PAP-483

Trinity Dam Auxiliary Outlet Works Hydraulic Laboratory Model Results

by

Clark P. Buyalski

Form DFC-11
(12-61)
Bureau of Reclamation

INFORMATIONAL ROUTING

PAP-483

D-1531
Current

D-1530

GPO 852320

AUG 30 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.

L. O. Timblin Jr.

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 6-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 roller to occur on top of the main water flow prism. The splash from the roller 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		Jet flow gate model			Prototype discharge Q ft^3/s
				H_0 = P1 upstream head			
		upstream head[1]	downstream head[2]	ft H_2O	mm[3] H_g	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: Trashrack = 0.01
(in terms of the velocity Entrance = 0.15
head) Bend = 0.05
Total K_e = 0.21

Assume rugosity $\varepsilon/D = 0.0007/7 = 0.0001$ 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.

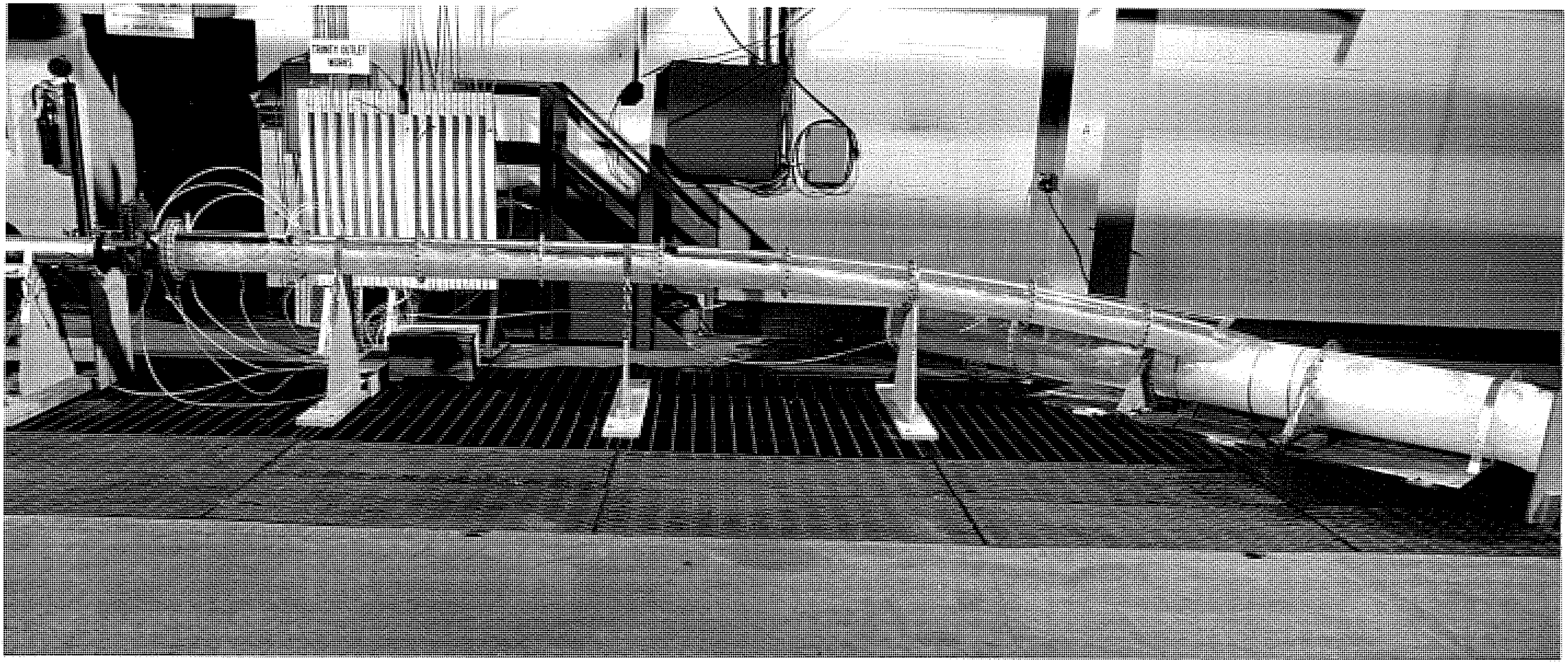


Figure 1. - General view of the modified Trinity Auxiliary Outlet Works 1:14.87 scale model operating at 100 percent gate opening.

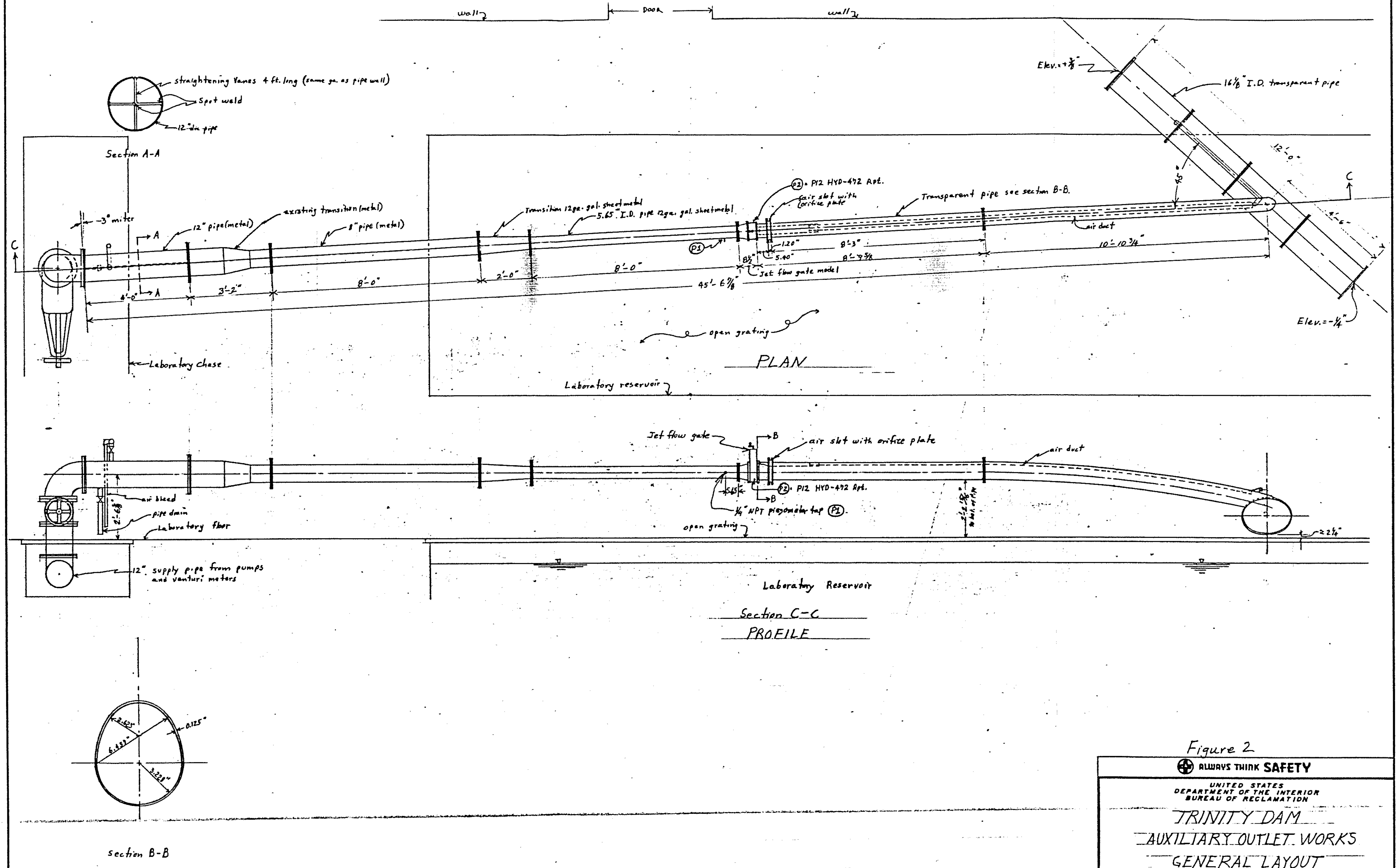


Figure 2

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRINITY DAM
AUXILIARY OUTLET WORKS
GENERAL LAYOUT

DESIGNED GD TECHNICAL APPROVAL
DRAWN SUBMITTED
CHECKED APPROVED
DENVER, COLORADO April 10, 1985

21" X 29"

