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HYDRAULIC LABORATORY REPORT NO. 55

HYDRAULIC MODEL STUDIES  
OF THE ROZA DIVERSION  
DAM--YAKIMA PROJECT,  
WASHINGTON

By

H. G. DEWY, JR., ASSISTANT ENGINEER

- - -  
Denver, Colorado,

June 27, 1939

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UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION

Branch of Design and Construction  
Engineering and Geological Control  
and Research Division  
Denver, Colorado  
June 27, 1939

Laboratory Report No. 55  
Hydraulic Laboratory  
Compiled by: H. G. Dewey, Jr.

Reviewed by:

Subject: Hydraulic model studies of the Roza Diversion Dam--Yakima Project, Washington.

#### INTRODUCTION

This is a report of the hydraulic model studies incorporated with the design of the Roza Diversion Dam and its appurtenant structures; a headworks, the Yakima Ridge Canal, and fish ladders. Situated in the Yakima River between Ellensburg and Yakima, Washington (Figures 1 and 2), the Diversion Dam, which is designed to pass 50,000 second-feet, enables 2,200 second-feet to be diverted through the headworks into the Yakima Ridge Canal. To divert this flow, the water surface in the Reservoir will be maintained at a constant level by two 14- by 110-foot roller gates at the Diversion Dam. The obstruction in the Yakima River caused by the Diversion Dam requires fish ladders at each abutment to enable salmon to continue upstream to the spawning grounds.

Hydraulic model studies were incorporated in the design of these structures to determine: (1) a correct headworks alignment; (2) the performance of the fish ladders; (3) a stilling pool at the toe of the Diversion Dam; and (4) calibration curves for the Dam and roller gates.

#### THE MODEL

A 1 to 48 scale model was built and tested in the Hydraulic Laboratory of the Bureau of Reclamation, Denver, Colorado (Figures 3, 4, and 5). The roller gates were made of seamless steel tubing and their traveling mechanism was included as shown in Section A-A, Figure 3, enabling duplication of prototype gate settings. The Diversion Dam was made of light-gage sheet metal to facilitate construction and to eliminate warping. Sufficient river topography was installed upstream and downstream from the Diversion Dam to provide proper flow conditions. The headworks of the Canal, complete with piers, trashracks, and fish screens, was constructed as a unit to facilitate changes in alignment. A small weir was installed under the downstream end of the model box enabling separate measurement of the flow in the Canal. The fish ladder and adjacent topography was carefully placed to assure the desired relation between the discharge in the fish ladder and in the river.

## FIGURE I

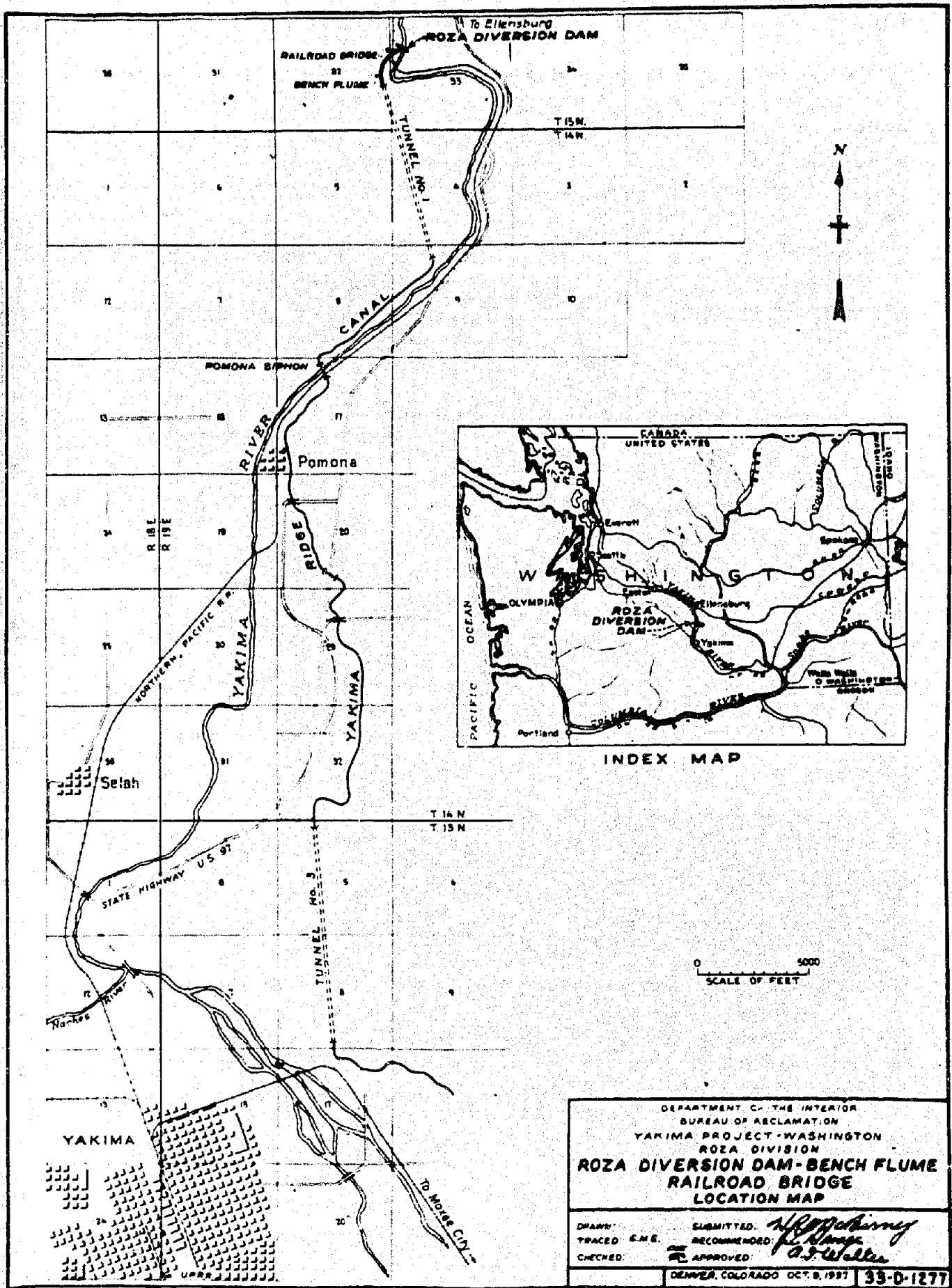


FIGURE 1

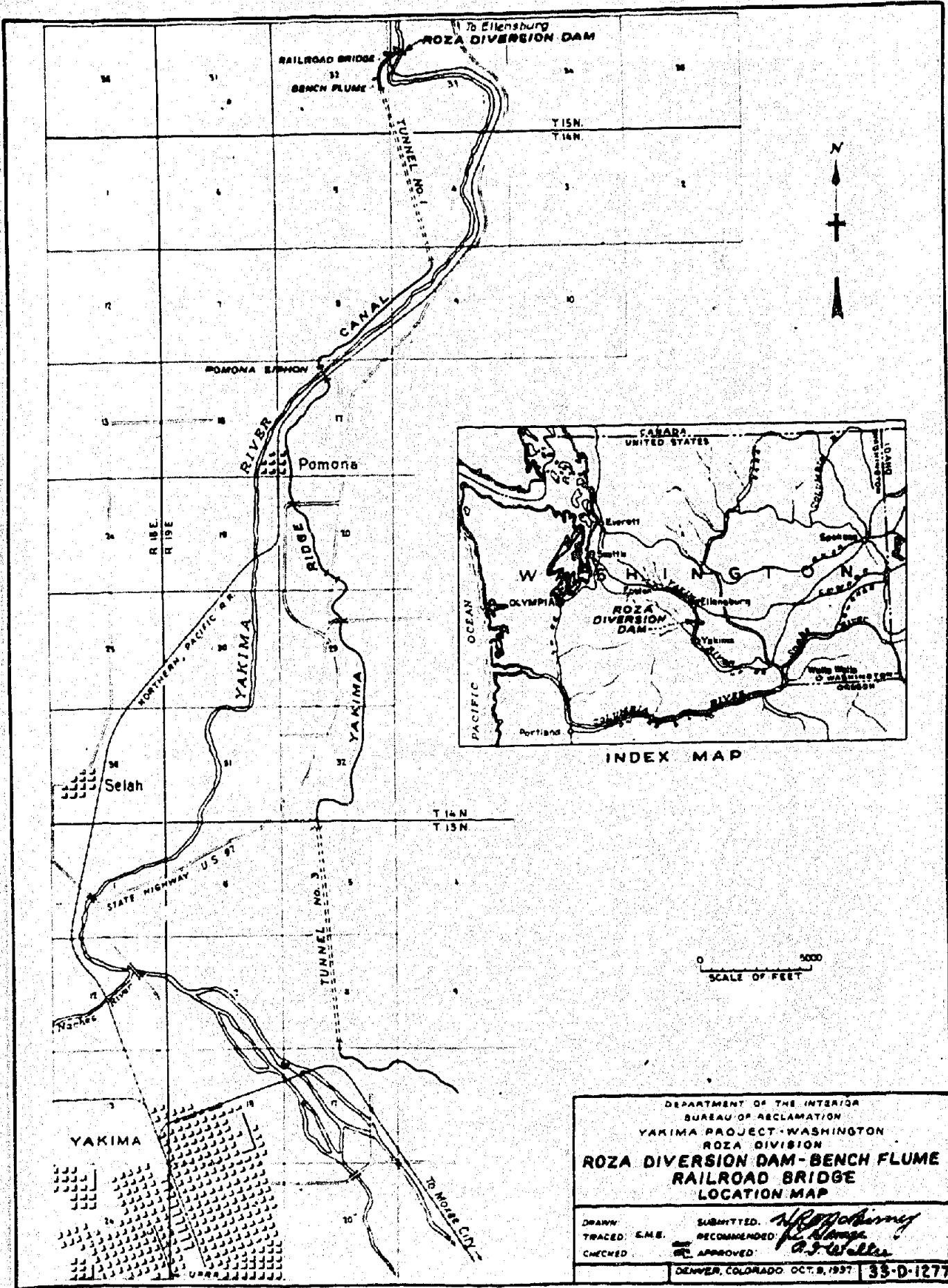
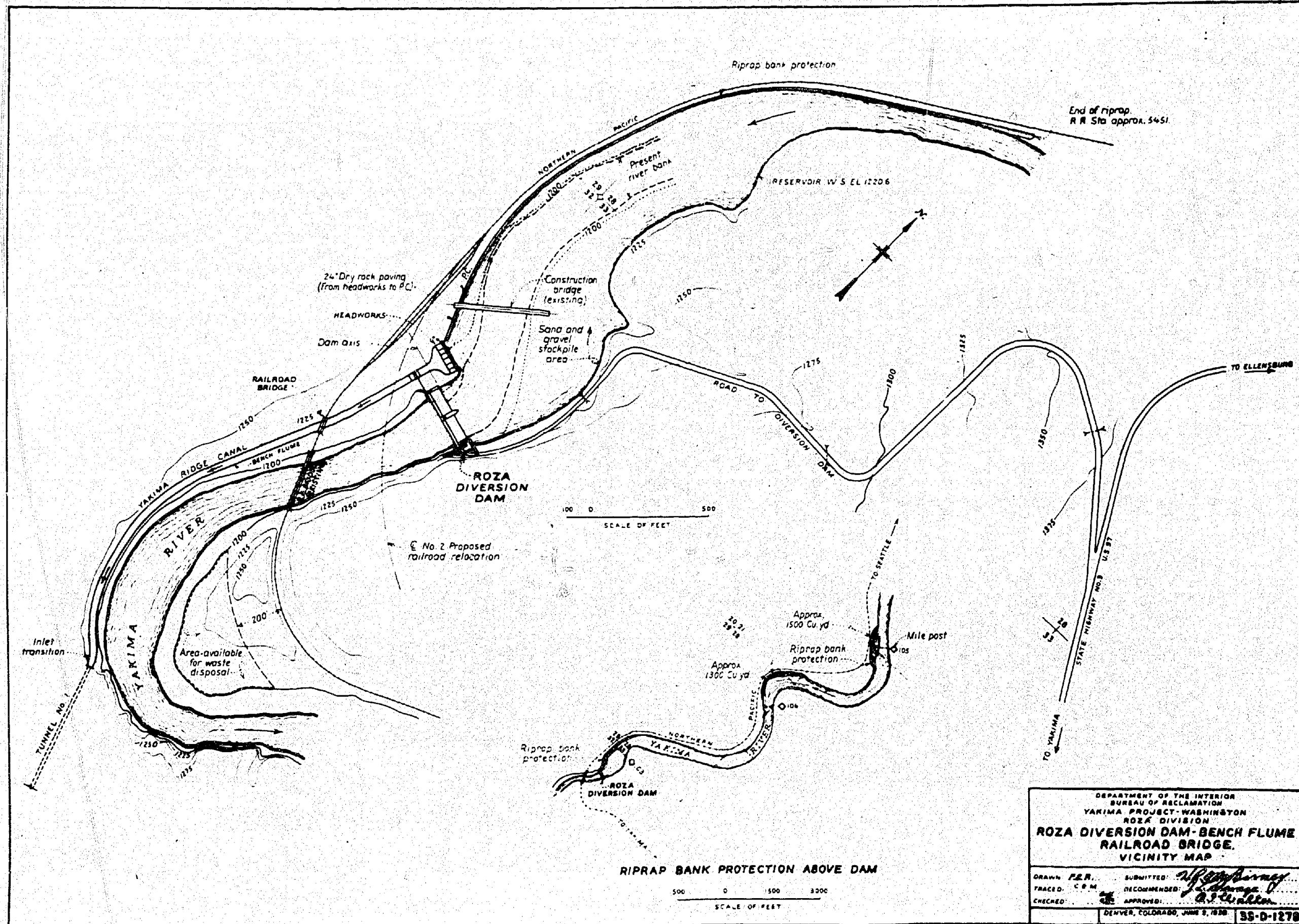


