H.R. Schroeder

PREPARED FOR THE USE OF DEPARTMENT OF
WATER RESOURCES, STATE OF CALIFORNIA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OROVILLE DAM POWERPLANT INTAKE STRUCTURES--CALIFORNIA DEPARTMENT OF WATER RESOURCES--STATE OF CALIFORNIA

Report No. Hyd-509

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

June 15, 1965

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OFFICE OF CHIEF ENGINEER
BUILDING 53, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO: D-293

June 15, 1965

Mr. William E. Warne, Director
Department of Water Resources
State of California
Sacramento, California 95802

Dear Mr. Warne:

I am pleased to submit Hydraulics Branch Report No. Hyd-509 which constitutes our final report on the hydraulic model studies for the intake structures for Oroville Dam Powerplant. I believe this report will satisfy the requirements of your office for a comprehensive discussion of the extensive test program.

Sincerely yours,

B. P. Bellport
Chief Engineer

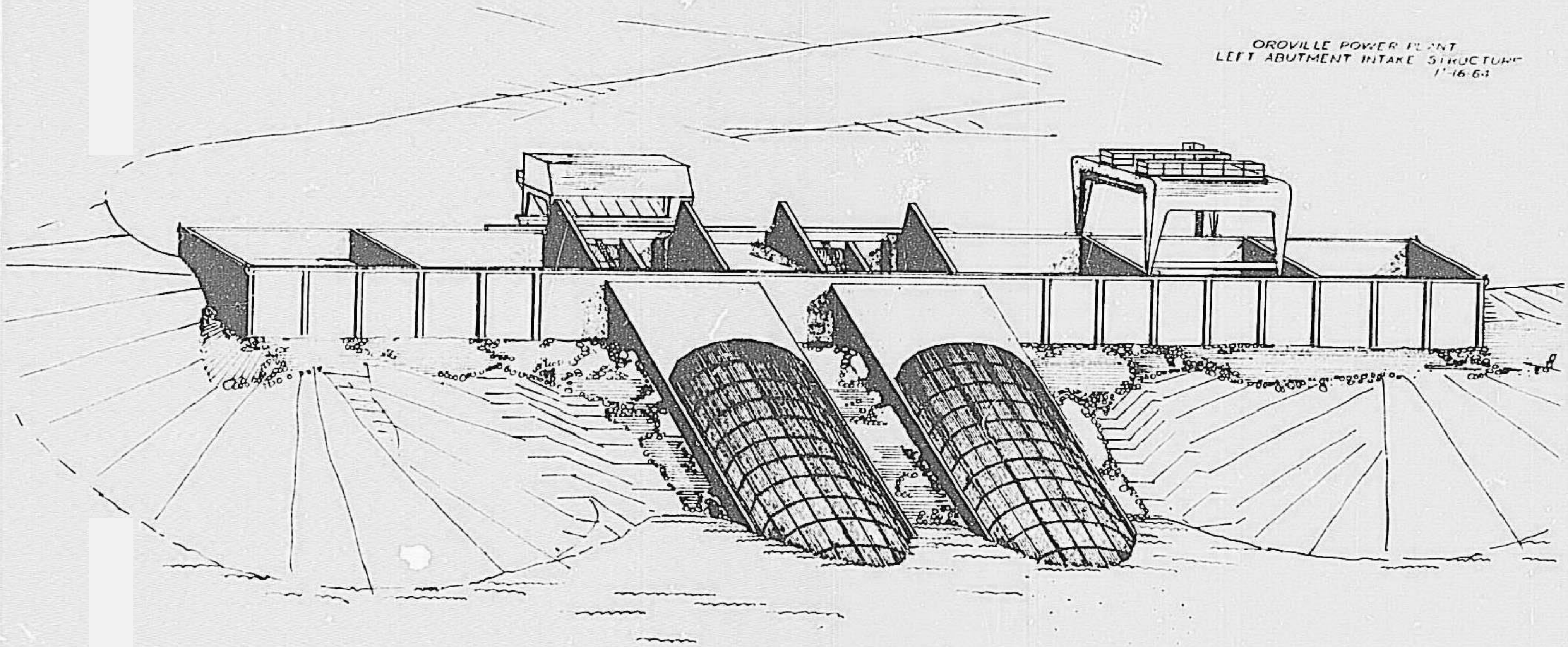
Enclosure

PREFACE

Hydraulic model studies of features of Oroville Dam and Powerplant were conducted in the Hydraulic Laboratory in Denver, Colorado. The studies were made under Contract No. 14-06-D-3399 between the California Department of Water Resources and the Bureau of Reclamation.

The designs were conceived and prepared by Department of Water Resources engineers. Model studies verified the general adequacy of the designs and also led to modifications needed to obtain more satisfactory performance. The high degree of cooperation that existed between the staffs of the two organizations helped materially in speeding final results.

During the course of the studies Messrs. H. G. Dewey, Jr., D. P. Thayer, and other members of the California staff visited the laboratory to observe the tests and discuss model results. Mr. K. G. Bucher of the Fluid Mechanics Section of the Department was assigned to the Bureau Laboratory for training and for assisting in the test program. Mr. G. W. Dukleth provided liaison between the Bureau and the Department.


OROVILLE POWER PLANT
LEFT ABUTMENT INTAKE STRUCTURE
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ABSTRACT

Hydraulic model studies helped determine head losses, differential pressures, vortex action, and general pressures for three proposed designs for the intake structure of the Oroville Dam underground powerplant. Agriculture and fish propagation downstream from the dam require control of the temperature of water released through the powerplant. This control is accomplished by withdrawing water from selected reservoir depths through ports or opened shutters placed along intake structures which slope up the side of the reservoir. Design I consisted of 650-foot-long trapezoidal channel with semicircular covering shells, a 60-foot-long trashrack-covered port at the base, and five additional 40-foot-long ports Flow through each port was controlled by thin semicylindrical shutters. The design was abandoned because of possible instability of the semicylindrical shutters and complicated, submerged mechanisms necessary to engage, move, and latch the shutters. Design II consisted of sloping channels with larger trapezoidal cross sections and continuous arched trashracks the full length of the structures. Under the trashracks, flat 40-foot-long by 45-foot-wide control shutters covered the intake channels. The shutters could be removed from the channels or reinstalled as reservoir level or temperature requirements changed. Design II was tested thoroughly and accepted for prototype use. However, unexpected foundation problems required structural modifications, culminating in Design III. This design utilized rectangular channels with lighter trashrack arches supplemented by tension beams across the channel at the base of each arch. Design III was adopted.

DESCRIPTORS-- *hydraulics/ *head losses/ *pressures/ hydraulic models/ flow control/ trapezoidal channels/ *vortices/ hydraulic structures/ underground powerplants/ intake gates/ trashracks/ *intake structures/ temperature/ model tests/ temperature control/ inlets/ research and development/ fish/ agriculture/ ports
IDENTIFIERS-- *Oroville Dam powerplant/ sloping intake structures/ California/ reentrant inlets/ shutters/ hydraulic design/ temperature control shutters

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
June 15, 1965

Report No. Hyd-509
Author: K. G. Bucher
Checked by: W. P. Simmons
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

HYDRAULIC MODEL STUDIES OF THE OROVILLE DAM POWERPLANT INTAKE STRUCTURES--CALIFORNIA DEPARTMENT OF WATER RESOURCES--STATE OF CALIFORNIA

PURPOSE

Model studies were made to investigate pressure conditions and head losses in the Oroville Powerplant intake structures, differential pressures acting on the control shutters, and vortex action in the reservoir above the intakes.

CONCLUSIONS

Design I

1. The head loss through the initial design was 4.2 feet of water at the maximum discharge of 8,600 cfs (cubic feet per second) in one intake.

2. The addition of a deflector to eliminate the recess at the end block at the bottom of the intake channel reduced head losses by 30 percent or 1.3 feet of water (Figure 21).

3. A shallow vortex formed above Port 2 for submergences up to 118 feet. The vortex did not draw air until the water level was low enough to expose the crown of the port (Figure 22).

4. Tests indicated that long-period pressure reversals were present on the semicylindrical temperature control shutters (Table 1).

5. All pressures measured along the channel transition and penstock transition were positive and, hence, satisfactory (Table 2).

6. Design I was abandoned at the recommendation of the Board of Consultants due to questions about stability of the lightweight shutters and the complicated handling equipment.

Design II

1. The head loss with four shutters in place was 2.8 feet at maximum discharge. This design reduced the head loss 33 percent or 1.4 feet when compared to the operation of Design I through Port 2 (Figures 26 and 21).

2. The addition of a curved deflector at the base of the channels reduced the head loss through the system by only 5 percent or 0.2 foot (Figure 26).

3. Qualitative tests indicated that 40 feet of submergence was required to avoid vortex problems for operation with five shutters and a discharge of 8,270 cfs.

4. The bases of the two intake structures on the right abutment should be placed so that flow can start at about reservoir elevation 685 to allow 45 feet of submergence for vortex-free operation at reservoir elevation 730.

5. Vortices formed inside the intake channels slightly upstream from the leading edge of the shutters (Figure 27).

6. The differential pressure curves of the control shutters are similar to curves on a re-entrant inlet (Figure 28).

7. A maximum differential of 6.1 feet will occur when operating with one shutter at maximum discharge (Figure 28).

8. No subatmospheric pressures were found in the channel transition or in the penstock transition. The minimum pressure was 98 feet of water above atmospheric (Table 4).

9. Design II was abandoned when foundation conditions were found to be unsuitable for the trapezoidal-shaped channels.

Design III

1. Increasing the depth of the leading edge of the shutters to reduce reentrant flow reduced the head loss by about 0.3 foot, and reduced the pressure differential across the leading edge of the gates by 1.0 foot (Figure 31). The increased depth simulated having the gate nose directly below a channel beam with no clearance space between them.

2. The reduction in head loss due to the presence of the channel beam decreased as the clearance between the shutter and beam increased (Figure 32).

3. With a clearance of 5-1/2 inches between the shutters and beams, the head losses and pressure differentials across the shutters were the same for a 90° corner, a 1-foot radius and a 2-foot radius on the bottom leading edge of the shutters.

4. Under optimum conditions, with a 5-1/2-inch clearance and with five shutters in place, the addition of channel beams reduced the head loss by 0.4 foot (Figures 26 and 33).

INTRODUCTION

Oroville Dam is located on the Feather River about 4 miles northeast of Oroville, California (Figure 1). This 747-foot-high earth and rock fill multipurpose dam is the key feature of the California Water Project. Water from the 3,500,000-acre-foot Oroville Reservoir will flow through 700 miles of rivers, aqueducts, pipelines, and tunnels to southern California (Figure 2).

A flood control outlet works and an emergency spillway are located on the right abutment of the dam (Figure 3). Two 35-foot-diameter diversion tunnels and a 600-megawatt underground powerplant are located in the left abutment. At a higher elevation on the left abutment are sloping intake structures which connect to the underground powerplant with 22-foot-diameter concrete-lined penstocks (Figures 3 and 4). Tunnel plugs will be placed in the diversion tunnels to convert the tunnels into a tailrace system for the powerplant. After initial diversion is completed, and until the powerplant is completed, river releases will be made through two Howell-Bunger valves located in the tunnel plug of Tunnel 2.

Rice production in lands irrigated by the Feather River requires warm water from the reservoir during the months of April through August. The California Department of Fish and Game requires water at about 53° F during the months of October through February for fish propagation at a hatchery at the city of Oroville. These requirements for controlled water temperatures necessitated an intake structure with provisions to control the level, and hence, temperature, at which water is taken from the reservoir. Intake structures that sloped up the side of the reservoir at an angle of 28° and utilized movable gates or shutters were selected as the most economical method of acquiring temperature control.

The unique shape of the intake structures presented many design problems, and hydraulic model studies were considered the most practicable method of answering specific questions on shutter vibration, head loss, boundary pressures, and vortex action. The California Department of Water Resources negotiated a contract with the Bureau of Reclamation to conduct comprehensive hydraulic model studies on the proposed intake structures. The model tests made and the results obtained from these studies are discussed in this report. During the course of the model studies, three designs of the left abutment intake structures were tested.

Design I

In cross section, the lower half of each channel was essentially trapezoidal and the upper half semicircular (Figure 5). Six trashrack-covered ports were located along each intake. The lowest port was 60 feet long. The 84-foot space to the next port was covered by a semicylindrical concrete shell. The remaining five ports were 40 feet long, spaced 80 feet center to center, with 40 feet of concrete shell between adjacent ports. The port could be closed by movable semicylindrical shutters (Figures 5 and 16). Two 20-foot-long shutters were used in each 40-foot port and three 20-foot-long shutters were used in the 60-foot port. When a 40-foot port was to be opened, a mechanical operator would engage the upper shutter and move it up the intake into position under the concrete shell with the end of the shutter flush with the edge of the port. The operator would then latch the shutter in place. Next, it would move to the second shutter and move it down the intake to a similar position under the shell and lock it in place. When the 60-foot port was to be opened, the operator would move all three shutters up the intake under the 84-foot-long concrete shell.

Design II

The initial concept of this design proposed a larger open-topped trapezoidal channel with flat shutters along the entire axis of the intake (Figure 6). A continuous trashrack was also provided. The shutters were coupled together with rods that telescoped into the shutters. When the uppermost shutter was drawn uphill, the rod slack was taken up, leaving about a 40-foot opening between it and the following shutter. Withdrawal of successive shutters would continue as the reservoir receded or if an opening at a lower elevation was desired. Full withdrawal of the shutters required hoisting trackage almost triple the length of the intake. After study, the Department of Water Resources adopted the basic idea of this proposal, but the shutter "train" was abandoned because of length of trackage and size of the hoisting mechanism required to draw the shutters up the intake.

The intake was redesigned with shutters that would be individually hoisted up the structure as the water surface receded or as the temperature requirements changed. The temperature control shutters were large flat panels 40 feet long by 45 feet wide. The removed shutters would be stored in bays at the service level of the structure (frontispiece). Design II is shown in Figure 7.

Design III

Unexpected foundation conditions uncovered during field excavation required elimination of the sloping walls of the trapezoidal channel of Design II, and the cross section of the channels was changed from trapezoidal to rectangular. Segmented arches made from stainless steel were specified for supporting the trashracks. Each arch required the addition of a channel beam across the intake channel to act as a tension member (Figures 8 and 19).

General

Two transitions were required in the base of each intake channel to lead the flow from the channels into the penstocks. The first transition consisted of surfaces that warped from the main channel cross section to a bellmouth-like shape (Figure 9). The second was a vertical transition that changed from the 17.5- by 22-foot rectangle at the channel base to the 22-foot diameter of the penstock (Figure 10). A coaster gate was positioned at the entrance to each penstock transition to serve as an emergency closure gate and to be used to seal off the penstocks for routine inspections and maintenance (Figure 11).

Concrete-lined penstocks extend from the bases of the intake channels to the underground powerplant. Maximum discharge through the turbines and, therefore, through the intakes occurs at water surface elevation 730 (Figure 12). At this maximum discharge, 8,600 and 7,900 cfs flow into the left and right intakes, respectively, for a total discharge of 16,500 cfs. The maximum water surface in the reservoir will be at elevation 900 feet.

Detailed discussions of hydraulic studies on the Oroville diversion tunnels, tailrace system, outlet works, spillway, shutter relief panel system, and intake gate downpull forces are discussed in other reports. 1/, 2/, 3/, 4/, 5/, 6/

MODELS

Design I

The model, built at a scale of 1:24 using the Froude criteria, represented the lower 360 feet of the intake structures and surrounding topography (Figures 13 and 14). The model was contained in a sheet-metal-lined headbox 22 feet long, 16 feet wide, and 9 feet deep. The floor of the box, which represented elevation 602, was placed 7 feet above the laboratory floor to allow clearance for the penstock transition and discharge system.

The left intake in the model represented Intake No. 1 of the prototype (Figure 3). Intake No. 1, which has the greater discharge of the two intakes for a given reservoir elevation, was built to exact scale and

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1/ Numbers refer to items in the bibliography.

was used for detailed testing (Figure 15-A). Included in this structure were the control shutters, intake gate, channel and penstock transitions, and a short length of 22-foot-diameter penstock.

The trapezoidal and semicircular sections of the intake channel were shaped from galvanized sheet metal and reinforced by heavy gage sheet metal stiffeners. The transition in the lower 150 feet of Channel No. 1 was shaped from waterproofed sugar pine wood. The transition warped from the trapezoidal cross section on the intake channel to the bellmouth-type entrance above the vertical penstock (Figure 9). Removable inserts could be placed at the base of the tower so the effect of different end shapes could be determined. The rectangular portion of the penstock transition was made from galvanized sheet metal and the transition from the rectangular section to the round penstock was made from transparent plastic. Thirty-four piezometers were placed along the channel and penstock transitions (Figure 24).

The semicylindrical control shutters for Intake No. 1 were fabricated by fastening rolled No. 16-gage brass skinplates to machined brass end rings (Figure 16-A). Fourteen piezometers were placed in one of the shutters to measure pressures on the shutter when it was placed at various locations under the concrete shell near the edge of the port (Figure 16-B).

The right intake represented Intake No. 2 and was modeled in general shape only (Figure 15-A). It was used when both intakes were operating simultaneously and was fabricated as a cylinder with openings at proper locations to represent intake ports. Trashracks were provided. A hinge was welded to the base of the cylinder so the intake could be tilted up to provide access for piezometer connections underneath.

Topography was constructed by cutting wooden contours and placing them to their appropriate elevation in the headbox. Expanded metal lath was formed over the contours and a 3/4-inch layer of concrete was placed over the lath to produce the finished surface (Figure 14-B).

Water was supplied to the model through the central laboratory supply system. Flow rates into the headbox were measured by permanently installed and calibrated Venturi meters. Flow through the model was discharged through two 12-inch pipes, one located below the base of each intake (Figure 13). An orifice plate was calibrated and placed on the end of the discharge pipe of the Intake No. 2. During simultaneous operation, the total discharge for a specific reservoir elevation for the two intakes was supplied to the headbox; flow through Intake No. 2 was measured by the orifice and throttled to give the appropriate discharge for that intake, the remaining water passed through Intake No. 1.

Design II

Design II required construction of a new channel for Intake No. 1 and modification of the channel for Intake No. 2. The invert half of Intake No. 1 and the trashrack arches were fabricated from No. 18-gage galvanized sheet metal. Struts between the trashrack arches were machined from aluminum bar stock (Figure 17-A). Two control shutters were represented in detail with piezometers along the underside of the shutter. The channel transition was fabricated by forming No. 28-gage sheet metal over templates. The penstock transition was unchanged. Forty-five piezometers were placed along the surfaces of the channel and penstock transitions. The completed model of Design II is shown in Figure 17-B.

Design III

The cross sections of the intake channels of Designs II and III, while not the same, were sufficiently similar that new channels did not have to be fabricated for the Design III hydraulic tests (Figure 18). The heavy haunched trashrack arches of Design II were replaced by accurately built models of the proposed lightweight steel arches, and a channel beam was added to the base of each arch to act as a tension member across the channel (Figure 19). In total, two 3-foot model sections of segmented lightweight arches were fabricated from No. 18-gage galvanized sheet metal.

INVESTIGATION

Design I

Model studies were made to evaluate head losses, determine minimum submergence for vortex-free operation at maximum discharge, investigate tendencies of the shutters to vibrate, and to determine the pressures acting on the channel and penstock transitions.

Head loss.--Head loss was determined by measuring the pressure difference from the reservoir water surface to the hydrostatic head at the piezometer ring below the penstock transition and subtracting the velocity head in the 22-foot-diameter penstock from the difference (Figure 20). The loss was expressed by the equation:

$$H_L = \frac{K V^2}{2g}$$

where

K = loss coefficient determined by model study
V = average velocity in 22-foot-diameter penstock (Q/A)
g = acceleration of gravity (32.2 feet per second per second)

Head loss measurements were made for the following conditions:

1. Flow through Ports 1* and 2 with the initial end block at the base of the intake structure

2. Flow through Port 2 with a curved deflector in the base of the intake structure

3. Flow through Port 2 with a vertical deflector in the base of the intake structure

The tests determined that the loss coefficient, K, was 0.24 when operating through Port 1, and 0.53 when operating through Port 2 when the initial end block was used. This was equivalent to losses of 1.9 and 4.2 feet, respectively, at the maximum discharge of 8,600 cfs through the intake (Figure 21). Deflectors were tried in the base of the structure to eliminate the recess at the end block and reduce the head loss. Tests with flow through Port 2 showed that K was reduced from 0.53 to about 0.37 for both the curved and vertical deflectors. This is a reduction in loss of 1.3 feet of water, or 30 percent, at maximum discharge.

Vortex study.--Qualitative tests were made to observe the vortex action in the reservoir above the ports. The tests were made with 8,600 cfs flowing through Intake No. 1 and 7,900 cfs flowing through Intake No. 2. The maximum reservoir elevation in the headbox was 820 feet and the elevation of the crown of the upstream edge of Port 2 was 702 feet. Small shallow vortices without air trails formed over Port 2 when the reservoir was at elevation 820. This same vortex action persisted as the reservoir was reduced to elevation 720. Below elevation 720, the vortex action increased until at elevation 710 a large clockwise vortex formed over Intake No. 1 and a counterclockwise vortex formed over Intake No. 2 (Figure 22-A). No air trails were visible at this submergence. The vortices decreased to strong eddies as the water surface was lowered to approach the trashrack members. When the water surface was decreased to elevation 700, a large clockwise vortex formed inside the channel of Intake No. 1 at a point upstream from the port (Figures 22-B and 22-C). An air trail was visible.

Shutter vibration.--Qualitative tests were made to evaluate the tendency of the semicylindrical shutters to vibrate. Water-filled manometers were connected to the 14 piezometers in the downstream shutter

*In this report, the lowest or 60-foot opening is referred to as Port 1 and the first and second 40-foot ports are referred to as Ports 2 and 3, respectively (Figure 23).

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of Port 2 of Intake No. 1 (Figure 16-B). The test shutter was placed in various positions under the center trashrack arch and at various distances under the concrete shell (Figure 23). The reservoir elevation was maintained at 790 feet; discharge through Intake No. 1 was 8,600 cfs; Port 1 was always closed; and Ports 2 and 3 were positioned as indicated in the test schedule (Figure 23).

The differential pressures (difference between reservoir and piezometric heads) were measured at each piezometer. Results for the 10 tests performed are listed in Table 1. Some of the pressures were unsteady and fluctuated between 2 limits (Tests 6, 8, 9, and 10). In Test 10, the pressures at Piezometers 1 and 10 fluctuated in opposite directions; Piezometer 1 increased from 4.8 to 8.8 feet while Piezometer 10 decreased from 9.4 to 5.0 feet. These pressures held steady for about 1 minute (model) and then reversed in about 2 minutes (model) and continued this cycle throughout this particular test.

