THE CALIBRATION OF A VENTURI METER IN A TURBINE PENSTOCK

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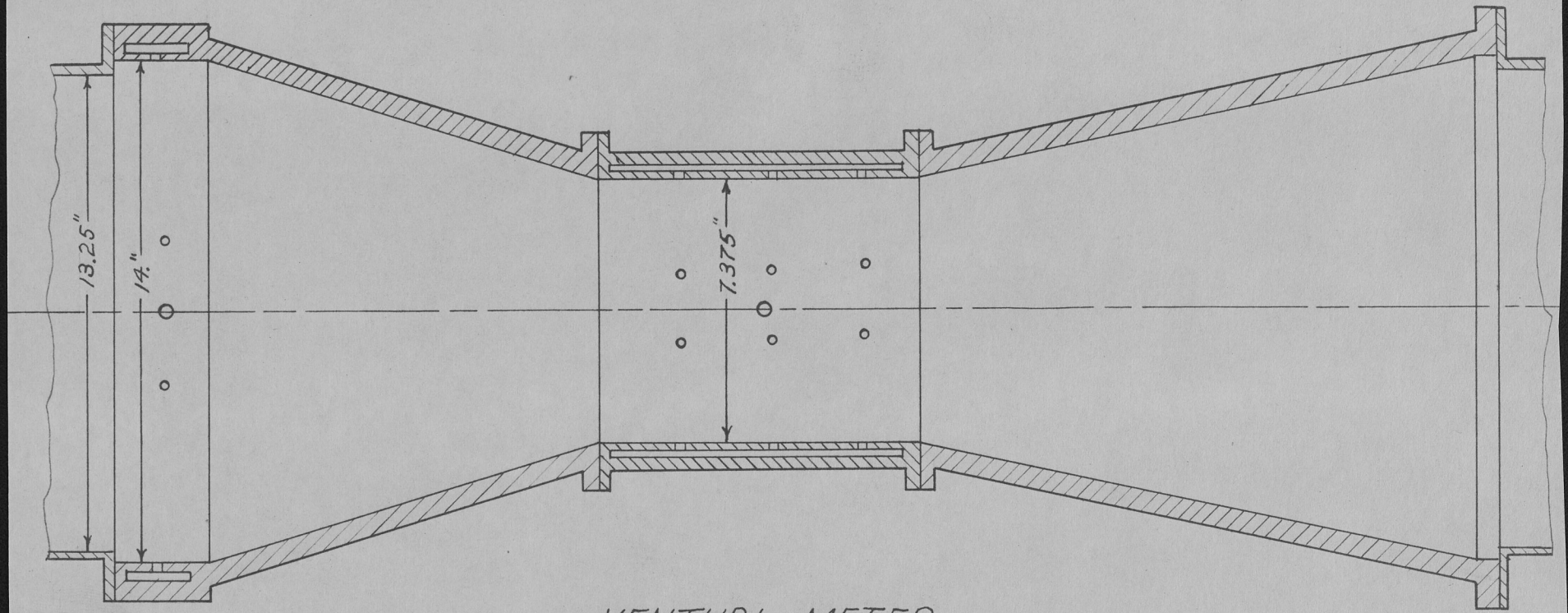
Chapter I

In 1930 there was installed in the Hydraulics Laboratory of the University of Tennessee, located in Ferris Hall, a model hydroelectric power plant. This plant was built around a nominal 10 inch Francis turbine with water supplied through a 13.25 inch spirally welded steel penstock. A 14 x 7 3/8 inch venturi meter was installed in this penstock for the purpose of measuring the flow of water through the turbine. Another means was also provided for measuring the flow of water through the turbine by a sharp crested suppressed weir which was located in the turbine tailrace.

Since that time, this plant has been used in the study of operating characteristics of the vertical turbine by each senior hydraulics class. It has been found in all these tests that the discharge as shown by the venturi meter differed considerably from the discharge as shown by the weir.

This has brought up the question as to which is the more reliable of the two methods of measuring this discharge. The object of this study is to determine the accuracy of the venturi meter and weir so that the discharge may be accurately determined in the future. This has never been performed because no direct method of calibration of either of these measuring devices had been included in the original design of the system. Therefore some means of measuring the quantity of flow had to be provided in order to make this study possible. After a thorough investigation of all possible measuring devices, it was decided that the pito-



VENTURI METER

NOT TO SCALE

meter should be used due to its accuracy in determinations of this sort.

It might be well to state at this point the factors upon which the decision(as to the use of the pitometer over other methods) was based. There are several other methods which might be used with varying accuracy depending upon the actual conditions of the individual problem. Some of these methods are:

1. Current meter measurements.
2. Salt dilution method.
3. Pressure variation method.
4. Color, floats, and moving screen measurements.
5. Weighing and timing of discharge.

All of the above methods were discarded because facilities for their use could not be provided and because all but the weighing method had insufficient accuracy to be considered. Weighing and timing was not deemed feasible because of the lack of equipment.

The study showed that a pitometer, with careful calibration and manipulation, would give errors no greater than about five per cent.

To make use of the pitometer in the penstock, it was necessary to install in the walls suitable connections to receive the pitometer. It was found that, due to the penstock wall being of such light steel plate, it was impossible to tap a connection in the line but that it was possible to weld same to the line. This method of attachment was used and later proved completely satisfactory. To

increase the accuracy of the test, taps were made to allow traverses of fluid velocity to be made along both vertical and horizontal diameters of the pipe.

Chapter II

With the installation of the taps completed, the problem arising was the accurate calibration of the pitometer to be used in the study. A standard six inch steel pipe was the largest available pipe in the laboratory emptying into a weighing tank. This pipe was already equipped with the necessary pitometer connections.

Three runs were made with varying rates of flow in the calibration of the pitometer. In each instance the velocity was measured at one-fourth inch intervals along the diameter of the pipe. These data were then used to plot a velocity diagram for that particular run. It has been found from past experience, that the most accurate method of obtaining the mean velocity in a pipe from a velocity diagram is to divide the cross sectional area of the pipe into a sufficient number of equal concentric areas to give an accurate mean velocity for the pipe. By assuming that the velocities at the center of each concentric area is the average velocity for that particular area, the mean velocity in the pipe may be determined by averaging these velocities as read from the plotted curve. Knowing the area of the pipe and the mean velocity of the water in the pipe, the discharge may be calculated by using the simple relation;

$Q = AV$

Where; Q = Discharge in Cu.Ft.per Sec.

A = Cross sectional area in sq. ft.

V = Mean velocity in ft. per sec.

The calibration factor of the pitometer may then be found by dividing the rate of discharge as found by actually

weighing and timing, by the rate of discharge as found by the pitometer method. Thus the velocity as measured by the pitometer, multiplied by this factor will give the actual velocity of the fluid at that point. Due to the fact that this pitometer had been used in general laboratory test work at the University for several years, a very good check was available on the accuracy of the factor found in the previously mentioned runs.

The next step in the study was the application of the pitometer method to the determination of the discharge in the turbine penstock. Because all tests on the vertical turbine were made at 0.2, 0.4, 0.6, 0.8, and full gate openings, it was decided that this study would be more useful if runs were made at these same gate openings. Time did not permit investigation at other gate openings which would have been desirable.

In this test, traverses were made along horizontal and vertical diameters of the penstock, velocities being obtained at one-half inch intervals on each traverse for each of the gate openings.

These data were plotted in a manner similar to the calibration curves except that each calculated velocity was corrected by means of the pitometer constant and actual velocities plotted. Mean velocities were obtained from each curve and used to calculate the discharge for each gate opening.

For each gate opening, accurate readings were taken of the following: The discharge as registered by the venturi

meter gage which read directly in cu. ft. per sec.; of the actual deflection of the mercury differential gage connected to the venturi meter; and of the hook gage which registers the height of water flowing over the weir. An accurate zero hook gage reading had been previously determined for the weir.

A constant head upon the system was maintained by means of a siphon overflow in the system surge tank and a constant discharge was maintained by keeping the load on the turbine constant for each traverse at the same gate opening.

Chapter III

Numerical Data

for

Calibration for Pitometer

General Data: Diam. of Pipe = 6.06"

Area of Pipe = 0.2005 sq. ft.

	Run 1		Run 2		Run 3	
	Wt. of Disch. = 10,000# Time=309.4 Sec.		Wt. of Disch. = 14.000# Time=360.7 Sec.		Wt. of Disch. = 19,000# Time =422.2 Sec.	
Distance in.	Def. in. of CCl_4	Velocity F.P.S.	Def. in. of CCl_4	Velocity F.P.S.	Def. in. of CCl_4	Velocity F.P.S.
0.25	0.40	1.30	2.20	2.64	0.80	1.61
0.50	2.40	2.76	3.40	3.28	4.40	3.72
0.75	2.80	2.97	4.40	3.72	5.80	4.28
1.00	3.00	3.08	4.80	3.89	6.00	4.34
1.25	3.20	3.18	5.00	3.96	6.40	4.50
1.50	3.40	3.28	5.20	4.04	6.80	4.62
1.75	3.60	3.37	5.50	4.17	7.00	4.70
2.00	3.80	3.46	5.60	4.20	7.30	4.80
2.25	3.90	3.51	5.80	4.28	7.60	4.88
2.50	4.00	3.56	5.90	4.31	7.90	4.97
2.75	4.10	3.60	6.00	4.34	8.00	5.01
3.00	4.20	3.64	6.10	4.42	8.10	5.03
3.25	4.25	3.67	6.00	4.34	8.10	5.03
3.50	4.20	3.64	5.90	4.31	8.00	5.01
3.75	4.10	3.60	5.85	4.29	8.00	5.01
4.00	4.00	3.56	5.70	4.23	7.90	4.97
4.25	3.85	3.49	5.60	4.20	7.80	4.95
4.50	3.80	3.46	5.50	4.17	7.60	4.88
4.75	3.65	3.40	5.20	4.04	7.20	4.77
5.00	3.40	3.28	5.00	3.96	6.80	4.62
5.25	3.15	3.16	4.60	3.81	6.20	4.42
5.50	2.60	2.87	4.20	3.64	5.70	4.22
5.75	2.40	2.76	3.80	3.46	5.00	3.96
6.00	1.80	2.40	2.80	2.97	4.00	3.56

Calculations for Calibration of Pitometer

Run 1

Actual Discharge = $\frac{10,000}{62.5 \times 309.4}$ = 0.518 C.F.S.

From Curve Sheet No. 1

V_1 = 2.47 F.P.S.

V_2 = 2.70 "

V_3 = 2.93 "

V_4 = 3.11 "

V_5 = 3.28 "

V_6 = 3.53 "

V_7 = 3.60 "

V_8 = 3.34 "

V_9 = 3.28 "

V_{10} = 3.06 "

V_{11} = -2.80 "

V_{12} = 2.26 "

36.47

$V_m = \frac{36.47}{12}$ = 3.04 F.P.S.

Pitometer Discharge = 0.2005 x 3.04 = 0.61 C.F.S.

Pitometer Calibration Factor = $\frac{0.518}{0.609}$ = 0.845

Run 2

Actual Discharge = $\frac{14,000}{62.5 \times 360.7}$ = 0.621 C.F.S.

