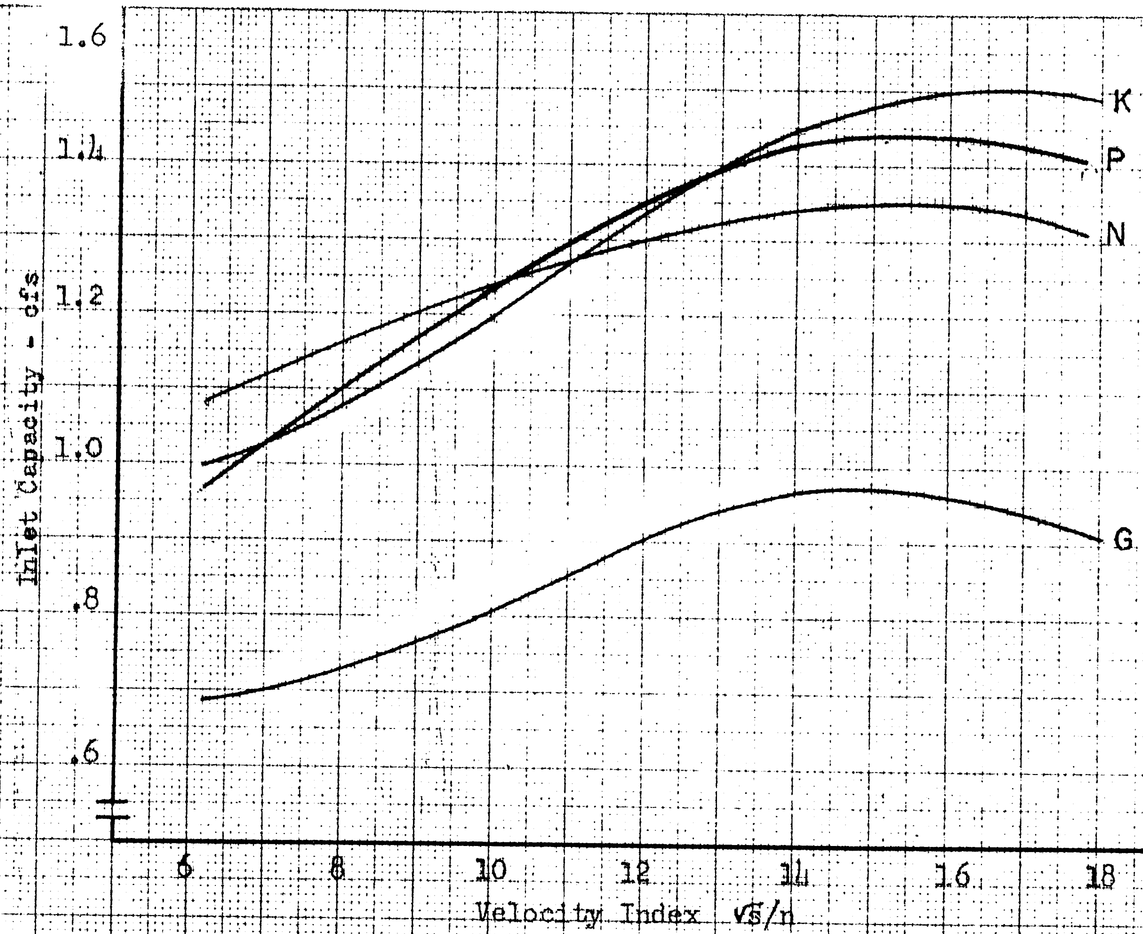


Fig. 12. INLET CAPACITIES CORRESPONDING TO CARRYOVER OF 0.30 CFS

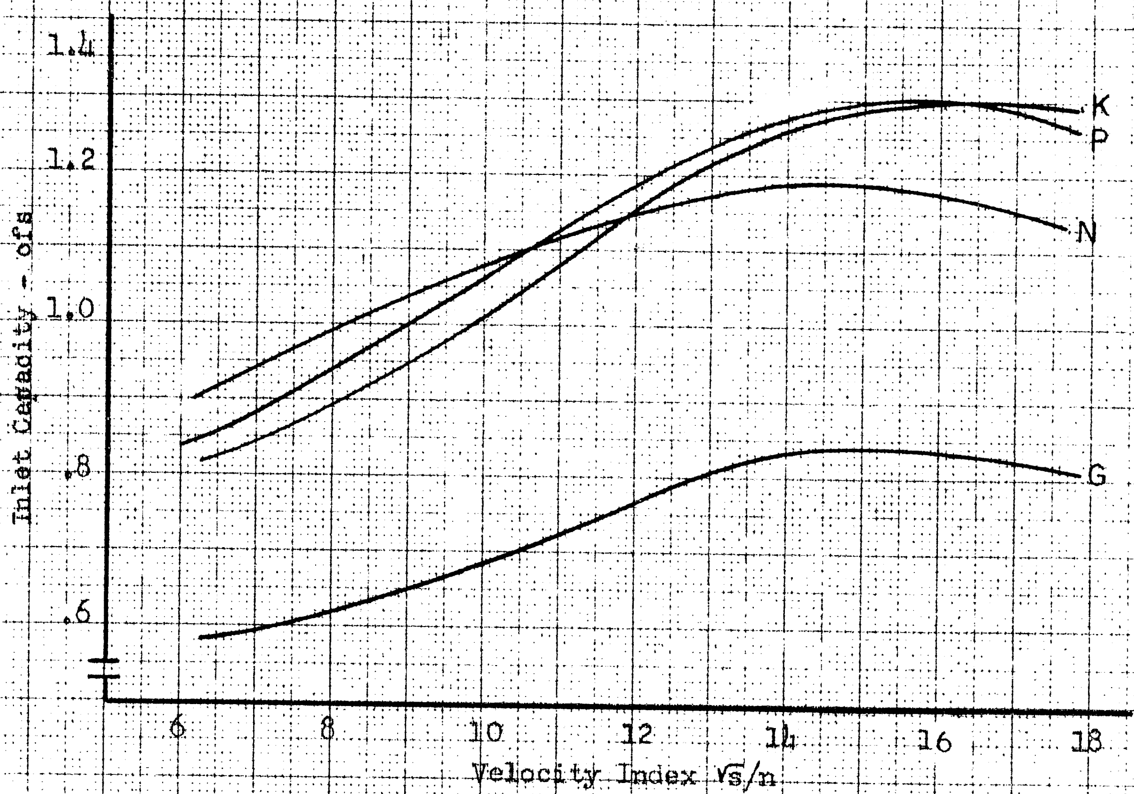


