UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE TRINITY DAM MORNING-GLORY SPILLWAY TRINITY RIVER DIVISION CENTRAL VALLEY PROJECT--CALIFORNIA

Hydraulic Laboratory Report No. Hyd-447

DIVISION OF ENGINEERING LABORATORIES

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SUMMARY

Studies of the Trinity Dam morning-glory spillway were made on a 1:30 scale model to develop the hydraulic design. The general investigation included:

1. Developing a spillway profile which exhibited acceptable pressure characteristics;

2. Shaping the surrounding topography to obtain satisfactory patterns in the approach flow;

3. Installing auxiliary structural features in the shaft below the crest to minimize tendencies toward spiral flow;

4. Developing the proper size of flow deflector in the shaft to prevent spiral flow, and providing an adequate air conduit at the underside of the deflector.

The preliminary design, Figure 4, included a spillway 53 feet in diameter, 7 guide piers on the crest, and a 90-degree segment of the crest blocked to prevent water flow and to allow free passage of air down the shaft. This design produced high negative pressures along the profile and severe spiral flow down the shaft. In the course of the studies to rectify these difficulties, 5 spillway profiles were tested in sequence, each design being derived from the one preceding it. The use of crest piers of various sizes, shapes, and positions, was thoroughly investigated as well as means to introduce air into the shaft of the structures for the prevention of high negative tunnel pressures.

Several sizes of flow deflectors were tested to determine the effect of each on the head required to pass the maximum discharge. A conduit of adequate proportions to supply air to the underside of the selected flow deflector was investigated, and rates of air intake for several spillway discharges were measured.

Three rib vanes were positioned in the shaft to reduce spiral flow, one of which was fitted with piezometers at the upper and lower ends to ascertain the magnitude of negative pressures which prevailed. The rib vane nose was proportioned by trial to reduce the subatmospheric pressures to acceptable values.

Considerable experimentation was done with shaping of the natural and artificial land features around the morning-glory to stabilize flow patterns in the spillway and in the approach. Changes in the topography were coordinated with changes in the spillway profile in an attempt to simplify or reduce the appurtenances used in the spillway.

The developed spillway profile, Figure 3, is capable of passing the maximum discharge of 24,000 cubic feet per second, with a crest head of 17 feet. The recommended diameter of the spillway, measured at the crest line, is 61.5 feet, and a single pier is used to guide flows toward the crest. A detailed description of the design is contained in the recommendations at the end of this report.

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Commissioner's Office--Denver
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INTRODUCTION

Trinity Dam located in California about 35 miles northwest of Redding, Figure 1, is a unit of much importance in the Central Valley Project. Principal features include an earthfill dam 2,400 feet long at the crest, and 450 feet high; a nongated morning-glory spillway, 60.25 feet in diameter of 24,000 cubic feet per second capacity; a powerplant to produce 96,000 kw; and an outlet works to discharge 6,000 cubic feet per second through two 84-inch hollow-jet valves. These features are shown in Figure 2.

The reservoir provides 2,500,000 acre-feet of storage at peak flood; of this amount, 2,160,000 acre-feet can be conserved, 25,000 acre-feet is dead storage, and 315,000 acre-feet is the surcharge maximum during flood. The surcharge is based on the spillway and outlet capacities being adequate to handle a peak inflow of 160,000 cubic feet per second with a 6-day volume not exceeding 489,000 acre-feet.

The morning-glory spillway located near the left abutment of the dam, Figures 2 and 3, is 54 feet in diameter at the crestline and has a single pier on the crest. The shaft below the crest is vertical for a distance of 120 feet, and the diameter decreases in that distance to 22.82 feet. The relatively long vertical drop was necessary in order to reach an adequate rock foundation for the crest structure. There are 2 vertical bends in the tunnel below the shaft; the upper one changes the flow direction 40°, the lower one 50°. The tunnel diameter is 20 feet downstream from the upper bend and throughout the remainder of the tunnel. Total drop from the crest to the invert elevation of the lower bend is 405 feet. Beyond the tunnel portal is 908 feet of concrete-lined open channel, including 70 feet at the lower end for a flip bucket. The bucket directs the water toward the natural river channel by turning the flow and lifting it into the air. This action also distributes the great amount of energy in the mass of high velocity water over a large area of the tailwater pool.

The preliminary design of the crest profile, Figure 4, was based on the results of investigations of the undernappe shape of water flowing over a sharp-crested circular weir. The recommended design procedures are reported in the Transactions of the American Society of Civil Engineers, Volume 121, 1959. 1/ Profiles obtained from these studies are correct when (1) the approaching flow is radial, and (2) the undernappe is at atmospheric pressure. For Trinity spillway, the first assumption is only partly true, and since the undernappe surface is in contact with a concrete surface, the second assumption may not be true. Therefore, the preliminary design must be regarded only as a starting point from which development tests may proceed.

To provide ideal approach flow conditions, a morning-glory spillway should be located so that the entering flow is radial at all points along the crest. For the Trinity spillway, the proximity of the adjacent hill and earth dam prohibit radial flow around 3/4 of the morning-glory periphery. For a given flow, the approach flow varies in direction, therefore, from radial to almost tangential, a condition conducive to vortex flow. These poor entrance conditions provided the principal difficulty in obtaining acceptable flow patterns over the crest and in the shaft below.

This investigation was concerned with the development of a crest profile having acceptable pressures throughout the discharge range; with reshaping the topography around and in the vicinity of the morning-glory to improve the approach flow conditions which affect the performance of the spillway; and with rectification of undesirable flow patterns in the shaft, tunnel and two tunnel bends. Discharge limitations required that the spillway pass no more than 24,000 second-feet at a crest head of 17.1 feet. Development of the structure at the outlet of the tunnel was part of a separate investigation made on another hydraulic model, and reported in Hydraulic Laboratory Report HYD-467.

THE MODEL

A model was built to a 1:30 scale to represent the morning-glory, a portion of the earthfill dam and natural topography adjacent to the spillway, an adequate area of reservoir, and the tunnel down to a point 240 feet beyond the lower of the two bends. The model layout is shown in Figure 5. Figure 6 is a general view of the model structure.

Metal lath and mortar, supported by wooden ribs, were used to construct the dam and topography in a sheet-metal lined head box. Topography

1/ "Determination of Pressure-Controlled Profiles", by William E. Wagner, Hydraulic Engineer, Bureau of Reclamation, Hydraulic Laboratory, Denver. One of 3 parts in Paper No. 2802 "Morning-glory Shaft Spillway A Symposium."

was built initially, as shown in Figure 4. A rock baffle along two sides of the head box served to minimize the turbulence in the inflowing water and to introduce water to the model reservoir in as uniform a manner as possible. The water supply pipe was divided into two branches to help equalize the distribution of flow through the baffle. The morning-glory spillway was formed in mortar and screeded to the shape of galvanized iron templates. The vertical shaft and tunnel were made of transparent plastic pipe to facilitate viewing of the flow throughout the structure.

In the preliminary crest design, 48 piezometers in 4 vertical sets of 12 each were provided to indicate the pressure distribution along the spillway surface, Figure 7. In three subsequent trial profiles, the number of piezometers was reduced to 24 in two rows; in the recommended design two rows of 13 piezometers each were installed.

Throughout the model studies, the angular positions of the piezometer rows were not changed, and in all tests, piezometers having the same numerical designation are at the same elevation.

Twenty-two piezometers were installed in the shaft between the concrete crest section and the start of the upper bend. They were used to determine the trend of pressures to be expected above the upper bend, and to obtain positive evidence that no areas of subatmospheric pressure existed. These were supplemented by 5 piezometers along the invert of the tunnel in the upper bend.

Five other piezometers were placed along the tunnel invert of the lower bend to give an indication of the pressures caused by changing the flow direction 50^{o} in the part of the tunnel where velocities reach a maximum.

Reservoir water surfaces were measured with a hook gage in a transparent plastic stilling well. The inlet of the well was located first at a point behind the mortar topography where turbulence would not influence the reading. Because of structural adjustments within the model which allowed the higher head upstream from the baffle to be reflected in the well, it became necessary to move the inlet to a point within the reservoir area as shown in Figure 5. Comparisons of reservoir levels beyond the influence of drawdown in the spillway with levels in the gage well were made for the full discharge range with an engineer's level to be sure they were in agreement.

Water was supplied from a large sump by a centrifugal pump. Discharges were measured by an 8-inch Venturi meter calibrated volumetrically and were controlled by a gate valve located 8 diameters downstream from the Venturi meter.

Changes in the morning-glory profile were anticipated from the start of these studies; therefore, provision was made for removing the concrete spillway structure without disturbing the surrounding topography or the shaft and tunnel. It was equally convenient to make alterations in the topography without removing the morning-glory crest structure. Such flexibility saved considerable labor during the course of the many structural and topographical changes that were necessary during the investigations.

THE INVESTIGATION

The Problem

The investigation was initiated to analyze the hydraulic adequacy of the preliminary design of the morning-glory spillway and to develop, in cooperation with the designers, whatever improvements might prove to be desirable. To accomplish these objectives, it was necessary to study the patterns existing in flows approaching the morning-glory, the behavior of flows on the profile in the crest region, and the characteristics of flows in the succeeding bends and tunnel below.

The extent to which studies would eventually be pursued could be determined only after the preliminary model had been operated and its performance analyzed. The principal problems which appeared to require solution after operating the preliminary design may be briefly stated as follows:

1. For discharges of 18,000 to 24,000 cfs, pressures along the profile were sufficiently subatmospheric for cavitation to occur in the prototype structure around much of the periphery of the spillway. The region of low pressures extended from the crest to about 20 feet below the crest. Thus, adjustment of the profile was required to raise the pressures to values nearer atmospheric.

2. Flow in the shaft was of a spiral type which persisted with little abatement through both bends and the horizontal tunnel. Excessive turbulence thereby resulted, and the bulked mixture of air and water impeded the flow of air along the crown of the tunnel. It was apparent that some means was required to direct the water along the invert of the shaft and tunnel and to control its course so that flow streamlines were parallel to the tunnel sides.

Although reshaping of the surrounding topography in the early stages of the investigation did not appear to offer any obvious advantages, later work with other spillway profiles proved that the topography could be altered to help stabilize the approach flows and to reduce the magnitude of the undesirable spiral flow in the tunnel. Such reshaping had only slight effect on profile pressures; therefore, this work could be carried on without seriously upsetting solutions to other parts of the problem.

The order in which the results of these studies are presented is chronological in general, and it reflects to some extent the necessity of meeting specifications issuance schedules. Some measurements, such as bend pressures, tunnel velocities, and air demand rates, were not made until the final morning-glory profile and topographic and structural modifications had been accepted, however.

During the course of the overall investigation, five different profile shapes were tested. In the material which follows, the testing of each profile will be discussed separately. Adjustment in topography will be reported in a separate section.

Throughout this report that part of the spillway which contributes flow primarily to the invert portion of the tunnel is referred to as the invert side; that part diammetrically opposite is called the crown side.

PROFILE I

Scheme 1

Description.--The preliminary design is shown in Figure 4. On the crown side of the spillway, one-quarter of the crest circumference was blocked to prevent flow of water. This was done to allow an unimpeded flow of air into the shaft. The outside diameter of the spillway was 53 feet, and the crest diameter was 50 feet.

First trial runs of the model were made with no reservoir topography in place. The morning-glory crest was about 30 feet (prototype) above the false floor beneath it, Figure 8. Seven radial piers were on the crest, two set 90° apart as partial support of the air intake wall between them, and five equally spaced on the open portion; thus, flow could enter the shaft through six openings. A line defining the tunnel bearing passed through the center point of the shaft and bisected the cutoff wall. Purposes of the cutoff wall were to allow free intake of air as a measure to prevent excessive negative pressures in the shaft and in the tunnel, and to induce the main body of water to follow the invert of the tunnel from the upper bend downward.

Profile coordinates are contained in Table 1.

Flow characteristics.--Flow at the spillway is shown in Figure 9. No water passed between Piers 1 and 7, and passage of air down the shaft was unrestricted for 5,600 and 11,200 second-feet. At 16,800 second-feet, the fin of air-water mixture, caused by the collision of all elements of flow between piers, became prominent enough to interfere with passage of air along the crown side of the shaft. Size and position of the fin were not steady, indicating that the flow between piers was not well distributed. At a discharge of 22,400 second-feet, considerable turbulence was created within the spillway, and the fin became a major element impeding the intake of air. From this discharge to the maximum of 24,000 cfs, air was taken rhythmically so that the fin, or boil, rose and fell rapidly. Directly over the crest, the water depth was fluctuating also; consequently, the reservoir water surface beyond the drawdown varied, though the frequency and amplitude of the fluctuations were lower than those well into the spillway.

Figure 9 may be used to visualize the dissymmetry of relative flow contributions between piers. Looking at Piers 6 and 7, most of the flow was concentrated on the left side of Pier 6. A similar disproportion existed between Piers 5 and 6, with more flow against Pier 5. The results of this flow pattern were twofold: (1) a high differential head acted on Pier 6, and (2) a flow conducive to spiralling down the shaft was maintained.

Flow in Bay 1-2 resembled that in Bay 6-7, with the higher head acting against Pier 1. This condition would not be as serious as the one described above since Pier 1 is supported by the wall between Piers 1 and 7, but the direction of flow down the shaft reinforces the spiral action originating on the opposite side of the crest. Flows in Bays 2-3 and 3-4 were nearly radial, and the flow in Bay 4-5, while not radial, caused little differential head on either of the adjacent piers.

For all discharges, flow characteristics in the shaft, in both bends, and in the downstream tunnel, were similar. The spiral flow and resulting turbulence mixed a large amount of air with the water, and bulking occurred. For discharges over 10,000 second-feet, spiral flow above the first bend caused enough disturbance to make some water cross over the tunnel crown. In the tunnel between bends, the main body of water swung from the one side to the other, and as it went into the lower bend, the flow crossed over the crown again. Downstream from the lower bend, the water continued to swing from side to side. Considering similar action in the prototype structure which has over 1,200 feet of straight conveyance downstream from the lower bend, it is doubtful that this motion would subside sufficiently for the flow to have a level water surface as it entered the flip bucket.

Following the trial runs made without reservoir topography, the land features in Figure 4 were installed. Flow characteristics described above were found in general to apply with the topography in place. Topography in some form was used in all tests which followed.

Head-discharge relationship.--For comparative purposes, head-discharge relationships for all preliminary spillway profiles have been plotted in groups on Figure 10, 11, and 12. Figure 13 shows the relationship for the recommended design.

Curve 1, Figure 10, shows that the variation of head with discharge for the preliminary design was almost linear for the range 5,000 to 25,000 second-feet. At 24,000 second-feet, the head was approximately 1.8 feet below that desired. No change in slope of the curve near maximum discharge was apparent, so it may be concluded that the crest was the hydraulic control feature for the full discharge range.

The coefficient of discharge was computed from $Q = CLH^{3/2}$, where L is the length of the spillway at crest elevation, and H is the difference between crest and reservoir water surface elevations. At maximum discharge C = 3.59.

All coefficients given in this report were computed for the maximum discharge at which flow free prevailed. No coefficients based on the preceding formula were computed for submerged flow.

Profile pressures.--The four rows of 12 piezometers installed in the profile are shown in Figure 7. Piezometers 1 through 12 were inoperative because the air intake wall prevented flow of water over them. Pressures are summarized in Table 2. For Data Set 1, it could be said generally that the higher negative pressures were encountered in the upper six piezometers of each row and that maximum discharge was required to produce those pressures. The highest negative pressure in each row occurred in the region of elevation 2367. A value of 15 feet of water below atmospheric was reached at Piezometer 39. Despite increasing velocity in the throat, the pressures steadily improved as seen by a rise in values as elevation 2340 was approached.

Submergence of the morning-glory was not evident visually, but the restoration of pressures to positive or near positive values at a discharge of 24,000 second-feet was taken to indicate that the boil had risen at least to elevation 2350, high enough to affect the lowest pair of piezometers in each row.

The position of the berm adjacent to the spillway with respect to the crest influences the angle at which water flows over the crest approach surface and the coefficient of discharge. If approach flow depth on the berm is not sufficient, the combination of velocity and poor approach angle are apt to produce negative pressures in the vicinity of the crest. This combination prevailed in the preliminary design with the topography in place. The pressure on the two upstream piezometers in each row, however, became excessively negative at 20,000 second-feet even without topography.

The instability of fin and water levels was directly reflected in the pressure readings. Pressures rose and fell with the water level; however, piezometers showing high negative pressures had a greater range of fluctuation. Along the arc where radial flow prevailed, fluctuations were greatest because variations in velocity seemed to be most pronounced there. Around the remainder of the crest, particularly in the region directly opposite the portion of radial flow, the average velocities were lower and the heads somewhat higher; consequently, negative pressures were not as high nor were the fluctuations as great.

Scheme 2

General operation.--To ascertain the effect of Piers 2 through 6, they were removed and the model was tested with discharges of 22,400 and 26,700 second-feet. The stability of the fin and flow patterns in the shaft and tunnel worsened somewhat because the straightening action provided by the piers was absent. As water swept around the cutoff wall toward Pier 7, a greater depression was created on the right of that pier. The decrease in effective crest length occasioned by this condition was more than offset by the increase in crest length gained through elimination of five piers.

Pressures that were low for Scheme 1 rose slightly, but they were still negative by more than 10 feet and therefore unacceptable.

Scheme 3

Description.--It was important to test the morning-glory without the auxiliary features such as crest piers and cutoff wall, because the information obtained could be compared with data from tests using various modifications. In previous tests without topography, the water had a more-or-less free access to the entire crest, though the velocities in the approach areas were probably affected by the vertical boundaries of the model head box walls. With the topography in place access from the southeast became severely restricted by the dam and hill in comparison with the relatively unobstructed approach possible from the northwest.

Flow characteristics.--Spillway flow is shown in Figure 14, the arrows indicate the direction of tunnel flow. Comparing these views with those of Figure 9, the fin had an entrance direction approximately 100^{o} counterclockwise from the tunnel line, or about 80^{o} clockwise from the original position. The shift was unfavorable to satisfactory tunnel flow because the intensity of spiral flow in the shaft became greater.

The fins differed in two important ways. First, without topography the fin was formed by the collision of opposing masses of water well down in the throat, and it lay below the elevation of the spillway crest. The latter fin was formed by flow along the face of the dam from the west intersecting that following the topography around the crest from the north; thus, it extended over the berm, the crest, and into the throat. Second, the first fin was composed of an air-water mixture, while the latter lacked any significant portion of air.

It is evident in Figure 14 that as the discharge increased, a severe vortex formed in the shaft. A further disturbance was caused by the slow swinging of the fin from side to side over a 20° arc. This shift appeared to be caused by variable intensities of flows, alternating from first the west and then around the crest from the north.

For discharges above 20,000 second-feet, the periodic bulking of water in the shaft caused by air-entrainment produced a rapid rise and fall in that portion of the fin over the shaft, through a range of 3 to 5 prototype feet. Vibration of the model structure could be felt when standing on the walkway. The cyclic rise and fall of the fin could also be heard as the shaft flow alternately accelerated and decelerated.

Photographs of the upper and lower bends companion to Figure 14 are shown in Figures 15 and 16. In views of the upper bend, the impact of high velocity flow elements on the tunnel surfaces can be identified from the mass of air-entrained water which appears downstream from the contact area. Note that the area moves clockwise up the sidewall of the tunnel from the invert as the discharge increases. Also, the area of impact shifted slightly for a given discharge.

Views of the lower bend, Figure 16, indicate that the flow swings from side to side within the bend, even for only 5,600 second-feet. For all flows over 10,000 second-feet, water crossed the crown of the tunnel in the upper bend, and for flows over 18,000 second-feet like action was visible in the lower bend. For maximum discharge water rolled over the crown continuously downstream from the lower bend.

Head-discharge relationship.--Curve 2 in Figure 10 shows a general decrease in operating heads for all discharges. For 24,000 second-feet, the head was 3.2 feet below the design head. The effect of vortex flow can be seen in the upturn of the curve which signifies a reduction in spillway capacity beginning about 23,000 second-feet. The change in slope signifies, also, that hydraulic control of the flow was shifting from the crest to the vertical shaft.

The coefficient of discharge for 23,000 second-feet was 2.69.

Profile pressures.--Complete pressure measurements are given in Data Set 2 of Table 2. Pressures on Piezometers 1 to 12 were much improved over those of the preliminary design being generally above atmospheric instead of considerably below atmospheric. Only three piezometers showed negative pressures at 10,000 second-feet, and all pressures were above atmospheric from 18,000 to 24,000 second-feet. No comparison was possible for Piezometers 13 to 24 since they were inactive in the preliminary design.

Piezometers 25 to 36 and 37 to 48 show the influence of water moving at higher velocities and somewhat lower heads than those prevailing at other piezometers rows. Maximum negative pressures were only about minus 9 feet of water, as compared to minus 15 feet of water in the preliminary design. Pressures near elevation 2350 and below were significantly positive at all piezometers for 24,000 second-feet; presumably pressures around the entire periphery from elevation 2350 and downward were positive.

Scheme 4

General operation.--Experience in previous tests on other morning-glory spillways pointed the desirability of providing some positive means for supplying air to the vertical shaft. Accordingly, as a first trial to provide a protected air intake which would not close as the discharge increased, a makeshift sheet metal conduit was placed 30° clockwise from the tunnel centerline, as shown in Figure 17A and B. An air intake 3 inches in diameter leads to a rectangular conduit 3/4 by 4 inches, which was formed to fit the spillway profile. The outlet end was about 4 inches below crest level. Four piers were placed on the crest, two adjacent to the air conduit and two others placed for best control of the crest flow.

Piezometer pressures worsened in comparison with those of the previous scheme. Higher negative values were reached in Piezometers 1 to 12 and 37 to 48, and the overall average pressure decreased at all discharges. The range of profile pressure fluctuations was reduced. The peripheral area under positive pressures at 24,000 second-feet decreased considerably.

An appreciable local drawdown occurred as the water flowed around the east side of the vertical pipe, and though no attempt had been made to shape this facility for best hydraulic operation, streamlining would be necessary in a refined design. The drawdown affected adversely the pressures on Piezometers 1 to 12, and poor flow distribution forced an excess of water against the left side of the adjacent pier, producing a high differential head on the pier. Changing the positions of the two piers opposite the air conduit did not affect the spillway operation significantly.

The use of this air intake device served to improve the stability of the boil. Flow visible from the surface was steady; however, the rate of air intake was not steady. A paper membrane covering half of the intake fluttered erratically, and even with the intake area unrestricted variation of air demand was audibly evident.

The head-discharge curve is shown as Curve 3 of Figure 10. The computed coefficient of discharge for Q = 24,000 cfs was approximately 2.9.

Scheme 5

General operation.--To give a fair trial to the air intake idea, a better proportioned sheet metal pier was provided on the crest, Figure 17C. A large sheet metal pier nose was extended over the berm to produce a more gradual transition in flow direction for water approaching the pier from the west. The pier extended from elevation 2388 to elevation 2343 and was shaped to allow unimpeded introduction of air to the shaft and tunnel. Two sheet metal guide vanes were also installed in the shaft between elevations 2350 and 2325. The guide vanes were added to help straighten the spiral flow in the remainder of the shaft and tunnel.

The degree of success which resulted was encouraging. Much of the tendency toward spiral flow was removed, and the results were sufficiently better to justify further experimentation, as explained in the following section.

With water flowing, the pier was rotated through a 40° angle each side of the tunnel line. Best performance was found at an angle 30° clockwise from the tunnel line. Without the pier nose, the head for maximum discharge was 18.8 feet; with the nose in place, the corresponding head was 15.8 feet. The difference can be explained by noting the change in location of the drawdown for flow with and without the nose in place. Without the nose the drawdown formed over the crest, and in effect the crest length available to flow was reduced. With the nose in place, drawdown occurred upstream from the crest so that more of the crest length was effective.

The pier was successful in providing a positive intake of air, but air was still drawn by the water through the unfilled center of the shaft. Until the crest submerged fully, air was always drawn into the shaft through vortices external of the pier. As the spillway throat area became filled with water, the intake of air through vortices gradually diminished to a negligible amount. Since the intake of air by vortex action varied rapidly and inconsistently, both the boil and reservoir elevations exhibited undesirable vertical instability. Likewise, fluctuating profile pressures at any discharge over 10,000 second-feet reflected the rapidly changing water surface elevations. Pressure averages are given in Table 2, Data Set 3.

Scheme 6

Description.--Since Scheme 5 showed that flow patterns in the shaft and tunnel below were much improved by the use of guide vanes, a pier with an air vent having approach nose and guide vane arrangment as an integral unit was built for evaluation. This design, Figure 18, was included in the first set of specifications issued for bid invitations. Walls of both approach nose and pier were built to scale and the guide vanes were given relative prototype thickness in contrast to the unrealistic thickness of the sheet metal vanes used in the previous scheme.

Though not called for in the first specifications design, a wedge-shaped deflector 10 feet high, between elevations 2248 and 2238, and projecting 2 feet into the flow at center, was tested with the pier and vane arrangement.

Flow characteristics.--Flow patterns at the crest are shown in Figure 19. For a discharge of 5,600 second-feet, the fin formed over the crest in such a position that in falling onto the half guide vane, the flow was divided unsymmetrically. Bearing of the fin was approximately northwest. Flow from the west around the pier nose produced some disturbance visible on the surface. At this discharge, air was free to pass into the shaft.

Flow lines for a discharge of 16,800 second-feet may be seen in Figure 19B. Intake of air was principally through the pier, some down the shaft on the side of radial flow, none through the passage adjacent to and counterclockwise from the pier, and only a small amount through the next opening between guide vanes. The air demand was nonuniform in rate and frequency cycle in all intakes. These factors combined to cause mild vibration of the model structure. Since water levels were affected by the varying air demand, the fin moved back and forth over a wider arc than before. The mass of this body of water was such that side-to-side movement eventually caused vertical motion in the reservoir water surface.

When the discharge neared 20,000 second-feet, almost all intake of air except that within the pier was cut off; however, intermittent slugs of air were taken down the shaft on the radial flow side. The fin was very large, increasing the depth and reducing the turbulence in the area of drawdown.

At 26,700 second-feet, the fin was less prominent. A vortex formed over the guide vanes. Air demand through the pier was not constant, and some vibration and accompanying noise were noticeable. The effective discharge area was reduced when guide vanes scaled to prototype thickness were used rather than sheet metal vanes. The spillway throat thus filled at a lower discharge.

The scale guide vanes performed satisfactorily in minimizing spiral flow in the shaft. However, they offered a serious restriction to the passage of debris which might reach the spillway. To assess the possibilities of plugging, timbers equivalent to 4 feet square in cross-section and 30 feet long were allowed to approach the spillway from all sides and at all discharges. The results are shown in Figure 20. An average of 7 of 10 timbers failed to pass the guide vanes into the throat. Since the timbers used did not have branches, such as fallen trees might have, it is probable that most large trees would fail to pass between the vanes.

Figures 21 and 22 illustrate the improvement in tunnel flow provided by the guide vanes. In general, it can be said that flows up to about 15,000 second-feet passed through the bends and tunnel with elements parallel to the sides of the tunnel with only a slight tendency to swing. Above this discharge, flow downstream from the bends began to oscillate across the tunnel centerline with sufficient energy to roll over the tunnel crown.

The frequency of vibrations seemed to be related through lag factors to the intake of air slugs at the spillway throat. Shortly after a momentary bulking of water by entrained air occurred, the flow crossed the tunnel crown and produced the accompanying vibrations.

A flow deflector was installed in the vertical shaft to provide a clear separation of air and water from the upper bend downward. It is shown in operation for three discharges in Figure 23. The deflector forced the flow to the outside of the bend and provided an air passage along the crown of the tunnel. It also helped to straighten the flow lines, preventing flow from spinning over the tunnel crown. In this first trial, no air was provided on the downstream side of the deflector. Even unaerated, however, the deflector gave indications that it would help perform the function desired. At discharges higher than 15,000 second-feet, the lack of air caused the void beneath the deflector to begin the fill with very turbulent water. Though the pressure reduction was not measured in the void, a 1/8-inch-diameter hole drilled in the pipe drew air into the void with a perceptible whistle.

Head-discharge relationship.--Curve 4 in Figure 10 shows the head-discharge relationship for this scheme. Capacity of the spillway increased for all heads. Above 23,000 second-feet, the slope of the curve increased as the throat began to fill and hydraulic control shifted away from the crest. The head for maximum required discharge 24,000 second-feet, was 14.6 feet or 2.5 feet below that desired.

Whether the deflector was exerting enough influence to accomplish a shift in hydraulic control from the crest to deflector is unknown, particularly since a similar increase in slope of the head-discharge curve had been observed in an earlier test without a deflector.

The coefficient of discharge computed for a discharge of 23,000 second-feet was 3.57.

Profile pressures.--The pressures measured for Scheme 6 are included under Data Set 4 of Table 2. There was some improvement in the overall pressure picture. Negative pressure areas either decreased in size or the magnitude of subatmospheric pressures decreased. Pressures on Piezometers 1 to 12 were positive for discharges over 20,000 second-feet, as were most pressures on the lowest four piezometers in each row. Lowest negative pressures of minus 11 feet occurred in Piezometers 13 to 24 for discharges of 20,000 second-feet and higher near the elevation of the crest.

Conclusions.--It was concluded that the restriction in flow area caused by the pier and guide vanes was too great for free passage of debris, and that since the structure continued to draw an appreciable amount of air down the center of the shaft independent of the pier, there was no adequate justification for providing such a pier. The structure was modified, therefore, and further tests conducted.

Scheme 7

General operation.--The pier with air vent and guide vanes were removed, and a single diametrical guide vane of 2-foot thickness was placed between elevations 2325 and 2350. The shaft deflector was not removed nor was an air supply conduit installed below it.

The guide vane was rotated in the shaft to find the position which was most conducive to satisfactory shaft and tunnel flow. In the selected position the fin which formed external of, and continued over, the crest was split by the vane at lower discharges. Figure 24 shows the appearance of reservoir flows for the full discharge range. Above 18,000 second-feet severe vortex action existed. Figure 24D shows the vortex as its most prominent stage. The operating noise level was probably the highest for any scheme tested.

At 26,700 second-feet, Figure 24E, the discharge was approaching that necessary for submergence of the spillway; consequently, the reservoir surface disturbance increased because air was being taken into the shaft in varying quantities instead of at a steady rate. The vertical position of the boil fluctuated rapidly.

Tunnel flow patterns were the best obtained up to this stage of the studies, as seen in the lower bend views, Figure 25. Occasional oscillations of the flow in the upper bend momentarily rolled water over the crown from both sides of the tunnel, but this action persisted only over the range of 21,000 to 24,000 second-feet.

Piezometer pressures are given in Data Set 5 of Table 2. A maximum negative pressure of minus 9 feet was observed on Piezometer 29 at 20,000 second-feet. Most pressures at 24,000 second-feet were positive.

The computed coefficient of discharge for 20,000 second-feet was 3.15.

The single guide vane did not restrict the passage of logs as severely as the multiple guide vane schemes. However, the presence of a severe vortex for discharges over 18,000 second-feet more than offset the advantage of the excellent tunnel flow patterns obtained at lower discharges.

Review of Test Data

The test data collected thus far in the investigations were thoroughly analyzed for any generalizations which could be derived from it. The following summary was compiled to serve as a guide in continuing the studies:

1. Placement of the morning-glory close to the hillside topography and the earth dam, which formed two sides of an enclosure, is the direct cause of unsymmetrical flow entering the spillway. Structural and topographical treatment unique to this spillway is required to obtain satisfactory flow in the spillway and tunnel. Lessons learned in the study may be applicable only in a general way to future designs.

2. The angle between the tunnel line and the general direction of approaching flows helps to produce spiral tunnel flow.

3. Piers on the crest do not exert sufficient straightening influence to prevent the spiralling of flow in the shaft. Also, when placed to accomplish an adjustment to radial direction of flow, there is an appreciable difference in the depth of flow on opposite sides of any pier, resulting in a high overturning force.

4. Blocking a portion of the crest length does not provide in itself the positive access of air necessary in the shaft.

5. Substitution of a vent for an air-intake wall allows a more positive intake of air, but since much of the air demand is satisfied through vortices external of the pier, the use of the pier does not seem justifiable. Because of the angle between the radial axis of the pier and the approaching flow, the flow accelerates as it passes around the pier causing a drawdown which extends over the crest. Special treatment of the pier design would be necessary to minimize this effect which results in a reduction of effective spillway crest length.

6. The berm adjacent to the spillway should be lowered as a measure to improve the crest coefficient of discharge. With a greater approach depth the angle at which flows rising from the berm pass over the spillway crest surface may produce more favorable pressures.

7. Adjustment of the spillway profile curve is required to reduce the negative pressures encountered. Some increase in the spillway crest length may be necessary to permit this adjustment.

8. A flow deflector in the vertical shaft seems to offer these desirable characteristics:

a. Flow on the crown side of the shaft would be directed toward the invert side.

b. Proper sizing of the deflector could result in a shift of hydraulic control from the crest to the deflector, thereby providing positive means to adjust the reservoir elevation for maximum discharge.

c. Should an air conduit on the underside of the deflector prove necessary to prevent subatmospheric pressures in that region, the introduction of large quantities of air should aid in keeping the tunnel from filling, thereby maintaining open-channel flow.

