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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. HYD-67

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TESTS ON 4-INCH PLUG VALVE

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HYDRAULIC MACHINERY LABORATORY
REPORT NO. HM-11

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Denver, Colorado,
October 10, 1939

HYD 67

Bureau of Reclamation
Hydraulic Machinery Laboratory

Denver, Colorado

October 10, 1939

Laboratory Report No. H. M. 11
Boulder Dam
Boulder Canyon Project
Compiled by: O. Hanson
Checked by: N. Noonan
Submitted by: G. J. Hornsby

Subject: Study of the torque developed by a four-inch plug valve at partial openings.

Purpose of the Test.

The bypass lines around the butterfly valves in the penstocks at Boulder Dam were originally controlled by hydraulically operated needle valves. Because of the highly corrosive action of the water and the necessarily close tolerances of the moving parts of the needle valves, the valves became corroded in such a manner as to make it impossible to operate them. These valves were removed and replaced by either gate valves or butterfly valves. A plug valve is being proposed for bypass control in future installations. A study of the torque developed during operation of this type of valve is necessary for safe and economical design.

Test Procedure.

A four-inch plug valve, shown on plate 1, was designed and built for this test. The plug was mounted on ball bearings and there was a 0.010-inch clearance between the plug and the body. This was done to reduce frictional forces to a minimum. A device, also shown on plate 1, was made for measuring the torque at any given valve opening.

The valve was set at a given opening and run under varying heads, the heads being regulated by various control settings on a variable speed motor-pump unit. Readings of torque, head, and discharge were taken for each pump setting for each of the various valve openings. At any partial opening, the valve has a tendency to close. Torque measurements as shown on the curves are the torques in inch-pounds required to resist the closing effort of the valve. The head as shown on the curves is the sum of the net head at the upstream side of the valve plus the velocity head at that point minus the pressure head below the valve. See charts, pages 3 and 4 for heads at these points.

Curves were drawn showing the relation of torque to head for given valve settings, figure No. 1, of torque to valve openings at constant heads, figure No. 2, and torque to valve openings

at constant pump settings, figure No. 3. Valve settings are based on "90°" being completely open, the valve actually being a section of the pipe and having zero torque at that setting. Eight degrees is the point of shut-off and zero degree the seating position for closure.

Discussion of Test and Conclusions.

The valve was run under heads varying from zero to the maximum capacity of the pump or about 100-foot head. For a given head the maximum closing torque occurred at a valve opening of $82\frac{1}{2}^{\circ}$. Such a set-up would occur only when the valve was very near an ideal entrance and with but a very short length of pipe downstream from the valve. Under a more normal condition with relatively long lengths of pipe either upstream or downstream from the valve or with a constriction downstream, the maximum torque will occur at a much smaller valve opening. This condition will more closely approximate the torque-valve opening curve for constant pump settings. Actually a constant pump setting does not duplicate a constant reservoir head, but it approaches that condition within the characteristics of the pump.

Pressures read by means of the piezometers placed one diameter downstream from the valve were used as pressures on the downstream side of the valve. This is correct at that point but will not show what is occurring just back of the plug. This probably accounts for some points breaking from a smooth curve. Pressures of as low as -17 feet of water were recorded at the point measured and from the sound and vibration just back of the plug it can be assumed that the vapor pressure of the water was reached at that section. Therefore, if a plug valve is to be used as a throttling valve, provision should be made to admit air just downstream from the plug.

For approximate computations of maximum torque developed on larger valves, multiply the maximum torque as developed by the four-inch valve by the cube of the scale ratios, by the ratio of the prototype head as compared to the head at which the four-inch valve was run.

Sample. Find the maximum torque developed by an eight-inch plug valve under a head of 600 feet.

