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UNITED STATES
DEPARTMENT OF THE INTERIOR
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HYDRAULIC LABORATORY REPORT NO. 25

- - -

MODEL STUDIES OF THE MECHANICS AND HYDRAULICS OF LARGE CONTROL GATE

- - -

by

N. NOONAN and G. J. HORNSBY

- - -

Denver, Colorado

June 17, 1937

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: MODEL STUDIES OF THE MECHANICS AND HYDRAULICS OF LARGE CONTROL GATE

Denver, Colorado, June 17, 1937.

MEMORANDUM TO THE CHIEF DESIGNING ENGINEER
(N. Noonan and G. J. Hornsby)

Subject: Model studies of the mechanics and hydraulics of large control gates.

1. Purpose of tests. The original purpose of this series of tests was to make a qualitative study of the performance of gates located at the face of dams or in penstocks and sluices. It was later deemed necessary to make a series of quantitative tests to determine hoist requirements and pressures exerted on gates due to hydrodynamic conditions. This information was especially desirable in connection with tractor gates, ring-follower gates, and cylinder-follower gates.

2. Operating principles of gates. The general design of a gate hoist provides for sufficient capacity to close or open the gate under full operating head. The usual method of computing the required force to operate a gate, that is, necessary hoist capacity, is to sum up the frictional resistances of the gate plus the weight of the moving parts for lifting the gate, and minus that weight for lowering the gate. The weight of the moving parts in water is equal to the "dead" weight of those parts minus the effect of buoyancy or uplift of the water. The frictional resistance varies for the different types of gates. In sliding gates this force is equal to from 0.3 to 0.75, depending on the material in the leaf and seat, of the water load on the leaf. In the case of fixed wheel gates the frictional resistance is equal to the axle friction plus the rolling friction of the wheel, plus a resistance due to the seals. If roller trains are used in place of wheels, the axle friction is eliminated, but a link friction must be added.

The force of friction plus or minus the weight of the gate must be considered in every hoist design. There are also hydraulic forces present which may increase the load on the hoist to a point where the above design, even with the customary factor of safety, is no longer safe. This force is caused by the unbalanced water pressures above and below a leaf when it is in a throttling position. The water passing below a flat bottom leaf exerts no pressure and may even create a partial vacuum on the under side of the leaf. As there is a pressure above the leaf, water pressure if the leaf is submerged and atmospheric pressure if it has a free water surface, the downward force is equal to the difference of the pressures above and below the gate in pounds per square inch multiplied by the area of the bottom of the leaf in square inches. By changing the shape of the bottom of the gate or of the approach, a pressure may be built up on the bottom of the leaf which will partially or completely eliminate the unbalanced condition. If the leaf is in a housing in the line, the pressure above the leaf, that is the pressure in the upper housing, can be controlled by careful selection of clearances between the leaf and housing, both on the upstream and downstream sides. Ring-follower gates are special cases and have additional forces caused by water passing through the fellow ring which is attached to and is a part of the leaf.

3. Tractor gate.

(a) Description of gate.—The "tractor gate" was developed to meet set requirements for an emergency gate for the power units at Norris Dam, the gate opening being 16.5 feet by 28.5 feet with a maximum head of 176 feet on the center line of the gate. It was desired that the gate and hoist be of such design that the gate, when not in use, could be raised above the water surface for storage and maintenance. This practically eliminated the use of a stem hoist. As a rope hoist cannot exert a downward thrust, the gate must be completely lowered by its weight alone. To do this, the friction must

be reduced to a minimum. This was accomplished by means of roller trains, the frictional resistance of the rollers being only about 0.01 of that caused by sliding surfaces. Due to the fact that the gate must be lowered by its weight in water, it was necessary to put the skin plate on the downstream face of the gate, allowing the water to completely fill the leaf section.

The next problem to be considered was the sealing of the gate under the 176-foot head. The common, flexible metal or rubber seal could not be used because of the high head and because of the drag offered by such a seal during the raising or lowering of the gate. Sealing by a metal-to-metal contact similar to the simple slide gate was deemed a desirable feature, so a movable wedge mounted on rollers was incorporated in the roller train, the wedge to be actuated by a toggle mechanism of such a design as to insure proper sequence of all movements in relation to the gate.

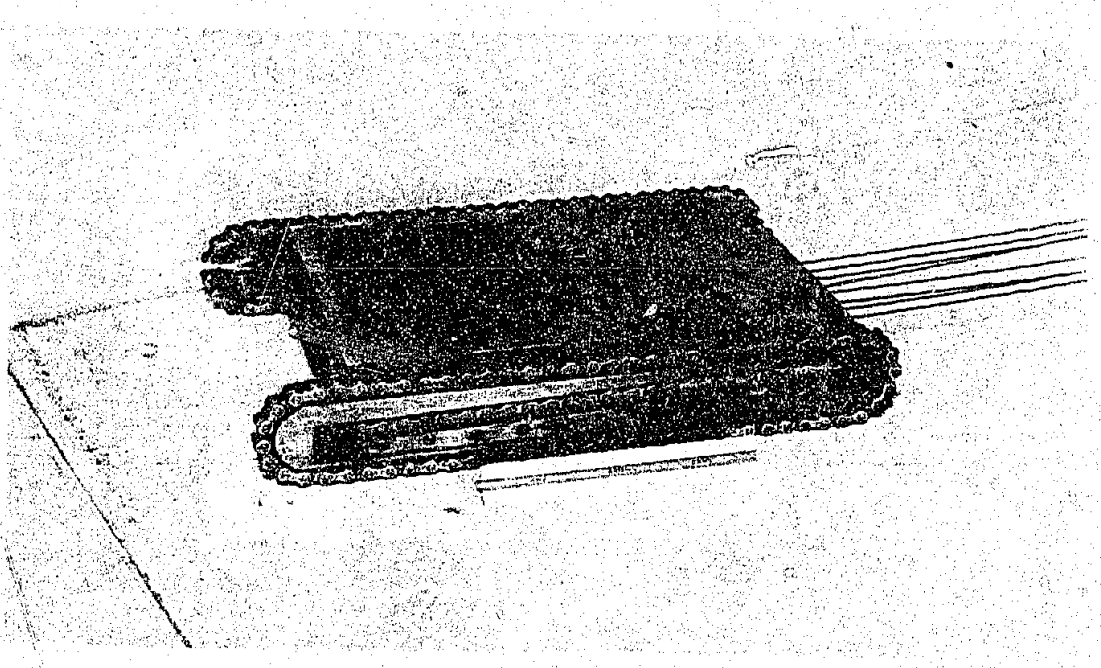
The sequence of the movements of the gate, starting from the above-water-surface position is as follows: The leaf is lowered on roller trains until it is directly in front of the frame opening; at this point the leaf rests on steps and the toggle allows the movable wedge to be lowered; meanwhile, the leaf moves in the downstream direction, transferring the water load from the rollers to the gate seat. Sealing is then accomplished in exactly the same manner as in the simple slide gate; that is, metal-to-metal contact. To open this gate the movable wedge is raised first, this move being made positive by the design of the toggle mechanism. As the wedge is raised, the gate moves upstream away from the seat, this time transferring the water load from the seat to the rollers. Then the leaf is raised on purely rolling surfaces. In short, the gate is raised or lowered as a "roller" gate and seals as a "slide" gate.

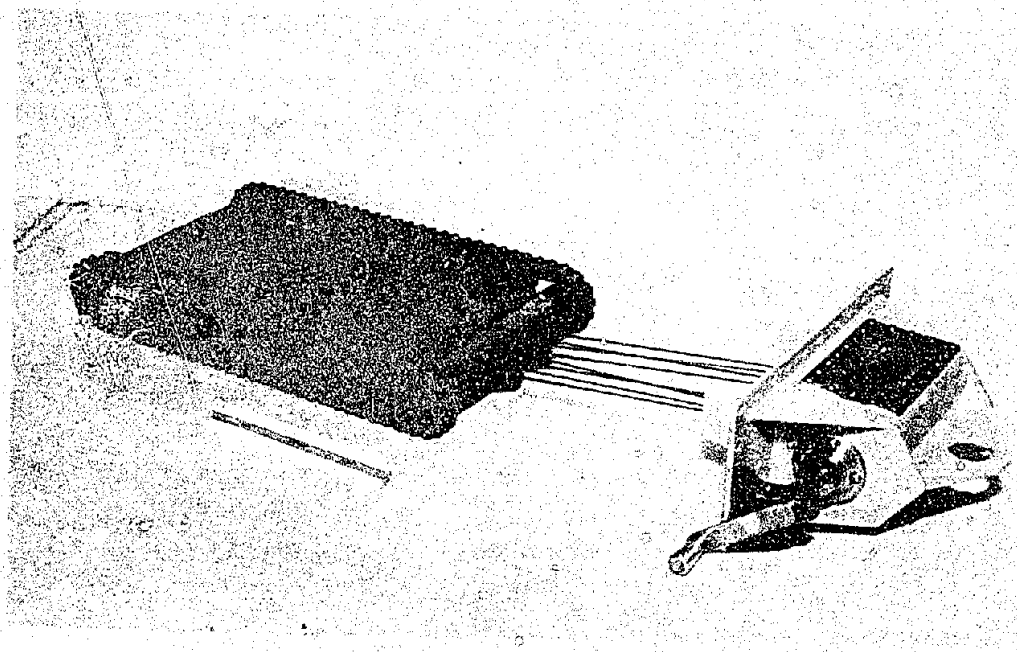
(b) Description of model.—In order to check the mechanics of the gate under working conditions, a 28 to 1 model was constructed

(see photographs on following page). The prototype gate was to operate on the face of the dam under 176 feet of water. As an exact duplicate set-up for mechanical or hydraulic tests, even at the 28 to 1 scale, would have required a large tank and overflow and would have made it almost impossible to observe the action of the leaf, a housing fitted with windows was used. (See drawing No. 222-D-817, page 5.)

(c) Flat bottom gates.—After testing and checking the mechanics of the leaf, a number of tests were made on the hydraulics of the gate. In order to determine the pressures and forces acting on the gate, a series of piezometers was attached in, below, and back of the leaf, and a spring scale was attached to the stem, the rope hoist having been replaced by a stem for the tests. As a result of the tests, the following general conclusions were found to hold for gates of this type.

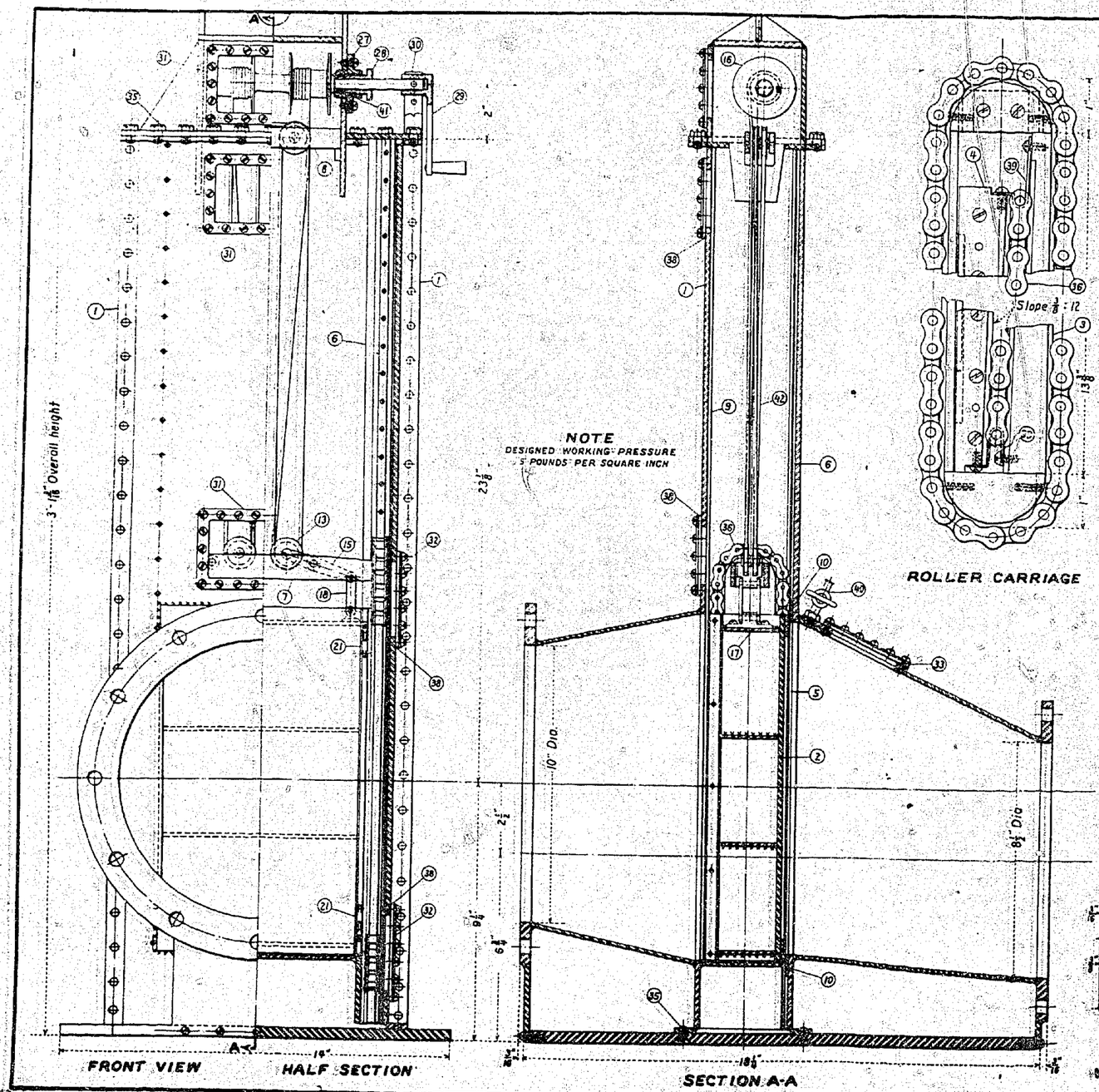
The gate as shown in sketch on page 6 has been raised to a point such that the distance from the bottom of the gate to the bottom seat is slightly less than one-third the thickness of the gate. At such a position, the section under the gate is similar to a "short tube" in effect. If the head on the gate is relatively low, less than 40 feet, the stream leaving the back edge of the gate is agitated and divergent. Due to this "breaking up" of the stream, its force is quickly dissipated. As there is practically no flow along the upstream face of the gate, the water pressure above and below each cross beam, except the bottom one, is very nearly balanced and is equal to the static pressure head at that point. Therefore, the pressure above the bottom beam is very nearly the static water pressure at that point, while the pressure below this beam is less than atmospheric (short-tube effect). This pressure difference applies a downward force on the leaf of slightly more than the operating water pressure on the bottom beam in pounds per square inch multiplied by the area of the bottom of the gate in square inches.

