University of Minnesota
St. Anthony Falls Hydraulic Laboratory

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MODEL STUDIES OF THE SAN LORENZO SPILLWAY EXECUTIVE HYDROELECTRIC COMMISSION LEMPA RIVER EL SALVADOR, CENTRAL AMERICA

by

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PREFACE

Two models of the spillway for the San Lorenzo Project on the Lempa River in El Salvador, Central America were constructed and tested at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. The purpose of the model studies was to observe the hydraulic characteristics of the flow in the approach, the spillway, and the tailrace. A 1:50 scale section model was constructed consisting of two bays of the six bay spillway and observations were made on two stilling basins with elevations of 10 m and 2 m to determine the optimum design. Initial observations were more qualitative in nature to aid in selecting an optimum design for the spillway. Final tests were more quantitative in nature and specific information on approach conditions, spillway rating curves, water surface profiles, pressures, both static and fluctuating, and erosion patterns in the tailrace were measured. A 1:100 scale comprehensive model was also constructed to observe the overall flow characteristics of the structure and verify observations made on the section model. These observations were more qualitative in nature. A photographic record of still photos was kept during the program, many of which are presented in this report.

The model studies described in this report were sponsored by Harza Engineering Company of Chicago, Illinois. Liaison between the Laboratory and Harza was mostly through Mr. Frank G. DeFazio, head of the Hydraulic Analysis and Design Division, and Dr. James E. Lindell. Richard Esser of Harza also spent an extended period of time at the Laboratory assisting in expediting the model program. Several other Harza personnel associated with the project visited the Laboratory during the course of the model studies including Messrs. Earl Beck, Hans Hasen, David Louie, Nathan Hopton, and Dave Kleiner. Also visiting the Laboratory and observing the models were special consultants Drs. Jack Hill of Denver, Colorado and Ken Lee from UCLA, Los Angeles, California; and Francisco E. Granadino from the Executive Hydraulic Commission of El Salvador, Central America. The model studies at the St. Anthony Falls Hydraulic Laboratory were performed by Warren Q. Dahlin and Joseph M. Wetzel with assistance from James Cardle. The models were fabricated in the Laboratory shops.

Model Studies of the
San Lorenzo Spillway
Executive Hydroelectric Commission
Lempa River
El Salvador, Central America

I. INTRODUCTION

The San Lorenzo Project is located on the Lempa River in El Salvador. It is the smallest of the Central America republics with an area of 8,260 square miles and a population of about 4 million. It is a mountainous country with many volcanoes and upland plains, bounded by Guatumala, Honduras, and a 160 mile coastline of the Pacific Ocean as shown on Chart 1. The republic is primarily agriculture but is developing its industry. The capital is San Salvador.

The tributaries of the Lempa River arise in the mountains of Honduras and El Salvador, combine and flow across El Salvador to the Pacific Ocean. Two dams have been constructed on the upper reaches of the Lempa for the purpose of generating hydroelectric power; the 5 De Noviembre Project completed in 1954, and the Cerron Grande Project completed in 1977 which is just upstream of 5 De Noviembre. The San Lorenzo Project is downstream of 5 De Noviembre at a site about 50 kilometers upstream of the mouth of the Lempa River. The San Lorenzo Project involves construction of a 46-meter-high dam, a 180 - MV powerhouse, and a 25,000 cms capacity spillway.

The San Lorenzo Project initially consisted of a 6-bay service spillway to pass normal flood flows and an overflow auxiliary spillway over the fill-dam to increase capacity for probable maximum flood (PMF) conditions. During the course of the model studies and based on further geologic surveys at the site, the spillway design was revised to an 8-bay-scheme service spillway with no auxiliary spillway. The initial 6-bay spillway had a dam crese elevation of 33 m, approach elevation of 22 m and 6 bays each 12.2 m wide with gates 12.2 m x 16.0 m. The spillway has a length of 109.06 m with the basin floor elevation to be determined by the model studies at either 10 m or 2 m and a 3 m high end sill. The tailrace is excavated to the elevation of the top of the end sill, either 13 m or 5 m, for 100 m downstream of the sill then slopes upward at a 10 to 1 slope to the river bed elevation of 17 m. These controlling dimensions are shown in Charts 2 and 3.

The model program consisted of the construction and testing of two models; first a 2-bay section model to determine the optimum basin elevation, and finally a comprehensive model incorporating the spillway design developed in the section model. A scale of 1:50 was selected for the section model and 1:100 for the comprehensive model.

A. Scale Relationships for Hydraulic Similarity

The geometrically similar prototype and model spillways represent hydraulic systems in which gravity is the predominant force in producing motion. At the relatively large scales used fluid friction and surface tension effects are negligible. In this type of hydraulic system, with gravity the governing force, the model-prototype relationships are determined by the Froude law of similarity and the following relationships are derived:

		1:50 Section Model	1:100 Comprehensive Model
$L_r = \frac{L_p}{L_m}$	=	50	100
$Q_r = (L_r)^{5/2}$	=	17,677.67	100,000
$V_r = (L_r)^{\frac{1}{2}}$	=	7.07	10
$T_r = (L_r)^{\frac{1}{2}}$	=	7.07	10
$P_r = L_r$	=	50	100

in which L is the length, Q is the discharge, V is the velocity, T is the time, and P is the pressure. The subscript r refers to the ratio; p to the prototype or full-scale, and m to the model. Using the above equations, the model discharges can be determined for selected prototype discharges and passed through the model and prototype values of headwater and tailwater transposed to model values by the L_r. Velocities and pressures measured in the model can be converted to prototype values with a high degree of accuracy. The erosion patterns developed in the model can be translated to prototype dimensions by means of the L_r, but this gives more of a qualitative indication of scour than a precise measure because the model cannot exactly simulate the resistance to erosion in the prototype. In the model a bed material was chosen whose critical tractive force was slightly less than the tractive force generated by the flow so that the bed material would move and show the erosion patterns if erosion was to occur.

II. EXPERIMENTAL TESTS ON SPILLWAY SECTION MODEL

A. Six Bay Scheme

The first objective of the model studies was to construct the 1:50 section model of the spillway modeling two of the six bays, make observations of pressures and water surface profiles, and erosion patterns in the tail-race downstream of the spillway with the stilling basin at an elevation of 10 m and alternately at 2 m. After selecting the optimum basin elevation and training wall geometry, more detailed observations and measurements were made to document the approach flow to the spillway, spillway rating curves, pressures on the spillway, both static and fluctuating, water surface profiles through the entire structure, and detailed erosion patterns in the tailrace. The 1:50 section model was located in a basin 2.74 m wide, 13.9 m long, and 1.83 m deep in the turbine room of the St. Anthony Falls Hydraulic Laboratory where the relatively large model discharges required were available. The section model is relatively large and Photos 1-3 show the model being observed by visiting personnel from Harza in Photo 1, Harza and the consulting board in Photo 2, and Harza and Executive Hydroelectric Commission in Photo 3.

1. Type A Spillway

The initial model constructed was designated as the Type A spillway. The overall model layout is shown on Chart 2; spillway crest, stilling basin, pier, and gate details on Chart 3, and stilling basin and wing-wall geometry on Chart 4. Significant elevations for Type A, as shown on the charts are: approach elevation of 22 m, dam crest elevation of 57.25 m, spillway crest elevation of 33.0 m, stilling basin elevation of 10 m, and a tailrace elevation of 13 m downstream of the basin sloping upward at a 10 to 1 slope to the river bed elevation of 17 m.

The spillway consists of two 12.2 m wide bays, separated by a full pier. A half pier was placed next to the viewing window to more closely simulate prototype flow conditions. The spillway crest, stilling basin, and piers were accurately machined and fabricated of lucite or clear plastic to specified dimensions (Photos 4 and 5). The two gates, each 12.2 m by 16.0 m were fabricated of brass in the model and provided with rubber seals.

The upstream retaining wall was constructed of sheet metal, the downstream training wall of plywood, and the upstream and downstream faces of the dam of plywood. The approach was made non-erodible, being molded of a lightweight concrete. A 30.48 cm supply line with a 15.24 cm by-pass for lower flows, both containing orifice flow meters and control valves, conveyed the inflow from the laboratory supply system to the model by gravity flow. A baffle screen was provided to reduce turbulence in the approach to the spillway.

The downstream tailrace was made erodible to study erosion patterns and facilitate the comparing of effectiveness of the various geometries tested in the model. A bed material was selected that would move slowly when subjected to the model flow conditions, thus giving a qualitative indication of the erosion pattern if erosion would occur in the prototype. The stone size distribution of the material selected is shown on Chart 5 and has a D_{50} = 8.8 mm (model). This material was readily available from a local gravel supplier as a standard screening.

To facilite molding of the tailrace, plywood templates were cut to the tailrace geometry, supported from overhead, and the bed material placed to conform to the templates. These templates were then used to remold the tailrace between runs thus giving the same starting configuration for the various geometries tested. At the downstream end of the model an adjustable weir was provided for tailwater control. The tailwater rating curve used in the model studies was supplied by Harza and reproduced on Chart 6.

The completed Type A model ready for testing is shown in Photos 6 and 7. Nylon cords have been placed on the bed to outline pertinent features. Photos 8 - 10 show the model in operation simulating normal flow conditions with Q = 10,300 cms, H.W. = 49 m, and T.W. = 27 m with the gates wide open. Photos 8 and 9 were exposed at a time of 1/5 sec, so that paper confetti spread on the water surface would delineate the flow patterns in the tailrace more effectively. The return currents back towards the the downstream training wall shown by the confetti streaks and the wave action combine to cause considerable erosion at the end of the wall. After 12 hours of flow with the normal discharge of 10,300 cms, the erosion is severe, as shown in Photos 12 and 13. In these photos nylon cords have been placed along the elevation contours to more clearly show the erosion pattern developed. The deepest point of erosion is just downstream of the end sill reaching an elevation of 3.7 m.

When the design flow of 18,000 cms is simulated in the model, the hydraulic jump is swept out of the stilling basin resulting in a deep scour hole downstream of the basin, as seen through the viewing section in Photo 11.

2. Type B Spillway

The Type B spillway is similar to Type A with the stilling basin lowered to elevation 2 m and the tailrace molded accordingly. The length of the spillway remains the same. These revisions are detailed on Charts 3 and 4 and Photos 14 and 15 show the revised model ready for testing. Photos 16 and 17 taken with an exposure time of 1/5 sec. show the flow patterns developed with a normal flow of 10,300 cms and may be compared to Photos 8 and 9 of Type A. The erosion pattern in the tailrace after 12 hours of flow is shown in Photos 18 and 19 for Type B and may be compared to Photos 12 and 13 for Type A. Comparisons indicate not much reduction in erosion, if any, in the region of the downstream training wall and in the tailrace for Type B.

3. Type B-1 Spillway

In an attempt to reduce erosion near the downstream left wing wall, a supplemental wing wall was added which consisted of a curved section with a 30 m radius and a 20 m length of straight wall. The total projection perpendicular to the spillway is 50 m, the same as for Types A and B. This arrangement was designated as Type B-1, with the dimensions given on Chart 4 and shown in Photos 20 and 21 of the model before testing. The normal flow of 10,300 cms is shown in Photos 22 - 24 and the resulting erosion pattern after 12 hours of flow in Photos 25 and 26. These photos can be compared to those for Types A and B and show no significant reduction in the amount of erosion.

4. Type A-1 Spillway

After testing Type A (basin elevation 10 m) and Type B (basin elevation 2 m) and comparing the results which indicated no significant improvement when the basin was lowered, it was judged desirable to revert back to the stilling basin at elevation 10 m. Also, at the prototype site, further geologic investigations had revealed that if the basin was to be excavated down to 2 m, the rock formation relied on to support the structure would be weakened and thus, the higher basin would be more desirable from the construction viewpoint.

In an attempt to reduce erosion, incorporated into this design (Type A-1) as well as subsequent Types A-2 and C, was a rounded wing wall design downstream of the stilling basin as dimensioned on Chart 4. In addition, Type A-1 also included two fillets in the stilling basin, one at the junction with the spillway chute and the other at the end sill (Chart 3). When the model was operated with various flows, it was evident that the fillets had the effect of making the stilling basin act like a flip-bucket shooting the sheet of water out into the tailrace causing considerable scour. Because of this undesirable characteristic, Type A-1 was observed briefly and judged not feasible for this project.

5. Type A-2 Spillway

Type A-2 spillway is similar to Type A-1 with the fillets in the stilling basin removed. The Type A-2 design is described on Charts 3, 4, and 7, with Chart 7 outlining the tailrace geometry in more detail. Photo 27 shows the Type A-2 model ready for testing; Photos 28 and 30 a flow of 10,000 cms in the model, and Photo 29 the erosion pattern in the tailrace after one hour of flow. The downstream curved-wing wall appears to noticeably reduce the scour in the wing wall area thus giving additional protection to the adjacent dam. Also, for a discharge of 10,000 cms the water surface profiles and tailrace profiles after one hour of flow were recorded and are presented on Charts 8 - 10, and the erosion pattern after one hour of flow is plotted on Chart 11. Similar types of observations were made with Q = 18,000 cms, H.W. = 56 m, and the T.W. = 30.5 m. Flow patterns in the tailrace are shown in Photos 31 - 33 and erosion patterns after two hours of flow in Photos 34 and 35. Water surface profiles and the erosion patterns recorded are presented in Charts 12 - 15.

The approach flow conditions to the spillway were also photographically recorded. Photo 36 shows the pattern for a flow of 10,000 cms and Photo 37 for a flow of 18,000 cms. For both discharges the secondary flow over the retaining wall causes considerable disturbance in the flow to the left bay, being more pronounced for the 18,000 cms discharge.

B. Eight Bay Scheme

1. Type C Spillway

In consideration of further hydrologic and geologic information, the design engineers decided it was necessary to change the basic design of the spillway from the 6 bay service spillway and overtopping auxiliary spillway for PMF conditions to an 8 bay service spillway scheme. All spillway elevations remained the same, except for the approach elevation which was raised from elevation 22 m to 26 m, as indicated on Charts 3 and 16. To provide for this change in the model, a layer of stones of the size used in the tailrace was placed in the approach to raise the elevation to 26 m. Other than this, no further physical revisions to the section model were required and the configuration was designated as the Type C spillway.

As the model has only 2 bays, in the 6 bay scheme the model inflow was 2/6 of the total flow for the entire spillway. For the 8 bay scheme, the model inflow required was 2/8 of the total spillway flow and was adjusted accordingly.

The Type C spillway represents the optimum design developed for the San Lorenzo Project. Consequently, more detailed investigations were conducted for this type. The original or starting geometry in the tailrace for the tests was the same as for Type A-2 shown in Photo 27 and on Chart 7. The only difference was in the raised approach for Type C. Photos 38 and 39 show the model in operation with a flow of 10,000 cms and Photo 40 the erosion pattern in the tailrace after one hour of flow. Photos 41 and 42 show a flow of 18,000 cms and 43 the erosion pattern after two hours of flow. Photos 44 and 45 show the approach flow conditions for flows of 10,000 cms and 18,000 cms, respectively.

Chart 16 shows the layout of the Type C spillway and locations of the pressure taps used for measuring both static, and in selected locations, the fluctuating pressures. The spillway rating curve of headwater versus discharge is presented on Chart 17 and the spillway rating curve of partial gate openings versus discharge on Chart 18.

In tests on Type C, the same prototype flows of 10,000 cms and 18,000 cms were run on the model. For the 10,000 cms flow the model discharge was lower than for the 6 bay scheme and the gates were closed to 10.4 m to bring the headwater up to 49 m, the same elevation as in previous tests. For the 10,000 cms flow the water surface profiles, tailrace profiles, and erosion pattern in the tailrace are presented on Charts 19 - 22; and for the 18,000 cms flow on Charts 23 - 26.

Piezometric pressures were measured along four lines through the spillway at the locations given on Chart 16. As partial gate openings could cause critical pressures on the spillway, considerable emphasis was placed on these tests. Observations were made with gate openings of 1, 2, 8, and 10.4 measured perpendicular to the spillway surface. For these tests the gate openings were carefully set and the flow adjusted to bring the headwater up to elevation 49 m. The resulting piezometric pressures are presented graphically on Charts 27 - 30. With gates wide open, pressures were measured with discharges set at 13,200, 18,000, and 28,000 cms and are presented on Charts 31 - 33. The flow of 28,000 cms was the maximum obtainable in the model and for this flow the pressures dropped to negative values over the spillway crest as shown on Chart 33. The actual measured piezometric pressure values for the various taps and flow conditions investigated are tabulated on Charts 34 - 37.

Fluctuating pressures were measured at selected critical locations on the spillway. For partial gate openings and lower flows tap locations 5, 6, 10, 11, and 13 were selected and for higher flow tap locations 10, 11, 13, 17, 18, and 19 were used. Measurements were made at these locations along three lines through the spillway; one meter from the left training wall, along the centerline of the left bay, and 1 meter from the right side of the full pier. The pressure measurements were made using a 1.758 Kgs/sq cm pressure transducer chamber mounted in a lucite block and connected to the selected tap with a rigid brass tube having a 1.59 mm diameter pressure line 38.1 mm long. The pressure fluctuations sensed by the transducer were transmitted by an electrical signal through a Sanborn amplifier to a recording oscilliscope where the fluctuations were displayed. The recordings shown on Charts 38 - 59 are duplications of photographs taken of the scope after a one minute run (model time). The scope was set so that the trace would make one sweep across the scope per second; thus each succeeding sweep is superimposed over the previous ones resulting in the wide bands shown. The photographs were taken with a 1 sec. time exposure; thus on some records the characteristics of the last individual trace can be seen as the whiter trace in the broad band. For small gate openings of 1 m with a flow of 1150 cms and 2 m openings with a flow of 2250 cms, the fluctuations recorded are shown on Charts 38 - 42, and Charts 43 - 47, respectively. No significantly low pressures were recorded, although one pressure dip reached zero as seen on Chart 46 at tap 10. With the gate opening of 8 m and corresponding flow of 7,900 cms, more significant negative pressures start to appear as can be seen on Charts 48 - 51. For example, pressure dips to elevation 6 m (-4 m pressure) occurred at tap 13 along the centerline of the left bay (Chart 50) and to elevation 6 m (-7 m pressure) at tap 18 (Chart 51). Pressure fluctuations with the gates wide open and a flow of 13,200 cms are presented on Charts 52 - 55. For this flow condition, the pressure dips reach a low elevation of 0 m (-13 m pressure) at tap 18 along the centerline of the left bay (Chart 55). For a flow of 28,000 cms, the fluctuations are presented on Charts 56 - 59, with pressure dips as low as elevation 0 m (-13 m pressure), again at tap 18 along the centerline of the left bay (Chart 59).

III. OBSERVATIONS ON COMPREHENSIVE MODEL - SIX-BAY SCHEME

The six-bay scheme comprehensive model as shown in Photos 46 and 47 was constructed concurrently with the section model. It was constructed to a scale of 1:100 and located on the river mezzanine floor of the Laboratory occupying a model basin 8.5 m wide by 18.3 m long. The inflow was pumped from the Mississippi River to the model through a 30.48 cm supply line with a 10.16 cm by-pass line for lower flows, both of these containing calibrated orifice flow meters and control valves. The flow entered the model through a T-shaped manifold to distribute the inflow and a mesh baffle to reduce turbulence. The approach to the spillway was made non-erodible and molded from lightweight concrete using imbedded metal templates as guides. The spillway crest was fabricated from fiberglass, the piers from wood, the spillway chute and stilling basin from lucite, the powerhouse from sheet metal, and the overflow auxiliary spillway of concrete. No radial gates were provided. The tailrace was made erodible and molded from gravel with a D_{50} = 0.6 mm (model) using wooden templates as guides. Chart 60 shows the tailrace material size distribution. An adjustable weir was provided at the downstream end to control the tailwater level.

The comprehensive model was used extensively for qualitative observations of flow and erosion patterns. The completed model ready for testing is shown in Photos 48 - 51. Photos 52 - 54 show the model in operation with a flow of 10,000 cms passing through the service spillway, and Photos 55 - 57 show both service and auxiliary spillways in operation with a combined flow of 18,000 cms.

IV. SUMMARY

1. Observations on the Type A spillway with the stilling basin at elevation 10 m showed that the hydraulic jump stayed in the basin for a flow of 10,300 cms, but considerable erosion took place in the region of the downstream wing wall. With the 18,000 cms flow, the hydraulic jump swept out of the basin, scouring the tailrace extensively.

2. The hydraulic jump remained in the stilling basin for Types B and B-1 (basin elevation at 2 m) for a flow of 10,300 cms, but considerable erosion occurred in the tailrace and near the left training wall.

3. Type A-1, which had the fillets in the stilling basin causing a flip-bucket action, resulted in extensive scour in the tailrace.

4. Observations on the Type A-2 spillway showed that the hydraulic jump stayed in the stilling basin for a flow of 10,000 cms and the rounded left wing wall appeared to reduce erosion in that area, thus providing more protection for the dam. With a flow of 18,000 cms, the jump swept out of the

basin and considerable scour occurred in the tailrace. Flow over the upstream left retaining wall caused considerable disturbance in the flow to the left bay.

5. The Type C spillway with the reduced unit discharge operated more effectively than Type A-2. For both flows of 10,000 cms and 18,000 cms, the hydraulic jumps remained in the stilling basin. The scour was also reduced but considerable erosion still occurred around the curved training wall for the 18,000 cms flow. The disturbance in the approach to the left bay was reduced. Some negative pressures were observed at the higher spillway flows. The seriousness of these negative pressures would depend on the occurrence frequency of these flow conditions.

6. Qualitative observations on the comprehensive model indicated derrick stone protection was needed downstream of the structure along both right and left banks, by the curved wing wall, and by the overflow-auxiliary spillway. Stones placed upstream between the service and auxiliary spillways mproved flow conditions in that area.

LIST OF PHOTOS

Photo No.

18	(Serial No. 264-47) Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.
19	(Serial No. 264-49) Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.
20	(Serial No. 264-59) Type B-1; The revised model ready for testing.
21	(Serial No. 264-60) Type B-1; The revised model ready for testing.
22	(Serial No. 264-66) Exposure time 1/5 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.
23	(Serial No. 264-68) Exposure time 1/5 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.
24	(Serial No. 264-69) Exposure time 1/100 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.
25	(Serial No. 264-70) Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.
26	(Serial No. 264-71) Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.
27	(Serial No. 264-230) Type A-2; The revised model ready for testing.
28	(Serial No. 264-236) Exposure time 1/10 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.
29	(Serial No. 264-243) Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 1 hour of flow.
30	(Serial No. 264-241) Exposure time 1/50 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.
31	(Serial No. 264-254) Exposure time 1/100 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.
32	(Serial No. 264-248) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.
33	(Serial No. 264-252) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.
34	(Serial No. 264-257) Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.

Photo No.

35 (Serial No. 264-258) Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.

36 (Serial No. 264-262) Exposure time 1/10 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the approach.

37 (Serial No. 264-267) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the approach.

38 (Serial No. 264-292) Exposure time 1/10 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

39 (Serial No. 264-297) Exposure time 1/50 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

40 (Serial No. 264-299) Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 1 hour of flow.

41 (Serial No. 264-304) Exposure time 1/10 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the tailrace.

42 (Serial No. 264-309) Exposure time 1/50 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the tailrace.

43 (Serial No. 264-310) Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.

44 (Serial No. 264-318) Exposure time 1/5 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the approach.

45 (Serial No. 264-323) Exposure time 1/5 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the approach.

46 (Serial No. 264-162) Harza and consulting board personnel observing the comprehensive model.

47 (Serial No. 264-176) Harza and Executive Hydroelectric Commission personnel observing the comprehensive model.

48 (Serial No. 264-159) The completed model ready for testing.

49 (Serial No. 264-160) The completed model ready for testing.

Photo No.	
50	(Serial No. 264-158) The completed model ready for testing.
51	(Serial No. 264-156) The completed model ready for testing.
52	(Serial No. 264-270) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow patterns in the model.
53	(Serial No. 264-274) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow pattern downstream of powerhouse and service spillway.
54	(Serial No. 264-275) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow pattern in approach to service spillway and powerhouse.
55	(Serial No. 264-281) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow patterns in the model.
56	(Serial No. 264-279) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow pattern downstream of powerhouse and service spillway.
57	(Serial No. 264-280) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow pattern in approach to service spillway and powerhouse.
58	(Serial No. 264-283) Q = 18,000 cms (both service and auxiliary spillways), H.W. $\cong$ 54 m, T.W. = 30.5 m; Flow patterns in the model.
59	(Serial No. 264-284) Q = 18,000 cms (both service and auxiliary spillways), H.W. $\cong$ 54 m, T.W. = 30.5 m; Flow pattern downstream of powerhouse and service spillway.
60	(Serial No. 264-285) Q = 18,000 cms (both service and auxiliary spillways), H.W. $\cong$ 54 m, T.W. = 30.5 m; Flow pattern in the approach.

Photo 1 - (Serial No. 264-126) Type A-2; Harza personnel observing the section model.

Photo 2 - (Serial No. 264-149) Type A-2; Harza and consulting board personnel observing the section model.

Photo 3 - (Serial No. 264-172) Type A-2; Harza and Executive Hydroelectric Commission personnel observing the section model.

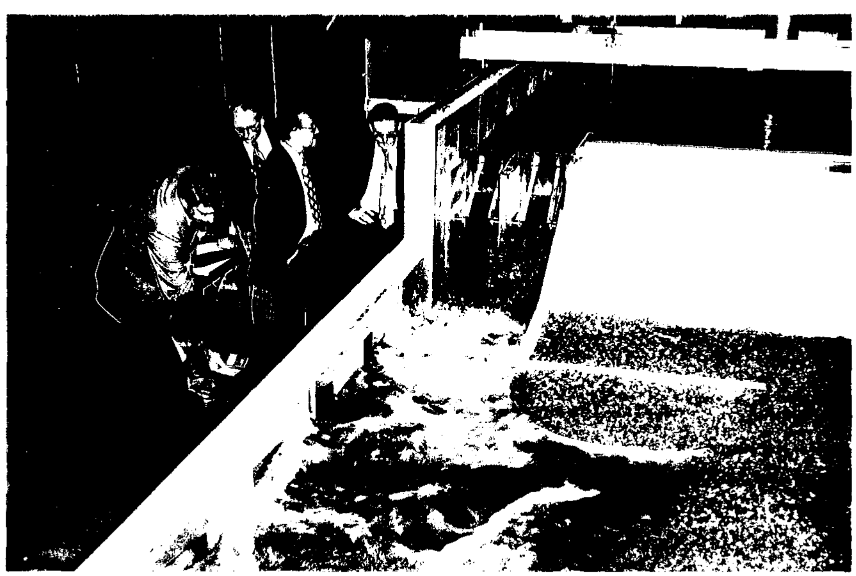
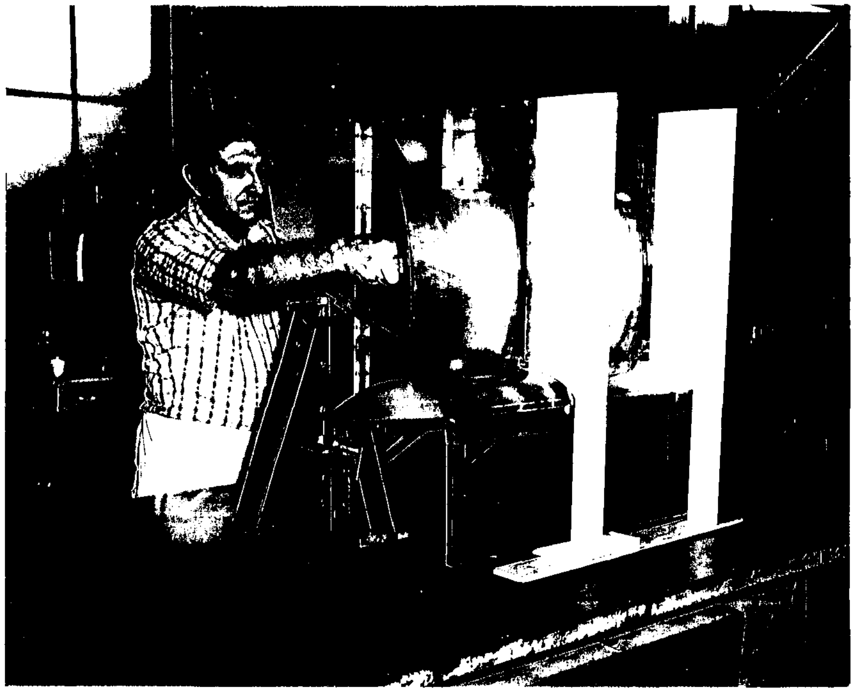


Photo 4 - (Serial No. 264-1) Type A; the control structure under construction.

Photo 5 - (Serial No. 264-4) Type A; the control structure under construction.



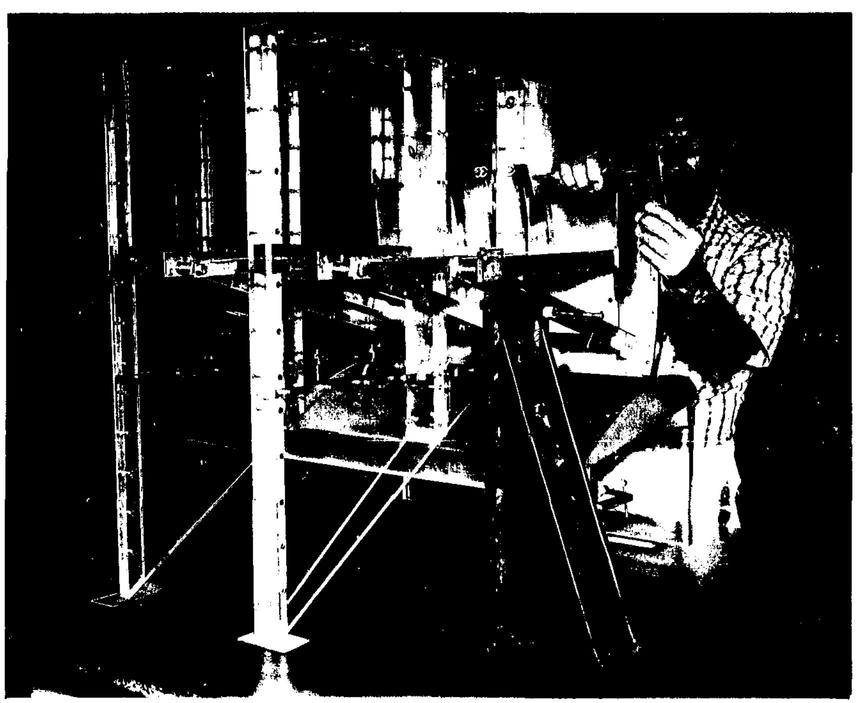
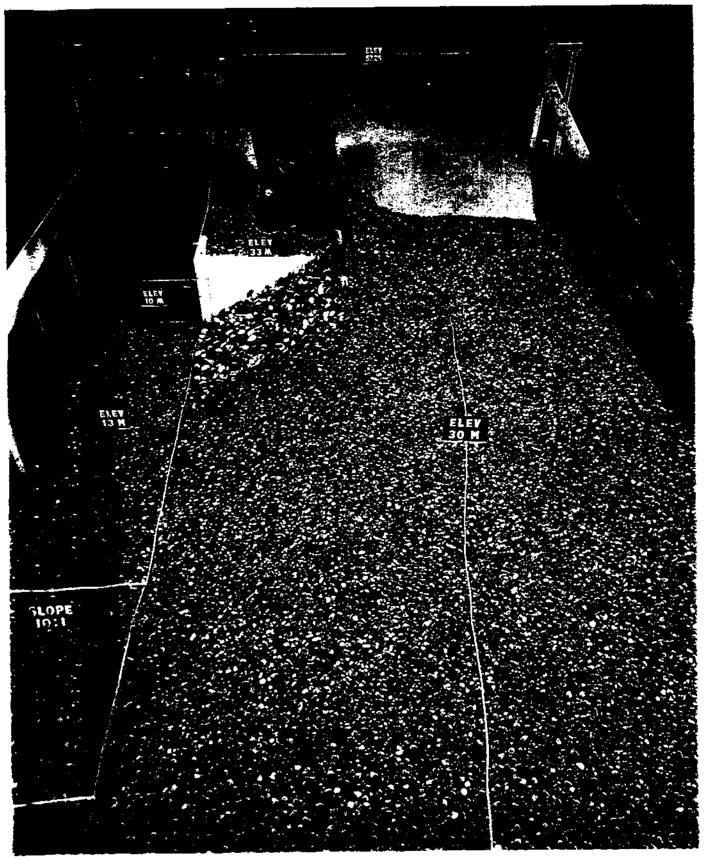


Photo 6 - (Serial No. 264-12) Type A; the completed model ready for testing.

Photo 7 - (Serial No. 264-15) Type A; the completed model ready for testing.


ELEV
33 M
ELEV
10 M
ELEV
13 M
ELEV
30 M
SLOPE
10:1

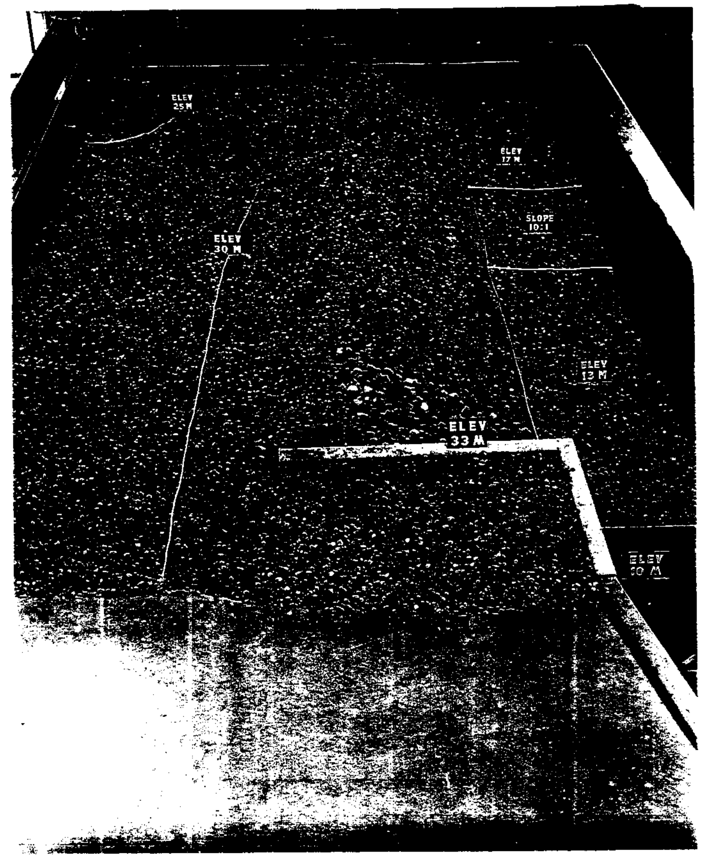
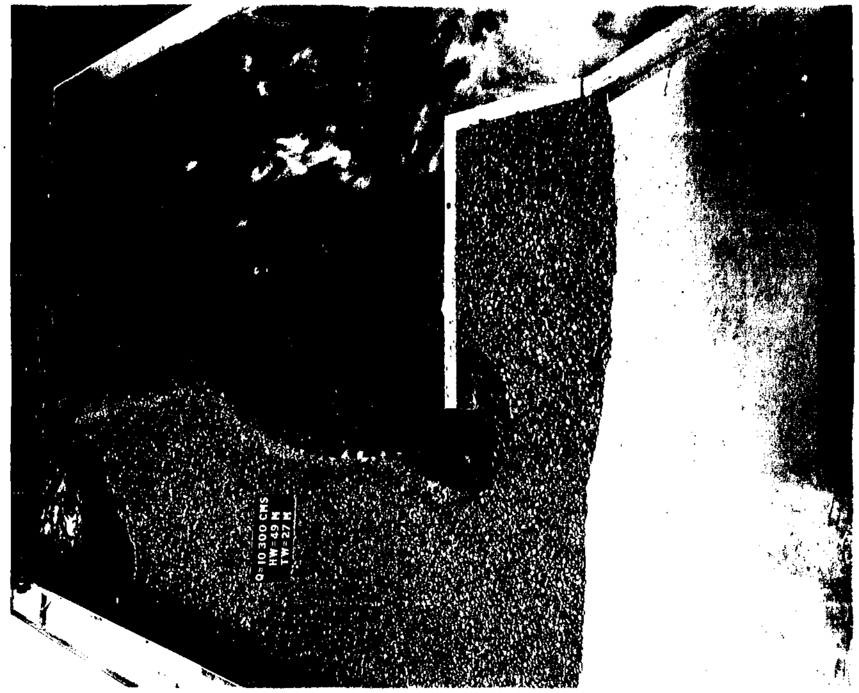

ELEV
25 M
ELEV
17 M
SLOPE
10:1
ELEV
30 M
ELEV
13 M
ELEV
33 M
ELEV
10 M

Photo 8 - (Serial No. 264-21) Exposure time 1/5 sec, Type A, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 9 - (Serial No. 264-17) Exposure time 1/5 sec, Type A, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.


Q=10 300 CMS
HW=49 M
TW=27 M


Q=10 300 CMS
HW=49 M
TW=27 M

Photo 10 - (Serial No. 264-28) Exposure time 1/50 sec, Type A, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 11 - (Serial No. 264-32) Exposure time 1/50 sec, Type A, Q = 18,000 cms, H.W. = 56.5 m, T.W. = 30.5 m; Flow pattern in the tailrace.

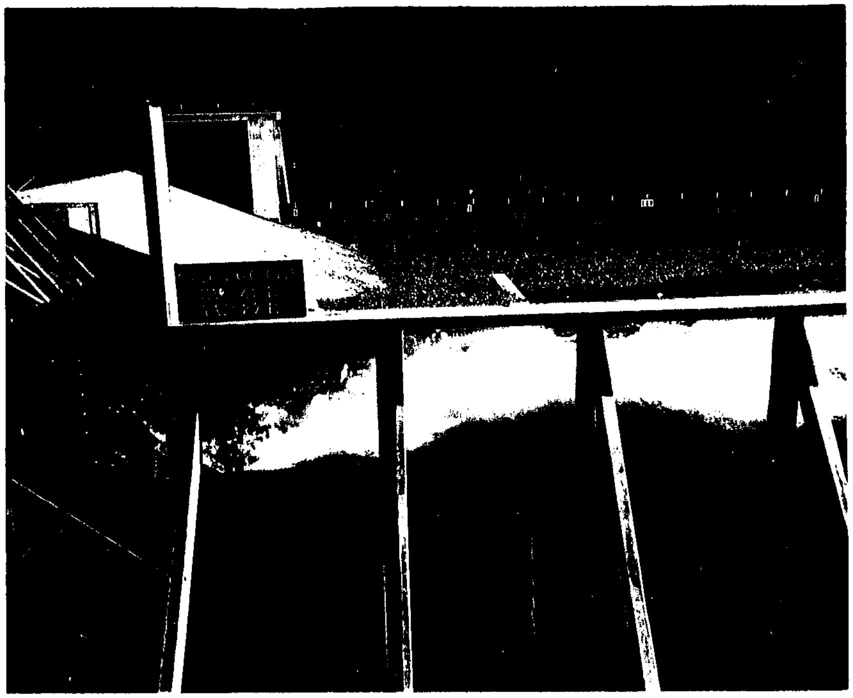


Photo 12 - (Serial No. 264-26) Type A, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.

Photo 13 - (Serial No. 264-27) Type A, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.


Q=10 300 CMS
HW=49 M
TW=27 M
ELEV
33 M
30
30
25
20
15
10
5

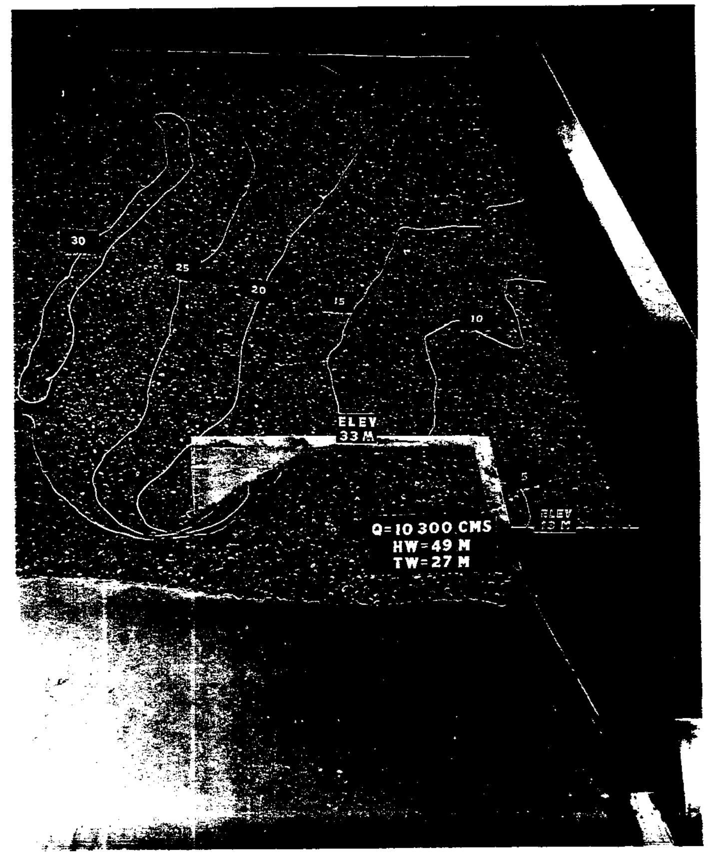
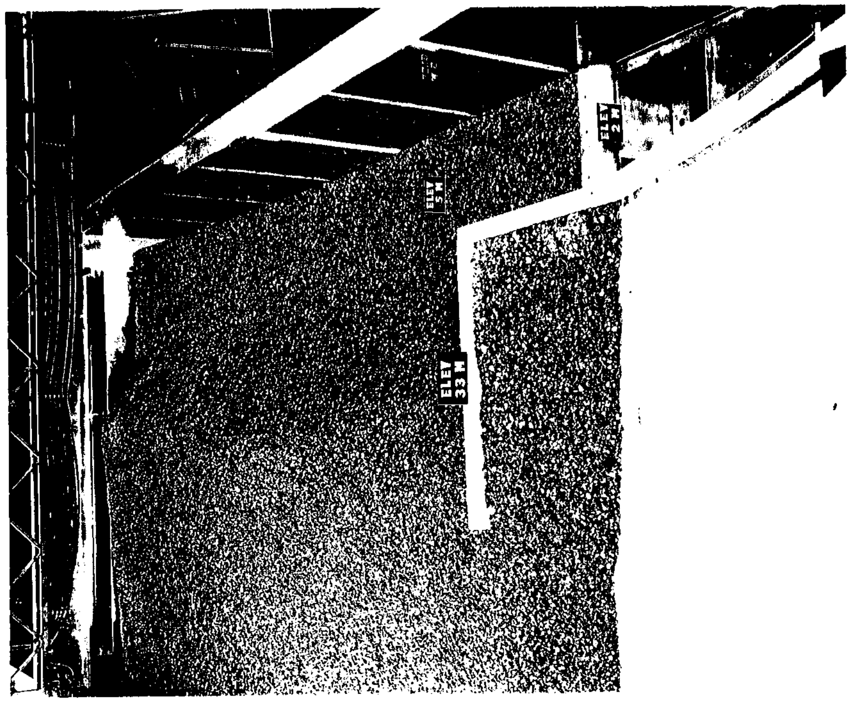

30
25
20
15
10
5
ELEV
33 M
Q=10 300 CMS
HW=49 M
TW=27 M

Photo 14 - (Serial No. 264-33) Type B; The revised model ready for testing.

Photo 15 - (Serial No. 264-34) Type B; The revised model ready for testing.


ELEV 2 M
ELEV 5 M
ELEV 33 M

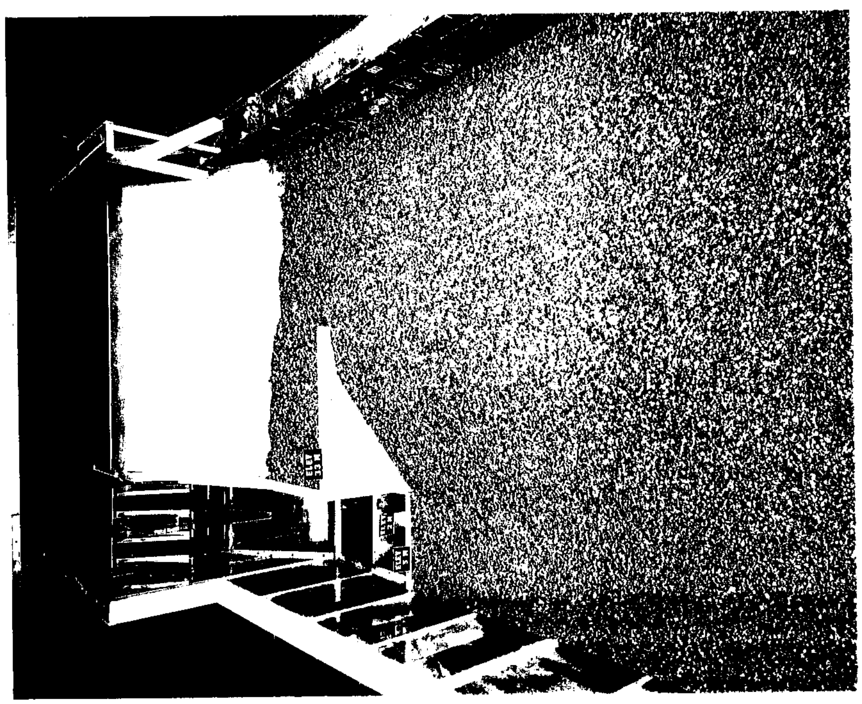
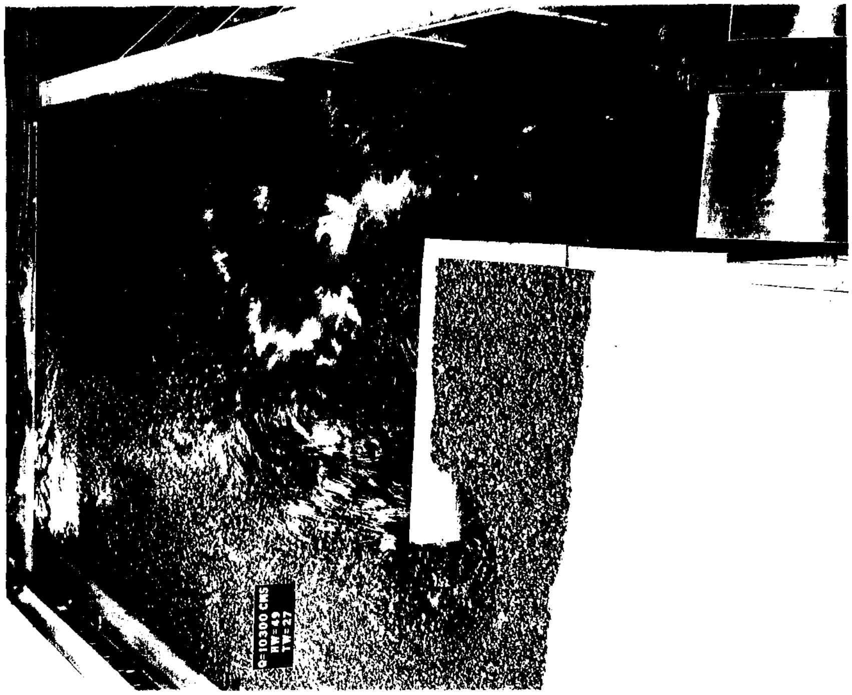


Photo 16 - (Serial No. 264-43) Exposure time 1/5 sec, Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 17 - (Serial No. 264-45) Exposure time 1/5 sec, Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.


