UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

FLOW CHARACTERISTICS IN A PIPELINE DOWNSTREAM FROM A SQUARE CORNERED ENTRANCE

Laboratory Report No. Hyd-422

DIVISION OF ENGINEERING LABORATORIES

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Symbols and Definitions

(See Figure 1)

x = distance along the pipe from the sharp entrance to any cross section, feet

d = inside diameter of the pipe, feet

h_v = velocity head, $\frac{V^2}{2g}$

ΔH_x = drop in pressure head between head pool and cross section x, feet of water

ΔH = drop in pressure head between head pool and station 12 inches from pipe inlet, feet of water

C_d = coefficient of discharge, $\frac{Q}{A\sqrt{2g\Delta H}}$

h = submergence of the pipe invert, feet

h/d = relative submergence

V = average velocity, $\frac{Q}{A}$

A = area of pipe cross section, square feet

Q = discharge, cfs

g = acceleration of gravity; 32.2 ft per sec.^{2}

R_e = Reynolds number, $\frac{Vd}{\nu}$

ν = kinematic viscosity of water, $\frac{ft^2}{sec}$

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Commissioner's Office, Denver Division of Engineering Laboratories Hydraulic Laboratory Branch Hydraulic Structures & Equipment Section Denver, Colorado	Laboratory Report No. Hyd-422 Written by: H. A. Babcock and, W. P. Simmons, Jr. Checked and reviewed by: J. W. Ball Submitted by: H. M. Martin

Subject: Flow characteristics in a pipeline downstream from a square cornered entrance

PURPOSE

The investigation was undertaken to obtain basic data on the flow conditions and pressure distribution downstream from a square cornered pipe entrance under various conditions of submergence, approach shape, and Reynolds' number. The information is intended for use as reference material in the calibration of meter gates.

CONCLUSIONS

1. The amount of submergence of the pipe entrance had considerable effect upon the coefficient of discharge when the submergence was less than 2 pipe diameters above the pipe invert (Figure 2, 3, 4, and 5). There was no appreciable effect at submergences between 2d and 4d, and only a slight effect between 4d and 5d. The coefficient of discharge, C_d was based on the pressure head in the conduit 12 inches downstream from the inlet.

2. The designs of the approach walls and floor had an appreciable effect upon C_d (Figure 4F). When an approach floor was used, changes in the walls had a pronounced effect at submergences less than 2d, but little effect at higher submergences. When no approach floor was used, changes in the walls had a noticeable effect at submergences less than 2d, and a moderate effect at higher submergences. The coefficients for the designs with the walls and floor (Inlets 1, 2, and 3), and with the floor but without the walls (Inlet 4) were about the same above a submergence of 2d. The coefficient for the design without the walls and approach floor (Inlet 5) was much higher. When walls were used without an approach floor (Inlets 6, 7, and 8) the coefficients were still higher.

3. In general, C_d increased as the wing walls were moved closer to the pipe when the floor was in place (Table 1). Removal of

the approach floor with and without walls caused a considerable change in the hydraulic gradient along the pipeline, and considerable increase in C_d based on the pressure reading 12 inches from the pipe entrance (Figure 4E).

4. Reynolds' number had a small but noticeable effect upon C_d in that C_d increased a small amount as R_e was increased.

5. The average C_d for the particular approach design, Table 1, may be used at submergences from 2d to 5d with an accuracy of ±3%.

6. The position of the piezometer tap in meter gate installations, which has been arbitrarily standardized at 12 inches from the pipe entrance regardless of pipe or gate diameter, apparently was selected solely from construction considerations. Hydraulic considerations show that the location should be a function of pipe diameter, thereby placing the tap in a better location on the hydraulic gradient, and obtaining more consistent differentials for all sized installations for given flow velocities in the pipelines. A station at some point within 1/3 diameter of the entrance appears desirable. Within these limits the hydraulic gradient is not excessively steep and the head differentials are high. The gradient is less steep at stations beyond $\frac{x}{d} = 1.5$, but the head differentials are low and small errors in reading would produce appreciable errors in the indicated rate of flow.

RECOMMENDATIONS

1. Insofar as is possible, design meter gate installations for submergences over the pipe invert of two or more pipe diameters.

2. Use the average C_d value obtained from Table 1 for the appropriate approach wall and floor design for submergences from 2 to 5d.

3. Consider establishing a new standard location for the pipe pressure tap of meter gate installations. A station on the pipe crown 1/3 or less diameter downstream of the entrance is suggested.

ACKNOWLEDGMENT

The pipe entrance study was carried on in the Bureau of Reclamation Hydraulic Laboratory. The senior author wishes to express his thanks to Mr. Harold M. Martin for the opportunity to work in such a stimulating environment, to the members of the Laboratory staff for their unfailing kindness, and particularly to Messrs. D. Colgate, J. C. Schuster, and W. P. Simmons, for their help.

INTRODUCTION

A typical meter gate installation includes two measuring wells. One is connected to the head water via a pipe through the headwall, and the other is connected to a point on the crown of the pipeline 12 inches downstream from the entrance. Discharge is computed from the gate opening and the difference in water levels in the two wells. The 12-inch distance has been maintained constant in all gate sizes, and thus there is no geometric similarity between gate installations of different diameters. Other dissimilarities exist due to differences in gate leaf guides, the shape of the gate leaf, etc., and these differences make calibration of each size desirable.

Errors as high as 18 percent have been reported by users of meter gates in irrigation distribution systems, and apparent inconsistencies have occurred during laboratory calibrations of these devices. Possible reasons for these field and laboratory discrepancies were thought to lie in the effect of Reynolds' number, degree of submergence, and approach geometry. Studies were therefore made to isolate, insofar as was practicable, the effect of each of these variables upon the pressure distribution downstream of a sharp cornered pipe entrance. The data obtained was intended to provide background material against which data on specific gate installations could be compared.

The plan was to measure piezometric head at various points along the crown of a pipe for ranges of Reynolds' number, submergence, and approach conditions. No attempt was made to represent field conditions, and the study was limited to a circular entrance with no obstruction such as a gate leaf present.

The upper limit of Reynolds' number was limited by the depth of the head box and the pipeline diameter to about 600,000. The lower limit was fixed at about 100,000 by the lowest head differential considered usable. The upper limit of submergence, measured above the pipeline invert, was about 5d. The lower limit was about 1.3d and was set by the elevation of the tailgate sill.

Because it would be impractical to compute the coefficient of discharge for all locations of the downstream tap, a distance of 12 inches was used for comparison between various Reynolds' numbers and approach conditions. The 12-inch distance was used because it is the standard presently used for meter gates. Dimensionless hydraulic gradients were prepared which permit computation of the coefficient for any other position of the downstream tap.

INVESTIGATION

Test Equipment

A schematic drawing of the test installation is given in Figure 1. Flow was provided to the head box by 8- and 12-inch centrifugal pumps, and the rate of flow was determined by 4-, 6-, 8-, and 12-inch venturi meters located near the pumps. Pressure taps (piezometers) were placed in the crown of the 10-inch plastic pipe as shown in Figure 1, and connected to single-leg water manometers on a gage board marked in feet, tenths of feet, and hundredths of feet.

Wing walls were represented by sheets of 3/4-inch plywood placed on either side of the pipe entrance. The flare of the walls relative to the axis of the pipe was about 6:1 but this figure was not exact, nor was it precisely the same for different spacings. However, the variation from the 6:1 flare was small, and considerable variation appears to be required to produce a noticeable difference in flow conditions in the pipe.

The wing walls were successively placed at $\frac{d}{4}$, $\frac{d}{2}$, and d distances from the edge of the pipe entrance, and were finally removed altogether. These arrangements were called Inlet 1, Inlet 2, Inlet 3, and Inlet 4, respectively, and all used the same approach floor (Figure 1). Tests were also made without walls and approach floor. This arrangement was called Inlet 5. Final tests were made without the approach floor, but with the approach walls at $\frac{d}{4}$, $\frac{d}{2}$, and d distances from the edge of the pipe. These arrangements were called Inlets 6, 7, and 8.