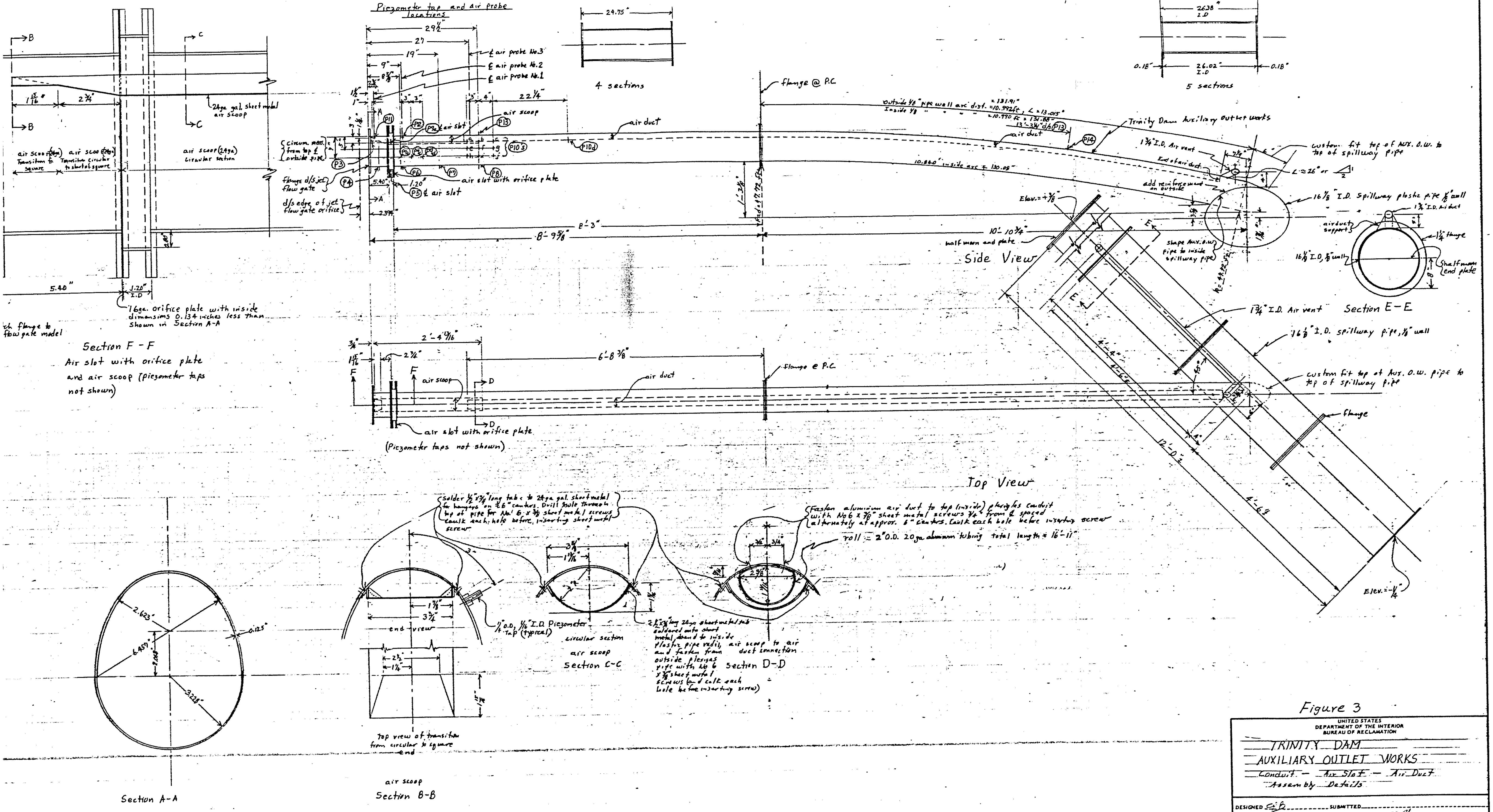


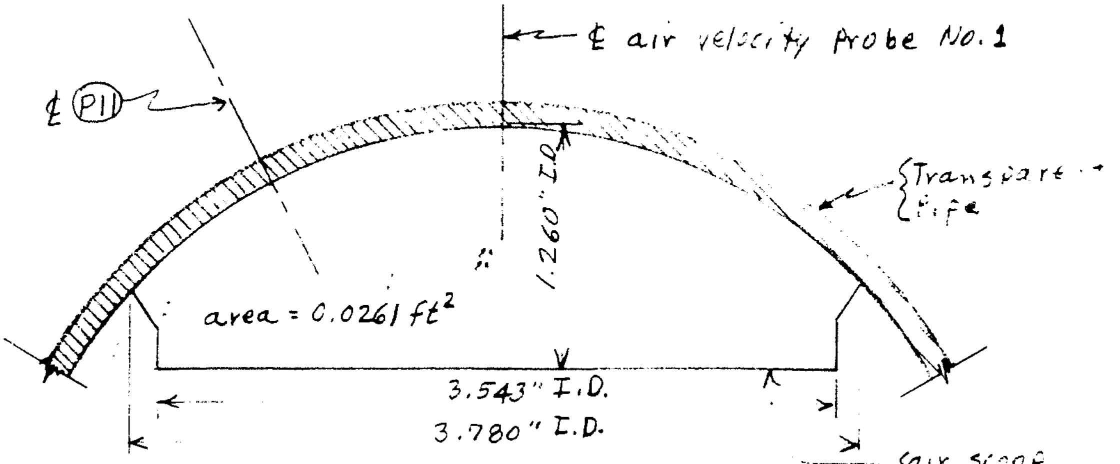
Figure 3

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

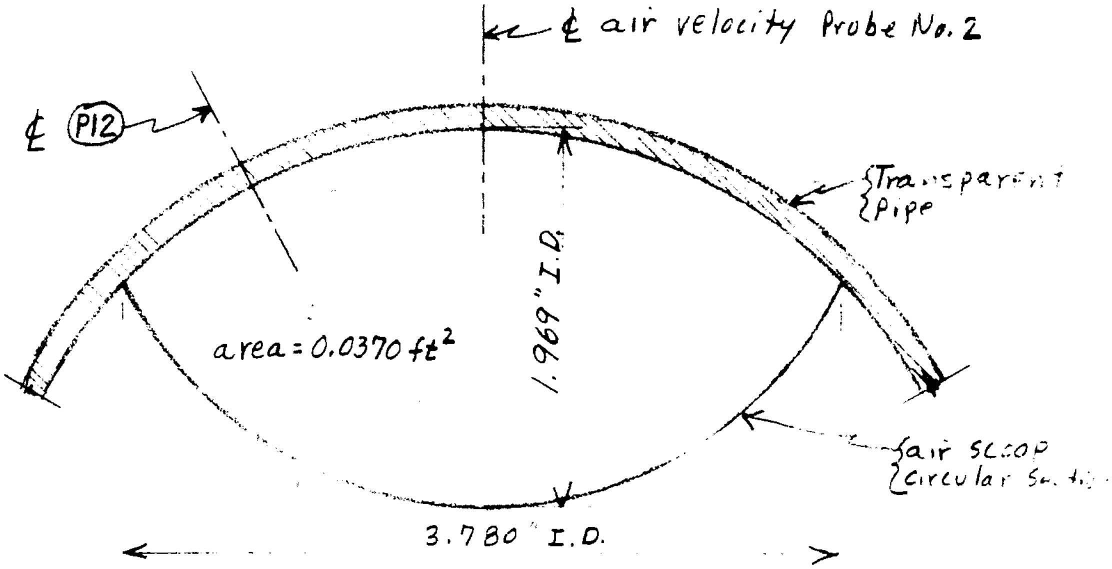
TRINITY DAM
AUXILIARY OUTLET WORKS
Conduit – Air Slot – Air Duct
Assembly Details

