University of Washington
Department of Civil and Environmental Engineering

THE MOSSYROCK DAM HYDRAULIC MODEL INVESTIGATION

E. P. Richey
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Water Resources Series
Technical Report No. 17
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Hydraulic Model Investigation

Conducted for

City of Tacoma
Department of Public Utilities
Light Division

Department of Civil Engineering
University of Washington
Seattle, Washington

CONTENTS

PREFACE

The hydraulic model investigation reported herein was authorized by a Memorandum of Agreement between the University of Washington and the City of Tacoma, Department of Public Utilities, Tacoma, Washington, dated October 15, 1963. All the work performed under this agreement was coordinated with the Harza Engineering Company of Chicago, Illinois, acting as the agent of the City of Tacoma.

The study was conducted at the Charles W. Harris Hydraulics Laboratory of the University of Washington during the period from October 1963 to December 1964 under the direction of Professors E. P. Richey and H. S. Strausser. Mr. Richard D. Unrue was in charge of the model construction and conducted much of the experimental program. A motion picture record of the major facets of the investigation was prepared by the Audio-Visual Services and is regarded as a part of this report.

Frequent consultations concerning phases of the investigation were held with Mr. Earl J. Beck, Project Manager for Harza Engineering Company and with Messrs. John D. Thompson, Supervisor, Civil Engineering, and Quentin Edson, Biologist of the City of Tacoma, Department of Public Utilities.

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SUMMARY

The principal features of concern in this study on the 1:60 scale model of the Mossyrock Dam are grouped for convenience of presentation into three main divisions, the Spillway, the Plunge Pool and the Fish Facilities. It was found possible to affect some changes in the flow characteristics in the plunge pool by altering the spillway geometry, so these two divisions are interrelated. A separate 1:6 scale model of a 5- pool section of the fish ladder was studied to guide a choice between two sets of geometry and to detail some of its hydraulics.

The approach conditions, flow around the pier noses and discharge capacity of the spillway as initially designed were all satisfactory. In order to modify flow conditions in the plunge pool, terminal buckets of warped and two forms of cylindrical sections were tested in various combinations. No significant change in the discharge capacity of the spillway accompanied the addition of the different buckets. The pressure loading added by the cylindrical sections was nominal; that added by the warped sections was quite large.

The first tests on the plunge pool were made with an erodible bed, and disclosed that extensive erosion was possible. The pool was then enlarged and stabilized. Velocity measurements were taken as extensively as possible to ascertain the magnitudes to be encountered under different discharges and spillway buckets. The jets from the initial spillway form penetrated to the floor of the plunge pool (Elev. 250) with a velocity of about 60 fps. By changing the

spillway buckets to the cylindrical and the warped forms, this velocity was reduced to about 20 fps. However, the surface wave heights were increased. Some combinations were developed which minimize the disadvantages of their component forms. Surging at the powerhouse was less than 5% of the gross head. To investigate the performance of the plunge pool with respect to erosional stability at the face of the dam, an erodible layer was placed on the plunge pool floor and the peak flood of 275,000 cfs was discharged over the spillway with various bucket combinations.

The performance of the fish facilities were investigated under different turbine flows and combinations. The effect of a lip or extension over the top of the draft tubes on the flow conditions in the vicinity of the powerhouse was investigated by photographic traces, dye and velocity measurements. A short-circuiting or recirculating flow was noted between the discharge of the slotted entrance and the intake to the pump supplying the ladder facility. The intake was relocated to overcome this unfavorable condition. A ring-jet valve and submerged, high-velocity jets were tested as two methods of passing minimum fish transportation water through the structure. The second of the two geometries proposed for the fish ladder was chosen as the preferred form.

MOSSYROCK DAM HYDRAULIC MODEL STUDY

PART I: INTRODUCTION

Description of the Prototype

1. The site of the Mossyrock Dam is on the Cowlitz River about 35 miles southwest of Mt. Rainier and near the headwaters of the reservoir of the Mayfield Dam. Although power generation is the main purpose of the structure, it will exert a considerable regulatory influence on the flow of the river. The Cowlitz supports important runs of salmon and steelhead trout so proper fish facilities will be a part of the structure.

2. The dam is an arch structure with a crest length of about 1200 feet and crest elevation of 785 feet above mean sea level. The mean river level at the site is near Elev. 425. The free-fall spillway, consisting of four bays, each 42'-6" wide with crests at Elev. 728 and controlled by tainter gates, is designed to pass a peak flow of 275,000 cfs. The powerhouse and fish collection facilities are located just downstream of the dam on the north side of the river.

Objectives of the Model Study

3. Since the jets from the spillway are to fall some 300 feet, the large amount of energy to be dissipated in the plunge pool raised questions regarding the necessary pool depth, the magnitude of velocities on key boundaries, surging and wave action, erosional tendencies, all factors difficult to determine without the assistance of a model. The performance of the spillway with respect to capacity and general characteristics was to be part of the study. The powerhouse, with simulated turbine flows and fish collection system was included to

assist in the determination of currents suitable for the proper functioning of the fish collection system. The fish ladder model, separate from the main model, was proposed to provide a basis of choice between two sets of geometry and to evaluate flow characteristics of the chosen set.

PART II: THE MODEL

Description

4. A steel tank 20' x 20' x 10' was fabricated to contain the dam and reservoir. These dimensions provided space on a 1:60 scale to include the left abutment (looking downstream) and nearly to the right abutment, about 1200 feet along the crest of the dam and for about 500 feet upstream of the spillway. The channel downstream of the dam was extended for about 1400 feet from the crest to a point just downstream of a prominent bend in the channel. At this terminal point, an adjustable, undershot weir was installed to serve as tailwater control to conform to established rating curves. The bottom of the model was set at Elev. 200, corresponding to the lowest point in the bedrock contours in the vicinity of the dam. Plates 1 and 2 show the model as constructed.

5. Topographic features were duplicated in the reservoir by molding thin aluminum sheeting to templates that outlined the surface topography. Below the dam, the bedrock contours were set for a distance of about 700 feet; these were blended into the surface topography outside the influence of the plunge pool, and the surface developed by trowelling a sand-cement mixture to the templates. The arch dam was formed of pumice block and brick, filled with mortar and reinforced.

The blocks were aligned on the upstream and downstream faces by striking the appropriate arch radii, and then bringing the surfaces to the final dimensions with a cover coat of plaster. The spillway section was machined from transparent plastic, with rolled aluminum sections for the control gates. The powerhouse was also made of plastic; the turbines were represented by butterfly valves.

6. The main water supply for the model came from a reservoir on the campus with a supplement for peak flow rates pumped from nearby Lake Union. The water supply for the fish facility was pumped directly from the tail pool through the simulated intake structure. The separate ladder model followed a 1:6 scale ratio and consisted of a 5-pool section of the prototype ladder. The model was installed in a 2-foot wide flume in the laboratory.

7. The typical Froude Law similarity criterion was assumed for interpretation of the model results. The rather large linear scale for the main model (1:60) was chosen to allow reliable reproduction of the low flows to be supplied for the fish facilities. Accordingly, the pertinent scale ratios are:

Property	Dam Model Scale Ratio	Ladder Model Scale Ratio
Length	1:60	1:6
Area	1:3600	1:36
Velocity and Time	1:7.746	1:2.449
Quantity	1:27.886	1:88.17

Instrumentation

8. The flow rates to the dam model were measured by a Venturi meter installed in the main supply line; the rate for the fish-attraction water was measured by an in-line meter of the flotation type. The flow rate for the separate ladder model was obtained by means of a Dahl tube.

9. The complex velocity field created in the plunge pool under any appreciable spillway discharge made measurements difficult to obtain, for the velocity at any point was habitually unsteady in magnitude and direction. The entrained air precluded the use of instruments of the Prandtl-tube class because of bubbles that would become trapped in the pressure leads. Finally, a very sensitive Statham gage was obtained for measuring dynamic pressures. An unbonded strain gage is the heart of this instrument that, when coupled to an oscillograph recorder, easily is capable of measuring pressures equivalent to 0.01 of a foot. Special probes were fashioned to measure pressures (a) through the jets, (b) in a horizontal plane, (c) parallel to the slope of the downstream face of the plunge pool, and (d) in the vicinity of the powerhouse. By referencing the gage to a static water level, the dynamic pressure could be recorded on the oscillograph. The surface waves and surges added a complication to this procedure which was countered by using a parallel-wire wave gage fed to the second channel of the recorder so that wave heights and pressures could be recorded simultaneously.

10. The measurement technique was to set the pressure gage at the desired elevation with the wave gage directly above it. The pressure gage would respond to the total pressure on the nose of the appropriate probe. The pressure equivalent to the height of any transient wave was assumed to be hydrostatic. Therefore, the wave height was subtracted from the total head measured by the pressure probe to obtain the velocity head on the nose of the probe. A sample record is shown as Fig. 1, where the transient nature of the pressure and wave traces is quite apparent. The time scale on the graph is 5 millimeters per second, so some of the peak values persist only for a few tenths of a second. For each record,

several pressure peaks consistent with the wave race were chosen and the velocity computed. A summary of these measurements is contained in Table 1, from which Figures 2-6 have been prepared. The title "Maximum Velocity" used on some of the figures is important, for it is the highest measured for a given record, rather than any average value. Conventional propellor-type velocity meters, dye traces and photographic methods were used to map out the fish-attraction currents.

PART III: TESTS, MODIFICATIONS AND RESULTS

The Spillway

11. The spillway, constructed from Drawing No. 158 SKC 444, has operated very satisfactorily throughout the flow range to the maximum flood of 275,000 cfs. A drawdown begins on the right pier at about 200,000 cfs and increases to about 10 feet at 275,000 cfs; the left pier shows a similar but milder tendency with a maximum of about 7 feet at the peak flow. No vortex formation has developed under any full-open gate combinations, but vortices do form at some part-gate settings. For example, with the pool at Elev. 770, gate 1 fully open, vortices form around gate 2 when it is partly open. The Head-Discharge Curve for all gates open is shown as Fig. 7. Plates 3 and 4 show the flow around the piers for flows of 125,000 cfs and 275,000 cfs; Plates 5 and 6 contrast the appearance of the jets from conventional and the cylindrical buckets. Plates 9, 10, 11, 12 and 13 show the jet and pool response to different buckets at flows of 100,000 cfs and 275,000 cfs.

12. The high velocities encountered in the plunge pool led to investigating possible changes in the spillway geometry to redirect the jets in such a manner that erosional tendencies might be reduced. Two

types of buckets, a cylindrical section with 0° and -20° exit angles, and a warped section (see Fig. 8 and Plate 7) in combination with the conventional terminal profile were tested with respect to the characteristics they produced in the plunge pool. These characteristics are discussed subsequently. The buckets had little effect on the Head-Discharge Curve, as may be seen by the experimental data plotted on Fig. 7. The hydraulic loading imposed by the different sections is shown on Figures 9a, b, c. The pressure head increases with the addition of the cylindrical sections, but remains less than the equivalent of the water depth over the spillway. The sections were designed to reduce the jet thickness by inducing a lateral spreading, which relieves the high pressure which would develop if the spreading were constrained.

13. The reduction in impact velocities achieved by the cylindrical sections led to the alteration of the profiles on Bays 1 and 4 in order to turn the jets away from the powerhouse and the left bank. A section was constructed by drawing a tangent to one side of the spillway at point "A" shown on Fig. 8 and a circle on the opposite side, then drawing straight lines between the tangent and the circle (see Plate 7). The axis of the jet is thus rotated to be nearly parallel to the longitudinal axis of the plunge pool, as demonstrated in Plate 8 at a flow of 25,000 cfs. A vertical deflector with a minimum length of five feet was added on the outside piers to keep the tip of the jet from spreading outward. The total head on the circle-end of the section is very high as shown on Fig. 9d. This value would taper down to the minimum level at the tangent end.

The Plunge Pool; Movable Bed

14. The first tests of the plunge pool were made with a movable bed of gravels classed as "3/8 minus". An objective was specified that a profile be outlined which would not be conducive to the formation of bars or deposits which would interfere seriously with the powerhouse performance for flows less than about 160,000 cfs. The flow rate was set at 170,000 cfs and run for successive periods of twenty minutes. At the end of each period, the gravel which built up at the end of the break in the slope from the river channel to the plunge pool was removed until no appreciable deposition accrued. The gravel was then regraded on a uniform slope from the river bed at Elev. 400 at distance of 520 feet from the axis of the dam (see Fig. 10) downward to Elev. 270, then level to the face of the dam.

15. The earlier tests had shown that the spill from Bays 1 and 2 struck the pool most favorably. The additional test procedure was then fixed that the gates would open in sequence from 1 to 4 only as required to maintain the reservoir pool at Elev. 770. Turbines 1 and 2 were opened to discharge 7200 cfs each, except for flows above 125,000 cfs when they were shut down completely. The flow rates were increased at intervals of 25,000 cfs up to 175,000 cfs and then to 275,000 cfs. At time intervals corresponding to 4 hours in the prototype, the flow was shut off and the topography was measured on a grid at 50-ft. intervals. The sequential erosion patterns are shown in Figures 11a-j. The gravel was not regraded between the different flow settings.

16. Several pertinent characteristics develop in this sequence of discharges. As the flow increases, more and more of the bedrock ridge opposite the powerhouse is exposed. A tightening of the contour lines is apparent between the river flows of 25,000 and 50,000 cfs, where the

edge of scour has advanced to a line between the 325 and 350 contours. The deepest point lies at the toe of the bedrock ridge. A bar begins to form at 50,000 cfs and is quite pronounced at the higher flows. Sorting of the gravel took place under the action of the jets. Samples taken from the face of the dam and from the downstream slope of the bedrock ridge showed an increase of 14% in the fine material (passing 1/8 mesh) in the gravel at the dam face and scarcely any less than 1/4-inch remaining in the sample from the bedrock ridge. There was a consistent trend to deposit material against the face of the dam. At flow rates of 125,000 cfs and higher, there is a very strong boil with surface elevations about 25 feet above the average tailwater level. At the peak flow of 275,000 cfs, the jets dug to Elev. 225 and shifted bricks laid on the model floor at Elev. 200. Figures 11g and 11h represent data taken prior to the established test sequence but show the progressive deposition against the face of the dam, the minimum elevations along the toe of the bedrock ridge and the first deposition of gravels against the draft tubes and on top of the fish facilities (Plate 14).

The Plunge Pool; Fixed Bed

17. The tests with the movable bed showed that erosion could be expected to extend to a considerable depth, so some form of stabilization was deemed essential. The boundaries of the pool were fixed with the bottom at Elev. 250, first to a distance of 230 feet, then to 280 feet downstream from the axis of the dam, then sloping upward at 1.5 horizontal to 1 vertical. This represents the limit imposed by the cofferdam location. The bedrock ridge opposite the powerhouse was removed to provide an unobstructed path for the jet from Bay 4.

18. The velocity with which the jet hits the plateau at Elev. 250

was desired to provide basic data for stability analyses. The decrease in the core velocity with depth was also obtained to show the pool depth necessary to provide an adequate reduction in velocity. With the hook-probe fitted to the pressure cell, traverses were made through the jets at selected elevations. Data for a single bay discharging 25,000 cfs (equivalent to 100,000 cfs for four bays) with the conventional, the 0° cylindrical, and the warped section are shown on Fig. 12. The velocity reduction with depth in the conventional jet follows quite closely the trend forecast from the studies on submerged jets appearing in "Engineering Hydraulics", H. Rouse, page 98, where the maximum core velocity is given as

$$V_{max} = 6.2\ V_o D_o / x$$

$$V_o = \sqrt{2g(758-467)} = 137 \text{ fps}$$

$$D_o = 0.22(60) = 13.2 \text{ ft. (model measurement)}$$

$$x = 476-250 = 217 \text{ ft.}$$

$$V_{max} = 52 \text{ fps}$$

The maximum core velocity may be reduced by either deepening the pool or by reducing the thickness of the jet at entry. The 0° bucket reduces the velocity at impact on the plateau to about 20 fps; no significant velocity could be detected in the jet from the warped section at Elev. 300. When combinations of the three bucket shapes are in operation, it is generally valid to assume that the velocity on the plateau at Elev. 250 will be that from the individual jets as shown on Fig. 12.

19. With 100,000 cfs flowing through the four bays, velocity profiles were obtained along the bottom, on the slope and other boundaries wherever possible. The velocity at any point is very unsteady so that, as already mentioned in paragraphs 9 and 10, dynamic pressures were picked up with

a sensitive gage and recorded by an oscillograph. Values obtained from the record are "maximum" velocities and under most circumstances persisted for only short intervals, with periods of 1 to 10 seconds between pulses. Since the unsteady velocity could cause more serious erosion than a steady flow, the peak values are shown in the various figures, with Table 1 to show typical ranges. The profiles reported are those on a longitudinal axis through the main zone of activity, usually the "D-line" of the model reference grid.

19a. With the four conventional bays, velocities of 60 fps (Fig. 2) were measured near the toe of the slope, with a peak of 64 fps in the core of the jet, which agrees well with that measured in the single jet. A pronounced boil develops at the face of the dam under this flow.

19b. When the buckets in Bays 2 and 3 are replaced by the 0° and -20° cylindrical sections, the velocities along the slope are reduced by almost 50% (Fig. 3) and the boil against the face of the dam does not form. The 0° buckets were placed on Bays 2 and 4 (Fig. 4) for comparative purposes, although the cylindrical bucket is not appropriate on Bay 4.

19c. The end slope of the plunge pool was moved to a position 280 feet from the dam axis to compensate for the revised position of the dam. With the 0° and -20° buckets in Bays 2 and 3, the conventional ones in Bays 1 and 4, the velocity along the slope (Fig. 5) has a peak of 28 fps. There is still the high velocity (47 fps) from the conventional jet impinging on the bottom of the plunge pool.

19d. When the combination in Para. 22 is modified by installing the warped sections on Bays 1 and 4, the velocities at the lower levels are reduced further, but the wave action at the surface is increased.

The velocities along the slope above Elev. 300 increased to a peak of 60 fps (Fig. 6). This high velocity zone was very narrow and unstable. With this combination the outside jets have been forced toward the center of the plunge pool and dissipation takes place in the upper layers, with increased surface evidence of this dissipation.

19e. Surface impact and boil areas and the velocities along the boundaries and at the pool surface are shown on Figures 13 and 14. Dye, yarn and confetti were used to ascertain directions, but the inherent unsteadiness makes measurement difficult. The magnitudes have been checked by various velocity probes as well as with small current meters. It was possible with these instruments to measure velocities when greater than about 1 fps in the model. Therefore, where a definite current was observed, but its magnitude less than this value, the broken arrow symbol was used to indicate direction and the fact that the magnitude was less than 6 fps prototype value. A wave, sometimes about 25 feet above the mean tailwater level, forms on the left bank near Station 11-G.

20. The surging at the powerhouse was investigated under different spillway combinations at the flow of 100,000 cfs. The pressure and wave gages were set at various locations and depths. The typical record shown on Fig. 15 for the conventional spillways yields a maximum surge of about 4 feet at Elev. 375. Results at flows of 75,000 cfs and 100,000 cfs with the warped and cylindrical sections are summarized in Table 2. At the higher flow a pressure near the surface (Elev. 453) indicates a surge or wave height of 13 feet; at the same location but at Elev. 390, the equivalent height drops to about 5 feet.

21. The several different spillway combinations were tested at the peak flow rate of 275,000 cfs to check primarily upon the erosional

tendencies at the toe of the dam. Loose gravel was placed in the plunge pool to Elev. 265 (Fig. 15 and Plate 16) and the peak flow run for a time corresponding to $2\frac{1}{2}$ hours in the prototype. Fig. 16 also represents the final model pool geometry.

21a. The disposition of the gravels after the run with the four conventional spillways is shown in Fig. 17 and Plate 16. Gravel has been removed from the toe of the dam; some was carried around the rock island, the rest was removed from the basin. The most prominent surface boiling in the plunge pool tends to be aligned on the powerhouse side of the pool center line.

21b. With conventional shapes on Bays 1 and 4, 0° and -20° buckets on Bays 2 and 3, the boil against the face of the dam does not develop. Surface wave action is more pronounced; the boil activity tends to be aligned along the pool centerline. The gravel for 60 feet downstream from the face of the dam (Fig. 18 and Plate 17) was undisturbed.

21c. With warped sections on all bays, the surface wave action is further increased. Waves surged up to Elev. 560 on the bank opposite the fish facilities. The main axis of the boil area develops on the left of the pool centerline; there is somewhat less wave action against the powerhouse. The gravel remained for a distance of 85 feet in front of the dam (Fig. 19 and Plate 18). Some gravel remained on the downstream slope.

21d. The erosion pattern after the maximum flow with Bays 1 and 4 warped; 2 and 3 conventional is shown on Fig. 20 and Plate 19 where the contribution to the erosion by the conventional jets is apparent. The erosion pattern and the general wave action is between the extremes of the basic forms.

21e. With Bays 1 and 4 warped, the 0° and -20° buckets on Bays 2 and

3, the response (Fig. 21 and Plate 20) is again a composite of the basic forms. The wave action is less than with all warped sections; somewhat more than with all conventional. The amount of gravel disturbed is about the same as with all warped sections installed.

22. The tests described in paragraph 21 indicated that further study should be made to substantiate a choice between the two spillway forms, i.e., all buckets warped or a combination with cylindrical sections on bays 2 and 3. The downstream slope of the plunge pool was relocated (Figure 21A) to conform to the contract drawing MA2110R1. To compare the performances between the two spillway forms, three indices were chosen:

a. The pressure probe was fixed 35 feet outward from SE-2 at Elev. 438 (Station 5, Fig. 27). This location was chosen on visual evidence of being representative of wave action directed toward the powerhouse.

b. The height of the boil-center in the plunge pool.

c. The height of the wave against the left canyon wall.

The flow rate was set at 50,000 cfs total, with turbines 1 and 2 discharging 7200 cfs each.

The comparative data for the two spillway configurations are summarized in Table 3 under "Station 5". Sample wave records are shown in Figures 28 A-D. With the oscillograph on the 100-scale, a deflection of one-half millimeter corresponds to about one foot of water in the prototype. The surge height (trough to crest) showed maxima of 10.8 feet and 5.4 feet for the combined buckets (configuration "A") and the warped buckets (configuration "B"), respectively. The boil-height was 5 feet lower for "A", but the wave on the left bank was 5-10 feet higher than for the "B" configuration. These data therefore directed the choice to the all warped sections on the spillway.

23. To re-check the erosion pattern under the impact of the peak flow of 275,000 cfs, a bottom layer of sand, a middle layer of pea gravel and a

top layer of crushed, white rock were placed over the upstream half of the floor of the plunge pool to Elev. 265. The disposition of the movable material after a run of 155 minutes at the peak flow is shown on Plate 20A and in Fig. 21A. A mixture of the materials may be seen in the photograph at the toe of the slope. The material at the base of the dam is not disturbed. The model was subsequently run for about two hours (15 hours prototype time) at a flow of 100,000 cfs to obtain some velocity data. No additional movement of the erodible material took place during this period.

24. Measurements of the velocity along the slope at a flow of 100,000 cfs were obtained by subtracting static pressures from total pressures as measured by the Statham gage. There is a relatively narrow band of high-velocity flow centered between the D and E lines (Fig. 14) extending upward from Elev. 300. Maximum velocity values reach nearly 60 fps (Fig. 6A). Although these high values persist for only short time intervals, erosion of the slope is to be expected for the periods of high flood flows. No appreciable velocity could be measured at the toe of the slope and small gravels tended to pile up there, further indicating that the high-speed core is in the upper levels. There is a circulation driven by the high-speed core which tends to pull gravels from the intersection of the slope with the thalweg downward along the lateral boundaries of the slope.

25. To investigate surging at the powerhouse, a grid was laid out as shown on Fig. 27 where points were taken at Elevations 400 and 433 over each draft tube of units 1 and 2 for the flow condition of 50,000 cfs total, with each turbine discharging 7200 cfs. Typical pressure records are shown in Figures 29 A-I, with summaries in Table 3. The largest value at Elev. 400 at the top of the draft tubes was 3.6 feet. The values just 15 feet below the surface (Elev. 433) yield a maximum of 5.4 feet. The "DURATION" column in Table 3 lists the time of the maximum surge from trough to crest. There is no consistent trend except that the times at Elev. 433 tend to be longer

than those at Elev. 400. The chart speed was increased from 5 to 25 mm per second to magnify the time scale (Figures 29 H-I), but still no significant differences were noted. The frequency of the surges appears to be completely random.

26. The effect at Station 4 of different gate closures is shown on the last part of Table 3. Surge data for the combination spillways at flows of 75,000 cfs and 100,000 cfs are included in Table 2. The surge pressures increase with the discharge and are greater near the surface than at draft tube depths.

Fish Attraction-Water Facilities

27. The comprehensive model included the duplication of the attraction flows at different turbine settings as created by the discharge from the slotted entrances and influenced by the water drawn in at the pump intake. The objectives of this portion of the study were to (1) observe and judge the suitability of the attraction flows, (2) provide current measurements to serve as background information, and (3) determine the influences of a 10-foot lip or deflector over the draft tubes on the currents in the immediate vicinity of the powerhouse. Another facet of the program, a means of releasing minimum flows during turbine shutdowns, will be treated in an addendum to this report. The following tabulation summarizes the several combinations of variables tested and serves as an index to the Figures and Plates to which references will be made in the ensuing discussion.

Summary Index of Powerhouse Velocity Traverses

Fig.	Elevation		Turbines		Deflector		Surface Pathlines	
	Tail-water	Traverse	No.	Q, cfs each	on	off	Plate	Fig.
22A	425.5	400	1	4400	x		24A	26A
B	"	"	1	"		x	B	
C	"	"	2	"	x		C	C
D	"	"	2	"		x	D	
E	"	"	3	"	x		E	E
F	"	"	3	"		x	F	F
G	430.5	410	1, 2	6400	x		G	G
H	"	"	1, 2	"		x	H	H
I	"	"	2, 3	"	x		I	I
J	"	"	2, 3	"		x	J	J
K	"	"	1, 3	"	x			
L	"	"	1, 3	"		x		
M	431.5	"	1, 2	7300	x		K	K
N	"	"	1, 2	"		x	L	L
O	"	"	2, 3	"	x			
P	"	"	2, 3	"		x		
Q	434	414	1, 2, 3	"	x		M	M
R	"	"	1, 2, 3	"		x	N	N

28. The pattern of the main currents in the pool changes somewhat from turbine to turbine, since the confinement of the jets reduces from being bounded on one side and the bottom at turbine #1 to essentially no restriction at turbine #3. There is generally a slow, elongated, counterclockwise circulation in the pool opposite the powerhouse. This motion is most clearly defined when only turbine #1 is operating. As the other turbines are added, the circulation tends to break into two cells with the one nearer the dam being the stronger. The flow from turbine #1 guides along the walls of the fish facilities, with less apparent upwelling than develops with turbine #3.

29. Each of the three methods of mapping the currents, the point velocity measurements, the dye paths and the surface pathlines, contributes to the documentation of the motion. The currents for the selected flows and the deflector "on" and "off" are depicted in three sets of diagrams; the point velocities in Figures 22 A to R, the surface pathlines and dye traces on Plates 24 A-N, and tracings of the pathlines in Figures 26 A-N. Two locations for the pump intake are shown in Plates 25 and 26.

30. The photographs (Plates 24 A-N) provide the best initial impression of the circulation pattern, for the time exposure of one second allows enough motion of the particles to trace out surface currents. The velocity scale is 1 inch to 6.7 feet per second. These surface currents also are indicative of those in the upper layers, as traced out by the dye from the slotted entrance. Plate 24A is a good example of the general motion with turbine #1 operating; the upwelling from turbine #3 appears clearly in Plate 24E; Plate 24M shows the greater width and higher velocities associated with the primary flow from all three turbines in operation.

31. The pathlines were traced from the photographs to aid in the interpretation of the flows close to the powerhouse. The presence of the deflector is most noticeable with only turbine #1 operating (Figures 26 A-B). The flow

from entrance, SE-1, is more effective with the deflector in place. This same trend is present to a lesser degree at other turbine combinations. A closed circulation developed near the SE-1 without the deflector (Figures 26 K-L) with turbines 1 and 2 operating. Although the deflector extends only 10 feet from the powerhouse wall, it does seem to allow the flows from the slotted entrances to be more distinctive close to the powerhouse. There is also evidence on the point-velocity data that the upwelling is thrust farther away from the powerhouse, as may be seen by viewing the paired diagrams in Figures 22 A-R.

32. The general fish-attraction flows were judged to be satisfactory with the exception of a short-circuiting between the flow from SE-1 and the pump intake. The amount of the short-circuiting depended more upon which turbine was operating than upon the amount of turbine discharge. When turbine #1 was operating, its discharge could supply the pump-intake quantity so that little water was recirculated. However, with turbine #2 operating (Fig. 25) the pump drew from the relatively still water in front of the intake with a very distinct draft from the water issuing from the slotted entrance. The experience with #3 turbine was similar. The intake was then moved downstream of the break in wall alignment of the fish facility (Fig. 26) with a marked reduction in the amount of water recirculated. The new entrance is close to the edge of the dropoff into the deep part of the pool to further reduce the tendency to tap the water from the slotted entrance.

Fish Ladder Model

33. A 5-pool section of the fish ladder was duplicated in a 1:6 scale model separate from the comprehensive one. Two sets of weir plates, Plan A and Plan B, (designated as "PLAN" and "ALTERNATE PLAN" on DWG NO MAX-02) were built for the 10-foot wide ladder. The width of the overflow weirs was three feet in Plan A (shown in Plate 21) and two feet in Plan B (Plate 22).

Plan B was recommended by the fisheries agencies after viewing the performance of the two sets. No data were compiled from Plan A. The principal requirements were (a) a velocity net on a grid system of two-foot centers horizontally and vertically, (b) a Head-Discharge Curve with the orifices and weirs alternately blocked, and (c) the discharge at the operating condition of a one-foot head drop between pools.

34. The grid system is defined in Figures 23 A and 23B. The velocity field in a typical pool is very complex and somewhat unsteady. The flows over the weirs and through the orifices interact with each other and the boundaries to produce the mean directions shown on the circulation diagrams shown in Figures 23B and 23C. Directions were obtained by following dye streaks and yarn attached to the velocity probes. Velocity magnitudes at the grid points are shown on Figures 23 D-F. The velocity probes are not directionally sensitive. For example, a downward current may be sensed by a pressure-type instrument or a reverse current will be recorded on a propellor-type meter. The dye staining the water in the pools shown in Plate 23 was injected on the upstream face of the central weir plate. A portion of this initial dosage was carried immediately through the orifice and has been mixed in the circulation in front of the downstream weir plate; some was carried forward to the upstream weir; some passed over the weir and clung to the downstream face. These motions are typical of the sections through weir-orifice centerlines. In the shear zones between the jets and near the faces of the weir plates, the current at a point changed direction frequently but average motion shown in a section through the ladder centerline results in a counterclockwise rotation. The mean directions shown on the circulation diagrams should be used with the velocity data to obtain an idea of the flow conditions in a typical pool. There is a direct flow from one orifice to the next; there is a rotation or circulation present at the other zones in the pool.

35. The discharge characteristics of the ladder were determined for the conditions of weir section blocked (Fig. 24) and the orifice blocked (Fig. 25). The discharge coefficient defined on the basis of the area of opening decreases with increasing head to become nearly constant at 0.85 at a head difference of 1.8 feet. The variations are easily attributed to the irregular geometry controlling the flow. The effective jet area as governed by the bevelled edges and the wing wall seems to shift with the flow rate. An empirical equation for the discharge coefficient over the main portion of the flow range is

$$C_D = 1.01 \Delta h^{-0.307} .$$

The discharge is then proportional to $\Delta h^{0.193}$ rather than to the square toot of the head difference. The highest three data points indicate that flow rate is proportional to the square root of the head difference.

36. The weir behaved more conventionally than the orifice and yielded a discharge coefficient of about 4.3 at the design head difference of 1.0 feet. The bevelled upstream face accounts for the high value for the coefficient. The head-discharge curve is very close to the expected slope of 1.5 to 1.

37. When the flow is passing through both openings, the jets influence each other as shown in the discussions in paragraph 23, so that a flow rate for the normal configuration (i.e., weirs and orifices open) cannot be taken as the sum of the individual contributions at any chosen head difference. For example, the discharge is 40.2 cfs under a 1-foot difference for the normal configuration; the sum of the individual discharges for that head difference would be 50.4 cfs.

PART IV: CONCLUSIONS

The spillway as designed needed no revision to accommodate the required flow rates. The different forms of spillway buckets tested did not alter significantly the Head-Discharge Curve. Some drawdown appeared on the lateral piers at discharges of 200,000 cfs and above, but the amount (10 feet at peak flow) was not considered a problem for the rare occurrence of such flows. With a high reservoir level vortices formed in a bay where the gate was partly open and the adjacent bay discharging with full-gate opening.

The movable-bed studies showed that there was considerable erosion potential in the jets at discharges in the order of 100,000 cfs and above. The side walls of the basin should be cut back to allow an unobstructed path for the jet from Bay 4 (south side).

The different terminal forms on the spillways provided some control over where the energy dissipation may be directed. For review purposes, their principal features are summarized as:

1. Conventional spillway.

    a. The striking velocity of the jets at Elev. 250 is near 60 fps for flows of 100,000 cfs; high velocities occur on the downstream slope of the plunge pool; a 25-ft. boil develops at the dam face.

    b. Under the peak flow, loose material is removed clear back to the face of the dam and the axis of the boil area is aligned on the powerhouse side of the plunge pool.

2. Cylindrical buckets.

    a. The jets are spread laterally so that more of the energy is dissipated in the upper layers.

    b. The striking velocity at Elev. 250 is near 20 fps; velocities on the plunge pool slope are less than with the conventional spillways.

    c. Under the peak flow, loose material is not disturbed from the toe of the dam; the axis of the boil lies along or to the left of the pool centerline.

    d. Surface wave action is increased over that from the conventional jets.

e. These buckets would be appropriate only on the interior bays because of the lateral spreading they induce.

3. Warped buckets.

   a. The bucket contour rotates the jet away from the canyon sidewalls so that its axis is nearly parallel to that of the plunge pool and also causes a spreading so that the striking velocity at Elev. 250 is less than with the cylindrical sections.

   b. Surface wave action is somewhat more pronounced than with cylindrical sections on the interior bays.

   c. Under the peak flow, the loose material at the toe of the dam is not disturbed; the boil axis tends to be on the left side of the plunge pool centerline.

   d. The pressure loadings on the buckets are high.

   e. Erosion is to be expected along the centerline of the downstream slope of the plunge pool above Elev. 300 when the flow rate approaches 100,000 cfs.

   f. Wave action against the powerhouse is milder than that from a combination with the cylindrical section on the interior bays.

The conventional spillways were deemed unsatisfactory because of erosional characteristics on the plunge pool floor and at the toe of the dam. The warped sections are recommended for all bays since they provide erosional stability at the toe of the dam, low impact velocities on the plunge pool floor, and less wave action at the powerhouse under nominal high flows than that created by cylindrical sections on the interior bays. A vertical deflector on the outside piers has been called for on Fig. 8. The interior piers also should be extended five feet to reduce the spray when either gates 1 or 4 might be closed with gates 2 or 3 opened.

Surge pressures at the powerhouse were less than 2% of the head difference between forebay and tailbay elevations at a river flow of 50,000 cfs. The duration of the individual surges varied from 1.9 seconds to 11.6 seconds in a random fashion. No persistent periodicity between the surges was detected.

Although final recommendations regarding the fish facilities may be discussed further with the agencies concerned, some definite conclusions are in order from the observed hydraulic performances. The pump intake for the fish-attraction water should be moved to a location downstream of the break in the alignment of the walls of fish facilities. Slotted Entrance 2 performs better than Slotted Entrance 3 under most flow conditions. The deflector over the draft tubes allows the attraction water from the slotted entrances to maintain better their identity, especially under a single-turbine operation. The second ladder plan having the 2-foot wide openings is to be preferred over the first plan. Additional studies are planned to develop further the method by which the minimum flows shall be released during periods of complete turbine shutdown.

TABLE I

JET AND BOUNDARY VELOCITIES

SINGLE SPILLWAY

Q = 25,000 cfs
#1 - Conventional
#2 - 0° Bucket
#3 - Warped Bucket
T. W. 467

Elevation Ft.	Max. Velocities - fps		
	Warped Bucket	Conventional	0° Bucket
250		54 - 55 - 64.3 - 58.1 54.2 - 62 - 59.6 - 60.4 58.9 - 59.4 - 59.4 - 64.4 52.7 - 52.7 - 54.2	
257			6.2 - 12.4
285			33 - 47 - 44 - 42
300		70 - 65 - 70 - 64	53.5 - 52 - 62.7 48.8 - 46.5 - 48.8 48.8
350	42.1 - 32.8 - 38.8 27.1 - 36.8	69.6 - 66.6 - 70.5 76.6 - 69 - 62 - 73.6 62	64.4 - 53.5 - 59.6 60.4 - 63.5 - 47.3
375	68.6 - 56.4 - 42.2 52.7 - 67.5		
400	72.5 - 67.5 - 62.2 77.2	95.2 - 89.2 - 89 - 91.5 95.2	76.7 - 70.5 - 69.1 68.2 - 75.2
425	85 - 104 - 102 91.5		
450	110.5 - 113.7	132 - 135 - 136	109 - 112 - 109 - 109

FOUR CONVENTIONAL SPILLWAYS

Q = 100,000 cfs

Elevation	Location	Max. Velocities - fps
257	D4 3/4	48 - 60.4 - 55.8 - 58 - 47.2 - 52.7 - 51.2
300	D4 3/4	17.8 - 26.4 - 19.4 - 10.1
	D6 1/2	61.2 - 38.8 - 43.4 - 32.6
350	D6 1/2	31.8 - 27.1 - 33.3 - 32.5
	D8	26.4 - 41 - 27.1 - 45.7 - 23.2 - 41 - 38.8
400	D8	30.2 - 29.4 - 24

TABLE I

FOUR SPILLWAYS

Q = 100,000 cfs

#1 and #3 Conventional
2 - #4 0° Buckets

Elevation - Ft.	Location	Max. Velocities - fps					
300	D6 1/2	48.8	49.6	49.6	50.4	48	48
		54.3	39.6	48.8	35	32.6	30.2
		45.6					
350	D6 1/2	42.6	21.7	0	48	15.5	0
		36.4	29.4	19.4	24.8	27.9	26.4
	D8	42.6	39.5	36 4	42.6	39.6	34.2
		36.4	41.8	34.2			
400	D6 1/2	0	14.7	12.4			
	D8	14	0	38.8	23.2	27.1	
		31.8	24.8	41.1			

FOUR SPILLWAYS

Q = 100,000 cfs

#1 Conventional **#2 0° Bucket**
#3 -20° Bucket **#4 Conventional**

Elevation - Ft.	Location	Max. Velocities - fps				
257	D4 3/4	30.2	18.6			
300	D4 3/4	20.9	24.8			
	D6 1/2	0	16.3	23.2	19.4	14.0
		21.7	8.5	21.7		
350	D8	17.8	24.0	0	17.8	

FOUR SPILLWAYS

Q = 100,000 cfs

See Fig. 6

1 & 4: Warped Bucket
2: 0° Bucket
3: -20° Bucket

Elevation - Ft.	Location	Max. Velocities - fps		
250	D 3/4-5	15	10	
	D 3/4-6	10		
300	D 3/4-6	43		
	D 3/4-7	53.5	50.5	59.8
350	D3/4-7	34		
	D3/4-9-1/4	39.3	34	

TABLE I

FOUR SPILLWAYS

Q = 100,000 cfs

See Fig. 5

#1 Conventional #2 0° Bucket
#3 -20° Bucket #4 Conventional

Elevation - Ft.	Location	Max. Velocities - fps				
257	D4	45.0	41.0	43.2	36.8	46.5
		35.0	28.5			
	D5	17.8	23.5	21.3	17.8	
	D6	27.1	23.2	27.9	19.1	
	E4	22.9	15.8			
	E4 1/2	22.9	25.3	32.6	28.4	25.9
		22.9	28.4			
	E6	25.6	21.7	20.9		
	F5	23.8	26.3	28.5		
	F6	21.7	27.9	20.2		
300	C-7	15				
	D-4 3/4	20.9	24.8			
	D-6 1/2	16.3	23.2	14	21.7	
	D7	18.7				
	E-7	27.8	39.5	18.7		
350	D-8	17.8	24	17.8		
	D 3/4-8	39.5	29.4	17.9	21.7	
	E-6	42.1	45.3			
	E-7	45.3	40.4	34.6		
400	C-4 1/2	19.4	27.1			
425						

FOUR WARPED BUCKETS

Q = 100,000 cfs

See Fig. 6A

Elevation - Ft	Location	Max. Velocities - fps			
257	$D\frac{1}{2}$-4 3/4	(See Fig. 6A)			
300	$D\frac{1}{2}-6\frac{1}{2}$	52.7	49.4	37.2	41.7
350	$D\frac{1}{2}-8\frac{1}{2}$	59	56	52.7	

TABLE 2

PRESSURE SURGES* ALONG POWERHOUSE

Q = 75,000 cfs

1 & 4 Warped
2 --0°
3 -20°
T.W. 459

Elevation	Location	Total Pressure Surge (ft)
443	Against face of PH between units 1 and 2	10.8
443	Between units 1 and 2 and 15 feet downstream from PH	9.0
443	Above exit to unit 1 and near slotted entrance of fishway	9.0
	Q = 100,000 cfs SAME SPILLWAY COMBINATION T.W. 467	
390	Between units 1 and 2 and 15 feet downstream from PH	6.0
448	Same location	9.6
390	Near exit to unit 1 and slotted entrance of fishway	4.8
443	Above exit to unit 1 and adjacent to slotted entrance of fishway	7.8
453	Same location	13.2
448	Above unit 3 and adjacent to slotted entrance of fishway	8.7

* trough-to-crest, height of pressure head fluctuation.

TABLE 3

SURGE* ALONG DOWNSTREAM FACE OF POWERHOUSE

FLOW RATES (cfs)

RIVER: 50,000
SPILLWAY: 35,600
TURBINES:
1. 7,200
2. 7,200
3.

ELEVATION
TAILWATER: 448.5

SPILLWAY CONFIGURATION
A. 1 & 4 Warped Buckets
2 0° Bucket
3 -20° Bucket
B. 4 Warped Buckets

* Trough-to-crest, height of pressure head fluctuation.

DEFLECTOR OFF

** See Fig. 27

STATION**	ELEVATION	SPILLWAY CONFIGURATION	SURGE * (ft)	DURATION * (sec)
5	438	A all gates open	10.8 8.4 9.6 10.8 10.8	5.4 6.2 3.9 3.1 3.9
5	438	B all gates open	5.4 4.2	6.2 6.2
5	438	B Gate 1 - closed 2, 3, and 4 - open	6.5 6.5 6.5 4.3	4.7 6.2 5.4 3.1
5	438	B Gate 2 - closed 1, 3 and 4 - open	4.3	3.9
5	438	B Gates 1 and 2 - closed 3 and 4 - open	8.1 6.5 7.2	7.0 7.0 5.4
1	400	B All gates open	2.4 3.0	1.9 4.0
	433	" " "	3.6 3.6	7.8 9.3
2	400	B All gates open	3.6 3.6	2.3 5.4
	433	" " "	3.6 4.3 5.4	8.5 8.5 11.6

T A B L E 3

SURGE * ALONG DOWNSTREAM FACE OF POWERHOUSE

STATION **	ELEVATION	SPILLWAY CONFIGURATION	SURGE * (ft)	DURATION * (sec)
3	400	B All gates open	1.8 2.7 2.7	5.4 2.3 1.9
	433	" " "	2.4 3.6 4.3	7 4.7 1.9
4	400	B All gates open	1.2 1.2 3.6	5.4 3.9 1.6
	433	" " "	3.6 3.6 3.6	7.0 2.3 5.4
4	400	B Gate 1 - closed 2, 3 & 4 - open	2.4 1.8 2.4	3.9 7.8 1.9
4	400	B Gate 2 - closed 1, 3 & 4 - open	2.4 1.8	3.9 3.9
4	400	B Gate 3 - closed 1, 2 & 4 - open	2.4	3.1
4	400	B Gate 4 - closed 1, 2 &3 open	3.0 3.6	7.0 2.3
4	400	B 1 & 4 - open 2 & 3 closed	4.8 2.4	5.4 6.2
4	400	B 3 & 4 -open 1 & 2 - closed	4.2 4.2 4.8 5.4	2.3 5.4 3.1 3.9
4	433	B 3 & 4 - open 1 & 2 - closed	6.6 4.2	4.7 5.4
4	433	B 1 & 2 - open 3 & 4 - closed	3.6 5.4 3.0 4.2	3.1 9.3 4.7 7.0

SAMPLE OF VELOCITY-WAVE RECORD

Q = 100,000 CFS

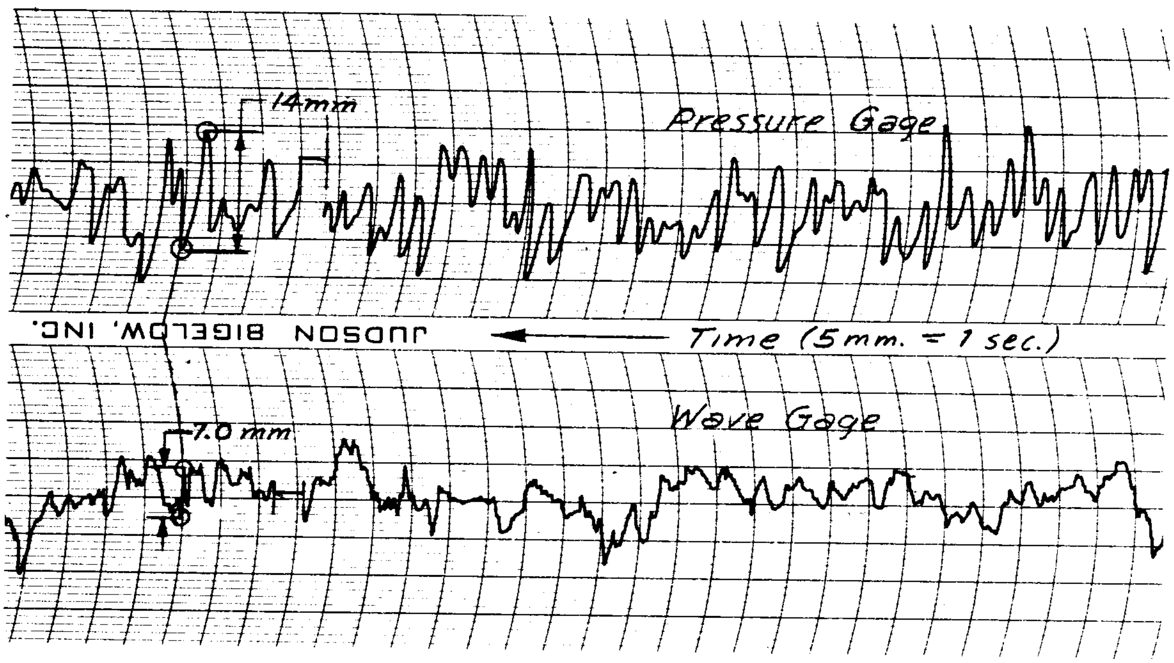
BAYS 1 AND 3 CONVENTIONAL

PRESSURE SCALE 100: 5 MM. = 0.078 PSI ≈ 0.18 FT. WATER

WAVE GAGE SCALE: 5 MM. = 1" WATER

TIME SCALE: 5 MM. = 1 SECOND

SLOPE PROBE AT ELEV. 300 AT D-8



SAMPLE VELOCITY CALCULATION:

$$\text{TOTAL PRESSURE HEAD} = \frac{14\ \text{MM.}}{(5\ \text{MM.} / 0.078\ \text{PSI})} \times \frac{144}{62.4} = 0.505\ \text{FT.}$$

$$\text{STATIC HEAD} = \frac{7.0\ \text{MM.}}{(5\ \text{MM.} / \text{INCH WATER})} \times \frac{1}{12} = 0.117\ \text{FT.}$$

$$\text{DYNAMIC HEAD} = 0.505\ \text{FT.} - 0.117\ \text{FT.} = 0.388\ \text{FT.}$$

$$\text{VELOCITY} = \sqrt{2G(0.388)} = \underline{\underline{5.0\ \text{FPS}}}\ (\text{MODEL})$$

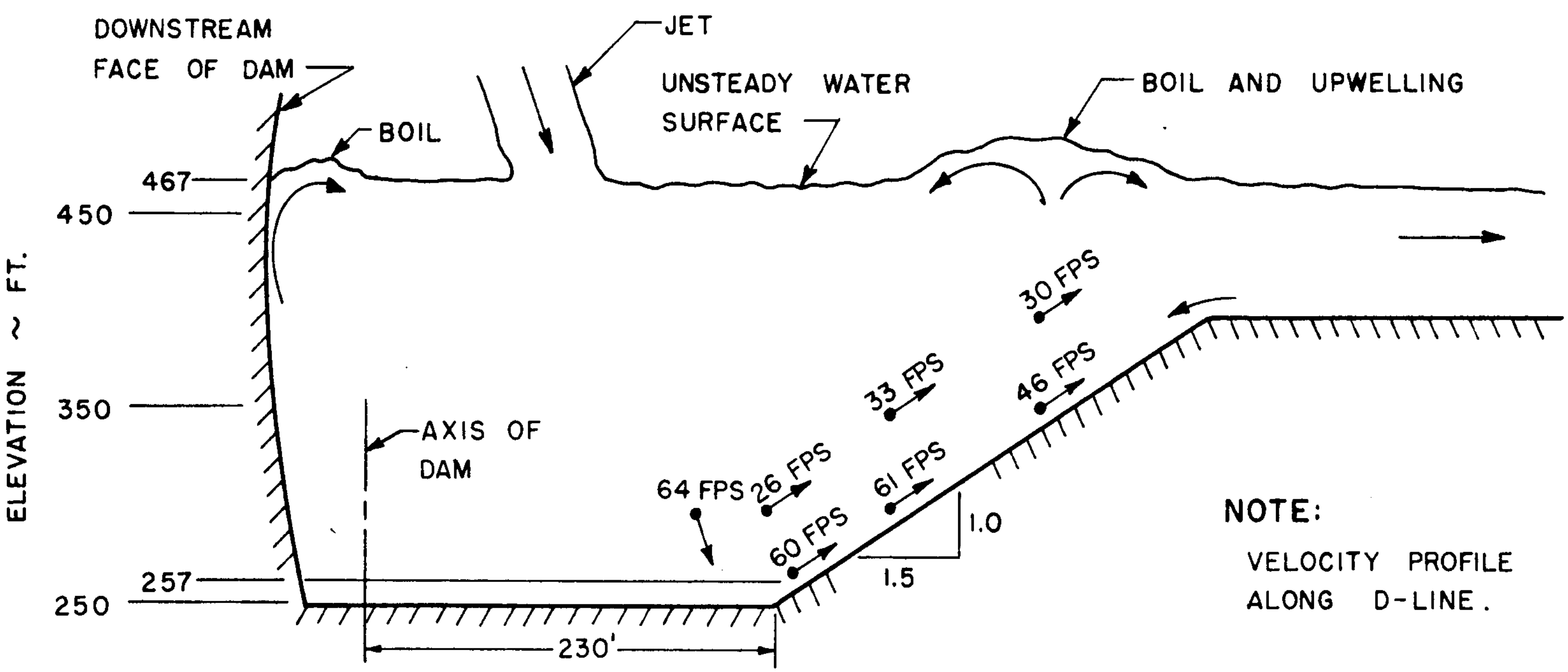
FIGURE 1

SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR CONVENTIONAL SPILLWAYS



NOTE:
VELOCITY PROFILE
ALONG D-LINE.

SCALE: 1" = 100'

FIGURE 2

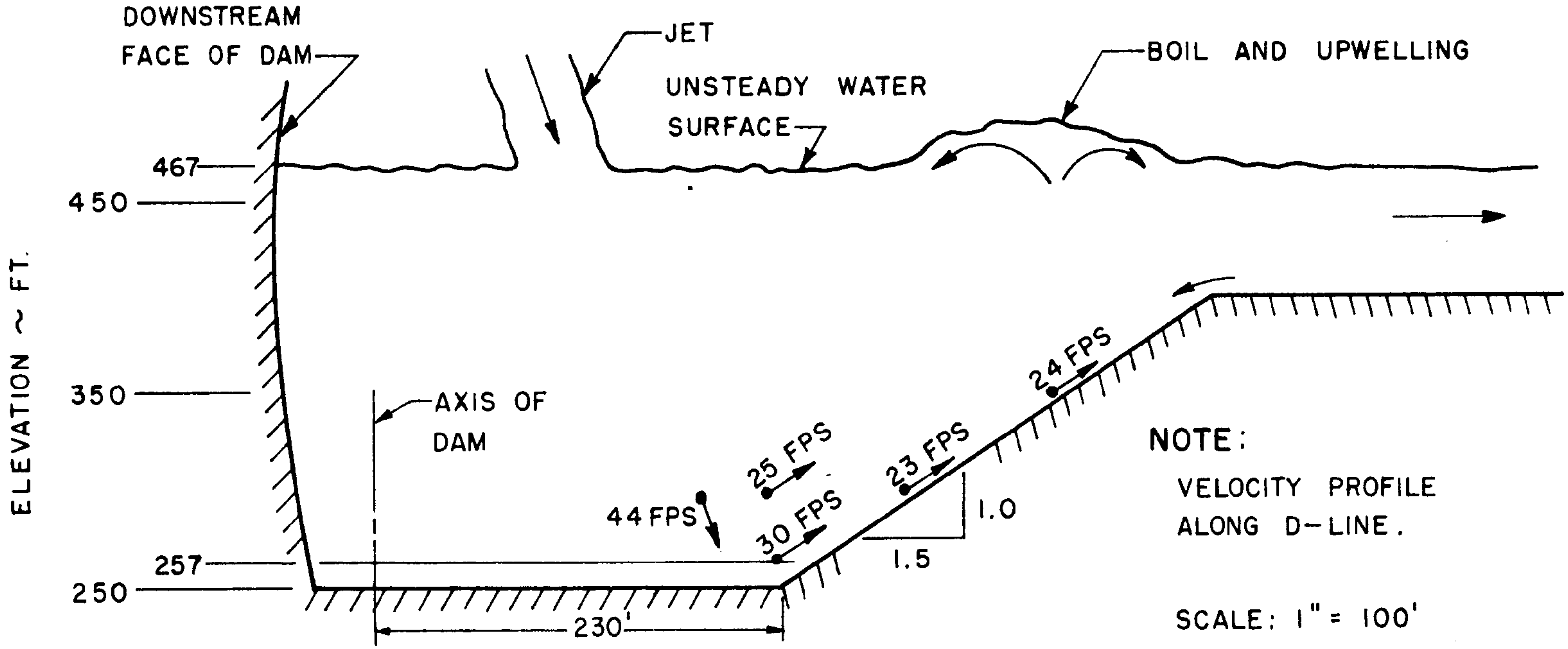
SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR SPILLWAYS

#1 CONVENTIONAL
#2 0° BUCKET
#3 −20° BUCKET
#4 CONVENTIONAL



NOTE:
VELOCITY PROFILE ALONG D-LINE.

