HYDRAULIC MODEL STUDY

Of The

MAKIO DAM SPILLWAY

AICHI IRRIGATION PROJECT.

Chubu District, Honshu Island

Japan.

Prepared For

Erik Floor & Associates, Inc.

by

S. S. Karaki and

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Colorado State Unviersity Research Foundation
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FOREWORD

This report presents the results of a hydraulic model study of the spillway at Makio Dam, located in Nagano Prefecture, Japan. The dam is to be constructed by the Aichi Irrigation Public Corporation. The study was conducted for the consulting engineering firm of Erik Floor & Associates, Inc., Chicago, Illinois. All phases of the investigation were undertaken in the Hydraulics Laboratory of Colorado State University, which is under the general technical and administrative supervision of A. R. Chamberlain, Chief of the Civil Engineering Section. Technical advice was received from A. J. Peterka of the United States Bureau of Reclamation, as consulting engineer to Colorado State University, for the model study.

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Chapter

SYNOPSIS

Hydraulic model studies of the Makio Dam Spillway were made on a 1:60 scale model. The purpose of the study was to check the original design and make modifications as necessary to develop an economical overall structure which would perform adequately. Data and notes taken on the flow in the model showed that the general performance of the preliminary design was satisfactory. However, some design modifications are recommended to improve performance and to reduce the cost of the structure. These modifications included the following: The shape of the approach channel walls was changed to improve flow conditions. The width of spillway chute was reduced from 49.6 to 47.2 meters. Two types of stilling basins were tested; stilling basin B, with modifications, Figure 37, was found to be hydraulically superior and was recommended for prototype construction. The preliminary design was reduced 15 meters in length to provide the minimum structure. The basin floor was lowered 2 meters because of changes in tail water elevations.

Photographs, water surface profiles, pressures, and other data, and a spillway rating curve were obtained during the testing program.

FIGURES

FIGURES - - Continued.

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I. INTRODUCTION

General Description of Project

Makio Dam is an 80-meter high rockfill dam on the Ōtaki River in Nagano Prefecture, approximately 8 kilometers south and east of Fukushima, Japan. Although the dam is being constructed as part of an irrigation project, it actually will provide multiple purposes:

    (1) Irrigation.

    (2) Storage for a power plant on the Ōtaki River, immediately below the dam.

    (3) Storage for regulation of flow for power plants on the Kiso River downstream of the junction with the Ōtaki River.

    (4) Water supply for domestic and industrial uses.

    (5) Flood protection of lower farm lands.

The project is being constructed with the financial assistance of the International Bank for Reconstruction and Development.

The spillway is of the chute type and is isolated from the dam on the left bank. See Figure 1 for a site plan of the dam and appurtenant works. The spillway crest is normal to the chute center line; the chute is of constant width and discharges into a hydraulic jump stilling basin.

Scope of Investigation

The purpose of the hydraulic model study was to check the preliminary design of the spillway and to make modifications in arrangement or dimensions as necessary to assure its proper hydraulic preformance. The scope of the investigation included the following studies:

    (1) Flow approaching the spillway crest.

    (2) Flow over the crest and around the piers.

    (3) Performance of two basic types of stilling basins.

    (4) Flow and scour conditions at various discharges in the discharge channel.

II. PROTOTYPE STRUCTURE

Spillway Approach

The preliminary designs of the spillway are shown in Figures 1, 2, and 3. The approach channel is approximately 300 meters long and narrows from about 250 meters in width at the entrance, Figure 1, to 95 meters at the beginning of the concrete approach walls. The walls, shown in Figures 2 and 3, are 40 meters long. Rip-rap is shown in the bottom of the approach channel for a length of 50 meters, followed by 65 meters of concrete slab paving extending to the spillway crest. The sides of the approach channel walls are protected with rip-rap beyond the ends of the approach walls.

Two designs of approach walls were proposed. The first design consisted of symmetrical vertical walls converging to the crest at an angle of $30^\circ 51'$ to the center line of the spillway as shown in Figure 2. The height varied from 15 meters at the upstream end to 18 meters near the crest because of the slope in the concrete floor of the approach section which lowered the floor 3 meters. The top of the wall was level with the top of the dam, El. 885 m. The alternate design had an unsymmetrical arrangement of the approach walls. The right wall was vertical and the left wall was warped as shown in Figure 3.

Spillway Gate Section and Chute

An ogee spillway designed for a maximum flood discharge of 3200 m^3/sec, Figure 2, 47.2 meters in length, was set with crest El. 870 m. Three spillway piers each 2.4 meters thick reduced the effective length of the crest to 40 meters; 4 bays each 10 meters long. Four radial gates, each 10 meters wide by 10.5 meters high, were used to control the flow over the spillway.

The spillway chute, 49.6 meters wide, was excavated in rock and inclined downward at thirty degrees from the junction with the crest to the beginning of the stilling basin. At the toe of the chute, blocks were set to aid development of the hydraulic jump in the stilling basin.

Spillway Stilling Basin

Two stilling basins, termed stilling basin A and stilling basin B, were proposed by the designers. Stilling basin A included a secondary weir or dam 10.5 meters high with the floor of the basin only 2 meters lower than the elevation of the discharge channel. In stilling Basin B, the floor was set 7 meters lower than the discharge channel and a stepped sill was used at the end of the basin.

Dimensions of stilling basin A are shown in Figure 2. The length of the basin was 102 meters, measured along the center line of the spillway from the toe of the chute to the face of the secondary dam. The walls of the basin diverged from the chute to a point 85 meters downstream. From there to a point 5 meters beyond the secondary dam the width of the basin was constant at 60 meters. The training walls of the secondary basin diverged to a point 35 meters downstream.

Dimensions of stilling basin B are shown in Figure 3. The length of the basin was 95 meters, measured along the center line of the spillway from the toe of the chute to the beginning of the stepped end sill. All lengths of stilling basin B, used in this report, have reference to the above line of measurement. The walls diverged in a manner similar to that of stilling basin A. The floor elevation of the stilling basin was El. 795 m. and the elevation of the top of the end sill was the same as that of the river bed, El. 802 m.

In the preliminary designs no protection of the bed and banks was indicated for the discharge channel.

III   THE MODEL

Construction

The model shown in Figures 4 and 5 is a 1:60 scale reproduction of the spillway and adjacent areas. A scale of 1:60 was chosen since it provided a model sufficiently large to supply accurate data and was in keeping with the available laboratory space and facilities. A larger model would have supplied little, if any, additional data and would have cost more to construct and test.

The overall dimensions of the head box were 12 feet long by 8 feet wide. The part of the approach channel constructed in the head box, shown in Figure 4, represented approximately 160 meters of the 300 meters of approach channel length. Velocities calculated for the channel upstream from this point yielded values sufficiently small to indicate that modeling of that section was unnecessary. Also, no peculiar hydraulic problems exist in that section of the channel.

The bed of the approach channel consisted of 3/4 in. gravel to assimilate the rip-rap indicated in the prototype design. The concrete paving was assimilated by plywood and the vertical approach walls by sheet metal. To dampen the disturbances in the flow after passing through the inlet diffuser, a rock baffle was set in the headbox normal to the center line of the spillway. A piezometer, connected to the headwater stilling well, was installed downstream from the rock baffle to measure water surface levels in the approach channel.

The spillway crest was constructed of sheet metal and was fitted with wood piers, constructed according to the plans of the preliminary design. To measure pressures along the spillway crest profile, 9 piezo-meters were installed and connected to water manometers. Spillway Crest Detail in Figure 4 shows the location of the piezometers.

The stilling basin was constructed so that testing of both types of stilling basins could be done without major reconstruction of the model. The initial floor of the model was constructed to the elevation required for stilling basin B, and falsework was overlaid so that stilling basin A could be tested first.

A transparent wall was set in one side of the stilling basin to facilitate observation and photography. Downstream topography was assimilated as closely as possible in a movable gravel bed and extended for 6 feet, as shown in Figure 4. To measure the tailwater level in the discharge channel a piezometer tap was made in the center of the channel and connected to the tailwater stilling well. The stilling well was graduated in model meters for ease of setting the desired tailwater depth. Control of the tailwater level was obtained with an adjustable gate.

Water Supply

Water was supplied to the model from a 14-in. turbine pump, and recirculated through the laboratory sump system. The flow into the model was measured with an orifice installed in the discharge line of the pump. The orifice was calibrated volumetrically at the beginning of the investigation.

IV. MODEL INVESTIGATION

The investigation was concerned with the hydraulic performance of the spillway and stilling basin and with the erosion of the movable (erodible) bed in the discharge channel caused by flow leaving the stilling basin. The maximum flood discharge of 3,200 m^3/sec was tested along with the design discharge of 2000 m^3/sec, and a smaller discharge of 1,000 m^3/sec to be certain that the spillway operated satisfactorily over the entire discharge range.

Spillway Approach

The spillway was first tested with the approach walls of Figure 2 in place. Figure 6 shows confetti traces which indicate the flow lines in the approach area for a flow of 3,200 m^3/sec. Note the absence of eddies. Figures 7 and 8 show flow at the spillway crest and approach wall. Because of the sharp intersection at the junction of the approach wall with the abutment piers, there was considerable drawdown on the spillway crest. In both photographs the discharge was the maximum flood flow of 3,200 m^3/sec.

The results of this test indicated that the width of the approach channel could be reduced and that some modification of the approach wall would be necessary to eliminate the excessive drawdown at the abutment piers.

With the warped wall of Figure 3 in place, instead of the vertical wall, the surface stream lines were smoother at the upstream end of the wall, Figure 9, but there was greater drawdown at the wall-pier junction. Compare the photographs of Figures 8 and 9.

The width of approach channel was decreased by placing gravel along the banks of the model until a satisfactory width was attained and several alignments of the approach walls were investigated. Figure 10 shows the recommended width of approach channel and alignment of the

approach walls, and Figures 11 and 12 show the resulting surface flow pattern and profile for a discharge of 3,200 m^3/sec. Note the smooth flow and absence of drawdown at the abutment pier.

Spillway Gate Section and Chute

Flow Characteristics - - Flow through the gate section is shown photographically in Figures 7 and 11 for the maximum discharge of 3,200 m^3/sec with the gates open for free flow. A standing wave at the pier noses caused a slightly uneven water surface across the crest of the spillway. In an attempt to reduce the wave, various pier shapes were tried, but because of the location of stop log grooves in the piers any streamlining of the noses would have had to project upstream from the crest. "Bullet-nosed" piers were tried, but the added frictional resistance of the longer piers somewhat offset the benefits derived by stream-lining the nose. Since the wave was more a matter of interest than concern, it was decided that the original pier shapes were satis-factory.

Figures 13, 14, and 15 are photographs showing flow conditions and profiles in the chute at the maximum discharge of 3,200 m^3/sec. In the preliminary design, the chute was wider than the crest width, because the abutment piers projected into the flow area defined by the chute walls. The abrupt offset at the downstream end of the abut-ment piers caused a water "fin" to develop along each chute wall, as shown in the photographs. The fins adjacent to the chute walls over-topped the walls at 3,200 m^3/sec discharge.

To eliminate the fin, the width of the chute was reduced so that it was equal to the width of the crest. Thus the faces of the abut-ment piers were in the same vertical plane as the chute walls. The effect can be seen in Figures 16 and 17. Note in Figure 16 that the height of the wall immediately adjacent to the abutment pier should be increased to contain the flow at maximum discharge. Figure 17 shows satisfactory conditions for 2,000 m^3/sec discharge.

Spillway Crest - Table 1 gives values of pressures on the spillway crest. It will be noted in the table that there was very little influence of changes in the approach wall with pressures on the crest. The minimum crest pressure noted for the maximum discharge of 3200 m^3/sec was 0.3 meter. Location of piezometers are shown on the crest detail of Figure 4. Because no negative pressures were developed on the spillway crest, the preliminary crest shape was considered satisfactory.

TABLE 1

TABLE OF PRESSURES IN METERS OF WATER
ALONG SPILLWAY CREST PROFILE
Q = 3200 m^3/sec

Piezometer No.	Preliminary Design with Vertical walls	Preliminary Design with Warped walls	Recommended Approach wall Design
1	13.3	13.3	13.3
2	4.7	4.7	4.6
3	2.4	2.4	2.3
4	0.3	0.3	0.3
5	1.4	1.2	1.2
6	2.0	2.0	2.0
7	1.5	1.4	1.4
8	2.7	2.6	2.7
9	4.1	4.0	4.1

Rating Curve - - With the modifications made in the spillway approach and in the chute walls at the gate section, the spillway crest was calibrated for both free and gate controlled flow. The rating curve is shown in Figure 18. The efficiency of the crest is indicated by the discharge coefficient in the equation:

$$Q = CLH^{3/2},$$

where:

Q = discharge in m^3/sec.,

C = coefficient of discharge,

L = effective crest length in meters,

H = total head or difference in elevation of reservoir surface and crest in meters.

For maximum discharge under free flow conditions, the coefficient is approximately 2.13 as shown by the curve of the coefficients. See Figure 19. Note that Figure 19 also shows the coefficient in terms of feet and cfs units. The value 3.8 indicates that the crest is very efficient. The water surface in the reservoir, at maximum discharge of 3,200 m^3/sec under free flow conditions, is at El. 881.2 m. The reservoir level anticipated by the designers was shown on the preliminary drawings as El. 883.5 m.

The spillway was also calibrated for gate-controlled flow, as shown in Figure 18, for use in prototype operation of the structure. The crest and gates were calibrated with the recommended approach walls and chute width in place in the model. Gate opening is defined as the vertical distance between the lower lip of the gate and the gate seat. The gate seat is at El. 869.843 m. The gates were operated uniformly.

Discharge curves for exact meter openings are shown in Figure 18. Discharges for openings involving fractions of meters

may be interpolated from the data shown. The dashed lower portion of the gate opening curves indicates a region which cannot be determined exactly in a model. However, the values shown by the dashed curves are believed to be essentially correct.

Spillway Stilling Basins

The two stilling basins were tested to develop the most economical basin consistent with adequate hydraulic performance. Two tailwater rating curves were used during the course of the investigation.

The original rating curve, shown in Figure 20, was used throughout the testing of both stilling basins. When the testing was completed, a new tailwater rating curve, also shown in Figure 20, was received from the designers as being representative of the tailwater elevations established by field investigators. The recommended stilling basin B was re-tested using the new tailwater rating curve. Stilling basin A was not re-tested however, as it had been previously concluded that stilling basin B was economically and hydraulically better suited to the locale.

Stilling Basin A - - The water surface profile in the basin for the preliminary design of stilling basin A is shown in Figure 21. (Figure 2 shows the details of the preliminary design of stilling basin A). The water surface was determined from average readings taken at numerous points on the grid on the stilling basin wall. See Figure 5 for the grid marked on the wall opposite the transparent wall. Because the theoretical sequent depth was not attained in the basin, the jump formed farther downstream than was desirable and the chute blocks were partially exposed. The flow, after passing over the secondary dam, formed a second hydraulic jump below the dam which was somewhat unstable and considerable water surface roughness was developed in the discharge channel.

Secondary dam heights of 10.5, 11.0, 11.5 and 12.3 meters were tested, with 3200 m^3/sec discharge to establish a more efficient hydraulic jump and to move the jump upstream to cover the chute blocks. These

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tests indicated that a height for the secondary dam of 12.3 meters provided sufficient depth over the chute blocks to prevent development of excessive negative pressures. It was considered desirable to reduce, or eliminate, negative pressures because of the associated possibility of cavitation. Cavitation would present considerable maintenance difficulties to the structure and hence add to maintenance costs.

The maximum negative pressures recorded on the chute blocks for each of the heights are given in Table 2.