From Curve Sheet No. 2

V_1 = 3.24 F.P.S.

V_2 = 3.48 "

V_3 = 3.68 "

V_4 = 3.87 "

V_5 = 4.06 F.P.S.

V_6 = 4.29 "

V_7 = 4.27 "

V_8 = 4.11 "

V_9 = 3.94 "

V_{10} = 3.73 "

V_{11} = 3.51 "

$V_{12} = \frac{-3.26}{45.44}$ "

$$V_m = \frac{45.44}{12} = 3.78 \text{ F.P.S.}$$

Pitometer Discharge = 0.2005 x 3.76 = 0.757 C.F.S.

Pitometer Calibration Factor = $\frac{0.621}{0.757}$ = 0.820

Run 3

Actual Discharge = $\frac{19{,}000}{62.5 \times 422.2}$ = 2.720 C.F.S.

From Curve Sheet No. 3

V_1 = 3.57 F.P.S.

V_2 = 3.85 "

V_3 = 4.12 "

V_4 = 4.37 "

V_5 = 4.58 "

V_6 = 4.92 "

V_7 = 5.01 "

V_8 = 4.85 "

V_9 = 4.62 "

V_{10} = 4.36 "

V_{11} = 4.06 "

$V_{12} = \frac{3.69}{52.00}$ "

$$V_m = \frac{52.00}{12} = 4.33 \text{ F.P.S.}$$

Pitometer Discharge = 0.2005 x 4.33 = 0.867 C.F.S.

Pitometer Calibration Factor = $\frac{0.720}{0.867}$ = 0.832

Average Pitometer Calibration Factor = $\frac{0.845 + 0.820 + 0.830}{3}$ = 0.832

PITOMETER CALIBRATION CURVE

Pipe Diam. = 6.065"

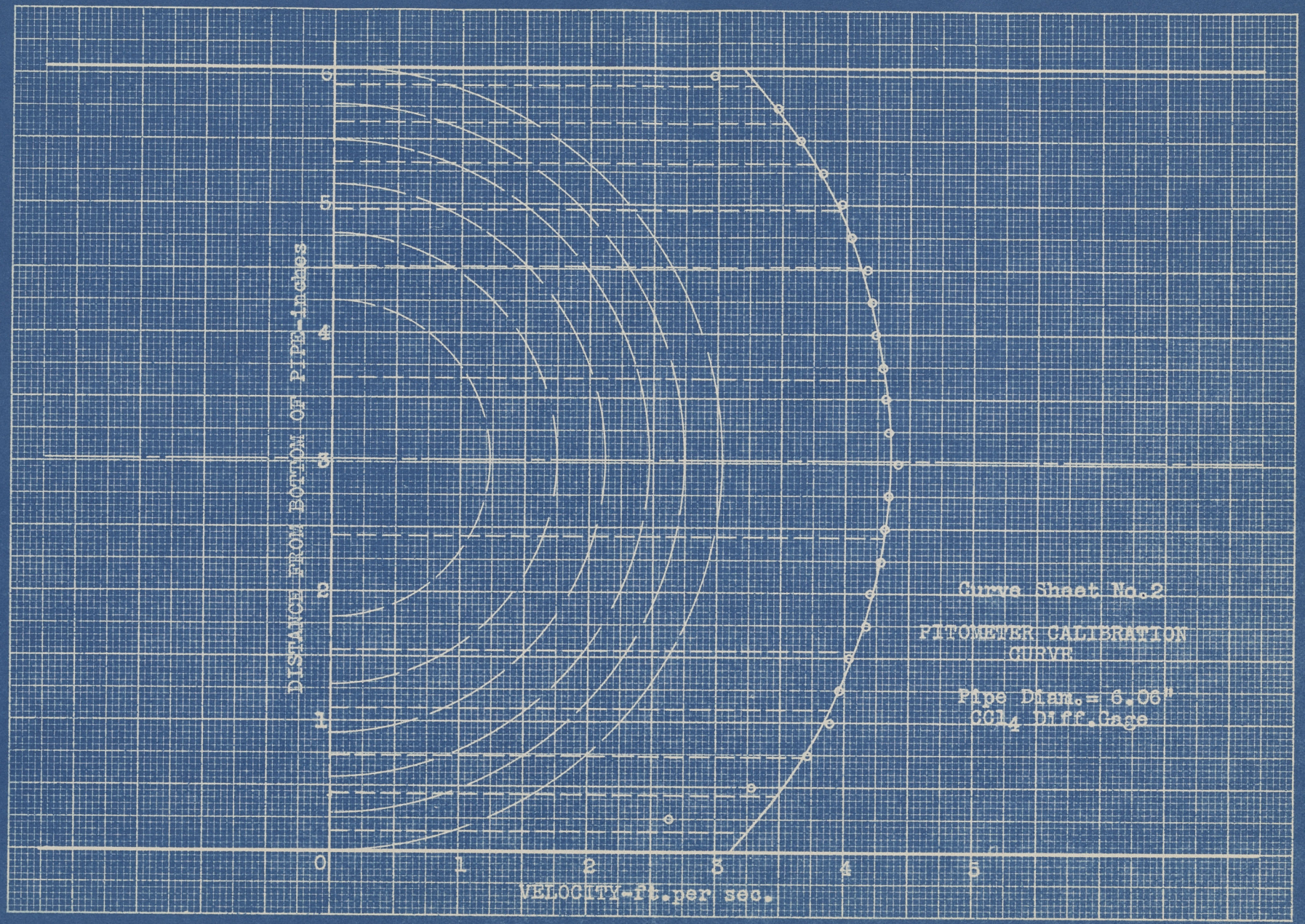
COL4 Diff. Gage

Curve Sheet No. 1 of 1 Sheets

DISTANCE FROM BOTTOM OF PIPE-inches

0 1 2 3 4 5 6

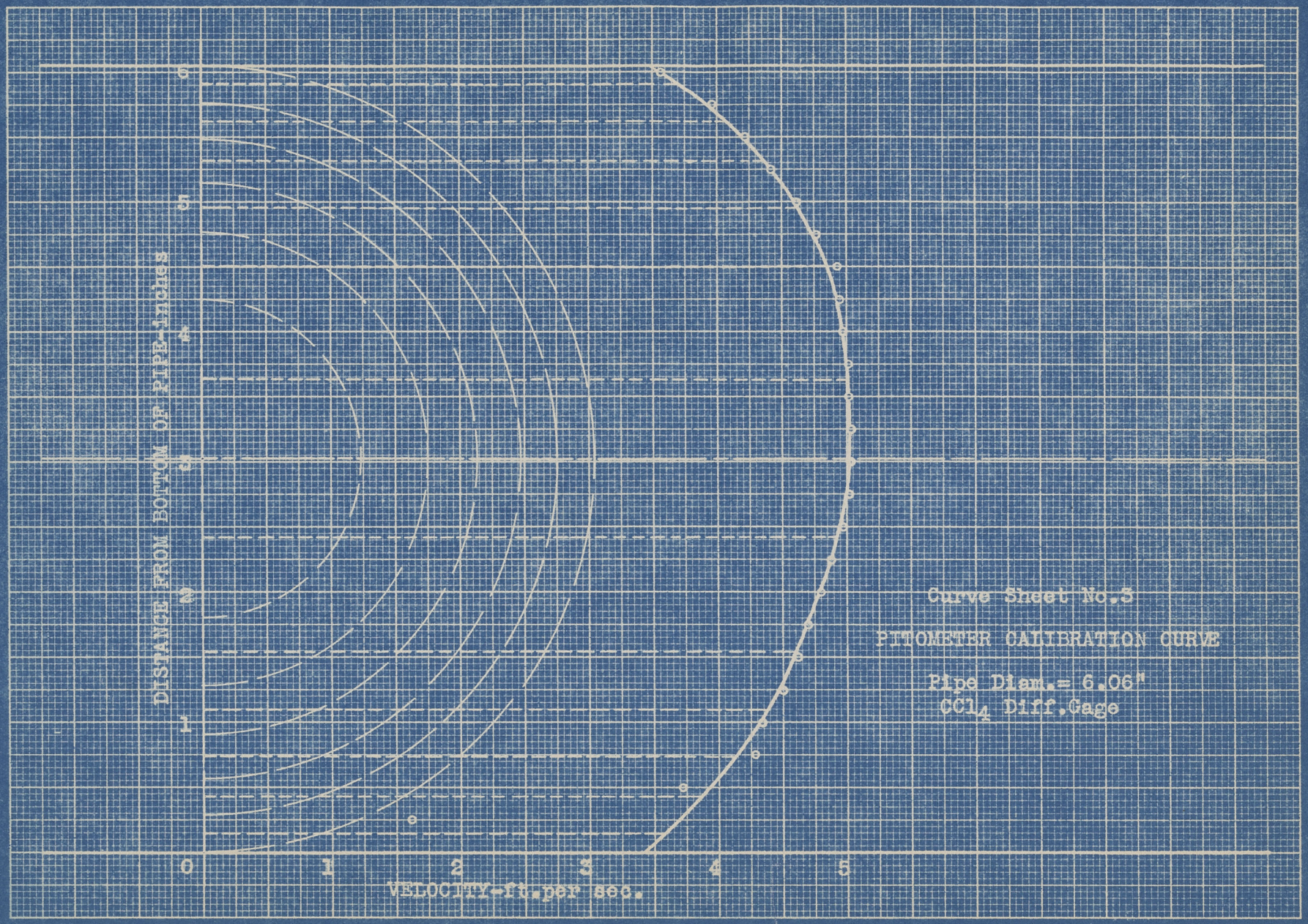
Velocity-ft. per sec.



Curve Sheet No.2

PITOMETER CALIBRATION CURVE

Pipe Diam.= 6.06"
CCl_4 Diff. Gage



Curve Sheet No.3

PITOMETER CALIBRATION CURVE

Pipe Diam.= 6.06"

CCl_4 Diff.Gage

Test Data for Venturi Meter

General Data: 0.2 Gate Opening

Speed of Turbine = 500 R.P.M.

Diam. of Pipe = 13.25 in.

Venturi Meter Gage Reading = 3.85 C.F.S.

Weir Hook Gage Reading = 1.219 Ft.

Deflection of Venturi Meter Gage = 2.438"Hg.

