UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MODEL--PROTOTYPE COMPARISON OF THE HYDRAULIC FORCES ACTING ON THE OUTLET COASTER GATE--SHASTA DAM--CENTRAL VALLEY PROJECT

Hydraulic Laboratory Report No. Hyd.-233

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

OCTOBER 25, 1948

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Research and Geology Division
Denver, Colorado
Date: October 25, 1948

Laboratory Report No. 233
Hydraulic Laboratory
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Reviewed by: C. W. Thomas
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Subject: Model--Prototype comparison of the hydraulic forces acting on the outlet coaster gate--Shasta Dam--Central Valley Project.

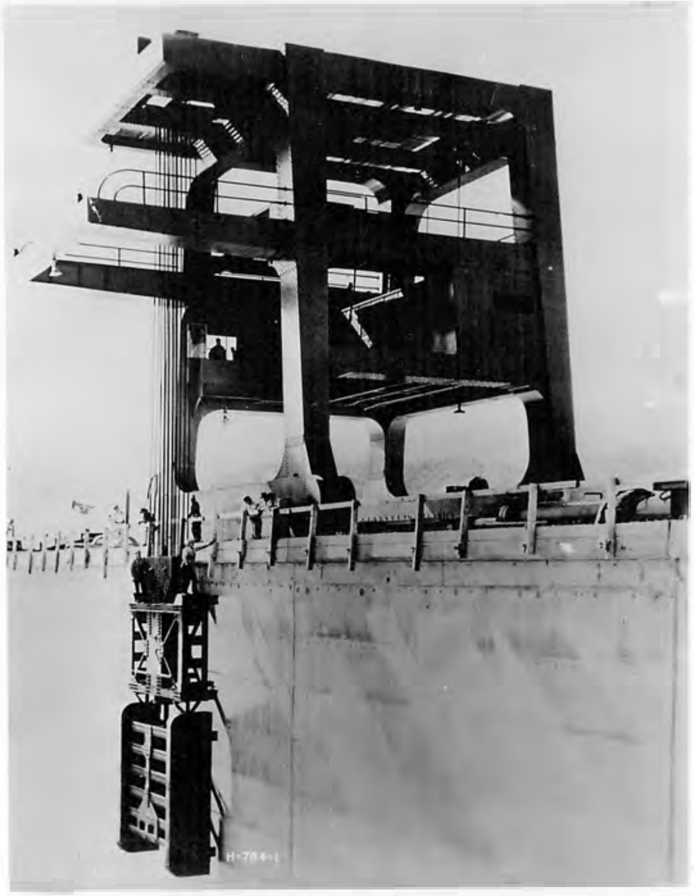
INTRODUCTION

Each of the 18 river outlets in the spillway section of Shasta Dam is provided with a single valve to accurately control the quantity of water released into the Sacramento River. A coaster gate is used to close the intake of any one of the passages for servicing and inspection of the control valves and conduits or for emergency closure in event of failure of a control valve.

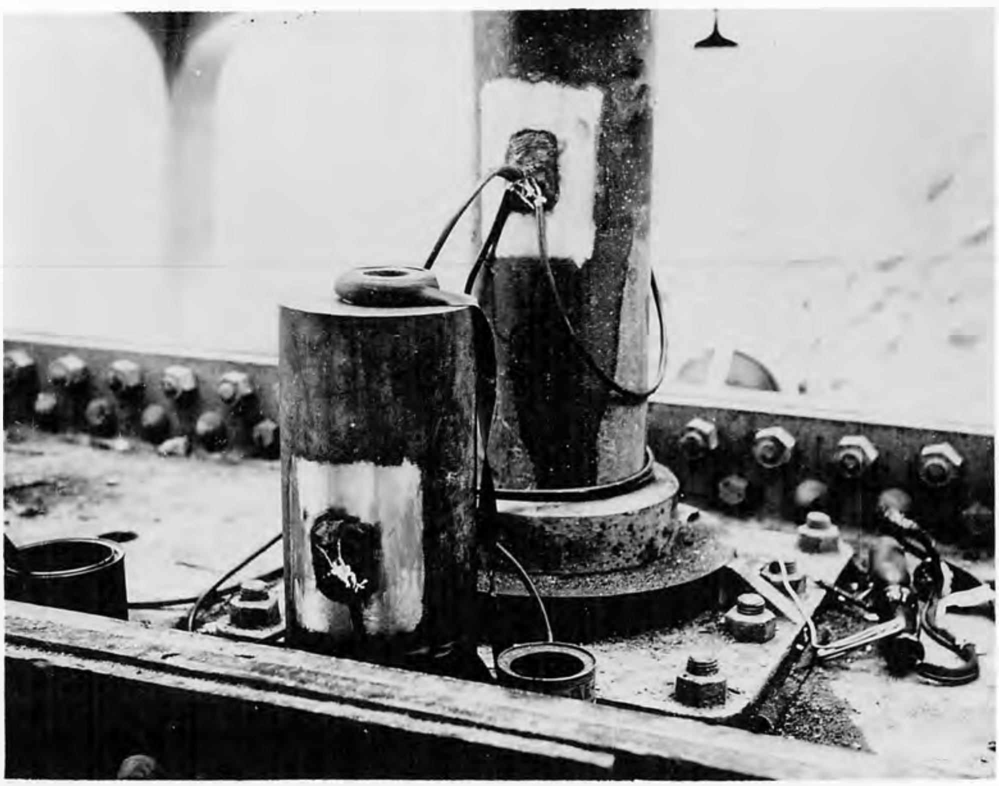
In simplicity, the coaster gate is a rectangular steel structure with a skin plate riveted to the downstream side of horizontal beams which are supported by vertical girders and mounted on roller trains, Figure 1A. In operation, the gate is lowered by its own weight in guides on the face of the dam. The outlets are arranged so that 14 sets of guides serve all 18 of the conduits, the 4 lower ones being served by the same guides as 4 in the intermediate tier. The coaster gate includes a device for engaging the stops to center the gate in front of any predetermined passage.

Metal covered rubber "music-note" seals are provided on the downstream side of the gate to contact the fixed seat on the face of the dam after the gate is in the closed position. Advantage is taken of the pressure differential across the gate to force the seals against the seat when the gate is closed or to retract the seals while moving the gate. This is accomplished by connecting a water passage immediately upstream from the "music-note" seals to the reservoir pressure or the reduced pressure on the downstream side of the gate by a two-way valve actuated by overtravel of the hoisting stem.

Normally, the gate is operated under balanced hydrostatic pressures with no flow through the outlet, however, design requirements were dictated by the conditions existing during an emergency closure under maximum head. Under these conditions the gate is subjected to large unbalanced pressures. The increase in velocity under the gate



A - Coaster Gate and Handling Equipment for River Outlets.



B - Strain gages for measuring forces on coaster gate.

SHASTA DAM

causes a reduction in pressure and creates a downpull force. The magnitude of this force could not be neglected in the design of the handling equipment which was limited by the permissible load on the bridge across the spillway. The force could only be approximated analytically since the pressures on the bottom of the gate are a function of the flow velocity, the shape of the bottom of the gate, and the gate opening. The value of the downpull force is therefore dependent upon the velocity distribution and flow pattern underneath the gate, since the pressure reduction at any point on the lower portion of the gate is equivalent to the velocity head at that point. Accordingly, a hydraulic model was utilized to evaluate the hydraulic forces.[1/] These studies also enabled the development of a new shape for the bottom of the gate which together with a properly shaped recess in the face of the dam above the inlet to the conduit, reduced the downpull force to a safe value. Numerically, this reduction was from 260,000 to 70,000 pounds.

To minimize the vibration caused by low pressures in the outlet entrance at partial gate openings, provision was made in the prototype structure to admit air to the area immediately downstream from the coaster gate. The size of the air supply line was established at 10-inch diameter as a result of investigations on a hydraulic model.[2/]

During the initial tests of the tube valve at Shasta Dam, advantage was taken of the opportunity to measure the downpull force of the coaster gate, the pressure developed inside the conduit, and the maximum quantity of air admitted to the downstream side of the gate.[3/] Emergency conditions were represented by operating the coaster gate over the lower river outlet through Block 45 with the tube valve 98 percent open. (The valve was not operated at the wide-open position because of the severe vibration encountered during the test of the tube valve.)

SUMMARY

The maximum hydraulic downpull force acting on the coaster gate for the river outlets was found to reasonably agree with the value determined on the hydraulic model. The recess provided in the face of the dam immediately above the entrance to the outlet was effective in equalizing the forces on the upper horizontal seal assembly.

[1/] Note: Numbers appearing, such as [1/] above, refer to the numbered references listed at the end of this report.

