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MODEL STUDY OF THE SPILLWAY AND TUNNEL FOR DORENA DAM, ROW RIVER, OREGON

Army Engineer Division North Pacific
Bonneville, Oregon

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WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

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REPORT NO. 11-1

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TABLE OF CONTENTS

TABLES

PHOTOGRAPHS

PLATES

Model Study of the SPILLWAY AND TUNNEL FOR DORENA DAM Row River, Oregon

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SYLLABUS

General

1. The model study of the Spillway and Tunnel for Dorena Dam was conducted at the Bonneville Hydraulic Laboratory, Bonneville, Oregon. The general purpose of this study was to determine by means of a 1-to-50 scale model the hydraulic characteristics of the originally-designed spillway, stilling basin, and outlet works of Dorena Dam and to develop satisfactory alternate designs for any of the features found to be hydraulically inadequate.

The Project

2. At the extreme right end of Dorena Dam, which is a part of the Willamette Basin Project of Oregon, an overflow spillway, stilling basin, and outlet works will furnish flood control and increased low-water flow for the Coast Fork and Willamette Rivers. The spillway with a crest length of 188 ft. and a height of 121 ft. was designed to pass flood flows up to a maximum of 95 400 c.f.s. The purpose of the outlet works, consisting of a tower and cylindrical control gate and a 15.5-ft. tunnel, was to regulate the reservoir elevation up to the height of the spillway crest by discharging normal river flows up to 5000 c.f.s. through the spillway chute into the stilling basin.

Results of the Model Study

3. A general summary of the study of various features of the spillway, stilling basin, outlet works, and conditions in the tailbay follows:

a. Spillway: (See Paragraphs 22 to 90). Undesirable flow characteristics such as eddies, water-surface draw-down, and general turbulence existed around the left and right abutments as originally designed. These conditions were alleviated by changing the slope transition and alignment of the left abutment (Left Abutment Plan I) and by removing the curved right abutment to make a smooth slope transition from the top of the chute upstream into the natural topography of the reservoir (Right Approach Wall Plan VII). It was found that, if the approach apron were raised to save excavation costs, the hydraulic efficiency of the approach channel was impaired. The original crest, which was designed for positive pressures up to the design head, was satisfactory insofar as obtaining design discharge, but by modifying the crest profile so that negative pressures obtained on the crest (Crest Plan IX), a greater efficiency of overflow was obtained. The average discharge coefficient of the original crest was 3.48 as compared to 3.66 for the final crest. Standing waves created by flow striking the converging chute sidewalls just below the crest were apparent for all discharges. At the maximum discharge, only 0.6-ft. freeboard obtained along the right sidewall of the originally-designed chute at sta. 10+25. It was found that no chute design in combination with the straight crest alignment appreciably suppressed these standing waves. However, by using a curved crest (Crest Plan X) and the resultant dish-shaped chute (Chute Plan P), these standing waves were greatly reduced for all flows. The originally-designed bucket with a 100-ft. radius between the inclined chute and stilling basin floor was satisfactory, but a 50-ft. radius bucket improved flow conditions in the stilling basin with the final baffle pier arrangement.

b. Stilling Basin: (See Paragraphs 91 to 109). The stilling basin floor and sidewalls remained as originally designed, as it was found that lowering the stilling basin floor to increase the range of discharges for which a hydraulic jump would form in the stilling basin was uneconomical. The original baffle design (Plan A) was found to be unsatisfactory as no hydraulic jump formed in the stilling basin for flows over 31 000 c.f.s. and spray overtopped the stilling basin sidewalls at the high discharges. As a result of the study of various types and arrangements of baffles, it was found that with three rows of vertical-faced baffles, graduated in size, a hydraulic jump formed in the stilling basin for discharges up to 55 000 c.f.s. and no undesirable spray action occurred with the higher discharges. Flows between 55 000 c.f.s. and 95 400 c.f.s. passed through the stilling basin with little decrease in velocity, but as such flows will occur infrequently and will do relatively little damage downstream from the stilling basin, it was considered uneconomical to revise the stilling basin to accommodate the higher discharges. The original end sill was found to be the most practical design for this feature of the stilling basin.

c. Tailbay: (See Paragraphs 110 to 119). Scour tendencies for the lower spillway discharges (below 45 000 c.f.s.) and tunnel flow were observed in the area just downstream from the center and both ends of the end sill. With higher discharges, the maximum scour occurred farther downstream and over a larger area. Large eddies were created on either side of the flow issuing from the stilling basin. At the maximum discharge, velocities of 15 ft. per sec. and wave crests 11.9 ft. above tailwater were observed along the toe of the dam adjacent to the spillway.

d. Outlet Works: (See Paragraphs 120 to 156). The distribution of flow into the intake ports of the originally-designed outlet tower was approximately equal and no undesirable pressure conditions were observed within the ports. Very turbulent conditions obtained in the tunnel elbow. Although open-channel flow obtained in the tunnel within the operating range, both open-channel and full-tunnel flow occurred at the higher discharges depending on the gate opening and stage of the pool. By placing fins in the elbow, open-channel flow was observed in the tunnel for all gate openings and pool elevations up to the crest of the spillway. However, placing of fins in the elbow was found unnecessary as the final lip-venting arrangement effected open-channel flow in the tunnel for all discharges up to 6900 c.f.s. By flaring the walls of the original tunnel outlet, the undesirable concentration of flow and resultant high velocities along the centerline of the stilling basin were reduced.

e. Final Design: A tabulation of the final prototype design features and operation data as well as recommended prototype tests are given in Paragraphs 158 to 161.

INTRODUCTION

Chronology of the Model Study

4. The important phases of the model study are listed in chronological order as follows:

Authorization	June 21, 1940
Design and Construction	June 25, 1940 to Aug. 27, 1940
Preliminary Operation	Aug. 28, 1940 to Sept. 4, 1940
Model Tests	Sept. 5, 1940 to Nov. 7, 1941
Preliminary Reports	Sept. 21, 1940 to Nov. 14, 1941
Final Report	Nov. 16, 1942

Personnel

5. The model study was conducted at the Bonneville Hydraulic Laboratory under the general direction of the Portland District Engineer. Construction of the model, testing operations, and preparation of the preliminary reports were conducted under the supervision of Robert B. Cochrane, Engineer and then Director of the Hydraulic Laboratory. Preparation of this final report was made under the supervision of George E. Hyde, Assistant Engineer, and present Laboratory Director. The design and construction of the model were completed under Carl A. G. Anderson, Assistant Engineer, while L. R. Metcalf, Junior Engineer, was the Project Engineer directly in charge of model operation. Alvin J. Chanda, Junior Engineer, compiled this final report. Assistants in model operation were F. Emerson Holliday and

Orville C. Johnson, Engineering Aides. William O. Dement, Principal Engineering Draftsman, supervised the drafting, while C. Robert Grim, Jr., Engineering Aide, and Wayne P. Buchanan, Assistant Photographer, had charge of the photography.

Method of Presenting Results

Preliminary Reports

6. Since design of the prototype spillway and tunnel structures were carried on by the Portland District Office simultaneously with the model testing program, it was important that the results of the various model tests be made available for use as soon as possible. Therefore, 37 preliminary reports on the results of the model study were issued during the period of September 21, 1940 to November 14, 1941 (see Appendix). These preliminary reports presented the purpose, procedure, results, and analyses of the tests, and included tables of data, drawings, and photographs to illustrate the details.

Final Report

7. This final report correlates and augments the data previously issued in preliminary report form. The main portion of the text is composed of four parts: THE PROTOTYPE which presents general information on the prototype project; THE MODEL STUDY which gives the theory and limitations of a spillway and tunnel model study, details of model construction, and testing procedure; MODEL TESTS which discusses the tests and accuracy of the model results; and FINAL PROTOTYPE DESIGN which points out the differences between the recommended and adopted final design and serves to correlate and present data for use in operation of the prototype spillway and outlet works and for

comparison with possible prototype tests. Tables, photographs, and plates supplement the text.

Acknowledgement and Liaison with Portland District Office

8. Throughout the period of model testing, close liaison was maintained with the Portland District Office through Messrs. Frank Kochis, Senior Engineer, and K. G. Tower, Associate Engineer. These engineers were largely responsible for the design of a great many of the features tested.

Definitions

9. In order to avoid confusion in reading this report and to prevent errors in changing from model to prototype values, all data herein are expressed in prototype terms unless otherwise noted. The datum used in expressing elevations in feet is mean sea level. "Left" and "right" indicate directions when looking downstream. The spillway is defined as including the left abutment, approach apron, right approach wall, crest, chute, and bucket. The stilling basin is considered as beginning at the end of the bucket and includes the baffles, end sill, and sidewalls. The outlet works consist of the outlet tower, tunnel elbow, 15.5-ft. diameter tunnel and tunnel outlet. Other definitions and explanations of the terminology are given throughout the report.

THE PROTOTYPE

Dorena Dam and Reservoir

10. Dorena Dam and Reservoir, a part of the Willamette River Basin Project of Oregon (see Plate 1), are located on the Row River approximately 20 miles south-southeast of Eugene, Oregon. The dam controls a drainage area of 265 square miles of the Umpqua National Forest and creates a storage reservoir with a usable storage capacity of 70 000 acre-feet. Since no generation of power is contemplated at Dorena Dam, it is the primary purpose of this structure to furnish flood control and increased low-water flow for the Coast Fork and Willamette Rivers. As shown on Plate 2, the dam will be of the earth-fill type and some 4700 ft. long with a top elevation of 864.0 ft. A spillway and outlet works will control the reservoir storage and prevent overtopping of the dam.

Spillway, Stilling Basin, and Outlet Works

11. At the extreme right end of the dam an overflow spillway and stilling basin will discharge all flows from 5000 c.f.s. up to the maximum design discharge of 95 400 c.f.s. The spillway will consist of a flat approach apron at elevation 818.0 ft., an ogee crest 188 ft. long at elevation 833.0 ft., a steeply-inclined chute 121 ft. in height tapering to a 120-ft. wide by 130.8-ft. long stilling basin. Three rows of baffle piers in the stilling basin will serve to stabilize the hydraulic jump therein for all flows up to 55 000 c.f.s. Normal control of the reservoir for pool elevations less than 833.0 ft. and discharges less than 5000 c.f.s. will be effected by operation of an outlet works consisting of an outlet tower and a 15.5-ft. diameter

tunnel which will discharge through the face of the spillway chute into the stilling basin. A 17-ft. cylindrical gate at the base of the outlet tower will control flow into the tunnel.

THE MODEL STUDY

Purpose

12. The purpose of this model study was to determine the hydraulic characteristics of the originally-designed spillway, stilling basin, and outlet works of Dorena Dam and to recommend any revisions deemed necessary to correct or improve those hydraulic characteristics. Specifically, the following features of these structures were to be investigated: (1) the spillway approach-apron elevation, right approach-wall alignment, right and left abutments, crest profile, chute-sidewall heights, and bucket radius; (2) baffle-pier plan in stilling basin and end sill design; and (3) the tower entrance-port design, elbow radius, and flare of the tunnel outlet. In addition to this information, it was necessary to determine the pattern and velocity of flow created in the tailbay area, especially at the toe of the dam and adjacent to the stilling basin sidewalls.

Authorization

13. Authority to construct the model was granted by the Chief of Engineers, U. S. Army, in the 2nd indorsement, dated June 21, 1940, to a letter of the District Engineer, Portland, Oregon, dated June 12, 1940, subject: "Hydraulic Model Studies, Dorena Dam and Reservoir, Row River, Oregon" to the Division Engineer, North Pacific Division. Additional tests and revisions in the testing program were requested from time to time so as to adapt the results of the model study to the progress of design work in the Office of the Portland District Engineer.

Theoretical and Practical Considerations

14. In order to simulate accurately prototype hydraulic conditions in a small scale model, it is necessary that dynamic similarity obtain between the model and prototype. Such dynamic similarity will obtain providing the model is constructed geometrically similar to the prototype and operated according to the criteria of Froude, Reynolds, Cauchy, and Weber. In model studies of spillways and outlet works, such fluid properties as vicosity, elasticity, and surface tension (involving the criteria of Reynolds, Cauchy, and Weber) have relatively little effect on model results, so it is common practice to eliminate these properties from consideration and interpret the model results as being effected entirely by gravitational forces, i.e., according to the Froude criterion.

15. After due consideration had been given to: (1) the theoretical factors mentioned in the preceding paragraph; (2) such details as model arrangement, shelter, water supply, forebay and tailbay construction, and fabrication of outlet tower and tunnel; and (3) the operation limitations on such items as velocity measurements, pressure observations, and water-surface gaging, it was concluded that a model built to a scale of 1 to 50 offered the best means of testing the original design and improving its hydraulic characteristics.

Interpretation of Model Results

16. Froudian scale ratios for interpreting model results into prototype values are given in the following table:

Dimension	Prototype Symbol	Model Symbol	Scale Relationship	
			Symbol	Numerical Value
Length	L_p	L_m	L_r	1/50
Area	A_p	A_m	$A_r = L_r^2$	1/2500
Time	T_p	T_m	$T_r = L_r^{1/2}$	1/7.07
Velocity	V_p	V_m	$V_r = L_r^{1/2}$	1/7.07
Discharge	Q_p	Q_m	$Q_r = L_r^{5/2}$	1/17678

Measurements of discharge, velocities, water-surface elevations, and pressures (down to -0.66 ft. and -0.40 ft. of water) were interpreted quantitatively into prototype values by means of the above scale relationships. The limiting model pressure of -0.66 ft. corresponds to an assumed prototype vapor pressure point under normal operating conditions of -33 ft. of water below which point cavitation would take place in the prototype structure. The value of -0.40 ft. corresponding to -20 ft. of water in the prototype was used as a limit of interpreting model pressures in the tunnel elbow and on the baffle piers in the stilling basin where it is known that such pressures fluctuate very rapidly and to a considerable extent. An open-type manometer tube (such as used in this model study) measures the average of rapidly-fluctuating pressures, and such a manometer might register an average negative pressure on a baffle pier which was considerably higher than water vapor pressure when instantaneous negative pressures indicative of cavitation might be occurring thereon. The value of -20 ft. was therefore arbitrarily chosen as a limiting value for interpreting such model pressures. The value of -33 ft. was used to interpret nonfluctuating pressures produced by steady flow. The quantitative interpretation into prototype values of model air entrainment through air vents or by vortex action is considered impossible. Relatively speaking, the model atmospheric pressure was considerably in excess of its scale value. Therefore, it appears reasonable to assume - although at the present time no knowledge or data are available on this subject - that this excessive air pressure caused a greater amount of air to flow into the model tunnel through the air vents than would flow relatively into the prototype tunnel. Discharge and pressure data procured from operation involving air entrainment must therefore necessarily be interpreted qualitatively rather than quantitatively. During certain tests, scouring action downstream from the end sill was studied; the results of such tests must be considered as qualitative and indicative only of the scouring action which will occur during prototype operation.

Description of Model

17. As shown on Plate 3 and in Photographs 1 and 2, the model consisted of a forebay extending some 900 ft. upstream from the crest of the spillway, a portion of the right end of the dam, the entire spillway and stilling basin, complete outlet works, and a tailbay extending some 1200 ft downstream from the end of the stilling basin.

18. Both the forebay and tailbay areas inclusive of the right end of the dam were molded in cement mortar to sheet metal templets (see Photograph 3). The spillway and stilling basin were constructed of plywood and were supported on wooden bents as shown in Photograph 4. The outlet tower (shown in Photograph 5) and tunnel (see Photographs 6 and 7) were fabricated of pyralin. An inspection gallery beneath the spillway (see Photograph 6) permitted operators to observe flow throughout the tunnel. Numerous piezometer

taps for observing pressures were located throughout the spillway, stilling basin, outlet tower, and tunnel. A traveling carriage mounted on rails was used to support Pitot tubes and point gages at any point in the flow throughout the spillway and stilling basin. Other appurtenances to the model consisted of hook gages and wells for measuring the water surface in the forebay and tailbay, a dye-injection apparatus for observing subsurface flow, and photographic platforms and lights. Discharge into the model for spillway and tunnel flow was supplied from a central recirculating sump and was measured by the two calibrated orifice meters shown on Plate 3.

19. Under the original design (Plan A) the tailbay excavation was to be rather shallow (elev. 725.0 ft. or rock, whichever was higher), and the tailwater curve (Curve A on Plate 4) was assumed to be the same as for natural conditions. Subsequent to Test 3, however, the tailbay was revised (Plan B) at the request of the Portland District Office, and Curves D and E on Plate 4 were adopted as the most probable tailwater curves for this area after construction was completed.

Operation Procedure

20. The model was first tested as a whole according to the original design of the Portland District Office, and experimental revisions were then made in the various features of the design (see Table A) with the purpose of improving hydraulic efficiency within limits of economy. Some of the changes in the features tested are shown in Photograph 8. The general procedure of testing was to work downstream taking in turn the various features of the design from the left abutment to the end sill of the stilling basin. Such a testing procedure at times precluded the necessity of observing data through-

out the entire model, so only such measurements that were pertinent to the design feature being studied were recorded. These measurements consisted of water-surface elevations, velocities, pressures, currents, and general flow characteristics taken during constant flow conditions at the particular point under observation. The spillway discharges simulated during the various tests were generally 15 000, 45 000, 70 000, and 95 400 c.f.s., except that during Tests 1 and 3, the maximum discharge used was 95 000 c.f.s. During tests on the spillway, the outlet tunnel was kept closed. Tunnel discharges during the tests varied up to a maximum of 11 000 c.f.s., although 5000 c.f.s. was the proposed maximum discharge for this structure. Photographic record of the model results was made throughout the course of the study.

21. Although the location of model gage E (N 4954, E 3066) was not geometrically the same as the location of prototype gage 2 (N 4370.5, E 3140.9), it was assumed that the tailwater elevation at the two gages would be similar; therefore, the tailwater in the model was regulated at gage E according to Curve A on Plate 4 during Tests 1-3 and according to Curve D during subsequent tests; Curve E was used during Test 24.

MODEL TESTS

Spillway

22. The original spillway design shown in Photographs 9 and 10 and on Plate 5 consisted of a left abutment, a flat approach apron, a right approach wall, a 200-ft. ogee crest, a chute section tapering from the crest length of 200 ft. to 120 ft. at the beginning of the stilling basin, and a 100-ft. radius bucket. In addition to the revision in the tailbay topography made by the Portland District Office subsequent to Test 3 (see Paragraph 19), the crest length was changed to 188 ft. Tests on the model as originally designed and upon the various improvement plans of the features of the spillway are given in the following paragraphs.

Left Abutment

23. The specific purpose of these tests was to observe flow conditions around the originally-designed left abutment and to make any necessary changes in the alignment or slope of the abutment face to improve the flow characteristics adjacent thereto. It is to be noted that Left Abutment Plans B, C, and D of the Portland District Office were not tested at the request of that office.

24. Left Abutment Plan A (Test 1): Details of Left Abutment Plan A are shown on Plate 7. No velocity measurements were taken around the face of the left abutment during this test, but visual observations showed that eddies and turbulence were effected in this area at all flows by the sharp curvature of the wall alignment and the sharp upstream corner adjacent to the face of the dam. At a discharge of 95 000 c.f.s. (see Photograph 11), an undesirable draw-down of the water surface of 2.5 to 3.0 ft. was observed

around the face of the left abutment. From these results it was concluded that either the elimination of the sharp upstream corner or a change in the alignment of the abutment face was necessary to improve the unsatisfactory flow conditions observed with Left Abutment Plan A.

25. Left Abutment Plan E (Test 4): Left Abutment Plan E (see Plate 7) was practically the same as Left Abutment Plan A except that the upstream corner was replaced by a 30-ft. radius curve. Since Left Abutment Plan E was a part of the general spillway revision discussed in Paragraph 22, slight changes were necessarily made in the toe of the transition slope and in the general position of the entire abutment. The face of Left Abutment Plan E remained on the same curvature as that of Plan A.

26. The results obtained with Plan E were only slightly better than those obtained with Plan A. Undesirable turbulence, eddies, and draw-down of the water surface around the abutment face were effected much the same as with Plan A, thus indicating that, for the most part, the sharp curvature of the wall alignment and not the upstream corner created the undesirable flow characteristics. Photograph 17 shows flow around the abutment face, while Plate 8 presents velocities measured adjacent thereto. These results showed that an increase in the radius of curvature of the abutment wall should be tested.

27. Left Abutment Plan F (Test 5): In accordance with the results obtained with the two previously-tested left abutment plans, the curvature of the abutment wall was increased considerably (see Plate 7) as compared with that of Left Abutment Plans A and E. It will be noted that this change extended the abutment farther upstream than either of the other two plans. No change was made in the transition slope.

28. Velocity measurements around Left Abutment Plan F are shown on

Plate 9. There was little difference in the magnitude of the observed velocities from those of Test 4 with Left Abutment Plan E (see Plates 8 and 9), but flow conditions in the vicinity of Left Abutment Plan F were considerably improved. The velocity of flow approaching the left abutment along the upstream face of the dam (see Plate 9) was relatively slow until it reached the face of the abutment; a considerable increase in the velocity was then imparted to the flow as it rounded this face. As shown on Plate 8, with discharges of 15 000 and 45 000 c.f.s., there was an eddy created at the upstream face of Left Abutment Plan E by the break in the alignment of the water's edge at the point where the transition slope intersected the abutment wall; Plate 9 shows that with the improved alignment of Left Abutment Plan F, this eddy did not occur during any of the four test flows. With both Left Abutment Plans E and F, a small eddy was observed near the water's edge at the point where the face of the dam intersected the abutment wall, but this eddy had no effect on flow around the abutment wall. Although not shown in Photograph 18, subsurface currents clung to the transition slope the same as shown in Photograph 20. Surface flow conditions, on the other hand, were improved from those shown in Photograph 17. Some draw-down of the water surface around the abutment wall obtained with Plan F, but its magnitude was appreciably smaller than the draw-down observed with the two previously-tested left abutments. It was thought, however, that further improvement could be made in the flow conditions by changing the abutment wall alignment.

29. <u>Left Abutment Plan G (Test 6)</u>: The alignment of Left Abutment Plan F was revised to that of Plan G (see Plate 7) by increasing the arc length of the 110-ft. radius curve and swinging the curve away from the centerline of the spillway; the radius of curvature of the upstream nose of the abutment was also increased. No change was made in the transition slope.

30. Comparison of velocity observations plotted on Plates 9 and 10 shows very little difference. However, the general characteristics of flow observed with Plan G were not as satisfactory as those observed with Plan F. Comparison of Photograph 19 with Photograph 18 shows the small diagonal standing waves extending downstream and away from the abutment face to be more pronounced with Plan G than with Plan F. Subsurface flow was much the same as with Plan F. It was also noted that the amount of draw-down in the water surface and turbulence of flow along the wall of the abutment was greater with Plan G than with Plan F. As with previous plans tested, a small eddy existed near the water's edge at the point where the abutment joined the upstream face of the dam. Left Abutment Plan G was considered less satisfactory than Left Abutment Plan F.

