UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF NAVAJO DAM DIVERSION AND OUTLET WORKS STRUCTURE

Hydraulic Laboratory Report No. Hyd-457

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
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Subject: Hydraulic model studies of Navajo Dam diversion and outlet works structure

SUMMARY

Hydraulic model studies of Navajo Dam diversion and outlet works structure were conducted on a 1:24 scale model to develop the hydraulic designs of the temporary and permanent stilling basins. During prototype construction of the lower portions of the dam, the partially completed outlet works basin will be used temporarily as an energy dissipator for diversion flows discharged through the 18-foot, 9-inch-diameter diversion tunnel. Later, second-stage concrete will be added to the diversion basin to convert it to the permanent outlet works stilling basin. Discharges through the permanent outlet works will be controlled by two 72-inch hollow-jet valves.

Performance of the diversion flow model showed the general concept of the preliminary design to be satisfactory. However, it was found desirable to add dentils to the sill located at the end of the horizontal apron and to lower the elevation of the basin apron 2 feet to prevent the design flow of 14,500 cfs from sweeping out of the basin without the formation of a hydraulic jump. It was necessary to eliminate abrupt slope changes in the floor between the tunnel outlet portal and the basin apron. This latter modification eliminated the subatmospheric pressures found to be sufficiently large in the preliminary design to cause cavitation erosion on the flow surfaces. A pier nose was added to the center dividing wall to eliminate excessive splashing and to protect the center wall from erosion by debris and by cavitation. An end sill was installed at the downstream end of the upward sloping transition apron to reduce the tendency to scour the discharge channel at the end of the sloping apron.

Tests on the model of the permanent outlet works works utilizing the two 72-inch hollow-jet valves for flow control showed the design to be satisfactory for prototype use. The hydraulic design was based on generalized procedures developed from an extensive research program given in Hydraulic Laboratory Report No. Hyd-446; no modifications were required.

ACKNOWLEDGMENT

The final plans evolved from this study were developed through the cooperation of the staffs of the Spillway and Outlet Works Section and the Hydraulic Laboratory during the period December 1957 to October 1958.

INTRODUCTION

Navajo Dam, part of the Colorado River Storage Project, is located on the San Juan River in northwestern New Mexico about 39 miles east of Farmington, New Mexico, Figure 1. The dam, Figure 2, is an earthfill structure approximately 3,800 feet long at the crest, 370 feet high above the riverbed, 3,600 feet wide at the base, and 30 feet wide at the crest. It will be the Bureau's second largest earthfill dam, having a volume of more than 26 million cubic yards. The hydraulic features include a spillway, an outlet works, and an auxiliary outlet works.

The spillway, Figure 2, is located in the right abutment and is uncontrolled. It is 138 feet wide at the crest and is designed to discharge 34,000 second-feet at maximum reservoir elevation. The flow falls 410 feet through an expanding chute into the stilling basin which is 195 feet wide by 163 feet long.

The auxiliary outlet works located in the right abutment beneath the center line of the spillway, Figure 3, discharges up to 1,200 second-feet into the spillway through the chute floor from a tunnel 6 feet wide by 8 feet high. The purpose of this structure is to control water releases while the diversion structure is being converted to the permanent outlet works structure. It may also be used after completion of the dam whenever the outlet works structure is shut down for repairs.

The primary outlet works structure, which is the subject of this study, is located in the right abutment adjacent and parallel to the spillway. During the early stages of construction, diverted riverflows will be discharged into the temporary stilling basin, a low head hydraulic jump-type stilling basin, Figures 2 through 7. The stilling basin is designed for a maximum diversion discharge of 14,500 cfs, entering the basin at a velocity of 52.5 feet per second from an 18-foot, 9-inch-diameter concrete tunnel. The flow falls 38.5 feet through the expanding diversion channel chute from the portal invert to the stilling basin apron in a horizontal distance of 143.76 feet. The stilling basin apron is horizontal at elevation 5678 and is 37 feet, 2 inches wide by 110 feet long. Along the center line, a dividing wall 37 feet high extends 55 feet downstream from the upstream end of the horizontal apron. The stilling basin training walls and a 1 on 6 upward sloping concrete apron extend 50 feet into the discharge channel. The discharge channel is 600 feet wide and extends downstream from both spillway and outlet works. The riprapped channel bottom is a continuation of the sloping apron, and slopes upward to elevation 5710. For the design flow of 14,500 cfs, the discharge channel may not be completely excavated and the tail water may be as high as elevation 5723, 45 feet above the apron. After construction materials have been excavated from the discharge channel to final bed elevation 5710, the tail water may be as low as elevation 5714, 36 feet above the apron, for the design flow.

After the auxiliary outlet works has been constructed, the diversion structure will be converted into the permanent outlet works structure. The permanent outlet works is designed to discharge 4,680 cfs through two 72-inch hollow-jet valves into a high head stilling basin of a special type. Each valve discharges the flow downward, at an angle of 24° to the horizontal, between two converging walls placed on a 30° sloping floor joining the horizontal stilling basin apron.

The part of the temporary basin downstream from the converging walls, Station 22+46.20, including the discharge channel, does not require modification for use as the permanent outlet works stilling basin; upstream from Station 22+46.20, the modifications require the addition of the special features used in the permanent basin.

THE MODEL

A 1:24 scale model, Figures 8, 9, 10, and 11, constructed and tested in the Bureau of Reclamation laboratories at Denver, Colorado, was used to develop the designs of the diversion and permanent outlet works stilling basins. The model was first constructed to represent the diversion outlet works stilling basin structure, including the downstream portion of the diversion tunnel and about 100 feet of discharge channel beyond the downstream end of the concrete apron.

Plywood coated with resin and painted to resist warping was used for the floor and left wall of the basin. The right wall of the basin contained two glass panels to observe the hydraulic action within the basin. The center dividing wall was made of sheet metal to prevent warping.

The diversion tunnel was simulated by a 9-3/8-inch-inside-diameter sheet metal pipe about 9 feet long. The pipe was connected to the 12-inch water supply piping by means of a 3-foot long transition section. Discharges were measured using calibrated venturi meters permanently installed in the laboratory.

The discharge channel downstream from the basin was molded in sand to provide a movable bed for scour tests. The tail-water elevation was controlled by means of an adjustable tailgate and was measured by use of a staff gage located on the wall of the tail box, Figure 8.

After completion of the diversion works study, the model was converted to represent the permanent outlet works. The diversion tunnel was replaced with a manifold and two supply pipes, one for each of the hollow-jet valves, Figure 8. (In the prototype, the supply pipes are installed in the diversion tunnel.) The valves were of machined brass and were operating models of the 72-inch prototype valves. They could be opened or closed to any desired opening. The 30° sloping floor and the converging walls were made of treated wood.

THE INVESTIGATION

The primary purpose of the investigation was to develop the hydraulic design of the outlet works stilling basin for diversion and permanent outlet works flow. In analyzing the requirements for the two types of stilling basin, 14,500 cfs at low head for the diversion basin and 4,580 cfs at high head for the permanent basin, it was thought that the basin required for the outlet works could be adapted for temporary use as the diversion basin. The purpose of the tests, therefore, was to find a basin which would perform adequately for diversion flows and which could be modified by the addition of appurtenances or second-stage concrete to provide optimum performance for the permanent structure.

Preliminary Basin for Diversion

The preliminary basin is shown in Figure 12. The shape and size were influenced by the requirements of the permanent basin; 4,580 cfs discharging from two 72-inch hollow-jet outlet works valves at high head and tail-water range between 5711 and 5715. However, the diversion requirement to discharge 14,500 cfs at low head with tail-water range between elevation 5714 and elevation 5723 made it necessary to increase the basin dimensions. The diversion basin apron was, therefore, about 2 feet lower and about 20 feet longer than required for the permanent basin and had an additional 50 feet of apron sloping upward at the rate of 6 to 1 into the discharge channel. The basin width was acceptable for both types of operation.

The performance of the diversion basin in discharging 14,500 cfs is shown in Figures 13 and 14. The test data are summarized in Table 1. At tail-water elevation 5717, the hydraulic jump was swept out of the upstream portion of the basin. Complete sweepout occurred at tail-water elevation 5714, and a considerable amount of splash occurred which was caused by the high velocity flow striking the upstream end of the center dividing wall. Scour in the movable bed was quite severe, Figure 15. For tail-water elevation 5723, waves were approximately 6 feet high at the tail-water gage. The basin, therefore, did not perform satisfactorily within the expected tail-water range for the design flow.

Pressures were measured beneath the jet and on the center dividing wall at the piezometers shown in Figures 10 and 11. For 14,500 cfs, pressures were considerably below atmospheric at Piezometers 3, 5, 10, 11, and 16. Pressures at Piezometers 3 and 5 were sufficiently low that cavitation could occur in the prototype, Table 2. Piezometers 3 and 5 are located in the floor of the diversion channel, just downstream from the abrupt changes in slope. Piezometers 10 and 11 are on the side of the center dividing wall near the upstream edge.

Piezometers 9, 12, and 16 showed less severe subatmospheric pressures. Piezometer 12 is on the basin floor immediately downstream from the slot at the upstream end of the basin; Piezometer 9 is downstream from Piezometer 5; and Piezometer 16 is on the right wall immediately downstream from the station at which the walls begin to flare.

Basin Scheme No. 2

To help keep the jump in the basin at low tail-water elevations and to reduce the scour in the discharge channel, dentils were installed on the sill at the downstream end of horizontal apron and an end sill was placed at the downstream end of the sloping apron, Figure 16. To reduce the splash and to protect the upstream end of the center dividing wall, a pier nose and a floor slot filler, both shown in Figure 16, were installed. To reduce subatmospheric pressures downstream from the abrupt slope changes beneath the jet, the intersections were rounded to the extent shown by the radii in Figure 16.

The hydraulic performance of the basin for the design flow at both high and low tail-water elevations, Figure 17, was improved, Table 1. For tail-water elevation 5723, the pressure at Piezometer 10 was above atmospheric, Table 2. For tail-water elevation 5714, the splash was eliminated; however, the subatmospheric pressure at Piezometer 10 was 20 feet below atmospheric as compared to 9 feet in the preliminary design, Tables 1 and 2. The subatmospheric pressure was less in the preliminary design because the blunt upstream end of the center wall caused the flow to break away from the sides of the center wall and some ventilation between the flow and the wall occurred for low tail waters. The tail water could be lowered 1 foot more than in the preliminary design before sweepout occurred. At tail-water elevation 5716, the flow swept out of the upstream portion of the basin, and at elevation 5713, the jump was swept completely out of the basin. At tail-water elevation 5714, before the tail water was lowered to elevation 5713, the jump moved out of the basin, but "hung" on the sloping apron at the downstream end of the basin. This was not satisfactory.

In the range of the expected tail water, elevation 5714 to 5723, scour in the discharge channel was reduced considerably from that which occurred with the preliminary basin. The reduction in scour was due primarily to the addition of the end sill on the sloping apron. The sill was, therefore, used in all other basin schemes tested (except Scheme 3) and is recommended for the prototype.

The arcs joining the slope changes on the floor beneath the jet were made successively greater by increasing the arc radius. The upstream curve was the more critical because submergence by the tail water helped to reduce the magnitude of the subatmospheric pressure at the lower arc. At the upper slope change, the subatmospheric pressure was reduced from 22 feet, with no rounding of the intersection, to 7 feet by using a 42-foot radius arc between the two slopes. Radii plotted versus pressure at Piezometer 3, Figure 18, showed a straight line relationship. Extrapolation of the straight line indicated that a 60-foot or more radius would be required to eliminate the subatmospheric pressure.

Basin Scheme No. 3

To improve the performance of the basin still further and increase the factor of safety against jump sweepout, Scheme 3, Figure 19, the basin floor was lowered 2 feet to elevation 5678. The center wall pier nose and the floor slot filler in Scheme 2 were used, but the dentils on the dentated sill and the end sill on the sloping apron were removed. The floor beneath the jets was replaced; 4 planes instead of 3 were used to approximate the trajectory curve of the jet. This increased the number of intersections to 3, but reduced the angle between successive planes. Twenty-foot vertical curves were used to connect the planes. This provided a smooth path for the flow to follow from one slope to the next.

The floor modification improved the pressures at Piezometers 3 and 5 sufficiently that they were near atmospheric or above for a discharge of 14,500 second-feet, Table 2. Performance in other respects was satisfactory, and this arrangement of floor planes was used in all succeeding basin schemes tested and is recommended for the prototype. Figures 3, 4, 5, 6, and 7 show the prototype installation.

The hydraulic jump was swept out of the upstream portion of the basin at tail-water elevation 5715, Table 1, and completely out of the basin at tail-water elevation 5712, giving 2 feet more tail-water range than in the preliminary design. The water surface roughness at the tail-water gage in the discharge channel was about the same as in the preliminary design, Table 1. Scour of the discharge channel was less than in the preliminary design, but it was believed that the end sill recommended in Scheme 2 would reduce the scour further.

Pressures on the side of the center wall at Piezometer 10 were as low as 24 feet below atmospheric for the design flow, Table 1; 4 feet lower than in Scheme 2. This was probably due in part to the additional 2 feet of drop to the lower basin floor and in part to the higher velocities resulting from smoothing the floor beneath the jet.

Other Basin Schemes

Several basin schemes were tested in an effort to prevent complete jump sweepout at tail-water elevation 5712 and to stabilize the hydraulic jump in the upstream portion of the basin for tail water as low as elevation 5714. It was found that if the jump could be held in the upstream portion of the basin, the subatmospheric pressure was reduced on the side of the center wall at Piezometer 10; and in addition, water surface roughness in the discharge channel was reduced. The pressure at Piezometer 10 was improved because the high velocity flow at the piezometer was submerged by the jump. Data from most of the schemes tested are summarized in Table 1.

Scheme 5 provided the best hydraulic performance. Six 12- by 12-inch timbers spaced 12 feet apart were placed transversely on the basin floor on each side of the center wall to act as intermediate sills to reduce the bottom velocity. The sill recommended in Scheme 2 was placed at the downstream end of the upward sloping apron. Performance of Scheme 5 is shown in Figure 20A for the design flow with the tail water at elevation 5714.

The water surface in the discharge channel was smoother than for any other modification tested, and the design flow did not sweep out of the upstream portion of the basin until the tail water had been lowered to elevation 5712. Because of the relatively high elevation of the movable bed, it was not possible to lower the tail water below elevation 5711 to determine the elevation at which complete sweepout would occur. However, the safety factor against sweepout was considered to be sufficient since the prototype discharge channel bed was to be at elevation 5710 or above. Because the jump stayed in the upstream portion of the basin for even low tail-water elevations, the subatmospheric pressure at Piezometer 10 on the side of the center wall was reduced from 24 feet to 14 feet of water. This scheme was not adopted, however, because it was feared that timbers placed on the floor might cause damage to the basin floor by cavitation erosion and by debris swirling around on the downstream side of each timber.

In Scheme 6, the timbers were relocated, this time on the sloping floor so that any possible cavitation damage would occur in the temporary structure and would be covered by second-stage concrete when the diversion works was converted to the outlet works. However, the timbers were not as effective in this location and, also, it was doubtful that the timbers could be fastened securely enough to prevent being torn loose by the force of the oncoming flow. Figure 21A shows the downstream flow conditions for this scheme.

In Scheme 7, the 12- by 12-inch timbers were replaced by four streamlined baffle piers on the basin floor at the downstream end of the center wall. The hydraulic performance of this basin discharging the design flow at tail-water elevation 5712 is shown in Figures 20B and 21B. The baffle piers were effective in holding the jump in the basin for tail-water elevation 5714, but were not as effective as the timbers. Pressures on the side of the center wall at Piezometer 10 were 20 feet below atmospheric.

To move the jump farther upstream in the basin for tail-water elevation 5714, and thereby reduce the magnitude of the subatmospheric pressure at Piezometer 10, Schemes 8 and 9 were tested, Figures 20C, 21C, and Table 2. In Scheme 8, five 12- by 12-inch timbers on the approach slope were used along with the four streamlined baffles at the downstream end of the center wall. In Scheme 9, six square-edged dentils were used on the sill at the downstream end of the horizontal apron instead of the five 12- by 12-inch timbers in the approach. In both of these schemes the jump moved upstream, and the subatmospheric pressures on the side of the center wall were improved. However, the timbers in Scheme 8 were objectionable for the reason discussed previously, and the baffles in Scheme 9 were objectionable because of the subatmospheric pressures that were found on them. For the diversion flow of 14,500 cfs, pressures were as low as 28 feet of water below atmospheric, Figure 22. Therefore, in Scheme 10, only the six square-edged dentils on the intermediate sill were used. For tail-water elevation 5714, the jump occurred farther downstream in the basin than for Schemes 5, 6, 7, 8, or 9, Figures 20D and 21D, and Table 1, but overall performance was considered to be satisfactory. However, the subatmospheric pressure problem on the side of the center wall at Piezometer 10 remained to be solved.

Recommended Basin for Diversion

The recommended scheme, Figures 4, 5, 6, 7, and 23, is identical to Scheme 10, except for the shape of the center wall pier nose, Figure 24. The pier nose was reshaped to improve the pressures on the side of the center wall. As a result, atmospheric pressure was recorded on the side of the center wall at Piezometer 10 for the design flow of 14,500 cfs with the tail water at or below elevation 5714. For tail waters above elevation 5714, pressures were above atmospheric. It was recommended that the portion of nose submerged in the oncoming flow be carefully constructed of concrete to provide a smooth surface and a smooth joint where the pier nose joins the center wall. The portion of nose above water may be constructed of timber to any reasonable shape, since its only purpose is to provide protection to the center wall from floating debris. Eventually, the concrete portion of the pier nose will be buried by the second-stage concrete, so that it is important that any damage which might occur, whether from cavitation or impact, be confined to the nose itself.

Two piezometers were installed on the concrete pier nose, Piezometers 13 and 14 on Figure 24, to determine whether subatmospheric pressures occurred on the pier nose. Pressures were found to be above atmospheric and no cavitation should occur in the prototype.

Characteristics of the hydraulic performance of the recommended design are recorded in Table 1, and flow conditions are shown in Figures 23, 25, and 26. The magnitude of the movable bed scour in the recommended design was much less than in the preliminary design, compare Figure 25 with Figure 15, and was considered to be satisfactory. However, it is recommended that the prototype discharge channel be riprapped as shown in Figure 7. For discharges less than the design flow shown in Figure 26, the operation was satisfactory in all respects.

Recommended Basin for Outlet Works

The recommended basin for diversion was tested for use in the outlet works. Second-stage concrete was added to the diversion channel as shown in Figures 4, 5, 6, and 7. The model of the recommended design is shown in Figure 8.

With both 72-inch valves operating fully open, the outlet works is designed to discharge (1) 4,580 cfs with 210 feet of head at the valves and tail water at elevation 5711, and (2) 4,680 cfs with 217 feet of head at the valves and tail water at elevation 5715. For emergency operation with one valve open 100 percent, the outlet works is designed to discharge (1) 2,710 cfs at a head of 308 feet with the tail water at elevation 2715, and (2) 2,650 cfs at a head of 278 feet with the tail water at elevation 5711.

The hydraulic design curves given in Hydraulic Laboratory Report No. Hyd-446 1/ were used to obtain the basin dimensions for each of the above operating conditions. The curves show that when 4,580 cfs is discharged at maximum head with the tail water at elevation 5711, the basin should be 102 feet long by 16.25 feet wide (per valve) and the horizontal apron should be placed at elevation 5681. For 4,680 cfs with the tail water at elevation 5715, the basin length and width should be the same, but the apron should be placed at elevation 5685. For one valve discharging 2,710 cfs at maximum head with tail water at elevation 5715, the apron should be 115 feet long by 17 feet wide and should be placed at elevation 5680. For one valve discharging 2,650 cfs and tail water at elevation 5711, the apron should be 111 feet long by 17 feet wide and at elevation 5678. Each of these basin designs will give optimum performance for the corresponding design condition.

Obviously, it is impossible to provide the best basin for each of the above operating conditions; it is, therefore, necessary to compromise and choose a basin that will perform well for the most usual operating condition and satisfactorily for the others. The most usual operating condition was considered to be Condition No. 1 for 2-valve operation which required a basin 102 feet long, 16.25 feet wide, and apron at elevation 5681.

For diversion-flow requirements, it was recommended that the main position of the basin be 110 feet long by 16.54 feet wide with the apron at elevation 5678. This basin is longer and wider than required for the permanent outlet works and the apron is 3 feet lower. However, the length and width are within practical limits and the tail water depth in the basin is not excessive to the extent that it impairs the operation of the permanent outlet works. The basin was tested to determine its adequacy for permanent outlet works operation. Particular attention was given to the deeper than necessary tail water and the effect of the extra length.

1/Hyd-446--"Hydraulic Design of the Hollow-jet Valve Stilling Basin," by G. L. Beichley and A. J. Peterka.

For 4,580 cfs, the tail water could not be lowered the full 3 feet to test the basin at the ideal tail-water depth because the downstream riverbed was too high. The depth could be reduced 2 feet to elevation 5709 as shown in Figure 27. The hydraulic performance was excellent and the apron was judged to be about 8 feet longer than necessary. This agreed with the length predicted from the curves of Hyd-446. 1/

The outlet works discharging 4,580 cfs into the basin with the tail water at minimum design elevation 5711 is shown in Figure 28. The performance was nearly as good as for tail-water elevation 5709, but as the tail water was raised above this point, the performance became poorer as shown in Figures 29 and 30 for 4,680 cfs. The energy dissipating action was less efficient as indicated by the turbulent boils which extended downstream into the discharge channel. However, the performance shown in Figure 29, which is also a design operating condition, is satisfactory; the performance shown in Figure 30 is considered satisfactory for emergency operation.