The testing of Design I was discontinued before dynamic pressure readings were made on the control shutters and before detailed investigations were made of any vibration tendencies.

General pressures.--Pressures were measured on the surfaces of the channel and penstock transitions (Figure 24) at the maximum discharge of 8,600 cfs for three flow conditions: through Port 1, through Port 2, or with a vertical deflector in the base of the intake. The pressures for these conditions were satisfactory and are listed in Table 2. The lowest pressure found was a positive 97 feet of water.

Further testing was discontinued when the Oroville Dam Board of Consultants recommended to the Department of Water Resources that this design be abandoned. The Consultants questioned the stability of the thin semicylindrical shutter and the feasibility of using complicated, submerged mechanical linkages to engage, move, and latch the shutters.

Design II

The intake channels of Design II were trapezoidal as in Design I, but of greater cross-sectional area. The semicircular shells and control shutters of Design I were replaced by 40-foot-long flat shutters. The shutters were placed end to end along the entire length of each channel. Above the shutters were trashracks that also covered the full length of each channel (Figure 7).

After the model was altered to represent intake Design II, studies were made of head loss, vortex action, transition pressures, and the differential pressures acting across the control shutters.

Head loss.--Tests were made to determine the loss coefficient, K, with up to six shutters in place on the intake channel. A table of the values of K is shown in Figure 25-A. At maximum discharge, 8,600 cfs, with no shutters in place, the head loss to the ring of piezometers below the penstock transition was 1.7 feet. The head loss, as defined by Equation 1, increased to 3.6 feet with the addition of one shutter, decreased to 2.8 feet with three shutters and gradually increased to 3.1 feet as up to six shutters were used.

The loss coefficient, K, is plotted, and projected for up to 12 shutters along the intake channel (Figure 25-B). The dip in the coefficient curve is consistent with the pressure curve of a re-entrant inlet. The addition of one shutter formed a type of re-entrant inlet, but one which was too short to allow full pressure recovery. As a second and third shutter were added, the increased passage length allowed better pressure recovery and lower losses. The addition of more shutters did not improve the pressure recovery and merely added friction loss, hence the slowly rising coefficient curve.

A curved deflector was added to the underside of the lowest shutter to eliminate a zone of stagnation in the intake at the intersection of the shutter and end block (Figure 26). The deflector reduced the head loss at maximum discharge by only 0.2 foot (Figure 26). Thus, the addition of a deflector to Design II did not reduce losses as markedly as the addition of a similar deflector to Design I (Figure 21). The greater effect of the deflector in Design I lay primarily in the fact that it eliminated the recess in the end block. There was no recess in Design II.

A test was made with five shutters in place and the intake gate removed. The value of K changed slightly from 0.36 to 0.33, a decrease in head loss of 0.3 foot at maximum discharge.

Vortex study.--Qualitative tests were made to determine the minimum reservoir elevation at which no air was drawn into the intake by vortices. These tests were made with the following conditions:

1. All shutters removed, single intake operation.

2. Five shutters in place, single intake operation.

3. Five shutters in place, both intakes operating.

The tests with all shutters removed for single intake operation were made to determine the minimum submergence to pass 8,600 cfs without air being drawn into the penstock by vortices. Tests indicated that the minimum submergence should be about 45 feet. At a 37-foot submergence, a large unstable vortex started to form in the intake channel; at a 31-foot submergence, a large stable vortex formed with an air trail extending down into the penstock (Figure 27-A). Observations at other submergences are listed in Table 3.

During single intake operation with five shutters in place, shallow vortices without air trails formed when Intake No. 1 was operating at reservoir elevation 745 at a discharge of 8,270 cfs. A large vortex with an air trail extending under the shutters formed when the reservoir was lowered to elevation 740 with a discharge of 8,380 cfs (Figure 27-B).

During tests with both intakes operating, flows into each intake were varied with reservoir elevation as shown in the discharge curves of Figure 12. Eddy action was strong in Intake No. 1, and a shallow vortex formed in Intake No. 2 at reservoir elevation 750. The eddy and vortex action increased as the reservoir elevation decreased. Large vortices with air trails were prominent in the channels of both intakes when reservoir elevation 740 was reached (Figure 27-C). It is interesting to note that the vortices have formed within the intake channels and that they are somewhat upstream from the leading edge of the shutters.

The upstream or leading edge of a group of five shutters is at about elevation 705 (left abutment). Therefore, the above qualitative tests indicate that when operating at near maximum discharge, 40 feet of submergence is required for single intake operation, and 45 feet of submergence is required when both intakes are operating.

The requirement for 45 feet of submergence to prevent severe vortex action when the reservoir is at elevation 730 necessitates placing the bases of the two intakes on the right abutment at elevation 685.

Differential pressures across shutters.--The relatively thin 40- by 45-foot shutters were designed for a uniform loading of 5 feet of water (a uniform differential pressure of 5 feet between the upper and underside of the shutter). Piezometers were placed on the underside of the shutters along the centerline, and model studies were made to determine the actual pressure differences.

Tests with one, three and four shutters on the intake were made with a discharge of 8,600 cfs. The maximum differentials were 6.1, 4.8 and 4.1 feet of water, respectively (Figures 28-A, 28-B, and 28-C). Tests with five shutters were run at a discharge of 8,270 cfs (reservoir elevation 745). At this condition, a maximum differential pressure of 3.8 feet of water occurred at the leading edge of the upstream shutter (Figure 28-D). A secondary, peak differential of 3.2 feet occurred in the area above the intake gate. When the test was repeated with the penstock intake gate removed, the maximum differential at the leading edge remained the same but the secondary peak decreased 0.4 foot (Figure 28-D).

The pattern of pressure intensity under the shutters is essentially the same as a re-entrant inlet. In a reentrant inlet, separation at the leading edge causes a local reduction of piezometric head. Maximum pressure recovery occurs about two pipe diameters downstream from the leading edge. 7/

A curve of differential pressure for five shutters, using the values for piezometric head found in a dimensionless curve for a re-entrant inlet, is shown in Figure 28-E. These values compare closely to the experimental values found at the leading edge with five shutters on the intake (Figure 28-D). The pressure intensity under the shutters deviated from that of the ideal re-entrant inlet because the cross-sectional area of the channel is constantly changing due to the channel transition and intake gate.

A curved deflector was installed on the underside of the lowest shutter of a five-shutter train to eliminate an area of stagnation at the intersection of the shutters and end block (Figure 29-A). The differential pressures at a discharge of 8,270 cfs were the same as the differentials without the deflector up to a point about 60 feet upstream from the end block (Figure 29-A). The pressures along the surface of the deflector remained about the same as the stagnation pressure on the end block. However, the differentials near the end of the deflector, at the gate recess, were slightly lower than the pressures without the deflector (Figures 29-A and 29-C). The indicated reduction of head loss was noted in the head loss study.

General pressures.--Tests were made of the pressures on the channel and penstock transition surfaces with zero, one, two, and four shutters in place, a reservoir elevation of 730 feet, and a discharge of 8,600 cfs. A test with five shutters was made at a discharge of 8,600 cfs but at a higher reservoir elevation, 760 feet, to avoid formation of vortices. No adverse pressures were found in the tests, and the lowest pressure was a positive 98.3 feet of water. This pressure occurred at Piezometer 1. A list of pressures for the above tests is presented in Table 4. Piezometer locations are shown in Figure 30.

Design III

Vortex and general pressure studies were not repeated for Design III. However, additional tests were made to evaluate head loss and differential pressures with the restricted clearances between the bottom of the channel beams and the top of the shutters, and the shape of the leading edge of the shutters.

Channel beams.--Preliminary tests were made with the old haunched trashrack arches of Design II in place to see if the channel beams shown in Figure 8 (Section B-B) could be used to lessen reentrant losses at the leading edge of the control shutters. Tests were made by attaching an extension to the leading edge of a shutter so that the top of the extension corresponded to the top of the channel beam (Figure 31). The extension reduced head loss by 0.3 foot at maximum discharge (Figure 31-A). A comparison of differential pressures across six shutters showed that the extension reduced the differentials by about 1.0 foot under the upstream shutter and about 0.4 foot under the remaining shutters (Figure 31-B). These preliminary tests were made with no clearance or gap between the shutter and the bottom of the channel beam.

Channel beams were then placed in the model and tests were made with clearances between the shutter and the beam of 0, 5-1/2, and 9 inches. The differential pressures for these clearances, and with the beam removed, are shown in Figure 32. It can be seen that as the gap between the shutter and beam increases, the differentials increase slightly.

The minimum clearance between the shutters and channel beams was set at 5-1/2 inches by the Department of Water Resources. With five shutters in place, the addition of the channel beams reduced the head loss by about 0.4 foot. The loss coefficient was reduced to 0.33 (Figure 33).

Leading-edge shapes.--Studies were made of three leading-edge shapes on the upstream shutter to determine if a small degree of streamlining would reduce head loss. Tests were made with a 90° corner, and with 1- and 2-foot-radius curves. The loss was 2.55 feet at maximum discharge for all three shapes (Figure 33).

Differential pressure measurements were made at 8,600 cfs using the shutters with the 1-foot radius on the leading edge. Tests were made with one, three, and four shutters in place. The maximum differentials were 4.8, 3.8, and 3.5 feet of water, respectively (Figure 34).

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2. "Hydraulic Model Studies of the Draft Tube Connections and Surge Characteristics of the Tailrace Tunnels for Oroville Powerplant," Report No. Hyd-507, by W. P. Simmons

3. "Hydraulic Model Studies of the Outlet Works for Oroville Dam," Report No. Hyd-508, by Donald Colgate

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7. Rouse, H., Elementary Mechanics of Fluids, New York: John Wiley and Sons, Incorporated, 1957

TABLE I

DIFFERENTIAL PRESSURES ACROSS CONTROL SHUTTERS
DESIGN I

DIFFERENTIAL PRESSURES, FEET OF WATER, PROTOTYPE

	TEST NUMBER	1	2	3	4	5	6	7	8	9	10
PIEZOMETER NUMBERS	1	5.3	2.9	2.4	2.2	6.2	15.4 - 5.0	4.6	9.8 - 5.3	12.7 - 9.4	4.8 - 8.8
	2	5.3	2.6	1.9	1.4	—	3.4	4.8	6.0 - 3.8	3.8	2.2
	3	2.2	2.4	0.2	0.2	5.0	3.6	2.4	5.3 - 4.3	4.6	3.4
	4	5.3	2.6	2.4	2.2	5.0	4.6	3.8	4.1	3.4	2.6
	5	5.3	2.6	1.9	1.9	4.8	3.8	2.6	4.1	3.6	3.1
	6	2.2	2.6	0.2	0.5	5.3	4.1	2.4	4.1	3.6	3.1
	7	4.8	2.4	2.2	0.2	6.7	5.0	3.4	5.0	2.9	3.4
	8	4.8	2.4	2.9	1.2	4.8	3.8	2.2	5.0	2.6	3.6
	9	2.2	2.2	0.2	0.5	5.3	4.1	2.4	4.8	2.9	3.6
	10	4.8	2.9	2.6	2.6	—	5.0 - 15.4	4.3	10.8 - 6.5	13.2	9.4 - 5.0
	11	4.8	2.6	2.2	1.9	4.8	5.0	2.2	4.3 - 5.8	4.1	2.6
	12	2.2	2.4	0.2	0.5	6.7	5.3	3.1	8.4 - 7.2	5.8	5.8
	13	4.6	2.2	1.7	1.9	5.5	4.3	2.9	4.3	2.6	2.6
	14	4.3	2.2	1.9	1.7	5.3	4.3	2.9	4.3	2.6	2.6

TEST CONDITIONS SHOWN IN FIGURE 23
PIEZOMETER LOCATIONS SHOWN IN FIGURE 16

DIFFERENTIAL PRESSURE = $H_{RESERVOIR} - H_{PIEZOMETER}$
RES. ELEV. 790, DISCHARGE = 8,600 CFS

OROVILLE DAM
POWER PLANT INTAKES

DATA FROM 1 : 24 MODEL

TABLE 2

MANOMETER PRESSURES ALONG CHANNEL AND PENSTOCK TRANSITIONS—DESIGN I

FEET OF WATER, PROTOTYPE

PIEZOMETER NUMBERS / TEST CONDITIONS	A	B	C
1	97.0	96.9	99.4
2	—	—	—
3	100.0	100.1	102.9
4	104.9	104.7	106.7
5	106.0	105.8	108.6
6	119.2	119.3	110.1
7	119.8	119.4	100.4
8	121.0	120.6	122.6
9	124.7	125.0	126.4
10	125.0	125.8	126.6
11	128.8	129.3	134.8
12	130.5	134.2	133.6
13	128.4	—	126.4
14	126.0	—	124.6
15	127.7	—	129.2
16	129.1	130.4	133.5
17	130.1	130.9	134.2
18	132.9	135.9	132.0
19	134.3	135.6	138.9
20	136.4	137.7	136.6
21	123.2	123.3	126.8
22	120.4	120.5	125.0
23	—	—	—
24	127.8	127.9	130.5
25	133.6	133.9	136.2
26	125.6	126.5	128.7
27	127.6	128.9	130.7
28	130.6	132.2	133.5
29	133.6	135.1	136.2
30	123.3	123.9	128.8
31	126.3	127.1	129.2
32	128.3	128.9	131.0
33	131.3	131.4	133.7
34	134.1	134.1	136.2
K	0.53	0.37	0.24

TEST CONDITIONS: RES. ELEV. 730 DISCHARGE - 8,600 CFS

A. FLOW THROUGH PORT 2, INITIAL END BLOCK

B. FLOW THROUGH PORT 2, VERTICAL END BLOCK

C. FLOW THROUGH PORT 1, INITIAL END BLOCK

PIEZOMETER LOCATIONS SHOWN IN FIGURE 24

OROVILLE DAM

POWER PLANT INTAKES

DATA FROM 1 : 24 MODEL

TABLE 3

SUBMERGENCE TEST OBSERVATIONS

SUBMERGENCE (FT. H_2O)	REMARKS
94	SMALL VORTEX ABOVE PENSTOCK; CONFETTI BOBS IN EYE OF VORTEX, NO AIR TRAIL.
90	SMALL CLOCKWISE VORTEX ABOVE PENSTOCK; NO AIR TRAIL.
82	VORTEX AND EDDY ACTION INCREASED. A COUNTERCLOCKWISE EDDY FORMING ON SHORE SIDE OF VORTEX. VORTEX OCCASSIONALLY PULLED CONFETTI ABOUT 0.5 FEET (MODEL) BELOW WATER SURFACE. VORTEX SMALL, NO AIR TRAIL.
71	SAME AS 82
60	VORTEX ABOVE PENSTOCK IS DIMINISHING
50	SMALL VORTICES, NO AIR TRAIL. BITS OF CONFETTI OCASSIONALLY DRAWN DOWN.
46	SAME AS 50, WITH MORE EDDY ACTION AROUND TRASH RACK MEMBERS.
37	LARGE VORTEX MAKING AND BREAKING. VORTEX LOCATED IN CHANNEL BEHIND EXPOSED TRASHRACK MEMBERS. CONFETTI DRAWN IN, AIR TRAIL INTO PENSTOCK.
31	LARGE VORTEX IN CHANNEL (FIGURE). AIR AND CONFETTI VISIBLE IN TRANSPARENT PENSTOCK TRANSITION.

CONDITIONS:

SINGLE INTAKE OPERATION

DISCHARGE – 8,600 CFS

OROVILLE DAM

POWER PLANT INTAKES

SUBMERGENCE TESTS – DESIGN II

DATA OF 1 : 24 MODEL

TABLE 4

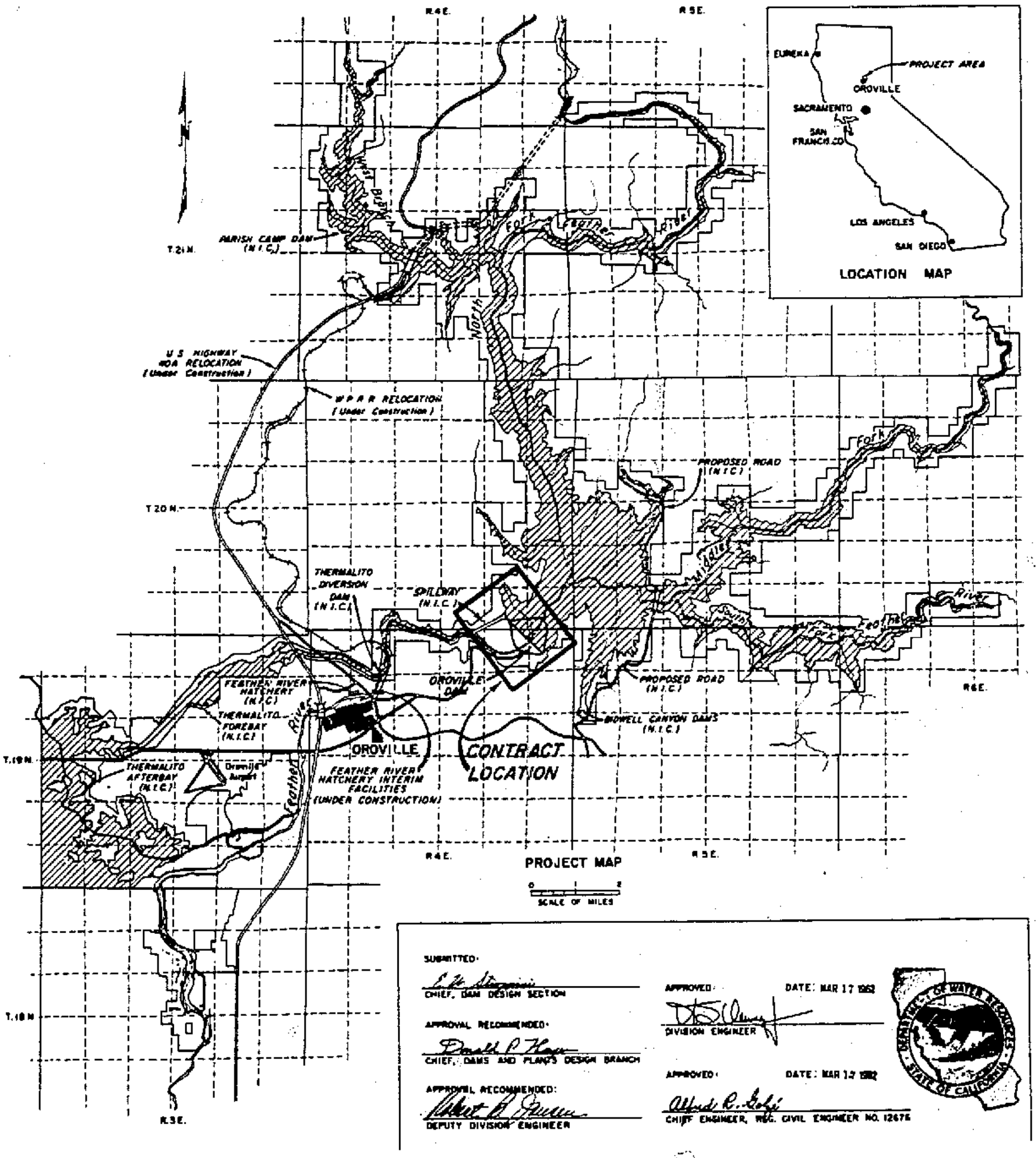
MANOMETER PRESSURES ALONG CHANNEL
AND PENSTOCK TRANSITIONS - DESIGN II
FEET OF WATER, PROTOTYPE

PIEZOMETER NUMBERS					
DISCHARGE	8,600	8,600	8,600	8,600	8,600
RES. ELEV.	730	730	730	730	730
SHUTTERS	0	1	2	4	5
1	102.7	102.2	98.3	99.0	139.0
2	111.9	111.4	107.0	108.0	138.0
3	111.4	106.8	108.0	108.0	138.0
4	116.5	111.9	112.1	112.7	142.6
5	107.0	107.4	107.4	107.2	137.0
6	107.5	102.2	105.1	105.3	135.3
7	109.9	104.6	107.5	107.7	137.7
8	117.0	111.7	114.6	115.1	145.0
9	121.2	116.3	119.2	119.2	149.0
10	124.1	119.5	121.9	122.0	151.9
11	125.5	122.1	124.0	123.8	153.5
12	124.7	122.8	124.0	123.5	152.8
13	127.2	124.5	125.5	125.3	155.2
14	127.4	124.7	125.7	125.2	155.4
15	126.7	124.5	125.4	125.2	155.4
16	135.7	128.2	132.0	129.4	158.6
17	134.0	131.1	132.0	131.4	161.3
18	125.5	123.5	124.0	124.8	154.3
19	130.1	129.8	129.5	130.3	160.0
20	124.9	129.9	127.0	126.6	156.3
21	128.2	130.1	129.6	128.7	158.9
22	112.5	113.2	113.4	112.5	142.5
23	123.2	119.3	121.7	122.5	151.7
24	129.2	128.9	128.7	128.3	158.5
25	130.2	129.5	128.7	127.8	158.0
26	133.4	130.5	131.0	130.1	160.3
27	134.2	131.0	131.7	131.0	161.0
28	135.2	132.3	132.8	132.3	162.3
29	139.0	137.3	138.0	136.8	166.8
30	130.7	133.3	130.2	130.5	160.2
31	136.7	136.4	125.9	135.5	165.4
32	123.5	113.1	117.4	118.9	148.9
33	123.8	113.2	118.9	119.5	149.2
34	128.5	121.7	124.8	125.1	153.4
35	133.2	128.9	130.8	130.8	160.6
36	136.0	132.3	133.5	133.6	163.5
37	—	—	—	—	—
38	130.7	124.7	127.1	127.8	157.6
39	133.5	128.4	130.3	131.1	160.6
40	136.5	132.1	133.5	133.8	163.5
41	126.2	117.0	120.6	122.3	152.3
42	129.0	121.7	124.8	126.3	156.0
43	129.5	124.7	127.3	128.3	157.8
44	133.6	128.9	130.8	131.6	161.3
45	136.0	132.3	133.8	134.3	164.0
K	0.21	0.45	0.37	0.36	0.37

