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Pueblo Dam - Hydraulic Model Study Report for Existing and Modified Spillway Geometries

Prepared by

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U.S. Department of the Interior
Bureau of Reclamation

March 2001

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Technical Memorandum No. PUE-8130-FD-TM-2000-1

Pueblo Dam - Hydraulic Model Report for Existing and Modified Stilling Basin Geometries

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03/15/01

Date

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ACKNOWLEDGMENTS

The investigations made using the hydraulic model were greatly facilitated by the assistance and advice provided by the following individuals: Brent Mefford, Bob Einhellig and Dean Conner, (D-8560). Neal Armstrong (D-8561) constructed an excellent model that performed well throughout the investigations involved in this study.

Phil Burgi, the Group Manager of D-8560, was especially accommodating when he agreed to allow the investigator for the model to be someone from outside his staff and at the same time make part of his staff available to provide advice and assistance when needed. This arrangement was made due to the heavy work load of his staff and the desire of the staff of the Waterways and Concrete Dams Group (D-8130) to maintain the schedule for their Corrective Action Study. The assistance and cooperation of Mr. Burgi and his staff is greatly appreciated.

PURPOSE

The original purpose of this model study was to evaluate various proposed modifications to the existing stilling basin at Pueblo Dam for satisfactory hydraulic performance. The geometry and scope of the proposed modifications resulted from designs and analyses of various alternatives developed during the Corrective Action Study (CAS) [1] that would provide for a satisfactory structural fix for the safety of dams deficiency. The deficiency was documented in the Modification Report [2]. The deficiency is due to low factors of safety for sliding stability of the overflow section of the concrete dam. The structural fix alternative that involved modifying the stilling basin, involves adding 60,000 cubic yards of roller compacted concrete (RCC) to the existing basin. The modification will result in a significant change in the geometry of the spillway stilling basin. The existing basin was sized and configured based on a three-dimensional hydraulic model study conducted during the original design of the dam.

After the modification to the stilling basin was studied, the model was modified to represent the geometry after the surface of the ogee shaped spillway crest was raised the equivalent of 12.2 feet as measured in the prototype. This portion of the study was made because of a desire to evaluate the hydraulic performance of the stilling basin and assess the impacts from raising the operating pool in order to provide additional reservoir storage volume [3]. The 12.2 foot raise was the highest spillway crest raise considered and it would provide for an increase in the operating pool of 75,000 acre-feet.

INTRODUCTION

A. Description of Pueblo Dam - Pueblo Dam (see Figure 1), part of the Fryingpan-Arkansas Project, is on the Arkansas River 6 miles west of the city of Pueblo in south-central Colorado. The project was authorized in 1962, and construction of the dam commenced in 1970 and was completed in 1975. In 1981 the left embankment was modified with a downstream stability berm. The dam and reservoir provide storage for irrigation, flood control, municipal and industrial water, and recreation. A fish hatchery located downstream from the dam provides fish for stocking Pueblo Reservoir and other reservoirs within the project. The reservoir has a total storage capacity of about 357,000 acre-feet at spillway crest elevation 4898.7.

Pueblo Dam is classified as high hazard, due to the potential for over 10,000 lives to be in jeopardy and the possibility of extensive economic damages along a 117-mile reach of the Arkansas River downstream from the dam, if dam failure occurred.

The dam is a composite concrete and earthfill structure approximately 10,230 feet long at crest elevation 4925. The concrete section has a structural height of approximately 245 feet to the lowest point in the foundation, and a hydraulic height of 187 feet. The earthfill portions consist of the left and right abutment embankments totaling 8,480 feet in length.

The central concrete dam consists of 23 massive-head buttresses. This section of the dam has a maximum structural height of approximately 245 feet, but is typically about 166 feet high from the foundation to the top of dam. It has a crest with a length of 1,750 feet at elevation 4921, which includes a 550-foot-long overflow spillway section and a 1,200-foot-long nonoverflow section. The top of the nonoverflow section contains upstream and downstream parapets to elevation 4925.25. The nonoverflow section has 16 buttress sections spaced on 75-foot centers, and is supported on the downstream side by 18-foot-wide concrete buttresses. The overflow section has 7 buttress sections spaced on 78.5-foot centers, and supported on the downstream side by 21.5-foot-wide concrete buttresses.

The embankment sections on the left and right abutments are zoned embankments, about 3,630 and 4,850 feet long, respectively, and contain a 30-foot-wide crest at elevation 4925.0, with a 3H:1V upstream slope and 2.5H:lV downstream slope. Each embankment section is cambered by up to 1.5 feet at the concrete section. The left embankment has a stability berm that was added in 1981.

B. Upstream basin description - Pueblo Dam is located on the Arkansas River about six miles west of the center of the city of Pueblo Colorado. The dam is the terminal structure for the entire Fryingpan-Arkansas Project. Pueblo Dam and Reservoir provide storage for water conservation, recreation, and flood control purposes. The entire drainage area above Pueblo Dam is 4,560 square miles. The probable maximum flood has a peak flow of 835,000 ft^3/sec [4].

C. Downstream conditions - Six miles downstream of Pueblo Dam is the city of Pueblo, Colorado which has a population of 100,000 people. The 117-mile reach of the Arkansas River between Pueblo Dam and John Martin Reservoir has a limited safe channel capacity which must be considered in all flood routing scenarios and proposed operation plans. The water from Pueblo Dam is used for irrigation, municipal, industrial, recreation and wildlife purposes.

D. Outlet works and spillway - Release facilities at the dam include a spillway and five sets of outlet works. The spillway, within the central concrete section, consists of a 550-foot-wide uncontrolled ogee crest at elevation 4898.7, downstream training walls, flip bucket energy dissipater, and a 550-foot-wide plunge pool at the downstream toe of the dam. Prior to the construction of the 1999 modification, the plunge pool was 80 feet long (upstream to downstream) at invert elevation 4710, which was 31.5 feet below the stream channel, and 45 feet below the surface of the buttress foundation. The discharge capacity of the spillway is 191,500 ft^3/sec at reservoir water surface elevation (RWSE) 4919.

Located beneath the spillway is the spillway outlet works, consisting of three identical outlets within buttress Nos. 9, 11, and 13, each containing a metal trashrack, a 6- by 6.5-foot steel lined conduit at sill elevation 4765.0, 6-foot by 6.5-foot emergency and 6-foot by 6.5-foot regulating gates, and a formed concrete conduit for release to the spillway stilling basin. Each conduit can release about 3,100 ft^3/sec at RWSE 4898.7. They were designed to release 2,730 ft^3/sec at RWSE. elevation 4868.

The river outlet works, is within the concrete section in buttress No. 16, which is a non-overflow section. It consists of a metal trashrack at the upstream end, a 4-foot-square steel liner at sill elevation 4764.0, 4- by 4-foot emergency and regulating gates, and a formed rectangular downstream conduit of varying dimension. The discharge capacity of the river outlet works is about 1,280 ft^3/sec at the design maximum reservoir elevation 4919.0.

The fish hatchery outlet works, in buttress No. 8, consists of four intakes at centerline elevations 4857.0, 4811.0, 4786.0, and 4763.0, and four 30-inch-diameter conduits entering a combined gate chamber with two 24-inch butterfly valves for each pipe. From the gate chamber, all flows are combined into one 30-inch-diameter steel outlet pipe which exits the buttress, to the fish hatchery, which was constructed in 1988. Release from the fish hatchery is restricted to 30 ft^3/sec.

The south outlet works, in buttress No. 7, consists of three multilevel intakes at centerline elevations 4840.0, 4805.0, and 4776.0, which combine to a single 48-inch-diameter outlet pipe. Flows are controlled by a 48-inch butterfly valve. The two upper intakes contain 72-inch-diameter cast iron slide gates at the upstream face of the dam, and the lower intake contains a 48-inch-diameter butterfly valve within a gate chamber in the upstream pipe section. A second 48-inch-diameter outlet pipe at inlet centerline elevation 4768.5, containing a single butterfly valve for regulation, is a standby system to be used when the other pipe is shut down for maintenance or repair. Both outlet pipes carry flow to the Fountain Valley Conduit system via a series of pumping plants. Combined discharge capacity from the two outlet pipes is about 700 ft^3/sec.

The Bessemer Ditch outlet works, located beneath the right abutment embankment, consists of an intake with a trashrack; a 7-foot-diameter upstream conduit; a gate chamber and shaft where flow bifurcates to two 3.5-foot by 3.5-foot emergency gates, and two 3.5-foot by 3.5-foot regulating gates: a 9.5-foot by 8.25-foot modified horseshoe downstream conduit: a stilling basin; wave suppressor structure; and outlet channel. The capacity of the downstream channel is 392 ft^3/sec.

CONCLUSIONS

1. The maximum difference in total pressure measured in the model for Modification No. 2 or No. 3 with existing tailwater conditions for a discharge of 110,000 ft^3/sec (the design discharge), was 20 feet of water (prototype). The 20 feet of water value was measured at pressure tap No. 3 with the Modification No. 2 geometry installed. The No. 3 tap was not available when the Modification No. 3 was tested. The 20 feet of water pressure is recommended for use in the design of the conventional concrete overlay that will be constructed over the Roller Compacted Concrete (RCC) that will be placed in the existing stilling basin.

2. The decrease in the value for the difference in total pressure is not sufficient enough to justify incorporating a downstream weir into the modification design in order to raise the tailwater levels.

3. The model can not be used to draw conclusions regarding the need to provide modifications to the stilling basin to ensure effective energy dissipation of the flow released from the spillway outlet works. The scale of the model was not appropriate for obtaining sufficiently accurate readings to aid in this evaluation. After the model studies were completed, analytical tools, design aids and engineering judgement were used by others to address the hydraulics of these three features [5].

4. Hydraulic performance of the modified stilling basin will be acceptable for the design discharge of 110,000 ft^3/sec if the highest crest raise (12.2 feet) that was considered during the pool raise study is constructed. If a specific crest raise alternative is identified in the future, or the design discharge is changed, consideration should be given to modifying the crest shape used in the modification in order to ensure that the jet impacts the stilling basin at a location sufficiently upstream of the impact blocks to provide for effective energy dissipation. Further model studies may be required to confirm the effectiveness of the stilling basin operation resulting from the crest raise design.

THE MODEL

The construction of the model incorporating the original geometry was completed in November of 1997. Beginning at that time and on an intermittent basis through August 1998, the hydraulic performance was investigated and measurements were taken while operating the model for a variety of flows and for the various geometries tested.

A 1:40 Froude scale sectional model was installed in a four foot wide testing flume located at the Bureau of Reclamations Water Resources Research Laboratory, located at the Technical Service Center in Denver Colorado. The model included a 160 foot length of the spillway crest (which is slightly longer than the width of two overflow buttresses), the downstream portions of the massive head buttresses and the stilling basin located immediately downstream of the spillway. The upstream portion of the massive head buttresses was not modeled because it has no effect on the hydraulic conditions associated with a spillway discharge. A piece of plywood was installed at the upstream end of the model at the same slope as the upstream face of the buttresses. Most of the model was constructed of plywood, except for the crest which was cut from a block of urethane foam. Sheet metal was used to construct the downstream portion of one of the three spillway outlet works that extends through the stem of a buttress. A sheet metal plate at the upstream end of the spillway outlet works conduit was installed as a gate that allowed for the flow through the conduit to be controlled. Piezometer taps were constructed using 1/16th-inch diameter tubing mounted flush to the flow surface. Flexible plastic tubing was connected to the pressure taps and then to a manifold that permitted the pressure to be transferred to the exterior of the model and then to additional plastic tubing to the manometer board where the pressure readings were made.

MODEL INVESTIGATIONS

The features of the various geometries investigated and the associated purpose, results, and conclusions are discussed in the following section. The five different geometries that were investigated are discussed below in the chronological order in which they were built and tested, with the earliest geometries listed first. Photo 1 shows the manometer board that was used to obtain the pressures from the model.

Figure 2 shows a chart of the prototype spillway discharges that were modeled and the associated Reservoir Water surface Elevation (RWSE) and tailwater elevations in the downstream channel.

Existing Geometry

Features - The model used the existing floor at elevation 4710. Figures 3 and 4 show the shop drawings used to construct the model. Figure 3 also shows the pressure tap locations. Photos 1 through 5 show the model with the existing geometry.

Purpose - Hydraulic conditions in the spillway stilling basin for the existing geometry were investigated in order to provide baseline values and observations that could be used later for comparison with results of model tests made with modified geometries.

Results - Baseline stilling basin pressures are given in Table 1 and Figure 5.

Modification No. 1

Features - The original geometry was modified by raising the floor of the stilling basin to elevation 4734.5 and adding a toe block by extending the horizontal surface at elevation 4755, another 45 feet downstream. A 1:1 slope provided the surface between 4755 and 4734.5. A solid, continuous weir was added downstream to serve as impact blocks. Figure 6 shows the shop drawing used to construct the model and the pressure tap locations. Photos 6 through 11 show the model with the Modification No. 1 geometry.

Purpose - Investigate the hydraulic performance of Modification No. 1. This was the first modified geometry that was investigated. The geometry was developed from the stability analyses performed for the CAS.

Results - Figure 7 and Table 2 show the results. Hydraulic conditions were significantly worse when compared with the existing geometry. The largest factor in this decrease in performance was most likely the decrease in the volume of water in the stilling basin that was available for energy dissipation. While the maximum fluctuation in pressure for a discharge of 110,000 ft^3/sec in the prototype was only 17.6 feet of water at tap No. 9 (see Table 2), it appeared that a large amount of turbulent flow was traveling downstream of the weir. The solid, continuous downstream weir did little more than serve as a minor "speed bump" in the flow, with only a small amount of energy dissipation evident.

Conclusion - The next modification studied should consist of a weir made up of individual impact blocks alternating with open spaces. Also, more of the original volume of the original stilling basin should be available. Both of these changes were suggested in order to improve the energy dissipating qualities of the stilling basins.

Modification No. 2

Features - The floor was lowered 4.5 feet to elevation 4730, from where it was for Modification No.1. The downstream slope on the toe block was changed from a 1:1 slope to a 2:1 slope. The impact blocks were installed alternating with equivalent length gaps. Additional pressure taps were installed. The additional taps made it possible to gather pressure readings from locations on the left and right side of the model, and from locations positioned longitudinally between the blocks and longitudinally in line with the center of the blocks. Figure 8 shows a Plan, Section and the pressure tap locations for Modification No. 2. Photos 12 through 17 show the model with the Modification No. 2 geometry.

Purpose - Determine if the hydraulic conditions are improved after the modifications are made. In addition, an investigation was made into the impacts of raising the tailwater 5 feet and then 10 feet, using discharges of 110,000, 191,500, and 278,000 ft^3/sec.

Results - Two separate tests were made using the Modification No. 2 geometry and the existing tailwater conditions. The values for difference in stagnation pressure resulting from the second test agrees relatively closely with the results obtained from the first test with the Modification No. 2 geometry. This is especially true for Tap No. 3 (20.0 feet of water vs. 18.4 feet of water reported for the first and second sets of tests, respectively). The values from the second test were recorded after observing the pressure fluctuations for a longer period than that which was used for the first test. The values from the second test confirm that the measured difference in stagnation pressure is greatest at Tap No. 3. Also of interest, are the readings from Tap No. 3R which is the same distance downstream as Tap No. 3, but located on the right side of the model. Tap No. 3R had a low and high reading slightly higher than Tap No. 3, but the difference between the extreme readings was only 11.6 feet of water as compared with 20.0 feet at Tap No. 3. Readings from Tap No. 3R reflect the hydraulic conditions immediately upstream of an impact block, while Tap No. 3 is immediately upstream of a space between impact blocks. Taps No. 5 and No. 5R which are a pair of taps that are an equal distance downstream with No. 5 on the left side of the model and No. 5R on the right side, provided results similar to those obtained from Taps No. 3 and No. 3R, with higher total pressures for the taps lined up with the centerline of the blocks (No. 3R and No. 5R), but higher difference in total pressure at the taps lined up with the space between the blocks (No. 3 and No. 5). The values from the second test are plotted in a table in Figure 9 and shown as tabulated values in Table 3.

