PAP-813

Analyses of Controlled-Release Capacity From Trinity Dam - Central Valley Project, Trinity River Division, California

June 22, 1999

by

Tony L. Wahl

PAP-813

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RES-3.50

JUN 22 1999

Mr. Dan Licht
USFWS/Arcata FWO
1125 16th Street, Room 209
Arcata, California 95521-5582

Subject: Analyses of Controlled-Release Capacity from Trinity Dam - Central Valley Project, Trinity River Division, California

Dear Mr. Licht:

The enclosed reports provide the results of our 1998 analysis of outlet works capacity at Trinity Dam, as well as background data regarding the capacity of the auxiliary outlet works. The analysis performed in 1998 focused on the combined operation of the river outlet works and powerplant to obtain increased releases for downstream habitat improvement. The capacity of the separate auxiliary outlet works was not analyzed, and was assumed to be the same as that shown on original drawings of the structure (drawing 416-D-171 in report HYD-472).

For purposes of considering habitat improvements that might be obtained from sustained increased releases, the maximum controlled release (river outlet works, powerplant, and auxiliary outlets all operating simultaneously) should be assumed to be the result from the 1998 study, 13,750 ft^3/s at reservoir elevation 2370. Since the time of the 1998 analysis, additional information has come to light from a 1985 study of the auxiliary outlet works jet flow gates (attached memorandum report PAP-483) that suggests the auxiliary outlet works capacity may be about 400 ft^3/s larger than that indicated on the original design drawings. To the best of our knowledge, this increased capacity has not been independently confirmed. Based on this information, it is possible that the maximum controlled release may be slightly higher than the result obtained in the 1998 study, but we do not recommend using any larger value until this has been confirmed by full-scale tests. We recommend that for purposes of assessing the impact of increased releases on downstream structures (e.g., roads, bridges, etc.), a range of uncertainty in the auxiliary outlet works capacity should be considered. The full uncertainty range should include not only the uncertainty of the auxiliary outlet works release capacity but any potential side channel inflows up to the point of interest and other hydraulic factors which will influence the discharge.

If you have questions about the enclosed reports or would like to discuss this matter further, please contact Tony Wahl at 303-445-2155 or Elisabeth Cohen at 303-445-3247.

Sincerely,

TONY L. WAHL

Tony L. Wahl
Technical Service Center
Hydraulic Engineer

for Elisabeth A. Cohen
Technical Service Center
Civil Engineer

Enclosure

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D-8560 Wahl

D-8130
PRJ-13.00

AUG 25 1998

MEMORANDUM

To: Area Manager, Northern California Area Office, Shasta Lake CA
Attention: Russell Smith, NC-300

From: Elisabeth A. Cohen, Waterways and Concrete Dams Group
Tony L. Wahl, Water Resources Research Laboratory

Subject: Maximum Controlled-Release Capacity from Trinity Dam - Central Valley Project, Trinity River Division, California

The Technical Service Center (TSC) has completed an analysis of the maximum controlled-flow release capacity from Trinity Dam. This analysis is based on a mathematical model of the combined operation of the river outlet works and powerplant, which use a shared tunnel and penstock system. The model was developed by the TSC and calibrated using data collected from two field tests conducted by Northern California Area Office staff on August 4 and August 6, 1998. The calibrated model predicts a maximum controlled-flow release of 13,750 ft^3/s at reservoir water surface elevation 2370 (crest of the uncontrolled spillway), which includes both the combined operation of the river outlet works and powerplant (using the high-head runners) and releases from the auxiliary outlet works system. The discharge capacity of the auxiliary outlet works, which is entirely separate from the river outlet works and powerplant, was not analyzed, but was assumed to be that shown on drawing 416-D-160.

Cavitation potential in the outlet works system was not analyzed. The increased discharge and reduced pressures caused by combined operations of the outlet works and powerplants do have the potential to create cavitating flow conditions. If prolonged combined operations of the river outlet works and powerplant occur in the future, we recommend that during such operations special attention be given to any abnormal noise levels that might indicate ongoing cavitation, and we recommend that the outlet works system be inspected for cavitation damage following those operations.

A revised controlled-flow release discharge curve is attached. The figure shows the river outlet works capacity under three different scenarios:

1) **River outlet works operating without powerplant** - This curve shows the discharge at 100 percent opening of the two hollow-jet valves, and indicates about 18 percent greater discharge than that shown on drawings 416-D-160 and 416-D-164. This increased discharge capacity was verified by the field test performed August 4, 1998.

2) **River outlet works in combination with powerplant (high-head runners)** - This curve shows the combined discharge when operating the hollow-jet valves at 100 percent opening and one or both turbines at full-gate, with the high-head runners installed. For reservoir

elevations below 2262, there will be insufficient head to operate the powerplant within the design head range for the high-head runners. Between elevation 2262 and 2290, there is only sufficient head to operate one turbine. Unit 1 should be operated in this case, since it has the most upstream connection to the outlet works penstock, and thus the most available head.

3) **River outlet works in combination with powerplant (low-head runners)** - This case is similar to (2), except that the low-head runners are installed in the powerplant. For reservoir elevations below 2213, there will be insufficient head to operate the powerplant within the design head range for the low-head runners. Between elevation 2213 and 2241, there is only sufficient head to operate one turbine. Again, unit 1 should be operated in this case, since it has the most upstream connection to the outlet works penstock, and thus the most available head. For reservoir elevations of 2332 and above, the combined operation of the outlet works and powerplant produces so much head loss that the low-head runners can still be used and will operate within their design net head range. However, the low-head runners are unlikely to be installed in the powerplant under these conditions, since they would operate at heads higher than their design range if the outlet works were not also operating. Thus, this portion of the discharge curve is shown as a dashed line. Note that the greatest release capacity is obtained by using the low-head runners in this range.

The release capacities described above and shown in the accompanying figure were determined using a mathematical model of the combined river outlet works and powerplant releases. The model computes friction and minor losses throughout the outlet works and powerplant tunnels, penstocks, and associated gates and valves. The net head on the turbines and hollow-jet outlet valves is determined by the model, and performance data for these components are used to determine the discharges. The initial analysis indicated significantly higher outlet works capacity than that shown on the design discharge curve in drawing 416-D-164. As a result, two field tests were performed, and assumed loss coefficients in the model were adjusted based on the results of the tests. Once the adjustments were made, the model was used to compute discharges for combined flows through the river outlet works and powerplant. The discharge curves show only the maximum release capacities; however, the model could be used to analyze other scenarios, such as partial opening of the hollow-jet valves or operation of the powerplant at conditions other than full-gate. The model is contained in a Lotus 1-2-3 spreadsheet, and can be provided to Regional or Area Office personnel upon request.

Two tests were performed to calibrate the model. On August 4, 1998, the river outlet works was operated at 60 percent and 100 percent valve openings. On August 6, 1998, the outlet works and powerplants were operated in combination with the river outlet works at 100 percent valve opening and the powerplant at near-full gate conditions, using the high-head runners. Pressures, reservoir levels, powerplant output, and other pertinent operational data were recorded. Discharge through the outlet works valves was determined using drawing 416-D-1084, and discharge through the powerplant was determined from tables in the SOP and from turbine performance curves on file in Denver. Discharges were not measured independently.

The overall result of the tests was to confirm the higher discharge capacities that were being predicted with the model (higher discharge than shown on drawings 416-D-160 and 416-D-164). The tests also assisted in the calibration of loss coefficients in the model associated with the combined operation of the outlet works and powerplant. It was not possible to perfectly tune the model to match all of the test results. Some possible reasons for remaining differences between the calibrated model and the results of the tests include nonconstant or nonlinear variation of loss coefficients during combined flow operations, random errors in pressure measurements and other test data, potential for bias in pressure measurements due to imperfect pressure taps and piezometer connections, and uncertainty in discharge determinations. The model was calibrated to more closely fit the test results from the 60 percent operation of the outlet works, since the lower flowrate during this test would minimize the magnitude of some of the potential errors. This causes the model to underpredict the observed pressure at the outlet works valves during the tests at 100 percent valve opening. Thus, the discharge from these valves is also underpredicted. Summaries of the model predictions and comparisons to the test observations are given in table 1. The differences between the predicted combined powerplant and outlet works flows and the estimated discharges during the field tests range from +1.6 percent to -4.6 percent.

The powerplant and river outlet works at Trinity Dam have not typically been operated in combination in the past, and methods for determining discharge have not considered the effects of combined operation. If combined operations become more prevalent in the future, discharges can be estimated as follows:

- Discharge through the river outlet works hollow-jet valves should be determined using drawing 416-D-1084 and the pressure readings from the two gauges attached to the 3-inch fill/bypass piping going around the ring-follower guard gates. These gages are located in the outlet works control house at elevation 1929.87, and are shown on drawing 416-D-300.

- Powerplant discharge can be determined by noting the reduction of pressure caused at the turbine penstock pressure gauges (under the penstocks at elev. 1896.75, tapped off near the butterfly valves) when the outlet works is placed into operation. This reduction of pressure can be used to determine an effective lake elevation, and the existing tables in the powerplant SOP can then be used to estimate the discharge. This technique was used for the August 6, 1998, test. Alternately, the pressure gauges can be used to determine the net head across the turbines, and discharge can be determined from the turbine characteristic curves.

We trust the information provided in this memorandum will meet your needs for the completion of the Trinity EIS. The information also needs to be included in the SOP and the drawing updated at the next opportunity. If additional details or assistance are necessary, please contact Tony Wahl at (303) 445-2155 or Bitsy Cohen at (303) 445-3247.

Elizabeth A Cohen
Tony L. Wahl

Copy to persons on next page

cc: Regional Director, Sacramento CA, Attention: MP-200 (Solbos)
Area Manager, Shasta Lake CA, Attention: NC-650 (Poore)

bc: D-8130 (Cohen, Hinchliff)
D-8313 (Prizio)
D-8420
D-8470
D-8560 (Wahl✓, Wittler)

WBR:TWahl/BCohen:fr:8/24/98:445-2155
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TABLE 1. – Comparison of key parameters from field tests and predictive model. The dual values (where shown) are recorded from both the upstream and downstream branches for the turbines and the outlet works or as incorporated into the model. There are both hollow-jet valves and ring-follower gates at the downstream end of the outlet works.

Test Scenario: 60 percent opening of **river outlet works** (hollow-jet valves) **at reservoir elevation** 2365.6. **Powerplant turbines at speed-no-load.**

Parameter	Prediction by calibrated model	Observed value during August 4, 1998 test
Pressure at turbine gages	186 / 184.8 psi	165 / 175 psi
Pressure at gages on fill/bypass lines around ring-follower gates	124.5 psi	117 / 125 psi
Hollow-jet valve flow	2,960 cfs (each)	2,870 / 2,960 cfs
TOTAL OUTLET WORKS DISCHARGE	5,920 cfs	5,830 cfs

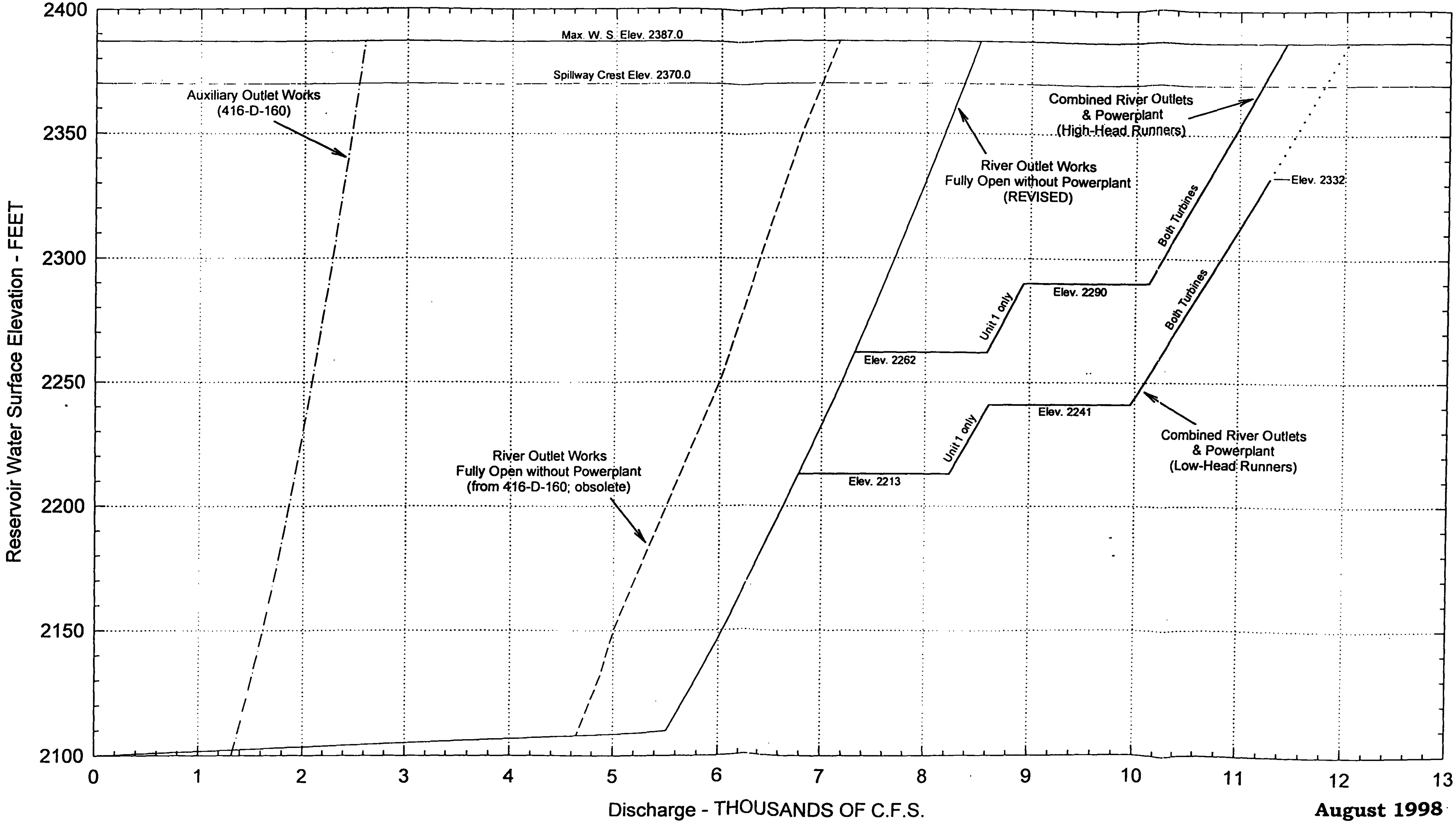
Test Scenario: 100 percent opening **of river outlet works** (hollow-jet valves) **at reservoir elevation** 2365.6. **Powerplant turbines at speed-no-load.**

Parameter	Prediction by calibrated model	Observed value during August 4, 1998 test
Pressure at turbine gages	170.5 / 168.1 psi	161 / Not Available
Pressure at gages on fill/bypass lines around ring-follower gates	63.8 psi	65 / 71 psi
Hollow-jet valve flow	4,140 cfs (each)	4,150 / 4,325 cfs
TOTAL OUTLET WORKS DISCHARGE	8,280 cfs	8,475 cfs

Test Scenario: 100 percent opening **of river outlet works** (hollow-jet valves) **at reservoir elevation** 2364.95. **Turbine units 1 and 2 operating at 95 and 90 percent gate, respectively.**

Parameter	Prediction by calibrated model	Observed value during August 6, 1998 test
Pressure at turbine gages	149.1 / 145.2 psi	140 / 147 psi
Turbine discharges	1,655 / 1,625 cfs 3,280 cfs (total)	3,370 cfs (total)
Pressure at gages on fill/bypass lines around ring-follower gates	56.7 psi	64 / 65 psi
Hollow-jet valve flow	3,935 cfs (each)	4,100 / 4,150 cfs
TOTAL OUTLET WORKS & POWERPLANT DISCHARGE	11,150 cfs	11,620 cfs

TRINITY DAM - Controlled Release Discharge Curves



August 1998

INFORMATIONAL ROUTING PAP-483

D-1530

AUG 3 0 1985

D-1531

Memorandum

To: Regional Director, Sacramento, California
Attention: MP-400

From: ACTING Chief, Division of Research and Laboratory Services

Subject: Trinity Dam Auxiliary Outlet Works - Hydraulic Laboratory Model Results

We have completed the hydraulic laboratory model study of the Trinity Dam auxiliary outlet works. Based on the results of our investigation, we have determined that the following modifications are required:

1. The existing 2-inch-high orifice ring on the upstream edge of the air slot needs to be reduced to a 1/2-inch offset (up to a height of about 8 feet above the conduit invert).

2. Install a deflector plate, 15 inches deep and 8 feet long, on the inside of the Trinity Dam spillway tunnel opposite the auxiliary outlet conduit exit.

3. Add a sealed bulkhead at the junction of the existing air scoop and aluminum air duct (at the downstream end of the steel liner section).

4. A much stronger aluminum air duct and the anchoring method is necessary.

Reducing the air slot orifice ring to a 1/2-inch offset significantly decreases the deflection and impingement of water flow against the top of the conduit at partial gate openings. The sealed bulkhead prevents water and air from being drawn into the air scoop at the downstream end. The deflector plate prevents water entering into the downstream end of the auxiliary outlet conduit and air duct system.

These modifications will provide a very smooth operation at all jet-flow gate openings. The potential for cavitation has been reduced considerably. However, at all gate openings, including 100 percent, water flow will impinge onto the bottom of the aluminum air duct system. Therefore, the integrity of the aluminum air duct structure needs to be improved.

A more detailed discussion providing the basis for the above recommendations is included as an enclosure to this memorandum.

We would be happy to discuss results of our Trinity Dam Auxiliary Outlet Works Model investigation with project personnel at their convenience.

Enclosure

Copy to: Regional Director, Sacramento, California, Attention: MP-200, MP-430
Project Superintendent, Redding, California
(with enclosure to each)

Blind to: D-430
D-220
D-223 (Gray)
D-1500
~~D-~~1530
D-1530A
D-1531 (PAP file)
D-1531
(with enclosure to each)

CPBuyalski:flh

TRINITY DAM AUXILIARY OUTLET WORKS LABORATORY MODEL EVALUATION OF THE OPERATING CHARACTERISTICS

by

Clark P. Buyalski

PURPOSE

A 1:14.87 scale hydraulic model of the Trinity Dam Auxiliary Outlet Works including a section of the spillway tunnel was designed and constructed to observe the operating characteristics of the jet-flow gate, the new air slot, and the air duct system. The air demand for the jet-flow gate and air slot and the coefficient of discharge for the jet-flow gate were also evaluated.

INTRODUCTION

The hydraulic model of the Trinity Dam Auxiliary Outlet Works from the jet-flow gate to the main spillway tunnel was constructed to a scale of 1:14.87 using field survey data furnished by the Shasta Field Office. The field survey provided the "as-built" dimensions for the air slot and air duct system including the outlet works and spillway tunnel invert elevations. The laboratory model followed the survey data very closely with the exception of the aluminum air duct.

The prototype aluminum air duct conformed to Federal Specification WW-P-402, Class II, Series A, Shape 3, No. 10 gauge sheet, having 1/2-in corrugations. The aluminum air duct was anchored to the top of the outlet works conduit with 3-in by 1/4-in steel straps at 2- to 5-ft spacings. The prototype aluminum air duct scaled to exact model dimensions would have been extremely difficult to construct. The No. 10 gauge would be equivalent to a thickness of three sheets of ordinary paper and the 1/2-in corrugations could not have been duplicated. For the model, a 2-in-diameter aluminum tubing having a 20-gauge wall thickness was used. The aluminum tubing was rolled to obtain the same basic "shape 3." The vertical height was maintained. However, the horizontal inside width was about 32 in (prototype) compared to the as-built inside dimension of 35 in. The 20-gauge wall thickness of the model aluminum air duct is equivalent to a 1/2-in prototype thickness. The model air duct was attached to the crown of the Plexiglas conduit with sheet metal screws staggered 3/4 in from the top centerline at 5-in centers. Overall the model aluminum air duct system installation was considerably more rigid compared to the prototype and slightly smaller in cross-section.

A general view of the completed Trinity model is shown in figure 1. Figures 2 and 3 show the general model layout and assembly details. Figure 4 shows the actual "as-built" model cross-sectional areas of the air scoop and aluminum air duct at the three air velocity probe locations. The general layout of the piezometer tap and air velocity probe locations are shown in figure 5 (the dimensions are shown in figures 2 and 3).

The 5.65-in model jet-flow gate used in this investigation was the same gate used in the original Trinity Dam auxiliary outlet works hydraulic model studies reported in HYD-472 dated Janaury 6, 1961. However, the HYD-472 studies did not model the total length of the egg shaped conduit, the intersection at the spillway tunnel, or the air slot. Therefore, the air demand characteristic were expected to be different, the current investigation provided the first opportunity to study the entire outlet works and the air slot design.

INITIAL TESTS

For the initial tests of the Trinity model the jet-flow gate was opened from 0 to 100 percent and then closed, simulating the January 10, 1985 field test conditions. Next, a series of steady-state flow condition tests were made at 10 percent gate opening increments to observe the flow characteristics. Several problem areas were immediately identified:

1. At partial gate openings from 0 to 80 percent, the jet from the gate deflected upward from the air slot orifice ring onto the bottom of the air duct system. The area of flow impingement on the bottom of the air duct system began about 6 ft (prototype) downstream of the air slot and continued downstream about 50 to 60 ft (prototype). The flow impingement area extended onto the aluminum air duct and would explain the partial failure observed after the January 10, 1985 field test (memorandum dated January 17, 1985, from Richard C. Kristof to Chief, Water O&M Branch, Mid-Pacific Regional Office).

2. At 40 to 70 percent gate openings, high negative pressures occurred in the model on the side wall at the downstream end of the steel liner near the top (P10b, figure 5). Also the negative pressure was fluctuating as low as -3.3 ft of water in the model which is below prototype vapor pressure.

3. At 70 percent gate opening, air and water entered into the air scoop at the downstream end at the junction with the aluminum air duct (refer to Section D-D, figure 3) which had been left open in the construction of the new air duct system. This opening, with air and water being drawn through it, could have been the primary cause of the high pressure fluctuations that occurred at the 70 percent gate opening.

4. The maximum air demand occurred between 50 and 70 percent gate openings, and appeared to be unreasonably high at the 70 percent gate opening. The high air demand that occurred could be the cause of the excessive air velocity through the floor drain from the gate chamber to the air slot noted during the Janaury 10, 1985 field test.

5. From 80 to 100 percent gate opening, some of the flow deflected back into the outlet works conduit and the aluminum air duct at the junction of the outlet works conduit with the spillway tunnel. Flow from the auxiliary outlet works impinged onto the opposite side of the spillway tunnel. Part of the flow was deflected upwards and towards the crown of the spillway tunnel reversing its direction by 360 degrees and entering back into the auxiliary outlet conduit. The reversed flow caused a roiler to occur on top of the main water flow prism. The splash from the roiler action combined with slugs of reversed flow were entering randomly into the downstream end of the aluminum air duct. The slugs of water would then be drawn up the air duct system to the jet-flow gate and would cause a significant momentary increase in the negative pressures at all piezometers.

6. The smoothest operation occurred at the 90 percent gate opening. The jet-flow gate leaf at the 90 percent position suppressed the wave action that occurred at the 100 percent gate opening. The roughest operation occurred at the 70 percent gate opening because of the severe flow impingement onto the bottom of the air duct system, and water and air surging into the downstream end of the air scoop.

TEST PROGRAM

Based on the initial tests, the following test program was developed to identify required modifications:

1. Install a sealed bulkhead at the downstream end of the air scoop at the junction of the aluminum air duct (section D-D, figure 3).

2. Install a deflector plate at the downstream end of the auxiliary outlet conduit (perpendicular to the crown), downstream from the end of the aluminum air duct.

