UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF GLEN ANNE DAM SPILLWAY AND STILLING BASIN CACHUMA PROJECT, CALIFORNIA

Laboratory Report No. Hyd-360

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

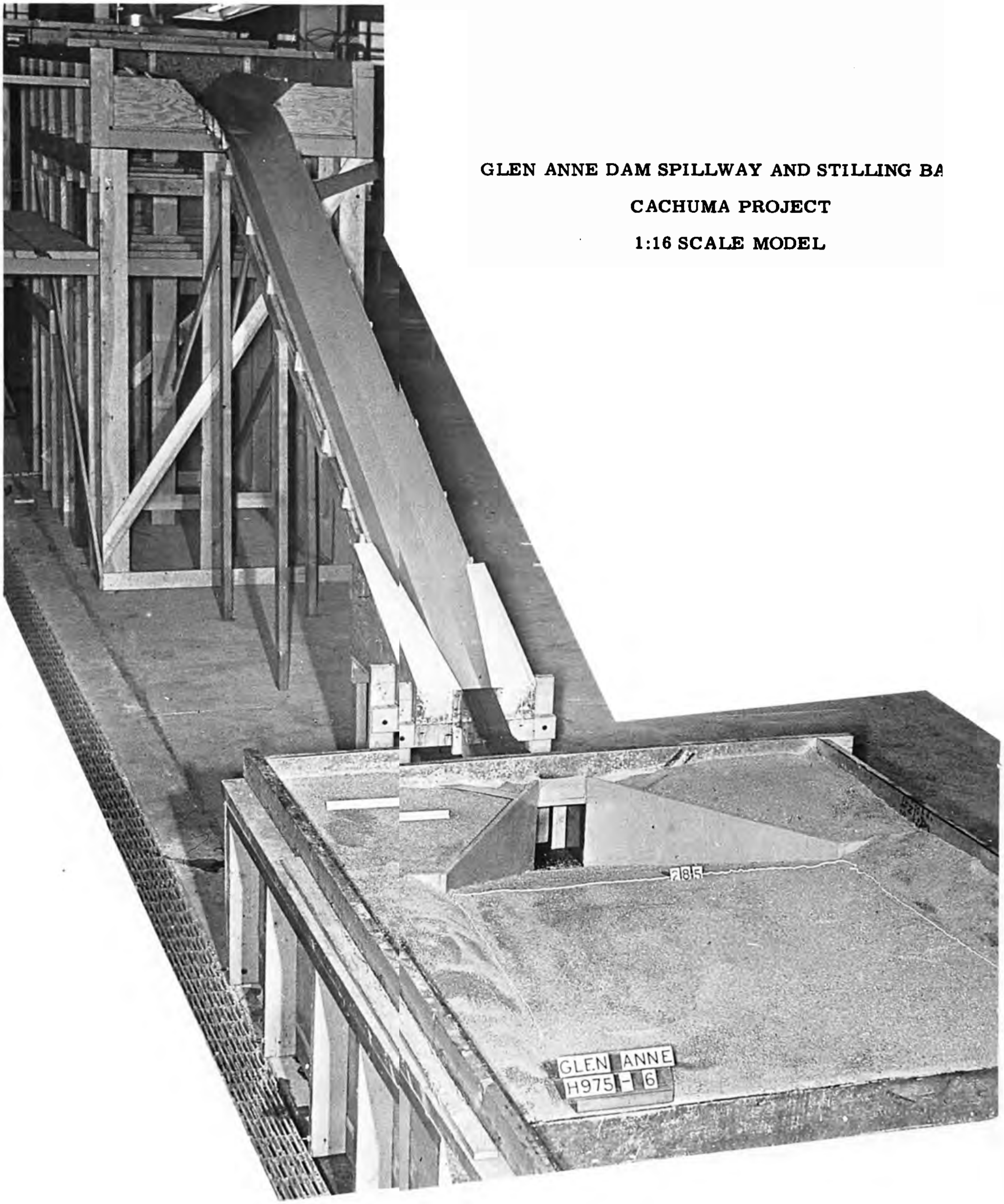
March 23, 1953

HYD 360

GLEN ANNE DAM SPILLWAY AND STILLING BA

CACHUMA PROJECT

1:16 SCALE MODEL



FRONTISPIECE

FOREWORD

Hydraulic model studies of the spillway and stilling basin for Glen Anne Dam, Cachuma Project, California, were conducted in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during March and April of 1951.

The final plans, evolved from this study, were developed through the cooperation of the staffs of the Spillway and Outlets Section No. 1 and the Hydraulic Laboratory.

During the course of the model studies, D. C. McConaughy and F. M. Holdaway of Spillways and Outlets Section No. 1, frequently visited the laboratory to observe the model operation and to discuss test results.

The studies were conducted by T. J. Rhone and the writer, P. "F." Enger. The investigations were under the supervision of A. J. Peterka and J. N. Bradley.

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Laboratory Report No. Hyd-360
Hydraulic Laboratory Section
Compiled by: P. F. Enger
Reviewed and
checked by: A. J. Peterka

Subject: Hydraulic model studies of Glen Anne Dam spillway and stilling basin--Cachuma Project, California

SUMMARY

A 1:16 scale model was used in the study of Glen Anne Dam spillway of the Cachuma Project, California. Tests were conducted primarily to determine the feasibility of using an enclosed stilling basin which utilized a hydraulic jump, operating under pressure, as an energy dissipating device, Figures 4 and 5.

The stilling basin was found to be feasible and further tests were made to develop the spillway and stilling basin to provide the best performance. Data were also obtained on pressures within the stilling basin to aid the designers in providing sufficient strength in the walls to withstand impact pressures created by the jump.

In developing the stilling basin to provide uniform distribution in the flow entering the river channel, 13 arrangements of piers and baffles were used. The stilling basin with Pier H installed (Figure 18) provided a satisfactory flow pattern. The stilling basin performance, with Pier H installed, is shown in Figures 22 to 24. The performance of the preliminary design is shown in Figure 13.

In the course of developing the stilling basin, it was found desirable to modify the entrance to the spillway chute, the entrance to the stilling basin, and the roof of the stilling basin. These modifications were made to improve flow conditions throughout the structure and to reduce splashing at the entrance to the stilling basin. Figure 6 shows the preliminary and recommended entrance to the spillway chute; Figure 9 shows the preliminary and recommended entrance to the stilling basin; Figures 9 and 12 show the preliminary stilling basin roof, and Figure 26 shows the recommended stilling basin roof.

Reluctance-type pressure cells were used to obtain pressures within the enclosed stilling basin. The cells, used with a recording

oscillograph, indicated pressures and fluctuations of pressures as large as 60 feet of water occurring on the inside surfaces of the stilling basin. A typical example of the recorded pressure variations may be seen in Figure 28.

In operation, the recommended design of the spillway and stilling basin resulted in a uniform velocity distribution at the stilling basin outlet, a smooth water surface in the spillway and in the transition from the stilling basin to the river channel, and a satisfactory scour pattern in the area downstream from the stilling basin. A drawing of the recommended prototype structure may be seen in Figures 2 and 4.

INTRODUCTION

The Glen Anne Dam is located approximately 10 miles northeast of Santa Barbara, California, as shown in Figure 1. The structure will provide a regulating reservoir for the Santa Ynez River. Santa Ynez River water will be brought from Cachuma Dam and Reservoir through the 6.4-mile long Tecolote Tunnel to irrigate almost 30,000 acres of land near Santa Barbara and to furnish annually 10,300 acre feet of municipal water to the city of Santa Barbara. The distribution of water from the Glen Anne Dam will be made by a 28-mile long South Coast Conduit.

The dam is a compacted earth structure approximately 250 feet in length and rising approximately 102 feet above the stream bed (Figure 2). At its maximum water surface elevation it has a storage capacity of 660 acre feet and covers an area of 19 acres, while at normal water surface elevation it has a storage capacity of 500 acre feet and covers an area of 16 acres, as shown in Figure 3.

The Glen Anne Dam spillway, shown in Figure 4, is approximately 430 feet in length and consists of a trapezoidal channel, 6 feet deep with a base width of 6 feet and 1:1 side slopes, which discharges into an enclosed stilling basin. The outstanding features of the stilling basin are its relatively small size, 17.5 by 9 by 12 feet, and its utilization of the hydraulic jump operating under pressure as an energy dissipating device.

To study the proposed structure, a 1:16 scale model of the spillway and stilling basin was constructed. To maintain the economic advantage of this type of stilling basin, it was necessary during the testing to develop a basin which would operate satisfactorily without increasing the over-all dimensions of the structure. Any appreciable increase in basin dimensions would have made the construction cost prohibitive. Tests were, therefore, confined to alterations of the internal arrangement of the basin.

During the course of the model study, additional problems developed. It was found necessary to improve flow conditions by modifying the entrance to the spillway chute and the entrance and roof of the stilling basin and to determine the pressures on the walls and roof of the stilling basin.

CONSTRUCTION AND OPERATION OF THE MODEL

The Glen Anne Dam spillway model was constructed to a scale of 1:16. The model included the approach to the spillway, the spillway chute, the transition tunnel approach to the stilling basin, the stilling basin, the transition to the discharge channel, and a portion of the discharge channel. The general features of the model are shown in Figure 5. The head box containing the approach to the spillway was constructed of wood and lined with sheet metal; the spillway chute was constructed of sheet metal with formed concrete at the warped transition section; the transition tunnel approach to the stilling basin and the stilling basin were constructed of wood with transparent plastic sides; and the transition to the discharge channel was a box constructed of wood, lined with sheet metal and filled with sand shaped to the expected contours of the flow channel.

Model discharges were measured by a laboratory Venturi meter in an 8-inch supply line. Water surface elevations in the model were determined by a point gage. For each test, photographs of the water surface conditions and the scour pattern were taken. Other data recorded were: discharge, water surface profiles and cross sections; headwater elevations; pressures on stilling basin walls; and the erosion profile.

THE INVESTIGATIONS

Spillway Entrance

The preliminary spillway entrance had a 10-foot rectangular weir at Station 1+50.00, as shown in Figures 6a and 7a. The crest of the weir was at elevation 385.00, and the bottom of the spillway immediately downstream from the weir was at elevation 383.00. In the preliminary tests flow over the weir created standing waves throughout the length of the chute. The wave pattern, an example of which may be seen in the photograph of Figure 7a, caused water to climb exceedingly high at several places on the spillway chute walls when 840 cfs was flowing over the weir. The undesirable wave pattern also created excessive splashing at the portal to the stilling basin.

To improve flow conditions in the spillway chute, the preliminary spillway entrance was redesigned. The rectangular weir was replaced by a gradually sloping approach from elevation 384.00 at Station 1+20.00 to elevation 385.00 at Station 1+50.00 followed by a uniform slope of 0.029 to Station 2+36.35. This spillway entrance, which is shown in Figures 6b and 7b, provided a satisfactory flow pattern for all discharges including the maximum of 910 cfs. Flow entered the spillway smoothly without evidence of a wave pattern as had occurred previously. There was no tendency for the water to climb the walls of the spillway chute at any point. The revised spillway entrance also increased the discharge, at the maximum headwater elevation of 393.8, from 840 cfs for the preliminary design to 910 cfs. A view of the revised spillway entrance in operation may be seen in Figure 7b. The revised spillway entrance was used in all succeeding tests and was recommended for use on the prototype structure.

Water Surface Profiles

After the spillway entrance was modified, water surface profiles throughout the spillway were recorded. These plotted profiles may be seen in Figure 8. These data were taken as an aid in determining the necessary height of the spillway walls and to be certain that the flow was symmetrical about the center line of the spillway chute. Longitudinal profiles along the center line of the spillway chute and at each wall were recorded and plotted as were cross section profiles at Stations 1+50.40, 1+76.70, 1+96.70, 2+36.35, 2+76.01, 2+90.03, 3+36.65, 3+87.25, and 4+57.10. The wall heights in the preliminary design were believed to be adequate and the symmetry of flow was considered satisfactory throughout the spillway.

Stilling Basin Entrance

The preliminary design of the tunnel entrance to the stilling basin had a rectangular opening 6 by 4.5 feet at Station 4+57.50, Figure 9a. Although this portal, as shown in Figures 10a and 11a, was capable of handling the maximum discharge, a considerable amount of water splashed onto the areas adjacent to the entrance. The splashing appeared to be caused by high velocity flow (approximately 63 feet per second) climbing the training walls of the warped transition just upstream from the portal, combined with surges of water, induced by the hydraulic jump, moving longitudinally in the tunnel. As the splashing at the tunnel portal was undesirable the portal opening was increased by raising the tunnel roof 3 feet at Station 4+57.50 to provide an opening 6 by 7.5 feet, as shown in Figure 9b.

The modified entrance, which is recommended for use in the prototype structure, resulted in improved performance for all discharges including the maximum of 910 cfs. Photographs of the flow entering the preliminary and recommended stilling basin entrances may be seen in Figures 10 and 11 .

Stilling Basin Design

Design No. 1--Preliminary. The preliminary stilling basin design, as shown in Figure 12, was a rectangular box, 17.5 by 9 by 12 feet, containing three vertical piers of triangular cross section; one on the center line of the stilling basin 2.5 feet from the upstream edge; and one on each side of the stilling basin 6 feet from the upstream edge. The upstream pier had its leading edge at Station 4+93.00, its downstream edge was at Station 4+95.50, and it was placed so that water was deflected at an angle of 45° from the stilling basin center line and toward the piers on the stilling basin walls. The upstream edge of the piers attached to the walls was at Station 4+96.50, and their downstream edge was at Station 4+99.00, they deflected the flow from the walls toward the center line of the stilling basin at an angle of 45°. At the end of the stilling basin, wing walls provided a transition to the river channel from a width of 9 feet to a width of 65 feet in a distance of 42 feet. In the same distance there was a rise of 14 feet from the stilling basin floor to the bed of the river channel.

Operation of the model indicated that water flowing between the downstream piers in the stilling basin formed a submerged jet which did not break up in the transition to the river channel but remained in an unstable form, switching from side to side. The unstable flow created an uneven distribution of velocities, an unsatisfactory water surface, and an unsatisfactory erosion pattern between the transition wing walls. Photographs of the water surface and erosion pattern may be seen in Figure 13, and a comparison of the erosion profile with that of other tests that follow may be seen in Figure 14. It was apparent that better operation would result if the submerged jet was dispersed.

From additional observations of the operation of the preliminary design it was noted that, due to the boiling effect of the water emerging from the stilling basin, water occasionally lapped over the transition wing walls. As a result of this and following tests, it was recommended that the height of the wing walls be increased by 3 feet.