However, contradictory to the prediction, this balancing action also occurred at the smaller gate openings causing an uplift force. This force was of insufficient magnitude to prevent satisfactory movement of the emergency gate.

The field test also included measurement of the quantity of air entering the outlet immediately downstream from the gate together with the pressure developed in this region. Although these data are not directly comparable to the laboratory results which revealed pressures sufficiently low to indicate dissimilarity between the hydraulic model and its prototype, the information will be of value in future design problems of similar nature.

Incidental to the scheduled program, manipulation of the gate prior to the test resulted in damage to the "music note" seals. Accordingly, a description of the impairment together with the apparent reason for the malfunctioning is included for application in similar problems.

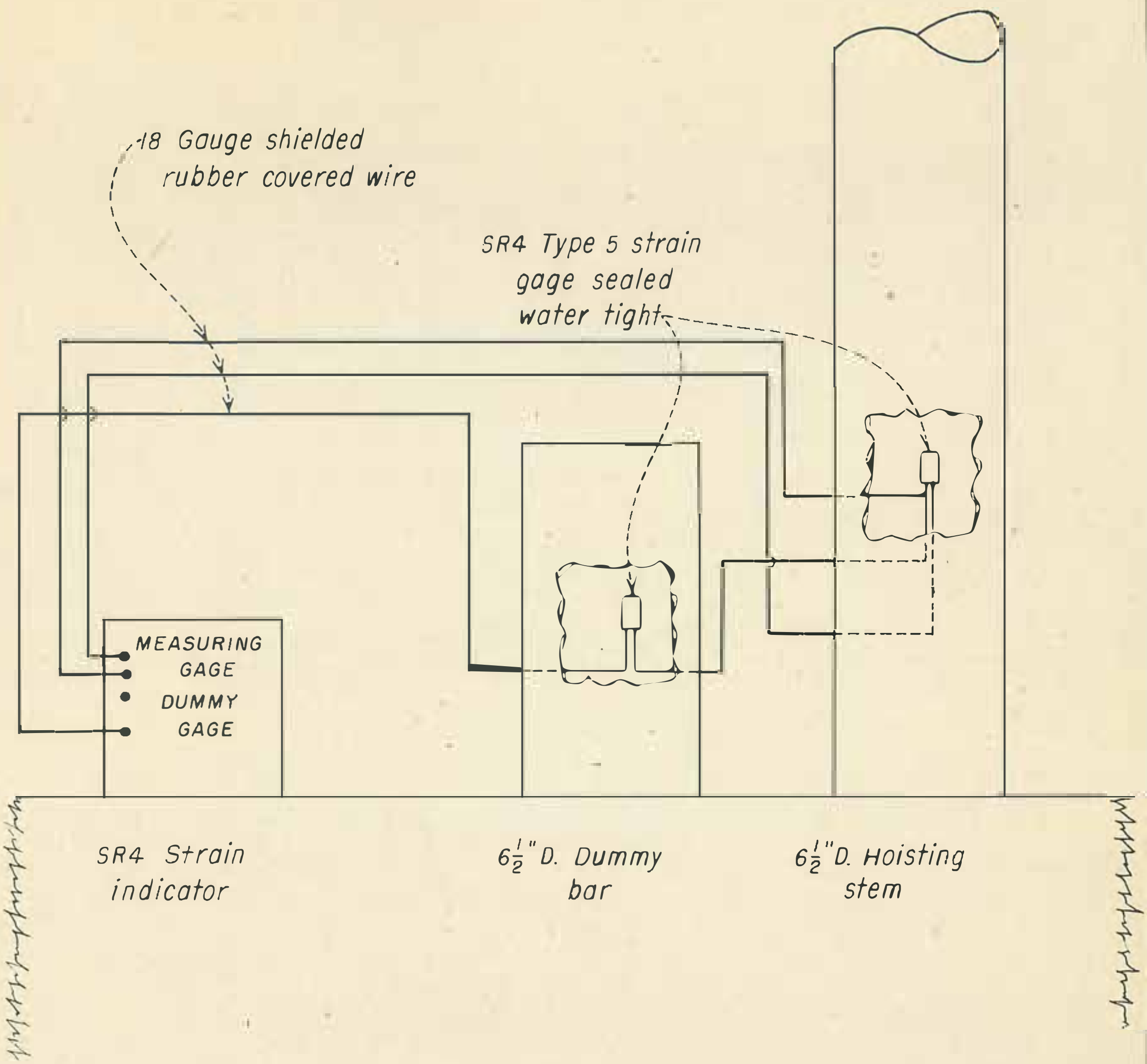
TEST EQUIPMENT

To evaluate the downpull force, the strain was measured by use of an SR-4 bonded resistance wire strain gage, Type A-5, mounted on the gate hoisting stem. The change in the resistance of the strain gage was measured by an instrument known as a Portable Strain Indicator manufactured by the Baldwin-Southwark Division of the Baldwin Locomotive Works in Philadelphia. The meter consists essentially of a Wheatstone bridge with a galvanometer together with variable resistors to maintain the balance of the bridge.

A second strain gage of the same type was secured to a dummy bar placed adjacent to the hoisting stem, Figure 1B. By using this dummy gage, a twofold purpose was accomplished: (1) all effects of temperature were automatically balanced out; and (2) the two resistance arms of the bridge were made more nearly identical. The wiring plan for the two gages and meter is shown on Figure 2. The gages were waterproofed with cold-applied mastic developed by the Chemistry Laboratory for concrete joint filler.

The position of the gate was indicated by utilizing an engineer's chain secured on a cable with one end anchored to the coaster gate and kept taut by a counterweight at the free end. This cable was rigged in such a way that the chain passed over the bridge across the spillway. The strain indicator and chain were grouped together permitting the recording of the data with a 35-mm motion picture camera operating at the approximate rate of 3 frames per second. A stop watch was included in the picture area to verify the clocks in the metering instrument. Figure 3 is an enlargement of one of the frames of the motion picture film.