FIGURE 2



**FIGURE 3**

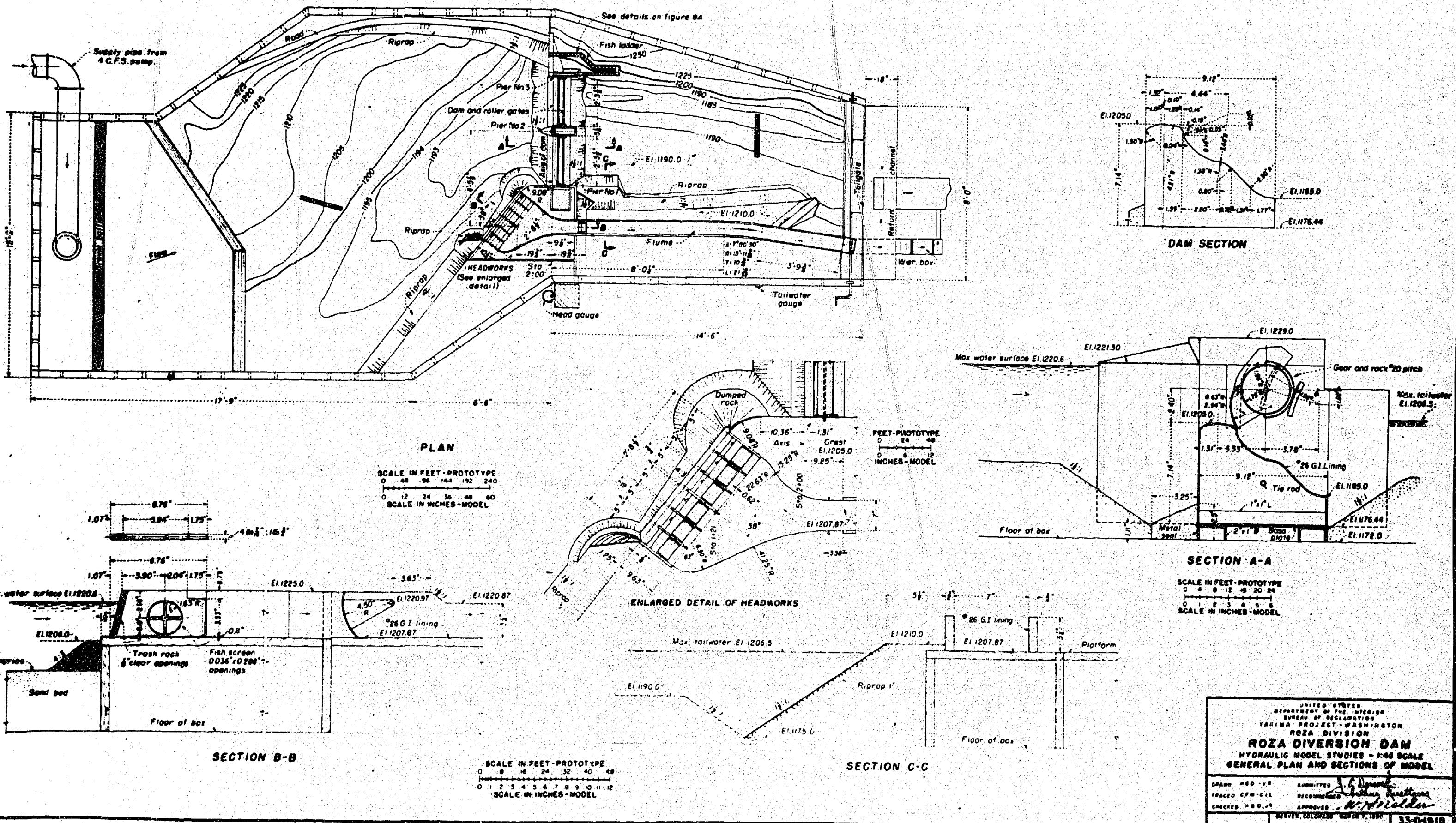
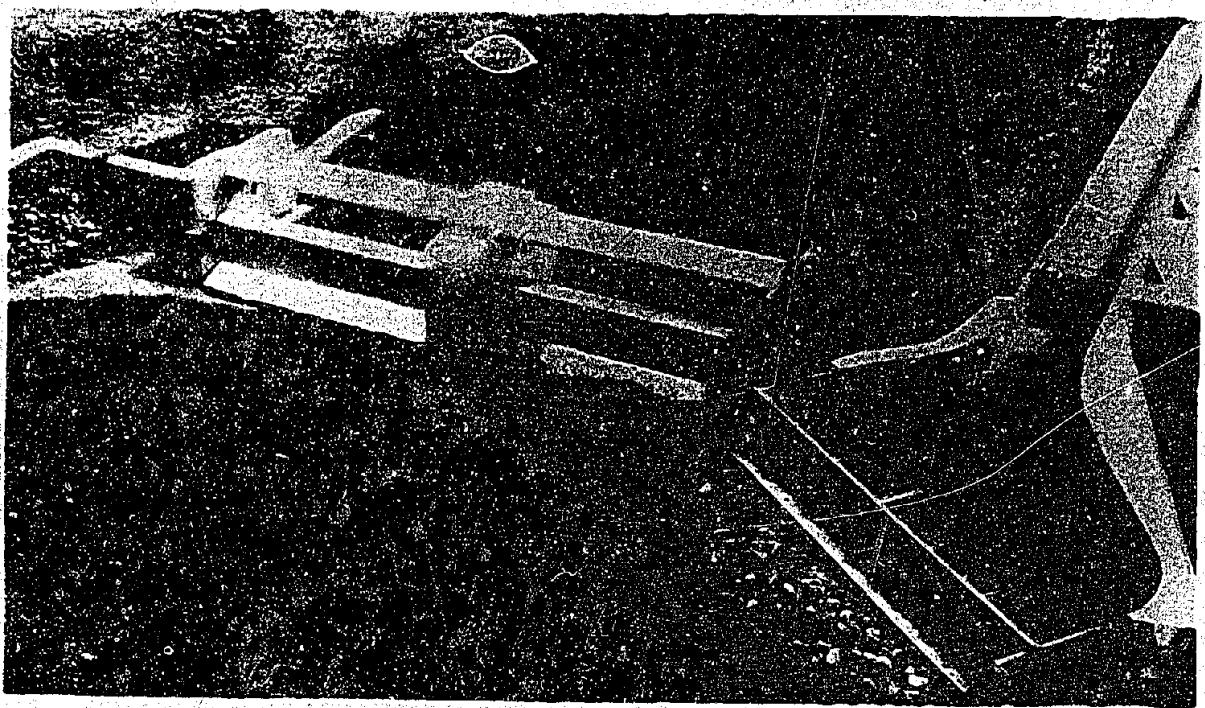
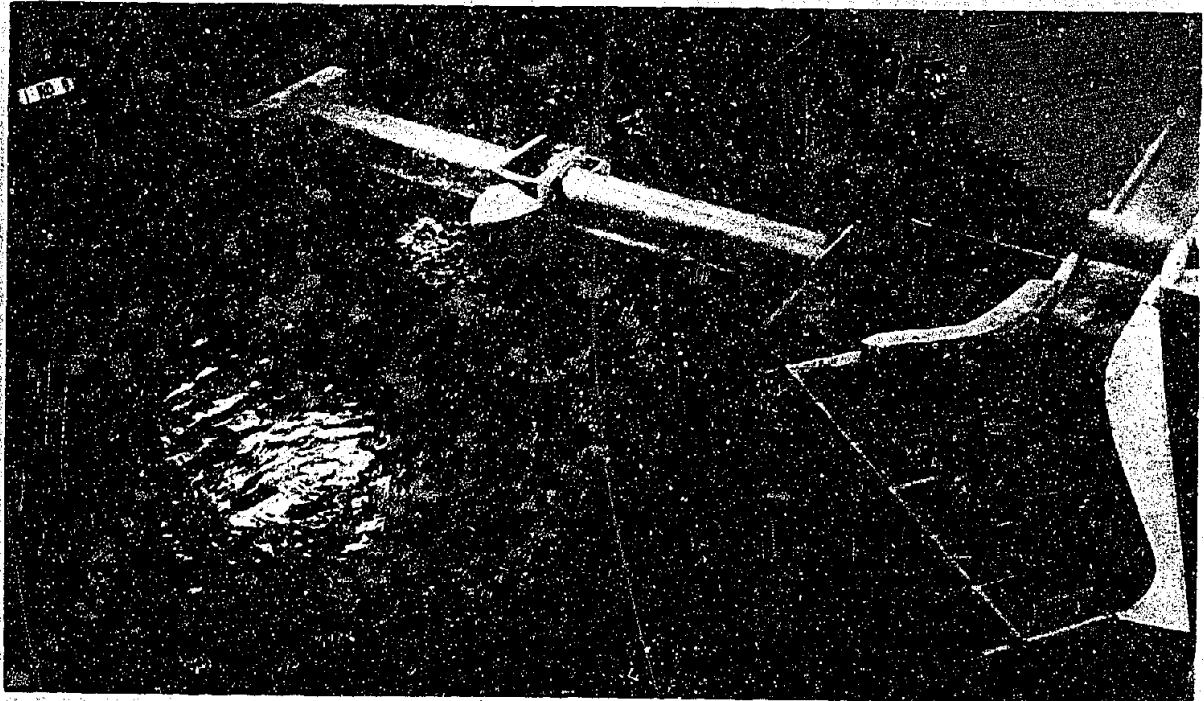


FIGURE 4



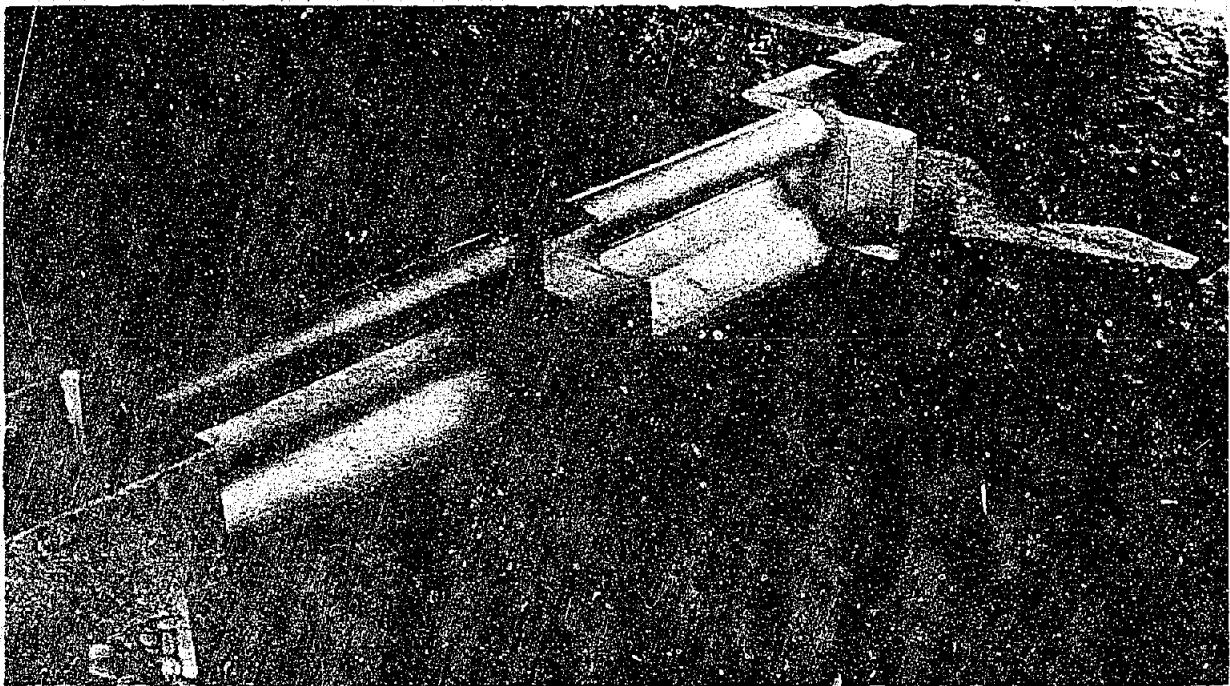
A. LOOKING UPSTREAM.



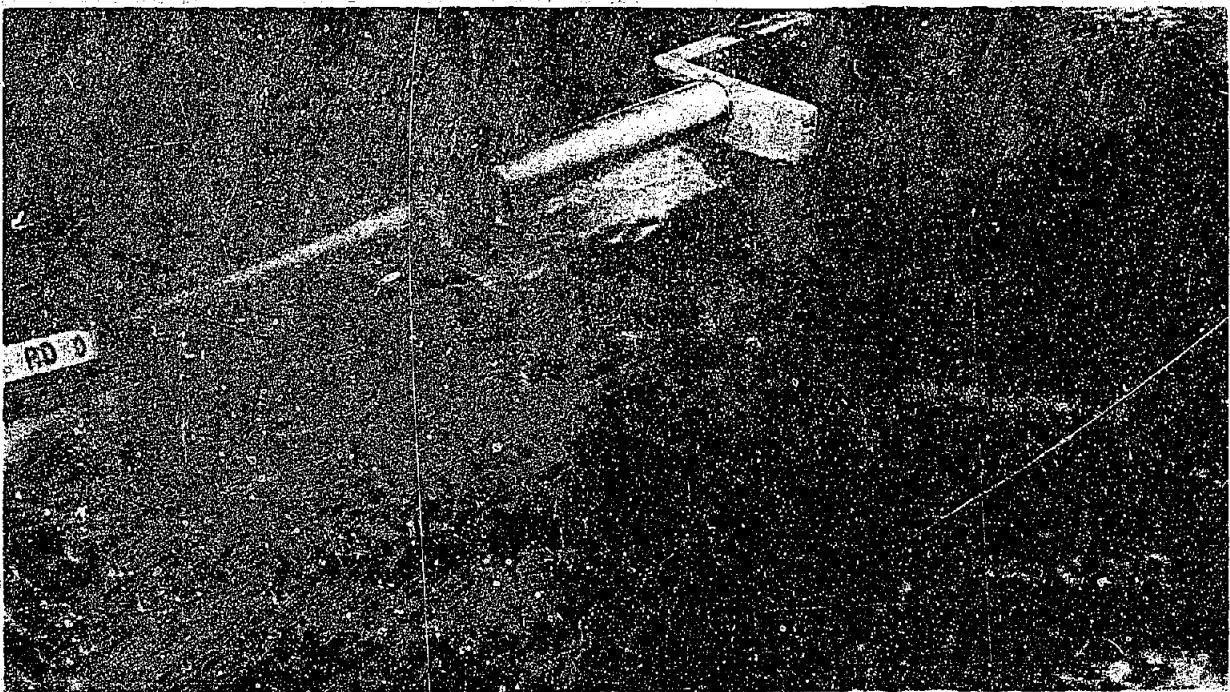
B. DISCHARGE 50,000 SECOND-FEET.  
CANAL DISCHARGE 2,200 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1206.5.

ORIGINAL DESIGN.

FIGURE 5



A. LOCKING DOWNSTREAM.



B. DISCHARGE 50.000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1206.5

ORIGINAL DESIGN.

## HEADWORKS STUDY

The headworks to the Yakima Ridge Canal consists of six openings or panels formed by piers which support a trashrack and fish screen between each opening (Section B-B, Figure 3). The width of openings are determined so that the velocity of the flow through them will not be greater than about two feet per second. This is necessary to prevent fish, especially fingerlings, from being trapped against the fish screens due to excessive velocities. The fish screens are required to prevent salmon and other fish from entering the Canal. The screens will be rotated slowly in the prototype to prevent debris from connecting on them, and a gantry will be provided to remove the fish screens from the headworks for cleaning (Section B-B, Figure 21). As the flow passes from the Reservoir through the openings and into a transition, it is controlled by a radial gate placed downstream from the Canal entrance (Section B-B, Figure 3).

It was necessary to study the alignment of the headworks in the model to obtain uniform flow distribution through each opening. The original alignment of the headworks was rotated  $38^{\circ}$  clockwise from a line normal to the axis of the Dam (Figures 3 and 6A). This alignment reduced the length of the vertical training wall extending from the headworks to the right abutment of the Dam, but it caused unsymmetrical flow through the headworks. Observations on the model revealed that most of the flow entered the two openings at the left side of the headworks, causing an eddy in the transition to the Canal. This eddy directed the flow upstream along the right side of the transition, causing the flow at that point to proceed through the openings and back into the river. To eliminate this unfavorable condition, the headworks was rotated  $38^{\circ}$  counterclockwise until its centerline became normal with the axis of the Dam (Figure 6B). With this alignment, the flow entered each opening more uniformly; the eddy in the transition was eliminated, enabling all the flow to proceed downstream through the transition and into the Canal.

