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OF WATER RESOURCES, STATE OF CALIFORNIA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF DOWNPULL FORCES ON THE OROVILLE DAM POWERPLANT INTAKE GATES

CALIFORNIA DEPARTMENT OF WATER RESOURCES

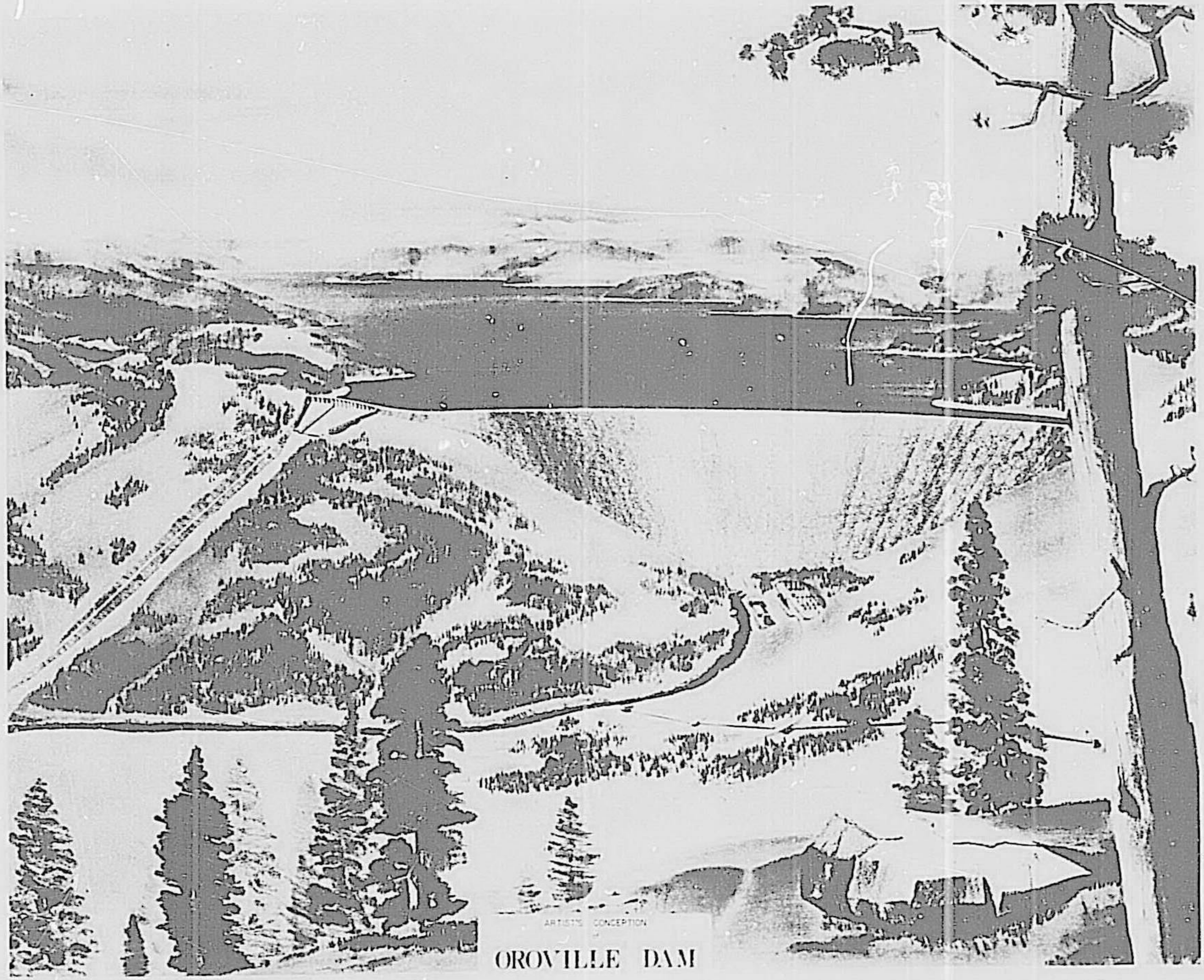
STATE OF CALIFORNIA

Report No. Hyd-540

Hydraulics Branch
DIVISION OF RESEARCH

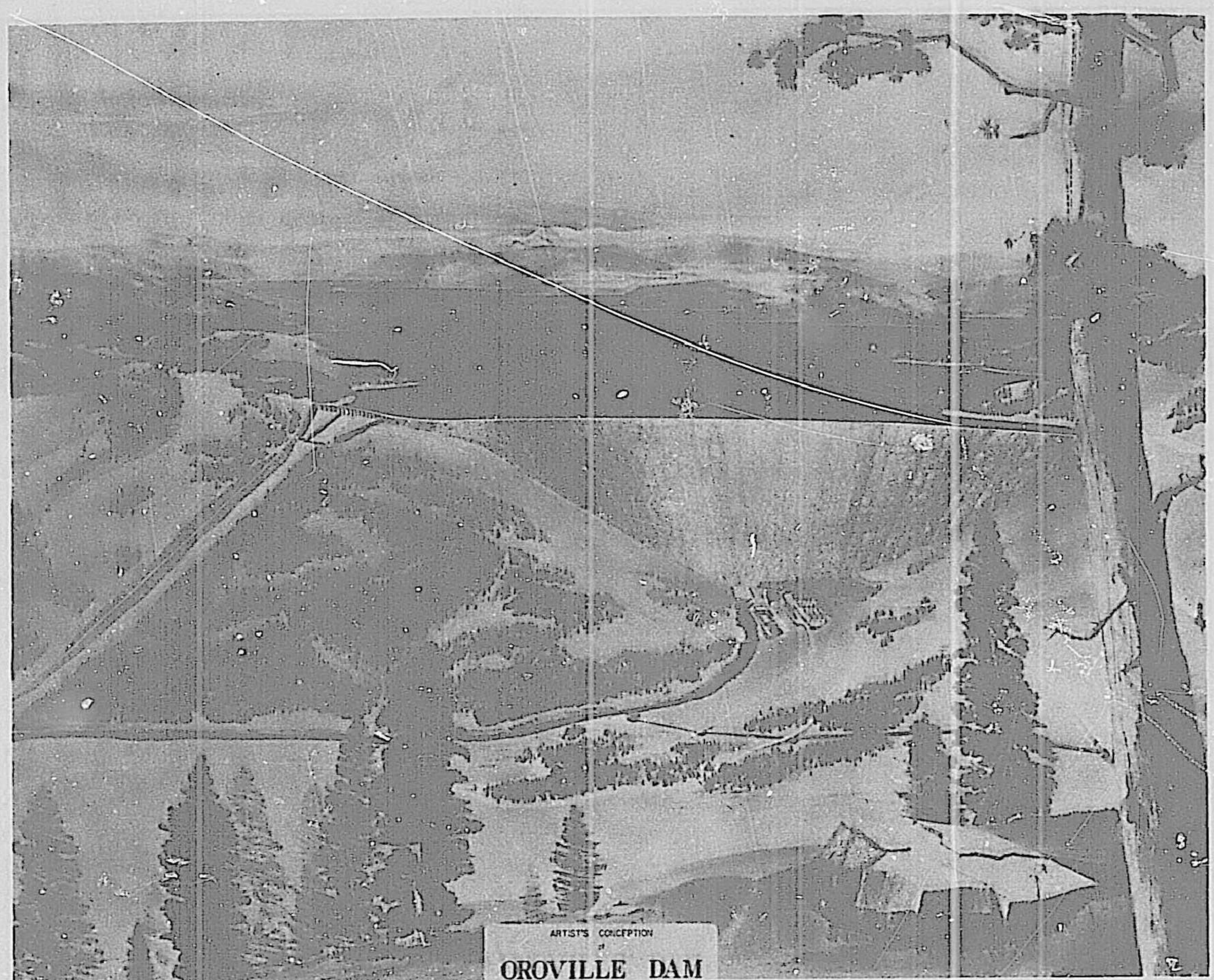
OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

September 30, 1964



ARTIST'S CONCEPTION

OROVILLE DAM



ARTIST'S CONCEPTION
of
OROVILLE DAM

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OFFICE OF CHIEF ENGINEER

IN REPLY
REFER TO:

BUILDING 53, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

Mr. William E. Warne, Director
Department of Water Resources
State of California
Sacramento, California 95802

Dear Mr. Warne:

I am pleased to submit Hydraulics Branch Report No. Hyd-540 which constitutes our final report on downpull studies conducted on the intake gates for Oroville Dam Powerplant. I believe this report will satisfy the requirements of your office for a comprehensive discussion of the extensive test program.

Sincerely yours,

B. P. Bellport
Chief Engineer

Enclosure

PREFACE

Hydraulic model studies of features of Oroville Dam and Powerplant were conducted in the Hydraulic Laboratory in Denver, Colorado. The studies were made under Contract No. 14-06-D-3399 between the California Department of Water Resources and the Bureau of Reclamation.

The designs were conceived and prepared by Department of Water Resources engineers. Model studies verified the general adequacy of the designs and also led to modifications needed to obtain more satisfactory performance. The high degree of cooperation that existed between the staffs of the two organizations helped materially in speeding final results.

During the course of the studies Messrs. H. G. Dewey, Jr., D. P. Thayer, G. W. Dukleth, and others of the California staff visited the laboratory to observe the tests and discuss model results. Mr. K. B. Bucher of the Fluid Mechanics Section of the Department was assigned to the Bureau laboratory for training and for assisting in the test program. Mr. Dukleth provided liaison between the Bureau and the Department.

CONTENTS

ABSTRACT

Hydraulic model studies to determine downpull forces occurring in the direction of travel of the 21- by 34-foot intake coaster gates for the Oroville Dam underground powerplant showed that the design was adequate. Ultimate development of the project calls for later construction of a second powerplant at the toe of the dam. Initially the complete left intake structure and the base of the right one will be built. Each intake structure includes two trashrack-covered sloping intake channels with large movable shutters. A coaster gate is positioned in each channel at the entrance to a vertical 22-foot-diameter penstock. Model studies were desirable because orientation and location of gate made theoretical downpull computations difficult. A maximum downpull force of about 376,000 pounds will occur at 25 percent gate opening for emergency closures during normal full-load powerplant operation at maximum reservoir elevation. No uplift forces were found at any gate opening or operating condition, and the shutters had little effect on the downpull. At maximum reservoir elevation, the intake gate assumes control of flow at 21 percent gate opening. The downpull forces on the 1:24 scale intake gate were computed by the pressure-area method. A method of computating turbine discharge with wicket gates moving to full open as the head is reduced during emergency closure of the intake gates is given. Dimensionless downpull and discharge coefficients included may be used for gate structures of similar geometric design.

DESCRIPTORS--Hydraulics/ *hydraulic downpull/ hydraulic models/ hydraulic gates and valves/ hydraulic machinery/ calculations/ model tests/ research and development/ discharge coefficients/ *intake gates/ coaster gates/ laboratory tests/ penstocks/ powerplants/ negative pressures/ uplift pressures/ underground powerplants/ trashracks/ discharges/ open channel flow/ *intake structures/

IDENTIFIERS--Oroville Dam Powerplant/ sloping intake structures/ wicket gates/ pressure-area method/ emergency closures/

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Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
September 30, 1964

Report No. Hyd-540
Author: K. G. Bucher
Checked by: W. P. Simmons
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

HYDRAULIC MODEL STUDIES OF DOWNPULL FORCES ON THE OROVILLE DAM POWERPLANT INTAKE GATES CALIFORNIA DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA

PURPOSE

Studies were made to determine the downpull forces that would occur in the direction of travel of the 21-foot-wide by 34-foot-long intake gates during emergency closure.

