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HYD 341

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC INVESTIGATION OF THE CONSOLIDATED IRRIGATION DISTRICT VENTURI-TYPE METERS

Hydraulic Laboratory Report No. Hyd. 341

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

September 29, 1953

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Laboratory Report No. Hyd-341
Hydraulic Laboratory Section
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Subject: Hydraulic investigation of the Consolidated Irrigation District venturi-type meters

PURPOSE

Determine rating curves, head losses due to the meters, and installation limitations.

CONCLUSIONS

1. The rating curves for the three test meters show good agreement with the general equation $Q = C_d A_1 A_2 \frac{\sqrt{2g\Delta H}}{\sqrt{A_1^2 - A_2^2}}$ when the actual throat diameter to pipe diameter ratio, R, is used instead of the nominal size (Figure 4).

2. Any variation in the ratio of pipe inside diameter to throat inside diameter will result in different calibration curves for meters of the same nominal pipe size. The joint at the throat should be kept as smooth as possible with no mortar protruding into the flow passage.

3. The relationship between the coefficient of discharge and throat velocity compares favorably with published characteristics for commercial iron or steel venturi meters (Figure 5).

4. The head loss due to the meter is low (Figure 6). This characteristic compares with losses given for commercial venturi meters.

5. To insure a measurable water surface in the throat measuring well at various discharges, the pipe outlet must have the submergence shown on Figure 9.

ACKNOWLEDGMENT

The laboratory tests of the Consolidated venturi meters were initiated by Mr. E. C. Fortier, Construction Engineer, Fresno,

California, in a letter to the Chief Engineer dated June 24, 1949. Two concrete test meters (sizes 16 x 9-1/4 inches and 20 x 12 inches) were furnished by the Consolidated Irrigation District, Selma, California. The study was conducted jointly by members of the Canals Branch and the Engineering Laboratories Branch.

INTRODUCTION

The Bureau of Reclamation in recent years initiated a program for the development and standardization of various water-measuring devices. Among the devices investigated for feasibility, flow characteristics, and operational limitations was the concrete venturi meter used by the Consolidated Irrigation District, Selma, California, and known as the Consolidated meter.

This meter consists of two precast sections of concrete pipe. One section combines a conical reducer from the pipe diameter to the throat diameter and the venturi throat, while the other section is an expanding conical unit from the throat diameter back to the pipe diameter (Figure 1) The sections of the venturi meter are cast with joints adaptable to standard concrete pipe. The differential head across the meter is obtained from piezometers located 12 inches upstream of the conical approach and midway of the throat section.

The laboratory tests performed on the two concrete meters, 16 x 9-1/4 inches and 20 x 12 inches, were supplemented by studies on an 8 x 5-1/3-inch venturi meter fabricated in the laboratory of sheet metal Figure 3 The study on an 8-inch meter was made since it was contemplated that a large number of turnouts would have small deliveries.

INVESTIGATION

The Laboratory Installation

The test installation used in the Hydraulic Laboratory is shown on (Figure 2). The flow was provided by a 12-inch centrifugal pump and measured by volumetrically calibrated venturi meters. The joint between the steel pipe and concrete meters was made watertight by first passing the concrete sections through a diamond saw to get smooth end surfaces, then greasing the surfaces and holding them tight against steel flanges welded to the steel pipe sections. Six tie rods between the two flanges were used to keep the joints tight. All rough edges were smoothed and recessions grouted prior to installing the meters. Static-head taps were installed in the steel pipe 6-pipe diameters downstream from the metering sections for the concrete meters and 18 diameters downstream for the sheet-metal meter to permit computation of the head loss due to the meter. A tailbox with a tailgate was installed on the outlet of the test structure to control the elevation of the hydraulic grade line. This outlet arrangement permitted the determination of the submergence requirements for meter turnouts.

Test Results

Capacity. Logarithmic plots of differential head (ΔH) versus discharge were made for the three test meters (Figure 4). The coefficient of discharge for each plotted point was computed from the following relationship which can be derived from Bernoulli's equation applied upstream of the conical approach and in the meter throat:

$$C_d = \frac{Q\sqrt{A_1{}^2 - A_2{}^2}}{A_1 A_2 \sqrt{2g\Delta H}}$$

Where

C_d = coefficient of discharge

Q = discharge, cfs

A_1 = area of pipe, ft^2

A_2 = area of throat, ft^2

g = gravitational force, 32.2 ft/sec^2

ΔH = differential head across meter, ft of water

Plots of C_d versus the throat velocity for the three test meters are shown on Figure 5. Using the average value for C_d at a particular velocity or discharge, the equations of the curves for the 8-, 16-, and 20-inch meters were determined as

$$Q = 1.39C_d \Delta H^{0.506},$$

$$Q = 3.97C_d \Delta H^{0.503}, \text{ and}$$

$$Q = 6.89\, C_d \Delta H^{0.500}$$

Previously in this report, it was stated that any variation of the ratio R or $\frac{D_1}{D_2}$ was a poor characteristic. For example in the equation for the 20 x 12-inch meter:

$$Q = 6.89C_d \Delta H^{0.500}$$

The constant 6.89 is a factor K, for the meter, which is comprised of A_1, A_2, and g, or:

$$K = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2g}$$

Any variation in R, from that for the nominal size, will change the value of K, and thus, the rating curve for the particular meter. The effect of this factor is shown clearly for the 20-inch meter where the throat diameter was actually 12-1/8-inches instead of 12 inches, (Figure 5).

