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COASTER GATE AND HANDLING EQUIPMENT

FOR RIVER OUTLET CONDUITS IN SHASTA DAM

by

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INTRODUCTION

Shasta Dam, one of the major features of the Central Valley Project, is located on the Sacramento River, nine miles above Redding, California. It is designed as a multipurpose dam with facilities for flood control, river regulation, and power generation.

Release of stored water for river regulation in excess of the capacity of the powerhouse turbines is accomplished by eighteen 102-inch diameter conduits in the spillway section of the dam. Each of these conduits is provided with a control valve. A coaster gate is used to close the intake of any one of the 18 conduits whenever required for inspection and servicing of the control valves and conduits. The gate may also be used for emergency closure in the event of failure of a control valve.

Normally the gate is operated under balanced hydrostatic pressures with no flow in the conduits. However, design conditions were taken as those which exist during emergency closure under maximum head when the gate is subjected to large unbalanced pressures.

As the gate is lowered under emergency conditions, the increase in velocity under the gate acts to decrease the pressures on the downstream face while those on the upstream face remain substantially constant. The frame of the gate must resist the resultant force which pushes it against the face of the dam, and the rollers supporting the gate must have a low frictional resistance or the gate cannot be lowered into the closed position by its own weight. Another effect of the high velocity flow is the reduction in pressure on the bottom of the gate which creates an additional force, referred to as downpull. Consideration of this force is important as it may be equal to or greater than the weight of the gate.

The hydrostatic pressures on the top of the gate can be calculated readily; but, unfortunately, calculations of the downpull force can be only approximate without detailed hydraulic laboratory studies. The pressures on the bottom of the gate are a function of the flow velocity under the gate, the shape of the gate bottom and the gate opening, and they may vary from full hydrostatic pressure to the vapor tension of water. The value of the downpull force is therefore dependent upon the velocity distribution and flow pattern beneath the gate, since the pressure reduction at any point on the gate bottom is equal to the velocity head at that point.

In previous designs, an approximation of the downpull force was considered satisfactory, but at Shasta Dam the estimated downpull on the coaster gate was so large that the total load on the handling equipment was about 60,000 pounds in excess of the permissible load. The gate was to be handled by a 125-ton gantry crane operating on the bridge across the spillway section of the dam. The capacity of this bridge was the limiting factor. Such a circumstance arose from the fact that the original plan was to handle the coaster gates from a barge and the bridge was designed for normal traffic load. When later in the design the handling equipment was transferred from the barge to the bridge, it was necessary to determine more accurately the downpull force and to reduce it, if possible, to avoid a drastic change in the design of the bridge across the spillway.

HYDRAULIC MODEL STUDIES

Hydraulic model studies were made to check the computed downpull and to develop a new shape for the gate bottom. Various shapes were tested and a satisfactory design was developed. A combination of this design and a properly proportioned recess in the face of the dam above the inlet reduced the downpull from the original value of 260,000 pounds to 70,000 pounds.

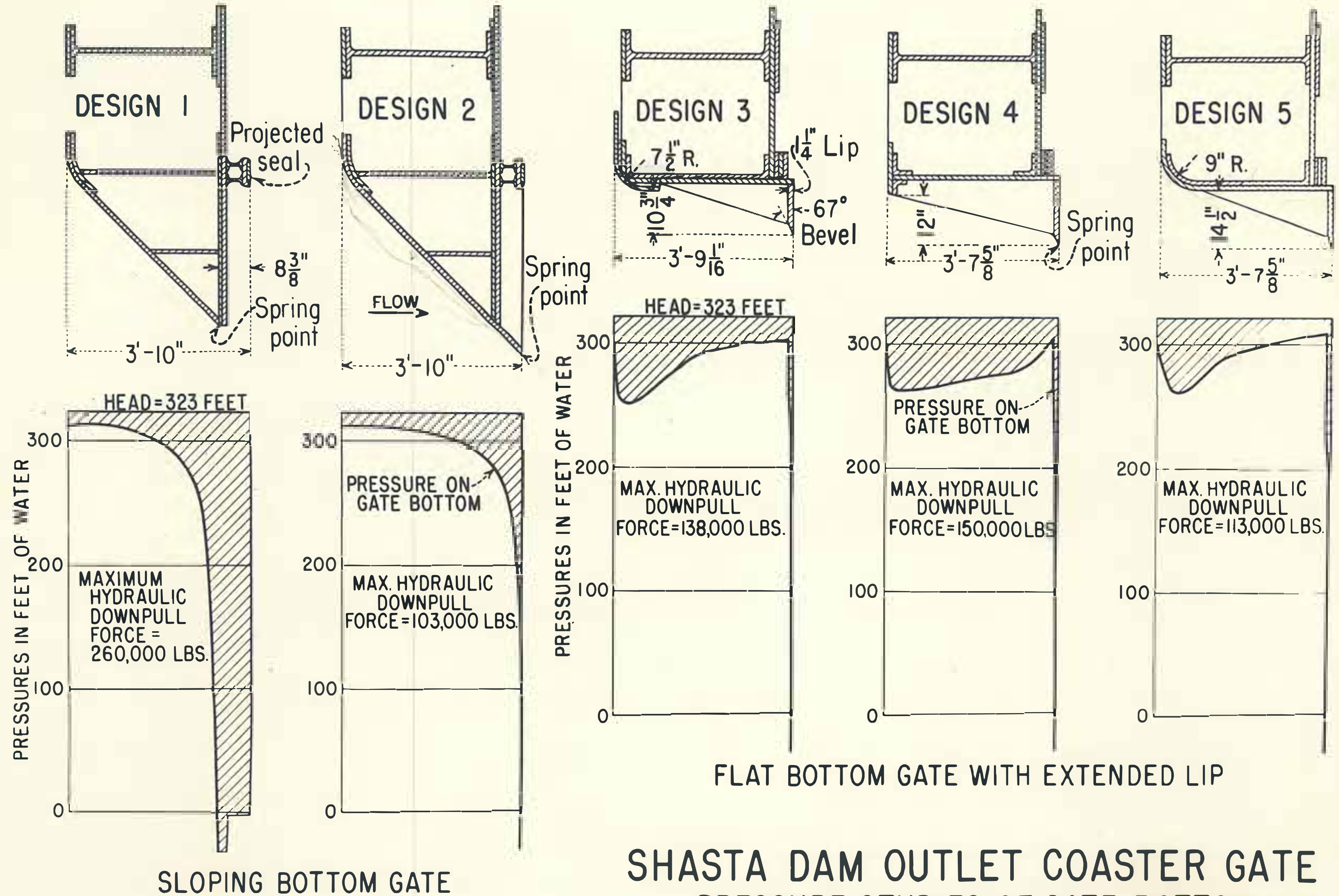
The studies were made with a model of the conduit and coaster gate built to a scale of one to 17. Test data included pressure measurements on the gate and in the outlet for several heads and gate openings. The downpull was determined by integrating the pressure curves shown in Figure 1. In the tests of the final design, the value obtained by pressure integration was verified by direct measurement with a spring scale.