SCALE: 1" = 100'

FIGURE 3

SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR SPILLWAYS

#1 AND #3 CONVENTIONAL

#2 AND #4 0° BUCKET

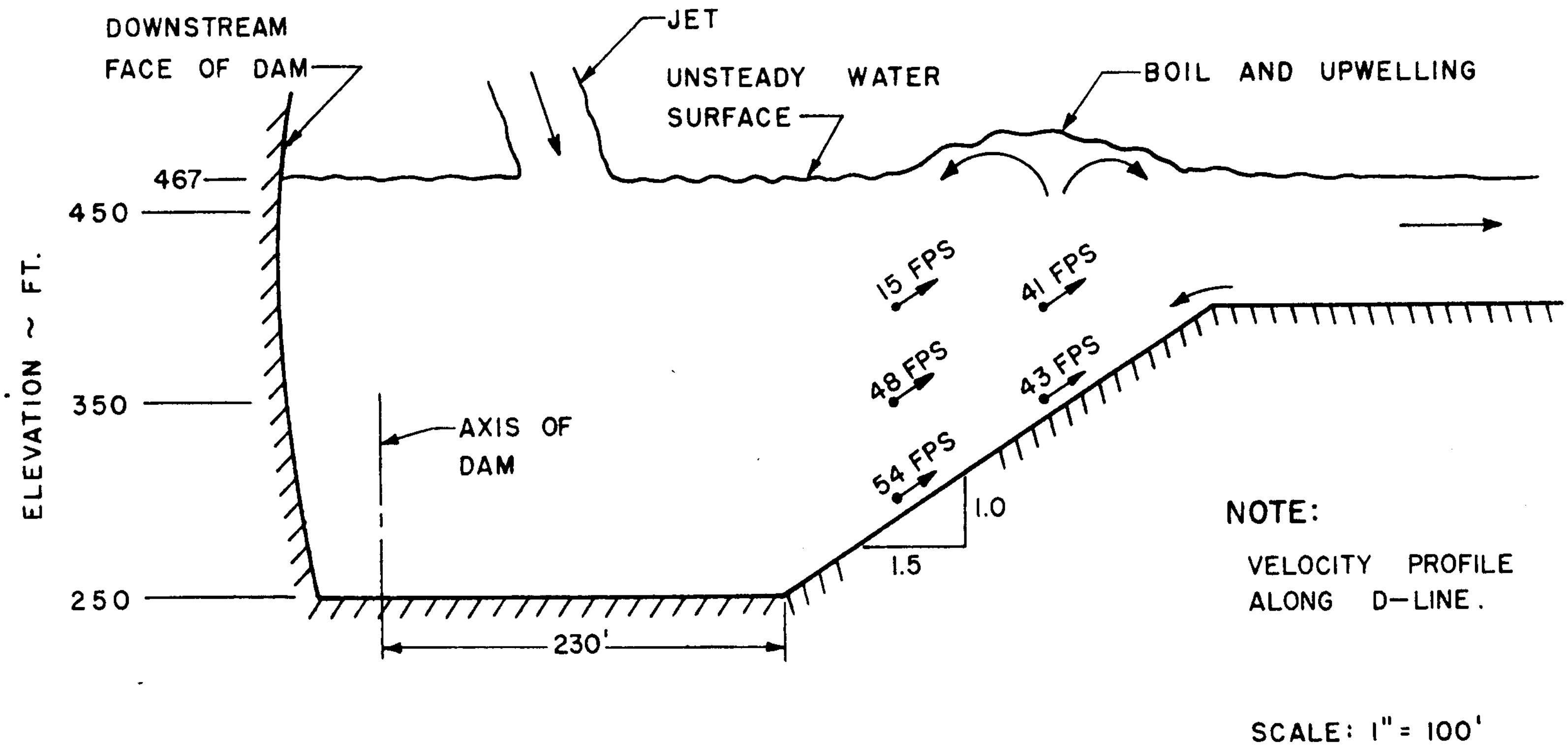


FIGURE 4

SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR SPILLWAYS

#1 CONVENTIONAL

#2 0° BUCKET

#3 −20° BUCKET

#4 CONVENTIONAL

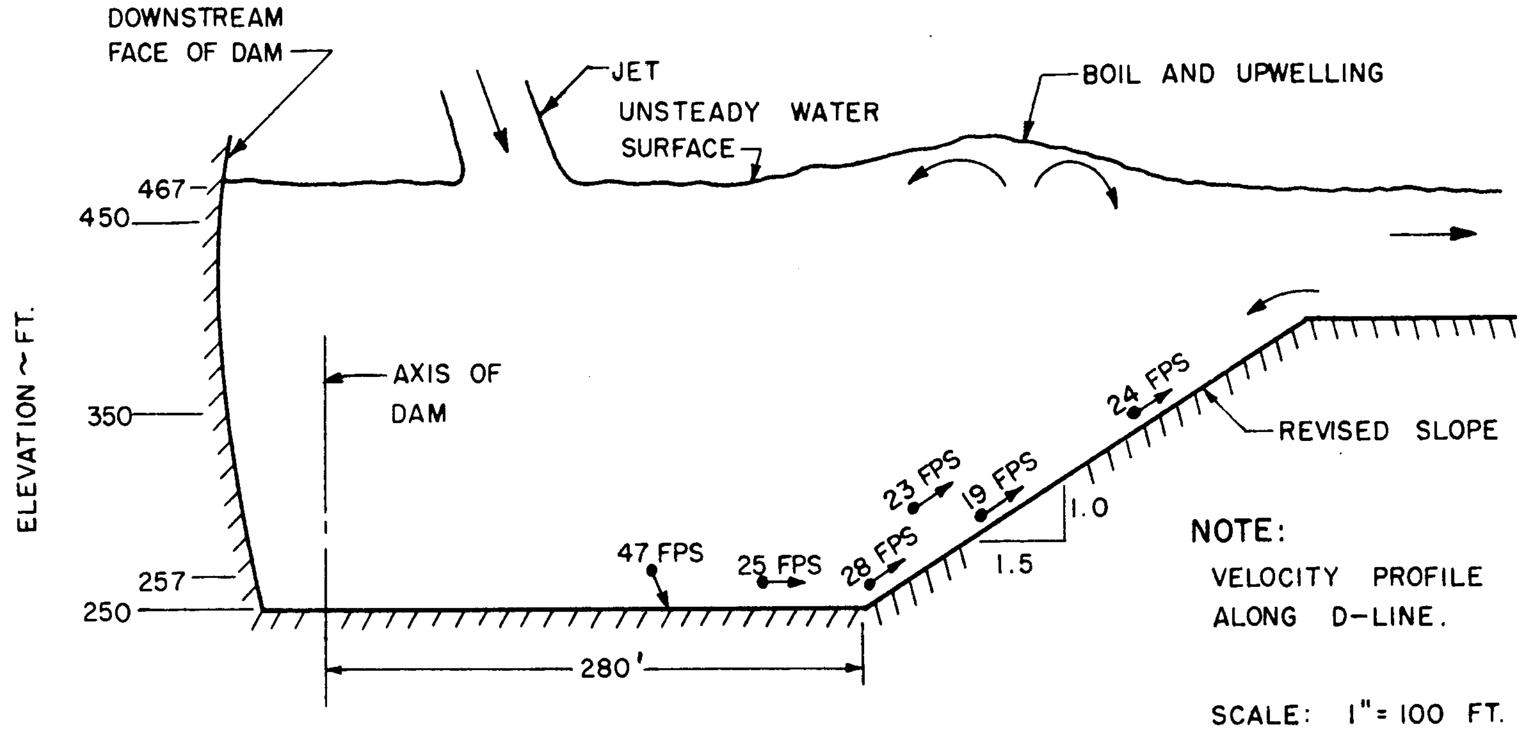


FIGURE 5

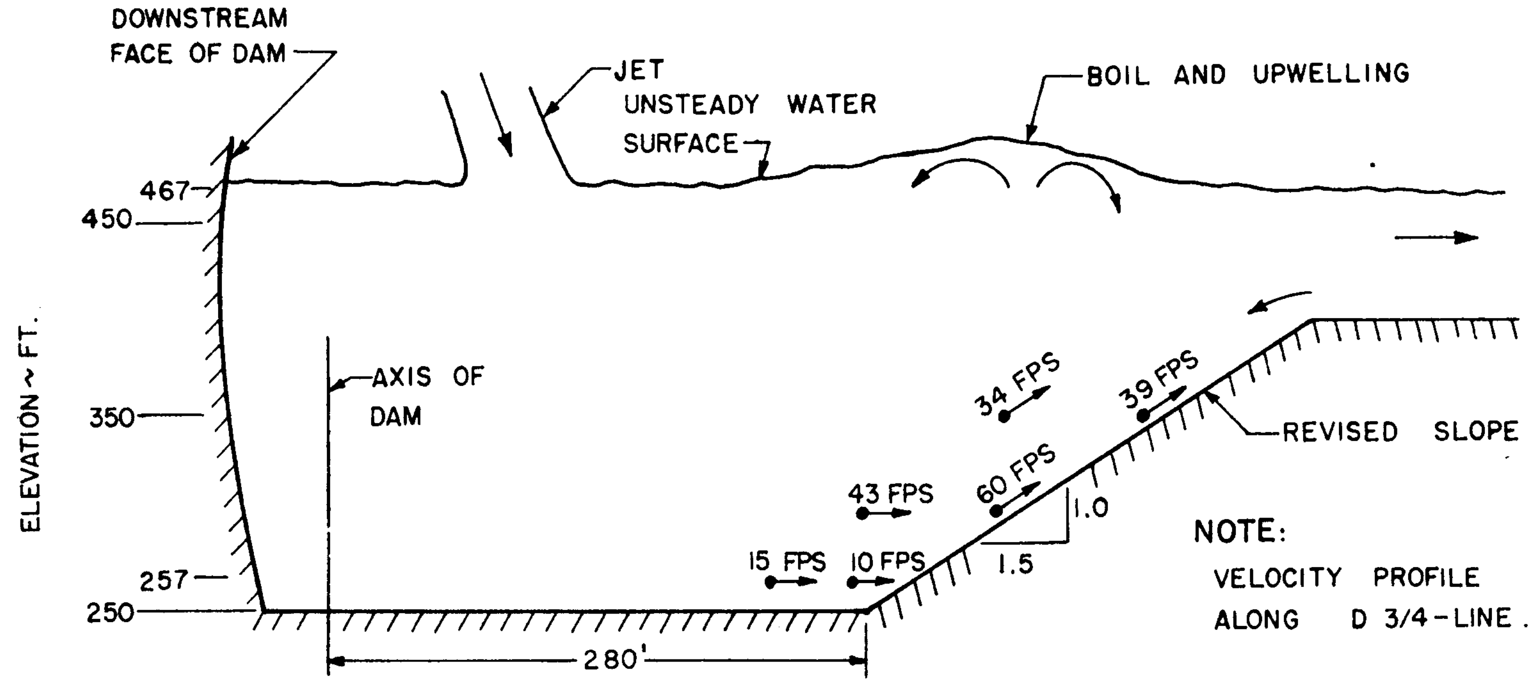
SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR SPILLWAYS

#1 WARPED BUCKET
#2 0° BUCKET
#3 −20° BUCKET
#4 WARPED BUCKET



NOTE:
VELOCITY PROFILE ALONG D 3/4-LINE.

SCALE: 1" = 100 FT.

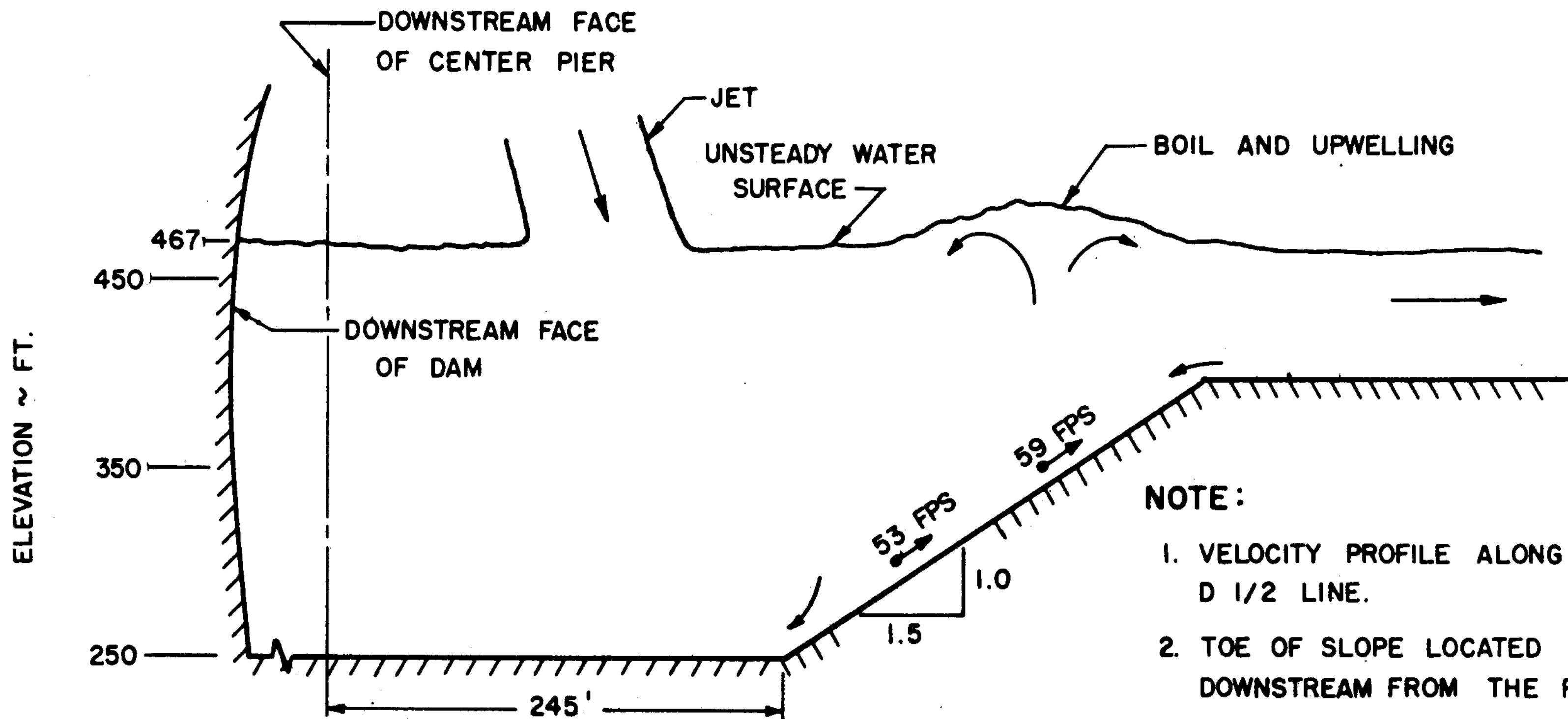
FIGURE 6

SPILLWAY JET PROFILE

MAXIMUM VELOCITY VS ELEVATION

Q = 100,000 CFS

FOUR WARPED BUCKETS



NOTE:

1. VELOCITY PROFILE ALONG D 1/2 LINE.
2. TOE OF SLOPE LOCATED 245 FT. DOWNSTREAM FROM THE FACE OF THE CENTER PIER.

SCALE: .1" = 100'

FIGURE 6A

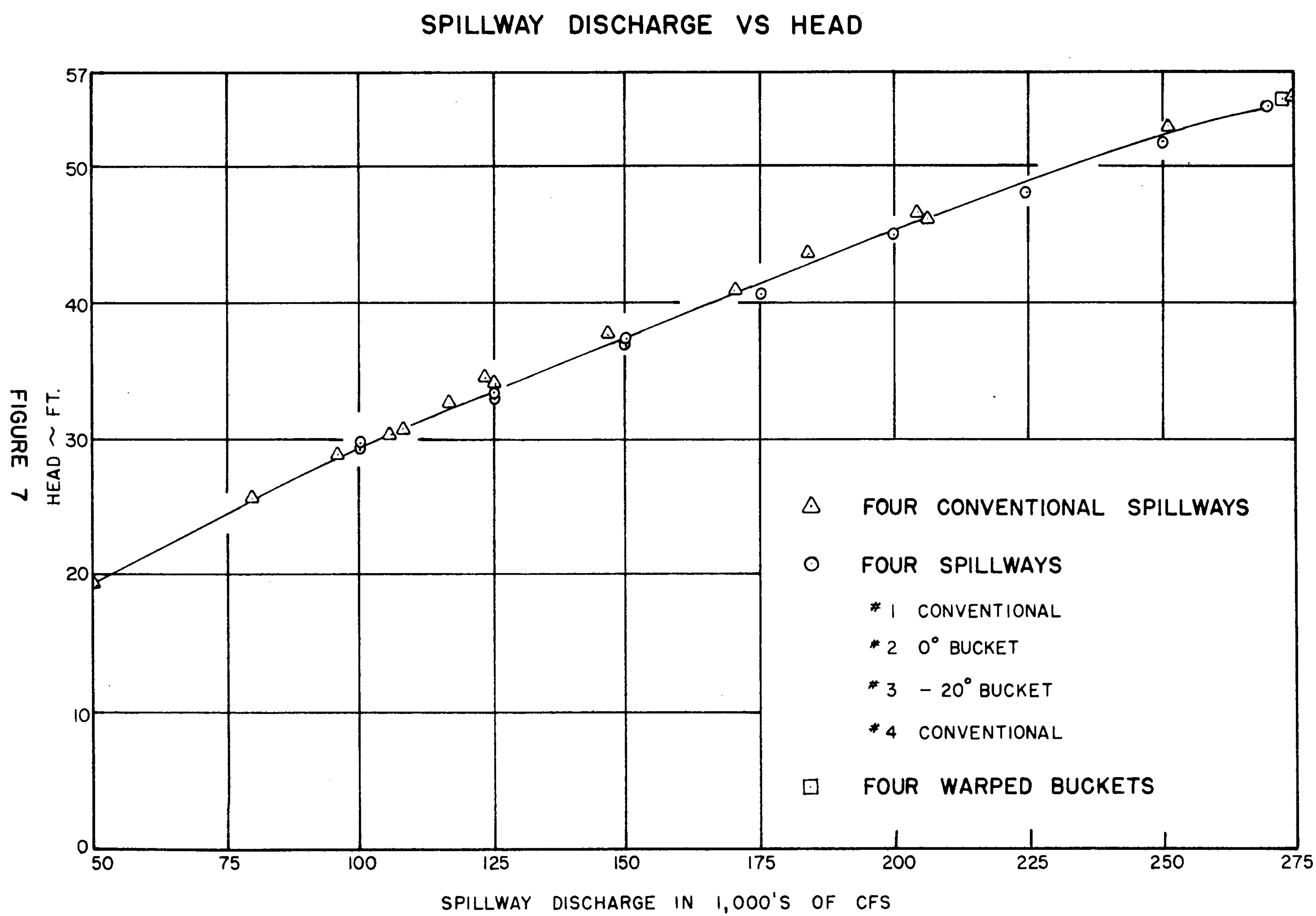
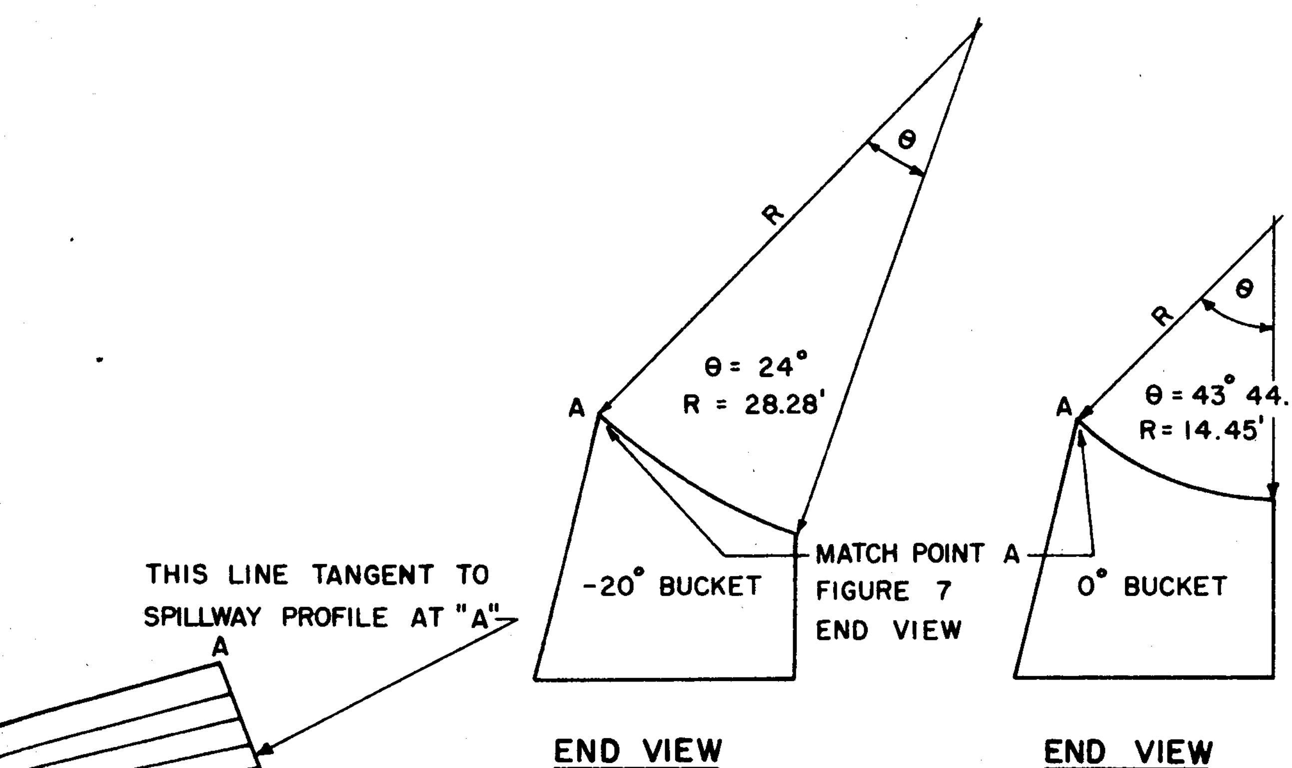
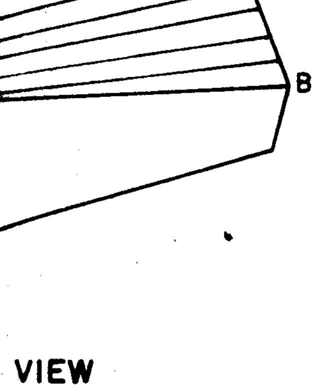

SPILLWAY DISCHARGE VS HEAD
HEAD ~ FT.
57
50
40
30
20
10
0
50
75
100
125
150
175
200
225
250
275
SPILLWAY DISCHARGE IN 1,000'S OF CFS
FOUR CONVENTIONAL SPILLWAYS
FOUR SPILLWAYS
1 CONVENTIONAL
2 0° BUCKET
3 - 20° BUCKET
4 CONVENTIONAL
FOUR WARPED BUCKETS

FIGURE 7

CYLINDRICAL BUCKETS





NOTE:

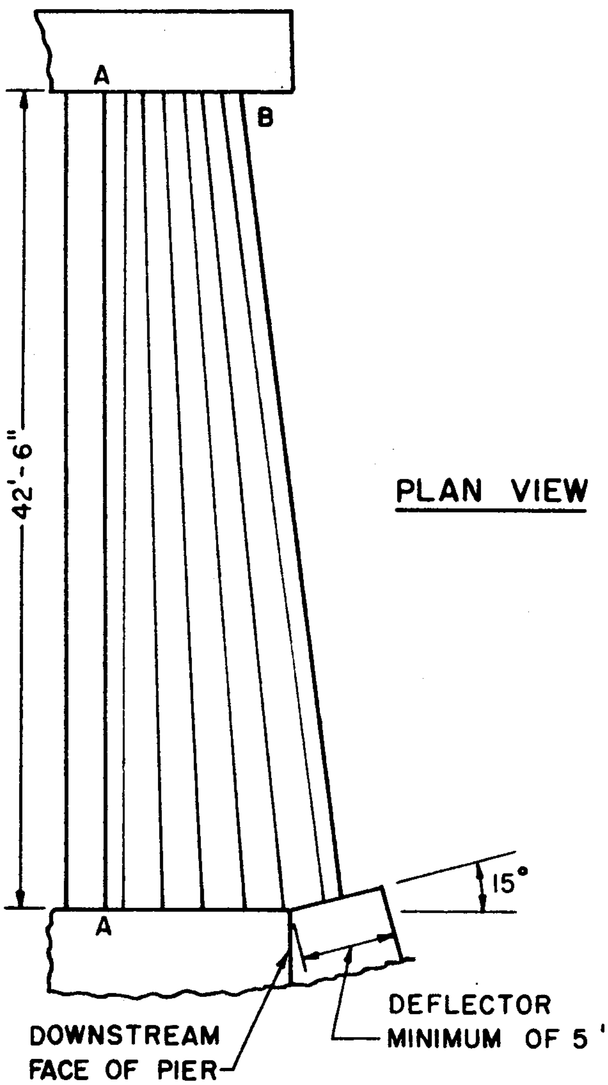
NO. 1 SPILLWAY SHOWN
NO. 2 SIMILAR
NO. 3 AND 4 OPPOSITE HAND

MOSSYROCK DAM
MODEL STUDY

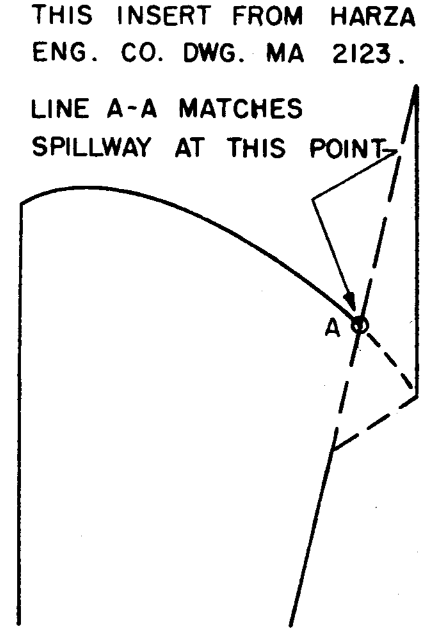
EXIT SECTIONS
WARPED AND CYLINDRICAL BUCKETS
FIGURE 8

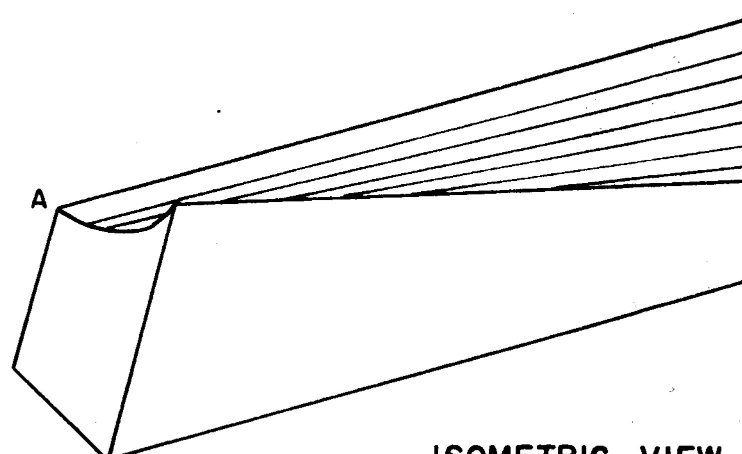
SCALE: 1" = 10' | DATE: NOV. 25, 1964

WARPED BUCKET

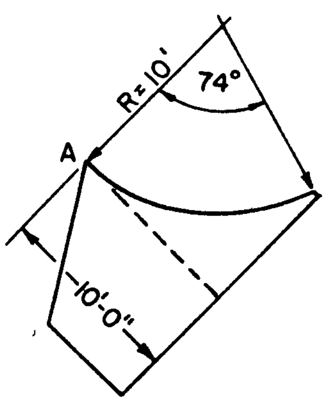


PLAN VIEW

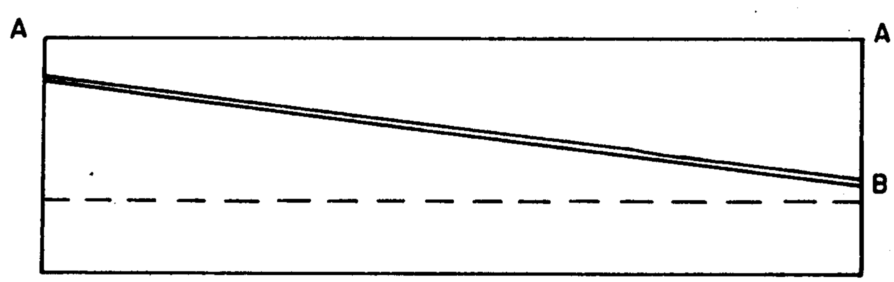




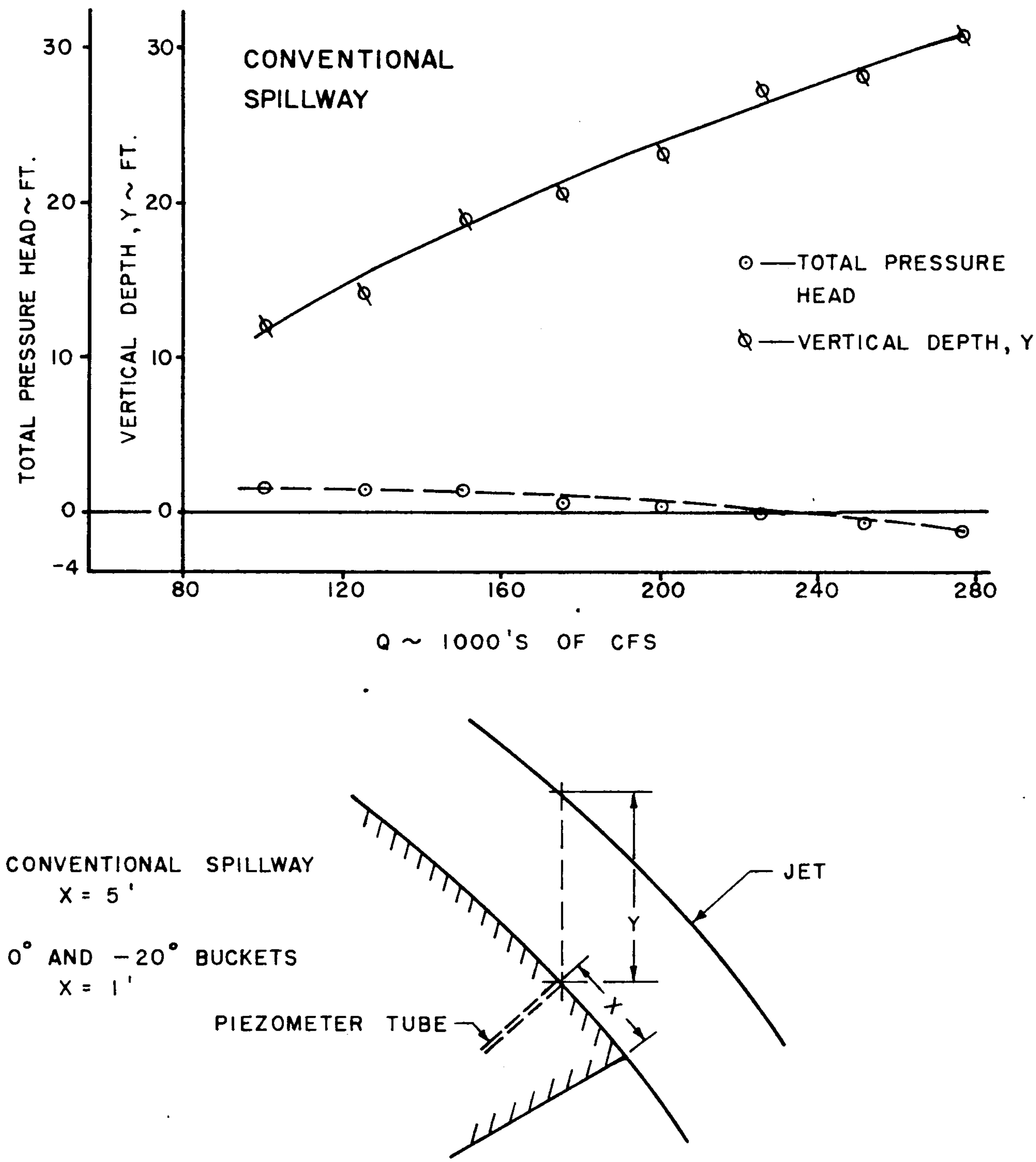
ISOMETRIC VIEW



END VIEW



FRONT VIEW



SPILLWAY PRESSURE-HEAD AND DEPTH

FIGURE 9A

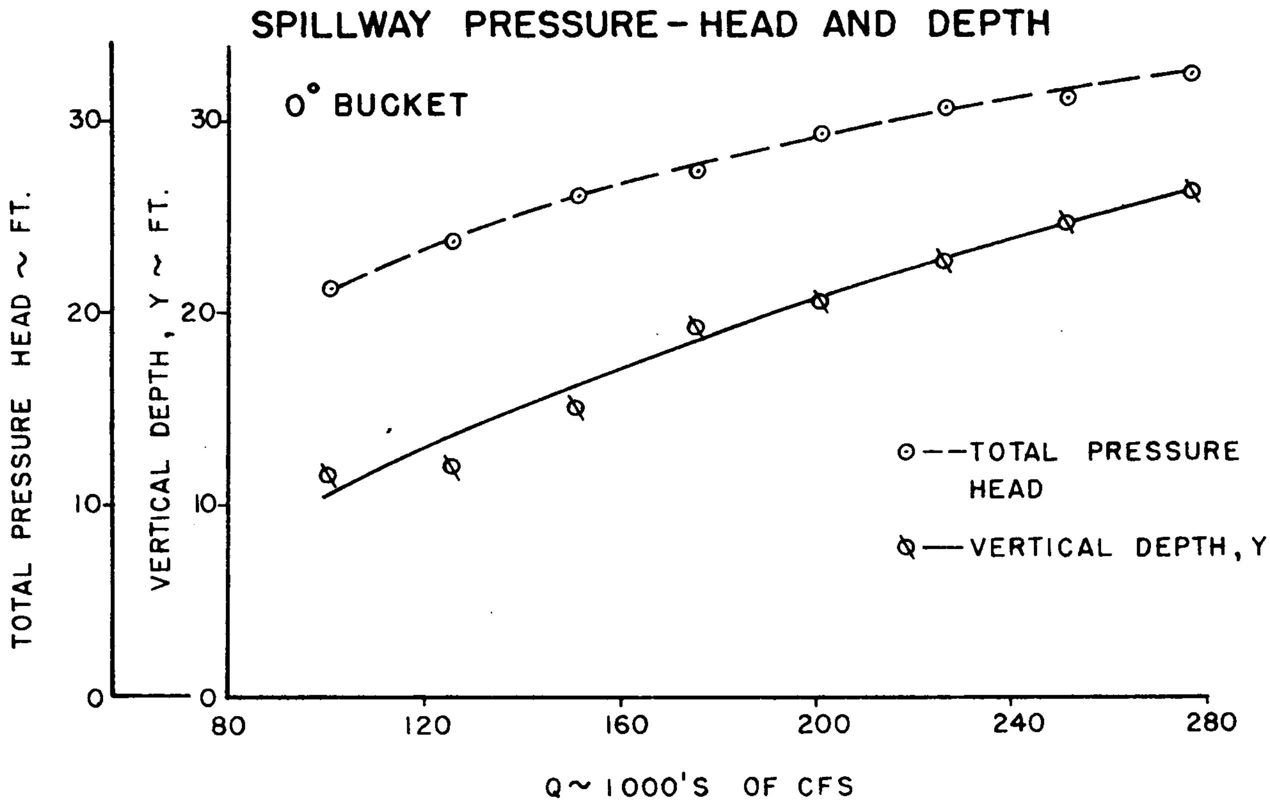


FIGURE 9 B

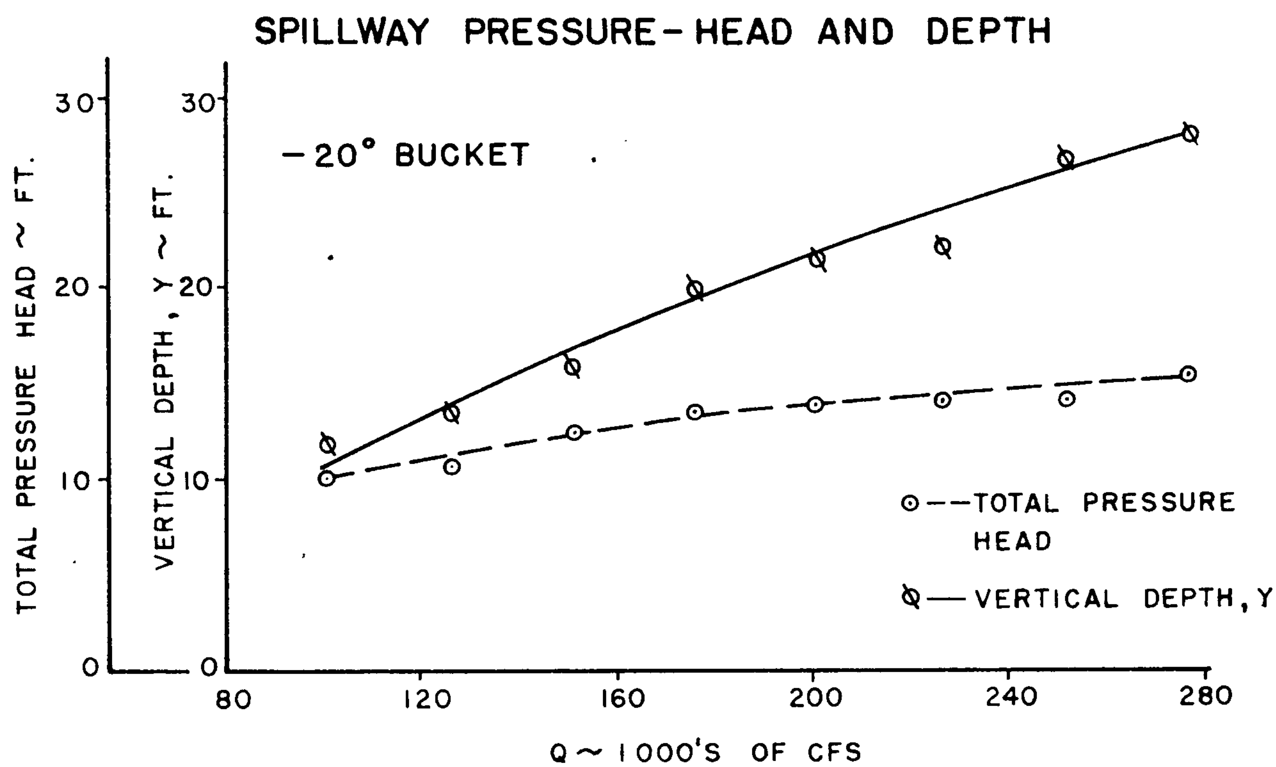


FIGURE 9C

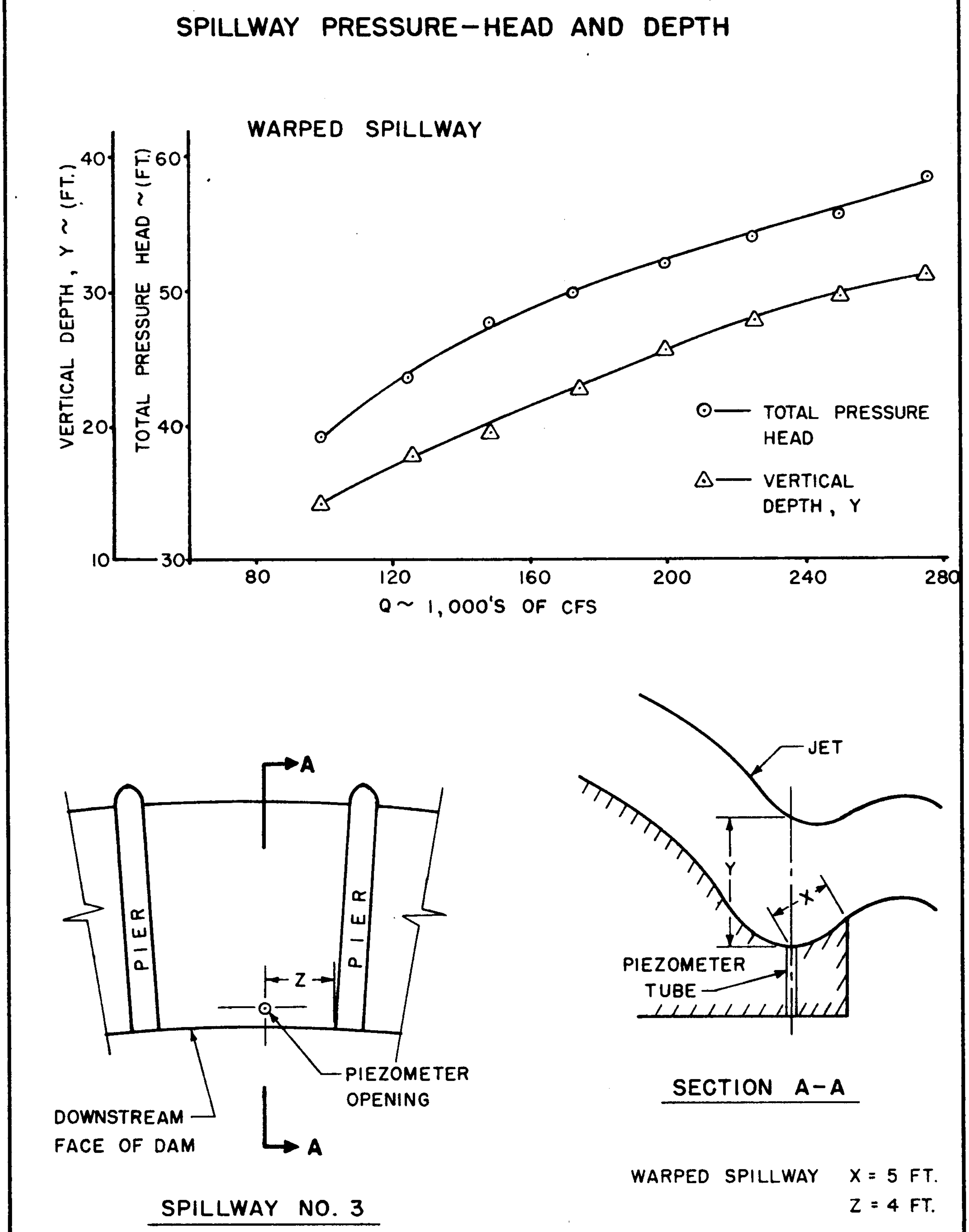

SPILLWAY PRESSURE-HEAD AND DEPTH
WARPED SPILLWAY
VERTICAL DEPTH , Y ~ (FT.)
TOTAL PRESSURE HEAD ~ (FT.)
10
20
30
40
30
40
50
60
80
120
160
200
240
280
Q ~ 1,000'S OF CFS
TOTAL PRESSURE HEAD
VERTICAL DEPTH , Y
A
PIER
PIER
Z
PIEZOMETER OPENING
DOWNSTREAM FACE OF DAM
A
SPILLWAY NO. 3
JET
Y
X
PIEZOMETER TUBE
SECTION A-A
WARPED SPILLWAY X = 5 FT.
Z = 4 FT.

FIGURE 9D

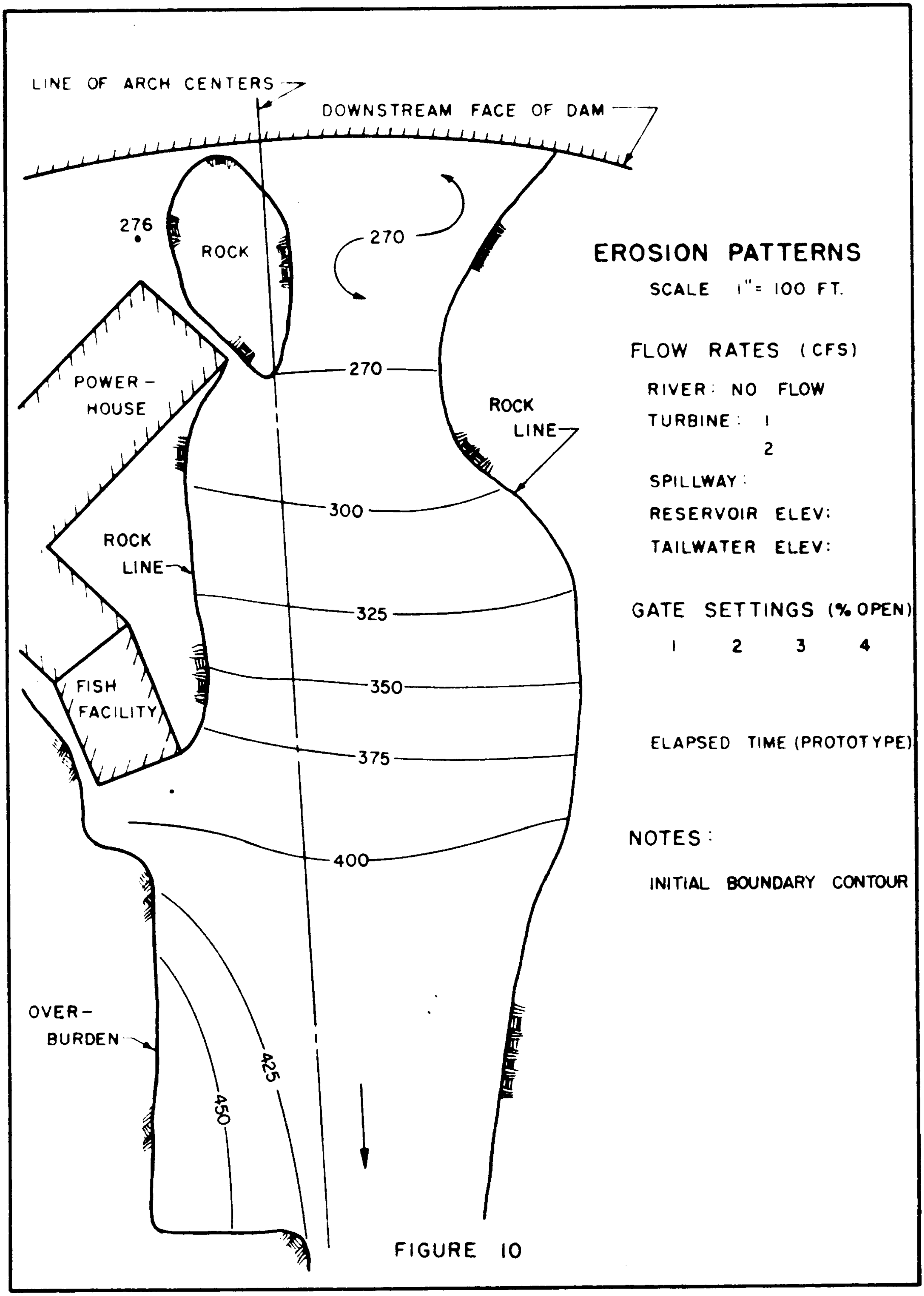
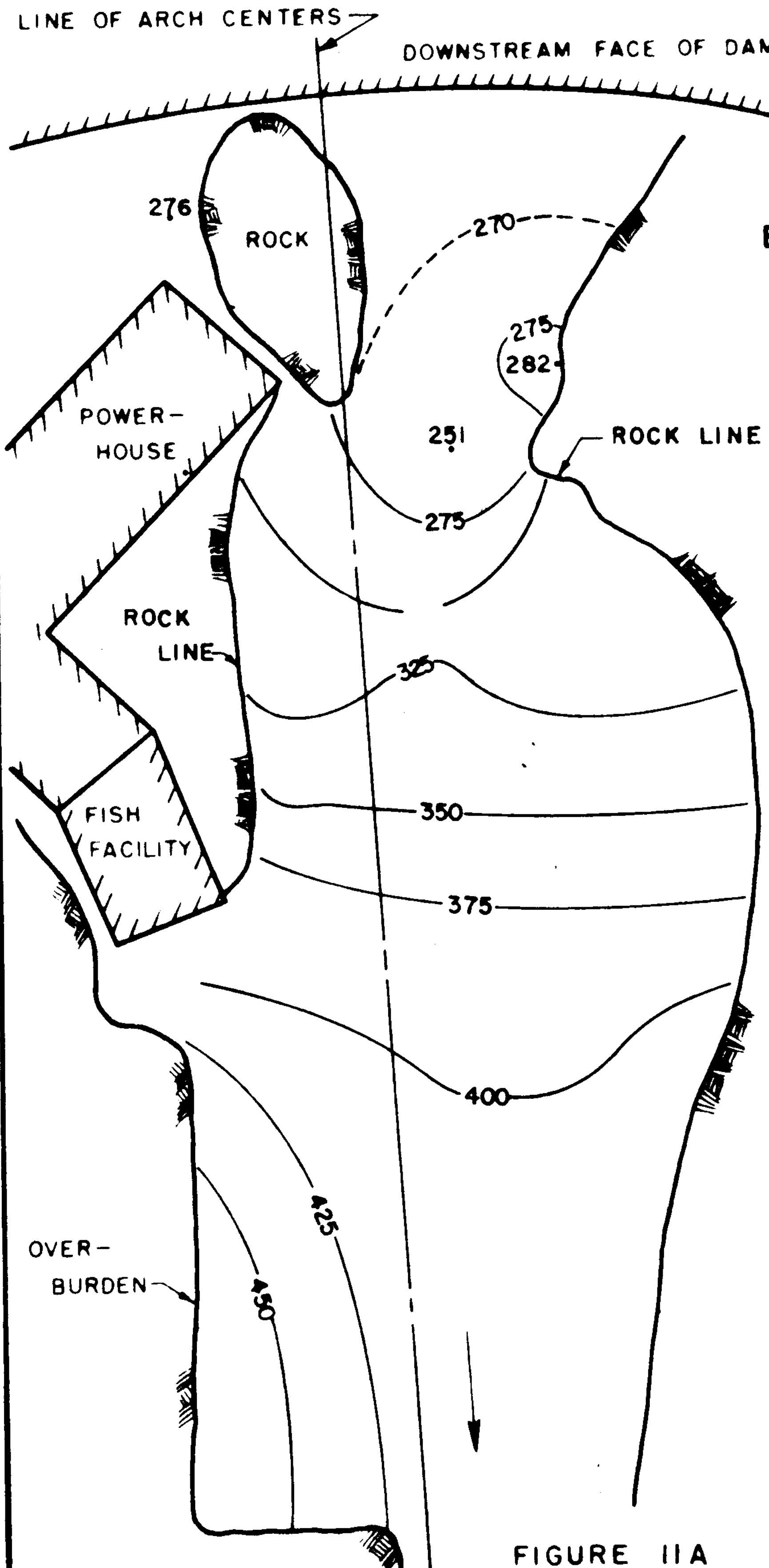

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
276
ROCK
270
270
POWER-
HOUSE
ROCK
LINE
ROCK
LINE
300
325
350
375
400
425
450
FISH
FACILITY
OVER-
BURDEN
EROSION PATTERNS
SCALE 1" = 100 FT.
FLOW RATES (CFS)
RIVER: NO FLOW
TURBINE: 1
2
SPILLWAY:
RESERVOIR ELEV:
TAILWATER ELEV:
GATE SETTINGS (% OPEN)
1 2 3 4
ELAPSED TIME (PROTOTYPE)
NOTES:
INITIAL BOUNDARY CONTOUR

FIGURE 10



EROSION PATTERNS

SCALE 1" = 100 FT.

FLOW RATES (CFS)

RIVER: 25,000

TURBINE: 1 7,200

2 7,200

SPILLWAY: 10,600

RESERVOIR ELEV 771

TAILWATER ELEV: 435

GATE SETTINGS (% OPEN)

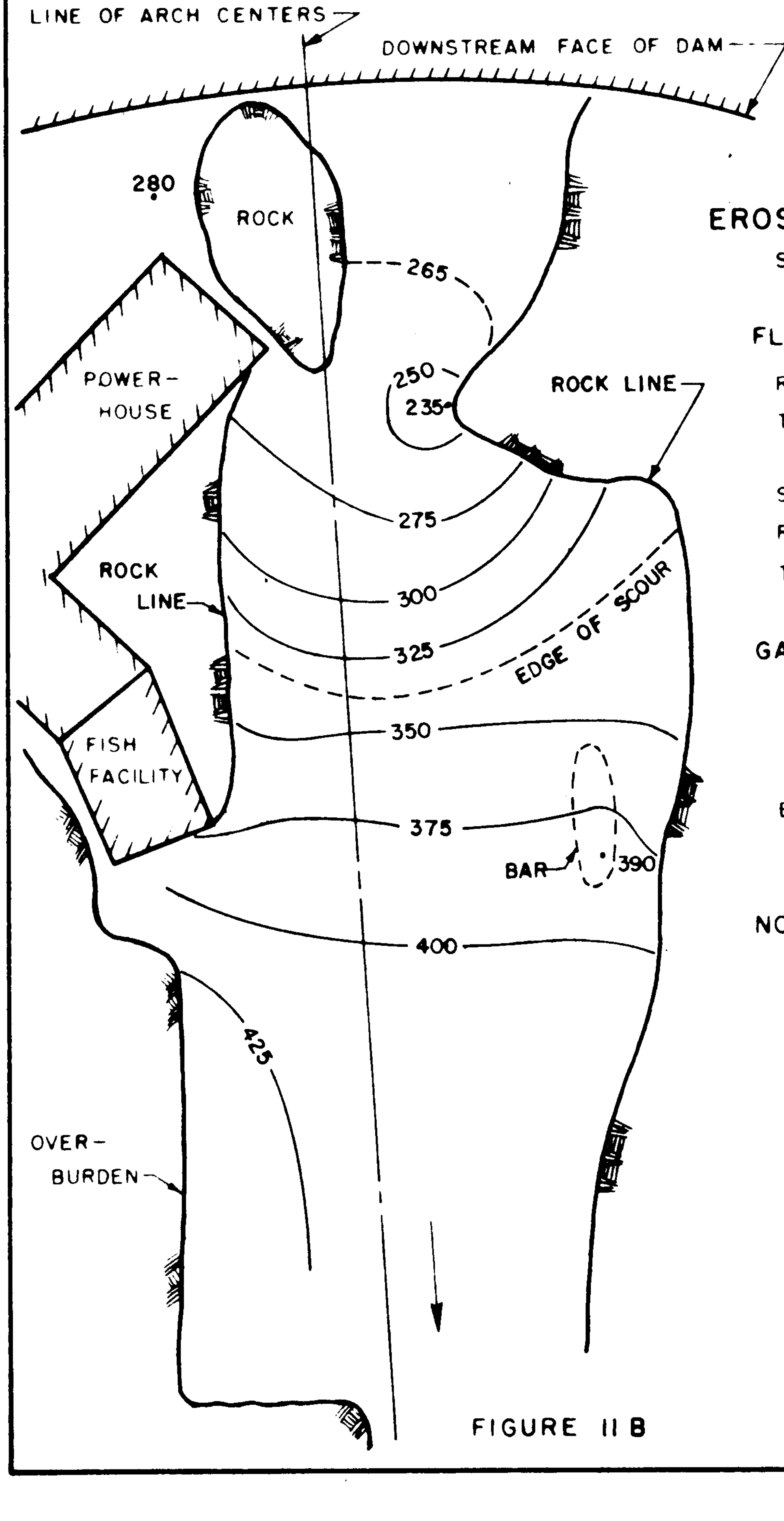
1	2	3	4
16.3			

ELAPSED TIME (PROTOTYPE)

271 MIN.

NOTES:

FIGURE 11A



EROSION PATTERNS

SCALE 1" = 100 FT.

FLOW RATES (CFS)

RIVER: 50,000

TURBINE: 1 7,200

2 7,200

SPILLWAY: 35,600

RESERVOIR ELEV: 770

TAILWATER ELEV: 450

GATE SETTINGS (% OPEN)

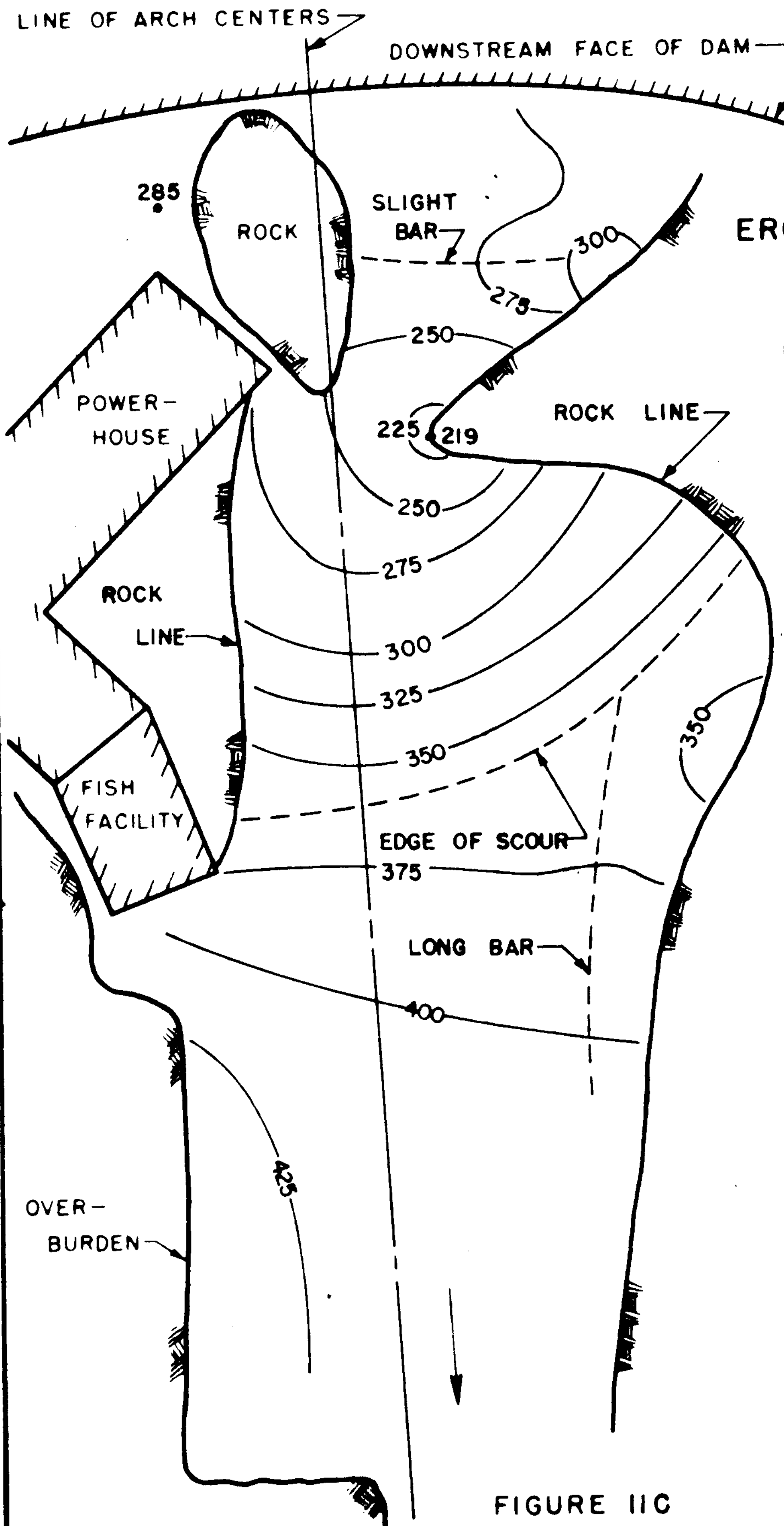
1	2	3	4
66.5			

ELAPSED TIME (PROTOTYPE)

271 MIN.

NOTES:

FIGURE 11 B



EROSION PATTERNS

SCALE 1" = 100 FT

FLOW RATES (CFS)

RIVER: 75,000
TURBINE: 1 7,200
2 7,200
SPILLWAY: 60,600
RESERVOIR ELEV 771
TAILWATER ELEV 460

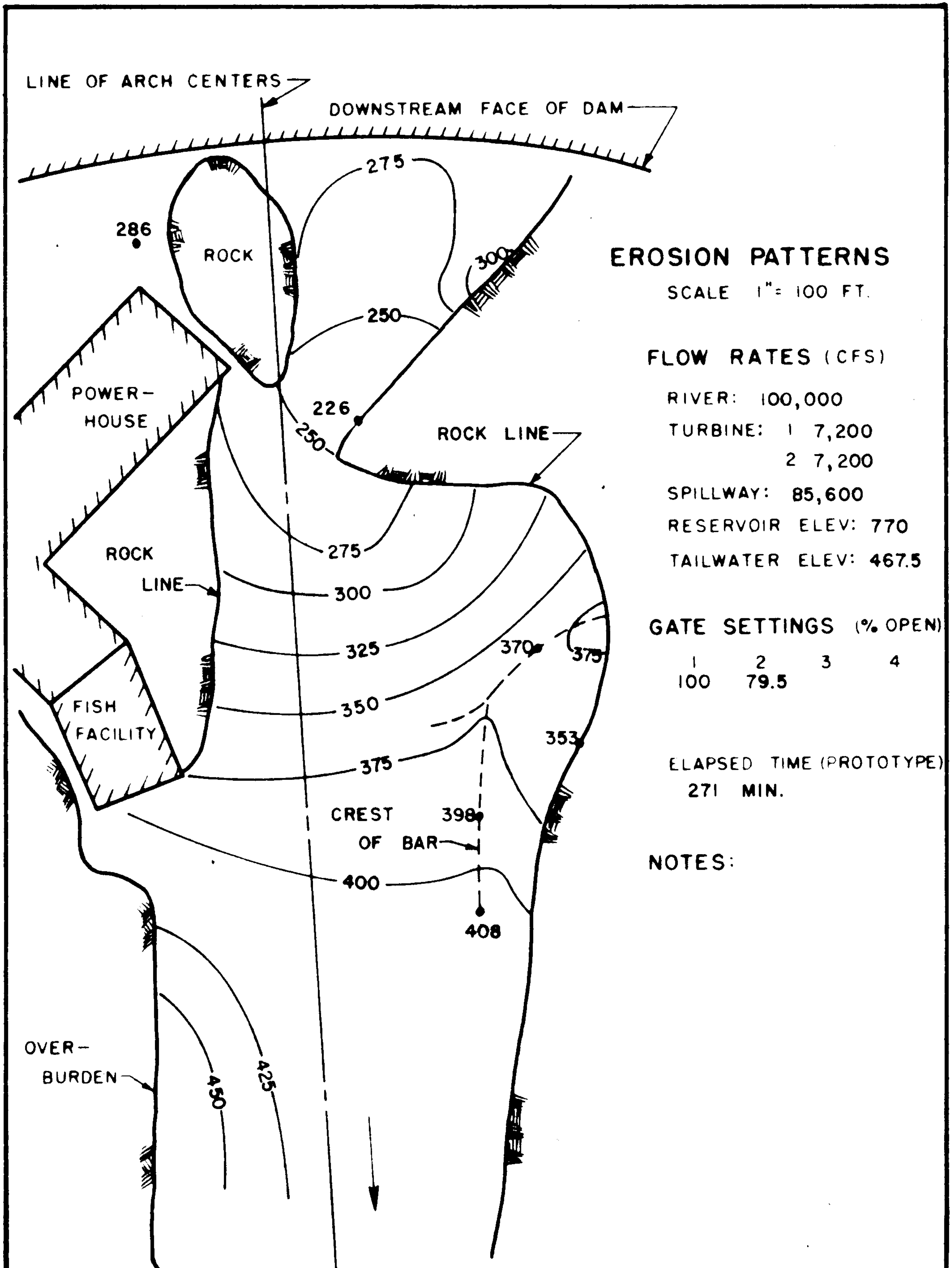
GATE SETTINGS (% OPEN)

1	2	3	4
100	26		

ELAPSED TIME (PROTOTYPE)
232 MIN.