Test Procedure

Water was pumped into the head box and the rate of flow was adjusted to give the desired Reynolds' number. When the flow rate made it necessary to change to a larger or smaller venturi meter, the flow measurements obtained by the meters were checked against one another and any slight discrepancy was eliminated by applying a suitable coefficient. Air was bled from the piezometer lines, and, after allowing sufficient time for the flow to come to a steady condition, the manometers were read. No provisions were made to dampen the fluctuations that occurred in the liquid columns and they were averaged visually. This procedure was time consuming, but it is felt that good accuracy resulted. The piezometric head was read at least to the nearest 0.01 foot, and at low Reynolds' numbers, estimated to the nearest 0.001 foot. After the readings were completed, the submergence was set for the next test by adjusting the tailgate. The discharge was read one or more times for each submergence, the water temperature was recorded, the piezometer lines were continually checked to guard against air pockets, and care was exercised to allow the flow to fully stabilize for each new setting of the tailgate.

The ranges of Reynolds' number used were:

Low	about 120,000
Medium low	about 200,000
Medium	about 325,000
Medium high	about 500,000
High	about 625,000

After the full range of submergences was tested for each of the five ranges of Reynolds' numbers, the wing walls were moved to a new position and the procedure repeated.

Analysis

In order for the data of this study to be used on pipe sizes other than the 10-inch size tested, it was necessary to present it in dimensionless form. The coefficient of discharge for the entrance, based on the drop in hydraulic gradient from the head pool to the station 12 inches downstream from the inlet, was plotted against the relative submergence on the entrance (Figures 2 and 3). The relative submergence was taken as the ratio of the water depth above the inlet invert divided by the pipeline diameter. In the case of the hydraulic gradient, the drop in hydraulic gradient, ΔH_x, divided by the velocity head, h_v, was plotted against the distance x along the pipe, divided by the pipe diameter, d, (Figures 6 and 7).

A coefficient of discharge, based on the pressure 12 inches from the entrance, was computed for each test made. Since there was no piezometer at the 12-inch station, the pressure was interpolated from the two nearest piezometers. Thus, 0.8 of the difference between piezometer No. 8 and piezometer No. 9 was added to the reading of piezometer No. 8 to obtain the pressure head 12 inches from the entrance. It is this coefficient that is plotted on Figures 2 and 3.

Next, each piezometer reading was subtracted from the head box reading for each test. This gave the drop in the hydraulic gradient at each piezometer, ΔH_x. This value was divided by h_v and thus the value of $\Delta H_x/h_v$ was obtained for each piezometer for each run. These values were then averaged for such submergence ratios as appeared to yield constant value of C_d. This invariably excluded submergence ratios below 2d, and frequently excluded submergences greater than 4d. The results are plotted in Figures 6 and 7.

The coefficient of discharge can be obtained from the dimensionless hydraulic gradient as follows:

$$Q = C_d A \sqrt{2g\Delta H_x}$$

and because $V = \frac{Q}{A}$,

$$V = C_d \sqrt{2g\Delta H_x}$$

Squaring both sides and dividing by 2g yields:

$$\frac{V^2}{2g} = C_d{}^2 \Delta H_x.$$

Which may be written in the more manageable form

$$C_d = \sqrt{\frac{h_v}{\Delta H_x}}$$

Thus C_d may be computed by obtaining $\frac{\Delta H_x}{h_v}$ and taking the square root of its reciprocal. For example, Figure 6A, which gives hydraulic gradients for Inlet 1, shows that for a medium Reynolds' number and for $x/d = 1.2 \Delta H_x/h_v = 1.81$. Therefore,

$$C_d = \sqrt{\frac{1}{1.81}} = 0.743$$

This is the coefficient of discharge for a tap 12 inches from the entrance in a 10-inch pipe.

In this way the coefficient for any size pipe may be obtained for different combinations of wing walls, Reynolds' number, and submergences between 2d and 4d.

Results

The relation of C_d to relative submergence at the five values of R_e for Inlets 1 through 8 is shown in Figures 2 and 3. Notice that for submergences smaller than 2d the coefficients of several designs change rapidly. For Inlets 1 and 2 the curves drop, for Inlet 4 the curve rises, and for Inlets 3 and 5 the curves are about level. For Inlets 6, 7, and 8, the curves drop slightly.

At submergences greater than 4d the curves of Inlets 1 and 2 exhibit a tendency to drop, while those for Inlets 3, 4, and 5 remain about constant. There is a slight drop in the curves for Inlets 6, 7, and 8. The curves for Inlets 5, 6, 7, and 8 are higher values than for the others, and Inlets 3 and 5 give the most constant values throughout the submergence range. Inlets 6, 7, and 8 also produce reasonably constant values.

The information given on the curves in Figures 2 and 3 is summarized on Table 1 for submergences from 2 to 4d. The table also gives the percent differences for the various coefficients. Notice the improvement in the averages that is made by omitting the coefficients for low and medium low Reynolds' numbers.

Figures 4 and 5 illustrate the relative significance of submergence and Reynolds' number. In these figures Reynolds' number is represented by a change in plotting symbol only. Notice that all data cluster within about ±3% of the median line, thereby showing that Reynolds' number, within the range tested, is relatively unimportant. Figure 4F shows the median lines for each approach arrangement plotted on the same sheet for comparison. Note that the coefficient of discharge based on the pressure 12 inches from the pipe inlet, was lowest when the approach floor was used with and without the guide walls (Inlets 1, 2, 3, and 4). The coefficient was higher when no floor or walls were used (Inlet 5), and was still higher when the guide walls were used without the floor (Inlets 6, 7, and 8). Note also the rapid change in the coefficient at submergences below 2d, and that as the wing walls are moved outward from the entrance the coefficient becomes more constant for Inlets 3, 4, and 5.

The curves in Figure 4F are the average for all Reynolds' numbers and it is reasonable that such curves could be used as a basis for rating tables or rating curves. For example, in the case of Inlet 3, it appears that a coefficient of 0.734 can be used for all Reynolds' numbers and all submergences above 2d with confidence that results would be obtained within ±3%.

The curves in Figures 6 and 7 show the hydraulic gradient along the pipeline for the various approach designs and Reynolds' number ranges. There is strong similarity between the curves with the floor in place (Inlets 1, 2, 3, and 4), and strong similarity between the curves without the floor in place (Inlets 5, 6, 7, and 8). In the latter case, the low point of the gradient dip at the vena contracta is closer to the pipe entrance, and the gradient rises sooner than in the other approach designs. The earlier rise of the gradient results in a higher piezometric pressure at $\frac{x}{d} = 1.2$, thus accounting for the higher C_d curve shown in Figures 2, 3, 4, and 5. These hydraulic gradients are for submergences between 2d and 4d above the pipe invert where C_d, as shown on Figures 2 and 3, is about constant. The gradients confirm the relatively minor role of Reynolds' number suggested by Figures 4 and 5.

An important point disclosed by these curves is that the downstream tap, which is usually placed 12 inches from the pipe entrance, could hardly have been put in a less desirable place. For gate sizes of 10 to 24 inches the tap falls in the steepest part of the hydraulic gradient, thus making the location of the tap critical. For larger gate sizes the tap is in a less critical region, but still gives a substantial variation in coefficient values.

A tap located at a constant $\frac{x}{d}$ distance of less than 1/3 diameter from the entrance would overcome the objectionable features of the 12-inch tap location. The only geometric dissimilarity in this case would be the differences in the gate leaf, seat, and supporting structures.