DESIGNED ________ SUBMITTED ________
DRAWN ________ RECOMMENDED ________
CHECKED ________ APPROVED ________

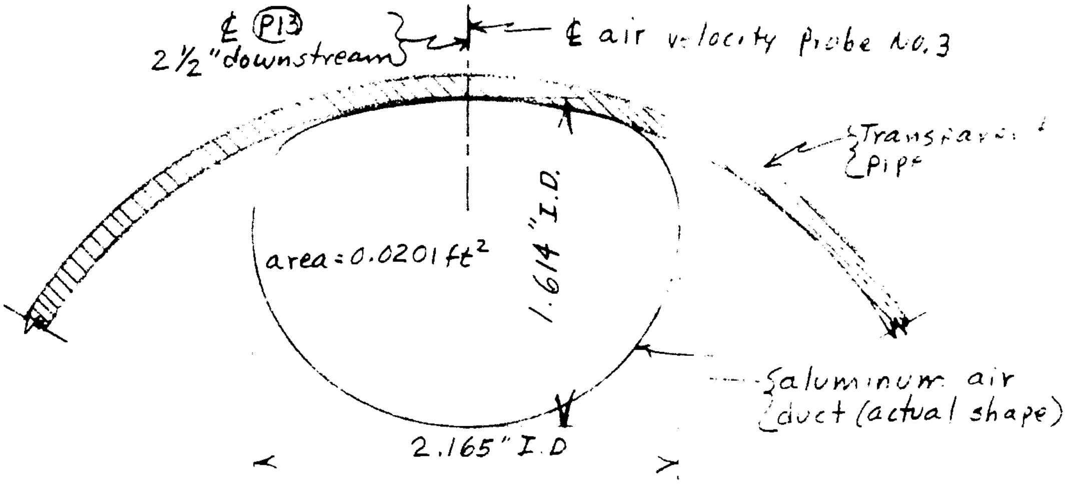
April 8, 1985



(a) air velocity probe No. 1 u/s air slot

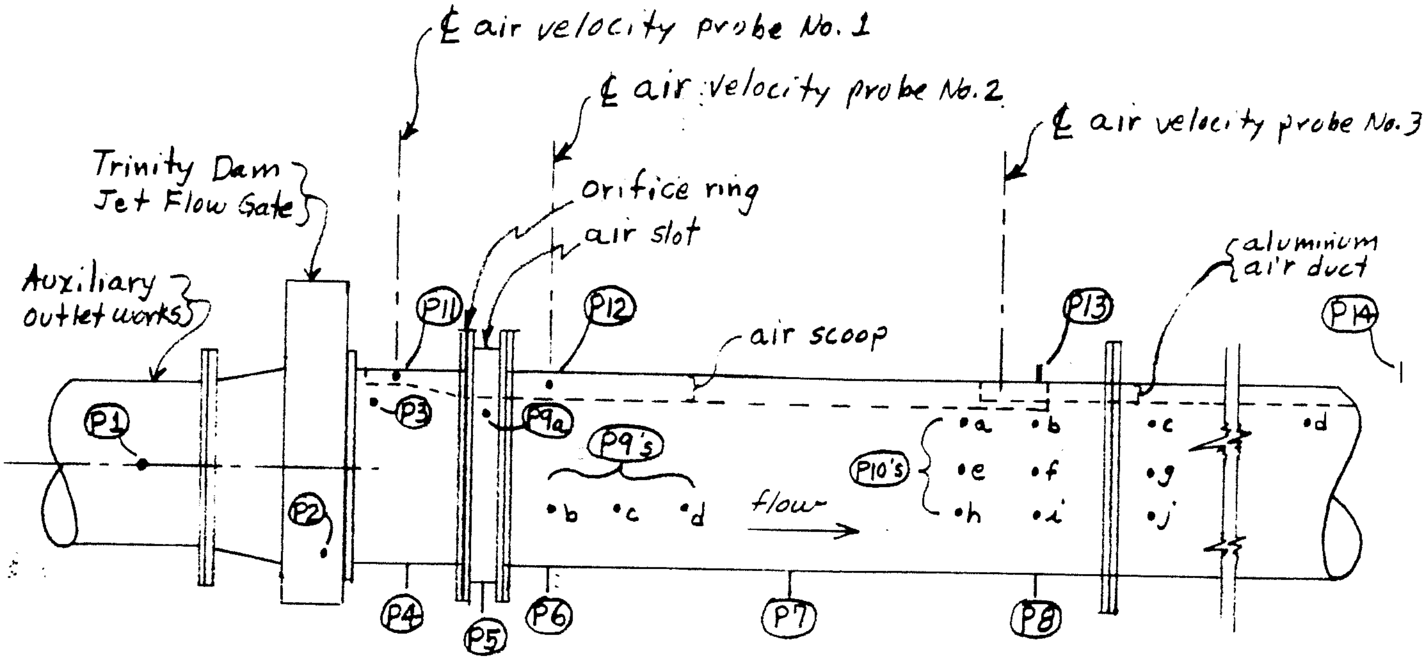


(b) air velocity probe No. 2 d/s air slot



(c) air velocity probe No. 3 upper end al. air duct

Figure 4 – Cross-sectional areas (as-built) of the Trinity Axiliary Outlet Works model air velocity probe (a) No. 1, (b) No. 2, and (c) No. 3 locations (actual size, Model scale 1:14.87)