PIEZOMETER LOCATIONS SHOWN IN FIGURE 30

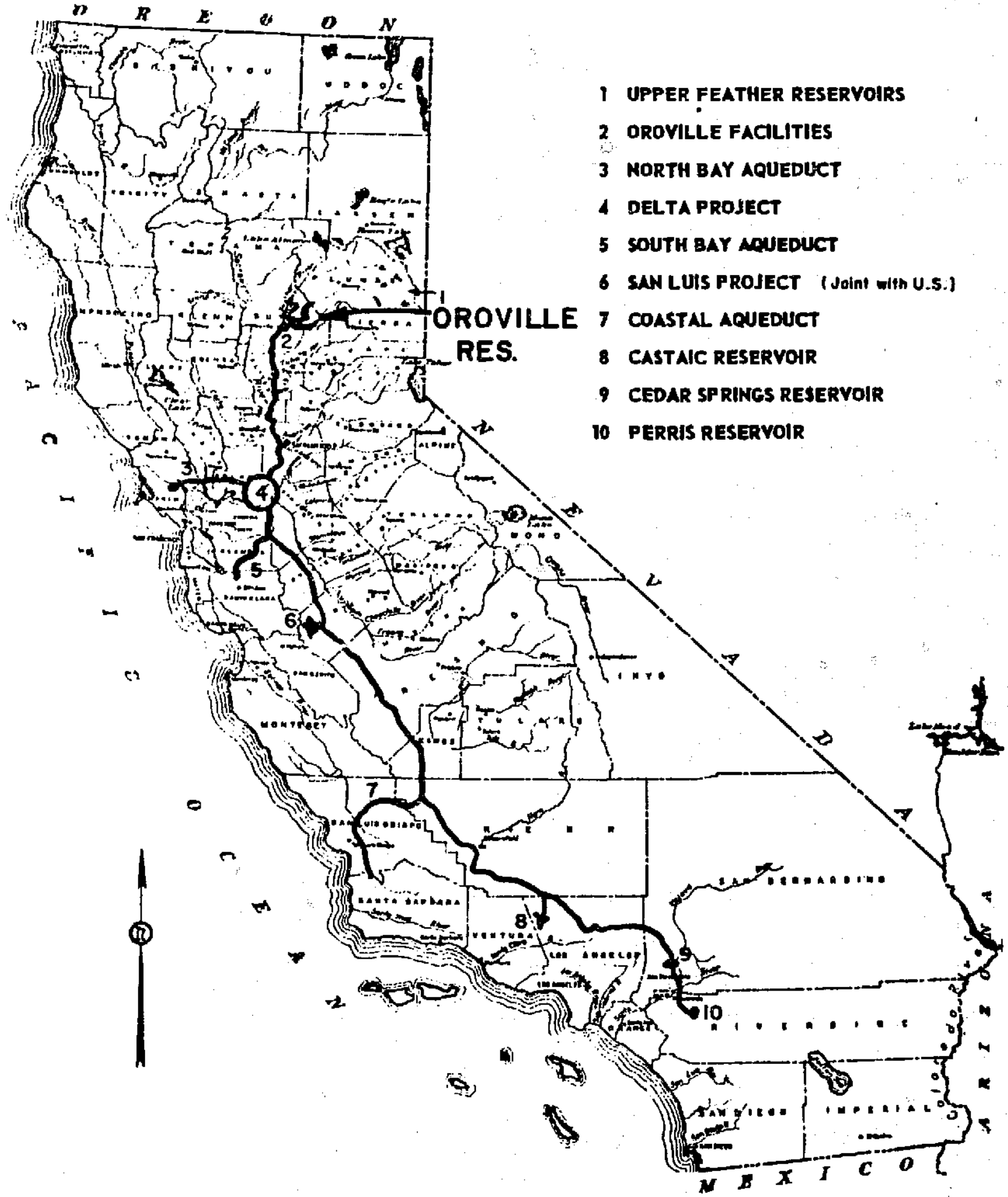
OROVILLE DAM
POWER PLANT INTAKES

DATA FROM 1 : 24 MODEL



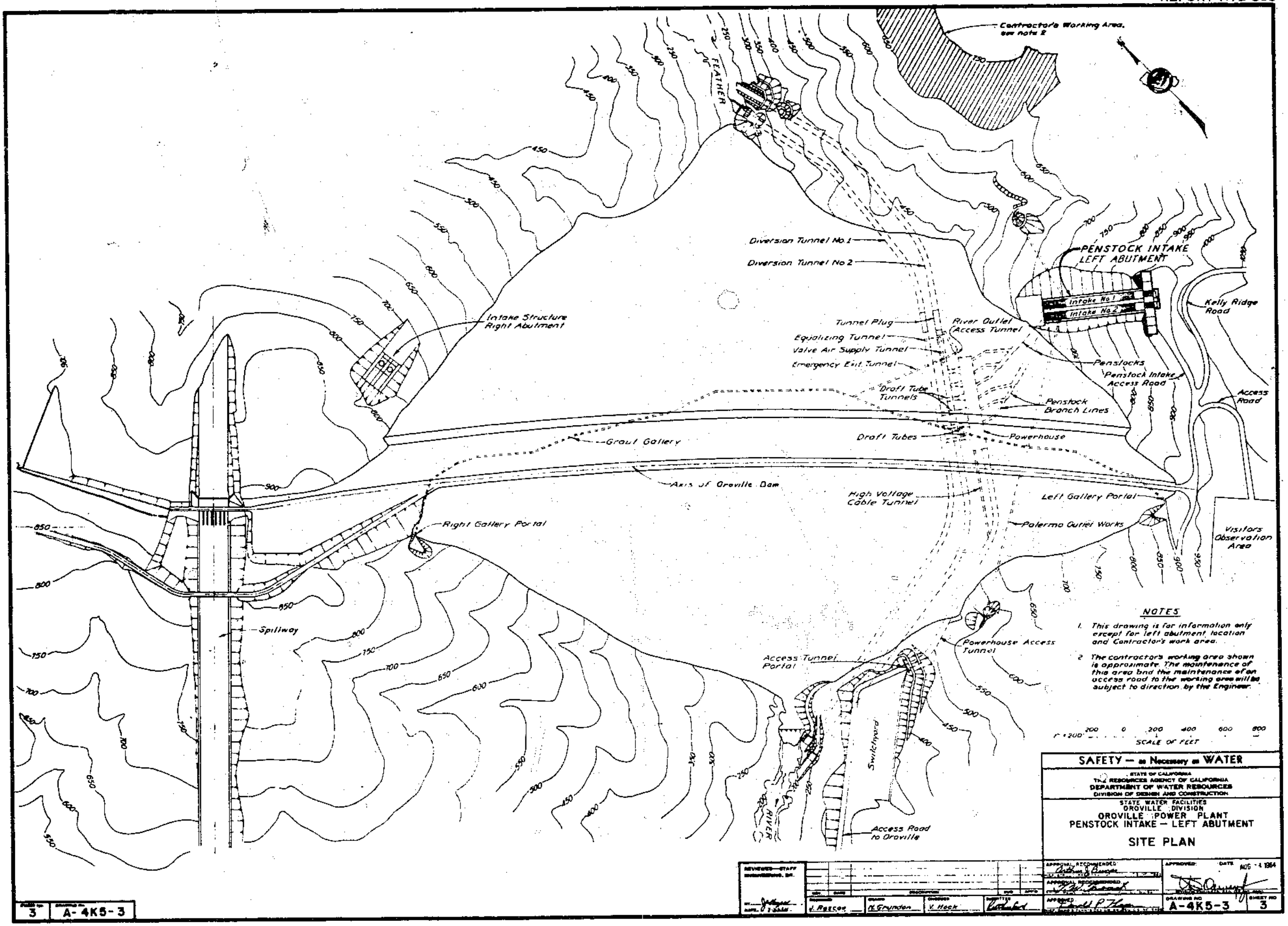
OROVILLE DAM
POWER PLANT INTAKE STRUCTURE STUDIES
LOCATION MAP

FIGURE 2
REPORT HYD-509



OROVILLE DAM
POWER PLANT INTAKES
CALIFORNIA STATE WATER PROJECT

FIGURE 3
REPORT HYD-509



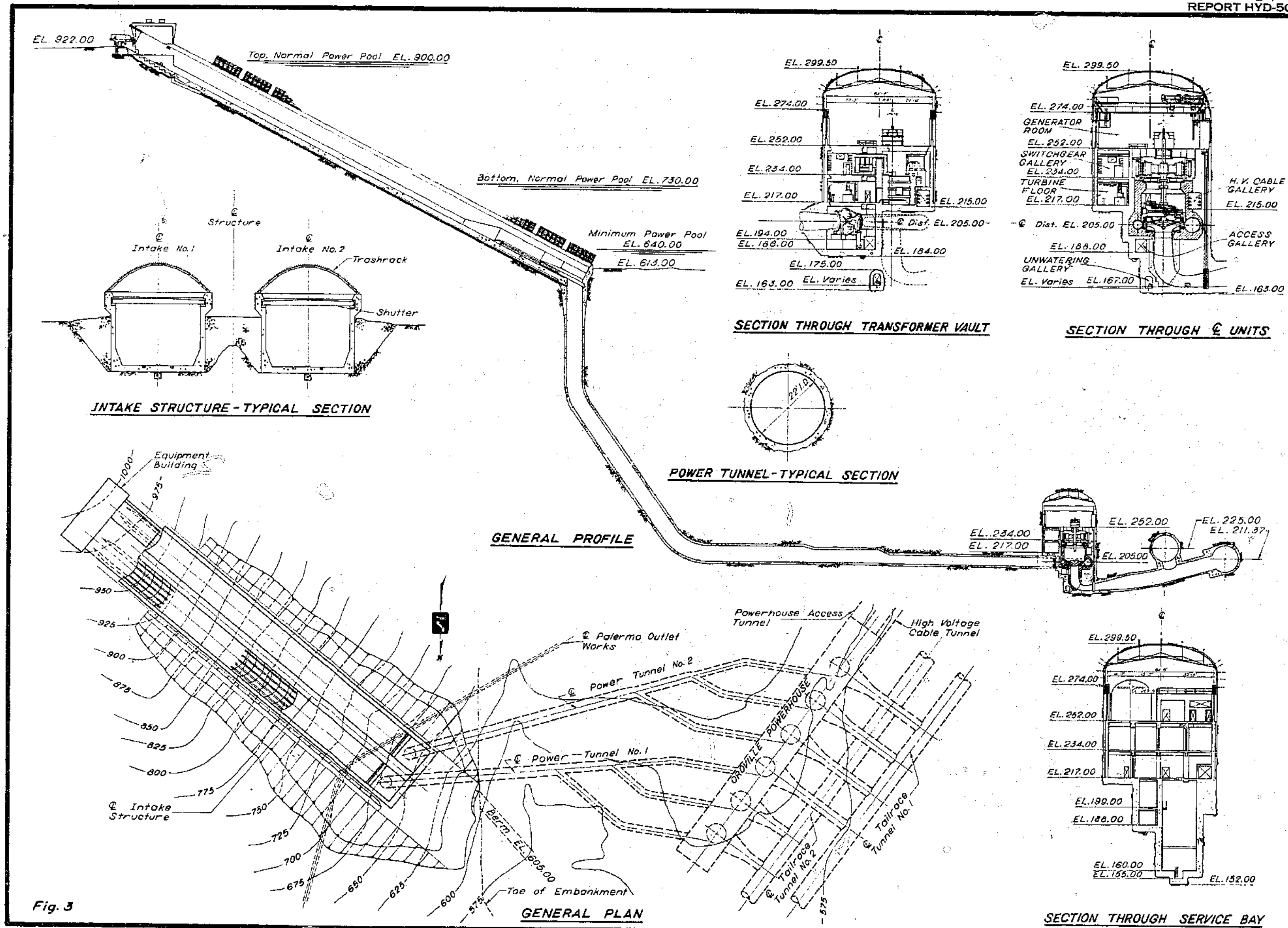

EL. 922.00
Top, Normal Power Pool EL. 900.00
Bottom, Normal Power Pool EL. 730.00
Minimum Power Pool EL. 640.00
EL. 613.00
℄ Structure
℄ Intake No. 1
℄ Intake No. 2
Trashrack
Shutter
INTAKE STRUCTURE-TYPICAL SECTION
EL. 299.50
EL. 274.00
EL. 252.00
EL. 234.00
EL. 217.00
EL. 215.00
℄ Dist. EL. 205.00
EL. 194.00
EL. 188.00
EL. 184.00
EL. 175.00
EL. Varies
EL. 163.00
SECTION THROUGH TRANSFORMER VAULT
GENERATOR ROOM
SWITCHGEAR GALLERY
TURBINE FLOOR
H.V. CABLE GALLERY
ACCESS GALLERY
UNWATERING GALLERY
EL. 167.00
SECTION THROUGH ℄ UNITS
22'-0"
POWER TUNNEL-TYPICAL SECTION
GENERAL PROFILE
EL. 225.00
EL. 211.37
EL. 205.00
Equipment Building
℄ Palermo Outlet Works
℄ Power Tunnel No. 2
℄ Power Tunnel No. 1
Powerhouse Access Tunnel
High Voltage Cable Tunnel
OROVILLE POWERHOUSE
℄ Tailrace Tunnel No. 2
℄ Tailrace Tunnel No. 1
℄ Intake Structure
Berm EL. 605.00
Toe of Embankment
GENERAL PLAN
EL. 199.00
EL. 160.00
EL. 155.00
EL. 152.00
SECTION THROUGH SERVICE BAY

Fig. 3

FIGURE 5
REPORT HYD-509

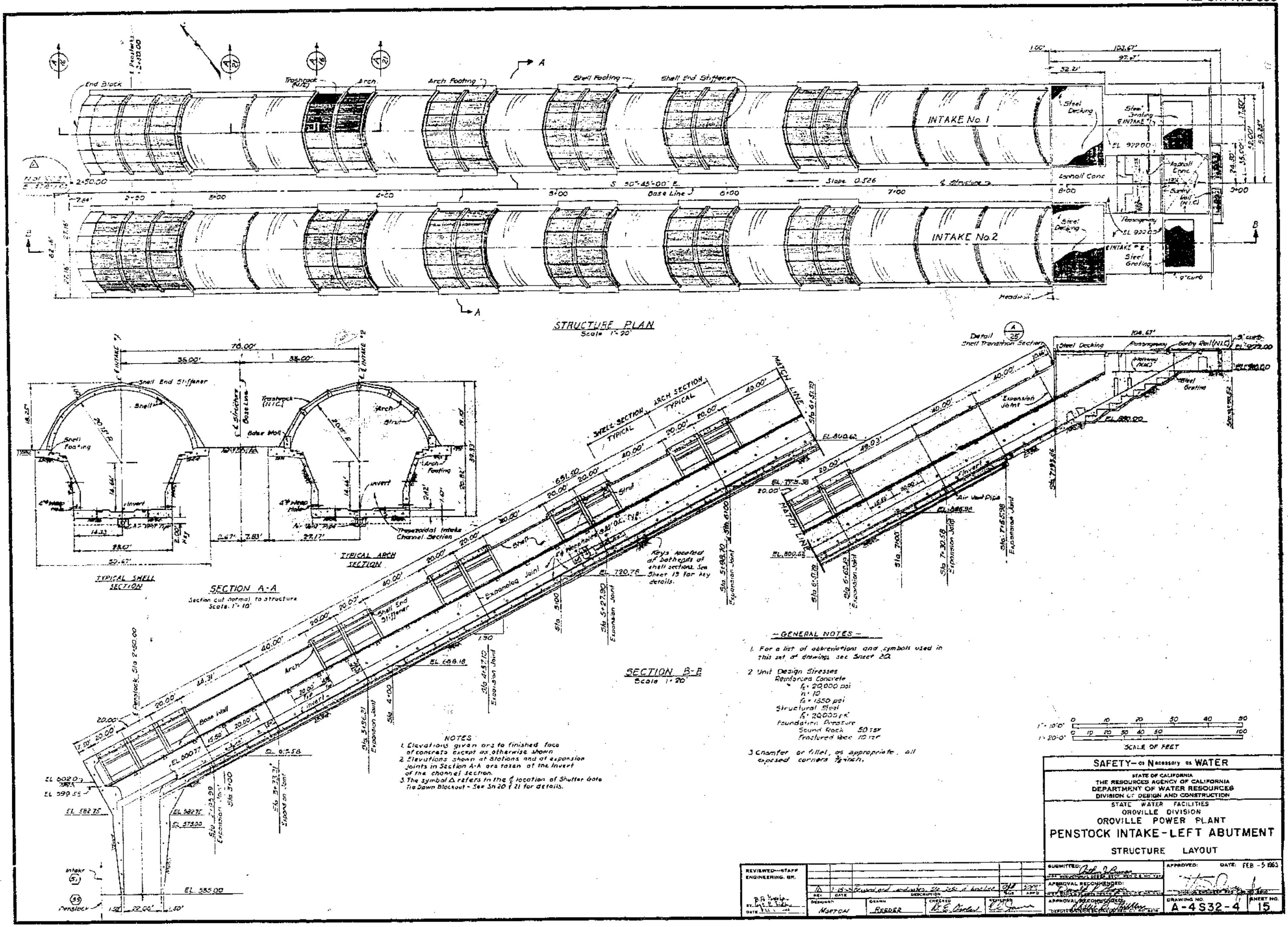
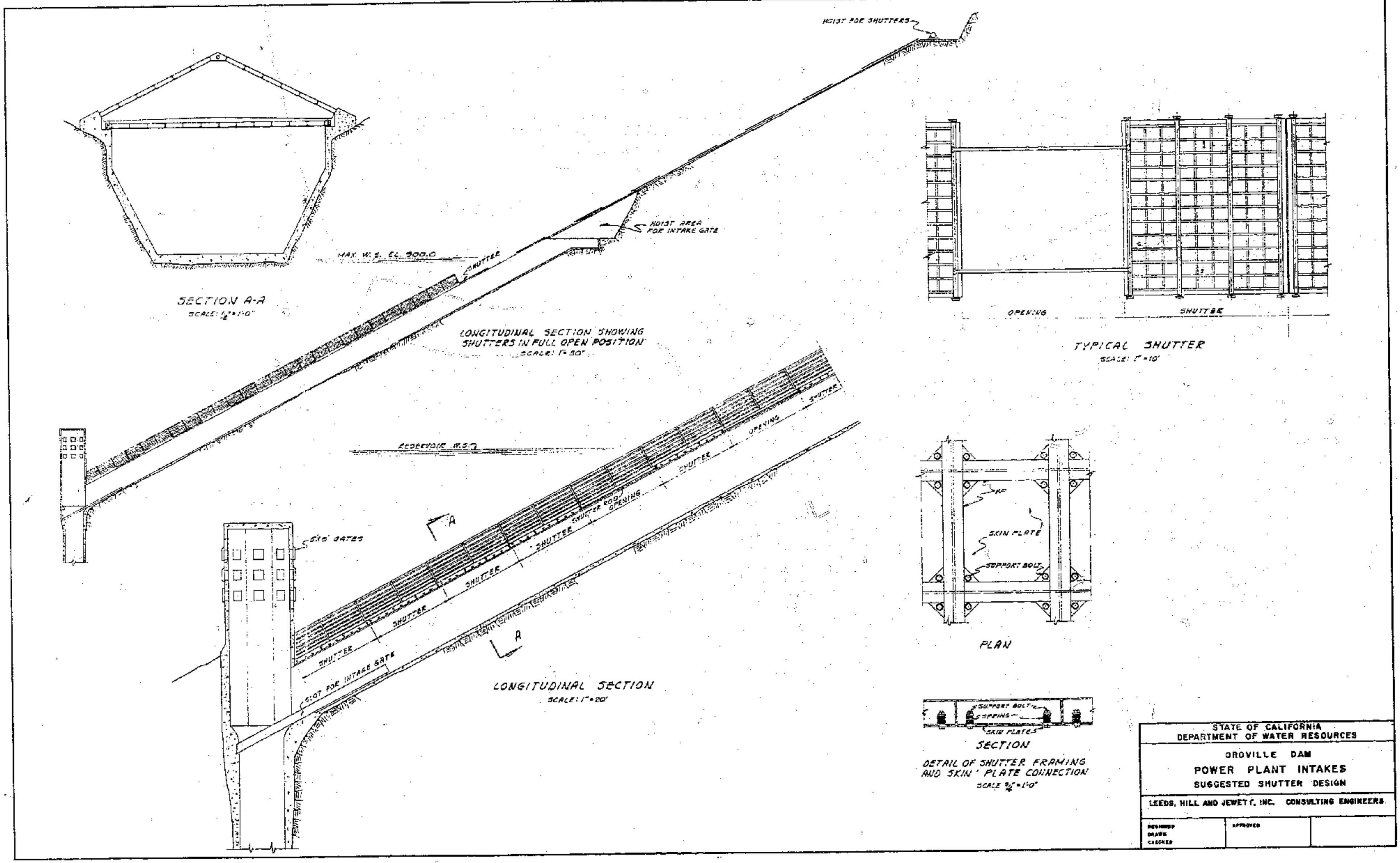
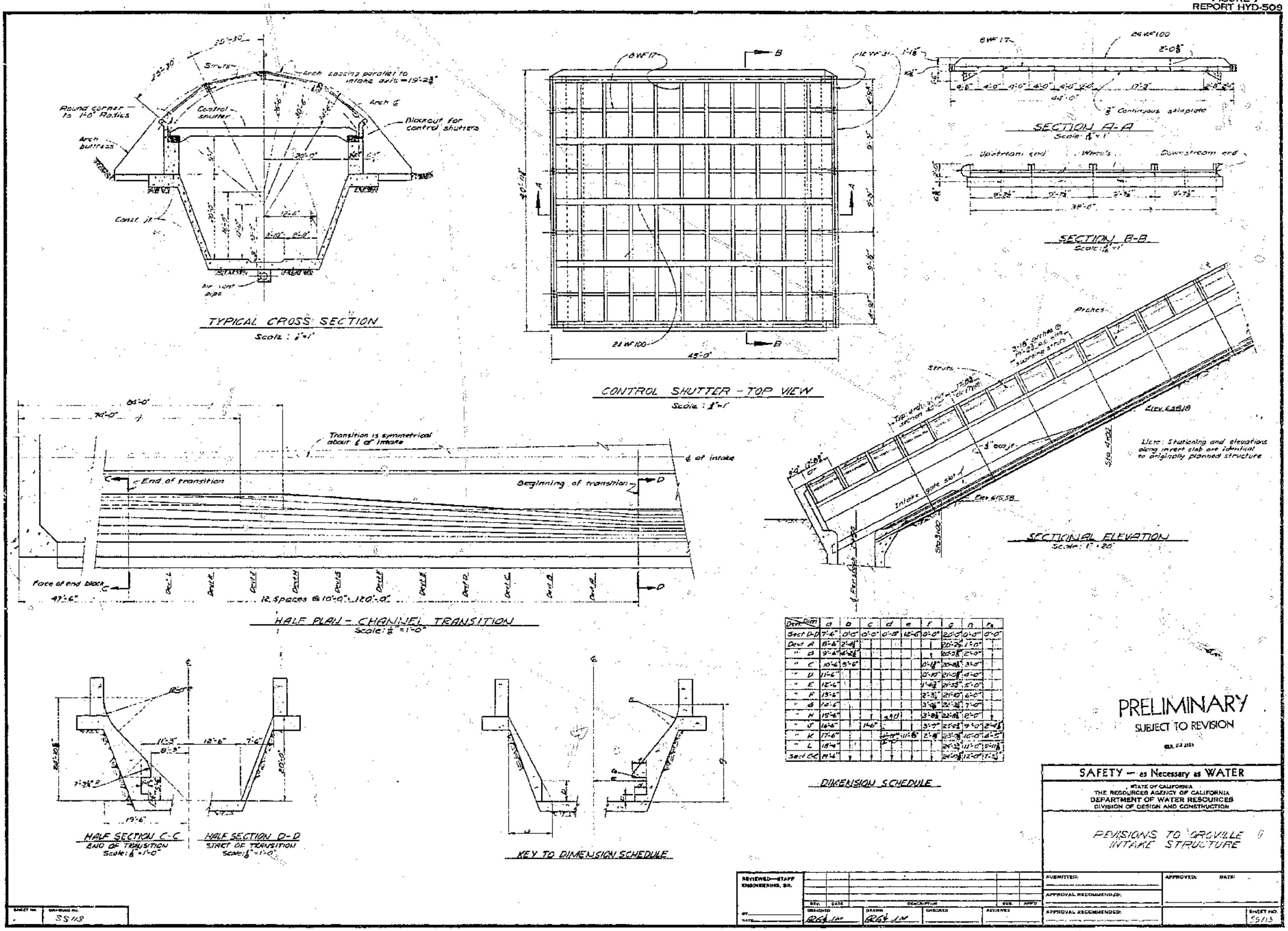