3. Modify the 2-in-high orifice ring at the upstream edge of the air slot to reduce the upward deflection of flow.

The above three modifications constituted the basic test program for the Trinity model studies. Before any modifications were made, however, test data were collected for the as-built configuration for comparative purposes.

TEST PROCEDURE

The calculation of the jet-flow gate, upstream pressure head vs. discharge vs. gate position, for steady-state flow conditions was determined by trail and error. The data used in the iterative procedure were based on (a) field measurements of the downstream head (obtained from the March 13-14, 1963 field test data book), (b) an estimate of the upstream penstock entrance and bend losses and friction losses using a Darcy-Weisbach friction factor * f = 0.012, and (c) the model gate coefficient of discharge from figure 10, report HYD-472. The trial and error calculations were made at 20 percent gate opening increments and are plotted in figure 6. Table 1 is a summary tabulation of the jet-flow gate model calibration and includes the calibration used at the intermediate 10 percent gate openings interpolated from figure 6 and the associated prototype discharge calculation. The calibration was based on a Trinity Dam Reservoir elevation of 2368.2 ft which is near to the crest elevation (2370.0 ft) of the morning glory spillway. *

Each steady-state test run was established for the selected gate position by regulating the model gate valve to obtain an upstream pressure head at P1 (refer to figures 2 and 5 for the location of P1) to the calibrated upstream head shown in figure 6 and listed in table 1. Therefore, the steady-state flow condition was based on the upstream head calibration and not the discharge calibration both being determined by iterative procedures discussed above. However, the resulting model discharge was in close agreement with the calibrated discharge.

For each steady-state test run, the average static pressure head at each piezometer location was recorded. If the pressure fluctuation was more than ±0.03 ft (model) from the average, a measurement of the maximum fluctuation was recorded. Air velocities were taken at three air velocity probe locations (shown in figures 2, 3, and 5). Location No. 1 is upstream of the air slot and location No. 2 is immediately downstream of the air slot, both are inside the air scoop. Location No. 3 is inside the aluminum air duct at the upstream end. Piezometer taps No. P11, P12, and P13, respectively, were used to obtain the static pressure head at the three air probe locations. The air velocity was determined from a hot wire anemometer which gave a direct readout in m/s. However, if the air was heavily laden with water or the velocity exceeded the maximum reading (30 m/s) of the hot-wire anemometer, a pitot tube was used to obtain a measurement of the air velocity head.

The discharge measurement for each steady-state test was made using the laboratory 4-, 6-, or 8-in venturi meter (NE. bank).

Steady-state test runs were made at the 20, 40, 70, and 100 percent gate openings (each having an identified problem area as previously discussed) for the as-built and the three modifications described below. Later additional steady-state test runs were made at the 30, 50, and 60 percent gate openings with the 1/2-in ring and the 2-in ramp configurations, modification No. 3.

Video tape recordings were made of the as-built configuration and after each modification for steady-state flow conditions at gate openings of 10, 40, 70, and 100 percent. Copies of the unedited tape recordings were sent to the Shasta Office and the Mid-Pacific Regional Office.

Modifications No. 1 and 2 were to reduce the extreme fluctuations of the air demand and negative pressures on the conduit side wall. Modifications No. 1 and 2, sealed bulkhead and the deflector plate, were combined. The first deflector plate was installed in the crown of auxiliary outlet

Table 1. - Summary of the Trinity jet-flow gate model calibration[4]

Jet flow gate opening (%)	Model gate leaf handle turns + degrees (initial = 4+320)	Model scale of March 13-14, 1963 field measurements: upstream head[1]	Model scale of March 13-14, 1963 field measurements: downstream head[2]	Jet flow gate model, H_o = P1 upstream head: ft H_2O	Jet flow gate model, H_o = P1 upstream head: mm[3] Hg	Jet flow gate model: discharge Q ft^3/s	Prototype discharge Q ft^3/s
0	0+0	24.83	0	24.83	556.4	0	0
10	7+129				550.0	0.30	256
20	14+258	24.01	-0.09	23.99	537.7	0.66	565
30	22+27				504.0	1.13	964
40	29+156	20.31	-0.31	19.52	437.4	1.67	1425
50	36+285				342.0	2.10	1791
60	44+54	13.62	-0.42	11.92	267.0	2.60	2221
70	51+183				196.0	2.92	2490
80	58+312	7.23	-0.33	5.68	127.2	3.17	2706
90	66+81				83.0	3.33	2836
100	73+210	3.43	-0.41	2.28	51.1	3.44	2936

1/ Not used in trial and error calculations but listed for comparative purposes.
2/ Used in trial and error calculations.
3/ Mercury manometer reading (mm) with 0 at P1 elevation.
4/ Head loss assumptions, K_e: (in terms of the velocity head)

Trashrack	=	0.01
Entrance	=	0.15
Bend	=	0.05
Total K_e	=	0.21

Assume rugosity ε/D = 0.0007/7 = 0.0001 and f = 0.012
Trinity Dam Reservoir elevation = 2368.2 feet

conduit (perpendicular to the centerline) 6 ft downstream from the end of the aluminum air duct and was 2 ft (prototype) in depth at the centerline. The deflector plate at this location was not completely satisfactory. The deflector plate combined with the bulkhead seal reduced the pressure fluctuations by about 60 percent at the 70 percent gate opening. However, some return flow on top of the main flow prism at the end of the auxiliary outlet conduit still occurred. Actually, it appeared to have increased because the reversed flow from the spillway tunnel was being deflected downwards into the roller area. The upstream edge of the deflector plate was catching the top of the roller on a random basis. The roller would then advance upstream. Twice during the 70 percent gate opening steady-state test run (No. 7), the roller submerged the downstream end of the aluminum air duct and primed the entire auxiliary outlet conduit and the air duct system, causing extremely high negative pressures. The high negative pressures were beyond the range of the manometers and could not be measured. The vertical deflector plate was moved down the opposite side of the spillway tunnel as shown in figure 7. The first deflector plate tested at this lcoation was 15 in deep by 6 ft, 10 in long (prototype). It was later modified by increasing the length to 8 ft (in the downstream direction). A general view of the return flow being deflected away from the entrance of the auxiliary outlet works conduit can be observed in figure 8.

The sealed bulkhead and the vertical deflector plate inside the spillway tunnel were in place for all subsequent modifictions made to the model.

For the third modification, the 2-in-high (prototype) offset orifice ring plate (figure 3) was replaced with an orifice ring plate having a 1/2-in-high offset. The smaller offset into the flow significantly improved the overall operating characteristics of the auxiliary outlet conduit and the air duct system. The average negative pressures and the pressure fluctuations were reduced significantly at gate openings above 40 percent. The air demand also decreased. The maximum air demand now occurred between 30 and 40 percent gate openings. The roughest operation (the highest pressure fluctuation) occurred at the 40 percent gate opening. However, it was considerably smoother compared to the "as-built" conditions which occurred at the 70 percent gate opening. Figure 9 shows the flow conditions at the 40 percent gate opening. The flow still impinges onto the bottom of the air duct system beginning about 20 ft and ending about 40 ft (prototype) downstream of the air slot. The impingement length was reduced about 70 percent compared to the 2-in orifice ring offset flow condition. However, the flow in the impingement area was well aerated with heavy wave action. Therefore, the flow in the impingement area did not completely seal off the upper portion of the conduit. The air pressure upstream and downstream of the impingement area remained relatively equal. The equalized air pressure prevented the development of large negative pressure fluctuations in the air duct system compared to the 2-in orifice ring offset flow conditon.

A 2-in (prototype) ramp offset having a 10:1 slope on the upstream side of the air slot was tested next as a variation of the third modification to the Trinity model. The 2-in (prototype) orifice ring used in the as-built configuration was reinstalled (after removing the 1/2-in ring). The 10:1 slope ramp was formed with automotive body filler placed to the top edge of the 2-in-high orifice ring offset. The ramp was formed on the inside circumference to 8 ft (prototype) above the conduit invert. The flow characteristics of the 2-in ramp were similar to the 1/2-in orifice ring offset. The 2-in ramp can be considered as an alternative to the 1/2-in ring. However, overall, the side wall and invert negative pressure measurements were slightly greater and the air demand was slightly higher with the 2-in ramp.

TEST RESULTS

General

The overall review of the test results of the as-built and the three modifications to the Trinity model can best be observed in figure 10. Figure 10 is a plot of the average static pressure head at the upstream end of the aluminum air duct (P13) versus the gate opening. The average static pressure head at P13 provides a good indication of the air demand requirements which can be used to evaluate the modifications. As illustrated, the maximum air demand for the as-built configuration occurred at the 70 percent gate opening.

Installing the sealed bulkhead and the downstream deflector plate, reduced the air demand requirements for gate openings greater than 40 percent gate. The 1/2-in orifice ring offset modification reduced the air demand significantly for gate openings above 40 percent. However, the air demand below 40 percent gate opening increased slightly. The air demand requirements for the 2-in ramp were similar to, but slightly greater than, the 1/2-in ring. The maximum air demand with the 1/2-in ring or 2-in ramp modification occurred at the 30 to 40 percent gate opening range.

Side wall pressure

Figure 11 shows the maximum average subatmospheric pressures that occurred on the side wall immediately downstream of the air slot and at the downstream end of the air scoop (P9's and P10's, figure 5). As illustrated, the largest negative pressure for the as-built configuration occurred at the 70 percent gate opening. It was at this point where the maximum pressure fluctuations of -3.3 ft (model) occurred (P10b, figure 5). At the 1:14.87 model scale, vapor pressures would have occurred in the prototype at this location. The sealed bulkhead and deflector plate reduced the maximum average negative pressure from -25.5 to -15.5 ft (prototype), a reduction of about 40 percent, at the 70 percent gate opening. The maximum pressure fluctuations also reduced to -1.2 ft (model), a reduction of about 60 percent compared to the -3.3 ft (model) for the as-built configuration.

The 1/2-in orifice ring offset modification reduced the side wall negative pressure significantly with the maximum average negative pressure of -12.7 ft (prototype) occurring at the 40 percent gate opening at P10f (figure 5). The maximum pressure fluctuation occurred at P10i and was -1.25 ft (model). The prototype maximum pressure fluctuation at this point would be -18.6 ft which is well above vapor pressure.

With the 1/2-in orifice ring offset modification the roughest operation now occurred at the 40 percent gate opening. However, the pressure head variation from the average is only about ±3 ft (prototype). This is not a serious problem and the jet flow gate could be operated successfully at the 40 percent opening on a continuous basis.

Figure 11 illustrates that the 2-in ramp modification is similar to the 1/2-in ring. However, the average negative pressure at the 40 percent gate opening increased to about -17.6 ft (prototype) with a maximum negative pressure fluctuation to about -23.0 ft (prototype). Therefore, the overall operating characteristics for the 1/2-in ring modification has less average negative pressure and pressure fluctuations compared to the 2-in ramp.

The maximum negative pressure occurred at the end of the air scoop which is also the end of the existing prototype steel liner. The vertical row of piezometer taps P10b, P10f, and P10i, figure 5, are located at the end of the steel liner. The vertical row downstream, piezometer taps P10c, P10g, and P10j, are 5 ft (prototype) downstream in the concrete-lined section of the egg shaped conduit. Figure 12 is a plot of the maximum average pressure at P10b, P10f, and P10i compared to the maximum at P10c, P10g, and P10j versus the percent gate opening, using the data from the 1/2-in ring modification test runs. The negative pressure is less in the concrete section with a maximum of -9.0 ft (prototype) occurring at the 40 percent gate opening. The relatively moderate negative pressures do not warrant the extension of the steel liner downstream for the protection against cavitation damage.

Invert pressure

In general, the negative pressures at the invert downstream of the air slot were less negative than the side wall pressures. Figure 13 shows the invert negative pressure measurements for the 1/2-in ring and the 2-in ramp configurations. The maximum negative pressure head downstream of the air slot for the 1/2-in ring occurred at the 50 percent gate opening and was -7.6 ft (prototype). For the 2-in ramp the maximum negative pressure head occurred at the 40 percent gate opening and was -13.3 ft (prototype).

Figure 13 also shows the pressure measurements upstream of the air slot. The pressures were generally positive for gate openings greater than 30 to 40 percent. The maximum average negative pressure of -15.0 ft (prototype) at P4 occurred at the 20 percent gate opening for the 2-in ring ramp. For the 1/2-in ring, the average maximum negative pressure also occurred at the 20 percent gate opening but was only -1.2 ft (prototype) and was positive for all openings greater than 20 percent.

The average maximum negative invert pressure at the centerline of the air slot (P5) for the 1/2-in ring and 2-in ramp configurations is shown in figure 14. The air slot pressure was very similar to the invert pressure downstream (as shown in figure 13). The air slot pressures were only slightly more negative than the invert pressures downstream. This indicates that the air slot is functioning efficiently. Considerable amount of water was present in the air slot for both the 1/2-in ring and 2-in ramp configurations. In both cases, water would splash upwards and fall back into the inside of the air scoop. The only way that the water could be aspirated from the air slot is to install a ramp offset below the invert downstream of the air slot (about 6 in below the invert at a 10:1 slope back to invert grade). This modification would be expensive to construct and cannot be justified for the added improvement to the air slot operation which may not provide a significant reduction in the potential for cavitation damage. The air slot downstream offset-ramp modification was not tested on the Trinity model.

Air demand

Air velocity point measurements were taken inside the air duct system at the three air velocity probe locations shown in figure 5. The three locations were (1) upstream of the air slot, (2) immediately downstream of the air slot, and (3) at the upper end of the aluminum air duct (refer to fig. 5). As discussed previously the air velocity was measured with a hot-wire anemometer or a pitot tube. The point measurements were obtained on the vertical centerline at about 5-mm intervals. The average velocity for each air velocity probe location was determined by averaging the point velocity measurements. The air discharge was then calculated using the appropriate cross-sectional areas of the air duct system shown in figure 4.

The results of the average air velocity measurements and air discharge calculations versus the percent gate opening are shown in figure 15 for the 1/2-in orifice ring offset modification. The maximum air flow inside the aluminum air duct occurred at the 40 percent gate opening. The maximum velocity was about 450 ft/s (prototype) with an air discharge of about 2,000 ft^3/s. Inside the air scoop the maximum air velocity was about 225 ft/s at the 40 percent gate opening. The air discharge requirement was about 1,840 ft^3/s downstream and 1,380 ft^3/s upstream of the air slot. The difference of about 460 ft^3/s air discharge was therefore being drawn into the air slot. The air slot discharge at air velocity probes No. 2 and 3, figure 15(b), should have been the same. The deviation shown is believed to be the result of the technique used to measure point velocity and to calculate the average velocity.

The air flow for the 1/2-in ring modification is considered to be appropriate for the Trinity Dam jet-flow gate. The area capacity of the air duct system as-built is adequate. However, it is very important that the entire length of the air duct system be sealed from the auxiliary outlet conduit except, of course, at the ends and at the air slot. Large leaks, such as experienced at the end of the air scoop in the as-built configuration, increase the air demand requirement. As a result the negative pressures on the side wall and invert in the conduit section immediately downstream of the jet-flow gate, will also increase substantially.

Jet-flow gate calibration

The discharge coefficient for the the jet-flow gate was re-evaluated using the 1/2-in orifice ring offset test run data. The laboratory data and the coefficient of discharge calculation are listed in table 2. The data points are plotted in figure 16, shown by the triangles. The coefficient of discharge calibration agrees closely with the previous model investigation as shown in figure 16 which was taken from report HYD-472, figure 10. However, the prototype jet-flow gate calibration has never been verified. The field test of March 13 and 14, 1963, did not include a measurement of the prototype discharge.

Spillway tunnel flow

It was of interest to field operating personnel to know if the auxiliary outlet works could be operated at the 100 percent gate opening when the Trinity Dam spillway was discharging 3,500 ft^3/s.

With the auxiliary outlet works operating at the 100 percent gate opening, and no spillway discharge, the water depth upstream from the auxiliary outlet conduit junction builds up to about 8 ft (prototype). Based on the general equation for a hydraulic jump in conduit flowing part full, it appears that with a conjugate depth of 8 ft only about 200 ft^3/s spillway discharge is required to wash out the hydraulic jump. Therefore, the flow conditions at the auxiliary outlet conduit junction should not cause any problems with the conduit flow or air demand requirements. The flow depth in the spillway tunnel for a spillway discharge of 3,500 ft^3/s would be about 3.6 ft (prototype), which is much less than the 8 ft that occurs when the auxiliary outlet only is operating.

Of concern, was a spillway discharge less than 200 ft^3/s which may cause the water level to rise above 8 ft and interfere with the auxiliary outlet conduit flow into the spillway tunnel. A fire hose having a flow representing about 75 ft^3/s (prototype) was discharged into the upper end of the Trinity model spillway tunnel. The increased flow into the spillway tunnel upstream did not raise the water level enough to cause a change in the flow conditions at the auxiliary outlet conduit junction when it was operating at a 100 percent flow condition. Therefore, spillway tunnel flow from upstream should not interfere with the operation of the auxiliary outlet works, at least up to a spillway discharge of 3,500 ft^3/s. To test the Trinity model, with a spillway discharge greater than 75 ft^3/s (prototype) would have required a major model change. However, the added cost did not seem necessary based on the fire hose test results which appeared to be the more critical flow condition.

CONCLUSIONS

Based on the above test results, the following conclusions are made:

1. The existing 2-in-high orifice ring offset at the upstream edge of the air slot should be reduced to a 1/2-in offset (to a height 8 ft above the conduit invert) to reduce flow impingement onto the bottom of the air duct system, thereby reducing the air demand and negative pressures on the conduit side wall.

Table 2. - Hydraulic model test jet-flow gate calibration using the 1/2-in orifice ring offset test run data[1/]

Gate opening %	Laboratory venturi discharge Q ft^3/s	Upstream head H_0 ft H_2O	Downstream head H_2 ft H_2O	Velocity head H_v ft H_2O	Total head ΔH_T ft H_2O	Coefficient of discharge C_d
20	0.646	23.894	-0.371	0.214	24.479	0.094
30	1.151	22.600	-0.597	0.680	23.877	0.169
40	1.657	19.588	-0.717	1.407	21.712	0.254
50	2.065	15.238	-0.389	2.186	17.813	0.350
60	2.536	11.936	-0.249	3.295	15.480	0.461
70	2.885	8.634	-0.158	4.265	13.057	0.572
100	3.388	2.309	-0.128	5.880	8.317	0.841
2/ 100	3.378	2.309	-0.116	5.847	8.272	0.841

1/ For nomenclature and the coefficient of discharge, C_d, equation, refer to figure 16.
2/ Data from the 2-in ramp offset test run.

2. The entire length of the air duct system must be sealed (except at the ends and at the air slot) and a perpendicular deflector plate installed as shown in figures 7 and 8 to reduce the air demand and the negative pressure fluctuations on the conduit side walls.

3. The structural integrity of the aluminum air duct must be increased to withstand (a) flow impingement that occurs at partial gate openings and (b) wave action that normally occurs at the 100 percent gate opening.

4. With the above three modifications, the jet-flow gate can successfully be operated continuously at any gate opening tested. However, we recommend the jet-flow gate not be operated at an opening less than 5 percent. The maximum air demand and roughest operating characteristics will occur at about the 40 percent gate opening. The smoothest operation occurs at the 90 percent gate opening.

5. The jet-flow gate coefficient of discharge reported in HYD-472 was verified by the current Trinity Dam Auxiliary Outlet Works model studies. However, the prototype jet-flow gate coefficient of discharge calibration has never been verified with appropriate field measurements.

6. The maximum air demand occurs at about the 40 percent gate opening and requires about 2,000 ft^3/s air discharge in the aluminum air duct. The capacity of the as-built air duct system is adequate.

7. Trinity Dam spillway discharges up to 3,500 ft^3/s should not interfere with the auxiliary outlet works operation.

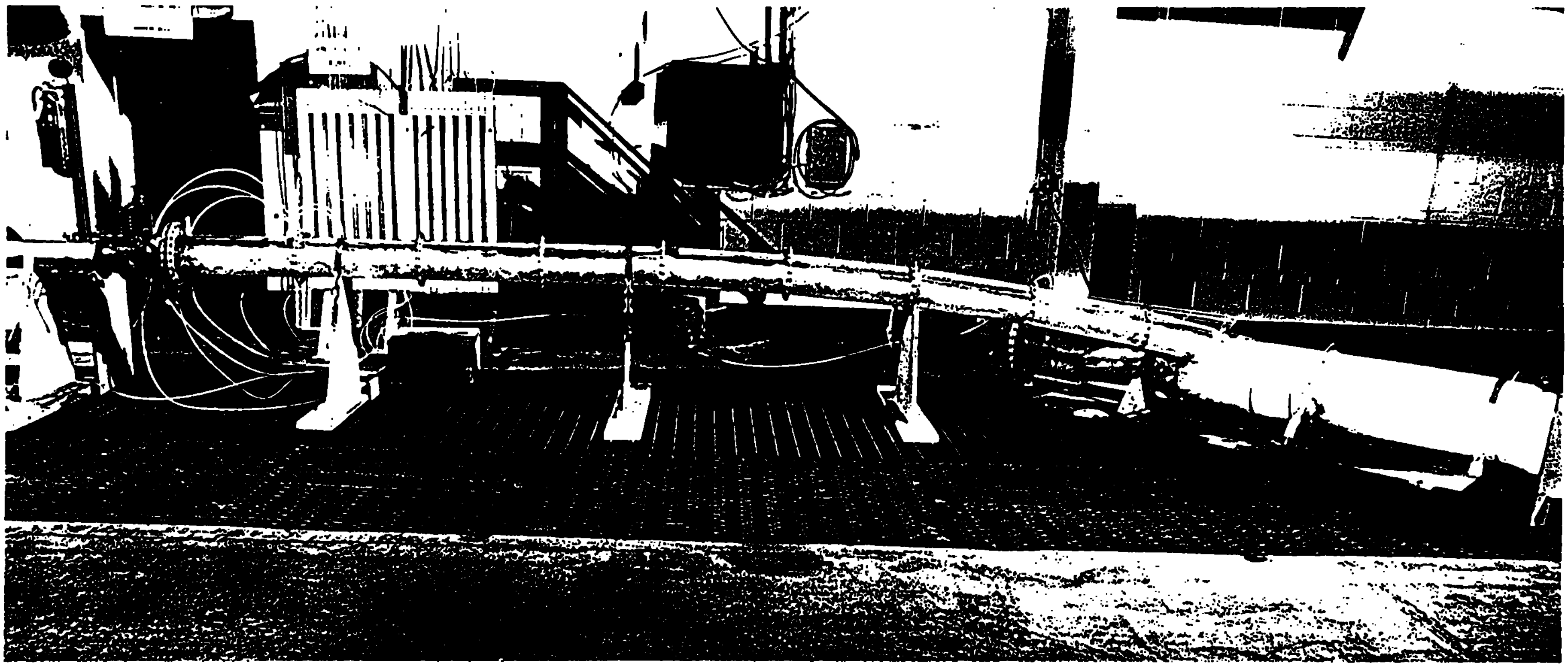


Figure 1. - General view of the modified Trinity Auxiliary Outlet Works 1:14.87 scale model operating at 100 percent gate opening.

