LIMITATIONS OF METERGATES

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ABSTRACT

The hydraulic characteristics of metergates and their limitations are discussed and methods of minimizing the errors introduced by physical and hydraulic characteristics are presented. Also included is an evaluation of the metergate as a measuring device for water in irrigation distribution systems.

INTRODUCTION

The problem of accurate and economical measurement of irrigation water has become very important in recent years. The problem will, without question, become more important in future years as the water resources of this country approach full development, and costs increase.

There have been investigations in recent years to develop new principles and new measuring devices to obtain more accurate and economical measurement of irrigation water. It is reasonable to assume that these investigations will continue with increased interest and that new, more accurate, and less costly devices or methods will be made available for irrigation systems of the future.

The measuring device to be discussed in this paper is not new, but it was not until recent years that its hydraulic and physical characteristics were found to have considerable influence on its accuracy, and hydraulic tests were made to evaluate this influence.

The device to be discussed is known as a metergate. It consists of a slide gate (with either circular or square bottom) placed over the upstream end of a pipe and controls releases from a canal to a lateral or a lateral to a ditch. The pipe passes through an embankment and usually its upstream end is contained in a vertical head wall with or without an approach channel. A typical metergate installation is shown in Figure 1. Flow through the gate is indicated by the differential head obtained from measurements of the hydraulic grade line at two locations, one in the upstream canal or reservoir from which the flow is taken and the other in the pipe crown a short distance downstream from the entrance and gate (Figure 2). Two measuring wells, one connected to the upstream water pool and the other to the pipe downstream from the gate, are provided for determining the differential head. Using the differential head and knowing the gate opening, the flow quantity is obtained from appropriate tables or charts. Since the hydraulic characteristics and limitations of the metergate had not been adequately

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delineated previously, a laboratory study was initiated by the Bureau of Reclamation. The work was accomplished over a period of several years, beginning in 1950 and ending in 1957. In general, this paper will present the results of the studies made in the Bureau laboratories during this period.

The capacity and accuracy of a metergate may be influenced by several factors; some are related to physical arrangement of the metergate while others are related to hydraulic characteristics. The important factors to be considered and discussed in this paper are:

(a) Gate design, including shape and arrangement

(b) Approach design, including position of walls and floor relative to the pipe entrance

(c) Submergence of metergate entrance

(d) Submergence of metergate outlet

(e) Length of metergate pipe

(f) Location of head-measuring taps

(g) The flow velocity.

The equation $Q = C_d A\sqrt{2g\Delta H}$ was used in the analysis, and the effects of the above variables on C_d were determined.

LABORATORY TEST INSTALLATION

The laboratory installation used for the metergate studies is shown schematically in Figure 3. Water to the test gate was supplied by four pumps (three 12-inch and one 8-inch). Venturi meters of various sizes located near the pumps provided accurate flow measurement over a wide range of discharges. Good flow distribution approaching the gate at low velocity was obtained by passing the water through a rock-filled baffle in the headbox. The upstream end of the metergate pipe, with the gate, was placed in one side of the 7-foot-wide by 11-foot-long by 10-foot-deep head box. The downstream end of the metergate pipe terminated in a 4-foot-wide by 6-foot-long by 6-foot-deep tailwater box. A hinged gate in the side of the tailwater box opposite the pipe exit provided a means of varying the submergence and changing the hydraulic grade line in the pipe.

Piezometer taps were placed in the crown of the pipe at different distances from the gate to record the pressure gradient in the pipe and to permit the application of the data to other gate sizes. The pressure taps were confined to the crown of the pipe because this location had been determined to be the most desirable. Rubber tubing was used to connect the taps to glass tubing mounted on a manometer board graduated in 0.01-foot increments. Two metergates, 18- and 24-inch, were tested in the setting described above. A 10-inch installation similar in arrangement, but without a gate over the entrance, was used for special research related to the confinement of entrances.

TEST PROCEDURES

The laboratory tests were made for a range of differential heads from 2 to 48 inches. The hydraulic grade line in the pipe was controlled by the hinged gate in the tailwater box to give readable water depths in the downstream head-measuring well.

The 18- and 24-inch gates were tested at gate opening increments of 2 inches. A gate position indicator in the form of a metal pointer was attached to the top of the gate stem with a stationary scale graduated in tenths of inches at one side to indicate the gate opening (Figure 4). A section of transparent pipe was placed immediately downstream from the 24-inch gate to permit visual observation of the flow conditions within the pipe immediately downstream from the gate (Figure 5). Smooth pipe was used in all test installations. In all tests constant flows to the metergate were first established. The hydraulic grade line was then adjusted and readings taken to determine pressures within the system, flow quantity, differential head, and flow action in the system. The tests were made for various approach confinements, discharges, gate openings, and tailwater conditions. The effect of the individual variables on the discharge coefficient was thus determined.

FACTORS THAT INFLUENCE CAPACITY OF METERGATES

Gate Design

The main difference in metergate capacity attributable to gate design occurs at partial openings and results from the shape of the gate (whether the leaf is circular or has a square bottom). Capacity curves or tables applicable to one design are not applicable to the other. For example, at a given head differential, the gate with the circular leaf will discharge about twice as much water at 20 percent gate opening as the gate with the square bottom (Figure 6). The area and shape of the gate opening in the two cases are quite different. Some influence is also introduced by the configuration, relative size, and positioning of the structural members of the gate framing and gate seat casting.

The gate framing usually has a minor influence unless some of the structural members are placed too close to the pipe entrance. Structural members of gate frames should be kept away from the edges of the opening to have the least influence.

The gate seat casting shape, including width of seat, its projection from the head wall to which it is fastened, and its general configuration, will have some influence on the gate capacity for a given differential head. This factor will usually be of minor proportions, but may introduce differences up to 2 or 3 percent. The influence of variations in entrance configuration is illustrated to some degree in Figure 7.

Approach Design

The influence of inlet confinement on the coefficient of discharge was investigated. Confinement of metergates is due mainly to the floor and side walls of the approach to the inlet. The position of the floor and side walls with respect to the pipe opening was varied.

Tests on wall confinement varied from that represented by the walls of the head box (representing the gate installed in a vertical head wall) to walls placed at different distances from the edges of the pipe inlet flaring outwardly at an 8:1 rate (Figure 8).

Tests on floor confinement varied from that represented by the bottom of the head box to a 2:1 downward sloping floor terminating at the head wall a short distance below the pipe inlet invert (Figure 8).

Because the pressure tap for the downstream head-measuring well is located in the crown of the pipe just downstream from the gate, it is certain that any changes in the stream lines that result in a redistribution of pressures in the vicinity of the tap will be reflected in the differential head. Therefore, any confinement that results in a change in pressure grade line at the pressure tap will indicate a change in coefficient. From the nature of the flow within the pipe immediately downstream from the gate, as shown in Figure 2, it is evident that the influence of confinement would be more predominant at wide open gate than at partial gate opening and that this influence would decrease as the gate leaf moved downward. The tests on the 18- and 24-inch installations confirmed this and indicated that the influence was negligible at gate openings less than 50 percent and that the confinement influence at full gate opening might be as much as 10 to 12 percent. Other variables influencing the coefficient with changes in confinement included position of downstream measuring well tap and inlet submergence. The influence of wall position, floor position, and location of pressure tap are shown in Figure 9. The tests showed that the influence of confinement could be kept at a minimum by controlling these variables.

Submergence of Metergate Entrance

The influence of submergence of the metergate entrance can vary widely depending on gate opening, position of the pressure tap for the downstream measuring well, and the confinement of the inlet. For most installations the discharge coefficient remained constant for large submergences and varied different degrees for small submergences.2/3/ The influence of small submergences has been observed by other investigators.4/ In all cases, the discharge coefficient for a particular physical setting (entrance confinement and gate setting) was substantially constant for submergences greater than 1 pipe diameter above the crown of the pipe entrance (Figure 10). Variations in the discharge coefficient due to low submergence occurred mainly for submergences less than 1 pipe diameter. The variation differed with gate opening and entrance confinement. The influence of submergence became less pronounced as the gate was lowered over the entrance and seemed to disappear at a gate opening of about 75 percent. This occurred for all entrance confinements where the approach walls were set back a distance of 1/4 pipe diameter or more from the edges of the entrance and the floor was placed 0.17 pipe diameter or more below the invert of the pipe entrance. Confinements of greater degree were not tested.