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

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

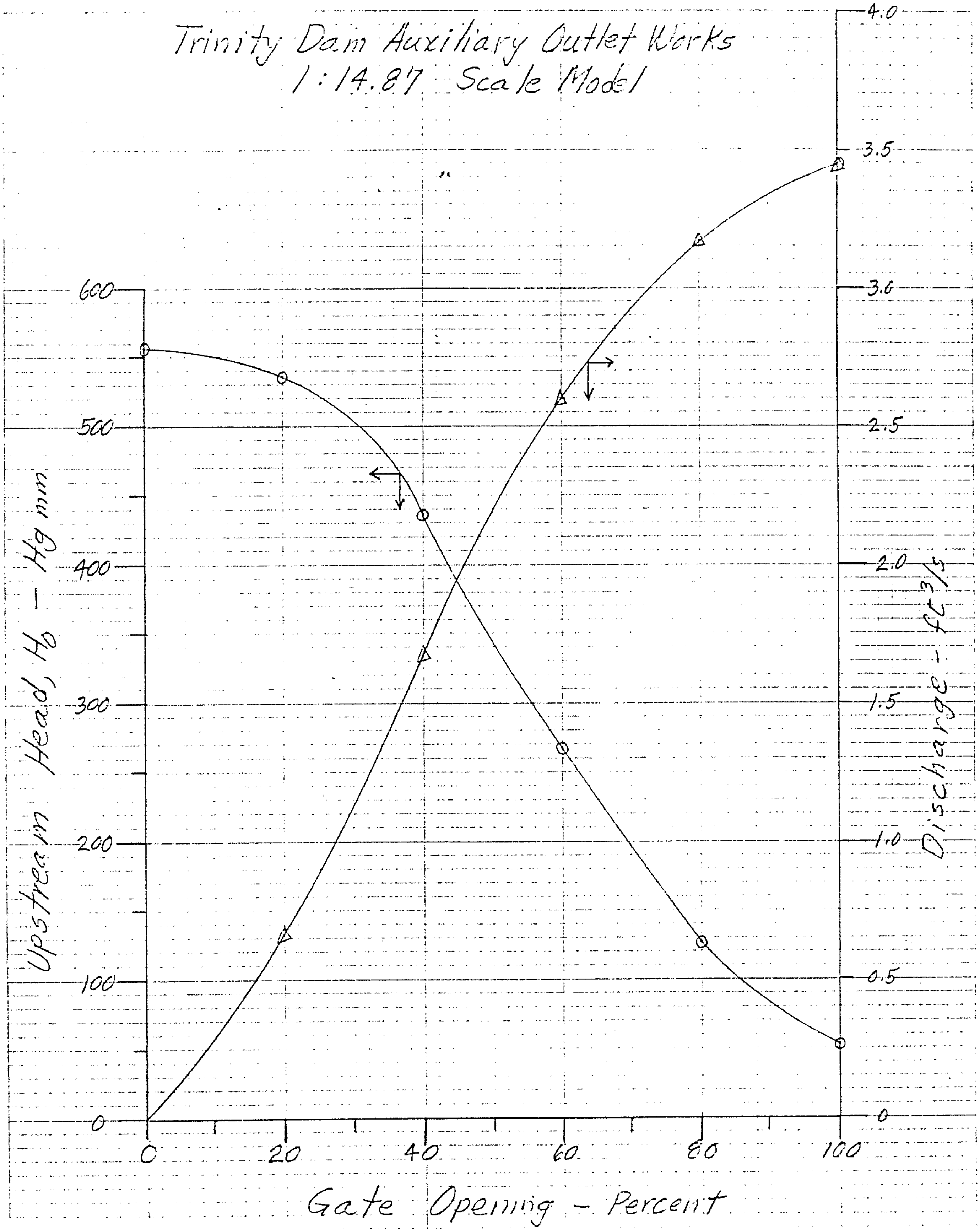
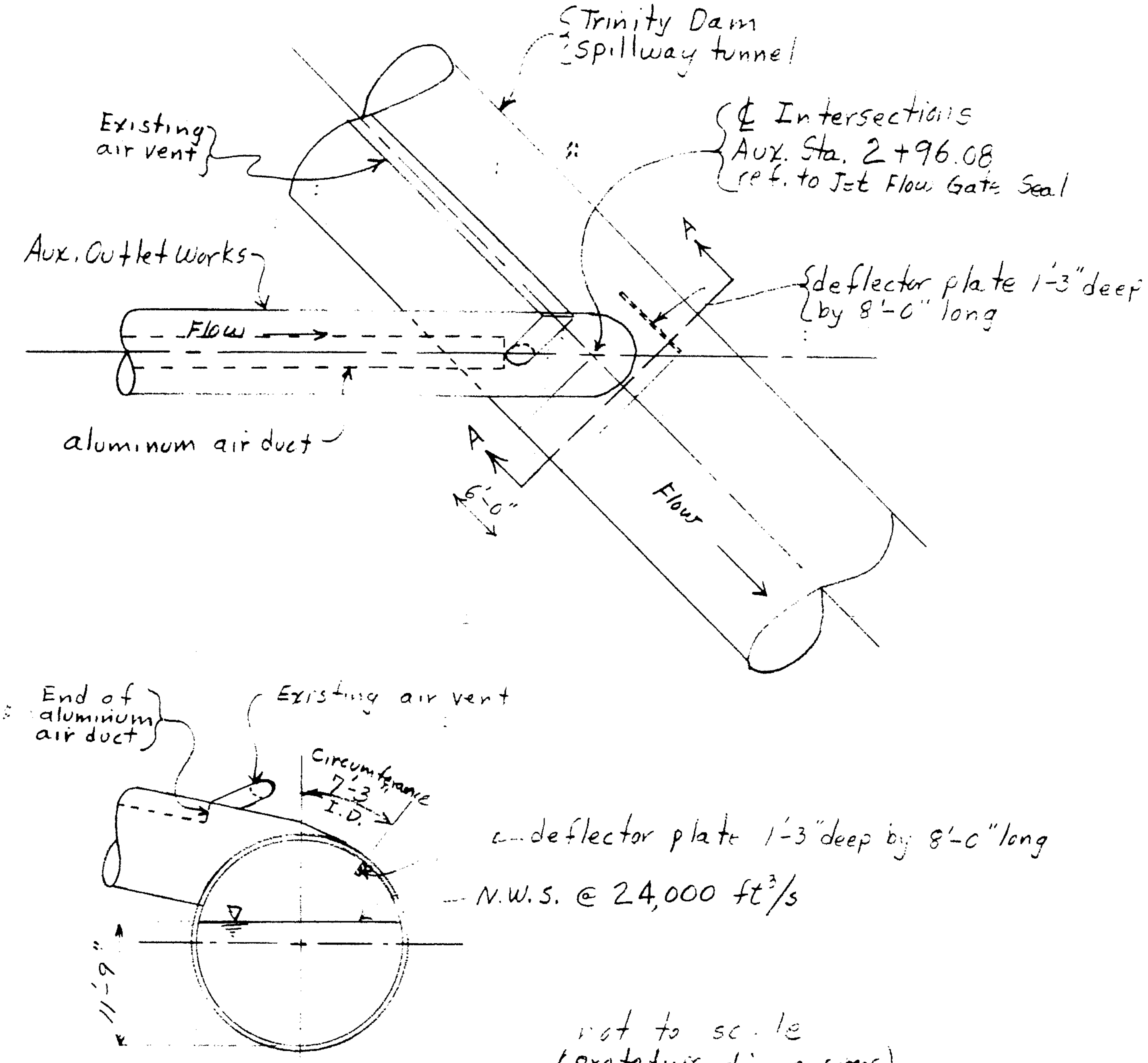

Trinity Dam Auxiliary Outlet Works
1:14.87 Scale Model

Figure 6- Trinity Dam Jet Flow Gate Model Calibration

6/26/85



not to scale
(prototype dimensions)

Section A-A

Figure 7 - Location of Spillway tunnel deflector plate

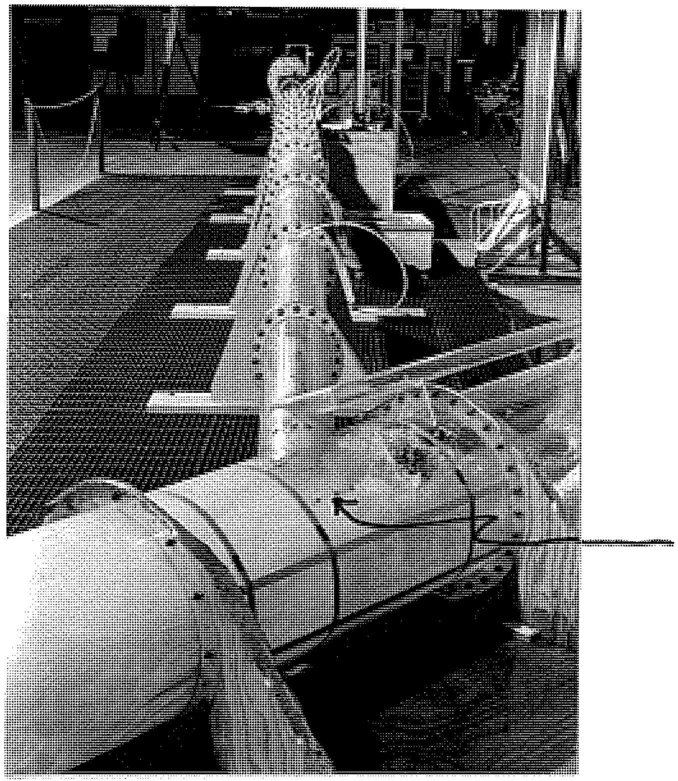


Figure 8. - General view of the vertical deflector plate installed inside the Trinity Dam spillway tunnel opposite the auxiliary outlet conduit entrance with the flow at 100 percent gate opening.