31. Left Abutment Plan H (Test 7): Reference to Plate 7 shows Left Abutment Plan H as tested. The extension of the wall on the dam side of the abutment was made in an effort to eliminate the eddy in that area. Comparison of Left Abutment Plans F, G, and H shows that the upstream point of Plan H extended to an intermediate position between Plans F and G. No change was made in the transition slope.

32. The velocities observed in the vicinity of Left Abutment Plan H were very much the same as those observed with Plans F and G (compare Plates 9, 10, and 11). The eddy formed along the wall on the dam side of the abutment was not eliminated by the wall extension, but it was decreased in size from that observed with Plans F and G. This improvement was not considered important as in none of the previous tests had this eddy been large enough to cause any appreciable effect on flow conditions. Photograph 20 depicts the flow around Left Abutment Plan H. The turbulence and draw-down of the water surface around the face of Left Abutment Plan H were slightly less

than observed with Plan G and were slightly greater than observed with Plan F. It will be noted in Photograph 20 that the subsurface flow around Left Abutment Plan H was decidedly irregular when compared with that shown in Photograph 21. Similar subsurface currents were observed with Left Abutment Plans F and G, although they do not show in Photographs 18 and 19. In general, Left Abutment Plan H was considered more satisfactory than Plan G and less satisfactory than Plan F.

33. Left Abutment Plan I (Test 11): Subsequent to the selection of Left Abutment Plan F, a revision in the transition slope at the toe of the wall was made by the Portland District Office. As shown on Plate 7, this revision consisted entirely of a modification of the transition slope, and no change was made in the alignment of the abutment wall. The new transition slope in conjunction with the alignment of the Plan F left abutment was termed Left Abutment Plan I.

34. Observations of velocities around the left abutment made during this test are presented on Plate 12. Comparison of these data with those observed with Left Abutment Plan F shows them to be approximately the same. Photograph 21 shows the surface and subsurface flow observed around Left Abutment Plan I; the dye streams depict the appreciable improvement in subsurface flow over the transition slope from that observed with Left Abutment Plan H. It was concluded that Left Abutment Plan I effected better flow conditions than any plan previously tested.

35. Summary - Left Abutment Plans: In general, the results of the tests made on various left abutment plans indicated the following:

a. Eddies, turbulence, and draw-down of the water surface adjacent to the wall of Left Abutment Plan A obtained with all discharges tested because of the relatively sharp curvature of that wall.

b. Flow conditions observed with Left Abutment Plan E were little improved over those observed with Plan A. Undesirable turbulence, eddies, and draw-down of the water surface still obtained because of the sharp curvature of the abutment wall.

c. Considerable improvement was effected by the revised alignment of Left Abutment Plan F in that the eddy along the upstream edge of the abutment was eliminated and a considerable decrease was made in the turbulence and draw-down around the abutment wall.

d. Left Abutment Plan G was less satisfactory than Plan F because turbulence and draw-down of the water surface adjacent to the abutment were more pronounced.

e. Flow around Left Abutment Plan H was slightly better than that observed with Plan G, but was less satisfactory than that which obtained with Plan F. Eddy conditions along the abutment wall facing the dam were less prevalent than with any previous plan tested.

f. Plan I effected little change from velocities and characteristics of surface flow observed with Plan F, but improvement was made in subsurface flow conditions.

Comparison of the foregoing results indicated Plan I as being the most satisfactory plan tested, and it was therefore selected for incorporation in the final spillway design.

Right Approach Wall

36. The term "right approach wall" as used in this report denotes the complete wall bounding the right side of the approach apron and extending from the axis of the spillway crest upstream to the point at which the cut slope of the wall intersects the natural topography of the reservoir. The various terms used in preliminary reports and correspondence to designate separate parts of the right approach wall have been deleted from this report.

37. The purpose of the tests made on the right approach wall was to study the characteristics of flow along that wall and to eliminate or alle-

viate any undesirable flow conditions that might exist. It was also desired to decrease the amount of excavation of the originally-designed right approach wall, if this could be done without producing unsatisfactory flow conditions.

38. Right Approach Wall Plan I (Test 1): Details of the originally-designed right approach wall (Plan I) are shown on Plate 13 and in Photograph 9. It will be noted that the section of the right approach wall immediately upstream from the crest consisted of a sharply-curved abutment similar to that of Left Abutment Plan A.

39. No velocity measurements were taken along the right approach wall during Test 1, but visual and photographic observations were made of flow conditions in that area. Photograph 16 shows flow around the curved abutment wall at the downstream end of the right approach wall, while flow along the full length of the wall is shown in Photograph 11. It will be noted from the latter photograph that a turbulent wake (manifested by boils and eddies) was created along the wall just downstream from the sharp intersection of the approach wall with the natural topography of the reservoir. It was believed that turbulence along the wall and contracted flow around the right abutment caused an uneven distribution of flow along the right side of the approach apron which affected flow over the crest. Visual observation of subsurface dye streams over the right side of the apron downstream from approximately sta. 8+00 indicated that there was a tendency for helicoidal flow to develop along the right approach wall in this area. It was concluded that the slope of the wall could be steepened to decrease the required excavation and the upstream corner could be rounded to prevent formation of eddies and boils just downstream therefrom.

40. Right Approach Wall Plan II (Test 4): Right Approach Wall Plan II

(shown on Plate 13) was a part of the general revision in basic design of the spillway mentioned Paragraph 22. It will be noted from a comparison of Plans I and II that the slope of the Plan II wall upstream from sta. 9+27 was 1 on 1/2 as compared with the slope of 1 on 1-1/2 of the Plan I wall upstream from sta. 9+85, the curved abutment wall of Plan I was replaced in Plan II by a transition slope varying from 1 on 1/4 at sta. 9+90 to 1 on 1/2 at sta. 9+27, and the position of the toe of Plan II right approach wall varied from 6 ft. to approximately 16 ft. nearer to the centerline of the spillway than did the toe of the Plan I wall. The above revisions resulted in a considerable saving in the excavation required for the right approach wall.

41. Velocity measurements taken along Right Approach Wall Plan II are presented on Plate 14. The velocity contours on this plate show that a turbulent wake was caused along the wall in a manner similer to that observed with Plan I. The intensity of eddy and boiling action within this area, however, was greater than observed with Plan I as shown in Photograph 22. Elimination of the sharply-curved right abutment improved flow conditions at the crest as shown in a comparison of Photographs 16 and 22, but it was concluded that flow along the length of the right approach wall was still too turbulent. It was believed that this turbulence could be diminished by rounding the upstream corner of the wall and that a greater saving in excavation cost could be made by further shifting of the toe alignment of the wall towards the spillway centerline.

42. Right Approach Wall Plan III (Test 9): A comparison of Right Approach Wall Plan III with Plan II (see Plate 13) shows that a complete revision was made in the alignment of the toe of that wall by the Portland District Office. The toe of the transition section of the wall was made

parallel to the spillway centerline rather than being on an angle thereto. Upstream from sta. 9+22.48, the toe of the wall was on a 475-ft. radius which intersected the spillway centerline at about sta. 6+43.5. The intersection of the upstream end of the wall and the topography was rounded to reduce turbulence in that area. A part of this rounding may be noted in Photograph 23.

43. Comparison of the velocities observed along Right Approach Wall Plan III (see Plate 15) with those observed along the Plan II wall (see Plate 14) shows the former to be of greater magnitude throughout. These increased velocities were due, of course, to the contraction of the spillway approach channel resulting from the revised alignment of the Plan III wall. Although rounding of the upstream corner effected a narrower turbulent wake than was observed with the Plan II wall (compare Photographs 22 and 23), the increased velocity of flow caused an increase in turbulence along the right approach wall. It was concluded that Right Approach Wall Plan III was less satisfactory than Plan II because too much contraction of the approach channel had been made by shifting the toe alignment of the wall towards the spillway centerline.

44. Right Approach Wall Plan IV (Test 11): To avoid increased velocities and turbulence effected by contracting the spillway approach channel as with the Plan III wall, the Plan IV wall was located farther away from the spillway centerline. Since rounding of the upstream end of the Plan III wall and the normal (to the crest) alignment of the downstream end of the wall had proved beneficial, these features were incorporated into the Plan IV wall. Details of Right Approach Wall Plan IV are shown on Plate 13. It will be noted that the location of the upstream end of the Plan IV wall was the same as that of the Plan II wall.

45. The velocity of flow along the Plan IV wall was less than the velocity of flow along the Plan III wall and was slightly greater than the velocity of flow along the Plan II wall (see Plates 14, 15, and 16). A comparison of the alignments of these three wall plans and the respective velocity observations shows that the velocity of flow along the right approach wall varied inversely with the distance between the toe of the wall and the centerline of the spillway. This variation in velocity was to be expected because of the change made in the cross-sectional area of the approach channel. Comparison of the velocity contours as shown on Plates 14, 15, and 16 shows that the area of turbulent wake along the Plan IV wall was less than with either Plans II or III. Due to combined decrease in eddy action and narrower wake, the turbulence along Right Approach Wall Plan IV was considerably less than with previously-tested plans as shown in Photograph 24.

46. <u>Right Approach Wall Plan V (Test 21)</u>: Subsequent to the study of Right Approach Wall Plan IV, a change was made by the Portland District Office in the alignment of the O. P. & E. Railroad which was located in the vicinity of the right approach wall (see Plate 13). As shown on Plate 5, the previous alignment of this railroad did not affect flow conditions along the right approach wall in any way. However, with the relocated railroad alignment, it was felt that further study of flow conditions along the right approach wall should be made in order to determine the effect of the railroad fill slope. In addition, at this time, it was deemed advisable to study alternate slopes of the right approach wall of 1 on 1/4 and 1 on 3/4. Information as to the hydraulic conditions obtaining with these alternate slopes was desired in case their use might be either permitted or necessitated by prototype geological conditions. In accordance with these conditions,

therefore, the fill of the relocated railroad was installed in the model and the Plan V wall was constructed with a slope of 1 on 3/4. The alignment of the toe of the Plan V wall remained the same as that of the Plan IV wall.

47. Reference to Plate 17 shows that the velocities observed along Right Approach Wall Plan V to be generally the same as those observed with Plan IV. The combination of the 1-on-3/4 slope of the Plan V wall and the railroad fill resulted in an improved alignment of flow at the upstream end of the wall and effected a decrease in the turbulent wake downstream from that point. Surface currents along the Plan V wall are shown in Photograph 25. It will be noted from this photograph that the alignment of the surface currents was more satisfactory than with any previous right approach wall plan tested.

48. Right Approach Wall Plan VI (Test 22): In accordance with the previous decision to study a 1-on-1/4 slope of the right approach wall, this slope was incorporated in the Plan VI wall. The alignment of the toe of the wall remained the same as that of the Plan V wall and no change was made in the railroad fill. Plate 13 presents in detail the features of the Plan VI wall.

49. Flow along the Plan VI wall is shown in Photograph 26. Velocities observed along the Plan VI wall were generally slightly higher than those observed along the Plan V wall. This increase was attributed to the decrease in cross-sectional area of the approach channel resulting from the steeper slope of the Plan VI wall. Comparison of the velocity contours as presented on Plates 17 and 18 shows that the turbulent wake along the Plan VI wall was narrower than along the Plan V wall, but the general turbulence in this area was increased. Two definite eddy areas existed - one just downstream from the protrusion of the end of the wall and one just upstream from that point.

It was apparent from tests on the Plan V and Plan VI walls that as the slope of the upstream end of the right approach wall approached that of the railroad fill (resulting in a decrease in the protrusion at the upstream end of the wall), flow conditions along the wall were improved.

50. Right Approach Wall Plan VII (Test 23): In view of the results of previous tests on the right approach wall, a smooth transition was installed between that wall and the railroad fill as shown on Plate 13. It will be noted that the Plan VII wall consisted of two separate transition sections, one of which extended from the upstream face of the crest to sta. 9+22.48, while the other extended from sta. 9+22.48 to the intersection of the wall with the railroad fill. The resulting break in alignment at sta. 9+22.48 was unavoidable, because it was necessary for geological reasons to maintain the 1-on-1/2 wall slope at that point.

51. Comparison of Plate 19 with Plates 14 to 18 shows flow conditions along the Plan VII wall to be materially improved over those obtained with Plans II to VI. No material change was made in the average velocities along the wall, but the distribution of flow was much more uniform as shown by the velocity contours. The turbulent wake along the wall was eliminated by the alignment of the Plan VII wall, and flow immediately adjacent to the wall was not slowed down by turbulence as in previous tests. Photograph 114 depicts the direction of subsurface flow along the right approach wall, while surface current directions along the Plan VII wall are shown by Photographs 27 and 115. Attention is invited to the smooth alignment of surface flow along the right wall as shown in these photographs. Results of this test on Right Approach Wall Plan VII showed flow conditions along the wall to be satisfactory for all discharges.

52. Summary - Right Approach Wall Plans: In general, the results of

the investigation of various plans of the right approach wall indicated the following:

a. Flow conditions along the originally-designed right approach wall (Plan I) were too turbulent and probably affected flow over the crest. It was also evident that a reduction might be made in the amount of excavation required.

b. Study of Plans II, III, and IV showed that any relatively large reduction in required excavation would have to be done at the expense of increased velocity of flow, increased eddy action, and more turbulent flow along the approach wall. Plan IV proved to be the best compromise of the above. Elimination of the curved abutment just upstream from the crest and a rounding of the upstream end of the wall proved to be beneficial from a hydraulic standpoint.

c. The relocation of the railroad fill at the upstream end of the wall improved flow conditions along the length of the wall.

d. Varying the slope of the wall (Plans V and VI) showed that as the slope of the upstream end of the wall approached the slope of the railroad fill, flow conditions were improved. Study of Plan VII, which featured a smooth transition of the upstream end of the wall into the slope of the railroad fill, further verified the above fact.

Plan VII was found to be the most satisfactory plan tested and was therefore recommended for the final design. In addition to the satisfactory flow conditions which obtained at all discharges, the Plan VII wall effected a considerable reduction in excavation required as compared with the original design.

Apron Floor Elevation

53. The terms "approach apron" or "apron floor" used in this report designate the floor of the approach channel from the crest upstream to the intersection with the natural topography of the reservoir. The specific

purpose of these tests was to determine if the apron floor could be raised to decrease excavation cost without creating any undesirable flow characteristics throughout the spillway. Four tests were made with two different combinations of left abutment and right approach wall plans and apron floor elevations of 818.0 ft. and 823.0 ft. (the spillway crest remained unchanged throughout these tests). The hydraulic data procured included pool elevations, velocities, water-surface elevations, pressures at the crest, and observation of the general characteristics of flow throughout the approach channel.

54. Apron Floor Elevation 818.0 Ft. (Test 9): The first investigation of the hydraulic conditions over the apron floor was made with Left Abutment Plan F and Right Approach Wall Plan III incorporated in the model. Plate 15 presents velocities observed along the right side of the approach channel. No velocities were taken at the left side of the approach channel at this time. Reference to Plate 20 shows the water-surface cross section at the crest axis for this test. Actual values for the elevation of the water-surface cross section and the elevation of the pool for discharges of 45 000 and 95 400 c.f.s. are given in Table B. It will be noted that the maximum superelevation of the water surface at the right side of the crest above the water surface at the centerline of the spillway amounted to 0.7 ft. at the 95 400-c.f.s. discharge. This superelevation was caused, of course, by curvature of flow over the apron. Maximum draw-down of the water surface around the left abutment below the water surface at the spillway centerline amounted to 1.0 ft.

55. Apron Floor Elevation 823.0 Ft. (Test 10): Following the procurement of data with features in the approach channel as outlined in the preceding paragraph, the apron floor was raised to elevation 823.0 ft. In

order to eliminate or reduce any roller action that might occur along the upstream edge of the apron floor because of the increase in elevation, that edge was rounded. All other features of the approach channel remained as in the previous test.

56. Comparison of data given in Table B shows that the raised apron floor (Test 10) increased the pool elevation a maximum of 0.4 ft. from that observed with the apron floor at elevation 818.0 ft. (Test 9). This increase in elevation of the pool was indicative of the decrease in the efficiency of the spillway. Reference to Plate 20 and Table B shows that, although the raised apron floor effected no increase in the superelevation of the water surface at the crest, the draw-down around the left abutment at the crest was considerably greater. This increase in draw-down of the water surface, of course, was due to increased velocity of flow approaching the crest. A comparison of Plates 15 and 21 shows that the velocity of flow increased 15 to 20 percent over the right side of the spillway apron as a result of decreasing the depth of the approach channel. As a result of this increased velocity, the eddy action was greater within the turbulent wake along the right approach wall. It was generally concluded that the results obtained by raising the apron floor from elevation 818.0 ft. to 823.0 ft. were unsatisfactory.

57. <u>Apron Floor Elevation 818.0 Ft. (Test 11)</u>: The second investigation of the characteristics of flow in the approach channel with apron floor at elevation 818.0 ft. was made with Left Abutment Plan I and Right Approach Wall Plan IV incorporated in the model. Data procured during this test are presented in Tables B and D and on Plates 12, 16, and 20.

58. As shown on Plate 20, the draw-down around the left abutment was slightly greater and the superelevation of the water surface at the right

side of the crest was slightly less than during Test 9. Reference to Table B shows that this draw-down was 1.2 ft. and the superelevation was 0.6 ft. for the 95 400-c.f.s. flow.

59. Apron Floor Elevation 823.0 Ft. (Test 12): As in Test 10, the apron floor was raised to elevation 823.0 ft. and the upstream edge was rounded. All other features of the spillway remained the same as in Test 11. Reference to Table B shows that the elevation of the pool for a discharge of 95 400 c.f.s. was increased some 0.3 ft. by the raised apron floor. A comparison of the water-surface elevations as presented in this table shows that the water surface was lower at the crest with the raised apron floor (Test 12) and that the draw-down at the left abutment was increased. The water-surface cross section for a discharge of 95 400 c.f.s. is shown on Plate 20 for both the 818.0-ft. apron floor (Test 11) and the 823.0-ft. apron floor (Test 12). It will be noted that for both conditions (see Table D), the pressures observed downstream from the crest axis were about the same. Upstream from the crest axis, however, the pressures observed with the apron floor at elevation 823.0 ft. were generally greater (less negative pressures) than those observed with the apron floor at elevation 818.0 ft. This variation of pressures was attributed to the decreased height of the spillway crest above the apron floor, or in other words, a decreased $\frac{\text{"d"}}{h}$ value. Comparison of Plates 12 and 16 with Plates 22 and 23, respectively, shows that the raised apron floor effected approximately 20 percent higher velocities around the left abutment and along the right approach wall. As in the previous test with the raised apron floor, eddy action and turbulence along the right approach wall were increased because of the increased velocity of flow over the spillway apron.

60. Summary - Apron Floor Elevation: The results effected by raising

the apron floor to elevation 823.0 ft. are summarized as follows:

a. The elevation of the pool was increased some 0.3 to 0.4 ft. at the maximum discharge of 95 400 c.f.s.

b. Velocity of flow over the apron was increased 15 to 20 percent.

c. Draw-down around the left abutment was increased as much as 2.0 ft. at the 95 400-c.f.s. flow.

d. Eddy action and general turbulence along the right approach wall were increased.

e. Negative pressures on the upstream lip of the crest were decreased.

It was concluded that, although raising the apron floor to elevation 823.0 ft. would effect a considerable saving in excavation cost, the resulting hydraulic conditions were entirely unsatisfactory when compared with those observed with the apron floor at elevation 818.0 ft.

<u>Crest</u>

61. The purpose of the spillway crest study was to determine the hydraulic efficiency of alternate crest profiles and, if necessary, to improve pressure conditions at the crest. No major change in the position of the crest could be made by the Laboratory as the crest was rigidly fixed by geologic conditions. For Tests 1 to 3 the maximum discharge used for testing was 95 000 c.f.s., while for subsequent tests discharges were simulated up to the maximum design discharge of 95 400 c.f.s. It is to be noted that Crest Plans IV to VIII of the Portland District Office were not tested at the request of that office.

62. <u>Crest Plan I (Test 1)</u>: Plate 5 shows the location of the originally-designed Plan I crest with reference to the various other features of the spillway, and Plate 25 presents a detailed profile of this crest. It

will be noted that the total length of Crest Plan I at the axis was 200 ft. Photograph 9 shows Crest Plan I in place in the model.

63. Due to the curved alignment of flow over the approach apron, the flow was concentrated on the right side of the crest as may be seen from water-surface elevations at the 95 000-c.f.s. flow given in Table B. Also listed in this table are elevations of the pool for discharges of 45 000 and 95 000 c.f.s. The coefficient curve for Crest Plan I is shown on Plate 26. It will be noted that the coefficient for a head of 24.8 ft. on the crest (95 000 c.f.s.) was 3.86 - the average coefficient over the range of operation was 3.48. Pressures observed on the crest (see Table C and Plate 29) were positive for all discharges tested. It will also be noted that the superelevation of the water surface at the crest is reflected in the pressure observations given in Table C. Crest Plan I was deemed satisfactory, but it was believed that greater efficiency could be secured by modifying the crest profile so that negative pressures would obtain on the crest.

64. <u>Crest Plan II (Test 5)</u>: The profile of Crest Plan II (see Plate 25) was designed with the purpose of increasing the discharge by inducing 15-ft. negative pressures on the crest at the maximum discharge of 95 400 c.f.s. In conjunction with the general revision of the complete spillway structure made subsequent to Test 3, the length of the crest was 188.0 ft.

65. The pool elevation with the Plan II crest was found to be appreciably higher for a given discharge than with Crest Plan I (see Table B). This increase was attributed mainly to the decreased length of the crest, though it may have been effected in part by changes made in the approach channel. Flow over the crest was superelevated due to the nonsymmetrical approach channel as was the case with Crest Plan I. The amount of this superelevation is shown by water-surface elevations given in Table B; it was slight

for flows of 45 000 c.f.s. and less, but resulted in an appreciable differential across the length of the crest for the maximum discharge. Crest Plan II was found to be more efficient throughout the complete range of discharge than was Crest Plan I (see Plate 26), as the average discharge coefficient was 3.57 as compared with 3.48 obtained with Crest Plan I. Reference to pressures which obtained on the Plan II crest (see Table C and Plate 29) shows that some negative pressures were observed, but they did not reach the expected value of -15.0 ft. It will be noted that the maximum negative pressures occurred upstream from the crest axis. These pressures again reflect the superelevation of the water surface over the crest. It was concluded that the results obtained with Crest Plan II were generally satisfactory, but further improvement could be made by reducing maximum negative pressures on the crest to -15.0 ft.

66. Crest Plan III (Test 11): Inasmuch as Crest Plan II had not produced the desired negative pressures, the crest profile was further revised to Crest Plan III as shown on Plate 25. No change was made in the length of the crest.

