EAGLE MOUNTAIN DAM SPILLWAY MODEL STUDY

Tarrant County Water Control
and Improvement District Number One
FORT WORTH, TEXAS

CIVIL ENGINEERING DEPARTMENT

ENGINEERING RESEARCH CENTER
COLORADO STATE UNIVERSITY
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EAGLE MOUNTAIN DAM SPILLWAY MODEL STUDY

Tarrant County Water Control
and Improvement District Number One
Fort Worth, Texas

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SUMMARY

The following is a model study report of a side channel spillway, conveyance channel and energy dissipation basin to be constructed at the Eagle Mountain Dam near Fort Worth, Texas. The purpose of the structure is to provide additional outflow from the reservoir for improved flood control capabilities. The design, construction and testing of the model was completed at the Hydraulics Laboratory, Engineering Research Center, Colorado State University. The work was sponsored by the Tarrant County Water Control and Improvement District Number One and supervised by the firm of Freese, Nichols and Endress of Fort Worth, Texas.

The report includes a discussion of the laboratory and facilities used to conduct the tests, a description, drawings and photographs of the model; and a discussion including photographs, of the performance of the side channel spillway, the conveyance channel and the energy dissipation basin for a wide range of flow conditions. The results of the tests verify that the structure will operate completely satisfactorily. At discharges above design (21,340 cfs) excessive submergence of the ogee crest occurred which resulted in decreased performance of the spillway. The sequence for opening or closing the gates was found to be of no importance; regardless of the opening sequence of the gates the structure operated properly.

INTRODUCTION

Background

The Eagle Mountain Dam was constructed in 1931-34 by the Tarrant County Water Control and Improvement District Number One. Its purpose was twofold: to provide a water supply for the city of Fort Worth, and to act as a flood control structure. Due to the increasing needs for more water, it has become necessary to maintain a maximum depth in the reservoir. Under this condition the reservoir loses much of its effectiveness as a flood control structure unless adequate outlet works are provided to handle large inflows caused by flooding conditions.

To improve the flood control capabilities of the reservoir it was proposed in 1965 that a morning glory spillway and outlet works be constructed to give the additional outflow capabilities. Such a structure was designed, and a model study conducted at Colorado State University. During the process of construction of the morning glory spillway and outlet tunnel, severe problems were encountered which resulted in ultimately abandoning the morning glory spillway system. It was therefore necessary to design another structure to handle the desired discharge.

Side Channel Spillway

A gated, side channel spillway was selected as the most suitable structure for satisfying the requirements. A spillway location was selected Northeast of the existing spillway with the conveyance channel passing beneath the existing roadway in a southerly direction, and the outflow from the energy dissipation basin being directed into the existing channel near the natural rock bridge below the existing spillway basin. A plan view and the location of the spillway structure relative to the existing dam is shown in Fig. 1. The major features of this structure are:

1. A gated ogee crest. The crest and its super structure were designed such that the 12 gates ordered for the morning glory spillway can be used for the side channel spillway.
2. A variable width side channel with a horizontal floor, and side walls sloping one to one.
3. A transition section from the trapezoidal shaped side channel to the vertical walled covered conveyance conduit.
4. A rectangular conveyance conduit with a dividing wall for support of the roadway and overburden.
5. A rectangular open channel 55 foot wide.
6. A vertical dropped energy dissipation basin and conveyance channel.

Scope of the Model Study

The model study was performed to evaluate the suitability, and modify where necessary, the original design of the side channel spillway structure. This was done by determining its performance under a wide variety of flow conditions. The following items were of specific interest:

1. Investigate the approach conditions to the side channel spillway so as to reduce to a minimum the amount of excavation.
2. Evaluate the performance of the ogee crest and side channel spillway for flows less than, equal to, and greater than the design discharge of 21,340 cfs.
3. Study the flow through the system for a variety of combinations of gate openings to determine if the gate opening sequence is critical.
4. Study the flow conditions at the approach to the covered section to determine if the flow is adequately divided between the two sections of

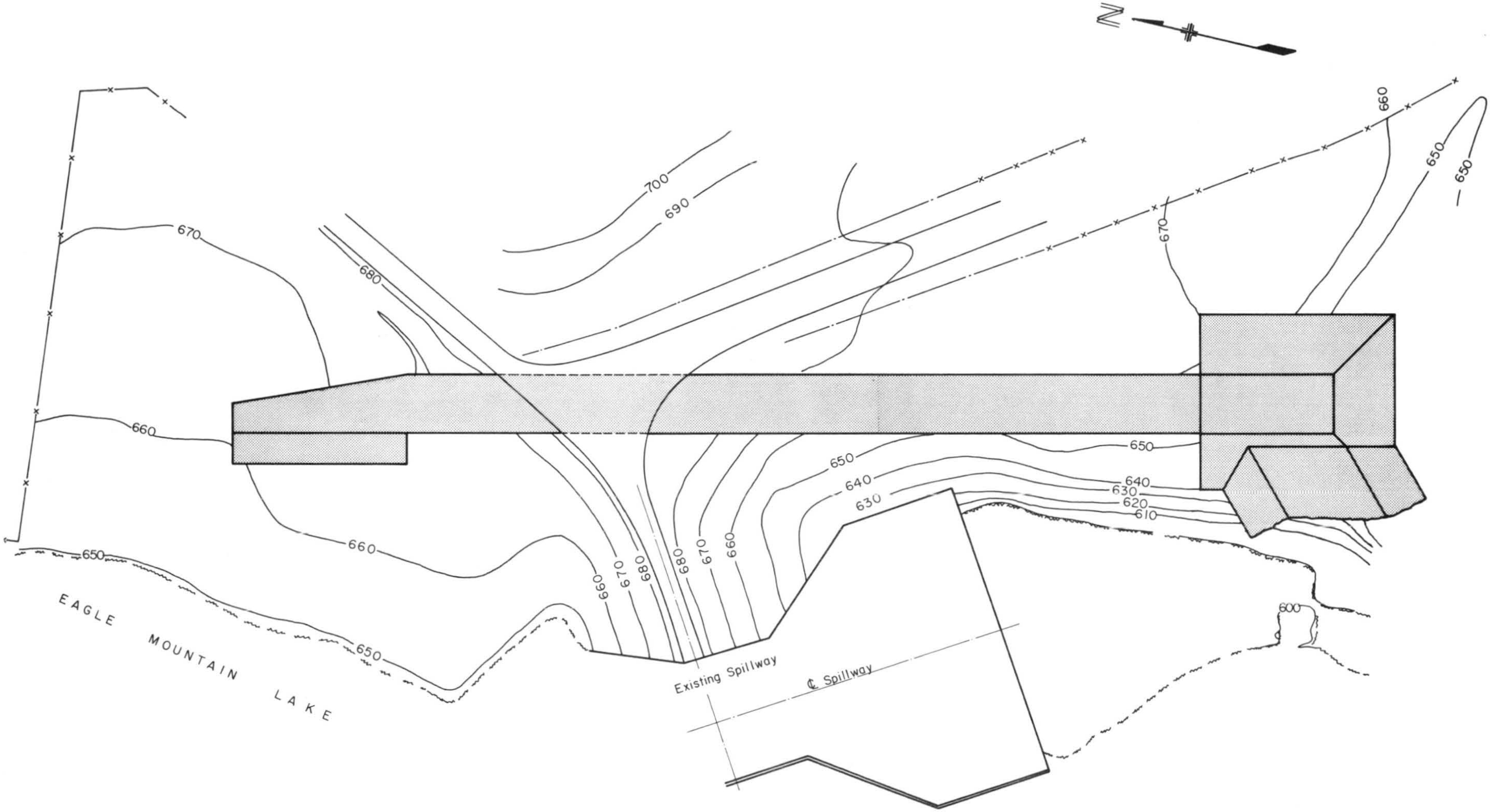


Fig. 1. Location of side channel spillway relative to existing dam

covered conduit and if excessive disturbance of the water surface is present.

5. Observe the general characteristics of the flow in both the closed and open conduit section and evaluate the minimum wall height in the open conduit section which will contain the flow for all discharges expected, with adequate free board.

6. Evaluate the performance of the energy dissipation basin and the general characteristics of the flow in the 80 foot wide conveyance channel.

7. Establish the relationship of discharge versus lake elevation for different flow conditions.

Model Scale and Similarity

Scale models can be used to predict prototype performance if both dynamic and kinematic similarity can be satisfied. Dynamic similarity requires a constant force ratio between forces in the model and prototype. Kinematic similarity requires a constant ratio of velocities. Applying dimensional analysis to an open channel flow problem of this type results in two similarity parameters: the Euler number and the Froude number.

With one degree of freedom inherent to the dimensional analysis method, the Euler number is automatically satisfied. Thus, the problem reduces to one of satisfying the Froude number in order to insure both dynamic and kinematic similarity between model and prototype.

A model scale of 30:1 was selected as the most satisfactory scale. With the model scale, or length ratio set at 30:1, and setting the gravity ratio and Froude number ratio at 1.0, a velocity ratio of 5.478, a pressure ratio of 30.0 and a discharge ratio of 4,930, are obtained for comparison between conditions in the prototype and those in the model.

THE MODEL

The model was constructed primarily from plywood and sugar pine, covered with fiberglass for waterproofing. A plan view and elevation of the model, after all modifications were completed, are shown in Fig. 2. Figure 3 is a photograph of the model. Detailed drawings of the major features of the model are presented and discussed in the following paragraphs.

Water is supplied to the model by a 14-inch turbine pump. The discharge was regulated by a bypass valve near the pump and by a throttling valve near the intake to the head box. Rock filled baffles were placed between the head box and the entrance to the model for distributing the flow in the head box and creating smooth flow conditions at the entrance to the side channel spillway. Discharge through the model was measured with a calibrated orifice placed in the 14-inch supply line. This orifice was previously calibrated with volumetric tanks in the laboratory.

Approach Channel

Details of the approach channel and head box are shown in Fig. 4. The bottom width of the channel is the same as the width of the ogee crest. It has a horizontal bottom at an elevation of 631 feet and side slopes of 1:1.

Ogee Crest

A photograph of the ogee crest is shown in Fig. 5. The crest was constructed from sugar pine covered with fiberglass and paint for water proofing. The piers were the ones used for the original study on the morning glory spillway. These piers, made of clear plastic, were modified for use with the ogee crest. The gates were made of wood with rubber O-rings used for obtaining a seal around the outside. These gates were the same gates as used for the morning glory spillway.

Cross sections of the ogee (overflow) crest and the trapezoidal side channel is shown in Fig. 6. The ogee crest and side channel spillway were designed according to the recommendations outlined by the Bureau of Reclamation in the book, "Design of Small Dams." Coordinates for the upper curve of the ogee crest are listed in Table 1. The crest is designed such that a profile of the ogee closely resembles the profile of the lower nape of a ventilated sheet falling from a sharp crested weir. By doing this, excessive positive or negative pressures on the crest are avoided.