9. Some as yet undetermined structural features within the spillway shaft are required to give axial direction to the flow, thereby reducing or eliminating spiral flow.

Topographical Modifications

Description.--The purposes of this report will be served best if departure from the chronological reporting is followed here and in the succeeding section. By visual means it became clear as the tests progressed that the relative positions of berm, dam, and natural topography were important in determining the balance of flow around the morning-glory, the formation and stability of the fin, and the operating head necessary to produce a particular discharge. Changes in the topography alone did not cause sufficient improvement in flow patterns, but in combination with auxiliary structural devices, such modifications proved to be worth evaluating. Figure 26 shows the modifications evaluated.

In the original design, Figure 4, the berm surrounding the morning-glory was at elevation 2364, 5 feet below the spillway crest. Minimum width was 20 feet on the east, southeast, and south and the maximum width was 25 feet on the northwest. Since the operating head for maximum discharge is 17.1 feet, and the total depth of flow over the berm is 23.1 feet, the depth from berm to crest amounts to 26 percent of the total.

By use of a dye stream, the approach paths of the water at various depths were made visible and rough comparisons of velocities could be made. The dye streams showed that water entered the area southeast of the spillway with high velocity from two directions, along the dam face from the east and along the natural topography from the north. The two components were vectorially opposed as well as tangential to the circular spillway. When the flows came together the flow direction changed from tangential to radial and the conversion of velocity head to pressure head was responsible for creating the prominent fin seen at most discharges. It was reasoned that if the depth of water in this region were increased, a reduction in tangential velocities might be realized and the magnitude of the fin reduced. The first topographical modification, Figure 26A, then consisted in part of lowering the berm to elevation 2358 while maintaining a minimum berm width of 10 feet. The depth from berm to crest was then 41 percent of the total water depth.

The effort was moderately successful in reducing the height of the fin. Tangential velocities were lowered, and the position of the fin rotated about 10° counterclockwise, or away from the tunnel line, a shift considered unfavorable since vortex formation was further encouraged. Vortex action at 20,000 second-feet was indeed more severe, and both the boil and reservoir elevations became less stable. Tunnel flow patterns were again erratic, and pressures near the crest in the region of radial flow dropped to about minus 12.5 feet of water. The coefficient of discharge at 26,700 second-feet was 2.84.

Rotation of the fin provided evidence that the quantity of water approaching along the dam from the east had increased whereas the quantity flowing around the spillway from the north had decreased. Consequently, it was reasoned that to restore the original fin position, or to move the fin closer to the tunnel line, it would be necessary to increase flow from the north. Since moving the spillway to the west was impracticable, the only recourse was to reshape the natural topography to produce a greater access area for flow north and east of the structure. In studying how much excavation was necessary, it was decided to excavate a 2:1 slope, the bearing of the slope contours to be true north-south, Figure 26A, from the dam to a point approximately 200 feet north of the structure. Such extensive excavation would not be practical for the prototype, but using it in the model would indicate the maximum benefit that could be derived from topographic modification.

Ideally, if a fin must be tolerated at all its axis should be on the tunnel centerline and it should discharge into the shaft on the invert side. The mass of water would then enter the tunnel in the most favorable manner since the flow would not require turning or straightening into the correct path. However, the location of this morning-glory makes attainment of the ideal impossible and a compromise must be accepted.

When the topography was changed as described in Figure 26A, the fin moved clockwise about 25° toward the tunnel centerline to a position approximately 70° counterclockwise from the tunnel line. In the new location the fin was compact, and it was more stable in size and position, though a slow angular swing of some 10° existed. Pressures near the crest were still about 13 feet of water below atmospheric, demonstrating once again that the shape of the spillway profile had greater influence on pressures than the topographical shapes external of the structure.

In Figures 26B and 26C are shown intermediate steps in topographic reshaping, and Figure 26D shows the final configuration used in the remaining tests. As might be expected, the fin rotated somewhat counterclockwise as the excavation was filled in toward the original topographic arrangement.

When it appeared that further restoration of topography would hinder the free passage of water from the north and upset the balance of contributing tangential flows at the fin, attention was focused on flow patterns in the draw formed by the intersection of natural topography with the upstream slope of the dam. It was suspected that the interaction of flows from the north and west was responsible in part for the instability in fin position. Exploration with dye streams at various depths along the draw showed that no consistent flow pattern prevailed; rather the region exhibited rapidly accelerating and decelerating flow elements acting in several directions at almost the same moment. Since the direction, as well as the amount of lateral swing of the fin was strongly influenced by such action, the fin swung through an arc of 15°.

To help alleviate the fin instability, the draw was filled and a minimum berm width of 6 feet maintained, Figure 26D. The curved transition between hillside and dam eliminated the troublesome region and brought about smooth changes in velocity where the fin formed. Though the fin still tended to swing, its movement occurred over a longer period in a much more passive manner. Checking subsurface flow characteristics again with the dye probe showed that the turbulence had subsided and smooth flow existed.

Concurrent with studies involving the topography, four different profile designs were constructed and tested. They will be discussed in succeeding sections of this report.

Auxiliary Structural Features

In the course of these investigations, certain structural additions were suggested from time to time as being desirable in securing better flow conditions in the shaft and tunnel section. Since their development was carried on independently of topographical and profile changes, each will be reported separately.

Rib Vanes.--Numerous preceding references have been made to vortex formation and spiral-type shaft flow. Attempts to eliminate such flows with topographical modifications and structural shapes on or near the crest were not successful to the degree required. Most structural shapes installed on the crest produced flow disturbances as undesirable as those from which relief was sought. Therefore, it was decided to try regaining control of the flow downstream from the crest in the vertical shaft.

To do this a single rib vane 2 feet thick, and projecting radially 4 feet into the flow, Figure 27A, extending from elevation 2250 to elevation 2330, was installed at a selected position on the shaft wall, approximately 100° counterclockwise from the tunnel line. The influence of this rib vane was noted for several discharges, and the position of the rib was varied in further trials. The results lead to the conclusions that such a vane could be effective in straightening flow but that more than one would be needed for maximum benefit.

Several single vanes of different radial height were tried. A practical height was sought since too great a projection would restrict the passage of debris in the shaft and a low height would not have adequate flow straightening influence. The 4-foot size seemed a reasonable compromise to satisfy these conflicting criteria.

Another vane was installed directly above the flow deflector on the tunnel line. It extended from elevation 2330 to an elevation just above the deflector. This vane was moved successively to three positions away from the tunnel line to ascertain the effect on flow patterns above and on the deflector, but no advantage in so placing it could be observed, and it was returned to the original position. As the size of the deflector was changed, the length of rib vane was adjusted. In the final design, the rib vane intersected the sloping surface of the deflector.

A third vane rib to supplement the two discussed above was installed between elevations 2250 and 2330. In the many following trials, the first and third rib vanes were individually moved around the shaft circumference in a search for the best combination of positions for all three. After tentative locations had been determined, the first and third rib vanes were moved individually to determine the sensitivity of the flow patterns to their respective positions. Fortunately, an angular range of $\pm 5^{\circ}$ could be permitted for each without significantly impairing their combined effects. This range is great enough to establish confidence that the positions indicated by the model studies can be relied upon for satisfactory operation in the prototype.

In the final positions, the vanes effectively reduce spiral flow in the shaft. For flows at depths up to the radial height nearly all elements are redirected to vertical paths. For depths greater than the radial height the influence of the vanes is still of sufficient magnitude to prevent the development of detrimental spiral action, so that the direction of flow at the downstream end of the shaft is essentially parallel to the vertical axis.

Water flowing down the shaft struck the upper ends of the vanes at a small acute angle with respect to the vertical axis of the vane. Some water was deflected downward along the vane, and some was deflected upward and over the rib; thus positive pressures may be expected in the area of impact, and negative pressures may be produced on the opposite side.

To eliminate objectionable negative pressures, the shapes of the upper ends of the rib vanes were determined from extensive hydraulic tests. Six of the many shapes investigated are shown in Figure 27, along with the piezometers employed to measure pressures, piezometer locations, and the numbering system for each rib vane. The recommended shape approximates that in Figure 27F. Results of all pressure measurements are summarized in Table 3.

The recommended location of the rib vanes is shown in Figure 28. The recommended design for the rib vane top is also shown in Figures 28 and 29.

Flow deflector.--In the "Review of Test Data" section, the desirability of a flow deflector was briefly discussed. Concurrent with modifications of the profile, tests were made on eight flow deflectors to evaluate their performance. For all sizes tested, from 2 by 10 feet to 7.15 by 24 feet (the first dimension is the radial projection and the second is the vertical height) the deflector had a beneficial effect in diverting water from the crown side of the shaft to the invert of the tunnel as the flow passed through the upper bend. The direction imparted to the flow leaving the deflector was, in general, parallel to the tunnel centerline.

Another important benefit of the deflector was the control it could exercise on the reservoir water surface elevation near maximum discharge. By increasing the radial projection, it was possible to shift the hydraulic control from the crest to the deflector. Thus, the type of flow was either weir flow when control was at the crest, or orifice flow when the deflector was the control. As the projection was increased for discharges over 21,000 cfs, the operating level of the reservoir rose, and by incremental adjustment, the recommended size for the design crest head could be determined. Sizes tested were as follows: 2 by 10, 4.25 by 18, 5 by 18, 6.25 by 24, 6.56 by 25, 5.97 by 25, 7.10 by 24, and 7.15 by 24.

The head-discharge curves, Figure 12, reflect the effect of the deflector. In all cases, the shift of hydraulic control from crest to deflector is evident as a change in slope of the curves. The reservoir level is very sensitive to deflector size because of the relationship between area of flow, A, and head, H, in $Q = CA\sqrt{2gH}$. For example, it was found by test that for a projection of 6.97 feet the design reservoir level was reached, but for a projection of 7.10 feet the design level was exceeded by many feet.

It was observed that spray was formed in the region immediately under the deflector. A small hole drilled through the shaft wall directly below the deflector allowed air to pass into the shaft with such velocity that a perceptible whistle was audible. A conduit was therefore provided to supply the air demand. The size was progressively increased from 2 by 4 feet to 2 by 10 feet. Piezometers on the underside of the deflector indicated that atmospheric pressures existed when the conduit was 2 by 8 feet, but an arbitrary increase to 2 by 10 feet was made to insure adequate capacity because of uncertainties in model-prototype relationships where air is used for ventilation purposes.

A single piezometer was installed in the center of the sloping face of the deflector to measure the impact pressure at maximum discharge. The pressure indicated on a deflector 6.97 by 10 feet was equivalent to about 70 feet of water. To reduce the face pressure, the deflector height was increased in successive steps to 25 feet, leaving unchanged the bottom elevation. The deflector 6.97 feet by 25 feet was fitted with piezometers on the sloping face and underside, as shown in Figure 30. Table 4 gives the pressures measured for 4 discharges on the recommended deflector. Piezometer 50, for 24,000 second-feet, showed a pressure of 54 feet of water. The impact pressure was therefore reduced by 16 feet of water when the deflector height was increased from 10 to 25 feet.

The deflector and air supply conduit shown in Figure 30 were recommended for prototype use. Later, in the specifications design, the flow deflector was increased in size from 6.97 by 25 feet to 7.10 by 25 feet. When model head-discharge relationships were applied to the design flood hydrograph, the air supply conduit was made 4.5 feet square when practical dimensions were determined.

The air demand of the recommended deflector 6.97 by 25 feet was measured so that comparisons could be made with future prototype measurements. A circular sharp-edged orifice was used to determine the quantity of air required for 7 spillway discharge rates. The coefficient of discharge of the orifice was assumed to be 0.60. Table 5 gives the air quantities in the model. Figure 31 was plotted from Table 5 to show the variation of air demand with spillway discharge. The maximum prototype demand of 78 second-feet is reached at 21,000 second-feet. At 24,000 second-feet, with the spillway submerged, the air demand shows a marked decrease to 60 second-feet. The general shape of the curve conforms well to a similar curve based on air demand measurements made at Shadehill Dam, shown in Figure 52 of Engineering Monograph No. 16.

The water discharge for which air demand is a maximum does not correspond to that which indicates an impending shift of hydraulic control from crest to deflector, Figure 13. From visual observation of flows above 21,000 second-feet, it did not appear that there was an increase in the intake of air through the water down the shaft to compensate for the decrease measured in the air conduit; to the contrary, this quantity seemed to decrease as the crest began to submerge. One plausible explanation is that a shift in control had begun near 21,000 second-feet, but the height of the boil in the shaft was not sufficient to affect the crest head until the discharge was 23,000 second-feet. Between 21,000 and 23,000 second-feet, there could be two controls; (1) the crest, and (2) an orifice in a horizontal plane of unstable elevation. Both controls adjust to discharge the same quantity of water at the same time. The point of reversal in the curve of Figure 31, therefore, may be an accurate indicator of the beginning of a shift in hydraulic control, to the spillway throat.

Spillway pier.--In the discussion of topographical modifications, page 19, the tendency of the water fin on the spillway crest to swing from side to side was mentioned. Finalized topography did not eliminate the movement, though the strength and range were much reduced. As a final step in stabilizing the fin position, a pier 30 feet high, 40 feet long, and 3 feet thick was located at the mean position of the fin, or 278° clockwise from the tunnel line, Figures 26D and 32. The pier nose extended 2 feet downstream from the crestline, with the remaining 38 feet extending radially to intersect the excavated slope in the topography. Above 5,000 second-feet, the reservoir level was high enough to allow a small amount of water to flow around the upstream end of the pier. No ill effects were observed from such flow even at maximum reservoir elevations; thus, it was not necessary for the pier top to extend into the topography. Considerable concrete can be saved by so limiting the pier length, and from the safety standpoint unauthorized persons will not have easy access to the pier top for use as an observation point.

For a period of a few seconds, small differential heads may act against the pier as the water level on each side fluctuates. Based on observations of the model, this head is expected to be less than 1 foot, unless high winds in the prototype increase the differential.

Interim Considerations

Despite all efforts toward reduction of negative profile pressures, by topographic reshaping, use of piers or flow directing walls, varying the distance from berm to crest, and the use of air intake devices, spillway profile pressures remained unsatisfactory. It was apparent that adjustments in the spillway profile itself would be required to provide satisfactory pressures.

In considering methods to be used in adjusting the preliminary profile conflicting courses of action were indicated by the information at hand. First, the diameter of the original morning-glory crest became larger than was believed necessary after the blocked part of the crest was opened. A revised crest with the full circumference used to discharge water should be of smaller diameter according to theory. On the other hand, negative pressures occurred because of the steep profile, and to relieve them the diameter should be increased. In the first case, decreasing the diameter could cause the operating head to increase above that desired; for the second case, the operating head would probably decrease below the design value. The courses of action chosen are discussed in the following paragraphs.

PROFILE II

Scheme 8

Description. --The original spillway diameter and the profile from spring point to crest were retained, but the profile downstream from the crest was revised, Figure 33. Auxiliary features used with Profile II include a deflector 5 by 18 feet, and three rib vanes in the final described positions. The deflector was aerated by a conduit 2 by 7 feet in cross-section. Profile I pressures had indicated that the region of high negative pressures was just downstream from the crest and that there was general improvement toward atmospheric values as the flow passed downstream and approached the upper bend. Therefore, the rate of change in slope downstream from the crest was decreased for the first 10 feet of drop, to elevation 2360, and increased from that point to elevation 2340 so as to use the same shaft diameter from the latter elevation downward. If the changes were of sufficient magnitude, negative pressures between elevations 2370 and 2360 or below could be expected to rise toward atmospheric while pressures near elevation 2340 would be expected to drop below atmospheric. Such changes would be considered as overall improvement.

The coordinates for all spillway profiles tested are contained in Table 1. To facilitate comparisons of them two plots were prepared: (1) profiles plotted from a common crest point without regard to crest diameter, Figure 33, and (2) profiles plotted in proper vertical and horizontal positions, Figure 34.

Though the adjustment from Profile I to Profile II appears minor in retrospect, it was necessarily a conservative step to learn how sensitive pressures were to profile slopes.

Flow characteristics.--No significant changes in reservoir surface flow patterns could be observed. The adjustment of the profile was not of sufficient magnitude to produce any noticeable effects.

Head-discharge relationship.--Curve 1 of Figure 11 shows the variation of crest head with discharge for Profile II. Less head was required to pass a given discharge with Profile II than with any scheme using Profile I. The upturn in the rating curve for Profile II showed that the deflector began to decrease the discharge and raise the head on the crest at a point near 24,000 second-feet, but the head at this discharge was over 4 feet lower than desired. The increase in deflector size from 2 by 10 feet to 5 by 18 feet was therefore inadequate to produce the design reservoir head.

The computed coefficient of discharge at 22,400 second-feet was 3.42.

Profile pressures.--Since the tests on Profile I served to identify the regions in which the more serious pressure problems would exist it was not necessary to construct Piezometers 1-12 and 13-24 in the succeeding profiles.

Data Set 9 of Table 2 gives the results of pressure measurements on Profile II. Compared with those in Data Set 6, little improvement was evident with Profile II. Along the portion of Profile II which was flatter than Profile I, there was a noticeable rise toward atmospheric pressure, but overall improvement was not significant.

PROFILE III

Scheme 9

Description.--Analysis of test results on Profile II gave rise to two conclusions which were applied in defining a new profile. First, the negative pressures on the short curve upstream of the crest, the approach curve, could be interpreted as indicating that flows rising from the berm passed the spillway spring point at an angle much steeper than the angle of a tangent drawn to the spillway surface at the point. It was believed that a milder curve downstream from the spring point would improve the pressures in this region. The first step in modifying Profile II, therefore, was to lengthen the approach curve, Figures 33 and 34.

Second, since changes made in the profile downstream from the crest for Profile II were demonstrated to be too mild to attain the pressures desired, the slope of the profile used for the first 8 feet of drop Profile III was much milder. Using the same spillway crest diameter, however, it was necessary to increase the slope of the profile between the elevations 2362 and 2340 so that the same shaft diameter could be used.

The spillway crest diameter of 50 feet was maintained, but the outside diameter was increased from 53 to 57.5 feet. This caused a small encroachment on the berm width, but the effect was not noticeable in operation. Coordinates for the profile are contained in Table 1.

The rib vanes and deflector were the same as used in tests on Profile II.

Flow characteristics. --No measurable departure from earlier flow patterns was observed.

Head-discharge relationship. --Curve 2 of Figure 11 shows that more head was required to pass a given discharge than was required with Profile II. Curves 1 and 2 are separated by about 0.5 foot. Though the crest diameter was not changed, flattening the profile in the crest region apparently made the spillway less efficient and produced a rise in operating head. Curve 2 also shows a gradual shift in hydraulic control from crest to the deflector. At 24,000 second-feet, the crest head was 13.5 feet, still about 3.5 feet short of the design head.

The computed coefficient of discharge based on a discharge of 22,400 second-feet was 2.87.

Profile pressures. --Data Set 10 of Table 2 is a summary of pressures measured on Profile III. Because the crest approach curve was lengthened an additional piezometer was installed in each row to better define the pressure variations upstream of the crest. The piezometers are identified as C and D, located as shown in Figure 33.

Increasing the approach curve length had the desired effect of raising pressures on that portion of the spillway. All pressures in the region were positive. The area of maximum negative pressures had moved down the spillway profile, due primarily to the increased profile slope below elevation 2362. This condition was anticipated, and no concern over its existence was felt since the steep slope of the model could be modified for the prototype design.

The overall performance for this profile was better than for the previous profiles.

PROFILE IV

Scheme 10

Description. --Profile IV is shown in Figures 33 and 34. The crest approach curve was the same as that for Profile III. The portion of the profile downstream of the crest was drastically modified in a deliberate effort to provide a limit so that an acceptable profile could be interpolated between Profiles III and IV.

To preserve the original diameter of the shaft at elevation 2340, it was necessary to greatly increase the rate of curvature of the profile near elevation 2364 and to approach elevation 2340 with a slope nearly vertical. It was expected that pressures along the profile above elevation 2365 would rise above those measured on Profile III, and that pressures below elevation 2364 would become increasingly negative. Coordinates for the profile are contained in Table 1.

The deflector size was 5 by 18 feet and was aerated with a 2- by 7-foot rectangular orifice. The rib vane locations were the same as tested with Profile II. Elevation of the berm was 2358.

Flow characteristics.--For flows up to about 15,000 second-feet, the appearance was much like that of the previous two profiles. For higher discharges, however, there was noticeable separation of the water from the spillway boundary in the vicinity of elevation 2364. The smooth upper surface was destroyed by rapid pressure fluctuations acting at the elevation of separation on the undernappe surface. Turbulence thus created gave the impression that the boil had reached elevation 2364 at a discharge lower than in previous profiles, whereas actually a boil had not formed anywhere in the shaft as yet.

A vortex with a diameter about half that of the spillway crest formed when the morning-glory submerged. The vortex decreased some in size for greater submergence, but it was still objectionable. Oscillations in the reservoir occurred, and vibration of the structure resulted from variations in the quantity of air drawn down the shaft.

Head-discharge relationship.--The head-discharge curve obtained for Profile IV, Curve 3 of Figure 11, was not appreciably different in shape from that derived from tests of Profile III; however, approximately 1-3/4 feet of additional head was required for all discharges. The characteristic upturn of the curve again occurred at 23,000 second-feet. This fact supported the contention that no boil existed at 15,000 second-feet. The operating head was about 1.2 feet below the design value.

Curve 3 gives a clear picture of the magnitude of the adjustment in profiles, and it serves to emphasize, and confirm the belief, that the departure from Profile III to Profile IV was too severe.

The computed coefficient of discharge for 22,400 second-feet was 2.24. (Coefficients for Profiles I (Scheme 1), II, and III, were 3.59, 3.42, and 2.87. respectively).

Profile pressures.--The pressures measured on Profile IV are summarized in Data Set 11 of Table 2. The effect on profile pressures for all discharges was readily apparent. Positive pressures on the crest approach curve were higher in general than similar pressures on Profile III. At 24,000 second-feet, a backwater influence from the relatively flat curve downstream of the crest raised pressures on the approach curve above those values obtained with Profile III.

Unsatisfactory negative pressures occurred as high as elevation 2367, and shaft pressures in general were lower than any measured previously.

PROFILE V

Scheme 11

Description.--The shape of the Profile V spillway relative to the other profiles is shown in Figure 33. The crest approach curve is identical to that used for Profiles III and IV. Downstream of the crest, however, the new profile lies between Profiles III and IV down to elevation 2361; below this elevation, the rate of change of slope increases to elevation 2340. The use of Profile V would result in a tunnel of reduced diameter at the same elevation; therefore, in order to retain the original tunnel diameter, it was necessary to increase both the crest and outside diameters by 4 feet. Profile V in its true position is shown in Figure 34. The slope of the profile curve is milder at all elevations than the slopes of Profiles I, II, and III. Below elevation 2366, the slope is less severe than that of Profile IV.

Because the morning-glory diameter had been increased, the spillway encroached on the original berm sufficiently to reduce the berm width to zero on the east and to negligible width in the southeast quadrant along the face of the dam. Elevation of the berm was 2358. The draw created by the intersection of natural topography with the dam had not been modified as described in an earlier section of this report. The morning-glory and adjacent topography are shown in Figure 35A. The deflector size and the rib vane locations remained unchanged from the setup with Profile II. Coordinates for the profile are contained in Table 1.

Flow characteristics.--Flow patterns at four discharges are shown in Figure 36. The fin position in Figure 36A for a discharge of 15,000 second-feet reflected the influence of greater contributions of flow from the west along the dam. As the discharge approached 20,000 second-feet, the fin shifted slightly clockwise. Finally at 22,500 second-feet, just before submergence of the spillway, the fin reached the position shown in Figure 36C. For this discharge, the elevation of the boil was fluctuating rapidly, and the reservoir water surface eventually oscillated rhythmically in response to this action. Below 22,500 second-feet, the fin position was unstable because the distribution of flow around the spillway varied over short periods.

For a discharge of 24,000 second-feet, Figure 36D, a large vortex formed over the shaft. The vortex shown is for maximum water surface level, but it was even larger in diameter at lower reservoir levels. A periodic rise and fall of the reservoir surface accompanied the variation in vortex size and considerable vibration of the model structure could be felt.

Head-discharge relationship.--Curve 4 of Figure 11 shows the variation of crest head with discharge. In comparison with Curve 3 for Profile IV, less head was required to pass a given discharge, and the discharge curve was not appreciably different than the one for Profile III.

The computed coefficient of discharge at 22,400 second-feet was 2.91, a substantial improvement over the coefficient for Profile IV, 2.24, and just slightly higher than that for Profile III, 2.87. The operating head at design discharge was about 3.5 feet, below the desired head.

Profile pressures.--Pressure measurements are summarized for this test setup in Data Set 12 of Table 2. In contrast to the pressures obtained with Profile IV, the pressure patterns with Profile V were considered quite satisfactory. The lowest negative pressure was -6 feet at elevation 2363, and pressures above and below this elevation were higher than atmospheric at the crest and elevation 2340, respectively.

Comparing pressures in Data Sets 10 and 12, those for Profile V showed further improvement. It had been determined from discussions with the designers that a profile exhibiting negative pressures no lower than -6 feet would be acceptable; Profile V was tentatively suggested for the final design.

In the transition range of discharges between unsubmerged and submerged conditions, all piezometric pressures fluctuated somewhat. Outside of this range, however, all pressures were reasonably constant as indicated by the steadiness of the liquid levels of the manometer tubes. In earlier tests of the other profiles, and particularly in the case of Profile I, there was considerable fluctuation in liquid levels throughout the discharge range.

Scheme 12

Description.--The flow characteristics of Scheme 11 formed the basis for reshaping the topography around the spillway. Natural topography to the east and northeast of the structure was modified as shown in Figures 26D and 35C. The draw to the southeast was filled in to provide a gradual transition in slope from that of the dam on the south to the slope of the reshaped topography on the east. The berm was widened on the east and south to provide a minimum width of 6 feet at elevation 2358.

Tests were run with and without a spillway pier described under the section, "Auxiliary Structural Features." In successive steps, the size of the shaft deflector was increased to 6.97 by 25 feet. The demand for air beneath the deflector was satisfied by enlarging the air vent to 2 by 10 feet in cross-section.

Coordinates for the profile and locations of the rib vanes were unchanged from Scheme 11.

Observations were made with a spillway pier in place and also without it, as follows:

Flow characteristics without spillway pier.--The existence of the draw at the intersection of the natural topography with the dam was detrimental to uniform flow into the spillway. The direction of flow at any point in the draw was variable with no consistent pattern observable. To reach the draw, water flowed through restricted passages between the crest structure and the dam or the natural topography. Having reached the draw, water velocities decreased and consequently the depth increased measurably. Earlier attempts had been made to reshape or fill the draw, but until complete topographic modification had been accomplished little improvement was noted.

Flow patterns for six discharges are shown in Figure 37A, B, C and Figure 38 A, B, and C. These views may be compared with those in Figure 14. Filling the draw produced a beneficial effect over the entire discharge range. The depth of water over the crest in the area normally occupied by the fin decreased so that a prominent fin did not form until the discharge was about 15,000 second-feet. For greater discharges, the fin had a clearly defined shape unlike previous fins.

The spillway submerges to the degree shown in Figure 38B for 23,000 second-feet. There was about a 400 second-foot range near 23,000 second-feet over which water coming from the southeast on the bearing of the fin appeared to override radial flow from the northeast. As the hydraulic control shifted from the crest to the shaft deflector and back, the period of submergence was about 4 seconds prototype. The reservoir surface was set into motion by this action.

For the maximum discharge of 24,000 second-feet, Figure 38C, a small vortex formed. The direction of rotation was always counterclockwise, and the center moved but slightly over the shaft.

The size of air orifice beneath the shaft deflector was considered adequate because pressures measured on the underside of the deflector for all discharges were atmospheric.

Flow characteristics with spillway pier.--It was noted in the above tests that the fin had a tendency to move slowly from side to side, through an angle of about 10°. The spillway pier described on page 25 stabilized the fin by providing a solid boundary for flows of opposing direction to strike; thus the effects of differential velocities no longer were manifest in a moving fin.

Flow patterns for five discharges with the spillway pier in place are shown in Figures 39 and 40. These views may be compared with those in which no pier was used. For discharges below that required for submergence of the crest, the advantage of the pier is found in stabilization of the fin. At maximum discharge, Figure 40B, the pier provided a control over vortex formation which had not been possible in any other scheme tried. As shown in the photograph, the water surface was more tranquil than ever before, and no sudden deviation in flow regimen occurred. Small vortices formed and disappeared, singly and in pairs. The directions of rotation were alternately clockwise and counterclockwise.

Tunnel flows are shown in Figures 41 and 42. Air and water masses remained separate at all discharges. Between 20,000 and 22,000 second-feet, a small proportion of the flow downstream from the upper bend occasionally crossed the crown of the tunnel, sometimes from one side and sometimes from the other; for the remainder of the discharge range the water remained centered over the tunnel invert without appreciable variation. In the horizontal tunnel downstream from the lower bend, the flow direction was generally parallel to the tunnel bearing with little side swing.

Head-discharge relationship.--Figure 12 illustrates the effect of a shaft deflector on the operating head. Differences in slopes and ordinate position of the curves from 5,000 to about 22,000 second-feet can be charged to various topographic arrangements or to the crest pier. Above 22,000 second-feet differences are caused principally by the sizes of shaft deflector being used. As the deflector size was increased in Curves 1, 2, 3, and 4, the portion of the curve reflecting orifice flow steepened until, in Curve 4, it was difficult to determine the discharge or crest head at which the transition from weir to orifice flow began.

Figure 13 shows the head-discharge curve for the recommended profile, deflector pier, rib vanes, shaft deflector, and modified topography.

The computed coefficient of discharge for a flow of 22,000 second-feet was 3.41.

Profile pressures.--Data Set 13 of Table 2 is a summary of pressure measurements obtained with the crest pier in place. The effects of using the crest pier and a larger air orifice are readily apparent. For 24,000 second-feet, all pressures were well above atmospheric; whereas, in Data Set 12, a few piezometers showed negative pressures. Of those above atmospheric, none were as high as indicated in Data Set 13.

The greatest subatmospheric pressure, -7 feet of water, occurred near elevation 2363 at 20,000 second-feet. This pressure prevails from about 18,000 second-feet to slightly over 21,000 second-feet.

Considering all profiles and structural features tested, and combinations thereof, the results obtained with this test scheme are the most satisfactory.

Pressures in Upper and Lower Tunnel bends.--Ten piezometers for measuring pressures along the inverts of the upper and lower bends are shown in Figure 43. Measured pressures were all above atmospheric, ranging from 3 to 49 feet of water, Table 2. Especial care in prototype forming and surface finishing was recommended to eliminate the possible harmful effects of high velocity flows.

Tunnel velocity measurements.--Depths of flow for five discharges were measured in the tunnel at a point 240 feet (prototype) downstream from the lower bend. Assuming a uniform distribution, the depths were converted to flow velocities, in model and prototype terms, Table 6. The highest measured velocity was 125 feet per second for maximum discharge. This compares with 143 feet per second assumed in the preliminary design.

It is known that the plastic pipe used in the model is rougher, (considering the model scale) even though the "n" value is 0.008, than the concrete in the prototype assumed to be 0.012. To obtain velocities in the model comparative to those in the prototype would have required corrective measures in the model. The velocity in the upper part of the model was probably very close to the correct value because skin friction losses had not yet accumulated to any degree. Velocities in the spillway and upper bend area of the model were therefore more in agreement than indicated by the measurements of Table 6. Velocities in the lower bend area of the model were probably less than those which would obtain in the prototype; however, this area and the tunnel downstream were not critical, with respect to velocity similitude and it is believed that the model represented the prototype to every necessary degree.

CONCLUSIONS CONCERNING PROTOTYPE FACILITIES

The following requirements for the prototype were derived from the model studies reported herein:

1. The morning-glory spillway should have an outside diameter of 61.5 feet, a crest diameter of 54 feet, and profile coordinates as listed under Profile V, Table 1. (A reduction of outside diameter to 60.25 feet was agreed upon following completion of these studies).

2. The berm should be placed at elevation 2358 and the width between spillway and topography should be not less than 6 feet.

3. A crest pier from the berm to elevation 2387 and approximately 40 feet long should be constructed with radial direction 278° clockwise of the crown point on the tunnel line, Figure 32. Thickness of the pier is not critical from a hydraulic standpoint except as it will increase or decrease the usable crest length; the pier used in the model tests was 3 feet thick.

4. A flow deflector in the shaft is required to divert the water from the crown side of the shaft to the invert side in the vicinity of the upper bend. A wedged-shaped deflector on the crown side between elevations 2257 and 2282, projecting radially 6.97 feet from the shaft boundary at the lower elevation, is recommended, Figures 3 and 30. The deflector should be placed so that it is symmetrical about a line defining the tunnel bearing.

5. An air conduit not less than 20 square feet in cross-section should be provided below the deflector to ventilate the upper end of the tunnel.

6. Three vertical rib vanes are required to reduce spiral flow down the shaft, Figures 28 and 29. Each is 2 feet thick and 4 feet in radial height and extends from elevation 2330 downward. With reference to the crown side of the shaft on the tunnel bearing, one rib vane intersects the sloping surface of the flow deflector. Another rib vane is located 108° clockwise from the reference point, and terminates at elevation 2255. The third rib vane is located 137° counterclockwise from the reference point, and the lower end is also at elevation 2255.