Designs No. 2, 3, and 4. To diffuse the jet observed in the preliminary design, baffle piers were added to the existing structure for Designs 2, 3, and 4. The arrangement of the baffles may be seen in Figure 15. In Design No. 2 the stilling basin floor was extended an additional 5 feet and triangular baffles 5 feet in length and 4 feet 4 inches in height were placed on the slope of the transition to the river channel. In Design No. 3 right-angle triangular baffles 4 feet 8 inches in length and 2 feet 10 inches in height were placed on the downstream end of the stilling basin roof with the right angle downstream. While in Design No. 4, right-angle triangular baffles 4 feet 8 inches in length and 5 feet 4 inches in height were placed on the downstream end of the stilling basin roof with the right angle upstream.

In operation the various baffles had different effects on the submerged jet. Design No. 2 had very little effect on the jet. The water leaving the stilling basin was similar to that shown in the photograph of Figure 16a, with the resulting scour pattern similar to that shown in the photograph of Figure 17a. The instability of outflowing water was still prevalent and there was no improvement of flow conditions over the preliminary design. Design No. 3 resulted in a slight improvement of flow in the transition from the stilling basin to the river channel, Figure 16b. The water surface conditions improved slightly; but the instability of flow in the transition was still present and resulted in an unsatisfactory velocity distribution and erosion pattern, Figure 17b. Design No. 4 proved the most satisfactory of the baffle pier designs. The water surface conditions were improved considerably, and the instability of the jet was decreased. However, the jet was still not fully broken up or dispersed; and an excessive amount of scour occurred in the transition section near the downstream end of the stilling basin. The resulting flow conditions were similar to those shown in the photograph of Figure 16b and the scour pattern similar to that shown in the photograph of Figure 17b.

<u>Design No. 5</u>. In observing the operation of previous designs it was noticed that a rolling wave formed in the transition tunnel near the entrance to the stilling basin, and that simultaneously a surge of water moved longitudinally near the tunnel portal. It was the opinion of the designers that this rolling wave might be broken up to eliminate the surge and improve the flow conditions downstream. In an attempt to break up the rolling wave a solid right-angle triangular baffle, placed in the tunnel upstream from the stilling basin, was utilized in Design No. 5. As shown in Figure 15, this baffle spanned the 6-foot width of the tunnel and was 3 feet 4 inches in length and height. It was placed on the tunnel roof with the right angle downstream and at the entrance to the stilling basin. As may be seen from a study of Figures 16a and 17a, the solid baffle had very little effect on the original pattern of flow leaving the stilling basin. The instability of the outflowing water was still prevalent and the jet was not dispersed. A rough water surface for high discharges was prevalent in the transition from the stilling basin to the river channel, and the scour pattern between the transition wing walls was considered unsatisfactory.

Design No. 6. Since the baffle piers used in the previous designs had a minor effect in dispersing the submerged jet, tests were made to determine the effectiveness of vertical piers in the stilling basin. It was anticipated that these piers would split the flow into equal parts, thus breaking up the jet and giving an equal distribution of velocities as the flow left the stilling basin. A total of eight pier arrangements were tried.

Tests showed that the pier arrangements split the flow with varying degrees of success. The various pier arrangements may be seen in Figure 18, and photographs illustrating the performance of the arrangements are shown in Figures 19 through 24. Flow characteristics of the pier arrangements are explained in the following paragraphs:

Pier A, B, C, D, and E.--The first five arrangements used single piers. Their dimensions and the position in which they were used are shown in Figure 18. Piers A, B, and C were diamond-shaped in cross section; they were placed symmetrically about the spillway center line with their downstream edges at Stations 5+08.00, 5+09.00, and 5+07.33, respectively. Pier D was triangular in cross section; it was placed symmetrically about the spillway center line with its downstream edge at Station 5+05.50. Pier E was rectangular in cross section; it was placed symmetrically about the spillway center line with its downstream edge at Station 5+09.00. These piers were all 6 feet 4 inches long, in cross section, except Pier D which was 3 feet 2 inches long. However, the piers varied in cross-sectional width: Pier A was 2 feet 8 inches in width; Piers B and D were 24 inches in width; Pier C was 16 inches in width; and Pier E was 12 inches in width.

Each of the five piers split the flow into two parts, thus removing some of the cause of the instability of flow in the transition observed in previous designs. Although the single piers all improved the flow conditions, they had a tendency to create a jet on each side of the stilling basin, thus leaving an area of relatively quiet water in the center of the channel. This action resulted in unsatisfactory erosion patterns and velocity distributions. Flow conditions and scour patterns were similar for all five of the preceding piers. Typical flow patterns showing the water leaving the stilling basin may be seen in the photographs of Figure 19, and typical scour patterns may be seen in the photographs of Figure 20.

Piers F and G.--As the use of a single pier in the downstream section of the stilling basin resulted in the formation of high velocity flow near the stilling basin walls, an effort was made to produce a more uniform flow distribution by substituting two piers for the single pier of the preceding designs. Piers F, shown in Figure 18, were first used to replace the single pier. It was thought that by properly spacing the upstream edges of these piers the jet could be split into three equal parts, thus giving a fairly uniform velocity distribution at the exit end of the stilling basin. As the exact characteristics of the jet after passing between the upstream piers were unknown, the spacing of the upstream edges of the two downstream piers was varied until the desired result was achieved.

As a first approximation the width of the jet was assumed to be approximately equal to the width of the opening between the two piers at Station 4+97.00 (Figure 18). An opening of 14 inches between the upstream edges of Piers F was tried. This spacing allowed excessive flow between the piers, indicating that there was probably some contraction of the jet in passing between the upstream piers.

For Piers G (Figure 18) the spacing between the upstream edges of the piers was reduced. An 8-inch opening between the upstream edges and a 3-foot opening at their downstream edges was provided. As in the previous design this arrangement consisted of two triangular piers 7 feet 4 inches in cross-sectional length and 14-1/2 inches in cross-sectional width. They were placed symmetrically about the spillway center line with their downstream edge at Station 5+09.00.

Piers G split the flow equally, thus resulting in: (1) an equal velocity distribution, (2) a smooth water surface, and (3) an acceptable erosion pattern, Figure 21. Although this arrangement gave excellent results, it was felt that the knife edges on the piers would be difficult to construct in the prototype; and that unless the pier noses were armored, they would easily be broken.

Although Piers G was not a practical solution to the problem, it did indicate that if the jet emerging from the stilling basin could be uniformly dispersed, satisfactory performance would result. Testing was therefore continued to find a pier arrangement that would accomplish the same result and also be structurally feasible.

Pier H (recommended).--As a result of experiments on previous designs, it was believed that one pier with circular openings through it could be constructed to produce flow conditions similar to Piers G and also be structurally sound. It was desired that the following conditions be met in designing the pier: (1) the distance between circular openings was to be kept at not less than one diameter for structural purposes, and (2) the openings were to be kept fairly large to help prevent them from becoming clogged with debris. From these limiting conditions Pier H, shown in Figure 18, was designed. This pier, which was placed symmetrically about the center line of the stilling basin, was trapezoidal in cross section; its downstream edge was 3 feet 2 inches in cross-sectional width; its upstream edge was 24 inches in cross-sectional width; and it was 3 feet 8 inches in cross-sectional length. There were five 12-inch diameter openings through the pier, and its downstream edge was placed at Station 5+05.83.

Pier H resulted in satisfactory performance for all discharges between 100 cfs and the maximum of 910 cfs. Between the discharges of 100 and 910 cfs this design produced: (1) a smooth water surface in the channel transition downstream from the stilling basin; (2) an even velocity distribution at the stilling basin exit; and (3) a satisfactory scour pattern in the channel transition. A photograph of the water surface for a discharge of 910 cfs may be seen in Figure 22a, and a photograph of the water surface for a discharge of 400 cfs may be seen in Figure 23a. The scour pattern for 910 cfs may be seen in Figures 22b and 23b.

With the holes of Pier H intentionally plugged, there was an indication of high velocity flow near the walls and some relatively quiet water in the center of the channel transition. However, the high velocities were not as pronounced as with the previously tested single piers; and the erosion pattern in the channel transition was considered satisfactory. Photographs of the water surface and scour pattern for Pier H with the holes intentionally plugged and a discharge of 910 cfs are shown in Figure 24.

As a result of the satisfactory flow characteristics, scour pattern, and structural soundness of Pier H, it is recommended that Pier H be constructed in the prototype as shown in Figure 18.

Stilling Basin Roof Tests

When operating the stilling basin with Pier H installed, it was noticed that at low flows (under 100 cfs) pockets of air formed on the roof of the stilling basin. After several of these pockets had formed, some of them were forced out of the exit of the basin. Since the top of the exit was submerged, these pockets left the basin with some force and resulted in a geyserlike action. This was considered an undesirable feature of the performance for low discharges because of the wave action initiated in the transition channel and because of the splash and spray formations occurring at the outlet. It was feared that the action in the prototype might be more severe than that indicated in the model.

Roof Design No. 1.--To prevent the air pockets from moving downstream at low discharges, a lip was placed across the top of the exit. The lip was the full width of the exit and extended toward the floor of the stilling basin; Figure 25. To prevent the air from leaving the exit, it was found that the lip should extend downward a minimum of 8 inches. The lip prevented the air bubbles from leaving the stilling basin until the flow was large enough to absorb the air in the form of fine grain bubbles that were normally present in flows over 100 cfs. However, at flows larger than 400 cfs, the lip caused the jet leaving the stilling basin to be directed downward resulting in considerably more scouring in the channel than occurred otherwise.

Roof Design No. 2.--As the lip proved unsatisfactory, tests were made using a sloping roof on the stilling basin (Figure 25). It was anticipated that the air carried into the stilling basin, instead of collecting against the roof, would be induced to flow upstream smoothly and evenly and be released into the atmosphere through the upstream end of the basin. The roof was sloped from the design elevation, 283.00, at Station 5+09.00, upstream to Station 4+70.10, Figure 25. Two slopes were tried: The first raised the roof a total of 8 inches at Station 4+70.10 giving a slope of 0.0171; the second raised the roof a total of 16 inches at Station 4+70.10 giving a slope of 0.0343.

The 8-inch raise prevented the air bursts at the spillway outlet for discharges up to 50 cfs, while the 16-inch raise was effective for discharges up to 70 cfs. Neither of these shapes was sufficient to prevent the bursts up to the desired discharge of 100 cfs so further tests were made.

Roof Design No. 3.--In an attempt to allow trapped air to flow uniformly along the roof to either end of the stilling basin, a slope in the stilling basin roof in both directions from Station 4+89.55 was created by raising the roof 8 inches at Stations 4+70.10 and 5+09.00, as shown in Figure 25.

At low discharges up to 30 cfs, the entrained air collected along the upstream roof and moved upstream, emerging from the tunnel portal. However, at discharges between 30 and 100 cfs, the air was carried to a point below the change of slope; and there, gathering in large pockets, erupted from the end of the stilling basin in the same manner as occurred with the flat roof. The appearance of the action indicated that further tests along these lines should not be attempted.

Roof Design No. 4.--To allow the air to flow along the stilling basin roof toward the outlet end and leave the stilling basin in a steady flow, the roof was next sloped upward from Station 4+70.10 to the end of the stilling basin, Station 5+09.00. A uniform slope of 0.0343 was used, thereby raising the roof a total of 16 inches at Station 5+09.00, Figure 25.

Very poor action resulted with this roof design, as the air escaped in even larger bursts than was noticed at the start of these tests. Further testing of this idea was abandoned.

Roof Design No. 5 (recommended).--A combination of the lip and sloping roof was found to be the most effective method of preventing air bursts. A 6-inch lip, across the exit of the stilling basin used with the 16-inch raise in the roof at Station 4+70.10, Figure 26, prevented the air from erupting for discharges to approximately 90 cfs or until just before the fine grain air bubbles appeared. This left a very short discharge range, approximately 10 cfs, in which the undesirable action took place. However, at discharges of 90 to 150 cfs, an occasional large air burst escaped from under the lip. Above and below this range, no air bursts were observed.

A scour test was run with the combination sloping roof and lip design in place for a discharge of 910 cfs. The scour pattern resulting from the test is shown in Figure 23b. The scour pattern was considered satisfactory as it revealed little change from the previously accepted scour pattern. Roof Design No. 5 is therefore recommended for prototype construction.

Pressure Measurements

Since the energy dissipating device was a hydraulic jump which created surges in the enclosed basin, pressure measurements on the walls and roof of the stilling basin were desired for design purposes. As a preliminary check of pressures, piezometers were installed on the stilling basin roof. The piezometers consisted of holes drilled in the roof with a plastic tube attached. Due to air entrained in the water of the stilling basin, a satisfactory reading could not be obtained. Air bubbles in the water column of the gage made it uncertain as to the true height of the water column. The piezometers did, however, indicate a large fluctuation in pressure; and it was feared that the water manometer was averaging a much larger fluctuation than was visible. It was felt that instantaneous pressures should be measured so that proper values would be available to design the basin. Pressures were measured with pressure cells, using a recording oscillograph to record the results. Reluctance-type pressure cells were connected by a bridge circuit to an oscillograph, Figure 27. The pressure cells were then connected to the pressure taps shown in Figure 18. Pressure fluctuations were transmitted to the cell which actuated the oscillograph to draw a curve of pressure versus time. Thus, the instantaneous value of the pressure and the range of fluctuation over a period of time could be obtained.

The record of pressures indicated a trend of fluctuation from maximum to minimum to maximum in a period of approximately 0.41 second. The maximum difference in the pressure occurred at Pressure Tap No. 1 (which was located on the wall of the stilling basin at Station 4+93.50 and elevation 277.00, as shown in Figure 18) and was approximately 60 feet of water. This maximum difference occurred approximately every 40 seconds for a discharge of 910 cfs. The pressure fluctuations showed a tendency to go below atmospheric pressure at Pressure Tap No. 2. (Pressure Tap No. 2 was located on the wall of the stilling basin at Station 5+00.67 and elevation 277.00.) A typical example of the negative fluctuations may be seen in Figure 28. Negative pressures were prevalent at Pressure Tap No. 2 for discharges of 600 cfs and over, and pressures as low as 27 feet of water below atmospheric were recorded. Although these low pressures indicated that cavitation might occur, it was the opinion of the designers that, because of the large amount of entrained air in the stilling basin and because cavitation pressures occurred for such a small percentage of the time, the structure would not be damaged.