TABLE 2

MAXIMUM NEGATIVE PRESSURES IN METERS
OF WATER ON CHUTE BLOCKS FOR
STILLING BASIN A.
$Q = 3200 \ m^3/sec.$
$L = 102 \ meters$
Original Tailwater Curve

Height of Secondary Dam	Piezometer[1] Number	Maximum Neg. Pressures in Meters
10.5	2	-10.0^2
11.0	2	-10.0^2
11.5	2	-6.8
12.3	2	-4.2

[1] Piezometer number indicates location as shown in Figure 25.

[2] Values are greater than maximum negative pressures possible, but are tabulated to indicate model results.

An effective method to shorten a stilling basin is to modify the hydraulic jump. This may be done by various arrangements of baffle piers and sills on the basin floor. The restriction on the arrangement is that the baffle piers and sills must be non-clogging. Experience and numerous experiments by personnel of the United States Bureau of Reclamation in Denver, Colorado, have indicated that for a basin of the size under consideration here, a single row of baffle piers placed favorably in the basin would be effective in shortening the basin. (A list of references is given in the Reference Section). Tests were therefore conducted with baffle piers to shorten the stilling basin.

Preliminary tests were conducted with three sizes of baffle piers, 3.6, 4.6, and 6.1 meters high. Only a single row was used. The spacing between piers were equal to the widths of the baffle piers. The dimensions of the baffle piers with piezometer locations on the piers are shown in Figure 25. To determine an effective location for the baffle piers, tests were made at quarter points in the length of the basin.

The results of tests for the three baffle piers at the first quarter point downstream from the toe of the chute, indicated an unsatisfactory location for all sizes. Excessive negative pressures were developed on the baffle piers and considerable turbulence existed in the stilling basin beyond the baffle piers. Two pier heights of 3.6 and 4.6 meters were found effective and applicable at the mid-point of the basin, but the 6.1-meter baffle pier was too high in relation to the sequent depth, as excessive turbulence was created beyond the baffle pier. Tests at the third quarter point showed that baffle piers in this location were not effective in shortening the hydraulic jump.

It was decided from the results of these tests that two sizes of baffle piers should be used in developing the stilling basin, and their locations should be confined near the mid-point of the stilling basin length.

During the tests with the baffle piers, it was noted that the hydraulic jump moved upstream and was stabilized. The control point for the hydraulic jump was transferred from the secondary dam to the baffle piers, and it was found that the preliminary height of secondary dam, 10.5 meters, was sufficient when the baffle piers were used.

The tests with baffle piers in the 102-meter long basin showed that a considerable length between the piers and the secondary dam was ineffective. Accordingly, in order to determine the shortest stilling basin, consistent with adequate performance, the length was reduced in increments of 10 meters from 102 meters to 82 meters. Each basin length was tested with and without baffle piers. The baffle piers were located at the mid-point of the stilling basin.

As noted previously, the preliminary design of stilling basin A was inadequate, for the hydraulic jump was not contained entirely within the basin. Use of both 3.6 and 4.6 meter baffle piers stabilized the jumps within the stilling basin. There were no negative pressures developed on either size of baffle piers with the maximum discharge of 3200 m^3/sec., although, negative pressures of -5.5 m. and -5.0 m. of water respectively existed at the chute blocks. Both sizes of baffle piers developed satisfactory pressures on chute blocks and baffle piers for the design discharge of 2000 m^3/sec.

Tests for the 92-meter basin length provided results which were satisfactory and is discussed below. The 82-meter basin was insufficient for development of an adequate hydraulic jump even with the 4.6 meter baffle pier in the stilling basin. A negative pressure of -4.0 meters was developed on the baffle piers for the maximum discharge.

Figure 22 shows a satisfactory basin 92 meters in length with 4.6-meter baffle piers located at the mid-point of the basin. Baffle piers 3.6 meters high provided negative pressures for 3200 m^3/sec discharge.

No negative pressures were measured for the 4.6-meter pier. Chute block pressures were negative and with both sizes of baffle piers the magnitudes were approximately the same. The hydraulic jump in the stilling basin with 3.6-meter high baffle piers is shown in Figure 22 A.

Figures 23 and 24 show flow conditions in the 92-meter stilling basin and 4.6-meter baffle piers for discharges of 2000 and 1000 m^3/sec respectively. Although negative pressures were measured on the chute blocks for a discharge of 3,200 m^3/sec., no negative pressures were measured for discharges of 2000 and 1000 m^3/sec. Table 3 gives a tabulation of pressures on the chute blocks and baffle piers. Location of piezometers is shown in Figure 25.

TABLE 3.

TABLE OF PRESSURES IN METERS OF WATER
ON CHUTE BLOCKS AND BAFFLE PIERS FOR STILLING BASIN A

Length of Stilling Basin = 92.0 meters

Height of Baffle Piers = 4.6 meters

Piezometer Number*	Q = 3,200 m^3/sec		Q = 2,000 m^3/sec		Q = 1,000 m^3/sec	
	Chute Blocks	Baffle Piers	Chute Blocks	Baffle Piers	Chute Blocks	Baffle Piers
1	-4.7	2.3	1.5	9.9	7.3	13.3
2	-6.4	2.0	1.5	9.3	7.5	11.9
3	-2.1	29.3	3.0	16.6	8.7	12.6
4	-6.0	--	0.9	--	7.0	--
5	-2.1	--	3.0	--	8.1	--
6	-1.4	--	4.1	--	7.9	--

* Piezometer locations are shown in Figure 25.

The water surface in the discharge channel for a flow of 3200 m^3/sec had waves up to 2.0 meters in height which were developed by the hydraulic jump, below the secondary dam. For 2000 m^3/sec waves were approximately 1.3 meters high and for 1000 m^3/sec waves were about 1.0 meter high.

In order to determine the scour potential for various conditions of flow, a study was made of the effect of various lengths of paved apron downstream from the secondary dam. The bed of the channel consisted of 3/4 to 1/4 in. gravel. Testing of 40, 28, and 18-meter lengths of aprons for a discharge of 3,200 m^3/sec indicated that essentially the same depth of scour occurred at the end of the apron in a one hour test period. A 1.5-meter high end sill with a 2:1 sloping upstream face and a vertical downstream face was subsequently tested at the end of each apron using the same discharge and test period. The results showed that 18 meters of paved apron length would be sufficient, provided an end sill was used. The scour hole which occurred with the end sill in place was located downstream from the structure and was not as deep as the scour hole formed at the end of the flat apron. One hour tests were also made for discharges of 2,000 and 1,000 m^3/sec and very little scour was found for either discharge.

Stilling Basin B with Original Tailwater Curve - - The prelimi-nary design of stilling basin B is shown in Figure 3. Figure 26 shows the hydraulic jump in the stilling basin for a discharge of 3,200 m^3/sec. From the traces of the air bubbles, a stagnant zone upstream from the end sill was evident, indicating the stilling basin was longer than necessary. Figures 27 and 28 show flow conditions for discharges of 2,000 and 1,000 m^3/sec respectively. Table 4 shows pressures on the chute blocks for the three discharges.

TABLE 4.

TABLE OF PRESSURES IN METERS OF WATER
ON CHUTE BLOCKS FOR PRELIMINARY STILLING BASIN B

Length of Stilling Basin = 95.0 meters.

No Baffle Piers

Original Tailwater Curve

Piezometer No.*	Q=3,200 m³/sec	Q= 2,000 m³/sec	Q=1,000 m³ sec
1	-0.8	3.9	7.6
2	-2.0	3.3	6.4
3	-1.1	2.6	6.0
4	-2.4	3.0	6.1
5	2.4	3.7	6.5
6	3.4	5.8	7.0

* Piezometer locations are shown in Figure 25.

From the performance of this stilling basin it was evident that no changes were necessary in the elevation of the basin floor, or in the height of the end sill. The stilling basin was subsequently reduced in length by moving the end sill upstream in increments of 10 meters. Each modified basin was tested for performance at the maximum discharge of 3,200 m³/sec. Figure 29 shows the hydraulic jump in the stilling basin 85 meters long. In Figure 30 the basin length is 75 meters. Comparing these two figures, it may be seen that the 75-meter basin is too short because the jump extends beyond the end sill. On the other hand, the 85-meter basin was somewhat longer than necessary to contain the jump. This was determined from a study of the motion of air bubbles in the basin.

Baffle piers were installed in the 75-meter basin to develop the jump in a shorter length. Two sizes of baffle piers, 3.6 meters and 4.6 meters high were installed at the midpoint of the basin. For the maximum discharge of 3,200 m^3/sec and for both sizes of baffle piers the chute block pressures were positive, but negative pressures were measured on the baffle piers. The 3.6-meter pier developed a maximum negative pressure of -3 meters and 4.6-meter pier a pressure of -5.8 meters. These values are indications of possible cavitation on the piers. Visual observation of the water surfaces in the discharge channel indicated that wave action with either baffle pier ranged from 2 to 2.5 meters in height. A table of wave heights for the various conditions of stilling basin B is given in Table 7.

Discussion with the designers on the results of tests, for the stilling basins at this stage of the investigation, led to the decision that stilling basin B was superior to stilling basin A on the basis of hydraulic performance. It was also decided by the designers that for the initial construction, baffle piers in the stilling basin would not be included because of the associated maintenance problems. However, it was desirable that tests be made of the recommended stilling basin with baffle piers to demonstrate additional stilling benefits. Results of these tests are included in Appendix A of this report.

Stilling Basin B with New Tailwater Curve - - The new tailwater curve shown in Figure 20 is appreciably lower than the original curve. It was noted in the previous tests that the original tailwater curve produced a depth in basin B that was close to the sequent depth at a discharge of 3,200 m^3/sec. Therefore, in adpoting the new tailwater curve it seemed necessary to lower the stilling basin floor to maintain a comparable relationship between sequent depth and tailwater depth at a discharge of 3,200 m^3/sec. To check this, the longer stilling basins of previous tests were retested with the new tailwater level and without change in the basin

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floor elevation. The hydraulic jumps formed well downstream from the chute blocks in all the basins tested; was inadequate and somewhat unstable but was not swept out. It was apparent that the basin floor would need to be lowered.

The stilling basin floor was subsequently lowered 2 meters and basin lengths of 85, 80, and 75 were tested at maximum discharge. These basin lengths were selected for final testing on the basis of the results of previous tests. A 9-meter high end sill was tried, but was found to cause considerable turbulence at the end sill. The height of end sill was reduced 2 meters - to 7 meters high, and stilling basin lengths of 85, 80, and 75 meters were again tested at maximum discharge. The 85-meter basin was found to be longer than necessary because a stagnant zone was developed in the basin upstream from the end sill. The 80-meter basin showed no stagnant zone, indicating sufficient basin length for the hydraulic jump. The adequacy of the 80-meter basin was subsequently proved by testing the 75-meter basin. The hydraulic jump for the 75-meter basin extended beyond the end sill indicating that the basin was too short. Table 5 shows a tabulation of pressures on the chute blocks for the three basins tested.

TABLE 5

TABLE OF PRESSURES IN METERS OF WATER

ON CHUTE BLOCKS FOR STILLING BASIN B

$Q = 3,200 \text{ m}^3/\text{sec}$

New Tailwater Curve

Piezometer Number *	Basin Length 85 m.	Basin Length 80 m.	Basin Length 75 m.
1	2.7	3.6	3.6
2	1.4	2.2	2.0
3	2.0	2.6	2.6
4	1.1	1.4	1.5
5	2.0	2.9	3.4
6	5.3	5.5	5.8

* Piezometer locations are shown in Figure 25.

Although pressures were positive in all three tests, slightly greater values were found when the basin was 80 meters long than when the basin was 85 meters long. This is an indication of the effectiveness of the 80-meter basin as compared to the 85-meter basin. In comparing the pressures for the 75-meter basin and the 80-meter basin no essential difference is noted. This was because the hydraulic jump extended beyond the end sill in the 75-meter basin.

On the basis of the tests described above, a stilling basin 80 meters long, having an end sill 7 meters high, was found to be best. Tests for smaller discharges of 2,000 and 1,000 m^3/sec showed the basin performance to be satisfactory. See Figures 31, 32, and 33 for photographs of flow in the recommended stilling basin at discharges of 3,200, 2,000, and 1,000 m^3/sec respectively. Chute block pressures for these tests are given in Table 6.

TABLE 6

TABLE OF PRESSURES IN METERS OF WATER
ON CHUTE BLOCKS FOR RECOMMENDED STILLING BASIN.

Length of Basin = 80 m.
New Tailwater Curve

Piezometer Number *	Q=3,200 m^3/sec	Q=2,000 m^3/sec	Q=1,000 m^3/sec
1	3.6	3.5	7.6
2	2.2	1.6	5.7
3	2.6	1.7	5.2
4	1.4	1.1	5.3
5	2.9	2.7	6.0
6	5.5	4.7	6.7

* Piezometer locations are shown in Figure 25.

TABLE 7

TABLE OF MAXIMUM WAVE HEIGHTS IN
THE DISCHARGE CHANNEL FOR STILLING BASIN B

Length of Basin in Meters	Height of Baffle piers in Meters	Tailwater Curve	DISCHARGES		
			Q=3,200 m^3/sec	Q=2,000 m^3/sec	Q=1,000 m^3/sec
95	None	Original	2.0	1.3	1.0
85	None	Original	2.5	--	--
75	None	Original	2.5	--	--
75	3.6	Original	2.2	--	--
75	4.6	Original	2.5	--	--
85	None	New	2.5	--	--
75	None	New	3.0	--	--
80	None	New	2.5	1.5	0.7
80	3.6	New	2.0	1.0	0.5
80	4.6	New	2.5	1.0	0.5

Table 7 gives values of maximum wave heights in the discharge channel downstream from the stilling basin.

Scour studies made with 3/4 to 1/4 in. gravel extending beyond the end of a 22-meter long paved channel bottom showed that appreciable scour did not occur during a 3-hour test period. The bed material was then changed to coarse sand with a median grain size of 1.85 mm. This material, although not representative of the bed material in the proto-type, made scour tendencies more visible. In order to determine the length of bed protection necessary in the discharge channel, various lengths of paving which extended downstream from the end sill at ele-vation 800 were tested. The lengths tested ranged from 12 meters to 42 meters in 10-meter increments. For a discharge of 3,200 m^3/sec and a test period of 30 minutes, about the same amount of scour occurred at the end of each paving length. A typical scour pattern is shown in Figure 34. Scour occurred in the area where the bed sloped upward from El. 800 m. to El. 802 m. When this sloped section was paved with rip-rap very little scour occurred farther downstream. Figures 35 and 36 show the condition of the discharge channel bed before and after the final scour test. The total length of paving represents 35 meters pro-totype. Although a portion of the total length is solid paving in the model, rip-rap may be used in the prototype. The rip-rap should be graded with individual pieces of about one meter in diameter as the upper limit in size.

V. THE RECOMMENDED SPILLWAY

The recommended spillway is shown in Figure 37 from the beginning of the approach walls to the ends of the training walls. The approach channel to the spillway in the preliminary design was wider than necessary and savings in excavation might be effected by reducing the channel to the alignment and dimensions shown in Figure 10.

The spillway approach walls were modified in alignment from the preliminary designs to eliminate the sharp junctions at the approach walls and abutment piers, and to improve the efficiency of the spillway crest. The preliminary designs shown in Figures 2 and 3 caused a sharp drawdown at the abutment piers which in effect reduced the width of the crest. Although the drawdown is not completely eliminated with the new alignment, the improvement is substantial in both the water surface profile and discharge over the spillway crest.

Because of the abrupt offset at the downstream end of the abutment piers, a water fin formed along the spillway chute walls. At a discharge of 3,200 m^3/sec the fins overtopped the walls of the preliminary design. By reducing the width of the chute so that the walls were in the same vertical plane as the inside of the abutment piers, the fin was eliminated. However, because of the improvement made in the approach wall alignment, which increased the capacity of the spillway, it will be necessary to increase the height of the chute walls immediately adjacent to the downstream end of the piers. The maximum depth of water normal to the chute at this point is about 7.5 meters.