7. Topographic boundaries in the vicinity of the morning-glory should be formed as indicated in Figure 26D to provide satisfactory entrance flow conditions.

Table I

TRINITY DAM MORNING-GLORY SPILLWAY
Crest Coordinates for Profiles I-V

Profile I Crest Diameter = 50 ft Outside Diameter = 53 ft		Profile II Crest Diameter = 50 ft Outside Diameter = 53 ft		Profile III Crest Diameter = 50 ft Outside Diameter = 57.5 ft		Profile IV Crest Diameter = 50 ft Outside Diameter = 57.5 ft		Profile V Crest Diameter = 54 ft Outside Diameter = 61.5 ft	
X Distance from crest center line in feet	Y Elevation in feet	X Distance from crest center line in feet	Y Elevation in feet	X Distance from crest center line in feet	Y Elevation in feet	X Distance from crest center line in feet	Y Elevation in feet	X Distance from crest center line in feet	Y Elevation in feet
.0	2370.0	0	2370.0	0	2370.0	0	2370.0	0	2370.0
-0.25	69.97	-0.25	69.97	-1.79	69.75	-1.79	69.75	1.79	69.75
-0.50	69.92	-0.50	69.92	-2.50	69.50	-2.50	69.50	-2.50	69.50
-0.75	69.85	-0.75	69.85	-3.00	69.25	-3.00	69.25	-3.00	69.25
-1.00	69.72	-1.00	69.72	-3.41	69.00	-3.41	69.00	-3.41	69.00
-1.25	69.55	-1.25	69.55	-3.75	68.75	-3.75	68.75	-3.75	68.75
-1.50	69.30	-1.50	69.30	1.70	69.75	3.08	69.75	1.87	69.75
0.56	69.95	1.62	69.75	2.39	69.50	4.27	69.50	2.65	69.50
0.81	69.90	2.18	69.50	2.98	69.25	5.07	69.25	3.28	69.25
1.32	69.80	2.64	69.25	3.41	69.00	5.72	69.00	3.74	69.00
1.64	69.60	3.02	69.00	4.10	68.50	6.72	68.50	4.60	68.50
2.24	69.30	3.63	68.50	4.85	68.00	7.51	68.00	5.26	68.00
2.67	69.00	4.14	68.00	5.88	67.00	8.63	67.00	6.40	67.00
3.27	68.50	5.00	67.00	6.70	66.00	9.39	66.00	7.29	66.00
3.76	68.00	5.69	66.00	7.39	65.00	9.87	65.00	8.03	65.00
4.59	67.00	6.28	65.00	8.38	63.00	10.15	63.75	9.15	63.00
5.24	66.00	7.18	63.00	9.02	61.00	10.30	50.00	9.99	61.00
5.81	65.00	7.88	61.00	9.69	58.00	10.37	40.00	10.97	58.00
6.70	63.00	8.70	58.00	10.10	55.00			11.54	55.00
7.37	61.00	9.24	55.00	10.30	50.00			12.07	50.00
8.14	58.00	9.75	50.00	10.33	45.00			12.29	45.00
8.70	55.00	10.11	45.00	10.37	40.00			12.37	40.00
9.44	50.00	10.37	40.00						
9.96	45.00								
10.37	40.00								

Table 2

SPILLWAY AND TUNNEL PRESSURES

Morning-Glory spillway and tunnel pressures

Data set	Design tested	Remarks	Discharge cfs	Reservoir Elevation ft	Piezometers on crown side along tunnel centerline											
					1	2	3	4	5	6	7	8	9	10	11	12
(1)	Preliminary design	90° crest blocked, 7 piers in place,	5,000	2375.3	2	0	0	-1	-1	-1	-1	-1	0	0	0	0
	Profile I	shaft clear	10,000	2377.3	1	-1	-3	-4	-3	-3	-3	-2	-1	-1	0	0
			15,000	2380.3	-1	-4	-6	-7	-6	-5	-4	-3	-2	-1	0	0
			20,000	2382.7	-2	-7	-10	-10	-9	-7	-5	-4	-2	-2	0	0
			24,000	2384.5	-3	-9	-11	-12	-9	-7	-5	-3	-2	-1	1	2
(2)	Preliminary design	No piers, crest unrestricted,	5,000	2374.5	2	1	0	0	0	0	0	0	0	0	0	0
	Profile I	shaft clear	10,000	2377.1	3	1	0	-1	-1	-1	0	0	1	2	2	2
			15,000	2379.6	4	2	0	0	0	0	1	1	2	2	2	2
			20,000	2382.0	5	3	1	0	1	1	2	2	2	2	3	3
			24,000	2384.1	8	5	5	4	5	5	5	5	5	5	5	5
(3)	Preliminary design	Air pier 30° clockwise from	5,000	2374.8	2	1	0	-1	0	0	0	0	0	0	0	0
	Profile I	crown side centerline	10,000	2377.9	3	0	-1	-2	-2	-2	-1	-1	0	0	6	0
			15,000	2380.7	3	0	-2	-4	-3	-2	-1	-1	0	0	3	1
			20,000	2383.2	3	-1	-3	-6	-4	-2	-1	-1	0	0	2	3
			24,000	2385.3	1	-3	-5	-6	-4	-2	-1	0	1	1	3	3
(4)	First specifications design, Profile I	With deflector 2' x 10' at P.C. of	5,000	2374.5	3	1	1	0	0	-1	0	0	0	0	0	0
		upper bend, no aeration	10,000	2377.3	3	1	0	-1	-1	-1	0	0	0	1	1	2
			15,000	2379.8	3	1	-1	-1	-1	-1	0	1	2	3	4	4
			20,000	2382.3	5	3	-2	1	-3	-3	4	4	4	4	4	2
			24,000	2384.4	9	7	6	6	-7	-7	7	7	6	6	4	2
(5)	Preliminary design	Same as (2) above, except single	5,000	2375.3	2	1	0	-1	-1	0	0	0	2			
	Profile I	guide vane in shaft, 2' thick	10,000	2377.3	3	1	0	-1	0	0	1	2	5			
		between elevations 2325 and 2350.	15,000	2379.4	4	2	0	0	0	1	2	3	6			
		Deflector same as (4), no aeration	20,000	2381.7	7	4	3	2	3	4	5	6	9			
			24,000	2384.2	10	8	8	7	8	8	8	9	11			
(6)	Profile I	Revised topog (Fig ___) berm at	15,000	2378.7	0	-2	-2	-3	-3	-3	-2	-2	-1	-1	1	2
		elevation 2358, free crest,	20,000	2380.7	0	-3	-4	-4	-4	-3	-2	-1	0	0	1	2
		deflector 5' x 18', aerated with	24,000	2382.9	5	3	2	2	3	4	4	5	6	7	8	10
		2'x7' orifice. 3 rib vanes in shaft														
(7)	Profile I	Same as (6), except deflector	20,000	2380.3	1	-3	-3	-5	-4	-4	-3	-1	-1	-2	2	2
		4.25' x 19'	24,000	2382.6	0	-3	-4	-5	-4	-3	-2	-1	0	1	2	4
(8)	Profile II	Same as (6)	10,000	2376.8												
			15,000	2378.8												
			20,000	2380.9												
			24,000	2383.3												
(9)	Profile II	Revised topog (Fig ___) berm at	15,000	2378.9												
		elevation 2358, free crest,	20,000	2380.6												
		deflector 5'x18', aerated with	24,000	2382.8												
		2'x7' orifice. 3 rib vanes in shaft														
(10)	Profile III	Same as (9)	10,000	2377.2												
			15,000	2379.2												
			20,000	2381.5												
			24,000	2383.9												
(11)	Profile IV	Same as (9)	10,000	2378.3												
			15,000	2380.8												
			20,000	2383.4												
			24,000	2386.0												
(12)	Profile V	Same as (9)	10,000	2377.2												
			15,000	2379.3												
			20,000	2381.5												
			24,000	2383.9												
(13)	Profile V	Revised topog, single pier	5,000	2374.3												
		(Fig ___) berm el 2358, deflector	10,000	2376.7												
		6.97' x 25', aerated with 2 x 10'	15,000	2378.7												
		orifice. 3 rib vanes in shaft	20,000	2380.5												
			24,000	2392.8												

Data set	Discharge cfs	Piezometers 67° 30' degrees clockwise from crown side centerline												Piezometers 157° 30' degrees clockwise from crown side centerline												
		13	14	15	16	17	18	19	20	21	22	23	24	C	25	26	27	28	29	30	31	32	33	34	35	36
(1)	5,000														2	1	0	-1	-1	-1	-1	-1	-1	0	0	0
	10,000														1	-1	-3	-3	-3	-3	-2	-1	-1	0	0	0
	15,000														0	-4	-5	-6	-5	-5	-3	-1	-1	0	0	0
	20,000														-1	-6	-8	-8	-6	-4	-2	-1	0	0	0	0
	24,000														-2	-8	-11	-10	-8	-4	-2	0	1	0	0	0
(2)	5,000	2	0	0	0	0	0	0	0	0	0	0	0		2	1	0	0	-1	-1	-1	0	-1	0	-1	0
	10,000	2	-1	0	-1	-1	-1	0	0	0	0	0	0		2	-1	-2	-3	-2	-2	-2	-1	-1	-1	-1	-1
	15,000	3	0	-1	-2	-2	-1	-1	0	0	0	0	1		0	-4	-5	-6	-5	-5	-5	-3	-2	-1	-2	-1
	20,000	2	-1	--	-3	-2	-2	-1	0	1	2	1	3		-2	-7	-9	-9	-8	-7	-5	-3	-1	1	1	2
	24,000	4	1	--	0	1	3	3	4	5	6	5	7		-2	-8	-9	-9	-6	-5	-3	-2	2	3	4	4
(3)	5,000	2	1	0	0	0	0	0	0	1	0	0	0		2	1	0	-1	-1	--	-1	-1	-1	0	-1	0
	10,000	3	0	1	-1	0	0	0	0	1	0	0	0		2	-2	-3	-4	-4	--	-3	-2	-2	-1	-1	-1
	15,000	3	0	-1	-1	0	0	0	0	1	0	0	0		0	-4	-7	-7	-7	--	-5	-4	-3	-2	0	1
	20,000	3	0	-2	-1	0	0	0	0	1	0	0	1		-1	-6	-9	-9	-8	--	-5	-3	-2	-1	-1	1
	24,000	4	-1	-2	0	0	1	2	3	4	3	3	3		0	-7	-9	-9	-7	--	-3	-2	-2	-1	-1	-1
(4)	5,000	2	0	0	-1	-1	-1	-1	0	1	1	0	0		2	1	0	-1	-1	-1	-1	-1	-1	-1	0	-1
	10,000	0	-3	-4	-3	-3	-2	-1	0	0	-1	0	0		2	-1	-3	-3	-3	-2	-2	-1	-1	0	0	0
	15,000	-3	-6	-7	-6	-4	-3	-2	-1	0	-1	-1	1		1	-3	-5	-5	-5	-3	-2	-1	0	0	0	-1
	20,000	-7	-11	-8	-6	-3	-1	0	1	3	0	0	2		1	-4	-6	-5	-4	-2	-1	0	1	1	0	-1
	24,000	-7	-11	-7	-4	-1	1	2	3	5	2	2	2		2	-1	-1	-3	-2	-1	0	1	1	2	0	0
(5)	5,000	2	1	0	-1	-1	-1	0	0	1	1	0	-1		2	0	-1	2	-1	-1	-1	0	1			
	10,000	2	0	-1	-1	-1	-1	-1	0	1	-1	0	0		1	-2	-3	-3	-3	-2	-2	-1	2			
	15,000	2	0	2	2	-2	-2	-1	0	1	-1	0	0		0	-4	-6	-6	-5	-4	-3	-1	3			
	20,000	3	0	-2	-3	-2	0	1	3	4	-4	5	3		-1	-7	-8	-7	-6	-2	-1	2	6			
	24,000	6	3	2	2	3	5	6	6	8	6	5	2		1	-5	-5	-4	2	2	3	6	10			
(6)	15,000	1	-2	-3	-4	-3	-3	-2	-2	-1	1	0	-1		-1	-4	-5	-5	-5	-4	-3	-3	-2	-1	0	-2
	20,000	0	-3	-5	-5	-4	-4	-3	-2	-1	0	0	1		-3	-7	-8	-8	-8	-7	-6	-4	-3	-4	-1	0
	24,000	3	1	0	1	1	2	-3	4	6	7	8	10		-1	-5	-5	-4	-3	-2	0	2	6	4	3	7
(7)	20,000	-1	-3	-4	-5	-4	-4	-3	-2	-1	-1	0	0		-3	-7	-8	-8	-7	-7	-6	-5	-4	-9	-1	1
	24,000	0	-4	-5	-6	-5	-4	-3	-2	-1	-1	0	1		-4	-9	-10	-10	-9	-8	-7	-5	-4	0	1	2
(8)	10,000														1	0	-2	-2	-4	-3	-3	-3	-3	-3	-1	0
	15,000														0	-2	-5	-5	-6	-5	-5	-5	-4	-4	-1	0
	20,000														-3	-5	-7	-7	-9	-7	-7	-7	-5	-4	-1	-1
	24,000														-2	-3	-5	-4	-5	-3	-2	-2	0	1	5	6
(9)	15,000														0	-2	-4	-4	-6	-5	-5	-5	-4	-4	-2	0
	20,000														-3	-5	-7	-7	-7	-8	-7	-6	-5	-4	0	-4
	24,000														-1	-3	-3	-3	-4	-3	-2	-1	0	2	7	11
(10)	10,000													5	3	2	0	-1	-3	-4	-3	--	-3	-3	0	0
	15,000													5	3	1	-1	-4	-5	-7	-6	--	-4	-4	-1	1
	20,000													5	3	0	-2	-6	-7	-9	-8	--	-4	-3	0	2
	24,000													6	5	2	-1	-4	-5	-7	-6	--	-2	-1	4	8
(11)	10,000													5	5	4	2	-2	-7	-13	-9	-2	0	-1	-2	-1
	15,000													6	6	4	1	-4	-13	-19	-12	-3	1	2	2	2
	20,000													7	7	5	2	-4	-13	-23	-14	-5	0	1	1	1
	24,000													10	10	8	5	-2	-13	-25	-16	-6	0	2	3	5
(12)	10,000													5	3	2	0	-2	-2	-2	-3	-3	-1	-2	-1	0
	15,000													6	4	2	0	-3	-4	-4	-6	-5	-3	-2	0	2
	20,000													7	4	2	-1	-4	-5	-5	-6	-4	-1	0	3	3
	24,000													8	5	3	1	-1	-2	-2	-3	-1	2	2	5	8
(13)	5,000													4	3	2	1	0	-1	-1	-1	-1	0	0	0	0
	10,000													5	4	2	1	-1	-2	-2	-3	-3	-2	-2	0	0
	15,000													6	4	2	-1	-3	-4	-4	-5	-5	-3	-3	-2	0
	20,000													6	3	1	-2	-4	-6	-6	-7	-7	-5	-2	-1	3
	24,000													21	20	19	18	18	17	13	17	18	19	20	24	29

Data set	Discharge cfs	Piezometers 247° 30' degrees clockwise from crown side centerline													Piezometers in deflector						Piezometers in upper bend invert side					Piezometers in lower bend invert side				
		D	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
(1)	5,000		2	1	1	-1	-1	-1	-1	-1	-1	0	0	0																
	10,000		0	-2	-4	-4	-4	-3	-2	-2	-1	0	0	0																
	15,000		-2	-5	-7	-8	-7	-5	-4	-3	-2	-1	0	-1																
	20,000		-5	-11	-12	-11	-9	-7	-5	-3	-2	-1	1	0																
	24,000		-7	-13	-15	-13	-11	-8	-5	-4	-2	0	1	2																
(2)	5,000		2	1	0	-1	-1	0	0	-1	-1	0	1	0																
	10,000		2	-1	3	-3	-3	-2	-2	-2	-1	-1	1	0																
	15,000		0	-4	-6	-6	-6	-5	-4	-3	-3	-1	1	0																
	20,000		-2	-7	-9	-10	-8	-7	-5	-4	-3	0	3	2																
	24,000		-2	-7	-9	-8	-6	-4	-2	0	1	3	6	6																
(3)	5,000		2	1	-1	-1	-1	-1	-1	-1	-1	0	0	0																
	10,000		1	-2	-4	-4	-4	-3	-3	-2	-2	-1	0	0																
	15,000		0	-5	-7	-8	-7	-6	-5	-3	-2	-1	0	-1																
	20,000		-2	-7	-10	-10	-8	-7	-4	-3	-2	0	1	0																
	24,000		-2	-8	-10	-10	-8	-6	-4	-2	-2	0	1	1																
(4)	5,000		2	1	0	-1	-1	-1	0	-1	-1	0	0	-1																
	10,000		1	-1	-3	-3	-3	-2	-2	-2	-1	-1	0	-1																
	15,000		0	-4	-6	-6	-5	-4	-3	-3	-2	0	1	1																
	20,000		0	-5	-6	-6	-4	-1	0	1	3	4	5	2																
	24,000		3	-3	-4	-2	-1	2	3	5	6	6	6	2																
(5)	5,000		2	0	-1	-2	-2	-1	-1	-1	-1	-1	0	-1																
	10,000		1	-1	-3	-3	0	-3	-2	-2	-2	-1	0	-1																
	15,000		0	-4	-6	-7	-5	-5	-4	-3	-3	-1	0	0																
	20,000		-2	-7	-9	-8	-7	-5	-3	-1	0	2	3	1																
	24,000		2	-3	-5	-2	-2	0	2	3	4	5	5	1																
(6)	15,000		-1	-4	-5	-5	-5	-4	-4	-3	-2	-2	-1	-2																
	20,000		-3	-7	-9	-9	-8	-7	-5	-5	-3	-2	0	-1																
	24,000		9	-1	-4	-5	-5	-3	-2	0	1	3	5	7																
(7)	20,000		-3	-6	-8	-9	-7	-7	-6	-5	-4	-2	0	1																
	24,000		-4	-8	-11	-11	-10	-8	-7	-6	-4	-2	1	0																
(8)	10,000		1	0	-2	-2	-6	-3	-4	-5	-1	-1	-1	0																
	15,000		0	-1	-5	-4	-9	-6	-6	-5	-3	-2	-1	0																
	20,000		-2	-3	-8	-7	-10	-7	-7	-5	-4	-3	0	-1																
	24,000		-1	-2	-6	-4	-5	-3	-1	-1	1	2	6	7																
(9)	15,000		0	-1	-5	-5	-5	-4	-4	-4	-3	-6	-1	0																
	20,000		-3	-3	-9	-7	-8	-7	-6	-6	-3	-2	0	0																
	24,000		0	0	-5	-3	-3	-1	-1	0	2	3	7	9																
(10)	10,000	5	3	2	0	-1	-2	-4	-4	-3	-1	-1	0	0																
	15,000	5	3	1	1	-3	-4	-7	-6	-5	-3	-2	-1	1																
	20,000	6	3	1	-1	-5	-7	-9	-8	-7	-5	-3	0	1																
	24,000	7	5	3	0	-3	-3	-7	-6	-5	-3	-2	-4	8																
(11)	10,000	5	5	4	2	-3	-8	-13	-9	-1	0	1	0	-1																
	15,000	5	6	4	1	-5	-13	-21	-16	-4	-1	1	2	0																
	20,000	6	7	5	1	-5	-15	-24	-19	-5	-2	1	1	1																
	24,000	9	10	8	4	-3	-14	-25	-19	-5	0	2	4	6																
(12)	10,000	5	3	3	1	0	-2	-2	-2	-3	-2	-2	-1	0																
	15,000	6	4	2	0	-2	-3	-4	-4	-5	-4	-3	-1	0																
	20,000	6	4	2	-1	-3	-5	-5	-5	-6	-5	-4	-2	0																
	24,000	8	6	4	2	1	-1	-1	-1	-2	-1	1	5	7																
(13)	5,000	4	3	2	1	0	0	0	-1	-1	-1	-1	0	1							3	30	24	10	16	8	16	9	3	11
	10,000	5	4	3	1	0	-1	-2	-2	-2	-2	-2	-1	1	9	6	2	0	0	0	6	33	28	19	25	12	28	18	13	15
	15,000	6	4	2	0	-1	-3	-3	-4	-4	-4	-3	-1	-1							11	30	33	27	30	15	37	28	23	20
	20,000	7	4	2	-1	-3	-5	-6	-6	-6	-5	-4	-2	1	21	21	5	0	0	0	37	24	38	35	36	20	46	37	30	24
	24,000	22	21	21	20	19	19	19	19	19	20	21	25	30	65	54	14	0	0	0	45	36	49	43	40	23	53	43	38	26

Table 3

TRINITY MORNING-GLORY SPILLWAY STUDIES
Rib Vane Pressures

Piezometer	Pressures in feet of water				
	Q = 5,000	Q = 10,000	Q = 15,000	Q = 20,000	Q = 24,000
Rib Vane in Figure 26(a)					
65	-3	0	2	5	23
66	0	0	-1	-3	28
67	-18	-16	-6	-1	31
68	-13	-18	-12	-24	19
69	-2	-3	-3	-10	27
70	1	2	2	4	37
71	-1	-1	0	-1	37
Rib Vane in Figure 26(b)					
65	0	3	5	5	22
66	-17	-28	-30	-18	24
67	-9	-7	-2	2	35
68	-6	-11	-17	-21	24
69	-1	-2	-5	-10	30
70	2	2	3	6	38
71	0	0	1	2	37
Rib Vane in Figure 26(c)					
65	1	4	6	5	27
66	-11	-14	-17	-11	23
67	-3	-4	-4	-2	23
68	-1	-2	-4	-3	31
69	0	0	-1	-2	33
70	-4	-4	-3	-1	32
71	0	0	0	0	35
Rib Vane in Figure 26(d)					
65	-3	-4	-6	-8	27
66	-2	-2	-2	-10	23
67	0	0	-1	-7	26
68	0	0	0	7	35
69	0	-1	-1	-3	32
70	0	-1	-1	-4	34
Rib Vane in Figure 26(e)					
65	-1	-2	-2	0	28
66	0	0	2	5	35
67	0	-1	-3	-3	32
68	0	0	-1	-3	33
69	0	1	1	-3	36
70	0	0	-1	-2	33
Rib Vane in Figure 26(f)					
65	-1	-3	-2	3	33
66	0	1	2	6	35
67	0	-1	0	1	35
68	1	2	2	4	34
69	0	-1	-3	-5	31
70	0	-1	-1	-1	32

Table 4

TRINITY MORNING-GLORY SPILLWAY STUDIES
Pressures on Flow Deflector

Piezometer	Pressures in feet of water			
	Q = 10,000	Q = 20,000	Q = 22,000	Q = 24,000
49	9	22	44	65
50	6	22	41	54
51	2	5	10	14
52	0	0	0	0
53	0	0	0	0
54	0	0	0	0

Table 5

AIR DEMAND FOR RECOMMENDED FLOW DEFLECTOR

Discharge in cubic feet per second			
Water		Air demand	
Prototype	Model	Model	Prototype
5,000	1.01	0.0047	23
10,000	2.03	.00685	34
15,000	3.04	.0093	46
20,000	4.06	.0144	71
21,000	4.26	.0159	78
22,500	4.56	.0136	67
24,000	4.87	.0123	61

Table 6

TRINITY MORNING-GLORY SPILLWAY STUDIES
Tunnel Velocities

Discharge, cfs	*Flow depth, feet	**Velocity, ft/sec	
		Model	Prototype
5,000	0.148	17.5	96
10,000	.226	19.4	107
15,000	.307	19.4	107
20,000	.368	20.5	113
24,000	.392	22.8	125

Tunnel diameter = 0.667 foot.

*Measured in model

**Computed from depth measurements

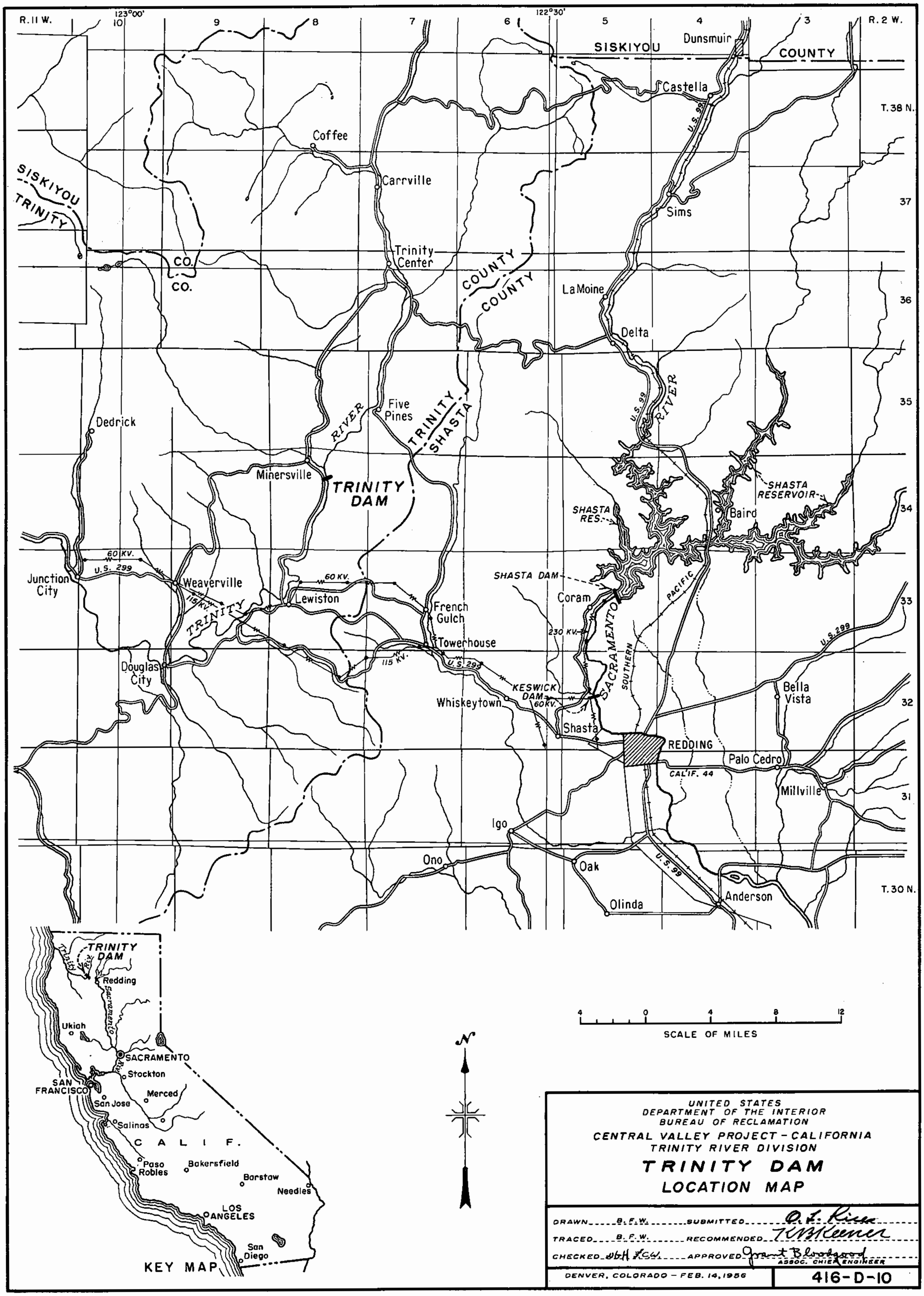
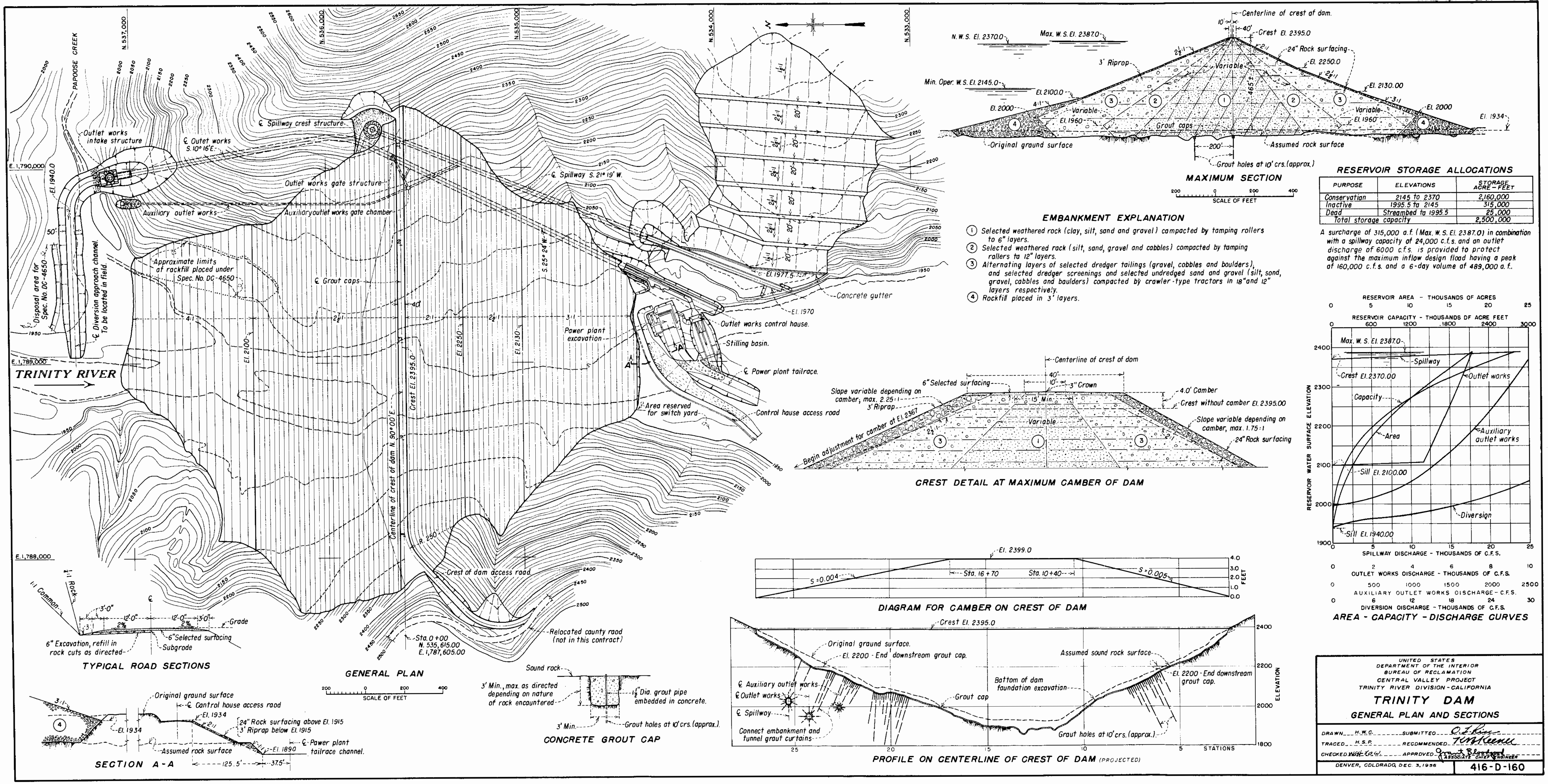
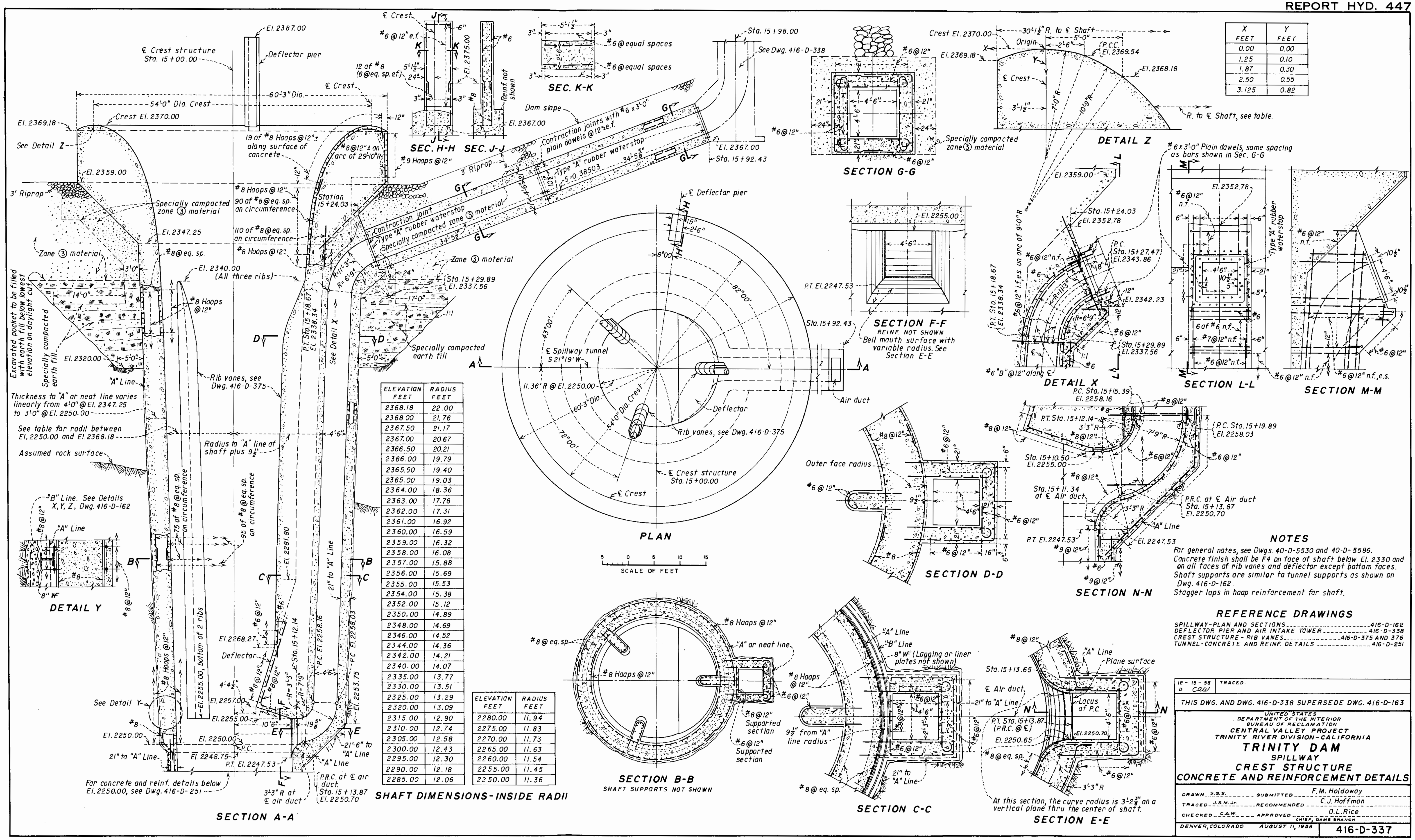