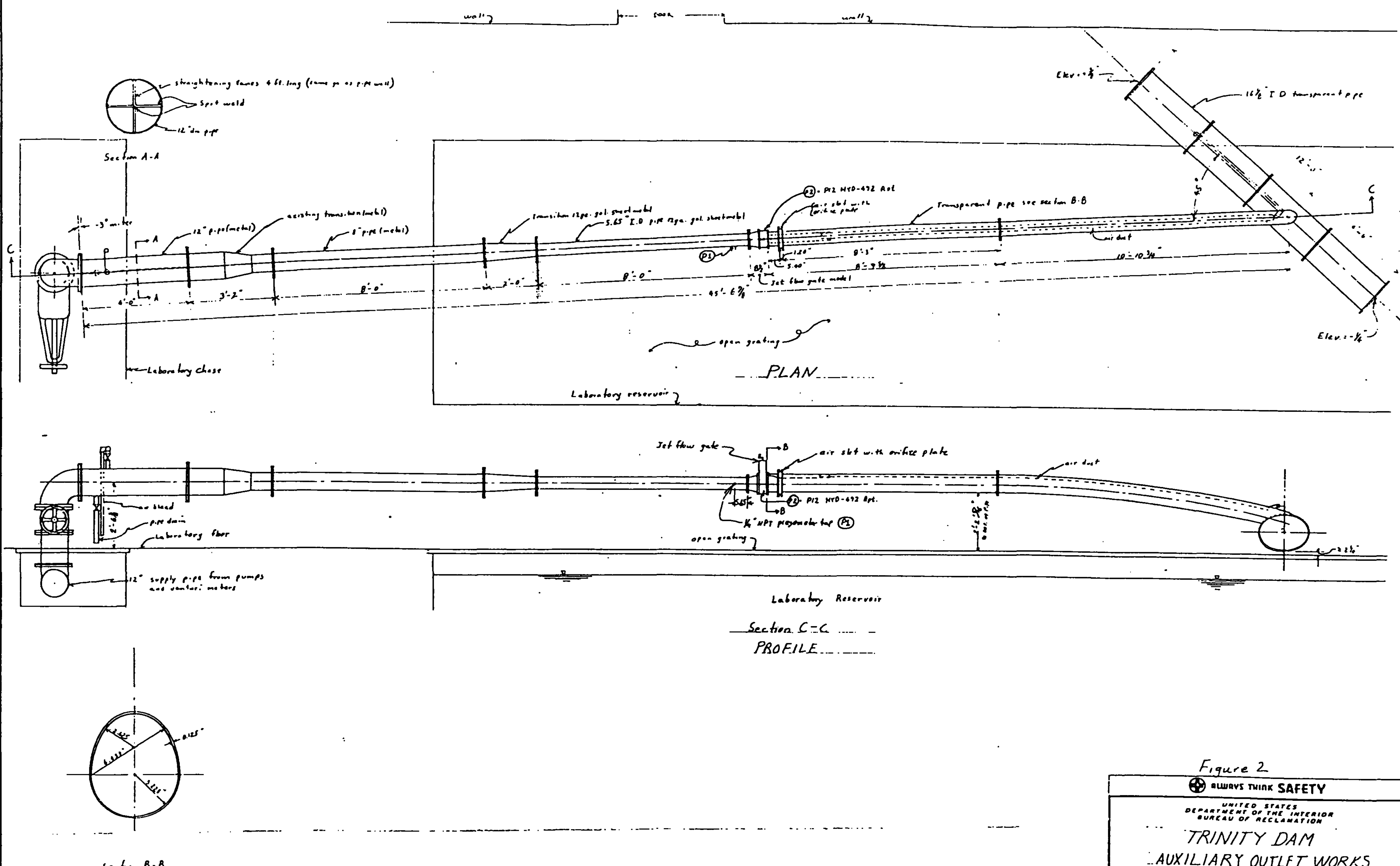


Figure 2

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRINITY DAM
AUXILIARY OUTLET WORKS
GENERAL LAYOUT

DESIGNED ... TECHNICAL APPROVAL ...
DRAWN ... SUBMITTED ...
CHECKED ... APPROVED ...
DENVER, COLORADO Apr. 16, 1955

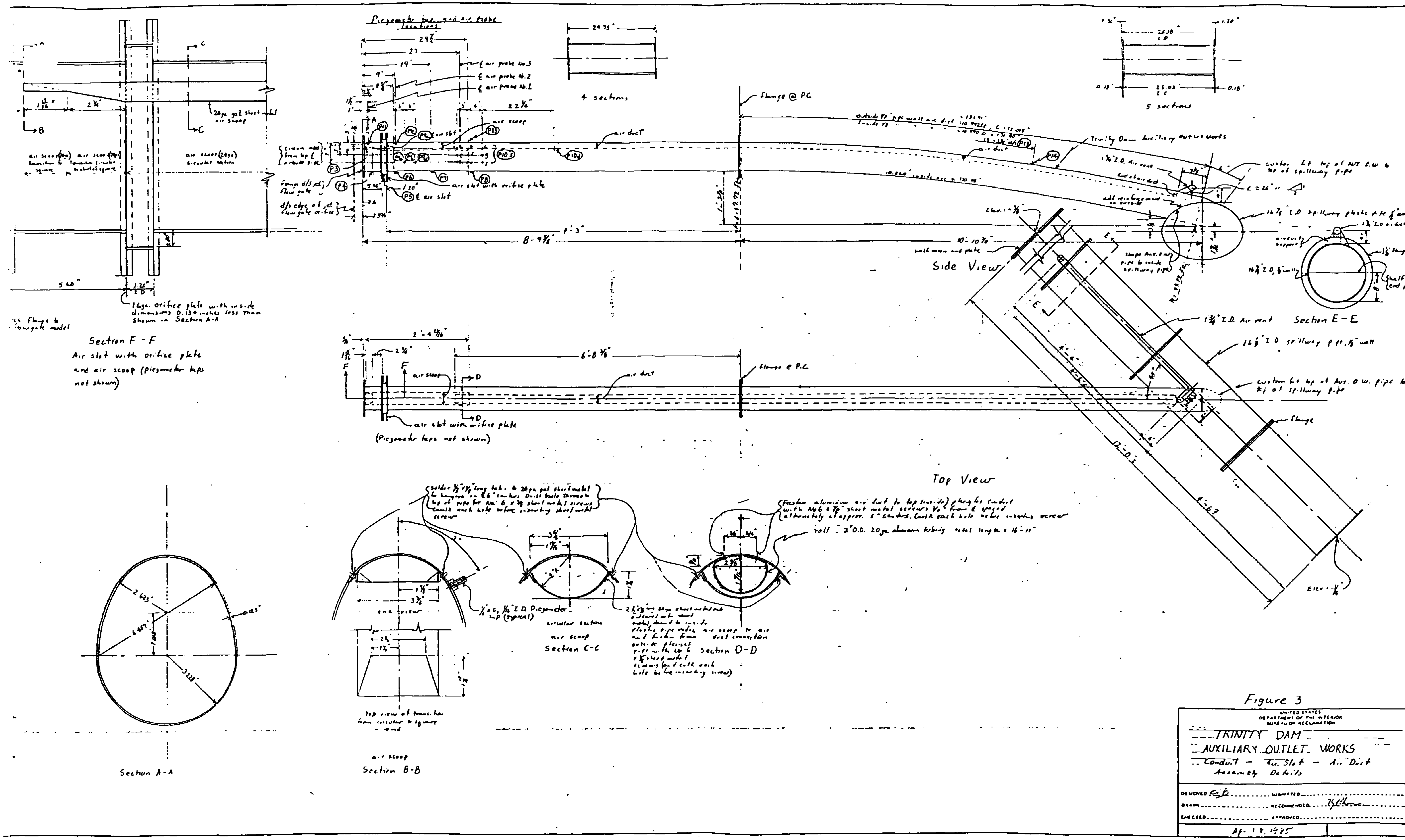


Figure 3

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRINITY DAM
AUXILIARY OUTLET WORKS
Conduit - Air Slot - Air Duct
Assembly Details

Apr. 14, 1975

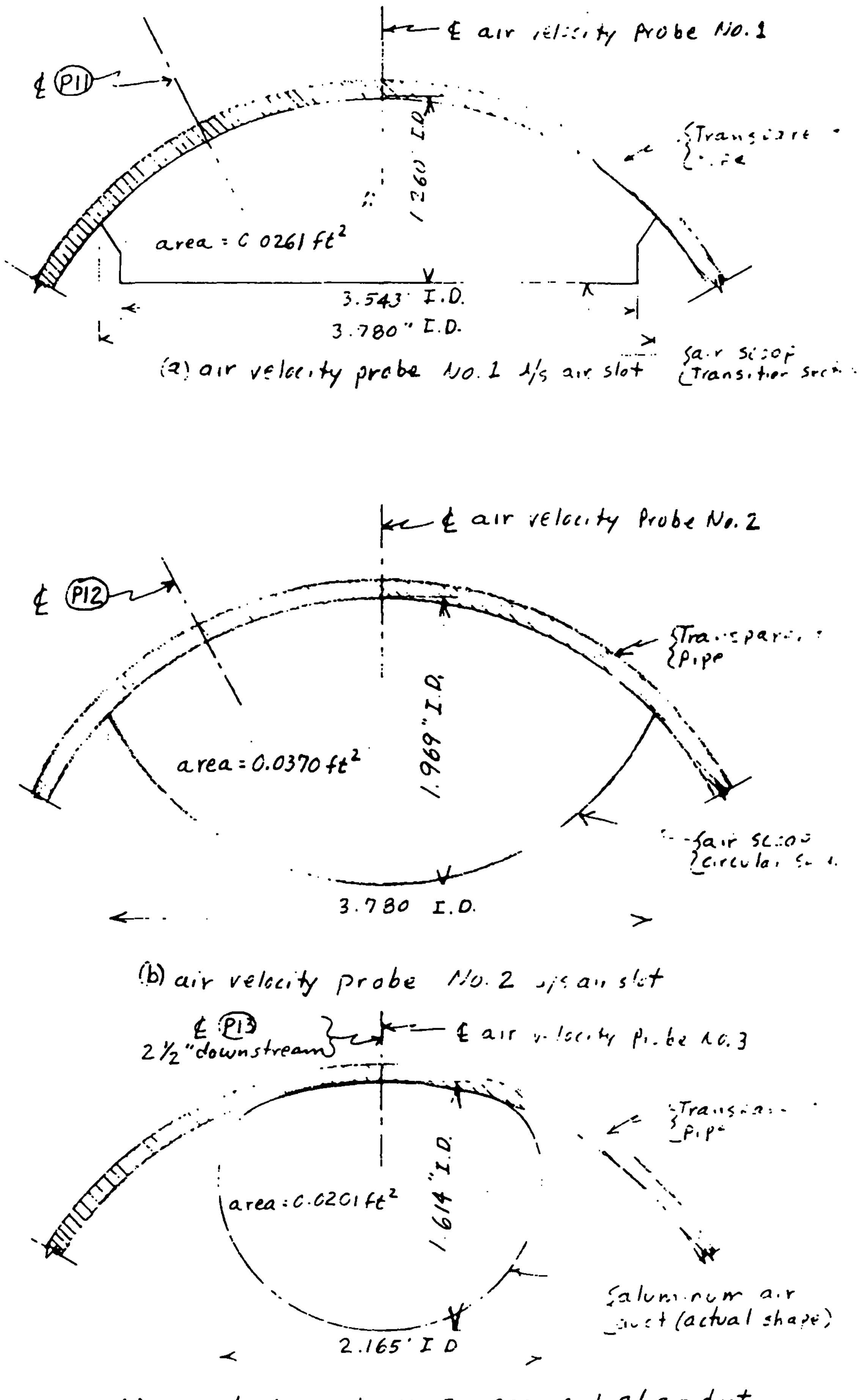
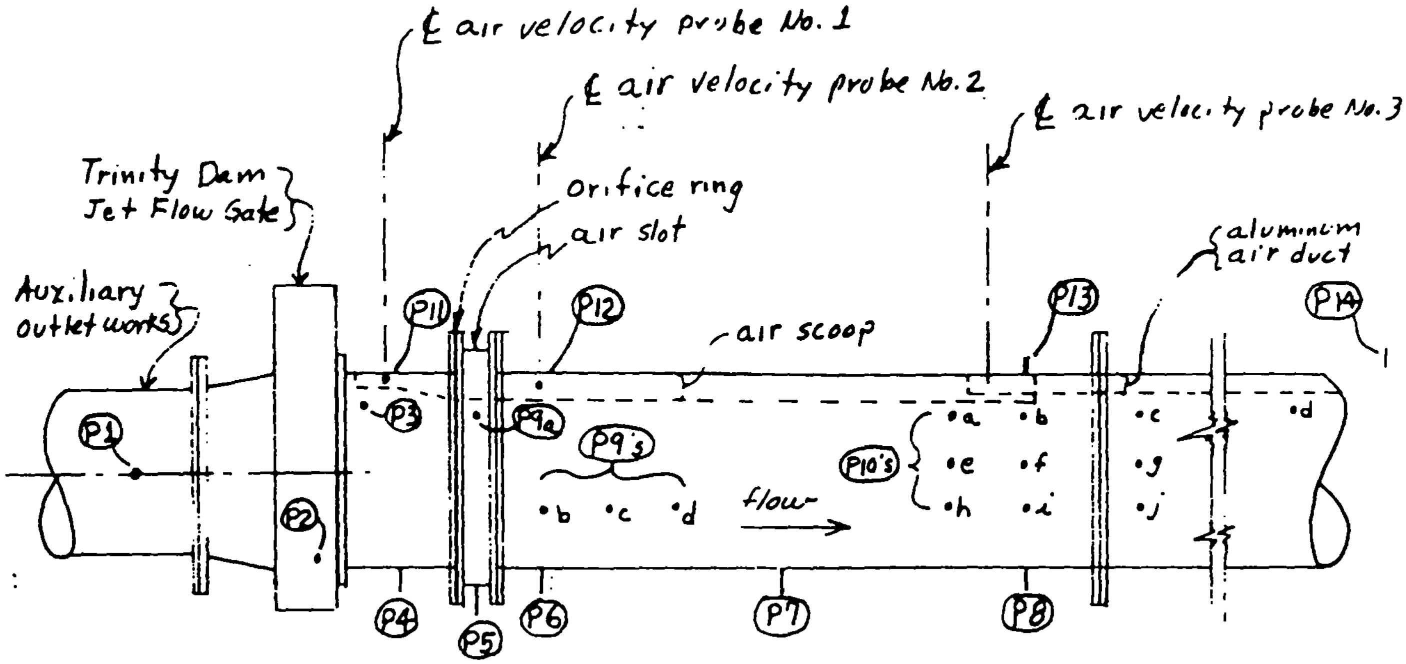


Figure 4 - Cross-sectional areas (as-built) of the Trinity Auxiliary Outlet Works model air velocity probe (a) No. 1, (b) No. 2, and (c) No. 3 locations (actual size, model scale 1:14.89)



Not to scale
(for demensioned locations refer to figures 2 & 3)

Figure 5 - General layout of piezometer tap and air velocity probe locations.

Trinity Dam Auxiliary Outlet Works
1:14.87 Scale Model

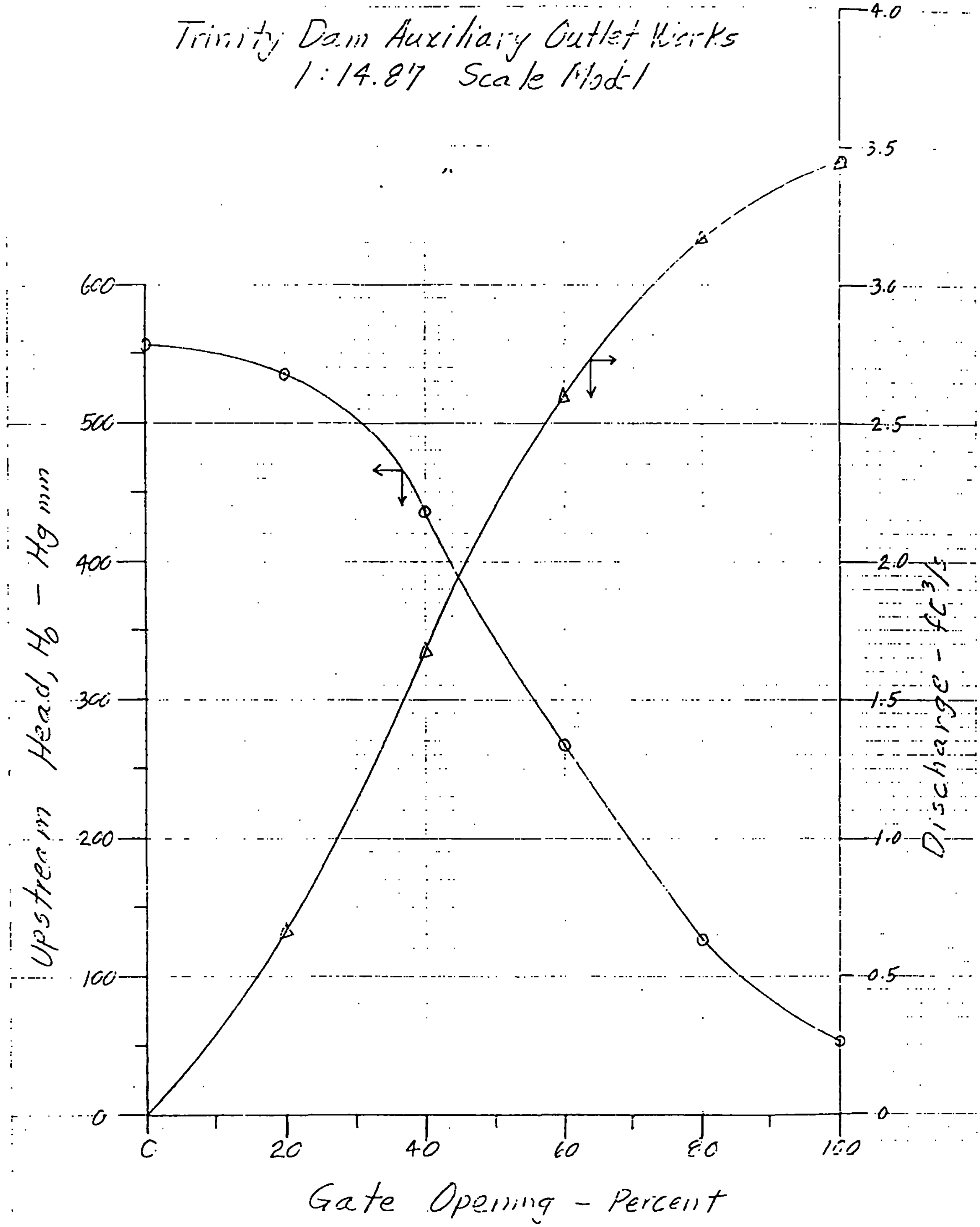
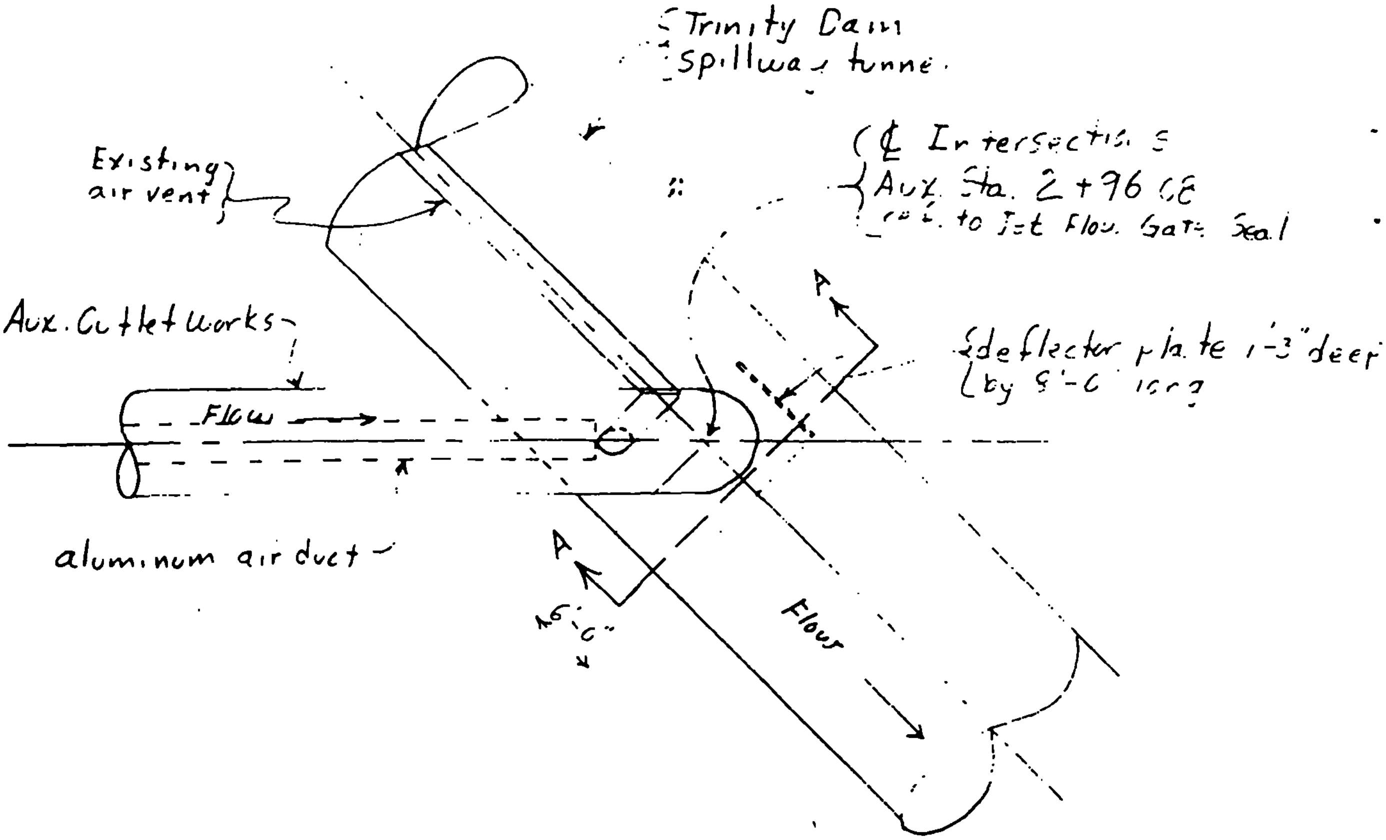
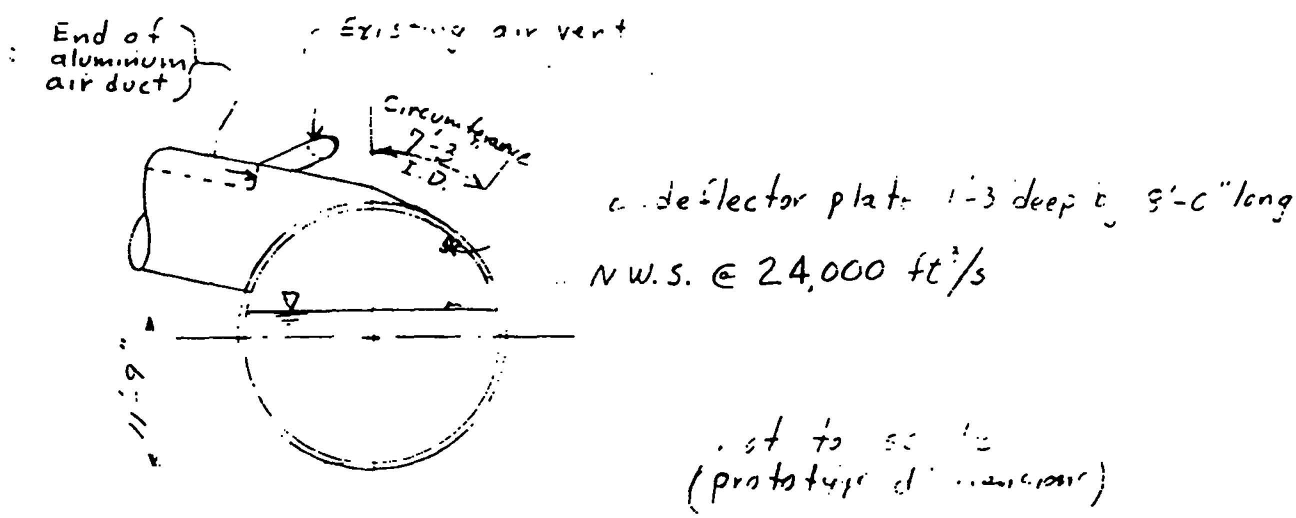


Figure 6- Trinity Dam Jet Flow Gate Model Calibration

cjv 6/26/85





Section A-A

Figure 7 - Location of spillway tunnel deflector plate

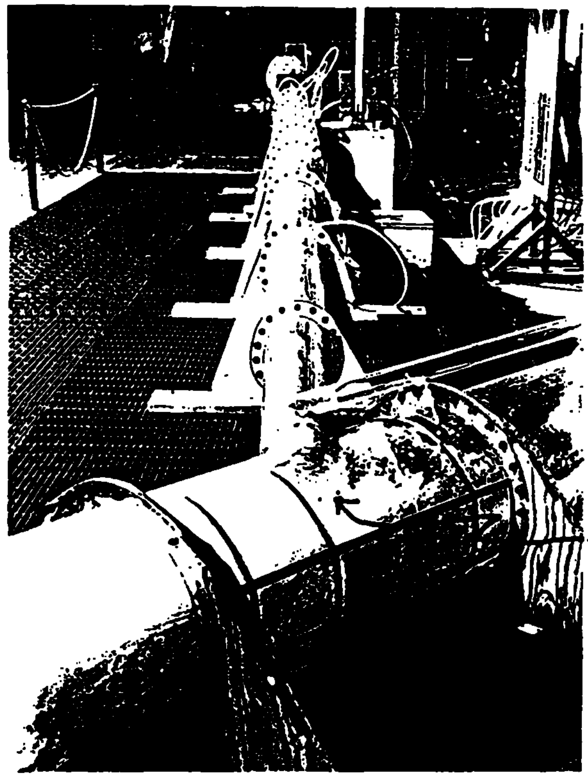


Figure 8. - General view of the vertical deflector plate installed inside the Trinity Dam spillway tunnel opposite the auxiliary outlet conduit entrance with the flow at 100 percent gate opening.