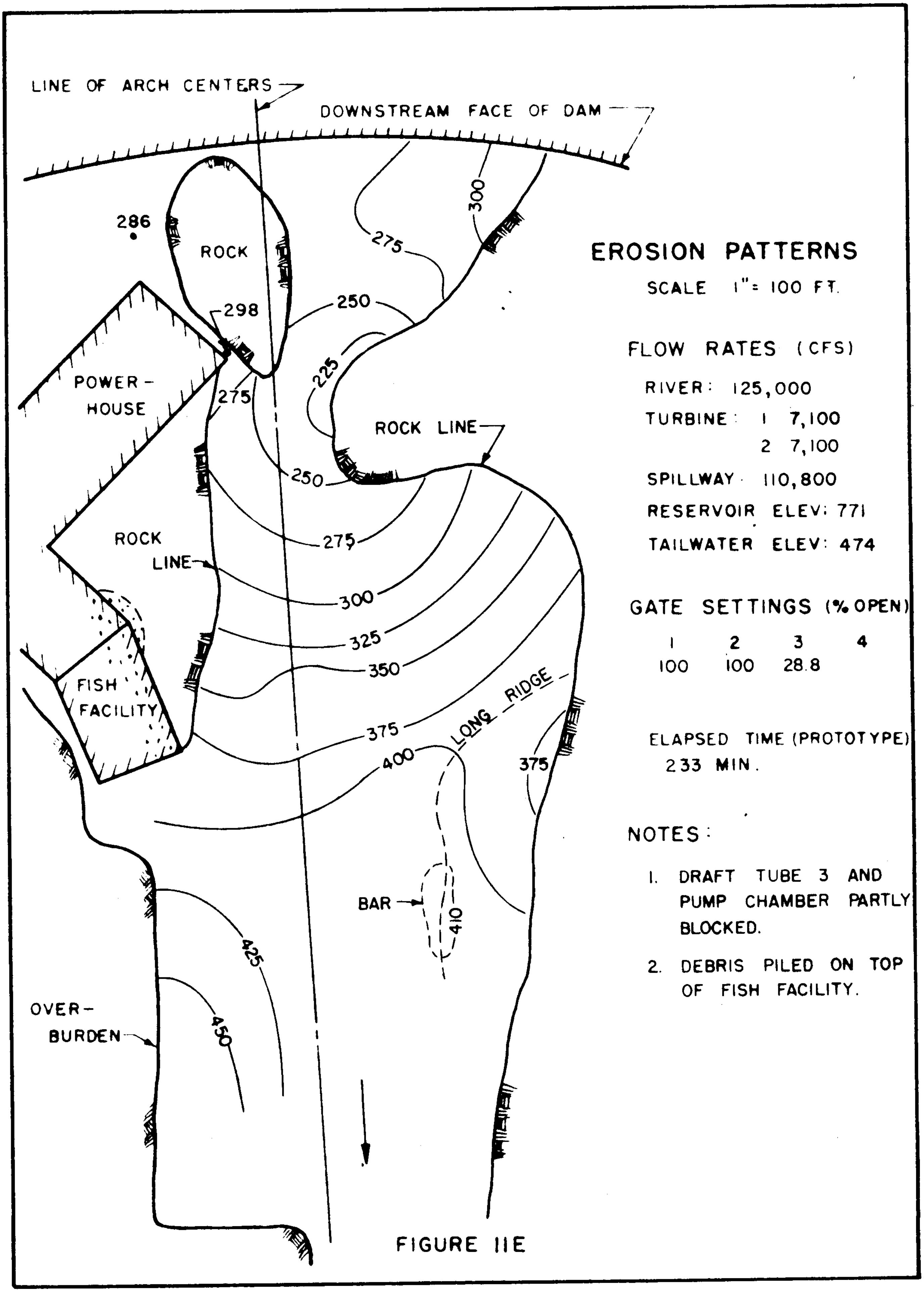
NOTES:

FIGURE 11C



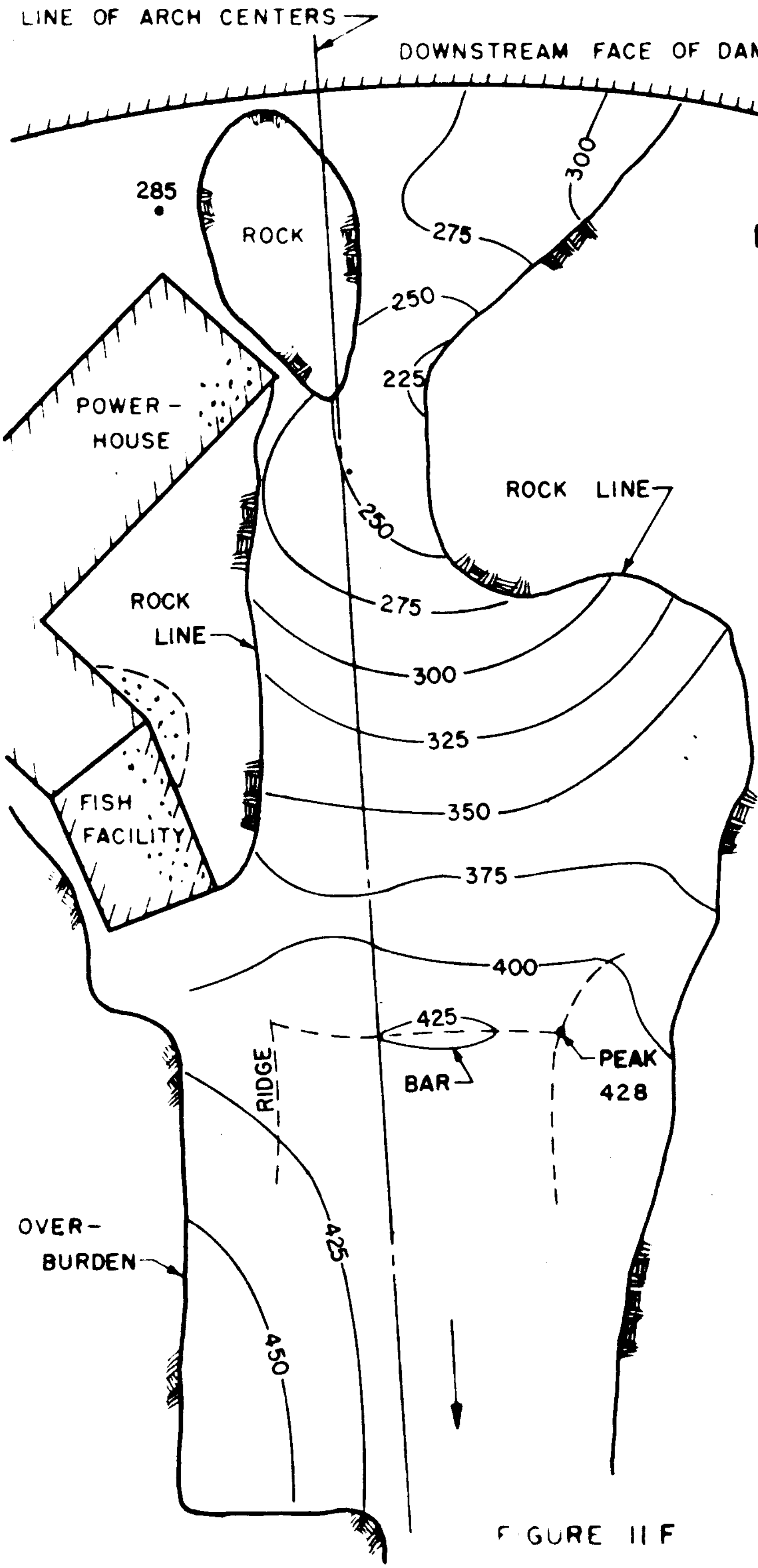
LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
275
286
ROCK
300
250
POWER-
HOUSE
226
250
ROCK LINE
ROCK
LINE
275
300
325
370
375
350
FISH
FACILITY
353
375
CREST
OF BAR
398
400
408
OVER-
BURDEN
450
425
EROSION PATTERNS
SCALE 1" = 100 FT.
FLOW RATES (CFS)
RIVER: 100,000
TURBINE: 1 7,200
2 7,200
SPILLWAY: 85,600
RESERVOIR ELEV: 770
TAILWATER ELEV: 467.5
GATE SETTINGS (% OPEN)
1 2 3 4
100 79.5
ELAPSED TIME (PROTOTYPE)
271 MIN.
NOTES:

FIGURE 11D



LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
286
ROCK
298
POWER-HOUSE
275
250
225
300
ROCK LINE
250
275
ROCK LINE
300
325
350
FISH FACILITY
375
400
LONG RIDGE
375
BAR
410
425
450
OVER-BURDEN
EROSION PATTERNS
SCALE 1" = 100 FT.
FLOW RATES (CFS)
RIVER: 125,000
TURBINE: 1 7,100
2 7,100
SPILLWAY 110,800
RESERVOIR ELEV: 771
TAILWATER ELEV: 474
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 28.8
ELAPSED TIME (PROTOTYPE)
233 MIN.
NOTES:
1. DRAFT TUBE 3 AND PUMP CHAMBER PARTLY BLOCKED.
2. DEBRIS PILED ON TOP OF FISH FACILITY.

FIGURE 11E



EROSION PATTERNS

SCALE 1" = 100 FT.

FLOW RATES (CFS)

RIVER: 150,000
TURBINE: 1
2
SPILLWAY: 150,000
RESERVOIR ELEV: 770
TAILWATER ELEV: 480

GATE SETTINGS (% OPEN)

1	2	3	4
100	100	100	19.3

ELAPSED TIME (PROTOTYPE)
271 MIN.

NOTES:

1. DEBRIS PILED ON TOP FISH FACILITY.
2. DRAFT TUBE 3 AND PUMP CHAMBER PARTLY BLOCKED.

FIGURE 11 F

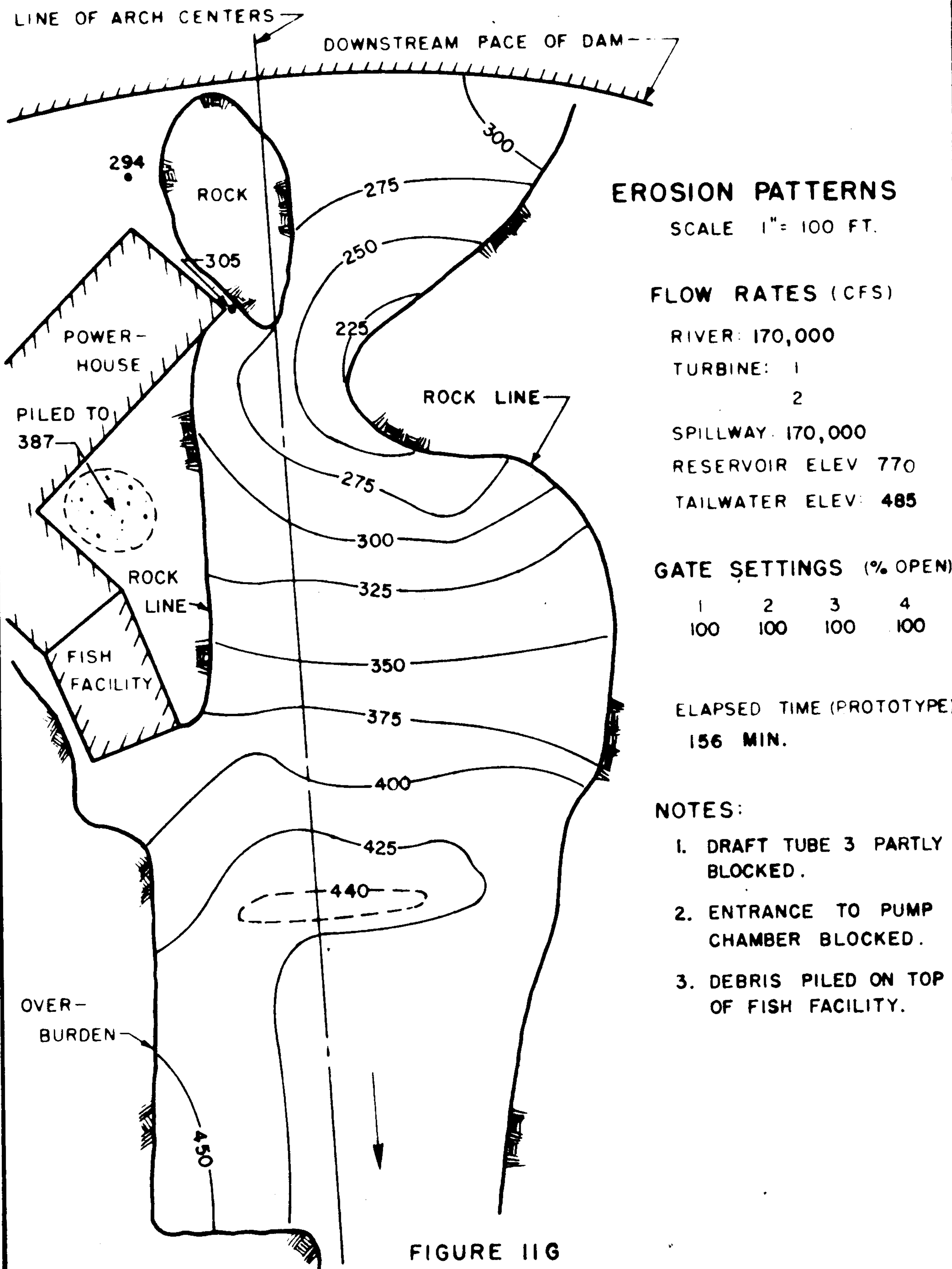
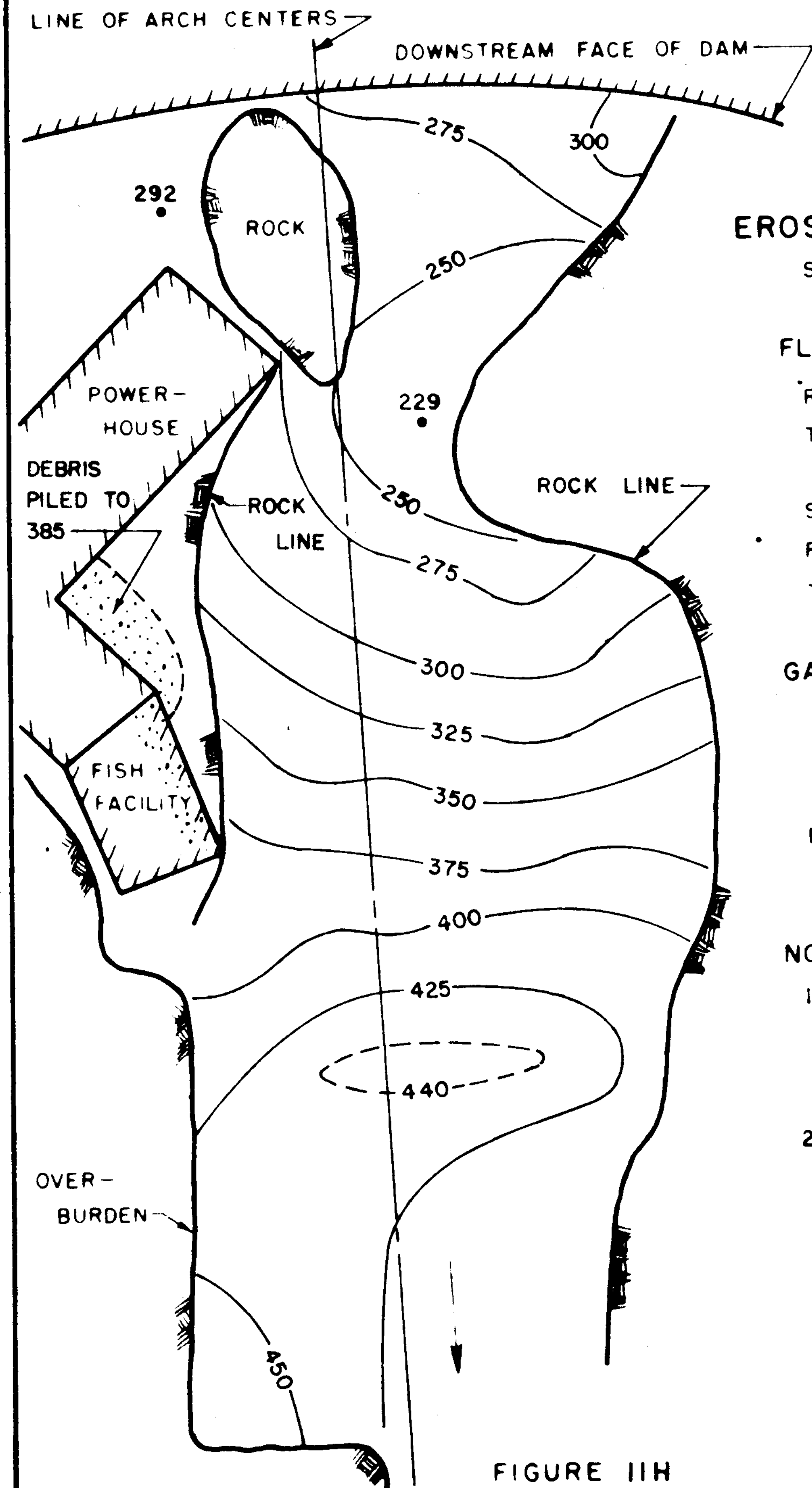

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
300
294
ROCK
275
305
250
225
POWER-HOUSE
ROCK LINE
PILED TO 387
275
300
ROCK LINE
325
FISH FACILITY
350
375
400
425
440
OVER-BURDEN
450
EROSION PATTERNS
SCALE 1" = 100 FT.
FLOW RATES (CFS)
RIVER: 170,000
TURBINE: 1
2
SPILLWAY: 170,000
RESERVOIR ELEV 770
TAILWATER ELEV: 485
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
ELAPSED TIME (PROTOTYPE)
156 MIN.
NOTES:
1. DRAFT TUBE 3 PARTLY BLOCKED.
2. ENTRANCE TO PUMP CHAMBER BLOCKED.
3. DEBRIS PILED ON TOP OF FISH FACILITY.

FIGURE 11G



EROSION PATTERNS

SCALE 1" = 100 FT

FLOW RATES (CFS)

RIVER 170,000
TURBINE: 1
2
SPILLWAY 170,000
RESERVOIR ELEV 770
TAILWATER ELEV 485

GATE SETTINGS (% OPEN)

1	2	3	4
100	100	100	100

ELAPSED TIME (PROTOTYPE)
271 MIN.

NOTES:

1. DRAFT TUBE 1 AND ENTRANCE TO PUMP CHAMBER PARTLY BLOCKED.
2. DEBRIS PILED ON TOP OF FISH FACILITY.

FIGURE 11H

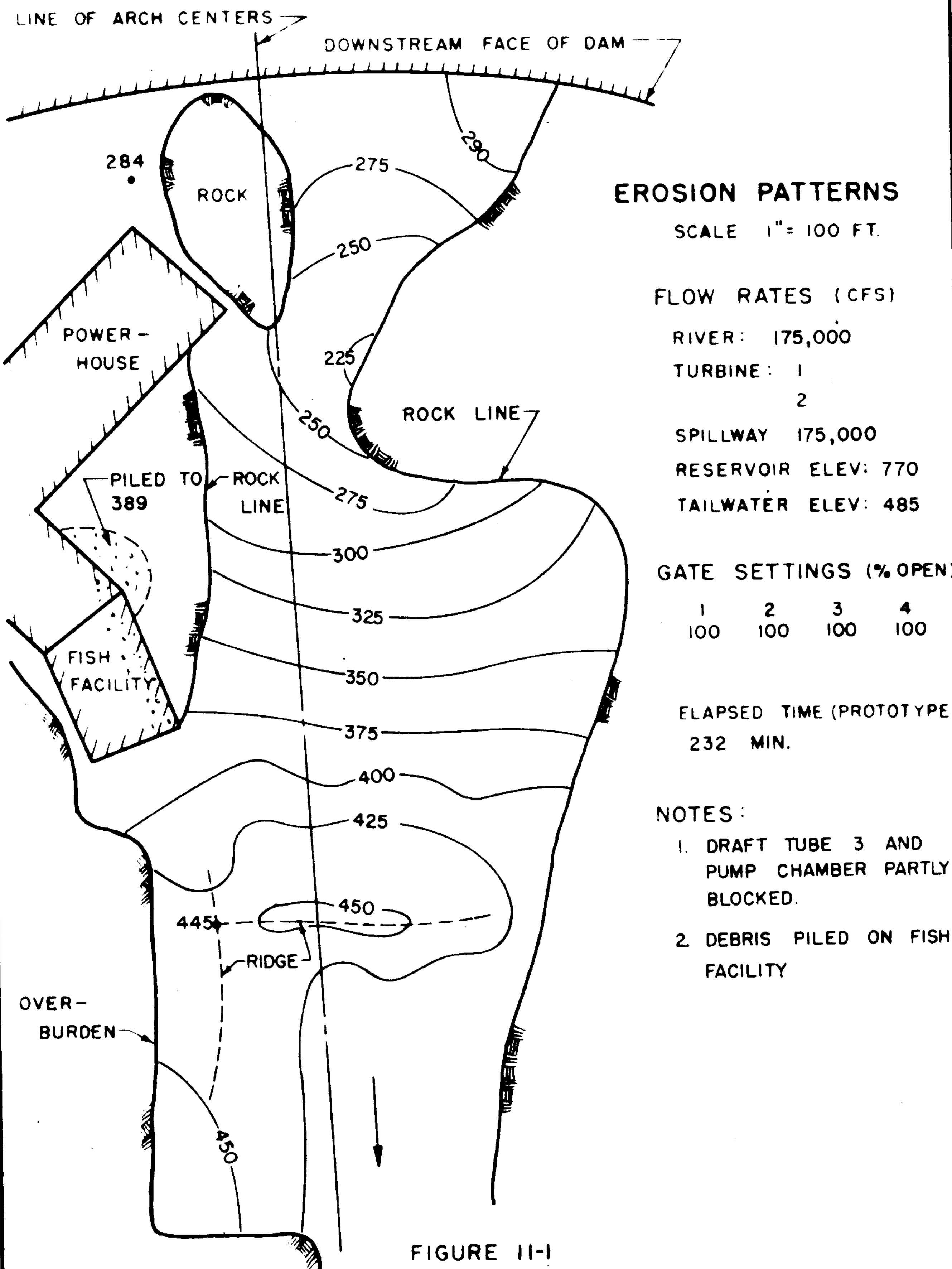
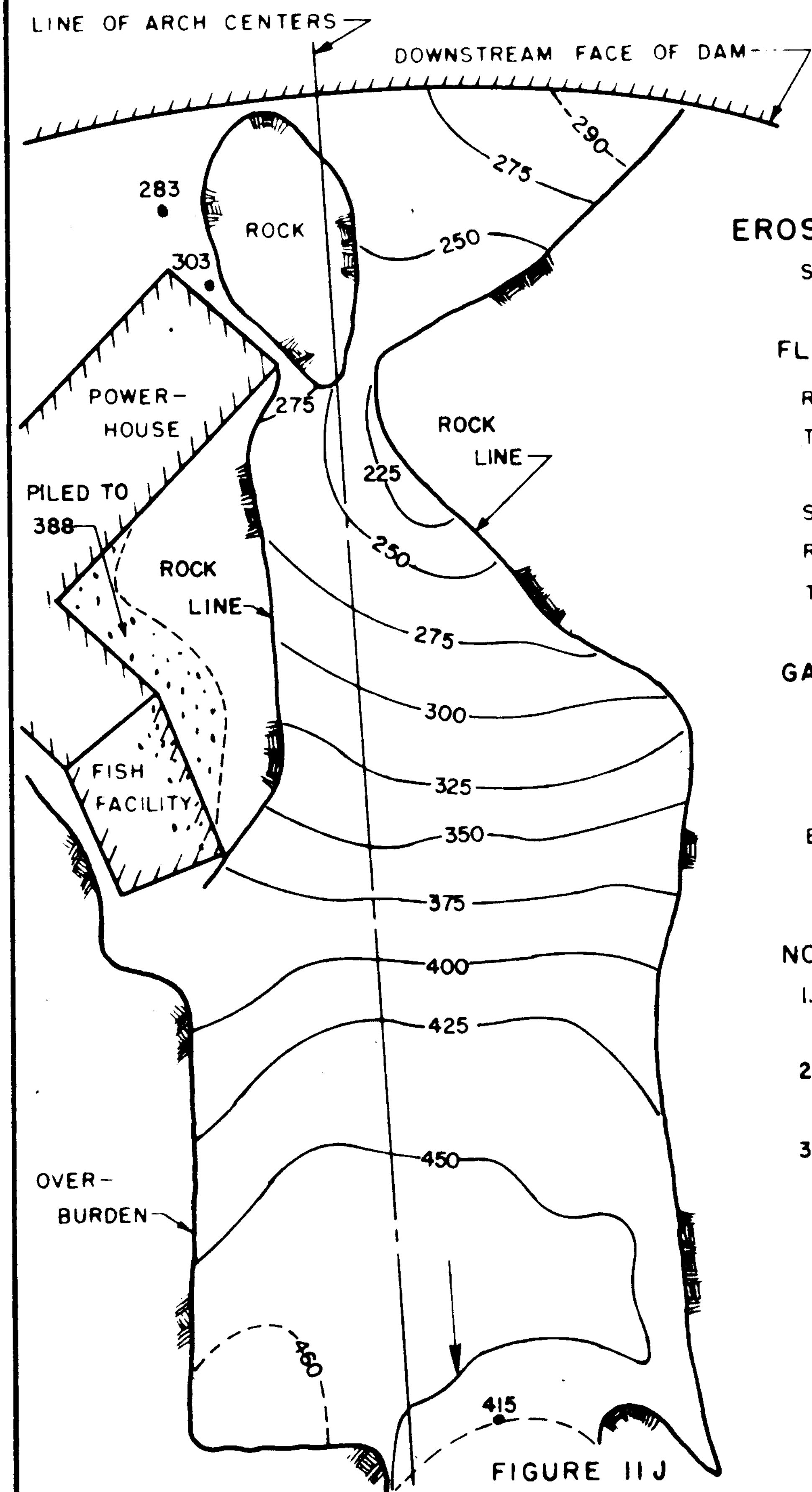

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
284
ROCK
275
290
250
225
POWER-HOUSE
ROCK LINE
250
PILED TO 389
ROCK LINE
275
300
325
350
375
FISH FACILITY
400
425
450
445
RIDGE
OVER-BURDEN
450
EROSION PATTERNS
SCALE 1" = 100 FT.
FLOW RATES (CFS)
RIVER: 175,000
TURBINE: 1
2
SPILLWAY 175,000
RESERVOIR ELEV: 770
TAILWATER ELEV: 485
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
ELAPSED TIME (PROTOTYPE)
232 MIN.
NOTES:
1. DRAFT TUBE 3 AND PUMP CHAMBER PARTLY BLOCKED.
2. DEBRIS PILED ON FISH FACILITY

FIGURE 11-1



EROSION PATTERNS

SCALE 1" = 100 FT.

FLOW RATES (CFS)

RIVER: 275,000
TURBINE: 1
2
SPILLWAY: 275,000
RESERVOIR ELEV: 782.9
TAILWATER ELEV: 505

GATE SETTINGS (% OPEN)

1	2	3	4
100	100	100	100

ELAPSED TIME (PROTOTYPE)
193 MIN.

NOTES:

1. DRAFT TUBES 1,2 AND 3 PARTLY BLOCKED.
2. PUMP CHAMBER PARTLY BLOCKED.
3. DEBRIS PILED ON FISH FACILITY.

FIGURE 11 J

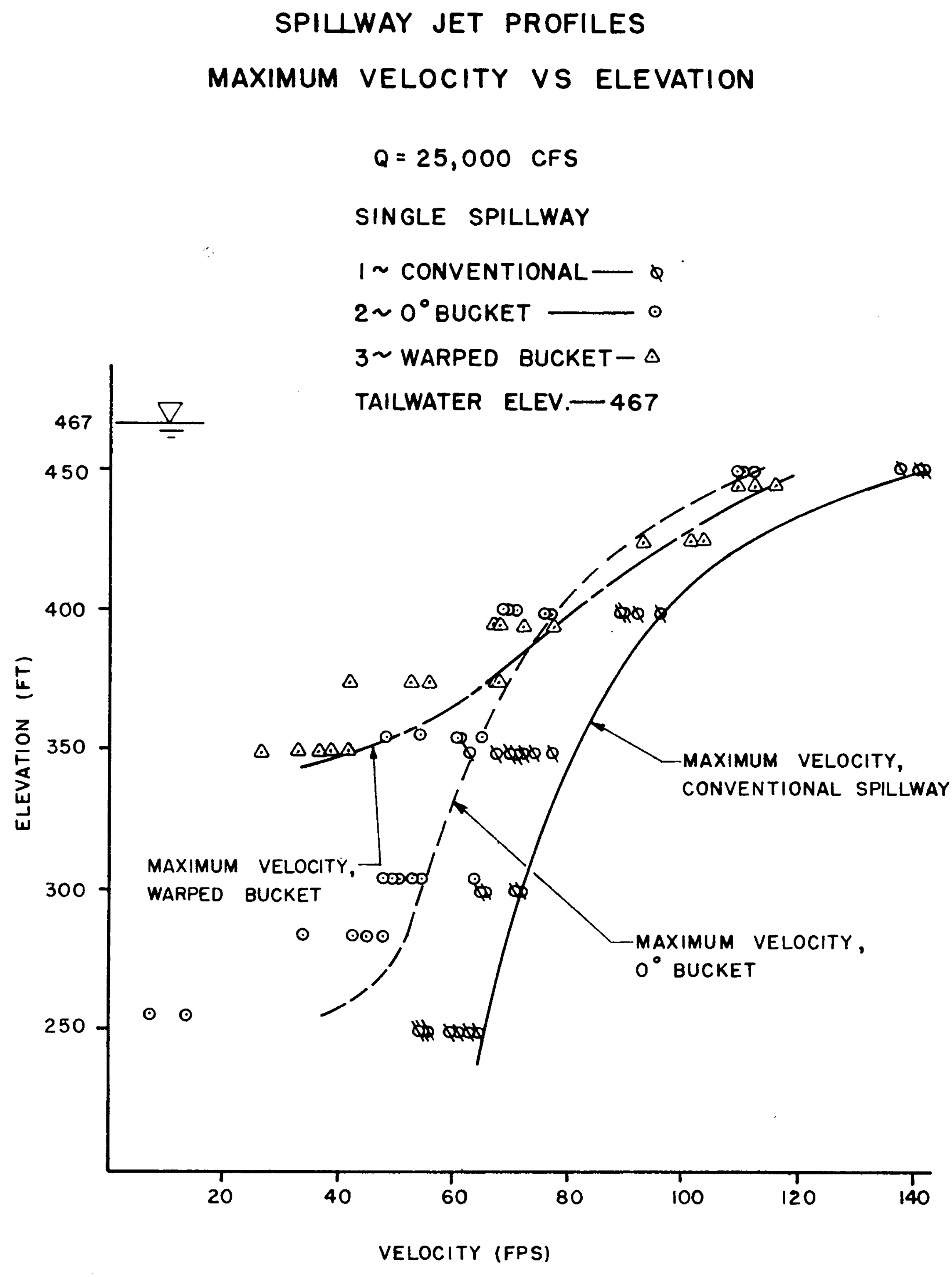
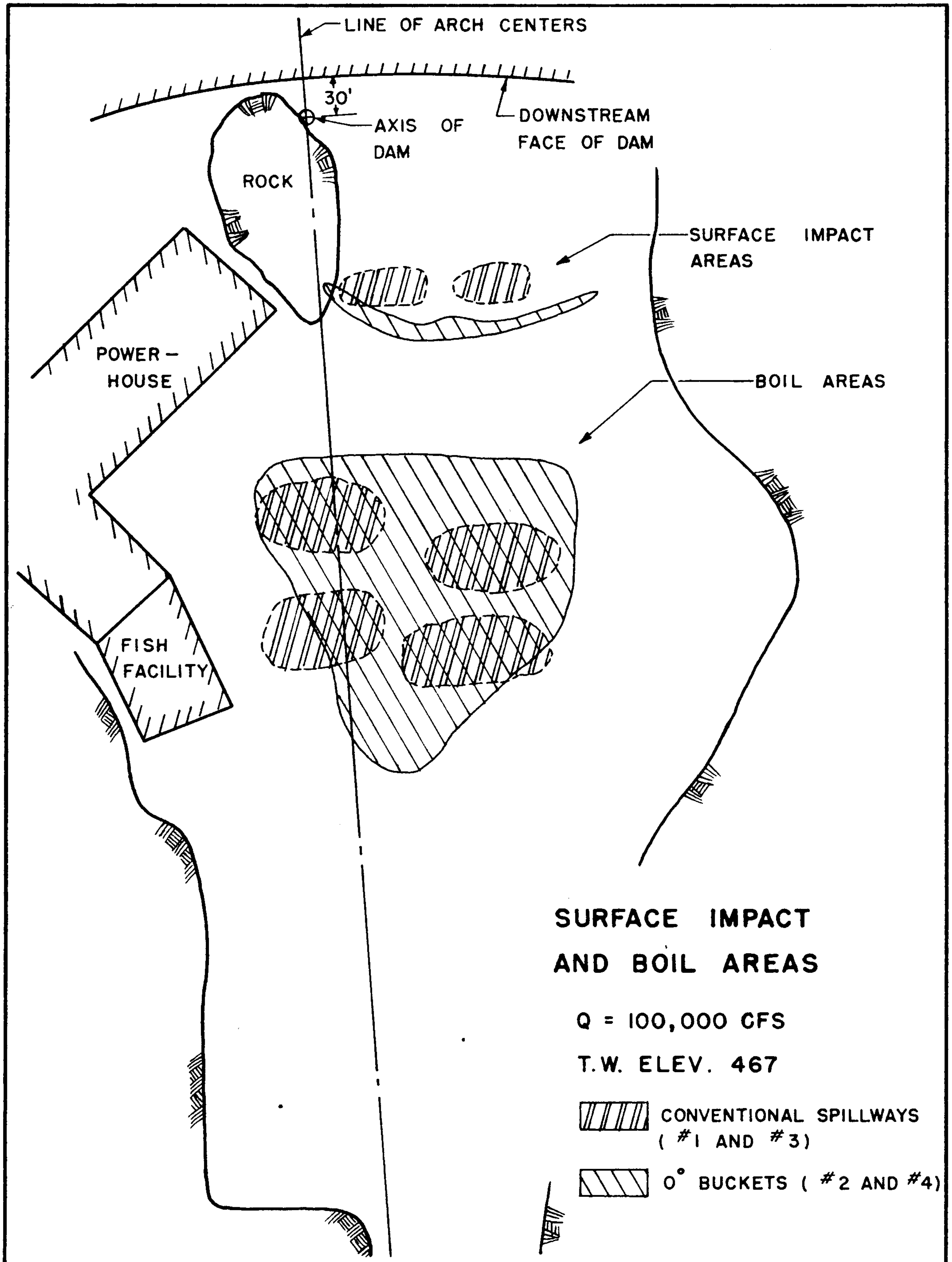

SPILLWAY JET PROFILES
MAXIMUM VELOCITY VS ELEVATION
Q = 25,000 CFS
SINGLE SPILLWAY
1 ~ CONVENTIONAL
2 ~ 0° BUCKET
3 ~ WARPED BUCKET
TAILWATER ELEV. — 467
467
450
400
350
300
250
ELEVATION (FT)
20
40
60
80
100
120
140
VELOCITY (FPS)
MAXIMUM VELOCITY, WARPED BUCKET
MAXIMUM VELOCITY, 0° BUCKET
MAXIMUM VELOCITY, CONVENTIONAL SPILLWAY

FIGURE 12



LINE OF ARCH CENTERS
30'
AXIS OF DAM
DOWNSTREAM FACE OF DAM
ROCK
SURFACE IMPACT AREAS
POWER-HOUSE
BOIL AREAS
FISH FACILITY
SURFACE IMPACT AND BOIL AREAS
Q = 100,000 CFS
T.W. ELEV. 467
CONVENTIONAL SPILLWAYS (#1 AND #3)
0° BUCKETS (#2 AND #4)

FIGURE 13

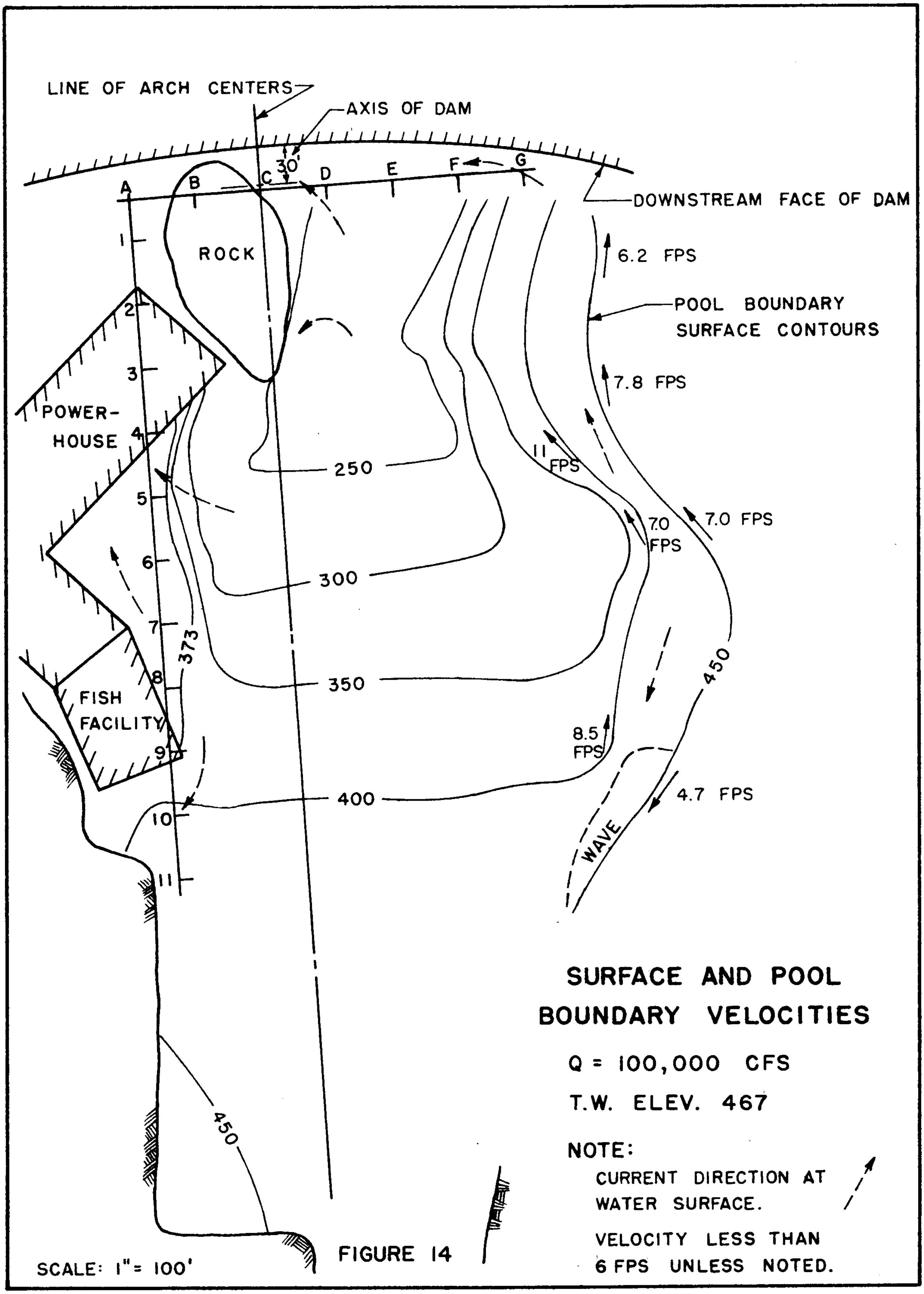

LINE OF ARCH CENTERS
AXIS OF DAM
30'
A
B
C
D
E
F
G
DOWNSTREAM FACE OF DAM
ROCK
6.2 FPS
POOL BOUNDARY
SURFACE CONTOURS
7.8 FPS
POWER-
HOUSE
250
11 FPS
7.0 FPS
7.0 FPS
300
373
350
450
FISH
FACILITY
8.5 FPS
4.7 FPS
400
WAVE
450
1
2
3
4
5
6
7
8
9
10
11
SURFACE AND POOL
BOUNDARY VELOCITIES
Q = 100,000 CFS
T.W. ELEV. 467
NOTE:
CURRENT DIRECTION AT
WATER SURFACE.
VELOCITY LESS THAN
6 FPS UNLESS NOTED.
SCALE: 1" = 100'

FIGURE 14

SAMPLE OF PRESSURE-WAVE RECORD

BETWEEN DRAFT TUBES 1 AND 2

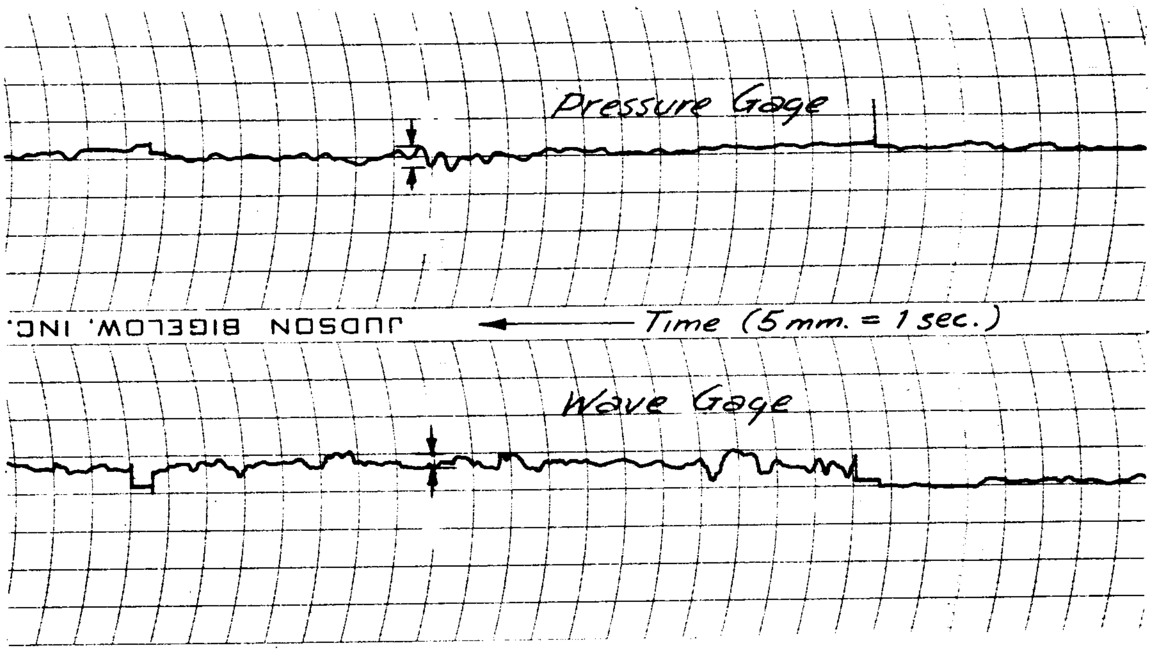
BAYS 1 AND 3 CONVENTIONAL

Q = 100,000 CFS

ELEV. 375

PRESSURE SCALE 100: 5 MM. = 0.078 PSI ≈ 0.18 FT. WATER

WAVE GAGE SCALE: 2.5 MM. = 1" WATER



SAMPLE PRESSURE CALCULATION:

TOTAL PRESSURE HEAD = 0.07 FT. (MODEL)

FIGURE 15

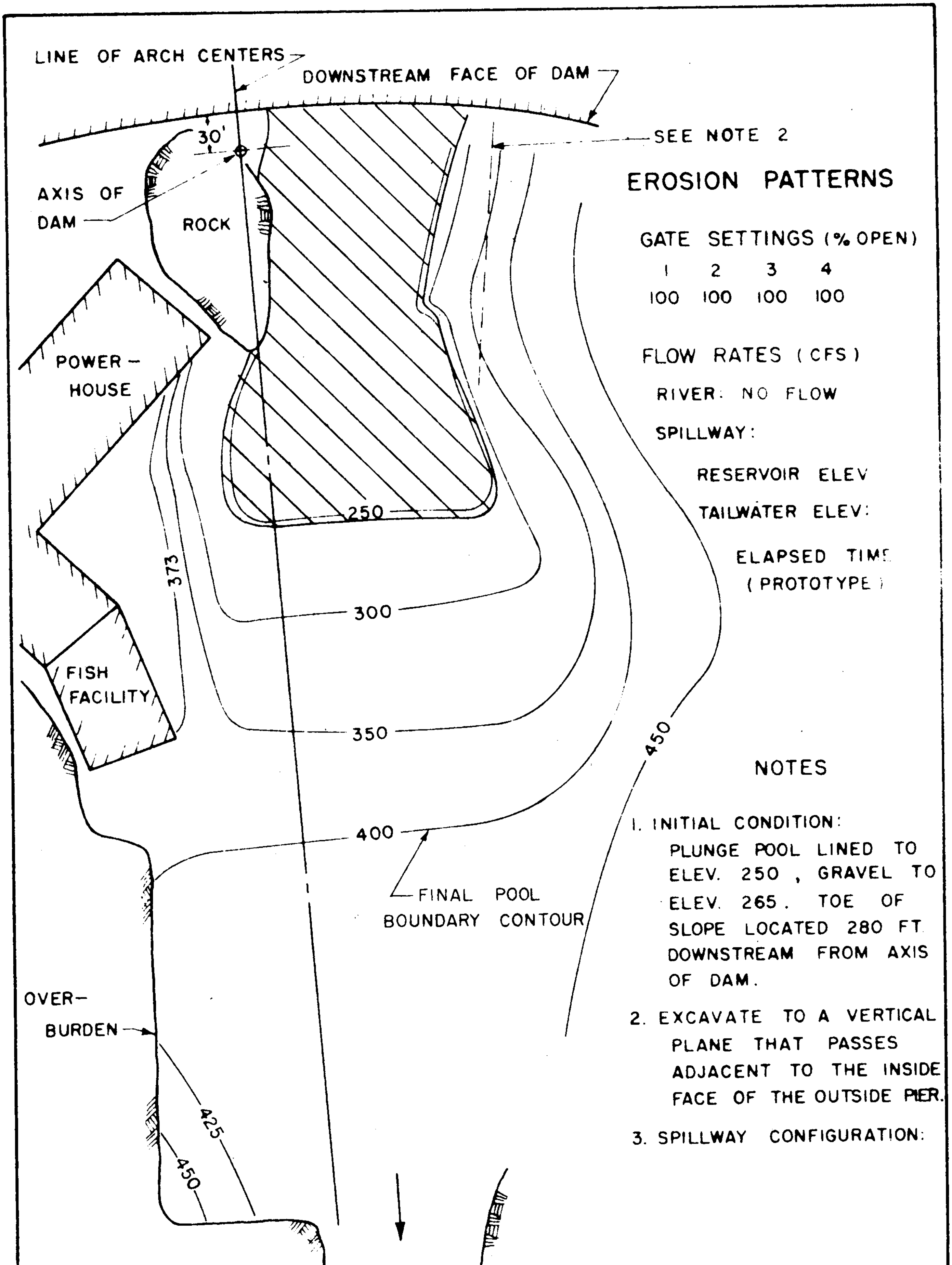
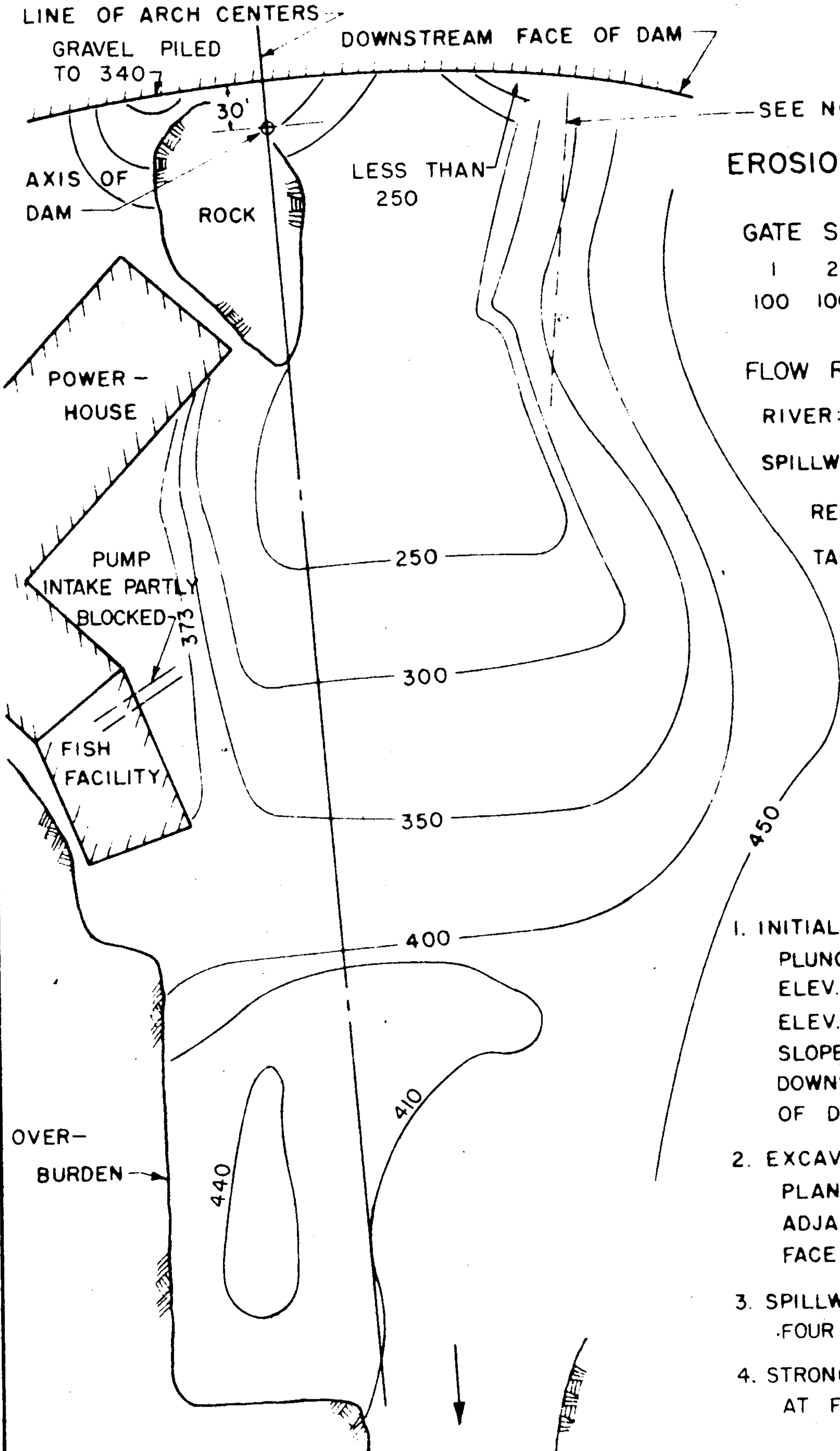

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
SEE NOTE 2
30'
AXIS OF DAM
ROCK
POWER-HOUSE
FISH FACILITY
250
300
350
373
400
450
425
450
FINAL POOL BOUNDARY CONTOUR
OVER-BURDEN
EROSION PATTERNS
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
FLOW RATES (CFS)
RIVER: NO FLOW
SPILLWAY:
RESERVOIR ELEV
TAILWATER ELEV:
ELAPSED TIME (PROTOTYPE)
NOTES
1. INITIAL CONDITION: PLUNGE POOL LINED TO ELEV. 250, GRAVEL TO ELEV. 265. TOE OF SLOPE LOCATED 280 FT DOWNSTREAM FROM AXIS OF DAM.
2. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
3. SPILLWAY CONFIGURATION:
SCALE: 1" = 100 FT.

FIGURE 16



EROSION PATTERNS

GATE SETTINGS (% OPEN)

1	2	3	4
100	100	100	100

FLOW RATES (CFS)

RIVER: 275,000

SPILLWAY: 275,000

RESERVOIR ELEV:

TAILWATER ELEV:

ELAPSED TIME (PROTOTYPE) 116 MIN.

NOTES

1. INITIAL CONDITION: PLUNGE POOL LINED TO ELEV. 250, GRAVEL TO ELEV. 265. TOE OF SLOPE LOCATED 280 FT DOWNSTREAM FROM AXIS OF DAM.
2. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
3. SPILLWAY CONFIGURATION: FOUR CONVENTIONAL.
4. STRONG BOIL AND UPWELLING AT FACE OF DAM.