	Vertical Traverse		Horizontal Traverse	
Distance in.	Deflection in. of CCl_4	Velocity F.P.S.	Deflection in. of CCl_4	Velocity F.P.S.
0.50	5.30	3.41	5.90	3.60
1.00	6.20	3.70	7.80	4.13
1.50	7.40	4.05	8.40	4.30
2.00	7.80	4.13	9.30	4.52
2.50	8.50	4.32	9.50	4.53
3.00	9.40	4.52	9.60	4.60
3.50	9.90	4.68	9.70	4.62
4.00	10.10	4.72	9.80	4.65
4.50	10.30	4.75	10.00	4.70
5.00	10.00	4.70	9.70	4.62
5.50	10.00	4.70	9.60	4.60
6.00	10.10	4.72	9.20	4.50
6.50	9.90	4.68	9.40	4.52
7.00	9.50	4.53	9.30	4.52
7.50	9.40	4.52	9.30	4.52
8.00	9.30	4.52	8.90	4.42
8.50	9.00	4.44	9.20	4.50
9.00	9.10	4.48	8.90	4.42
9.50	8.60	4.35	8.70	4.38
10.00	8.30	4.28	8.30	4.28
10.50	7.50	4.05	7.50	4.05
11.00	6.80	3.86	7.00	3.90
11.50	6.60	3.81	6.60	3.81
12.00	6.20	3.68	6.10	3.61
12.50	5.80	3.57	5.10	3.35
13.00	3.50	2.77	2.70	2.45

Test Data for Venturi Meter

General Data: 0.4 Gate Opening

Speed of Turbine = 490 R.P.M.

Diam. of Pipe = 13.25 in.

Venturi Meter Gage Reading = 6.25 C.F.S.

Weir Hook Gage Reading = 1.362 ft.

Deflection of Venturi Meter Gage = 6.25" Hg.

	Vertical Traverse		Horizontal Traverse	
Distance in.	Deflection in. of CCl_4	Velocity F.P.S.	Deflection in. of CCl_4	Velocity F.P.S.
0.50	14.0	5.55	18.0	6.30
1.00	17.0	6.15	20.0	6.65
1.50	19.0	6.50	22.0	7.00
2.00	21.0	6.82	24.0	7.30
2.50	21.6	6.92	24.6	7.40
3.00	22.0	7.00	25.0	7.45
3.50	23.2	7.15	25.2	7.46
4.00	23.8	7.25	25.4	7.48
4.50	24.0	7.30	25.6	7.50
5.00	24.2	7.32	25.7	7.52
5.50	24.4	7.33	25.7	7.52
6.00	24.6	7.35	25.7	7.53
6.50	24.7	7.36	25.8	7.52
7.00	24.6	7.35	25.6	7.50
7.50	23.4	7.20	25.4	7.48
8.00	23.6	7.23	25.2	7.46
8.50	23.4	7.20	25.0	7.45
9.00	23.2	7.17	24.8	7.43
9.50	23.0	7.15	24.6	7.40
10.00	23.6	7.08	23.2	7.10
10.50	21.4	6.90	22.4	7.00
11.00	20.0	6.65	21.0	6.82
11.50	18.8	6.45	19.6	6.80
12.00	16.6	6.08	16.6	6.08
12.50	15.0	5.75	13.0	5.37
13.00	19.0	4.45	8.0	4.20

Test Data for Venturi Meter

General Data: 0.6 Gate Opening.

Speed of Turbine = 500 R.P.M.

Diam. of Pipe = 13.25 in.

Venturi Meter Gage Reading = 7.05 C.F.S.

Deflection of Venturi Meter Gage = 7.88"Hg.

Weir Hook Gage Reading = 1.440 ft.

	Vertical Traverse		Horizontal Traverse	
Distance in.	Deflection in. of Hg.	Velocity F.P.S.	Deflection in. of Hg.	Velocity F.P.S.
0.50	1.00	6.82	1.20	7.45
1.00	1.30	7.80	1.40	8.05
1.50	1.40	8.05	1.60	8.65
2.00	1.60	8.65	1.70	8.90
2.50	1.70	8.90	1.80	9.15
3.00	1.80	9.15	1.83	9.23
3.50	1.90	9.40	1.85	9.25
4.00	1.95	9.40	1.87	9.32
4.50	1.95	9.55	1.90	9.40
5.00	1.95	9.55	1.92	9.43
5.50	2.00	9.55	1.95	9.55
6.00	2.00	9.65	1.98	9.60
6.50	1.95	9.65	2.00	9.65
7.00	1.90	9.55	1.98	9.60
7.50	1.90	9.40	1.95	9.55
8.00	1.90	9.40	1.90	9.40
8.50	1.90	9.40	1.80	9.15
9.00	1.85	9.25	1.70	8.90
9.50	1.85	9.25	1.60	8.65
10.00	1.80	9.15	1.60	8.65
10.50	1.70	8.90	1.50	8.40
11.00	1.60	8.65	1.40	8.05
11.50	1.40	8.05	1.30	7.80
12.00	1.20	7.45	1.20	7.45
12.50	1.00	6.82	1.00	6.82
13.00	0.60	5.30	0.60	5.30

Test Data for Venturi Meter

General Data: 0.8 Gate Opening

Speed of Turbine = 499 R.P.M.

Diam. of Pipe = 13.25"

Venturi Meter Gage Reading = 7.90 C.F.S.

Deflection of Venturi Meter Gage = 10.12"Hg.

Weir Hook Gage Reading = 1.490 ft.

	Vertical Traverse		Horizontal Traverse	
Distance in.	Deflection in. of Hg.	Velocity F.P.S.	Deflection in. of Hg.	Velocity F.P.S.
0.50	1.20	7.45	1.60	8.65
1.00	1.60	8.65	1.80	9.15
1.50	1.80	9.15	2.00	9.65
2.00	2.00	9.65	2.20	10.10
2.50	2.10	9.90	2.30	10.30
3.00	2.20	10.10	2.40	10.55
3.50	2.30	10.30	2.43	10.60
4.00	2.40	10.55	2.45	10.65
4.50	2.42	10.60	2.46	10.66
5.00	2.45	10.65	2.47	10.68
5.50	2.48	10.70	2.48	10.70
6.00	2.50	10.75	2.50	10.75
6.50	2.49	10.72	2.50	10.75
7.00	2.45	10.65	2.45	10.65
7.50	2.43	10.60	2.43	10.60
8.00	2.40	10.55	2.40	10.55
8.50	2.35	10.40	2.38	10.50
9.00	2.30	10.30	2.34	10.40
9.50	2.25	10.20	2.30	10.30
10.00	2.21	10.10	2.20	10.10
10.50	2.00	9.65	2.19	10.05
11.00	1.90	9.40	2.15	10.00
11.50	1.80	9.15	2.10	9.90
12.00	1.70	8.90	1.80	9.15
12.50	1.60	8.65	1.40	8.05
13.00	1.20	7.45	1.00	6.82

Test Data for Venturi Meter

General Data: Full Gate Opening

Speed of Turbine = 500 R.P.M.

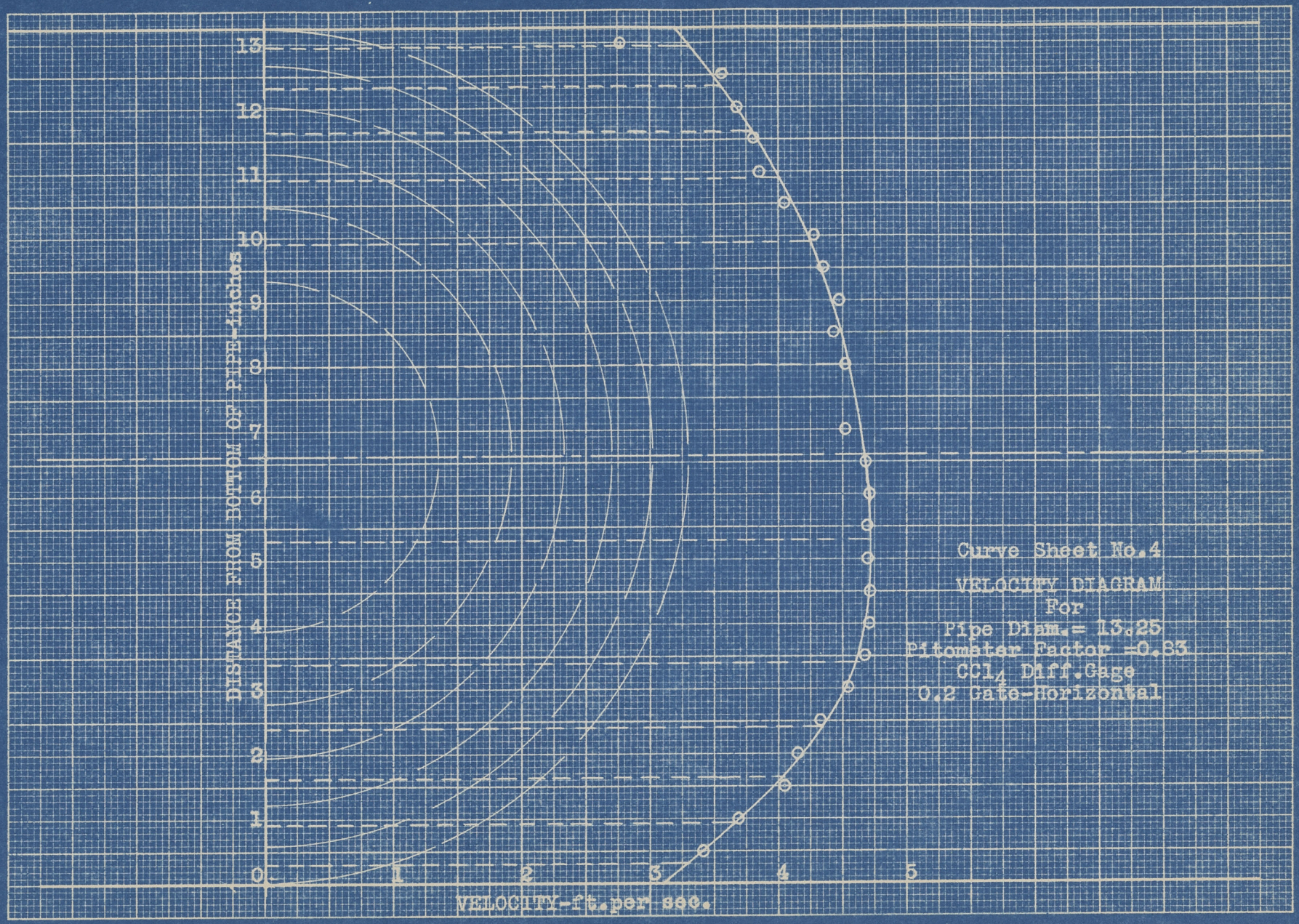
Diam. of Pipe = 13.25"