At a 50-foot head the maximum torque in the four-inch valve was 180 inch-pounds. Therefore

$$180 \times \left(\frac{8}{4}\right)^3 \times \frac{600}{50} = 180 \times 8 \times 12 \text{ or } 17{,}280 \text{ inch-pounds torque.}$$

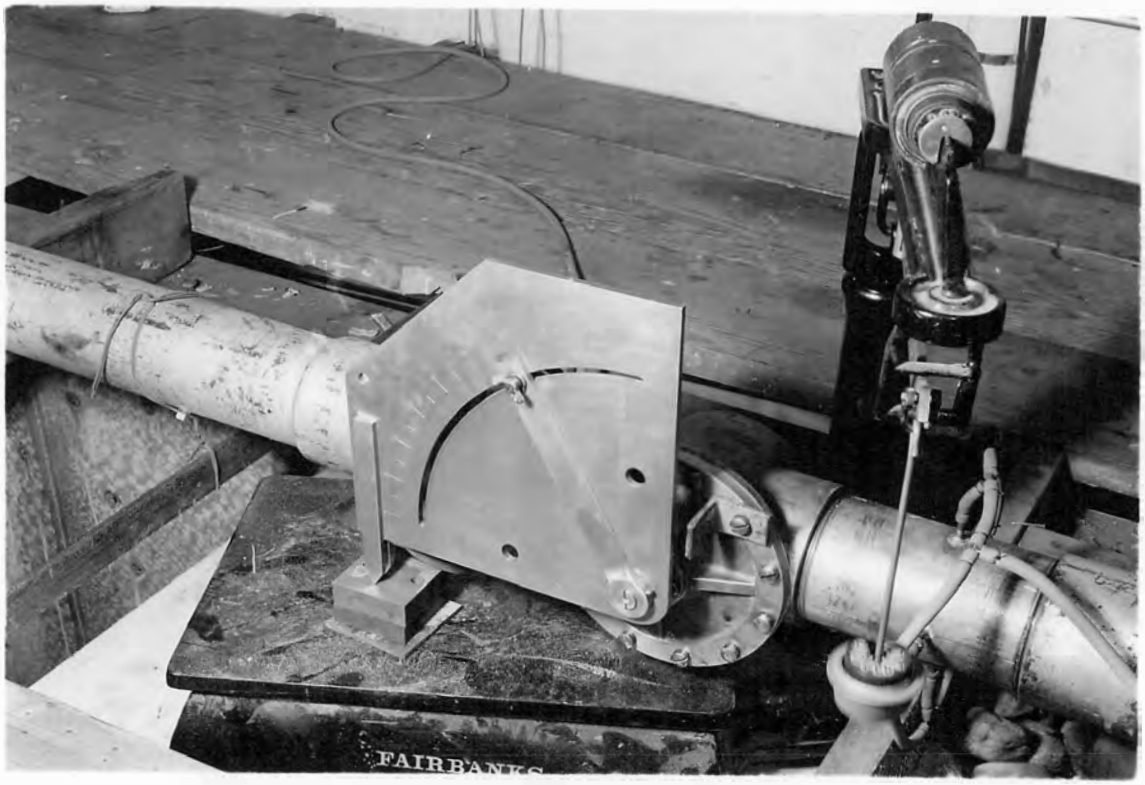
FOUR-INCH PLUG VALVE

Denver, Colorado, October 6, 1939.