SCALE: 1" = 100 FT

FIGURE 17

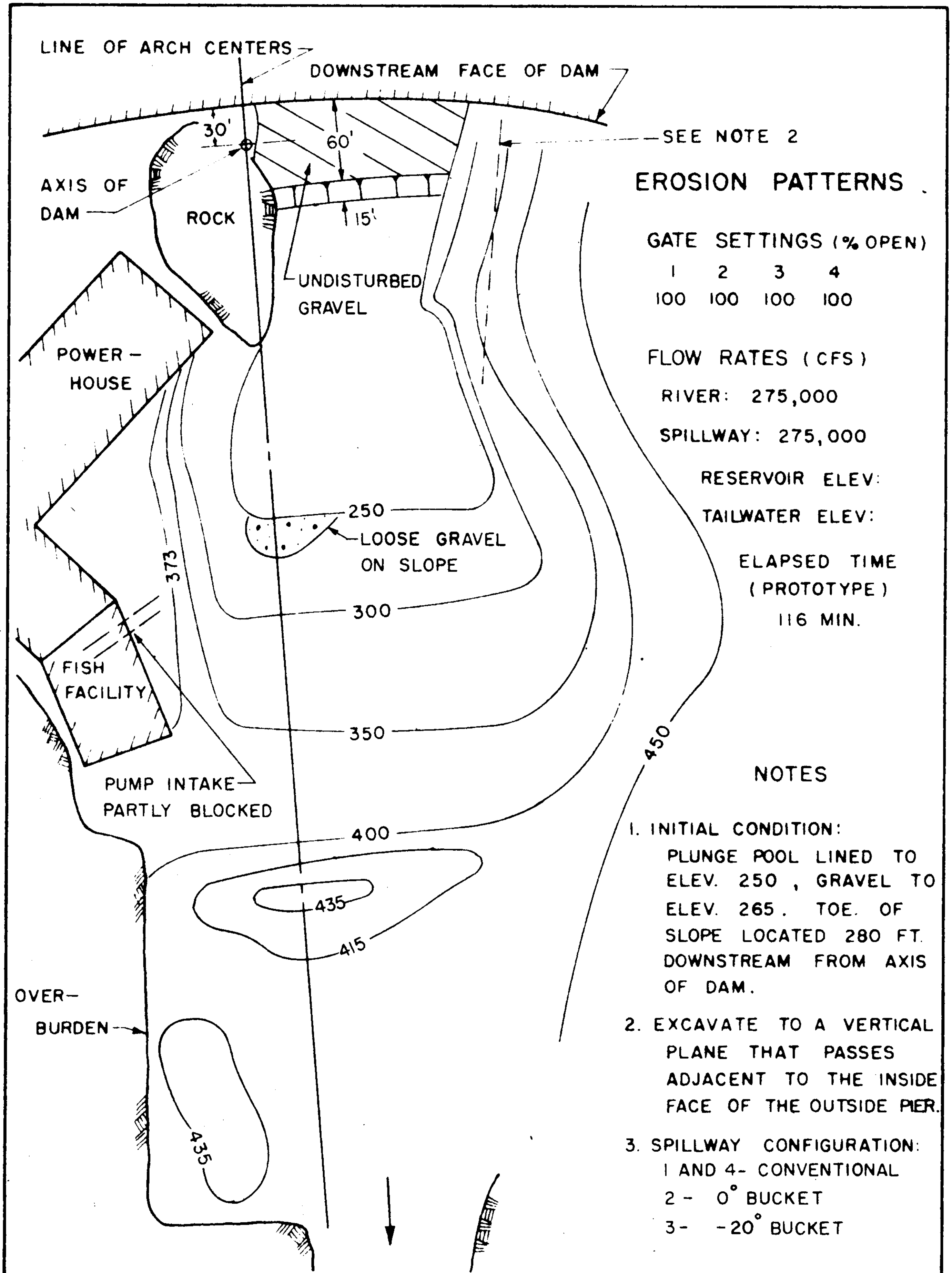
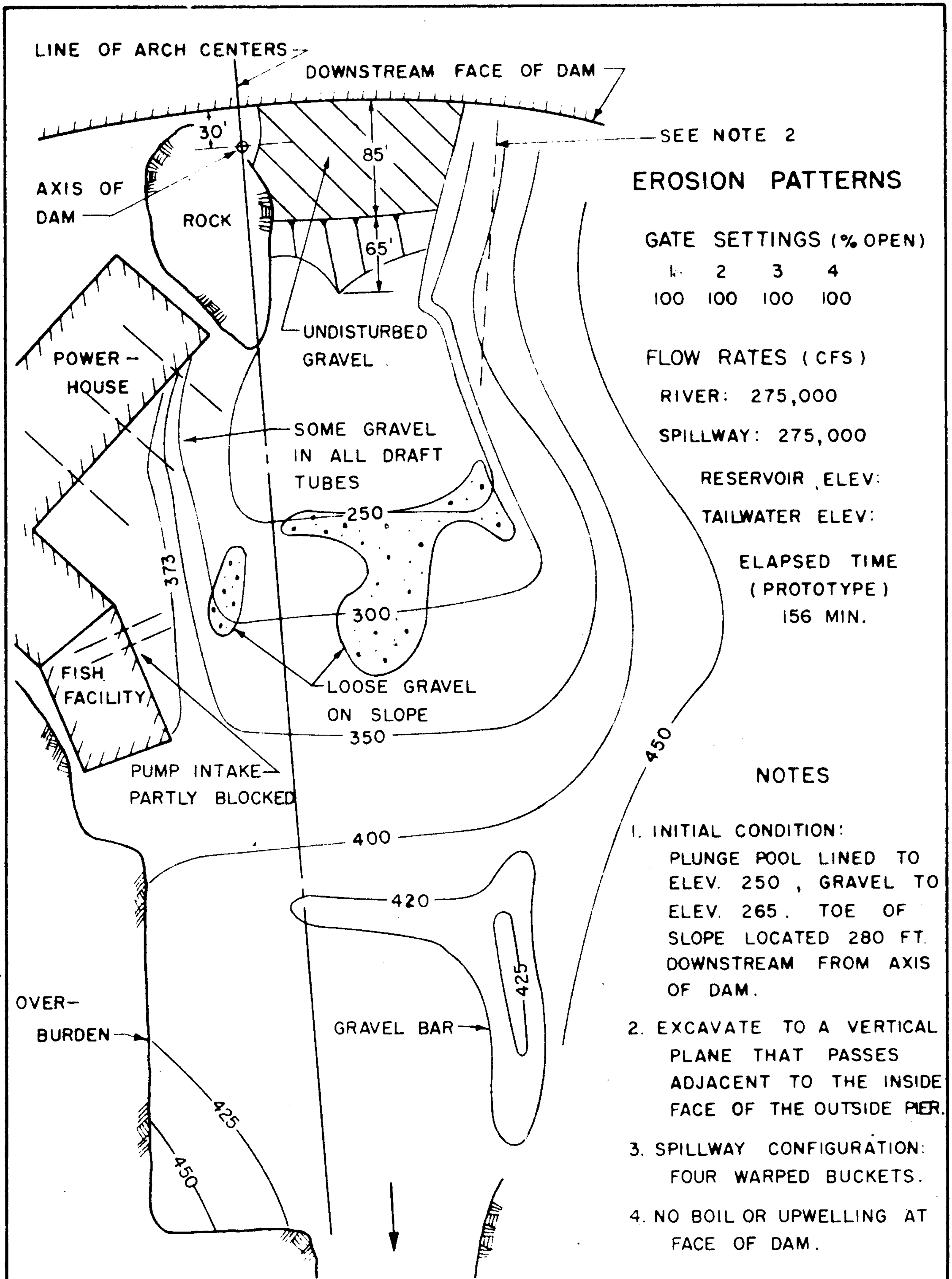
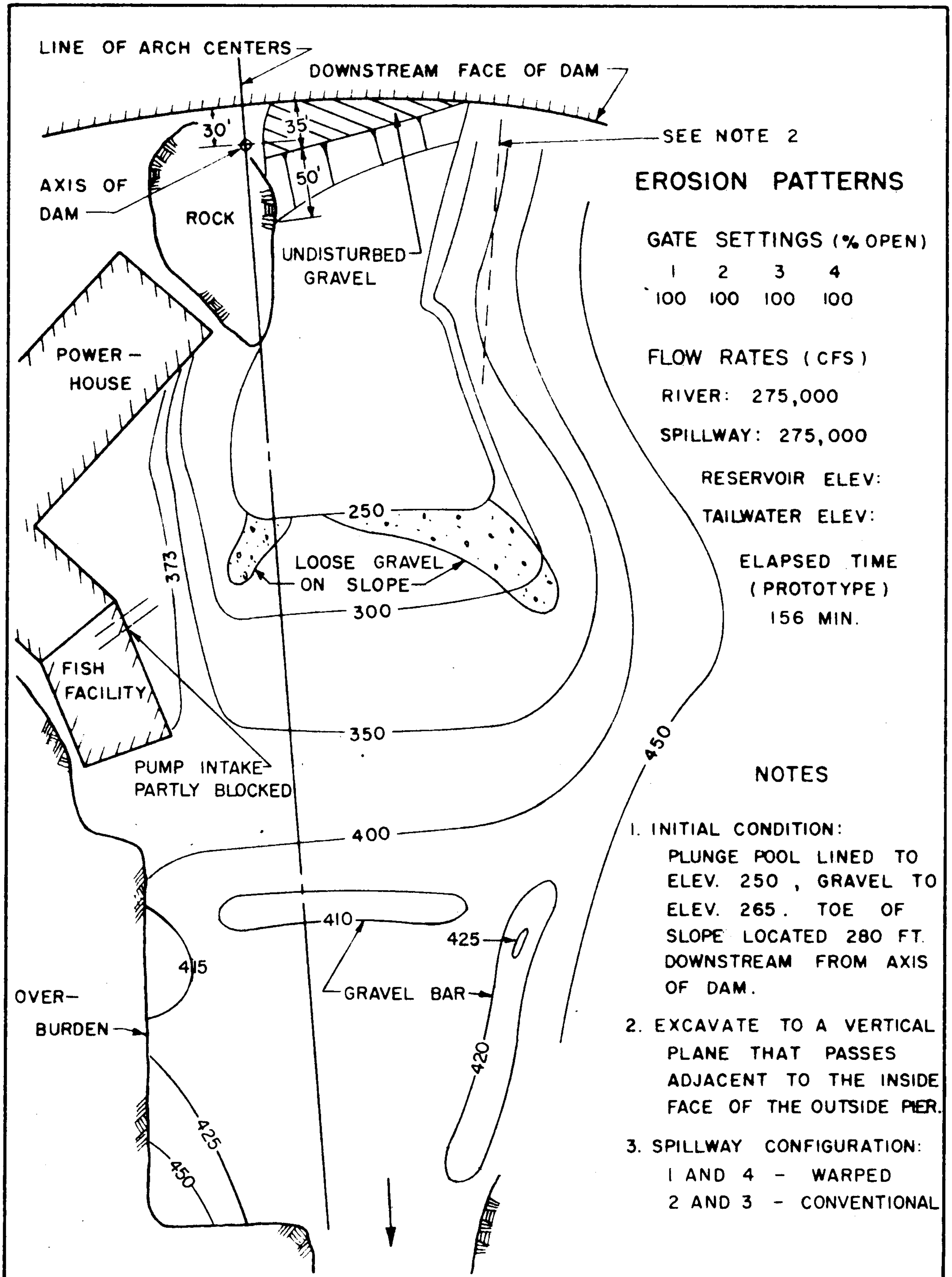

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
SEE NOTE 2
30'
60'
15'
AXIS OF DAM
ROCK
UNDISTURBED GRAVEL
POWER-HOUSE
250
LOOSE GRAVEL ON SLOPE
373
300
FISH FACILITY
350
PUMP INTAKE PARTLY BLOCKED
400
435
415
450
OVER-BURDEN
435
EROSION PATTERNS
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
FLOW RATES (CFS)
RIVER: 275,000
SPILLWAY: 275,000
RESERVOIR ELEV:
TAILWATER ELEV:
ELAPSED TIME (PROTOTYPE)
116 MIN.
NOTES
1. INITIAL CONDITION:
PLUNGE POOL LINED TO ELEV. 250, GRAVEL TO ELEV. 265. TOE OF SLOPE LOCATED 280 FT. DOWNSTREAM FROM AXIS OF DAM.
2. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
3. SPILLWAY CONFIGURATION:
1 AND 4- CONVENTIONAL
2 - 0° BUCKET
3 - -20° BUCKET
SCALE: 1" = 100 FT.

FIGURE 18



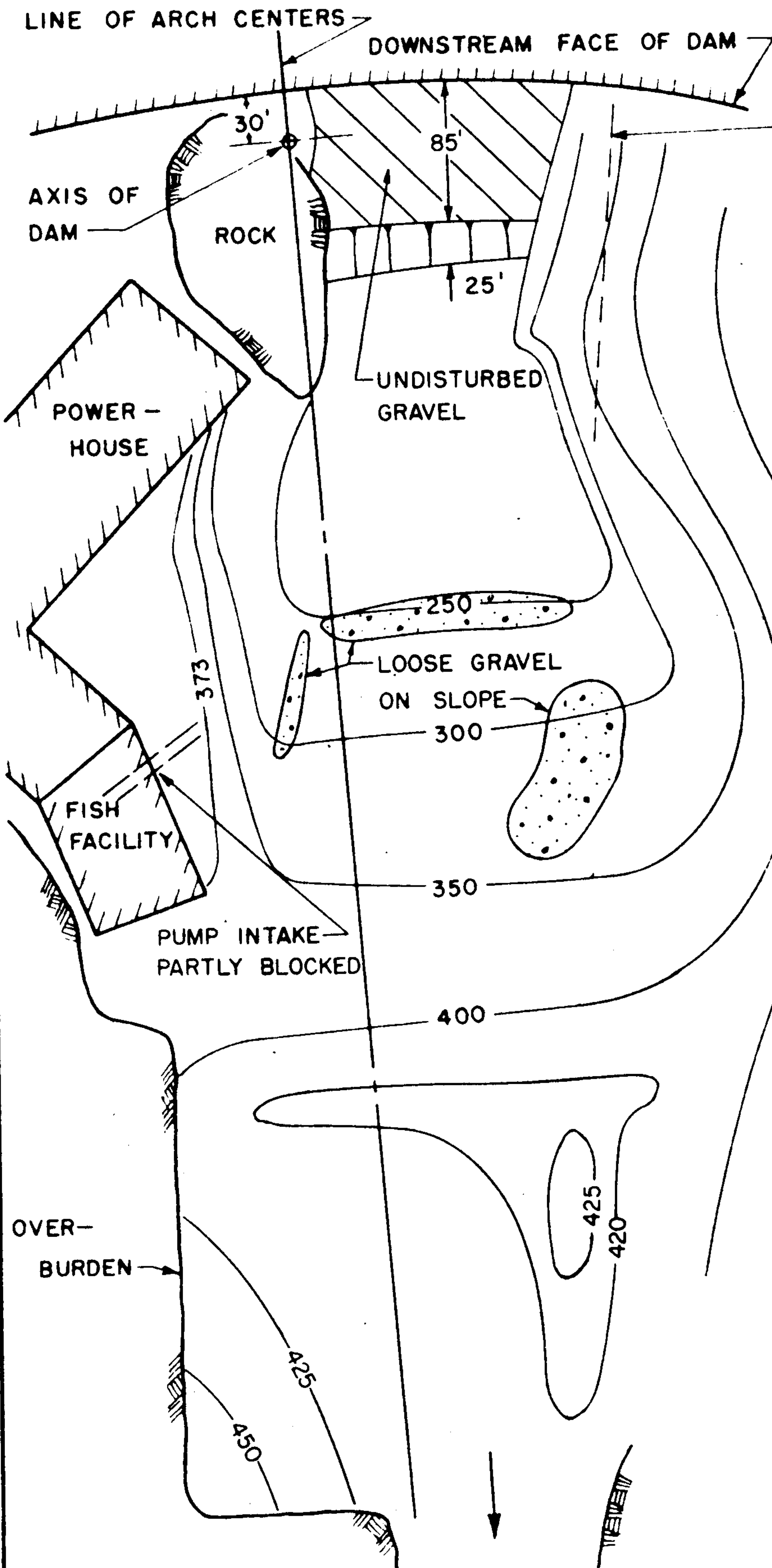
LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
SEE NOTE 2
30'
85'
65'
AXIS OF DAM
ROCK
UNDISTURBED GRAVEL
POWER-HOUSE
SOME GRAVEL IN ALL DRAFT TUBES
250
300
373
LOOSE GRAVEL ON SLOPE
FISH FACILITY
PUMP INTAKE PARTLY BLOCKED
350
400
420
425
450
GRAVEL BAR
OVER-BURDEN
425
450
SCALE: 1" = 100 FT.
EROSION PATTERNS
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
FLOW RATES (CFS)
RIVER: 275,000
SPILLWAY: 275,000
RESERVOIR ELEV:
TAILWATER ELEV:
ELAPSED TIME (PROTOTYPE) 156 MIN.
NOTES
1. INITIAL CONDITION: PLUNGE POOL LINED TO ELEV. 250, GRAVEL TO ELEV. 265. TOE OF SLOPE LOCATED 280 FT. DOWNSTREAM FROM AXIS OF DAM.
2. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
3. SPILLWAY CONFIGURATION: FOUR WARPED BUCKETS.
4. NO BOIL OR UPWELLING AT FACE OF DAM.

FIGURE 19



SCALE: 1" = 100 FT.

FIGURE 20



EROSION PATTERNS

GATE SETTINGS (% OPEN)

1	2	3	4
100	100	100	100

FLOW RATES (CFS)

RIVER: 275,000

SPILLWAY: 275,000

RESERVOIR ELEV:

TAILWATER ELEV:

ELAPSED TIME (PROTOTYPE) 156 MIN.

NOTES

1. INITIAL CONDITION: PLUNGE POOL LINED TO ELEV. 250, GRAVEL TO ELEV. 265. TOE OF SLOPE LOCATED 280 FT. DOWNSTREAM FROM AXIS OF DAM.
2. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
3. SPILLWAY CONFIGURATION:
   1 AND 4 - WARPED
   2 - 0° BUCKET
   3 - −20° BUCKET

SCALE: 1" = 100 FT.

FIGURE 21

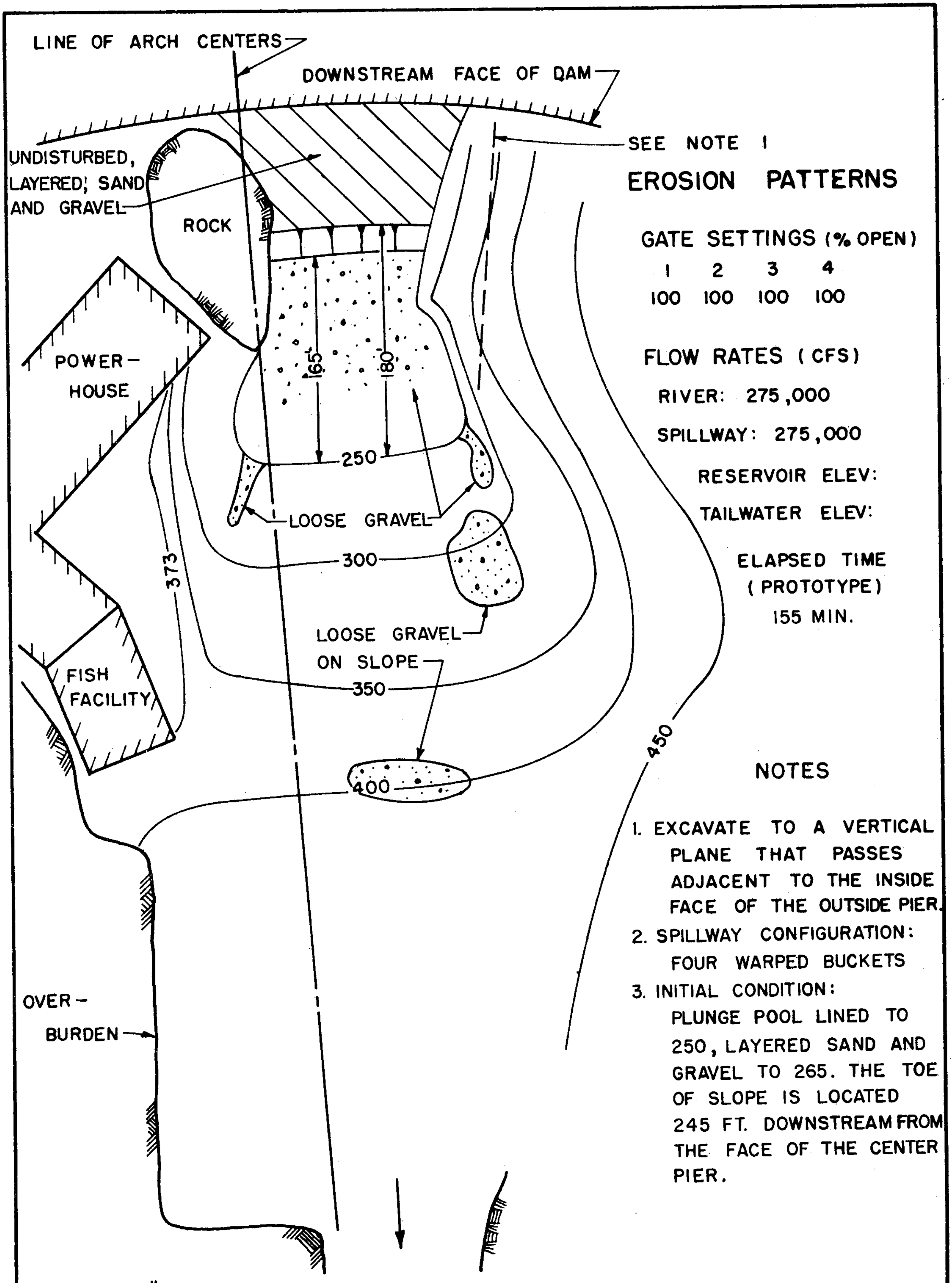

LINE OF ARCH CENTERS
DOWNSTREAM FACE OF DAM
SEE NOTE 1
UNDISTURBED, LAYERED, SAND AND GRAVEL
ROCK
POWER-HOUSE
FISH FACILITY
OVER-BURDEN
165'
180'
250
300
350
373
400
450
LOOSE GRAVEL
LOOSE GRAVEL ON SLOPE
EROSION PATTERNS
GATE SETTINGS (% OPEN)
1 2 3 4
100 100 100 100
FLOW RATES (CFS)
RIVER: 275,000
SPILLWAY: 275,000
RESERVOIR ELEV:
TAILWATER ELEV:
ELAPSED TIME (PROTOTYPE)
155 MIN.
NOTES
1. EXCAVATE TO A VERTICAL PLANE THAT PASSES ADJACENT TO THE INSIDE FACE OF THE OUTSIDE PIER.
2. SPILLWAY CONFIGURATION: FOUR WARPED BUCKETS
3. INITIAL CONDITION: PLUNGE POOL LINED TO 250, LAYERED SAND AND GRAVEL TO 265. THE TOE OF SLOPE IS LOCATED 245 FT. DOWNSTREAM FROM THE FACE OF THE CENTER PIER.
SCALE: 1" = 100 FT.

FIGURE 21A

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON X OFF __

FLOWRATES (CFS)
- RIVER: 4,400
- SPILLWAY:
- TURBINE:
  1. 4,400
  2.
  3.
- FISH FLOW; 428

ELEVATIONS
- RESERVOIR: 600
- TAILWATER: 425.5

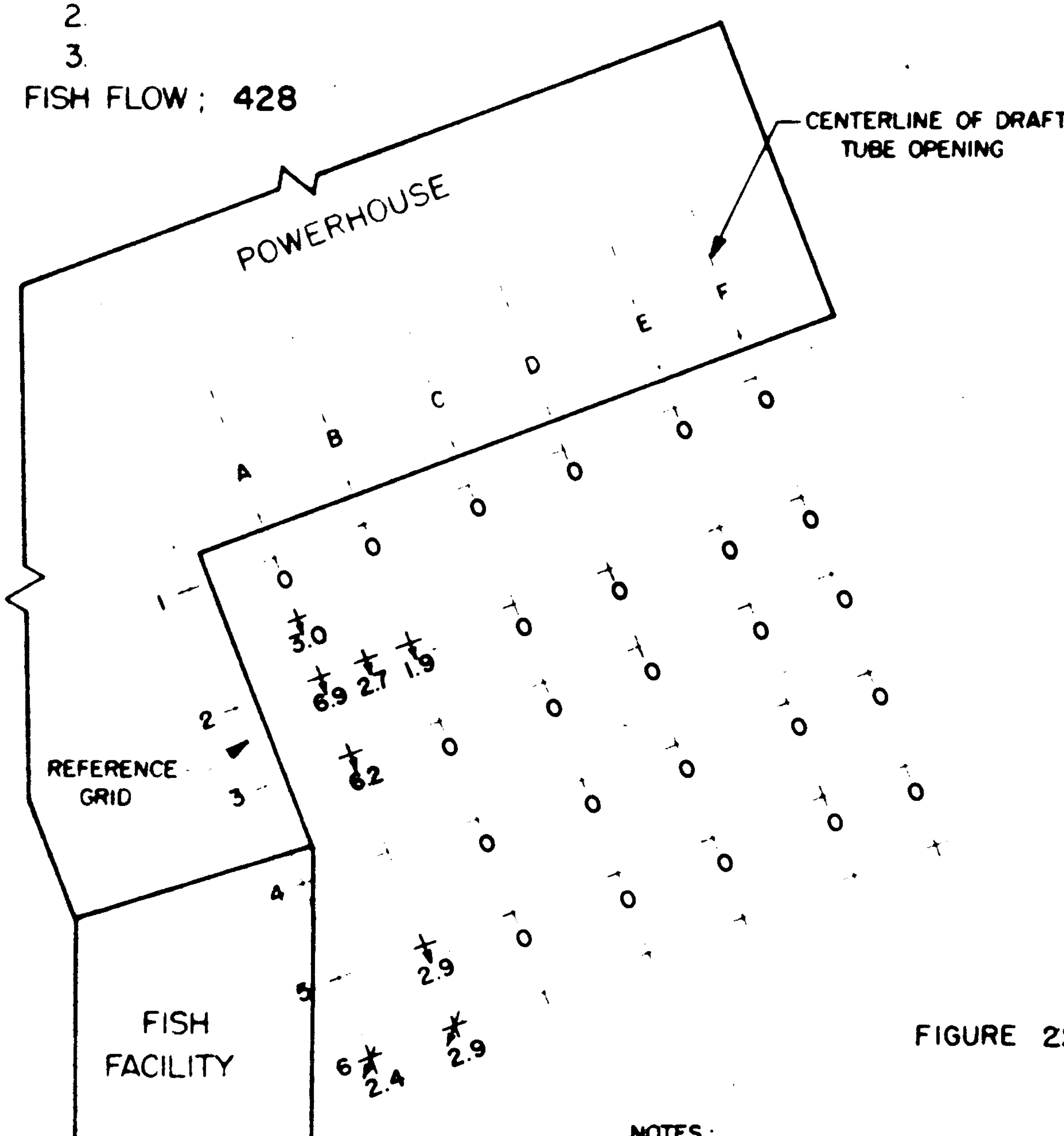


FIGURE 22 A

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON__ OFF X

FLOWRATES (CFS)

RIVER: 4,400
SPILLWAY:
TURBINE:
1. 4,400
2.
3.
FISH FLOW: 428

ELEVATIONS

RESERVOIR: 600
TAILWATER: 425.5

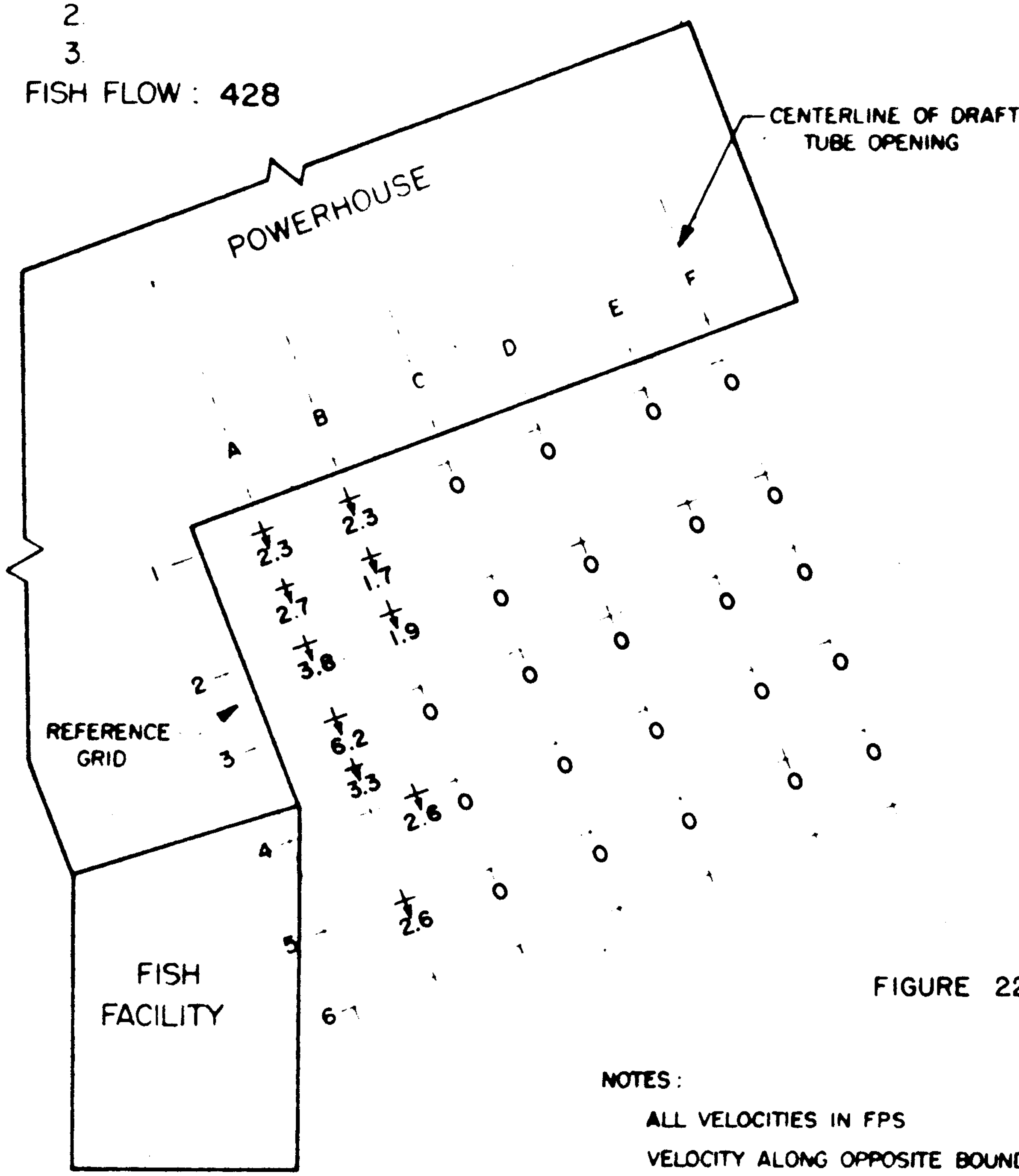


FIGURE 22 B

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON X OFF ___

FLOWRATES (CFS)

RIVER: 4,400
SPILLWAY:
TURBINE:
1.
2. 4,400
3.
FISH FLOW: 428

ELEVATIONS

RESERVOIR: 600
TAILWATER: 425.5

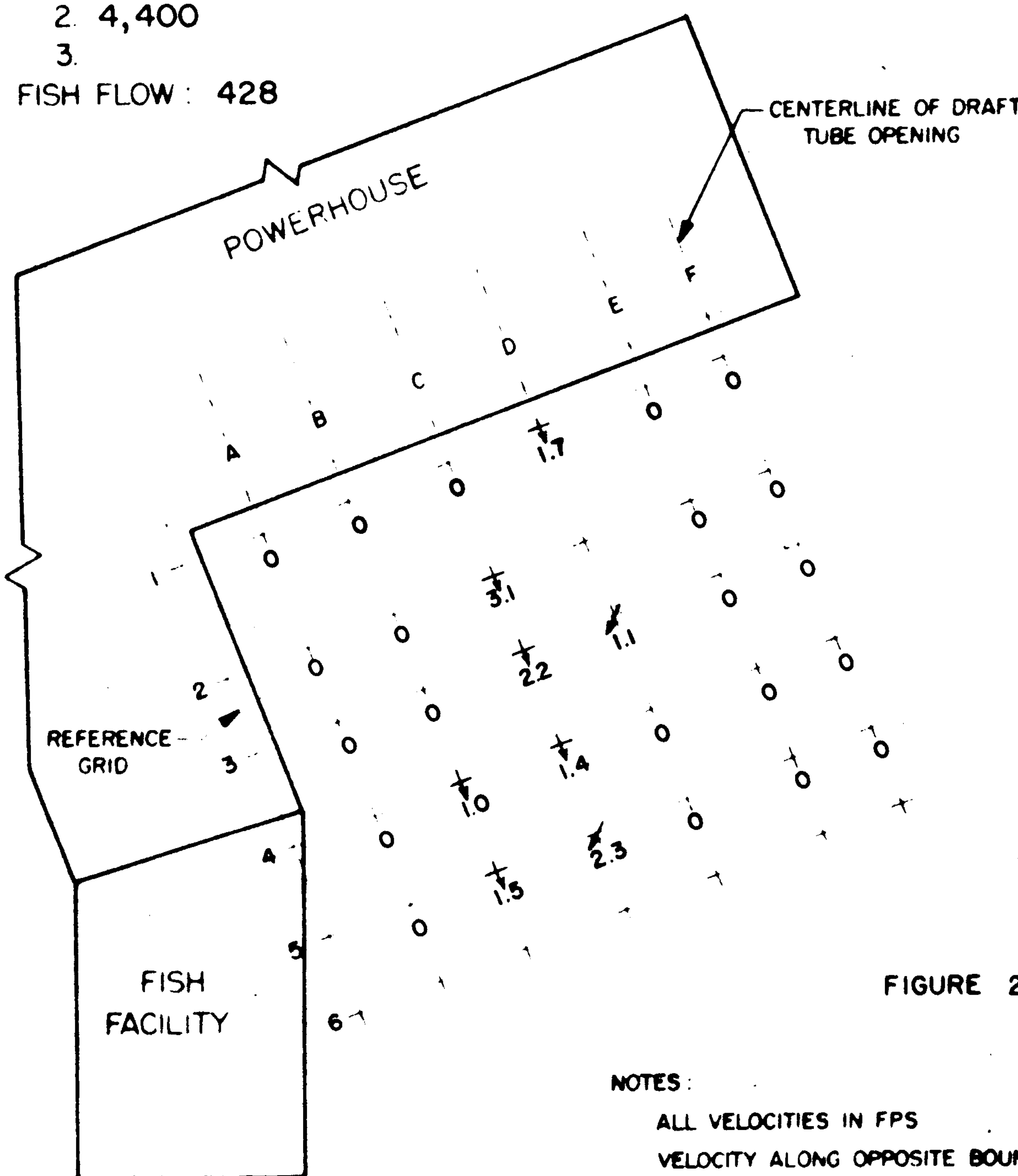


FIGURE 22 C

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON___ OFF X

FLOWRATES (CFS)

- RIVER: 4,400
- SPILLWAY:
- TURBINE:
  1.
  2. 4,400
  3.
- FISH FLOW: 428

ELEVATIONS

- RESERVOIR: 600
- TAILWATER: 425.5

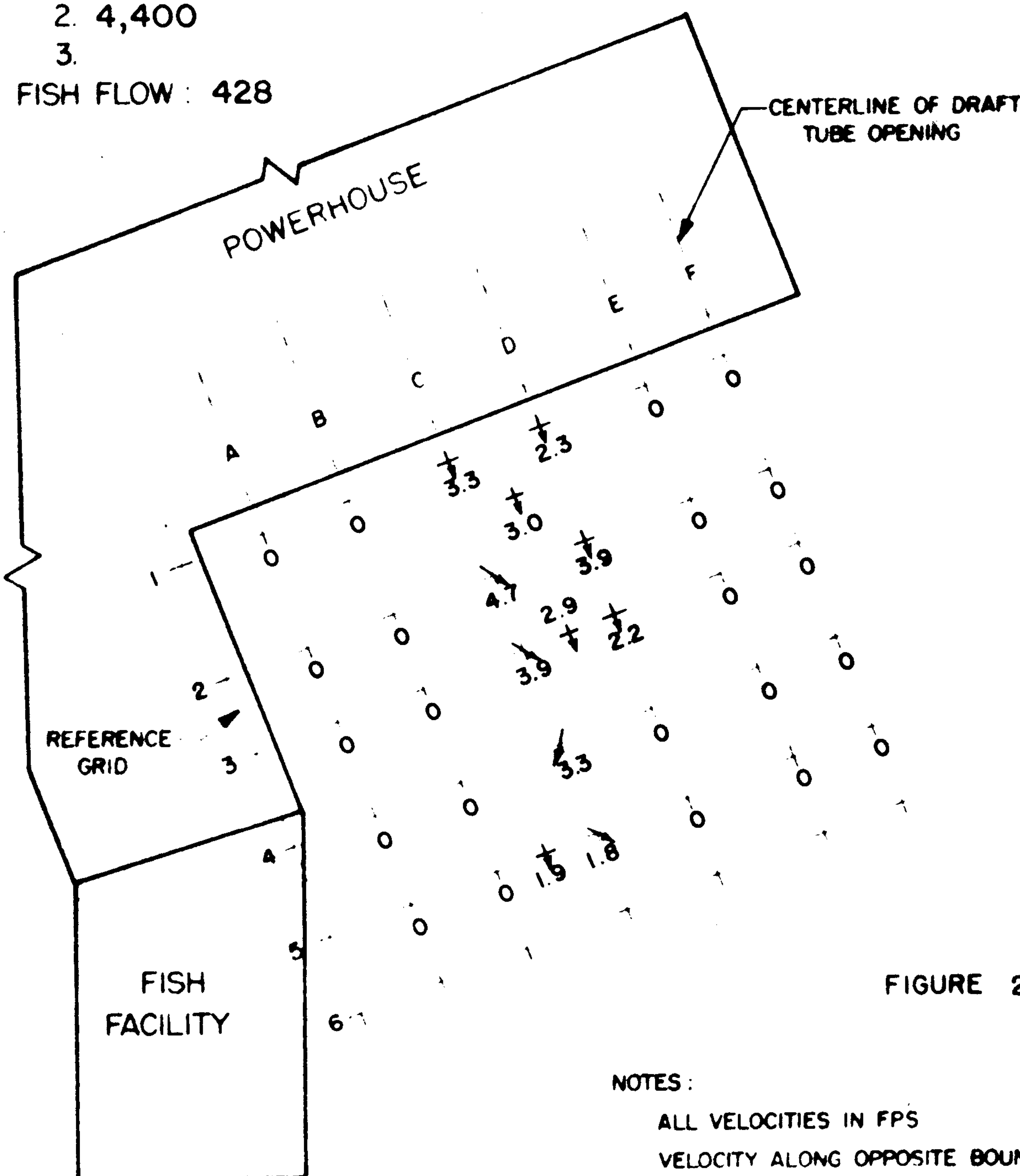


FIGURE 22 D

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON X OFF __

FLOWRATES (CFS)
- RIVER: 4,400
- SPILLWAY:
- TURBINE:
  1.
  2.
  3. 4,400
- FISH FLOW: 428

ELEVATIONS
- RESERVOIR: 600
- TAILWATER: 425.5

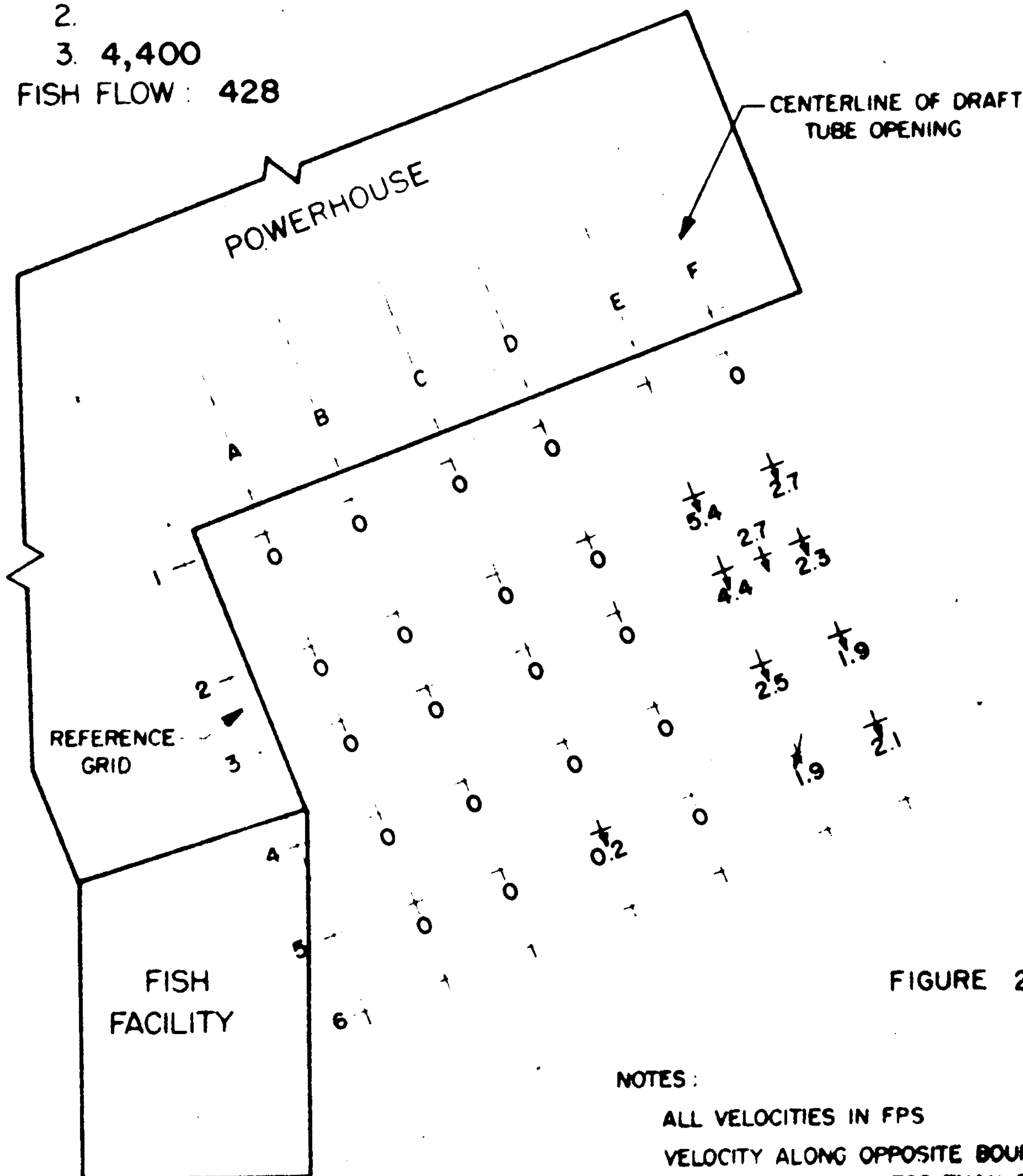


FIGURE 22 E

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 400
DEFLECTOR ON__ OFF X

FLOWRATES (CFS)
- RIVER: 4,400
- SPILLWAY:
- TURBINE:
  1.
  2.
  3. 4,400
- FISH FLOW: 428

ELEVATIONS
- RESERVOIR: 600
- TAILWATER: 425.5

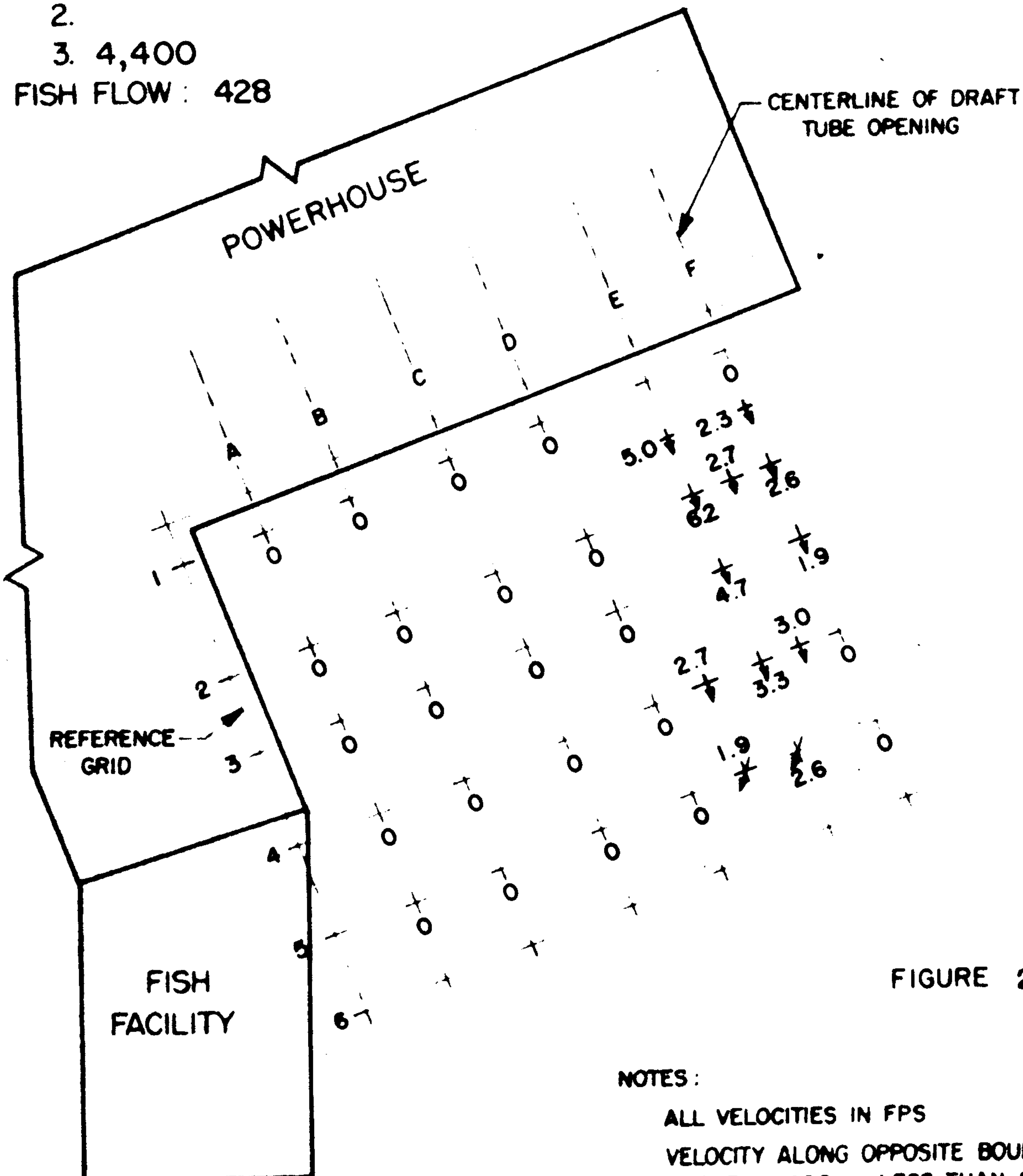


FIGURE 22 F

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 400 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON x OFF __

FLOWRATES (CFS)

RIVER: 12,800
SPILLWAY:
TURBINE:
1. 6,400
2. 6,400
3.

FISH FLOW: 550

ELEVATIONS

RESERVOIR: 700
TAILWATER: 430.5

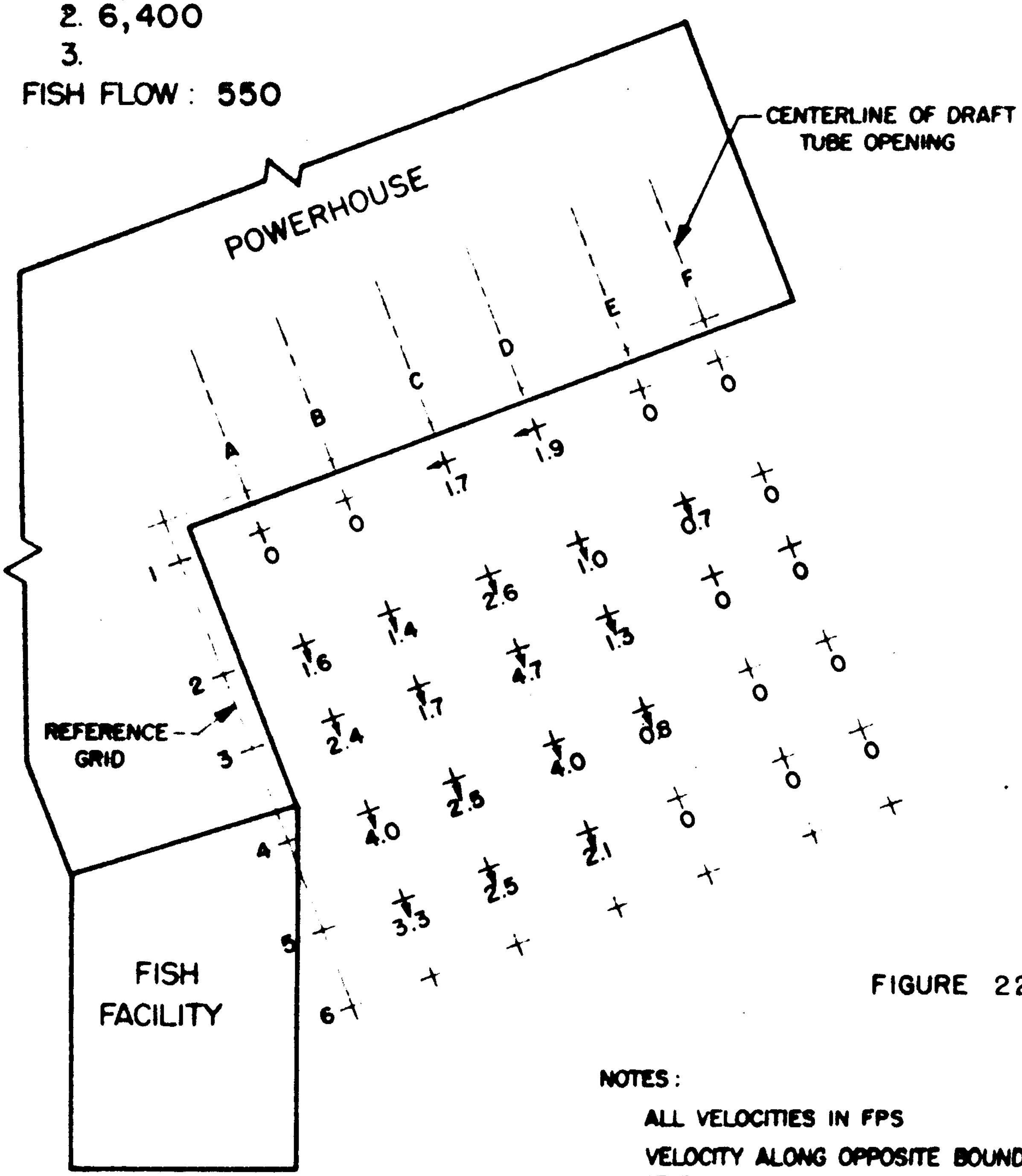


FIGURE 22 G

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON__ OFF_X_

FLOWRATES (CFS)
- RIVER: 12,800
- SPILLWAY:
- TURBINE:
  1. 6,400
  2. 6,400
  3.
- FISH FLOW: 550

ELEVATIONS
- RESERVOIR: 700
- TAILWATER: 430.5

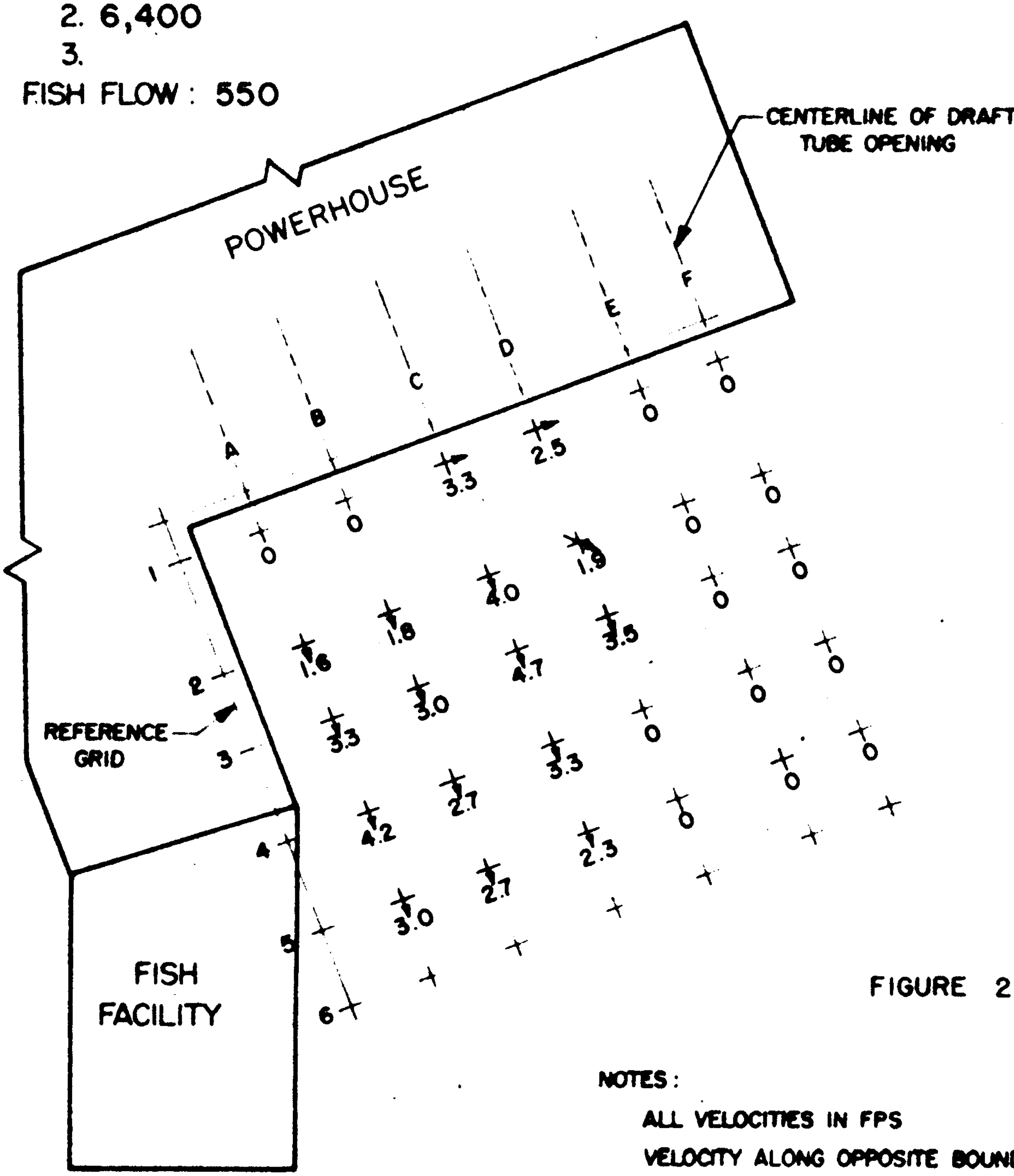


FIGURE 22 H

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON_X_ OFF__

FLOWRATES (CFS)
- RIVER: 12,800
- SPILLWAY:
- TURBINE:
  1.
  2. 6,400
  3. 6,400
- FISH FLOW: 550

ELEVATIONS
- RESERVOIR: 700
- TAILWATER: 430.5

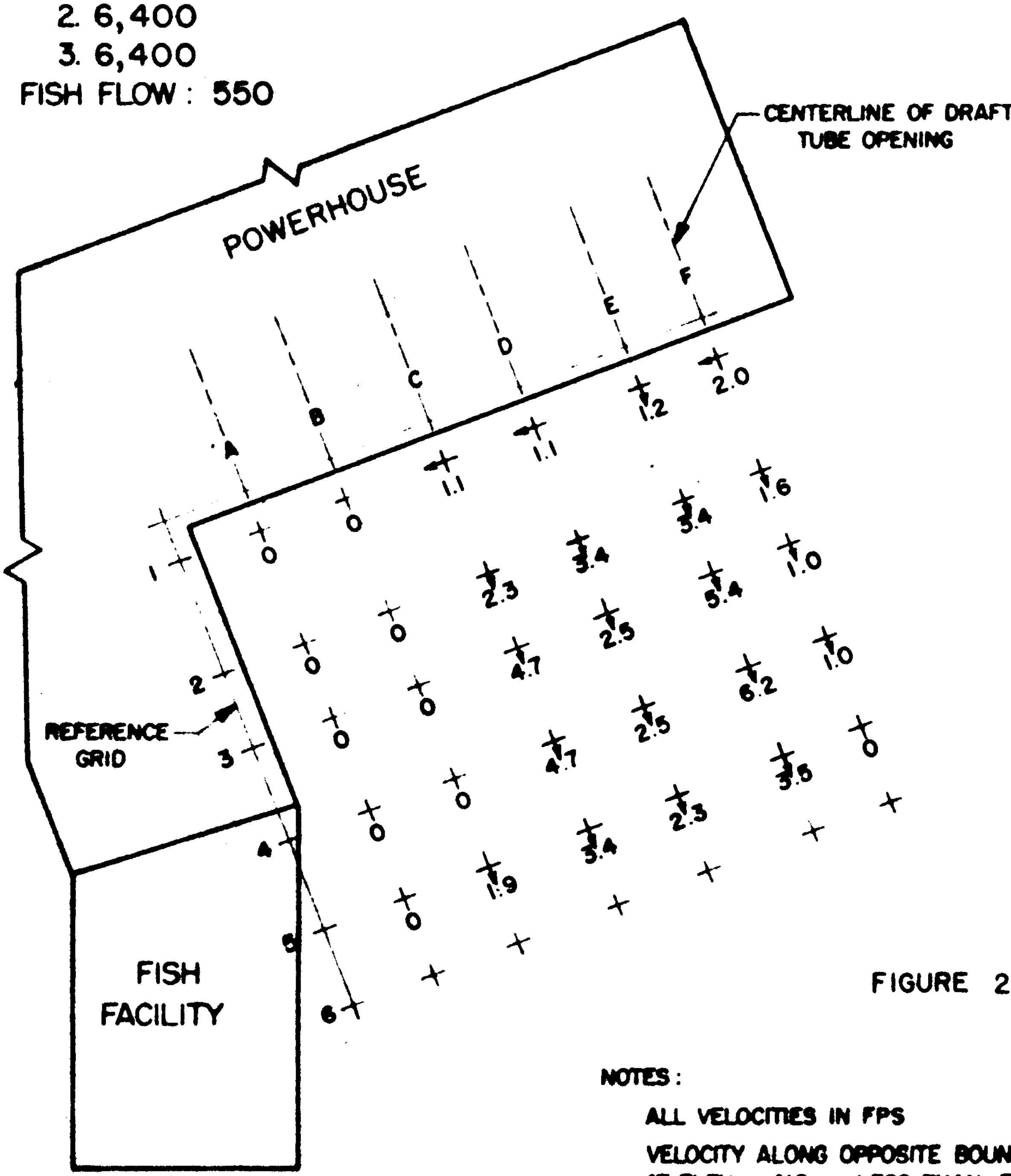


FIGURE 22-1

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON__ OFF X

FLOWRATES (CFS)
- RIVER: 12,800
- SPILLWAY:
- TURBINE:
  1.
  2. 6,400
  3. 6,400
- FISH FLOW: 550

ELEVATIONS
- RESERVOIR: 700
- TAILWATER: 430.5

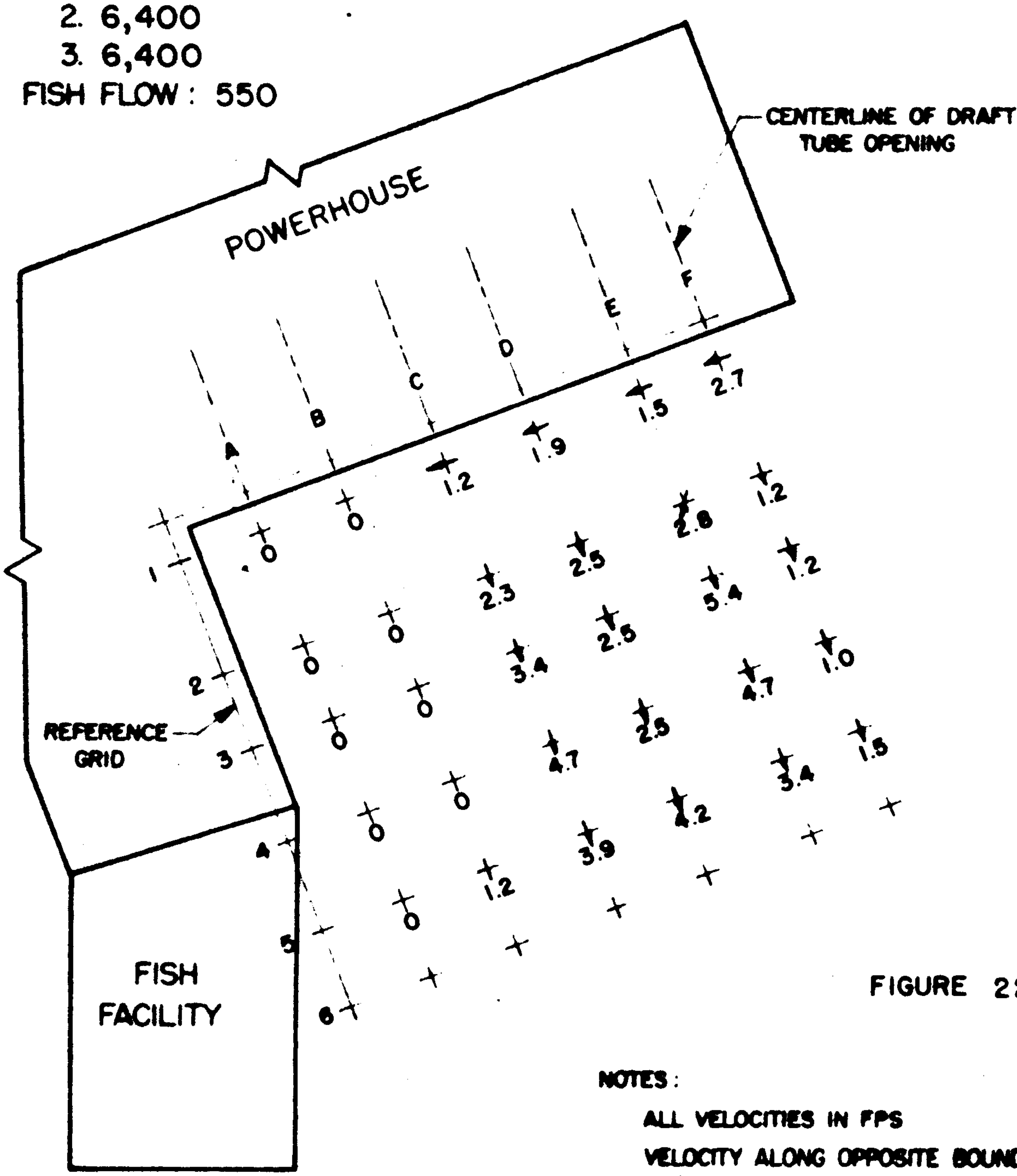


FIGURE 22 J

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

[redacted]

