HIGH HEAD VARIABLE MULTIPLE ORIFICE THROTTLING VALVE

by

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(PAP file)

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Memorandum

Memorandum — Denver, Colorado

TO : Chief, Mechanical Branch — DATE: November 28, 1988

THROUGH: Chief, Research and Laboratory Services Division Graham 11/30/88
Chief, Electrical and Mechanical Engineering Division WRA 12-1-88

FROM : Chief, Hydraulics Branch

SUBJECT : High Head Variable Multiple Orifice Throttling Valve (Hydraulic Research)

A report detailing results of submerged release tests on the subject valve is enclosed.

These tests indicate that the valve is well suited for flow control and energy dissipation at differential heads up to 350 feet.

The equations and graphs given in the report can be used to design valves for various field applications.

Maximum differential heads and discharge coefficients at various openings can be determined from the report. Some additional tests are planned to document free (no back pressure) discharge conditions. However, this report contains most of the information necessary to determine the valve characteristics.

Enclosure

cc: D-3750
(w/encl)
D-3750A
(w/encl)
D-3751 (PAP file)
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D-3752
(w/encl)
D-3752 (Peck)
(w/encl)
D-3423 (Beard)
(w/encl)
D-3422 (Mette)
(w/encl)

WBR:CAPugh:flh:10/11/88:2360152
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INTRODUCTION

The high head variable multiple orifice throttling valve was designed to eliminate some major problems associated with flow control under conditions of high differential head. Flow control devices such as butterfly valves, gate valves, ball valves, and plug valves presently used, because of availability and cost, are not able to withstand long term operation at high differential heads. While these valves are able to release much larger quantities of water than the same nominal size of multiple orifice valve, the high energy levels in the flow often result in severe cavitation, vibration, and high noise levels. These problems greatly reduce valve life and are a source of danger to personnel and to the safety of the structure.

The high head variable multiple orifice throttling valve is well suited for use in bypass filling lines, high head siphon drains, and high head pump lines. This valve should have applications for both free flow and submerged releases.

This report details results of submerged release tests performed on the valve. The high head test facility in the hydraulic laboratory was utilized in conducting these tests. The test facility can produce heads up to 400 feet at a flow of 4.46 ft^3/s.

GATE CONSTRUCTION

The valve (figures 1 and 2) is comprised of the following components: a flanged cylindrical pipe section (1), a pair of multiported orifice plates (2 and 3) with matched holes separated by a low friction bearing surface (4), an alignment spindle (5), a threaded operating shaft (6), with pin and slider (7), packing gland (8), packing box (9), mounting bracket (10), outer bearing (11), and hand crank (12). The downstream orifice plate (3) is welded to the flanged cylindrical pipe section (1) and provides the flange surface for attaching downstream piping.

The upstream plate is rotatable so that when the valve is closed, none of the holes in the upstream plate are aligned with the holes in the fixed downstream plate. With movement of the hand crank toward the open position, the upstream plate rotates in relation to the downstream plate, and increasing orifice segments become aligned, until at full opening all holes in both plates are totally aligned.

Testing was performed on a 6-inch valve that contains four 1-7/16-inch-diameter holes centered on a 2.1-inch radius from centerline, and four 5/8-inch-diameter holes centered on a 0.95-inch radius from centerline (figure 2). The holes constrict in the downstream direction through the upstream plate, maintain the same diameter through the low friction bearing surface, and 1/4 inch into the downstream plate, then expand suddenly to 2-inch diameter for the larger holes and 1-inch diameter for the smaller holes (figure 3). This configuration is designed to prevent cavitation damage, suppress short tube formation, and provide circulation to the control surfaces. Other combinations of holes may be used, with the smaller holes being the most satisfactory from an energy dissipation stand point, but more prone to clogging. The downstream side of the valve is designed to provide mounting for an 8-inch pipe flange. This enlargement is used to protect the downstream piping from cavitation damage resulting from high intensity shear.

SUBMERGED RELEASE TESTS ON MULTIPLE ORIFICE THROTTLING VALVE

Data for the tests were obtained in terms of percent of stem travel. At 100 percent stem travel the orifices of the upstream and downstream plates are completely aligned and the maximum flow area is achieved. One hundred per cent stem travel was measured at 1.87 inches from the closed position in the model valve.

The upstream plate rotates through a 19.6° angle when the stem is moved from the closed position to the 100 percent open position (stem travel = 1.87 inches). Flow area through the valve as a function of stem travel can be determined from the geometry of the valve and the configuration of the ports.

A section of clear 8-inch-diameter Plexiglas pipe was installed immediately downstream of the valve to allow observation of the valve face (figure 4) and the flow downstream of the valve. At partial valve openings a vortex is created downstream from the valve (figure 5). This vortex converts a portion of the linear momentum to angular momentum which should result in increased energy dissipation. The vortex also helps to keep the cavitation towards the center of the flow, thus preventing cavitation damage on the pipe boundary downstream of the valve. At larger valve openings the rotation decreases (figure 6) until at 100 percent valve opening there is essentially no rotation.

The valve was operated with up to 100 feet of upstream pressure at 100 percent stem travel and with up to 350 feet upstream pressure at 33 percent stem travel. Downstream pressure varied approximately 3 feet and therefore was essentially constant in comparison to the upstream pressure. After many hours of operation no cavitation damage was evident on the Plexiglas pipe downstream of the valve or on the valve face.

The discharge coefficient was computed at various valve openings (figure 7) using the equation:

$$C_D = Q/[(\pi D^2/4)\ (2gH)^{1/2}] \qquad (1)$$

where: Q = discharge in ft^3/s
D = inside diameter of pipe immediately upstream of the valve in feet
g = gravitational acceleration in ft/s^2
H = pressure head loss through the valve in feet

The following equation was developed from the average discharge coefficient at each valve opening:

$$C_D = 0.0001211\ X^{1.6595} \qquad (2)$$

where X is the percent of maximum sleeve travel.

The curve on figure 7 was drawn with the use of equation 2. Equation 2 gives a good estimate of the discharge coefficient up to 75 percent stem travel.

Above 75 percent stem travel the discharge coefficient varies with upstream and downstream pressure as well as with percent stem travel (figure 8).

The farthest right data point at each stem position (figure 8) was obtained with the high head pump on low speed. Therefore, no lower upstream pressures could be obtained.

Severe vibration of the valve and the adjacent downstream pipe occurred at the farthest left data points (figure 8) for stem travels of 44 to 100 percent. At the farthest left data point for stem travels of 22 and 33 percent, the high head pump was operated close to its maximum speed.

The following regression equation was developed for the discharge coefficient for percent stem travel between 75 and 100 percent:

$$C_D = 0.0004967\ (P_d/P_u)\ e^{.06781X} + 0.0001753\ X^{1.5645} \qquad (3)$$

where: P_d = pressure downstream of the valve
P_u = pressure upstream of the valve and
e = 2.7183

Shown plotted on figures 9, 10, 11 are all the discharge coefficients obtained at valve openings greater than 75 percent stem travel. The curves on figures 9, 10, 11 were drawn with the use of equation 3.

Listed in table 1 are values of discharge coefficient for various combinations of percent stem travel and percent downstream pressure of upstream pressure [100 (P_d/P_u)]. The discharge coefficients in table 1 were calculated with the use of equation 3.

It is recommended that equation 2 be used to determine the discharge coefficient for stem travel between 0 and 75 percent. Rough estimates of the discharge coefficient at stem travel between 75 and 100 percent may also be obtained with the use of equation 2. Equation 3 should be used to obtain accurate estimates of discharge coefficient at stem travel between 75 and 100 percent. Table 1 may be used in lieu of equation 3.

Pressure recovery data for various valve openings are plotted on figures 12 through 19. With the exception of the data for 350 feet of upstream head on the valve at 33 percent stem travel (figure 13), the recovery is virtually complete 15 inches downstream of the valve face.

CONCLUSIONS

The high head variable multiple orifice throttling valve is well suited for flow control under conditions of high differential head. The 6-inch model valve was operated at differential heads up to 350 feet, with no apparent cavitation damage to the valve or downstream pipe.

Figure 20 is a plot of percent stem travel vs. the ratio of the lowest downstream pressure/upstream pressure. These points correspond to the greatest pressure differential. Above 33 percent stem travel the valve and downstream pipe vibrated severely at the points plotted on figure 20. Below 33 percent stem travel upstream pressure was limited by the pressure available from the high head pump. Vibration at stem travels of 33 percent and less was not severe at the points plotted on figure 20. The best fit line of the data points plotted on figure 20 results in the equation:

$$Z = 0.042\,x + 1.111 \tag{4}$$

where: Z = 100 times the downstream pressure divided by the upstream pressure.

If the downstream pressure is known, equation 4 can be used to estimate the maximum upstream pressure allowable for a given valve opening. Severe vibration of the valve and downstream pipe will occur at the upstream head calculated with the use of equation 4 at stem travels greater than 33 percent. Upstream heads greater than those calculated with the use of equation 4 can probably be allowed at stem travels of 33 percent and less. However, the pump head available was not high enough to determine limiting values at stem travel less than 33 percent.

Equation 2 should be used to calculate the valve discharge coefficient for stem travels between 0 and 75 percent. Above 75 percent stem travel, equation 3 should be used to determine the discharge coefficient. Pressure recovery is virtually complete 2-1/2 valve diameters downstream of the valve.

FUTURE TESTS

Additional testing to obtain operating characteristics under free discharge conditions is planned. These tests will also be conducted in the hydraulic laboratory's high head test facility.

Table 1. - Discharge coefficient for stem travel above 75 percent.