Table 2 shows the coefficients for a tap located near the gate seat at $\frac{x}{d} = 0.06$. These coefficients may be compared with those for a tap located at $\frac{x}{d} = 1.2$, Table 1. The coefficients are more nearly constant for the $\frac{x}{d} = 0.06$ tap location.

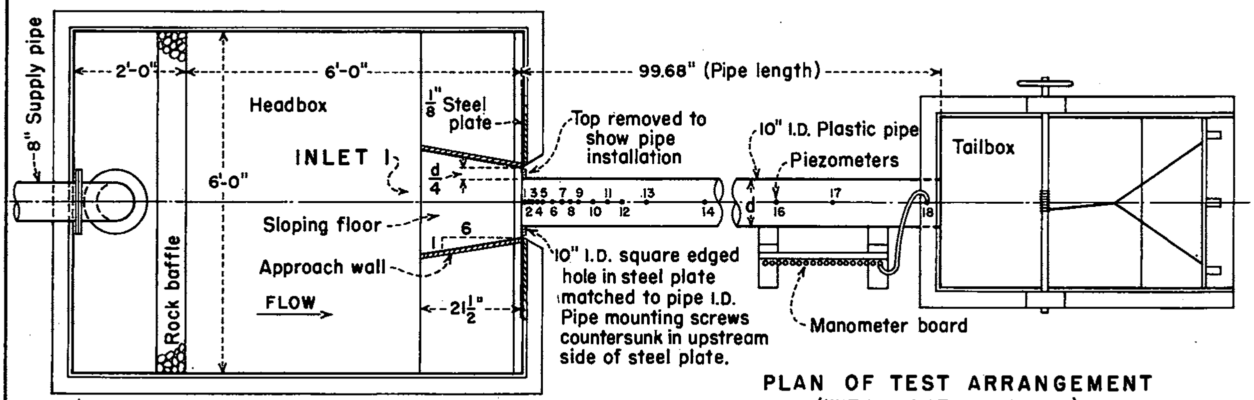
The average of all C_d values of Table 1 is 0.774 and the maximum variation is 3.1 percent. The smallest individual coefficient obtained for any of the test points was 0.616, which differs from the average by about 20 percent (Figure 4A). This reading was taken at an extremely low submergence. The highest coefficient obtained was 0.831, which is about 7 percent greater than the average (Figure 5A). This reading was taken at a medium-low submergence with approach walls but without an approach floor.

Table 1

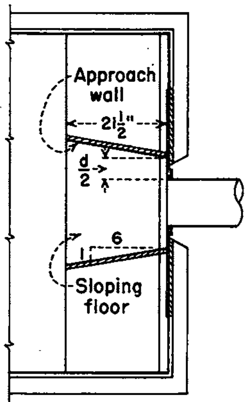
Reynolds' Number	Coefficient of Discharge Based on a Tap 12 inches from Entrance of a 10-inch Pipe--Submergence 2 to 4d above Invert							
	Inlet 1	Inlet 2	Inlet 3	Inlet 4	Inlet 5	Inlet 6	Inlet 7	Inlet 8
120,000	0.731	0.713	0.728	0.720	0.787			
200,000	0.732	0.737	0.727	0.730	0.810	0.820	0.820	0.820
325,000	0.741	0.739	0.739	0.738	0.804			
500,000	0.755	0.744	0.734	0.736	0.800	0.820	0.813	0.802
625,000	0.755	0.747	0.744	0.734	0.800			
Average	0.743±1.6%	0.736±3.1%	0.734±1.3%	0.732±1.6%	0.800±1.6%	0.820	0.817	0.811
Average 3 high R_e's	0.750±1.2%	0.744±0.5%	0.739±0.7%	0.736±0.2%	0.801±0.4%			

Table 2

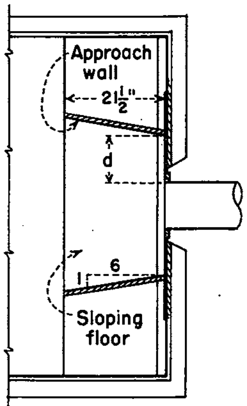
Reynolds' Number	Coefficient of Discharge Based on a Tap 0.6 inch Inside the Gate Seat (0.06d)							
	Inlet 1	Inlet 2	Inlet 3	Inlet 4	Inlet 5	Inlet 6	Inlet 7	Inlet 8
120,000	0.625	0.617	0.621	0.612	0.596			
200,000	0.624	0.627	0.625	0.620	0.611	0.630	0.619	0.613
325,000	0.631	0.627	0.625	0.624	0.610			
500,000	0.632	0.630	0.625	0.623	0.606	0.627	0.615	0.610
625,000	0.633	0.630	0.629	0.621	0.604			
Average	0.629±1%	0.626±1.4%	0.625±0.6%	0.620±1.3%	0.605±1.5%	0.629±0.3%	0.617±0.3%	0.612±0.3%



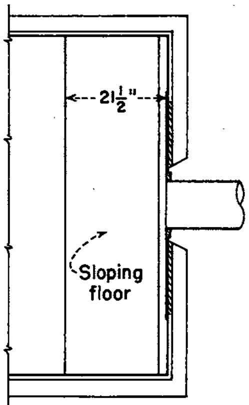
PLAN OF TEST ARRANGEMENT
(WITH INLET 1 IN PLACE)



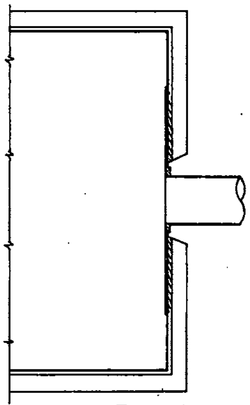
INLET 2



INLET 3

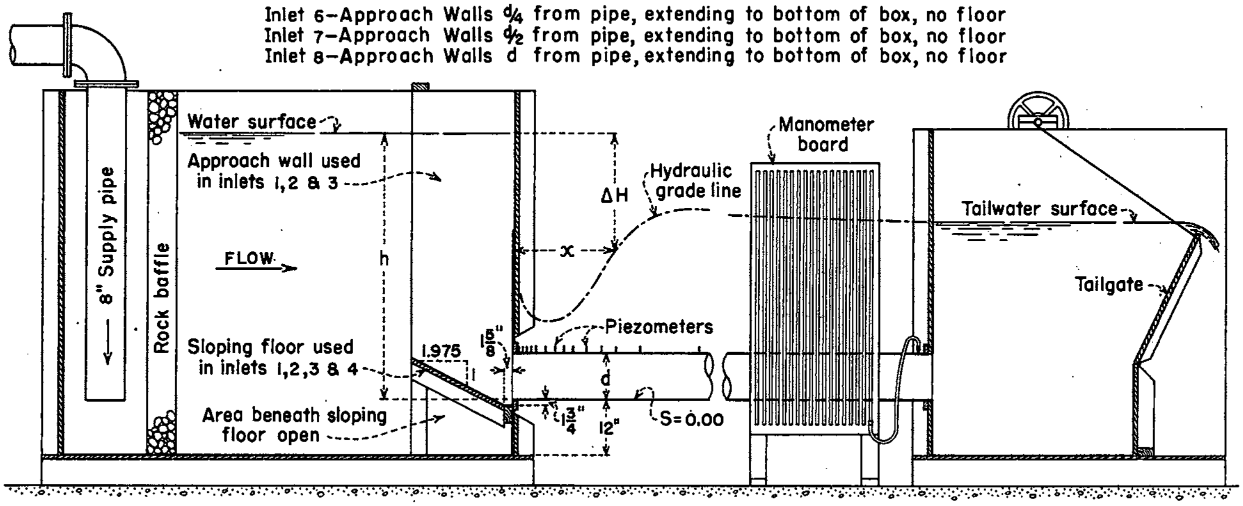


INLET 4



INLET 5

Inlet 6–Approach Walls d/4 from pipe, extending to bottom of box, no floor
Inlet 7–Approach Walls d/2 from pipe, extending to bottom of box, no floor
Inlet 8–Approach Walls d from pipe, extending to bottom of box, no floor