Computations were made to determine the variation in the ratio R from the nominal dimensions which would result in ± 2, ± 3, and ± 5 percent error in discharge for the various size meters. The results of these computations are shown on Figure 6 and are compared to plots using A. S. T. M. diametral tolerances for concrete pipe. These data show that tolerances for the meter dimensions must be small compared to those of A. S. T. M. for concrete pipe, if the error due to the variation in the ratio R is to be kept small. It seems that the tolerances to limit errors to plus or minus 3 percent are not unreasonable and could be adhered to by using suitable metal forms in the meter construction. It can be shown by computation that when the difference of the two inside diameters (pipe and throat) of a meter decreases from that of the nominal meter the meter reads high, and conversely, when the difference of the two inside diameters increases from the nominal the meter reads low.

Head loss. The head loss due to the meters was computed giving the curves on Figure 7. To obtain this head loss, the difference in static head at points P_1 and P_3, Figure 3, was corrected by subtracting the computed friction loss in the pipe downstream of the meter to the P_3 station. The friction loss was determined using the Darcy equation:

$$H_L = f \frac{1}{d} \frac{V^2}{2g}$$

with the applicable value of "f" taken from King's Handbook of Hydraulics. The head loss as a percentage of the differential head across the meter is shown in Figure 8. King's Handbook of Hydraulics states this loss to be 10 to 20 percent with a decrease in percentage as the discharge or meter size is increased. Although the curves of Figure 8 are within the limits stated by King, there is no apparent trend with respect to meter size. This can be explained, in part at least, by the fact that for the meters tested, the diameter ratio R differed in all three cases. Also, on the two concrete meters, the joint connecting the two sections of the meter was somewhat inaccessible, which resulted in a rather rough surface and a slight change in cross section due to grouting the joint.

Downstream submergence. With insufficient submergence on the outlet of the turnout, it is possible not to have a measurable water surface in the downstream well. Using the tailgate on the tailbox of the laboratory installation, the amount of submergence necessary to give a positive pressure at the throat tap was determined Curves showing the required submergence for the meters tested, along with a schematic drawing indicating the procedure used, are shown on Figure 9. If this static pressure shown on Figure 9 does not give sufficient depth in the measuring well for certain recording devices such as hook gages, etc., the submergence must be increased by the required amount. The pipe must be flowing full to have the meters operate as intended.

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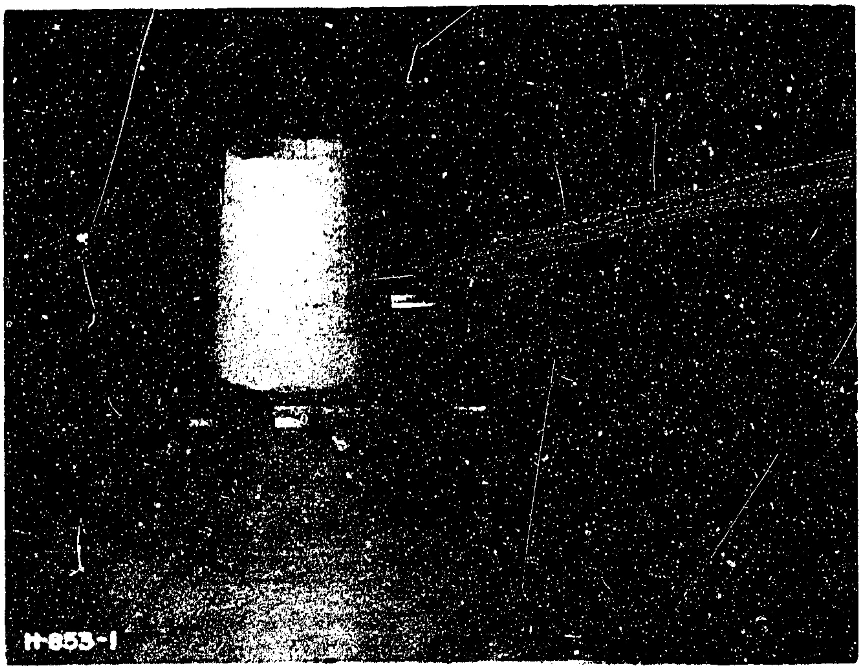
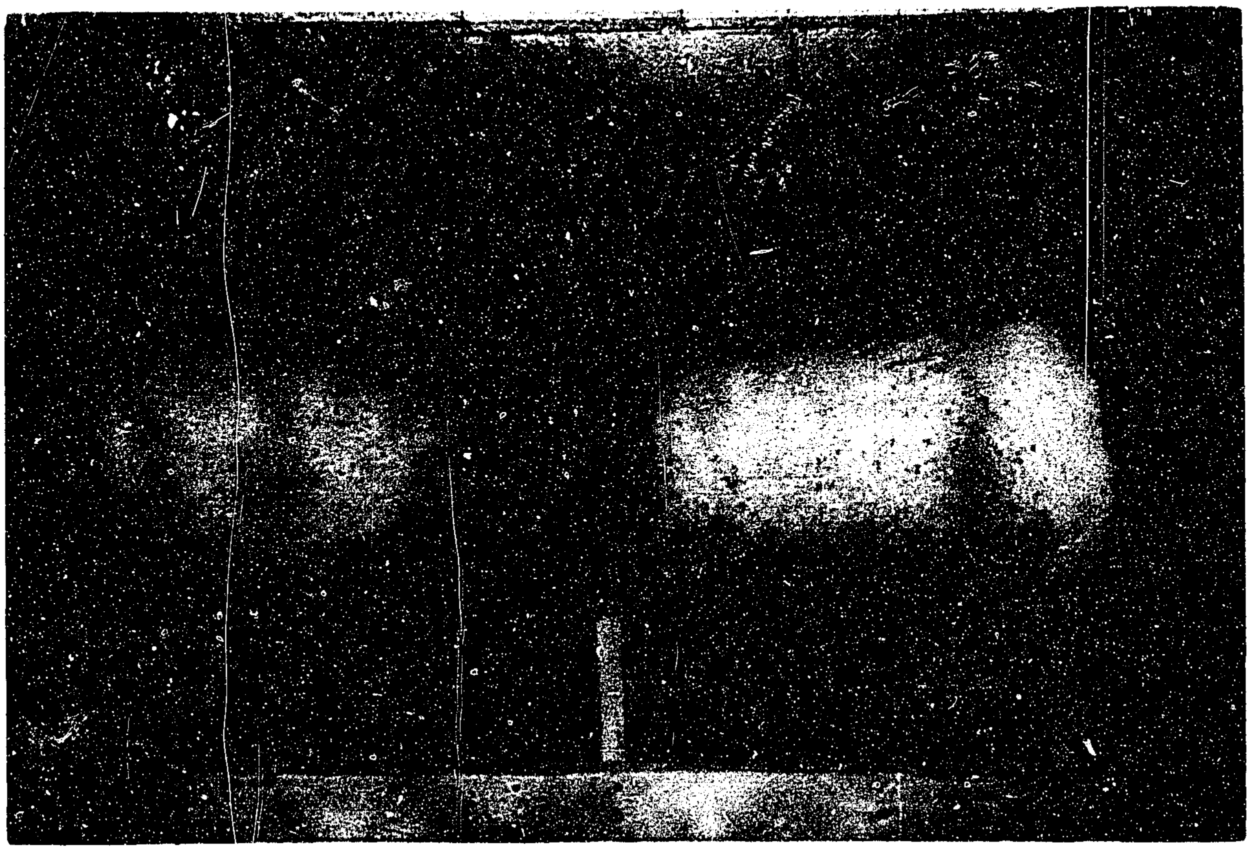