Q=10300 CMS
HW=49
TW=27

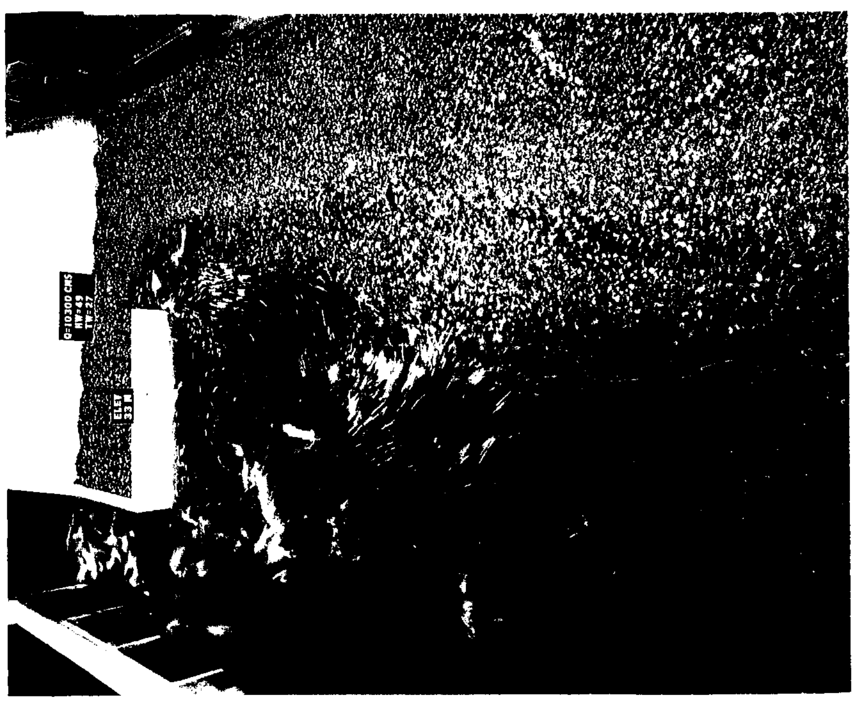
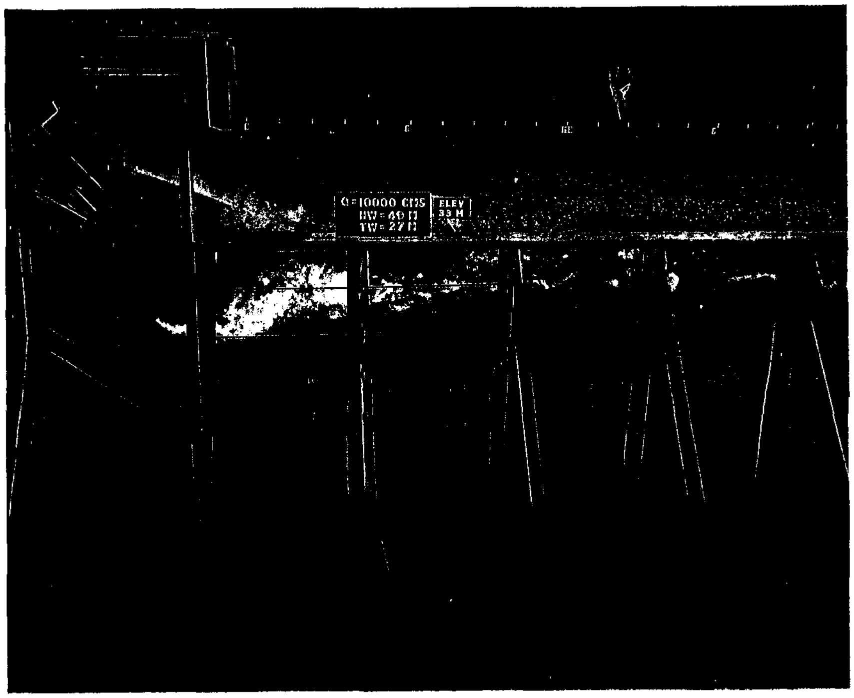

Q=10300 CMS
HW=49
TW=27
ELEV
33 M

Photo 18 - (Serial No. 264-47) Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.

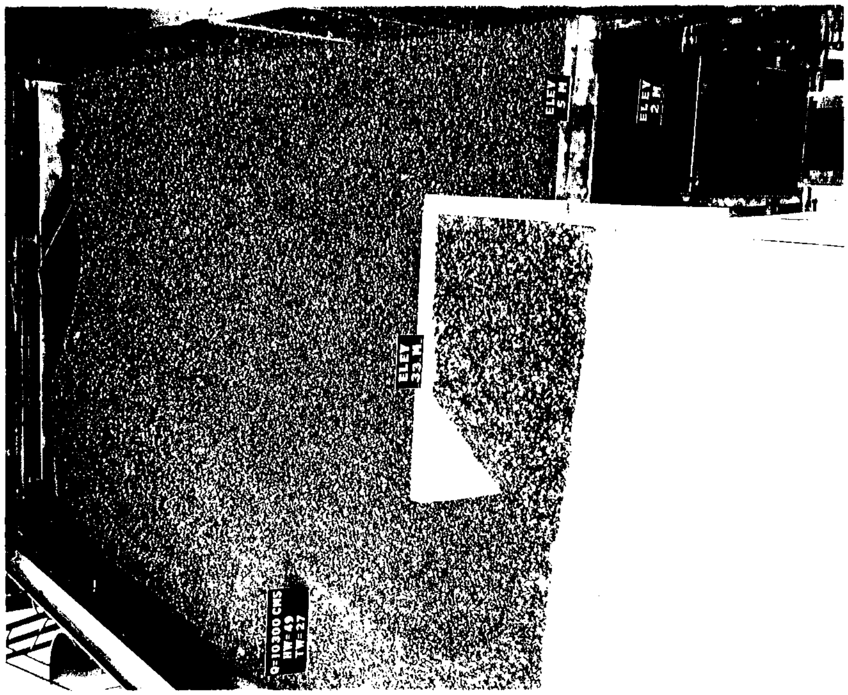
Photo 19 - (Serial No. 264-49) Type B, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.


Q=10000 CMS
HW=40 M
TW=27 M
ELEV
33 M


Q=18000 CMS
HW=56 M
TW=30.6 M
ELEV
33 M
20
10
2

Photo 20 - (Serial No. 264-59) Type B-1; The revised model ready for testing.

Photo 21 - (Serial No. 264-60) Type B-1; The revised model ready for testing.


Q=10300 CMS
HW=49
TW=27
ELEV

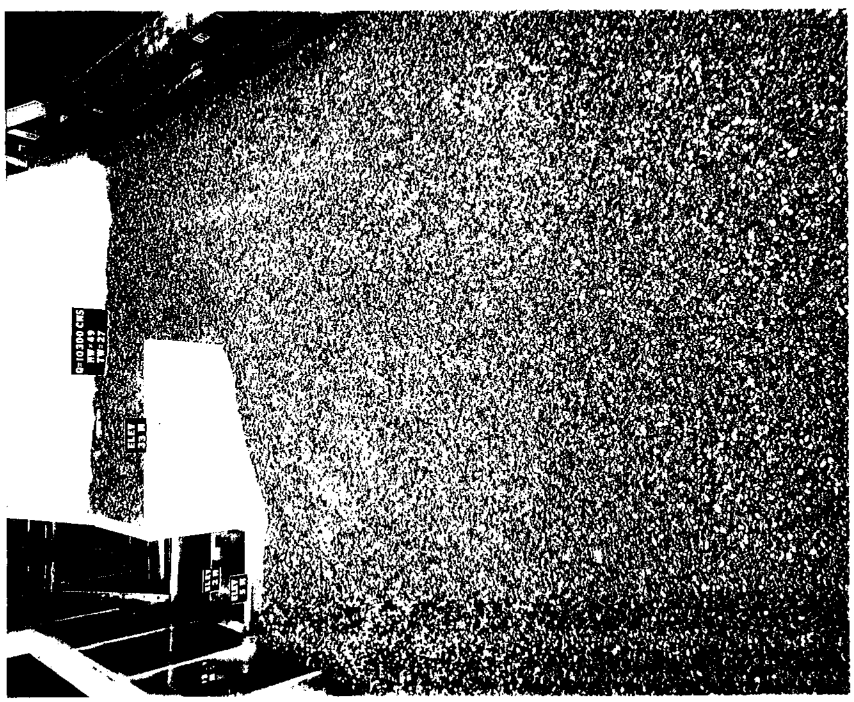
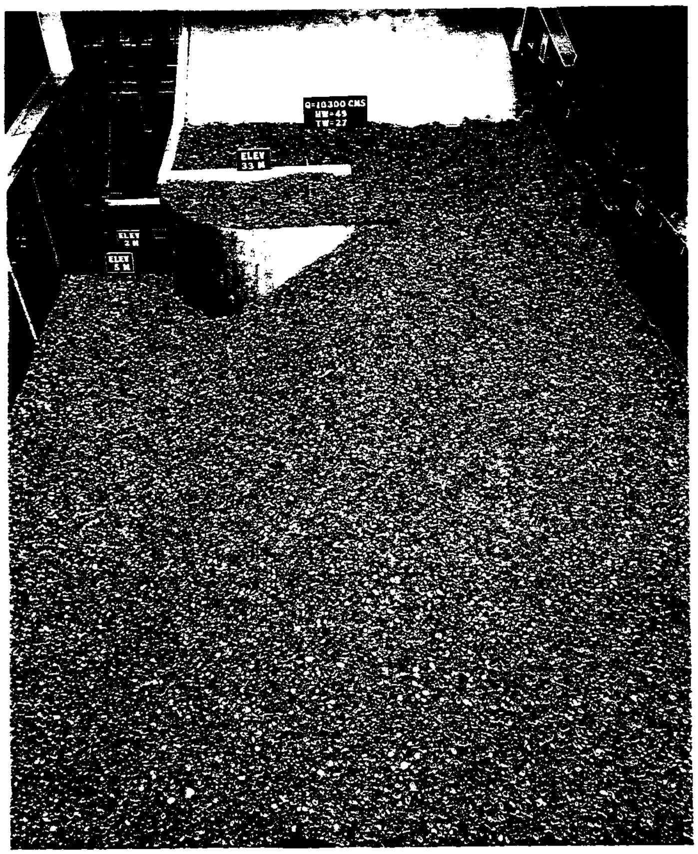

Q=10300 CMS
HW=49
TW=27
ELEV

Photo 22 - (Serial No. 264-66) Exposure time 1/5 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 23 - (Serial No. 264-68) Exposure time 1/5 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.


Q=10300 CMS
HW=49
TW=27
ELEV
33 M
ELEV
2 M
ELEV
5 M


Q=10300 CMS
HW=49
TW=27
ELEV
33 M
ELEV
5 M
ELEV
2 M

Photo 24 - (Serial No. 264-69) Exposure time 1/100 sec, Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.


Q=10300 CMS
HW=49
TW=27
ELEV
33 M
10
2

Photo 25 - (Serial No. 264-70) Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.

Photo 26 - (Serial No. 264-71) Type B-1, Q = 10,300 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 12 hours of flow.


ELEV
33 M
Q=10300 CMS
HW=49
TW=27

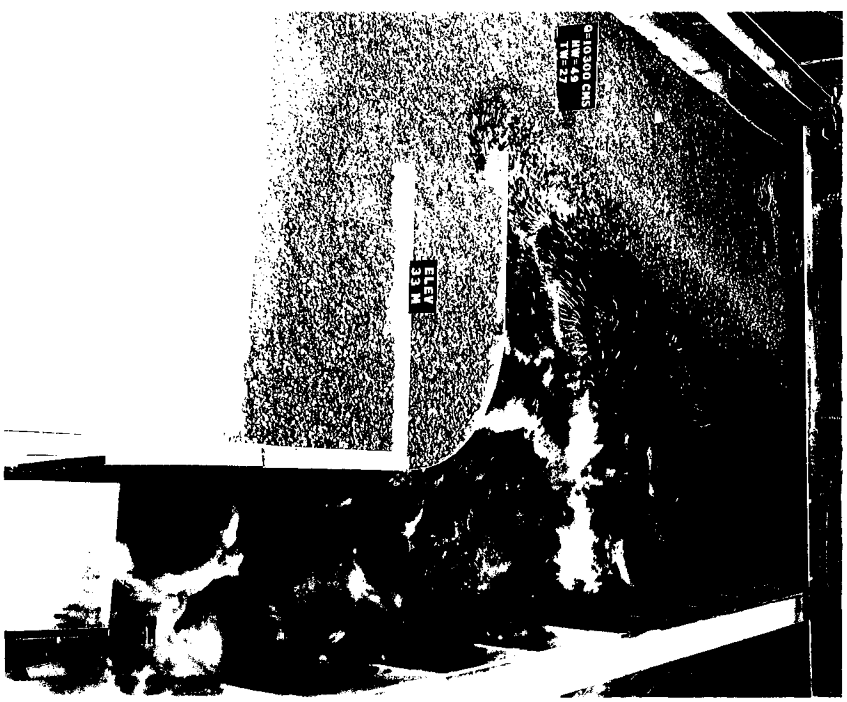
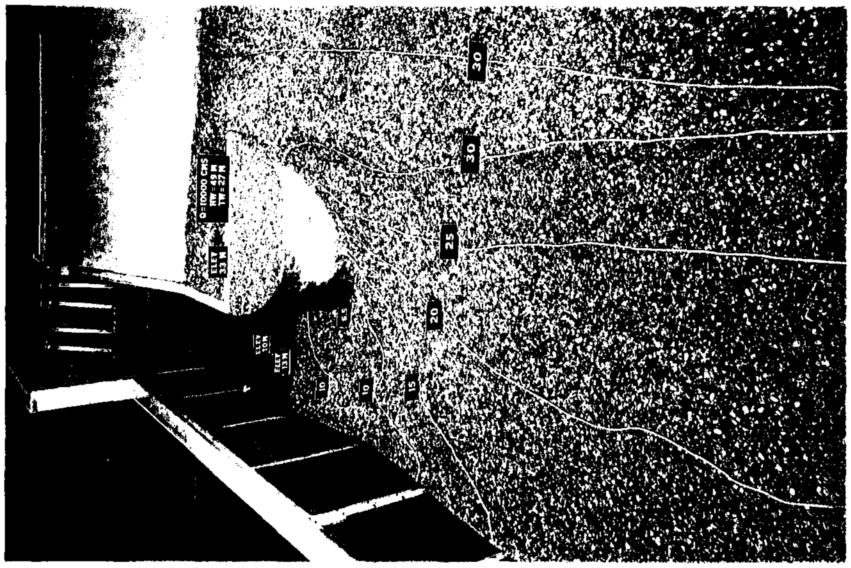
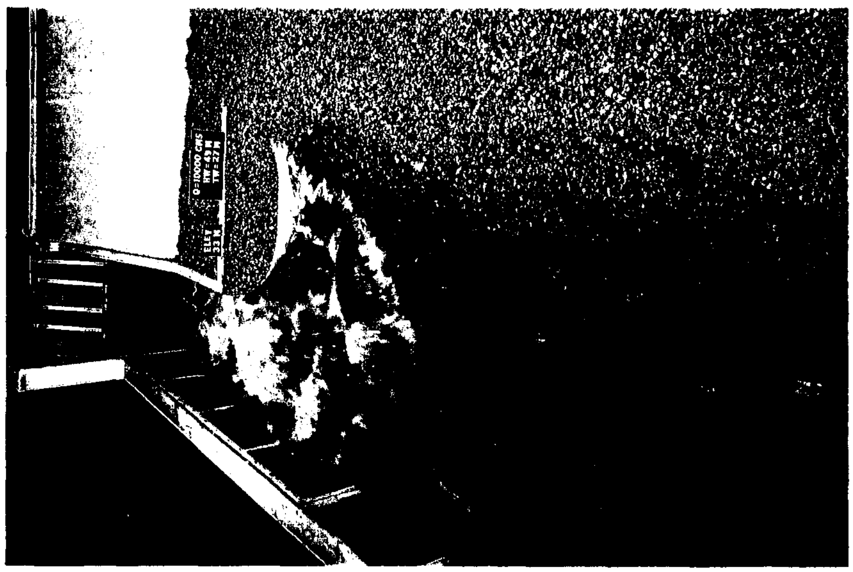

Q=10300 CMS
HW=49
TW=27
ELEV
33 M

Photo 27 - (Serial No. 264-230) Type A-2; The revised model ready for testing.

Photo 28 - (Serial No. 264-236) Exposure time 1/10 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 29 - (Serial No. 264-243) Type A-2, Q = 10,000 cms, H.W. = 27 m; Erosion pattern in the tailrace after 1 hour of flow.


Q=10000 CMS
HW=49 M
TW=27 M
ELEV 33 M
ELEV 13 M
30
30
25
20
15
10
10


Q=10000 CMS
HW=49 M
TW=27 M
ELEV 33 M

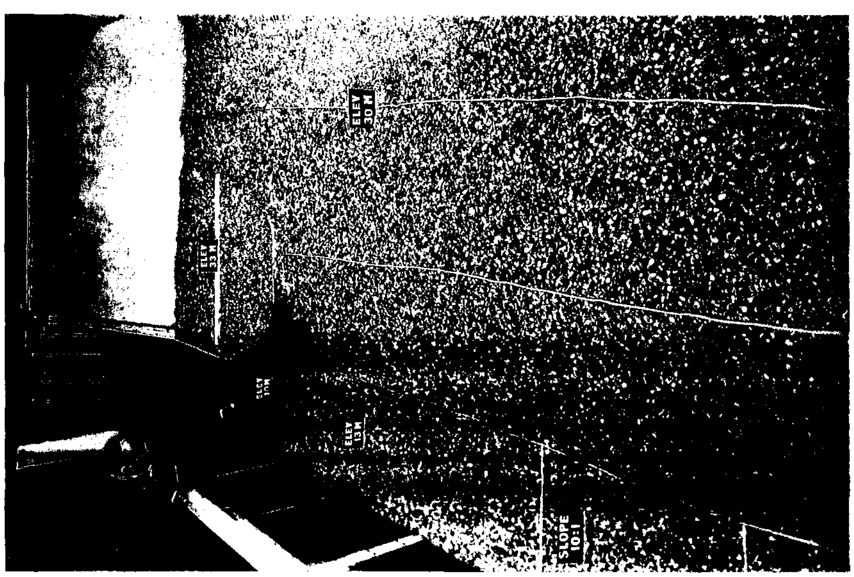
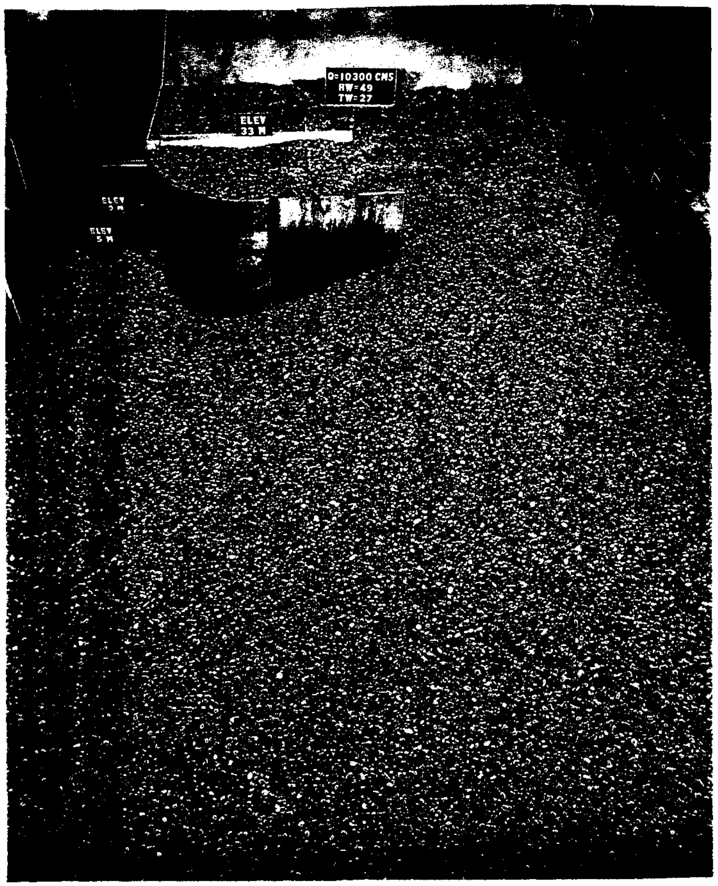

ELEV 30 M
ELEV 33 M
ELEV 13 M
SLOPE 10:1

Photo 30 - (Serial No. 264-241) Exposure time 1/50 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m Flow pattern in the tailrace.

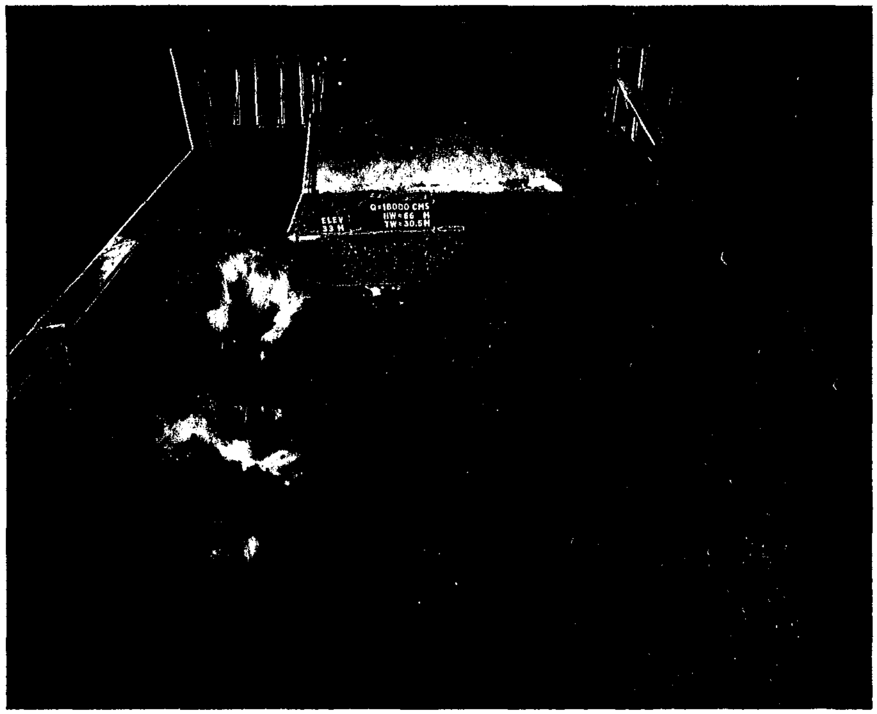
Photo 31 - (Serial No. 264-254) Exposure time 1/100 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.


Q=10300 CMS
HW=49
TW=27
ELEV
33 M


Q=10300 CMS
HW=49
TW=27
ELEV
33 M
ELEV
5 M
ELEV
2 M

Photo 32 - (Serial No. 264-248) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.

Photo 33 - (Serial No. 264-252) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the tailrace.


Q=18000 CMS
HW=56 M
TW=30.5M
ELEV
33 M

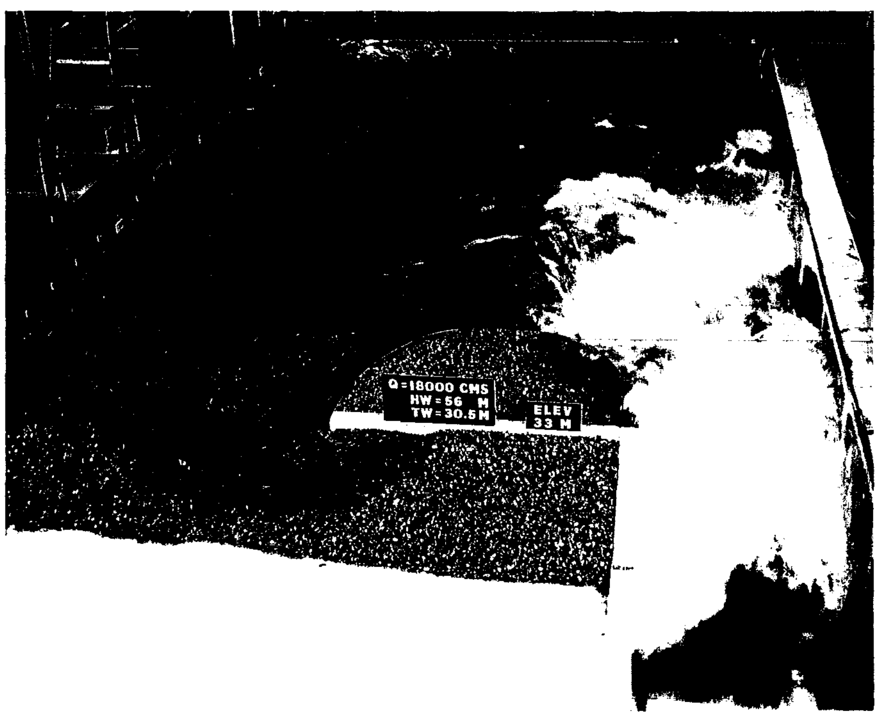
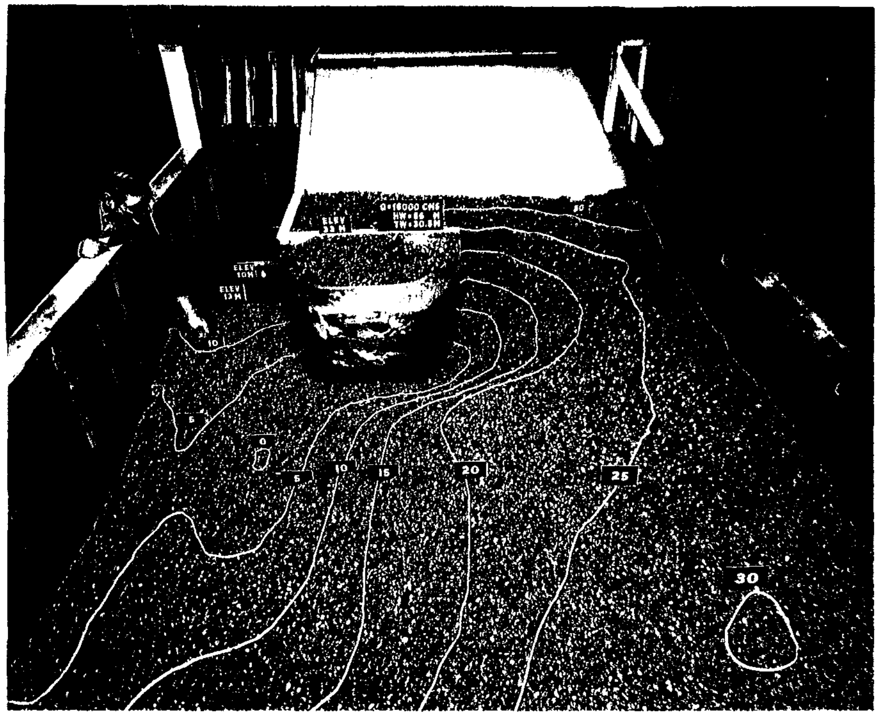

Q=18000 CMS
HW=56 M
TW=30.5M
ELEV
33 M

Photo 34 - (Serial No. 264-257) Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.

Photo 35 - (Serial No. 264-258) Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.


Q=18000 CMS
HW=56 M
TW=30.5M
ELEV
33 M
ELEV
13 M
10
5
0
5
10
15
20
25
30

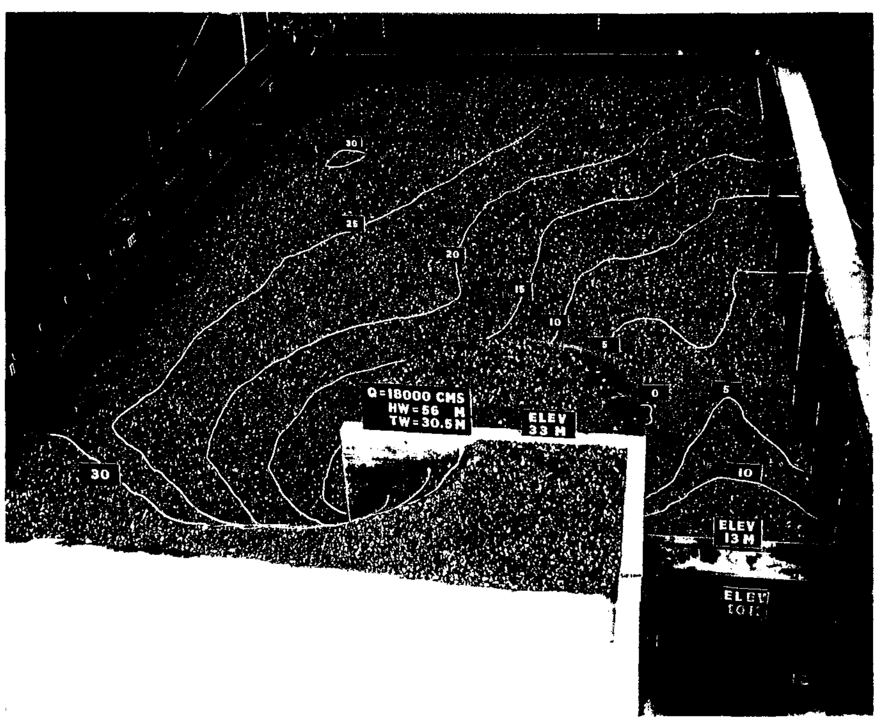
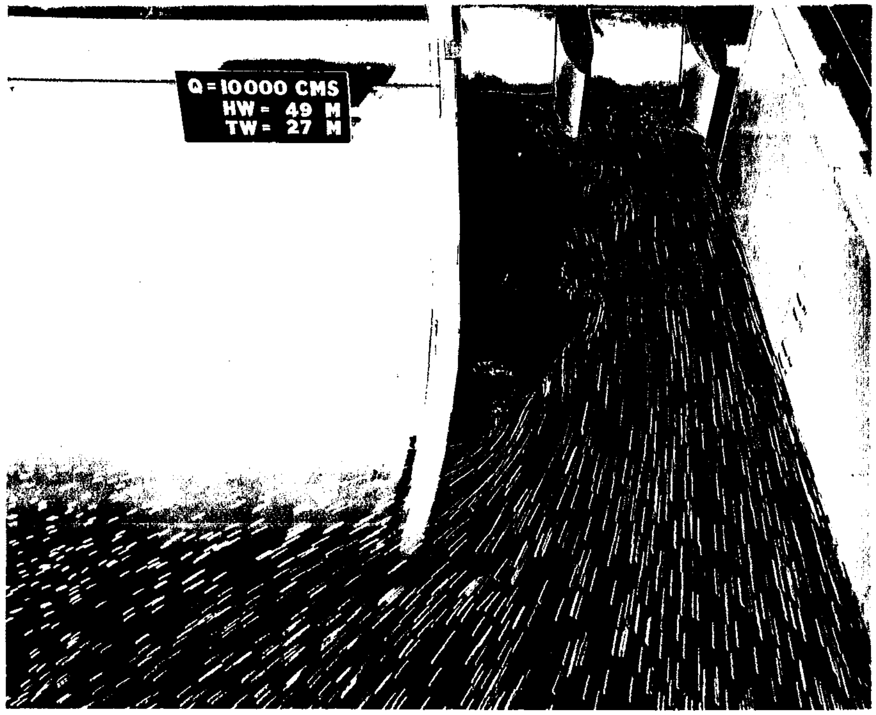

30
25
20
15
10
5
0
5
10
Q=18000 CMS
HW=56 M
TW=30.5 M
ELEV
33 M
30
10
ELEV
13 M

Photo 36 - (Serial No. 264-262) Exposure time 1/10 sec, Type A-2, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the approach.

Photo 37 - (Serial No. 264-267) Exposure time 1/10 sec, Type A-2, Q = 18,000 cms, H.W. = 56 m, T.W. = 30.5 m; Flow pattern in the approach.


Q = 10000 CMS
HW = 49 M
TW = 27 M

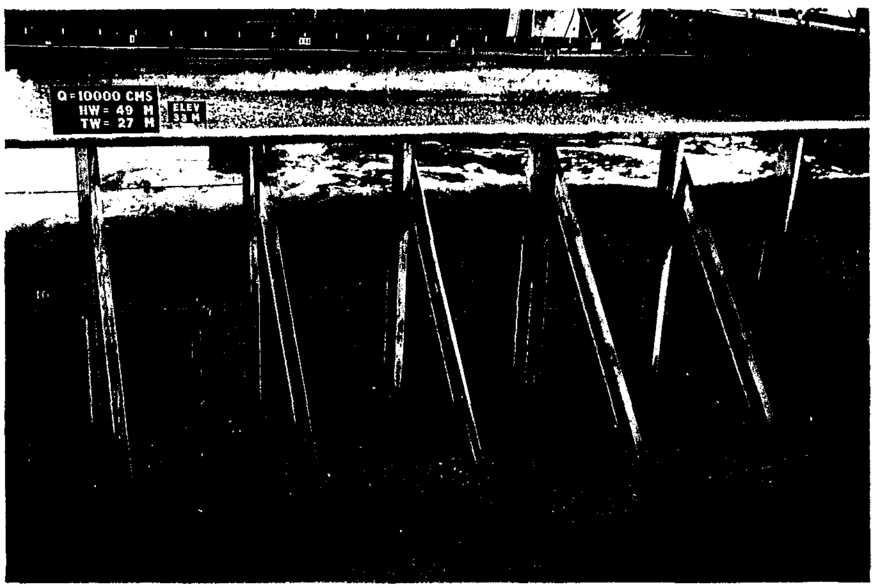

Q = 18000 CMS
HW = 51.8 M
TW = 30.5 M

Photo 38 - (Serial No. 264-292) Exposure time 1/10 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 39 - (Serial No. 264-297) Exposure time 1/50 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the tailrace.

Photo 40 - (Serial No. 264-299) Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Erosion pattern in the tailrace after 1 hour of flow.


Q=10000 CMS
HW= 49 M
TW= 27 M
ELEV
33 M


Q=10000 CMS
HW= 49 M
TW= 27 M
ELEV
33 M

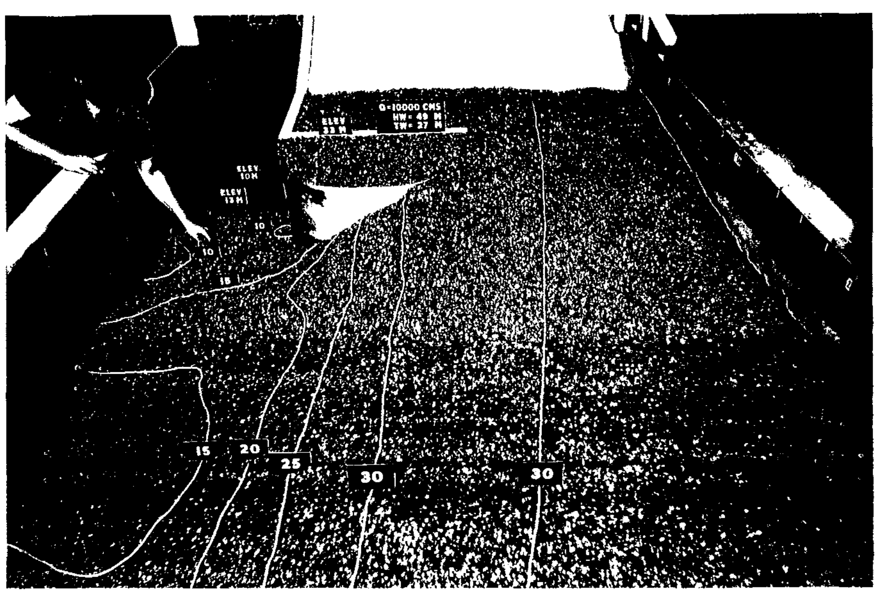
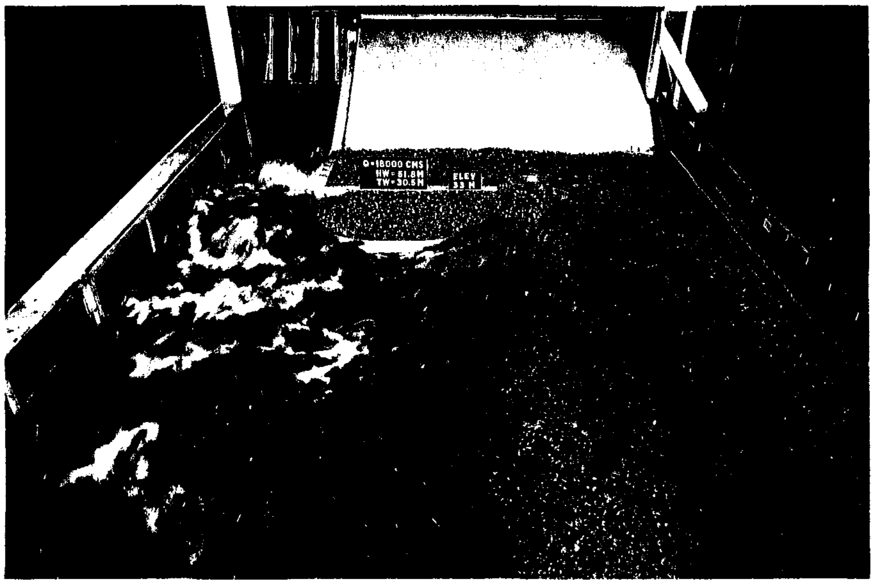
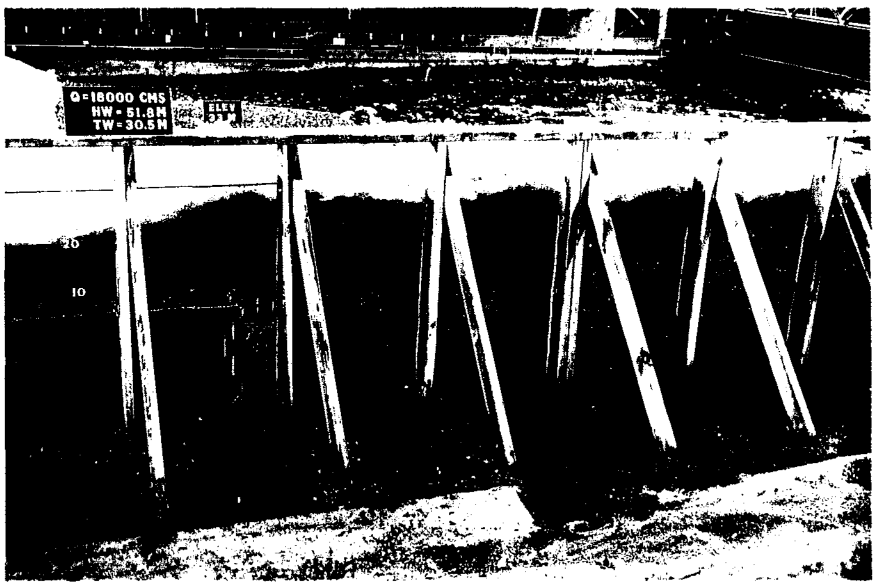

Q=10000 CMS
HW= 49 M
TW= 27 M
ELEV
33 M
15
20
25
30
30

Photo 41 - (Serial No. 264-304) Exposure time 1/10 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the tailrace.

Photo 42 - (Serial No. 264-309) Exposure time 1/50 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the tailrace.

Photo 43 - (Serial No. 264-310) Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Erosion pattern in the tailrace after 2 hours of flow.


Q=18000 CMS
HW=51.8M
TW=30.5M
ELEV
33 M


Q=18000 CMS
HW=51.8M
TW=30.5M
ELEV
20
10

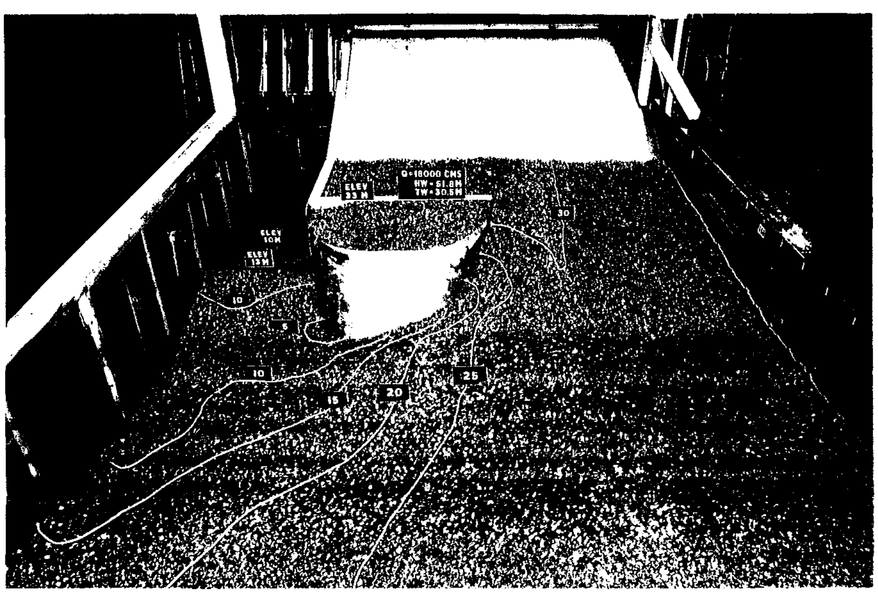
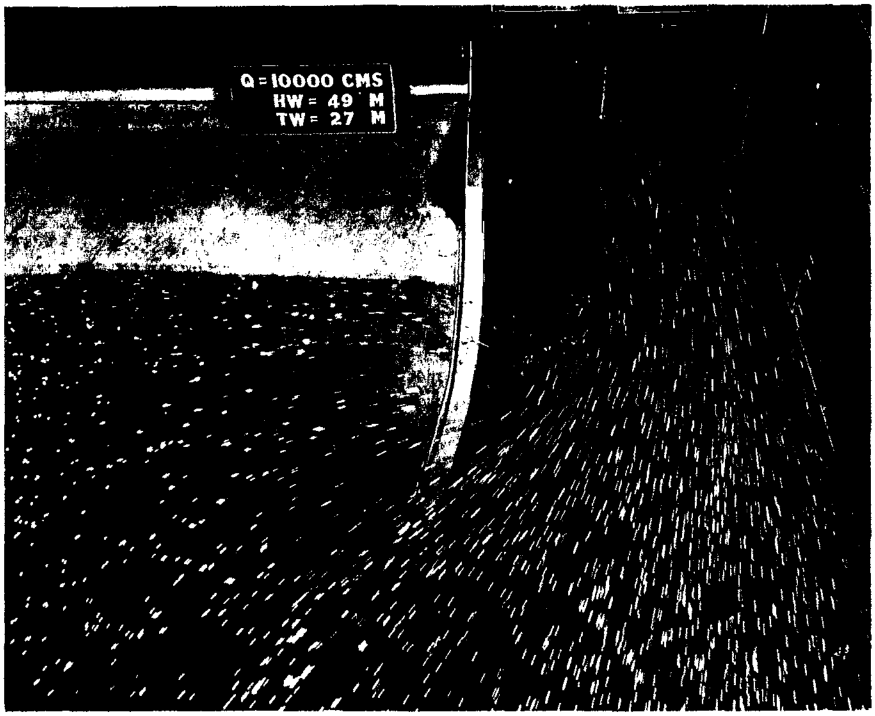

Q=18000 CMS
HW=51.8M
TW=30.5M
ELEV
33 M
ELEV
10M
ELEV
13 M
10
5
10
15
20
25
30

Photo 44 - (Serial No. 264-318) Exposure time 1/5 sec, Type C, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m; Flow pattern in the approach.

Photo 45 - (Serial No. 264-323) Exposure time 1/5 sec, Type C, Q = 18,000 cms, H.W. = 52.2 m (sign incorrect), T.W. = 30.5 m; Flow pattern in the approach.


Q=10000 CMS
HW= 49 M
TW= 27 M

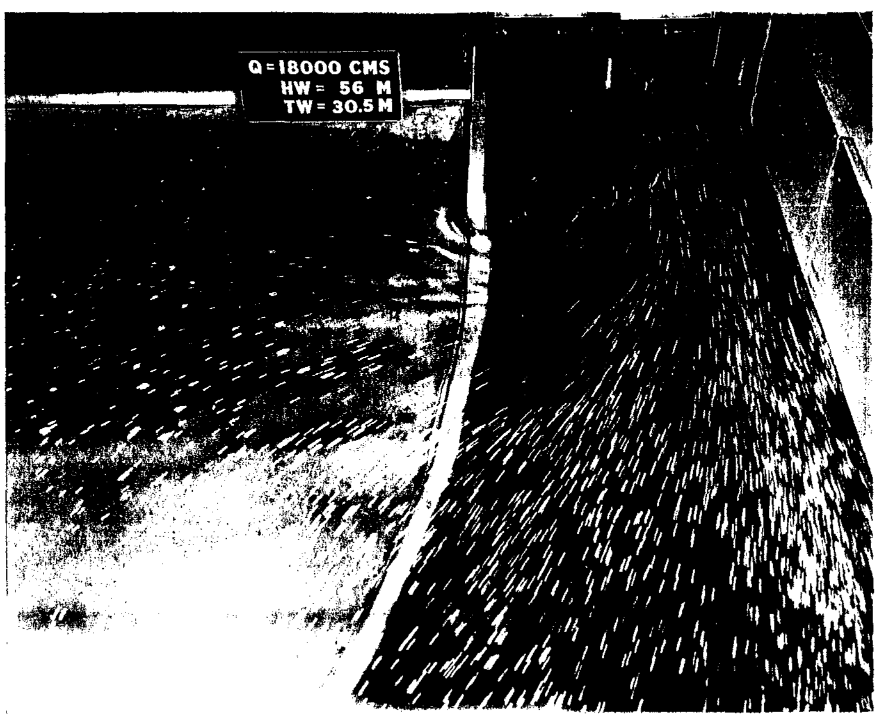
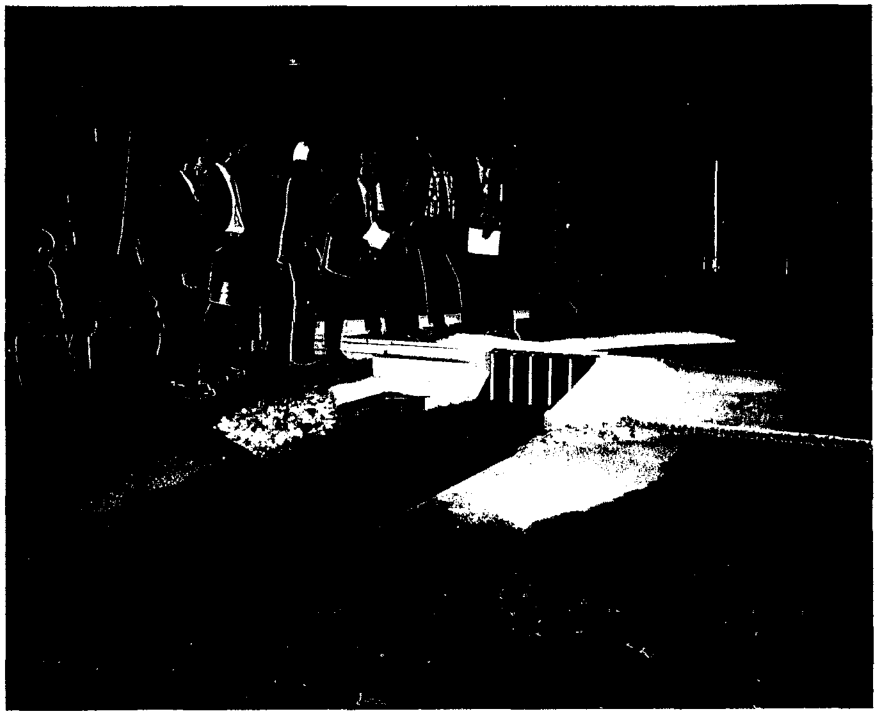

Q=18000 CMS
HW= 56 M
TW= 30.5 M

Photo 46 - (Serial No. 264-162) Harza and consulting board personnel observing the comprehensive model.

Photo 47 - (Serial No. 264-176) Harza and Executive Hydroelectric Commission personnel observing the comprehensive model.