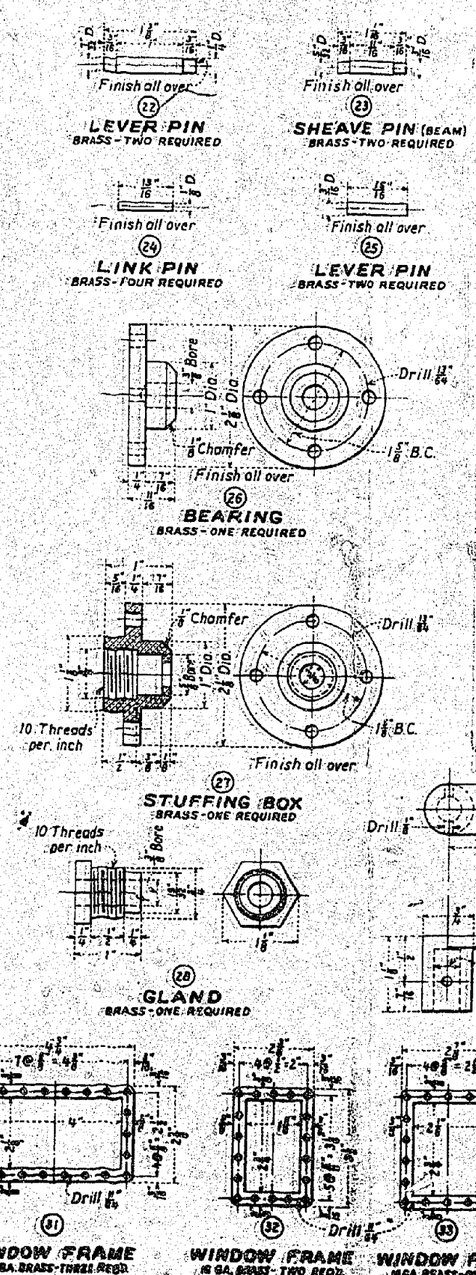




Tractor Gate Leaf

28:1 Model





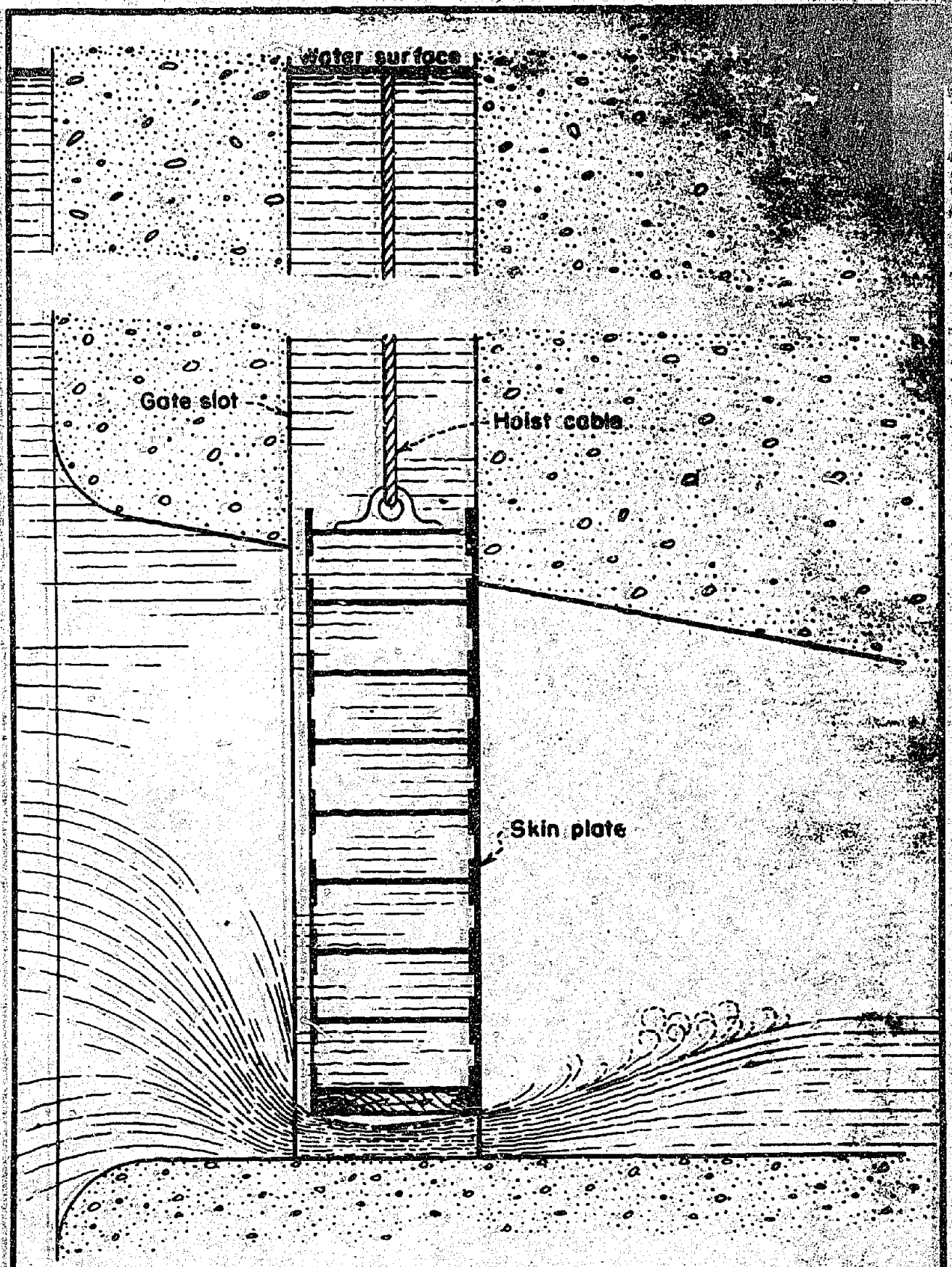
LIST OF PARTS

PART NUMBER	DESCRIPTION	MATERIAL	NUMBER REQUIRED	SHEET NUMBER
1	Gate housing	Steel plate	1	2
2	Leaf	Steel plate	1	3
3	Roller carriage	Brass	2	3
4	Roller wedge	Brass	2	3
5	Roller track	Brass	2	3
6	Roller track	Brass	2	3
7	Cross head	Brass	1	3
8	Lifting beam	Brass	1	3
9	Track	Brass	2	3
10	Housing seat	Brass	2	3
11	Leaf seat	Brass	2	3
12	Leaf seat	Brass	2	3
13	Sheave	Brass	6	3
14	Sheave	Brass	2	3
15	Lever	Brass	2	3
16	Hoist drum	Bronze	1	3
17	Bearing	Brass	2	3
18	Link	Brass	4	3
19	Sheave guard	Brass	1	3
20	Sheave guard	Brass	2	3
21	Contact roller	Brass	4	3
22	Lever pin	Brass	2	1
23	Sheave pin (Beam)	Brass	2	1
24	Link pin	Brass	4	1
25	Lever pin	Brass	2	1
26	Bearing	Brass	1	1
27	Stuffing box	Brass	1	1
28	Gland	Brass	1	1
29	Crank	Brass	1	1
30	Brake	Brass	1	1
31	Window frame	Brass	3	1
32	Window frame	Brass	2	1
33	Window frame	Brass	1	1
34	1/4 x 5/8 Hex. head cap screws	Steel	80	No detail
35	1/4 x 1 1/2 Flat head cap screws	Steel	28	"
36	Roller chain 1/2" pitch, 5/8" dia roller		8 Ft.	"
37	Roller chain connecting link		6	"
38	Pyralin windows		6	"
39	Equalizing chain		4	"
40	Petcock 1/8"		1	"
41	Packing		2	"
42	Light sash cord		15 Ft.	"

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT—WASHINGTON

GRAND COULEE POWER PLANT
15.5' x 28.5' TRACTOR INTAKE GATE
TEST MODEL
ASSEMBLY AND LIST OF PARTS

DRAWN H.H.K.-M.R. SUBMITTED
TRACED E.R.C.-M.A. RECOMMENDED
CHECKED R.E. APPROVED



SUBMERGED GATE

FIG. 2

222-D-1767

Considering the same gate as discussed above, but operating under a higher head (as was the case at Morris Dam), the stream will take more the shape of a jet being discharged from a sharp-edged orifice, the short-tube effect breaking down as the velocity increases.

The stream, being no longer "broomy", will continue in a fairly solid, clear jet for some distance after leaving the upstream edge of the leaf. As the discharge pipe fills with water, submerging the jet, there is a change in the shape of the jet and also in the coefficient of discharge. At partial gate openings, with the discharge pipe flowing full, there is a partial vacuum formed back of the leaf. This may be reduced by installing an air vent near the leaf in the discharge line. The pressure below the leaf at free discharge is atmospheric, but it is less than atmospheric if the jet is just submerged or if there is a partial vacuum in the discharge pipe. So the pressure below the bottom beam is atmospheric or less and, as before, the pressure above the beam is practically full head-water pressure, making the downpull again equal to slightly more than the operating water pressure in pounds per square inch on the bottom beam multiplied by the area of the bottom of the gate in square inches. The maximum downpull on a flat bottom gate occurs at a gate opening equal to about one-third the thickness of the leaf.

(d) Effect of sloping bottom of gate.--This downpull can be greatly reduced by changing the shape of the bottom of the gate, as shown in figure 4.

If this leaf is raised the same amount as in the two previously mentioned gates, the distance X becomes the depth of the controlling discharge area. The remainder of the gate leaf is at various distances from the seat and therefore a given amount of water will have a changing velocity as it passes under the leaf. The velocity at point B, ignoring losses and contractions, is half that at A. As the velocity varies as the square root of the head, only one-quarter

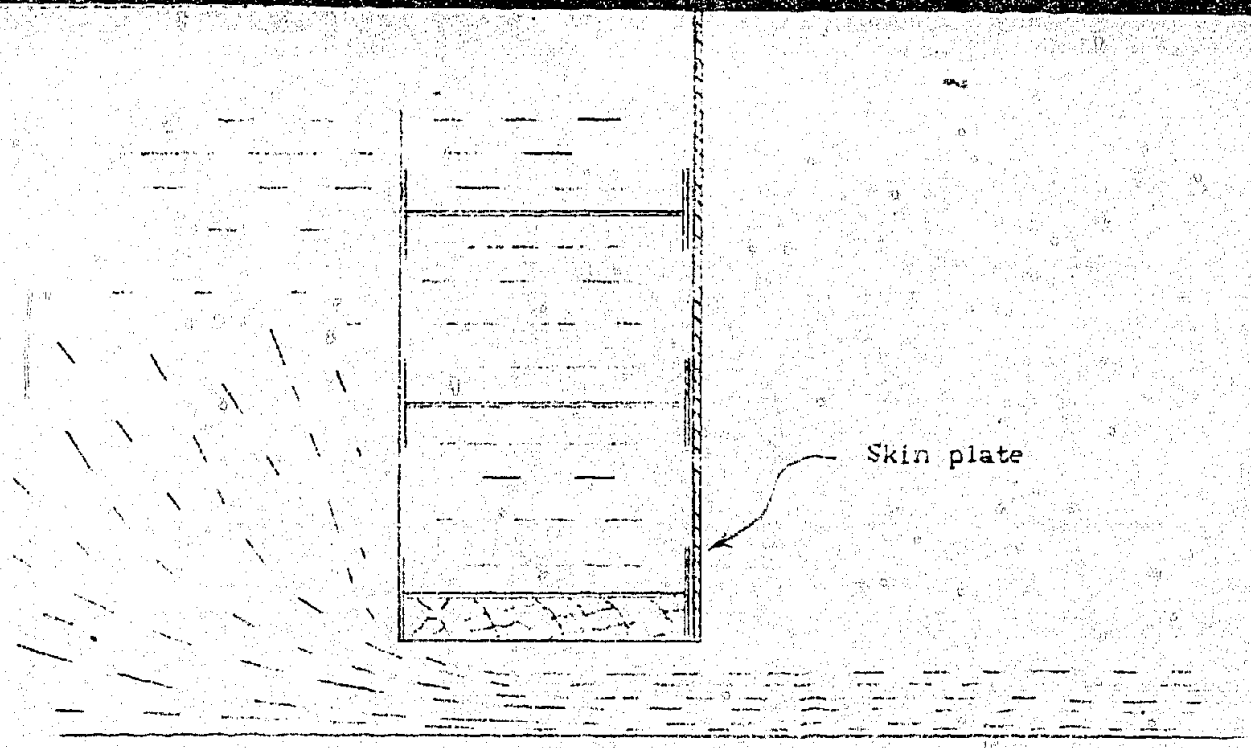


Figure 3

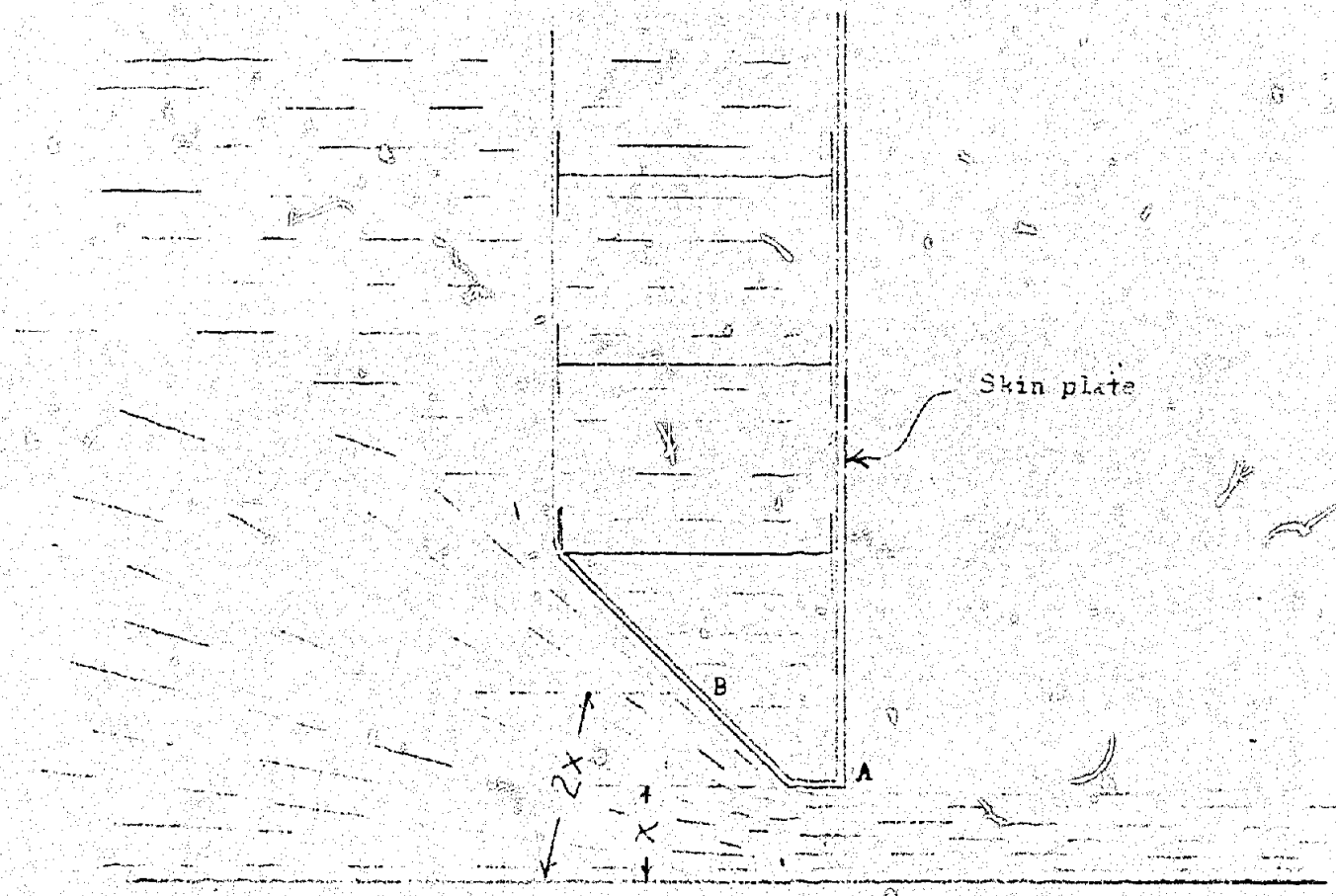


Figure 4

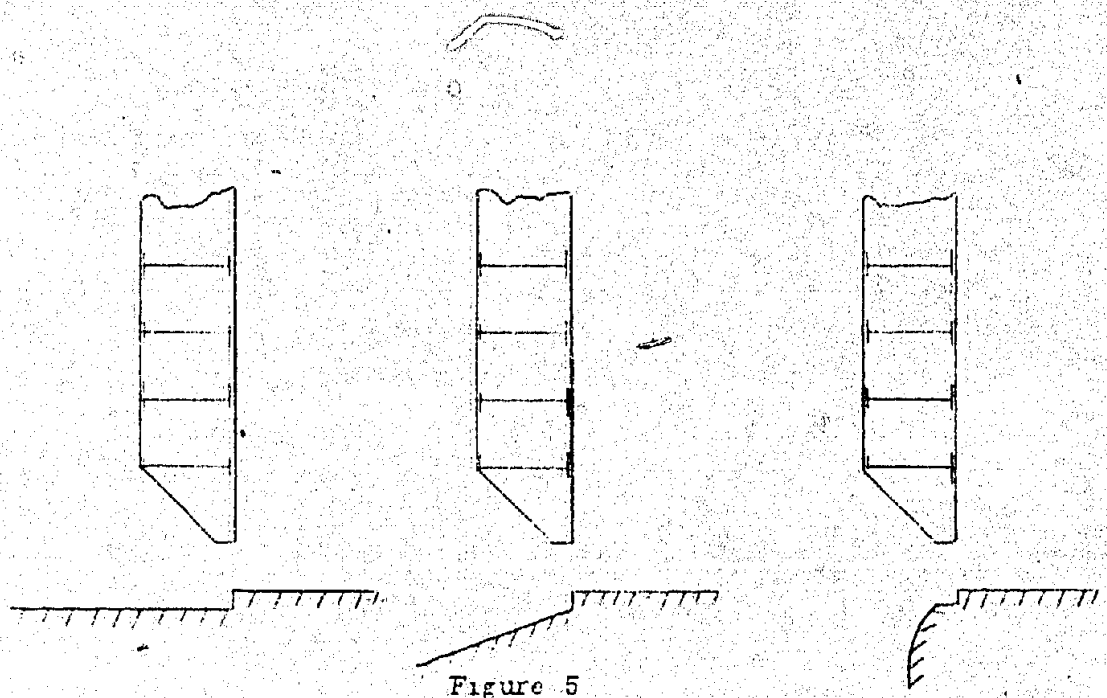


Figure 5

of the static head at B has been converted into velocity head. Therefore the uplift or pressure at B is equal to three-quarters of the head on the gate. As the leaf is raised, the ratio of openings at B and A change from an infinite value at complete closure to 2 to 1 as shown and on to nearly 1 to 1 as the gate is completely opened. At a nearly 1 to 1 ratio, the sloping bottom leaf is practically no better than the flat bottom leaf, but as a rule the gross area of the gate opening is large compared to the opening of the far end of the discharge pipe; therefore the pipe will flow full and form a back pressure before the leaf is completely raised. In this way the back pressure comes into play about the time the major effect of the sloping bottom is lost.