With the gate of the original design in the full-open position, and a head representing the maximum of 323 feet, the downpull was approximately 75,000 pounds. As the gate was lowered the downpull gradually increased to a maximum of 260,000 pounds at an opening of about 8 feet 6 inches and then decreased gradually to zero for the closed position.

The typical variation of downpull with gate opening, which is shown graphically in Figure 3, may be explained by a consideration of the variation in magnitude and distribution of velocity under the gate. When the gate was fully opened the discharge was a function of the size of the outlet conduit and its frictional resistance. As the gate was lowered it created a restriction in conduit cross-section; and, since the discharge was not reduced in the same proportion, there was an increase in velocity and a reduction in pressure under the gate and for a short distance downstream. The decrease in pressure caused an increase in downpull.

Since the conduit was vented downstream from the gate, air relief was obtained when the restriction in area was sufficient to lower the pressure at that point to atmospheric pressure. When the pressure downstream from the gate was restrained from decreasing to any appreciable extent by the presence of air relief, it may be said that the gate became a control. The discharge under this condition became a function of gate opening and head and was not affected by the conduit. At the gate opening corresponding to

FIGURE 1



SHASTA DAM OUTLET COASTER GATE
PRESSURE STUDIES OF GATE BOTTOM

maximum downpull, the gate became a control and the velocity along its bottom reached its maximum value. For lesser gate openings, the velocity at the downstream edge of the bottom was increased slightly by a minor decrease in pressure downstream from the gate. However, at these openings the proportions and shape of the gate bottom relative to the size of the opening changed in such a manner that the velocity along it actually decreased and pressures increased enough to lower the value of downpull.

At small openings on the original design the jet under the gate impinged on the top of the conduit and interfered with proper action of the vent.

REDUCTION OF DOWNPULL IN ORIGINAL DESIGN

The hydraulic downpull force of 260,000 pounds, as determined by the pressure tests, did not agree with the original analytical estimate of 160,000 pounds. A review of the original calculations indicated that the estimate of 160,000 pounds considered only the pressure reduction on the sloping portion of the gate bottom and assumed that a recess in the face of the dam above the outlet entrance would balance the pressures on the projected seals. The model test was made without a recess, and the unbalanced pressures on the top seal contributed at least 100,000 pounds to the total downpull of 260,000 pounds. A recess in the model of the original design would have tended to balance the pressures on the top seal, and it was possible that a closer agreement might have been obtained. However, the downpull would still have been excessive; therefore, consideration was given to reduction of the force by revision of the shape of the gate bottom. The effectiveness of a recess in the face of the dam was determined only for the most satisfactory gate bottom and will be discussed subsequently.

Studies of the flow under the gate and the pressure on its bottom indicated that a large reduction of downpull could be obtained by a simple revision of the bottom. The flow under the gate and into the outlet was studied by observing the movements of paper particles in the head tank through a window. The particles approached the outlet from all directions, moving slowly until they were within a few inches of the outlet, where they appeared to be drawn instantaneously into it, indicating a rapid increase in velocity close to the outlet entrance. This rapid increase in velocity was also shown by the pressure gradient across the 45-degree sloping portion of the bottom of the gate (Figure 1, Design 1). At the upstream edge the pressures were practically hydrostatic. On approaching the outlet, the pressure reduction was gradual, at first, but it became rapid close to the downstream edge. At the point where the 45-degree slope ended, the pressure reached a minimum. This was the spring point of the gate, that is, the point where the water normally sprang free of the gate bottom to form a jet in the conduit.

The face of the gate projected a distance of 8-3/8 inches beyond the spring point as shown in Figure 1. The pressure forces acting upward on this projection were much lower than those acting downward so that it contributed an excessively large part of the downpull when its relatively narrow width was considered. By comparison, the much larger area of the 45-degree sloping bottom played only a minor role because the low pressure prevailed only in the vicinity of the spring point. The original bottom design was revised by extending the sloping portion until it underlay the projecting seal, as shown in Figure 1, Design 2. This change placed the spring point close to the face of the dam and eliminated the undesirable projecting area. The pressure distribution on the revised gate bottom is shown in Figure 1, Design 3. The shape of the pressure curve remained the same but the elimination of the projection and its unbalanced loading reduced the downpull from 260,000 to 103,000 pounds.

In contrast to the original design where the maximum downpull occurred when the conduit was not completely filled with water, the maximum value with the revised gate occurred while the conduit was filled with water, just before a slight additional closure would lower the pressures so that the conduit would take some air through the vent. In addition to reducing the downpull, this revised design changed the shape of the jet flowing into the outlet so that the jet at no time impinged on top of the conduit to restrict the air vent, as was the case in the original design when the gate was open between 2 and 3-1/2 feet.

EFFECT OF EXTENDED LIP BELOW DOWNSTREAM EDGE OF FLAT-BOTTOM GATE

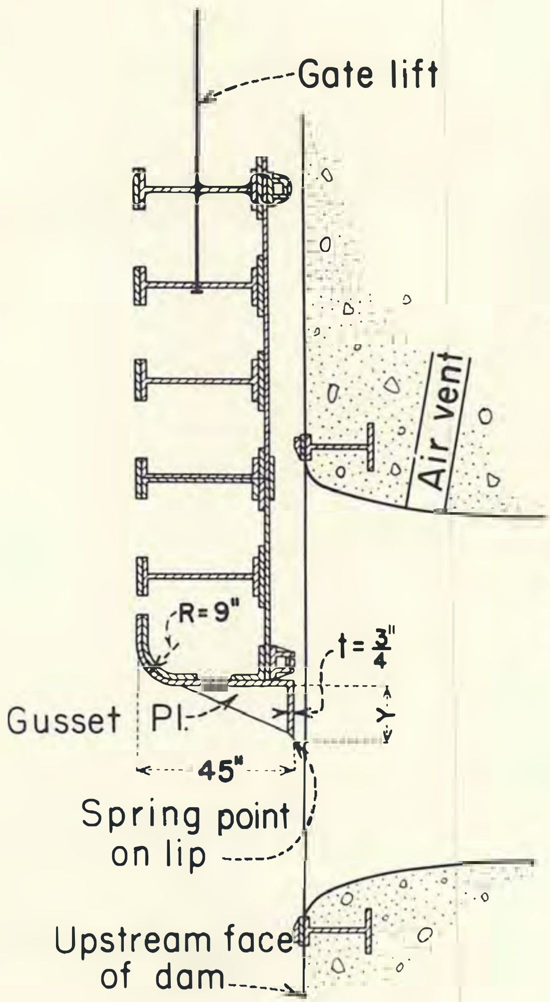
Although the revision of the bottom accomplished the desired reduction in downpull, the gate was not satisfactory structurally. The sloping bottom would have been difficult to fabricate and heavy plates would have been required to withstand the loads on its downstream edge. Thus it was necessary to make further tests to develop some other type of gate which would have even less downpull or at least a more acceptable structural design for the bottom.