As pointed out by A.J. Peterka in "The Effects of Entrained Air on Cavitation Pitting," Hydraulic Laboratory PAP No. 38, laboratory tests have shown that water containing as little as 0.1 percent of air, under ideal conditions, reduces the pitting that would otherwise occur; and that larger amounts of air have a much greater success in reducing the pitting. Figures 29 and 30 show the effect of entrained air on cavitation erosion. In cavitation tests on the samples shown, the only variable was the amount of entrained air in the water.

THE RECOMMENDED DESIGN

The recommended design of the spillway and stilling basin structure evolved from the model studies is shown on Figures 4 and 26. Figure 4 shows the recommended spillway chute entrance, stilling basin entrance, and stilling basin pier design. Figure 26 shows the recommended roof and pier design. Figures 22 to 24, inclusive, show the operation of the recommended stilling basin for various discharges to a maximum of 910 cfs.

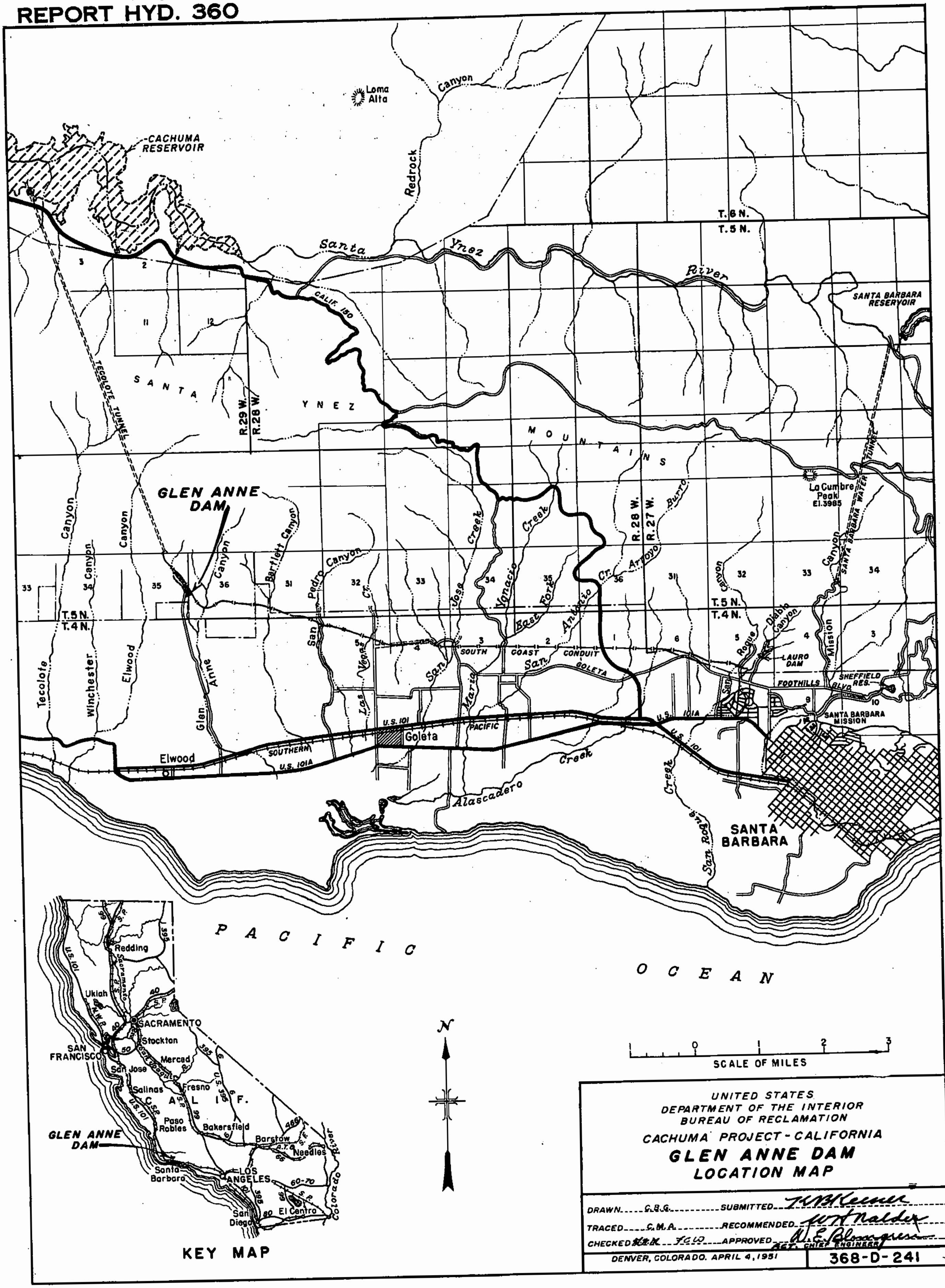
A study of Figure 8 reveals that when the recommended spillway entrance is installed, water surface profiles throughout the spillway section are satisfactory. Figure 8 also reveals that the preliminary spillway chute side wall heights are adequate for discharges up to and including the maximum of 910 cfs. It may be noted in Figure 7 that the recommended spillway entrance shows a marked improvement over the preliminary spillway entrance.

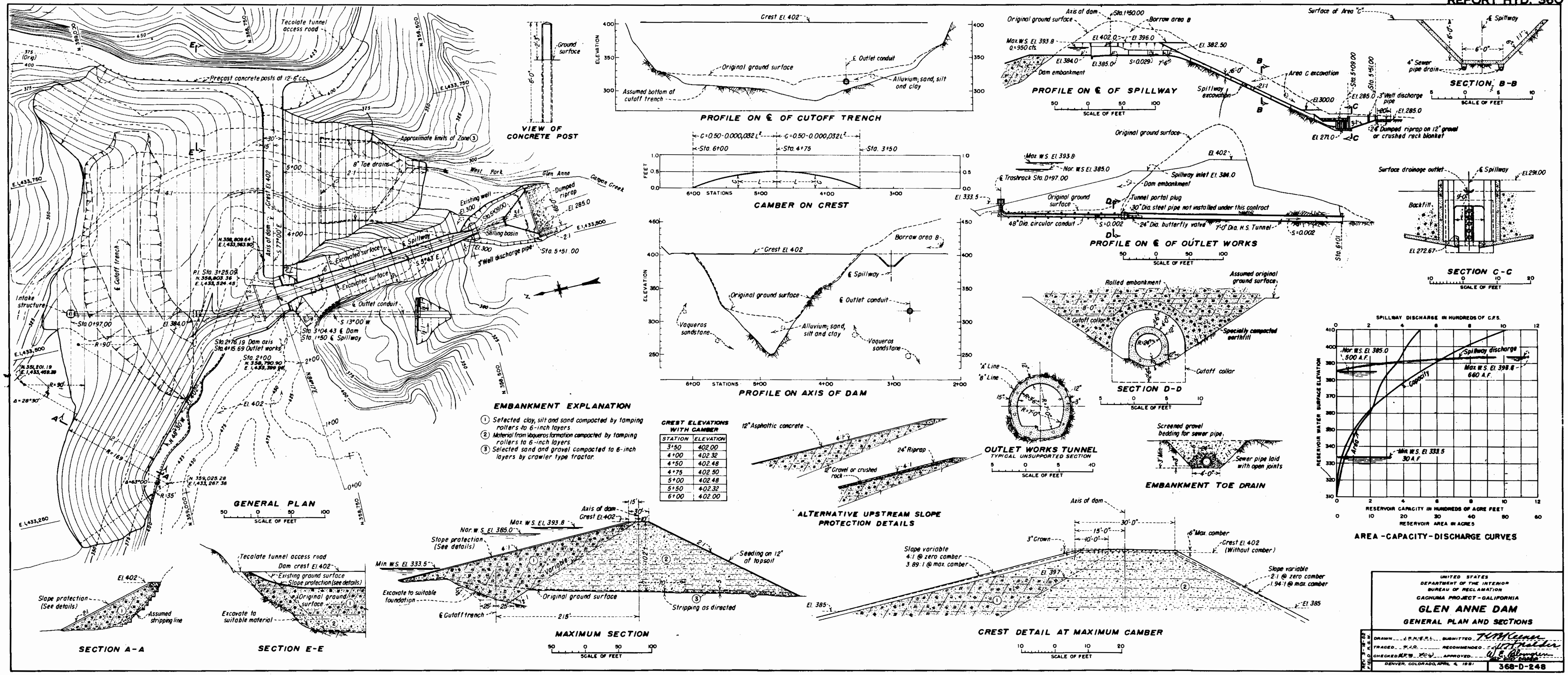
Studies made on the stilling basin indicated that good performance resulted when Pier H, shown in Figure 18, was added to the preliminary stilling basin. Other recommendations for improving the operation of the stilling basin include: a revision of the tunnel portal as shown in Figure 9, and a revision of the stilling basin roof as shown in Figure 26.

A study of the photographs in Figures 22 through 24 reveals that the channel transition wing walls are subject to water occasionally lapping over them. Therefore, it is recommended that the wing walls from the stilling basin to the river channel have their top elevation increased to 291.00.

Pressure measurements were obtained along the stilling basin walls for discharges from 400 to 910 cfs. The measurements indicated localized pressures of 60 feet of water. It is recommended that the pressures indicated by Figure 28 be used in designing the walls of the prototype stilling basin, and that a system of checking for high instantaneous pressures in the prototype be devised. Although pressures of 27 feet of water below atmospheric were recorded, they were not considered dangerous as large amounts of air were entrained in the water, and the low pressures were instantaneous, acting for only a small percentage of the total time.

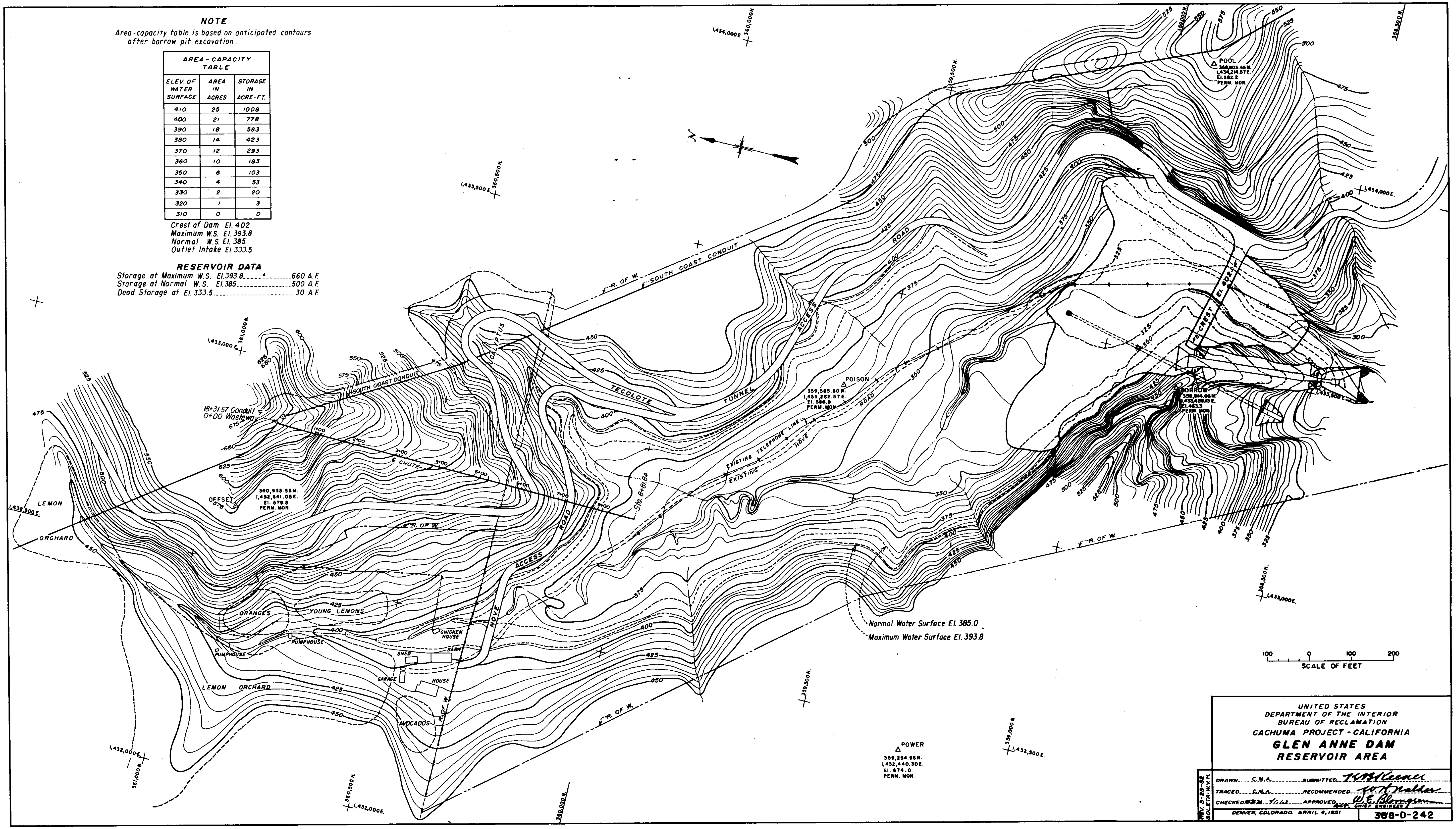
FIGURE 1
REPORT HYD. 360





CREST ELEVATIONS WITH CAMBER

STATION	ELEVATION
3+50	402.00
4+00	402.32
4+50	402.48
4+75	402.50
5+00	402.48
5+50	402.32
6+00	402.00



NOTE

Area-capacity table is based on anticipated contours after barrow pit excavation.

AREA-CAPACITY TABLE

ELEV. OF WATER SURFACE	AREA IN ACRES	STORAGE IN ACRE-FT.
410	25	1008
400	21	778
390	18	583
380	14	423
370	12	293
360	10	183
350	6	103
340	4	53
330	2	20
320	1	3
310	0	0

Crest of Dam El. 402
Maximum W.S. El. 393.8
Normal W.S. El. 385
Outlet Intake El. 333.5

RESERVOIR DATA

Storage at Maximum W.S. El. 393.8 .... 660 A.F.
Storage at Normal W.S. El. 385 .... 500 A.F.
Dead Storage at El. 333.5 .... 30 A.F.