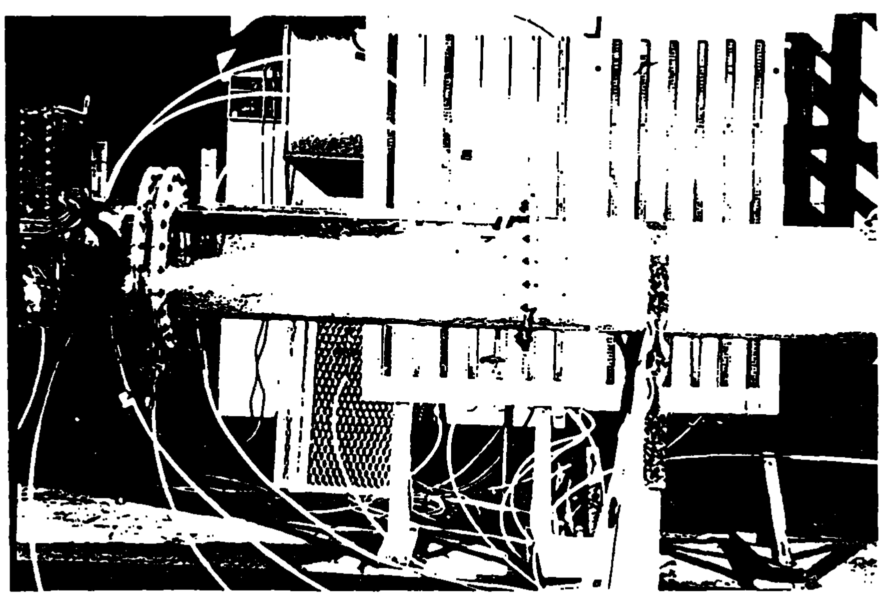


Figure 9. - General view of the flow impingement onto the bottom of the [illegible] system at 40 percent gate opening [illegible] the 1/2-in-high [illegible] ring orifice installed.

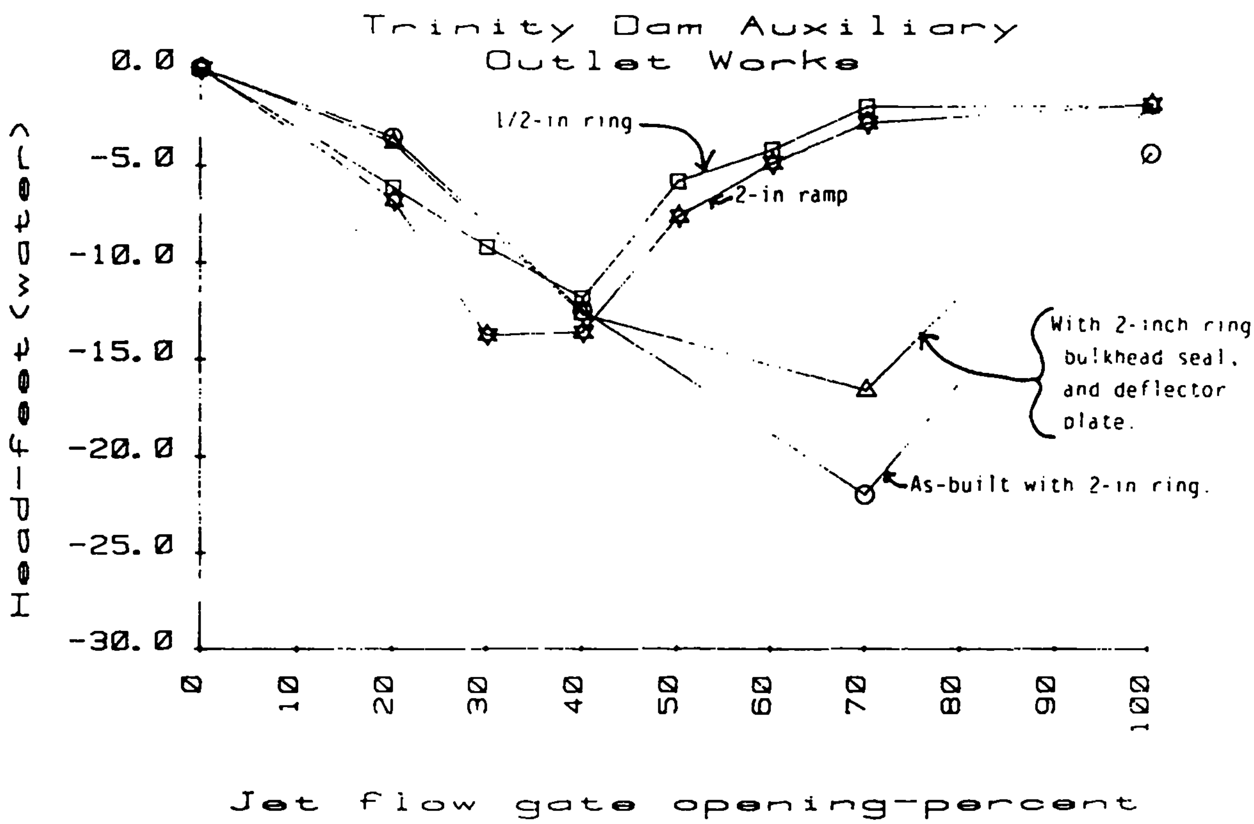
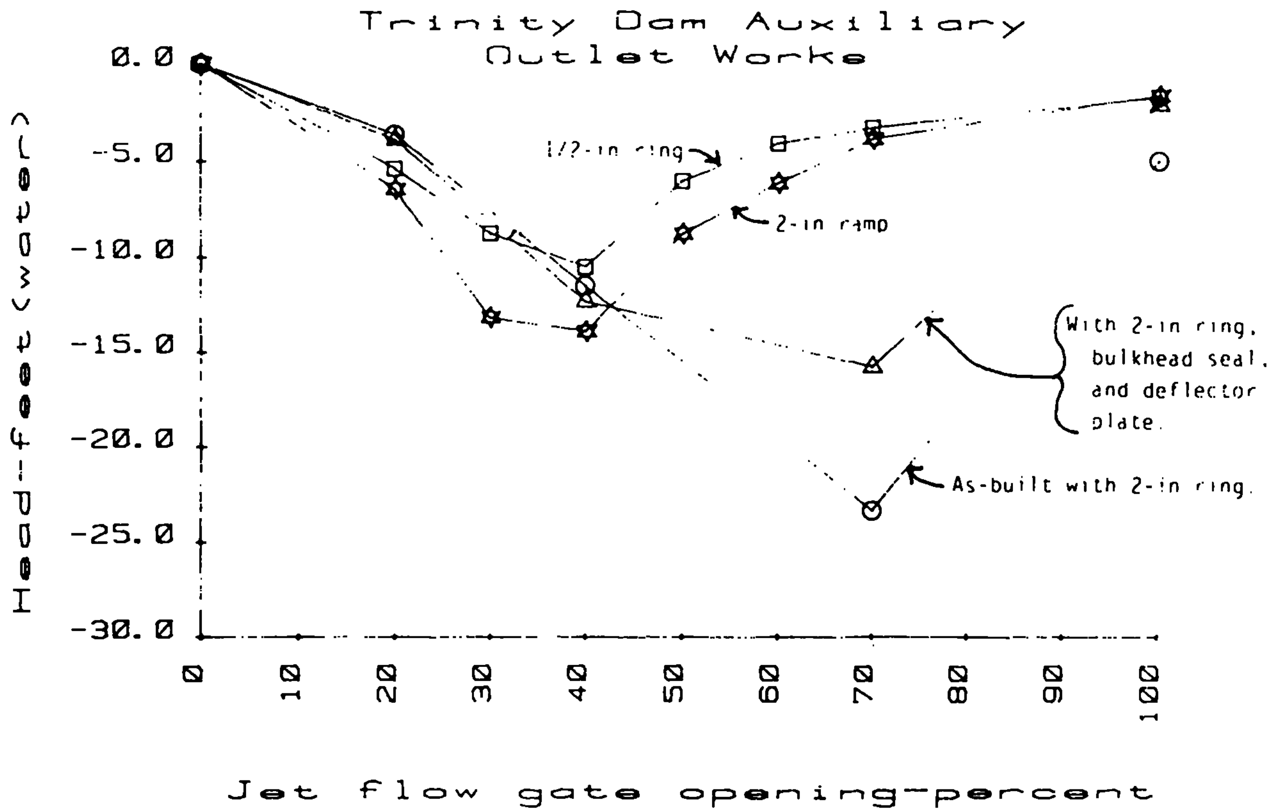
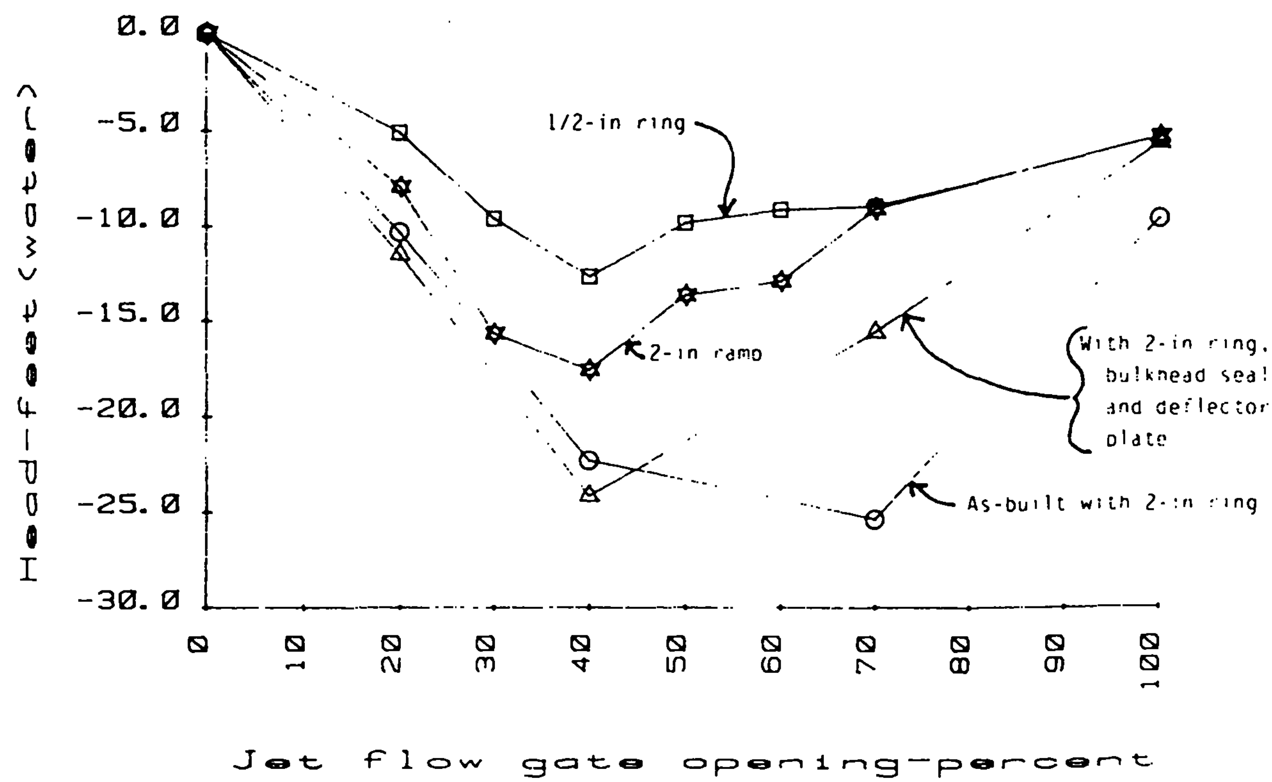


Figure 10. - Average static air pressure head inside upstream end of aluminum air duct (P13) vs. gate opening.



(a) Immediately downstream of air slot
(maximum of P9b, P9c, or P9d)



(b) Downstream of air slot at end of steel liner
(maximum of P10a through P10j)

Figure 11. - Average side wall pressure head at (a) immediately downstream of air slot and (b) at end of steel liner vs. gate opening.

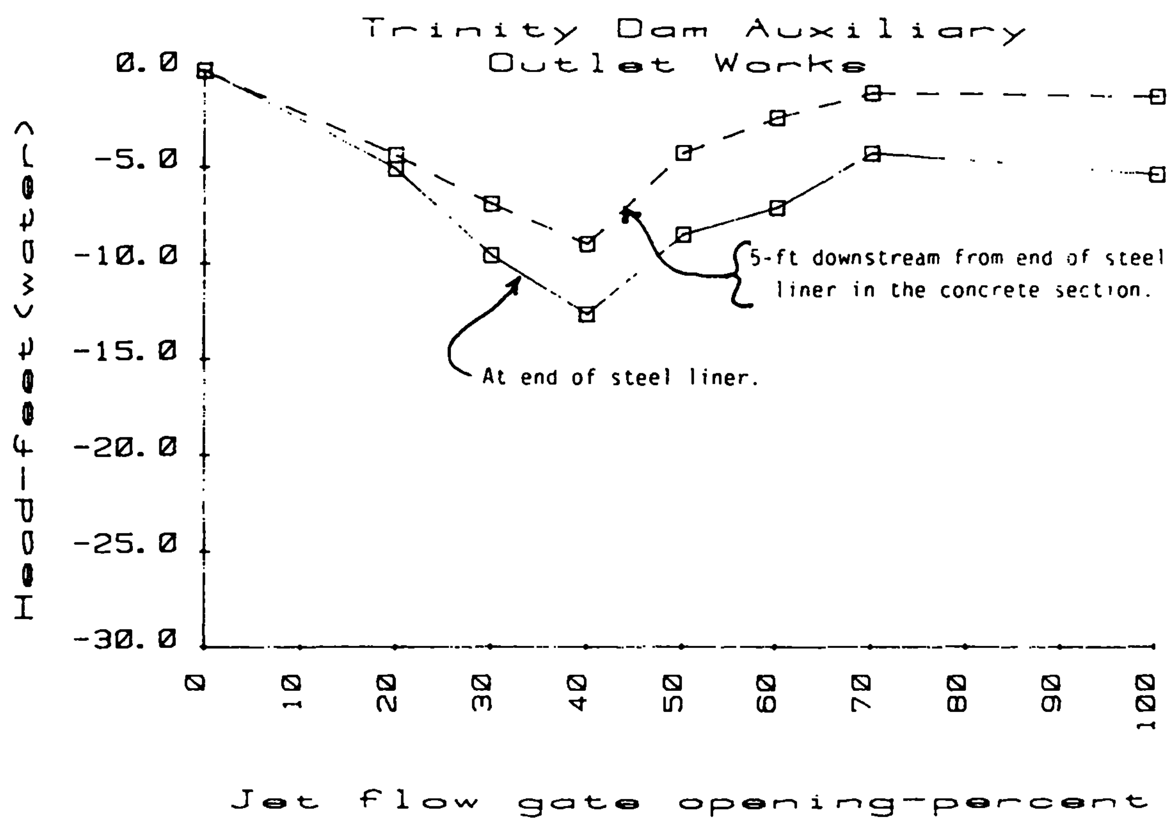


Figure 12. - Average side wall pressure head at the end of the steel liner (maximum of P10b, P10f, or P10i) compared to 5-ft downstream in the concrete section (maximum of P10c, P10g, or P10j) based on the 1/2-in high orifice ring offset configuration vs. gate opening.

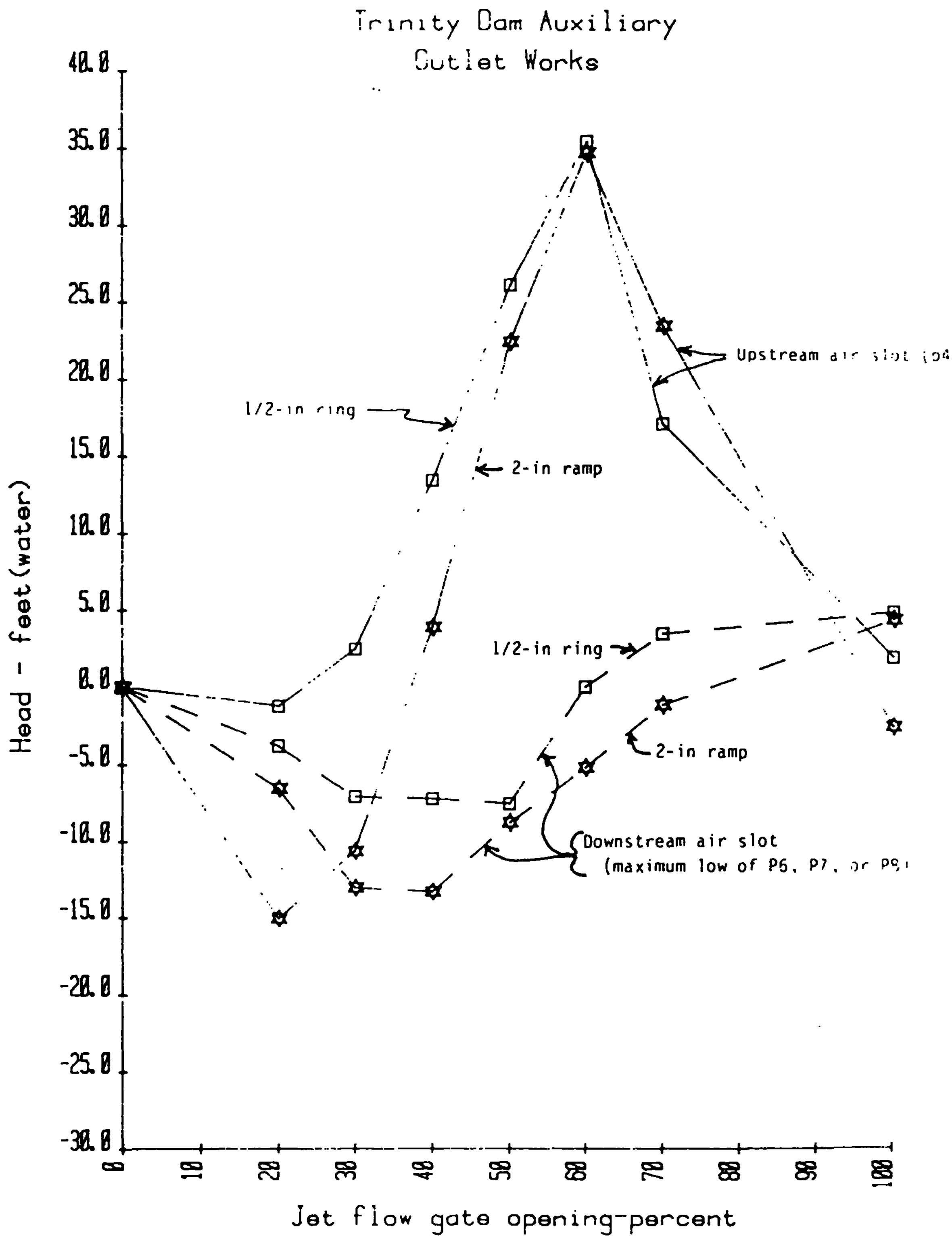


Figure 13. - Average invert pressure head upstream and downstream of air slot vs. gate opening.