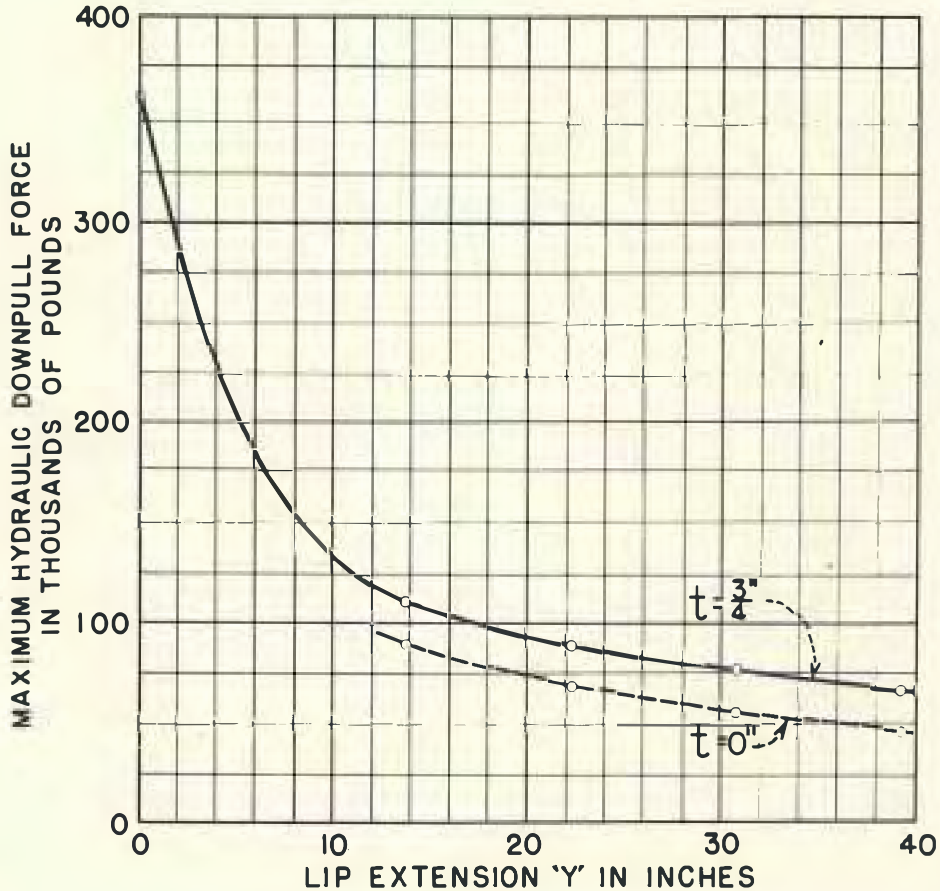
The original tests indicated that a gate having a minimum downpull would be one with a lip placed at the downstream edge of the bottom and extended vertically below the gate. This would place the spring point at a greater distance from the bottom and the effect of the rapid drop in pressure which occurs near the spring point would be exerted on the vertical plane of the extended lip and would not contribute to downpull. To verify these indications, tests were made with an extended lip. The length of the lip was varied in successive steps, from zero to a length nearly equal to the thickness of the gate.

The complete shape of the gate bottom which will be referred to hereafter as the basic shape, is shown in Figure 2. The bottom was faired into the upstream plate on a 9-inch radius, to minimize the local reduction of pressure on the bottom where the flow down the upstream face of the gate changes direction below the gate. The extended lip was 3/4-inch thick, and its bottom was beveled at 45 degrees to place the spring point at the downstream edge of the lip and reduce the effect of the thickness upon the downpull. The extended lip was supported by gusset plates attached to the bottom of the gate. These plates were in the plane of flow so that their effect upon the downpull would be small and could be ignored.

The pressure gradients as determined in what will be referred to as general tests were similar to those of Design 5, Figure 1, except that negative pressures occurred on the bottom of the lip. There was some reduction of pressure near the upstream plane, as was anticipated, since the flow down the upstream face of the gate had to change its direction. However, the pressure increased rapidly, becoming a maximum at the downstream corner where the lip joins the gate bottom. This effect indicated that not only does the extended lip keep the rapid reduction in pressure near the spring point on the vertical plane of the lip where it cannot cause downpull, but it also tends to form a stagnation point which increases in the downstream corner.

Although the bottom of the lip was beveled at 45 degrees to place the





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OUTLET COASTER GATE
EFFECT OF LIP EXTENSION ON HYDRAULIC DOWNPULL

spring point on its downstream edge, the spring point actually occurred at the upstream edge of the lip. The resulting negative pressures on the bottom of the lip would cause a downpull of approximately 15,000 pounds when the lip was 3/4 inch thick, as indicated in Figure 2.

The variation of maximum downpull force with length of lip extension is shown graphically in Figure 2. The longest extension considered was approximately equal to the thickness of the gate, as a greater extension would be impractical structurally. The graph shows that an extension of 40 inches would reduce the downpull to approximately 65,000 pounds. As the extension was decreased, the downpull increased gradually until at a lip extension of 14 inches the value was 110,000 pounds. A further decrease in the extension caused a more rapid increase in downpull which finally became 360,000 pounds when there was no extension.

STRUCTURAL DESIGNS OF FLAT-BOTTOM GATE WITH EXTENDED LIP

A flat-bottom gate with an extended lip below its downstream edge, which would develop a downpull equal to that of the sloping-bottom gate of Design 2, Figure 1, (or about 100,000 pounds), would require a lip extension of 17 inches. This was not practical, since the horizontal forces on it would be excessive. Nevertheless, a flat-bottom gate having an extended lip was a simple design compared with the sloping bottom of Design 2.

Design 3 was more acceptable than the basic shape from a structural viewpoint, having a lip extension of 10-3/4 inches which, from the curve of Figure 2, corresponds to a downpull of approximately 130,000 pounds. The radius of the curved portion of the bottom was made 7-1/2 inches instead of 9 inches, and the thickness of the lip was made 1-1/4 instead of 3/4 inch. It was anticipated that the smaller radius would increase the downpull a small amount. The bottom of the lip was beveled at a steeper angle, 67 degrees, which placed the spring point at its downstream edge and reduced the downpull on the lip (Figure 1). The tests showed that the downpull would be approximately 138,000 pounds. Piezometers placed on the lip to determine pressures, indicated that the portion of the downpull due to the 1-1/4-inch lip was nearly equal to that of the 3/4-inch lip of the general test in which the spring point was at its upstream edge. Accordingly, the curve of Figure 2 was used to predict the downpull of a gate having 1-1/4-inch lip with a 67-degree bevel at its bottom.

In Design 4, Figure 1, a simplification of the structural details was made by using flat plates and angles to eliminate the curved section of the gate bottom. The end of the plate at the upstream edge was rounded to avoid a sharp corner at that point. A 1-1/4-inch lip having a steep bevel, similar to Design 3, was extended 12 inches below the upstream edge. The downpull was 150,000 pounds, which represented a 25 percent increase over that obtained in the general test with a 9-inch radius and a 12-inch lip extension. Neither Design 3 nor 4 was satisfactory for the Shasta Dam outlet coaster gates because their downpulls, of 138,000 and 150,000 pounds, respectively, exceeded the allowable limit.