Overall, significant improvements in the hydraulic performance were observed when compared with the conditions that existed for Modification No.1. The change in location and the new configuration of blocks alternating with open spaces were apparently responsible for the flow being effectively broken up resulting in turbulence and improved energy dissipation. The level of turbulence downstream of the impact blocks is greatly improved when compared with the conditions seen with Modification No. 1. However, there is a concern that at the higher discharges (greater than 110,000 ft^3/sec), the jet seemed to be impinging at a location too close to the impact blocks to allow for effective energy dissipation before flowing downstream.

The results from the investigation of the impacts of raising the tailwater levels for each of the three discharges that were studied are discussed below.

> For a discharge of 110,000 cfs, Figure 10 shows that in general, an increase in tailwater results in a decrease in the difference in total pressure. A significant exception is tap No. 3R which shows a higher difference in total pressure for 10 feet of added tailwater than for zero or 5 feet of added tailwater.
>
> For a discharge of 191,500 cfs, Figure 11 shows that the difference in total pressure increases at taps No. 3 and 3A when 5 feet of tailwater is added. The largest difference in total pressure measured at this discharge level for all of the tailwater levels was at tap No. 3 with 5 feet of tailwater added. At tap No. 3R there is only a slight decrease in the difference in total pressure when 5 feet of tailwater is added.

For a discharge of 278,000 cfs, Figure 12 shows that the difference in total pressure increases at taps No. 2A, 3A, 3B and 4, when 5 feet of tailwater is added. The maximum difference in total pressure measured with 5 feet of tailwater added (tap No. 2A) is only slightly less than the difference in total pressure measured at tap No. 3 for no tailwater added. Figure 13 shows on one chart, the results for the three discharges and three tailwater levels that were used.

Conclusion - Two conclusions were made as a result of this part of the study. The first conclusion was to move the impact blocks downstream in order to optimize the hydraulic performance for all discharges in the operational range. The second conclusion was that hydraulic performance would not be significantly improved by adding tailwater.

Modification No. 3

Features - The only change from the Modification No. 2 geometry was to move the blocks downstream by 6.7 feet in the prototype, which is equivalent to two inches in the model. Figure 14 shows a Plan, Section and the pressure tap locations for Modification No. 3. Photos 20 through 22 show the model with the Modification No. 3 geometry.

Purpose - Evaluate the hydraulic conditions after the modifications are made. Perform tests using discharges equal to and greater than 110,000 ft^3/sec.

When looking at the results shown in Figure 15 and Table 5, the following results can be identified regarding the performance of Modification No. 3 compared with Modification No. 2:

- For a discharge equivalent to 110,000 ft^3/sec in the prototype, there are five positive and five negative values indicating that there are an equal number of taps that show that one modification has better performance than the other. At tap No. 3R, the largest increase in the difference between the differential in pressures occurs, with a positive value of four feet of water. This would indicate that Modification No. 2 has better hydraulic performance than Modification No. 3, for this discharge level.

- For a discharge equivalent to 191,500 ft^3/sec in the prototype, there are six positive values and four values equal to or less than zero, which indicates that Modification No. 2 has better performance than Modification No. 3, for this discharge level. At tap No. 3R, the largest increase in the difference between the differential in pressures occurs, with a positive value of 12 feet of water. This would indicate that Modification No. 2 has better performance than Modification No. 3, for this discharge level.

- For a discharge equivalent to 278,000 ft^3/sec in the prototype, there are five positive values and five negative values, which indicates that the hydraulic performance of the two modifications are very similar, for this discharge level.

When comparing the results from tests using a discharge equivalent to 110,000 ft^3/sec with the Modification No. 2 and the Modification No. 3 geometries, the following results were obtained:

- At tap No. 3A, the largest increase in the difference between the differential in pressures occurred, with a positive value of 15.6 feet of water. This would indicate that Modification No. 2 has better hydraulic performance than Modification No. 3, for this discharge level.

- At tap No. 2A, the pressure differential measured with Modification No. 2 is 36 feet of water as compared with 21.2 feet of water for Modification No. 3. This would indicate that Modification No. 3 has better hydraulic performance than Modification No. 2, for this discharge level.

- The largest difference in pressure differentials measured at taps that were present in both modifications, was 0.8 feet. Modification No. 2 had a pressure of 34 feet of water as compared with 33.2 feet of water for Modification No. 3., for this discharge level.

Note - Video tape of Modification No. 3 was taken. Photographs were not taken.

Conclusion - The jet impacts sufficiently upstream from the impact blocks for all discharge levels for effective energy dissipation to occur. There is less turbulence leaving the end of the stilling basin for Modification No. 3 as compared with Modification No. 2. This configuration results in the most acceptable hydraulic performance of the various geometries tested and should be used as the modification to the prototype.

Modification No. 4

Features - The three and 3/16th inch vertical movement of the ogee spillway crest surface above the position that was used for all other modifications, was the only change from the Modification No. 3 geometry. This increase in elevation represented 12.2 feet in the prototype and corresponded to the maximum crest raise that was considered as part of a study of rasing the elevation of the overeating pool of the reservoir. Figure 16 shows a section of the raised crest. The pressure tap locations are the same as for Modification No. 3 which are shown in Figure 14. Photos were not taken of the model with the Modification No. 4 geometry.

Purpose - Determine if the hydraulic conditions are acceptable after the modifications are made

Results - The results indicate that for any given discharge, the location where the jet impinges along the length of the stilling basin has moved in a downstream direction, as expected. A portion of the increased potential energy at the various flow rates due to the increased crest elevation, is converted into pressure when the jet hits the floor of the stilling basin and a portion is dissipated in the cushion of water above the floor.

Data obtained from tests using the design discharge of 110,000 ft^3/sec (see Figure 15 and Table 6), showed that the largest variation in total pressure measured in the model with the crest raise geometry (Modification No. 4), was 22.8 feet (prototype) of water. Previous tests using the Modification No. 2 geometry resulted in a maximum variation of 20 feet of water. The pressure taps in the model that experienced these variations are located in sequential order with the tap with the highest variation for Modification No. 2 immediately upstream of the tap with the highest variation for the crest raise geometry (Modification No. 4).

The design of the overlay concrete and the associated anchor bars for the Safety of Dams (SOD) modification resulted in a relatively high factor of safety against any failure that would lead to erosion of the overlay concrete for discharges up to the design discharge. The magnitude of the increase in the variation of the total pressure for the crest raise geometry (Modification No. 4) will result in a decrease in this factor of safety, but the value will remain at an acceptable level. The SOD modification design incorporated a variety of conservative assumptions regarding the design load which were also used in evaluating the design for the Crest Raise geometry (Modification No. 4).

In addition, the ability of the jet in the prototype to spread in areal extent while falling the approximately 181 feet from the spillway crest to the floor of the basin, is not effectively duplicated in the model. The "spread" in the prototype would result in less impact pressures than if the jet stayed fully intact. The error caused by this effect not being fully duplicated in the model results in a conservative estimate of the actual pressures involved.

<u>Conclusion</u> - The hydraulic conditions that result from using the same stilling basin geometry as for Modification No. 3 and the crest at the higher elevation are acceptable for the design discharge of 110,000 ft^3/sec.

Note - Video tape of Modification No. 4 was taken. Photographs were not taken.

References

[1] Technical Memorandum No. PUE-8110-CAA-98-1, "Corrective Action Alternative Evaluation - Pueblo Dam - Fryingpan-Arkansas Project, Colorado," Bureau of Reclamation, June 1998.

[2] "Modification Report," Great Plains Region, U.S. Bureau of Reclamation, Denver, CO; April 1998, Bureau of Reclamation, Great Plains Region, Billings Montana, April 1998.

[3] "Study to Raise the Operating Pool for Southeastern Colorado Water and Storage Needs Assessment Enterprise", Bureau of Reclamation, August 31, 1999.

[4] Pueblo Dam - Frying Pan-Arkansas Project - "Probable Maximum Flood Study", K.L. Bullard and V. Leverson, U.S. Bureau of Reclamation, June 1991.

[5] Technical Memorandum No. PUE-8130-CAS-TM-97-1, "Hydrologic and Hydraulic Analyses for the MDA and CAS", Bureau of Reclamation, Draft February 2001.

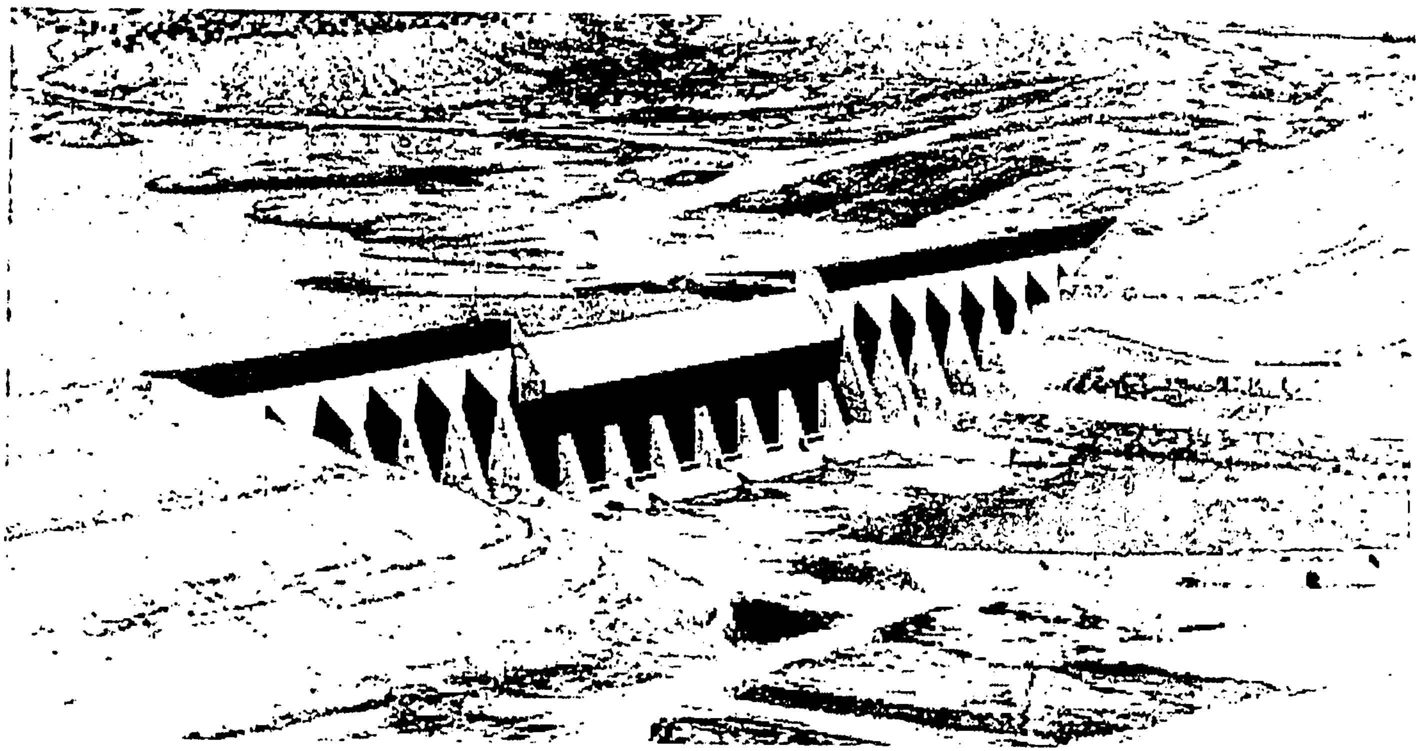


Figure 1 - Aerial view of Pueblo Dam from a location downstream of the dam and to the southeast of the spillway stilling basin