Fig. 11. INLET CAPACITIES CORRESPONDING TO CARRYOVER OF 0.20 CFS

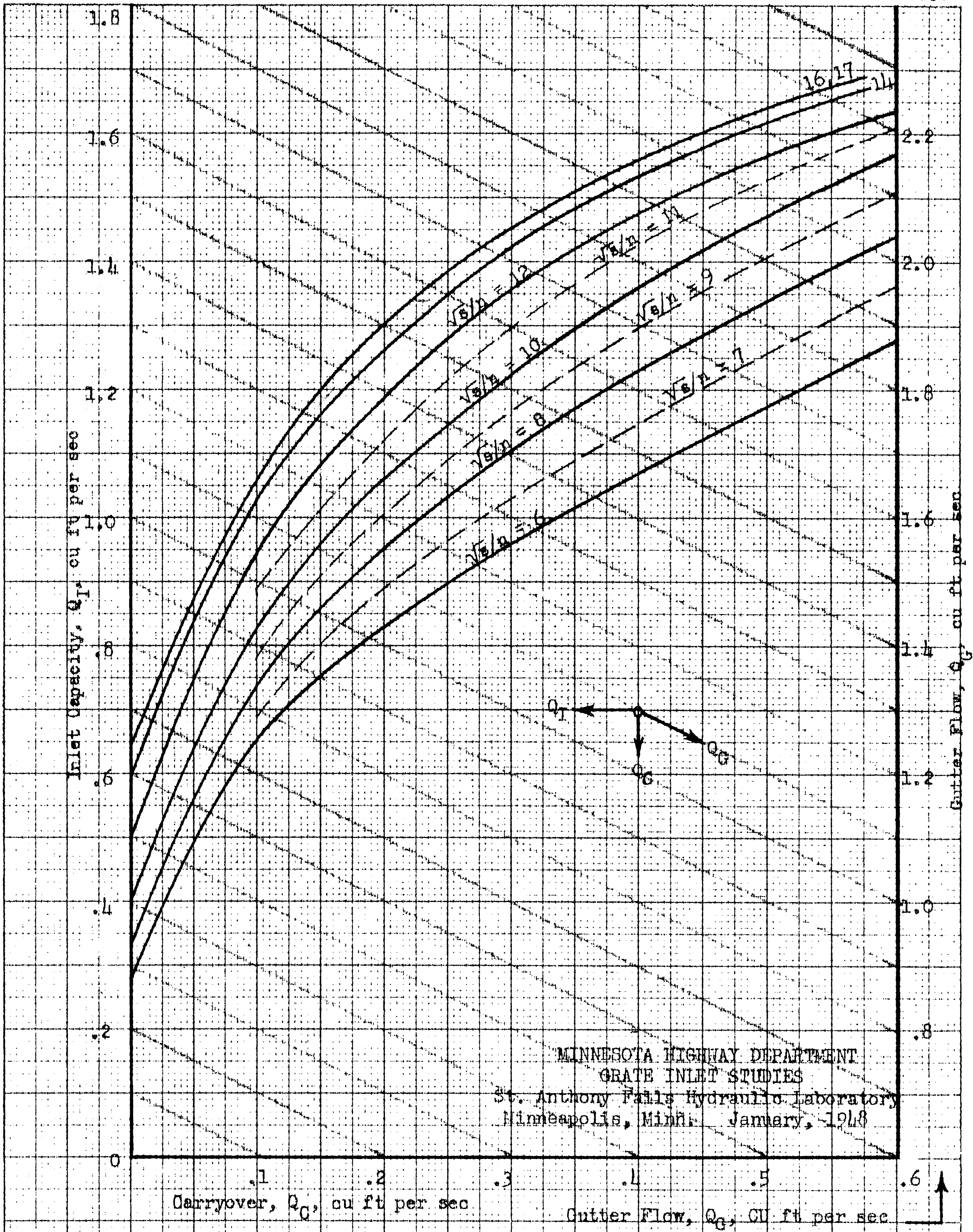


Fig. 13. RATING CURVES FOR INLET P AT VARIOUS VELOCITY INDEXES