FIGURE 2

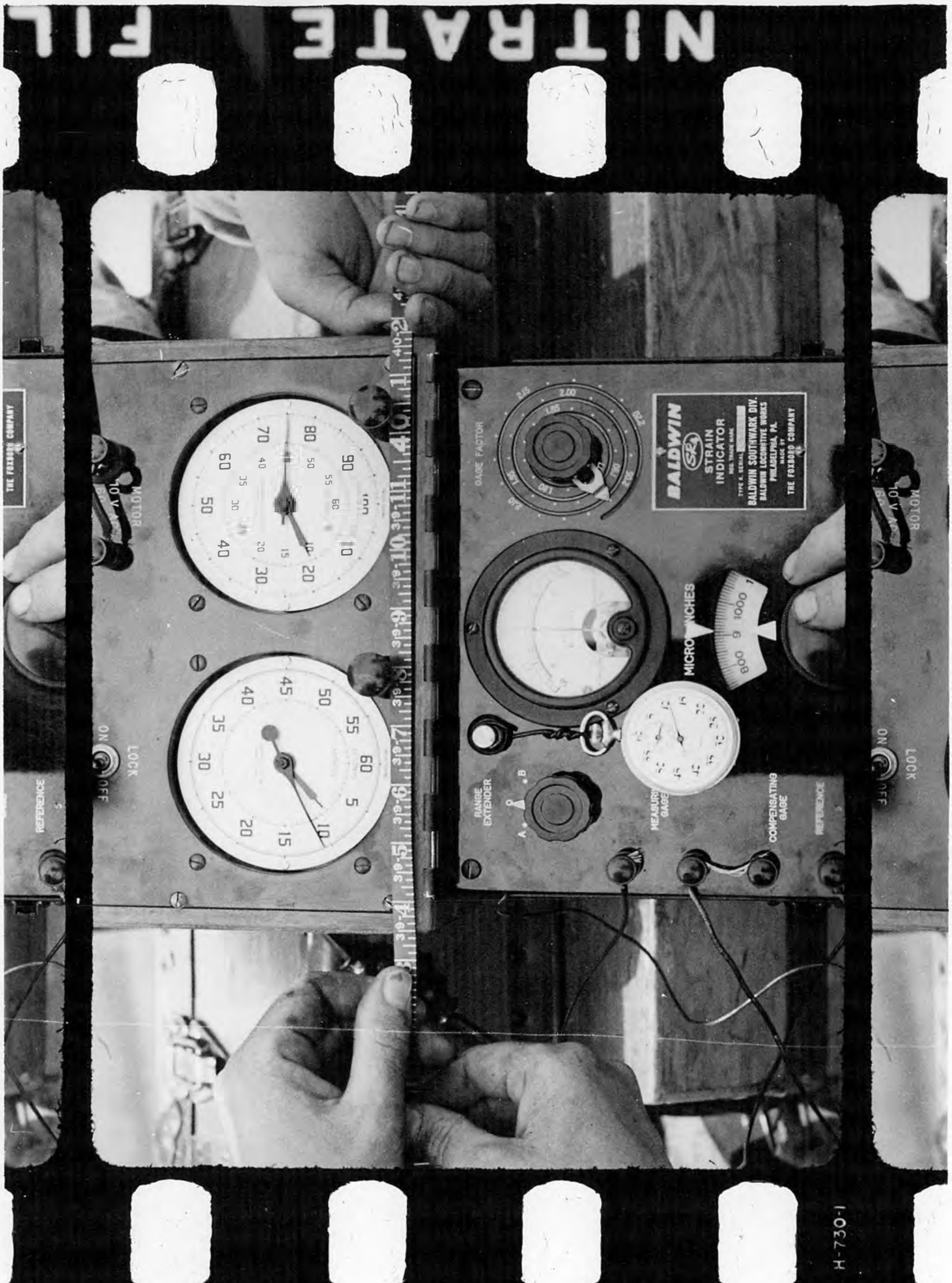


SHASTA DAM

MEASUREMENT OF HYDRAULIC FORCES ON OUTLET COASTER GATE

R.W.B. AUG. 10, 1948

Figure 3



Method of recording data for
outlet coaster gate tests.
SHASTA DAM

Simultaneously with the determination of the strain, the maximum quantity of air admitted immediately downstream from the coaster gate was ascertained by utilizing a Cole Pitometer manufactured by the Pitometer Log Corporation, New York. The orifice tips of the instrument were placed in the center of the 20-inch-diameter pipe which, by means of a manually controlled valve, was connected to the 10-inch pipe leading to the crown of the conduit immediately downstream from the entrance, Figure 4. A recording was also made of the minimum pressure in the outlet by observing the maximum deflection of a mercury U-tube connected to a piezometer on the left end of the horizontal axis 17 inches from the face of the dam.

TEST PROCEDURE

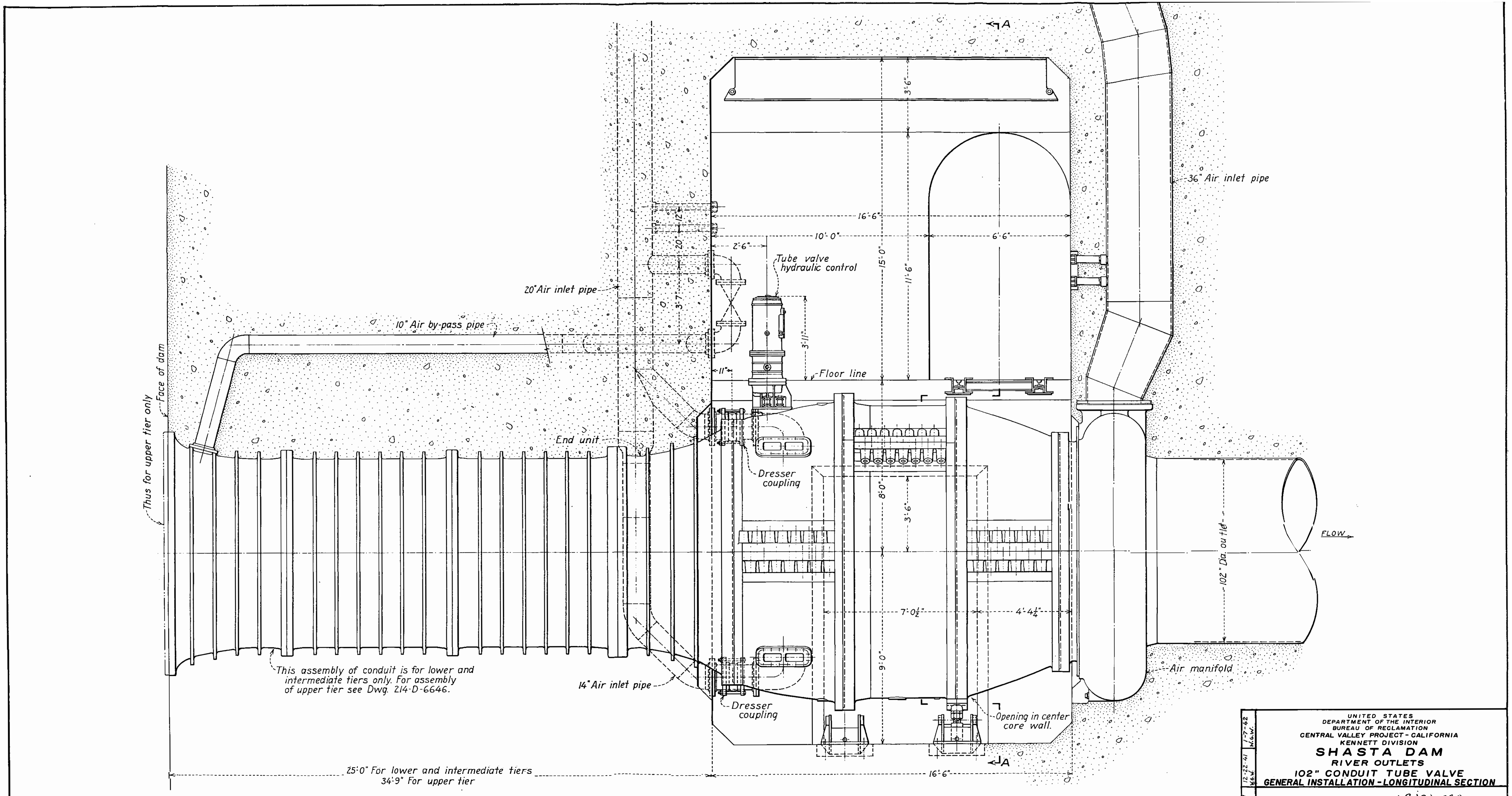
The test was performed by starting with the coaster gate in the closed position (tube valve 98-percent open). The observations of strain, air velocity, and pressure were made while raising the gate to a position several feet above the entrance to the outlet where unbalanced hydraulic forces no longer acted on the gate. Strain measurements were again recorded while lowering the gate to the sealing position. The head on the centerline of the conduit during the manipulation of the gate was 265 feet compared to the maximum design head of 323 feet.

During the performance of the test, the balance of the galvanometer in the strain indicator was maintained manually without difficulty. A continuous record of the strain and gate position was obtained with the 35-mm motion picture camera.

TEST RESULTS

The relation between the readings of the strain indicator, gate-position chain, and time shown on Figure 5 was obtained from the motion picture film. The gate opening, expressed in percent, represents the true opening after allowing for the lip of the gate shown in the sketch on Figure 6.

To convert the strain into force in pounds, the strain indicator was read with no load on the hoisting stem (the gate resting on the stops) and while the gate was suspended in still water. The difference in these two readings was 89 units. Then by knowing the weight of the gate in air, it is possible to compute the force in pounds represented by a single unit of the strain as follows:



SECTION B-B
FROM DWG. 214-D-6619

UNITED STATES
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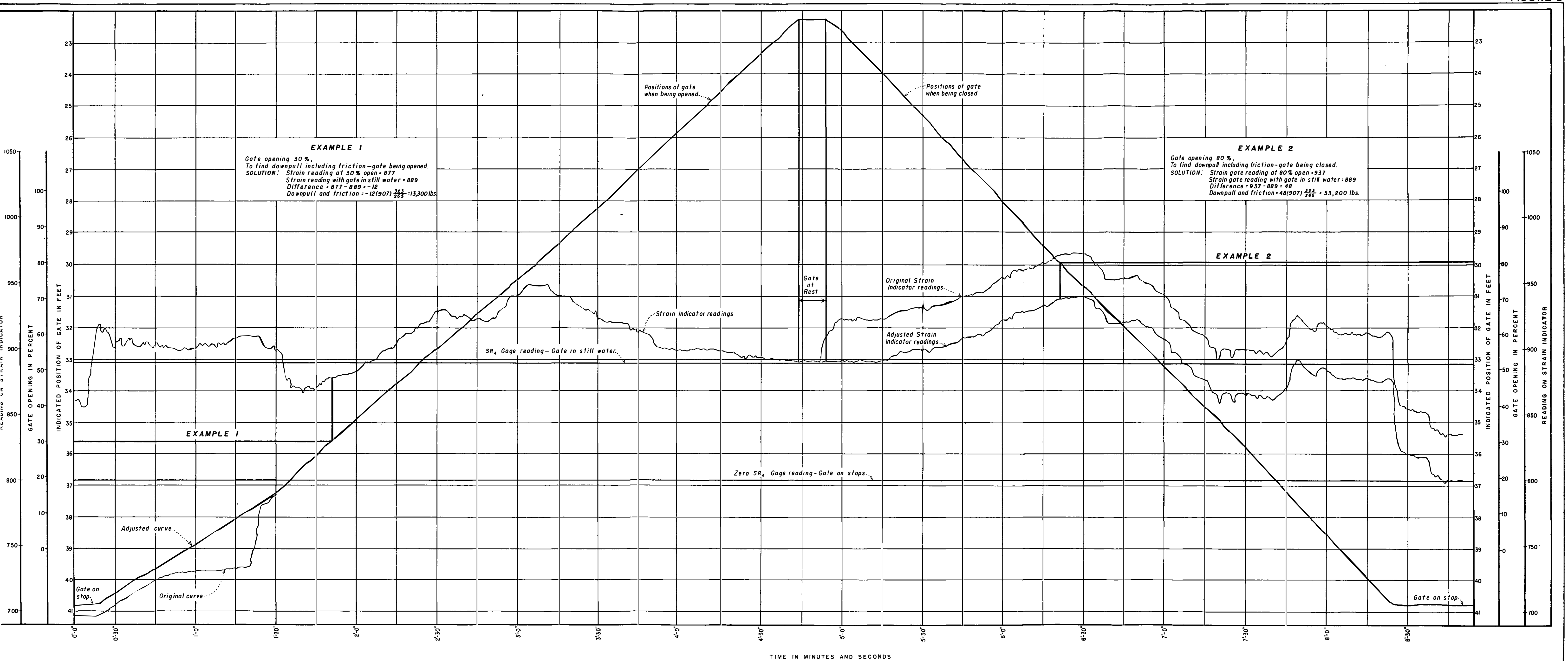
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM
RIVER OUTLETS
102" CONDUIT TUBE VALVE
GENERAL INSTALLATION - LONGITUDINAL SECTION