Outlet Submergence

The submergence of the outlet end of the metergate pipe in itself has no influence on the coefficient of the metergate. It is, however, important in two respects. It establishes the pressure grade within the pipe and, to a small degree, sets the upstream submergence. The outlet submergence must be sufficient at all times to keep the pipe full and hold the pressure grade at the pressure tap high enough to give a readable water surface in the head-measuring well. The curves in Figure 11 can be used to determine the required outlet submergence. The submergence required to give a readable water surface in the head-measuring well varies with the gate opening and is a maximum for an opening of about 75 percent. It is this maximum which should be considered in determining the required submergence for any metergate installation. This required submergence is not significantly different for different metergate sizes or pipe tap locations, but varies with head.

Length of Metergate Pipe

The metergate pipe downstream from the gate should be of sufficient length that a rather uniform velocity distribution exists at its downstream end. This will assure a minimum exit velocity with minimum erosion in the downstream ditch and will assure that the pipe always runs full. The metergate tests indicated that the minimum length of the pipe should be approximately 7 pipe diameters (Figure 12).

2/"Flow Characteristics in a Pipeline Downstream from a Square-cornered Entrance," Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-422.

3/"Flow Characteristics and Limitations of Screw Lift Metergates," Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-471.

4/"Ausfluss, Curchfluss, Strahlreaktion, and Strahldruck in neuer Bechtrochtung" (Discharge, Underflow, Jet Propulsion, and Jet Forces from a New Viewpoint) by Von theodor Musterle, Die Wasserwirtschaft, September 1960.

Location of Pressure Tap for Downstream Head-measuring Well

The location of the pressure tap for the downstream measuring well has considerable influence on the coefficient of discharge under certain conditions. This difference is most pronounced at large gate openings and results from difference in the pressure grade line at the different locations. Thus, the water surface in the downstream head-measuring well (which determines the differential head and discharge coefficient) is affected by the location of the pressure tap, introducing a change in discharge coefficient. Location of the tap on the periphery of the pipe at a given station along the pipe thus will introduce a change in coefficient (Figure 13). Location of the tap at different stations along the pipe will also introduce changes in the coefficient (Figure 14). The changes will be more rapid where the pressure gradient is steep. The influence of pressure tap location, within reasonable limits, is reduced to negligible proportions if the maximum gate opening is limited to about 75 percent. In cases where the maximum opening of the metergate is limited to 50 percent to minimize confinement influence, tap location becomes unimportant.

Velocity of Flow in Metergate

The velocity of flow in metergates is considered to be in the low range, perhaps up to 6 or 7 feet per second under special conditions, but mostly below about 4 feet per second to prevent undue erosion in the downstream ditch or channel. Except for the extremely low velocities, the flow will be turbulent. However, some influence might be expected from viscosity (Reynold's number) at the very low velocities. Tests conducted in the laboratory indicated this to be true, but that the influence would be negligible over the flow range at which most metergates would be used. For Reynold's number of 2.0×10^5 and larger in the 10-inch pipe, the influence was very minor. The influence was slightly greater at Reynold's numbers of about 1.0×10^5. In most installations, the influence of viscosity (Reynold's number) need not be a consideration.

SUMMARY

1. The metergate is an accurate water-measuring device, provided certain limitations are observed and the differential heads and gate openings are accurately measured.

2. It is important that the gate opening be known or set accurately; otherwise accurate discharge measurements are not possible.

3. Errors in discharges will be very small for various sizes of metergates that are geometrically similar to the test installation used to obtain the hydraulic characteristics of the metergate.

4. All hydraulic characteristics for metergates with circular and square leaves are not the same; thus, the discharge curves and tables for one are not applicable to the other, except at 100 percent gate openings.

5. Limiting the maximum gate opening to 50 percent will reduce to negligible proportions any error which would be introduced by a reasonable confinement of the entrance.

6. A metergate must have at least one pipe diameter submergence of the upstream end to eliminate the influence of small submergences, or the maximum gate opening must be limited to 75 percent to minimize this influence.

7. A metergate must have sufficient submergence of the downstream end of its pipe to provide a readable water surface in the head-measuring well.

8. The pipe length downstream from the gate should be at least 7 pipe diameters to assure a reasonably uniform velocity distribution and minimum velocity at the exit, and to minimize erosion downstream.

9. Limiting the maximum gate opening to 75 percent will reduce to negligible proportions any error which would be introduced by mislocation of the downstream head-measuring well tap.

10. The present metergate design is not the optimum for flow measurement accuracy. The practice of placing the tap to the downstream head-measuring well 12 inches downstream from the gate makes each metergate size and setting a special problem requiring either strict operational limitations or individual calibration unless the maximum gate opening is limited to 75 percent.

11. For best overall results, the tap to the downstream head-measuring well for the various gate sizes should be at geometrically similar locations and preferably where the hydraulic gradient is not steep. The tests indicated the optimum location to be in the crown of the pipe about 1/3 pipe diameter downstream from the gate.