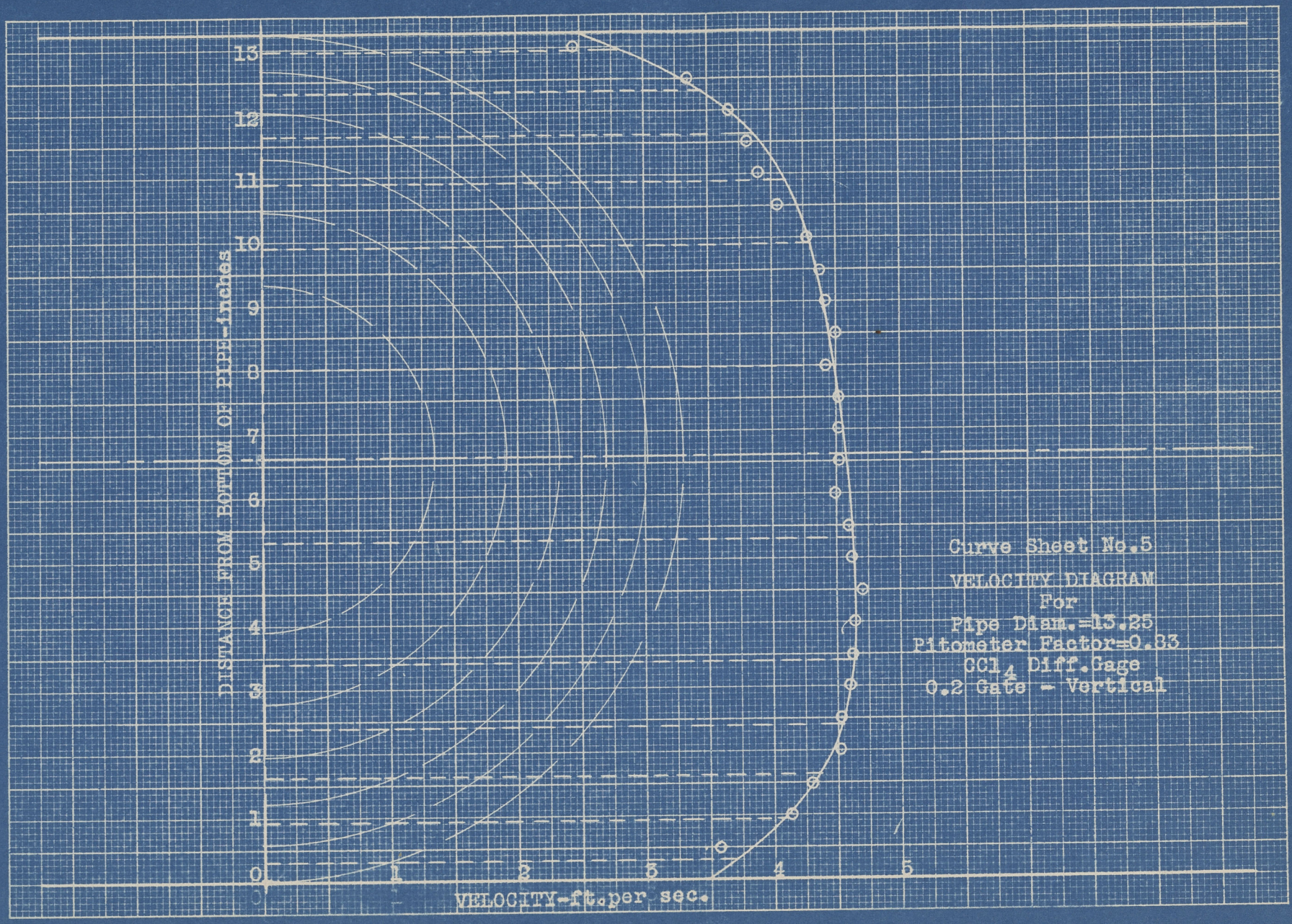
Venturi Meter Gage Reading = 8.45 C.F.S.

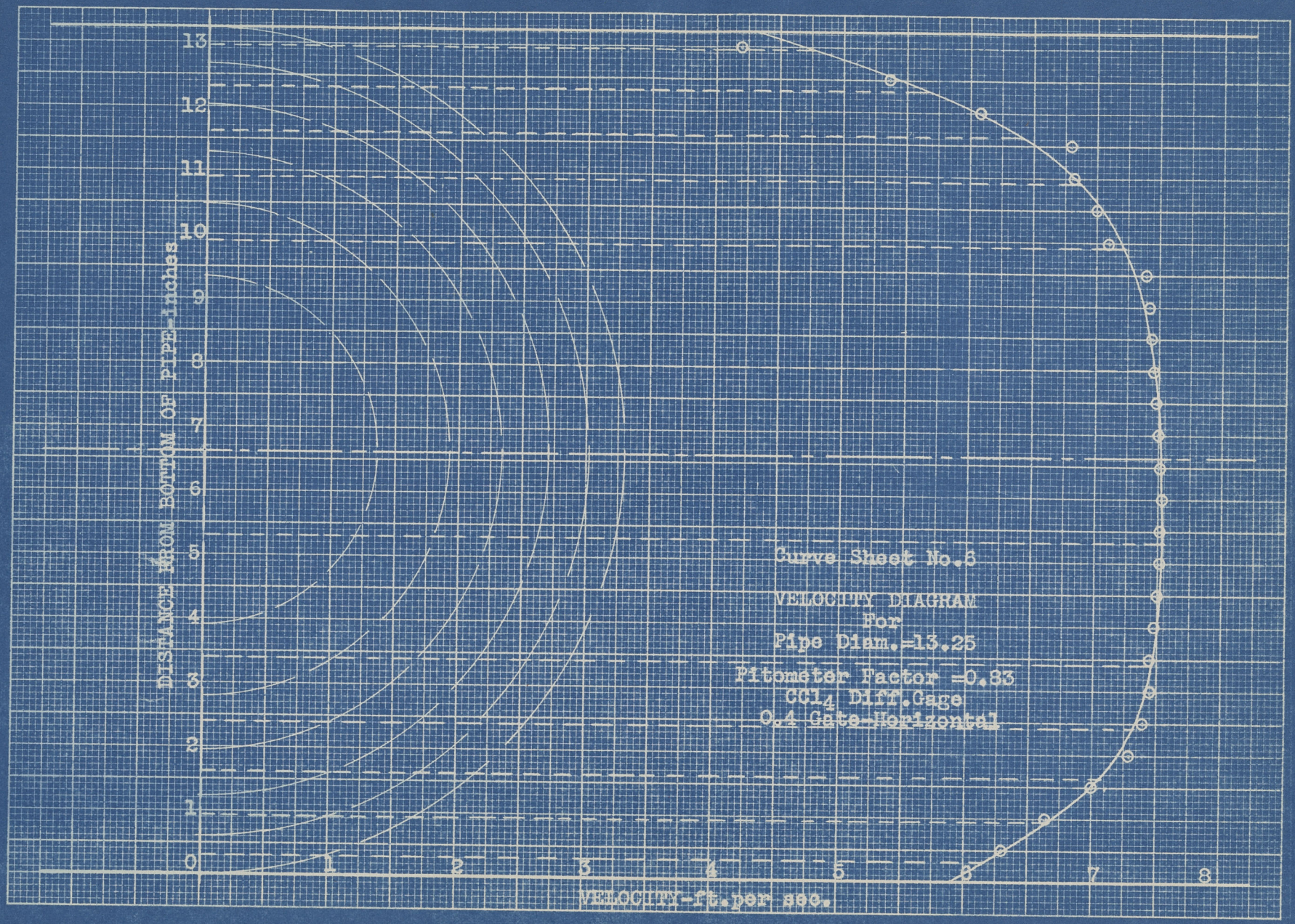
Deflection of Venturi Meter Gage = 11.40"Hg.

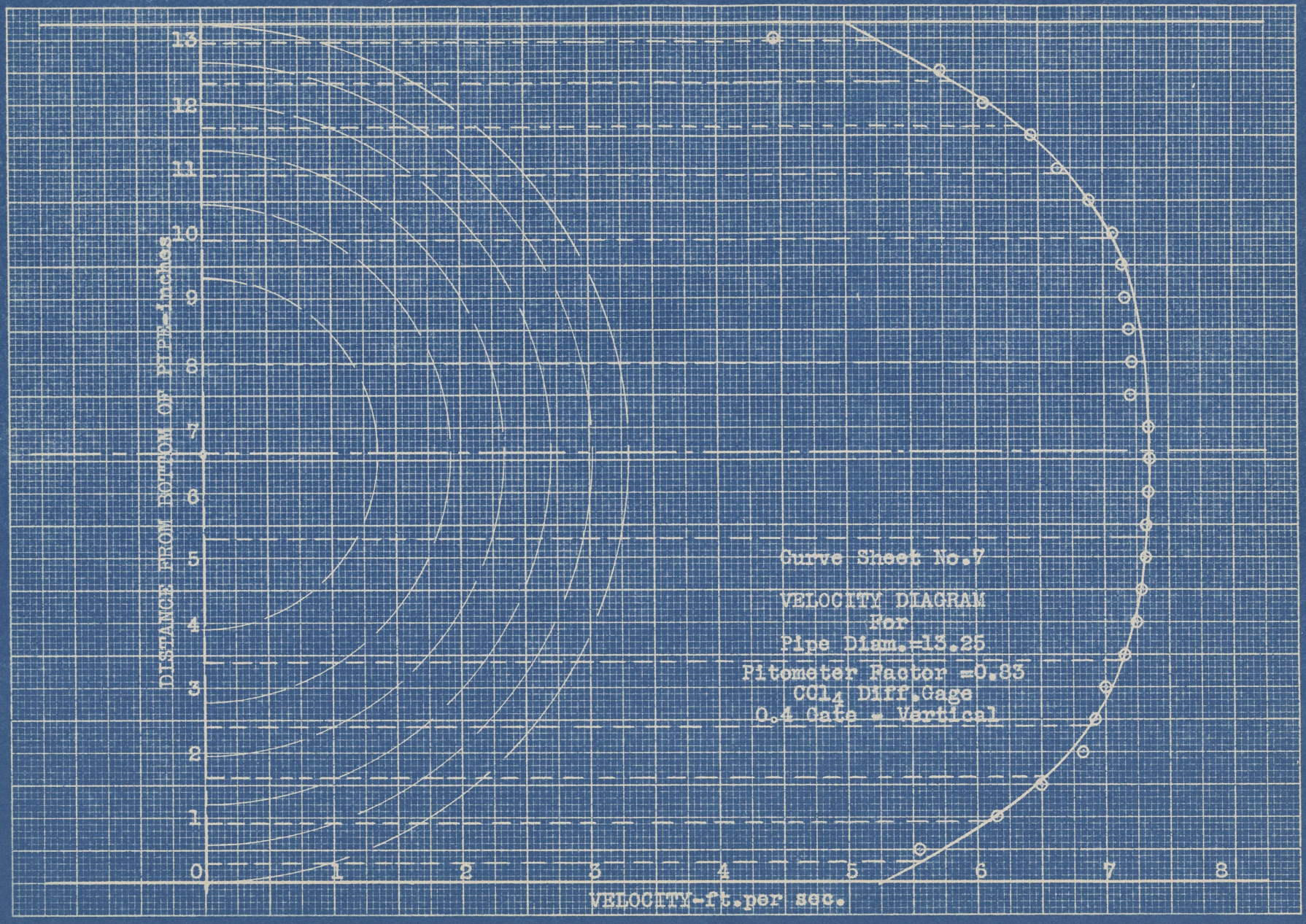
Weir Hook Gage Reading = 1.520 ft.