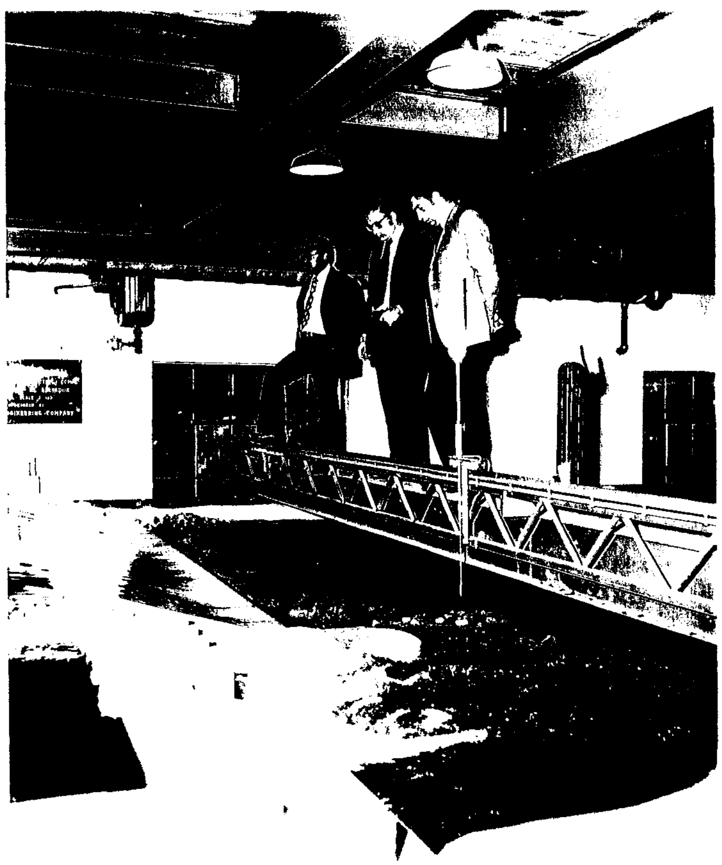
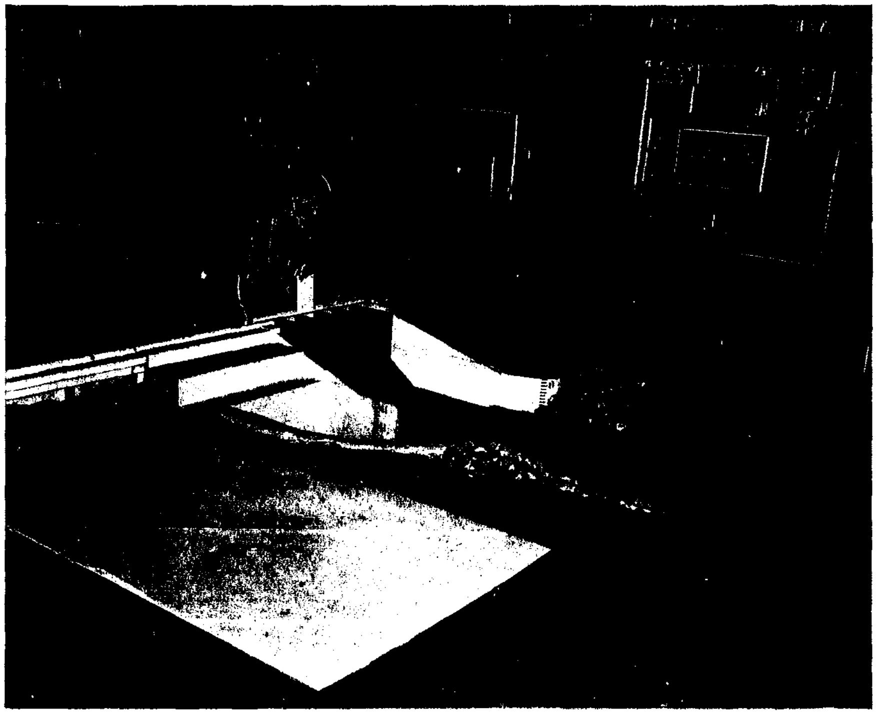


Photo 48 - (Serial No. 264-159) The completed model ready for testing.

Photo 49 - (Serial No. 264-160) The completed model ready for testing.



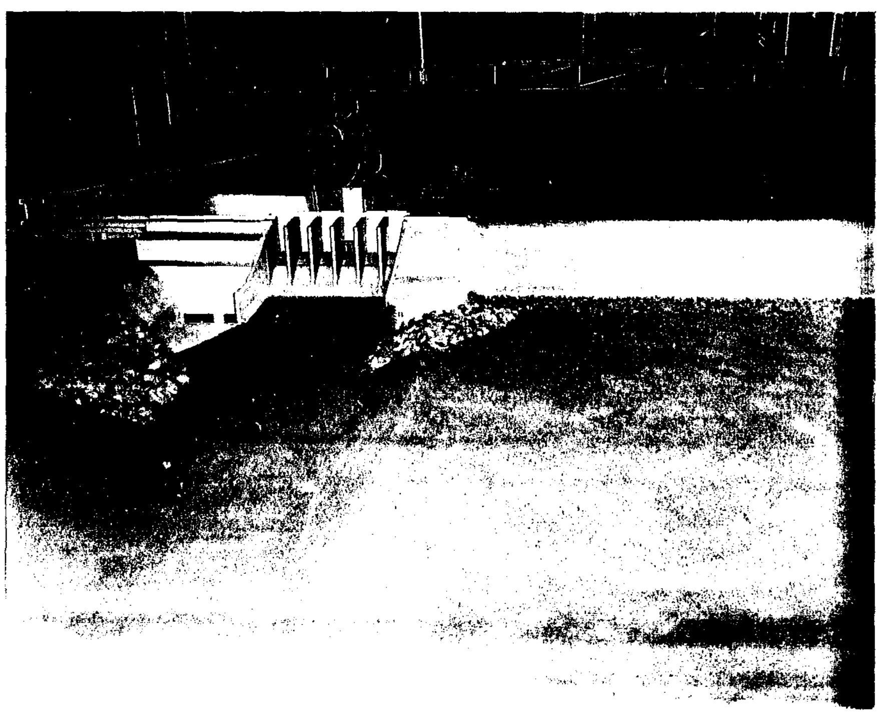
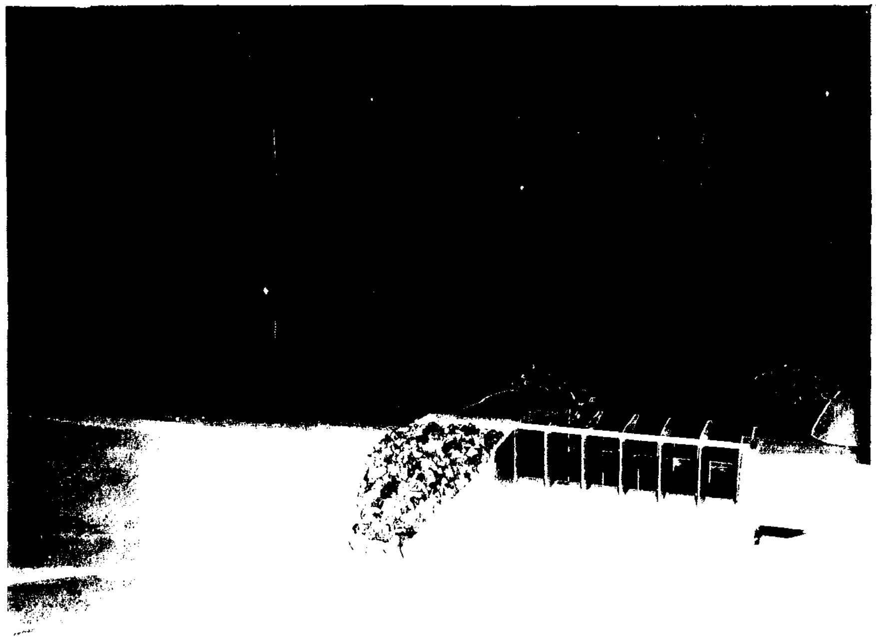


Photo 50 - (Serial No. 264-158) The completed model ready for testing.

Photo 51 - (Serial No. 264-156) The completed model ready for testing.



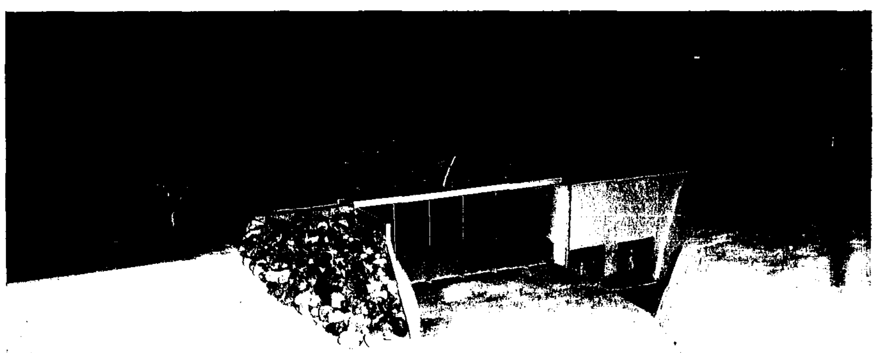
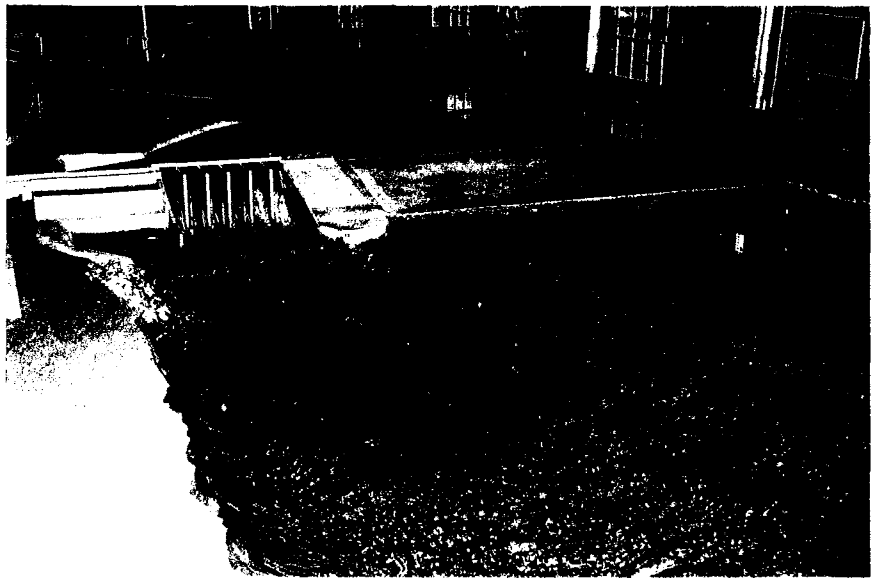


Photo 52 - (Serial No. 264-270) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow patterns in the model.

Photo 53 - (Serial No. 264-274) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow pattern downstream of powerhouse and service spillway.

Photo 54 - (Serial No. 264-275) Q = 10,000 cms (service spillway only), H.W. = 49 m, T.W. = 27 m; Flow pattern in approach to service spillway and powerhouse.



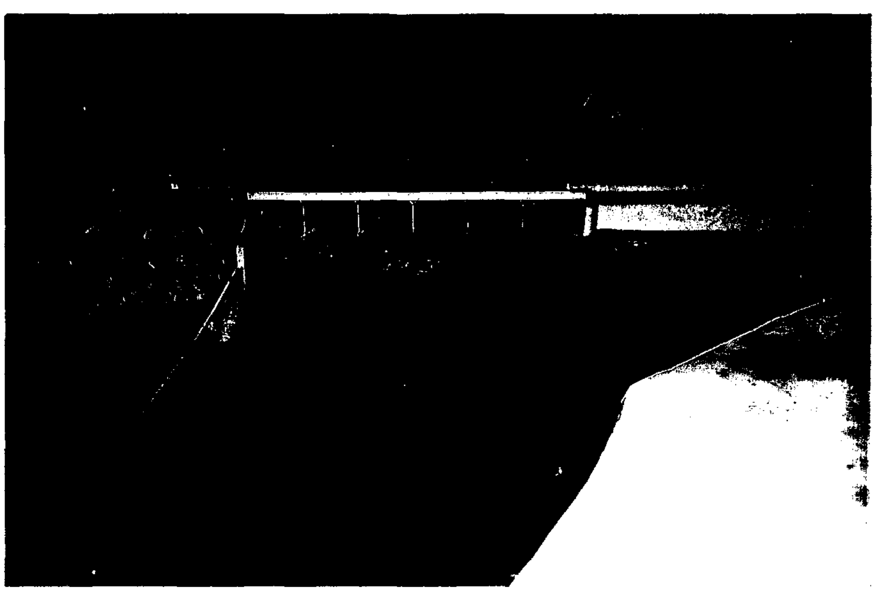
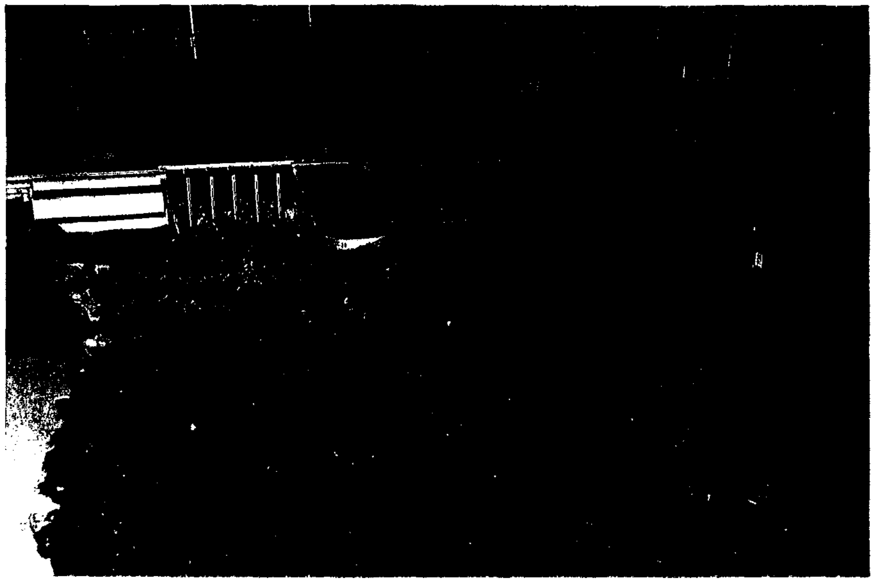
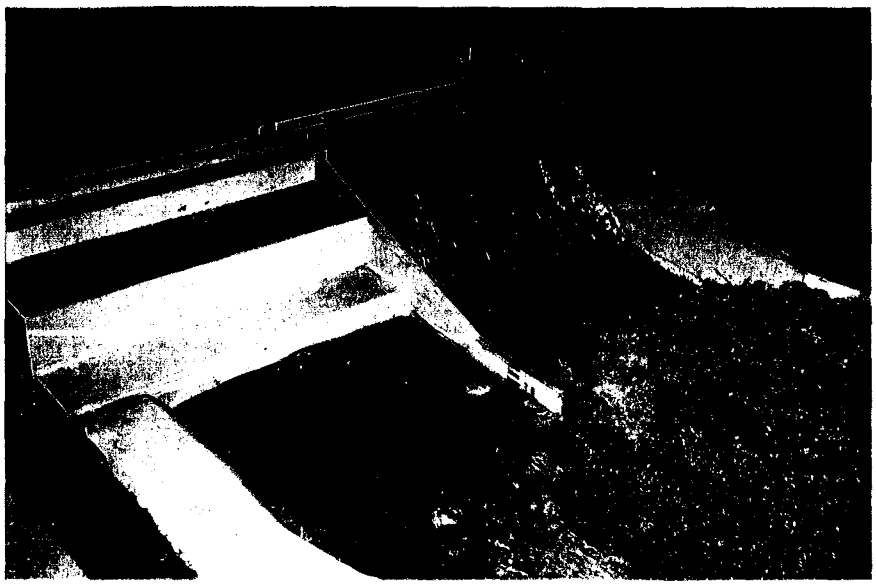


Photo 55 - (Serial No. 264-281) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow patterns in the model.

Photo 56 - (Serial No. 264-279) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow pattern downstream of powerhouse and service spillway.

Photo 57 - (Serial No. 264-280) Q = 18,000 cms (service spillway only), H.W. = 56 m, T.W. = 30.5 m; Flow pattern in approach to service spillway and powerhouse.





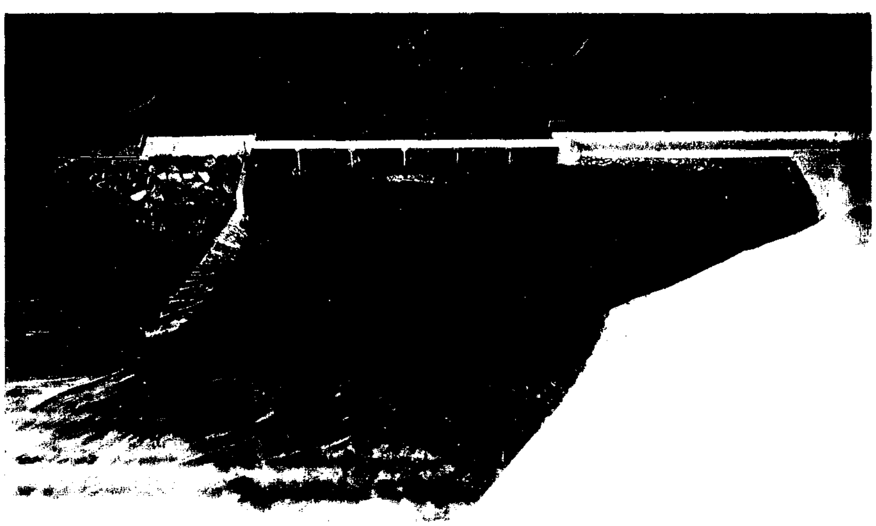
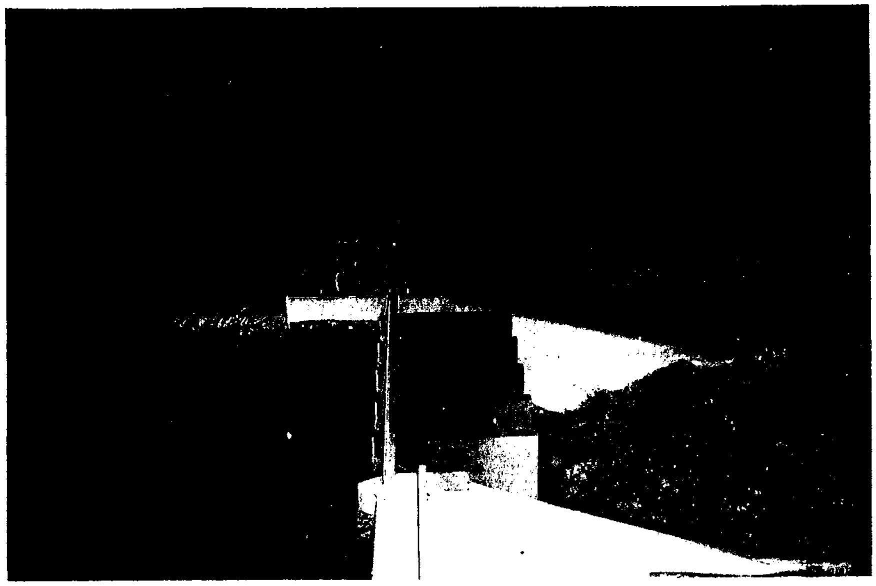
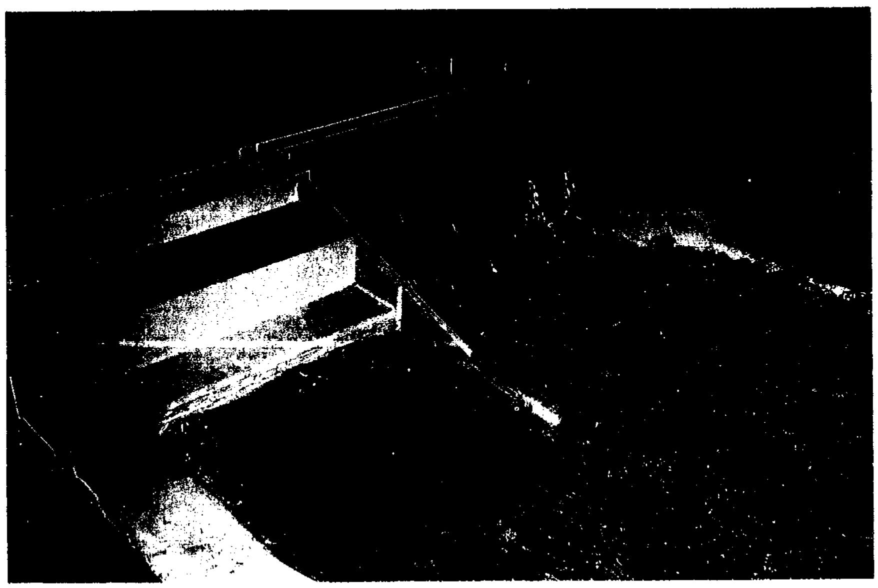


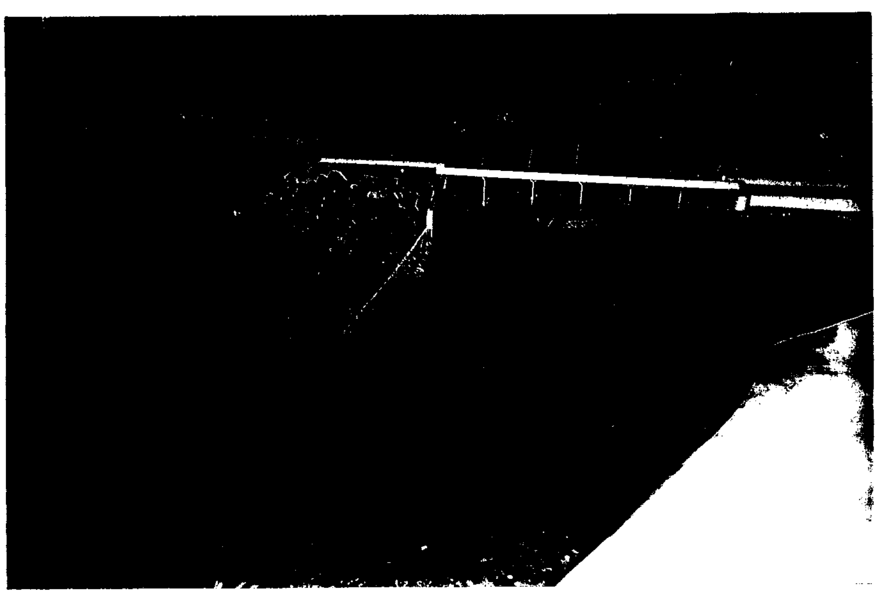
Photo 58 - (Serial No. 264-283) Q = 18,000 cms (both service and auxiliary spillways), H.W. ≅ 54 m, T.W. = 30.5 m; Flow patterns in the model.

Photo 59 - (Serial No. 264-284) Q = 18,000 cms (both service and auxiliary spillways, H.W. ≅ 54 m, T.W. = 30.5 m; Flow pattern downstream of powerhouse and service spillway.

Photo 60 - (Serial No. 264-285) Q = 18,000 cms (both service and auxiliary spillways), H.W. ≅ 54 m, T.W. = 30.5 m; Flow pattern in the approach.







LIST OF CHARTS

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19	(264B504-15) Type C spillway; Water surface profiles through spillway, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m, Gate opening = 10.4 m.
20	(264B504-13) Type C spillway; Water surface profiles in tailrace. Tailrace profiles after 1 hour of flow, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m, Gate opening = 10.4 m.
21	(264B504-17) Type C spillway; Water surface profiles in tailrace. Tailrace profiles after 1 hour of flow, Q = 10,000 cms, H.W. = 49 m, T.W. = 27 m, Gate opening = 10.4 m.
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27	(264B504-21) Type C spillway; Piezometric pressures, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.
28	(264B504-22) Type C spillway; Piezometric pressures, Q = 2,250 cms H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.
29	(264B504-23) Type C spillway; Piezometric pressures, Q = 7,900 cms H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m.
30	(264B504-24) Type C spillway; Piezometric pressures, Q = 10,000 cı H.W. = 49 m, T.W. = 27 m, Gate opening = 10.4 m.
31	(264B504-25) Type C spillway; Piezometric pressures, Q = 13,200 cı H.W. = 49 m, T.W. = 28.4 m, Gates wide open.
32	(264B504-26) Type C spillway; Piezometric pressures, Q = 18,000 cı H.W. = 52.2 m, T.W. = 30.5 m, Gates wide open.

Chart No.

33 (264B504-27) Type C spillway; Piezometric pressures, Q = 28,000 cms H.W. = 58 m, T.W. = 34.1 m, Gates wide open.

34 (264A2318-23) Type C spillway; Piezometric pressures.

35 (264A2318-24) Type C spillway; Piezometric pressures.

36 (264A2318-25) Type C spillway; Piezometric pressures.

37 (264A2318-26) Type C spillway; Piezometric pressures.

38 (264A2318-1) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.

39 (264A2318-2) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.

40 (264A2318-3) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.

41 (264A2318-4) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.

42 (264A2318-5) Type C spillway; Typical pressure fluctuations one meter from right side of pier, Q = 1150 cms, H.W. = 49 m, T.W. = 20 m, Gate opening = 1 m.

43 (264A2318-6) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.

44 (264A2318-7) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.

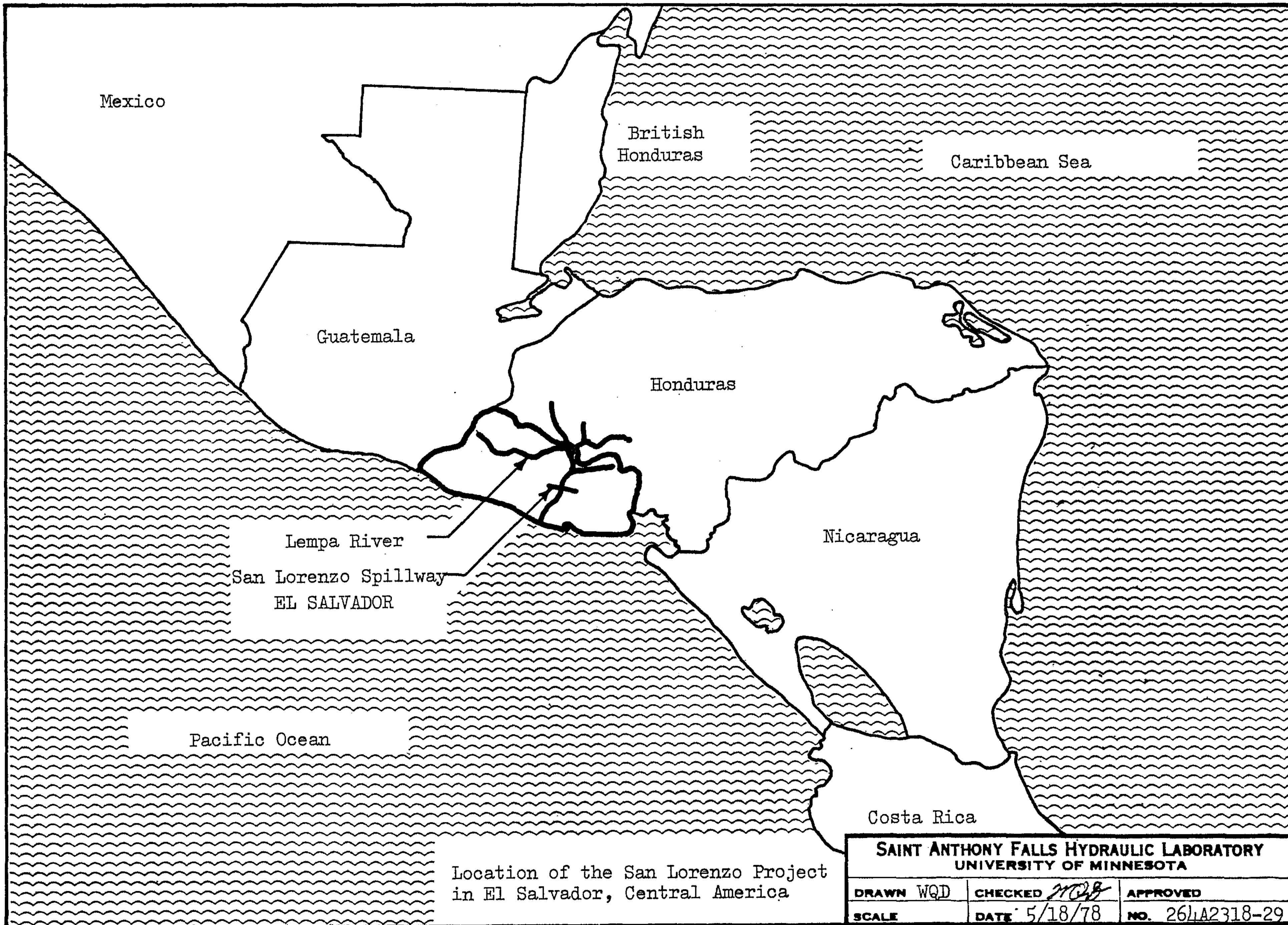
45 (264A2318-8) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.

46 (264A2318-9) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.

47 (264A2318-10) Type C spillway; Typical pressure fluctuations one meter from right side of pier, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m.

Chart No.

Chart No.	
48	(264A2318-11) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m.
49	(264A2318-12) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m.
50	(264A2318-13) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m.
51	(264A2318-14) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m.
52	(264A2318-15) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open.
53	(264A2318-16) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open.
54	(264A2318-17) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open.
55	(264A2318-18) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open.
56	(264A2318-19) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m, Gates wide open.
57	(264A2318-20) Type C spillway; Typical pressure fluctuations one meter from left training wall, Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m, Gates wide open.
58	(264A2318-21) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m, Gates wide open.
59	(264A2318-22) Type C spillway; Typical pressure fluctuations along centerline of left bay, Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m, Gates wide open.
60	(264A2318-31) Tailrace material size distribution for comprehensive model.

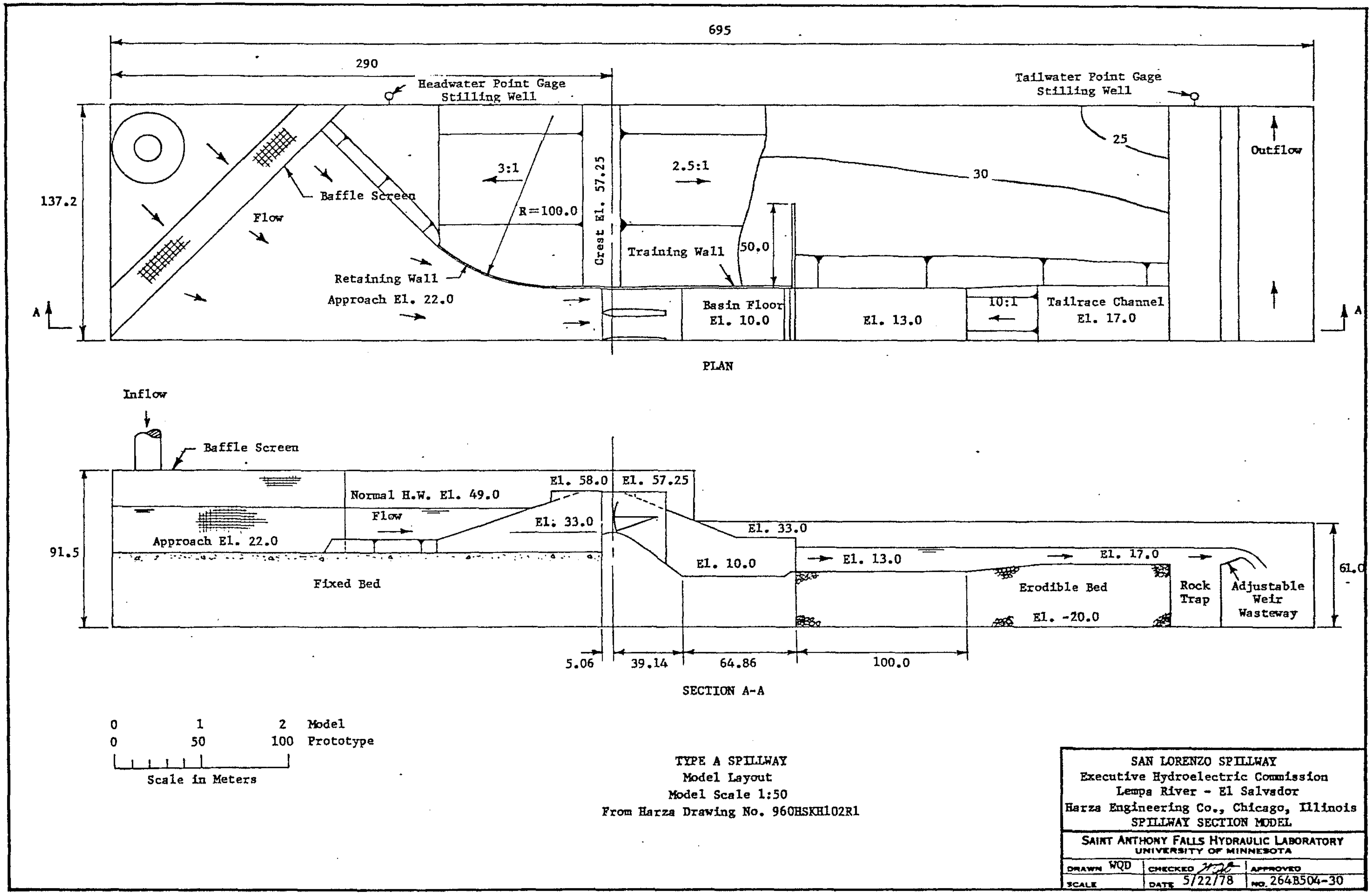


Location of the San Lorenzo Project
in El Salvador, Central America

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/18/78	NO. 264A2318-29

Chart 1


695
290
Headwater Point Gage
Stilling Well
Tailwater Point Gage
Stilling Well
137.2
Baffle Screen
Flow
3:1
R=100.0
Crest El. 57.25
2.5:1
25
30
Outflow
50.0
Training Wall
Retaining Wall
Approach El. 22.0
Basin Floor
El. 10.0
El. 13.0
10:1
Tailrace Channel
El. 17.0
A
A
PLAN
Inflow
Baffle Screen
Normal H.W. El. 49.0
El. 58.0
El. 57.25
Flow
El. 33.0
El. 33.0
91.5
Approach El. 22.0
El. 10.0
El. 13.0
El. 17.0
61.0
Fixed Bed
Erodible Bed
El. -20.0
Rock
Trap
Adjustable
Weir
Wasteway
5.06
39.14
64.86
100.0
SECTION A-A
0 1 2 Model
0 50 100 Prototype
Scale in Meters
TYPE A SPILLWAY
Model Layout
Model Scale 1:50
From Harza Drawing No. 960HSKH102R1
SAN LORENZO SPILLWAY
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
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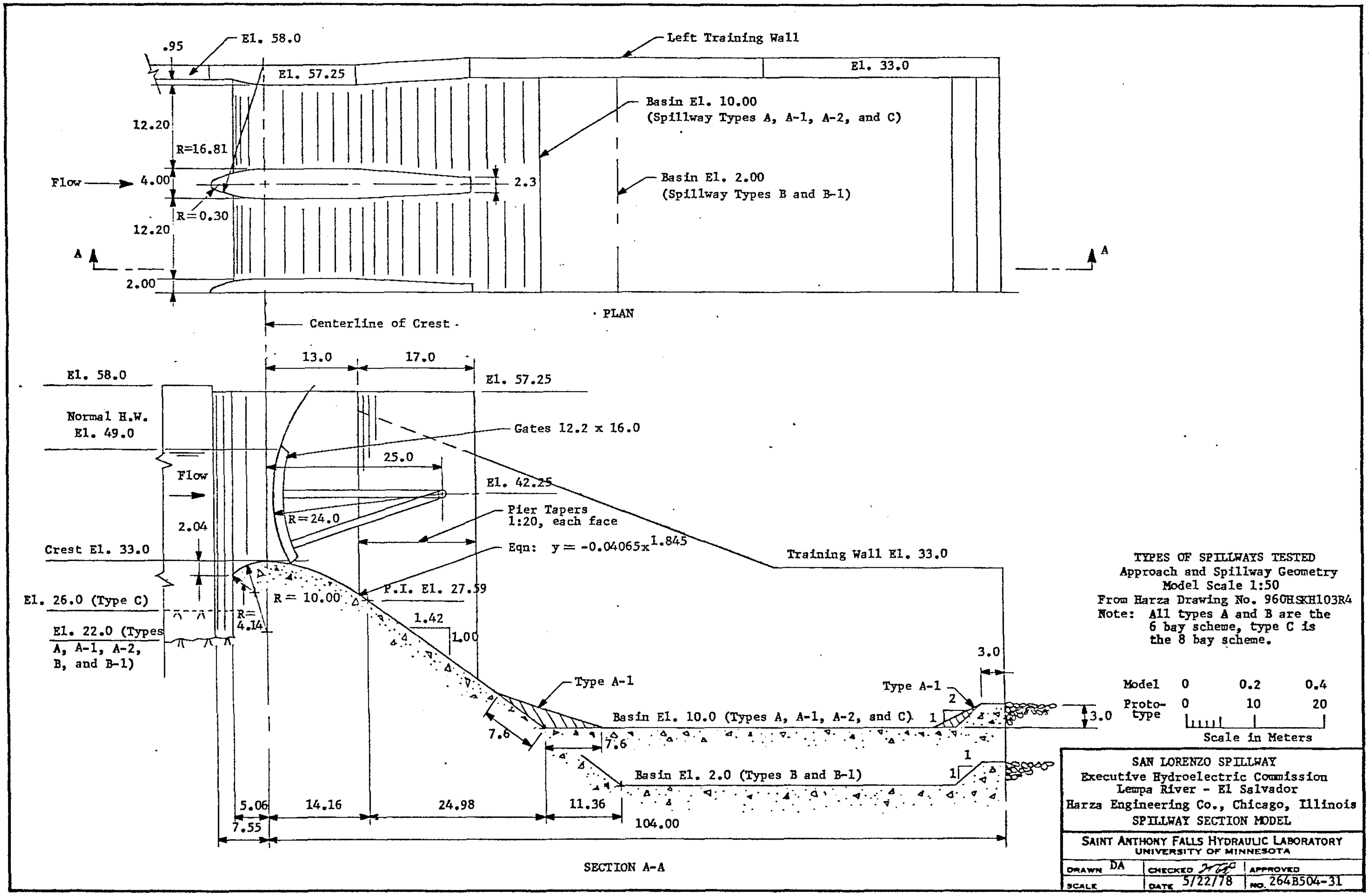
CHECKED
APPROVED
SCALE
DATE 5/22/78
NO. 264B504-30

Chart 2



.95
El. 58.0
Left Training Wall
El. 57.25
El. 33.0
12.20
R=16.81
Basin El. 10.00
(Spillway Types A, A-1, A-2, and C)
Flow
4.00
2.3
R=0.30
Basin El. 2.00
(Spillway Types B and B-1)
12.20
A
A
2.00
PLAN
Centerline of Crest
13.0
17.0
El. 58.0
El. 57.25
Normal H.W.
El. 49.0
Gates 12.2 x 16.0
25.0
Flow
El. 42.25
R=24.0
Pier Tapers
1:20, each face
2.04
Eqn: y = -0.04065x^1.845
Crest El. 33.0
Training Wall El. 33.0
P.I. El. 27.59
El. 26.0 (Type C)
R = 10.00
R=
4.14
1.42
1.00
El. 22.0 (Types
A, A-1, A-2,
B, and B-1)
Type A-1
Type A-1
3.0
2
Basin El. 10.0 (Types A, A-1, A-2, and C)
1
3.0
7.6
7.6
1
Basin El. 2.0 (Types B and B-1)
1
5.06
14.16
24.98
11.36
7.55
104.00
SECTION A-A
TYPES OF SPILLWAYS TESTED
Approach and Spillway Geometry
Model Scale 1:50
From Harza Drawing No. 960HSKH103R4
Note: All types A and B are the
6 bay scheme, type C is
the 8 bay scheme.
Model 0 0.2 0.4
Proto-type 0 10 20
Scale in Meters
SAN LORENZO SPILLWAY
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
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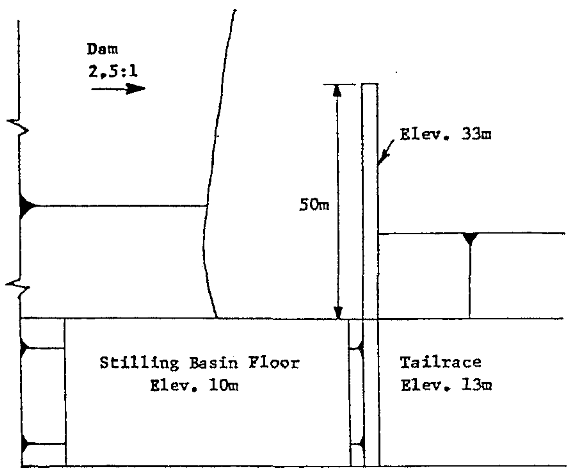
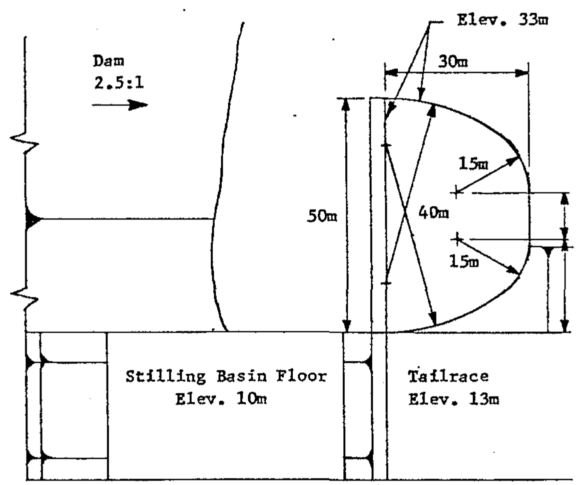
CHECKED
APPROVED
SCALE
DATE 5/22/78
NO. 264B504-31

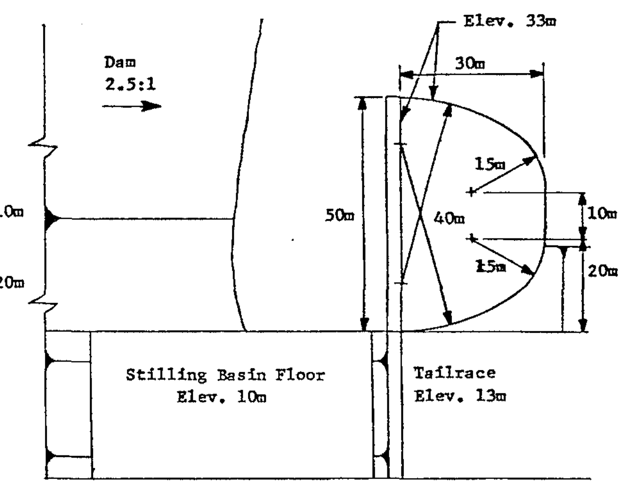
Chart 3



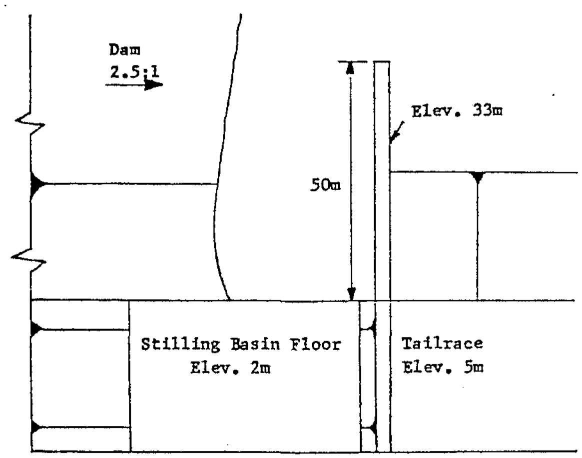
Type A Spillway



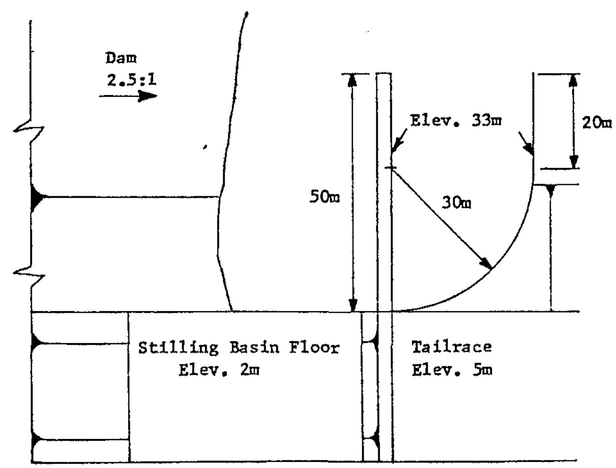
Type A-1 Spillway



Type A-2 and C Spillways



Type B Spillway



Type B-1 Spillway

TYPES OF SPILLWAYS TESTED
Stilling Basin and Wingwall Geometry
Model Scale 1:50
Note: All types A and B are the 6 bay scheme, type C is the 8 bay scheme.