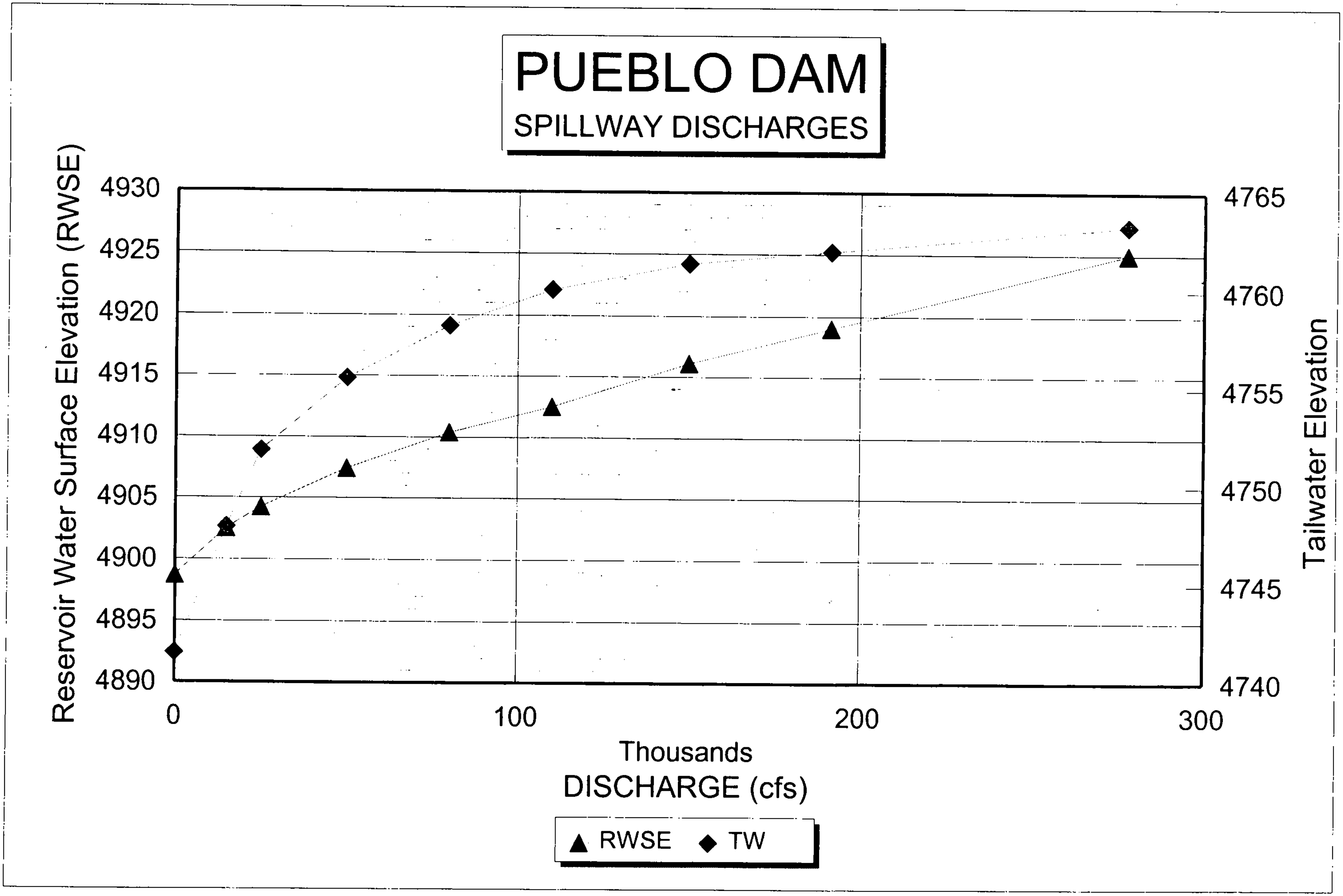
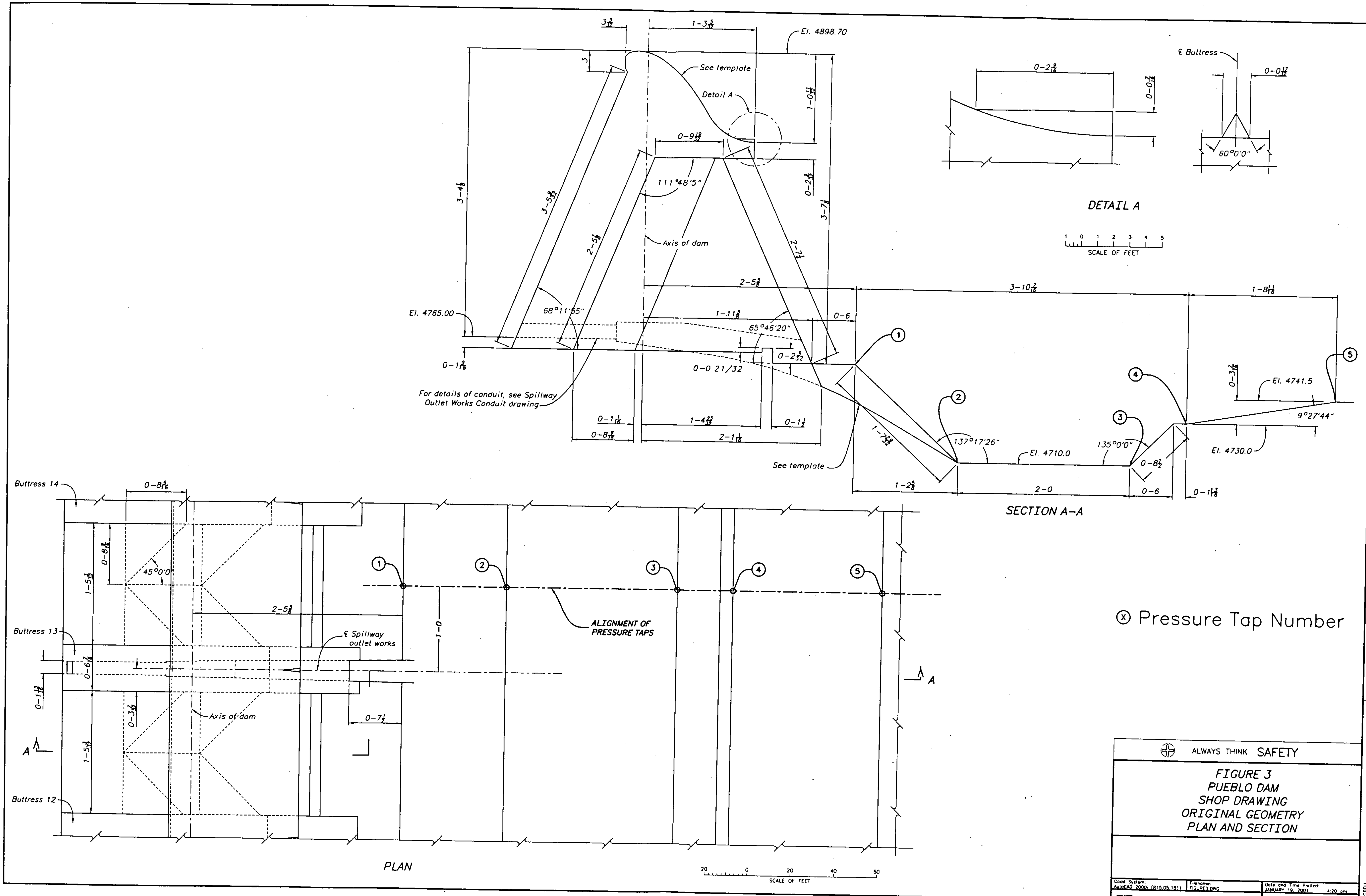
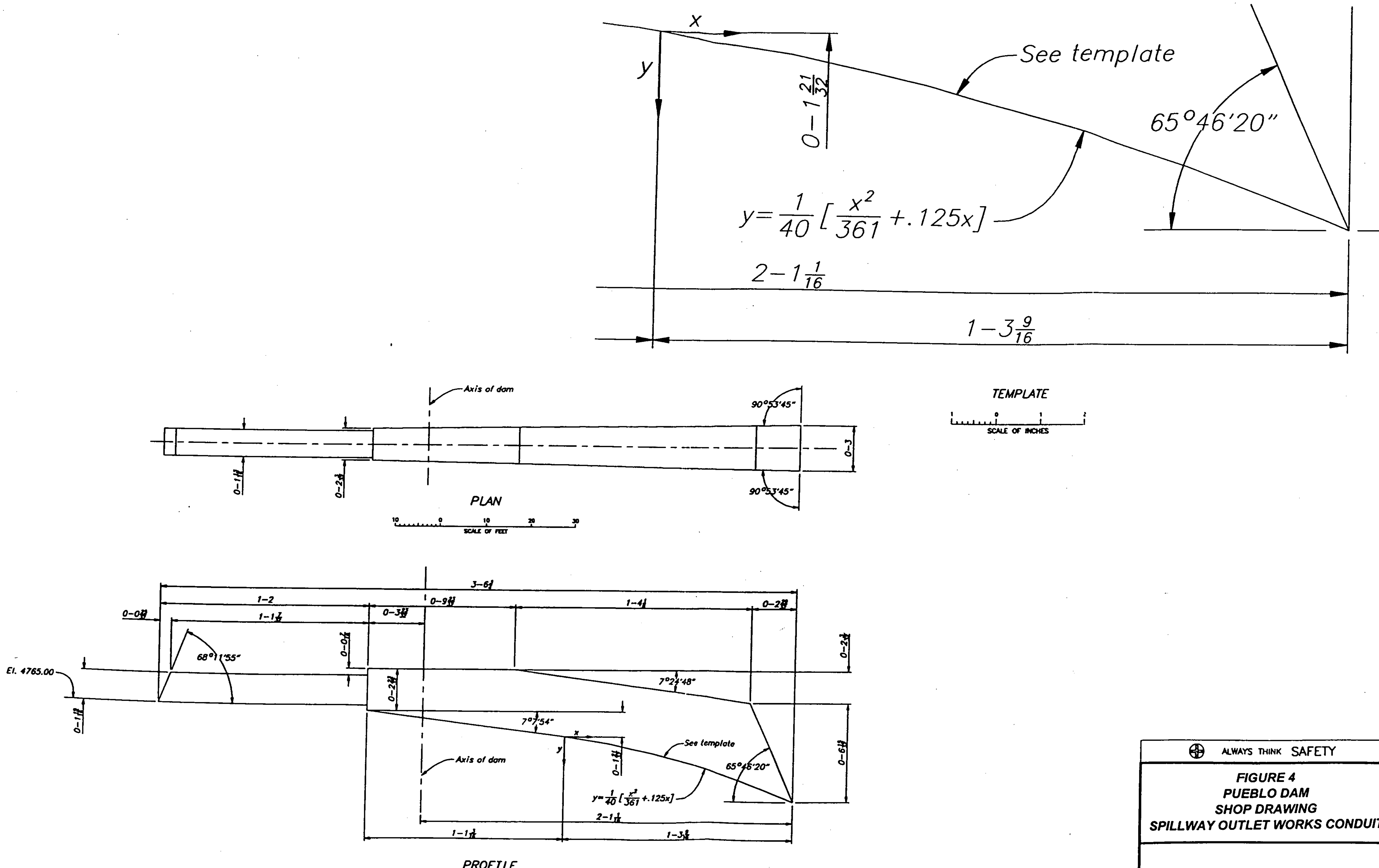


FIGURE 2 - Spillway Operation Parameters



El. 4898.70
See template
Detail A
111°48'5"
Axis of dam
68°11'55"
65°46'20"
El. 4765.00
0-0 21/32
For details of conduit, see Spillway Outlet Works Conduit drawing
See template
137°17'26"
El. 4710.0
135°0'0"
El. 4730.0
El. 4741.5
9°27'44"
SECTION A-A
DETAIL A
60°0'0"
℄ Buttress
SCALE OF FEET
Buttress 14
Buttress 13
Buttress 12
45°0'0"
ALIGNMENT OF PRESSURE TAPS
℄ Spillway outlet works
Axis of dam
PLAN
SCALE OF FEET
Ⓧ Pressure Tap Number
ALWAYS THINK SAFETY
FIGURE 3
PUEBLO DAM
SHOP DRAWING
ORIGINAL GEOMETRY
PLAN AND SECTION
Date and Time Plotted: JANUARY 19, 2001 4:20 pm



ALWAYS THINK SAFETY

FIGURE 4
PUEBLO DAM
SHOP DRAWING
SPILLWAY OUTLET WORKS CONDUIT

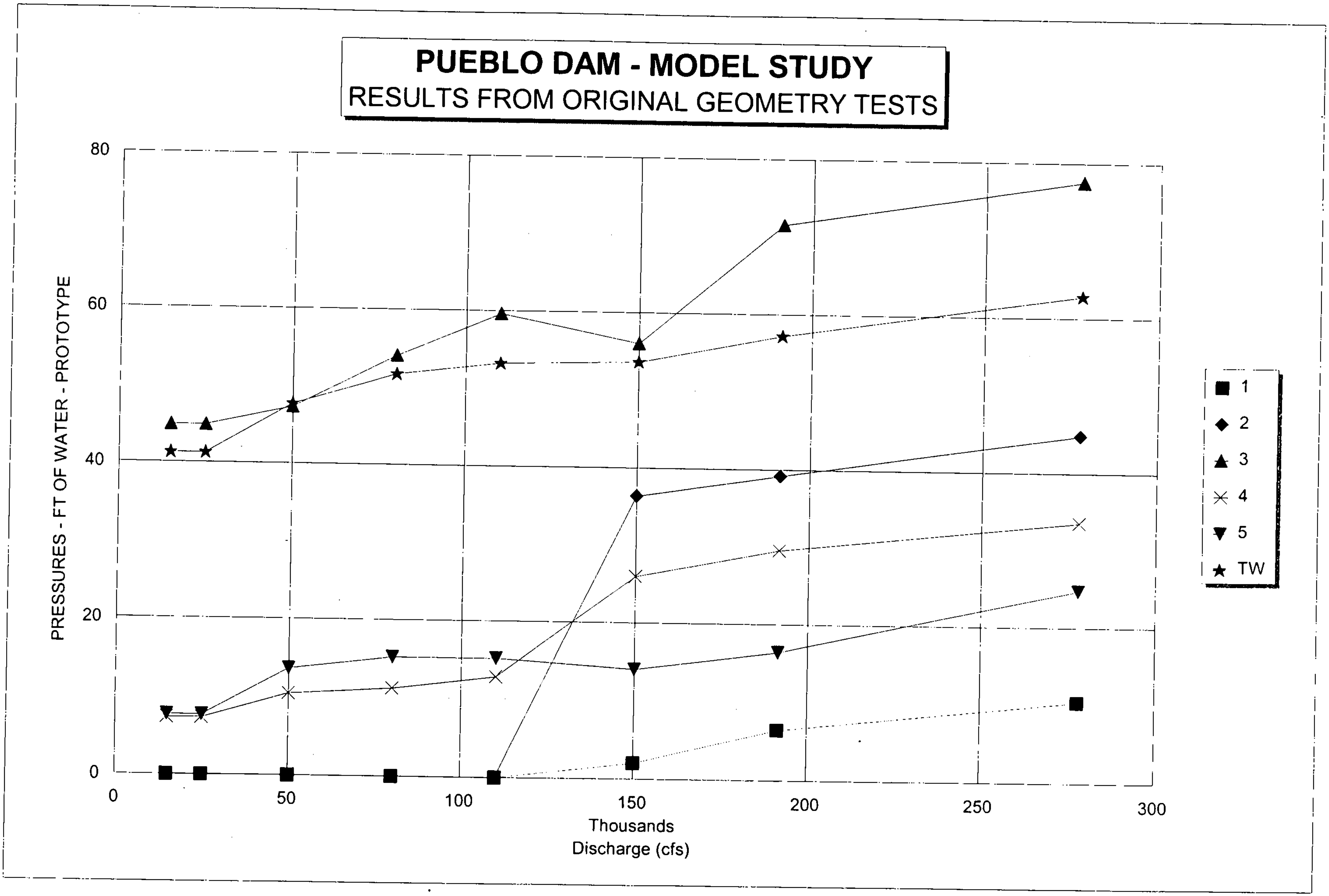
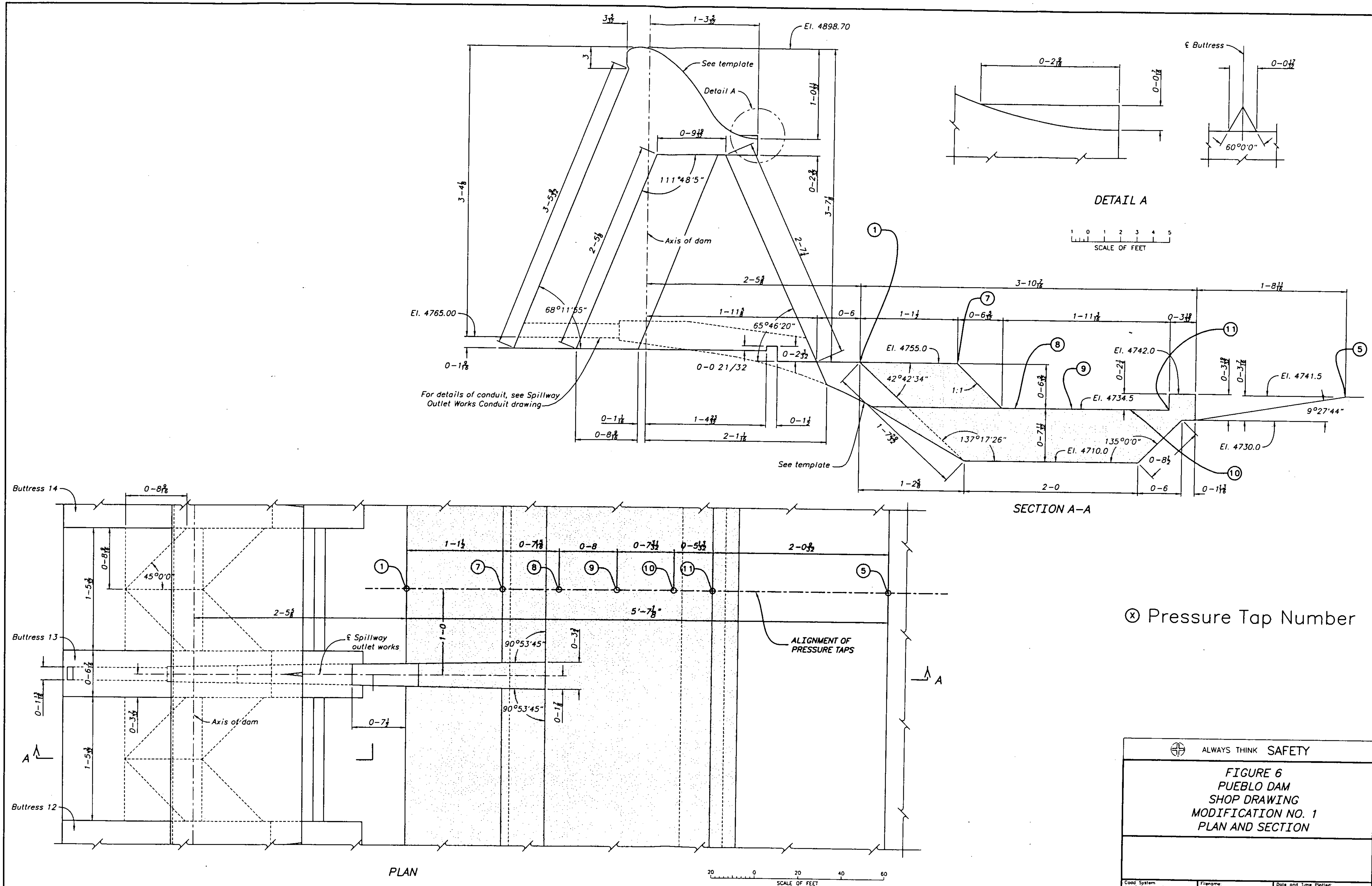