Two other emergency operating conditions using only one valve are shown in Figures 31 and 32. Here again the lower tail water provides the best energy dissipating action and the smoothest water surface in the discharge channel. The performance for both operating conditions is satisfactory for short operating periods.

The complete range of possible discharges and corresponding tail-water elevations for 2-valve operation was investigated. Photographs showing 50 percent of the design flow discharging through the valves 50 percent open, and through the valves 100 percent open, with tail-water elevations 5711 and 5723 are given in Figure 33. Of these operating conditions, maximum head with minimum tail water, Figures 33A and 33B, produced the roughest water surface. However, the water surface was smoother than for the design flow, and movement of bed material in the discharge channel was negligible. No other hydraulic problems were encountered.

Scour in the discharge channel was investigated in the model using an erodible sandbed, Figure 8. For 2-valve operation at maximum design head and discharge, Figure 34A, the sand movement was slight as indicated in a 1-hour model test with tail water at elevation 5713. For 1-valve operation, some sand was deposited in the basin downstream from the closed valve. Additional scour tests were made using stones placed on the sans to simulate the prototype riprap, Figure 34B. The stones remained in place for both 2-valve and 1-valve operation.

The following additional model data are summarized in Table 3. Pressures at the piezometers installed earlier on the center dividing wall of the diversion basin, Figures 10 and 11, were all above atmospheric pressure when the outlet works was operated. The pressures, in general, were equal to static head or the depth of water above the piezometer. Water-surface fluctuations measured at the staff gage in the discharge channel were not considered to be excessive. The maximum fluctuation was approximately 1 foot and occurred for one valve operating at maximum design capacity. The tail-water elevation at which the stilling action was swept out of the upstream portion of the basin provided more sweep-out safety factor than is ordinarily necessary. For 1-valve operation, the tail-water elevation had to be lowered more than 5 feet below channel bed elevation 5710 before sweepout occurred; for 2-valve operation, more than 8 feet. To accomplish this in the model, the channel bed was lowered approximately 10 feet before the test began. In the prototype an extreme amount of degradation of the channel would be necessary before the stilling action could be impaired by low tail water.

Table 1

DIVERSION MODEL TEST DATA SUMMARY

Scheme	Figures	Approach trajectory	Basin floor el	Center wall nose piece and floor slot filler	12 x 12 timbers	Baffles at end of center wall	Dentils on sill at end of horiz. apron	Sill at end of sloping apron	Tail water for complete sweep-out	Tail-water el at which sweep-out begins	Subatmospheric pressure at piezometer No. 10* for tail-water el 5714 (ft of water)	Wave height at tail-water gage for tail-water el 5723 (ft)	Wave height at tail-water gage for tail-water el 5714 (ft)
Preliminary	12 thru 15	Preliminary	5680	No	No	No	No	No	5714	5717	9		
No. 2	16 and 17	Scheme 2	5680	Yes	No	No	Yes	Yes	5713	5716	20		
No. 3	19	Recommended	5678	Yes Scheme No. 2	No	No	No	No	5712	5715	24	5-1/2	--
No. 4	--	Recommended	5678	Yes Scheme No. 2	No	No	No	Yes	--	5714	24	6	--
No. 5	20A	Recommended	5678	Yes Scheme No. 2	6 on basin floor	No	No	Yes	--	5712	14	4	3
No. 6	21A	Recommended	5678	Yes Scheme No. 2	5 in diversion channel	No	No	Yes	--	5712	14	5	4

Table 1--Continued

Scheme	Figures	Approach trajectory	Basin floor el	Center wall nose piece and floor slot filler	12 x 12 timbers	Baffles at end of center wall	Dentils on sill at end of horiz. apron	Sill at end of sloping apron	Tail water for complete sweep-out	Tail-water el at which sweep-out begins	Subatmospheric pressure at piezometer No. 10* for tail-water el 5714 (ft of water)	Wave height at tail-water gage for tail-water el 5723 (ft)	Wave height at tail-water gage for tail-water el 5714 (ft)
No. 7	20B and 21B	Recommended	5678	Yes Scheme No. 2	No	Yes	No	Yes	--	5713	20	5	4
No. 8	20C and 21C	Recommended	5678	Yes Scheme No. 2	5 in diversion channel	Yes	No	Yes	--	5712	14	4	3
No. 9	20D and 21D and 9	Recommended	5678	Yes Scheme No. 2	No	Yes	Yes	Yes	--	5712	15	5-1/2	3-1/2
No. 10	20D and 21D	Recommended	5678	Yes Scheme No. 2	No	No	Yes	Yes		5714	20	5-1/2	4
Recommended	25	Recommended	5678	Recommended scheme	No	No	Yes	Yes		5714	0		

*See Figures 10 and 11 for Piezometer 10 location.

Table 2

DIVERSION BASIN PRESSURES
14,500 cfs

Model arrangement	Tail-water elevation	Piezometric pressures in feet of water: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Preliminary	5723	+12	+11	-22	+1	-16	+19	+23	-1	+ 2	- 1	- 5	+25	+32	+33	+2	-3	+11	+5
	5714	+12	+11	-22	+1	-16	+19	+23	-1	- 2	- 9	- 8	- 3						
Scheme No. 2	5723	+11	+11	-13	±0	- 7	+18	+22	-1	+ 4	+16	+32	+28	+33	+34				
	5714	+11	+11	-13	±0	-12	+13	+22	-1	- 3	-20	+ 2	- 8	+ 2	+ 2				
Scheme No. 3	5723	+ 7	+ 4	+ 1	±0	± 0	+ 5		+3	+10	+14	+30	+42						
	5714	+ 7	+ 4	+ 1	-1	- 1	+ 5		+1	+ 2	-24	+ 2	+24						

See Figures 10 and 11 for piezometer locations.
See Figure 12 for preliminary basin.
See Figure 16 for Scheme No. 2
See Figure 19 for Scheme No. 3.

Table 3

RECOMMENDED OUTLET WORKS MODEL TEST DATA SUMMARY

Discharge (cfs)	Valves used	Percent, open	Head at valves (feet)	Tail-water: elevation of gage (feet)	Pressures in feet of water: Piez No. 10	Piez No. 11	Piez No. 12	Piez No. 13	Water surface fluctuation at tail-water gage (feet)	Tail-water elevation (feet) For sweepout
4680	Both	100	217	5715	+21	+26	+57	+23	0.75±	5702
4580	Both	100	210	5711	+14	+19	+59	+22	0.50±	5702
2710	Right	100	308	5715	+17	+22	+39	+33		5705
2650	Right	100	278	5711	+10	+16	+37	+30	1.00±	5705

See Figures 8, 9, and 10 for tail-water gage location.
See Figures 10 and 11 for piezometer locations.
Zero pressure is atmospheric; plus is above atmospheric.
At sweepout tail-water elevation the turbulent stilling action is out of upstream portion of basin and on the verge of complete sweepout from basin.

FIGURE I
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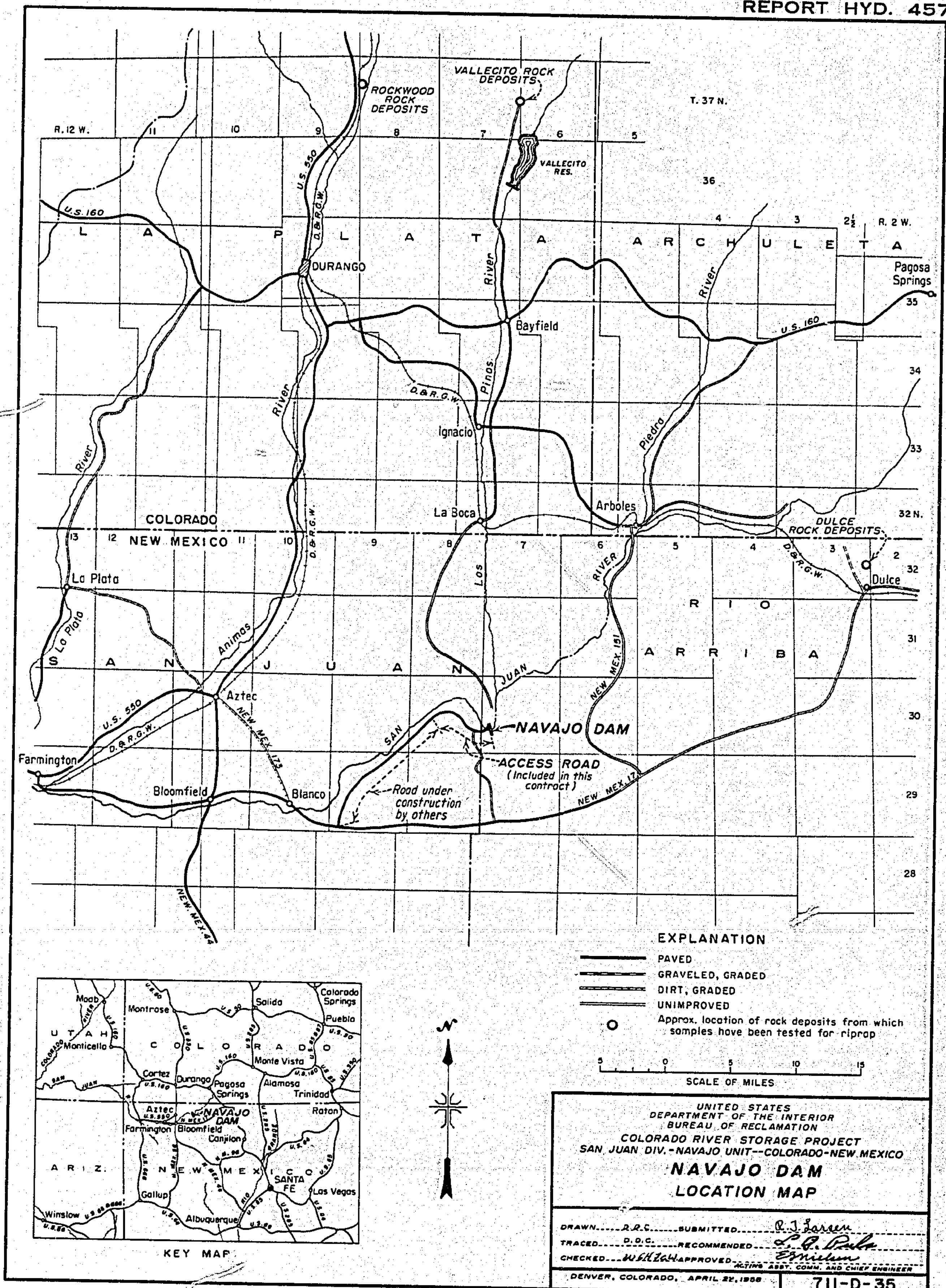
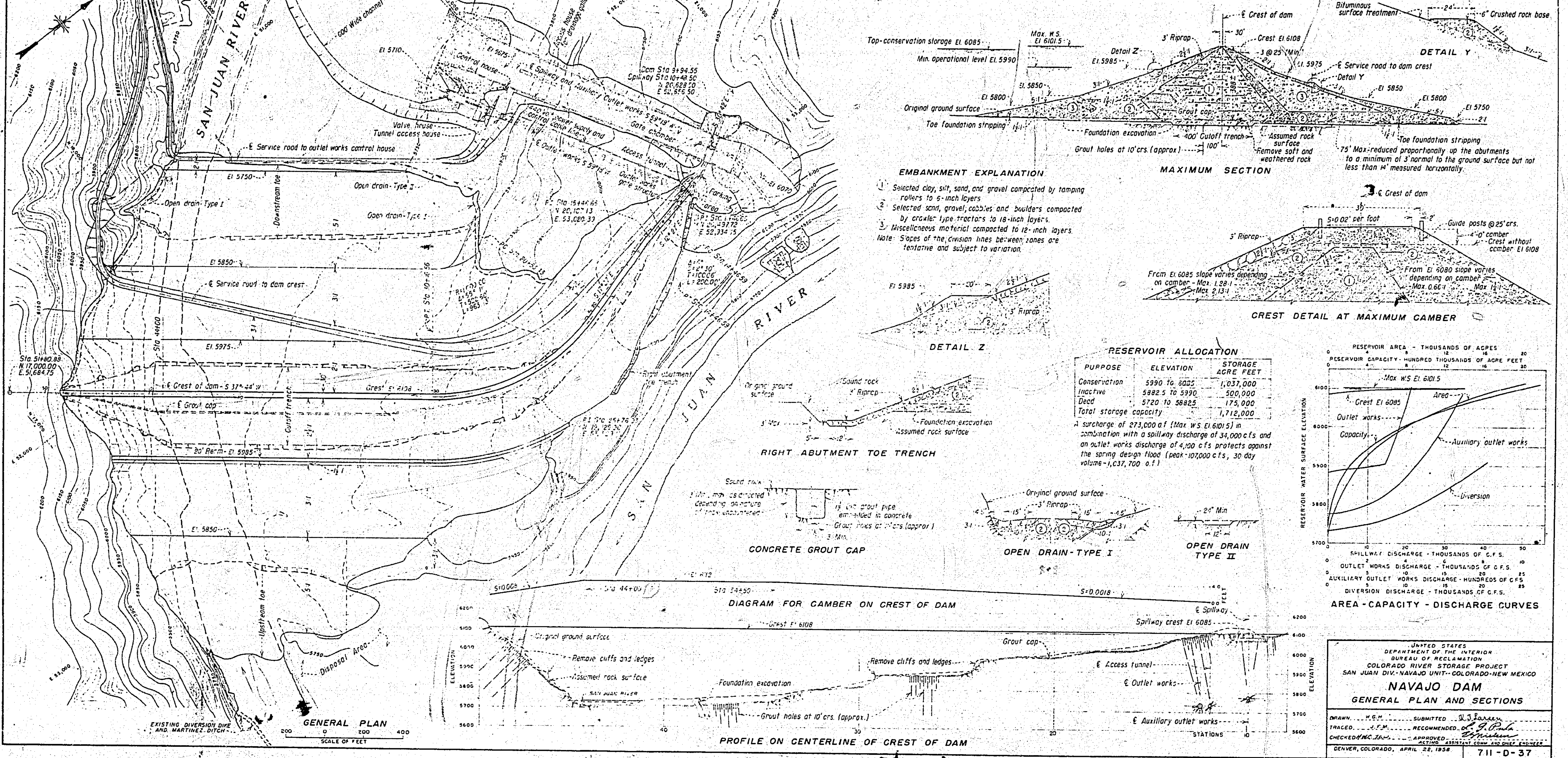


FIGURE 2
REPORT HYD. 457



RESERVOIR ALLOCATION

PURPOSE	ELEVATION	STORAGE ACRE FEET
Conservation	5990 to 6085	1,037,000
Inactive	5882.5 to 5990	500,000
Dead	5720 to 5882.5	175,000
Total storage capacity		1,712,000