Percent stem travel	Downstream pressure divided by upstream pressure (Percent)								
	2	6	10	14	18	22	26	30	34
75	.152	.155	.158	.162	.165	*	*	*	*
76	.155	.159	.162	.166	.169	*	*	*	*
77	.159	.162	.166	.170	.173	*	*	*	*
78	.162	.166	.170	.174	.178	*	*	*	*
79	.165	.170	.174	.178	.182	.186	*	*	*
80	.169	.173	.178	.182	.187	.191	*	*	*
81	.172	.177	.182	.187	.191	.196	*	*	*
82	.176	.181	.186	.191	.196	.201	*	*	*
83	.179	.185	.190	.196	.201	.207	*	*	*
84	.183	.189	.194	.200	.206	.212	*	*	*
85	.186	.193	.199	.205	.211	.218	*	*	*
86	.190	.197	.203	.210	.217	.224	*	*	*
87	.193	.201	.208	.215	.222	.230	.237	*	*
88	.197	.205	.213	.220	.228	.236	.244	*	*
89	.201	.209	.217	.226	.234	.242	.251	*	*
90	.205	.213	.222	.231	.240	.249	.258	*	*
91	.208	.218	.227	.237	.246	.256	.265	*	*
92	.212	.222	.233	.243	.253	.263	.273	*	*
93	.216	.227	.238	.249	.260	.271	.281	*	*
94	.220	.232	.243	.255	.267	.278	.290	.302	*
95	.224	.236	.249	.261	.274	.286	.299	.311	*
96	.228	.241	.255	.268	.281	.295	.308	.321	*
97	.232	.246	.261	.275	.289	.304	.318	.332	*
98	.236	.252	.267	.282	.297	.313	.328	.343	*
99	.240	.257	.273	.290	.306	.322	.339	.355	*
100	.245	.262	.280	.297	.315	.332	.350	.367	.385

*Data were not obtained. Upstream pressure is less than the pressure the high head pump produces at its lowest speed. The discharge coefficient can be exptrapolated into this range with the use of equation 6.

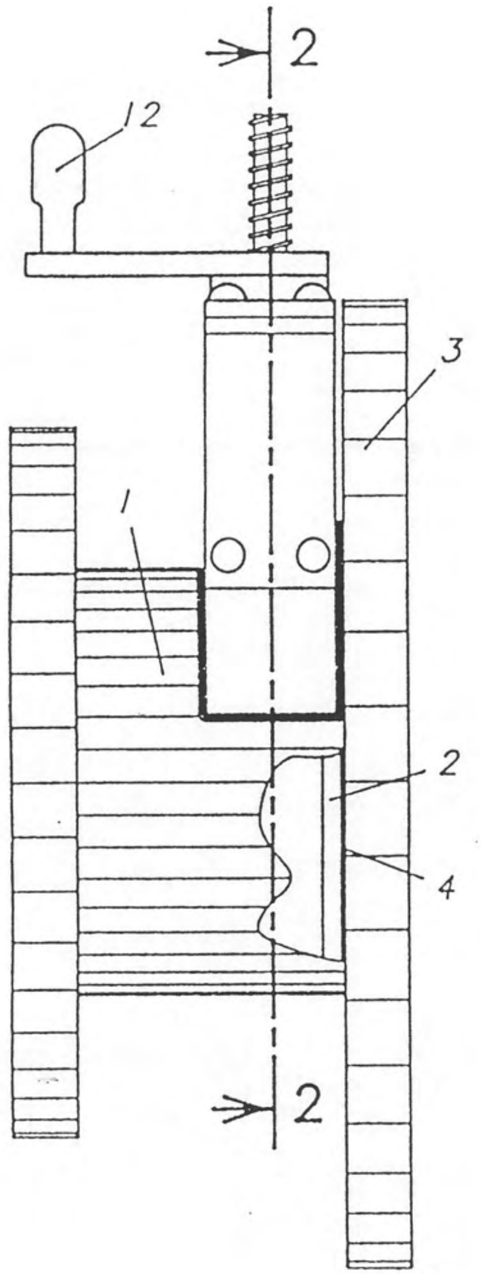


Figure 1. - Side view of valve.

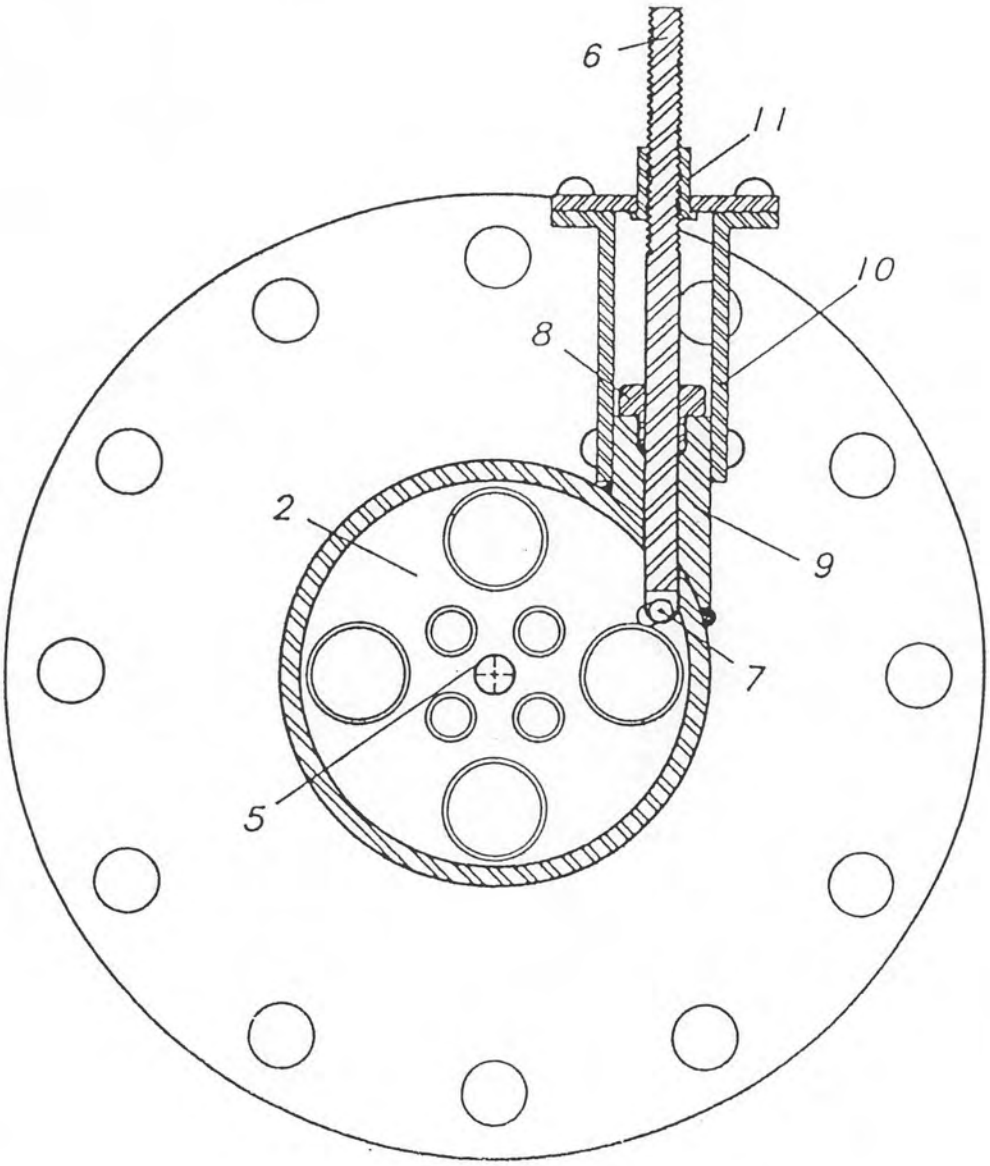


Figure 2. - Section through valve.

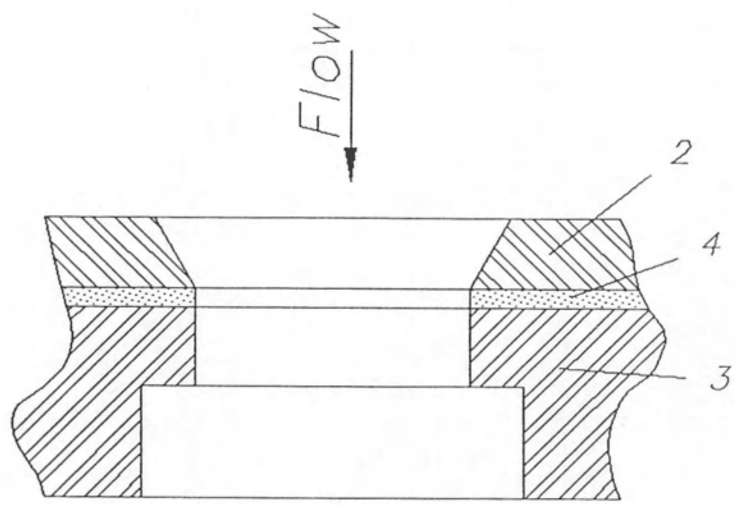


Figure 3. - Section through valve orifice (shown in 100 percent open position.

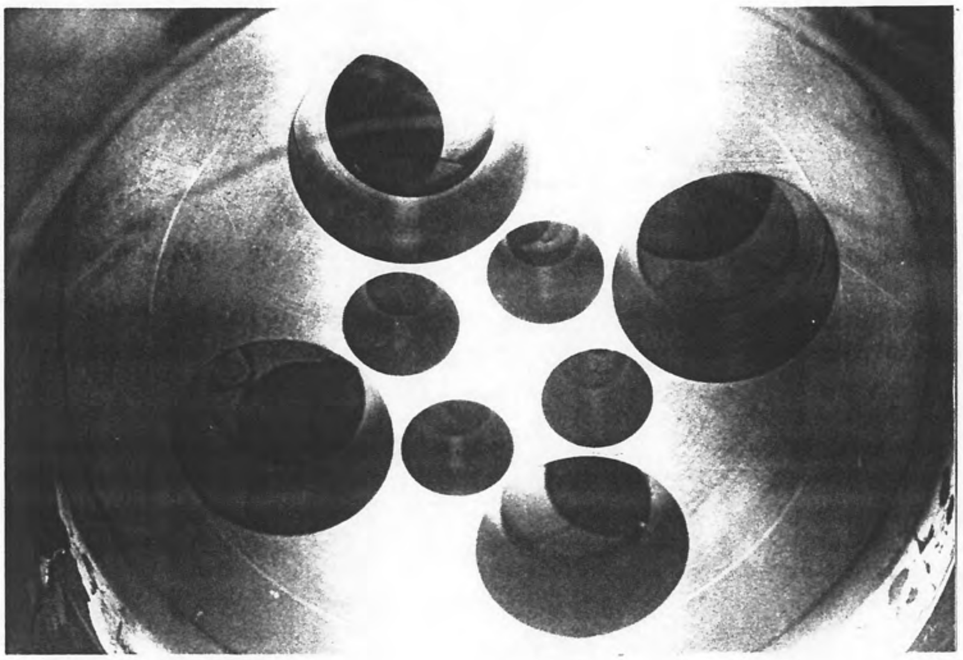


Figure 4. - View of valve face at 76 percent stem travel and upstream head of 40 feet (looking upstream).