The pressure on the bottom of the leaf may be further increased by changing the shape of the bottom of the frame and approach, as shown in figure 5.

In all cases it will be noticed that the area back of the controlling surface has been increased. The downpull, due to unbalanced pressures at any gate opening, may be approximately calculated on the basis of varying velocity heads below the gate leaf.

All the above conditions are based on a submerged leaf having the skin plate on the downstream side. If the gate is submerged, but with the skin plate on the upstream side, the unbalanced pressures will be between the top and bottom of the gate. If the gate has a free water surface and has the skin plate on the downstream side, the above-discussed conditions for the bottom beam will still hold, but if the skin plate is on the upstream side, only atmospheric pressure acts on the top of the gate, and then the bottom beam should either be vented or shaped so as to prevent a less than atmospheric pressure under the bottom beam.

The photograph below shows water being discharged from a gate having the skin plate on the upstream side and having a free surface.

Head on gate about 35 feet. Note the type of discharge.

Figure 6

50- by 50-foot Regulating Gate - Gurnsey Dam.

(e) Test data.--The following data was taken during tests on the tractor gate. It will be noticed that the pressure above the bottom beam drops sharply in the model tests; actually this pressure in a gate on the face of a dam should drop by about the amount the gate is raised. In this set-up the pump was so small that at one-half gate opening the line pressure had dropped nearly 80 percent. Such a test, to get prototype scale, would require a large constant head tank.

TRACTOR GATE MODEL
NORRIS DAM

I-Beam Type Bottom Beam

Movement of Gate in Inches	Pressure Above Bottom Beam lb. per sq. in.	Average Pressure Bottom Side of Bottom Beam lb. per sq. in.	Differences of Pressures in lb. per sq. in.
0	5.9	5.9	0
Wedge raised	5.7	5.5	0.2
1/2	5.2	4.7	0.5
1	4.4	3.3	1.1
1-1/2	3.4	1.4	2.0
2	2.65	0.25	2.4
2-1/2	2.1	-0.2	2.3
3	1.8	-0.35	2.15
4	1.5	0	1.5
5	1.35	0.25	1.1
6	1.3	0.5	0.8
7	1.2	0.65	0.55
8	1.15	0.8	0.35
10	1.1	1.0	1

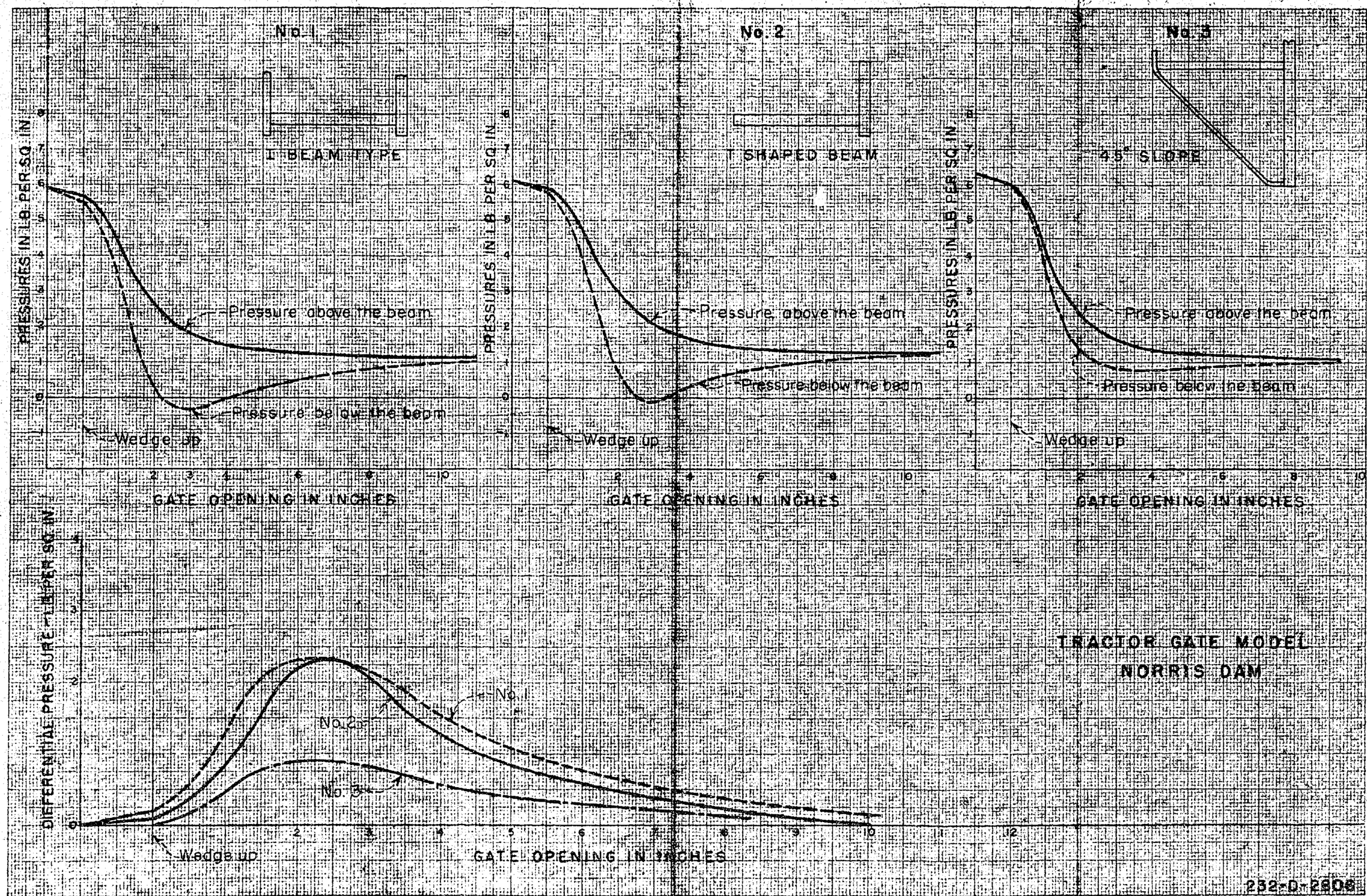
Note: The gate was raised one-fourth inch before the bottom of the leaf was even with the top of the bottom frame seat.

TRACTOR GATE MODEL
MORRIS DAM

T-Shaped Bottom Beam

Movement of Gate in Inches	Pressure Above Bottom Beam lb. per sq. in.	Average Pressure Bottom Side of Bottom Beam lb. per sq. in.	Differences of Pressures in lb. per sq. in.
0	6.1	6.1	0
Wedge raised	5.9	5.8	0.1
1/2	5.5	5.1	0.4
1	4.7	3.8	0.9
1-1/2	3.7	2.1	1.6
2	2.9	0.7	2.2
2-1/2	2.4	0	2.4
3	2.0	-0.1	2.1
4	1.7	0.4	1.3
5	1.5	0.7	0.8
6	1.4	0.8	0.6
7	1.35	0.95	0.4
8	1.3	1.05	0.25
10	1.25	1.2	0.05

Note: The gate was raised one-fourth inch before the bottom of the leaf was even with the top of the bottom frame seat.

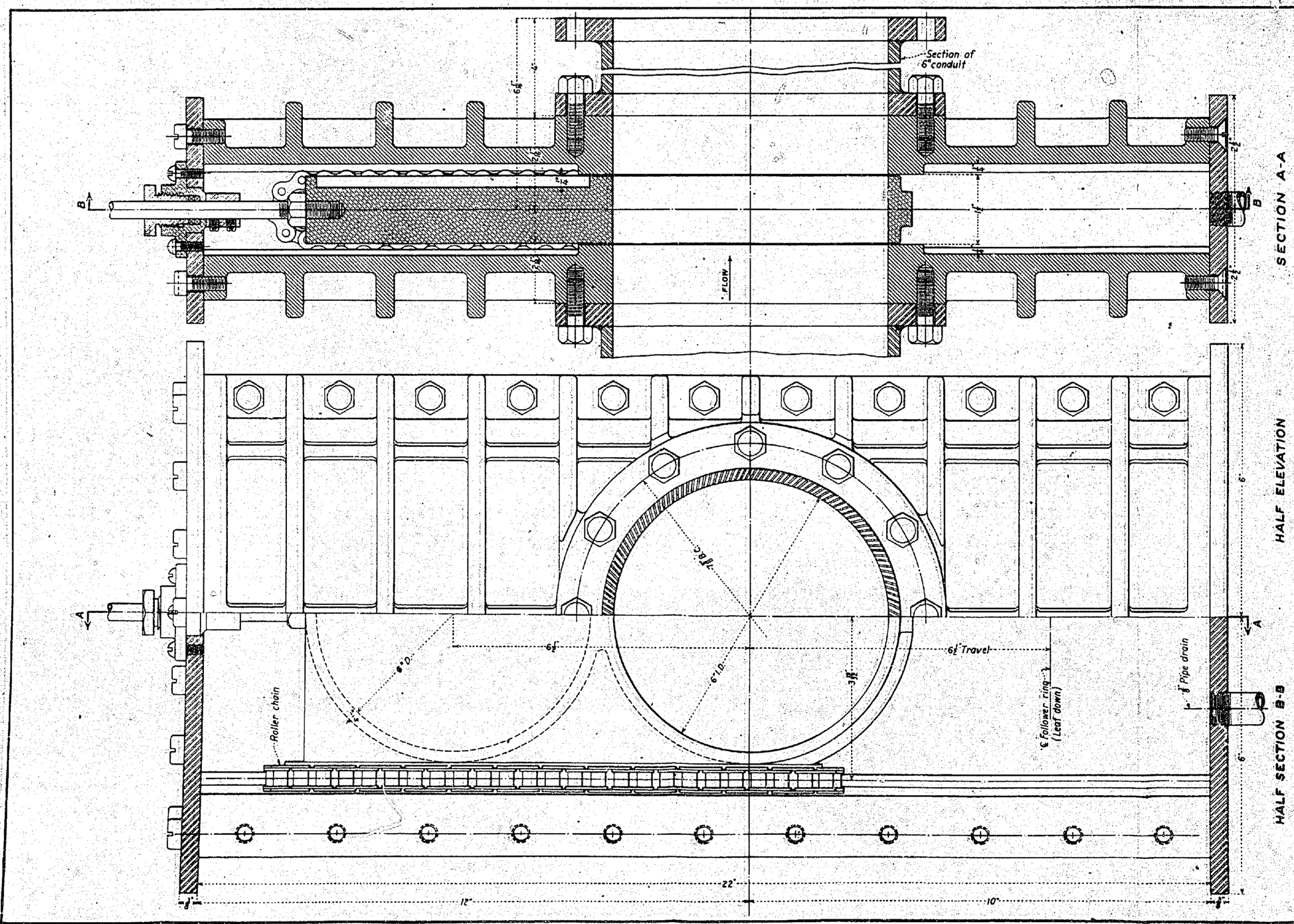

No. 1
I BEAM TYPE
PRESSURES IN LB. PER SQ. IN.
Pressure above the beam
Pressure below the beam
Wedge up
GATE OPENING IN INCHES
No. 2
T SHAPED BEAM
PRESSURES IN LB. PER SQ. IN.
Pressure above the beam
Pressure below the beam
Wedge up
GATE OPENING IN INCHES
No. 3
45° SLOPE
PRESSURES IN LB. PER SQ. IN.
Pressure above the beam
Pressure below the beam
Wedge up
GATE OPENING IN INCHES
DIFFERENTIAL PRESSURE - LB. PER SQ. IN.
No. 1
No. 2
No. 3
Wedge up
GATE OPENING IN INCHES
TRACTOR GATE MODEL
NORRIS DAM
232-D-2806

4. Ring-follower gate.

(a) Description of gate.—A ring-follower gate, as implied by the name, consists of a leaf with a following ring having the same inside diameter as the conduit and a housing of sufficient depth to accommodate the ring. The leaf may be raised and lowered on either sliding or rolling surfaces and may have any of a number of types of seating arrangements. When closed, the ring-follower leaf is similar to any leaf placed in a given housing, but when fully opened the ring, which is essentially a section of conduit, is brought in line with the opening and presents a smooth, continuous water passage. Such a gate is particularly well suited as an emergency gate for a turbine or needle valve, as there is practically no loss or turbulence when it is in a fully open position.

Ring-follower gates, when used as emergency gates, are for the protection, inspection, and maintenance of valves or turbines. The gates, under normal operating conditions, are to be opened and closed under balanced pressures, but in the case of an emergency might be operated under the full operating head. Ring-follower gates may also be used as regulating gates, where the degree of regulation is limited to one gate in a battery of gates, as is the case at Grand Coulee Dam where sixty 102-inch gates are proposed. As the gate is being raised or lowered, large forces, due both to dynamic and static water reactions, act on the leaf. Tests were run to determine the extent of these forces and also a means of reducing or controlling them.