(A) 20 x 12-inch meter prior to assembly



(B) 16 x 9-1/4-inch meter assembled

TESTS OF CONSOLIDATED VENTURI METERS

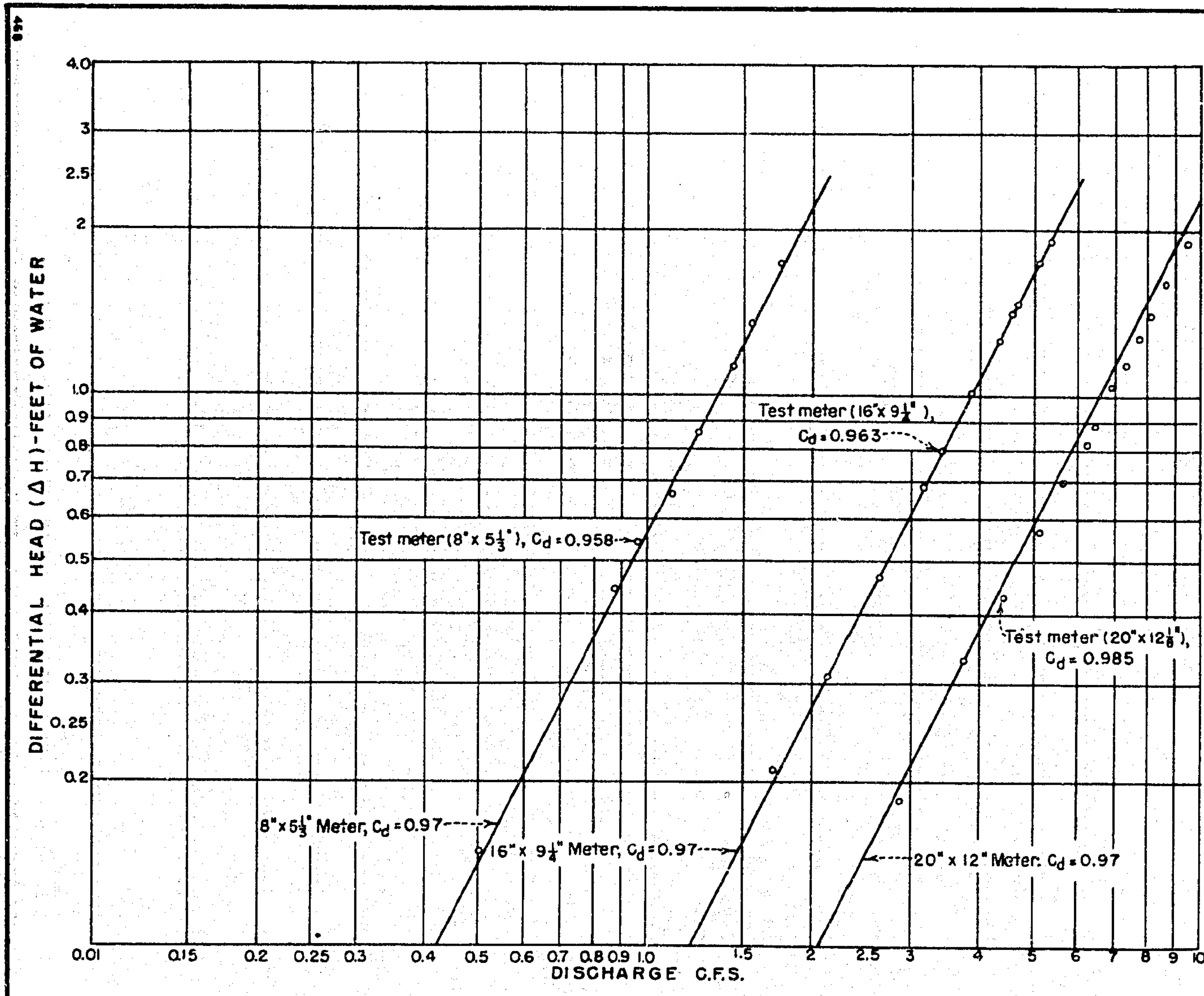
Unassembled and Assembled Venturi Meters