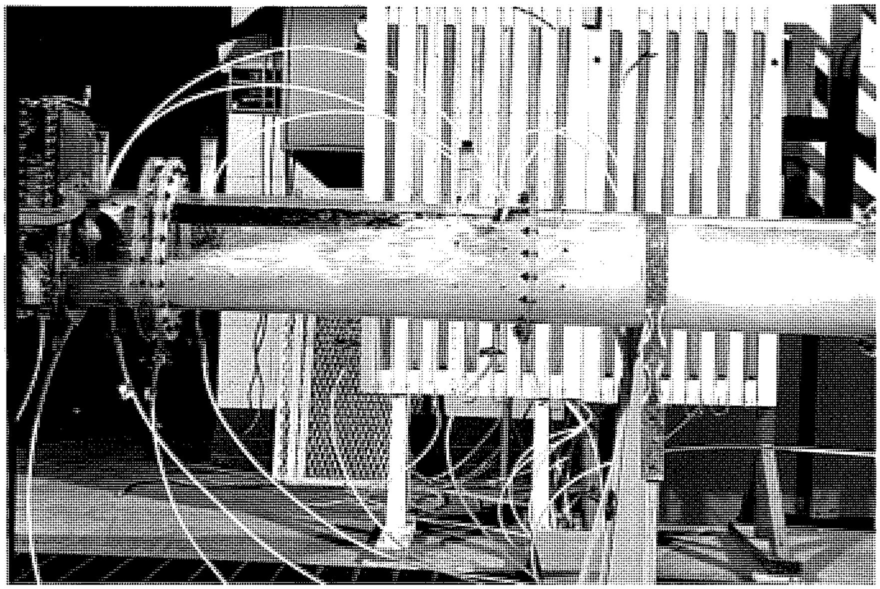


Figure 9. - General view of the flow impingement onto the bottom of the air duct system at 40 percent gate opening flow with the 1/2-in-high offset ring orifice installed.

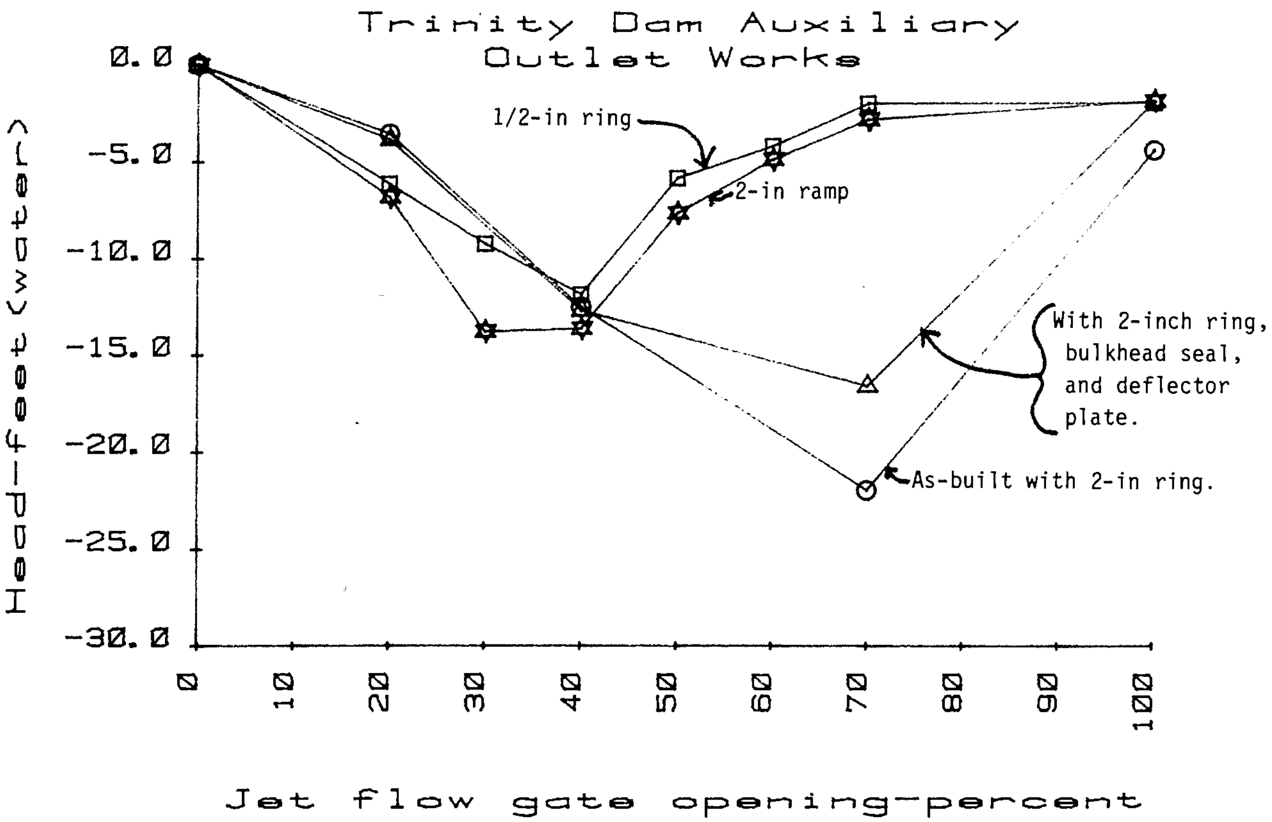
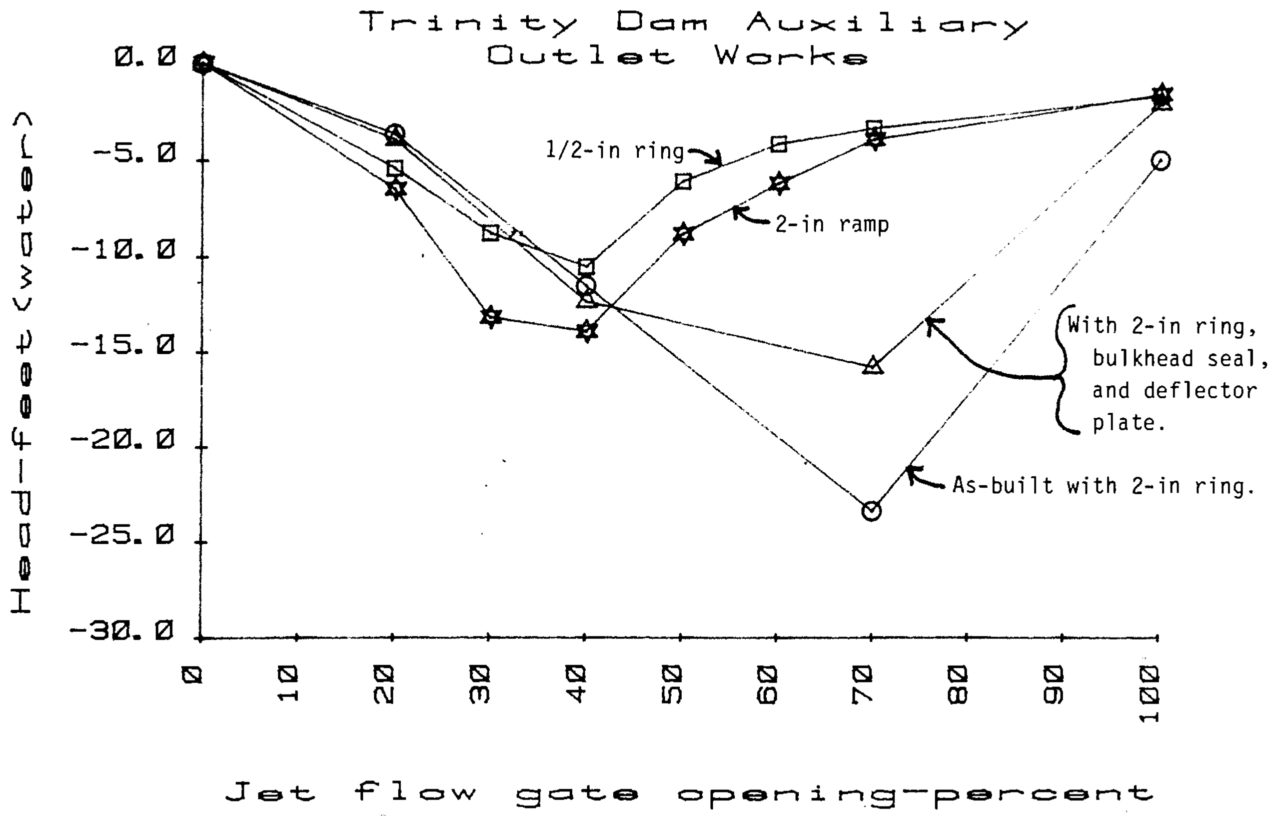
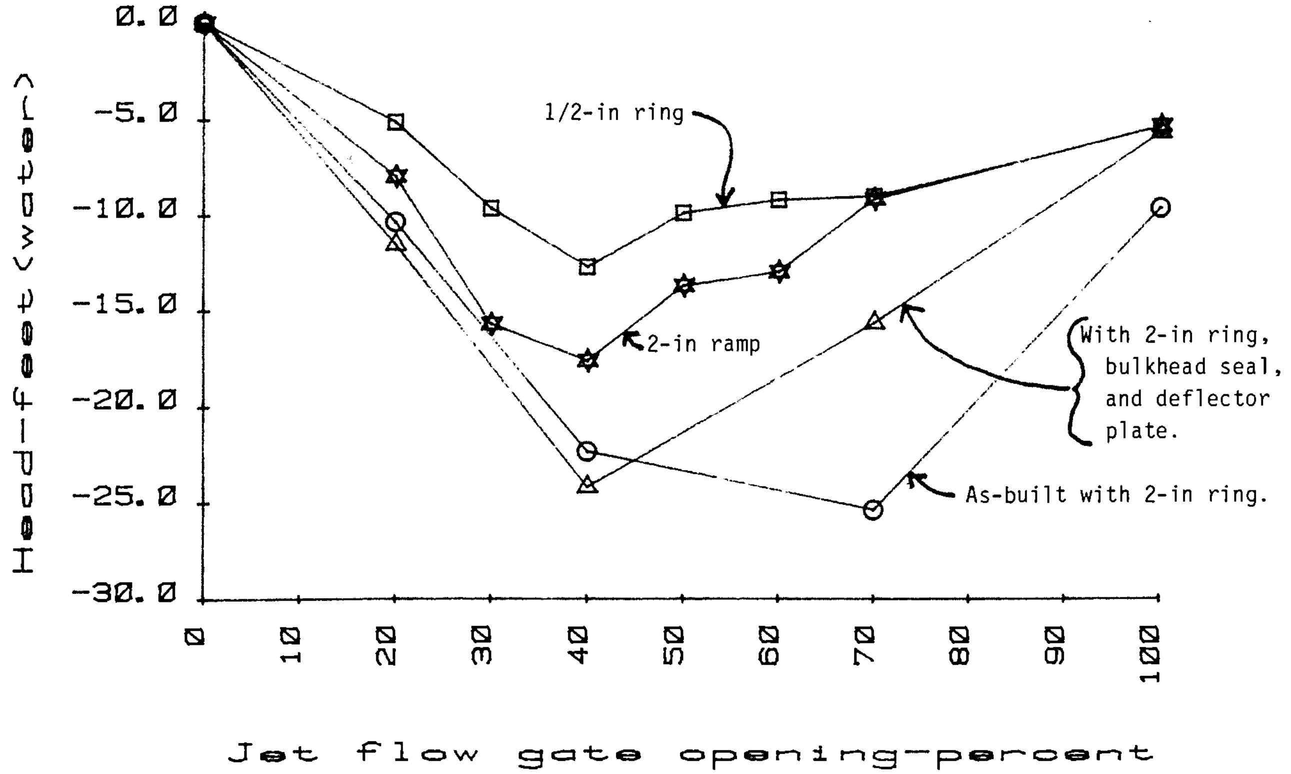