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON X OFF __

FLOWRATES (CFS)
- RIVER: 12,800
- SPILLWAY:
- TURBINE:
  1. 6,400
  2.
  3. 6,400
- FISH FLOW: 550

ELEVATIONS
- RESERVOIR: 700
- TAILWATER: 430.5

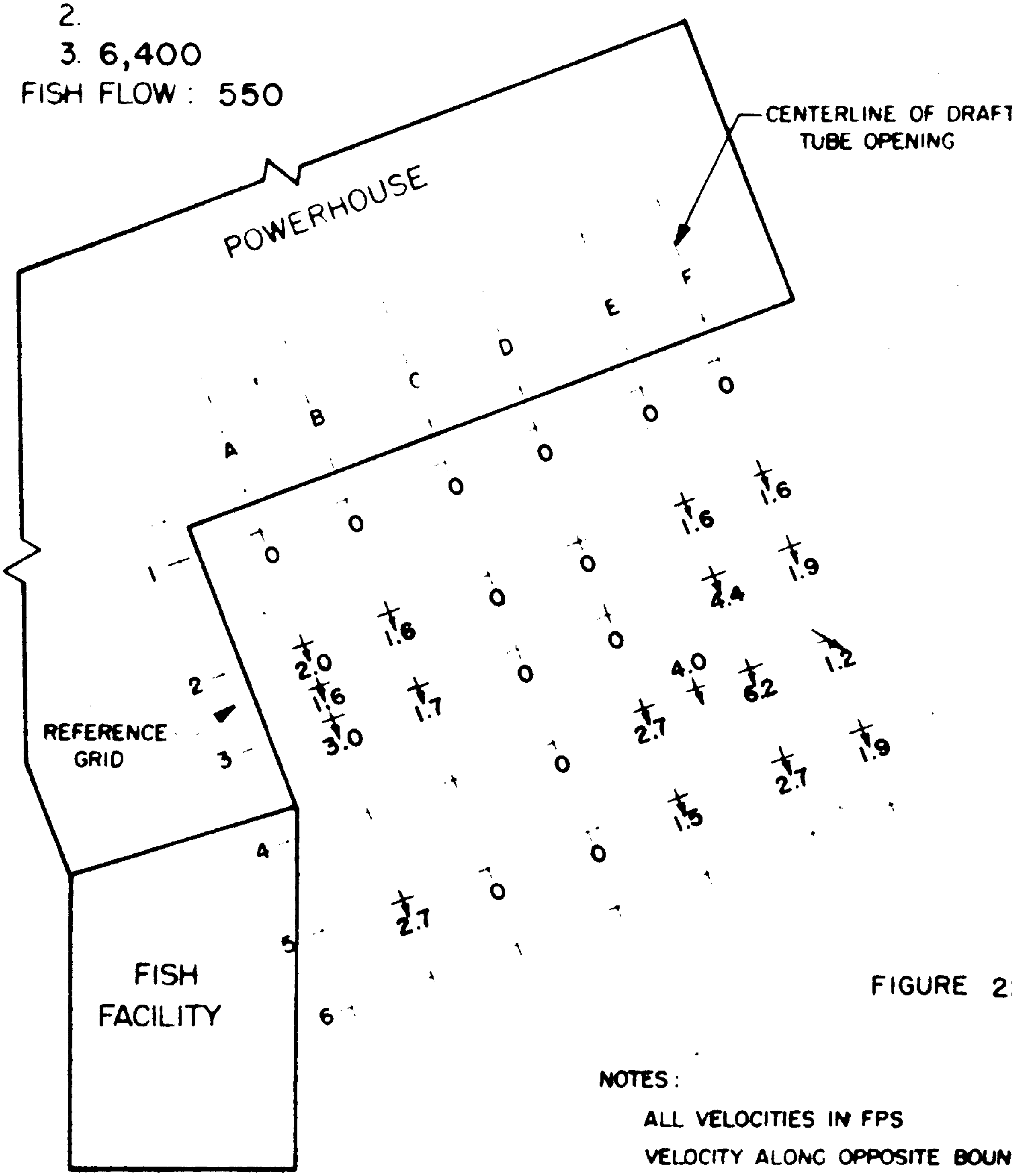


FIGURE 22 K

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON __ OFF _X_

FLOWRATES (CFS)
- RIVER: 12,800
- SPILLWAY:
- TURBINE:
  1. 6,400
  2.
  3. 6,400
- FISH FLOW: 550

ELEVATIONS
- RESERVOIR: 700
- TAILWATER: 430.5

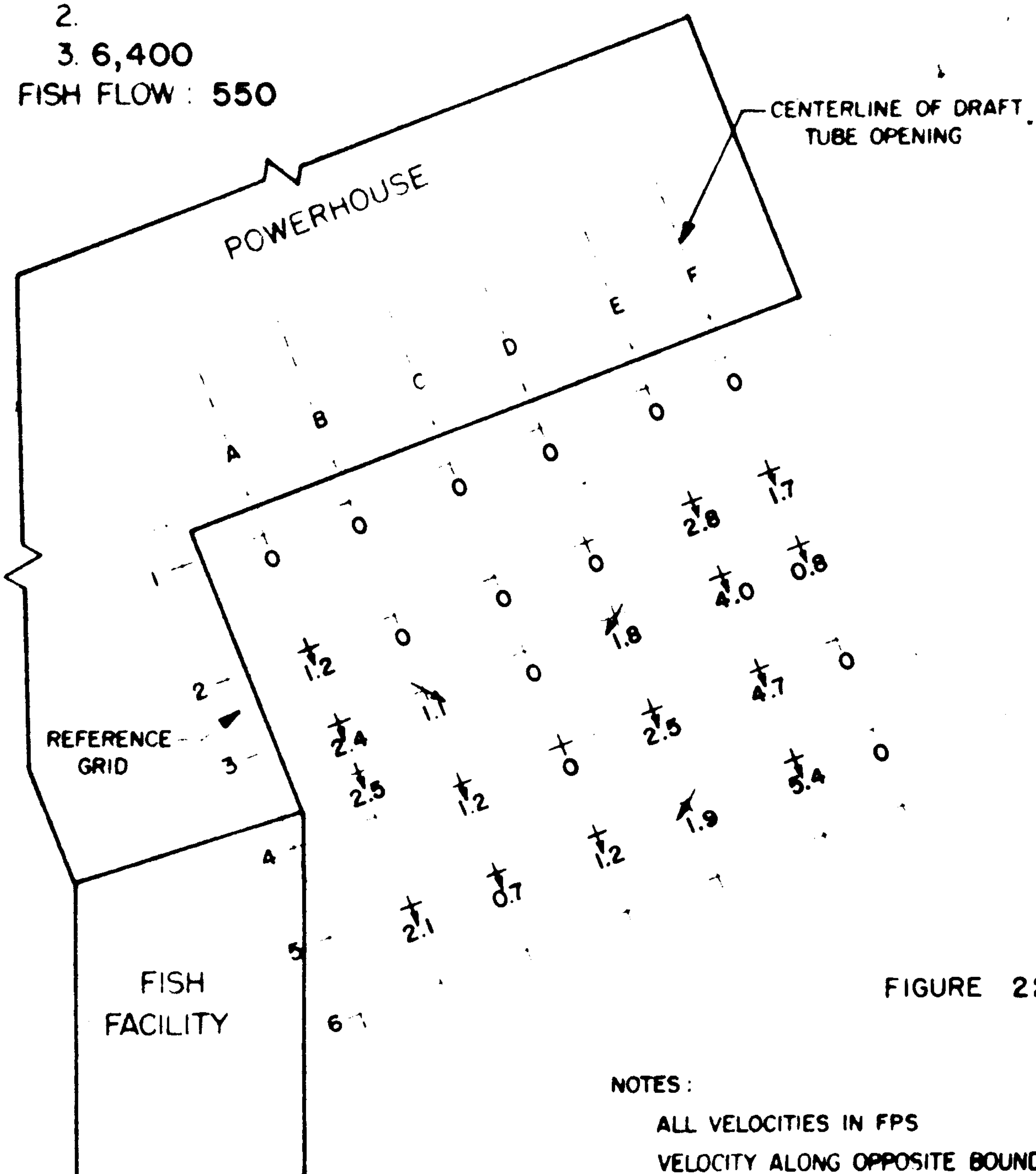


FIGURE 22 L

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 2.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON x OFF __

FLOWRATES (CFS)

- RIVER: 14,600
- SPILLWAY:
- TURBINE:
  1. 7,300
  2. 7,300
  3.
- FISH FLOW: 578

ELEVATIONS

- RESERVOIR: 770
- TAILWATER: 431.5

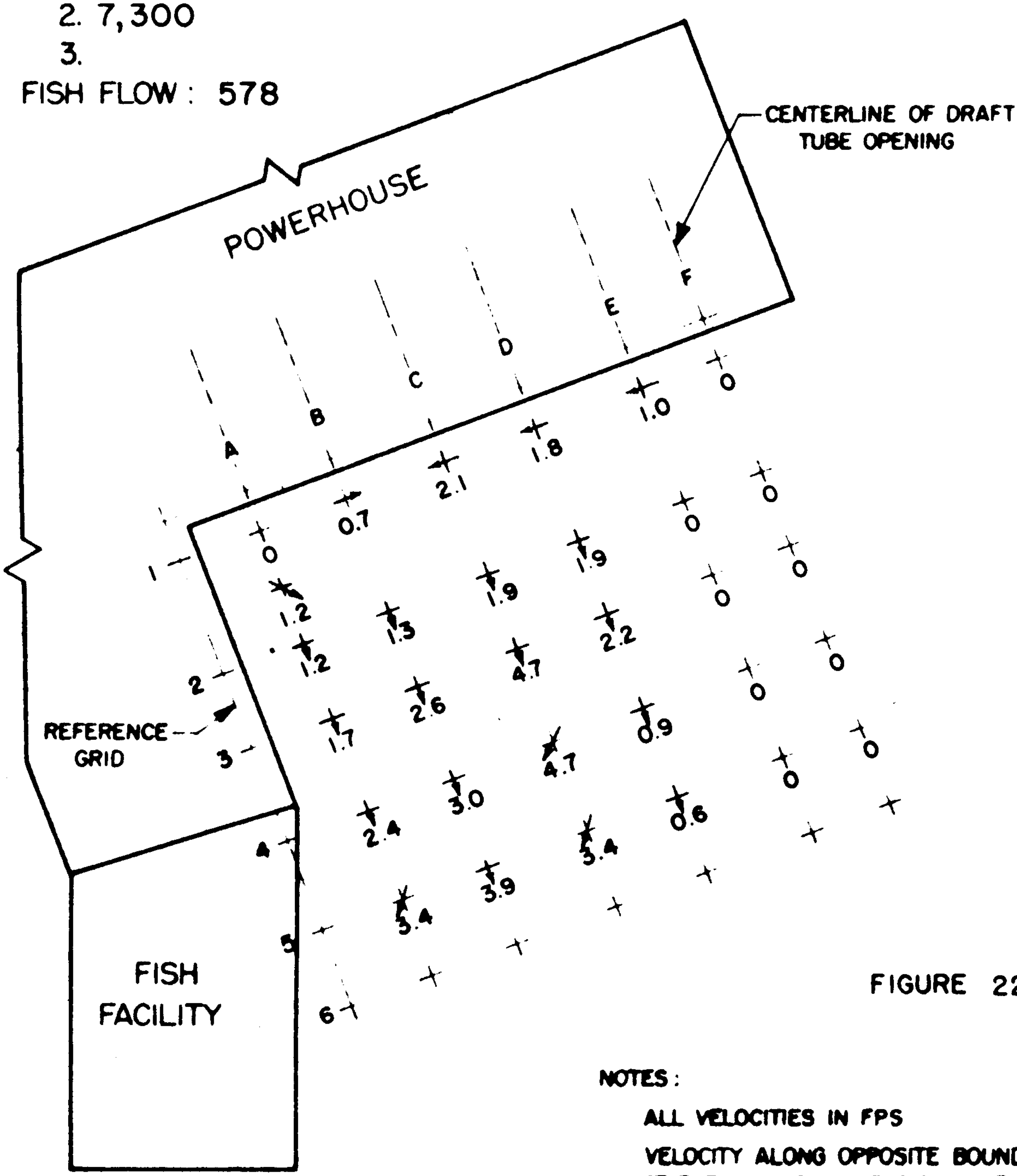


FIGURE 22 M

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON__ OFF_X_

FLOWRATES (CFS)
- RIVER: 14,600
- SPILLWAY:
- TURBINE:
  1. 7,300
  2. 7,300
  3.
- FISH FLOW: 578

ELEVATIONS
- RESERVOIR: 770
- TAILWATER: 431.5

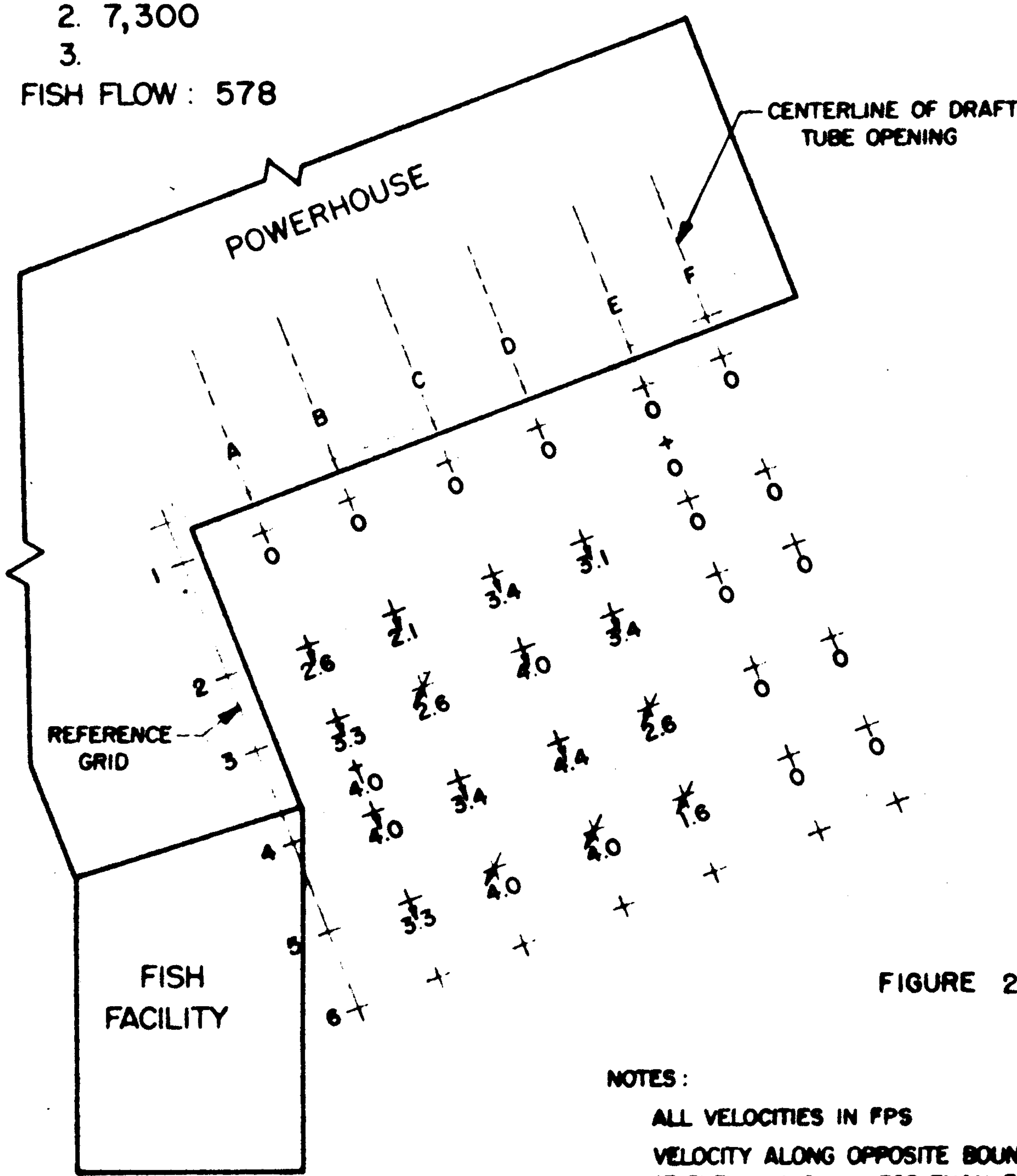


FIGURE 22 N

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON X OFF __

FLOWRATES (CFS)
- RIVER: 14,600
- SPILLWAY:
- TURBINE:
  1.
  2. 7,300
  3. 7,300
- FISH FLOW: 578

ELEVATIONS
- RESERVOIR: 770
- TAILWATER: 431.5

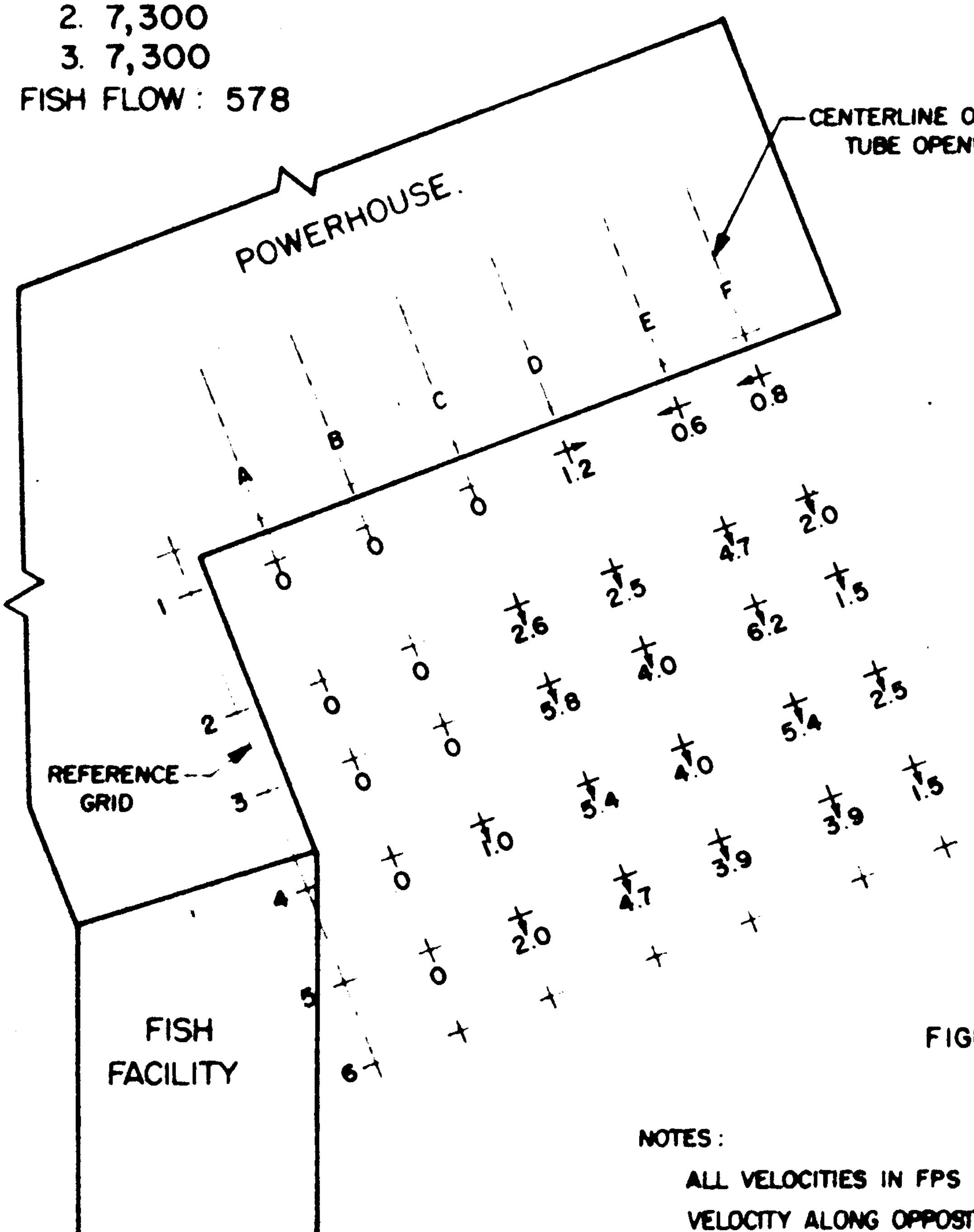


FIGURE 22-0

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 410
DEFLECTOR ON__ OFF X

FLOWRATES (CFS)
- RIVER: 14,600
- SPILLWAY:
- TURBINE:
  1.
  2. 7,300
  3. 7,300
- FISH FLOW: 578

ELEVATIONS
- RESERVOIR: 770
- TAILWATER: 431.5

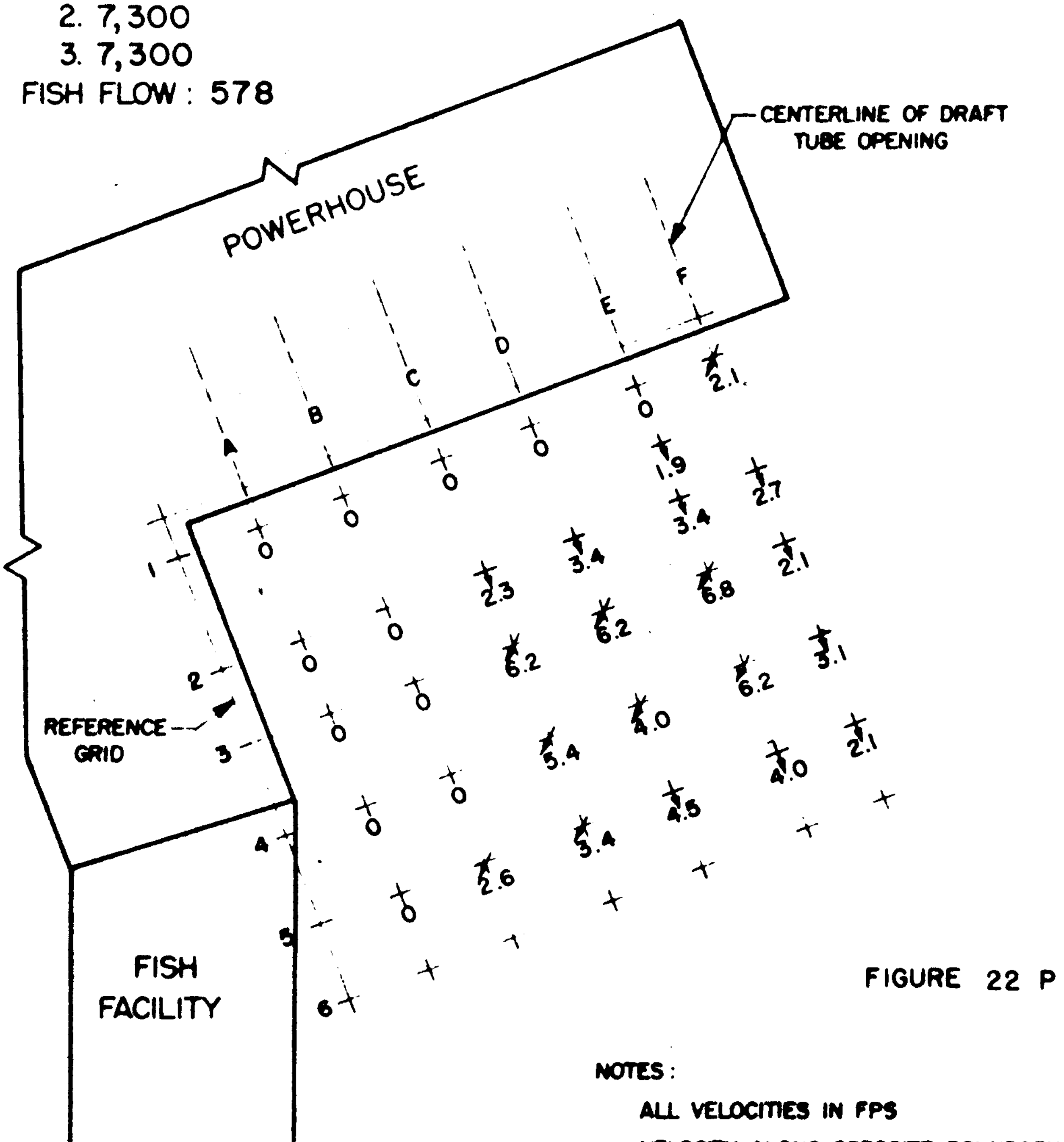


FIGURE 22 P

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 410 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 414
DEFLECTOR ON _X_ OFF ___

FLOWRATES (CFS)
- RIVER: 21,600
- SPILLWAY:
- TURBINE:
  1. 7,200
  2. 7,200
  3. 7,200
- FISH FLOW: 640

ELEVATIONS
- RESERVOIR: 770
- TAILWATER: 434

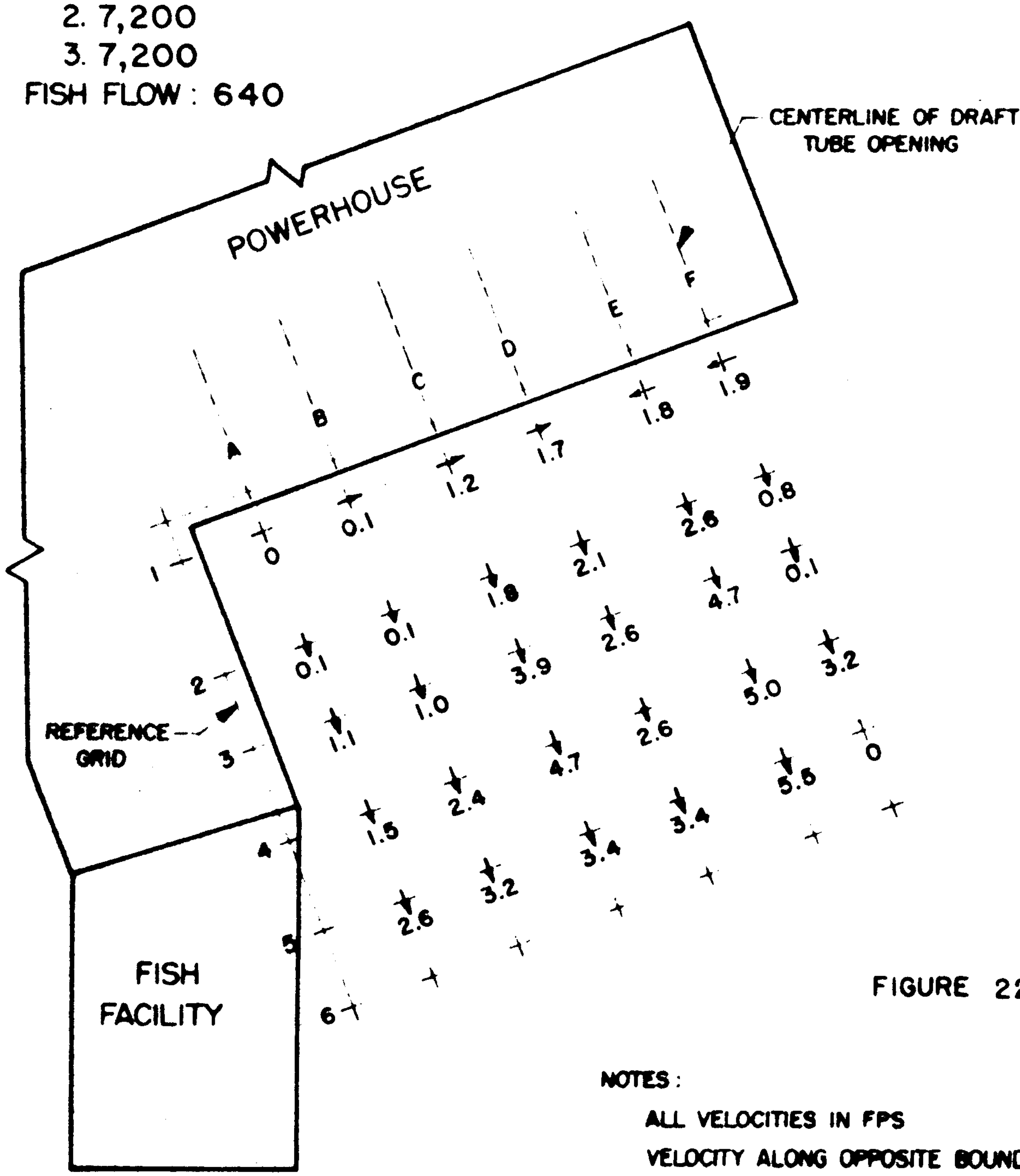


FIGURE 22 Q

NOTES:

ALL VELOCITIES IN FPS

VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 414 LESS THAN 3.5 FPS

SCALE: 1" = 50 FT.

POWERHOUSE DISCHARGE
VELOCITY TRAVERSE AT ELEVATION 414
DEFLECTOR ON__ OFF_X_

FLOWRATES (CFS)
- RIVER: 21,600
- SPILLWAY:
- TURBINE:
  1. 7,200
  2. 7,200
  3. 7,200
- FISH FLOW: 640

ELEVATIONS
- RESERVOIR: 770
- TAILWATER: 434

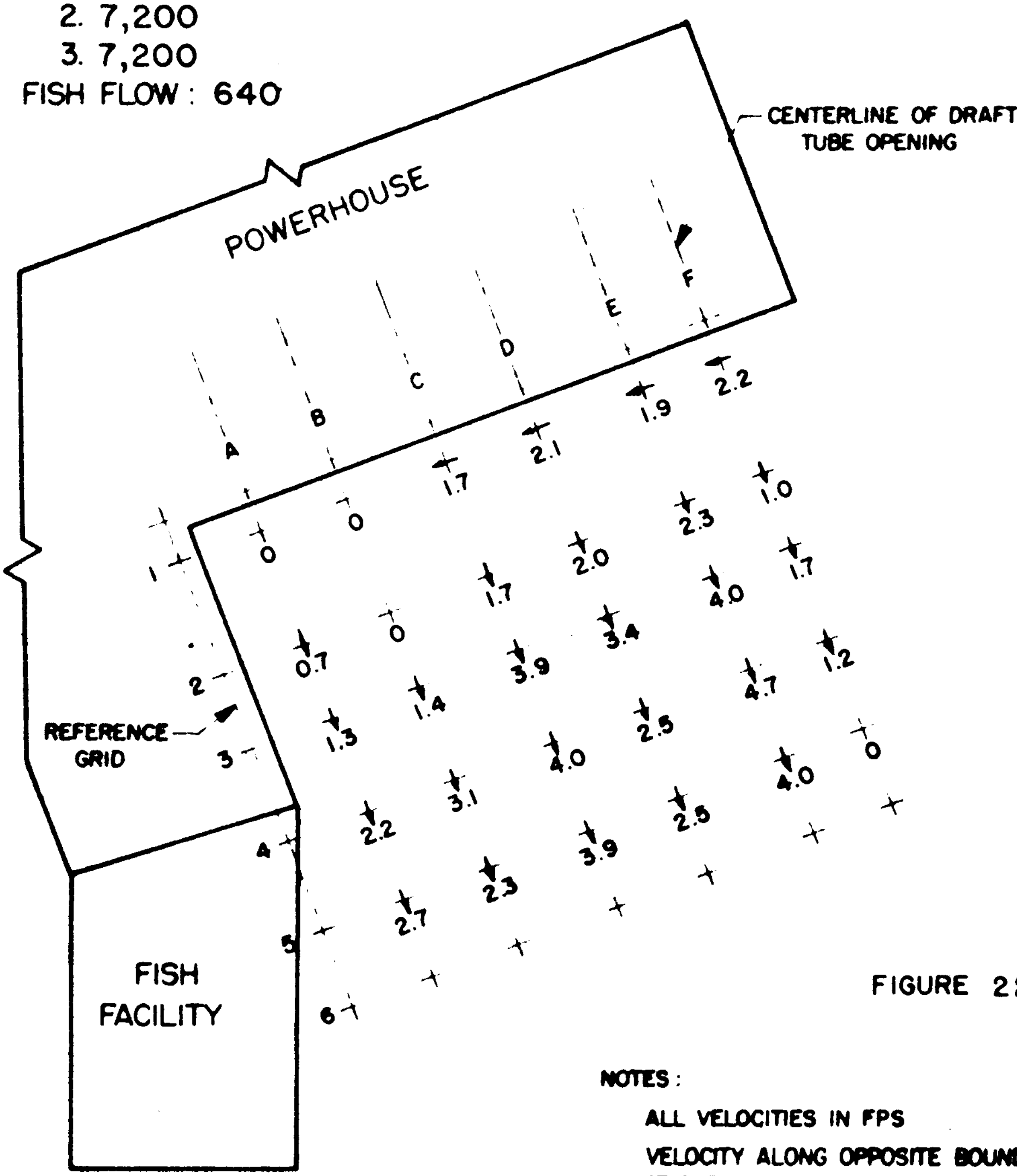


FIGURE 22 R

NOTES:

ALL VELOCITIES IN FPS

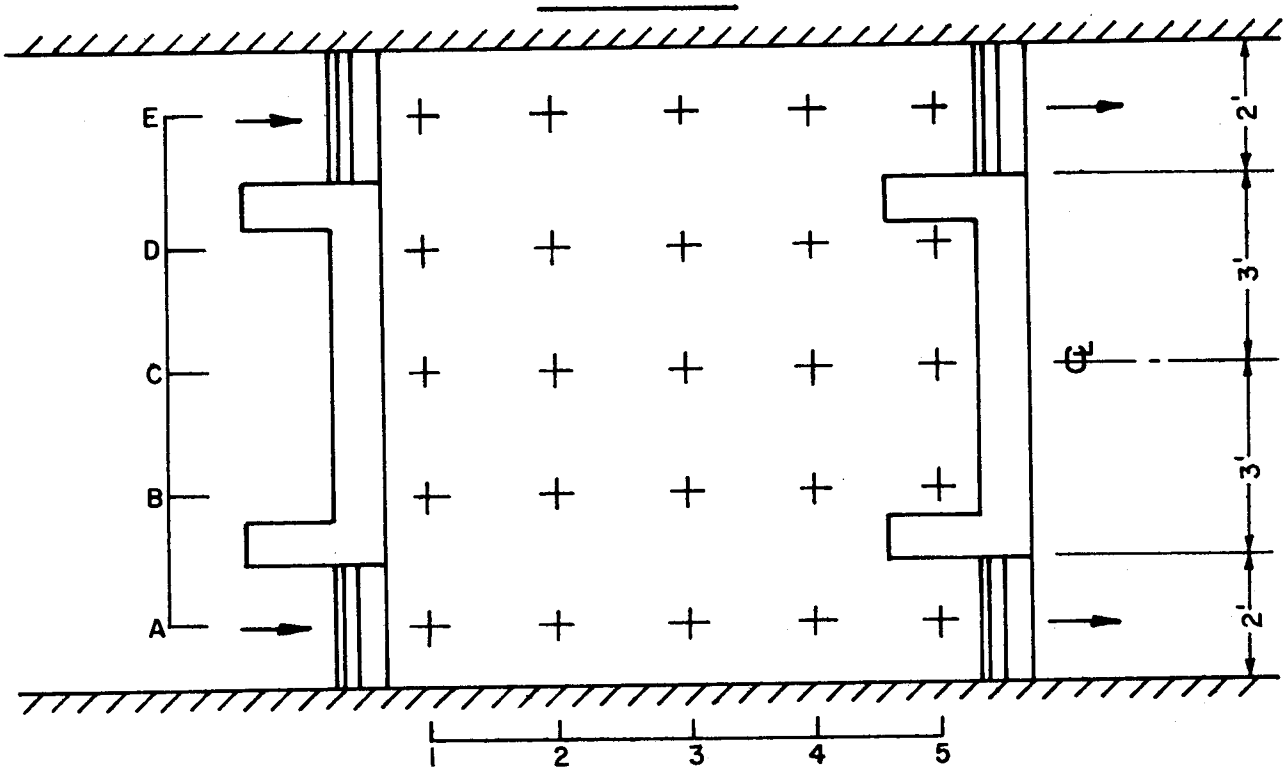
VELOCITY ALONG OPPOSITE BOUNDARY AT ELEV. 414 LESS THAN 3.0 FPS

SCALE: 1" = 50 FT.

MOSSYROCK FISH LADDER
TYPICAL POOL

REFERENCE GRID FOR VELOCITY DISTRIBUTION

PLAN VIEW



SCALE: 1" = 3'

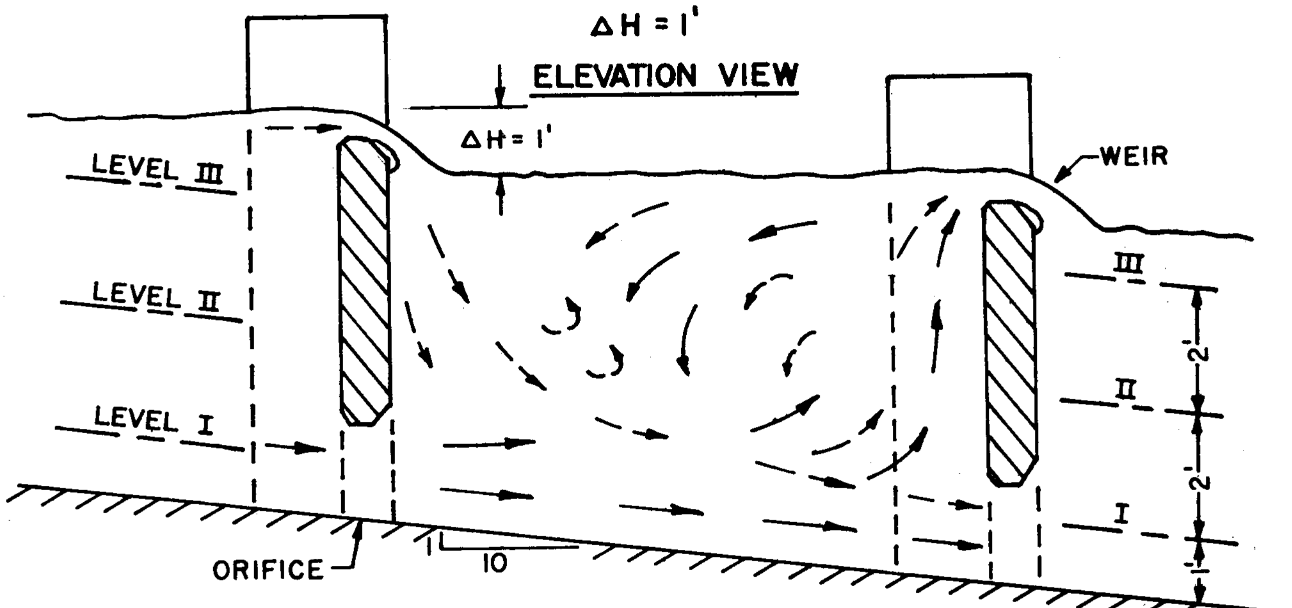
FIGURE 23 A

VELOCITY PROFILE ALONG A-LINE

Q = 40.2 CFS

ΔH = 1'

ELEVATION VIEW



SCALE 1" = 3'

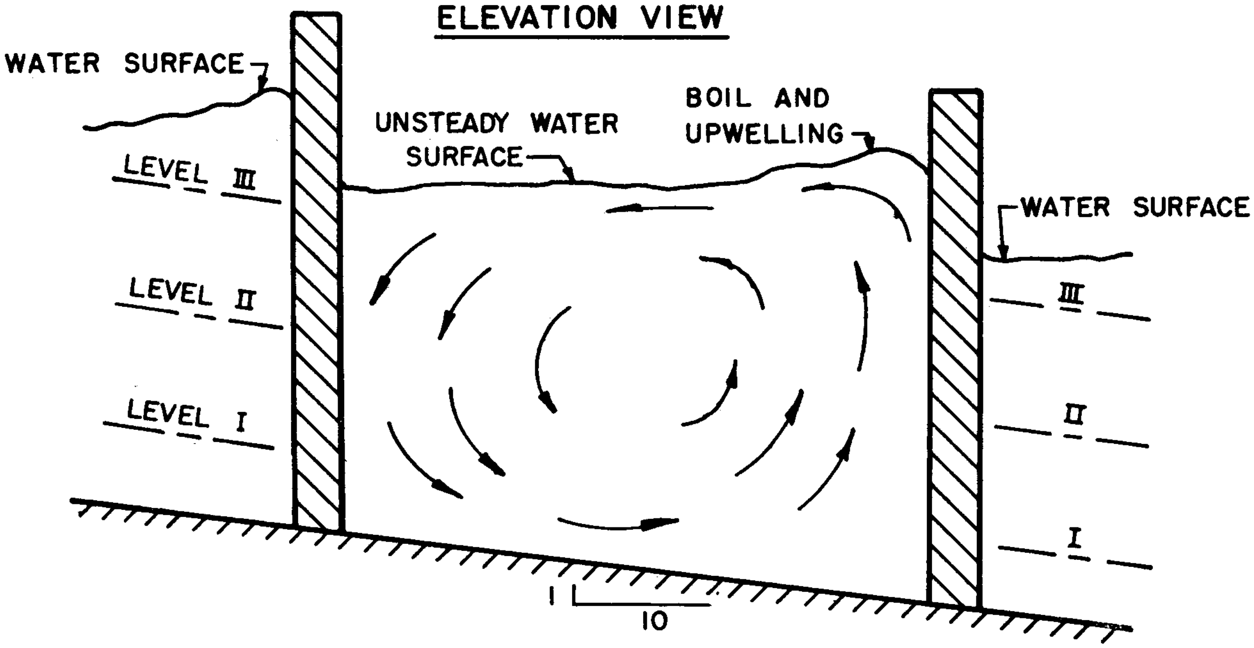
FIGURE 23 B

MOSSYROCK FISH LADDER

VELOCITY PROFILE ALONG C-LINE

Q = 40.2 CFS ΔH = 1 FT.

ELEVATION VIEW



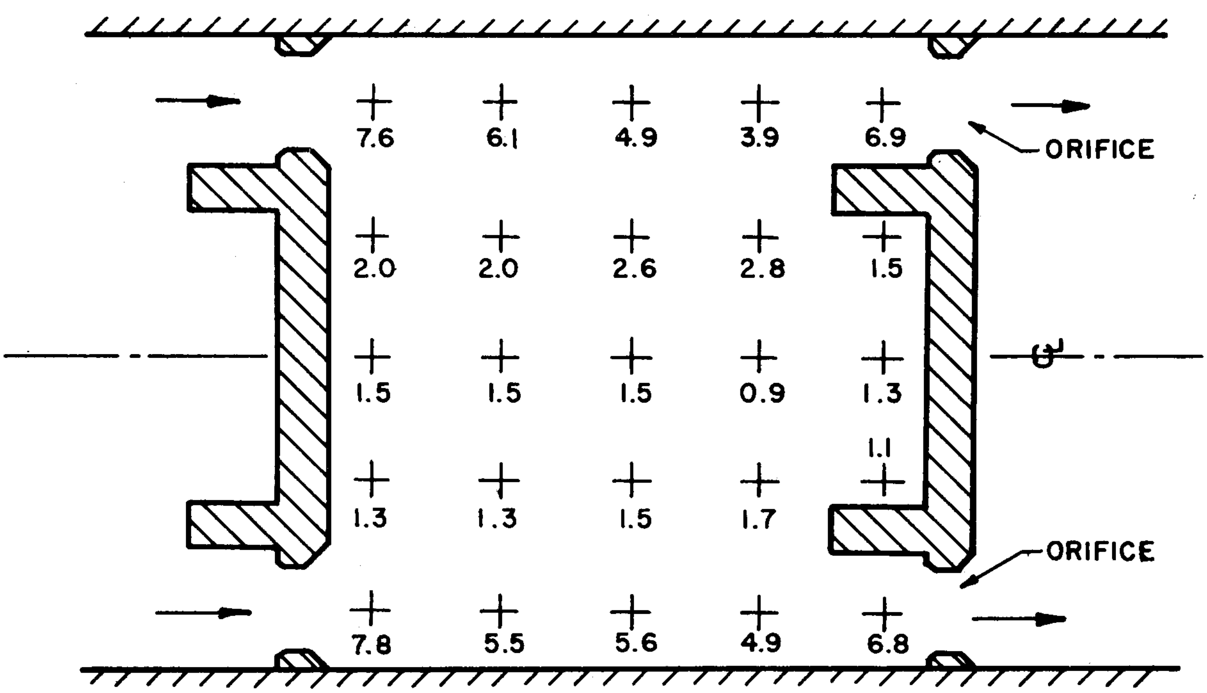
SCALE: 1" = 3'

FIGURE 23 C

VELOCITY DISTRIBUTION – LEVEL I

Q = 40.2 CFS

ΔH = 1 FT.



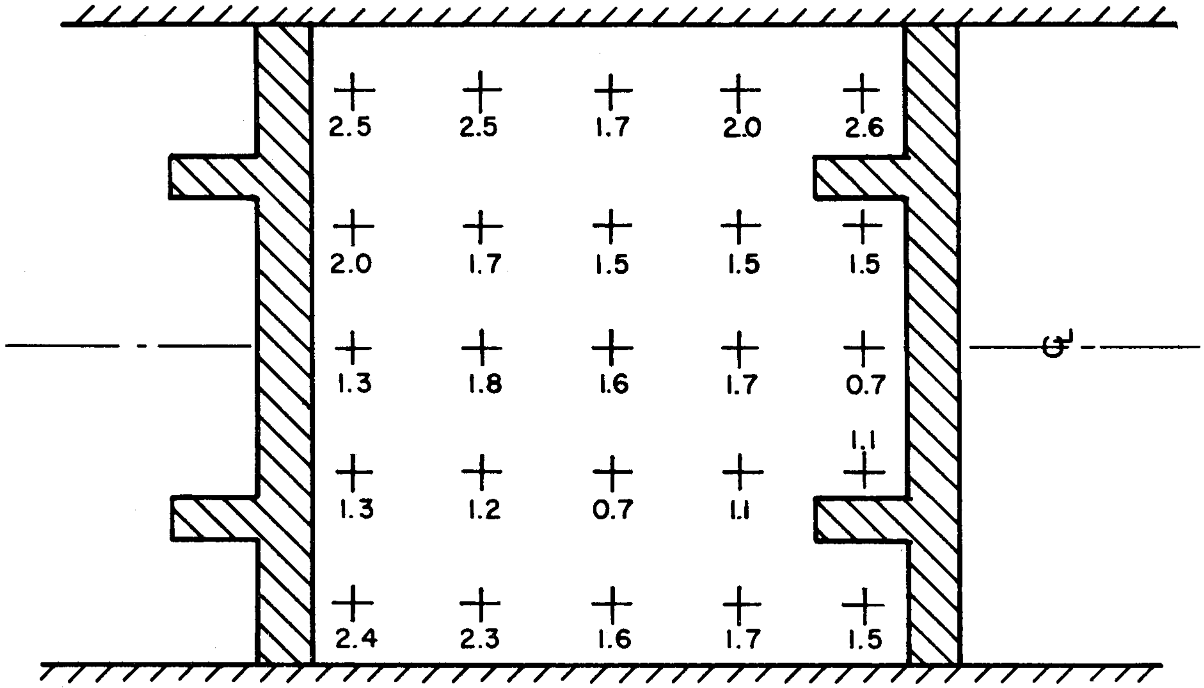
SCALE: 1" = 3'

FIGURE 23 D

MOSSYROCK FISH LADDER

VELOCITY DISTRIBUTION — LEVEL II

Q = 40.2 CFS ΔH = 1 FT.



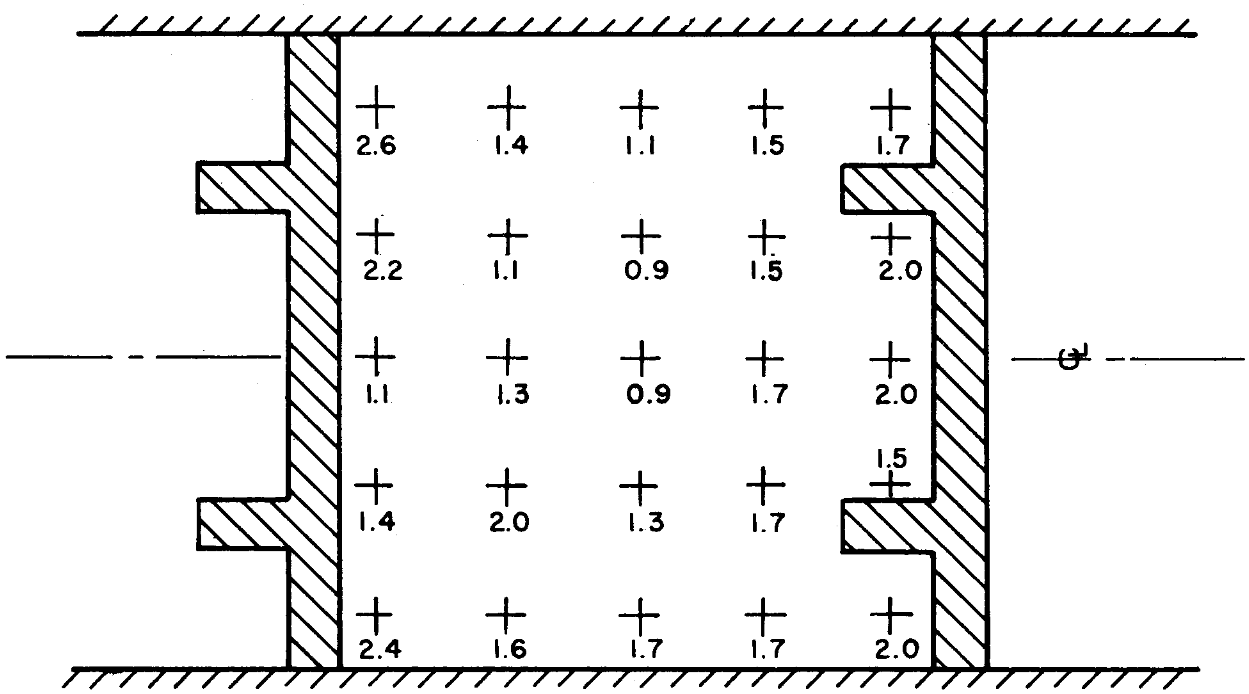
SCALE: 1" = 3'

FIGURE 23 E

VELOCITY DISTRIBUTION — LEVEL III

Q = 40.2 CFS

ΔH = 1 FT.



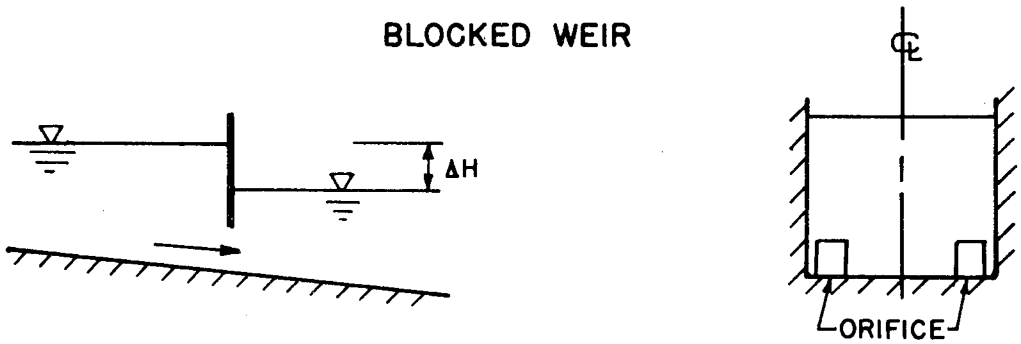
SCALE: 1" = 3'

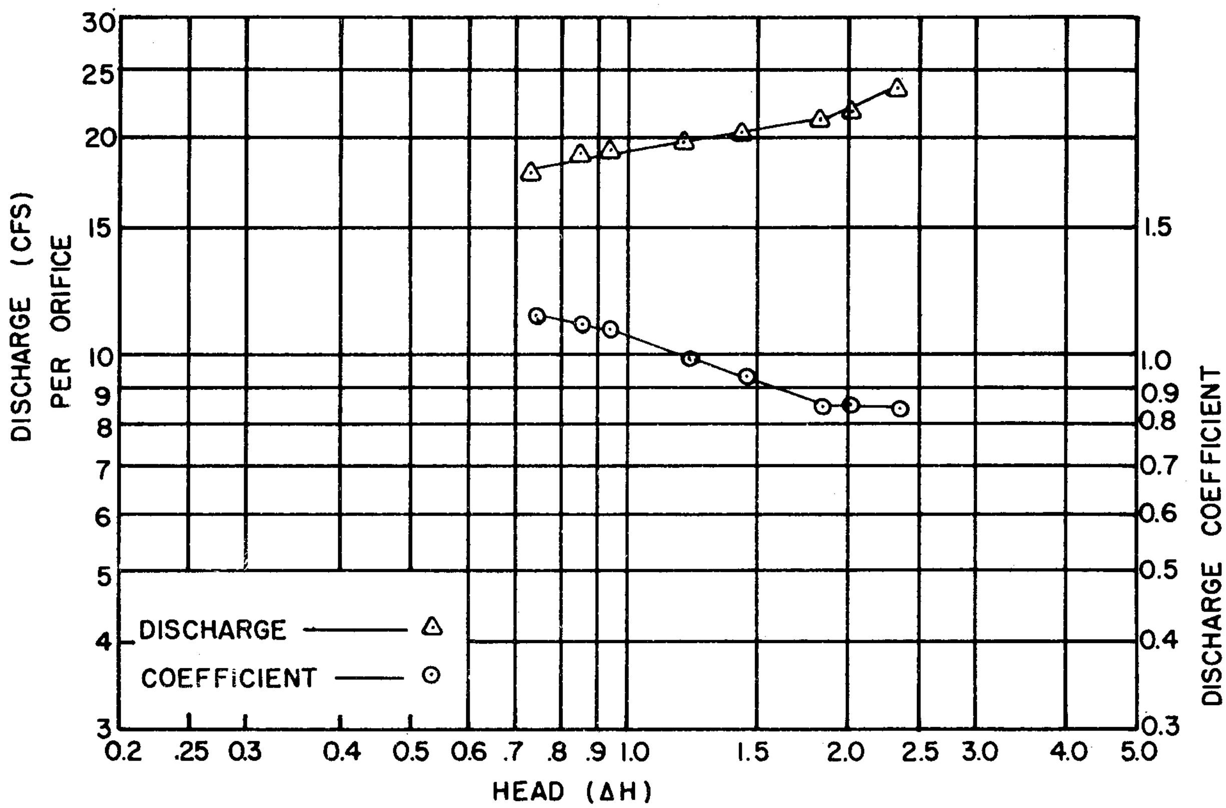
FIGURE 23 F

MOSSYROCK FISH LADDER
TYPICAL POOL
CALIBRATION CURVE

DEFINITION SKETCH

BLOCKED WEIR





NOTE

When the ladder is operating normally the discharge is 40.2 cfs and a one-foot difference between pools. Therefore, the correct discharge cannot be computed as a sum of discharges from individual openings.

COEFFICIENT OF DISCHARGE

$$C = \frac{Q}{A\sqrt{2g\Delta H}}$$

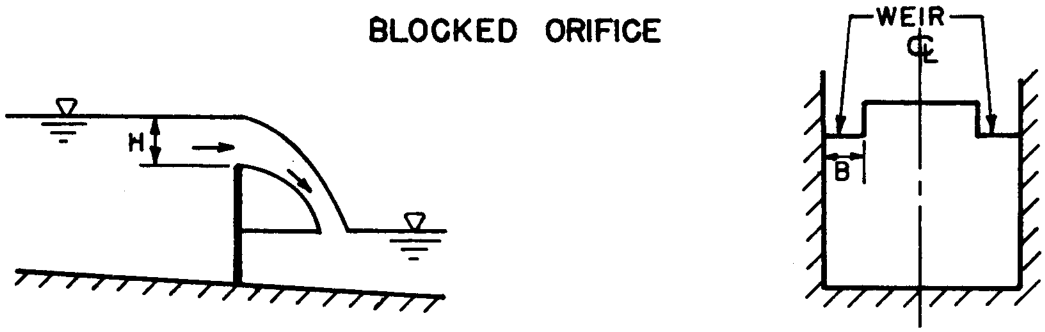
AREA OF OPENING PER ORIFICE

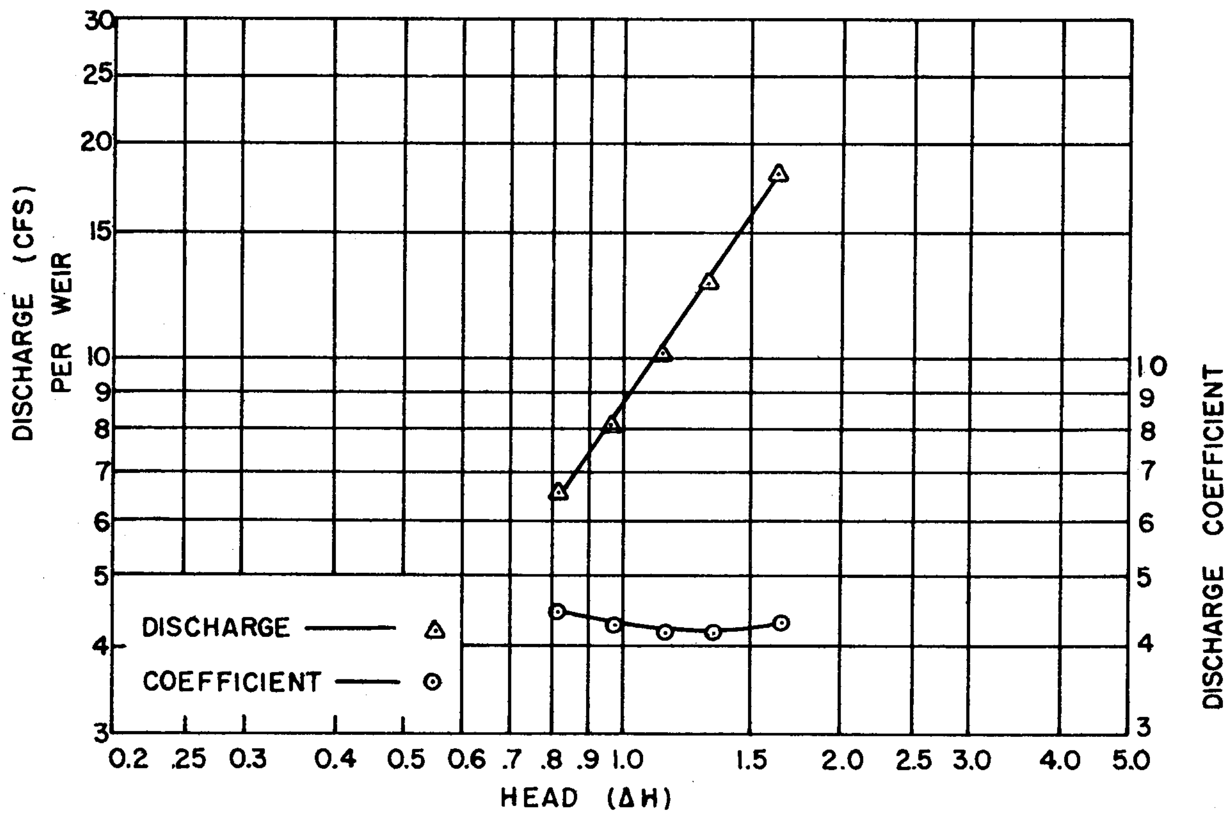
$A = 1.5 \times 1.5 = 2.25$ SQ. FT.