LONGITUDINAL SECTION OF TEST ARRANGEMENT

PIEZOMETER LOCATIONS FROM UPSTREAM END OF PIPE

PIEZOMETER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
x/d	0.061	0.136	0.236	0.334	0.436	0.638	0.838	1.038	1.238	1.538	1.838	2.139	2.693	3.908	5.095	6.292	7.462	9.687
x INCHES	0.61	1.36	2.36	3.34	4.36	6.38	8.38	10.38	12.38	15.38	18.38	21.39	26.93	39.08	50.95	62.92	74.62	96.87

A STUDY OF
FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

SCHEMATIC DRAWINGS OF MODEL AND INLET DESIGNS

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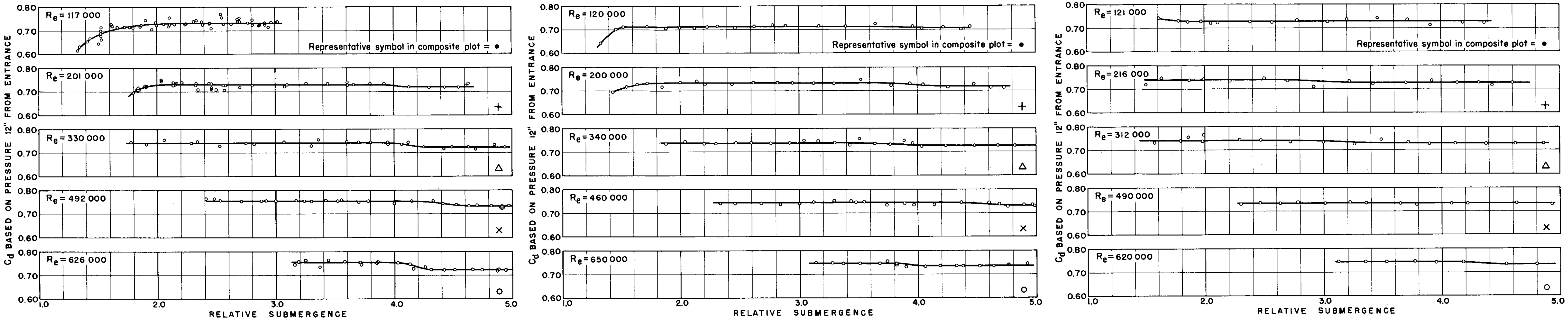
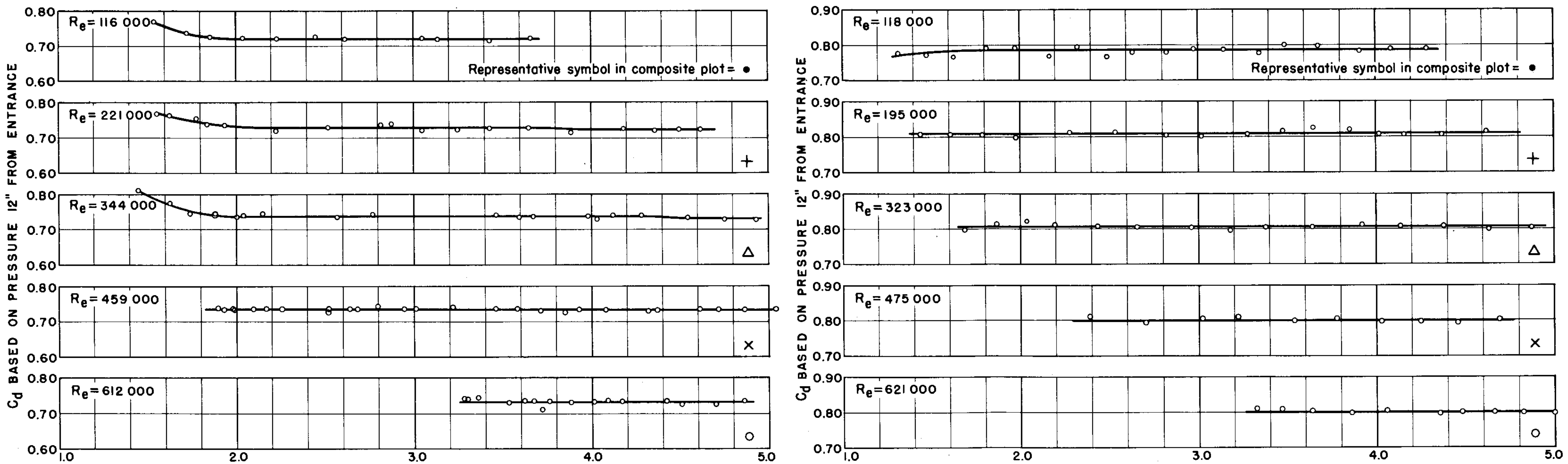


A. APPROACH WALLS $d/4$ FROM PIPE SIDES, FLOOR IN PLACE — INLET 1

B. APPROACH WALLS $d/2$ FROM PIPE SIDES, FLOOR IN PLACE — INLET 2

C. APPROACH WALLS d FROM PIPE SIDES, FLOOR IN PLACE — INLET 3



D. APPROACH WALLS REMOVED, FLOOR IN PLACE — INLET 4

E. APPROACH WALLS AND FLOOR REMOVED — INLET 5

EXPLANATION

Reynolds' number, $R_e = \frac{Vd}{\nu}$

Coefficient of discharge, $C_d = \frac{Q}{A\sqrt{2g\Delta H}}$ where–

Q is the rate of flow, c.f.s.;

A is the pipe cross section area in square feet; and

ΔH is the difference in hydraulic grade from the headwater to a point on the pipe crown 12 inches from the inlet in feet of water.

Relative submergence = $\frac{\text{depth of water above pipe invert}}{\text{diameter of pipe}}$