SISKIYOU COUNTY
TRINITY CO.
SISKIYOU CO.
TRINITY COUNTY
SHASTA COUNTY
Dunsmuir
Castella
Coffee
Carrville
Sims
Trinity Center
LaMoine
Delta
Five Pines
Dedrick
Minersville
TRINITY DAM
SHASTA RES.
SHASTA RESERVOIR
Baird
SHASTA DAM
Junction City
Weaverville
Lewiston
French Gulch
Coram
Towerhouse
Douglas City
KESWICK DAM
Whiskeytown
Shasta
REDDING
Palo Cedro
Bella Vista
Millville
Igo
Ono
Oak
Olinda
Anderson
U.S. 99
U.S. 299
CALIF. 44
SOUTHERN PACIFIC
SACRAMENTO RIVER
TRINITY RIVER
KEY MAP
TRINITY DAM
Redding
Ukiah
SACRAMENTO
Stockton
SAN FRANCISCO
San Jose
Merced
Salinas
C A L I F.
Paso Robles
Bakersfield
Barstow
Needles
LOS ANGELES
San Diego
SCALE OF MILES
N
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
TRINITY RIVER DIVISION
TRINITY DAM
LOCATION MAP
DRAWN B.F.W. SUBMITTED
TRACED B.F.W. RECOMMENDED
CHECKED APPROVED Grant Bloodgood ASSOC. CHIEF ENGINEER
DENVER, COLORADO - FEB. 14, 1956
416-D-10

FIGURE 2
REPORT HYD. 447



RESERVOIR STORAGE ALLOCATIONS

PURPOSE	ELEVATIONS	STORAGE ACRE-FEET
Conservation	2145 to 2370	2,160,000
Inactive	1995.5 to 2145	315,000
Dead	Streambed to 1995.5	25,000
Total storage capacity		2,500,000



X FEET	Y FEET
0.00	0.00
1.25	0.10
1.87	0.30
2.50	0.55
3.125	0.82

SHAFT DIMENSIONS-INSIDE RADII

ELEVATION FEET	RADIUS FEET
2368.18	22.00
2368.00	21.76
2367.50	21.17
2367.00	20.67
2366.50	20.21
2366.00	19.79
2365.50	19.40
2365.00	19.03
2364.00	18.36
2363.00	17.78
2362.00	17.31
2361.00	16.92
2360.00	16.59
2359.00	16.32
2358.00	16.08
2357.00	15.88
2356.00	15.69
2355.00	15.53
2354.00	15.38
2352.00	15.12
2350.00	14.89
2348.00	14.69
2346.00	14.52
2344.00	14.36
2342.00	14.21
2340.00	14.07
2335.00	13.77
2330.00	13.51
2325.00	13.29
2320.00	13.09
2315.00	12.90
2310.00	12.74
2305.00	12.58
2300.00	12.43
2295.00	12.30
2290.00	12.18
2285.00	12.06

ELEVATION FEET	RADIUS FEET
2280.00	11.94
2275.00	11.83
2270.00	11.73
2265.00	11.63
2260.00	11.54
2255.00	11.45
2250.00	11.36

NOTES

For general notes, see Dwgs. 40-D-5530 and 40-D-5586.
Concrete finish shall be F4 on face of shaft below El. 2330 and on all faces of rib vanes and deflector except bottom faces.
Shaft supports are similar to tunnel supports as shown on Dwg. 416-D-162.
Stagger laps in hoop reinforcement for shaft.

REFERENCE DRAWINGS

SPILLWAY-PLAN AND SECTIONS 416-D-162
DEFLECTOR PIER AND AIR INTAKE TOWER 416-D-338
CREST STRUCTURE - RIB VANES .... 416-D-375 AND 376
TUNNEL-CONCRETE AND REINF. DETAILS 416-D-251

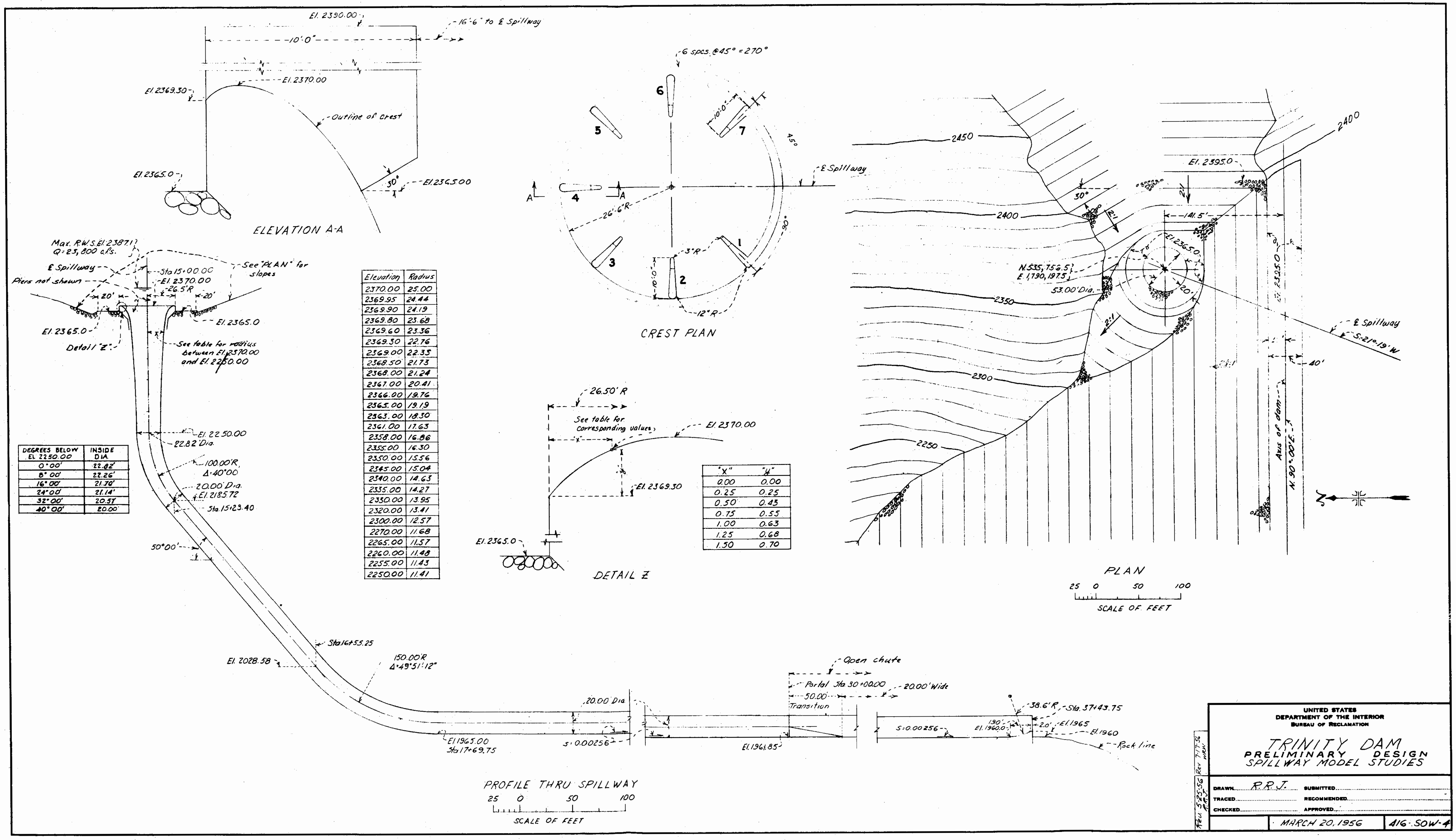
12-15-58 D CAW | TRACED.

THIS DWG. AND DWG. 416-D-338 SUPERSEDE DWG. 416-D-163

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION-CALIFORNIA

TRINITY DAM
SPILLWAY
CREST STRUCTURE
CONCRETE AND REINFORCEMENT DETAILS

DRAWN S.G.S. SUBMITTED F.M. Holdoway
TRACED J.S.M. Jr. RECOMMENDED C.J. Hoffman
CHECKED C.A.W. APPROVED O.L. Rice, CHIEF, DAMS BRANCH
DENVER, COLORADO AUGUST 11, 1958 | 416-D-337



Elevation	Radius
2370.00	25.00
2369.95	24.44
2369.90	24.19
2369.80	23.68
2369.60	23.36
2369.30	22.76
2369.00	22.35
2368.50	21.73
2368.00	21.24
2367.00	20.41
2366.00	19.76
2365.00	19.19
2363.00	18.30
2361.00	17.63
2358.00	16.86
2355.00	16.30
2350.00	15.56
2345.00	15.04
2340.00	14.63
2335.00	14.27
2330.00	13.95
2320.00	13.41
2300.00	12.57
2270.00	11.68
2265.00	11.57
2260.00	11.48
2255.00	11.43
2250.00	11.41

DEGREES BELOW EL. 2250.00	INSIDE DIA.
0°00'	22.82'
8°00'	22.26'
16°00'	21.70'
24°00'	21.14'
32°00'	20.57'
40°00'	20.00'

"X"	"Y"
0.00	0.00
0.25	0.25
0.50	0.43
0.75	0.55
1.00	0.63
1.25	0.68
1.50	0.70

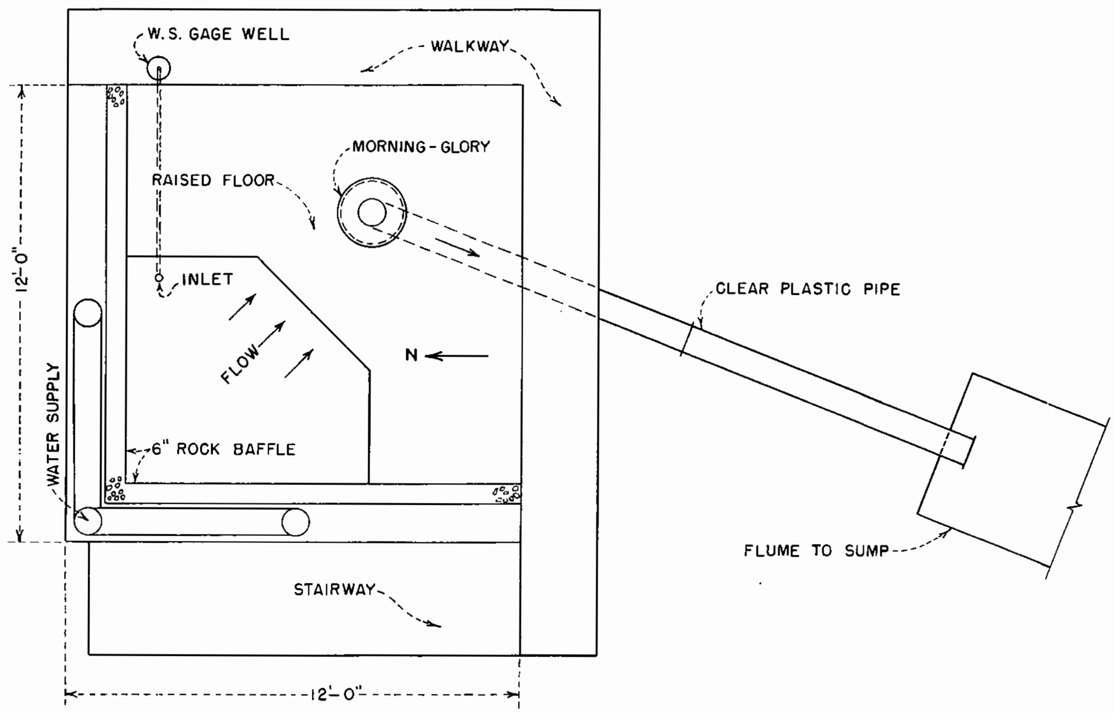
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

TRINITY DAM
PRELIMINARY DESIGN
SPILLWAY MODEL STUDIES

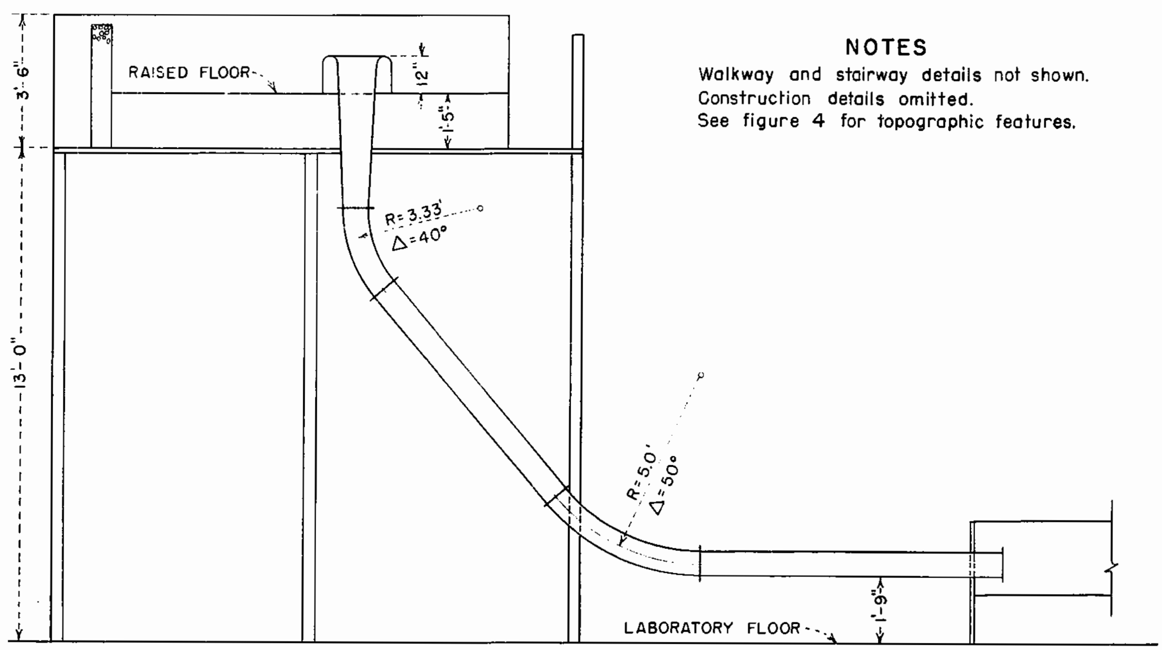
Rev. 5-25-56 R.R.J.
Rev. 7-7-56 W.R.W.

DRAWN R.R.J. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED

MARCH 20, 1956 416-SOW-4



PLAN



NOTES

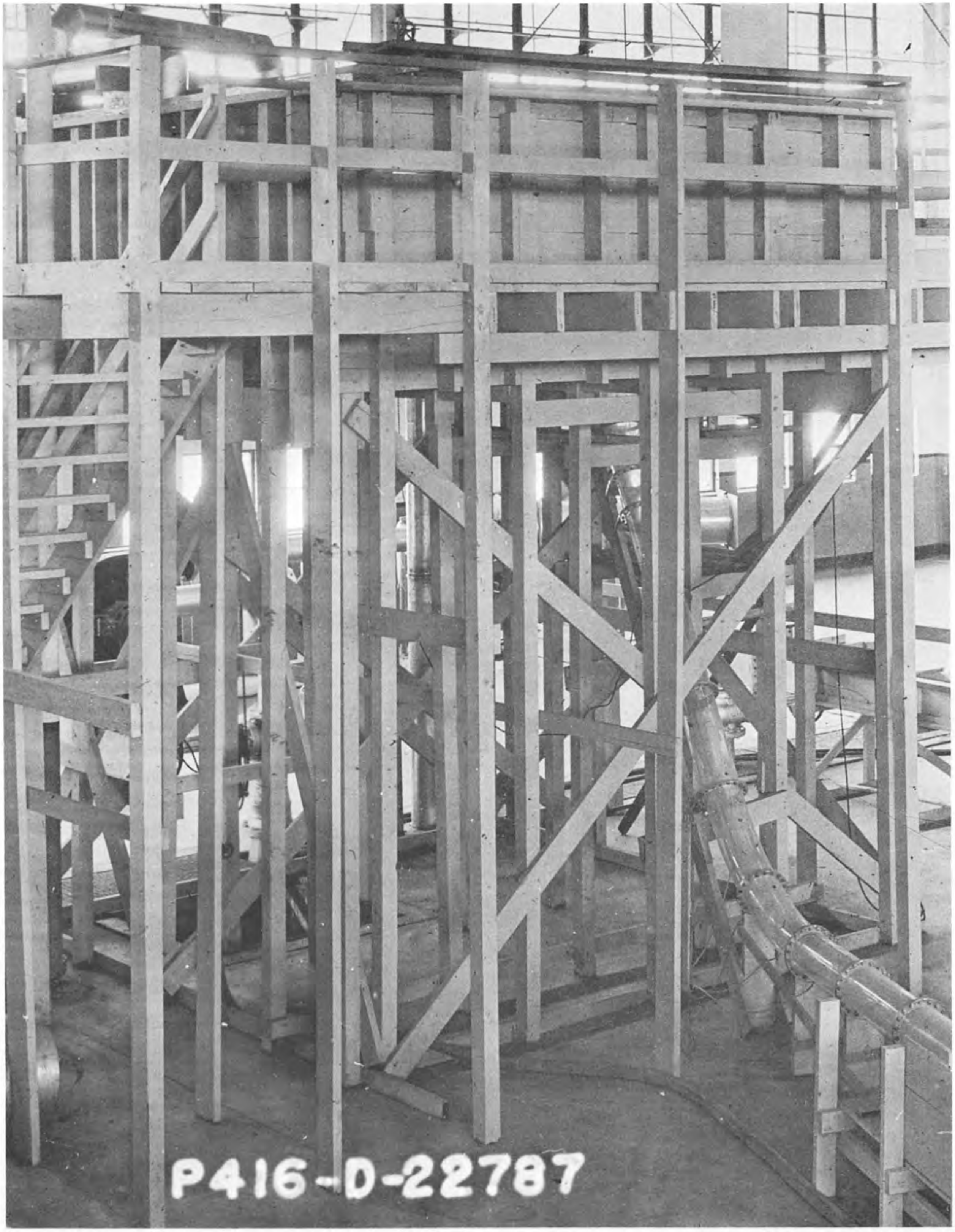
Walkway and stairway details not shown.
Construction details omitted.
See figure 4 for topographic features.