Stilling basin B, with modifications from the preliminary design, for hydraulic and economic reasons, is recommended for use in the prototype. The length of stilling basin can be reduced from 95 meters to 80 meters, a reduction of 15 meters from the preliminary design. Channel bed protection downstream from the end sill can be

-22-

reduced from 50 meters to 35 meters in length and may be com-
prised of graded rip-rap with the maximum size about one meter in
diameter. Although the training walls were not investigated in the
model because they were not considered to be part of the hydraulic
design, they may be ended at the end sill if geological and topographi-
cal conditions permit. The sides of the excavated channel may then
need to be protected with rip-rap, similar to the bed rip-rap.

The stilling basin floor was lowered 2 meters - to El. 793,
because of a change in the tailwater rating curve. The hydraulic
jump in the recommended stilling basin is shown in Figure 31 for a
discharge of 3,200 m^3/sec. For this discharge the following condi-
tions were measured in the model:

$$D_1 = 1.86 \text{ meters}$$
$$D_2 = 20.8 \text{ meters}$$

Wave heights in discharge channel about
2.5 meters.

From these values the following may be calculated:

$$V_1 = 36.4 \text{ m/sec.}$$
$$F_1 = 8.5$$
$$\frac{D_2}{D_1} = 11.2$$

and the length of basin $= 3.85 \, D_2$.

Discharges of 3,200 m^3/sec and less, will be passed safely
through the recommended stilling basin. No unusual maintenance
problems should be expected on the chute blocks, since pressures will
be positive for the entire range and no cavitation should occur.

The foregoing recommendations, based on the model investi-
gation, will provide a spillway and stilling basin which will be hydrau-
lically adequate and economical to construct.

REFEREMCES

1. Bradley, J. N., and Peterka, A. J. The Hydraulic Design of Stilling Basins: Hydraulic Jumps on a Horizontal Apron (Basin I) Proc. Paper 1401. A.S.C.E. Jour. of Hyd. Div. Oct. 1957.

2. Bradley, J. N., and Peterka, A. J. The Hydraulic Design of Stilling Basins: High Dams, Earth Dams, and Large Canal Structures. (Basin II) Proc. Paper 1402. A.S.C.E. Jour. of Hyd. Div. Oct. 1957.

3. Bradley, J. N., and Peterka, A. J. The Hydraulic Design of Stilling Basins: Short Stilling Basin for Canal Structures, Small Outlets, and Small Spillways (Basin III) Proc. Paper 1403. A.S.C.E. Jour. of Hyd. Div. Oct. 1957.

4. Bradley, J. N., and Peterka, A. J. The Hydraulic Design of Stilling Basins: Stilling Basin and Wave Suppressors for Canal Structures, Outlet Works and Diversion Dams. (Basin IV) Proc. Paper 1404. A.S.C.E. Jour. of Hyd. Div. Oct. 1957.
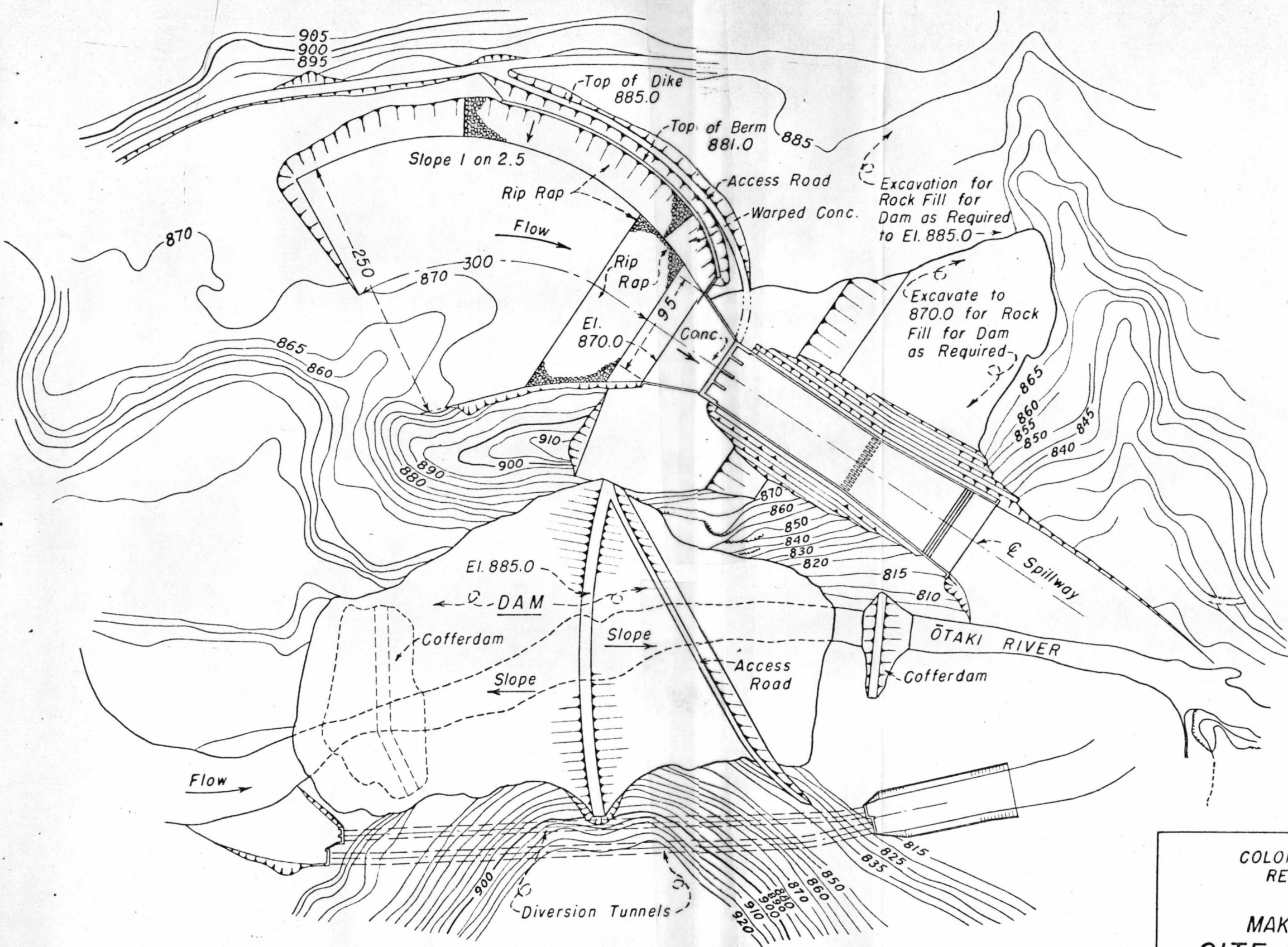
905
900
895

Top of Dike
885.0

Top of Berm
881.0

885

Access Road

Excavation for
Rock Fill for
Dam as Required
to El. 885.0

Slope 1 on 2.5

Rip Rap

Warped Conc.

Flow

870

Rip
Rap

250

870

300

Excavate to
870.0 for Rock
Fill for Dam
as Required

865
860
855
850
840
845

El.
870.0

95

Conc.

865
860

910

900

880

890

870
860
850
840
830
820

815

℄ Spillway

810

El. 885.0

℄ DAM

Cofferdam

Slope

Access
Road

ŌTAKI RIVER

Slope

Cofferdam

Flow

815
825
835

900

870
860
850

Diversion Tunnels

920
910
900
890
880

0   50   100 meters

SCALE

PLAN

40.0
127.0
102.0
17.5 Dam
35.0
16.4
85.0
-5.0

95.0
2.4
10.0
2.4
2.4
49.6
℄ Spillway
60.0
70.0
30° 51'
Paving
El. 802.0

SPILLWAY CREST DETAIL
Scale 1" = 4 m

3.2
2.37
1.39
Crest El. 870.0
$X^{1.836} = 1.936\,H^{0.836}\,Y$
El. 868.3
5.5
30°
R = 2.1
El. 867.0
R = 6.8
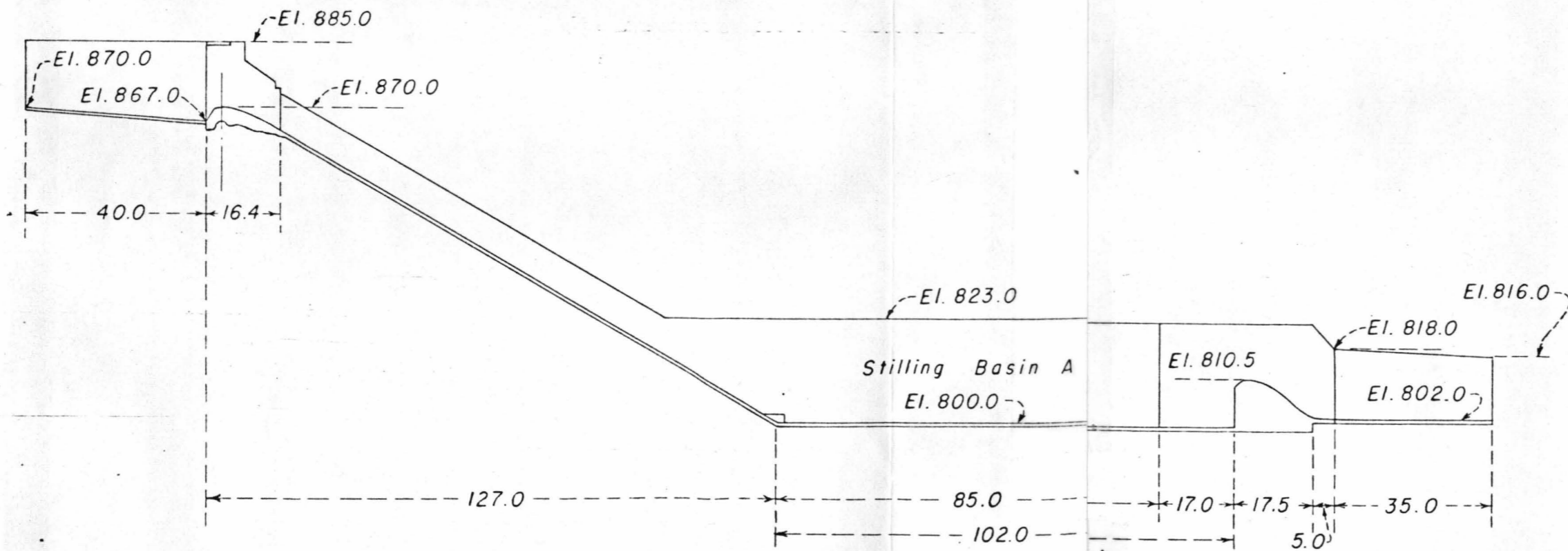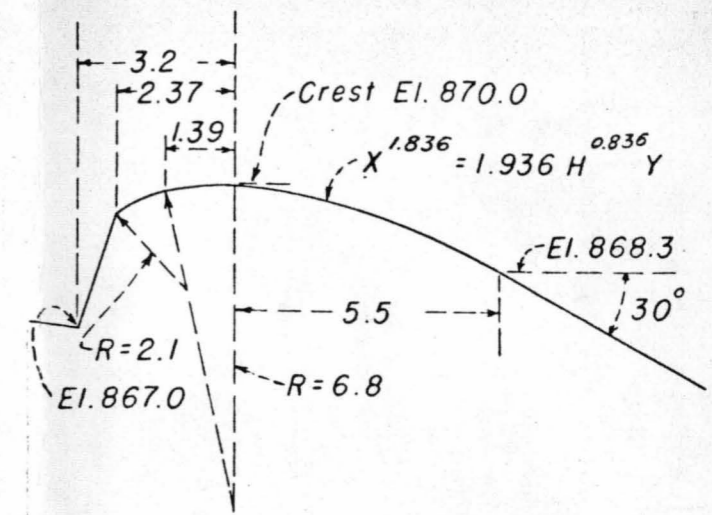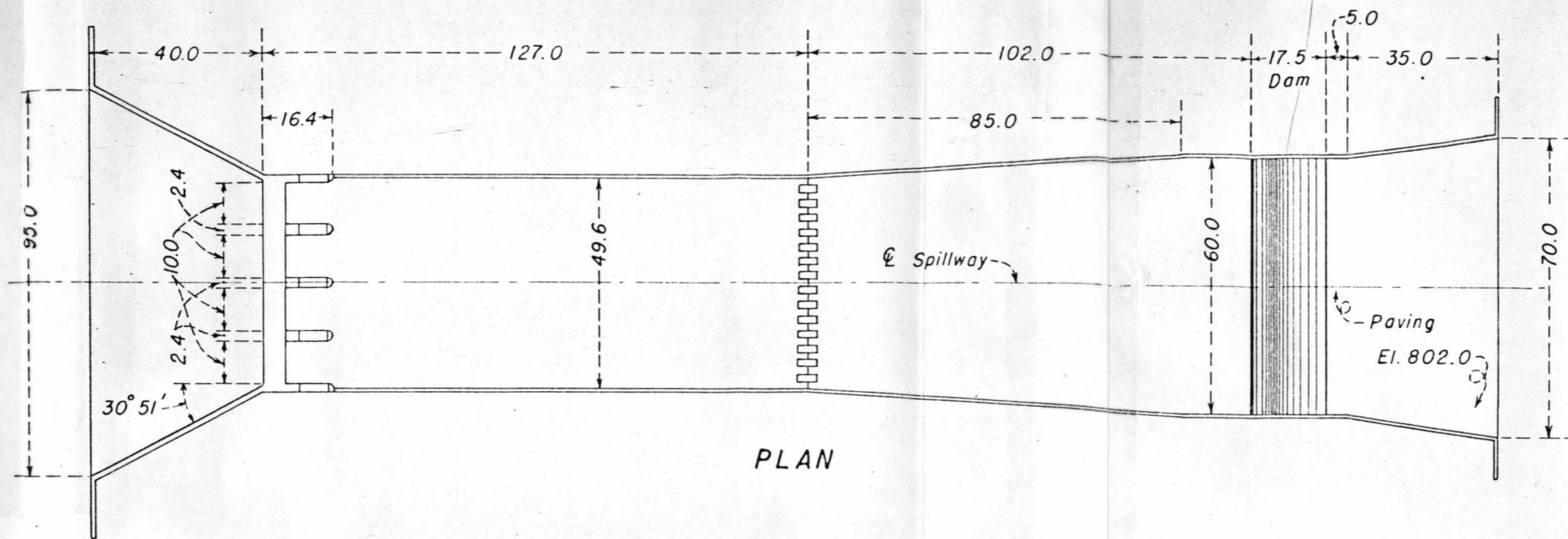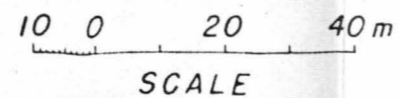
NOTES

The preliminary design is designated
stilling basin A.

The approach walls shown are one of
the preliminary designs.

All dimensions and elevations are in
meters unless otherwise indicated.