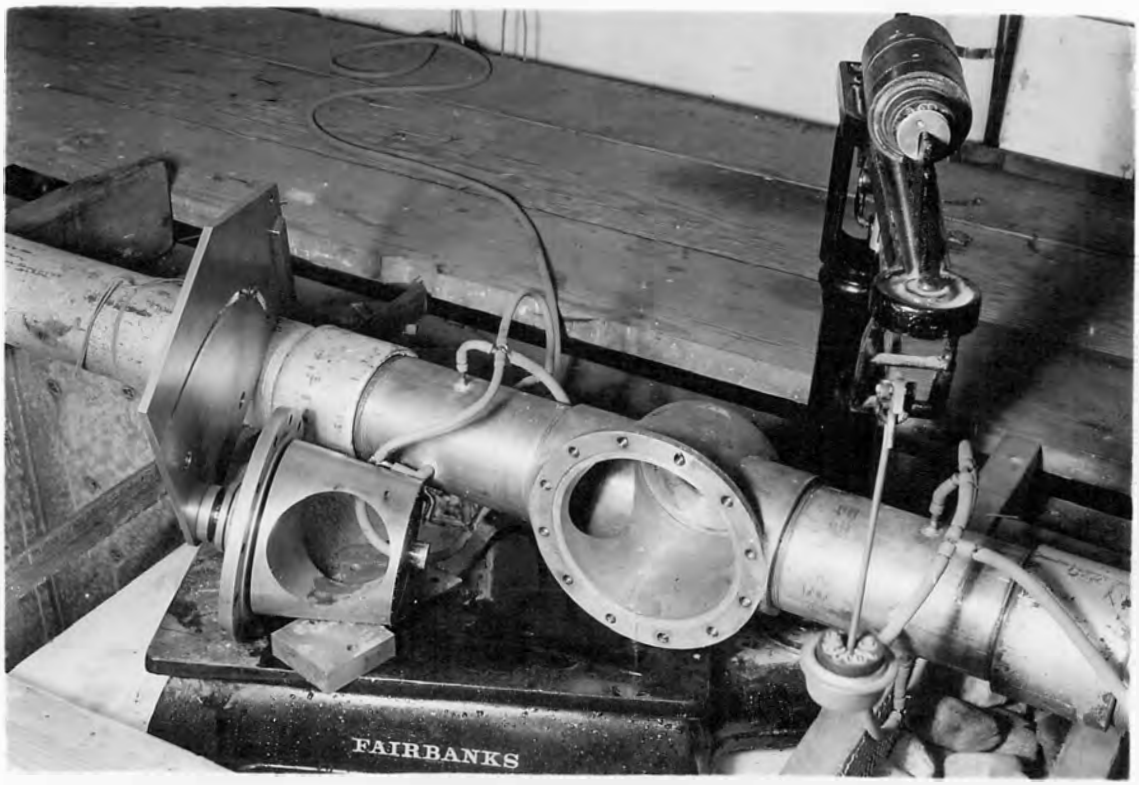
Torque equals 0 for valve 90° open and for valve openings of 8° or less.

Pump setting	Degrees open	Q c.f.s.	Head (H_u) upstream	Head (H_o) downstream	Head (H_v) velocity	Total head $H_u+H_v-H_o$	Torque in.-lbs.
			Ft. of H_2O	Ft. of H_2O	Ft. of H_2O	Ft. of H_2O	
1	87½	1.87	3.94	0.95	7.00	9.99	34.2
3		2.43	7.48	4.49	12.05	16.04	24.6
5		2.95	11.70	8.63	17.76	20.83	37.4
7		3.46	17.00	13.60	24.44	27.84	53.1
9		3.72	21.35	17.48	28.22	32.09	66.4
11		4.09	24.60	20.65	34.20	38.15	76.9
1	85	1.89	4.48	0.95	7.28	10.81	25.4
3		2.42	8.16	4.35	11.98	15.79	42.3
5		2.93	12.79	8.57	17.53	21.75	62.5
7		3.44	18.35	13.19	24.14	29.30	86.3
9		3.78	24.05	16.80	29.15	36.40	105.7
11		4.03	26.38	19.71	33.20	39.77	123.3
1	82½	1.87	4.89	0.68	7.13	11.34	30.4
3		2.38	8.98	3.94	11.54	16.58	51.3
5		2.87	14.01	7.75	16.83	23.09	76.5
7		3.38	20.13	12.31	23.36	31.18	106.5
9		3.71	24.85	15.78	28.09	37.16	128.8
11		3.97	28.82	18.62	32.19	42.39	148.8
1	80	1.85	5.58	0.41	7.08	12.25	34.9
3		2.34	10.20	3.54	11.18	17.84	57.3
5		2.81	15.78	7.14	16.12	24.76	82.6
7		3.29	22.70	10.52	22.10	34.28	112.6
9		3.62	28.00	14.49	26.78	40.29	138.4
11		3.85	32.50	17.08	30.24	45.66	158.1
1	75	1.74	7.47	-0.61	6.17	14.25	37.7
3		2.19	13.18	+1.77	9.80	21.21	61.8
5		2.64	20.25	4.35	14.21	30.11	100.6
7		3.08	28.65	7.68	19.38	40.35	122.8
9		3.38	35.35	9.92	23.30	48.73	148.1
11		3.58	40.80	10.81	26.15	56.14	166.8
1	70	1.61	9.79	-3.12	5.29	18.20	43.6
3		2.01	16.85	-2.31	8.25	27.41	70.8
5		2.41	25.59	-1.29	11.85	38.73	101.5
7		2.80	35.83	-2.31	16.02	54.16	139.5
9		3.06	43.90	+4.75	19.10	58.25	167.2
11		3.24	47.70	9.25	21.44	59.89	190.5