100 0 100 200
SCALE OF FEET

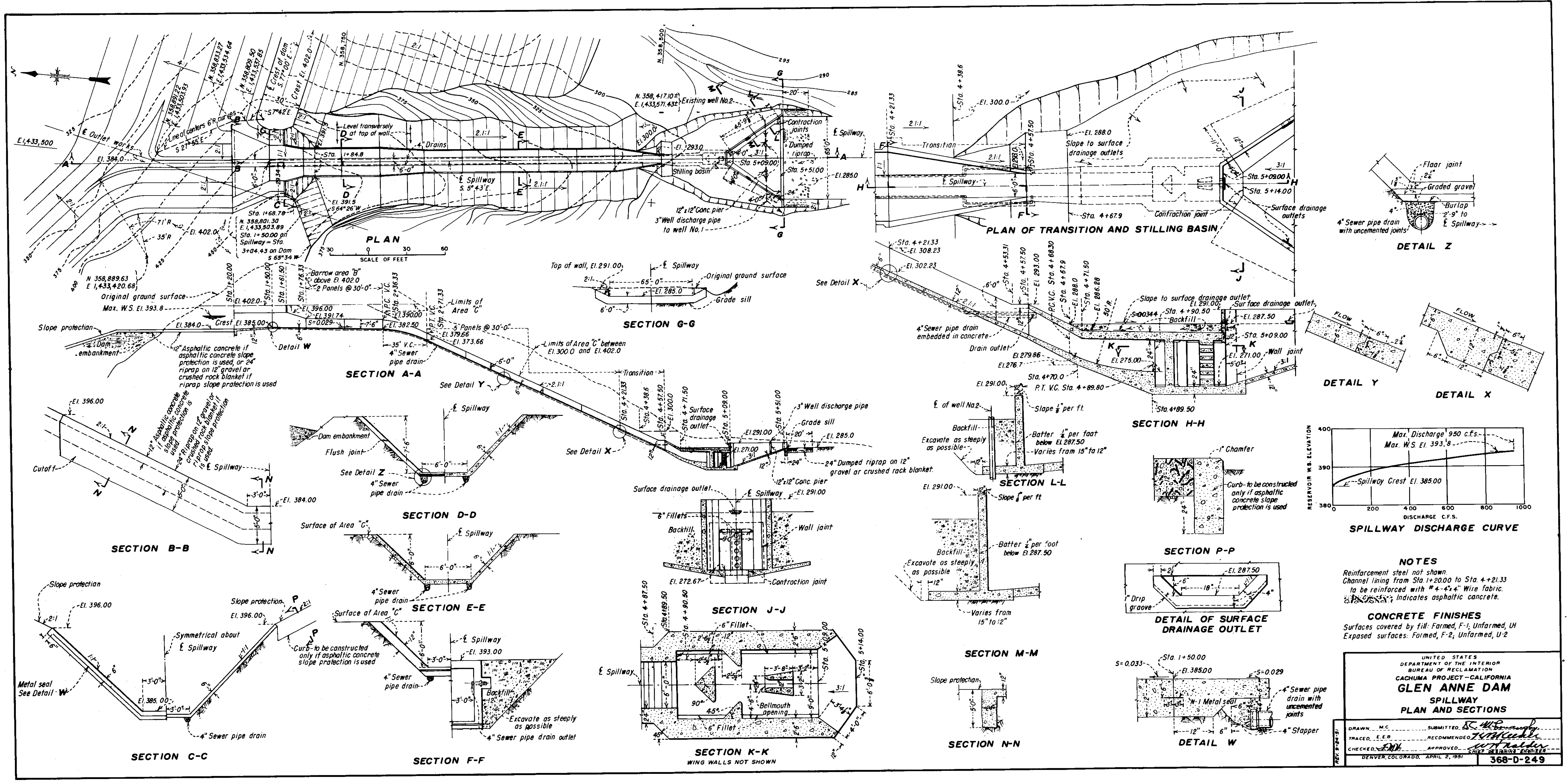
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CACHUMA PROJECT - CALIFORNIA

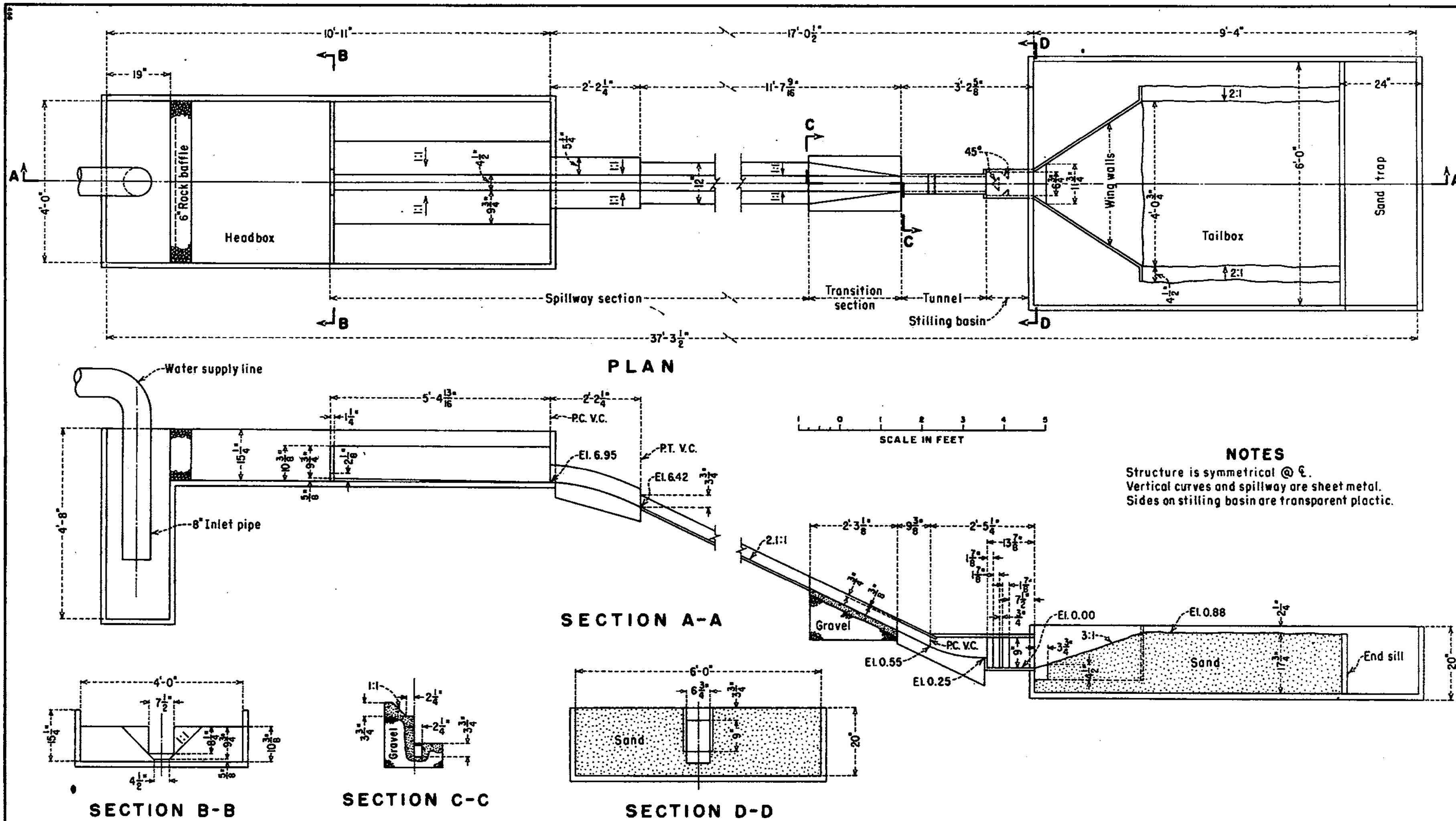
GLEN ANNE DAM
RESERVOIR AREA

DRAWN C.M.A.	SUBMITTED [signature]
TRACED C.M.A.	RECOMMENDED [signature]
CHECKED Y.C.W.	APPROVED W. E. Blomgren, ASST. CHIEF ENGINEER
DENVER, COLORADO. APRIL 4, 1951	368-D-242

REV. 5-26-52 GOLETA-W.V.H.

FIGURE 4
REPORT HYD. 360





GLEN ANNE DAM SPILLWAY AND STILLING BASIN

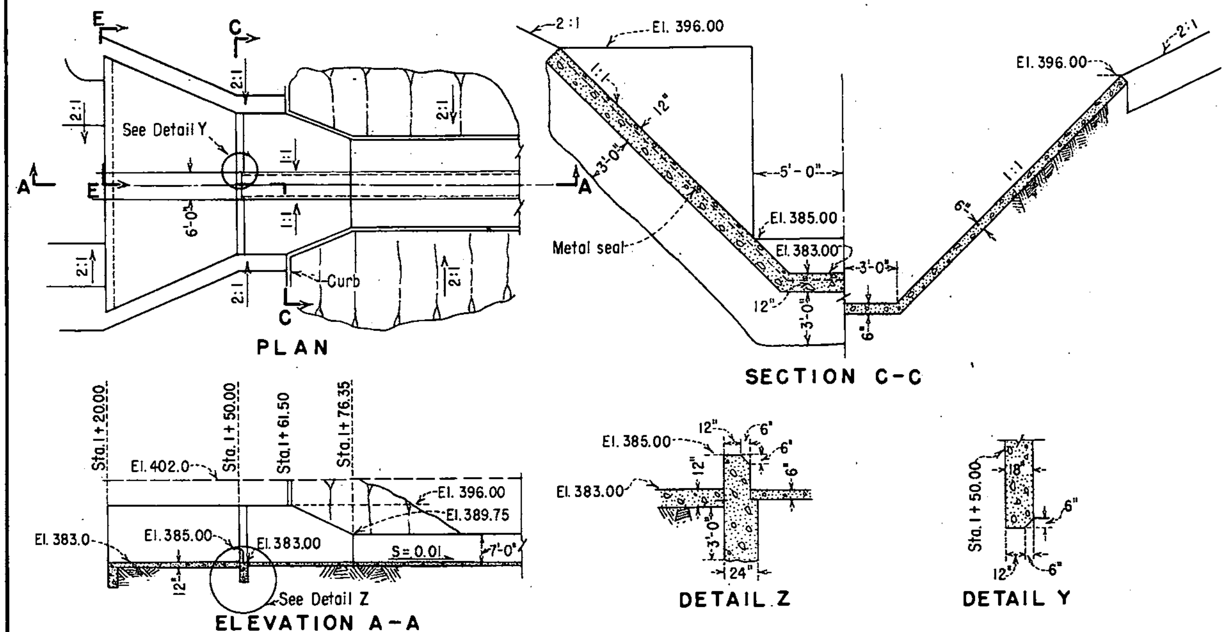
CACHUMA PROJECT

PRELIMINARY DESIGN

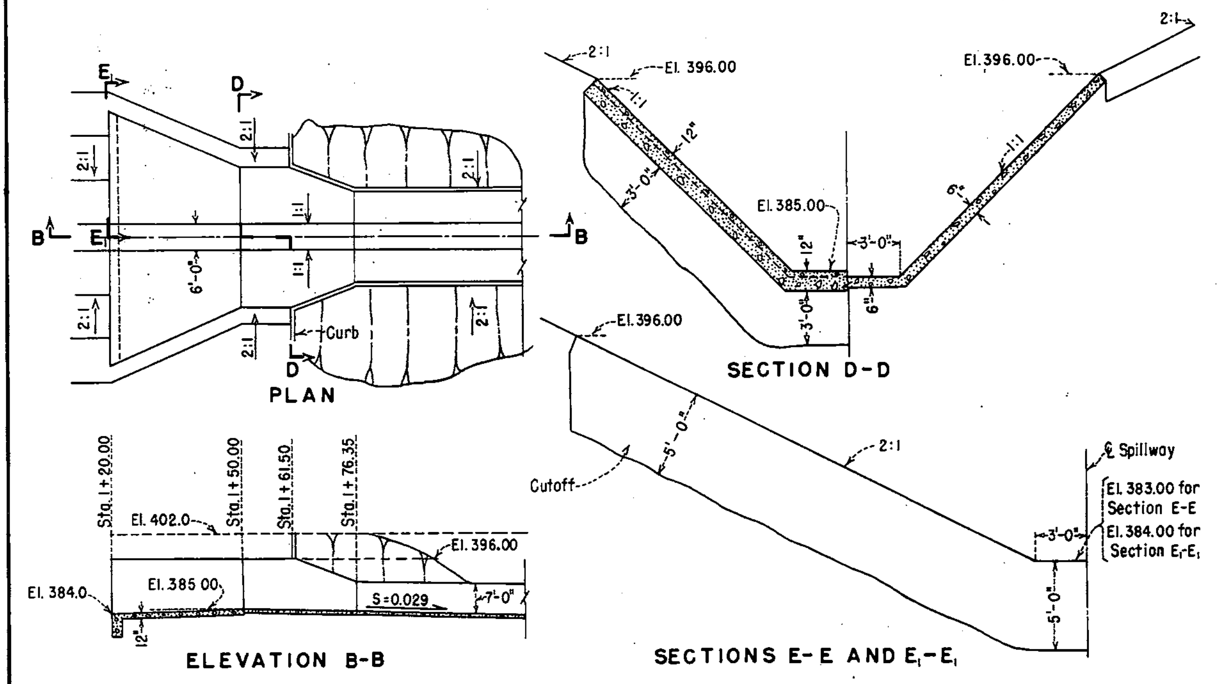
DATA FROM 1:16 SCALE MODEL

FIGURE 5
REPORT HYD. 360

FIGURE 6
REPORT HYD. 360



(a) PRELIMINARY DESIGN OF SPILLWAY ENTRANCE



(b) RECOMMENDED DESIGN OF SPILLWAY ENTRANCE

NOTES
Spillway is symmetrical about ℄

10 0 10 20 30 40 50
SCALE OF FEET

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

SPILLWAY ENTRANCES PRELIMINARY AND RECOMMENDED

DATA FROM 1:16 SCALE MODEL

466

(a) Preliminary design - 840 cfs.

(b) Recommended design - 910 cfs.