A new analysis of the stresses on the bottom of a gate with the basic shape used in the general test, Figure 2, revealed that it would be structurally sound if the lip extension did not exceed 14-1/2 inches. Figure 2 indicated that such a design would develop a downpull of 110,000 pounds. Since this value was not excessive, Design 5 was constructed and tested (Figure 1). It differed from the gate of the general test in that a 1-1/4-inch lip with a 67-degree bevel at its bottom was used instead of 3/4-inch lip with a 45 degree bevel. The measured downpull of 112,000 pounds checked the predicted value of 110,000 pounds.

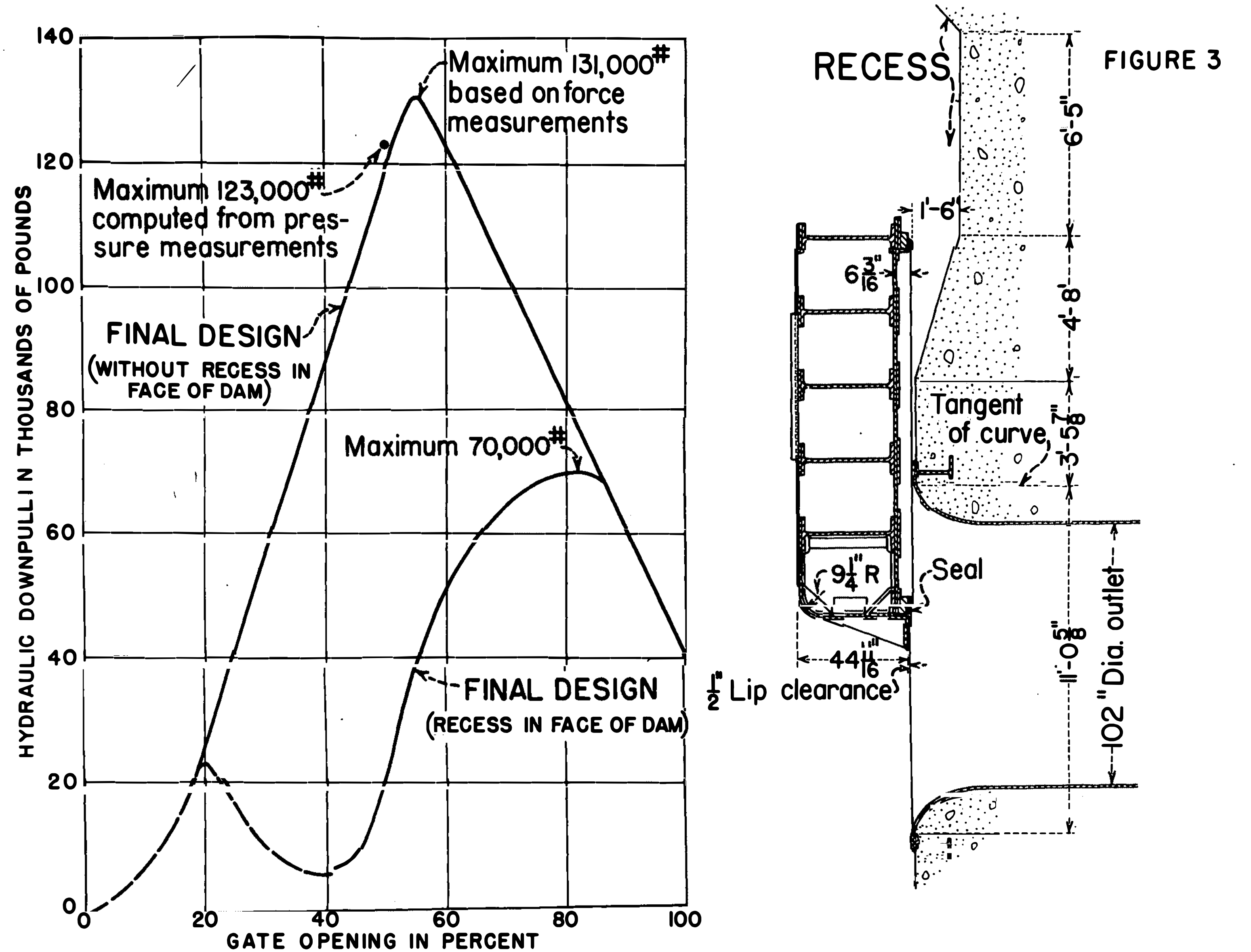
The final design of the Shasta outlet coaster gate was developed from Design 5. The width was increased from 43-5/8 to 44-11/16 inches for structural reasons, and a clearance of 1/2-inch between the lip and the seal seats was introduced to facilitate operation of the gate. The maximum downpull as determined by pressure measurements was increased to 122,000 pounds by these changes. An independent check of the downpull by direct measurement with a spring scale indicated that a slightly larger downpull of 131,000 pounds occurred at a gate opening of 55 percent. The latter value was accepted as the more accurate one as it was impractical to take the number of pressure measurements required for a comparable accuracy.

The over-all effect of the gusset plates was determined by a test with the plates removed. No appreciable difference in downpull could be detected. If plates were terminated at the point where the bevel of the lip begins as shown in Figure 1, their effect of downpull was negligible.

EFFECT OF RECESS IN THE FACE OF THE DAM

It had been appreciated that any one of the various designs of the gate could have been improved from the standpoint of downpull by introducing a recess in the face of the dam. This improvement was deliberately withheld until the best shape of gate bottom was determined.

To understand the action of the recess, it must be noted that the seals of the gate project beyond the skin plate. With no recess, the pressures on the top seal were unbalanced when the gate was partially closed. The full reservoir head acted on the outside, or topside, while the low pressure which prevailed downstream from the gate was exerted on the inside, or lower side. The resulting downward force, which at times was as large



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HYDRAULIC DOWNPULL OF FINAL DESIGN