SECTION THROUGH CENTER LINE

-El. 885.0
-El. 870.0
El. 867.0
-El. 870.0
40.0
16.4
-El. 823.0
El. 816.0
-El. 818.0
Stilling Basin A
El. 800.0
El. 810.5
El. 802.0
127.0
85.0
17.0
17.5
35.0
102.0
5.0

10 0 20 40 m
SCALE

PLAN

40.0 | 135.66 | 95.0 | 55.84

16.5

16.4

78.0

6.0

95.0

47.2

Warped Approach Wall

Chute

49.6

60.0

70.0

₵ Spillway

Paved Apron

5.0

SECTION THROUGH CENTER LINE

El. 885.0

El. 870.0

El. 867.0

Crest El. 870.0

40.0

16.4

30°

Top of Wall El. 818.0

El. 818.0

El. 816.0

Stilling Basin B Floor El. 795.0

Apron El. 802.0

135.66

95.0

6.0

49.84

10 0   20   40 m

SCALE

COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
MAKIO DAM SPILLWAY
STILLING BASIN B
ALTERNATE PRELIMINARY DESIGN

Drawn by S.K.	Approved S. Karaki
Traced by S.A.	
Checked by S.K.	

| 782 | SEPTEMBER 1958 | FIG. 3 |

12'-0"

8'-0"

4'-0"

4'-0"

Wave Damping Board

Baffle

Rock

Slope

25/32

6 9/16 + 37/64

37/64

4 1/16

Line of Piezometers
See Spillway
Crest Detail

Stilling Well Tap
in Floor of
Approach Channel

Manometer Board
for Crest
Piezometers

Headwater
Stilling Well

Secondary Dam

Rip Rap

Tail Gate

Outlet

Stilling Well Tap
in Floor of Model

Tailwater
Stilling Well

2'-8 9/16"

11 5/32" + 11 31/64" + 3 9/32"

3'-0"

6'-0"

3'-0"

6'-11 3/8"   4'-7 51/64"   1'-10 41/64" 2'-2 1/4"   6'-0"   1'-9"

PLAN

₵ Crest

2 3 4 5 6 7

1 1/8"   5/16   3/16   8

3"   9

3"

**SPILLWAY CREST DETAIL
LOCATION OF PIEZOMETERS**

NOTES

In this schematic drawing only the warped
approach wall arrangement and stilling
basin A are shown.
Stilling basin B was obtained by removing
the false floor arrangement in the
model.
Model scale 1:60
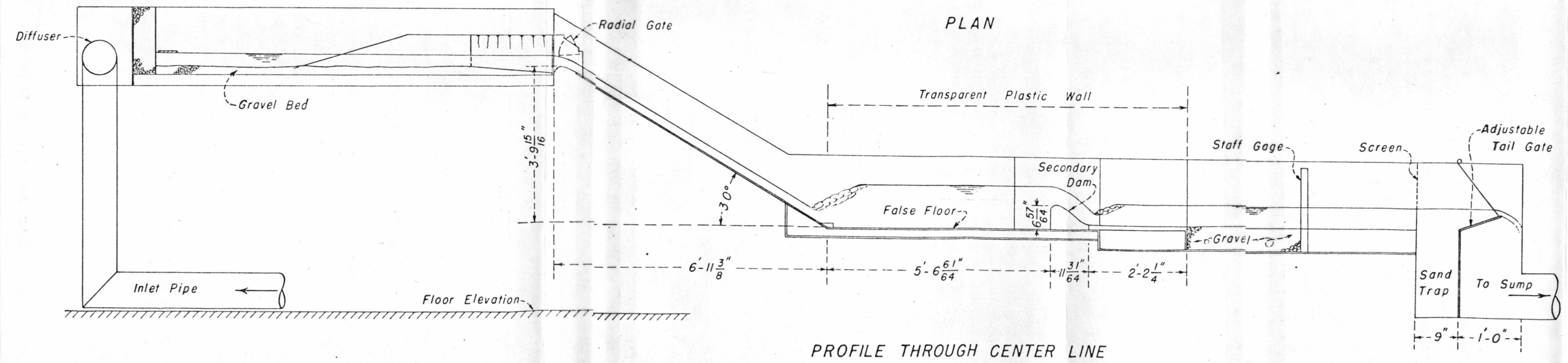
Diffuser

Radial Gate

Gravel Bed

Transparent Plastic Wall

3'-9 15/16"

3'-0"

Secondary
Dam

False Floor

57/64"

Gravel

Staff Gage

Screen

Adjustable
Tail Gate

Sand
Trap

To Sump

Inlet Pipe

Floor Elevation

6'-11 3/8"   5'-6 61/64"   11 31/64"   2'-2 1/4"

9"   1'-0"

PROFILE THROUGH CENTER LINE
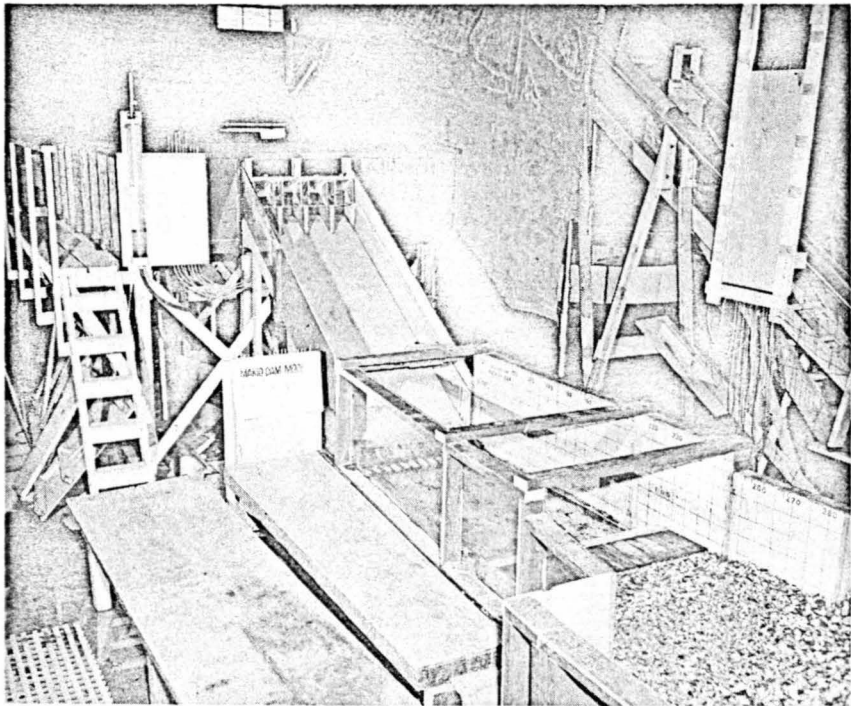
Fig. 5 General photograph of model.
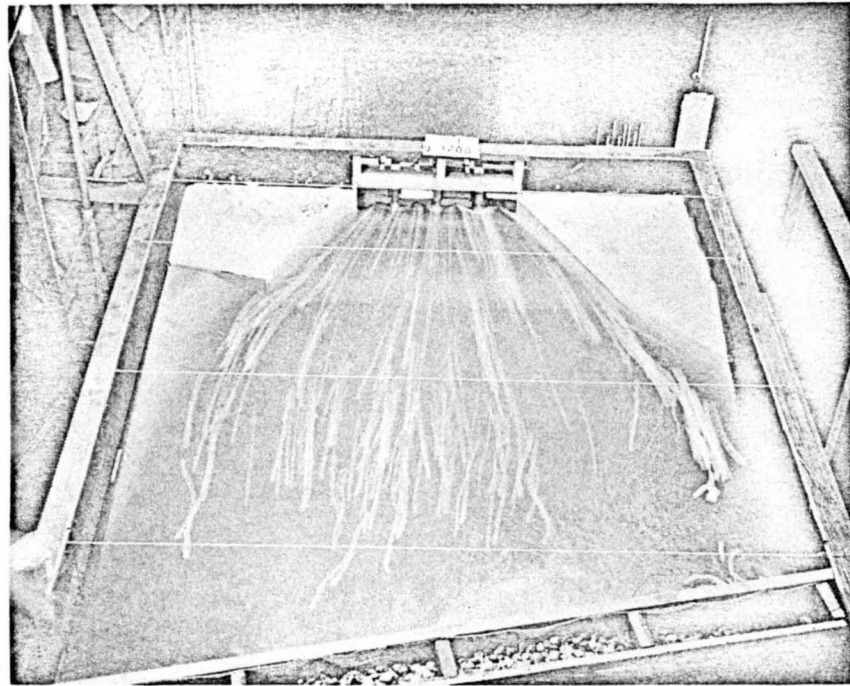
Fig. 6 Flow pattern in approach channel with vertical walls in preliminary design of Figure 2.
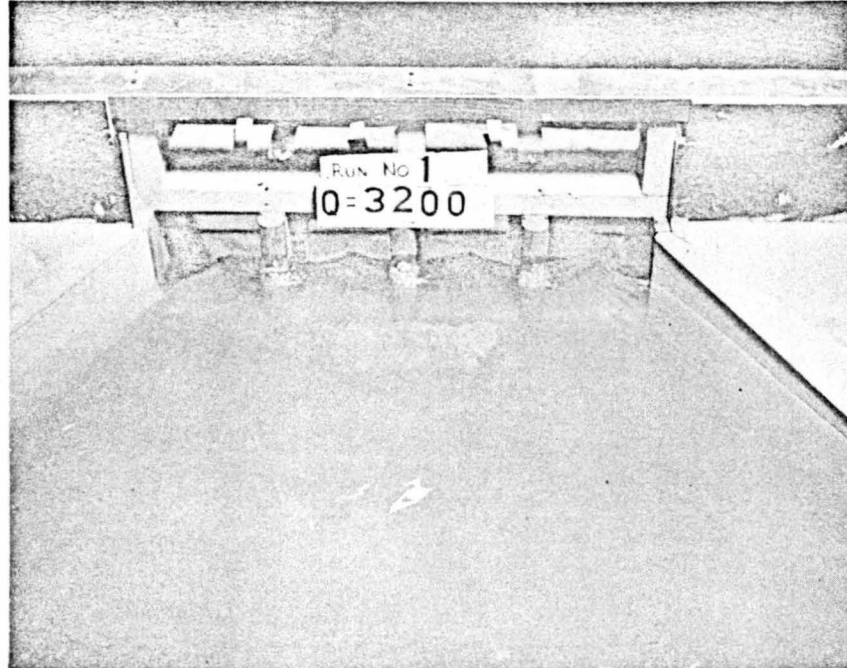
Fig. 7 Flow at spillway crest with vertical walls in preliminary design of Figure 2.
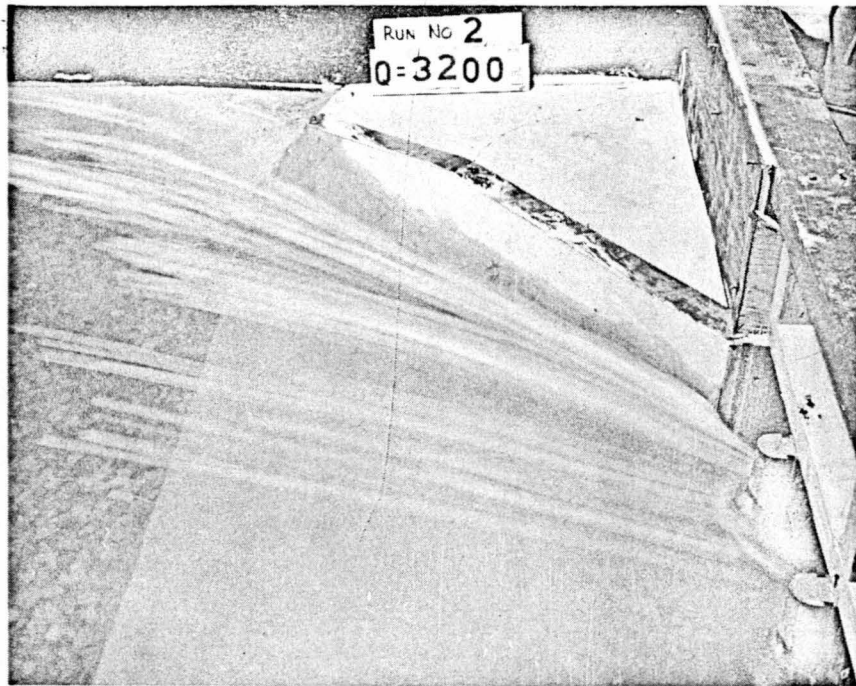
Fig. 8   Flow at left vertical approach wall
         for preliminary design of Figure 2.
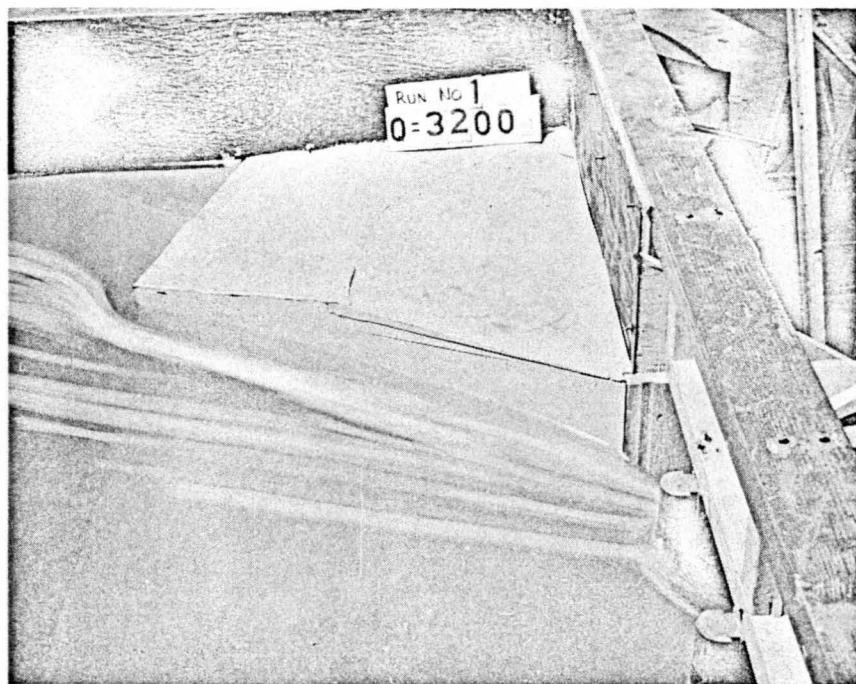
Fig. 9   Flow at wall for the alternate design
         of approach wall of Figure 3.
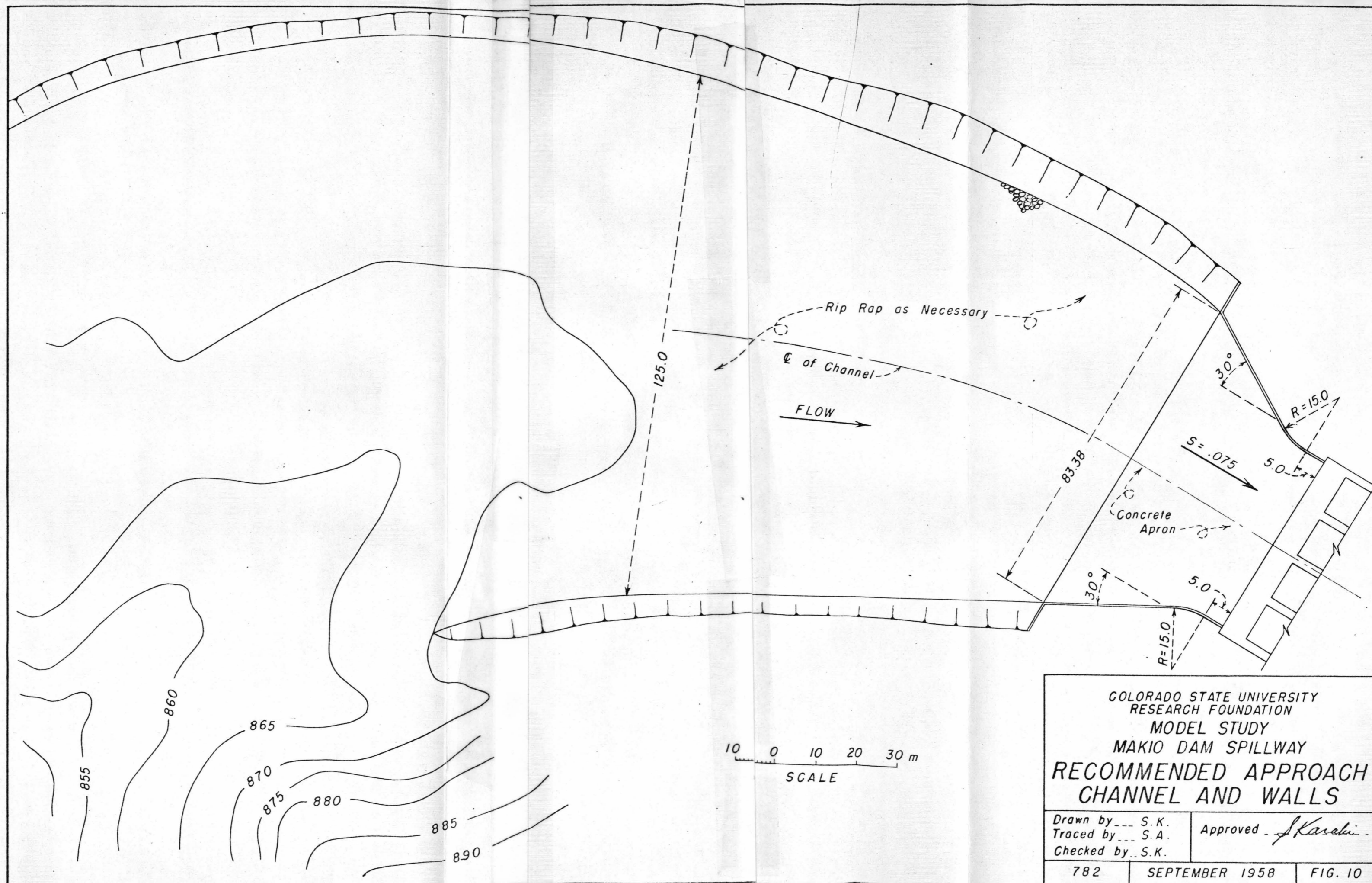
Rip Rap as Necessary

₵ of Channel

FLOW

125.0

83.38

30°

R = 15.0

5.0

S = .075

Concrete Apron

30°

5.0

R = 15.0

855
860
865
870
875
880
885
890

10   0   10   20   30 m
SCALE

COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
MAKIO DAM SPILLWAY
RECOMMENDED APPROACH
CHANNEL AND WALLS

Drawn by ___ S.K.
Traced by ___ S.A.   Approved ___ S. Karaki
Checked by ___ S.K.