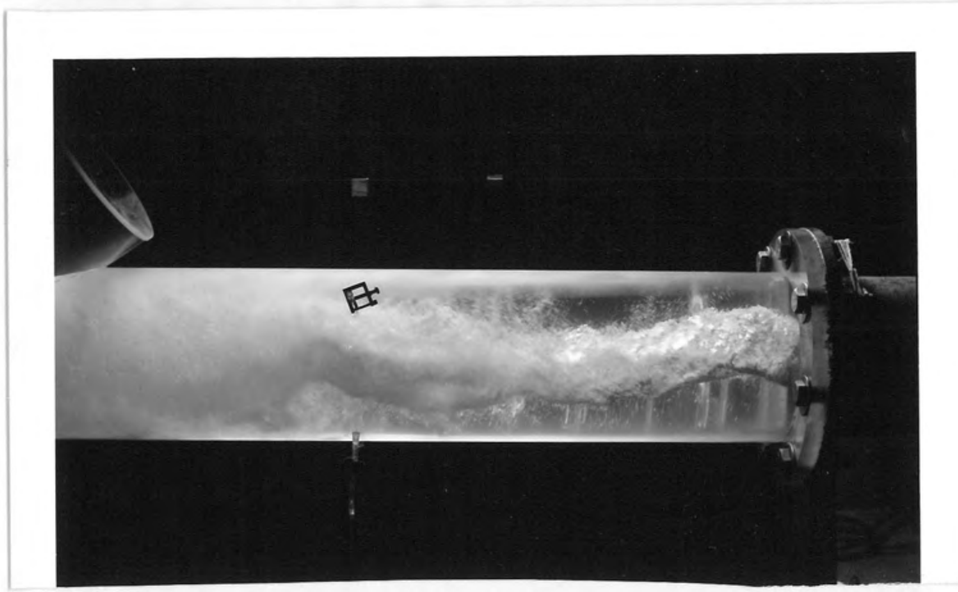


Figure 5a. - Stem travel = 33 percent, upstream head = 255 feet (flow left to right).

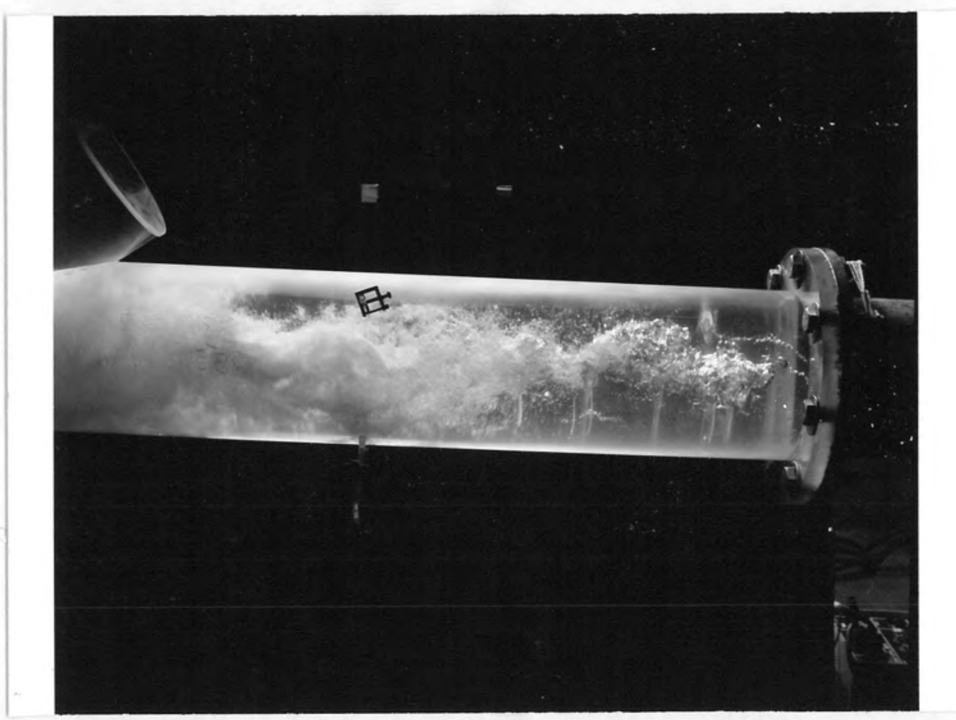


Figure 5b. - Stem travel = 55 percent, upstream head = 196 feet (flow left to right).

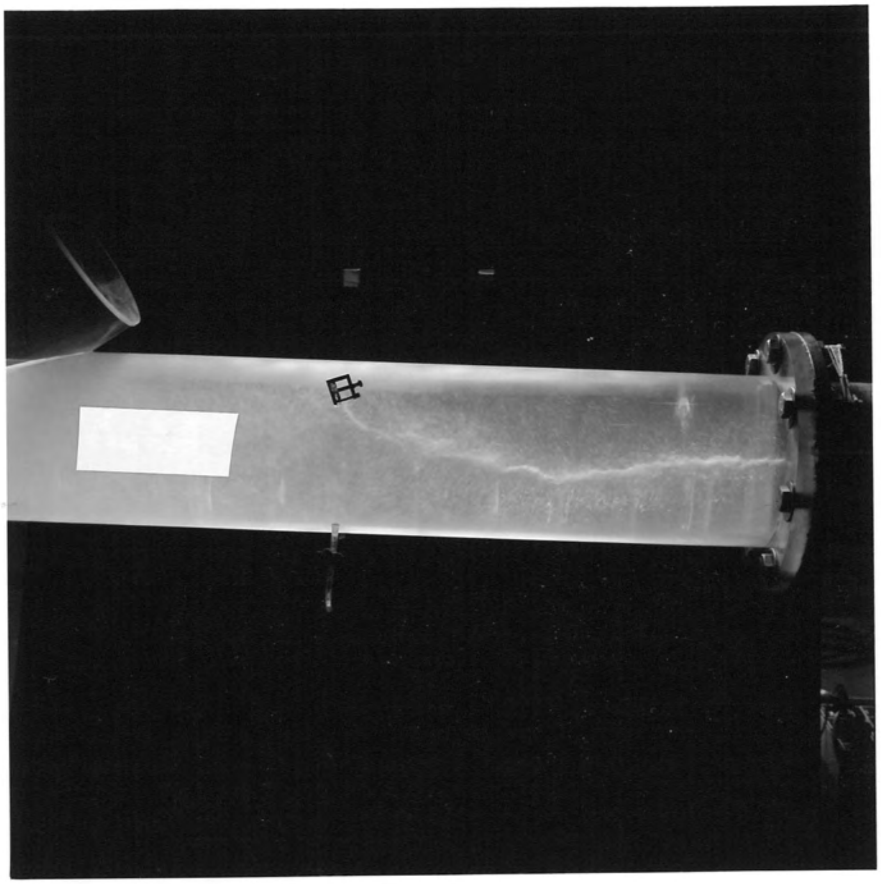


Figure 6. - Stem travel = 76 percent, upstream head = 100 feet (flow left to right).

Figure 7.

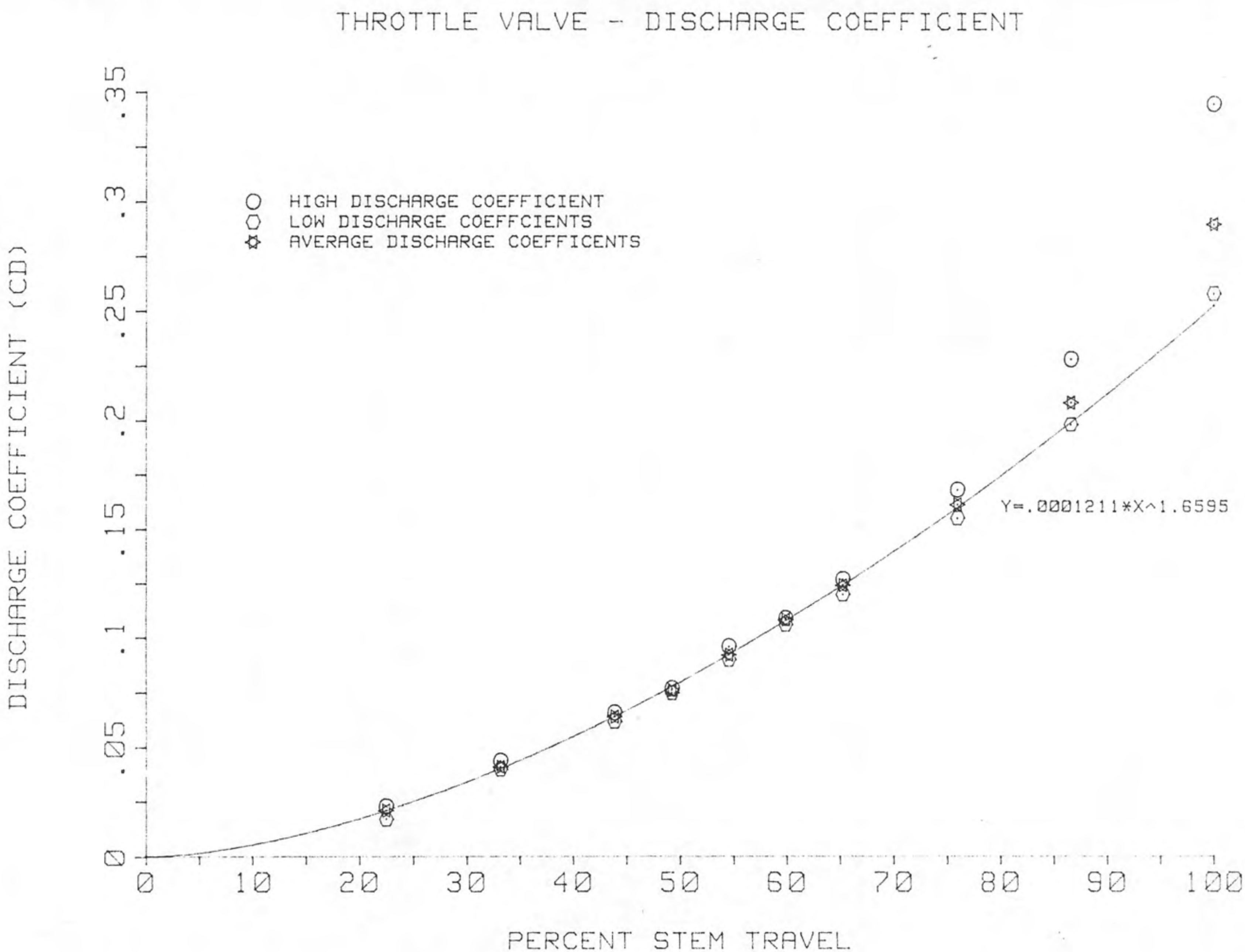

THROTTLE VALVE - DISCHARGE COEFFICIENT
HIGH DISCHARGE COEFFICIENT
LOW DISCHARGE COEFFCIENTS
AVERAGE DISCHARGE COEFFICENTS
Y=.0001211*X^1.6595
DISCHARGE COEFFICIENT (CD)
0
.05
.1
.15
.2
.25
.3
.35
0
10
20
30
40
50
60
70
80
90
100
PERCENT STEM TRAVEL