FIGURE 3
REPORT HYD. 457

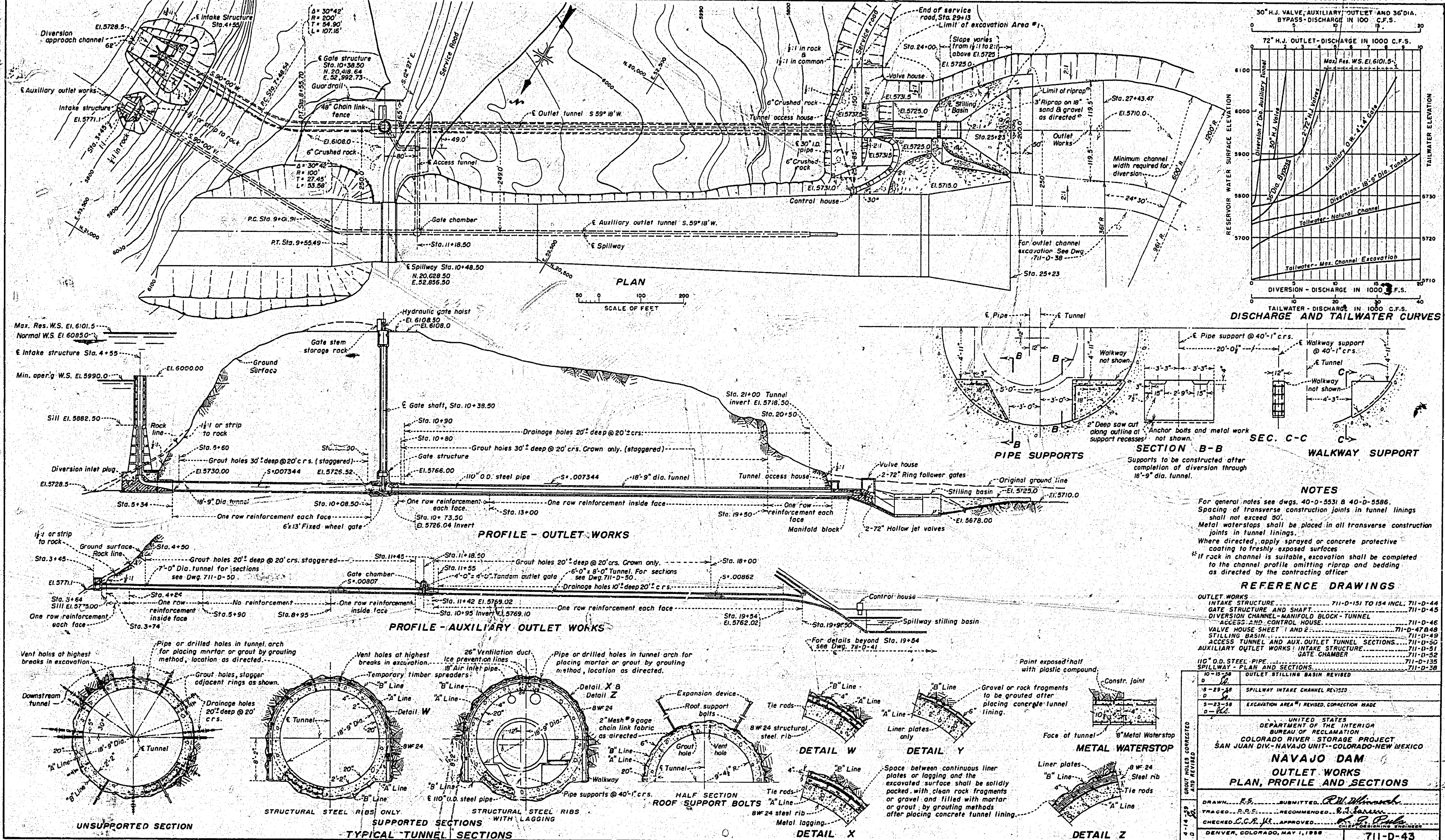


FIGURE 4
REPORT HYD. 457

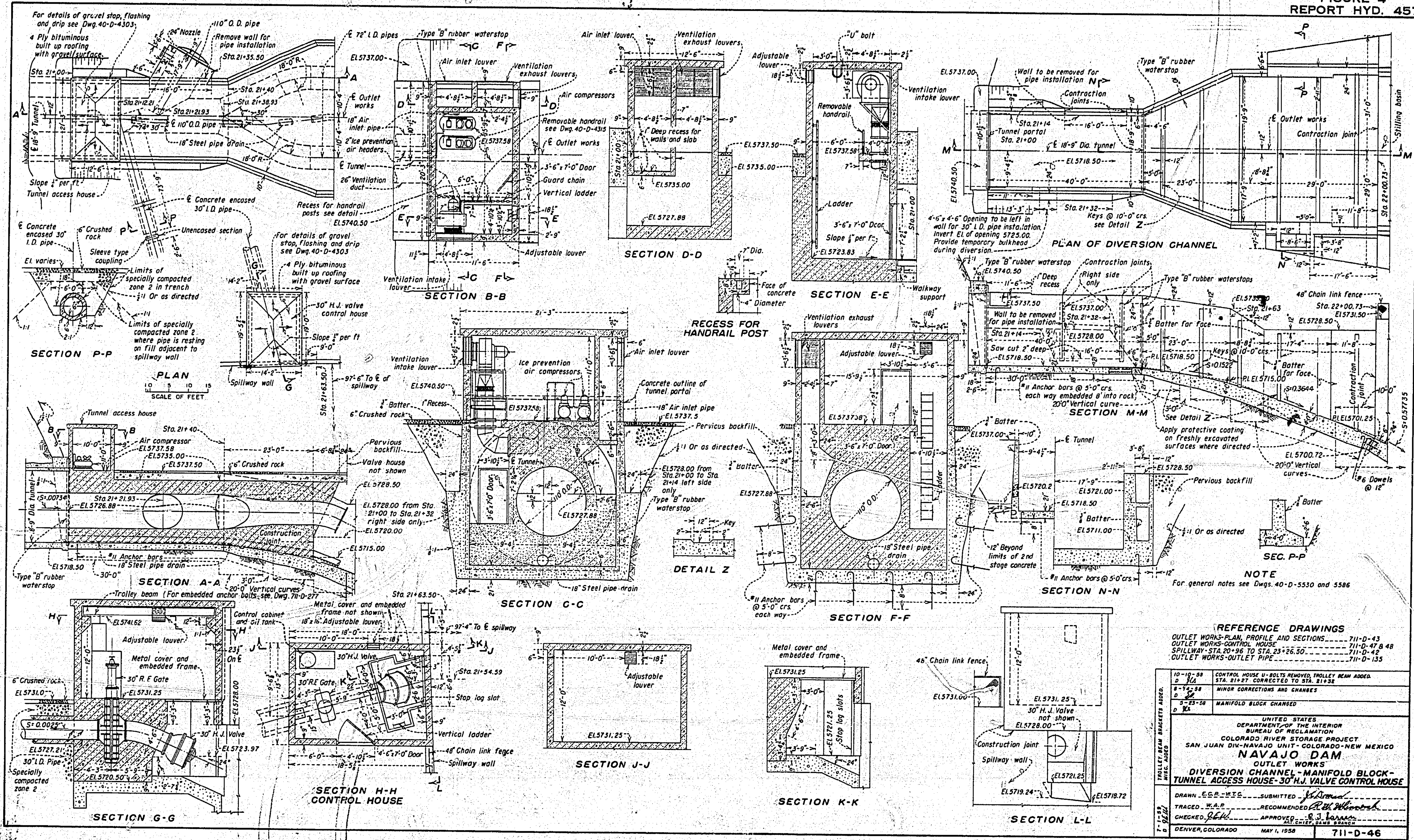
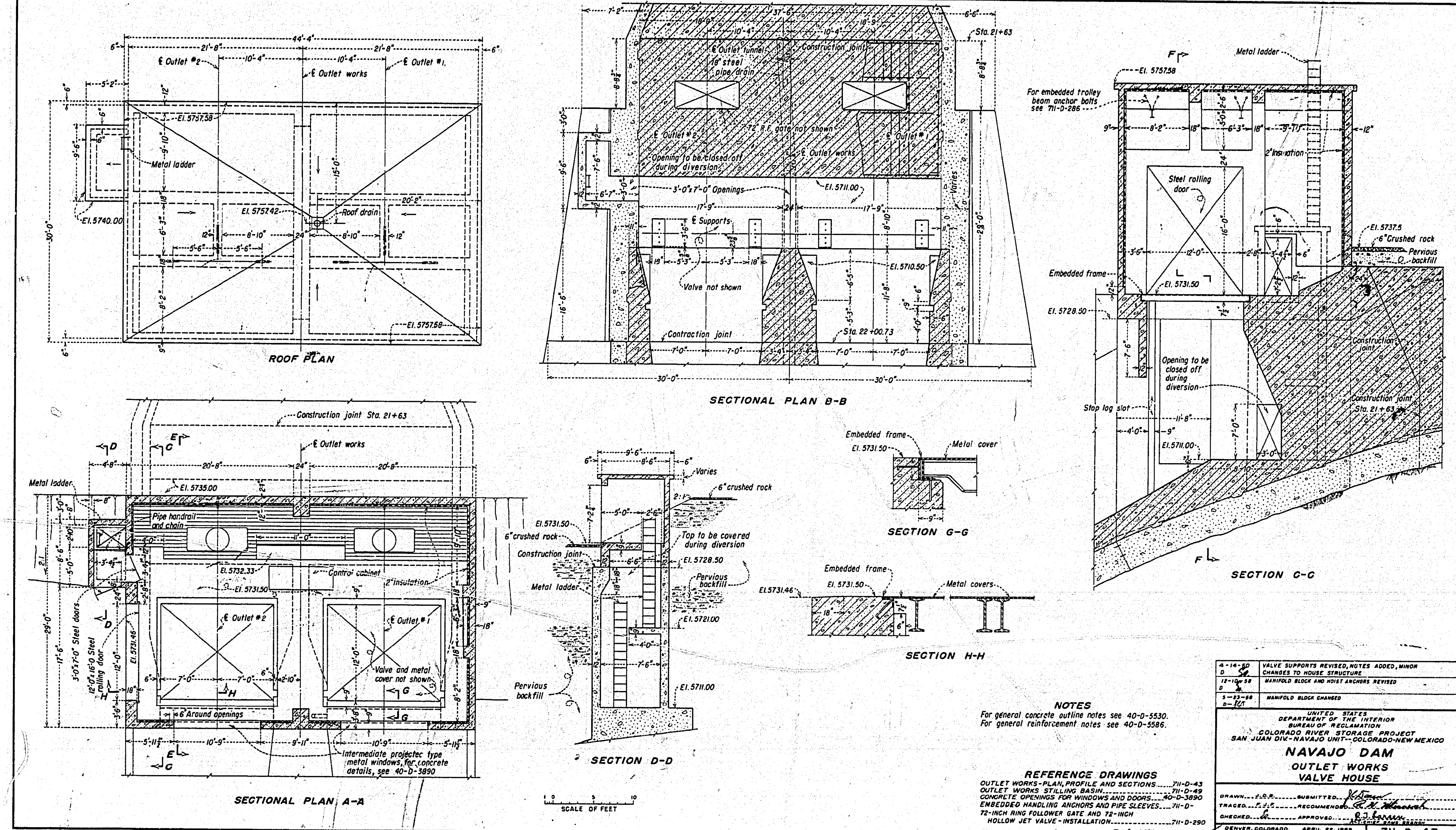


FIGURE 5
REPORT HYD. 457



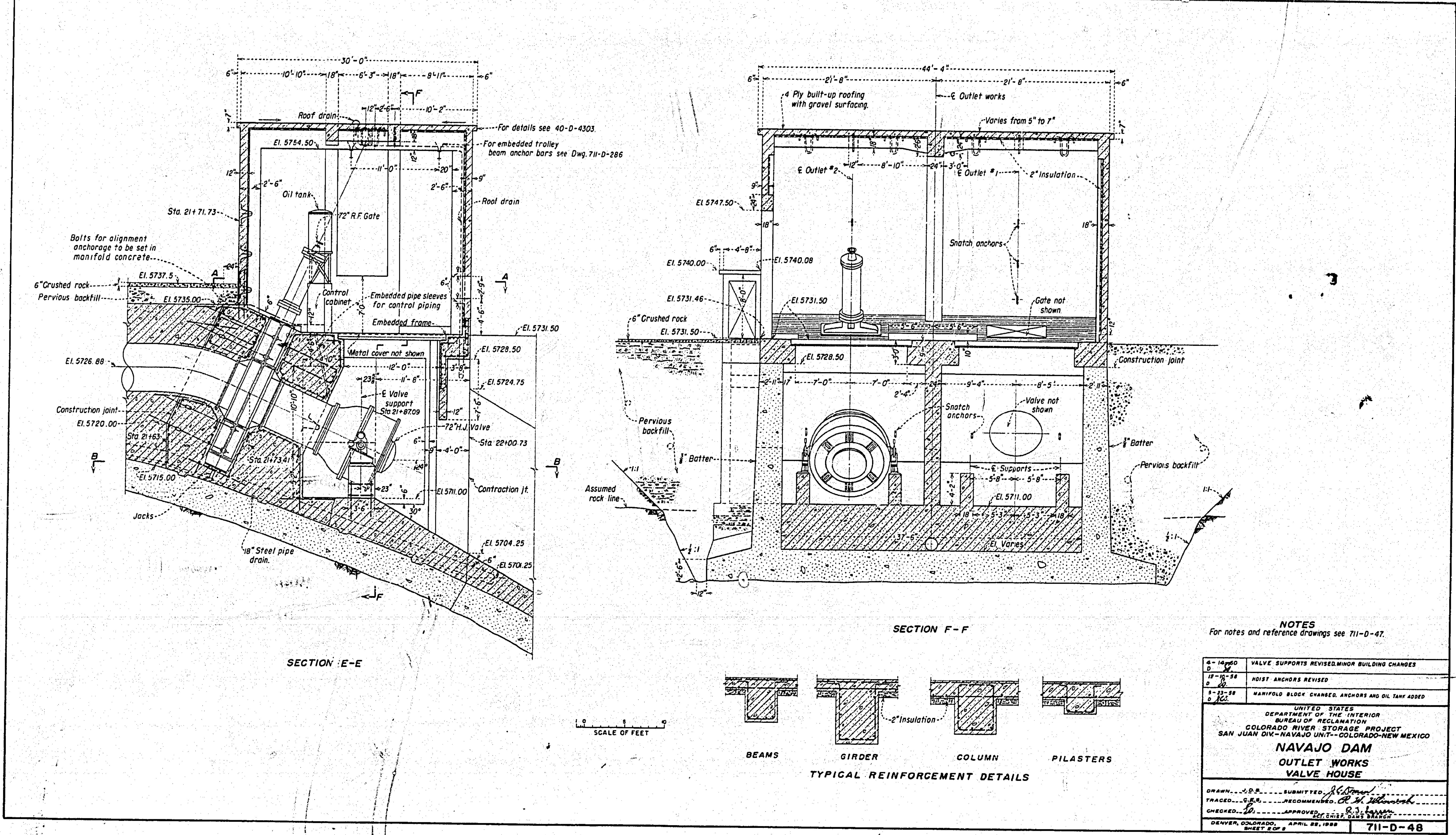
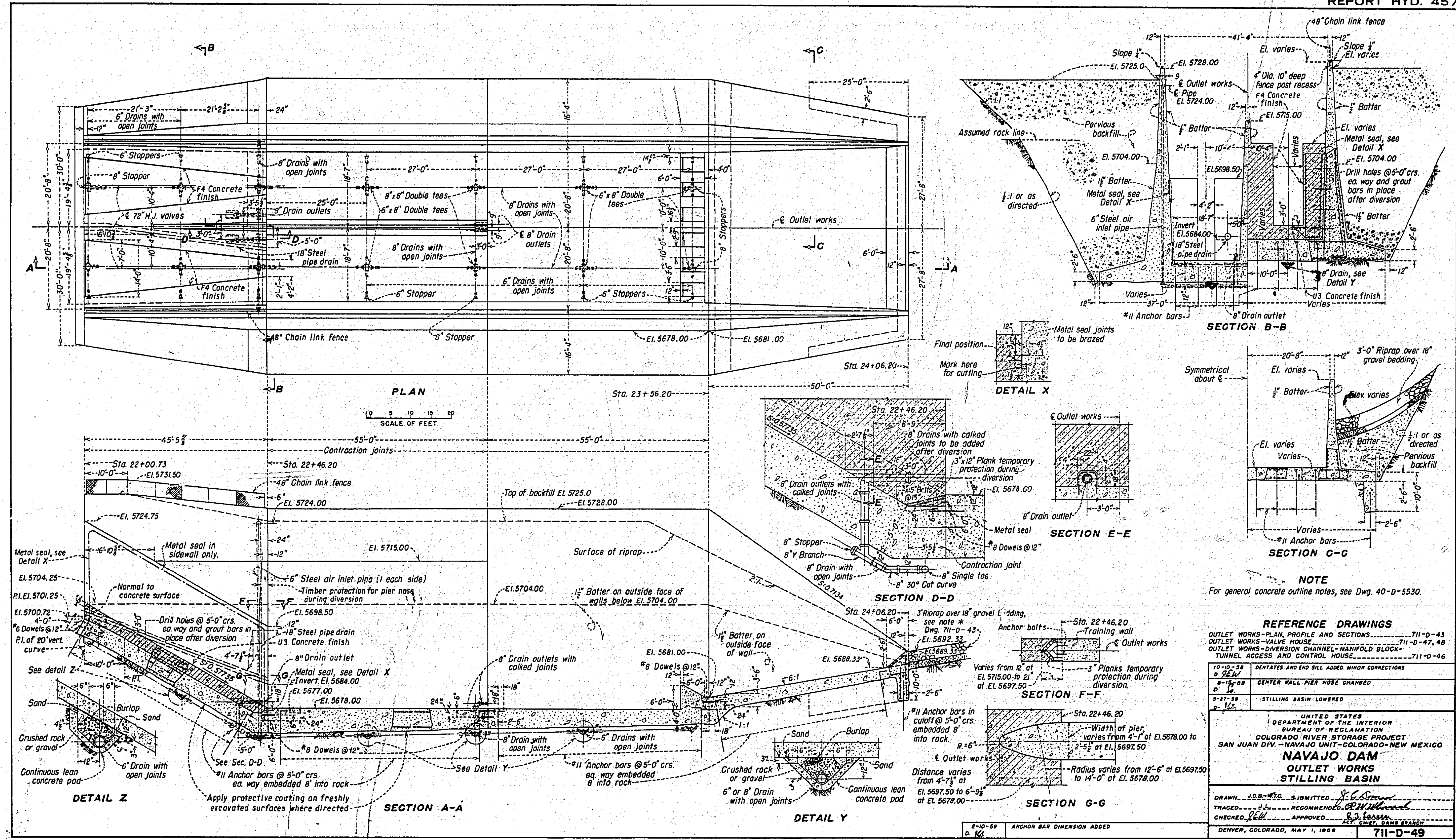
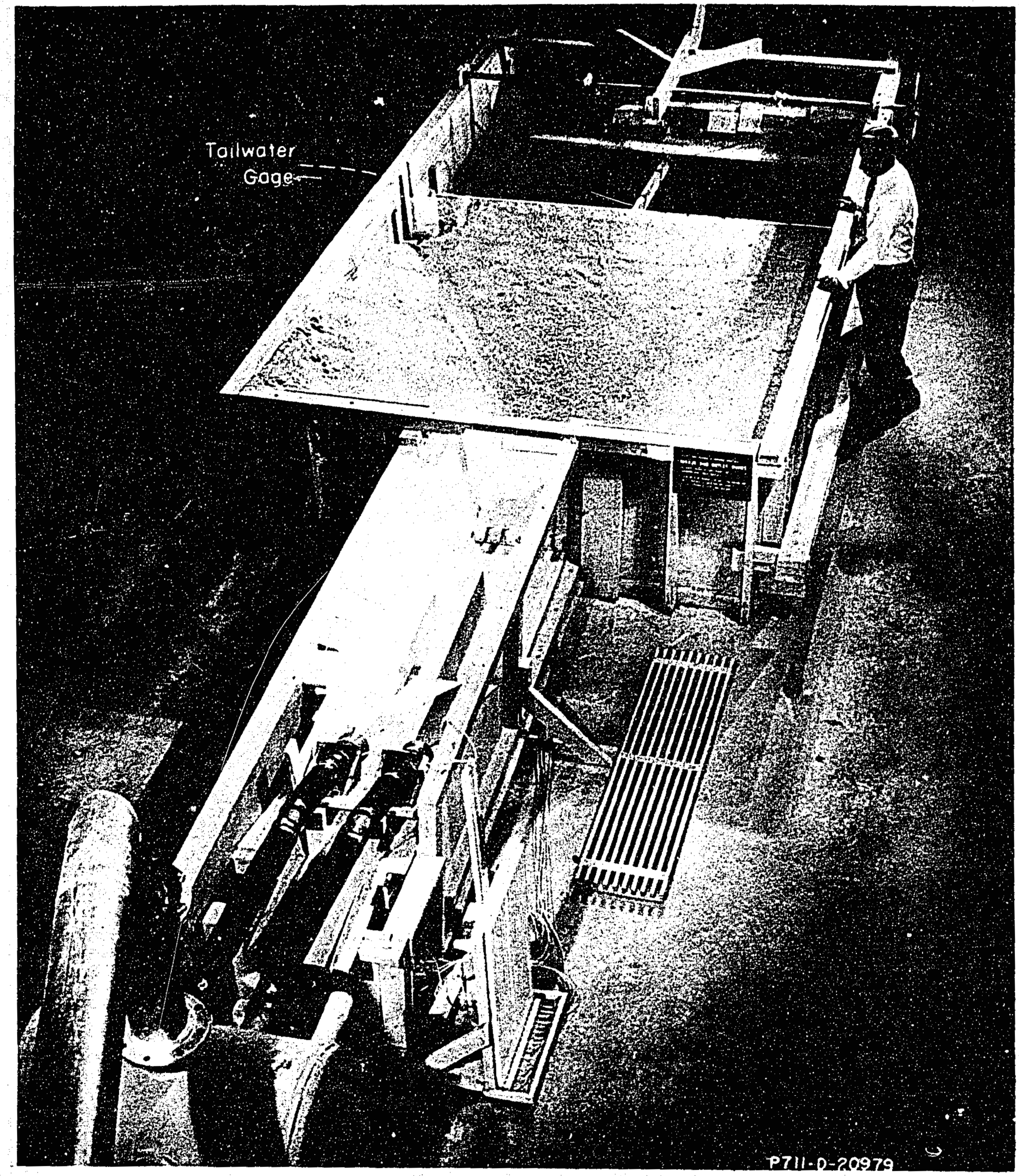

SECTION E-E
SECTION F-F
Roof drain
For details see 40-D-4303
For embedded trolley beam anchor bars see Dwg. 711-D-286
Oil tank
72" R.F. Gate
Sta. 21+71.73
Bolts for alignment anchorage to be set in manifold concrete
6" Crushed rock
Pervious backfill
El. 5737.5
El. 5735.00
El. 5754.50
Control cabinet
Embedded pipe sleeves for control piping
Embedded frame
Metal cover not shown
El. 5731.50
El. 5728.50
El. 5724.75
El. 5726.88
Construction joint
El. 5720.00
Sta. 21+63
Sta. 21+73.41
℄ Valve support Sta 21+87.09
72" H.J. Valve
Sta. 22+00.73
El. 5715.00
El. 5711.00
Contraction jt.
Jacks
18" Steel pipe drain.
El. 5704.25
El. 5701.25
4 Ply built-up roofing with gravel surfacing.
℄ Outlet works
Varies from 5" to 7"
℄ Outlet #2
℄ Outlet #1
2" Insulation
El. 5747.50
Snatch anchors
El. 5740.00
El. 5740.08
El. 5731.46
El. 5731.50
Gate not shown
6" Crushed rock
El. 5731.50
El. 5728.50
Construction joint
Pervious backfill
Snatch anchors
Valve not shown
⅛" Batter
Assumed rock line
℄ Supports
El. 5711.00
El. Varies
SCALE OF FEET
BEAMS
GIRDER
COLUMN
PILASTERS
2" Insulation
TYPICAL REINFORCEMENT DETAILS
NOTES
For notes and reference drawings see 711-D-47.
VALVE SUPPORTS REVISED, MINOR BUILDING CHANGES
HOIST ANCHORS REVISED
MANIFOLD BLOCK CHANGED, ANCHORS AND OIL TANK ADDED
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
SAN JUAN DIV.--NAVAJO UNIT--COLORADO-NEW MEXICO
NAVAJO DAM
OUTLET WORKS
VALVE HOUSE
DENVER, COLORADO, APRIL 22, 1958
711-D-48

FIGURE 7
REPORT HYD. 457

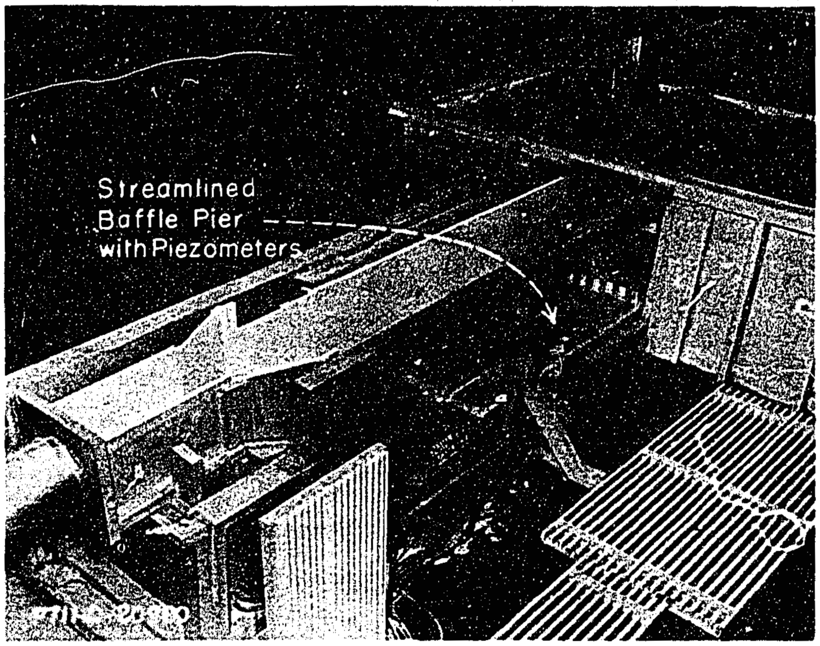




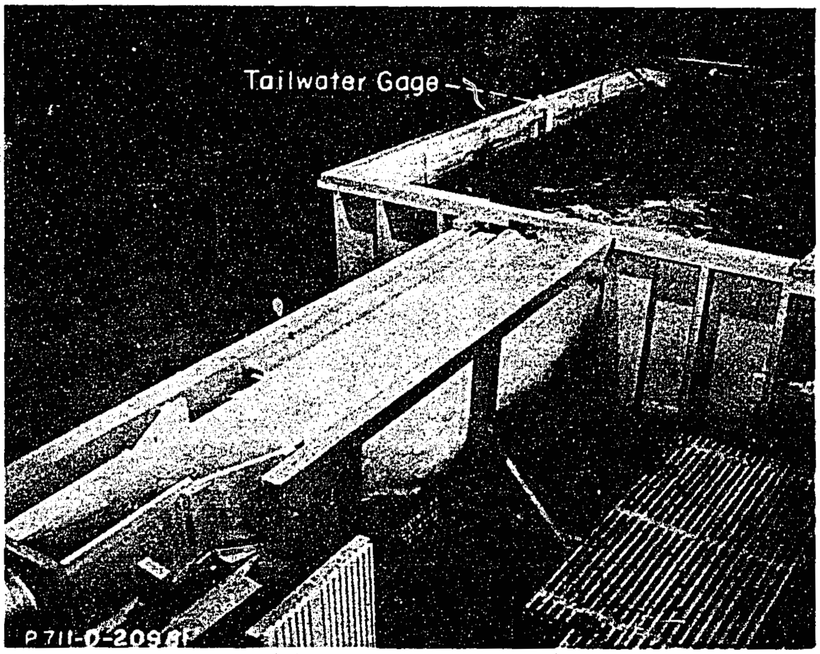
Recommended Permanent Outlet Works Basin