CONCLUSIONS

1. The maximum downpull force of about 376,000 pounds will occur at a 25 percent gate opening for an emergency closure during normal full-load powerplant operation at reservoir elevation 900 (Figure 13A).

2. No uplift forces were found at any gate opening or operating condition (Figure 13B).

3. Dimensionless discharge and downpull coefficients may be used for gate structures of similar geometric design (Figures 8 and 12).

4. In general, the shutters had little effect on the downpull.

5. At reservoir elevation 900, the intake gate assumes control of flow at 21 percent gate opening (Figure 10C). At lower reservoir elevations the gate assumes control at slightly larger openings.

INTRODUCTION

The 747-foot-high earth and rock fill Oroville Dam is located on the Feather River about 4 miles northeast of Oroville, California (Figure 1). An underground powerplant with a rated capacity of 600 megawatts will be constructed in the left abutment of this multipurpose feature. Ultimate development will be the construction of an exposed powerplant at the toe of the dam on the right abutment. During initial construction, the base of the right intake structure and the complete left intake structure will be built. The intakes for the powerplants will be located on the sides of the reservoir about 1,000 feet upstream from the axis of the dam (Figure 2). Each intake structure consists of two trashrack-covered channels spaced 70 feet, center to center. Under the trashracks and over the top of the channels are large movable shutters that permit selecting the level, and therefore, the temperature of the water released through the powerplant into the river. The trashracks are supported by concrete arches and struts along the full length of the structures (Figure 3).

The left intake structure is about 650 feet long and is inclined up the side of the reservoir at a slope of 27°45'. In the base of each of the two sloping channels is a transition into a vertical 22-foot-diameter penstock (Figure 4). Positioned at the entrance to each penstock transition is a coaster gate which serves as an emergency closure gate and will also be used to seal off the penstocks for routine inspections and maintenance (Figure 5). These 21-foot-wide by 34-foot-long by 2-1/4-foot-thick gates and their hydraulic operators are locked into position by hydraulically operated bolts. The hydraulic operator power units contain sealed pumps, oil reservoirs, and hydraulic controls that will move the gates across the penstock transitions in 5 minutes.

The concrete-lined penstocks extend from the base of the intake channels through sound rock to the underground powerplant. Ruptures in these penstocks are very improbable. Therefore, the most severe emergency closure condition anticipated for the intake gate is accidental closure with all powerplant turbines in operation.

The California Department of Water Resources requested that model studies be made to determine the downpull forces that would occur in the direction of travel of the intake gates. The model study was desirable because the orientation and location of the gate made theoretical downpull computations difficult. Pressures on piezometers in the model gate were read and recorded for various gate openings, discharges, and reservoir elevations. From these pressures, the downpull forces were computed by the pressure-area method. The test equipment used in the model studies, the analytical procedures followed, and the results obtained are discussed in this report.

Detailed hydraulic studies of the left intake structure and other features of the Oroville Dam and Spillway are discussed in other reports. 1/, 2/, 3/, 4/, 5/

1/Numbers refer to Bibliography.

MODEL

The model of the intake gate was built at a scale ratio of 1:24 to allow testing in the already-constructed 1:24 model of the left intake structure (Figure 6). The gate was fabricated from machined brass bar stock and 1/8-inch brass plate. The seals on the underside of the gate (Figure 7A) were designed as part of the gate body and were machined after the gate was assembled. The general shape of the roller trains was machined from bar stock and bolted to the sides of the gate body (Figure 7B). The gate moved on a machined seat that was made from cast brass pieces to insure surfaces that would remain flat during machining. No attempt was made to make the weight of the model gate equivalent to that of the prototype gate.

The orientation, location, and weight of the model gate dictated that the pressure-area method be used to determine the downpull forces. Accordingly, 15 piezometers were placed in the gate to measure pressures on the ends and underside of the gate. Previous laboratory experience showed that pressures, measured on the bottom of a gate along the centerline of the flow passage, are reasonably representative of pressures nearer the walls. On the model intake gate, Piezometers 1 through 8 were placed near the centerline of the lip, and to check the distribution assumption, Piezometers 9 through 11 were placed in line with the edge of the gate slot. Piezometers 12, 13 and 15 measured the pressures acting on the transverse gate seals (Figures 7 and 11).

The long, 1/16-inch-internal-diameter piezometer leads were bundled together and passed through a narrow slot in the floor of the intake channel (Figures 6C and 7). Below the slot the piezometer leads were connected by plastic tubing to a coupling panel in the floor of the headbox. From there the leads were connected to a manometer board.

The hydraulic operator of the intake gate (Figures 5 and 7) was modeled in general shape only. Two threaded rods passed through a transverse member of the operator which was bolted to the floor of the intake channel. The gate was moved by turning the rods with a crank. The rods were connected together by a chain and sprocket drive (Figure 7).

Flow into the headbox, and subsequently past the intake gate, was measured by Venturi meters in the laboratory supply system. The reservoir elevation and the rate of flow out of the headbox were controlled by valves in the discharge system.

INVESTIGATION

Discharge Coefficients

The discharge coefficients of the intake gate were determined for the full range of gate positions and reservoir elevations. The discharge coefficient was defined by the equation:

$$C_d = \frac{Q}{A_p \sqrt{2\,gH}}$$

where: Q = discharge in cubic feet per second
A_p = cross-sectional area of penstock (square feet)
H = head differential across the gate (feet)

The head differential, H, was determined by subtracting the head (in terms of piezometric elevation) at a ring of piezometers one pipe diameter below the penstock transition from the reservoir elevation (Figure 4A). The position of the intake gate was expressed as percent gate opening, where the opening was taken as the distance from the center of the lower seal seat to the center of the lower seal on the gate (Figure 4B). This gate opening was divided by the 30-foot distance between the lower and upper seal seat centerlines. Thus, the gate was 100 percent open when the center of the lower gate seal coincided with the center of the upper seat. A plot of C_d versus gate opening is shown in Figure 8.

Discharge for Downpull Tests

When gate closure occurs, the head losses and differential head across the gate will increase as the gate is moved across the penstock entrance. During normal powerplant operation, these additional head losses will be compensated by automatic opening of the turbine wicket gates. The wicket gates are fully opened at critical head, which is at reservoir elevation 730, or at an equivalent head which results when the subtraction of velocity head and gate losses from reservoir elevation produces a piezometric elevation equal to that of reservoir elevation 730 under normal conditions.

The discharge criteria for various reservoir elevations at different gate positions were not available, so the needed data were derived by computation. The computations assumed that the downpull tests would be made with four shutters on the intake channel. Previous tests determined that the head loss coefficient, K, in terms of velocity head in the penstock, with four shutters in place and with the intake gate fully opened was 0.36. The head loss was measured from the reservoir surface to the ring of piezometers below the penstock transition

(Figure 4). Values of discharge for reservoir elevations ranging from 580 to 900 feet were selected from the powerplant discharge rating curve (Figure 9A). For each selected discharge the velocity head in the penstock, H_v, and the loss from the reservoir surface to the ring of piezometer in the penstock, KH_v, were computed. The computed loss plus velocity head in the penstock were subtracted from the reservoir elevation to obtain the theoretical piezometric elevation at the ring of piezometers in the penstock.

Example: From Figure 9A, for Penstock 1, and reservoir elevation 730

Discharge = 8,600 cubic feet per second

Area of penstock = 380 square feet

$$\text{Velocity head + head loss} = 1.36 \left[\frac{(8,600)^2}{(380)^2}\right] \frac{1}{2g}$$

$$= 10.81 \text{ feet}$$

Piezometric elevation, H_p = 730.00 - 10.81 = 719.19 feet

The above process was continued for reservoir elevations ranging from 580 to 900 feet. The curves of discharge versus piezometric elevation in the penstock are shown in Figure 9B. These curves will be used in Part 4 of the following development.

When the intake gate moves across the penstock transition, the differential head increases, the discharge coefficient decreases, the discharge increases to a maximum of 8,600 cubic feet per second as the wicket gates open and then decreases as the intake gates assume control. Also, the initial operating discharge varies with the reservoir elevation (Figure 9A). A curve that correlates all of these parameters was plotted as follows:

1. Values of C_d for intake gate openings ranging from 21 to 100 percent open were selected from Figure 8.

2. Using the selected values of C_d, the differential head across the intake gate was computed for discharges of 5,000, 6,000, 7,000, 8,000, and 9,000 cubic feet per second by the equation:

$$H = \frac{Q^2}{C_d{}^2 A_p{}^2 2g}$$

3. A curve of H versus Q was plotted for each gate opening, Figure 10A and 10B.

4. Superimposed on the above family of curves were plotted the discharges that would result if closure was initiated at reservoir

elevations of 730, 760, 790, 820, and 900 feet (Figures 10A and 10B). These discharges were determined as follows:

a. By previous definition, H = reservoir elevation minus H_p; therefore, H_p = reservoir elevation minus H.

b. From Figure 9A an initial reservoir elevation and discharge were selected. For example, reservoir elevation 820, Q = 7,120 cubic feet per second.

c. As the differential head, H, increases, the piezometric elevation, H_p, decreases and the discharge varies. For example: assume H = 20, 40, and 60 feet. The resulting piezometric elevations are: 820 - 20 = 800, 820 - 40 = 780, 820 - 60 = 760. From Figure 9B, the discharges that correspond to these piezometric elevations are 7,300, 7,550, and 7,830 cubic feet per second, respectively.

d. The above process was continued with H varying from 10 to 180 feet for each of the five selected reservoir elevations. Curves of discharge versus differential for each reservoir elevation were plotted over the family of gate opening curves (Figures 10A and 10B).

5. Data contained in Figures 10A and 10B were plotted in Figure 10C in a more convenient form, i.e., discharge versus gate opening for reservoir elevations 730, 760, 790, 820, and 920.

6. The points where the intake gate theoretically assumes control of the discharge were computed and plotted on Figure 10C. These points were found by a trial and error matching of discharges from Figures 10A and 10B with discharges computed by the equation:

$$Q = C_d A_p \sqrt{2gH'}$$

where H' = the head between the reservoir surface and the midpoint of gate opening

The discharges for the downpull tests were derived with the assumption that the pressure under the intake gate would remain atmospheric after the gate assumed control of the flow. A 24-inch-diameter air vent is provided in the prototype structure for this purpose (Figure 5). Computation methods are given later in the report for cases where subatmospheric pressures are present under the gate.

Downpull Coefficients

For each downpull test, the intake gate was set at a specific opening, a discharge and reservoir elevation were selected from Figure 9A and established in the model. After a stable flow condition was reached, the piezometric heads of the 15-gate piezometers were read from water-filled manometers and recorded.

In the pressure-area method of downpull computation, the pressure of each contributing piezometer was multiplied by a specific area to obtain the force acting on that area. The forces were then algebraically summed to give the resulting model downpull. For the intake gate, the area of influence for each piezometer was taken as a projected band on a plane perpendicular to the axis of the intake gate (Figure 11). The band width was taken from midpoint to midpoint between piezometers on the gate lip, and the band length was the width of the gate body, not including the roller trains (Figure 11). The pressure distribution was fairly uniform across the lip so the pressures of Piezometers 9, 10, and 11 were not included in the downpull computations. An example of the piezometric pressures and pressure-area computations is shown in the appendix.