(A) Measuring wells used in laboratory for tests on 8 x 5-1/3-inch sheet metal meter.

(B) Test installation for 8 x 5-1/3-inch meter

TESTS OF CONSOLIDATED VENTURI METERS

Test Installation of 8 x 5-1/3-inch Sheet Metal Venturi Meter



NOTE

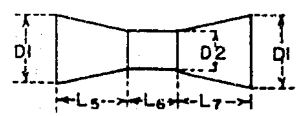
Equation for line through test points for
3-inch meter, $Q = 1.39\, C_d \Delta H^{0.506}$
16-inch meter, $Q = 3.97\, C_d \Delta H^{0.503}$
20-inch meter, $Q = 6.89\, C_d \Delta H^{0.500}$

Lines on this figure are for nominal size meters using –

$$Q = \frac{C_d A_1 A_2 \sqrt{2g\Delta H}}{\sqrt{A_1^2 - A_2^2}}$$

Where:

Q = Discharge in cfs.
A_1 = Area pipe at upstream pressure tap, sq. ft.
A_2 = Area throat, sq. ft.
C_d = Coefficient of discharge, 0.97
g = gravitational force, 32.2 ft. per sec.^{2}
ΔH = Differential pressure, ft. of water



METER SIZE	D_1	D_2	L_5	L_6	L_7
8"	8"	5.33"	0'-10.67"	0'-5.33"	0'-10.67"
16"	16"	9.25"	1'-7"	0'-9.25"	2'-8.25"
20"	20"	12-12"	1'-8"	1'-0"	2'-6.50"

TESTS OF CONSOLIDATED VENTURI METERS

RATING CURVES FOR 8, 16 AND 20-INCH METERS

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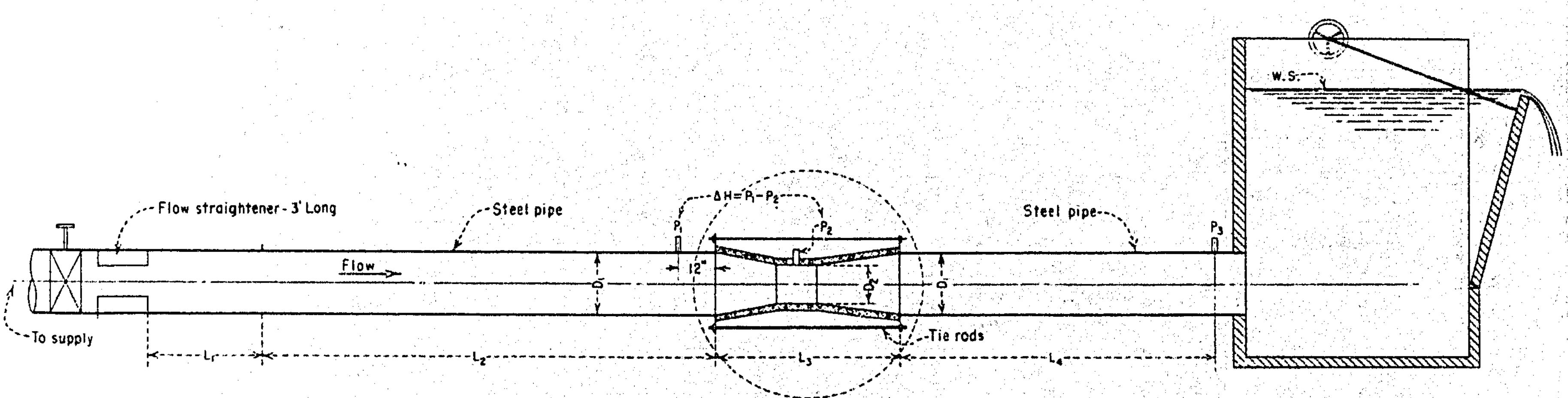
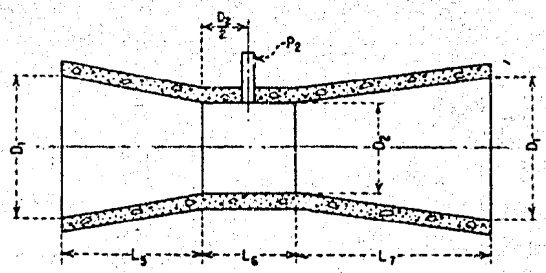


DETAIL "A"

METER SIZE	D_1	D_2	L_1	L_2	L_3	L_4	L_5	L_6	L_7	$R = \frac{D_1}{D_2}$
8"	8"	5.33"	2'-0"	20'-0"	2'-2.625"	12'-0"	0'-10.67"	0'-5.33"	0'-10.67"	1.50
16"	16"	9.25"	3'-0"	17'-0"	5'-0.50"	8'-0"	1'-7"	0'-9.25"	2'-8.25"	1.73
20"	20"	12.12"	5'-0"	15'-0"	5'-2.50"	10'-0"	1'-8"	1'-0"	2'-6.50"	1.65



