

HYD 472

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UNITED STATES
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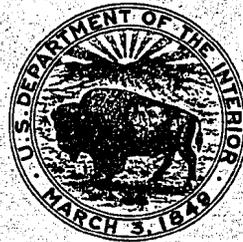
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HYDRAULIC MODEL STUDIES OF THE TRINITY DAM
AUXILIARY OUTLET WORKS JET-FLOW GATE
CENTRAL VALLEY PROJECT, CALIFORNIA

Hydraulic Laboratory Report No. Hyd-472

DIVISION OF ENGINEERING LABORATORIES



COMMISSIONER'S OFFICE
DENVER, COLORADO

January 6, 1961

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UNITED STATES
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Commissioner's Office--Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Denver, Colorado
January 6, 1961

Laboratory Report No. Hyd-472
Compiled by: W. P. Simmons, Jr.
Checked by: W. E. Wagner
Reviewed by: J. W. Ball
Submitted by: H. M. Martin

Subject: Hydraulic model studies of the Trinity Dam Auxiliary outlet works jet-flow gate--Central Valley Project, California

PURPOSE

Studies were conducted to determine operating characteristics, coefficients of discharge, and air demand for the most recent jet-flow gate design discharging freely into the atmosphere or into a partly filled conduit.

CONCLUSIONS

1. The revised and simplified jet-flow gate performed in very nearly the same way as the original design developed for Shasta Dam. Operation is characterized by relative freedom from vibration, absence of cavitation, no hydraulic downpull on the gate leaf, considerable spray around the jet, and heavy air demand.
2. The coefficient of discharge for the fully opened gate is 0.833 based upon the orifice area, the total head upstream and the pressure head downstream (Figure 10). A curve of C_d versus gate opening is presented and the data are applicable to both free discharge and conduit discharge conditions.
3. Small changes in gate opening at the near closed positions produce large percentage changes in effective flow area. Gate leaf positioning, or leaf position indicating are very important and must be closely controlled if agreement is expected between computed and actual prototype flow releases.

4. At partial gate openings, small fins of water occurred at the corners formed by the gate leaf bottom and the edges of the gate orifice. The fins struck the downstream slot corners (Figure 9) and partly filled the slots with relatively slow moving water. This is the same action that occurs in the Shasta gates and no trouble or maintenance problems have been encountered in the field installations.

5. Air demand increased rapidly as the model operating head was raised on the gate (Figures 13-19).

6. Air demand, as measured through the air inlet system, increased as the length of the downstream conduit increased (Figure 19). Part of this rise was believed due to a greater entrainment action in the longer conduit. In addition, part of the measured rise was due to the fact that a greater percentage of the total quantity of air actually being entrained had to go through the inlet system because, as the conduit became longer, it became more difficult for air to move upstream in the fluidway above the water surface. Thus, a greater percentage of the actual demand was measured when long conduits were used.

7. The vital need of aeration to the system was illustrated by severe negative pressures and a partial collapse of the 120-inch long conduit that occurred when the air supply was cut off during a run with a 100-percent gate opening and a 38-foot model head.

INTRODUCTION

The "jet-flow gate" is a high head regulating control structure (Figure 1) developed in 1946 by the Bureau of Reclamation for use in the upper and intermediate outlet tiers at Shasta Dam. ^{1/} It consists of a movable gate leaf enclosed in a special frame or housing with a contracting orifice on the upstream side and a larger sized opening on the downstream side. The Shasta gates were fitted to 102-inch-diameter inlet and outlet conduits and had an orifice diameter of 96 inches. Air was admitted into the conduits just downstream from the gates.

The unique feature of the gate consists of the carefully planned contraction of flow as water passes through it. This contraction is obtained by diverging the walls of the approach conduit and then contracting the flow area with a 45-degree converging cone that terminated in a circular orifice (Figure 1). In cases where the

^{1/}Refers to reference at end of report.

leaf throttles the flow, the spring point at the upstream bottom edge of the leaf produces part of the contraction. By proper design, the required amount of contraction is obtained to allow the jet to pass the gate slots before it again touches the conduit walls. Thus the flow does not strike the gate slots, and the usual difficulties with negative pressures and cavitation at gate slots are avoided.

Air is required around the jet to maintain the free-flow conditions, and provisions must be made for its admission. Tests have shown that if the air is introduced at the top of the conduit at the downstream face of the leaf, it will be drawn into the regions where aeration is needed.

Experiences with the prototype Shasta gates show that the design performs extremely well. No operational difficulties or unreasonable maintenance problems have occurred, and operators find the gates easy to handle.

A graph showing discharge coefficients for various gate openings for the Shasta gate and conduit system was prepared from model study data obtained at the time the final design was evolved (Figure 1). These coefficients, based upon the conduit area and the reservoir head above the gate, are for the entire outlet conduit system, not just for the gate itself.

In years following the initial development and use of the gates at Shasta Dam, the basic design has been extended to other structures. The degree of freedom available in designing the newer gates was greater than at Shasta where the conduits were already embedded in the dam. Simplifications and design changes have therefore been possible. These included using an orifice of the same diameter as the approaching pipeline, a conic expanding section, a greater vertical drop from the orifice lip to the gate frame invert, and larger conduits (or in some cases, free discharge) downstream. The 84-inch jet-flow gate for the Trinity Dam auxiliary outlet works is the latest and most advanced of these designs (Figures 2 through 5).

Detailed information concerning the operating characteristics, coefficients of discharge, pressure conditions, and air demand at various gate openings, was desired for this newer design. Model studies were made to obtain this information, and discussions of the model, the tests, and the results are given in this report.

THE MODEL

A 1:14.87 scale model of the Trinity jet-flow gate was obtained by using the upstream body of the original Shasta model and by adding a new upstream conic expanding section, new side plates, a new floor plate, a new leaf, and new downstream body and conduit sections (Figure 6). Particular attention was given to the shape of the orifice lip, the ring seal just downstream from the lip, the gate leaf bottom, and the leaf, wheel tracks, and downstream frame. The general geometry of the leaf, tracks and frame affect the path the air must take to reach and aerate the jet. A protractor scale graduated in degrees was attached to the top of the gate bonnet below the leaf operating crank so accurate gate settings could be obtained by appropriate turns of the lifting screw.

A 24-inch-long transparent plastic conduit section downstream from the gate allowed flow conditions to be observed inside the conduit. Sheet metal sections were added to the plastic conduit to make total lengths of 48, 72, 96, and 120 inches. The air conduit, which is formed by a partition at the top of the main conduit, was included in the sections. An air inlet measuring station, consisting of a vertical 3-inch pipe fitted with appropriate flat plate inlet orifices, was built onto one 24-inch-long, sheet metal section. The air conduit was sealed off at the downstream end of this pipe so that all air that entered the system came through the orifice meter. The metering section was always placed at the downstream end of the pipe system.

One-sixteenth-inch-diameter piezometers were provided at the reference station ahead of the gate and at points within the gate and conduit where low pressures were considered possible (Figure 6). The pressures acting at these points were measured by single- and double-leg water manometers and by a mercury manometer. The rate of flow was measured by calibrated 4-, 6-, 8-, and 12-inch venturi meters in the laboratory water supply system. Very small flows were measured by a laboratory-designed and calibrated orifice-venturi meter using 1.250- and 1.750-inch flat plate orifices. Flow was provided by a 12-inch centrifugal pump operating alone, or by two 12-inch pumps operating in series. The water leaving the model was directed into the laboratory storage reservoir for recirculation.

INVESTIGATION

Method of Testing

Tests were made by setting the gate to the desired opening and passing water through it. Measurements were made of water and air flow rates with appropriate pressures acting in the system. For the calibration data, at least five discharge settings were made at each gate opening with heads ranging from 20 to 57 feet, model. The data were plotted as H versus Q^2 . A straight line of best fit was drawn through the points for each gate opening to establish the mean values used in determining the coefficients. Several spot checks were made to check the reproducibility of the gate settings and data. Reynolds numbers for the test points ranged from the lowest of 3.1×10^4 at a 5-percent opening to 2.0×10^6 for full opening. These values were based upon the diameter of, and the velocity within, the 5.65-inch conduit and orifice. On the basis of the velocity through the gate opening, and on equivalent diameter for the opening, the minimum value becomes 2.25×10^5 .

Tests were first made with the gate discharging freely into the atmosphere. Other tests with various conduit lengths installed downstream from the gate showed that air demand was appreciable and that the pressure regime downstream from the gate was affected by conduit length and quantity of air supplied.

Discharge Into the Atmosphere

The flow under free discharge conditions at various gate openings is shown in Figure 7. Considerable spray occurred at all openings. The pressures to be expected under a 370-foot operating head are given in Figure 8. Pressure factors, by which the pressures can be determined for other prototype heads are also given. These pressure factors are dimensionless and are defined as $\frac{h_x - h_0}{H_t - h_2}$ where h_x is the pressure head at a particular piezometer, h_0 is the pressure head at the reference station one conduit diameter upstream from the gate, H_t is the total head at the reference station, $(h_0 + h_v)$, and h_2 is the pressure head just downstream from the gate. The value of h_2 is measured at Piezometer 15, Figure 6, and is atmospheric if no conduit is used. Prototype pressure values are obtained by using the factor for the piezometer in question, and introducing into the equation appropriate prototype values of H_t and h_2 and h_0 .

At small gate openings, minute errors in positioning the leaf resulted in large changes, percentage-wise, in effective opening. This made accurate positioning of the model leaf imperative in order to obtain consistent data. Similarly, accurate positioning of the prototype leaf will be imperative to obtain reasonable correlation between actual and computed outlet releases. Zero opening is obtained when the bottom upstream edge of the leaf is level with the orifice invert. 100-percent opening is obtained when the leaf bottom is level with the orifice crown.

A slight flow interference occurs in the gate at the beginning of the downstream frame, particularly at small openings (Figure 9A). Small feathery fins of water form at the corners of the jet as it passes through the control area in the gate. A part of each of these fins strikes the downstream frame and is deflected into the slot and track area. Enough water is deflected to partly fill the slots with turbulent, aerated, relatively slow moving water. This action is greatest at small gate openings, particularly at about 5 percent. No damage or difficulty is expected on the gate due to this minor interference. This is attested by the fact that the same interference was present in the Shasta model and prototype gates, 1/ and no trouble has been experienced after extensive field operation.

The coefficient curve based on the orifice (or conduit) area for the modern jet-flow gate and upon the head differential across the gate was determined (Figure 10). The coefficients are considered appropriate for use for all jet-flow gates of recent design. The curve for the Shasta gates, based on the same parameters, also appears in Figure 10.

Because no water is present within the gate bonnet, no water load occurs on top of the gate leaf. Similarly, the bottom of the leaf is free of water and is subjected only to an air load. Thus, there is no appreciable downpull force on the leaf during gate operation, and no heavy loads are imposed upon the lifting stems and hoists. Movement of the gate leaf is relatively friction-free because the leaf is carried on wheels that roll on metal tracks. The greatest source of friction occurs at the large circular seal which is always held in contact with the upstream face of the leaf (Figure 5).

Discharge Into a Conduit--Free Water Surface

Tests with various conduit lengths of the same cross-section placed downstream from the gate showed that a number of factors affected

the water flow and air demand. The conduits were egg-shaped in cross-section, 6.457 inches wide and 7.919 inches high (Figures 6 and 12). Lengths ranged from 24 inches to 120 inches, or the equivalent of 3.72 to 18.58 times the downstream conduit width, D_2 .

Small fins of water continued to strike the downstream gate frame and rise up the sides of the downstream conduit and then fall back to the bottom (Figure 9B). Part of the water was deflected into the slots. No difficulty is expected with this minor action.

Effect of Air System Restrictions. The first tests were made with a conduit 72 inches long. Orifice plates with diameters of 1.00, 1.50, 1.90, and 2.75 inches were used on the air inlet entrance to determine the effect of restrictions on the air flow. All tests were made with the gate 100 percent open and at model heads ranging from 10 to 50 feet. The 1.00-inch orifice showed a definite restrictive effect (Figure 13). A much less restrictive effect occurred with the 1.50-inch orifice. Little difference occurred between the 1.90- and the 2.75-inch orifices. The appearance of the jet was not materially affected by these different restrictions in the air supply system.

To reduce the number of test variables and to ease analysis of the data all subsequent tests were run with the same orifice plate. The 1.90-inch orifice was selected for the purpose because it provided reasonable differentials for low-flow measurements, without producing appreciable restrictive effect at high flows.

Effect of Head. An increase in model operating head, and hence discharge, had the effect of appreciably increasing the air demand and the ratio of air flow to water flow (Figures 13 through 19). Also the quantity of spray around the jet increased rapidly as the model head increased. Conversely, increases in upstream head produced decreases in head in the conduit just downstream from the gate. This was expected because as greater quantities of air are carried away by the water and spray at higher flows, lower pressures must necessarily result in the downstream conduit.