NAVAJO DAM
1:24 Scale Model Used to Develop
Diversion and Permanent Outlet Works
Stilling Basins

Figure 9
Report HYD 457



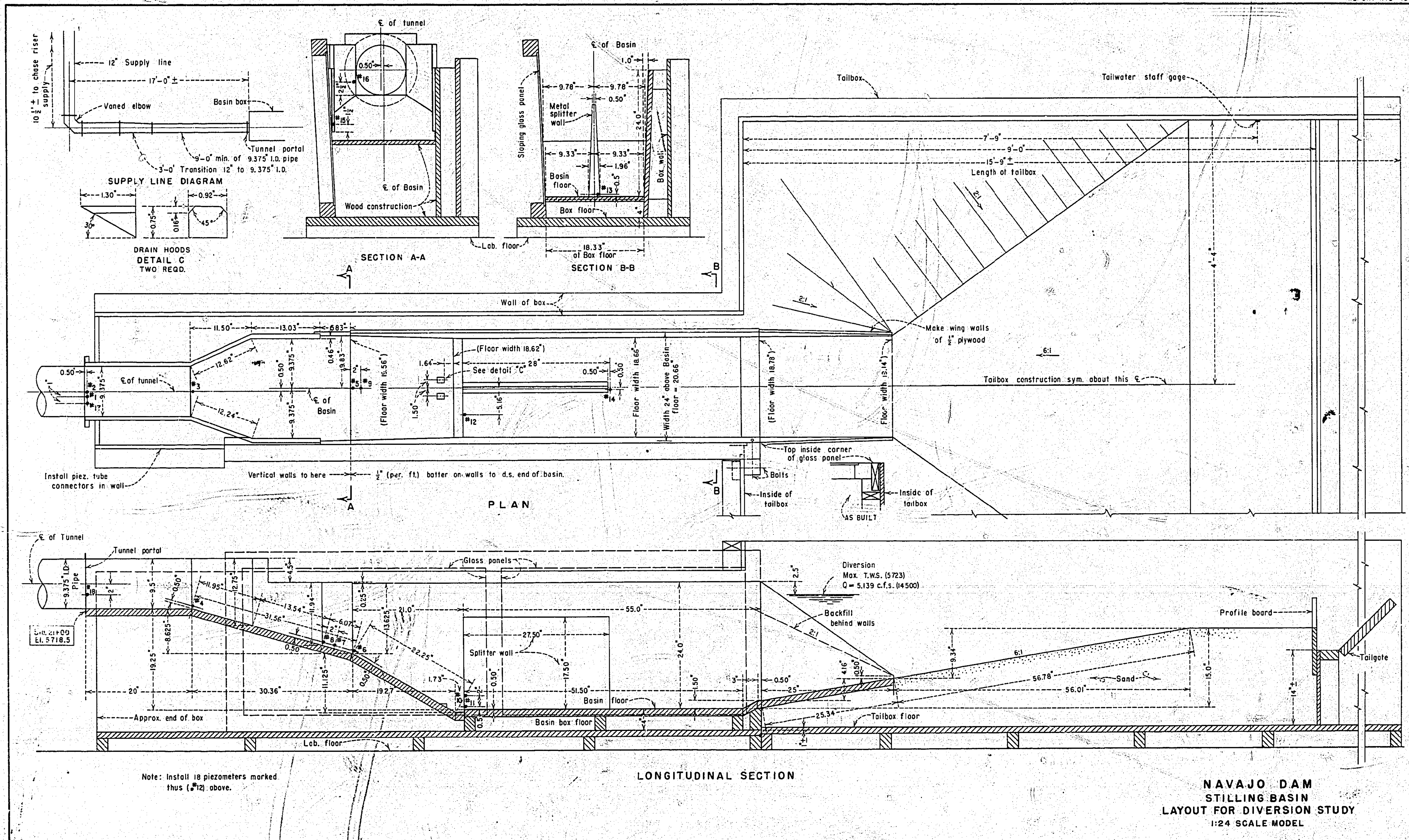
Intermediate baffle piers were not recommended for prototype use



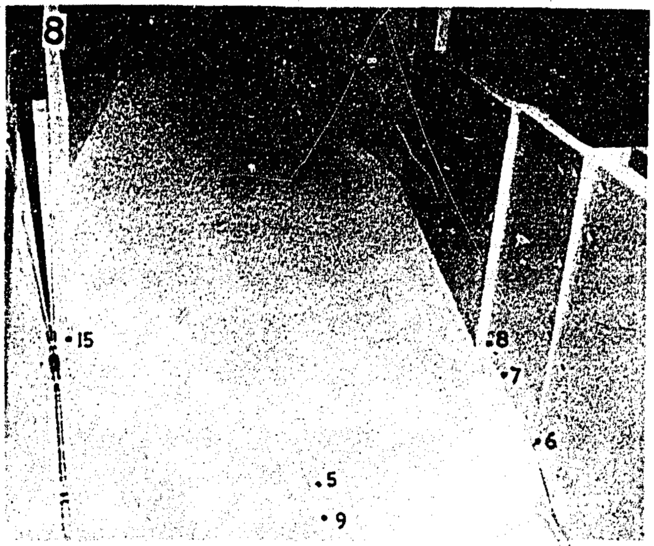
Design Discharge - 14,500 CFS
Tailwater Elevation 5716

NAVAJO DAM
Diversion Stilling Basin - Scheme #9
1:24 Scale Model

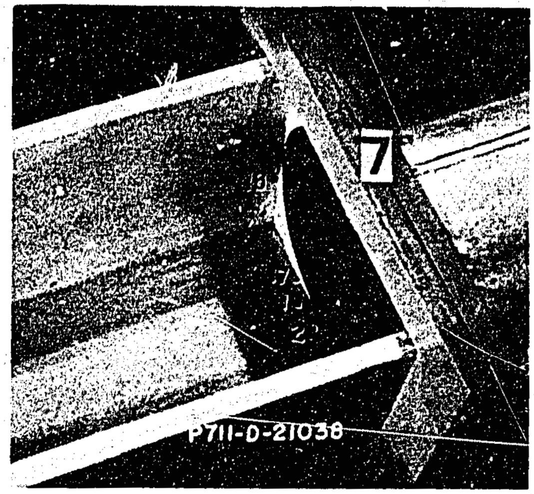
FIGURE 10
REPORT HYD 457



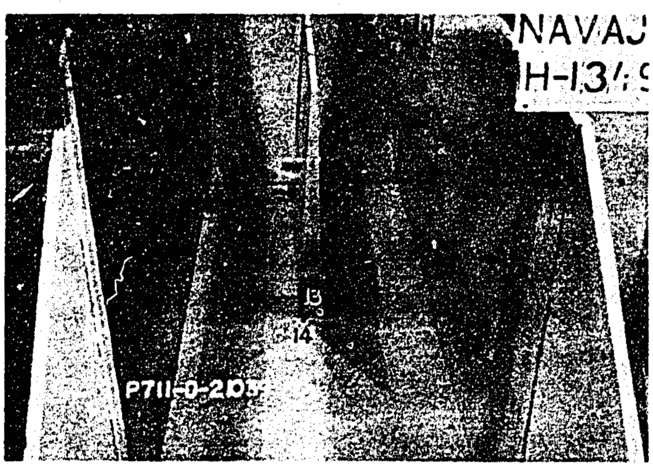
NAVAJO DAM
STILLING BASIN
LAYOUT FOR DIVERSION STUDY
1:24 SCALE MODEL



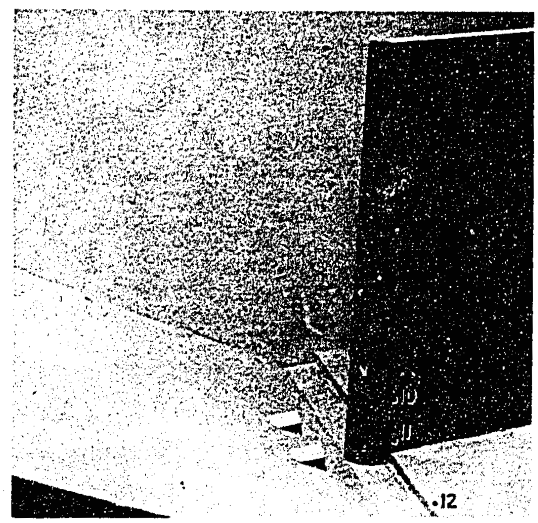
A Diversion Channel
Looking Upstream



B Diversion tunnel outlet portal



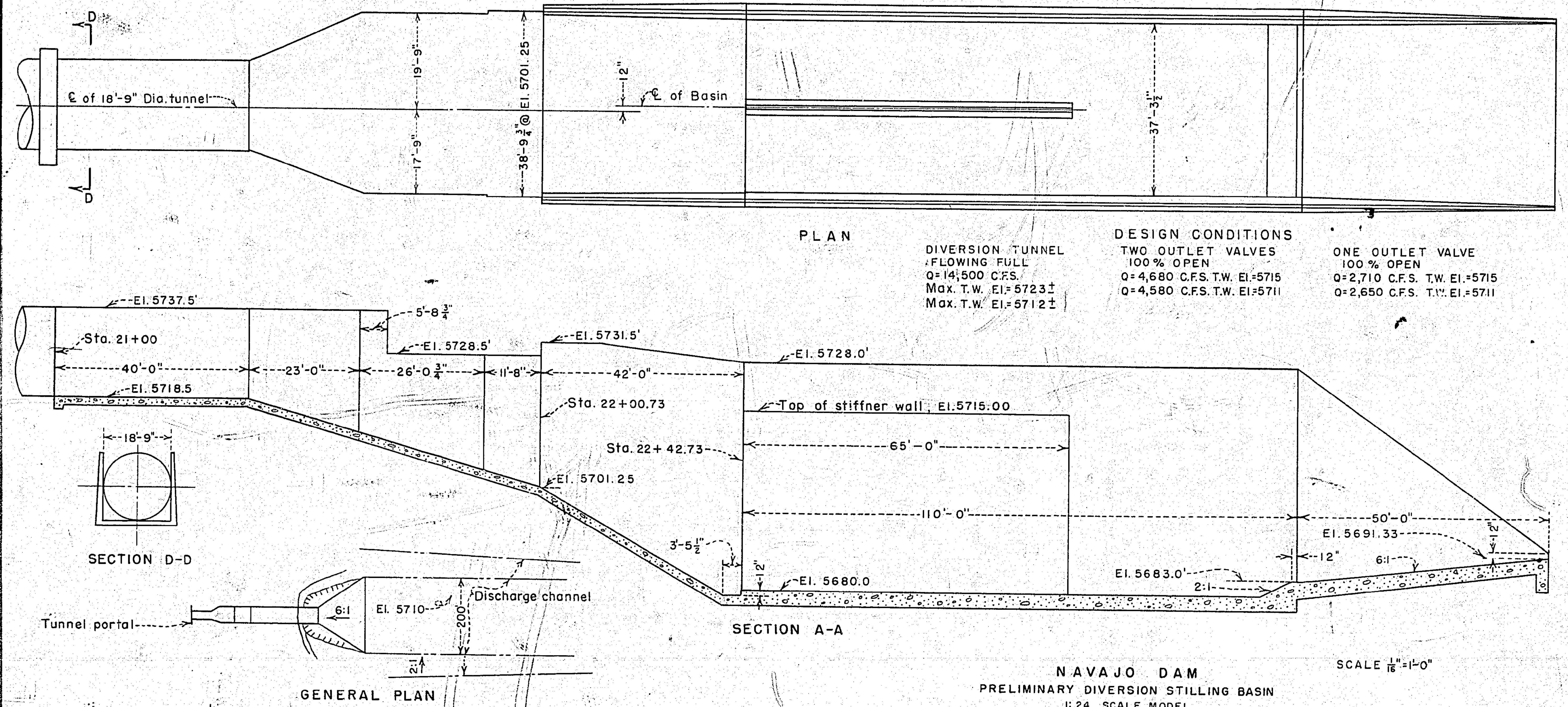
C Stilling basin looking upstream



D Two drains and pier nose
at upstream end of basin
dividing wall.

Numbers and circled points designate piezometer locations.

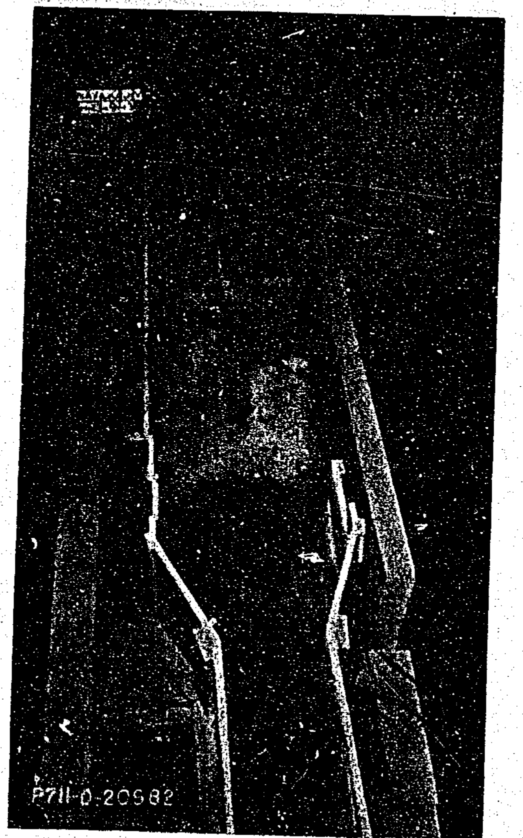
NAVAJO DAM
Diversion Model Piezometer Locations
1:24 SCALE MODEL

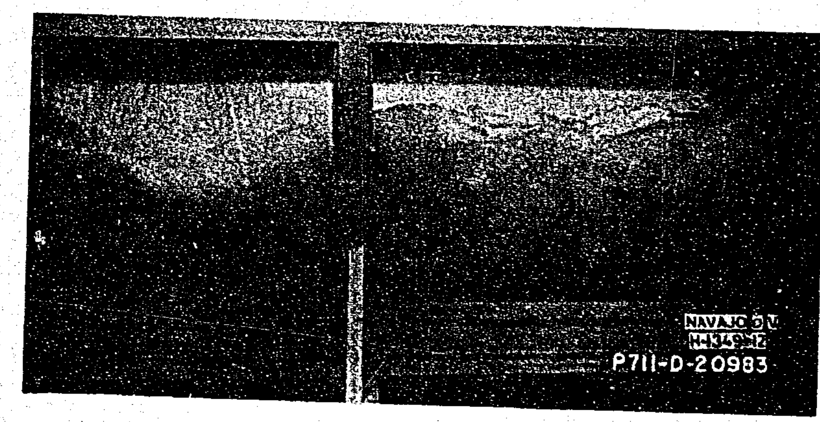


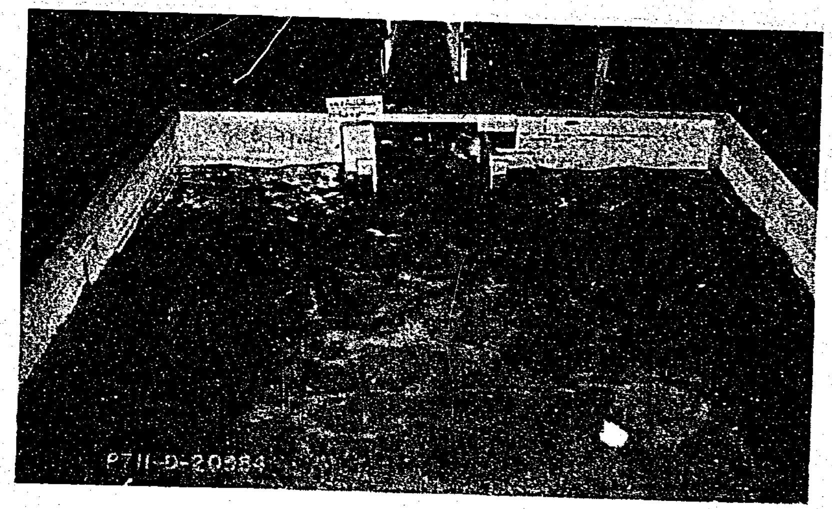
SCALE 1/16"=1'-0"

NAVAJO DAM
PRELIMINARY DIVERSION STILLING BASIN
1:24 SCALE MODEL

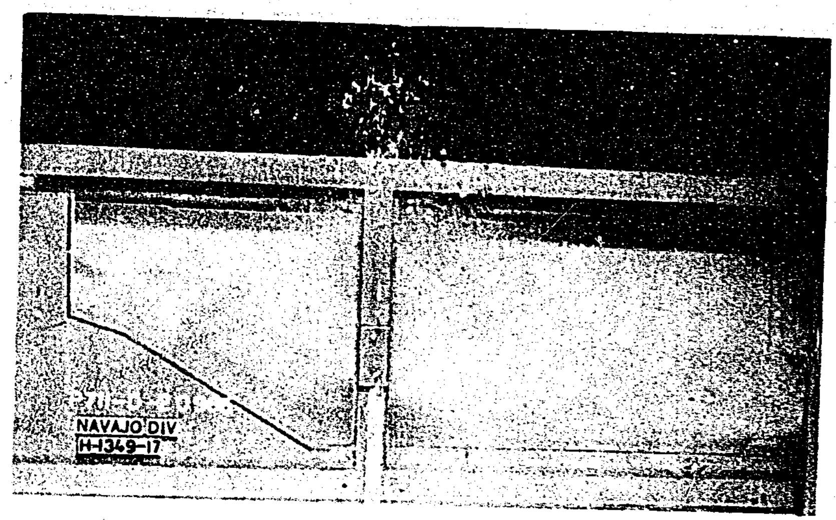
597



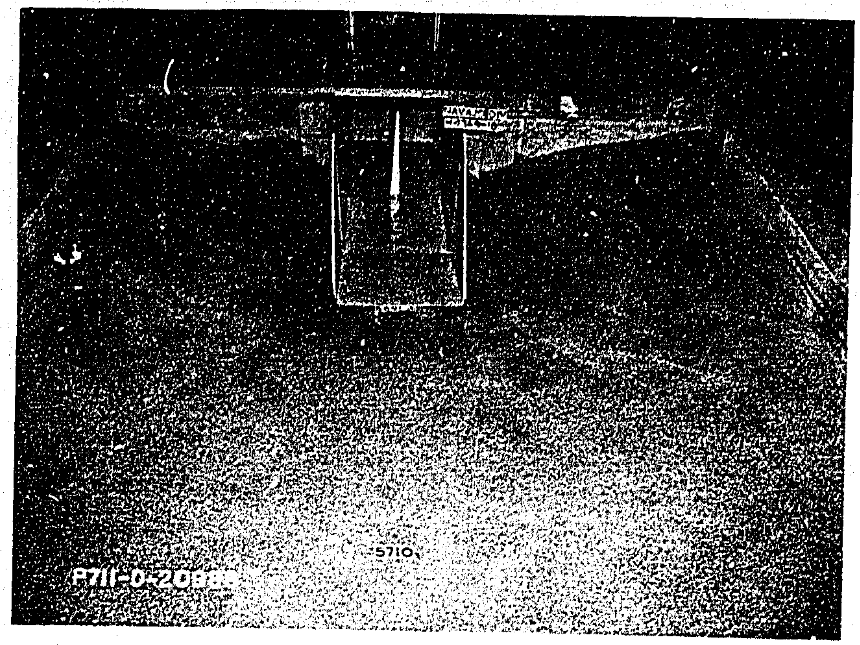




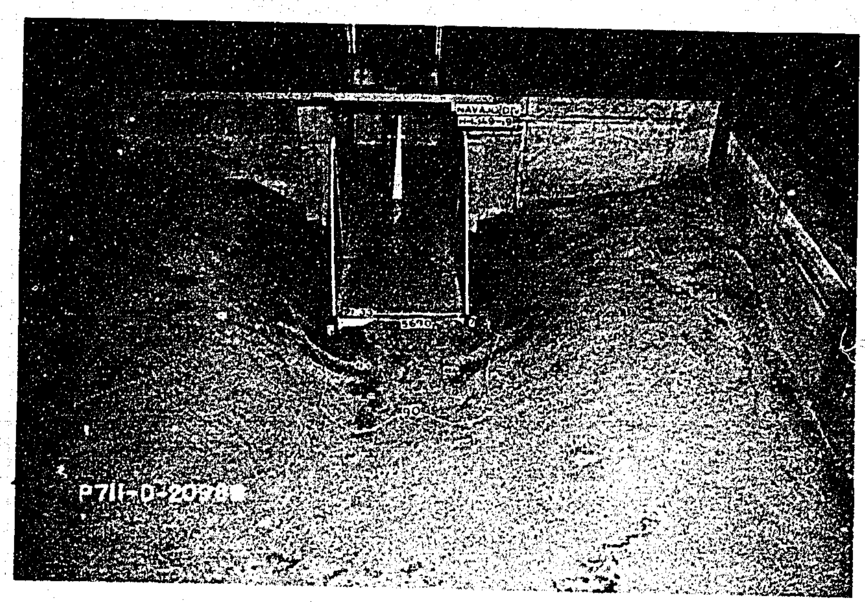
NAVAJO DAM
Preliminary Diversion Basin - 14,500 CFS - Tailwater Elevation 5723
1:24 Scale Model