Although the flow conditions were improved, it was necessary to move the headworks 45 feet downstream to reduce the length of the vertical training wall extending from the headworks to the right abutment of the Dam (Figure 6C). This did not affect the uniform flow distribution, but the reduction in length of the transition caused small waves or ripples on the water surface at the entrance to the Canal. The transition was designed, therefore, to give uniform acceleration and reduction in depth in the transition. The waves or ripples were eliminated, but this transition (not shown) was too abrupt because its walls projected too far in front of each side opening. Accordingly, the velocity of the flow through each side opening was apparently deflected upwards at the transition walls, causing eddies or vortices to develop. A slight change in the shape of the transition eliminated these undesirable eddies or vortices, and this

FIGURE 6

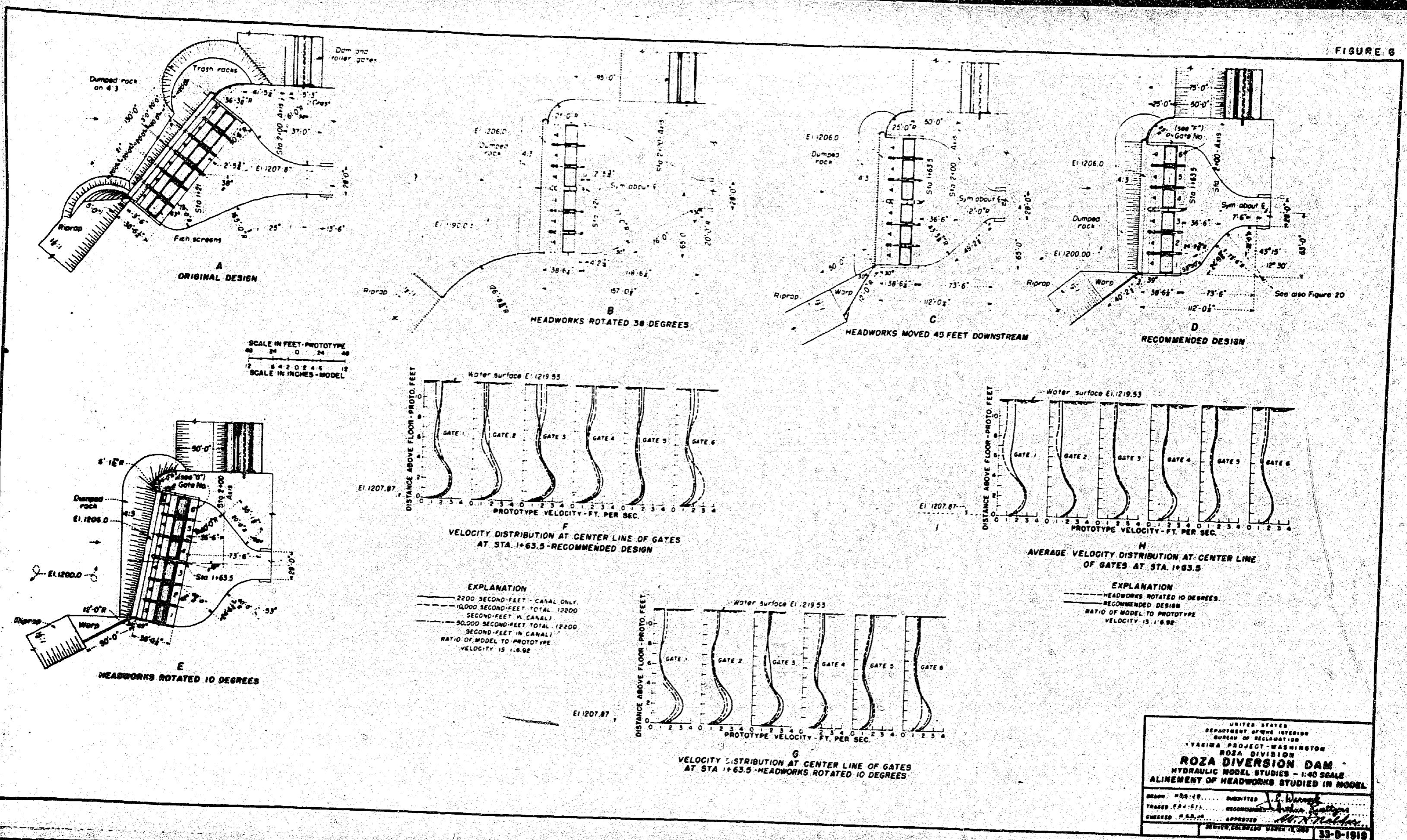
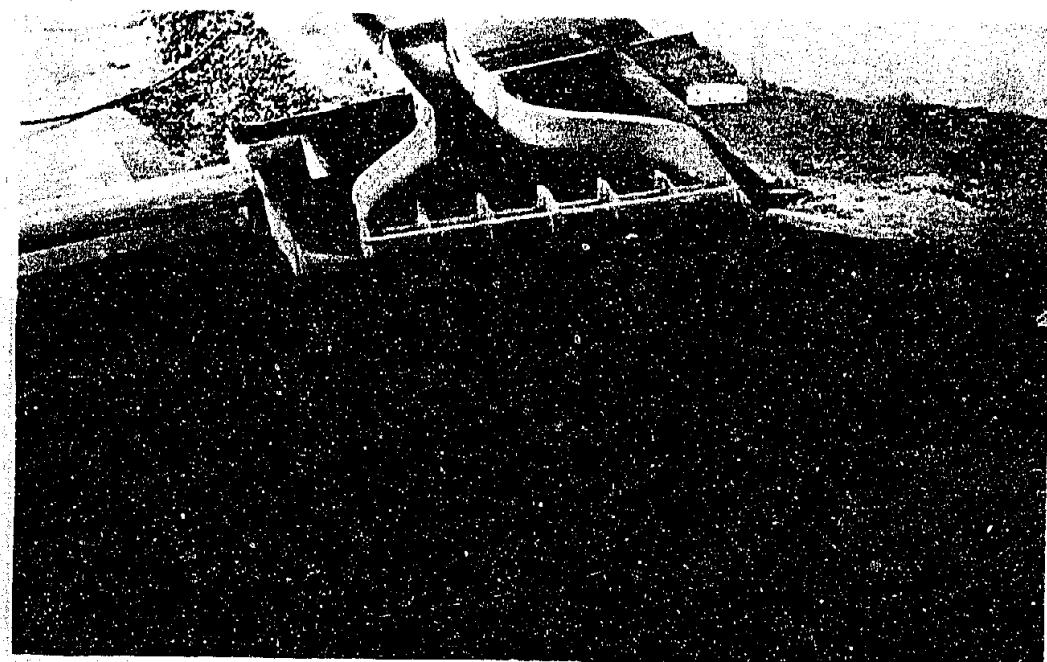


FIGURE 7



A. HEADWORKS ROTATED TEN DEGREES.



B. RECOMMENDED DESIGN.

HEADWORKS.

shape was adopted in the recommended design shown on Figures 6D and 7B.

The position of the warp and the 1:1 side slope in the recommended design eliminated a large eddy which formed in other designs, during higher discharges, upstream from the headworks along the 1:1 riprapped slope. Although this eddy did not occur, it prevented the formation of a more uniform velocity distribution in the approach of the headworks. By introducing dye into the flow, a study was made of the streamlines occurring along the side slope and the warp. This permitted the position of the warp and the side slope to be readily determined which would give a better velocity distribution at the approach.

To check the flow distribution through the headworks of the recommended design, velocity measurements were taken at the center-line of each opening (trashracks and fish screen in place) at Station 1+63.5 (Figure 6D). These measurements were taken with 2,200 second-feet flowing through the headworks into the Canal; first, with no flow over the Diversion Dam, and then with a total combined flow (Canal plus Diversion Dam) of 10,000 and 50,000 second-feet. The flow distribution (Figure 6F) is seen to be quite uniform through each opening but also somewhat better in the first two openings than for the alignment shown on Figures 6E and 7A in which the headworks has been rotated 10°. The velocity data for this design are shown on Figure 6G. The average velocity of each design for the three discharges is shown on Figure 6H.

It was hoped that if the headworks were rotated 10° clockwise that a saving could be made by reducing the length of the vertical training-wall extending from the headworks to the right abutment of the Dam. This was not realized, however, because a rotation of 10° affected the velocity distribution, and it did not permit any reduction of length of training-wall, since some curvature of the wall was necessary at the right end of the headworks. Any additional change in alignment in this direction would approach the unfavorable conditions existing with the original alignment.

At maximum or near maximum discharge, considerable turbulence and boiling occurred with each headworks alignment near the right abutment of the Dam, a few feet upstream from the right roller gate. This condition was not considered serious enough to require elimination. Its cause was never fully determined, but it may have been due in part to the drawdown occurring in the flow as it passed around the curved part of the vertical wall at the right end of the headworks. During large discharges, the velocity of approach to the roller gates is considerable, and any drawdown occurring under this condition may have created this turbulence. At low discharges, turbulence is nearly eliminated, but a vortex forms in its place. It may be necessary to remove any debris at the water surface which becomes trapped near this vortex.

## FISH LADDER STUDY

The presence of salmon in the Yakima River during spawning season requires fish ladders to be installed at the Diversion Dam to enable the fish to pass that obstruction. There are at least five features to be included in the design of any fish ladder: (1) salmon must be able to pass through a fish ladder with a minimum of effort and injury; (2) the entrance to the fish ladder should be placed in the immediate vicinity of the obstruction to be passed; (3) some means should be provided at the entrance to the fish ladder to attract the salmon from the main flow of the river; (4) the flow within the fish ladder should have a relatively low velocity and be free from excessive turbulence; and (5) the exit of a fish ladder should not be placed near a gate structure.

Salmon do not feed during migration to their spawning grounds but live from the stored energy in their bodies. This requires an easy passage to be provided at any obstruction. If injury occurs, a protective film on the body of the salmon may be broken, enabling fungi to attack the fish which may prove fatal. During the migration from the ocean, the Pacific salmon proceed only upstream and will not reverse their direction. This makes it essential to have the fish ladder entrance adjacent to the main obstruction in the river enabling the salmon to proceed immediately upstream into the ladder. In addition, the salmon must be quickly attracted to the entrance by turbulence created by the flow from the fish ladder as the flow spills into the river. As the salmon proceed up the fish ladder, some turbulence must be created by allowing the flow to spill over weirs installed in the ladder. If this turbulence is excessive, the salmon may jump out of the ladder, and if the velocity of the water in the fish ladder is excessive, it may require the expending of too much energy by the salmon. Should an exit of a fish ladder be placed too near a gate structure, the fish leaving the ladder may be caught in the swiftly moving water discharging into the gate and be swept downstream.

The original fish ladder design (Figures 8A and 9A) was inadequate because it did not include all the foregoing features. Although the position of the exit and the velocity of flow in the ladder was satisfactory, it would be necessary for salmon to reverse their direction to enter the lower leg sloping into the river (Section A-A, Figure 8A). During flow over the Diversion Dam, this leg filled with gravel, which was also undesirable. No definite entrance or attraction was provided, and as the flow in the fish ladder entered the right-angled bend at the top of the lower leg, the flow spilled out of the ladder. This condition probably would have resulted in fish leaping completely out of the ladder.

### FIGURE 9

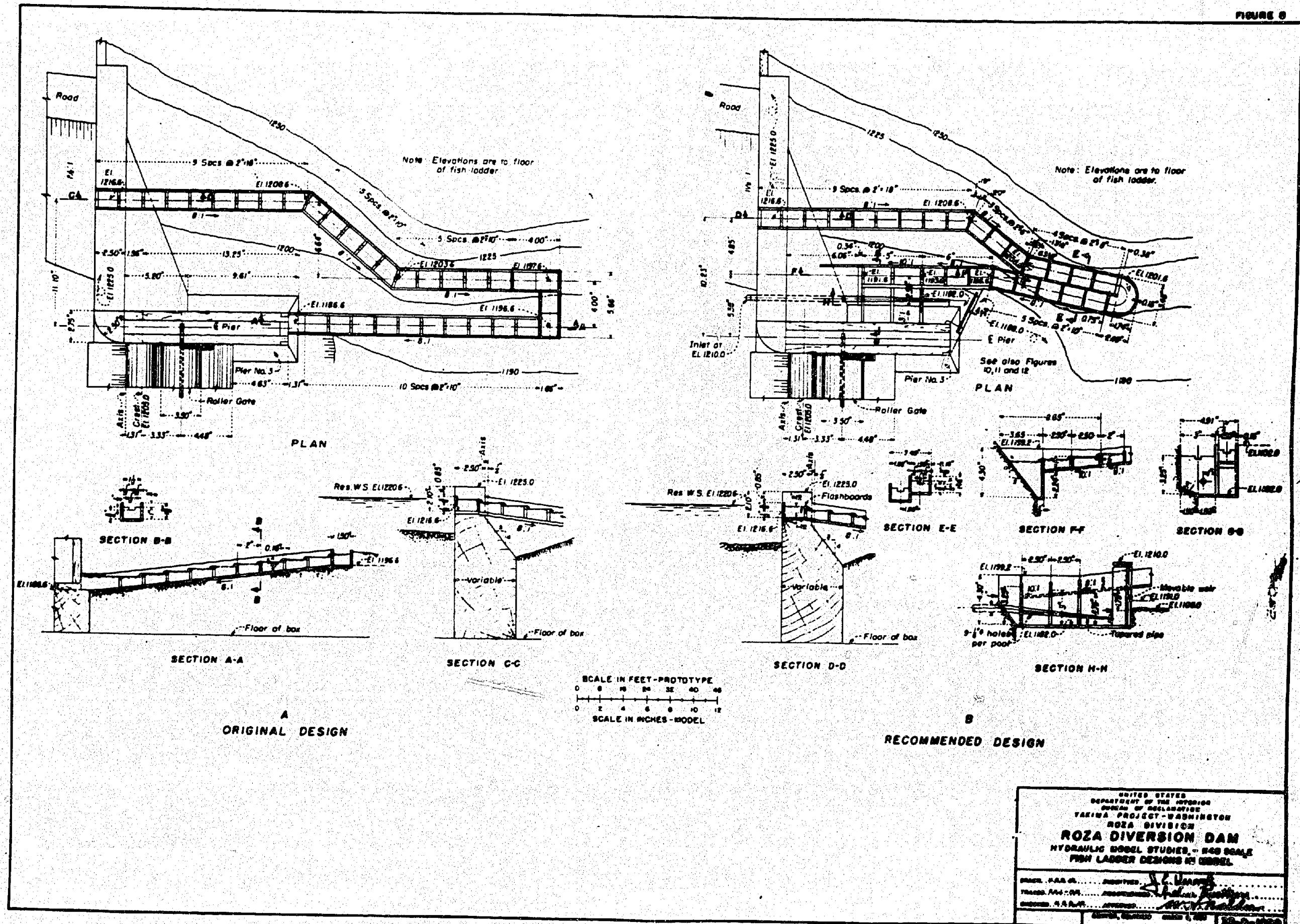


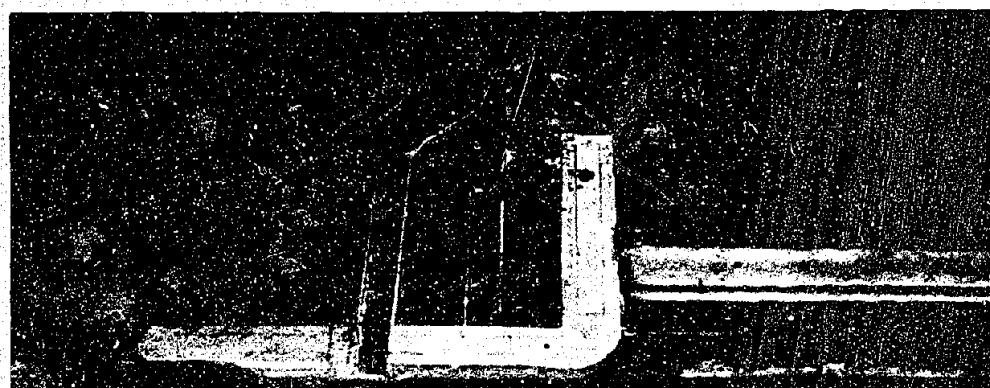
FIGURE 9



A. ORIGINAL DESIGN.



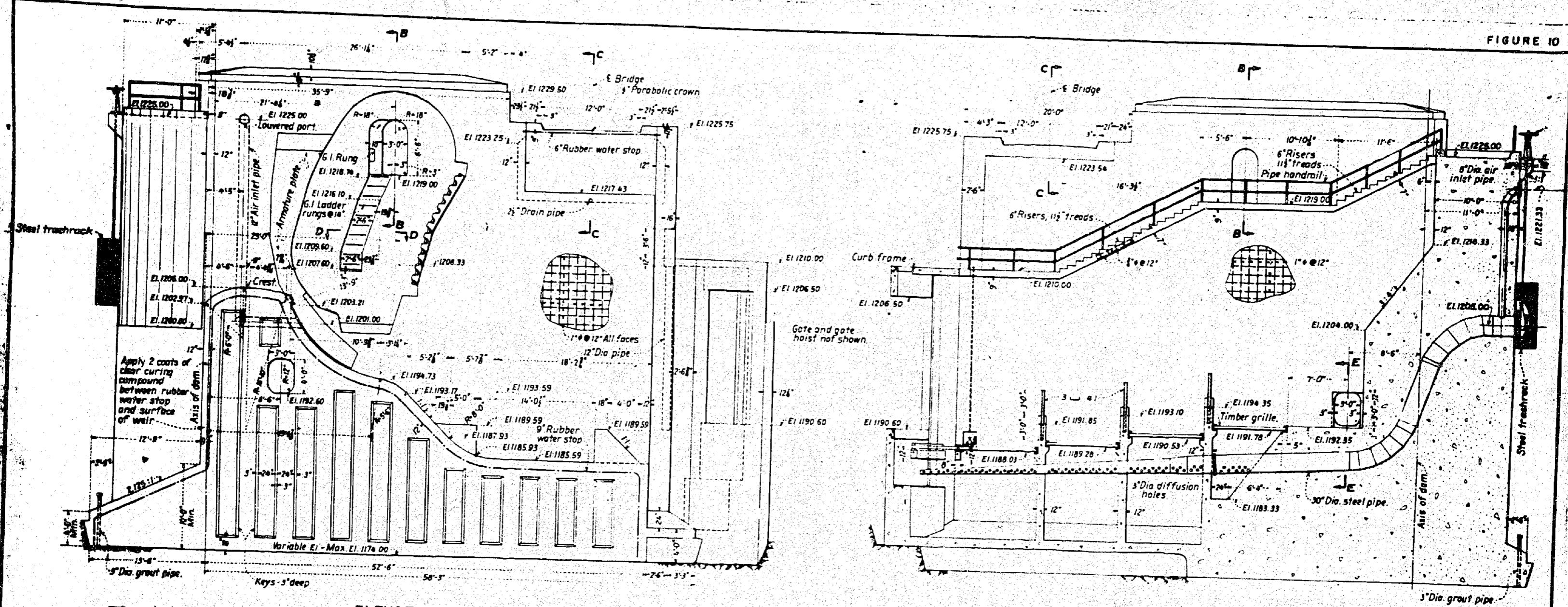
B. RECOMMENDED DESIGN.