FIGURE 6
REPORT HYD-509

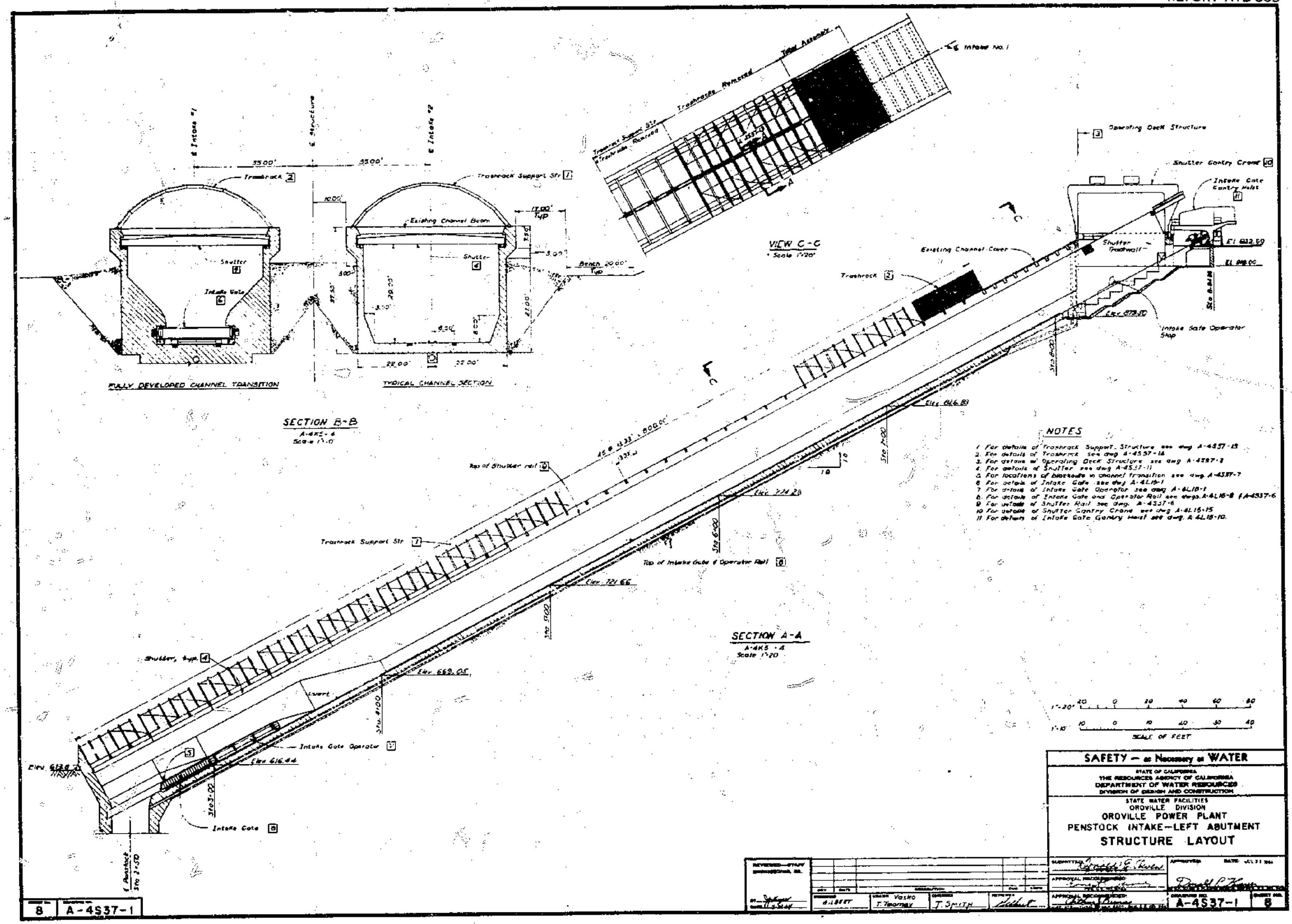


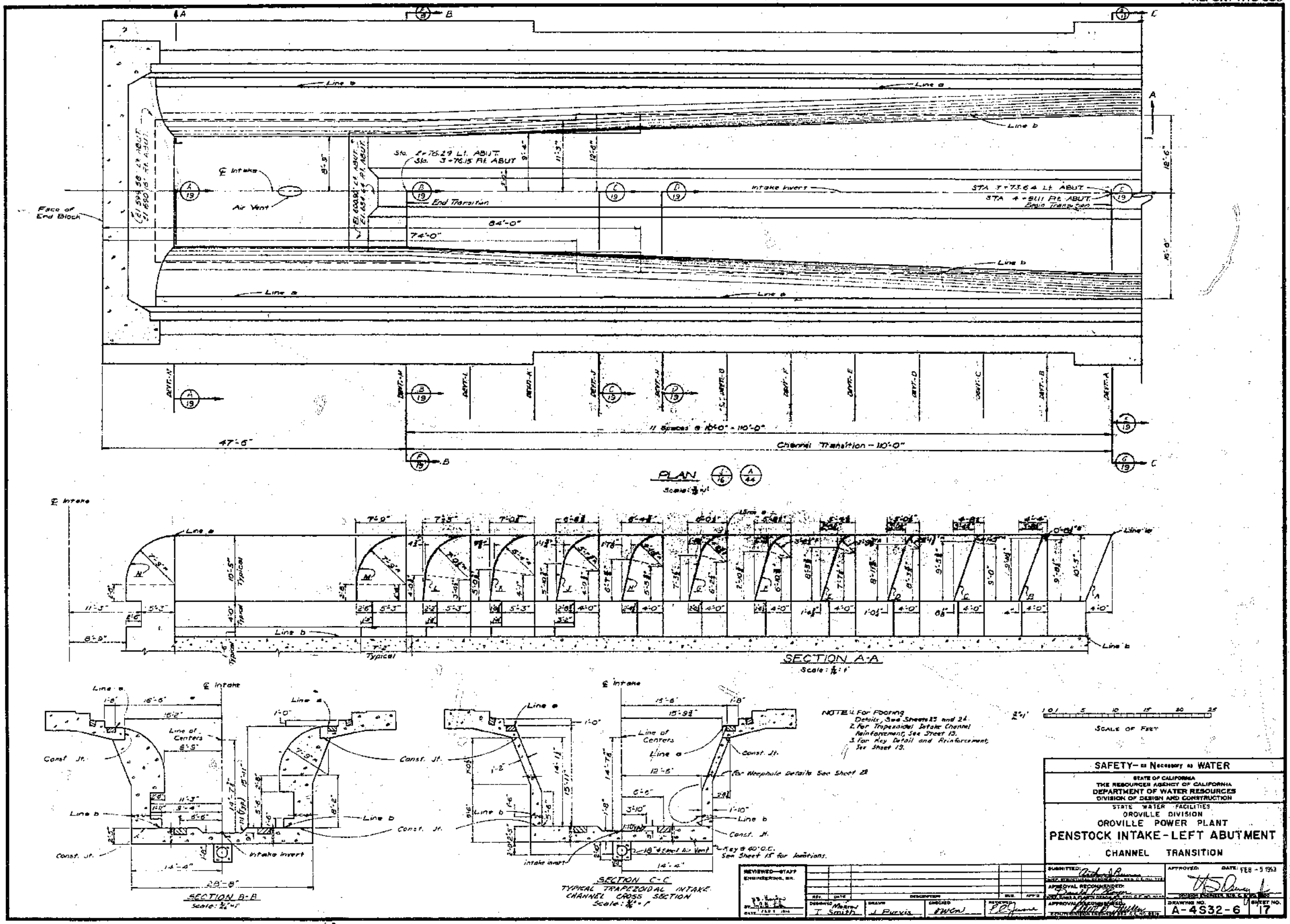


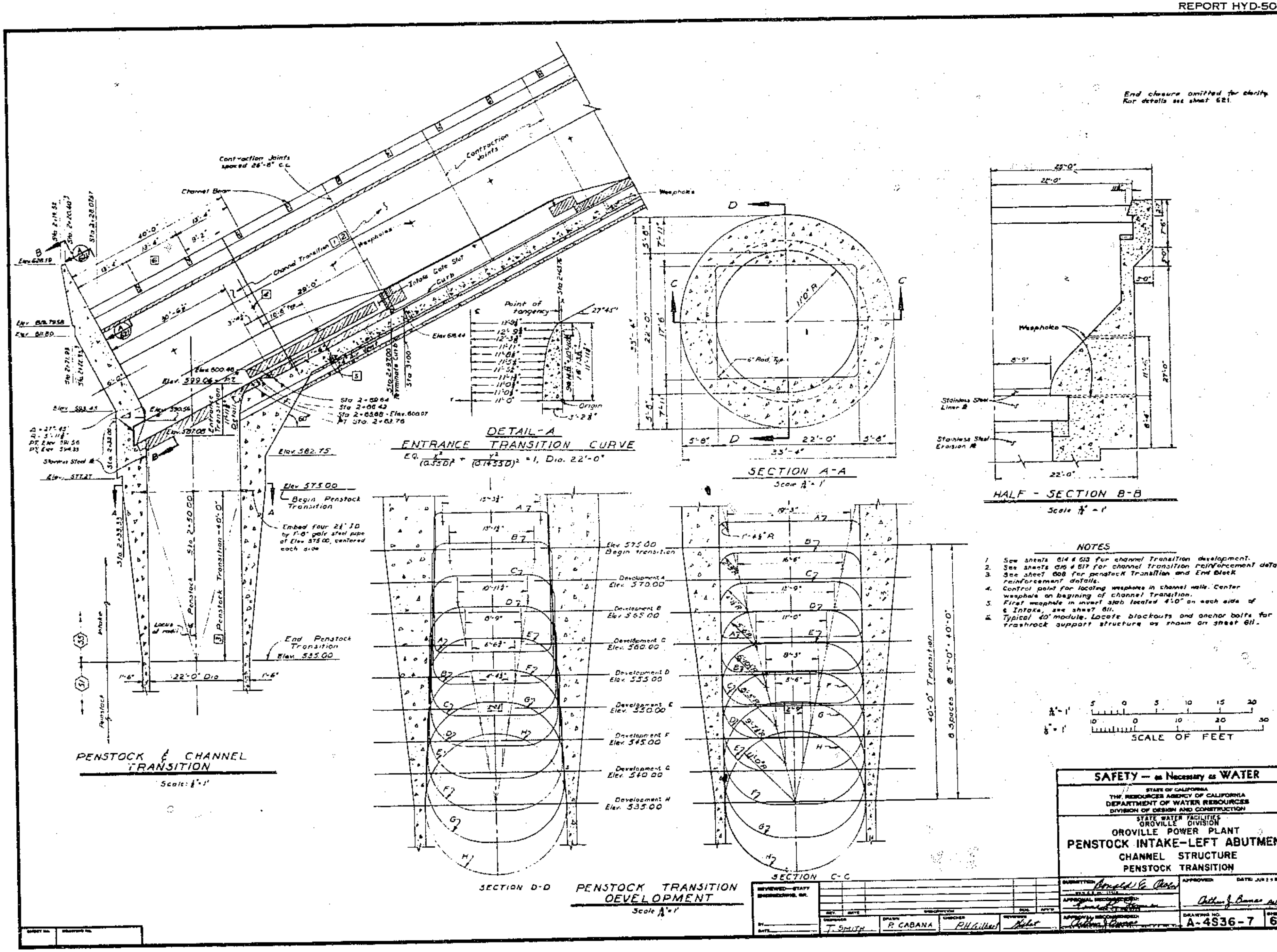
Devl. \ Dim	a	b	c	d	e	f	g	h	r3
Sect D-D	7'-6"	0'-0"	0'-0"	0'-0"	12'-6"	0'-0"	20'-0"	0'-0"	0'-0"
Devl A	8'-6"	2'-4¾"					20'-2½"	1'-0"	
" B	9'-6"	4'-2½"					20'-5⅞"	2'-0"	
" C	10'-6"	5'-6"				0'-1⅞"	20'-8⅞"	3'-0"	
" D	11'-6"					0'-10"	21'-0⅞"	4'-0"	
" E	12'-6"					1'-6¾"	21'-5¾"	5'-0"	
" F	13'-6"					2'-3¼"	21'-10"	6'-0"	
" G	14'-6"					3'-0¼"	22'-3½"	7'-0"	
" H	15'-6"			±10'		3'-8½"	22'-8½"	8'-0"	
" J	16'-6"		1'-6"			3'-7"	23'-2½"	9'-0"	2'-4⅛"
" K	17'-6"			4'-11" 2'-0"	11'-6"	2'-4"	23'-7⅜"	10'-0"	4'-5"
" L	18'-6"						24'-3½"	11'-0"	5'-11⅛"
Sect C-C	19'-6"						24'-9⅞"	12'-0"	7'-3¾"

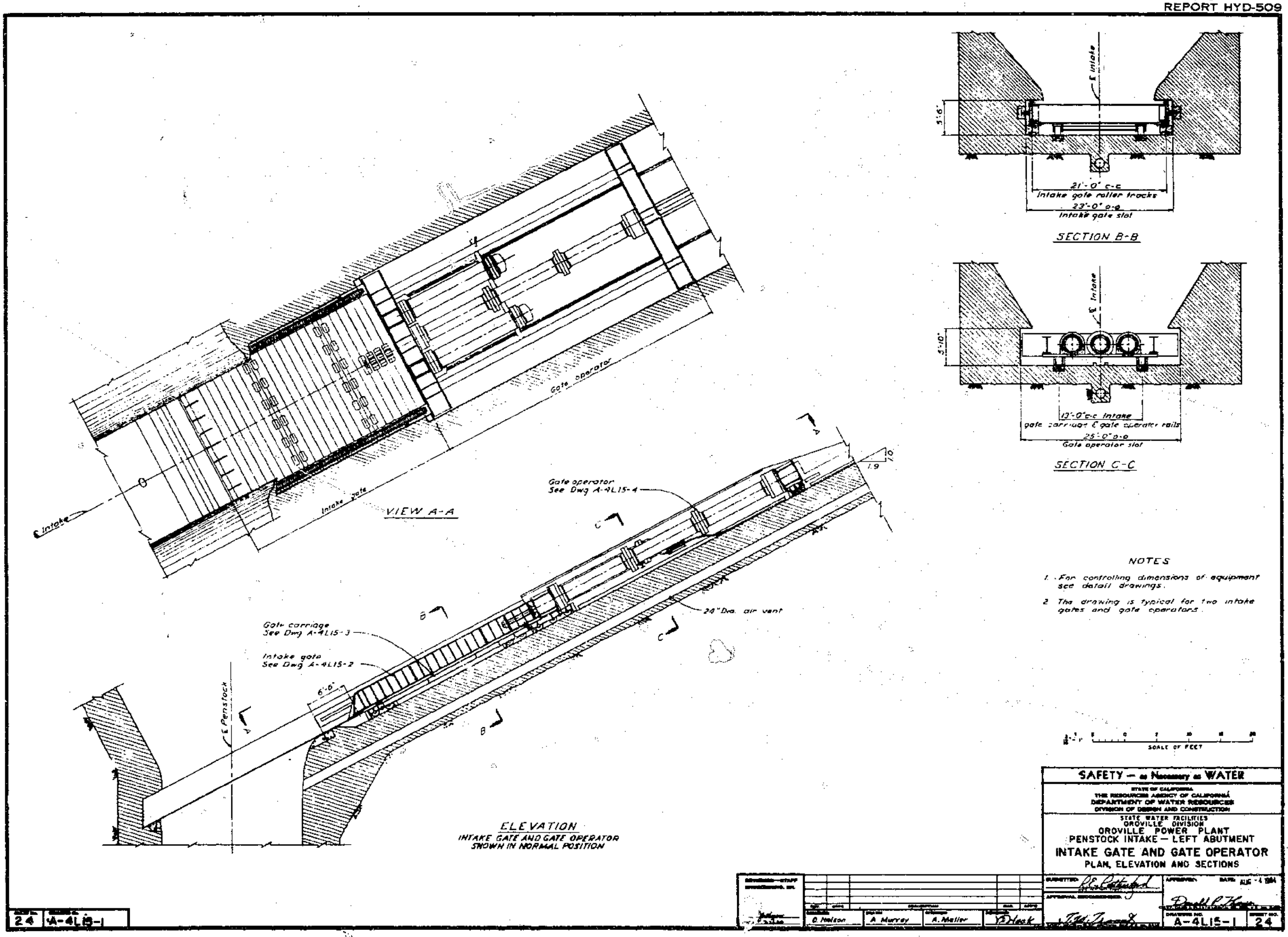
DIMENSION SCHEDULE

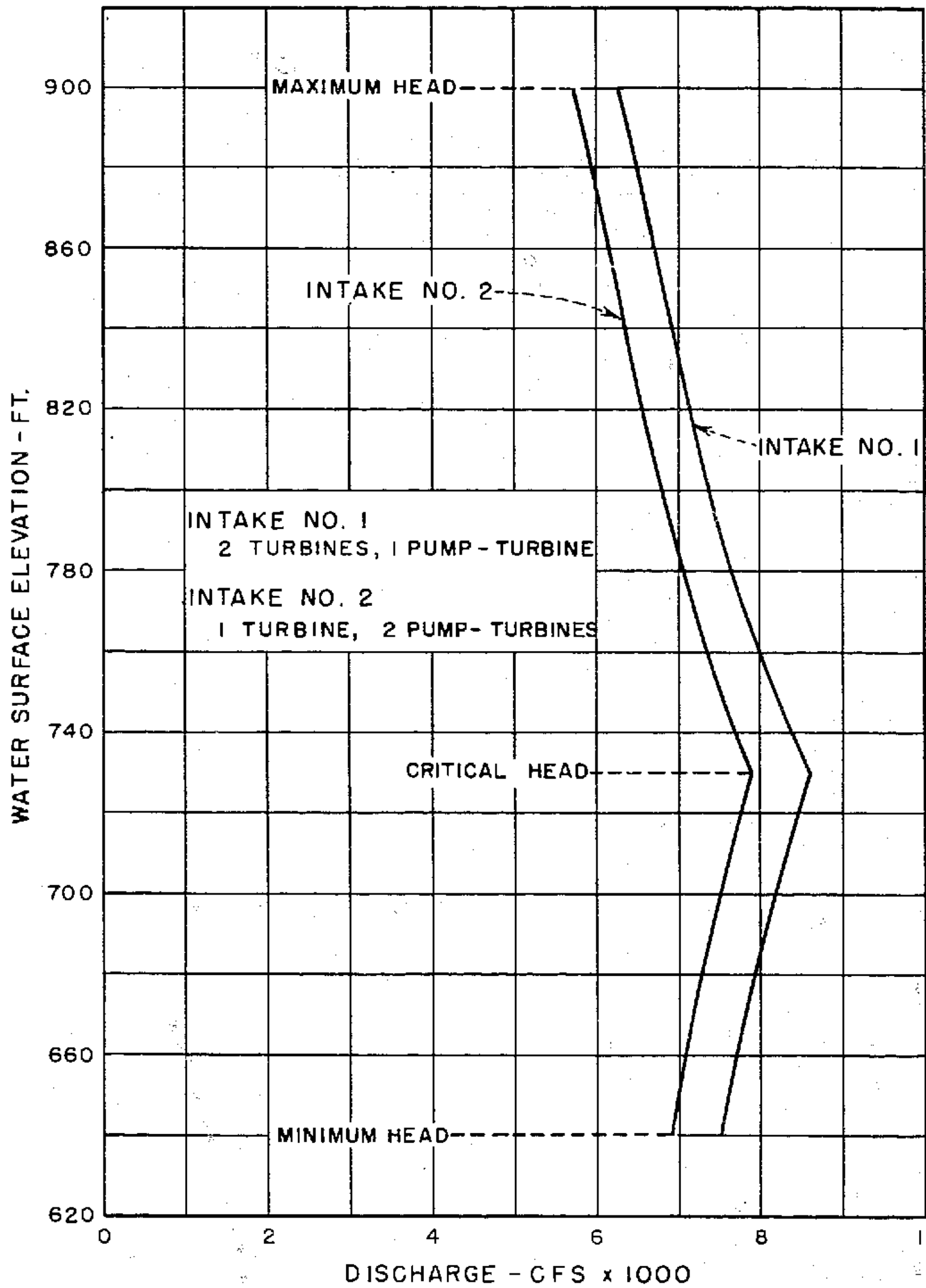
FIGURE 8
REPORT HYD-509




PLAN
SECTION A-A
SECTION B-B
SECTION C-C
TYPICAL TRAPEZOIDAL INTAKE CHANNEL CROSS SECTION
NOTE: 1. For Footing Details, See Sheets 23 and 24.
2. For Trapezoidal Intake Channel Reinforcement, See Sheet 13.
3. For Key Detail and Reinforcement See Sheet 13.
SCALE OF FEET
SAFETY—is Necessary as WATER
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
OROVILLE DIVISION
OROVILLE POWER PLANT
PENSTOCK INTAKE-LEFT ABUTMENT
CHANNEL TRANSITION
DRAWING NO. A-4S32-6
SHEET NO. 17