Figure 10. - Average static air pressure head inside upstream end of aluminum air duct (P13) vs. gate opening.



(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.

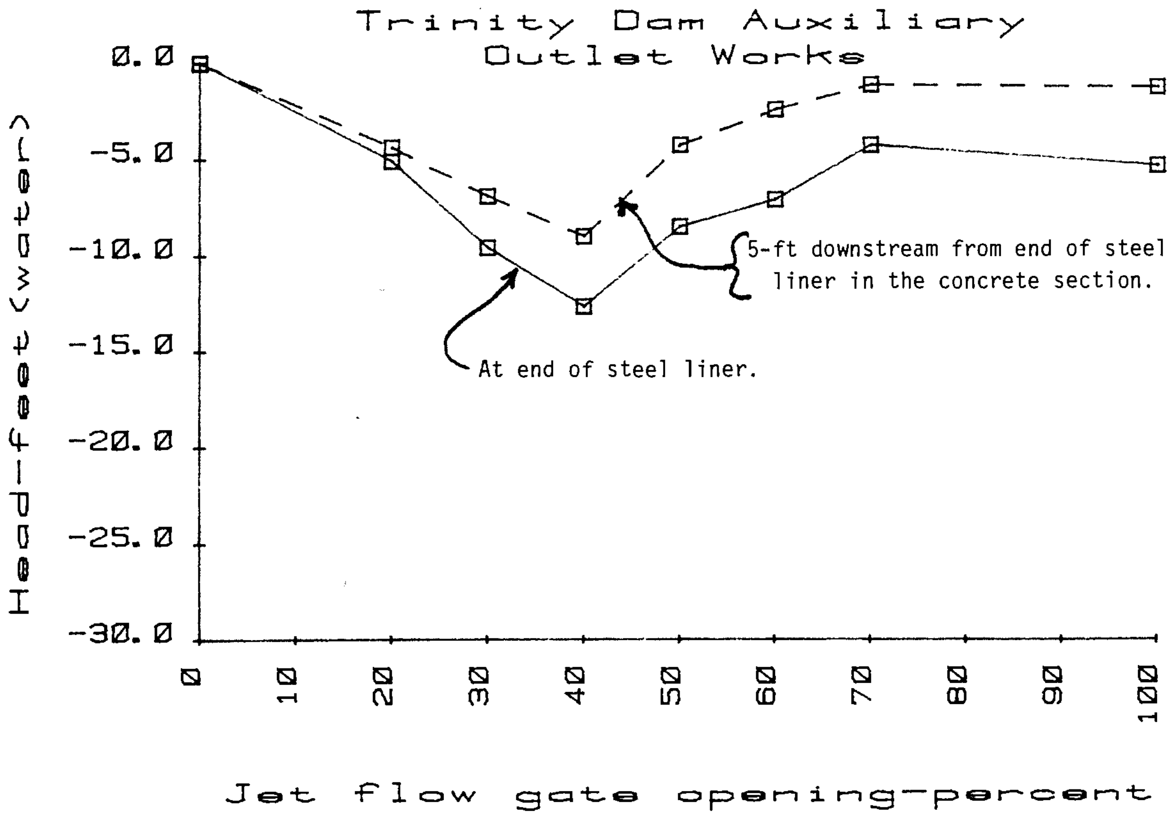


Figure 12. - Average side wall pressure head at the end of the steel liner (maximum of P10b, P10f, or P10i) compared to 5-ft downstream in the concrete section (maximum of P10c, P10g, or P10j) based on the 1/2-in high orifice ring offset configuration vs. gate opening.

