UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC LABORATORY REPORT NO. 86

MODEL STUDIES PERTAINING TO AERATION OF COASTER GATES DURING EMERGENCY CLOSURE

By

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Denver, Colorado

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HYD-86

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Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
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Laboratory Report No. 86
Hydraulic Laboratory
Compiled by: J. W. Ball

INTRODUCTION

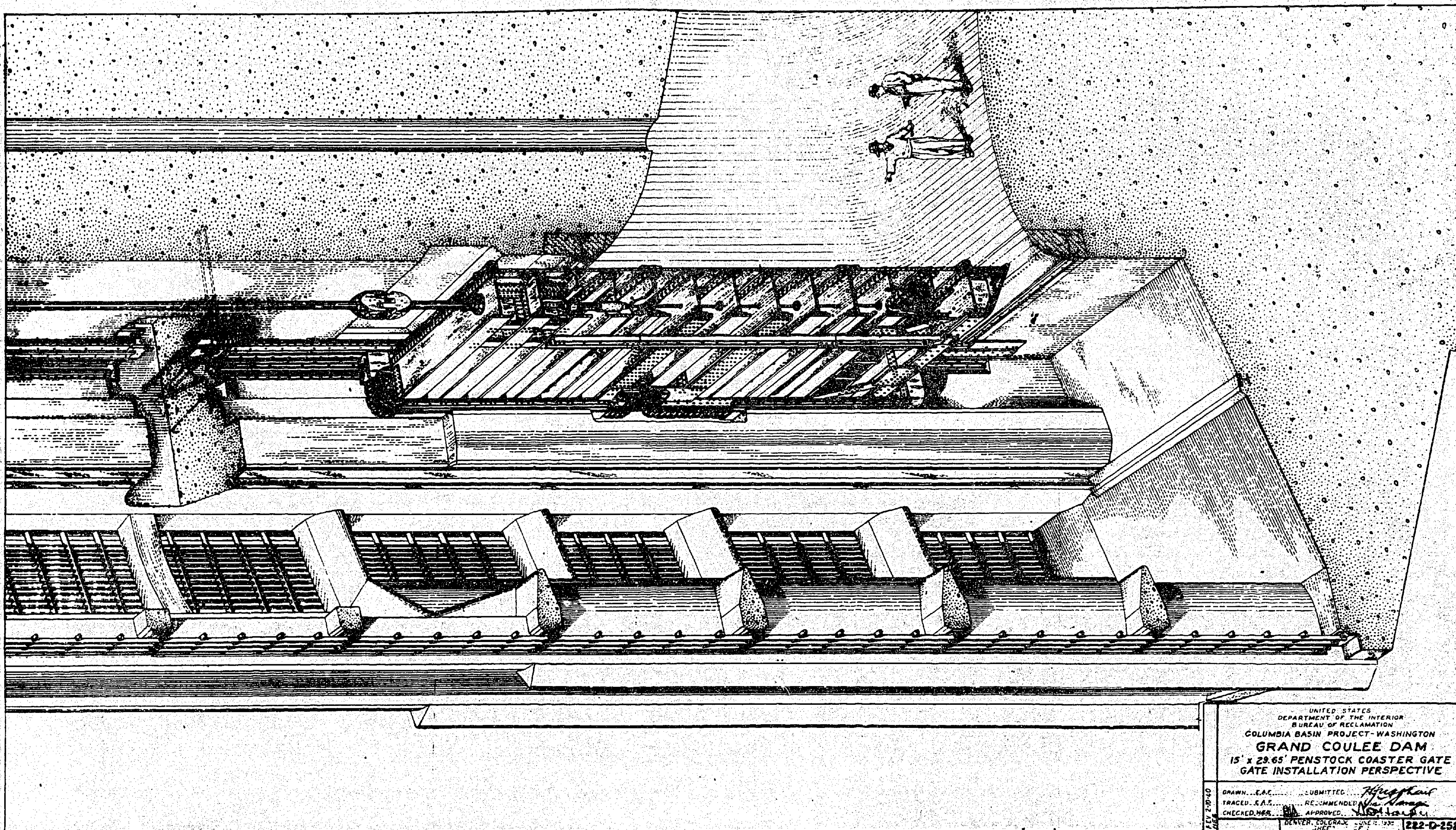
In nearly all river outlets designed previous to those for the Friant and Shasta Dams each outlet conduit was equipped with two gates or valves, one for regular operation and the other for emergency use in case the first failed to function.

This arrangement limited the duties of a coaster gate to those of a bulkhead, its purpose being to seal the outlet conduit at the upstream end, thereby making the entire length accessible for inspection or repairs. The gate was never expected to be lowered into place with the outlet discharging.

The function of the coaster gate changed materially when the emergency gate or valve was omitted, as in the case of the Friant and Shasta designs. Besides acting as a seal it had to assume emergency duties, one being to close the outlet conduit during operation at full capacity. This condition, representing the control valve jammed in the open position, was considered the worst under which the gate would have to operate, the velocity in the conduit and differential pressures on the gate being a maximum. The function was similar to that of a coaster gate used in emergency closure of power penstocks, Figure 1.

Use of the coaster gate under these conditions was expected to be infrequent, thus the outlets would rarely be subjected to cavitation due to the presence of negative pressures in the bell entrance.

FIGURE 1



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
GRAND COULEE DAM
15' x 29.65' PENSTOCK COASTER GATE
GATE INSTALLATION PERSPECTIVE
DRAWN...E.A.E.
TRACED...E.A.E.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO
SHEET
222-D-2588
REV 2-10-40

Moreover, the time to close it would be of such short duration that no damage should result. From this standpoint the presence of near absolute pressures would not be objectionable. However, should they contribute to vibration, their reduction or elimination would become imperative. It was for the purpose of investigating the behavior of the coaster gate functioning under emergency conditions that hydraulic model studies were made in the Bureau of Reclamation hydraulic laboratory. The fact that cavitation was of minor consideration, resolved the problem into one concerned mainly with investigating the presence of vibration and evolving a means of reducing it to a minimum.

The model. Because of the similarity between the designs of the Friant and Shasta outlets at the time these tests were instigated, it was possible to utilize an existing 1:17 model of the Shasta outlets, Figure 2. The model was comprised of a head tank fabricated from steel plates, a bell entrance machined from a brass casting, and sections of six-inch pyralin pipe shaped to the outlet profile.

The bell entrance was fastened to the outlet end of the head tank so that a steel plate in the tank represented the face of the dam. The coaster gate of galvanized sheet metal, constructed similar to the preliminary design for the Shasta Dam Penstocks, Figures 3 and 4, operated in slide grooves attached to this plate. A piece of threaded brass tubing, fastened loosely to the gate and connected to a duct through the gate, provided a passage for admitting air to the bell entrance and a means for raising and lowering the gate. Flexible connections between the stem and gate allowed free movement in case the gate vibrated. Location of the vent system in the stem permitted initial studies to be made without altering the bell entrance used intermittently for tests on the Shasta outlet and tube valve. The supply duct size was varied by placing 1/8- to 7/8-inch telescopic brass tubing in the gate stem.

A pressure gage, reading in feet of water and attached by a short length of pipe to the downstream end of the head tank, was used to record the head on the outlet.