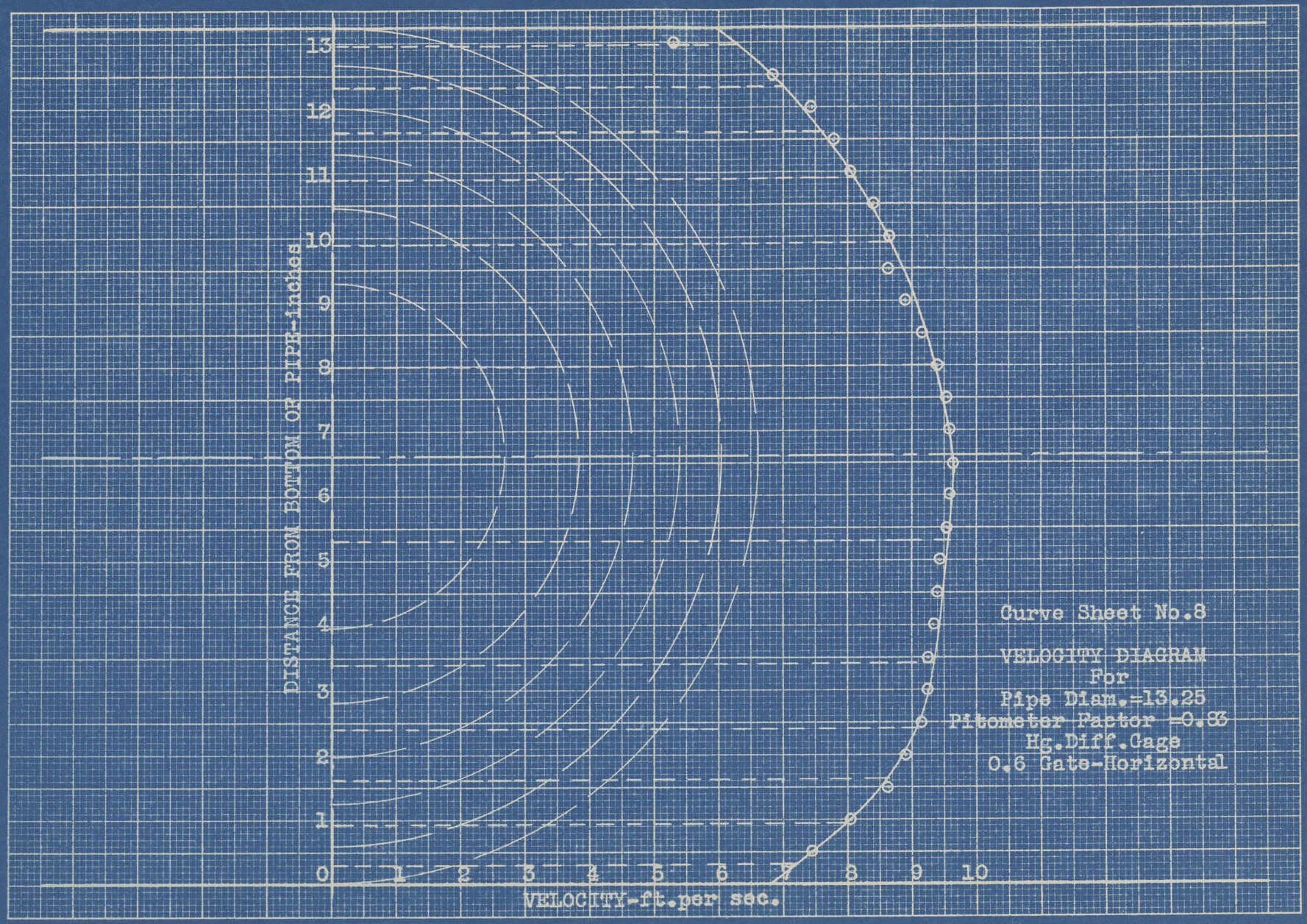
	Vertical Traverse		Horizontal Traverse	
Distance in.	Deflection in. of Hg.	Velocity F.P.S.	Deflection in. of Hg.	Velocity F.P.S.
0.50	1.30	7.80	1.80	9.65
1.00	1.80	9.15	2.00	10.30
1.50	2.00	9.65	2.30	10.55
2.00	2.20	10.10	2.40	10.75
2.50	2.40	10.55	2.50	11.00
3.00	2.50	10.75	2.60	11.20
3.50	2.60	11.00	2.70	11.30
4.00	2.70	11.20	2.75	11.40
4.50	2.75	11.30	2.80	11.45
5.00	2.80	11.40	2.83	11.50
5.50	2.82	11.45	2.85	11.52
6.00	2.85	11.50	2.88	11.50
6.50	2.85	11.50	2.85	11.40
7.00	2.82	11.45	2.80	11.35
7.50	2.76	11.30	2.78	11.25
8.00	2.70	11.20	2.72	11.10
8.50	2.65	11.10	2.65	10.80
9.00	2.60	11.00	2.54	10.75
9.50	2.50	10.75	2.50	10.60
10.00	2.45	10.65	2.43	10.50
10.50	2.40	10.55	2.38	10.30
11.00	2.35	10.40	2.30	10.10
11.50	2.30	10.30	2.20	9.65
12.00	2.10	9.90	2.00	8.65
12.50	1.85	8.25	1.80	7.50
13.00	1.20	7.45	0.88	6.10

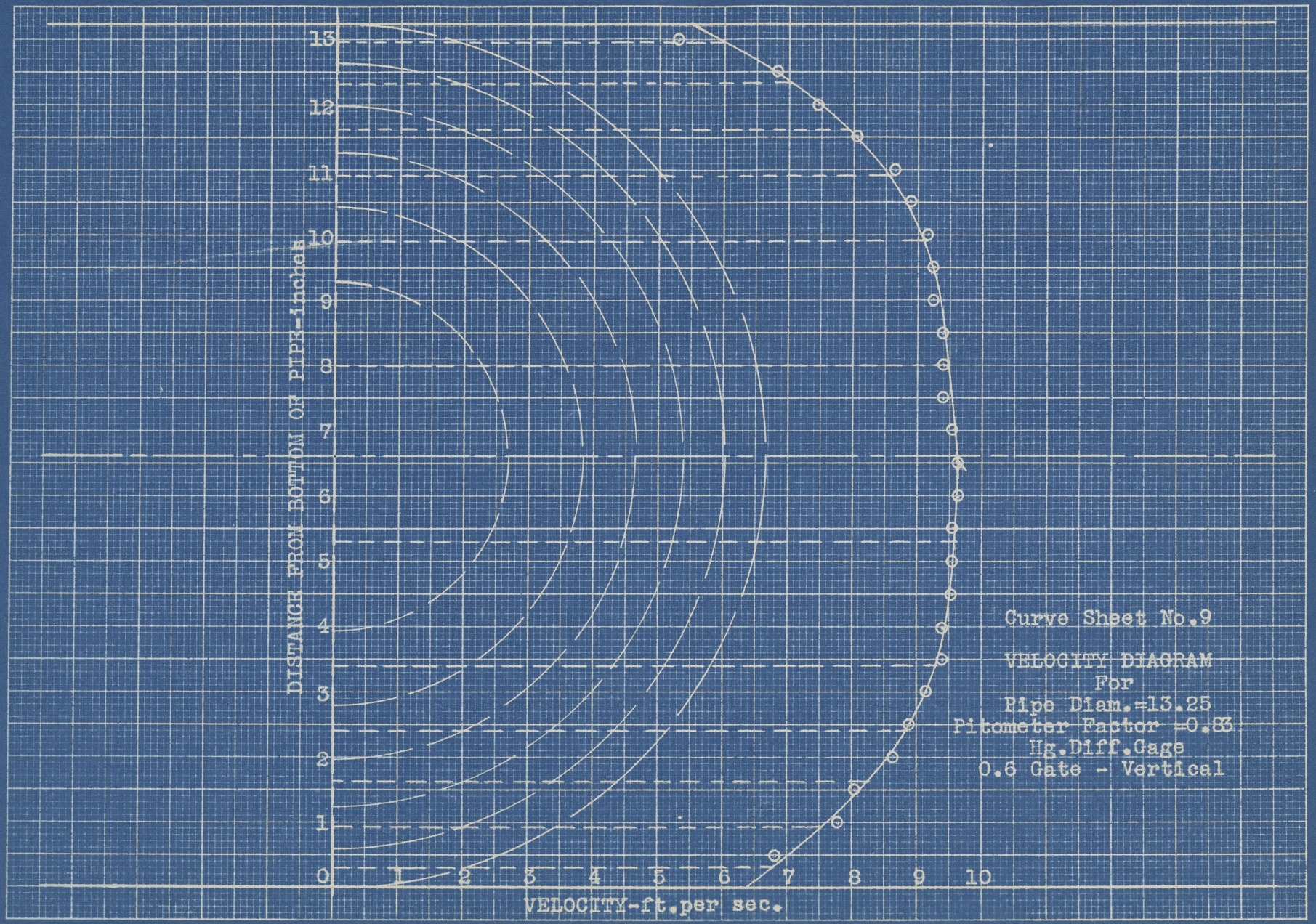

DISTANCE FROM BOTTOM OF PIPE-Inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
VELOCITY-ft.per sec.
Curve Sheet No.4
VELOCITY DIAGRAM
For
Pipe Diam.= 13.25
Pitometer Factor =0.83
CCl_4 Diff.Gage
0.2 Gate-Horizontal