12. Usually the viscosity influence is negligible for metergates and need not be considered.

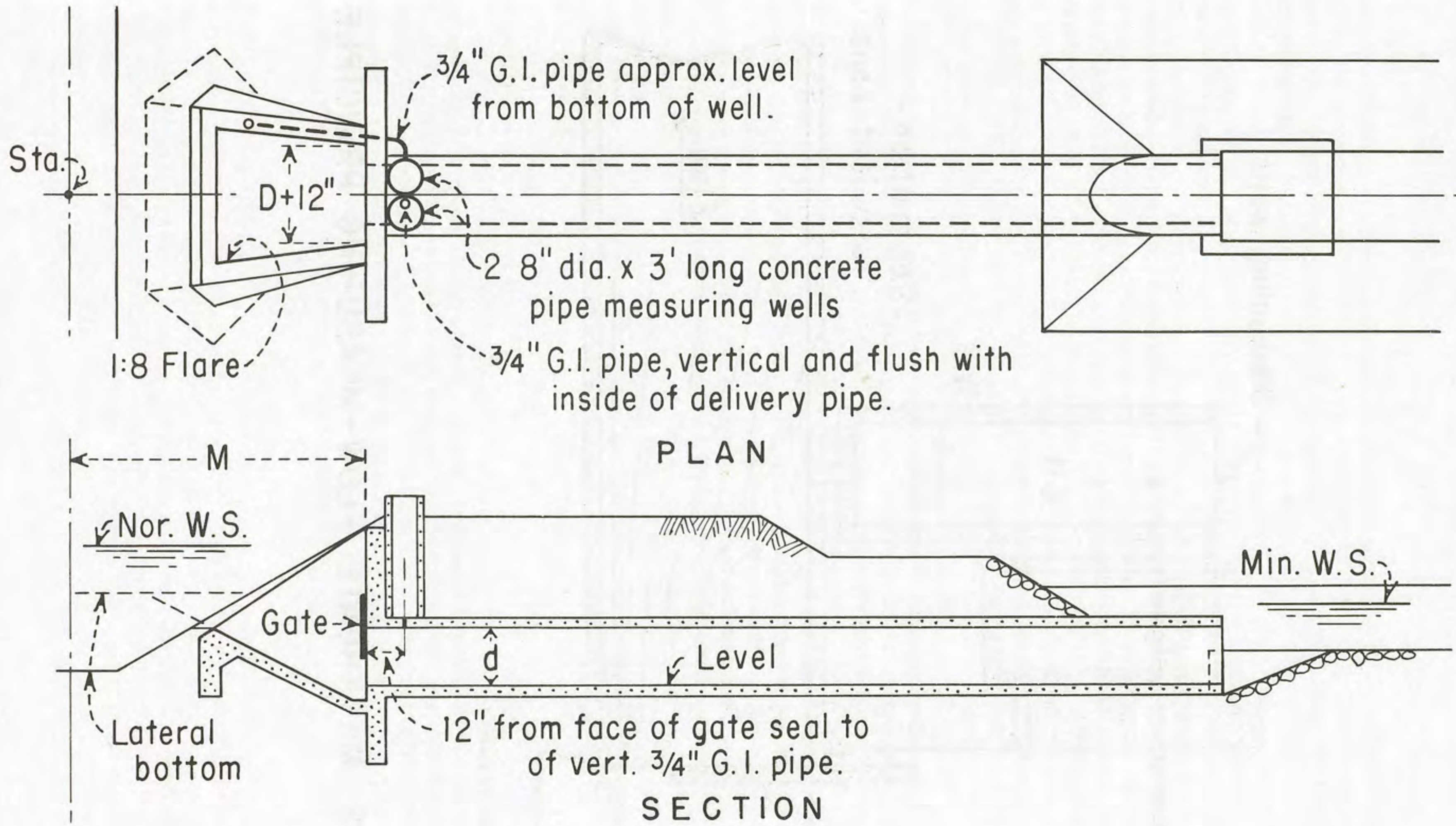


FIGURE I. TYPICAL FIELD INSTALLATION OF METERGATE

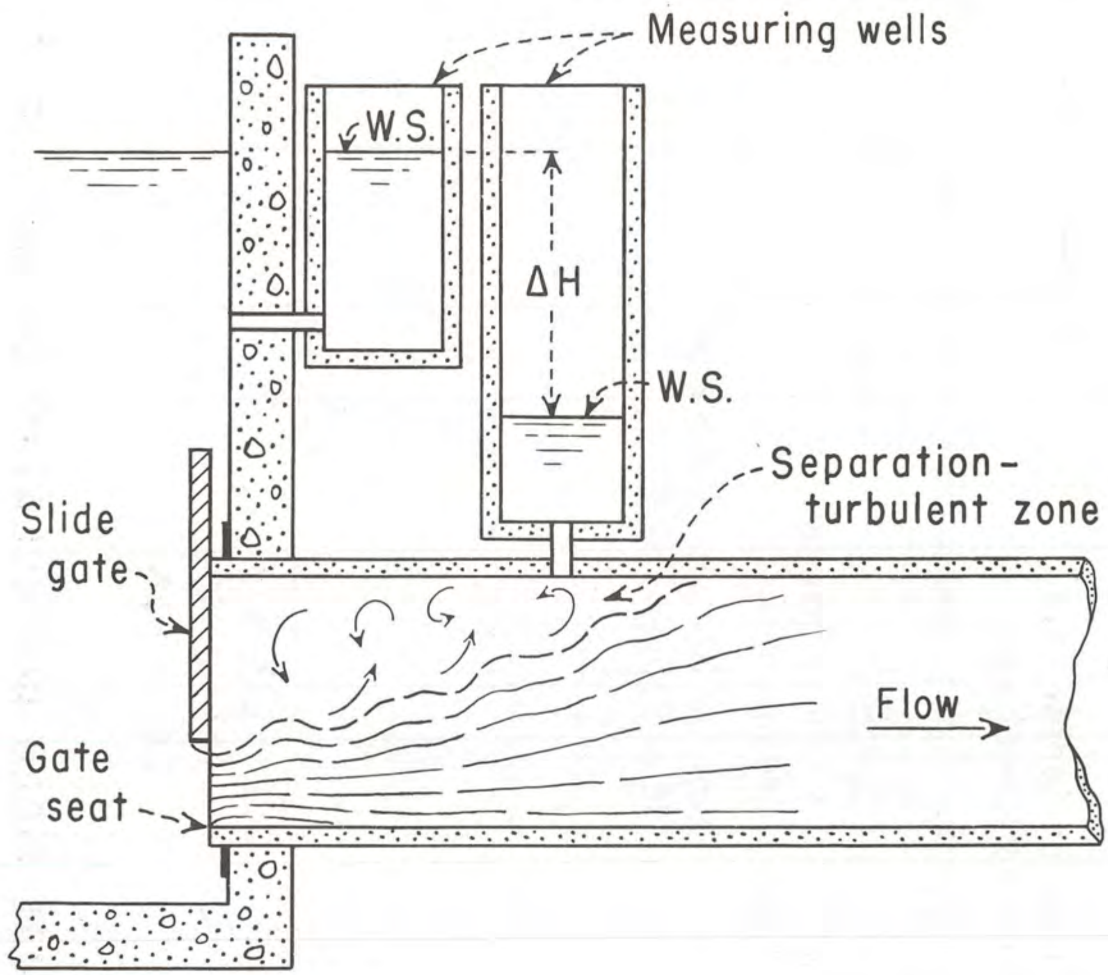
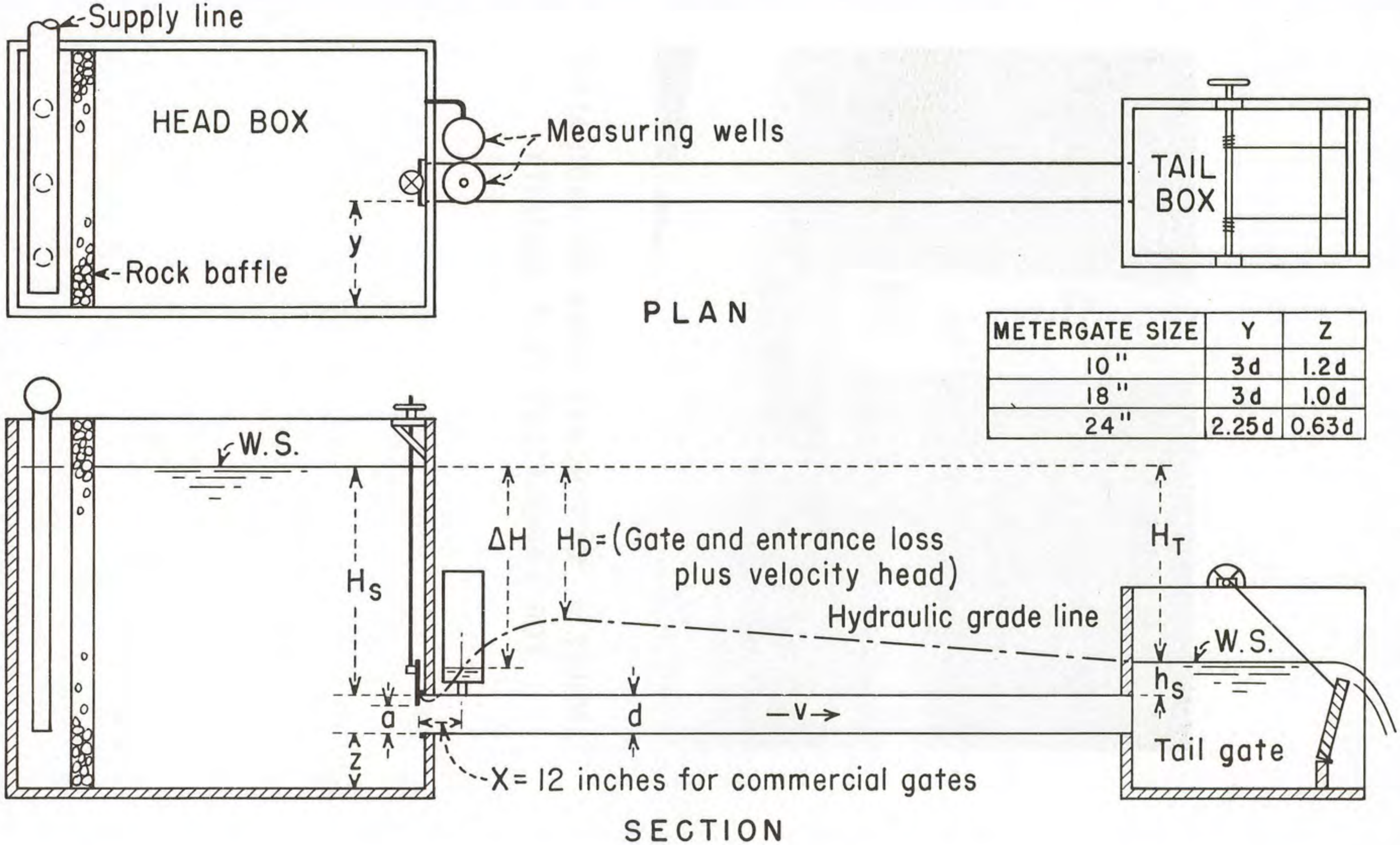