67. Reference to Table B shows that Crest Plan III (Test 11) effected a reduction of 0.3 ft. in the elevation of the pool for the maximum discharge of 95 400 c.f.s. from that which obtained with Crest Plan II (Test 5). Comparison of water-surface elevations for Crest Plan II and Crest Plan III shows the latter water-surface cross section to be slightly lower. It will be noted from the crest coefficient curves on Plate 26, that Crest Plan III was more efficient than Crest Plan II, especially in the lower range of discharge. The average discharge coefficient for the former crest was 3.74 as compared with a value of 3.57 for Crest Plan II. Plate 29 shows a marked difference in the pressure grade lines for Crest Plans II and III, both as

to the magnitude of pressures across the length of crest and in the pattern of the pressure grade lines. The nappe tended to spring clear of the crest at the upstream lip, then impinge on the flat portion upstream from the crest axis, and then again spring clear; thus creating two distinct zones of negative pressure. The maximum negative pressure observed with Crest Plan III was -14.0 ft. (see Table D); this value was considered sufficiently close to the desired value of -15.0 ft. However, due to the abrupt change in curvature of the crest profile, separation occurred between the lip at sta. 9+99.03 and sta. 10+02.77; this separation was manifested by a small vertical roller which was observed to form on the crest between these two stations.

68. Crest Plan IX (Test 24): It had been observed during the previous test that separation occurred on the Plan III crest. In an effort to eliminate this undesirable condition and at the same time maintain the Crest Plan III efficiency, the Plan IX crest was designed. It will be noted (see Plate 25) that downstream from the axis the profile of Crest Plan IX was identical with that of Crest Plan III, while upstream from the crest axis the flat upstream portion of the Plan III crest was replaced by a curved lip. No change was made in the length or position of the crest.

69. It was observed with Crest Plan IX that the pool elevation and the water surface at the crest for the 45 000- and 95 400-c.f.s. flow were slightly lower, thus showing that Crest Plan IX was more efficient than Crest Plan III (see Tests 11 and 24 in Table B); however, Plate 26 shows that for pool elevations below 848.5 ft. (discharges less than 45 000 c.f.s.), Crest Plan IX was less efficient than Plan III. The average discharge coefficient was 3.66 with Plan IX as compared with 3.74 with Plan III. Longitudinal water-surface profiles on the centerline of the Plan IX crest are presented

on Plate 28. With a discharge of 95 400 c.f.s., a draw-down of approximately 7.0 ft. existed between the pool at elevation 858.2 ft. and the water-surface elevation at the crest. Plate 29 shows a marked difference in the pressure grade lines observed with Crest Plans IX and III. With the Plan IX profile, there was but one "over-all" zone of negative pressure, since with the rounded upstream lip the nappe tended to spring clear at a higher angle and thus avoid impinging on the upstream face. However, it will be noted from Tables D and E, that the maximum negative pressure occurred at the crest lip and was approximately of the same magnitude for both crest plans. As was the case in previous tests, the magnitude of pressures varied across the crest length because of the superelevation of the water surface. No separation, as indicated by roller action, was observed on the Plan IX crest. From these results, it was apparent that Crest Plan IX was more desirable than Crest Plan III with respect to uniformity of pressure pattern over the crest and absence of separation on the upstream portion of the crest.

70. <u>Crest Plan X (Test 25A)</u>: Crest Plan X was designed on a curved alignment principally to improve flow conditions in the chute, a detailed explanation of which will be presented later in this report under Chute Plan P. However, it was also desired to maintain the hydraulic efficiency and generally satisfactory flow conditions obtained with Crest Plan IX. It is these latter results with which this part of the report will be concerned. In plan, Crest Plan X was constructed on a 449.98-ft. radius curve (see Plate 30) with the station of the axis at the ends of the crest being the same (10+02.77) as that of the Plan IX crest. Upstream from the crest axis the profile of Plan X was identical with that of Plan IX (see Plate 25), while downstream from the axis, it differed slightly due to the varying slope of the chute floor. The length of the Plan X crest, as measured along the axis,

was slightly more than the length of the Plan IX crest, because of the curved alignment. Photograph 44 shows the Plan X crest in place in the model.

71. The elevation of the pool and of the water surface at the crest axis was found to be slightly lower with Crest Plan X than with Crest Plan IX (see Table B) due to the longer length of the former crest. As shown on Plate 26, Crest Plan X was more efficient than Crest Plan IX up to a head on the crest of about 17 ft. (approximately 52 000 c.f.s.); above that head, Crest Plan X was less efficient. The average discharge coefficient was 3.72 as compared with 3.66 with Plan IX. It will be noted from Plate 29, that the pressure grade lines for Crest Plan X were generally higher throughout than those for Crest Plan IX. Reference to Table E shows that this variation prevailed throughout the length of crest. At the higher discharges, the decrease in negative pressures on the crest is in accordance with the decreased efficiency of the Plan X crest. It was concluded that Crest Plan X was more satisfactory than Crest Plan IX insofar as flow conditions at the crest itself were concerned. The slight decrease in the discharge coefficient for flows above 52 000 c.f.s. effected by Crest Plan X was not considered to be important as flows of this magnitude will rarely occur in the prototype.

72. <u>Summary - Crest Plans</u>: The foregoing results of the study of various crest plans may be briefly summarized as follows:

a. Crest Plan I was found to be satisfactory, but it was believed that a greater efficiency of overflow could be obtained by modifying the crest profile to induce negative pressures of -15.0 ft. on the crest at maximum discharge. The average discharge coefficient was 3.48.

b. Crest Plan II effected generally satisfactory results, although the desired maximum negative pressures of -15.0 ft. were not obtained. An increase in the elevation of the pool resulted from the decreased crest length. The average crest coefficient was 3.57.

c. Crest Plan III created maximum negative pressures sufficiently close to the desired value of -15.0 ft. This crest was also more efficient than either Crest Plans I or II especially in the lower range of discharge; the average coefficient was 3.74. However, separation was observed to occur as indicated by roller action just upstream from the crest axis.

d. Crest Plan IX was considered better than Crest Plan III because of the more uniform pressure pattern and elimination of separation on the crest. Plan IX was less efficient than Plan III for flows less than 45 000 c.f.s. and more efficient for flows greater than 45 000 c.f.s. The average discharge coefficient was 3.66.

e. Crest Plan X was more efficient than Crest Plan IX for discharges up to 52 000 c.f.s. - above this flow, however, it was less efficient. The average discharge coefficient was 3.72. Pressures on the crest, in general, were slightly greater than with Crest Plan IX.

Crest Plan X was considered more satisfactory than any other plan tested insofar as hydraulic characteristics of the crest itself were concerned.

Chute

73. The chute is defined as the converging and steeply-inclined section of the spillway extending from the crest axis to the beginning of the upward-curved bucket. The purpose of the tests on various chute plans was to determine their adequacy to pass discharges up to 95 400 c.f.s. without effecting overtopping of the sidewalls or uneven distribution of flow into the stilling basin.

74. Chute Plan A (Test 1): Details of Chute Plan A (original design) are shown on Plate 5. It will be noted from this plate that the chute extended from sta. 10+00 to sta. 12+26.32 on a downward slope of 1 on 2. From the crest length of 200 ft. the chute converged in width to 120 ft. at the end of the bucket at sta. 12+71.04.

75. Pressures in the chute as observed with piezometers 19 to 30, inclusive, were positive for all flows (see Table F). Although the velocity of flow entering the chute (see Plate 35) increased with discharge, velocities at the bottom of the chute were practically the same for all discharges as gravity was the predominating force effecting flow in the chute. Standing waves were observed to occur throughout Chute Plan A for all discharges up to 95 000 c.f.s. (see Photographs 12 to 16 and Plate 31). These standing waves were created just below the crest where the flow struck the converging sidewalls with supercritical velocity. As shown on Plate 31, the standing waves along the right side of the chute were slightly higher than those along the left side; the reason for this difference, of course, was due to the superelevation of flow over the crest. At sta. 10+25, near overtopping of the right sidewall (freeboard was 0.6 ft.) was observed as shown in Photograph 11 and on Plate 31. Comparison of Photographs 12 to 16 shows that, as the discharge became greater, the standing waves increased in height and converged nearer the centerline of the chute and thus concentrated the flow into the center of the stilling basin. From these results it was apparent that revisions in the originally-designed chute were necessary to prevent the formation of standing waves or to diminish their effect upon flow into the stilling basin.

76. <u>Chute Plans B to N (Test 3)</u>: In view of the results obtained with the Plan A chute, it was believed that special attention should be given to eliminating standing waves in the chute and then spreading the converging flow at the bottom of the chute uniformly over the entire width of the stilling basin. To accomplish these results, a number of chute plans were investigated (see Photographs 28 to 44). Complete data were not observed with these plans inasmuch as visual and photographic data (see Photographs 45 to 61)

proved to be sufficient basis for deciding their relative merits. Following is a brief summary of the features of these plans and of the results obtained with each:

a. Plan B: This plan consisted of a fillet and hump arrangement. One fillet, 12 ft. high, 70 ft. long, and 20 ft. wide, was installed along each sidewall just downstream from the crest to divert flow towards the center of the chute. The purpose of the hump (maximum height of 11 ft. on centerline at sta. 11+75) was to spread flow more uniformly into the stilling basin. Operation with this plan showed that for all discharges the hump in the chute floor forced the standing waves towards the sidewalls of the chute and concentrated the flow at the sides of the stilling basin. At the maximum discharge (95 400 c.f.s.), the fillet at the left sidewall caused flow to overtop that wall.

b. Plan C: In this plan, the chute floor was raised along the sidewalls between the crest and sta. 12+25 and was humped along the centerline between sta. 11+25 and sta. 13+00. The maximum height of the raise along the sidewalls was some 14 ft. at sta. 11+25. The apex of the hump along the centerline was at sta. 12+25 and was 6 ft. above the original chute floor. The hump at sta. 12+25 was found to be helpful in diverting flow more uniformly across the width of the stilling basin. Raising the floor along the sidewalls, however, was not effective in eliminating standing waves and was the cause of considerable reduction in freeboard along the chute walls during maximum discharge.

c. Plan D: This plan was similar to Plan C, except the hump on the chute centerline was increased to 7.5 ft. at sta. 12+00, and the raising of the floor along the sidewalls was increased to a maximum of 17 ft. at sta. 11+00. In addition, the cross section of the chute at the point of maximum raising of the floor along the sidewalls was concave in shape rather than being in the shape of a shallow "V" as in Plan C, and the hump at sta. 12+00 was round in cross section. The general results obtained with Plan D were similar to those obtained with Plan C, in that the standing waves were not eliminated by raising the floor along the sidewalls and the hump aided in distributing flow more evenly into the stilling basin. The increased raising of the floor along the sidewalls, however, resulted in overtopping of the right sidewall at a discharge of 80 000 c.f.s.

d. Plan E: Because the humps of Plans C and D had been found beneficial to some extent in distributing flow evenly across the stilling basin and raising the floor along the sidewalls had been found unsatisfactory in all respects, it was decided to investigate conditions effected by the hump alone. Plan E consisted essentially of a rounded hump with maximum height of 7.5 ft. on the chute centerline at sta. 11+50. A fairly satisfactory distribution of flow into the stilling basin was effected at a discharge of 45 000 c.f.s., but for discharges below and above 45 000 c.f.s., flow was first concentrated at the sides and then at the center of the stilling basin, respectively. Pronounced standing waves obtained in the chute for all discharges.

e. Plan E-1: This plan was essentially the same as Plan E, except the maximum height of the hump was increased to 15 ft. The increased height of this hump further diverted flow towards the chute sidewalls and caused unsatisfactory concentration of flow at the sides of the stilling basin. Pronounced standing waves existed in the chute for all discharges.

f. Plan E-2: This plan consisted of a single hump in the chute floor which was essentially the same as Plan E-1, except the height of the hump was reduced to 3.75 ft. This plan showed an improvement in flow conditions from those of Plan E-1 as standing waves in the chute were less pronounced and a better distribution of flow was obtained into the stilling basin. The results obtained with Plan E-2, however, were no more satisfactory than those obtained with Plan A (original design).

g. Plan E-3: For this plan, the hump in the chute floor was constructed to a height of 11.25 ft. The results obtained were less satisfactory than those obtained with Plan E-2 and were very similar to those obtained with Plan E-1.

h. Plan F: This plan consisted of four longitudinal training walls 4 ft. in height, spaced equally across the width of the chute, and extending from sta. 10+20 to sta. 12+00. The primary purpose of the training walls was to produce an even distribution of flow throughout the chute and stilling basin. These training walls were found to be beneficial in distributing flows of less than 45 000 c.f.s. At a discharge of 45 000 c.f.s. and greater, however, the standing waves overrode the downstream ends of the outside training walls and caused a concentration of flow in the center of the stilling basin.

i. Plan G: This plan was similar to Plan F except the height of the training walls was increased to 8 ft. to eliminate overriding of the walls by standing waves. The results obtained were very similar to those of Plan F, since the Plan G walls were also overridden by standing waves although at a slightly higher discharge.

j. Plan H: From the results observed with Plan G, it was apparent that the two center training walls served no particular purpose and the outside training walls were of insufficient height. Accordingly, for Plan H, the two center walls were omitted and the height of the two outside walls was increased to 16 ft. The walls were also shifted downstream between sta. 10+75 and sta. 12+50. The results of this test were more satisfactory than those of either Plans F or G, as a fairly even distribution of flow into the stilling basin was obtained up to a discharge of about 70 000 c.f.s. Above that discharge, the standing waves overrode the downstream ends of the training walls with a resulting concentration of flow in the center of the stilling basin. Although the training walls of Plan H proved to be fairly satisfactory, it was thought that further study of this type of plan was not warranted because the walls would have to be constructed to an impractical height.

k. Plan I: This plan consisted of four sills extending diagonally away from each chute wall. These sills were 4 ft. high and 8 ft., 16 ft., 24 ft., and 32 ft. in length. The sills were located between sta. 10+80 and sta. 11+70 such that the alignment of their inner ends coincided with the outer limits (towards chute centerline) of the standing waves which developed in the chute. It was thought that this plan might be effective in dissipating the standing waves. Operation of the model with this plan installed showed that the sills were ineffective in diminishing standing waves and that they caused a high degree of turbulence in the chute and stilling basin and overtopping of the chute sidewalls.

l. Plan J: For this plan, three chevron-shaped sills were located on the centerline of the chute between sta. 10+50 and sta. 12+00. These sills were 4 ft. in height, and their outer ends were located approximately on the line of the standing waves. It was thought that such a sill arrangement might serve to retard the velocity of flow in the chute and effect an improvement in the distribution of flow entering the stilling basin. Results of the test showed that, although the sills did effect a retardation in the velocity of flow in the chute, they caused extremely unsatisfactory flow conditions downstream therefrom. At all discharges, the sills deflected flow upward and caused overtopping of both chute sidewalls.

m. Plan K: For this plan, the two upstream chevron-shaped sills of Plan J were removed and the downstream sill was left in its original position with its upstream point at sta. 11+50 and downstream points at sta. 12+00. It was thought that this single sill might divert some of the flow towards the sides of the stilling basin without overtopping the sidewalls as was observed with Plan J. Observation of this plan in operation showed that the single sill diverted practically all of the lower discharges to the sides of the stilling basin and that the higher discharges overrode the sill with little change in direction.

n. Plan L: Seven transverse rows of baffles in the chute equally spaced between sta. 10+50 and sta. 11+50 were installed for Plan L. These baffles were 4 ft. high and 4 ft. square and were spaced 12 ft. on centers in the rows. The rows of baffles were staggered. The results obtained with this plan were not satisfactory because of the extreme turbulence created in the chute at lower discharges, although the standing waves were almost entirely eliminated. At lower discharges a fountain effect was formed by each individual baffle. As the discharge was increased, these fountains were drowned out until, at the maximum discharge, the water surface in the chute was fairly uniform. A considerable improvement was effected in stilling basin action because of the decreased velocity of flow in the chute, although a concentration of flow in the center of the stilling basin still obtained at the higher discharges.

o. Plan M: For this plan, the size, number, and location of the baffles remained the same as for Plan L, but the alignment of each individual baffle was twisted in such a manner as to divert the flow toward the centerline in the upstream end of the chute and toward the sides in the downstream portion of the chute. It was thought that this twisting of the baffles would result in an improved distribution of flow into the stilling basin and reduced turbulence in the chute. The results obtained with Plan M were very similar to those obtained with Plan L. Some improvement was effected in the distribution of flow, but extremely turbulent conditions still existed in the chute at the lower discharges. At the maximum discharge, the water surface in the chute was fairly smooth with little evidence of standing waves.

p. Plan N: This plan consisted of an ogee crest on a curved alignment (with the corresponding dished spillway floor) whose radius was such that the crest was normal to the sidewalls at the point of intersection. In addition to this change in the crest, the sidewalls were made vertical at that point of intersection. Because of the temporary construction of this plan, discharges greater than 45 000 c.f.s. could not be simulated. Within this range of discharge, however, standing waves in the chute were practically eliminated and a fairly uniform distribution of flow existed into the stilling basin.

Of the above plans tested, Plans L, M, and N were the only plans in which the standing waves in the chute were reduced. With two of those plans (L and M) this reduction in standing waves was accomplished by undesirable turbulence at the lower discharges. The high training walls of Plan H created a fairly uniform distribution of energy in the stilling basin, but did not eliminate the standing waves in the chute. In view of these results, it was decided that Plan N was the only plan which warranted further study.

77. Chute Plan O (Test 24): This plan of the spillway chute was a part of the general revision made in the basic design of the spillway structure subsequent to Test 3. As a result of shortening the length of the spillway crest to 188 ft. at that time, the convergence in the alignment of the chute walls was decreased. All other features of the chute remained the same as in Plan A. Plan O chute (see Photograph 43) was in place in the model throughout a large part of the testing program, and several sets of data were observed with this plan. The results observed with Plan O chute which follow,

however, were observed at a time when all other features incorporated in the model were of the final design.

78. Comparison of the water-surface cross sections observed throughout Chute Plans A and O (see Plates 31 and 32) shows them to be of the same general pattern, with the depth of flow in the Plan O chute being slightly greater because of the decreased width of the chute. It will be noted that the right sidewall was overtopped at sta. 10+25 at the maximum discharge of 95 400 c.f.s. and that the standing waves in the Plan O chute were slightly smaller than those obtained with Plan A; this was due, of course, to the decreased taper of the chute sidewalls. Comparison of pressures observed with Chute Plans A and O (see Tables F and H) shows the latter to be higher. This difference is attributed mainly to the increased depth of flow throughout Chute Plan O. Velocities observed in Chute Plan O were found to be similar in magnitude to those observed with Plan A as shown by a comparison of Plates 35 and 36. As with Chute Plan A standing waves caused an unsatisfactory distribution of flow into the stilling basin for all discharges and overtopping of the right sidewall of the chute at maximum discharge.

79. Chute Plan P (Test 25A): It had been decided previously (refer to Paragraphs 72 and 76) that further study of a curved spillway crest and accompanying dish-shaped chute was warranted. Plan P chute was therefore installed in the model in conjunction with Crest Plan X as shown on Plate 30 and in Photograph 44.

80. Observation of various discharges throughout the Plan P chute showed a material reduction in the height of standing waves. This reduction may be seen by comparing the water-surface cross sections as shown on Plates 31, 32, and 33. It will also be noted that the freeboard along the chute sidewalls was increased. Comparison of Photograph 61 with Photo-

graphs 13 and 60, respectively, also shows that the standing waves in the Plan P chute were much less prevalent than in Chute Plans A and O. Although standing waves in the chute had been materially reduced for higher discharges and had been practically eliminated for lower discharges, it was observed that no appreciable improvement was effected in the distribution of flow entering the stilling basin. Pressure readings observed with Chute Plan P (refer to Table I) were found to differ in magnitude from those observed with Chute Plan O (refer to Table H). This difference is attributed mainly to the variation in flow distribution across the chute. No velocity measurements were taken with this plan.

81. Summary - Chute Plans: Following is a brief summary of the results of the foregoing study of various chute plans:

a. Chute Plan A was found to be generally unsatisfactory because of standing waves that obtained in the chute for all discharges up to 95 000 c.f.s. These standing waves reduced freeboard to 0.6 ft. along the right sidewall at sta. 10+25 and effected undesirable distribution of flow into the stilling basin.

b. The study of Chute Plans B to M, inclusive, showed that none of these plans eliminated standing waves in the chute or prevented uneven distribution of flow into the stilling basin. Plan N, in conjunction with Crest Plan X, effected considerably smaller standing waves in the chute as to justify further study.

c. In general, the results obtained with Chute Plan O were found to be similar to those obtained with Plan A. Standing waves caused an unsatisfactory distribution of flow in the chute and into the stilling basin for all discharges. The greater depth of flow in the chute resulting from the decreased crest length caused standing waves to overtop the right sidewall just below the crest during maximum discharge.

d. Chute Plan P effected a considerable decrease in the magnitude of standing waves and increased the amount of freeboard along the chute sidewalls. However, no improvement was made in the distribution of flow entering the stilling basin.

In view of the foregoing results obtained with various plans of the spillway chute, it was decided that Chute Plan P was the most satisfactory plan tested.

Bucket

82. The term "spillway bucket" as used in this report denotes the concave or angular section of the spillway extending between the inclined chute and the horizontal floor of the stilling basin. It was thought that, if the spillway bucket could be shortened so as to increase the effective length of the stilling basin, the efficiency of the latter as an energy dissipator might be improved. The purpose of the spillway bucket study, therefore, was to investigate several types of buckets in conjunction with different baffle plans and determine if such revisions would effect increased stilling basin efficiency. The hydraulic jump and stilling basin action in general were used as a basis of comparing the several bucket plans tested.

83. 100-Ft. Radius Bucket (Test 18E): Details of the originally-designed 100-ft. radius bucket are shown on Plate 37. Since various baffle plans had been tested in the model prior to testing the bucket plans, Plan I baffles (see Plate 40) were in place in the stilling basin during Test 18E.

84. Operation of the model with the 100-ft. radius bucket gave fairly satisfactory hydraulic jump action in the stilling basin; a stable jump obtained up to and including a discharge of 45 000 c.f.s. as shown in Photograph 62.

85. Intersecting-Planes Bucket (Tests 18A and 18B): For this plan,

the 100-ft. radius bucket of the original design was removed to permit the chute floor to extend downward and intersect the horizontal floor of the stilling basin at sta. 12+47.44 as shown on Plate 37 - thus forming the "intersecting-planes bucket". With this plan, the stilling basin was 137.56 ft. long or 23.6 ft. longer than the original stilling basin.

86. The intersecting-planes bucket was first tested (Test 18A) in conjunction with Plan I baffles (see Plate 40). With this combination, a satisfactory hydraulic jump obtained in the stilling basin up to and including a discharge of 40 000 c.f.s. At a flow of 45 000 c.f.s., however, the hydraulic jump was not stable and flow overrode the right side of the upstream row of baffles as shown in Photograph 63. It was thus apparent that the intersecting-planes bucket in conjunction with Plan I baffles had lowered the efficiency of the stilling basin from that obtained with the 100-ft. radius bucket.