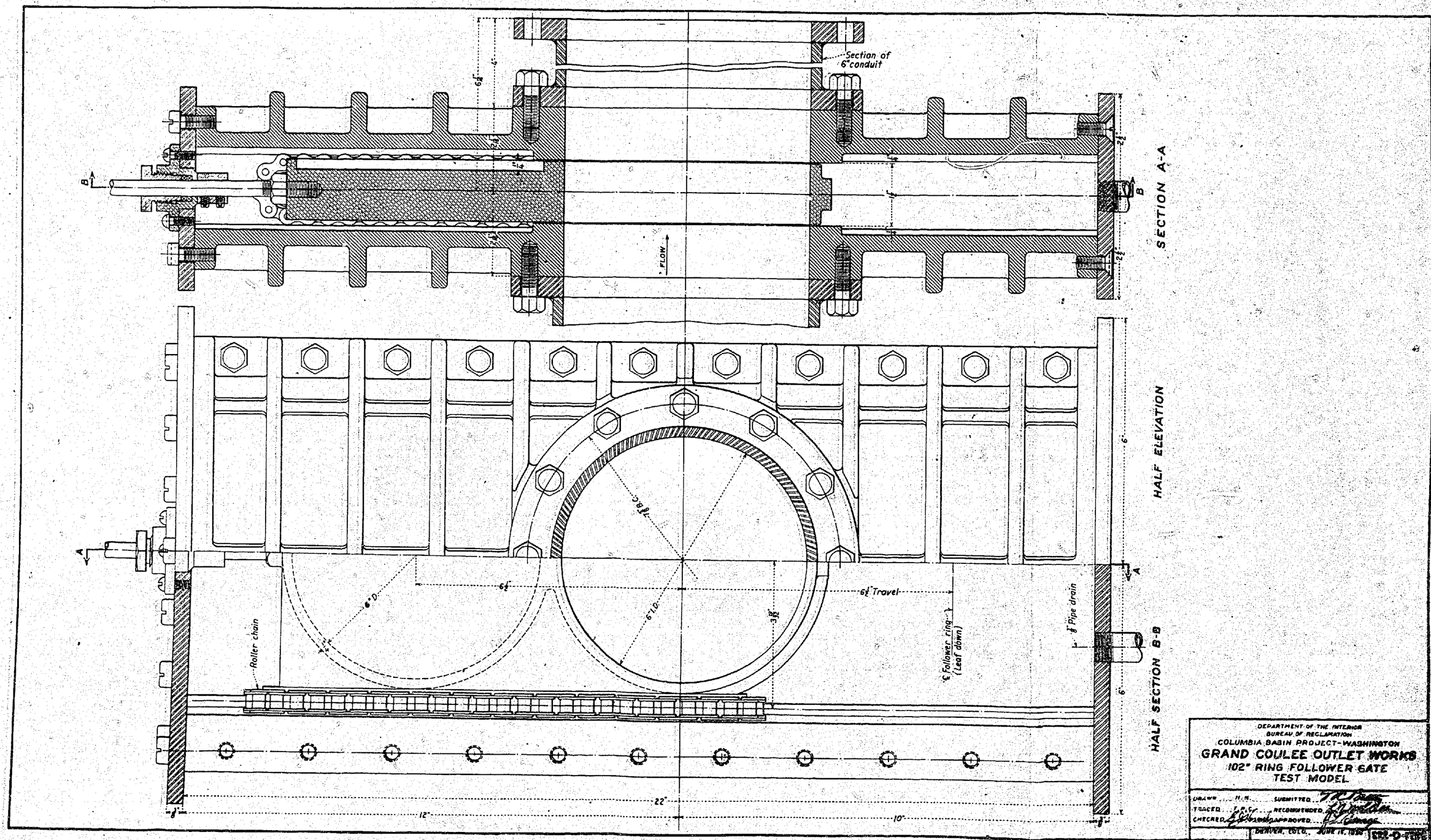
(b) Description of model.—A 6-inch ring-follower gate model (drawing No. 222-D-1752) was made for this purpose. The water load on the leaf was carried on roller chains, the leaf never actually seating against the housing. By use of the rollers the friction between the leaf and housing was reduced to a minimum. Spring scales were attached to the stem and in this way the stem loads were read directly in pounds. Piezometers were placed in the pipe and housing for pressure readings, and the amount of water passing through the system was measured by means of a V-notch weir.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT—WASHINGTON

GRAND COULEE OUTLET WORKS
102" RING FOLLOWER GATE
TEST MODEL

DRAWN H.H. SUBMITTED
TRACED J.R.C. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., JUNE 15, 1938


Section of 6" conduit
FLOW
SECTION A-A
HALF ELEVATION
HALF SECTION B-B
Roller chain
6' Travel
6' Follower ring (Leaf down)
8" Pipe drain
DEPARTMENT OF THE INTERIOR
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COLUMBIA BASIN PROJECT-WASHINGTON
GRAND COULEE OUTLET WORKS
102" RING FOLLOWER GATE
TEST MODEL

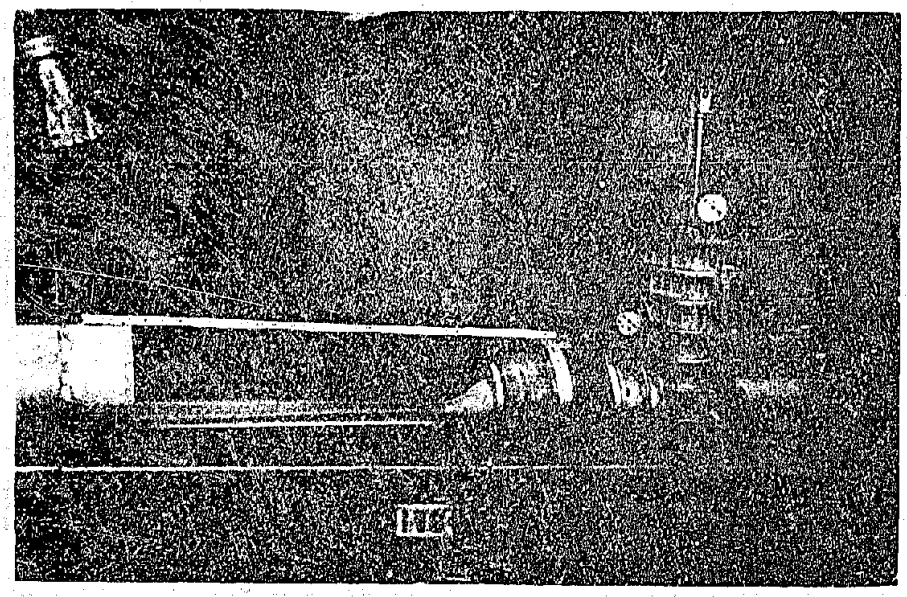


Figure 7

Above is a photograph of the 6-inch ring-follower gate model in line with a 5-inch interior-type needle valve.

Ring-follower gate is fully open, needle valve is 20 percent open, and the line pressure is 28 pounds per square inch.

(c) Hydraulic forces acting on gate.—The effect of the dynamic pressures will be discussed first.

The sketch above shows the leaf in a half-open position. Due to the semielliptical shaped water passage and the odd shape of the approach section, it is almost impossible to establish accurate flow lines. The flow lines indicated are those of a rectangular pipe section and leaf having a relatively high line pressure and discharging into a short pipe. With a lower pressure, the stream leaving the back edge of the leaf tends to be "broomy". The flow lines may be considered quite similar to this at the center-line section of the ring-follower gate.

The roller forming a part of the approach has little or no effect on the vertical forces acting on the leaf. The upper surface of this stream has the same tendency to break from the upper half of the ring as did the stream from the bottom of the previously discussed roller gates, meaning that the pressure on the upper half of the ring will be either atmospheric or less, depending on the head on the gate and the discharge conditions. The roller above the bottom half of the ring is rotating at a rate which is determined by the friction of the water passing above the roller and by the resistance to rotation of the ring and sides of the housing. As the rotating fluid, due to centrifugal force, exerts a pressure in its radial direction on the confining surfaces, it causes a downward pressure on the ring and tends to raise the lower surface of the stream. Due to the fact that the water is not entering the restricted opening symmetrically about its horizontal center line, a second force is applied to the leaf. At least a portion of the stream makes a slight turn as it enters the gate and it has an effect similar to that produced by directing a stream of water onto a flat plate. The vertical component of this force will be a function of the velocity and volume of the stream and of the angle that it makes with the plate. The amount of force exerted by the above-mentioned factors could be measured only by means of the spring scale on the gate stem. This gave the total downpull caused by the combined forces on a 6-inch gate directly in pounds.

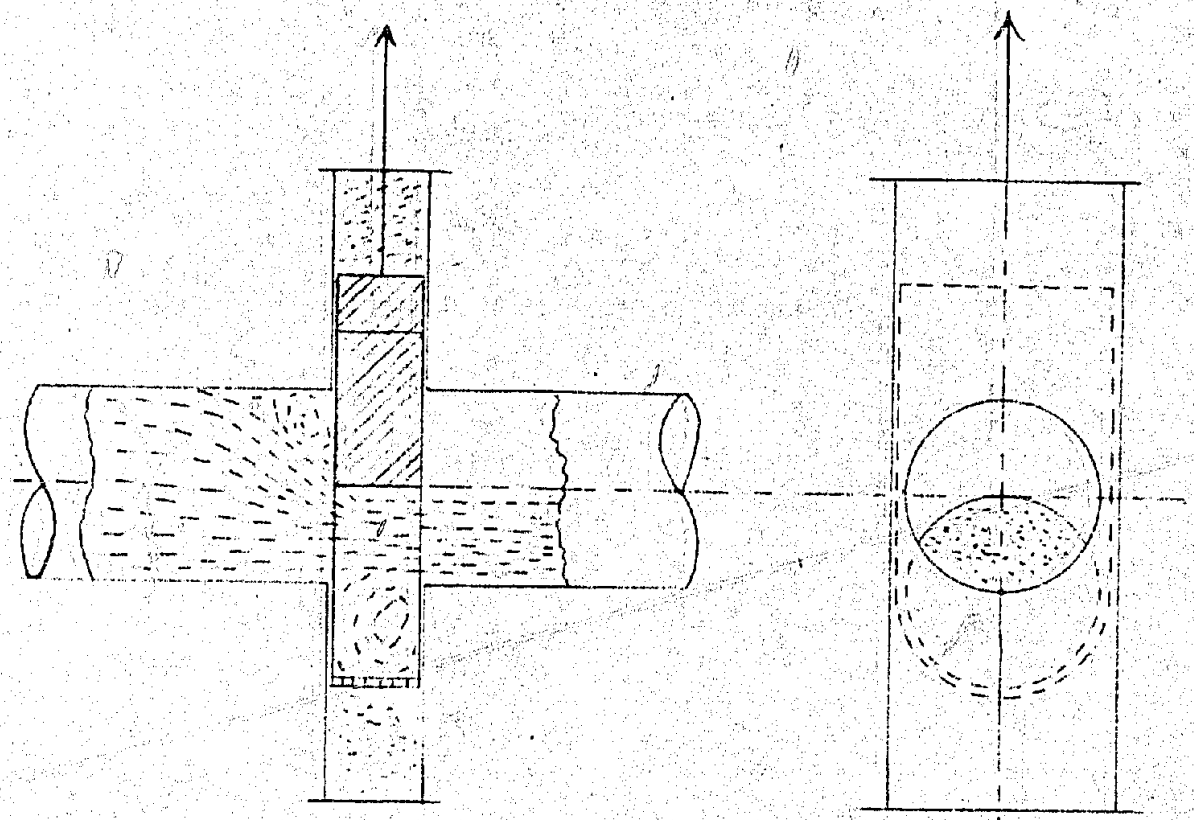


Figure 8

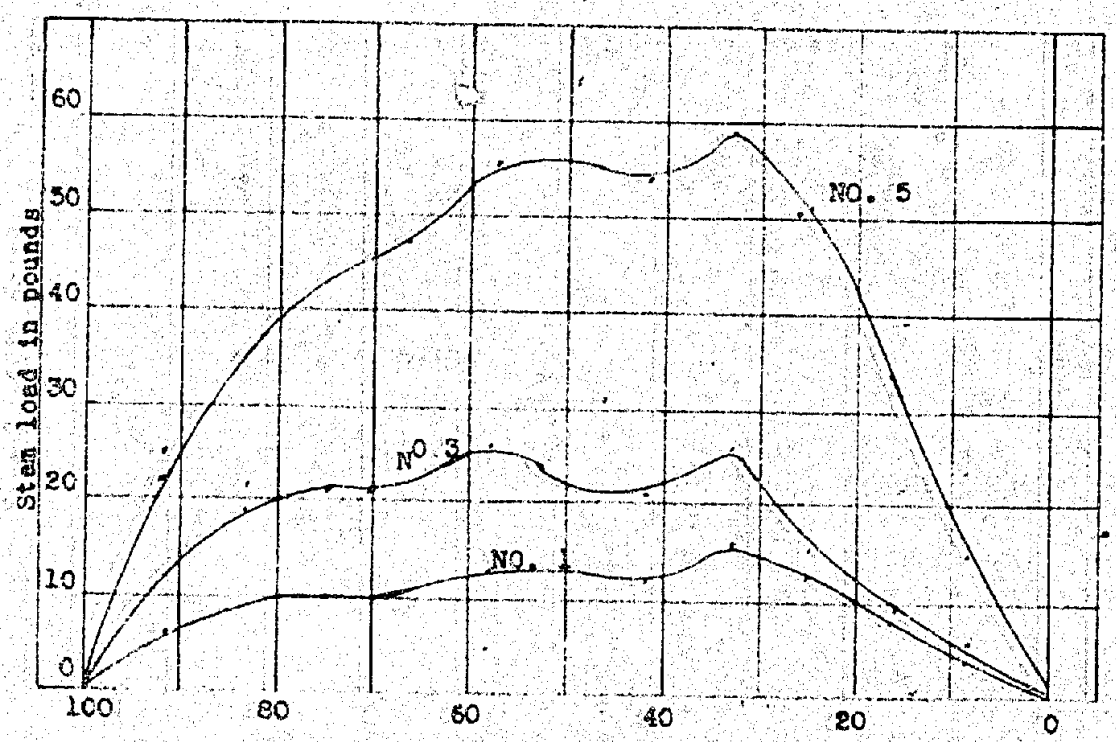


Figure 9

The following curves give the ratio of pull to gate opening under various pressure heads. In this case the pressure head was maintained by means of a 3,000-gallon-per-minute centrifugal pump driven by a variable-speed 75-horsepower motor.

Head on closed gate. For curve No. 1, 20.7 feet of water; No. 3, 24.5 feet; and No. 5, 62.0 feet (see test data page 30).

This force, at the maximum point, is equal to approximately one-quarter of the operating head in pounds per square inch multiplied by the projected area of the ring in square inches (inside diameter). How close this rule will hold for actual gates in service can be told only by running tests on such gates under field conditions.

The above-mentioned forces are due to water passing through the ring portion of the leaf. There is a second set of forces which act on the top and bottom projected areas of the leaf, including the roller trains. Such forces are caused by pressures of relatively still water and will be spoken of as static water pressures.

Referring to the sketch of the ring-follower gate, page 18, it can be seen that the water in the lower housing below the leaf is out of the main stream and is practically static. It is assumed that the side clearances between the leaf and housing are sufficiently close to allow but a relatively small amount of water to pass between the upper and lower housings. The pressure in the lower housing is about one-half line pressure at 10 percent closure, and it remains at about that ratio until 60 percent closed, "line pressure" being considered the pressure in the line for any given gate opening. As closure is continued, the pressure ratio decreases, reaching a minimum of one-third of the line pressure at a 10 percent opening, then increases to full line pressure as the gate is completely closed. The pressures in the lower housing were not affected by small changes of upstream and downstream clearances between the leaf and housing.

The control of pressures above the leaf is strictly a matter of clearances. If there is, as shown in the sketch, a relatively large clearance between the leaf and the upstream housing compared to the clearance on the downstream side, the pressure in the upper housing will be very nearly equal to the line pressure. If the two clearances are equal, the pressure above the leaf will approximately equal the average of the upstream and downstream pressures. By making the clearance small on the upstream side and relatively large on the downstream side, similar to the case of the leaf shown on drawing 222-D-1752, the pressure in the upper housing will be governed by the pressure in the discharge conduit. In this case the pressure in the upper housing will range from less than atmospheric to but a few pounds pressure.

The effects of the pressures in the upper and lower housings may combine to form a maximum downward force equal to two-thirds of the line pressure multiplied by the cross-sectional area of the gate to a maximum uplift equal to one-half the line pressure multiplied by that same area. In either case the point of maximum force on the leaf occurs when the gate is nearly closed and the line pressure is practically equal to the full head on the gate. Therefore, by a careful selection of clearances a gate may be designed in such a way that the static and dynamic forces present while operating the leaf will tend to oppose each other, thus effecting a great saving on necessary hoist requirements.