Figure 8. Variation of discharge coefficients

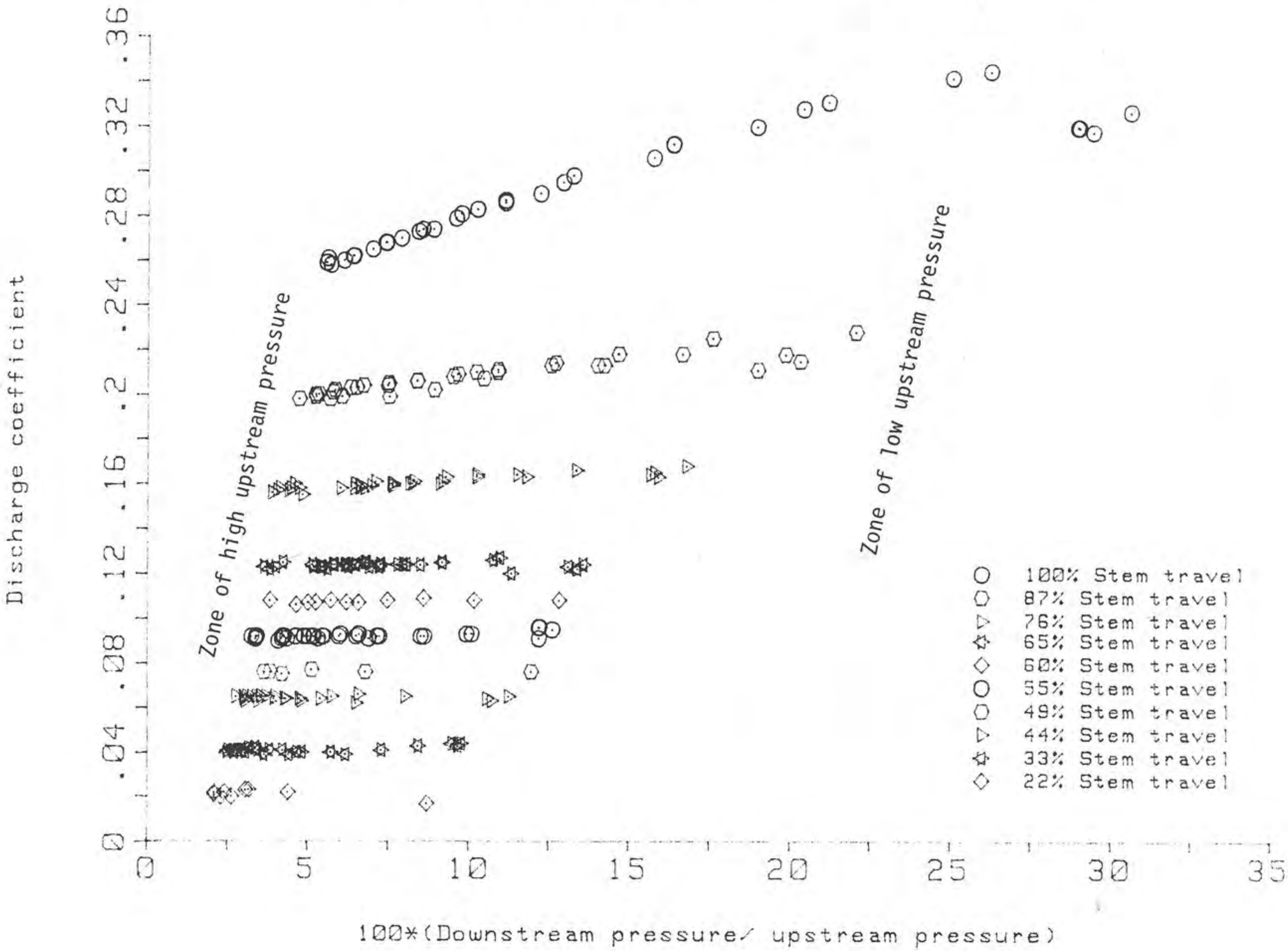
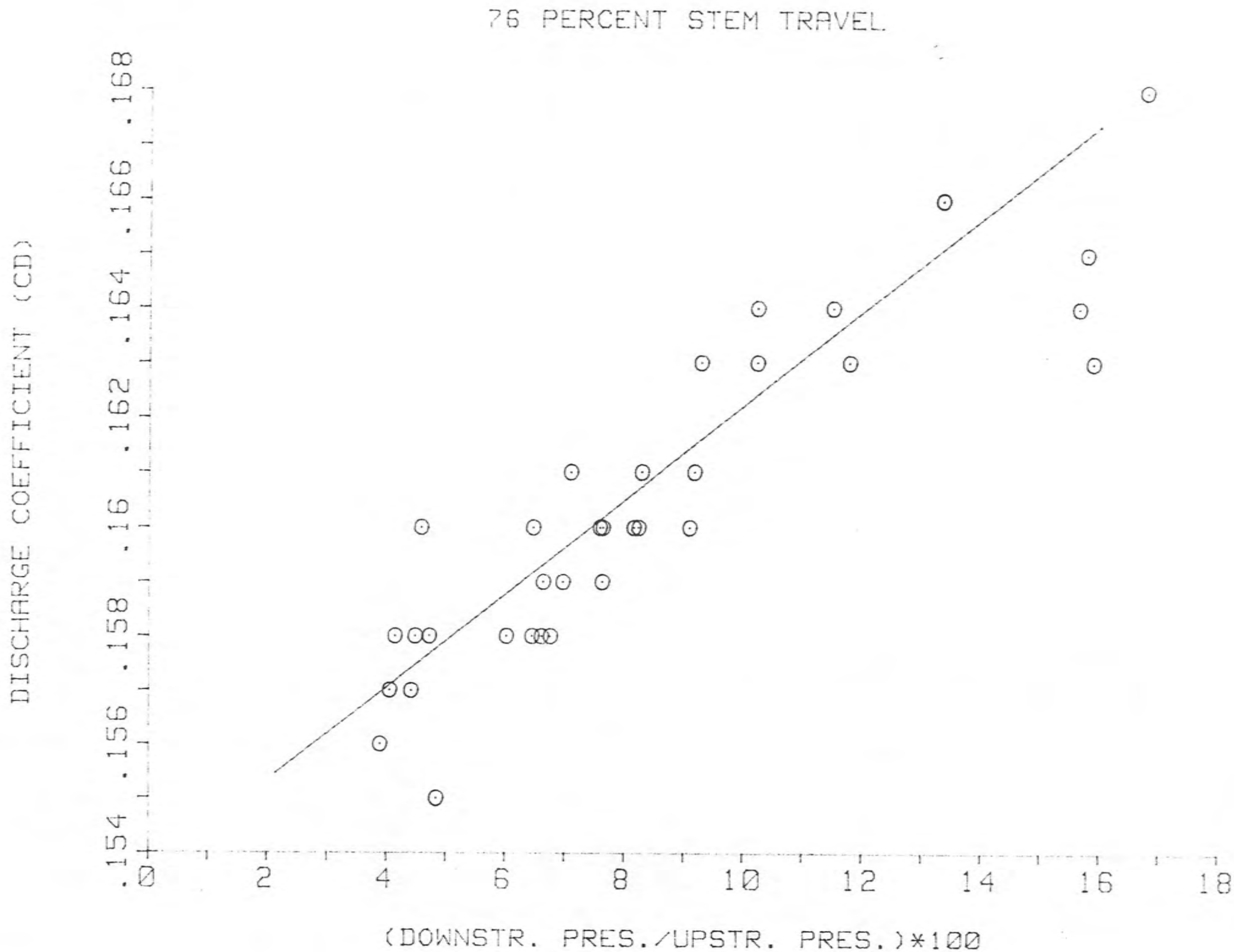


Figure 9.



76 PERCENT STEM TRAVEL
DISCHARGE COEFFICIENT (CD)
.154
.156
.158
.16
.162
.164
.166
.168
.0
2
4
6
8
10
12
14
16
18
(DOWNSTR. PRES./UPSTR. PRES.)*100

Figure 10.