FIGURE 2. METERGATE FLOW-MEASURING PRINCIPLE



METERGATE SIZE	Y	Z
10"	3d	1.2d
18"	3d	1.0d
24"	2.25d	0.63d

FIGURE 3. LABORATORY TEST FACILITY FOR METERGATES

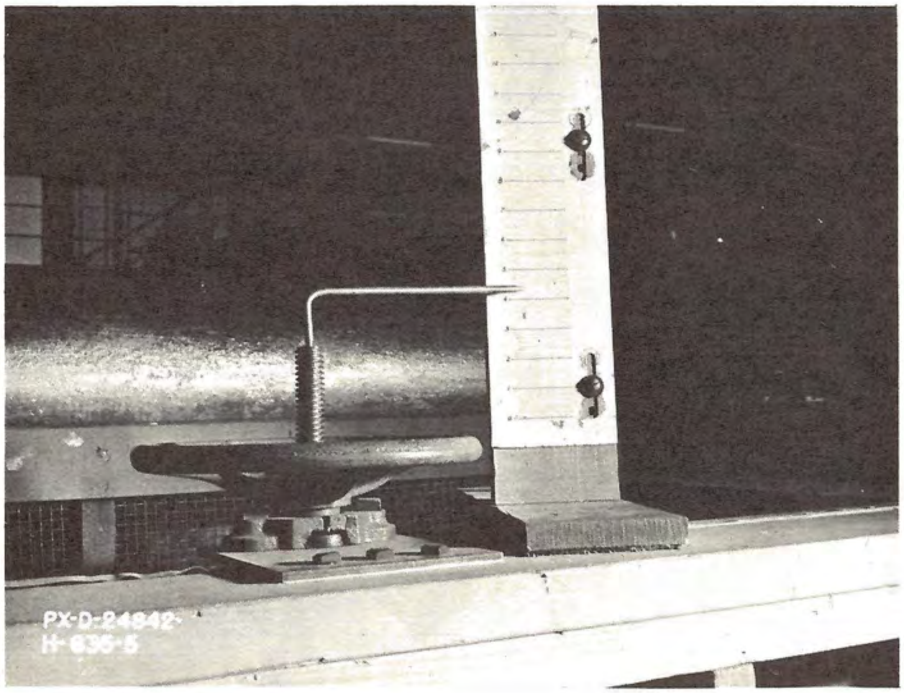


FIGURE 4. METERGATE OPENING INDICATOR
FOR LABORATORY TEST FACILITY

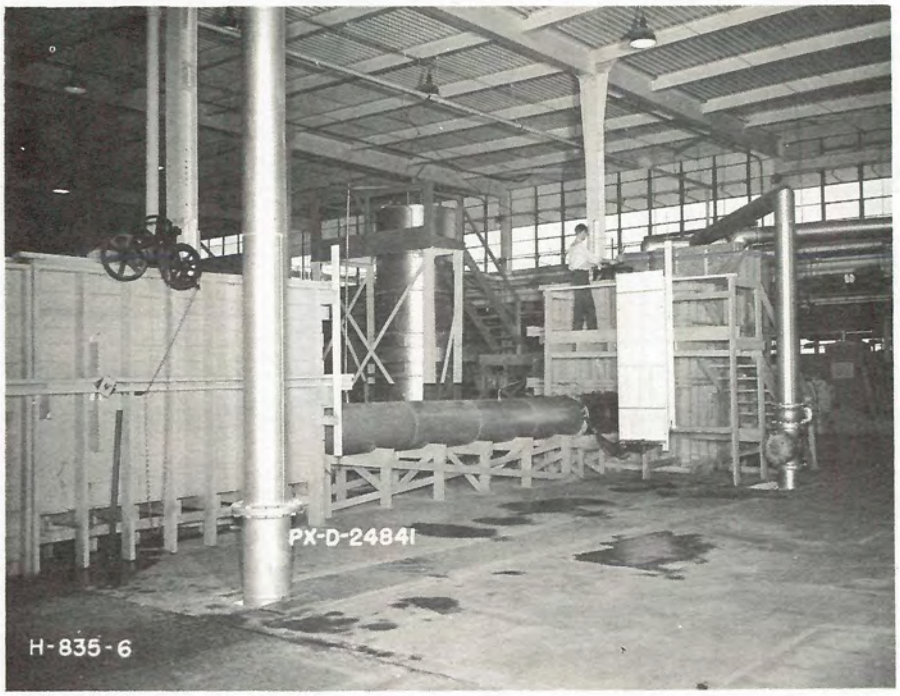


FIGURE 5. LABORATORY INSTALLATION OF 24-INCH METERGATE