Figure 5 - Existing Geometry - Results



ALWAYS THINK SAFETY

FIGURE 6
PUEBLO DAM
SHOP DRAWING
MODIFICATION NO. 1
PLAN AND SECTION

Cadd System: AutoCAD 2000: (R15.05.181) | Filename: FIGURE6.DWG | Date and Time Plotted: JANUARY 19, 2001 3:28 pm

PUEBLO DAM
RESULTS FROM TESTS USING:

ORIGINAL GEOMETRY

Q prototype (cfs)	RWS ELEV	TW ELEV	PRESSURES - FT OF WATER - PROTOTYPE FOR TAP NO: 1	2	3	4	5	TW
0	4898.7	4741.5	N/A	N/A	N/A	N/A	N/A	N/A
15000	4902.53	4747.9	0.00	0.00	44.80	7.20	7.60	41.20
25000	4904.23	4751.8	0.00	0.00	44.80	7.20	7.60	41.20
50000	4907.38	4755.5	0.00	0.00	47.20	10.40	13.60	47.60
80000	4910.38	4758.2	0.00	0.00	54.00	11.20	15.20	51.60
110000	4912.49	4760.05	0.00	0.00	59.60	12.80	15.20	53.20
150000	4916.12	4761.38	2.00	36.40	56.00	26.00	14.00	53.60
191500	4919	4762	6.40	39.20	71.60	29.60	16.40	57.20
277958	4925	4763.29	10.40	44.80	77.60	33.60	24.80	62.80
			10.4	44.8	77.6	33.6	24.8	62.8

Table 1- Existing Geometry - Results

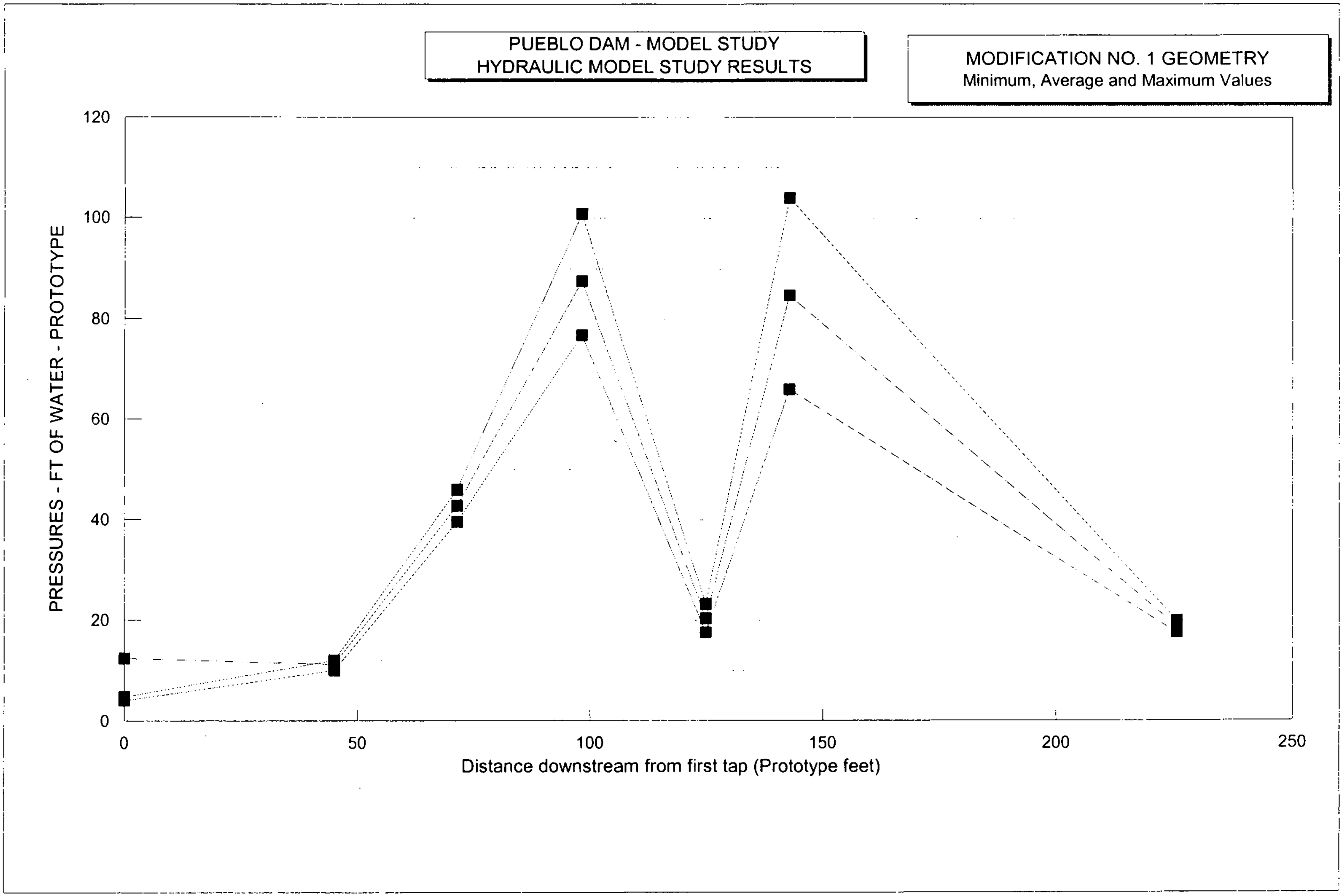


Figure 7 - Modification No. 1 Geometry - Results

PUEBLO DAM - MODEL STUDY

Tap No.	1	7	8	9	10	11	12
Relative distance downstream (ft)	0.0	45.0	71.5	98.2	124.8	142.8	225.6

RESULTS FROM TESTS USING:

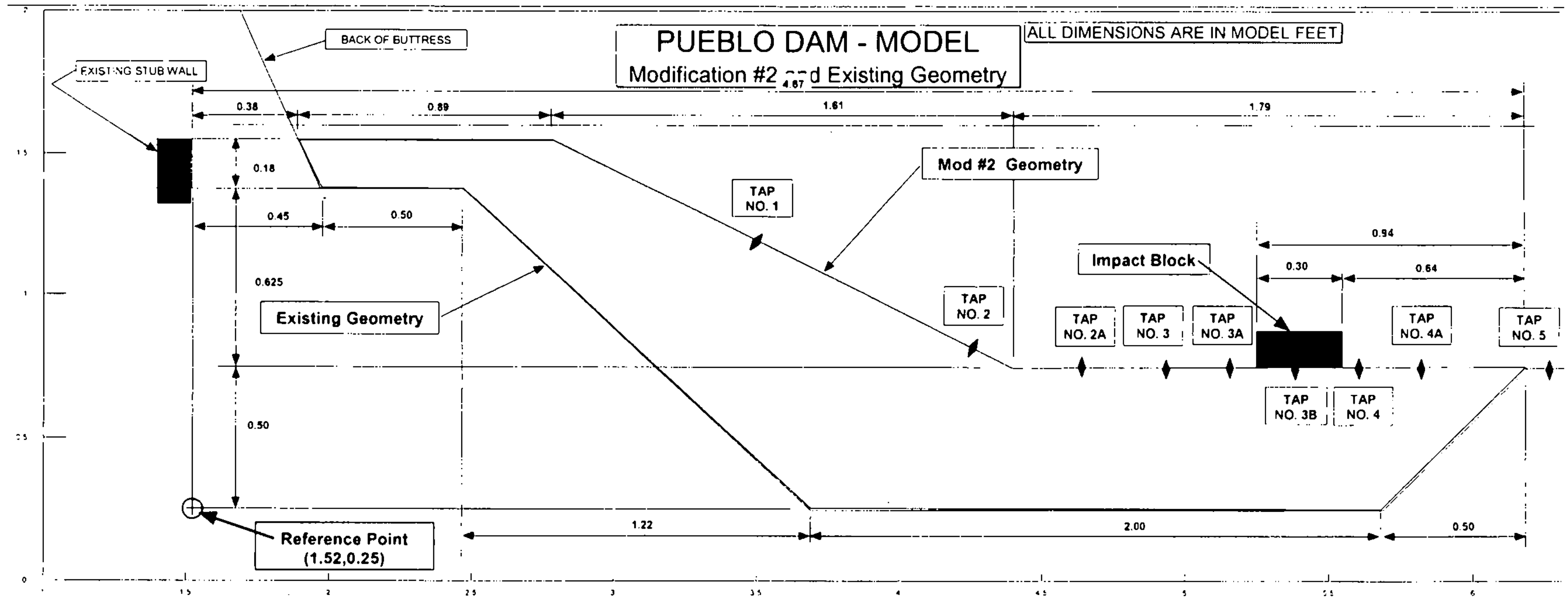
MODIFICATION NO. 1 GEOMETRY

DISCHARGE — PRESSURES - FT OF WATER - PROTOTYPE

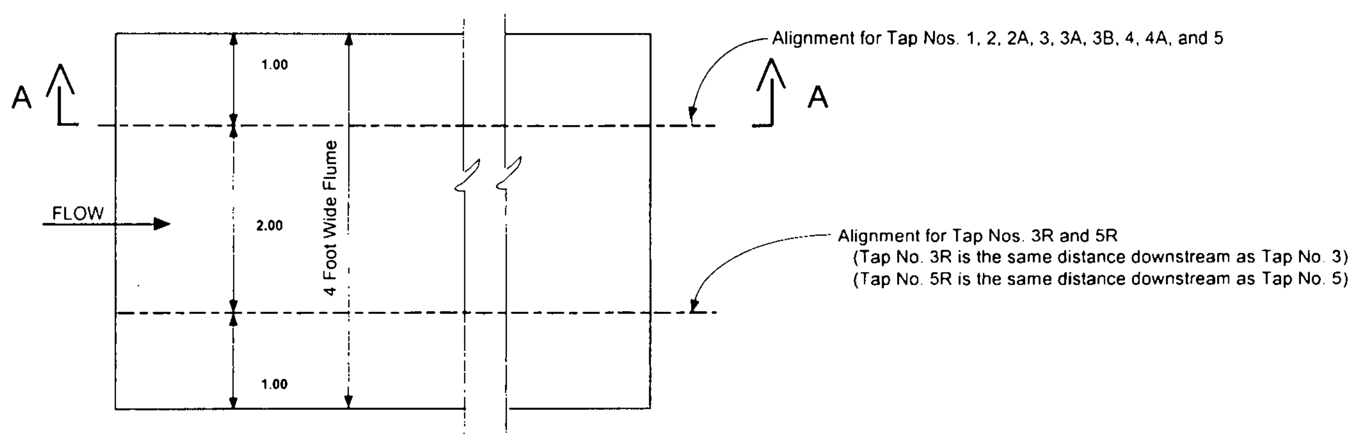
Discharge (c	QmSECT	RWS	TW	1			7			8		
(cfs)	(cfs)	ELEV	ELEV	AVE	MIN	MAX	AVE	MIN	MAX	AVE	MIN	MAX
0	0.000	4898.7	4741.5	N/A	0.0	0.0	N/A	0.0	0.0	N/A	0.0	0.0
15000	0.431	4902.5	4747.9	N/A	0.0	0.0	N/A	0.0	0.0		no fluctuation	
25000	0.719	4904.2	4751.8	N/A	0.0	0.0	N/A	0.0	0.0	12.8	no fluctuation	
50000	1.437	4907.4	4755.5	N/A	0.0	0.0	N/A	0.0	0.0	16.4	no fluctuation	
80000	2.300	4910.4	4758.2	N/A	0.0	0.0	N/A	0.0	0.0	16.4	no fluctuation	
110000	3.162	4912.5	4760.1	4.4	4.0	4.8	3.2	no fluctuation		19.6	no fluctuation	
150000	4.312	4916.1	4761.4	8.4	no fluctuation		6.4	6.0	6.8	27.2	25.6	28.8
191500	5.505	4919.0	4762.0	10.4	no fluctuation		6.8	6.4	7.2	26.4	21.2	31.6
277958	7.991	4925.0	4763.3	12.4	no fluctuation		11.2	10.0	12.0	42.8	39.6	46.0
			MAXIMUMS	12.4	4.0	4.8	11.2	10.0	12.0	42.8	39.6	46.0

Qprototype	9			10			11			5			6		
(cfs)	AVE	MIN	MAX	AVE	MIN	MAX	AVE	MIN	MAX	AVE	MIN	MAX	AVE	MIN	MAX
0	N/A	0.0	0.0	N/A	0.0	0.0	N/A	0.0	0.0	N/A	0.0	0.0	N/A	0.0	0.0
15000	12.4	no fluctuation		14.0	no fluctuation		10.4	no fluctuation		6.4	no fluctuation		41.2	no fluctuation	
25000	11.2	no fluctuation		15.6	no fluctuation		13.2	no fluctuation		8.8	no fluctuation		44.0	no fluctuation	
50000	34.8	32.0	37.6	13.2	no fluctuation		28.0	no fluctuation		12.0	no fluctuation		46.8	no fluctuation	
80000	46.0	39.6	52.8	12.0	11.6	12.4	54.0	52.0	56.0	11.6	-56.0	-56.0	48.0	no fluctuation	
110000	44.8	36.0	53.6	18.8	16.0	21.6	72.0	64.0	80.0	13.2	12.8	13.6	51.6	no fluctuation	
150000	76.0	64.8	87.6	20.4	17.6	23.2	70.0	48.0	92.0	14.0	13.2	14.8	55.2	no fluctuation	
191500	87.2	76.8	97.6	19.6	17.2	22.4	84.8	66.0	104.0	12.4	10.4	14.4	56.0	no fluctuation	
277958	87.6	74.8	100.8	14.0	7.6	20.4	53.6	33.6	74.0	18.8	17.6	20.0	62.4	62.0	62.8
MAXIMUMS	87.6	76.8	100.8	20.4	17.6	23.2	84.8	66.0	104.0	18.8	17.6	20.0	62.4	62.0	62.8

Table 2 - Modification No. 1 Geometry - Results



SECTION A-A



PLAN

Pressure Tap Coordinates

Tap No.	X	Y
1	3.51	1.19
2	4.26	0.81
2A	4.64	0.75
3	4.94	0.75
3A	5.16	0.75
3B	5.38	0.75
4	5.60	0.75
4A	5.83	0.75
5	6.27	0.75
3R	4.94	0.75
5R	6.27	0.75