87. The intersecting-planes bucket was next investigated in conjunction with Plan M baffles (see Plate 41). Baffle Plan M was the same as Baffle Plan I, except the upstream and middle rows of baffle piers were moved upstream 10 ft. and 5 ft., respectively, to take advantage of the longer stilling basin created by the intersecting-planes bucket. From observation of flow in the stilling basin, it was found that moving a part of the baffles upstream materially improved stilling basin action which obtained with the intersecting-planes bucket and the Plan I baffles. A stable hydraulic jump (see Photograph 64) was obtained with discharges up through 45 000 c.f.s. It appeared, therefore, that if the intersecting-planes bucket were to be used, the Plan M baffles should be installed in the stilling basin.

88. <u>50-Ft. Radius Bucket (Tests 18C and 18D)</u>: In addition to the two previously-tested bucket plans, an intermediate bucket with a radius of

50 ft. was studied. This design (see Plate 37) lengthened the original stilling basin to 125.76 ft. Flow conditions in the stilling basin effected by the 50-ft. radius bucket and the Plan I baffles (Test 18C) were similar to those of Test 18A. At a discharge of 45 000 c.f.s., the hydraulic jump was not stable and flow overrode the right side of the upstream row of baffles as shown in Photograph 65.

89. Inasmuch as the results of the previous test were unsatisfactory, it was decided to move all three rows of baffles upstream to positions shown as Plan N baffles (see Plate 41) for Test 18D. No change was made in the 50-ft. radius bucket. The stilling basin action was improved from that previously observed with the Plan I baffles and was quite similar to that observed with the intersecting-planes bucket and the Plan M baffles. As shown in Photograph 66, the jump covered the upstream row of baffles at a discharge of 45 000 c.f.s.

90. Summary - Bucket Plans: The results of the above tests are summarized as follows:

a. Lengthening the stilling basin by use of an intersecting-planes or a 50-ft. radius bucket without changing the location of the Plan I baffles lessened the efficiency of the stilling basin.

b. When the Plan M or N baffles were used in conjunction with the intersecting-planes bucket or the 50-ft. radius bucket, respectively, these buckets effected just as satisfactory stilling basin action as did the 100-ft. radius bucket of the original design.

At the end of the foregoing tests, it was concluded that the best plan tested combined the 50-ft. radius bucket with the Plan N baffles, because it afforded a smoother transition between the chute and stilling basin floors than did the intersecting-planes bucket and provided a greater effective length of stilling basin than did the 100-ft. radius bucket.

Stilling Basin

91. The originally-designed stilling basin shown on Plate 5 and in Photograph 10 was considered as beginning at the end of the bucket at sta. 12+71.04 and extending downstream to sta. 13+90 (inclusive of the sidewalls, baffles, and end sill). Tests on this structure incorporated various baffle plans, simulated lowering of the basin floor, and several end sill designs. The following paragraphs discuss the results obtained with the various improvement plans tested.

Baffles

92. The specific purpose of the baffle tests was to determine an arrangement of baffle piers that would effect a stable hydraulic jump in the stilling basin for all discharges up to and including 45 000 c.f.s. and that would not cause spray action therein to overtop the sidewalls up to a maximum discharge of 95 400 c.f.s. Test data procured with each plan consisted of visual and photographic observations of flow conditions in the stilling basin and pressure measurements on the baffle piers, stilling basin floor, and sidewalls. It is to be noted that, in the analysis of pressures measured on the baffle piers, the cavitation limit was raised from -33 ft. to -20 ft. to allow for the effect of instantaneous pressures which would create cavitation, but would not register in an open-manometer column.

93. Baffle Plan A (Tests 1 and 11): The originally-designed baffles, the details of which are shown on Plate 38, were tested twice: first, with tailwater curve A (Test 1); and second, with tailwater curve D (Test 11) .. both of these curves are shown on Plate 4.

94. Photographs 12 to 16 and Table F present data observed during Test 1. It was observed that a satisfactory hydraulic jump occurred in the stilling

basin for discharges up to and including 45 000 c.f.s. (see Photograph 13). For greater discharges, however, flow overrode the baffles and spray overtopped the right sidewall of the stilling basin. At the maximum discharge of 95 000 c.f.s., velocities observed just downstream from the end sill were only 30% less than the high velocities at the foot of the chute. Reference to Table F shows that high negative pressures occurred on the downstream faces of the upstream row of baffles. These negative pressures were of sufficient intensity on the downstream faces of baffles A and B as to indicate cavitation would occur in the prototype. Due to uneven distribution of flow into the stilling basin, negative pressures at this point on baffle C were only about one-half of those observed on baffles A and B.

95. With tailwater curve D during Test 11, it was observed that a stable hydraulic jump occurred in the stilling basin for discharges only up to 31 000 c.f.s. Photograph 68 shows a discharge of 45 000 c.f.s. over Baffle Plan A during this test when the tailwater was approximately 6 ft. lower than during Test 1. It will be noted that the flow overrode the upstream row of baffles. Inasmuch as tailwater curve D (Plate 4) was used throughout the remainder of the study, it was obvious that changes were necessary in the baffles to effect a stabilized hydraulic jump for all discharges below 45 000 c.f.s.

96. Baffle Plans B to L (Test 13): In accordance with the results obtained in the study of the Plan A baffles, Baffle Plans B to L, inclusive, were devised with the purpose of developing a baffle arrangement that would produce a satisfactory hydraulic jump in the stilling basin for all discharges up to 45 000 c.f.s. and would prevent unsatisfactory spray action at the higher discharges. The details of these plans are given on Plates 38, 39, and 40, while Photographs 69 to 79, inclusive, show them in opera-

tion. All plans in this group were tested with the 100-ft. radius bucket. Curve D on Plate 4 was used in regulating the tailwater elevation. The following subparagraphs contain the results obtained with each of the plans tested including the results obtained with no baffles in the stilling basin (see Photograph 67).

a. No Baffles (Test 13A): To form a basis of comparison with subsequently tested baffle plans, flow through the stilling basin without baffles was observed. The greatest discharge at which a stable hydraulic jump occurred within the stilling basin was 25 000 c.f.s. With a discharge greater than 25 000 c.f.s., the flow impinged directly on the end sill with the major portion being deflected upward. At the 95 400-c.f.s. discharge, flow was deflected as high as 90 ft. above the top of the end sill at sta. 14+65.

b. Baffle Plan B (Test 13B): The size and location of the baffles of Plan B were the same as in Plan A, except the upstream baffles were reversed and one additional baffle was placed at each end of the upstream row. With this arrangement, a jump obtained in the stilling basin for discharges up to 50 000 c.f.s. At higher discharges, the water was deflected upward into undesirable spray action by the vertical faces of the upstream baffles. At a flow of 70 000 c.f.s. the right sidewall was overtopped, and at a discharge of 95 400 c.f.s. both sidewalls were overtopped.

c. Baffle Plan C (Test 13C): Comparison of Baffle Plans B and C shows that they were the same except for the "stepped" design of the baffle piers. With such a baffle arrangement, a hydraulic jump was formed in the stilling basin for discharges only up to 30 000 c.f.s. At the 45 000-c.f.s. discharge, the flow was deflected upward into spray action by the upstream row of baffles; higher flows overrode the baffles. No further study of the stepped type baffles was made as they were not considered as effective as the vertical-face type baffles.

d. Baffle Plan D (Test 13D): The baffle arrangement of Plan D was similar to that of Plan B, except both rows of baffles were moved approximately 16 ft. upstream. The baffles were of original size, shape, and spacing, and the vertical faces were placed upstream with the exception of the end baffles of the upstream row. These two baffles were placed with their sloping faces upstream to reduce the undesirable upward deflection created by these baffles during the high flows as was observed with Baffle Plan B. Wedge fillets were added between the two end baffles and the stilling basin wall to simulate probable prototype construction. During operation, the Plan D baffles created a hydraulic jump in the stilling basin for discharges up to 31 000 c.f.s. At the 45 000-c.f.s. discharge, however, the vertical faces of the first row of baffles deflected a portion of the flow upward to an elevation of 792 ft. at sta. 13+25, and both sidewalls were overtopped. As the discharge was increased above 45 000 c.f.s., the depth of flow along the centerline of the stilling basin was slightly decreased, but spray was still deflected over the sidewalls. In general, it appeared that no advantage was to be gained by maintaining the same height of baffles and moving them upstream.

e. <u>Baffle Plan E (Test 13E)</u>: The Plan E and Plan D baffle arrangements were similar except the baffles of Plan E were moved 33 ft. downstream. A hydraulic jump was obtained for all discharges up to 45 000 c.f.s. Moving the baffles downstream, however, decreased the length of the jump. At the 70 000-c.f.s. flow, the water was deflected upward by the first row of baffles to elevation 805 ft. at sta. 13+90. As the discharge was increased to 95 400 c.f.s., the flow overrode the first row of baffles and was deflected over the sidewalls, but the flow was not deflected as high as was observed with the previous baffle plans tested.

f. <u>Baffle Plan F (Test 13F)</u>: Plan F baffles consisted of the Plan D baffles moved 16 ft. downstream to a point approximately halfway between the location of the Plans D and E baffles. A hydraulic jump was observed to form with the Plan F baffles for all discharges up to 45 000 c.f.s., but upward spray action ensued similar to that observed with the Plan D baffles. For higher discharges, flow conditions in the stilling basin were similar to those with the Plan E baffles. It was concluded that the baffle arrangement of Plan F was more efficient than that of Plan D and less efficient than that of Plan E.

g. <u>Baffle Plan G (Test 13G)</u>: The baffles of Plan G were arranged in three rows. The first or upstream row consisted of 17 baffles one-half original size, the second row contained 10 baffles three-fourths original size, and the third or downstream row consisted of 9 original-size baffles. The end baffles of the first and third rows were installed with their sloping faces upstream with wedge fillets between the baffles and the stilling basin wall. A fairly satisfactory jump obtained in the stilling basin for the 45 000-c.f.s. discharge, but it was noted that the end baffles of the first row still tended to deflect the flow upward along the stilling basin walls. For the higher discharges, however, the flow was not deflected upward as much as was observed with previous baffle plans. The maximum height to which spray rose during the 95 400-c.f.s. discharge was elevation 765 ft. at sta. 14+25. Comparison of the results of Baffle Plans E and G indicated that increasing the number of baffles and decreasing the height of the baffles in the upstream rows was definitely an improvement, especially in reducing the undesirable spray action at the higher discharges.

h. Baffle Plan H (Test 13H): For Baffle Plan H, the arrangement used for Plan G was modified by removing the two end baffles of the upstream row, moving the second and third rows upstream, reversing the end baffles of the third row, and adding a fourth row consisting of 8 original-size baffles. The jump in the stilling basin was fairly satisfactory at a discharge of 45 000 c.f.s. The flow conditions in the stilling basin for the 70 000- and 95 400-c.f.s. discharges were similar to those observed with Baffle Plan G. The results of testing with Baffle Plan H indicated that a fourth row of baffles did not create any improvement in flow conditions within the stilling basin.

i. Baffle Plan I (Test 13J): Baffle Plan I consisted of a revision of the Plan H baffles: the fourth row of baffles was removed, the wedge-shaped fillets between the end baffles of the third row and the wall were removed, and one additional baffle was added to each of the two upstream rows. With this arrangement, a fairly satisfactory jump obtained in the stilling basin for the 45 000-c.f.s. flow. With discharges greater than 45 000 c.f.s., however, the flow overrode the upstream row of baffles, except along the sidewalls. No spray deflection over the sidewalls was observed with this baffle plan. It was concluded that Baffle Plan I was the most effective baffle arrangement tested thus far, as it created a stable hydraulic jump at a discharge of 45 000 c.f.s. as required and effected no undesirable spray action at the higher flows.

j. Baffle Plan J (Test 13K): Baffle Plan J was the same as Baffle Plan I except the alignment of the baffle rows was changed to make an angle of 60 degrees with the centerline of the stilling basin. The purpose of this alignment was to effect a more even energy distribution in the stilling basin by diverting some of the flow from the center towards the sidewalls. Operation showed that this baffle arrangement did not achieve its purpose and that 30 000 c.f.s. was the maximum discharge at which a jump could be obtained in the stilling basin.

k. Baffle Plan K (Test 13L): Baffle Plan K was devised in a further effort to divert some of the flow from the center to the sides of the stilling basin. This plan was the same as Baffle Plan I except that the baffles for Plan K were cut on a 30° skew. Operation revealed that this arrangement was slightly better than Plan J, but the maximum discharge at which the jump obtained in the stilling basin was only 40 000 c.f.s. Flow conditions for 45 000 c.f.s. were similar to those obtained with Plan J. From the results obtained with Baffle Plans J and K, it was apparent that any attempt to divert some of the flow from the center of the stilling basin only resulted in a decreased effectiveness of the baffles and consequent lowering of the maximum discharge at which a hydraulic jump was formed.

l. Baffle Plan L (Test 13M): To ascertain if moving the original baffle system (Plan A) upstream would effect results similar to those obtained with Baffle Plan I, Baffle Plan L was tested in the model. This arrangement proved to be unsatisfactory, as 30 000 c.f.s. was the maximum discharge at which a jump occurred in the stilling basin. With higher discharges the flow was deflected upward by the sloping faces of the baffles in the upstream row similar to that observed with Baffle Plan A.

97. Baffle Plans M and N (Tests 18B and 18D): As explained in Paragraph 96, Baffle Plan I was developed for use with the 100-ft. radius bucket. To obtain results equally effective with the intersecting-planes and 50-ft. radius buckets, Baffle Plans M and N (see Plate 41) were devised, respectively. These two plans consisted merely of a change in position of the rows of the Plan I baffles (see Plate 40). As shown on Photographs 76, 80, and 81, the results obtained with Baffle Plans I, M, and N were quite

similar. Pressures observed on ten baffles of Plan N are given in Table G. Comparison of these pressures with those presented in Table F shows that both positive and negative pressures on the upstream baffles were more intense as a result of the greater velocity of flow down the narrower Plan O chute. The pressures on the downstream baffles of Plan N, however, were less intense than those of Plan A due to the greater decrease in velocity in this area; thus showing the greater efficiency of the Plan N baffles. Again, cavitation was indicated on the downstream faces of the upstream row of baffles.

98. Baffle Plan O (Test 24): In a further effort to increase the efficiency of the baffle system, the Plan N baffles were increased in height from 4.25, 6.38, and 8.5 ft. to 6.0, 9.0, and 12.0 ft. (see Plan O baffles on Plate 41). Photographs 81 and 82 show that flow conditions in the stilling basin at 45 000 c.f.s. were much the same as with the Plan N baffles. With the Plan O baffles, however, a stable jump was obtained for all flows up to 55 000 c.f.s. (see Photograph 116). It was observed that the upstream, middle, and downstream rows of baffles successively were exposed by flows of 60 000, 65 000, and 70 000 c.f.s. With the 95 400-c.f.s. flow, shooting flow occurred through the stilling basin and some spray overtopped the downstream ends of the sidewalls. Comparison of pressures given in Table H with those of Table G shows that, for the most part, raising the baffle height raised the pressures, i.e. increased the positive pressures and decreased the negative pressures. Pressures on the downstream faces of the upstream row of baffles indicated that cavitation would occur at these points in the prototype structure during the higher flows. Water-surface elevations and velocities observed in the stilling basin with the Plan O baffles are given on Plates 43 to 46, while water-surface cross sections from sta. 12+50 to sta.

16+00 for the 45 000-c.f.s. and 95 400-c.f.s. discharges are given in Plate 47. The high ridge of spray in the center of the stilling basin can be noted at sta. 13+00 and sta. 13+50 on this last plate. No difference in stilling basin action was observed by regulating the tailwater according to curve E on Plate 4.

99. Baffle Plan P (Test 25A): Test 25A featured a curved crest and a dish-shaped chute as shown on Plate 30. With this spillway design, the end baffles of the two upstream rows of Plan O were observed to cause overtopping of the left sidewall for discharges of 70 000 c.f.s. and greater. As a result of several trial revisions of Baffle Plan O, it was found that this overtopping of the left sidewall could be eliminated for all discharges by reducing the height of the first and second baffles at the left end of the upstream row and the left end baffle of the middle row. This baffle arrangement constituted Plan P and is shown on Plate 41.

100. Flow conditions in the stilling basin were generally the same as those observed with Baffle Plan O. Photograph 83 illustrates the 45 000-c.f.s. flow. Pressures on various baffles of Baffle Plan P are given in Table I, and, in general, they were decreased from those obtained with the Plan O baffles (see Table H).

101. Pressure data obtained so far on the baffle piers include observations taken on the vertical and sloping faces only. To supplement these data and obtain a better idea of the pressure distribution on the individual baffle piers, baffle A (see sketch on Table I) was replaced by a similar baffle with piezometer taps located as shown by sketch on Table J. Baffle A was selected because the greatest negative pressures had been observed heretofore at this location. Table J shows that the greatest negative pressures occurred along the upstream edge of the side faces with successively

less intense negative pressures being effected on the top and sloping faces of the baffle. These pressures were obtained in the usual manner by means of an open-manometer tube and represent average values only. These pressures fluctuated from as little as ±0.3 ft. to as much as ±23.5 ft. from the pressures given in Table J. Taking into consideration such fluctuations and the limit of -20 ft., the pressures observed indicated that cavitation would occur on baffle A when flow reached approximately 22 000 c.f.s. It was believed that by slightly rounding the upstream edges of the baffle piers, the high negative pressures might be alleviated without affecting the efficiency of the baffles to any great extent.

102. Summary - Baffle Plans: The results of the tests made with the various baffle arrangements in the stilling basin are summarized as follows:

a. The originally-designed baffles effected a satisfactory hydraulic jump in the stilling basin for flows up to 31 000 c.f.s. At higher discharges, flows overrode the baffles and spray overtopped the right sidewall of the stilling basin.

b. Testing with Baffle Plans A to F, inclusive, and L indicated that effective stilling basin action could not be accomplished with two rows of baffles.

c. The "stepped" baffles of Plan C were less effective than the baffles of the original design.

d. Three rows of baffles, graduated in size and placed with their vertical faces upstream, effected the best stilling basin action for all flows. Baffle Plans I, M, and N were found to be the most effective for the 100-ft. radius, intersecting-planes, and 50-ft. radius buckets, respectively.

e. The addition of a fourth row of baffles, as in Plan H, contributed nothing to the effectiveness of stilling basin action.

f. Attempts to create better energy distribution in the stilling basin by the skewed arrangements of Plans J and K were unsuccessful. These arrangements decreased the effectiveness of the baffles without effecting the energy distribution.

g. Baffle Plans O and P produced the best results in connection with the straight and curved crest alignment, respectively. A hydraulic jump was observed to occur for all discharges up to 55 000 c.f.s. With Baffle Plans O and P, negative pressures, indicating the occurrence of cavitation, obtained on the sloping faces of the baffles in the upstream row for discharges of 70 000 c.f.s. and greater.

h. Supplemental investigation of the pressures on the sides and top of a single baffle pier in the upstream row showed that cavitation tendencies existed in these areas for discharges of 22 000 c.f.s. and greater.

It was concluded that Baffle Plan P effected the best results in conjunction with Crest Plan X and Chute Plan P.

Floor Elevation

103. Although lowering the stilling basin floor elevation from 712.0 ft. of the original design would prove very costly in the prototype structure, a study was made (Test 15) to determine what benefits might be derived from such a change. Rather than make the extensive changes involved in actually lowering the model stilling basin floor, the tailwater was increased to approximate the effect of such a change. It was determined that it would be necessary to lower the floor elevation about 6 ft. for every 10 000-c.f.s. increase in discharge for which a hydraulic jump would occur in the stilling basin. The benefits derived from such a change were considered entirely uneconomical and no further study was made with regard to lowering the stilling basin floor.

End Sill

104. During previous tests, it was observed that a hydraulic jump occurred in the stilling basin with no baffles for all flows up to 25 000 c.f.s. and with Baffle Plan I for all flows up to 45 000 c.f.s.; higher

flows passed through the stilling basin with little decrease in velocity and dissipation of energy. Since the portion of the tailbay downstream from the stilling basin is composed of solid rock, it was therefore desired to determine if some type of curved or inclined end sill would "flip" these higher discharges over the area immediately downstream from the end sill so as to avoid endangering the structure. If all flows greater than 25 000 c.f.s. could be successfully passed over the end sill, the necessity for baffles in the stilling basin would be precluded. Due to the fluctuating pressures observed on the end sill, the limit of interpretation was placed at -20 ft. as was done in the analysis of baffle pressure data.

105. End Sill Plan A (Tests 13A and 13J): The details of the Plan A end sill (original design) are shown on Plates 5 and 42 and in Photographs 9 and 10. As previously stated (Paragraph 96 a), a satisfactory jump was formed without baffles in the stilling basin for discharges up to 25 000 c.f.s. For higher discharges the original end sill caused the major portion of the flow to be deflected upward with the remaining portion rolling back upstream. Photograph 67 shows flow conditions during a discharge of 45 000 c.f.s. Pressures observed on the end sill for discharges of 45 000 c.f.s., 70 000 c.f.s., and 95 400 c.f.s. are given in Table K. These pressures show that there was no tendency for flow to spring from the end sill as no negative pressures were observed thereon.

106. With the Plan I baffles (see Plate 40) installed in the stilling basin (Test 13J), a stable jump obtained for discharges up to 45 000 c.f.s. as shown by Photograph 76. The results effected by this arrangement were given in Paragraph 96 i. Pressures on the end sill observed during this test are given in Table K and indicated a lesser tendency for the flow to spring clear of the end sill than was observed with no baffles in the

stilling basin.