Pump setting	Degrees open	Q c.f.s.	Head (H_u) upstream	Head (H_o) downstream	Head (H_v) velocity	Total head $H_u+H_v-H_o$	Torque in.-lbs.
			Ft. of H_2O	Ft. of H_2O	Ft. of H_2O	Ft. of H_2O	
1	60	1.25	15.09	-5.98	3.19	24.26	49.5
3		1.52	25.59	-6.66	4.71	36.96	79.7
5		1.82	40.40	-7.21	6.76	54.37	115.3
7		2.09	55.40	-10.60	8.91	74.91	153.4
9		2.26	62.40	-14.13	10.42	86.95	179.9
11		2.38	70.40	-17.12	11.55	99.07	200.3
1	50	0.90	19.70	-6.59	1.64	27.93	48.0
3		1.05	32.50	-7.61	2.24	42.35	75.4
5		1.24	46.40	-8.70	3.13	58.23	104.0
7		1.42	62.40	-11.29	4.12	77.81	137.1
9		1.53	73.40	-13.32	4.79	91.51	160.8
11		1.61	82.20	-14.82	5.29	102.31	177.1
1	40	0.60	22.98	-6.59	0.73	30.30	40.2
3		0.73	37.15	-7.61	1.08	45.84	62.4
5		0.82	52.10	-8.36	1.37	61.83	87.1
7		0.88	68.50	-9.64	1.58	79.72	112.7
9		0.94	79.20	-10.68	1.81	91.69	129.3
11		0.99	87.60	-11.41	1.99	101.00	142.3
1	30	0.40	25.10	-6.12	0.33	31.55	26.9
3		0.50	39.30	-7.01	0.51	46.82	40.5
5		0.54	54.80	-8.22	0.59	63.61	54.9
7		0.60	71.20	-8.83	0.73	80.76	69.9
9		0.62	81.80	-9.38	0.79	91.97	81.4
11		0.65	89.60	-9.93	0.86	100.39	88.1
1	20	0.30	25.82	-3.80	0.11	29.73	17.1
3		0.30	40.80	-4.22	0.11	45.13	25.9
5		0.30	56.10	-4.89	0.11	61.10	34.7
7		0.30	72.10	-5.64	0.11	77.85	44.2
9		0.30	82.90	-6.12	0.11	89.13	50.9
11		0.30	90.40	-6.39	0.11	96.90	54.9