FIGURE 24

MOSSYROCK FISH LADDER
TYPICAL POOL
CALIBRATION CURVE

DEFINITION SKETCH
BLOCKED ORIFICE





NOTE

When the ladder is operating normally the discharge is 40.2 cfs and a one-foot difference between pools. Therefore, the correct discharge cannot be computed as a sum of discharges from individual openings.

COEFFICIENT,

$$K = \frac{Q}{B(H)^{3/2}}$$

WHERE B = 2'

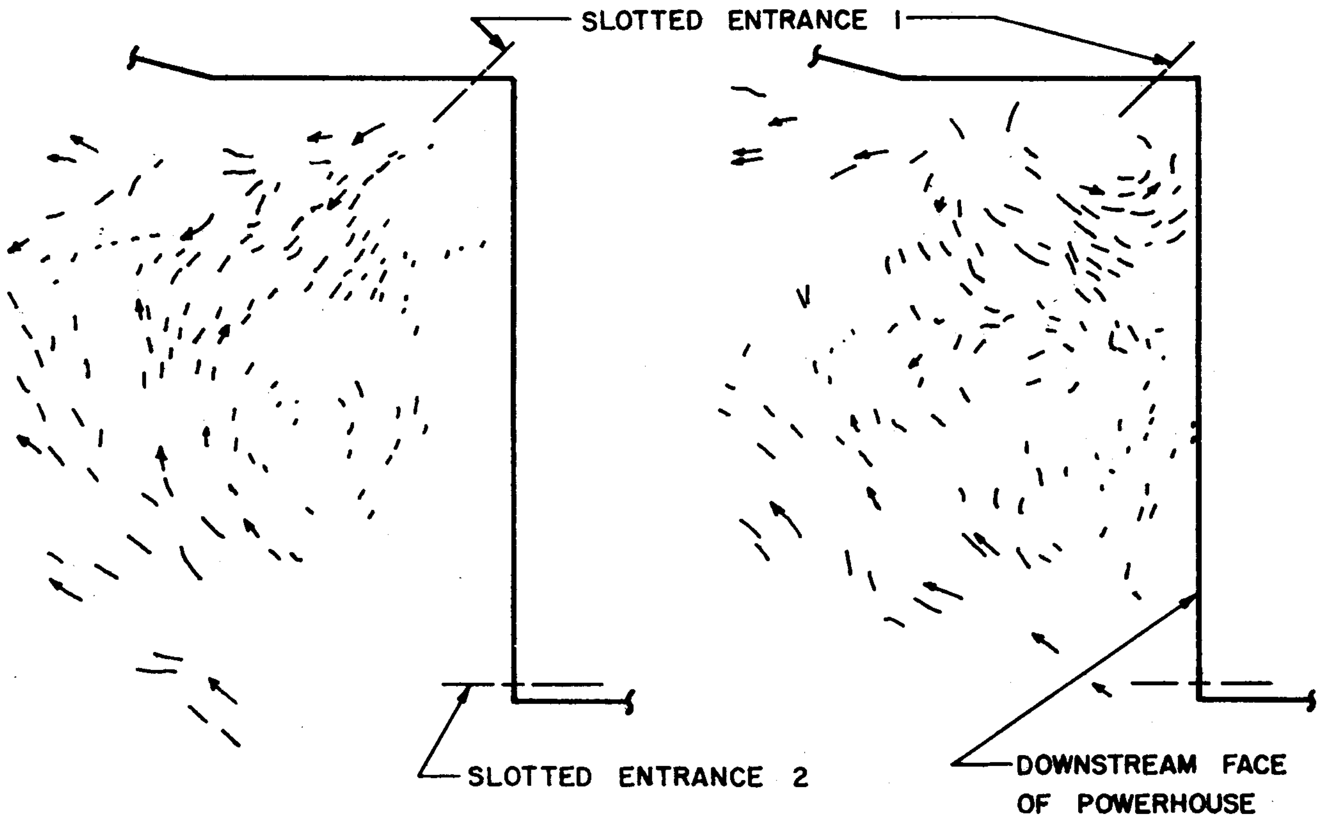
FIGURE 25

POWERHOUSE DISCHARGE

SURFACE PATHLINES

TRACED FROM PLATES 24 A—N

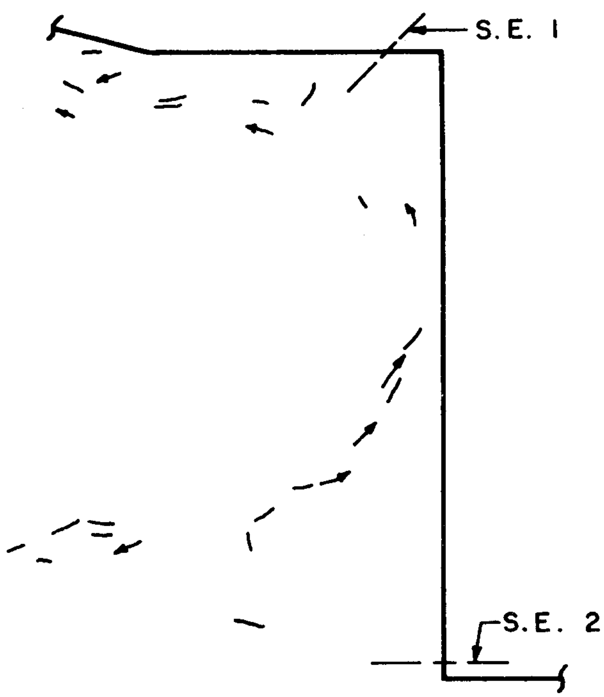
VELOCITY SCALE: 1" = 6.7 FPS

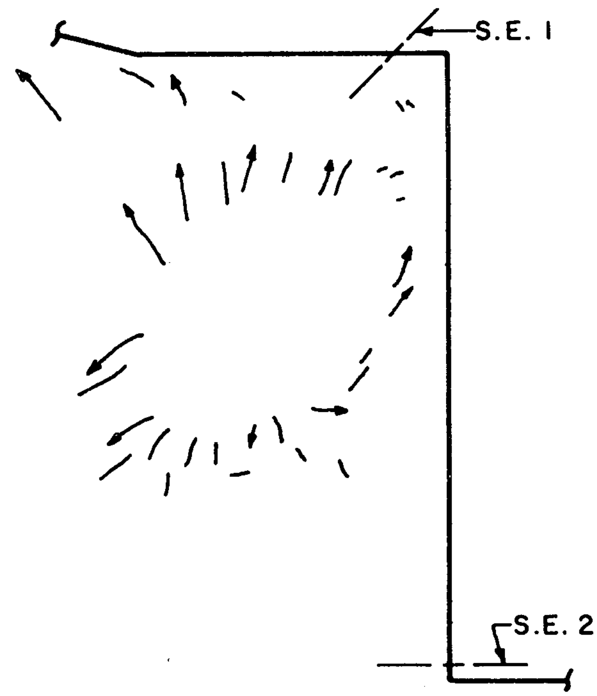


<u>DEFLECTOR ON</u> TURBINE 1 Q = 4400 CFS <u>DEFLECTOR OFF</u>

FIGURE 26-A FIGURE 26-B

POWERHOUSE DISCHARGE, SURFACE PATHLINES

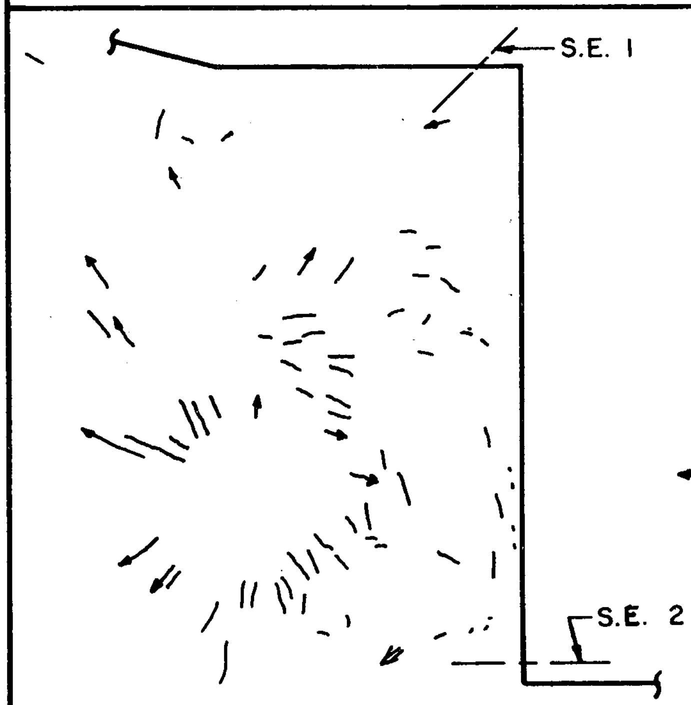


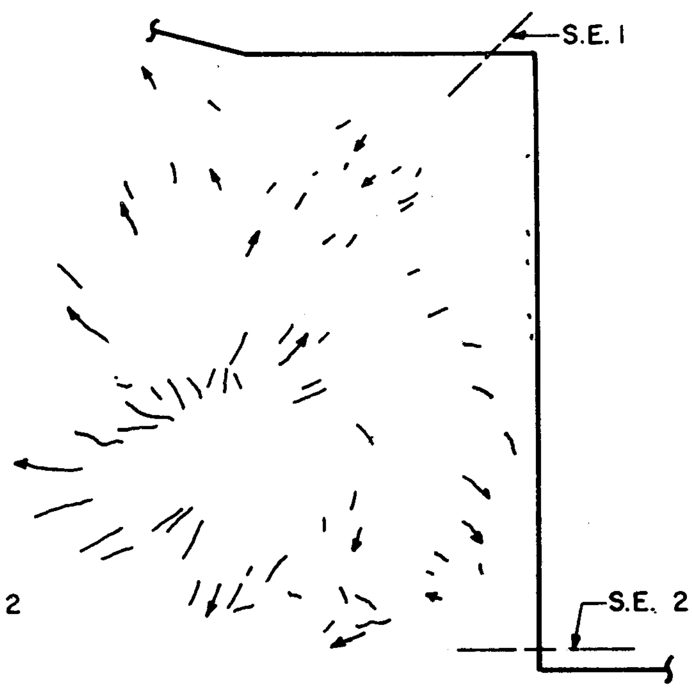


DEFLECTOR ON — TURBINE 2 Q = 4400 CFS — DEFLECTOR OFF

FIGURE 26-C

FIGURE 26-D



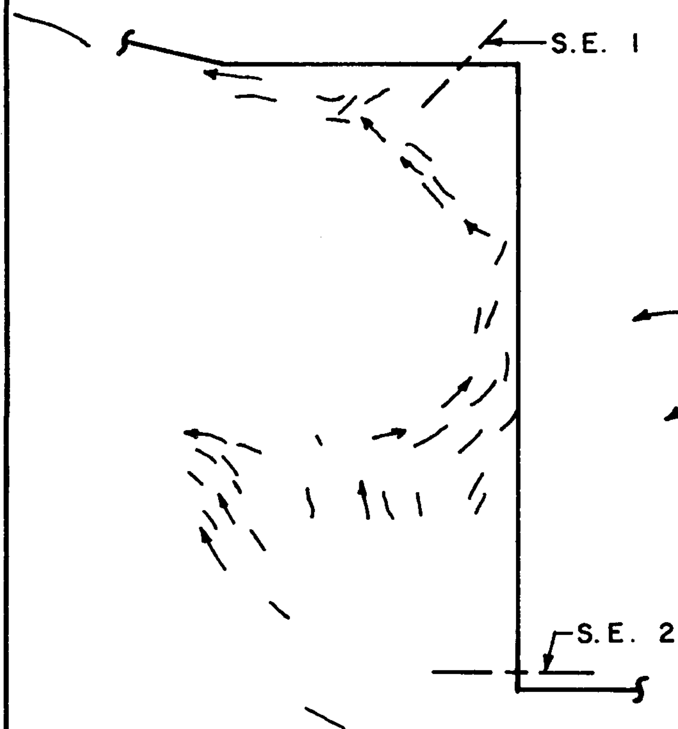


DEFLECTOR ON — TURBINE 3 Q = 4400 CFS — DEFLECTOR OFF

FIGURE 26-E

FIGURE 26-F

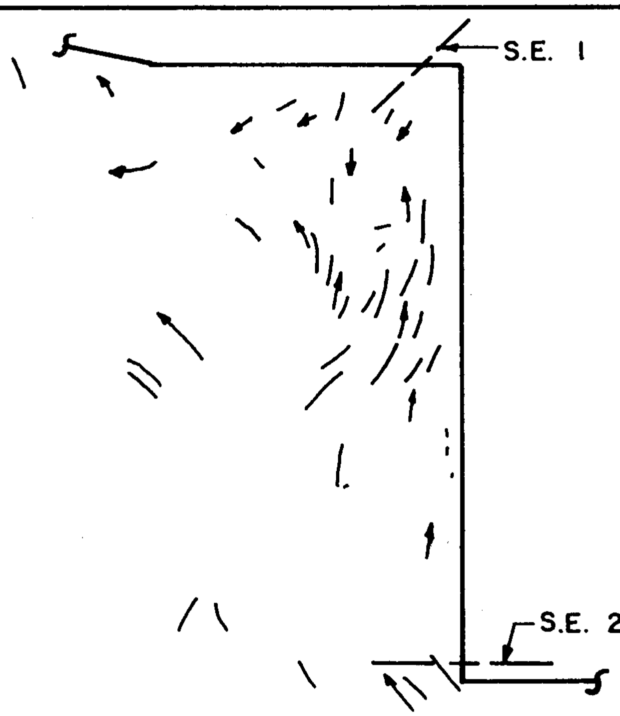
POWERHOUSE DISCHARGE, SURFACE PATHLINES

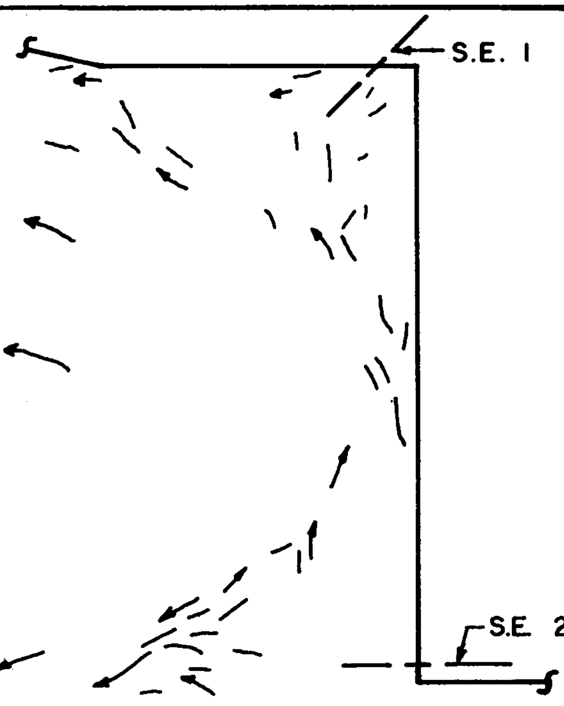


DEFLECTOR ON — TURBINES 1 AND 2, 6400 CFS EACH — DEFLECTOR OFF

FIGURE 26-G

FIGURE 26-H





DEFLECTOR ON — TURBINES 2 AND 3, 6400 CFS EACH — DEFLECTOR OFF

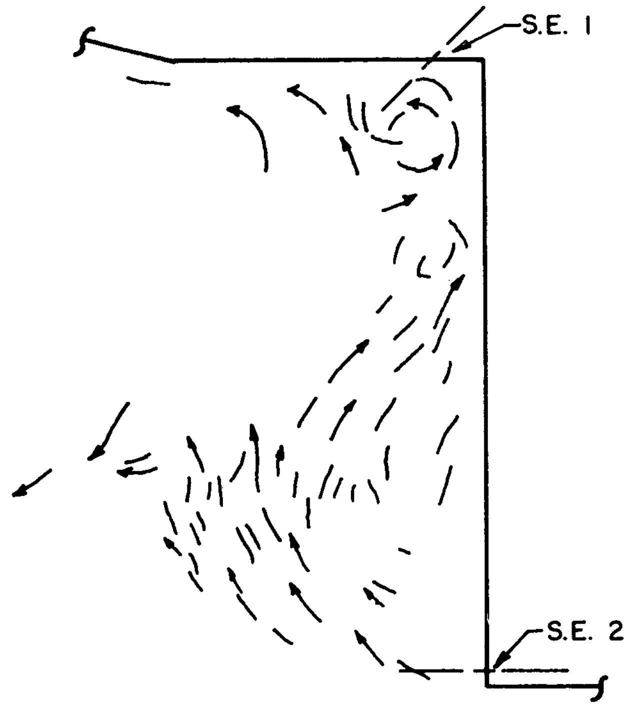
FIGURE 26-I

FIGURE 26-J

POWERHOUSE DISCHARGE, SURFACE PATHLINES

DEFLECTOR ON

FIGURE 26—K



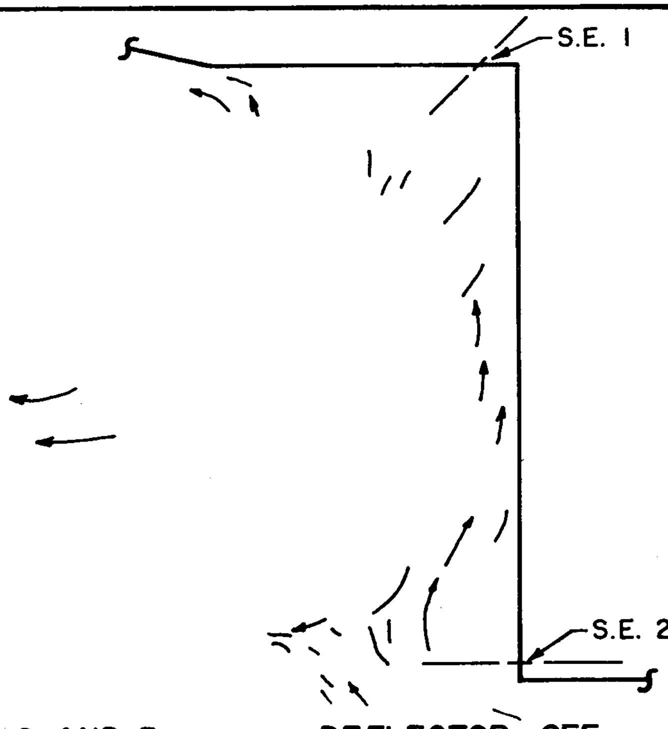
DEFLECTOR OFF

FIGURE 26—L

TURBINES 1 AND 2
7300 CFS EACH

DEFLECTOR ON

FIGURE 26—M

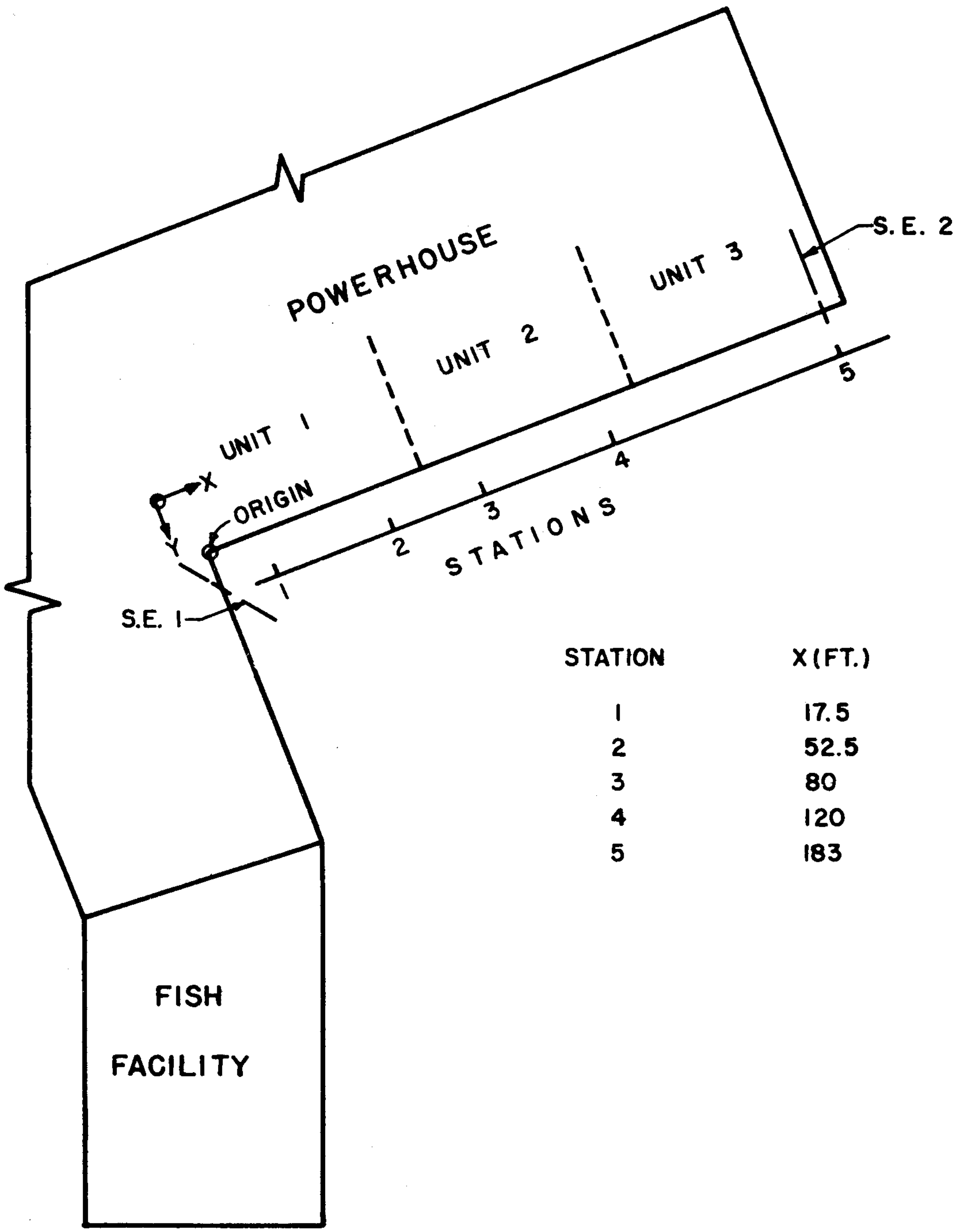


DEFLECTOR OFF

FIGURE 26—N

TURBINES 1, 2 AND 3
7300 CFS EACH

LOCATION OF PRESSURE PROBE



STATION	X (FT.)	Y (FT.)
1	17.5	10
2	52.5	12.5
3	80	12.5
4	120	12.5
5	183	35

SCALE: 1" = 50 FT.

FIGURE 27

SAMPLE OF PRESSURE-WAVE RECORD

SURGE[2] ALONG DOWNSTREAM FACE OF POWERHOUSE

FOUR WARPED BUCKETS

FLOW RATES (CFS)

RIVER: 50,000
SPILLWAY: 35,600
TURBINES:
1. 7,200
2. 7,200

TAILWATER ELEV: 448.5
DEFLECTOR OFF
PRESSURE SCALE:
1 MM. = 2.16 FT. (SURGE)
TIME SCALE:
5 MM. = 7.74 SEC.

STA. 5
ELEV. 438
ALL GATES OPEN

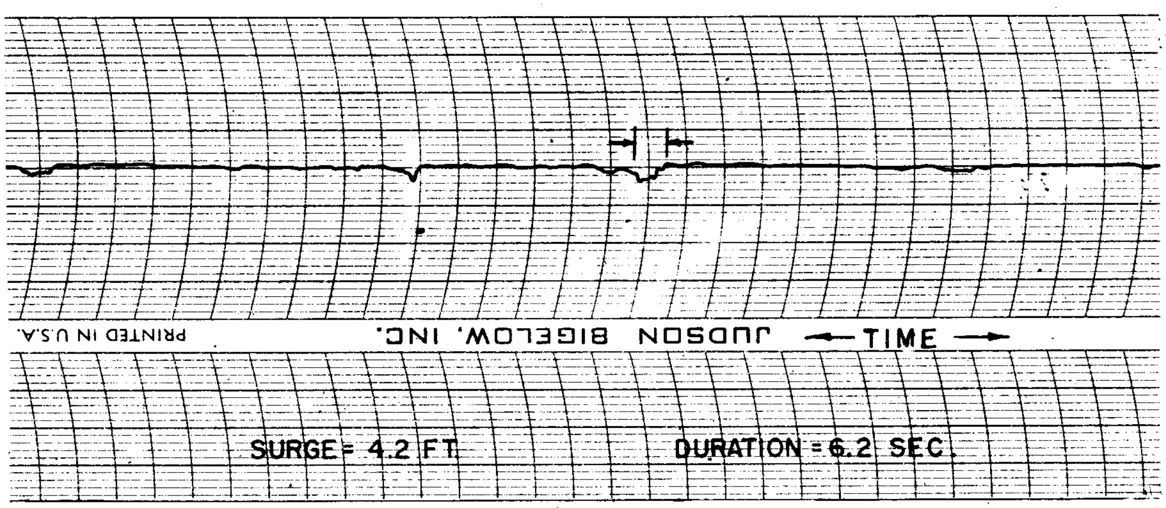


FIGURE 28 A

NOTE:

1. REFERENCE, SEE FIG. 27 AND TABLE 3.
2. TROUGH-TO-CREST, HEIGHT OF PRESSURE FLUCTUATION.

SAMPLE OF PRESSURE-WAVE RECORD

(CONTINUED)

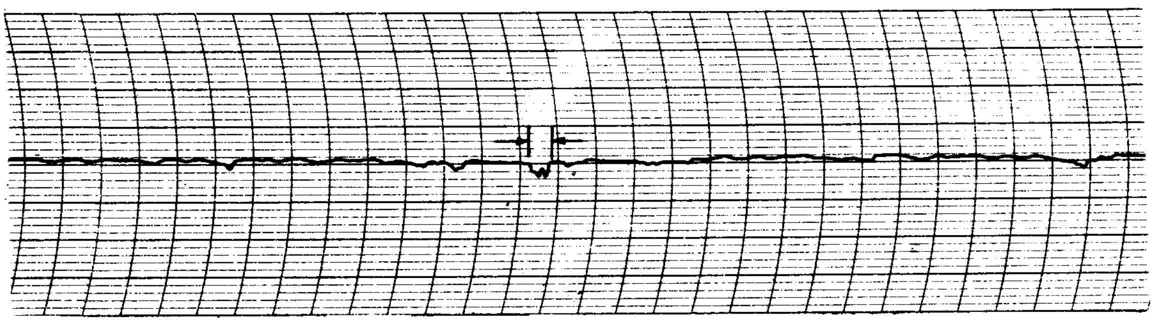
STA. 5 ELEV. 438

GATE 1 - CLOSED
2,3 & 4 OPEN

SURGE = 6.5 FT.
DURATION = 5.4 SEC.

FIGURE 28 B

STA. 5 ELEV. 438



GATE 2 - CLOSED
1,3 & 4 OPEN

SURGE = 4.3 FT.
DURATION = 3.9 SEC.

FIGURE 28 C

STA. 5 ELEV. 438

GATES 1 & 2 - CLOSED
3 & 4 OPEN

SURGE = 8.1 FT.
DURATION = 7.0 SEC.

FIGURE 28 D

SAMPLE OF PRESSURE-WAVE RECORD

SURGE[2] ALONG DOWNSTREAM FACE OF POWERHOUSE

FOUR WARPED BUCKETS

FLOW RATES (CFS)

RIVER: 50,000
SPILLWAY: 35,600
TURBINES:
1. 7,200
2. 7,200

TAILWATER ELEV: 448.5
DEFLECTOR OFF
PRESSURE SCALE:
1 MM. = 1.08 FT. (SURGE)
TIME SCALES:
5 MM. = 7.74 SEC.
25MM. = 7.74 SEC. (FIGS. 29H & I)

STA. 3
ELEV. 400
ALL GATES OPEN

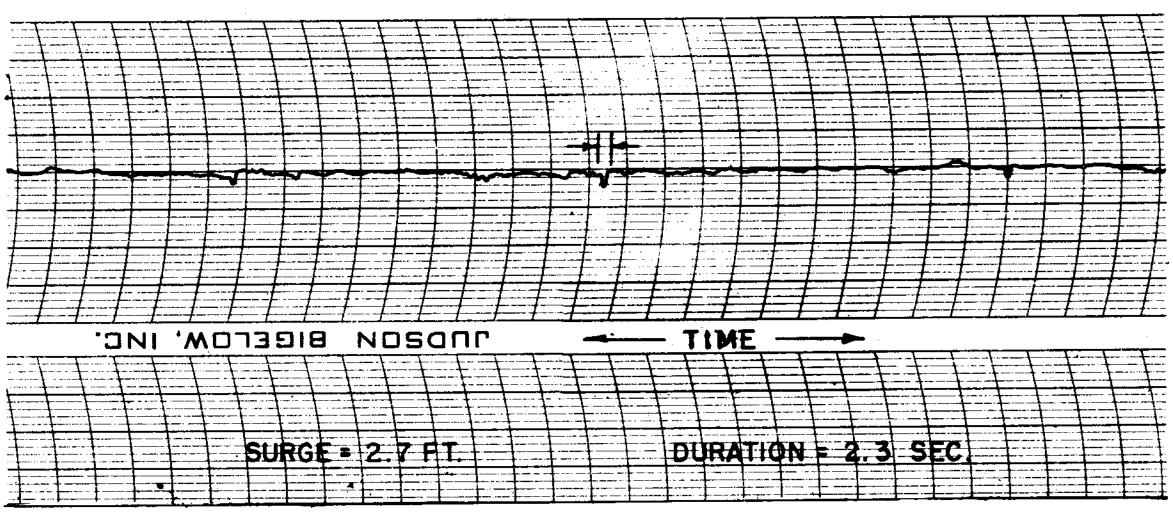


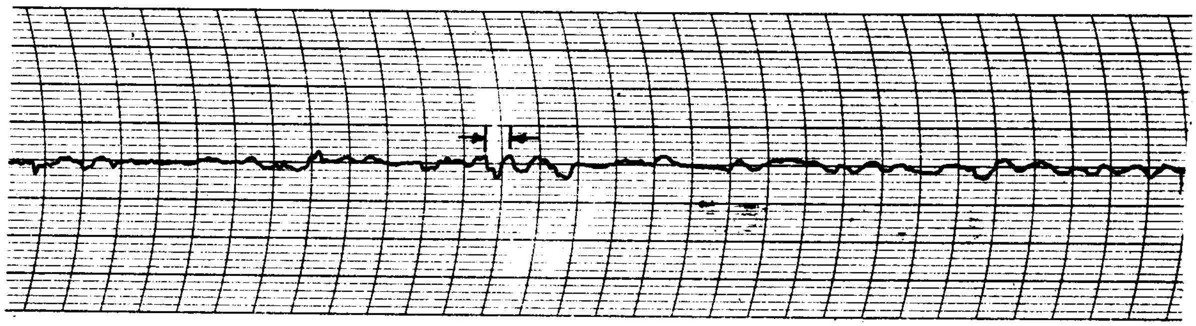
FIGURE 29 A

NOTE:
1. REFERENCE, SEE FIG. 27 AND TABLE 3.
2. TROUGH-TO-CREST, HEIGHT OF PRESSURE FLUCTUATION.

SAMPLE OF PRESSURE-WAVE RECORD

(CONTINUED)

STA. 3 ELEV. 433

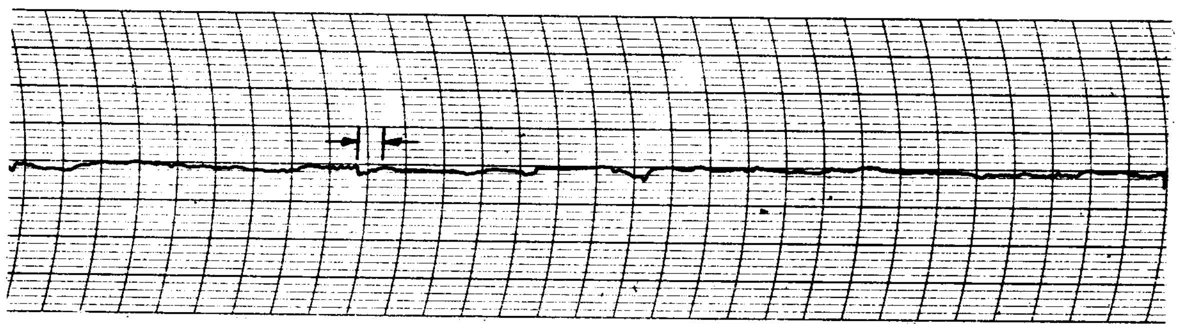


ALL GATES OPEN

SURGE = 3.6 FT.
DURATION = 4.7 SEC.

FIGURE 29 B

STA. 4 ELEV. 400

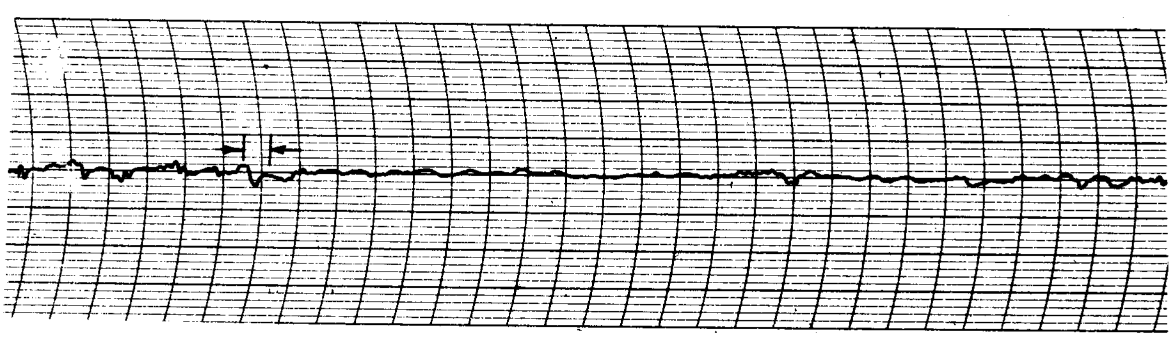


ALL GATES OPEN

SURGE = 1.2 FT.
DURATION = 3.9 SEC.

FIGURE 29 C

STA. 4 ELEV. 433



ALL GATES OPEN

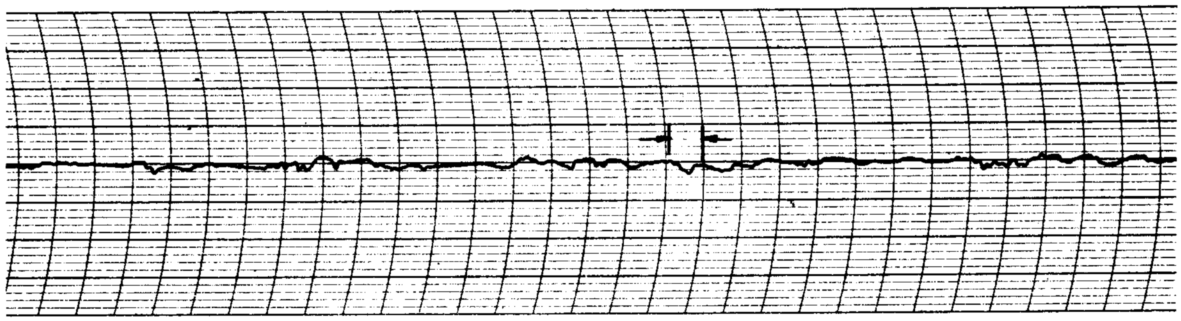
SURGE = 3.6 FT.
DURATION = 5.4 SEC.

FIGURE 29 D

SAMPLE OF PRESSURE-WAVE RECORD

(CONTINUED)

STA. 4 ELEV. 400



GATE 1-CLOSED
2,3 & 4 OPEN

SURGE = 1.8 FT.
DURATION = 7.8 SEC.

FIGURE 29 E

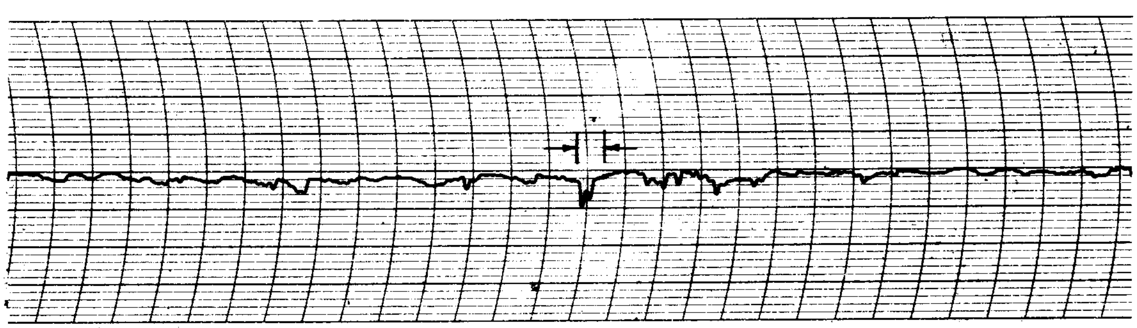
STA. 4 ELEV. 400

GATE 2-CLOSED
1,3 & 4 OPEN

SURGE = 2.4 FT.
DURATION = 3.9 SEC.

FIGURE 29 F

STA. 4 ELEV. 400



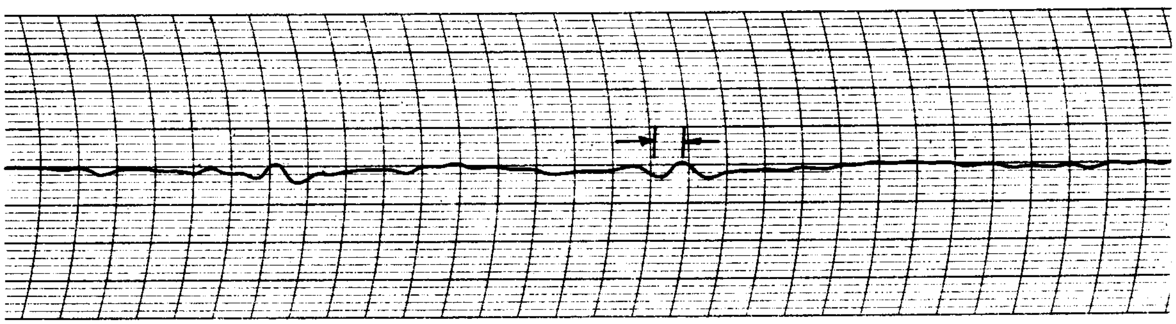
GATES 1 & 4 OPEN
2 & 3 -CLOSED

SURGE = 4.8 FT.
DURATION = 5.4 SEC.

FIGURE 29 G

SAMPLE OF PRESSURE-WAVE RECORD
(CONTINUED)

STA. 3 ELEV. 400

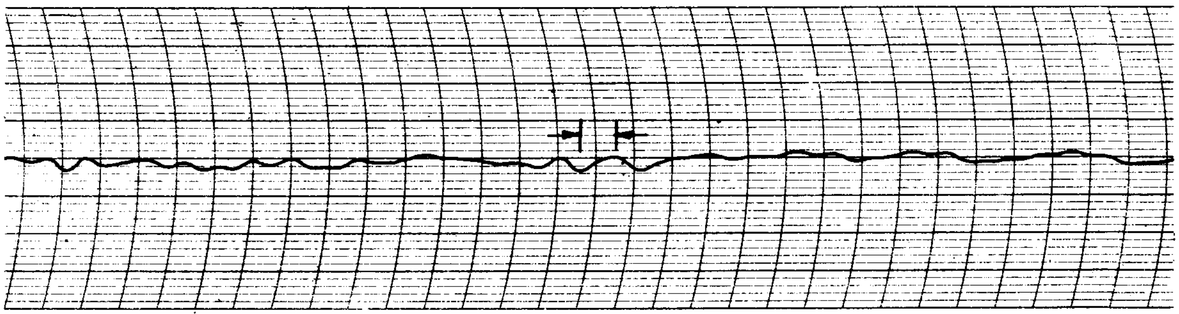


ALL GATES OPEN

SURGE = 2.2 FT.
DURATION = 1.4 SEC.

FIGURE 29 H

STA. 3 ELEV. 433



ALL GATES OPEN

SURGE = 2.2 FT.
DURATION = 1.6 SEC.