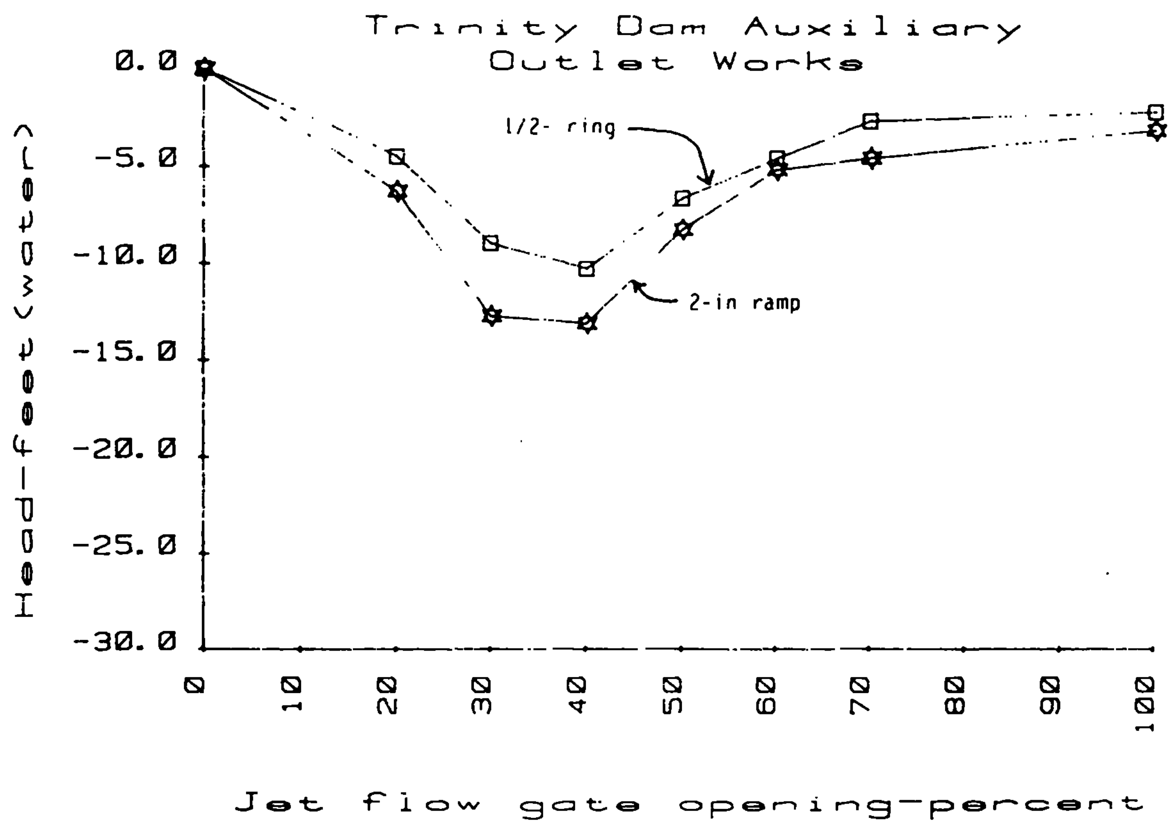
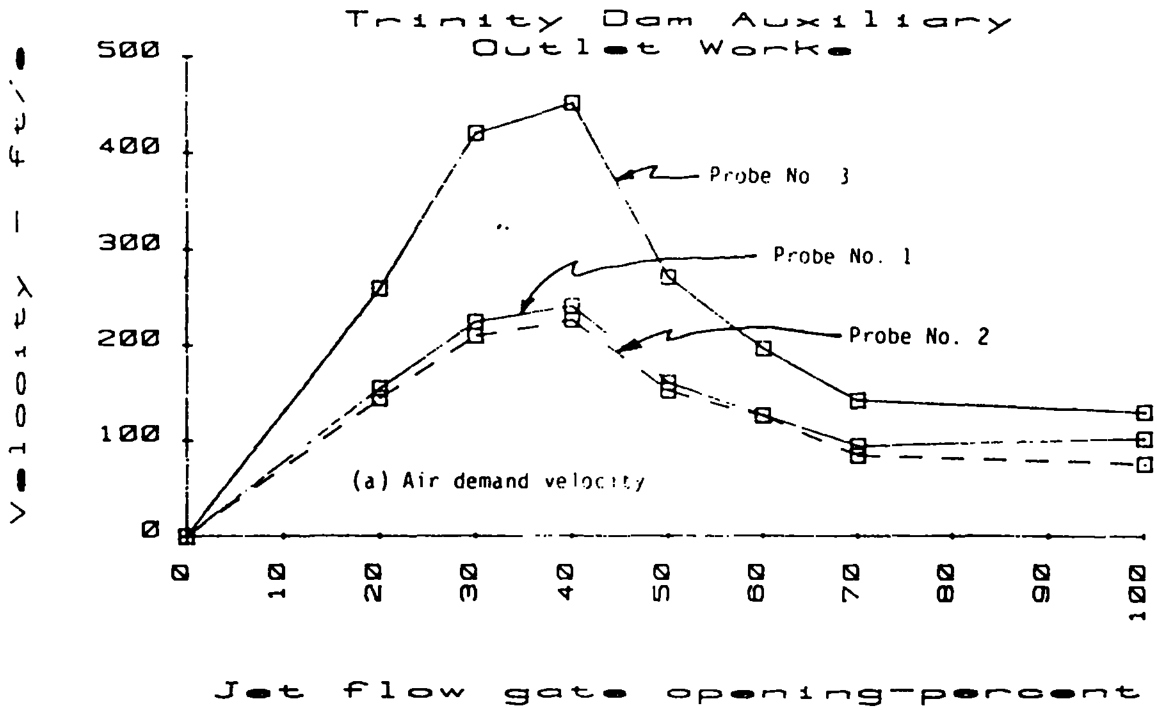


Figure 14. - Average invert pressure head at the centerline of the air slot (P5).



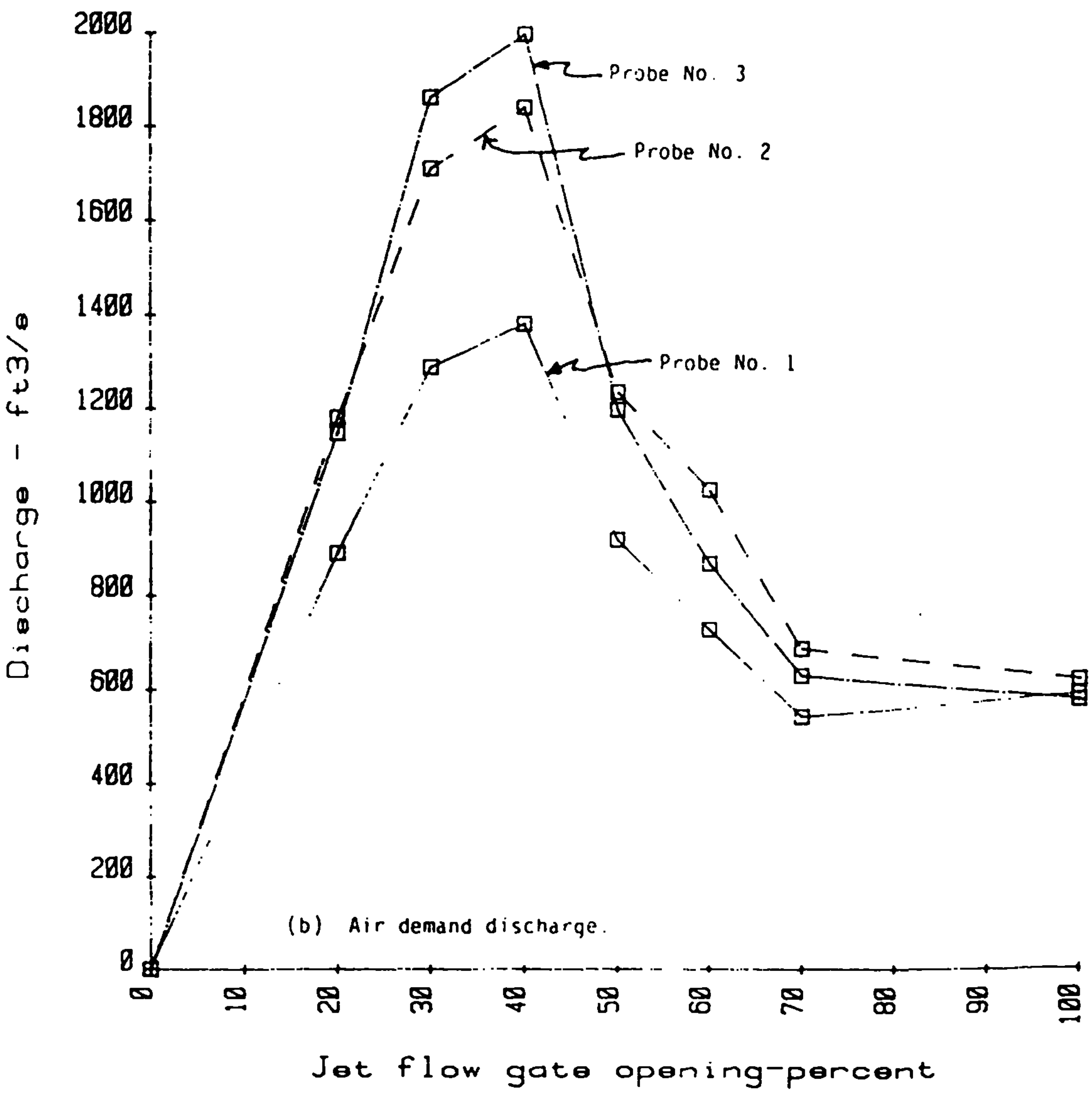
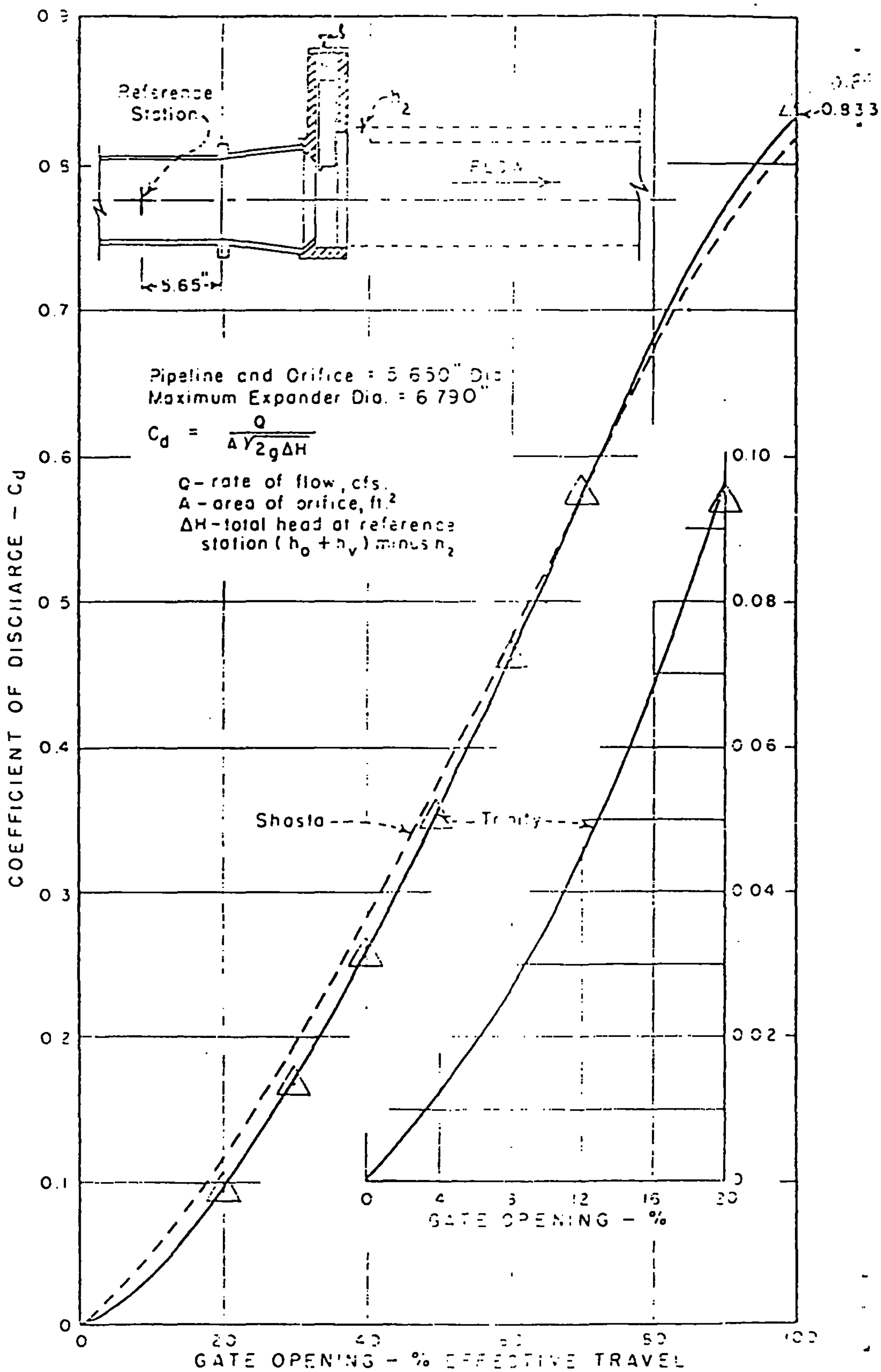


Figure 15. - Air demand (a) velocity and (b) discharge at the three air velocity probe locations based on 1/2-in-high orifice ring offset configuration vs. gate opening.



JET FLOW GATE

TRINITY AUXILIARY OUTLET WORKS

COEFFICIENT OF DISCHARGE-VS-GATE OPENING

Data From 1:14.87 Hydraulic Model

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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

CONTENTS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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 $\frac{h_x - h_o}{H_t - h_2}$ where h_x is the pressure head at a particular piezometer, h_o 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, $(h_o + h_v)$, 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_o.

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.

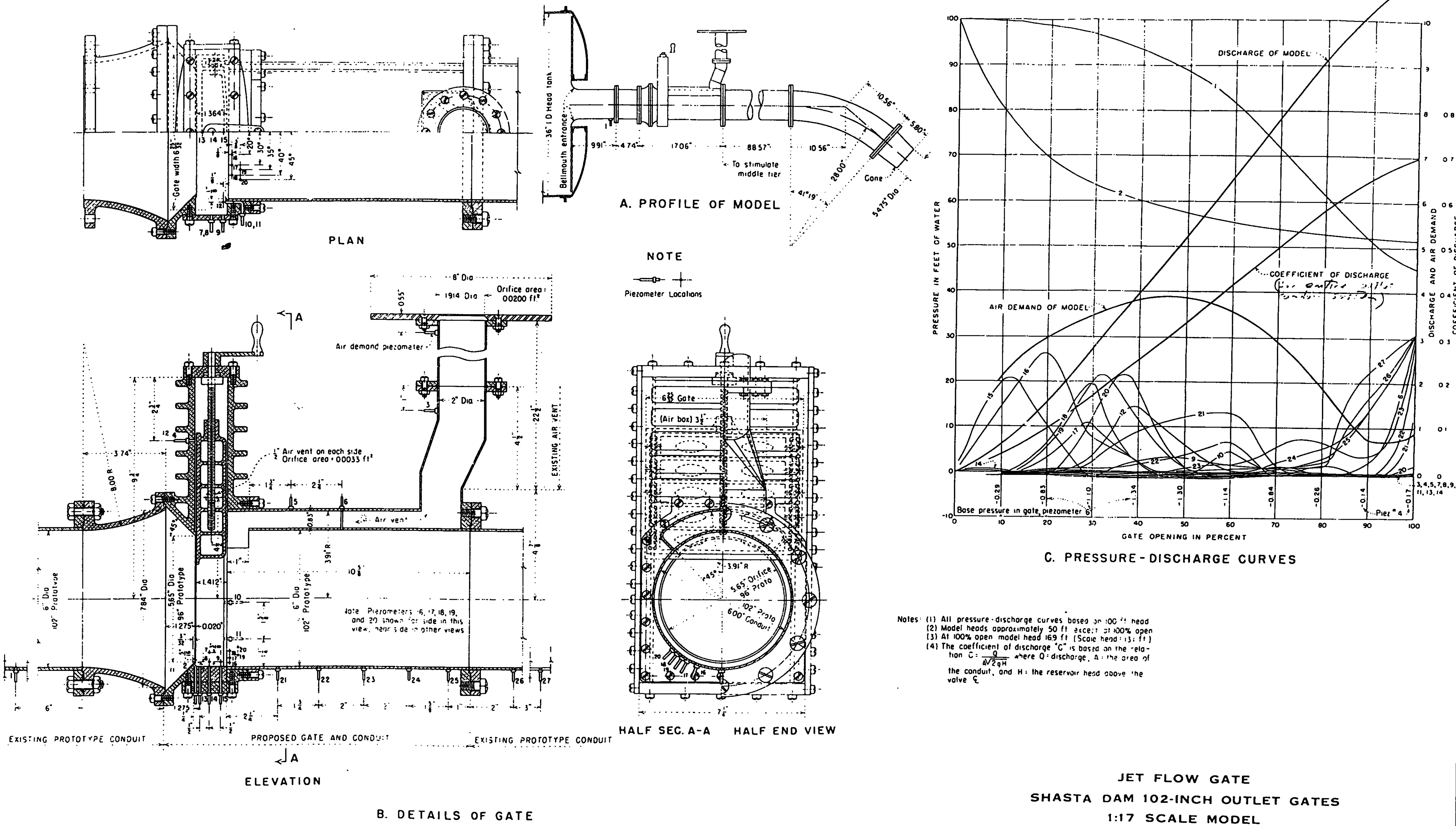
Effect of Froude Number. Kalinske and Robertson 2/ have shown that the rate of air entrainment in a hydraulic jump in a circular pipe is related to the entering Froude number minus 1 (Figure 20). Prototype outlet works air demand data obtained by the United States Corps of Engineers 3/ also shows a relationship, 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.

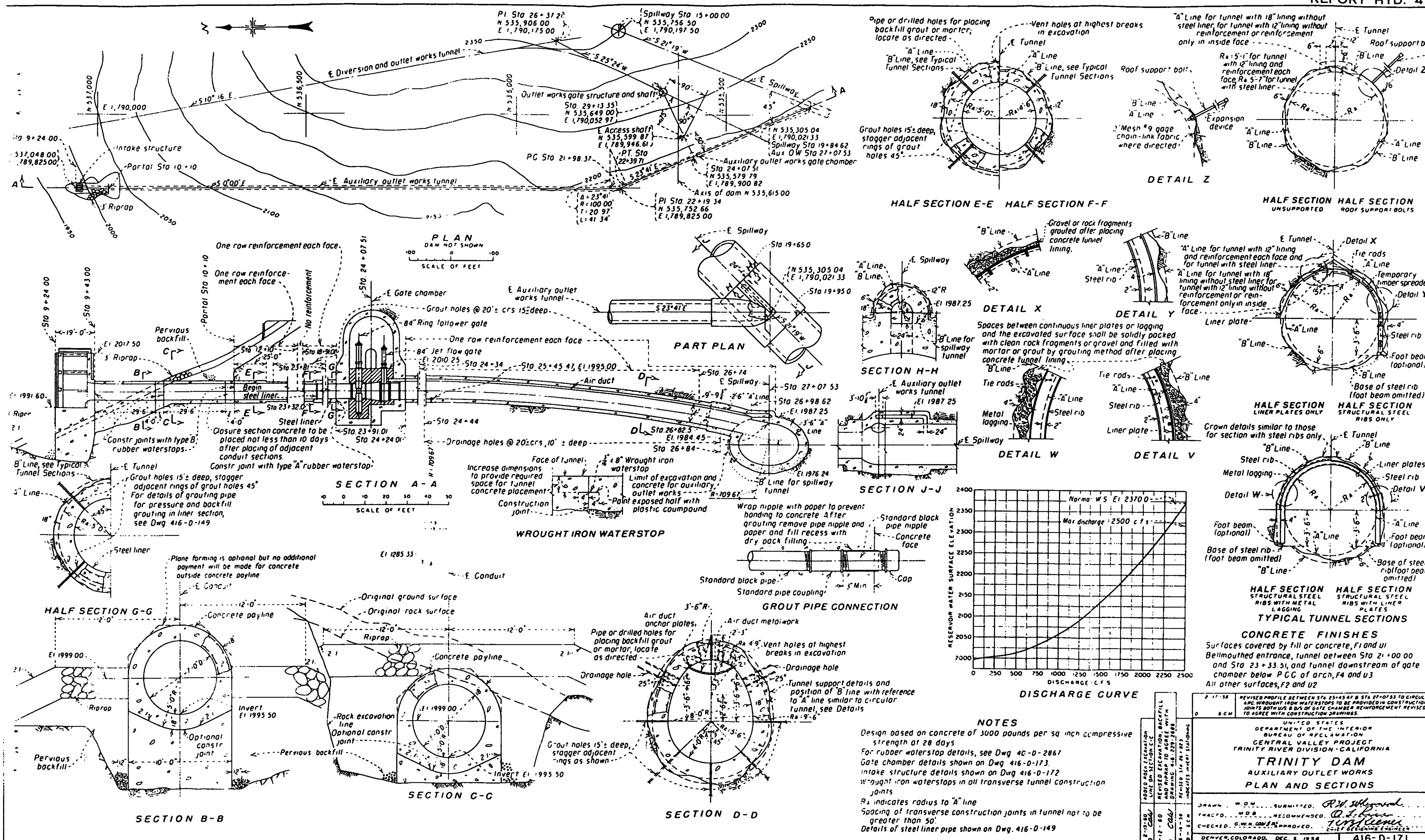
1/"The Hydraulic Design of a Control Gate for the 102-inch Outlets in Shasta Dam", by F. C. Lowe, Report No. Hyd. 201, USBR.

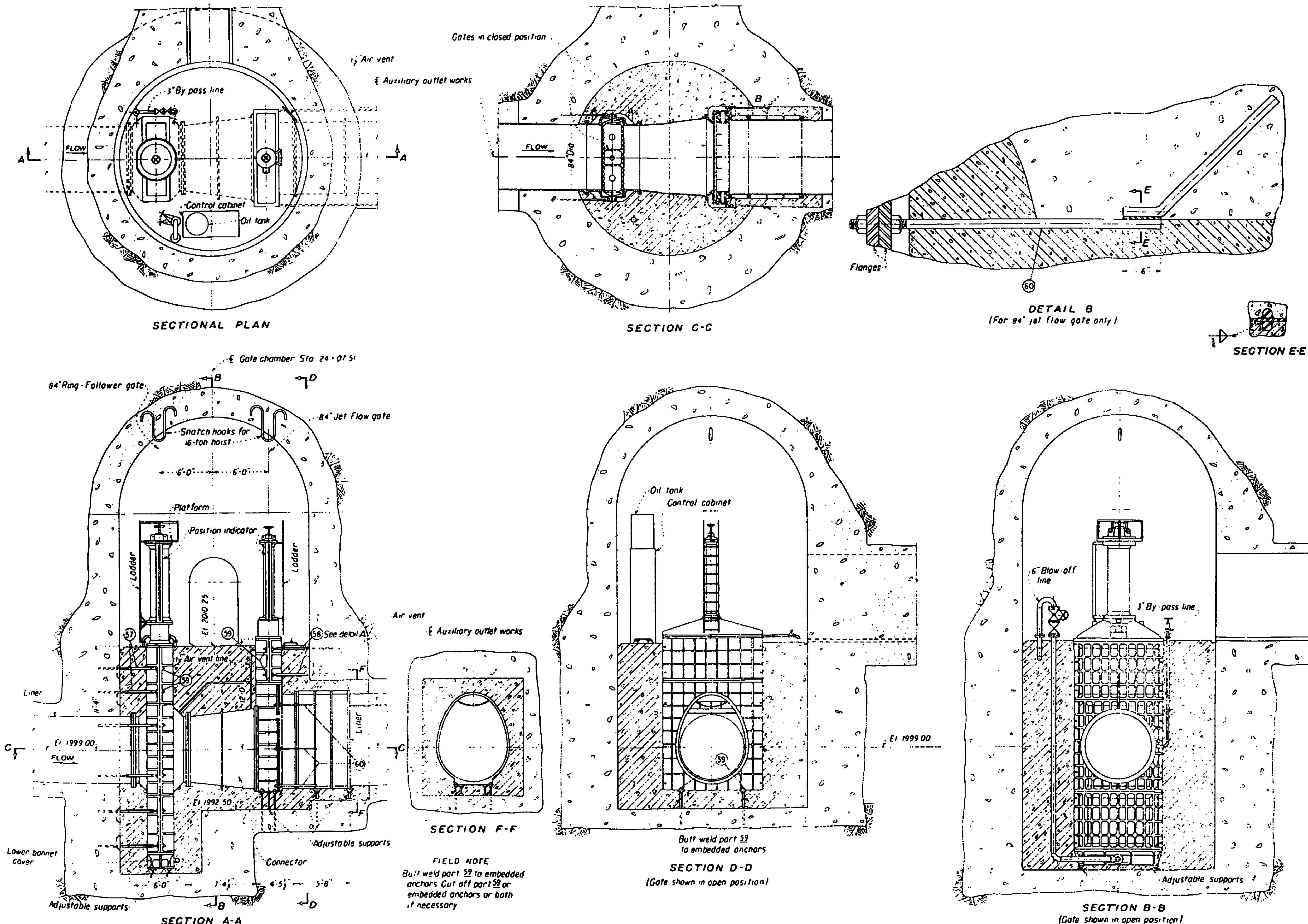
2/"Entrainment of Air in Flowing Water--Closed Conduit Flow", by A. A. Kalinske and J. W. Robertson, Transactions, ASCE, Vol. 108, 1943.

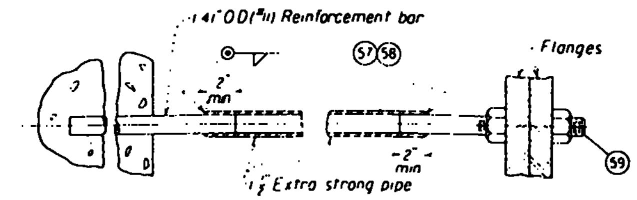
3/"Hydraulic Design Criteria", Sheet 050-1, United States Army Corps of Engineers.