The powerplant rating curves indicate that the reservoir can fluctuate between elevations 640 and 900 (Figure 9A). However, the maximum reservoir elevation obtainable in the model was 820 feet. Therefore, downpull data were obtained from the model for reservoir elevations 730, 760, 790, and 820, and the data were extrapolated to reservoir elevation 900. Downpull was computed for the various gate openings at each of the above reservoir elevations. Then a dimensionless coefficient (Figure 12), was computed for each test using the downpull and discharge as factors. No uplift forces were found at any gate opening or operating condition (Figure 13).

Many of the downpull tests were repeated with the shutters removed. Generally, the removal of shutters had very little effect on the downpull.

Difficulty was experienced in obtaining downpull coefficients at gate openings less 10 percent. The gate is essentially closed at about the 8 percent position because the gate lip reaches the lower seal seat. The small discharges in this range are very difficult to measure with precision. Due to the manner in which discharge appears in the downpull coefficient, errors in measurement of small discharges result in large deviations in coefficient values. The coefficients at gate openings below 10 percent were not plotted in Figure 12 because of this scatter.

The coefficients of downpull were not affected by changes in reservoir elevation. Therefore, the dimensionless coefficients of Figure 12 can readily be used for computation of downpull forces at any reasonable water surface level, including elevation 900.

Application of Data

The downpull forces for reservoir elevation 900 were computed by the equation:

$$\text{Downpull} = \frac{C_{dp} Q^2 \quad \gamma A_g}{A_p^2 2g} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: C_{dp} = downpull coefficient (Figure 12)

Q = discharge in cubic feet per second (Figure 10C)

γ = specific weight of water (62.4 pounds per cubic foot)

A_g = cross-sectional area of intake gate (61.4 square feet)

A_p = cross-sectional area of penstock (380 square feet)

g = acceleration of gravity (32.2-feet-per-second per second)

For example:

A 25 percent gate opening at reservoir elevation 900

C_{dp} = 13.85 (Figure 12)

Q = 8,120 cubic feet per second (Figure 10C)

$$\text{Downpull} = \frac{13.85\ (8,120)^2\ 62.4\ (61.4)}{(380)^2 2g}$$

$$= 376,000 \text{ pounds}$$

The downpull forces determined for reservoir elevations 730 and 900 are plotted in Figure 13A. The downpull computed for reservoir elevations 760, 790, and 820 lie between these two curves. Figure 13B shows a comparison of downpull forces determined directly from model data for reservoir elevation 820 and by computation using the downpull coefficients. Agreement is excellent.

The discharge curves of Figure 10C were based on the condition with four shutters on the intake channel. The loss coefficient, K, with all shutters removed is 0.21, compared to 0.36 with four shutters in place. However, the maximum velocity head in the penstock is only 7.95 feet, and the use of a lower K factor will not significantly change the piezometric head-versus-discharge curves (Figure 9B) or the discharge curves of Figures 10A and 10B. The discharge-versus-percent gate opening curves (Figure 10C) may be used for any number of shutters with an error less than 1 percent at maximum downpull.

The condition when subatmospheric pressures exist under the intake gate when the gate has control of the flow has not been discussed. In this situation, the subatmospheric pressure is added to the head acting on the gate, and the discharge is computed using the increased head. The downpull forces are then computed by the same downpull equation (Equation 1) using the increased discharge.

For example:

Reservoir elevation 900, 20 percent gate opening, pressure under gate = 15 feet of water below atmospheric, head at mid-point of gate opening = 313 feet

$H = 313 + 15 = 328$ feet

$Q = A_p C_d \sqrt{2gH}$

$= 380\,(0.12)\,\sqrt{2g\,(328)}$

$Q = 6,630$ cubic feet per second

$$\text{Downpull} = \frac{18.3\,(6,630)^2\;62.4\;(61.4)}{(380)^2\;(32.2)(2)}$$

$$= 332,000 \text{ pounds}$$

In the above example, the 15-foot subatmospheric pressure increased the discharge from the initial value of 6,480 to 6,630 cubic feet per second. The corresponding downpull forces increased from 316,000 to 332,000 pounds, or an increase of about 4 percent.

The downpull forces may be computed for any reservoir elevation by deriving a discharge curve (Figure 10C) as outlined in this report and by using the downpull coefficient curve (Figure 12).

The downpull and discharge coefficients presented in this report may be used for installations that are geometrically similar to the Oroville intake gate.

APPENDIX

APPENDIX

The downpull forces on the intake gate were computed by the pressure-area method. Typical pressure readings from the 1:24 scale model for various gate openings at reservoir elevation 820 are presented in Table 1. The downpull computation for one of the gate positions given in Table 1 is shown in the sample calculation.

Table 1

Piezometer readings, feet of water, model
Reservoir elevation 820 Four shutters

	Gate opening	33.9	32.2	30.5	27.2	25.5	23.9	22.2	20.5
	Cubic-feet-per-second prototype	8,075	8,600	8,325	7,800	7,500	7,100	6,650	5,680
Piezometer numbers	1	8.30	8.14	8.14	8.11	8.09	8.11	8.16	8.34
	2	6.99	6.47	6.42	6.19	6.00	5.94	6.01	6.52
	3	6.23	5.44	5.32	4.72	4.29	4.15	4.13	4.86
	4	6.25	5.49	5.41	4.89	4.30	3.98	4.01	4.88
	5	6.26	5.54	5.44	5.12	5.05	5.10	5.17	5.71
	6	6.28	5.62	5.53	5.52	5.70	5.89	6.06	6.45
	7	6.82	6.29	6.17	6.32	6.37	6.52	6.69	6.98
	8	5.10	3.84	3.47	2.17	1.28	0.61	-0.19	0.45
	9	6.51	5.81	5.56	5.32	5.25	5.11	5.20	6.32
	10	6.13	5.36	5.06	4.83	4.66	4.41	4.48	5.28
	11	7.60	7.17	6.71	7.01	6.78	6.36	6.40	7.00
	12	5.08	3.79	3.42	2.12	1.21	0.45	-0.30	0.34
	13	5.57	4.40	4.05	2.83	2.02	1.25	0.45	1.11
	14	9.00	9.00	9.00	9.01	9.01	9.02	9.02	9.04
	15	8.65	8.55	8.54	8.47	8.40	8.36	8.68	8.31
	62*	9.07	9.07	9.07	9.07	9.07	9.07	9.07	9.07

*Piezometer 62 registers model reservoir elevation.

SAMPLE CALCULATION OF DOWNPULL FORCES BY PRESSURE-AREA METHOD

23.9 percent gate opening   Discharge = 7,100 cubic feet per second
Reservoir elevation = 820   Four shutters in place

Piezometer number	Piezometer reading (Table 1) (Ft H_2O)	Band width (Figure 11)	Band length (Figure 11)	Area $(in.)^2$	Force Ft H_2O $in.^2$
3	4.15	0.12	9.50	1.14	-4.73
4	3.98	0.30	9.50	2.85	-11.35
5	5.10	0.50	9.50	4.75	-24.23
6	5.89	0.49	9.50	4.66	-27.45
7	6.52	0.21	9.50	2.00	-13.03
(7-12)	6.07	0.16	9.50	1.52	-9.22
(12-13)	0.80	0.19	9.50	1.81	+1.45
14	9.02	1.80	9.50	17.10	+154.17
15	8.36	0.19	9.50	1.81	-15.13
		Σ Force			+50.48

Multiplication factor:

Force prototype = Force model x $(L_R)^3$

$$\frac{62.4 \times (L_R)^3}{144} = \frac{62.4 \times 24^3}{144} = 5,990 \; (\#/\text{Ft } H_2O \text{ in.}^2)$$

Downpull = 50.48 x 5,990 = 302,380#

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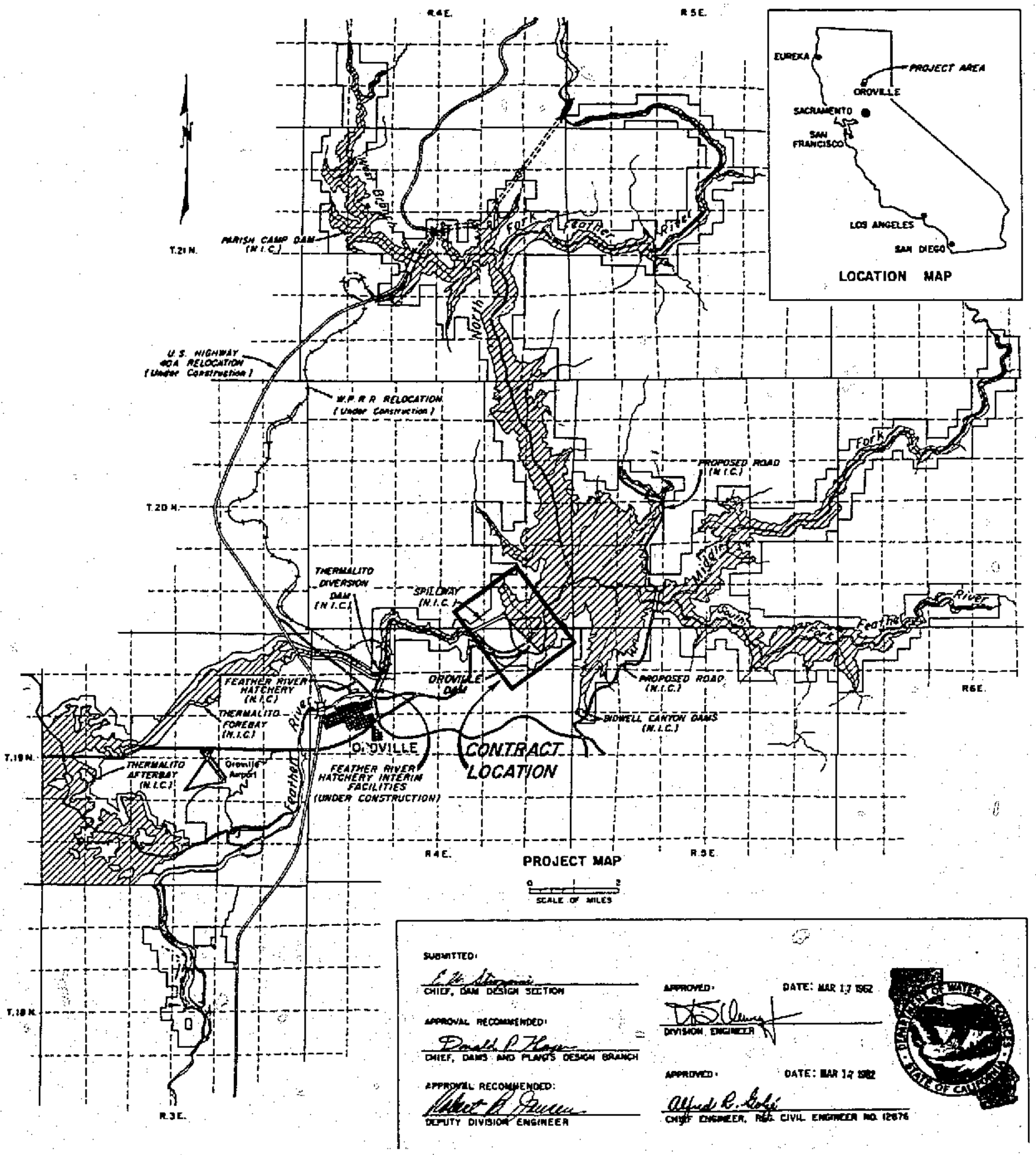
FIGURE 1
REPORT HYD. 540



OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
LOCATION MAP

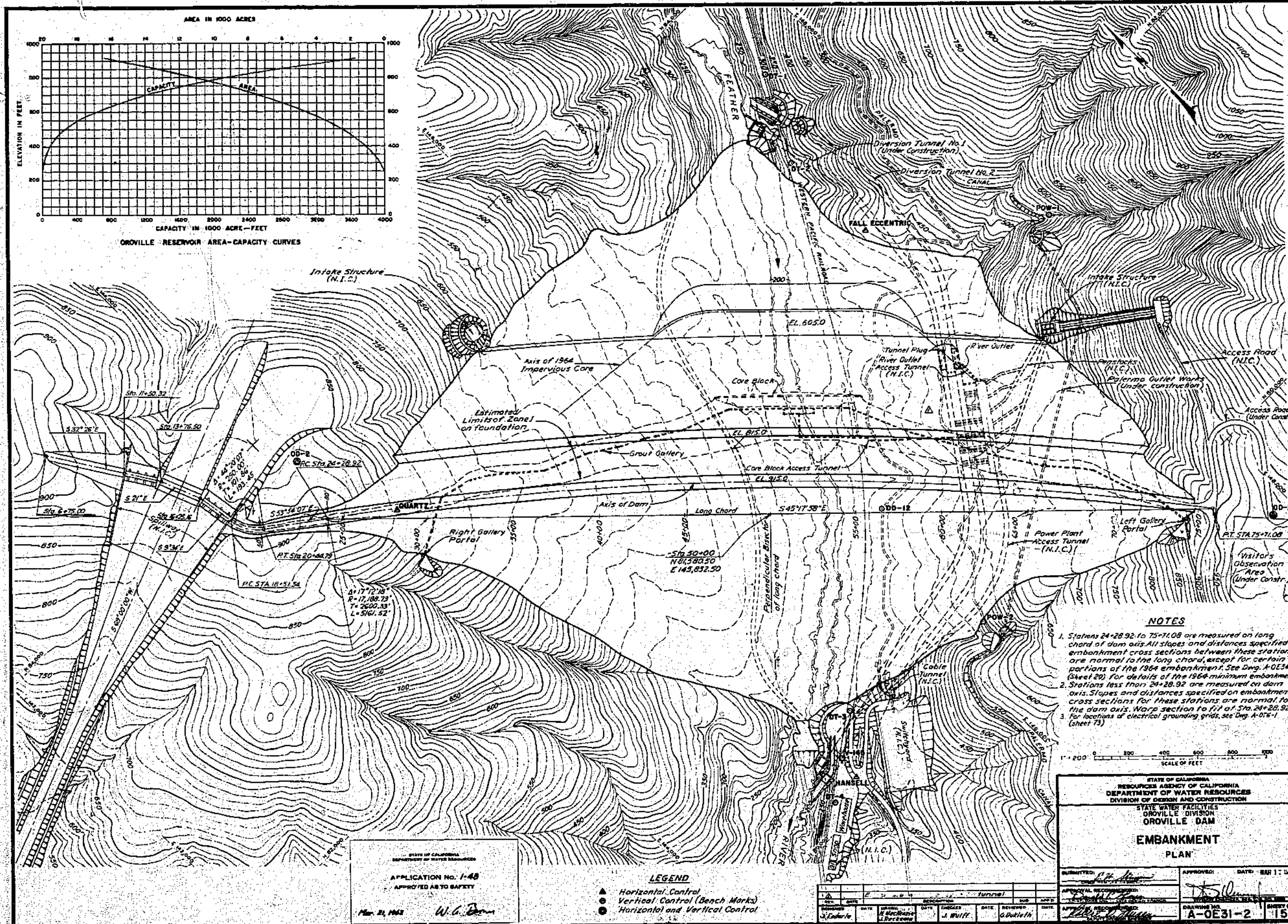
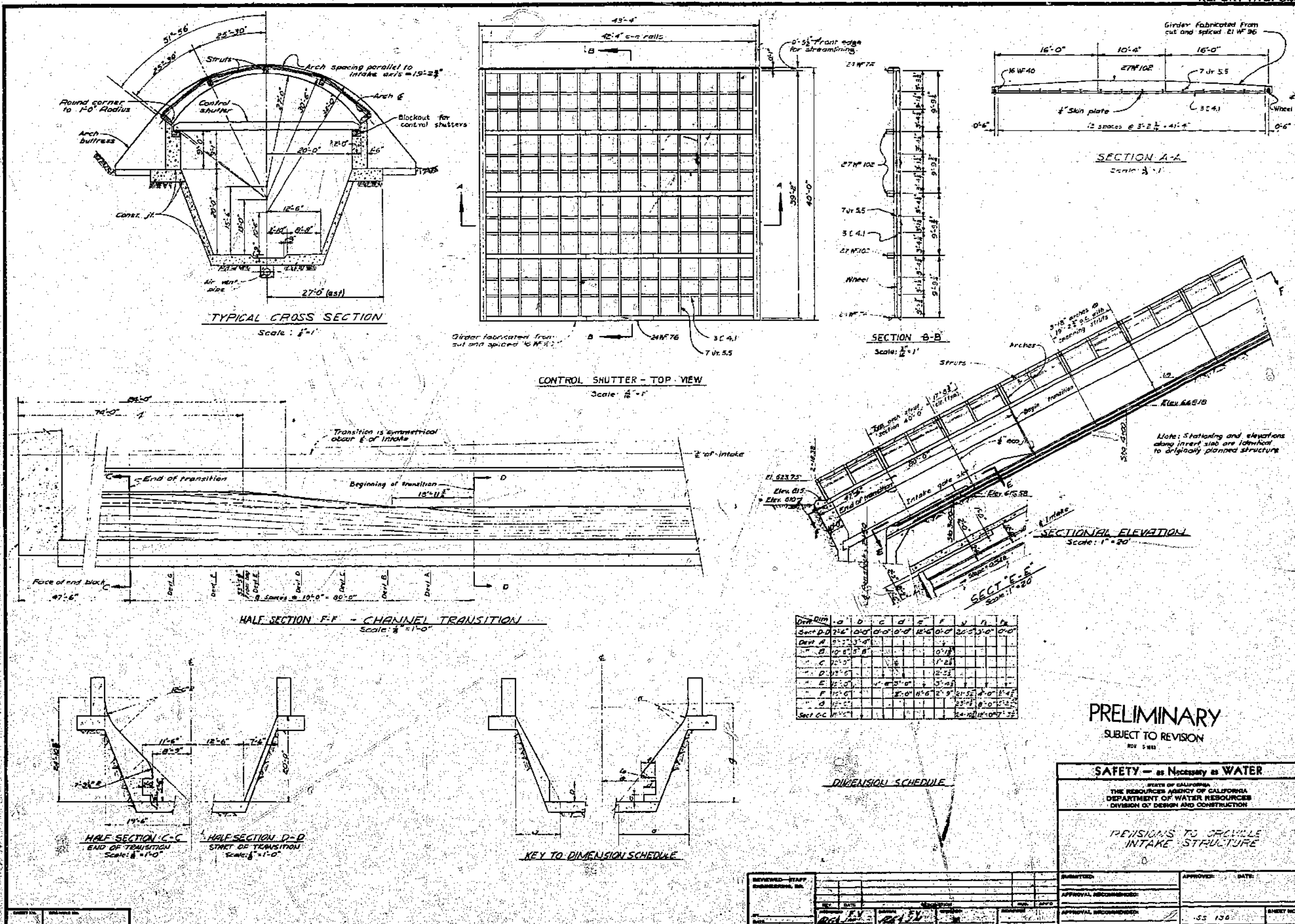
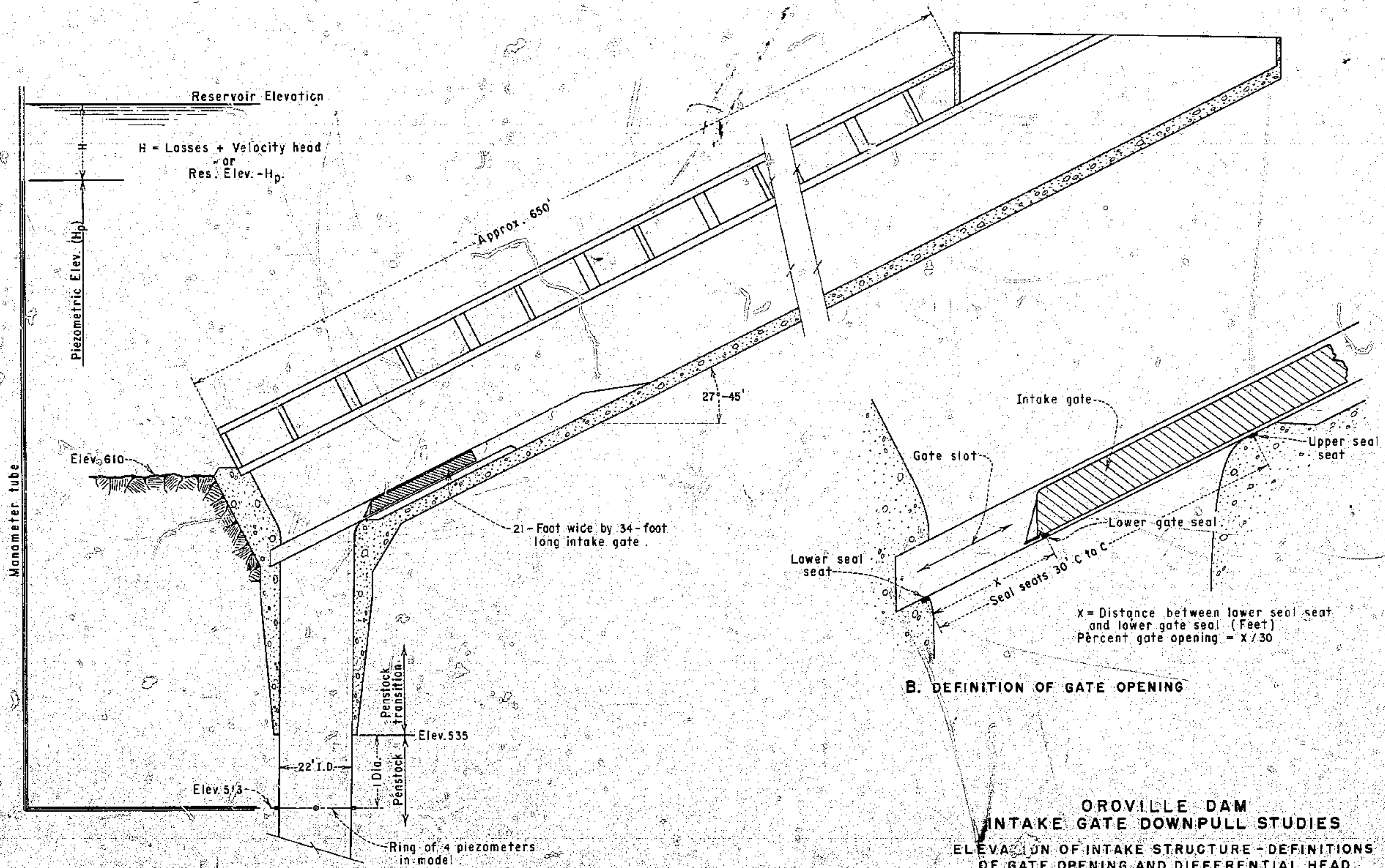