DRAWN B.H.S.-J.D. SUBMITTED L.N. McClellan
TRACED H.R.S. RECOMMENDED J.L. Savage
CHECKED H.I.P.S. APPROVED [signature]
DENVER, COLORADO, JUNE 2, 1941
SHEET 1 OF 2
214-D-6618
REV. 8-15-41, 12-22-41, 1-7-42

FIGURE 5

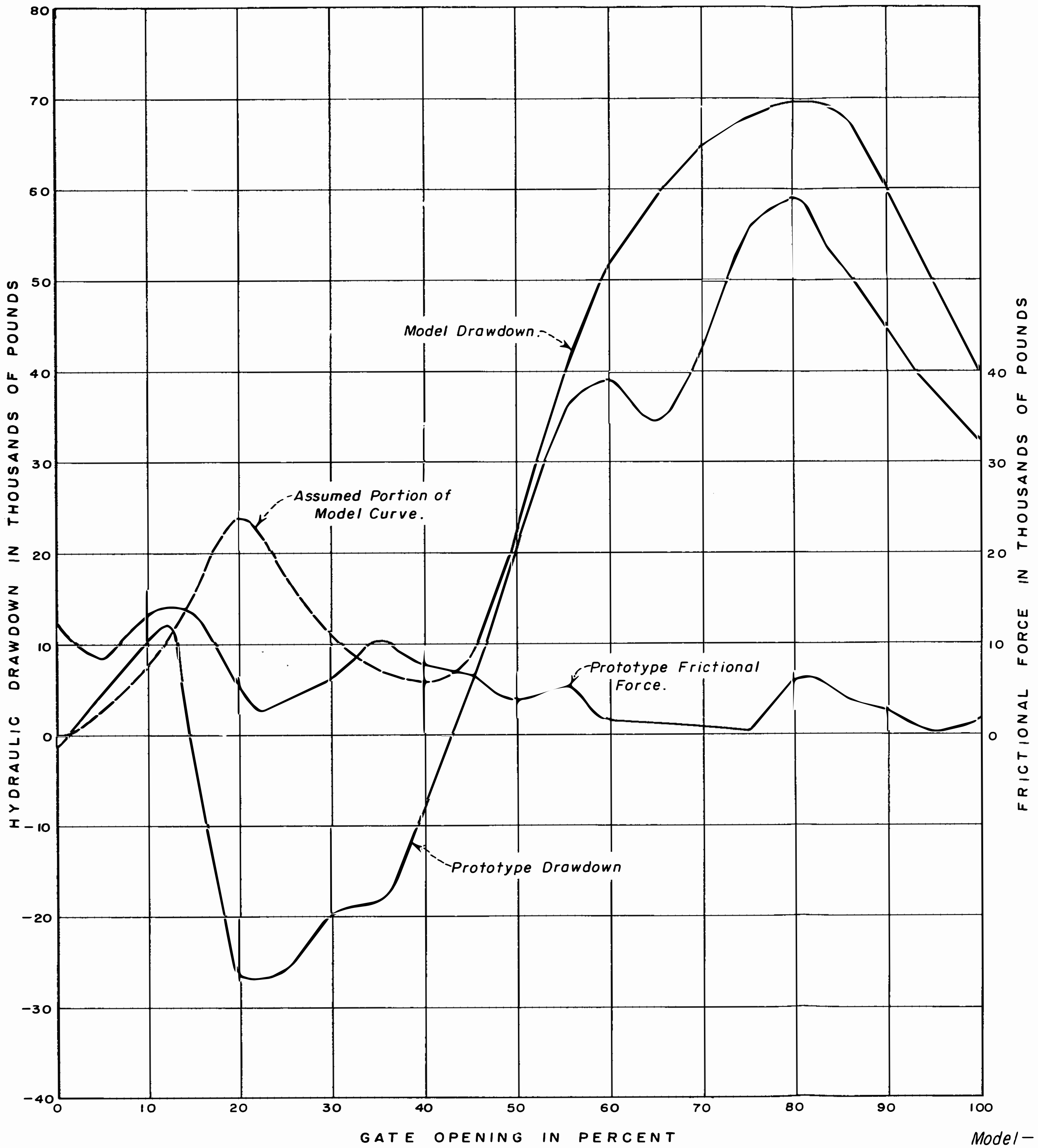


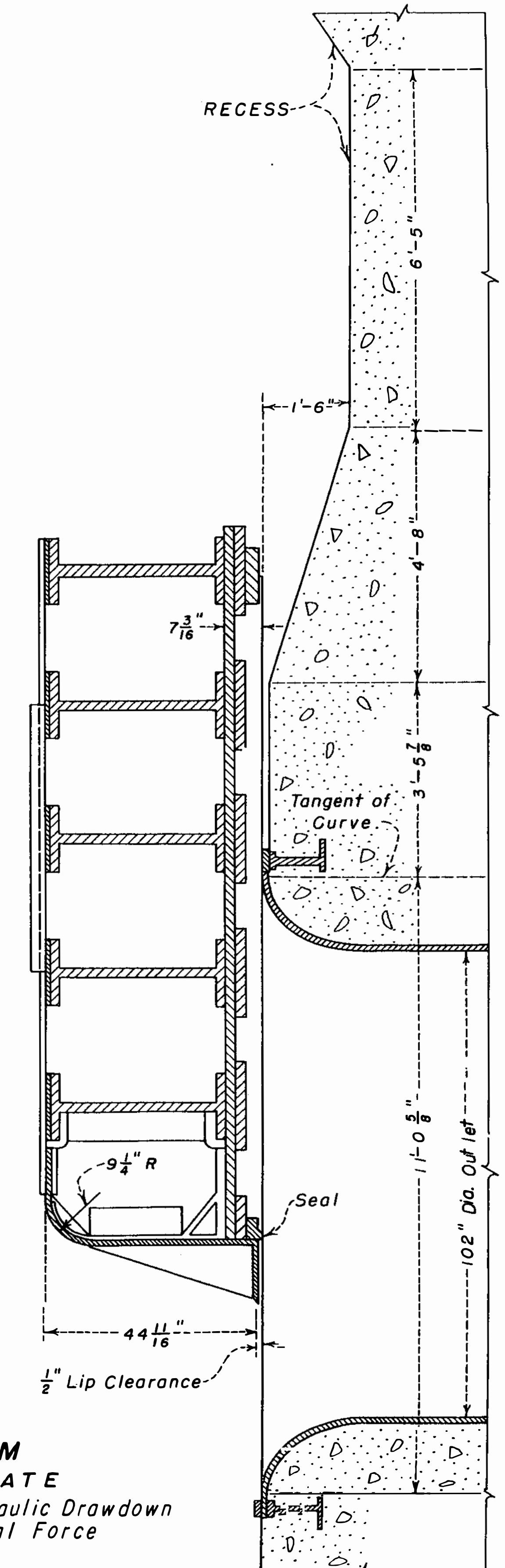
SHASTA DAM COASTER GATE TEST

RIGHT OUTLET — BLOCK 45 — LOWER TIER

ORIGINAL AND ADJUSTED CURVES OF STRAIN vs GATE POSITION

6-21-48





SHASTA DAM

OUTLET COASTER GATE

Model—Prototype Comparison of Hydraulic Drawdown And Prototype Frictional Force

Weight of gate in air = 92,527 pounds

$$\text{Specific gravity of steel} = \frac{\text{weight in air}}{\text{wt. of equal volume of water}}$$

$$7.83 = \frac{92,527}{\text{wt. of equal volume of water}}$$

$$\text{Weight of equal volume of water} = \frac{92,527}{7.83} = 11,817$$

By Archimedes' principle:

Wt. of gate submerged = wt. in air - wt. of equal volume of water

= 92,527 - 11,817 = 80,710 pounds

Hence, $\frac{80,710}{89}$ = 907 pounds = one unit of the strain indicator.