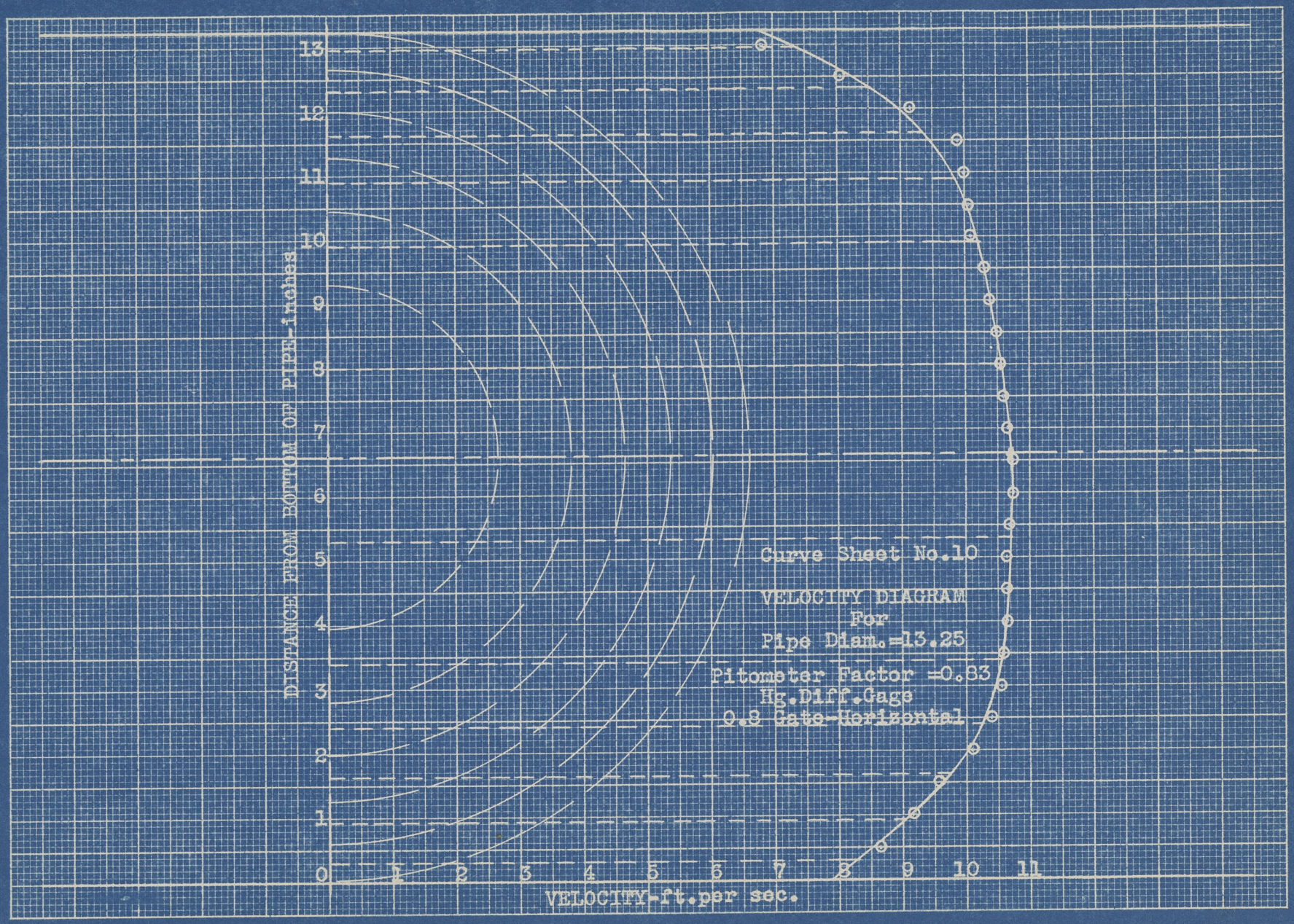

DISTANCE FROM BOTTOM OF PIPE-inches
VELOCITY-ft.per sec.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Curve Sheet No.5
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor=0.83
CCl4 Diff.Gage
0.2 Gate - Vertical

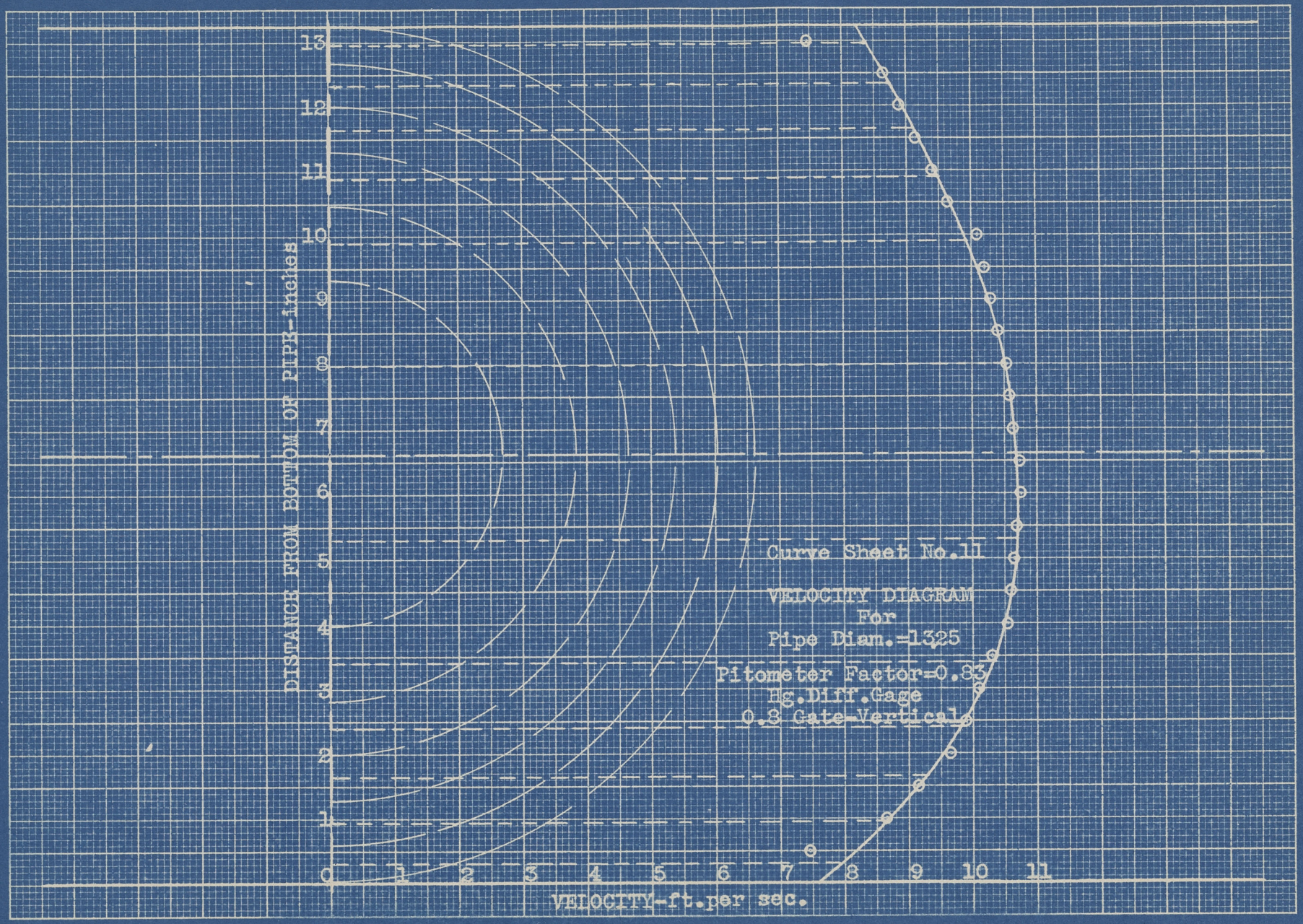

DISTANCE FROM BOTTOM OF PIPE-Inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
5
6
7
8
VELOCITY-ft.per sec.
Curve Sheet No.8
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor =0.83
CCl4 Diff.Gage
0.4 Gate-Horizontal

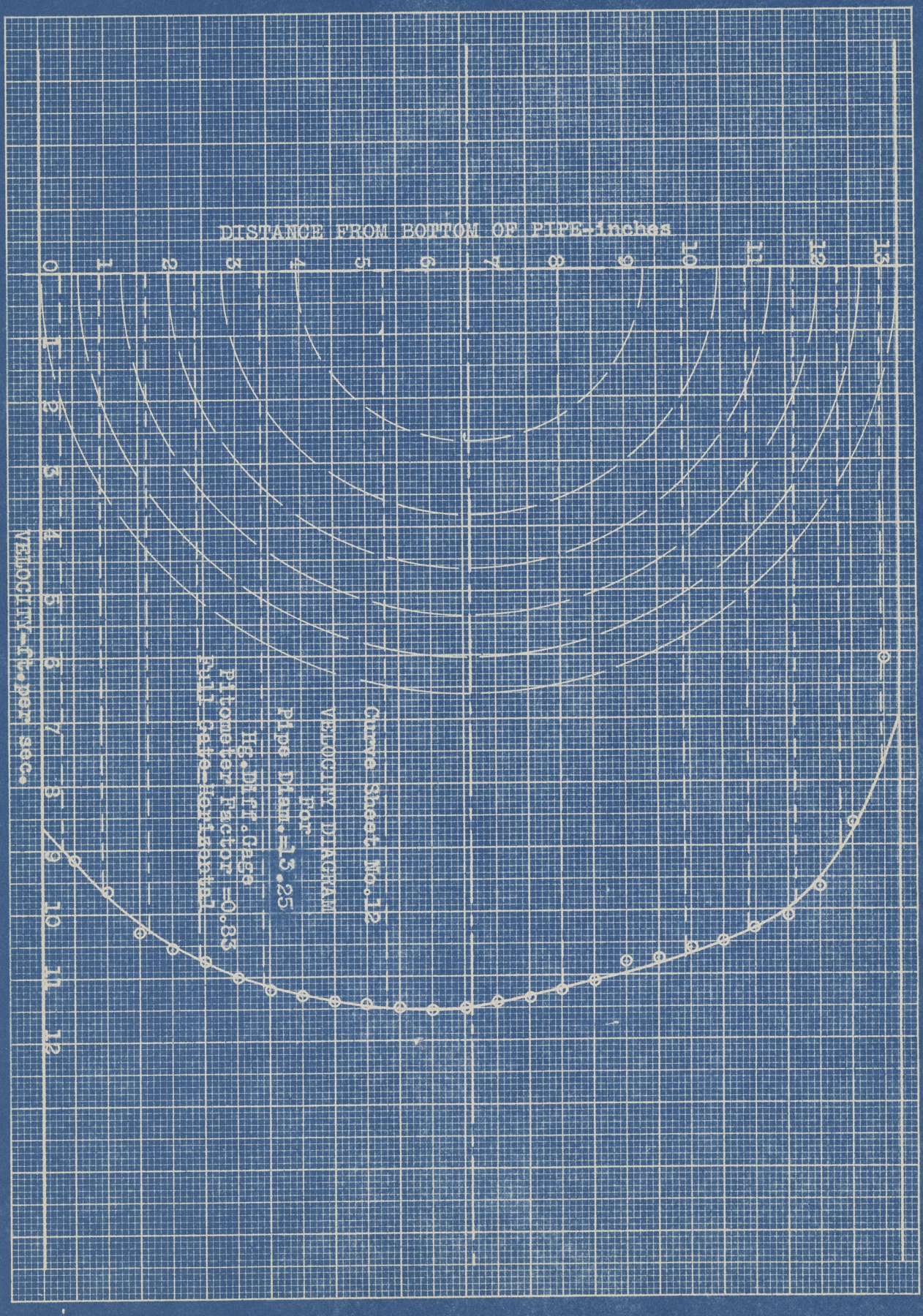

DISTANCE FROM BOTTOM OF PIPE-Inches
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
VELOCITY-ft.per sec.
Curve Sheet No.7
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor =0.83
CCl4 Diff.Gage
0.4 Gate - Vertical