107. <u>End Sill Plans I to VI (Test 16)</u>: The details of End Sill Plans I to VI are shown on Plate 42. The results obtained with these revisions in the end sill design are given in the following subparagraphs:

a. <u>End Sill Plan I With No Baffles (Test 16B)</u>: With the Plan I end sill, no hydraulic jump was obtained in the stilling basin for flows greater than 18 500 c.f.s., since the inclined face of this end sill offered less resistance to flow than did the vertical face of the originally-designed end sill. With higher discharges, the flow was deflected to some extent beyond the end sill. As shown in Photograph 84, the concentration of flow in the center and right side of the stilling basin was quite pronounced. Due to the greater mass of water, the end sill was not very effective in deflecting flow from this part of the stilling basin. This condition is emphasized by comparing the pressures observed on the end sill which were all positive and were highest on the center and on the right side (see Table K).

b. <u>End Sill Plan I With Baffle Plan I (Test 16A)</u>: With this arrangement, flows of 45 000 c.f.s. and greater were deflected over the end sill by the baffles. Furthermore, no hydraulic jump could be obtained in the stilling basin for the 45 000-c.f.s. discharge due to the lessened baffling effect of the end sill. From these observations, it was apparent that the Plan I end sill was not only ineffective in flipping the higher discharges downstream therefrom with baffles in the stilling basin, but it reduced the efficiency of the stilling basin as an energy dissipator at the lower discharges.

c. <u>End Sill Plan II With No Baffles (Test 16C)</u>: With this end sill, an effort was made to deflect the flow more satisfactorily by decreasing the slope on the upstream face of the end sill (see Plate 42). The results obtained with the Plan II end sill were very unsatisfactory. The maximum discharge for which a hydraulic jump would occur in the stilling basin was 16 600 c.f.s. Flow conditions at the 95 400-c.f.s. discharge are shown in Photograph 85. At this discharge, the flow overrode the end sill with practically no upward deflection. As shown by Table K, negative pressures indicative of cavitation were observed on the end sill. These negative pressures showed that a strong tendency existed for the flow to spring clear of the end sill, but lack of aeration prevented such flip action.

d. <u>End Sill Plan III With No Baffles (Test 16D)</u>: The Plan III end sill was designed with a concave upstream face to provide a smoother transition and a steeper slope than the Plan II end sill. Observations made with flows up to 70 000 c.f.s. revealed that, although no extension of the range of the hydraulic jump was effected, the Plan III end sill was more effective in producing the desired flip action. At the 95 400-c.f.s. discharge, the results obtained with Plan II and Plan III end sills were similar (compare Photographs 85 and 86). As recorded in Table K, negative pressures observed on the end sill were slightly less than those effected by the Plan II end sill.

e. <u>End Sill Plan III With Baffle Plan I (Test 16G)</u>: With this arrangement, the maximum discharge at which a jump obtained in the stilling basin was 35 000 c.f.s. For all discharges greater than 35 000 c.f.s., flow conditions were similar to those effected by the combination of the Plan I end sill and Plan I baffles. Reference to Table K shows that for discharges of 70 000 and 95 400 c.f.s., the pressures observed were similar for the two combinations of end sills and baffles, but that pressures observed with Plan III end sill and baffles for the 50 000-c.f.s. discharge were considerably higher.

f. <u>End Sill Plan IV With No Baffles (Test 16E)</u>: In order to obtain better deflection of flow at the higher discharges, the upstream face of the Plan IV end sill was designed with a shorter radius of curvature than was used for the Plan III end sill (see Plate 42). The results observed with this design were very similar to those obtained with the Plan I end sill. The flow was deflected upward and downstream to about the same extent for both end sill designs. The observed pressures (see Table K) were positive and were slightly greater than those observed with the Plan I end sill. Photograph 87 shows the slightly greater tendency of the flow to adhere to the end sill, as indicated by the pressures.

g. <u>End Sill Plan IV With Baffle Plan I (Test 16F)</u>: With this combination of end sill and baffles, the highest discharge at which a hydraulic jump could be obtained in the stilling basin was 40 000 c.f.s. For the higher discharges, the Plan IV end sill had little effect as the major portion of the flow was deflected over the end sill by the baffles. Reference to Table K shows that the pressures were similar to those observed with End Sill Plans A and I with baffles.

h. End Sill Plan V With Baffle Plan I (Test 16H): The results recorded in Subparagraphs a to g above indicated that any addition made to the original end sill (Plan A) below elevation 725.0 ft. was not effective in producing the desired flip action in conjunction with Baffle Plan I. In addition all end sills tested had lowered the maximum discharge at which a hydraulic jump obtained in the stilling basin. It was believed that, if the end sill were raised to some elevation higher than 725.0 ft. and a sloping face added on the upstream side, it might be effective in deflecting some of the flow that overrode the baffles on the higher discharges. The results of several trial revisions showed that the end sill could not be raised above elevation 729.0 ft. without submerging the tunnel outlet. Accordingly, the Plan V end sill (see Plate 42) was installed. Operation revealed that the Plan V end sill was not effective in deflecting the higher flows, because the baffles still deflected the flow above the end sill as with the previous plans tested. It was found, however, that a jump obtained in the stilling basin with baffles for discharges up to 50 000 c.f.s. These results showed that the end sill could not be raised high enough to induce the desired flip action without interfering with tunnel flow by submerging the outlet.

i. End Sill Plan VI With Baffle Plan I (Test 16I): For this end sill design, that part of the Plan V end sill upstream from sta. 13+85 was removed. During a tunnel discharge of 5000 c.f.s. with the pool at 832.0 ft., open-channel flow existed with an approximate 9.0-ft. depth of flow at sta. 11+50, and no tendency for a shift to full-tunnel flow was observed. For spillway discharges up to 55 000 c.f.s., a stable hydraulic jump obtained in the stilling basin. For the higher discharges, flow conditions in the stilling basin were similar to those of previous end sill tests with the Plan I baffles.

108. Summary - End Sill Plans: The results of the end sill study are summarized as follows:

a. No end sill design tested was effective in producing a jump without baffles for discharges in excess of 25 000 c.f.s. The original design, Plan A, was the most efficient in this respect.

b. With the end sill at elevation 725.0 ft. and with baffles in the stilling basin, no revision in the front face of the end sill was effective in producing flip action at discharges exceeding 45 000 c.f.s. Furthermore, any revision under these conditions lowered the efficiency of the stilling basin in dissipating the energy of flow for discharges of less than 45 000 c.f.s.

c. With the end sill at elevation 725.0 ft. and no baffles in the stilling basin, End Sill Plans II and III developed a tendency toward flip action (as indicated by negative pressure observations), but lack of aeration at the end sill prevented such action.

d. It was found that the elevation of the end sill could not be raised sufficiently to permit aeration and effect consequent flip action without adversely affecting the tunnel flow.

e. Raising the elevation of the end sill to 729.0 ft. (Plans V and VI) with baffles in the stilling basin increased the maximum discharge at which jump action obtained. With the Plan VI end sill, the hydraulic jump was satisfactory at a discharge of 55 000 c.f.s.

109. Although the Plan VI end sill with baffles successfully induced jump action in the stilling basin for discharges up to 55 000 c.f.s., the Sill Plan A (original design) involving less construction cost was recommended for the final design, because the design criteria of jump action for discharges up to 45 000 c.f.s. and no undesirable spray action for the higher discharges were satisfied.

Tailbay

110. Although it was realized that the area of the model tailbay was insufficient to permit exact simulation of the hydraulic conditions which

will obtain downstream from the dam as a result of spillway flow, the determination of approximate data on scour tendencies downstream from the end sill, current directions throughout the model tailbay, and velocity of flow and wave heights at the toe of the dam were nevertheless requested. It should be realized therefore that the following information should be interpreted as indicative only of the hydraulic flow conditions which will occur in the prototype tailbay. As mentioned in Paragraph 19, the tailbay topography was revised (Plan B) to simulate more accurately this area after construction of the project. The tailwater was regulated according to curve D on Plate 4.

Scour Tendencies

111. Erosion tests were made to investigate the tendency for scour downstream from the stilling-basin end sill. Inasmuch as it was impossible in the model to simulate quantitatively the resistance to erosion of the prototype material, the scour observed during these tests is only an indication that scour is likely to occur at corresponding points in the prototype. To obtain sufficient movement of the material within reasonable time the size of the bed material used varied with the discharge simulated. That part of the model downstream from the end sill in which the scour effect was observed is shown as the movable bed area on Plate 3. The area extended downstream from the end sill to about sta. 17+00. Prior to each scour determination, the topography of the movable bed was molded to conform with the Plan B topography. The design status of the other features of the model as used for the scour determinations is shown in Table A.

112. Bed Material, 1/8-Inch Gravel (Test 19C): The scour effect of 5000-c.f.s. discharge (tunnel or spillway flow) was first observed with 1/8-inch gravel as the movable bed material. Operation showed very little

movement of the bed material resulted from this flow. In general, slight scour was evident near the ends of the end sill for spillway flow and on centerline at about sta. 14+05 for tunnel discharge.

113. Bed Material, Sand (Test 19E): To obtain more bed movement and a better indication of scouring tendencies for 5000-c.f.s. flow, the movable bed area was molded in sand. The material eroded from the movable bed was deposited in a similar pattern for both tunnel and spillway flows. During the one-hour (model) run with a spillway discharge of 5000 c.f.s., the maximum tendency for scour during the first part of the run was just downstream from the right and left ends of the end sill. Later in the run, the maximum tendency for scour shifted to the centerline and occurred in the area just downstream from the end sill at about sta. 14+05. Plate 49 shows the scour pattern effected with sand as the bed material for the 5000-c.f.s. tunnel flow. At the beginning of this run, which was also operated for one hour (model), the maximum tendency for scour was on centerline and just downstream from the end sill. After about 20 minutes (model) of operation, the maximum movement of material took place in the areas just downstream from the right and left ends of the end sill. The scour patterns at the end of the spillway and tunnel flows were therefore similar.

114. Bed Material, 1/4-Inch Gravel (Test 19A): With the movable bed molded with 1/4-inch gravel, runs of one-hour (model) duration were made with spillway flows of 10 000 c.f.s. and 20 000 c.f.s. Scouring tendencies were observed to be similar for the two flows. Due to the size of the bed material, the movement effected by the 10 000-c.f.s. flow was slight; however, it was observed that most of the scour occurred during the first 15 minutes (model) of the run with initial erosion taking place just downstream from each end of the end sill. Maximum scour subsequently occurred between these

points at about sta. 14+00. The scour pattern effected by the 20 000-c.f.s. flow is shown on Plate 50. The scour occurred in the same manner as was observed with the 10 000-c.f.s. flow with the major part of the erosion taking place during the first 20 minutes (model) of operation. Reference to Plate 50 shows the maximum depth of scour at sta. 14+30.

115. Bed Material, 1/2-Inch Gravel (Test 19B): To offer greater resistance to the higher flows, the movable bed was molded of 1/2-inch gravel. Plate 51 shows the scour pattern that resulted from a one-hour (model) run with a spillway discharge of 45 000 c.f.s. For the first two minutes (model) of the run, the hydraulic jump was satisfactory; however, during this time sufficient material had eroded just downstream from the end sill to lower the tailwater and cause the jump to break partially on the right side of the stilling basin. The scouring action continued throughout the run. Reference to Plate 51 shows that the maximum tendency for scour was about 40 ft. left of centerline at sta. 14+15. A short run (15 minutes model) was made with a flow of 70 000 c.f.s., but the bed material was not heavy enough to give a satisfactory scour pattern at this discharge. The results, however, indicated that the maximum scouring tendency would be located closer to centerline and farther downstream than was observed with the 45 000-c.f.s. flow.

116. Bed Material, 1-Inch Gravel (Test 19D): With the movable bed area molded with 1-inch gravel, runs of one-hour (model) duration each were made with spillway discharges of 70 000 and 95 400 c.f.s. The resulting scour pattern effected by the 70 000-c.f.s. flow showed that the maximum scouring tendency was on centerline at about sta. 15+10 and that very little scouring tendency existed adjacent to the end sill. As shown on Plate 52, at the end of the run with the 95 400-c.f.s. spillway flow, the bed material had eroded

to the concrete floor (elevation 700 ft.) of the movable bed area downstream from sta. 14+80.

117. Summary - Scour Tendencies: The foregoing scour tests are summarized as follows:

a. For the lower spillway flows (below 45 000 c.f.s.) at which a hydraulic jump obtained in the stilling basin, initial erosion took place just downstream from the right and left ends of the end sill; after these two points had scoured to some extent, the tendency for erosion shifted toward the centerline.

b. With the 45 000-c.f.s. discharge, initial erosion just downstream from the end sill lowered the tailwater sufficiently to cause a partial breaking of the hydraulic jump.

c. For the higher discharges (above 45 000 c.f.s.), when no jump occurred in the stilling basin, the maximum tendency for scour was greater and occurred farther downstream than with the lower discharges; the scour tendency just downstream from the end sill was relatively small compared to the maximum scour.

d. With a tunnel discharge of 5000 c.f.s., the initial scour occurred on the centerline just downstream from the end sill; after considerable erosion had taken place at this point, the scouring tendency shifted to areas just downstream from the right and left ends of the end sill.

Current Directions

118. Surface currents in the model tailbay for discharges of 45 000 c.f.s. and 95 400 c.f.s. are presented on Plate 53. The current directions were sketched from visual observation of the movement of confetti on the tailbay water surface during Test 20. Although the currents were probably affected to a considerable extent by the limits of the model tailbay and the position of the tailgate, it is believed that they are an approximation of the currents to be expected in this area in the prototype. Observations indicated that the slack water area to the left of the stilling basin cen-

terline at approximately sta. 22+00 and the eddy just downstream to the left of the end sill existed for all discharges.

Conditions at Toe of Dam

119. The following table presents the extent of wave action at the toe of the dam and the maximum subsurface velocities parallel thereto which were observed during Test 24. The data, due to the limits of the model tailbay, can only be considered as approximate.

Spillway Discharge c.f.s.	Tailwater Elevation ft.	Wave Height Above T.W. Elev.		Maximum Velocity ft./sec.
		Maximum ft.	Minimum ft.	
15 000	730.3	+ 2.2	- 0.8	3
45 000	737.6	+ 3.4	- 0.6	6
70 000	740.2	+ 8.8	- 1.7	7
95 400	742.1	+11.9	- 1.1	15

For discharges of 45 000 c.f.s. and less, the two areas along the toe of the dam affected by wave action were small; one area was located just to the left of the stilling basin wall, and the other area was located between the two eddies. As the discharge increased, these areas became larger, until at the 95 400-c.f.s. discharge, wave action was observed along the toe of the dam from the stilling basin to the left edge of the tailbay. The maximum velocities given in the above table were observed along the toe of the dam about opposite spillway sta. 18+00.

Outlet Works

120. The essential features of the outlet works were the outlet tower,

tunnel elbow, 15.5-ft. diameter tunnel, and tunnel outlet (see Photographs 88 to 91 and Plates 54 and 55). In addition to these features, the original design incorporated a tunnel vent at sta. 6+03.50, while the final design included a lip-venting arrangement supplementary to the tunnel vent. Although the above plates show the final design of the outlet works in connection with the final spillway design, the only changes made in the design of the original outlet works were revisions in the design of the tunnel vent and tunnel outlet and in the addition of the lip vents. The only feature of the final spillway design which would affect the operation of the tunnel was the revised baffle arrangement.

121. The design plan of operation of the outlet works was to limit the tunnel flow to a maximum of 5000 c.f.s. for all pool elevations up to 833.0 ft. so as to insure open-channel flow in the tunnel at all times; it is not planned to operate the tunnel when spillway flow occurrs. Although full-tunnel flow in itself would not be undesirable, the positive bore action* which would occur when changing from open-channel to full-tunnel flow might prove destructive to the structure.

Outlet Tower

122. As shown on Plate 55 and in Photographs 5 and 80, the control features of the outlet tower consisted of four 7.0-ft. x 9.0-ft. intake ports and a 17.0-ft. diameter vertical-lift cylinder gate to admit flow into the 15.5-ft. tunnel. A 7.0-ft. x 9.0-ft. emergency gate was provided for each port. The purpose of the tests on the outlet tower was to investigate the

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* Bore: A moving direct hydraulic jump; a positive bore results in flow at greater than critical depth, while a negative bore results in flow at less than critical depth.

hydraulic characteristics of the intake ports and to rate the cylinder gate.

123. Intake Ports (Test 2A): The design of the intake ports was found to be satisfactory in that all pressures observed in the ports (piezometers 78 to 81 and 83 to 85) were positive as well as the pressures in the emergency gate slots (piezometer 82). These pressures for the original outlet works design are listed in Tables M and N while Tables P, Q, and R present pressures at these points for various revisions of the outlet works design. The average distribution of inflow between the intake ports was about equal; the downstream and right side ports each passed about 26 percent of the flow and the upstream and left side ports passed about 23 and 25 percent of the flow, respectively. The pattern of flow entering the ports is shown by Photograph 89. Vortex action over the intake ports was observed with the cylinder gate 1/2, 3/4, and full open for all pool elevations between 760.0 ft. and 833.0 ft. With gate 1/4 open, vortex action obtained with pool elevations from 760.0 ft. to 800.0 ft. This action was slight under all conditions and no air was entrained into the ports.

124. Cylinder Gate (Tests 2A and 29): The 17.0-ft. cylinder gate was rated in the 1/4-, 1/2-, 3/4-, and full-open positions for pool elevations up to 833.0 ft. The tailwater was regulated according to curve D on Plate 4. Since changes made in the tunnel air vent design modified the cylinder gate rating curves, discussion of these curves for both the original design (Test 2A) and the final design (Test 29) are presented in the following subparagraphs:

a. Original Design: Inspection of the rating curves on Plate 56 shows that for discharges above 5000 c.f.s. with the cylinder gate 1/2, 3/4, and full open, open-channel and full-tunnel flow occurred depending on the pool elevation and whether the pool was rising or falling. Open-channel flow occurred on a rising stage up to a certain pool elevation (indicated by a horizontal line on the rating curves) where a positive bore occurred to fill the tunnel. When full-tunnel flow obtained, it was necessary to lower the pool to some elevation between 778 and 768 ft. in order to create a slow-moving negative bore that would result in open-channel flow in the tunnel. It will be noted that when full-tunnel flow occurred with the cylinder gate full open, a smaller discharge obtained than with the cylinder gate 3/4 open. This was probably due to the fact that smoother inflow occurred with the cylinder gate 3/4 open and the flow which passed under the edge of the gate was deflected directly into the tunnel. On the other hand, when the gate was full open, flow from the ports met "head-on", and greater turbulence was developed with consequent greater head loss and smaller discharge. Comparison of the water-surface elevation in the tower at pool elevation 832.0 ft. with the cylinder gate 3/4 and full open (Table N) gives further evidence of this greater head loss and turbulence in the tower with the cylinder gate full open. It should be noted from the rating curves that open-channel flow was observed to occur at all pool elevations for discharges within the proposed operating range (5000 c.f.s. and less).

b. Final Design: The rating curves obtained with the final design are shown on Plate 57. In comparing these curves with those obtained with the original design (see Plate 56), several improvements in operating characteristics are apparent. Open-channel flow occurred for all discharges up to 6900 c.f.s. in the tunnel on both rising and falling pool stages up to elevation 833.0 ft. for the gate 1/4 and 1/2 open and up to pool elevations 805.0 ft. and 800.0 ft. for the gate 3/4 and full open, respectively. The change from open-channel flow to full-tunnel flow for the latter two gate openings occurred smoothly through a transition stage of pool elevations shown as unstable areas on Plate 57. It will be noted that the discharges for the 3/4 and full gate openings were less than with the original design and that the discharge increased rather than decreased when the gate opening was changed from 3/4 to full open.

125. Tower Water-Surface Elevation (Test 29): Plate 58 shows the elevation of the water surface in the tower as observed with various gate openings and at various pool elevations plotted against discharge. These points gave

a fairly smooth curve regardless of gate opening. Such a condition was to be expected since both the discharge through the tunnel and the head in the tower are functions of the velocity head at the tunnel lip. Hence, gaging of the tower water-surface elevation will serve to indicate the discharge passing through the outlet works.

126. Summary - Outlet Tower: The above study of the outlet tower is summarized as follows:

a. Approximate even distribution of flow into the intake ports obtained at all times. Slight vortex, which entrained no air, was observed over the ports.

b. No undesirable pressures were observed in the intake ports or emergency gate slots.

c. With the original design: open-channel flow occurred for all discharges less than 5000 c.f.s.; under certain conditions during greater discharges tunnel bore action occurred and effected full-tunnel flow; and the cylinder gate effected no control on the flow when opened beyond the 3/4-open position.

d. With the final design: open-channel flow occurred for all discharges below 6900 c.f.s.; full-tunnel flow was observed with the 3/4- and full-open position to occur slowly and with no evidence of tunnel bore action; and opening the cylinder gate from the 3/4- to full-open position increased the discharge.

Tunnel Elbow

127. The tunnel elbow was designated as that part of the outlet works between the base of the outlet tower and nearly horizontal section of the outlet tunnel. The lip of the tunnel elbow refers to the curved transition between the P.C. of the elbow and the base of the outlet tower. For tests on the tunnel elbow, features of the model were as shown in Table A. In addition, the tunnel outlet used with Elbow Plans A, B, and C was the final tunnel outlet (Plan K); the design of the Plan D elbow necessitated a slight revision in the tunnel outlet (Plan L). The purpose of the tests on the

tunnel elbow was: (1) to investigate the hydraulic characteristics of the originally-designed elbow (Plan A); and (2) to study the hydraulic characteristics of different elbow plans designed to eliminate any undesirable phenomena observed with the originally-designed tunnel elbow. Data were purposely taken with discharges and pool elevations outside the operating range so as to obtain complete information.

128. Tunnel Elbow Plan A (Test 2A): The Plan A tunnel elbow (original design) shown on Plates 55 and 59 and in Photographs 5 and 90 featured a sharply-curved conduit from the outlet tower into the horizontal tunnel. A tunnel air vent (Plan A) at sta. 6+03.50 as shown on Plate 65 was used in testing this elbow plan.

129. As a result of the sharp curvature, considerable turbulence was observed in the elbow and negative pressures indicative of cavitation were developed at piezometers 87 and 88 with either the tunnel vent open or closed (see Tables M and N). For the most part, however, these excessive negative pressures occurred during operation with discharge in excess of the limiting flow of 5000 c.f.s. Negative pressures at the P.T. of the elbow (piezometers 90 to 93) were slight for flows less than 5000 c.f.s.

130. Tunnel Elbow Plan B (Test 25B): In an effort to reduce the high negative pressures and turbulent flow conditions which were observed with the Plan A elbow, curved fins were installed in the elbow to guide the flow smoothly into the tunnel. After some preliminary investigation as to length, number, and placing of the fins, the Plan B elbow (see Plate 59 and Photograph 8) was designed.

131. With this fin installation in the model elbow, open-channel flow obtained in the tunnel for all gate openings and pool elevations up to 833.0 ft. The reduction in discharge which occurred when the cylinder gate

opening was increased from 3/4 to full open without the fins (see Table N) was not observed with the fins (see Table O); in fact, no difference could be ascertained between the rating curves for the 3/4- and full-open gate. Although not shown in Tables N and O, open-channel discharge with the finned elbow was slightly greater than was observed without the fins. This improvement in operating characteristics was due, no doubt, to the fact that the fins guided the flow around the elbow in such a manner that turbulence and splashing were largely eliminated. Comparison of the pressures observed without fins (Table N) and with fins (Table O) shows that the excessive negative pressures at piezometer 88 were eliminated by the fins with the gate 1/2 open and were considerably reduced with the gate 3/4 and full open. Pressures at piezometers 86, 87, and 89, however, were lowered to the extent that a possibility of cavitation was indicated at piezometers 87 and 89 for the 1/4- and 1/3-open gate at the 832.0-ft. pool.

132. Tunnel Elbow Plan C (Test 26): The Plan C elbow (see Plate 59 and Photograph 8) was designed to effect full-tunnel flow for all gate openings and pool elevations. If such operation could be achieved, the benefit would be twofold: increased tunnel efficiency would permit a decrease in tunnel diameter; and limitations placed on the height of the end sill by open-channel flow in the tunnel could be removed (see Paragraph 107 h). In addition, the longer radius of curvature of the elbow might cause a reduction in the negative pressures previously observed at the lip of the elbow.