Effect of Gate Opening. As the gate was opened from fully closed to the 50-percent opened position, air demand increased, particularly at the 25- and 40-foot heads (Figures 14 through 18). The flow in a 24-inch-long conduit with a 40-foot head, is shown in Figure 11. Further opening at the 25 and 40-foot heads produced a condition where the water jet occasionally became relatively

smooth, and then broke up again to produce a great deal of spray. The air demand was affected by the jet changes and was greatest when the spray was greatest. The unstable region is indicated in the curves of Figures 15 through 18. No surging or appreciable pressure variations occurred in the hydraulic system while the unstable conditions were being experienced. At a 60-percent gate opening the flow became stable again and the air demand dropped to that experienced at a 40-percent opening. The demand progressively increased at 70-, 80-, and 90-percent openings, and then rose rapidly to the peak demand at the 100-percent opening.

Runs made with a 10-foot model head did not produce the unstable conditions at the 50- to 60-percent gate openings, and did not produce an intermediate peak demand at these openings.

Effect of Conduit Length. Several lengths of downstream conduit were tested to determine the effect of length upon air demand, and to insure having sufficient length to obtain satisfactory representation of the very long prototype conduit. Data obtained in these tests are applicable only to the type of jet released by a jet-flow gate, and to the conduit cross-sectional shape and area ratios used.

The rate of flow through the air inlet system followed erratic patterns as the conduit length was increased (Figure 19). Generally similar patterns occurred at 25- and 40-foot heads at a 100-percent gate opening. In these cases the air demand increased as the conduit was lengthened to about $7 D_2$, then dropped slightly as the conduit was further lengthened to about $12 D_2$. A general rise in demand occurred with further lengthening between $12 D_2$ and $18.57 D_2$ the maximum length tested. The 10-foot head data showed a different pattern with a peak demand at about a $12 D_2$ conduit length and lower demands with shorter and longer conduits.

Quite different patterns occurred with 50-percent gate openings at the 25- and 40-foot heads. Sharp rises in demand accompanied conduit lengthening up to about $12 D_2$. With the 40-foot head, a more gradual rise followed up to the $18.58 D_2$ length. The 25-foot head data showed a peak demand at a $15 D_2$ length and a drop with further lengthening. The 10-foot head, 50-percent gate opening data showed about the same pattern as did the 100-percent gate opening. In all cases, the demand at 50-percent gate opening was much less than for the 100-percent opening.

An appreciable, but unmeasured portion of the total air demand of the system was supplied by air entering at the outlet end of the conduit and moving upstream along the top of the fluidway. This reentrant air was particularly noticeable with the shortest conduits; however, even with a conduit length of $18.58 D_2$, a small part of the total air demand appeared to be obtained in this manner.

In summary, the type of jet emanating from the gate and the geometry of the conduit downstream apparently interact to produce air demands that vary erratically as the conduit length is changed. Stable, predictable conditions were not completely achieved, even with a conduit $18.58 D_2$ long. It did appear, however, that further increases in length would have only minor effect upon the air demand, and further tests were deemed unnecessary.

Effect of Closing Air Inlet. Drastic pressure reductions occurred in the gate and conduit system when the air flow through the inlet was severely restricted. Tests were made with the 120-inch-long conduit, a 37.8-foot model head, and with the gate wide open. The discharge was 7.35 cfs, and the upstream conduit piezometric pressure was 10.10 feet. The air flow was slowly restricted by sliding a cover over the opening of the 1.90-inch-diameter air inlet orifice. Pressures immediately lowered throughout the system. The downstream conduit began to collapse when the pressure in it reached minus 17 feet. The reference station pressure reached minus 7 feet. The air inlet restriction was quickly removed to avoid more extensive damage. The test served as a graphic example of the importance of adequate aeration of prototype gates discharging into tunnels so that satisfactory pressure gradients will be maintained and so that cavitation and other damage will be avoided.

Effect of Froude Number. Kalinske and Robertson ^{2/} have shown that the rate of air entrainment in a hydraulic jump in a circular pipe is related to the entering Froude number minus 1 (Figure 20). Prototype outlet works air demand data obtained by the United States Corps of Engineers ^{3/} also shows a relationship, and a suggested design curve has been presented (Figure 20). The model data from the Trinity jet-flow gate is shown on the same plot, and conforms generally to the Kalinske and Robertson data.

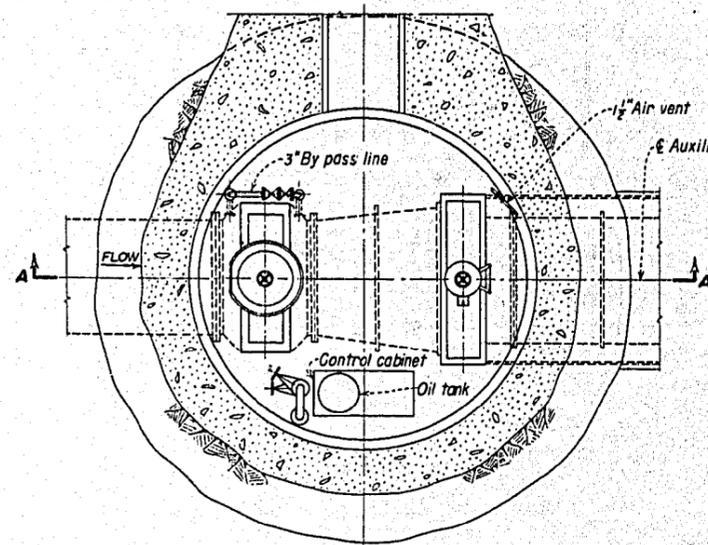
Interpretation of the Trinity model results in terms of prototype performance must be approached with caution. First, there was no hydraulic jump in the conduits and air pumping was due to insufflation and boundary drag. Secondly, the velocities used

in the Froude number calculations were the computed vena contracta velocities using the full head. And thirdly, the depths used were the computed depths in the downstream conduit assuming that the flow was traveling at the vena contracta velocities. These manipulations were necessary to obtain a basis for comparison with the existing data and are believed to be justified. They may also be used for later comparisons with prototype jet-flow gate data, as it becomes available, but they cannot, as yet, be regarded as established rules.

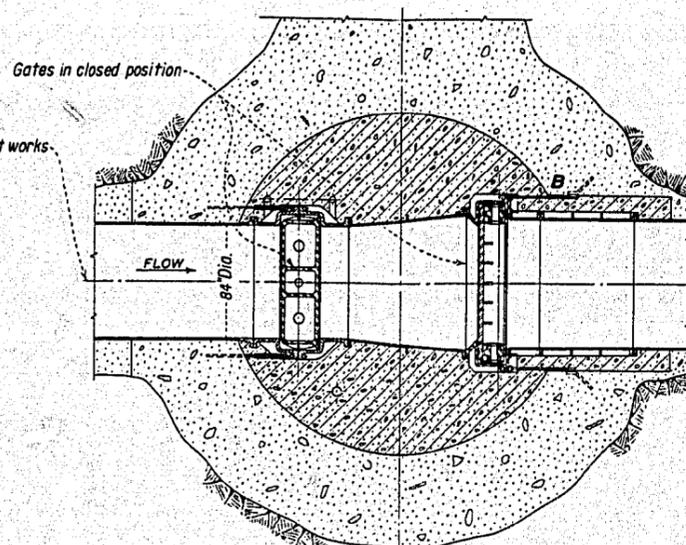
1/"The Hydraulic Design of a Control Gate for the 102-inch Outlets in Shasta Dam", by F. C. Lowe, Report No. Hyd. 201, USBR.

2/"Entrainment of Air in Flowing Water--Closed Conduit Flow", by A. A. Kalinske and J. W. Robertson, Transactions, ASCE, Vol. 108, 1943.

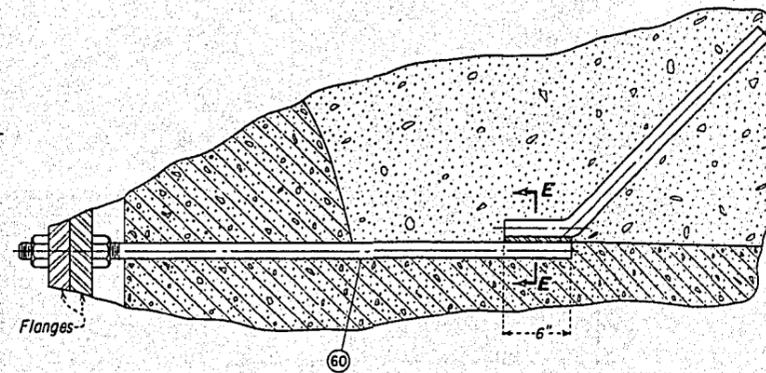
3/"Hydraulic Design Criteria", Sheet 050-1, United States Army Corps of Engineers.



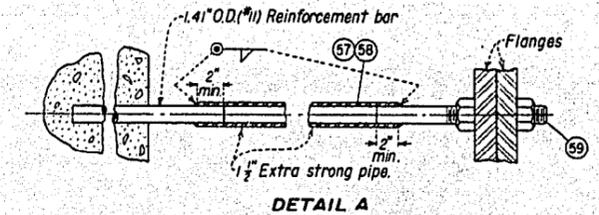
SECTIONAL PLAN



SECTION C-C



DETAIL B
(For 84" jet flow gate only.)



DETAIL A

NOTE
All 1.41" dia. (#11) reinforcement bar anchors and all adjustable supports shall be furnished by the contractor. Parts 57, 58, 59, and 62 will be furnished with 84" jet flow gate.

INSTALLATION INSTRUCTIONS

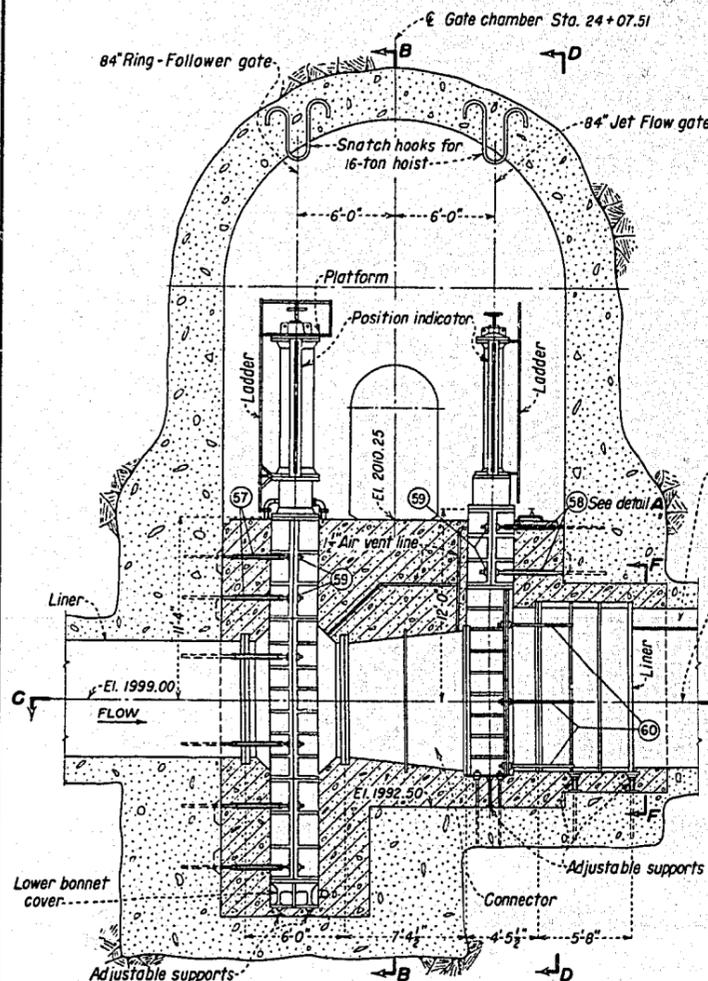
1. Install the portion of the gates that is to be embedded below elevation 2010.25.
2. The embedded portion of the gates shall be completely assembled except for the gate leaves and hoists.
3. Support the gates and downstream liner on adjustable supports. Bolt up the gates, liners, and connector.
4. Assemble and weld all anchor bolts as shown.
5. Align the gates by adjusting the nuts on the anchor bolts and the adjustable supports which shall remain embedded.
6. The first concrete lift shall fill the ringfollower blackout to elevation 1992.50. The second lift shall come to 6 inches above the bottom of the jet flow gate. Thereafter the concrete shall be placed around the gate in 3 ft. but not more than 5 foot lifts and the alignment shall be rechecked after each lift.
7. For further instructions for aligning and embedding the gates and for fairing the water passageway, see Paragraphs 140 and 142 of Specification No. DC-4824.