C. RECOMMENDED DESIGN.

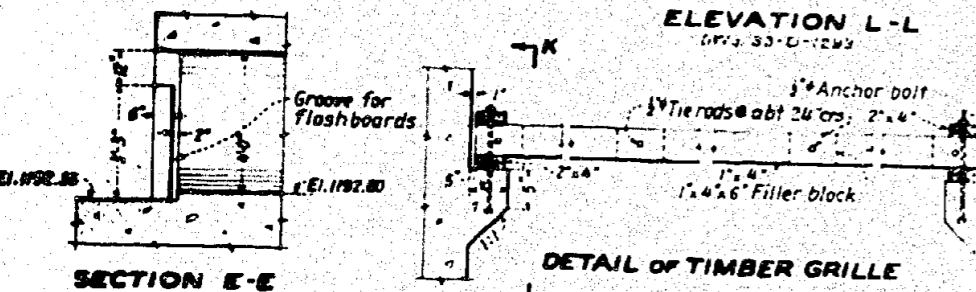
FISH LADDER.

## FIGURE 10



**ELEVATION L-L**

**ELEVATOR**  
**(500-345-1000)**



**SECTION E-E**

G.I. Ladder  
rungs @ 16" c/s  
1" x 12" Both ways

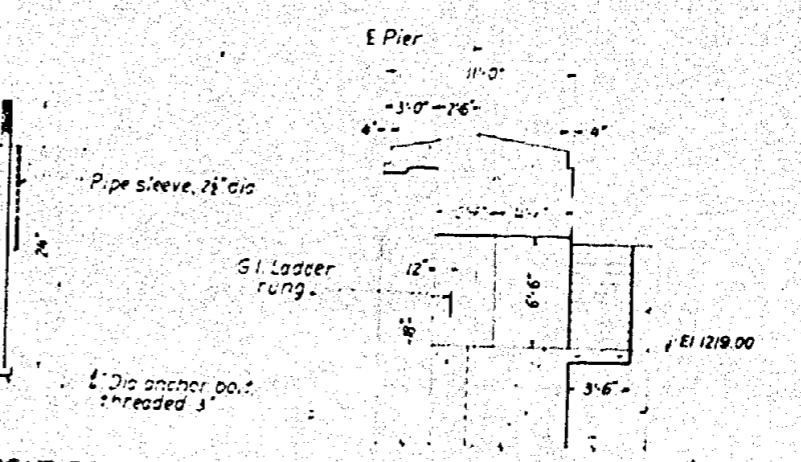
**SECTION D-D**

**SECTION K-F**

## **ANCHOR BOLT DETAIL FOR BRIDGE BEARING**

**SECTION A-A**

DWG J3-D-1203



## **REFERENCE DRAWINGS**

SION PIPE	33-D-1588
DATE	33-D-1802
RAIL DETAILS	33-D-187-188 A :
DRILL	33-D-1636
RACK	33-D-
DATE	33-D-1814 1977

DEPARTMENT OF THE INTERIOR  
BUREAU OF RECLAMATION  
YAKIMA PROJECT-WASHINGTON  
ROZA DIVISION  
**OZA DIVERSION DAM**  
PIER NO. 3  
ELEVATION-SECTIONS

U.S. FED. SUBMITTED	<i>Alfred J. Johnson</i>
N.H.	RECOMMENDED
J.S.C.	APPROVED
DENVER, COLORADO MAY 31, 1940	
55-0-1286	

## FIGURE II

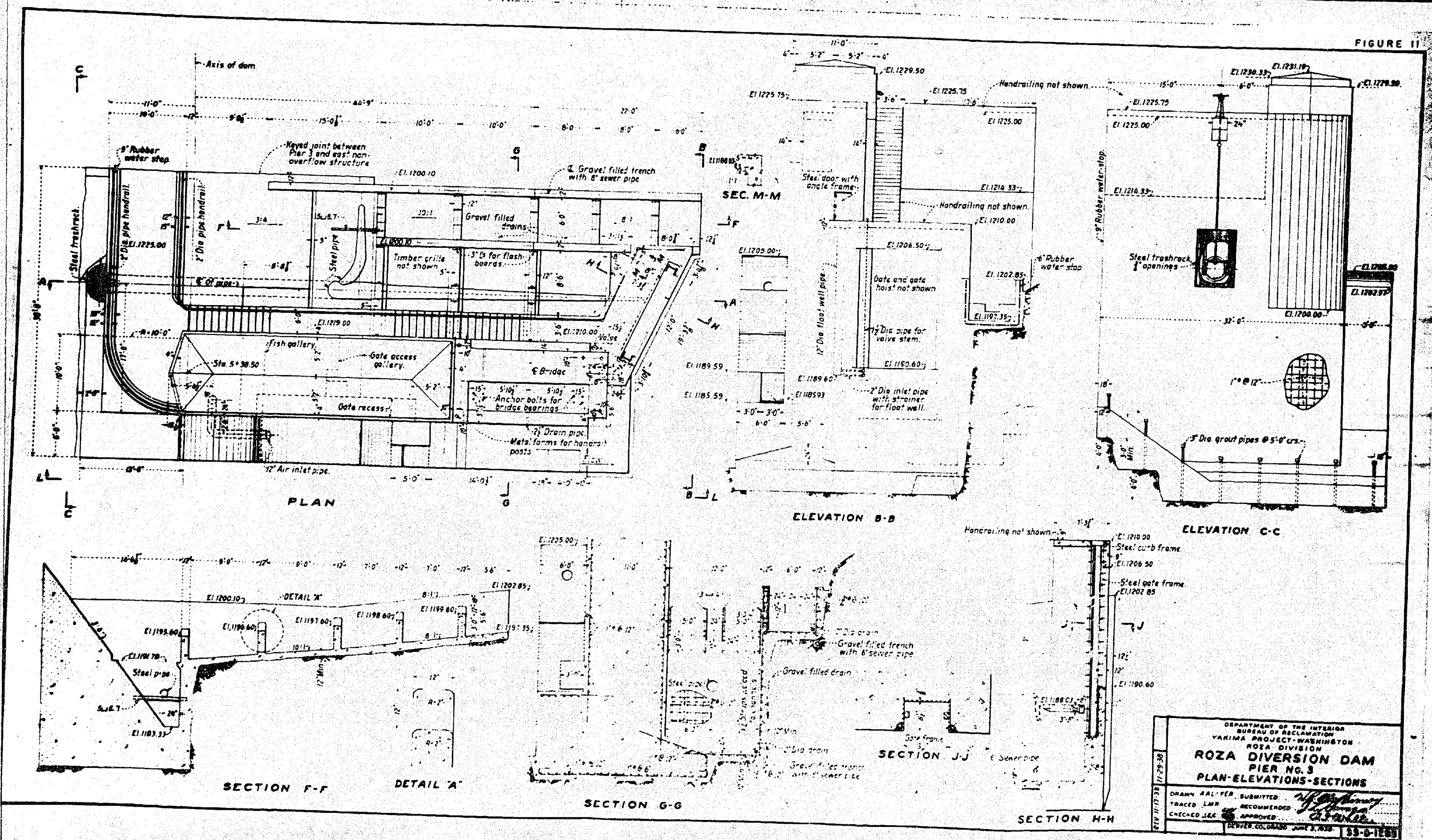


FIGURE 12

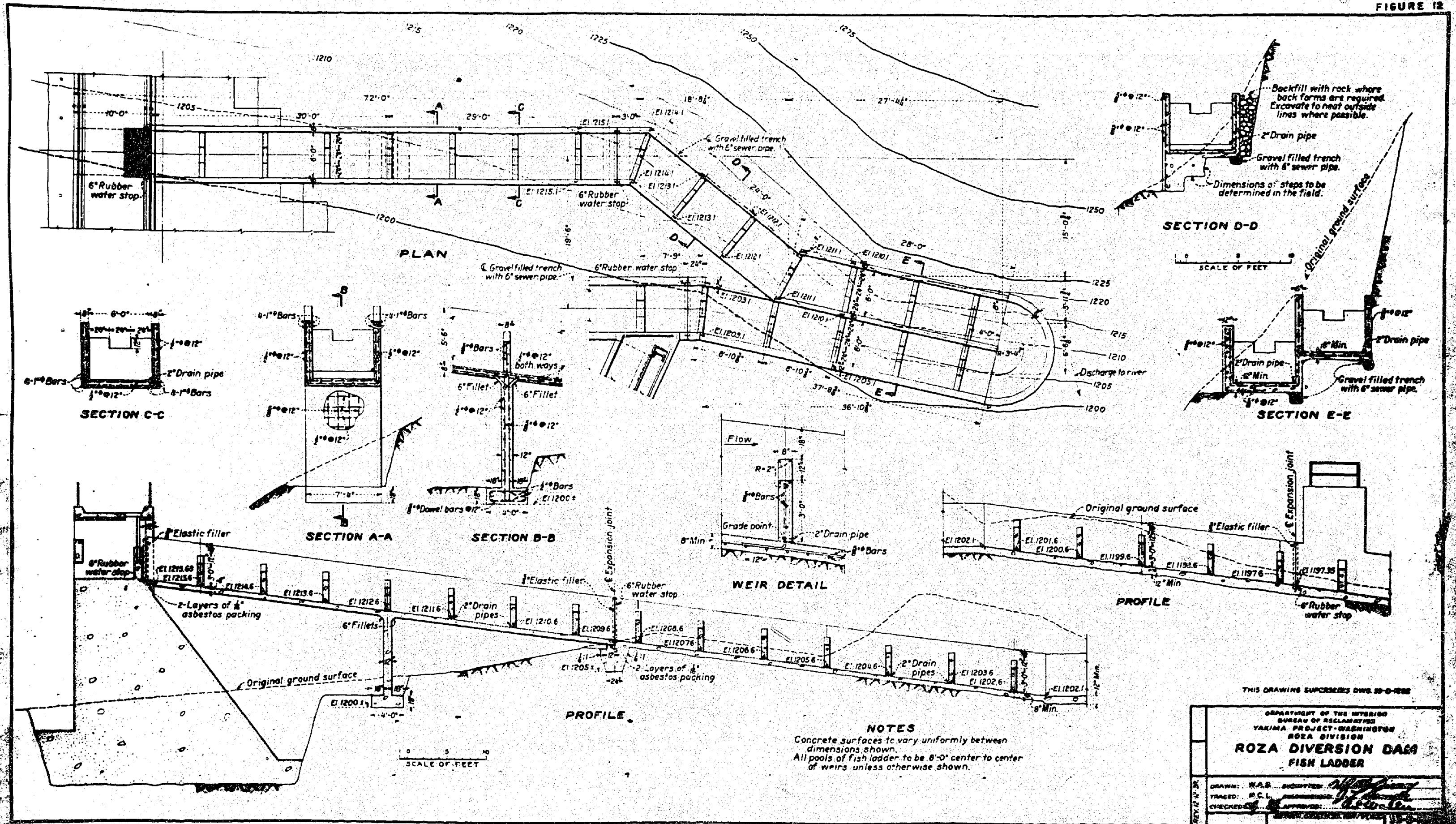


FIGURE 18

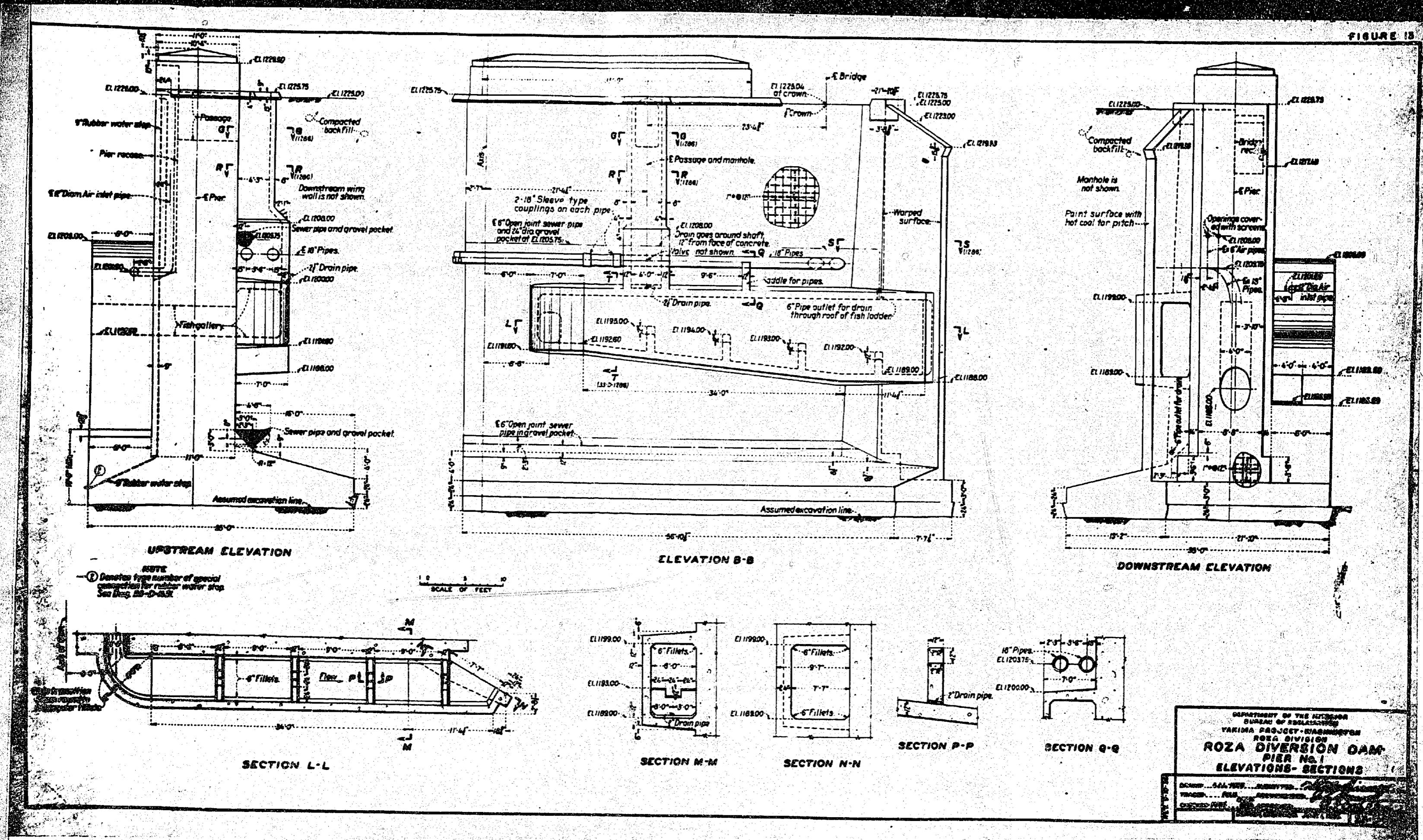
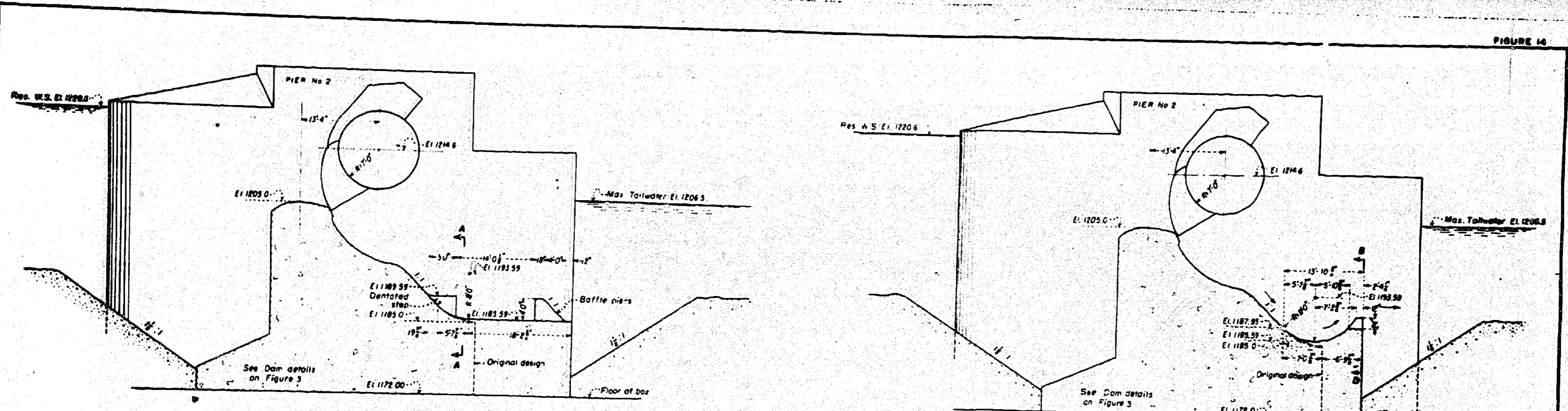
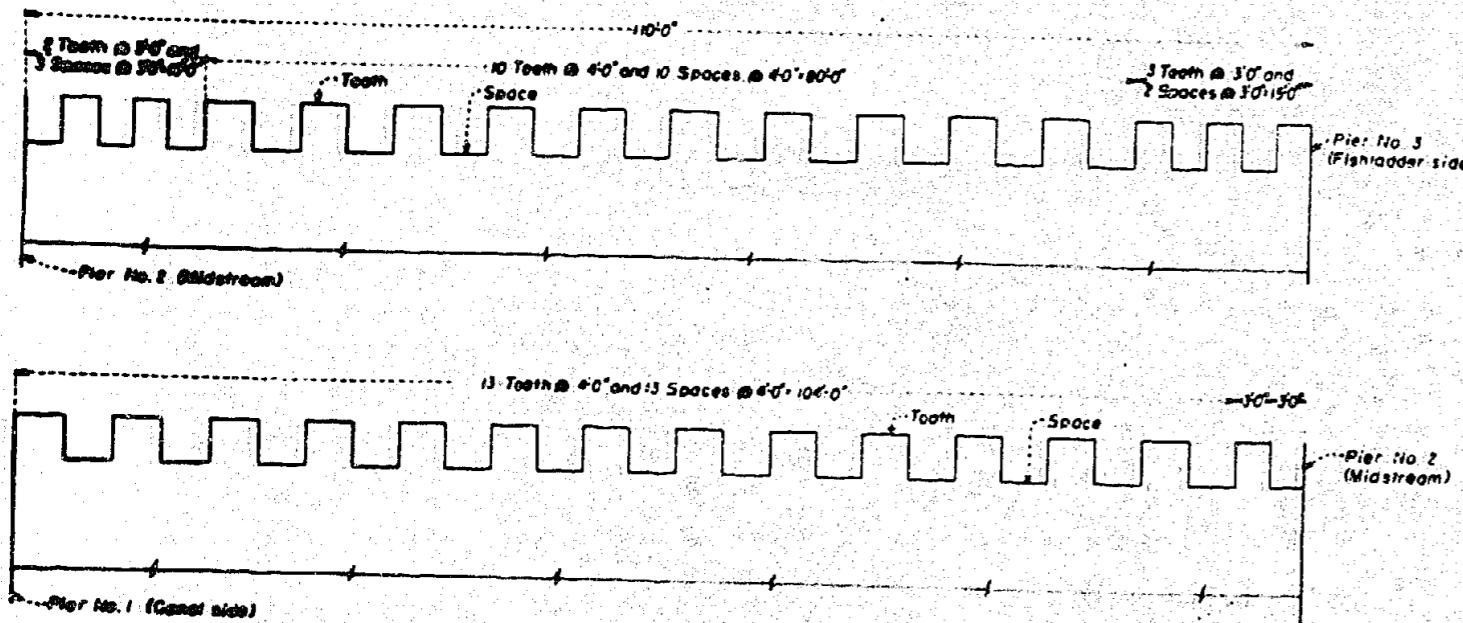