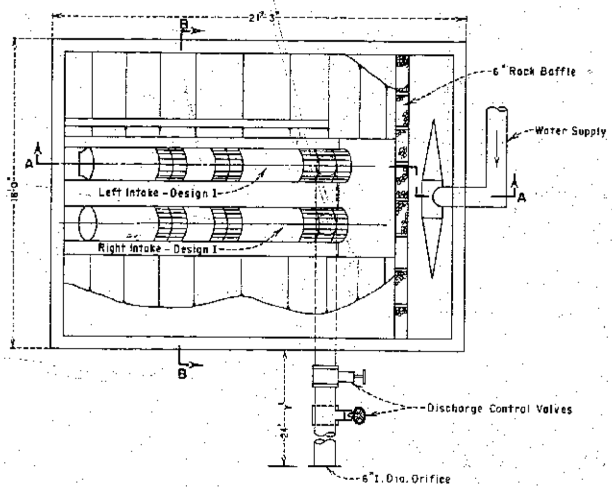

End closure omitted for clarity. For details see sheet 621.
PENSTOCK ℄ CHANNEL TRANSITION
Scale: 1/8" = 1'
DETAIL-A
ENTRANCE TRANSITION CURVE
SECTION A-A
HALF - SECTION B-B
SECTION D-D
SECTION C-C
PENSTOCK TRANSITION DEVELOPMENT
NOTES
1. See sheets 614 & 613 for channel transition development.
2. See sheets 616 & 617 for channel transition reinforcement details.
3. See sheet 608 for penstock transition and end block reinforcement details.
4. Control point for locating weepholes in channel walls. Center weephole on beginning of channel transition.
5. First weephole in invert slab located 4'-0" on each side of ℄ Intake, see sheet 611.
6. Typical 60' module. Locate blockouts and anchor bolts for trashrack support structure as shown on sheet 611.
SCALE OF FEET
SAFETY — as Necessary as WATER
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
OROVILLE DIVISION
OROVILLE POWER PLANT
PENSTOCK INTAKE-LEFT ABUTMENT
CHANNEL STRUCTURE
PENSTOCK TRANSITION
A-4S36-7
607


SECTION B-B
℄ Intake
5'-6"
21'-0" c-c
Intake gate roller tracks
23'-0" o-o
Intake gate slot
SECTION C-C
℄ Intake
5'-10"
13'-0" c-c Intake
gate carriage & gate operator rails
25'-0" o-o
Gate operator slot
VIEW A-A
℄ Intake
Intake gate
Gate operator
Gate operator
See Dwg A-4L15-4
Gate carriage
See Dwg A-4L15-3
Intake gate
See Dwg A-4L15-2
6'-6"
℄ Penstock
24" Dia. air vent
1.9
1.0
ELEVATION
INTAKE GATE AND GATE OPERATOR
SHOWN IN NORMAL POSITION
NOTES
1. For controlling dimensions of equipment see detail drawings.
2. The drawing is typical for two intake gates and gate operators.
SCALE OF FEET
SAFETY — as Necessary as WATER
STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
STATE WATER FACILITIES
OROVILLE DIVISION
OROVILLE POWER PLANT
PENSTOCK INTAKE — LEFT ABUTMENT
INTAKE GATE AND GATE OPERATOR
PLAN, ELEVATION AND SECTIONS
AUG - 4 1964
A-4L15-1
24
D. Nelson
A. Murray
A. Meller
24
A-4L15-1

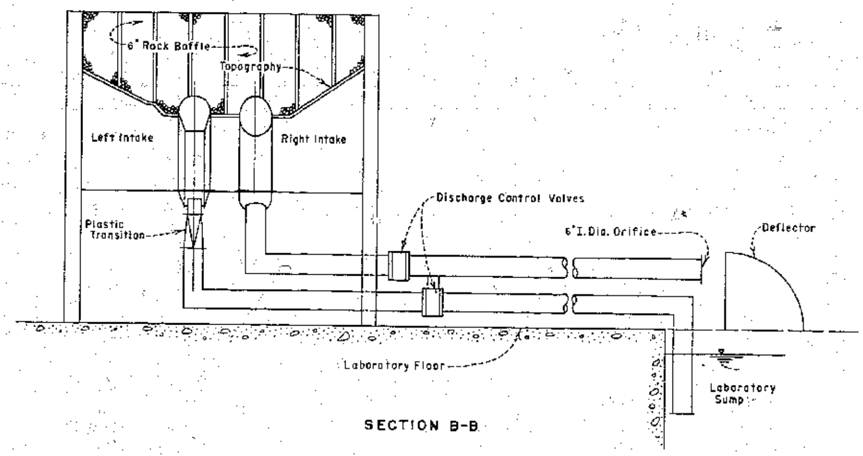


OROVILLE DAM
POWER PLANT INTAKES
DISCHARGE RATING CURVE

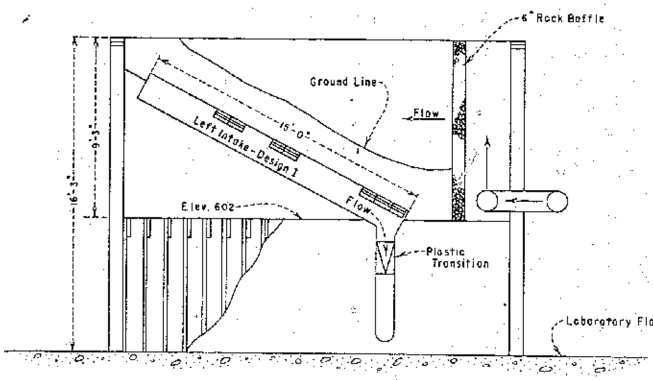
694



PLAN



SECTION B-B

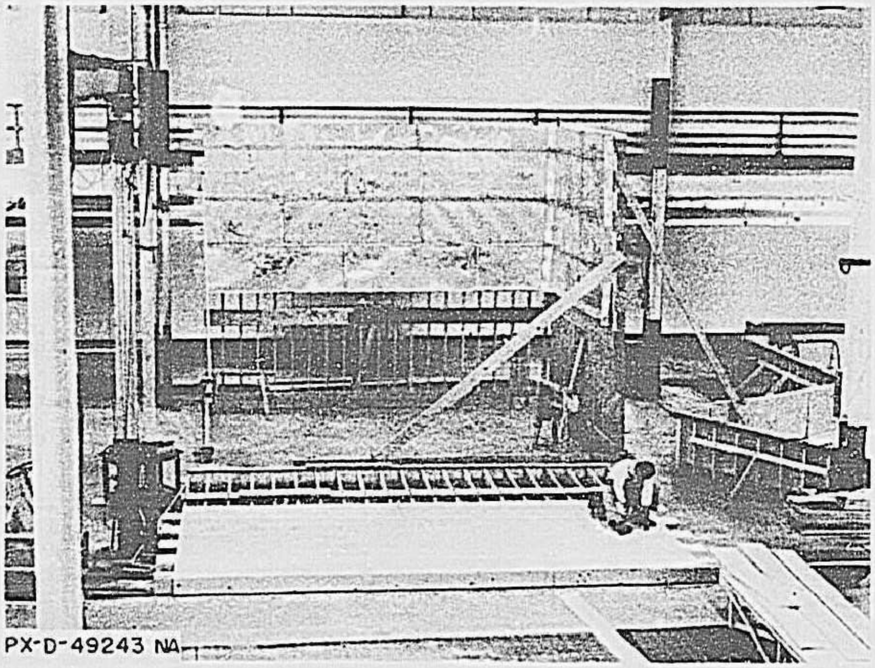


SECTION A-A

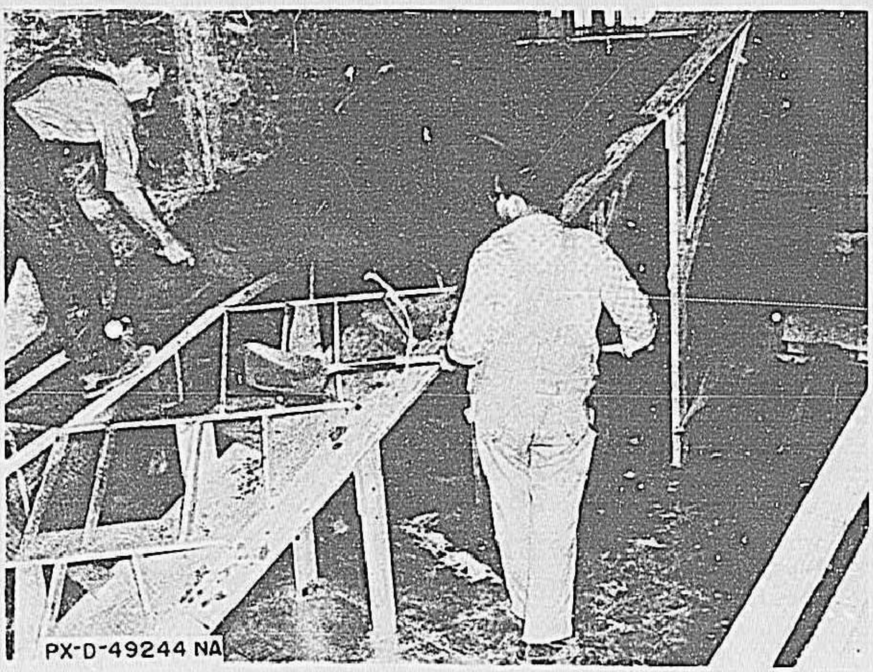
NOTES
Walkway and stairway details not shown.
Construction details omitted.
All dimensions - feet and inches model.

OROVILLE DAM
POWER PLANT INTAKES
MODEL LAYOUT
1:24 SCALE MODEL

694



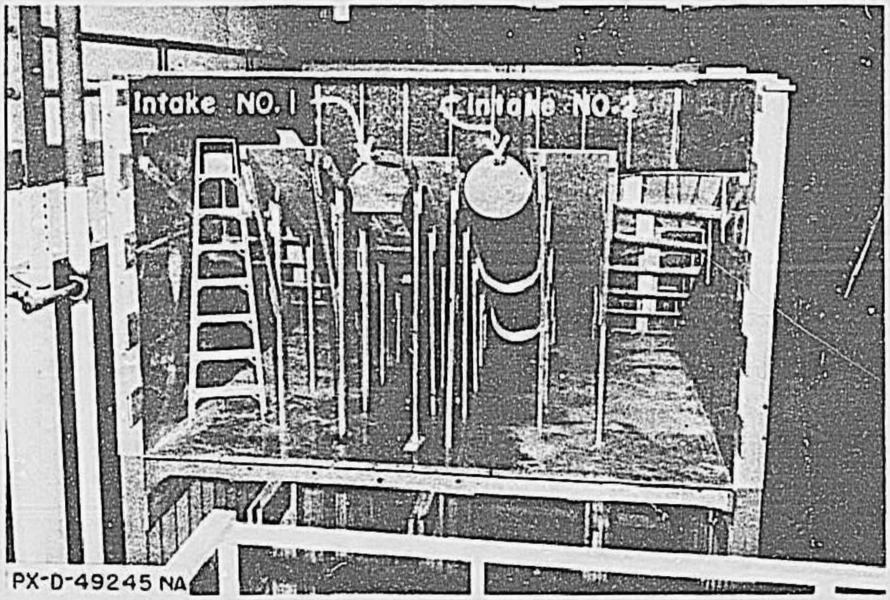
A. The walls of the headbox were constructed flat on laboratory floor, lined with sheet metal, soldered, and then tilted up into position. The floor of the box is 7 feet above the laboratory floor.



B. Topography was formed by cutting contours from wood and placing them at their appropriate elevation. A 3/4-inch layer of concrete placed over metal lath produced the finished surface.

OROVILLE DAM
POWERPLANT INTAKES
Construction of Headbox and Topography

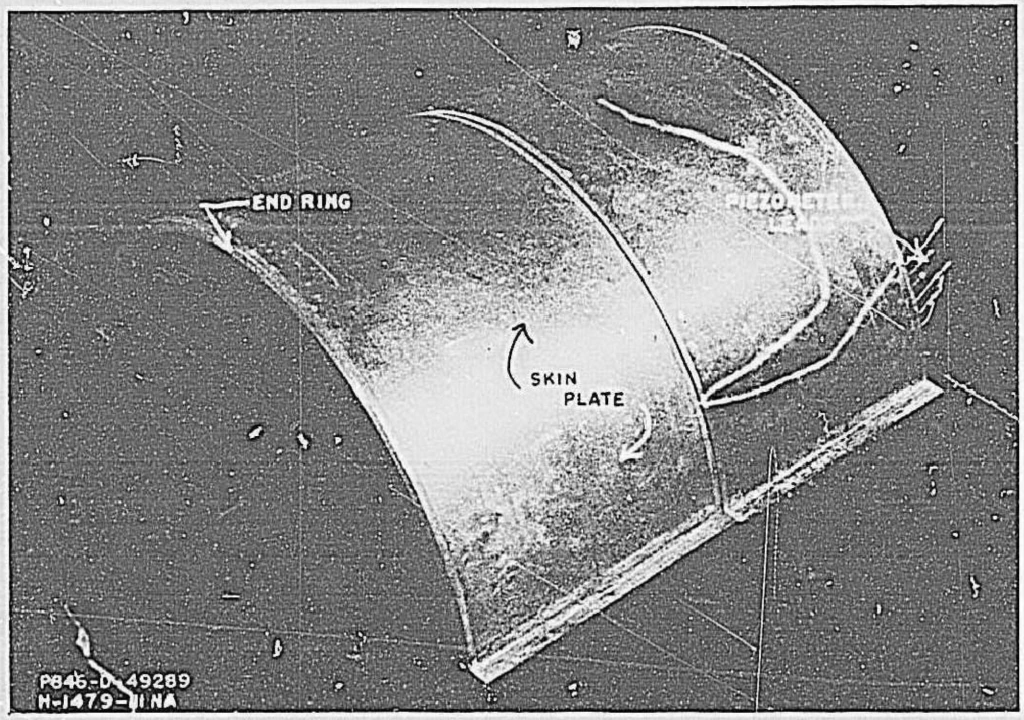
FIGURE 15
Report Hyd-509



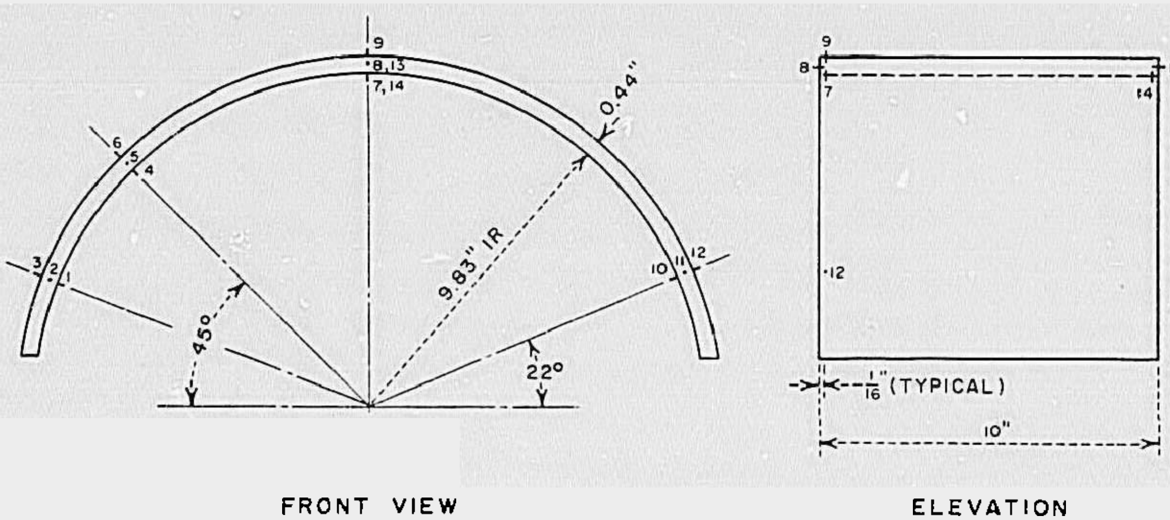
A. The left intake was built to exact scale. The right intake was fabricated as a cylinder to represent the general shape of the intake.

B. The model contained two intake structures and surrounding topography. The right intake could be tilted up to provide access for piezometer connections.

OROVILLE DAM
POWERPLANT INTAKES
General Views of Model--Design I



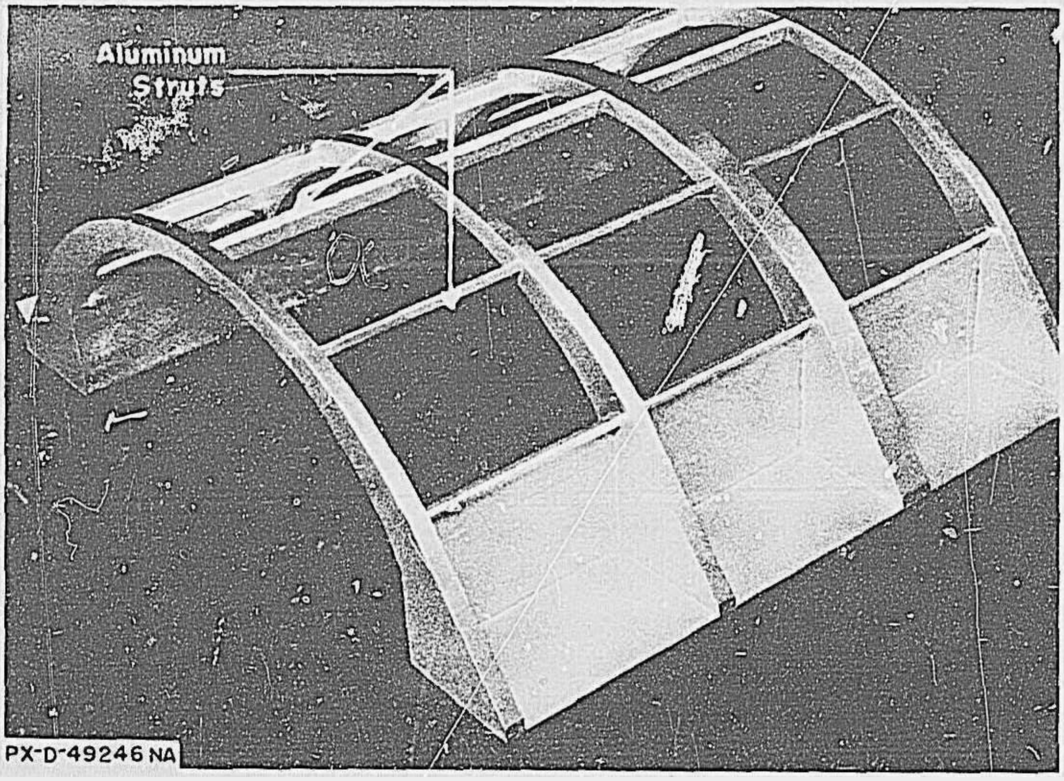
A. CONTROL SHUTTERS WERE FABRICATED BY FASTENING ROLLED SKINPLATES TO MACHINED END RINGS. FOURTEEN PIEZOMETERS WERE PLACED IN THE RIGHT SHUTTER.



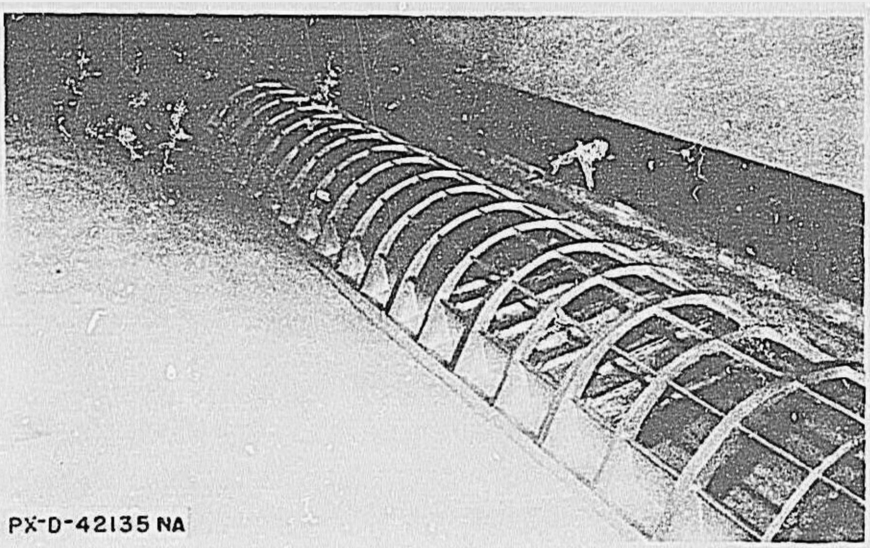
B. PIEZOMETER LOCATIONS

OROVILLE DAM
POWER PLANT INTAKES
SEMICYLINDRICAL SHUTTERS - DESIGN I
1 : 24 SCALE MODEL

FIGURE 17
Report Hyd-509

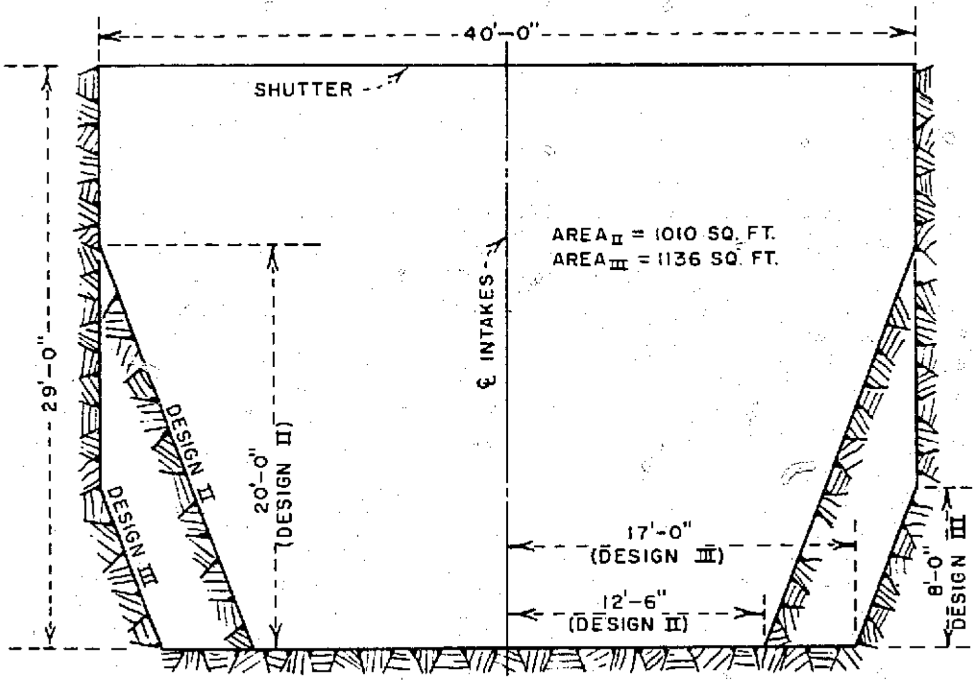


A. Haunched trashrack arches were fabricated from No. 18-gage sheet metal. Struts between the arches were machined from aluminum bar stock.