The two examples on Figure 5 further illustrate the procedure in obtaining force from the strain-gage readings.

It should be realized that the accuracy of the test results is dependent upon the weight of the coaster gate in air. This weight can be computed, however, the tolerances allowable will introduce errors of unknown value. Accordingly, the weight of 92,527 pounds was assumed as correct since this value is shown, exclusive of dunnage, on the itemized list of materials which accompanied the bill of lading for shipment of the gate. This weight is presumably the result of Paragraph 25 of Specifications No. 1682-D which states in part, "the contractor shall, in the presence of the inspector, weigh all finished materials on the most accurate scales available, and a complete list of such net weights, exclusive of boxes, crates, or skids, shall be furnished to the contracting officer."

A discrepancy in the gate position indicator occurred during the initial part of the test due to failure of releasing the brake on the hoist used to lower the counterweight on the cable supporting the engineer's chain. The sudden jerk on the line when the brake was released caused a shift in the zero of the tape, which was corrected by observing the reading when the gate was lowered to the stops at the completion of the test.

A second inconsistency was apparent in that the strain increased approximately 30 points while the gate was suspended above the opening where balanced pressures existed. An additional increase of 6 points occurred during the closing cycle as evidenced by a comparison of the strain with the gate resting on the stops at the conclusion of the observations with that existing at the start of the test. Accordingly, the portion of the curve expressing the relation of strain to gate position during the closing cycle was lowered approximately 36 points to obtain the true value. The relation between strain, gate position, and time after correcting the inconsistencies is apparent from Figure 5.

The increase of 36 points in the strain can only be attributed to the occurrence of a leak in the insulated wire permitting water to contact the electrical conductor, thereby increasing the resistance. This condition is further exemplified by the fact that the first entry of water would cause the greater increase in resistance corresponding to the 30 points while increasing the length of the electrical conductor in contact with moisture would cause a lesser change in the resistance resulting in the 6-point value.

From the data obtained, it is possible to evaluate:

a. The friction force

b. The hydraulic downpull force acting on the gate

c. The maximum quantity of air supplied to the downstream side of the gate and the minimum pressure in the conduit

These three items will be discussed in the order listed.

The Friction Force

From the following, it is apparent that one-half of the difference between the forces during the closing and opening cycle represents the force to overcome friction:

$$\begin{aligned} \text{opening force} &= \text{net thrust} + \text{friction} \\ \underline{\text{closing force}} &\underline{= \text{net thrust} - \text{friction}} \\ \text{opening force} - \text{closing force} &= 2\ \text{friction} \end{aligned}$$

$$\text{or friction} = \frac{\text{opening force} - \text{closing force}}{2}$$

The relation between the friction force and gate opening is shown on Figure 6. All forces shown in this report are based on the maximum design head of 323 feet by increasing the values actually measured on the prototype structure by the ratio of $\frac{323}{265}$. In analyzing the results, it must be assumed that a linear relationship exists between the stress developed on the periphery of the hoisting stem and the total force acting on this member, and further, that a similar relationship exists between the deformation of the strain gage and its resistance.

The Hydraulic Downpull Force Acting on the Gate

The hydraulic downpull force was obtained by eliminating the forces due to friction and the weight of the gate. The relationship of this force to gate opening is shown on Figure 6. To permit comparison, the curve determined from observations on the hydraulic model is shown on the same plot. It may be seen that the maximum drawdown is 59,000 pounds of 11,000 pounds less than predicted. This variance of approximately 15.7 percent is not greater than should be expected for this type of measurement.

The characteristic of the curve determined on the prototype is different than the one obtained from the model at gate openings of 55 to 65 percent. The reason for the nonsimilarity is not apparent but is relatively unimportant in this region. However, the peculiar characteristic of the curve may have been caused by a mechanical condition resulting in a very small frictional force. In fact, the prototype data showed a negative friction force between gate openings of 67 to 73 percent which indicated that this force was less than the accuracy of the measurements.

Considerable variation exists between the model and prototype downpull curves for gate openings of 12 to 45 percent, due to the effect of the recess in the face of the dam immediately above the entrance to the outlet. As previously stated, this recess was one of the two design methods utilized to reduce the downpull force to a minimum; the other one being a lip on the bottom of the gate. The purpose of the depression was to balance the hydrostatic pressure on the upper horizontal projected seal assembly. Without such a recess the pressure on the lower side of the seal assembly would be low, the same as the pressure in the outlet entrance, hence the static pressure on top of the projection would exert a downward force increasing the total downpull. At the smaller gate openings, however, the model demonstrated that a negative downpull or uplift force existed which together with the friction force might prevent the lowering of the coaster gate. To avoid this condition, the recess was tapered so that as the gate closed the recess would begin to lose its effectiveness at an opening of 45 percent and become entirely ineffective at an opening of 20 percent. It is apparent that the recess would also lose its effect at gate openings larger than approximately 80 percent since the lower horizontal projected seal assembly would then occupy a position causing unbalanced pressure.

Referring to Figure 6, uplift forces did exist indicating that the recess did not begin to lose its effectiveness until the gate was lowered to an opening of approximately 20 percent. This exemplifies the possibility of encountering a condition preventing the closure of a gate without applying mechanical forces in addition to the dead weight.

The portion of the model curve representing downpull for gate openings less than 45 percent is indicated as a dotted line inasmuch as the recess corresponding to the prototype structure could not have been duplicated on the hydraulic model without a major structural revision. Accordingly, the downpull forces in this region were predicted from a general study on the hydraulic model utilizing recesses smaller than desired.

<u>The Maximum Quantity of Air Supplied to the Downstream Side of the Gate and the Minimum Pressure in the Conduit</u>

The maximum quantity of air flowing into the outlet adjacent to the coaster gate was evaluated by utilizing a cole pitometer with the orifice tips located in the center of the 20-inch pipe. The deflection obtained in a water manometer connected to the instrument permitted the determination of the air velocity in the center of the pipe. This velocity was computed as follows:

Diff. head of water manometer = 0.69 foot

Dry bulb = 65° F = 18.3° C

Wet bulb = 60.5° F = 15.8° C

Barometer = 29.4" = 747-mm mercury

Density of moist air,

$$D = 1.2929 \frac{(273.13)}{T} \frac{(B-0.3783e)}{760}$$

where T = absolute temperature

B = barometric pressure in mm of mercury

e = vapor pressure of the moisture in the air in mm of mercury

$$D = 1.2118 \frac{(747 - 0.47)}{760} = 1.2118\ (0.982)$$

$$= 1.19 \text{ grams per liter}$$

$$D = 1.19 \frac{(28.317)}{453.5} = 0.0743 \text{ lb/ft}^3$$

$$\frac{62.4}{0.0743}(0.69) = 579.49 \text{ ft of air} = h$$

$$V = \sqrt{2gh}$$

$$V = \sqrt{64.32(579.49)} = \sqrt{37272.7968}$$

$$= 193.06 \text{ ft/sec}$$

Pitometer coefficient by extrapolation of rating curve supplied by Pitometer Log Corporation = 0.809

True V = 193.06(0.809) = 156.19 ft/sec. This value represents the velocity at the center of the 20-inch-diameter pipe. The average velocity is chosen as 0.873 times the maximum[4], or 156.19(0.873) = 136.35 ft/sec