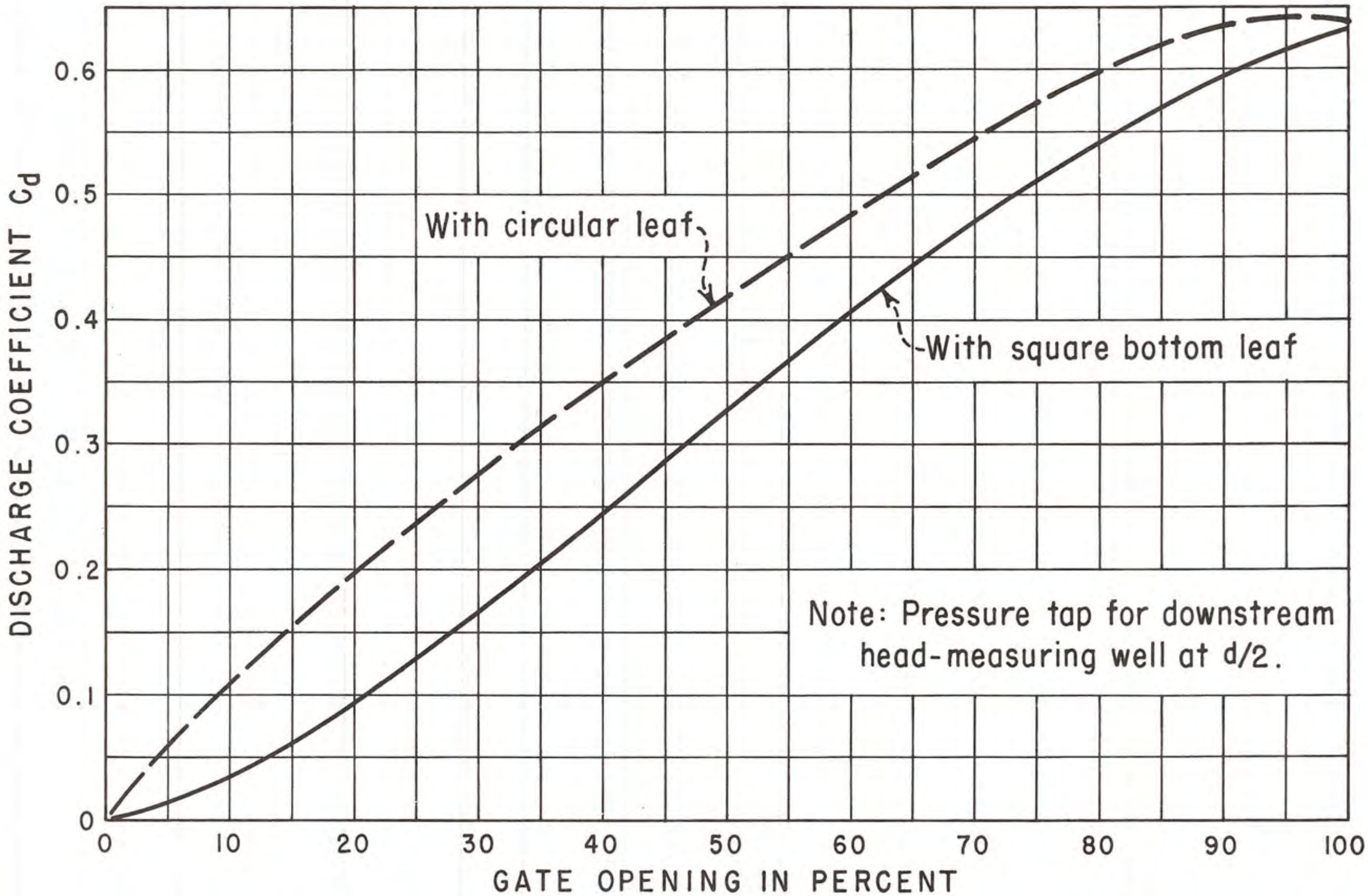


FIGURE 6. DISCHARGE COEFFICIENTS, 24-INCH METERGATES, CIRCULAR AND SQUARE BOTTOM LEAVES, CONFINED ENTRANCE

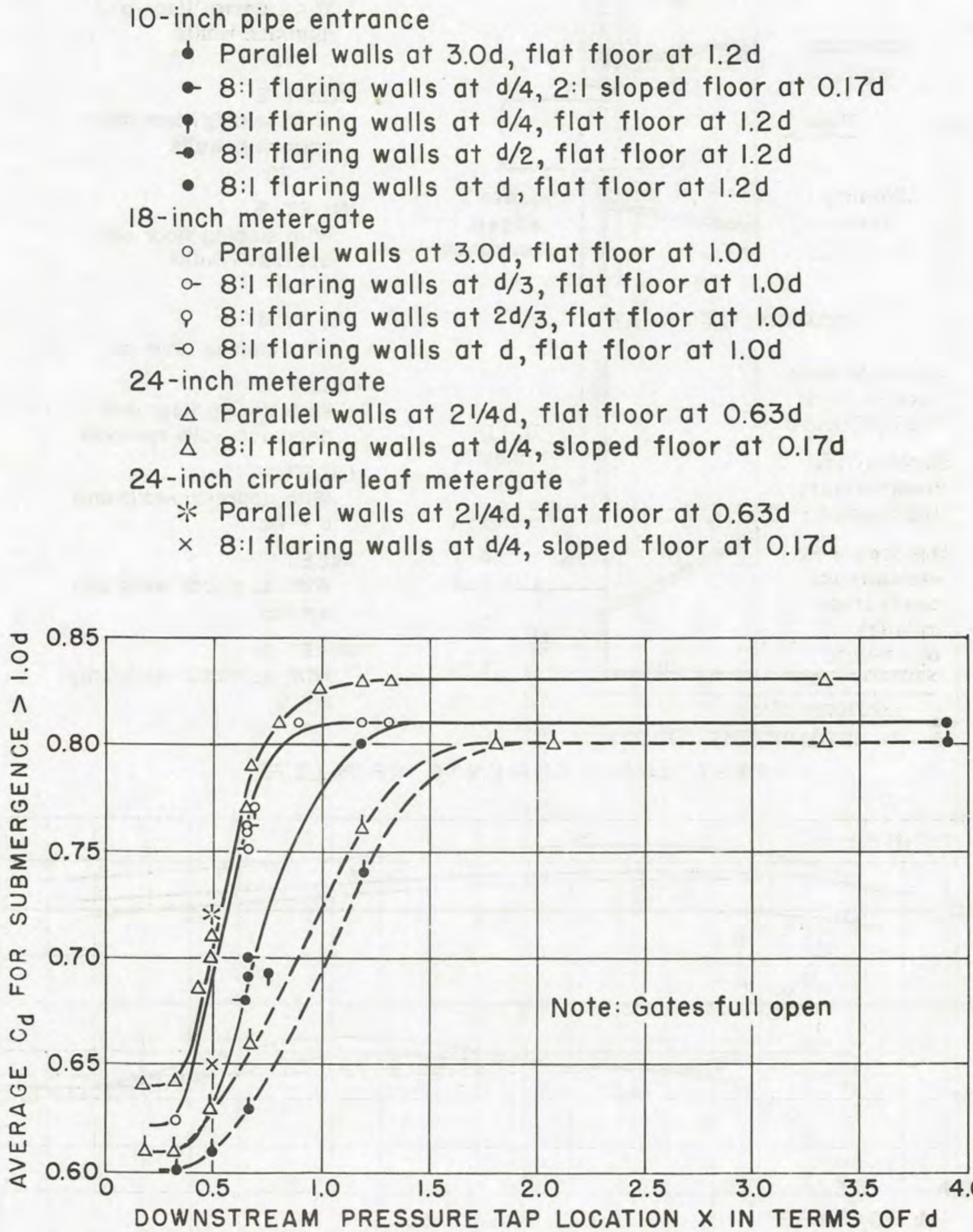


FIGURE 7. VARIATION IN DISCHARGE COEFFICIENTS OF METERGATES WITH DOWNSTREAM PRESSURE TAP LOCATION AND ENTRANCE CONFINEMENT

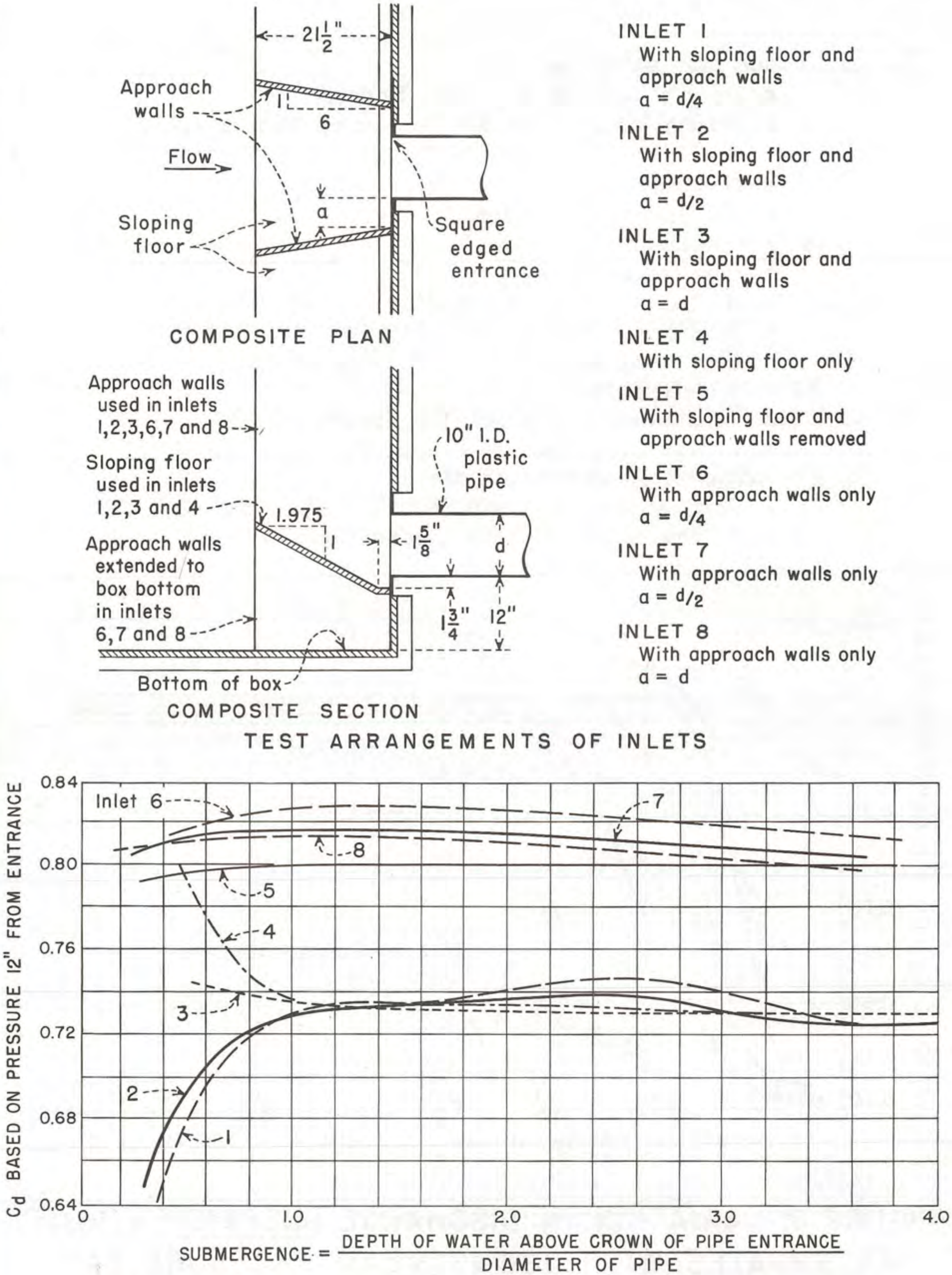
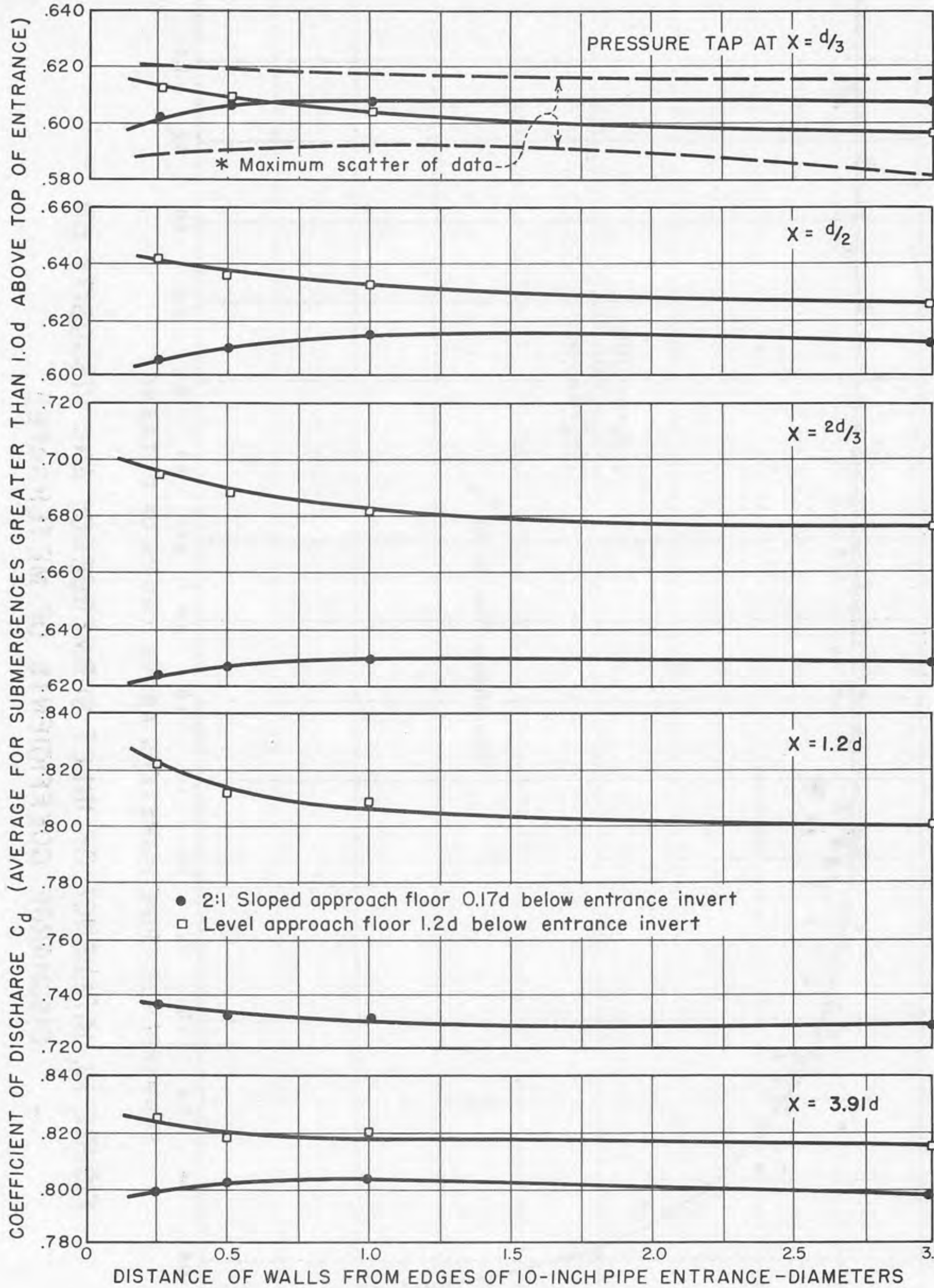