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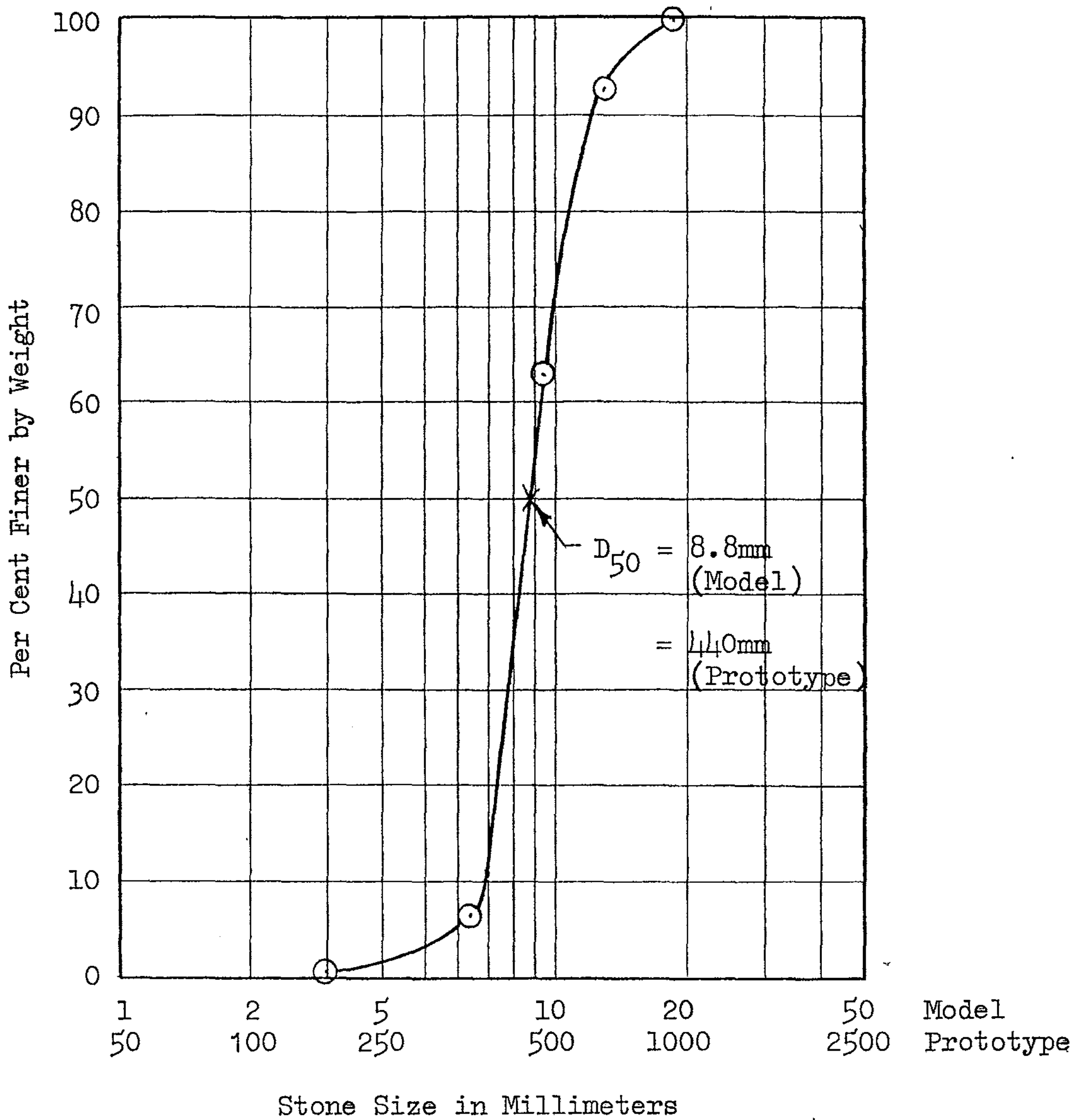
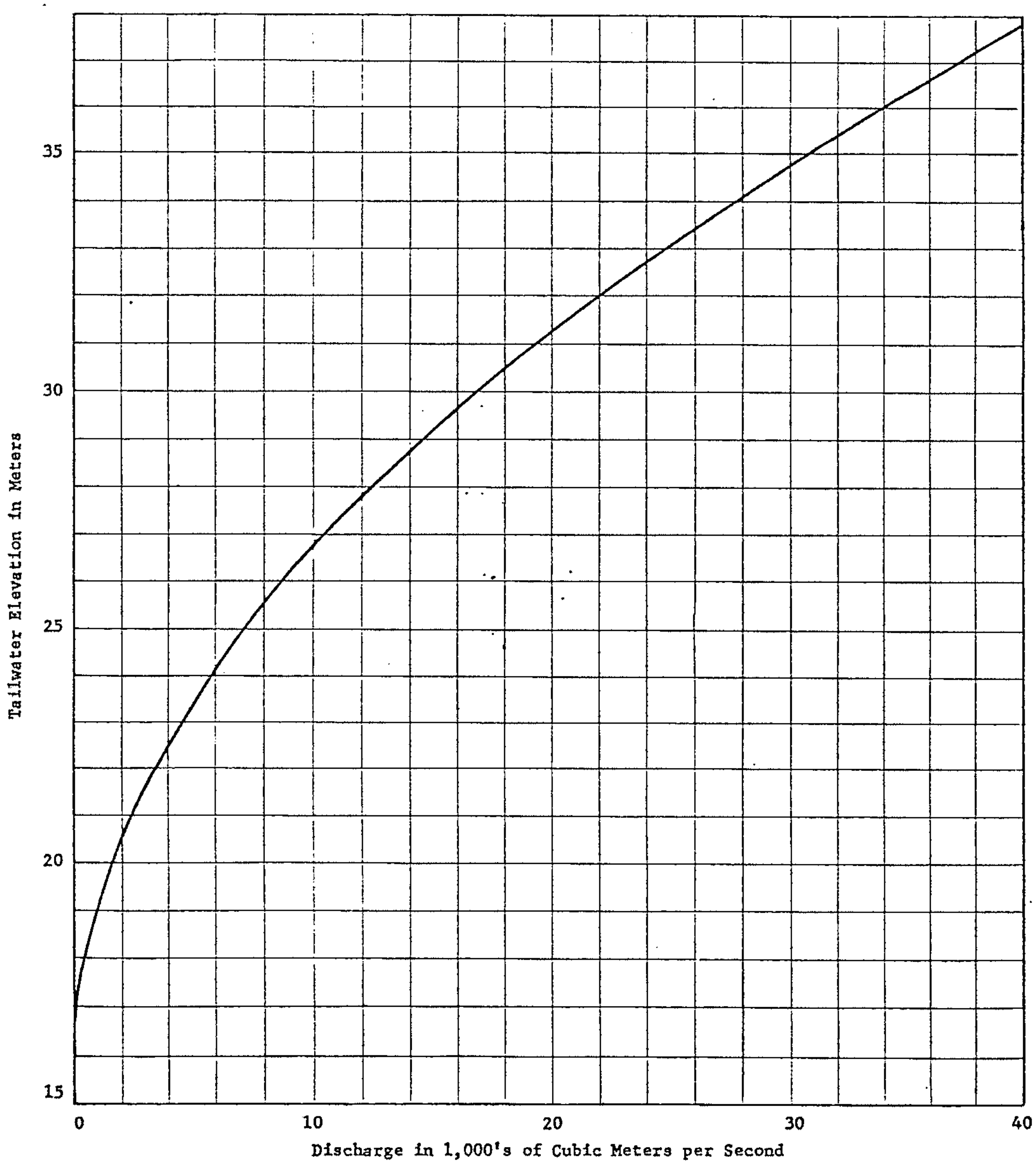
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-29

Chart 4



STONE SIZE DISTRIBUTION
Section Model Scale 1:50

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 5/18/78	NO. 264A2318-30



Tailwater Rating Curve
Tailwater versus Discharge
Model Scale 1:50

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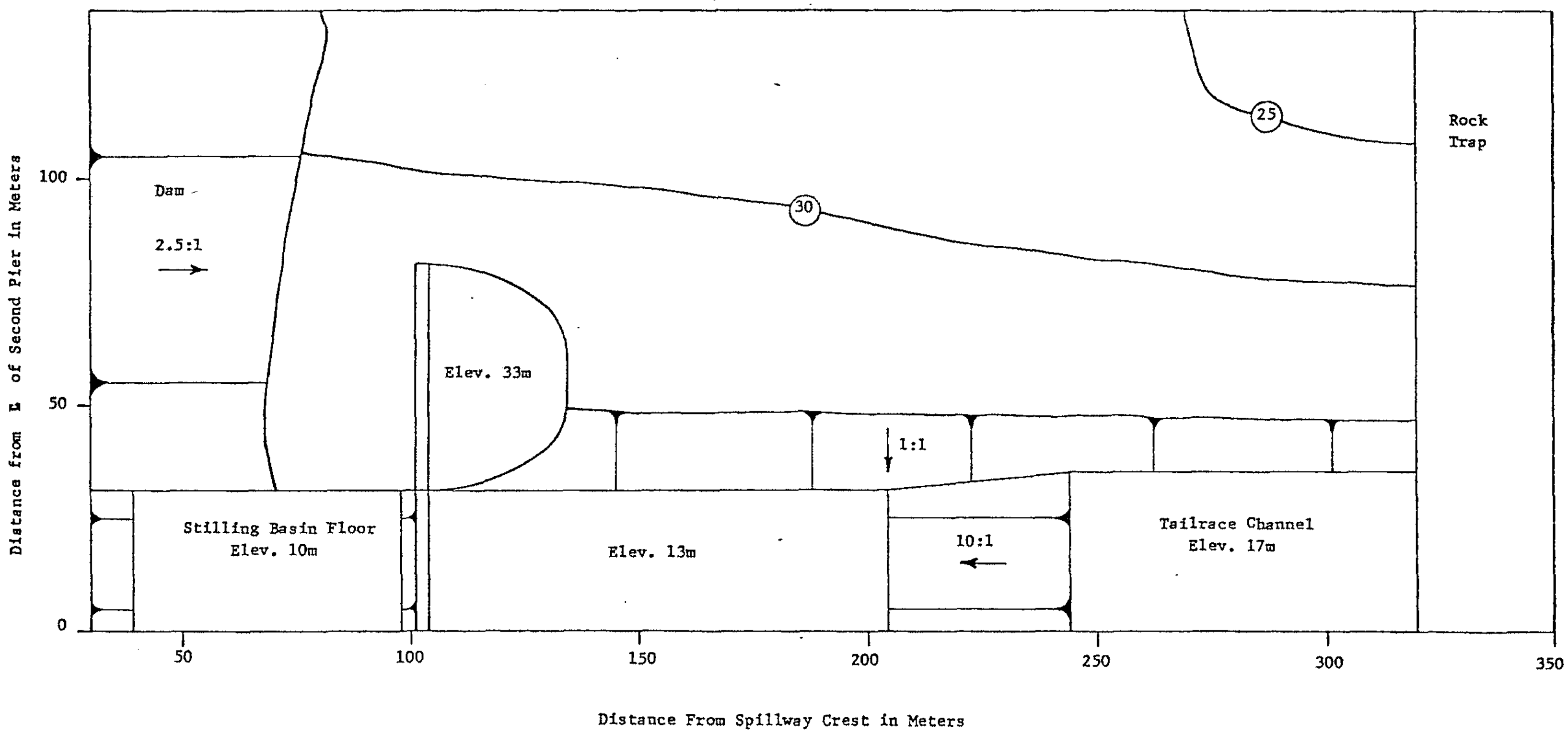
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-28

Chart 6



TYPE A-2 SPILLWAY
Original Geometry
Model Scale 1:50
Contour elevations are given in meters.

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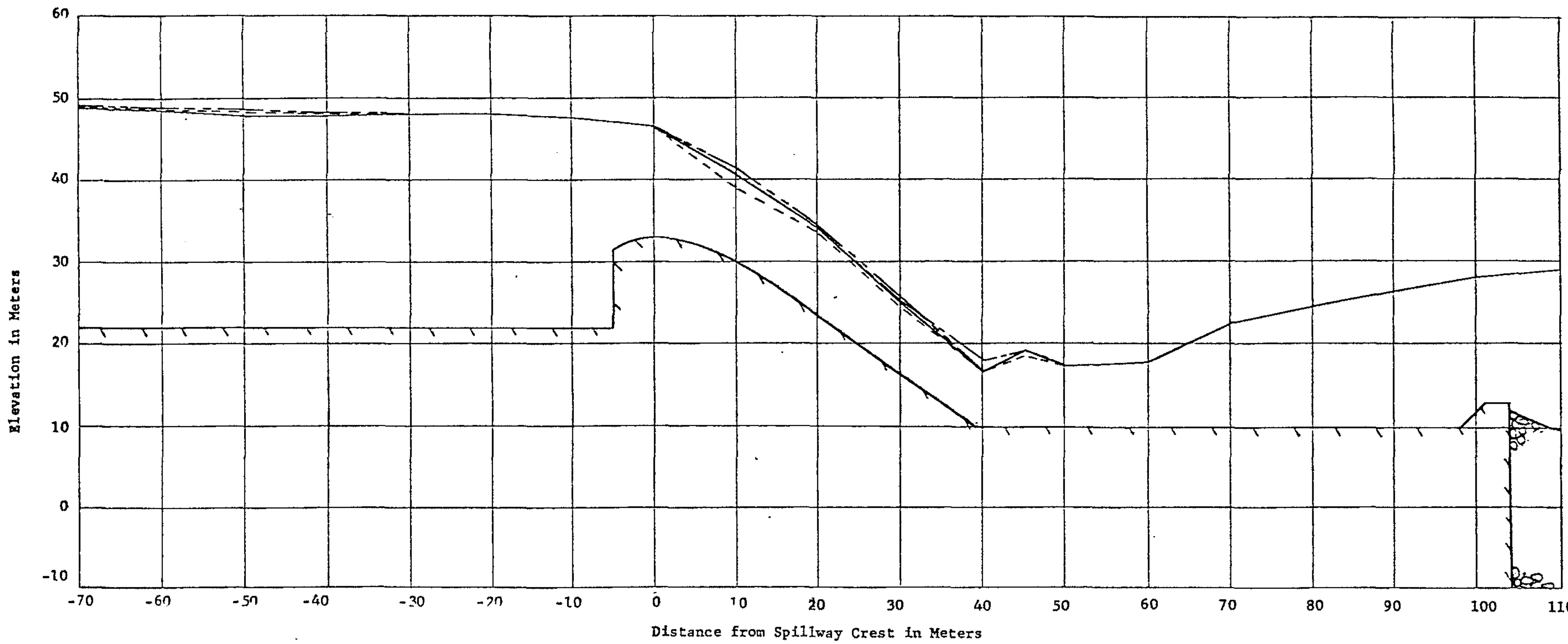
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/27/78	NO. 264B504-2

Chart 7



TYPE A-2 SPILLWAY
Water Surface Profiles Through Spillway
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m

——-—— Along left training wall
———— Along centerline of left bay
------ Along left side of pier 1
——--— Along right side of pier 1

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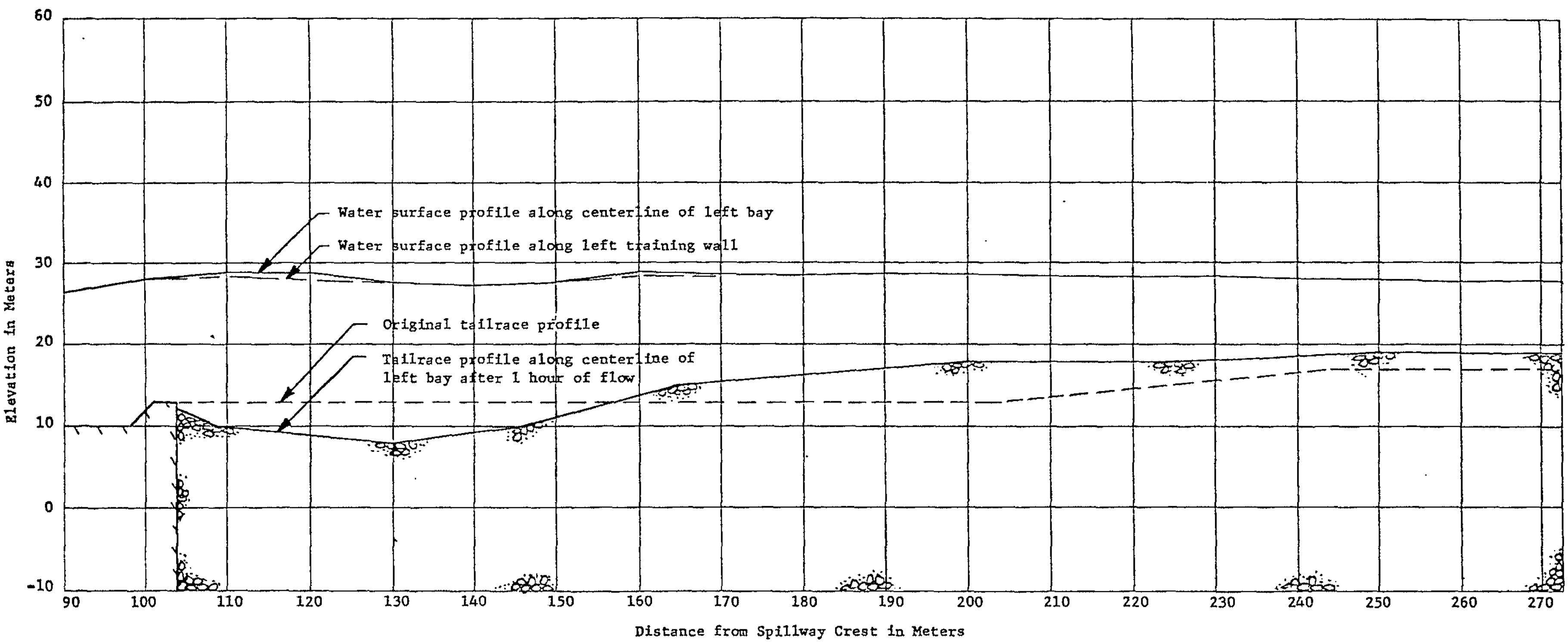
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-5

Chart 8



TYPE A-2 SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profile after 1 Hour of Flow
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m

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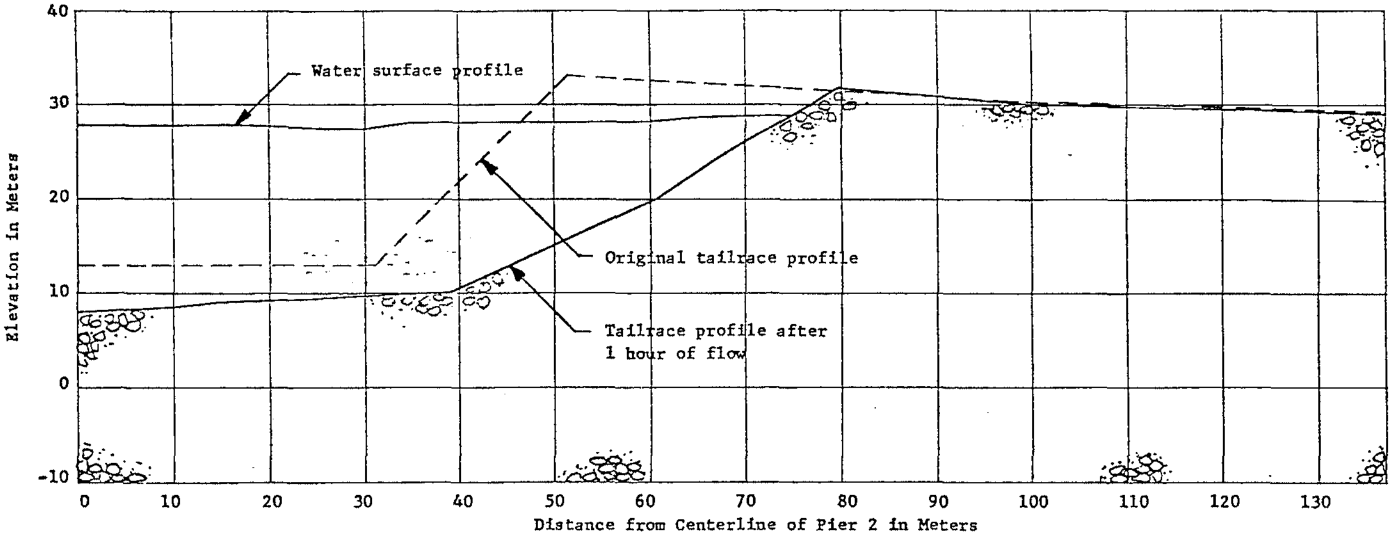
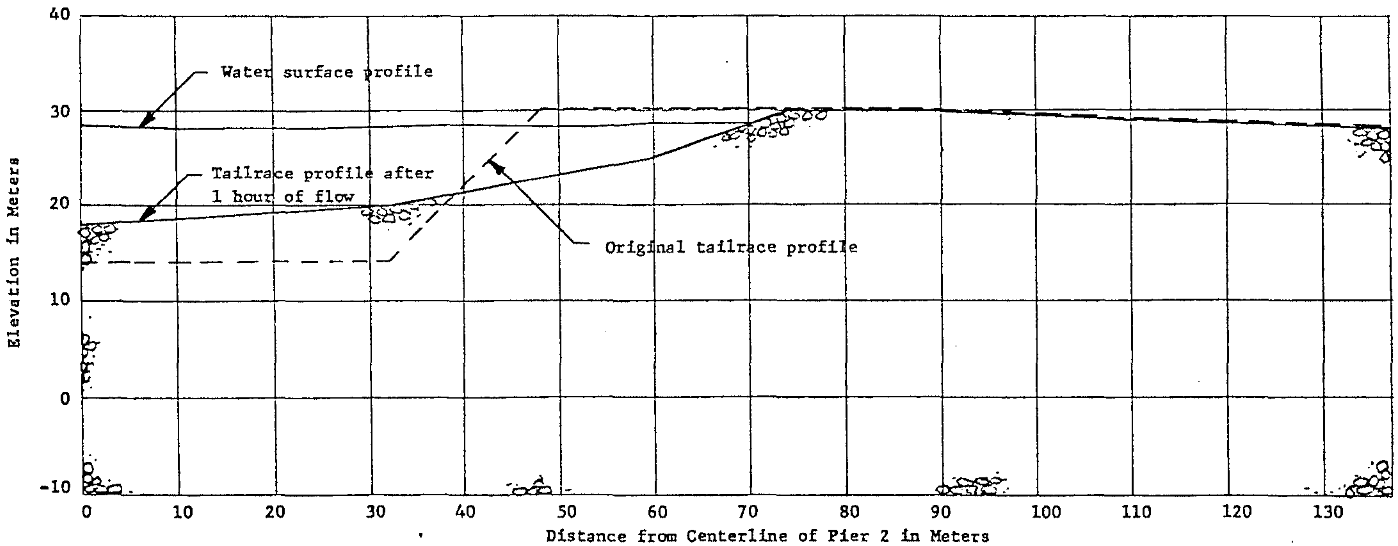
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-6

Chart 9



Cross-Section 135 Meters Downstream from Spillway Crest



Cross-Section 216 Meters Downstream from Spillway Crest

TYPE A-2 SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profiles after 1 Hour of Flow
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m

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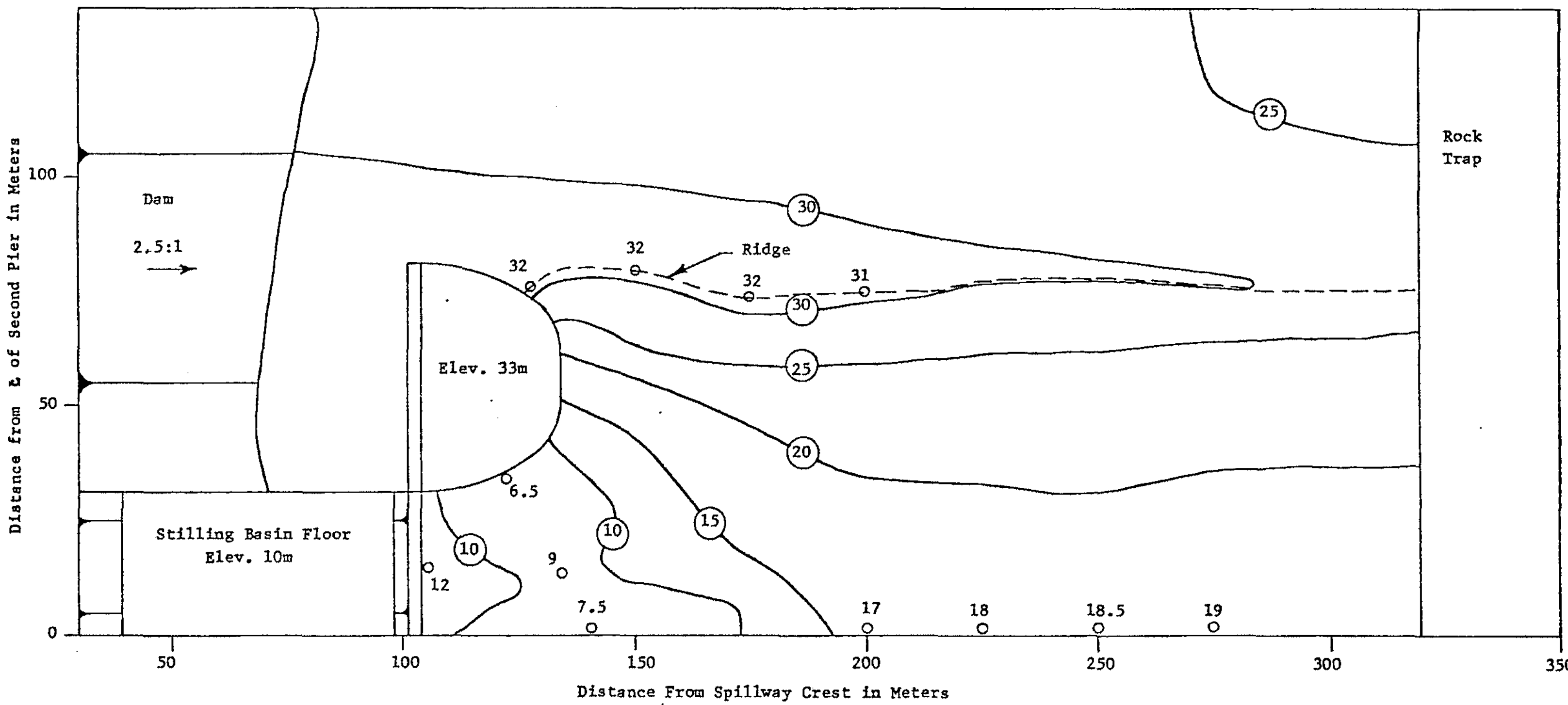
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-7

Chart 10



TYPE A-2 SPILLWAY
Erosion Pattern After 1 Hour of Flow
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m
Contour elevations are given in meters.
O Point elevations in meters.

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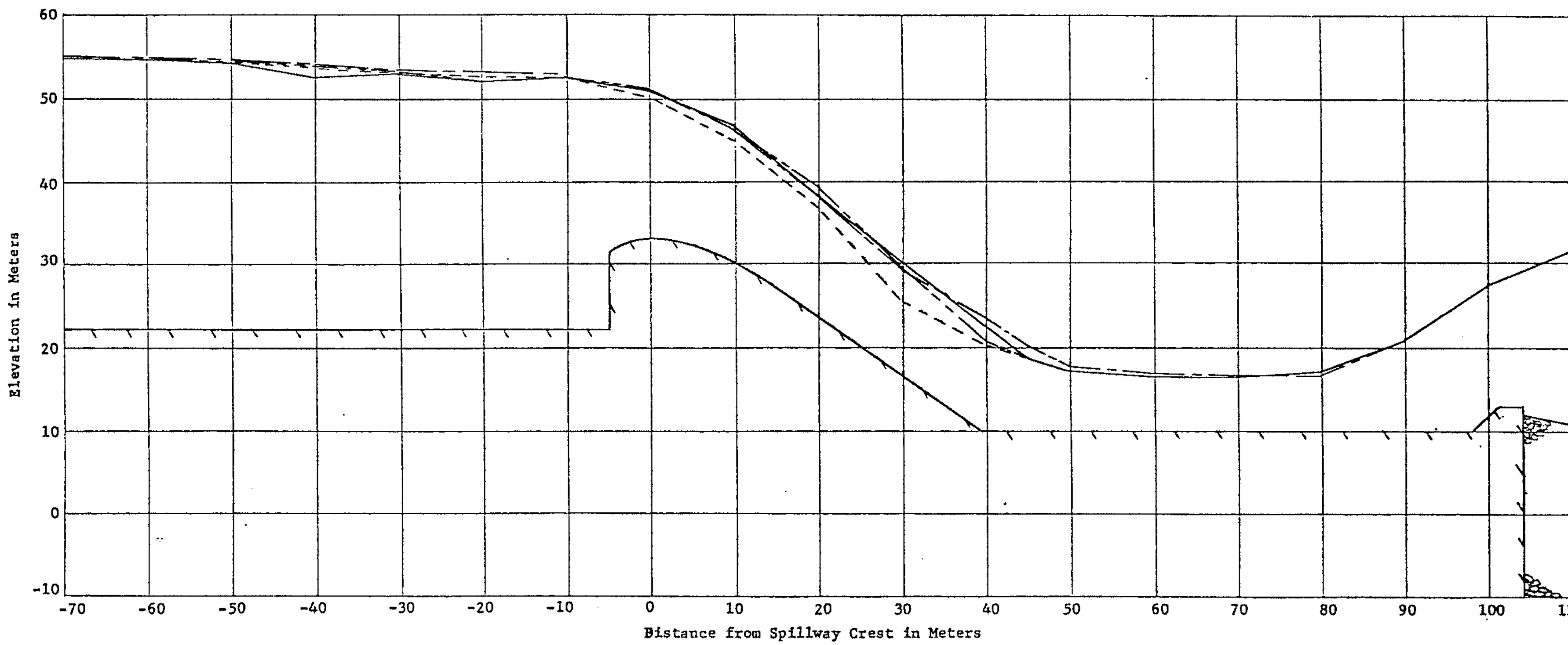
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/27/78	NO. 264B504-3

Chart 11



TYPE A-2 SPILLWAY
Water Surface Profiles Through Spillway
Model Scale 1:50
Q = 18,000 cms, H.W. = 56m, T.W. = 30.5m

Along left training wall
Along centerline of left bay
Along left side of pier 1
Along right side of pier 1

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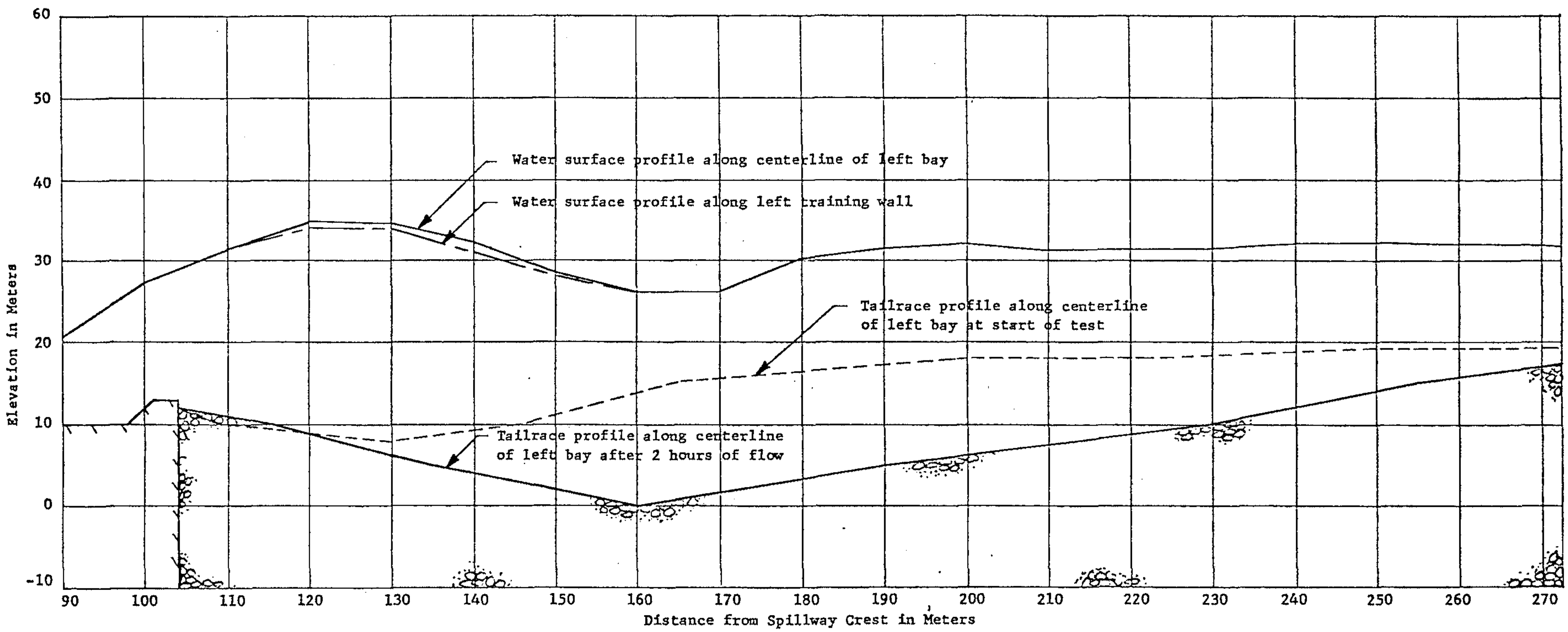
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-8

Chart 12



TYPE A-2 SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profile after 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 56m, T.W. = 30.5m

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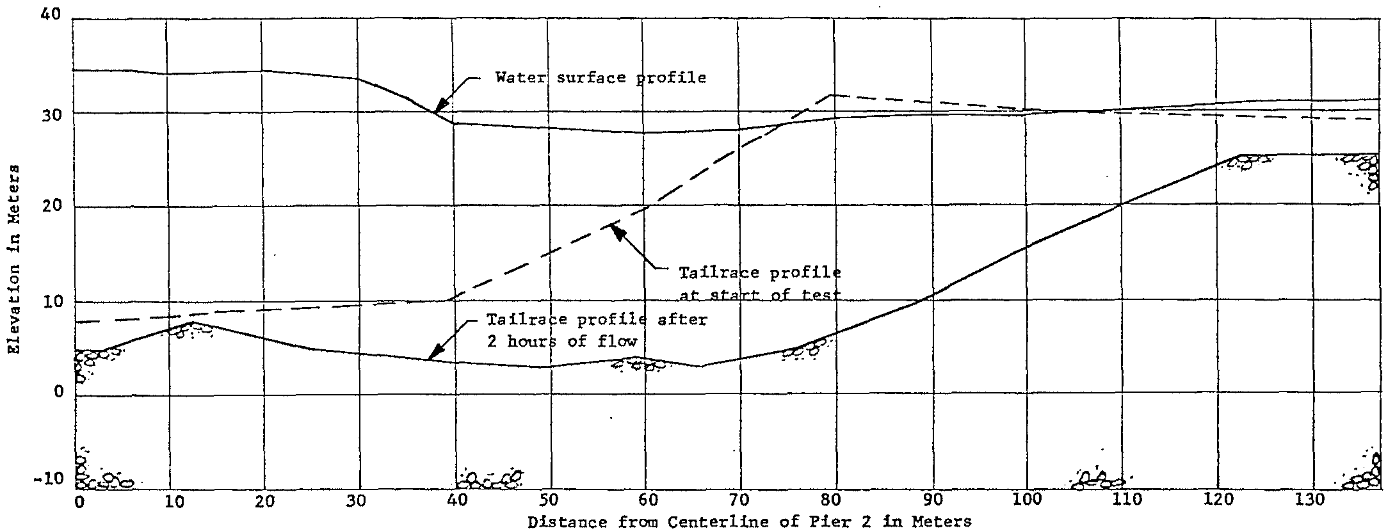
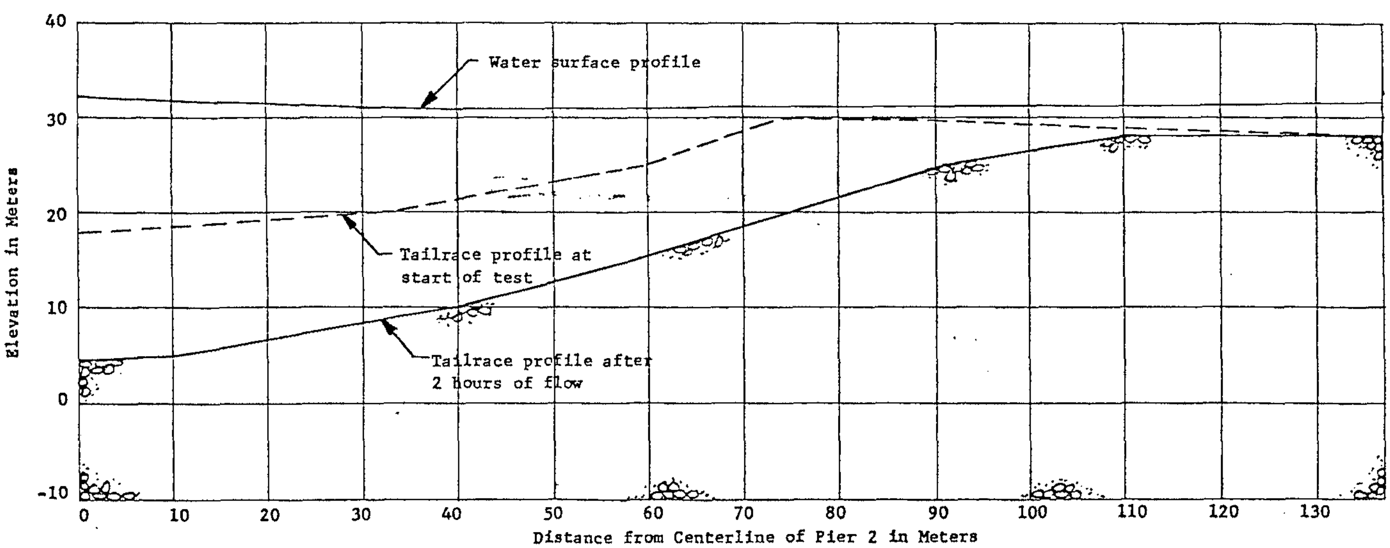
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-9

Chart 13



Cross-Section 135 Meters Downstream from Spillway Crest



Cross-Section 216 Meters Downstream from Spillway Crest

TYPE A-2 SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profiles after 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 56m, T.W. = 30.5m

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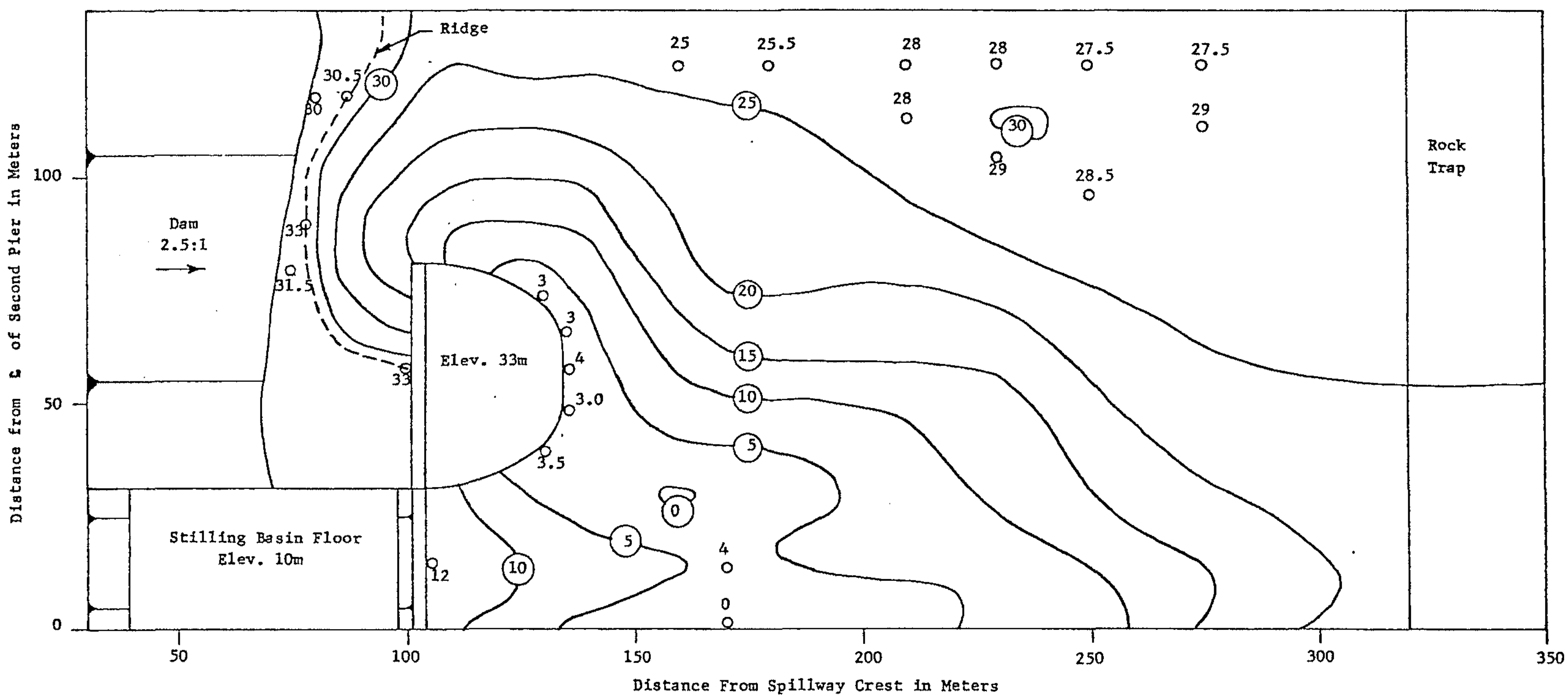
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 3/10/78	NO. 264B504-10

Chart 14



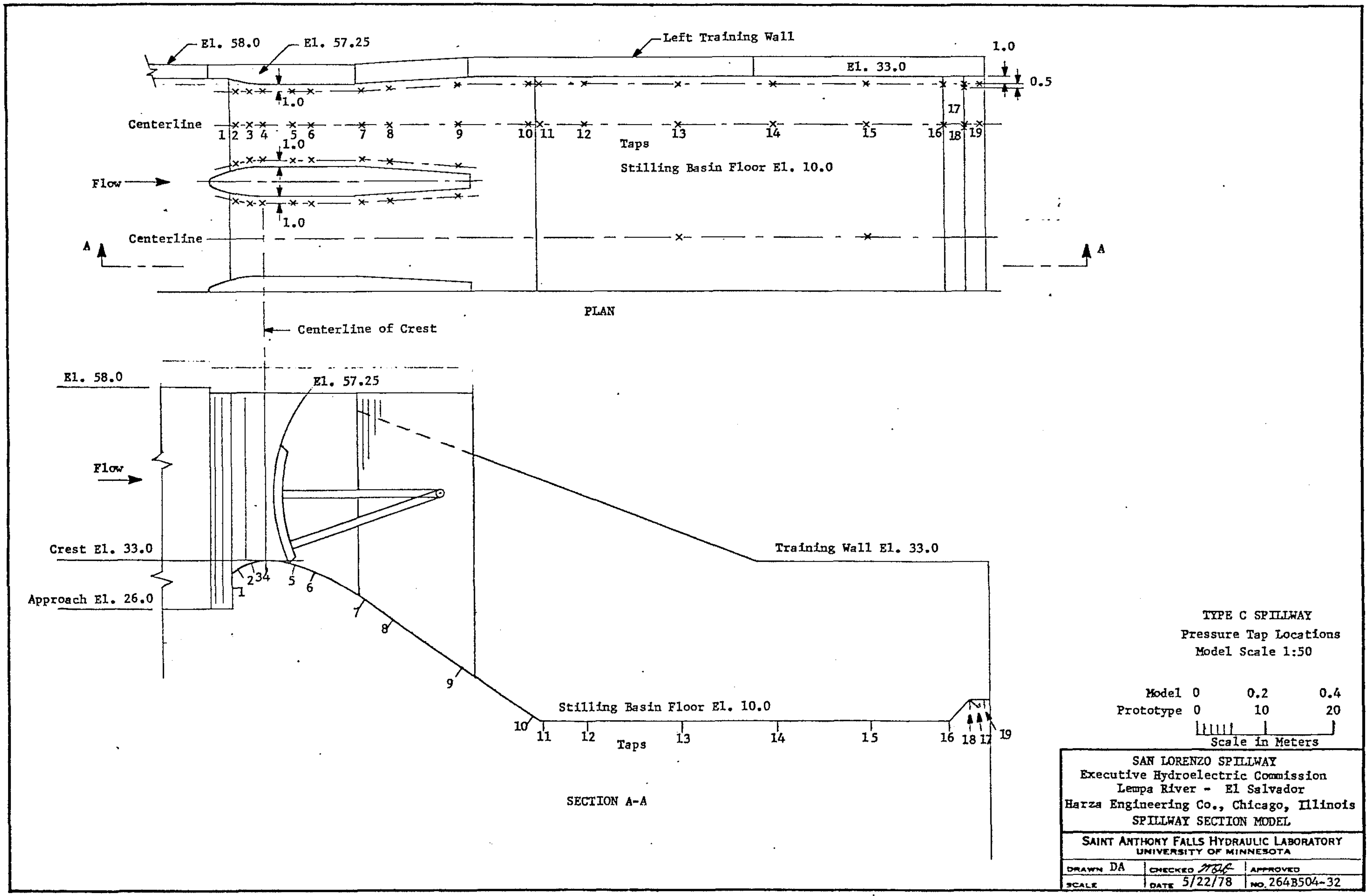
TYPE A-2 SPILLWAY
Erosion Pattern Afters 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 56m, T.W. = 30.5m
Contour elevations are given in meters
O Point elevations in meters

SAN LORENZO SPILLWAY
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 2/27/78	NO. 264F504-4

Chart 15


El. 58.0
El. 57.25
Left Training Wall
1.0
El. 33.0
0.5
1.0
Centerline
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Taps
Stilling Basin Floor El. 10.0
Flow
Centerline
A
A
PLAN
Centerline of Crest
El. 58.0
El. 57.25
Flow
Crest El. 33.0
Approach El. 26.0
Training Wall El. 33.0
Stilling Basin Floor El. 10.0
Taps
SECTION A-A
TYPE C SPILLWAY
Pressure Tap Locations
Model Scale 1:50
Model 0 0.2 0.4
Prototype 0 10 20
Scale in Meters
SAN LORENZO SPILLWAY
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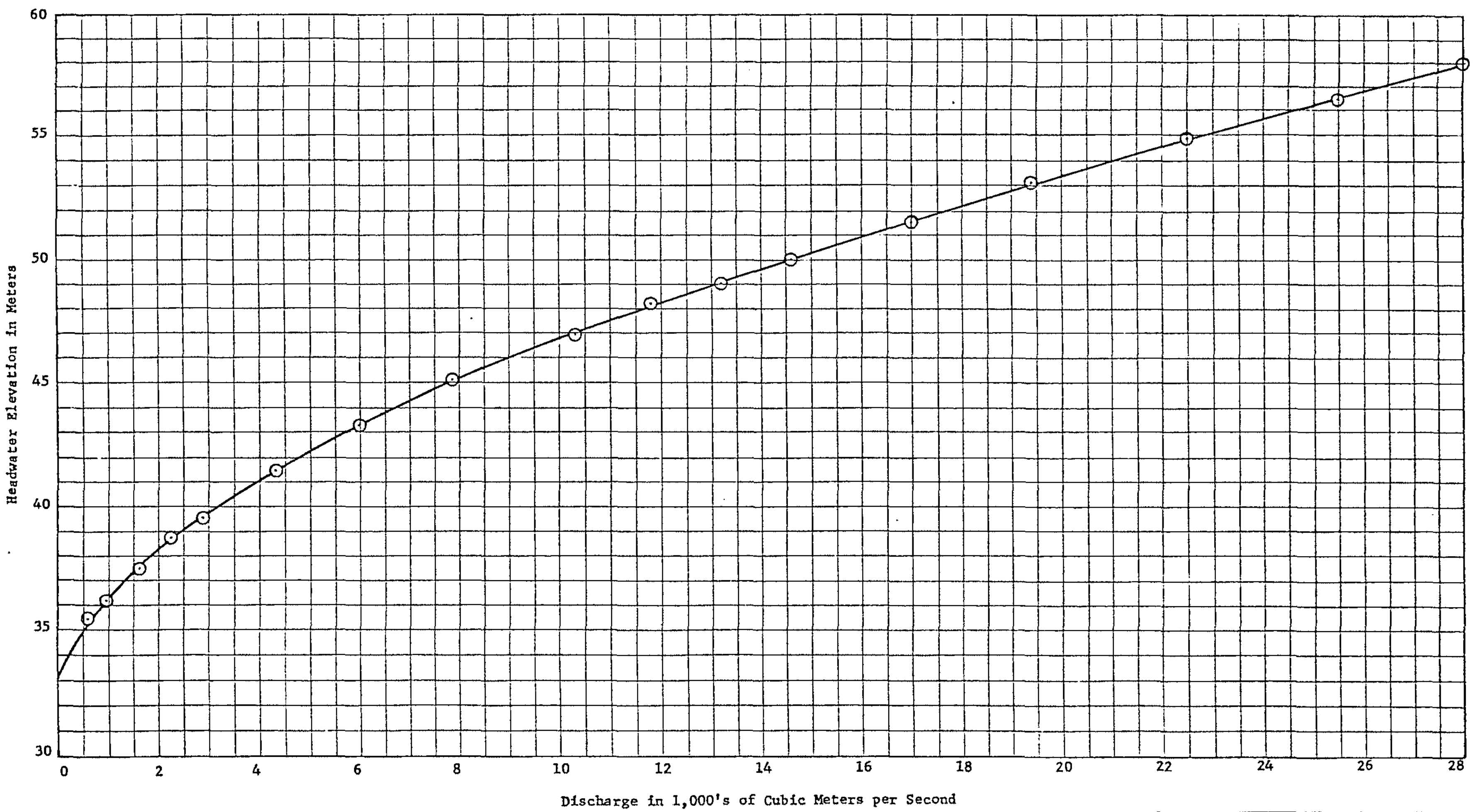
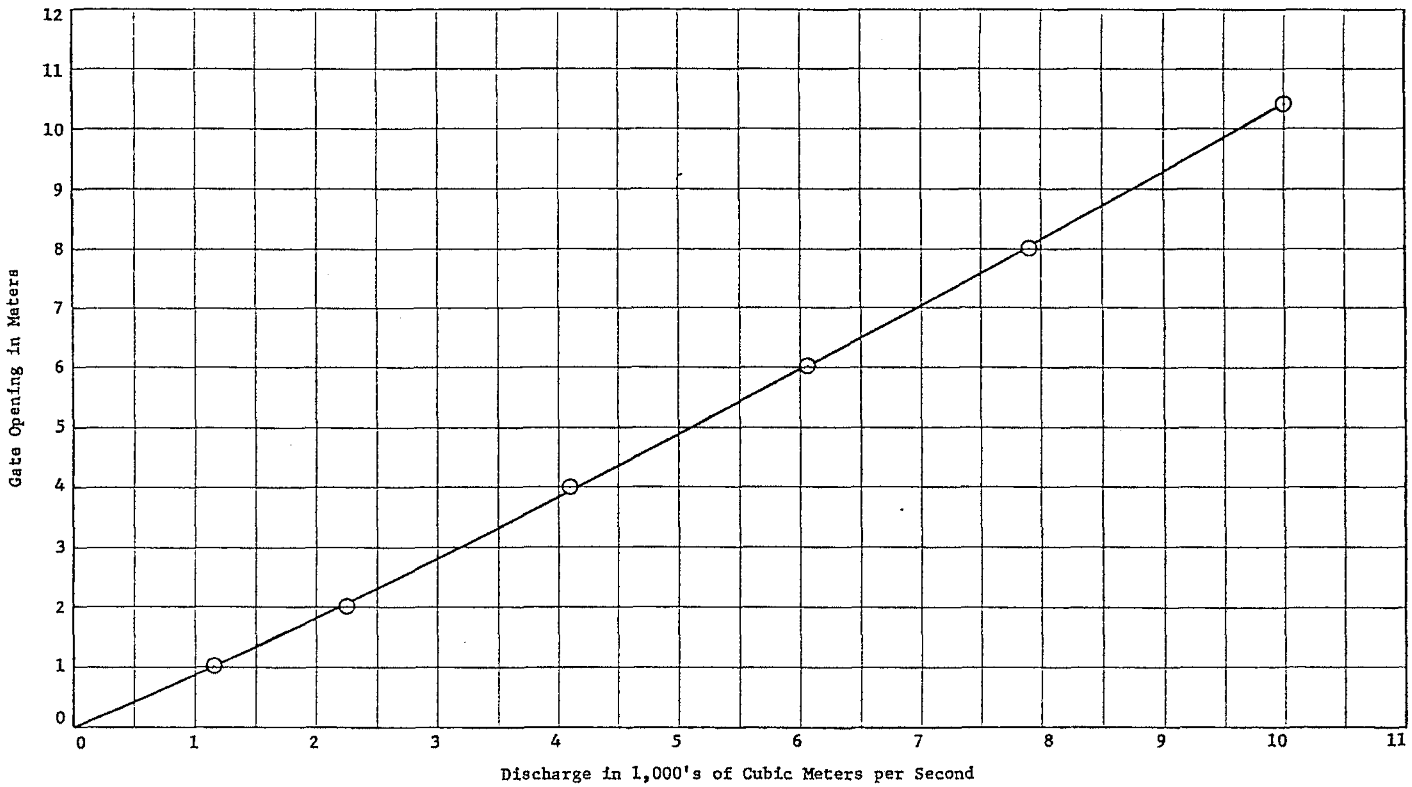
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED
APPROVED
SCALE
DATE 5/22/78
NO. 264B504-32
Chart 16