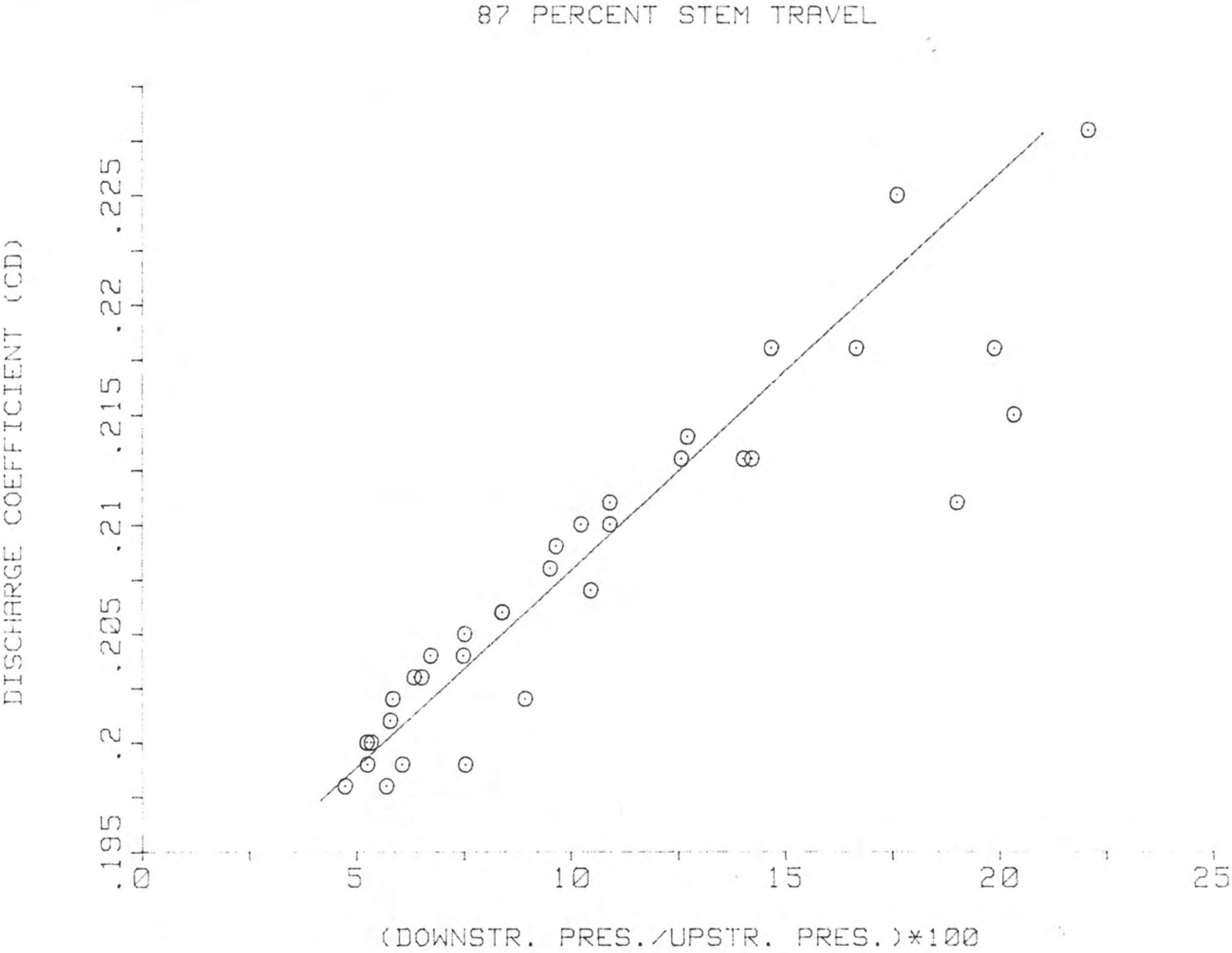

87 PERCENT STEM TRAVEL
DISCHARGE COEFFICIENT (CD)
.195
.2
.205
.21
.215
.22
.225
.0
5
10
15
20
25
(DOWNSTR. PRES./UPSTR. PRES.)*100

Figure 11.

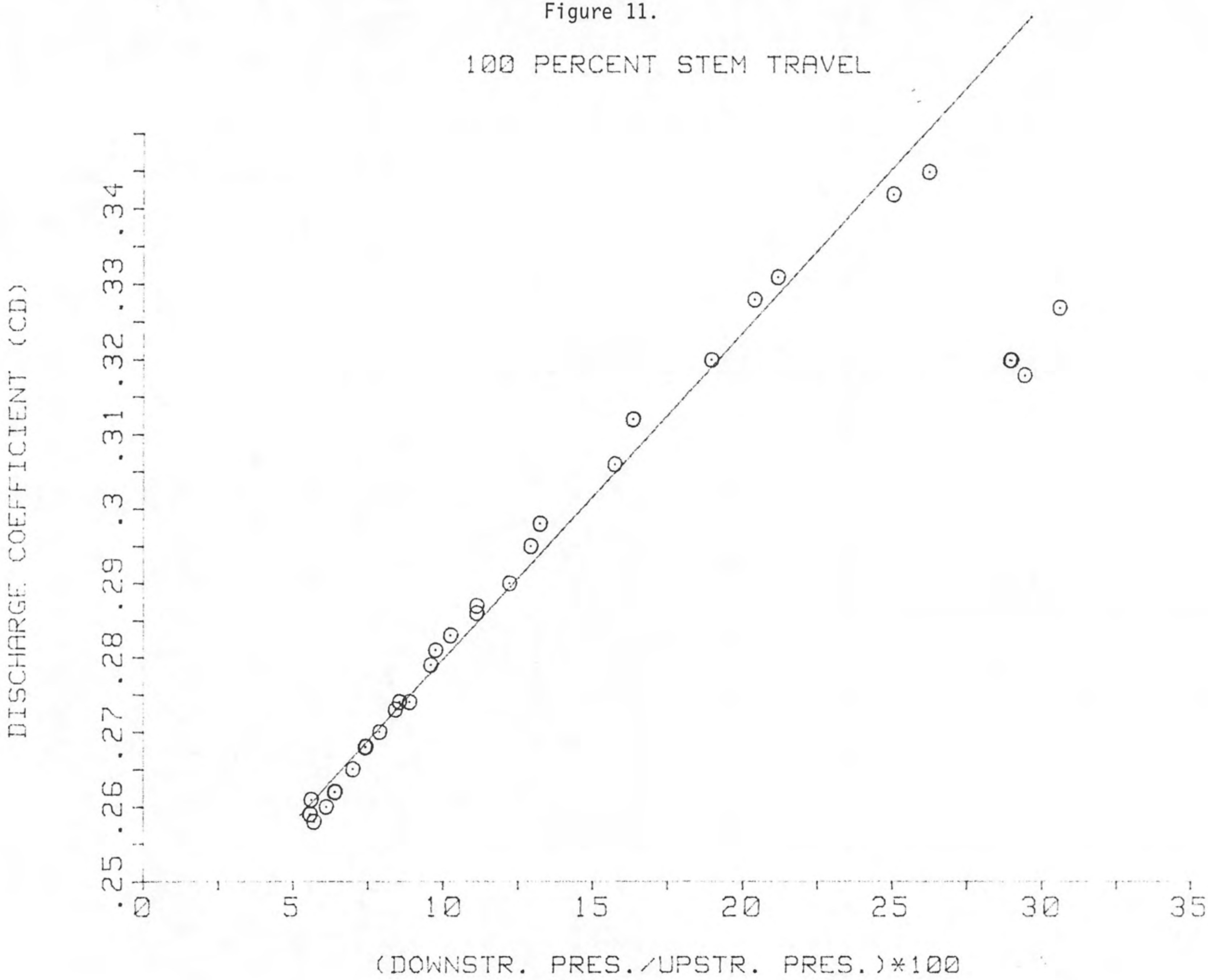
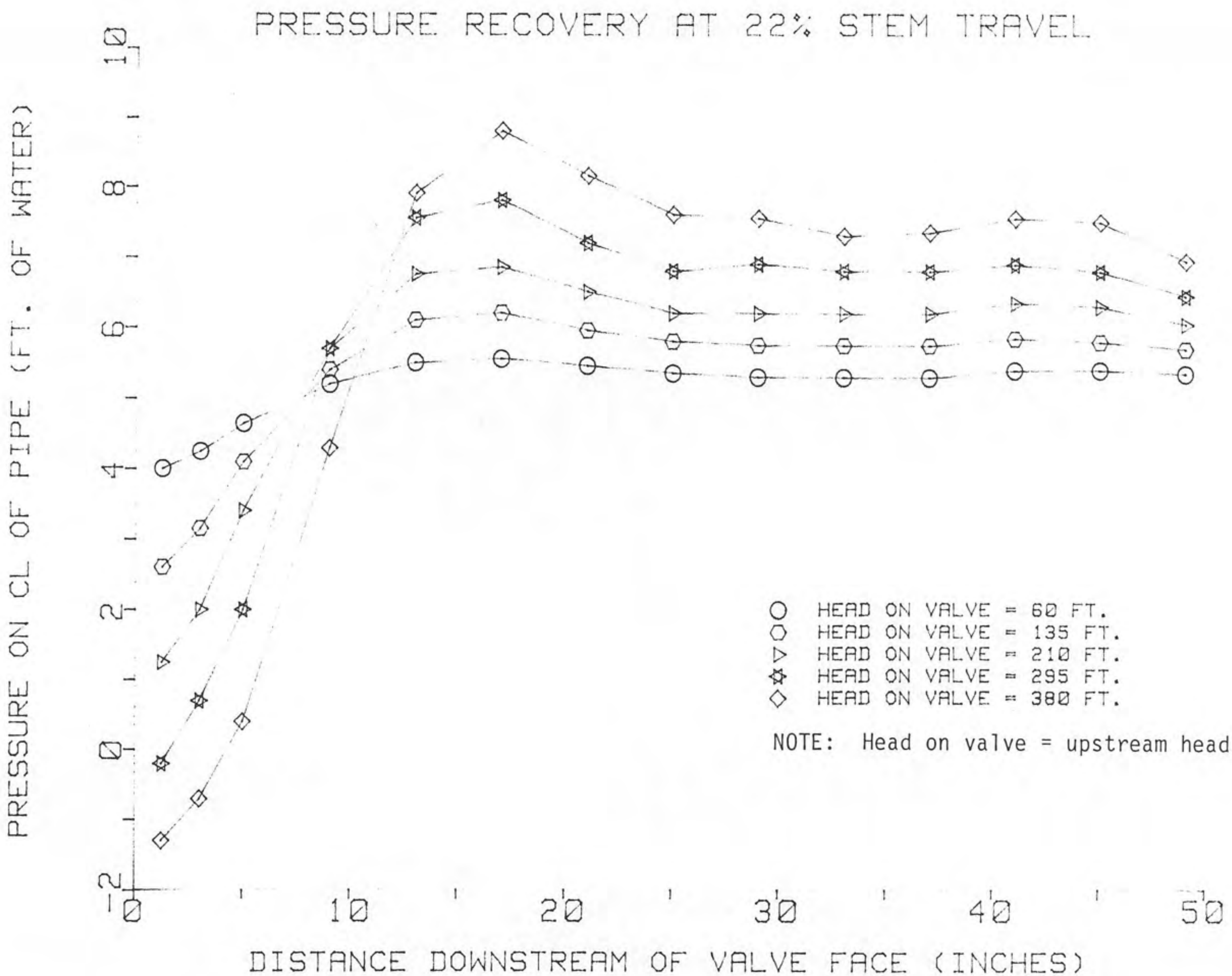
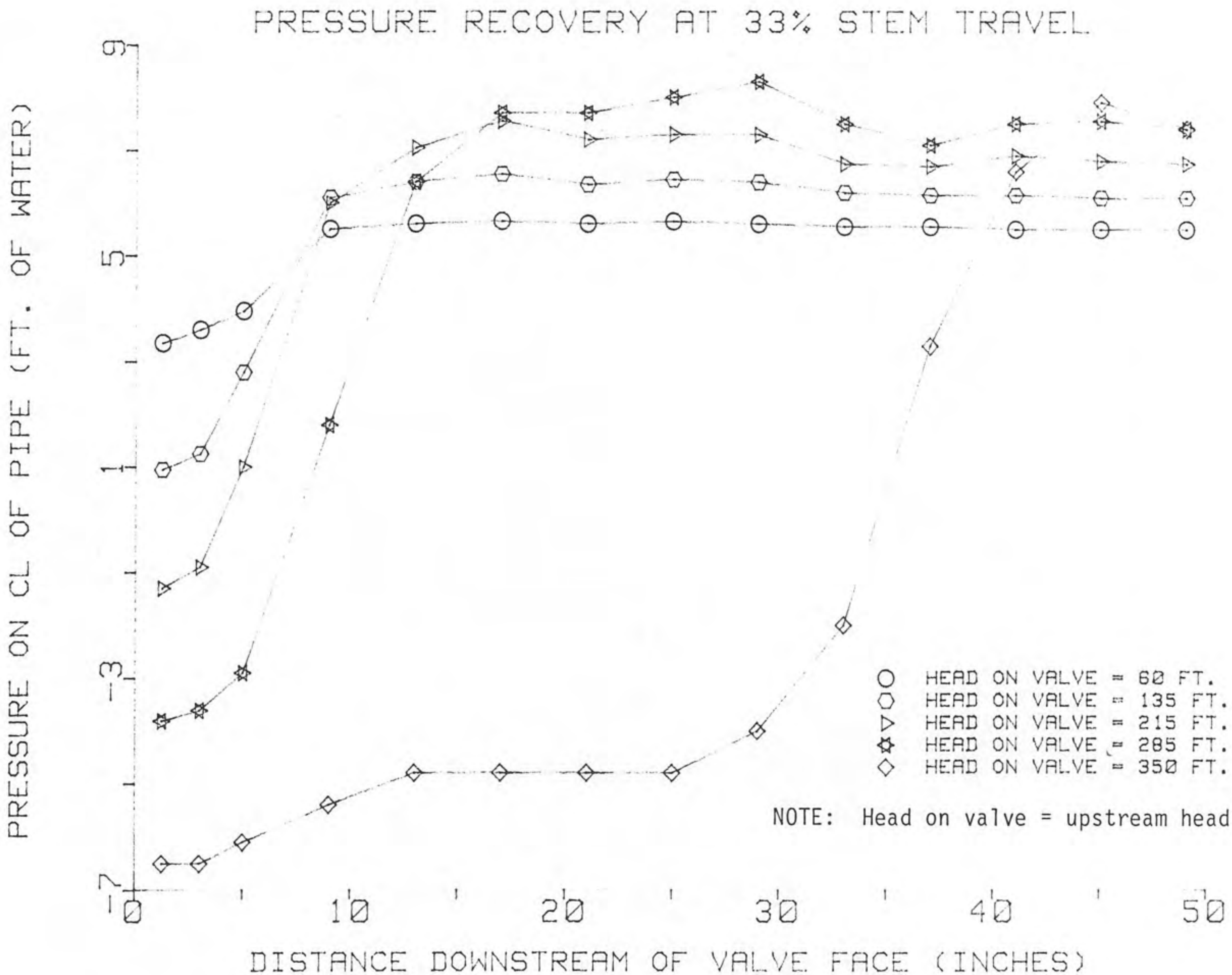