782   SEPTEMBER 1958   FIG. 10

Fig. 11   Flow pattern for recommended
           approach wall design of Figure 10.
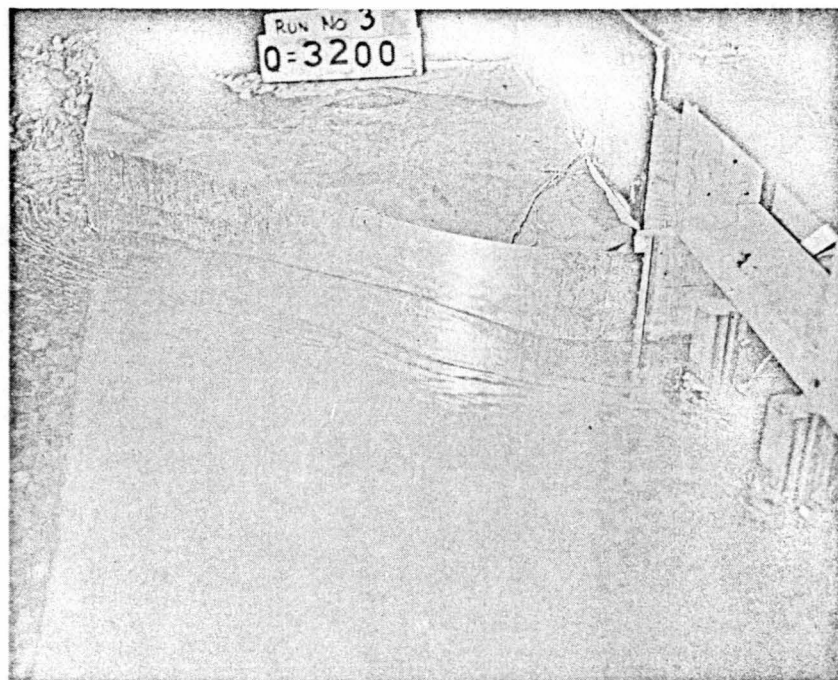
Fig. 12   Flow along left wall with recommended
           approach wall design of Figure 10.

Fig. 13   Flow in chute with preliminary
approach wall design and chute
width.
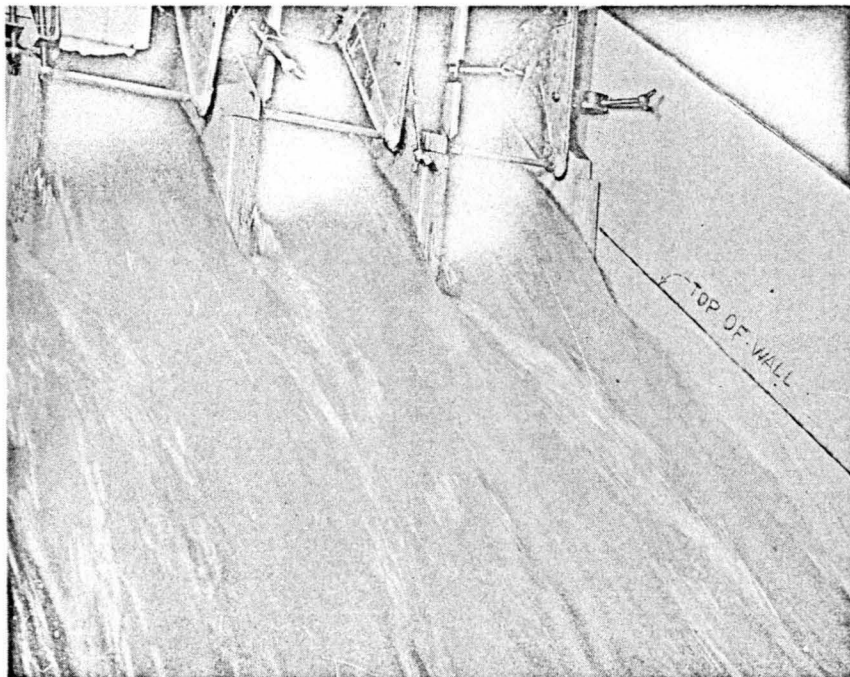
Fig. 14   Development of fins below piers.
Note particularly the fin at the
chute wall.
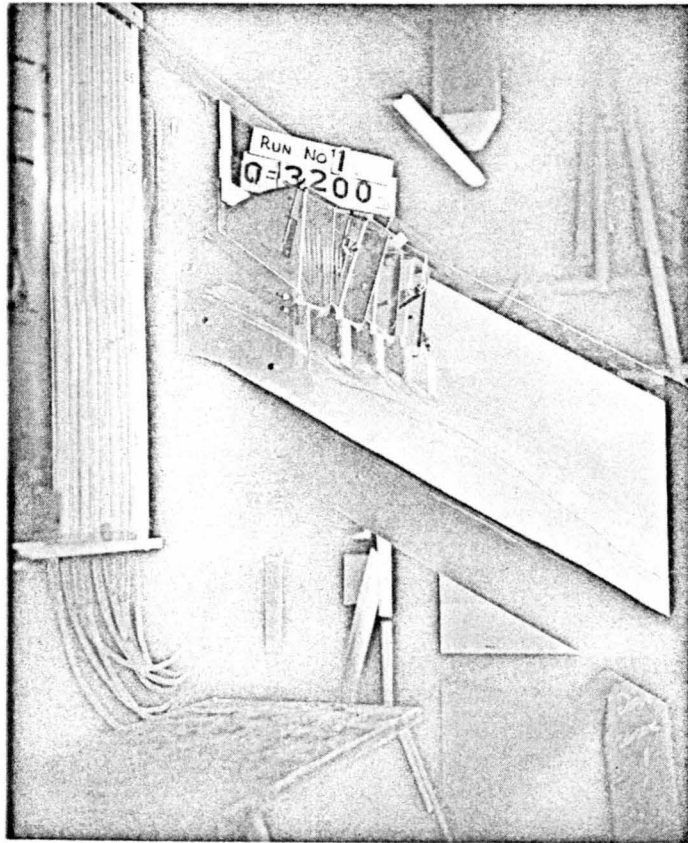
Fig. 15 Side view of fins below piers.
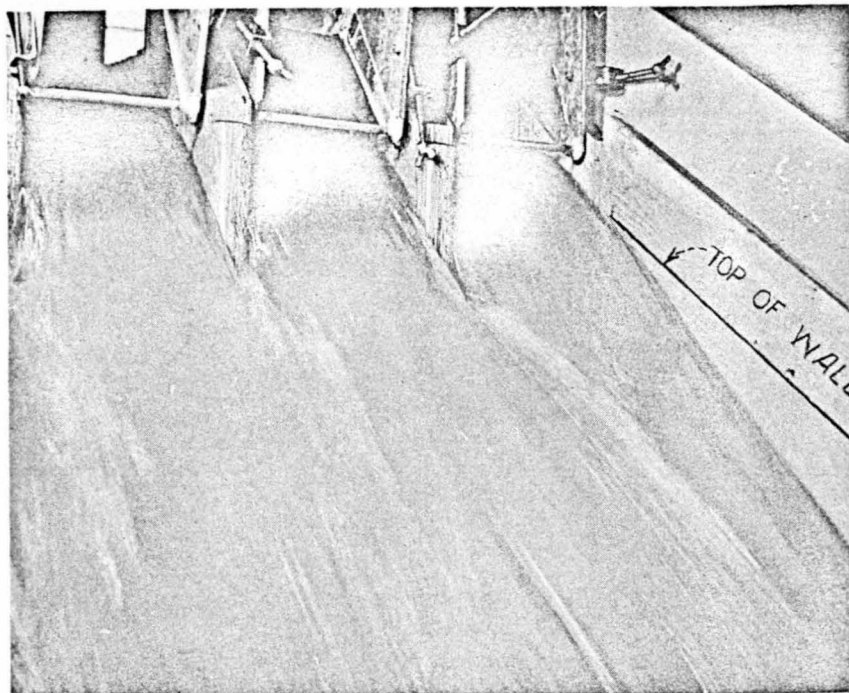
Fig. 16   Flow along chute wall with recommended spillway chute
for discharge of 3200 m³/sec. Abutment pier and chute
wall are in the same vertical plane.
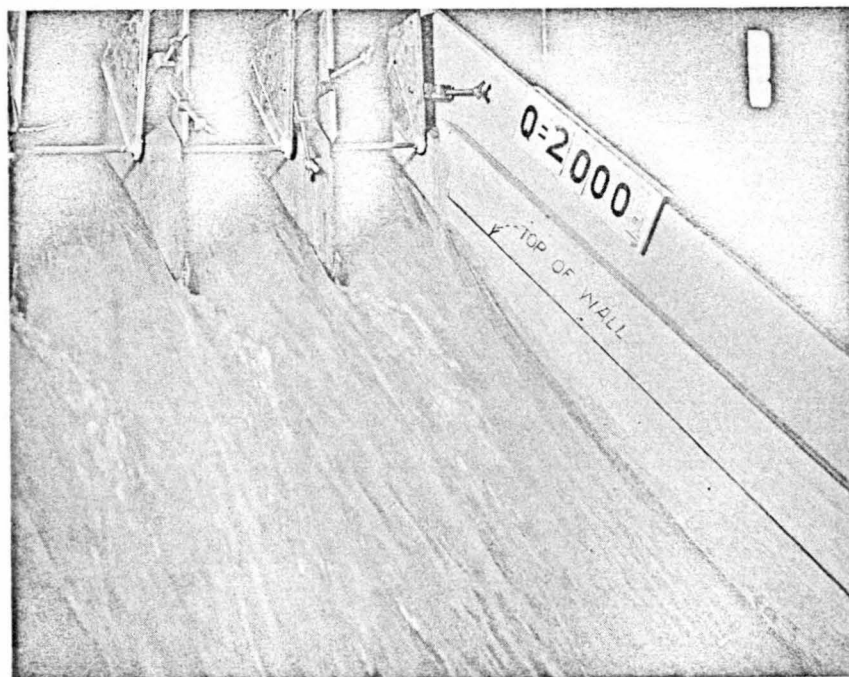
Fig. 17   Flow along chute wall with recommended spillway chute
for discharge of 2000 m³/sec. Abutment pier and chute
wall are in the same vertical plane.

Reservoir Elevation, Meters

887
86
885
84
83
82
81
880
79
78
77
76
875
74
73
72
71
870

Top of Gate

Max. Reservoir Elev. 883.5

1 = Gate Opening in Meters

2   3   4   5   6   7   8   9

2   3   4   5   6   7   8   9

2   3   4   5   6   7   8   9

Gate Opening

Crest El. 870

El. 869.843

Gate Opening is the Vertical Distance Between
the Lower Lip of Gate & Sill El. 869.843

0   200   400   600   800   1000   1200   1400   1600   1800   2000   2200   2400   2600

2800   3000   3200 m³/sec.

Discharge Over Spillway
4 Gates Opened Uniformly
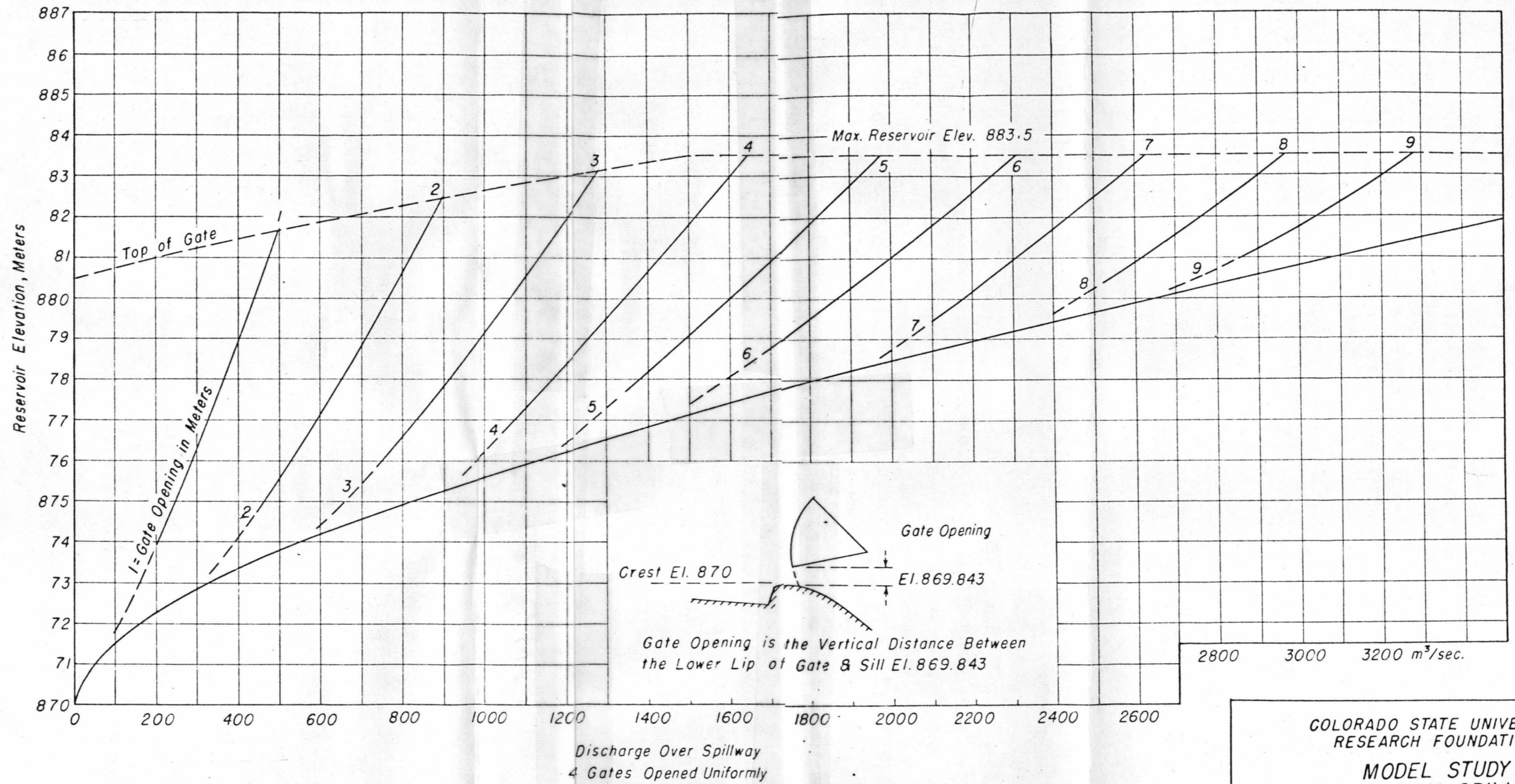
COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION

MODEL STUDY
MAKIO DAM SPILLWAY

SPILLWAY RATING CURVES

Drawn by __ M.Sh.A.
Traced by __ S.A.   Approved S. Karchi
Checked by __ S.K.