TABLE I

COORDINATES OF OGEE CREST

Downstream Coordinates		Upstream Coordinates	
x	y	x	y
1.00	.060	0	0
2.00	.218	0.720	0.046
3.00	.460	1.440	0.189
4.00	.786	2.160	0.463
5.00	1.188	2.880	0.944
6.00	1.664	3.244	0.513
7.00	2.214		
8.00	2.834		
9.00	3.524		
10.00	4.282		
12.00	6.000		
13.15	7.107 *		
14.00	7.980		

*Point of tangency 1:1 slope

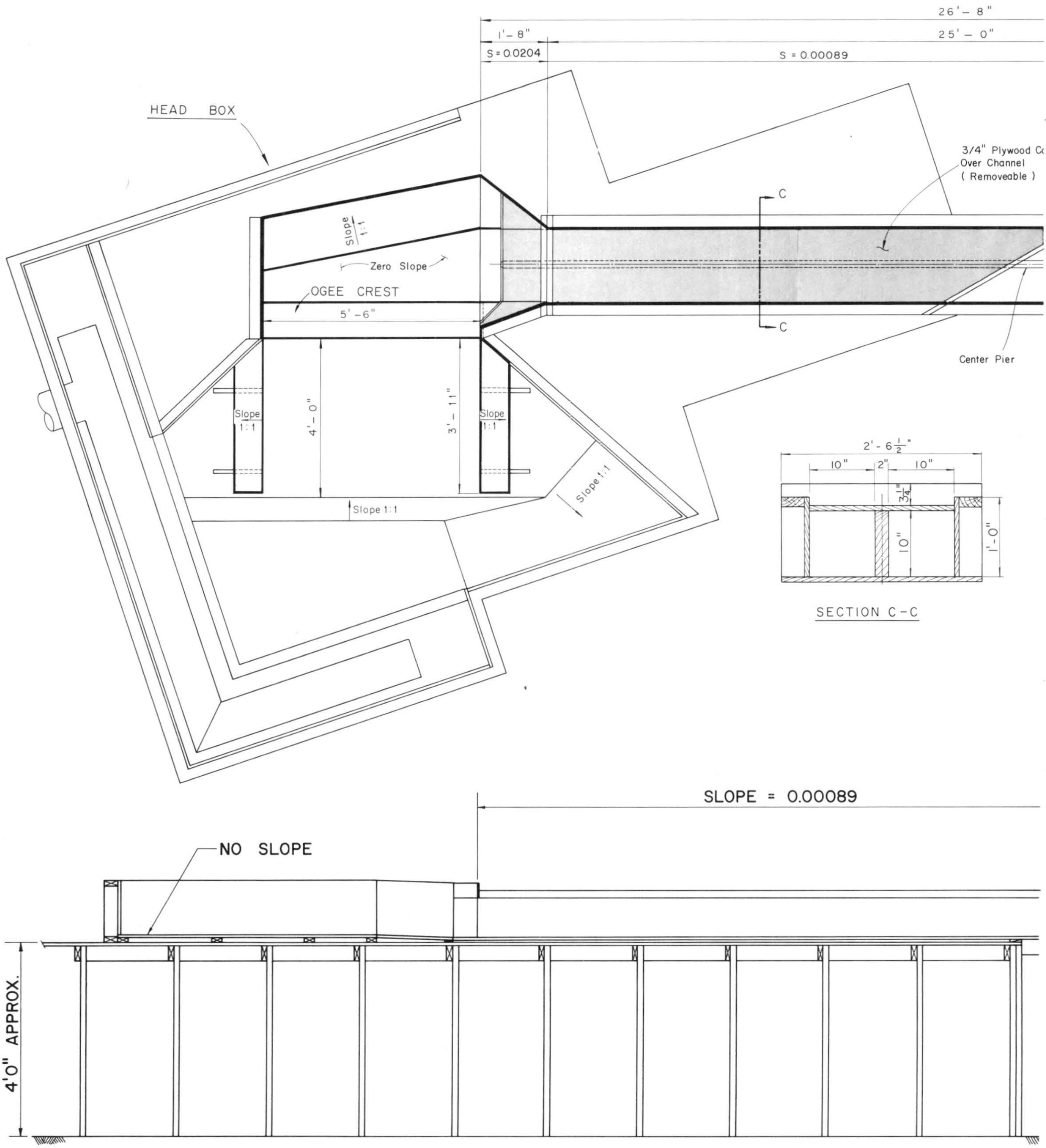


Fig. 2. Plan view and center line profile of the Eagle Mountain Dam Spillway model

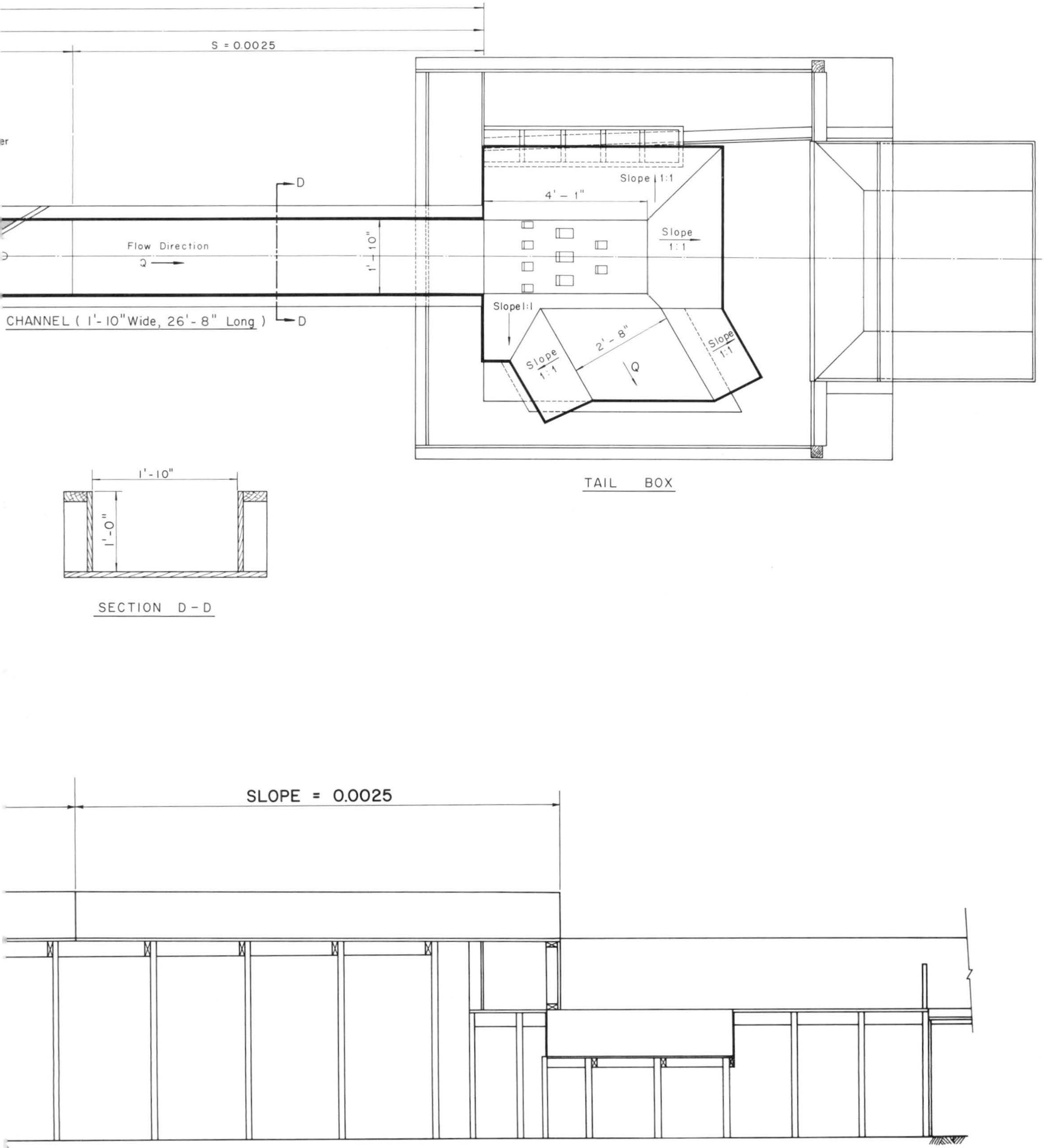


Fig. 2. **Plan view and center line profile of the Eagle Mountain Dam Spillway model**