100 PERCENT STEM TRAVEL
DISCHARGE COEFFICIENT (CD)
.25
.26
.27
.28
.29
.3
.31
.32
.33
.34
0
5
10
15
20
25
30
35
(DOWNSTR. PRES./UPSTR. PRES.)*100

Figure 12.



NOTE: Head on valve = upstream head on valve.

Figure 13



NOTE: Head on valve = upstream head on valve.

Figure 14.

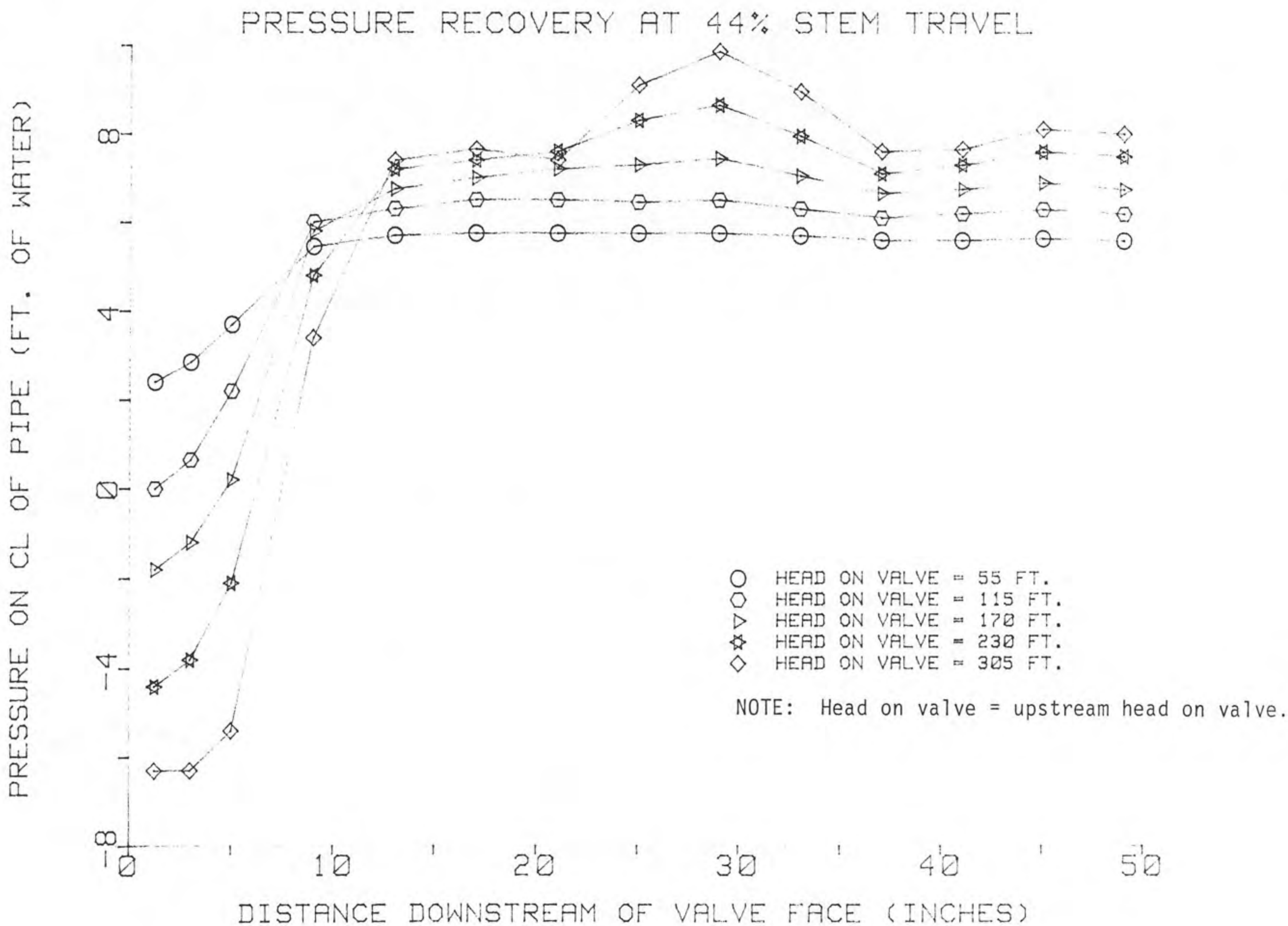

PRESSURE RECOVERY AT 44% STEM TRAVEL
PRESSURE ON CL OF PIPE (FT. OF WATER)
8
4
0
-4
-8
0
10
20
30
40
50
DISTANCE DOWNSTREAM OF VALVE FACE (INCHES)
HEAD ON VALVE = 55 FT.
HEAD ON VALVE = 115 FT.
HEAD ON VALVE = 170 FT.
HEAD ON VALVE = 230 FT.
HEAD ON VALVE = 305 FT.
NOTE: Head on valve = upstream head on valve.

Figure 15.