TYPE C SPILLWAY
Spillway Rating Curve
Headwater versus Discharge
Gates Wide Open
Model Scale 1:50

SAN LORENZO SPILLWAY Executive Hydroelectric Commission Lempa River - El Salvador Harza Engineering Co., Chicago, Illinois SPILLWAY SECTION MODEL		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/8/78	NO. 264B504-19

Chart 17



TYPE C SPILLWAY
Spillway Rating Curve
Partial Gate Openings versus Discharge
Headwater Elevation = 49.0 Meters
Model Scale 1:50

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Executive Hydroelectric Commission
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Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

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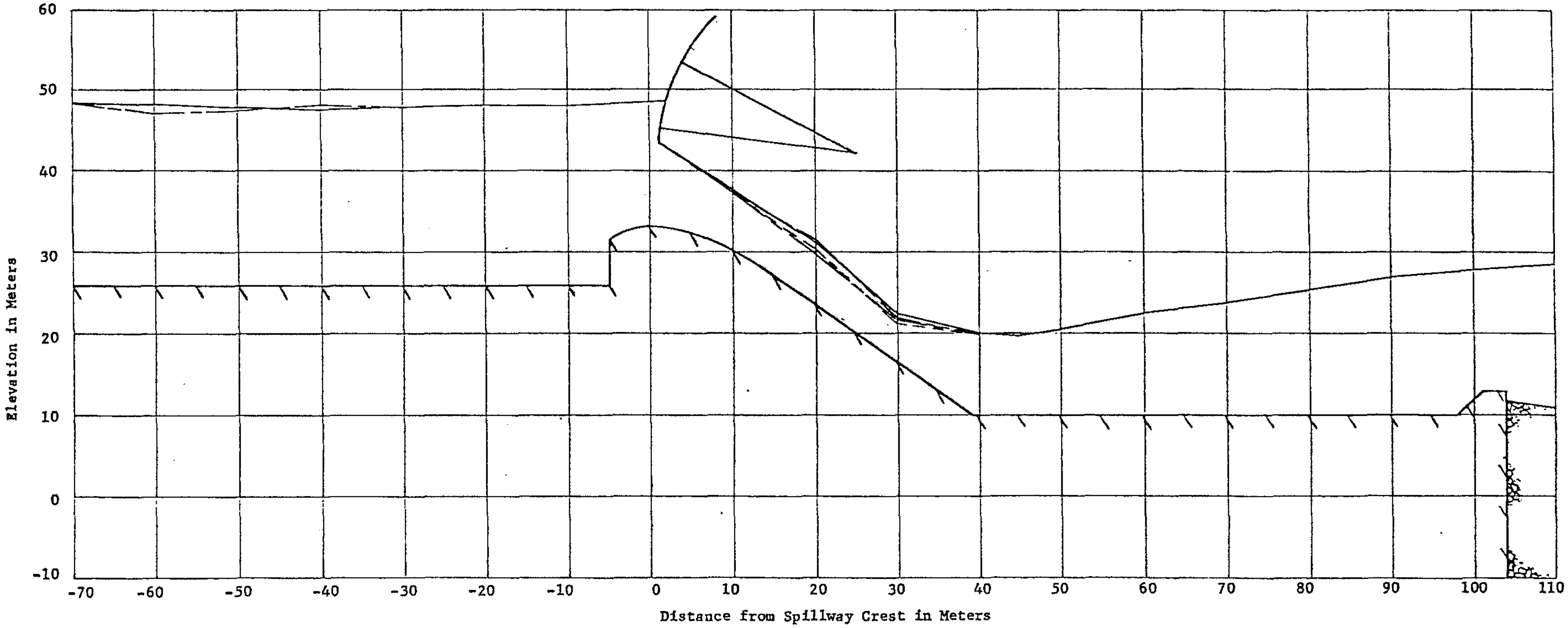
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/8/78	NO. 264B504-20



TYPE C SPILLWAY
Water Surface Profiles Through Spillway
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m
Gate opening = 10.4m

— — — Along left training wall
——— Along centerline of left bay
– – – – – Along left side of pier 1
— — — — Along right side of pier 1

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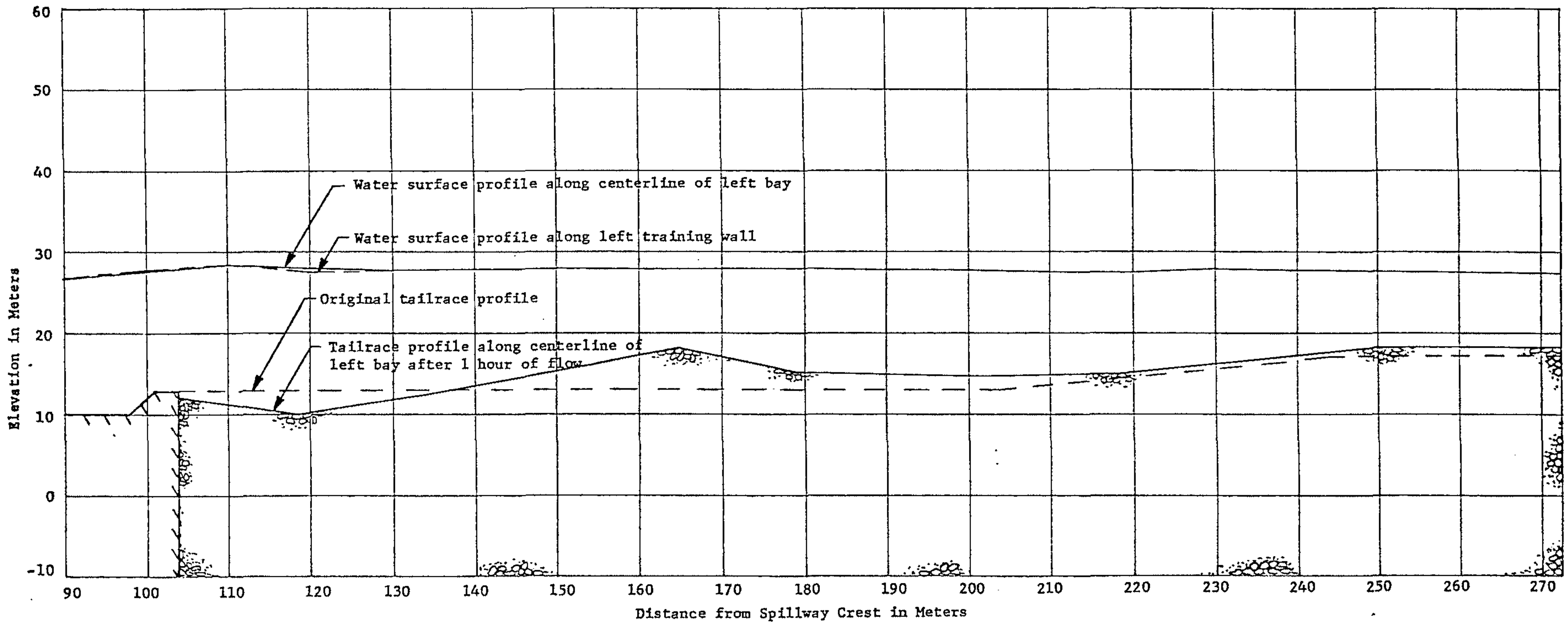
DRAWN DA	CHECKED HBB	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-15

Chart 19



TYPE C SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profile after 1 Hour of Flow
Model Scale 1:50
ϕ = 10,000 cms, H.W. = 49m, T.W. = 27m
Gate opening = 10.4m

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SPILLWAY SECTION MODEL

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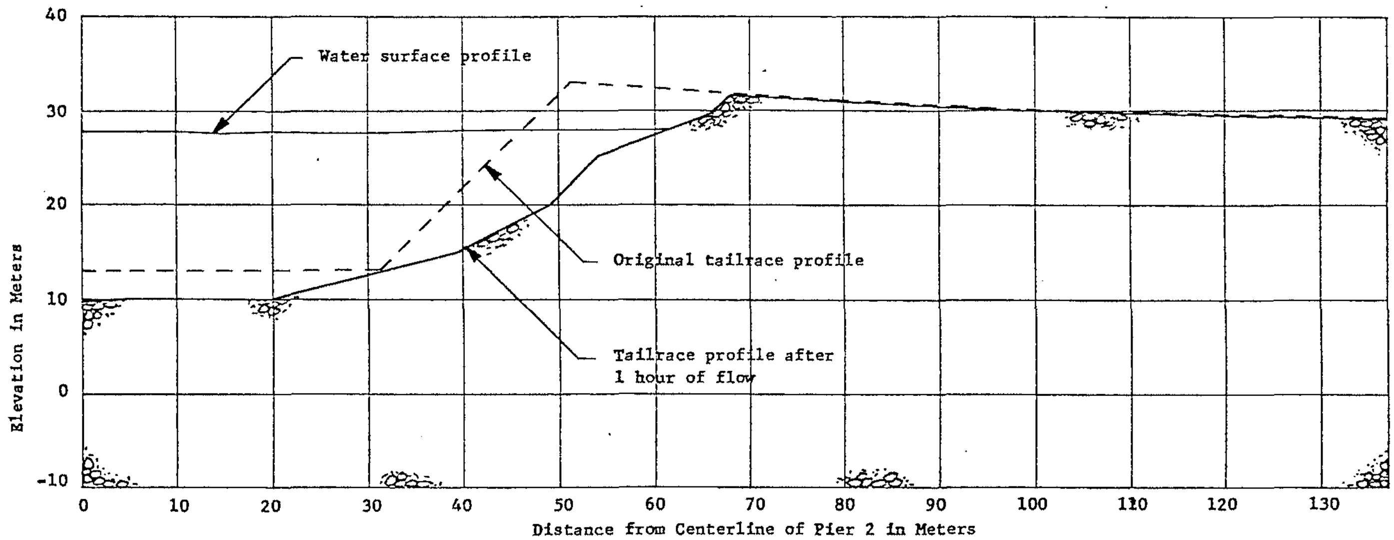
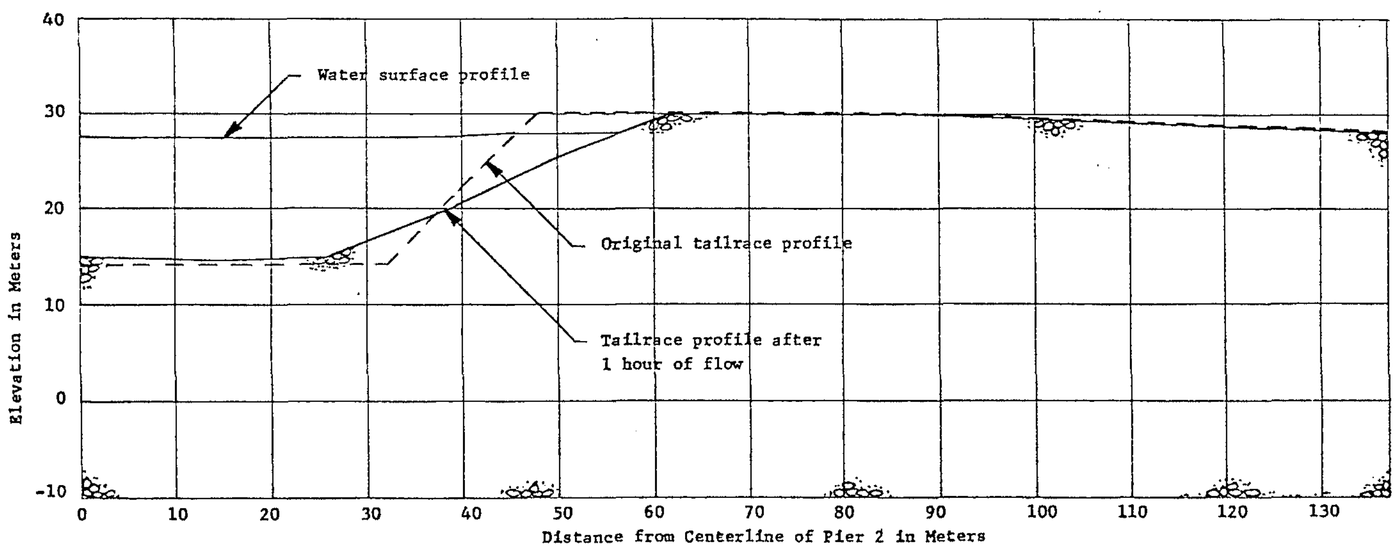
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-13

Chart 20



Cross-Section 135 Meters Downstream from Spillway Crest



Cross-Section 216 Meters Downstream from Spillway Crest

TYPE C SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profiles after 1 Hour of Flow
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m
Gate opening = 10.4m

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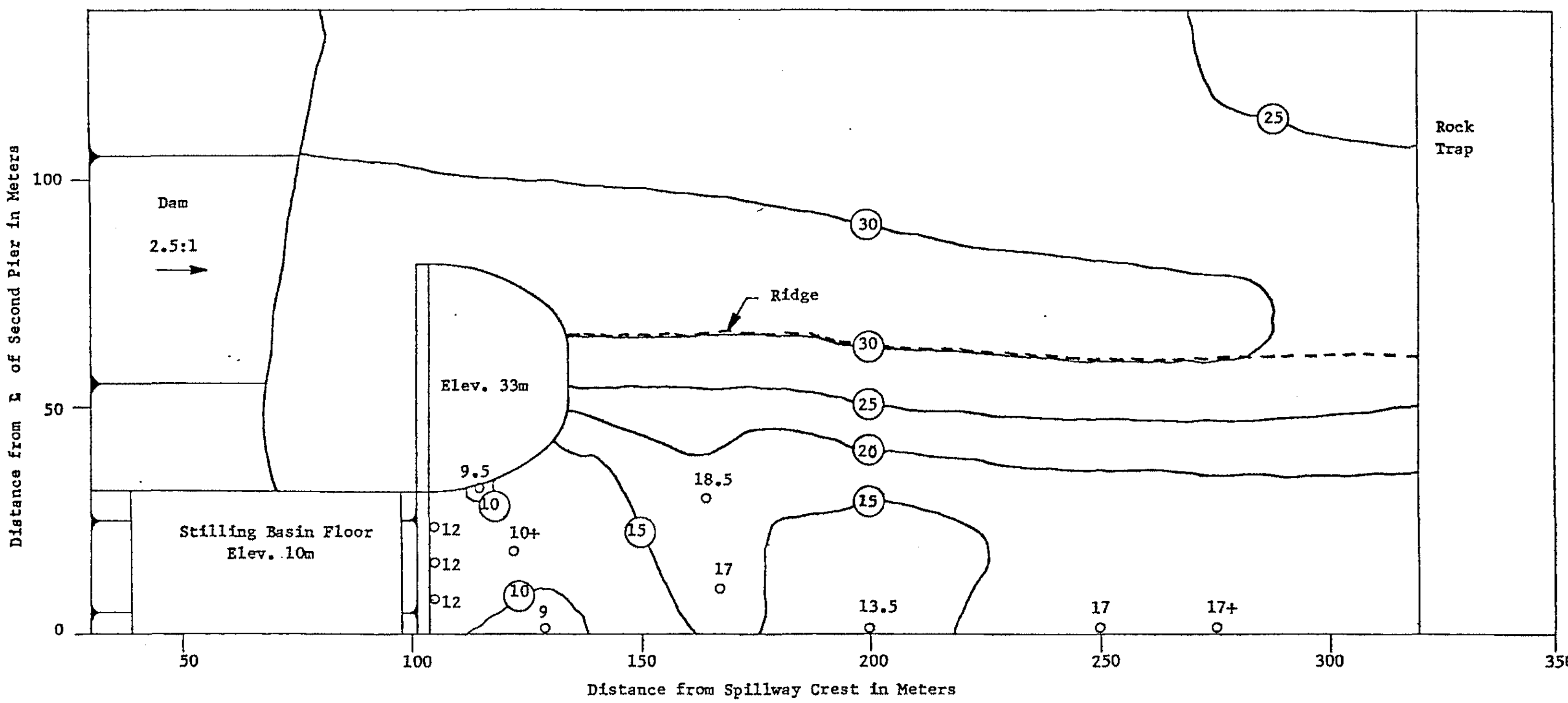
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-17

Chart 21



TYPE C SPILLWAY
Erosion Pattern After 1 Hour of Flow
Model Scale 1:50
Q = 10,000 cms, H.W. = 49m, T.W. = 27m
Gate opening = 10.4m
Contour elevations are given in meters
○ Point elevationsin meters

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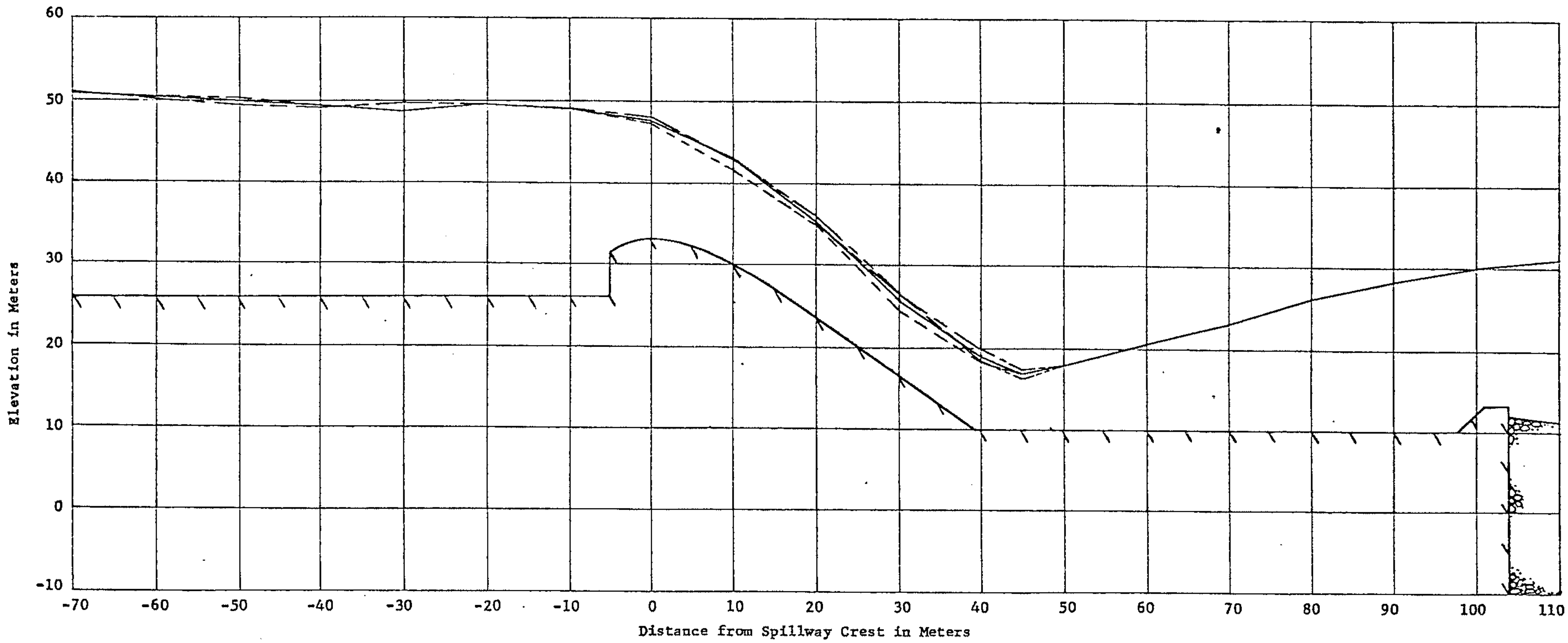
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-11

Chart 22



TYPE C SPILLWAY
Water Surface Profiles Through Spillway
Model Scale 1:50
Q = 18,000 cms, H.W. = 52.2m, T.W. = 30.5m

— — — Along left training wall
——— Along centerline of left bay
– – ––– Along left side of pier 1
—— – – — Along right side of pier 1

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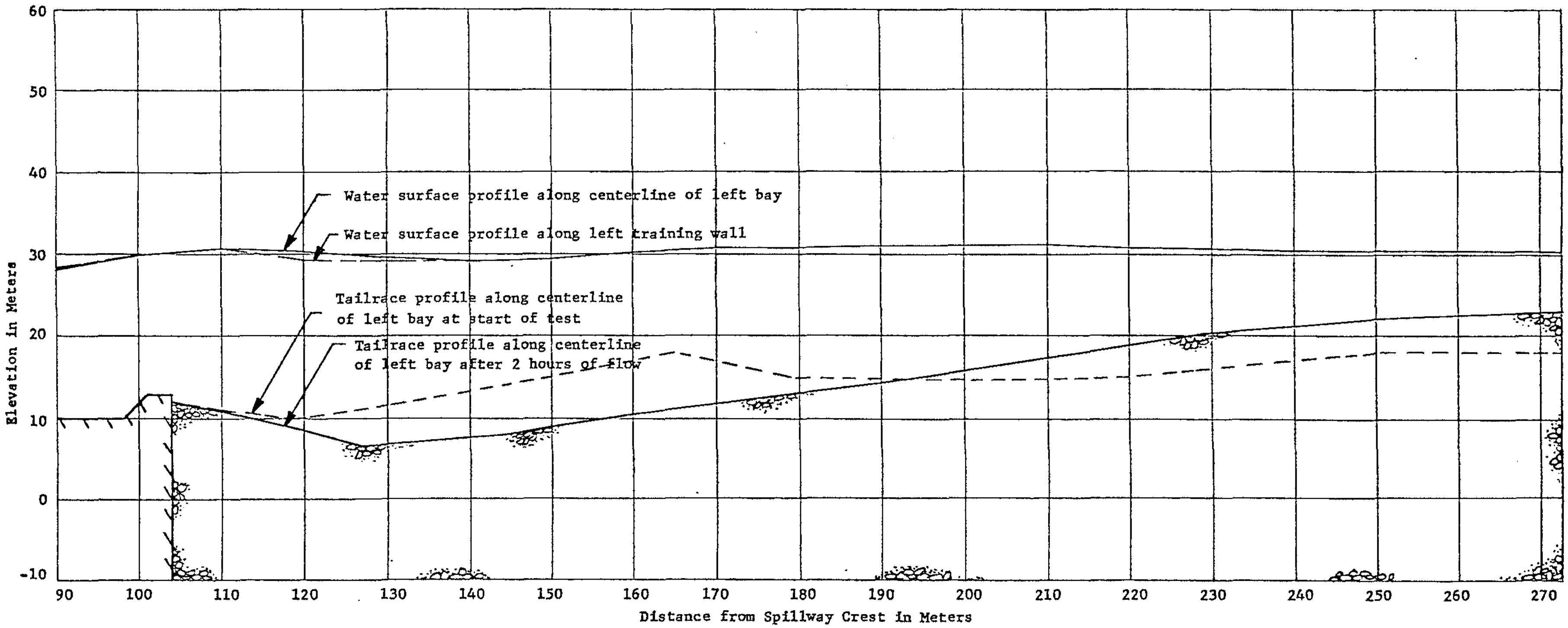
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA	
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-16

Chart 23



TYPE C SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profile after 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 52.2m, T.W. = 30.5m

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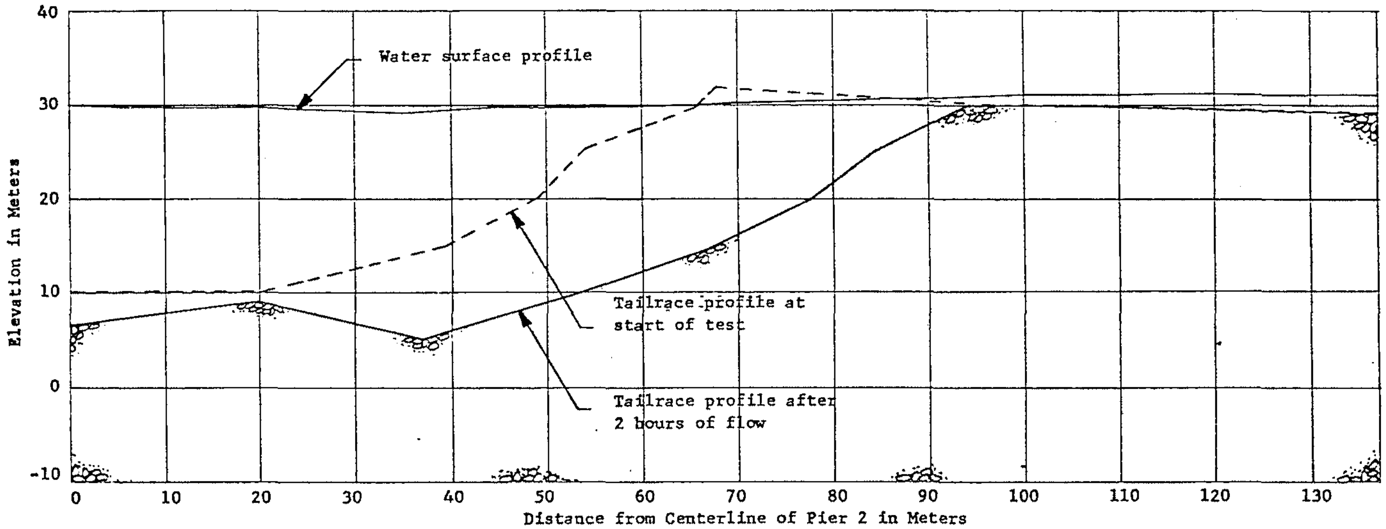
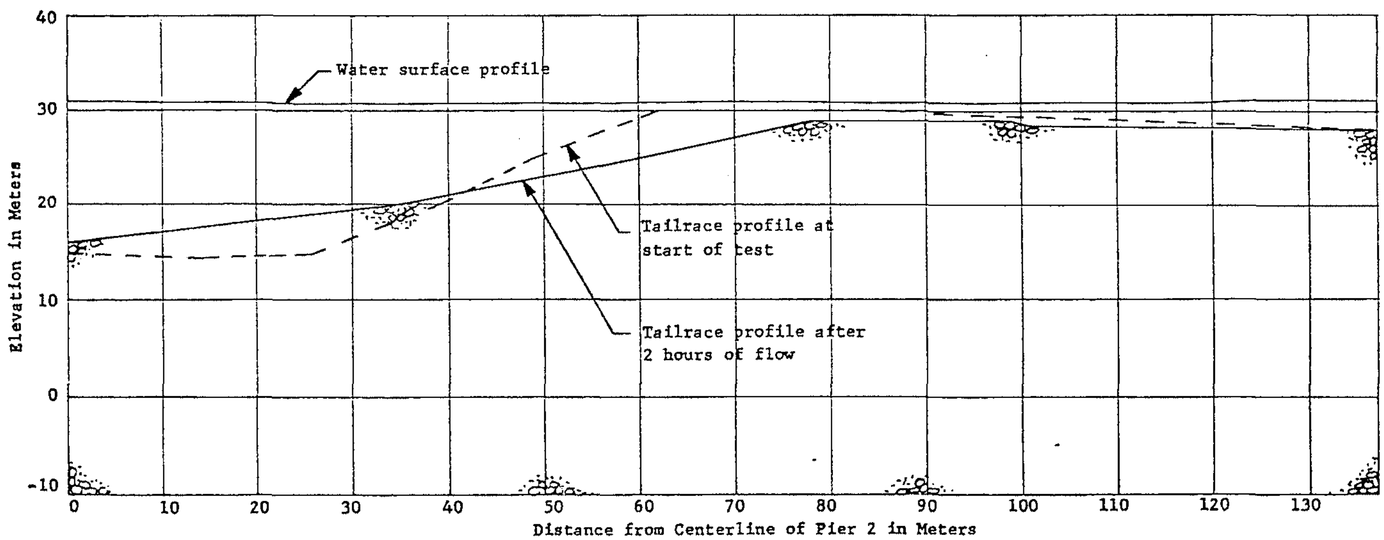
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-14

Chart 24



Cross-Section 135 Meters Downstream from Spillway Crest



Cross-Section 216 Meters Downstream from Spillway Crest

TYPE C SPILLWAY
Water Surface Profiles in Tailrace
Tailrace Profiles after 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 52.2m, T.W. = 30.5m

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Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

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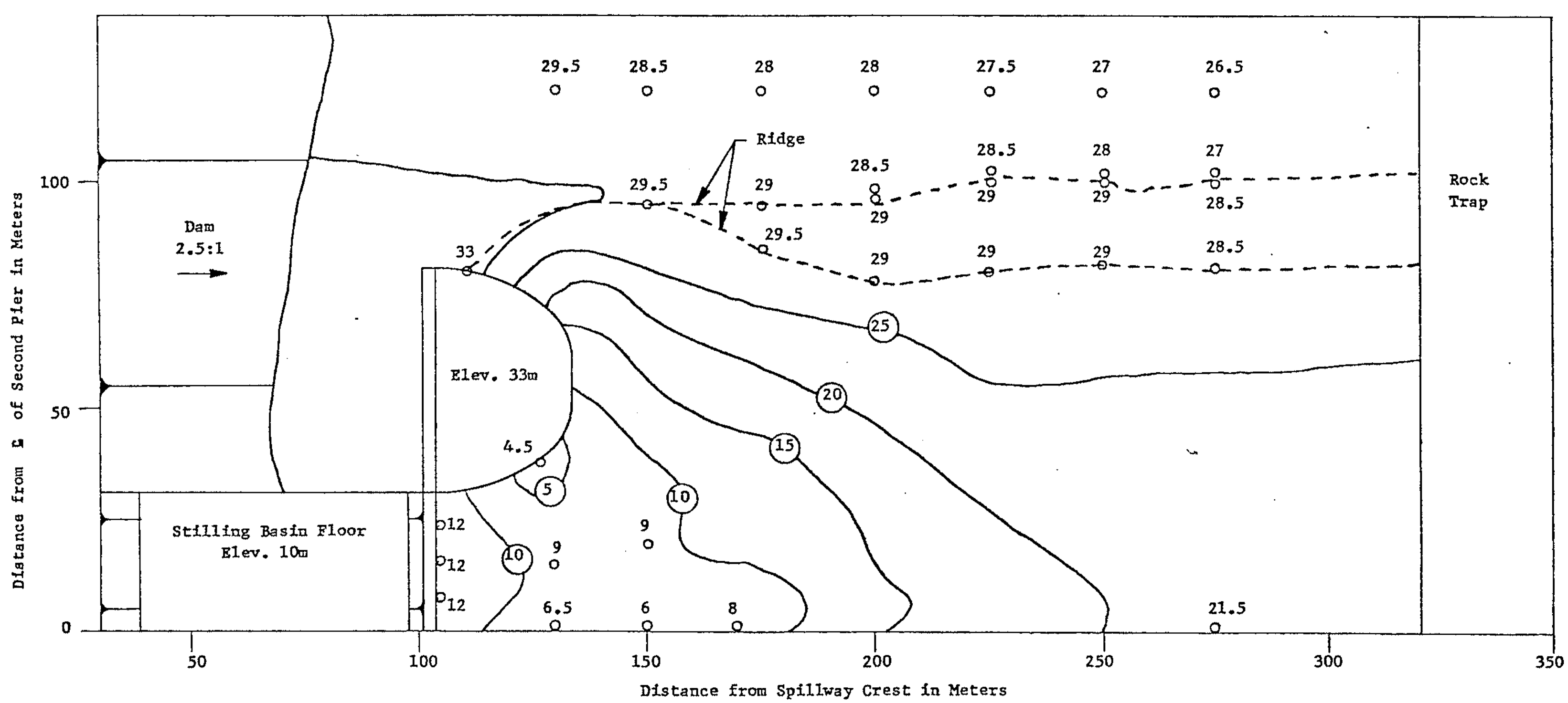
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-18

Chart 25



TYPE C SPILLWAY
Erosion Pattern After 2 Hours of Flow
Model Scale 1:50
Q = 18,000 cms, H.W. = 52.2m, T.W. = 30.5m
Contour elevations are given in meters
O Point elevations in meters

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Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

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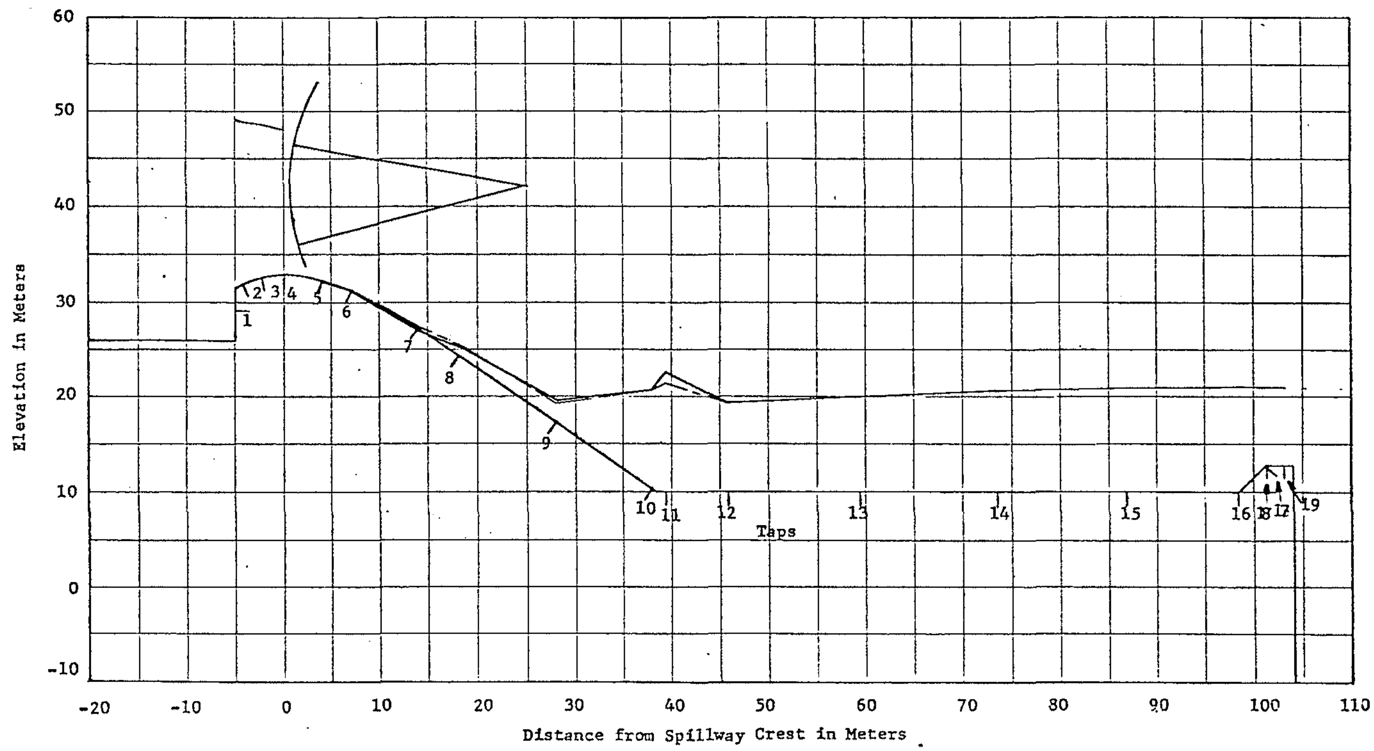
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 4/20/78	NO. 264B504-12

Chart 26



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 1150 cms, H.W. = 49.0m, T.W. = 20.0m
Gate opening = 1m

— — — Along left training wall
——— Along centerline of left bay
- - - - - Along left side of pier 1
— - — - Along right side of pier 1

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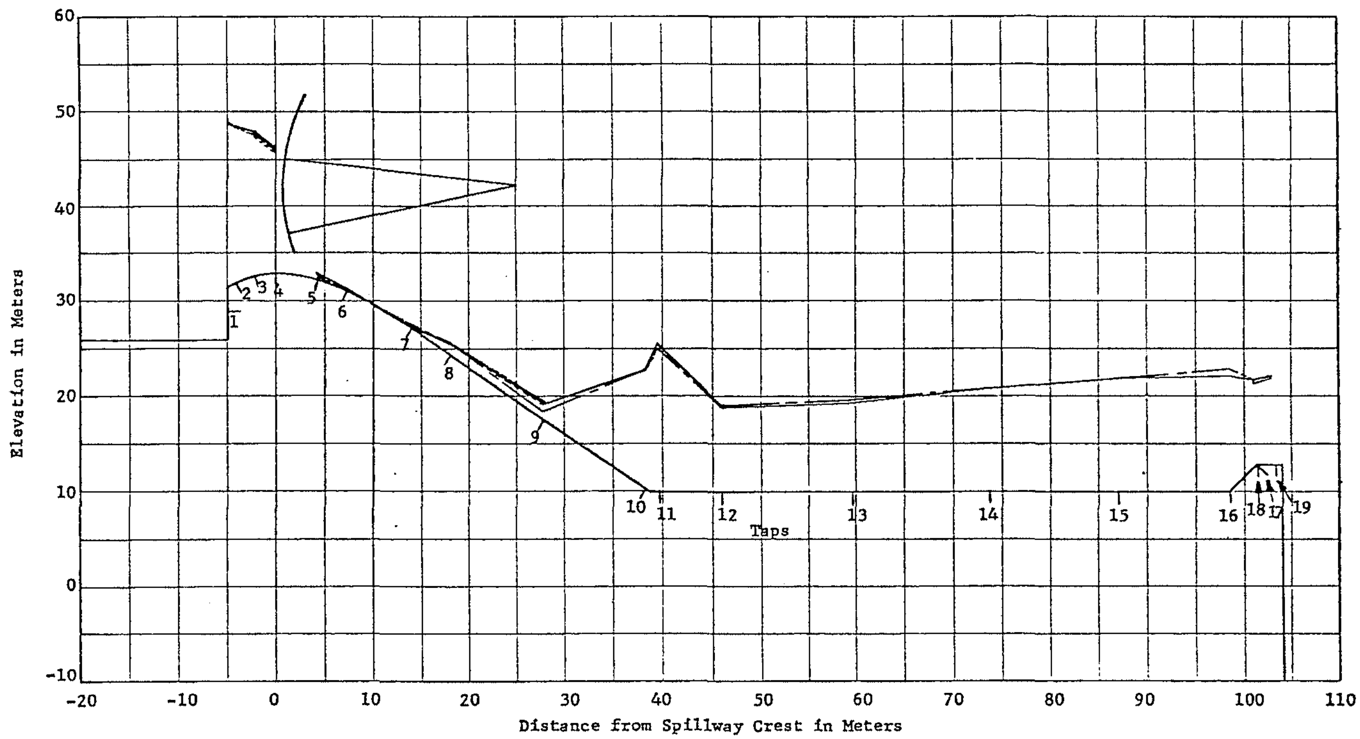
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-21

Chart 27



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 2250 cms, H.W. = 49.0m, T.W. = 20.9m
Gate opening = 2m

—— — —— Along left training wall
———— Along centerline of left bay
- - - - - - Along left side of pier 1
—— - - - Along right side of pier 1

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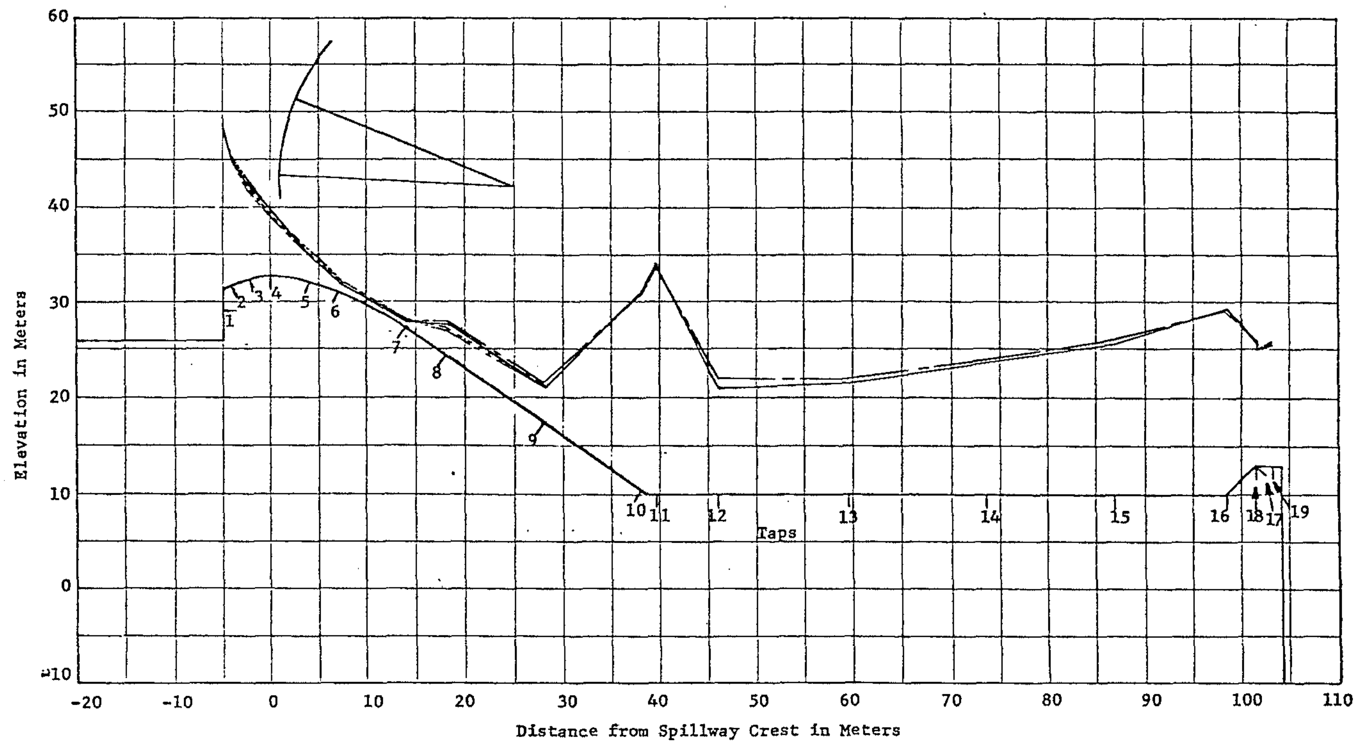
DRAWN DA	CHECKED [signature]	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-22

Chart 28



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 7900 cms, H.W. = 49.0m, T.W. = 25.5m
Gate opening = 8m

—— – —— Along left training wall
———— Along centerline of left bay
– – – – – Along left side of pier 1
—— – – Along right side of pier 1

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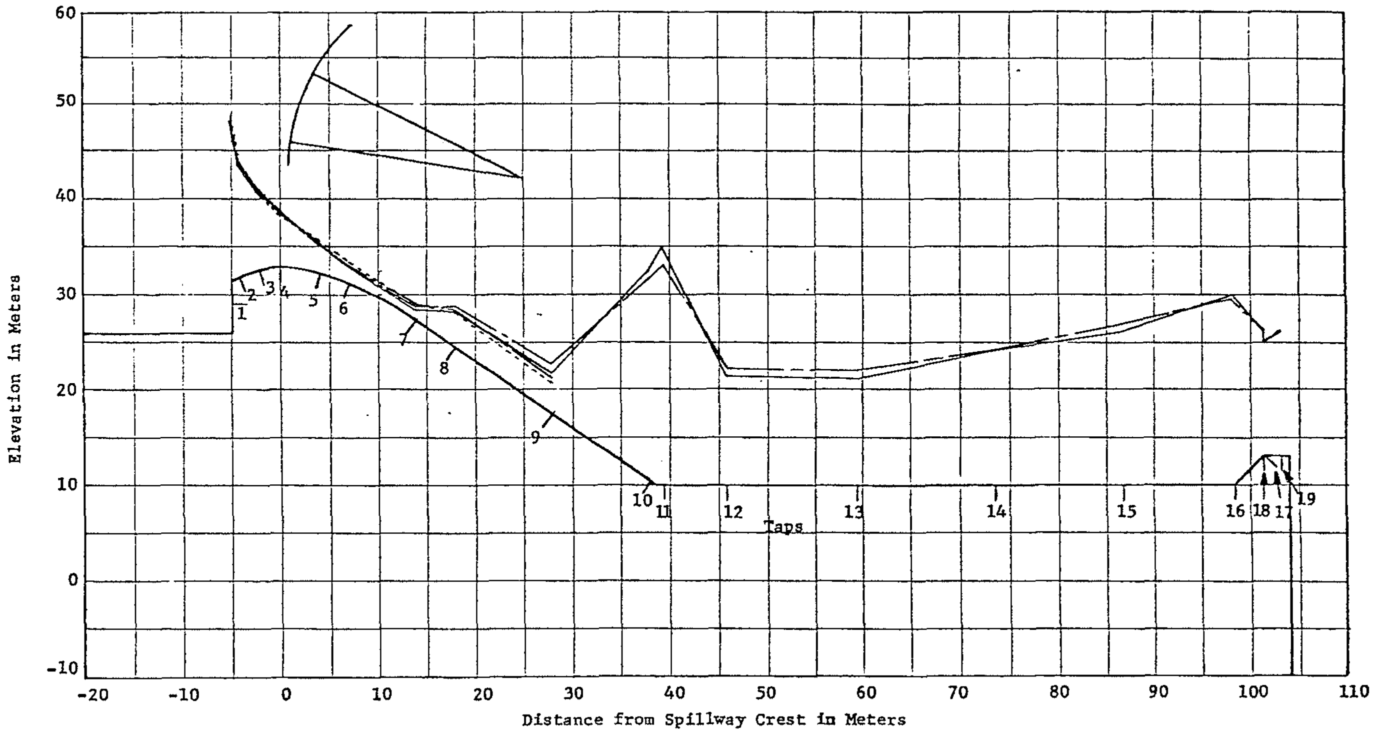
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-23