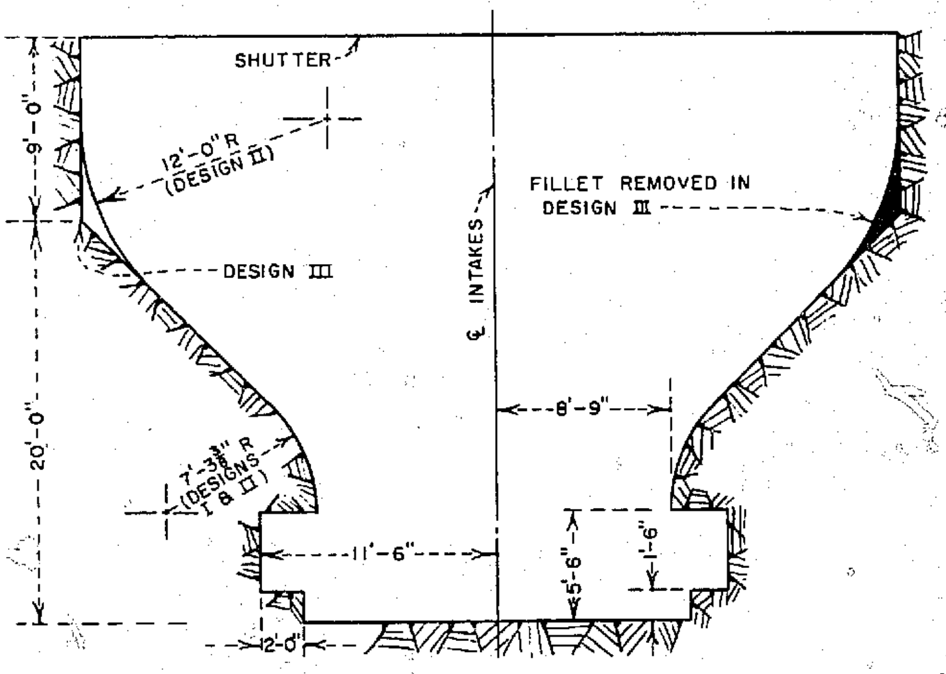


B. General view of intakes. Eight shutters are in place under trashrack arches of Intake No. 1.

OROVILLE DAM
POWERPLANT INTAKE
General Views of Trashrack
Section and Intake Model--Design II
1:24 Scale Model



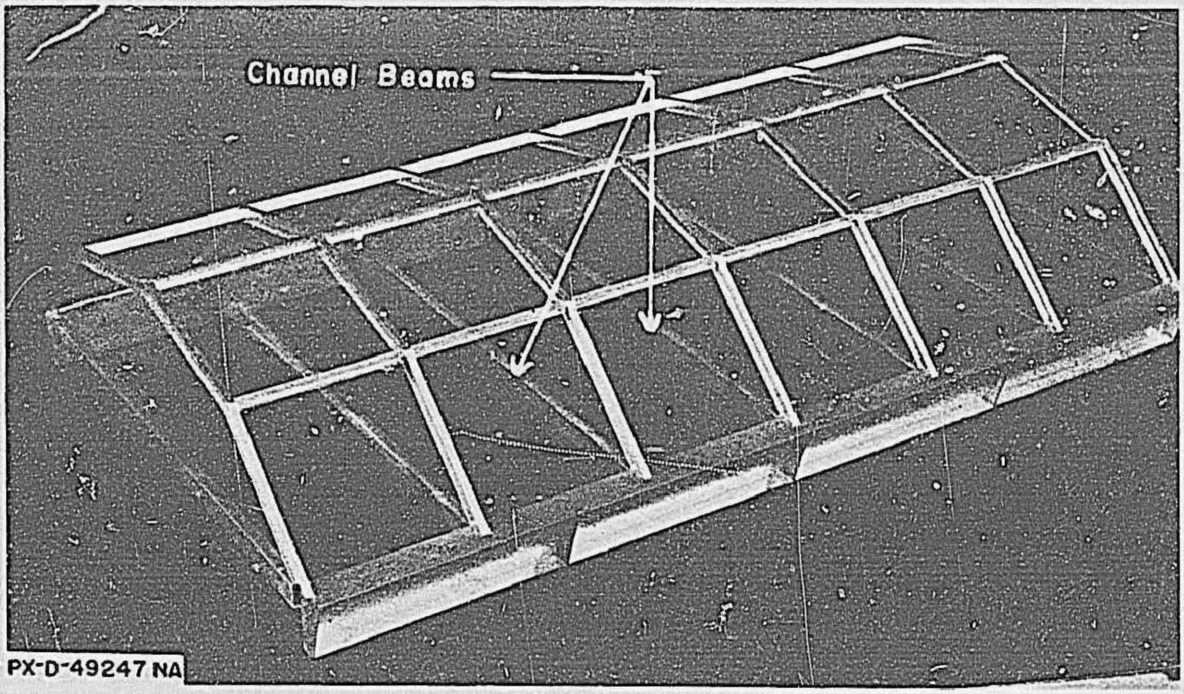
CROSS-SECTION OF INTAKE CHANNEL



CROSS-SECTION THROUGH FULLY DEVELOPED TRANSITION

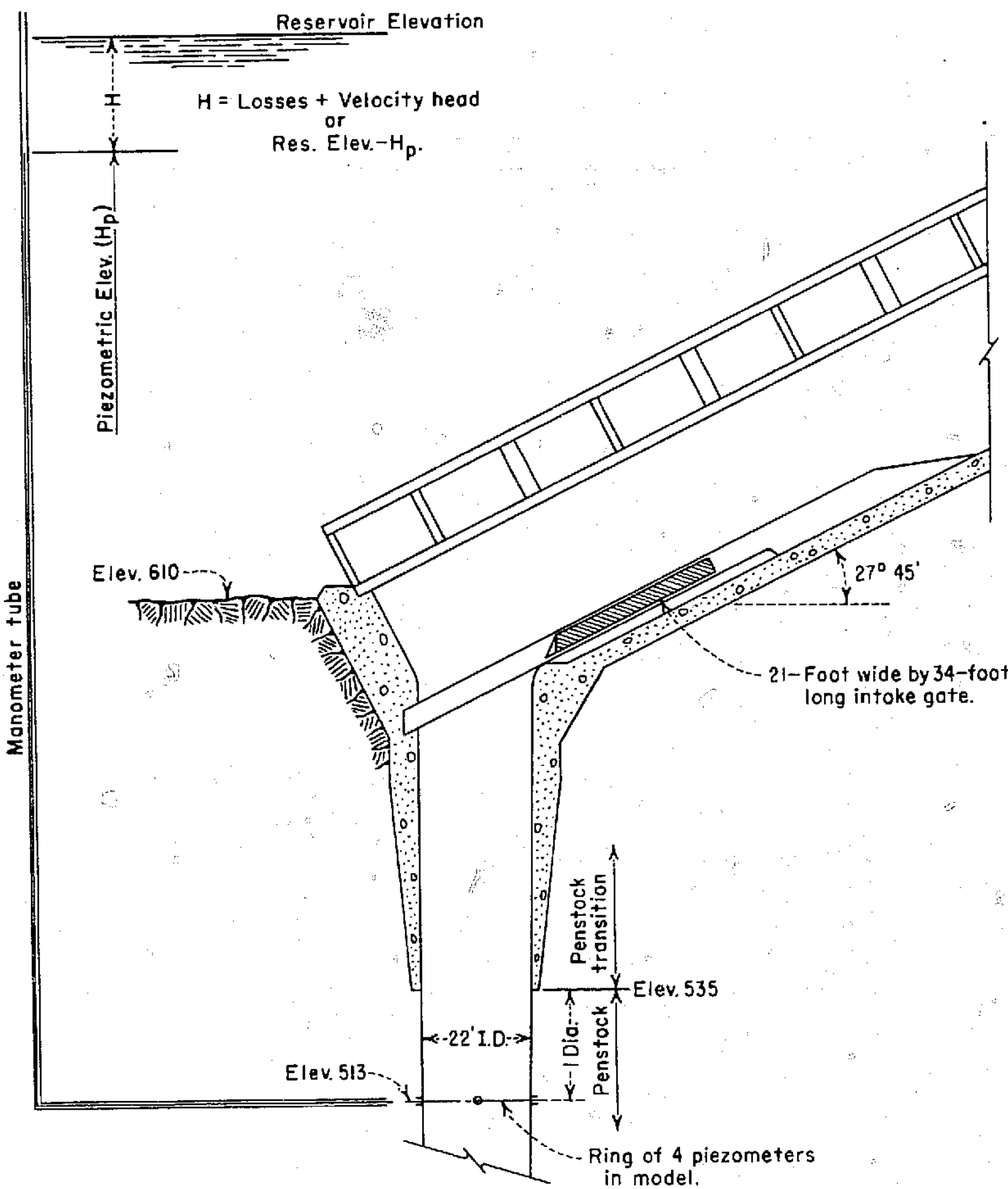
OROVILLE DAM
POWER PLANT INTAKES
COMPARISON OF CROSS-SECTIONS
OF DESIGN II AND III

FIGURE 19
Report Hyd-509



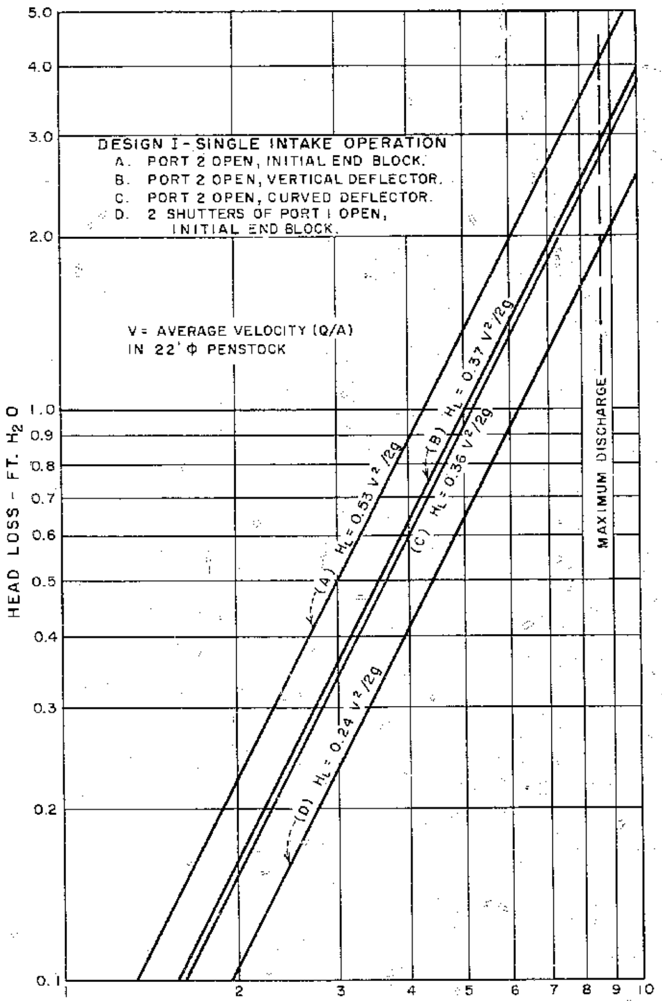
Structural elements of the segmented arch trashrack were fabricated from No. 18-gage galvanized sheet metal. A channel beam formed the tension member at base of each arch.

OROVILLE DAM
POWERPLANT INTAKES
Segmented Arch Trashracks--Design III
1:24 Scale Model

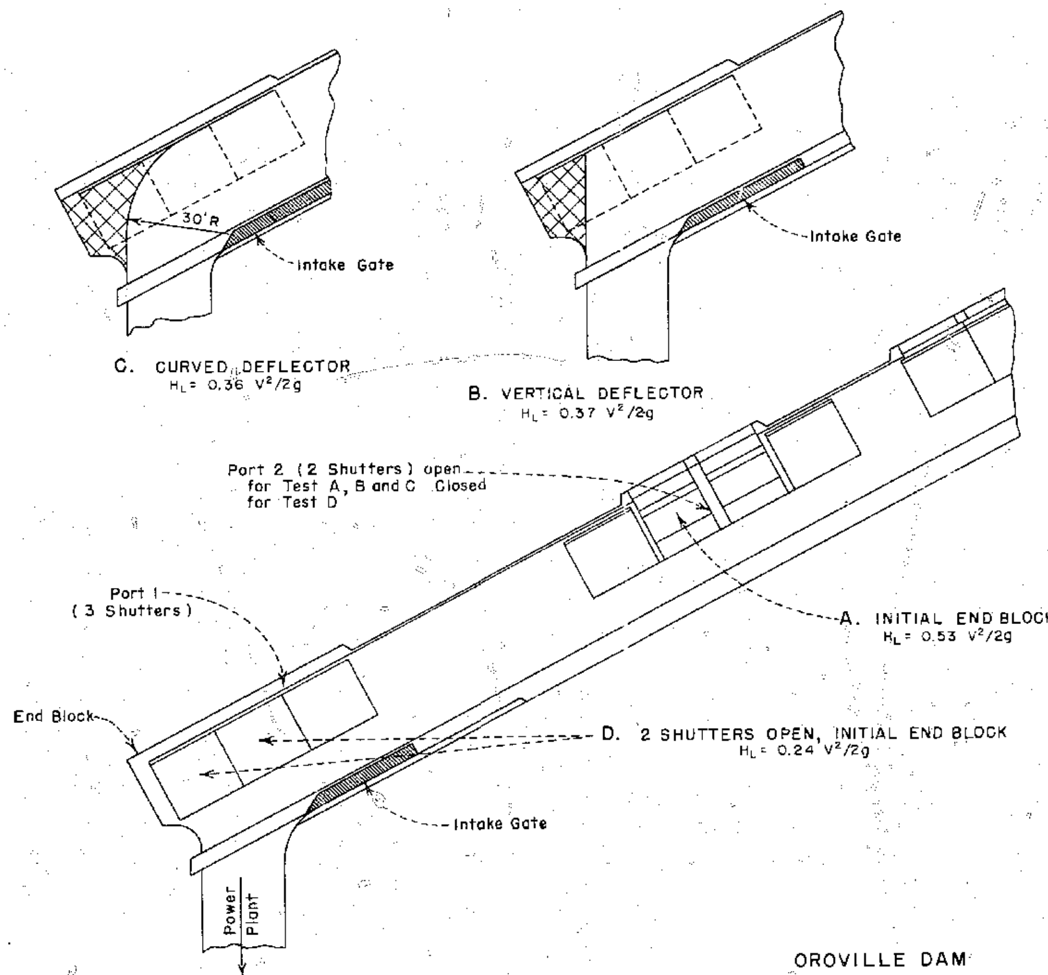


OROVILLE DAM
POWER PLANT INTAKES

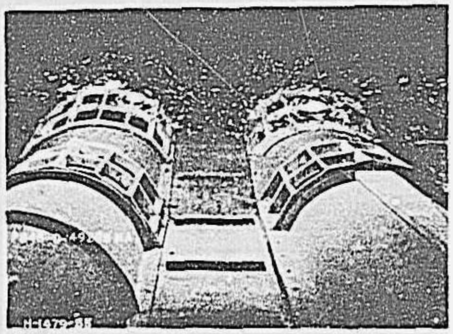
ELEVATION OF INTAKE STRUCTURE AND DEFINITION OF HEAD LOSS MEASUREMENT



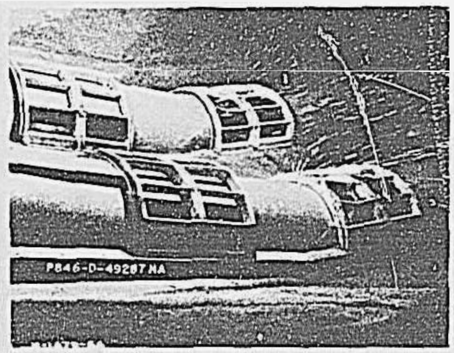
HEAD LOSS VS DISCHARGE
DATA FROM 1:24 MODEL



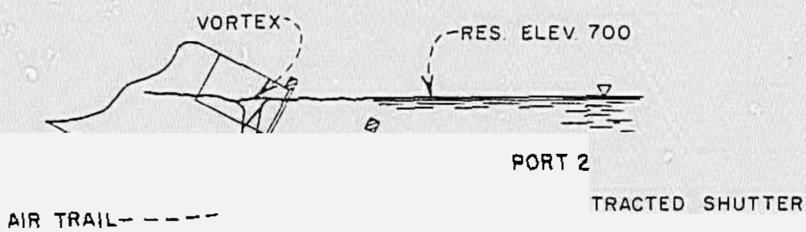
OROVILLE DAM
POWER PLANT INTAKES
HEAD LOSS TESTS - DESIGN I
1:24 SCALE MODEL



A. RESERVOIR ELEVATION 710
LARGE CLOCKWISE VORTEX FORMED OVER INTAKE NO.1 WHILE COUNTERCLOCKWISE VORTEX FORMED OVER INTAKE NO.2
(½ SECOND TIME EXPOSURE)



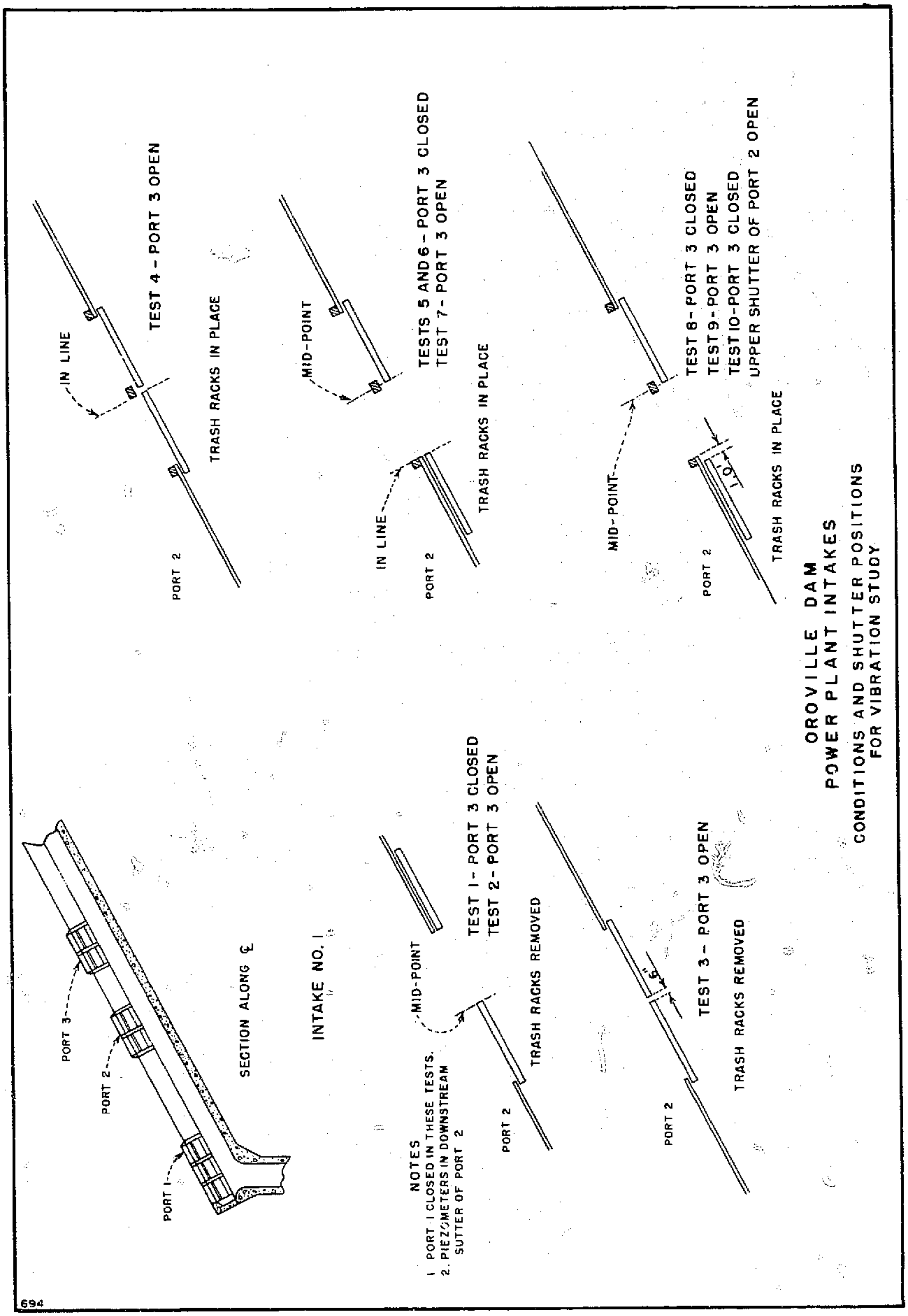
B. RESERVOIR ELEVATION 700
LARGE VORTICIES, CLOCKWISE IN INTAKE NO. 1, COUNTERCLOCKWISE IN INTAKE NO.2, FORMED IN THE INTAKE CHANNELS.
(½ SECOND TIME EXPOSURE)



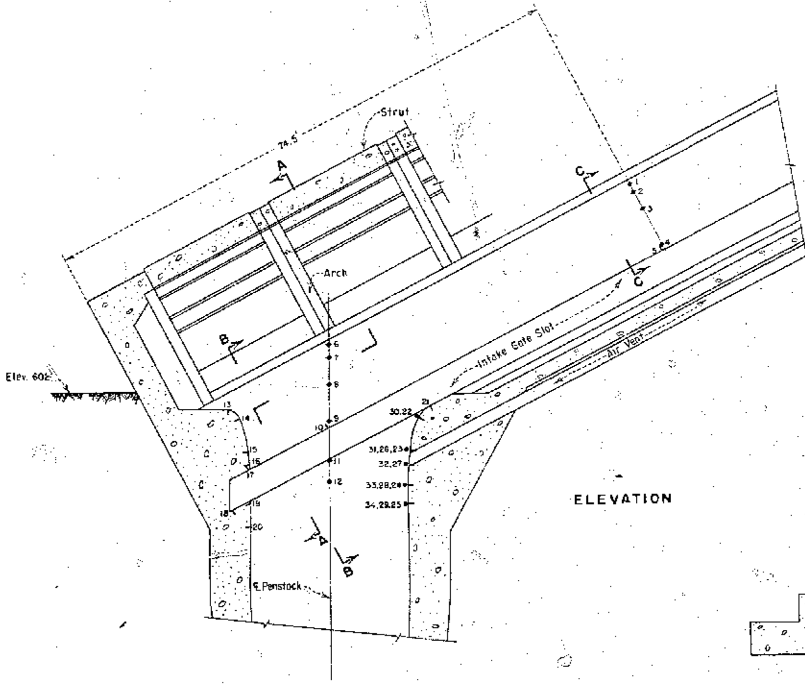
C. LOCATION OF VORTEX IN INTAKE CHANNELS
SIMULTANEOUS OPERATION – 8,600 CFS INTAKE NO 1, 7,900 CFS INTAKE NO.2.