A STUDY OF
FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

COEFFICIENT OF DISCHARGE VS. RELATIVE SUBMERGENCE FOR VARIOUS REYNOLDS' NUMBERS

INLET DESIGNS 1, 2, 3, 4, & 5

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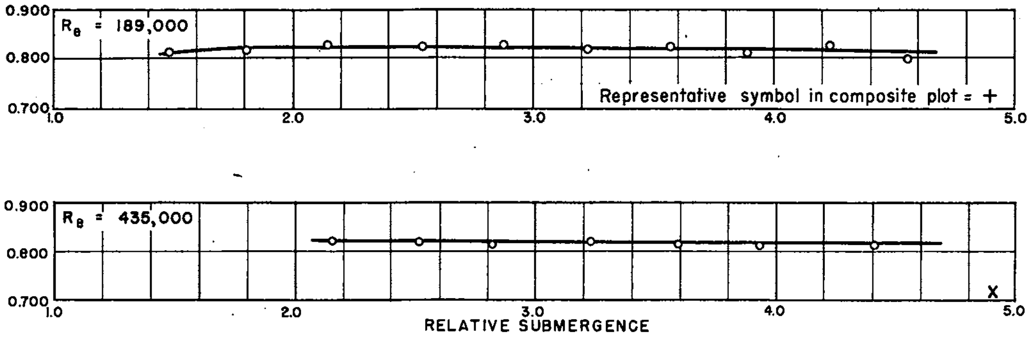
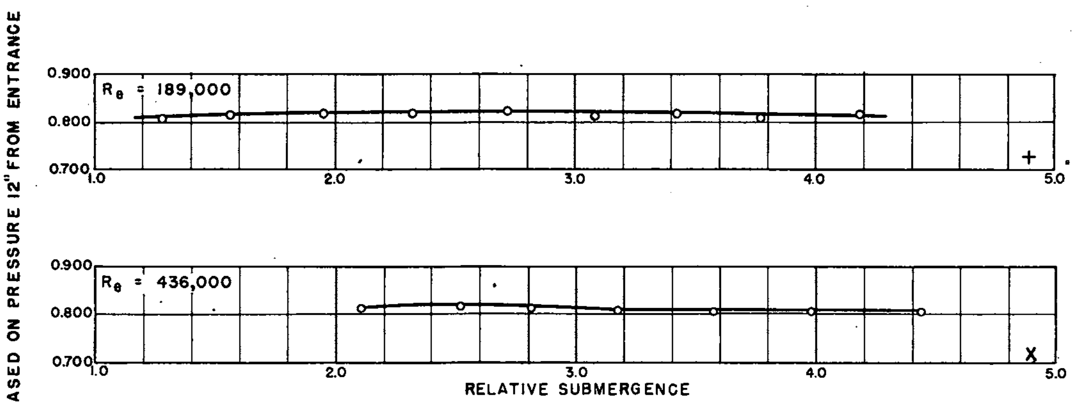
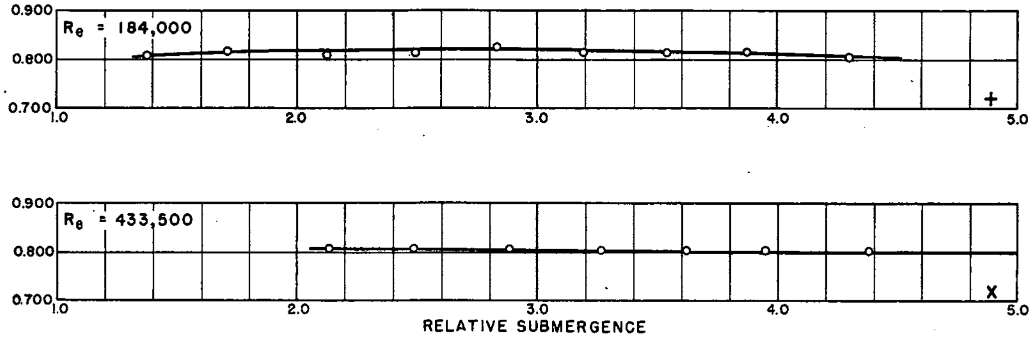
FIGURE 3
REPORT HYD. 422



A. APPROACH WALLS d/4 FROM PIPE SIDES, NO FLOOR — INLET 6



B. APPROACH WALLS d/2 FROM PIPE SIDES, NO FLOOR — INLET 7



C. APPROACH WALLS d FROM PIPE SIDES, NO FLOOR — INLET 8

EXPLANATION

Reynolds' number, $R_e = \frac{Vd}{\nu}$

Coefficient of discharge, $C_d = \frac{Q}{A\sqrt{2g\Delta H}}$ where —

Q is the rate of flow, c.f.s
A is the pipe cross section area in square feet, and
ΔH is the difference in hydraulic grade from the headwater to a point on the pipe crown 12 inches from the inlet, in feet of water.

Relative submergence = $\frac{\text{depth of water above pipe invert}}{\text{diameter of pipe}}$

A STUDY OF FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

COEFFICIENT OF DISCHARGE VS. RELATIVE SUBMERGENCE FOR VARIOUS REYNOLDS' NUMBERS

INLET DESIGNS 6, 7, & 8

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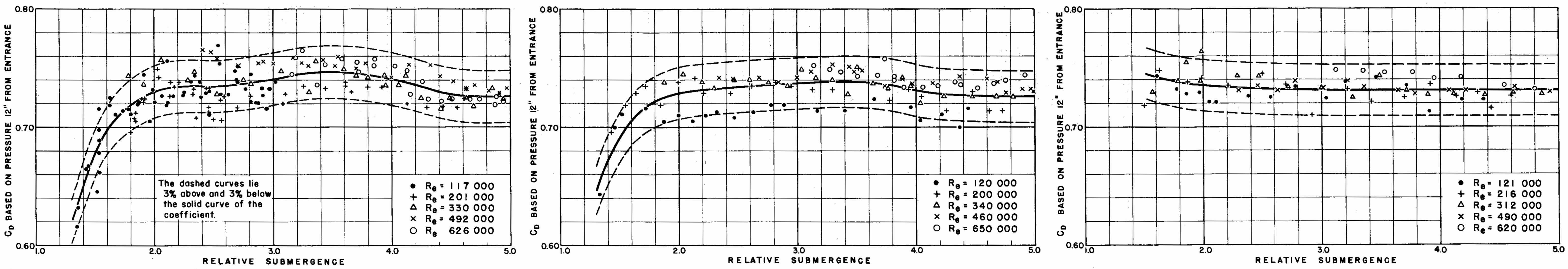
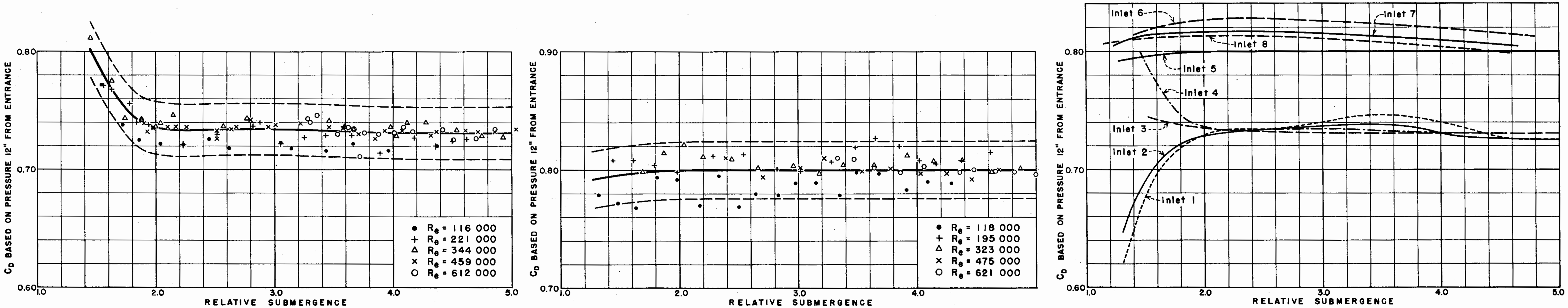


The dashed curves lie 3% above and 3% below the solid curve of the coefficient.