The static and dynamic forces mentioned above act on a ring-follower gate whether it is raised or lowered on either rolling or sliding surfaces. On rolling surfaces these forces may be large compared to the rolling resistance plus the dead weight of the gate. In such a case careful balancing is required if the saving in hoist capacity, due to the use of rollers, is to be fully utilized. If sliding surfaces are to be used, the hoist, being necessarily of such

6-INCH RING-FOLLOWER GATE MODEL
LARGE UPSTREAM CLEARANCE. TEST NO. 1
Leaf in Reversed Position from That Shown in Accompanying Drawing

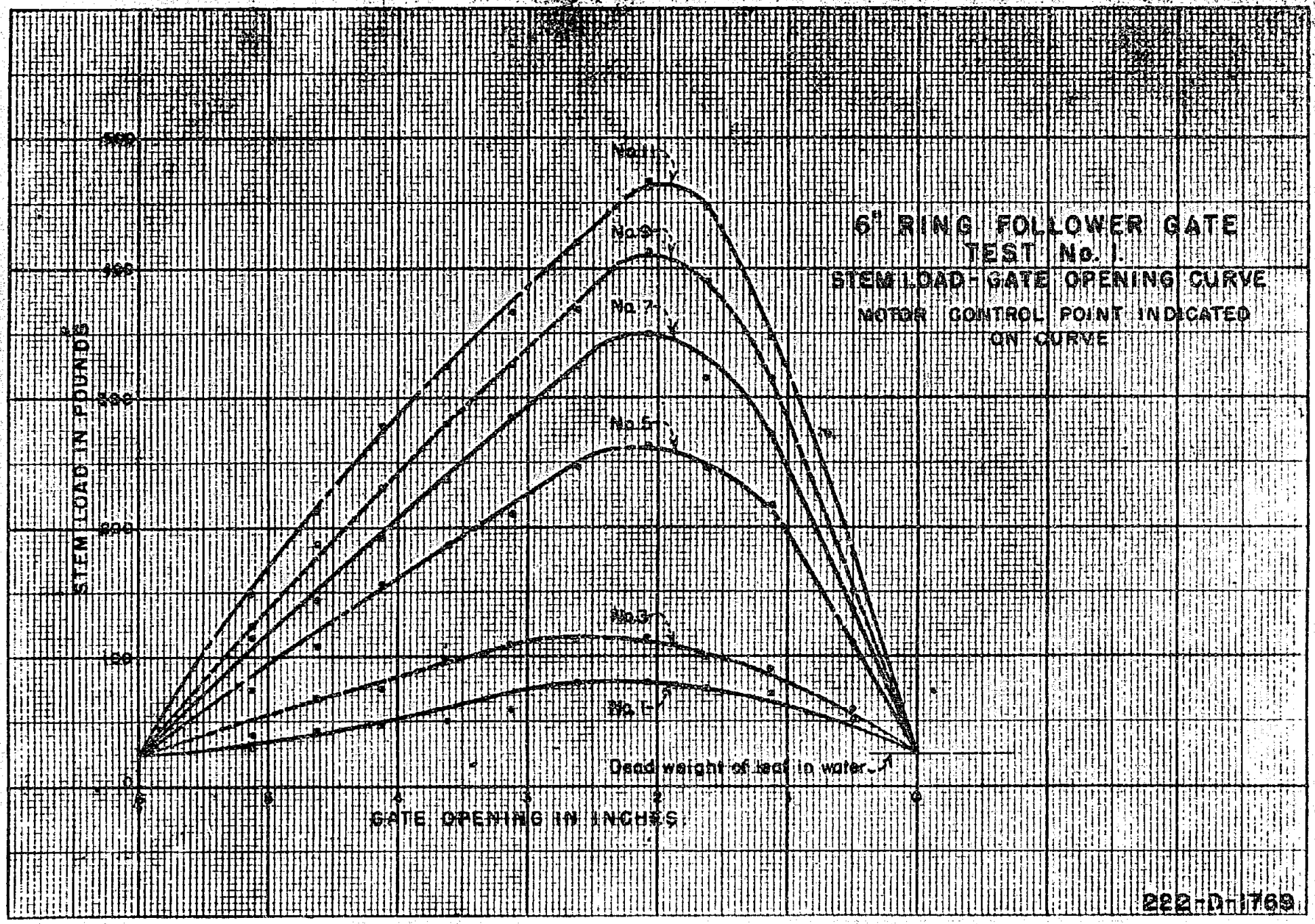
Paradox Gate with Needle Valve in Line, Model of Boulder Canyon Outlet Works

Gate Opening in Inches	Upper Housing Pressure lb. per sq. in.	Lower Housing Pressure lb. per sq. in.	Stem Load in Pounds
	Motor Control No. 1		
6	2	2	23
5-1/8	3	1	30
4-5/8	3	1	42
4-1/8	4	1-1/2	48
3-5/8	4	2	51
3-1/8	5	3	60
2-5/8	5	3	78
2-1/8	6	3	78
1-5/8	6-1/2	3	75
1-1/8	7	4	72
5/8	7	6	54
0	7	7	21
	Motor Control No. 3		
6	5-1/2	6	23
5-1/8	5-1/2	6	42
4-5/8	6	6	48
4-1/8	6-1/2	6	51
3-5/8	7	6	60
3-1/8	8	4-1/2	78
2-5/8	9	4	78
2-1/8	9	4-1/2	75
1-5/8	9-1/2	4-1/2	72
1-1/8	10	5	54
5/8	10	8	21
0			
	Motor Control No. 5		
6	10	11	23
5-1/8	10	10	75
4-5/8	12	7	108
4-1/8	14	6	156
3-5/8	15	6-1/2	186
3-1/8	17	7	210
2-5/8	20	7	246
2-1/8	23	9	264
1-5/8	24	10	246
1-1/8	25	12	219
5/8	25	18	108
0	25	23	21

6-INCH RING-FOLLOWER GATE MODEL
LARGE UPSTREAM CLEARANCE. TEST NO. 1
Leaf in Reversed Position from That Shown in Accompanying Drawing

Paradox Gate with Needle Valve in Line, Model of Boulder Canyon Outlet Works

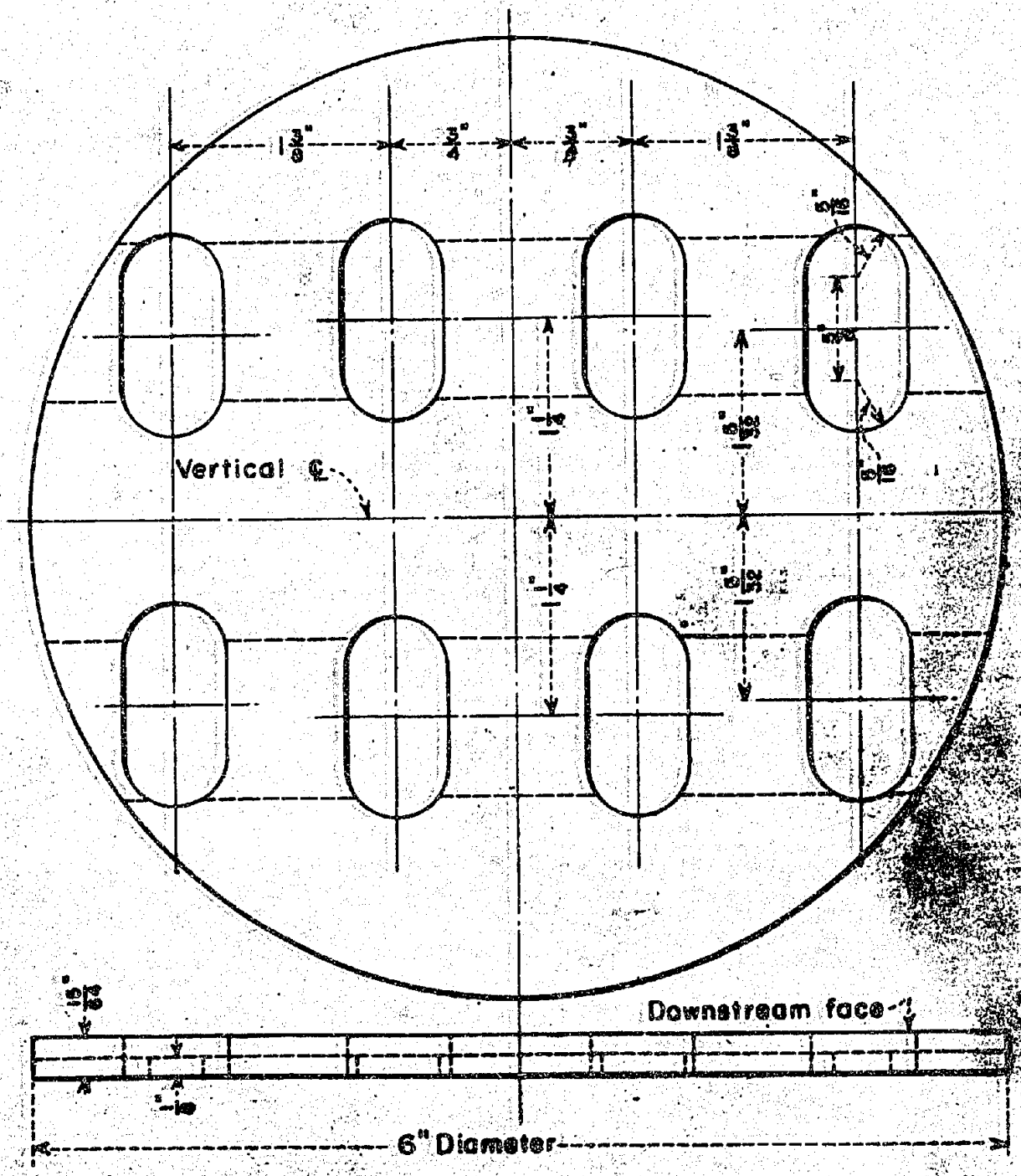
Gate Opening in Inches	Upper Housing Pressure lb. per sq. in.	Lower Housing Pressure lb. per sq. in.	Stem Load in Pounds
Motor Control No. 7			
6	14	15	23
5-1/8	15	14	114
4-5/8	18	10	144
4-1/8	20	8	192
3-5/8	22	9	237
3-1/8	24	10	285
2-5/8	27	11	324
2-1/8	30	12	351
1-5/8	32	14	315
1-1/8	34	16	270
5/8	34	25	138
0	34	33	21
Motor Control No. 9			
6	16	17	23
5-1/8	18	16	120
4-5/8	20	12	189
4-1/8	24	11	231
3-5/8	26	11	279
3-1/8	30	12	324
2-5/8	33	13	372
2-1/8	36	14	414
1-5/8	37	16	390
1-1/8	38	19	315
5/8	39	28	150
0	39	38	21
Motor Control No. 11			
6	20	21	23
5-1/8	23	18	150
4-5/8	25	14	216
4-1/8	27	13	279
3-5/8	30	14	324
3-1/8	33	14	366
2-5/8	37	15	420
2-1/8	42	16	468
1-5/8	42	18	447
1-1/8	43	21	348
5/8	43	31	180
0	43	42	23



EUGENE DIETZGEN CO. CHICAGO-NEW YORK NO. 350

(c) Alterations and results.—After testing the gate with the relatively large clearances between the leaf and upstream side of the housing, the leaf was reversed; that is, placed in the position shown on the drawing. The following data was obtained with the leaf in this position: With gate half opened, 3-inch gate opening, and the motor control set at No. 1, No. 3, and No. 5, the stem load was 18 pounds, 15 pounds, and 0 pounds, respectively. At the No. 5 setting the hoist was removed and the gate remained at that 3-inch opening. By increasing the head on the gate, control points, No. 7, No. 9, and No. 11, the opening was increased to 3-1/4 inches, 3-1/2 inches, and 3-5/8 inches, respectively, the leaf being raised and held in position by water pressures only. At No. 9 motor control, 42-pound maximum head, a downward force of approximately 70 pounds on the stem was required to close the gate.

The tests proved that the stem load could be controlled by varying the clearances between the leaf and housing. Therefore, a series of attempts were made to determine a set of clearances which would give a fairly well-balanced load throughout the travel of the gate. The disk shown on the following page was inserted in the space provided in the leaf, downstream side, and the following results were obtained.



DISC
BRASS ONE REQ'D

FOR GRAND COULEE 6" GATE MODEL

FIG. 10

222-D-1768

6-INCH RING-FOLLOWER GATE (6-INCH MODEL)

6-Inch Pipe Downstream from Gate - Grand Coulee Model, Aug. 5, 1936

Motor Control No. 1 - Head on Gate = 17.85'

Gate Opening Percent	Upper Hous. Ft. of H_2O	Lower Hous. Ft. of H_2O	Line Pressure Ft. of H_2O	Discharge Line Ft. of H_2O	Load on Hoist Lb.	Q Sec. Ft.	Stem Load Minus Wt. of Moving Parts
100.0	1.42	1.42	0.85	0.42	21.5	3.02	0.0
91.7	0.57	0.85	1.42	0.14	33.0	2.97	11.5
83.3	1.70	2.97	4.82	-0.14	25.0	2.60	3.5
75.0	1.56	3.40	6.23	-0.14	22.0	2.33	0.5
66.7	1.84	4.25	7.79	-0.14	23.0	2.02	1.5
58.3	1.84	4.67	8.07	-0.14	24.0	1.75	2.5
50.0	1.98	5.10	10.91	-0.14	21.5	1.45	0.0
41.7	2.07	5.67	12.32	-0.14	19.0	1.18	-2.5
33.3	2.97	5.95	13.74	-0.14	21.0	0.92	-0.5
25.0	2.69	5.67	15.02	-0.21	20.0	0.65	-1.5
16.7	3.12	4.96	16.29	-0.42	21.0	0.59	-0.5
8.3	6.37	5.24	16.86	-0.07	29.5	0.18	8.0
0.0	9.07	6.37	17.71	0.00	37.0	-	16.5
-6.3	17.00	17.00	17.85	0.00	21.5	-	0.0

Motor Control No. 2 - Head on Gate = 22.10'

100.0	1.84	1.84	1.13	0.64	21.5	3.56	0.0
91.7	0.28	0.71	1.84	0.14	36.5	3.51	15.0
83.3	1.56	3.12	6.09	-0.14	27.5	3.07	6.0
75.0	1.42	3.97	8.22	-0.57	24.5	2.73	3.0
66.7	2.27	5.24	10.62	-0.57	24.5	2.39	3.0
58.3	2.55	6.37	13.03	-0.57	25.0	2.05	3.5
50.0	2.69	6.94	15.30	-0.21	23.0	1.69	1.5
41.7	3.26	7.65	17.00	-0.14	22.0	1.36	0.5
33.3	3.82	7.93	18.70	-0.14	24.5	1.02	3.0
25.0	3.40	7.08	20.12	-0.21	23.0	0.76	1.5
16.7	4.11	6.37	21.11	-0.42	24.0	0.46	2.5
8.3	8.22	5.67	21.25	-0.14	36.5	0.19	1.5
0.0	12.19	7.93	21.82	0.00	44.0	-	16.5
-6.3	20.97	20.97	22.10	0.00	21.5	-	0.0

6-INCH RING-FOLLOWER GATE (6-INCH MODEL)
6-Inch Pipe Downstream from Gate - Grand Coulee Model, Aug. 5, 1936

Motor Control No. 3 - Head on Gate = 23.23'