AREA IN 1000 ACRES
ELEVATION IN FEET
CAPACITY
AREA
CAPACITY IN 1000 ACRE—FEET
OROVILLE RESERVOIR AREA-CAPACITY CURVES
FEATHER
RIVER
Western Pacific Railroad
Diversion Tunnel No. 1 (Under Construction)
Diversion Tunnel No. 2
FALL ECCENTRIC
Intake Structure (N.I.C.)
Access Road (N.I.C.)
Penstocks (N.I.C.)
Palermo Outlet Works (Under construction)
Access Road (Under Constr.)
River Outlet
Tunnel Plug
River Outlet Access Tunnel (N.I.C.)
Core Block
EL. 605.0
Axis of 1964 Impervious Core
Estimated Limits of Zone 1 on foundation
EL. 815.0
Grout Gallery
Core Block Access Tunnel
EL. 915.0
Axis of Dam
Long Chord
S45°17'58"E
Perpendicular Bisector of long chord
Sta. 50+00
N 61,580.50
E 145,832.50
Right Gallery Portal
Left Gallery Portal
Power Plant Access Tunnel (N.I.C.)
P.T. STA 75+71.08
Visitors Observation Area (Under Constr.)
Cable Tunnel (N.I.C.)
Switchyard (N.I.C.)
HANSELL
Spillway (N.I.C.)
P.C. Sta 24+28.92
P.T. Sta 20+68.79
P.C. STA 18+51.34
Δ=17°12'18"
R=17,188.73'
T=2600.33'
L=5161.52'
NOTES
1. Stations 24+28.92 to 75+71.08 are measured on long chord of dam axis. All slopes and distances specified on embankment cross sections between these stations are normal to the long chord, except for certain portions of the 1964 embankment. See Dwg. A-0E34-1 (Sheet 20) for details of the 1964 minimum embankment.
2. Stations less than 24+28.92 are measured on dam axis. Slopes and distances specified on embankment cross sections for these stations are normal to the dam axis. Warp section to fit at Sta. 24+28.92.
3. For locations of electrical grounding grids, see Dwg. A-0T6-1 (sheet 73)
1" = 200'
SCALE OF FEET
LEGEND
Horizontal Control
Vertical Control (Bench Marks)
Horizontal and Vertical Control
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
APPLICATION No. 1-48
APPROVED AS TO SAFETY
STATE OF CALIFORNIA
RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
OROVILLE DIVISION
OROVILLE DAM
EMBANKMENT
PLAN
DRAWING NO. A-0E31-2
SHEET NO. 15

FIGURE 3
REPORT HYD. 540





B. DEFINITION OF GATE OPENING

A. ELEVATION OF INTAKE STRUCTURE AND DEFINITION OF DIFFERENTIAL HEAD (H)

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
ELEVATION OF INTAKE STRUCTURE - DEFINITIONS OF GATE OPENING AND DIFFERENTIAL HEAD

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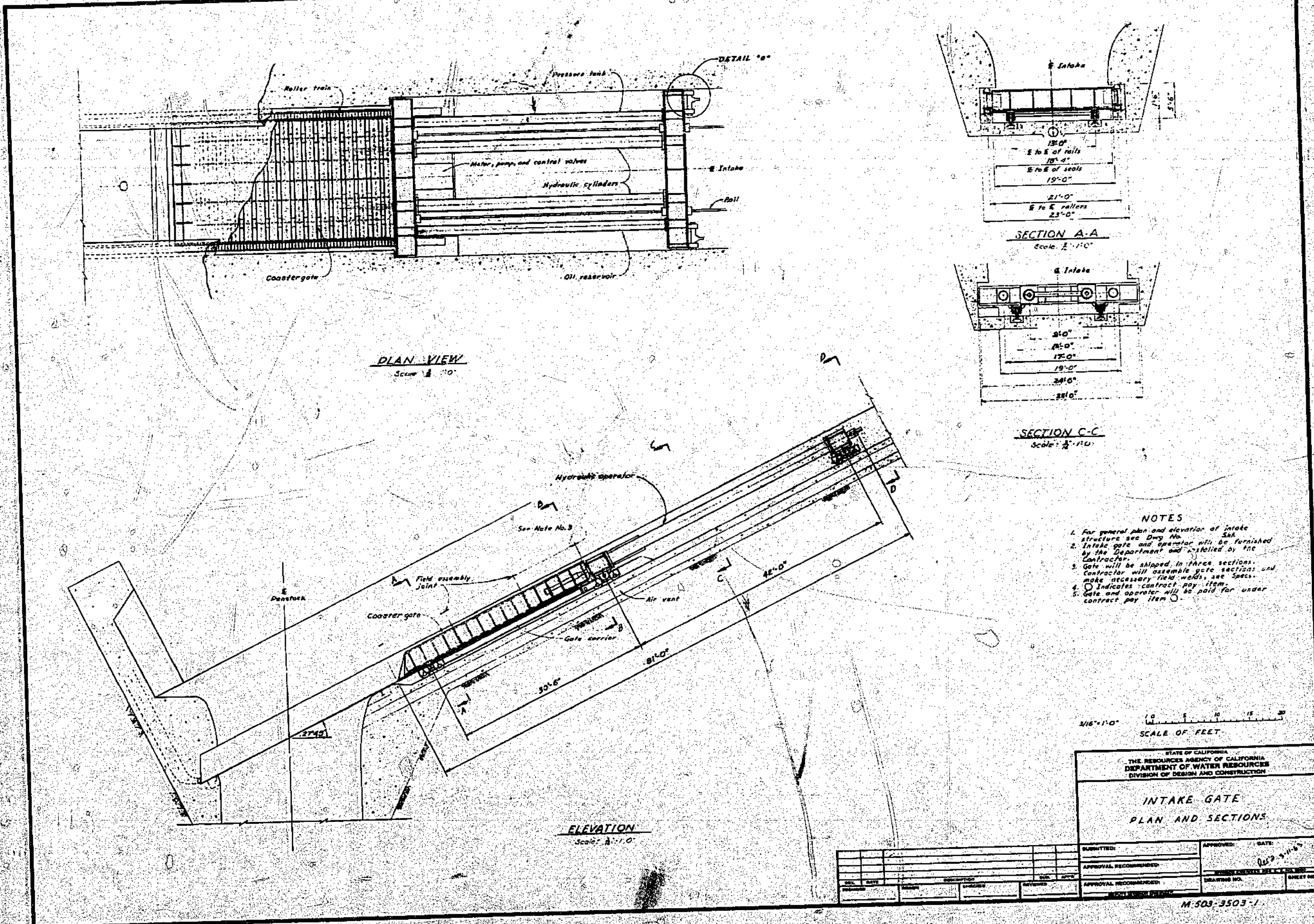
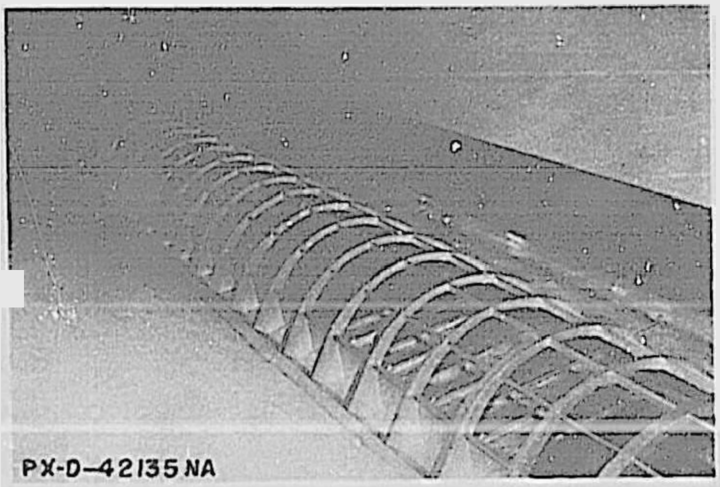
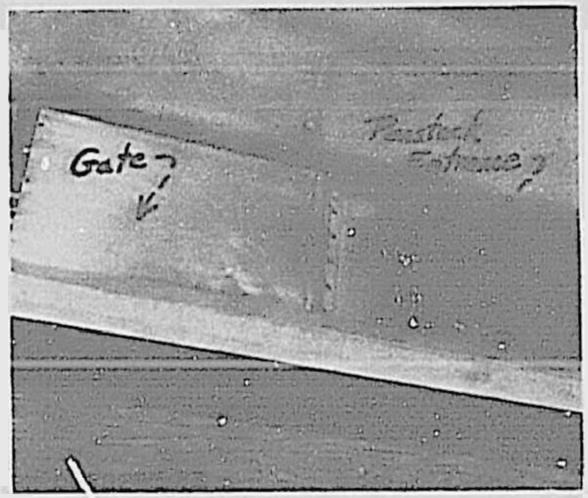
FIGURE 5
REPORT HYD. 540

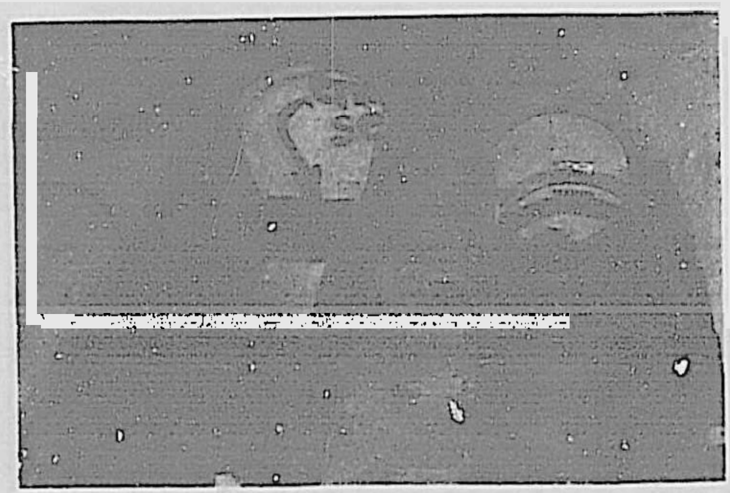




A. General view of intake model. Gate studies were conducted in detailed structure at left. Eight shutters are in place under trashracks.