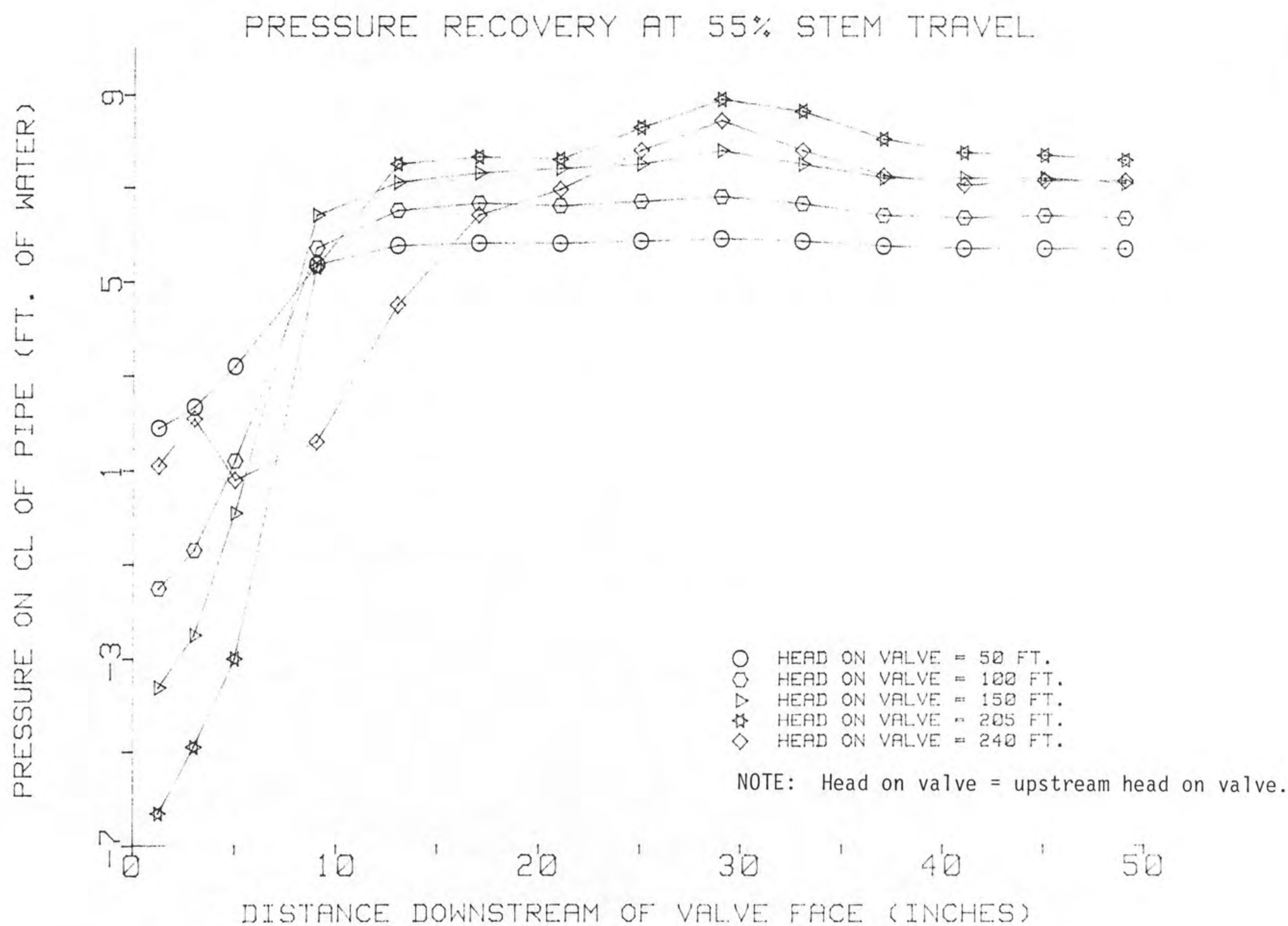
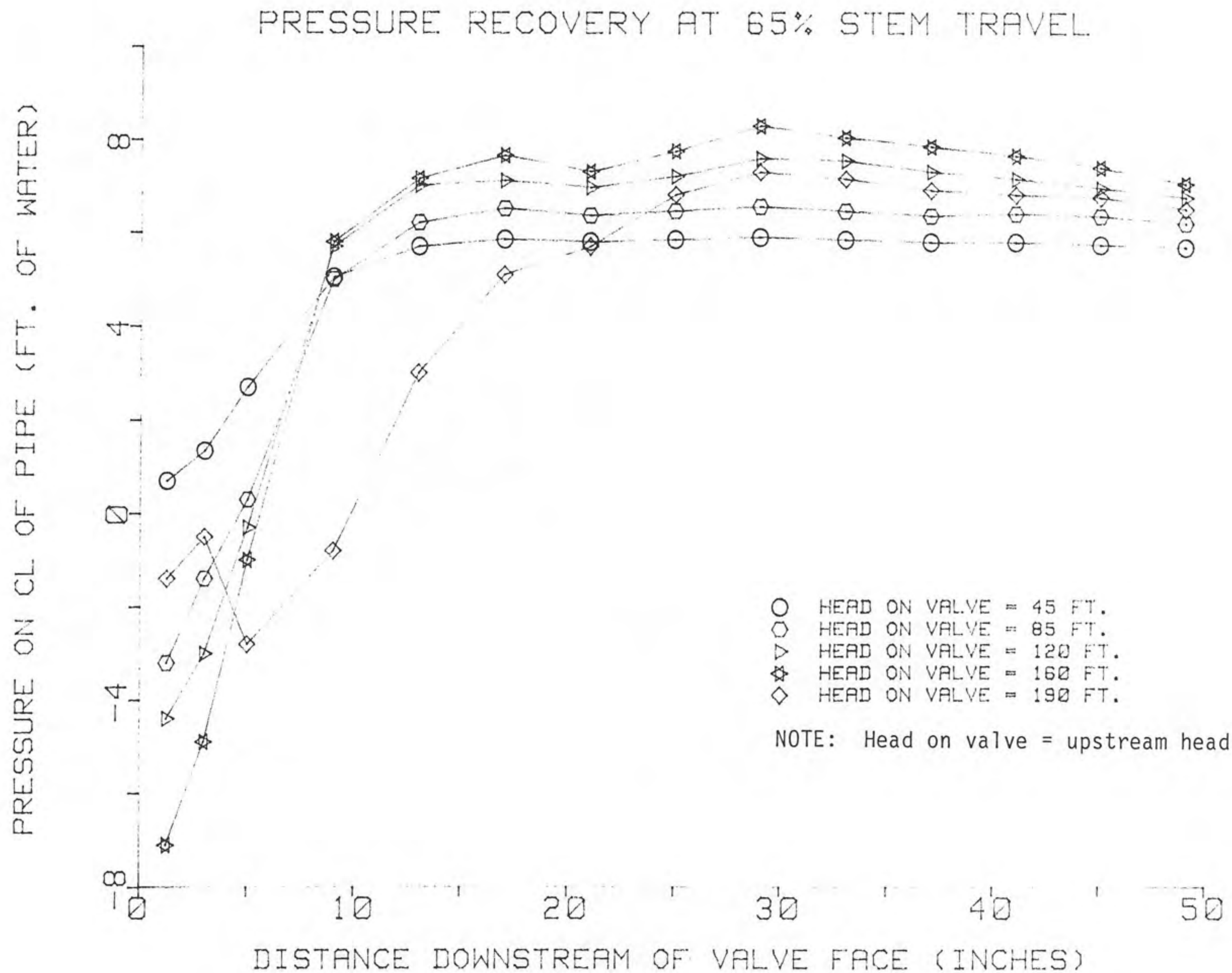

PRESSURE RECOVERY AT 55% STEM TRAVEL
PRESSURE ON CL OF PIPE (FT. OF WATER)
9
5
1
-3
-7
0
10
20
30
40
50
DISTANCE DOWNSTREAM OF VALVE FACE (INCHES)
HEAD ON VALVE = 50 FT.
HEAD ON VALVE = 100 FT.
HEAD ON VALVE = 150 FT.
HEAD ON VALVE = 205 FT.
HEAD ON VALVE = 240 FT.
NOTE: Head on valve = upstream head on valve.

Figure 16.



NOTE: Head on valve = upstream head on valve.

Figure 17.