133. Comparison of discharges for corresponding pool elevations and gate openings listed in Tables N and O shows that the Plan C elbow was slightly less efficient than either the Plan A or B elbows with the gate 1/4 open, was just as efficient at the 1/3 gate opening, and was more efficient at the 1/2, 3/4, and full gate openings. The tunnel was observed to

flow full for the 1/3 gate opening at pool elevation 832.0 ft. and for all pool stages with gate openings of 1/2 or larger. Open-channel flow obtained, however, with the gate 1/4 open. Air was entrained through the cylindrical gate into the tunnel for all pool elevations with the 1/2 gate opening or less, and a small amount of air was entrained with the 3/4 gate opening at low pool elevations. At pool elevations of 770.5, 800.0, and 832.0 ft. with the gate 1/4 open and at pool elevation 770.5 ft. with the gate 1/2 open, a large part of the entrained air surged back upstream along the inner side of the tunnel elbow. The pressures observed in connection with the Plan C elbow are presented in Table O. Comparison of these pressures with those observed with the Plan A elbow (Table N) and the Plan B elbow (Table O) shows that no material improvement in pressures was observed and that in some cases outside the operating range, pressures were less satisfactory at piezometers 88 and 89.

134. Tunnel Elbow Plan D (Test 27): In a further effort to obtain full-tunnel flow at all pool stages and gate settings and at the same time effect a reduction in the negative pressures existing at the lip, Plan D elbow (see Plate 59 and Photograph 8) was designed with a long radius bend and an increased radius of curvature at the lip. With this elbow the tunnel sloped upward on a 0.01169 slope to the floor of the stilling basin which made some changes necessary in the shape of the tunnel outlet. The flare of the walls of the tunnel outlet, however, remained as with Plans A, B, and C elbows. No air vent was used with this elbow design.

135. The desired full-tunnel flow under all conditions of operation could not be obtained. With the cylinder gate 1/4 open and the pool at 770.5 ft., the vertical elbow was flowing part full with a hydraulic jump at the P.T. of the elbow. Downstream from the P.T., the tunnel flowed full

except for air (entrained through the tower) flowing along the tunnel roof. As the pool elevation reached 777.0 ft., the hydraulic jump moved downstream until by the time the pool had reached elevation 787.0 ft., the hydraulic jump had moved to the downstream end of the tunnel and open-channel flow obtained throughout the tunnel. Open-channel flow also obtained with the cylinder gate 0.3 open at pool elevation 833.0 ft. The tunnel flowed full for pool elevations up to 833.0 ft. with the 1/2, 3/4, and full gate openings. Air was entrained with the gate 1/2 open, but no air was entrained with the 3/4 and full gate openings. For all discharges at which air was entrained into the tunnel elbow, some turbulence was caused at the tunnel outlet (which was completely submerged) by the escape of the entrained air. Comparison of discharges obtained with the various elbow plans (see Tables N, O, and P) shows that the Plan D elbow was the most efficient and that no difference in discharge occurred between the 3/4 and full gate openings. Comparing pressures observed at the lip (piezometers 86 to 89) for Plan D elbow (Table P) with those observed with Plans A, B, and C (Tables N and O) shows that increasing the radius of the lip for the most part increased rather than decreased the negative pressures in this region for discharges within the operating range (5000 c.f.s. or less), although for the higher discharges considerable improvement in the pressures is shown. In comparing tunnel pressures observed with the Plan A elbow (Table N) and the Plan D elbow (Table P), it will be noted that greater negative pressures obtained in the downstream end of the tunnel with the latter elbow at the 3/4 and full gate openings with pool elevation 832.0 ft., thus indicating that the hydraulic grade line had dropped below the tunnel invert.

136. Summary - Tunnel Elbow Plans: The results obtained with the four elbow plans are summarized as follows:

a. Although extreme turbulence obtained in the originally-designed elbow, no excessive negative pressures and open-channel flow were observed for all discharges within the operating range. For discharges above the maximum limit of 5000 c.f.s., negative pressures indicative of cavitation were created at the lip of the elbow.

b. Fins installed in the elbow effected open-channel flow for all gate openings and stages of the pool up to 833.0 ft. and reduced excessive negative pressures on the lip of the elbow.

c. Increasing the radius of curvature of the elbow as in Plans C and D was considered unsatisfactory, as both open-channel and full-tunnel flow were obtained within the proposed range of operation.

It was concluded that the finned elbow (Elbow Plan B) was the most satisfactory of the elbow plans tested. Subsequent air vent tests showed, however, that it was not necessary to place fins in the elbow to effect open-channel flow in the tunnel and that Tunnel Elbow Plan A was satisfactory.

15.5-Ft. Tunnel

137. The alignment of the 15.5-ft. tunnel shown on Plate 54 remained the same throughout all tests, except for Tunnel Elbow Plan D when the longer radius of that elbow necessitated sloping the tunnel upward rather than downward to the outlet. The tunnel diameter remained unchanged since attempts to increase the tunnel discharge by inducing full-tunnel flow were unsuccessful (see Tunnel Elbow Plans C and D), and since testing of Tunnel Elbow Plan B showed that with proper elbow design, open-channel flow would exist for all gate openings and pool elevations up to 833.0 ft. The transition section between sta. 11+49.96 and sta. 11+99.96 also remained the same throughout all tests.

138. To ascertain the effect of horizontal curvature on flow in the tunnel, the height of the water surface above the invert was observed for

various pool elevations and cylinder gate openings. These data taken with the outlet works as originally designed (except for the tunnel outlet) are given in Table L. The pool elevations and cylinder gate openings were selected so that open-channel flow obtained in the tunnel. The extent of the horizontal curve (sta. 7+13.11 to sta. 9+71.46) is shown by the depressed water surface along the left wall and the raised water surface along the right wall. The maximum superelevation of flow varied from 3.0 ft. at sta. 9+50 with the gate 1/4 open and the pool at elevation 770.5 ft. to 8.0 ft. at sta. 7+50 with the cylinder gate 1/2 open and the pool at elevation 825.0 ft. In general from the data observed, the superelevation of flow was greater and the maximum superelevation occurred closer to the P.C. of the curve (sta. 7+13.11) as the discharge increased. The superelevation of the water surface in the tunnel was measurable in most cases to sta. 11+00 and in some cases to sta. 11+50.

Tunnel Outlet

139. The purpose of the tests on the tunnel outlet was to develop a tunnel outlet design that would distribute tunnel flow throughout the stilling basin without adversely affecting spillway discharge into the stilling basin. In addition, it was desired that the alignment of the outlet be satisfactory from a construction standpoint. The various tunnel outlet plans tested are shown on Plates 60 and 61 and in Photographs 92 to 102, inclusive. Flow conditions in the stilling basin for a tunnel discharge of 5000 c.f.s. at pool elevation 832.0 ft. are shown in Photographs 103 to 113, inclusive.

140. Tunnel Outlet Plan A (Tests 11, 13H, and 17G): Tunnel Outlet Plan A (original design), as shown on Plate 60 and in Photograph 92, was formed by the intersection of the inverted U-shaped tunnel section and the spillway

chute and stilling basin bucket with no divergence or flaring of the sidewalls.

141. Prior to the time at which a detailed study was made of the tunnel outlet, spillway flow passing down the chute and over the open tunnel outlet was observed to drop to the floor of the tunnel and rebound in such a manner as to create undesirable spray action in the stilling basin. To reduce such spray action, two types of "eyebrows" placed on the chute sloor just upstream from the tunnel outlet were tested. One was in the form of a flat wedge, 25.0 ft. long, 15.5 ft. wide, and 4.5 ft. thick on the downstream edge; the other eyebrow was triangular in section 29.0 ft. long and the downstream end, which was normal to the chute floor, was 18.0 ft. wide and 9.0 ft. high. Operation revealed that neither eyebrow was effective in decreasing the undesirable spray action. Photograph 75 depicts flow conditions in connection with the wedge type eyebrow. It was obvious, therefore, that such spray action and consequent uneven distribution of flow into the stilling basin were due primarily to the intersection of the standing waves in the chute and that these undesirable conditions could not be alleviated by any type of eyebrow placed above the tunnel outlet to deflect the spillway flow.

142. Photograph 103 shows flow conditions effected by this tunnel outlet for a tunnel discharge of 5000 c.f.s. In all cases it was observed that flow from the tunnel was concentrated along the centerline of the stilling basin with upstream currents along the sidewalls. The concentration of flow along the centerline of the stilling basin and the resulting high velocity of flow across the end sill are shown in the velocity plot for Plan A on Plate 62. Inspection of this plate shows that the maximum velocity of flow across the end sill was approximately 22 ft. per sec. Flow conditions during

spillway flow were the same as previously observed.

143. Tunnel Outlet Plan B (Test 14): Tunnel Outlet Plan B was devised in an effort to decrease undesirable spray action caused by spillway flow rebounding from the floor of the tunnel outlet. As shown on Plate 60 and in Photograph 93, the only change from Plan A was in the floor of the tunnel outlet which was lowered by means of a 6-ft. vertical drop at sta. 11+99.96 to the elevation of the stilling basin floor. It was believed that the increased depth of water in the tunnel outlet would cushion the impingement of spillway flow and thus decrease undesirable spray action.

144. Observation showed that no decrease in spray action from spillway flow was effected by this revision of the tunnel outlet. Furthermore, by comparing Photographs 103 and 104, it will be seen that the concentration of tunnel flow along the centerline of the stilling basin was the same as with Tunnel Outlet Plan A.

145. Tunnel Outlet Plans C to H (Tests 17A to 17F): As shown on Plates 60 and 61 and in Photographs 94 to 99, inclusive, Tunnel Outlet Plans C to H consisted of various alignments of the outlet sidewalls supplemented in some plans with deflector blocks. The purpose of the deflector blocks was to spread tunnel flow over a larger area of the stilling basin thereby decreasing velocities within the stilling basin and over the end sill. A brief discussion of the conditions and the results of testing of this group of tunnel outlets follows:

a. Tunnel Outlet Plan C (Test 17A): The flare of the sidewalls and the deflector block used for Tunnel Outlet Plan C are shown on Plate 60 and in Photograph 94. With this tunnel outlet design, it was observed that flow from the tunnel struck the nose of the deflector block and was partly deflected upward as spray and that zones of separation (eddies and slack water areas) developed immediately adjacent to the walls of the tunnel outlet (see Photograph 105). It was apparent from these observations that tunnel flow could not make the rather abrupt change in direction at the tunnel portal and follow the flared walls of the tunnel outlet even though aided by the deflector block. With discharge over the spillway, flow struck the deflector block and caused a vertical roller along each sidewall of the outlet. Velocities observed at sta. 13+50 and sta. 14+00, for a tunnel discharge of 5000 c.f.s. (see Plate 62), showed considerable improvement in flow distribution over the end sill, although a concentration of flow along the right side of the stilling basin was observed. From these results, it appeared that this combination of sidewall flare and deflector block was not completely satisfactory.

b. <u>Tunnel Outlet Plan D (Test 17B)</u>: The deflector block used in Tunnel Outlet Plan C was removed for this test. Otherwise, Tunnel Outlet Plans C and D were the same. Photograph 95 shows this outlet in the model. Operation revealed that flow from the tunnel outlet was more satisfactory than that obtained with Tunnel Outlet Plan C, although zones of separation still existed along the sides of the flared tunnel outlet. Reference to Plate 62 shows that concentration of flow along the centerline was increased over that observed with the Plan C outlet, more upstream flow existed along the sidewalls of the stilling basin, and the velocities over the end sill were quite uniform. Photograph 106 depicts flow conditions in the stilling basin for a tunnel discharge of 5000 c.f.s. With flow down the spillway, conditions in the stilling basin were much better than those effected with Tunnel Outlet Plan C as the removal of the deflector block eliminated the vertical rollers previously observed.

c. <u>Tunnel Outlet Plan E (Test 17C)</u>: Although the large deflector block used in Tunnel Outlet Plan C had proved unsatisfactory, it was thought that a smaller block might effect better tunnel flow distribution without causing the undesirable characteristics previously observed. Accordingly, Tunnel Outlet Plan E (see Plate 60 and Photograph 96) was designed using a small triangular-shaped block which was placed well upstream in the tunnel outlet so that it would not interfere with spillway flow. Although some of the tunnel flow tended to override this deflector block, observations made with a discharge of 5000 c.f.s. showed some improvement in flow distribution and decrease in maximum velocity at sta. 13+50 as compared with Plan D (see Plate 62). Photograph 107 shows flow conditions in the stilling basin effected by tunnel discharge. Flow conditions with spillway discharge were similar to those observed with Tunnel Outlet Plan D as the small deflector block did not affect spillway flow. It was concluded from the above results that Tunnel Outlet Plan E was an improvement over the plans previously tested.

d. <u>Tunnel Outlet Plan F (Test 17D)</u>: In an effort to improve further the distribution of tunnel flow into the stilling basin without adversely affecting spillway flow, Tunnel Outlet Plan F was designed using the same flare of outlet sidewalls as was used for Plans C, D, and E, but employing a larger deflector block than was used with Tunnel Outlet Plan E. This design is shown on Plate 60 and in Photograph 97. Operation with a tunnel discharge of 5000 c.f.s. revealed that flow from the tunnel overrode the deflector block with very little flow being diverted toward the sides of the tunnel outlet. Flow in the stilling basin was not as well distributed with this outlet plan as was observed with Tunnel Outlet Plan E as may be seen by comparing Photographs 107 and 108 and the velocity cross sections on Plate 62. As shown on this plate, the velocities at sta. 13+50 for Tunnel Outlet Plan F were very similar to those observed with Plan D, thus indicating that the Plan F deflector block was almost ineffective in distributing tunnel flow into the stilling basin. Spillway discharge was not affected by the deflector block and resulting flow conditions in the stilling basin were the same as those obtained with Tunnel Outlet Plans D and E.

e. <u>Tunnel Outlet Plan G (Test 17E)</u>: The results of previous tests showed that the deflector blocks used were not entirely successful in distributing tunnel flow into the stilling basin and that some of the flow overrode the deflector blocks and resulted in undesirable turbulence in the tunnel outlet. Accordingly, a deflector block was designed with its top shaped so as to reduce turbulence in the flow that passed over it, and its sides were made vertical in an effort to divert a greater part of the flow toward the flared sides of the tunnel outlet. As shown on Plates 60 and 61, Tunnel Outlet Plans E, F, and G differed only in the deflector blocks used. Photograph 98 shows Tunnel Outlet Plan G installed in the model. With a tunnel discharge of 5000 c.f.s., Tunnel Outlet Plan G effected slightly better distribution of flow into the stilling basin than had been previously observed (see Photograph 109 and Plate 63). Furthermore, the deflector block did not have any effect on spillway flow. Although the foregoing results indicated that Tunnel Outlet Plan G was the best tunnel outlet plan developed thus far, it was questionable whether the installation of a deflector block of any type would have any real value, since end sill velocities in the model were not materially changed by the various types of deflector blocks used (see Plates 62 and 63).

f. Tunnel Outlet Plan H (Test 17F): It was thought that if the chute floor could be extended down over the tunnel outlet for some distance, the amount of spray caused by spillway flow rebounding off the floor of the tunnel outlet would be reduced and the tunnel flow would be contracted and spread out into the stilling basin thus obviating the need for a deflector block. The results of several trial extensions of the chute floor showed that it could be extended to sta. 12+21 without causing the flow in the tunnel to change from open-channel to full-tunnel flow with the tunnel air vent open. This chute floor extension in conjunction with the sidewall flare used for Tunnel Outlet Plans D, E, F, and G was designated as Tunnel Outlet Plan H (see Photograph 99 and Plate 61). During operation with a tunnel discharge of 5000 c.f.s., flow from the tunnel was concentrated on the left side of the stilling basin as shown in Photograph 110. Plate 63 shows that this uneven distribution of flow was still evident at sta. 14+00. Closing the tunnel air vent caused flow in the tunnel to change from open-channel to full-tunnel flow, and full-tunnel flow persisted even though the air vent was again opened. As had been expected, the floor extension effected a considerable decrease in spray action during spillway flow. From the foregoing results, it was apparent that Tunnel Outlet Plan H effected no great improvement in the distribution of tunnel flow in the stilling basin and that the chute floor extension might act as a control on tunnel flow and was therefore to be avoided.

146. Tunnel Outlet Plans I and J (Tests 17H and 17I): In testing Tunnel Outlet Plan D, zones of separation occurred along the flared sidewalls of the tunnel outlet, thus indicating that the flare was too abrupt for the flow to follow. In addition, it was obvious that any reduction in the amount of tunnel outlet flare would benefit flow over the spillway, because of the reduced area of the tunnel outlet. It was believed, therefore, that

the amount of flare in the sidewalls of the tunnel outlet might be reduced so as to eliminate these zones of separation and improve the spillway flow without producing any undesirable change in the distribution of tunnel flow into the stilling basin. Accordingly, two different flares of the tunnel outlet, each less than the flare used for Tunnel Outlet Plan D were tested. A brief description of these two flares and the results obtained with each follows:

a. Tunnel Outlet Plan I (Test 17H): As shown on Plate 61 and in Photograph 100, the flaring of the tunnel outlet was reduced on a parabolic alignment to 39.8 ft. for Tunnel Outlet Plan I. For the 5000-c.f.s. tunnel discharge, a comparison of Photographs 106 and 111 and of the velocity cross sections on Plates 62 and 63 for Tunnel Outlet Plans D and I shows that distribution of tunnel flow into the stilling basin was quite similar for the two plans; although the velocities were slightly higher with the latter plan. Tunnel Outlet Plan I, however, was successful in decreasing the extent of the zones of separation along the sidewalls of the outlet and in improving conditions during spillway flow. On the basis of the foregoing results, it was concluded that the improvement in spillway flow conditions more than compensated for the slight undesirable increase in velocities over the end sill with tunnel discharge.

b. Tunnel Outlet Plan J (Test 17I): In an effort to eliminate the slight increase in end sill velocities observed with Tunnel Outlet Plan I, the flaring of the sidewalls was increased to 44.8 ft. The alignment of the sidewall flare, however, was straight as with all plans except Plan I. Tunnel Outlet Plan J is shown in Photograph 101 and on Plate 61. It was thought that this slight increase in sidewall flare might improve the velocity distribution over the end sill without undesirably affecting spillway flow. The distribution of tunnel flow in the stilling basin that was obtained with Tunnel Outlet Plan J was very similar to that observed with Plans D and I (see Photographs 106, 111, and 112). The zones of separation, however, were more extensive than were observed with Tunnel Outlet Plan I, and the flow conditions at the tunnel outlet with spillway discharge were not as satisfactory.

From the above results, it was concluded that Tunnel Outlet Plan I was more satisfactory than Tunnel Outlet Plans D and J.

147. Tunnel Outlet Plan K (Test 18E): The divergence or flare of the sidewalls used for Tunnel Outlet Plan I was on a parabolic alignment. To facilitate construction, it was desirable to use a similar alignment made up of circular arcs and straight lines. Accordingly, Plan K (see Plate 61 and Photograph 102) was designed with practically the same flare of the sidewalls, but using circular arcs and straight lines in the sidewall alignments. With a tunnel discharge of 5000 c.f.s., flow conditions in the stilling basin with Tunnel Outlet Plan K were very similar to those observed with Tunnel Outlet Plan I (see Photographs 111 and 113). Velocities at sta. 14+00 were about the same with Tunnel Outlet Plans I and K (see Plate 63), although the flow distribution at sta. 13+50 was improved by Tunnel Outlet Plan K. No change in spillway flow conditions from those obtaining with Tunnel Outlet Plan I was observed. Tunnel Outlet Plan K was also tested with the 50-ft. radius bucket and Baffle Plan O. Velocities observed in the stilling basin and downstream therefrom during a tunnel discharge of 5000 c.f.s. are presented on Plate 64. Photograph 118 shows this tunnel flow entering the stilling basin.

148. Tunnel Outlet Plan L (Test 27): Tunnel Outlet Plan L (not shown) was a modification of Tunnel Outlet Plan K made necessary by the long radius of curvature used for Tunnel Elbow Plan D (see Paragraph 134). With this elbow plan, the tunnel sloped upward, thus changing the floor and roof alignments of the outlet; however the flaring of the tunnel walls remained as in Tunnel Outlet Plan K. As concluded in Paragraph 136 c, Tunnel Elbow Plan D proved unsatisfactory, and for this reason no data were taken in connection with Tunnel Outlet Plan L.

149. Summary - Tunnel Outlet Plans: The results obtained with the

various Tunnel Outlet Plans are summarized as follows:

a. Neither one of the two types of "eyebrows" tested, which were placed just upstream from the top of the tunnel outlet, was effective in deflecting spillway flow away from the tunnel outlet and reducing resultant spray action.

b. Tunnel Outlet Plan A (original design) produced an undesirable concentration of tunnel flow along the centerline of the stilling basin with resultant velocities as high as 22.0 ft. per sec. across the end sill.

c. The attempt to reduce spray action by increasing the depth of water in the tunnel outlet as in Tunnel Outlet Plan B was unsuccessful.

d. Deflector blocks used in Tunnel Outlet Plans C, E, F, and G to improve the distribution of tunnel flow into the stilling basin were of questionable value since the end sill velocities were not greatly reduced by any of the deflector blocks tested.

e. Of the three tunnel outlet flares (Plans D, I, and J), Plan I effected the best distribution of tunnel flow into the stilling basin without creating excessive areas of slack water along the sidewalls of the tunnel outlet; in addition, satisfactory spillway flow conditions were observed with Tunnel Outlet Plan I.

f. Tunnel Outlet Plan K, a construction modification of Plan I, effected slightly improved tunnel flow conditions in the stilling basin without adversely affecting spillway flow as compared with Plan I.

From the above results it was concluded that Tunnel Outlet Plan K was the best outlet plan tested from the combined standpoint of ease of construction and superior flow characteristics.

Air Vents

150. It had been observed in connection with the tunnel elbow study (see Paragraphs 127 to 136) that negative pressures of considerable magnitude occurred on the curved lip of the elbow. To alleviate these undesir-

able pressures, it was evident that air should be introduced to the lip of the elbow by some sort of a venting arrangement; air so admitted would assist in stabilizing open-channel flow in the tunnel. It was realized, of course, that no quantitative determination of vent size could be made in the model due to the nonsimulation of atmospheric pressure. However, the location and general design of a suitable model venting arrangement would be applicable to the prototype. The study of the air vent problem was made using Tunnel Elbow Plan A and Tunnel Outlet Plan K. The details of the various venting plans tested are shown on Plate 65.