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
FLOW ENTERING SPILLWAY
Data from 1:16 scale model

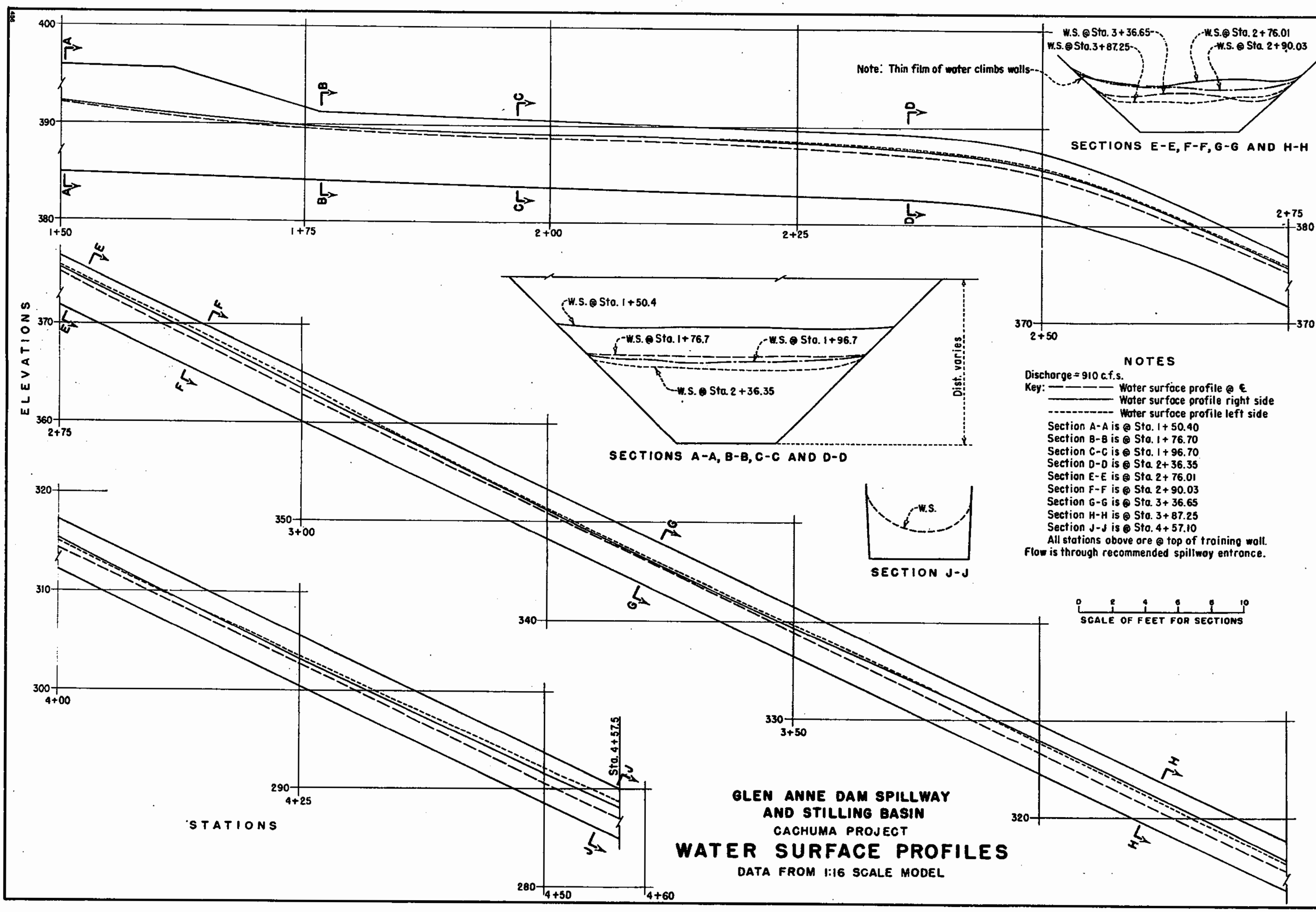
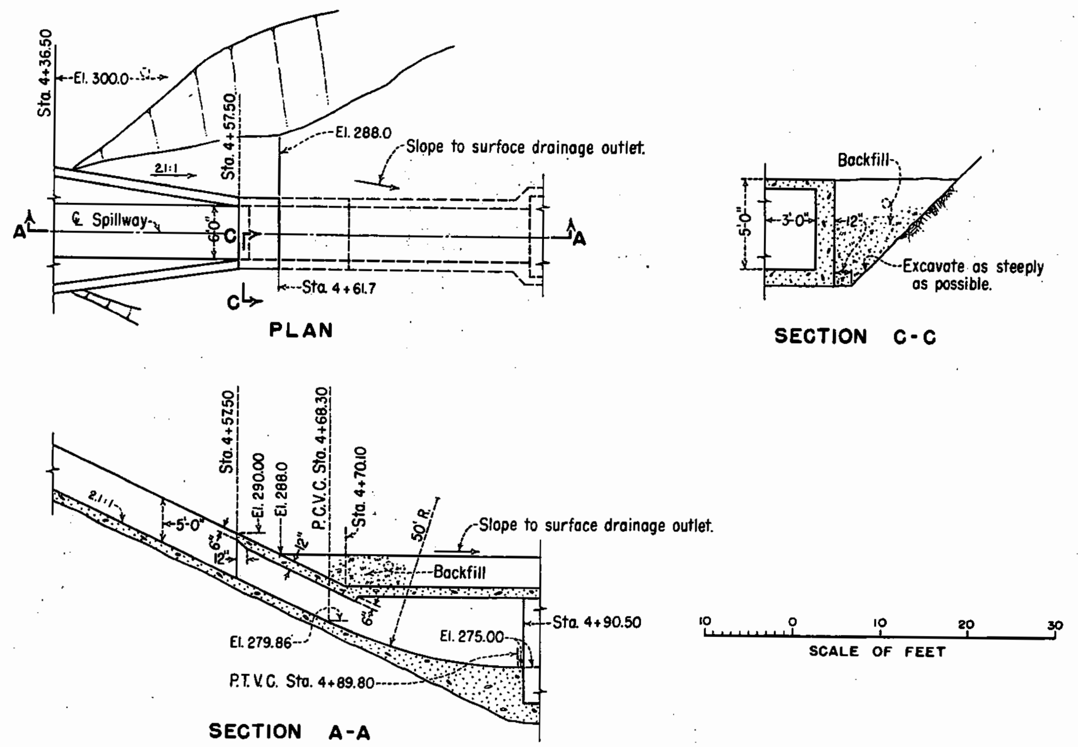
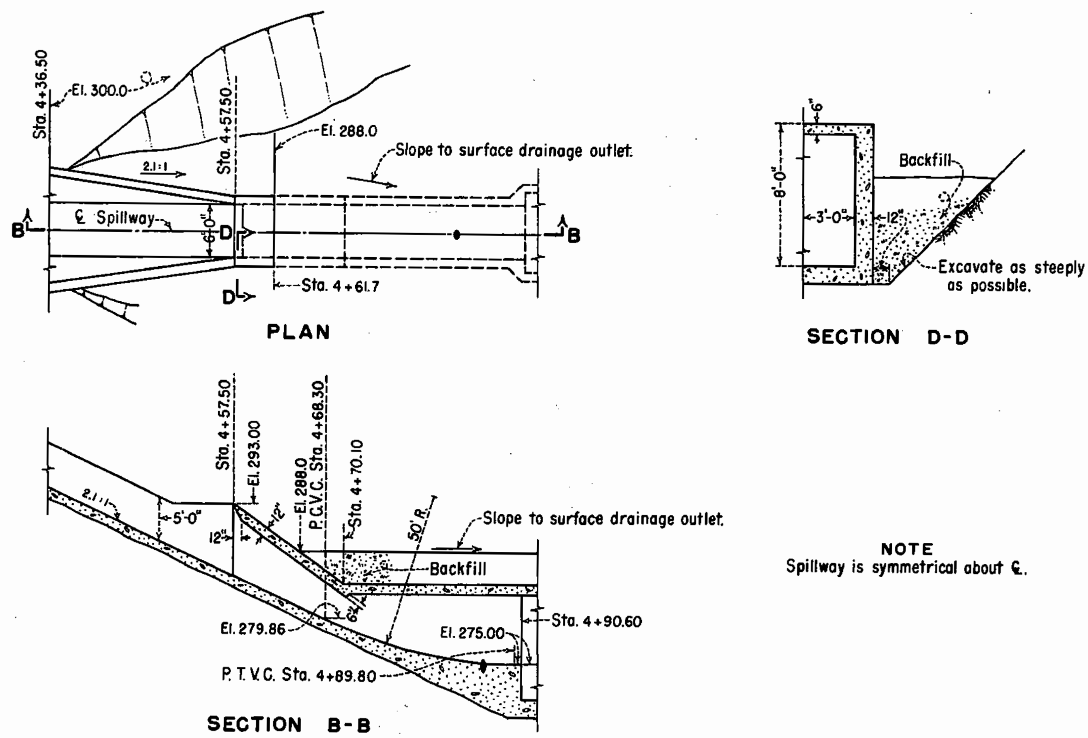


FIGURE 8
REPORT HYD. 360



(a) PRELIMINARY DESIGN OF THE TUNNEL ENTRANCE TO THE STILLING BASIN



(b) RECOMMENDED DESIGN OF THE TUNNEL ENTRANCE TO THE STILLING BASIN

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

STILLING BASIN ENTRANCE
PRELIMINARY AND RECOMMENDED

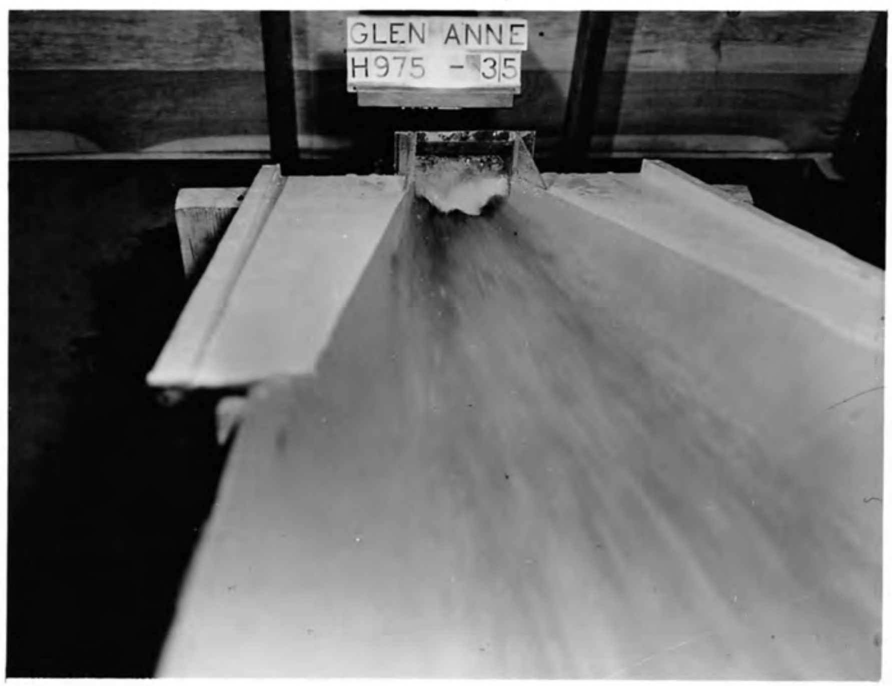
DATA FROM 1:16 SCALE MODEL

(a) Preliminary design - 840 cfs.

(b) Recommended design - 910 cfs.

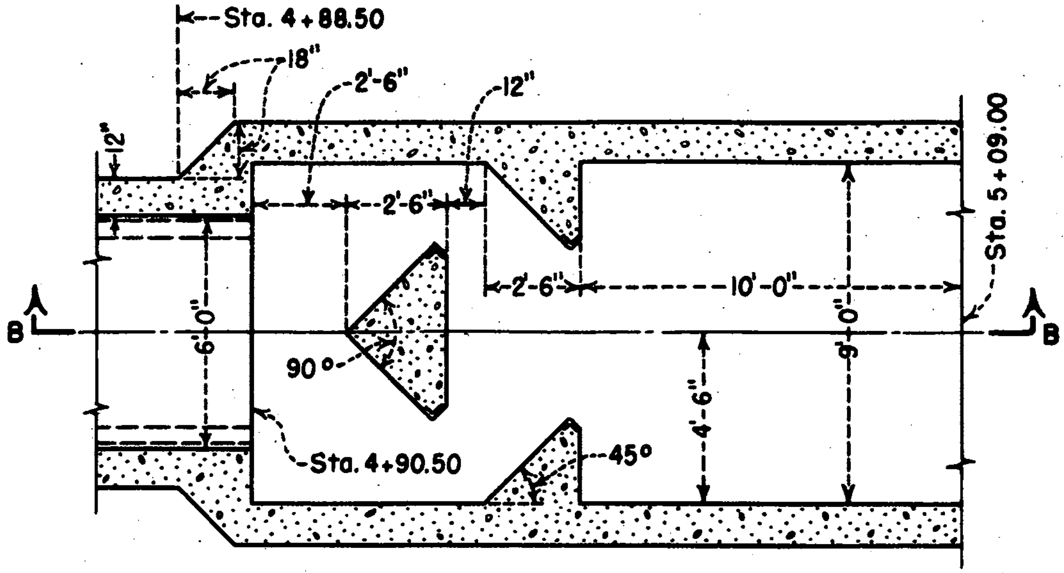
GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
FLOW THROUGH STILLING BASIN ENTRANCE
Data from 1:16 scale model

(a) Preliminary entrance - 840 cfs.

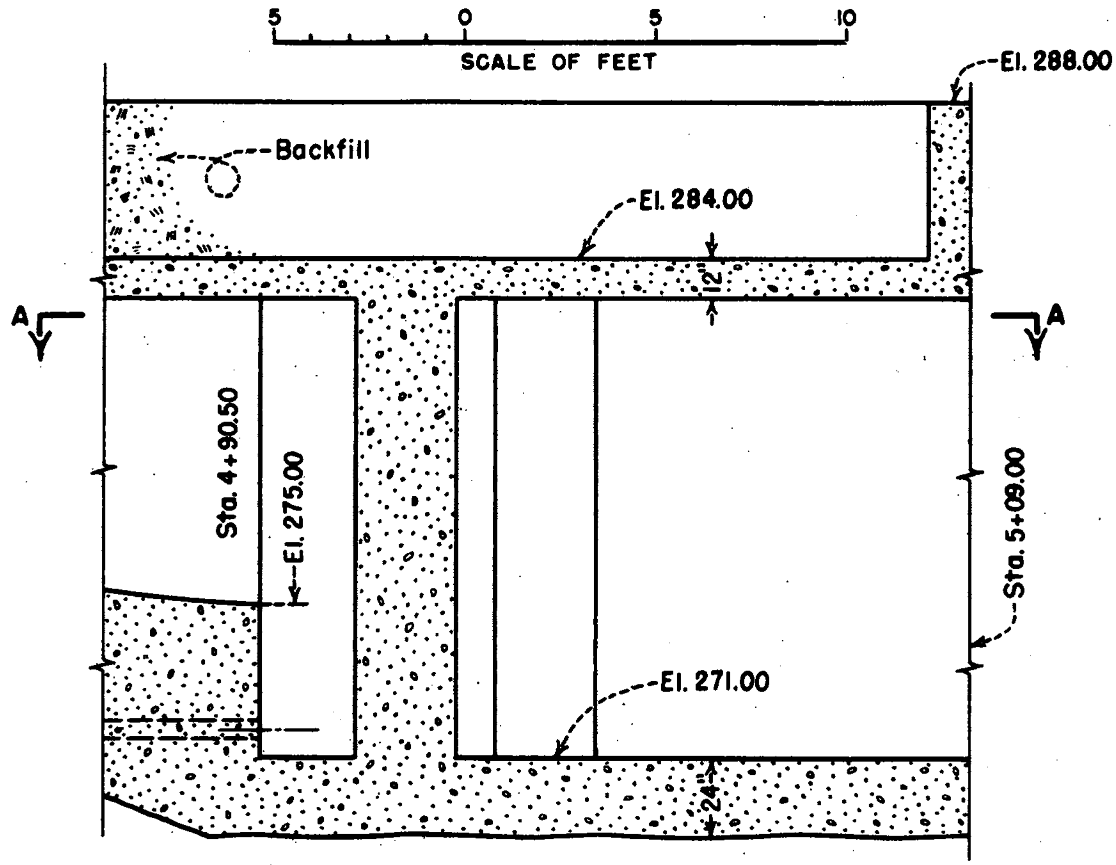


(b) Recommended entrance - 910 cfs.