Chart 29



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 10,000 cms, H.W. = 49.0m, T.W. = 27.0m
Gate opening = 10.4m

— — — Along left training wall
——— Along centerline of left bay
- - - - - - Along left side of pier 1
— - - - - Along right side of pier 1

SAN LORENZO SPILLWAY Executive Hydroelectric Commission Lempa River - El Salvador Harza Engineering Co., Chicago, Illinois SPILLWAY SECTION MODEL		
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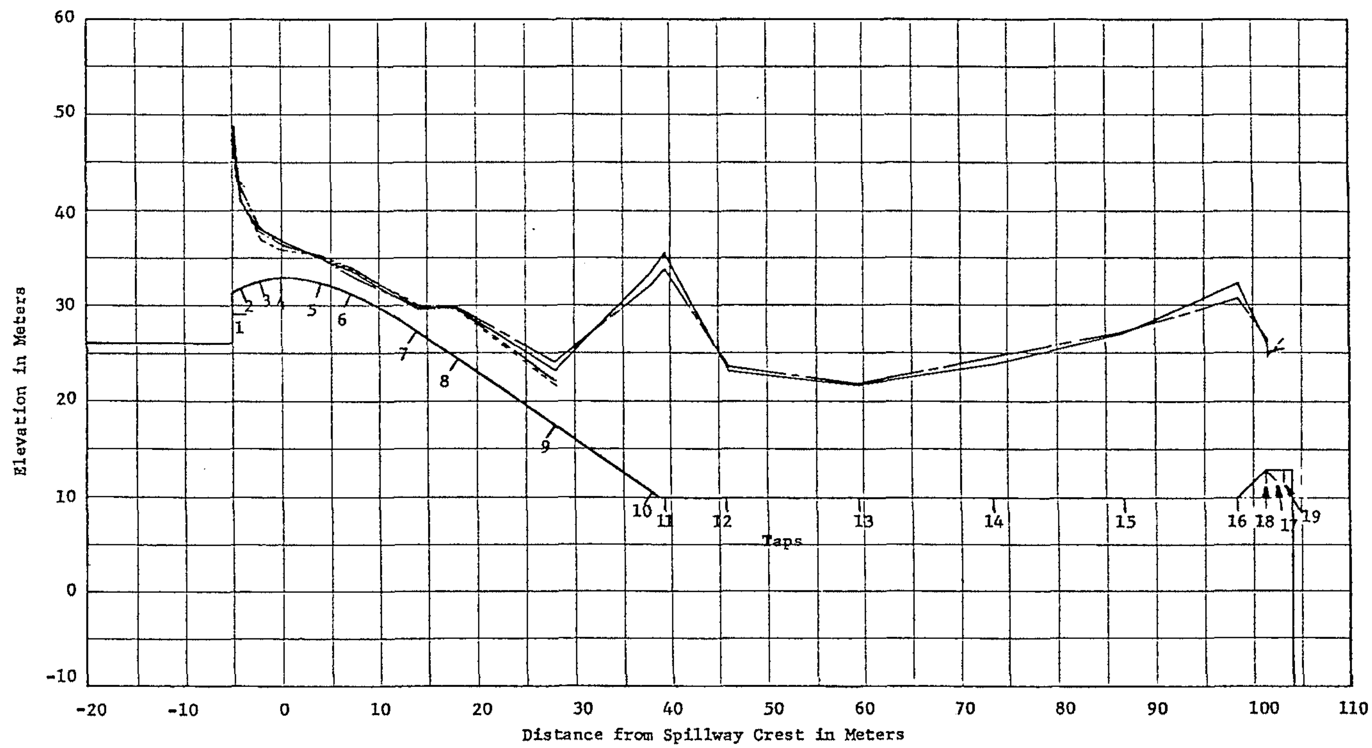
DRAWN DA	CHECKED [illegible]	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-24

Chart 30



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 13,200 cms, H.W. = 49.0m, T.W. = 28.4m
Gates wide open

——— Along left training wall
———— Along centerline of left bay
----- Along left side of pier 1
———-- Along right side of pier 1

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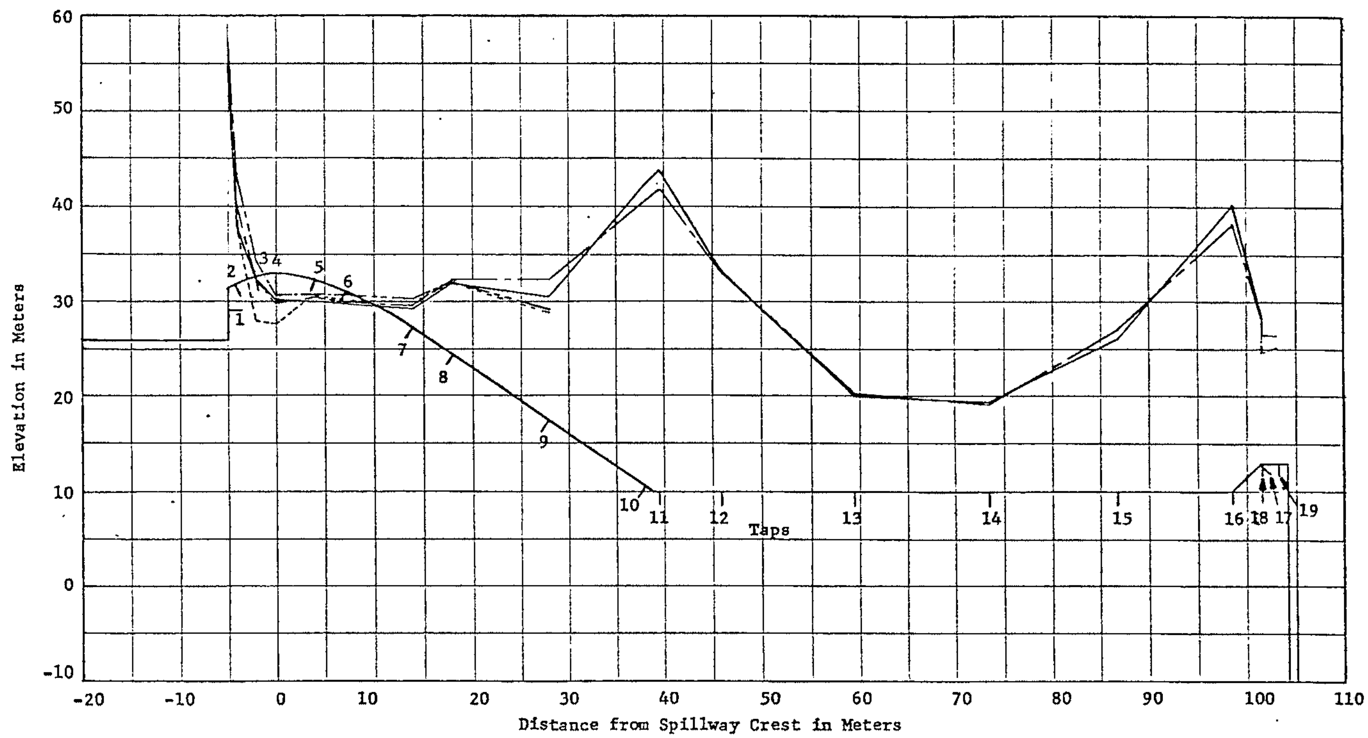
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-25

Chart 31



TYPE C SPILLWAY
Piezometric Pressures
Model Scale 1:50
Q = 28,000 cms, H.W. = 58.0m, T.W. = 34.1m
Gates wide open

—— – – —— Along left training wall
———————— Along centerline of left bay
– – – – – – Along left side of pier 1
———— – – – – Along right side of pier 1

SAN LORENZO SPILLWAY
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN DA	CHECKED	APPROVED
SCALE	DATE 5/12/78	NO. 264B504-27

Chart 33

Piezometric Pressures - Elevation in Meters

Tap No.	Elev. Meters	One Meter from Left Wall	Along Centerline of Left Bay	One Meter from Left Side of Pier	One Meter from Right Side of Pier	Along Centerline of Right Bay
Q = 1150 cms, H.W. = 49.0 m, T.W. = 20.0 m, Gate Opening = 1 m						
1	28.96	49.1	49.1	49.0	49.0	
2	32.03	48.9	48.9	48.9	48.9	
3	32.80	48.7	48.7	48.6	48.6	
4	33.00	48.2	48.2	48.1	48.0	
5	32.48	32.1	32.2	32.3	32.2	
6	31.53	31.3	31.3	31.3	31.3	
7	27.64	27.5	27.1	27.6	27.6	
8	24.89	25.4	25.2	25.1	25.1	
9	17.84	19.4	19.8	19.8	19.9	
10	10.80	20.8	20.9			
11	10.00	21.6	22.6			
12	10.00	19.5	19.5			
13	10.00	20.2	20.2			20.2
14	10.00	20.8	20.9			
15	10.00	21.0	21.0			20.9
16	10.00	21.3	21.2			
17	12.97	20.8	21.0			
18	13.00	20.8	21.0			
19	13.00	20.9	21.0			
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m, Gate Opening = 2 m						
1	28.96	48.9	49.0	48.9	48.9	
2	32.03	48.5	48.5	48.5	48.3	
3	32.80	47.8	48.0	47.7	47.7	
4	33.00	46.1	46.2	45.9	45.8	
5	32.48	32.7	32.9	32.9	32.7	
6	31.53	31.2	31.2	31.2	31.1	
7	27.64	27.5	27.1	27.6	27.6	
8	24.89	25.7	25.7	25.6	25.6	
9	17.84	18.6	19.4	19.4	19.6	
10	10.80	22.8	22.8			
11	10.00	25.1	25.7			
12	10.00	19.3	18.9			
13	10.00	19.8	19.6			19.6
14	10.00	21.0	21.0			
15	10.00	21.9	21.8			21.7
16	10.00	22.9	22.2			
17	12.97	21.7	21.7			
18	13.00	21.4	21.7			
19	13.00	21.8	22.1			

SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Model Scale 1:50
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED DA	APPROVED
SCALE	DATE 5/9/78	NO. 264A2318 - 23

Piezometric Pressures - Elevation in Meters

Tap No.	Elev. Meters	One Meter from Left Wall	Along Centerline of Left Bay	One Meter from Left Side of Pier	One Meter from Right Side of Pier	Along Centerline of Right Bay
Q = 7900 cms, H.W. = 49.0 m, T.W. = 25.5 m, Gate Opening = 8 m						
1	28.96	48.6	48.6	48.9	48.9	
2	32.03	45.2	45.0	45.0	45.6	
3	32.80	42.1	42.5	42.0	42.4	
4	33.00	39.3	39.8	39.5	39.5	
5	32.48	34.8	34.8	35.3	34.8	
6	31.53	32.2	32.1	32.5	32.2	
7	27.64	28.3	28.0	28.4	28.4	
8	24.89	28.2	27.9	27.3	27.6	
9	17.84	21.7	21.2	21.2	20.9	
10	10.80	30.8	31.3			
11	10.00	33.9	34.3			
12	10.00	22.1	21.0			
13	10.00	22.1	21.6			21.9
14	10.00	24.0	23.7			
15	10.00	26.0	25.6			25.6
16	10.00	29.0	29.3			
17	12.97	26.0	25.7			
18	13.00	25.2	25.0			
19	13.00	25.9	25.5			
Q = 10,000 cms, H.W. = 49.0 m, T.W. = 27.0 m, Gate Opening = 10.4 m						
1	28.96	48.3	48.3	48.7	48.7	
2	32.03	43.9	43.6	43.8	44.7	
3	32.80	40.7	41.1	40.2	41.1	
4	33.00	38.4	39.0	38.3	38.6	
5	32.48	35.1	35.3	35.6	35.3	
6	31.53	33.0	32.9	33.2	33.0	
7	27.64	28.8	28.5	29.0	29.0	
8	24.89	28.9	28.5	28.3	28.5	
9	17.84	22.8	21.9	20.7	21.3	
10	10.80	31.7	32.7			
11	10.00	33.1	35.0			
12	10.00	22.3	21.4			
13	10.00	22.1	21.3			21.9
14	10.00	24.2	24.0			
15	10.00	26.8	26.1			26.3
16	10.00	29.6	29.9			
17	12.97	26.3	26.0			
18	13.00	24.9	24.9			
19	13.00	26.1	25.9			

SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway   Model Scale 1:50
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED DA	APPROVED
SCALE	DATE 5/9/78	NO. 264A2318 -24

Piezometric Pressures - Elevation in Meters

Tap No.	Elev. Meters	One Meter from Left Wall	Along Centerline of Left Bay	One Meter from Left Side of Pier	One Meter from Right Side of Pier	Along Centerline of Right Bay
	Q = 13,200 cms, H.W. = 49.0 m, T.W. = 28.4 m, Gates wide open					
1	28.96	47.7	48.0	48.7	48.7	
2	32.03	41.6	41.1	41.0	42.6	
3	32.80	38.2	38.3	36.9	38.4	
4	33.00	36.5	36.8	35.8	36.5	
5	32.48	35.1	35.0	35.3	35.3	
6	31.53	33.6	33.5	33.6	33.7	
7	27.64	29.8	29.6	30.1	30.2	
8	24.89	29.9	29.7	29.6	29.8	
9	17.84	24.1	23.2	21.6	22.1	
10	10.80	32.3	33.6			
11	10.00	33.9	35.6			
12	10.00	23.6	23.2			
13	10.00	21.9	21.7			22.1
14	10.00	24.6	24.0			
15	10.00	27.1	27.0			26.9
16	10.00	30.9	32.2			
17	12.97	26.5	26.1			
18	13.00	24.7	25.2			
19	13.00	26.5	25.5			
	Q = 18,000 cms, H.W. = 52.2 m, T.W. = 30.5 m, Gates wide open					
1	28.96	50.4	50.6	51.7	51.8	
2	32.03	41.6	40.7	40.6	43.3	
3	32.80	36.9	37.2	35.0	37.7	
4	33.00	34.9	35.5	33.9	35.1	
5	32.48	34.1	34.1	34.4	34.5	
6	31.53	32.9	32.7	33.0	33.2	
7	27.64	29.8	29.7	30.3	30.4	
8	24.89	30.9	30.6	30.4	30.8	
9	17.84	26.6	25.1	23.3	23.6	
10	10.80	35.1	36.5			
11	10.00	36.7	38.4			
12	10.00	25.1	24.6			
13	10.00	19.4	18.4			18.5
14	10.00	22.2	21.3			
15	10.00	25.7	25.7			26.4
16	10.00	32.6	35.0			
17	12.97	26.1	26.6			
18	13.00	24.1	24.7			
19	13.00	25.4	24.9			

SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Model Scale 1:50
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED DA	APPROVED
SCALE	DATE 5/9/78	NO. 264A2318 - 25

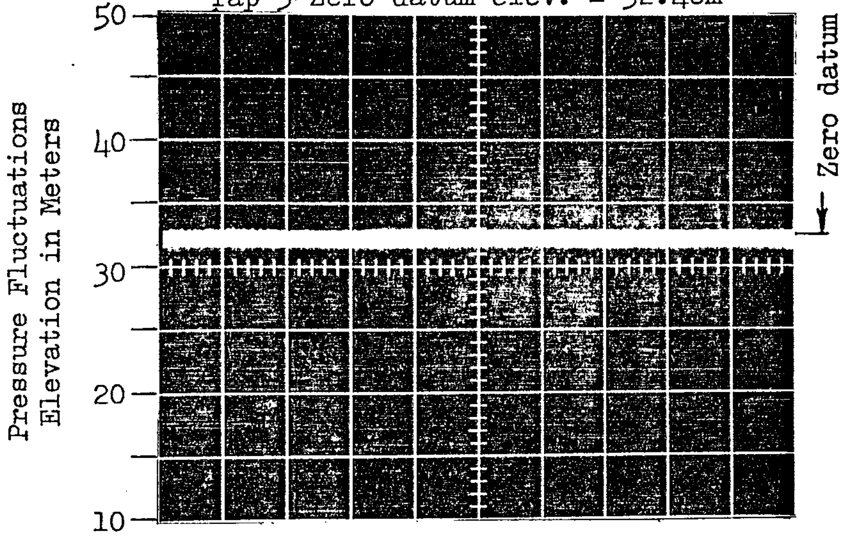
Piezometric Pressures - Elevation in Meters

Tap No.	Elev. Meters	One Meter from Left Wall	Along Centerline of Left Bay	One Meter from Left Side of Pier	One Meter from Right Side of Pier	Along Centerline of Right Bay
Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m, Gates wide open						
1	28.96	54.3	54.8	56.1	57.2	
2	32.03	40.2	37.6	37.3	43.1	
3	32.80	32.0	32.2	28.0	34.1	
4	33.00	29.8	30.3	27.6	30.7	
5	32.48	30.6	30.2	30.7	30.9	
6	31.53	30.1	29.7	30.3	30.7	
7	27.64	29.7	29.4	30.1	30.4	
8	24.89	32.3	32.0	32.0	32.3	
9	17.84	32.3	30.6	28.8	29.2	
10	10.80	40.6	42.4			
11	10.00	41.7	43.6			
12	10.00	32.9	33.1			
13	10.00	20.4	20.0			19.5
14	10.00	19.1	19.4			
15	10.00	27.0	26.1			27.8
16	10.00	38.2	40.1			
17	12.97	27.8	28.4			
18	13.00	24.5	26.6			
19	13.00	25.2	26.5			

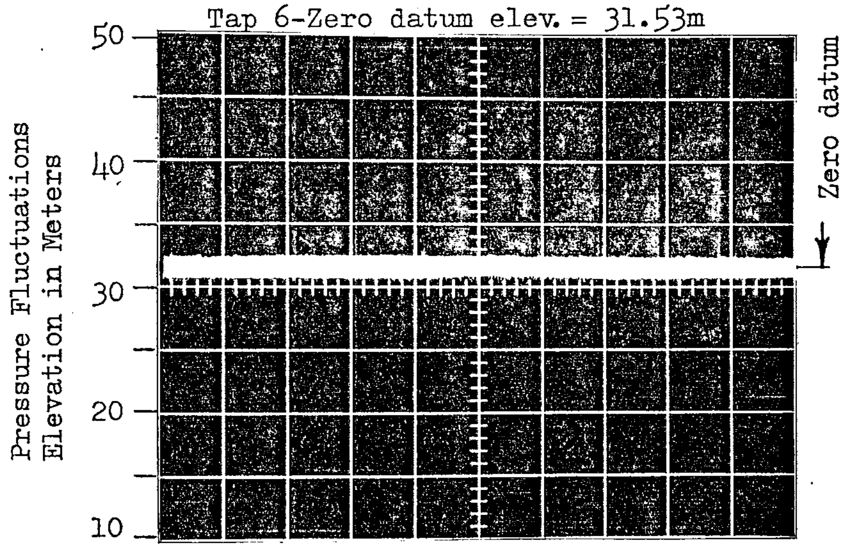
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Model Scale 1:50
Piezometric Pressures

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED DA	APPROVED
SCALE	DATE 5/9/78	NO. 264A2318 - 26

Tap 5-Zero datum elev. = 32.48m

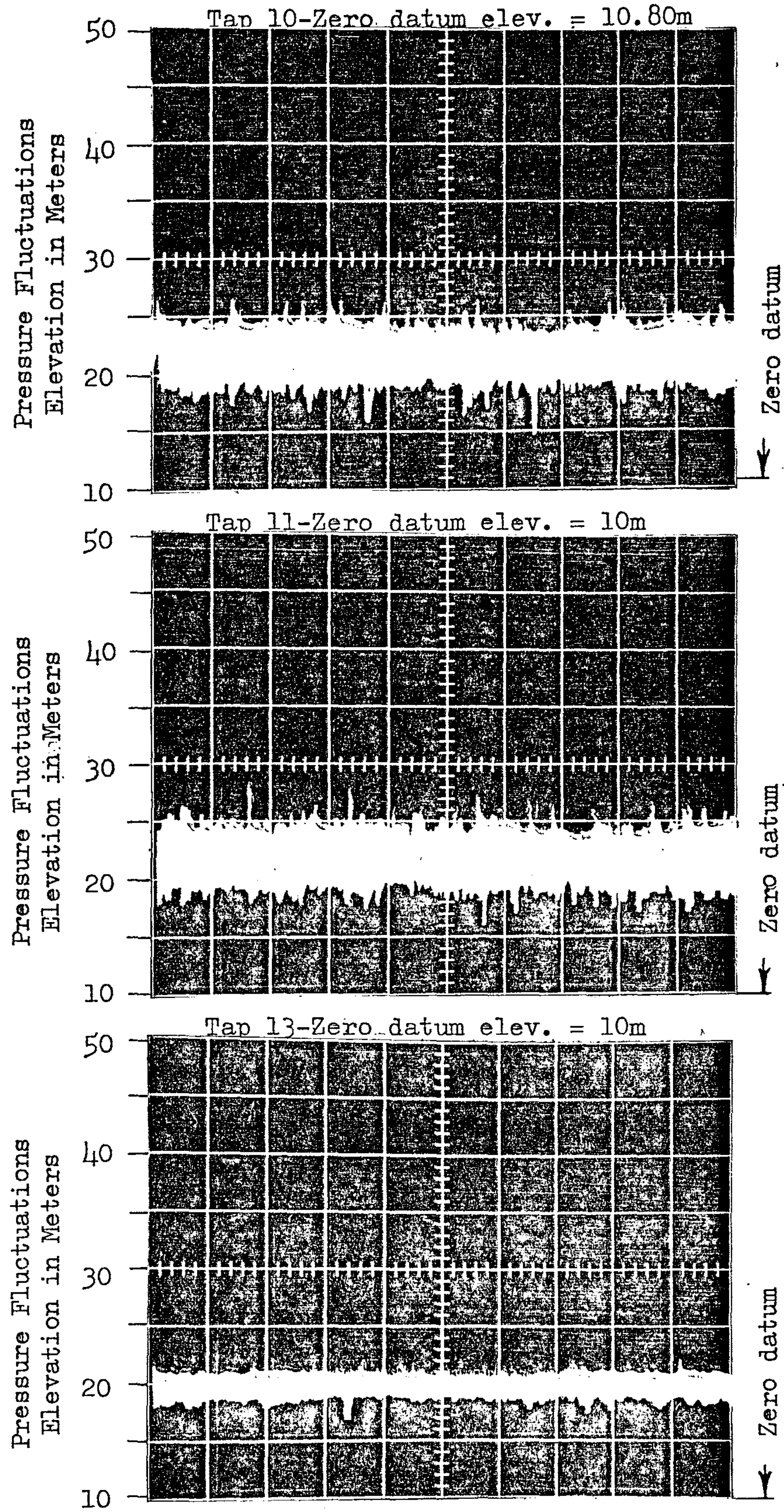


Tap 6-Zero datum elev. = 31.53m



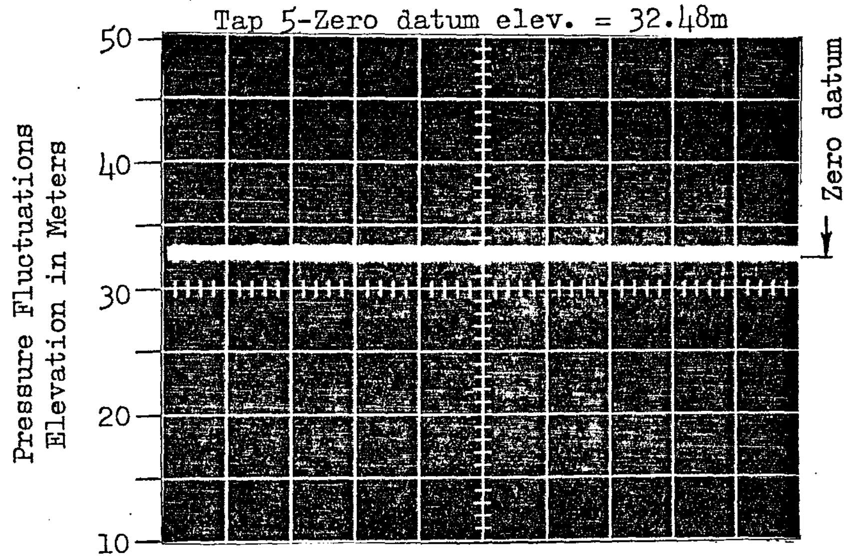
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 1150 cms, H.W. = 49.0 m, T.W. = 20.0 m
Gate opening = 1 m
Model time of record = 1 minute

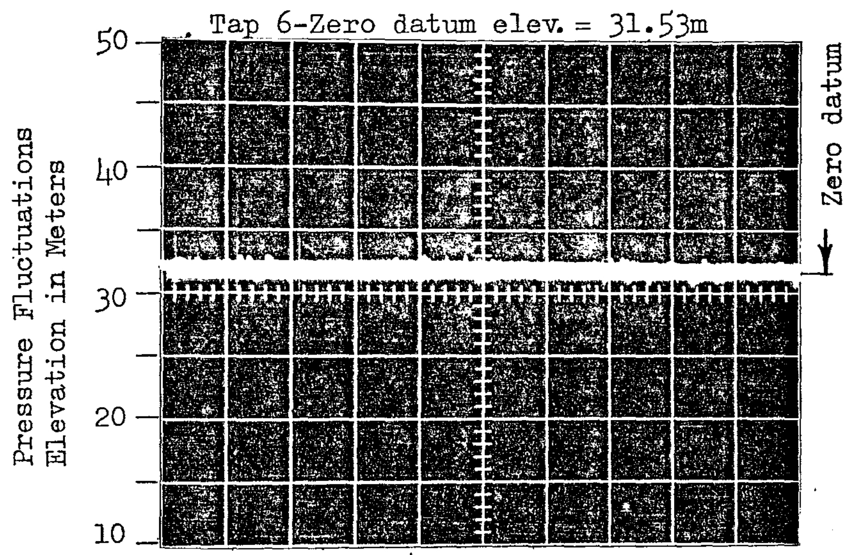
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-1



SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 1150 cms, H.W. = 49.0 m, T.W. = 20.0m
Gate opening = 1 m
Model time of record = 1 minute

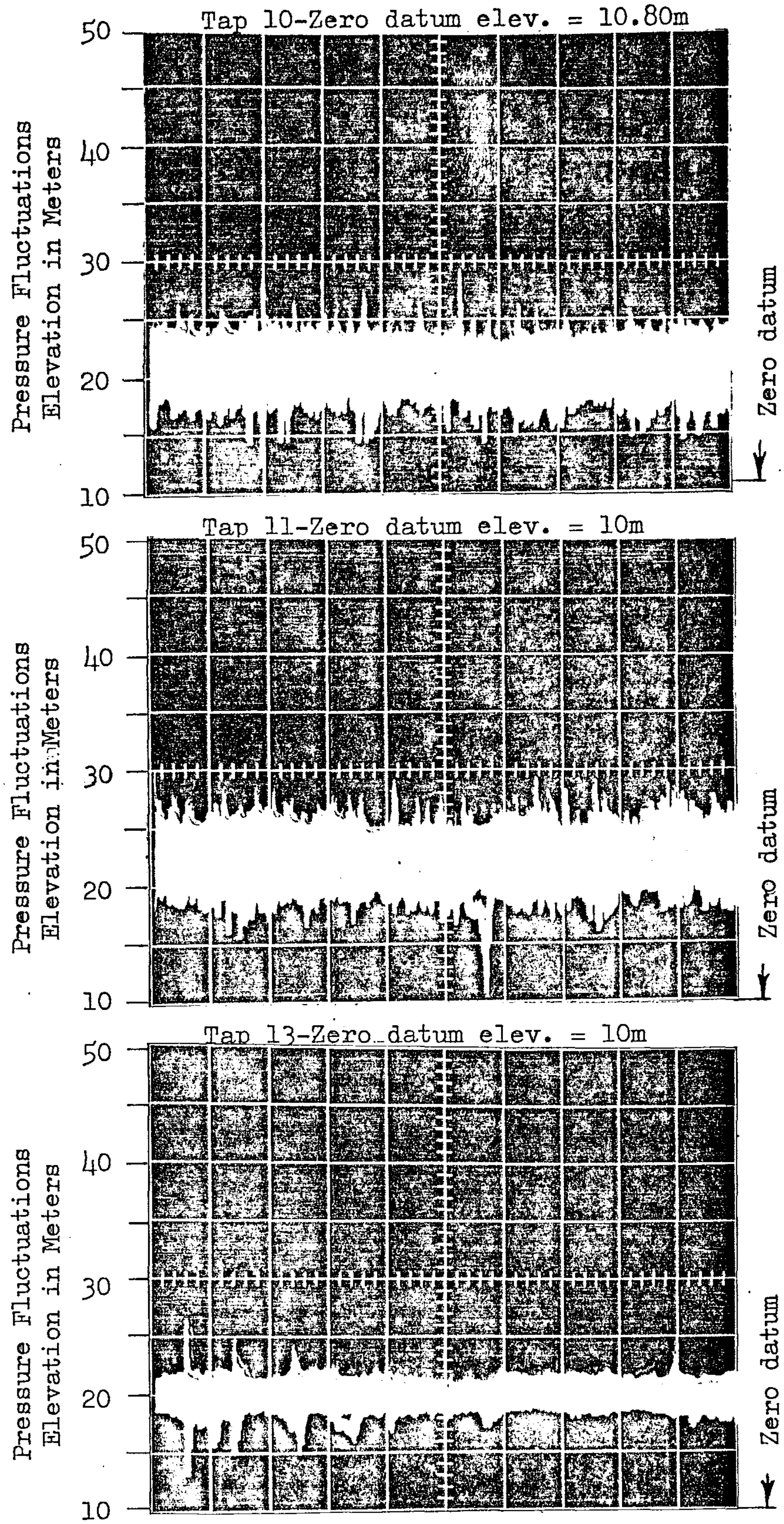
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-2





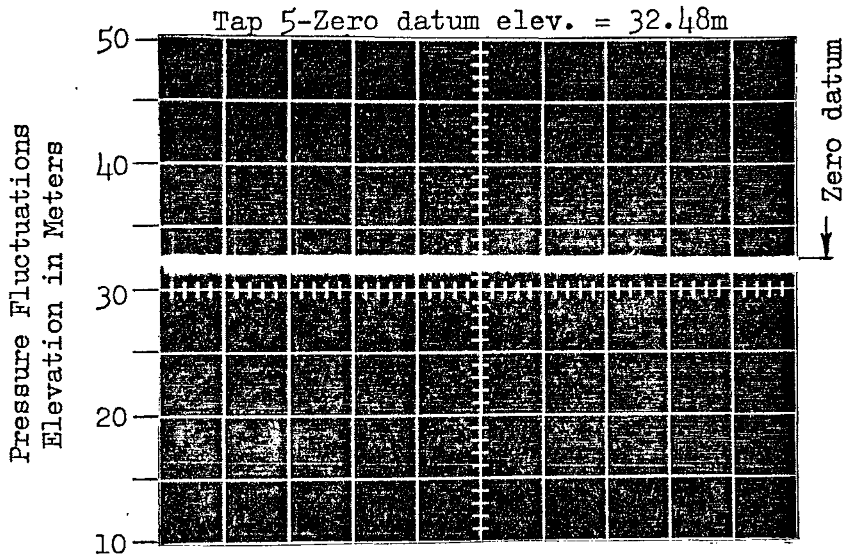
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 1150 cms, H.W. = 49.0 m, T.W. = 20.0 m
Gate opening = 1 m
Model time of record = 1 minute

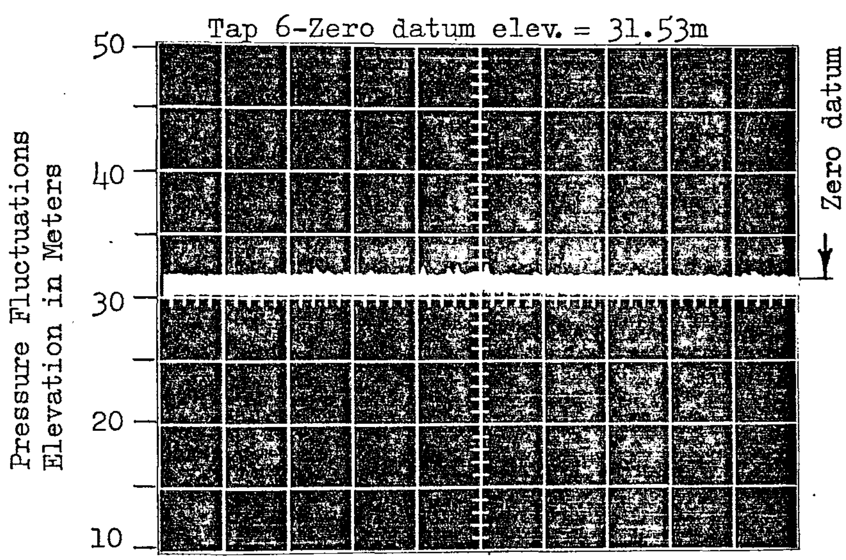
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-3



SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 1150 cms, H.W. = 49.0m, T.W. =20.0 m
Gate opening = 1 m
Model time of record = 1 minute

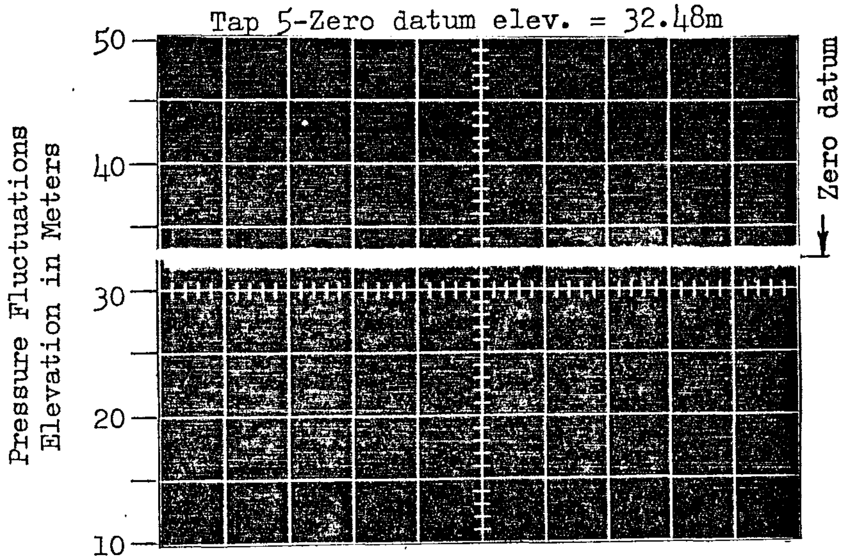
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-4

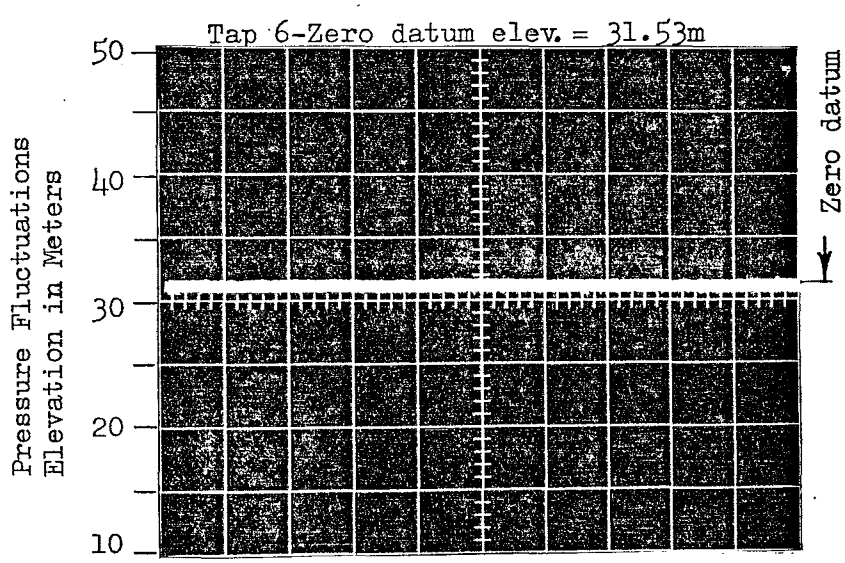




SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Right Side of Pier
Q = 1150 cms, H.W. = 49.0 m, T.W. = 20.0 m
Gate opening = 1 m
Model time of record = 1 minute

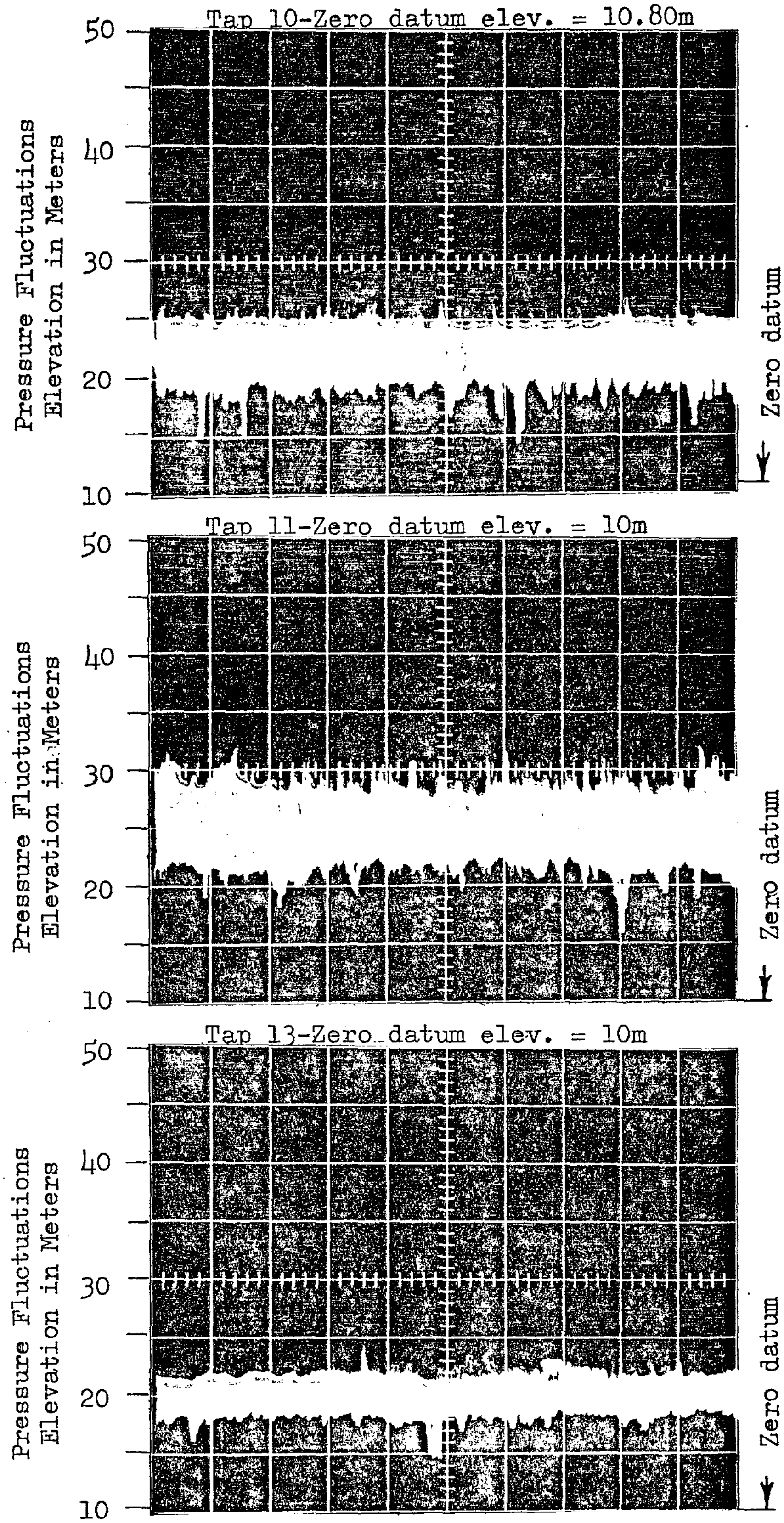
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-5





SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m
Gate opening = 2 m
Model time of record = 1 minute

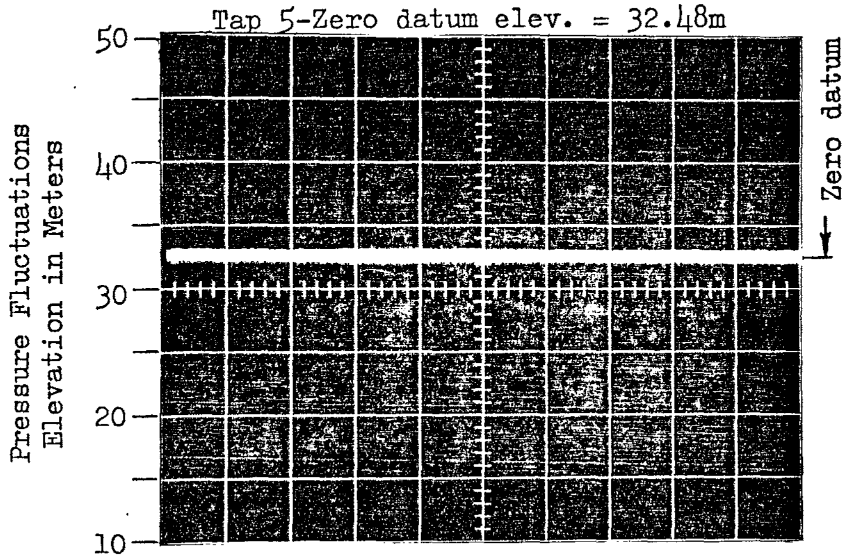
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED JRQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-6

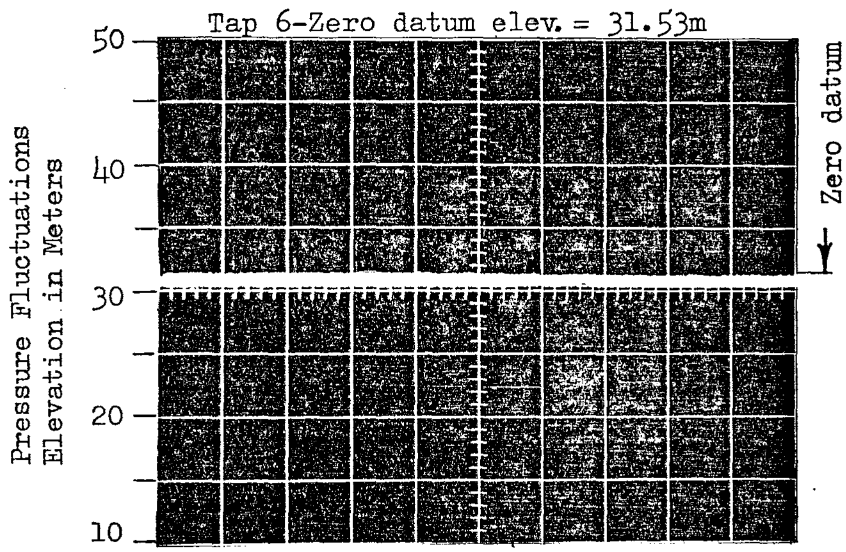


SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m

Gate opening = 2 m
Model time of record = 1 minute

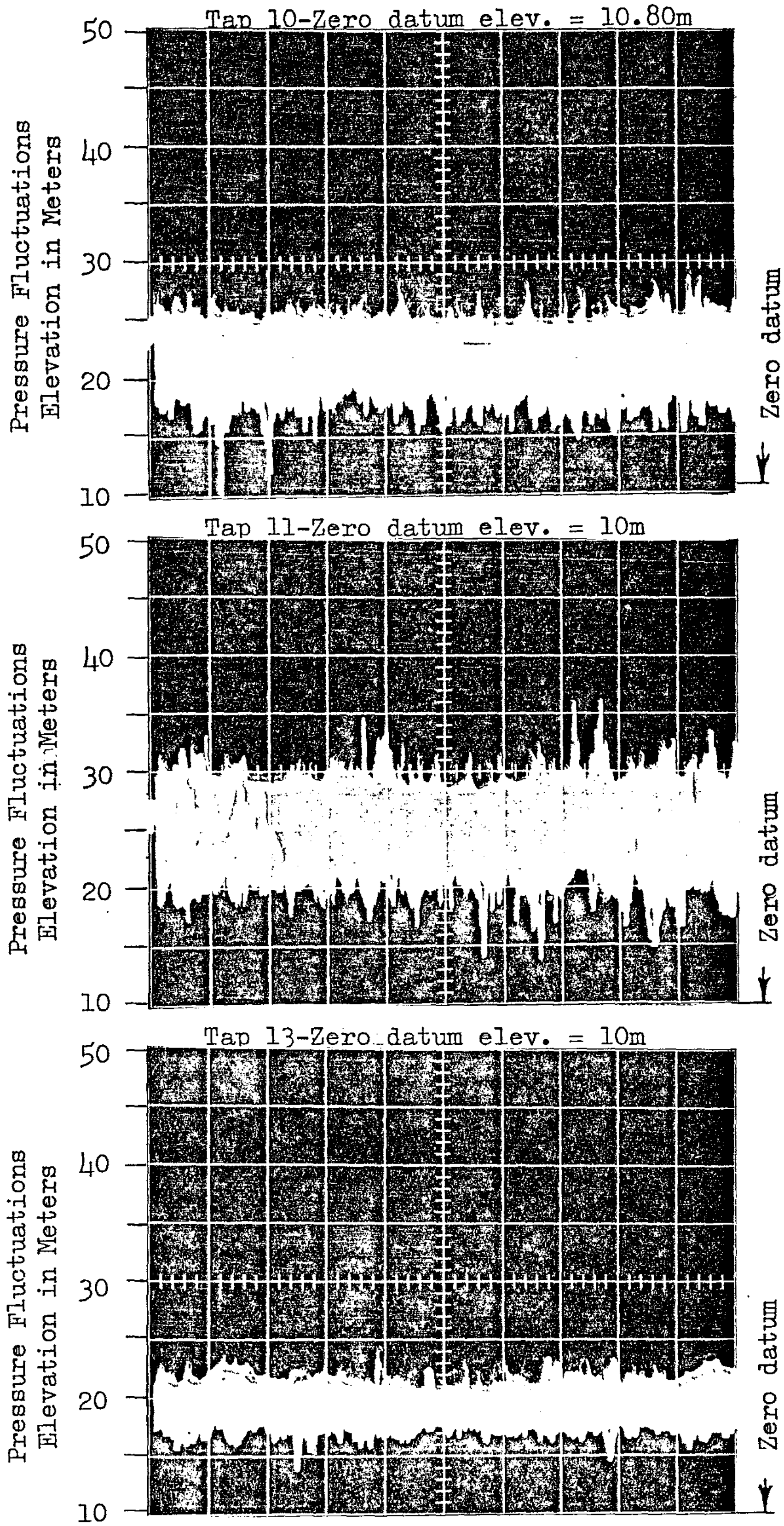
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-7