Figure 8 - Modification No. 2 - Plan and Section

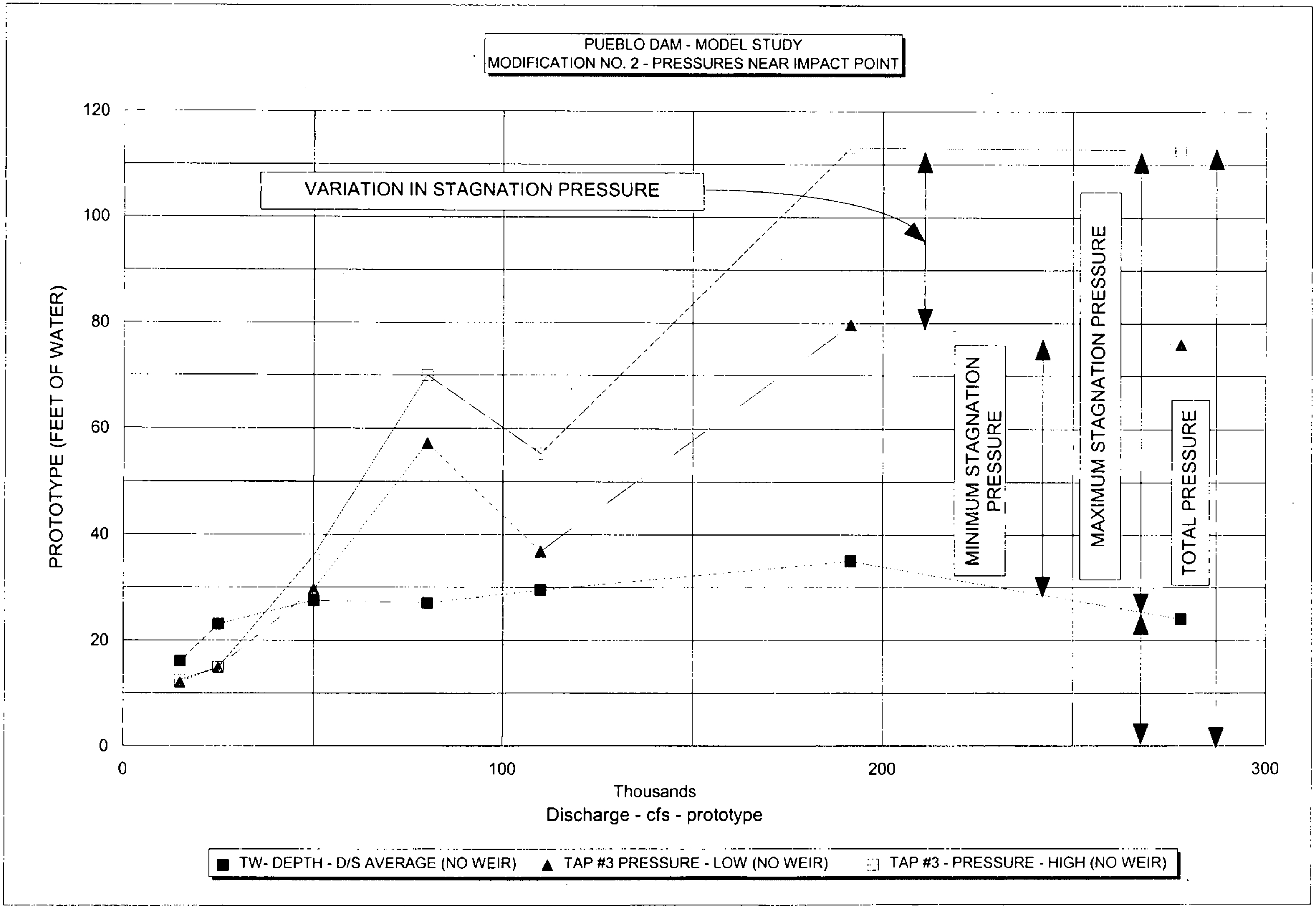


Figure 9 - Modification No. 2 Geometry - Results

PUEBLO DAM
MODIFICATION NO. 2
STUDY OF PRESSURE CHANGES CAUSED BY
CHANGES IN TW, FOR HIGHER DISCHARGES

PRESSURE READINGS - ABOVE MODEL SURFACE (FEET OF WATER)

[ ] SAME VALUES AS PREVIOUS READINGS

	PREVIOUS READINGS			READINGS 2/10 98			DELTA PREVIOUS-2/10/98	
Q prototype (cfs)	TAP #3 LOW	TAP #3 HIGH	DELTA	TAP #3 LOW	TAP #3 HIGH	DELTA	TAP #3 LOW	TAP #3 HIGH
0	0	0	0	0	0	0	n/a	n/a
15,000	12	12.4	0.4	12	12.4	0.4	n/a	n/a
25,000	14.8			14.8			n/a	n/a
50,000	29.6	36	6.4	29.6	36	6.4	n/a	n/a
80,000	57.2	70	12.8	57.2	70	12.8	n/a	n/a
110,000	36.8	55.2	18.4	26.80	46.80	20	10	8.4
191,500	79.6	113.2	33.6	74.40	105.60	31.2	5.2	7.6
277,958	76	112.8	36.8	52.80	96.80	44	23.2	16