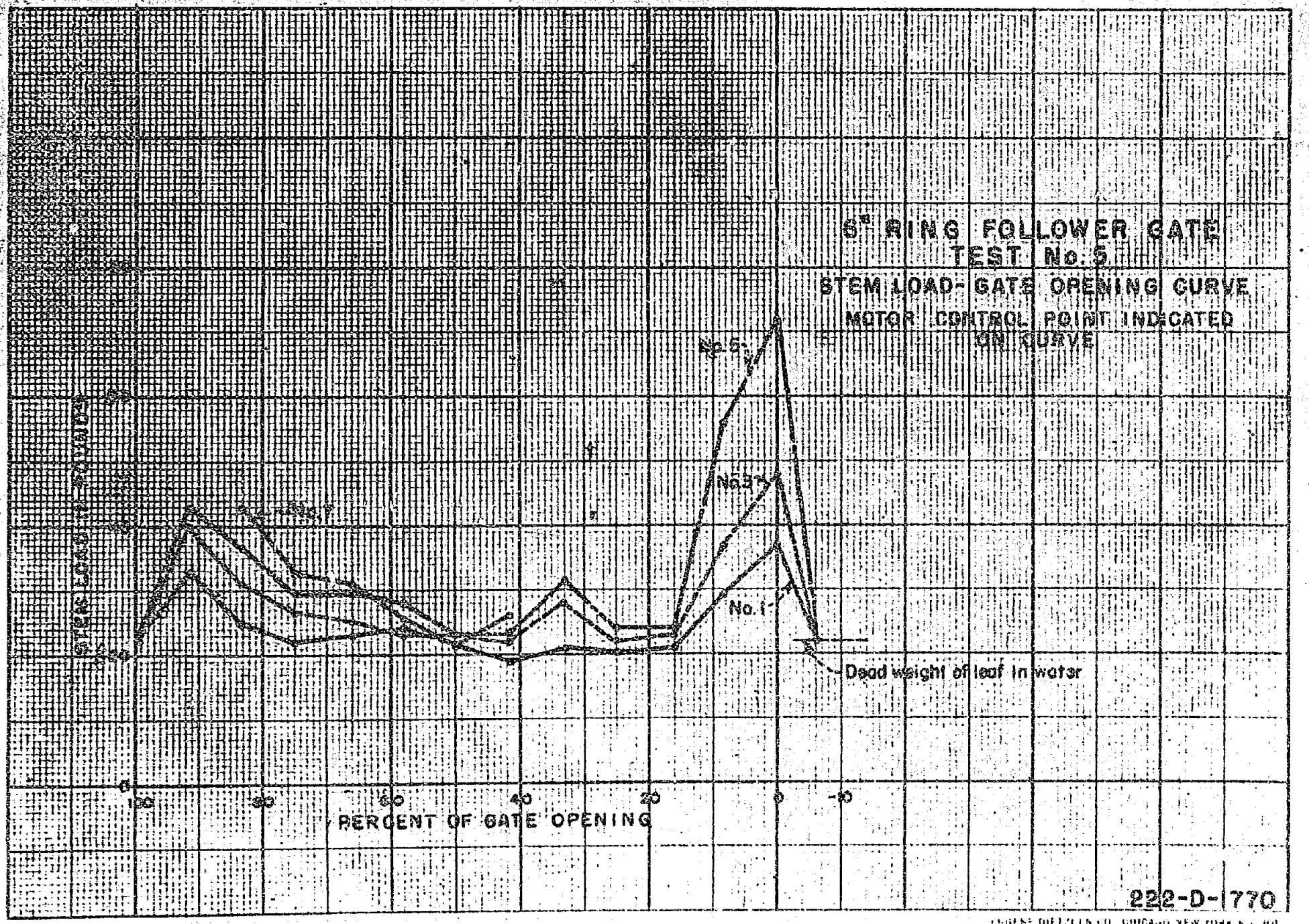
Gate Opening Percent	Upper Housing Pressure Ft. of H_2O	Lower Housing Pressure Ft. of H_2O	Line Pressure Ft. of H_2O	Discharge Line Ft. of H_2O	Load on Hoist Lb.	Q Sec. Ft.
100.0	3.12	3.12	1.70	0.85	21.5	4.60
91.7	0.57	0.85	2.97	0.14	40.0	4.48
83.3	1.70	4.67	9.35	-0.42	31.0	3.99
75.0	1.13	6.09	13.17	-1.27	26.5	3.42
66.7	2.83	8.22	16.43	-1.06	25.0	2.99
58.3	3.54	8.78	18.42	-0.99	23.0	2.46
50.0	3.82	9.63	20.40	-0.57	23.0	1.99
41.7	3.97	9.92	22.10	-0.42	22.0	1.58
33.3	4.53	9.07	22.95	-0.42	28.0	1.22
25.0	4.11	8.07	23.09	-0.71	22.0	0.80
16.7	4.53	7.08	23.23	-0.71	23.0	0.49
8.3	8.92	7.22	23.23	-0.14	37.0	0.20
0.0	12.90	8.36	22.95	0.00	48.0	-
06.3	21.82	21.82	23.09	0.00	21.5	-

Motor Control No. 5 - Head on Gate = 60.49'

100.0	5.52	5.38	3.26	2.41	21.5	6.45
91.7	4.25	5.24	10.20	-0.42	43.0	6.04
83.3	3.26	8.22	17.57	-1.27	37.0	5.53
75.0	2.12	11.05	25.07	-2.97	29.5	5.00
66.7	3.68	14.59	31.73	-3.68	29.5	4.34
58.3	5.67	17.42	38.25	-3.68	28.0	3.69
50.0	6.23	18.84	43.63	-3.40	23.0	3.03
41.7	7.93	20.68	48.87	-2.55	23.0	2.39
33.3	9.35	19.83	51.99	-2.69	31.5	1.76
25.0	8.07	18.56	55.82	-3.82	24.0	1.23
16.7	11.05	16.86	57.94	-1.98	23.0	0.76
8.3	22.67	17.99	58.51	-0.42	56.0	0.36
0.0	33.43	29.94	59.78	0.00	72.0	-
-6.3	58.22	58.22	60.49	0.00	21.5	-

Motor Control No. 7

83.3	4.53	11.62	23.23	-1.98	43.0	-
75.0	3.26	15.72	36.28	-4.25	32.5	-
66.7	-	-	-	-	31.0	-
58.3	8.22	22.38	54.55	-5.67	25.0	-
50.0	8.07	23.94	61.91	-4.82	21.5	-
41.7	10.20	28.19	67.15	-4.25	26.0	-



EUGENE DIETZGEN CO., CHICAGO NEW YORK No. 150

The load-gate opening curve for the Grand Coulee gate model shows a rather well-balanced design, the high point being found at about 10 percent gate opening. The reason for a maximum stem load is that at this point the downstream clearance has been reduced so as to equal about the same or less than the upstream clearance.

Next, a test was run to determine the effect of water passing through the ring section as the leaf is raised or lowered. By use of a bleeder line from the pump to the upper housing, the pressures in the upper and lower housings could be balanced. The remaining force, that caused by the water passing through the leaf, was measured directly by means of a spring scale attached to the stem.

The following results were obtained:

RING-FOLLOWER GATE (6-INCH MODEL)

August 13, 1936.

Motor Control No. 1 - Head on Gate = 20.67' H_2O

Gate Opening Percent	Top & Bottom Housing Pressure Ft. of H_2O	Line Pressure Ft. of H_2O	Hoist Load Lb.	Dynamic Force Lb.	
100.0	0.28 T	1.84	22	0	
91.7	Balanced	3.54	28	6	
83.3	"	4.82	31	9	
75.0	"	5.67	32	10	
66.7	"	8.78	32	10	
58.3	"	10.55	35	13	
50.0	"	12.18	35	13	
41.7	"	13.60	34	12	
33.3	"	15.00	38	16	
25.0	"	16.28	35	13	
16.7	"	17.41	30	8	
8.3	1.70 T	18.70	33	4	Based on 10 sq.in. area
0.0	3.40 T	20.10	37	0	" " " " " "
-6.3	-	20.67	22	0	

RING-FOLLOWER GATE (6-INCH MODEL)

August 13, 1936.

Motor Control No. 2 - Head on Gate = 23.40' H_2O

Gate Opening Percent	Top & Bottom Housing Pressure Ft. of H_2O	Line Pressure Ft. of H_2O	Hoist Load Lb.	Dynamic Force Lb.	
100.0	0.14 Top	1.13	22	0	
91.7	Balanced	-	38	16	
83.3	"	6.52	34	12	
75.0	"	8.92	35	13	
66.7	"	11.61	38	16	
58.3	"	14.02	39	17	
50.0	"	16.44	40	18	
41.7	"	18.28	39	17	
33.3	"	19.70	45	23	
25.0	"	21.40	38	16	
16.7	"	22.67	33	11	
8.3	2.27 T	23.40	39	7	Based on 10 sq.in. area
0.0	3.40 T	23.40	38	1	" " " "
-6.3	-	23.40	22	-	

Motor Control No. 3 - Head on Gate = 24.53' H_2O

100.0	0.28 T	2.13	22	0	
91.7	Balanced	2.97	44	22	
23.3	"	9.28	41	19	
75.0	"	12.67	43	21	
66.7	"	16.06	42	20	
58.3	"	19.00	48	26	
50.0	"	21.25	41.5	19.5	
41.7	"	22.62	43	21	
33.3	"	23.80	48	26	
25.0	"	24.53	37	15	
16.7	"	24.53	31	9	
8.3	1.77 T	24.38	34	5	Based on 10 sq.in.area
0.0	3.97 T	24.08	37	-2	" " " "
-6.3	-	24.38	22	-	

RING-FOLLOWER GATE (6-INCH MODEL)

August 13, 1936.

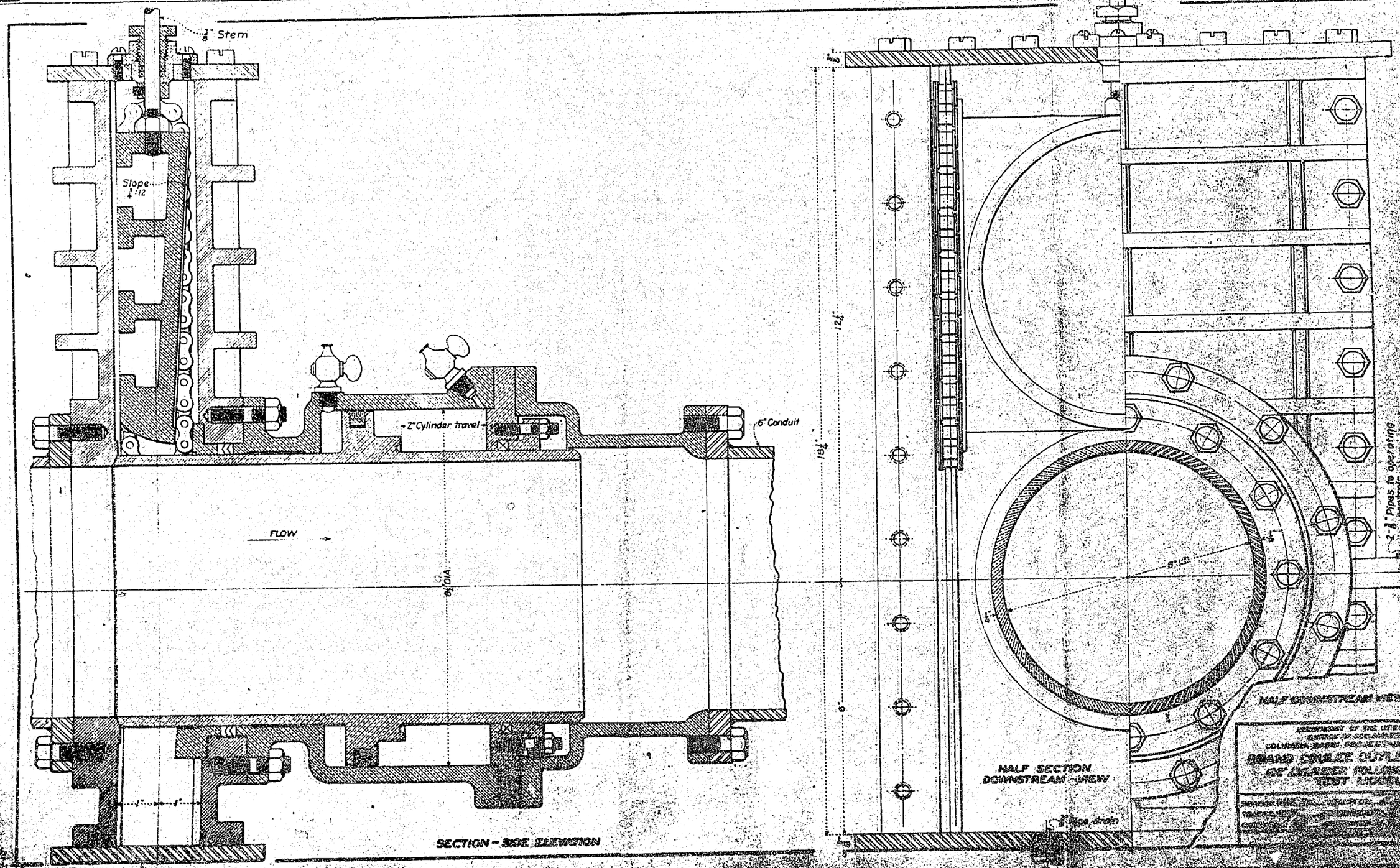
Motor Control No. 5 - Head on Gate = 61.95' H_2O

Gate Opening Percent	Top & Bottom Housing Pressure Ft. of H_2O	Line Pressure Ft. of H_2O	Hoist Load Lb.	Dynamic Force Lb.	
100.0	0.21 T	3.40	22	0	
91.7	Balanced	10.62	47	25	
83.3	"	17.56	43	21	
75.0	"	25.93	65	43	
66.7	"	33.03	69	47	
58.3	"	38.55	78	56	
50.0	"	44.37	78	56	
41.7	"	49.75	76	54	
33.3	"	54.00	81	59	
25.0	"	56.90	73	51	
16.7	"	59.50	56	34	
8.3	6.66	61.20	66	15	Based on 10 sq. in. area
0.0	9.06	61.95	66	5	" " " " "
-6.3	-	61.95	22	-	

See discussion of dynamic forces on paradox gates for curves, page 19.

5. Cylinder-follower gate.

(a) Description of gate and model.—The cylinder-follower gate, drawing No. 222-D-1753, derives its name from the movable cylinder. This cylinder may be placed on either the upstream or downstream side of the leaf. It is moved into position by means of water pressure. In this particular gate, with the leaf in a raised position, the cylinder may be moved upstream, making a continuous water passage through the housing. The cylinder, when moved into this position, also seals the water from the housing, allowing inspection and maintenance of the gate without throwing the line out of service. The accompanying photograph illustrates that fact. The cylinder-follower gate, 6-inch model, in line with a ring-follower gate and needle valve, has a line pressure of 10 pounds per square inch. By moving the cylinder upstream the leaf may be removed from the housing without


Stem
Slope 1:12
2" Cylinder travel
6" Conduit
FLOW
DIA.
SECTION – SIDE ELEVATION
HALF SECTION DOWNSTREAM VIEW
HALF DOWNSTREAM VIEW
2-1" Pipes to operating controls
Ice drain
BEAVER COULEE OUTLET
TEST MODEL

interrupting the flow of water. The needle valve was throttled down until a pressure of 35 pounds per square inch was recorded without leakage into the housing.

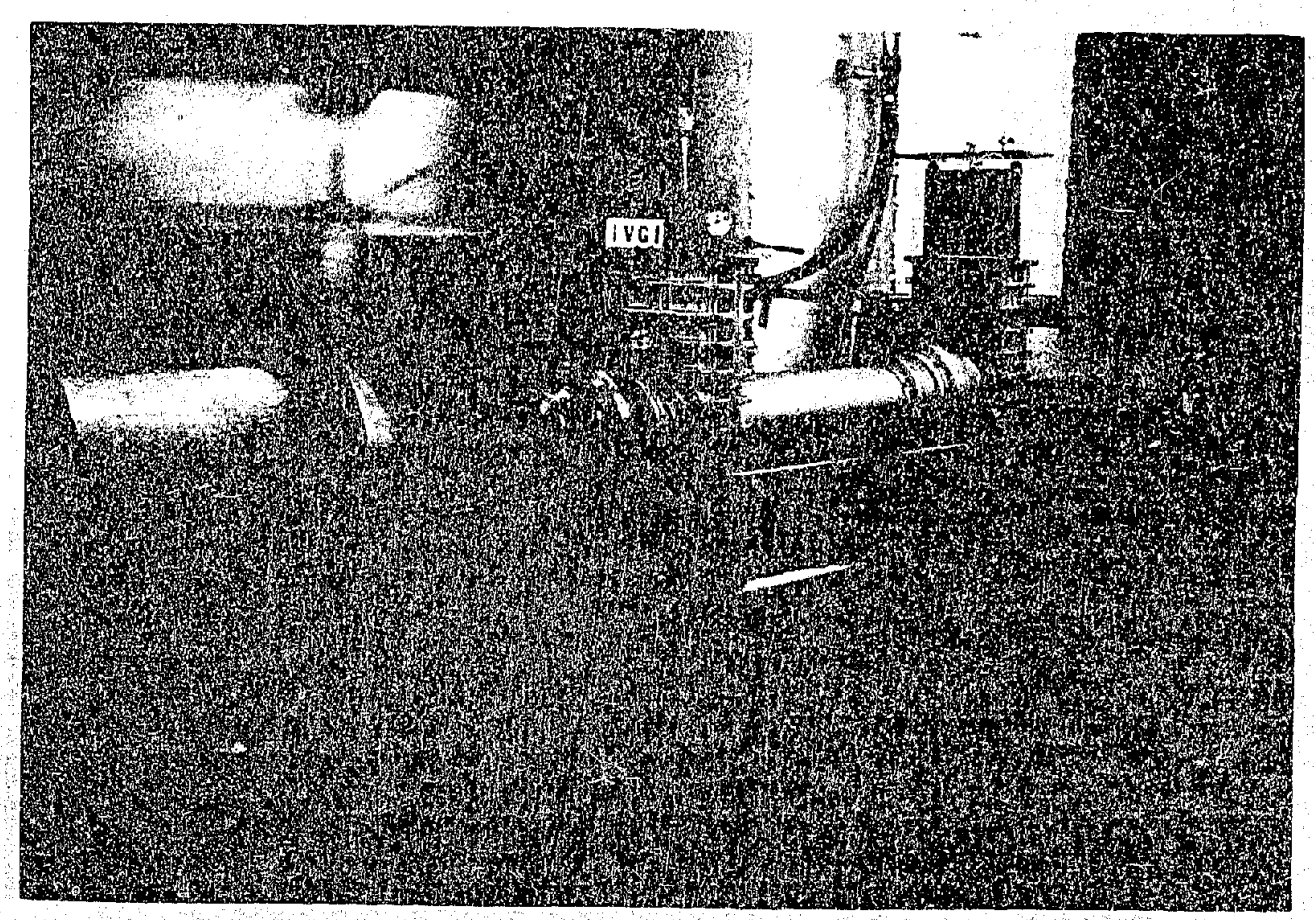


Figure 11

The seating surface of the leaf is set at a slight taper, 1/4 inch to 12 inches, the matching seat on the housing being set at the same taper. By tapering the seats in this fashion and by carrying the water load of the leaf on roller chains, the seats do not come into contact except when the gate is completely closed. Sealing

in the model was accomplished by leaf-to-housing contact, similar to a slide gate. The prototype will have a spring- or rubber-loaded ring seal.