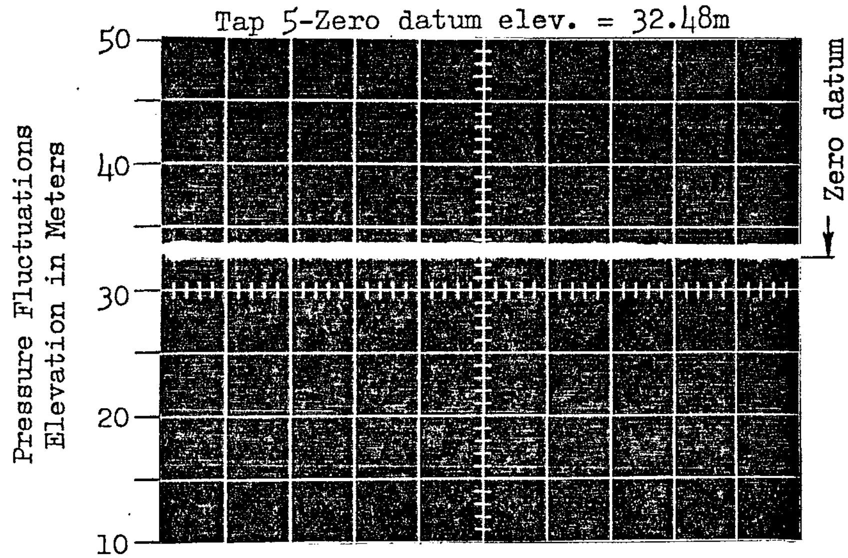
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m
Gate opening = 2m
Model time of record = 1 minute

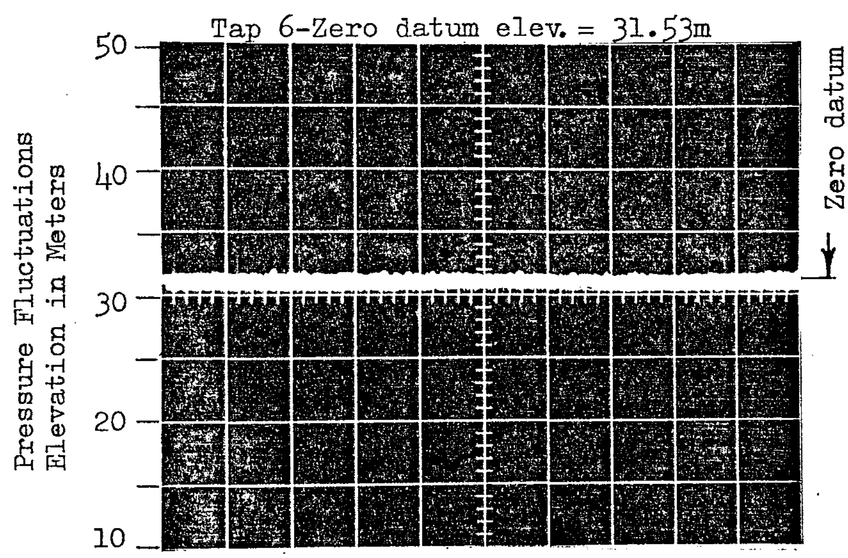
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-8



SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m
Gate opening = 2 m
Model time of record = 1 minute

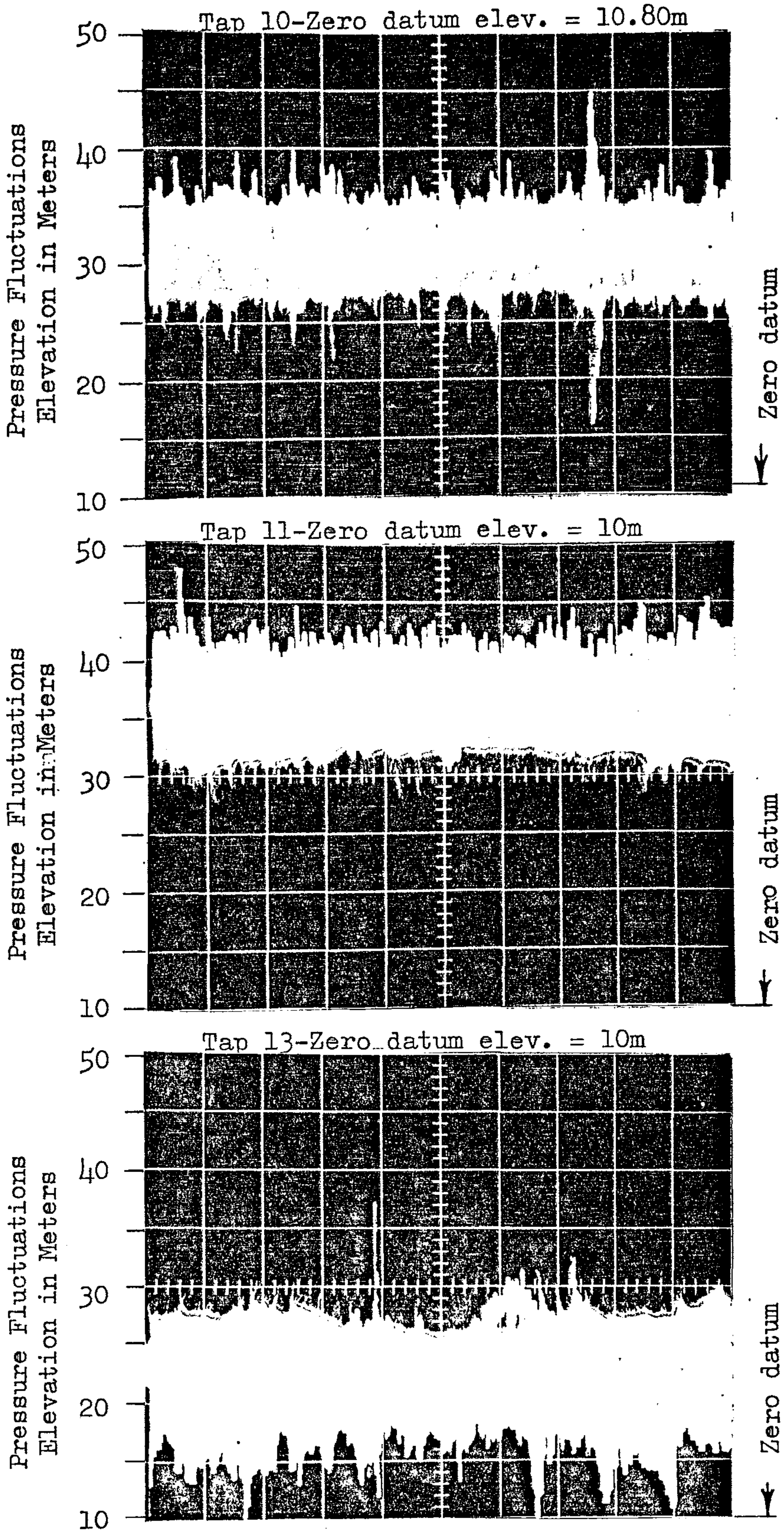
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED MQC	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-9





SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Right Side of Pier
Q = 2250 cms, H.W. = 49.0 m, T.W. = 20.9 m
Gate opening = 2 m
Model time of record = 1 minute

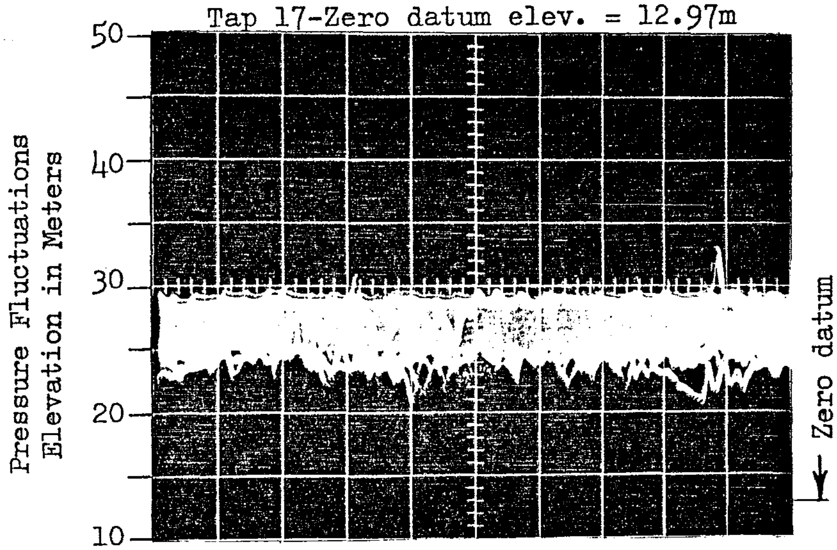
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-10



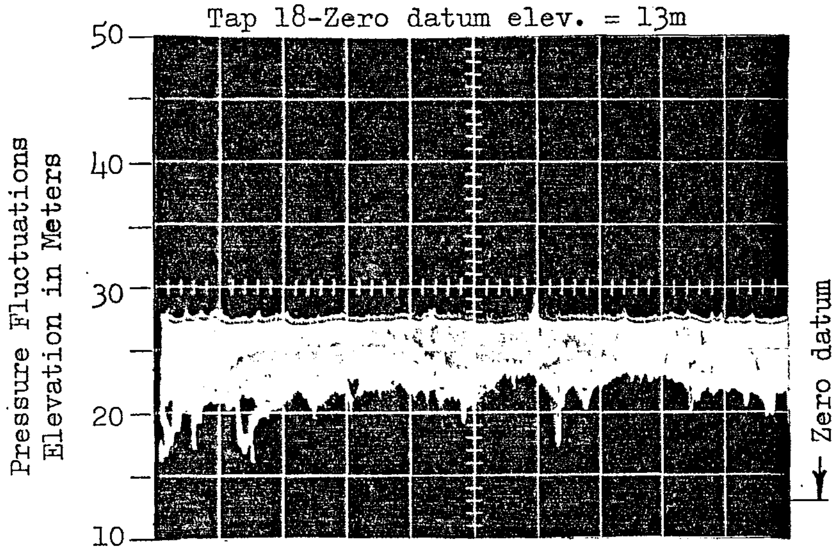
SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 7900 cms, H.W. = 49.0 m, T.W. = 25.5m
Gate opening = 8 m
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-11

Tap 17-Zero datum elev. = 12.97m

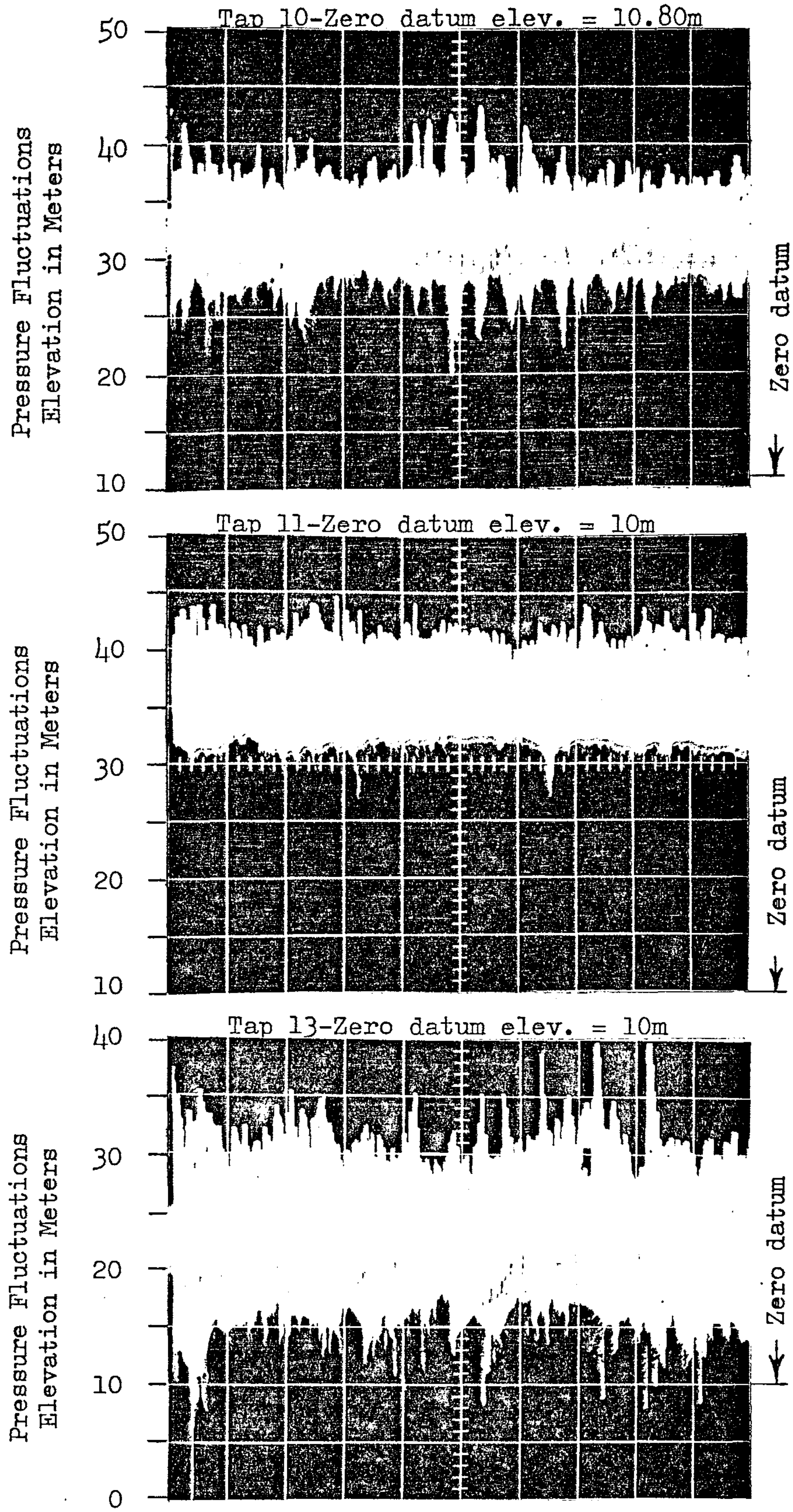


Tap 18-Zero datum elev. = 13m



SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 7900 cms, H.W. = 49.0 m, T.W. = 25.5 m
Gate opening = 8 m
Model time of record = 1 minute

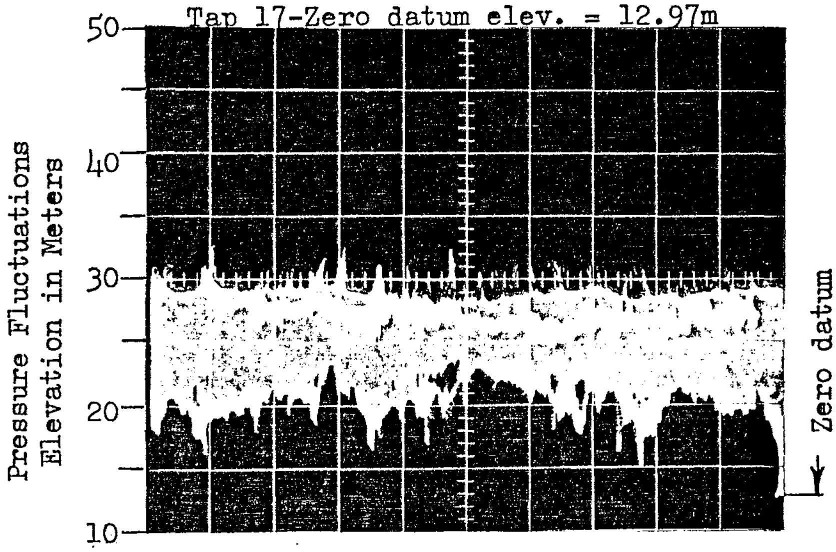
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-12

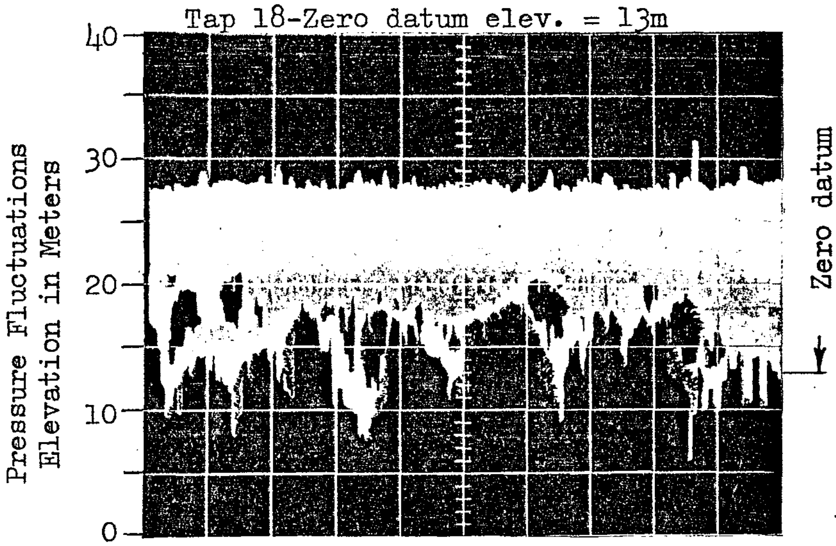


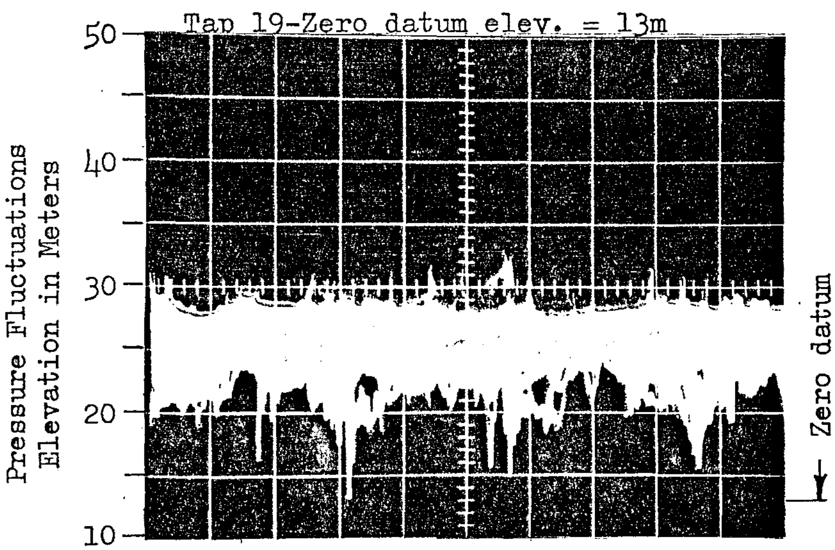
SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 7900 cms, H.W. =49.0 m, T.W. =25.5m

Gate opening = 8 m
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-13



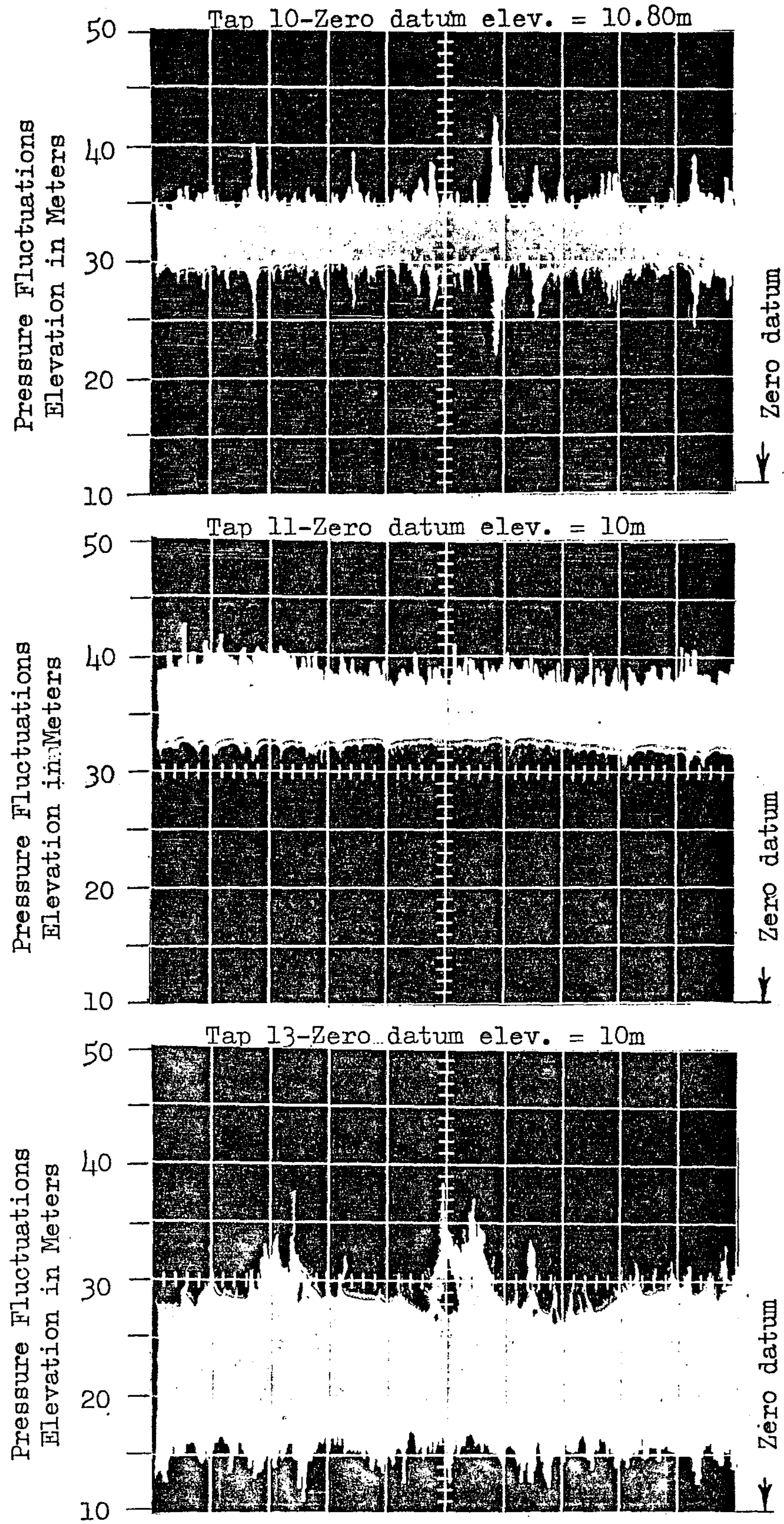




SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 7900 cms, H.W. = 49.0 m, T.W. = 25.5 m

Gate opening = 8 m
Model time of record = 1 minute

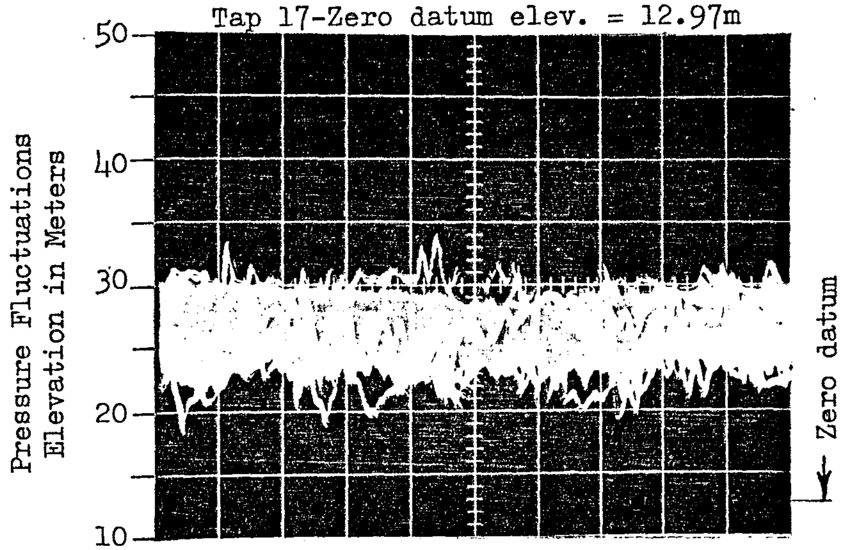
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-14



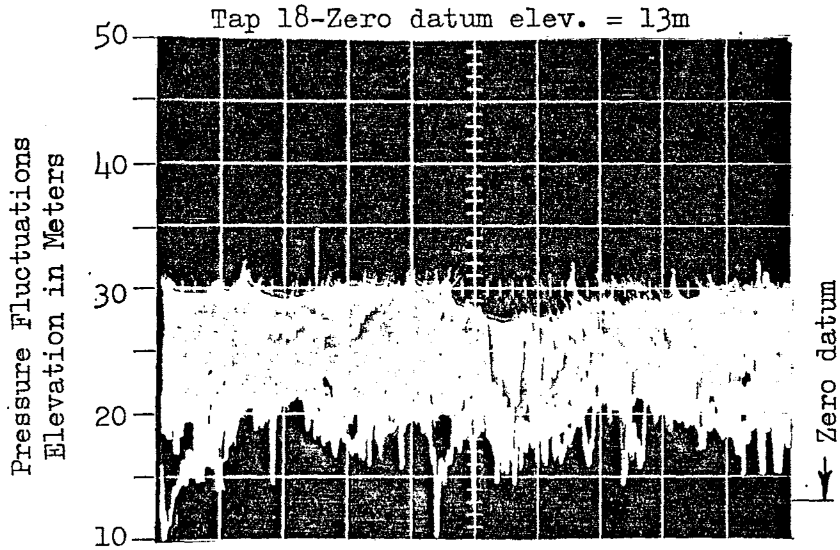
SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 13,200 cms, H.W. = 49.0 m, T.W. = 28.4 m
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED WQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-15

Tap 17-Zero datum elev. = 12.97m

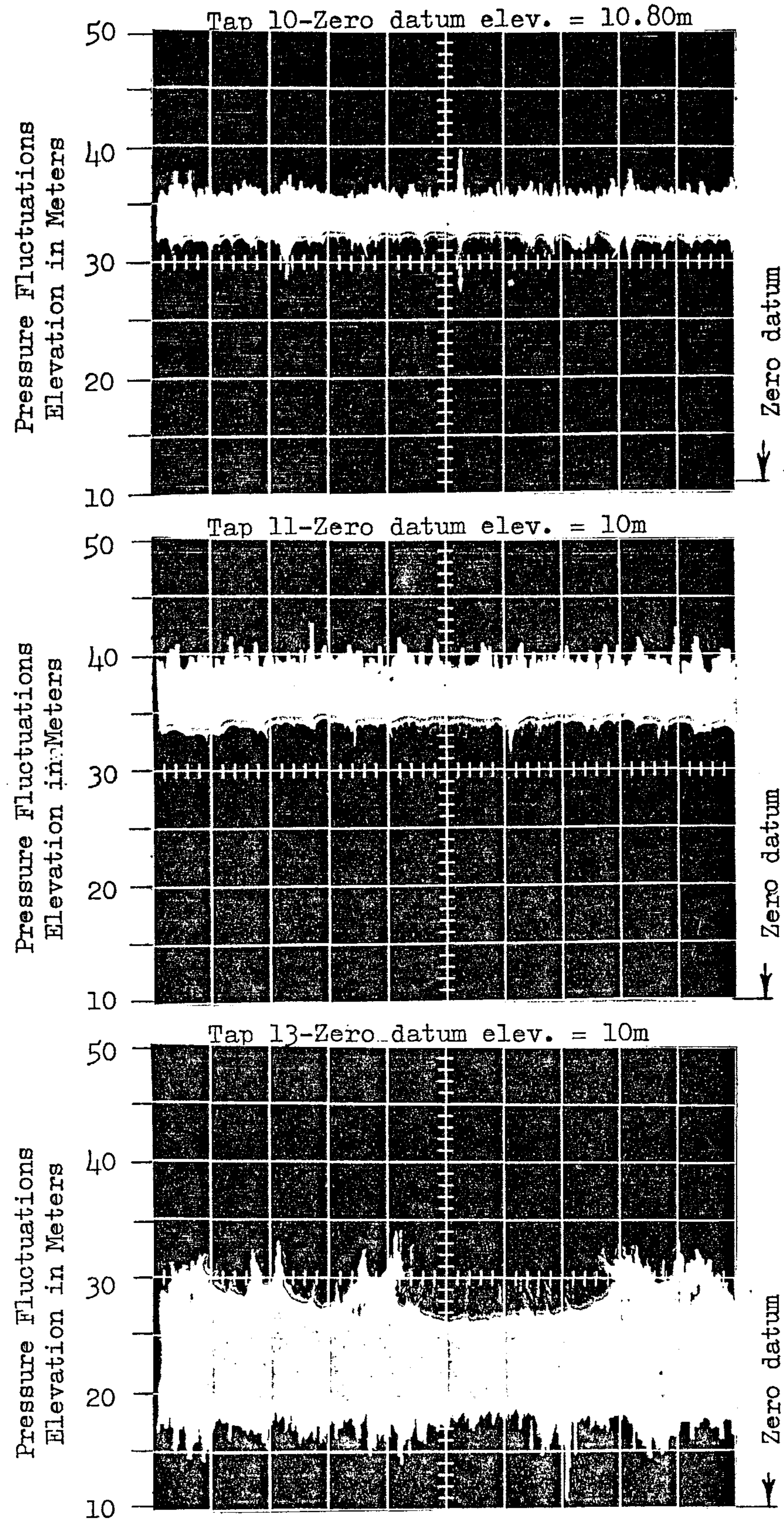


Tap 18-Zero datum elev. = 13m



SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 13,200 cms, H.W. = 49.0 m, T.W. = 28.4 m
Gates wide open.
Model time of record = 1 minute

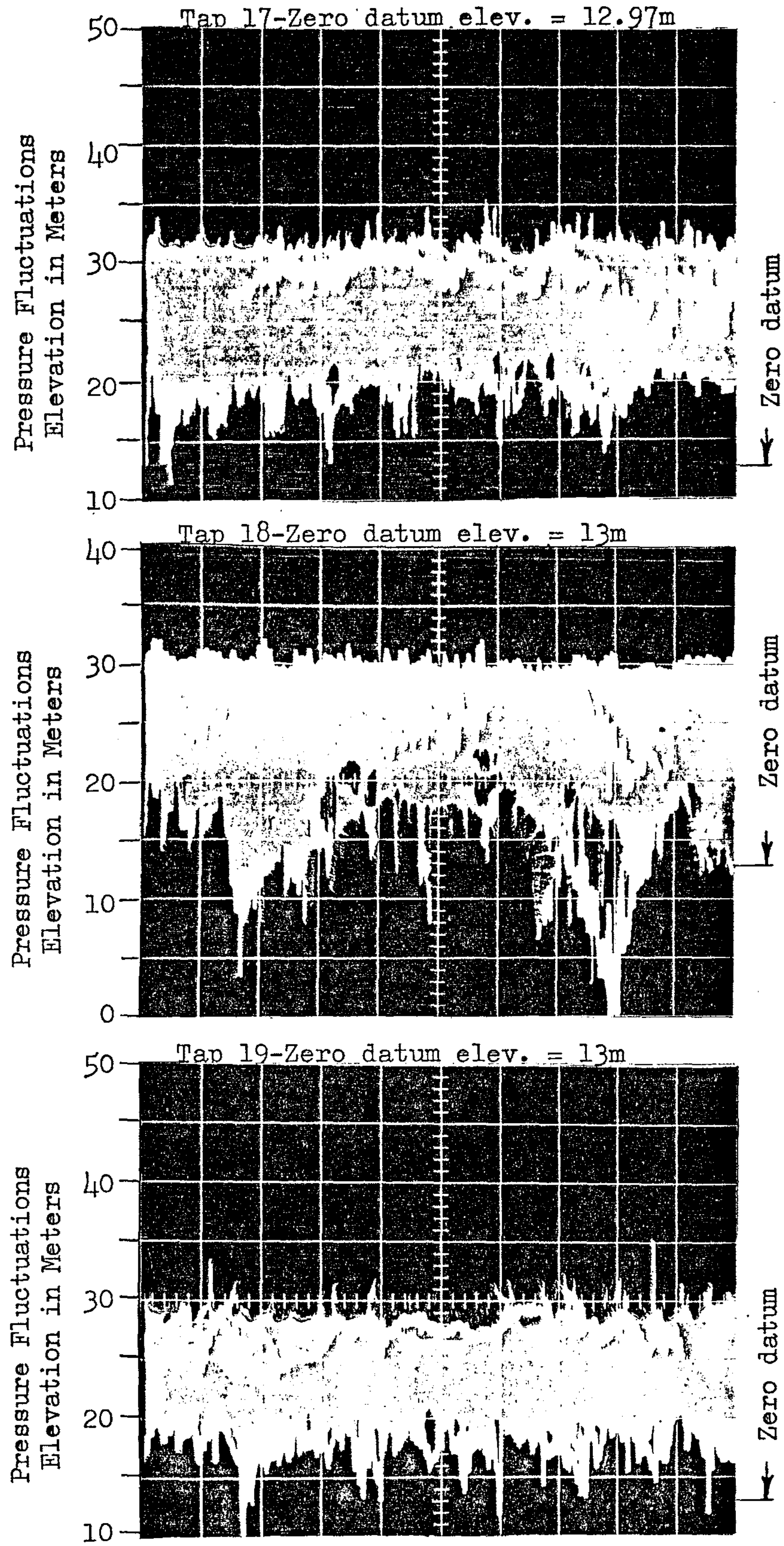
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-16



SAN LORENZO SPILLWAY - SECTION MODEL
Type C SPILLWAY Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 13,200 cms, H.W. = 49.0 m, T.W. = 28.4 m

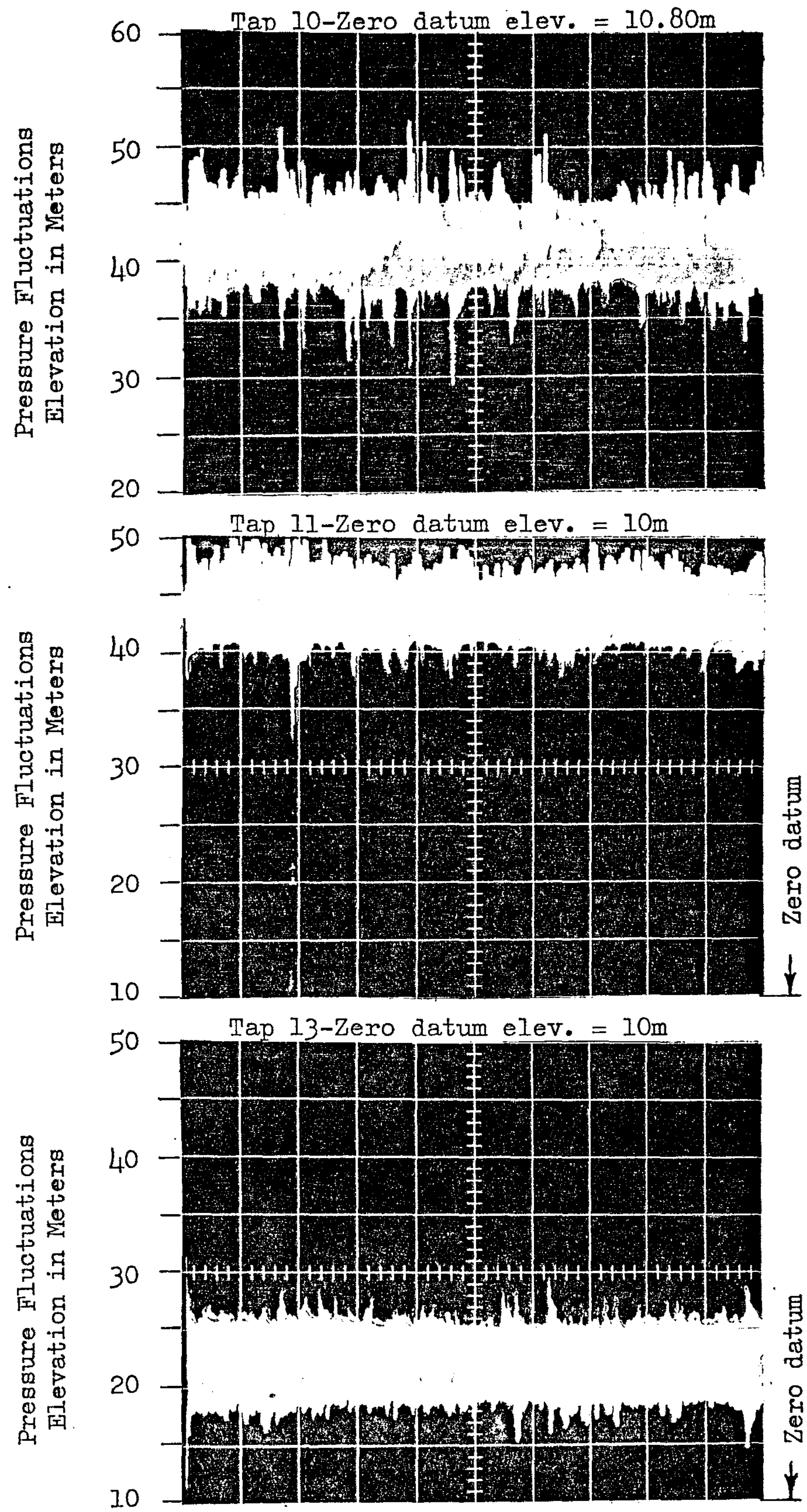
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED JWQD	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-17



SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 13,200 cms, H.W. =49.0 m, T.W. =28.4 m
Gates wide open.
Model time of record = 1 minute

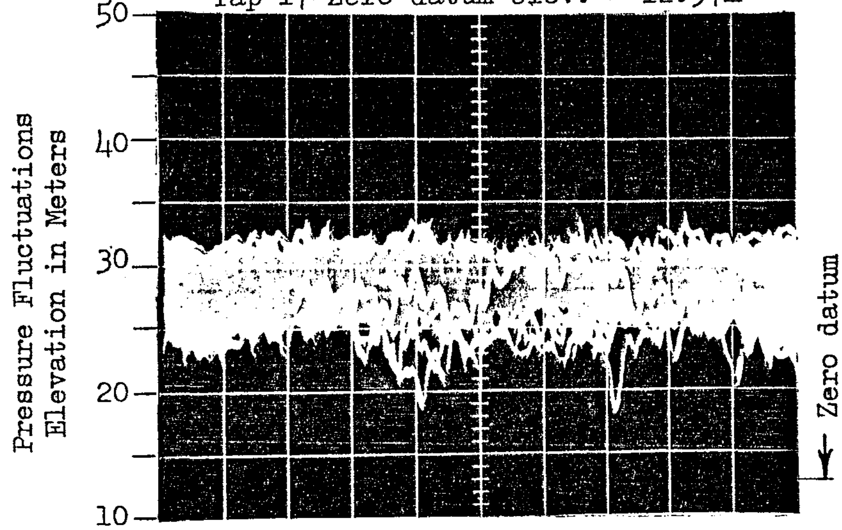
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-18



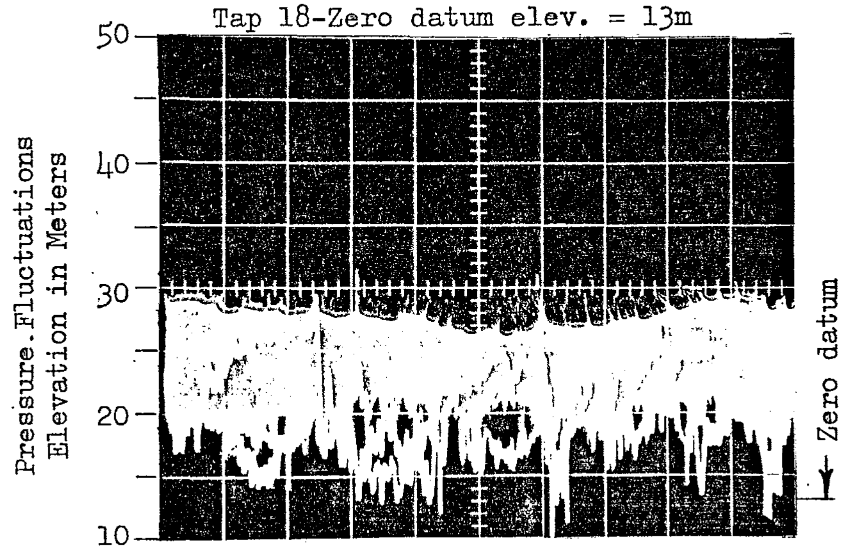
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-19

Tap 17-Zero datum elev. = 12.97m

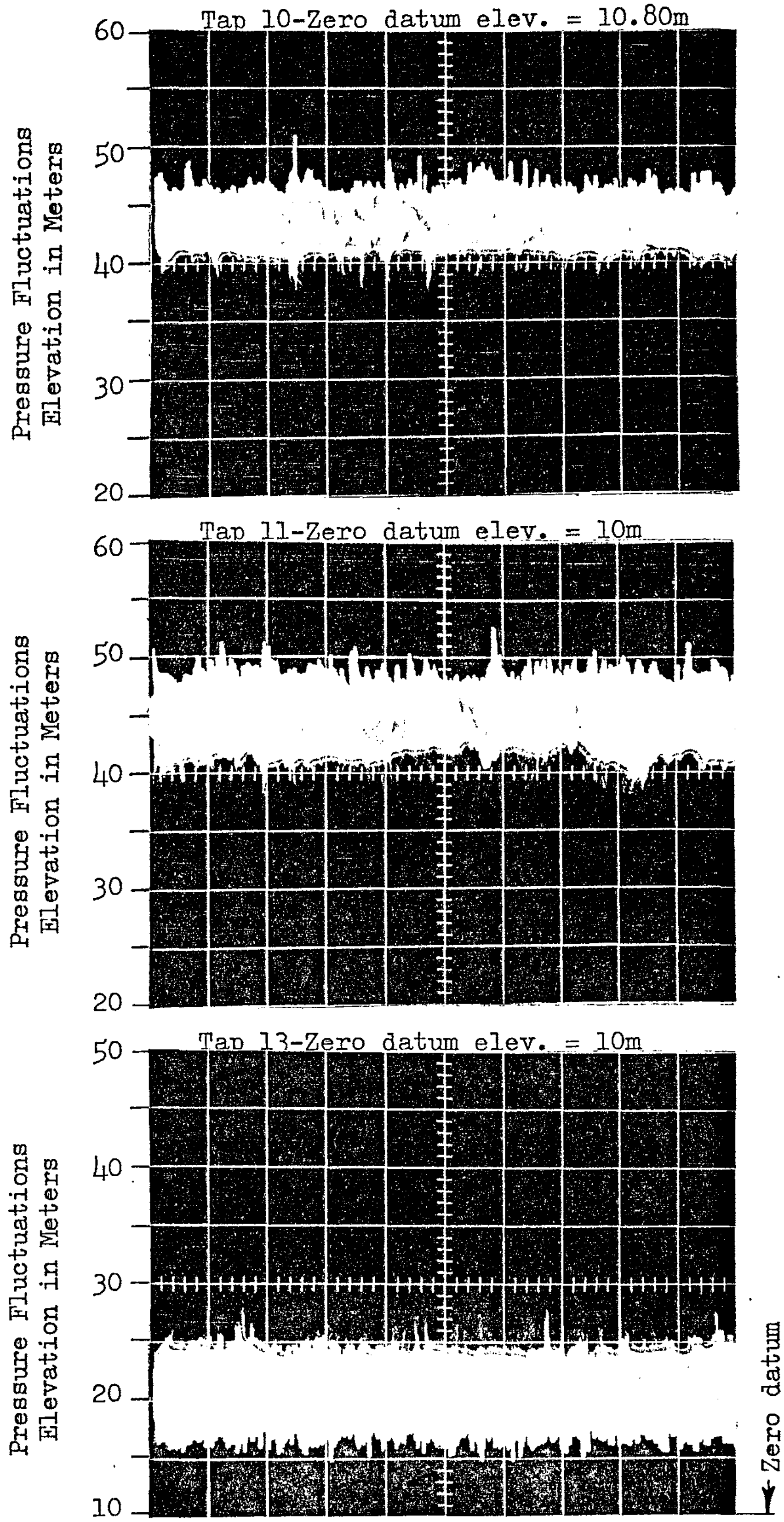


Tap 18-Zero datum elev. = 13m



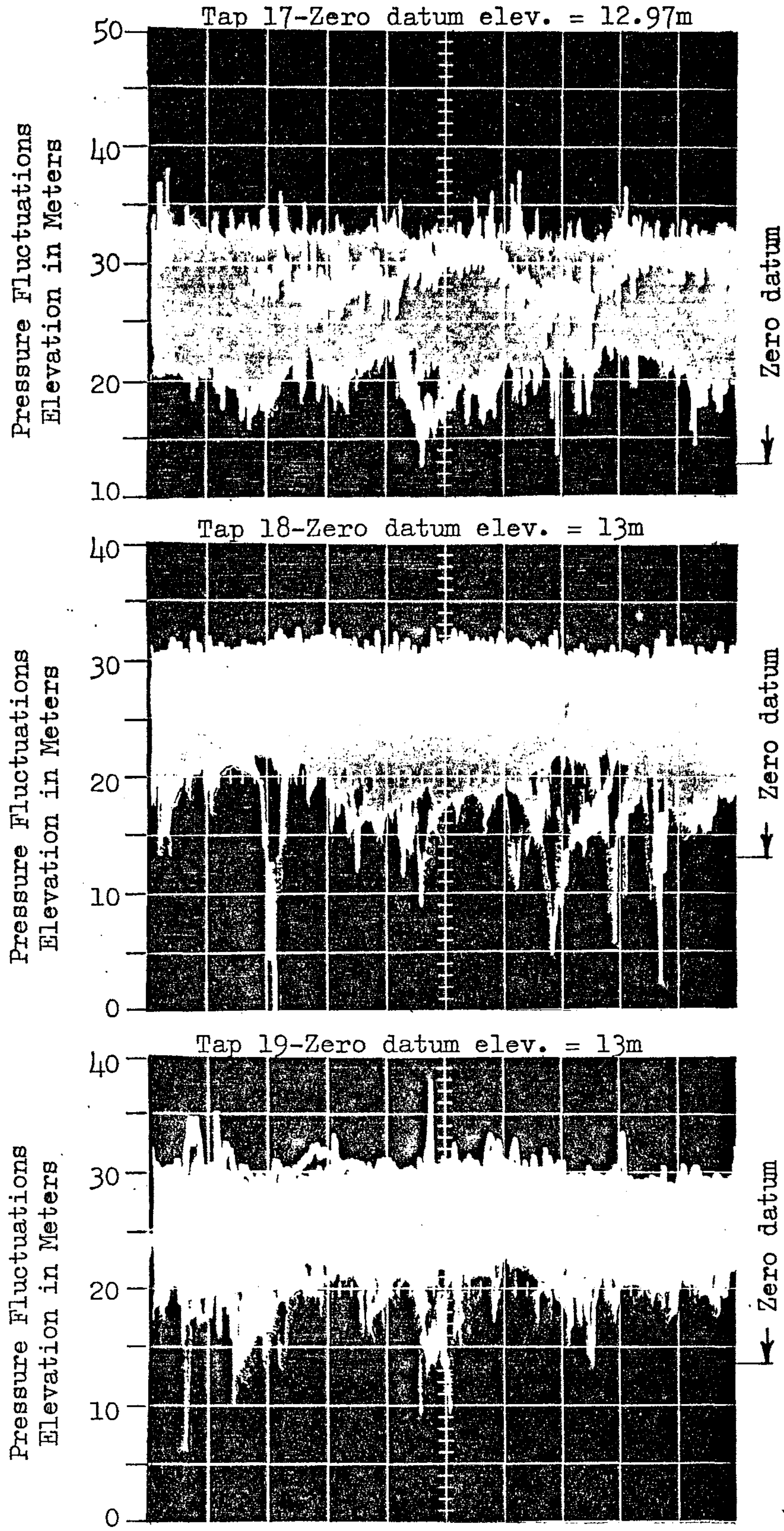
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
One Meter from Left Training Wall
Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [signature]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-20



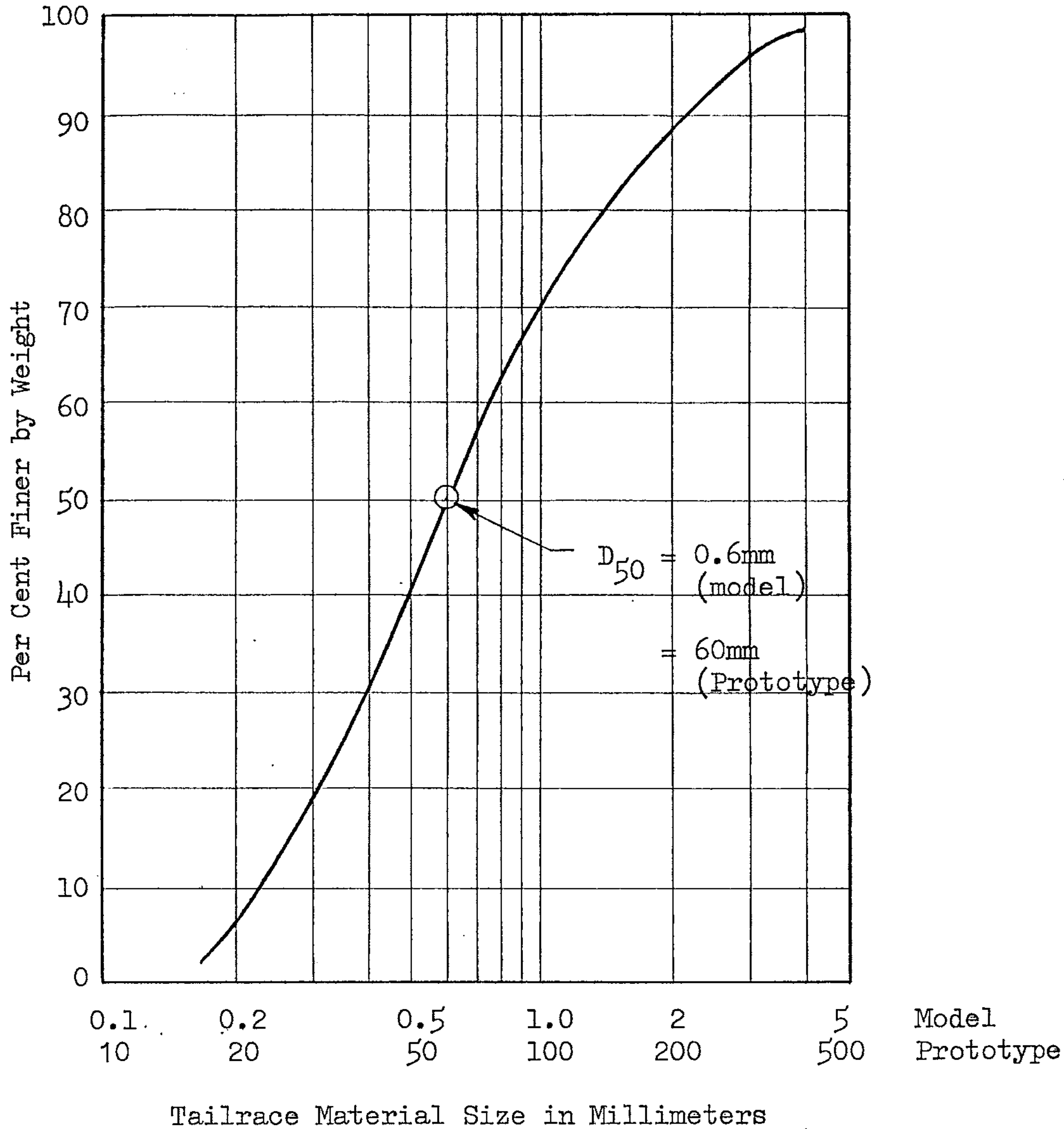
SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 5/5/78	NO. 261A2318-21



SAN LORENZO SPILLWAY - SECTION MODEL
Type C Spillway Scale 1:50
Typical Pressure Fluctuations
Along Centerline of Left Bay
Q = 28,000 cms, H.W. = 58.0 m, T.W. = 34.1 m
Gates wide open.
Model time of record = 1 minute

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN WQD	CHECKED [illegible]	APPROVED
SCALE	DATE 5/5/78	NO. 264A2318-22



TAILRACE MATERIAL SIZE DISTRIBUTION
Comprehensive Model   Scale 1:100

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
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SCALE	DATE 5/18/78	NO. 264A2318-31

University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 173

MODEL STUDIES OF THE SAN LORENZO SPILLWAY EXECUTIVE HYDROELECTRIC COMMISSION LEMPA RIVER EL SALVADOR, CENTRAL AMERICA

Supplement 1. Effect of Aeration Ramps on Flow Pattern

by

Joseph M. Wetzel

and

Warren Q. Dahlin

Prepared for

HARZA ENGINEERING COMPANY
Chicago, Illinois

April, 1980
Minneapolis, Minnesota

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Photo 16 (Serial No. 264-391) Type C-1 with 2 m by 2 m air vent downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 17 (Serial No. 264-393) Type C-1 with 0.4 m dia. vent pipe downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

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Photo 19 (Serial No. 264-328) Type C-2, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m; Flow pattern downstream of the piers.