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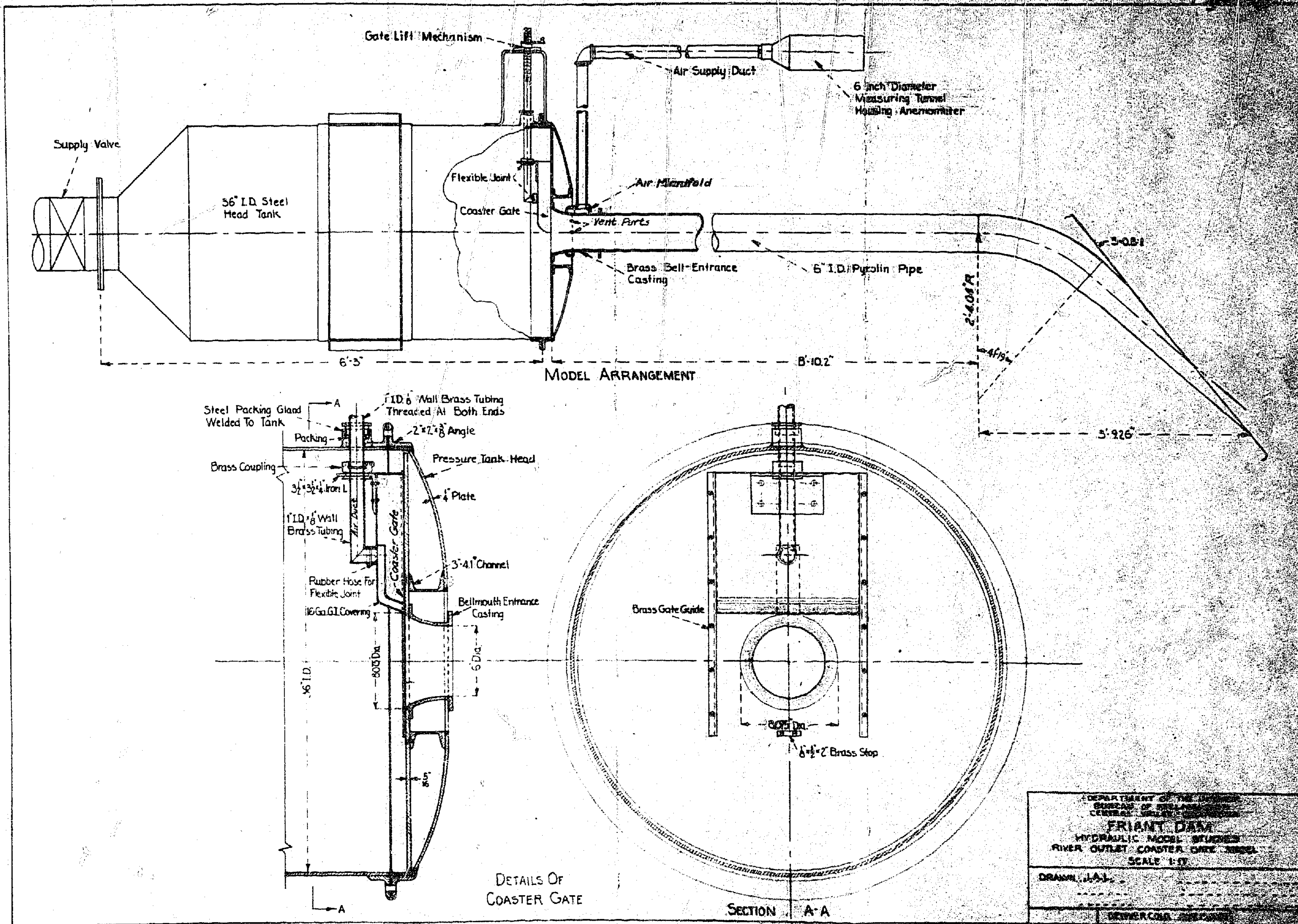
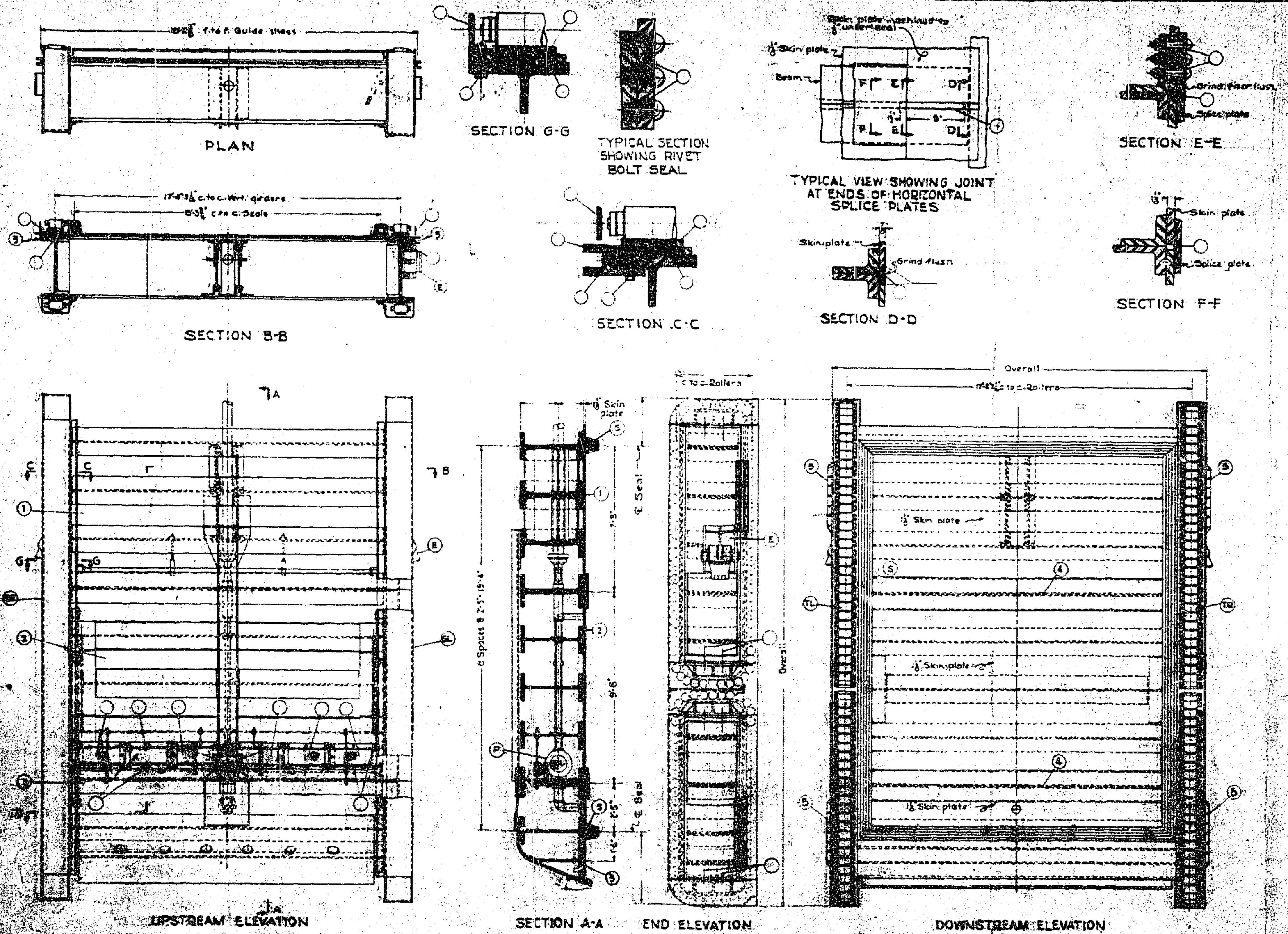


Gate Lift Mechanism
Air Supply Duct
6 inch Diameter
Measuring Tunnel
Housing Anemometer
Supply Valve
36" I.D. Steel
Head Tank
Flexible Joint
Air Manifold
Coaster Gate
Vent Ports
Brass Bell-Entrance
Casting
6" I.D. Pyralin Pipe
2'-4.01"R
6'-3"
8'-10.2"
3'-9.26"
MODEL ARRANGEMENT
Steel Packing Gland
Welded To Tank
1" I.D. 1/8" Wall Brass Tubing
Threaded At Both Ends
Packing
2"×2"×1/8" Angle
Pressure Tank Head
Brass Coupling
1/4" Plate
1" I.D. 1/8" Wall
Brass Tubing
Air Duct
Coaster Gate
3"-4.1" Channel
Rubber Hose For
Flexible Joint
16 Ga. G.I. Covering
Bellmouth Entrance
Casting
8.03 Dia
6" Dia
36" I.D.
5/16"
DETAILS OF
COASTER GATE
Brass Gate Guide
8.03 Dia
Brass Stop
SECTION A-A
FRIANT DAM
HYDRAULIC MODEL
RIVER OUTLET COASTER
DRAWN J.A.L.

FIGURE 3



LIST OF PARTS - ONE GATE LEAF

DRAWING NUMBER	PART No.	No. REQ'D	DESCRIPTION	MATERIAL CLASSIFICATION	[illegible]	[illegible]
214-D-	1	1	Top Unit	Steel		
214-D-	2	1	Intermediate Unit	Steel		
214-D-	3	1	Bottom Unit	Steel		
No Detail	4	*	Joint Filler	Cast lead & Lead wool	[illegible]	
214-D-	5	4	Guide shoe	Bronze		

* Quantities shown are net. Furnish 10% excess.
* Supply sufficient quantity of joint filler to pack joints indicated on downstream elevation.
† Manufacturer to fill in number of material used and forward a copy to the Bureau of Reclamation.

NOTE

All parts shall be marked or tagged with the mark number as shown with each detail as