Table 3 - Modification No. 2 Geometry - Results

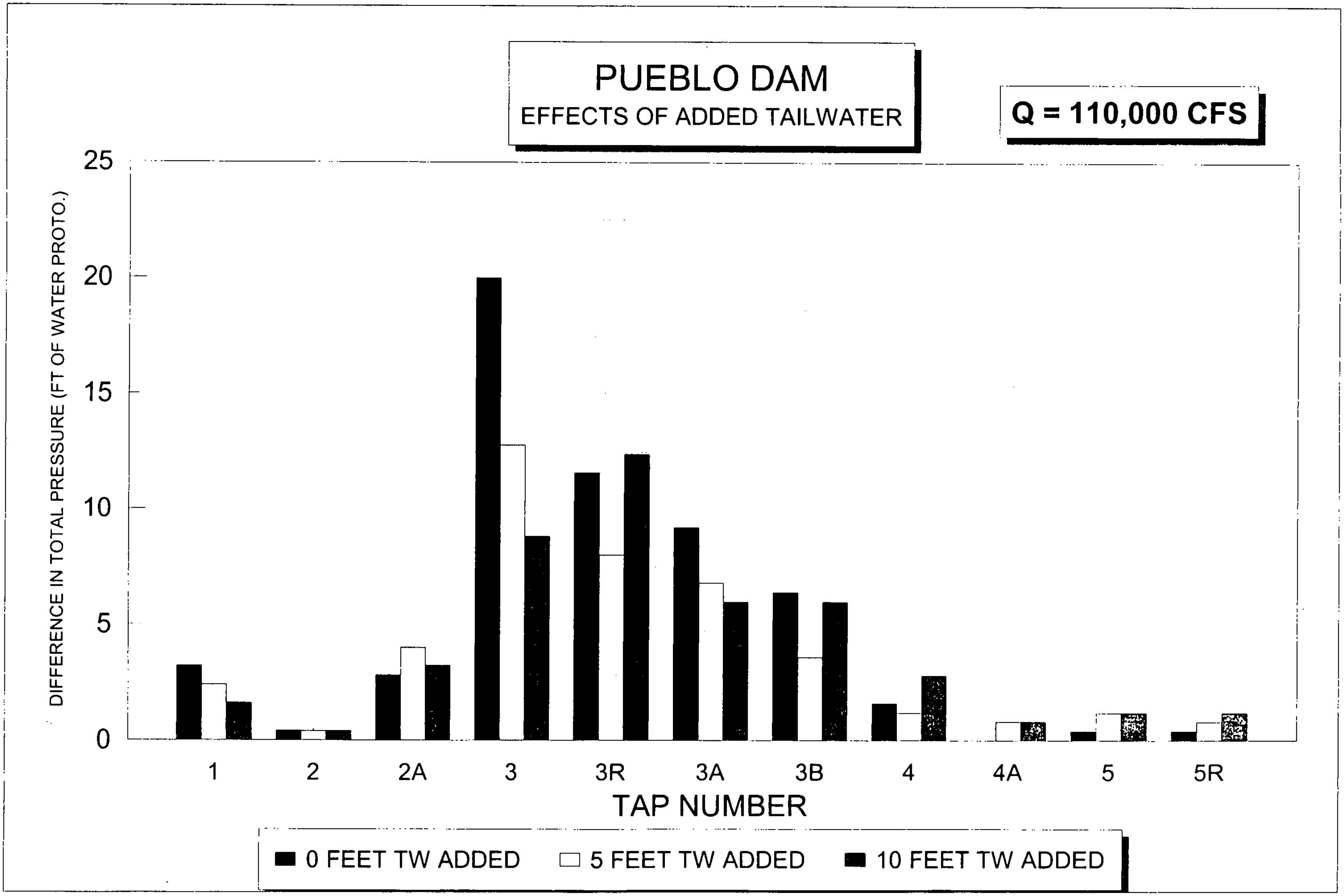


Figure 10 - Modification No. 2 Geometry - Tailwater for Q = 110,000 cfs

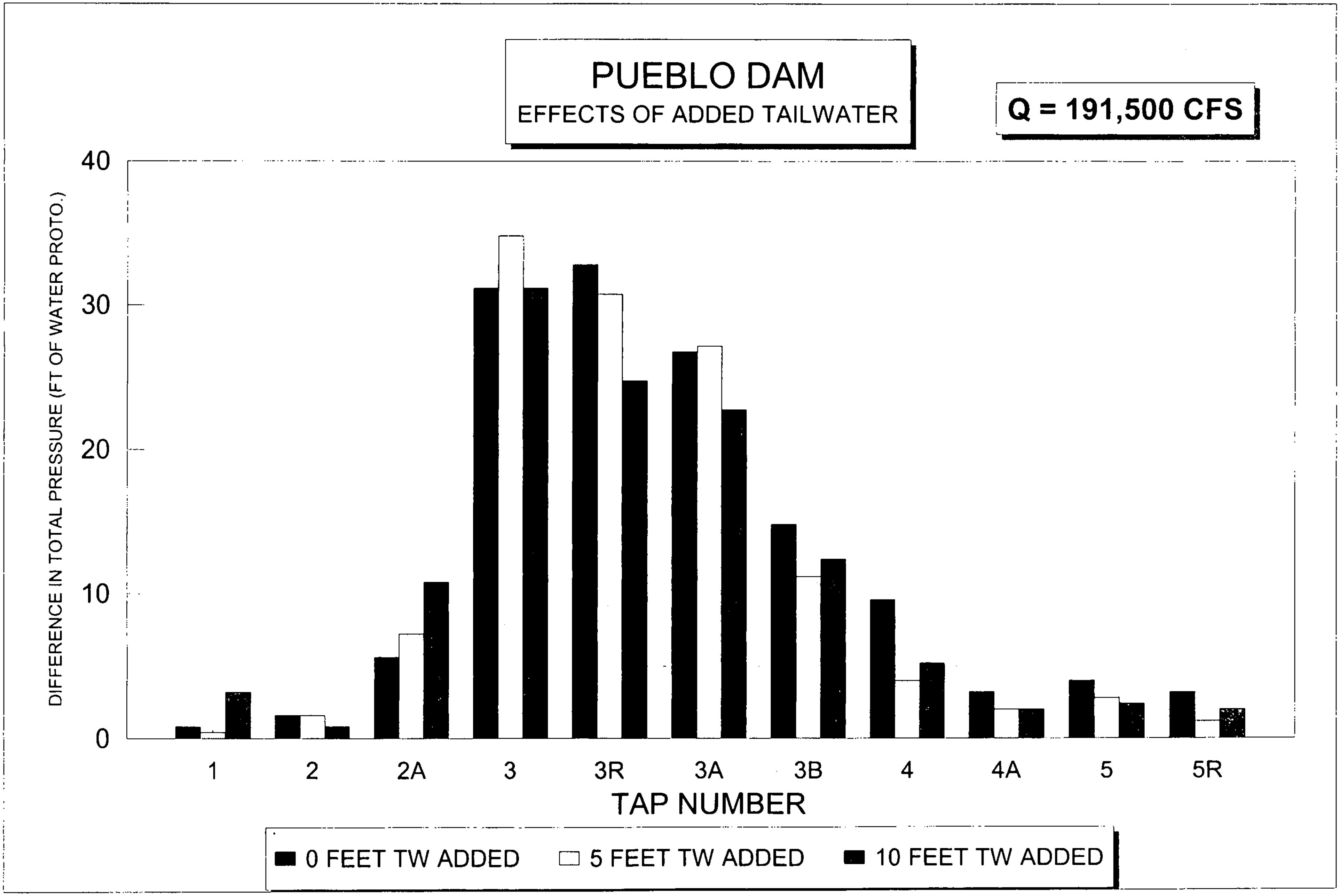


Figure 11 - Modification No. 2 Geometry - Tailwater for Q = 191,500 cfs

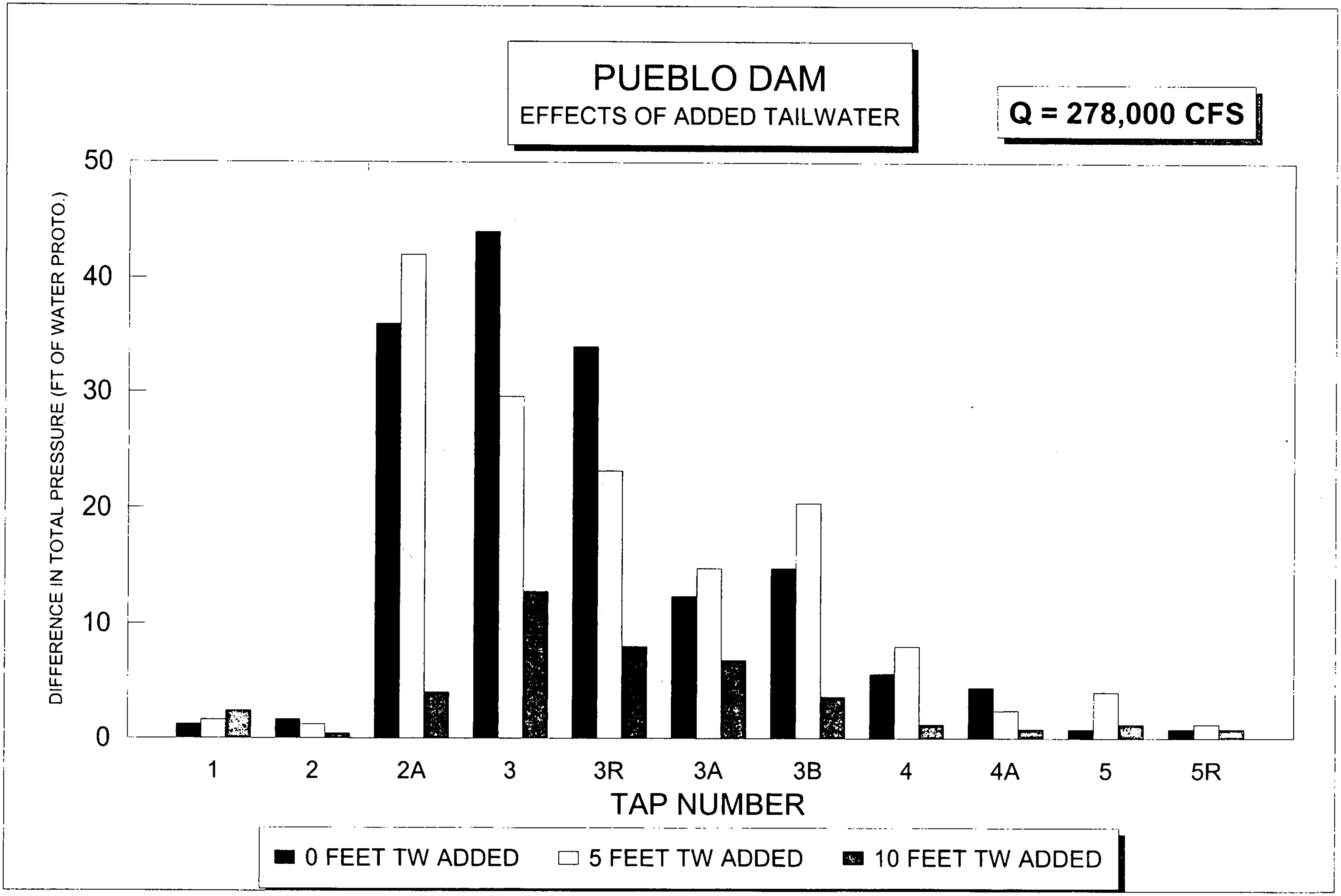


Figure 12 - Modification No. 2 Geometry - Tailwater for Q = 278,000 cfs

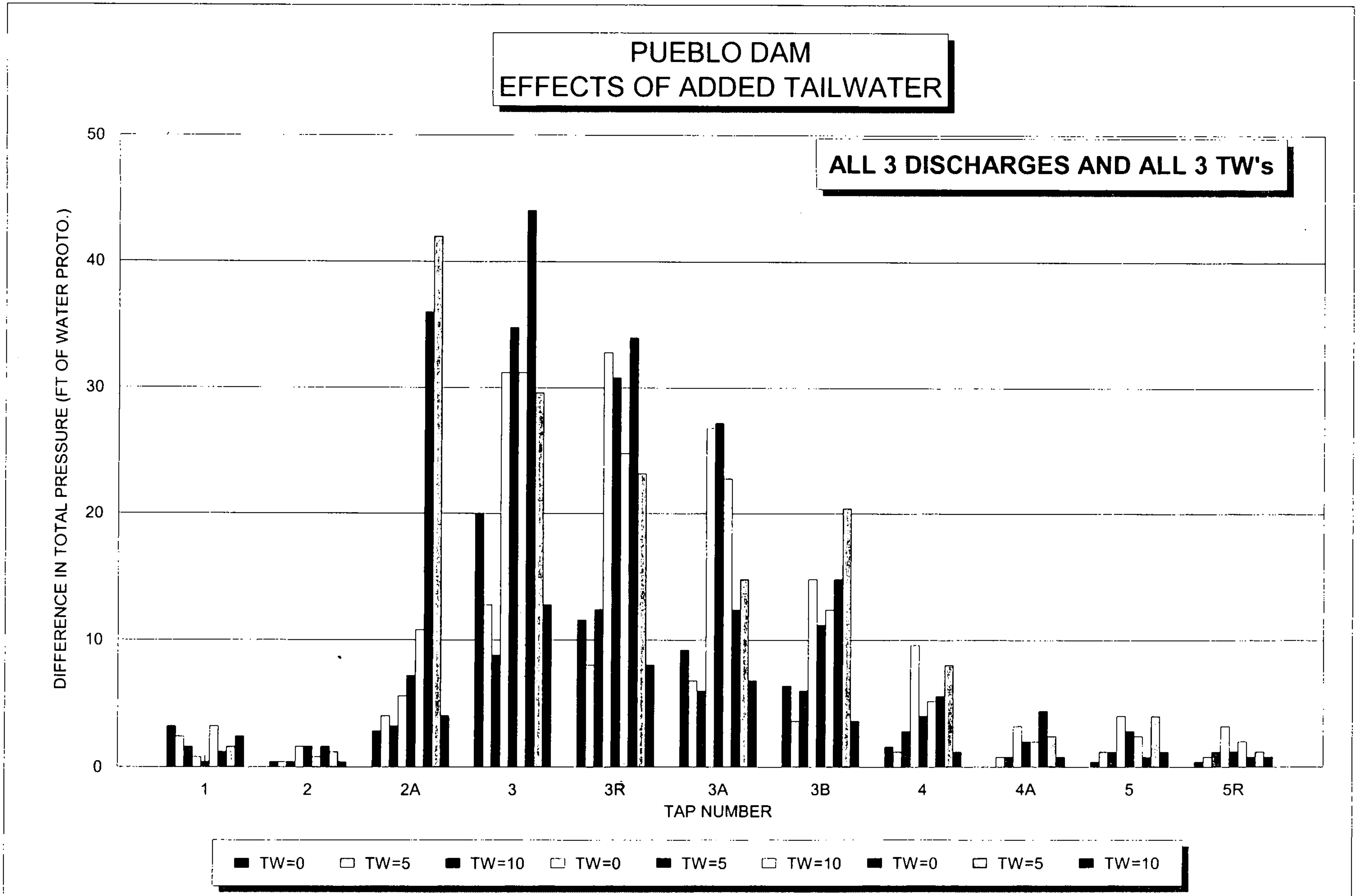


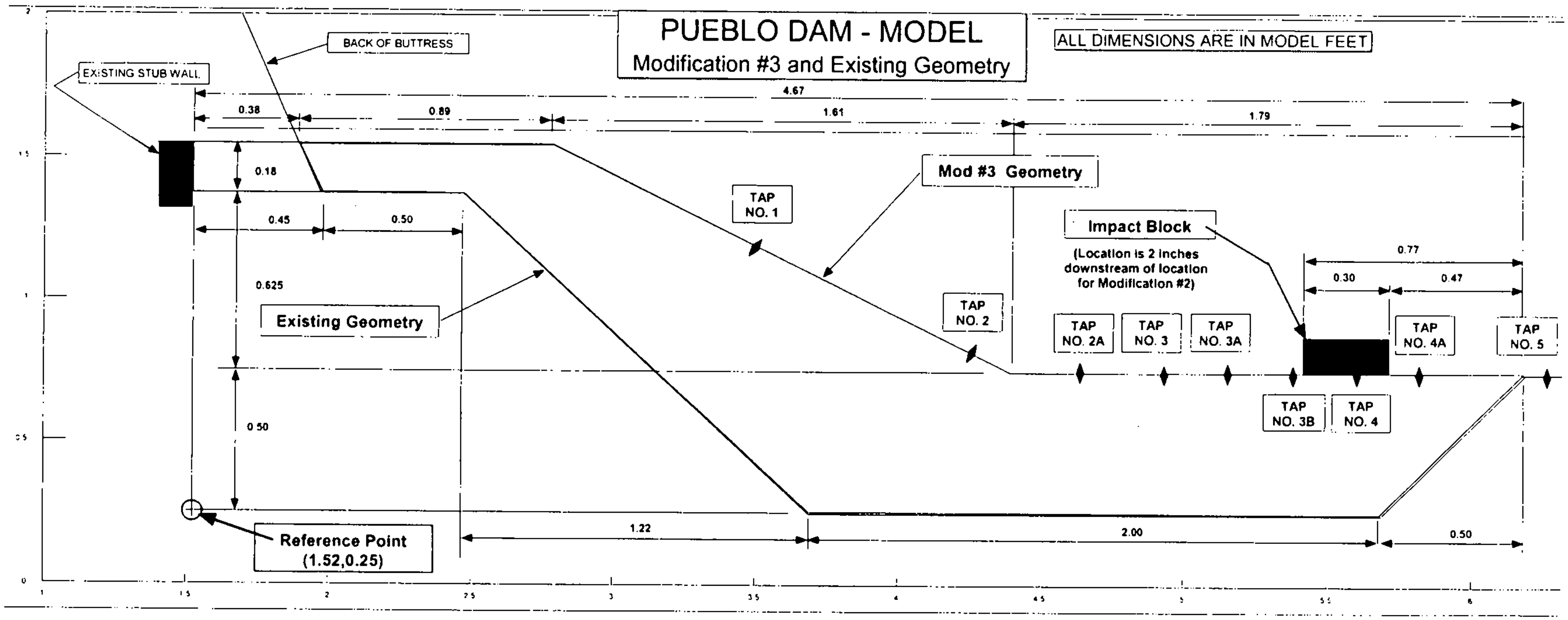
Figure 13 - Modification No. 2 Geometry - Results

PUEBLO DAM
Modification No. 2
STUDY OF PRESSURE CHANGES CAUSED BY
CHANGES IN TW, FOR HIGHER DISCHARGES

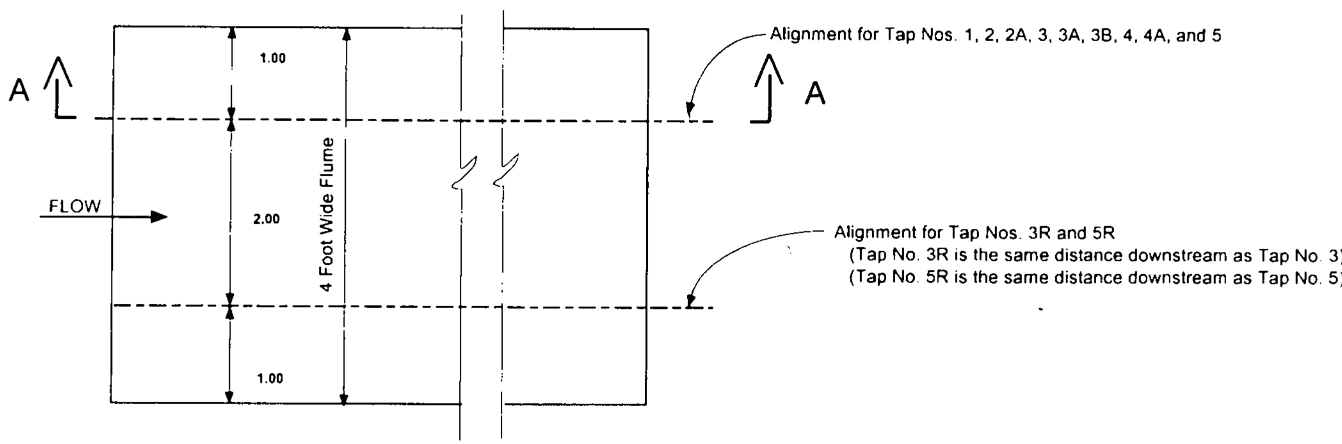
DIFFERENCE IN TOTAL PRESSURES ABOVE FLOOR SURFACE
FEET OF WATER (PROTOTYPE)

Q = --->	110,000			191,500			278,000		
TAP #	TW=0	TW=5	TW=10	TW=0	TW=5	TW=10	TW=0	TW=5	TW=10
1	3.2	2.4	1.6	0.8	0.4	3.2	1.2	1.6	2.4
2	0.4	0.4	0.4	1.6	1.6	0.8	1.6	1.2	0.4
2A	2.8	4	3.2	5.6	7.2	10.8	36	42	4
3	20	16.8	16	31.2	34.8	31.2	44	29.6	12.8
3R	11.6	15.2	12.4	32.8	30.8	24.8	34	23.2	8
3A	9.2	6.8	3.2	26.8	27.2	22.8	12.4	14.8	6.8
3B	6.4	3.6	6	14.8	11.2	12.4	14.8	20.4	3.6
4	1.6	1.2	2.8	9.6	4	5.2	5.6	8	1.2
4A	0	0.8	0.8	3.2	2	2	4.4	2.4	0.8
5	0.4	1.2	1.2	4	2.8	2.4	0.8	4	1.2
5R	0.4	0.8	1.2	3.2	1.2	2	0.8	1.2	0.8

Table 4 - Modification No. 2 Geometry - Three Tailwater Levels - Results



SECTION A-A

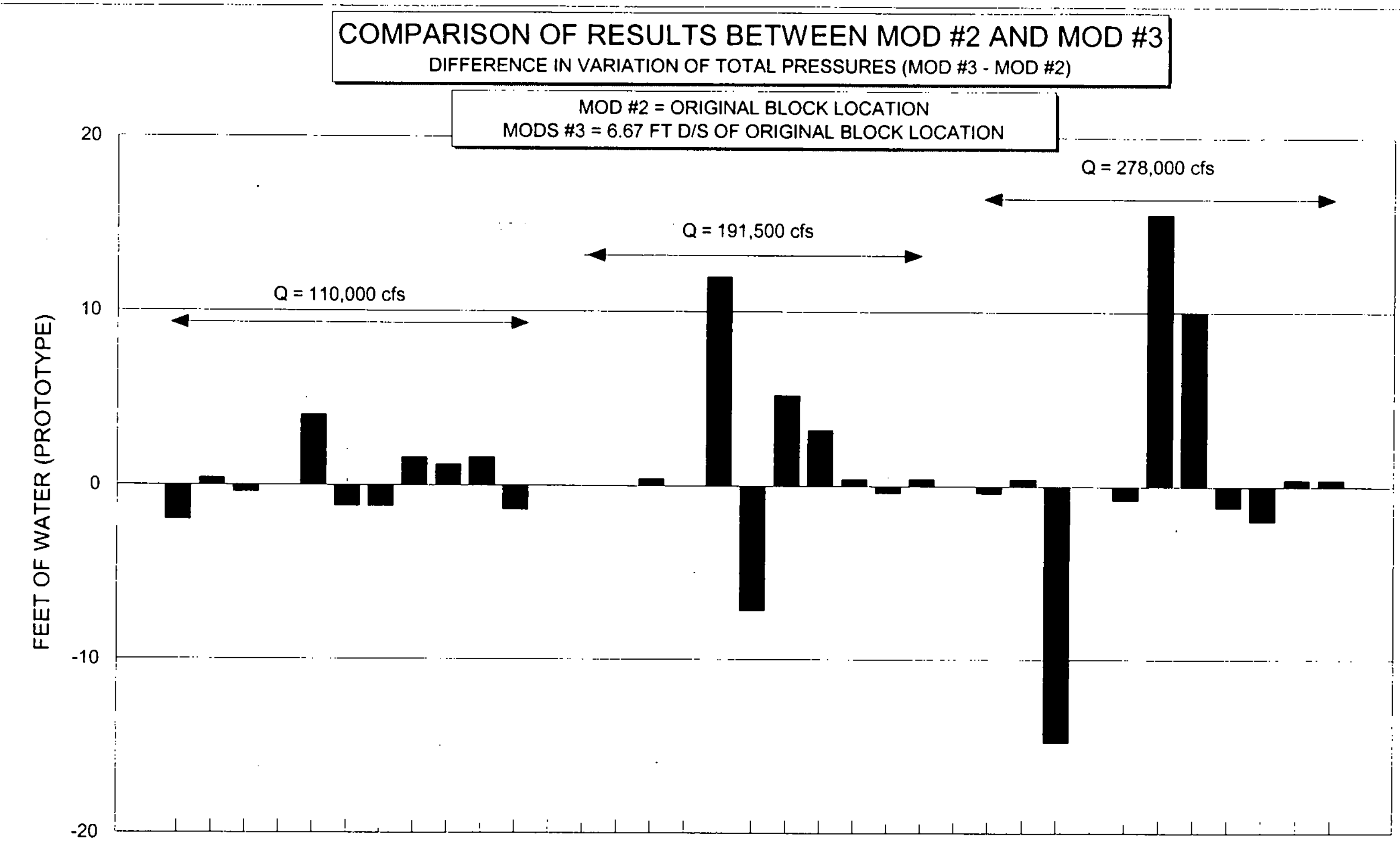


PLAN

Pressure Tap Coordinates

Tap No.	X	Y
1	3.51	1.19
2	4.26	0.81
2A	4.64	0.75
3	4.94	0.75
3A	5.16	0.75
3B	5.38	0.75
4	5.60	0.75
4A	5.83	0.75
5	6.27	0.75
3R	4.94	0.75
5R	6.27	0.75