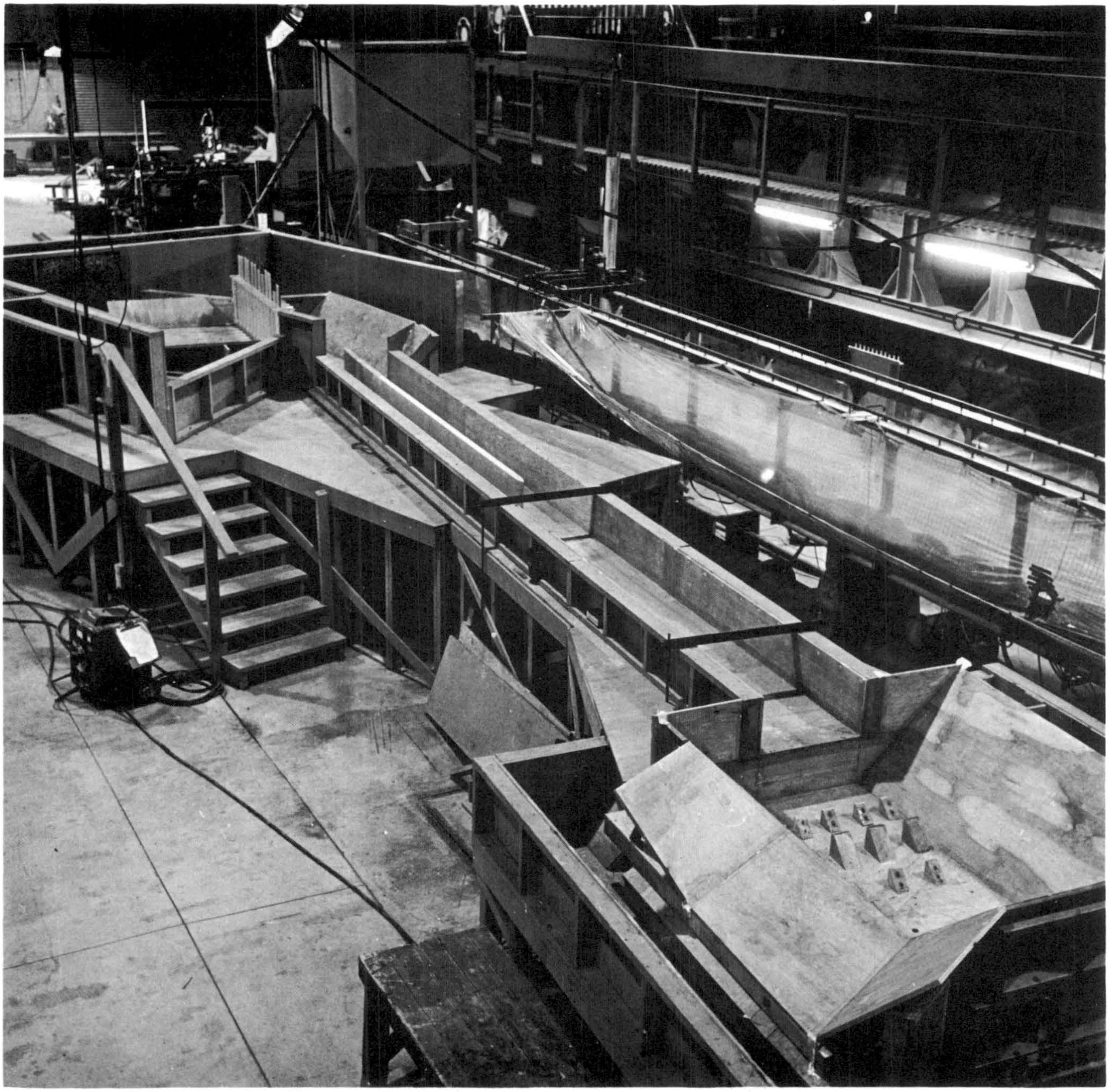


Fig. 3. Photograph of the Eagle Mountain Dam Spillway model

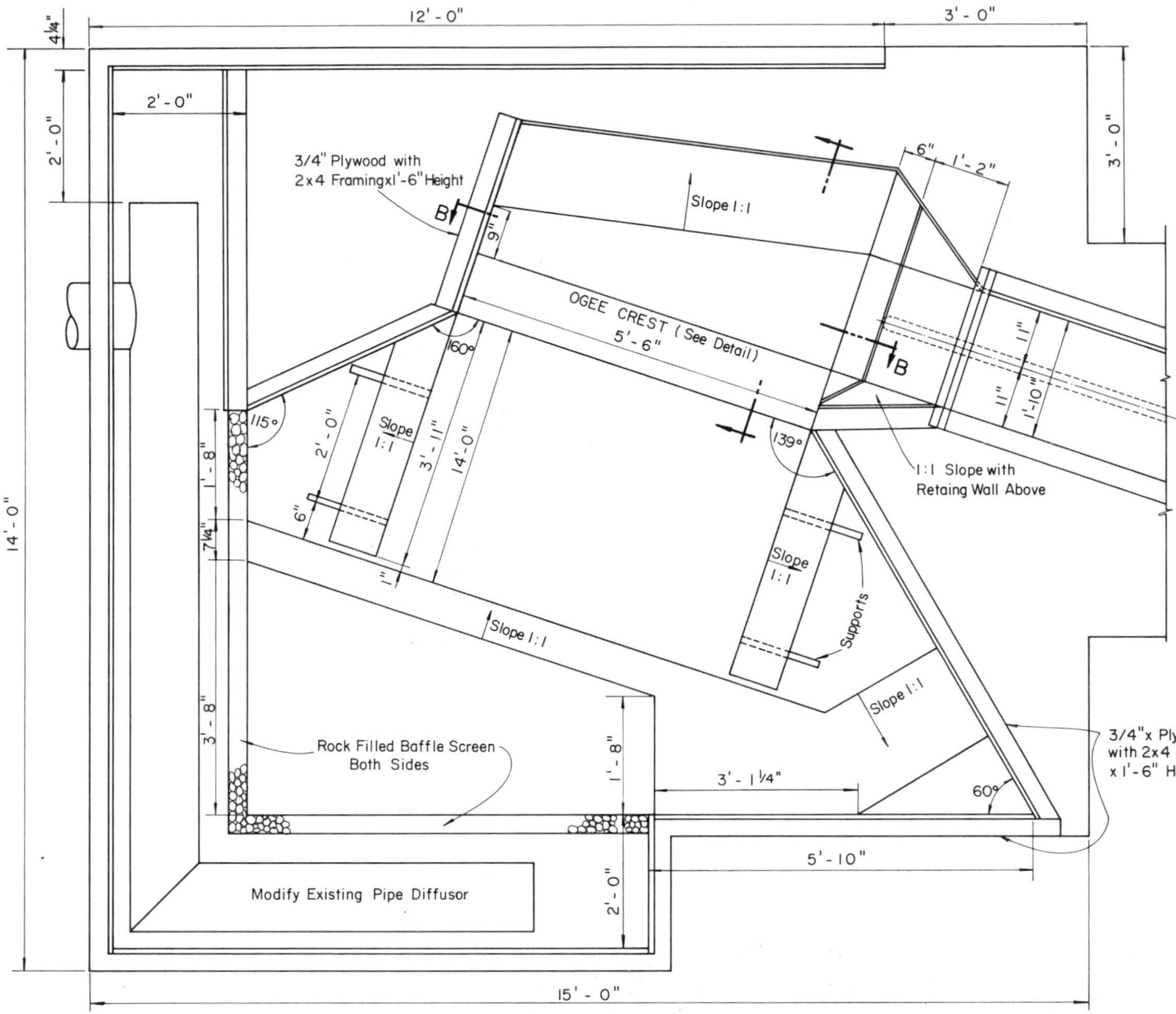


Fig. 4. Head box details of the model

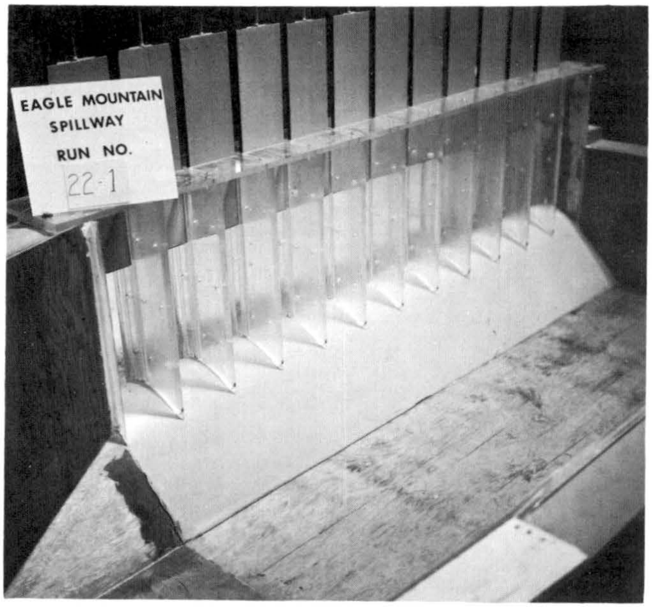


Fig. 5. Photograph of the ogee crest and side channel

The crest elevation is 637 feet and the normal lake water surface elevation is 649 feet, making a design head of H_d = 12 feet for the spillway. The excavated approach channel is at an elevation of 631 feet, such that P = 637 - 631 = 6 ft. With H_d = 12.0 and $\frac{P}{H_d}$ = 0.5, a coefficient C = 3.80 was selected for the equation $Q = CH^{3/2}$. Using this equation and a width per bay of 11.25 feet the designed discharge of 21,340 cfs is obtained.

Side Channel

The trapezoidal side channel, shown in Fig. 7, with side slopes of one to one was selected as a compromise between hydraulic and structural considerations. On the left side (section AA of Fig. 6) the side slope becomes tangent to the ogee crest. On the right side, the one to one slope continues up the bank to a height greater than the normal water surface elevation. Section BB of Fig. 6 shows a cross section of the side channel and entrance to the covered section. The bottom of the side channel is horizontal at an elevation of 617 feet and varies in width from 25 feet at the upstream end to 55 feet at the downstream end. The side channel was designed such that at prototype discharge, the submergence of the crest at the upstream end of the channel does not exceed 75 percent.

Transition Section

The transition between the trapezoidal side channel and the rectangular covered section is shown in Fig. 8 and Sections BB of Fig. 6. In the original design, a warped section was used to make the transition from the sloping side channel to the vertical wall of the covered section. The change shown in Fig. 8 was made to reduce the cost of construction since forming warped sections is extremely expensive.

Conveyance Channel

The conveyance channel consists of two portions: an upstream covered, divided section and a downstream open channel section. These two channels can be seen in Figs. 2 and 3. The covered section was necessary since the channel cuts across an existing roadway. The covered conduit was designed with a slope of 0.00089 such that sub-critical flow occurs in this section. The downstream open channel section was designed with a slope of 0.0025 with super-critical flow. Cross sections of both reaches of the channel are shown on Fig. 2, Sections CC and DD. It was decided to have super-critical flow in the open channel portion so that the height of the walls could be reduced.

Energy Dissipator

A vertical drop energy dissipation basin was chosen as the most satisfactory for this structure. A photograph of the basin and conveyance channel is shown in Fig. 9. A plan view and cross sections of the basin and conveyance channel are shown in Fig. 11 and Fig. 12, Sections EE and FF. This structure consists of a 25 foot vertical drop dissipation basin and a 80 foot wide conveyance channel to direct the water towards the natural rock bridge downstream. The basin and conveyance channel were constructed