782   SEPTEMBER 1958   FIG. 18
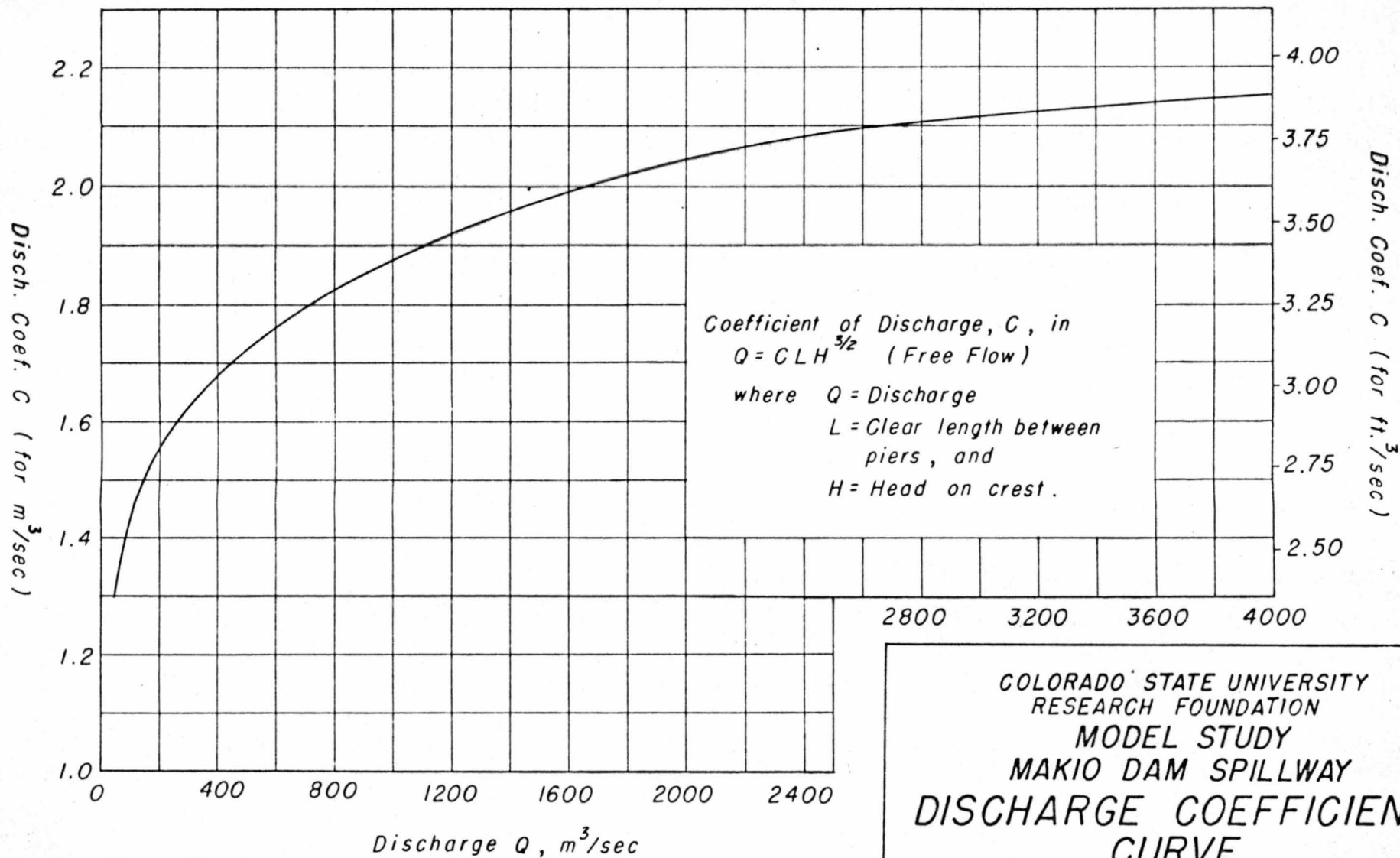
Coefficient of Discharge, C, in

$Q = C L H^{3/2}$ (Free Flow)

where   Q = Discharge

L = Clear length between piers, and

H = Head on crest.

Disch. Coef. C (for m³/sec)

Disch. Coef. C (for ft.³/sec)

Discharge Q, m³/sec

Water Surface Elevation , m

Discharge Q , m³/sec

Original Tailwater
Rating Curve

New Tailwater
Rating Curve

(813.8)

(810.0)

(806.3)

COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
MAKIO DAM SPILLWAY

TAILWATER RATING CURVES

Drawn by _ M.Sh.A.
Traced by _ S.A.
Checked by _ S.K.

Approved S. Kasaki

782   SEPTEMBER   1958   FIG. 20

Distance From Face of Dam

100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260

Elevation

825
820
815
810
805
800

← ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ 102.0 ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ →
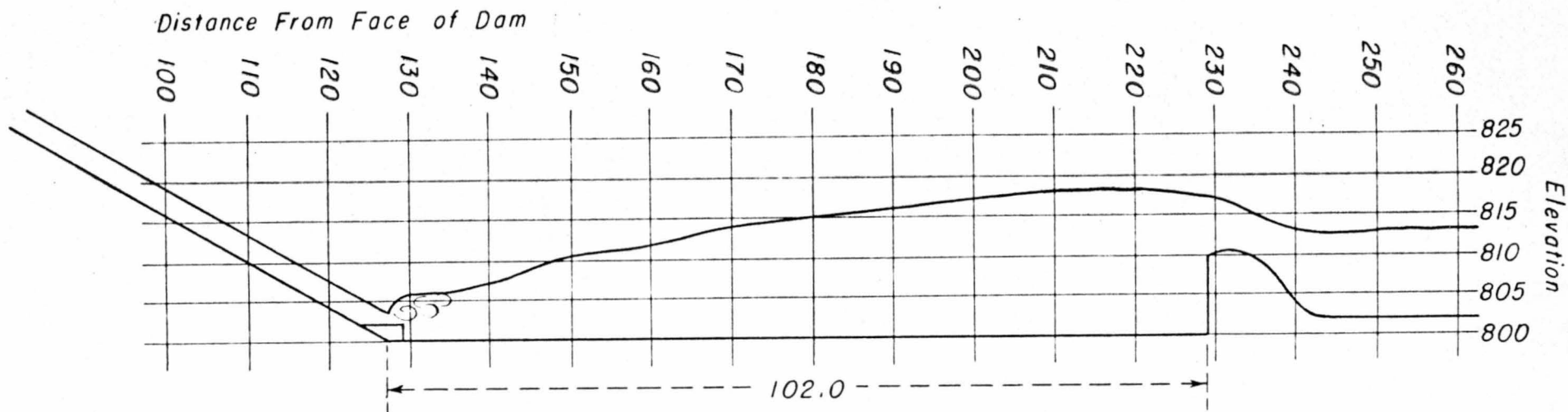
NOTES

Stilling basin A is shown in Figure 2.
All dimensions are in meters unless
otherwise indicated.

COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
MAKIO DAM SPILLWAY
STILLING BASIN A
WATER SURFACE PROFILE FOR
DISCHARGE OF 3200 M³/SEC.

Drawn by ___ S.K.
Traced by ___ S.A.
Checked by ___ S.K.

Approved S. Karaki

| 782 | SEPTEMBER 1958 | FIG. 21 |
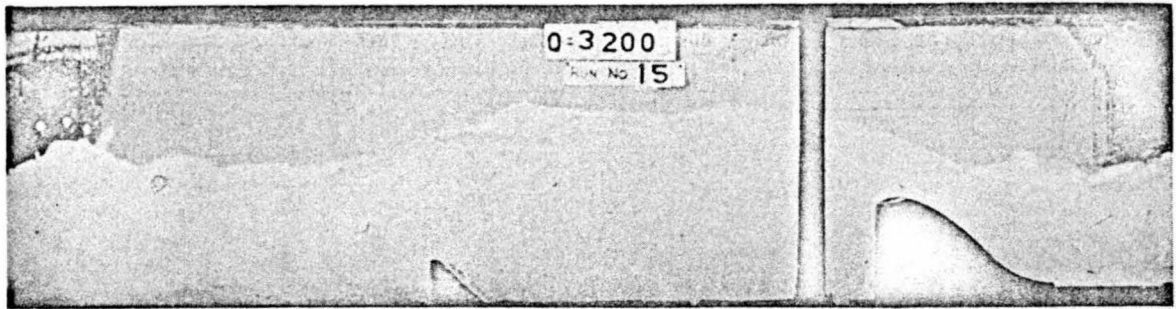
Fig. 22 Flow in 92 meter stilling basin with 4.6 meter high baffle piers. D scharge 3200 m³/sec. Tailwater set from old rating curve.

Fig. 22 A Flow in 92 meter stilling basin with 3.6 meter high baffle piers. Discharge 3200 m³/sec. Tailwater set from old rating curve.
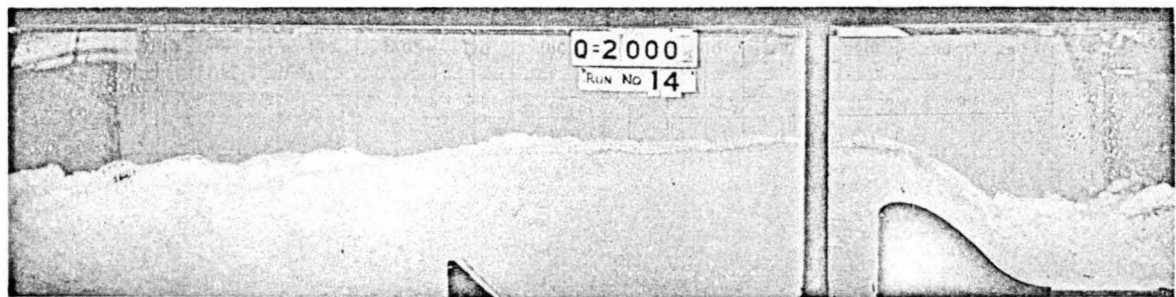
Fig. 23 Flow in 92 meter stilling basin with 4.6 meter high baffle piers. Discharge 2000 m³/sec. Tailwater set from old rating curve.
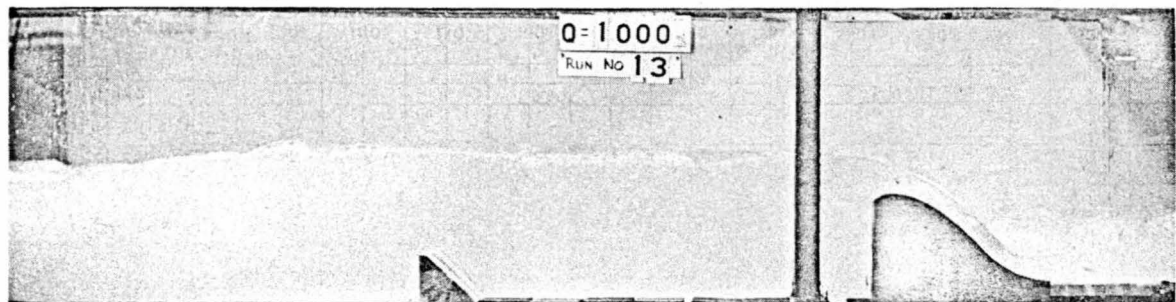
Fig. 24 Flow in 92 meter stilling basin with 4.6 meter high baffle piers. Discharge 1000 m³/sec. Tailwater set from old rating curve.
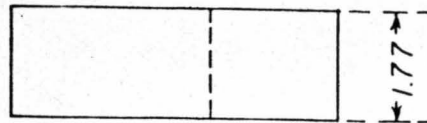
PLAN
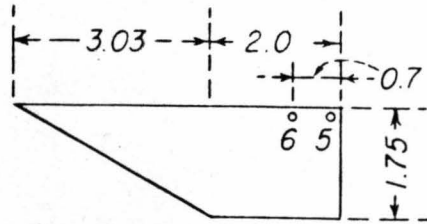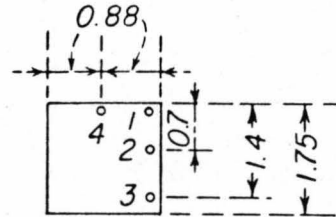
ELEVATION   END VIEW

CHUTE BLOCK
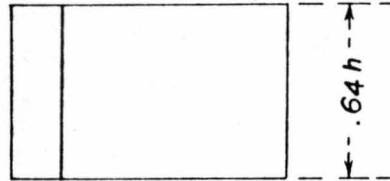
PLAN
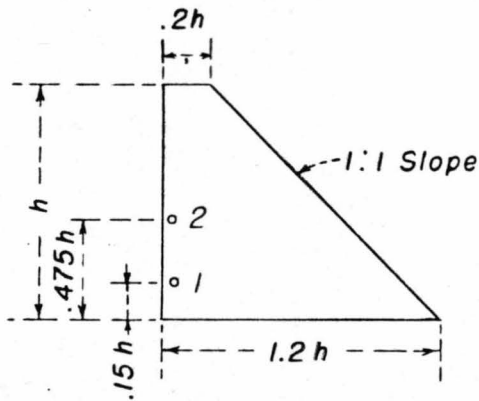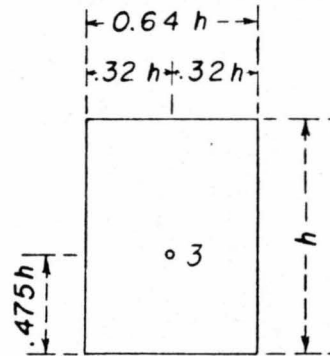
ELEVATION   END VIEW