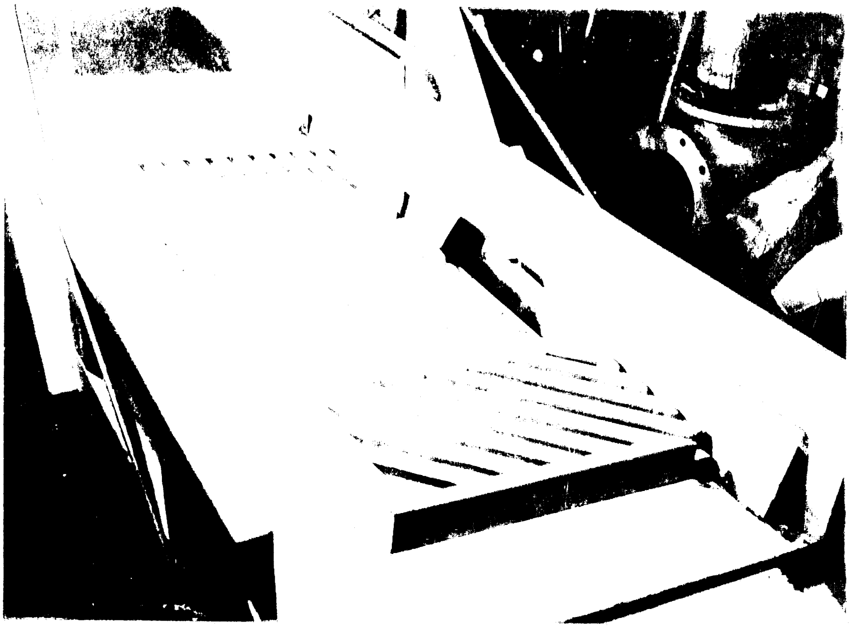


Fig. 14. Experimental Inlets in Test Gutter. L to R: Inlets D, E, F (installed), and K