REFERENCE DRAWING

FUSION WELDING SYMBOLS X-D-2883

SHASTA DAM

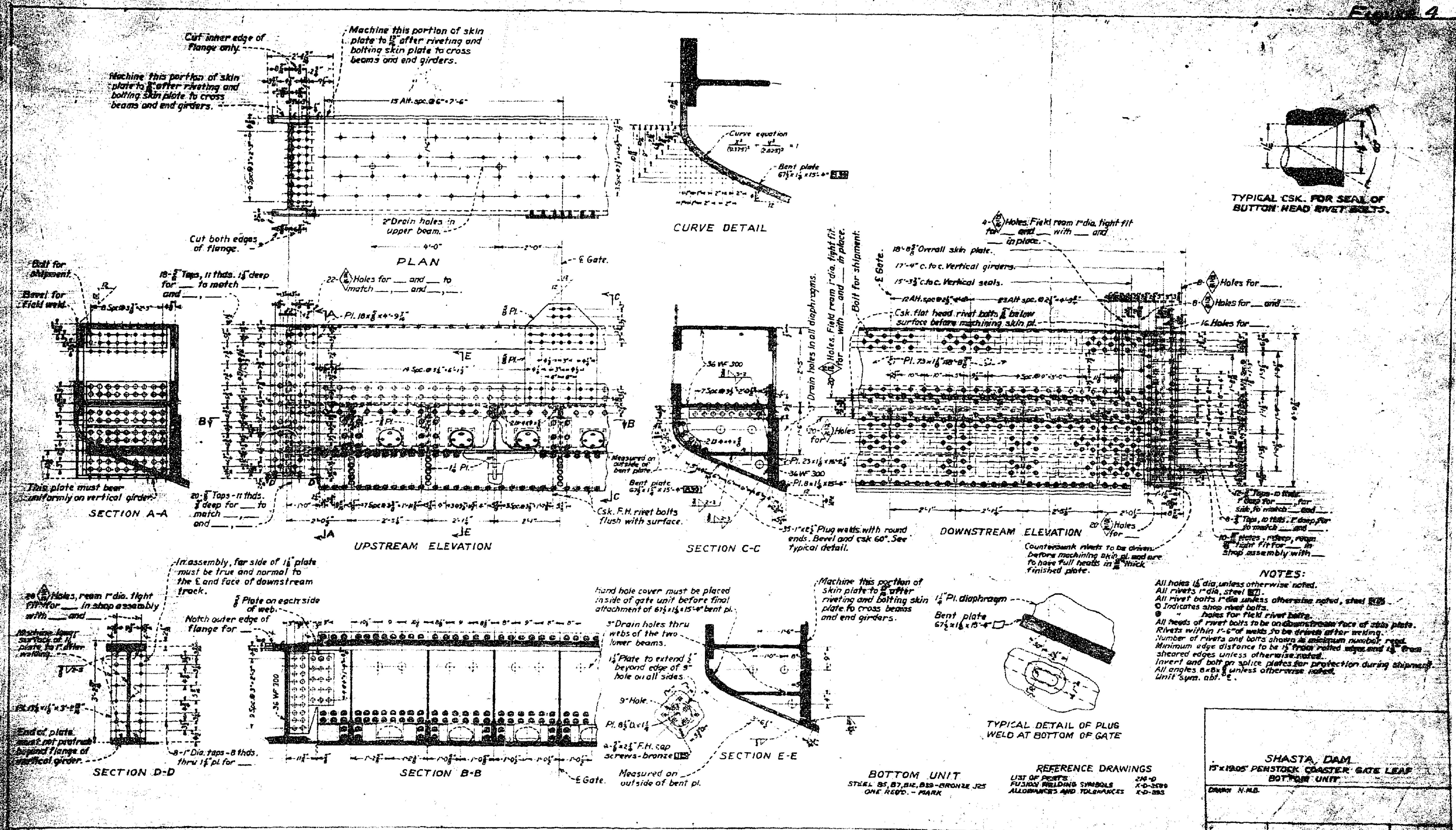


Figure 4
PLAN
CURVE DETAIL
TYPICAL CSK. FOR SEAL OF BUTTON HEAD RIVET BOLTS.
SECTION A-A
UPSTREAM ELEVATION
SECTION C-C
DOWNSTREAM ELEVATION
SECTION D-D
SECTION B-B
SECTION E-E
TYPICAL DETAIL OF PLUG WELD AT BOTTOM OF GATE
Machine this portion of skin plate to 1/8" after riveting and bolting skin plate to cross beams and end girders.
Cut inner edge of flange only.
Cut both edges of flange.
2" Drain holes in upper beam.
This plate must bear uniformly on vertical girder.
Csk. F.H. rivet bolts flush with surface.
Csk. flat head rivet bolts 1/8 below surface before machining skin pl.
Countersunk rivets to be driven before machining skin pl. and are to have full heads in 5/8 thick finished plate.
3" Drain holes in all diaphragms.
Bolt for shipment.
Hand hole cover must be placed inside of gate unit before final attachment of 67 1/2 x 1 1/4 x 15'-4" bent pl.
3" Drain holes thru webs of the two lower beams.
Measured on outside of bent pl.
NOTES:
All holes 1 1/16" dia. unless otherwise noted.
All rivets 1" dia., steel.
All rivet bolts 1" dia. unless otherwise noted, steel.
Indicates shop rivet bolts.
Holes for field rivet bolts.
All heads of rivet bolts to be on downstream face of skin plate.
Rivets within 1'-6" of welds to be driven after welding.
Number of rivets and bolts shown is minimum number req'd.
Minimum edge distance to be 1 1/2" from rolled edges and 1 3/4" from sheared edges unless otherwise noted.
Invert and bolt on splice plates for protection during shipment.
All angles 8x8x 5/8 unless otherwise noted.
Unit sym. abt. ℄.
BOTTOM UNIT
REFERENCE DRAWINGS
SHASTA DAM
15' x 19.05' PENSTOCK COASTER GATE LEAF
BOTTOM UNIT

Pressures in the outlet conduit were recorded by manometers attached by rubber tubing to piezometric openings in the outlet wall. Uncertainty concerning the outlet control valve design at the time these tests were conducted made it desirable to perform them without the valve. Moreover, it was felt that the reduced loss due to its omission would induce a factor of safety.

Hydraulic similitude. Much could be said concerning model properties which are essential to attain exact similitude. Many of these properties cannot be controlled and others are of minor importance in hydraulic testing, so the subject will be discussed only briefly in this report.

Exact similitude is never attained when the liquid used on the model is the same as exists on the prototype, mainly because of the incorrect relationship existing between viscous properties. This relationship is of little concern in open-channel models where appreciable depths are used and the liquid has a low viscosity. The same holds true in closed conduit flow when both the model and prototype operate with values of Reynolds' number above or below the critical range. The case is different, however, if Reynolds' number on the model is below the critical range and that for the prototype is above. To assure similar flow when this condition obtains, it is necessary to increase the size of the model or in some manner increase Reynolds' number above the critical range. Inability to utilize a larger model and impracticability of employing a liquid with less viscosity forces one to resort to other methods. One effectively used is the increasing of the operating heads on the model to values much greater than those representing the prototype heads.

Reynolds' number was near the critical range when the 1 to 17 outlet model used for these studies was operated at heads representative of the prototype. For this reason it was deemed desirable to conduct the tests with heads greatly in excess of those representing the prototype. This procedure assured operation at values of Reynolds' number beyond the critical range and in addition provided a more reliable means of establishing the relation between head and critical flow conditions.

Vibration of model. The model was first operated without aeration. Although vibration was present no movement of the gate was noted. Apparently the pressure differential on the gate was sufficient to hold it firmly against the plate representing the face of the dam, thus preventing any movement. Vibration of the entire model occurred at all gate openings, becoming more intense as the head increased. This condition was attributed to the large negative pressures in the bell entrance, which also varied as the head. Although the gate did not seem to be directly affected, it was believed desirable to eliminate as much of the vibration as possible. Aeration of the negative pressure region seemed the only practicable way to accomplish this. Moreover, relieving the negative pressure would reduce the downstream force on the gate and facilitate its operation.

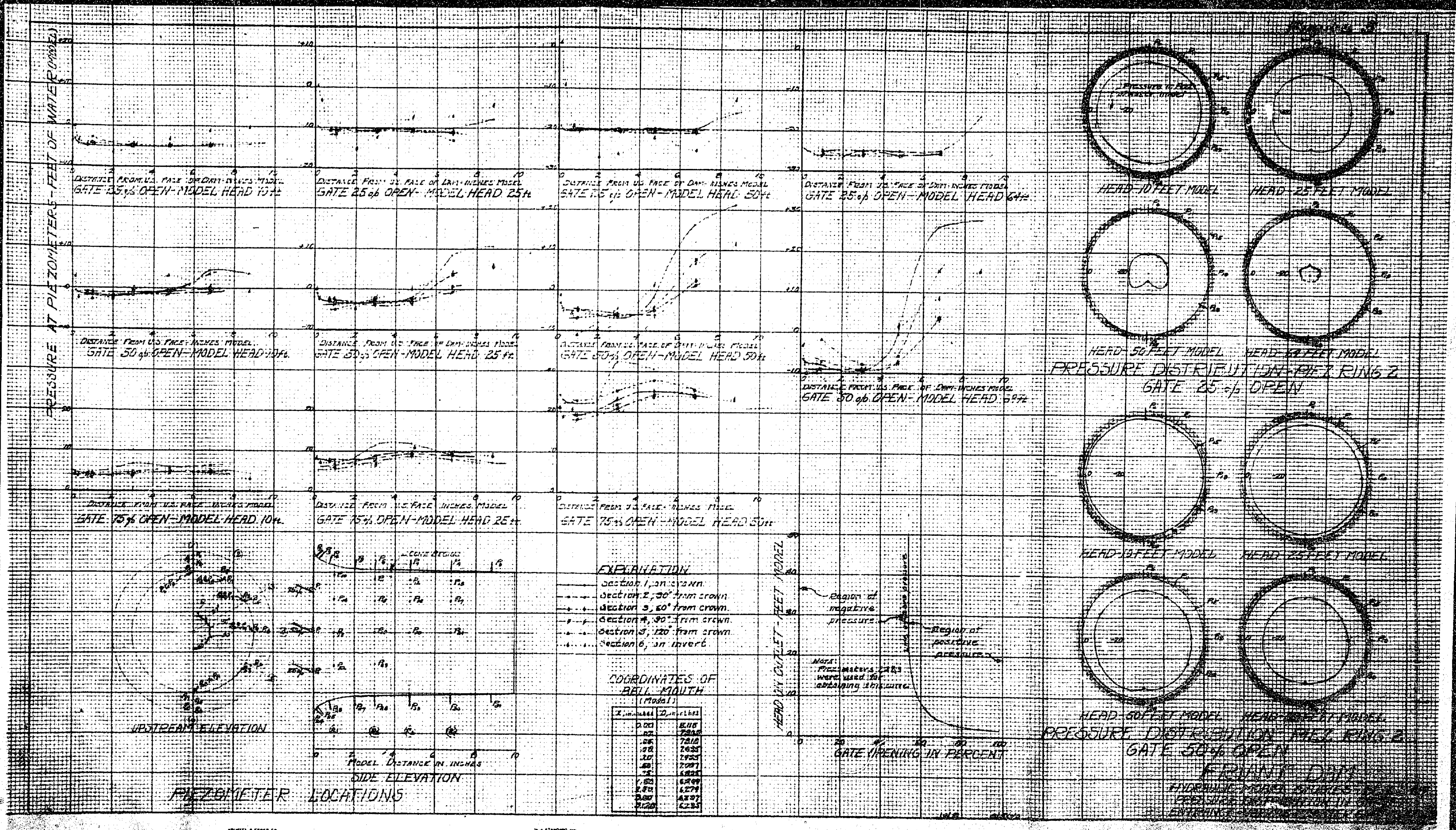
Effect of aeration on model vibration. The admission of air to the bell entrance was found to affect the vibration intensity. By using supply ducts up to one inch in diameter it was ascertained that the intensity increased slightly for duct sizes up to one-fourth inch, then decreased rapidly as the size increased, being much less for the one-inch duct than when no air was admitted. This indicated that considerable damping could be accomplished by aeration. However, a more detailed model arrangement including a variable vent system and a means of recording the vibration intensity, was needed to determine if the duct size was critical. In order that this model be of the greatest value it was also necessary to determine the most desirable points for admitting air. Pressure distribution in the outlet was obtained for this purpose.