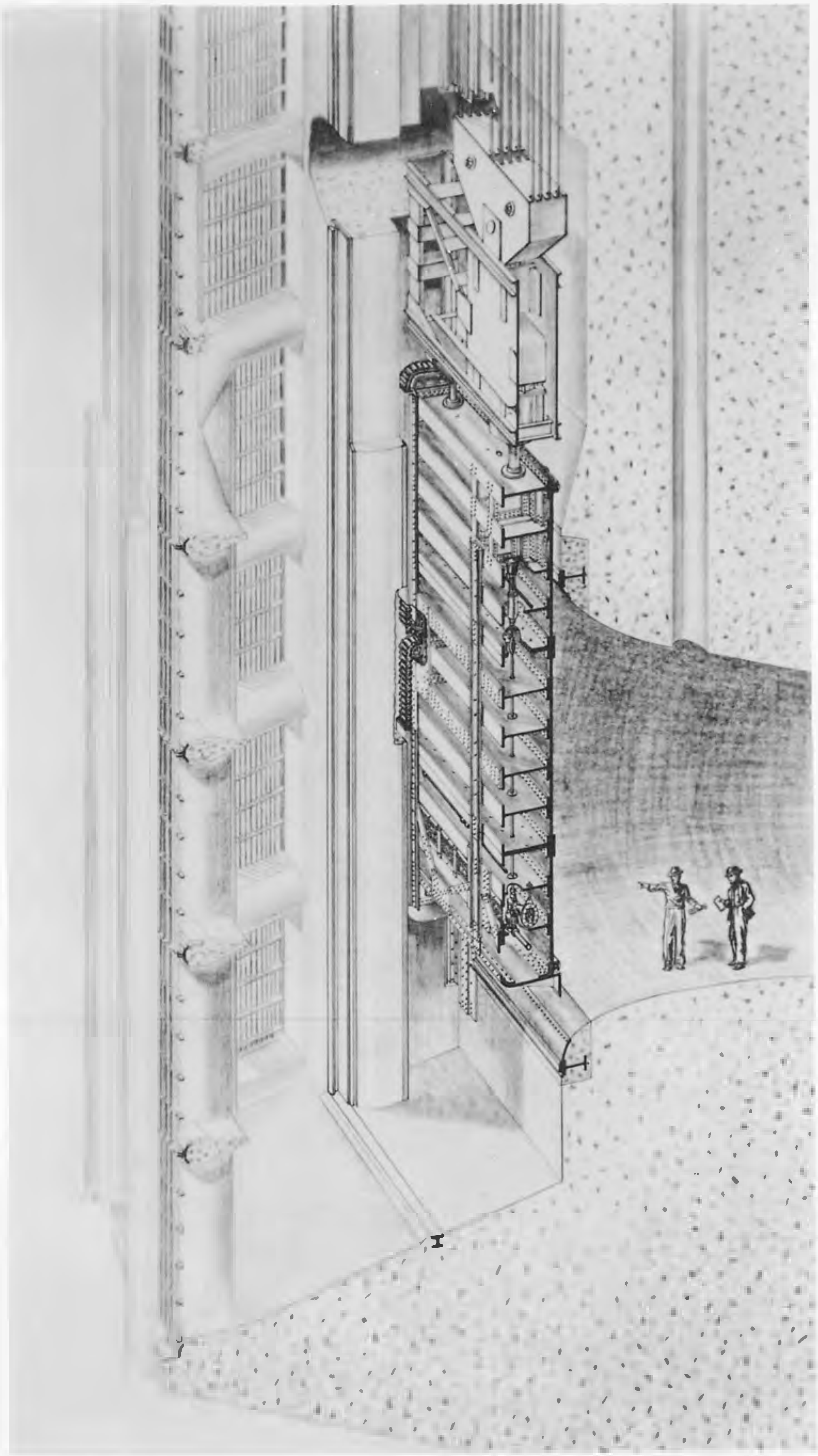
as 100,000 pounds, depending upon the pressure in the outlet entrance downstream from the gate, contributed a large portion of the downpull on the gate. With a recess, starting a short distance above the gate seat, the increase in the clearance between the seal and the face of the recess decreased the velocity of flow around the seal and reduced the pressure differential.

Tests showed that the recess performed its desired function of reducing the maximum downpull if its depth was made several times larger than the seal extension. At all openings, the pressures on the upper seal were nearly balanced. For gate openings less than 40 percent the presence of a recess with a uniform depth introduced an undesirable complication. With the downpull force on the top seal eliminated by the recess, the increase in pressure which occurred at small gate openings over that portion of the bottom which underlay the seal was large enough to reverse the direction of the net hydraulic load. The gate was actually subjected to an uplift force large enough to offset its weight.

The effectiveness of the recess in balancing the pressures on the top seal was directly proportional to its depth. By varying the depth in the manner shown in Figure 3, the reversal of net force on the gate was eliminated and the downpull varied as shown in Figure 3. The maximum downpull of 70,000 pounds occurred at a gate opening of 80 percent.

Since the dead weight of the gate and lifting mechanism is 90,000 and 10,000 pounds, respectively, the maximum total load on the gantry crane, including a downpull of 70,000 pounds, will be 170,000 pounds. This is less than the permissible load on the bridge, so the design was accepted as being satisfactory.

Figure 4



Typical coaster gate installation.

THE COASTER GATE

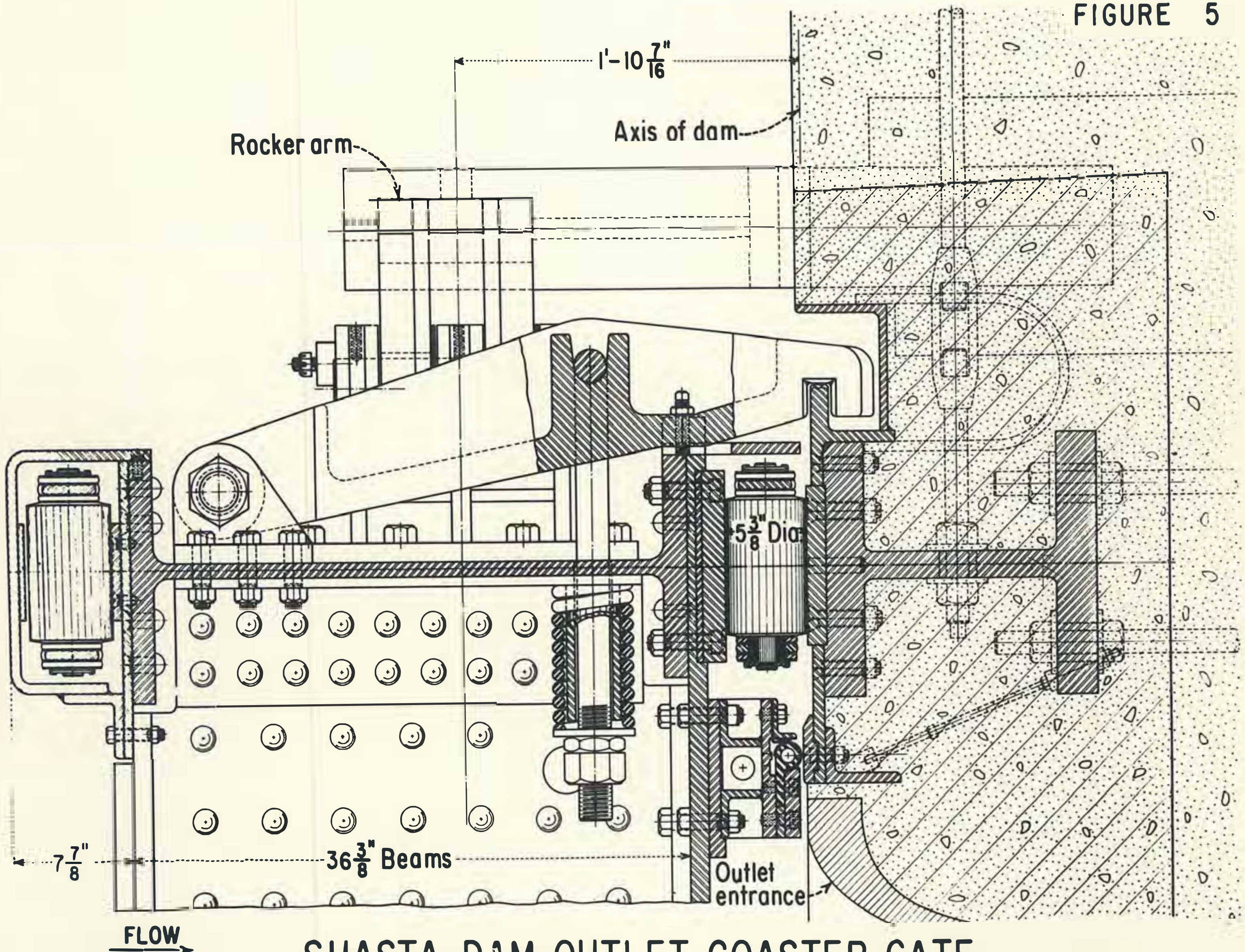
The coaster gate is mounted on endless roller trains, and is lowered by its own weight in structural guides provided in the face of the dam to an accurate position over the intakes (Figure 4). The gate consists primarily of a downstream skin plate mounted on horizontal beams which are supported by vertical girders at the sides.