GLEN ANNE DAM AND STILLING BASIN
Cachuma Project
FLOW INTO TUNNEL PORTALS OF STILLING BASIN ENTRANCE
Data from 1:16 scale model



SECTION A-A



ELEVATION B-B

Note: Stilling basin is symmetrical about ℄.

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

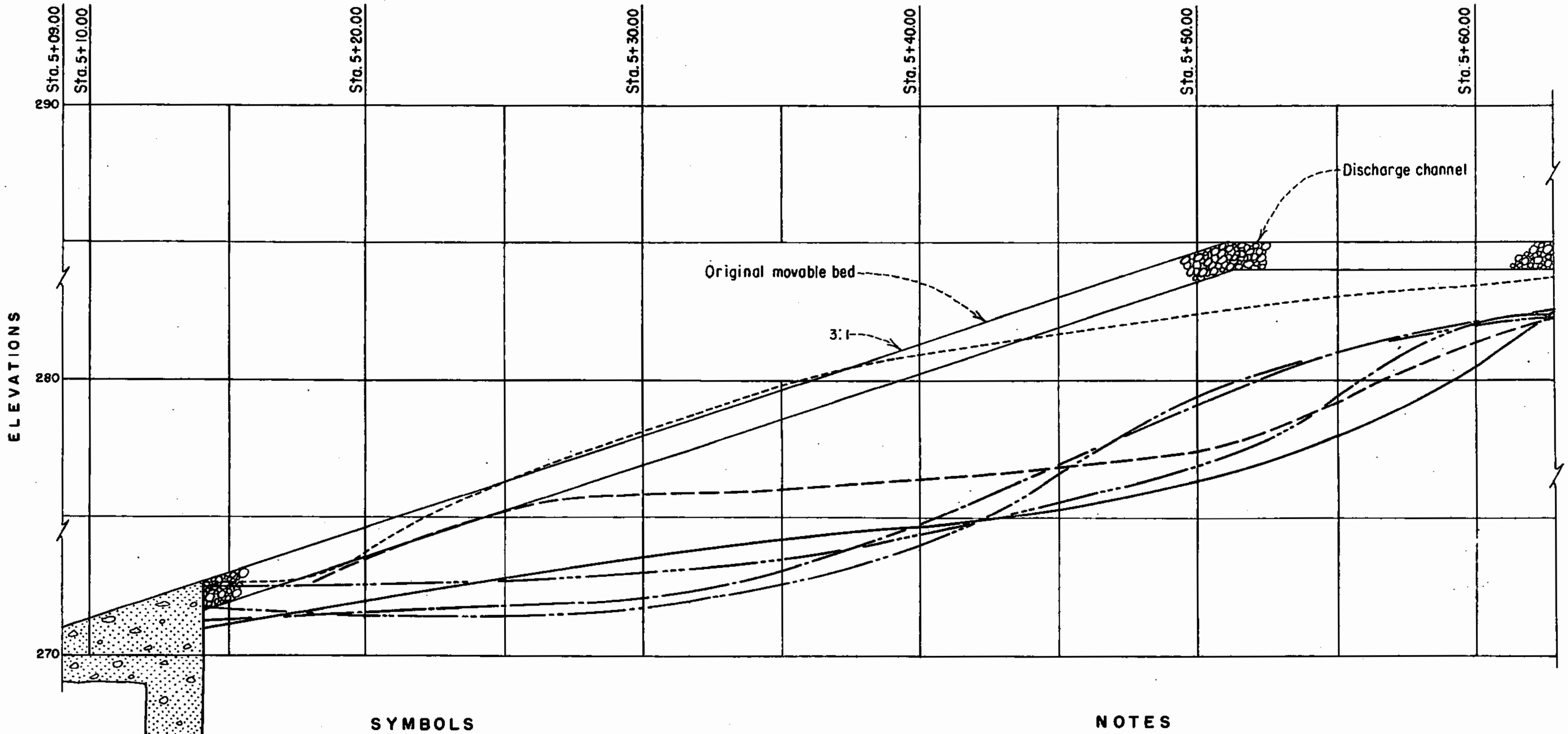
PRELIMINARY STILLING BASIN DESIGN

1:16 SCALE MODEL STUDY

(a) Water leaving preliminary stilling basin - 840 cfs.

(b) Scour after 30 minutes of model operation

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
PERFORMANCE OF PRELIMINARY DESIGN
Data from 1:16 scale model



SYMBOLS

- Design No. 1 - preliminary
- Design No. 2
- Design No. 3
- Design No. 4
- Design No. 5
- Design No. 6 - Pier "H" Recommended

NOTES

Erosion profiles taken on the ℄ of the discharge channel after 30 minutes of model operation.
Discharge used in preliminary design - 840 c.f.s.
Discharge used for other designs - 910 c.f.s.

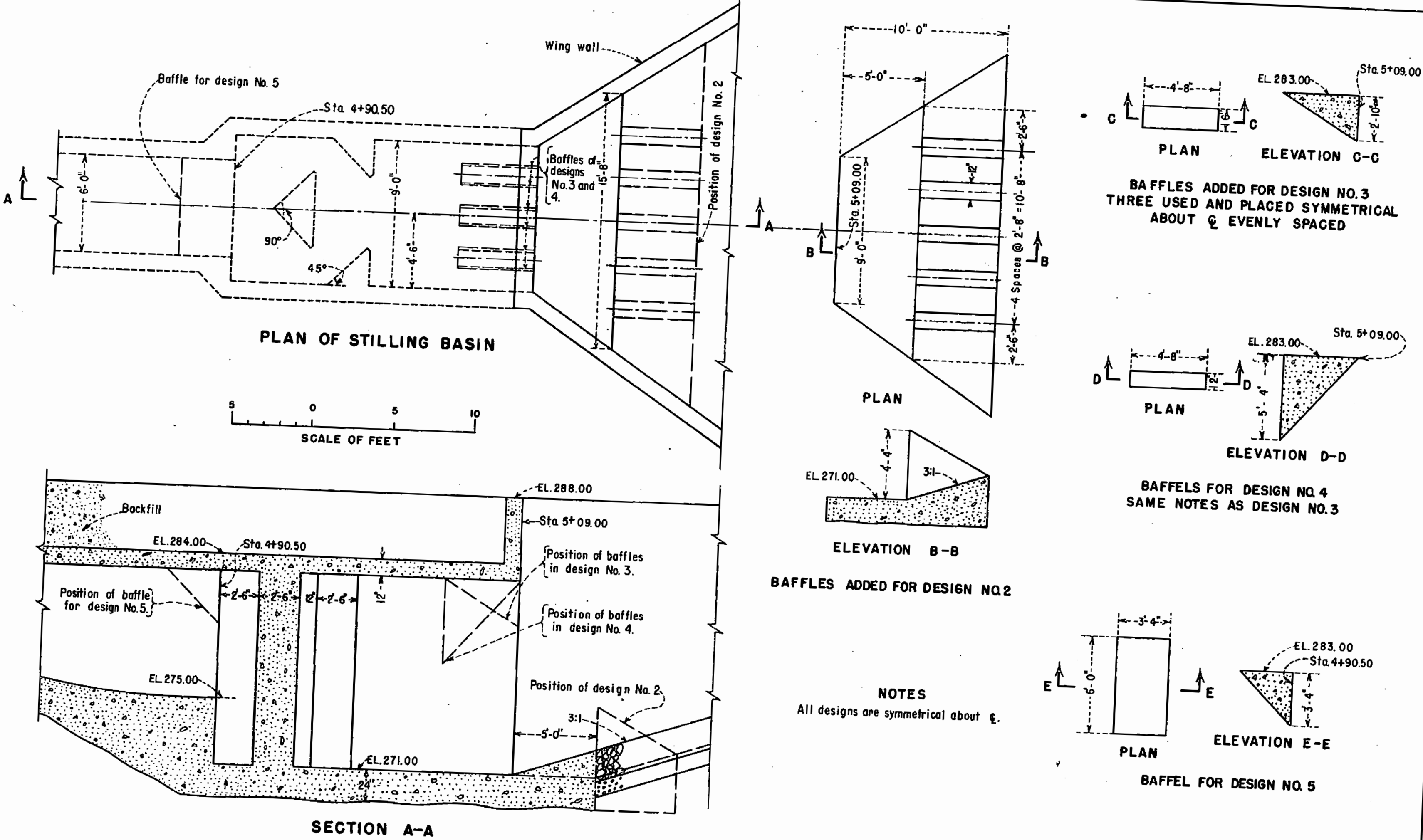
GLEN ANNE DAM SPILLWAY AND STILLING BASIN

CACHUMA PROJECT

EROSION PROFILES

DATA FROM 1:16 SCALE MODEL

FIGURE 14
REPORT HYD. 360



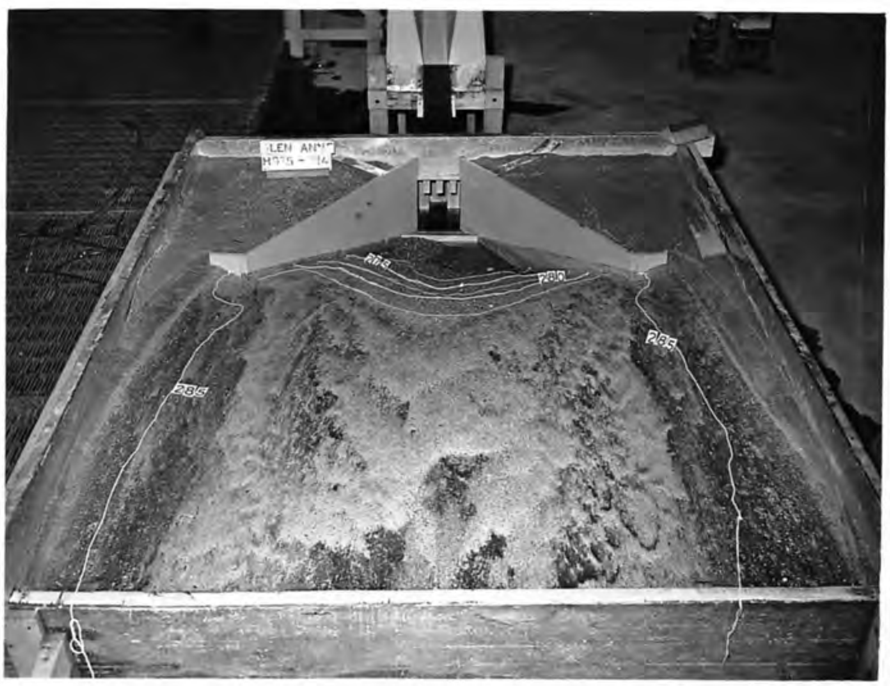
GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT
STILLING BASIN DESIGNS No. 2, 3, 4 AND 5
DATA FROM 1:16 SCALE MODEL

(a) Design No. 5

(b) Design No. 3

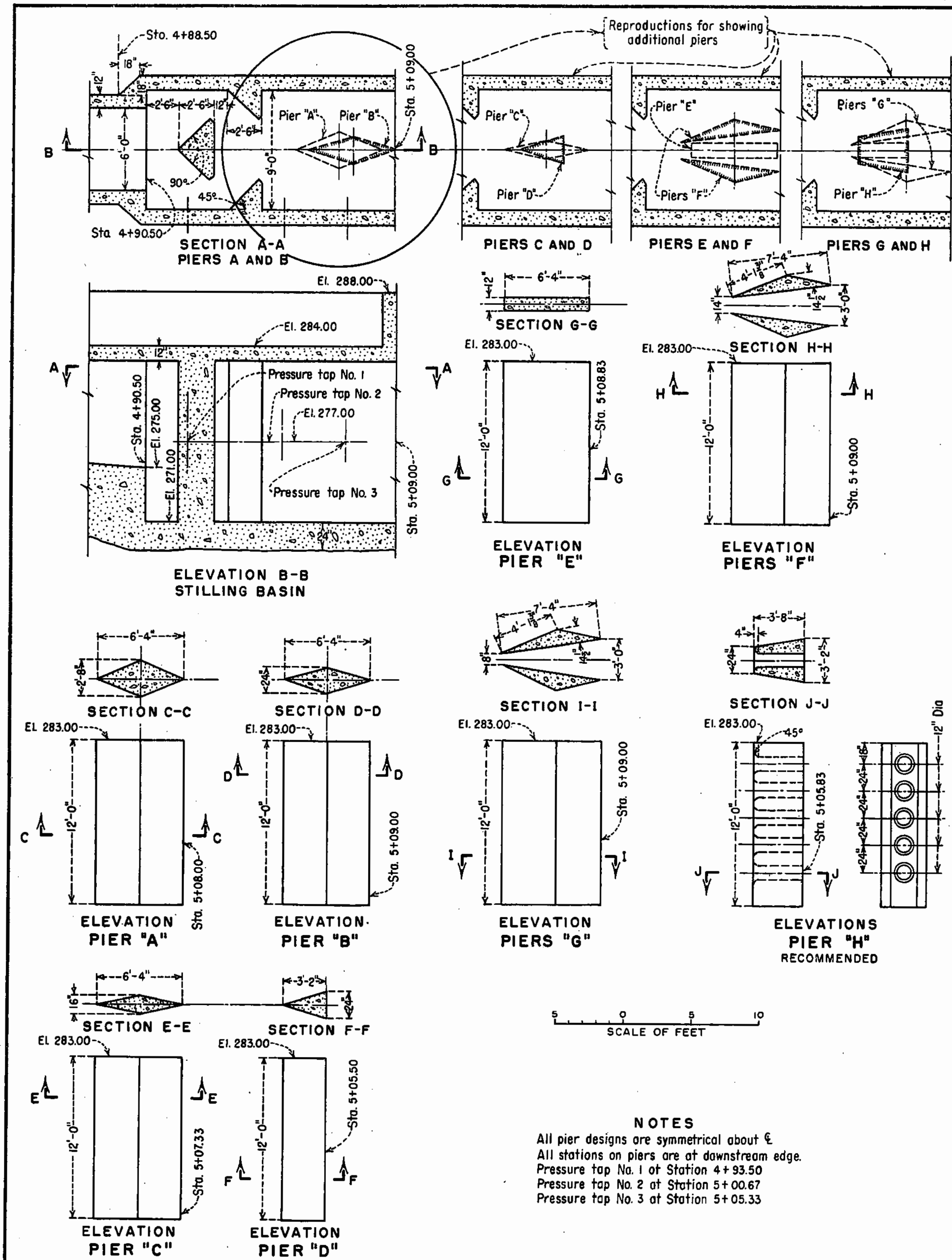
GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
FLOW LEAVING STILLING BASIN - 910 cfs - DESIGNS No. 3 and 5
Data from 1:16 scale model