Vent location governed by conduit pressures. Since the flow of air between two points is proportional to the pressure drop between them, the most desirable place for admission of air to a region of subatmospheric pressure would seem to be that at which the negative pressure is the greatest. However, this is not necessarily true when the pressure in all parts of the region is quickly equalized by the admission of air. Under this condition it would be essential only that the vents enter at some point within this region. This condition being anticipated in the Friant outlet downstream from the coaster gate made it essential to ascertain the extent of the subatmospheric region under the various operating conditions. Accordingly, piezometer readings were taken for gate openings of 25, 50, and 75 percent at heads ranging from 10 to 68 feet. (Gate opening being defined as the ratio between the distance from the bottom edge of the gate to the outer edge of the bell entrance and the maximum diameter of the entrance.)

The longitudinal limit of the negative pressure region, which encircled the outlet jet in the bell entrance, was found to vary directly as the head and inversely as the gate opening. Changes from negative to positive pressure on the crown and invert of the bell entrance occurred at 0.8 and 0.6 conduit diameter downstream from the face of the entrance for 0.5 gate opening and a 10-foot head (model), Figure 5. For greater gate openings and smaller heads the negative pressures were so small that venting for these conditions was not deemed necessary. Moreover, properly located vents would serve to aerate most of these cases. The limits for 0.5 gate opening and a 10-foot head were therefore used as a criterion in establishing the longitudinal vent location on the model, the distance from the upstream end being arbitrarily chosen as half of the conduit diameter. That it would not be necessary to limit venting to the crown was shown by the equal distribution of negative pressure on the circumference of the outlet. This characteristic permits admission of air at more than one point on the circumference of the pipe and allows the openings in the wall to be much smaller and therefore less susceptible to local cavitation. Venting in this manner would be more complete than a single opening, because air could be admitted near the invert.

From the pressure studies it was concluded that a very satisfactory position for the vents would be in the wall of the bell entrance one-half conduit diameter from the upstream end.

New bell-entrance design. Upon completion of the initial tests it was decided that a new bell entrance, with a variable supply duct,



PRESSURE AT PIEZOMETERS - FEET OF WATER (MODEL)
DISTANCE FROM U.S. FACE OF DAM - INCHES MODEL
GATE 25% OPEN - MODEL HEAD 10 ft
GATE 25% OPEN - MODEL HEAD 25 ft
GATE 25% OPEN - MODEL HEAD 50 ft
GATE 25% OPEN - MODEL HEAD 64 ft
GATE 50% OPEN - MODEL HEAD 10 ft
GATE 50% OPEN - MODEL HEAD 25 ft
GATE 50% OPEN - MODEL HEAD 50 ft
GATE 50% OPEN - MODEL HEAD 59 ft
GATE 75% OPEN - MODEL HEAD 10 ft
GATE 75% OPEN - MODEL HEAD 25 ft
GATE 75% OPEN - MODEL HEAD 50 ft
HEAD 10 FEET MODEL
HEAD 25 FEET MODEL
HEAD 50 FEET MODEL
PRESSURE DISTRIBUTION - PIEZ. RING 2
GATE 25% OPEN
GATE 50% OPEN
EXPLANATION
Section 1, on crown.
Section 2, 30° from crown.
Section 3, 60° from crown.
Section 4, 90° from crown.
Section 5, 120° from crown.
Section 6, on invert.
COORDINATES OF BELL MOUTH
(Model)
HEAD ON OUTLET - FEET MODEL
Region of negative pressure
Region of positive pressure
GATE OPENING IN PERCENT
UPSTREAM ELEVATION
SIDE ELEVATION
MODEL DISTANCE IN INCHES
PIEZOMETER LOCATIONS
FRIANT DAM

a manifold, and variable vent openings, would give results of a more general nature as well as provide a means of determining the proper air supply duct size. Accordingly, a flexible bell entrance was constructed, Figure 6.

The air supply duct of this system was formed from standard pipe and fittings to facilitate rapid changes from one arrangement to another. With this arrangement it was possible to test duct sizes up to 1¼ inches in diameter.

An anemometer placed in a measuring tunnel attached to the supply duct recorded the air flow through it for the various operating conditions.

The special hardwood clamp, designed to support strain gages and a metal reed for measuring the vibration intensity, was fastened on the pyralin pipe immediately downstream from the entrance casting.

Piezometers were installed in the entrance wall for ascertaining the degree of aeration.

Effect of supply duct size on negative pressure in bell entrance. Records from the piezometers in the crown of the entrance for various heads and supply duct sizes disclosed that a rapid rise in pressure occurred when the size was increased from one-half inch to one inch and that the change became more gradual with further increase in size. This characteristic, which became less pronounced as the gate closed, was similar for all gate openings and definitely indicated the size of the air supply duct to the critical, Figure 7. This size was found to be about one inch on the model, and did not very with the model head. However, in some instances the change in pressure was still quite rapid when the duct diameter was increased to 1¼ inches, indicating the latter to be the more desirable criterion, especially for the smaller gate openings. Considering the relatively greater friction on the model, both sizes should be more efficient than indicated and supply duct sizes based on the one-inch pipe should prove satisfactory. Curves for obtaining the proper air supply duct size for any given outlet conduit diameter were prepared. These curves, based on the model sizes of 1 and 1¼ inches,