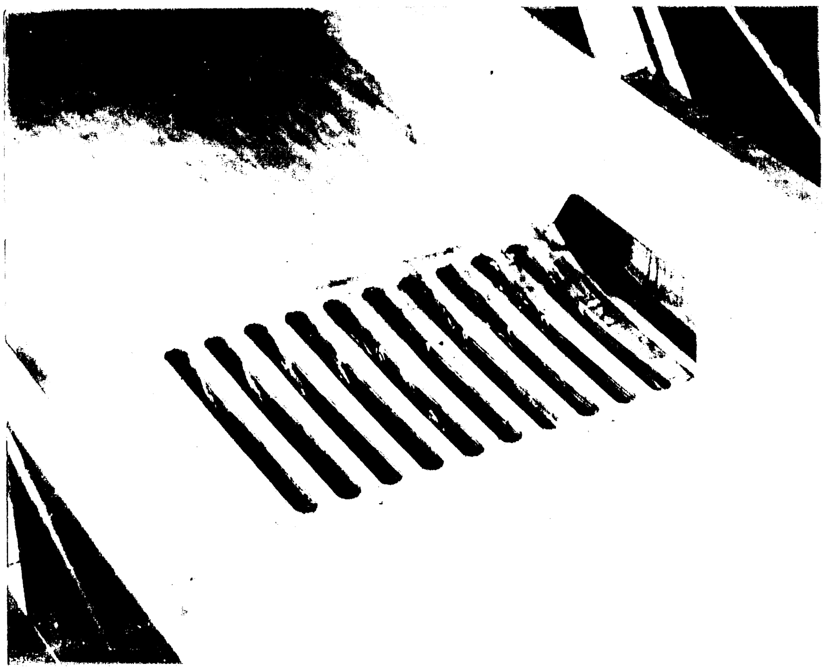


Fig. 15. Experimental Inlet K, $\sqrt{s}/n = 14.0$. $Q_G = 1.05$, $Q_I = 0.96$, $Q_C = 0.09$ cu ft per sec.

Fig. 16. Experimental Inlet L, $\sqrt{S}/n = 14.0$.
$Q_G = 1.05$, $Q_I = 0.89$, $Q_C = 0.16$ cu ft per sec

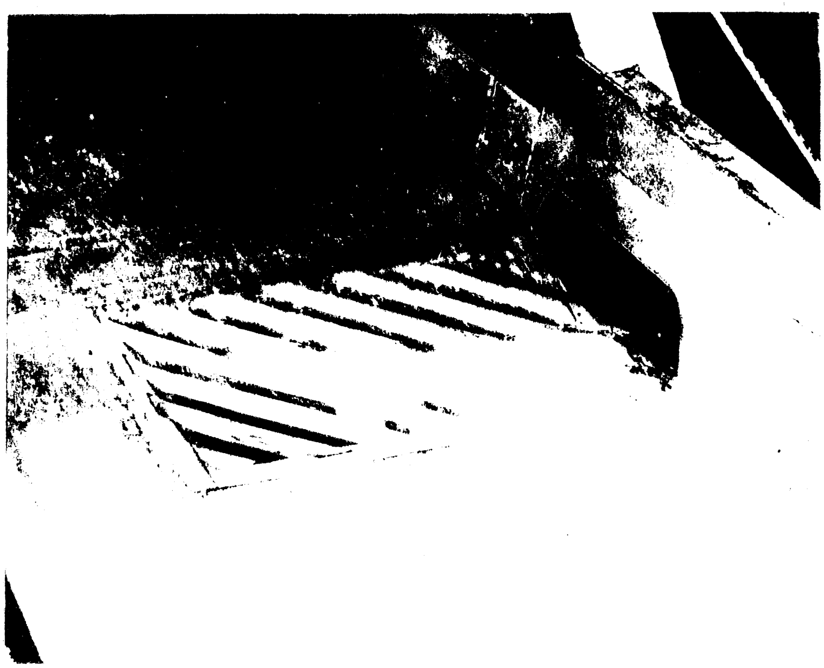


Fig. 17. Experimental Inlet N, $\sqrt{S}/n = 14.0$.
$Q_G = 1.10$, $Q_I = 0.99$, $Q_C = 0.11$ cu ft per sec

Fig. 18. Experimental Inlet [illegible], $\sqrt{s}/n = 14.0$
$Q_G = 1.10$, $Q_I = 1.01$, $Q_C = 0.09$ cu ft per sec