LIST OF DRAWINGS

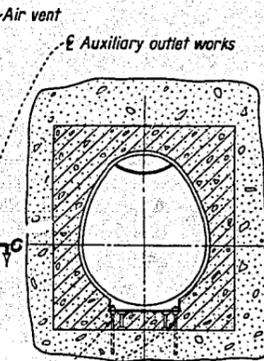
AUXILIARY OUTLET WORKS	
84" RING FOLLOWER AND JET FLOW GATES- INSTALLATION-LIST OF DRAWINGS.....	416-D-314
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84" RING FOLLOWER AND JET FLOW GATES- ALIGNMENT ANCHORAGE.....	416-D-359

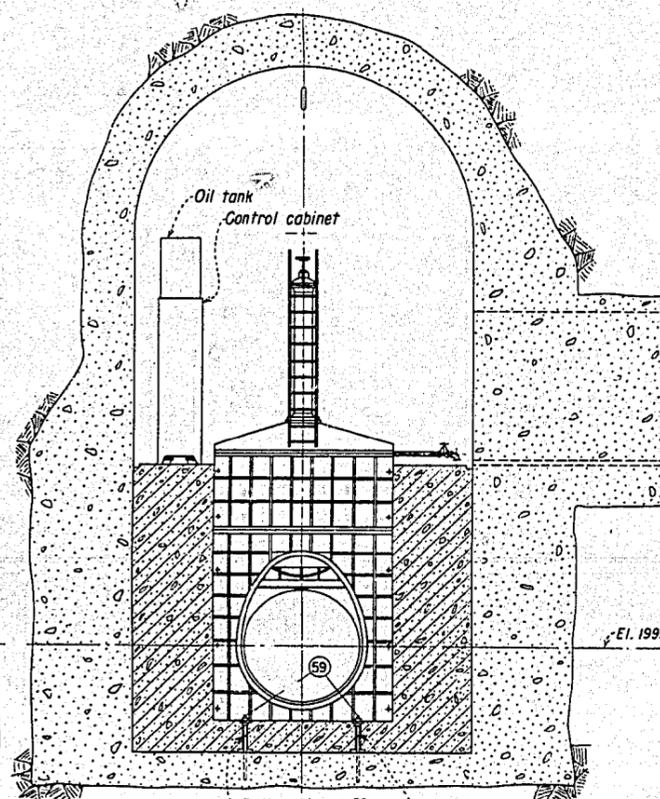


SECTION A-A

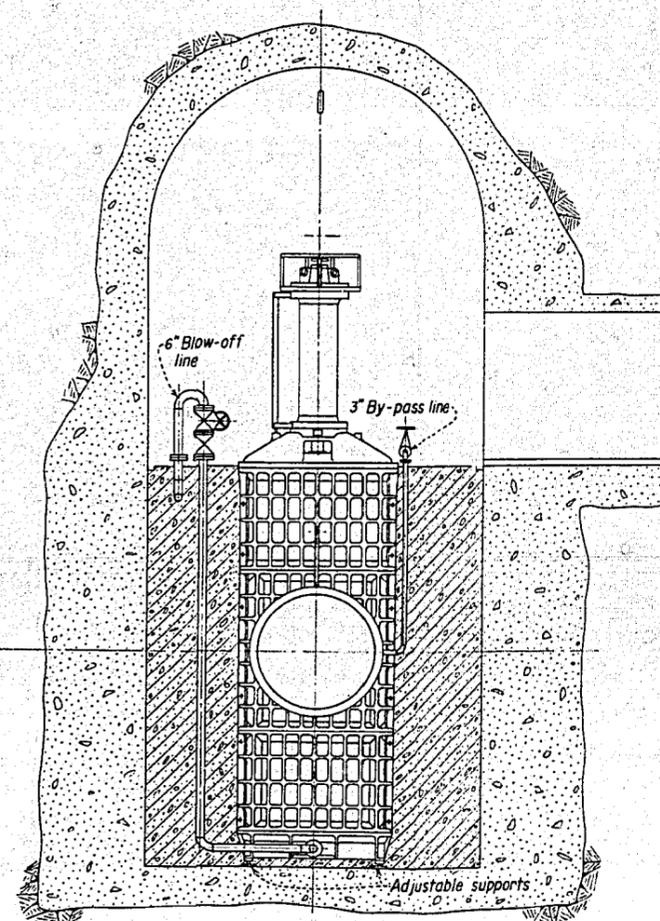


SECTION F-F

FIELD NOTE
Butt weld part 59 to embedded anchors. Cut off part 59 or embedded anchors or both if necessary.

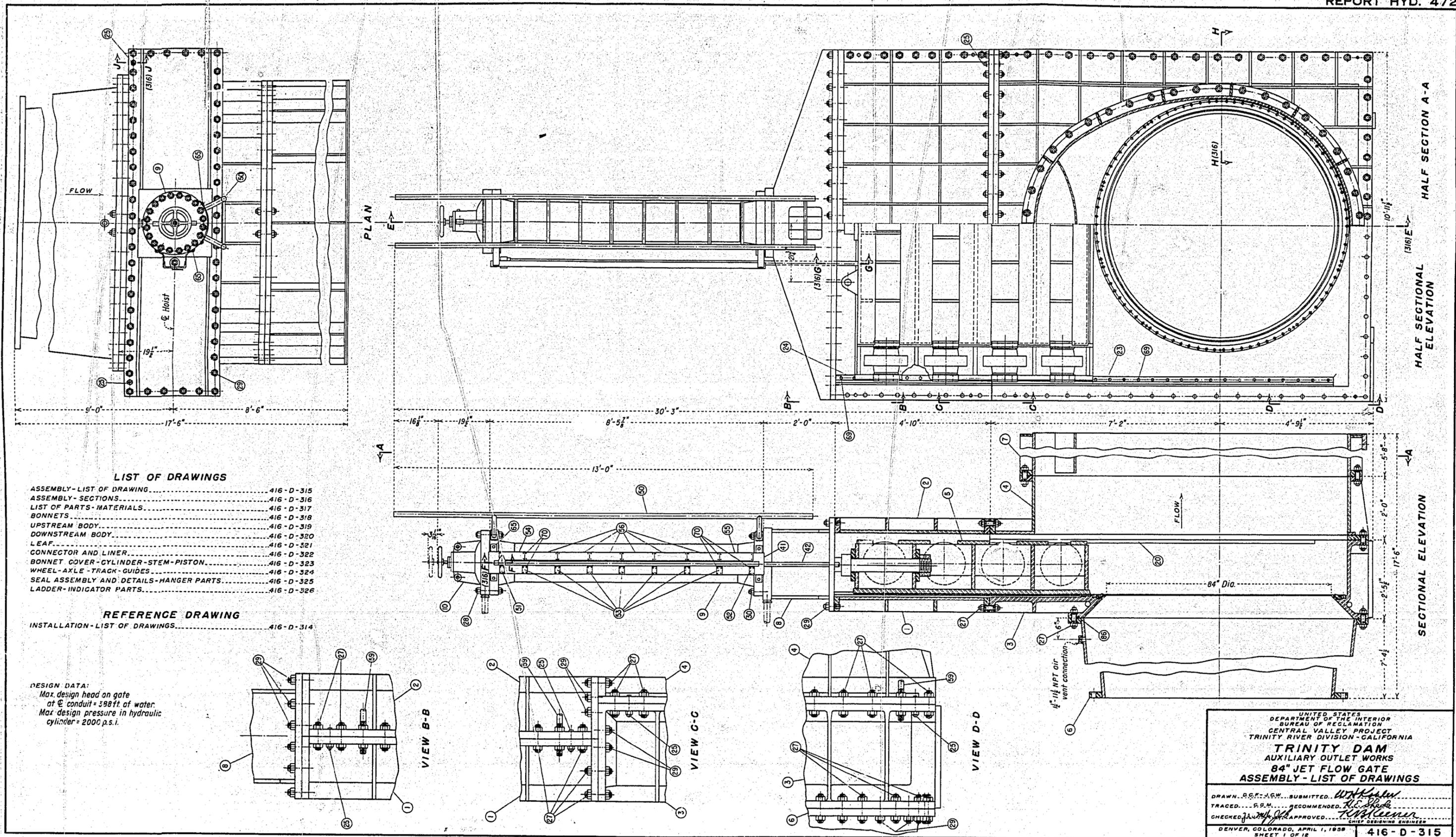


SECTION D-D
(Gate shown in open position)



SECTION B-B
(Gate shown in open position)

4-28-36 D. 276	TRACED.
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION CENTRAL VALLEY PROJECT TRINITY RIVER DIVISION - CALIFORNIA	
TRINITY DAM AUXILIARY OUTLET WORKS 84" RING FOLLOWER AND JET FLOW GATES INSTALLATION-LIST OF DRAWINGS	
DRAWN M.T.W.-R.L.T. SUBMITTED.....	W.M. Kohler
TRACED.....S.F.S. RECOMMENDED.....	H.E. Shedd
CHECKED J.A.R.-J.C.O. APPROVED.....	K.B. Keenan
DENVER, COLORADO, JAN. 31, 1936	SHEET 1 OF 1
	416-D-314



LIST OF DRAWINGS

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SEAL ASSEMBLY AND DETAILS - HANGER PARTS.....	416-D-325
LADDER - INDICATOR PARTS.....	416-D-326

REFERENCE DRAWING

INSTALLATION - LIST OF DRAWINGS.....	416-D-314
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DESIGN DATA:
 Max. design head on gate
 at @ conduit = 388 ft. of water.
 Max. design pressure in hydraulic
 cylinder = 2000 p.s.i.

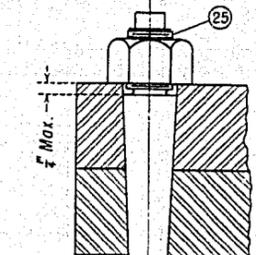
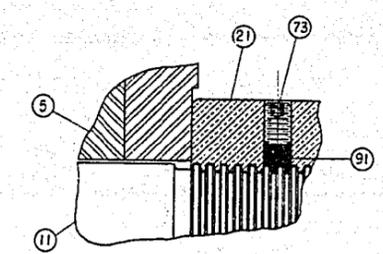
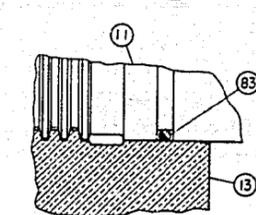
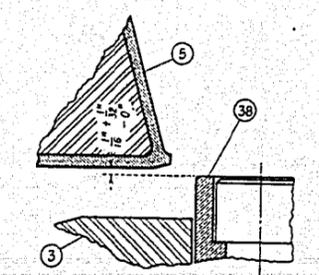
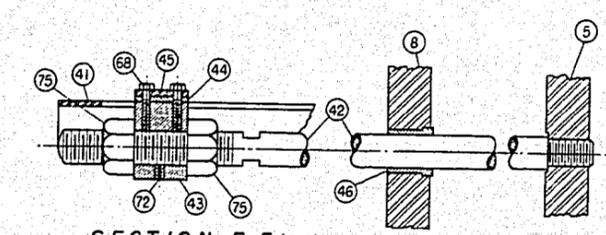
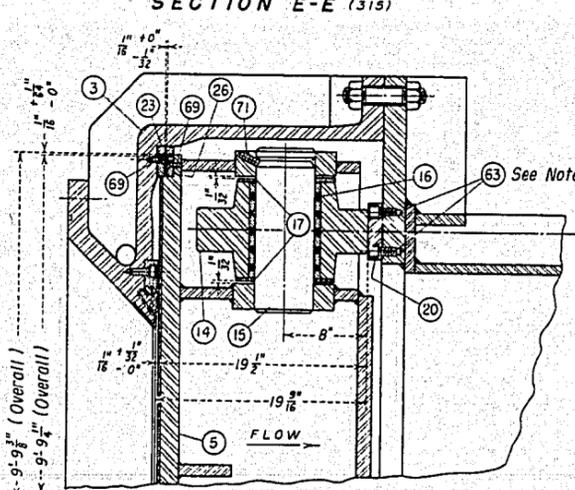
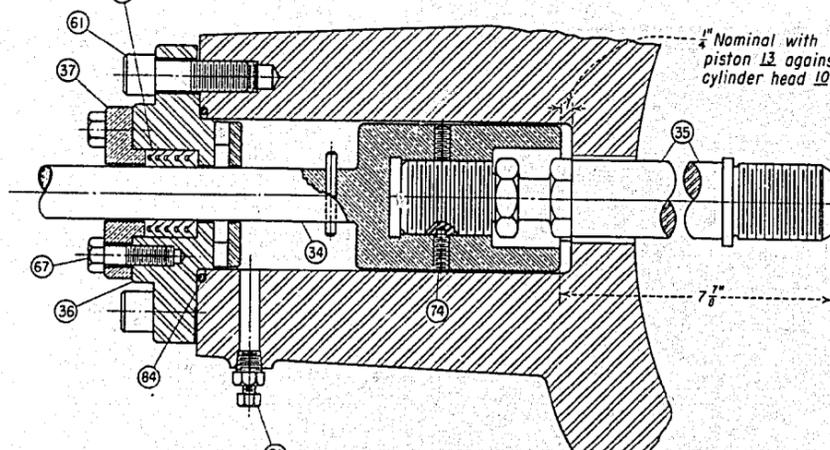
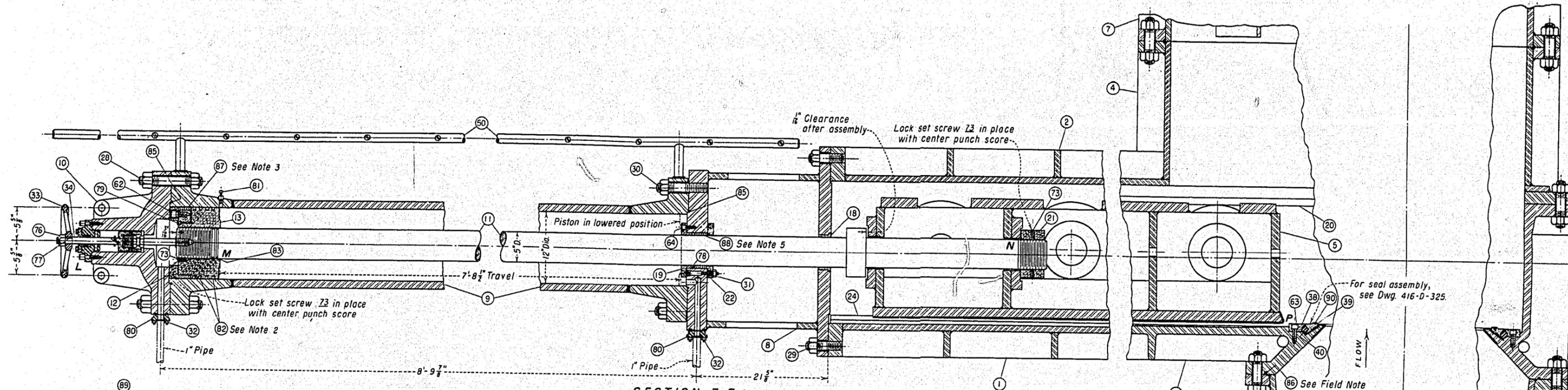
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**TRINITY DAM
 AUXILIARY OUTLET WORKS
 84" JET FLOW GATE
 ASSEMBLY - LIST OF DRAWINGS**