FIGURE 10



**SECTION A-A**  
ARRANGEMENT OF DENTATED STEPS  
(BAFFLE PIERS ARE PLACED OPPOSITE SPACES)



**SECTION B-B**  
ARRANGEMENT OF TEETH  
(SYMMETRICAL ABOUT CENTER LINE OF PIER NO. 2)

SCALE IN FEET - PROTOTYPE  
0 4 8 12 16 20 24  
0 1 2 3 4 5 6  
SCALE IN INCHES - MODEL

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION TAKIWA PROJECT - WASHINGTON ROZA DIVISION	ROZA DIVISION
<b>ROZA DIVERSION DAM</b>	
HYDRAULIC MODEL STUDIES - 1:40 SCALE	
FLOOD PREVENTION STUDIES IN MODEL	
MAINT. AGENT NAME, F.R.-44 ADDRESS CITY, STATE PHONE NO. SIGNED A. M. Mallon	RECEIVED NAME, F.R.-44 ADDRESS CITY, STATE PHONE NO. SIGNED A. M. Mallon

55-D-1022

After a new design had been made to include all desirable features and had been installed in the model, representatives from the Bureau of Fisheries, Seattle, Washington, observed its performance and agreed on the recommended design shown on Figures 9B, 9C, and 9D. In this design, additional water (80 second-feet) was admitted into the lower pools by installing a pipe from the Reservoir to the fish ladder (Figures 9B and 10). This additional discharge, together with the flow of the fish ladder (6 second-feet), caused increased turbulence in the river as the flow spilled over an adjustable weir at the fish ladder entrance (Figures 9B; Section E-E, Figure 11, and Figure 12). The addition of this weir permits regulation of the flow spilling into the river with respect to tailwater changes.

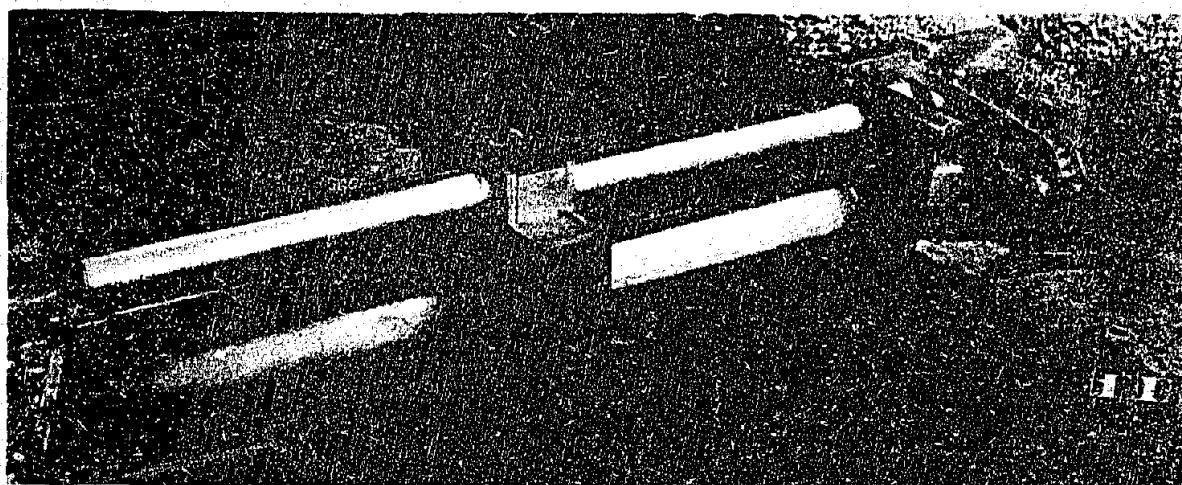
When the Diversion Dam was operating, an undesirable eddy formed in the river at the entrance to the fish ladder. The velocity in the eddy was considered excessive and its upstream component was not conducive to salmon finding the entrance. A small training-wall placed a few feet downstream from the entrance (Figures 9B and 9C) reduced the size and the velocity of the eddy; but it was decided to locate the training-wall in the field upon completion of the prototype structure.

One important feature was added during the study of the fish ladder problem. In the event salmon should proceed upstream along the right bank of the river, it was considered probable that fish would be attracted by the flow from the right section of the Diversion Dam. Unless a fish ladder was installed in this area, the salmon would probably attempt to jump the Diversion Dam instead of proceeding across the river to the fish ladder on the opposite bank. Consequently, it was considered advisable to install an additional fish ladder at the right abutment of the Diversion Dam (Figure 13). A tunnel will be provided through the Dam to connect this fish ladder with the lower pool of the one installed at the left abutment (Figures 10 and 13). It was considered unnecessary to install the added fish ladder and connecting tunnel in the model.

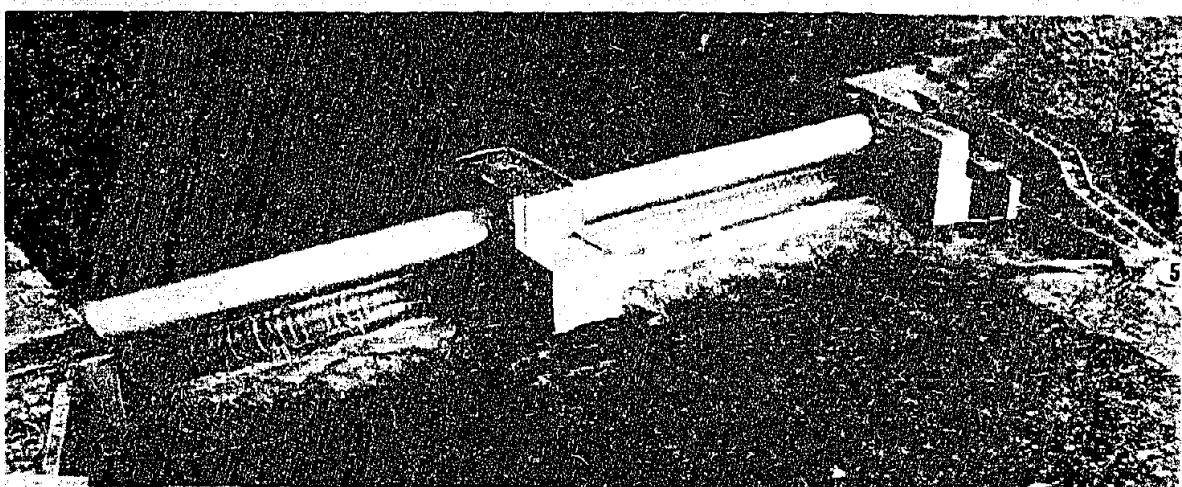
#### SCOUR PREVENTION AT TOE OF DAM

The original design of the Diversion Dam did not include a stilling pool for preventing scour at the toe, principally because it was believed that the basaltic rock of the foundation would resist scouring. Experience shows, however, that even the best bedrock may eventually scour, and as a matter of safety, a stilling pool should be included in a design of this type. A tendency for scour to occur in the model was noted during a discharge representing 50,000 second-feet, the maximum discharge. In a short time the gravel in the riverbed was completely removed to the bottom of the model box (elevation 1172.0) for a prototype distance of about fifty feet downstream.