Figure 14 - Modification No. 3 - Plan and Section



TAP #	1	2	2A	3	3R	3A	3B	4	4A	5	5R
Mod #3-Mod #2	-2.0	0.4	-0.4		4.0	-1.2	-1.2	1.6	1.2	1.6	-1.4

TAP #	1	2	2A	3	3R	3A	3B	4	4A	5	5R
Mod #3-Mod #2	0.0	0.0	0.4		12.0	-7.2	5.2	3.2	0.4	-0.4	0.4

TAP #	1	2	2A	3	3R	3A	3B	4	4A	5	5R
Mod #3-Mod #2	-0.4	0.4	-14.8		-0.8	15.6	10.0	-1.2	-2.0	0.4	0.4

Figure 15 - Modification No. 2 and No. 3 Geometries - Results

PUEBLO DAM
COMPARISON OF RESULTS BETWEEN MOD #2 AND MOD #3
VALUES IN TABLE ARE IN UNITS OF --- FEET OF WATER (PROTOTYPE)
LOW AND HIGH VALUES ARE TOTAL PRESSURES

MOD #2 = ORIGINAL BLOCK LOCATION
MODS #3 = 6.67 FT D/S OF ORIGINAL BLOCK LOCATION

	DIST.	MODIFICATION #2 Q=110,000			MODIFICATION #3 Q=110,000			DELTA
TAP #	D/S	LOW	HIGH	DELTA	LOW	HIGH	DELTA	#3-#2
1	140.67	5.20	8.40	3.20	4.80	6.00	1.20	-2
2	170.67	13.20	13.60	0.40	13.60	14.40	0.80	0.4
2A	185.84	16.00	18.80	2.80	13.20	15.60	2.40	-0.4
3	197.50	26.80	46.80	20.00				
3R	200.5	38.00	49.60	11.60	51.60	67.20	15.60	4
3A	206.39	50.80	60.00	9.20	35.60	43.60	8.00	-1.2
3B	215.10	22.80	29.20	6.40	37.60	42.80	5.20	-1.2
4	223.90	16.00	17.60	1.60	13.20	16.40	3.20	1.6
4A	232.74	20.40	20.40	0.00	18.80	20.00	1.20	1.2
5	250.70	22.00	22.40	0.40	21.20	23.20	2.00	1.6
5R	253.2	23.60	24.00	3.00	23.20	24.80	1.60	-1.4
	MAX	50.8	60	20	51.6	67.2	15.6	4
	MIN	5.2	8.4	0	4.8	6	0.8	-2
							NEGATIVES	5

	DIST.	MODIFICATION #2 Q=191,500			MODIFICATION #3 Q=191,500			DELTA
TAP #	D/S	LOW	HIGH	DELTA	LOW	HIGH	DELTA	#3-#2
1	140.67	7.20	8.00	0.80	7.60	8.40	0.80	0
2	170.67	12.00	13.60	1.60	15.60	17.20	1.60	0
2A	185.84	17.20	22.80	5.60	18.40	24.40	6.00	0.4
3	197.50	74.40	105.60	31.20				
3R	200.5	67.60	100.40	32.80	67.20	112.00	44.80	12
3A	206.39	70.40	97.20	26.80	38.80	58.40	19.60	-7.2
3B	215.10	35.60	50.40	14.80	48.40	68.40	20.00	5.2
4	223.90	10.40	20.00	9.60	6.40	19.20	12.80	3.2
4A	232.74	19.20	22.40	3.20	16.80	20.40	3.60	0.4
5	250.70	20.80	24.80	4.00	18.40	22.00	3.60	-0.4
5R	253.2	19.60	22.80	3.20	21.60	25.20	3.60	0.4
	MAX	74.4	105.6	32.8	67.2	112	44.8	12
	MIN	7.2	8	0.8	6.4	8.4	0.8	-7.2
							NEGATIVES	2

	DIST.	MODIFICATION #2 Q=278,000			MODIFICATION #3 Q=278,000			DELTA
TAP #	D/S	LOW	HIGH	DELTA	LOW	HIGH	DELTA	#3-#2
1	140.67	6.80	8.00	1.20	7.60	8.40	0.80	-0.4
2	170.67	16.40	18.00	1.60	18.00	20.00	2.00	0.4
2A	185.84	98.40	134.40	36.00	88.80	110.00	21.20	-14.8
3	197.50	52.80	96.80	44.00				
3R	200.5	64.40	98.40	34.00	55.60	88.80	33.20	-0.8
3A	206.39	72.80	85.20	12.40	42.80	70.80	28.00	15.6
3B	215.10	32.00	46.80	14.80	52.00	76.80	24.80	10
4	223.90	0.80	6.40	5.60	3.60	8.00	4.40	-1.2
4A	232.74	0.00	4.40	4.40	3.60	6.00	2.40	-2
5	250.70	-4.00	-3.20	0.80	0.00	1.20	1.20	0.4
5R	253.2	-0.80	0.00	0.80	-2.40	-1.20	1.20	0.4
	MAX	98.4	134.4	44	88.8	110	33.2	15.6
	MIN	-4	-3.2	0.8	-2.4	-1.2	0.8	-14.8
							NEGATIVES	5

Table 5 - Modification No. 2 and No. 3 Geometries - Results

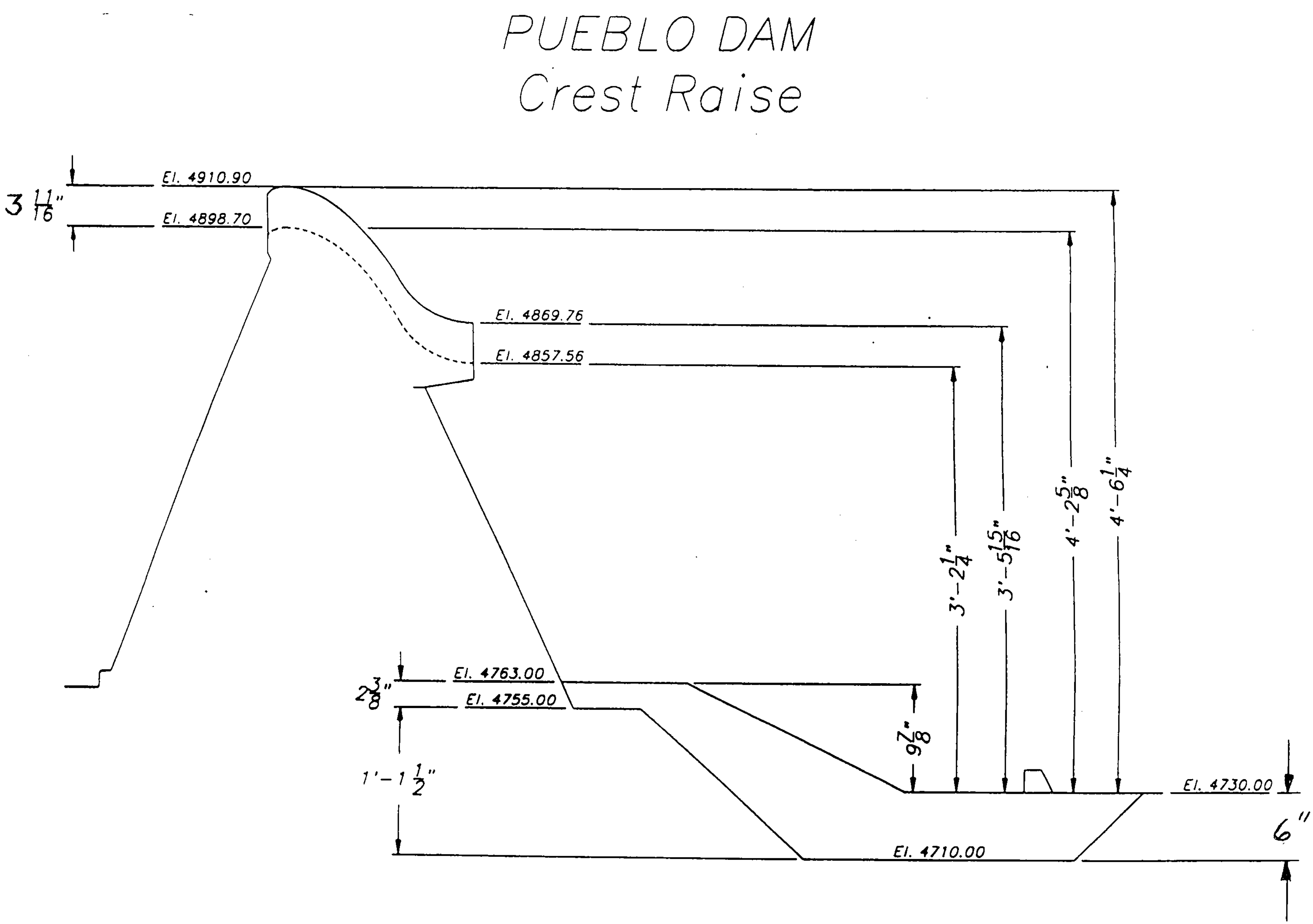


Figure 16 - Modification No. 4 - Crest Raise - Section

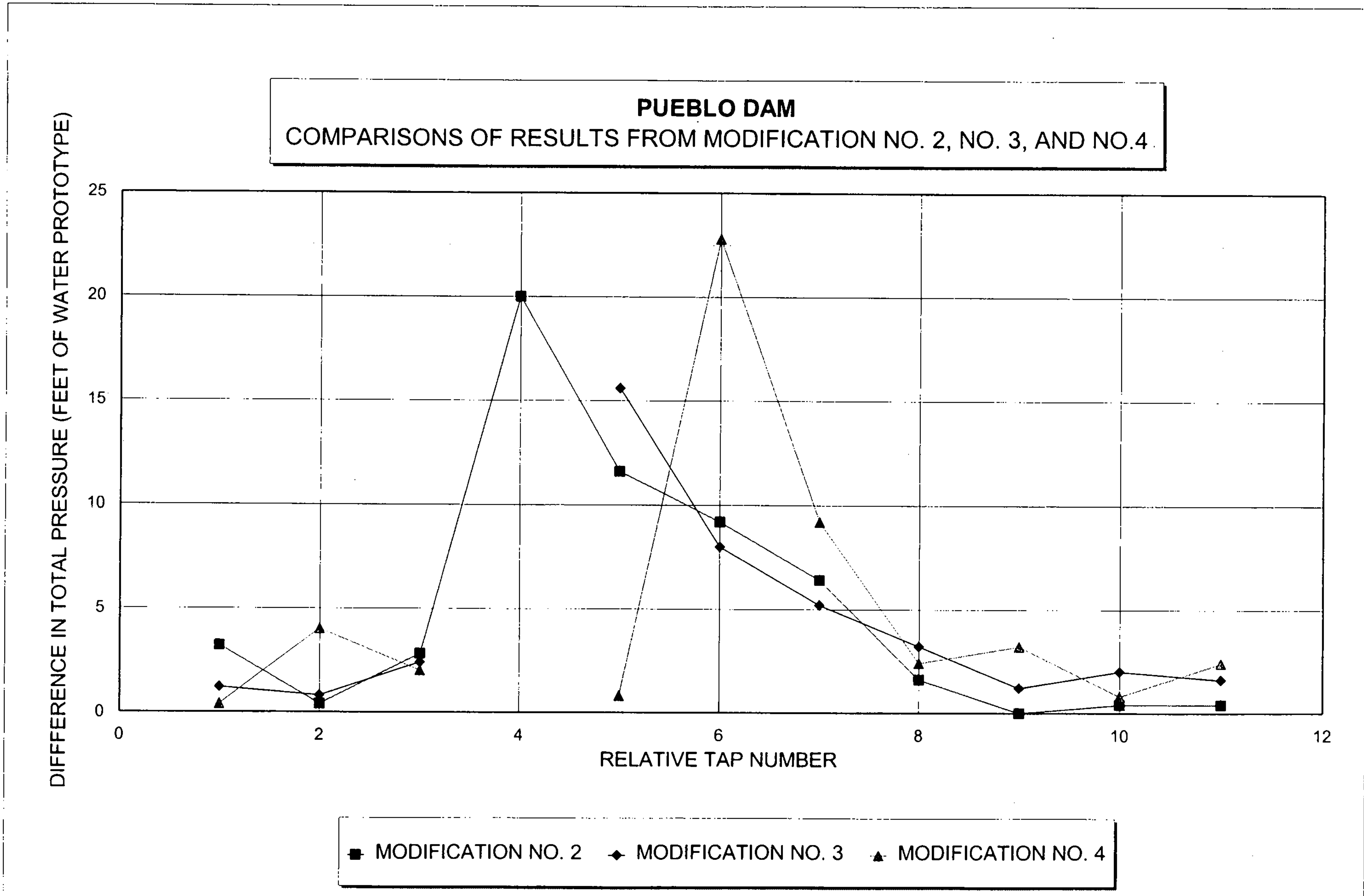


FIGURE 17 - Modification No. 2, No. 3, and No. 4 Geometries - Results

PUEBLO DAM
COMPARISONS OF RESULTS FROM MODIFICATION NO. 2, NO. 3, AND NO.4

CREST GEOMETRY		MODIFICATION NO. 2	MODIFICATION NO. 3	MODIFICATION NO. 4
BLOCK LOCATION		ORIGINAL (U/S)	SPECIFICATION	SPECIFICATION
SPILLWAY CREST ELEVATION		**4898.7**	**4898.7**	**4910.9**
DISCHARGE		Q = 110,000 cfs	Q = 110,000 cfs	Q = 110,000 cfs
TAP #	RELATIVE LOCATION	DIFFFERENCE IN TOTAL PRESSURE FEET OF WATER (PROTOTYPE)		
1	1	3.20	1.20	0.40
2	2	0.40	0.80	4.00
2A	3	2.80	2.40	2.00
3	4	20.00		
3R	**5**	11.60	15.60	0.80
3A	6	9.20	8.00	22.80
3B	7	6.40	5.20	9.20
4	8	1.60	3.20	2.40
4A	9	0.00	1.20	3.20
5	10	0.40	2.00	0.80
5R	**11**	0.40	1.60	2.40

NOTE THE LOCATIONS WITH A BLANK ENTRY FOR TAP #3 ARE DUE TO THE FACT THAT A DYNAMIC PRESSURE TRANSDUCER REPLACED THE "STATIC" PRESSURE TAP AFTER THE SOD MODIFICATION STUDY WAS COMPLETED AND THERE WAS NO LONGER A WAY OF OBTAINING "STATIC" VALUES

Table 6 - Modification No. 2, No. 3, and No. 4 Geometries - Results for a discharge equivalent to 110,000 cfs in the prototype

Photo No. 1

Existing Geometry - Empty model looking upstream in the 4-foot wide testing flume, towards the portion of the stilling basin and dam that was modeled. Pens on right side indicate location of pressure taps. Model is 4 feet wide.