(a) Design No. 5



(b) Design No. 3

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
SCOUR PATTERN AFTER 30 MINUTES OF MODEL OPERATION AT 910 cfs.
DESIGNS No. 3 and 5
Data from 1:16 scale model

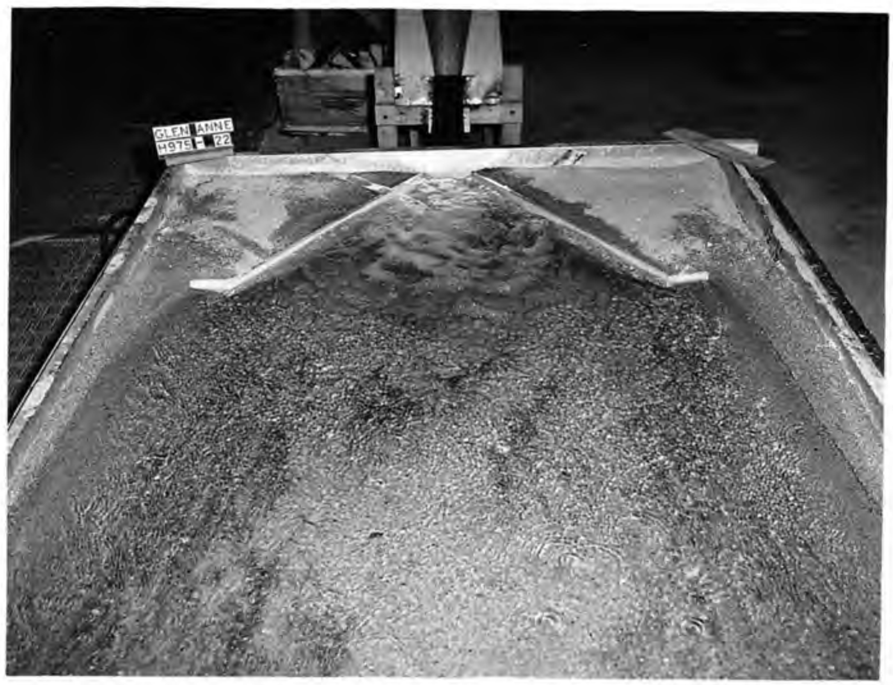


NOTES
All pier designs are symmetrical about ℄
All stations on piers are at downstream edge.
Pressure tap No. 1 at Station 4+93.50
Pressure tap No. 2 at Station 5+00.67
Pressure tap No. 3 at Station 5+05.33

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT
DESIGN No. 6
DATA FROM 1:16 SCALE MODEL

488

(a) Pier B



(b) Pier C

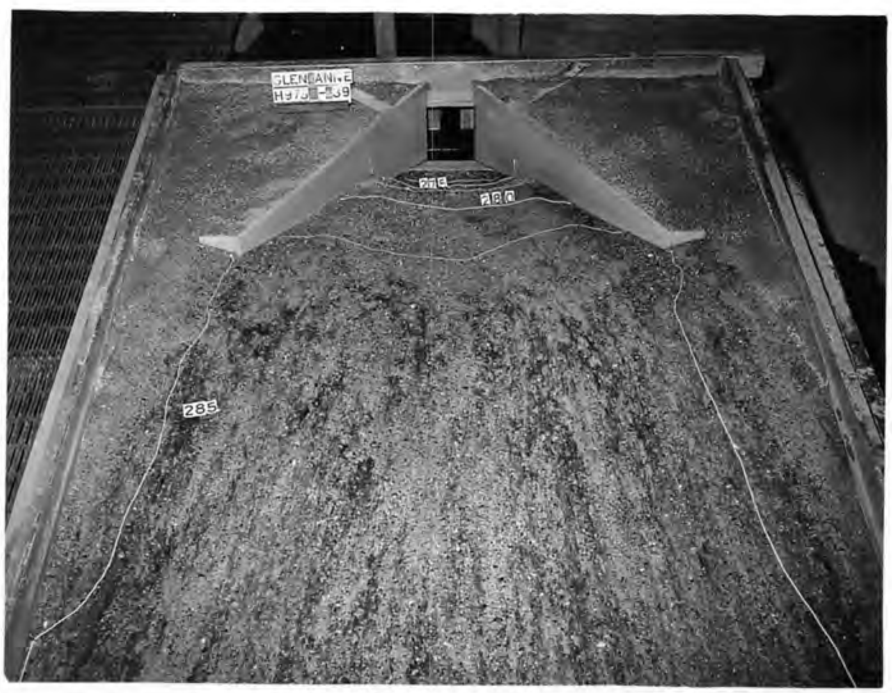
GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
FLOW LEAVING STILLING BASIN - 910 cfs - DESIGN No. 6 PIERS B AND C
Data from 1:16 scale model

(a) Pier B

(b) Pier C

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
SCOUR PATTERN AFTER 30 MINUTES OF MODEL OPERATION
AT 910 cfs - DESIGN No. 6 - PIERS B AND C
Data from 1:16 scale model

(a) Water Leaving Stilling Basin - 910 cfs.



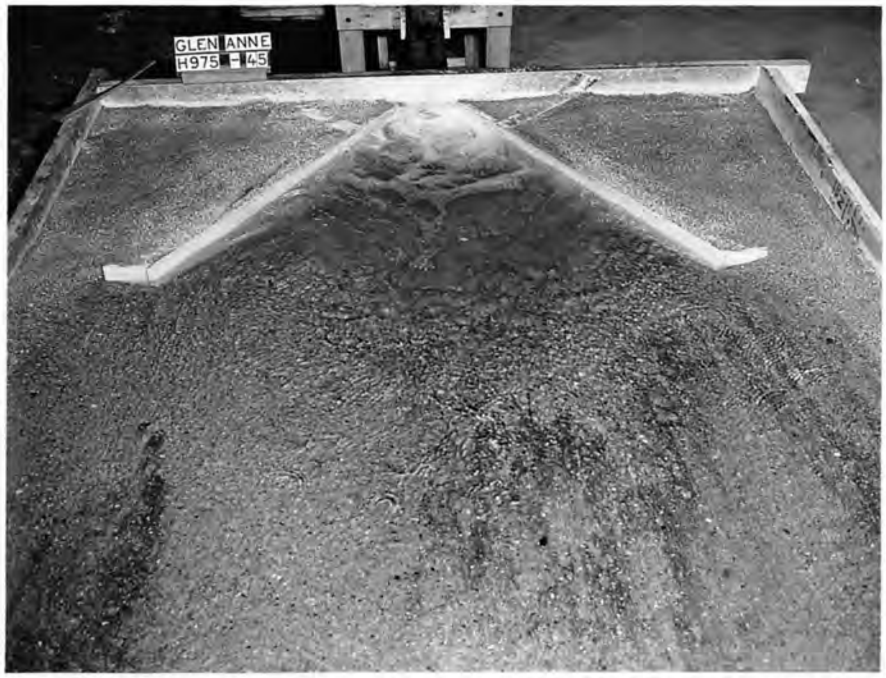
(b) Scour After 30 Minutes of Model Operation

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
PERFORMANCE OF DESIGN No. 6 - PIER G
Data from 1:16 scale model

(a) Water Leaving Stilling Basin - 910 cfs.

(b) Scour After 30 Minutes of Model Operation

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
PERFORMANCE OF DESIGN No. 6 - PIER H (RECOMMENDED)
Data from 1:16 scale model



(a) Water Leaving Stilling Basin - 400 cfs

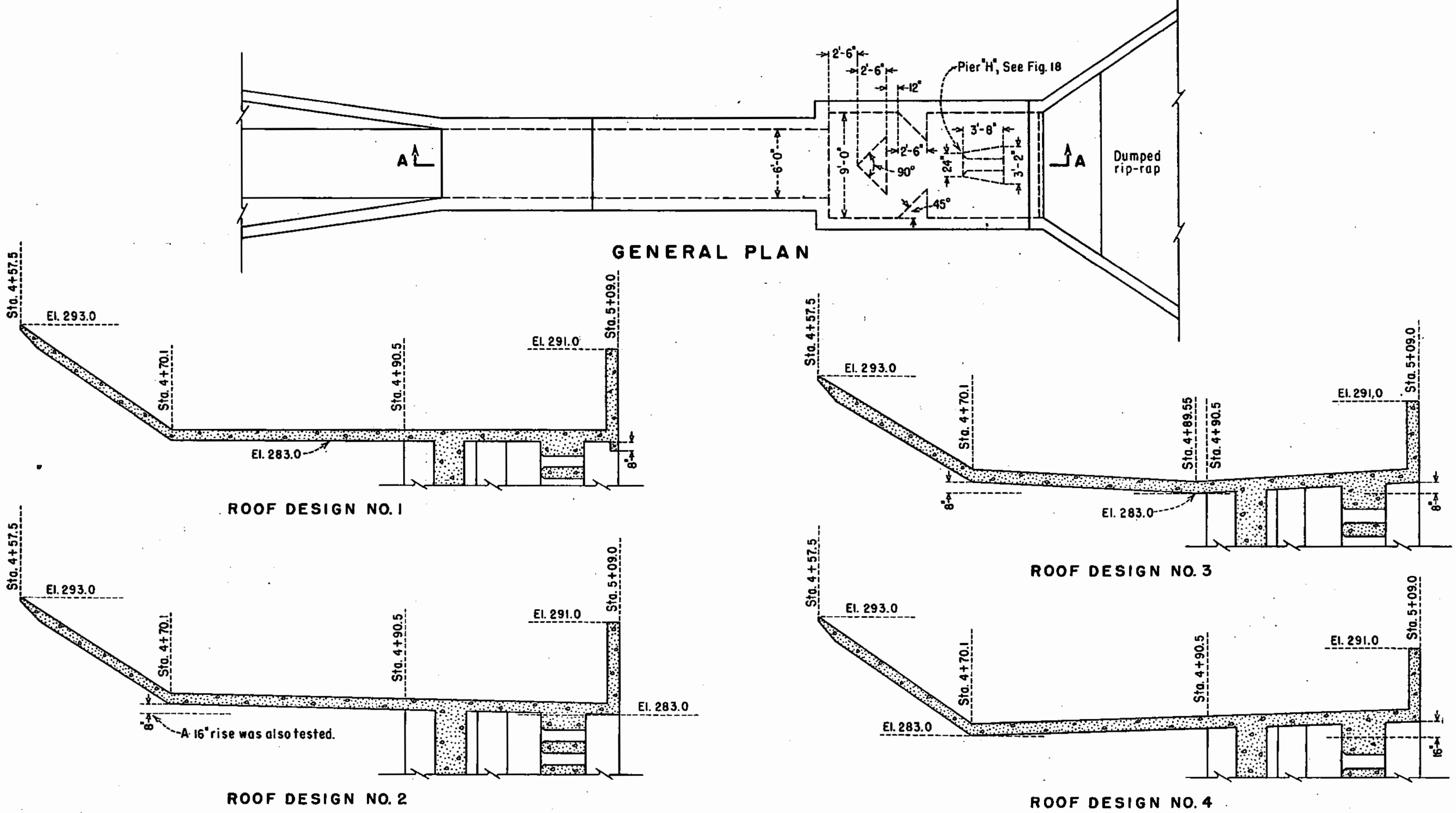
(b) Scour After 30 Minutes of Model Operation at 910 cfs

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
PERFORMANCE OF DESIGN No. 6 - PIER H (RECOMMENDED)
AND RECOMMENDED ROOF DESIGN
Data from 1:16 scale model

(a) Water Leaving Stilling Basin - 910 cfs

(b) Scour After 30 Minutes of Model Operation

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
PERFORMANCE OF RECOMMENDED DESIGN (No. 6 - PIER H)
WITH HOLES INTENTIONALLY PLUGGED
Data from 1:16 scale model