The roller trains around each vertical girder transmit the water load on the gate to tracks on the face of the dam at the inlet. The tracks are fastened to large DB-sections embedded in blockouts provided in the original concrete of the dam (Figure 5). A rectangular steel framework embedded in the concrete around the circular inlet supports accurately finished seal seats which project slightly from the face of the dam.
When the gate is used to close one of the conduits in the lower tier,
it is subjected to a head of some 330 feet, equivalent to 22,000 pounds per square feet or a total load of approximately 2,750,000 pounds. As the gate weighs only 90,000 pounds, roller trains were selected to minimize the friction forces so that the gate would close under its own dead weight.

Metal-covered rubber "music-note" seals (Figure 5) are provided on the downstream face of the skin plate. The design utilizes the flexibility of a rubber hinge which permits close local adjustment but retains the rigidity of metal to support the load of approximately 125 pounds per lineal inch to which the seals are subjected when the gate is in the closed position. The rubber core also permits simple butt and miter joints to be used in the seal as the load on the seal is converted to axial compression which acts to seal the joints.

Advantage is taken of the pressure differential across the gate to retract

FIGURE 5



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SLOT SECTION

the seals when the gate is closing under flow. This eliminates drag on the seals and materially reduces the force resisting closure just as the gate is seated. To accomplish retraction, the area immediately back of the seals is closed at the sides. This forms a continuous water-tight rectangular chamber having the movable portion of the rubber seal for one of the sides. Pipes connect this chamber, through a two-way valve, to either the reservoir pressure on the upstream side of the gate or to the reduced pressure on the downstream side of the gate.

The valve is operated by the overtravel of the relatively heavy gate lifting stem. While the gate is supported by the lifting stem, the valve position admits the downstream pressure to the seal chamber and the seal retracts approximately 3/16 inch. As soon as the gate is seated in the closed position over the inlet, a four-inch overtravel of the lifting stem reverses the valve to admit reservoir pressure to the seal chamber and the seals are forced into contact with the seat.

Channel-shaped guide shoes at each corner of the gate engage tongues on the guides in the face of the dam (Figure 5). The distance, face to face, of 1/4 inch in each shoe except for a short distance near the conduit opening. Below an elevation slightly greater than one gate height above the top of the conduit opening the clearance is reduced to practically zero by making longer tongues on the guides. This causes the gate to be squared as accurately as possible with the tracks just before it receives the water load when closing under emergency flow conditions. The shoes are spring-loaded with snubbed springs set with an initial compression sufficient to prevent deflection during this operation.

After the gate receives water load, it is practically impossible to guide the rollers or the gate, because of the extremely high unit contact pressure between the rollers and the track. The spring loading of the shoes allows the gate to move laterally as much as 1/2 inch in either direction, while closing under load, without excessive binding or probable breaking of the shoes. When the load on the gate is removed, the capacity of the springs is sufficient to square it again.

OPERATION OF THE GATE

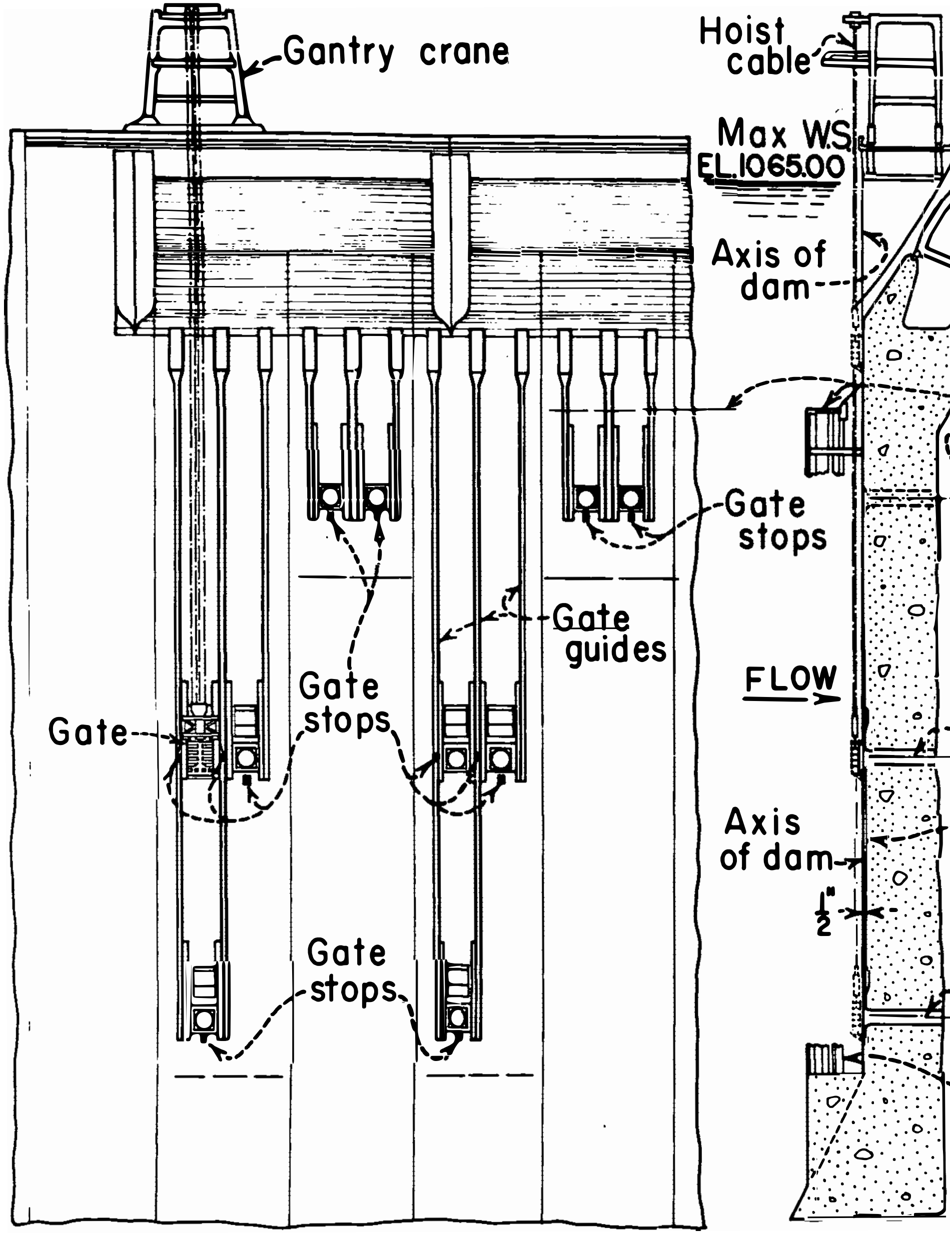
The gate is stored in a covered pit in the top of the dam. Except in case of emergency, it is used only during a few months of the year, when conditions are most favorable for inspection and servicing of the control valves and conduits.