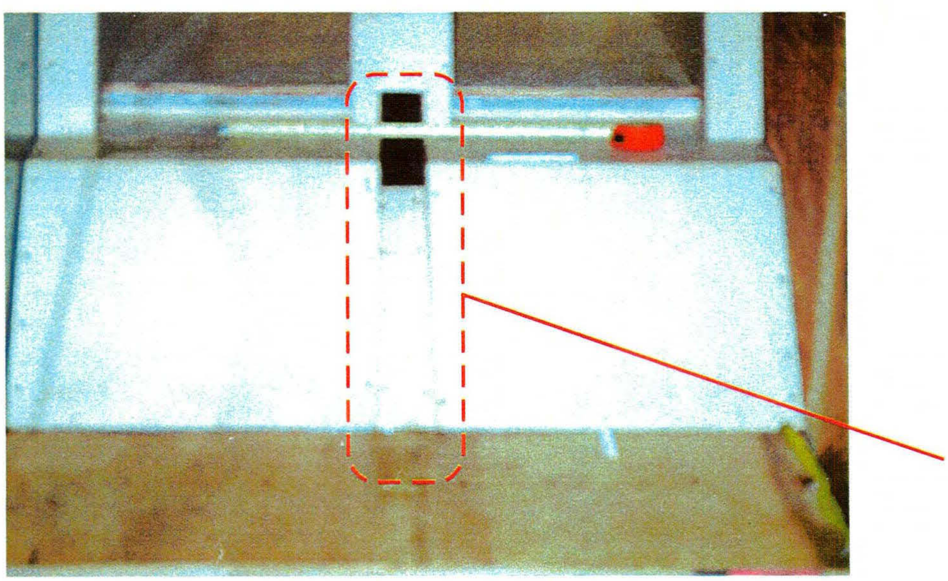


Photo No. 2

Existing Geometry - Close-up of empty model looking upstream towards stilling basin and dam. Pens on right side indicate location of some of the pressure taps. Model is 4 feet wide. Spillway Outlet Works downstream opening and chute is shown at the base of the buttress in the center of the photo.

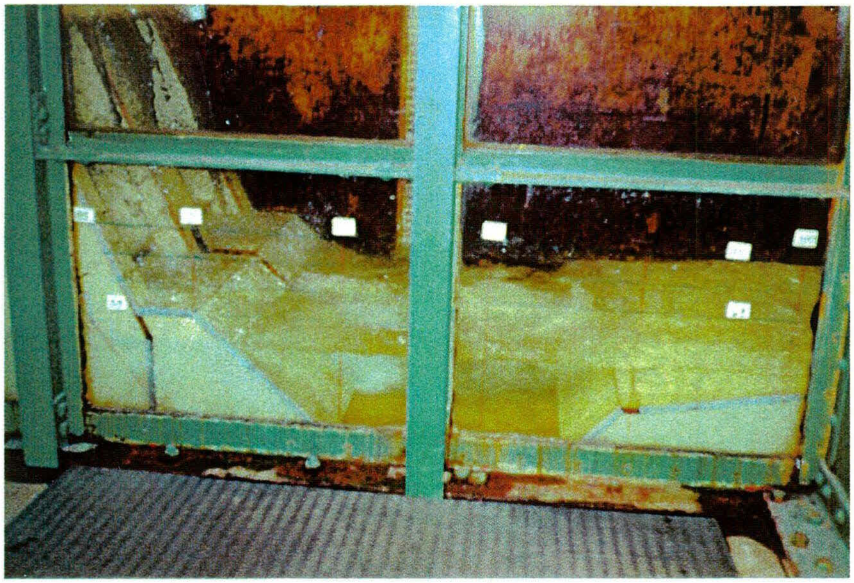


Photo No. 3

Existing Geometry - Spillway Outlet Works discharging with minimum tailwater conditions.

Flow is left to right.

Photo No. 4

Existing Geometry - Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge.

Flow is left to right. Notice large amount of "whitewater" flowing beyond the end of the concrete lined portion of the stilling basin

Unlined channel downstream

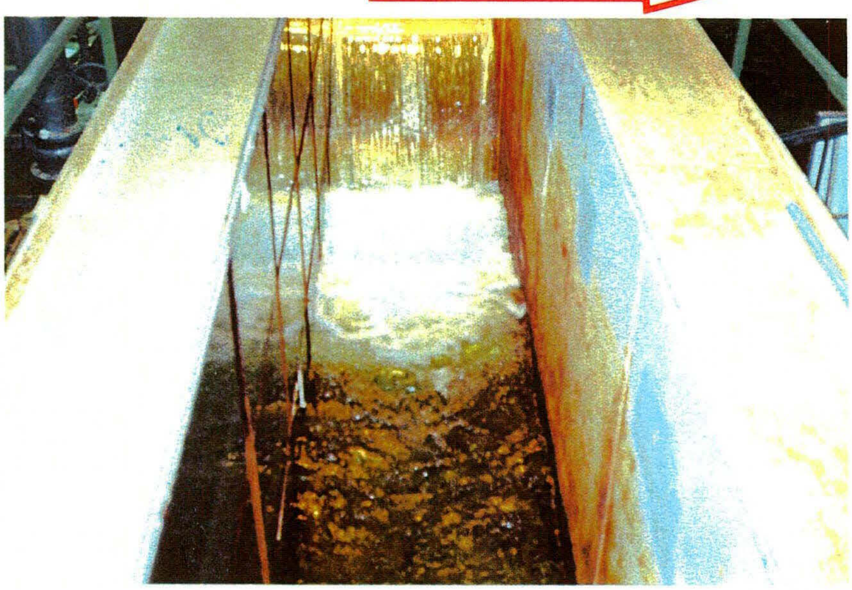


Photo No. 5

Existing Geometry - Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge.

Photo is taken from a walkway above the model and located downstream. Flow is towards bottom of photo.

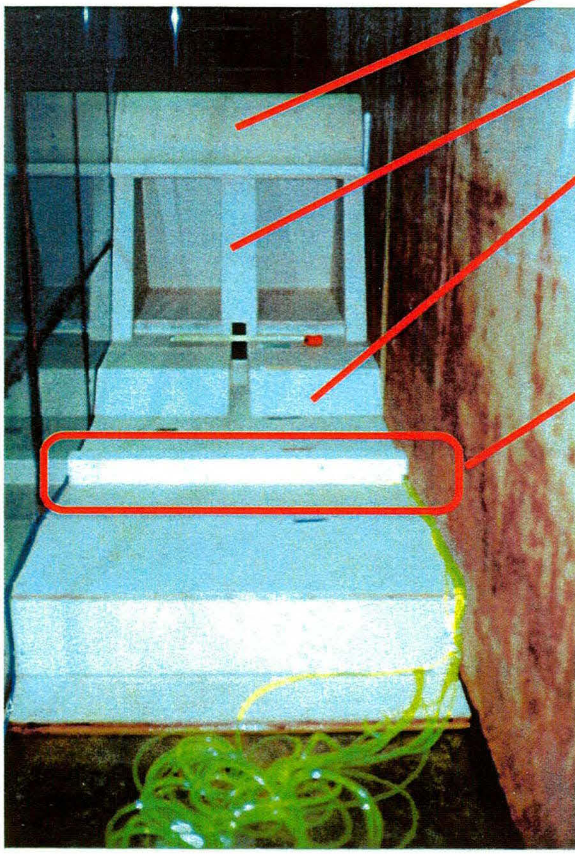


Photo No. 6

Modification No.1 - Changes consist of toe block with a horizontal surface at elevation 4755 and a 1:1 slope on the downstream surface
Continuous weir used for impact blocks. Floor raised to elev. 4734.

View of empty model looking upstream in the 4-foot wide testing flume, towards the portion of the stilling basin and dam that was modeled. Pens on right side indicate location of pressure taps. Model is 4 feet wide.

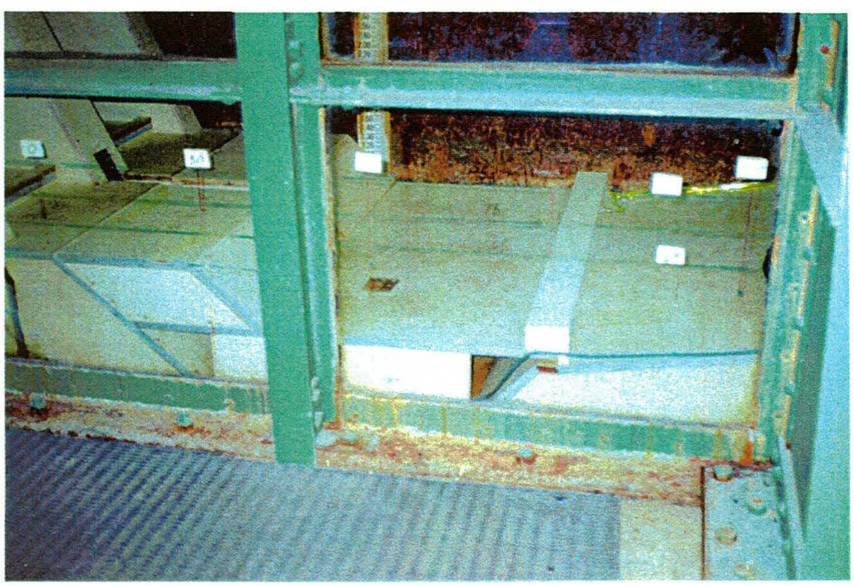


Photo No. 7

Modification No.1 - Changes consist of toe block with a horizontal surface at elevation 4755 and a 1:1 slope on the downstream surface
Continuous weir used for impact blocks. Floor raised to elev. 4734.

Empty model looking from the right side normal to the direction of flow. Notice that the modification was built on top of the existing geometry.

Photo No. 8

Modification No.1 - Changes consist of toe block with a horizontal surface at elevation 4755 and a 1:1 slope on the downstream surface Continuous weir used for impact blocks. Floor raised to elev. 4734.

View looking downward and upstream on the toe block, raised floor and weir. Pens on right side indicate location of pressure taps. Model is 4 feet wide.

Object on left side is a dynamic pressure tap that was never used.

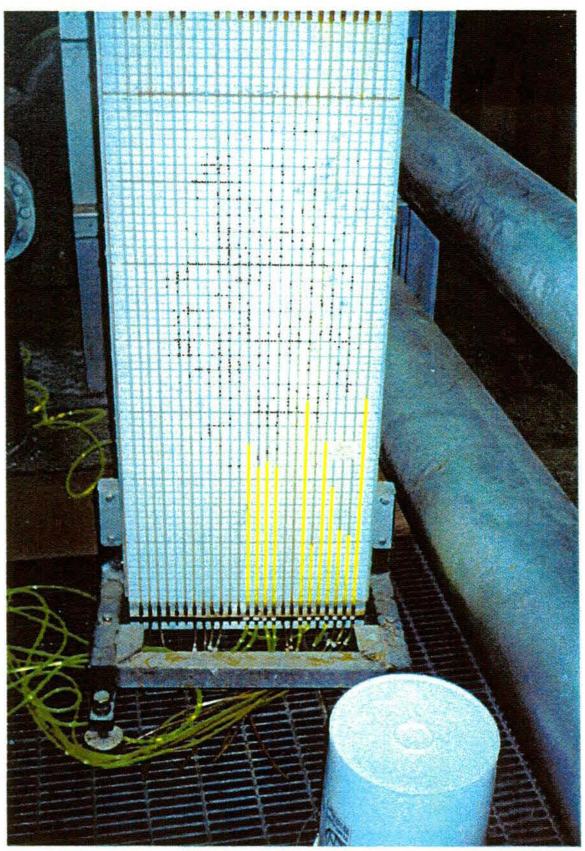


Photo No. 9

View of the Manometer board used to observe the pressure experienced by the various pressure taps installed in the model. The columns of water that are dyed yellow and that appear on the right side of the board are connected to the taps in the model.

Photo No.10

Modification No.1 - Changes consist of toe block with a horizontal surface at elevation 4755 and a 1:1 slope on the downstream surface Continuous weir used for impact blocks. Floor raised to elev. 4734.

Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge.

Flow is left to right. Notice the lack of energy dissipation caused by the continuous weir impact block.

Photo No. 11

Modification No.1 - Changes consist of toe block with a horizontal surface at elevation 4755 and a 1:1 slope on the downstream surface Continuous weir used for impact blocks. Floor raised to elev. 4734.

Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge.

Photo is taken from a walkway above the model and located downstream.

Flow is towards bottom of photo.

Photo No.12

Modification No.2 - Changes consist of toe block with a horizontal surface at elevation 4762 and a 2:1 slope on the downstream surface impact blocks alternating with equal open spaces. Impact blocks moved upstream. Floor raised to elev. 4730.
Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge
Flow is left to right.
Note the tight roller that occurs just upstream of the impact blocks.

Impact Blocks

Photo No. 13

Same features as Photo No. 12, but zoomed in view

Impact Blocks

Photo No.14

Modification No.2 - Changes consist of toe block with a horizontal surface at elevation 4762 and a 2:1 slope on the downstream surface impact blocks alternating with equal open spaces. Impact blocks moved upstream. Floor raised to elev. 4730.
Unit discharge equivalent to 110,000 ft^3/sec in the prototype. This is the design discharge.
Photo is taken from a walkway above the model and located downstream.
Flow is towards bottom of photo.

Photo No.15

Same features as Photo No. 14, but zoomed in view.

Photo No.16

Modification No.2 - Changes consist of toe block with a horizontal surface at elevation 4762 and a 2:1 slope on the downstream surface impact blocks alternating with equal open spaces. Impact blocks moved upstream. Floor raised to elev. 4730.

Unit discharge equivalent to 278,000 ft^3/sec in the prototype. This is the discharge that would result from a Probable Maximum Flood..

Flow is left to right.

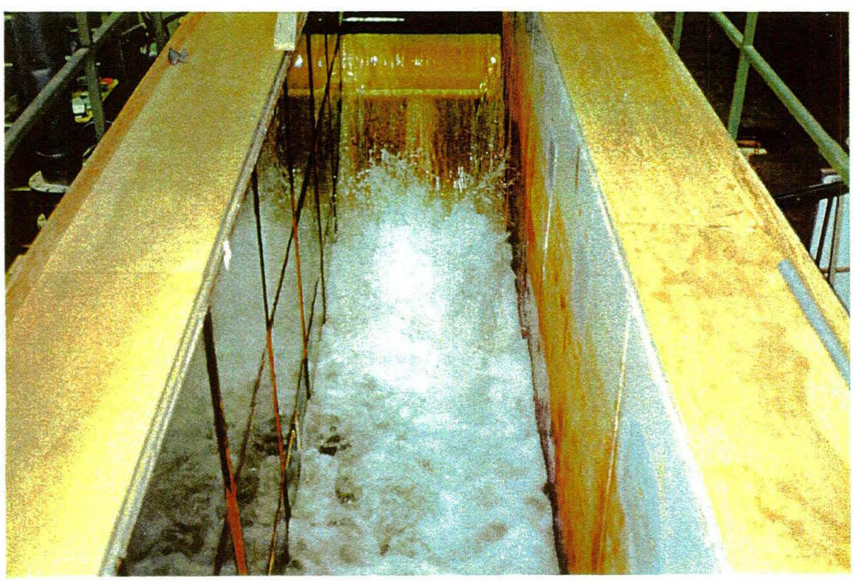


Photo No.17

Modification No.2 - Changes consist of toe block with a horizontal surface at elevation 4762 and a 2:1 slope on the downstream surface impact blocks alternating with equal open spaces. Impact blocks moved upstream. Floor raised to elev. 4730.
Unit discharge equivalent to 278,000 ft^3/sec in the prototype. This is the discharge that would result from a Probable Maximum Flood..

Photo is taken from a walkway above the model and located downstream. Flow is towards bottom of photo.