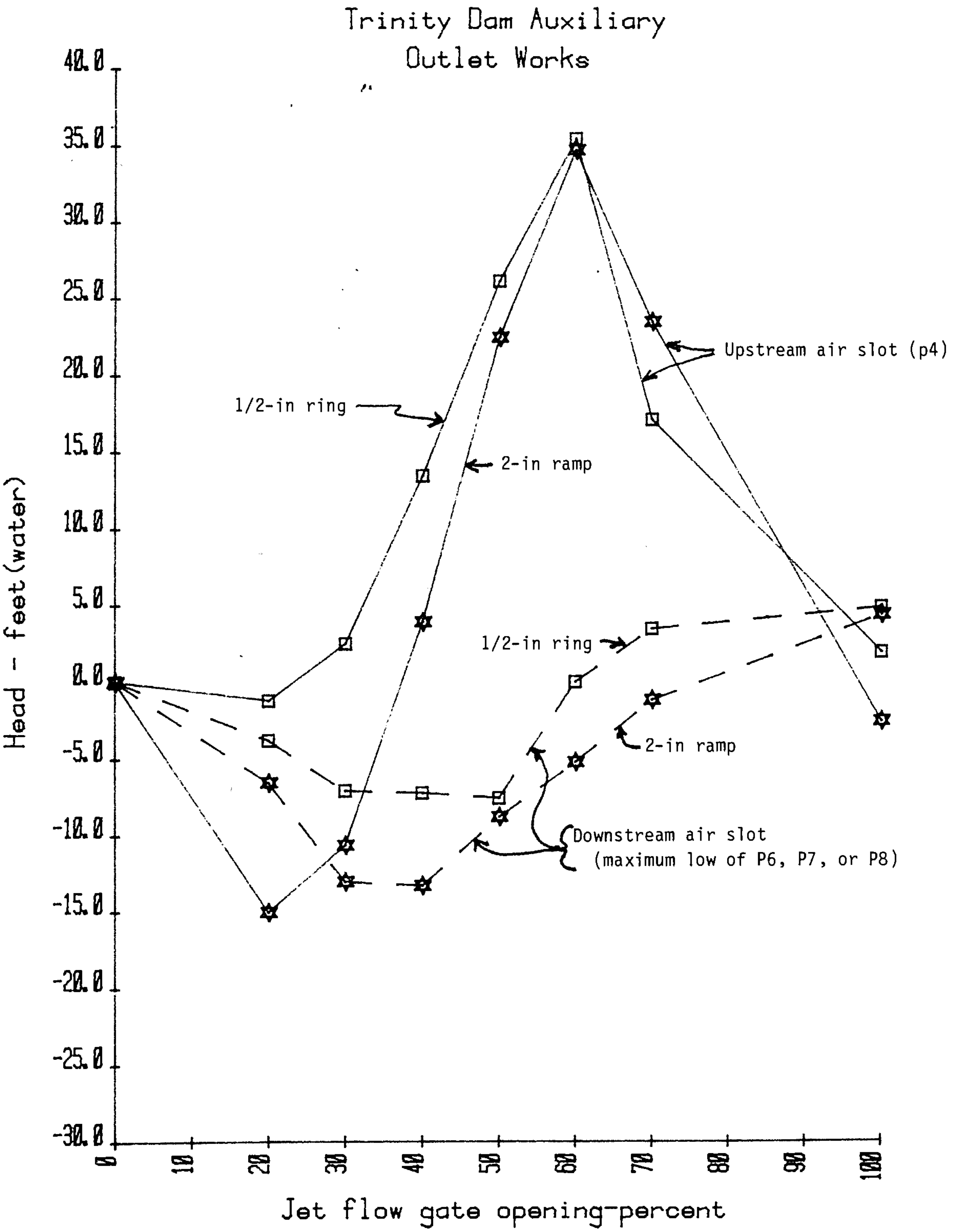


Figure 13. - Average invert pressure head upstream and downstream of air slot vs. gate opening.

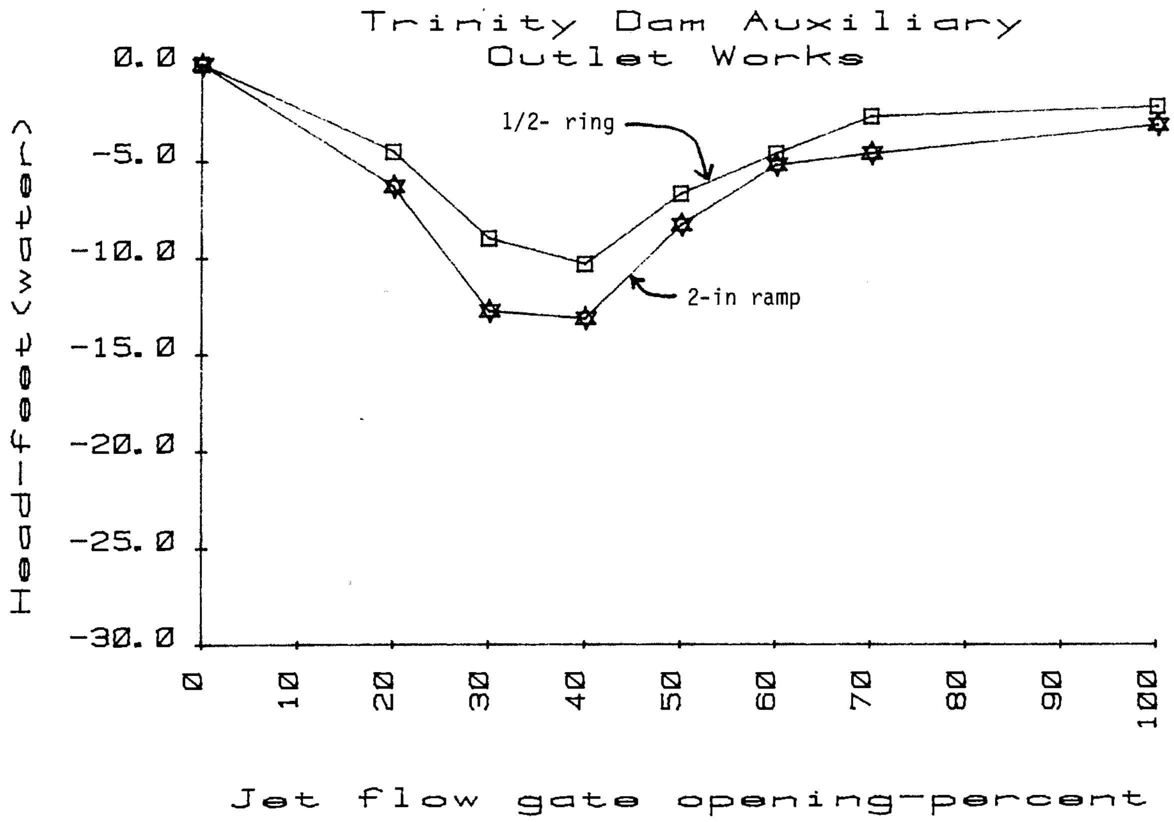


Figure 14. - Average invert pressure head at the centerline of the air slot (P5).