SECTION THROUGH MORNING-GLORY AND PLASTIC PIPE

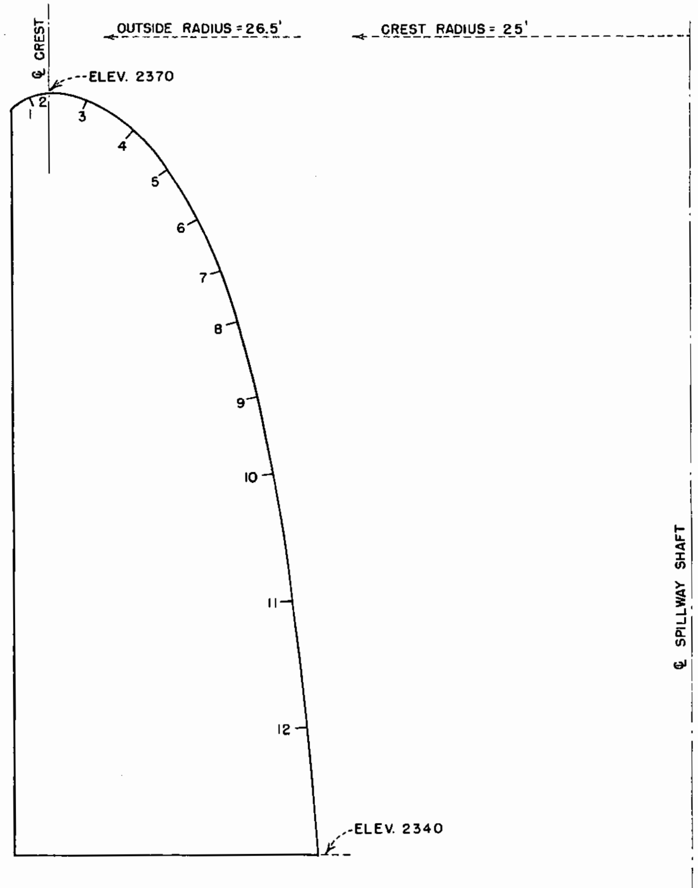
TRINITY MORNING-GLORY SPILLWAY

MODEL LAYOUT

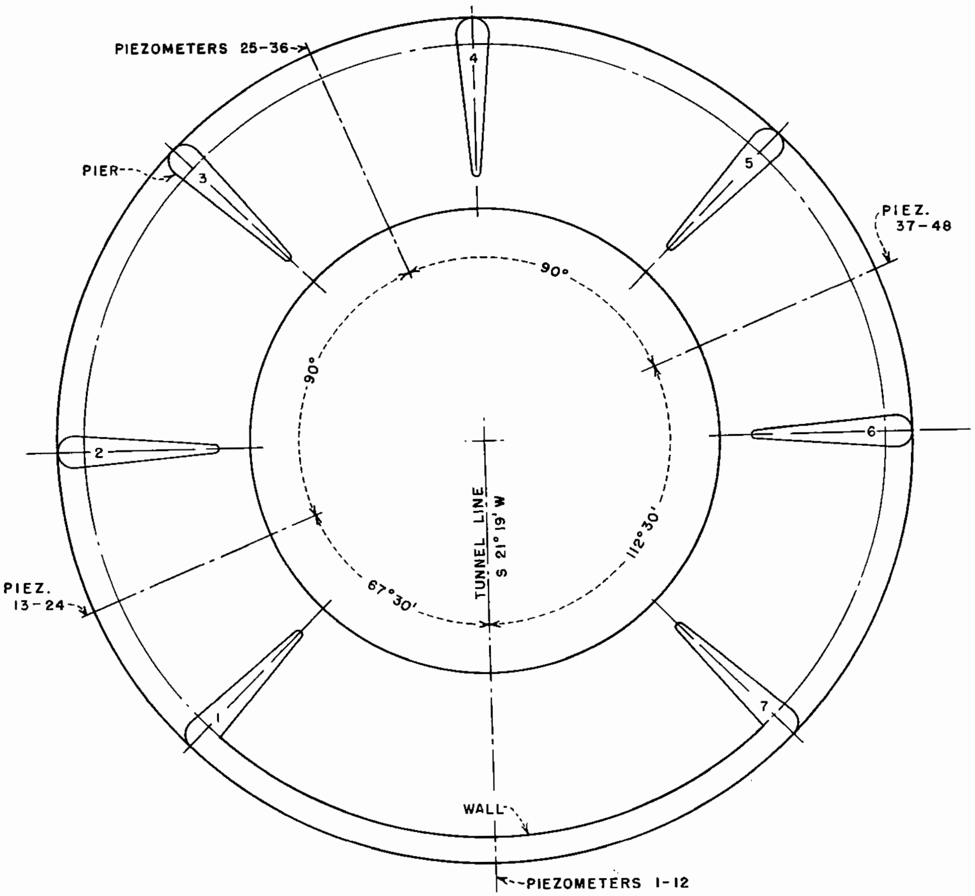
1:30 MODEL



TRINITY MORNING-GLORY SPILLWAY
1:30 MODEL HEADBOX AND TUNNEL



SECTION
SHOWING PIEZOMETER LOCATIONS

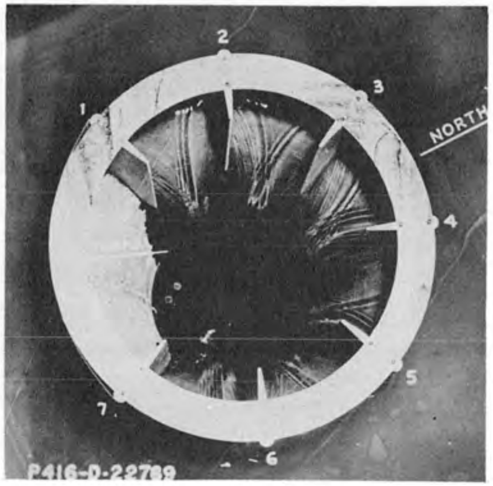


PLAN
SHOWING PIEZOMETER SETS

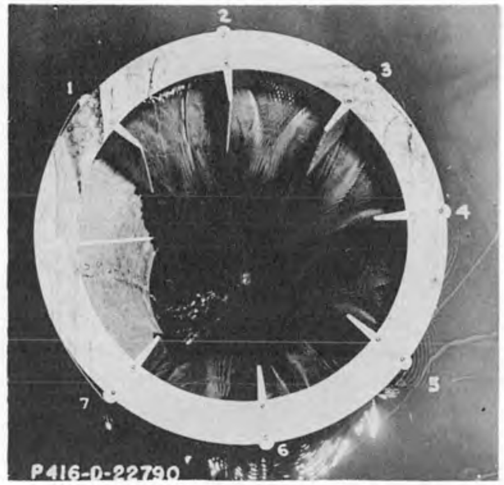
TRINITY MORNING-GLORY SPILLWAY
PRELIMINARY CREST DESIGN
1:30 MODEL

FIGURE 7
REPORT HYD. 447

TRINITY MORNING-GLORY SPILLWAY
MORNING-GLORY STRUCTURE BEFORE
INSTALLATION OF TOPOGRAPHY
1:30 MODEL

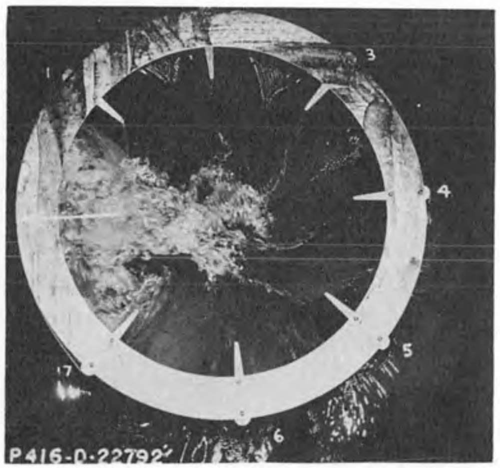


A. Discharge 5,600 cfs

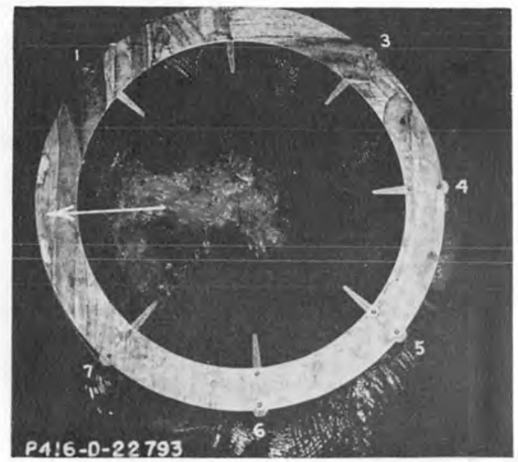


B. Discharge 11,200 cfs

C. Discharge 16,800 cfs

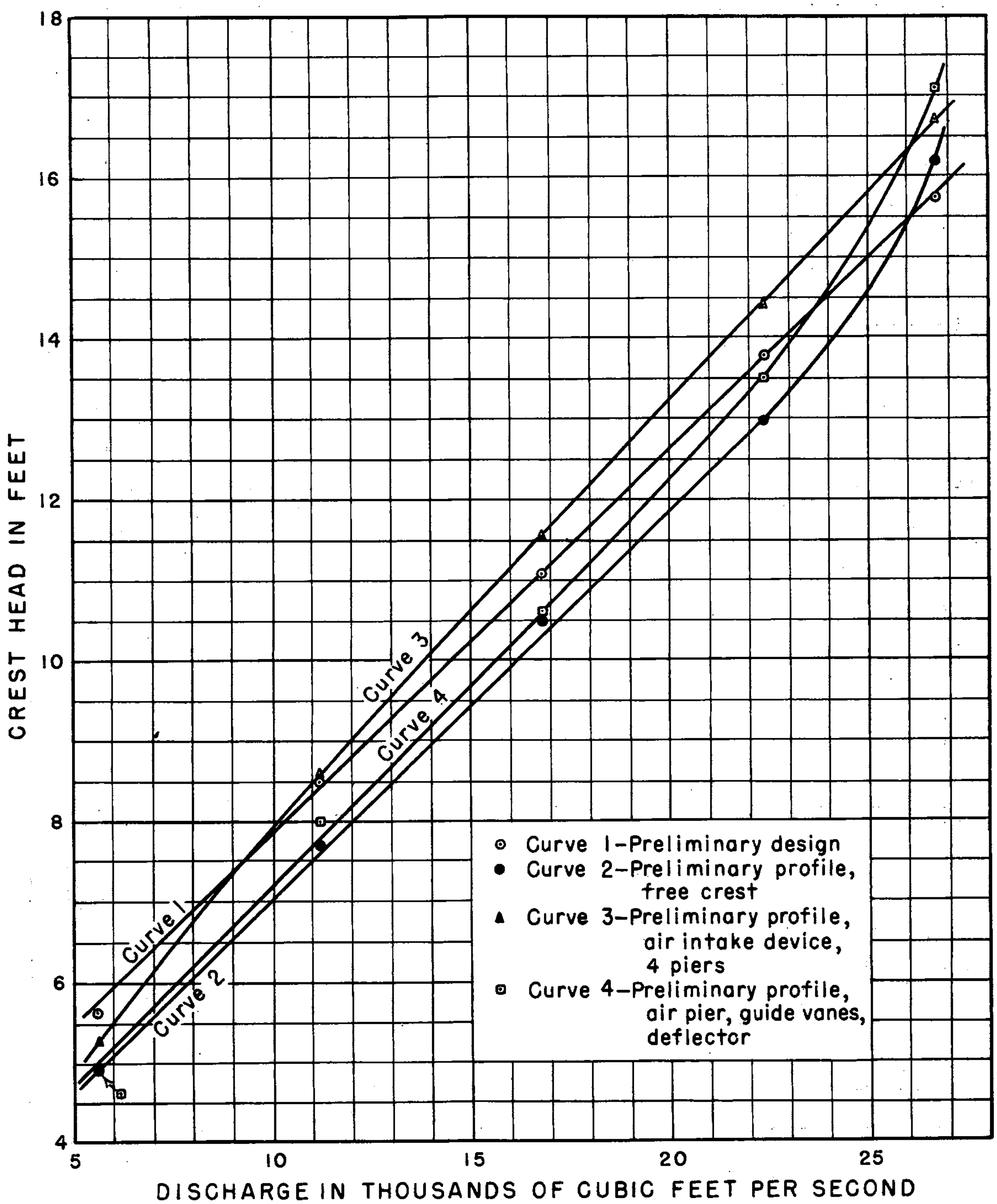


D. Discharge 22,400 cfs



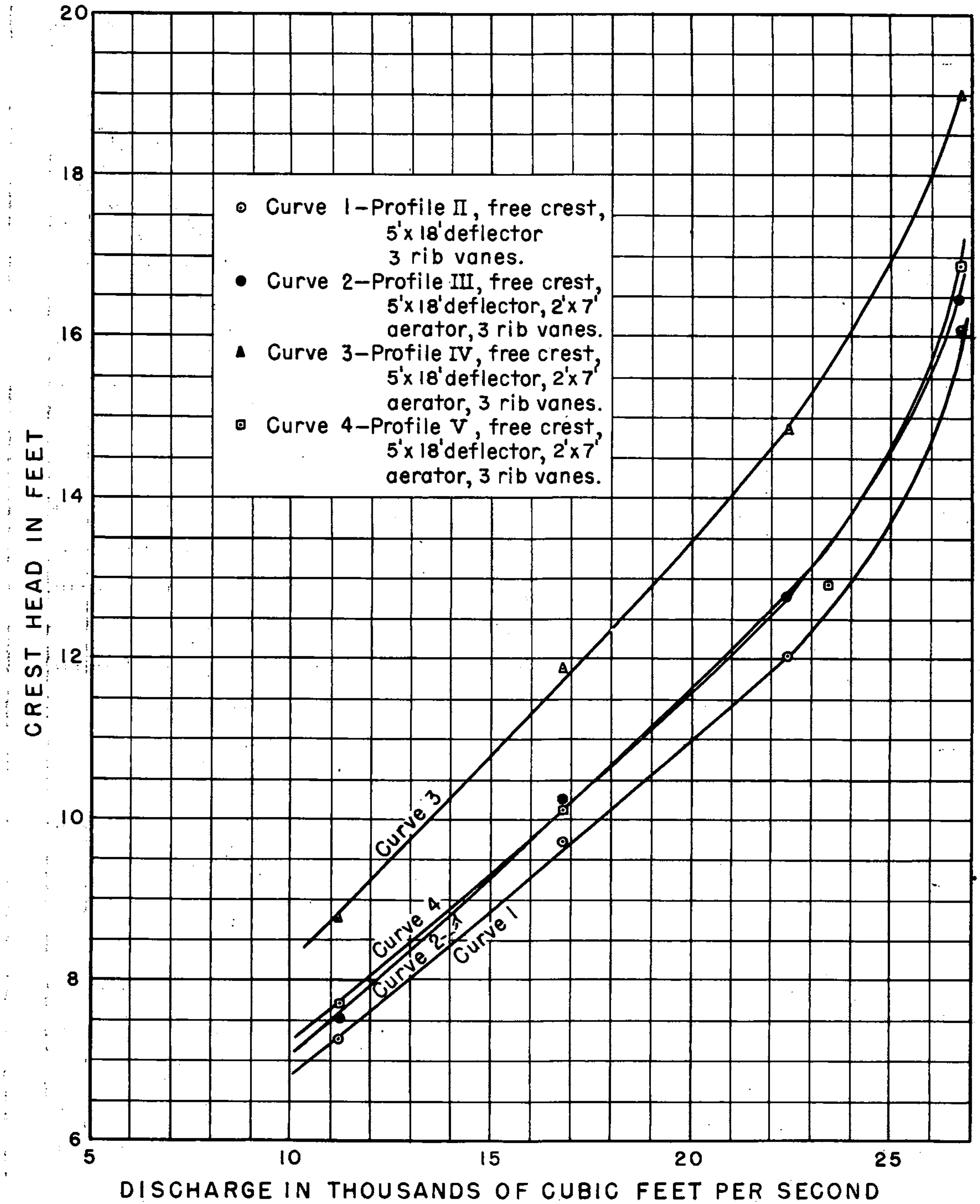
E. Discharge 26,700 cfs

TRINITY MORNING-GLORY SPILLWAY
CREST FLOWS, PRELIMINARY DESIGN, 1:30 MODEL



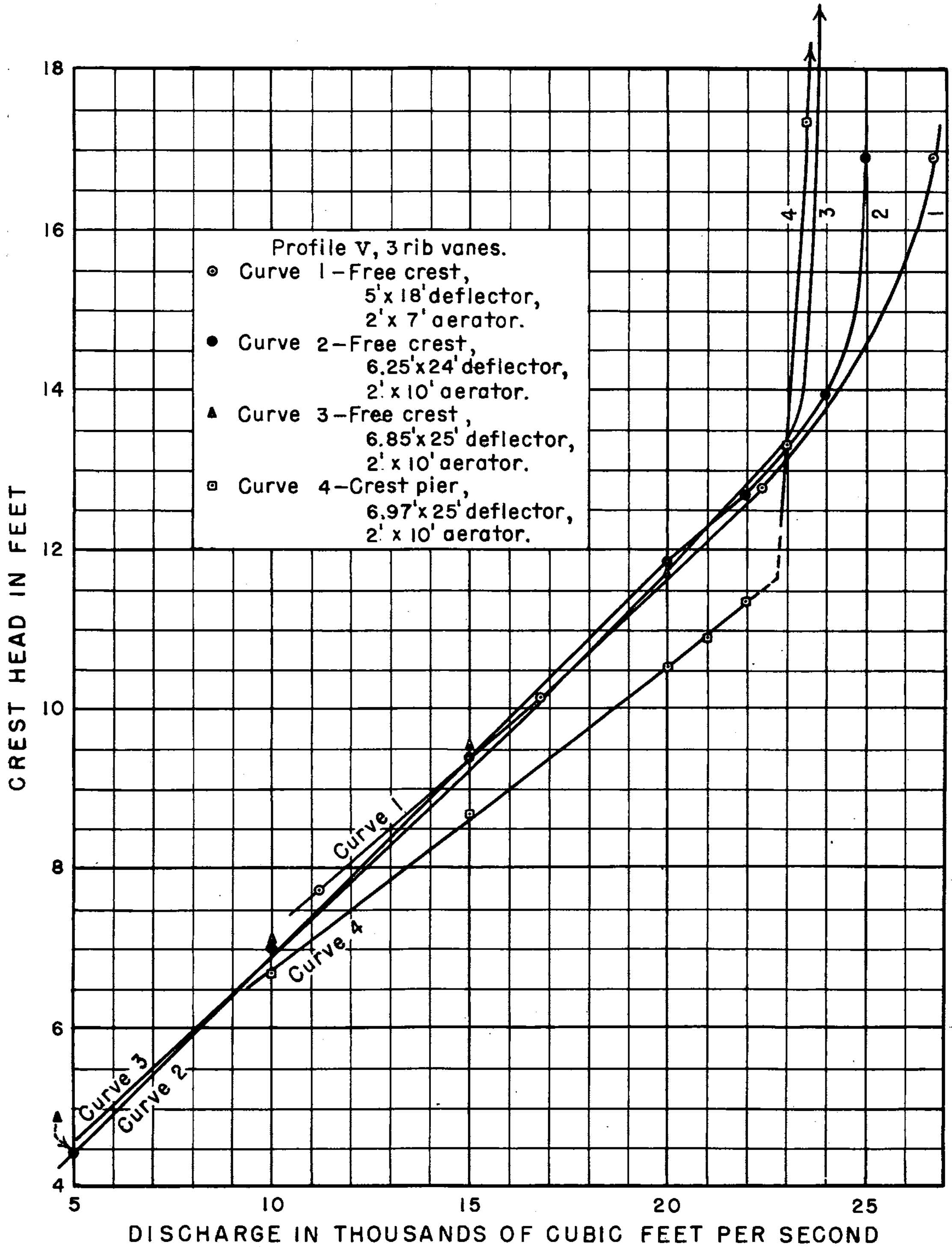
TRINITY MORNING - GLORY SPILLWAY

HEAD - DISCHARGE CURVES
PRELIMINARY PROFILE
1:30 MODEL



TRINITY MORNING-GLORY SPILLWAY

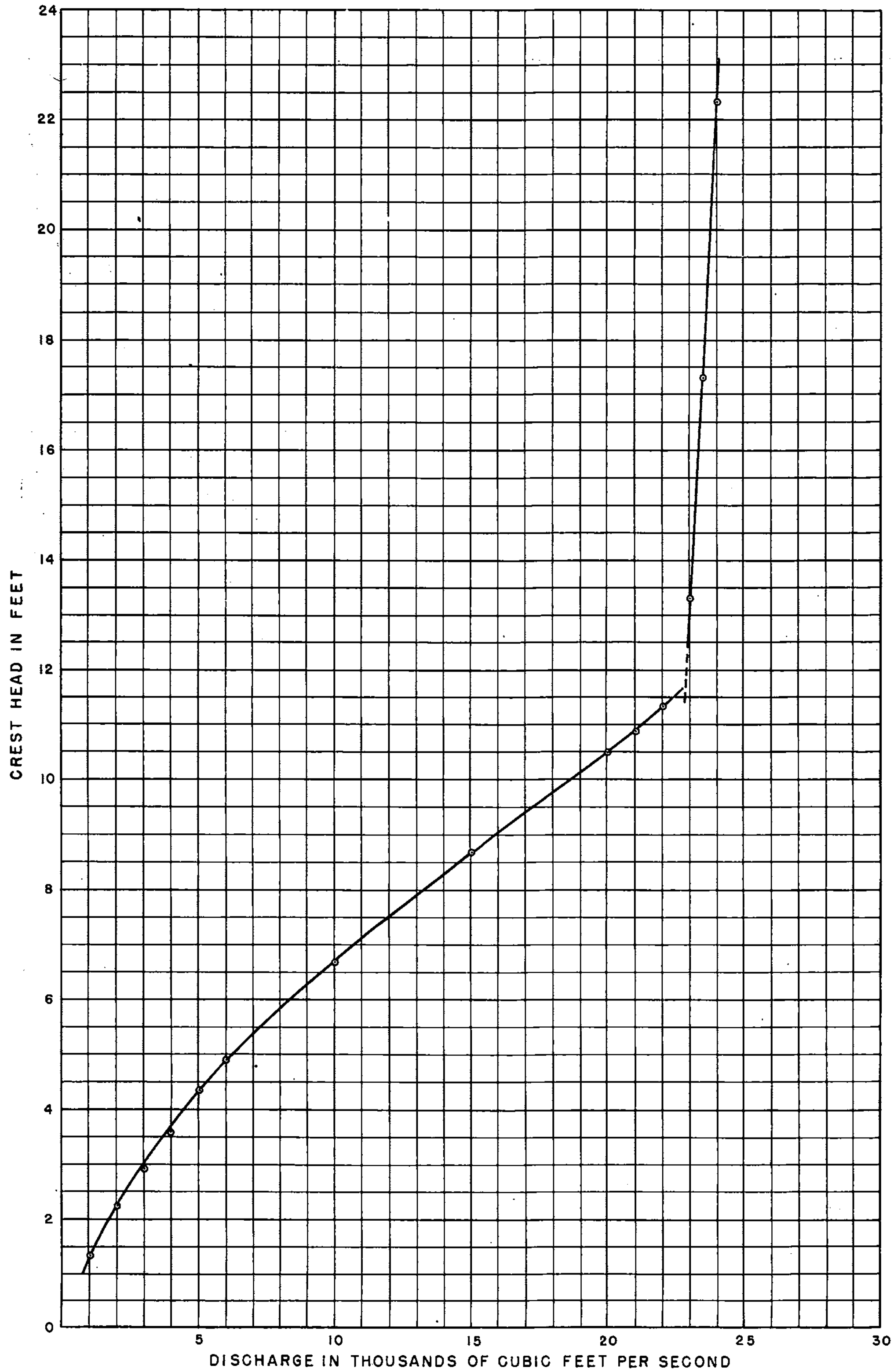
HEAD - DISCHARGE CURVES
VARIOUS CREST PROFILES
1:30 MODEL



TRINITY MORNING - GLORY SPILLWAY

HEAD - DISCHARGE CURVES
CREST PROFILE V
1:30 MODEL

FIGURE 13
REPORT HYD. 447



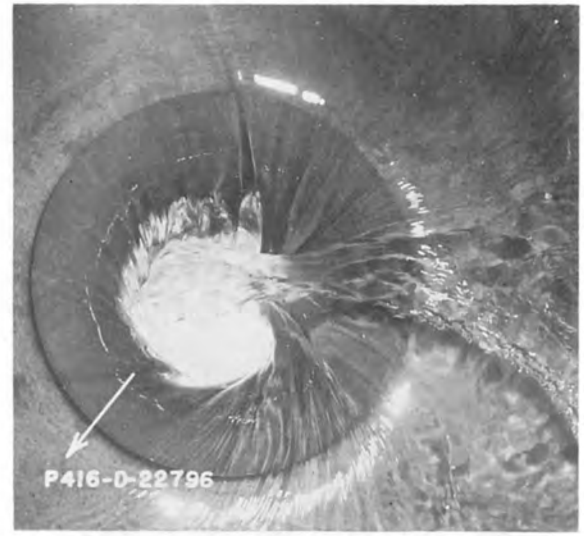
TRINITY MORNING-GLORY SPILLWAY

HEAD - DISCHARGE CURVE FOR RECOMMENDED DESIGN

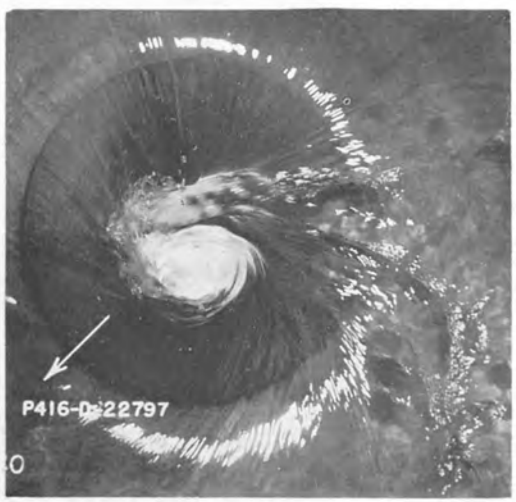
1:30 MODEL

A. Discharge 5,600 cfs

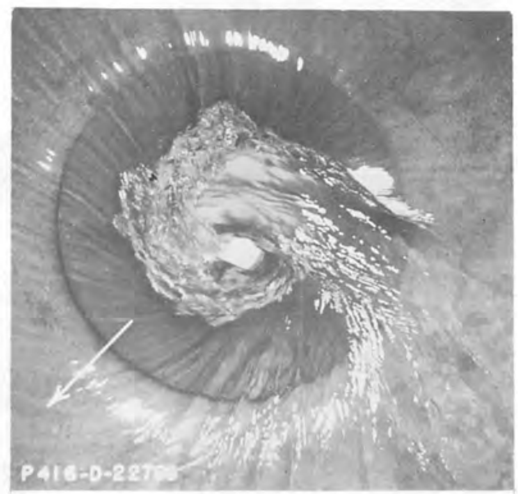
B. Discharge 11,200 cfs



C. Discharge 16,800 cfs



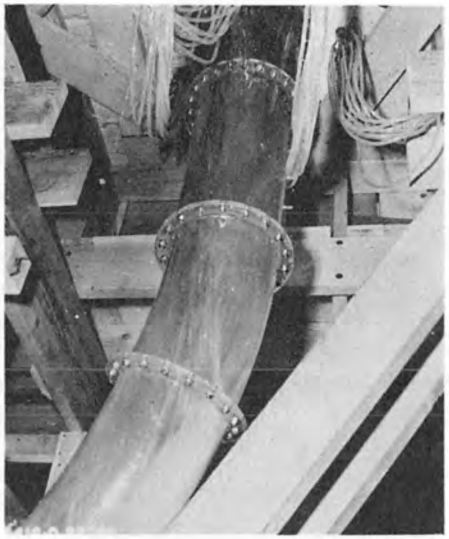
D. Discharge 22,400 cfs



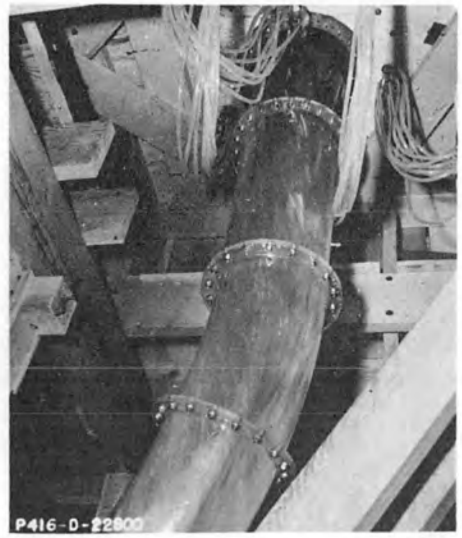
E. Discharge 26,700 cfs

TRINITY MORNING-GLORY SPILLWAY
CREST FLOWS, FREE CREST, PRELIMINARY PROFILE
1:30 MODEL

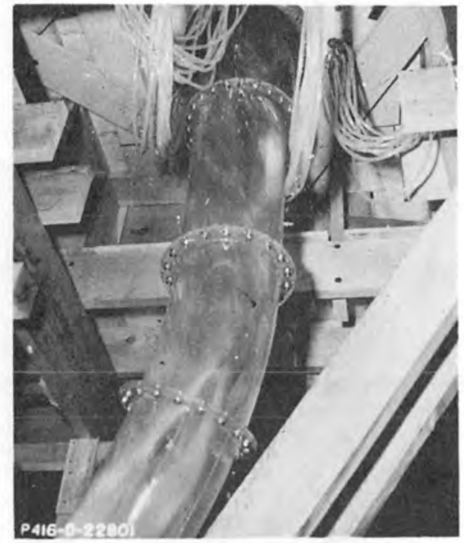
Figure 14
Report HYD - 447



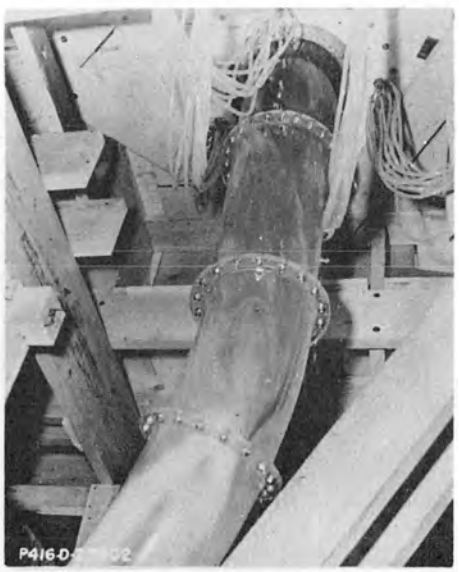
A. Discharge 5,600 cfs



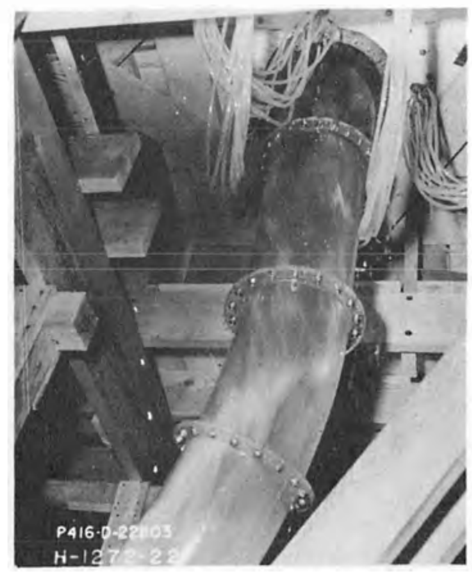
B. Discharge 11,200 cfs



C. Discharge 16,800 cfs



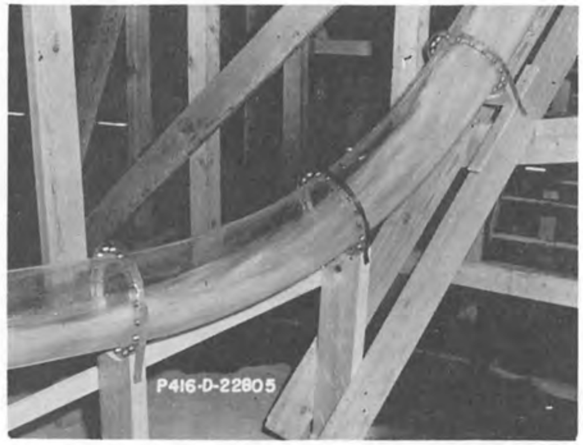
D. Discharge 22,400 cfs



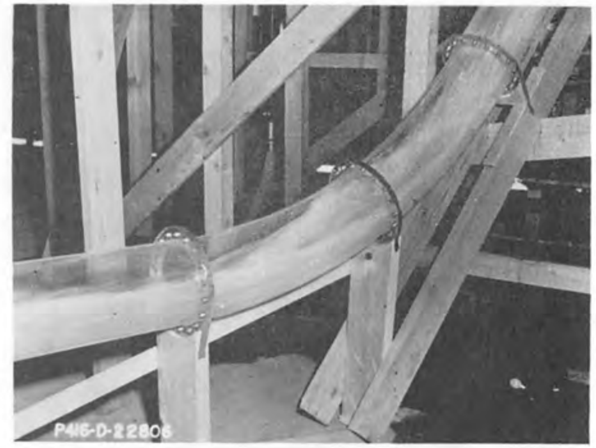
E. Discharge 26,700 cfs

TRINITY MORNING-GLORY SPILLWAY
FLOW IN UPPER BEND
PRELIMINARY SPILLWAY PROFILE
1:30 MODEL

A. Discharge 5,600 cfs



B. Discharge 11,200 cfs

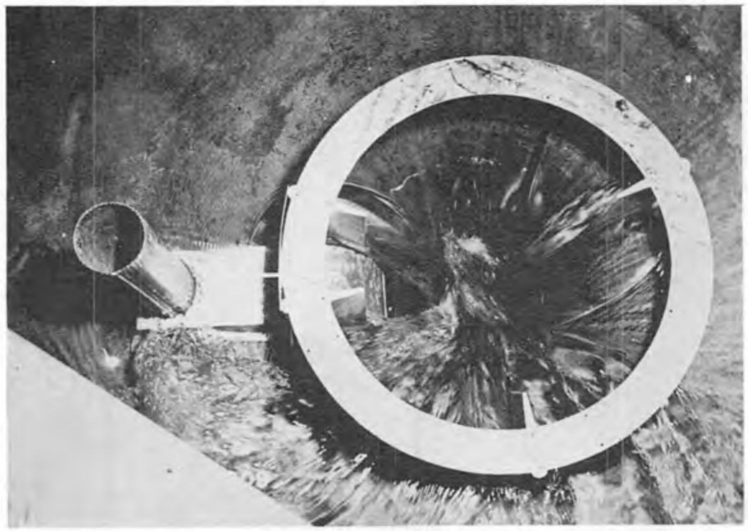


C. Discharge 16,800 cfs

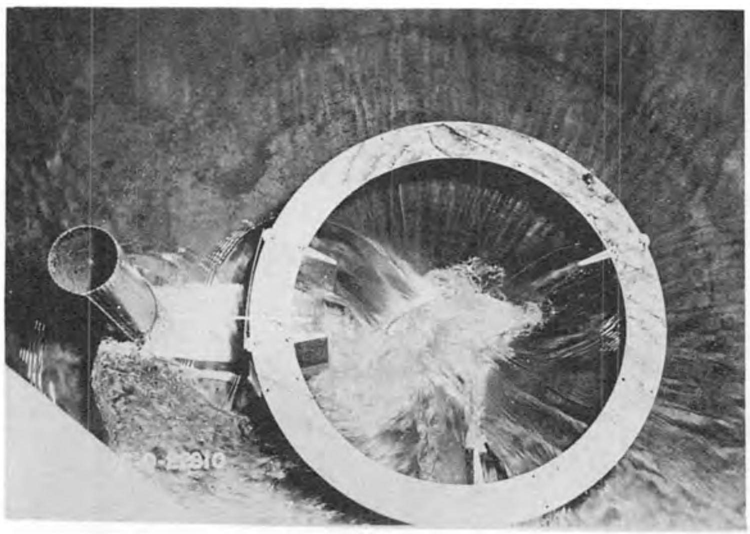
D. Discharge 22,400 cfs

E. Discharge 26,700 cfs

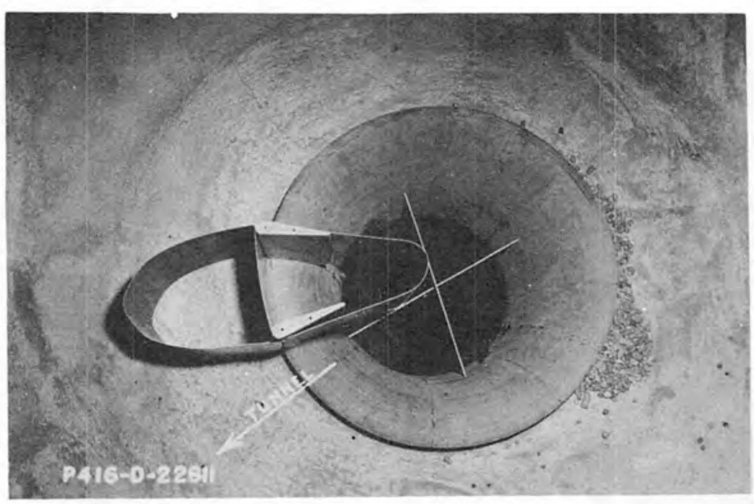
TRINITY MORNING-GLORY SPILLWAY
FLOW IN LOWER BEND
PRELIMINARY SPILLWAY PROFILE
1:30 MODEL



A. Air Intake Device, 4 piers, Discharge 16,800 cfs

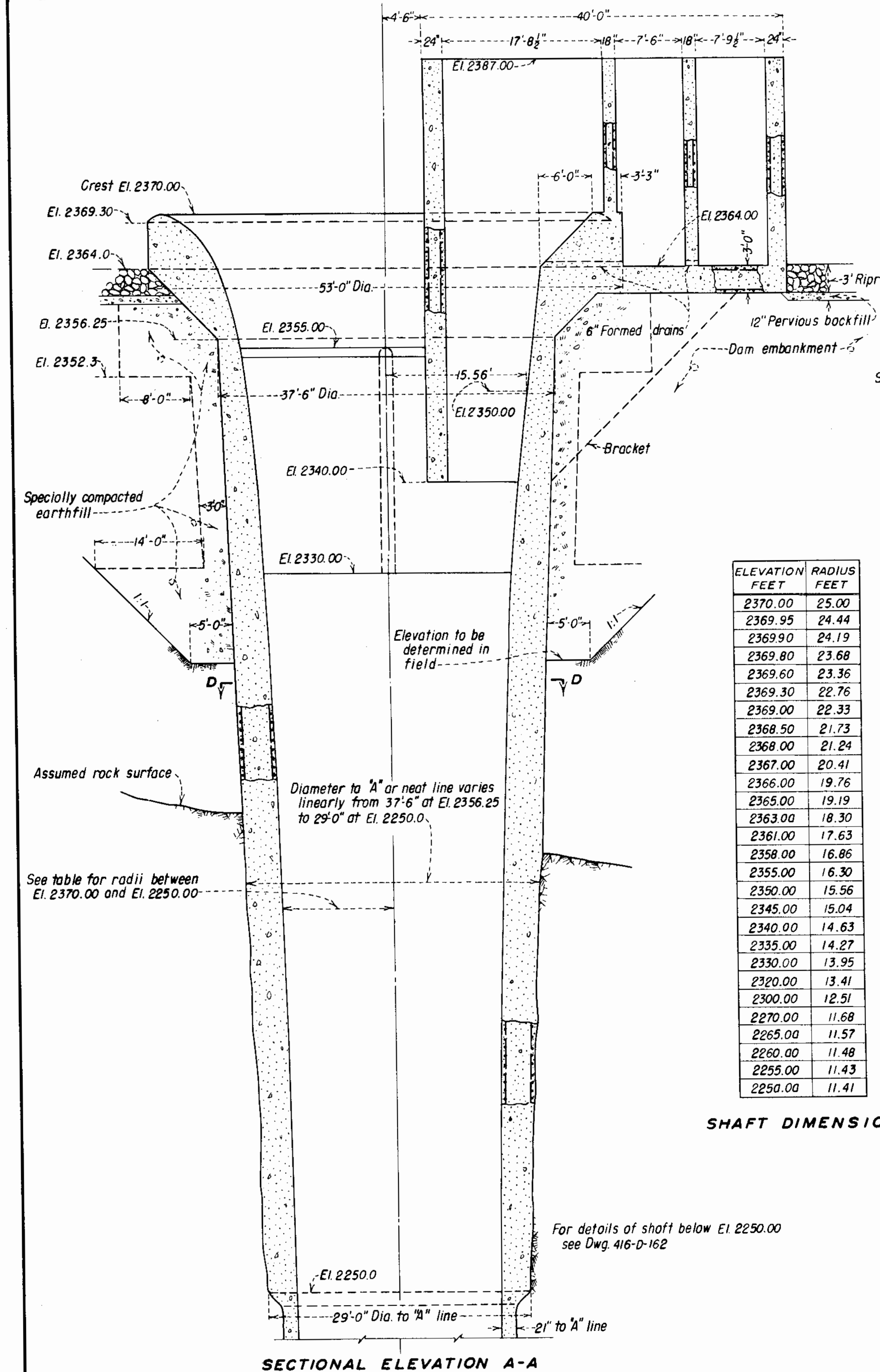


B. Air Intake Device, 4 piers, Discharge 26,700 cfs



C. Air Intake Pier, Metal Guide Vanes, No Flow

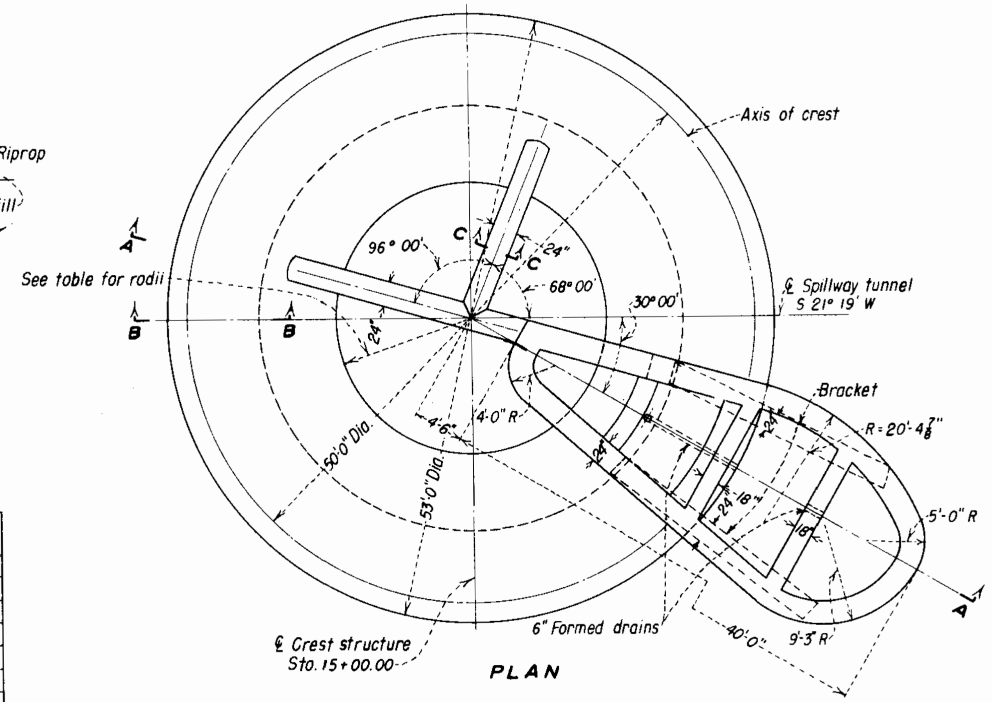
TRINITY MORNING-GLORY SPILLWAY
PRELIMINARY PROFILE, AIR INTAKE DEVICES
1:30 MODEL



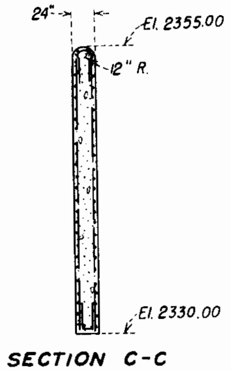
SECTIONAL ELEVATION A-A

SHAFT DIMENSIONS

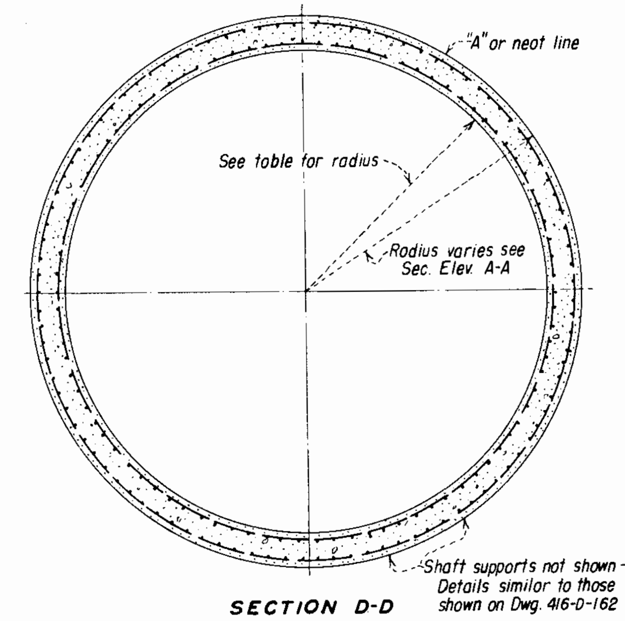
ELEVATION FEET	RADIUS FEET
2370.00	25.00
2369.95	24.44
2369.90	24.19
2369.80	23.68
2369.60	23.36
2369.30	22.76
2369.00	22.33
2368.50	21.73
2368.00	21.24
2367.00	20.41
2366.00	19.76
2365.00	19.19
2363.00	18.30
2361.00	17.63
2358.00	16.86
2355.00	16.30
2350.00	15.56
2345.00	15.04
2340.00	14.63
2335.00	14.27
2330.00	13.95
2320.00	13.41
2300.00	12.51
2270.00	11.68
2265.00	11.57
2260.00	11.48
2255.00	11.43
2250.00	11.41