DRAWN... P.S.M. ... SUBMITTED... *W.H. Kahan*
 TRACED... P.S.M. ... RECOMMENDED... *T.C. Smith*
 CHECKED... *J. M. ...* ... APPROVED... *T. McKeen*
CHIEF DESIGNING ENGINEER

DENVER, COLORADO, APRIL 1, 1938
 SHEET 1 OF 12

416-D-315



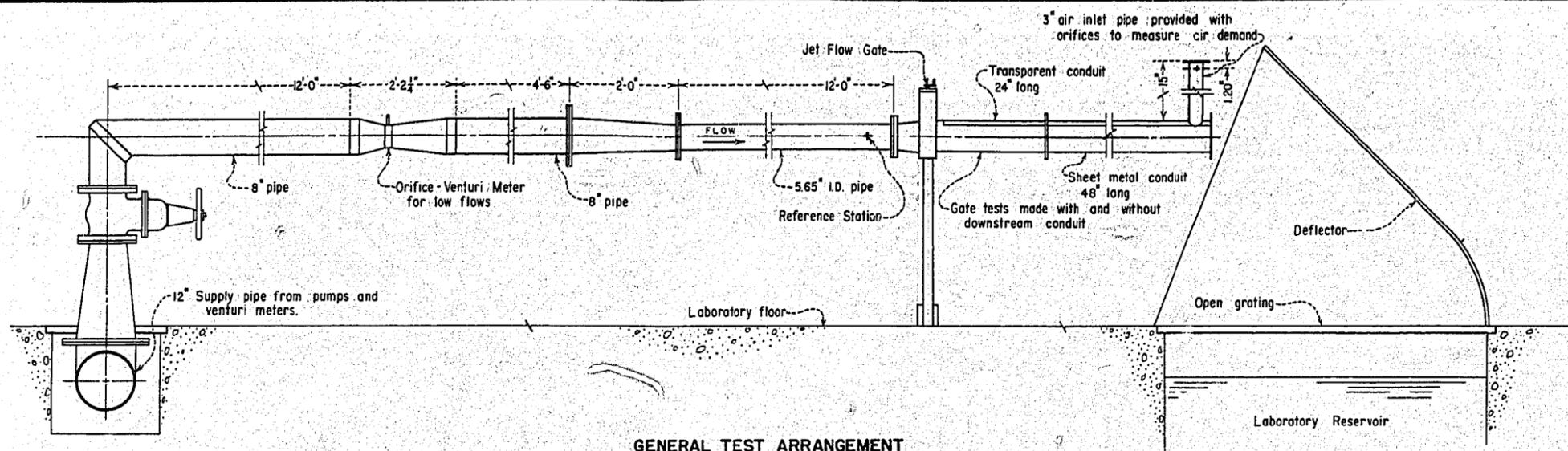
NOTES

1. The contact surfaces of the wheels and the track shall lie in a true plane with a maximum deviation of 0.010" in 5 feet. The upstream and downstream sliding surfaces of the guides and the seal surfaces shall be in a plane parallel to the track and the clearances, as shown in Section H-H, shall be accurately throughout the travel. See specifications.
2. Assemble piston rings with the pressure side of two rings turned up and the other two turned down.
3. To replace packing 82, (with pressure under piston 13) remove plug 22 to relieve pressure from packing recess. After replacing packing 82, replace plug 22.
4. Lock screws 63 and 62 in parts 20, 23, 24, 26, and 32, at three points with center punch scores.
5. All V-type packing to be snug but not tightly compressed when glands are secured in place.

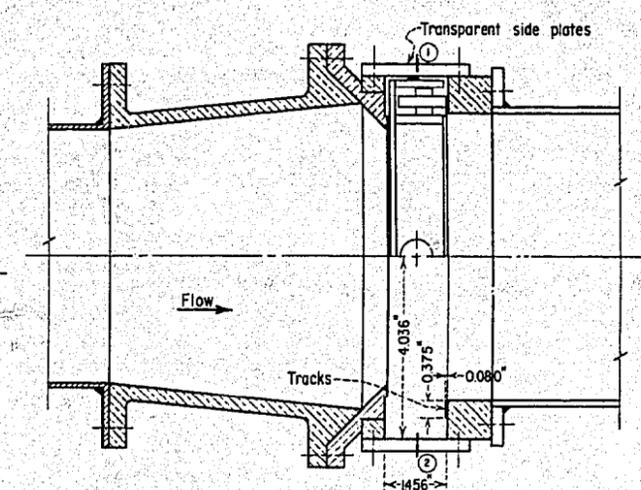
FIELD NOTE

Gasket 86 to be cemented tightly at ends to provide a continuous seal.

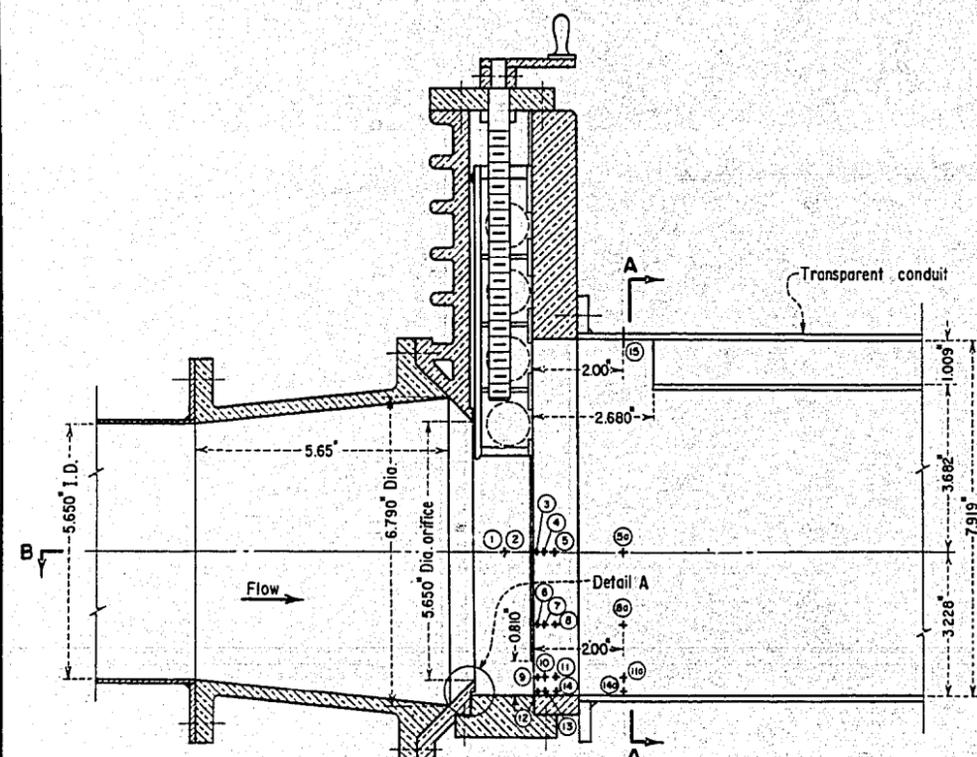
7-15-58	SECTIONING OF OVERLAY ON PARTS 3 AND 5 AND SECTIONING OF PARTS 11, 34, AND 42 WAS FOR STAINLESS STEEL
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION CENTRAL VALLEY PROJECT TRINITY RIVER DIVISION - CALIFORNIA TRINITY DAM AUXILIARY OUTLET WORKS 84" JET FLOW GATE ASSEMBLY - SECTIONS	
DRAWN: M.T.W.	SUBMITTED: <i>W.H. Shaw</i>
TRACED: R.P.W.	RECOMMENDED: <i>B.C. Shada</i>
CHECKED: <i>J.W. [Signature]</i>	APPROVED: <i>[Signature]</i> CHIEF, DESIGNING ENGINEER
DENVER, COLORADO, APRIL 1, 1958	
SHEET 2 OF 12	
416-D-316	



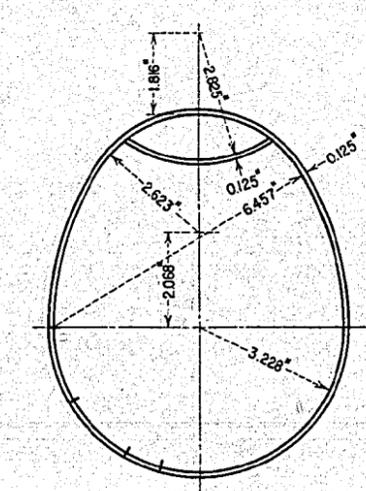
GENERAL TEST ARRANGEMENT



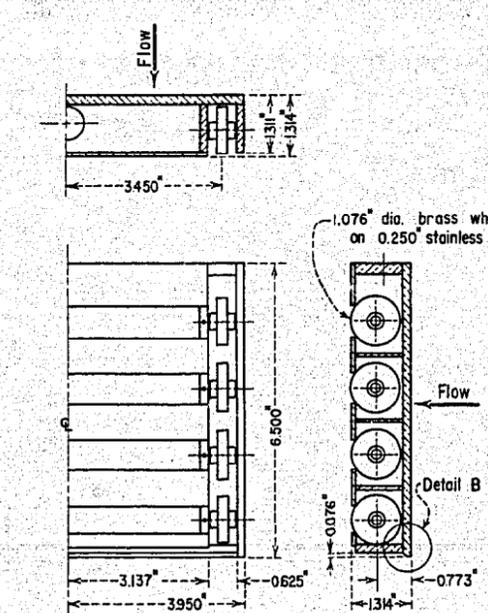
SECTION B-B



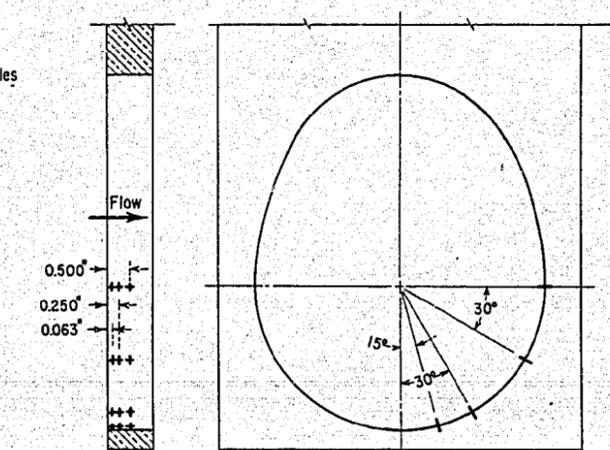
ELEVATION



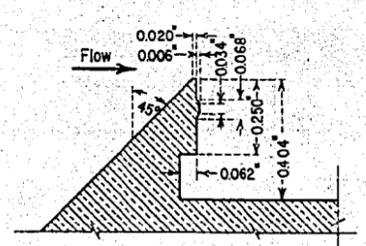
SECTION A-A
TRANSPARENT CONDUIT
(Also typical of metal conduit)



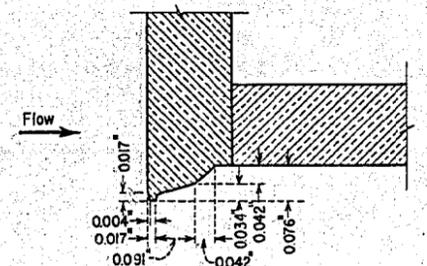
GATE LEAF
VIEWED FROM DOWNSTREAM
(Symmetrical about ϵ .)



PIEZOMETERS
DOWNSTREAM FRAME
Piezometers to be 0.063" diameter, drilled normal to the flow surface, and with all roughnesses and burrs removed.