FIGURE 8. EFFECTS OF INLET SUBMERGENCE ON COEFFICIENTS OF DISCHARGE FOR METERGATES WITH VARIOUS INLET COEFFICIENTS



* Maximum scatter of data from average about ± 3% for all tap locations.

FIGURE 9. INFLUENCE OF APPROACH WALL, FLOOR, AND PRESSURE TAP LOCATIONS ON DISCHARGE COEFFICIENT OF METERGATES

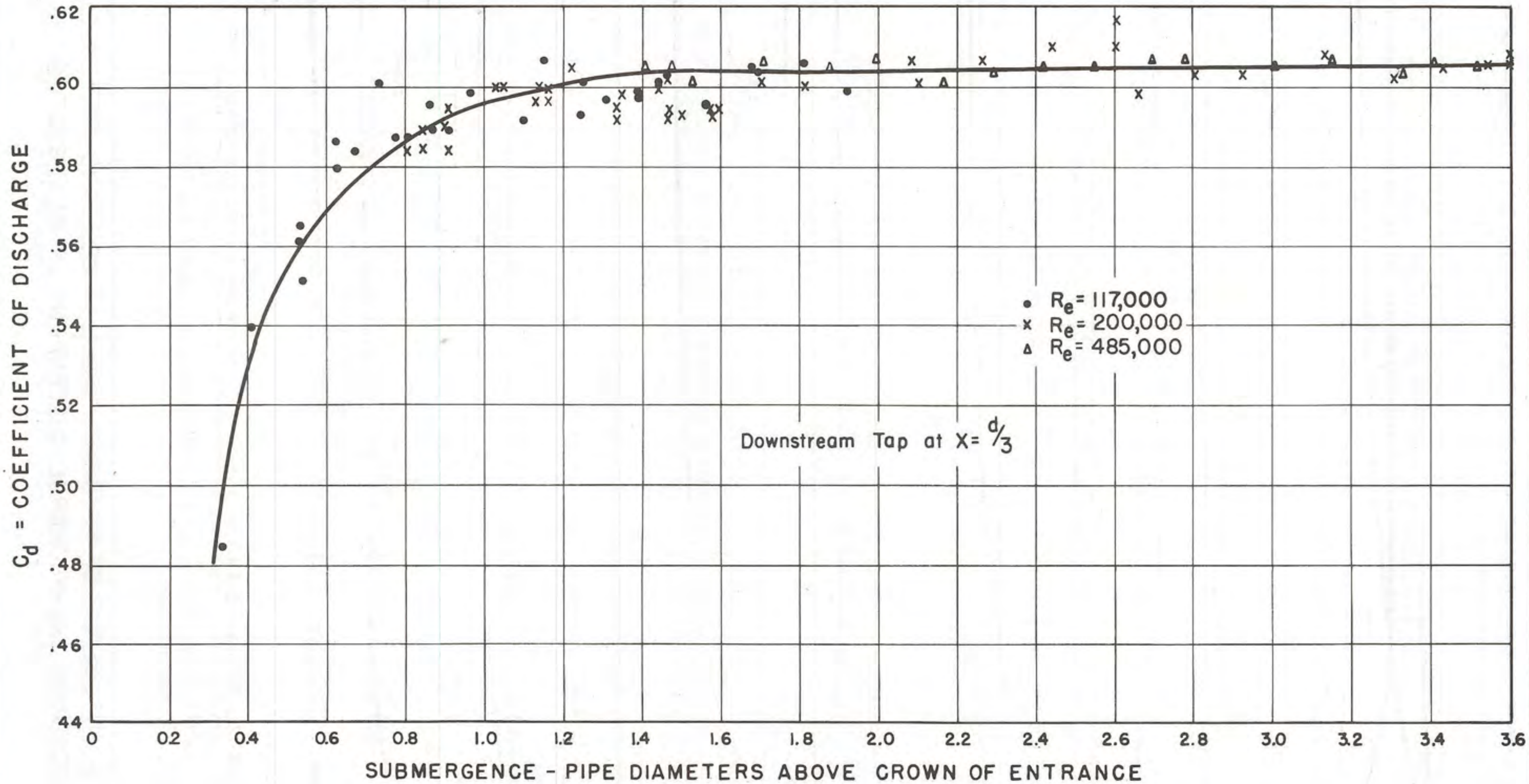
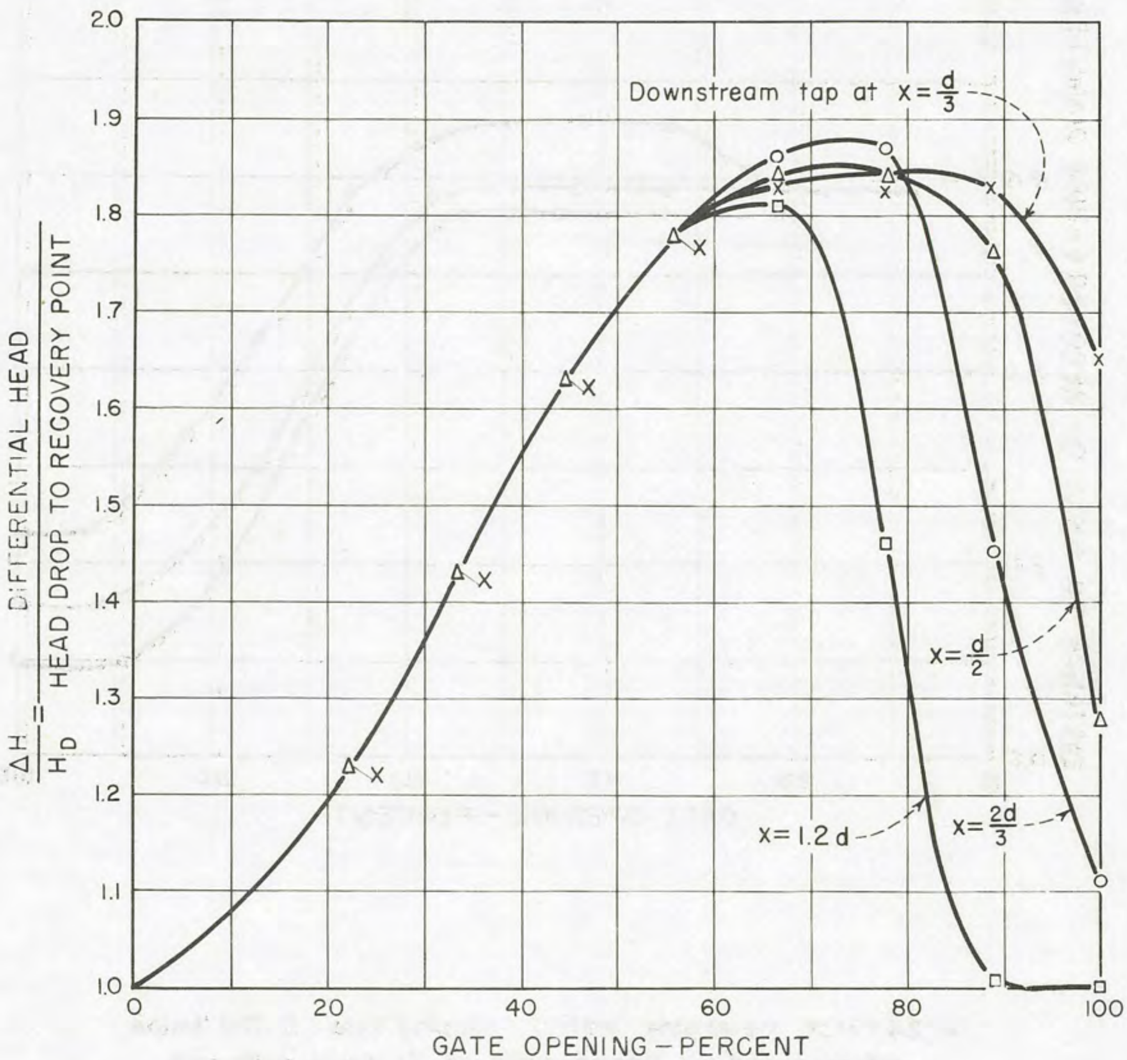