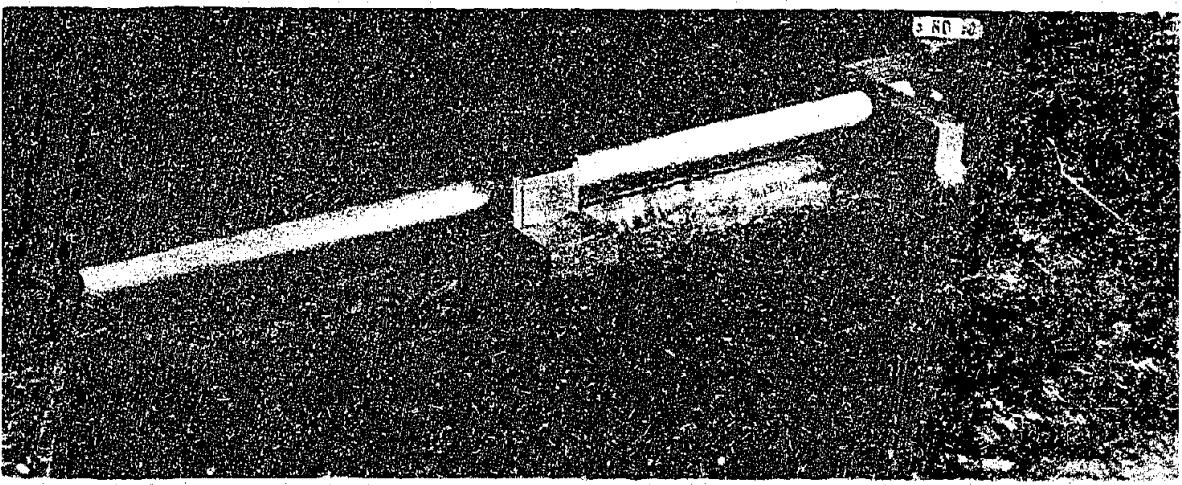
FIGURE 15



A. DENTATED BUCKET.

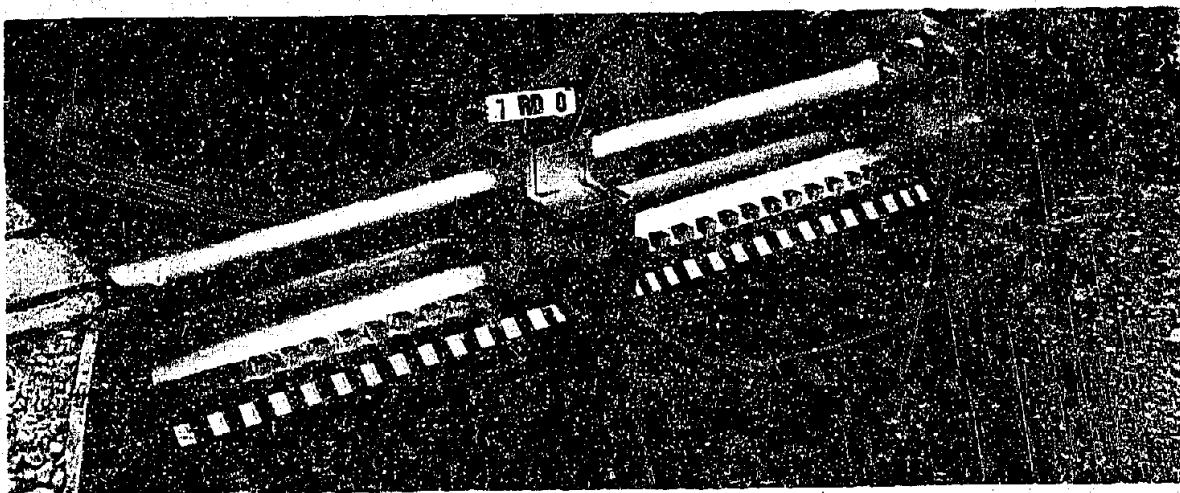


B. DISCHARGE 10,000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1197.3

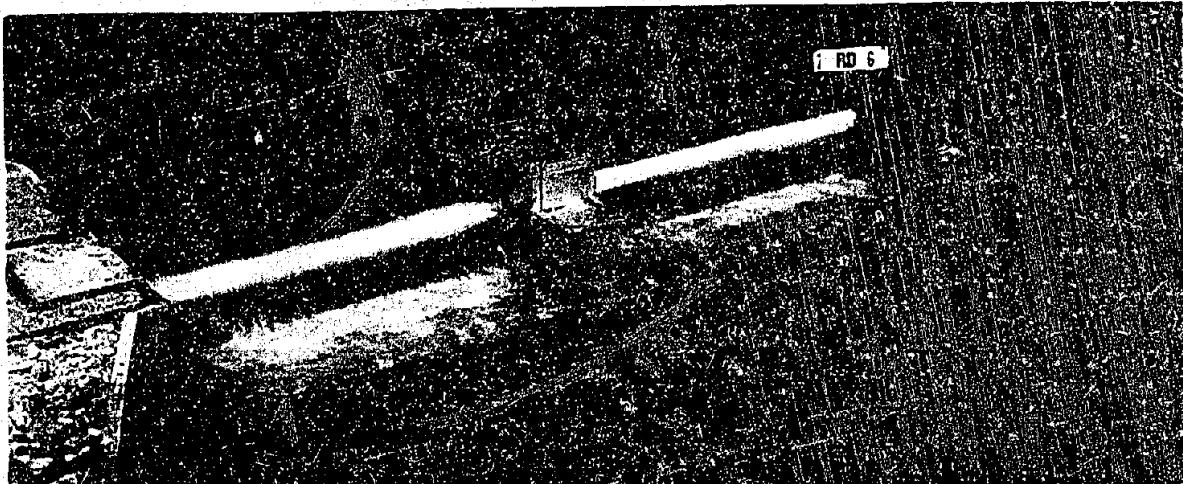


C. DISCHARGE 50,000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1206.5

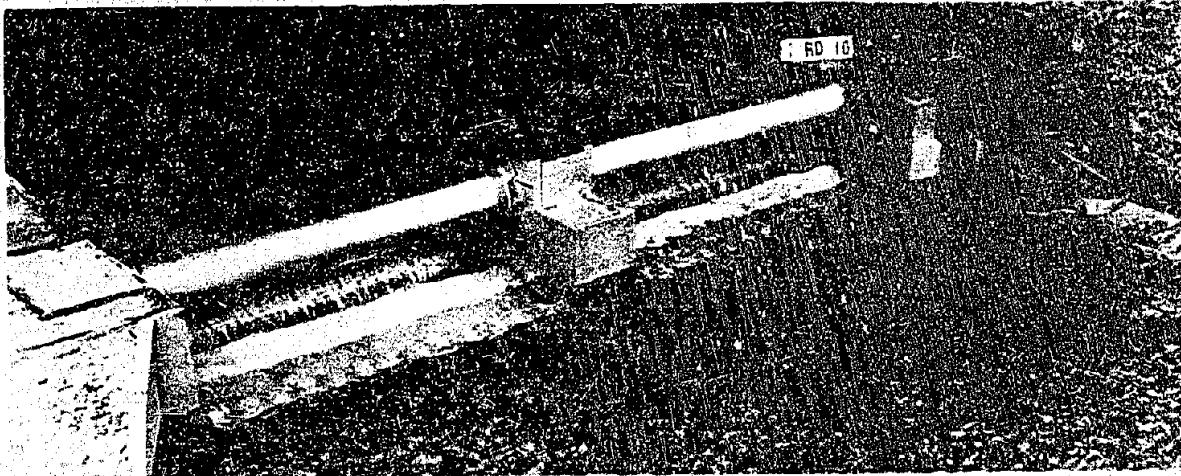
DENTATED BUCKET DESIGN



A. DENTATED APRON



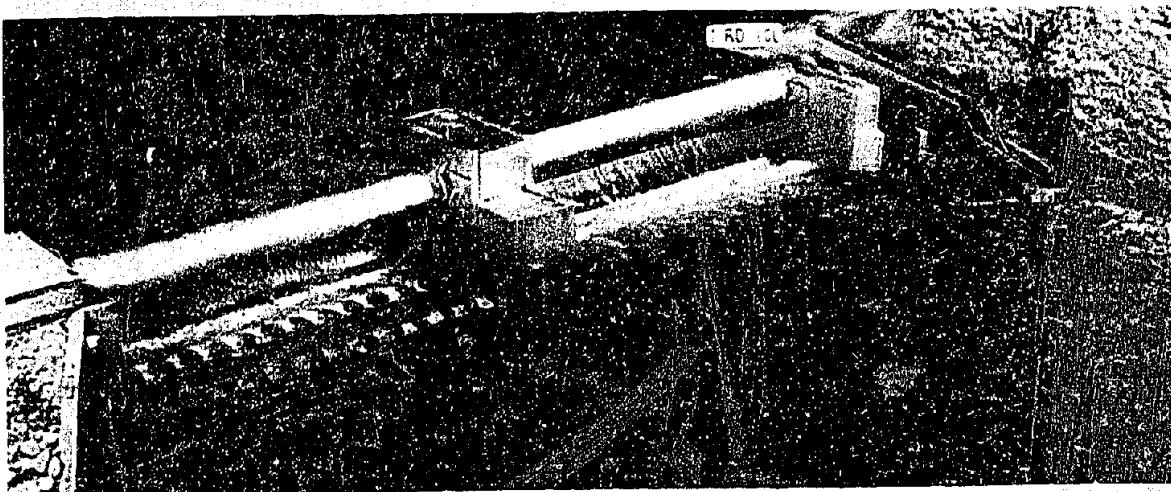
B. DISCHARGE 6,000 SECOND-FEET OVER GATES  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1195.8



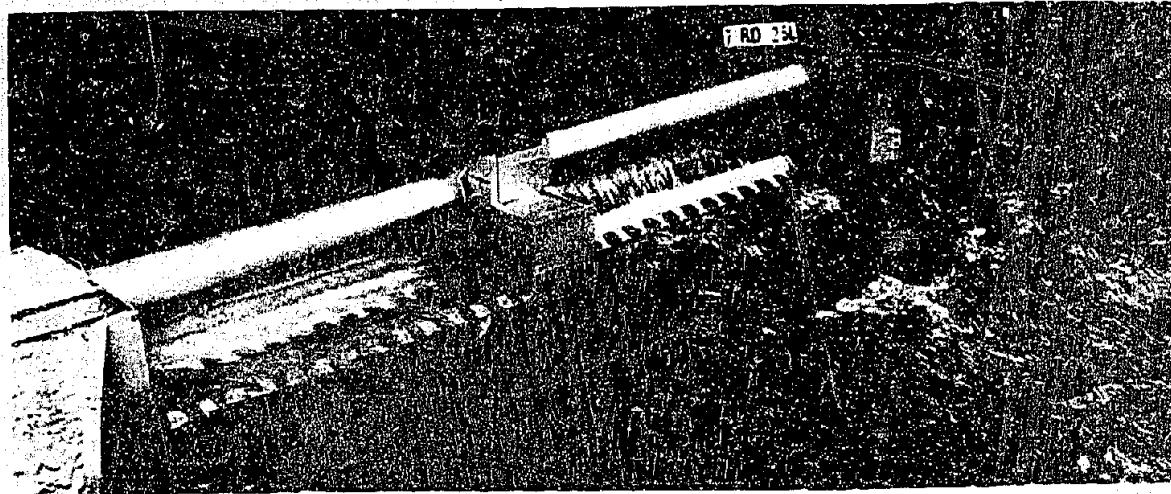
C. DISCHARGE 10,000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1197.3

RECOMMENDED DESIGN

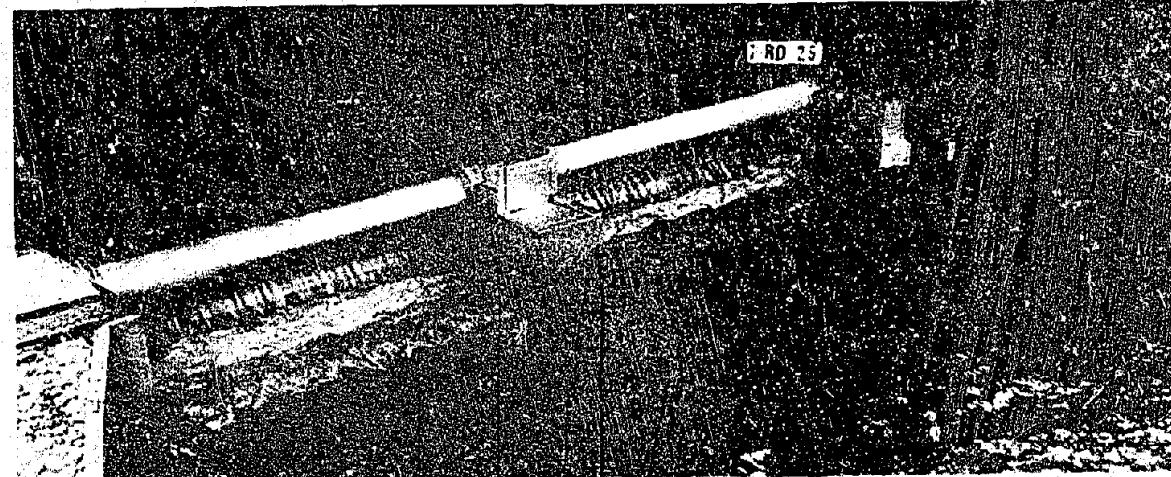
FIGURE 17



A. DISCHARGE 10,000 SECOND-FEET LEFT GATE  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1197.3



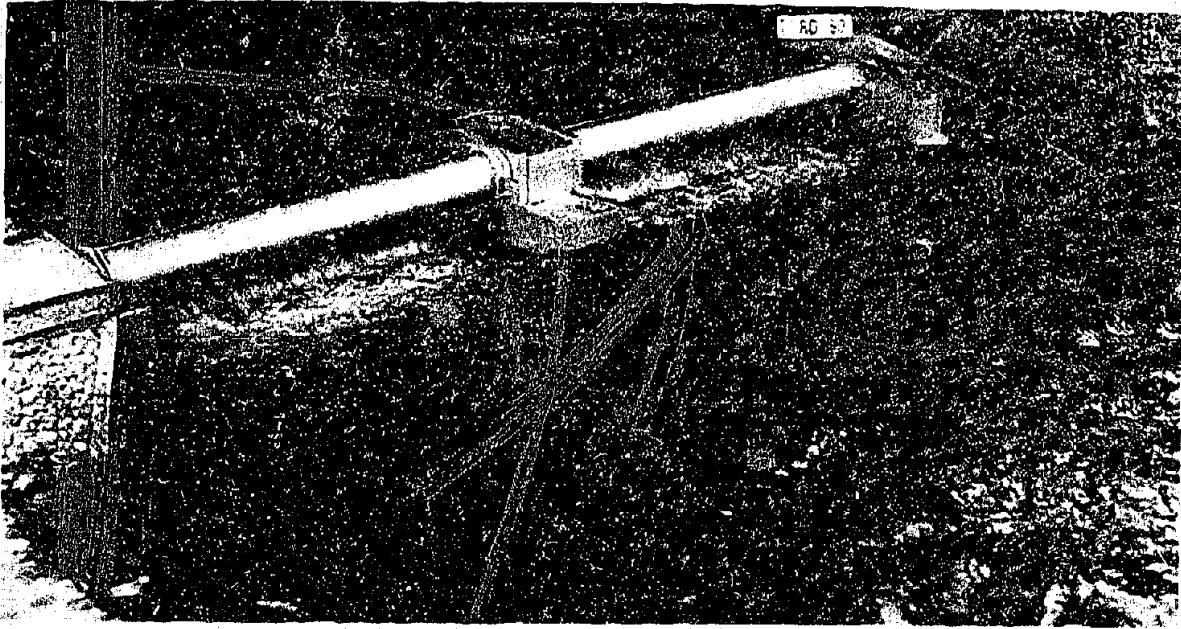
B. DISCHARGE 25,000 SECOND-FEET LEFT GATE  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1201.0



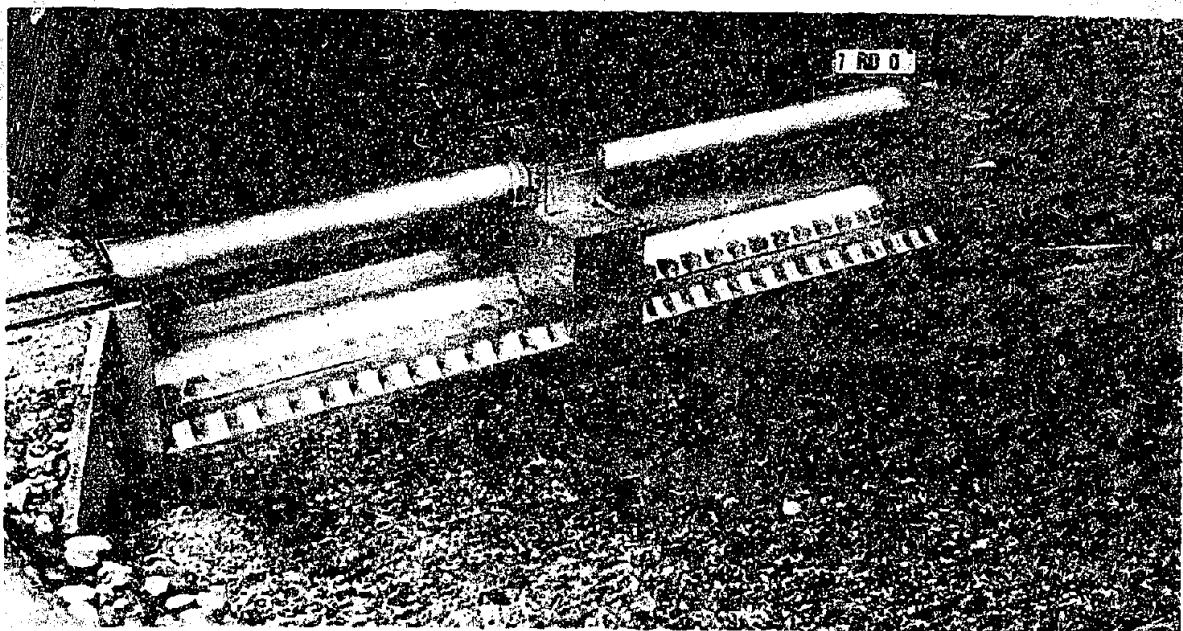
C. DISCHARGE 25,000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1201.0

RECOMMENDED DESIGN

FIGURE 18



A. DISCHARGE 50.000 SECOND-FEET  
POND ELEVATION 1220.6  
TAILWATER ELEVATION 1206.



B. SCOUR AFTER TWO HOURS-DISCHARGE 50.000 SECOND-FEET

RECOMMENDED DESIGN.