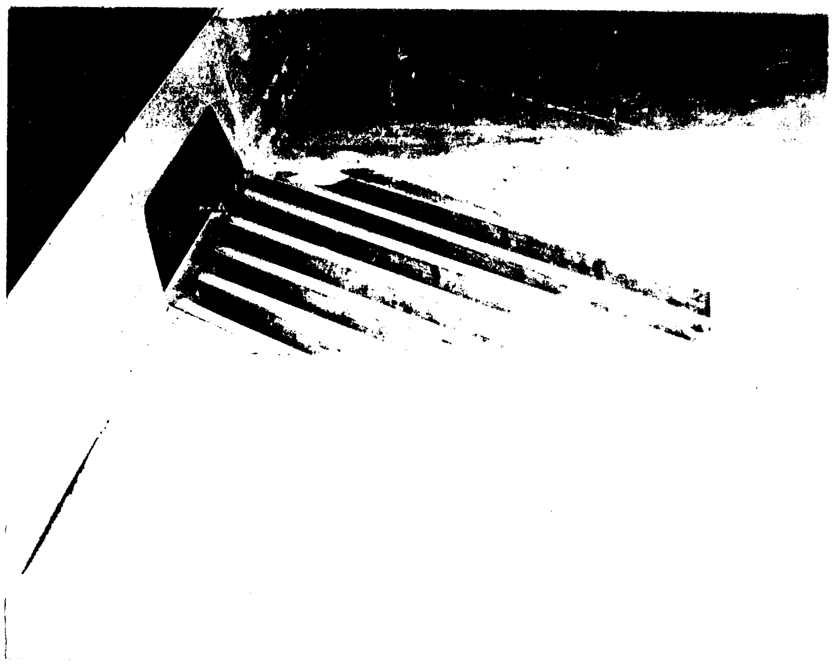


Fig. 19. Upstream view of Experimental Inlet P

APPENDIX II. - TABLES

TABLES 2 - 5. OBSERVED CAPACITIES OF INLET K AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 2. Inlet K, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
K301	2.02	0.34	0.08	2.10	0.42	1.68
K302	1.60	0.22	0.02	1.62	0.24	1.38
K303	1.26	0.14	0.00	1.26	0.14	1.12
K304	0.94	0.07	0.00	0.94	0.07	0.87
K305	0.62	0.02	0.00	0.62	0.02	0.60
K306	0.30	0.01	0.00	0.30	0.01	0.29

TABLE 3. Inlet K, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

K201	2.02	0.35	0.12	2.14	0.47	1.67
K202	1.57	0.21	0.04	1.61	0.25	1.36
K203	1.23	0.13	0.01	1.24	0.14	1.10
K204	0.92	0.07	0.00	0.92	0.07	0.85
K205	0.61	0.03	0.00	0.61	0.03	0.58
K206	0.25	0.01	0.00	0.25	0.01	0.24

TABLE 4. Inlet K, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

K101	1.99	0.39	0.22	2.21	0.61	1.60
K102	1.57	0.27	0.10	1.67	0.37	1.30
K103	1.27	0.19	0.05	1.32	0.24	1.08
K104	0.90	0.11	0.01	0.91	0.12	0.79
K105	0.62	0.04	0.00	0.62	0.04	0.58
K106	0.30	0.01	0.00	0.30	0.01	0.29

TABLE 5. Inlet K, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

K901	2.08	0.45	0.36	2.44	0.81	1.63
K902	1.70	0.33	0.23	1.93	0.56	1.37
K903	1.37	0.24	0.13	1.50	0.37	1.13
K904	1.11	0.18	0.07	1.18	0.25	0.93
K905	0.82	0.12	0.02	0.84	0.14	0.70
K906	0.60	0.07	0.01	0.61	0.08	0.53
K907	0.30	0.02	0.00	0.30	0.02	0.28
K908	0.15	0.01	0.00	0.15	0.01	0.14

TABLES 6 - 9. OBSERVED CAPACITIES OF INLET L AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 6. Inlet L, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
L301	2.03	0.69	0.08	2.11	0.77	1.34
L302	1.57	0.41	0.02	1.59	0.43	1.16
L303	1.25	0.27	0.00	1.25	0.27	0.98
L304	0.94	0.15	0.00	0.94	0.15	0.79
L305	0.62	0.06	0.00	0.62	0.06	0.56
L306	0.39	0.01	0.00	0.39	0.01	0.38

TABLE 7. Inlet L, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

L201	2.00	0.63	0.11	2.11	0.74	1.37
L202	1.56	0.42	0.04	1.60	0.46	1.14
L203	1.26	0.22	0.01	1.27	0.23	1.04
L204	0.94	0.12	0.00	0.94	0.12	0.82
L205	1.59	0.40	0.04	1.63	0.44	1.19
L206	0.62	0.05	0.00	0.62	0.05	0.57
L207	0.38	0.00	0.00	0.38	0.00	0.38