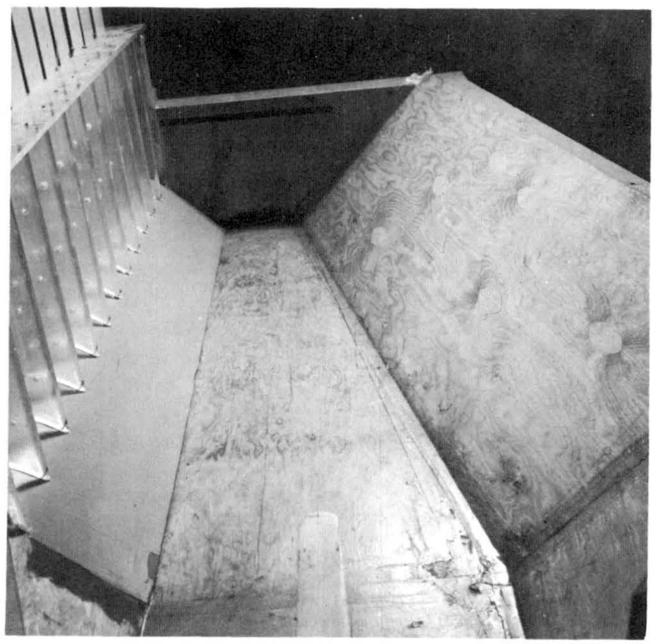


Fig. 7. Photograph of side channel

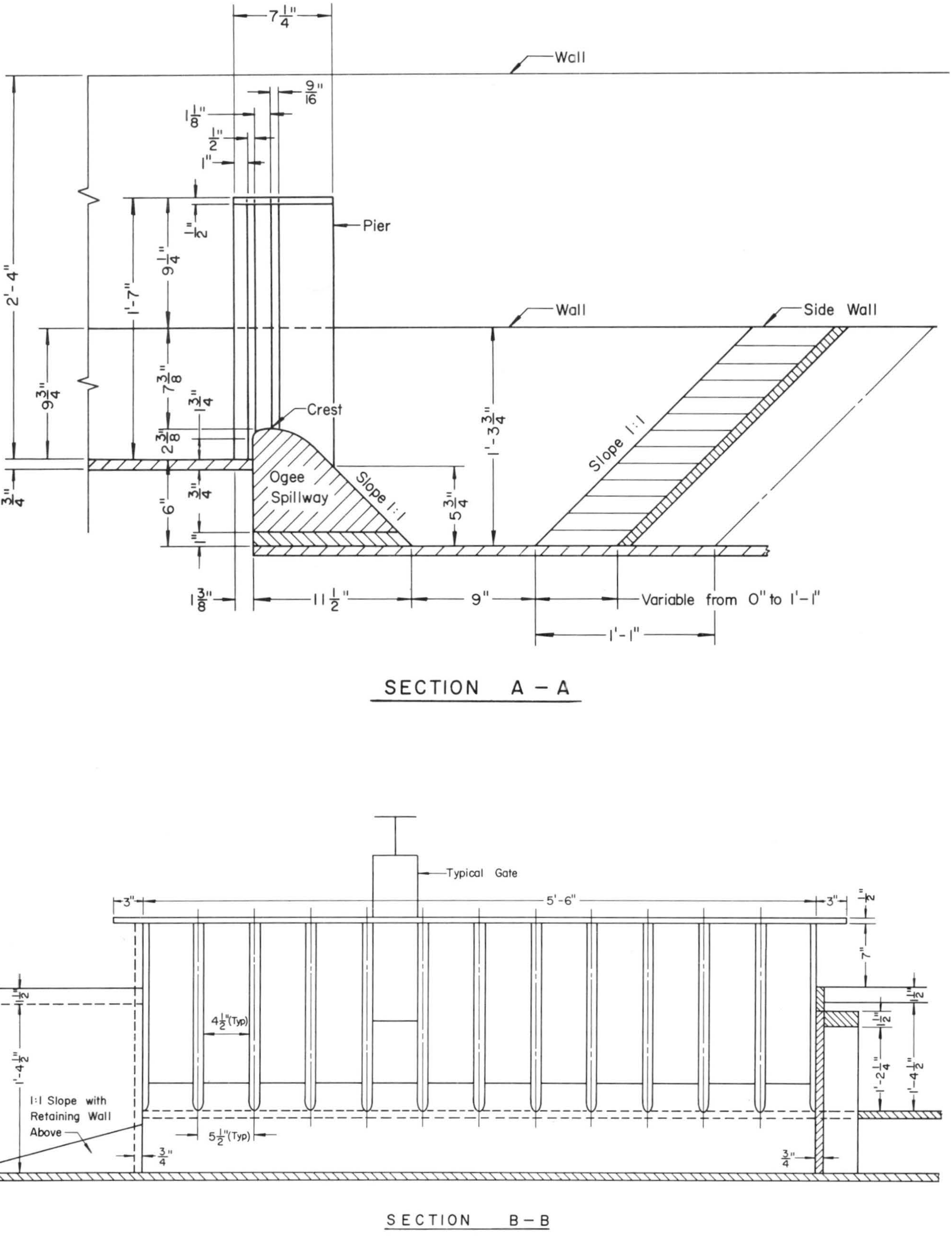


Fig. 6. Section drawings of the ogee crest and side channel

with side sloping walls at one to one. The baffle blocks are placed in the energy dissipation basin to break up the jet and reduce height of boiling in the channel.

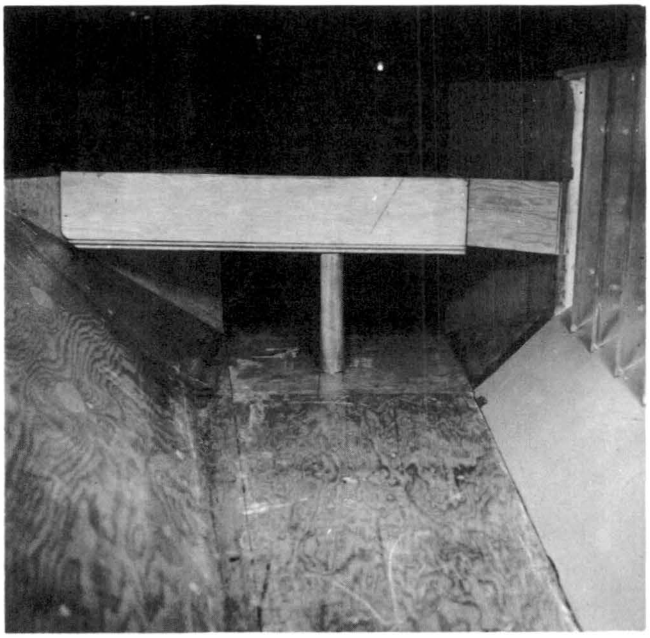


Fig. 8. Photograph of the transition section

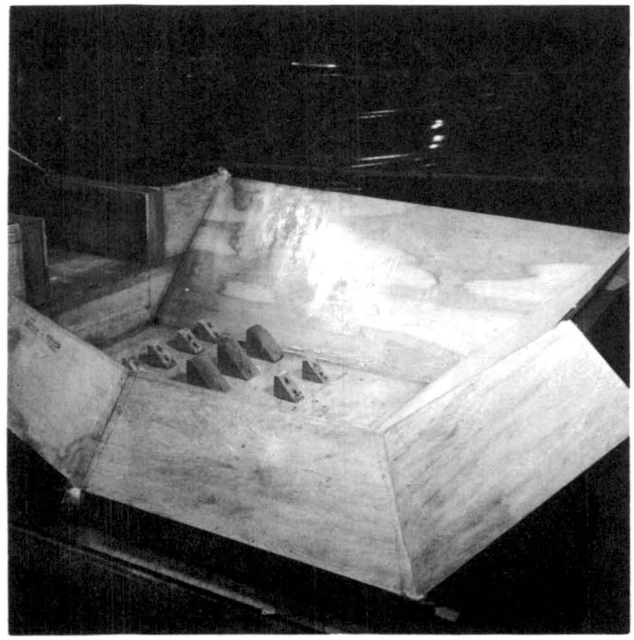


Fig. 9. Photograph of energy dissipation basin and conveyance channel

RESULTS

The final configuration of the model, as described by the drawings included in this report, operated with complete satisfaction. During the course of the model study a number of changes in the basic design were implemented. These changes were made primarily to reduce construction and excavation costs.

The following is a discussion of the performance of the several components of the model, beginning with the approach channel and ending with the flow in the 80 ft. wide conveyance channel from the energy dissipation basin.

Approach Channel

The side channel spillway is to be placed in such a location at the dam that an approach channel must be excavated. In the preliminary design of the structure the approach channel was flared out at an angle of approximately 45 degrees on both sides of the spillway. The flow conditions approaching the ogee crest in the model with the approach channel in this arrangement are shown in Fig. 10. As can be seen in the photograph, the water surface approaching the crest is very smooth.