A. APPROACH WALLS $d/4$ FROM PIPE SIDES, FLOOR IN PLACE – INLET 1

B. APPROACH WALLS $d/2$ FROM PIPE SIDES, FLOOR IN PLACE – INLET 2

C. APPROACH WALLS d FROM PIPE SIDES, FLOOR IN PLACE – INLET 3



D. APPROACH WALLS REMOVED, FLOOR IN PLACE – INLET 4

E. APPROACH WALLS AND FLOOR REMOVED – INLET 5

F. MEDIAN VALUES FOR DIFFERENT APPROACH CONDITIONS

EXPLANATION

Reynolds' number, $R_e = \frac{Vd}{\nu}$

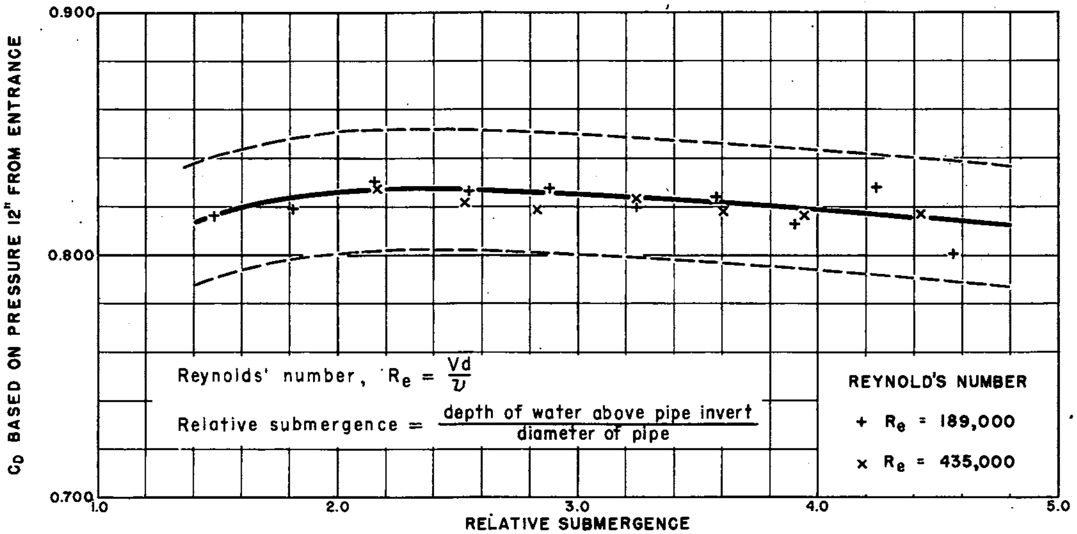
Relative submergence = $\frac{\text{depth of water above pipe invert}}{\text{diameter of pipe}}$

Coefficient of discharge, $C_d = \frac{Q}{A\sqrt{2g\Delta H}}$ where—

Q is the rate of flow, c.f.s.
A is the pipe cross section area in square feet, and
ΔH is the difference in hydraulic grade from the headwater to a point on the pipe crown 12 inches from the inlet in feet of water.

A STUDY OF
FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRENCES

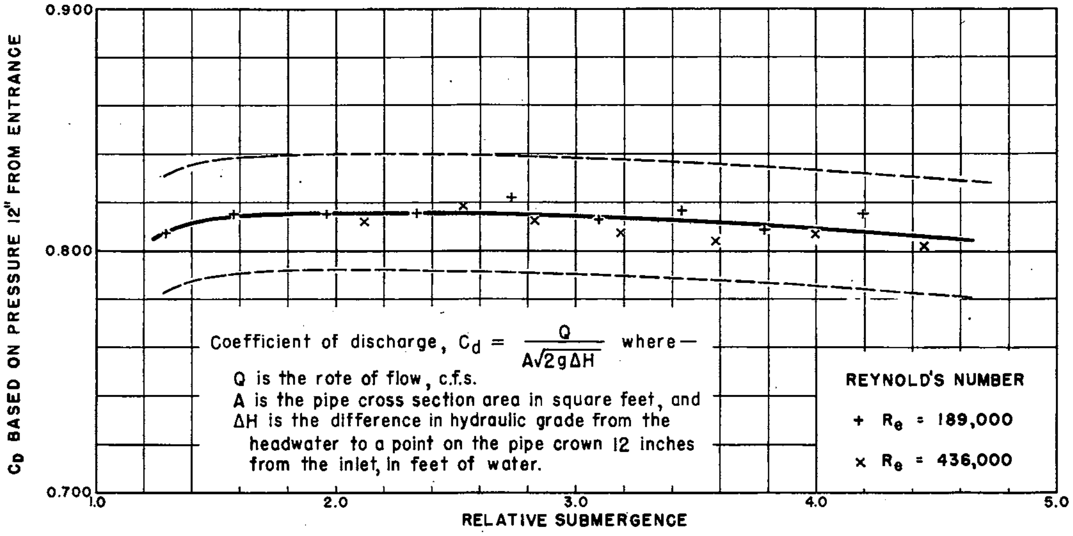
COEFFICIENT OF DISCHARGE VS. RELATIVE SUBMERGENCE
COMPOSITE PLOTS OF REYNOLDS' NUMBER
INLET DESIGNS 1,2,3,4,&5



Reynolds' number, $R_e = \frac{Vd}{\nu}$

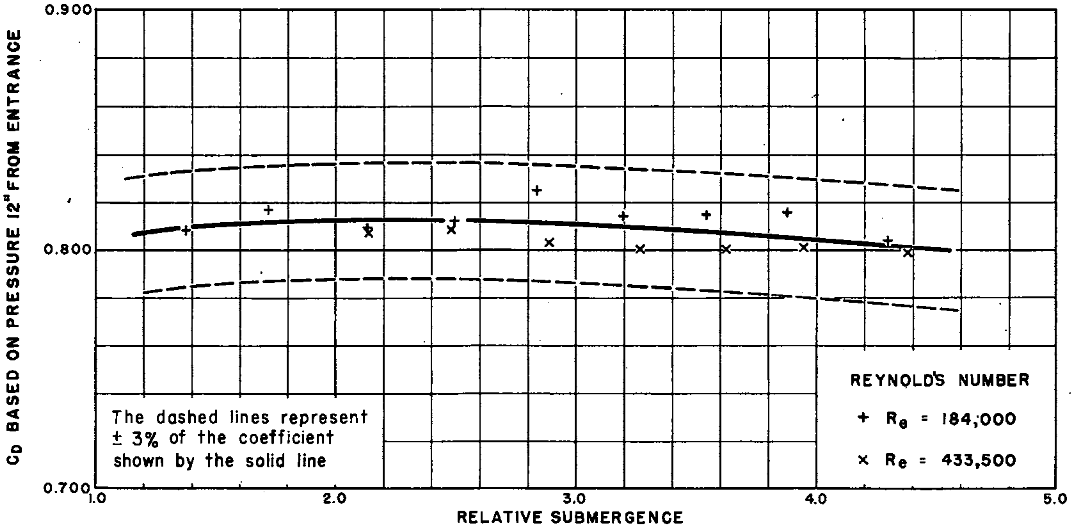
Relative submergence = $\frac{\text{depth of water above pipe invert}}{\text{diameter of pipe}}$

A. APPROACH WALLS d/4 FROM PIPE SIDES, NO FLOOR – INLET 6



Coefficient of discharge, $C_d = \frac{Q}{A\sqrt{2g\Delta H}}$ where—
Q is the rate of flow, c.f.s.
A is the pipe cross section area in square feet, and
ΔH is the difference in hydraulic grade from the headwater to a point on the pipe crown 12 inches from the inlet, in feet of water.

B. APPROACH WALLS d/2 FROM PIPE SIDES, NO FLOOR – INLET 7



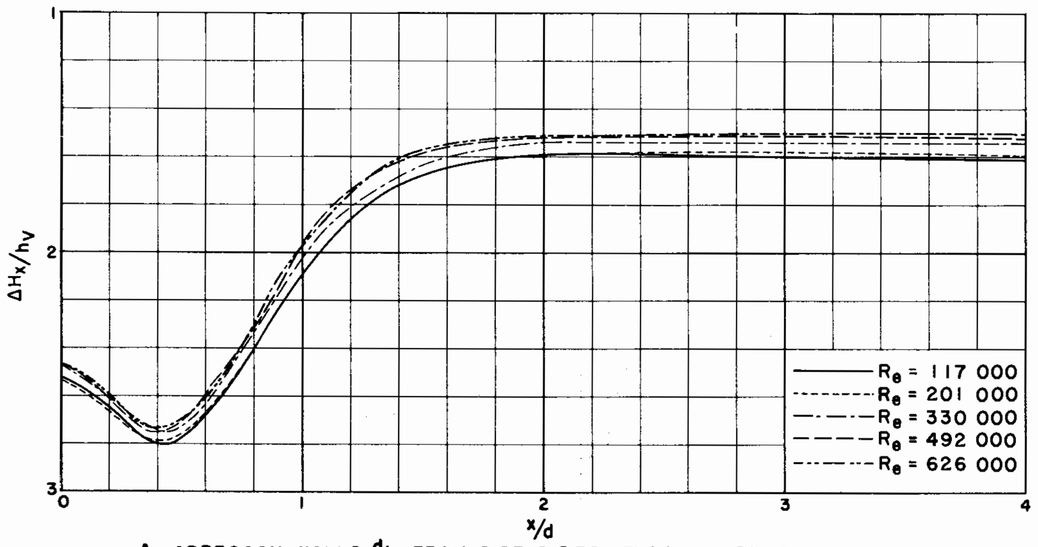
The dashed lines represent ± 3% of the coefficient shown by the solid line