TABLE 8. Inlet L, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

L101	1.99	0.60	0.22	2.21	0.82	1.39
L102	1.55	0.36	0.10	1.65	0.46	1.19
L103	1.25	0.21	0.05	1.30	0.26	1.04
L104	0.95	0.13	0.01	0.96	0.14	0.82
L105	0.62	0.04	0.00	0.62	0.04	0.58
L106	0.39	0.00	0.00	0.39	0.00	0.39

TABLE 9. Inlet L, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

L901	1.97	0.60	0.32	2.29	0.92	1.37
L902	1.57	0.37	0.19	1.76	0.56	1.20
L903	1.27	0.23	0.10	1.37	0.33	1.04
L904	0.98	0.13	0.05	1.03	0.18	0.85
L905	0.62	0.06	0.01	0.63	0.07	0.56
L906	0.34	0.01	0.00	0.34	0.01	0.33

TABLES 10 - 13. OBSERVED CAPACITIES OF INLET M AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 10. Inlet M, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
M301	1.96	0.45	0.07	2.03	0.52	1.51
M302	1.62	0.31	0.02	1.64	0.33	1.31
M303	1.27	0.21	0.00	1.27	0.21	1.06
M304	1.00	0.12	0.00	1.00	0.12	0.88
M305	0.73	0.06	0.00	0.73	0.06	0.67
M306	0.34	0.01	0.00	0.34	0.01	0.33

TABLE 11. Inlet M, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

M201	1.98	0.46	0.11	2.09	0.57	1.52
M202	1.62	0.31	0.04	1.66	0.35	1.31
M203	1.30	0.20	0.01	1.31	0.21	1.10
M204	1.01	0.12	0.00	1.01	0.12	0.89
M205	0.70	0.05	0.00	0.70	0.05	0.65
M206	0.40	0.00	0.00	0.40	0.00	0.40

TABLE 12. Inlet M, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

M101	1.95	0.45	0.20	2.15	0.65	1.50
M102	1.62	0.32	0.12	1.74	0.44	1.30
M103	1.31	0.21	0.05	1.36	0.26	1.10
M104	1.03	0.12	0.02	1.05	0.14	0.91
M105	0.68	0.04	0.00	0.68	0.04	0.64
M106	0.37	0.00	0.00	0.37	0.00	0.37

TABLE 13. Inlet M, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

M901	2.00	0.48	0.33	2.33	0.81	1.52
M902	1.61	0.31	0.20	1.81	0.51	1.30
M903	1.30	0.21	0.11	1.41	0.32	1.09
M904	0.94	0.12	0.04	0.98	0.16	0.82
M905	0.60	0.05	0.01	0.61	0.06	0.55
M906	0.31	0.01	0.00	0.31	0.01	0.30

TABLES 14 - 17. OBSERVED CAPACITIES OF INLET N AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 14. Inlet N, Test Slope = 3.0%, $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
N301	1.96	0.41	0.07	2.03	0.48	1.55
N302	1.59	0.27	0.02	1.61	0.29	1.32
N303	1.29	0.18	0.00	1.29	0.18	1.11
N304	0.95	0.09	0.00	0.95	0.09	0.86
N305	0.60	0.02	0.00	0.60	0.02	0.58

TABLE 15. Inlet N, Test Slope = 2.0%, $\sqrt{s}/n$ = 14.0

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
N201	1.98	0.43	0.11	2.09	0.54	1.55
N202	1.60	0.26	0.04	1.64	0.30	1.34
N203	1.26	0.15	0.01	1.27	0.16	1.11
N204	0.96	0.08	0.00	0.96	0.08	0.88
N205	0.58	0.01	0.00	0.58	0.01	0.57

TABLE 16. Inlet N, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
N101	1.96	0.40	0.21	2.17	0.61	1.56
N102	1.56	0.26	0.10	1.66	0.36	1.30
N103	1.26	0.16	0.05	1.31	0.21	1.10
N104	0.92	0.09	0.01	0.93	0.10	0.83
N105	0.60	0.02	0.00	0.60	0.02	0.58