NAVAJO DAM
Preliminary Diversion Basin - 14,500 CFS - Tailwater Elevation 5714
1:24 Scale Model

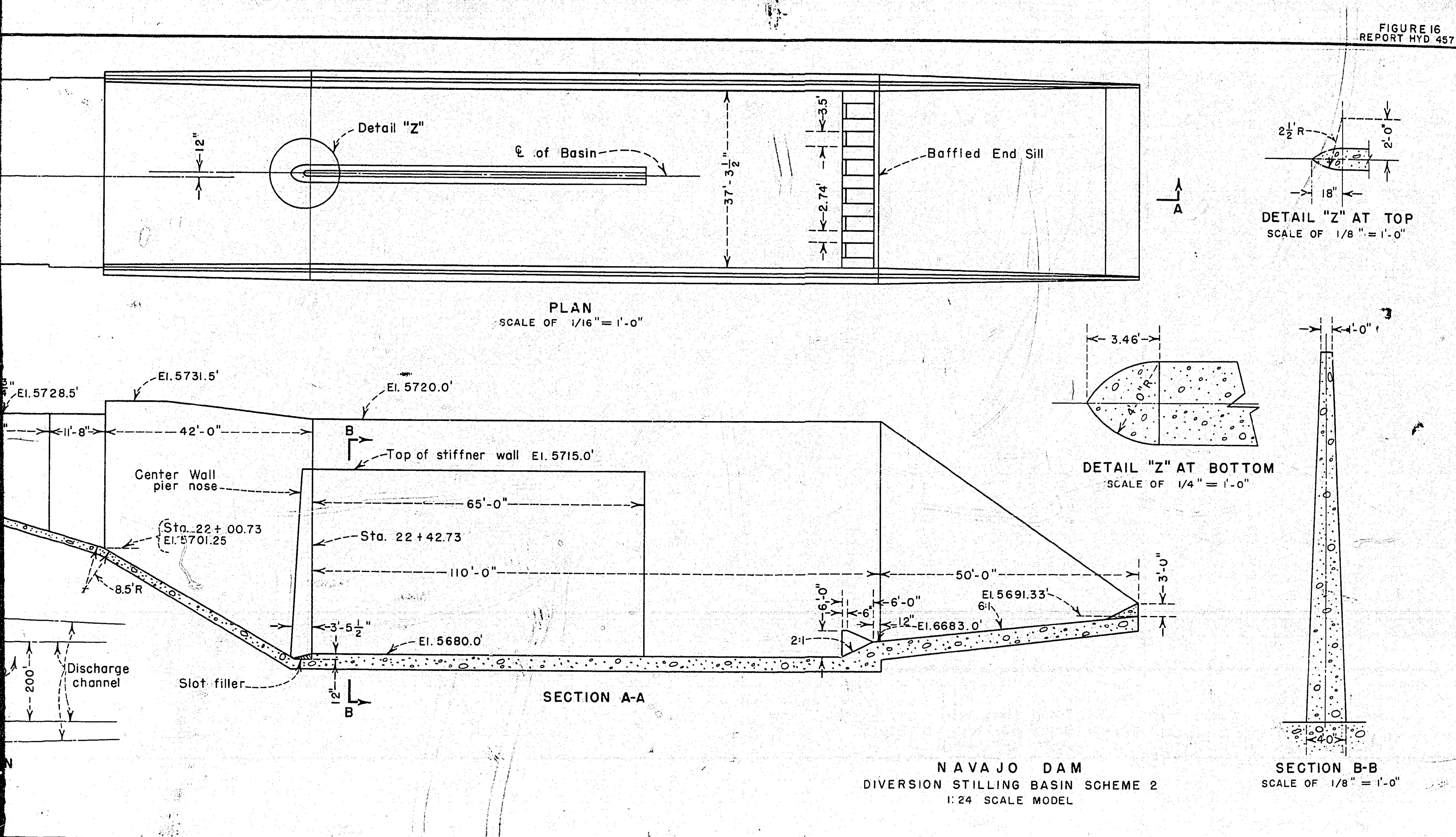


A. Before Model Erosion Test

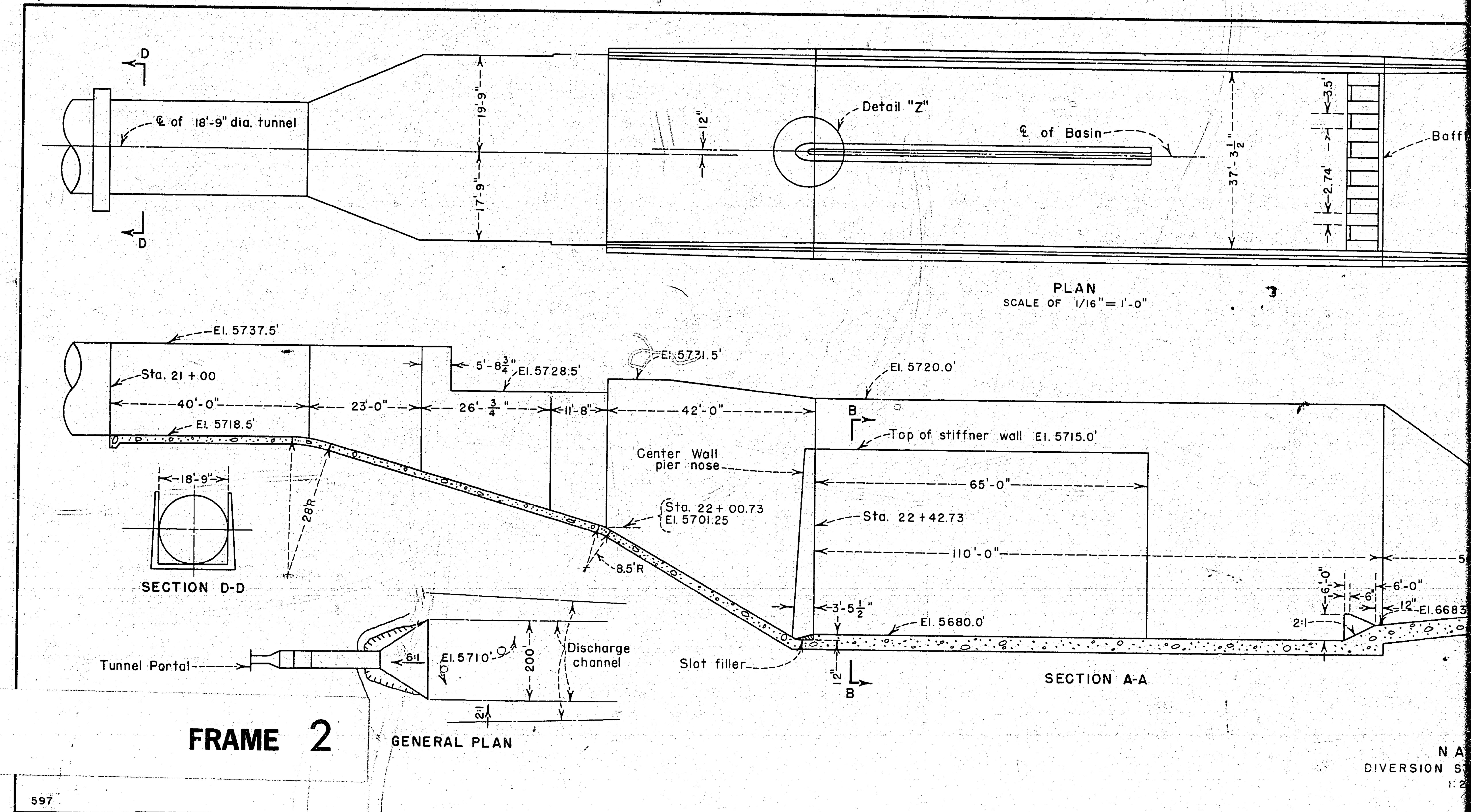


B. After one hour model erosion test
14,500 CFS - Tailwater elevation
5718.5

NAVAJO DAM
Preliminary Diversion Basin - Scour Test
1:24 Scale Model

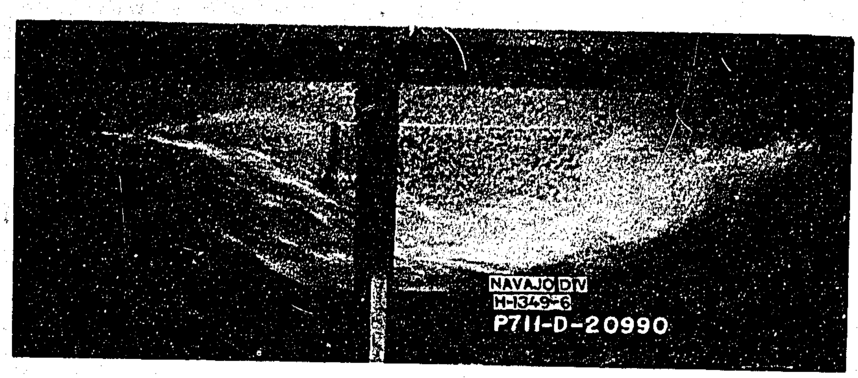


NAVAJO DAM
DIVERSION STILLING BASIN SCHEME 2
1:24 SCALE MODEL

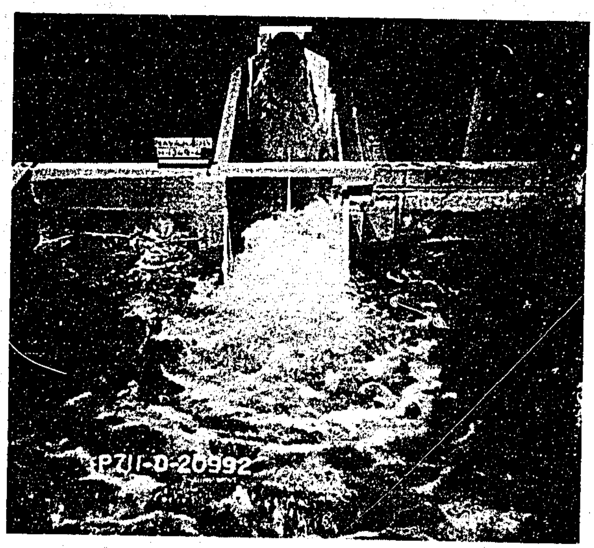

D
℄ of 18'-9" dia. tunnel
19'-9"
17'-9"
12"
Detail "Z"
℄ of Basin
37'-3 1/2"
3.5'
2.74'
Baff
PLAN
SCALE OF 1/16" = 1'-0"
El. 5737.5'
Sta. 21 + 00
5'-8 3/4"
El. 5728.5'
El. 5731.5'
El. 5720.0'
40'-0"
23'-0"
26'-3/4"
11'-8"
42'-0"
El. 5718.5'
B
Top of stiffner wall El. 5715.0'
Center Wall pier nose
65'-0"
18'-9"
28'R
Sta. 22 + 00.73
El. 5701.25
Sta. 22 + 42.73
110'-0"
8.5'R
SECTION D-D
6'-0"
6'-0"
6"
12"
El. 6683
3'-5 1/2"
El. 5680.0'
2:1
Tunnel Portal
6:1
El. 5710'
200
Discharge channel
Slot filler
12"
SECTION A-A
2:1
GENERAL PLAN
N A
DIVERSION S
1:2

FRAME 2

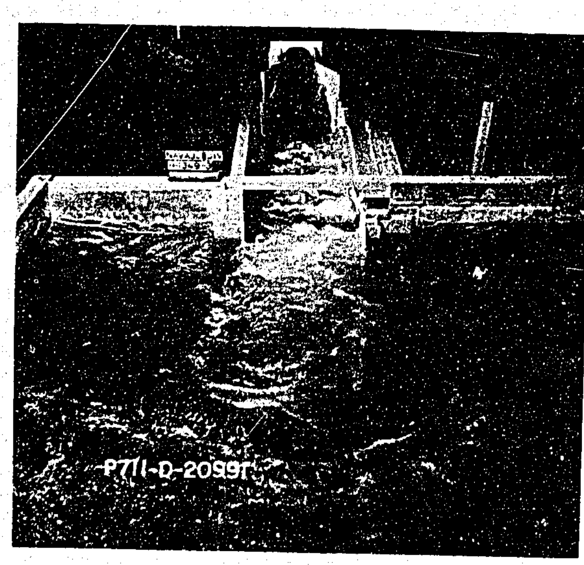
597



A. Tailwater Elevation 5716



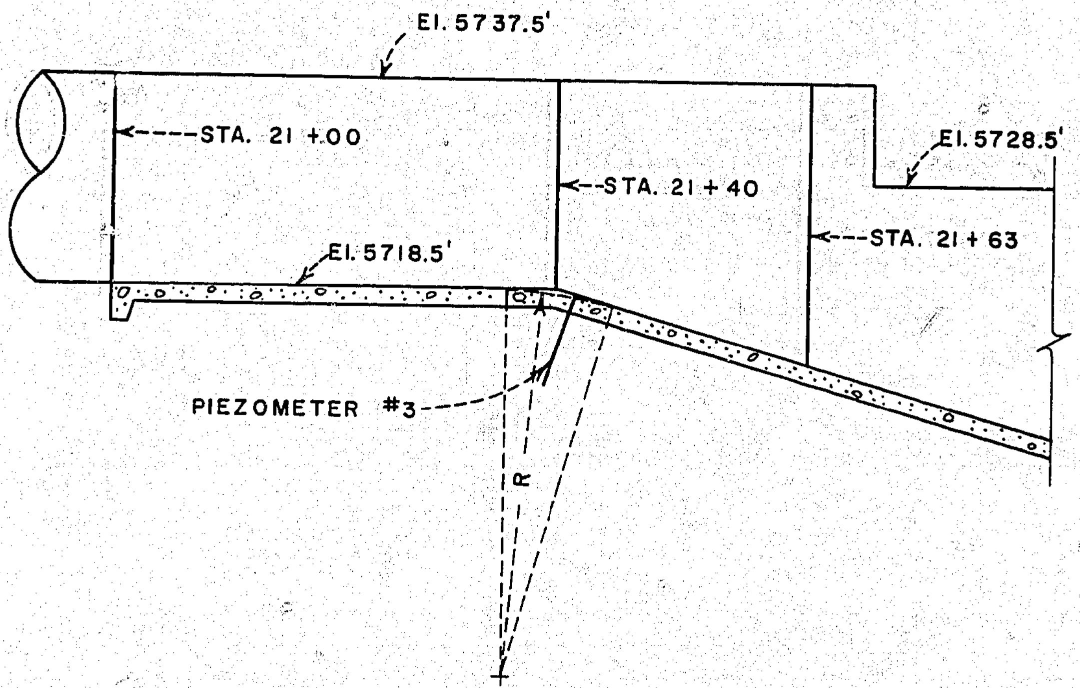
B Same as in A



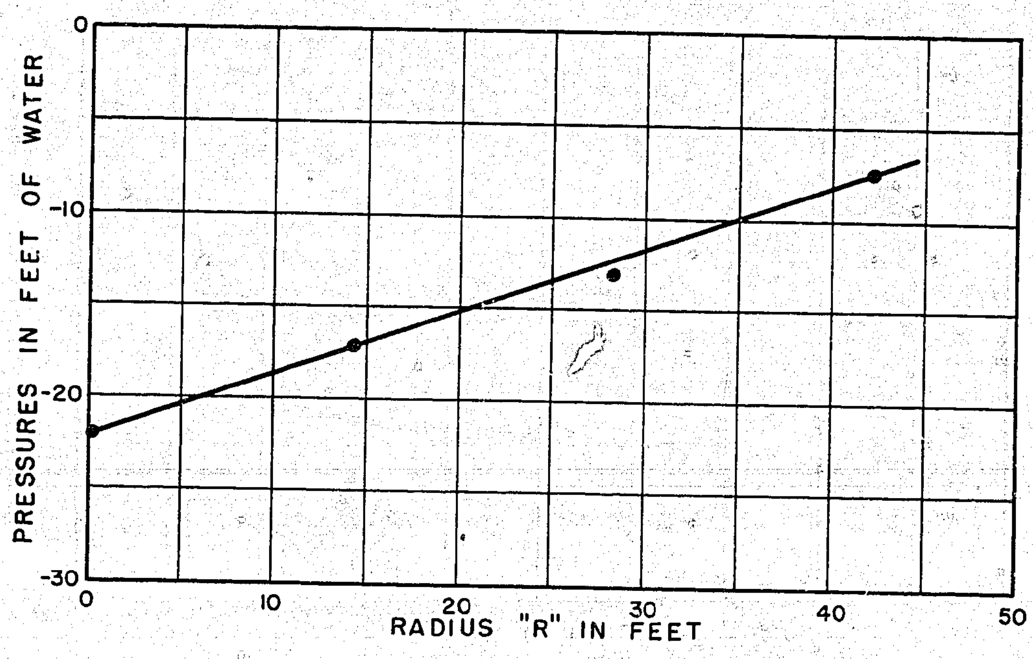
C Same as in D

D Tailwater Elevation 5723

NAVAJO DAM
Diversion Stilling Basin Scheme #2 - 14,500 CFS
1:24 Scale Model



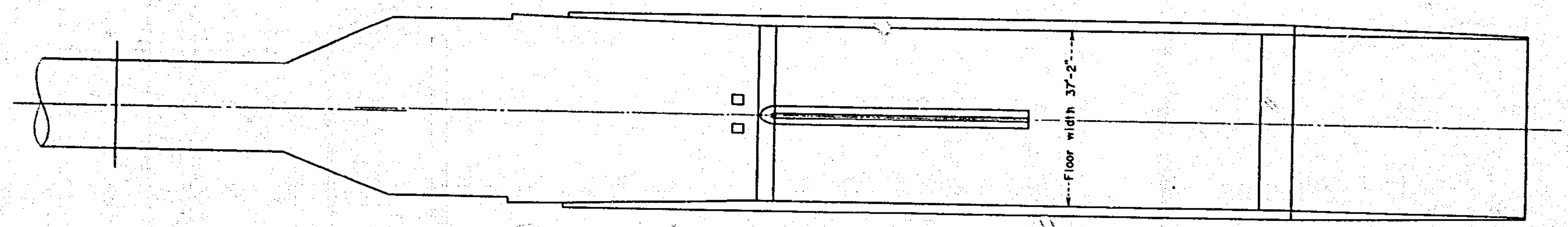
SECTION ON ℄ OF SCHEME #2

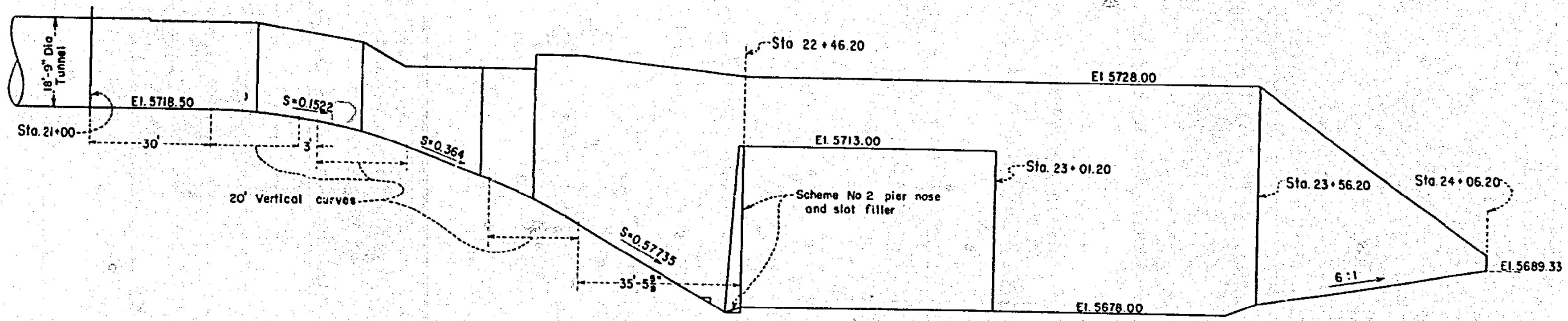


NAVAJO DAM

DIVERSION CHANNEL PRESSURES AT PIEZ. 3 IN SCHEME 2

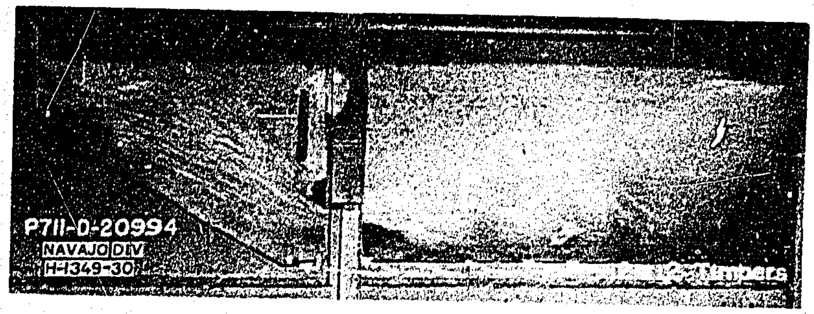
1:24 SCALE MODEL





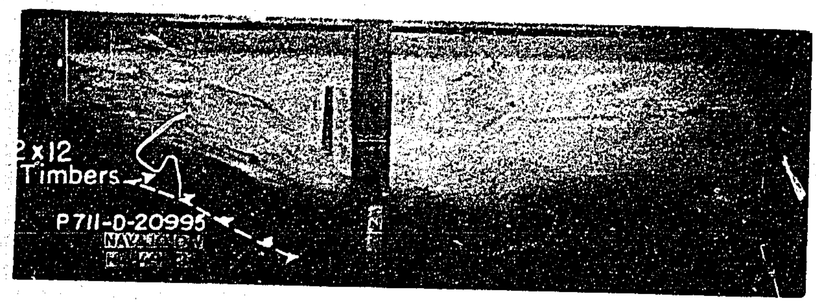
NAVAJO DAM
DIVERSION STILLING BASIN SCHEME 3
1:24 SCALE MODEL

397

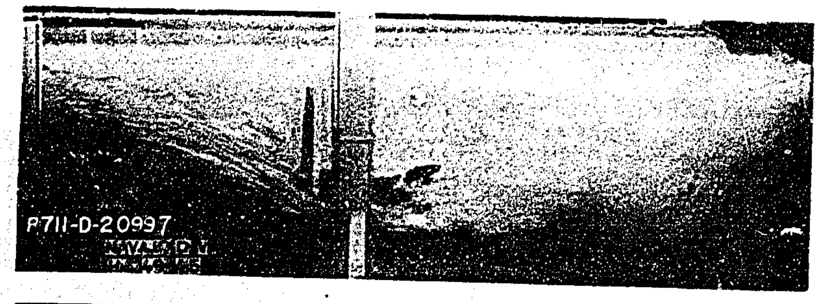


A. Scheme #5
Six 12" x 12" Timbers spaced 12 feet apart on basin apron plus a 3-foot high sill at downstream end of sloping apron.