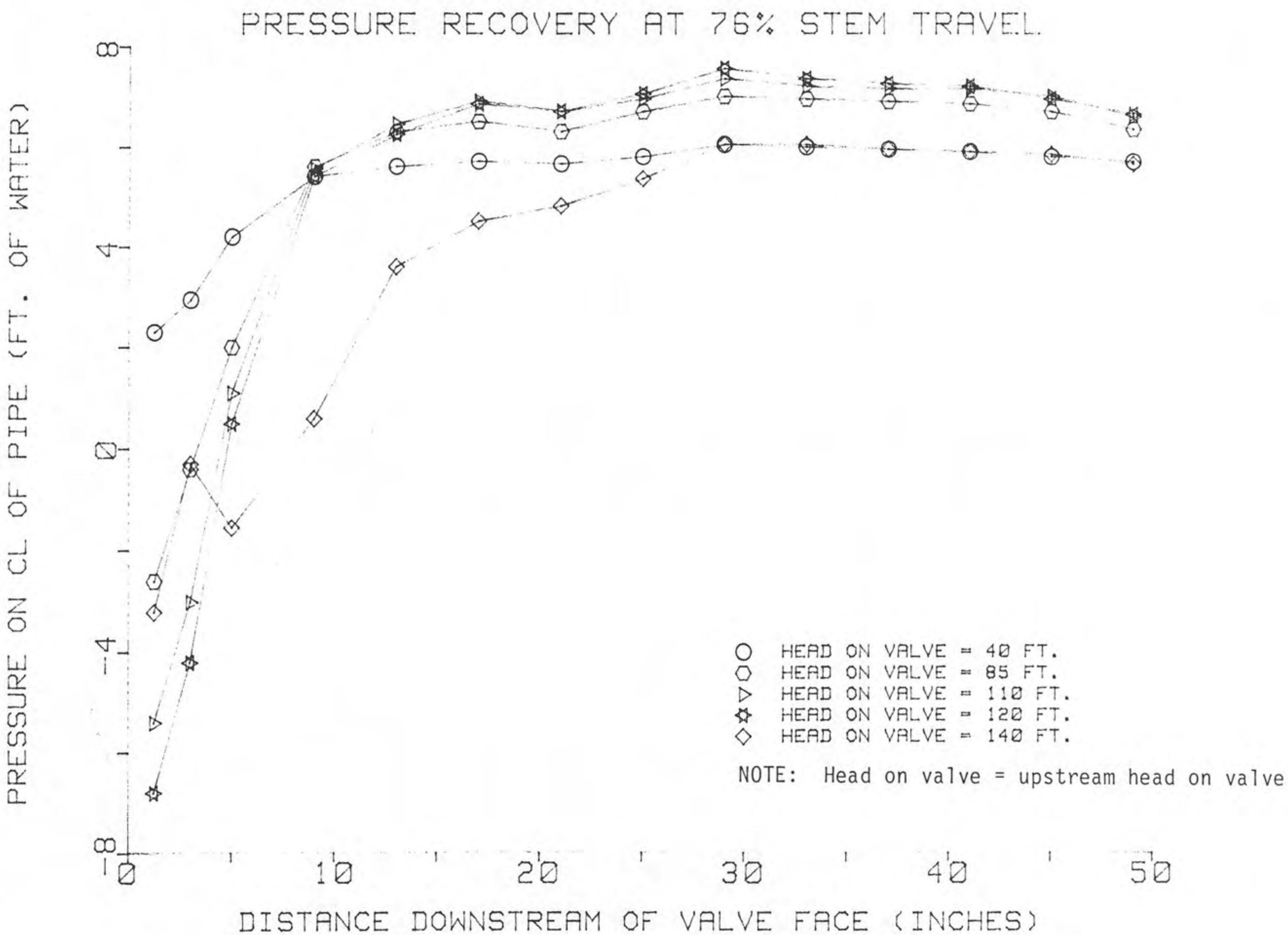
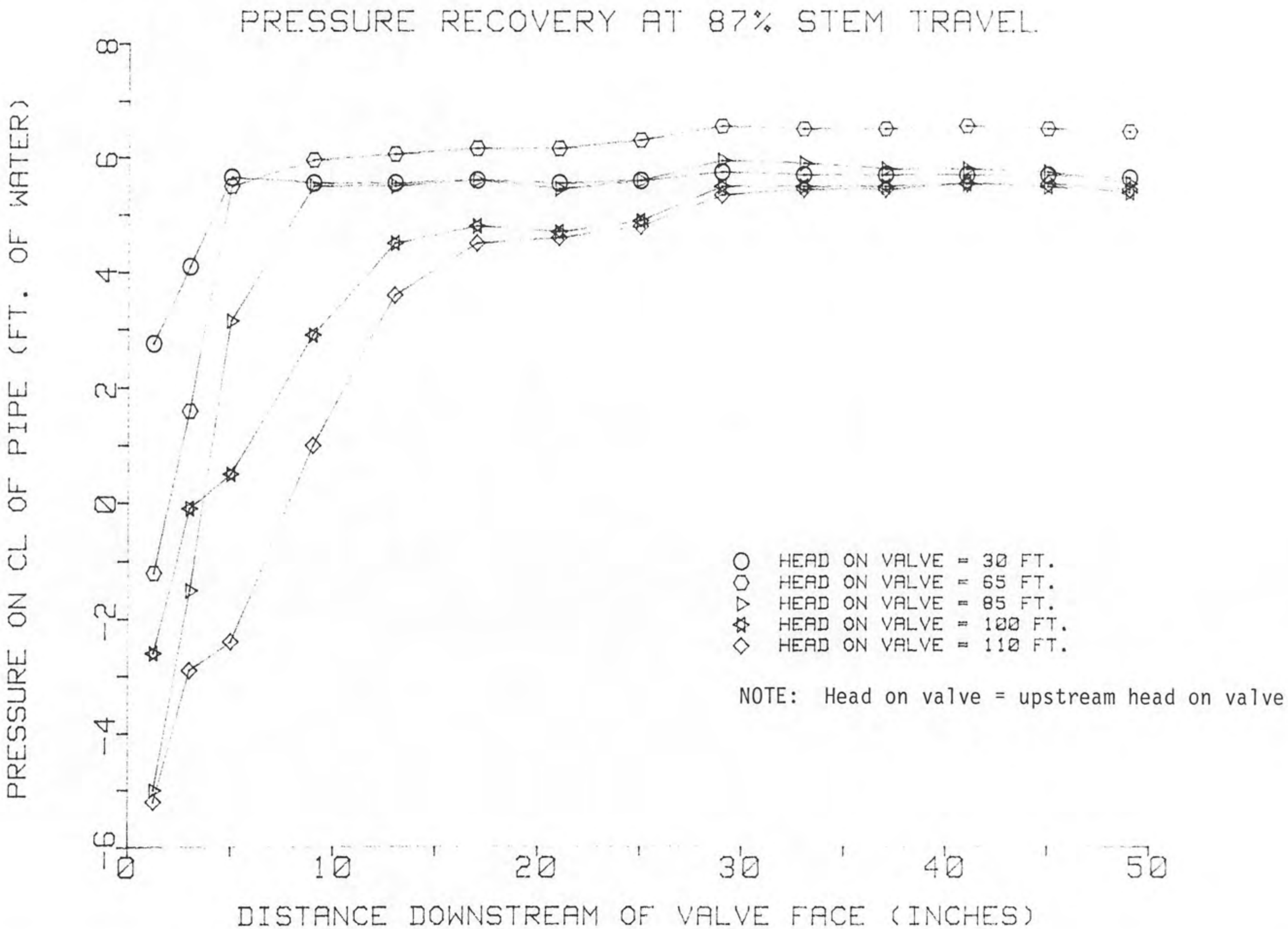

PRESSURE RECOVERY AT 76% STEM TRAVEL
PRESSURE ON CL OF PIPE (FT. OF WATER)
8
4
0
-4
-8
0
10
20
30
40
50
DISTANCE DOWNSTREAM OF VALVE FACE (INCHES)
HEAD ON VALVE = 40 FT.
HEAD ON VALVE = 85 FT.
HEAD ON VALVE = 110 FT.
HEAD ON VALVE = 120 FT.
HEAD ON VALVE = 140 FT.
NOTE: Head on valve = upstream head on valve.

Figure 18.



PRESSURE RECOVERY AT 87% STEM TRAVEL
PRESSURE ON CL OF PIPE (FT. OF WATER)
-6
-4
-2
0
2
4
6
8
0
10
20
30
40
50
DISTANCE DOWNSTREAM OF VALVE FACE (INCHES)
HEAD ON VALVE = 30 FT.
HEAD ON VALVE = 65 FT.
HEAD ON VALVE = 85 FT.
HEAD ON VALVE = 100 FT.
HEAD ON VALVE = 110 FT.
NOTE: Head on valve = upstream head on valve.

Figure 19.

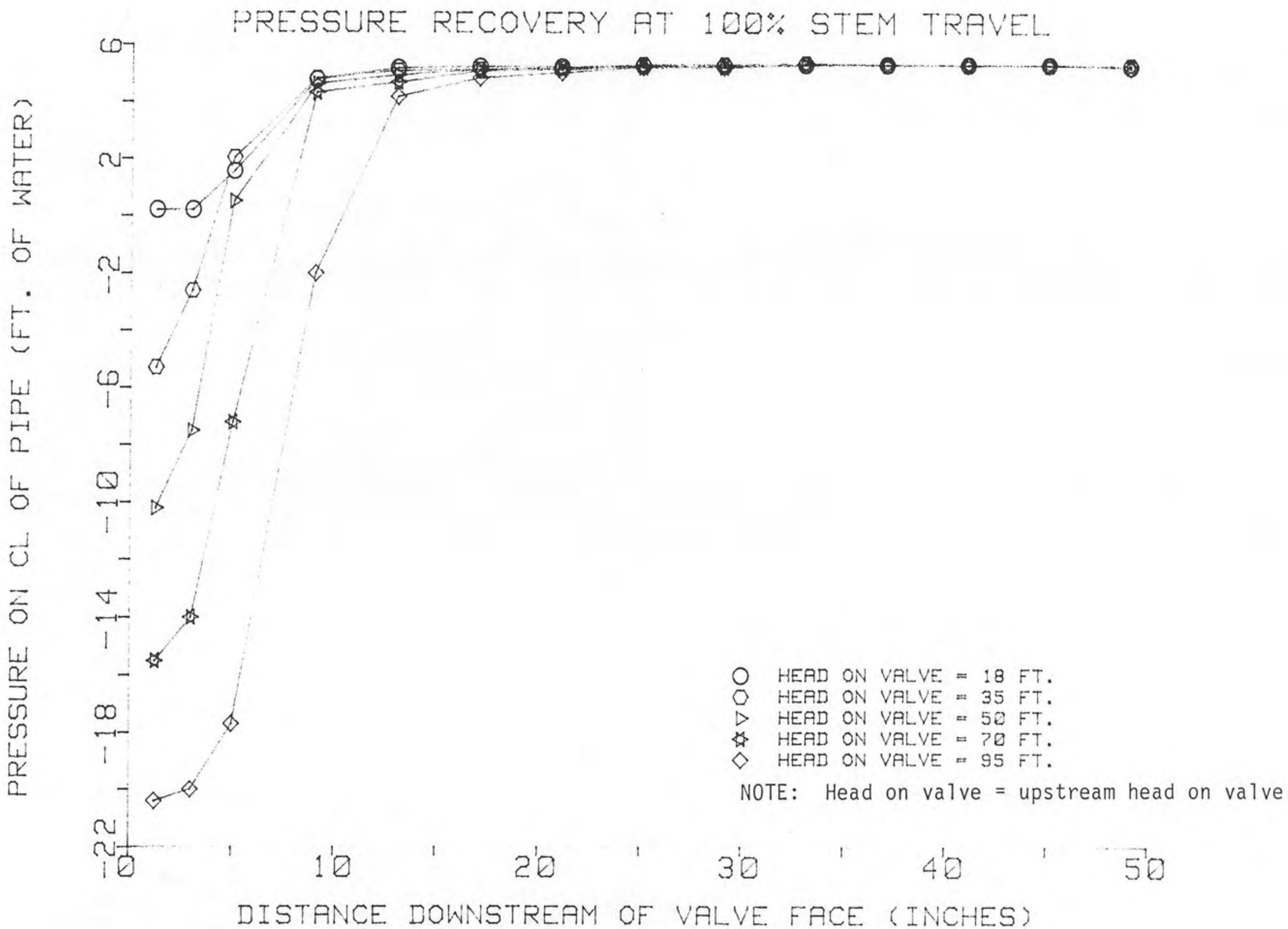

PRESSURE RECOVERY AT 100% STEM TRAVEL
PRESSURE ON CL OF PIPE (FT. OF WATER)
6
2
-2
-6
-10
-14
-18
-22
0
10
20
30
40
50
DISTANCE DOWNSTREAM OF VALVE FACE (INCHES)
HEAD ON VALVE = 18 FT.
HEAD ON VALVE = 35 FT.
HEAD ON VALVE = 50 FT.
HEAD ON VALVE = 70 FT.
HEAD ON VALVE = 95 FT.
NOTE: Head on valve = upstream head on valve.

Figure 20. Minimum percent downstream pres. of upstream pres.