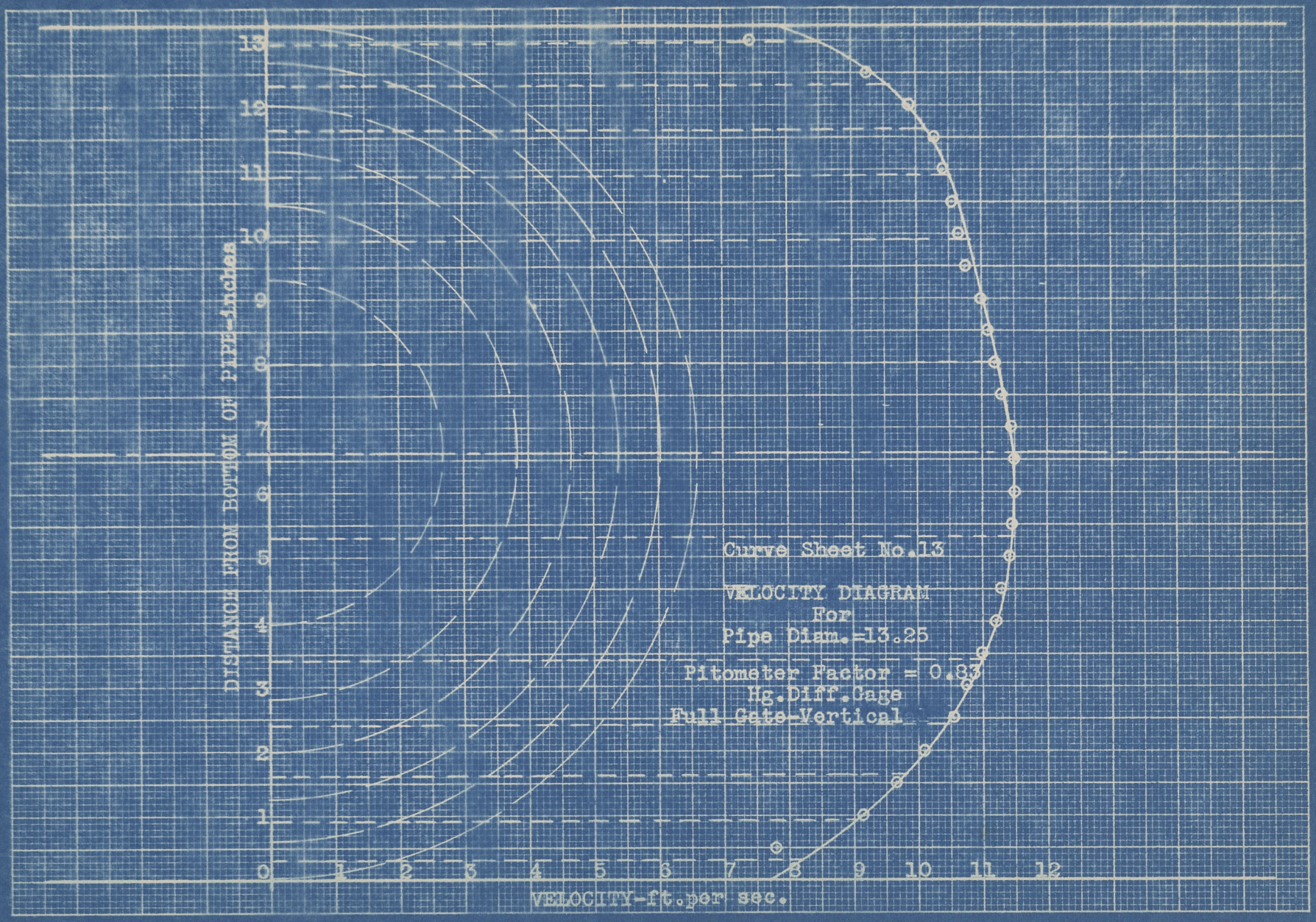

DISTANCE FROM BOTTOM OF PIPE-inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
VELOCITY-ft.per sec.
0
1
2
3
4
5
6
7
8
9
10
Curve Sheet No.8
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor =0.83
Hg.Diff.Gage
0.6 Gate-Horizontal


DISTANCE FROM BOTTOM OF PIPE-inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
5
6
7
8
9
10
VELOCITY-ft.per sec.
Curve Sheet No.9
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor =0.83
Hg.Diff.Gage
0.6 Gate - Vertical


DISTANCE FROM BOTTOM OF PIPE-inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
5
6
7
8
9
10
11
VELOCITY-ft.per sec.
Curve Sheet No.10
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor =0.83
Hg.Diff.Gage
0.8 Gate-Horizontal


DISTANCE FROM BOTTOM OF PIPE-inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
VELOCITY-ft.per sec.
0
1
2
3
4
5
6
7
8
9
10
11
Curve Sheet No.11
VELOCITY DIAGRAM
For
Pipe Diam.=1325
Pitometer Factor=0.83
Hg.Diff.Gage
0.3 Gate-Vertical


DISTANCE FROM BOTTOM OF PIPE-inches
0 1 2 3 4 5 6 7 8 9 10 11 12 13
VELOCITY-ft. per sec.
1 2 3 4 5 6 7 8 9 10 11 12
Curve Sheet No. 12
VELOCITY DIAGRAM
For
Pipe Diam. = 3.25
Hg. Diff. Gage
Pitometer Factor = 0.85
Full Water Horizontal


DISTANCE FROM BOTTOM OF PIPE-Inches
0
1
2
3
4
5
6
7
8
9
10
11
12
13
VELOCITY-ft.per sec.
0
1
2
3
4
5
6
7
8
9
10
11
12
Curve Sheet No.13
VELOCITY DIAGRAM
For
Pipe Diam.=13.25
Pitometer Factor = 0.83
Hg.Diff.Gage
Full Gate-Vertical

Calculations

for

Determining Pitometer Discharge

	0.2 Gate Opening		0.4 Gate Opening		0.6 Gate Opening	
	Vertical	Horiz.	Vertical	Horiz.	Vertical	Horiz.
V_1	3.30	3.70	5.55	6.15	6.78	7.20
V_2	3.66	4.07	6.07	6.64	7.53	8.00
V_3	4.03	4.36	6.52	7.06	8.25	8.62
V_4	4.34	4.53	6.87	7.31	8.82	9.08
V_5	4.60	4.64	7.13	7.45	9.30	9.33
V_6	4.71	4.63	7.33	7.54	9.57	9.57
V_7	4.55	4.49	7.32	7.46	9.48	9.36
V_8	4.25	4.30	7.07	7.21	9.10	8.66
V_9	4.00	4.10	6.74	6.86	8.52	8.10
V_{10}	3.80	3.85	6.36	6.41	7.90	7.60
V_{11}	3.55	3.45	5.83	5.67	7.02	7.00
V_{12}	3.30	2.80	5.28	4.76	6.00	6.28
	48.09	48.91	78.04	80.52	98.28	98.80

Calculations

for

Determining Pitometer Discharge Cont.

	0.8 Gate Opening		Full Gate Opening	
	Vertical	Horizontal	Vertical	Horizontal
V_1	7.91	8.28	8.16	9.00
V_2	8.62	9.02	9.02	9.62
V_3	9.30	9.75	9.81	10.25
V_4	9.80	10.25	10.42	10.70
V_5	10.31	10.55	11.00	11.10
V_6	10.70	10.70	11.46	11.50
V_7	10.50	10.55	11.23	11.20
V_8	9.91	10.20	10.80	10.70
V_9	9.48	9.83	10.50	10.30
V_{10}	9.10	9.32	10.12	9.89
V_{11}	8.72	8.50	9.55	9.05
V_{12}	8.38	7.32	8.45	7.73
	112.73	114.27	120.52	121.04

$V_{m0.2} = \frac{48.09}{12} = 4.00$ F.P.S.

$V_{m0.2} = \frac{48.91}{12} = 4.08$ "

$V_{m0.4} = \frac{78.04}{12} = 6.50$ "

$V_{m0.4} = \frac{80.52}{12} = 6.71$ "

$V_{m0.6} = \frac{98.28}{12} = 8.19$ "

$V_{m0.6} = \frac{98.80}{12} = 8.23$ F.P.S.

$V_{m0.8} = \frac{112.73}{12} = 9.39$ "

$V_{m0.8} = \frac{114.27}{12} = 9.52$ "

$V_{mfull} = \frac{120.52}{12} = 10.04$ "

$V_{mfull} = \frac{121.04}{12} = 10.09$ "

Pitometer Discharge

Area of 13.25" Pipe = 0.956 sq. ft.

0.2 Gate Opening--Q = 0.956 x 4.00 = 3.83 C.F.S.

Q = 0.956 x 4.08 = 3.90 C.F.S.

Average = 3.87 C.F.S.

0.4 Gate Opening--Q = 0.956 x 6.50 = 6.21 C.F.S.

Q = 0.956 x 6.71 = 6.42 C.F.S.

Average = 6.32 C.F.S.

0.6 Gate Opening--Q = 0.956 x 8.19 = 7.83 C.F.S.

Q = 0.956 x 8.23 = 7.87 C.F.S.

Average = 7.85 C.F.S.

0.8 Gate Opening--Q = 0.956 x 9.39 = 8.98 C.F.S.

Q = 0.956 x 9.52 = 9.11 C.F.S.

Average = 9.00 C.F.S.

Full Gate Opening-Q = 0.956 x10.04 = 9.60 C.F.S.

Q = 0.956 x10.09 = 9.62 C.F.S.

Average = 9.62 C.F.S.

Calculations for Weir Discharge

$Q = 3.34LH^{1.47}\left(1 \neq 0.56\frac{(LH)^2}{(A)}\right)$ Zero Hook Gage Reading =0.849 Ft.

0.2 Gate Opening

H = 0.513 ft.

$$Q = 16.4(0.37)^{1.47}\left(1 \neq 0.56\left(\frac{(4.91 \times 0.37)^2}{(4.91 \times 3.02)}\right)\right)$$

$$Q = 16.4 \times 0.232(1 \neq 0.0084)$$

$$Q = 16.4 \times 0.232 \times 1.0084 = 3.83 \text{ C.F.S.}$$

0.4 Gate Opening

$$H = 0.513 \text{ ft.}$$

$$Q = 16.4(0.313)^{1.47}\left(1 \neq 0.56\left(\frac{(4.91 \times 0.513)^2}{(4.91 \times 3.163)}\right)\right)$$

$$Q = 16.4 \times 0.3745(1 \neq 0.0147)$$

$$Q = 16.4 \times 0.3745 \times 1.0147 = 6.23 \text{ C.F.S.}$$

0.6 Gate Opening

$$H = 0.591 \text{ ft.}$$

$$Q = 16.4(0.591)^{1.47}\left(1 \neq 0.56\left(\frac{(4.91 \times 0.591)^2}{(4.91 \times 3.241)}\right)\right)$$

$$Q = 16.4 \times 0.5205(1 \neq 0.0186)$$

$$Q = 16.4 \times 0.5205 \times 1.0186 = 7.70 \text{ C.F.S.}$$

0.8 Gate Opening

$$H = 0.641 \text{ ft.}$$

$$Q = 16.4(0.641)^{1.47}\left(1 \neq 0.56\left(\frac{(4.91 \times 0.641)^2}{(4.91 \times 3.291)}\right)\right)$$

$$Q = 16.4 \times 0.5205(1 \neq 0.0213)$$

$$Q = 16.4 \times 0.5205 \times 1.0213 = 8.74 \text{ C.F.S.}$$

Full Gate Opening

$$H = 0.671 \text{ ft.}$$

$$Q = 16.4(0.671)^{1.47}\left(1 \neq 0.56\left(\frac{(4.91 \times 0.671)^2}{(4.91 \times 3.291)}\right)\right)$$