DETAIL A
ORIFICE AND SEAL



DETAIL B
GATE LEAF BOTTOM

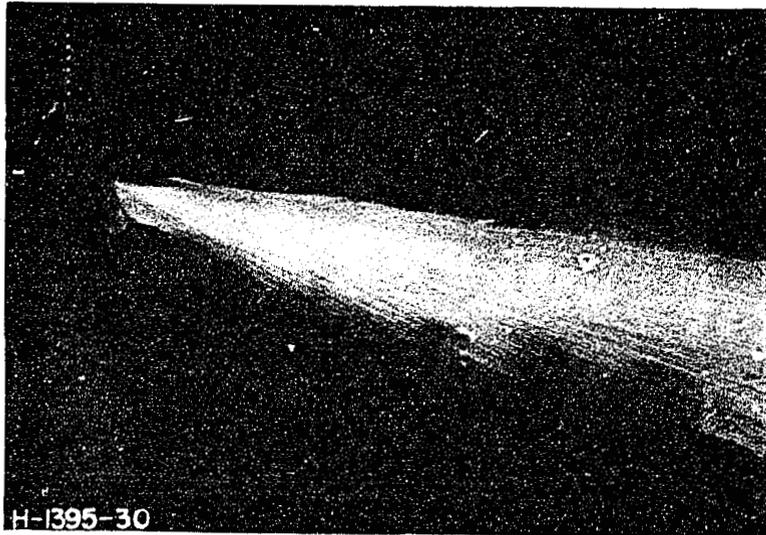
JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
1:14.87 SCALE MODEL



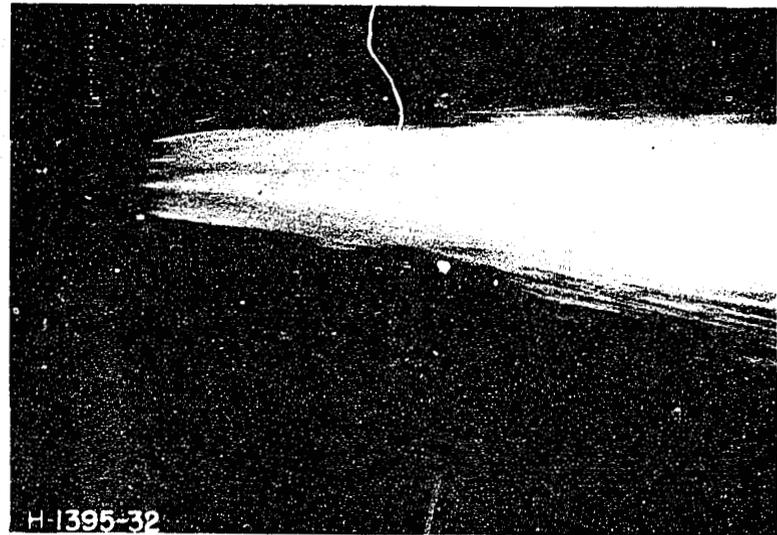
A. Gate 20% open



B. Gate 40% open



C. Gate 60% open



D. Gate 100% open

JET FLOW GATE
Trinity Auxiliary Outlet Works
Free Discharge From Gate - 40-Foot Head

GATE OPENING PERCENT	PIEZOMETERS															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
5	—	—	-1.000	-1.000	-1.000	-0.999	-0.999	-0.999	-1.000	-1.000	-1.000	-0.929	-0.986	-0.987		
10	—	—	-1.000	-0.999	-1.000	-0.999	-0.999	-0.999	-0.999	-0.999	-0.999	-0.962	-0.915	-0.876		
15	-0.998	-0.996	-0.996	-0.996	-0.996	-0.997	-0.996	-0.997	-0.996	-0.997	-0.790	-0.823	-0.910	-0.994	-0.981	-0.981
20	-0.995	-0.991	-0.992	-0.990	-0.992	-0.991	-0.991	-0.991	-0.985	-0.966	-0.905	-0.810	-0.992	-0.988	-0.981	
30	-0.972	-0.972	-0.970	-0.970	-0.970	-0.971	-0.971	-0.971	-0.971	-0.970	-0.961	-0.945	-0.943	-0.971	-0.970	
40	-0.936	-0.935	-0.933	-0.933	-0.934	-0.731	-0.741	-0.813	-0.934	-0.930	-0.930	-0.934	-0.934	-0.934	-0.934	
50	-0.873	-0.872	-0.872	-0.872	-0.873	-0.860	-0.940	-0.818	-0.874	-0.874	-0.874	-0.874	-0.873	-0.874	-0.874	
60	-0.790	-0.791	-0.785	-0.786	-0.785	-0.789	-0.788	-0.786	-0.790	-0.790	-0.790	-0.790	-0.789	-0.790	-0.790	
70	-0.679	-0.680	-0.632	-0.634	-0.632	-0.679	-0.679	-0.679	-0.679	-0.680	-0.679	-0.679	-0.679	-0.679	-0.679	
80	-0.540	-0.540	-0.538	-0.538	-0.538	-0.541	-0.541	-0.541	-0.540	-0.541	-0.540	-0.540	-0.540	-0.540	-0.540	
90	-0.408	-0.408	-0.378	-0.409	-0.408	-0.409	-0.408	-0.408	-0.408	-0.408	-0.408	-0.408	-0.407	-0.408	-0.408	
100	-0.305	-0.308	-0.305	-0.304	-0.305	-0.305	-0.305	-0.305	-0.304	-0.306	-0.306	-0.306	-0.305	-0.305	-0.305	

A. PRESSURE FACTORS - NO CONDUIT DOWNSTREAM

$$\text{Pressure Factor} = \frac{h_x - h_0}{H_T - h_2} = \frac{h_x - h_0}{H_T}$$

GATE OPENING PERCENT	PIEZOMETERS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
5	—	—	+0.06	+0.06	+0.09	+0.41	+0.41	+0.18	-0.25	-0.25	-0.13	+27.53	+12.94	+5.07
10	—	—	-0.34	-0.19	-0.30	-0.09	-0.09	-0.09	-0.09	+0.01	+0.12	+14.38	+32.62	+49.75
15	-0.06	-0.06	-0.17	+0.06	-0.06	-0.44	-0.06	-0.44	+0.01	+0.12	+0.12	+14.38	+32.62	+49.75
20	-1.81	-0.09	-0.32	+0.10	-0.32	-0.21	-0.09	+2.12	+1.36	+33.20	+68.72	+0.45	+5.76	+17.60
30	-0.28	-0.60	+0.49	+0.37	-0.06	+0.06	+0.14	+0.14	+0.37	+3.75	+10.19	+10.85	+0.14	+0.37
40	-8.28	-1.25	-0.16	-0.16	+0.70	+78.18	+74.03	+45.51	-0.86	+0.70	-0.97	-0.86	-0.70	-0.55
50	+0.46	+0.81	+0.81	+0.62	+0.38	+5.51	+13.19	+21.68	-0.20	-0.20	+0.04	-0.08	+0.15	+0.04
60	-0.97	-1.59	+0.73	+0.54	+0.97	-0.62	-0.12	+0.62	-0.97	-1.09	-0.86	-0.97	-0.74	-0.86
70	-1.69	-2.12	+16.47	+16.73	+16.47	-1.81	-1.69	-1.81	-1.81	-2.12	-1.69	-1.69	-1.69	-1.81
80	-0.39	-0.58	+0.54	+0.46	+0.20	-0.70	-0.70	-0.82	-0.59	-0.70	-0.50	-0.39	-0.39	-0.50
90	+0.05	+0.01	+11.65	-0.26	-0.06	-0.37	-0.16	-0.37	-0.06	-0.16	-0.17	+0.05	+0.27	+0.05
100	+0.17	-0.97	+0.17	+0.91	+0.37	+0.26	+0.06	+0.26	+0.52	-0.06	+0.06	+0.06	+0.26	+0.17

B. PROTOTYPE PRESSURES - 388 FOOT HEAD - NO CONDUIT

GATE OPENING PERCENT	PIEZOMETERS																			
	1	2	3	4	5a	6	7	8	8a	9	10	11	11a	12	13	14	14a	15		
20	-0.992	-0.991	-0.990	-0.862	-0.986	—	-0.985	-0.985	-0.986	—	-0.962	-0.870	-0.827	—	-0.980	-0.955	-0.908	—	-0.986	
30	-0.972	-0.972	-0.972	-0.846	-0.972	—	-0.963	-0.971	-0.972	—	-0.966	-0.983	-0.928	—	-0.968	-0.959	-0.937	—	-0.971	
40	-0.935	—	-0.934	-0.877	-0.934	—	-0.751	-0.751	-0.798	—	-0.932	-0.920	-0.919	—	-0.933	-0.929	-0.920	—	-0.945	
50	-0.874	—	-0.875	-0.750	-0.875	-0.874	-0.854	-0.865	-0.807	-0.789	-0.874	-0.872	-0.895	-0.737	-0.875	-0.871	-0.874	-0.715	-0.874	
60	-0.790	—	-0.782	-0.681	-0.785	-0.790	-0.790	-0.787	-0.784	-0.758	-0.790	-0.791	-0.785	-0.758	-0.791	-0.791	-0.791	-0.791	-0.757	-0.787
70	-0.676	-0.676	-0.629	-0.628	-0.628	-0.640	-0.676	-0.676	-0.676	-0.671	-0.676	-0.676	-0.676	-0.674	-0.676	-0.676	-0.676	-0.676	-0.673	-0.676
80	-0.539	-0.340	-0.539	-0.538	-0.537	-0.533	-0.541	-0.540	-0.540	-0.528	-0.540	-0.540	-0.539	-0.539	-0.539	-0.539	-0.539	-0.539	-0.538	-0.539
90	-0.410	-0.410	-0.411	-0.410	-0.411	-0.408	-0.411	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.409
100	-0.303	-0.303	-0.303	-0.303	-0.303	-0.303	-0.305	-0.305	-0.302	-0.304	-0.304	-0.301	-0.303	-0.303	-0.303	-0.301	-0.303	-0.303	-0.303	-0.303

C. PRESSURE FACTORS - 72" LONG MODEL CONDUIT DOWNSTREAM

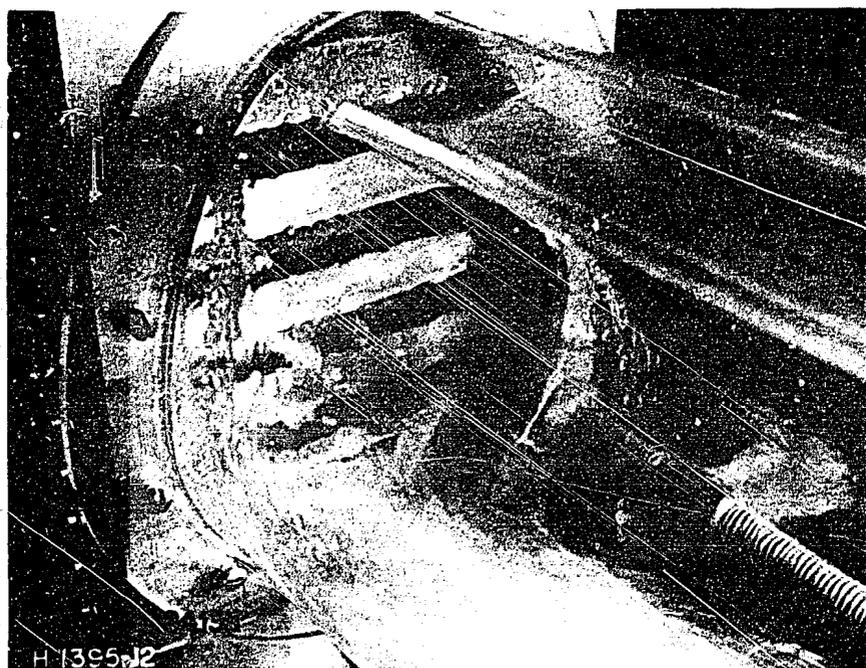
$$\text{Pressure Factor} = \frac{h_x - h_0}{H_T - h_2}$$

where h_x = piezometer pressure, ft. water.
 h_0 = pressure in conduit 1 diameter upstream from gate, ft. water.
 $H_T = h_0 + h_v$ = total head at reference station, ft. water.
 h_2 = pressure in downstream conduit (piez 15), ft. water.
 (atmospheric when no conduit is present.)