Inside diameter of 20-inch pipe = 19.182 inches

Area of 20-inch pipe $= 1/4\,\pi \left(\frac{19.182}{12}\right)^2$

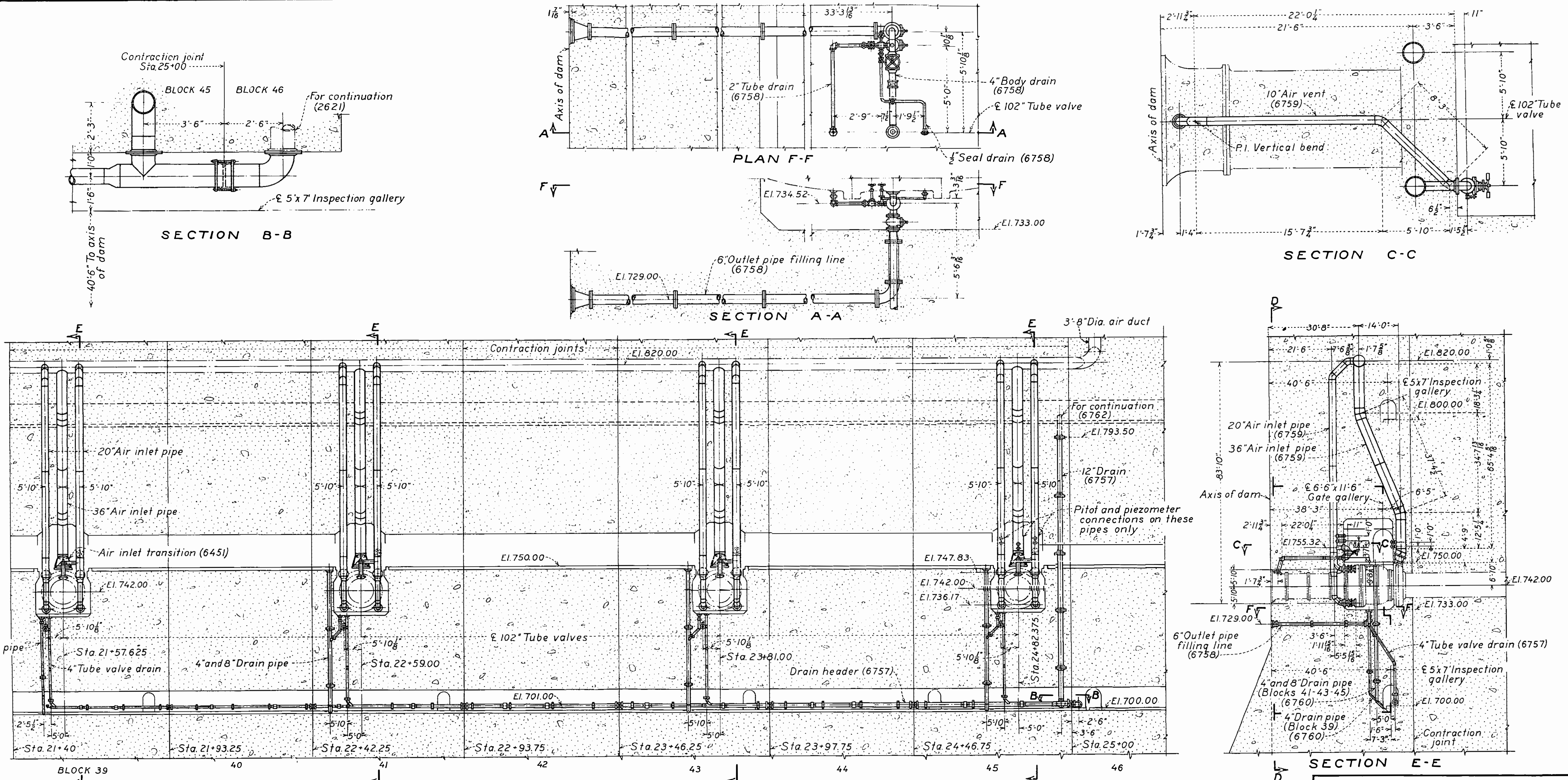
$= 2.007$ sq ft

$Q = 2.007\ (136.35) = 273.55$ cu ft/sec

The minimum pressure developed in the outlet immediately downstream from the gate obtained by means of a mercury U-tube connected to the piezometer, previously described, was recorded as -22.98 feet of water. At first glance it appears that the maximum quantity of air was flowing since the pressure in the conduit was considerably less than one-half atmosphere. However, when the losses are considered in the air supply line, it becomes apparent that the velocity measured in the 20-inch duct with the Cole Pitometer is essentially correct. Writing Bernoulli's equation between a point in the gallery at the start of the 3-foot 8-inch duct, Figure 7, and a point in the outlet where the pressure was measured reveals that the head required to produce the flow is approximately the same as the available head. The following computation verifies this statement. It is assumed that all of the air enters the intake in Block 46 which is much closer to the outlet tested. No other outlets were operating during the test

Q = 273.55 cu ft/sec (measured)

FIGURE 7



REFERENCE DRAWINGS

PLAN EL. 700-BLOCK 39 TO BLOCK 45	214-D-2929
PLAN EL. 700-BLOCK 46 TO BLOCK 52	214-D-2930
PLAN EL. 750-BLOCK 39 TO BLOCK 45	214-D-2933
PLAN EL. 800-BLOCK 39 TO BLOCK 45	214-D-2937
3'-8" DIA. AIR DUCT-EL. 820 TO EL. 850	214-D-6244
PLAN AND SECTIONS-EL. 742	214-D-6816
102" CONDUIT TUBE VALVE ASSEMBLY	214-D-6620
102" TUBE VALVE CONDUIT	214-D-6646
DRAIN HEADER AT EL. 700	214-D-2621

UPSTREAM ELEVATION D-D

LIST OF DRAWINGS

RIVER OUTLETS - ELEVATION 742.00

GENERAL ARRANGEMENT	214-D-6756
DRAIN HEADER	214-D-6757
DRAIN AND FILLING LINES	214-D-6758
AIR INLET PIPING	214-D-6759
GUTTER AND VALVE CHAMBER DRAINS	214-D-6760
AIR INLET TRANSITION	214-D-6451

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM

RIVER OUTLETS - ELEVATION 742
102" CONDUIT TUBE VALVE CONTROL PIPING
GENERAL ARRANGEMENT

DRAWN: D.L.K.-W.O.S. SUBMITTED: [signature]
TRACED: E.W.S.-B.H.W. RECOMMENDED: [signature]
CHECKED: E.L.G.-C.H.W. APPROVED: [signature]
REV. 12-15-41
DENVER, COLORADO AUG. 5, 1941 214-D-6756

Losses in 3-foot 8-inch duct,

$$\text{entrance} = 0.50 \frac{V^2_{3'-8''}}{2g}$$

$$1\text{-}90^\circ \text{ elbow} = 0.15 \frac{V^2_{3'-8''}}{2g}$$

$$1\text{-}30^\circ \text{ elbow} = 0.11 \frac{V^2_{3'-8''}}{2g}$$

$$\text{friction} = f \frac{L}{D} \frac{V^2_{3'-8''}}{2g} = 0.012 \frac{90}{3.667} \frac{V^2_{3'-8''}}{2g}$$

$$= 0.29 \frac{V^2_{3'-8''}}{2g}$$

$$\text{total loss} = 1.05 \frac{V^2_{3'-8''}}{2g}$$

$$V_{3'-8''} = \frac{273.55}{10.56} = 25.9 \text{ ft/sec}$$

Losses in 20-inch duct,

$$\text{entrance} = 0.50 \frac{V^2_{20}}{2g}$$

$$2\text{-}45^\circ \text{ elbows} = 0.24 \frac{V^2_{20}}{2g}$$

$$\text{friction} = 0.012 \frac{70}{1.625} \frac{V^2_{20}}{2g}$$

$$= 0.52 \frac{V^2_{20}}{2g}$$

$$\text{total loss} = 1.26 \frac{V^2_{20}}{2g}$$

$$V_{20} = \frac{273.55}{2.007} = 136.30 \text{ ft/sec}$$

Losses in 10-inch duct,

$$\text{entrance} = 0.50 \frac{V^2_{10}}{2g}$$

$$2\text{-}90^\circ \text{ elbows} = 0.80 \frac{V^2_{10}}{2g}$$

$$\text{gate valve} = 0.10 \frac{V^2_{10}}{2g}$$

$$1\text{-}75^\circ \text{ elbow} = 0.15 \frac{V^2_{10}}{2g}$$

$$2\text{-}45^\circ \text{ elbows} = 0.24 \frac{V^2_{10}}{2g}$$

$$\text{friction} = 0.012 \frac{36}{0.835} \frac{V^2_{10}}{2g} = 0.52 \frac{V^2_{10}}{2g}$$

$$\text{total loss} = 2.31 \frac{V^2_{10}}{2g}$$

$$V_{10} = \frac{273.55}{0.5476} = 499.54 \text{ ft/sec}$$

Total of losses in 3-foot 8-inch, 20-inch, and 10-inch ducts,

$$H' = 1.05 \frac{V^2_{3'-8''}}{2g} + 1.26 \frac{V^2_{20}}{2g} + 2.31 \frac{V^2_{10}}{2g}$$

$$H' = 1.05 \frac{\overline{25.9}^2}{2g} + 1.26 \frac{\overline{136.30}^2}{2g} + 2.31 \frac{\overline{499.54}^2}{2g}$$

$$H' = 9336.92 \text{ feet of air}$$

Head required to produce the discharge of 273.55 cfs,

$$H = 9336.92 + \frac{V^2_{10}}{2g} = 9336.92 + \frac{\overline{499.54}^2}{2g}$$

$$= 13{,}216.59 \text{ feet of air}$$

The available head is the difference between the atmospheric pressure and that in the outlet which was -22.98 feet of water. Hence, the available head = $\frac{22.98(62.4)}{0.0743}$ = 19,299 feet of air. Therefore, the available head is greater than that required to produce the discharge of 273.55 cfs. However, the discrepancy is relatively small as demonstrated in the following computation assuming a discharge of 330 cfs. The losses in terms of the velocity head will remain unchanged.