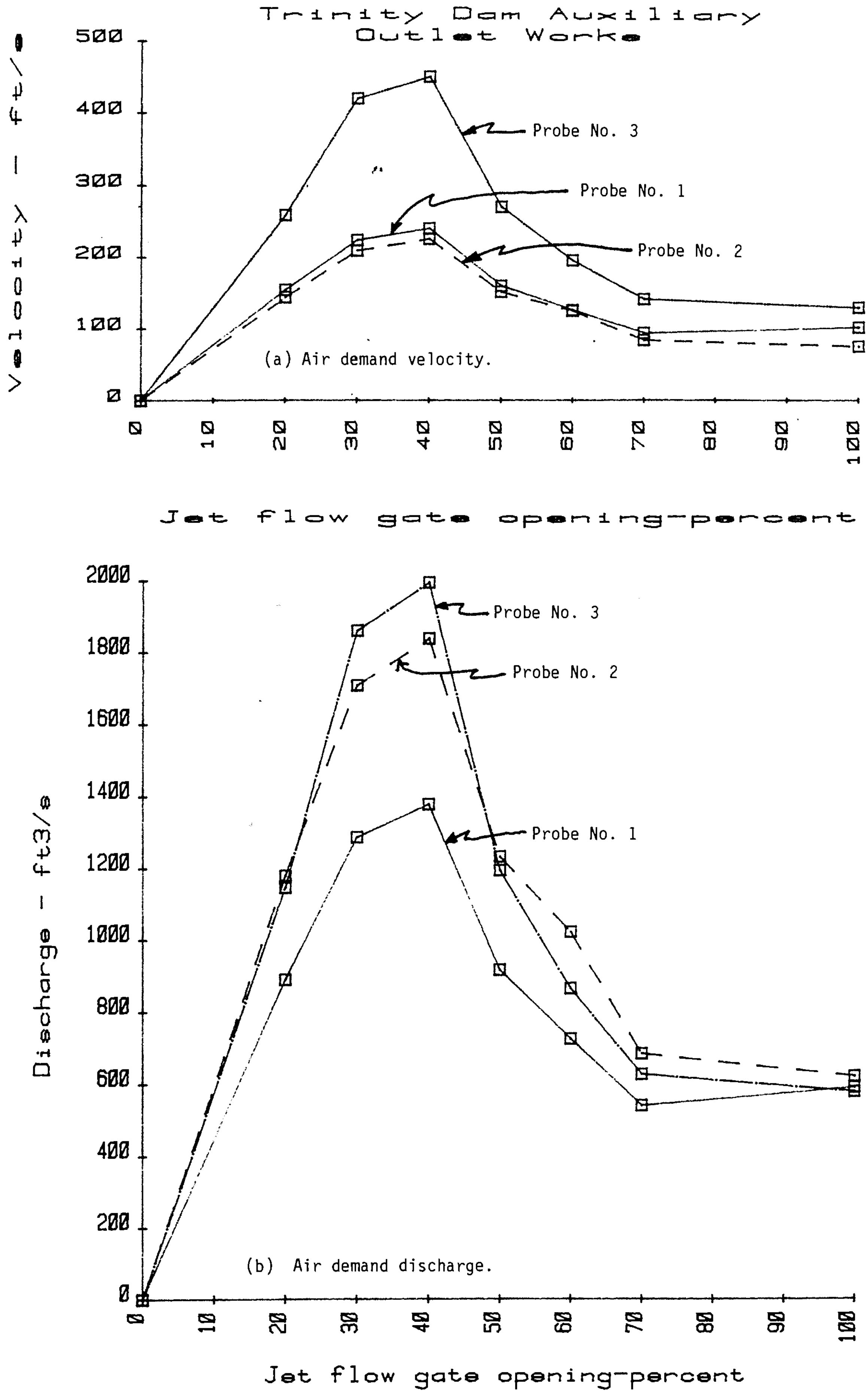
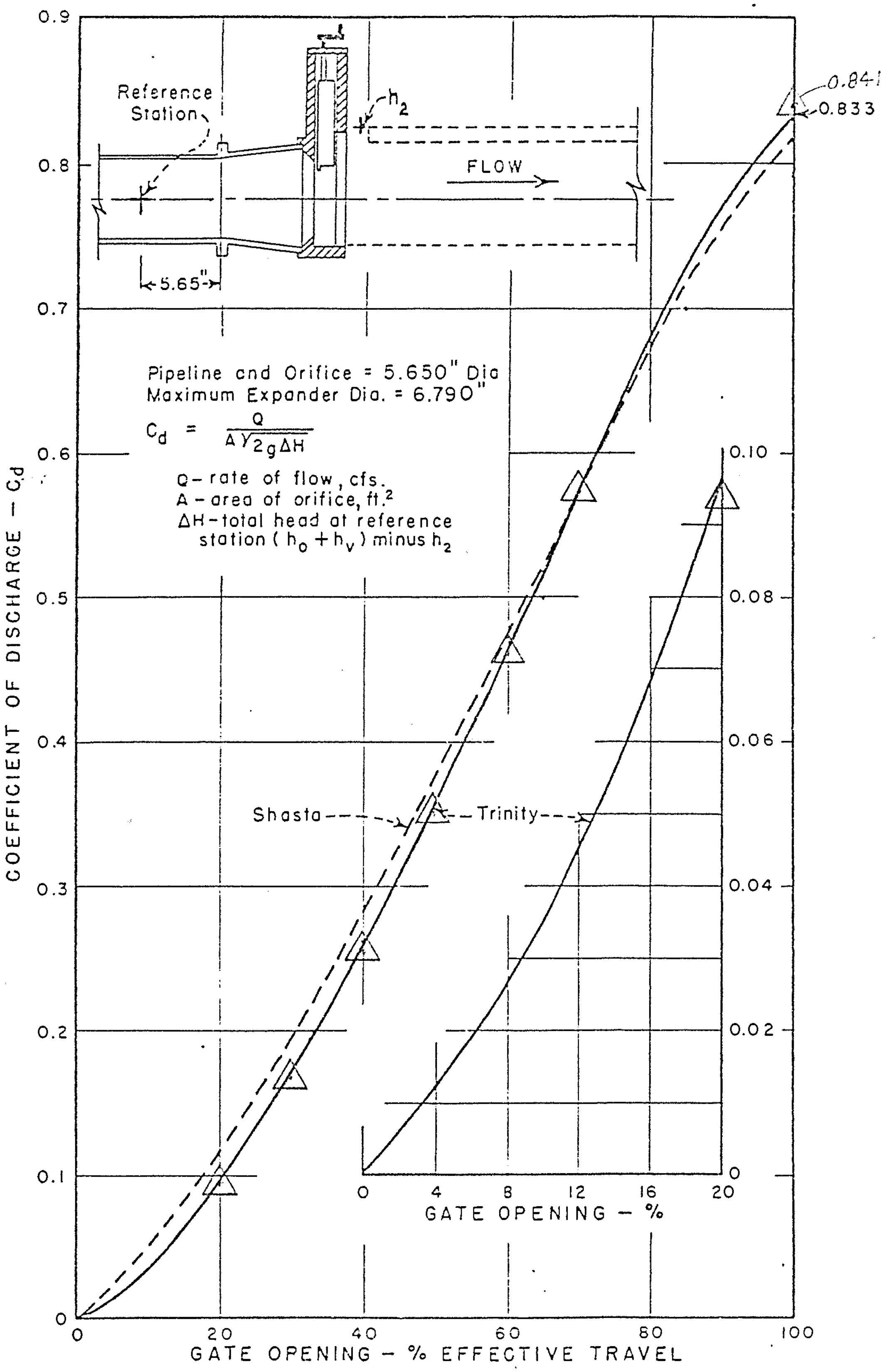


Figure 15. - Air demand (a) velocity and (b) discharge at the three air velocity probe locations based on 1/2-in-high orifice ring offset configuration vs. gate opening.

FIGURE 10
REPORT HYD. 472



JET FLOW GATE △ *Trinity Model Calibration August 1985*

TRINITY AUXILIARY OUTLET WORKS

COEFFICIENT OF DISCHARGE-VS-GATE OPENING

Data From 1:14.87 Hydraulic Model *Figure 16*

625