JET FLOW GATE
 TRINITY AUXILIARY OUTLET WORKS
 PRESSURES AND PRESSURE FACTORS
 Data From 1:14.87 Hydraulic Model

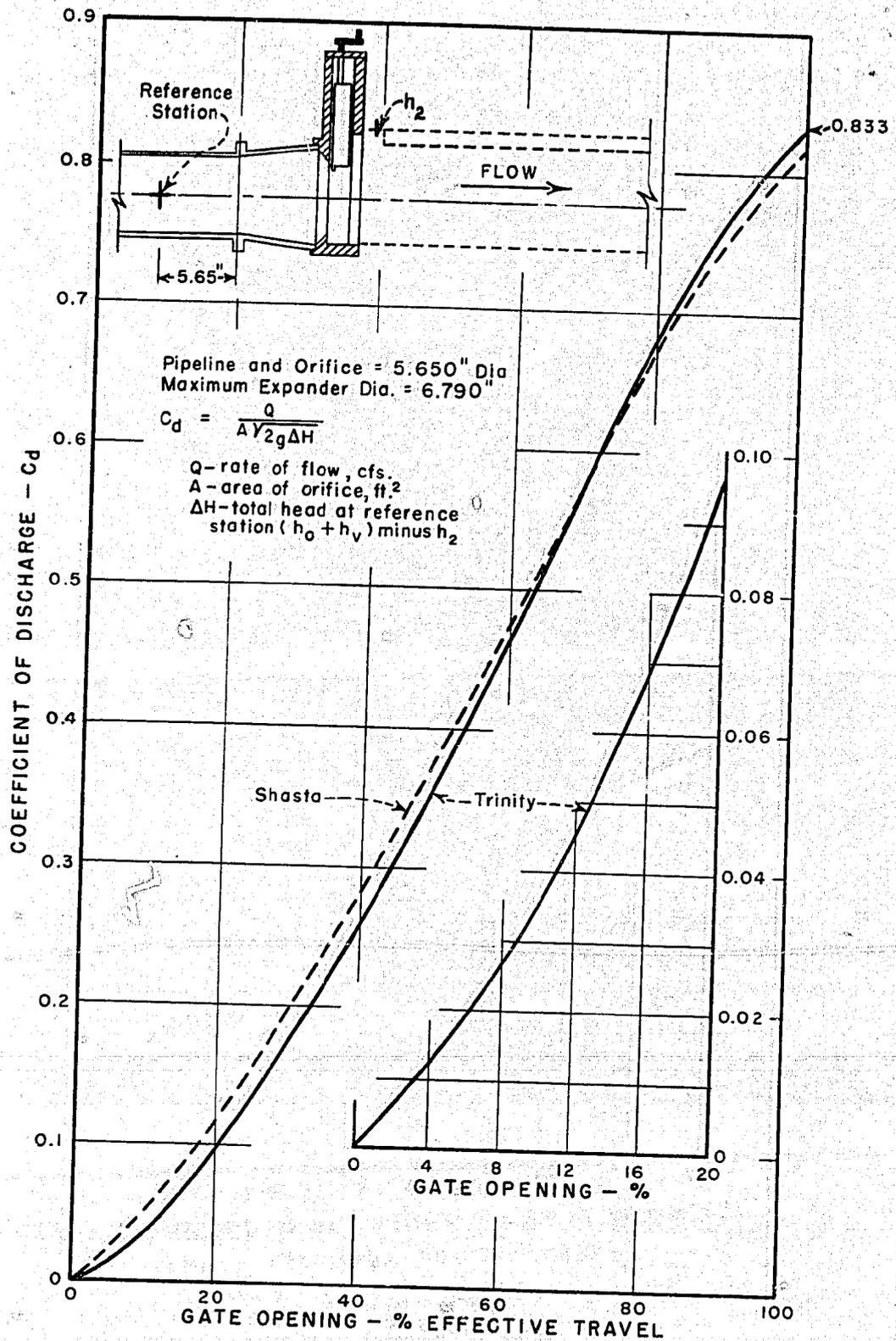


A. Free discharge into atmosphere. $H_T = 40$ feet



B. Discharge into conduit. $H_T = 40$ feet

JET FLOW GATE
Trinity Auxiliary Outlet Works
Flow Interference at Downstream Frame - 5% open
1:14.87 Scale Model



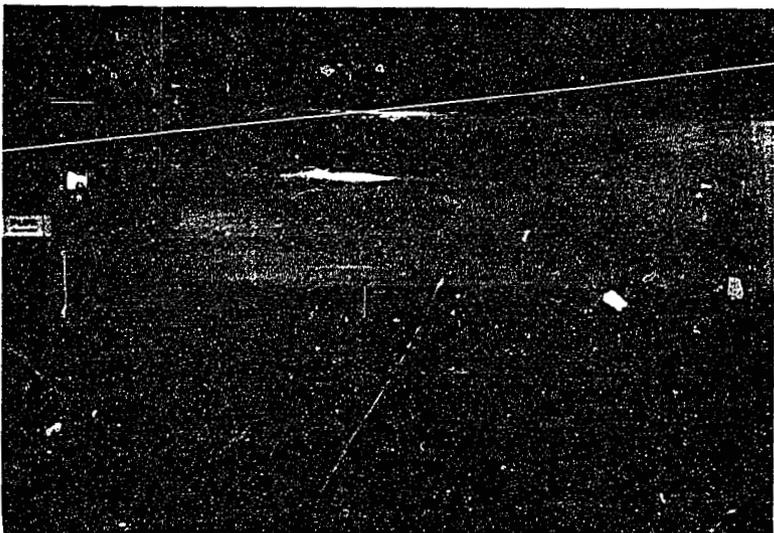
JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
COEFFICIENT OF DISCHARGE-VS-GATE OPENING
 Data From 1:14.87 Hydraulic Model



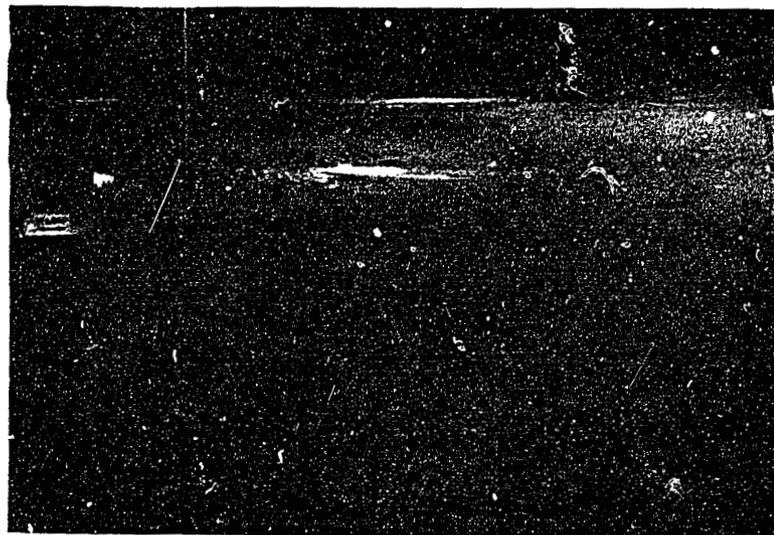
A. Gate 20% open



B. Gate 40% open

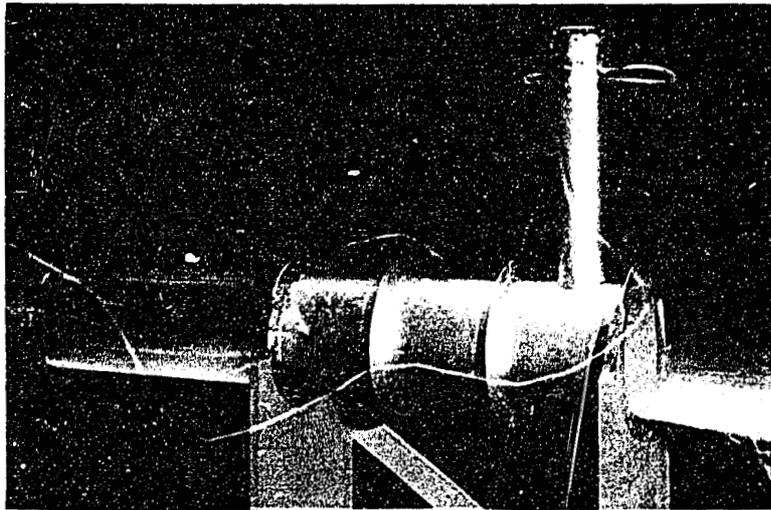


C. Gate 60% open

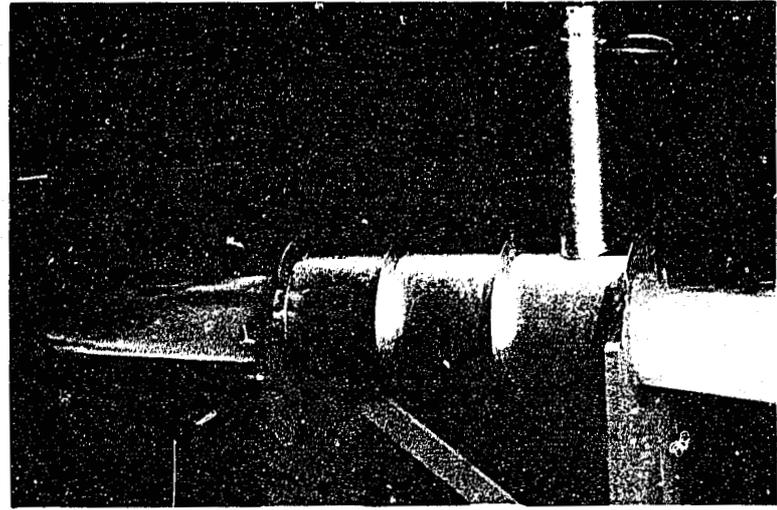


D. Gate 100% open

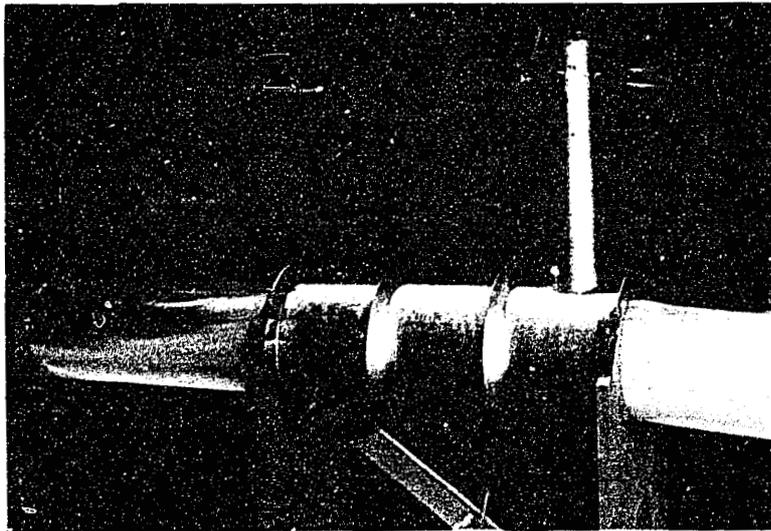
JET FLOW GATE
Trinity Auxiliary Outlet Works
Flow With 24-inch Long Conduit - 40-Foot Head



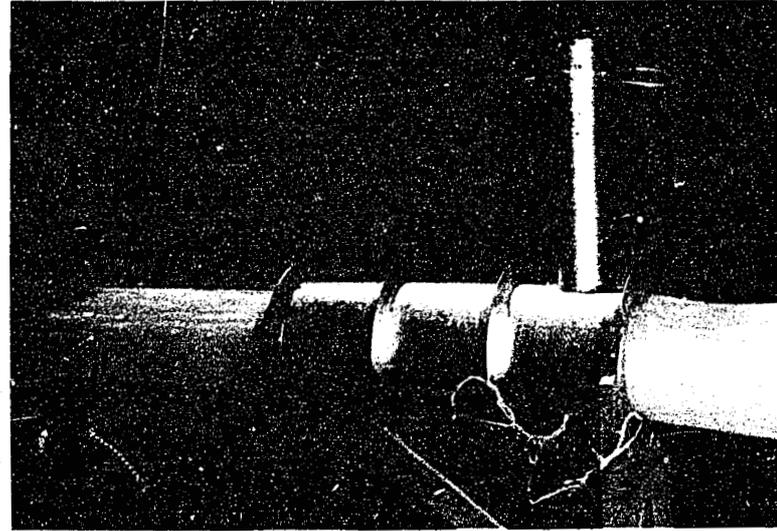
A. Gate 20% open



B. Gate 40% open

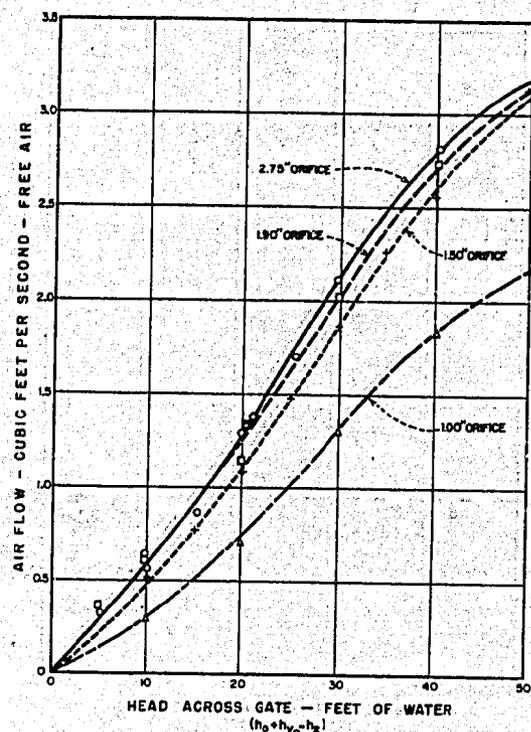


C. Gate 60% open

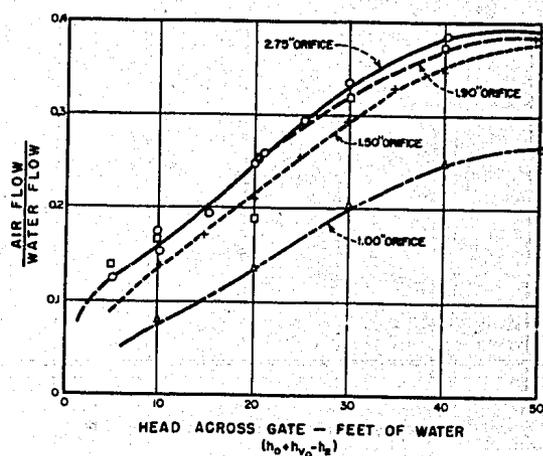


D. Gate 100% open

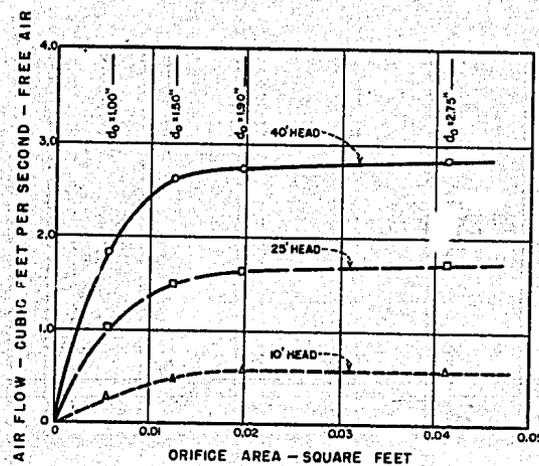
JET FLOW GATE
Trinity Auxiliary Outlet Works
Flow With 48-Inch Long Conduit - 40-Foot Head