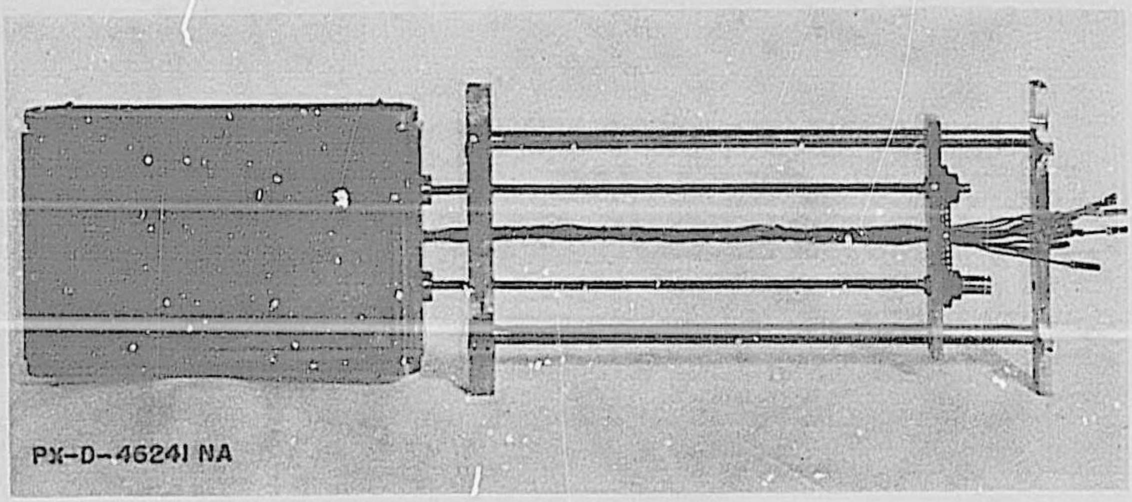
B. In its normal position the gate is above the entrance to the penstock transition.



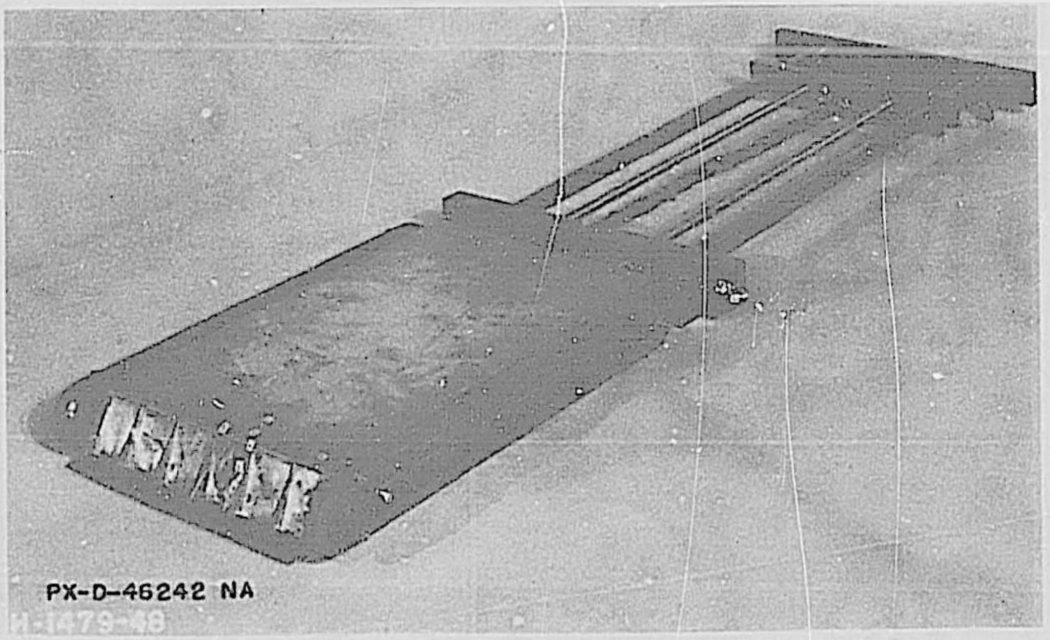
C. The gate moved on a machined seat. Piezometer leads from the gate passed through a slot in the channel floor and were connected to a junction panel in the floor of the model.

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES

General Views of 1:24 Model



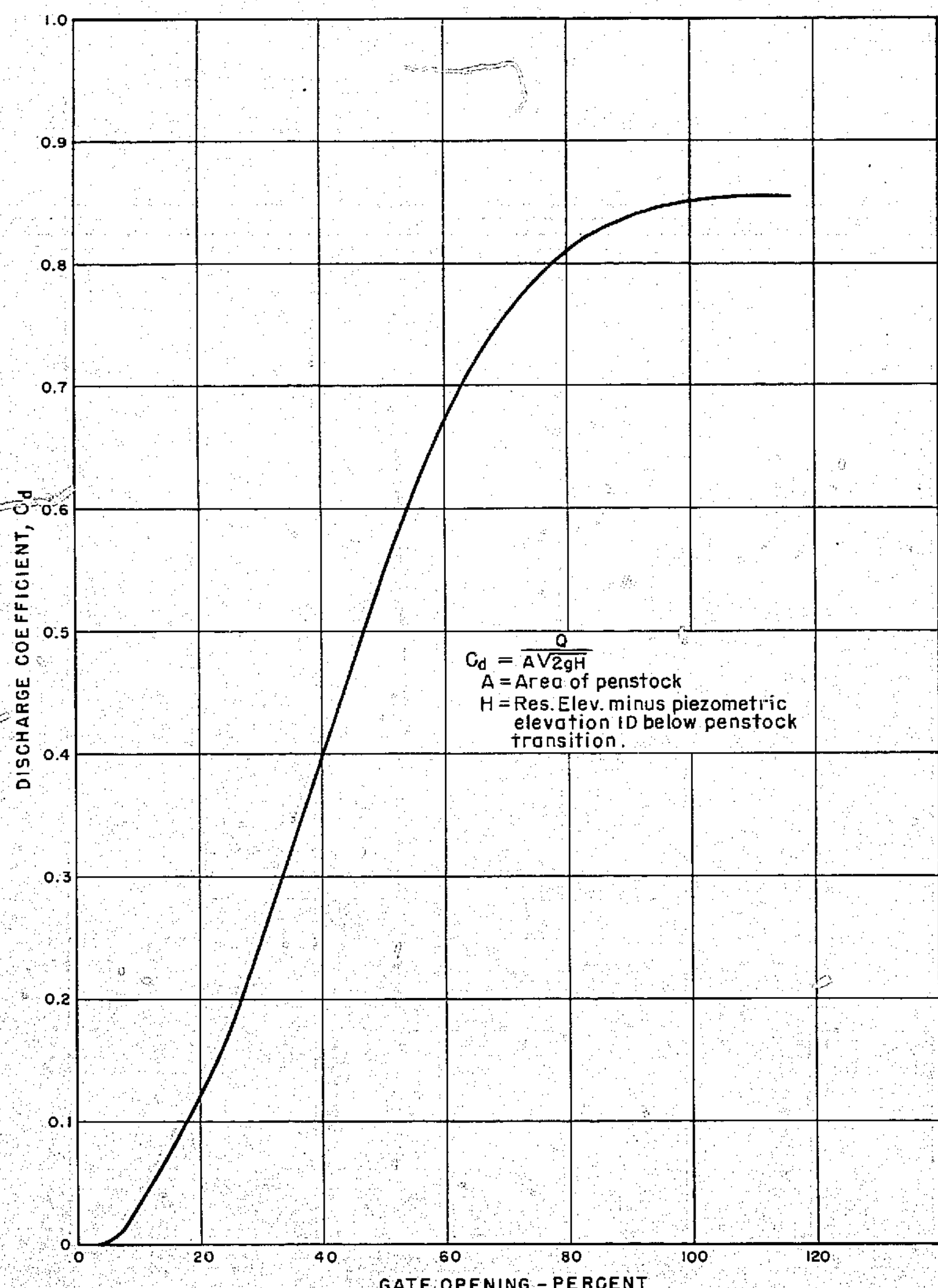
A. Underside of intake gate and operator. The gate was moved by turning the threaded rods with a crank. The rods are linked together by a chain and sprocket gear drive. The bundle of tubing is the piezometer leads.



B. Fifteen piezometers were placed in the gate to measure pressures for downpull computations. Ten piezometers were placed in the downstream end (small numbers on gate), one on upstream end and four on the underside. The oblong shapes on the side of the gate represent the coaster trains.