Fig. 10. Flow conditions approaching the ogee crest

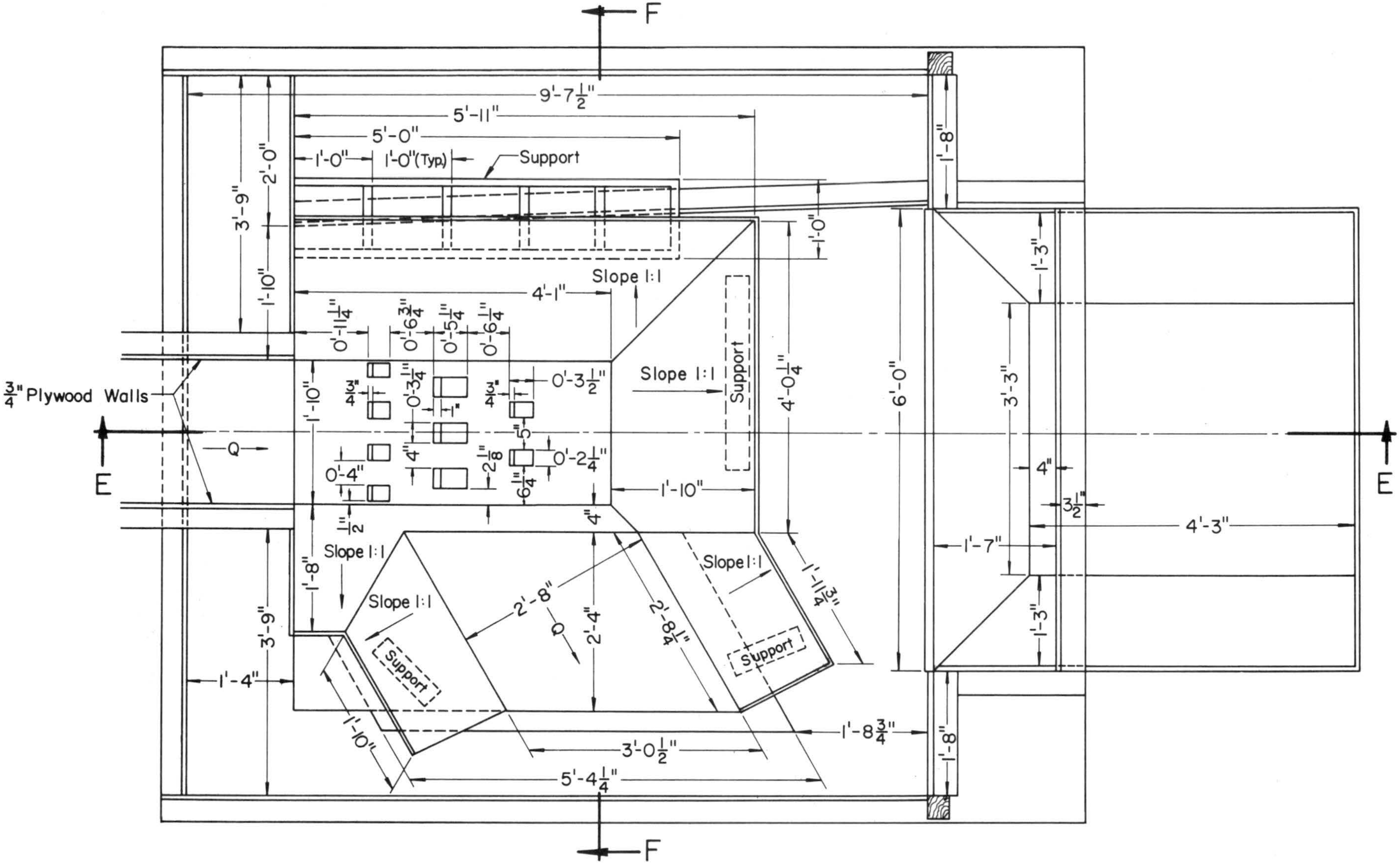
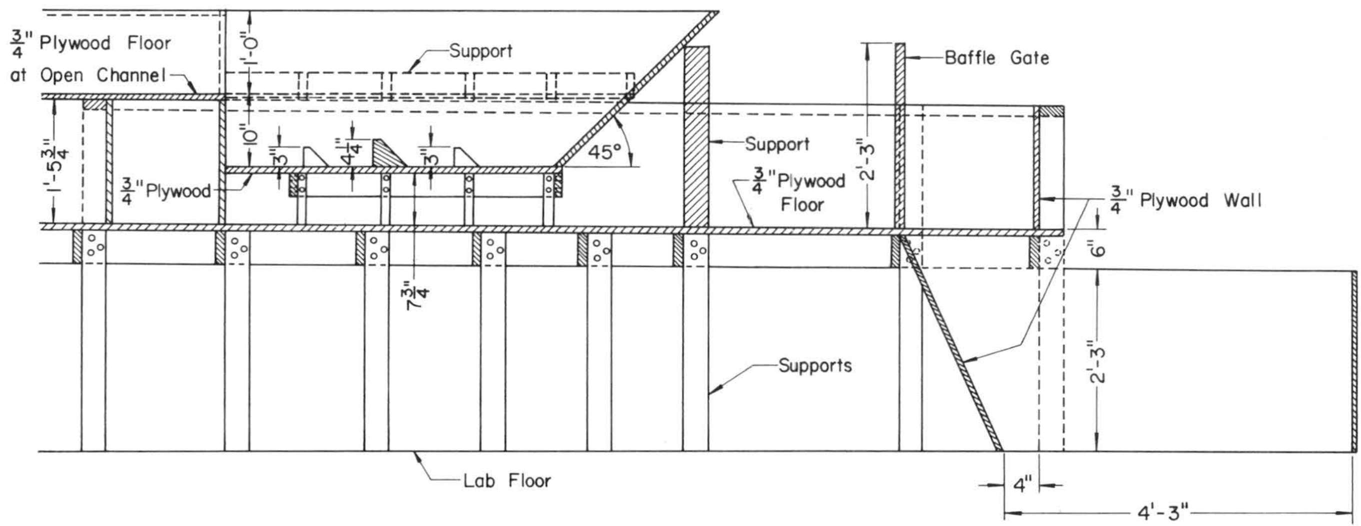
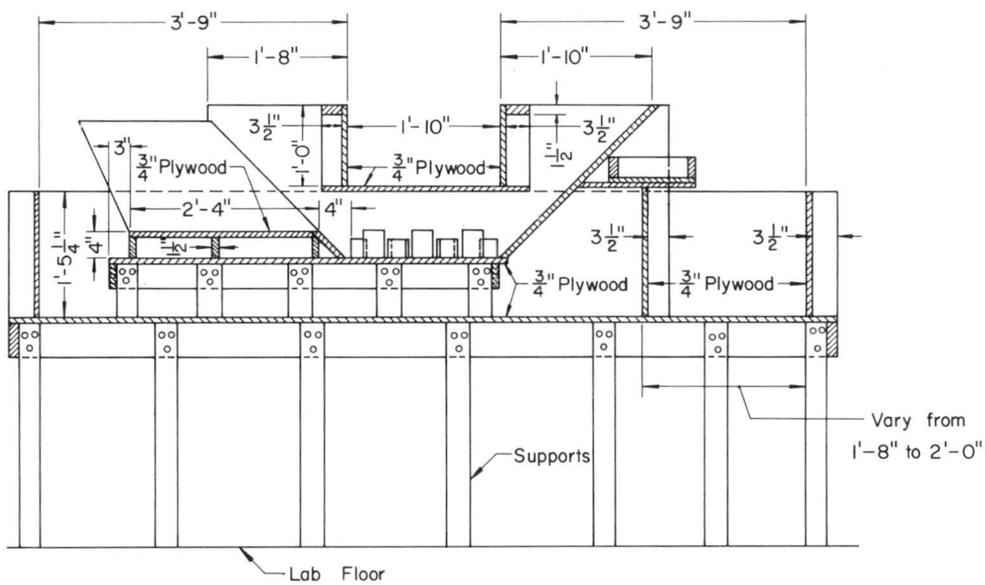


Fig. 11. Details of the energy dissipation basin, conveyance channel and tail box



SECTION E - E



SECTION F - F

Fig. 12. Section drawings of the energy dissipation basin, conveyance channel and tail box

In order to reduce the amount of excavation needed for the approach channel, the entrance conditions to the spillway were modified as shown in Figs. 2 and 13. For this modification the approach channel was formed such that the bottom has the same width as the ogee crest with side slopes of one to one. At the design discharge of 21,340 cfs, the velocity in the approach channel with this configuration is approximately 7 feet per second.

Figure 13 shows some disturbances in the approaching flow at the far side of the spillway. This condition is due to the manner in which the flow approaches the temporary sloping wall. As shown in Fig. 2, the head box extends beyond the temporary side wall used to simulate the modified approach channel. Under these conditions the flow is forced to turn a sharp angle from behind the side wall so that it is directed down the approach channel. This results in vortices being shed from the end of the temporary wall. If sufficient room in the model were available to extend the approach channel further, to simulate actual prototype conditions, this situation would be eliminated.

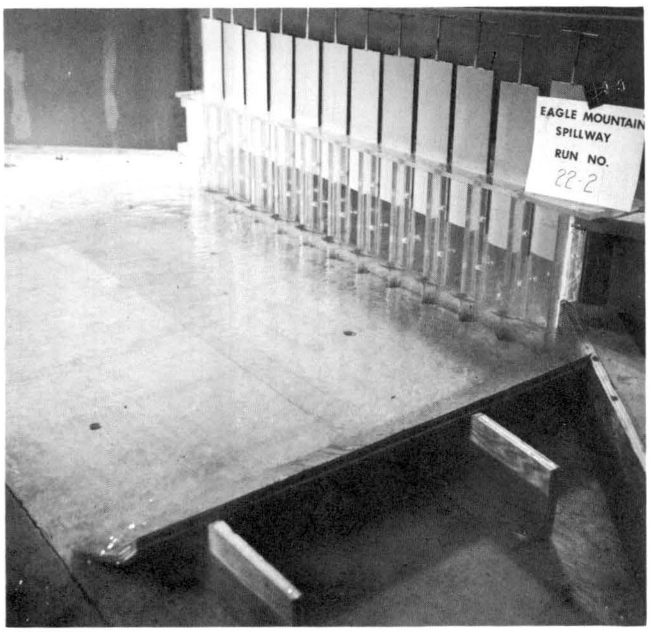


Fig. 13. Flow conditions approaching the ogee crest

With the exception of the above mentioned difficulty, which will not exist in the prototype, the flow condition approaching the side channel spillway with the approach channel modified as shown in Fig. 2 and 13 is completely satisfactory.

Ogee Crest

The ogee crest, approach channel and side channel were designed to pass a discharge of 21,340 cfs at a lake elevation of 649 feet, a crest elevation of 637 feet and an approach channel elevation of 631 feet with all 12 gates open. The stage-discharge data for the Eagle Mountain Dam Spillway with all gates open are presented in Fig. 14 and Table 2.

Figure 14 shows that between discharges of 10,000 cfs and the design discharge of 21,340 cfs, a linear relationship exists between lake elevation and discharge for the structure with all gates open. Above the design discharge, excessive submergence of the ogee crest occurs and the lake elevation must rise sharply in order to effect a measureable increase in the discharge. Below a discharge of 10,000 cfs the basic operation of the ogee crest is altered and the curve falls off.

The stage-discharge relationship for the structure with gates 3, 6 and 9 open (the gates are labeled from the left gate to the far right gate consecutively looking in the direction of flow) is shown as the far left curve in Fig. 14 and listed in Table III. A similar relationship for the structure with the odd numbered gates open is expressed by the curve second from the left in Fig. 14, with the data listed in Table IV.

The remaining curve in Fig. 14 is for all gates opened but with the far conduit closed in the covered section of the channel. At small discharges this curve becomes coincident with the curve for all gates open. At larger discharges, submergence of the crest, caused by reducing the flow from the side channel results in the two curves diverging.

Side Channel

The final configuration of the side channel in the model is shown in Figs. 4, 6 and 7. The side channel, as shown in these figures, represents two major changes in the original design: (1) The side slope on the far side of the channel was changed from 0.5:1 to 1:1 to reduce the construction costs and (2) the upstream end of the channel was reduced in width to 1/2 the original design. The actual construction of the prototype may contain further modifications. Specifically, some of the vertical retaining walls may be replaced by slope paving to further reduce the cost of construction.

The flow conditions in the side channel at design discharge are shown in Fig. 15. Some surging of the water surface in the side channel was noted in the original design. This was caused by a separation zone just downstream of gate #12 being periodically swept away. To eliminate this condition a rounded section was placed just downstream of gate #12 as shown in Fig. 16. This modification reduced the surging in the side channel but created more disturbances near the entrance to the covered section.

When the transition section was modified and the dividing wall of the conveyance channel extended further into the side channel this surging condition was eliminated.

It was also of interest to determine the performance of the side channel under various flows less than and greater than the design discharge.