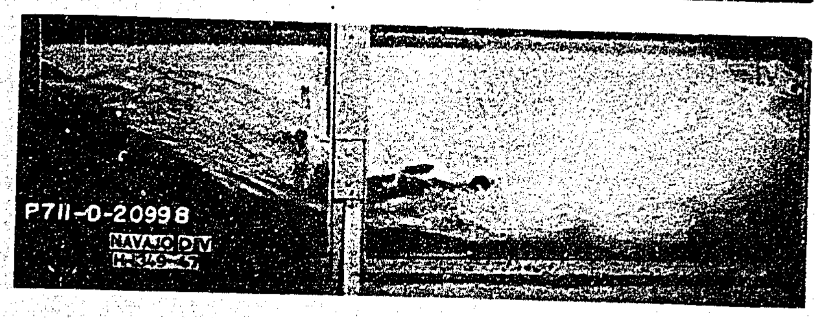
B. Scheme #7
Four streamlined baffles at downstream end of center wall and plus end sill in A above.



C. Scheme #8
Five 12" x 12" timbers spaced 12 feet apart in diversion channel plus four streamlined baffles in B above and end sill in A above.



D. Scheme #10
Square edged dentated sill at downstream end of horizontal apron and an end sill as in A above.



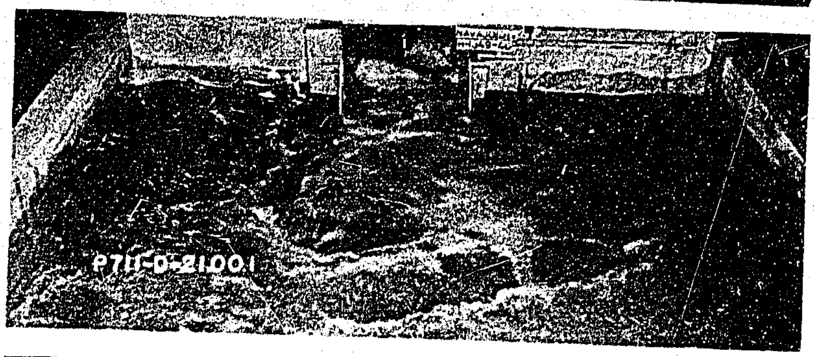
E. Same as D except without end sill.

Note: Apron elevation 5678; tailwater elevation 5714.
Center wall pier nose and slot filler are in place.

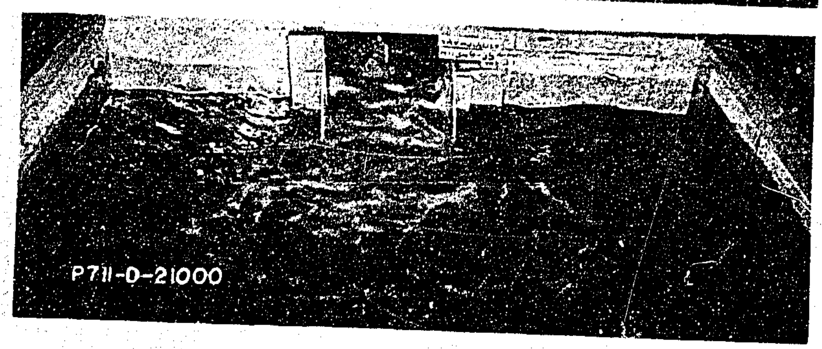
NAVAJO DAM
Modified Diversion Basin Designs--14,500 CFS
1:24 Scale Model

Figure 21
Report HYD 457

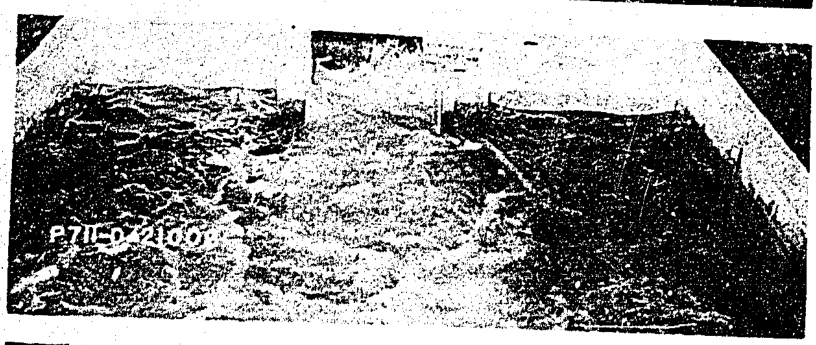
A. Scheme #6
Same as C in Fig. 20
except without stream-
lined baffles.



B. Scheme #7
Same as B in Fig. 20



C. Scheme #8
Same as C in Figure 20

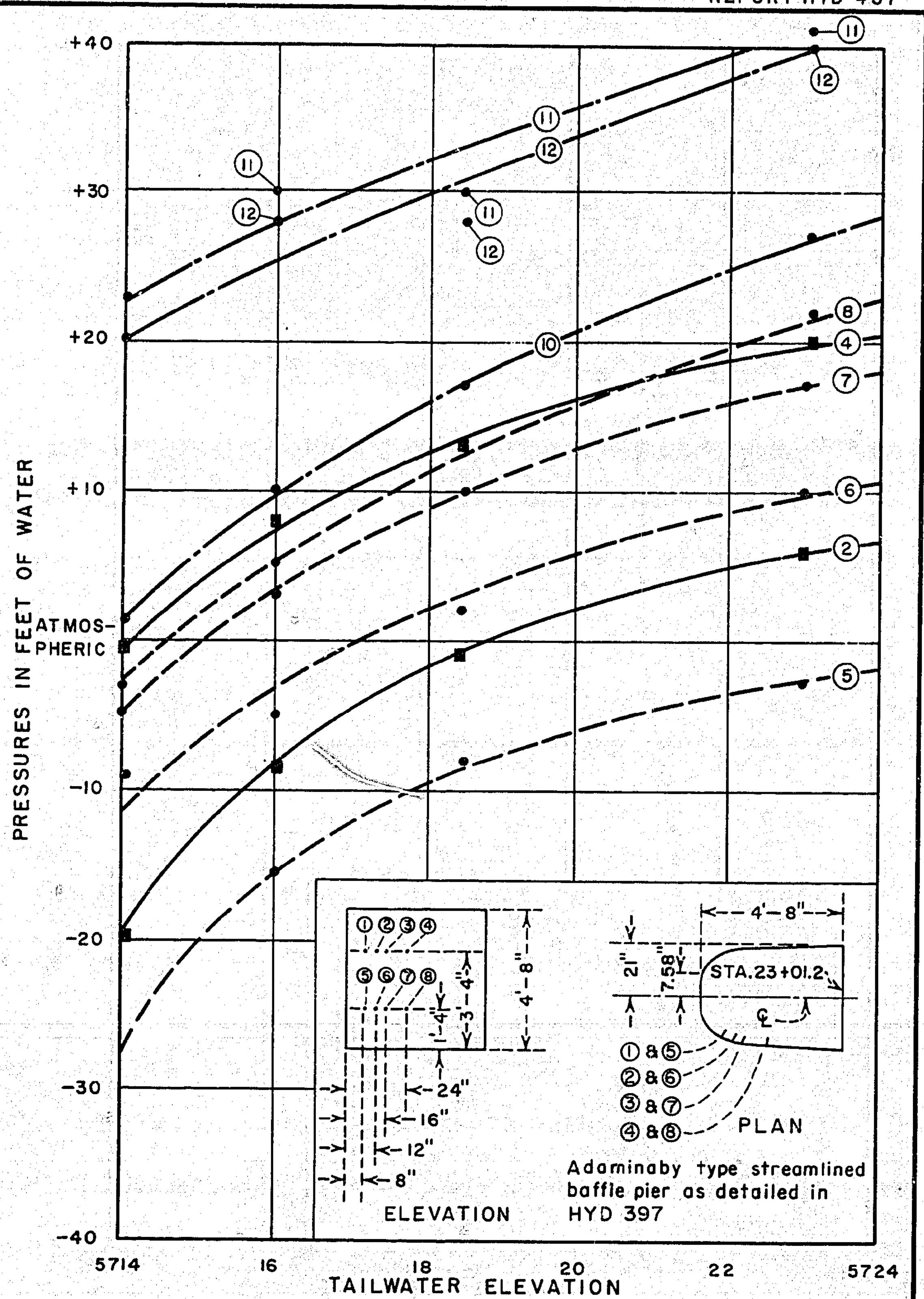


D. Scheme #10
Same as D in Fig. 20
Recommended

E. Same as E in Figure 20

Note: Tailwater is at elevation
5714.

NAVAJO DAM
Modified Diversion Basin Designs--14,500 CFS in Discharge Channel
1:24 Scale Model

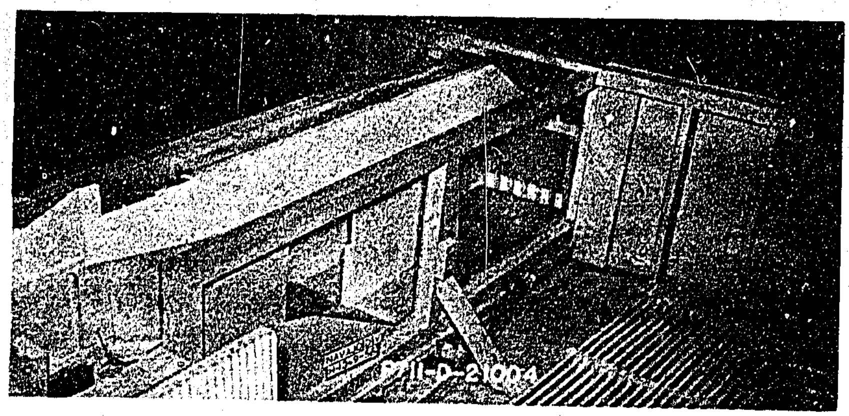


See Figure 9 and Table II for description of Scheme 9. (NO.) Designates Piezometers. Piezometers 10, 11, and 12 are located as shown in Figures 10 and 11D.

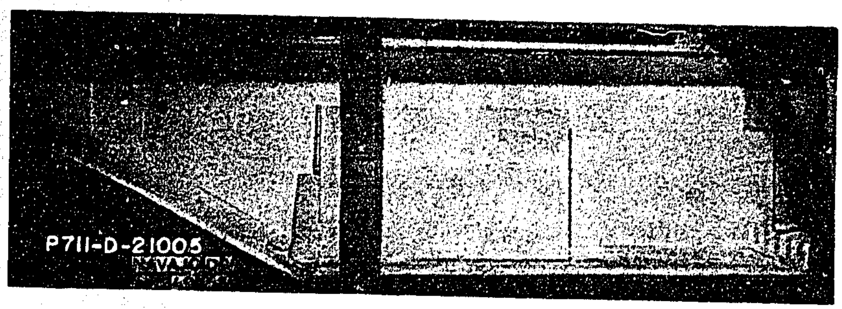
NAVAJO DAM

BAFFLE PIER PRESSURES IN DIVERSION SCHEME 9—14,500 CFS

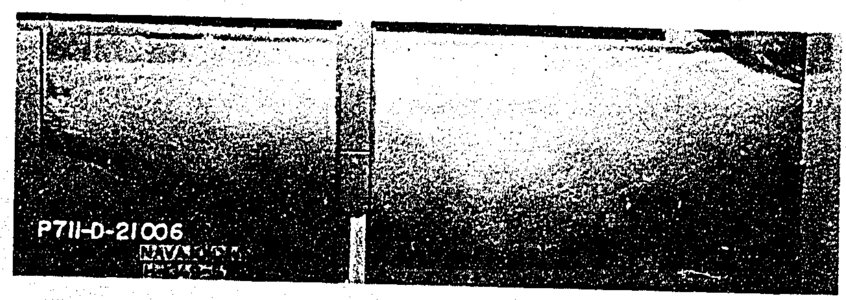
1:24 SCALE MODEL



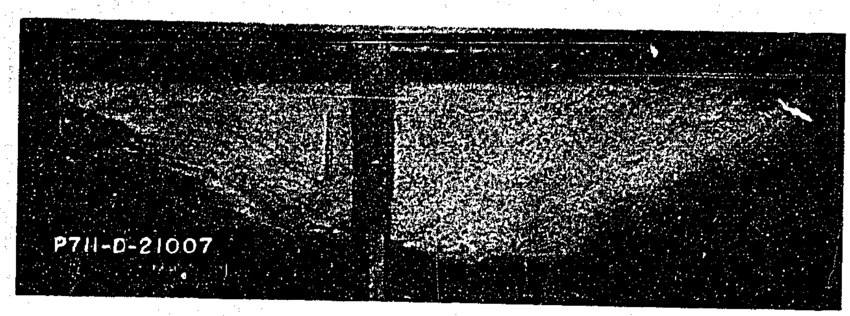
Looking Downstream



Side View

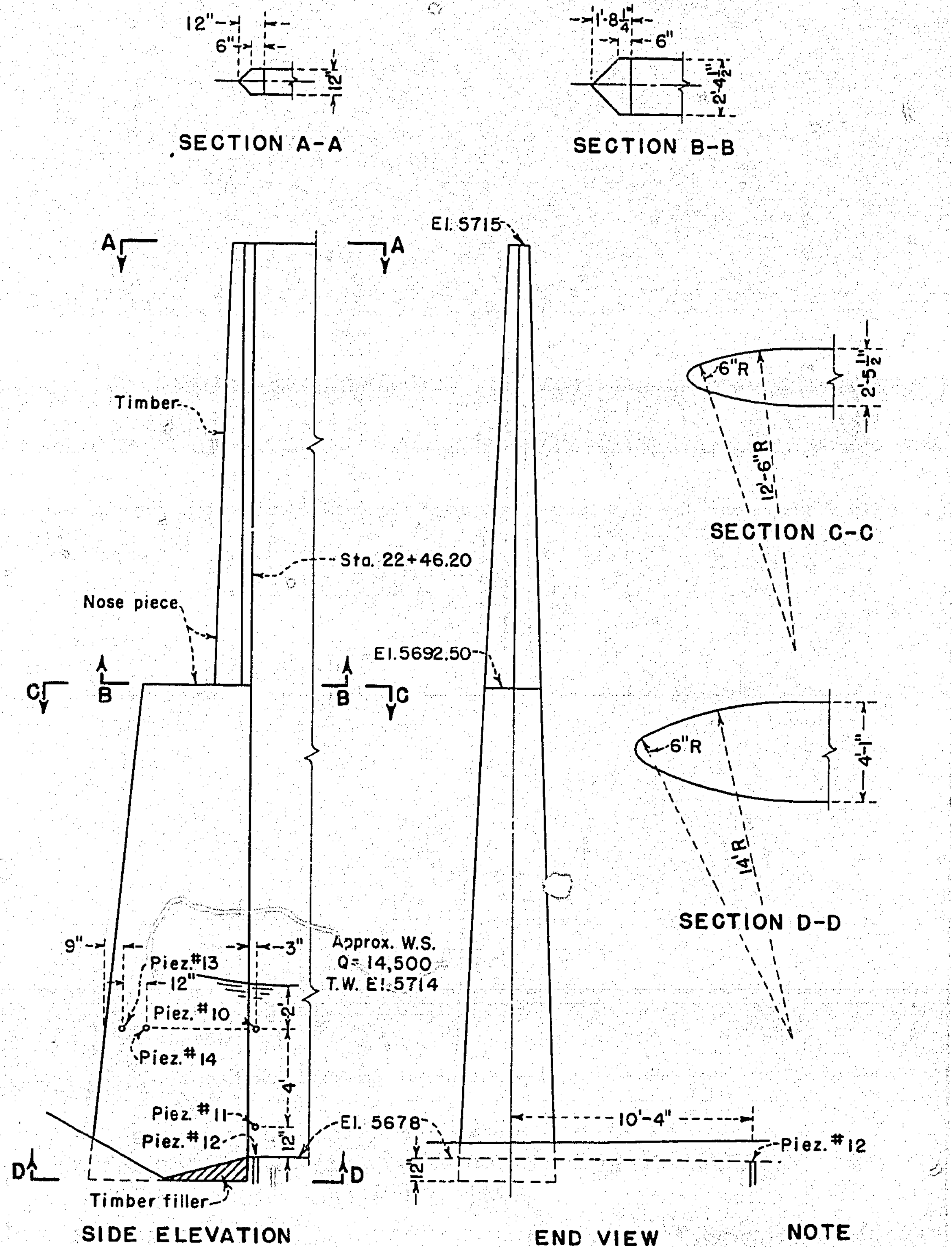


Side View - T.W. El. 5723



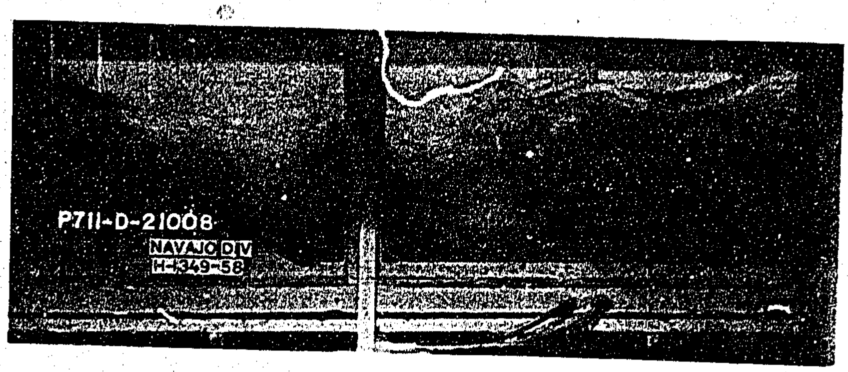
Side View - T. W. El. 5714

NAVAJO DAM
Recommended Diversion Basin - Dry Model and 14,500 CFS Discharging
1:24 Scale Model



NOTE
For 14,500 cfs and T.W. El. 5714 pressures at all piezometers are atmospheric or above

NAVAJO DAM
RECOMMENDED CENTER WALL PIER NOSE DIVERSION
1:24 SCALE MODEL

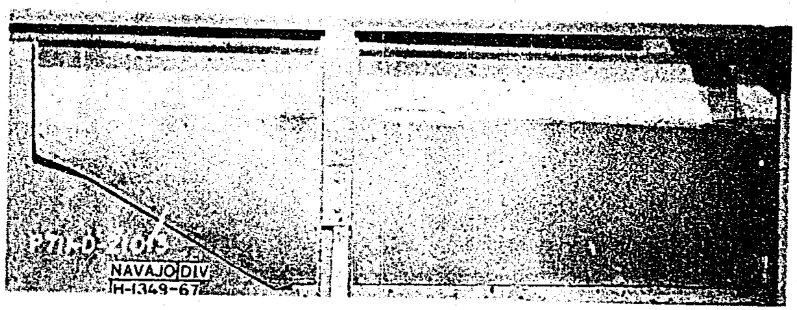


A. Stilling Basin

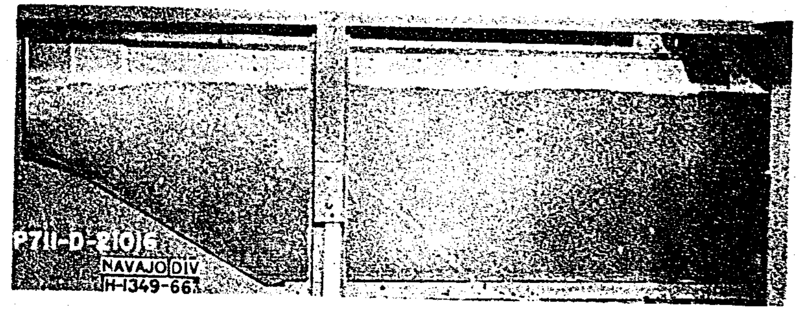
B. Discharge Channel

C. Erosion after one hour model operation

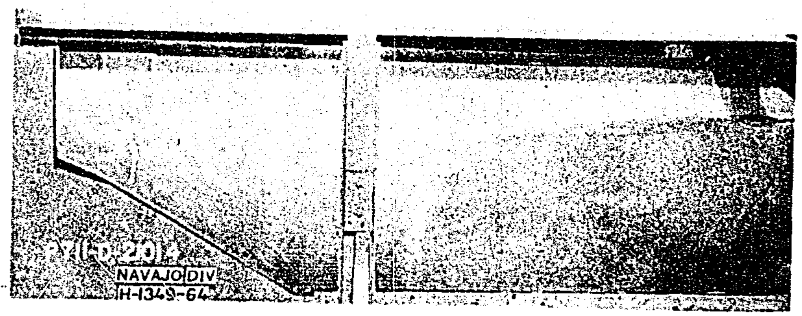
NAVAJO DAM
Recommended Diversion Basin - 14,500 CFS and Scour Test
T.W. El. 5718.5
1:24 Scale Model