OROVILLE DAM
POWER PLANT INTAKES
VORTEX STUDY – DESIGN I
1 : 24 SCALE MODEL

FIGURE 23
REPORT HYD-509



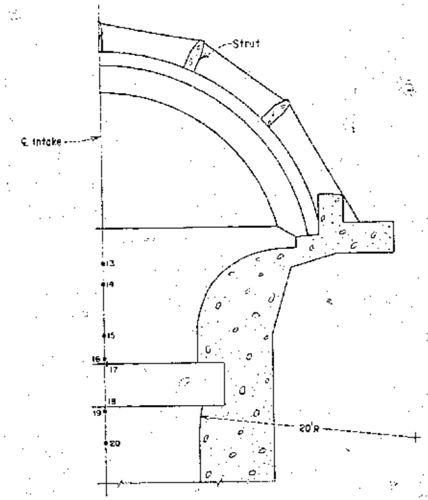
OROVILLE DAM
POWER PLANT INTAKES
CONDITIONS AND SHUTTER POSITIONS
FOR VIBRATION STUDY



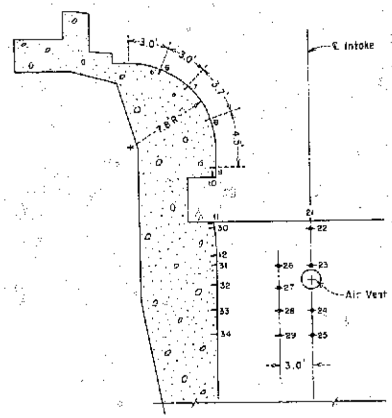
ELEVATION

PIEZOMETER	ELEVATION
1	630.0
2	629.0
3	626.8
4	621.7
5	620.8
6	607.6
7	605.2
8	602.0
9	596.8
10	595.0
11	591.3
12	589.4
13	598.6
14	597.2
15	592.6
16	590.7
17	590.2
18	584.5
19	585.5
20	582.0
21	599.0
22	597.5
23	592.8
24	587.8
25	585.3
26	592.8
27	590.8
28	587.8
29	585.3
30	597.5
31	592.8
32	590.8
33	587.8
34	585.3

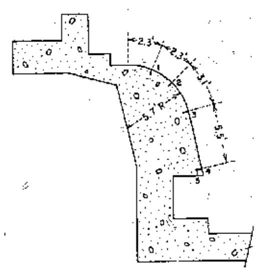
PIEZOMETER ELEVATIONS



SECTION A-A



SECTION B-B



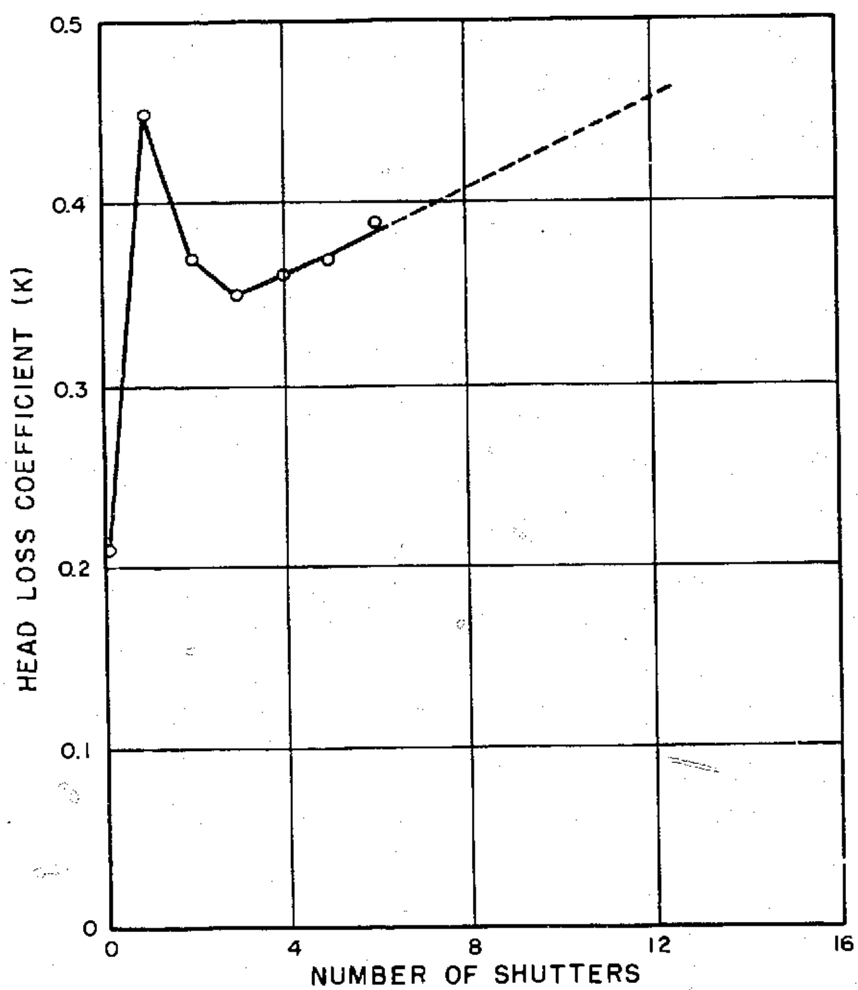
SECTION C-C

OROVILLE DAM
POWER PLANT INTAKES
PIEZOMETER LOCATIONS – DESIGN I

1:24 SCALE MODEL

NUMBER OF SHUTTERS	K	DISCHARGE	H_L
0	0.21	8,600	1.66
1	0.45	8,600	3.57
2	0.37	8,600	2.93
3	0.35	8,600	2.77
4	0.36	8,600	2.85
5	0.37	8,600	2.93
6	0.39	8,600	3.09

A—HEAD LOSS - 0 TO 6 SHUTTERS

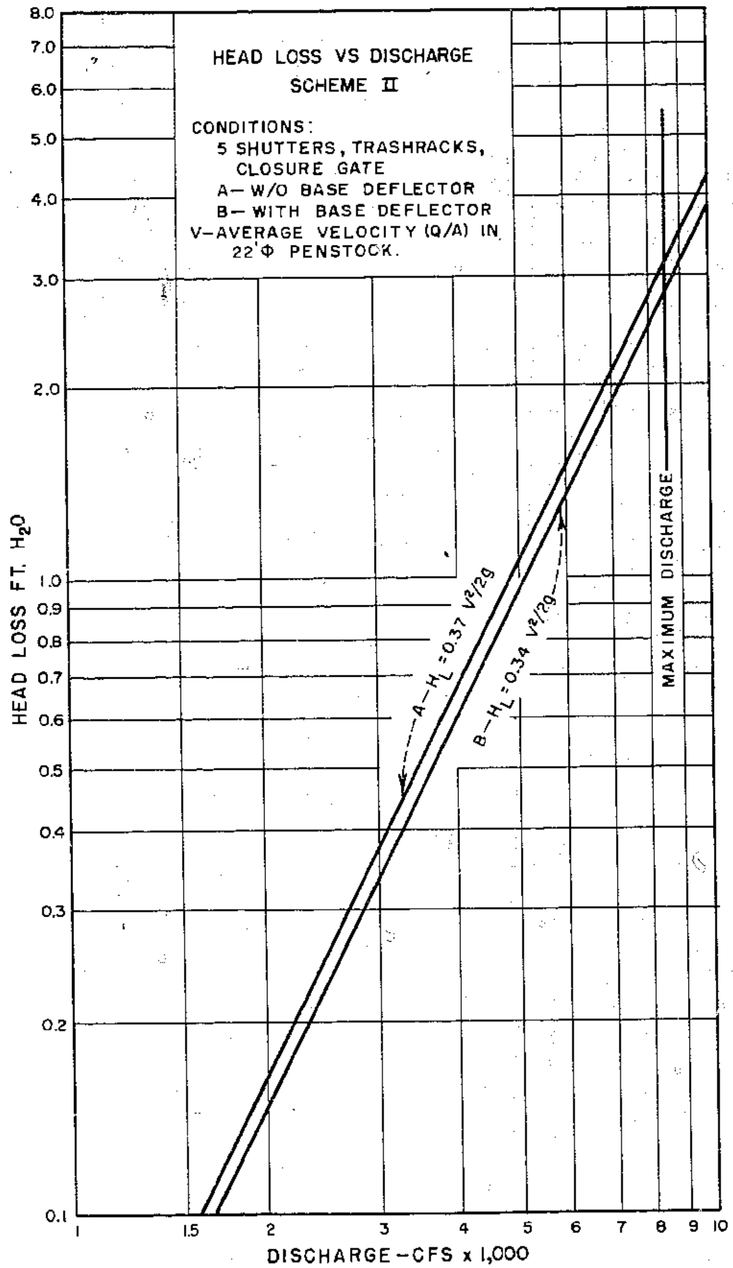


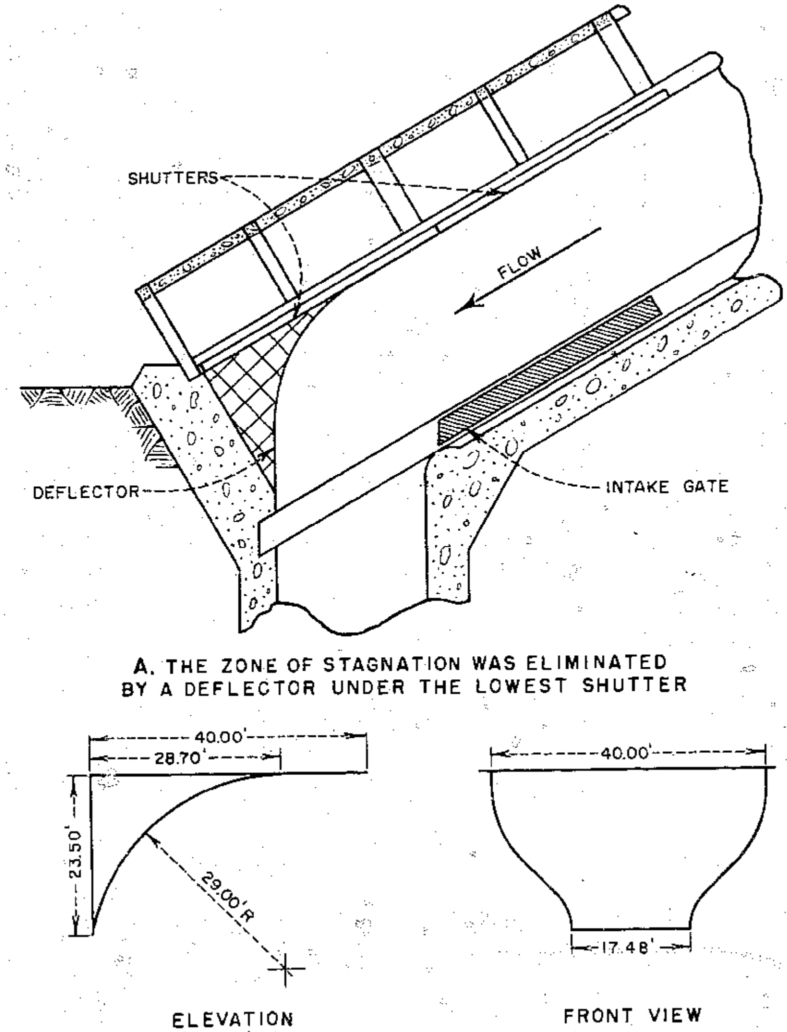
B-HEAD LOSS COEFFICIENTS

OROVILLE DAM
POWER PLANT INTAKES

LOSS COEFFICIENTS AND HEAD LOSS FOR SHUTTERS - DESIGN II

DATA FROM 1:24 MODEL

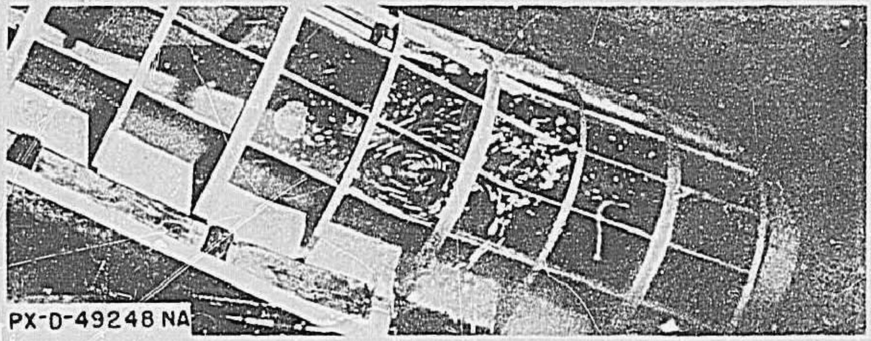




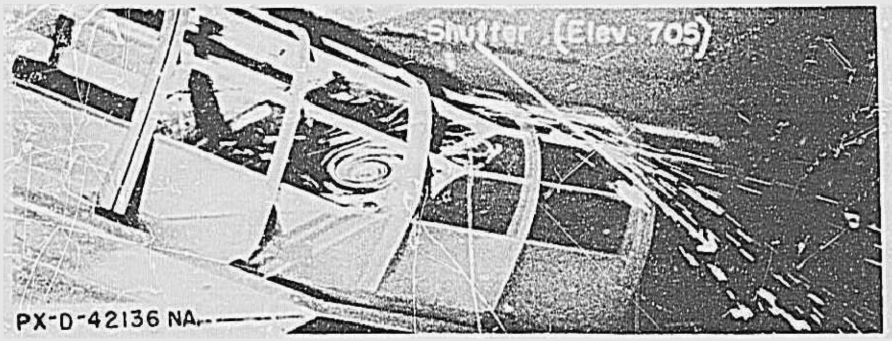
A. THE ZONE OF STAGNATION WAS ELIMINATED BY A DEFLECTOR UNDER THE LOWEST SHUTTER

OROVILLE DAM
POWER PLANT INTAKES
BASE DEFLECTOR - DESIGN II
1 : 24 SCALE MODEL

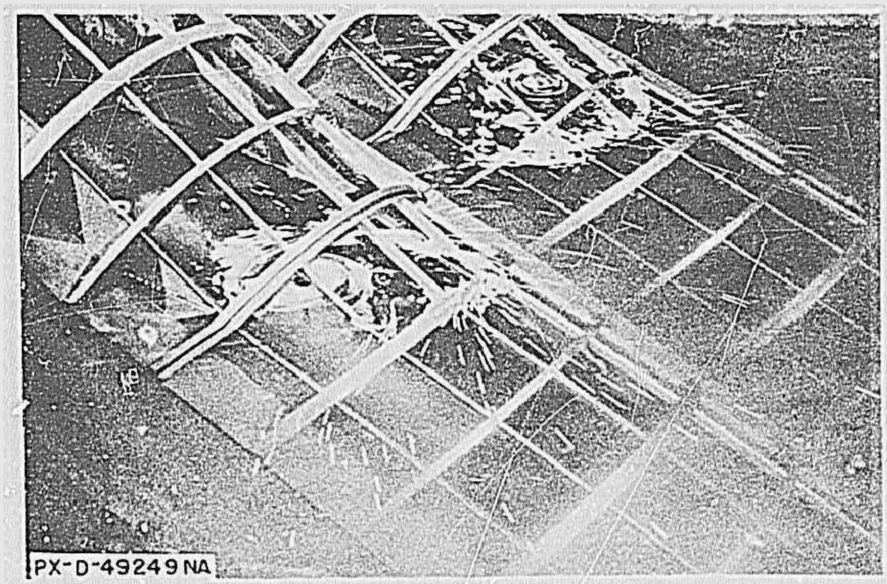
FIGURE 27
Report Hyd-509



A. Reservoir elevation 646--Large vortex in channel. Air drawn into penstock. All shutters removed, 31 feet submergence. (1/2-second time exposure.)

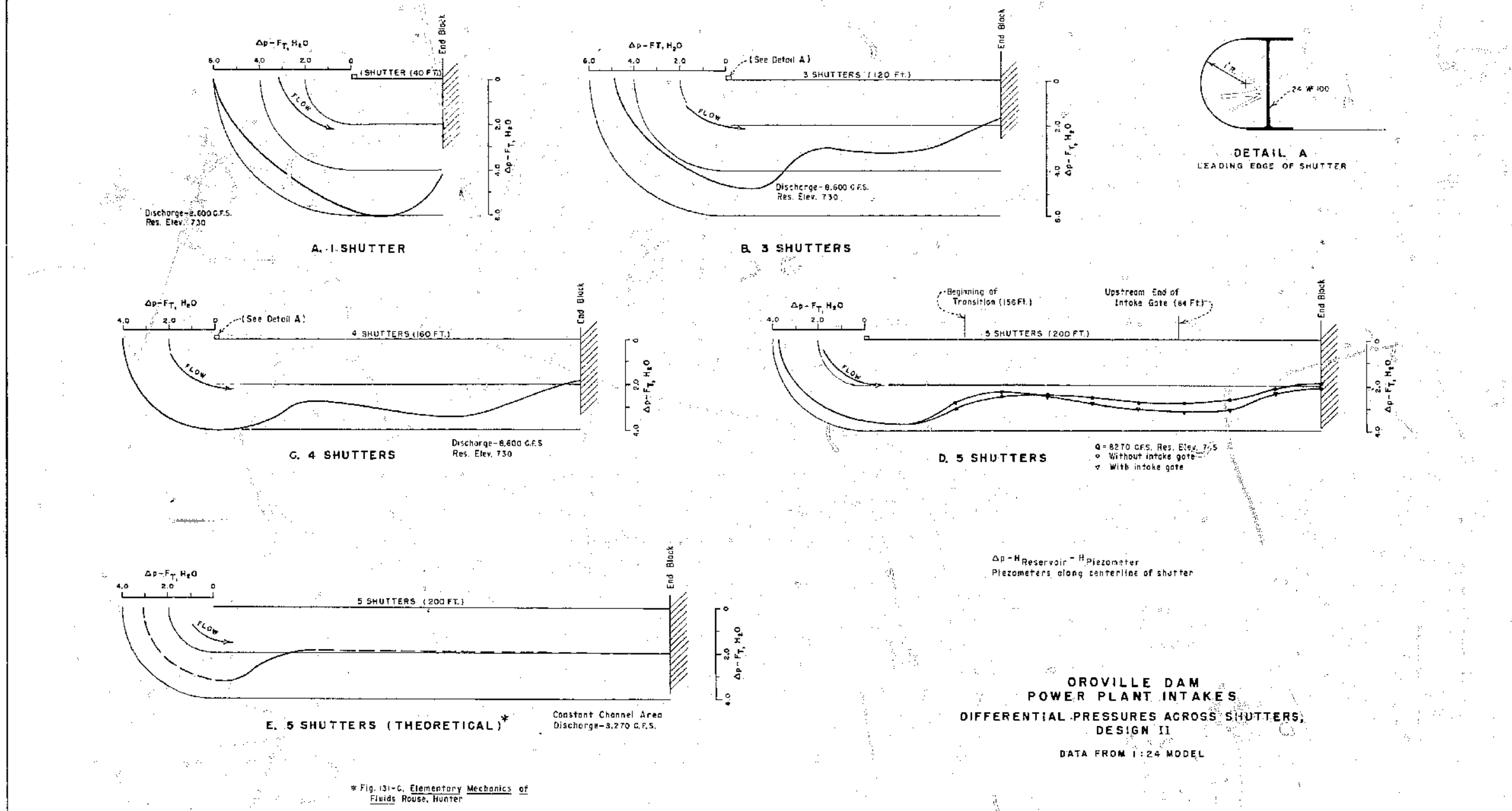


B. Single intake operation, reservoir elevation 740, discharge 8,380 cfs. Five shutters in place. Large vortex formed with air trail extending under shutters, 35 feet submergence. (1/2-second time exposure.)

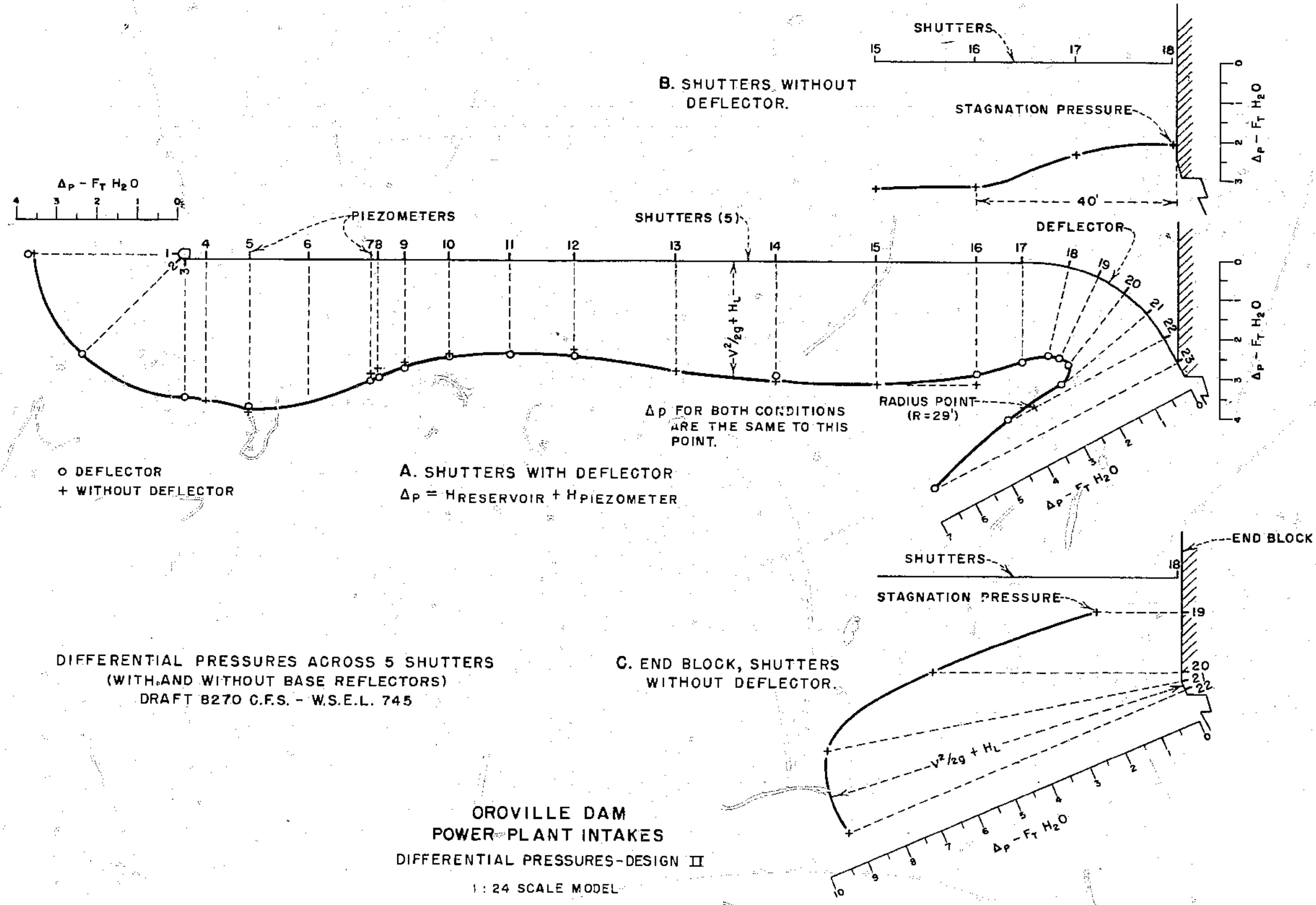


Simultaneous operation, reservoir elevation 740, 8375 cfs Intake No. 1; 7,700 cfs Intake No. 2. Large vortices with air trails formed in both channels. 35 feet submergence (1/2-second time exposure).