PLAN



SECTION C-C



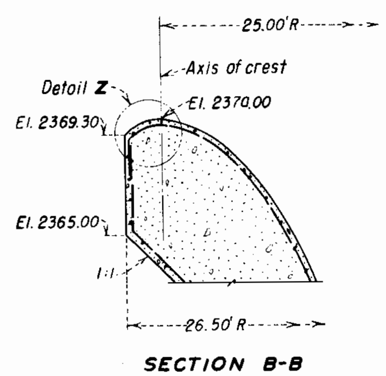
SECTION D-D

REFERENCE DRAWING

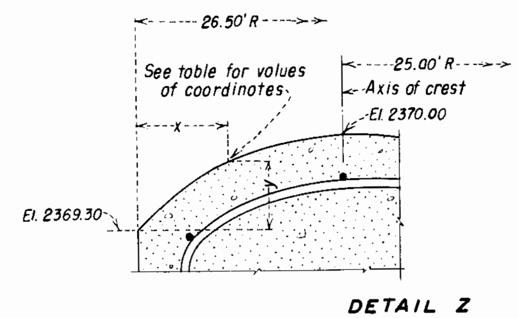
SPILLWAY PLAN AND SECTIONS.......416-D-162

NOTES

Design based on concrete with minimum compressive strength of 3000 pounds per square inch at 28 days
Chamfer all exposed, formed corners ¾" unless otherwise noted
All exposed, unformed corners to be tooled round
For concrete finishes see Dwg. 416-D-162



SECTION B-B



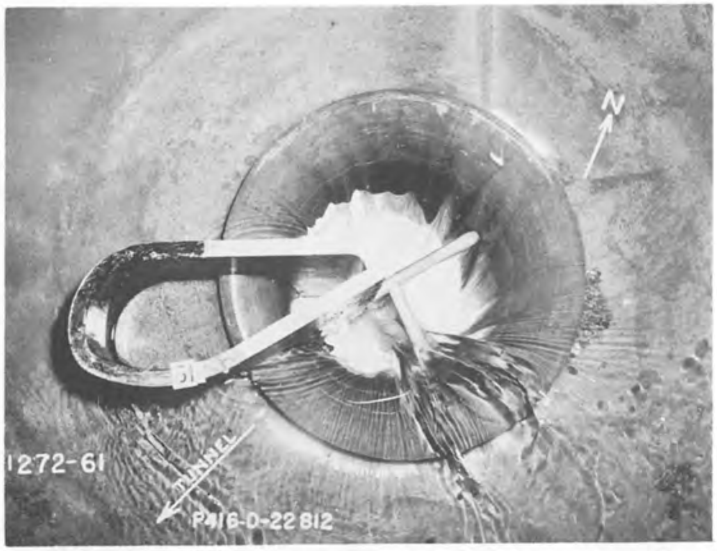
DETAIL Z

X FEET	Y FEET
0.00	0.00
0.25	0.25
0.50	0.43
0.75	0.55
1.00	0.63
1.25	0.68
1.50	0.70

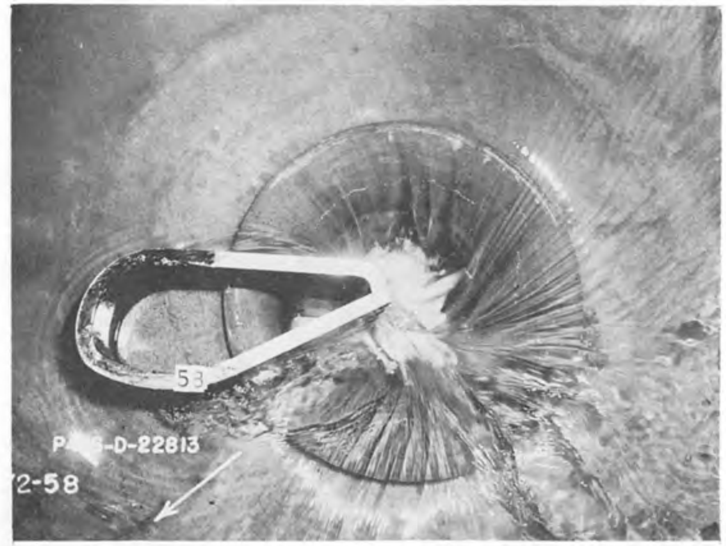
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION-CALIFORNIA

TRINITY DAM
SPILLWAY
CREST STRUCTURE

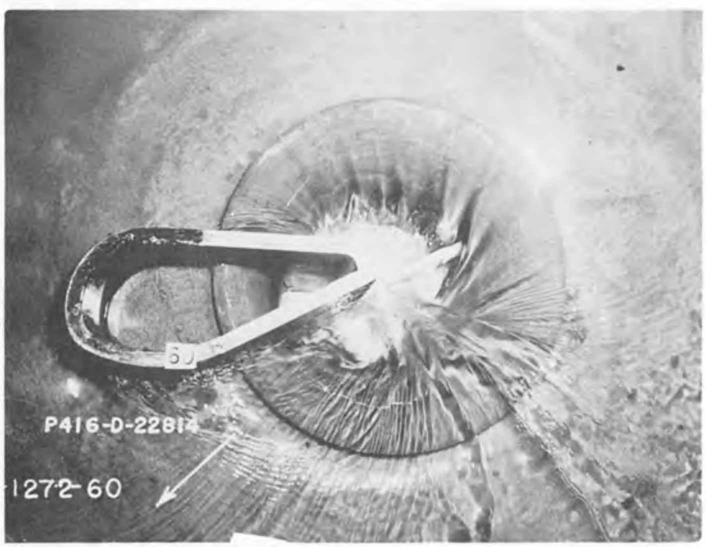
DRAWN W.R.W. SUBMITTED L. M. Holloway
TRACED N.R.W. RECOMMENDED R. W. Wagner
CHECKED G.W.K. APPROVED [signature] CHIEF DAMS BRANCH
DENVER, COLORADO, DEC. 3, 1956 416-D-163



A. Discharge 5,600 cfs



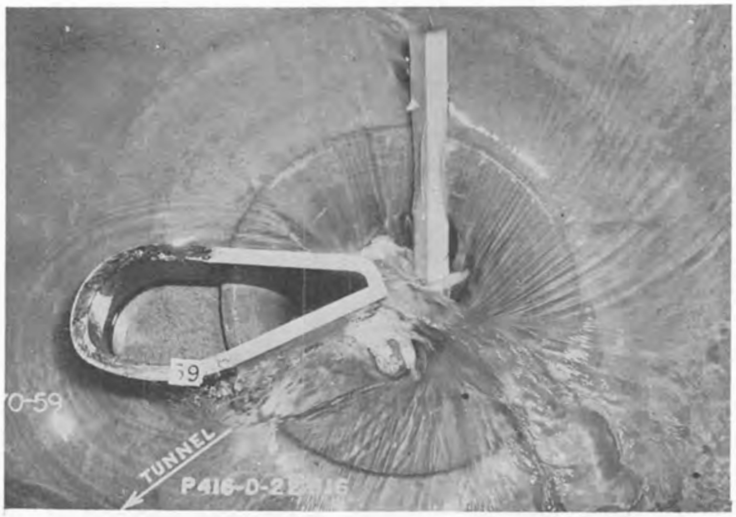
B. Discharge 16,800 cfs



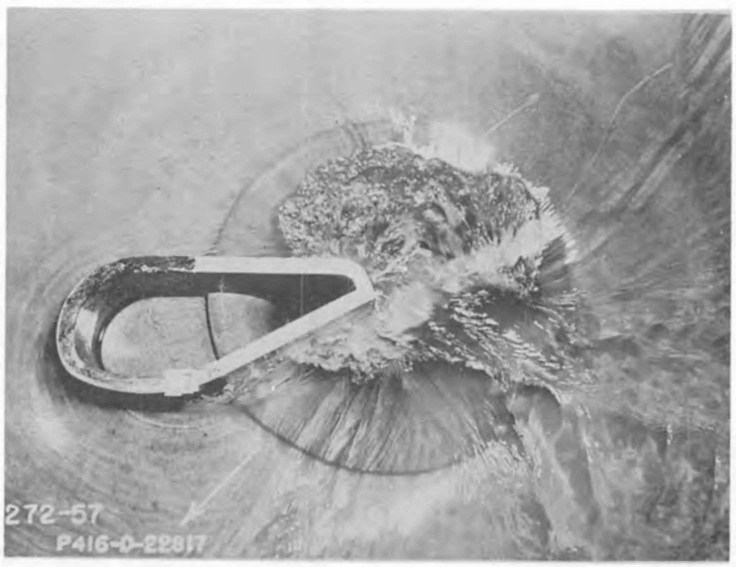
C. Discharge 22,400 cfs

D. Discharge 26,700 cfs

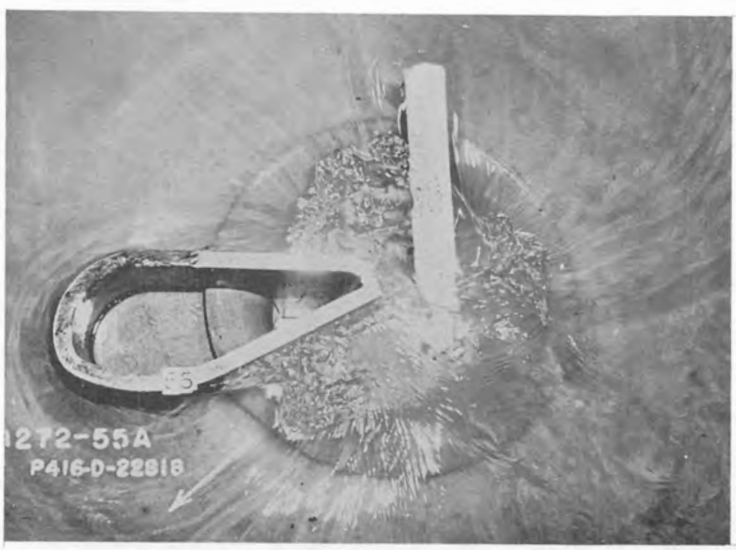
TRINITY MORNING-GLORY SPILLWAY
PRELIMINARY PROFILE, SCALED AIR INTAKE PIER AND GUIDE VANES
1:30 MODEL



A. Discharge 16,800 cfs

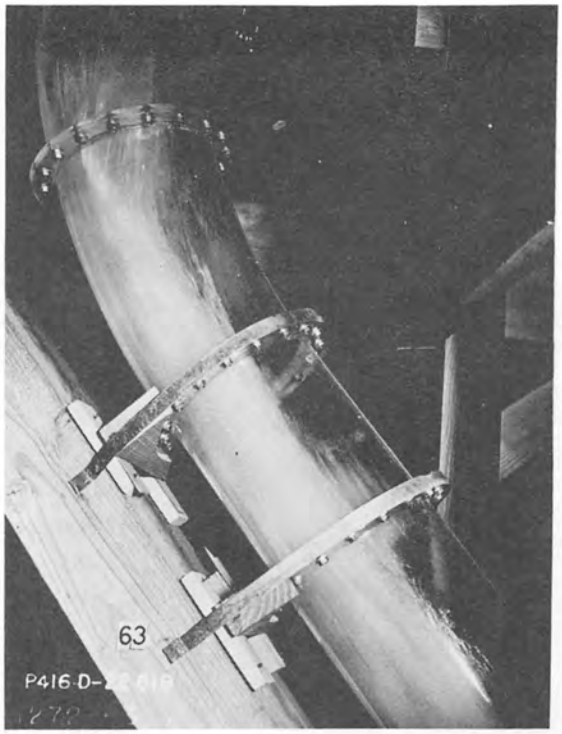


B. Discharge 22,400 cfs

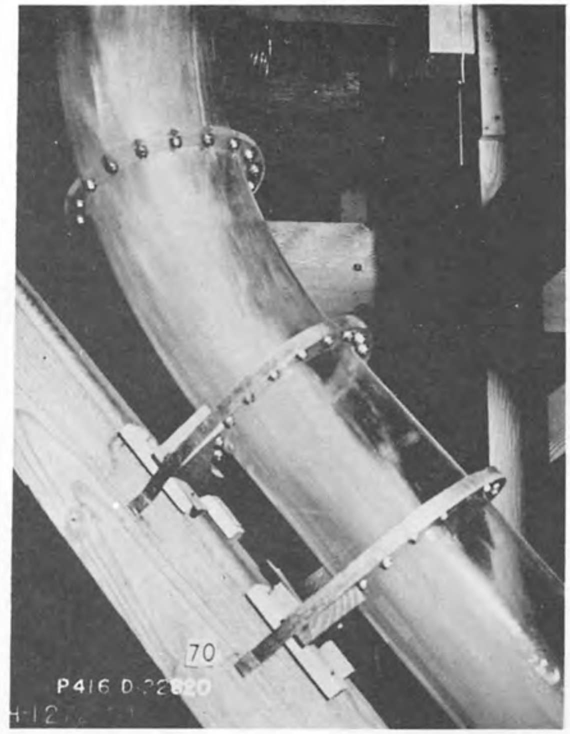


C. Discharge 26,700 cfs

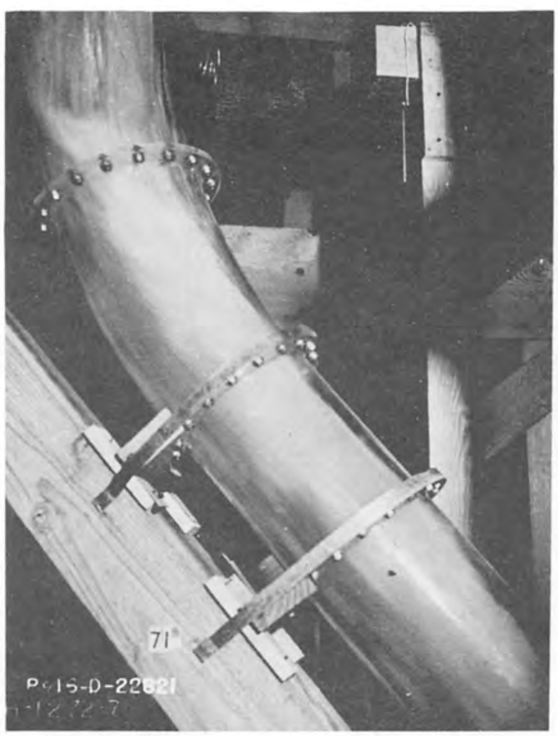
TRINITY MORNING-GLORY SPILLWAY
PRELIMINARY PROFILE, SCALED AIR INTAKE PIER AND GUIDE VANES
LOGS JAMMED IN THROAT OF STRUCTURE
1:30 MODEL



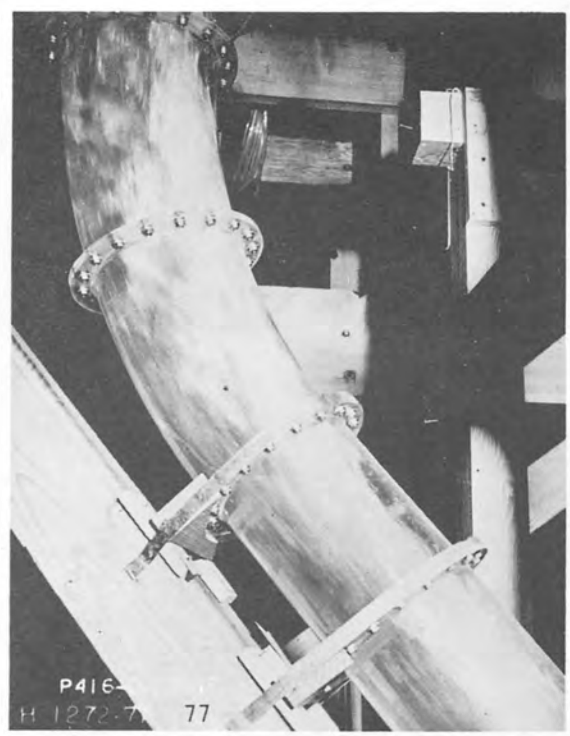
A. Discharge 11,200 cfs



B. Discharge 16,800 cfs

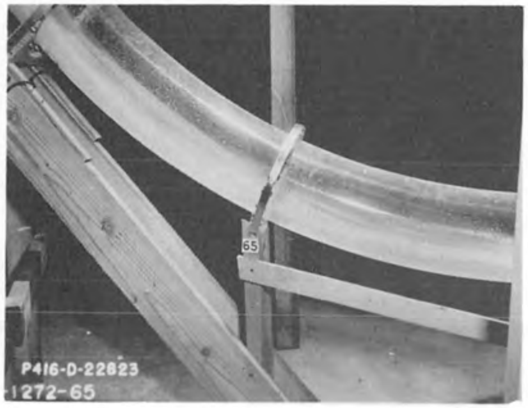


C. Discharge 22,400 cfs

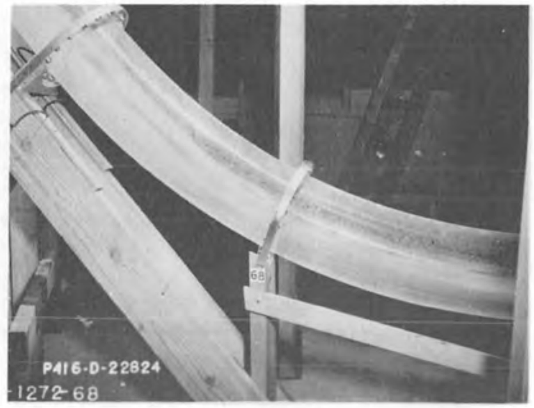


D. Discharge 26,700 cfs

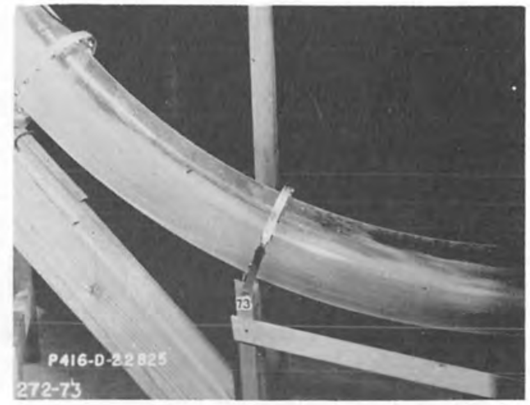
TRINITY MORNING-GLORY SPILLWAY
FLOWS IN UPPER BEND
PRELIMINARY PROFILE, SCALED AIR INTAKE PIER AND GUIDE VANES
1:30 MODEL



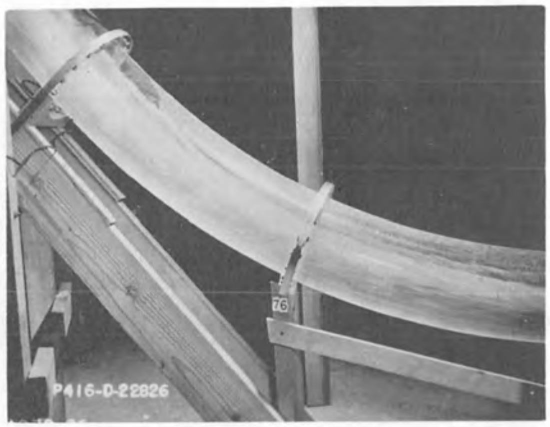
A. Discharge 11,200 cfs



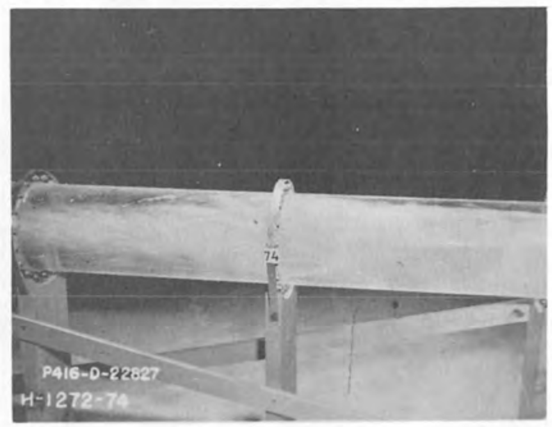
B. Discharge 16,800 cfs



C. Discharge 22,400 cfs

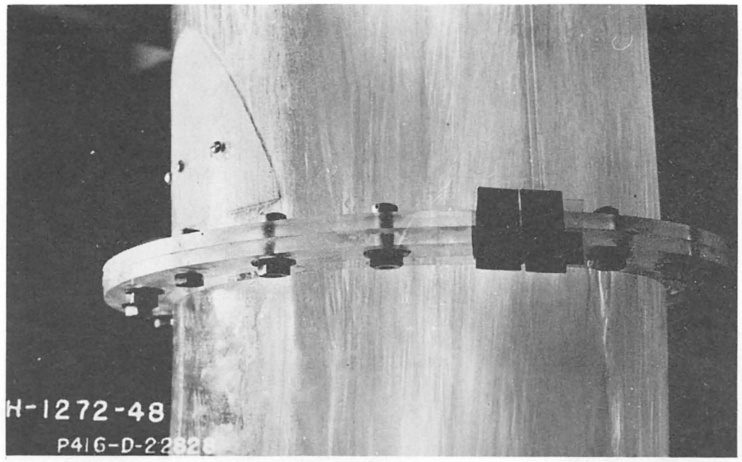


D. Discharge 26,700 cfs

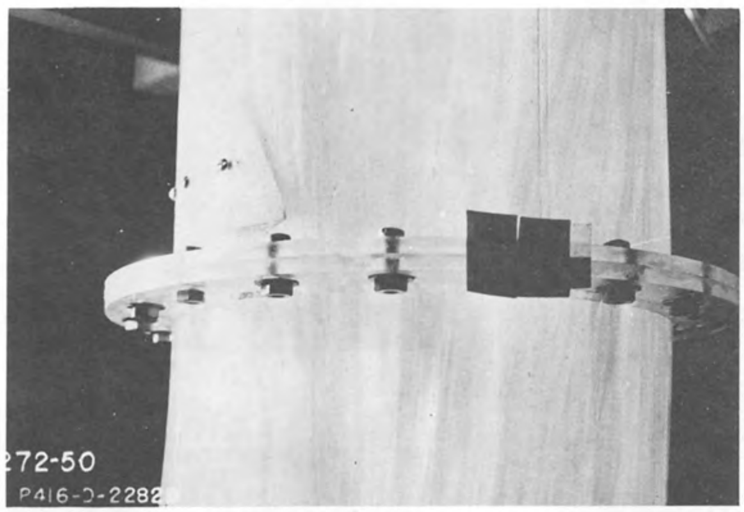


E. Discharge 22,400 cfs

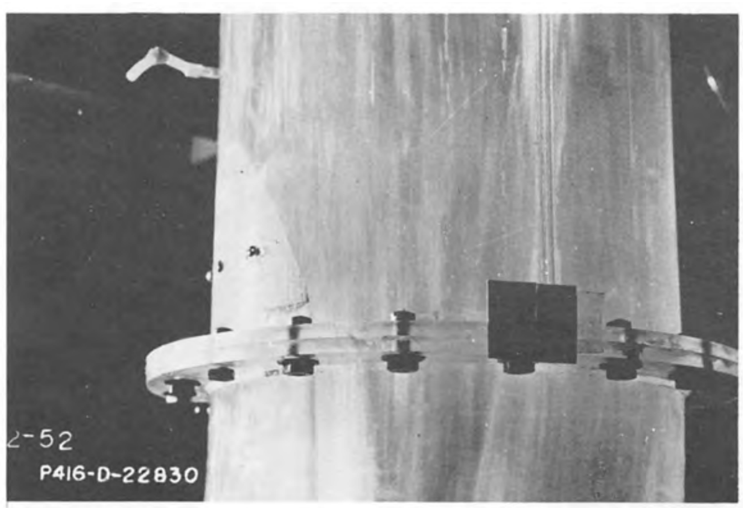
TRINITY MORNING-GLORY SPILLWAY
FLOW IN LOWER BEND AND TUNNEL
PRELIMINARY PROFILE, SCALED AIR INTAKE PIER AND GUIDE VANES
1:30 MODEL



A. Discharge 5,600 cfs

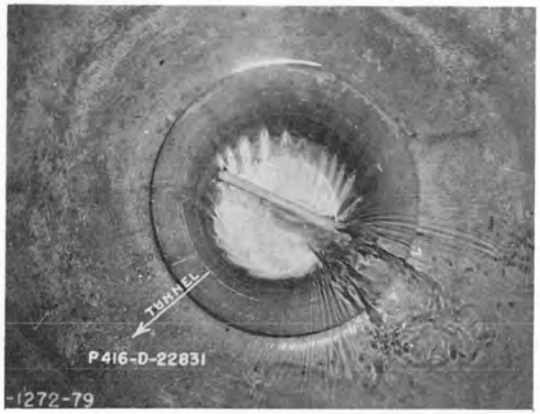


B. Discharge 16,800 cfs

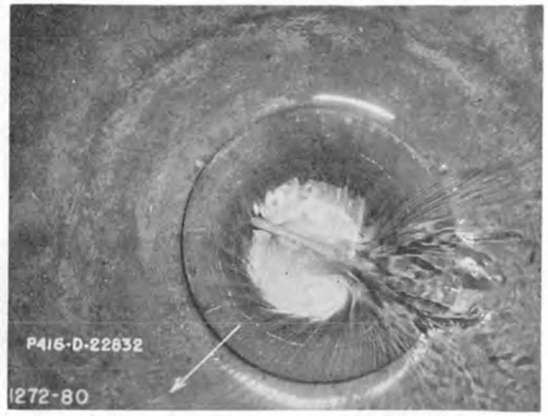


C. Discharge 26,700 cfs

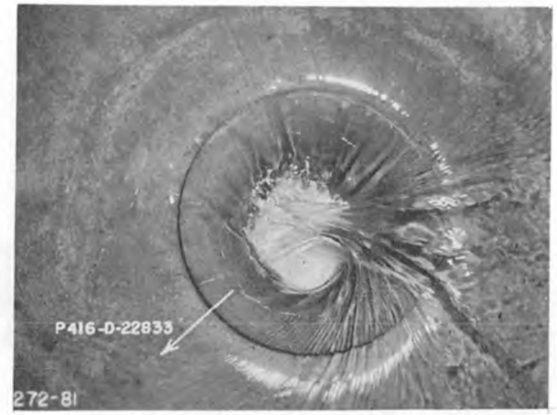
TRINITY MORNING-GLORY SPILLWAY
PRELIMINARY PROFILE, FLOWS AT PRELIMINARY DEFLECTOR
1:30 MODEL



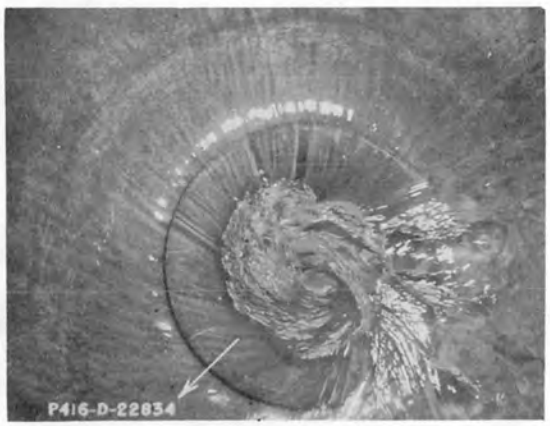
A. Discharge 5,600 cfs



B. Discharge 11,200 cfs



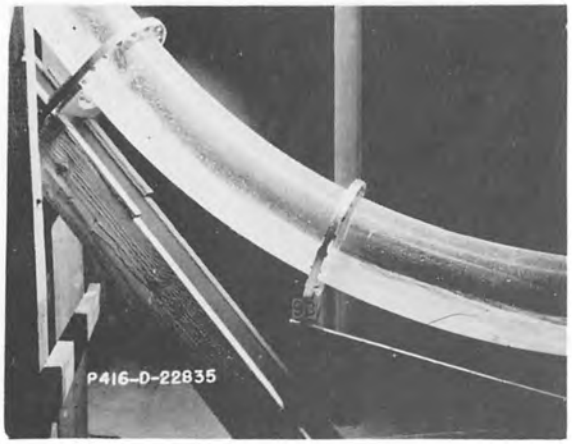
C. Discharge 16,800 cfs



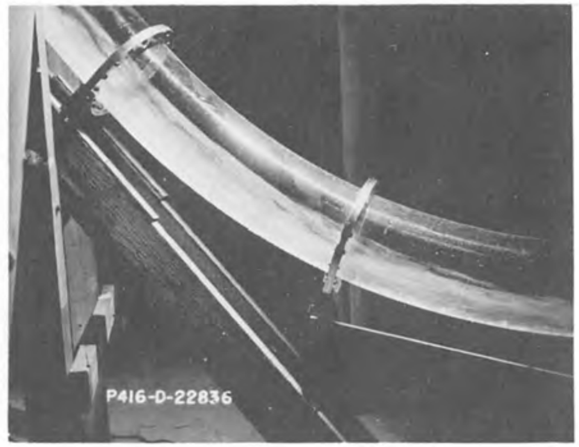
D. Discharge 22,400 cfs

E. Discharge 26,700 cfs

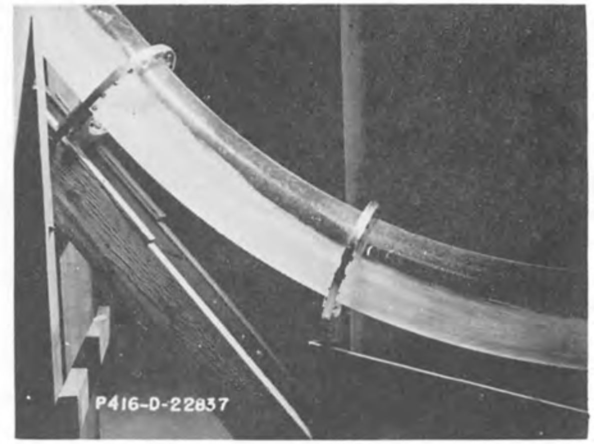
TRINITY MORNING-GLORY SPILLWAY
FLOW WITH SINGLE DIAMMETRICAL GUIDE VANE, PRELIMINARY PROFILE
1:30 MODEL