Discharge = 3, 625 cfs   T. W. El. 5711

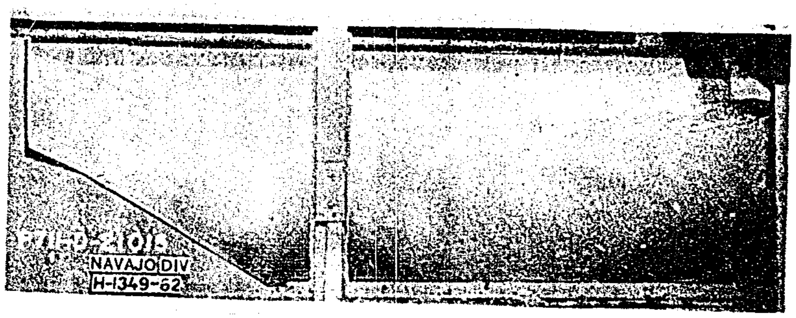


Discharge = 3, 625 cfs   T. W. El. 5718

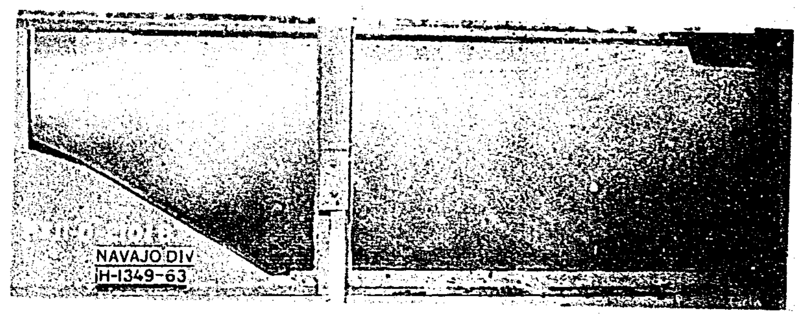


Discharge = 7, 250 cfs   T. W. El. 5713

Discharge = 7, 250   T. W. El. 5721

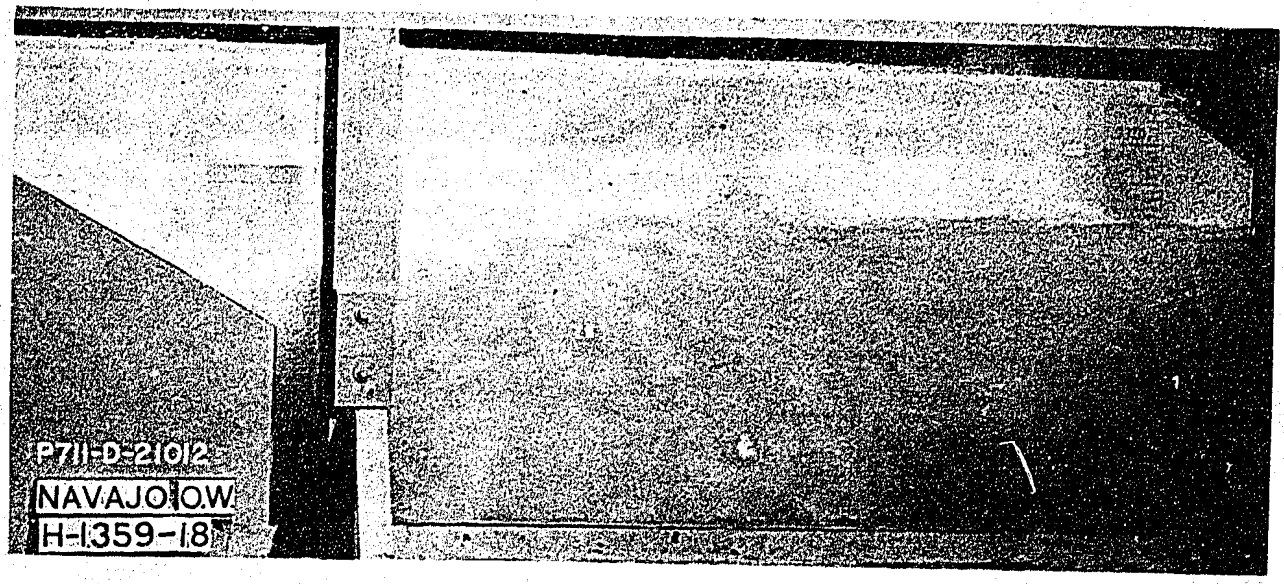


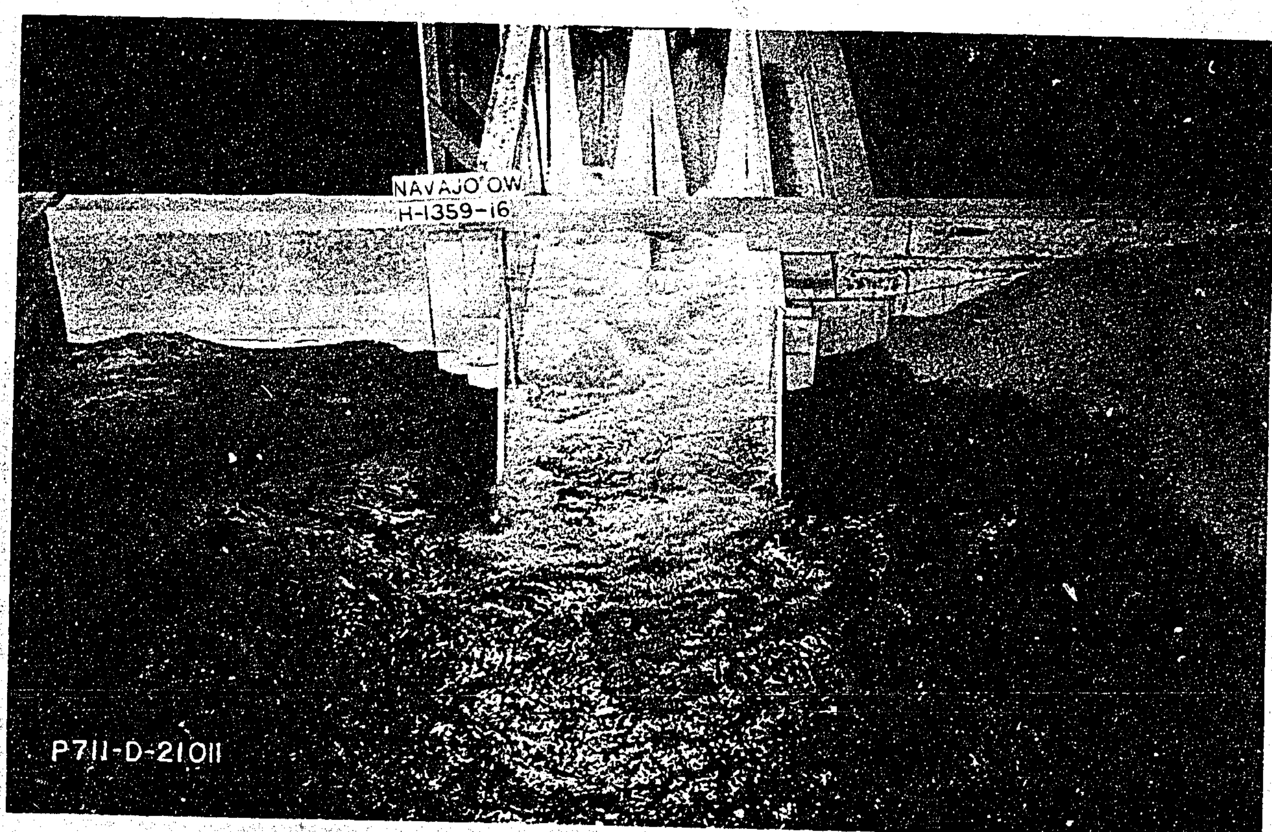
Discharge = 10, 875 cfs   T. W. El. 5714



Discharge = 10, 875 cfs   T. W. El. 5722

NAVAJO DAM
Flow Conditions in the Recommended Diversion Basin
1:24 Scale Model

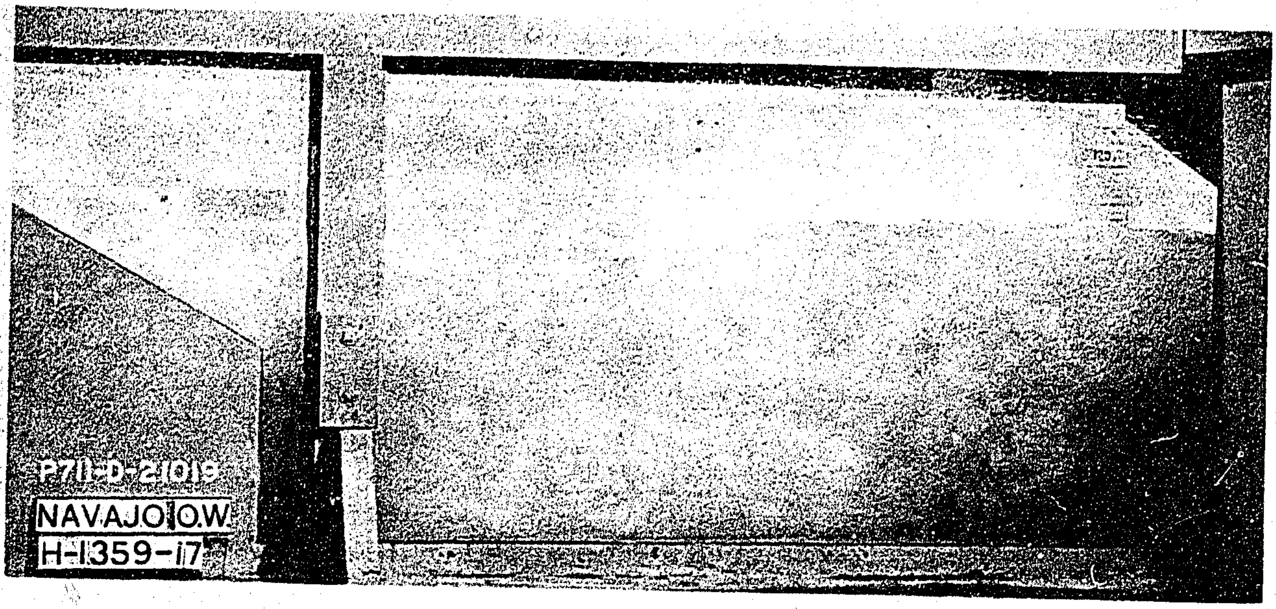


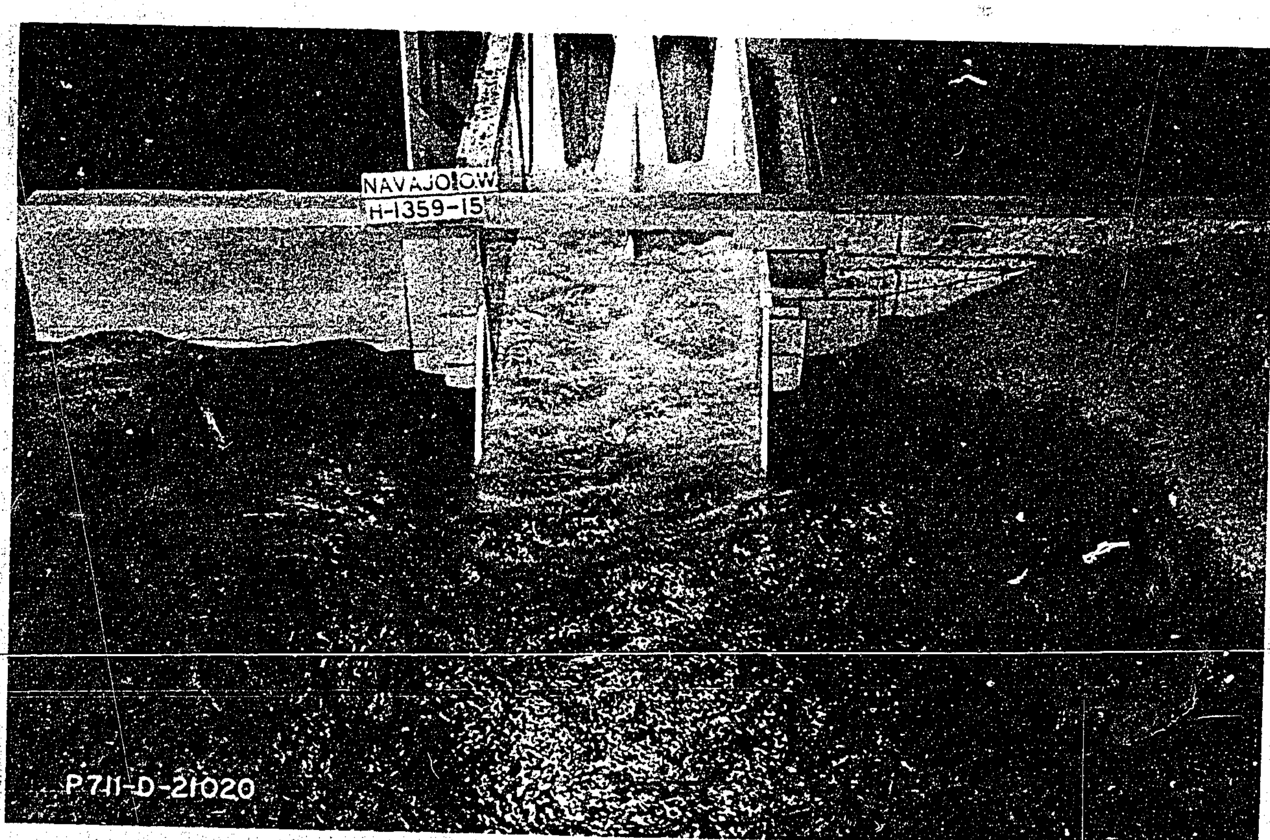


Note: 217 feet of head at valves 100 percent open

NAVAJO DAM
Recommended Outlet Works Basin--4580 CFS--Tailwater Elevation 5709
1:24 Scale Model

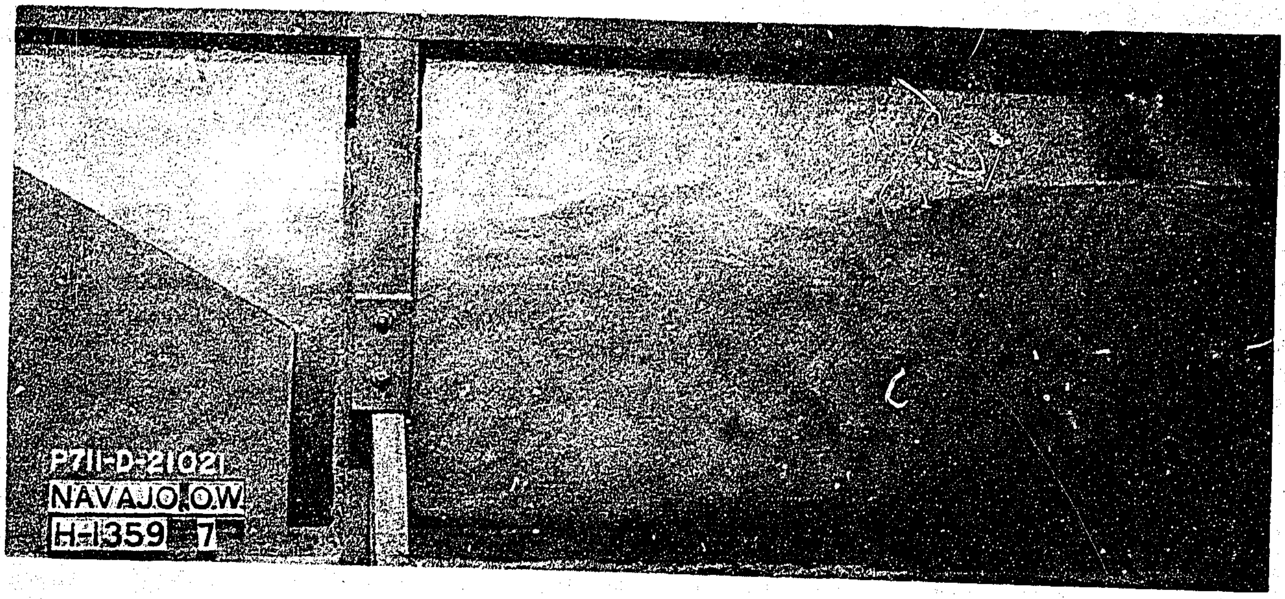
Figure 28
Report HYD 457

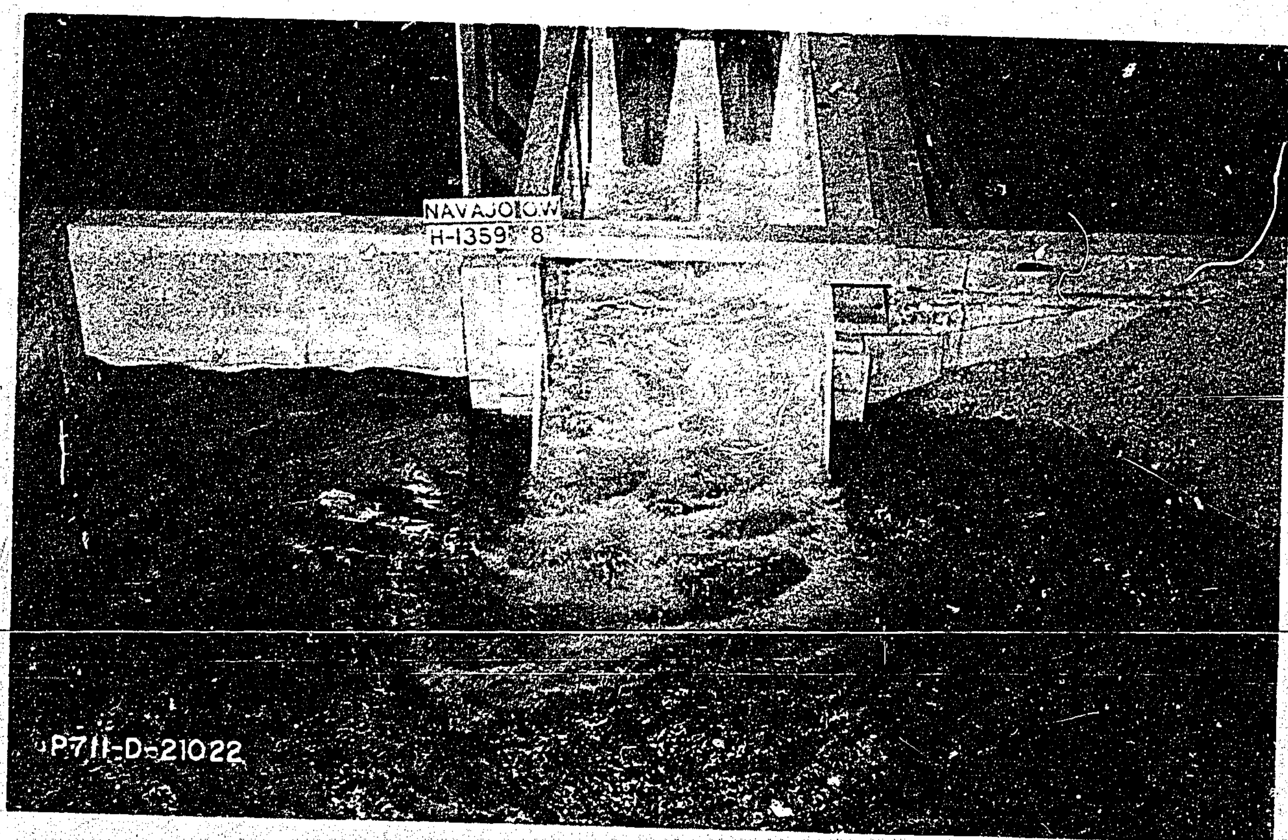




Note: 210 feet of head at valves 100 percent open

NAVAJO DAM
Recommended Outlet Works Basin--4580 CFS--Tailwater Elevation 5711
1:24 Scale Model