**FIGURE 19**

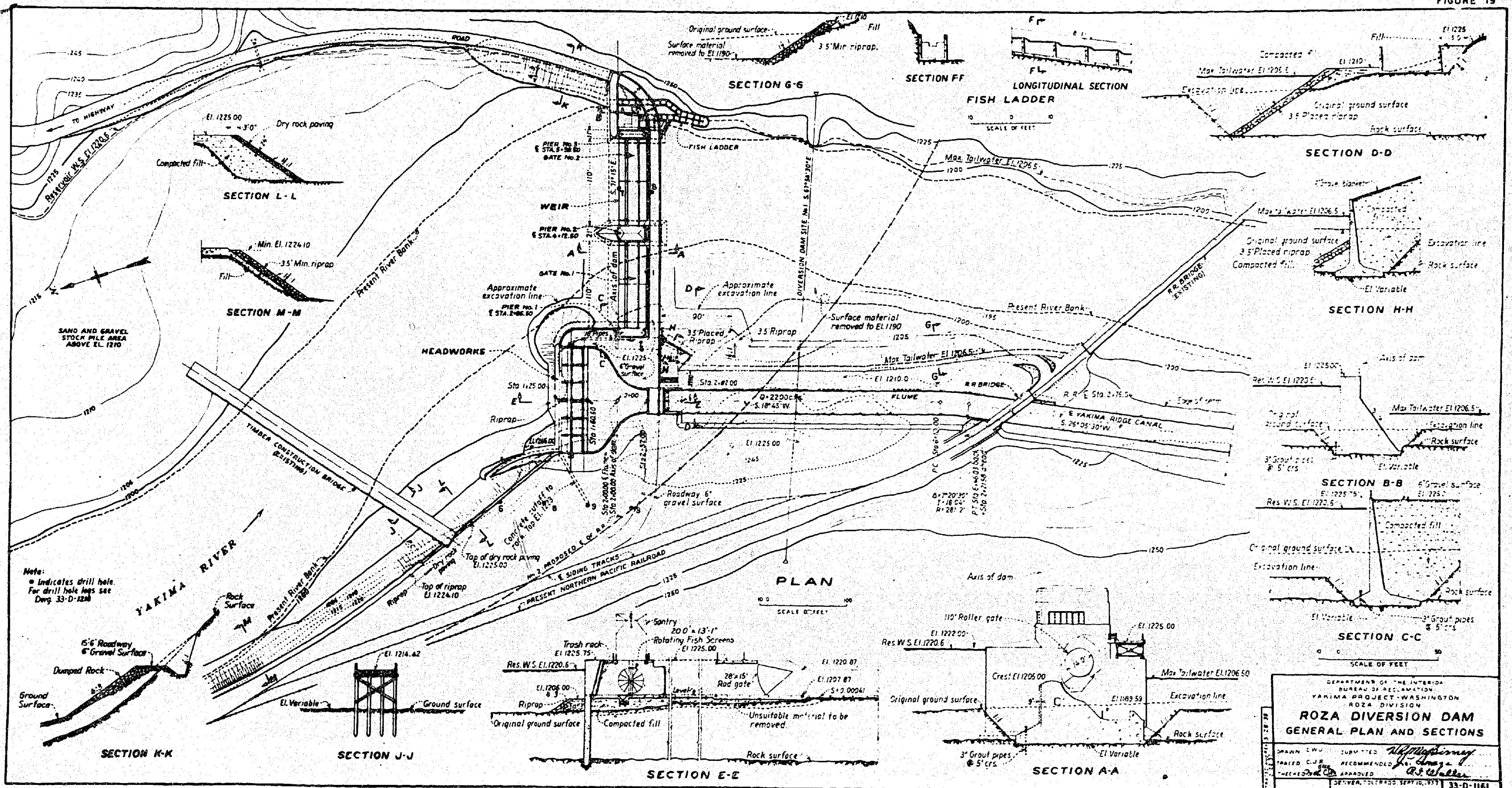
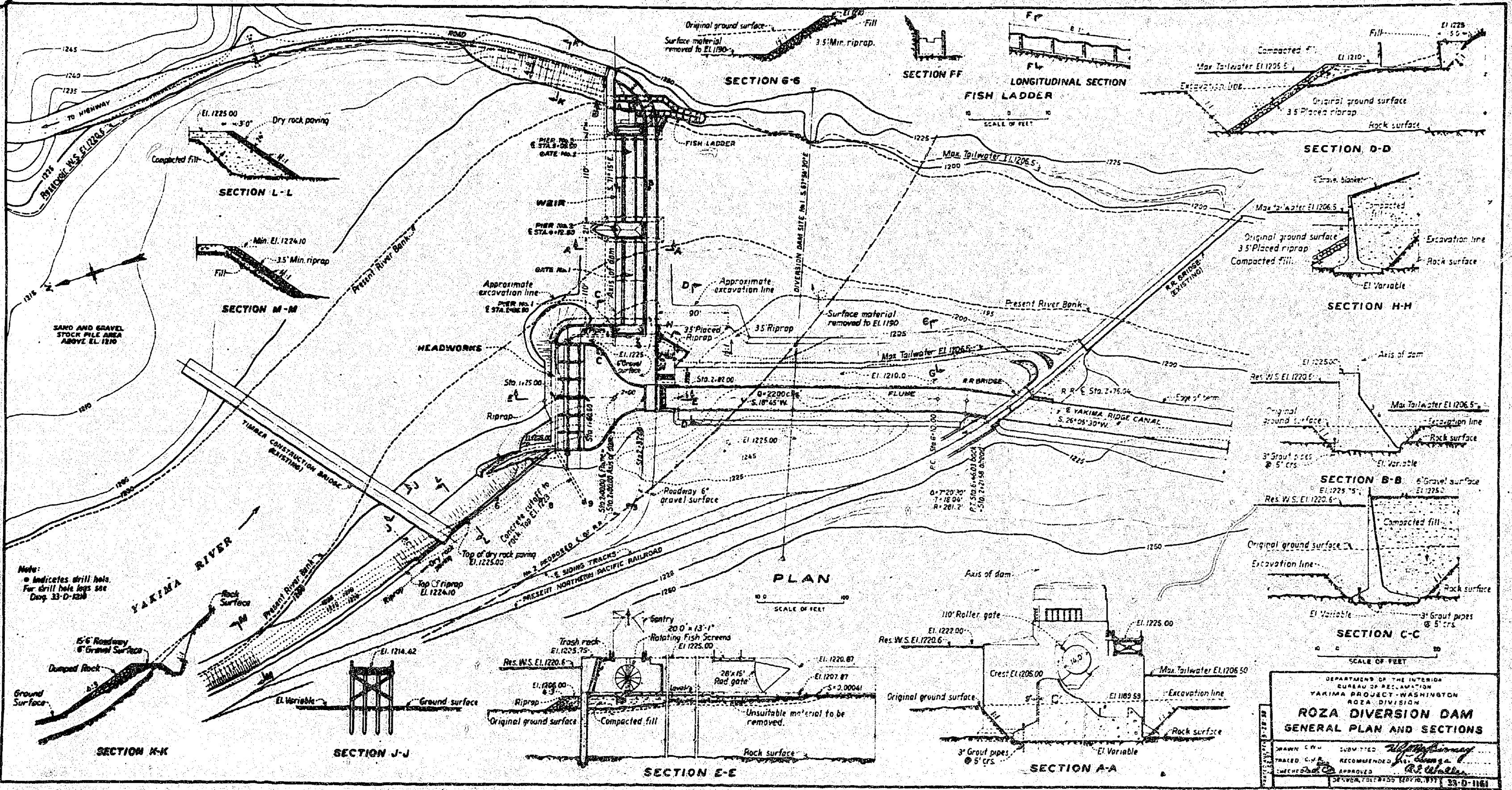


FIGURE 19



**FIGURE 20**

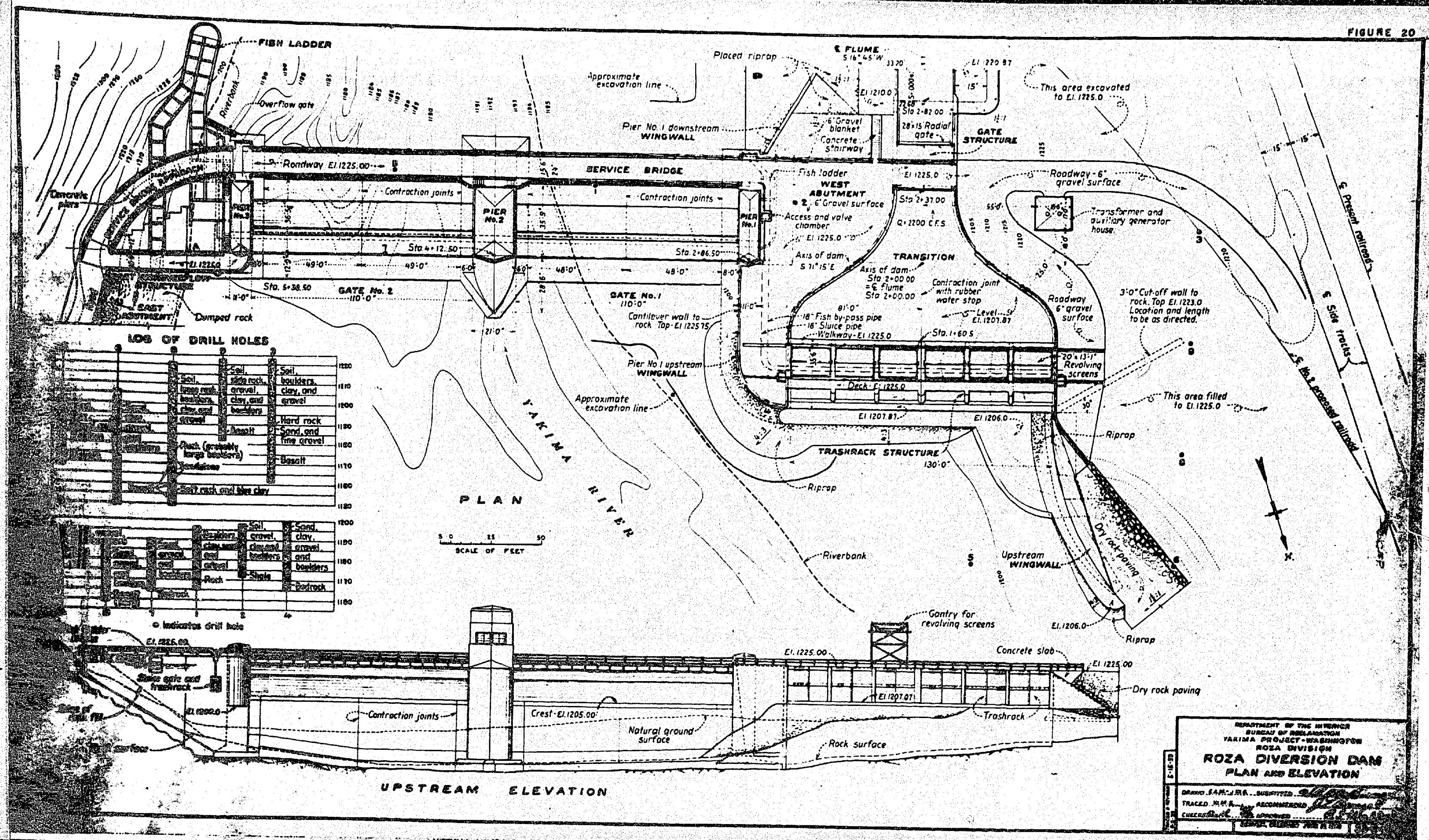
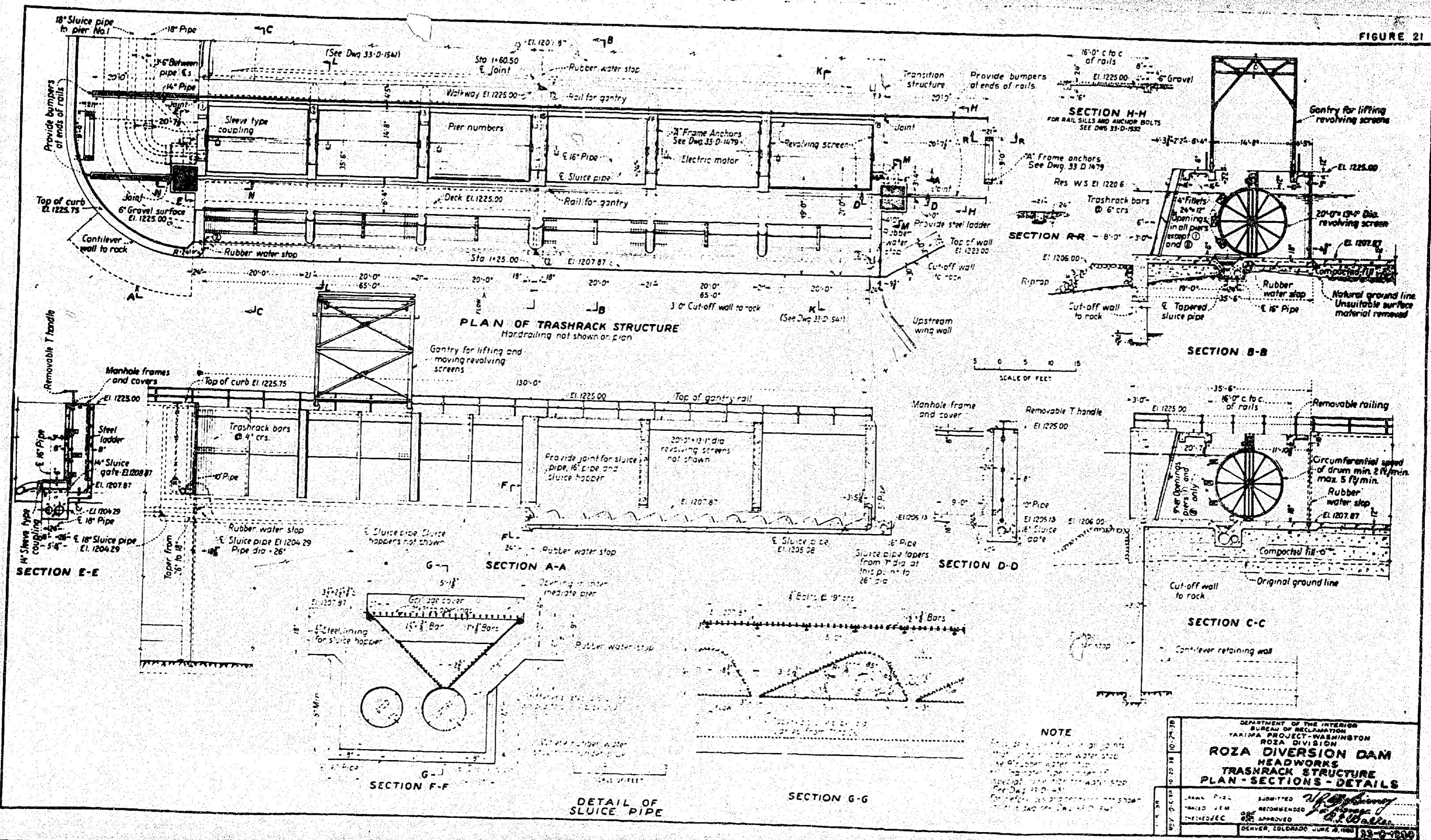


FIGURE 21



Two designs were developed in the model to reduce scouring at the toe of the Dam: a dentated bucket and a dentated apron (Figure 14). The dentated bucket was developed after tests had been made with various radii and positions of a bucket. It was determined difficult to obtain a bucket which would operate effectively at maximum discharge, the thickness of jet flowing over the toe being unmeasurable, and to prevent excessive scour, the bucket had to be placed as close as possible to the toe of the Dam. As a direct result it was difficult to deflect the thick jet upwards in a bucket of small radius. Because of this difficulty, the flow oscillated between a diving jet, which scoured severely, and a roller, which prevented scouring. The bucket shown on Figures 14B and 15A finally eliminated the oscillation in the flow, but the boiling above the bucket was excessive. Dentates were cut into the bucket to reduce this boil, but this did not prove effective. (Figures 15B and C).

The dentated bucket was abandoned in favor of a dentated apron (Figure 14A), which was adopted as the recommended design. Although this design was more costly, the improvement in the flow conditions warranted the added expense. By comparing the flow conditions of the recommended design (Figures 16, 17, and 18) with the flow conditions of the dentated bucket (Figure 15), the building of the latter design is apparent.

The apron of the recommended design was placed at the elevation necessary for the formation of a hydraulic jump, and after coarse dentates had been determined, a discharge representing 50,000 second-feet was run in the model for two hours, the riverbed consisting of 1/4-inch gravel. The resulting scour is shown on Figure 16B. An additional scour test was made using fine sand; the scour was still slight at the end of a two-hour run at maximum discharge.

In the event that a flood of 25,000 second-feet could be passed by only one roller gate, this condition was studied in the model (Figure 17B). It is seen that the jet at the apron is deflected above the tailwater instead of taking the form of a hydraulic jump. Observations on the model disclosed a ground roller which moved material upstream to the toe of the Dam, eliminating any danger of scour at that point. The riverbed of the model was scoured, however, immediately below the point at which the deflected jet plunged into the tailwater; but this scouring is far enough downstream from the Dam to be of little concern. Figure 16B shows the roller gates submerged with a discharge of 6,000 second-feet passing over the gates. This permits removal of ice formations from the reservoir adjacent to the gates.

#### CALIBRATION OF DIVERSION DAM AND ROLLER GATES

The calibration study was divided into three parts: (1) free discharge at the Diversion Dam; (2) discharge under the roller gates; and (3) discharge over the left roller gate. Figure 22 shows rating curves for free discharge at the Dam, including curves of discharge versus head and coefficient of discharge versus head, for both crests

operating simultaneously and separately. The velocity of approach has not been included in the relation  $Q = CLH\bar{v}/2$ .

Figure 23 shows curves for discharge and coefficient of discharge versus gate opening for flow under each roller gate, a separate calibration for each gate; the other basic data are also shown. During this calibration the reservoir (model) was maintained at elevation 12246.

Figure 24 shows experimental and theoretical rating curves for flow over the left roller gate. The experimental coefficients of discharge were obtained from the relation:

where  $Q$  = discharge per foot

$C$  = coefficient of discharge

A = head on gate (Figure 24)

the theoretical coefficients of discharge were obtained from the relations:

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$$C = (x_1 + d - h') \cdot \sqrt{\frac{2gh'}{d^3}} \cdot \log_e\left(\frac{x_1 + d - h'}{x_1}\right) \dots \dots \dots \quad (3)$$

## **What's**

$r_1$  = radius of roller gate (7 feet 0 inch) (Figure 24).

$h'$  = total available head at point on water surface above gate through the vertical (Figure 24).

$d$  = head on gate (Figure 24).

$C$  = coefficient of discharge.