151. Tunnel Vent Plan A (Test 2A): Tunnel Vent Plan A (original design - see Plate 65) consisted of a single 1.5-ft. diameter vent pipe opening into the top of the tunnel at sta. 6+03.50. Comparison of the pressures observed at piezometers 86 to 93, inclusive, with the tunnel vent closed (Table M) and open (Table N) shows that the vent effected a considerable reduction in negative pressures. By opening the vent, the negative pressures at piezometer 92 were reduced to a maximum of -22.0 ft. The negative pressures at the lip (piezometers 86 to 89) were reduced, but cavitational tendencies still existed under certain conditions of pool elevation and gate opening.

152. Lip Vent Plan A and Tunnel Vent Plan B (Test 2B): As the tunnel vent was not effective in reducing negative pressures at the lip sufficiently to suppress cavitational tendencies, Lip Vent Plan A (see Plate 65) was designed to admit air to this low pressure region. This plan consisted of a manifold surrounding the lip with two rows of 120 one-inch holes opening into the tunnel. The outlet of the original tunnel vent at the top of the tunnel was increased in area to give more efficient action. The revised tunnel vent is shown as Tunnel Vent Plan B on Plate 65 and was tested in

conjunction with Lip Vent Plan A.

153. Operation revealed that this lip-venting plan was not satisfactory. With the pool at elevation 832.0 ft. and the cylinder gate 1/4 and 1/3 open, a very small amount of air was taken through the lip vent holes on the downstream side of the tunnel elbow. Opening and closing the tunnel air vent under these conditions had little or no effect on the flow as the tunnel was flowing part full and the vent was not in contact with the water. With the 3/4 and full gate openings and the pool at elevation 832.0 ft. (tunnel flowing full), the manifold surrounding the lip remained completely full of water and consequently no air was admitted to the lip through the vent holes. During all runs, positive pressures on the upstream side of the elbow (see piezometers 86 and L in Table Q) and negative pressures on the downstream side of the elbow (see piezometers 88 and O in Table Q) caused water to circulate through the manifold from the upstream to the downstream side of the elbow. Opening the tunnel air vent with the tunnel flowing full caused no change in the above conditions, but did allow a steady flow of air into the tunnel. Inspection of Table Q shows that opening and closing the manifold vent pipes had little effect on the pressures. Opening and closing the tunnel vent, however, effected substantial reduction in the negative pressures at the lip and at the P.T. of the elbow.

154. Lip Vent Plan B and Tunnel Vent Plan B (Test 29): Inasmuch as the main disadvantage of Lip Vent Plan A was the circulation of water from the upstream to the downstream side of the elbow with resultant exclusion of air from the vents, preliminary investigations were made with the manifold divided into four sections. Since the pressures in the upstream side of the elbow were always positive, the upstream section was closed off and the vent pipes to the other three sections arranged so that they could be independently

controlled. Preliminary operation revealed that this arrangement of the lip vents effected considerable reduction in the negative pressures at the lip; however, these negative pressures were still of considerable magnitude. In an effort to reduce further the negative pressures occurring at the lip, the 60 one-inch diameter vent holes in each section were replaced by 20 three-inch diameter openings. This revised lip-venting arrangement is shown as Lip Vent Plan B on Plate 65. As shown on this plate, the two rows of 10 three-inch openings were located only in front of the port openings. The area of these 60 three-inch openings was slightly more than twice that of the original 240 one-inch vent holes. Since Tunnel Vent Plan B was observed to act satisfactorily, its design remained unchanged.

155. Model testing showed that this venting arrangement effected open-channel flow in the tunnel for all discharges up to 6900 c.f.s. (see Paragraph 124 b), thus precluding the necessity of placing fins in the elbow (as in Tunnel Elbow Plan B) to effect such open-channel flow. The pressures observed are given in Table R. Comparing the pressures with the vents open and closed emphasizes the effectiveness of this venting arrangement in controlling negative pressures at the lip and in the elbow. With all vents open and with pool elevations and gate openings used with previously-tested vent plans, the maximum negative pressure observed within the outlet works was -3.2 ft. at piezometer 0 for the 5000-c.f.s. flow as compared with -15.5 ft. at piezometer 89 with the original design (see Table N) and -15.9 ft. at piezometer 87 with Lip Vent Plan A and Tunnel Vent Plan B (see Table Q) for the same flow. While investigating the lower flows, it was found with Lip Vent and Tunnel Vent Plans B and a discharge of 1000 c.f.s. that higher negative pressures were obtained (see Table R); the maximum negative pressure observed was -9.7 ft. at piezometer 86 with the pool at elevation 832.0 ft.

and the cylinder gate 0.052 open. The combination of the following two factors no doubt caused this condition: (1) at the low discharges no water stood in the tower and elbow because the flow from each port spilled individually into the elbow; and (2) the part of the lip upon which this pressure was recorded was not vented (see Paragraph 154). It is possible that a greater negative pressure might obtain with a smaller gate opening at pool elevation 832.0 ft., but this possibility was not checked as the small model scale in combination with the measuring device used precluded the accurate measurement of discharges less than 1000 c.f.s. However, the occurrence of this negative pressure area at low flows could be obviated by either replacing the deleted manifold section of the lip vent or closing the emergency gate in the port on the unvented side of the lip for the low discharges.

156. Summary - Air Vent Plans: The results obtained in the foregoing vent plan study are summarized as follows:

a. The original vent plan, consisting of a tunnel vent only, did not sufficiently control negative pressures occurring at the lip of the elbow.

b. Lip Vent Plan A proved unsatisfactory because water flowed from the high pressure to the low pressure area of the lip of the elbow through the manifold and precluded the admission of air.

c. With the lip vent manifold divided into sections as in Lip Vent Plan B, satisfactory control of negative pressures in the lip of the elbow was accomplished for flows as low as 1000 c.f.s.

d. Enlarging the outlet of the tunnel vent as in Tunnel Vent Plan B improved the action of this vent.

e. If operation with a pool elevation of 832.0 ft. and a discharge less than 1000 c.f.s. is contemplated, it might be necessary to install the fourth lip vent section which was omitted from Lip Vent Plan B.

f. **Lip Vent and Tunnel Vent Plans B effected open-channel flow over a wide range of pool elevations and gate openings including the operating range.**

Since, at flows of 1000 c.f.s. and less, there is a possibility that high negative pressures might develop on the unvented portion of the lip, it is recommended that the fourth manifold section and vents be added to Lip Vent Plan B for the final design.

Summary of Model Tests

157. A detailed summary of the results of the model tests and the conclusions reached were presented at the end of each section as follows:

Feature Tested	Presented in Paragraph
Left Abutment	35
Right Approach Wall	52
Apron Floor Elevation	60
Crest	72
Chute	81
Bucket	90
Baffles	102
Stilling Basin Floor Elevation	103
End Sill	108
Tailbay Scouring Tendencies	117
Tailbay Current Directions	118
Conditions at Toe of Dam	119
Outlet Tower	126
Tunnel Elbow	136

Feature Tested	Presented in Paragraph
15.5-Ft. Tunnel	137
Tunnel Outlet	149
Air Vents	156

A general summary of the entire model study is presented in the syllabus of this report (see Paragraphs 1 to 3).

FINAL PROTOTYPE DESIGN

Recommended and Adopted Final Design

158. The following tabulation shows the relation between the final design as recommended on the basis of the model tests and that adopted for prototype design by the Portland District Office:

Feature	Final Design Plan	
	Recommended	Adopted
Left Abutment	I	I
Right Approach Wall	VII	VII (revised)
Approach Apron Elev.	818.0 ft.	818.0 ft.
Crest	X	IX
Chute	P	O
Bucket	50-ft. radius	50-ft. radius
Baffles	P	O
Stilling Basin Floor Elev.	712.0 ft.	712.0 ft.
End Sill	A	A
Outlet Tower	Original design	Original design
Tunnel Elbow	A	A
Tunnel Outlet	K	K
Tunnel Vent	B	B
Lip Vents	B (revised)	B (revised)

Inspection of the above table shows that all features of the adopted final design were the same as recommended on the basis of model tests, except the right approach wall, crest, chute, and baffles. These differences are explained as follows:

a. Right Approach Wall: The recommended final design and the adopted final design of the right approach wall are shown on Plates 13 and 6, respectively. The major difference between these designs was in the toe alignment of the wall which was made to effect a saving in excavation costs. Although this change resulted in a break in the smooth transition of the recommended wall and would probably cause some eddy action along that wall, it is believed that this action would not be too objectionable.

b. Crest, Chute, and Baffles: At the time that tests on the spillway crest and chute were completed, considerable progress had been made on the detailed design of Crest Plan IX and Chute Plan O as the adopted final design. In view of this fact and because the hydraulic characteristics of Crest Plan IX and Chute Plan O were sufficiently satisfactory for the discharges that would normally occur in the prototype, it was decided that the expense of changing the design and the increased construction cost of the curved crest (Plan X) and the dish-shaped chute (Plan P) were not warranted. In order that Chute Plan O might be used, however, it was necessary to increase the height of the sidewalls to prevent overtopping at the high discharges. Reference to Plate 34 shows the water-surface profiles that were measured in the model during Test 24 superimposed on the Plan O sidewalls and the higher sidewalls of the adopted final design. Details of the adopted final design of the spillway crest and chute are shown on Plates 6 and 25. Since Baffle Plan O was developed in connection with Crest Plan IX and Chute Plan O, it was adopted for the final prototype baffle design.

Operation Data

159. Data pertaining to the operation of the prototype structures are presented in the tables and on the plates as follows:

a. Spillway

(1) Rating Curves	Plate 27
(2) Pressures	
(a) Crest	Table E and Plate 29
(b) Chute	Table H
(3) Velocities	
(a) Approach Channel	Plates 12, 19, and 24
(b) Chute	Plate 36
(4) Water-Surface Elevations	
(a) Crest	Table B and Plate 28
(b) Chute	Plates 32 and 34

b. Stilling Basin and End Sill

(1) Pressures	Table H
(2) Velocities	Plates 43 to 46, and 64
(3) Water-Surface Elevations	Plates 43 to 47

c. Tailbay

(1) Velocities	Plates 48 and 64 and Paragraph 119
(2) Current Directions	Plate 53
(3) Water-Surface Elevations	Plate 47
(4) Scour Tendencies	Plates 49 to 52
(5) Wave Action at Toe of Dam	Paragraph 119

d. Outlet Works

(1) Rating Curve	Plate 57
(2) Tower Water-Surface Elevation	Plate 58
(3) Pressures	Table R
(4) Velocities - Tunnel Outlet	Plate 64
(5) Water-Surface Elev. - Tunnel	Table L

Recommended Prototype Tests

160. For the purpose of comparing model and prototype pressure data, the installation of piezometers in the prototype is recommended as follows:

a. Spillway Crest: Piezometers should be located at the crest on the spillway centerline at stations 9+99.42, 10+00.92, 10+02.77, 10+05.77, 10+08.56, and 10+20.27. Data taken with these piezometers would be comparable to similar data taken at model piezometers 7 to 12 in Table E - Crest Plan IX.

b. Stilling Basin: In the stilling basin, the baffles offer an opportunity to check the occurrence of negative pressures indicated by the model tests. For this reason, it is recommended that piezometers be installed in baffles D, H, and J (see sketch on Table H) as follows: one each in the center of the upstream and downstream faces; and one each on the right sides, six inches from the upstream face and in the center vertically. Pressure data taken at these piezometers could be compared with data taken on similar baffles in the model as given in Table H for the upstream and downstream faces and Table J for the side faces.

c. Outlet Works: To check the pressures observed in the model outlet works, it is recommended that piezometers be installed in the prototype corresponding to model piezometers 80, S, 86, 87, 88, 89, 90, 94, 98, and 102. The location of these piezometers with accompanying model data are given in Table R.

161. As a check on the prototype operation of the 15.5-ft. tunnel, it is recommended that an automatic recorder be installed to measure the water-surface elevation in the outlet tower. With the elevation of the water surface within the tower known, the tunnel discharge can be determined from the curve on Plate 58. It would also be desirable to establish a current meter rating station downstream from the dam so that both the spillway and tunnel discharges could be measured and compared with the model data.

CONCLUSIONS

162. The conduct of this model study and the results obtained have been discussed in the foregoing paragraphs of this report. There have also been pointed out the theoretical and practical considerations pertinent to a model study of this type and the model results have been interpreted into prototype terms and presented in the tables, photographs, and plates. In all, 29 tests (some involving as many as 12 different experiments) were made to check and revise the various features of the originally-designed spillway, stilling basin, and outlet works to achieve the recommended and adopted final designs. The model study was responsible for effecting changes in the design of the right approach wall, left abutment, chute sidewalls, bucket, baffle system, tunnel and lip air vents, and the tunnel outlet. The hydraulic characteristics of the outlet tower and of various designs of the approach apron floor elevation, crest profile, chute, stilling basin floor elevation, and end sill were determined so as to establish their worth. The purpose of the model study is believed to be fulfilled, in that the structures of the adopted final design are believed to be characterized by a good balance between hydraulic efficiency and engineering economy.

Submitted:

George E. Hyde

George E. Hyde,
Assistant Hydraulic Engineer,
Director, Bonneville Hydraulic Laboratory.

Approved:

R. B. Cochrane

R. B. Cochrane,
Captain, Corps of Engineers,
Area Engineer.

TABLES

TABLE A
FEATURES TESTED

Test	SPILLWAY								TUNNEL				Tailbay
	Right Approach Wall	Left Abutment	Apron Floor Elevation in Ft. M.S.L.	Crest	Chute	Bucket	Baffle	End Sill	Air Vents Lip	Air Vents Tunnel	Elbow	Outlet	
1	Plan I	Plan A	818	Plan I	Plan A	100 Ft. Rad.	Plan A	Plan A	None	Plan A	Plan A	Plan A	Plan A
2	•	•	•	•	•	• •	•	•	•	•	•	•	•
2 A	Plan VII	Plan I	•	Plan IX	Plan C	50 Ft. Rad.	Plan C	•	•	•	•	Plan K	Plan B
3 B	Plan I	Plan A	•	Plan I	Plan B	100 Ft. Rad.	Plan A	•	•	•	•	Plan A	Plan A
3 C	•	•	•	•	• C	• •	•	•	•	•	•	•	•
3 D	•	•	•	•	• D	• •	•	•	•	•	•	•	•
3 E	•	•	•	•	• E	• •	•	•	•	•	•	•	•
3 E-1	•	•	•	•	• E-1	• •	•	•	•	•	•	•	•
3 E-2	•	•	•	•	• E-2	• •	•	•	•	•	•	•	•
3 E-3	•	•	•		• E-3	• •	•	•	•	•	•	•	•
3 F	•	•	•		• F	• •	•	•	•	•	•	•	•
3 G	•	•	•	•	• G	• •	•	•	•	•	•	•	•
3 H	•	•	•	•	• H	• •	•	•	•	•	•	•	•
3 I	•	•	•	•	• I	• •	•	•	•	•	•	•	•
3 J	•	•	•	•	• J	• •	•	•	•	•	•	•	•
3 K	•	•	•	•	• K	• •	•	•	•	•	•	•	•
3 L	•	•	•	•	• L	• •	•	•	•	•	•	•	•
3 M	•	•	•	•	• M	• •	•	•	•	•	•	•	•
3 N	•	•	•	•	• N	• •	•	•	•	•	•	•	•
4	Plan II	Plan E	•	Plan I'	Plan C	• •	•	•	•	•	•	•	Plan B
5	•	• F	•	•	•	• •	•	•	•	•	•	•	•
6	•	•	•	•	•	• •	•	•	•	•	•	•	•
7	•	• H	•	•	•	• •	•	•	•	•	•	•	•
8	•	• F	•	Plan III	•	• •	•	•	•	•	•	•	•
9	Plan III	• F	•	•	•	• •	•	•	•	•	•	•	•
10	•	• F	825	•	•	• •	•	•	•	•	•	•	•
11	Plan IV	Plan I	818	•	•	• •	•	•	•	•	•	•	•
12	•	•	825	•	•	• •	•	•	•	•	•	•	•
13 A	•	•	818	•	•	• •	None	•	•	•	•	•	•
13 B	•	•	•	•	•	• •	Plan B	•	•	•	•	•	•
13 C	•	•	•	•	•	• •	• C	•	•	•	•	•	•
13 D	•	•	•	•	•	• •	• D	•	•	•	•	•	•
13 E	•	•	•	•	•	• •	• E	•	•	•	•	•	•
13 F	•	•	•	•	•	• •	• F	•	•	•	•	•	•
13 G	•	•	•	•	•	• •	• G	•	•	•	•	•	•
13 H	•	•	•	•	•	• •	• H	•	•	•	•	•	•
13 J	•	•	•	•	•	• •	• I	•	•	•	•	•	•
13 K	•	•	•	•	•	• •	• J	•	•	•	•	•	•
13 L	•	•	•	•	•	• •	• K	•	•	•	•	•	•
13 M	•	•	•	•	•	• •	• L	•	•	•	•	•	•

14	Plan IV	Plan I	Ind	Plan III	Plan O	100 Ft. Ext.	Plan I	Plan A	None	Plan A	Plan A	Plan B	Plan D
15	.	.	.	.	.	. .	.	.	.	.	.	.	.
16 A	.	.	.	.	.	. .	.	Plan I	.	.	.	.	.
16 B	.	.	.	.	.	. .	None	. I	.	.	.	.	.
16 C	.	.	.	.	.	. .	.	. II	.	.	.	.	.
16 D	.	.	.	.	.	. .	.	. III	.	.	.	.	.
16 E	.	.	.	.	.	. .	.	. IV	.	.	.	.	.
16 F	.	.	.	.	.	. .	Plan I	. IV	.	.	.	.	.
16 G	.	.	.	.	.	. .	.	. III	.	.	.	.	.
16 H	.	.	.	.	.	. .	.	. V	.	.	.	.	.
16 I	.	.	.	.	.	. .	.	. VI	.	.	.	.	.
17 A	.	.	.	.	.	. .	.	Plan A	.	.	.	Plan C	.
17 B	.	.	.	.	.	. .	.	.	.	.	.	. D	.
17 C	.	.	.	.	.	. .	.	.	.	.	.	. E	.
17 D	.	.	.	.	.	. .	.	.	.	.	.	. F	.
17 E	.	.	.	.	.	. .	.	.	.	.	.	. G	.
17 F	.	.	.	.	.	. .	.	.	.	.	.	. H	.
17 G	.	.	.	.	.	. .	.	.	.	.	.	. A	.
17 H	.	.	.	.	.	. .	.	.	.	.	.	. I	.
17 I	.	.	.	.	.	. .	.	.	.	.	.	. J	.
18 A	.	.	.	.	.	Inter. Planes	.	.	.	.	.	Plan K	.
18 B	.	.	.	.	.	. .	Plan M	.	.	.	.	.	.
18 C	.	.	.	.	.	50 Ft. Ext.	. I	.	.	.	.	.	.
18 D	.	.	.	.	.	. .	. N	.	.	.	.	.	.
18 E	.	.	.	.	.	100 Ft. Ext.	. I	.	.	.	.	.	.
19 A	.	.	.	.	.	50 Ft. Ext.	Plan N	.	.	.	.	.	Plan B
19 B	.	.	.	.	.	. .	.	.	.	.	.	.	with
19 C	.	.	.	.	.	. .	.	.	.	.	.	.	Movable
19 D	.	.	.	.	.	. .	.	.	.	.	.	.	End
19 E	.	.	.	.	.	. .	.	.	.	.	.	.	
20	.	.	.	Plan IX	.	. .	.	.	.	.	.	.	Plan
21	Plan V	.	.	.	.	. .	.	.	.	.	.		.
22	. VI	.	.	.	.	. .	.	.	.	.	.	.	.
23	Plan VII	.	.	.	.	. .	.	.	.	.	.	.	.
24	.	.	.	.	.	. .	Plan O	.	.	.	.	.	.
25 A	.	.	.	Plan X	Plan P	. .	Plan P	.	.	.	.	.	.
25 B	.	.	.	.	.	. .	.	.	.	.	Plan B	.	.
26	.	.	.	.	.	. .	.	.	.	None	. C	.	.
27	.	.	.	.	.	. .	.	.	.	.	. D	Plan L	.
28	.	.	.	.	.	. .	.	.	A	B	. A	. K	.
29	.	.	.	.	.	. .	.	.	B	B	. A	. K	.

TABLE A (Cont'd)

TABLE B

TRANSVERSE WATER – SURFACE ELEVATIONS AT CREST

Test	Crest Plan	Discharge in C.F.S.	Pool Elevation Feet M.S.L.	WATER SURFACE ELEVATION IN FEET M.S.L.								
				Left Side				Center-line	Right Side			
				Water's Edge	Distance in Feet				Distance in Feet			Water's Edge
					90	75	50		50	75	90	
1	I	45 000	848.4	845.2	844.6*	844.5	844.5	844.5	844.4	844.4	844.5	845.2
		95 000	857.8	850.9	850.0*	850.8	851.0	851.1	851.2	851.1	- - -	851.5
4	II	45 000	848.8	845.0	844.5	844.4	844.5	844.6	844.6	844.7	845.0	845.1
		95 400	858.6	850.2	850.0	850.8	851.2	851.5	851.7	851.9	852.2	852.2
5	II	45 000	848.8	844.9	844.4	844.4	844.4	844.4	844.6	844.8	844.9	845.1
		95 400	858.6	850.5	850.6	850.9	851.2	851.4	851.7	851.8	852.2	852.1
6	II	45 000	848.9	845.0	844.6	844.5	844.6	844.6	844.8	844.9	845.0	845.3
		95 400	858.6	850.1	850.0	850.8	851.2	851.6	851.8	852.0	852.2	852.2
7	II	45 000	848.8	845.0	844.6	844.6	844.6	844.6	844.6	844.9	845.0	845.2
		95 400	858.6	850.2	850.2	851.0	851.4	851.4	851.8	851.8	852.2	852.2
8	III	45 000	848.3	844.9	844.4	844.2	844.4	844.4	844.4	844.6	844.6	845.0
		95 400	858.0	850.4	850.2	850.8	851.2	851.4	851.6	851.6	852.0	852.1
9	III	45 000	848.4	845.0	844.5	844.4	844.5	844.5	844.6	844.6	844.8	845.2
		95 400	858.2	850.6	850.5	850.9	851.2	851.5	851.6	851.8	852.2	852.2
10	III	45 000	848.6	844.6	844.2	844.1	844.2	844.3	844.4	844.5	844.6	844.9
		95 400	858.6	848.1	848.2	849.6	850.6	851.1	851.3	851.6	851.9	851.8
11	III	45 000	848.6	845.2	844.4	844.3	844.4	844.5	844.6	844.6	844.8	845.0
		95 400	858.3	850.4	850.3	850.7	851.2	851.5	851.6	851.8	852.1	852.0
12	III	45 000	848.7	844.5	844.4	844.2	844.4	844.4	844.5	844.6	844.8	844.7
		95 400	858.6	848.4	848.5	850.0	850.6	851.2	851.4	851.5	851.8	851.6
20	II	45 000	848.5	844.7	844.0*	844.2	844.2	844.4	844.3	844.4	844.5°	844.7
		95 400	858.2	850.4	-----	850.4/	850.9	851.2	851.5	851.6/	852.0	851.6
21	II	45 000	848.5	844.6	844.2	844.2	844.2	844.4	844.4	844.4	844.6	845.2
		95 400	858.2	850.3	850.2	850.4	850.8	851.1	851.2	851.4	851.8	852.0
22	II	45 000	848.5	844.8	844.1	844.1	844.2	844.3	844.3	844.4	844.8	845.2
		95 400	858.2	850.4	850.4	850.5	850.9	851.2	851.4	851.6	852.0	852.8
23-24	II	45 000	848.5	844.9	844.2	844.2	844.2	844.3	844.4	844.4	844.8	845.1
		95 400	858.2	850.4	850.2	850.6	850.9	851.2	851.4	851.6	852.0	852.8
23A	I	45 000	848.4	844.5	844.1	844.2	844.5	844.6	844.6	844.5	844.6	845.0
		95 400	858.1	850.3	850.2	850.5	851.1	851.5	851.6	851.5	851.5	852.0

* Reading taken at 95 feet left of centerline.