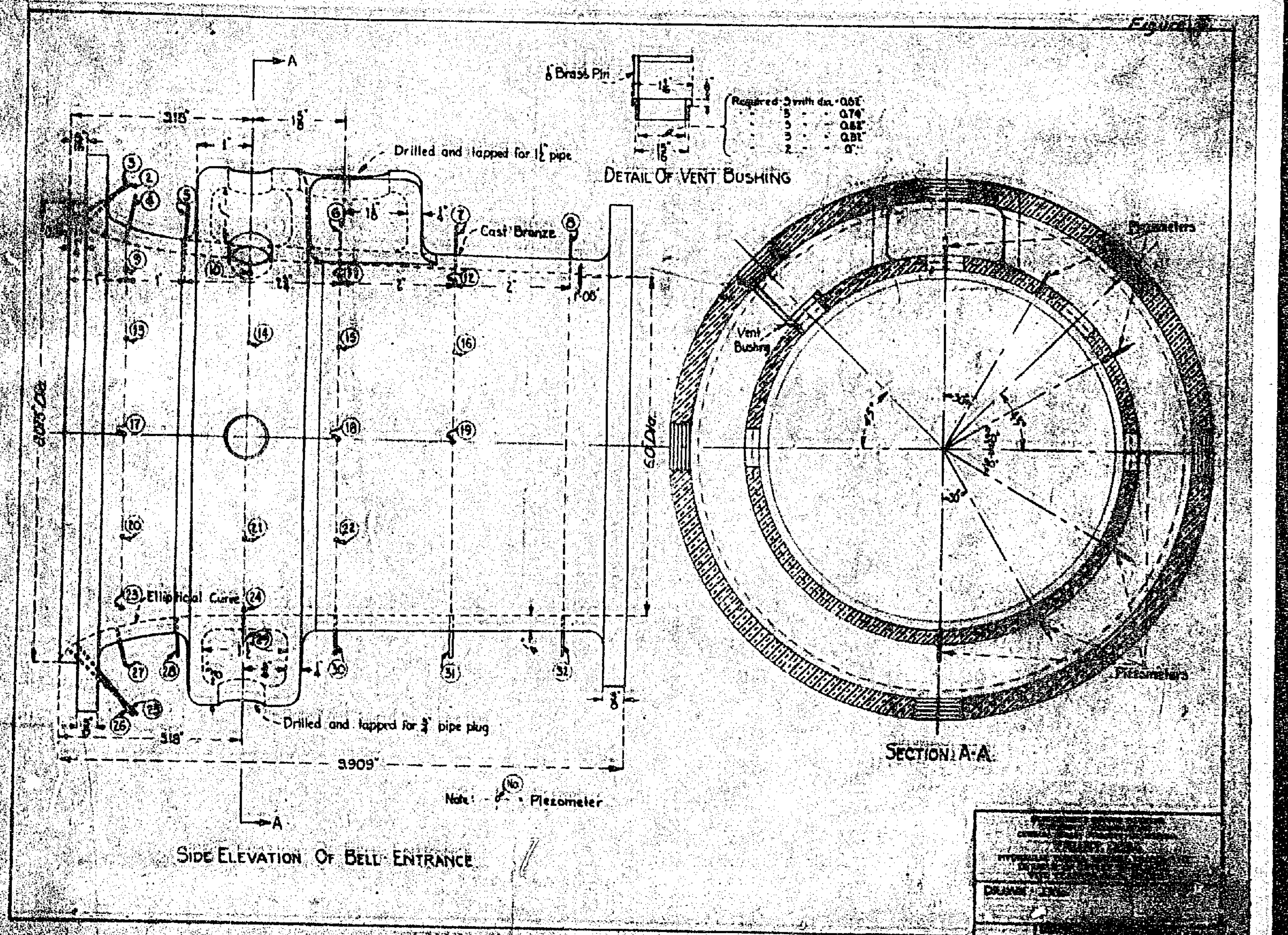


Figure
⅛" Brass Pin
Required: 3 with dia. 0.62"
5 - 0.74"
5 - 0.82"
3 - 0.87"
2 - 0"
Detail Of Vent Bushing
Drilled and tapped for 1½" pipe
Cast Bronze
Elliptical Curve
Drilled and tapped for ⅜" pipe plug
3.909"
60 Dia.
Note: (No.) Piezometer
Side Elevation Of Bell Entrance
Vent Bushing
Piezometers
Section A-A

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were obtained by assuming the model to represent outlet conduits of various diameters, Figure 7.

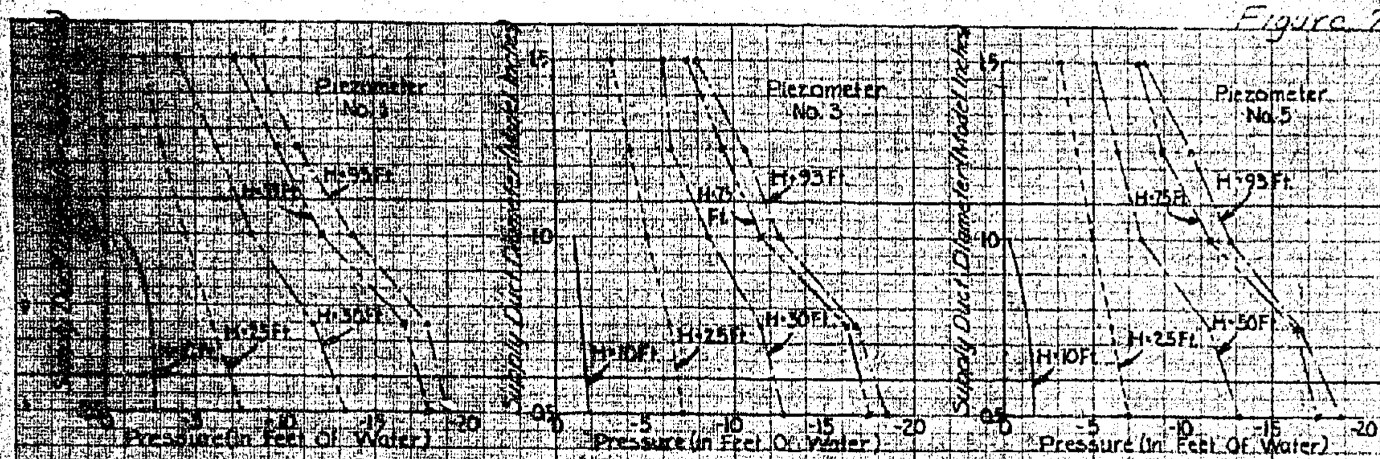
Effect of supply duct size on vibration of the model. It had been definitely determined in the initial studies that some relation existed between the supply duct size and the vibration of the model. Since both the pressures and vibration varied as the duct size it seemed that some relation should exist between them. It was necessary to determine the vibration intensity in order to ascertain if such a relationship existed. Examination of the model in operation disclosed several sources of vibration other than that due to the low pressure in the outlet entrance. To eliminate these extraneous vibrations would have required a very elaborate model arrangement. Even then the intensity would have been only relative and not transferable to the prototype. Moreover, it was believed that the critical duct size could be determined without the use of such an elaborate model.

Assuming the performance of the model and prototype to be similar and the critical air supply duct size not to very with the head on the outlet, the results from the less elaborate model should give an adequate solution to the coaster-gate problem.

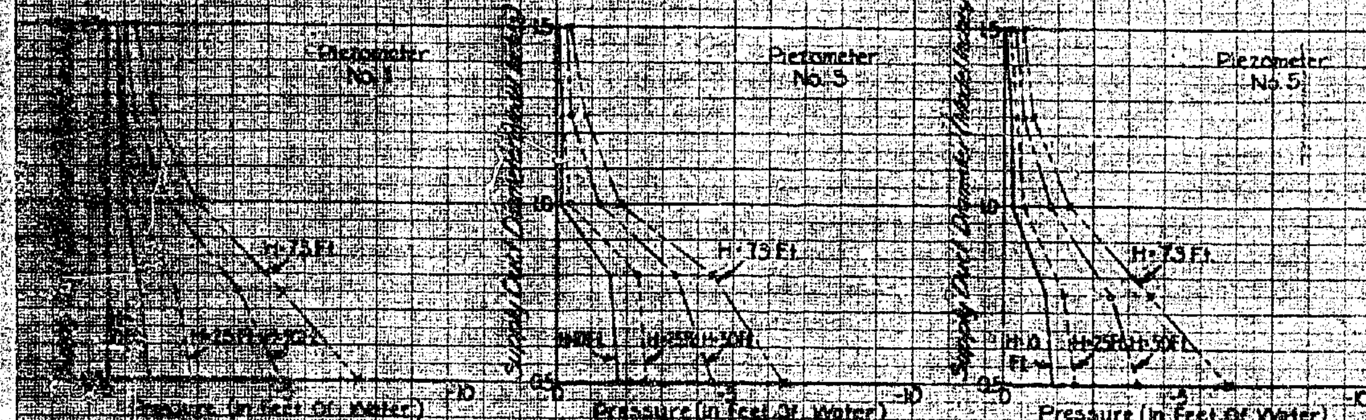
Vibration pulsations in the pyralin section immediately downstream from the entrance casting were visible. A specially built clamp of hardwood with extension arms for mounting De Forest strain gages, was placed on this section of pyralin pipe, Figure 8. The location was close to the subatmospheric region below the coaster gate where it was believed the apparatus would record principally the vibration from this source.

It was found impossible to obtain complete records with the strain gages. Without aeration at high heads the vibration was so intense that the inertia of the clamp prevented it from keeping contact with the pipe. Increasing the tension on the clamp spring to remedy this condition prevented the recording of vibrations of only slightly less intensity. For this reason strain-gage records were used only to check the reliability of a simpler method, the measurement of the displacement of a vibrating reed. A piece of thin steel measuring tape was fastened to the clamp

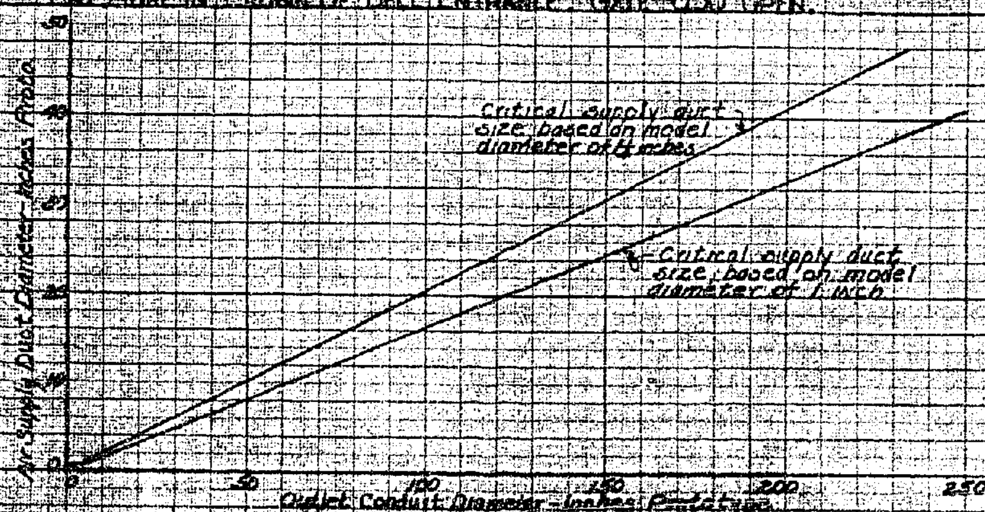
Figure 7



PRESSURE IN CROWN OF BELL ENTRANCE, GATE 0.75 OPEN



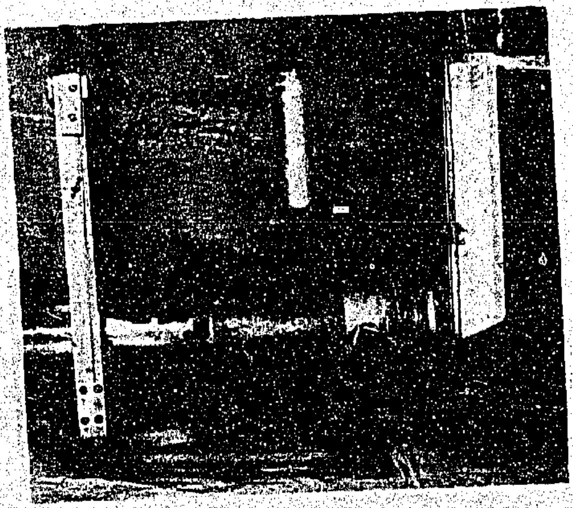
PRESSURE IN CROWN OF BELL ENTRANCE, GATE 0.50 OPEN.