Test Assembly Showing Torque Measuring Arm



View Showing Plug and Valve Body

FIGURE 1

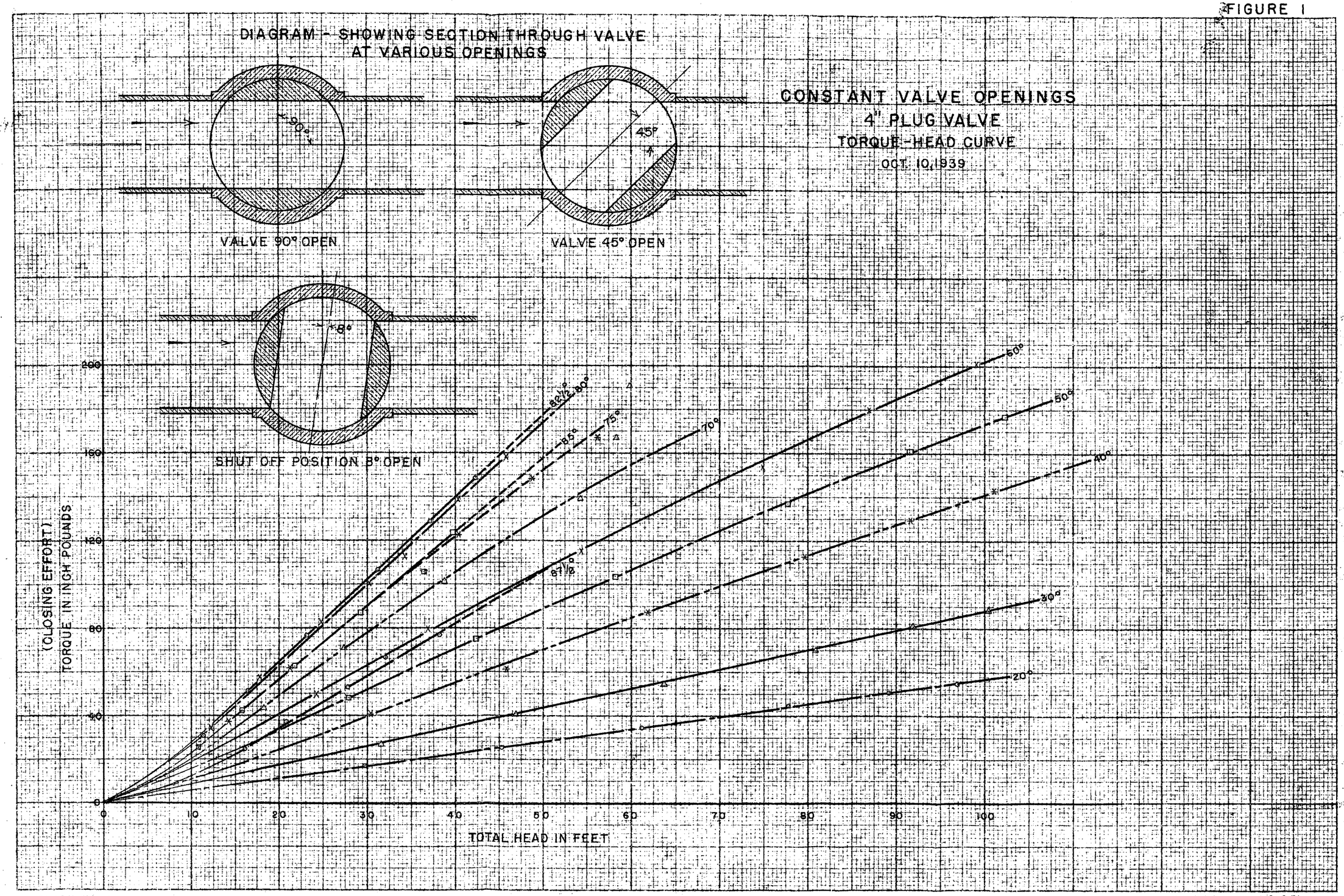


DIAGRAM - SHOWING SECTION THROUGH VALVE
AT VARIOUS OPENINGS
90°
VALVE 90° OPEN
45°
VALVE 45° OPEN
8°
SHUT OFF POSITION 8° OPEN
CONSTANT VALVE OPENINGS
4" PLUG VALVE
TORQUE-HEAD CURVE
OCT. 10, 1939
(CLOSING EFFORT)
TORQUE IN INCH POUNDS
TOTAL HEAD IN FEET
0
40
80
120
160
200
10
20
30
40
50
60
70
80
90
100
90°
85½°
80°
75°
70°
65°
60°
50°
40°
30°
20°
8½°