(b) Discussion of hydraulic forces.--The forces on this leaf during closing or opening operations were quite well balanced. An uplift was caused by the use of a sloping bottom on the leaf and because of a square gate operating in a round conduit. This uplift is balanced by a pressure in the upper housing, this pressure being controlled by clearances between the leaf and the housing, as in the case of the ring-follower gate. The downstream clearance in this case is inherent because of the slope of the seat, making the upstream clearance the controlling factor. As the gate is closed, the pressure in the housing, that is, above and below the leaf, is equal to the head on the gate. Due to the differences of the effective areas of the top and bottom of the gate there is a downpull equal to that difference of areas in square inches multiplied by the water pressure in pounds per square inch. If the clearances between the leaf and housing are properly proportioned, the downpull at closure is the maximum hydraulic force to be considered in the design of a hoist for this type of leaf.

(c) Test data.--Test data from 6-inch cylinder-follower gate is shown in the following table.

6-INCH CYLINDER FOLLOWER GATE

Arapahoe Street Laboratory,
June 12, 1936.

Meter Setting No. 1

Gate Opening in Inches	Pressure at Pump lb./sq.in.	Upper Bonnet Pressure lb./sq.in.	Pressure at Bottom of Housing lb./sq.in.	Load on Stem in lb.
6	5.0	2.0	2.0	15.0
4-1/2	5.0	2.0	2.0	15.0
3-3/4	-	-	2.0	23.0
3	5.0	1.5	-	27.5

6-INCH CYLINDER FOLLOWER GATE

Motor Setting No. 1 (Cont'd.)

Gate Opening in Inches	Pressure at Pump lb/sq.in.	Upper Bonnet Pressure lb./sq. in.	Pressure at Bottom of Housing lb./sq.in.	Load on Stem in lb.
2-1/4	6.3	1.5	3.0	28.0
1-1/2	6.5	2.0	4.0	27.5
0-3/4	8.0	3.5	6.7	28.0
0	8.0	8.0	7.0	35.5
0-1/8	12.3	9.0	8.0	38.0

Motor Setting No. 3

6	9.0	4.5	5.5	15.0
4-1/2	9.0	4.0	6.0	12.0
3-3/4	-	-	-	25.0
3	10.0	3.5	4.0	33.0
2-1/4	10.5	3.0	4.3	37.0
1-1/2	10.5	4.0	5.5	35.0
0-3/4	11.5	5.5	7.0	37.0
0	16.0	12.0	13.0	52.0
-0-1/8	17.0	12.5	14.0	62.5

Motor Setting No. 5

6	18.5	8.0	8.5	15.0
4-1/2	18.5	8.0	8.0	26.0
3-3/4	-	-	-	35.5
3	19.5	9.5	11.5	52.5
2-1/4	21.5	7.0	9.0	58.5
1-1/2	24.5	10.0	13.0	50.0
0-3/4	26.0	14.0	16.5	61.0
0	27.0	22.0	22.0	80.0
-0-1/8	31.3	26.0	28.0	96.0

Motor Setting No. 7

6	26.0	11.5	12.0	15.0
4-1/2	26.0	11.0	11.5	28.0
3-3/4	-	-	-	49.0
3	27.0	11.0	15.0	65.0
2-1/4	29.5	11.5	13.0	73.0
1-1/2	32.0	14.0	16.5	68.0
0-3/4	33.5	18.0	22.0	73.5
0	34.5	29.0	30.0	95.0
-0-1/8	37.5	34.0	35.0	116.0

6-INCH CYLINDER FOLLOWER GATE

Motor Setting No. 9

Gate Opening in Inches	Pressure at Pump lb./sq. in.	Upper Bonnet Pressure lb./sq.in.	Pressure at Bottom of Housing lb./sq.in.	Load on Stem in lb.
6	32.0	15.0	14.5	15.0
4-1/2	32.0	14.0	15.0	29.0
3-3/4	-	-	-	54.0
3	33.5	11.0	15.0	74.0
2-1/4	36.0	14.0	15.0	84.5
1-1/2	37.5	17.0	20.0	82.0
0-3/4	39.5	22.5	25.5	80.0
0	40.0	32.5	33.0	114.0
-0-1/8	42.0	40.0	40.0	130.0

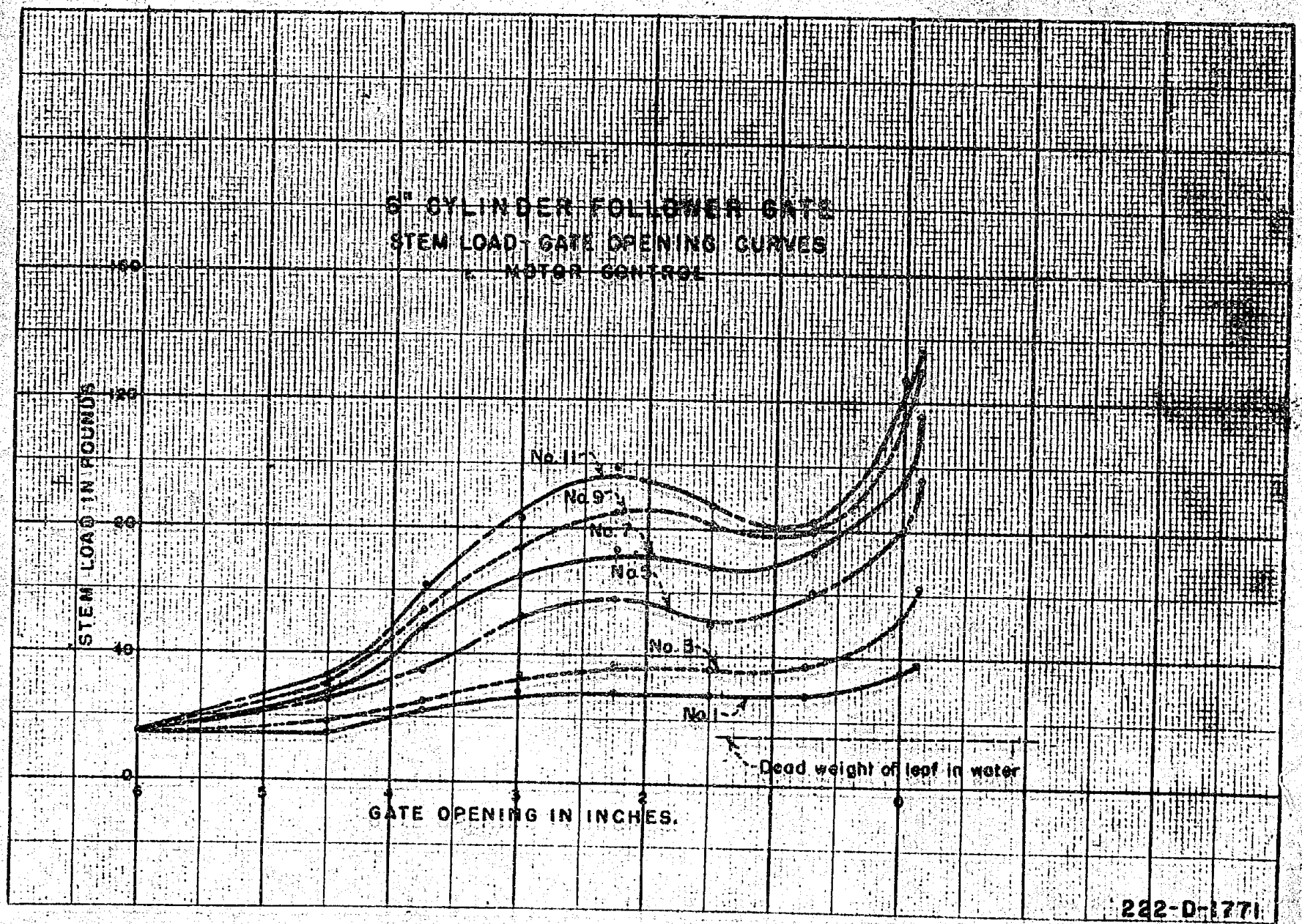
Motor Setting No. 11

6	38.0	18.0	17.0	15.0
4-1/2	38.0	16.0	17.0	32.5
3-3/4	-	-	-	62.0
3	39.0	12.0	16.0	83.0
2-1/4	40.5	16.0	17.0	99.0
1-1/2	42.0	20.0	22.0	86.5
0-3/4	44.0	25.0	28.0	82.5
0	44.0	38.0	44.0	127.0
-0-1/8	44.0	42.0	43.0	136.0

6. General Summary. Hoist requirements to operate any type of a regulating are: Friction plus or minus the weight of the moving parts, minus the effect of buoyancy, plus the static or dynamic water pressures acting on the leaf. The maximum possible effect of pressures acting on a tractor gate on the face of a dam, having skin plate on the downstream side, is the sum of the water pressure-head on the bottom beam in pounds per square inch and the 14-pound per square inch atmospheric pressure multiplied by the area of the bottom of the gate in square inches. If the skin plate is on the upstream face of the gate, the water pressure is measured on

the top of the gate. This holds for either submerged or free water surface types of gates. This pressure effect may be partially or completely eliminated by proper shaping or venting of the bottom of the gate and approach. If the gate is to be used in a pressure line, the pressure above the gate may be controlled by careful selection of clearances between the leaf and housing, both on the upstream and downstream sides. The ring-follower gate is a special case of the tractor gate in a pressure line and it has four surfaces which may be acted upon by water pressures, giving a possible downpull of two-thirds of the pressure head in pounds per square inch multiplied by the projected area of the top of the leaf in square inches, or an uplift of one-half of the pressure head in pounds per square inch multiplied by the same area. By proper selection of clearances these forces may be balanced so as to produce but a slight effect on hoist requirements.

Another feature to be considered in the design of two gates in a line, one acting as an operating gate, the other as an emergency gate, is the distance between gates. This distance must be great enough to allow a "hydraulic jump" to form between gates with upstream gate at a throttling position, or the downstream gate, which might be a needle valve, must be designed to withstand the force of the "off center" jet.



DIETZGEN CO. CHICAGO-NEW YORK NO. 150

Denver, Colorado, March 9, 1938.

MEMORANDUM TO MR. W. C. BEATTY
(W. Noonan)

Subject: Field tests on downpull on 16.5-foot by 28.5-foot Morris tractor gate being lowered under emergency conditions, and a comparison of calculated loads for the same conditions.

Reference

Memorandum to Chief Designing Engineer: Model Studies of the Mechanics and Hydraulics of Large Control Gates - June 17, 1937.

Test Data.

Curves furnished by TVA. Photostats pages 3 and 4.

Calculations from Test Data.

Weight of moving parts in air (estimated). . . . . .240,000 lb.
Weight of moving parts in water 6.8/7.8 x 240,000. .209,000 lb.
Use 210,000-pound weight in water.

From curves No. 1 and 2:

Thirteen units represent power developed lowering the gate under balanced conditions.

Thirty-five units represent power used in raising the gate under balanced conditions.

Therefore:

210,000 - friction	= 13 units	
210,000 + friction	= 35 units	
2 friction	= 22 units	
Friction	= 11 units	
35 - 11	= 24 units	= 210,000 lb.
1 unit	= 8,750 lb.	
11 units	= 96,250 lb.	= friction.

For all calculations the friction is assumed to be proportional to the load. In this computation the friction is 11/24 or 0.458 of the load.

From curve No. 3, power developed, wicket gates blocked open during lowering the gate (emergency condition).

Fourteen units = load on hoist before gate reached the opening. Therefore, the increased load on the cable or "downpull", at any position is equal to: (reading in units at that position minus 14) x 1.458 x 8,750.

Maximum "downpull" = (32-14) x 1.458 x 8,750 = 230,000 lb. See curves for loads at various gate openings.

Gate openings in feet are marked on curve No. 3. It will be noted that the curve crosses the 14 unit line at one foot opening or one foot from the gate limit. On the "downpull" gate opening curve this position is considered zero gate opening. This one foot should indicate the distance from the sill to the stop. Actually the sill is only eight inches above the stop. This difference and possibly a slight difference in the position of the maximum "downpull" is probably due to the stretch in the cable.

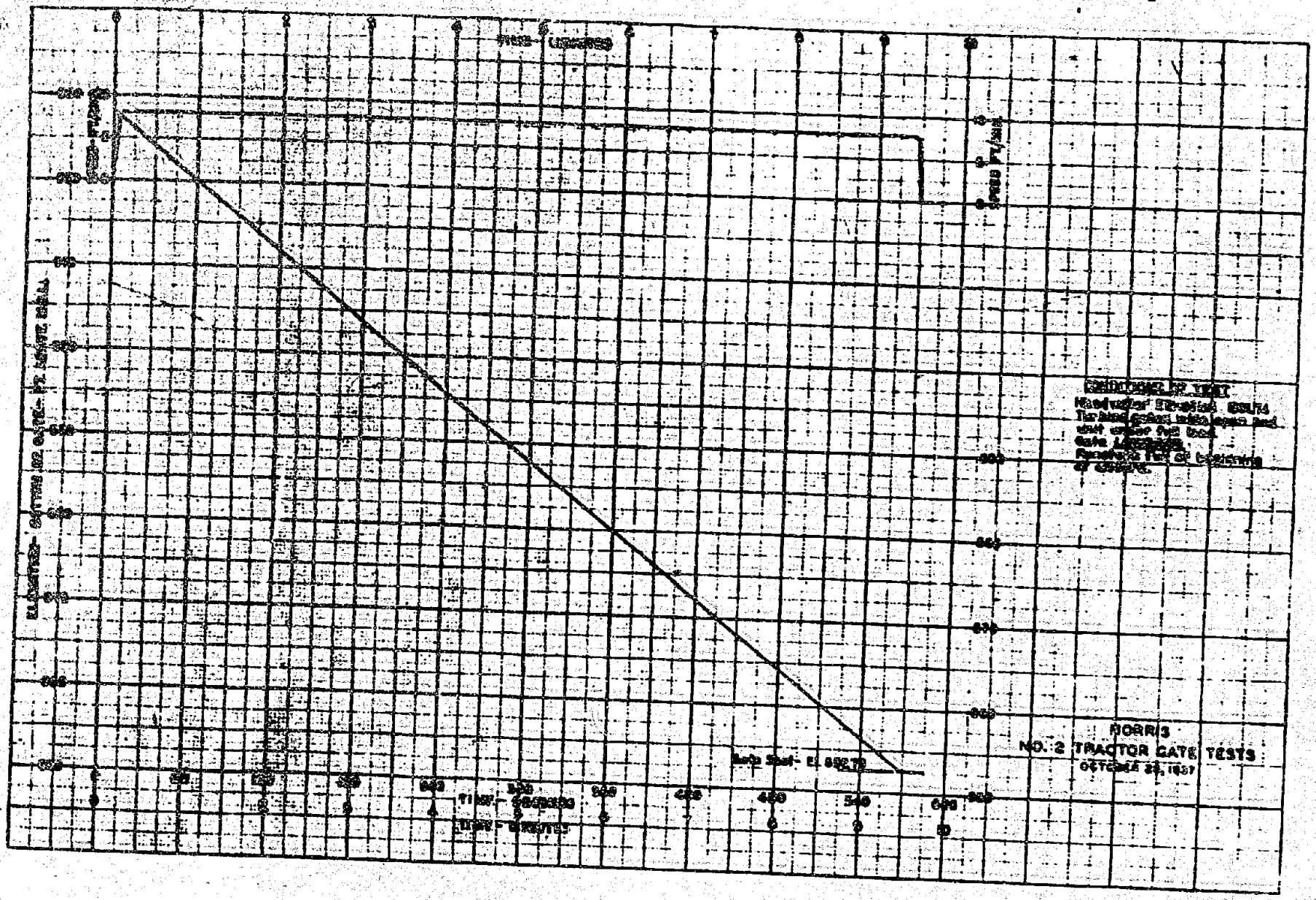
Calculation of "downpull" on Morris tractor gate.