JET FLOW GATE
SHASTA DAM 102-INCH OUTLET GATES
1:17 SCALE MODEL


PLAN
DAM NOT SHOWN
SCALE OF FEET
PART PLAN
SECTION A-A
SECTION H-H
SECTION J-J
HALF SECTION E-E HALF SECTION F-F
DETAIL Z
HALF SECTION UNSUPPORTED
HALF SECTION ROOF SUPPORT BOLTS
DETAIL X
DETAIL Y
DETAIL W
DETAIL V
HALF SECTION LINER PLATES ONLY
HALF SECTION STRUCTURAL STEEL RIBS ONLY
HALF SECTION STRUCTURAL STEEL RIBS WITH METAL LAGGING
HALF SECTION STRUCTURAL STEEL RIBS WITH LINER PLATES
TYPICAL TUNNEL SECTIONS
WROUGHT IRON WATERSTOP
GROUT PIPE CONNECTION
DISCHARGE CURVE
HALF SECTION G-G
SECTION B-B
SECTION C-C
SECTION D-D
CONCRETE FINISHES
Surfaces covered by fill or concrete, F1 and U1
Bellmouthed entrance, tunnel between Sta 21+00.00 and Sta 23+33.51, and tunnel downstream of gate chamber below P.C.C. of arch, F4 and U3
All other surfaces, F2 and U2
NOTES
Design based on concrete of 3000 pounds per sq inch compressive strength at 28 days
For rubber waterstop details, see Dwg 40-D-2867
Gate chamber details shown on Dwg 416-D-173
Intake structure details shown on Dwg 416-D-172
Wrought iron waterstops in all transverse tunnel construction joints
R4 indicates radius to "A" line
Spacing of transverse construction joints in tunnel not to be greater than 50'
Details of steel liner pipe shown on Dwg. 416-D-149
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION - CALIFORNIA
TRINITY DAM
AUXILIARY OUTLET WORKS
PLAN AND SECTIONS
DENVER, COLORADO, DEC. 3, 1956
416-D-171





NOTE

All 1.41" dia (#11) reinforcement bar anchors and all adjustable supports shall be furnished by the contractor. Parts 57, 58, 59, and 60 will be furnished with 84" jet flow gate

INSTALLATION INSTRUTIONS

1. Install the portion of the gates that is to be embedded below elevation 2010.25.
2. The embeded 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. Aline 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 ring follower blockout 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 alinement shall be rechecked after each lift.
7. For further instructions for alining 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
84" JET FLOW GATE-ASSEMBLY-LIST OF DRAWINGS	416-D-315
84" RING FOLLOWER GATE-ASSEMBLY-LIST OF DRAWINGS	416-D-74
84" RING FOLLOWER GATE-AUXILIARY PIPING-LIST OF PARTS	416-D-301
84" RING FOLLOWER AND JET FLOW GATES-CONTROLS-INSTALLATION-LIST OF DRAWINGS	416-D-272

REFERENCE DRAWINGS

AUXILIARY OUTLET WORKS	
GATE CHAMBER-CONCRETE DETAILS	416-D-246
84" RING FOLLOWER AND JET FLOW GATES-ALINEMENT ANCHORAGE	416-D-359

4-28-58 D
TRACED

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CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION - CALIFORNIA

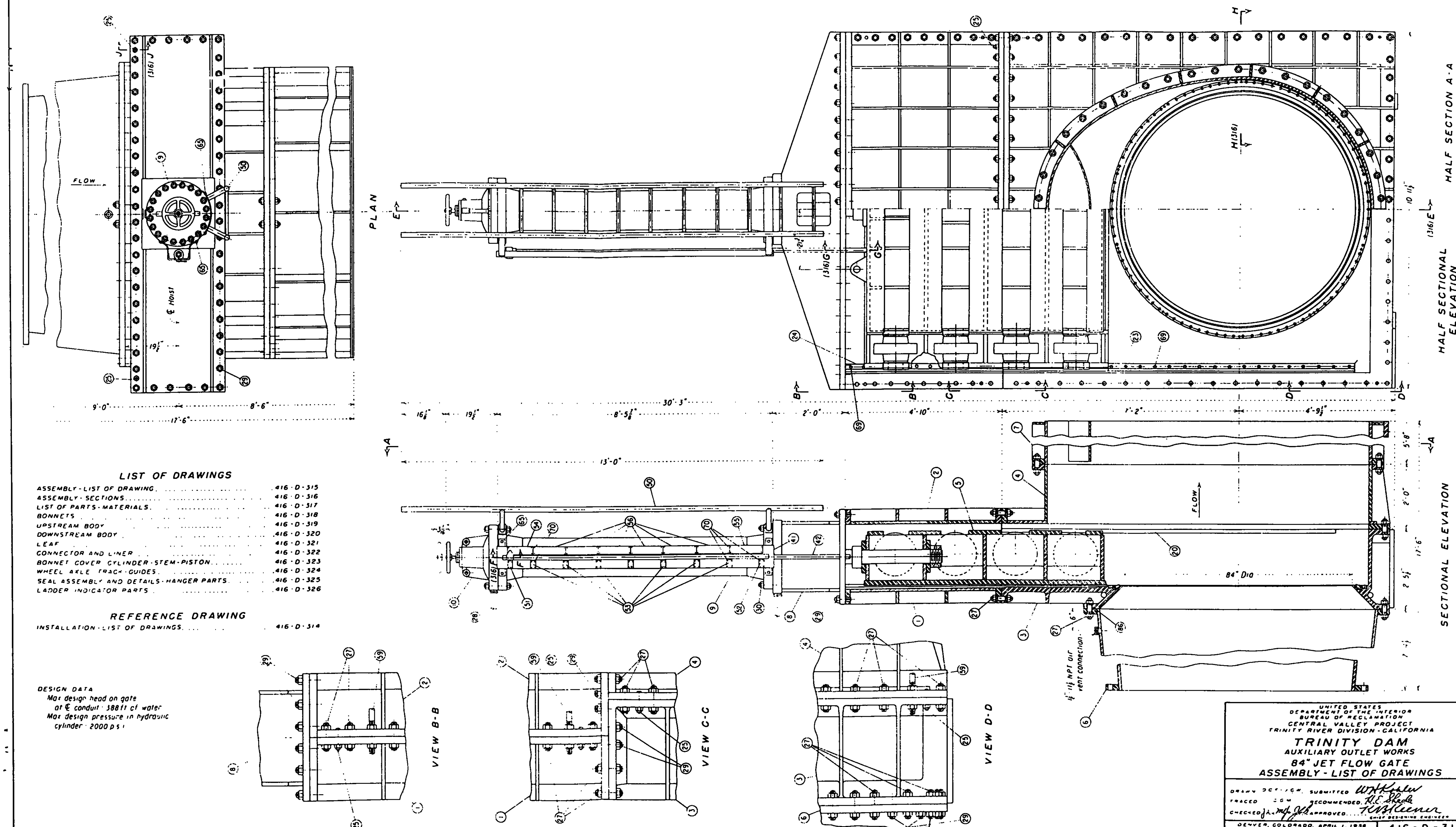
TRINITY DAM
AUXILIARY OUTLET WORKS

84" RING FOLLOWER AND JET FLOW GATES INSTALLATION-LIST OF DRAWINGS

DRAWN H.T.W.-R.L.T. SUBMITTED W.H. Kohler
TRACED J.S.S. RECOMMENDED H.E. Sheda
CHECKED J.A.R.-J.C.B. APPROVED K.B. Keener, CHIEF DESIGNING ENGINEER

DENVER, COLORADO, JAN. 31, 1958
SHEET 1 OF 1

416-D-314



LIST OF DRAWINGS

ASSEMBLY - LIST OF DRAWING	416-D-315
ASSEMBLY - SECTIONS	416-D-316
LIST OF PARTS - MATERIALS	416-D-317
BONNETS	416-D-318
UPSTREAM BODY	416-D-319
DOWNSTREAM BODY	416-D-320
LEAF	416-D-321
CONNECTOR AND LINER	416-D-322
BONNET COVER CYLINDER - STEM - PISTON	416-D-323
WHEEL AXLE TRACK - GUIDES	416-D-324
SEAL ASSEMBLY AND DETAILS - HANGER PARTS	416-D-325
LADDER INDICATOR PARTS	416-D-326

REFERENCE DRAWING

INSTALLATION - LIST OF DRAWINGS	416-D-314

DESIGN DATA
Max design head on gate at ℄ conduit - 388 ft of water
Max design pressure in hydraulic cylinder - 2000 psi

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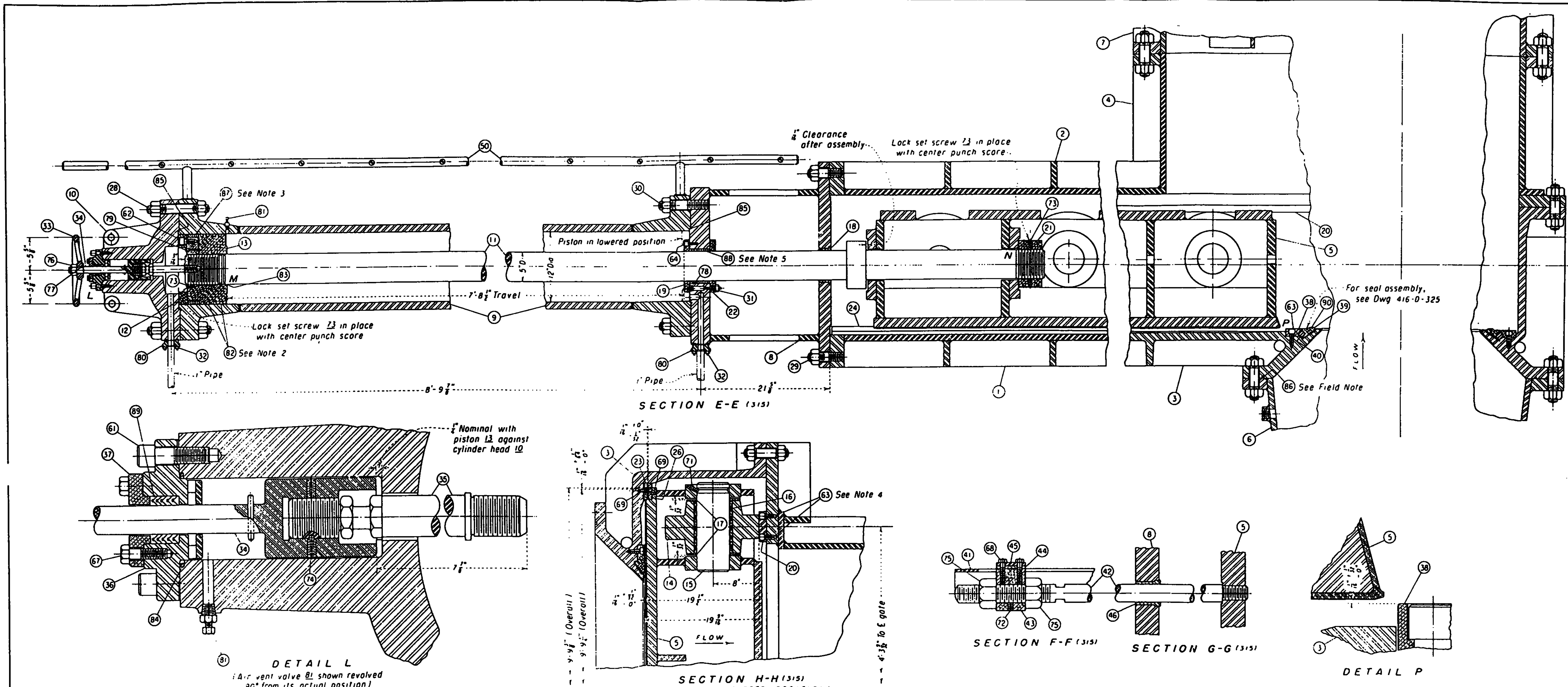
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION - CALIFORNIA

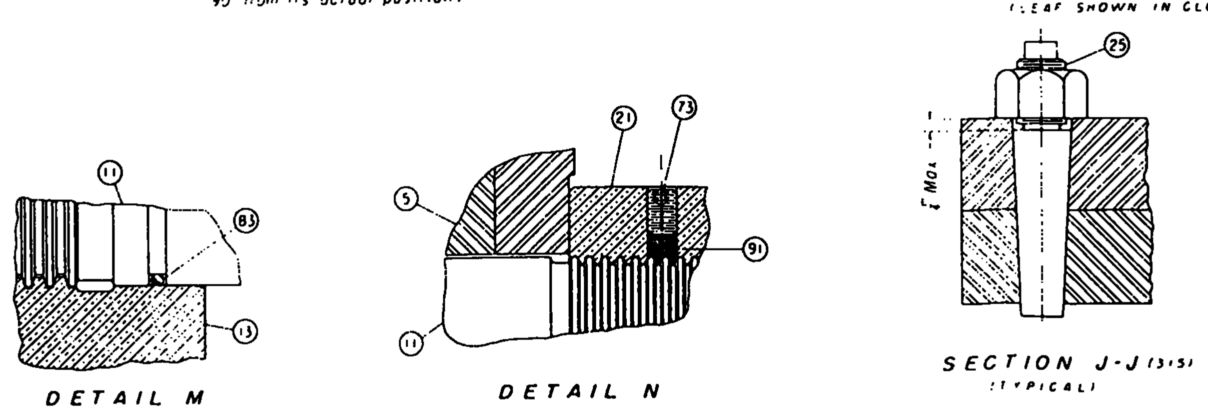
TRINITY DAM
AUXILIARY OUTLET WORKS
84" JET FLOW GATE
ASSEMBLY - LIST OF DRAWINGS

DRAWN DCF-JGW. SUBMITTED W.H. Kohler
TRACED JGW RECOMMENDED H.E. Sheda
CHECKED [illegible] APPROVED K.B. Keener, CHIEF DESIGNING ENGINEER

DENVER, COLORADO, APRIL 1, 1958
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 87, (with pressure under piston 13) remove plug 79 to relieve pressure from packing recess. After replacing packing 87, replace plug 79
4. Lock screws 63 and 69 in parts 20, 23, 24, 26, and 38, 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 D	SECTIONING OF OVERLAY ON PARTS 3 AND 5 AND SECTIONING FOR PARTS 11, 34, AND 42 WAS FOR STAINLESS STEEL

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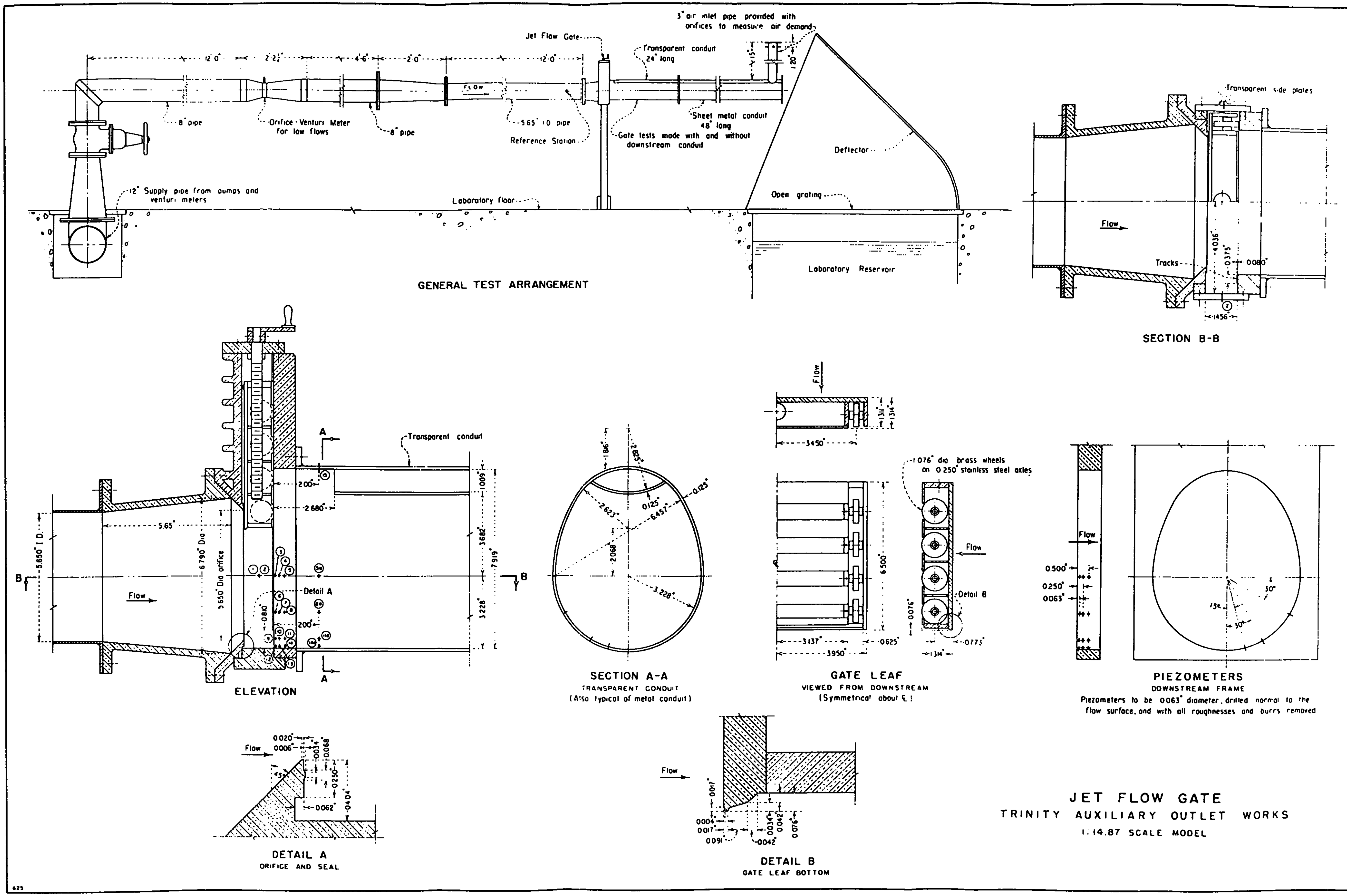
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION - CALIFORNIA

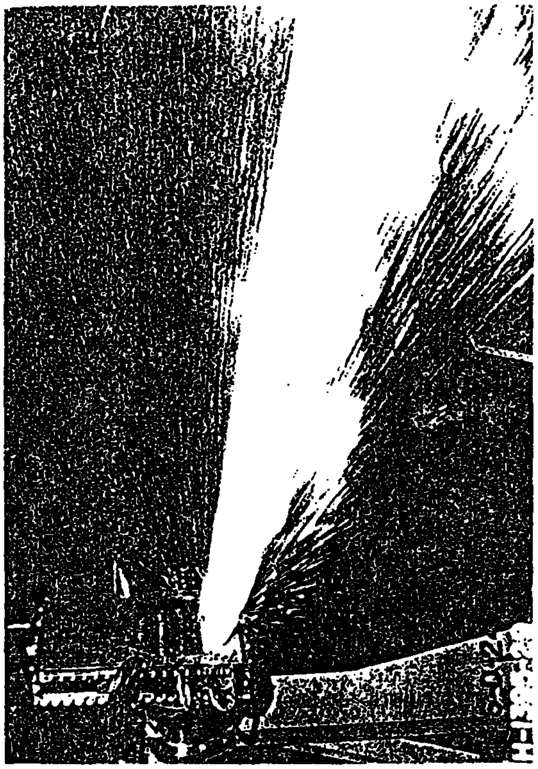
TRINITY DAM
AUXILIARY OUTLET WORKS
84" JET FLOW GATE
ASSEMBLY - SECTIONS

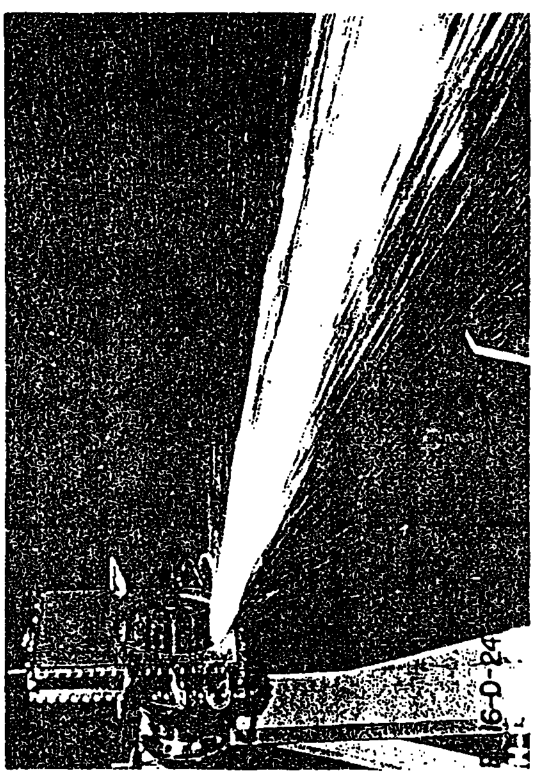
DRAWN R.T.W. SUBMITTED W.H. Kohler
TRACED R.T.W. RECOMMENDED H.E. Sheda
CHECKED J.W.McJ. APPROVED [signature] CHIEF DESIGNING ENGINEER

DENVER, COLORADO APRIL 1, 1958 SHEET 2 OF 12 | 416-D-316



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





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	-0.966	-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	-0.996	-0.996	-0.996	-0.996	-0.996	-0.997	-0.996	-0.997	-0.790	-0.823	-0.910	-0.994	-0.981	-0.951
20	-0.995	-0.991	-0.992	-0.990	-0.992	-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	-0.971	-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
50	-0.873	-0.872	-0.872	-0.872	-0.873	-0.860	-0.840	-0.818	-0.874	-0.874	-0.874	-0.874	-0.873	-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
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
80	-0.540	-0.540	-0.538	-0.538	-0.536	-0.541	-0.541	-0.541	-0.540	-0.541	-0.540	-0.540	-0.540	-0.540
90	-0.408	-0.408	-0.378	-0.409	-0.408	-0.409	-0.408	-0.409	-0.408	-0.408	-0.408	-0.408	-0.407	-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

A. PRESSURE FACTORS — NO CONDUIT DOWNSTREAM

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

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	+80.11	+67.15	+33.41	+ 0.91	+ 5.76	+17.60
20	- 1.81	-0.09	- 0.32	+ 0.10	- 0.32	- 0.21	- 0.09	+ 2.12	+11.36	+33.20	+68.72	- 0.45	- 0.11	+ 3.91
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	-0.59	+ 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 – 380 FOOT HEAD – NO CONDUIT

GATE OPENING PERCENT	PIEZOMETERS																		
	1	2	3	4	5	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	-0.807	-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	-0.713	-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	-0.757	-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	-0.673	-0.676
80	-0.539	-0.540	-0.539	-0.538	-0.537	-0.533	-0.541	-0.540	-0.540	-0.538	-0.540	-0.540	-0.540	-0.539	-0.539	-0.539	-0.539	-0.538	-0.539
90	-0.410	-0.410	-0.411	-0.410	-0.411	-0.409	-0.411	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.410	-0.415	-0.410	-0.409
100	-0.303	-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

C. PRESSURE FACTORS – 72" LONG MODEL CONDUIT DOWNSTREAM

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

where h_x = piezometer pressure, ft water

h_o = pressure in conduit 1 diameter upstream from gate, ft water

$H_T = h_o + h_v$ = total head at reference station, ft water

h_2 = pressure in downstream conduit (piez 15), ft water (atmospheric when no conduit is present)