AIR DUCT SIZE FOR VARIOUS OUTLET CONDUIT DIAMETERS
(BASED ON MODEL AIR DUCT DIAMETERS OF 1 AND 1½ INCHES)

FRIANT DAM
MASTER GATE STUDIES - 1:17 MODEL
AIR DUCT SIZE DETERMINED FROM
BELL ENTRANCE PRESSURES

FIGURE 8



Side view of model gate, bell-entrance
and vibration clamp

View of vibration clamp showing reed
and De Forest strain gage.

MODEL BELL-ENTRANCE, COASTER GATE AND VIBRATION RECORDER

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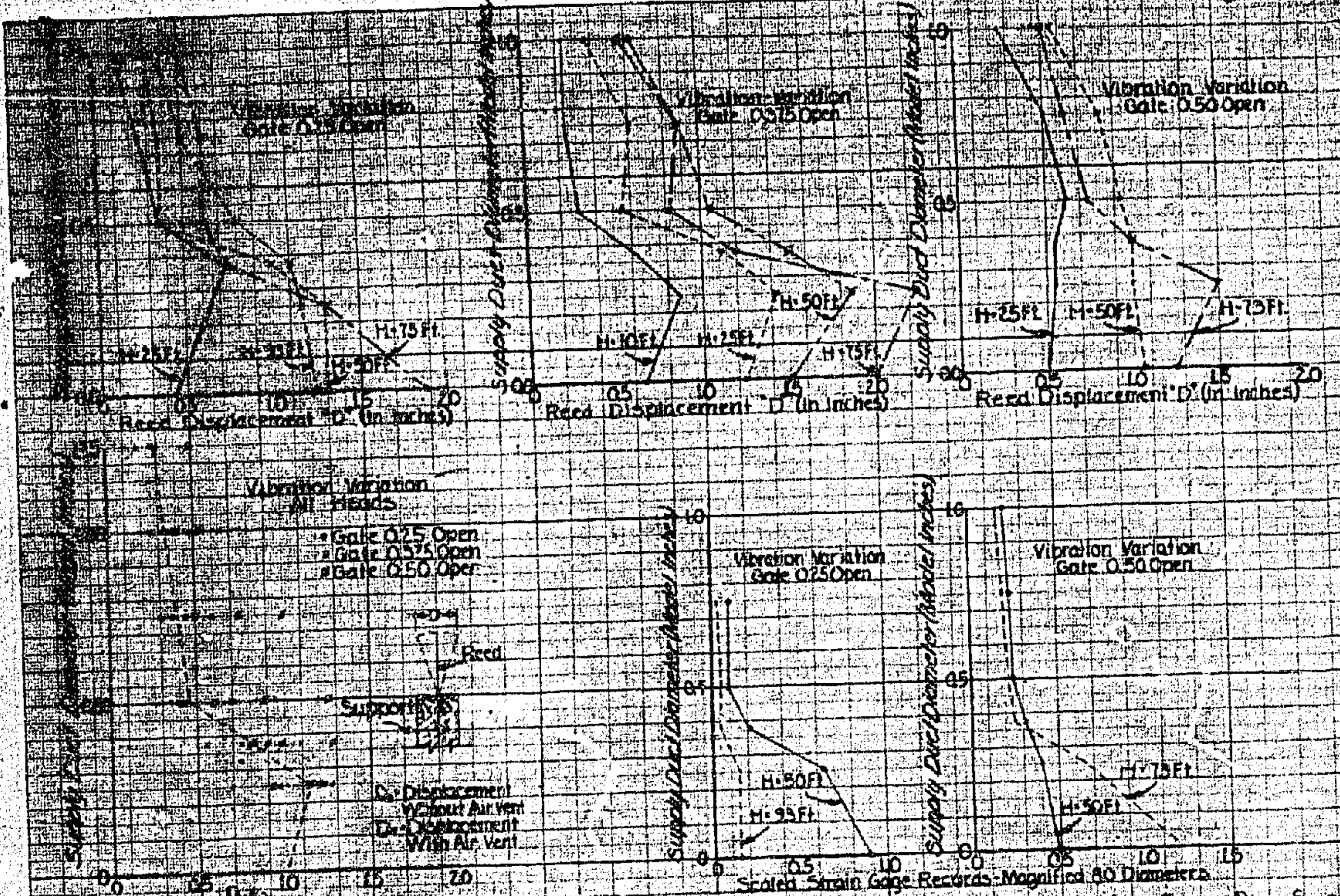
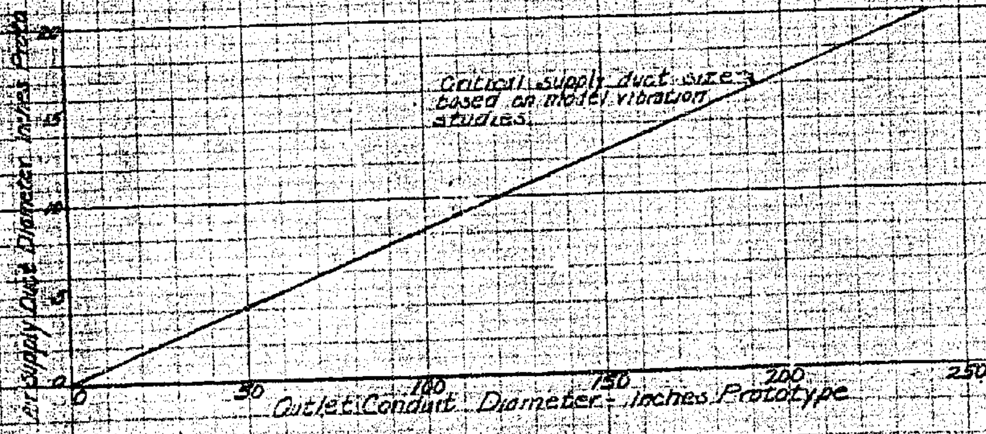
Figure 9



VIBRATION VARIATION IN RIVER OUTLET MODEL - FOR VARIOUS HEADS, GATE OPENINGS, AND SUPPLY DUCT SIZES.



AIR DUCT SIZE FOR VARIOUS OUTLET CONDUIT DIAMETERS

(BASED ON MODEL SUPPLY DUCT DIAMETER OF ½ INCH)