C. APPROACH WALLS d FROM PIPE SIDES, NO FLOOR – INLET 8

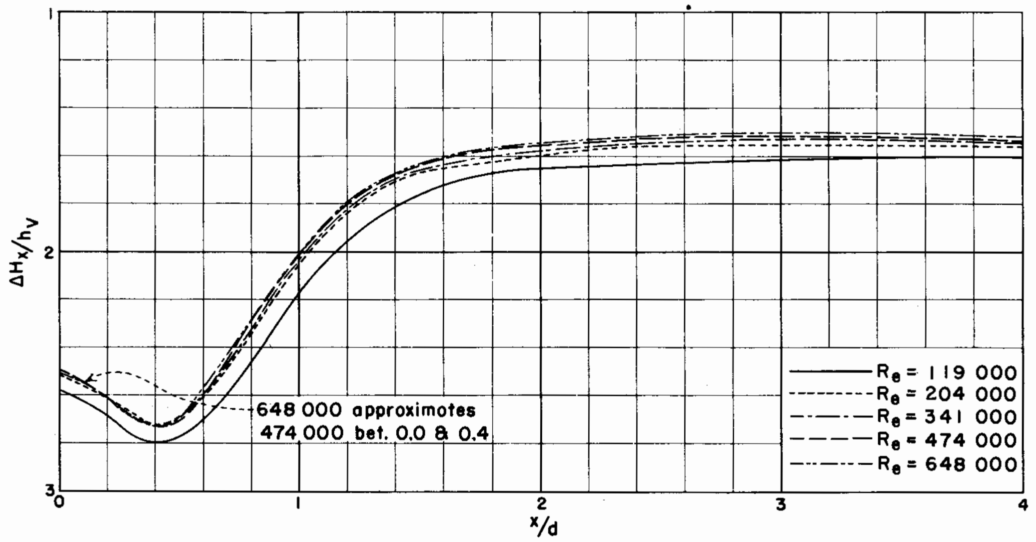
A STUDY OF FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

COEFFICIENT OF DISCHARGE VS. RELATIVE SUBMERGENCE
COMPOSITE PLOTS OF REYNOLDS' NUMBER

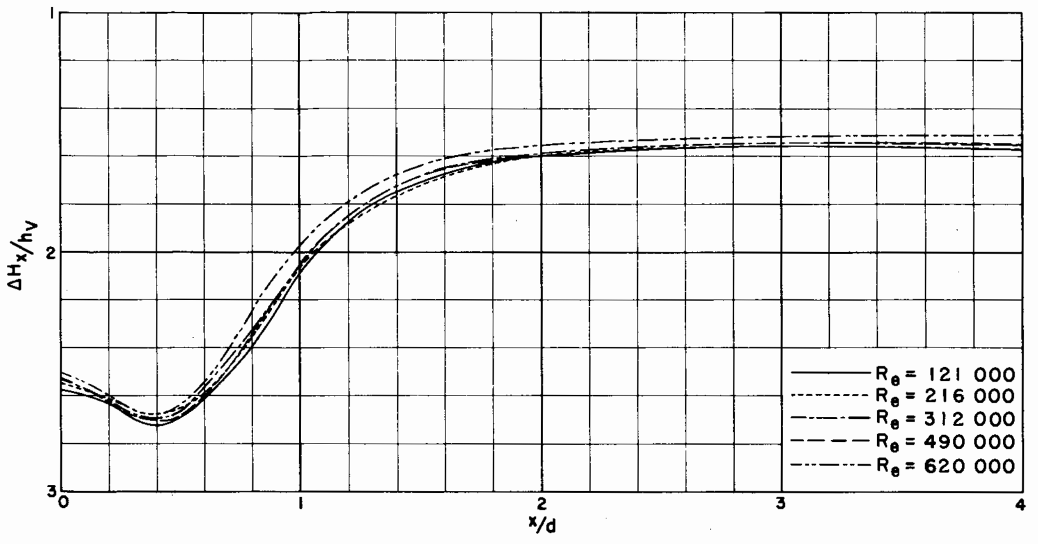
INLET DESIGNS 6, 7, & 8



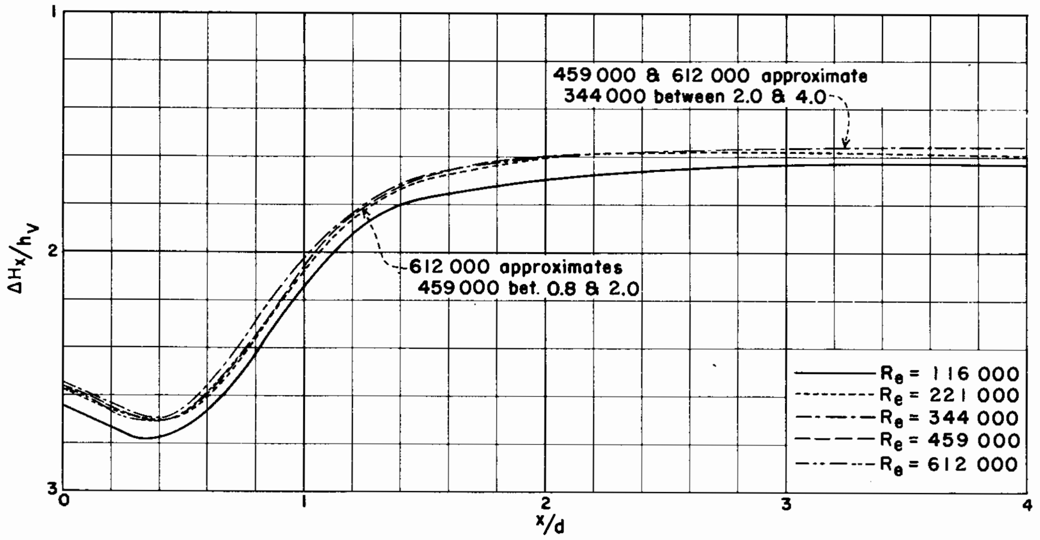
A. APPROACH WALLS d/4 FROM PIPE SIDES, FLOOR IN PLACE — INLET 1



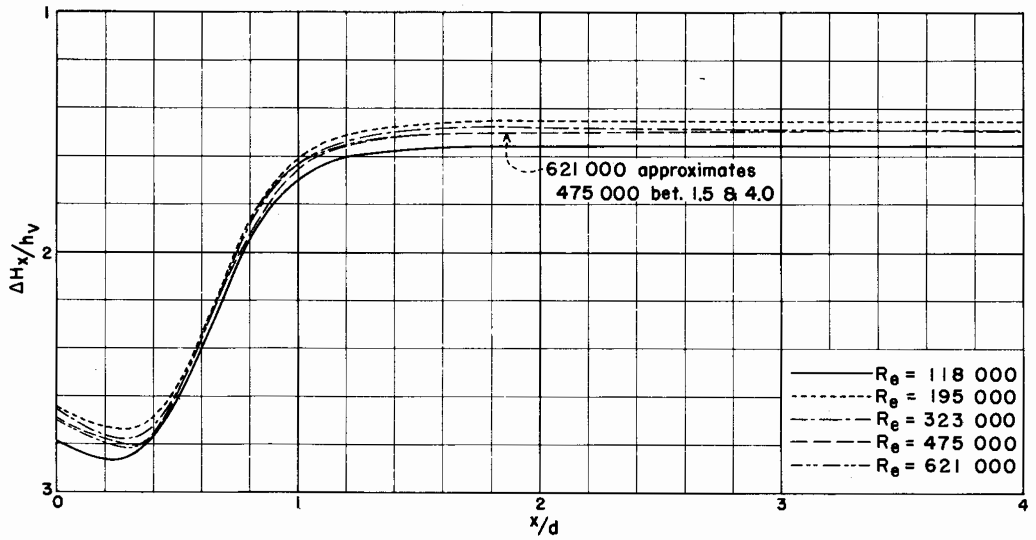
B. APPROACH WALLS d/2 FROM PIPE SIDES, FLOOR IN PLACE — INLET 2