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES

General Views of Model Intake Gate and Operator



OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES

DISCHARGE COEFFICIENT vs. GATE OPENING

DATA FROM 1:24 SCALE MODEL

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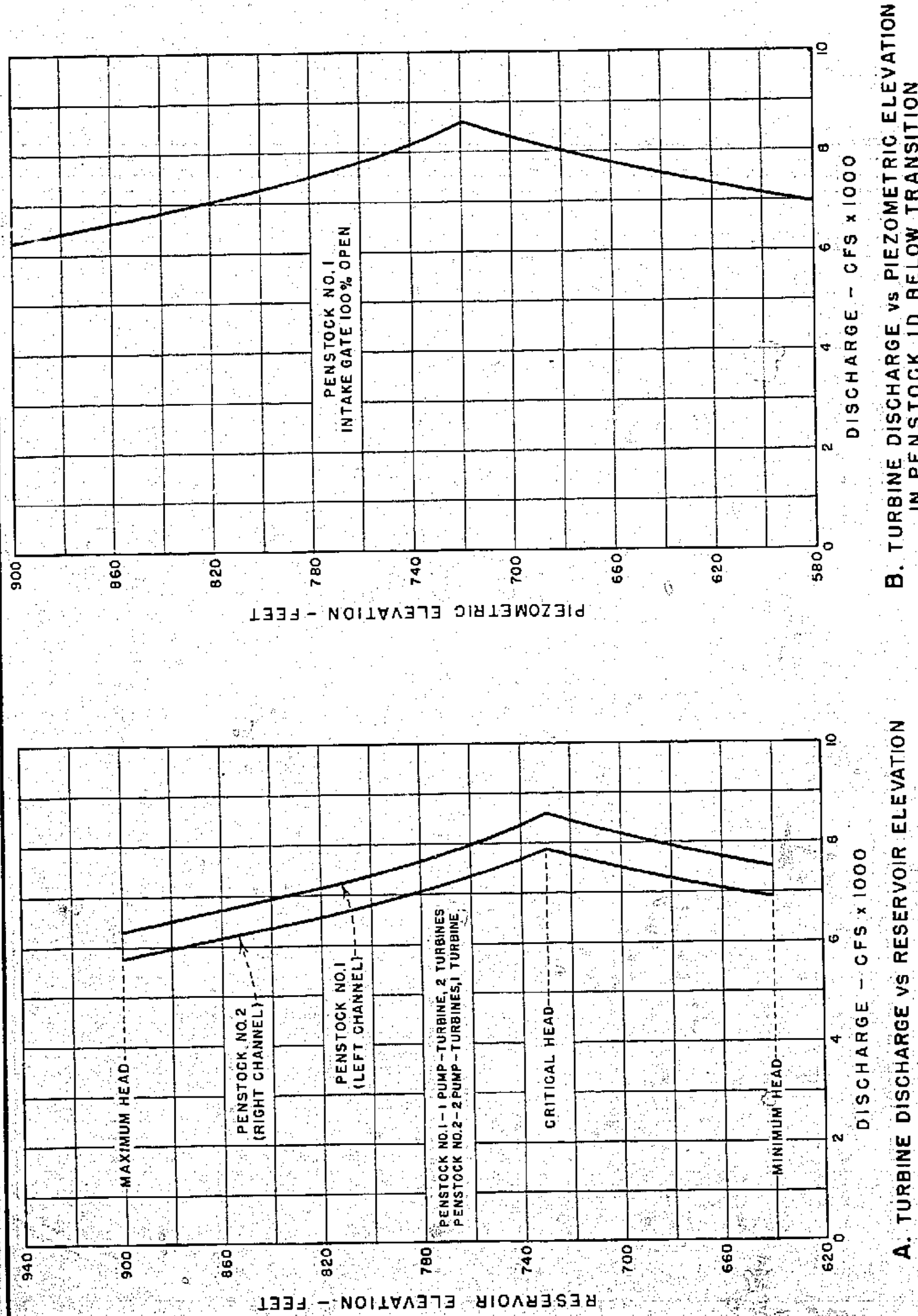
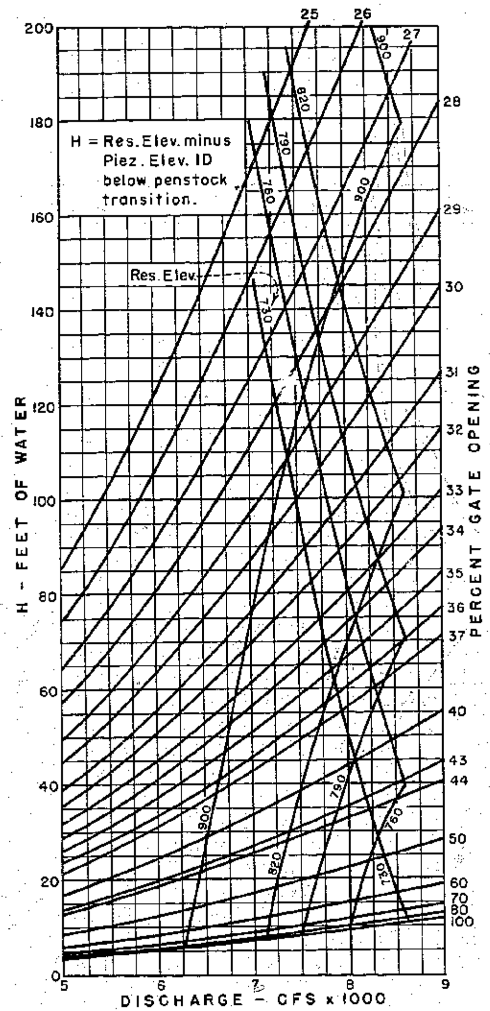
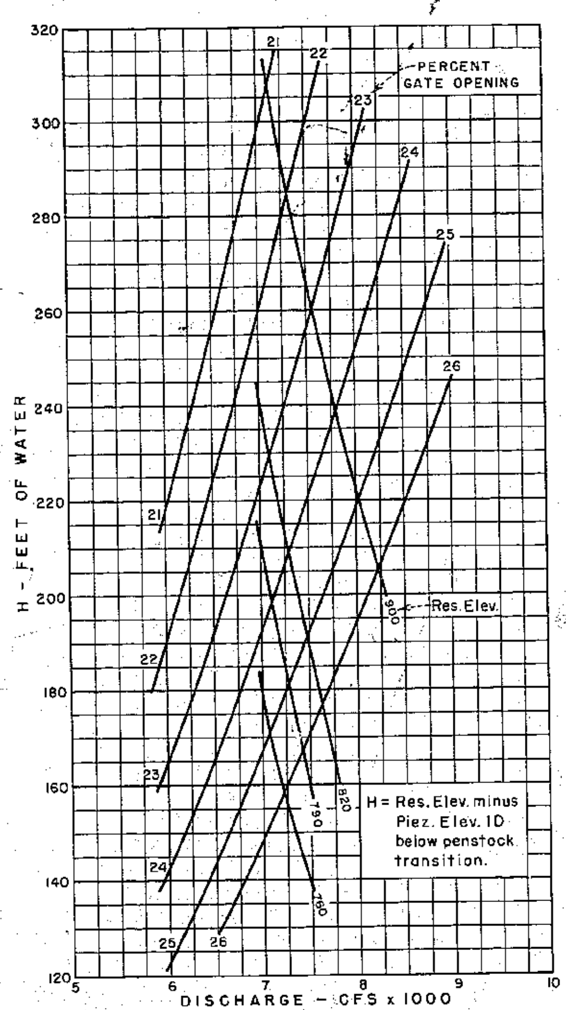


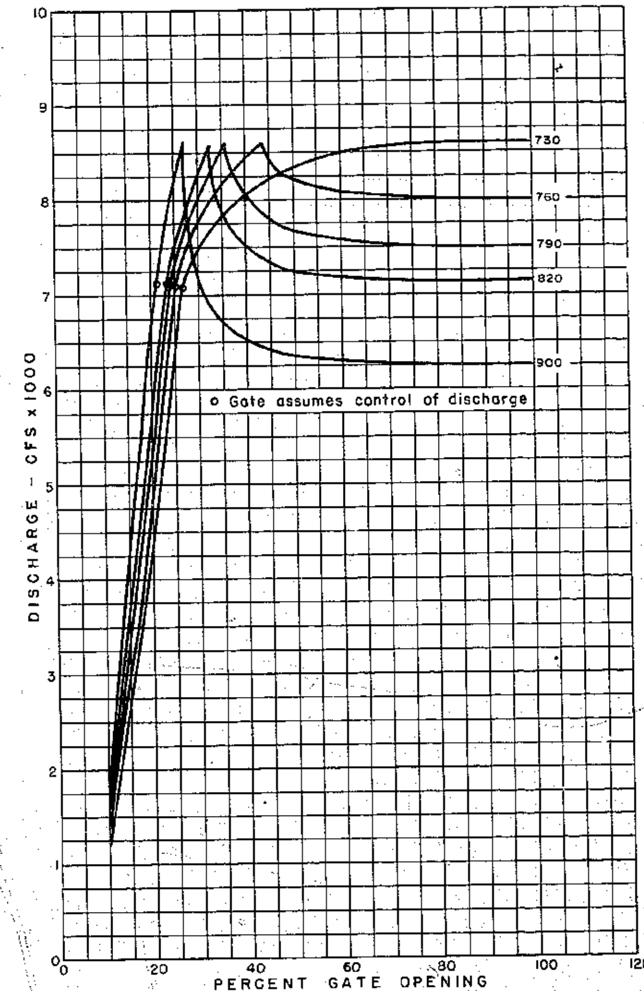
OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
TURBINE DISCHARGE CURVES



A. DIFFERENTIAL HEAD vs DISCHARGE AND PERCENT GATE OPENING



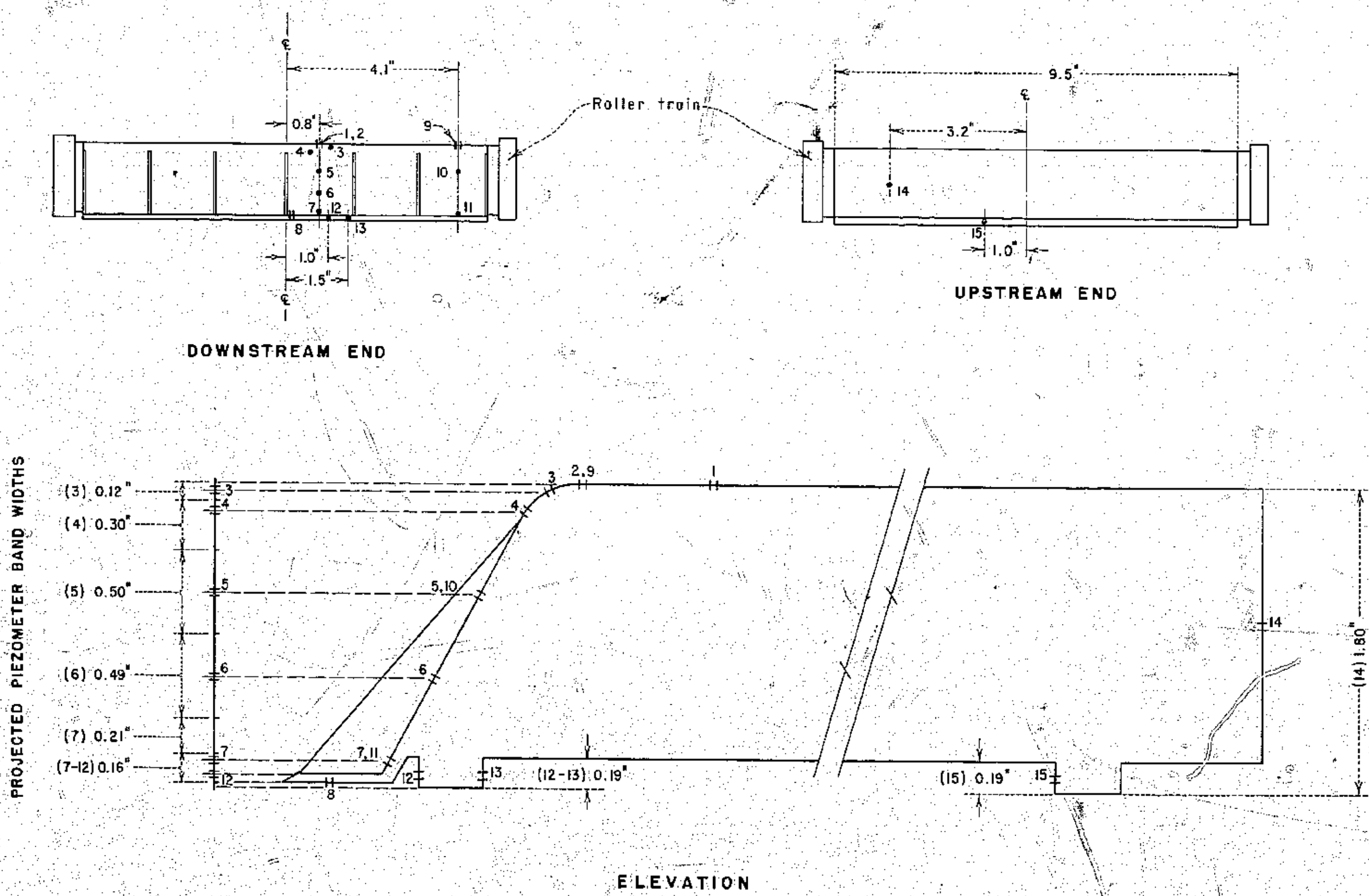
B. DIFFERENTIAL HEAD vs DISCHARGE AND PERCENT GATE OPENING