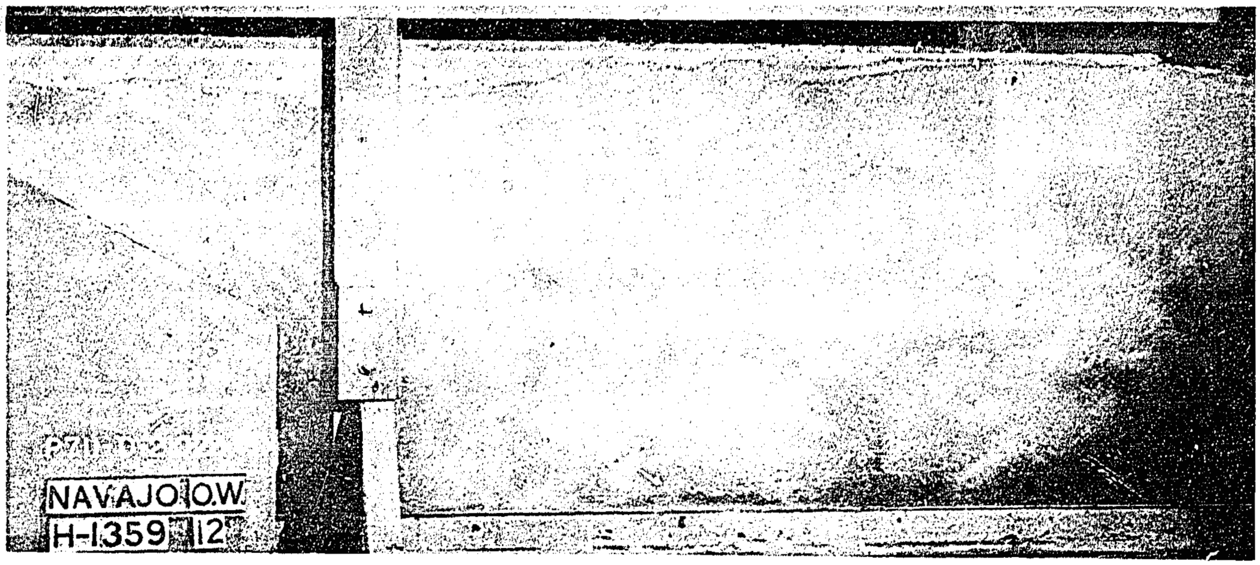


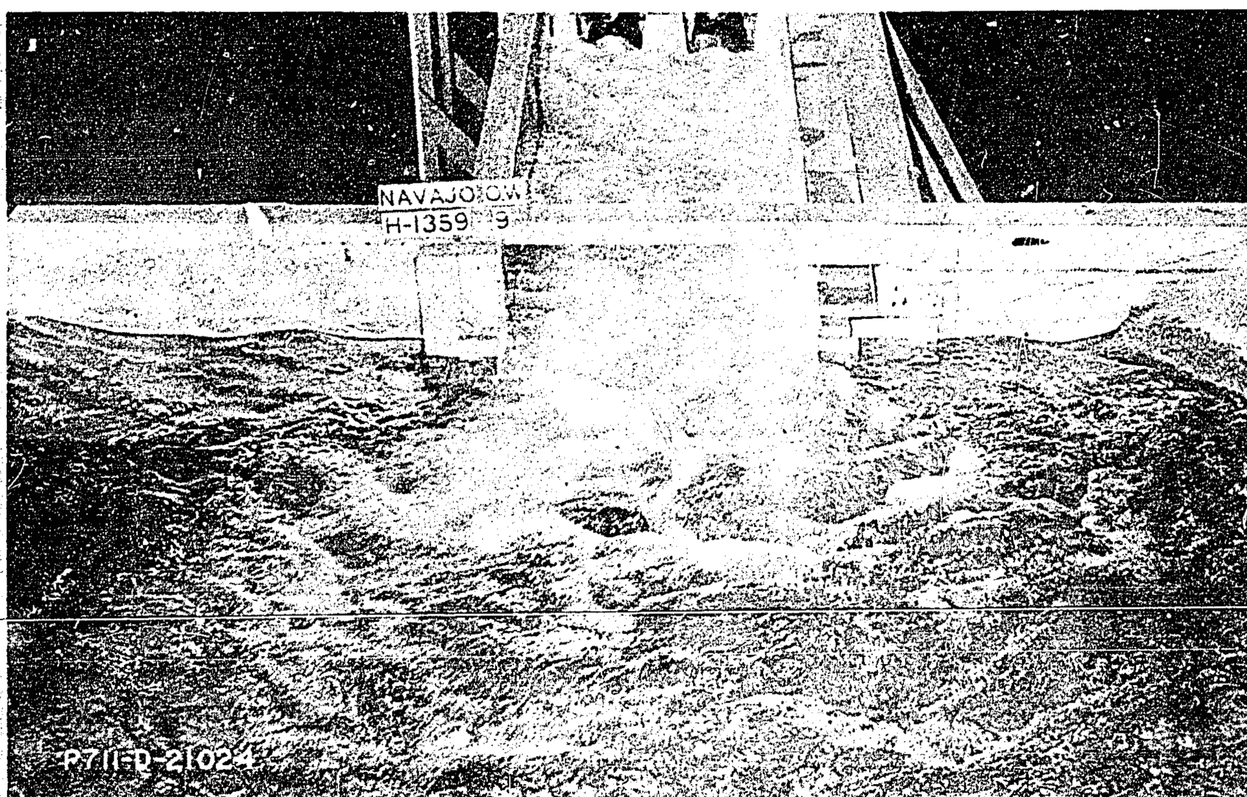


Note: 217 feet of head at valves 100 percent open
Water surface fluctuation at tailwater gage is 0.8 foot

NAVAJO DAM
Recommended Outlet Works Basin--4680 CFS--Tailwater Elevation 5714
1:24 Scale Model

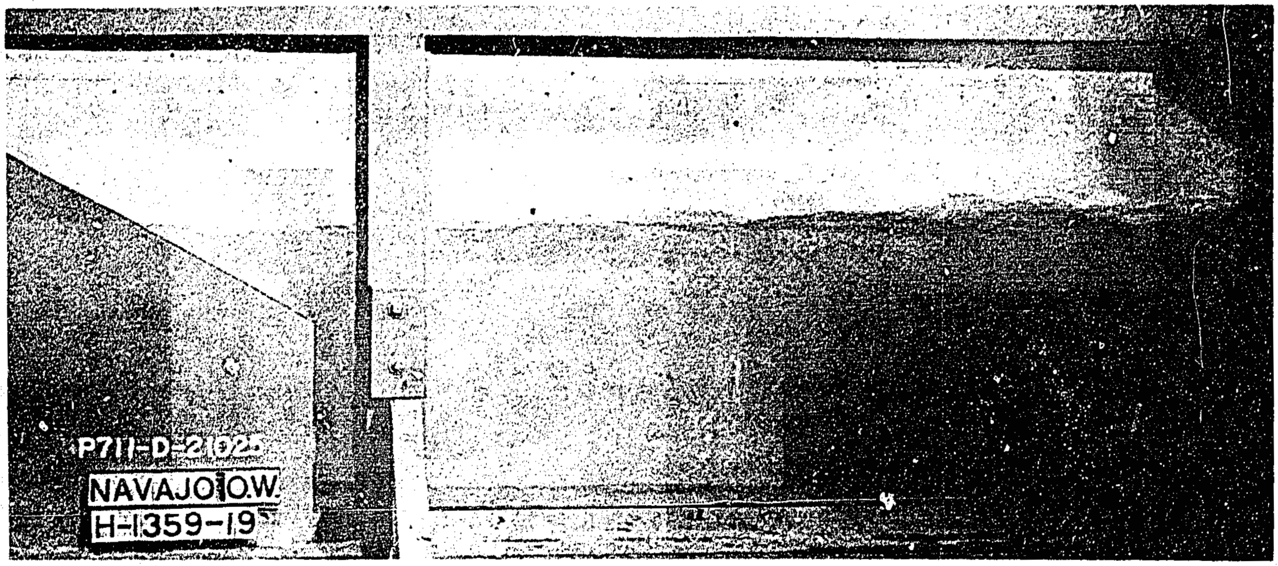
Figure 30
Report HYD 457





Note: 217 feet of head at valves 100 percent open

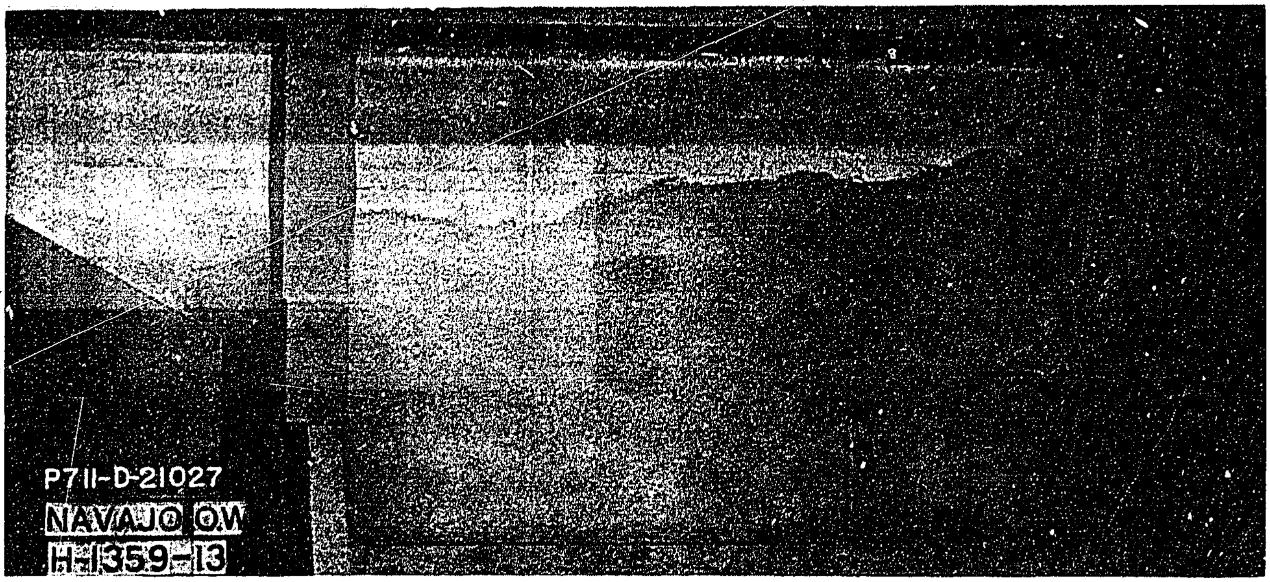
NAVAJO DAM
Recommended Outlet Works Basin--4680 CFS--Tailwater Elevation 5723
1:24 Scale Model

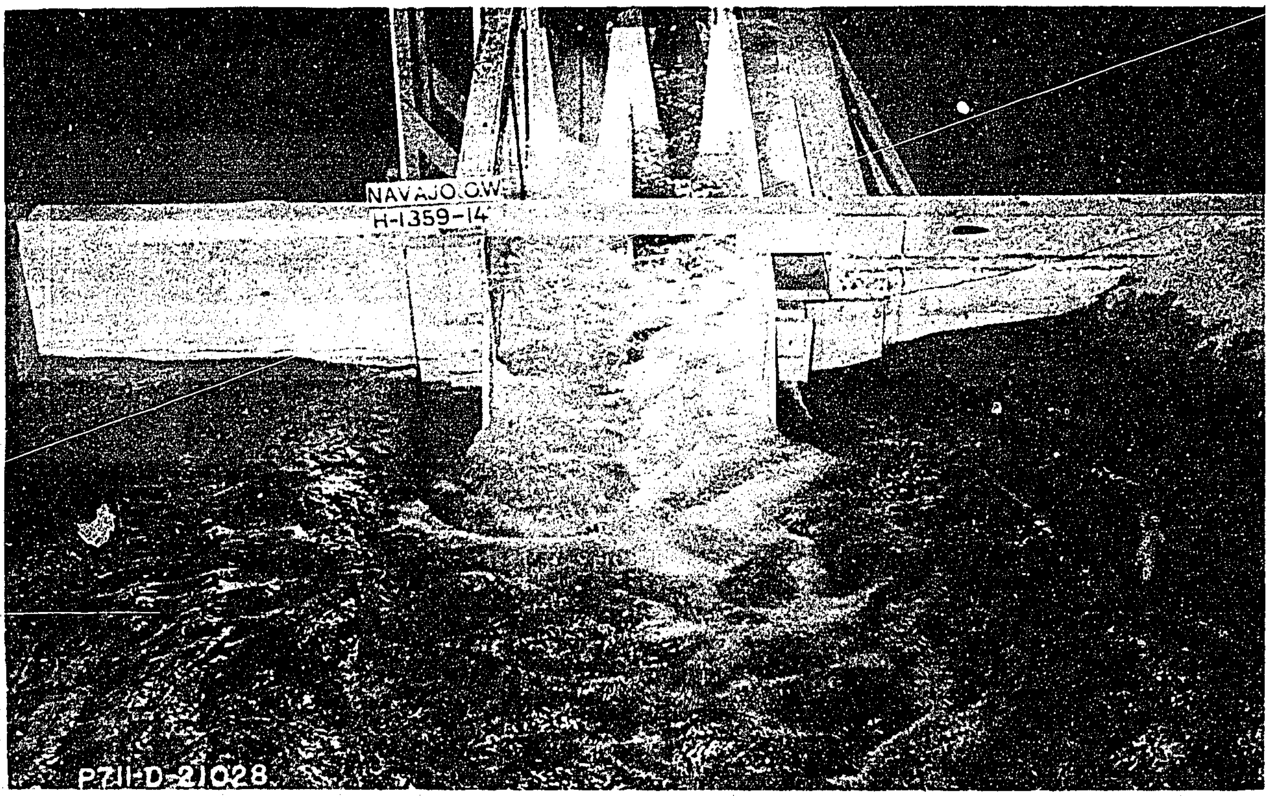


Note: 278 feet of head at left valve 100 percent open

NAVAJO DAM
Recommended Outlet Works Basin--2650 CFS--Tailwater Elevation 5711
1:24 Scale Model

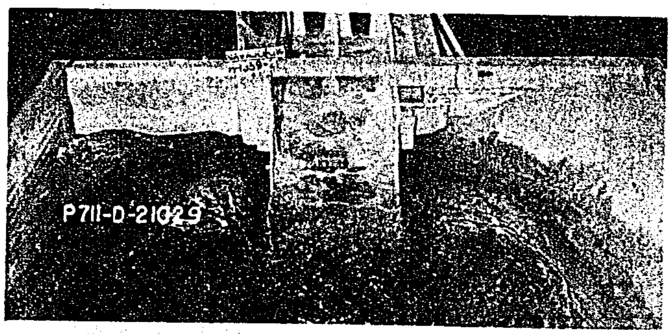
Figure 32
Report HYD 457



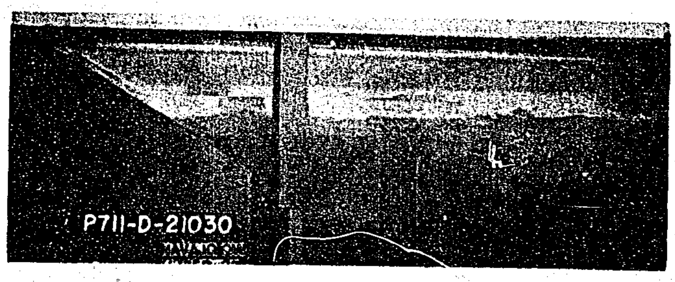


Note: 308 feet of head at right valve 100 percent open

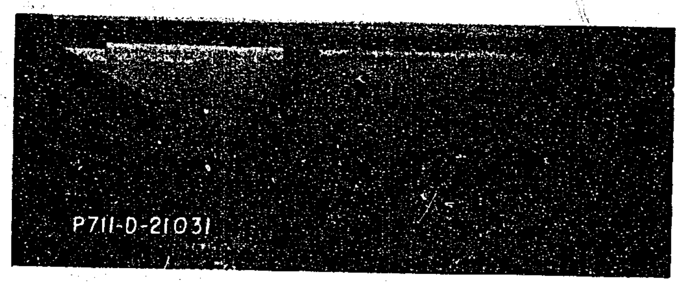
NAVAJO DAM
Recommended Outlet Works Basin - 2710 CFS - Tailwater Elevation 5715
1:24 Scale Model



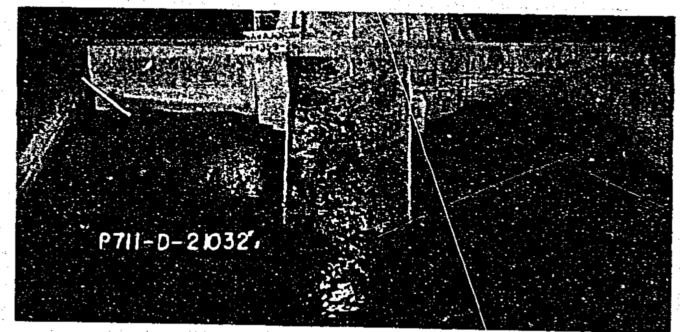
A. **Valves** 50% open, Head **166 feet**, T.W. El 5711



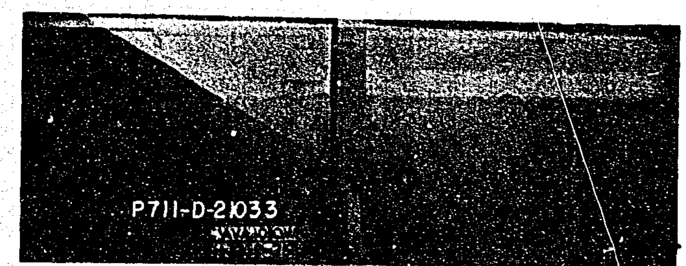
B. Same as A



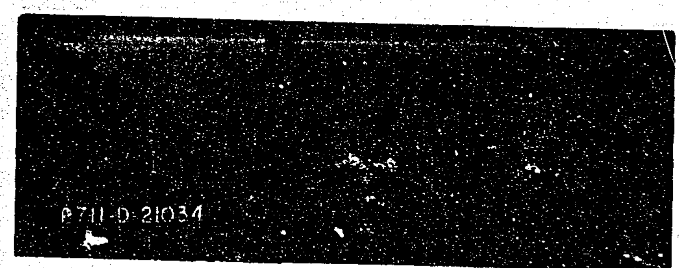
C. Same as A except T.W. El. 5723



C. Valves 100% open, Head 54 feet, T.W. El. 5711



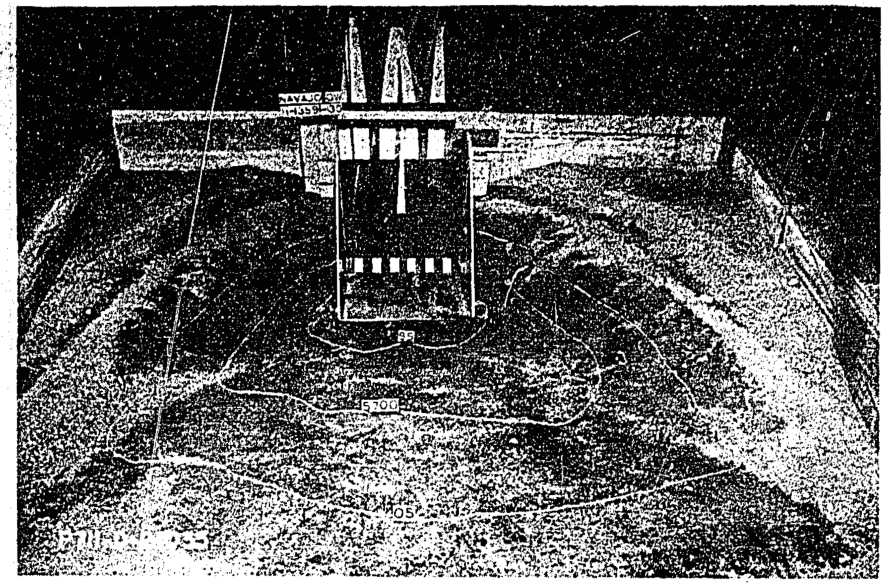
D. Same as C.



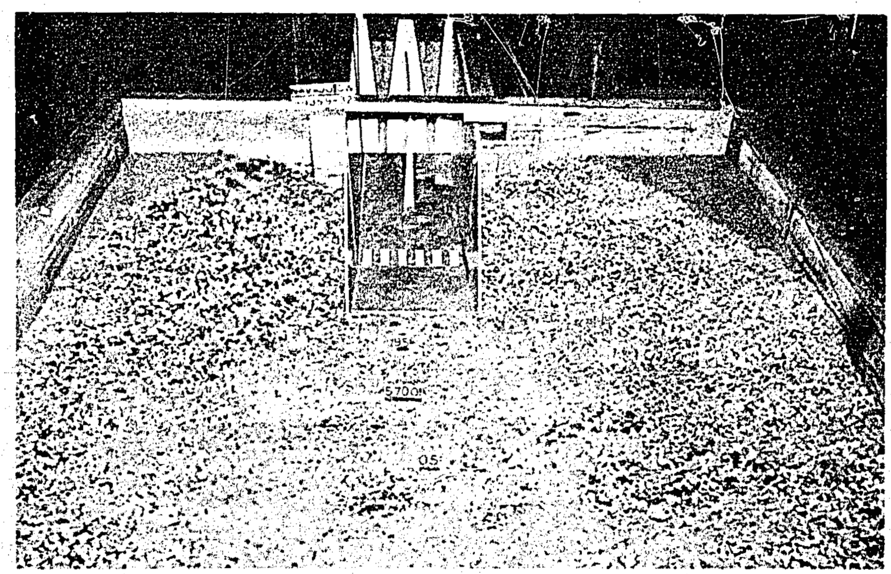
E. Same as C except T.W. El. 5723

NAVAJO DAM
Recommended Outlet Works Basin - 2,340 CFS
1:24 Scale Model

Figure 34
Report HYD 457



A. Head at valves 100 percent open 217 feet. Tailwater elevation 5713. Erosion pattern in sand after a one hour model test run.



B. **Head** at valves 100 percent open 217 feet. Tailwater elevation 5713. Erosion pattern in riprap after 5 hour model test run.

NAVAJO DAM
Recommended Outlet Works Basin--Scour Tests--4,680 CFS
1:24 Scale Model