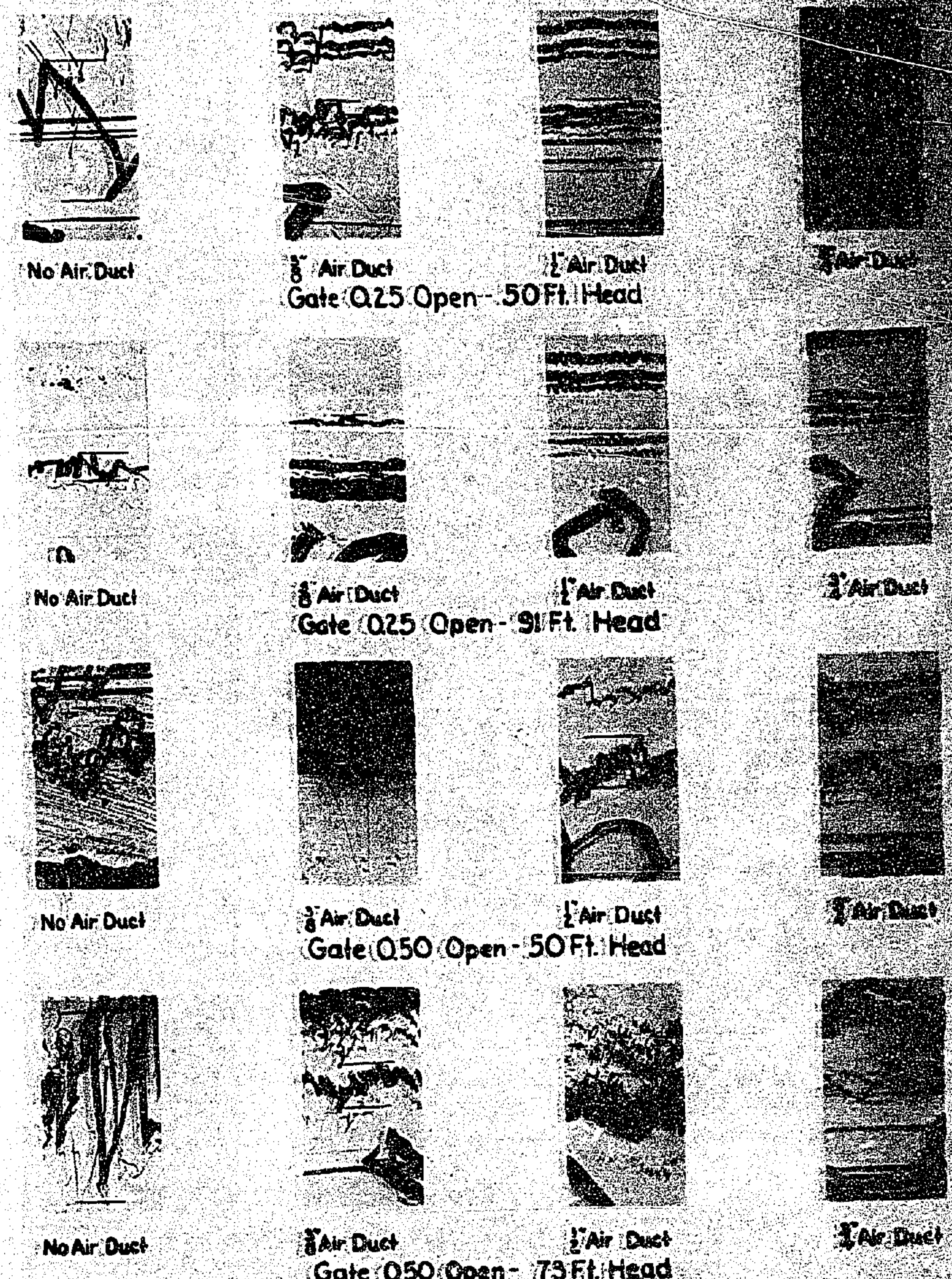
FRIANT DAM

COASTER GATE STUDIES 1:17 MODEL

AIR DUCT SIZE DETERMINED BY VIBRATION STUDIES to form a reed, the displacement of which under the various conditions was believed proportional to the vibration intensity. Plotted records for the various operating conditions disclosed that in all cases the maximum damping effect was attained by the time the model supply duct reached one-half inch in diameter, Figure 9. Some of these curves substantiated the earlier tests which indicated an increase in vibration for very small air ducts. Since this characteristic was not recorded by the strain gages it was attributed to an unknown source. The strain-gage readings, obtained by scaling 80-diameter photomicrographs of the target records, Figure 10, were considered more accurate. However, the same critical size was obtained in both cases, so either method would have sufficed. In these tests the reed records were more useful because they represented the trend over a wider range in operating conditions.

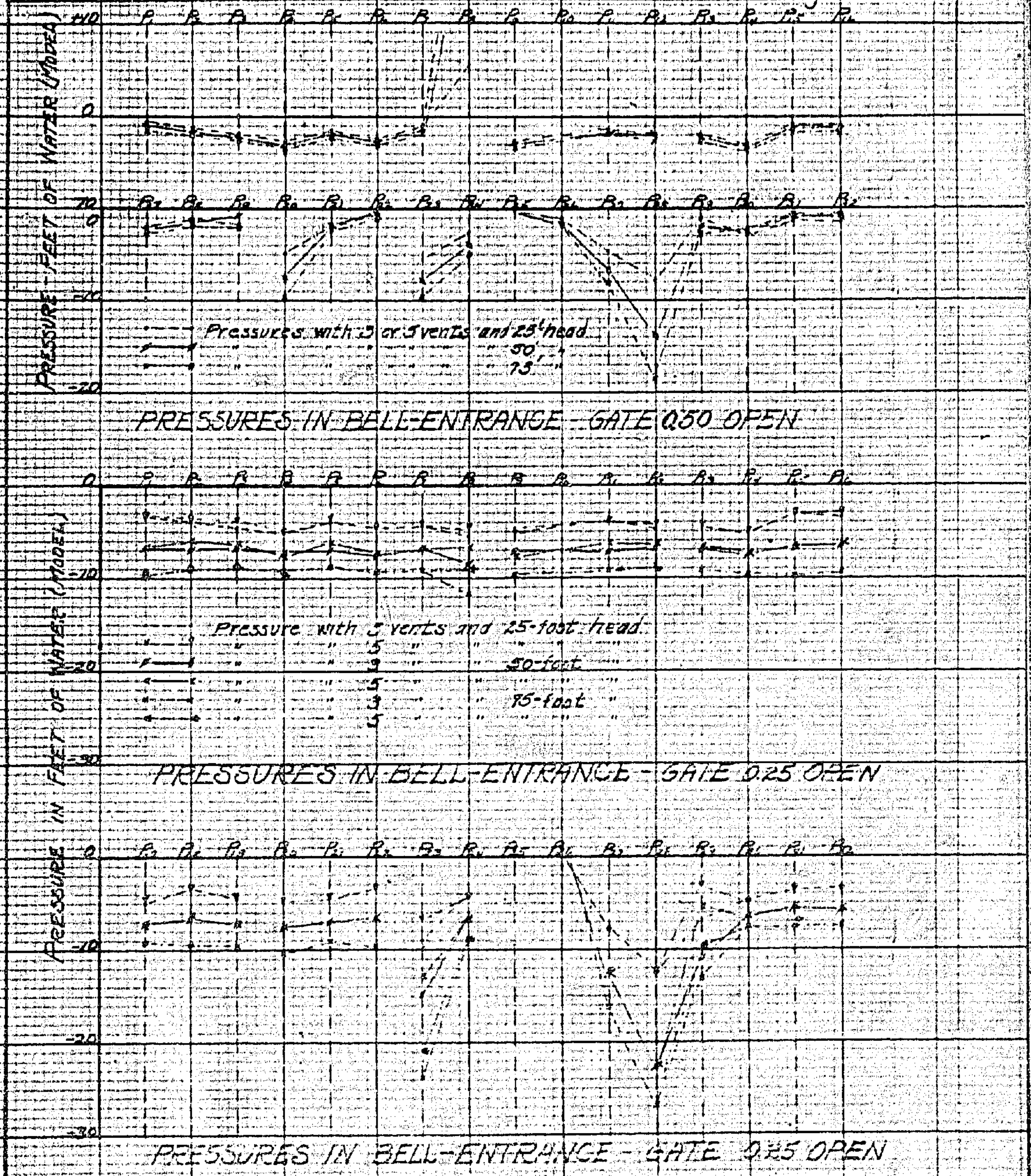
The critical duct diameter, found to be slightly less then one-half inch in all cases, did not vary with the head, in fact, a slight reduction was noted in several instances when the head was increased. On this basis, assuming various scale ratios for the model, it was possible to ascertain the critical supply duct size for various outlet conduit diameters, Figure 9.

<u>Location of vent openings in outlet conduit</u>. Pressures obtained for the $1\frac{1}{2}$-inch air supply pipe for various heads, with three and five vents from the air manifold to the conduit, disclosed that pressures on and near the invert were not relieved to the same extent as those on the side and crown when the air was admitted at points on or above the horizontal centerline, Figure 11. Evidently air must be admitted near the invert to successfully relieve the region of subatmospheric pressure. Since the pressures on the invert never contact the coaster gate, it is questionable if they would effect its operation or cause it to vibrate. However, should it be deemed desirable to aerate the outlet in this region vents could be placed near the invert. Should this be done care should be taken to locate them where they would not be in danger of becoming plugged by sediment or foreign material in the water. In any case, it



STRAIN GAGE RECORDS SHOWING
RELATIVE INTENSITY OF MODEL VIBRATION

Figure 11



FRIANT DAM

COASTER GATE STUDIES

PRESSURE DISTRIBUTION IN MODEL BELL-ENTRANCE - 1½-INCH AIR SUPPLY DUCT WITH 3 AND 5 VENT OPENINGS VARYING HEAD AND GATE OPENING is believed that aeration should be made at more than one point. Besides giving more equalized pressures, this method, by its smaller openings through the wall of the outlet, becomes less conducive to local cavitation. (Smaller holes cause less disturbance and are less likely to set up conditions resulting in cavitation.) Six port holes from the manifold through the wall of the outlet should give ample aeration. These openings should have a combined area slightly greater than that of the supply duct to offset the losses at their entrances. It seems that aeration would be most effective and uniform with the lowest vents placed 30 degrees off the invert.

RESULTS AND CONCLUSIONS

Infrequent operation of the coaster gate under emergency conditions and the short period of time required to effect its closure under these conditions made the elimination of cavitation due to negative pressures in the bell entrance a minor consideration, thus resolving the problem into one dealing mainly with vibration.

The use of the same liquid on the model as exists on the prototype made exact similitude impossible. It would have been impracticable, if not impossible, to employ a liquid having the viscous qualities dictated by the model scale. The model was operated under heads greatly in excess of that representing the maximum on the prototype, to offset this condition as much as possible. This procedure also assured operation with values of Reynolds' number beyond the critical range. The reliability of the model data is believed to be increased by the fact that the model was operated in this manner.

Initial tests disclosed the presence of negative pressures in the bell entrance immediately downstream from the coaster gate for all heads with gate openings of 54 percent or less. This region of negative pressure was found to be a source of vibration, not effecting the gate itself, but the model as a whole. Although it was believed that the vibration would not be harmful to the mechanical operation of the gate, it was thought desirable to reduce it as much as possible. The admission of air to the negative pressure region was found to damp the vibration materially, thus testing reverted to aeration of the bell entrance.

Since venting must be done within the negative pressure area to be effective, piezometer records were obtained to ascertain the extent of this region under the various operating conditions.