FIGURE 2

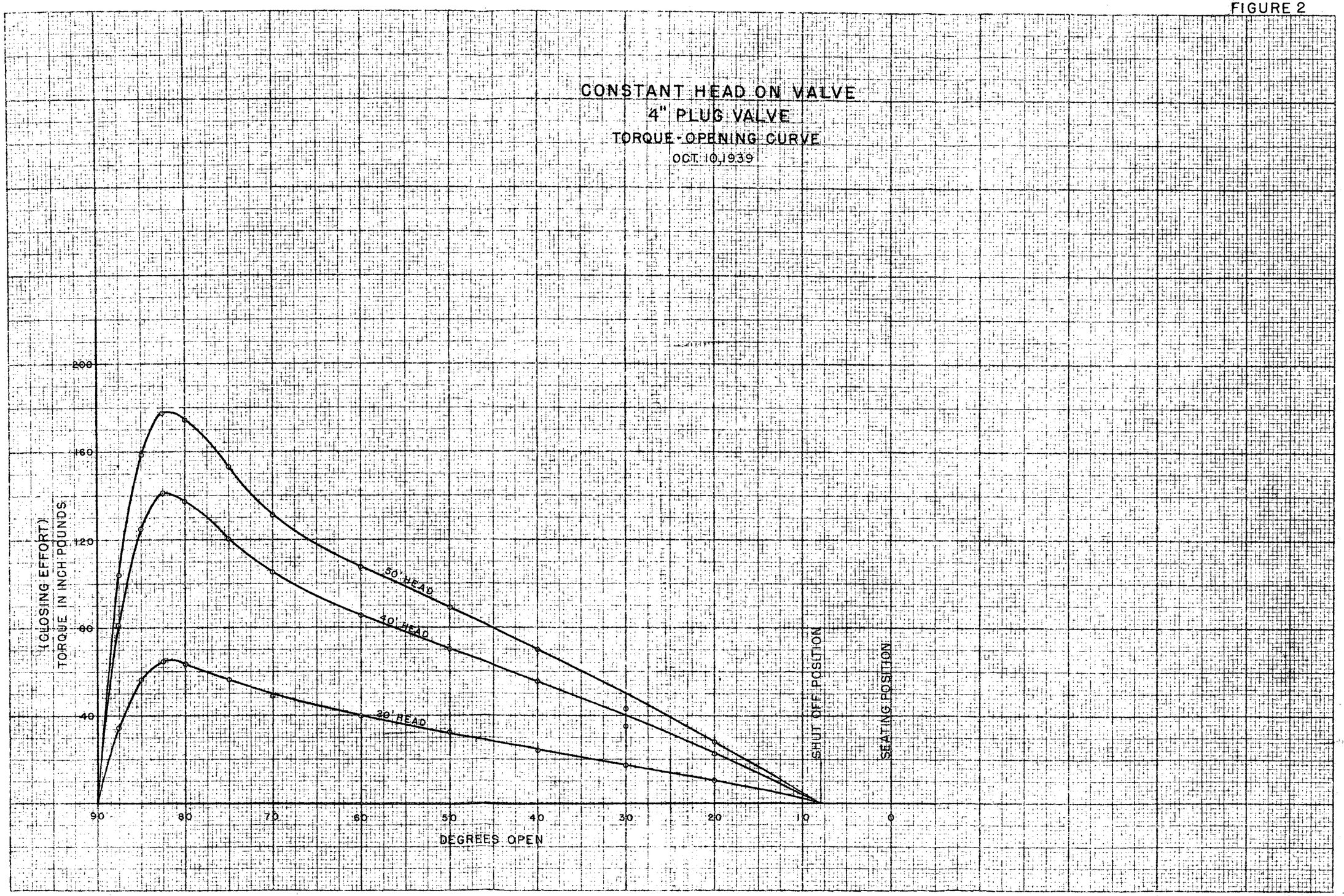
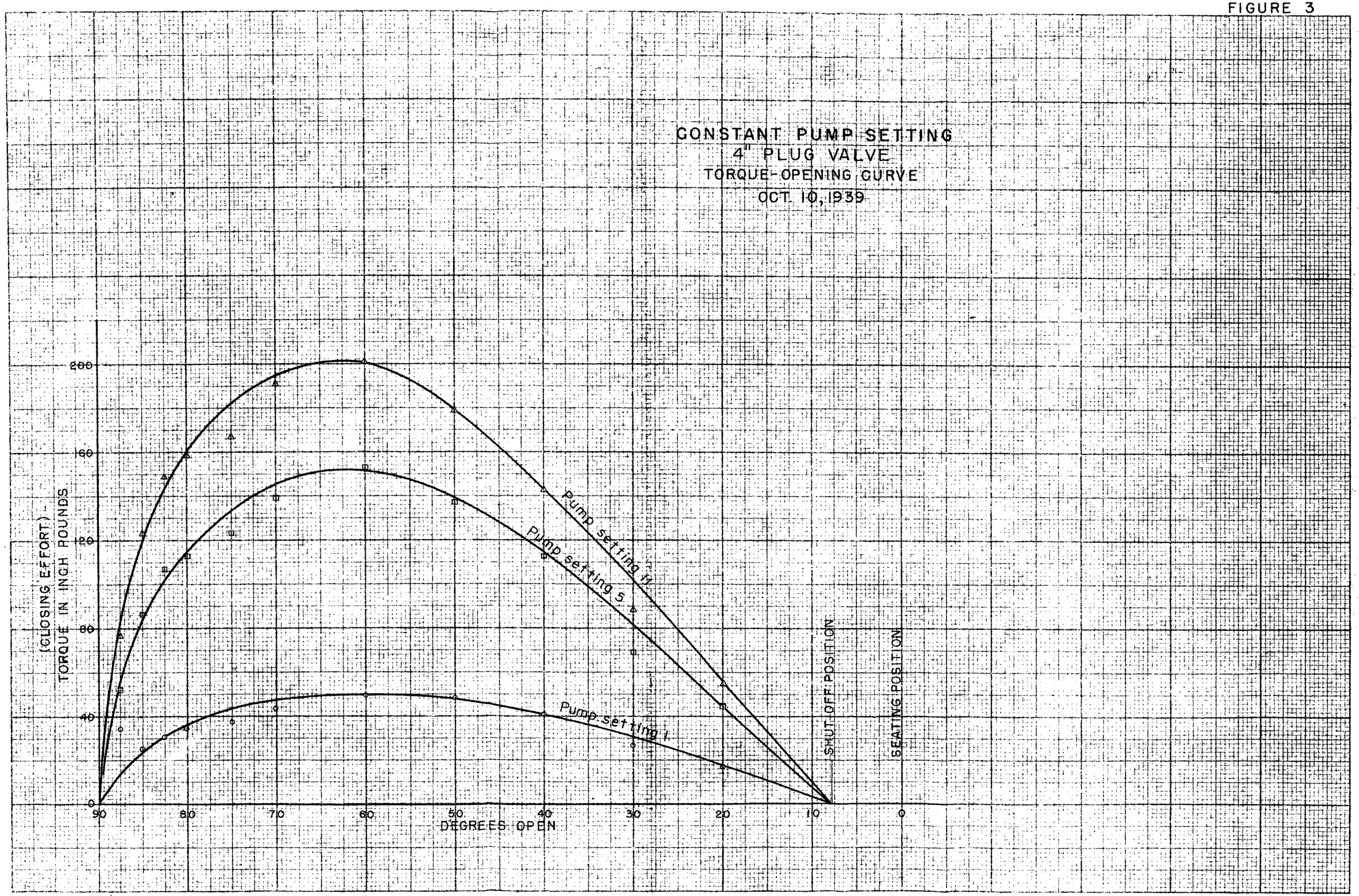

CONSTANT HEAD ON VALVE
4" PLUG VALVE
TORQUE-OPENING CURVE
OCT. 10, 1939
(CLOSING EFFORT)
TORQUE IN INCH POUNDS
200
160
120
80
40
50' HEAD
40' HEAD
20' HEAD
SHUT OFF POSITION
SEATING POSITION
90
80
70
60
50
40
30
20
10
0
DEGREES OPEN

FIGURE 3



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