FIGURE 29 I

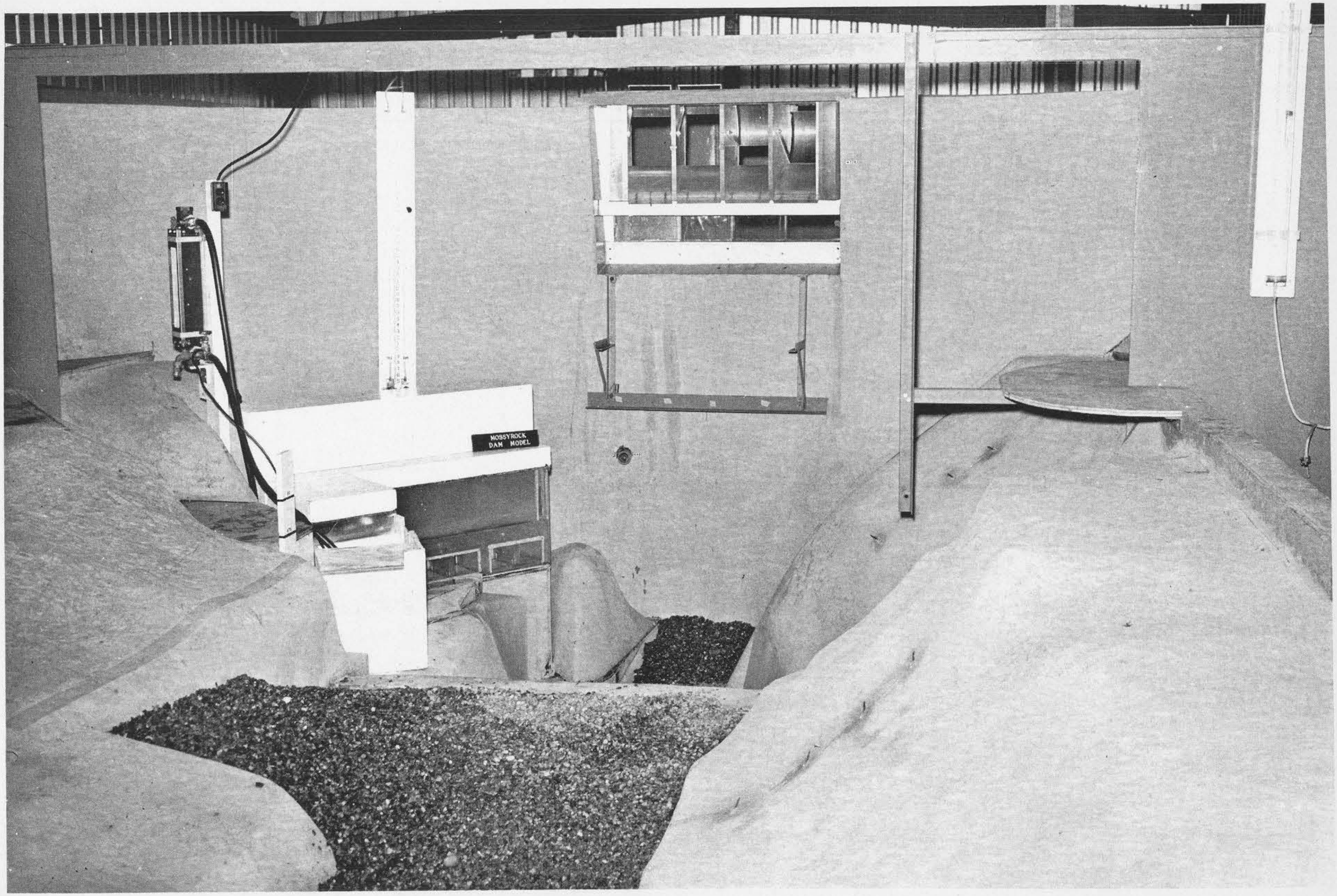


Plate 1

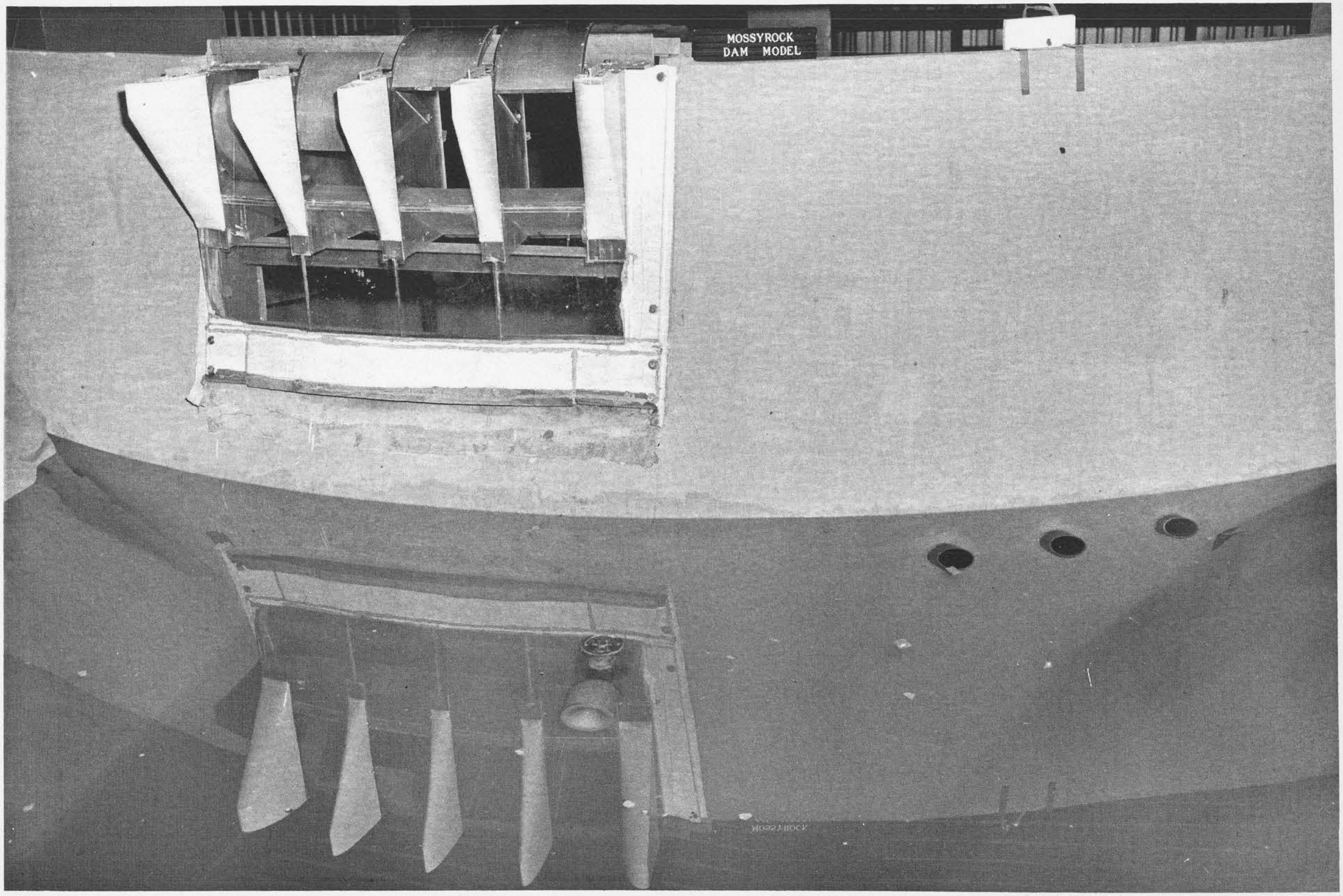


Plate 2

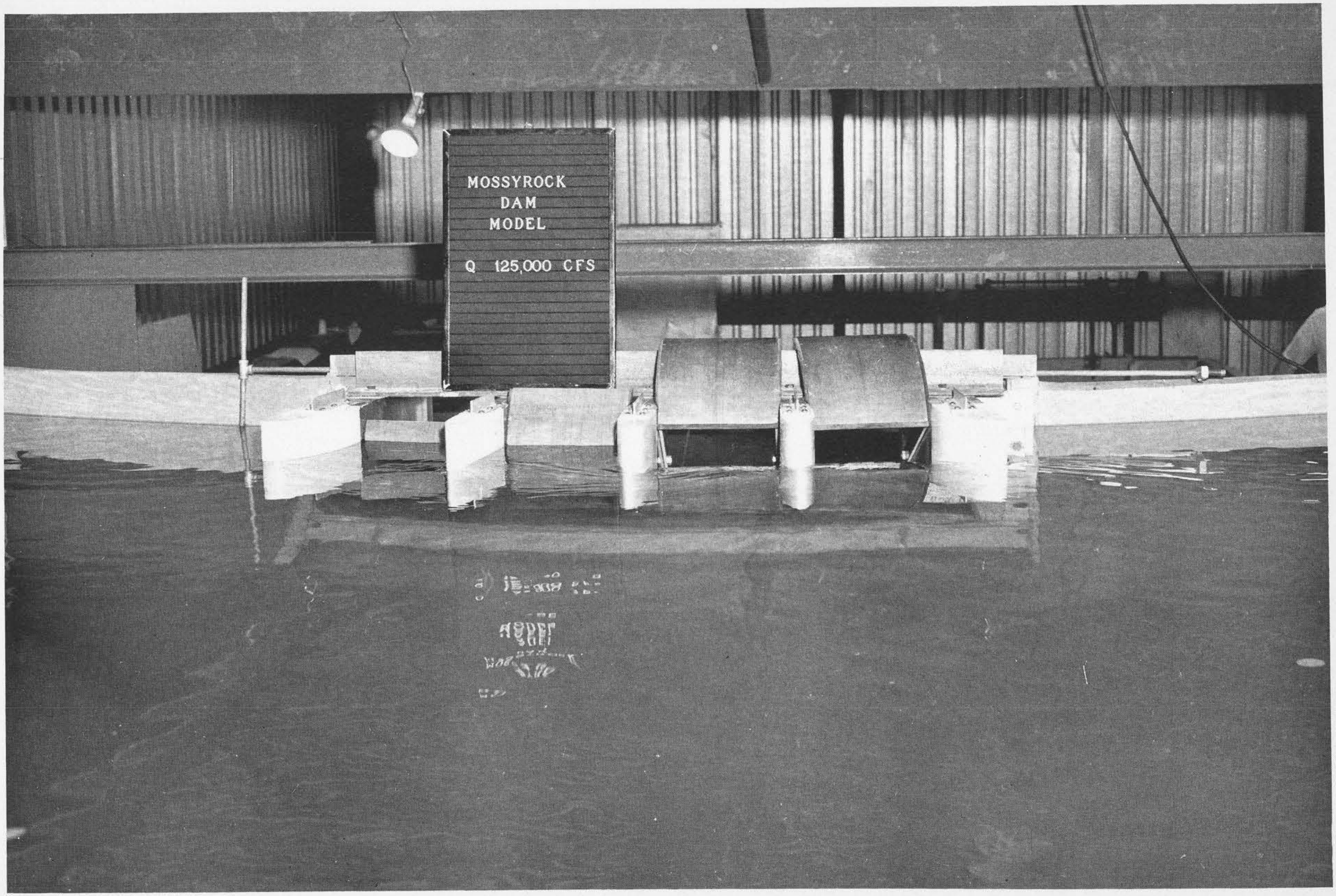


Plate 3

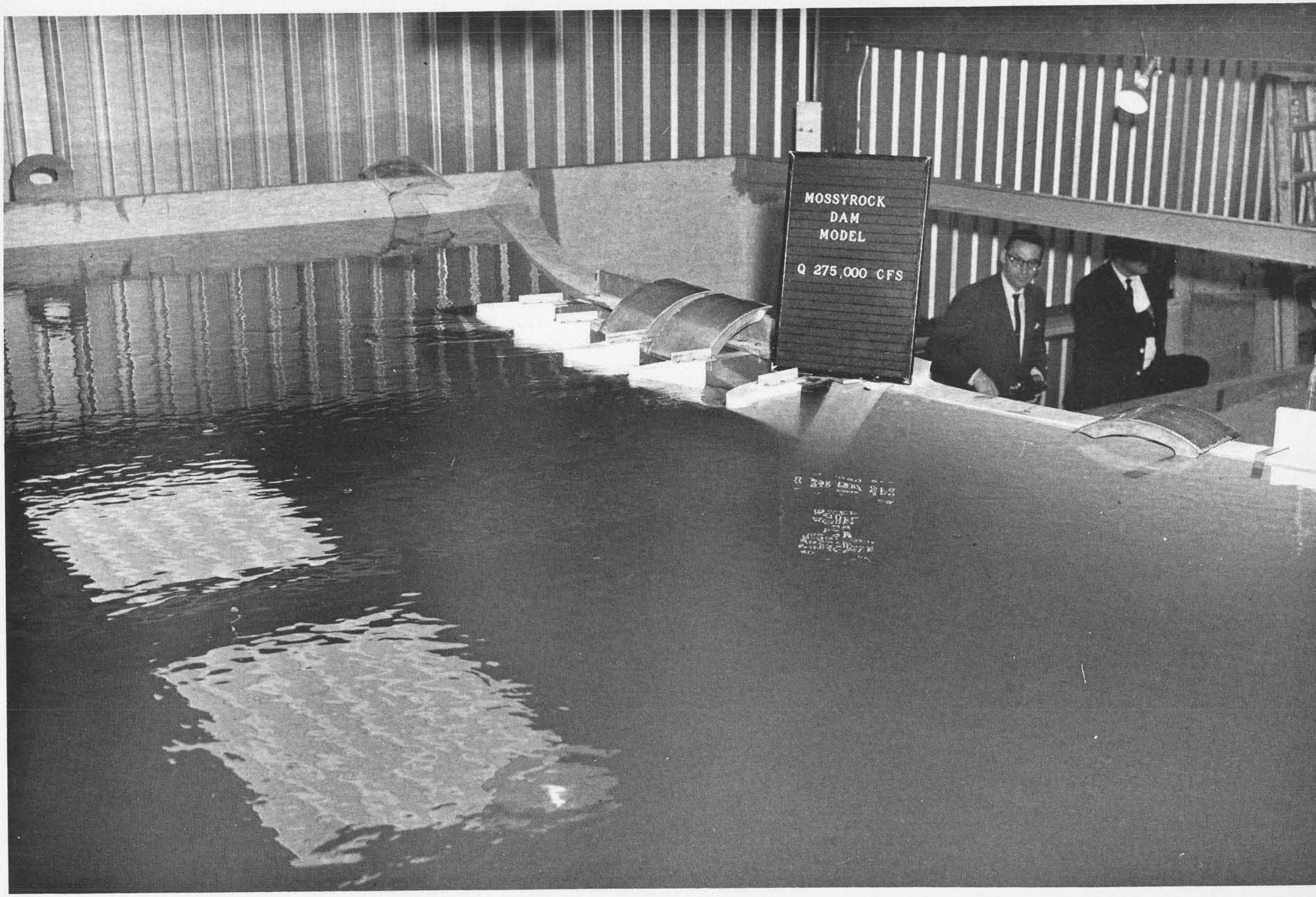


Plate 4


MOSSYROCK
DAM
MODEL
Q 100,000 CFS
TW 467
GATES 1 & 4
4 0° BUCKET
500
475

Plate 5

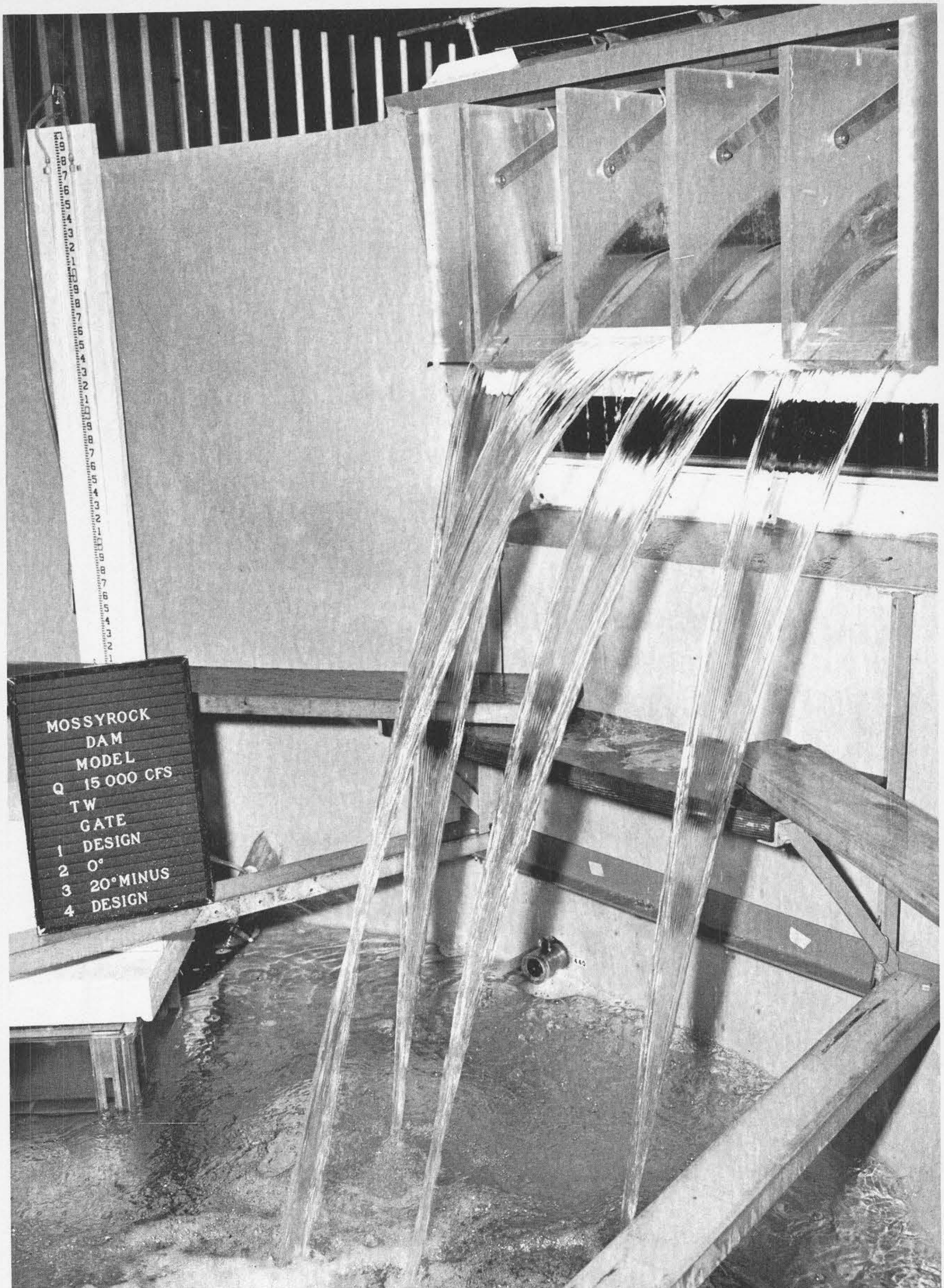

MOSSYROCK
DAM
MODEL
Q 15 000 CFS
TW
GATE
1 DESIGN
2 0°
3 20° MINUS
4 DESIGN

Plate 6

Plate 7

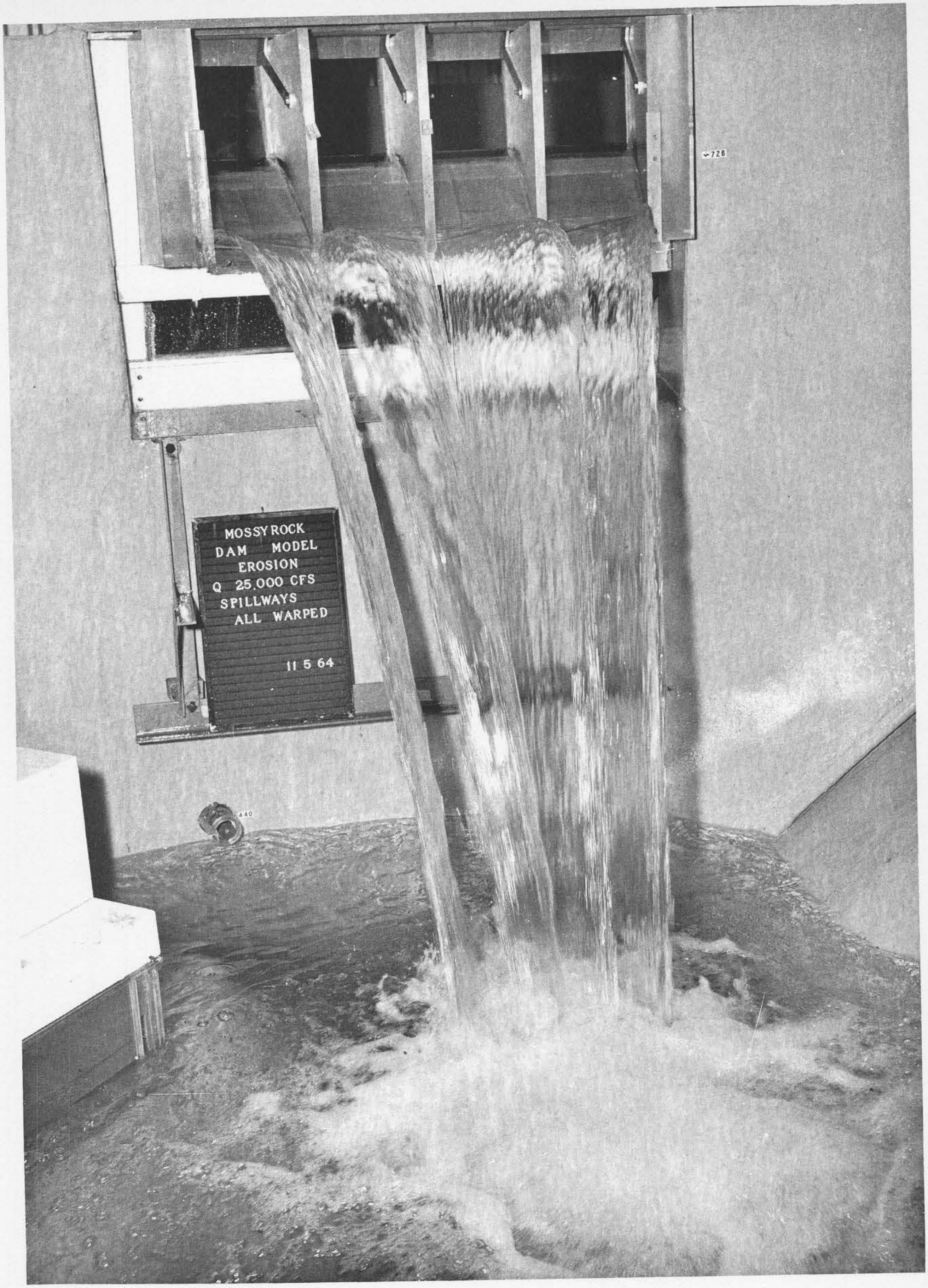

MOSSYROCK
DAM MODEL
EROSION
Q 25,000 CFS
SPILLWAYS
ALL WARPED
11 5 64

Plate 8

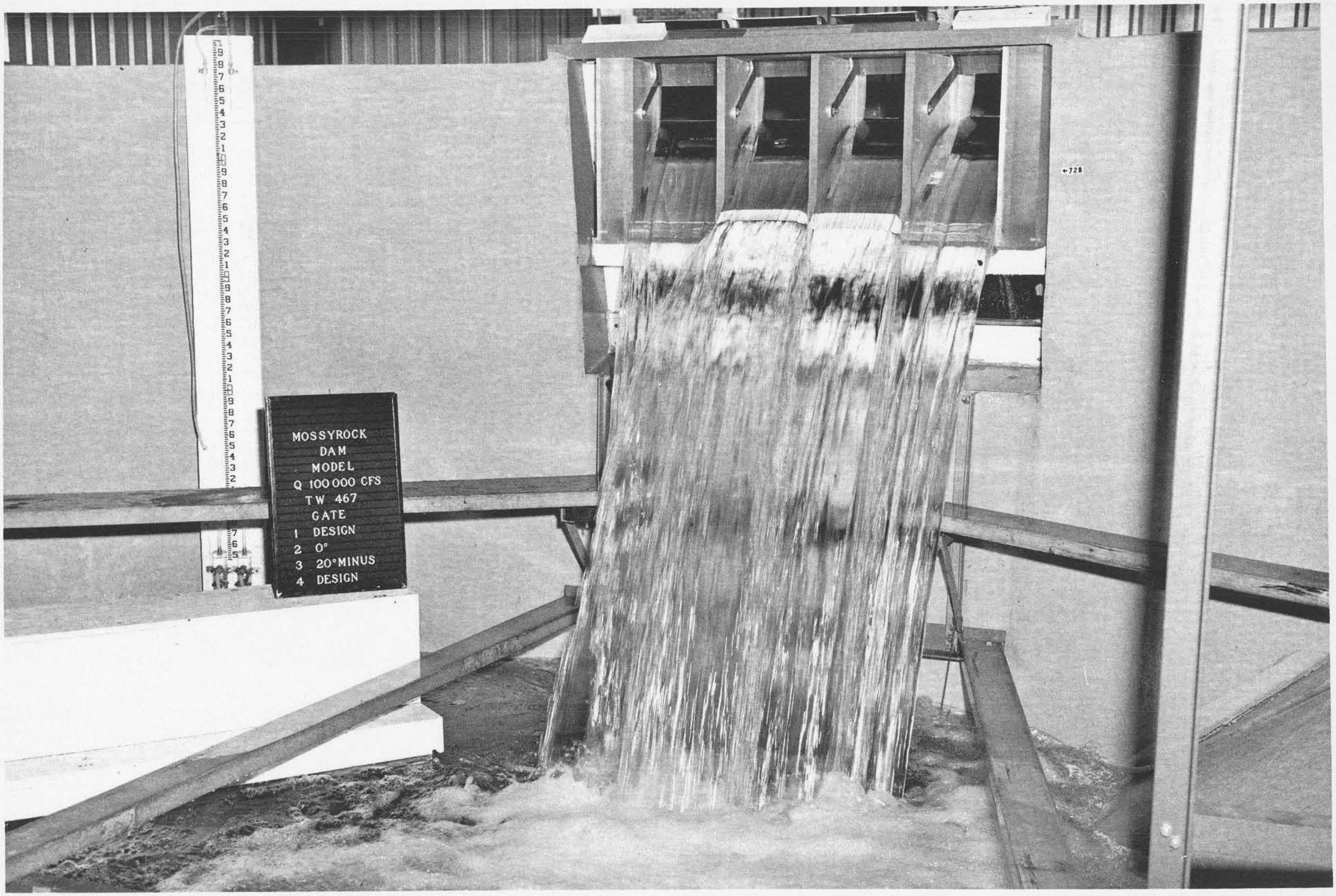

MOSSYROCK
DAM
MODEL
Q 100 000 CFS
TW 467
GATE
1 DESIGN
2 0°
3 20° MINUS
4 DESIGN

Plate 9

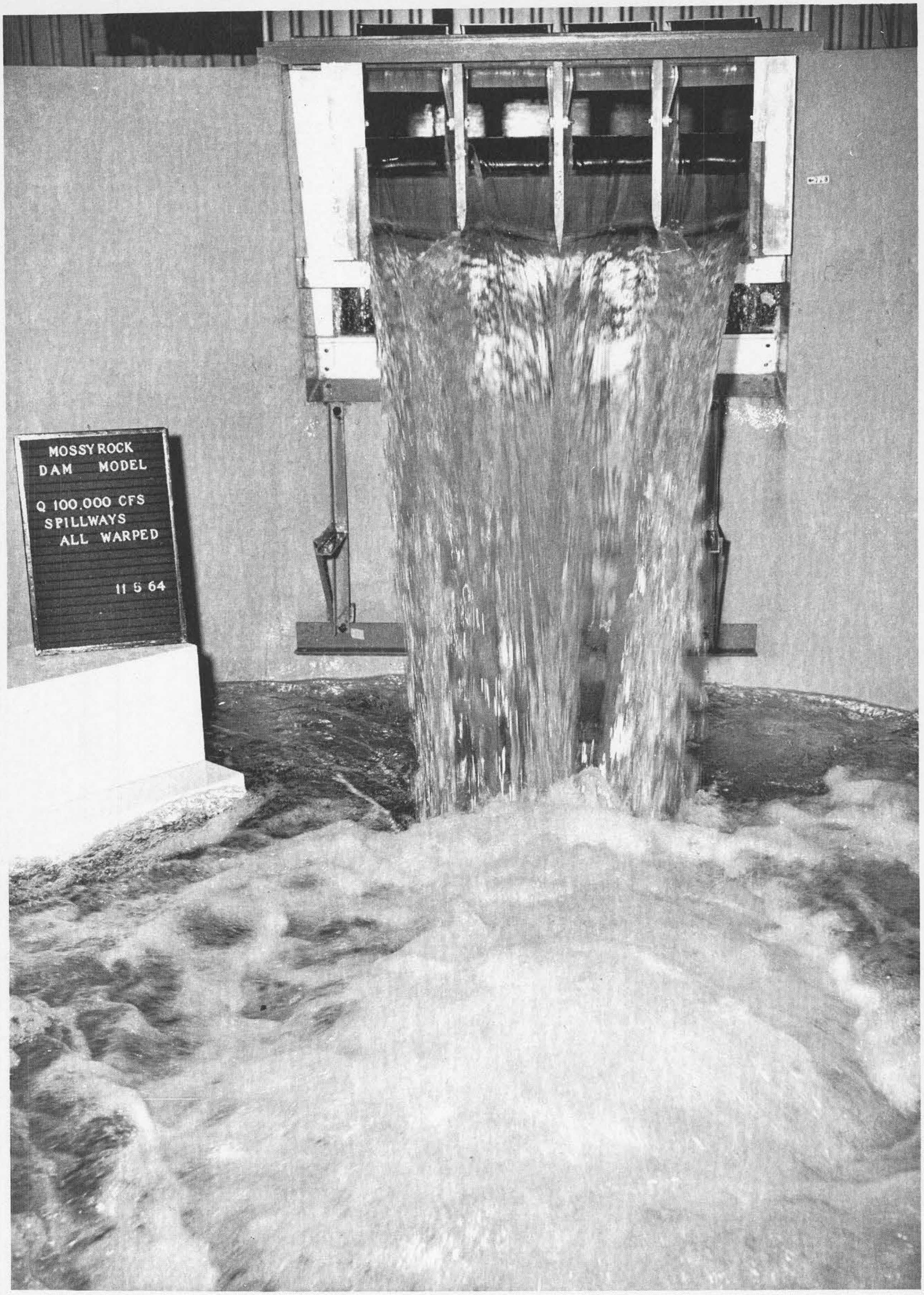

MOSSY ROCK
DAM MODEL
Q 100,000 CFS
SPILLWAYS
ALL WARPED
11 5 64

Plate 10


MOSSYROCK
DAM MODEL
Q 275,000 CFS
SPILLWAYS
ALL WARPED
11 5 64

Plate 11

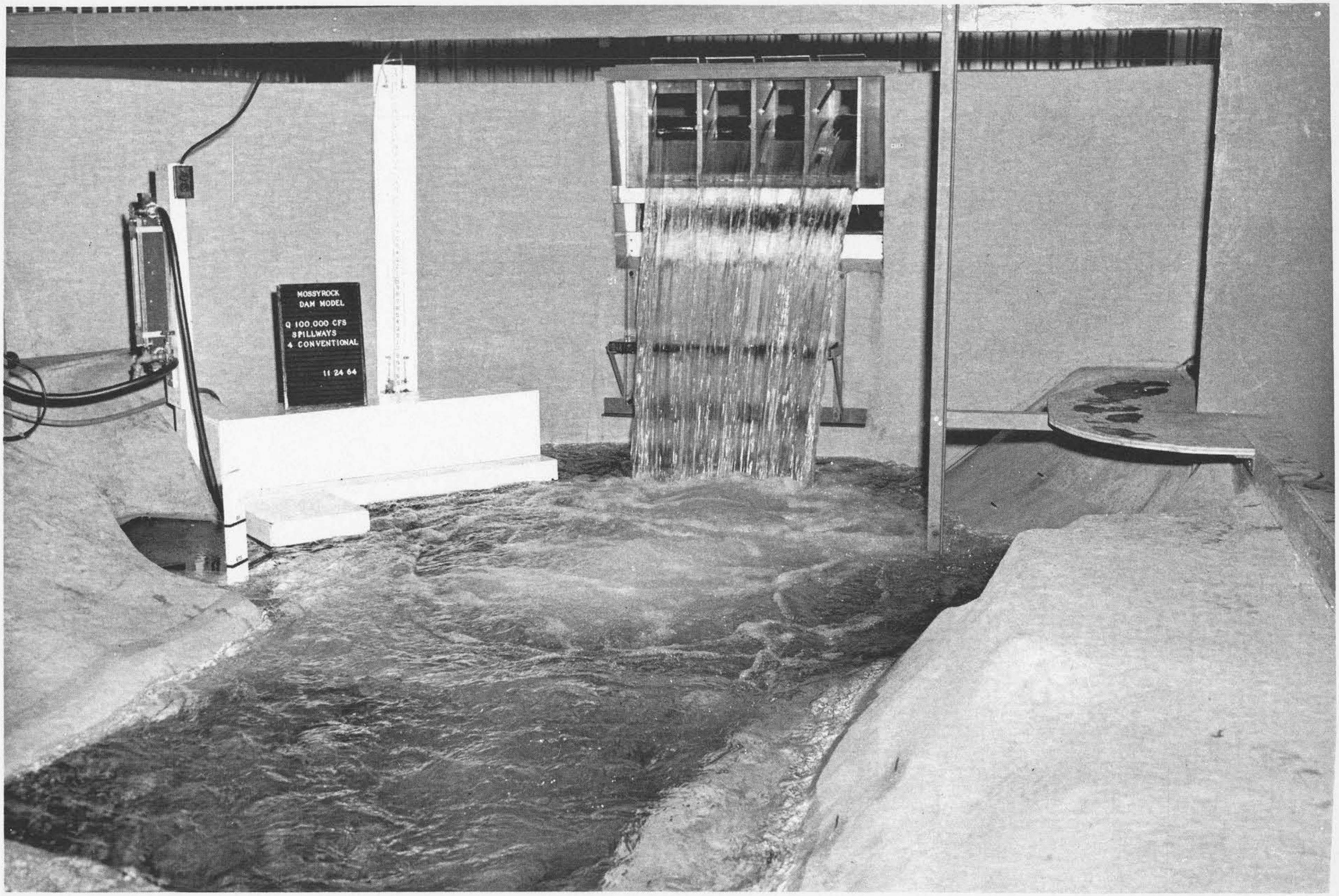

MOSSYROCK
DAM MODEL
Q 100,000 CFS
SPILLWAYS
4 CONVENTIONAL
11 24 64

Plate 12

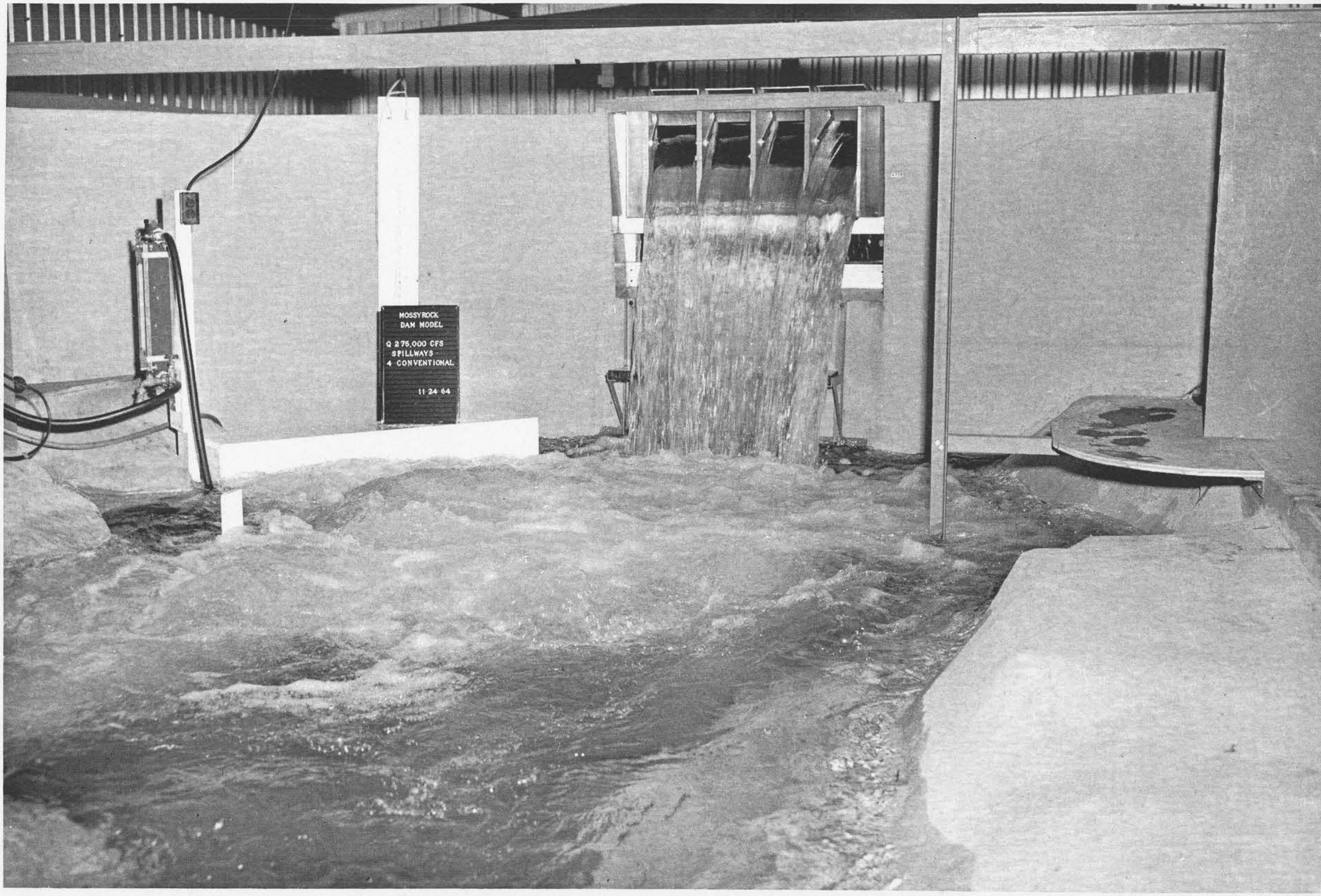

MOSSYROCK
DAM MODEL
Q 275,000 CFS
SPILLWAYS
4 CONVENTIONAL
11 24 64

Plate 13

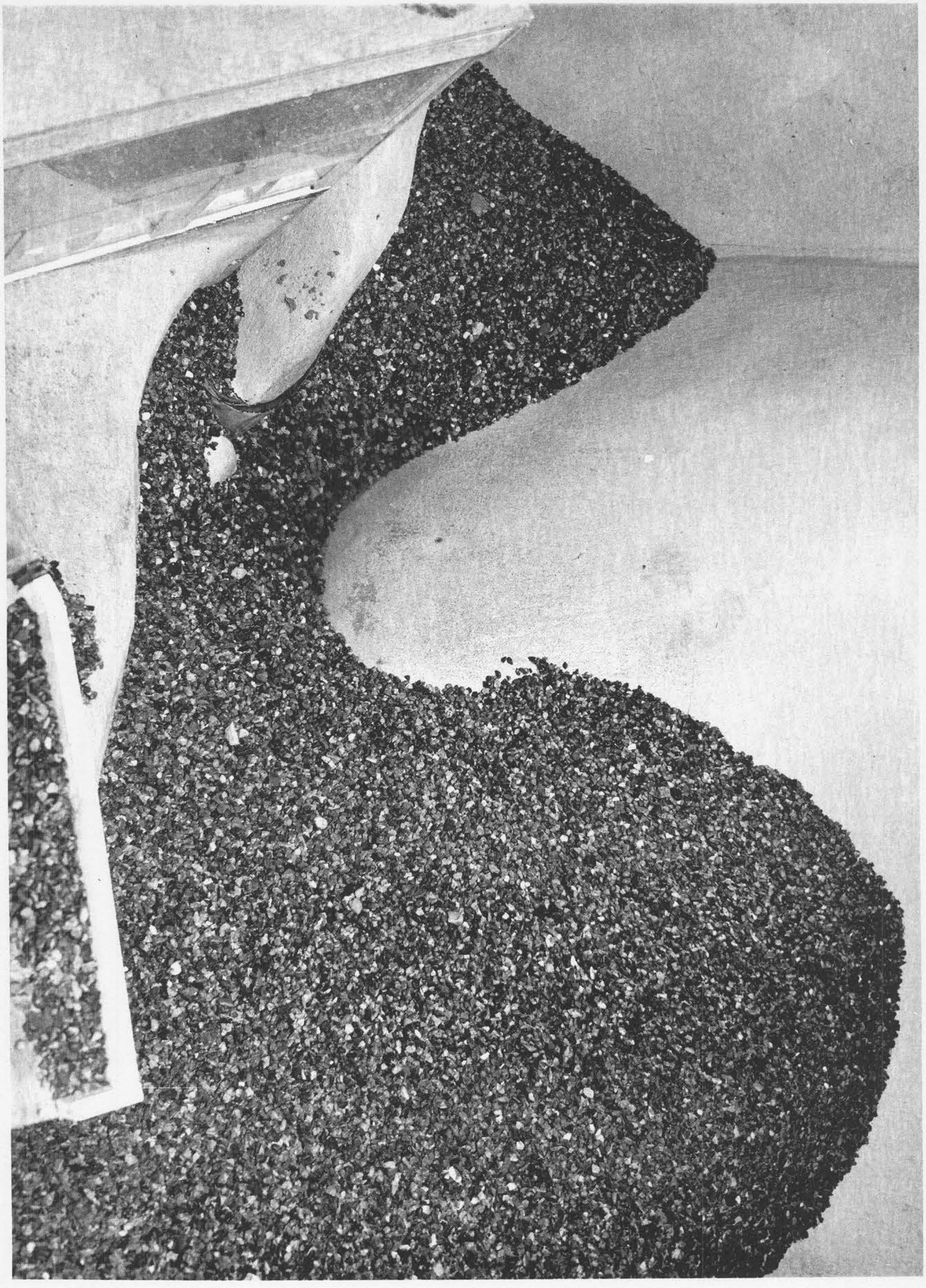


Plate 14

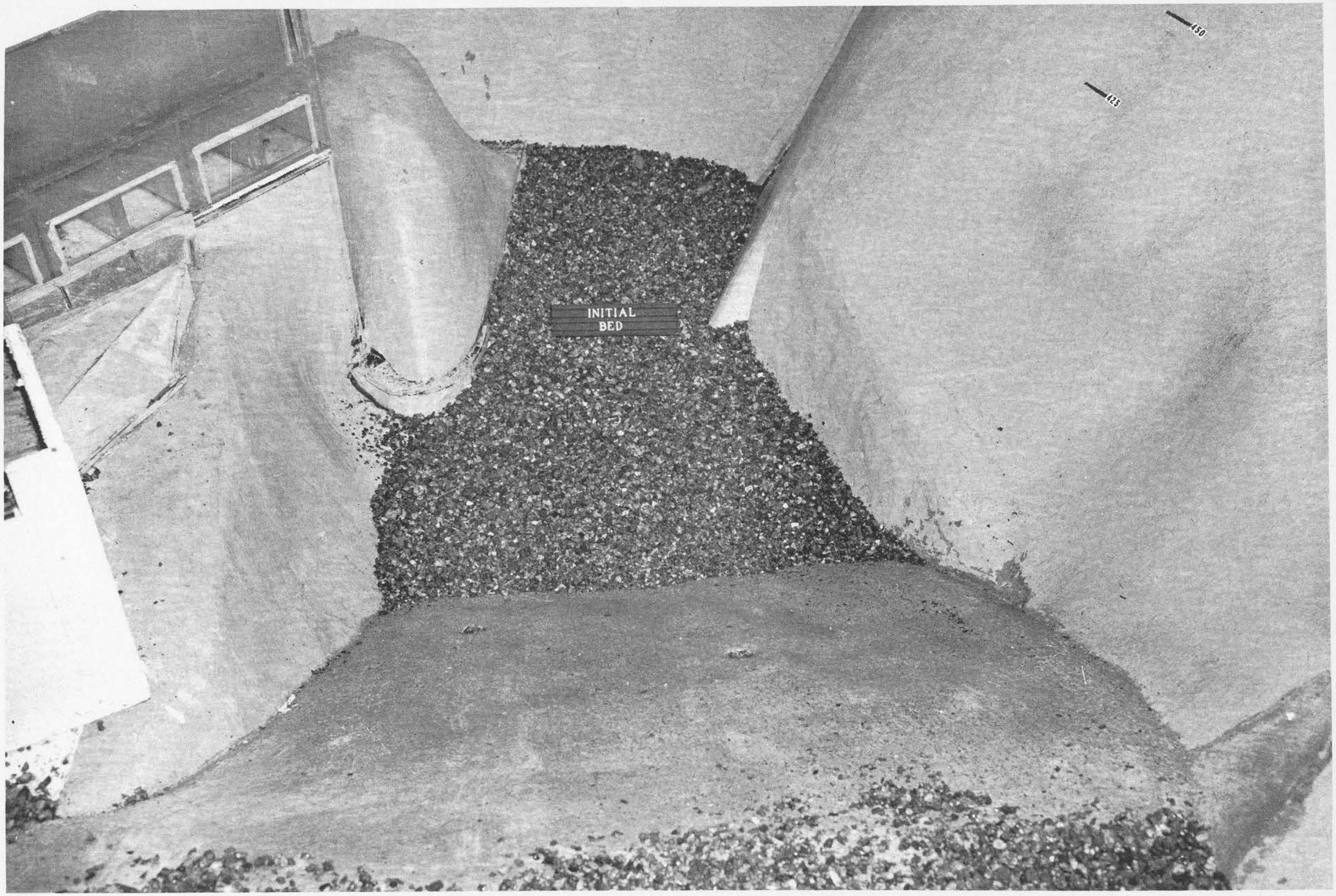


Plate 15

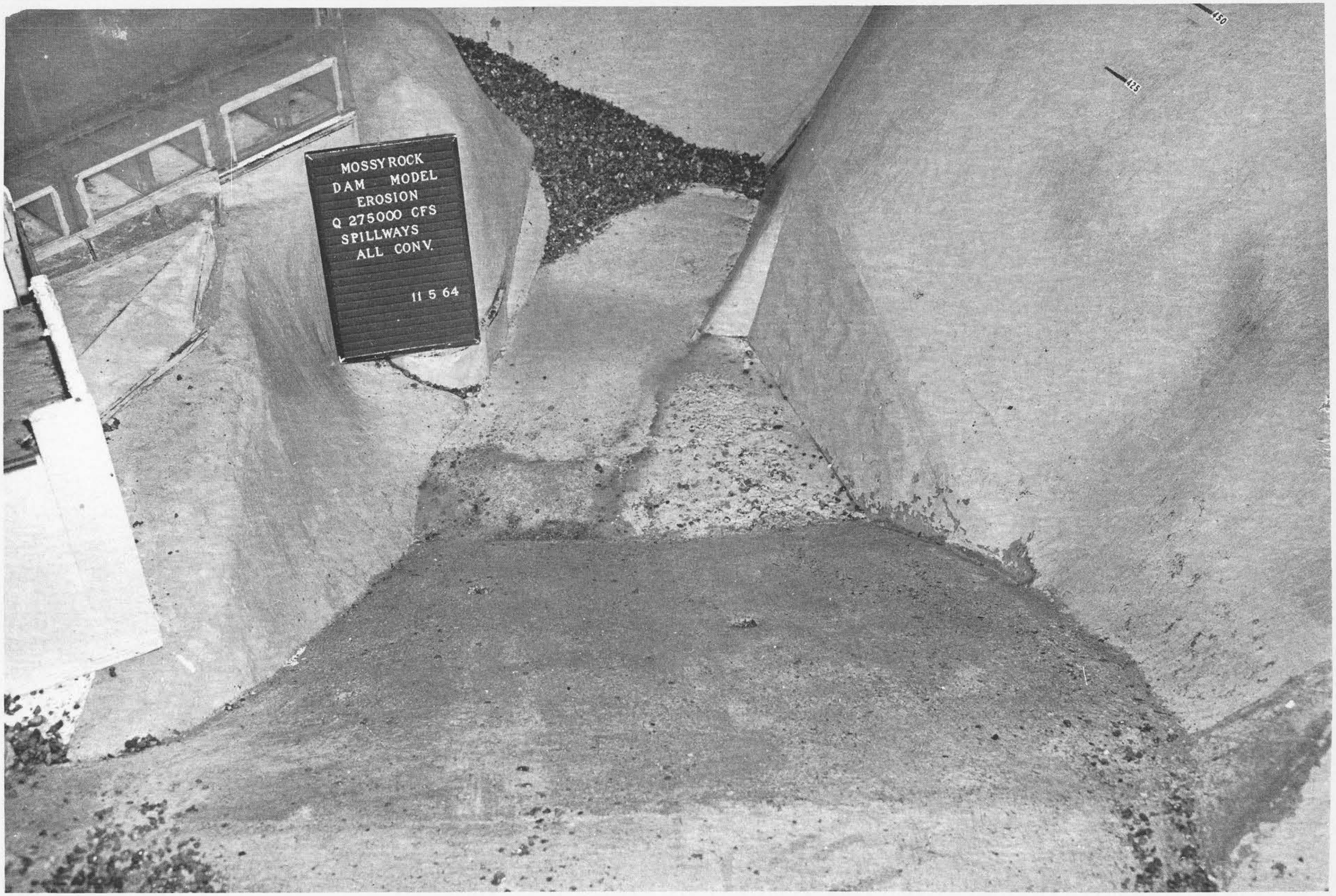

MOSSYROCK
DAM MODEL
EROSION
Q 275000 CFS
SPILLWAYS
ALL CONV.
11 5 64
450
425

Plate 16

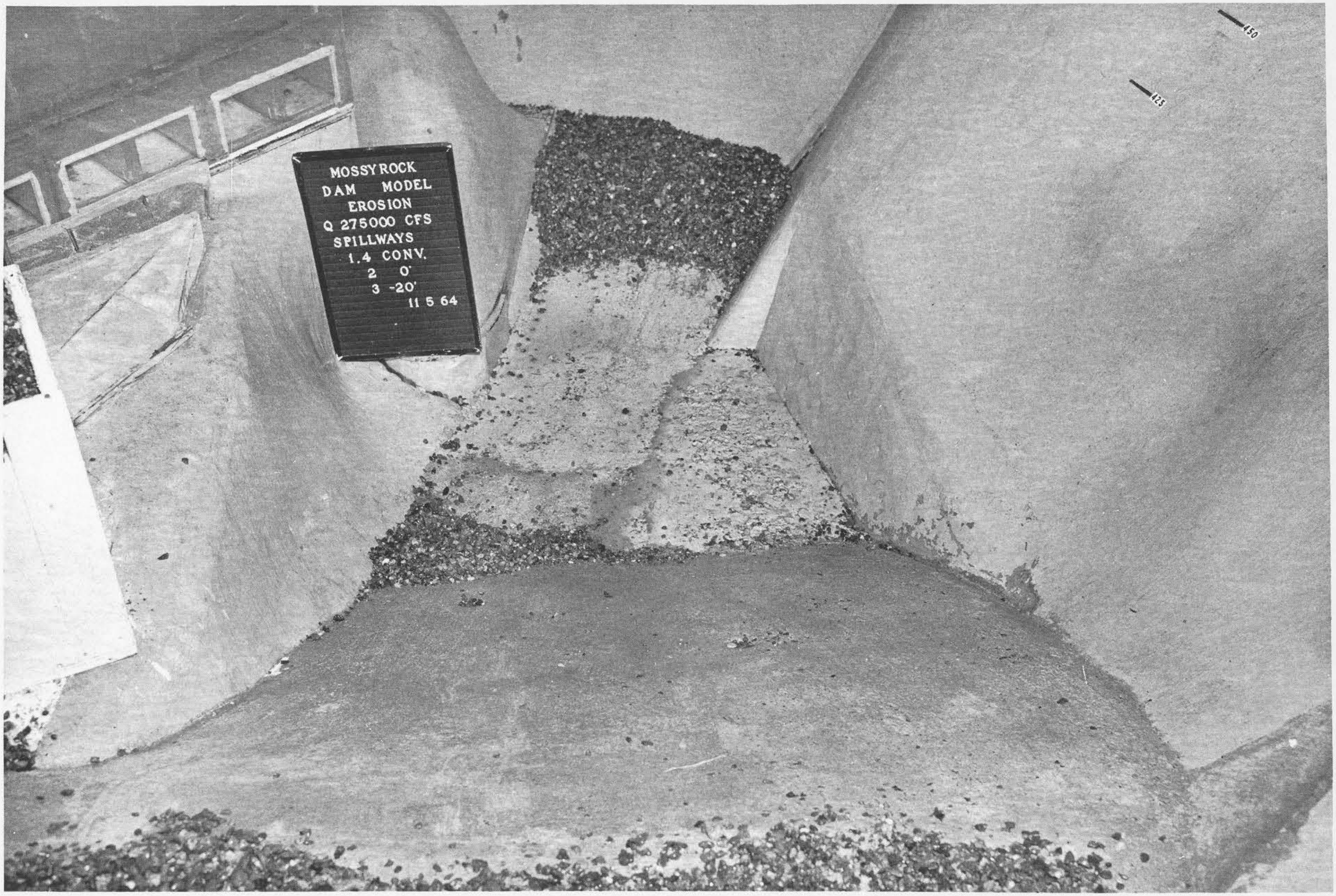

MOSSYROCK
DAM MODEL
EROSION
Q 275000 CFS
SPILLWAYS
1.4 CONV.
2 0'
3 -20'
11 5 64
450
425

Plate 17

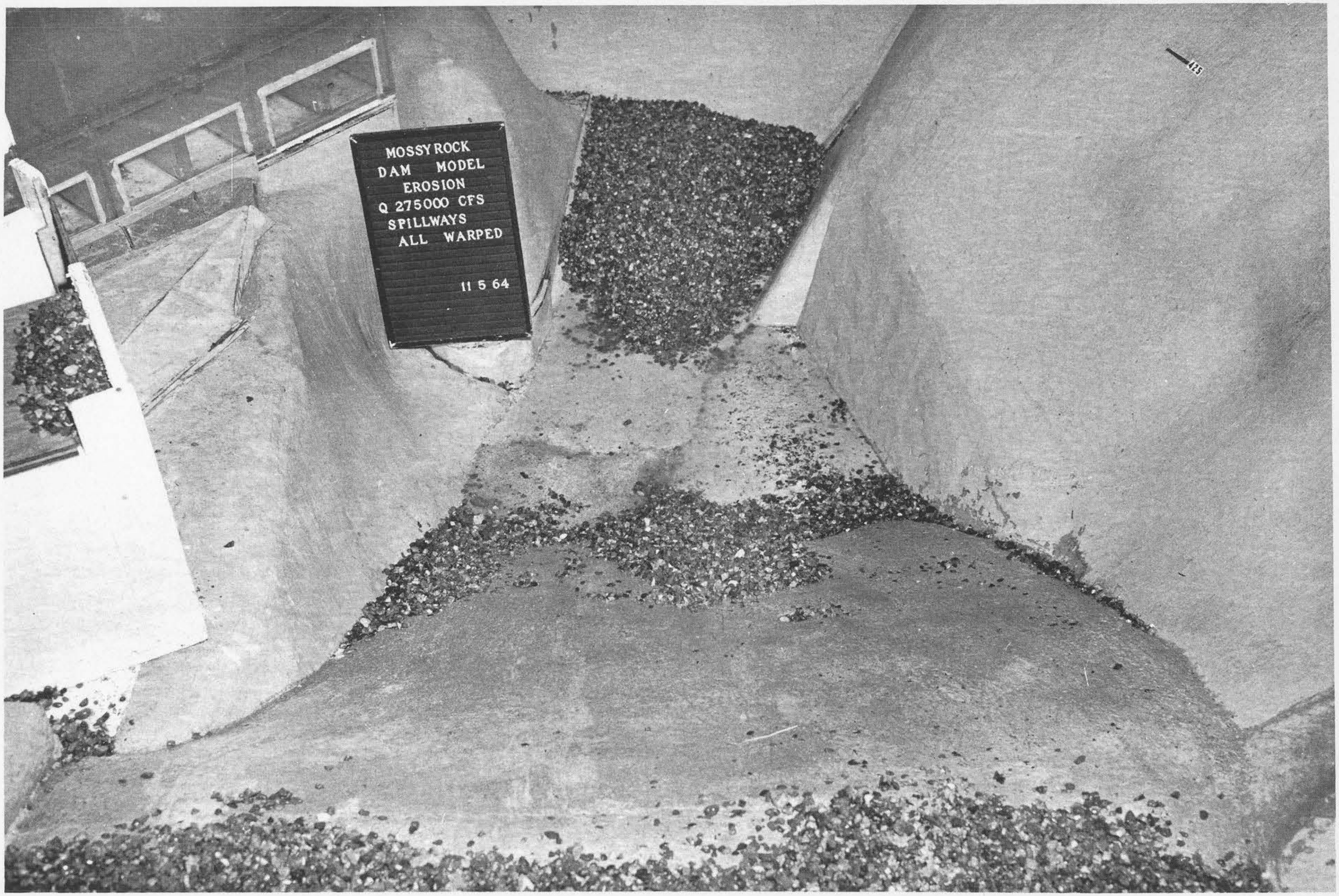

MOSSY ROCK
DAM MODEL
EROSION
Q 275000 CFS
SPILLWAYS
ALL WARPED
11 5 64
425

Plate 18

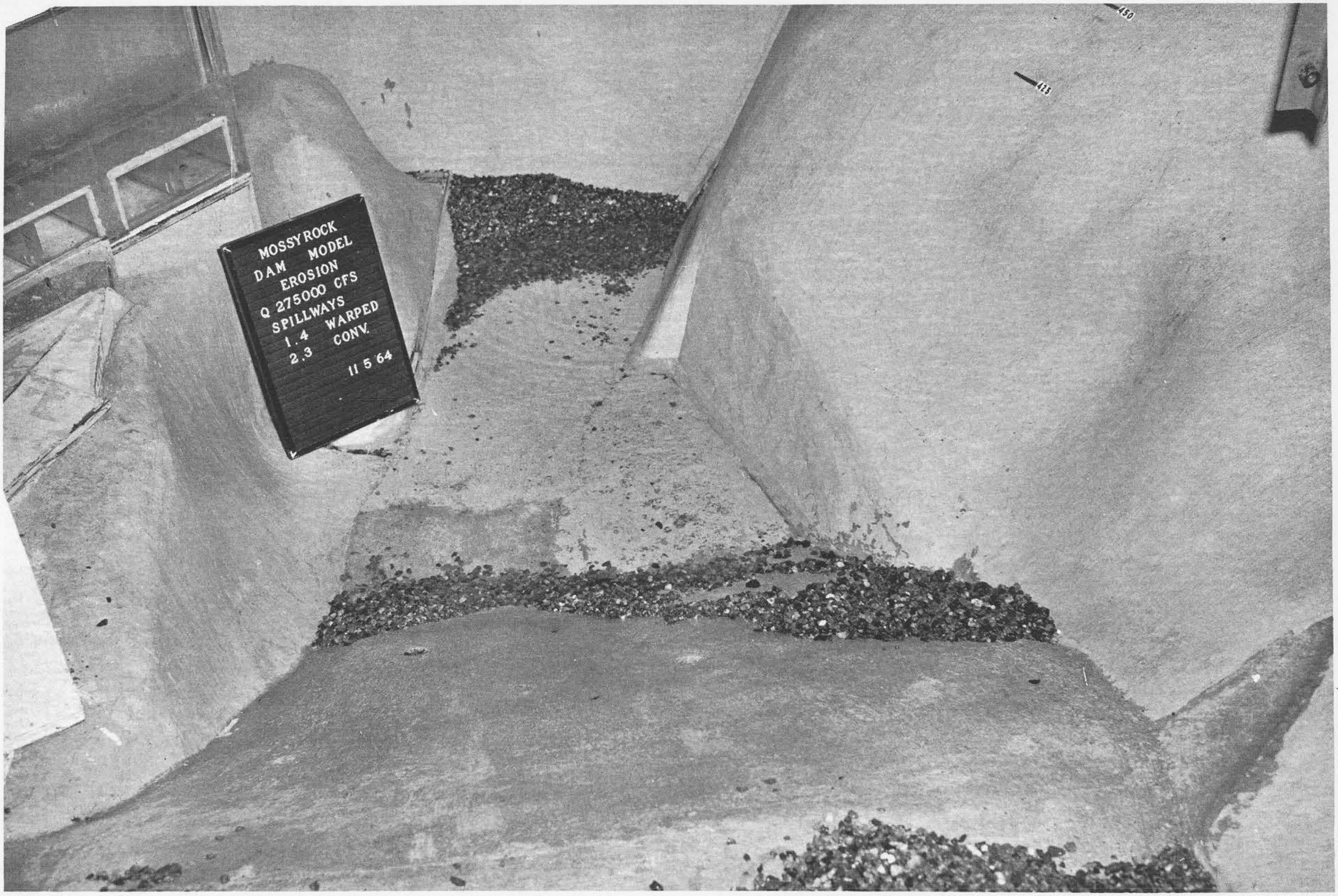

MOSSYROCK
DAM MODEL
EROSION
Q 275000 CFS
SPILLWAYS
1.4 WARPED
2.3 CONV.
11 5 64
450
425

Plate 19

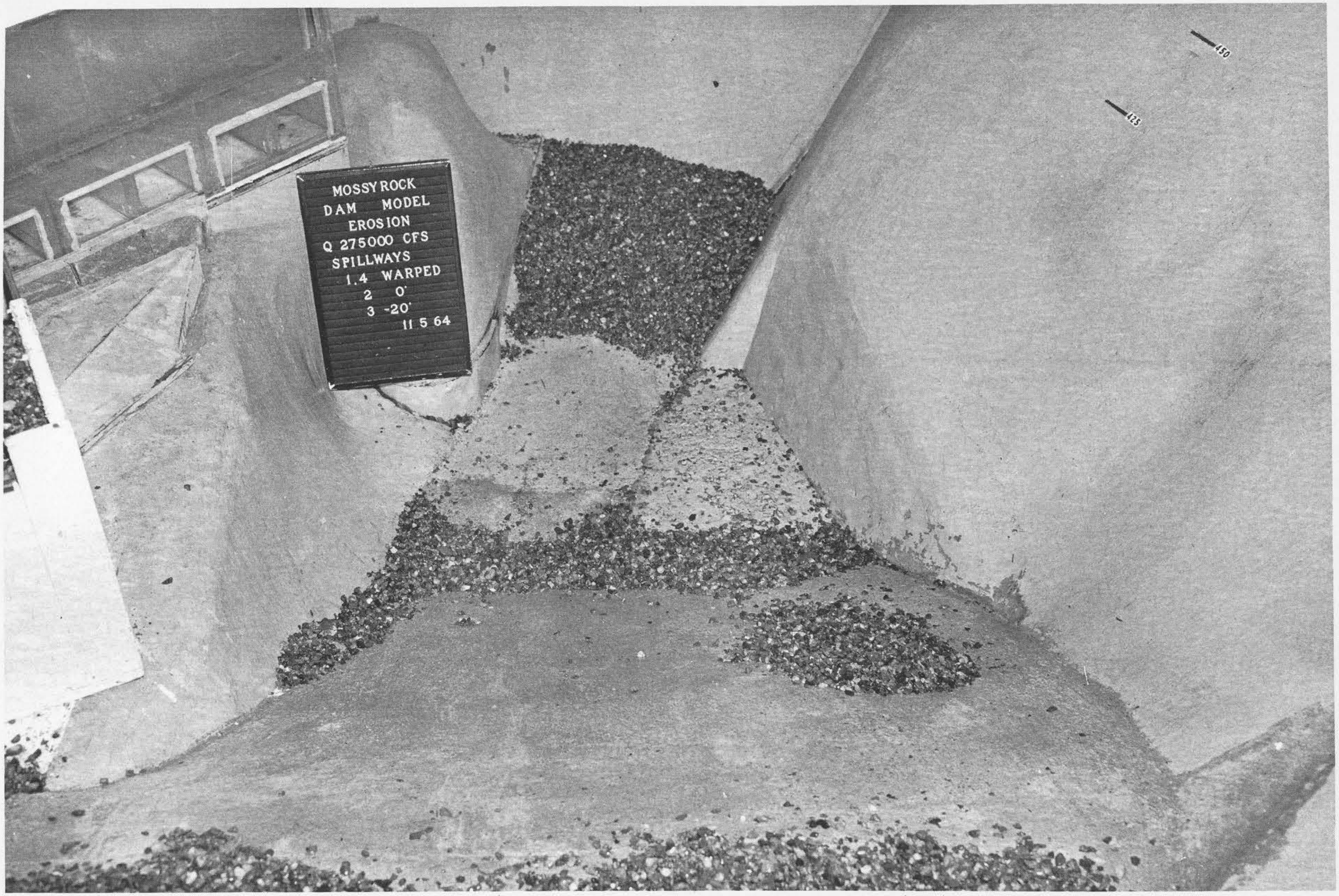

MOSSYROCK
DAM MODEL
EROSION
Q 275000 CFS
SPILLWAYS
1.4 WARPED
2 0'
3 -20'
11 5 64
450
425

Plate 20

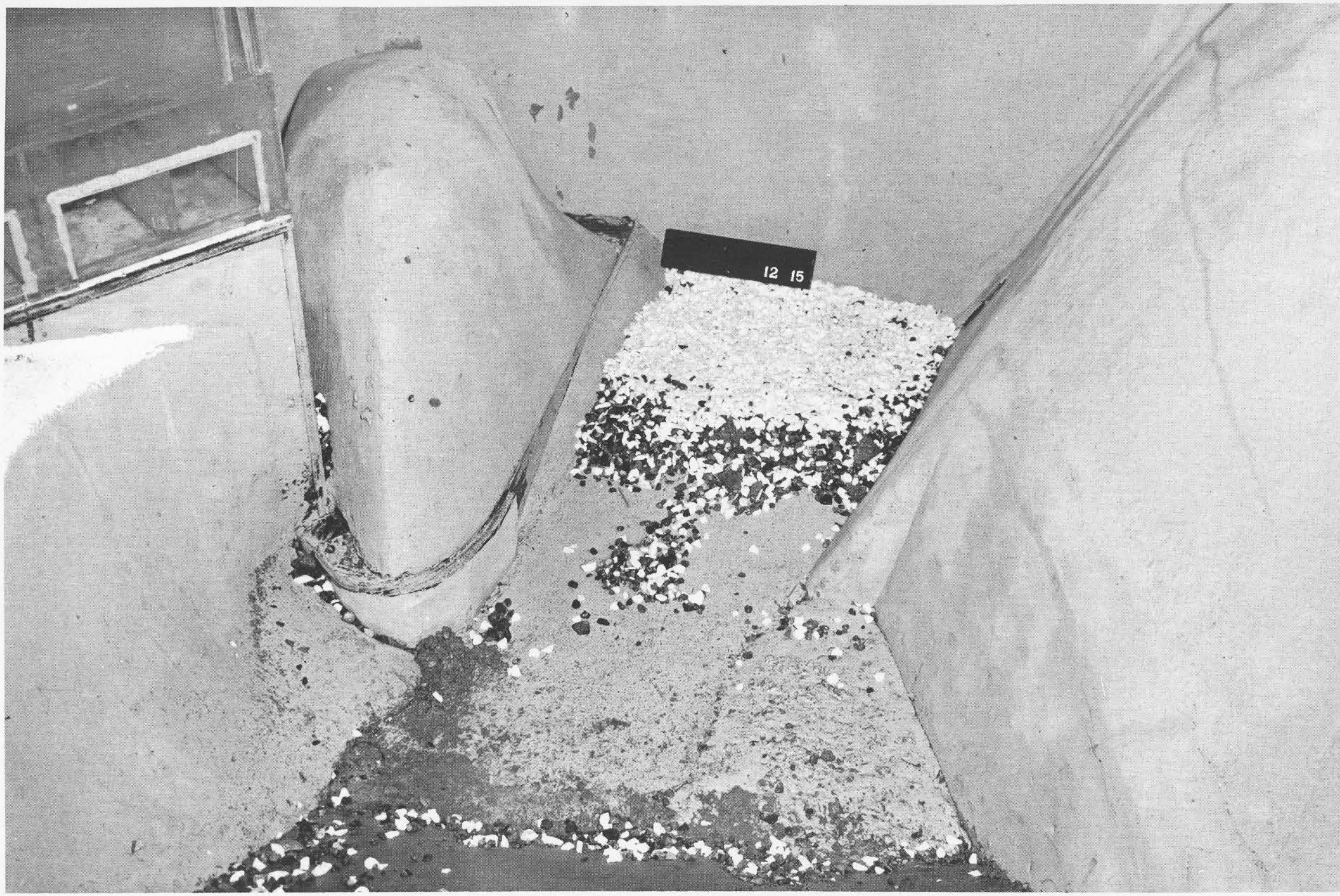


Plate 20A

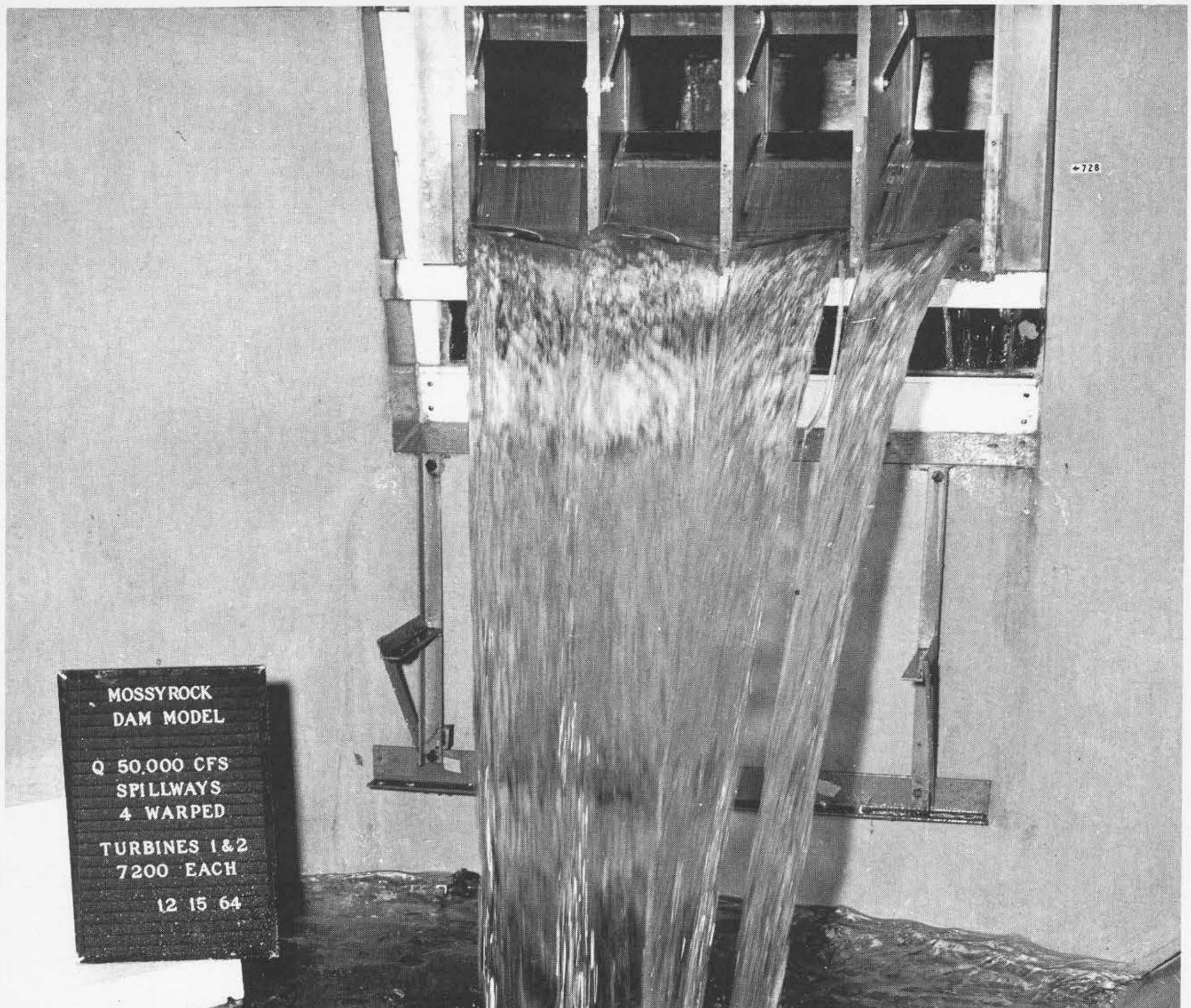

MOSSYROCK
DAM MODEL
Q 50,000 CFS
SPILLWAYS
4 WARPED
TURBINES 1&2
7200 EACH
12 15 64

Plate 20B

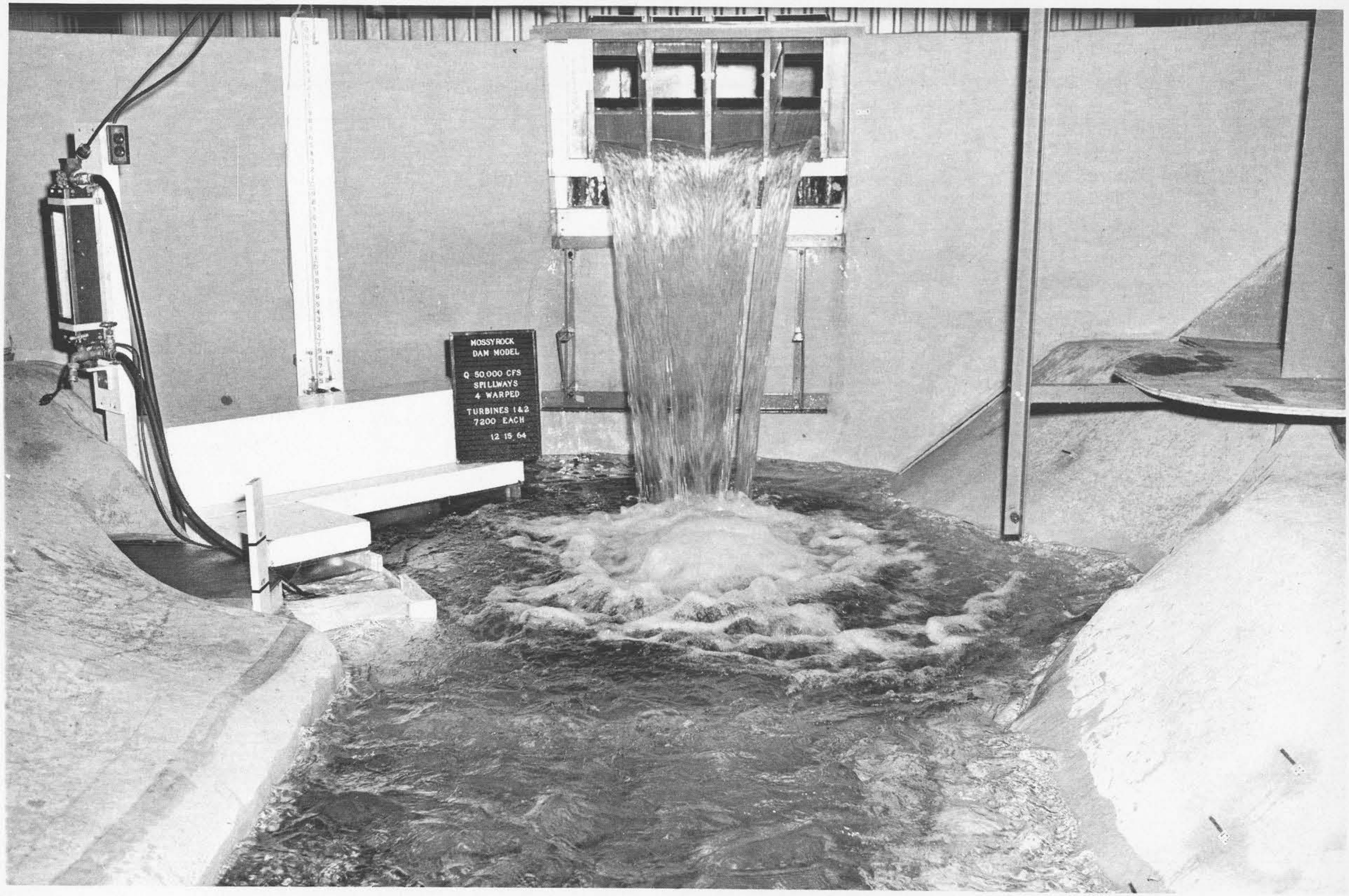

MOSSYROCK
DAM MODEL
Q 50,000 CFS
SPILLWAYS
4 WARPED
TURBINES 1&2
7200 EACH
12 15 64

Plate 20C

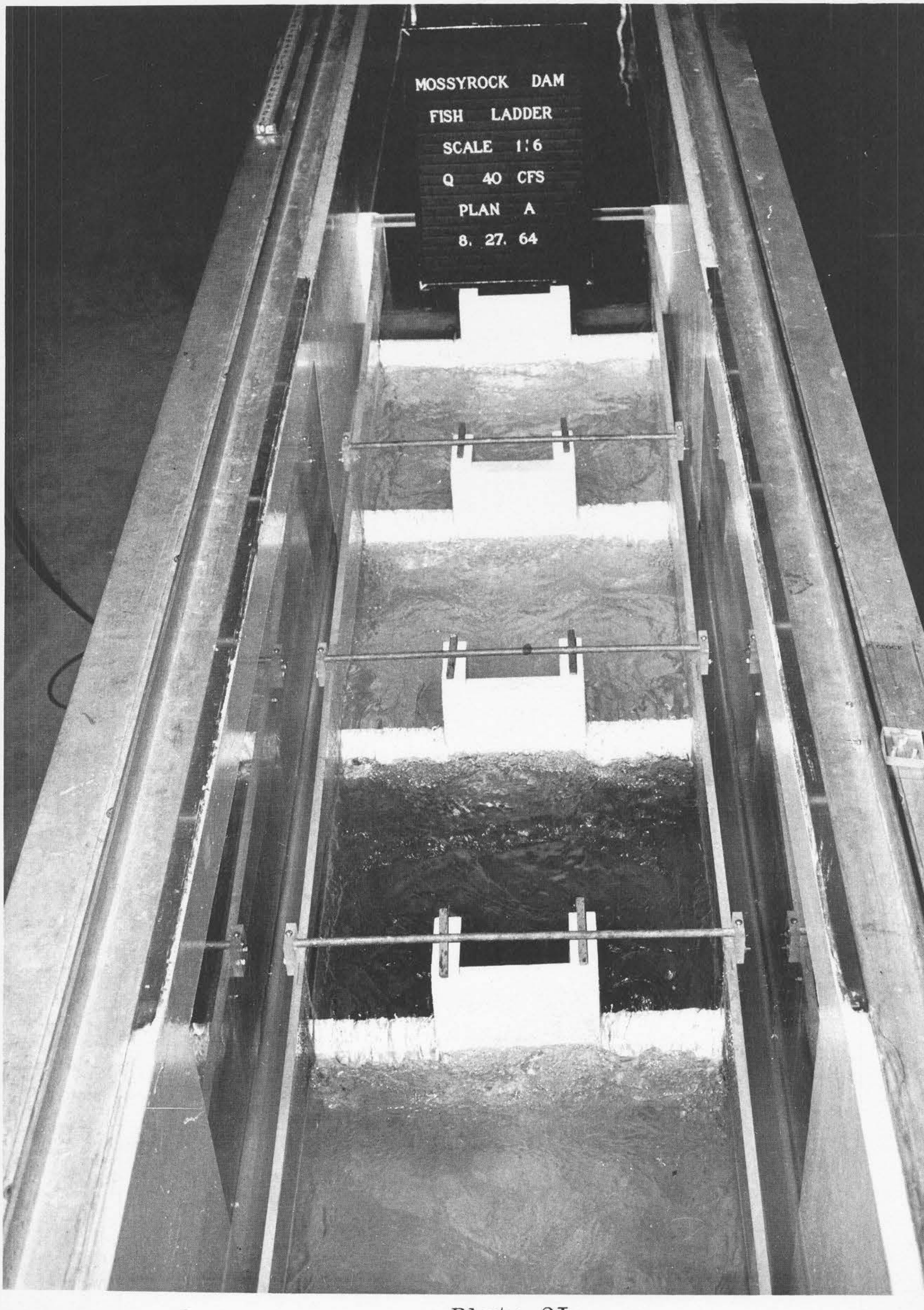


Plate 2I

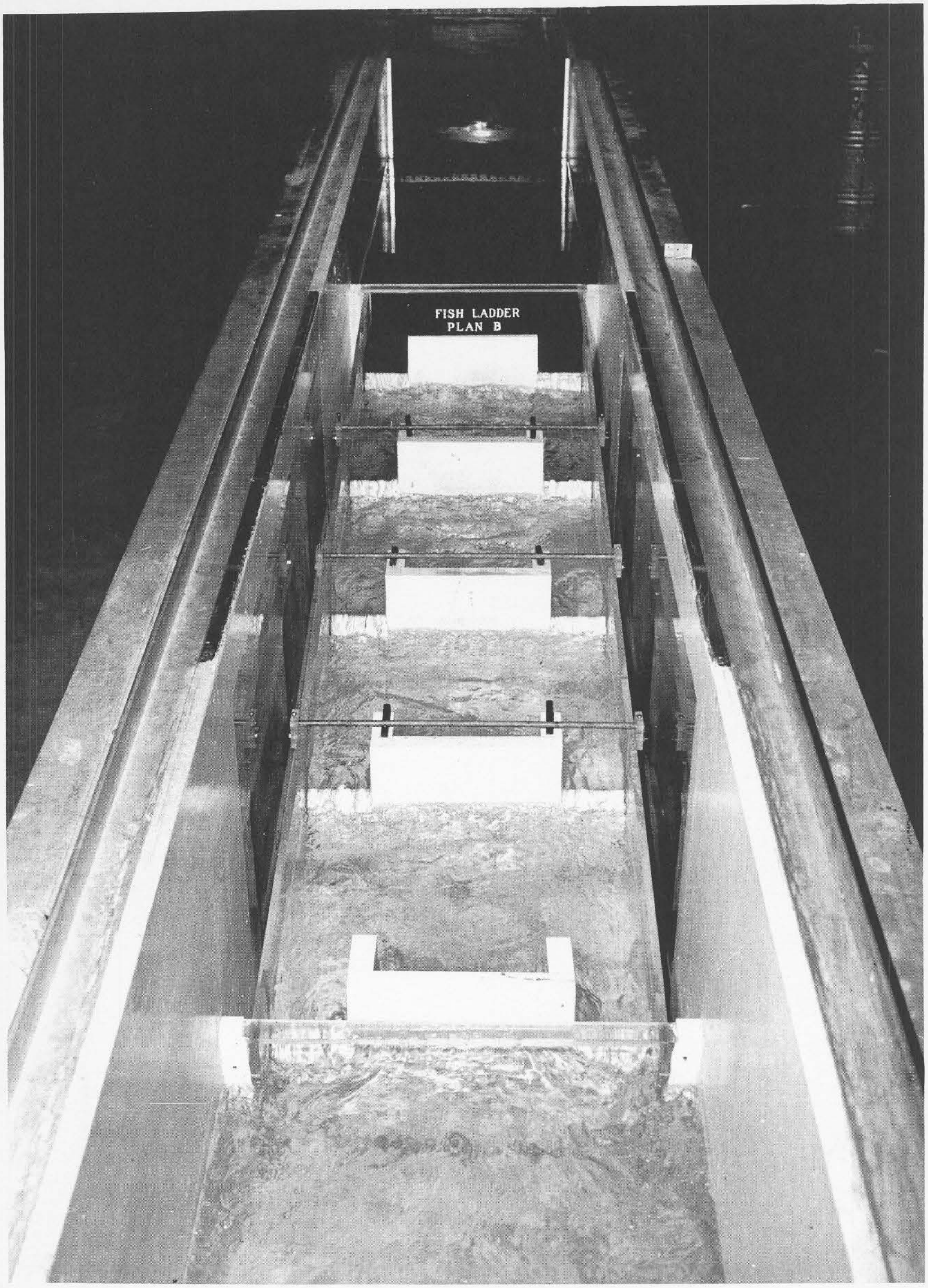


Plate 22

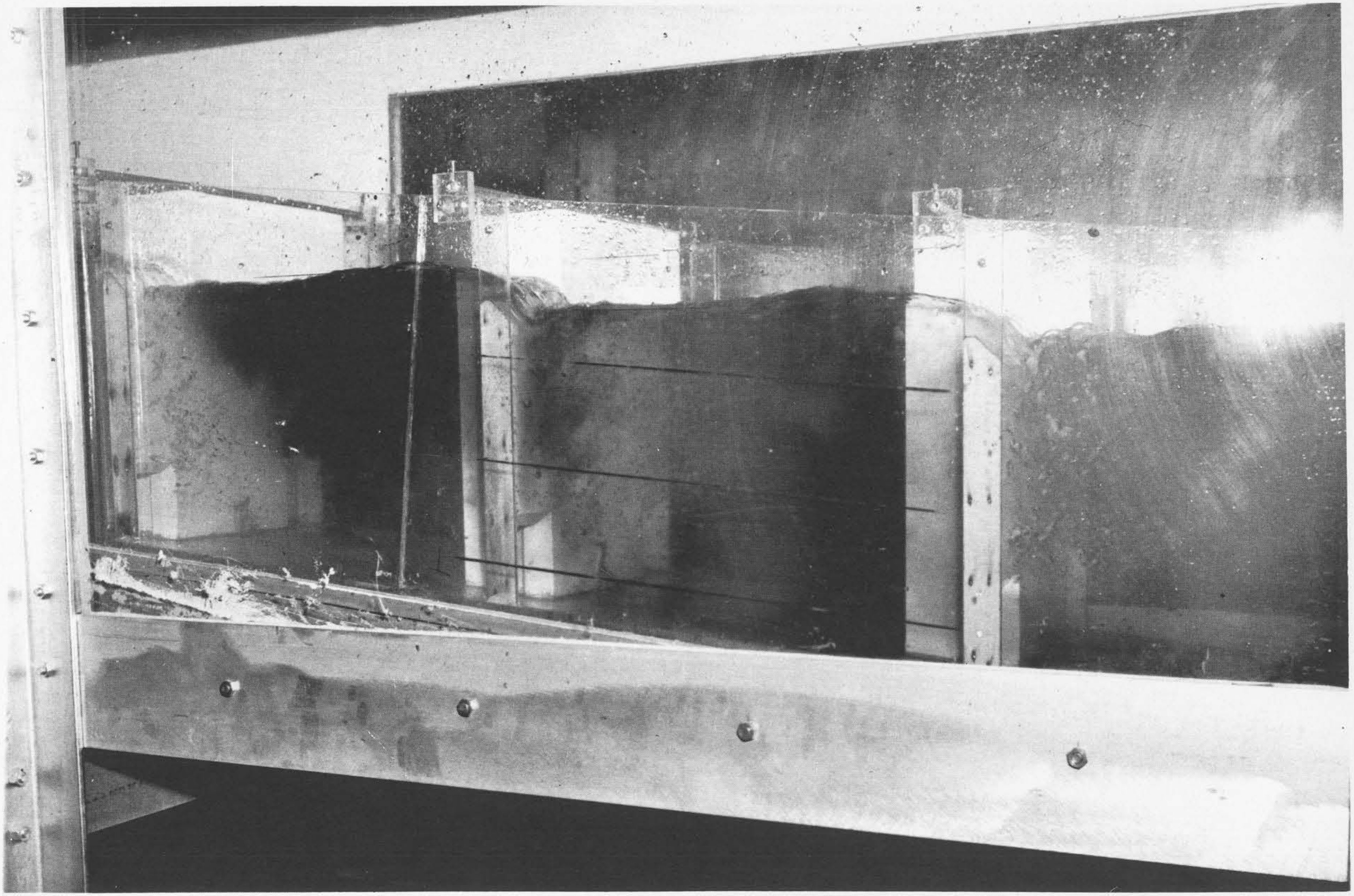


Plate 23


MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 4400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