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Photo 21 (Serial No. 264-333) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern in the spillway.

Photo 22 (Serial No. 264-337) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern downstream of the piers.

Photo 23 (Serial No. 264-339) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern from below showing aeration caused by the ramps.

Photo 24 (Serial No. 264-342) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern in the spillway.

Photo 25 (Serial No. 264-345) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern downstream of the piers.

Photo 26 (Serial No. 264-349) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 27 (Serial No. 264-354) Type C-2 with a 2 m by 2 m air vent downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 28 (Serial No. 264-356) Type C-2 with 0.4 m dia. vent pipe downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

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Model Studies of the
San Lorenzo Spillway
Executive Hydroelectric Commission
Lempa River
El Salvador, Central America

Supplement 1. Effect of Aeration Ramps on Flow Pattern

I. INTRODUCTION

This report supplements Project Report No. 173, "Model Studies of the San Lorenzo Spillway, Executive Hydroelectric Commission, Lempa River, El Salvador, Central America." In the previous studies fluctuating pressures were measured at various selected locations on the spillway. At some locations on the floor of the spillway basin an occasional negative pressure peak of large amplitude was detected and this became the subject of considerable concern. As these negative fluctuations could possibly result in cavitation,the use of aeration ramps on the spillway was considered as a means of relieving this condition. A supplemental study was conducted at the St. Anthony Falls Hydraulic Laboratory to investigate the cavity formation associated with two ramp geometries and various flow conditions specified by the sponsor. Visual and photographic documentation of the flow was made, and the results are summarized herein.

II. EFFECT OF AERATION RAMPS ON FLOW PATTERN

The effect of aeration ramps on the flow pattern in the stilling basin was observed on the existing 1:50 scale section model, which includes two bays of the eight bay prototype. The section model was constructed for the earlier studies and has been described in Project Report No. 173.

A. Type C Spillway

The optimum design developed previously was designated as a Type C spillway as shown on Chart 1 and the aeration studies were conducted on this type. The Type C spillway, which has no aeration ramps, is shown in Photos 1 through 6, for various flow conditions to serve as a basis of comparison. These three flow conditions were selected by the sponsor for evaluation of the aeration ramps. Photos 1 and 2 show the flow pattern in the basin with a discharge of 2250 cms, tailwater elevation of 20.9 m, and gate opening of 2 m. Photos 3 and 4 show a discharge of 7900 cms, tailwater of 25.5 m, and gate opening of 8 m. Photos 5 and 6 show the flow pattern with gates wide open, a discharge of 13,200 cms, and tailwater of 28.4 m. For all three of these flow conditions the headwater was maintained at 49 m.

B. Type C-1 Spillway

The aeration ramps were installed in both bays between the piers. The vertical face of the ramps was flush with the downstream end of the piers as shown on Chart 1. The first ramps installed were 0.4 m high and 1.8015 m long (8 mm and 36 mm respectively in the model) corresponding to alternate No. 1 on Harza drawing number 995SKH551R1 and shown on Chart 2. For convenience in the model studies, this design was designated as Type C-1. The ramps were machined out of aluminum and screwed in place. The upstream edge of the ramp was carefully feathered and screw holes were filled with a plastic body putty to provide a smooth ramp surface.

More extensive observations were made on Type C-1 to determine the range of flows in which there was an air cavity downstream of the ramps and extending the full width of the flow. Observations were made at gate opening intervals of 1 m starting with a 2 m gate opening and continuing until the gates were wide open or clear of the water. The headwater was maintained at 49.0 m and the tailwater set to correspond to the discharge. The table on Chart 3 summarizes the test flow conditions and visual observations made regarding cavity size and frequency of occurrence. These observations are of a qualitative nature rather than quantitative. At a gate opening of 2 m and corresponding discharge of 2250 cms, no continuous cavity was observed. The flow downstream of the ramp ventilated and formed a short cavity of about 1 m length occasionally. Photo 7 shows the flow pattern from the right side and Photo 8 from downstream of the piers. These photos may be compared to Photos 1 and 2 of the Type C spillway without the ramps. To provide a better view of the cavity formation and aeration, pictures were taken from below and through the transparent-lucite spillway chute. A mirror was mounted under the spillway chute and the camera focused on the mirror. The resulting view is shown in Photo 9 for the flow condition with the 2 m gate opening. It should be noted that in all photos taken through the underside of the chute, the half-pier is on the left and the training wall is on the right of the photo. A 15 cm scale was attached to the underside of the chute to make it convenient in estimating cavity length. The zero on the metric scale was lined up vertically with the downstream edge of the ramps and piers, although it appears to be offset in the photo. This is due to the camera angle. A small cavity may be seen on the left side near the half-pier, and other aeration can be observed which may be associated with the hydraulic jump.

At a 3 m gate opening a cavity of about 3 m long was observed almost continuously (Chart 3). The cavity collapsed momentarily at random points across the chute. At a 4 m gate opening the cavity was about 3.5 m long and this cavity persisted for gate openings of up to 8 m. Typical photos of this behavior are shown in Photos 10 through 12 with the gate opening of 8 m. The nature of the cavity is clearly shown in Photos 11 and 12. Photos 10 and 11 may also be compared to Photos 3 and 4 of the Type C spillway. For a gate opening of 9 m, the estimated cavity length was about 2 m and was quite stable, and for a 10 m gate opening the cavity was somewhat shorter and only occurred about one-half of the time.

With the gates wide open and a flow of 13,200 cms, no cavity occurred in the vicinity of the piers as shown in Photos 13 through 15. At this flow the water depth was considerably greater and may have restricted the air flow down the back of the piers to the ramps.

In an attempt to increase the air supply to the base of the ramps, two venting schemes were tried. A 2 m x 2 m channel, open to the atmosphere and with its lower end cut at about a 45 degree angle, was placed directly behind the pier. The outline of this conduit can be seen in Photo 16. A slight increase in cavity development was noted but was not considered significant. The other scheme consisted of a circular vent pipe of 0.4 m diameter which was bent at right angles with its outlet placed directly behind the vertical face of the ramp. Photo 17 shows this pipe and the resulting aeration. Again, the cavity was not greatly increased and did not extend completely across the ramp.

C. Type C-2 Spillway

The Type C-2 spillway had a higher (0.6 m) and longer (2.7023 m) air ramp than Type C-1 (Chart 2). The model dimensions were 12 mm high and 54 mm long. These ramps corresponded to alternate No. 2 on Harza drawing number 995 SKH551R1.

Observations were made for the same flow conditions as previously discussed. The summary of observations on the Type C-2 geometry is outlined on Chart 3, and Photos 18 through 28 show the flow patterns. The flow patterns in these photos of Type C-2 may be compared with photos of similar flow conditions for Types C-1 and C. The flow patterns for Type C-2 appear similar to those for Type C-1 with some slight variations. An almost continuous cavity occurred for the same range of gate openings from 3 to 9 m and corresponding discharges from 3200 cms to 8790 cms. The length of the cavity appeared to be somewhat shorter for Type C-2 with an approximate length of 3 m as outlined on Chart 3. The air cavities shown on Photos 22 and 23 for Type C-2 with a flow of 7900 cms and gate opening of 8 m appear slightly shorter than the cavities for Type C-1 and the same flow conditions shown on Photos 11 and 12. The cavity length fluctuated with time, and this could account for some of the differences in the photos.

III. SUMMARY

The results of the tests on the aeration ramps on the 1:50 scale model should be considered of a qualitative nature. As the ramps did not prove to be effective in maintaining a well developed cavity, no attempts were made to measure the air concentration of the air-water mixture in the basin. A summary of the visual observations is as follows.

1. The Type C-1 geometry resulted in a cavity about 3.5 m long. An almost continuous or steady cavity existed with gate openings varying from 3 to 9 m, for which the discharges at a constant head of 49 m varied from 3200 to 8790 cms, respectively. A cavity could not be maintained with the gates wide open.

2. The Type C-2 geometry incorporating the longer and thicker ramp resulted in a slightly shorter cavity of about 3 m long. The cavity was essentially continuous or stable for the same gate openings and discharges as for Type C-1. Again, a cavity could not be maintained with the gates wide open.

3. Attempts to provide additional air flow through vents placed behind the pier for both ramp types did not significantly improve ventilation characteristics for the condition with gates wide open at a discharge of 13,200 cms.

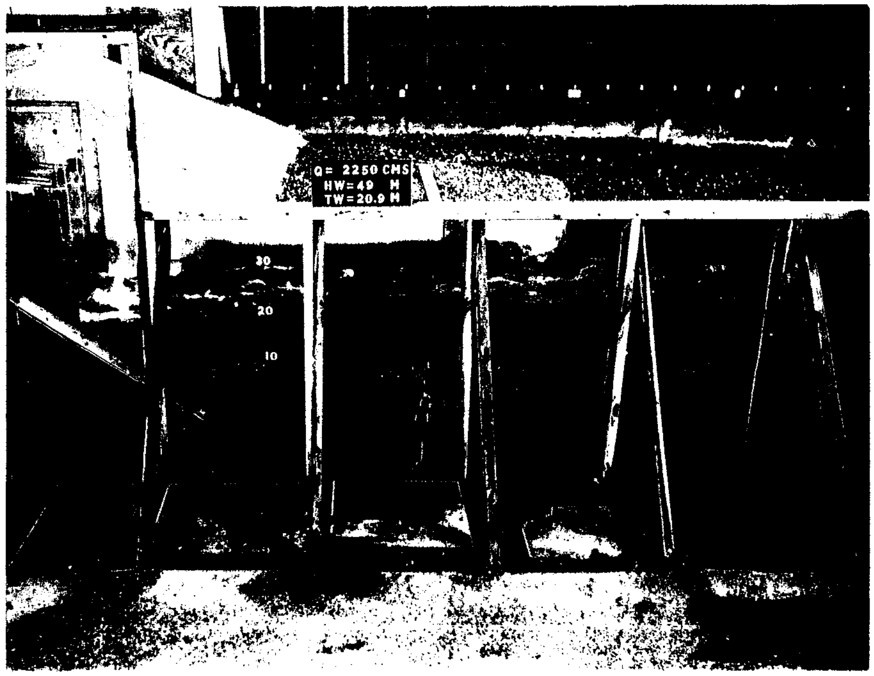


Photo 1 - (Serial No. 264-357) Type C, Q = 2250 cms,
H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m;
Flow pattern in the spillway.

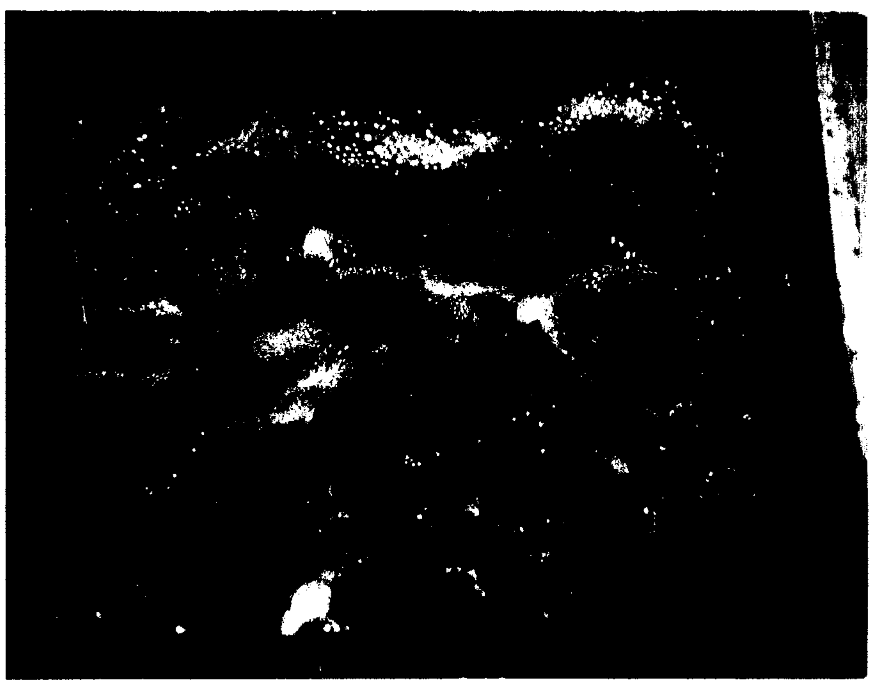


Photo 2 - (Serial No. 264-359) Type C, Q = 2250 cms,
H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m;
Flow pattern downstream of the piers.

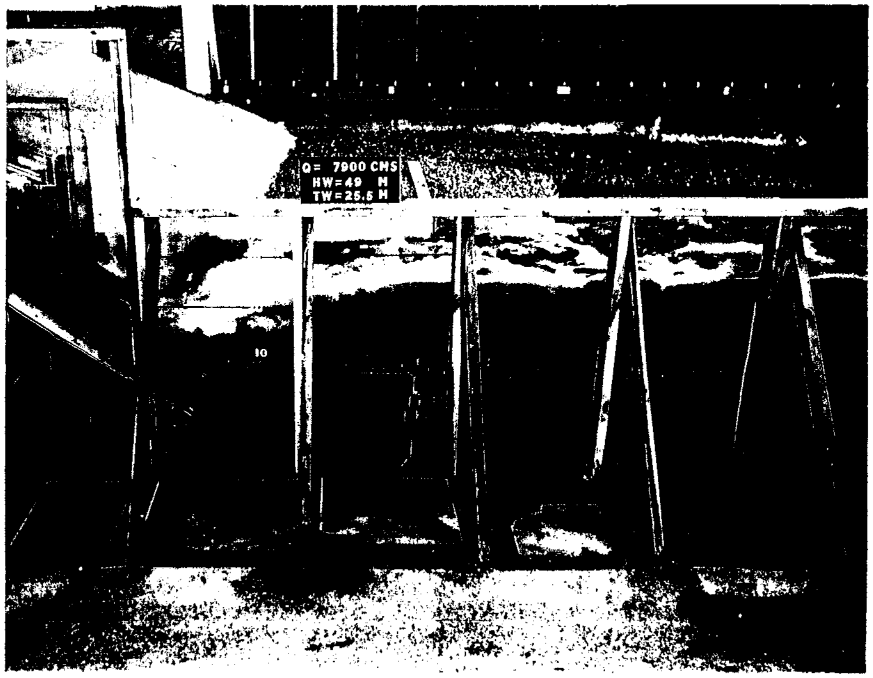


Photo 3 - (Serial No. 264-361) Type C, Q = 7900 cms,
H.W. = 49 m, T.W. = 25.5 m, Gate Opening = 8 m;
Flow pattern in the spillway.

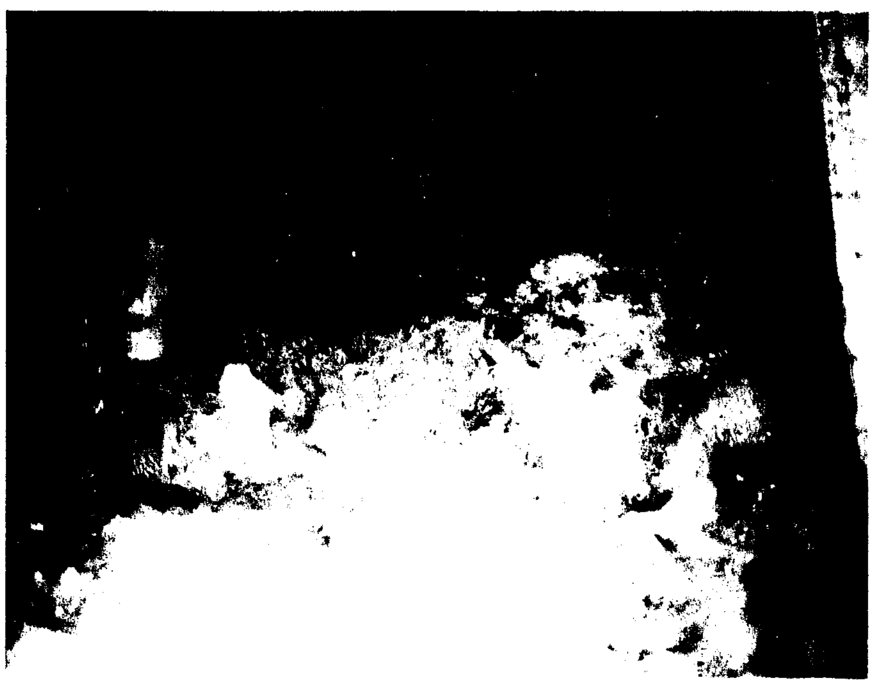


Photo 4 - (Serial No. 264-364) Type C, Q = 7900 cms,
H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m;
Flow pattern downstream of the piers.

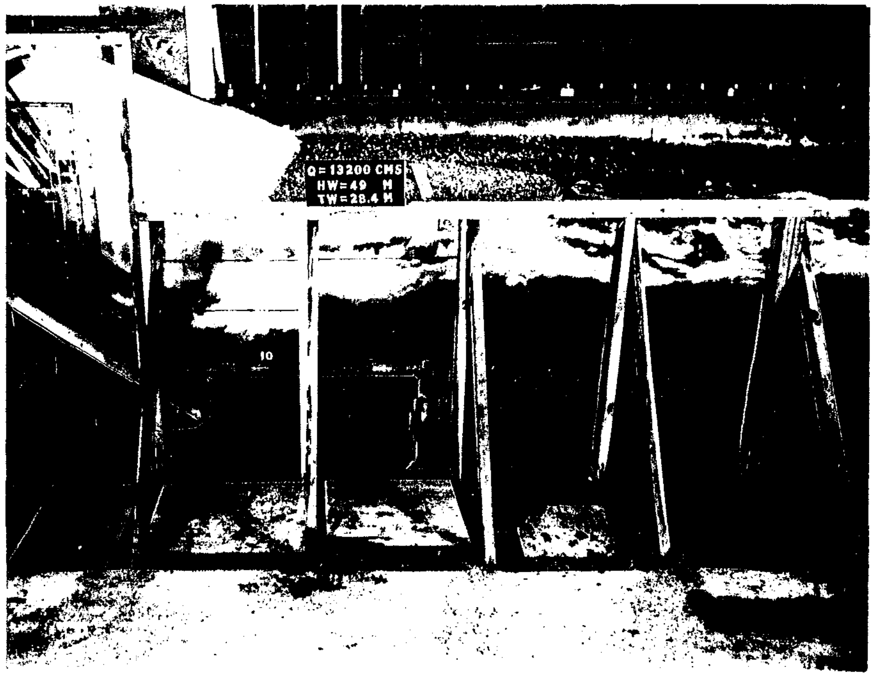


Photo 5 - (Serial No. 264-367) Type C, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern in the spillway.

Photo 6 - (Serial No. 264-368) Type C, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern downstream of the piers.

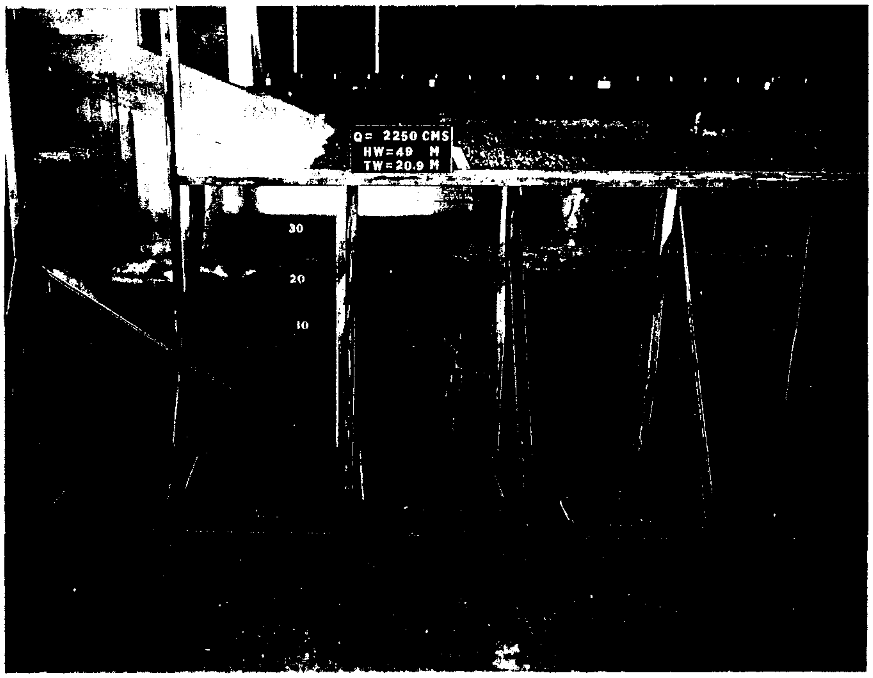


Photo 7 - (Serial No. 264-371) Type C-1, Q = 2250 cms,
H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m;
Flow pattern in the spillway.

Photo 8 - (Serial No. 264-374) Type C-1, Q = 2250 cms,
H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m;
Flow pattern downstream of the piers.

Photo 9 - (Serial No. 264-376) Type C-1, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m; Flow pattern from below showing aeration caused by the ramps.

Photo 10 - (Serial No. 264-377) Type C-1, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern in the spillway.

Photo 11 - (Serial No. 264-380) Type C-1, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m , Gate opening = 8 m; Flow pattern downstream of the piers.

Photo 12 - (Serial No. 264-382) Type C-1, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern from below showing aeration caused by the ramps.

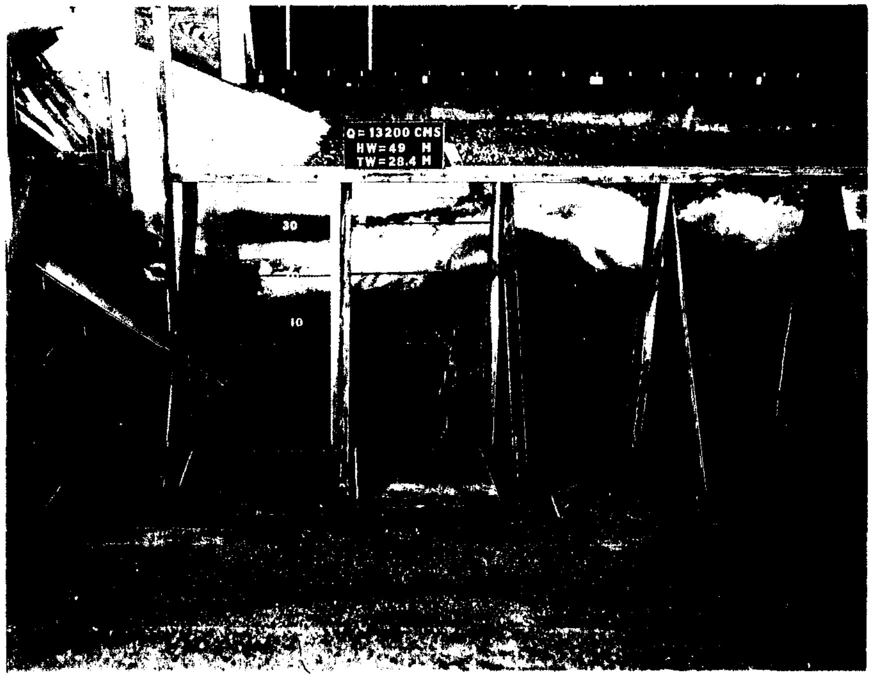


Photo 13 - (Serial No. 264-383) Type C-1, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern in the spillway.

Photo 14 - (Serial No. 264-386) Type C-1, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern downstream of the piers.

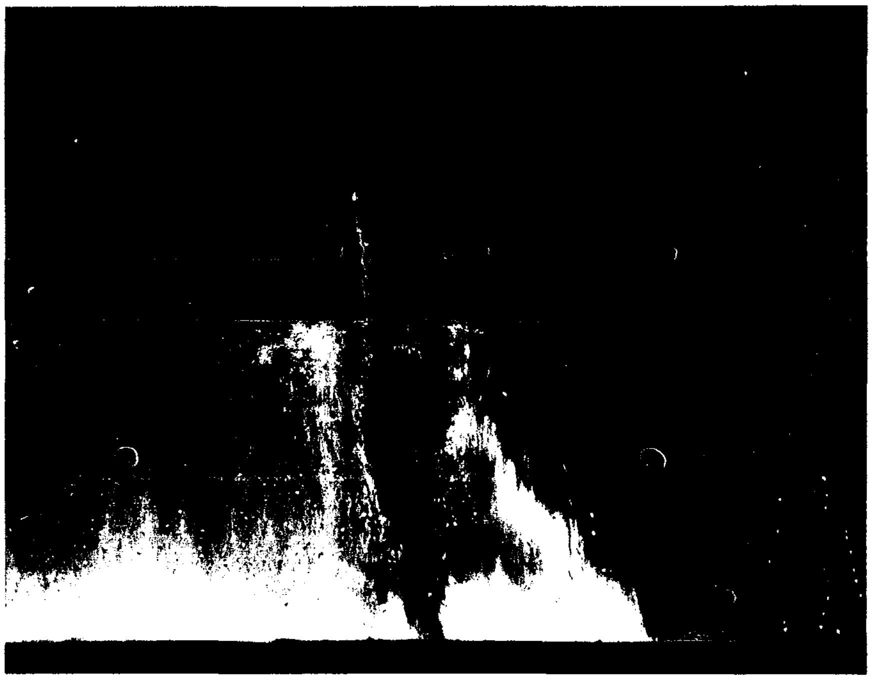


Photo 15 - (Serial No. 264-387) Type C-1, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 16 - (Serial No. 264-391) Type C-1 with 2 m by 2 m air vent downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 17 - (Serial No. 264-393) Type C-1 with 0.4 m dia. vent pipe downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

Photo 18 - (Serial No. 264-325) Type C-2, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m; Flow pattern in the spillway.

Photo 19 - (Serial No. 264-328) Type C-2, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m; Flow pattern downstream of the piers.

Photo 20 - (Serial No. 264-329) Type C-2, Q = 2250 cms, H.W. = 49 m, T.W. = 20.9 m, Gate opening = 2 m; Flow pattern from below showing aeration caused by the ramps.

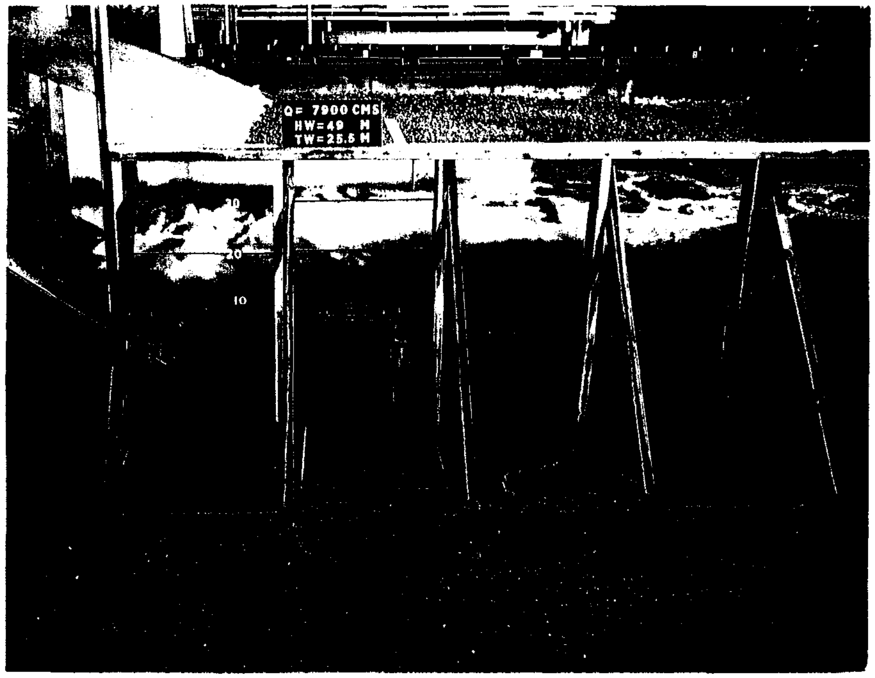


Photo 21 - (Serial No. 264-333) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern in the spillway.

Photo 22 - (Serial No. 264-337) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate opening = 8 m; Flow pattern downstream of the piers.

Photo 23 - (Serial No. 264-339) Type C-2, Q = 7900 cms, H.W. = 49 m, T.W. = 25.5 m, Gate Opening = 8 m; Flow pattern from below showing aeration caused by the ramps.

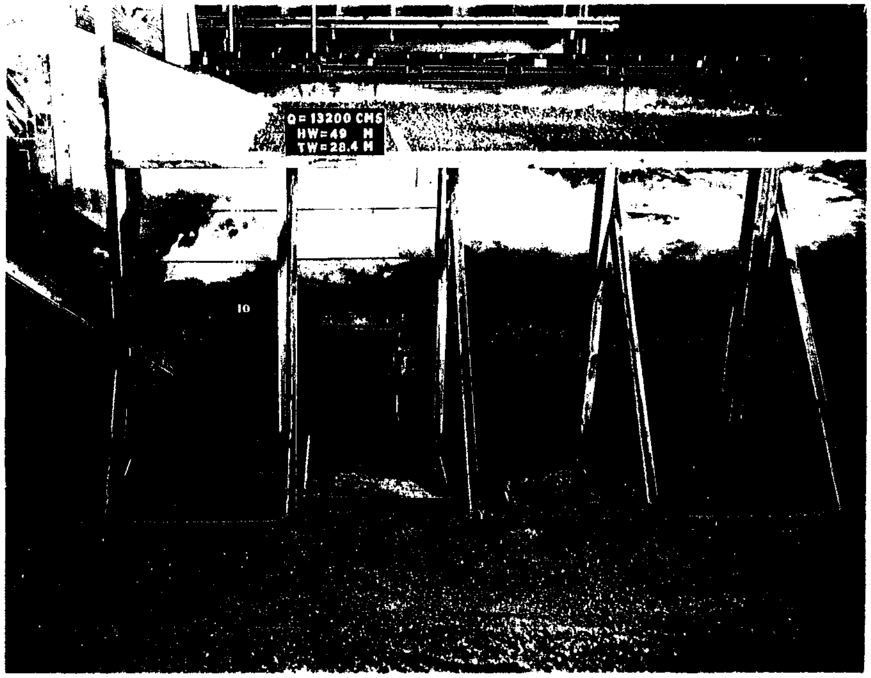


Photo 24 - (Serial No. 264-342) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern in the spillway.

Photo 25 - (Serial No. 264-345) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern downstream of the piers.

Photo 26 - (Serial No. 264-349) Type C-2, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

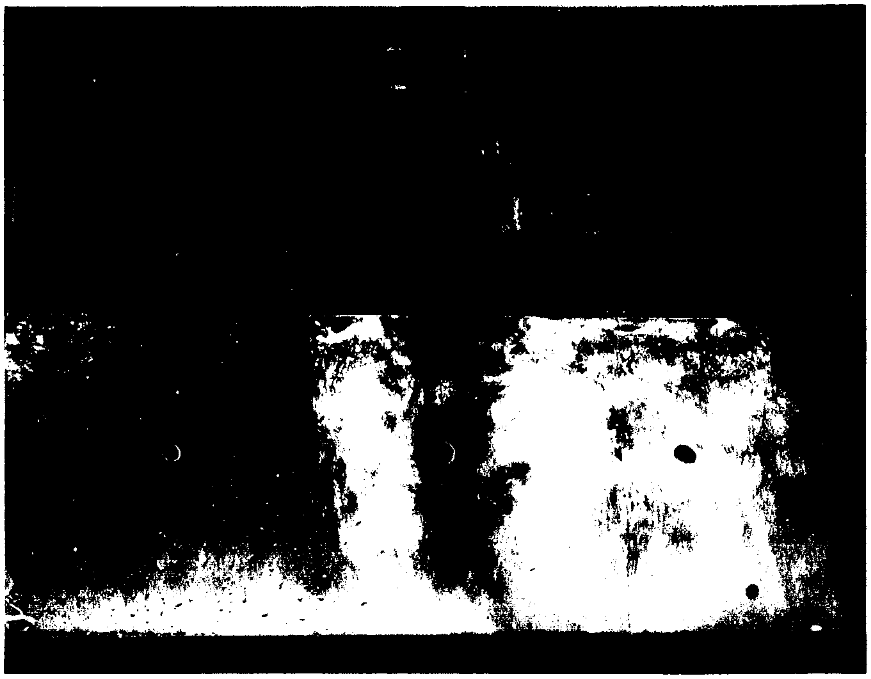


Photo 27 - (Serial No. 264-354) Type C-2 with a 2 m × 2 m air vent downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

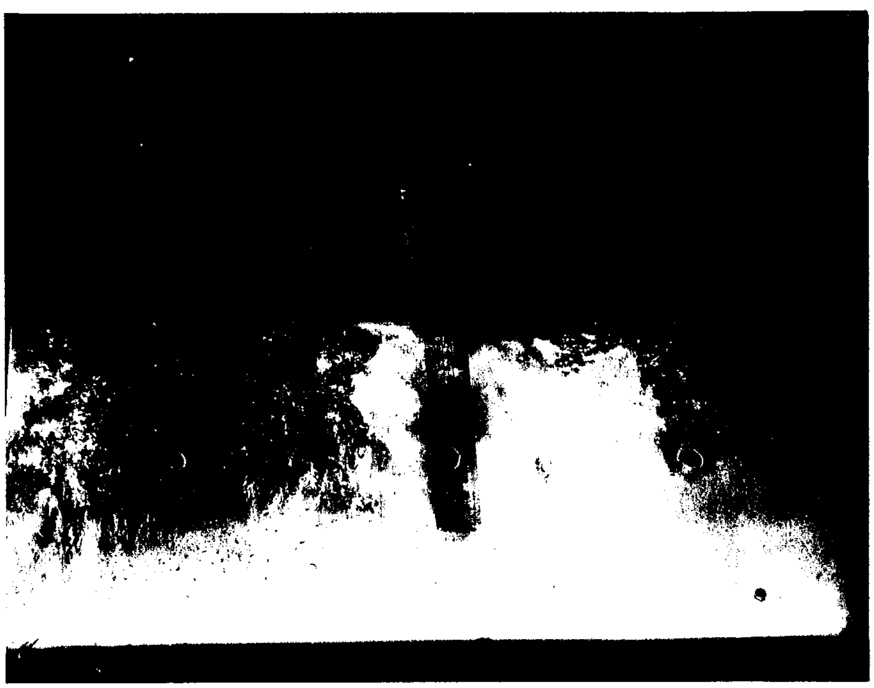


Photo 28 - (Serial No. 264-356) Type C-2 with 0.4 m dia. vent pipe downstream of pier, Q = 13,200 cms, H.W. = 49 m, T.W. = 28.4 m, Gates wide open; Flow pattern from below showing aeration caused by the ramps.

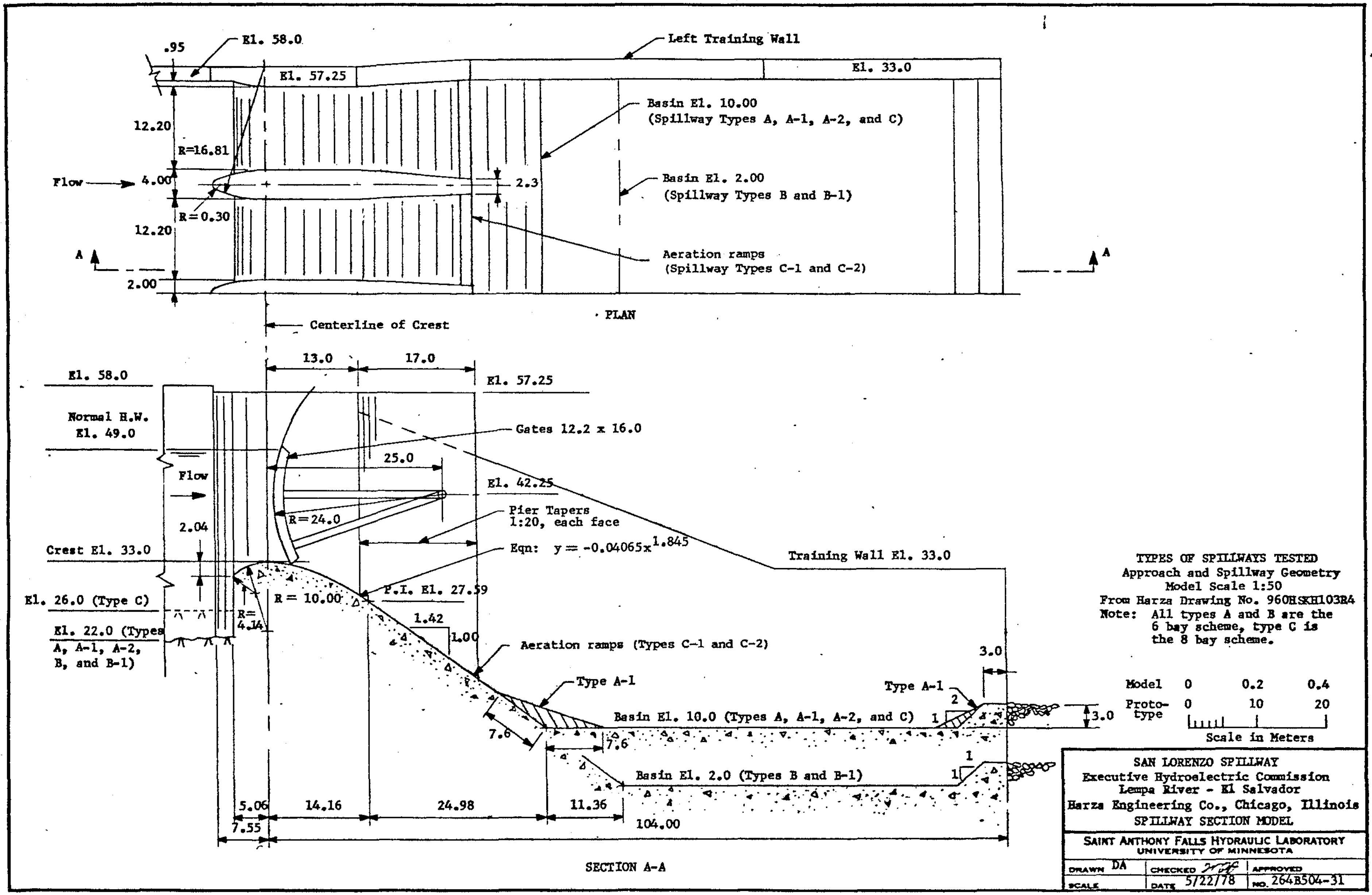
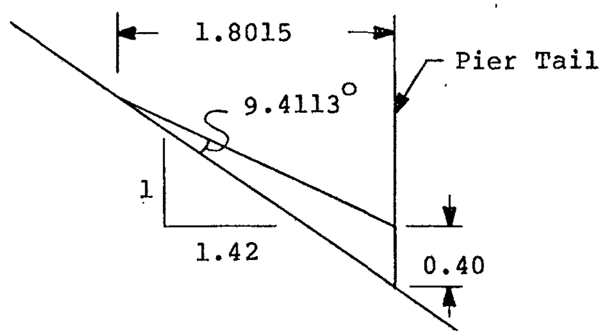
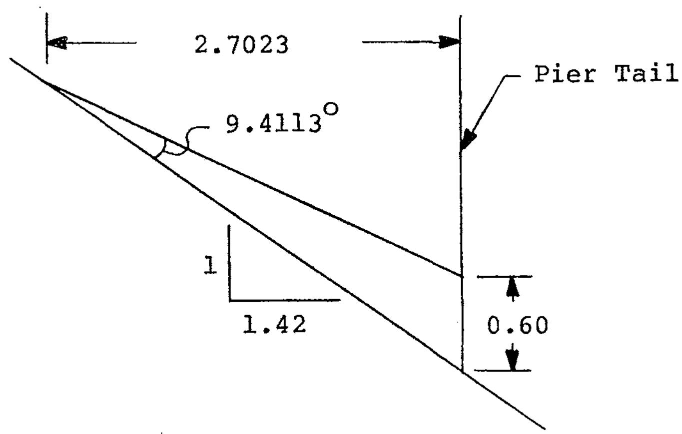

El. 58.0
.95
Left Training Wall
El. 57.25
El. 33.0
12.20
R=16.81
Basin El. 10.00
(Spillway Types A, A-1, A-2, and C)
Flow
4.00
2.3
Basin El. 2.00
(Spillway Types B and B-1)
R=0.30
12.20
A
Aeration ramps
(Spillway Types C-1 and C-2)
2.00
PLAN
Centerline of Crest
13.0
17.0
El. 58.0
El. 57.25
Normal H.W.
El. 49.0
Gates 12.2 x 16.0
25.0
Flow
El. 42.25
R=24.0
Pier Tapers
1:20, each face
2.04
Eqn: $y = -0.04065x^{1.845}$
Crest El. 33.0
Training Wall El. 33.0
El. 26.0 (Type C)
R = 10.00
P.I. El. 27.59
R=
4.14
1.42
1.00
El. 22.0 (Types
A, A-1, A-2,
B, and B-1)
Aeration ramps (Types C-1 and C-2)
Type A-1
Type A-1
3.0
2
1
3.0
7.6
7.6
Basin El. 10.0 (Types A, A-1, A-2, and C)
Basin El. 2.0 (Types B and B-1)
1
1
5.06
14.16
24.98
11.36
7.55
104.00
SECTION A-A
TYPES OF SPILLWAYS TESTED
Approach and Spillway Geometry
Model Scale 1:50
From Harza Drawing No. 960HSKH103R4
Note: All types A and B are the
6 bay scheme, type C is
the 8 bay scheme.
Model 0 0.2 0.4
Proto-type 0 10 20
Scale in Meters
SAN LORENZO SPILLWAY
Executive Hydroelectric Commission
Lempa River - El Salvador
Harza Engineering Co., Chicago, Illinois
SPILLWAY SECTION MODEL
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DA
CHECKED
APPROVED
SCALE
DATE 5/22/78
NO. 264B504-31

CHART 1

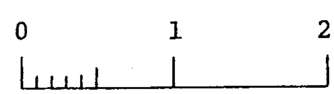


Type C-1 (Alternate 1)



Type C-2 (Alternate 2)

TYPES OF AERATION RAMPS TESTED
Model Scale 1:50
From Harza Drawing No. 995SKH551R1



Scale in Meters

SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN D.A.	CHECKED	APPROVED
SCALE	DATE 4/15/80	NO. 264A2318-62

Type	Q	H.W.	T.W.	Gate opening	Cavity Size	Cavity Occurrence
	cms	m	m	m	m	
C-1	2,250	49.0	20.9	2	1	Short cavity occasionally
C-1	3,200	49.0	21.8	3	3	Almost continuous
C-1	4,200	49.0	22.8	4	3.5	Almost continuous
C-1	6,080	49.0	24.2	6	3.5	Almost continuous
C-1	7,900	49.0	25.5	8	3.5	Almost continuous
C-1	8,790	49.0	26.2	9	2	Almost continuous
C-1	9,680	49.0	26.6	10	1.5	About one-half of the time
C-1	13,200	49.0	28.4	Wide	0	None-some air entrainment by piers
C-2	2,250	49.0	20.9	2	1	Short cavity occasionally
C-2	3,200	49.0	21.8	3	2.5	Almost continuous
C-2	4,200	49.0	22.8	4	3	Almost continuous
C-2	6,080	49.0	24.2	6	3	Almost continuous
C-2	7,900	49.0	25.5	8	3	Almost continuous
C-2	8,790	49.0	26.2	9	2	Almost continuous
C-2	9,680	49.0	26.6	10	1	About one-half of the time
C-2	13,200	49.0	28.4	Wide	0	None-some air entrainment by piers

SUMMARY OF OBSERVATIONS
ON AERATION RAMP STUDIES
Model Scale 1:50

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE	DATE 4/15/80	NO. 264A2318-63