BAFFLE PIER

COLORADO STATE UNIVERSITY
RESEARCH FOUNDATION
MODEL STUDY
MAKIO DAM SPILLWAY
LOCATION OF
PIEZOMETERS

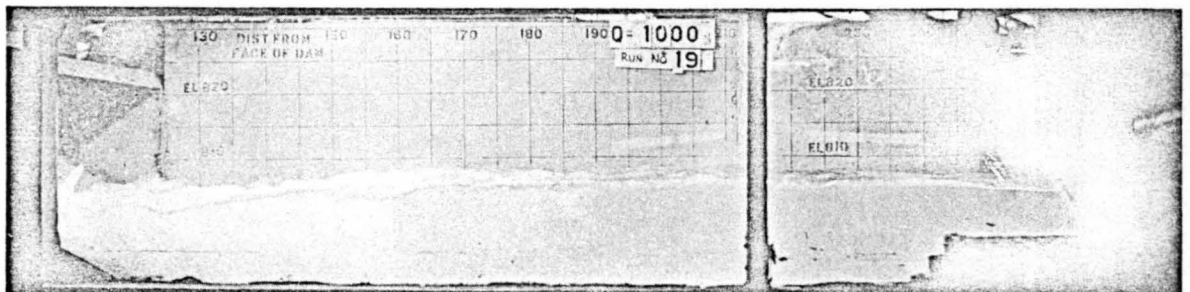| Drawn by___ S.K. | Approved *S. Karaki* |
| Traced by___ S.A. | |
| Checked by__S.K. | |

| 782 | SEPTEMBER 1958 | FIG. 25 |
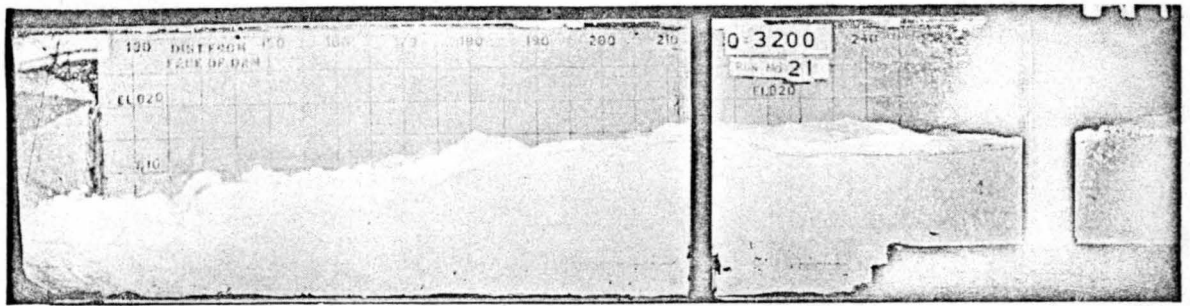
Fig. 26   Flow in preliminary design of stilling basin B.
Discharge 3200 m³/sec.   Tailwater set from original
rating curve.
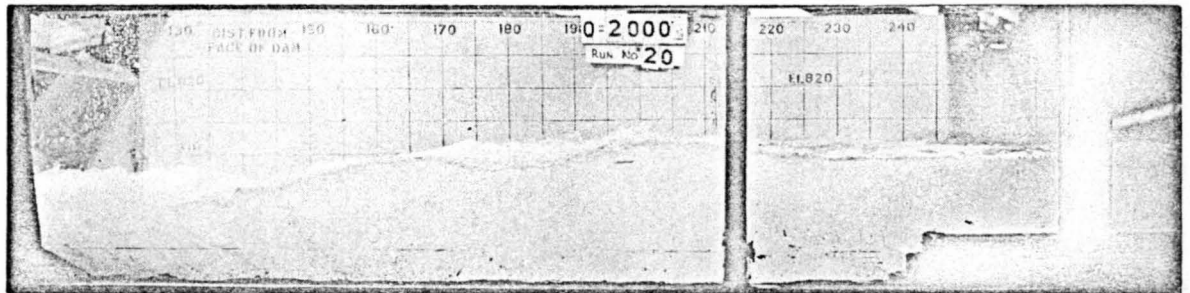
Fig. 27   Flow in preliminary design of stilling basin B.
Discharge 2000 m³/sec.   Tailwater set from original
rating curve.

Fig. 28   Flow in preliminary design of stilling basin B.
Discharge 1000 m3/sec.   Tailwater set from original
rating curve.
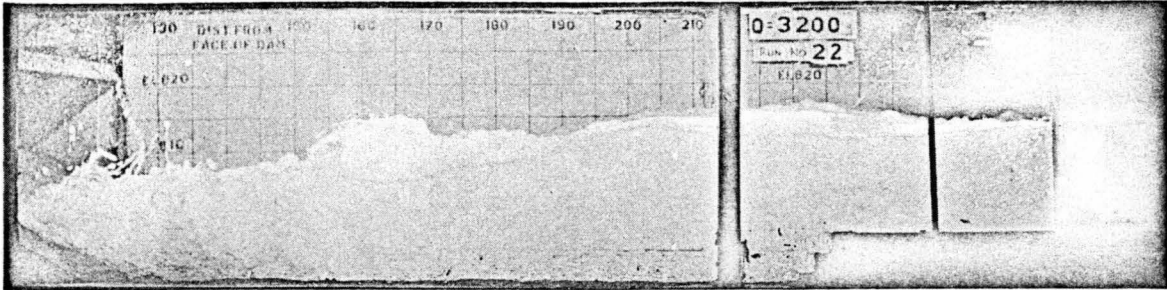
Fig. 29 Flow in stilling basin B shortened 10 meters to 85 meters
in length Discharge 3200 m³/sec. Tailwater set from
original rating curve.
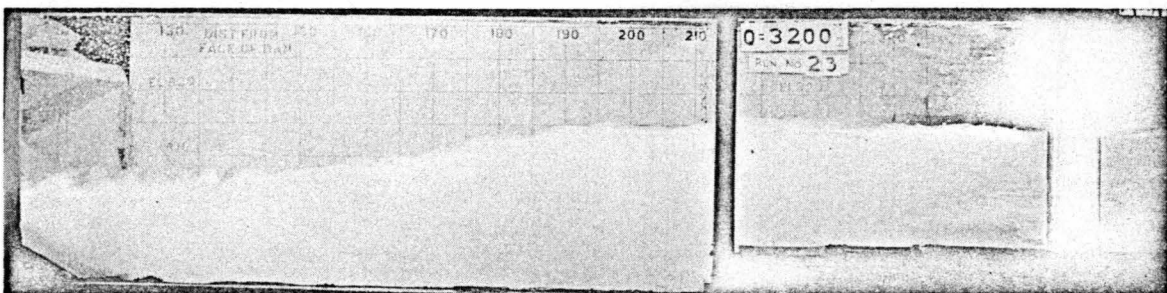
Fig. 30 Flow in stilling basin B shortened 20 meters to 75 meters
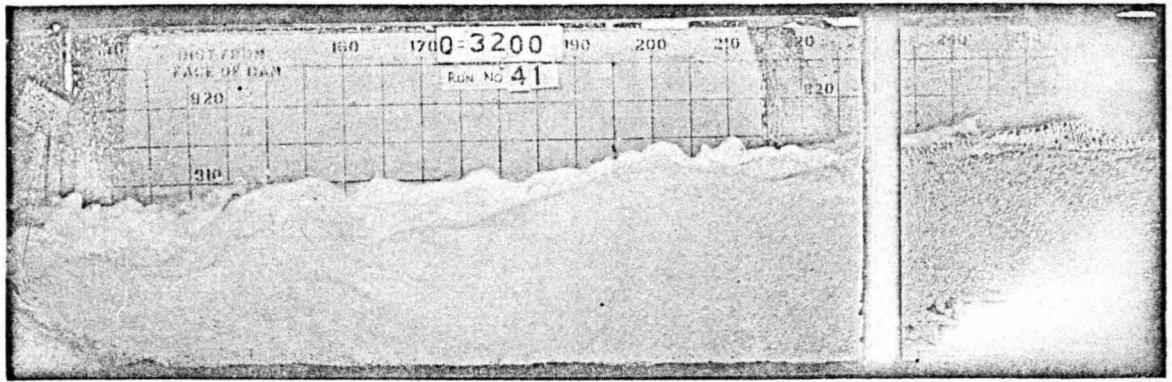in length. Discharnge 3200 m³/sec. Tailwater set from
original rating curve.

Fig. 31 Flow in recommended stilling basin. Discharge of 3200 m^3/sec. Tailwater set from new rating curve.
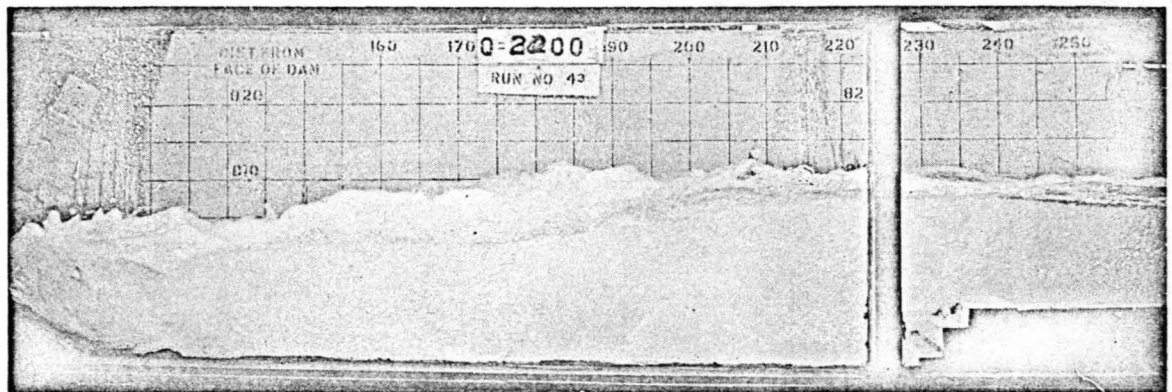

Fig. 32 Flow in recommended stilling basin. Discharge of 2000 m^3/sec. Tailwater set from new rating curve.
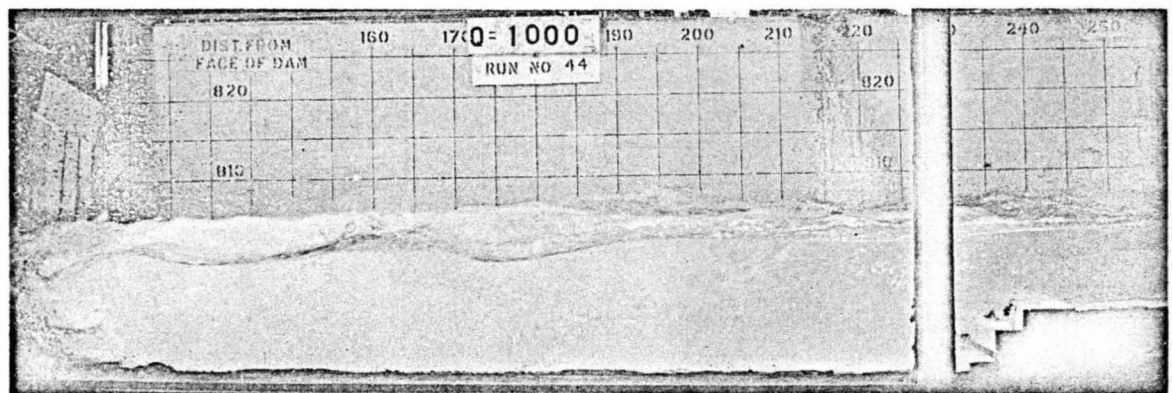

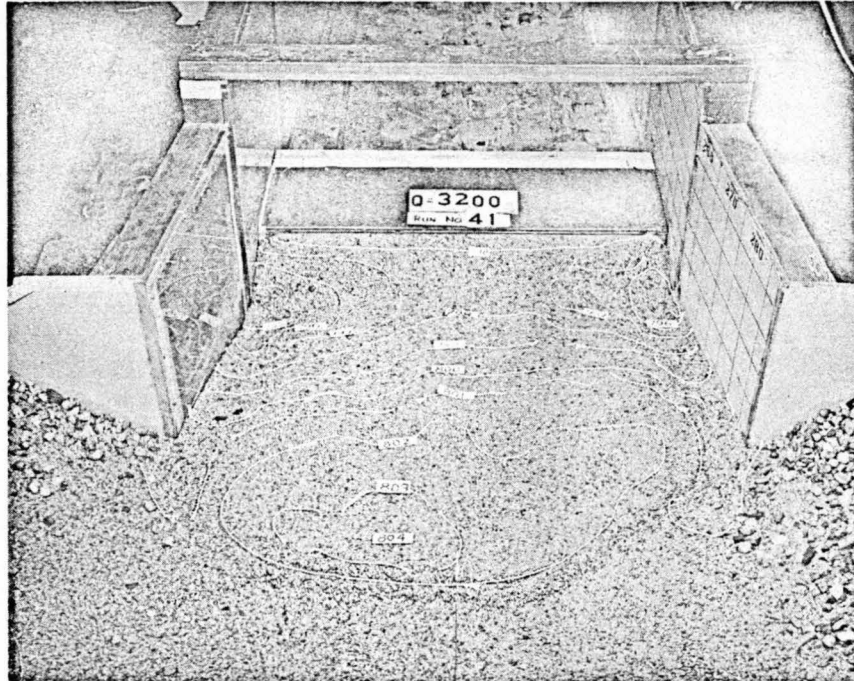Fig. 33 Flow in recommended stilling basin. Discharge of 1000 m^3/sec. Tailwater set from new rating curve.
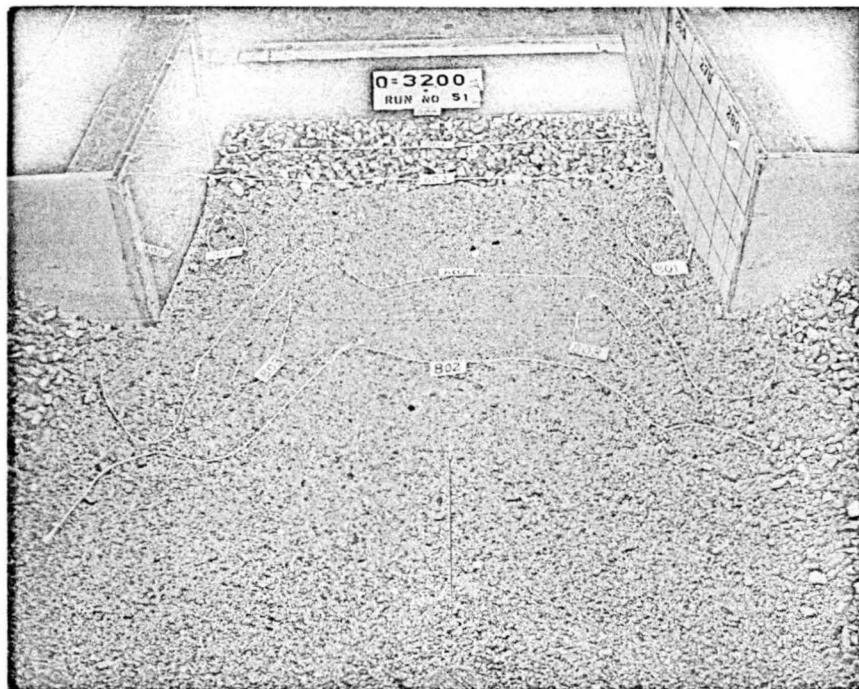
Fig. 34 Typical scour pattern in discharge channel after 30-
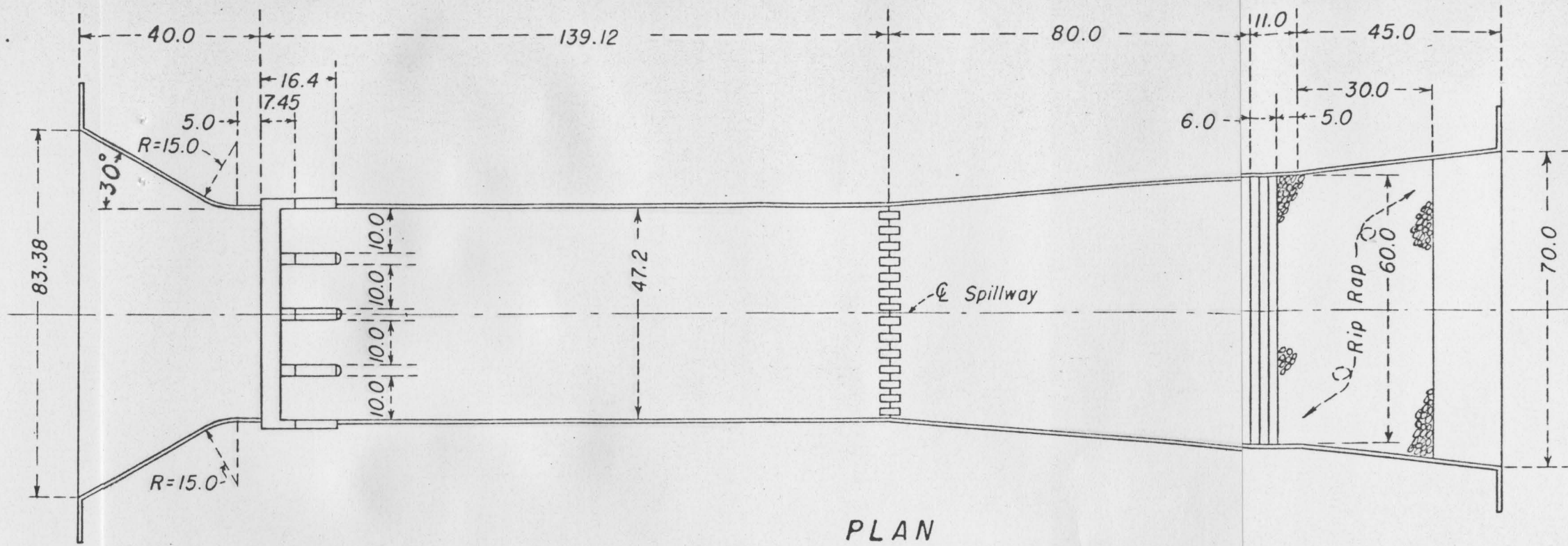minute test with stilling basin B 80 meters long.
Discharge was 3200 m³/sec.
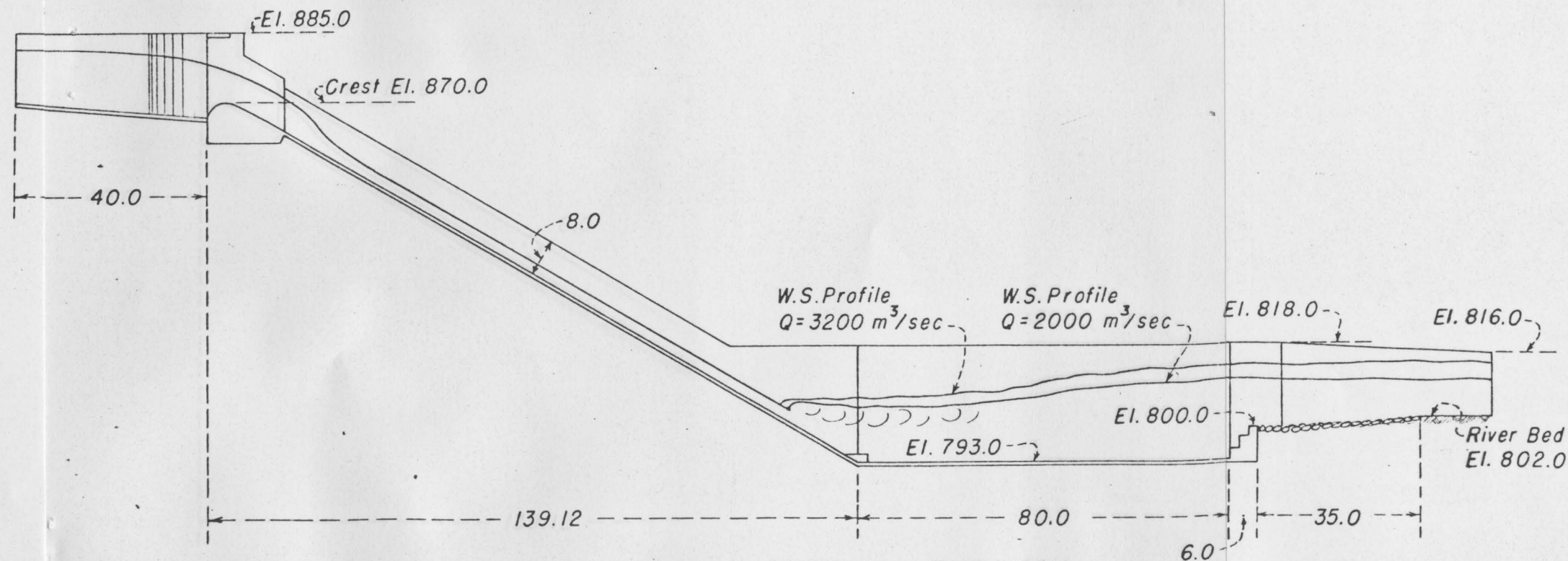
Fig. 35 Protection of discharge channel bed for total length of 35
meters beyond end sill.