A. AIR FLOW vs. HEAD



B. AIR-WATER RATIO vs. HEAD

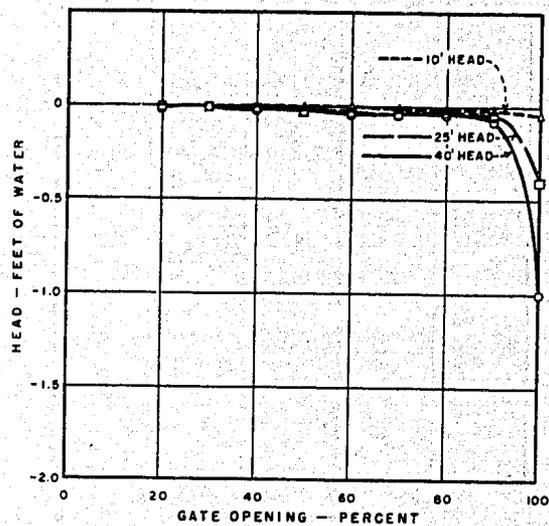


C. AIR FLOW vs. ORIFICE AREA

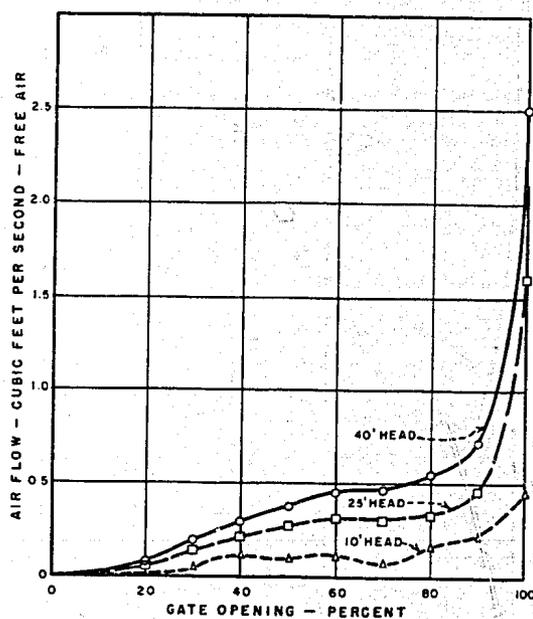
JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
EFFECT OF AIR INLET ORIFICE SIZE ON AIR DEMAND
GATE 100% OPEN - CONDUIT 72 INCHES LONG (11.15D)

Data From 1:14.87 Hydraulic Model

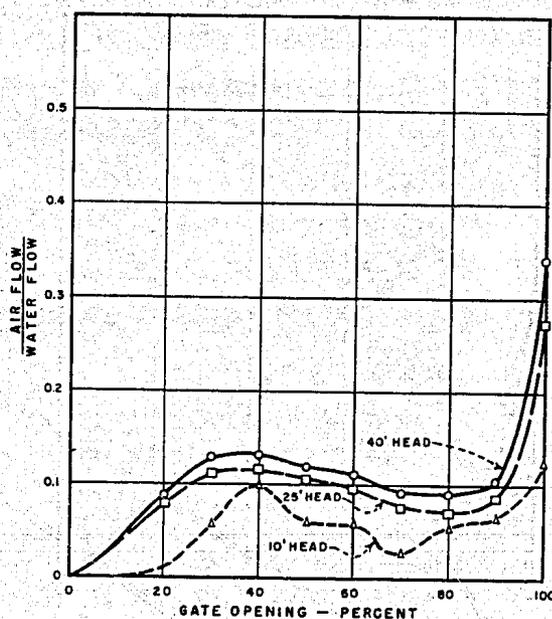
FIGURE 14
REPORT HYD 472



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



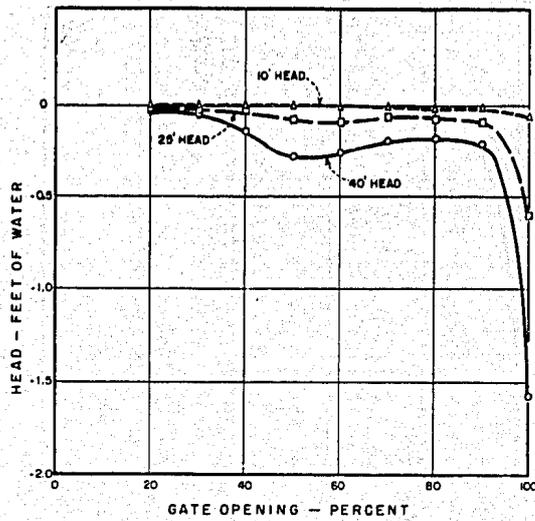
B. AIR FLOW vs. GATE OPENING



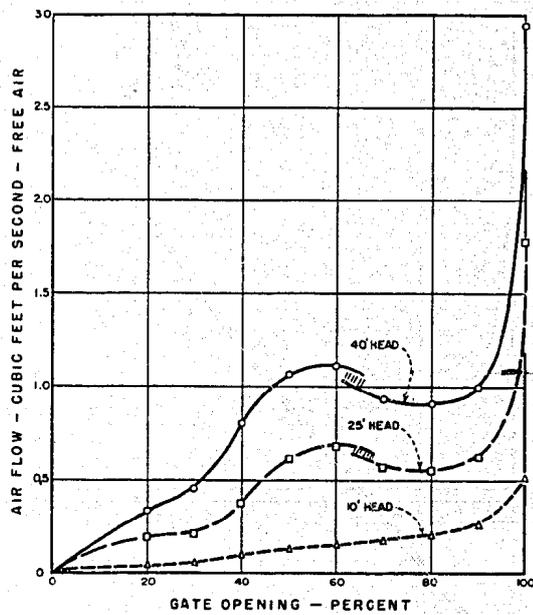
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
AIR DEMAND WITH
CONDUIT 24 INCHES LONG (3.72D)

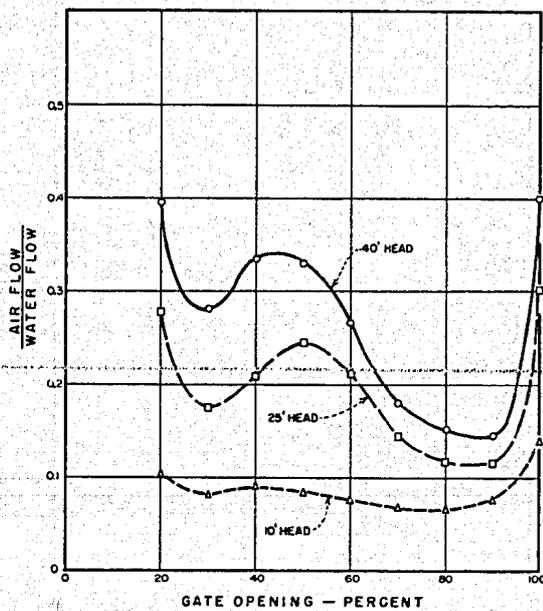
Data From 1:14.87 Hydraulic Model



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



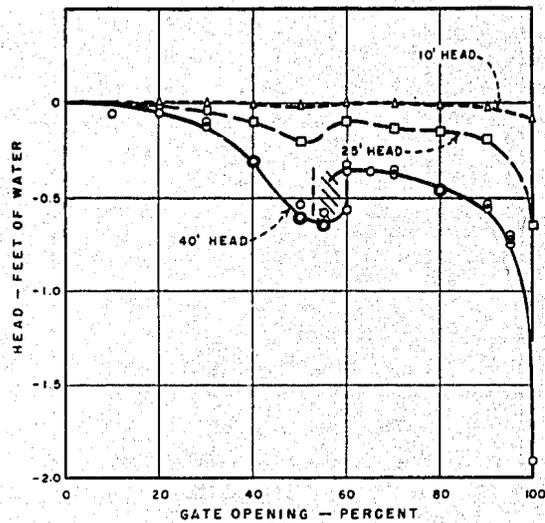
B. AIR FLOW vs. GATE OPENING



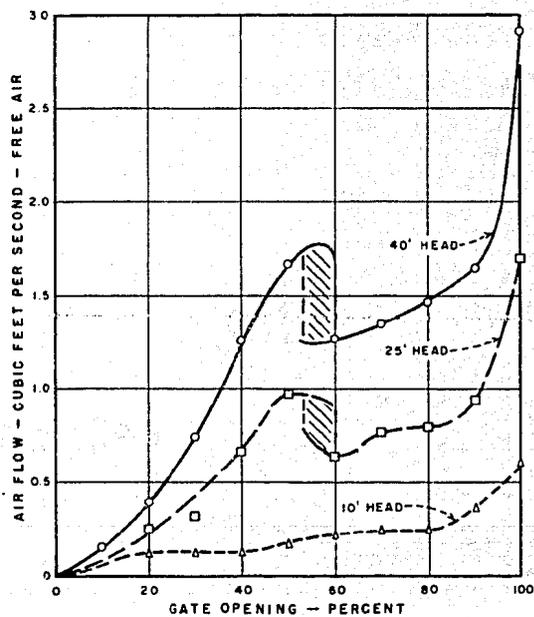
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
AIR DEMAND WITH
CONDUIT 48 INCHES LONG (7.43D)
Data From 1:14.87 Hydraulic Model

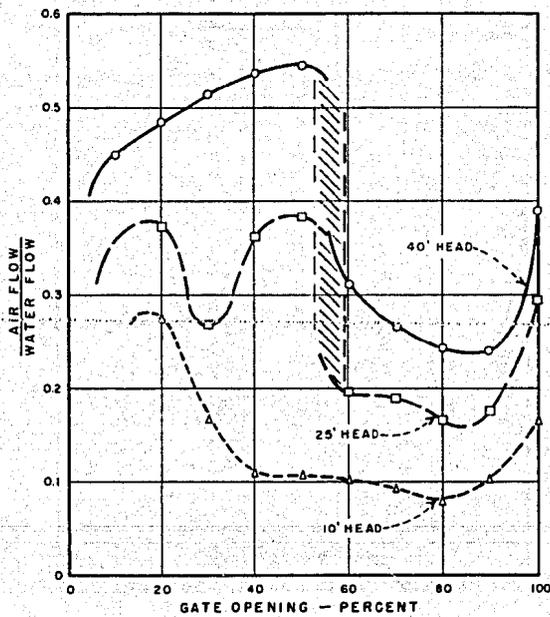
FIGURE 16
REPORT HYD 472



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



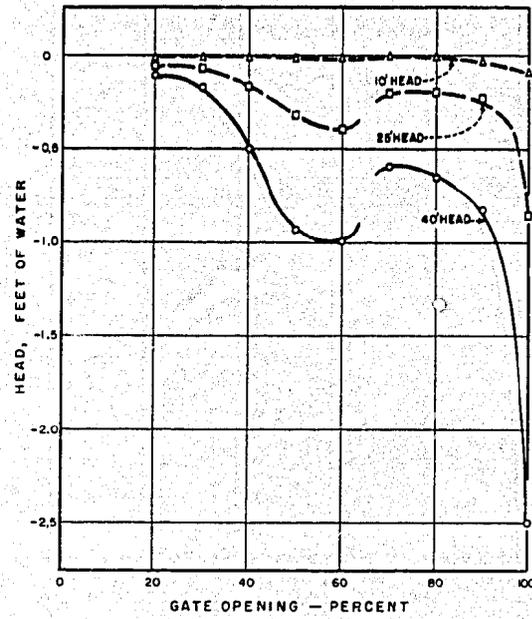
B. AIR FLOW vs. GATE OPENING



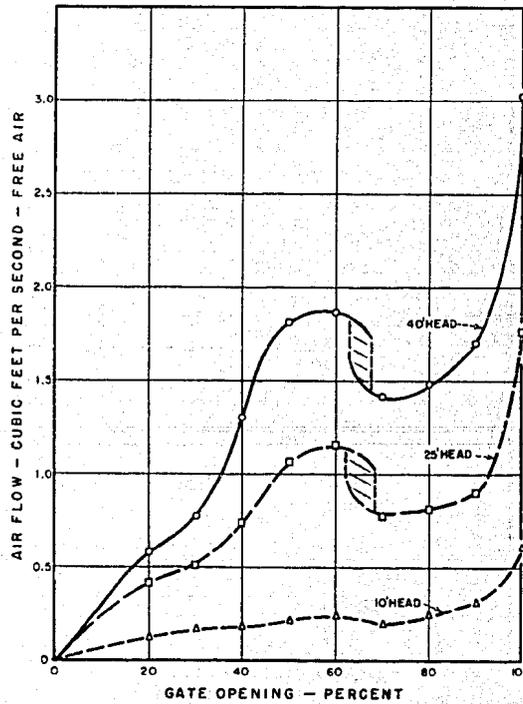
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
AIR DEMAND WITH
CONDUIT 72 INCHES LONG (11.15 D)