SECTION A-A

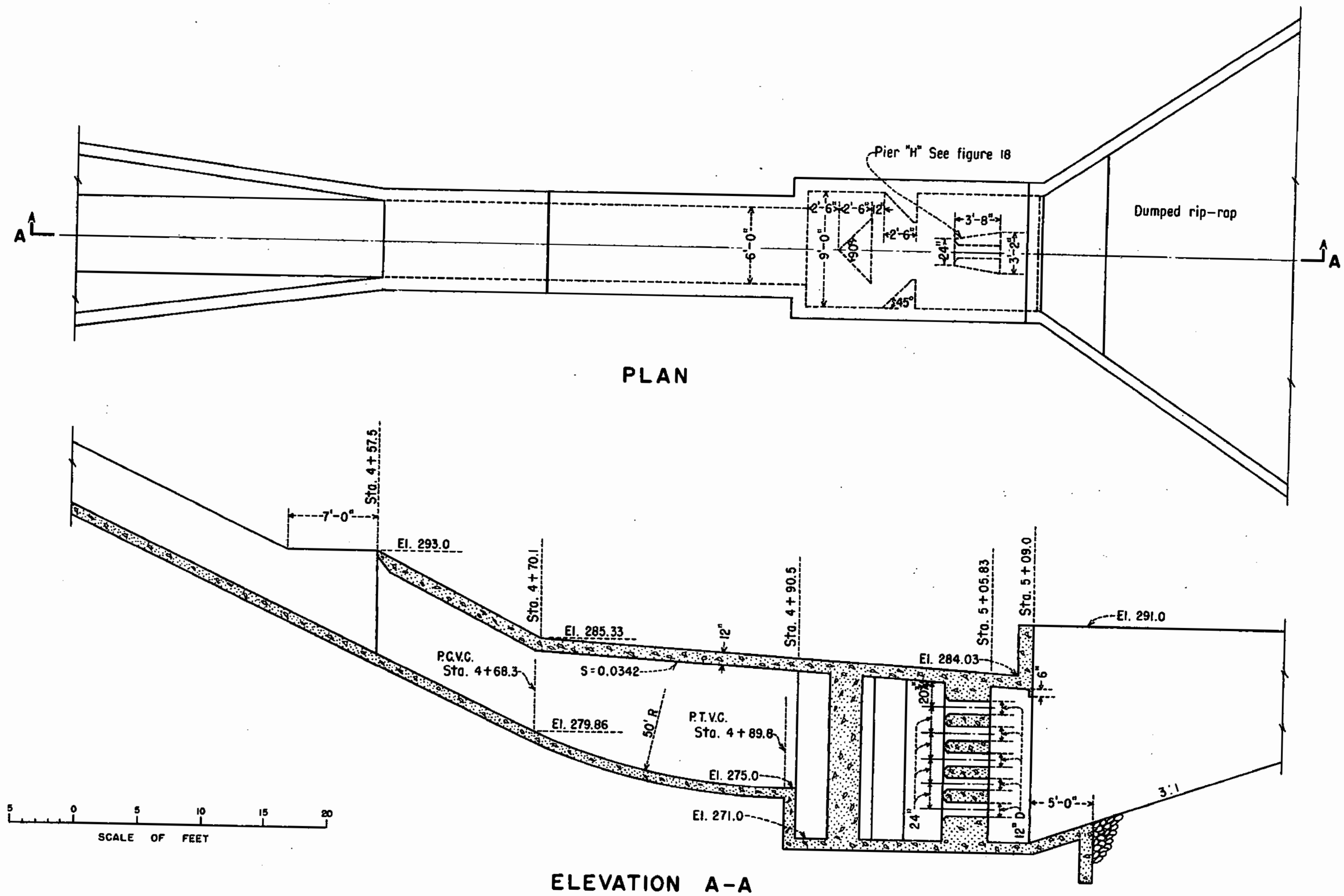
GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

ROOF DESIGNS. No. 1, 2, 3 AND 4

DATA FROM 1:16 SCALE MODEL

FIGURE 25
REPORT HYD. 360

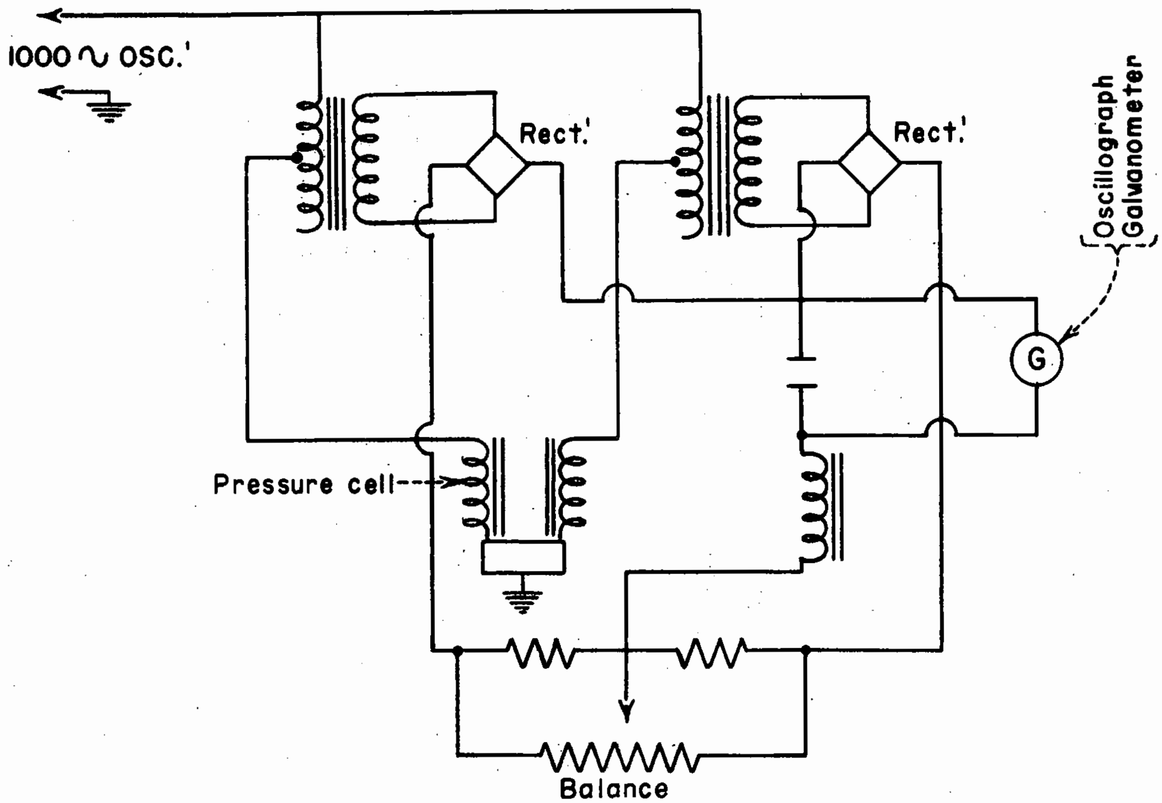
FIGURE 26
REPORT HYD. 360



GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

ROOF DESIGN No. 5 - RECOMMENDED

DATA FROM 1:16 SCALE MODEL



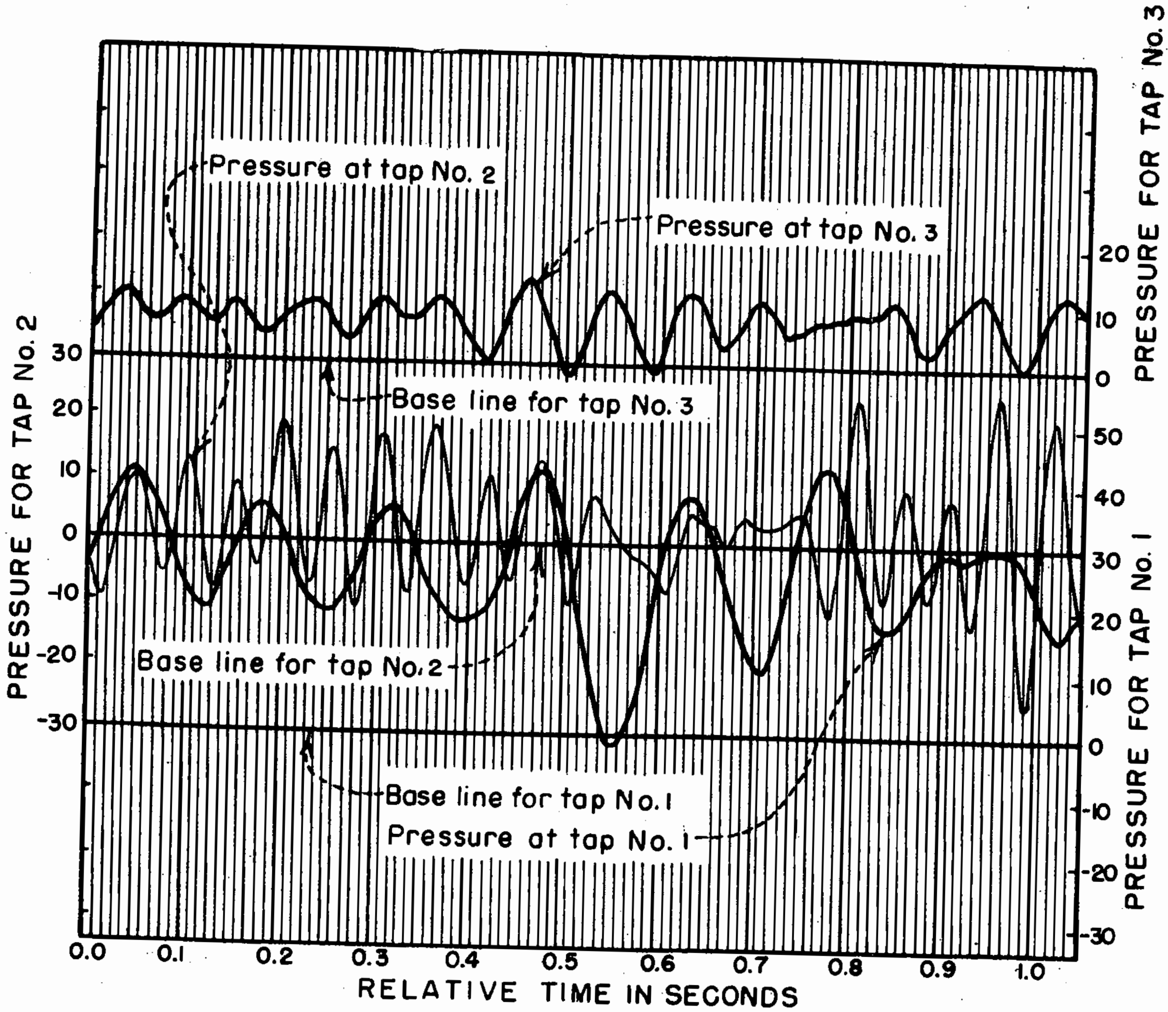
NOTES

A reluctance type pressure cell with the armature displaced by a solid enclosed diaphram was used in an impedance type bridge. The bridge circuit was supplied by a 1000 cycle oscillator. After the bridge was balanced, any unbalance, due to diaphram displacement in the pressure cell, was rectified and recorded as direct current through an oscillograph galvanometer.

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

CIRCUIT FOR PRESSURE CELLS

1:16 SCALE MODEL STUDY



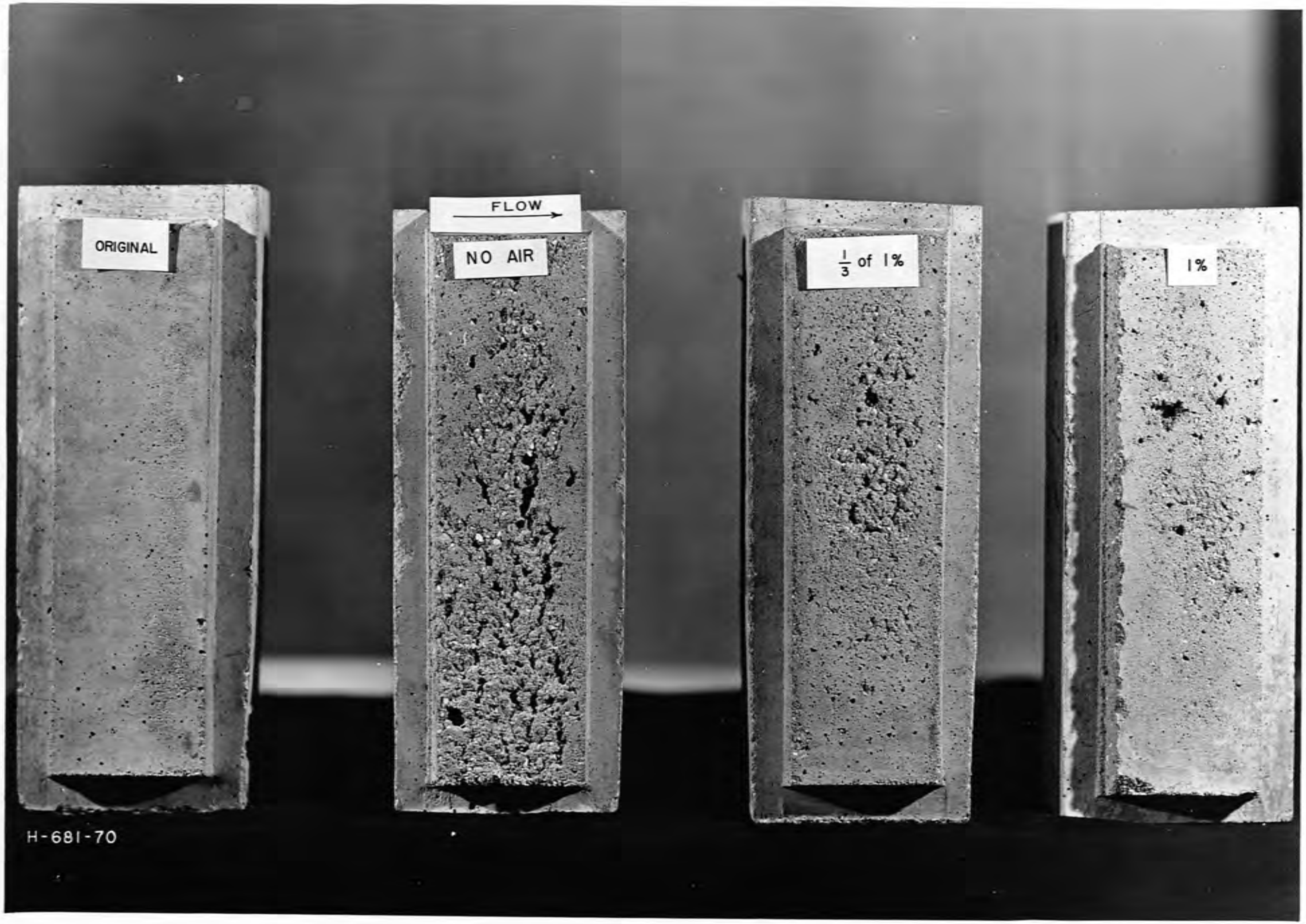
NOTES

Base lines are atmospheric pressure.
Refer to Figure 18 for pressure taps locations.
Refer to Figure 27 for pressure cell set up.
Discharge for recording was 910 c.f.s.
Pressures are in ft. of water.

GLEN ANNE DAM SPILLWAY
AND STILLING BASIN
CACHUMA PROJECT

INSTANTANEOUS PRESSURES

1:16 SCALE MODEL STUDY



GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
EFFECTS OF ENTRAINED AIR ON CAVITATION DAMAGE (0 to 1%)

GLEN ANNE DAM SPILLWAY AND STILLING BASIN
Cachuma Project
EFFECTS OF ENTRAINED AIR ON CAVITATION DAMAGE (2 to 10%)