Given:

Water elevation. . . . . .1001.74 ft.
Gate stop elevation. . . . . 852.78 ft.
Sill elevation . . . . . 853.45 ft.
Normal tail-water elevation. . . . . 833 ft.
1001.74 - 833 = 168.74 ft. head on turbine .
Load on turbine = 55,300 kilowatts. (Given)
Assume 85 percent efficiency.

$$Q = \frac{55,300 \times 746}{62.5 \times 168.74 \times 0.85} = 4,600 \text{ c.f.s.}$$

CURVE No. 4
CURVE No. 3
CURVE No. 2
CURVE No. 1
KILOWATTS
POWER
Chart Speed 3" per min.


MORRIS
NO. 2 TRACTOR GATE TESTS
OCTOBER 23, 1957
SPEED FT/SEC
TIME - SECONDS
B 20608

Area of wicket gate based on coefficient of discharge of 1.0 -

$$A = \frac{Q}{\sqrt{2gh}} = \frac{4,600}{8.02\ \sqrt{168.74}} = 44.2 \text{ sq. ft.}$$

This gate area and a coefficient of discharge of 0.90 through the tractor gate opening were used in calculating the pressure drop through the tractor gate.

"Downpull" is defined as the difference in hoist load between operating the gate under balanced conditions and under emergency or free discharge conditions. This difference is caused by a reduction of water pressure acting upward on the bottom of the gate leaf.

Assuming the bottom I-beam of the gate is perforated as shown, then the full static head will be exerted at (1). Let (2) be any section below the gate leaf.

Then writing Bernoulli's theorem from positions (1) to (2)

$$H_{(1)} = h_{(2)} + \frac{V_{(2)}^2}{2g} + F_{(2)}$$

where

$H_{(1)}$ = the unit pressure acting downward, in feet of water.

$h_{(2)}$ = the unit pressure acting upward, in feet of water.

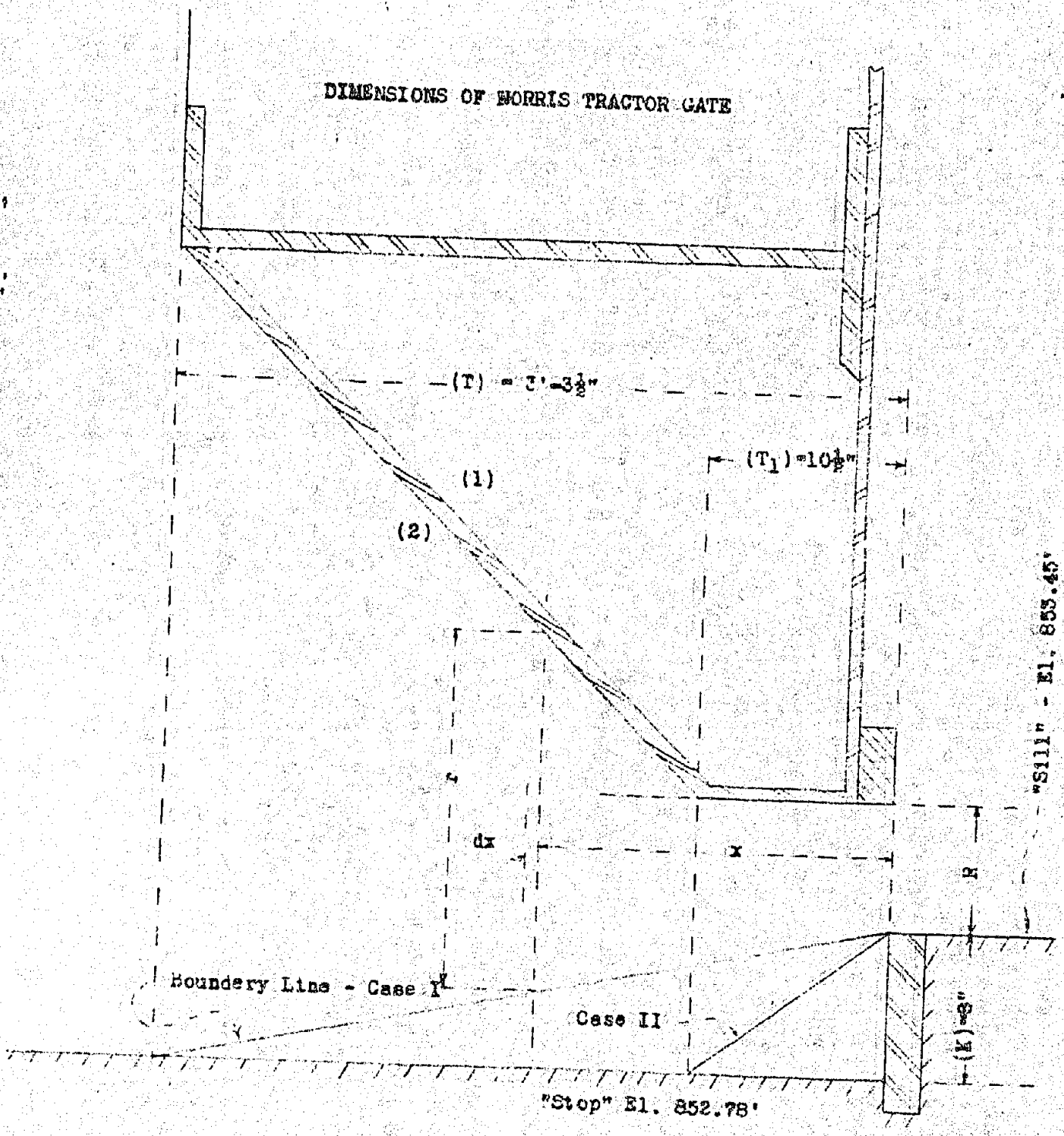
$V_{(2)}$ = the velocity of the water flowing under the gate in feet per second.

$F_{(2)}$ = the friction losses, in feet of water.

Friction losses are being ignored in this computation, therefore:

$$H_{(1)} - h_{(2)} = \frac{V_{(2)}^2}{2g}$$

or the difference in unit pressures is then equal to the velocity head of the water passing below the gate. Then the summation of the velocity heads below the gate leaf is equal to the "downpull" on the gate.



R = gate opening in inches (controlling section).
T_1 = 10-1/2 inches
T = 39-1/2 inches.
K = 8 inches
Slope for Case I = (m) = 0.202532.
Slope for Case II = (m) = 0.761904.
n = 45° slope = 1.00

Also, the velocity of the water flowing under the gate is given by:

$$V = Q \div CA$$

Considering a unit width of opening of depth, r,

$$V = Q \div Cr$$

as $$V = \sqrt{2gh}, h = \frac{V^2}{2g}$$

substituting $$h = \frac{Q^2}{2gC^2r^2} = \frac{\text{constant}}{r^2},$$

or the head is inversely proportional to the square of the depth of the opening. Since the depth of the opening varies under the gate leaf, the velocity heads will vary inversely as r^2.

In order to calculate the "downpull", which is equal to the summation of the velocity heads of the water flowing under the gate, the effective thickness of the gate having a zero upward pressure is computed.

Let

T_e = effective thickness of the gate.

T = thickness of the gate = 39-1/2 inches.

R = depth of the gate opening at the controlling section.

Then

$$T_e = \frac{R^2 T}{r^2}$$

The "downpull" is then equal to the effective thickness (T_e) multiplied by the width of the gate opening in inches and the pressure drop through the gate in pounds.

It will be noted that in raising such a gate the effective width of the gate approaches the actual width of the gate and in the case of a free discharge the "downpull" will approach that for a flat-bottom gate.

Calculations for Case I based on boundary line (I)

Let

m = slope of boundary line.

n = slope of gate bottom.

x = distance from controlling section.

Then

$$T_e = \int_0^{T_1} \frac{R^2 dx}{(R + mx)^2} + \int_{T_1}^{T} \frac{R^2 dx}{R - T_1 + (m+n) \times 2}$$

$$= \frac{-R^2}{m(R + mT_1)} + \frac{R^2}{mR} - \frac{R^2}{(m+n)\ R-T_1 + (m+n)\ T}$$

$$+ \frac{R^2}{(m+n)\ (R+mT_1)}$$

Substituting values for m, n, T, and T_1 and combining terms,

$$T_e = R^2 \left[\frac{-4.105912}{R + 2.126582} + \frac{4.937491}{R} - \frac{0.831579}{R + 37.000} \right]$$

Example: Let R = 24 inches

T_e = 576 (-0.157155 + 0.205729 - 0.013632)

T_e = 20.13 inches or effective width of gate.

"Downpull" = P x 0.433 x T_e x W.

= 127 x 0.433 x 20.13 x 198

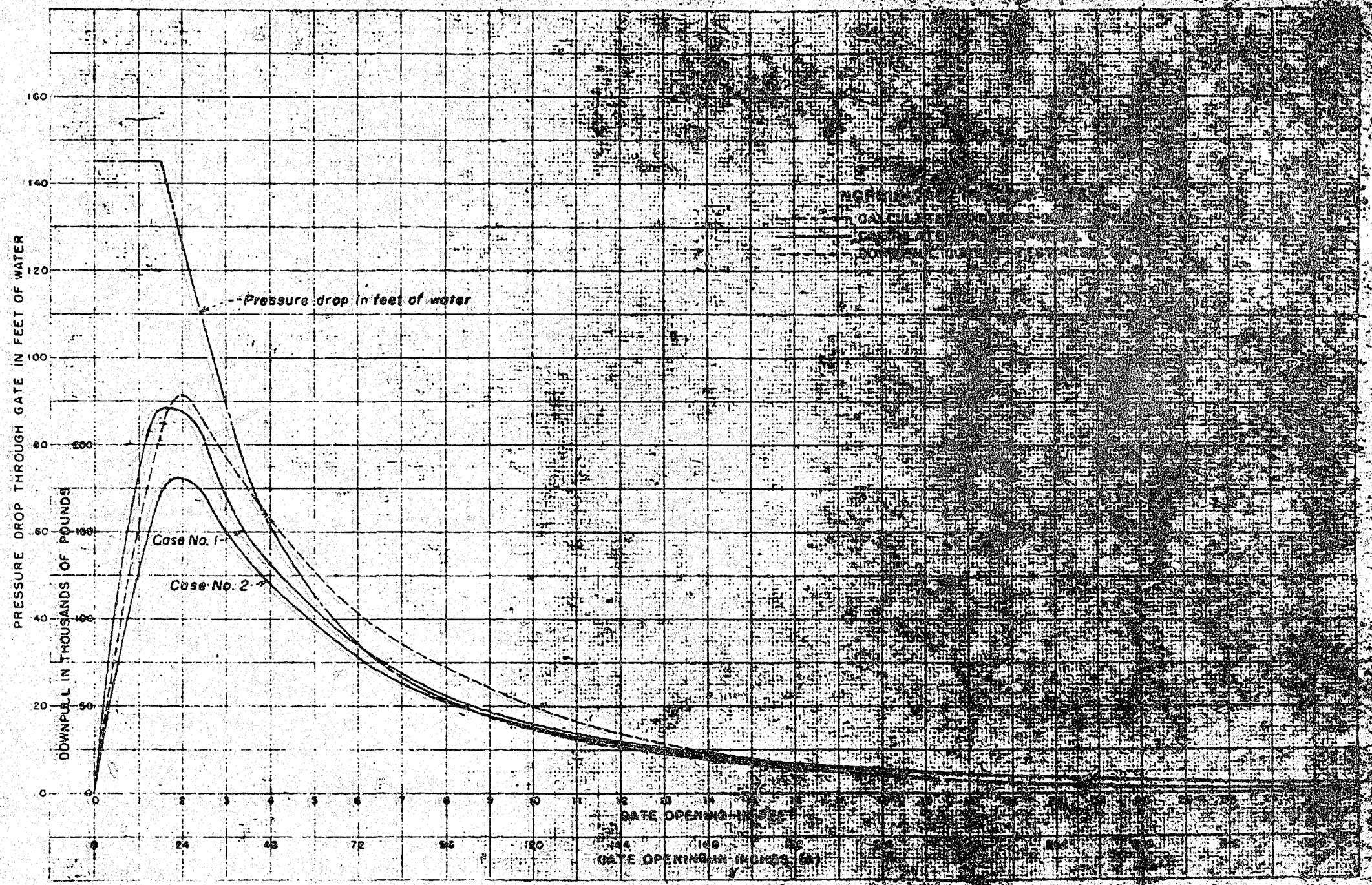
= 219,180 lb.

where

P = pressure drop through gate in feet of water,

W = width of gate opening in inches.

The effect of regain of velocity head in the penstock was neglected.


PRESSURE DROP THROUGH GATE IN FEET OF WATER
DOWNPULL IN THOUSANDS OF POUNDS
160
140
120
100
80
60
40
20
0
600
500
400
300
200
100
0
--Pressure drop in feet of water
Case No. 1
Case No. 2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
GATE OPENING IN FEET
0
24
48
72
96
120
144
168
GATE OPENING IN INCHES

. Calculations, Case II, based on boundary line (II)

$$T_e = \int_0^{T_1} \frac{R^2\,dx}{(A + mx)^2} + \int_{T_1}^{T} \frac{R^2\,dx}{R + K + (x - T_1)\,n^2}$$

$$= \frac{-R^2}{m(R + mT_1)} + \frac{R^2}{mR} - \frac{R^2}{n(R + K - nT_1 + nT)} + \frac{R^2}{n\,(R + K)}$$

Substituting values for m, n, T_1, T, and K, and combining terms,

$$T_e = R^2 \left[\frac{-0.312502}{R + 8.000} + \frac{1.312502}{R} - \frac{1}{R + 37.000}\right]$$

Example: Let R = 24 inches.

T_e = 576 (-0.009766 + 0.054688 - 0.016393)

T_e = 576 x 0.028529 = 16.43 inches.

Downpull = P x 0.433 x T_e x W.

= 127 x 0.433 x 16.43 x 198.

= 178,893 lb.

Discussion of Results.

It will be noted from the "downpull" gate openings curves that the "downpull" as shown by the test curve reaches a higher maximum than either of the calculated curves, also that there is a separation of the curves from the maximum position until a gate opening of about 13 feet is reached. Reasons for the differences may be: (1) Neither of the boundary lines used is correct but is merely an approximation. The boundary lines will not remain constant for all gate openings. (2) The coefficient of discharge was assumed to be 0.90 and constant for all gate openings. The coefficient is probably a

variable, especially before and after the penstock has filled. (3) Regain of velocity head was neglected, this is probably the greatest source of error. (4) All calculations are based on a stabilized flow for each position, but in actual conditions the effect of the gate being continually lowered will make some difference in the downpull. (5) Stretch in the cables may shift the position of gate openings slightly. (6) Roller friction has been neglected.

In spite of the above-listed possible sources of error, it is believed that "downpull" can be calculated in this manner consistently within 15 percent of the actual "downpull".

Curve No. 4 (raising gate balanced condition) apparently shows that the penstock was not completely full. Note the character of the curve until a balanced condition was produced.

A set of pressure readings taken downstream from the gate would be very helpful in calculating the regain of velocity head in the penstock.

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