The minimum longitudinal limit of the subatmospheric region recorded on the model was 0.8 and 0.6 conduit diameter from the upstream end on the crown and invert, respectively. It is believed that locating the air vent 0.5 diameter downstream would provide aeration for conditions arising from any decrease in head. It is therefore, recommended that a distance of one-half diameter be used in future designs. Air vents in this location would be in the region of less curvature on the bell entrance, thus less disturbance would result and cavitation would be less likely to occur regardless of the size of the opening in the wall of the outlet conduit.

Equal distribution of pressure on the circumference of the outlet entrance, without aeration, proved that it was not essential to restrict venting to the crown of the outlet conduit, making it possible to utilize a manifold with several openings into the interior of the conduit.

After the initial tests had proven that aeration of the negative pressure region below the coaster gate was necessary to damp the vibration resulting therefrom and had indicated the most desirable longitudinal location of the vents to be one-half diameter downstream from the face of the bell entrance, a new entrance, incorporating these findings, was constructed. It contained a manifold with provisions for changing the size and number of ports from it into the conduit.

Three vent ports from the air manifold to the outlet conduit, two placed 45 degrees from the vertical axis and one on the vertical axis, produced desirable damping effects. Piezometer readings, however, showed less reduction in pressure on the invert than in the crown so two more vents were placed 90 degrees from the vertical axis. No further reduction in pressures on the invert was noted, signifying that vents should be placed near the invert to obtain complete equalization of pressures. The effect of providing additional ports nearer the invert was not investigated since their location in this region would be governed more by the possibility of becoming plugged by sediment or foreign matter in the water.

An air manifold with vent openings spaced about the circumference would probably produce the most desirable pressure conditions. No doubt more air is needed in the crown than any other point, thus the vent spacing should provide more openings near that part of the outlet conduit. However, some air should be admitted near the invert to relieve the pressure under the outlet jet. This is indicated by the fact that the pressure on the invert remained constant with three and five ports placed in the upper half of the conduit, Figure 11. The selection of the number of vent ports is left to the designer. However, the entrance loss to these ports should be taken into account and their area increased accordingly, making their combined area larger than that of the air supply duct.

Vibration intensity recorded by the displacement of a vibrating reed and De Forest strain gages, disclosed a critical air supply pipe size to obtain a maximum damping on the model. This size, one-half inch model, did not increase with increase in head, in fact it was found to decrease in several cases. A relation between the prototype outlet diameter and the critical air supply duct size based on this conclusion was obtained by assuming that the model represented conduits of various sizes, Figure 9. When using these data it should be remembered that the relationship is based on the results from one model and that the prototype might deviate slightly, thus sizes smaller than indicated by these tests should never be used. Extensive testing on at least two, but preferably three, elaborately constructed models would be necessary to accurately establish this relationship over a wide range.

Urgent work in the laboratory and the limited time to obtain results prevented the conducting of such an extensive program. Moreover, the current problem had been treated satisfactorily and the data were believed to be sufficiently of a dimensionless nature to form a basis for future designs. It is believed, however, that additional studies should be made at the first opportunity.

Pressure records for various gate openings and heads disclosed a critical duct size also existed for relieving the negative pressures in the entrance. This size was different from that shown by the vibration studies, thus the relation between supply duct size, vibration, and pressure was not as had been expected, a much larger duct being required to relieve the pressure than to damp the vibration. A one-inch diameter model duct proved to be the critical size for relieving pressures in the majority of cases. Only in a few instances did the size approach 1¼ inches, the additional change in pressure obtained by using the larger size was very small, being zero for heads representing the prototype and two feet of water for the very high heads. Use of the data based on the larger size does not seem justified under these conditions. However, since a conservative designer might prefer the larger size, curves obtained in a similar manner to that for the vibration studies and based on both sizes are presented, Figure 7.

It is evident from the model studies that designing for critical pressure conditions automatically takes care of vibration, thus in designing duct sizes for relieving pressures downstream from a coaster gate, one need not be concerned with vibration.

Whether or not air-duct designs should be based on the relief of negative pressures or the damping of vibration in the emergency operation of coaster gates, is a matter for conjecture. The uncertain relation between negative pressures on the model and prototype would seem to favor designs based on the reduction of negative pressures.

Because of the various sources of model vibration and the daming and amplifying effects that might exist for different heads, it is felt that comparison of the vibration intensities for various heads is not reliable. However, for constant gate opening and constant head the vibration due to factors other than the air supply duct size should remain unchanged, thus indicating the relative damping due to duct size only.

Although the Friant outlet design was changed materially from that tested, it is believed that the data are still applicable. Moreover, the results of these tests should be helpful in determining the vent sizes necessary for coaster-gate closures of power penstocks.

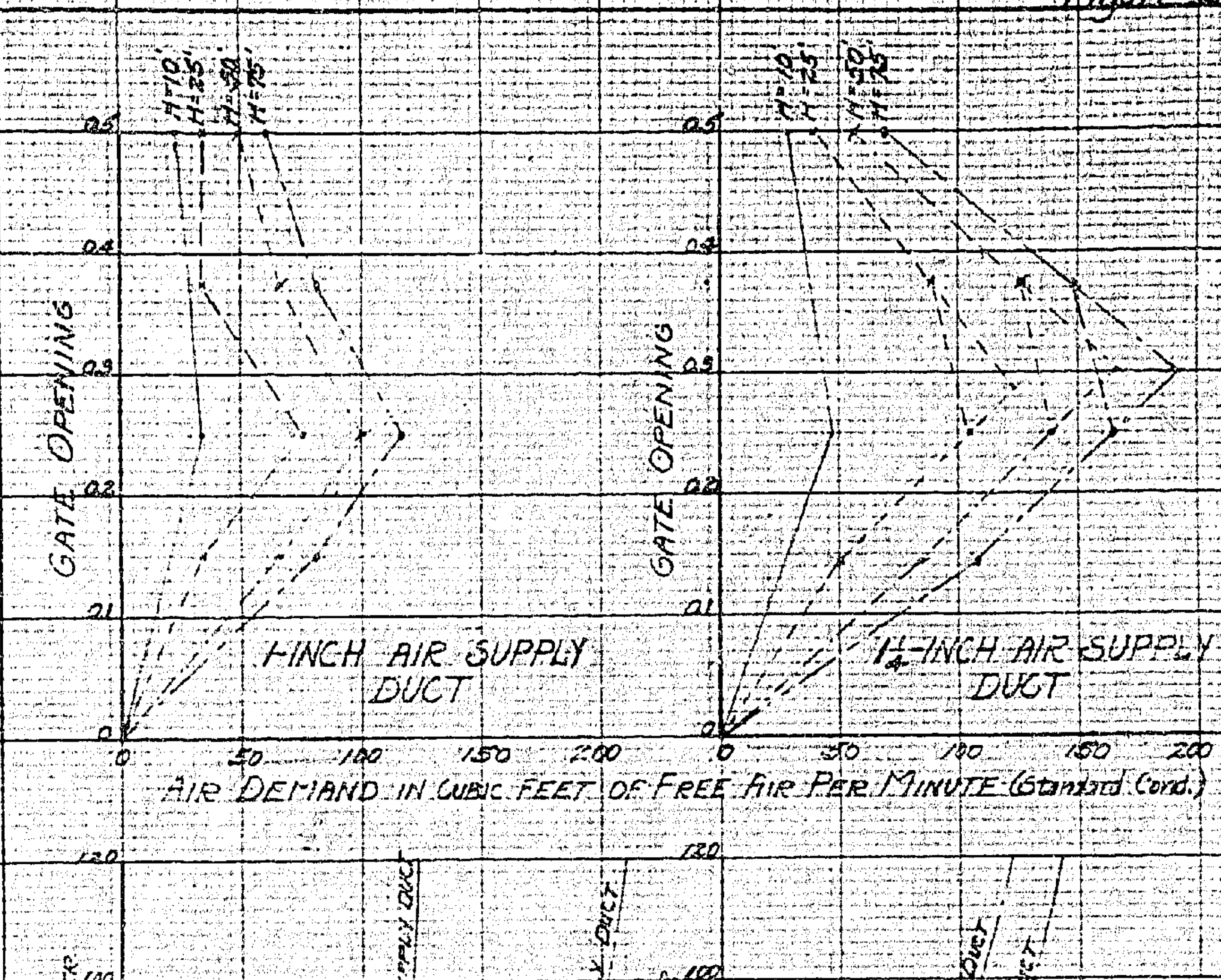
Measurement of air flow through the supply duct, while of very little practical value, showed the greatest demand for air occurred between gate openings of 25 and 30 percent for all heads, Figure 12.

In these tests no attempt was made to determine the proper shape for the bottom edge of the coaster gate, considerable work having previously been done along that line in connection with gate valves.

At the completion of these tests, the purchase of the Friant entrance castings had progressed to such an extent that changes were not advisable unless the air-supply ducts proved to be smaller than the critical size to damp vibration. Checking disclosed the ducts to be slightly larger than the critical so no changes were recommended.

Should progress on the Shasta entrance designs be sufficiently in the preliminary stages to enable incorporation of the features indicated by the model, it is suggested that the final design be governed by these tests. A system with air manifold and vent ports is believed superior to the usual arrangement of one large opening in the curved portion of the bell-mounted entrance.

Figure 22



FRIANT DAM

COASTER GATE STUDIES

MODEL AIR DEMAND AND CONDUIT PRESSURE FOR 1- AND 1¼-INCH SUPPLY DUCT

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