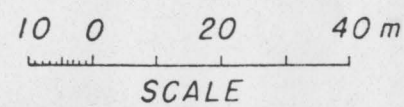

Fig. 36 After 30 minute test. Note condition of rip rap and small
amount of erosion on bed of discharge channel downstream.

PLAN

SECTION THROUGH
CENTER LINE

NOTES

All dimensions are in meters unless otherwise
   indicated.
Pertinent dimensions only are shown.

10 0   20   40 m
SCALE

COLORADO STATE UNIVERSITY RESEARCH FOUNDATION		
MODEL STUDY MAKIO DAM SPILLWAY		
RECOMMENDED SPILLWAY		
Drawn by___S.K. Traced by__S.A. Checked by__S.K.	Approved S. Karaki	
782	SEPTEMBER 1958	FIG. 37

APPENDIX A.

Results of Tests With
Baffle Piers In The
Recommended Stilling Basin

Results of tests for stilling basin B, 80 meters in length, and with 3.6 meters high baffle piers are included in this Appendix. Figures A-1 and A-2 show the hydraulic jump in the stilling basin for discharges of 3200 and 2000 m³/sec respectively. Table A-1 gives pressures in meters of water on chute blocks and baffle piers in the stilling basin for discharges of 3200, 2000, and 1000 m³/sec.

Fig. A-1 Flow in stilling basin B with baffle piers 3.6 meters high located midpoint in the basin. Discharge is 3200 m³/sec. tailwater set from new rating curve.
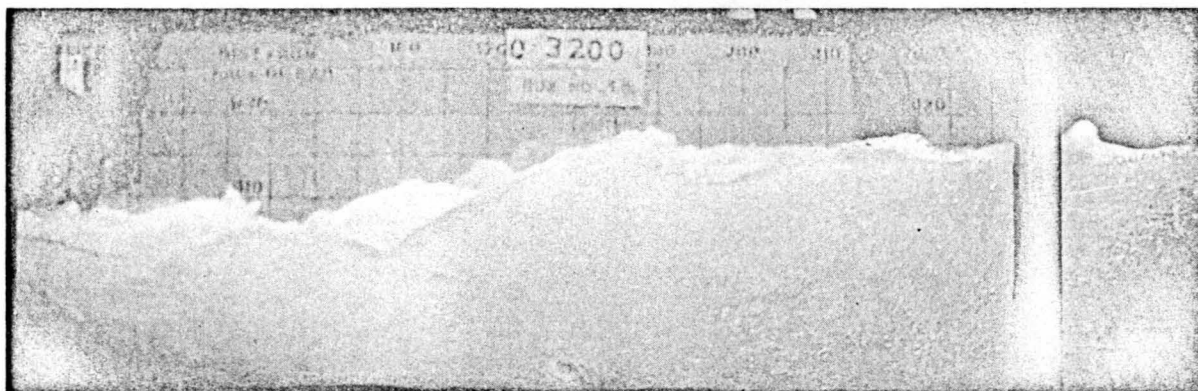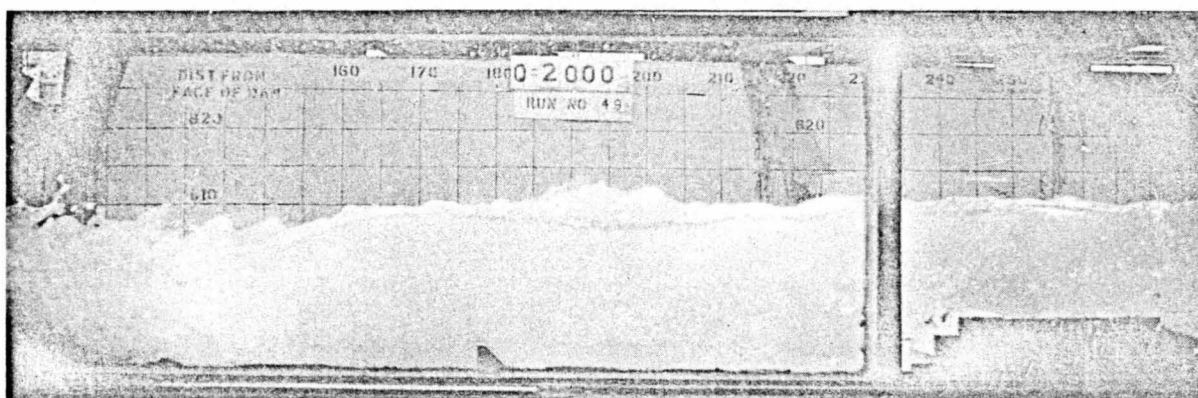

Fig. A-2 Flow in stilling basin B with baffle piers 3.6 meters high located midpoint in the basin. Discharge is 2000 m³/sec. tailwater set from new rating curve.

TABLE A-1

TABLE OF PRESSURES IN METERS OF WATER

ON CHUTE BLOCKS AND BAFFLE PIERS FOR

STILLING BASIN B.

Length of Stilling Basin = 80 Meters
Height of Baffle Piers = 3.6 Meters

Piezometer Number*	Q=3,200 m^3/sec		Q=2,000 m^3/sec		Q=1,000 m^3/sec	
	Chute Blocks	Baffle Piers	Chute Blocks	Baffle Piers	Chute Blocks	Baffle Piers
1	6.9	-6.1	5.3	0.5	9.1	6.2
2	5.4	-6.8	3.1	0.1	6.2	7.2
3	5.3	35.6	2.7	25.4	5.6	15.2
4	4.6	----	2.2	----	5.3	----
5	6.4	----	4.0	----	6.0	----
6	8.8	----	6.0	----	6.7	----

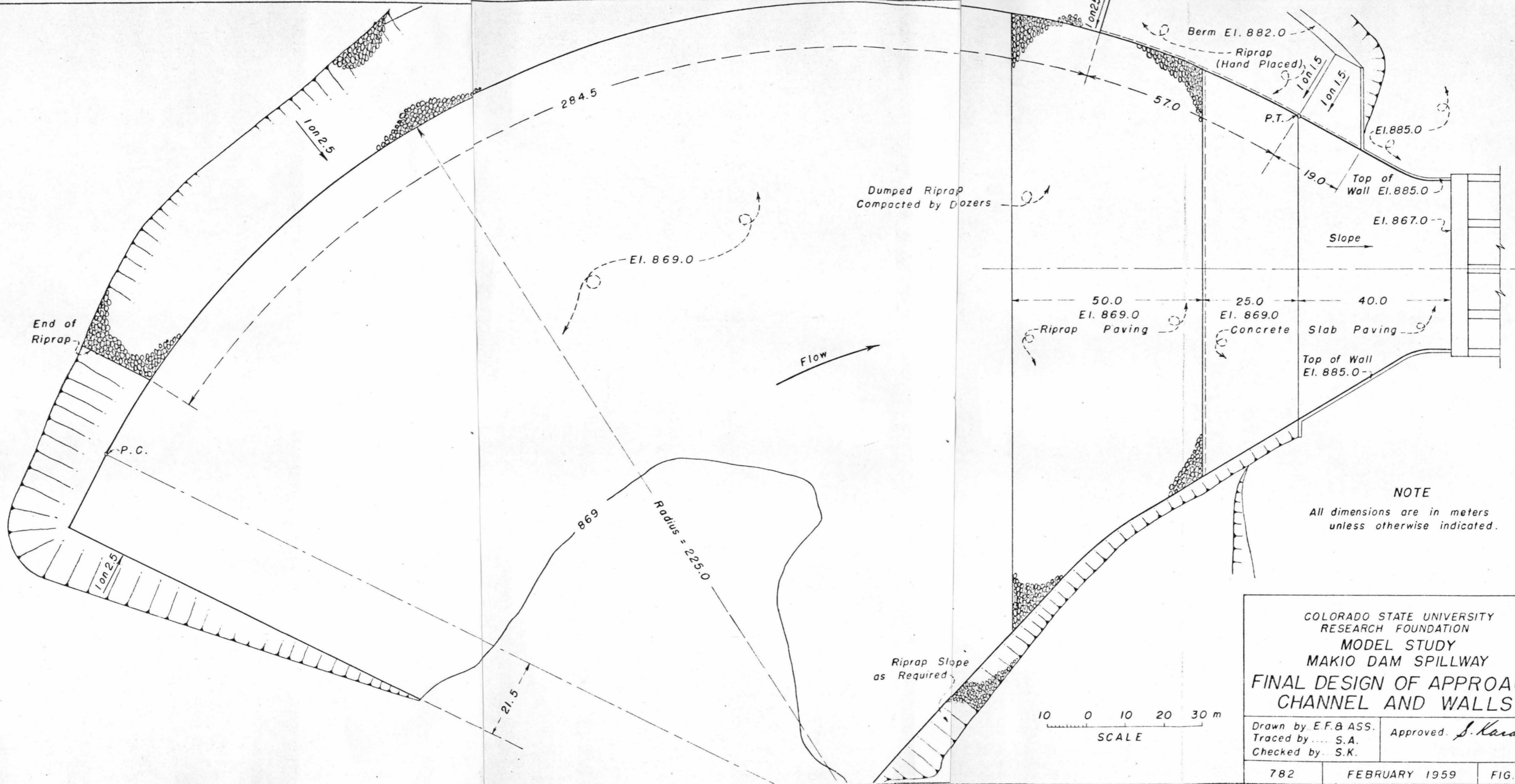* Piezometer locations are shown in Figure 25.

APPENDIX B.

Final Design of

Spillway Approach Walls.

Figure B-1 in this Appendix shows the spillway approach walls as designed for construction, and submitted to the writers for discussion on hydraulic performance. This final design was made by Erik Floor & Associates, Inc. Model tests on the spillway approaches were completed and the draft of the final report was submitted.

The difference between Figure B-1 and Figure 37 is the reduction in length of the left spillway approach wall by 19 meters. This reduction was made to eliminate as much of the high approach wall as possible for economic reasons.

Reduction in the length of the wall will not materially affect the hydraulic performance of the spillway, since the substantial increase in efficiency of the crest from the preliminary design was effected by providing 5 meters of vertical wall upstream of the abutment piers on both sides, and eliminated the sharp junction of the walls and abutment piers. The converging walls at 30^0 joined with the 5-meter length of walls with circular arcs of 15-meter radii to avoid an abrupt change in direction of flow, and thus control the drawdown to a practical minimum. These conditions are unaffected in Figure B-1. The shorter left wall will place the end of the wall in a zone of greater velocity of flow than in the recommended design, consequently developing somewhat greater surface disturbances which will be translated downstream along the wall. The differences in the nature of the surface waves will have negligible effect on the hydraulic performance of the spillway crest. Further reduction in wall length should be avoided.

284.5

1 on 2.5

Dumped Riprap
Compacted by Dozers

El. 869.0

End of
Riprap

Flow

P.C.

869

Radius = 225.0

1 on 2.5

21.5

Riprap Slope
as Required

Berm El. 882.0

1 on 2.5

Riprap
(Hand Placed)

57.0

1 on 1.5

1 on 1.5

P.T.

El. 885.0

19.0

Top of
Wall El. 885.0

El. 867.0

Slope

50.0
El. 869.0
Riprap   Paving

25.0
El. 869.0
Concrete   Slab   Paving

40.0

Top of Wall
El. 885.0

NOTE

All dimensions are in meters
unless otherwise indicated.

10   0   10   20   30 m

SCALE