Accordingly,

$$H' = 1.05 \frac{V^2_{3'-8"}}{2g} + 1.26 \frac{V^2_{20}}{2g} + 2.31 \frac{V^2_{10}}{2g}$$

$$V_{3'-8"} = \frac{330}{10.56} = 31.25 \text{ ft/sec}$$

$$V_{20} = \frac{330}{2.007} = 164.42 \text{ ft/sec}$$

$$V_{10} = \frac{330}{0.5476} = 602.63 \text{ ft/sec}$$

$$H' = 1.05 \frac{\overline{31.25}^2}{2g} + 1.26 \frac{\overline{164.42}^2}{2g} + 2.31 \frac{\overline{602.63}^2}{2g}$$

$$= 13{,}588.22 \text{ feet of air}$$

Head required to produce the discharge of 330 cfs,

$$H = 13{,}588.22 + \frac{V^2_{10}}{2g} = 19{,}234.41 \text{ feet of air}$$

This head of 19,234.41 feet of air to produce a flow of 330 cfs compares favorably with the available head. The difference between the measured discharge of 273.55 and 330 is approximately 17 percent which is within the expected accuracy of the results.

As previously stated the pressure in the conduit at the piezometer located at the left extremity of the horizontal axis 17 inches from the face of the dam was -22.98 feet of water. The pressure determined in the 1:17 scale hydraulic model under similar conditions of head was -3.75 feet of water indicating that vapor pressure would be obtained on the prototype. This apparent dissimilarity between the model and prototype is readily explained when consideration is given to the fact that any quantity of air admitted in the prototype structure would expand and prevent the attainment of vapor pressure. Hence, it is not possible to attain vapor pressure if any air is admitted. The fact that the usual similarity between model and prototype does not exist under this condition has been recognized for several years, but very little information has been obtained to bridge this gap.

During the design studies it was not intended that the quantity of air admitted on the downstream side of the coaster gate would be sufficient to prevent the formation of pressures conducive to cavitation, since the duration of the infrequent operation of the coaster gate under emergency conditions would be insufficient to cause damage. The function of the air was to prevent excessive vibration.

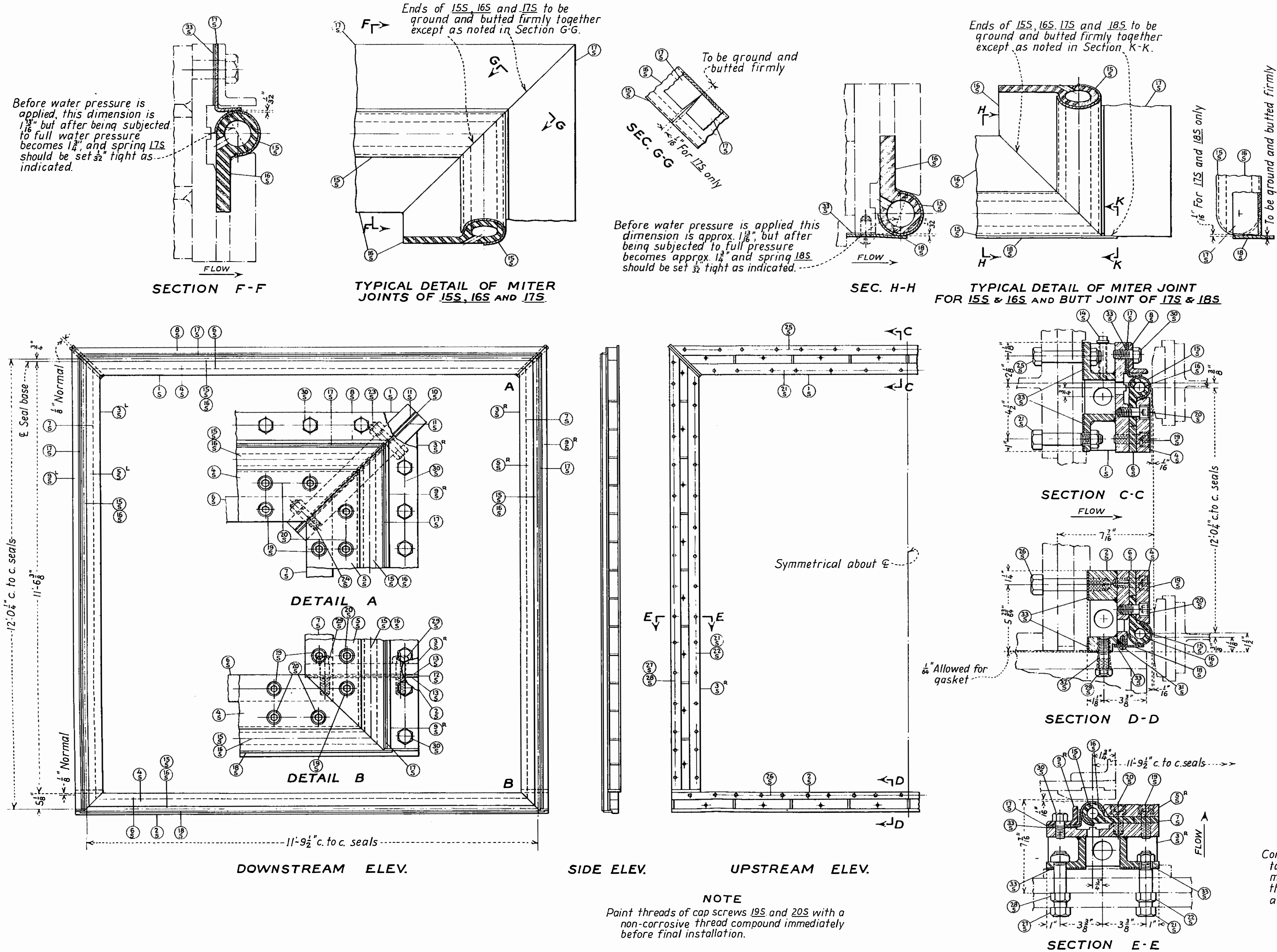
The audible sound which occurred in the gallery adjacent to the coaster gate during the represented emergency condition revealed that cavitation did occur. The magnitude of this sound can best be described as being sufficient to prevent conversation at any possible voice level. However, there was no indication of excessive vibration.

THE "MUSIC NOTE" SEALS

Previous to the conduct of the test of the coaster gate the "music note" seals had been damaged and removed from the gate. Since the guards, Parts 8S, $9S^R$, and $9S^L$, Figure 8, were in place, the space between the gate and the seal seat on the face of the dam was only slightly greater than with the seals in place. This factor could not conceivably affect the magnitude of the maximum downpull force but could possibly result in a lower gate position at the point where the recess became ineffective. However, any effect due to the absence of the seals is considered to be negligible.

The circumstances surrounding the damage of the "music note" seals were not a part of the testing procedure, but the facts are stated to assist the designing engineer in future problems of similar nature.