OROVILLE DAM
POWERPLANT INTAKES
Vortex Study--Design II
1:24 Scale Model

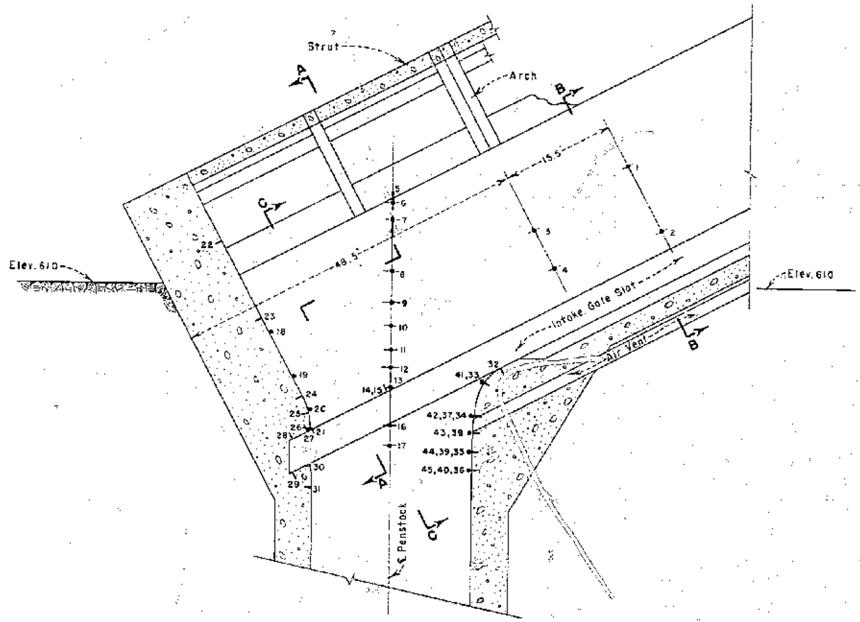


OROVILLE DAM
POWER PLANT INTAKES
DIFFERENTIAL PRESSURES ACROSS SHUTTERS, DESIGN II
DATA FROM 1:24 MODEL

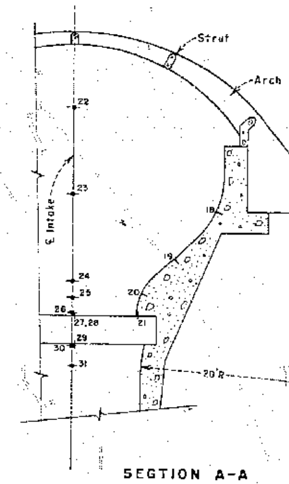


DIFFERENTIAL PRESSURES ACROSS 5 SHUTTERS
(WITH AND WITHOUT BASE REFLECTORS)
DRAFT 8270 C.F.S. - W.S.E.L. 745

OROVILLE DAM
POWER PLANT INTAKES
DIFFERENTIAL PRESSURES-DESIGN II
1 : 24 SCALE MODEL



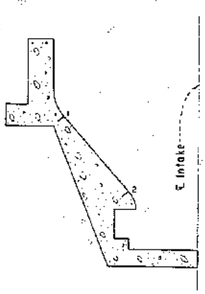
ELEVATION



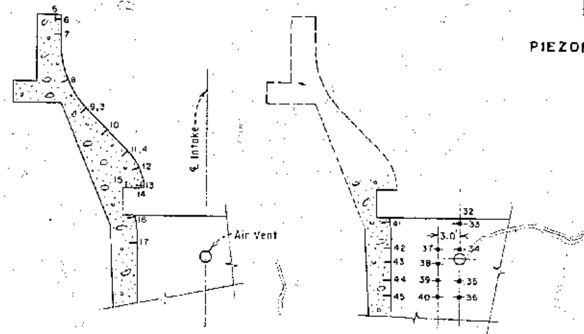
SECTION A-A

PIEZOMETER	ELEVATION
1	627.0
2	617.8
3	618.0
4	612.7
5	622.2
6	621.7
7	619.3
8	612.2
9	607.8
10	604.6
11	601.3
12	598.7
13	596.0
14	595.8
15	595.8
16	590.9
17	588.0
18	603.7
19	597.7
20	593.0
21	590.2
22	616.2
23	605.5
24	594.7
25	592.5
26	591.6
27	590.0
28	598.7
29	584.2
30	585.3
31	582.2
32	599.0
33	597.5
34	592.8
35	587.8
36	585.3
37	592.8
38	590.8
39	587.6
40	585.3
41	597.5
42	592.8
43	590.6
44	587.8
45	585.3

PIEZOMETER ELEVATIONS

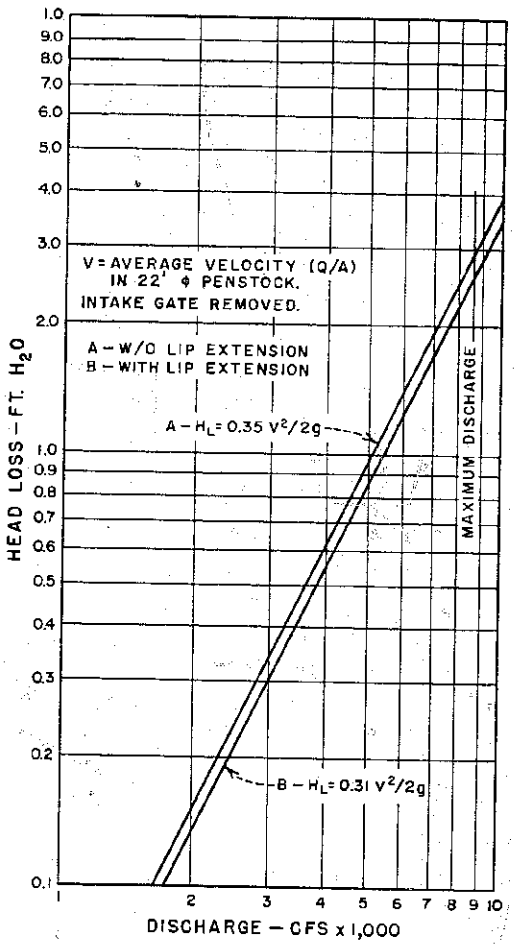


SECTION B-B

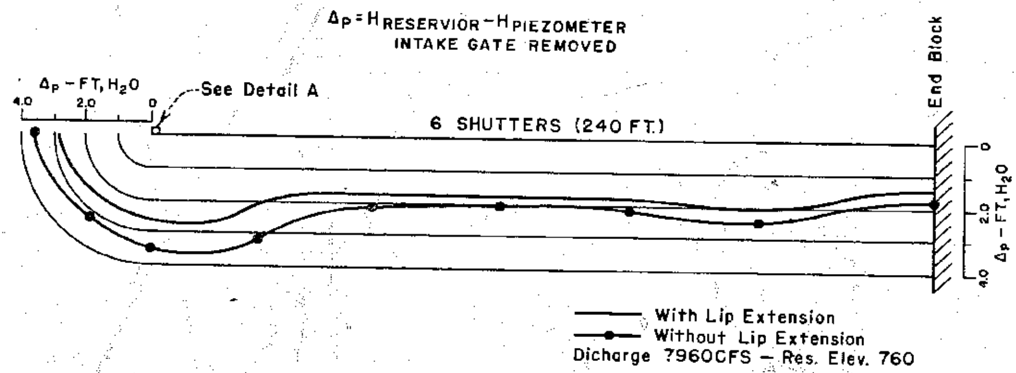


SECTION C-C

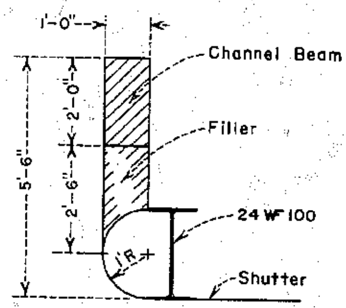
OROVILLE DAM
POWER PLANT INTAKES
PIEZOMETER LOCATIONS - DESIGN II
1:24 SCALE MODEL



A. HEAD LOSS VS. DISCHARGE

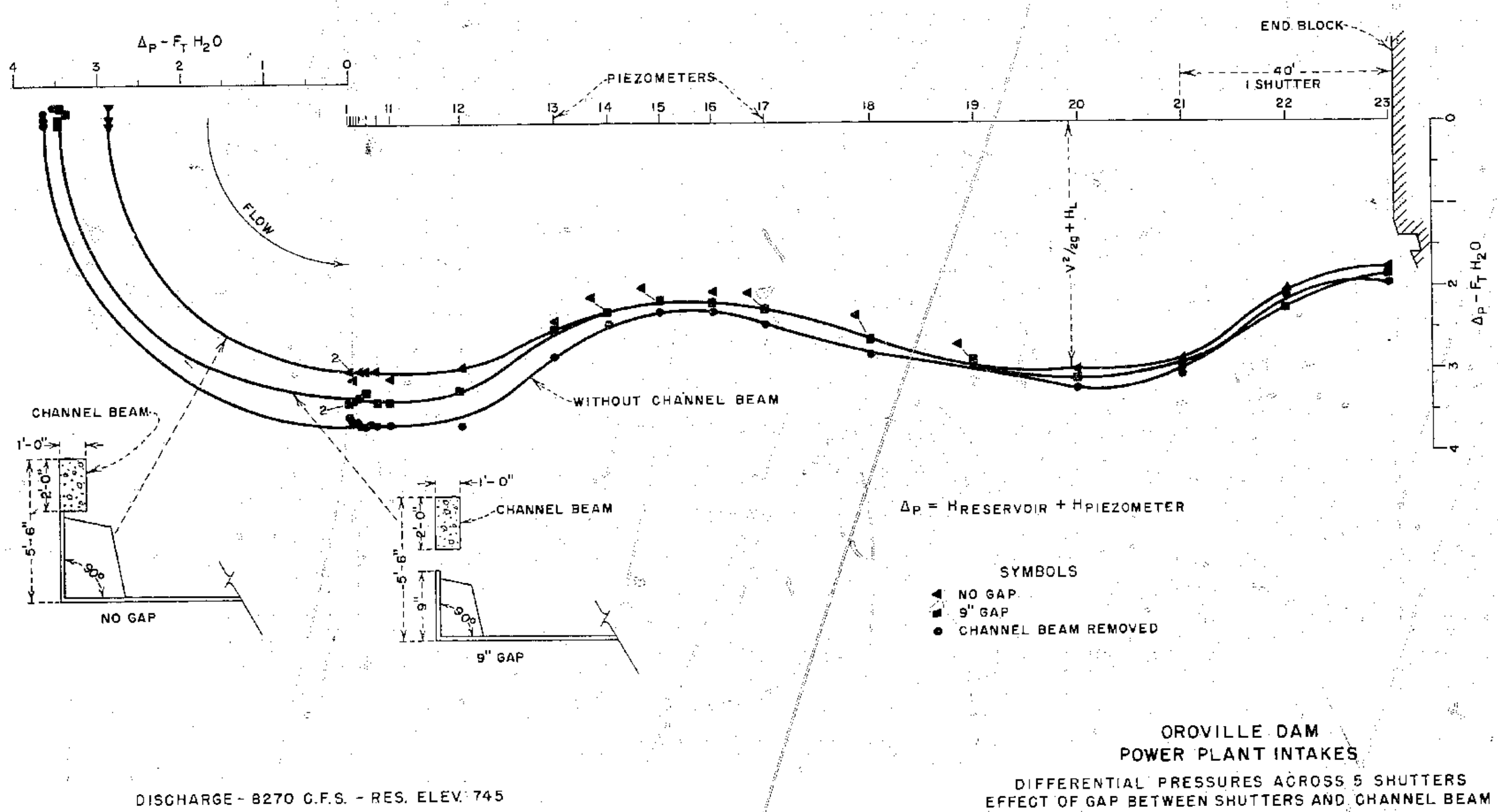


B. DIFFERENTIAL PRESSURES ACROSS 6 SHUTTERS



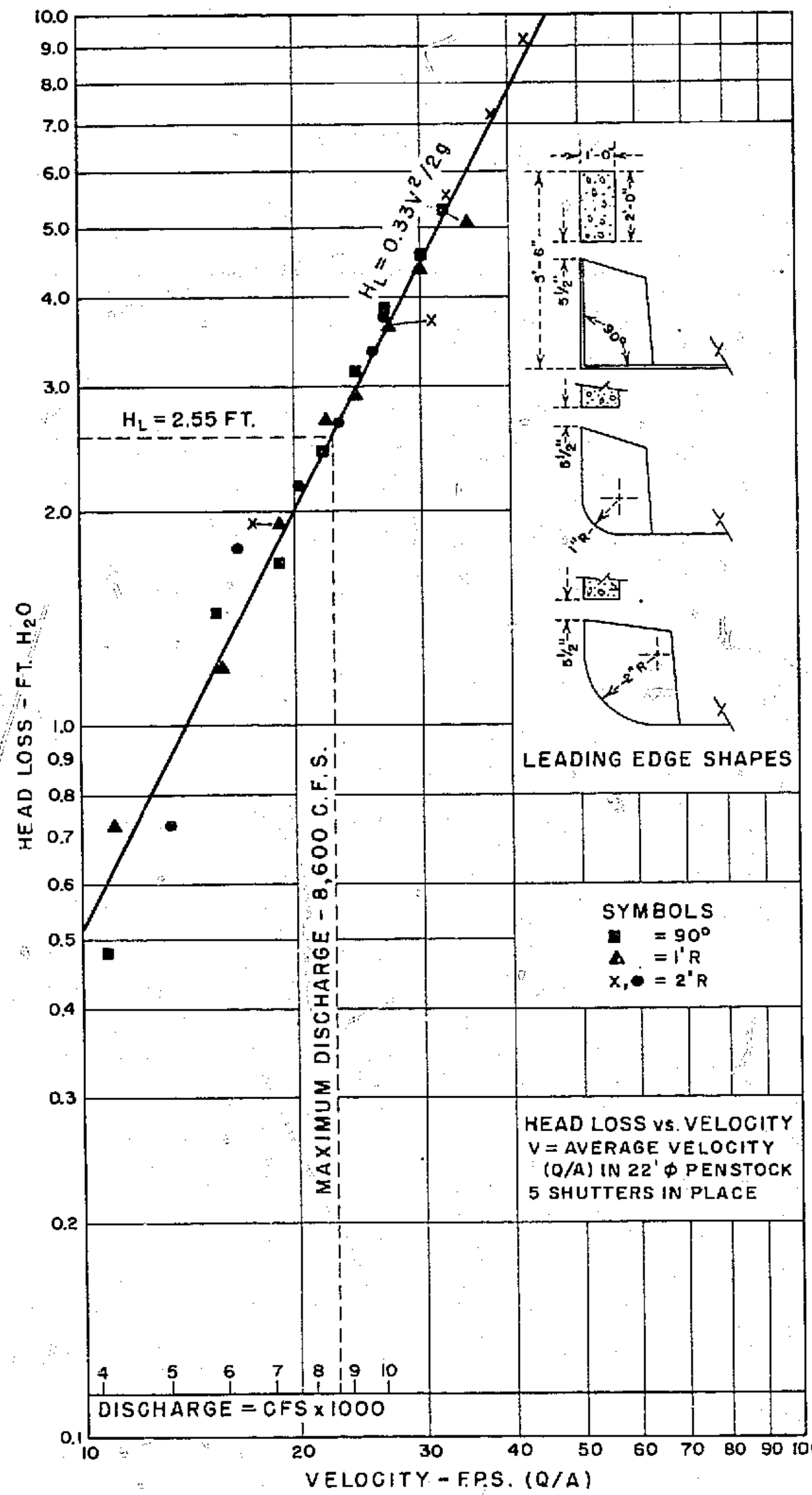
DETAIL A
(LIP EXTENSION)

OROVILLE DAM
POWER PLANT INTAKES
HEAD LOSS AND DIFFERENTIAL PRESSURES,
6 SHUTTERS - DESIGN III
DATA FROM 1:24 MODEL



OROVILLE DAM
POWER PLANT INTAKES
DIFFERENTIAL PRESSURES ACROSS 5 SHUTTERS
EFFECT OF GAP BETWEEN SHUTTERS AND CHANNEL BEAM

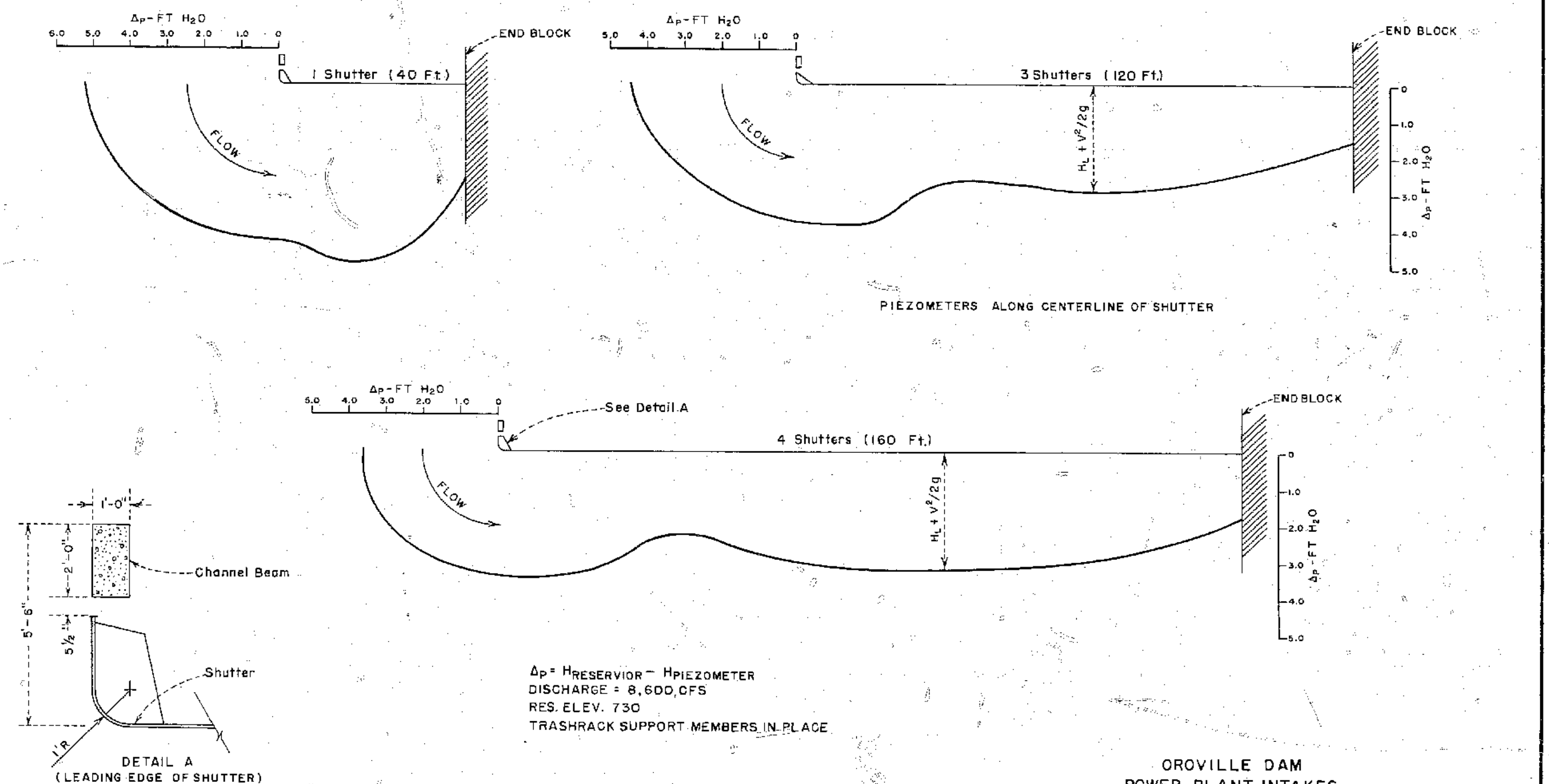
694



OROVILLE DAM
POWER PLANT INTAKES

LEADING EDGE HEAD LOSS - DESIGN III

DATA FROM 1:24 MODEL



OROVILLE DAM
POWER PLANT INTAKES
DIFFERENTIAL PRESSURES ACROSS 1,3 AND 4 SHUTTERS-DESIGN III
DATA FROM 1:24 MODEL

7-1750
(10-64)

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	9,463.58	Cubic centimeters
	0.946358	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.02903* (exactly)	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter

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ABSTRACT

Hydraulic model studies helped determine head losses, differential pressures, vortex action, and general pressures for three proposed designs for the intake structure of the Oroville Dam underground powerplant. Agriculture and fish propagation downstream from the dam require control of the temperature of water released through the powerplant. This control is accomplished by withdrawing water from selected reservoir depths through ports or opened shutters placed along intake structures which slope up the side of the reservoir. Design I consisted of 650-foot-long trapezoidal channel with semicircular covering shells, a 60-foot-long trashrack-covered port at the base, and five additional 40-foot-long ports. Flow through each port was controlled by thin semicylindrical shutters. The design was abandoned because of possible instability of the semi-cylindrical shutters and complicated, submerged mechanisms necessary to engage, move, and latch the shutters. Design II consisted of sloping channels with larger trapezoidal cross sections and continuous arched trashracks the full length of the structures. Under the trashracks, flat 40-foot-long by 45-foot-wide control shutters covered the intake channels. The shutters could be removed from the channels or reinstalled as reservoir level or temperature requirements changed. Design II was tested thoroughly and accepted for prototype use. However, unexpected foundation problems required structural modifications, culminating in Design III. This design utilized rectangular channels with lighter trashrack arches supplemented by tension beams across the channel at the base of each arch. Design III was adopted.

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