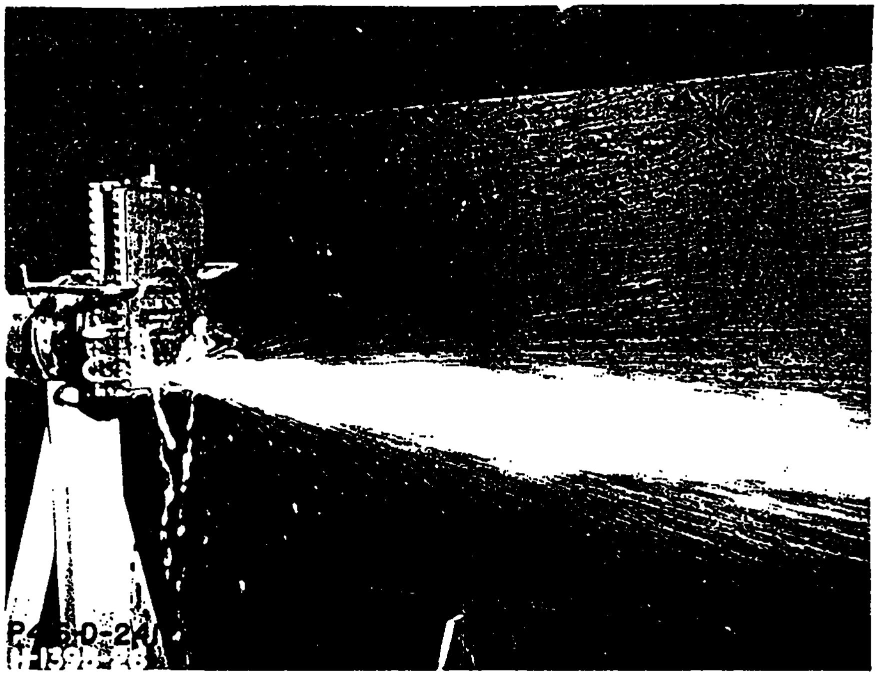
JET FLOW GATE

TRINITY AUXILIARY OUTLET WORKS

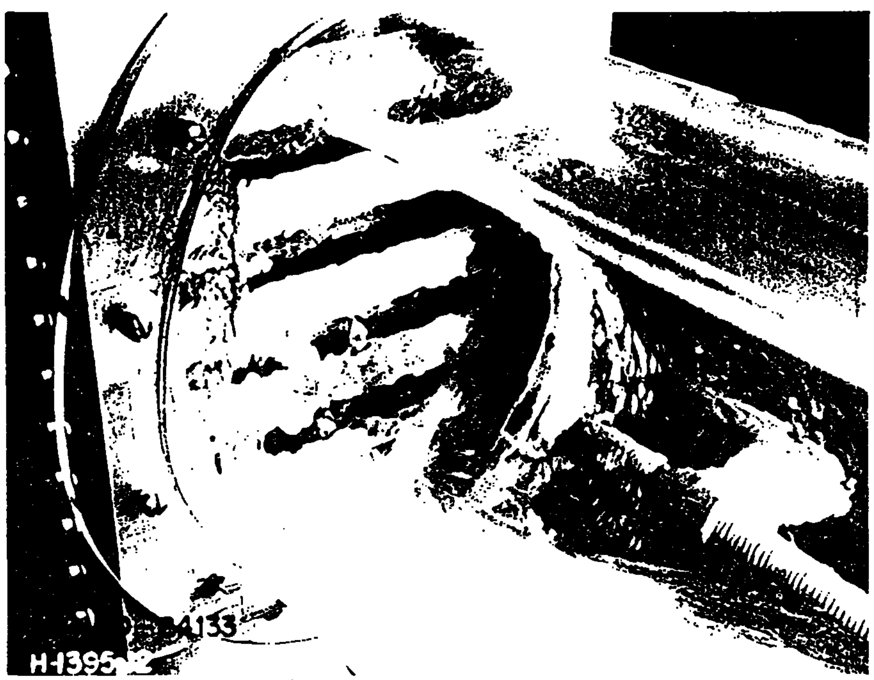
PRESSURES AND PRESSURE FACTORS

Data From 1:14.87 Hydraulic Model

625

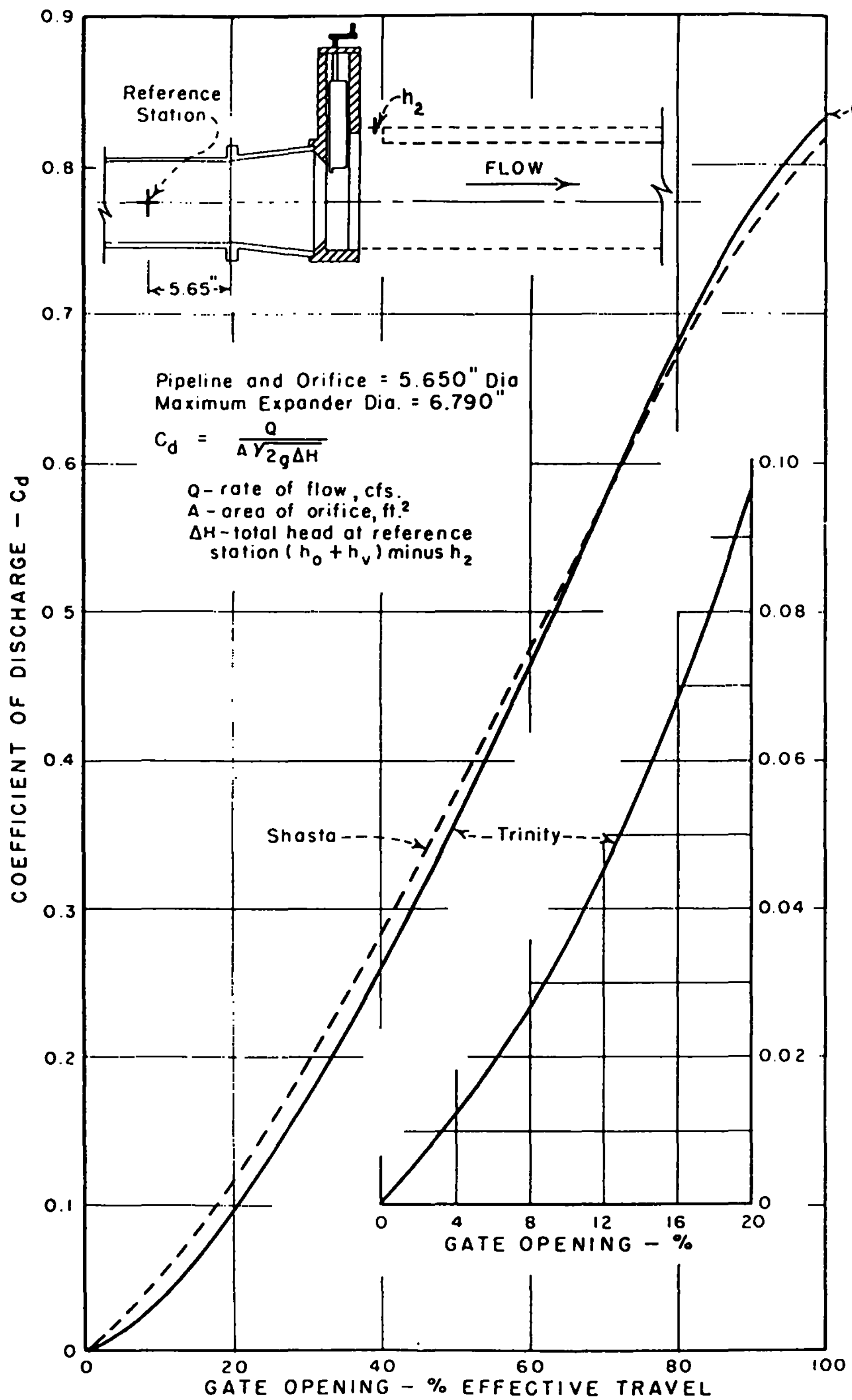


A. Free discharge into atmosphere. H_T [illegible] 4 feet



B. Discharge into conduit. H_T [illegible] 40 feet

JET FLOW GATE
[illegible] Auxiliary Outlet Works
Flow Interference of Downstream Frame [illegible]
1:14.87 Scale Model

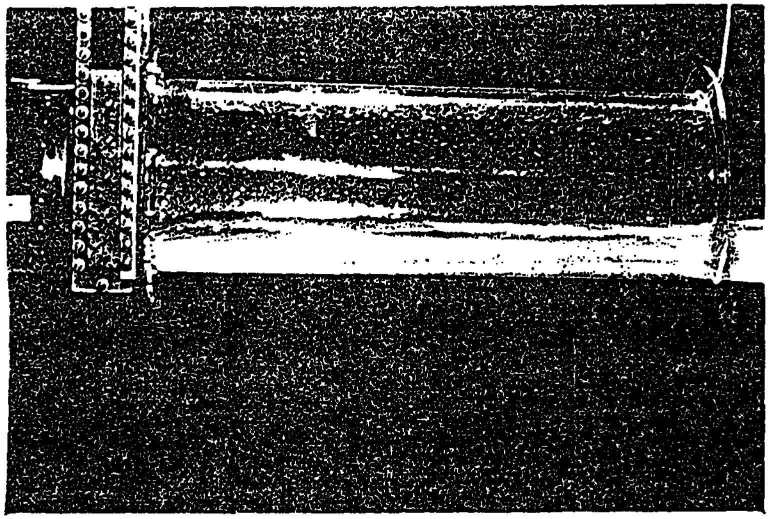


JET FLOW GATE

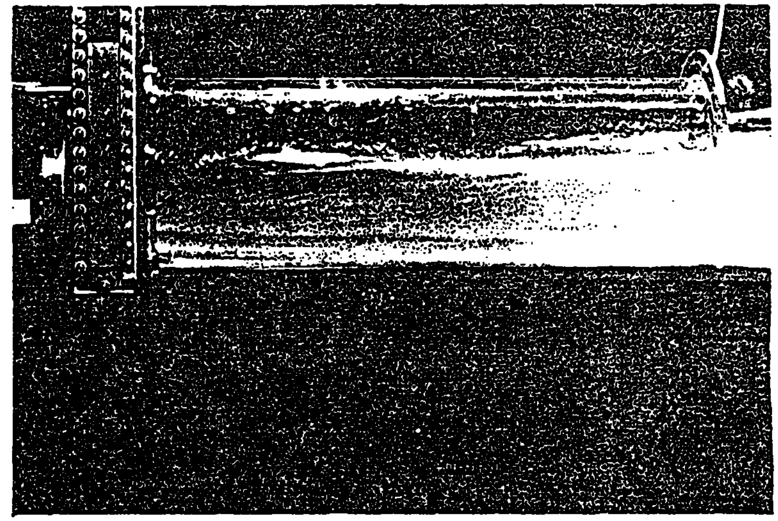
TRINITY AUXILIARY OUTLET WORKS

COEFFICIENT OF DISCHARGE-VS-GATE OPENING

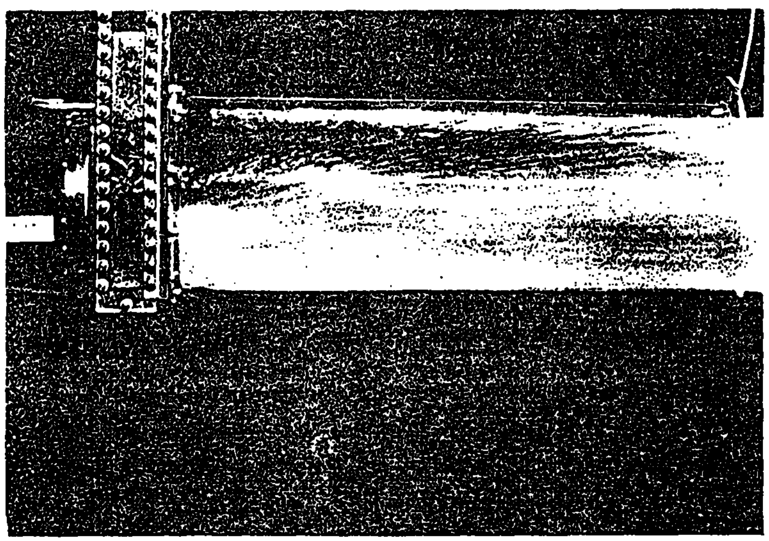
Data From 1:14.87 Hydraulic Model



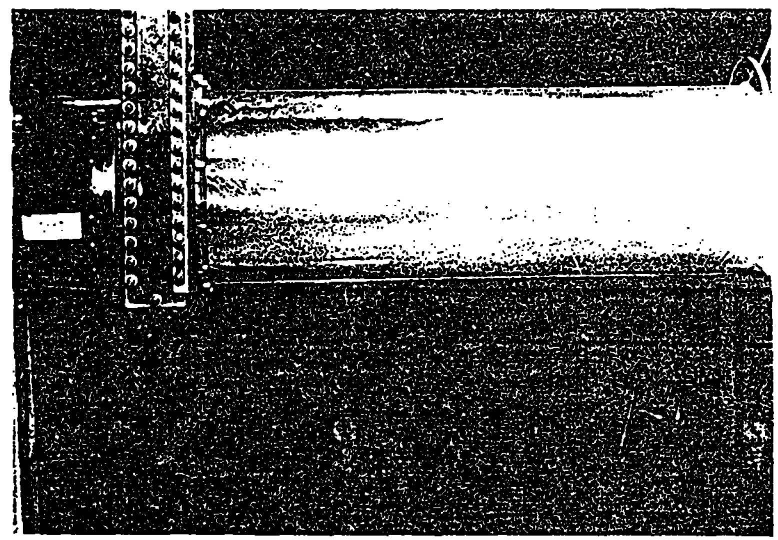
[illegible]



B - Gate [illegible] open

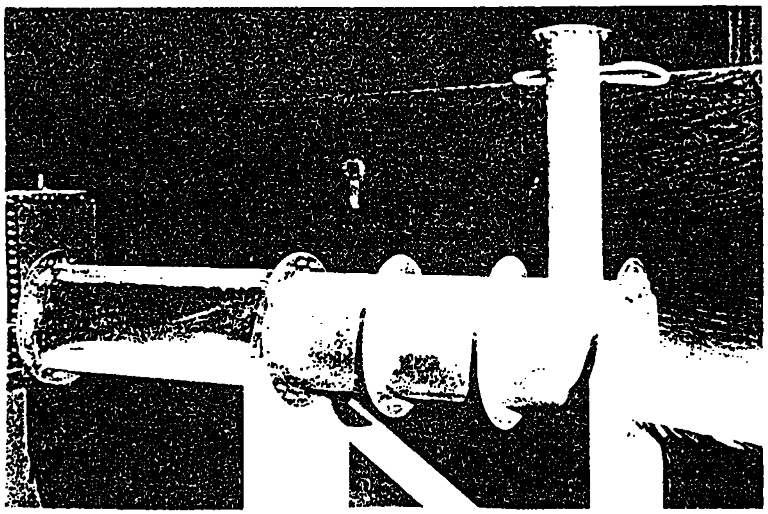


[illegible] open

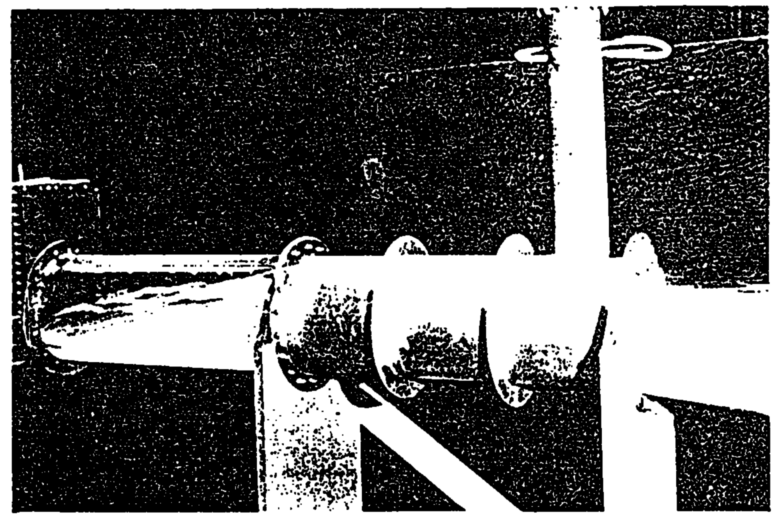


D - Gate [illegible] open

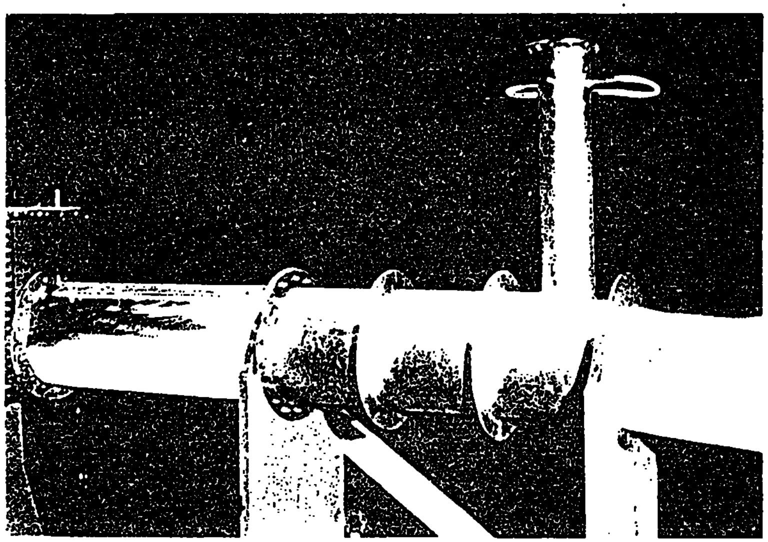
JET FLOW GATE
[illegible] Auxiliary Outlet Works
[illegible] Long Conduit [illegible] Head

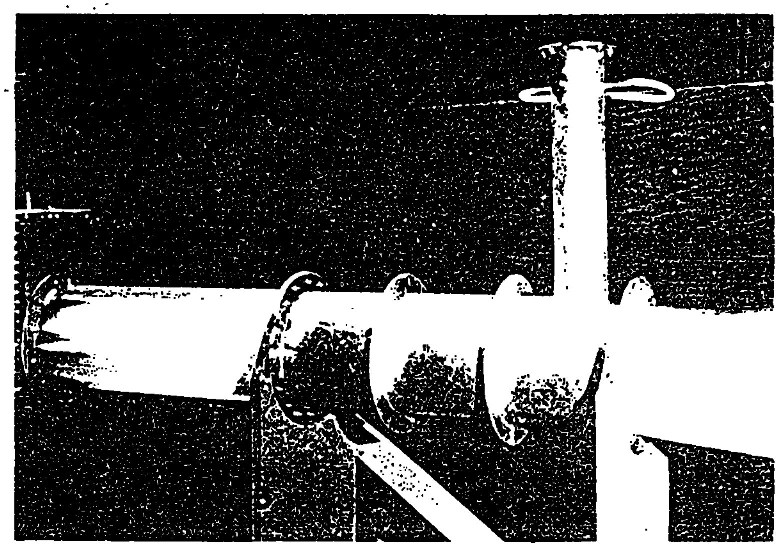


... Gate ..% open



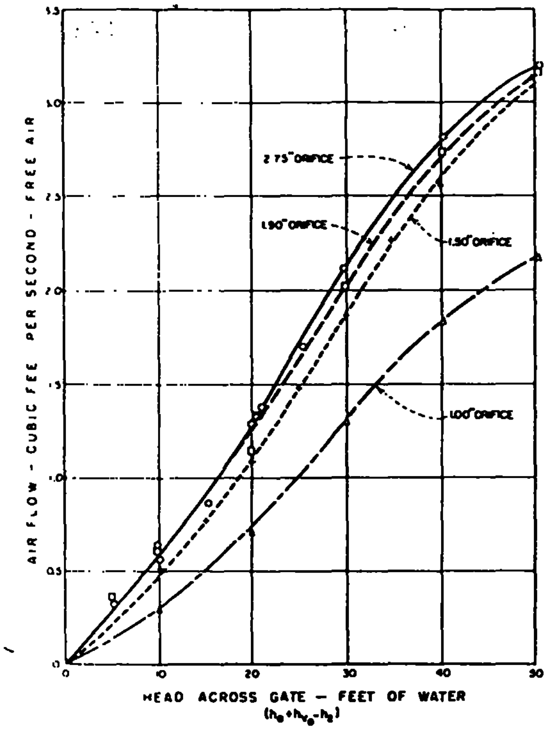
B. Gate 40% open



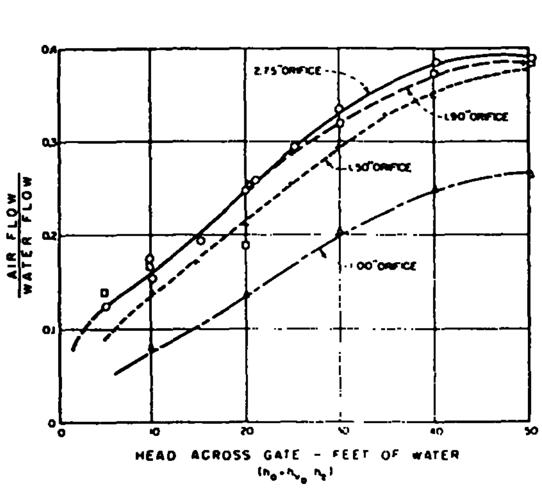


D. Gate ..% open

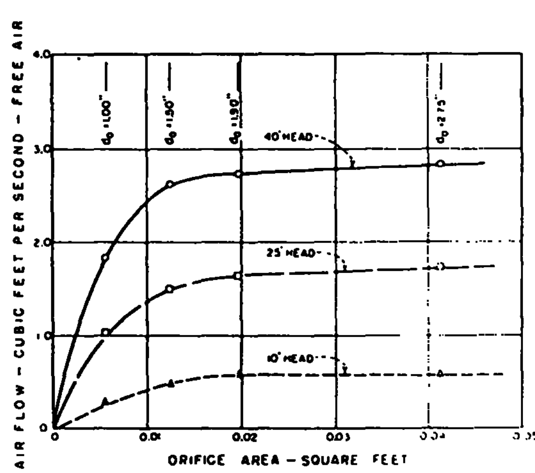
... FLOW GATE
... Outlet Works
... Capacity, 40 Foot ...