The inlets to the conduits through the dam are arranged so that fourteen sets of guides serve the eighteen conduits. The four conduits of the lower tier, which are 335 feet below the spillway bridge, are served by the same set of guides as four of the conduits of the intermediate tier, which are 235 feet below the spillway bridge (Figure 6). The other ten conduits are served by individual sets of guides.

The placing of the gate in the guides on the face of the dam requires careful handling. The gate must be lowered approximately 90 feet below the bridge, and 75 feet below the normal water surface before engaging the guides. The upper ends of each set of guides are tapered in the plane parallel to the face of the dam in such a way that in the event that the gate is lowered slightly off-center, it is forced to correct itself and allow the channel-shaped shoes on the gate to engage the tongues on the vertical guides.

Engagement of the shoes in the direction normal to the face of the dam

FIGURE 6



SHASTA DAM

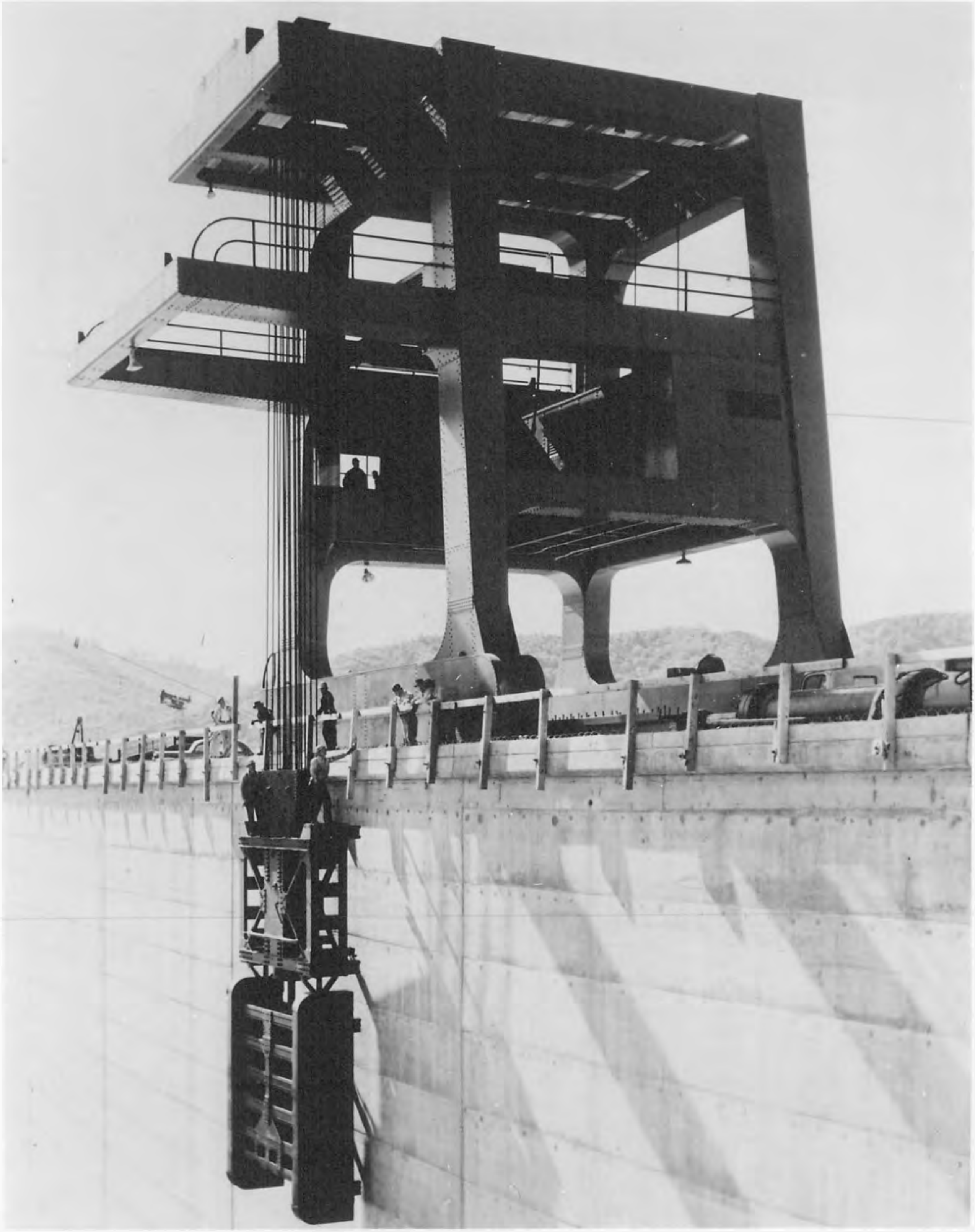
OUTLET COASTER GATE

LOCATION OF OUTLETS AND GUIDES ON UPSTREAM FACE OF DAM is provided for in the following manner. The gate is lowered in a plane slightly upstream from the face of the dam until it is below the sloping face of the spillway crest. It is then snubbed back into contact with the face of the dam by snubbing ropes (Figure 6) from the downstream edge of the bridge structure. Continued lowering will then cause the gate shoes to engage the guides and the operation can continue.

A gate-lifting frame (Figure 7) with a semi-automatic grappling mechanism is used to handle the gate. After the gate is seated in front of a conduit, the lifting frame may be released from the gate and hoisted to the bridge. This arrangement is necessary as the gate is required to remain in place in front of a conduit for several weeks at a time and the crane must be free to perform its other functions.

The position of the gate cannot be observed after it is lowered into the water. Consequently, a safety device is provided to indicate proper engagement of the gate shoes. This device consists of ropes attached to a tripping mechanism at each lower corner of the gate. When the shoes engage the tongues of the guides, the rope is released by the tripping mechanism. Two men are stationed on the bridge to pay out the tell-tale ropes as the gate is lowered. If both ropes are released after lowering the gate a reasonable distance below the top of the guides, it is evident that the guides have been engaged properly.

Lowering is continued until the gate is supported by stops on the guides at the inlet of the conduit. The stops are located so that the gate comes to rest exactly in the closed position in front of the inlet. The lifting frame continued downward approximately four inches until it comes to rest on the top of the gate. The four-inch travel of the lifting stem down into



Gantry crane in use with lifting mechanism and outlet conduit coaster gate suspended from 125-ton fixed hoist.