DETAIL "A"

TESTS OF CONSOLIDATED VENTURI METERS

LABORATORY TEST INSTALLATION

FIGURE 3
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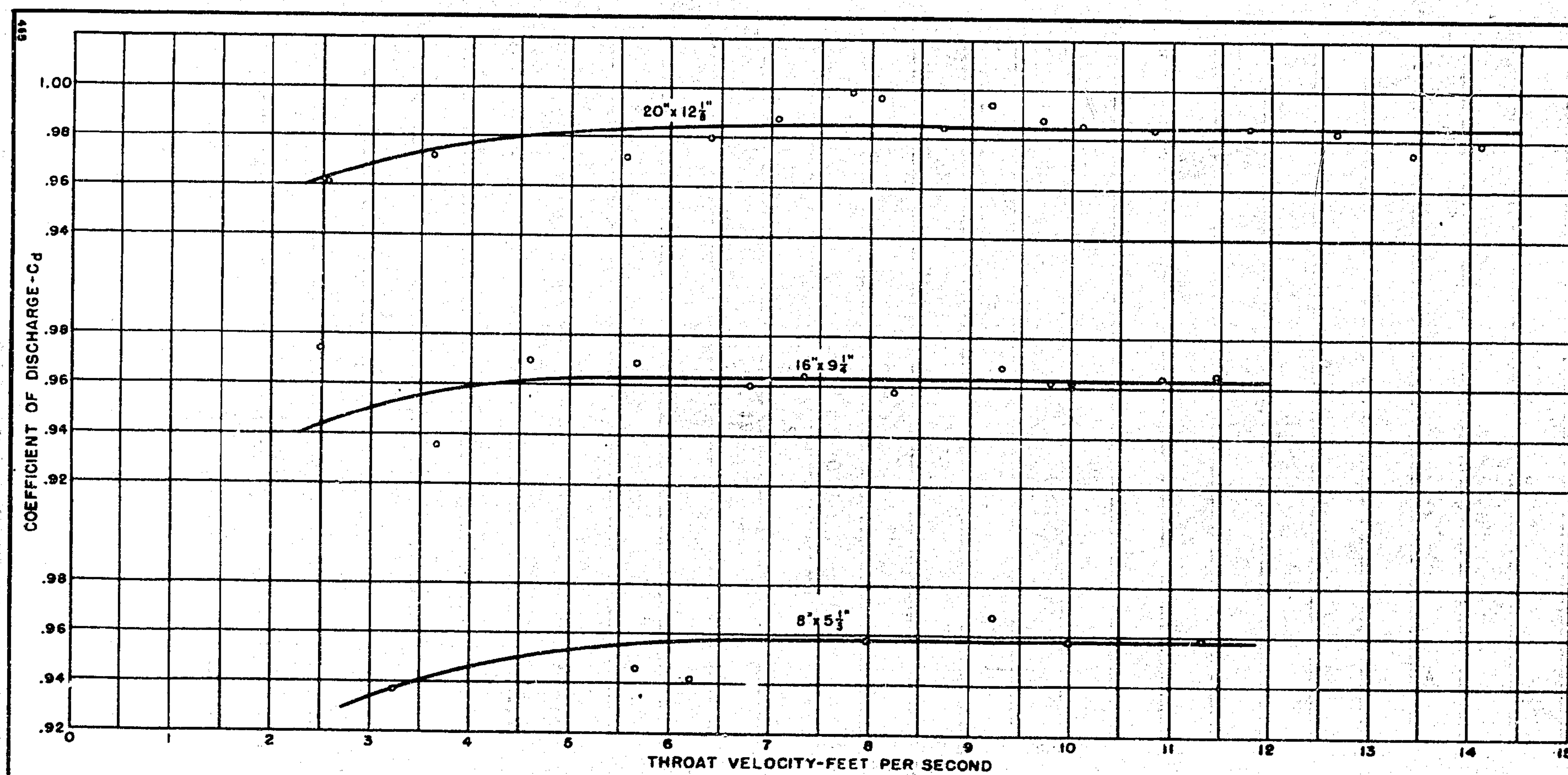

$$C_d = Q\frac{\sqrt{A_1^2 - A_2^2}}{A_1 A_2\sqrt{2g\Delta H}}$$

where:

Q = Discharge in c.f.s.
A_1 = Area pipe at upstream pressure tap-sq. ft.
A_2 = Area throat-sq. ft.
g = Gravitational force-(32.2 ft. per sec ^{2})
ΔH = Differential pressure-ft. of water