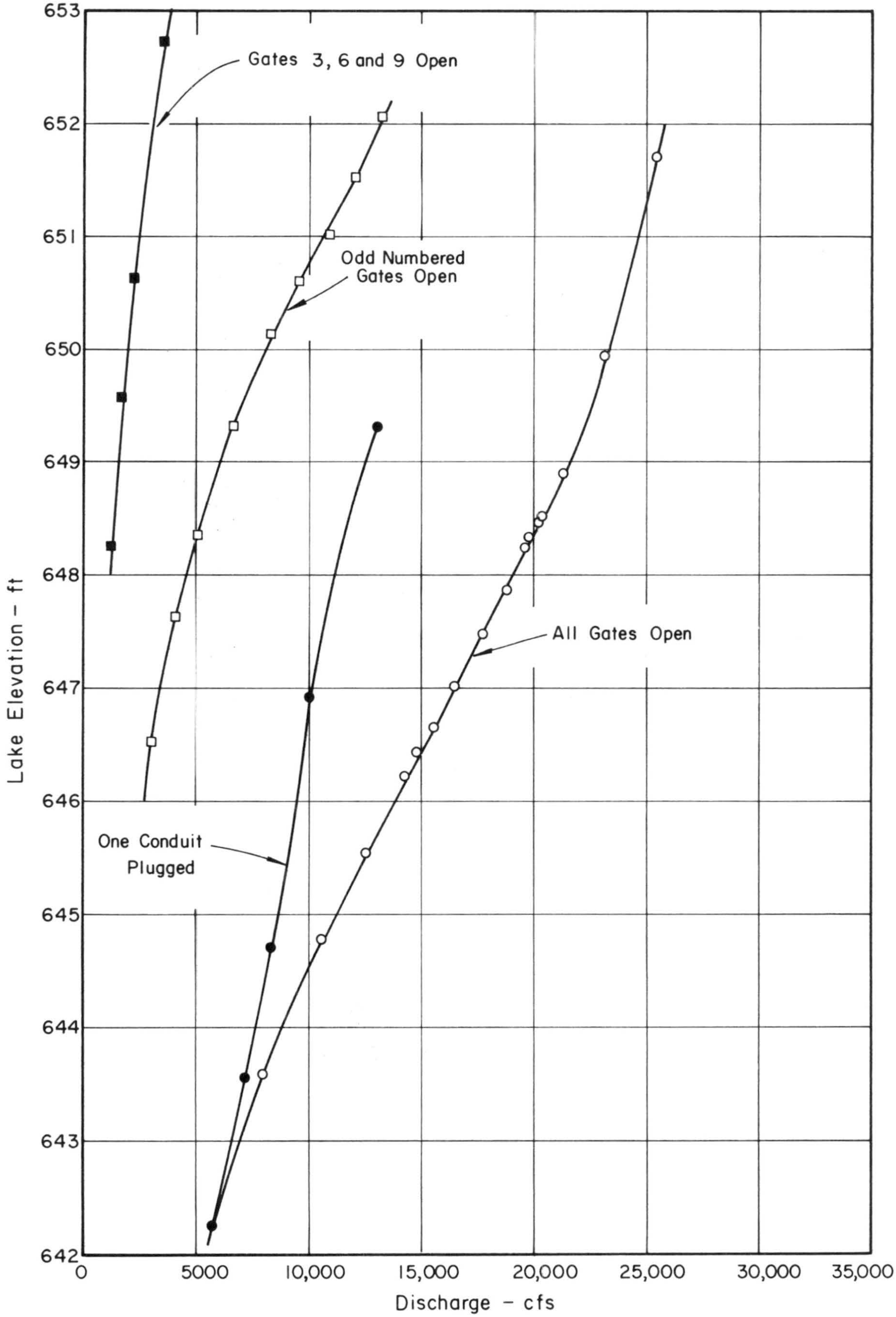


Fig. 14. Stage-discharge curves for various combinations of gates opened

TABLE II

STAGE-DISCHARGE DATA FOR THE EAGLE MOUNTAIN DAM SPILLWAY WITH ALL GATES OPEN

Lake Elevation ft.	Discharge cfs.	Lake Elevation ft.	Discharge cfs.
648.88	21,350	646.21	14,480
648.49	20,320	644.77	10,700
648.34	19,870	643.57	8,090
648.25	19,710	646.42	14,800
647.86	18,860	645.55	12,700
647.47	17,780	648.49	20,300
647.02	16,530	649.93	23,320
646.66	15,690	651.70	25,550

TABLE III

STAGE-DISCHARGE DATA FOR THE EAGLE MOUNTAIN DAM SPILLWAY WITH ODD NUMBERED GATES OPEN

Lake Elevation ft.	Discharge cfs.	Lake Elevation ft.	Discharge cfs.
652.06	13,250	649.30	6,740
651.52	12,030	648.34	5,140
651.10	10,900	647.62	4,220
650.59	9,590	646.51	3,070
650.14	8,370	645.04	1,740

TABLE IV

STAGE-DISCHARGE DATA FOR THE EAGLE MOUNTAIN DAM SPILLWAY WITH GATES 3, 6 AND 9 OPEN

Lake Elevation ft.	Discharge cfs.	Lake Elevation ft.	Discharge cfs.
652.75	3,610	649.57	1,740
650.65	2,270	648.28	1,310

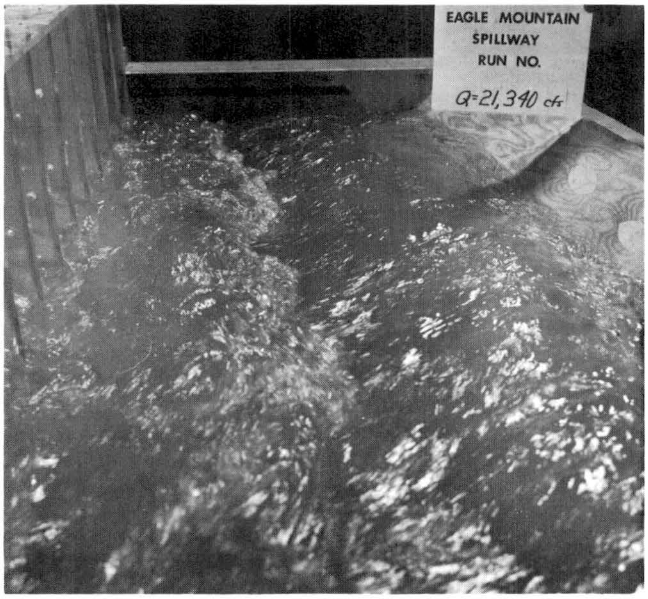


Fig. 15. Flow in side channel at design discharge

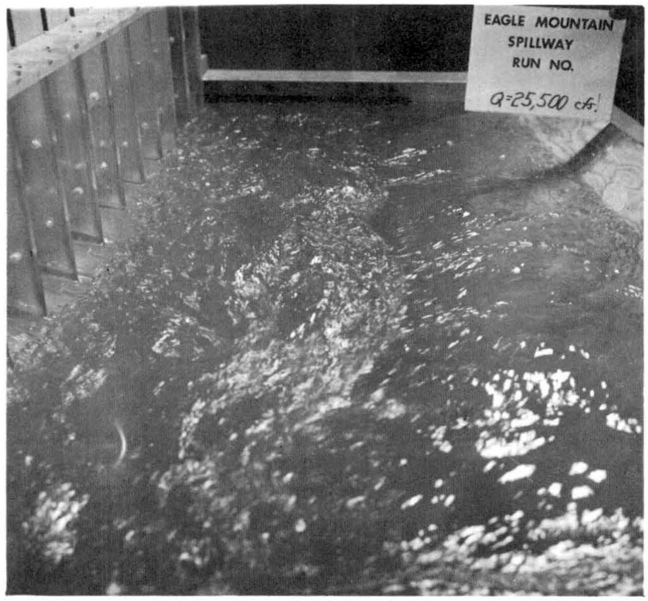


Fig. 17. Flow in side channel at a discharge of 25,500 cfs.

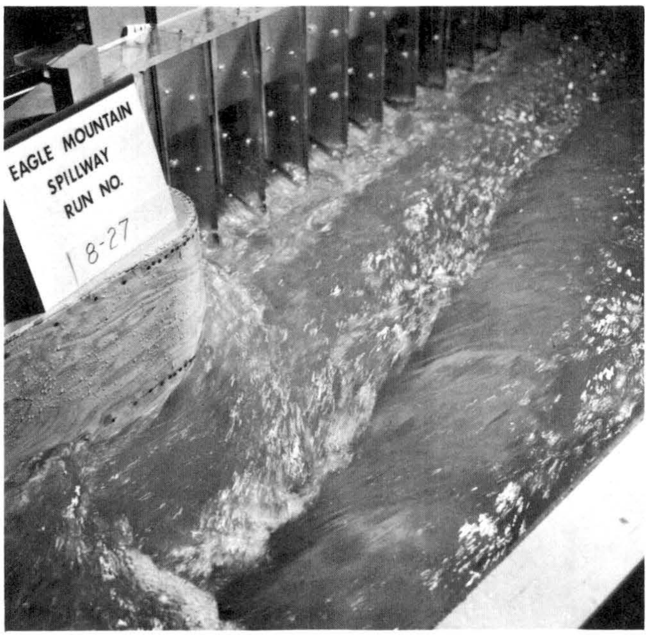


Fig. 16. Flow in side channel with modified transition section

Fig. 18. Flow in side channel at a discharge of 25,500 cfs

Figures 17 and 18 show the flow conditions in the side channel for a discharge of 25,500 cfs. For this run, the depth in the side channel was such that the upstream end of the ogee crest was completely submerged. This resulted in decreased performance of the spillway structure as can be seen in Fig. 14.

The flow in the side channel at this discharge (25,500 cfs) is unstable. Comparing Figs. 17 and 18 the unsteadiness can be observed. The flow conditions shown in Fig. 17 are similar to the normal conditions for smaller discharges. Figure 18 shows a large wave which tends to submerge the ogee crest for the full length of the structure. This condition resulted in fluctuation in the lake elevation of $\pm .0125$ ft in the model. It is felt that the structure will operate satisfactorily at this discharge but with decreased efficiency and increased surging in the side channel.

Figures 19 and 20 show the surface profile in the side channel at discharges of 14,500 and 10,700 cfs respectively. For these flow rates, and for all flows less than the design discharge the side channel spillway performed very well.

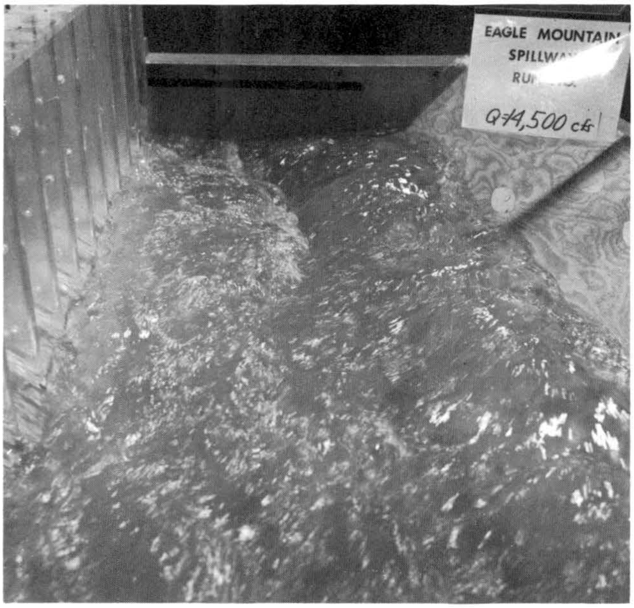


Fig. 19. Flow in side channel at a discharge of 14,500 cfs

Fig. 20. Flow in side channel at a discharge of 10,700 cfs

Gating sequence-Tests were conducted on the model to determine if the sequence with which the gates were open or closed was critical. Tests were conducted with several combinations of gates being opened. The results of these tests show that the sequence with which the gates were opened was not an important factor and that the complete structure operated satisfactorily regardless of which gates were open.