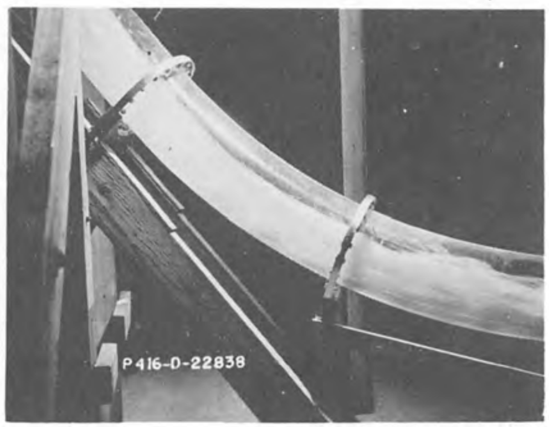
A. Discharge 5,600 cfs



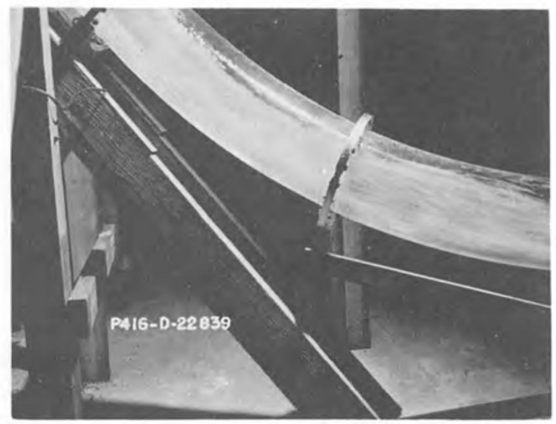
B. Discharge 11,700 cfs



C. Discharge 16,800 cfs



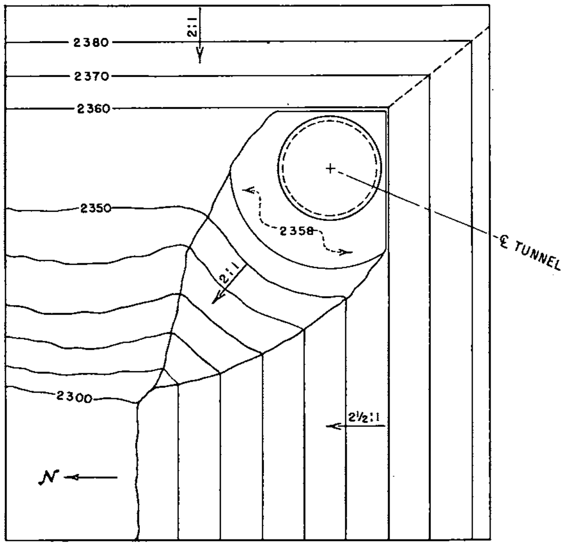
D. Discharge 22,400 cfs



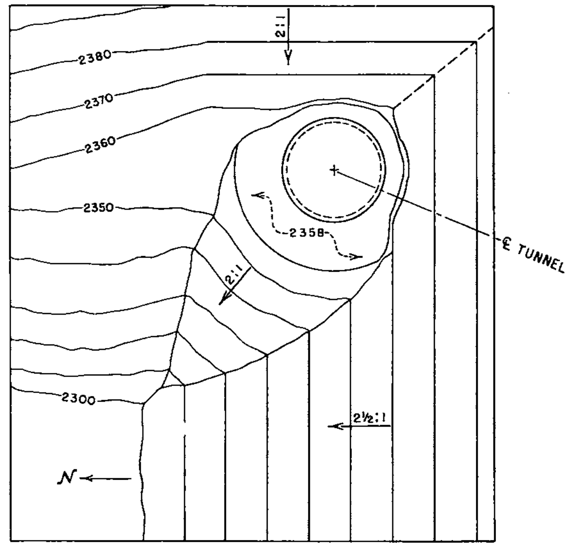
E. Discharge 26,700 cfs

TRINITY MORNING-GLORY SPILLWAY
FLOWS IN LOWER BEND
PRELIMINARY PROFILE, SINGLE DIAMMETRICAL GUIDE VANE
1:30 MODEL

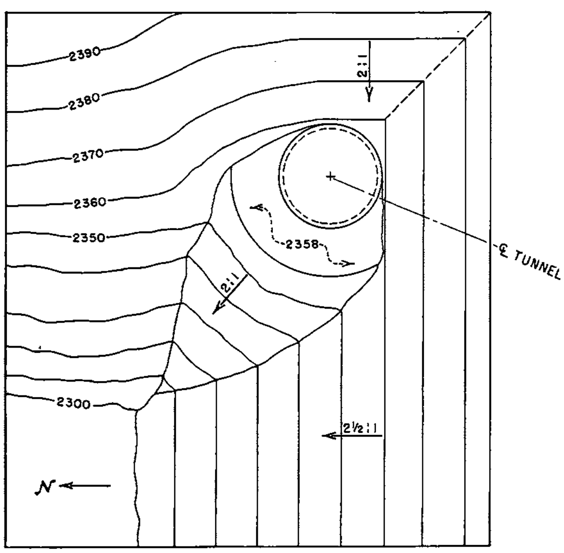
Figure 25
Report HYD - 447



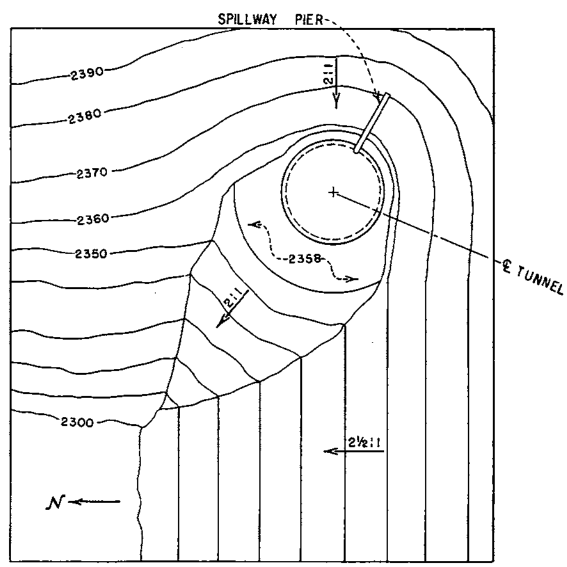
A.– FIRST MODIFICATION



B.– SECOND MODIFICATION



C.– THIRD MODIFICATION

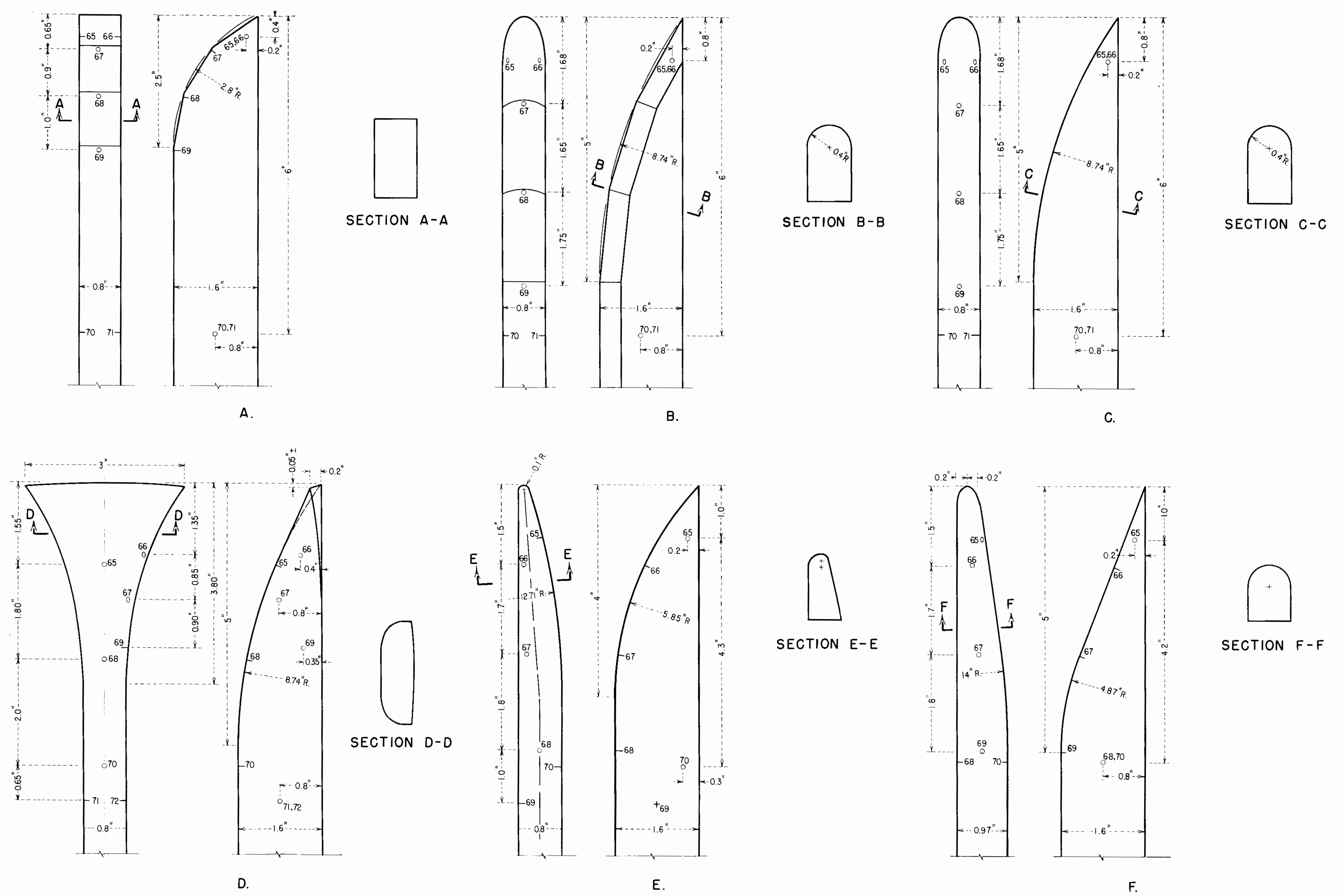


D.– RECOMMENDED CONFIGURATION

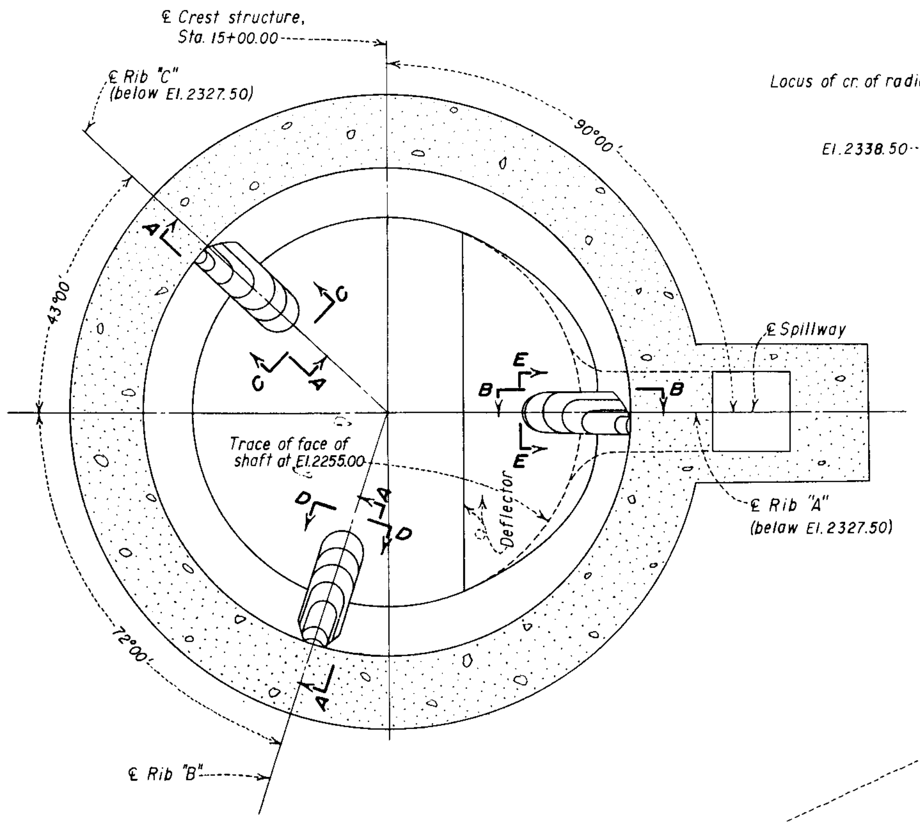
TRINITY MORNING-GLORY SPILLWAY

MODIFICATIONS OF TOPOGRAPHIC FEATURES

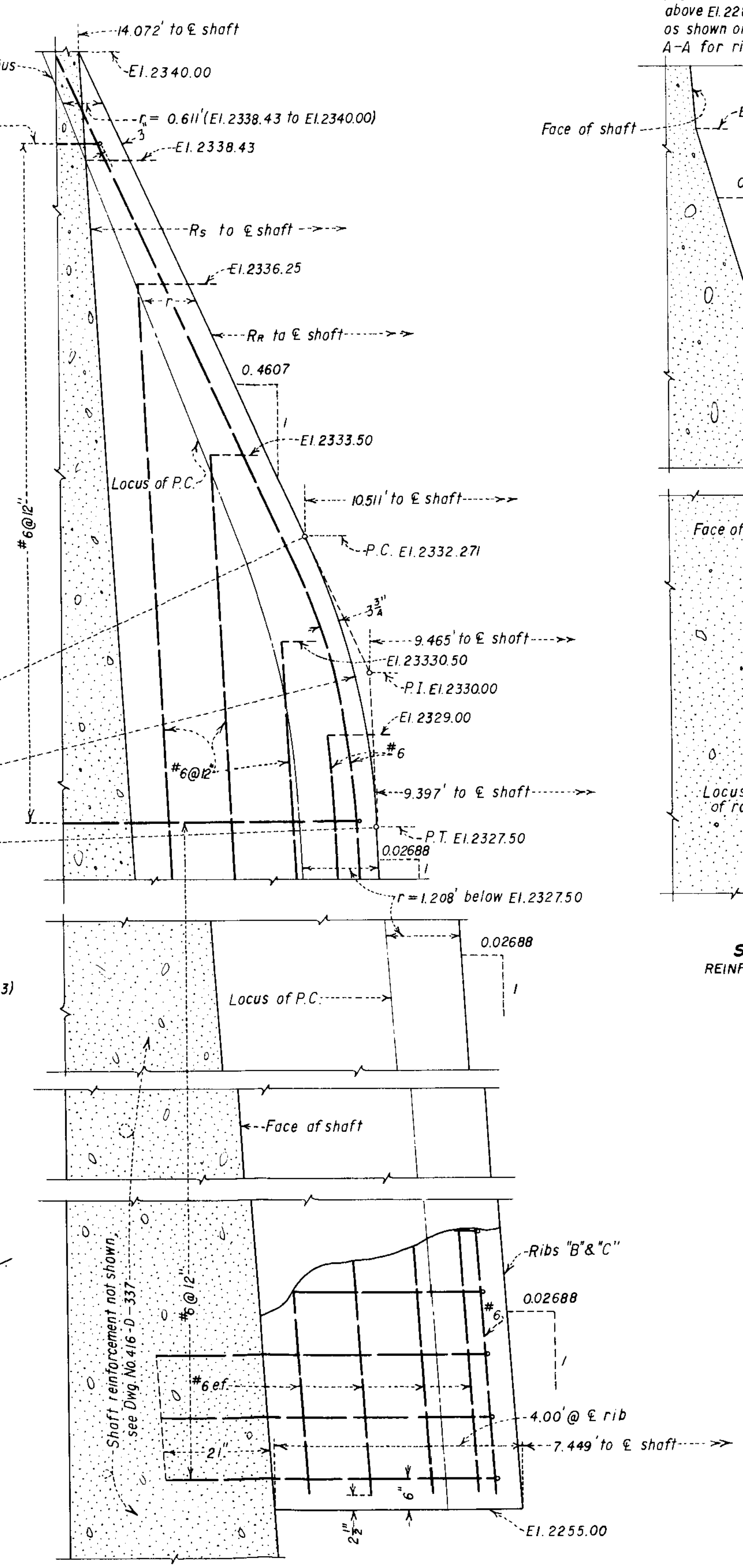
1:30 MODEL



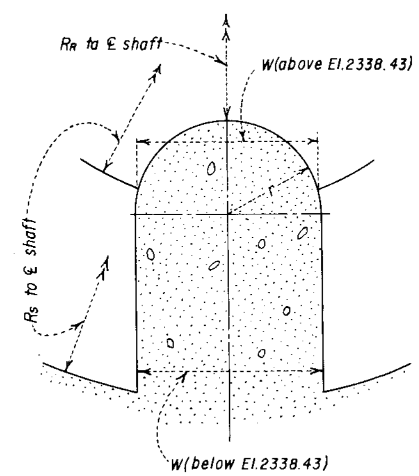
TRINITY MORNING-GLORY SPILLWAY
RIB VANE DESIGNS-TOP DETAILS
1:30 MODEL



SECTIONAL PLAN
El. 2340.00



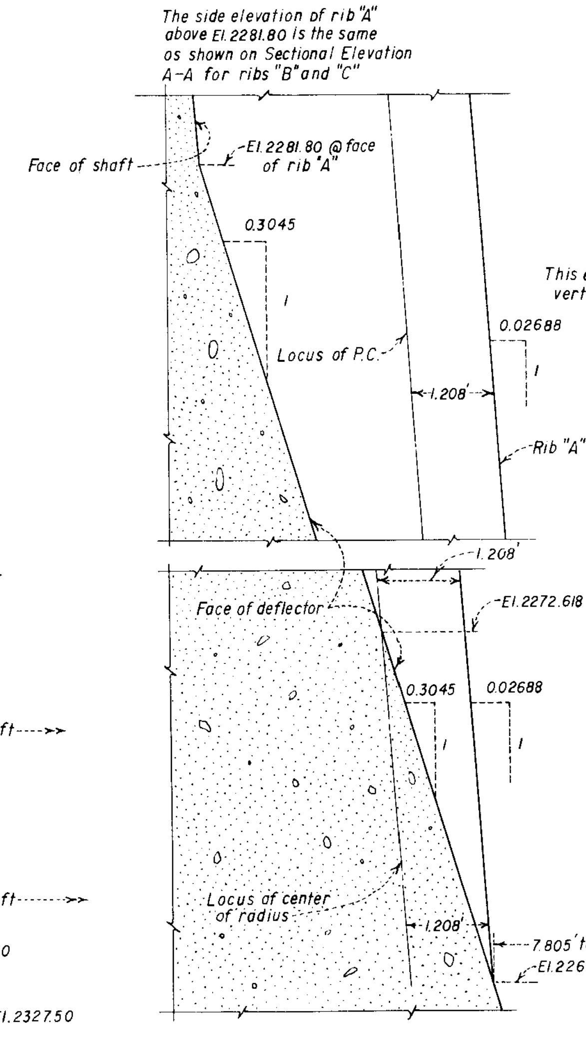
SECTIONAL ELEVATION A-A



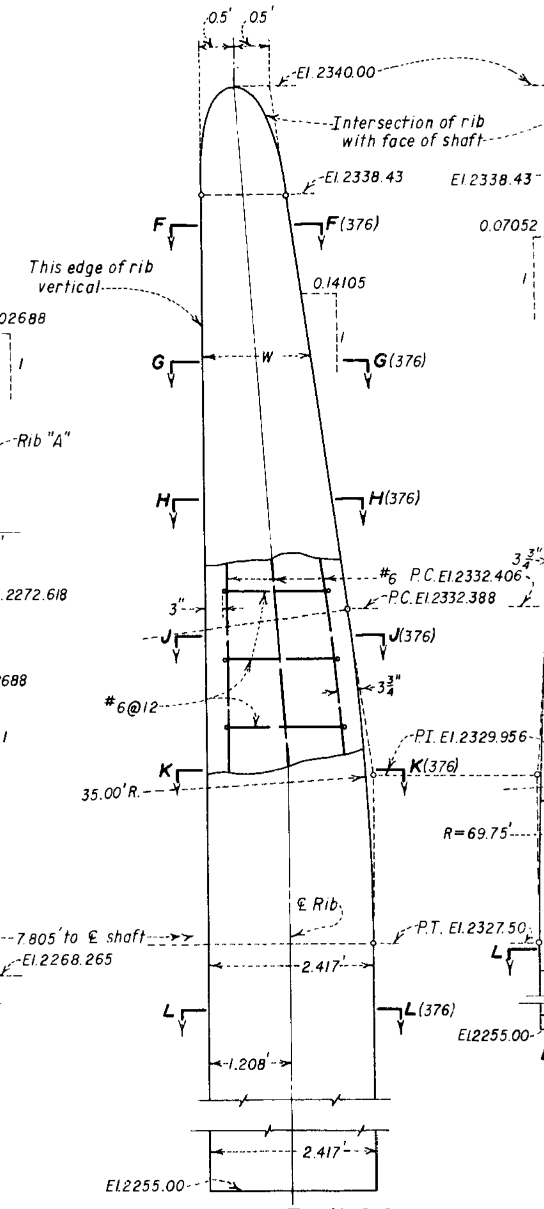
ELEV (Ft.)	R_S (Ft.)	R_R (Ft.)	W (Ft.)	r (Ft.)
2340.00	14.072	14.072	0	0.611
2339.95	14.068	14.049	0.301	0.611
2339.90	14.065	14.025	0.423	0.611
2339.80	14.059	13.979	0.590	0.611
2339.60	14.046	13.887	0.807	0.611
2339.30	14.026	13.749	1.011	0.611
2339.00	14.007	13.611	1.134	0.611
2338.70	13.989	13.473	1.201	0.611
2338.43	13.972	13.348	1.221	0.611
2338.00	13.946	13.150	1.282	0.641
2337.00	13.886	12.689	1.423	0.712
2336.00	13.828	12.229	1.564	0.782
2335.00	13.771	11.768	1.705	0.853
2334.00	13.717	11.307	1.846	0.923
2333.00	13.664	10.847	1.987	0.994
2332.41	13.634	10.576	2.070	1.035
2332.39	13.633	10.567	2.073	1.037
2332.27	13.627	10.511	2.089	1.044
2332.00	13.613	10.390	2.126	1.063
2331.00	13.563	10.010	2.241	1.121
2330.00	13.514	9.726	2.327	1.164
2329.00	13.466	9.531	2.385	1.192
2328.00	13.420	9.421	2.413	1.207
2327.50	13.397	9.397	2.417	1.208
2255.00	11.449	7.449	2.417	1.208

For intermediate values of Rs between El. 2255 and El. 2325, see Dwg. 416-D-337.

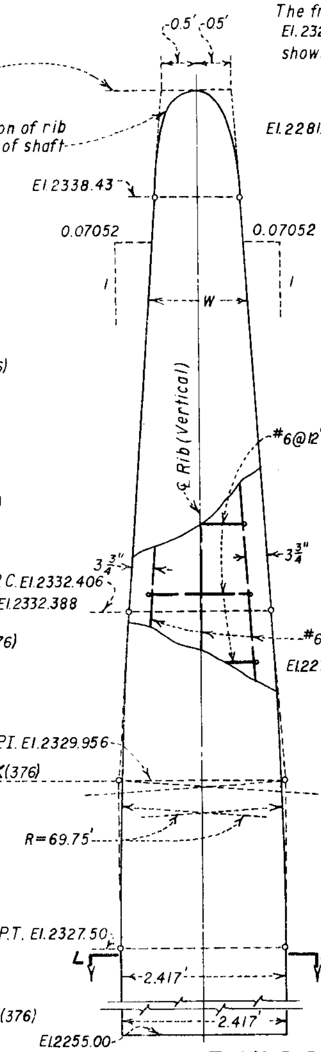
RIB DIMENSIONS



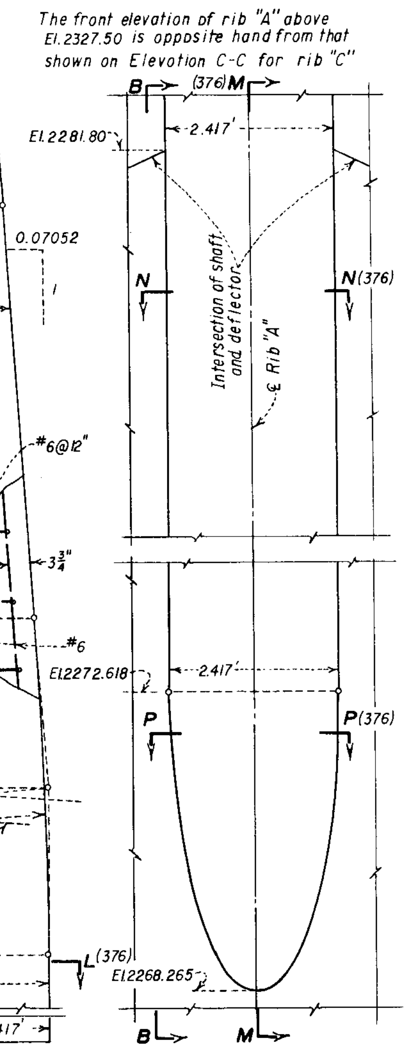
SECTION B-B
REINFORCEMENT NOT SHOWN



ELEVATION C-C
RIB "C"



ELEVATION D-D
RIB "B"



ELEVATION E-E
RIB "A"

NOTES

For general notes, see Dwgs. 40-D-5530 and 40-D-5586.
Concrete finish shall be F4 on all faces of rib vanes except bottom faces.
Dimensions given to 3 decimal places for control in interpolation.

REFERENCE DRAWINGS

CREST STRUCTURE-CONCRETE AND REINFORCEMENT DETAILS 416-D-337
RIB VANES-CONCRETE AND REINFORCEMENT DETAILS, SHEET 2 .... 416-D-376

12-9-58 D CAW | TRACED.

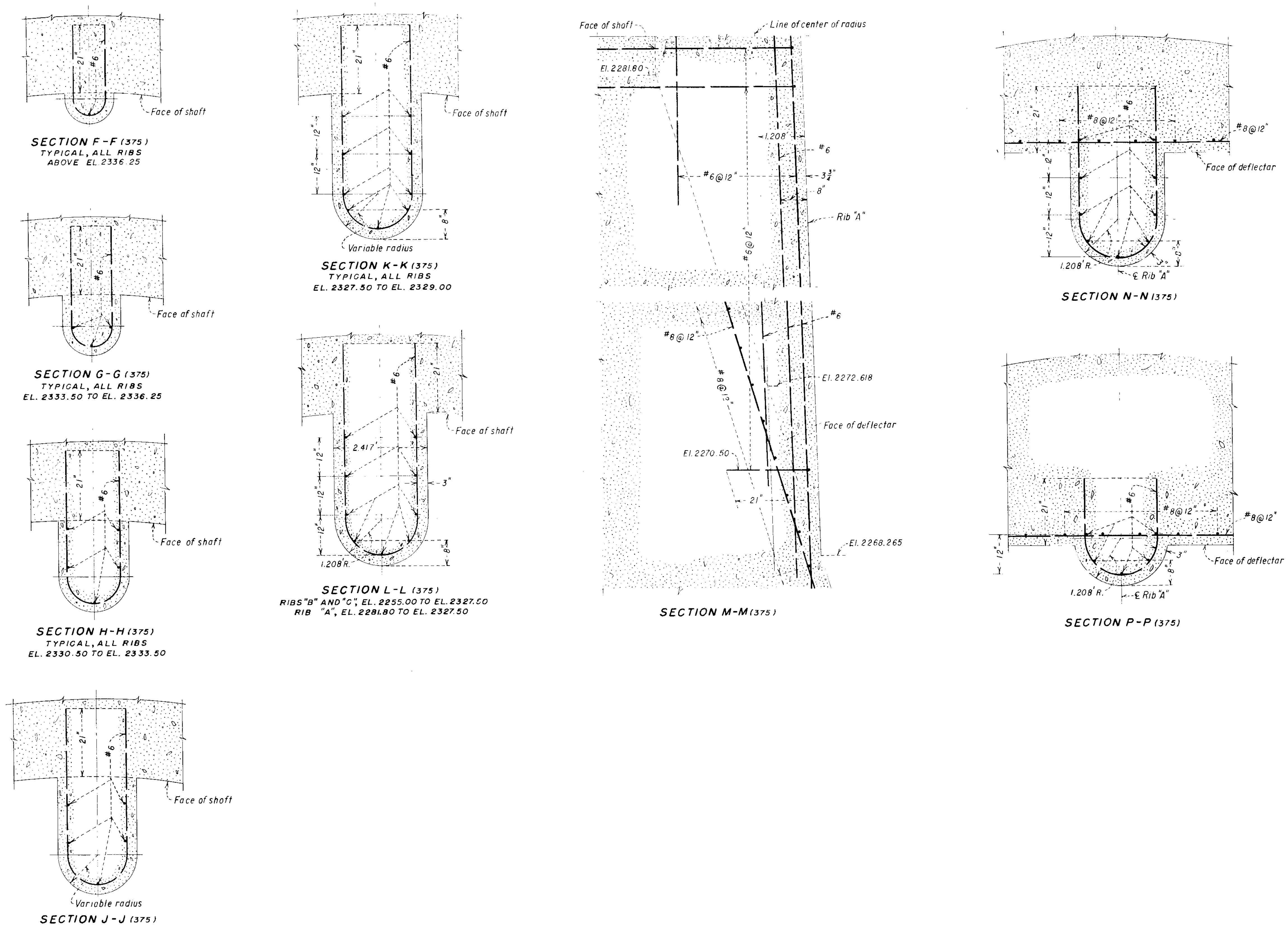
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION-CALIFORNIA

TRINITY DAM
SPILLWAY
CREST STRUCTURE-RIB VANES
CONCRETE AND REINFORCEMENT DETAILS

DRAWN G.C.M. SUBMITTED F.M. Holdaway
TRACED D.W.G. RECOMMENDED C.J. Hoffman
CHECKED C.A.W. APPROVED O.L. Rice, CHIEF, DAMS BRANCH

DENVER, COLORADO, AUGUST 13, 1958
SHEET 1 OF 2

416-D-375



NOTES

Shaft reinforcement not shown.

REFERENCE DRAWINGS

CREST STRUCTURE-CONCRETE AND REINFORCEMENT DETAILS 416-D-337
RIB VANES-CONCRETE AND REINFORCEMENT DETAILS, SHEET 1 .... 416-D-375

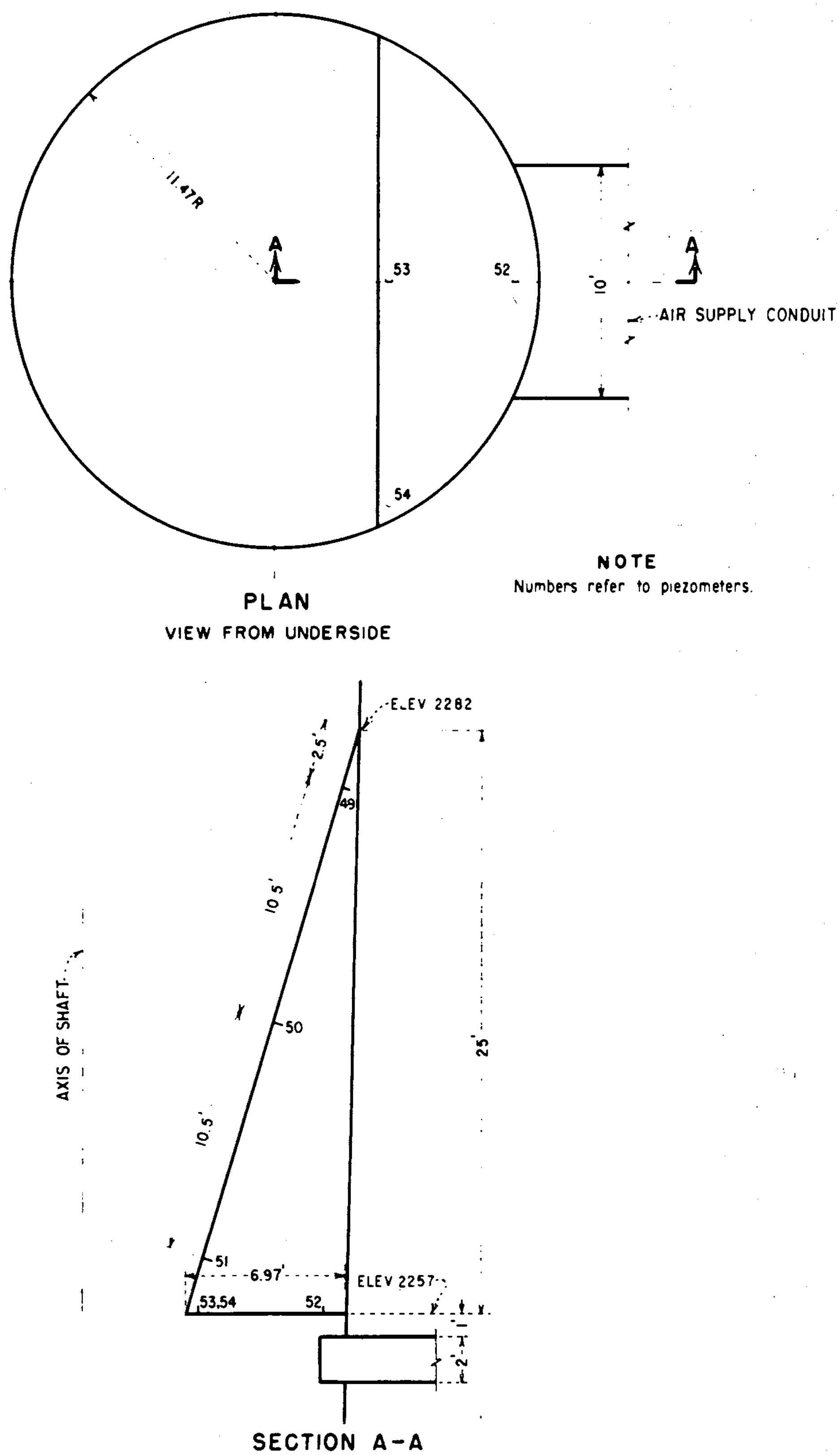
12-15-58 D CAW	TRACED

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION-CALIFORNIA

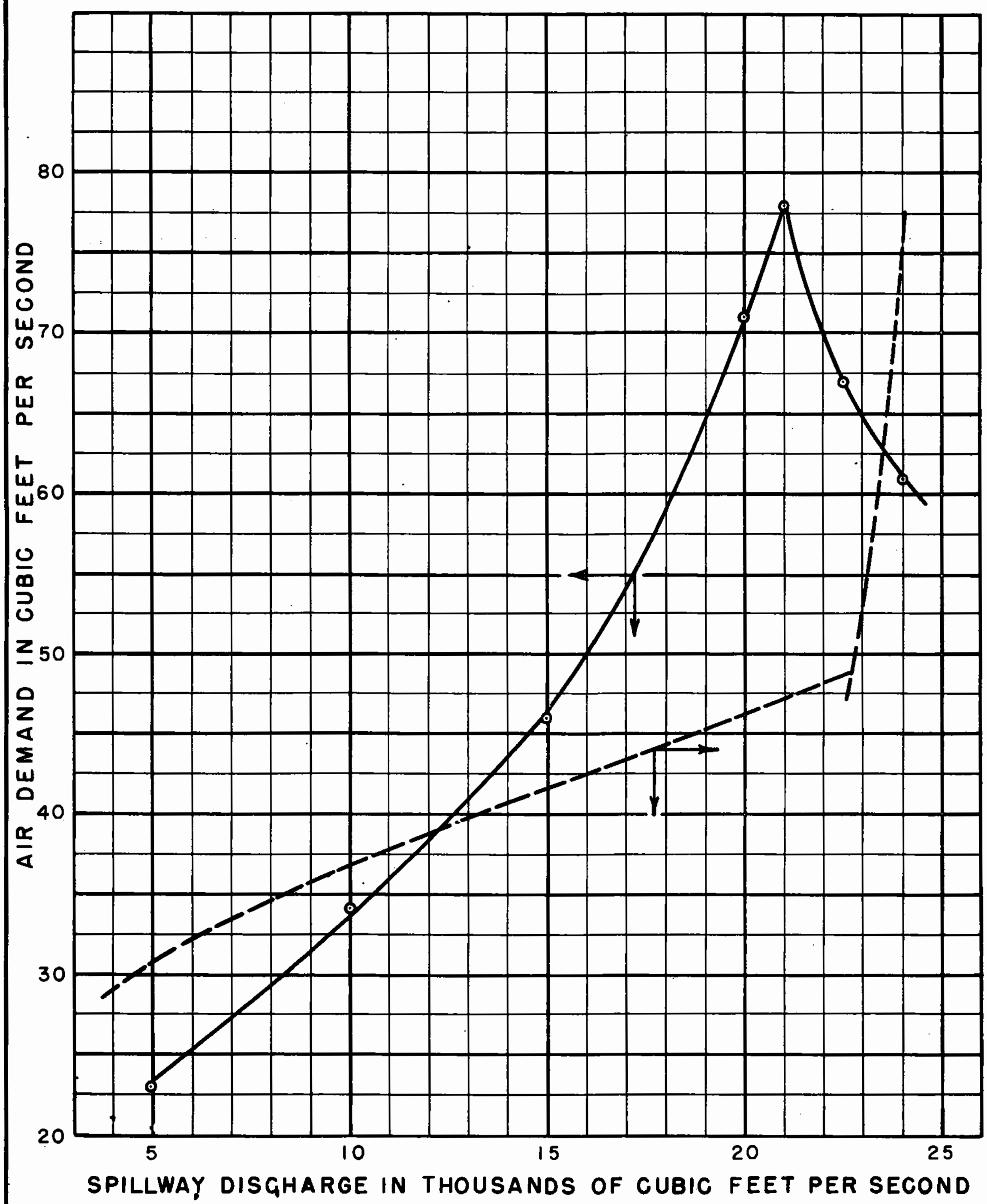
TRINITY DAM
SPILLWAY
CREST STRUCTURE - RIB VANES
CONCRETE AND REINFORCEMENT DETAILS