$$Q = 16.4 \times 0.556(1 \neq 0.0229)$$

$$Q = 16.4 \times 0.556 \times 1.0229 = 9.35 \text{ C.F.S.}$$

Calculations

for

Venturi Meter Gage Deflection Discharges

$$Q = A\sqrt{\frac{2g(12.6\ Z)}{144}}$$

$$Q = 2.518\sqrt{Z}$$

0.2 Gate Opening--Q = 3.92 C.F.S.

0.4 Gate Opening--Q = 6.29 C.F.S.

0.6 Gate Opening--Q = 7.05 C.F.S.

0.8 Gate Opening--Q = 8.00 C.F.S.

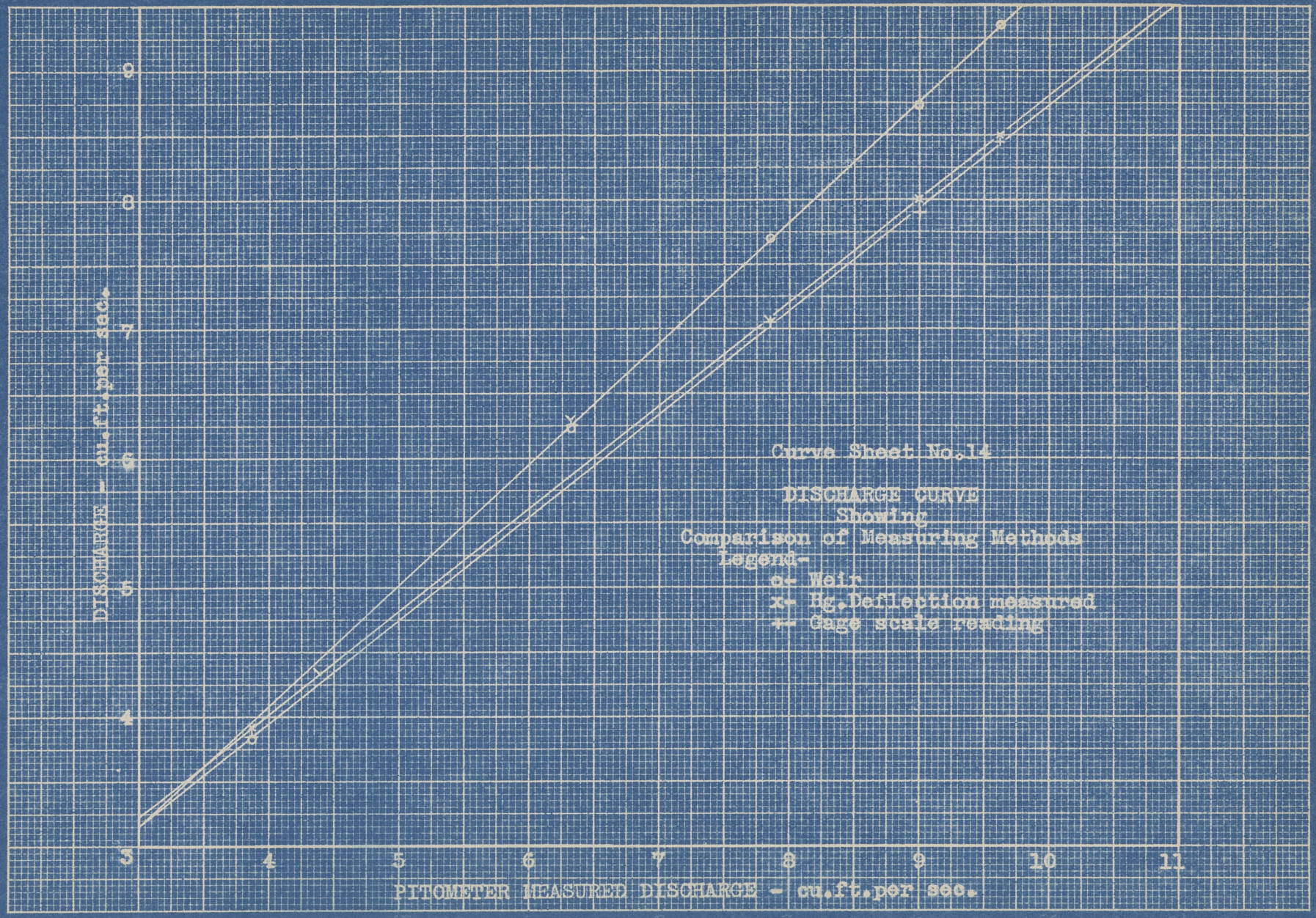
Full Gate Opening-Q = 8.50 C.F.S.

Discharges & Factors

Using

The Pitometer As The Base

	Venturi Meter Gage Reading		Venturi Meter Gage Def.		Weir		Pitometer Discharge
Gate Opening	Q C.F.S.	Factor	Q C.F.S.	Factor	Q C.F.S.	Factor	Q C.F.S.
0.2	3.85	1.005	3.92	0.987	3.83	1.010	3.87
0.4	6.25	1.011	6.29	1.006	6.23	1.014	8.32
0.6	7.05	1.112	7.05	1.112	7.70	1.020	7.85
0.8	7.90	1.140	8.00	1.125	8.74	1.030	9.00
Full	8.45	1.140	8.50	1.131	9.35	1.030	9.62


DISCHARGE - cu.ft.per sec.
9
8
7
6
5
4
3
4
5
6
7
8
9
10
11
PITOMETER MEASURED DISCHARGE - cu.ft.per sec.
Curve Sheet No.14
DISCHARGE CURVE
Showing
Comparison of Measuring Methods
Legend-
o- Weir
x- Hg.Deflection measured
+- Gage scale reading

Chapter IV

This study had led the observers to conclude that the entire venturi meter setup in the penstock is too large for the line. This conclusion is made from a study of the different measuring methods. It can be easily seen from these curves, that the discharge as measured by the venturi meter scale and Hg. deflection shows a steadily increasing error as the rate of discharge increases. Information was not obtainable as to the value of the venturi meter constant used by the manufacturer in calculating the scale to read directly in cu. ft. per sec. Some constant was obviously used as shown by these curves being parallel and calculations indicate a constant of 0.991.

The accuracy of this study was further brought out with the comparison of pitometer discharges against discharges as calculated by King's formula from data taken on the sharp crested weir observed in the system. Against a straight line relation was obtained between the two discharges(weir against pitometer). The discharge as measured by the permanent device, in this case the weir, showed a continually increasing error of registering too small as the rate of discharge increased. This error increased at a much smaller rate than did that found with the venturi meter and showed an error of only 0.25 cu. ft. per sec. at an actual discharge of 9 cu. ft. per sec.

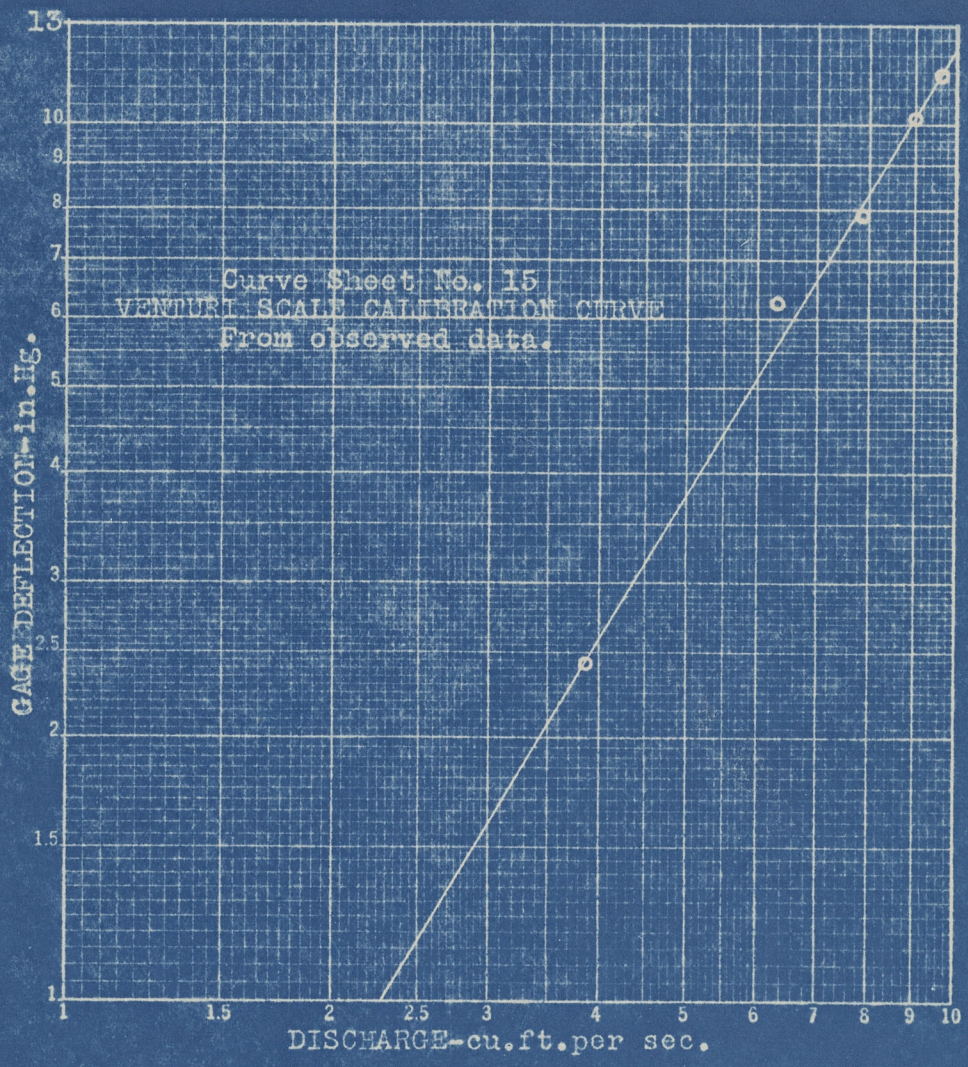
A note of importance at this point is that the preliminary study showed the sharp crested weir to be approx-

imately one-fourth of an inch lower at one end than the other. A zero hook gage reading was obtained with water flowing over no part of the weir but with a level found at approximately the weir center. (Surface tension holds the flow at the lower end.) The effect of this error in the weir setup is difficult to predict. From the results obtained from this study, one is led to conclude that more discharge will pass the weir than will be registered in King's formula. The scope of this study was not such as to allow a more definite statement to be made on this point.

From the data obtained in this study, the authors suggest the following procedure in the calibration of the venturi meter scale to allow it to read the correct discharge through the meter from any rate of flow.

From the data included in this study, curve sheet No. 15 was plotted showing actual discharge through the line against Hg. column deflection. This corresponding information could be cut into the face of the scale. By so doing, at all varying rates of flow, a very accurate result could be obtained at any rate.

If this previous method is not desirable a further suggestion would be that a scale reading in inches be substituted for the existing scale. The deflection as found with the use of this scale could be applied to curve sheet No. 15 and the actual discharge read from this curve.


Curve Sheet No. 15
VENTURI SCALE CALIBRATION CURVE
From observed data.
GAGE DEFLECTION-in.Hg.
13
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
1.5
2
2.5
3
4
5
6
7
8
9
10
DISCHARGE-cu.ft.per sec.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name Roscoe W. Morton

Title Professor of Mechanical Engineering