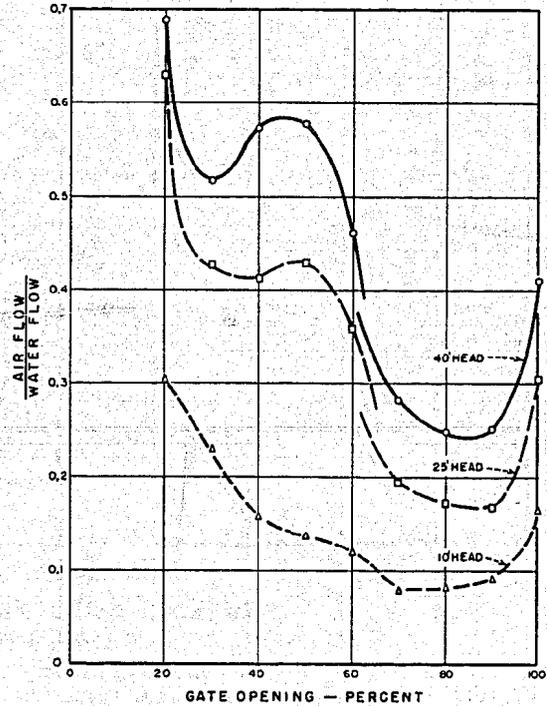
Data From 1:14.87 Hydraulic Model



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



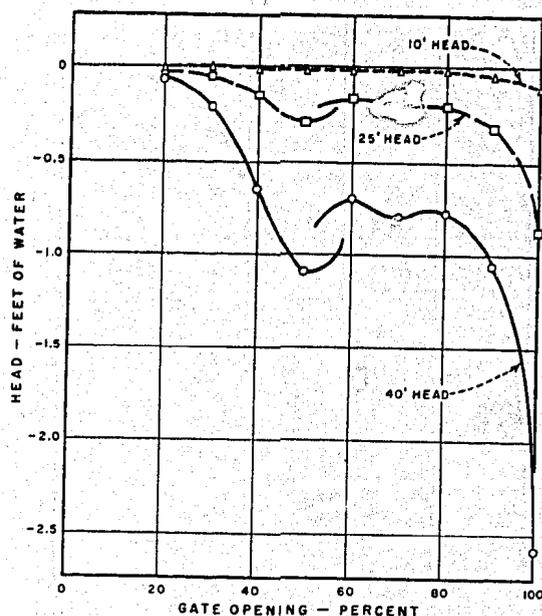
B. AIR FLOW vs. GATE OPENING



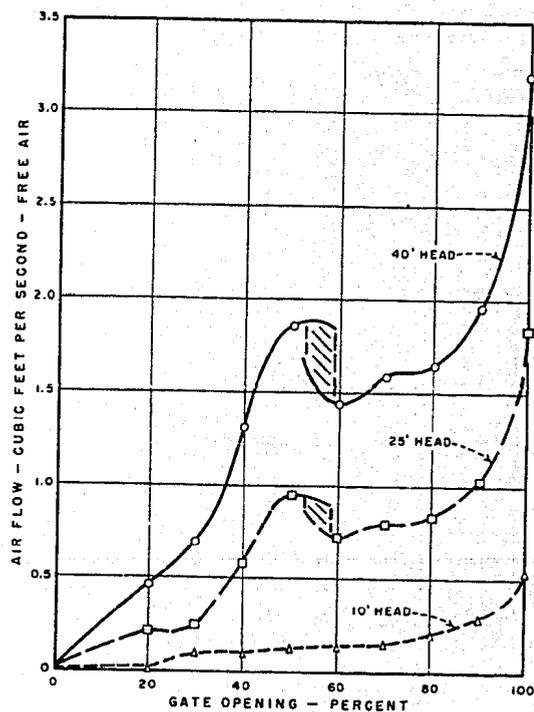
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE
 TRINITY AUXILIARY OUTLET WORKS
 AIR DEMAND WITH
 CONDUIT 96 INCHES LONG (14.87 D)
 Data From 1:14.87 Hydraulic Model

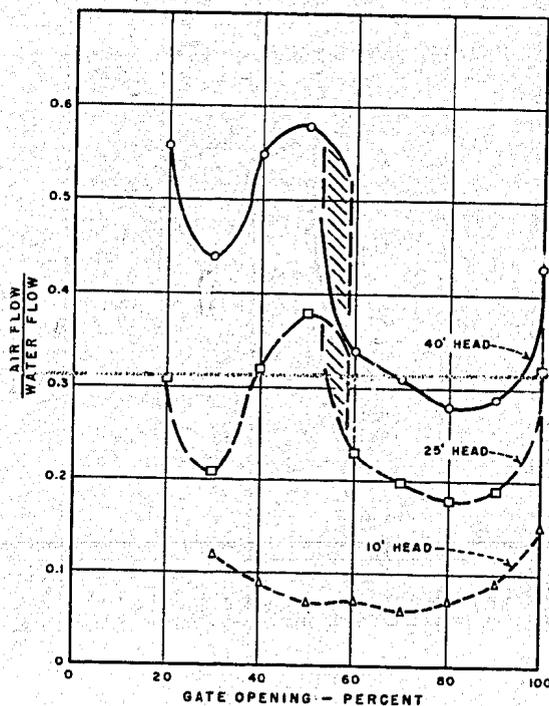
FIGURE 18
REPORT HYD. 472



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



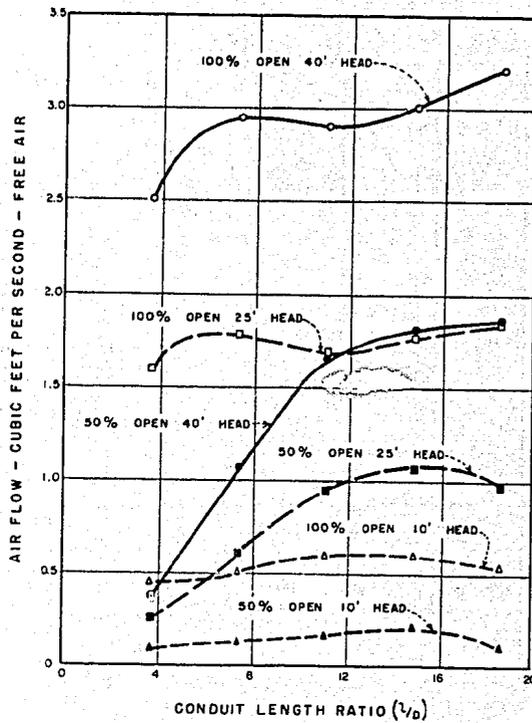
B. AIR FLOW vs. GATE OPENING



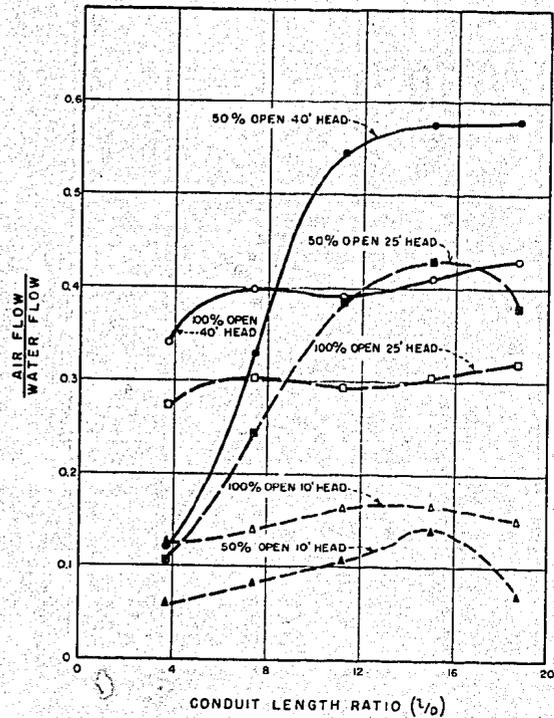
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
AIR DEMAND WITH
CONDUIT 120 INCHES LONG (18.58D)

Data From 1:14.87 Hydraulic Model



A. AIR FLOW vs. CONDUIT LENGTH

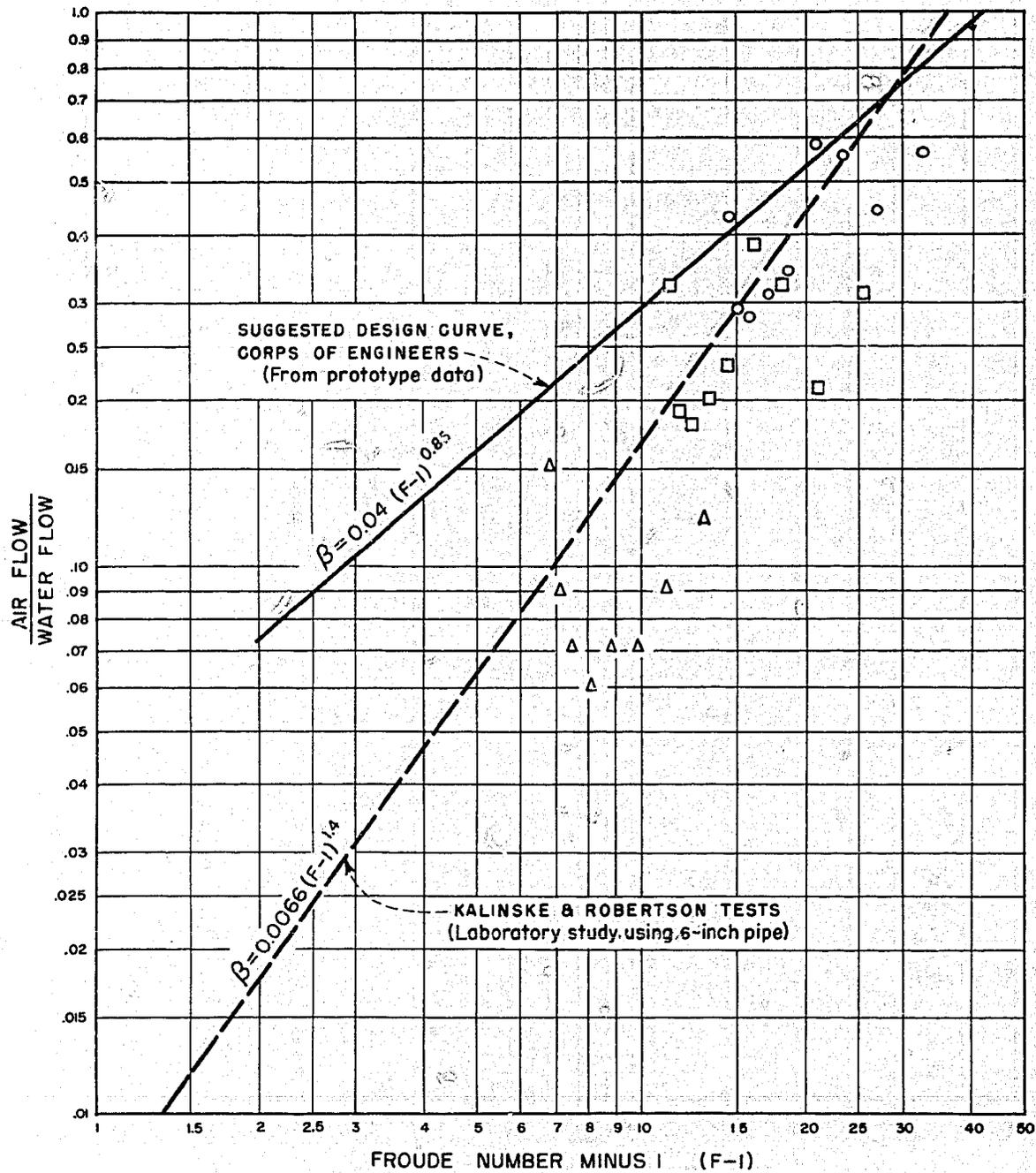


B. AIR-WATER RATIO vs. CONDUIT LENGTH

JET FLOW GATE
TRINITY AUXILIARY OUTLET WORKS
EFFECT OF MODEL CONDUIT LENGTH
ON AIR DEMAND

Data From 1:14.87 Hydraulic Model

FIGURE 20
REPORT HYD 472



EXPLANATION

Δ = 10' head \square = 25' head \circ = 40' head
 $F = V / \sqrt{gd}$ (FROUDE NUMBER)
 V = Water velocity at vena contracta
 d = Depth in downstream conduit using vena contracta area
 g = Acceleration of gravity

JET FLOW GATE

TRINITY AUXILIARY OUTLET WORKS

EFFECT OF FROUDE NUMBER ON AIR-WATER RATIO

Data From 1:14.87 Hydraulic Model
5.65-Inch Pipe