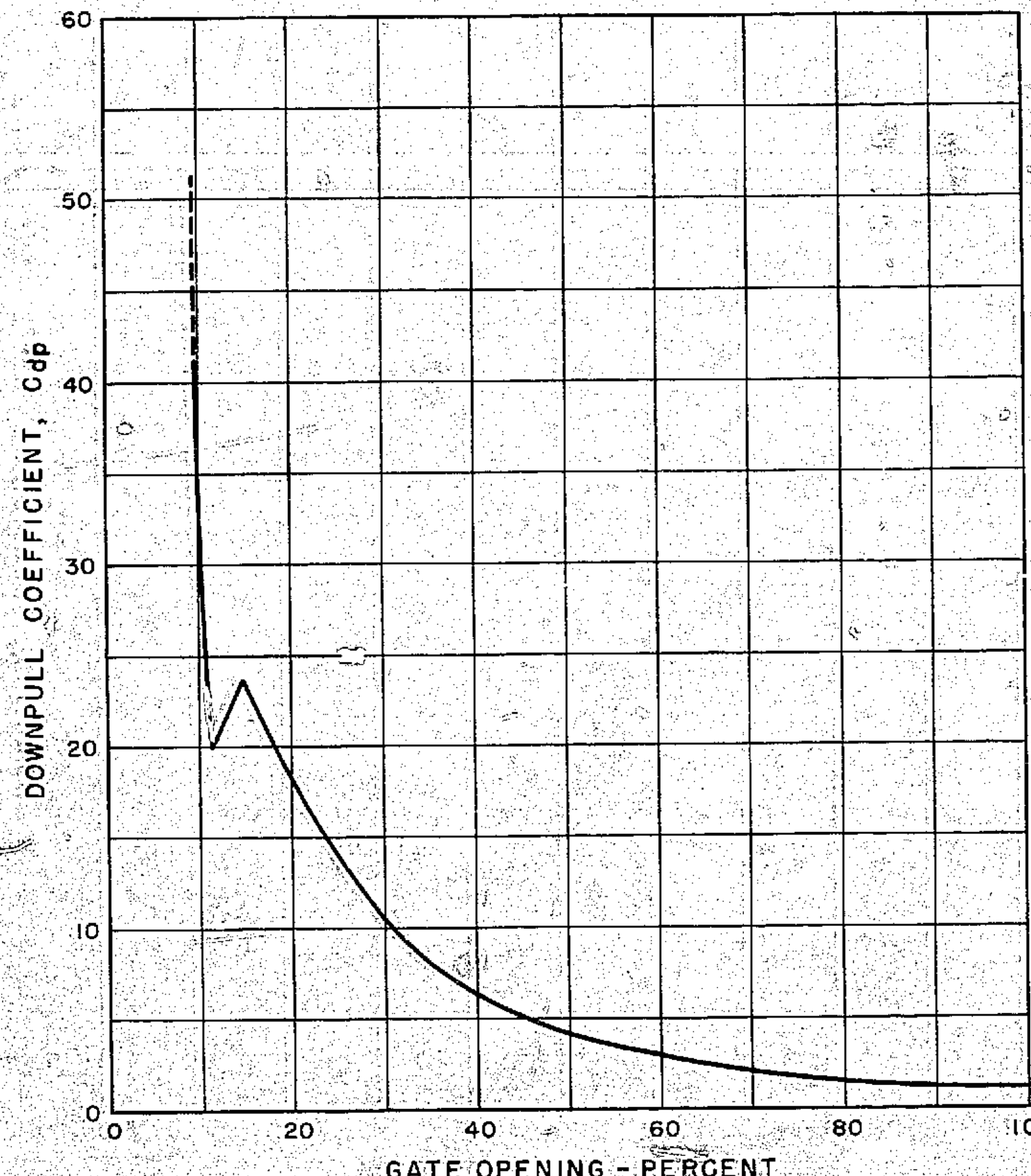
C. TURBINE DISCHARGE vs PERCENT GATE OPENING FOR RES. ELEV. 730, 760, 790, 820 AND 900

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
DIFFERENTIAL HEAD AND TURBINE DISCHARGE FOR VARIOUS GATE OPENINGS

683



OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
PIEZOMETER LOCATIONS AND PROJECTED BAND WIDTHS FOR PRESSURE - AREA COMPUTATIONS
1:24 SCALE MODEL



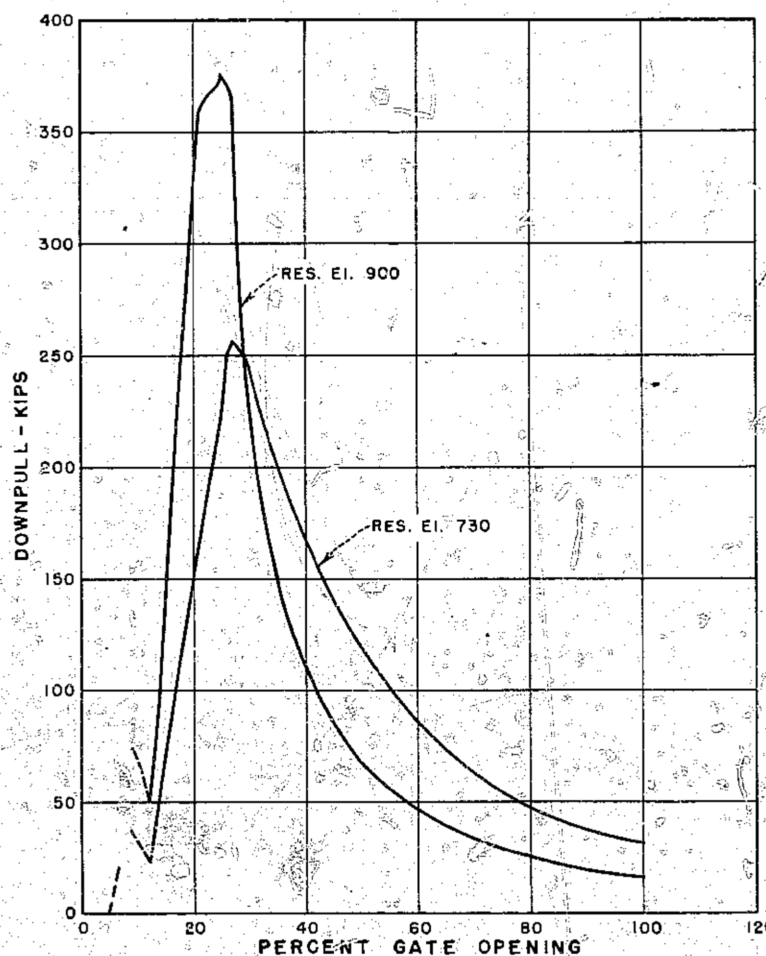
$$C_{dp} = \frac{\text{Downpull [lbs]} \cdot (\text{Area of Penstock})^2\ [\text{ft}^4] \cdot 2g\ [\text{ft/sec}^2]}{(\text{Discharge})^2\ [\text{ft}^6/\text{sec}^2] \cdot \gamma\ [\text{lbs/ft}^3] \cdot \text{Cross-Sectional Area of gate}\ [\text{ft}^2]}$$

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES

DOWNPULL COEFFICENTS

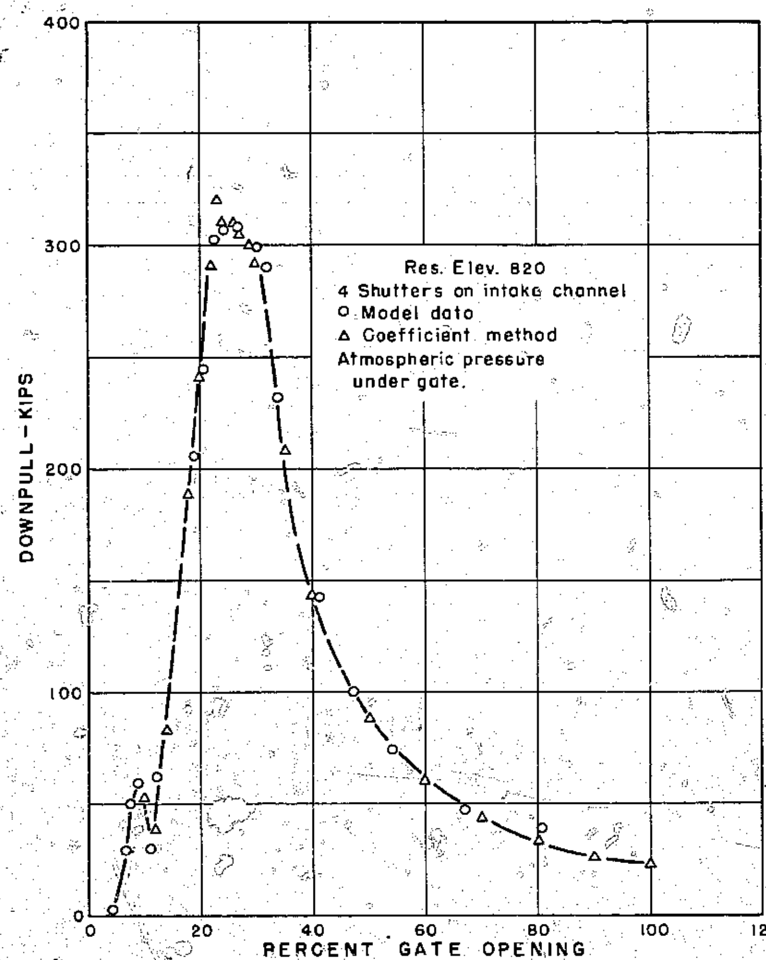
DATA FROM 1:24 SCALE MODEL

683



A. DOWNPULL VS. PERCENT GATE OPENING FOR RES. ELEV. 730 AND 900

$$\text{Downpull} = \frac{C_{dp} \cdot Q^2 \cdot \gamma \cdot \text{Cross-Sectional Area of Gate}}{(\text{Area of Penstock})^2 \cdot 2g}$$



B. COMPARISON OF DOWNPULL FORCES COMPUTED FROM 1:24 MODEL DATA AND FROM DOWNPULL COEFFICIENTS

OROVILLE DAM
INTAKE GATE DOWNPULL STUDIES
PROTOTYPE DOWNPULL FORCES
DATA FROM 1:24 SCALE MODEL

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GPO 845-408

7-1750
(10-64)

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

GPO 845-237

ABSTRACT

Hydraulic model studies to determine downpull forces occurring in the direction of travel of the 21- by 34-foot intake coaster gates for the Oroville Dam underground powerplant showed that the design was adequate. Ultimate development of the project calls for later construction of a second powerplant at the toe of the dam. Initially the complete left intake structure and the base of the right one will be built. Each intake structure includes two trashrack-covered sloping intake channels with large movable shutters. A coaster gate is positioned in each channel at the entrance to a vertical 22-foot-diameter penstock. Model studies were desirable because orientation and location of gate made theoretical downpull computations difficult. A maximum downpull force of about 376,000 pounds will occur at 25 percent gate opening for emergency closures during normal full-load powerplant operation at maximum reservoir elevation. No uplift forces were found at any gate opening or operating condition, and the shutters had little effect on the downpull. At maximum reservoir elevation, the intake gate assumes control of flow at 21 percent gate opening. The downpull forces on the 1:24 scale intake gate were computed by the pressure-area method. A method of computating turbine discharge with wicket gates moving to full open as the head is reduced during emergency closure of the intake gates is given. Dimensionless downpull and discharge coefficients included may be used for gate structures of similar geometric design.

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Hyd-540
Bucher, K. G.
HYDRAULIC MODEL STUDIES OF THE DOWNPULL FORCES ON THE OROVILLE INTAKE GATES
Laboratory Report, Bureau of Reclamation, Denver, 12 pp., 13 Figures, 1 Table, 5 References, 1964

DESCRIPTORS--Hydraulics/ *hydraulic downpull/ hydraulic models/ hydraulic gates and valves/ hydraulic machinery/ calculations/ model tests/ research and development/ discharge coefficients/ *intake gates/ coaster gates/ laboratory tests/ penstocks/ powerplants/ negative pressures/ uplift pressures/ underground powerplants/ trashracks/ discharges/ open channel flow/ *intake structures/

IDENTIFIERS--Oroville Dam Powerplant/ sloping intake structures/ wicket gates/ pressure-area method/ emergency closures/

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