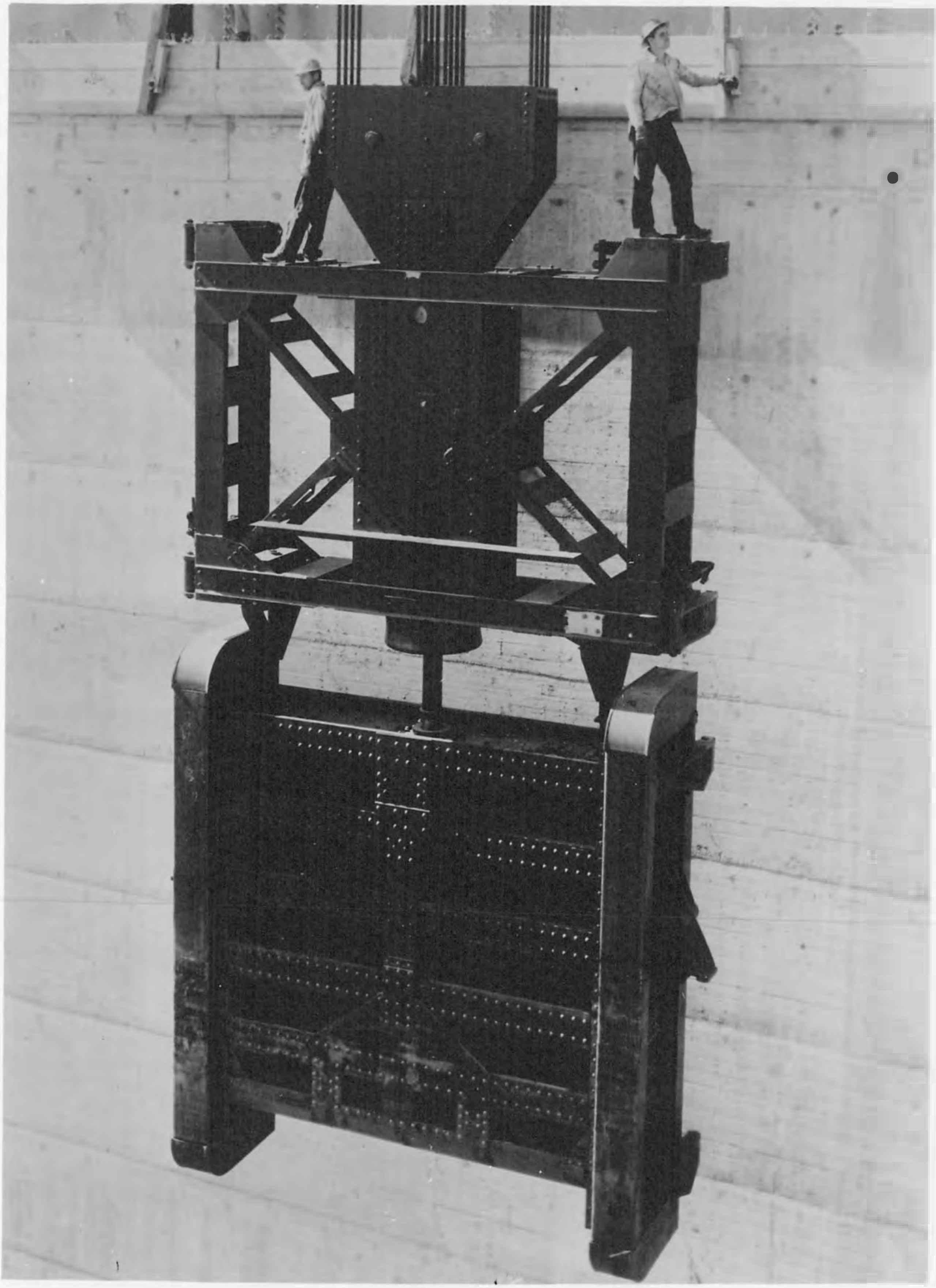
the gate causes the gate seals to close. The same motion causes the grappling mechanism in the lifting frame to release and a slack-cable limit switch, located on the crane, stops the lowering motion of the hoist.

If only one conduit is served by a set of guides, a single stop is provided in the face of the dam directly below the conduit opening. Where two conduits are served by the same set of guides, that is, where one conduit is located above the other, a single stop is provided directly under the lower one. Stops for the upper one are located at the sides of the conduit (Figure 6). Rocker arms, or pawls, are provided at each side of the gate and are inter-connected by a linked tension bar. When it is desired to close the upper conduit, the bar is extended and the rocker arms are pushed outward to a position where they will contact the stops at the sides of the upper conduit and act as an equalizer as the gate comes to rest. If the lower conduit is to be closed, the bar is retracted so that the rocker arms (Figure 7) will clear the stops at the sides of the upper conduit and the gate comes to rest on the single stop below the lower conduit.

To remove the gate, the above operations are reversed, except that the tell-tale ropes are attached to the tripping mechanism at each lower corner of the lifting frame.

GANTRY CRANE

The crane, an outdoor traveling gantry type, Figure 8, is electrically-operated and is provided with a 125-ton fixed hoist which handles the gates and a 25-ton trolley hoist which handles parts of gates during assembly and is used infrequently to install stop logs in front of the power penstocks. The 125-ton capacity was determined by the installation and servicing conditions of the coaster gates for the main power penstock inlets. These inlets



Outlet conduit coaster gate and gate-lifting frame with semi-automatic grappling mechanism.

are located in the curved portion of the dam, where the solid construction will support practically any crane load. As previously mentioned, the bridge structure over the spillway portion of the dam in which the river outlets are located, made it economically desirable to limit the crane load at this point to only a fraction of the hoist capacity in order to avoid a heavy and expensive structure which would not be otherwise required. The crane can transfer a load from any point on the dam to the overhung position upstream from the face of the dam. All gates are installed and operated from the overhung position.

The crane operates on 27-foot gage tracks. The tracks are straight for approximately 375 feet on the bridge structure over the spillway section at the center of the dam. The remainder of the track has a 2500-foot radius of curvature for a distance of 1425 feet along the roadway on top of the right abutment.

The combination of straight and curved track made it impractical to use the conventional drive with one motor driving a shaft leading to the trucks of either side. Instead separate motors were mounted on each of four trucks with 50 percent of the track wheels driving. Direct current for operation of the four 8-horsepower shunt-wound motors is provided by a generator-set. The use of direct current was made necessary by the unequal loading of the motors.

Accurate spotting of the gates is provided by direct current, motor-operated hoists and Maxspeed control. In case the gate should encounter some obstruction in the guides, a special type of control was provided for the hoist. This control limits the maximum lifting effort when the crane is located on the bridge. If a conventional hoist with alternating current motor and standard control had been provided, the maximum lifting effort on the crane hook under a 275 percent breakdown torque of the motor would have been approximately 350 tons. The modified Maxspeed control limits the lifting effort at the hook to 175 tons. The control is the full-magnetic, reversing, master type. It has definite time limit acceleration relays and six speeds in each direction of operation. Due to the extremely long lift of 360 feet, a mechanical load brake was not considered feasible and direct current dynamic braking was provided.

A panel of indicating lights in the operator's cage warns him when the gate is approximately 16 feet above the closed position in front of any conduit. A lighting system, including flood lights, was installed on the crane so that the gates could be operated at night.