A. AIR FLOW vs. HEAD



B. AIR-WATER RATIO vs HEAD



C. AIR FLOW vs. ORIFICE AREA

JET FLOW GATE

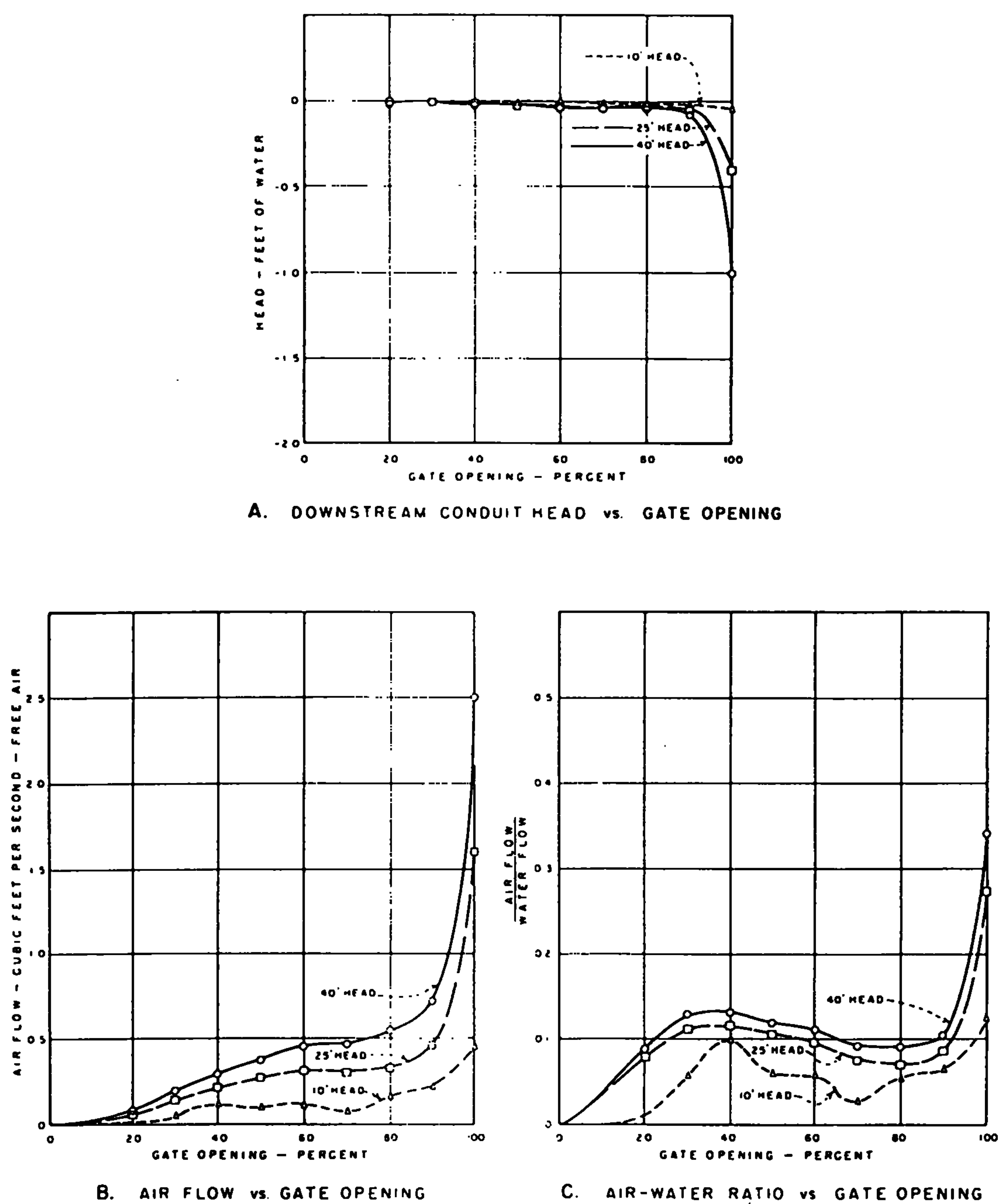
TRINITY AUXILIARY OUTLET WORKS

EFFECT OF AIR INLET ORIFICE SIZE ON AIR DEMAND

GATE 100% OPEN - CONDUIT 72 INCHES LONG (11.15 D)

Data From 1:14.87 Hydraulic Model

FIGURE 14
REPORT HYD 472

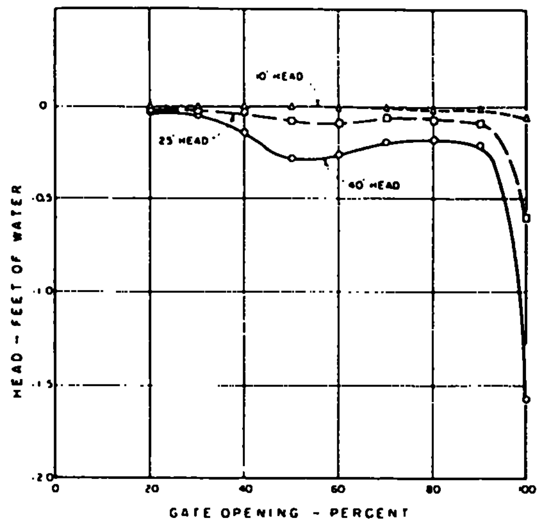


JET FLOW GATE

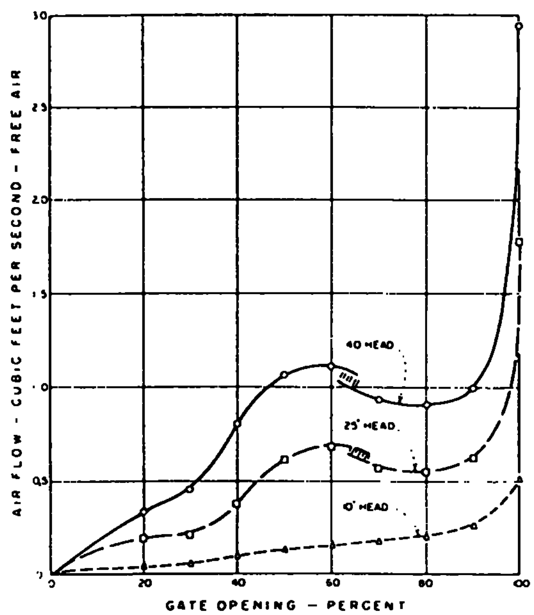
TRINITY AUXILIARY OUTLET WORKS

AIR DEMAND WITH
CONDUIT 24 INCHES LONG (3.72D)

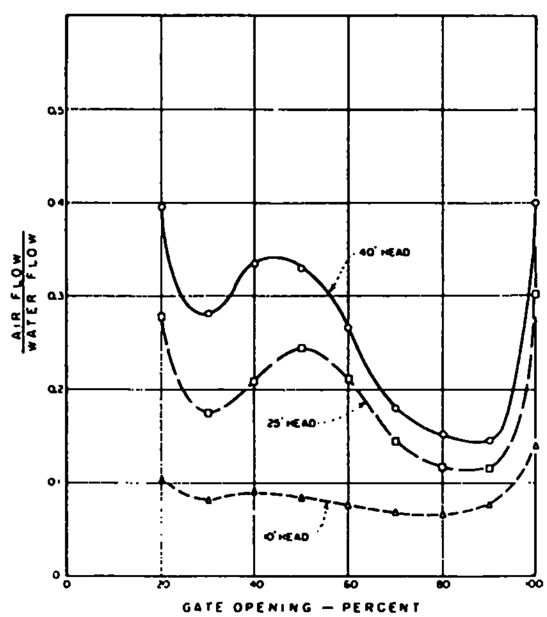
Data From 1:14.87 Hydraulic Model



A. DOWNSTREAM CONDUIT HEAD vs GATE OPENING



B. AIR FLOW vs GATE OPENING



C. AIR-WATER RATIO vs. GATE OPENING

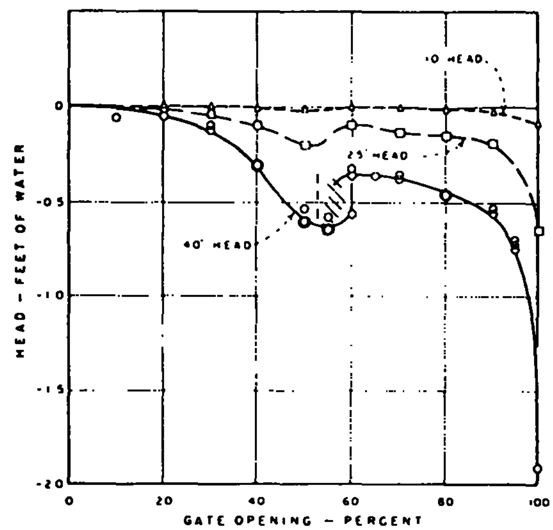
JET FLOW GATE

TRINITY AUXILIARY OUTLET WORKS

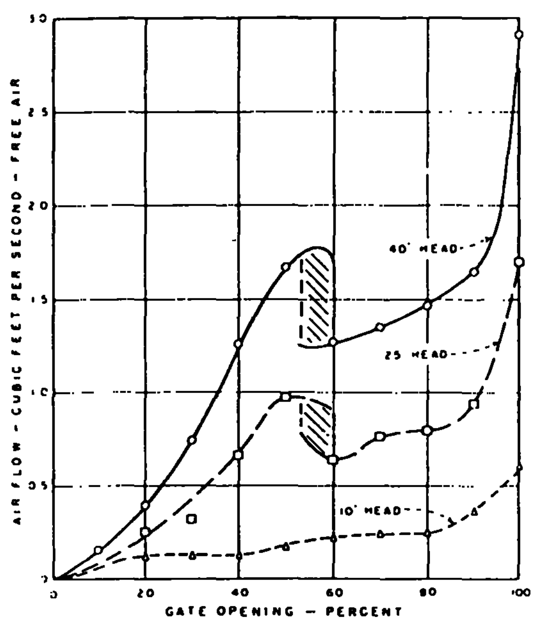
AIR DEMAND WITH
CONDUIT 48 INCHES LONG (7.43D)

Data From 1:14.87 Hydraulic Model

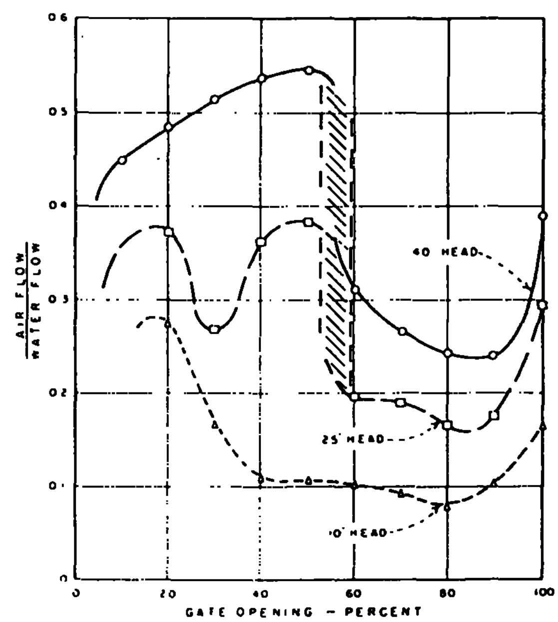
FIGURE 16
REPORT HYD 477



A. DOWNSTREAM CONDUIT HEAD vs GATE OPENING



B. AIR FLOW vs. GATE OPENING



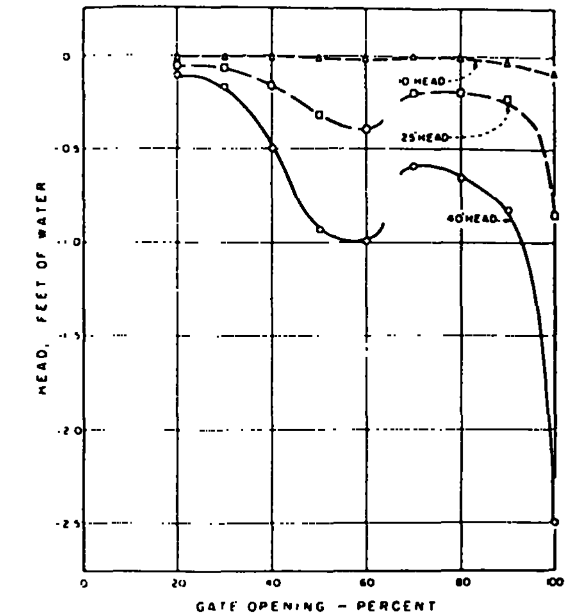
C. AIR-WATER RATIO vs. GATE OPENING

JET FLOW GATE

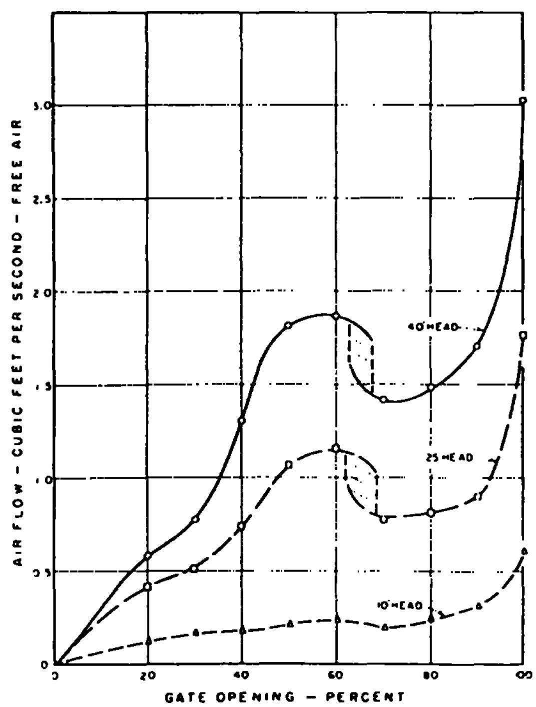
TRINITY AUXILIARY OUTLET WORKS

AIR DEMAND WITH
CONDUIT 72 INCHES LONG (11.15D)

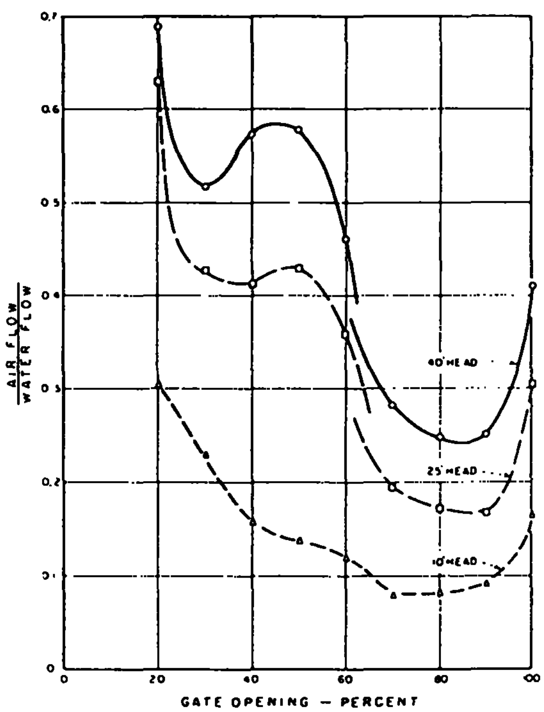
Data From 1:14.87 Hydraulic Model



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



B. AIR FLOW vs. GATE OPENING



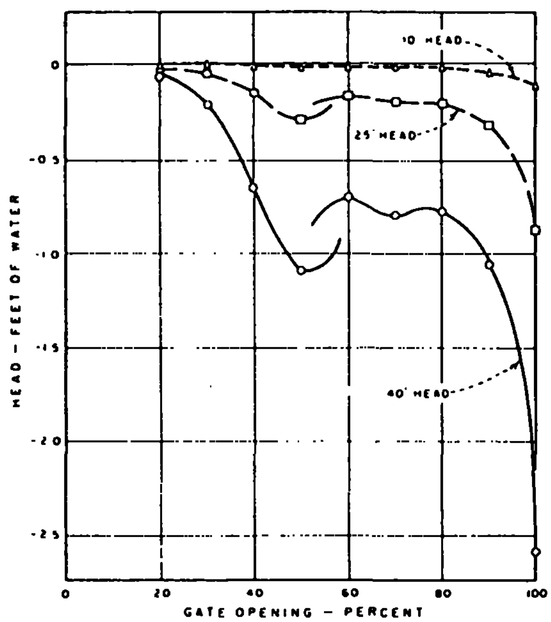
C. AIR-WATER RATIO vs GATE OPENING

JET FLOW GATE

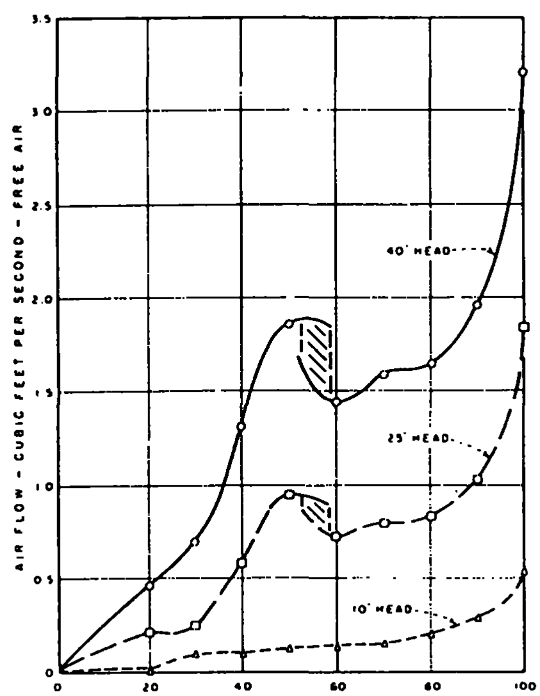
TRINITY AUXILIARY OUTLET WORKS

AIR DEMAND WITH
CONDUIT 96 INCHES LONG (14.87 D)

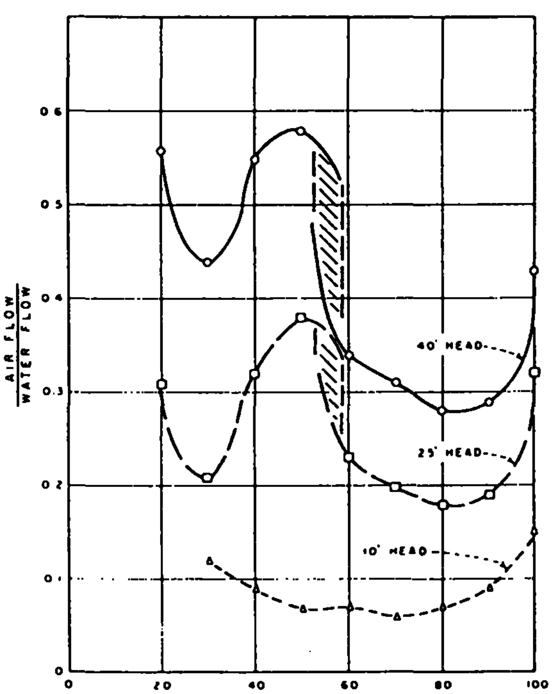
Data From 1:14.87 Hydraulic Model



A. DOWNSTREAM CONDUIT HEAD vs. GATE OPENING



B. AIR FLOW vs. GATE OPENING



C. AIR-WATER RATIO vs. GATE OPENING

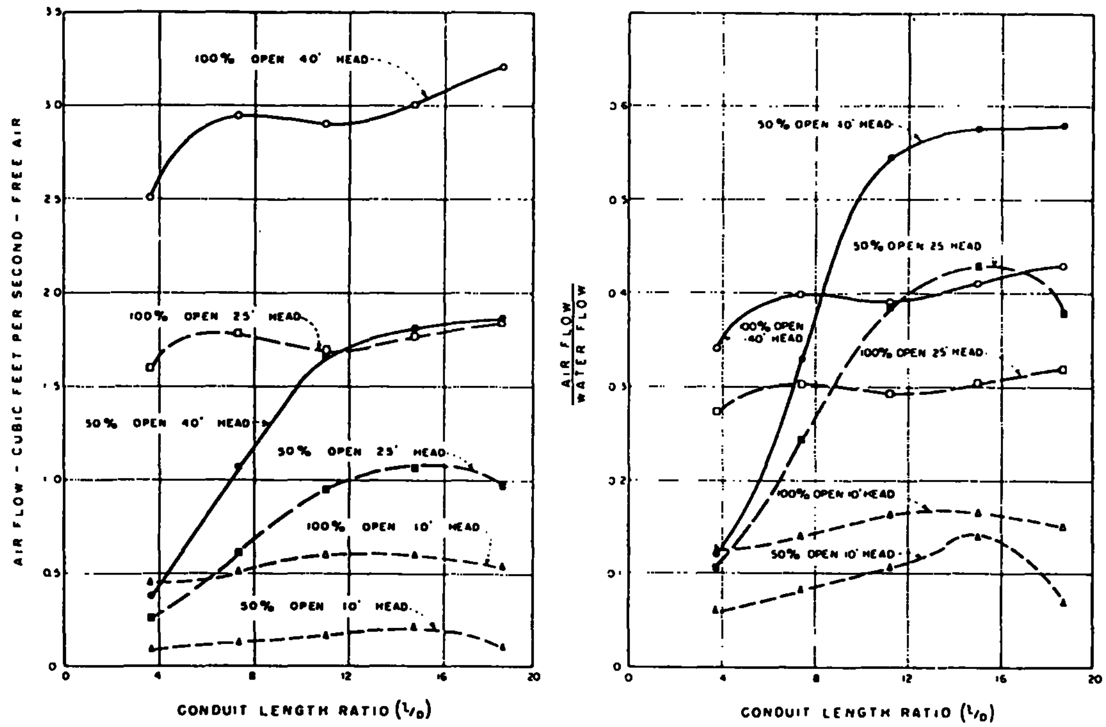
JET FLOW GATE

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

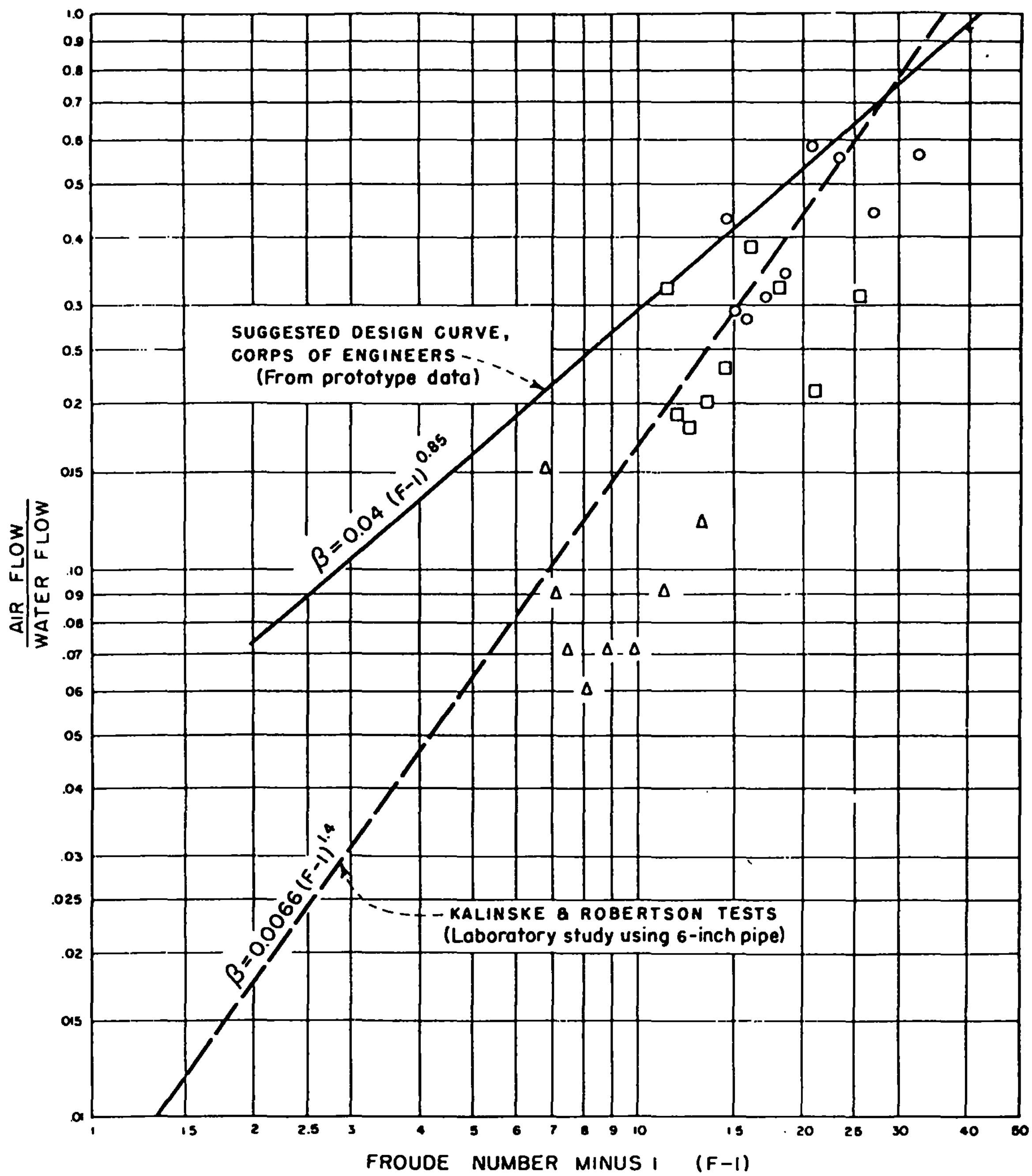
B. AIR-WATER RATIO vs CONDUIT LENGTH

JET FLOW GATE

TRINITY AUXILIARY OUTLET WORKS

EFFECT OF MODEL CONDUIT LENGTH ON AIR DEMAND

Data From 1:14.87 Hydraulic Model



EXPLANATION

Δ = 10' head □ = 25' head o = 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

GPO 843225