TESTS OF CONSOLIDATED VENTURI METERS

COEFFICIENT OF DISCHARGE VS THROAT VELOCITY FOR 8, 16 AND 20-INCH TEST METERS

FIGURE 5
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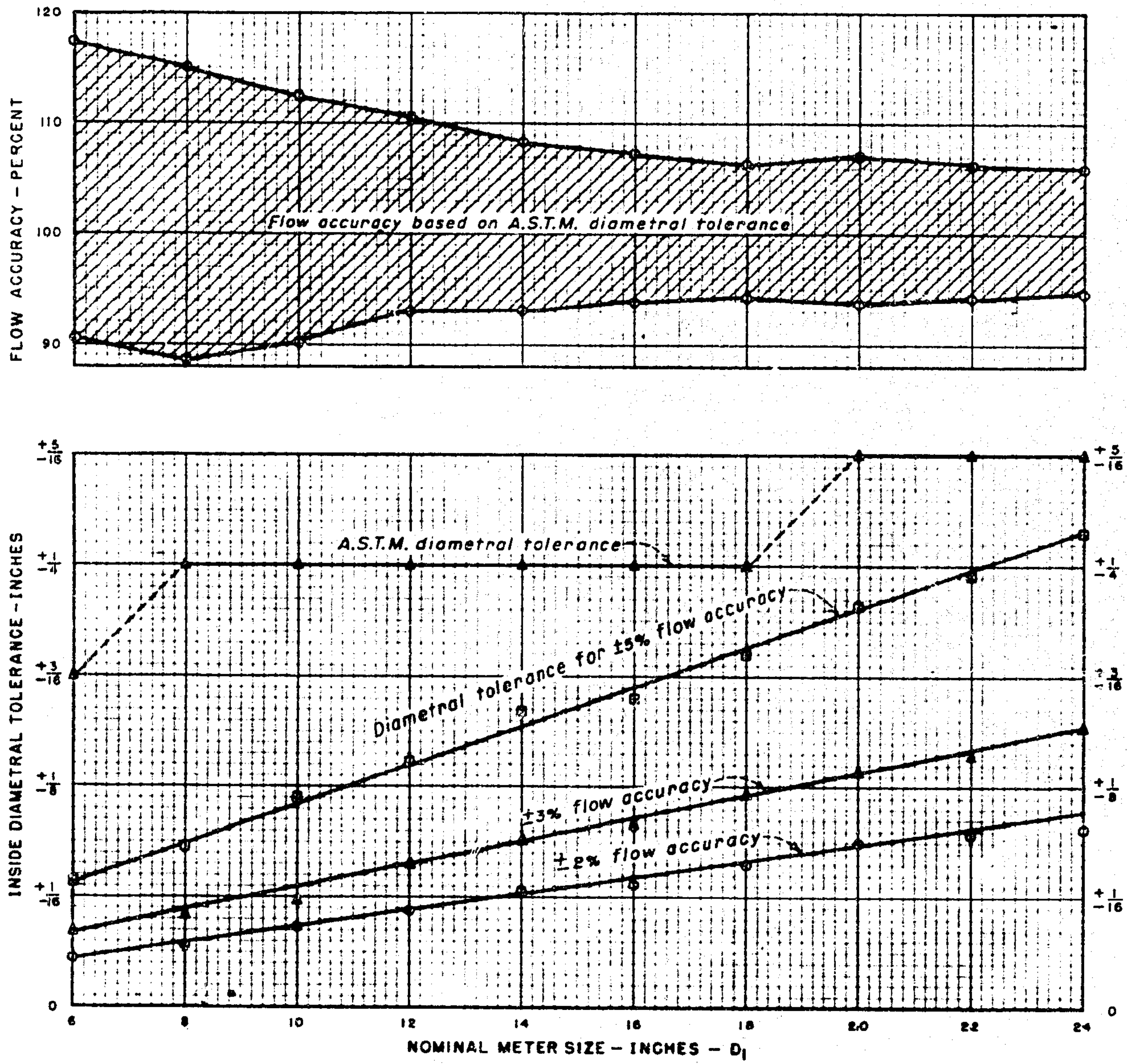

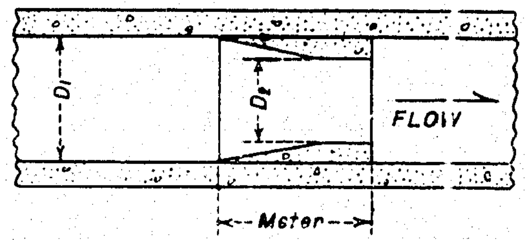

NOTES

1. All flow accuracy curves are based on a ratio of $\frac{D_1}{D_2} = 1.5$
2. Curves are independent of meter details; e.g., semi-venturi as shown in sketch, full venturi with gradual expansion, angle of convergence and divergence, location of pressure taps, etc.