By assuming values of  $d$  in equation (2),  $r_1$  being constant, a trial and error solution will determine corresponding values of  $h'$ . Using these values of  $d$  and  $h'$ , the theoretical coefficients of discharge  $C$  are obtained from equation (3). The derivation of equations (2) and (3) may be found in Technical Memorandum No. 562, "Design of Roller Gates," by C. P. Vetter.

A comparison of the experimental and theoretical discharge coefficients shows the latter to be about eight percent greater. Sufficient experimental data were taken to permit its substitution into equation (3), the relation for theoretical coefficients of discharge. When this is done, the coefficients obtained are nearly equal to the theoretical coefficients obtained by assuming various values of  $d$  and  $h'$  in equations (2) and (3). Compare coefficient versus head ( $d$ ) curves on Figure 24 of "Theoretical" and "Experimental Based on Theoretical." Similarly, if the experimental coefficients obtained from equation (3) are used to determine the discharge from equation (1),

**FIGURE 22**

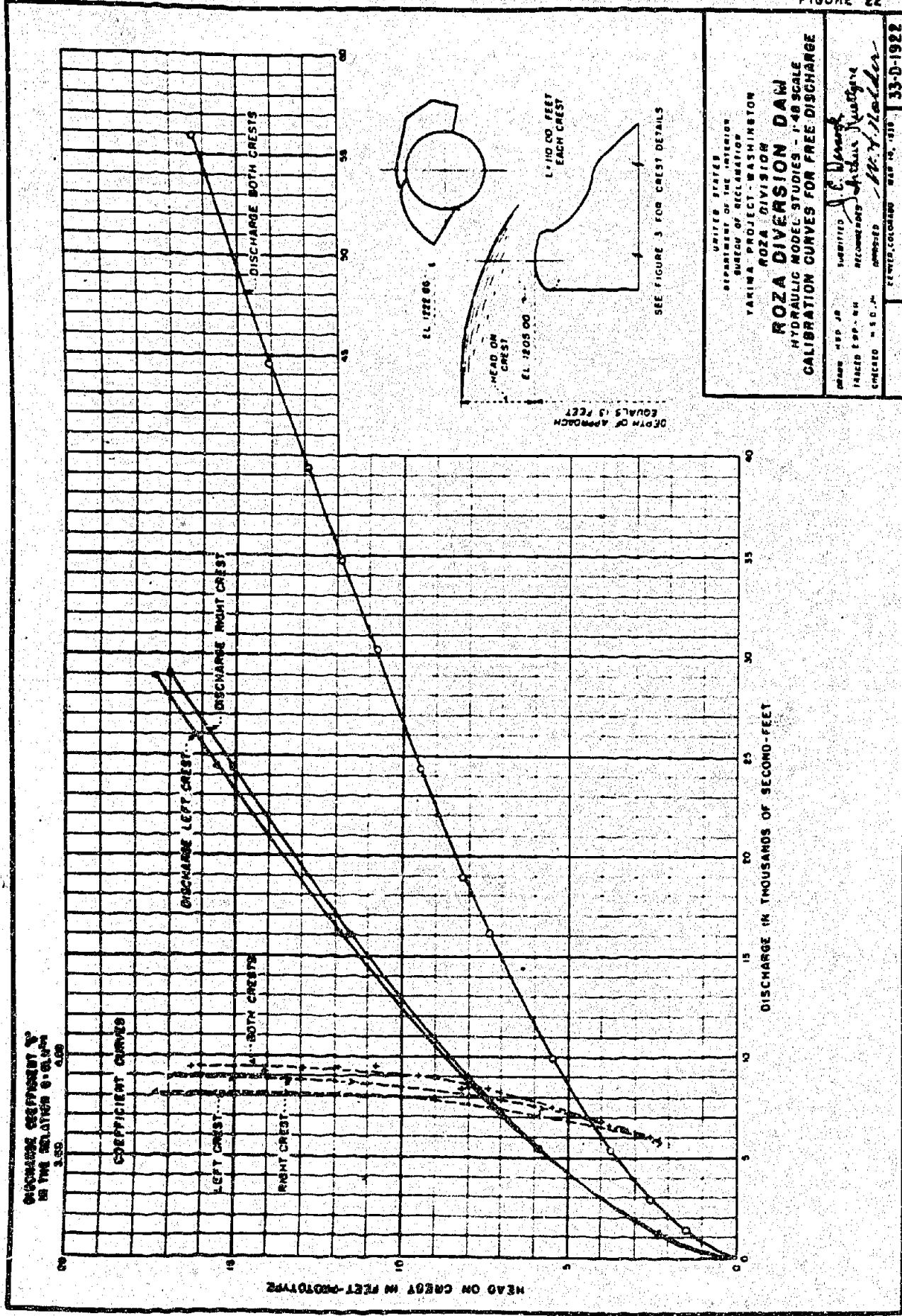
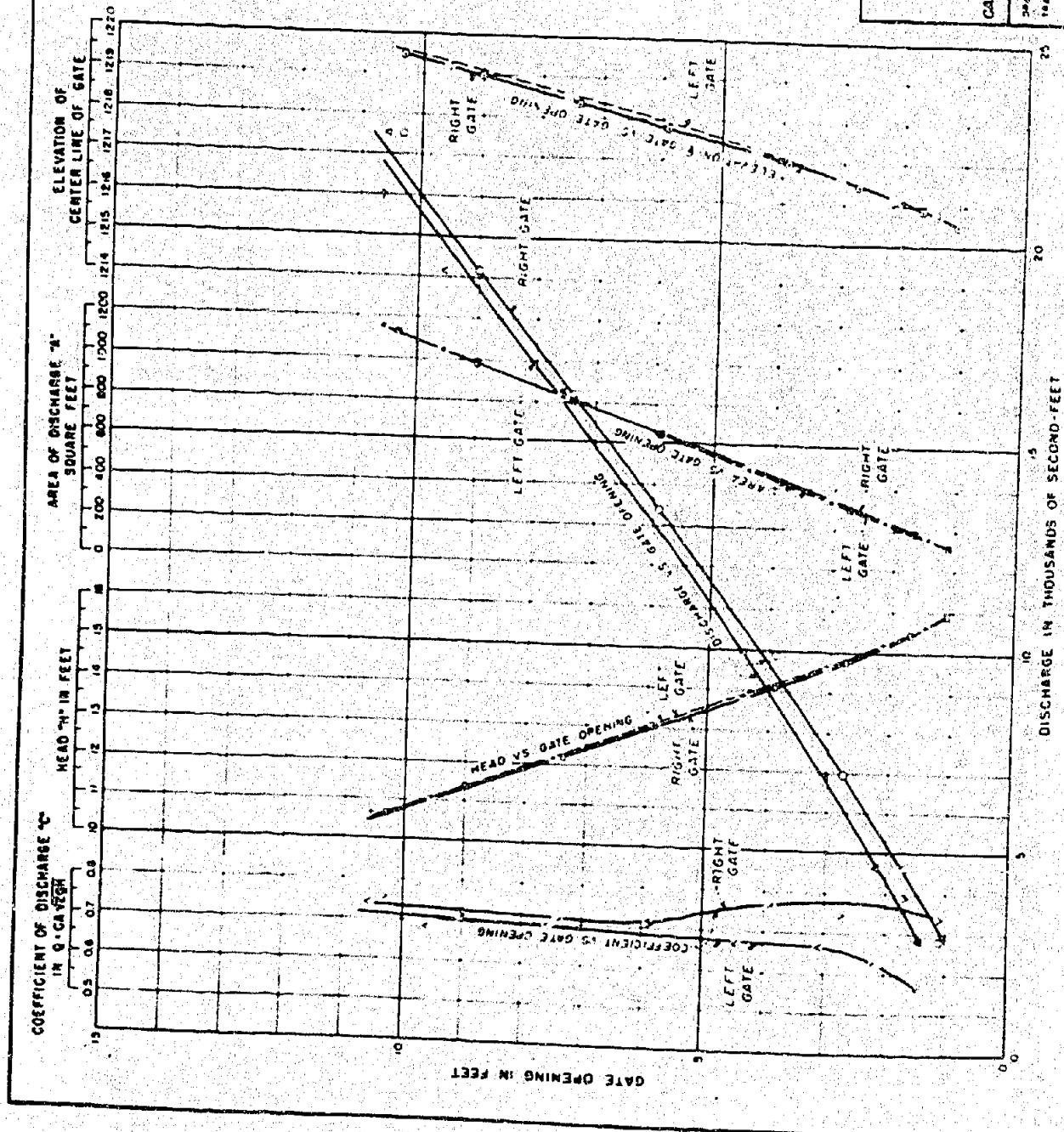


FIGURE 23



### ROZA DIVERSION DAM

HYDRAULIC MODEL STUDIES - 1:48 SCALE

CALIBRATION CURVES FOR FLOW UNDER ROLLER GATES

YANKEE DIVISION  
DIVISION OF HYDRAULIC ENGINEERING  
U.S. BUREAU OF RECLAMATION

DATE DRAWN: 1-15-59  
DRAWN BY: J.W.  
RECORDED BY: J.W.  
APPROVED BY: J.W.  
JAN. 15, 1959

330-1923

FIGURE 20

United States  
Department of the Interior  
Bureau of Reclamation  
Tallmadge Project - Washington  
ROZA DIVISION  
HYDRAULIC MODEL STUDIES - 1:10 SCALE  
DIVERSION CURVES FOR 150' OVERLIFT GATE

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REMOVED

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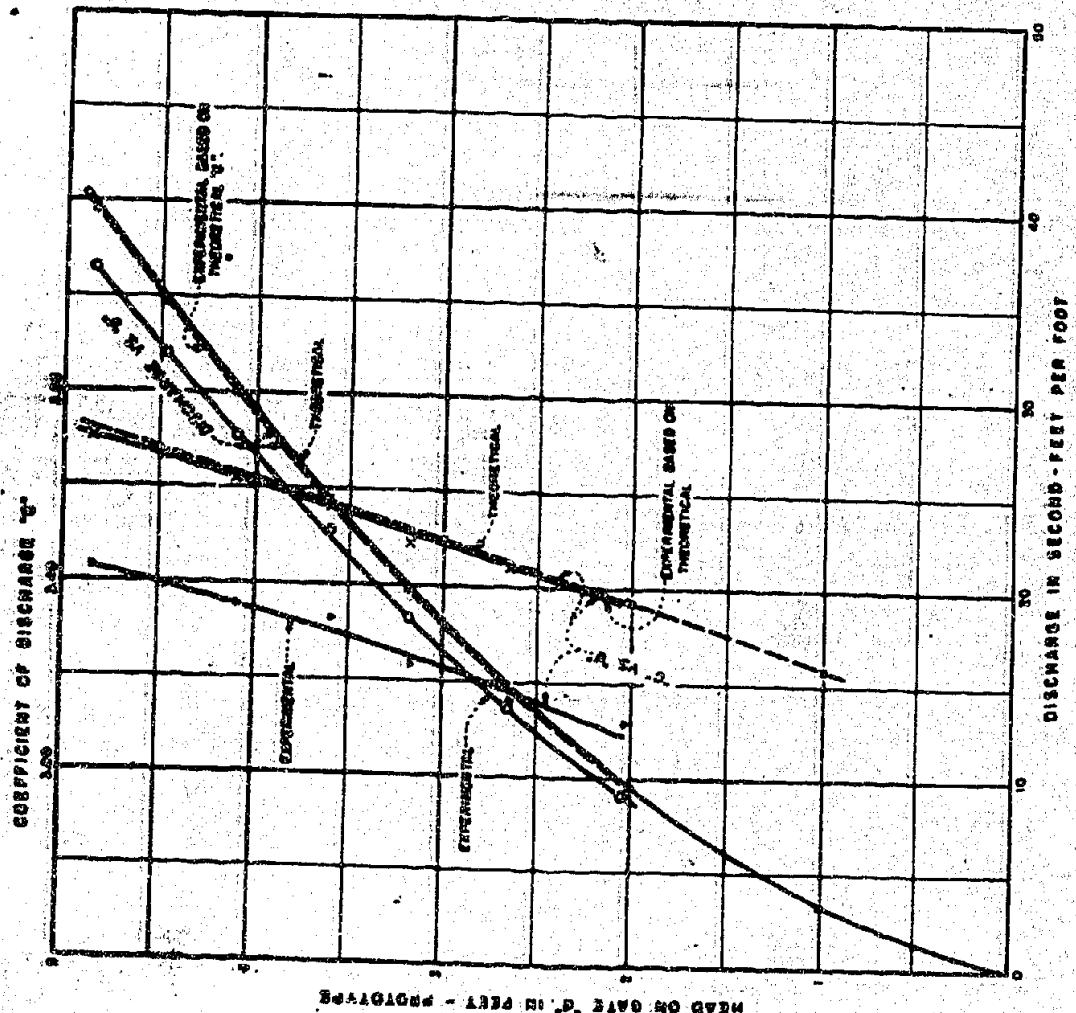
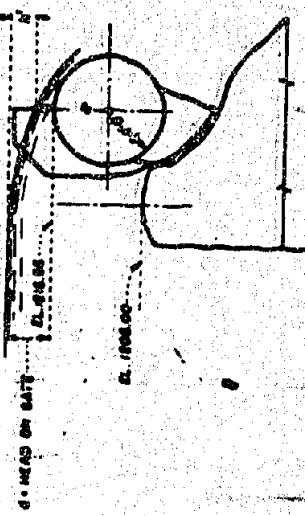
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DRAWINGS - 1938 NO. D. 2140 NO. 0734

the resulting head versus discharge curve, "Experimental Based-on Theoretical C" (Figure 24), agrees nearly with the "Theoretical" discharge curve obtained from equation (1), but using values of  $C$  computed from equations (2) and (3). The experimental discharge versus head curve is also about eight percent less than the theoretical curve (Figure 24), since the experimental coefficients are about eight percent less than the theoretical.

A closer agreement between purely experimental coefficients of discharge and those obtained from theoretical considerations is not expected, since the experimental coefficients are based on the usual weir relation  $Q = CLH^{3/2}$ . The theoretical values of the discharge coefficient, on the other hand, are based on principles and assumptions of hydrodynamics as expressed in equations (2) and (3). It is interesting to note, however, that when experimental data are substituted in equation (3) instead of equation (1), the theoretical and experimental coefficients more nearly agree. This evidently confirms the theoretical assumptions. Closer agreement is particularly difficult to obtain here, because of the small scale model and the small model discharges. The eight percent variation may be accounted for in the errors of discharge and other experimental measurements. This is evident, since the experimental data substituted in equation (3) is independent of any discharge measurements, but the experimental values of  $C$  obtained from equation (3) agree closely with the theoretical values as has been shown.

#### CONCLUSIONS

From the model studies it was possible to obtain a satisfactory headworks alignment which produced a uniform flow distribution through the headworks (Figures 5D and 7B). A satisfactory fish ladder design was evolved in the model (Figures 9B, 9C, and 9D). This study also revealed the necessity of placing an additional fish ladder at the right abutment of the Diversion Dam (Figure 15). Although the bedrock at the foundation of the Dam is basalt, the model of the original design disclosed a tendency for excessive scour to occur during maximum discharge. A denticulated apron was evolved adopting a hydraulic jump to eliminate excessive scouring at all discharges (Figures 14A, 16, 17, and 18). Figure 19 shows the completed recommended design; additional details are shown on Figures 20 and 21.

One of the most important features of this study was the development of a correct fish ladder design. The salmon industry in the Pacific Northwest is quite extensive. It is essential, therefore, to provide fish ladders at obstructions in the river which salmon follow from the ocean to their spawning grounds. Fish ladder designs should include all the features listed on Page 11. It is also important to prevent salmon from entering canals; otherwise some may never reach the spawning grounds.

Good design practice includes stilling pools for preventing scour at the toe of an overfall dam. Even if the bedrock of the foundation is durable and can probably resist scouring, it is advisable to take necessary precautions and provide some means of protecting the channel at the toe of a dam from scour.

No definite rule can be stated regarding the alignment of a headworks at a diversion dam. In this particular study, however, uniform flow distribution through the headworks was best obtained when the line of openings was not parallel to the direction of flow in the river. This assumes some velocity across the face of the headworks due to flow passing over the diversion dam. If there is no velocity across the face of the headworks, then the headworks alignment is not very important as far as uniform flow distribution is concerned.

From the calibration study, it is evident that the theoretical relations for determining coefficients of discharge for flow over roller gates are justified.