TABLE 17. Inlet N, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

Test Number	Observed Gutter Disch. Q'_G	Observed Carryover Q'_C	Discharge Correction	Corrected Gutter Disch. Q_G	Corrected Carryover Q_C	Inlet Capacity Q_I
N901	1.97	0.40	0.32	2.29	0.72	1.57
N902	1.59	0.27	0.19	1.78	0.46	1.32
N903	1.26	0.19	0.10	1.36	0.29	1.07
N904	0.94	0.11	0.04	0.98	0.15	0.83
N905	0.68	0.07	0.01	0.69	0.08	0.61
N906	0.31	0.01	0.00	0.31	0.01	0.30

TABLES 18 - 21. OBSERVED CAPACITIES OF INLET P
AT VARIOUS SLOPES AND GUTTER DISCHARGES

TABLE 18. Inlet P, Test Slope = 3.0% $\sqrt{s}/n$ = 17.2

Test Number	Observed Gutter Disch.	Observed Carryover	Discharge Correction	Corrected Gutter Disch.	Corrected Carryover	Inlet Capacity
	Q'_G	Q'_C		Q_G	Q_C	Q_I
P301	2.05	0.41	0.08	2.13	0.49	1.64
P302	1.69	0.27	0.03	1.72	0.30	1.42
P303	1.41	0.16	0.01	1.42	0.17	1.25
P304	1.11	0.09	0.00	1.11	0.09	1.02
P305	0.88	0.04	0.00	0.88	0.04	0.84
P306	0.65	0.00	0.00	0.65	0.00	0.65
P307	1.73	0.29	0.03	1.76	0.32	1.44
P308	1.97	0.37	0.07	2.04	0.44	1.60

TABLE 19. Inlet P, Test Slope = 2.0% $\sqrt{s}/n$ = 14.0

P201	2.00	0.39	0.11	2.11	0.50	1.61
P202	1.69	0.24	0.05	1.74	0.29	1.45
P203	1.38	0.15	0.02	1.40	0.17	1.23
P204	1.11	0.10	0.00	1.11	0.10	1.01
P205	0.84	0.04	0.00	0.84	0.04	0.80
P206	0.60	0.00	0.00	0.60	0.00	0.60
P207	1.19	0.11	0.01	1.20	0.12	1.08
P208	1.88	0.33	0.09	1.97	0.42	1.55
P209	1.54	0.20	0.04	1.58	0.24	1.34

TABLE 20. Inlet P, Test Slope = 1.0%, $\sqrt{s}/n$ = 9.8

P101	1.99	0.41	0.22	2.21	0.63	1.58
P102	1.60	0.27	0.11	1.71	0.38	1.33
P103	1.25	0.17	0.05	1.30	0.22	1.08
P104	0.95	0.10	0.01	0.96	0.11	0.85
P105	0.61	0.02	0.00	0.61	0.02	0.59
P106	0.41	0.00	0.00	0.41	0.00	0.41

TABLE 21. Inlet P, Test Slope = 0.5%, $\sqrt{s}/n$ = 6.6

P901	1.99	0.47	0.33	2.32	0.80	1.52
P902	1.59	0.33	0.19	1.78	0.52	1.26
P903	1.27	0.23	0.10	1.37	0.33	1.04
P904	0.93	0.12	0.04	0.97	0.16	0.81
P905	0.60	0.04	0.01	0.61	0.05	0.56
P906	0.30	0.00	0.00	0.30	0.00	0.30

TABLE 22. DEBRIS TESTS OF VARIOUS INLETS AT VELOCITY INDEX OF 14.0

Series	Observed Gutter Disch.	Pcs. Debris Introduced	Pcs. Lodged On Inlet	% Passing Inlet	Debris Rating
	Q'_G	(Av. of 3 trials)		Av.	
K	1.10	50	4.7	90.6	v.g.-exc.
L	1.10	50	33.0	34.0	poor
M	1.10	50	16.0	68.0	good
N	1.10	50	13.0	74.0	good
P	1.10	50	9.0	82.0	v.good

Notes:

K - Leaves pass through openings easily, but some grass straddles bars and remains lodged.

L - Both leaves and grass catch on bars readily.

M - Approximately 90 per cent of leaves pass through openings. All of grass goes through or moves to ends of bars.

N,P - Approximately 90 per cent of leaves pass through openings. All of grass goes through or moves along bars to curb openings.

Debris Rating Scale:

Very poor	0 - 20 %
Poor	20 - 40 %
Fair	40 - 60 %
Good	60 - 80 %
Very good	80 - 90 %
Excellent	90 - 100 %