1 4400
2&3 0
E FLOW
428

Plate 24A

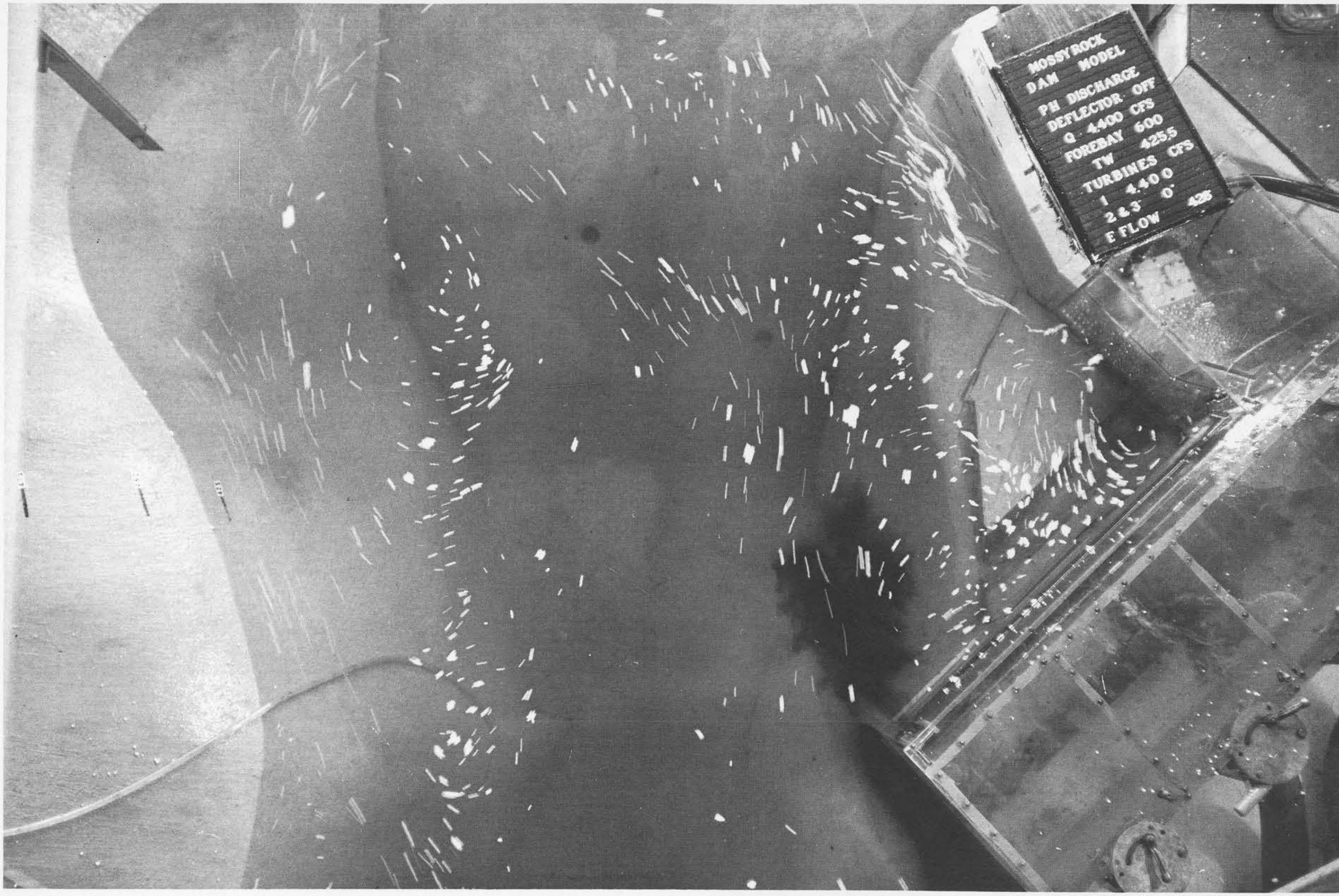

MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 4,400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
1 4,400
2 & 3 0
E FLOW 426

Plate 24B

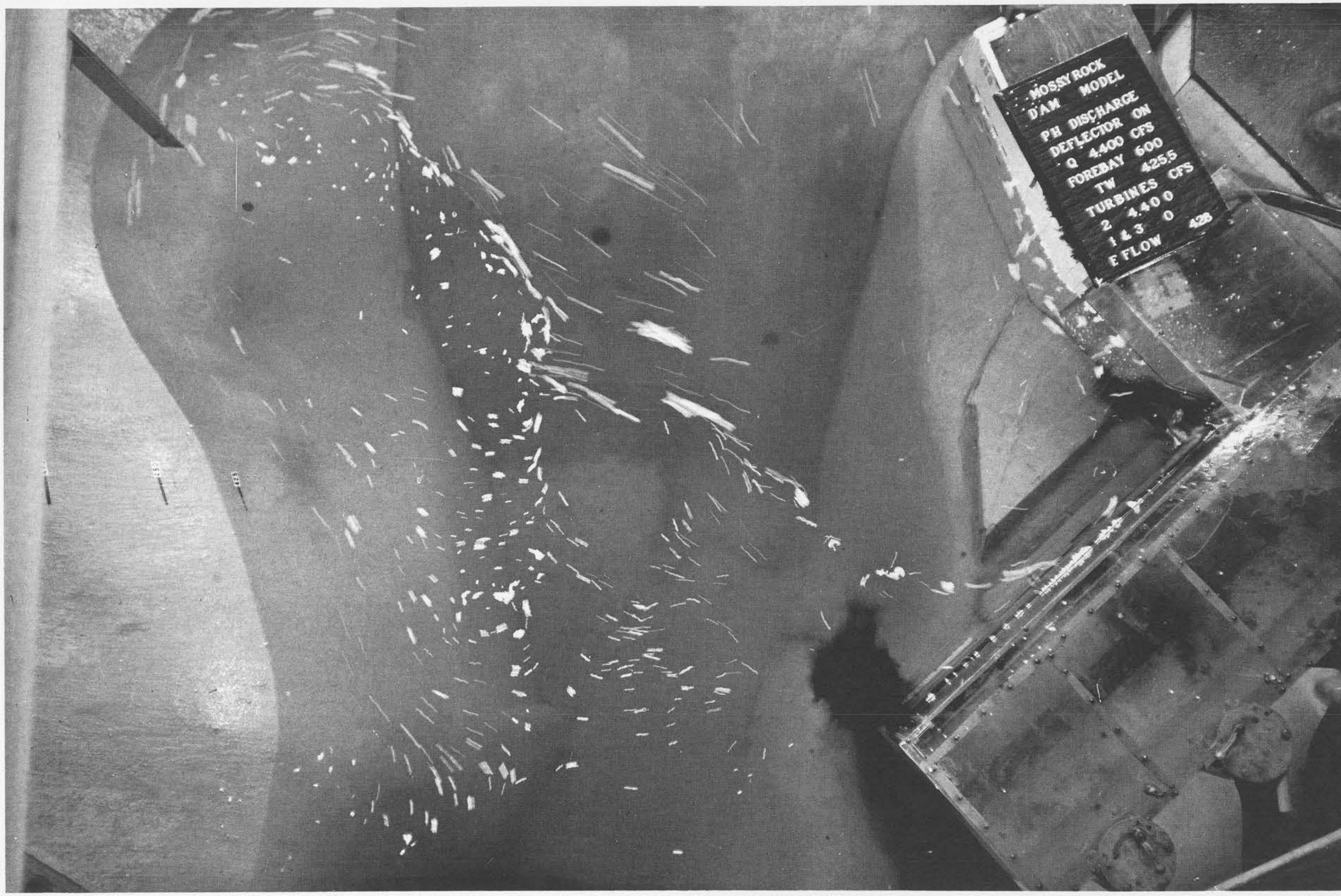

MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 4,400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
2 4,400
1 & 3 0
E FLOW
428

Plate 24C

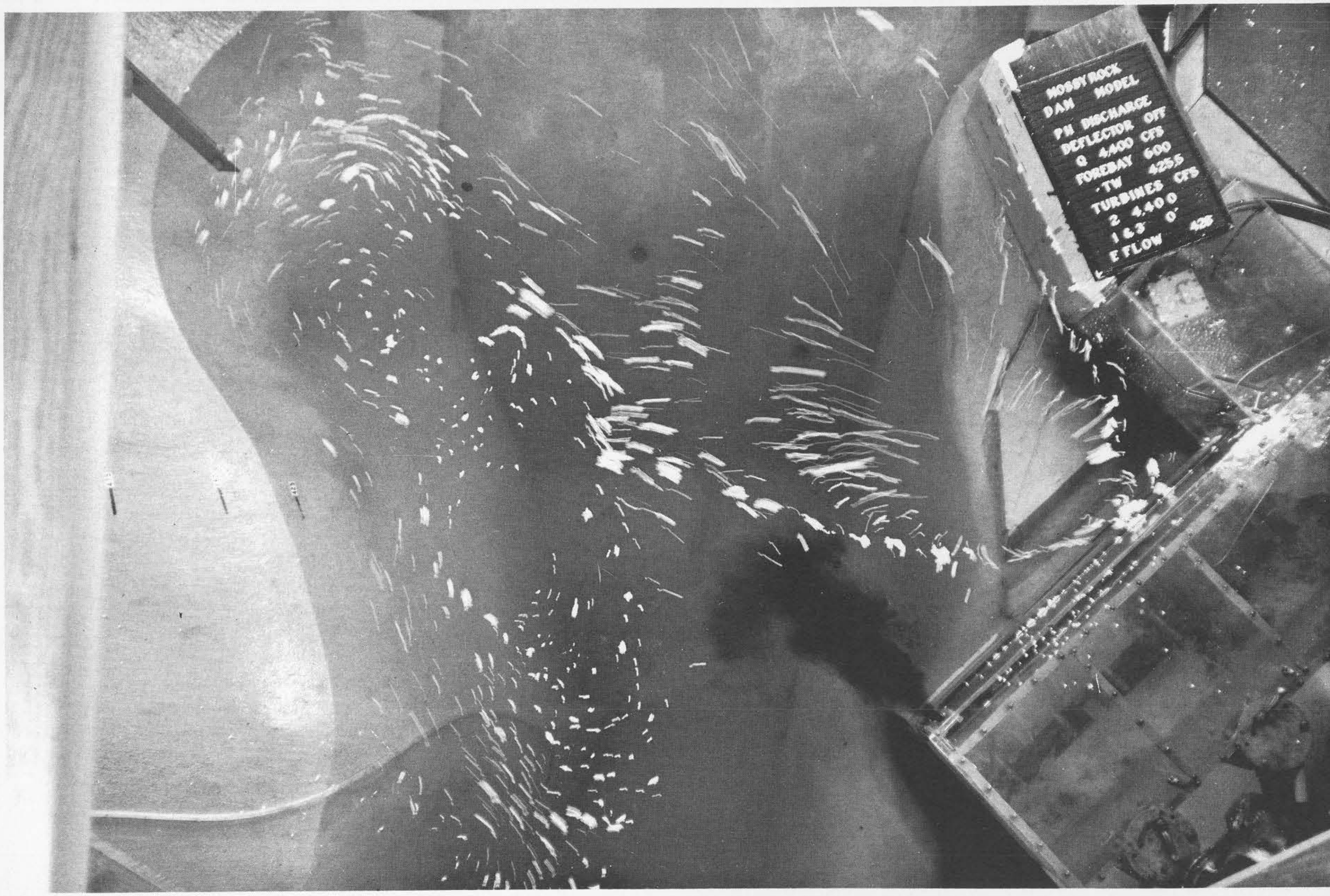

MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 4,400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
2 4,400
1 & 3 0
E FLOW 425

Plate 24D

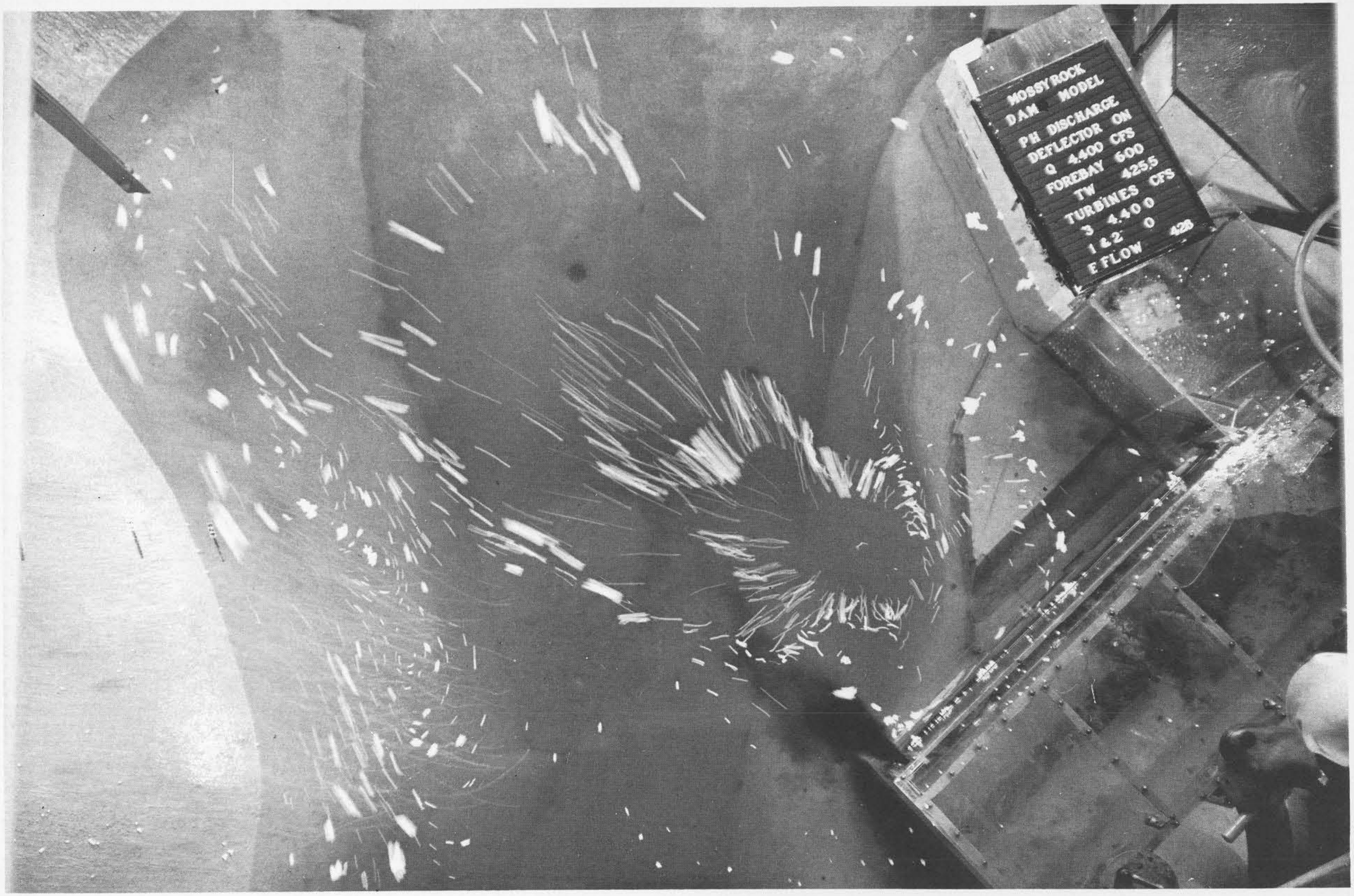

MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 4,400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
3 4,400
1 & 2 0
E FLOW 428

Plate 24E


MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 4,400 CFS
FOREBAY 600
TW 425.5
TURBINES CFS
3 4,400
1 & 2 0
E FLOW
426

Plate 24F

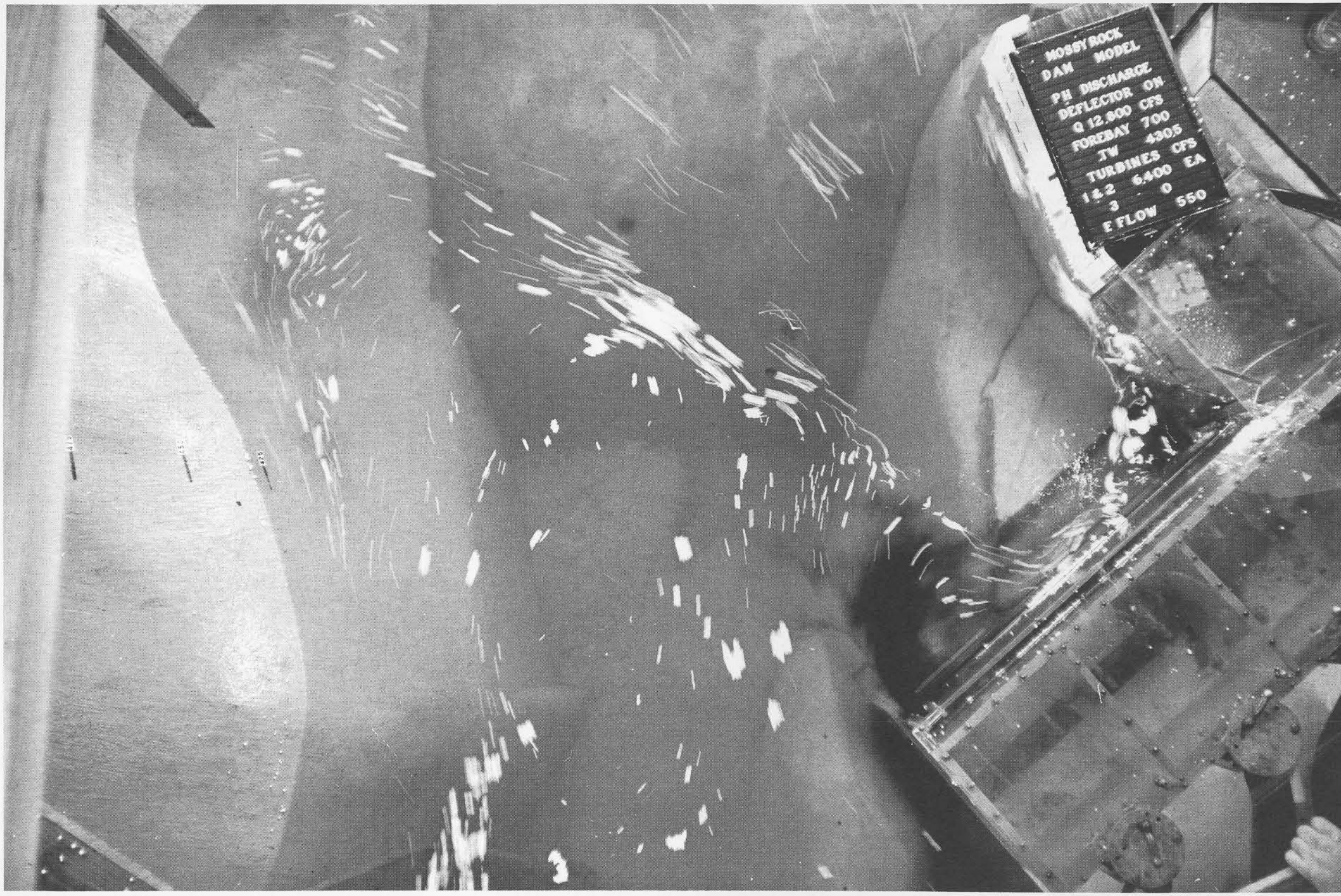

MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 12,800 CFS
FOREBAY 700
TW 4305
TURBINES CFS
1&2 6,400 EA
3 0
E FLOW 550

Plate 24G

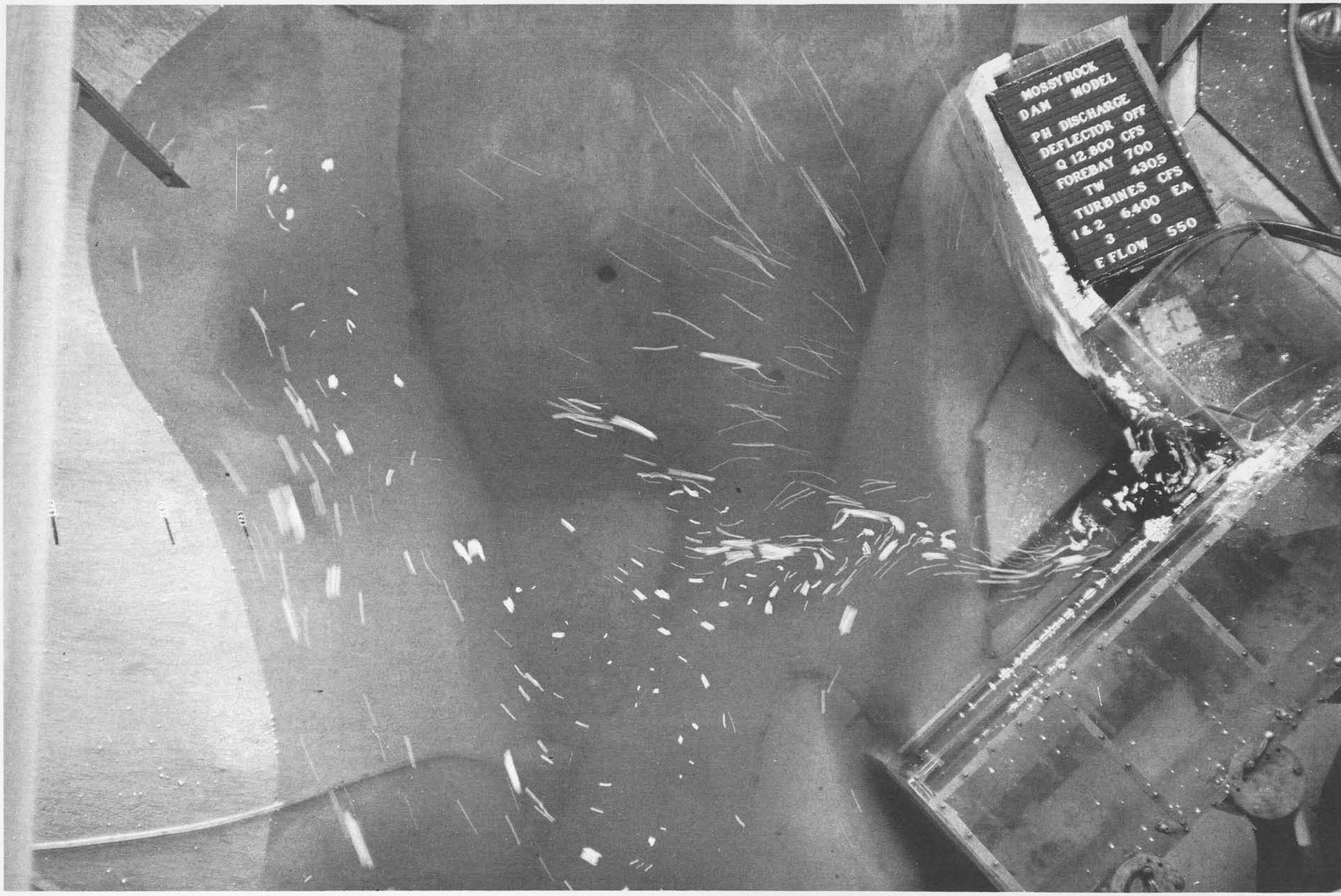

MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 12,800 CFS
FOREBAY 700
TW 4305
TURBINES CFS
1&2 6,400 EA
3 0
E FLOW 550

Plate 24H


MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 12,800 CFS
FOREBAY 700
TW 4305
TURBINES CFS
2&3 6,400 EA
1 0
E FLOW 550

Plate 24I

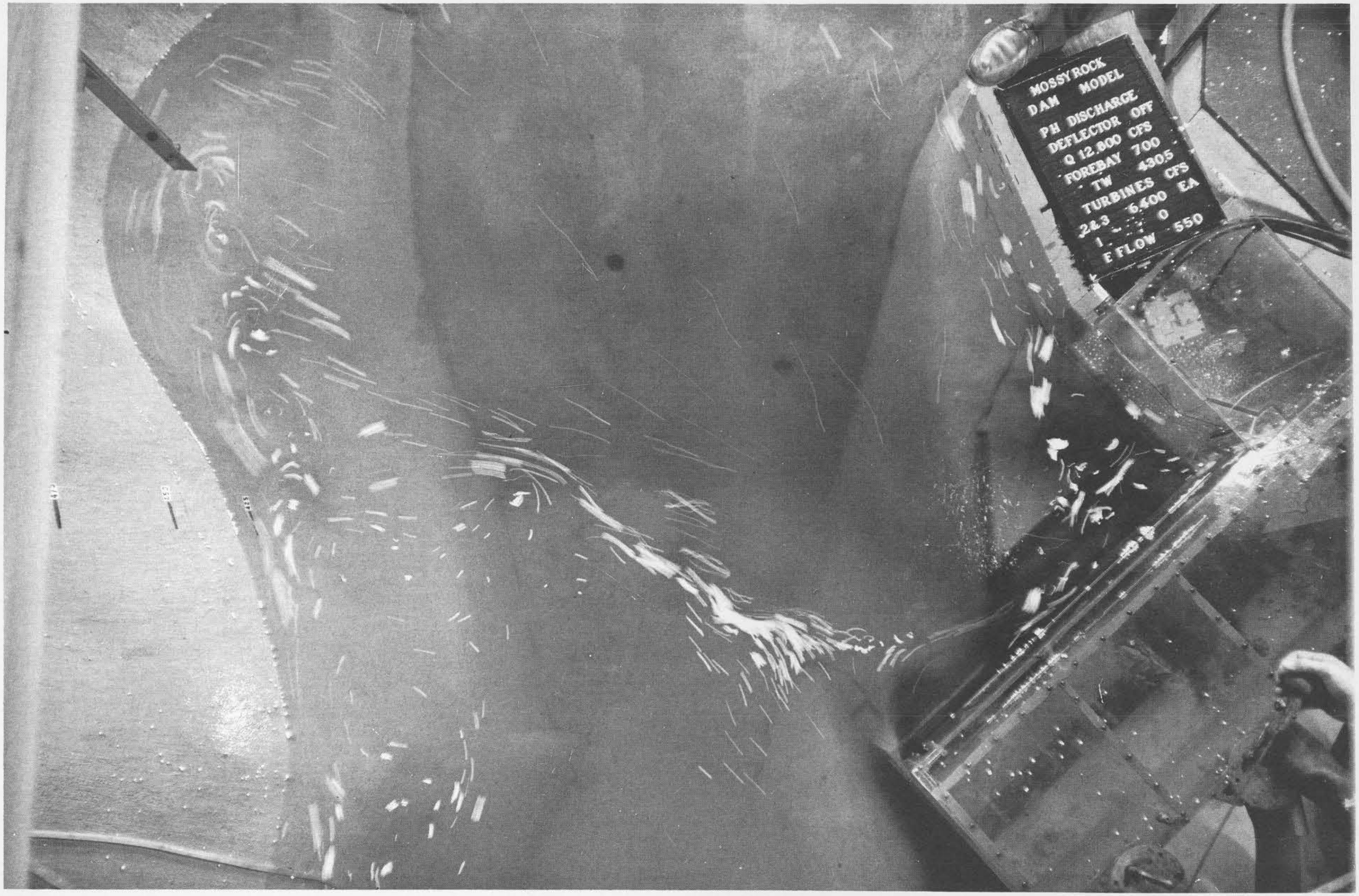

MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 12,800 CFS
FOREBAY 700
TW 4305
TURBINES CFS
2&3 6,400 EA
1 0
E FLOW 550

Plate 24J

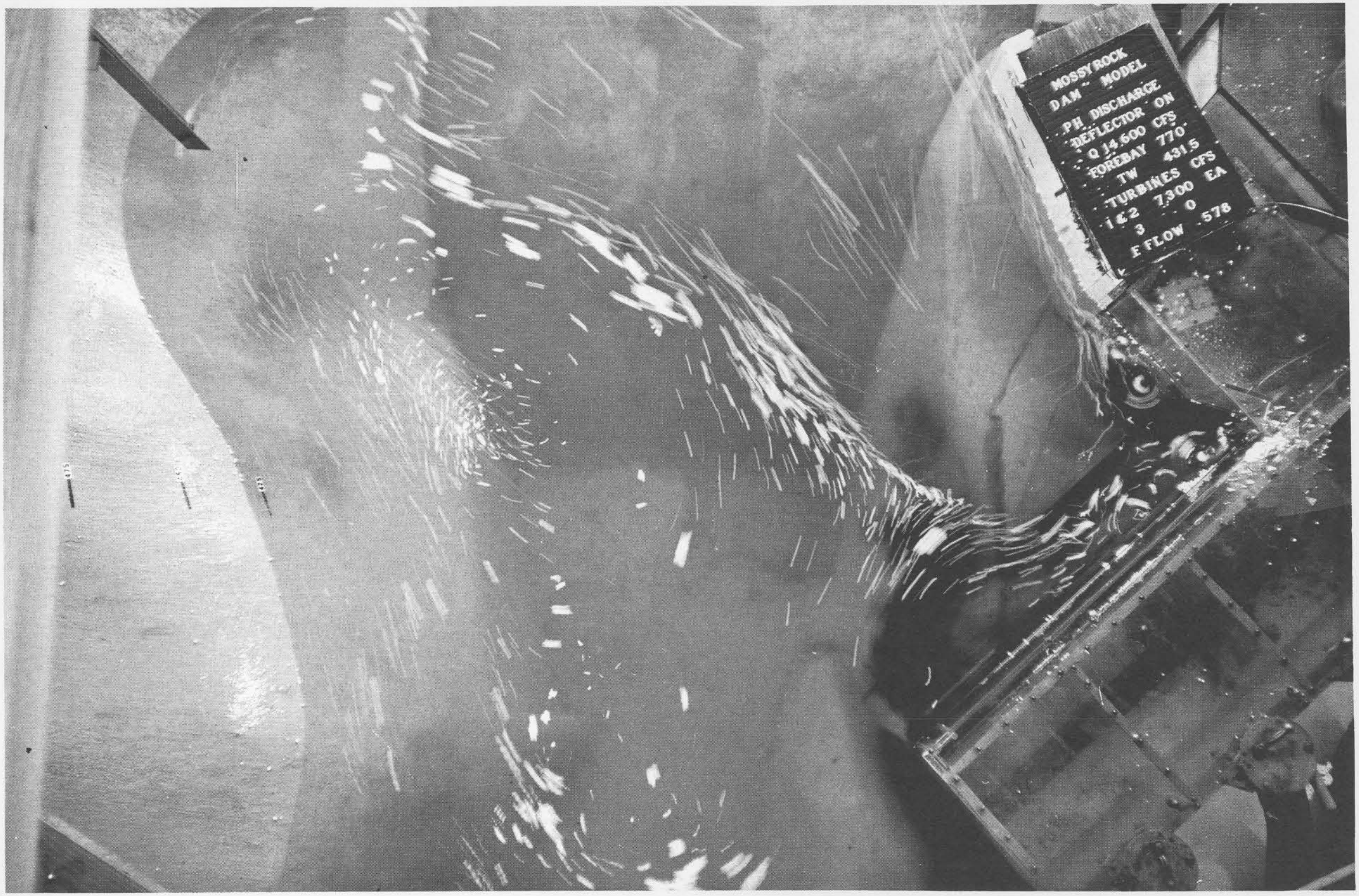

MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 14,600 CFS
FOREBAY 770
TW 431.5
TURBINES CFS
1&2 7300 EA
3 0
E FLOW 578

Plate 24K


MOSSYROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 14,600 CFS
FOREBAY 770
TW 431.5
TURBINES CFS
1&2 7300 EA
3 0
E FLOW 578

Plate 24L

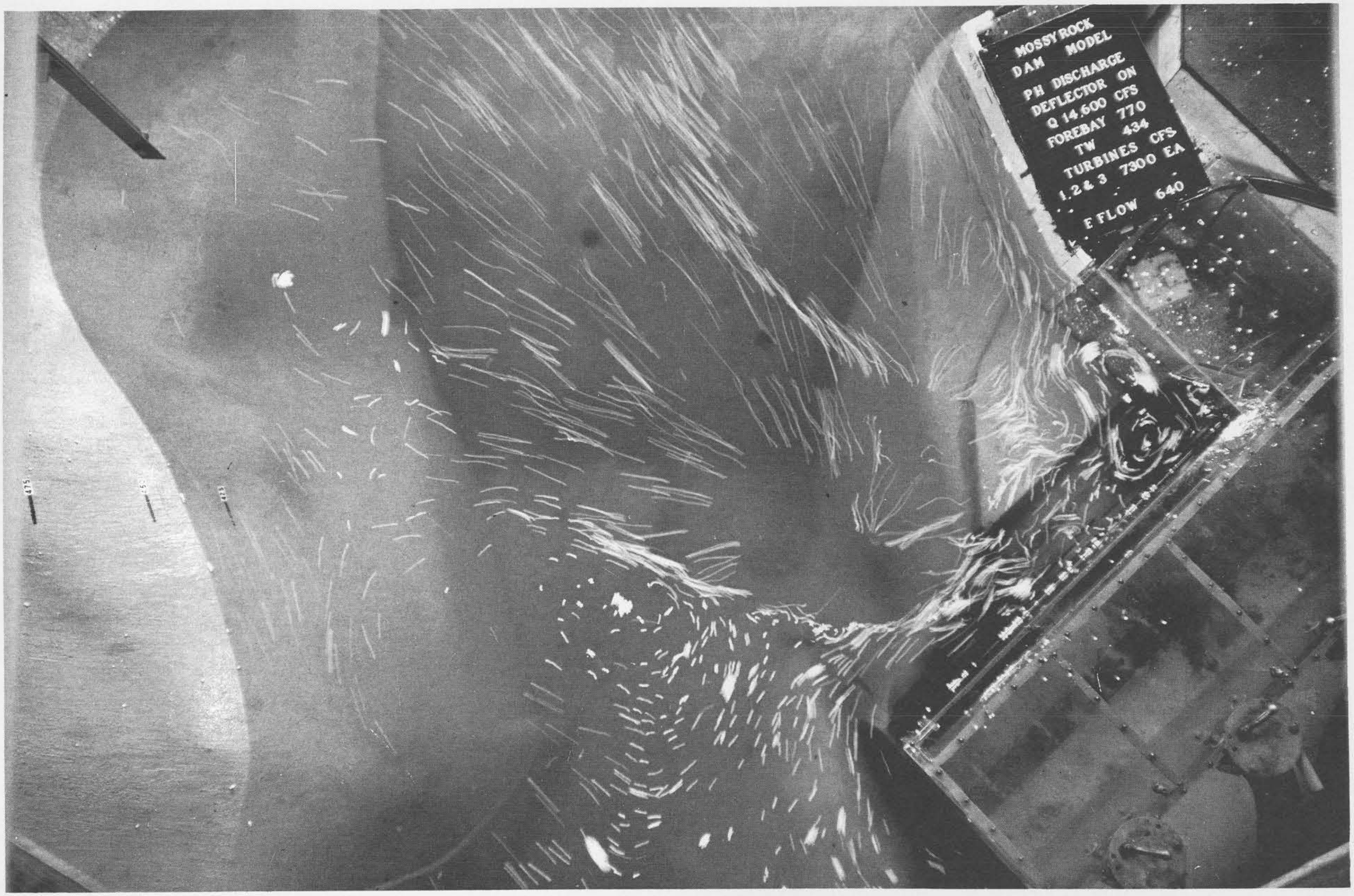

MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR ON
Q 14,600 CFS
FOREBAY 770
TW 434
TURBINES CFS
1,2 & 3 7300 EA
E FLOW 640

Plate 24M

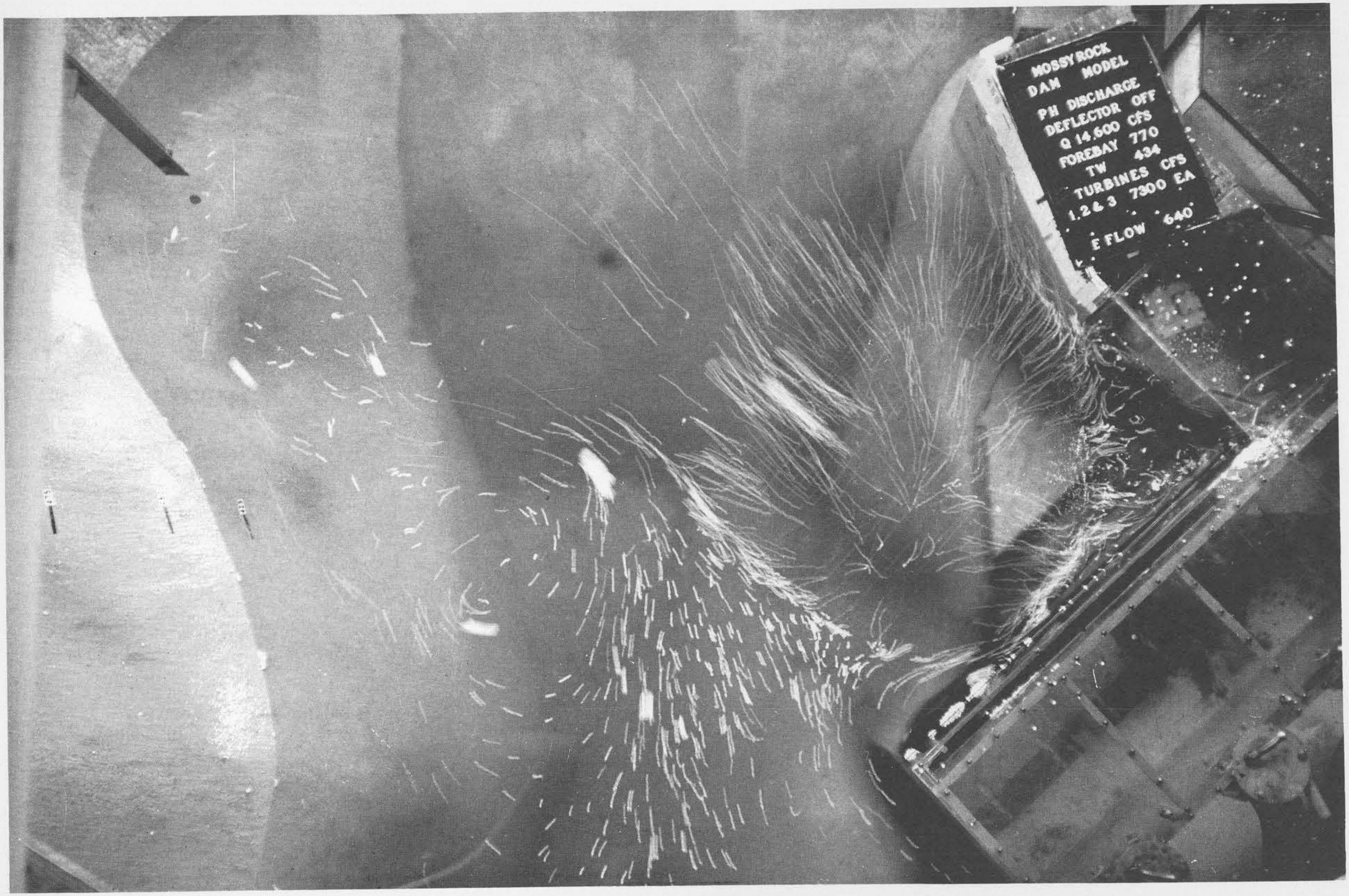

MOSSY ROCK
DAM MODEL
PH DISCHARGE
DEFLECTOR OFF
Q 14,600 CFS
FOREBAY 770
TW 434
TURBINES CFS
1,2 & 3 7300 EA
E FLOW 640

Plate 24N

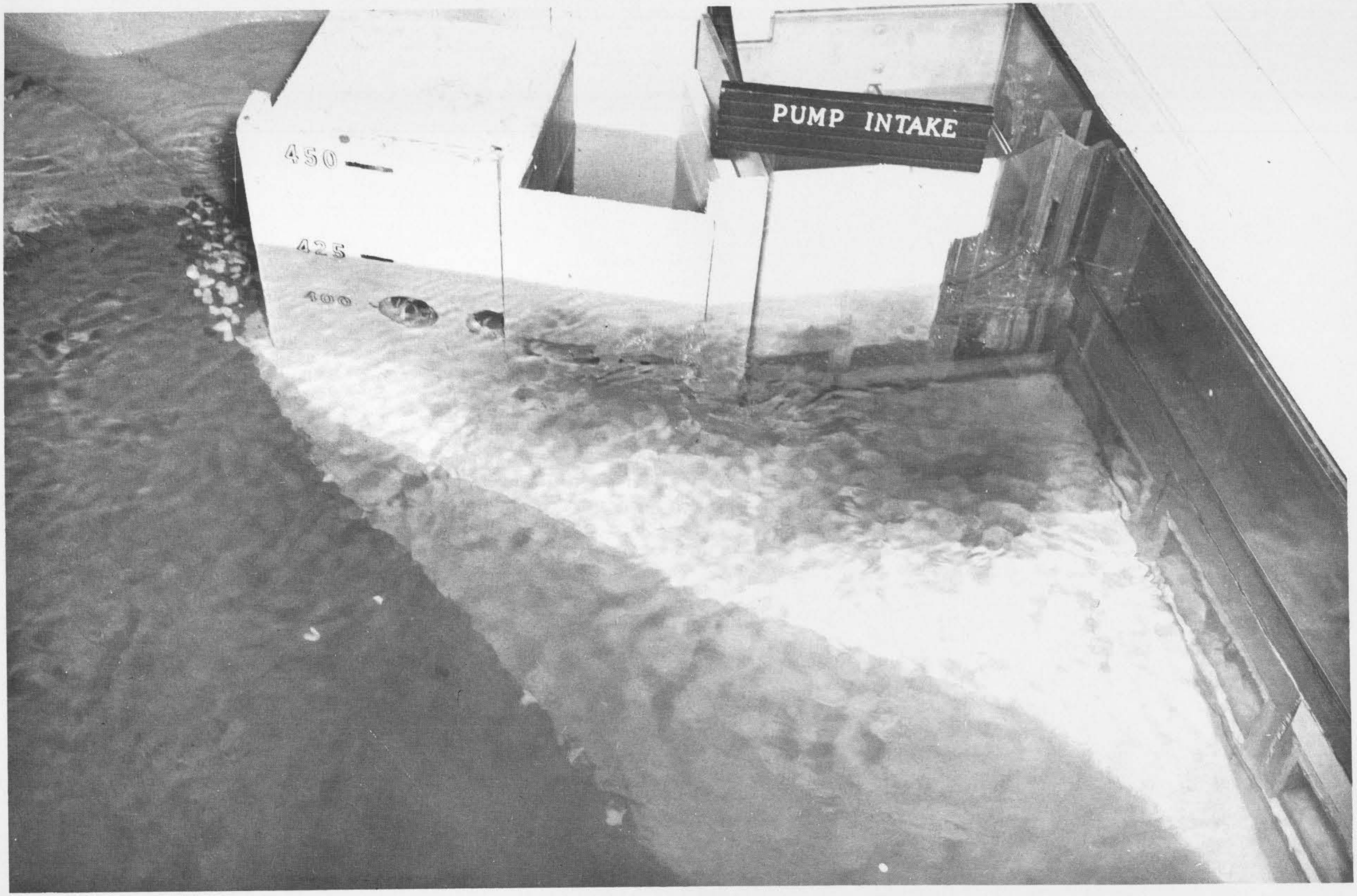


Plate 25

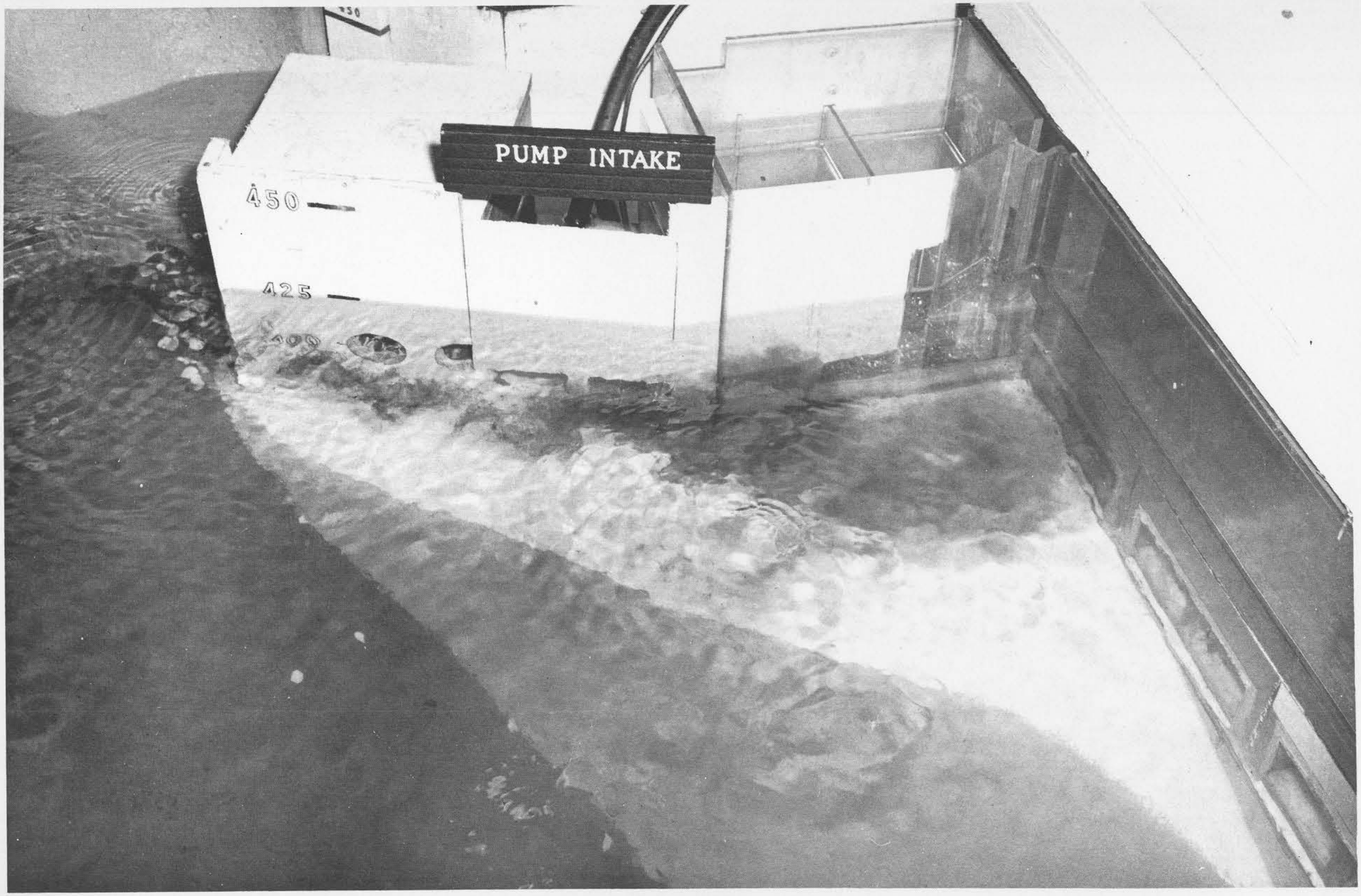


Plate 26