FIGURE 10. INFLUENCE OF INLET SUBMERGENCE AND VISCOSITY ON DISCHARGE COEFFICIENTS OF METERGATES



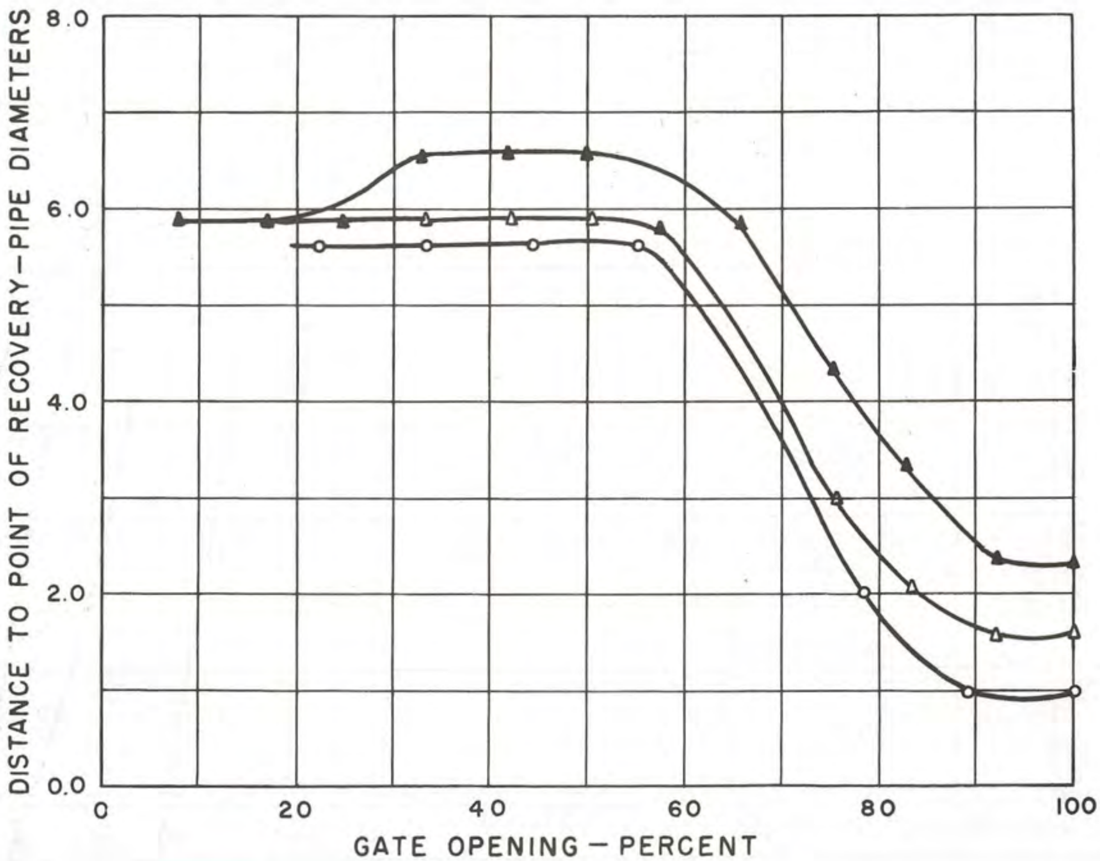
NOTES

Upstream submergence greater than 1.0d

Floor 1.0d below invert of entrance and walls 3.0d from edges of entrance.

Zero gate opening – Bottom of leaf at invert of entrance.

FIGURE 11. PRESSURE FACTORS FOR VARIOUS OPENINGS AND PRESSURE TAP LOCATIONS – 18-INCH METERGATE WITH LEVEL FLOOR AND PARALLEL WALLS



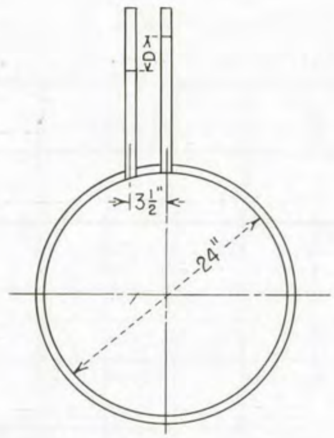
▲ 24-inch metergate with 2:1 sloping floor 0.17d below entrance and 8:1 flaring walls at $d/4$ from entrance.

△ 24-inch metergate with level floor 0.63 d below entrance and parallel walls at $2\frac{1}{4}$ d from entrance.

○ 18-inch metergate with level floor 1.0 d below entrance and parallel walls at 3 d from entrance.