TESTS OF CONSOLIDATED VENTURI METERS

FLOW ACCURACY VS. INSIDE DIAMETRAL TOLERANCE

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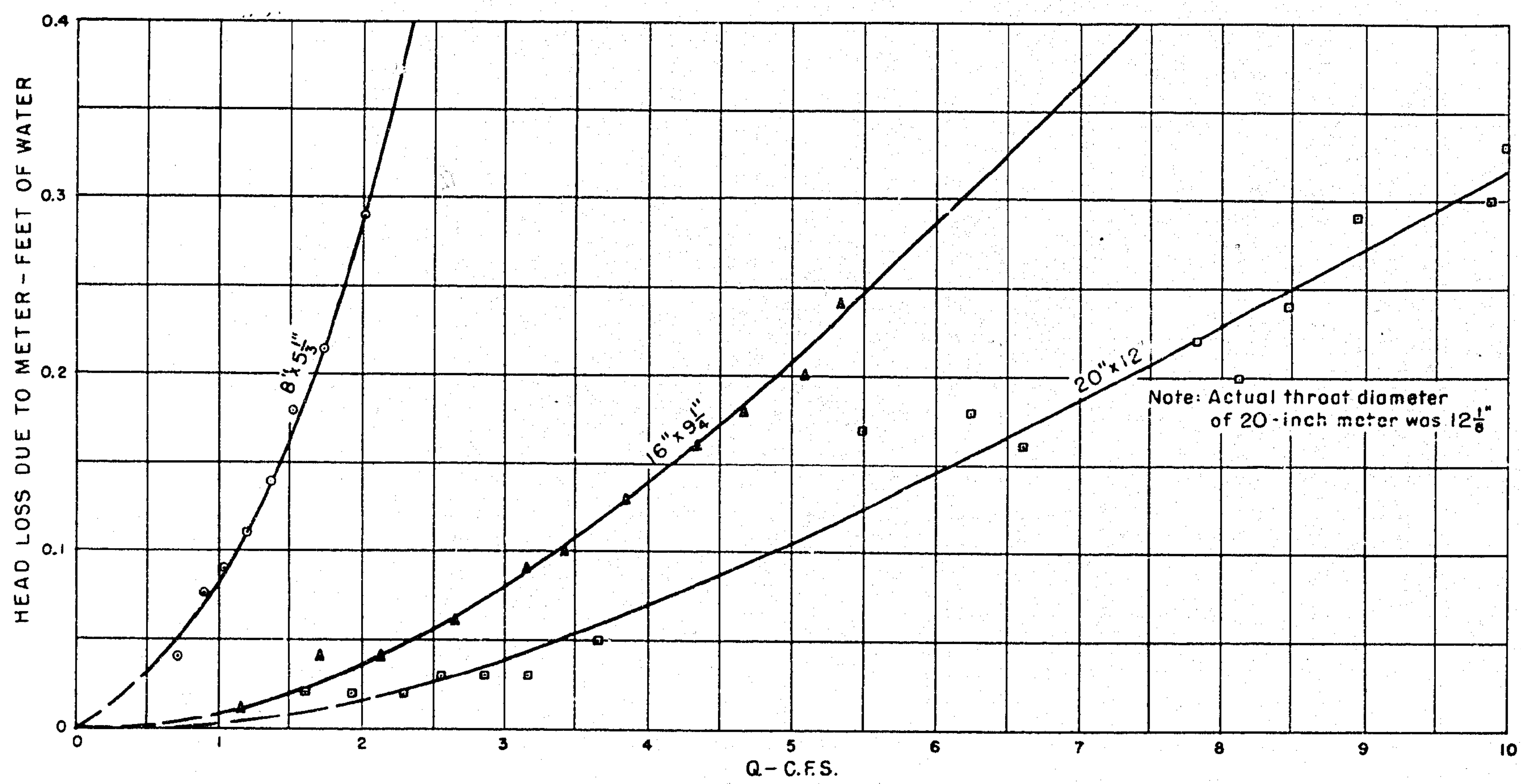