Figures 21 through 24 show the operation of the side channel for various combinations of gates opened. Figure 21 shows the flow with gates 1 and 2 open. Figure 22 is for gates 11 and 12 open. Figure 23 is for gates 1-6 open and Fig. 24 shows the flow with gates 7-12 open. Although the flow in the side channel is satisfactory regardless of which gates are open, the flow conditions appear to be better with the downstream gates in operation (compare Figs. 22 and 24, with Figs. 21 and 23).

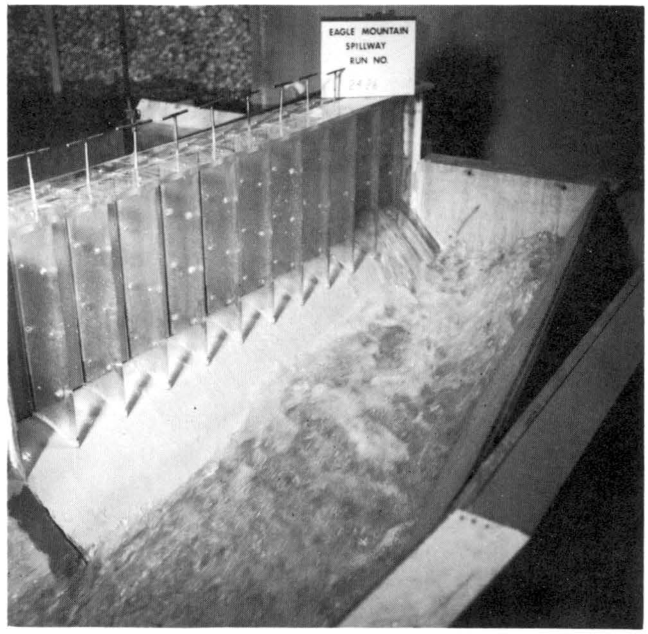


Fig. 21. Flow in side channel with gates 1 and 2 open

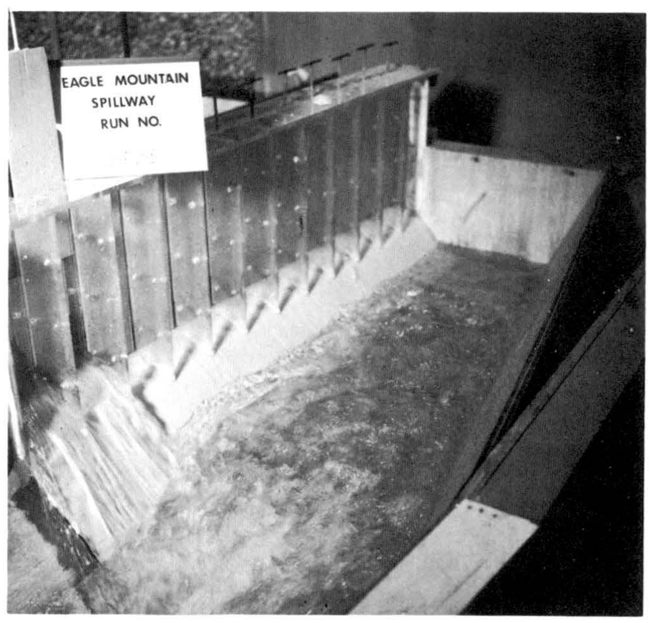


Fig. 22. Flow in side channel with gates 11 and 12 open

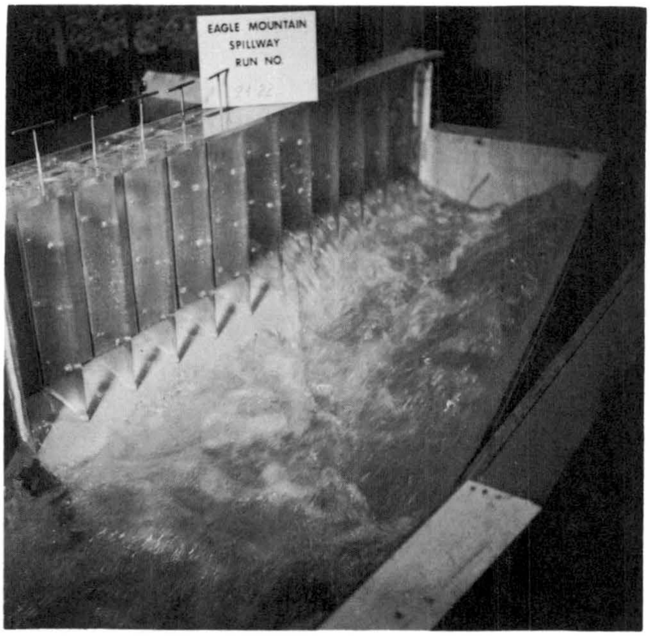


Fig. 23. Flow in side channel with gates 1-6 open

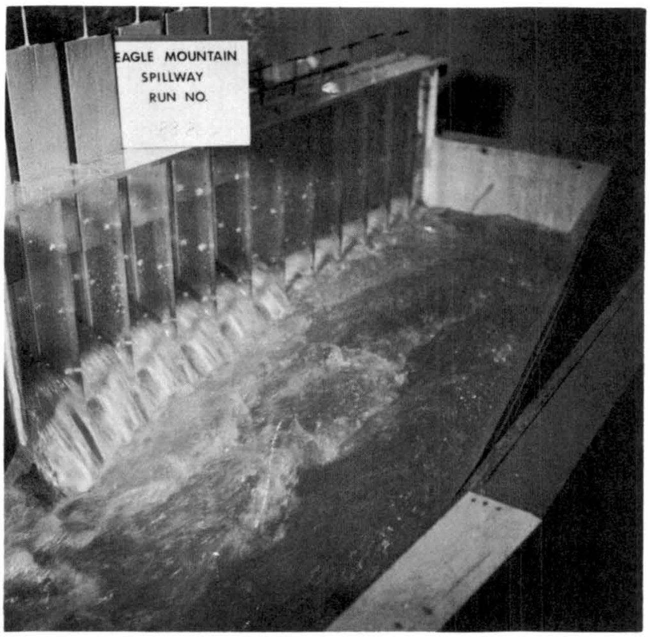


Fig. 24. Flow in side channel with gates 7-12 open

Tests were also conducted to determine the characteristics of the flow if the gates were operated as sluice gates. Figure 25 is an example of the flow conditions over the ogee crest and in the side channel spillway for sluice gating conditions. Figure 25 indicates that the side channel operates properly under sluice gating conditions. However, no investigation was made to determine if the design of the gates and seals are such that they can be operated as sluice gates.

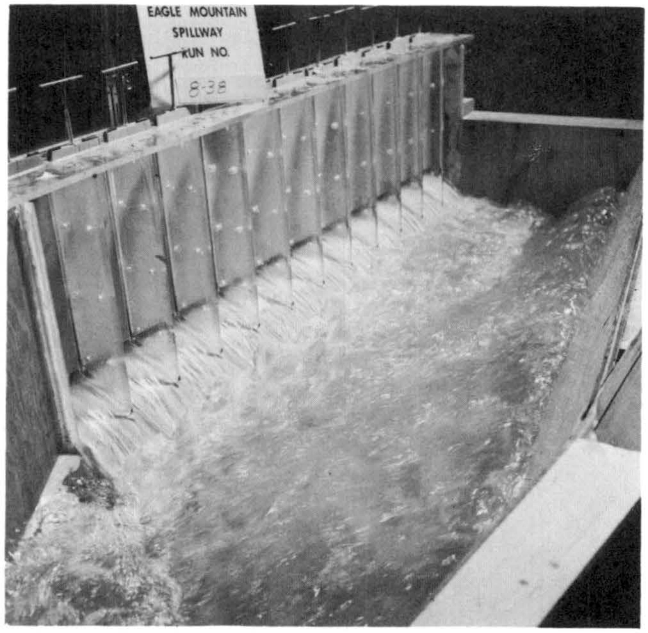


Fig. 25. Flow in side channel with all gates operating as sluice gates

Transition Section

The original transition between the trapezoidal side channel and the rectangular covered section of the conveyance channel was a warped section. When the far wall of the side channel was changed from a slope of 0.5:1 to 1:1 this warped section was eliminated. It was replaced by two plain sections shown in Figs. 6 and 8. It is the understanding of the author that the prototype will be constructed with sloped paving for the transition section such that no vertical retaining walls other than that necessary for the closed conduit section will be used.

Both transition sections modeled operated without any difficulties. The water surface through the transition was not excessively uneven or turbulent and the flow was approximately equally divided between the two sections of the covered conduit.

For all discharges equal to or less than the design discharge, the entrance to the covered section of the channel did not flow full. At discharges above approximately 22,000 cfs, the entrance to the covered section became submerged. Figure 26 shows this submergence at a discharge of 22,300 cfs. However, even when the entrance was submerged, the side channel, transition section and conveyance channel operated with no difficulties except for decreased performance in the stage-discharge relationship at large discharges.

The operation of the side channel, transition section and closed conduit section for the left conduit closed (looking in the direction of flow) is shown in

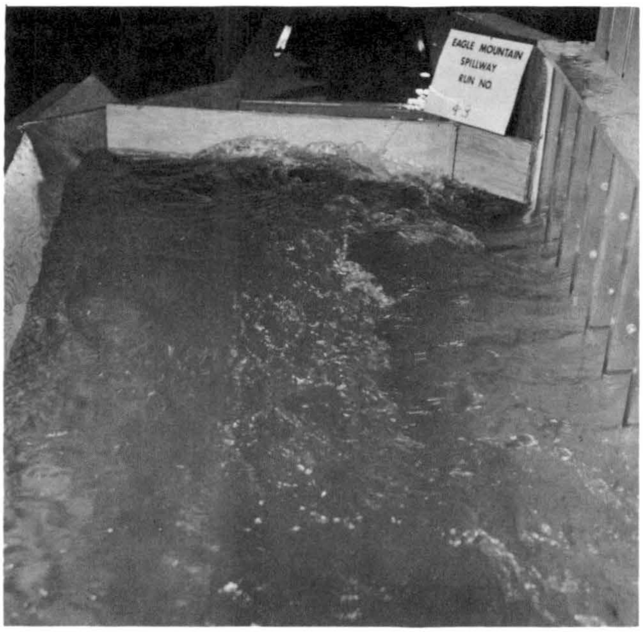


Fig. 26. Flow approaching transition section at a discharge of 22,300 cfs.

Figs. 27-29. The discharges are 7,380, 8,400 and 13,100 cfs for Figs. 27, 28 and 29 respectively. It is apparent from these photographs that the side channel operates very well with one conduit closed. The obvious drawback is in the reduced capacity of the overall system.