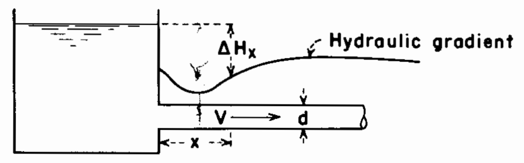
C. APPROACH WALLS d FROM PIPE SIDES, FLOOR IN PLACE — INLET 3



D. APPROACH WALLS REMOVED, FLOOR IN PLACE — INLET 4



E. APPROACH WALLS AND FLOOR REMOVED — INLET 5



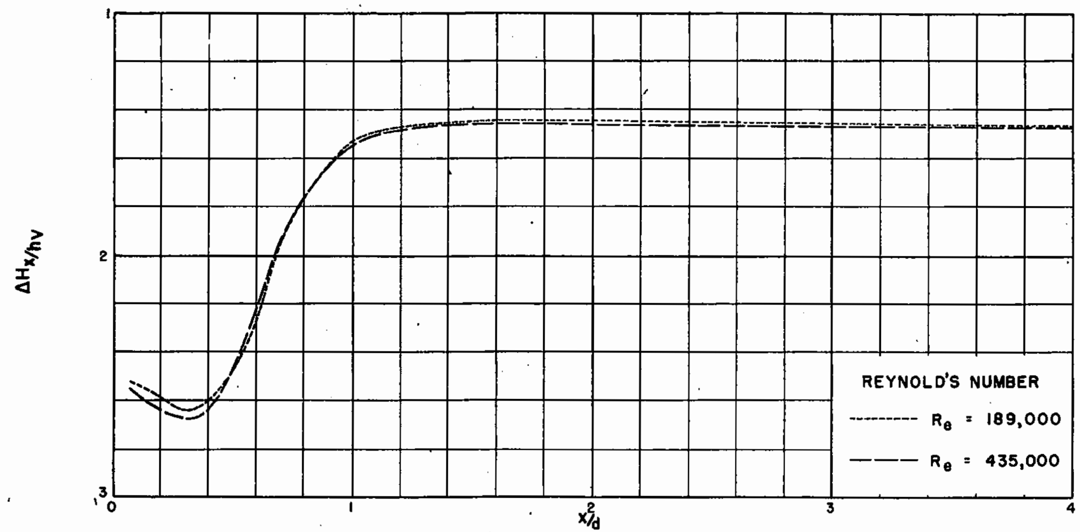
$h_v = \frac{V^2}{2g}$ $V = \frac{\text{Rate of flow}}{\text{Pipe cross-sectional area}}$

F. EXPLANATION

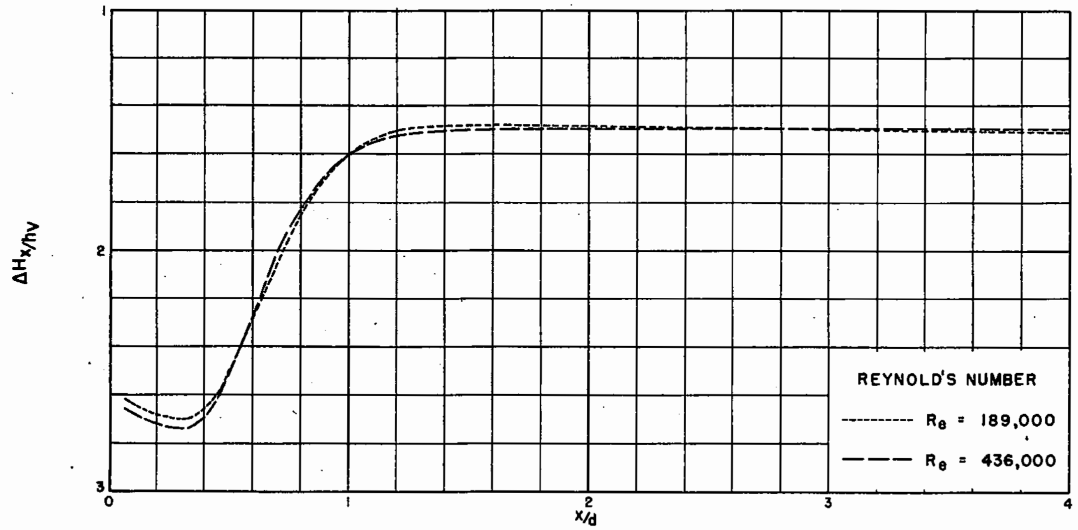
A STUDY OF
FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

HYDRAULIC GRADIENT
VERSUS
DISTANCE ALONG PIPELINE
INLET DESIGNS 1,2,3,4,&5

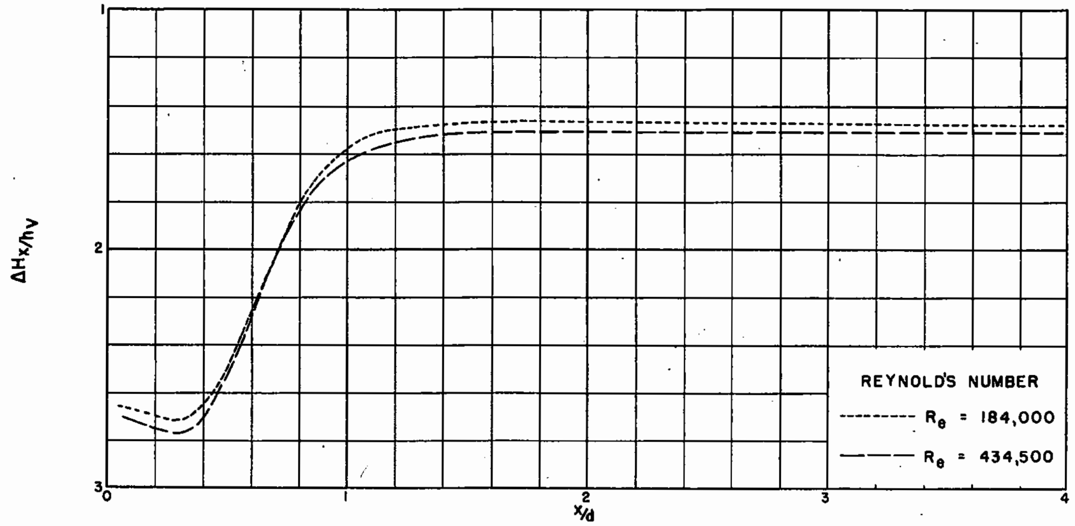
567



A. APPROACH WALLS d/4 FROM PIPE SIDES, NO FLOOR – INLET 6



B. APPROACH WALLS d/2 FROM PIPE SIDES, NO FLOOR – INLET 7



C. APPROACH WALLS d FROM PIPE SIDES, NO FLOOR – INLET 8

A STUDY OF FLOW CHARACTERISTICS IN PIPELINES
WITH SHARP CORNERED ENTRANCES

HYDRAULIC GRADIENT
VERSUS
DISTANCE ALONG PIPELINE

INLET DESIGNS 6, 7 & 8