DRAWN G.C.M. SUBMITTED F. M. Holdaway
TRACED H.J.W. RECOMMENDED C.J. Hoffman
CHECKED C.A.W. APPROVED O.L. Rice CHIEF, DAMS BRANCH

DENVER, COLORADO, AUGUST 13, 1958 SHEET 2 OF 2 | 416-D-376



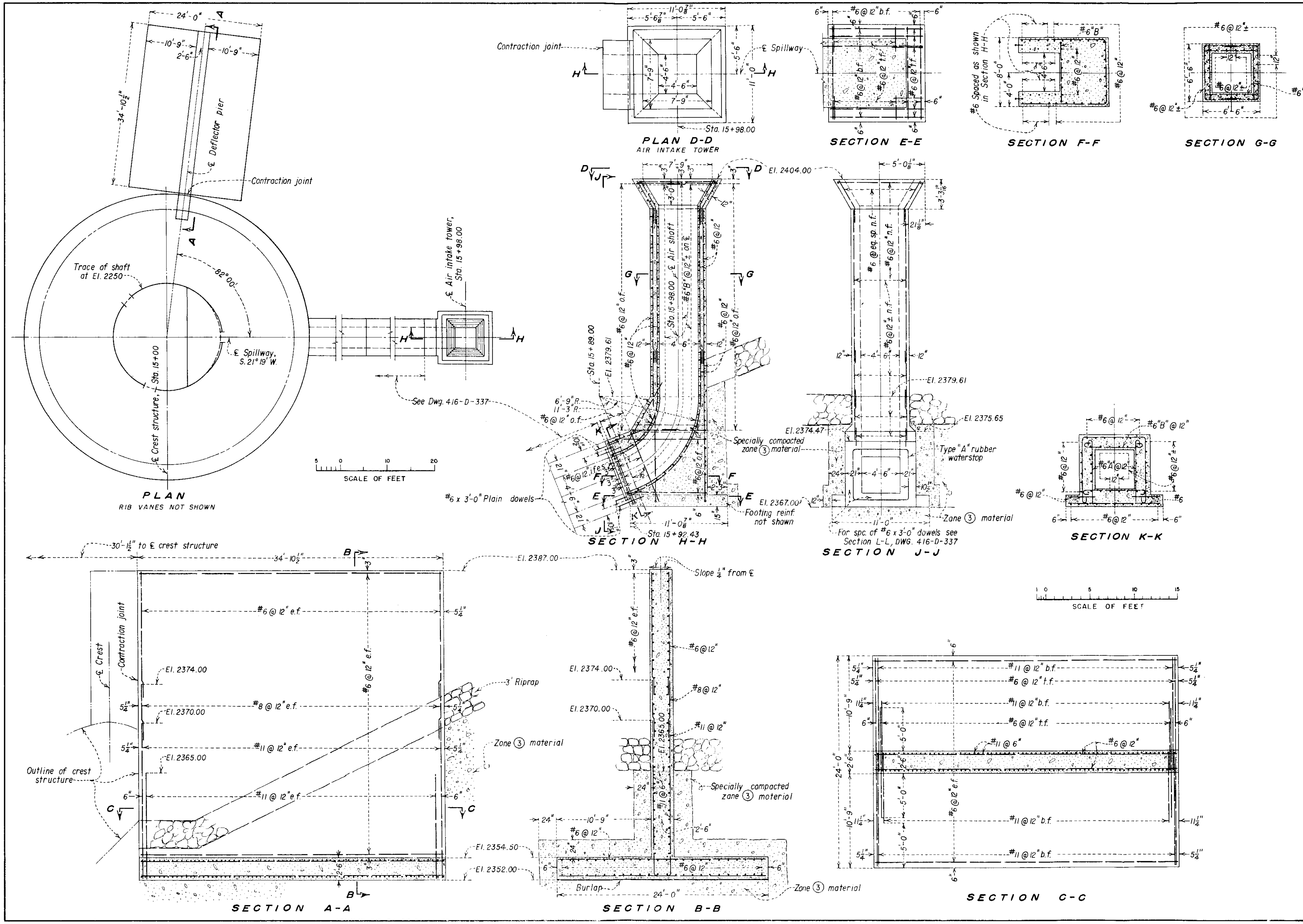
TRINITY MORNING-GLORY SPILLWAY
FLOW DEFLECTOR
1:30 MODEL



TRINITY MORNING-GLORY SPILLWAY

DEFLECTOR AIR DEMAND VS. SPILLWAY DISCHARGE
RECOMMENDED DEFLECTOR 6.97' x 25'

1:30 MODEL



NOTES
For general notes, see Dwg 40-D-5530 and Dwg. 40-D-5586

REFERENCE DRAWINGS
SPILLWAY - PLAN AND SECTIONS 416-D-162
CREST STRUCTURE - CONCRETE AND REINFORCEMENT DETAILS 416-D-337

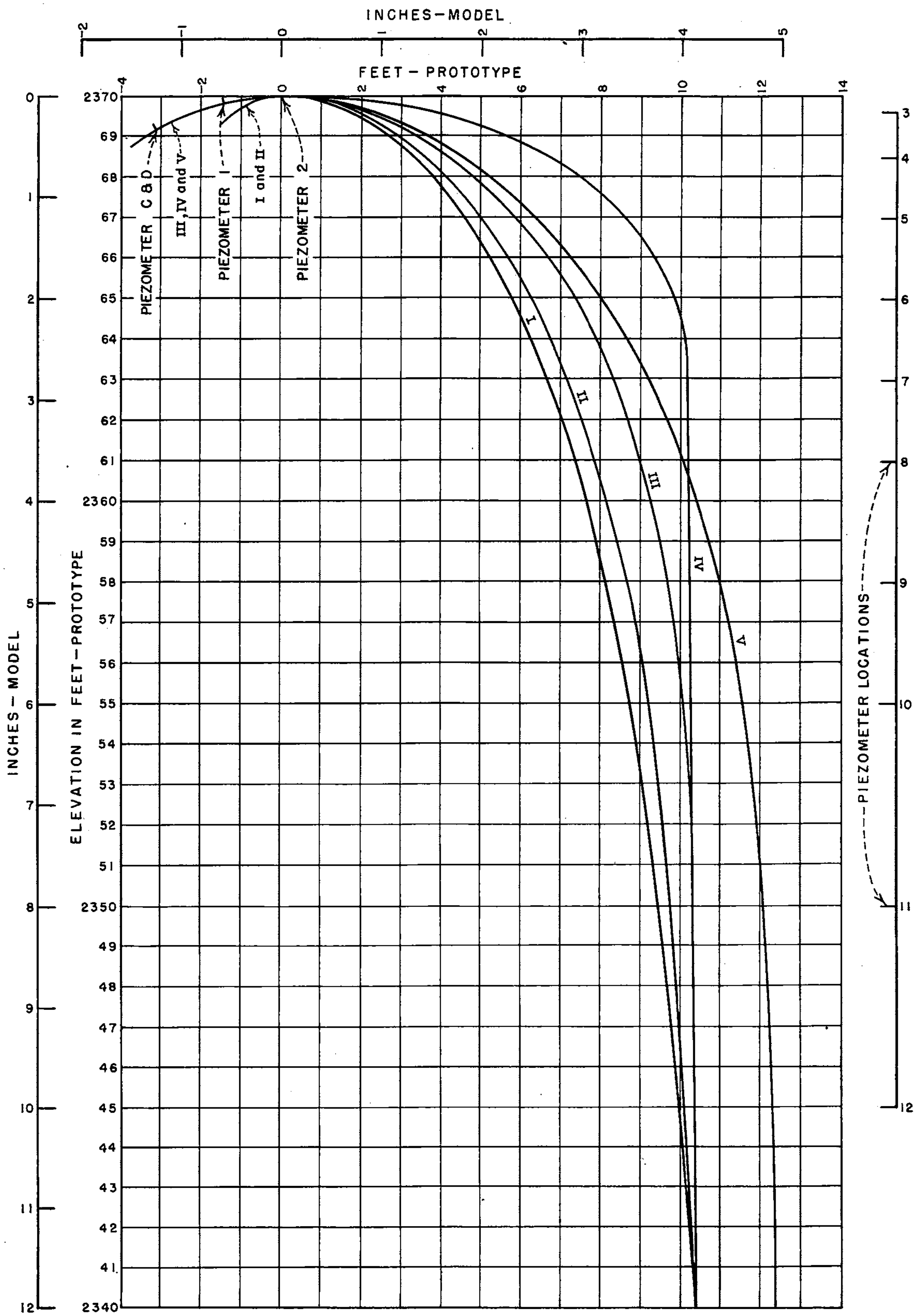
12-17-58 D CAW | TRACED.

THIS DRAWING AND DWG. 416-D-337 SUPERSEDE DWG. 416-D-163

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
TRINITY RIVER DIVISION - CALIFORNIA

TRINITY DAM
SPILLWAY
DEFLECTOR PIER AND AIR INTAKE TOWER
CONCRETE AND REINFORCEMENT DETAILS

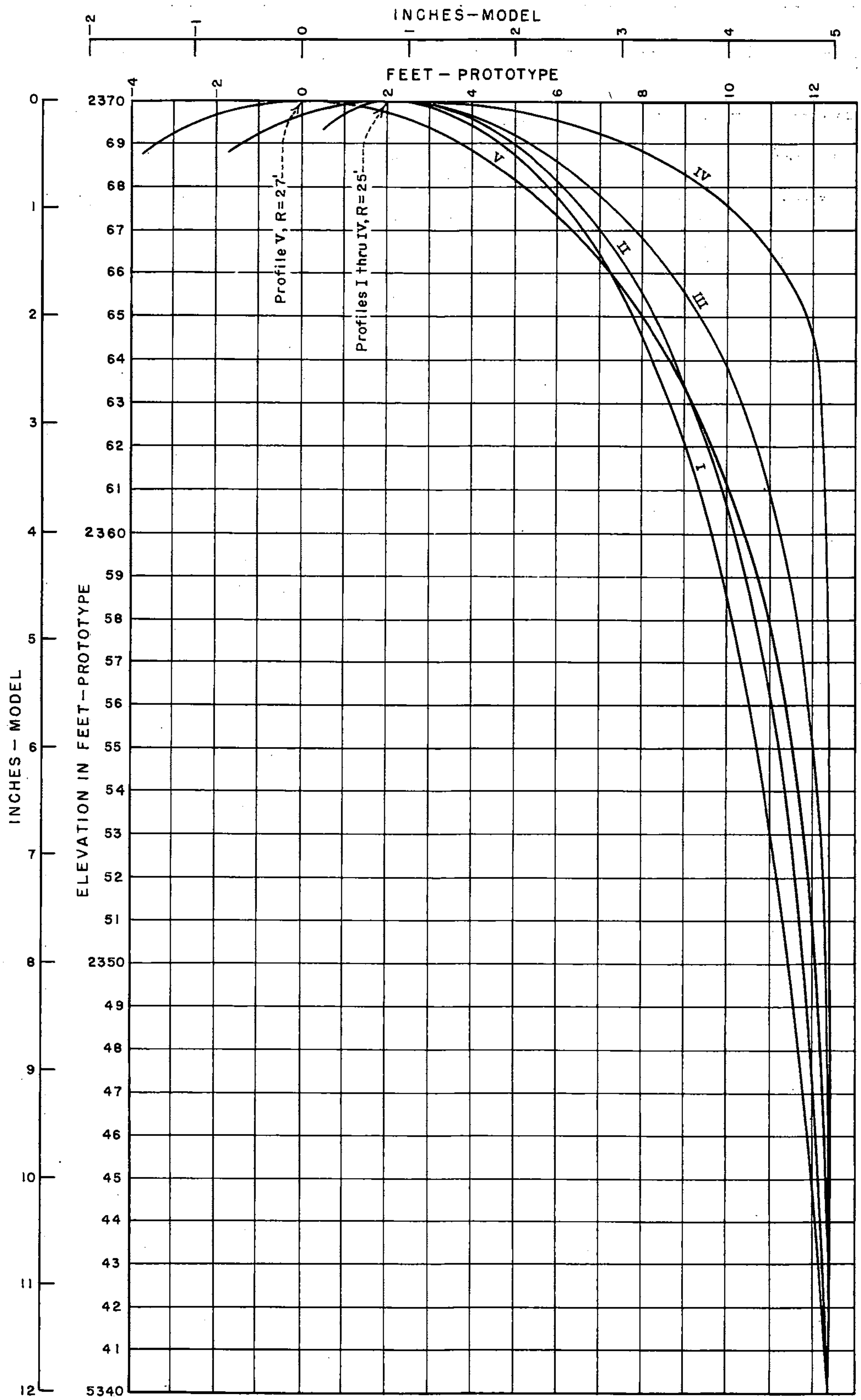
DRAWN ... S.S.S. ... SUBMITTED ... F. M. Holdaway
TRACED ... R.T.S. ... RECOMMENDED ... C. J. Hoffman
CHECKED ... C. A. W. ... APPROVED ... O. L. Rice
CHIEF, DAMS BRANCH
DENVER, COLORADO, AUGUST 11, 1958 | 416-D-338



TRINITY MORNING-GLORY SPILLWAY

PROFILES I-V PLOTTED WITH COMMON CREST DIAMETER

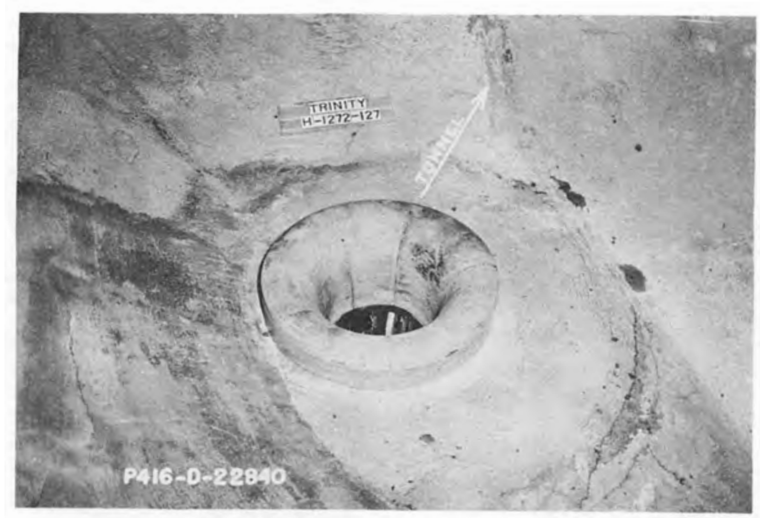
1:30 MODEL



TRINITY MORNING-GLORY SPILLWAY

PROFILES I-V PLOTTED IN TRUE RELATIVE POSITIONS

1:30 MODEL



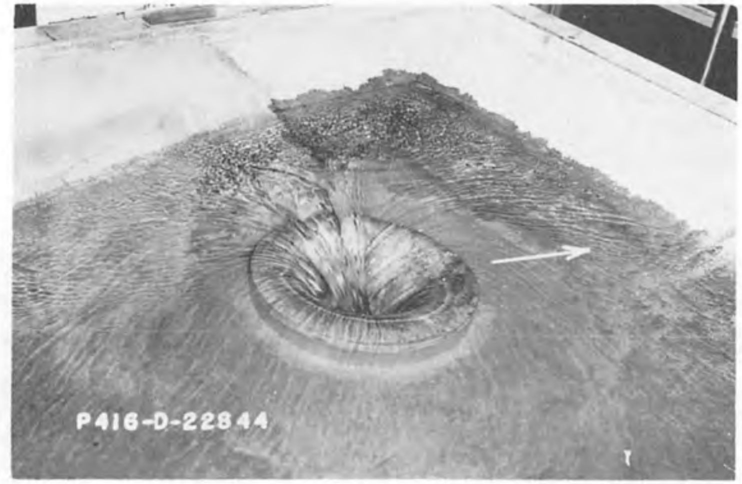
A. Preliminary Topography

B. Final Topography

C. Final Topography with Spillway Pier

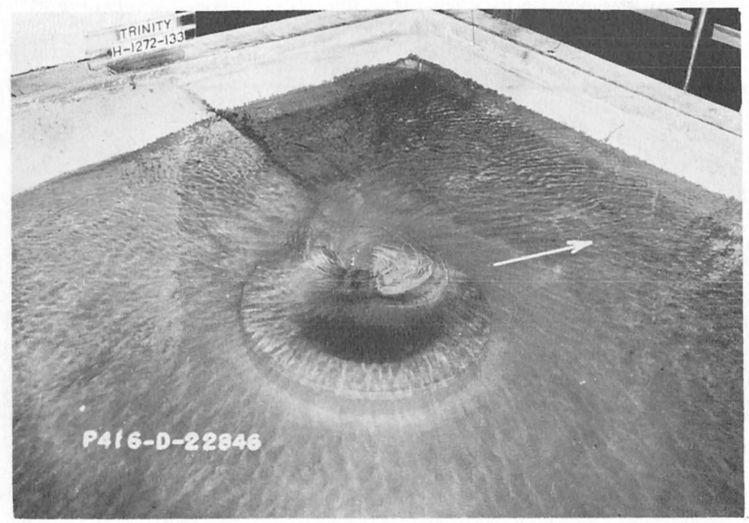
TRINITY MORNING-GLORY SPILLWAY
TOPOGRAPHY CHANGES WITH RECOMMENDED PROFILE
1:30 MODEL

A. Discharge 15,000 cfs



B. Discharge 20,000 cfs

C. Discharge 22,500 cfs



D. Discharge 24,000 cfs

TRINITY MORNING-GLORY SPILLWAY
PERFORMANCE OF RECOMMENDED PROFILE WITH PRELIMINARY TOPOGRAPHY
1:30 MODEL

A. Discharge 5,000 cfs

B. Discharge 10,000 cfs

C. Discharge 15,000 cfs

TRINITY MORNING-GLORY SPILLWAY
PERFORMANCE OF RECOMMENDED PROFILE WITH FINAL TOPOGRAPHY
1:30 MODEL

A. Discharge 20,000 cfs

B. Discharge 23,000 cfs

C. Discharge 24,000 cfs

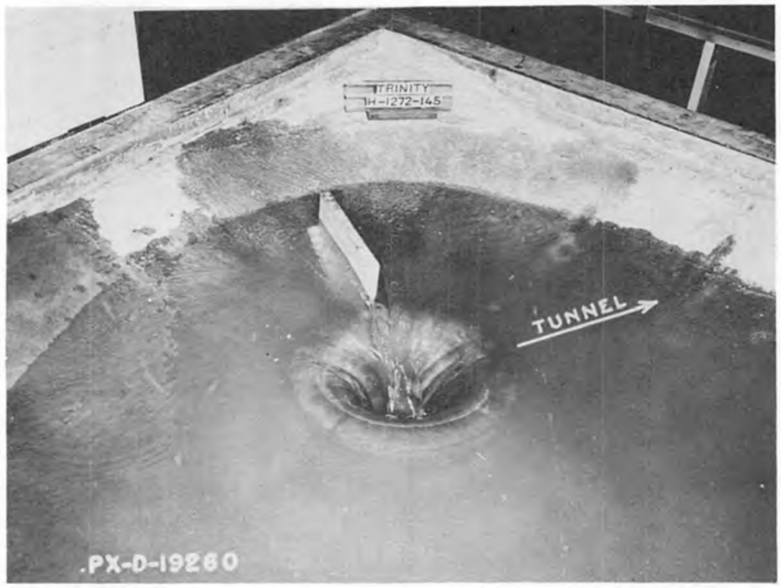
TRINITY MORNING-GLORY SPILLWAY
PERFORMANCE OF RECOMMENDED PROFILE WITH FINAL TOPOGRAPHY
1:30 MODEL

A. Discharge 5,000 cfs

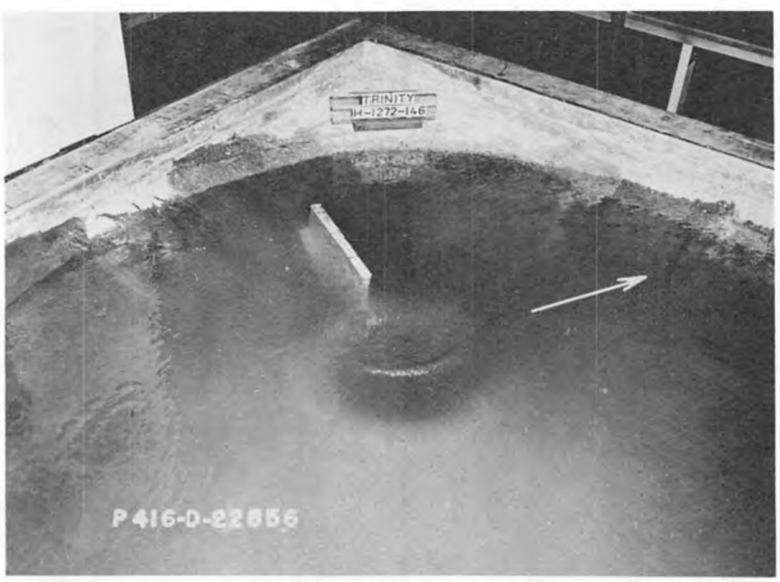
B. Discharge 10,000 cfs

C. Discharge 15,000 cfs

TRINITY MORNING-GLORY SPILLWAY
OPERATION OF RECOMMENDED DESIGN
1:30 MODEL



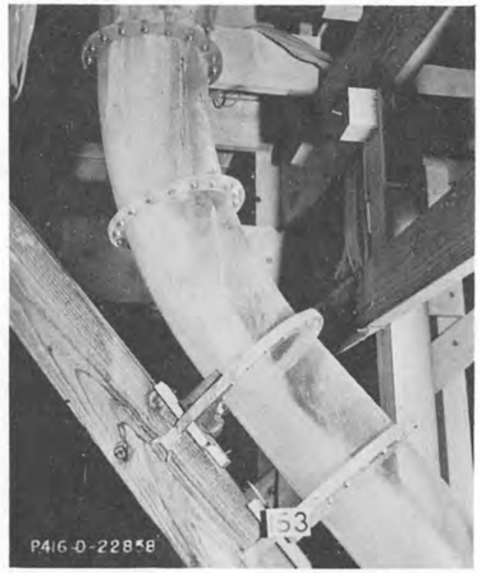
A. Discharge 20,000 cfs



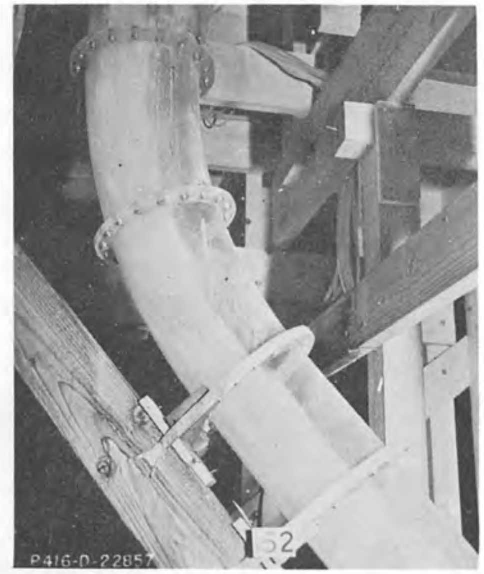
B. Discharge 24,000 cfs

TRINITY MORNING-GLORY SPILLWAY
OPERATION OF RECOMMENDED DESIGN
1:30 MODEL

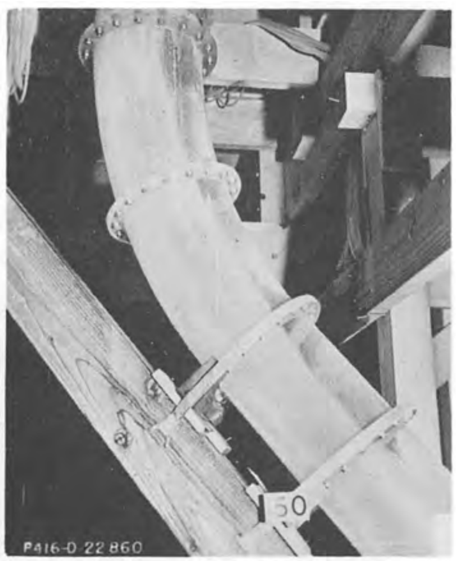
A. Discharge 5,000 cfs



B. Discharge 10,000 cfs

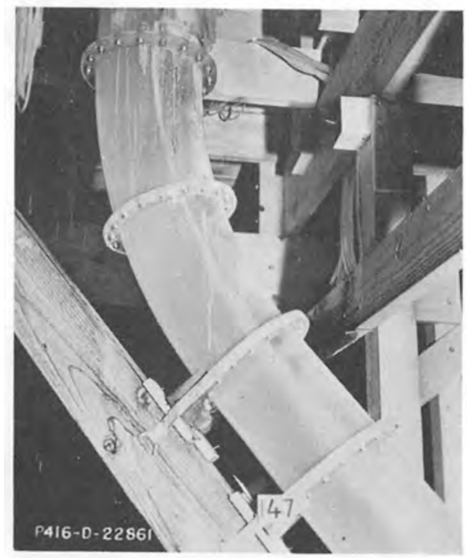


C. Discharge 15,000 cfs

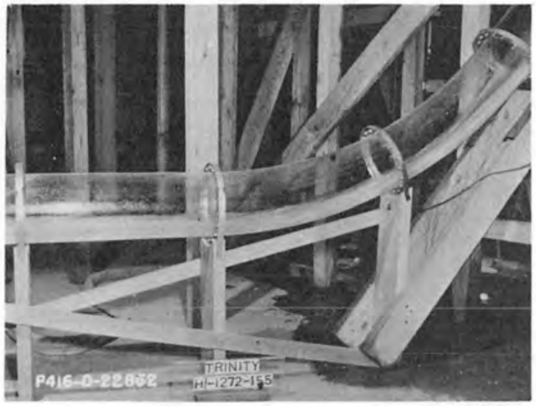


D. Discharge 20,000 cfs

TRINITY MORNING-GLORY SPILLWAY
RECOMMENDED DESIGN
FLOW IN UPPER BEND
1:30 MODEL



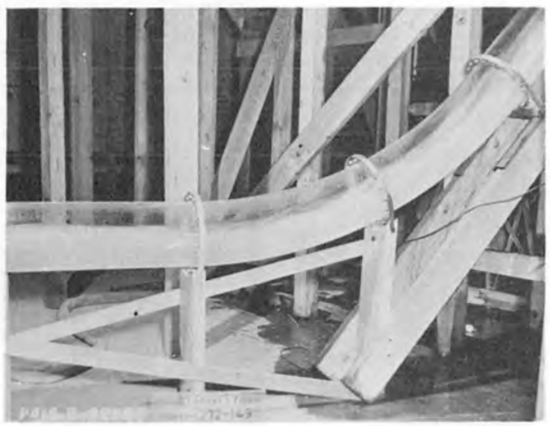
E. Discharge 24,000 cfs



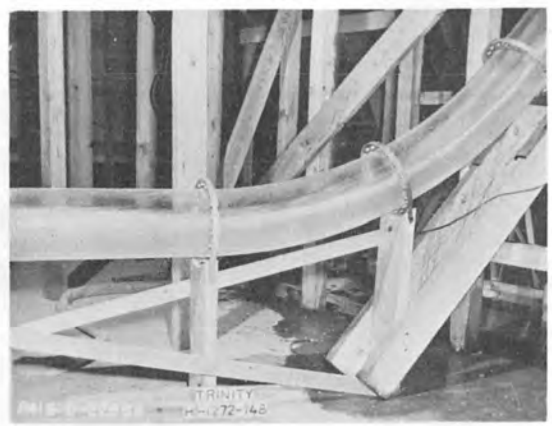
A. Discharge 5,000 cfs

B. Discharge 10,000 cfs

C. Discharge 15,000 cfs

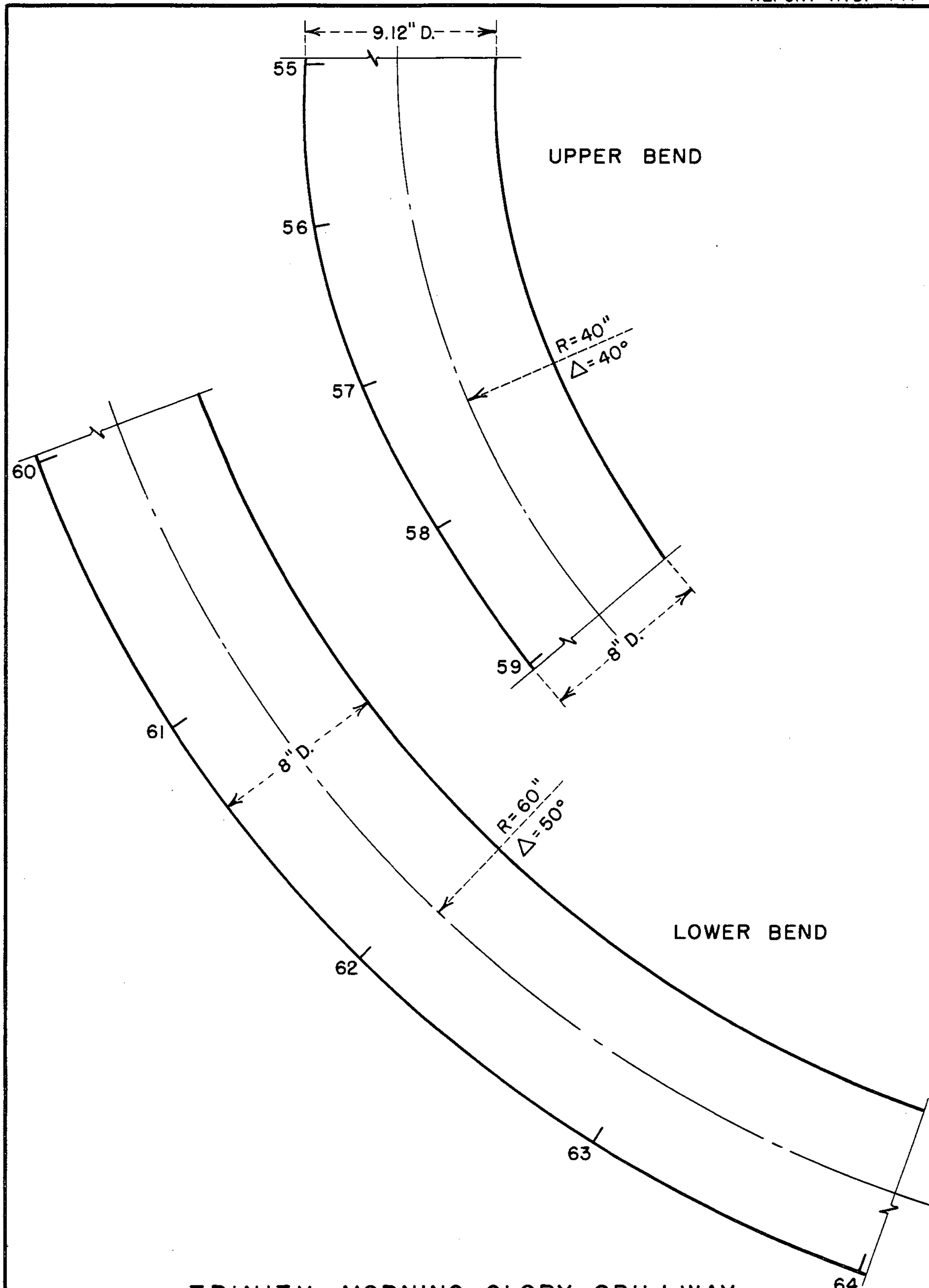


D. Discharge 20,000 cfs



E. Discharge 24,000 cfs

TRINITY MORNING-GLORY SPILLWAY
RECOMMENDED DESIGN
FLOW IN LOWER BEND
1:30 MODEL



TRINITY MORNING-GLORY SPILLWAY
UPPER AND LOWER BEND PIEZOMETERS
1: 30 MODEL

GPO 840988