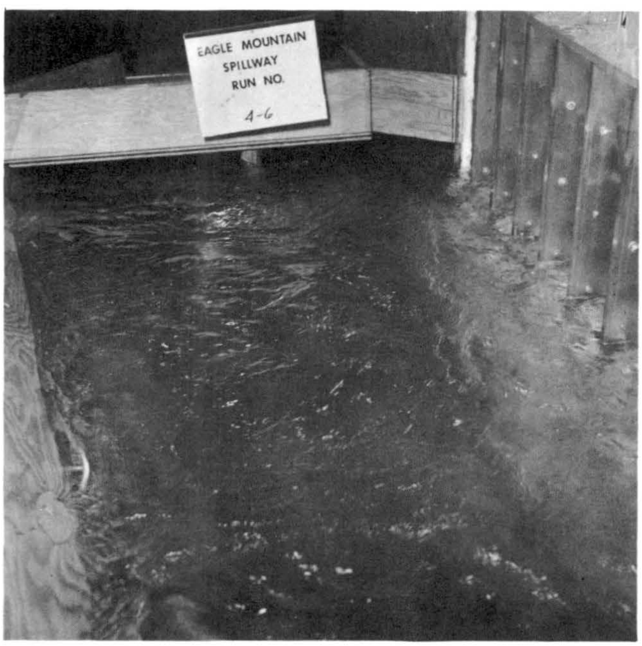


Fig. 27. Flow approaching transition section with one conduit closed at discharge of 7,380 cfs

Fig. 28. Flow approaching transition section with one conduit closed at discharge of 8,400 cfs

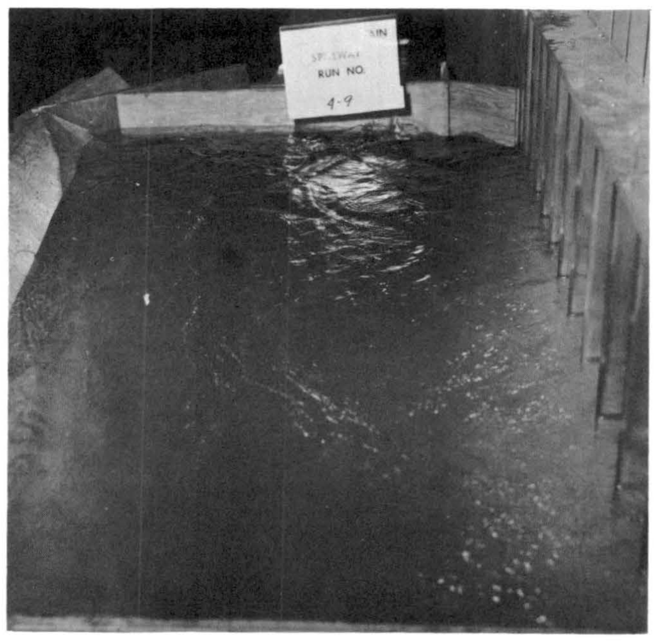


Fig. 29. Flow approaching transition section with one conduit closed at discharge of 13,100

Conveyance Channel

The conveyance channel is divided into two sections: (1) a covered, divided, closed conduit section and (2) a rectangular, open channel section. The model was designed such that sub-critical flow occurs in the covered section and super-critical flow in the open channel section. This decision was arrived at on the basis of two factors: (1) the flow issuing from the covered section becomes super-critical due to the change in the hydraulic characteristics of the two channels caused by the discontinuity of the large dividing wall. In order to eliminate this condition it would be necessary to increase the depth of flow in the open channel section almost to the top of the vertical walls in order to suppress this condition. (2) With super-critical flow in the open channel section, the height of the vertical walls necessary to enclose the flow can be significantly reduced. Tests indicated that the height of walls can be reduced in the section by approximately 12 feet and still maintain adequate freeboard for all discharges tested.

The flow conditions in the conveyance channel at design discharge with the cover removed from the divided section are shown in Figs. 30 and 31. Waves approximately 30 inches high are created by the super-critical flow conditions at the exit from the covered section. These waves extend the full length of the open channel section. It is felt that this disturbance of the water surface shown in both Figs. 30 and 31, is of no concern and will not adversely affect the operation of the structure.

When the structure is operated with one conduit plugged, very large waves are created in the open channel section. For a discharge of 10,000 cfs the flow emerging from the closed conduit is shown in Fig. 32. This figure shows that a large wave is created on the right side of the channel (looking upstream). Although this wave is approximately 10 feet high it is contained in the channel with about 15 feet of freeboard. These figures are based on a wall height in the open channel portion of 18 feet.

Fig. 31. Wave formation in conveyance channel

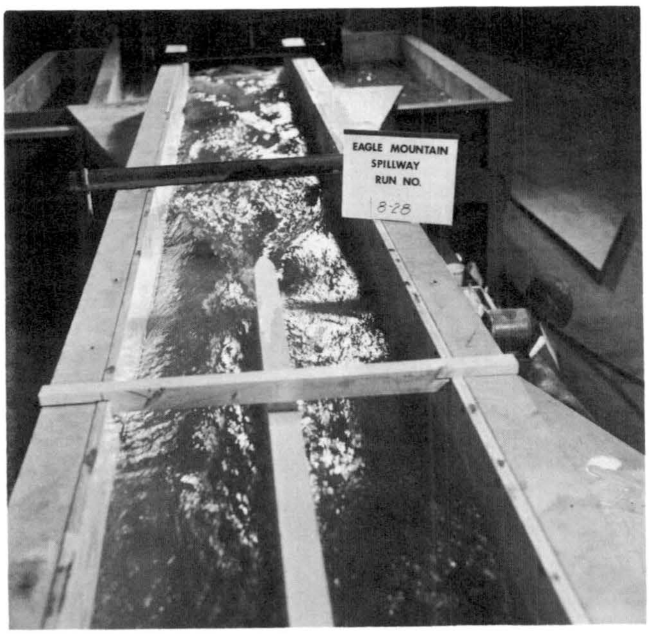


Fig. 30. Wave formation in conveyance channel

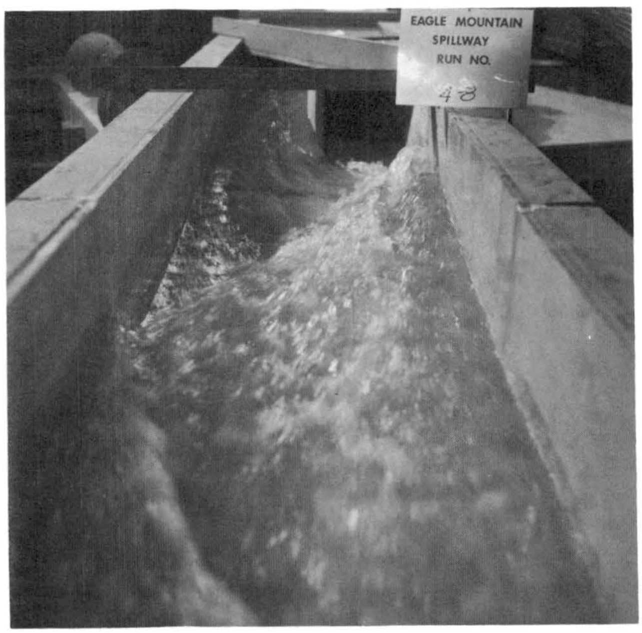


Fig. 32. Flow in conveyance channel with one conduit closed

Energy Dissipation Basin

The major modifications in the model were in the energy dissipation basin. The original design consisted of a 120 foot circular dissipation basin with the floor approximately 50 feet below the end of the conveyance channel. After proper blocking was placed in the circular energy dissipation basin to break up the falling jet, the basin operated with no difficulties. Figure 33 is a photograph of the operation of the basin at design discharge.

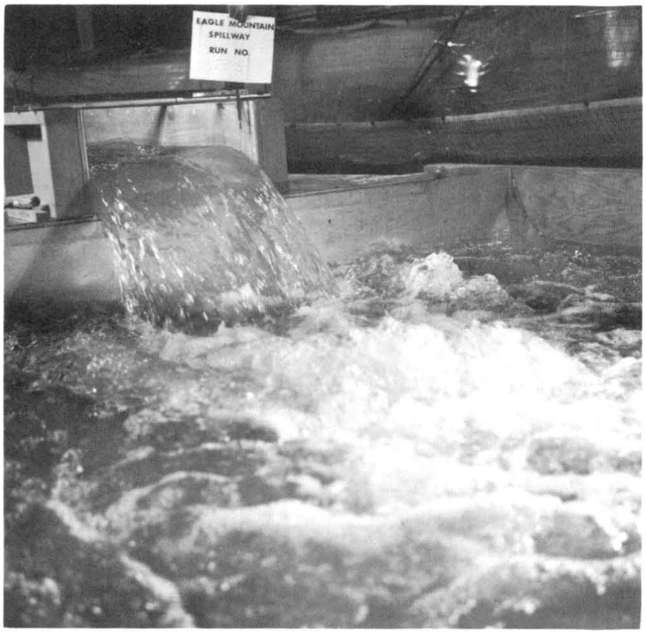


Fig. 33. Operation of circular energy dissipator

Fig. 34. Flow in energy dissipation basin at discharge of 10, 700 cfs

Even though the original design was satisfactory, it was desirable to modify the energy dissipation basin so as to minimize the amount of excavation necessary. To accomplish this, numerous configurations of basins were tried in an attempt to find the minimum sized basin which would function properly, the final design is that shown in Fig. 9 with details contained in Figs. 10 and 11. Operation of the energy dissipation basin and conveyance channel are shown in Figs. 34, 35 and 36 for discharges of 10, 700, 21, 340 (design) and 27, 000 cfs, respectively. For the full range of flow conditions expected in the prototype the basin and channel operated satisfactorily.

Fig. 35. Flow in energy dissipation basin at discharge of 21, 340 cfs at design discharge

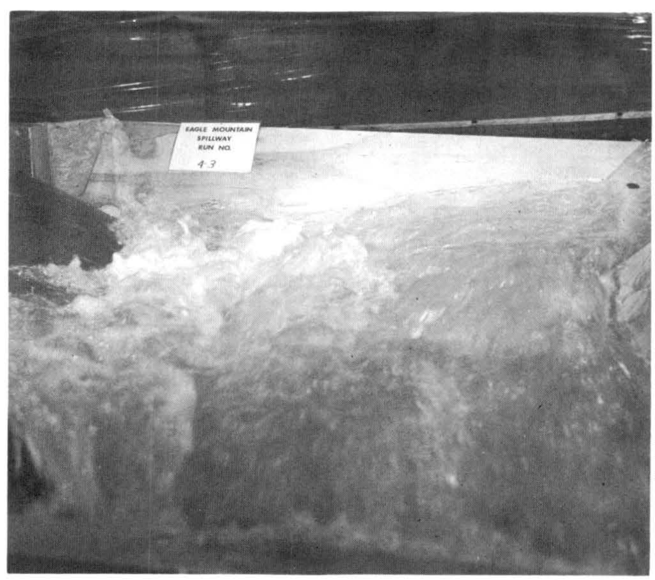


Fig. 36. Flow in energy dissipation basin at discharge of 27, 000 cfs at design discharge