Upstream submergence greater than d.

FIGURE 12. LENGTH OF PIPE REQUIRED FOR PRESSURE RECOVERY IN METERGATE



Percent error in $\Delta H = \frac{D}{\Delta H} \times 100$

Gate opening.	20"	24"
Average % error in ΔH.	7.5%	3%
Average % error in discharge.	2.8%	1.7%

D - Difference in pressure head between the piezometer on top of pipe and piezometer offset $3\frac{1}{2}$". Both piezometers one foot D.S. of gate seat - feet

ΔH - Difference in W.S. in measuring wells - feet

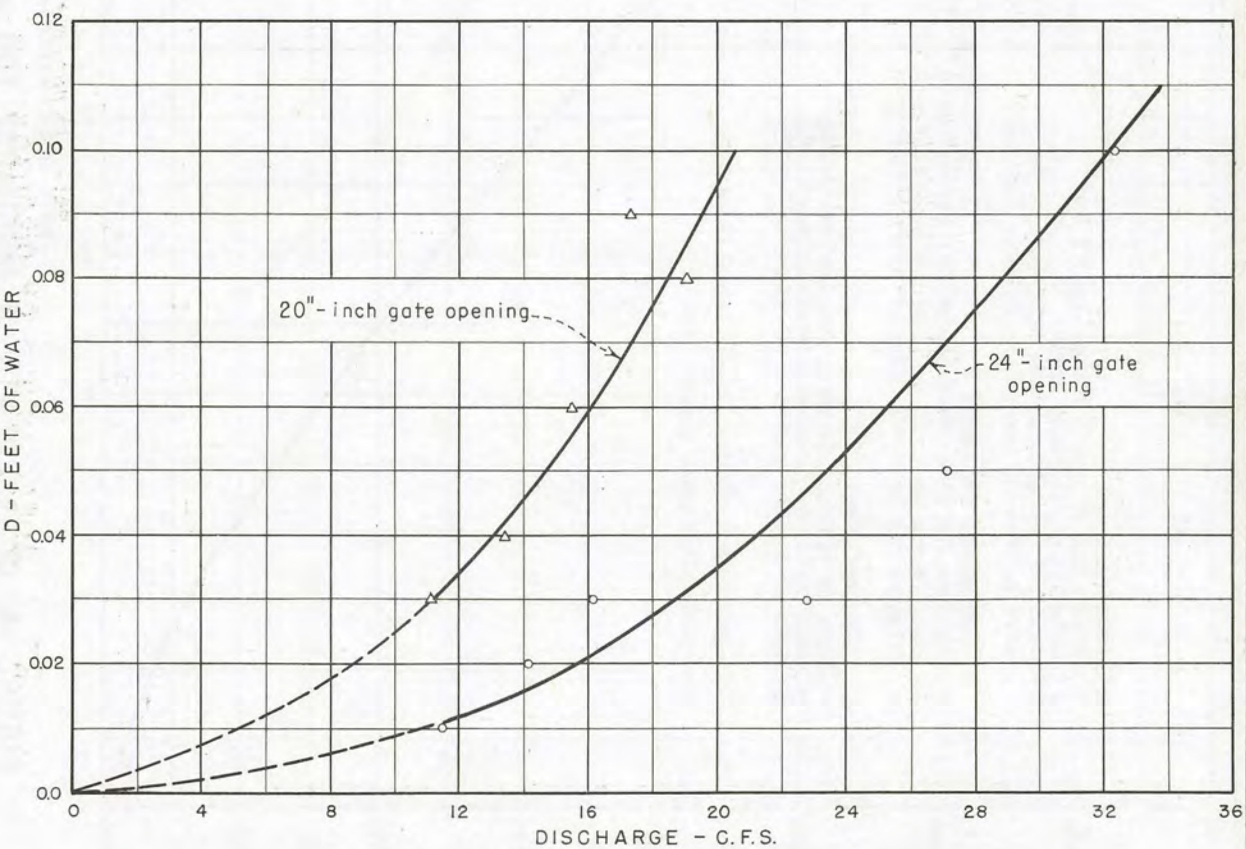


FIGURE 13. EFFECT OF LATERAL OFFSETTING OF PRESSURE TAP FOR DOWNSTREAM HEAD-MEASURING WELL — 24-INCH METERGATE

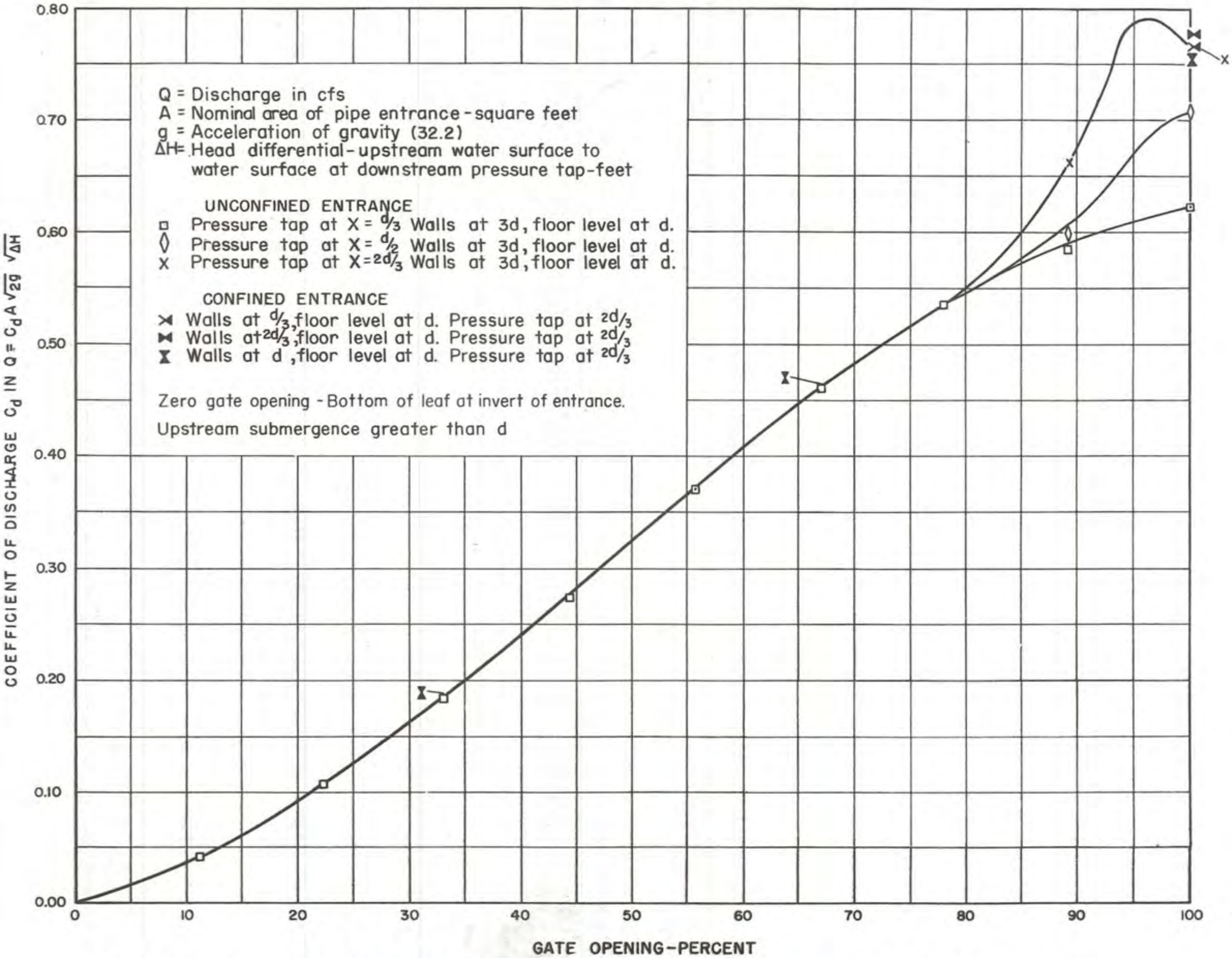


FIGURE 14. COEFFICIENTS OF DISCHARGE FOR VARIOUS GATE OPENINGS AND PRESSURE TAP LOCATIONS — 18-INCH METERGATE

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