TESTS OF CONSOLIDATED VENTURI METERS

METER DISCHARGE VS HEAD LOSS FOR 8, 16 AND 20-INCH TEST METERS

FIGURE 7
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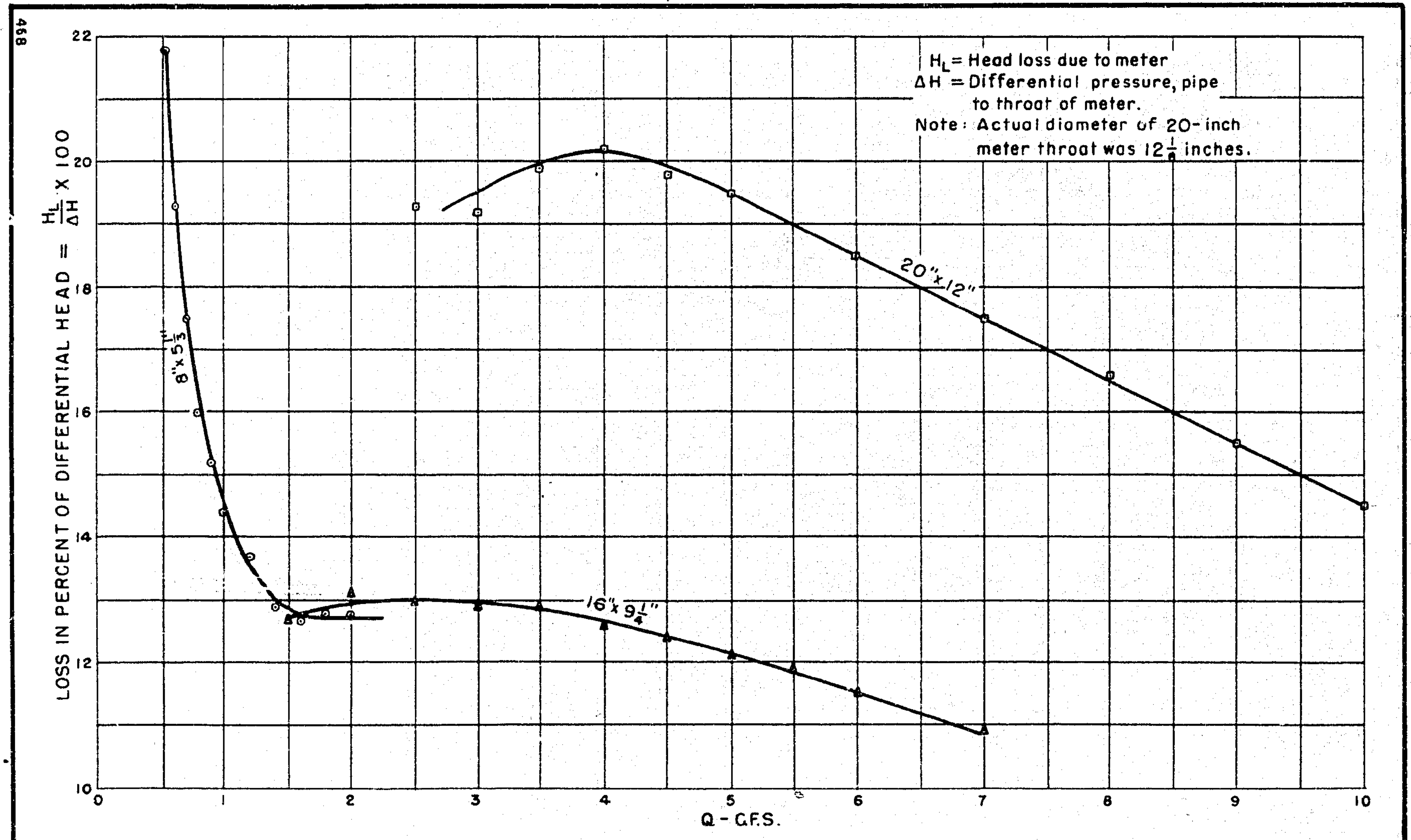
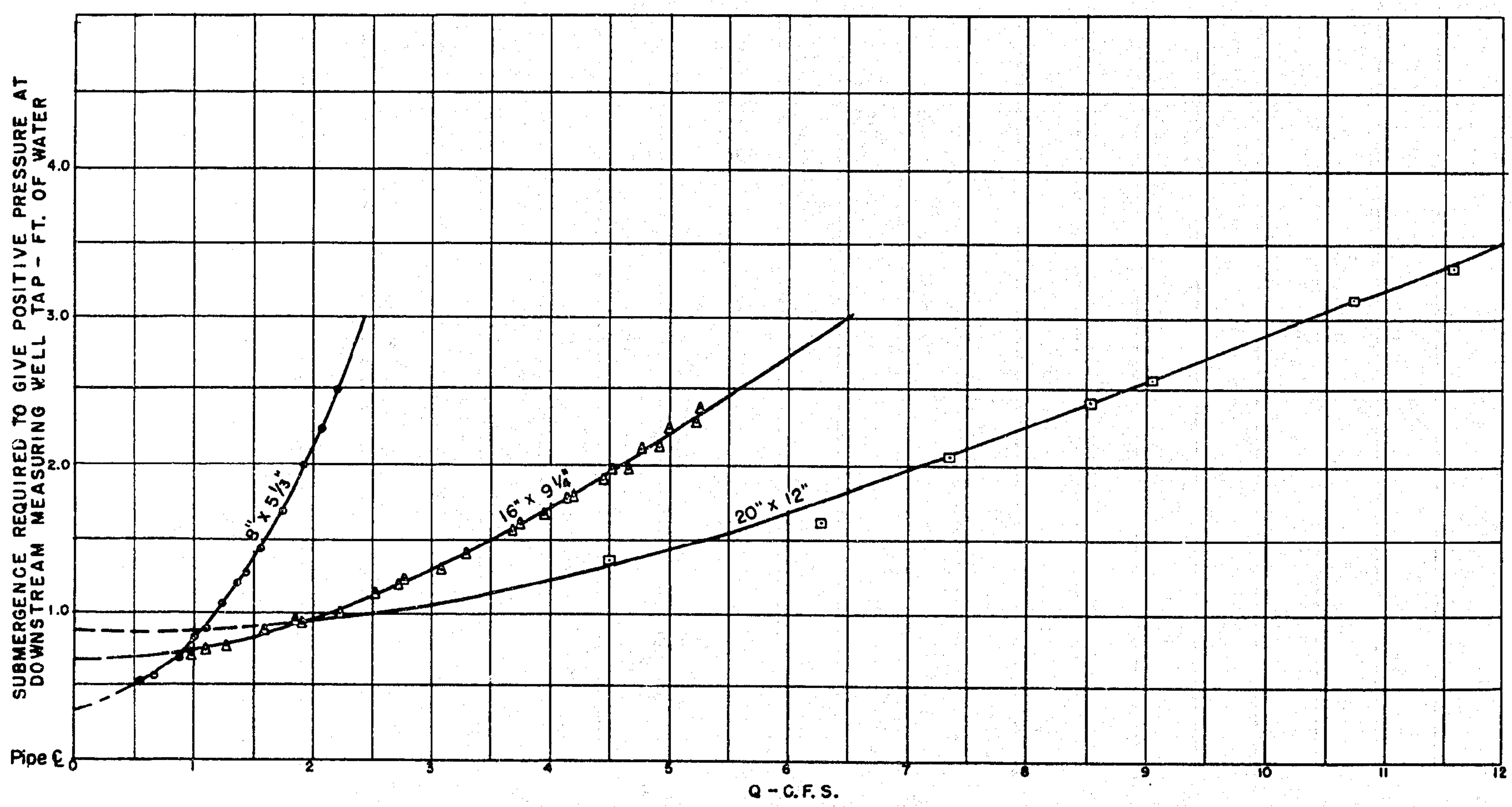


TESTS OF CONSOLIDATED VENTURI METERS

METER DISCHARGE VS HEAD LOSS, H_L, EXPRESSED AS A PERCENTAGE OF DIFFERENTIAL HEAD, ΔH. 8, 16 AND 20-INCH TEST METERS



TESTS OF CONSOLIDATED VENTURI METERS

OUTLET SUBMERGENCE REQUIREMENTS FOR 8, 16 AND 20-INCH TEST METERS

FIGURE 9
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