Prior to the failure of the seals the gate had never been operated with unbalanced pressure, but upon completion of the work inside the lower river outlet in Block 45 preparatory to studying the hydraulic features of the tube valve the coaster gate was raised approximately 2 feet with balanced pressure, then completely lowered with unbalanced pressure. After again balancing the pressure the gate was raised to the surface. The purpose of this manipulation was to ascertain if the



LIST OF PARTS - SEALS FOR ONE GATE LEAF

DRAWING NUMBER	PART NO.	NO. REQD.	DESCRIPTION	MATERIAL CLASSIFICATION	USED WITH
214-D-9443	1S	1	Top seal base	Steel	
"	2S	1	Bottom seal base	Steel	
214-D-9444	3S^R	1	Vertical seal base	Steel	
"	3S^L	1	Vertical seal base	Steel	
"	4S	2	Horizontal clamp	Steel	1S and 2S
"	5S R/L	1/1	Vertical clamp	Steel	3S
"	6S	2	Horizontal filler	Steel	1S and 2S
"	7S	2	Vertical filler	Steel	3S
"	8S	1	Horizontal guard	Steel	1S
"	9S^R	1	Vertical guard	Steel	3S
"	9S^L	1	Vertical guard	Steel	3S
"	10S	2	Shim	Brass or steel	1S and 3S
"	11S	4	Gasket	GARLOCK NO. 681 OR EQUIVALENT	1S and 3S
"	12S	2	Shim	Brass or steel	2S and 3S
"	13S	4	Gasket	GARLOCK NO. 681 OR EQUIVALENT	2S and 3S
214-D-9445	14S	2	Air vent	Brass	1S
"	15S	49 L.F.	Tubing	STEEL-BRASS-STAINLESS STEEL-OR CU. NI. ALLOY	16S
"	✲16S	49 L.F.	Rubber seal	Rubber	15S
"	17S	38 L.F.	Spring	BRASS-STAINLESS STEEL-STEEL-OR CU. NI. ALLOY	1S and 3S
"	18S	13 L.F.	Spring	BRASS-STAINLESS STEEL-STEEL-OR CU. NI. ALLOY	2S
"	19S	80+8	Socket head cap screw	Steel	1S, 2S, 3S, 4S 5S, 6S & 7S
"	20S	158+16	Socket head cap screw	Steel	1S, 2S, 3S, 4S 5S, 6S & 7S
"	21S	30+3	Special bolt with nut	Steel	1S and 3S
"	22S	14+2	Special bolt with nut	Steel	3S
"	23S	2+1	Special bolt with nut	Steel	1S and 3S
"	24S	2+1	Stud with nut	Steel	1S and 3S
No detail	⊗ 25S	16+2	7/8" x 5" Hex. hd. bolt with hex. nut	Steel	1S
"	⊗ 26S	20+2	1" x 5" Hex. head cap screw	Steel	2S
"	⊗ 27S	18+2	7/8" x 5" Hex. head cap screw	Steel	3S
"	⊗ 28S	14+2	7/8" x 3 1/2" Hex head cap screw	Steel	3S
"	⊗ 29S	22+2	3/4" x 2 1/2" Hex. head cap screw	Steel	2, 2S, 3S
"	⊗ 30S	127+13	3/4" x 1 1/4" Hex. head cap screw	Steel	1S, 3S, 17S AND 33S
"	⊗ 31S	37+4	3/8" x 3/4" Rd. head cap screw	Steel	2S and 18S
214-D-9445	⊗ 32S	10+2	Dowel	Steel	2S
No detail	⊗ 33S	†	Gasket - 1/32" thick	GARLOCK NO. 681 OR EQUIVALENT	
214-D-9445	34S	2	Drill for rubber - For 3/8" hole	Steel	16S
X-D-311	35S	2	Drill for rubber - For 3/4" hole	Steel	16S

† Furnish in rolls or sheets in sufficient amount to cover areas under bases 1S, 2S, 3S^R and 3S^L and springs 17S and 18S indicated in Sections C-C, D-D, E-E, F-F, and H-H.
Where materials are specified on the drawings but are not further covered by detailed specifications, the contractor shall furnish high class commercial grades of materials that are satisfactory to the contracting officer.
✲ Furnished by the Government.
⊗ Use 9442 as prefix of the mark number.

LIST OF DRAWINGS

SEAL ASSEMBLY ~ LIST OF PARTS 214-D-9442
TOP AND BOTTOM SEAL BASES 214-D-9443
VERTICAL SEAL BASES - CLAMPS - FILLERS - GUARDS 214-D-9444
VENT - TUBING - SEAL - SPRINGS - BOLTS 214-D-9445

REFERENCE DRAWINGS

11.05' x 11.05' COASTER GATE LEAF - ASSEMBLY 214-D-9436
ALLOWANCES AND TOLERANCES FOR METAL FITS X-D-893

NOTE

Paint threads of cap screws 19S and 20S with a non-corrosive thread compound immediately before final installation.

NOTE

Contractor shall mark or tag each part with the mark number shown with the corresponding detail, as: 9442-2S.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
KENNETT DIVISION

SHASTA DAM
RIVER OUTLETS
11.05' x 11.05' COASTER GATE LEAF
SEALS
ASSEMBLY - LIST OF PARTS

DRAWN E. C. C. SUBMITTED [signature]
TRACED W. M. S. RECOMMENDED [signature]
CHECKED [initials] APPROVED [signature]
DENVER, COLORADO, DEC. 10, 1942
SHEET 7 OF 17
REV. 1-28-43 / 5-24-43

214-D-9442

rollers turned properly, as some doubt existed relative to the ability of the rollers to turn in their rusted condition. The failure of a roller to function could be determined by inspection after the gate was placed on top of the dam.

An inspection revealed that the roller trains performed satisfactorily, but the metal sheath (Part 15S, Figure 8) had been completely torn from the top horizontal seal, and the rubber seal was torn or cut for a distance of 3 feet from the right end (facing downstream). The bottom horizontal metal sheath was bent completely out of shape, severed in the center, and merely hanging from the two ends. The upper 18 inches of the two side sheaths had been smashed.

It is significant that the bottom sheath was rolled upward revealing that the damage had occurred while the gate was being lowered. The flattened portion of the side sheaths indicate that the upper portion of the side seals which were above the seat on the face of the dam were extended while lowering the gate with unbalanced pressure and that the force against the seat as the gate lowered was great enough to smash the sheaths. Hence, it can only be concluded that the seals were protruded when the gate was operated with unbalanced pressure.

The failure of the seals to retract because of faulty operation of the seal actuator assembly cannot be considered, as inspection by project personnel revealed that the apparatus was in proper working condition; therefore, it must be assumed that the "music note" seals were extended because of hydraulic forces. It was noted that the portion of Parts 17S and 18S which contact the flexible seal, Figure 8, was crooked, and hence, a continuous contact could not conceivably be obtained. This factor alone would prevent retraction of the seals by admitting reservoir pressure to the channel behind the seals.

There are two obvious reasons which may have contributed to the failure of the springs (Parts 17S and 18S) to seal the chamber immediately behind the seals: (1) Steel was used instead of brass because of the critical material situation imposed by the recent war; and (2) the tolerances maintained during the assembly of the mechanism may not have been as rigid as desired. The importance of the latter factor cannot be overemphasized and was demonstrated in the hydraulic model study[5] made in connection with the design of the gate seals.

It should be pointed out that the seals under consideration are obsolete, since in later designs the metal sheath has been replaced by a brass section welded to the rubber to prevent extrusion. Although this new type seal may minimize the possibility of extrusion of the rubber, it is not conceivable that its performance will be materially different than the one described for Shasta Dam unless the channel behind the seals is closed to enable the development of a low pressure to retract the seals.

The leakage past the coaster gate while the work was being performed preparatory to testing the tube valve was insignificant, but project personnel advised that on all previous occasions the leakage was quite high, impeding access to the interior of the conduit. It is quite certain that at least a portion of the difficulty in obtaining a good seal was due to the presence of construction debris such as pieces of reinforcing steel left in the entrance to the outlets prevented proper action of the seals. However, this factor would have no bearing on the failure of the seals to retract.

RECOMMENDATIONS

Because of the wide variation of the hydraulic forces acting on the prototype coaster gate compared to those determined on the hydraulic model between gate openings of 12 and 45 percent, additional laboratory study is desired to evaluate the effect of the recess. This information is particularly desirable since the model study did not include the recess corresponding to the field structure due to the necessity of abandoning the model for more urgent work before making major alterations involved in constructing the recess. The investigation should also include other gate-seal assemblies not influenced by the desire to utilize materials on hand. A third important factor which could be beneficially evaluated is the relation of the quantity of air admitted on the downstream side of the gate to the hydraulic downpull forces.

Such a program properly integrated with field observations on existing structures would undoubtedly provide more tools for the designer. The inauguration of the study should be preceded by a thorough investigation of work previously performed on similar gates with particular reference to the Corps of Engineers, Department of the Army, which is known to be confronted with similar design problems.

BIBLIOGRAPHY

1. Coaster Gate and Handling Equipment for River Outlet Conduits in Shasta Dam, by Jacob E. Warnock and Howard J. Pound, Tran. A.S.M.E., April 1946, p. 199.

2. Hydraulic Laboratory Report No. 86, "Model Studies Pertaining to Aeration of Coaster Gates during Emergency Closure," by J. W. Ball, dated August 15, 1940.

3. Field Trip Report No. 267, "Testing of Lower River Outlet in Block 45--Shasta Dam," by D. M. Lancaster and F. C. Lowe, August 26, 1947.

4. Merriman and Wiggin Handbook, p. 1340.

5. Hydraulic Laboratory Report No. 128, "Hydraulic Model Studies of Gate-seal Designs and Tests for Grand Coulee and Shasta Dams" by E. S. Gray, June 1943.