° Reading taken at 85 feet left and right of centerline.

/ Reading taken at 80 feet left and right of centerline.

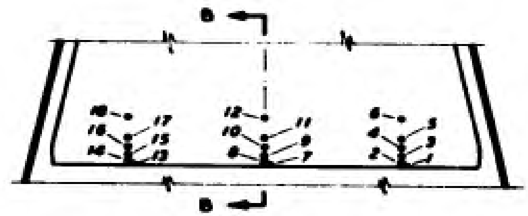
TABLE B

TABLE C

PRESSURES — CREST PLANS I AND II

PLAN

SECTION A-A



PLAN

SECTION B-B

CREST PLAN I — TEST 1

Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 000
				Head on Piezometer in Feet of Water			
1	9+93.37	60.0 Rt.	850.1	9.4	14.7	16.7	17.9
2	9+96.00	"	852.2	3.8	7.7	7.4	6.2
3	10+00.00	"	853.0	3.8	4.6	4.0	2.6
4	10+05.85	"	852.2	2.4	3.8	4.0	3.6
5	10+11.85	"	850.1	1.9	4.8	5.7	6.4
6	10+21.85	"	845.1	2.5	6.8	9.7	12.0
7	9+93.37	Centerline	850.1	9.4	13.9	16.1	17.4
8	9+96.00	"	852.2	2.8	7.6	7.3	6.2
9	10+00.00	"	853.0	3.8	4.3	3.5	1.9
10	10+05.85	"	852.2	2.7	4.8	4.5	4.2
11	10+11.85	"	850.1	2.1	4.4	5.5	6.3
12	10+21.85	"	845.1	1.9	5.9	8.7	10.6
13	9+93.37	60.0 Lt.	850.1	9.3	13.9	14.3	16.2
14	9+96.00	"	852.2	3.7	7.1	[illegible]	4.4
15	10+00.00	"	853.0	3.6	4.1	2.8	0.9
16	10+05.85	"	852.2	2.5	3.9	4.0	3.2
17	10+11.85	"	850.1	1.9	4.8	4.2	5.6
18	10+21.85	"	845.1	2.3	6.4	8.9	10.9

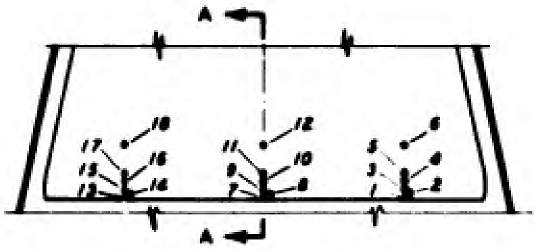
CREST PLAN II — TEST 5

Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
1	9+77.48	60.5 Rt.	851.1	8.0	10.1	9.0	8.2
2	9+79.61	60.5 Rt.	852.6	4.4	2.4	- 0.7	- 5.2
3	10+01.85	"	853.0	3.5	2.2	0.0	- 3.0
4	10+03.71	"	852.5	2.6	2.6	2.0	0.6
5	10+05.30	"	851.1	3.0	4.7	5.4	5.7
6	10+15.50	"	846.1	3.0	7.2	10.0	11.9
7	9+77.48	2.5 Rt.	851.1	8.2	10.0	9.7	8.2
8	9+79.61	Centerline	852.6	4.6	2.4	- 1.6	- 6.2
9	10+01.85	"	853.0	3.8	2.3	0.0	- 3.2
10	10+03.71	"	852.5	2.5	2.6	1.6	- 0.3
11	10+05.30	"	851.1	2.7	4.5	4.9	4.3
12	10+15.50	"	846.1	3.0	7.5	9.9	11.6
13	9+77.48	57.5 Lt.	851.1	8.0	9.4	7.9	6.6
14	9+79.61	60.5 Lt.	852.6	4.4	2.0	- 2.4	- 7.5
15	10+01.85	"	853.0	3.7	2.2	- 0.8	- 3.8
16	10+03.71	"	852.5	2.6	2.7	1.5	- 0.3
17	10+05.30	"	851.1	2.8	4.2	4.6	4.4
18	10+15.50	"	846.1	3.0	7.0	9.4	11.2

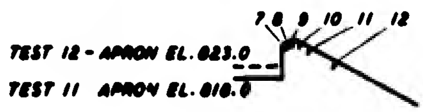
TABLE D

PRESSURES – CREST PLAN III

TESTS 11 AND 12



PLAN

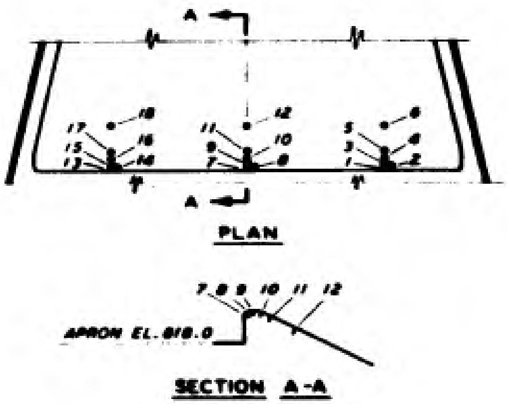


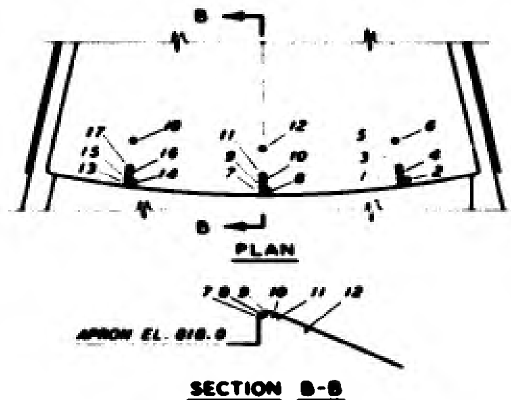
SECTION A-A

Piezometer				Apron El. 818.0 Ft. - Test 11				Apron El. 823.0 Ft. - Test 12			
				Discharge in c.f.s.							
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water							
1	9+99.52	60.0 Rt.	831.7	4.7	1.0	- 4.7	-12.2	5.4	3.0	- 0.2	- 4.5
2	10+01.14	62.5 Rt.	832.5	4.5	5.6	4.1	1.3	5.4	6.0	5.2	3.8
3	10+02.77	60.0 Rt.	833.0	2.2	- 1.0	- 5.0	-10.0	2.2	- 1.1	- 5.6	-10.0
4	10+05.77	"	832.5	2.4	1.6	0.3	- 1.5	2.5	1.7	- 0.2	- 1.5
5	10+08.96	"	831.4	2.8	4.0	4.4	4.2	2.8	4.2	4.1	4.4
6	10+20.87	"	825.6	3.2	7.7	10.4	12.8	3.2	7.8	10.3	13.0
7	9+99.52	Centerline	831.7	5.1	0.9	- 5.0	-12.7	5.3	2.5	- 2.2	- 8.2
8	10+01.14	2.5 Rt.	832.5	5.0	5.7	3.6	0.9	5.4	6.6	4.3	2.5
9	10+02.77	Centerline	833.0	2.5	- 0.8	- 4.9	-10.2	2.5	- 0.8	- 5.3	-10.2
10	10+05.77	"	832.5	2.5	1.6	- 0.1	- 2.7	2.5	1.5	- 0.7	- 2.7
11	10+08.96	"	831.4	2.8	3.7	3.7	3.1	2.8	3.7	3.4	2.8
12	10+20.87	"	825.6	3.2	7.5	10.2	12.2	3.3	7.7	9.8	12.2
13	9+99.52	60.0 Lt.	831.7	4.9	0.4	- 6.3	-14.0	5.3	1.7	- 3.4	-10.5
14	10+01.14	27.5 Lt.	832.5	5.0	5.3	7.3	- 0.5	5.5	5.8	5.6	1.1
15	10+02.77	60.0 Lt.	833.0	2.0	- 1.3	- 6.3	-12.0	2.0	- 2.0	- 7.1	-14.2
16	10+05.77	"	832.5	2.3	1.3	- 0.7	- 3.7	2.3	1.1	- 1.6	- 4.6
17	10+08.96	"	831.4	2.8	4.8	4.4	3.6	2.8	4.4	3.9	3.2
18	10+20.87	"	825.6	3.0	7.6	10.0	11.8	3.2	7.5	9.5	11.6

TABLE E

PRESSURES — CREST PLANS IX AND X





CREST PLAN IX — TEST 24

Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
1	9+99.42	60.0 Rt.	832.0	5.1	1.8	- 3.3	-10.0
2	10+00.92	62.5 Rt.	832.8	4.0	1.5	- 2.3	- 6.5
3	10+02.77	60.0 Rt.	833.0	3.4	1.3	- 1.8	- 5.2
4	10+05.77	"	832.5	2.8	2.3	1.0	- 0.5
5	10+08.56	"	831.4	3.0	4.2	4.4	4.3
6	10+20.27	"	825.6	3.1	7.7	10.5	12.8
7	9+99.42	Centerline	832.0	5.2	1.0	- 5.6	-12.5
8	10+00.92	2.5 Rt.	832.8	4.0	0.9	- 3.2	- 8.2
9	10+02.77	Centerline	833.0	3.3	1.2	- 1.7	- 5.5
10	10+05.77	"	832.5	2.7	1.9	0.4	- 1.9
11	10+08.56	"	831.4	3.1	4.3	4.4	4.0
12	10+20.27	"	825.6	3.0	7.3	9.7	11.7
13	9+99.42	60.0 Lt.	832.0	4.9	0.4	- 5.9	-14.0
14	10+00.92	57.5 Lt.	832.8	4.1	1.4	- 3.1	- 8.1
15	10+02.77	60.0 Lt.	833.0	3.2	0.7	- 2.8	- 7.2
16	10+05.77	"	832.5	2.7	1.9	0.2	- 2.0
17	10+08.56	"	831.4	3.1	4.0	4.1	3.3
18	10+20.27	"	825.6	3.2	7.5	9.9	11.8

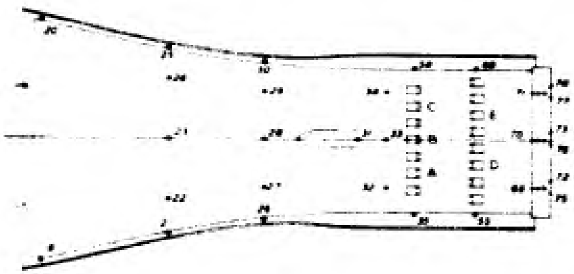
CREST PLAN X — TEST 25A

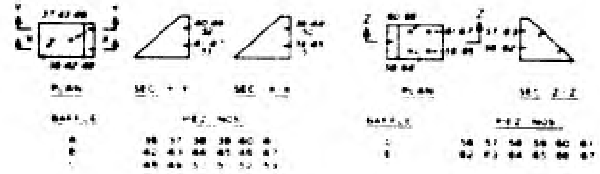
Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
1	9+93.52	60.3 Rt.	832.0	5.5	3.2	- 1.5	- 7.4
2	9+95.34	62.6 Rt.	832.8	3.9	1.1	- 3.3	- 8.2
3	9+96.84	59.8 Rt.	833.0	3.3	1.3	- 2.0	- 5.6
4	9+99.81	59.4 Rt.	832.5	2.7	2.7	1.4	- 0.3
5	10+02.97	58.9 Rt.	831.4	3.3	4.8	5.3	5.1
6	10+14.18	57.5 Rt.	825.6	3.4	7.9	10.5	12.9
7	9+89.49	Centerline	832.0	5.5	2.5	- 1.8	- 6.4
8	9+90.99	2.5 Rt.	832.8	4.1	1.4	- 2.6	- 7.1
9	9+92.84	Centerline	833.0	3.1	0.9	- 2.7	- 6.5
10	9+95.84	"	832.5	2.5	2.3	0.9	- 0.8
11	9+98.65	"	831.4	3.4	5.0	5.5	5.4
12	10+10.34	"	825.9	3.4	7.9	10.4	12.5
13	9+93.52	60.3 Lt.	832.0	5.6	3.3	- 1.6	- 7.7
14	9+94.67	57.6 Lt.	832.8	4.1	1.2	- 4.2	- 9.9
15	9+96.84	59.8 Lt.	833.0	2.9	0.0	- 4.6	- 9.8
16	9+99.81	59.4 Lt.	832.5	2.5	1.8	- 0.2	- 2.8
17	10+02.97	58.9 Lt.	831.4	3.4	4.4	4.6	3.9
18	10+14.18	57.5 Lt.	825.6	3.4	7.5	10.0	11.9

TABLE F.

PRESSURES – CHUTE AND BAFFLE PLANS A

TEST 1





Piezometer Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	Discharge in c.f.s. 15 000	45 000	70 000	95 000
				Head on Piezometer in Feet of Water			
19	10+00.00	100.6 Rt.	835.5	2.7	6.5	8.1	8.9
20	-	100.6 Lt.	835.5	2.7	6.3	7.7	8.0
21	11+00.00	77.4 Rt.	766.2	1.3	4.8	7.3	9.6
22	-	50.0 Rt.	765.7	1.5	4.5	7.6	10.2
23	-	Centerline	765.7	1.5	4.0	5.9	7.6
24	-	50.0 Lt.	765.7	1.4	4.3	6.9	9.2
25	11+00.00	77.4 Lt.	768.2	1.2	3.9	6.2	7.9
26	11+75.00	65.9 Rt.	750.7	0.3	3.1	5.4	7.5
27	-	40.0 Rt.	748.2	0.1	4.6	7.2	9.4
28	-	Centerline	748.2	1.0	2.7	4.4	6.0
29	-	40.0 Lt.	748.2	2.3	5.8	8.3	10.0
30	-	65.9 Lt.	750.7	0.6	3.1	4.9	6.5
31	12+54.96	Centerline	713.3	14.2	5.7	12.7	24.2
32	12+71.04	40.0 Rt.	712.0	20.6	21.5	13.7	29.8
33	-	Centerline	712.0	19.3	18.5	16.8	36.6
34	-	40.0 Lt.	712.0	22.2	25.5	16.5	31.3
35	12+93.00	60.6 Rt.	714.5	18.5	15.0	10.2	3.5
36	12+83.50	28.0 Rt.	714.5	20.7	61.5	79.5	66.5
37	12+93.00	20.0 Rt.	718.0	18.0	25.5	33.0	50.0
38	12+97.50	30.0 Rt.	712.0	15.5	-10.0	- 3.0	-38.0
39	-	30.0 Rt.	714.5	13.0	- 1.5	- 2.5	-33.5
40	-	26.0 Rt.	710.0	11.5	-10.0	- 4.0	-39.0
41	-	26.0 Rt.	714.5	17.0	- 3.5	- 2.5	-31.5
42	12+83.50	Centerline	714.5	20.5	45.5	76.5	90.5
43	12+93.00	Centerline	714.0	17.0	25.0	40.0	53.0
44	12+97.50	2.0 Rt.	713.0	18.0	- 6.0	-38.0	-35.0
45	-	2.0 Rt.	714.5	22.0	0.5	-26.5	-27.5
46	-	2.0 Lt.	710.0	15.0	+ 3.0	-34.0	-32.0
47	-	2.0 Lt.	714.5	21.5	0.5	-25.5	-27.5
48	12+83.50	20.0 Lt.	714.5	27.3	60.5	70.5	50.5

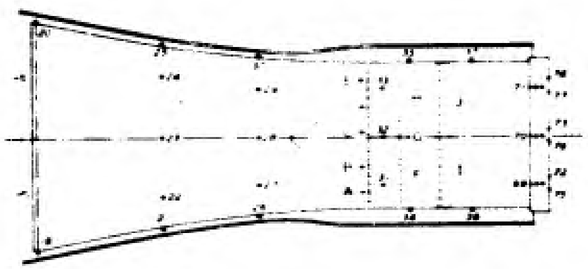
Piezometer Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	Discharge in c.f.s. 15 000	45 000	70 000	95 000
				Head on Piezometer in Feet of Water			
49	12+93.00	28.0 Lt.	718.0	18.5	25.0	37.0	50.0
50	12+97.50	26.0 Lt.	718.0	12.0	- 7.0	- 2.0	-17.0
51	-	26.0 Lt.	714.5	15.9	- 2.5	- 0.5	-16.5
52	-	30.0 Lt.	718.0	15.5	- 6.0	- 3.0	-18.0
53	-	30.0 Lt.	714.5	17.3	- 0.5	- 0.5	-15.5
54	12+93.00	60.6 Lt.	714.5	19.6	18.0	17.9	19.5
55	13+41.00	60.6 Rt.	714.5	22.3	27.3	23.9	9.0
56	13+36.50	21.0 Rt.	714.5	22.0	56.5	55.5	80.5
57	-	21.0 Rt.	718.0	18.4	50.0	45.0	85.0
58	13+41.00	25.0 Rt.	718.0	18.5	16.0	11.0	- 5.0
59	13+44.50	25.0 Rt.	714.5	22.0	22.5	17.5	2.5
60	13+41.00	19.0 Rt.	718.0	10.5	16.0	13.0	- 6.0
61	13+44.50	19.0 Rt.	714.5	22.0	22.5	20.5	5.5
62	13+36.50	21.0 Lt.	714.5	22.3	53.5	45.5	62.5
63	-	21.0 Lt.	710.0	18.5	49.0	40.0	58.0
64	13+41.00	19.0 Lt.	710.0	18.5	16.0	15.0	2.0
65	13+44.50	19.0 Lt.	714.5	22.0	21.5	21.5	12.5
66	13+41.00	25.0 Lt.	718.0	18.3	15.0	14.0	1.0
67	13+44.50	25.0 Lt.	714.5	21.3	20.5	20.5	11.5
68	13+41.00	60.6 Lt.	714.5	22.5	28.1	24.3	22.3
69	13+85.00	40.0 Rt.	714.5	25.0	33.5	34.5	32.5
70	-	Centerline	714.5	22.5	34.5	41.5	40.5
71	-	40.0 Lt.	714.5	22.5	30.5	31.5	35.5
72	13+90.00	40.0 Rt.	725.0	9.5	13.0	15.0	17.0
73	-	Centerline	725.0	10.8	11.0	10.0	11.0
74	-	40.0 Lt.	725.0	10.0	15.0	20.0	28.0
75	13+95.00	40.0 Rt.	725.0	10.0	15.0	13.0	18.0
76	-	Centerline	725.0	10.8	15.0	16.0	16.0
77	-	40.0 Lt.	725.0	10.5	16.0	21.0	22.0

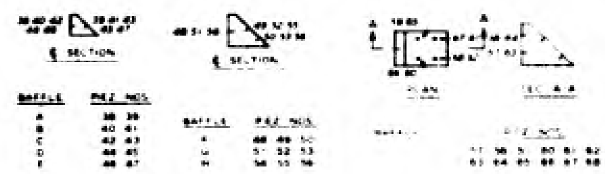
Note: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

TABLE G

PRESSURES - CHUTE PLAN O AND BAFFLE PLAN N

TEST 20





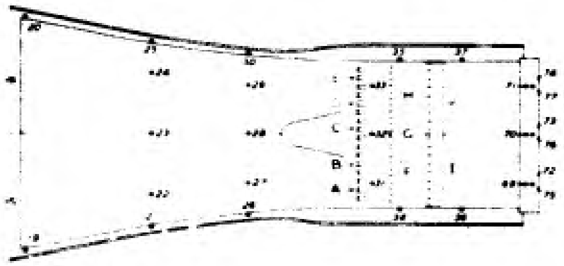
Piezometer				Discharge in c.f.s.			
				15 000	45 000	70 000	95 400
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	Head on Piezometer in Feet of Water			
19	10+01.85	94.6 Rt.	835.5	3.4	7.3	9.1	10.2
20	"	94.6 Lt.	835.5	3.1	5.2	5.6	5.2
21	11+00.00	75.0 Rt.	788.2	1.4	4.8	7.3	10.1
22	"	50.0 Rt.	785.7	3.0	7.5	10.6	13.8
23	"	Centerline	785.7	3.0	6.3	8.5	10.5
24	"	50.0 Lt.	785.7	2.9	7.2	9.7	12.0
25	11+00.00	75.0 Lt.	788.2	1.6	4.5	6.4	8.5
26	11+75.00	65.1 Rt.	750.7	-0.2	3.5	6.1	8.6
27	"	40.0 Rt.	748.2	2.8	7.9	11.2	13.2
28	"	Centerline	748.2	4.7	7.0	9.0	11.0
29	"	40.0 Lt.	748.2	4.6	6.2	10.8	12.6
30	"	65.1 Lt.	750.7	3.3	7.6	9.3	11.1
31	12+71.34	40.0 Rt.	712.0	25.3	24.0	26.0	32.7
32	"	Centerline	712.0	21.6	22.3	27.0	34.2
33	"	40.0 Lt.	712.0	22.7	25.8	22.2	27.0
34	12+93.00	60.6 Rt.	714.5	19.0	19.3	3.6	10.1
35	"	60.6 Lt.	714.5	19.5	25.5	12.0	14.6
36	13+41.00	60.6 Rt.	714.5	20.5	28.5	21.0	24.0
37	13+41.00	60.6 Lt.	714.5	20.5	27.7	29.7	25.1
38	12+59.34	45.5 Rt.	714.0	83.0	119.0	122.0	125.5
39	12+62.43	45.5 Rt.	714.0	-0.5	-31.5	-40.5	-35.0
40	12+59.34	24.5 Rt.	714.0	30.0	106.5	119.0	120.0
41	12+62.43	24.5 Rt.	714.0	-1.5	-27.5	-34.0	-25.0
42	12+59.34	3.5 Lt.	714.0	28.0	121.0	126.0	120.0
43	12+62.43	3.5 Lt.	714.0	18.5	-15.5	-26.0	-18.0
44	12+59.34	24.5 Lt.	714.0	36.5	122.0	112.0	118.0
45	12+62.49	24.5 Lt.	714.0	11.5	-25.0	-36.5	-29.0
46	12+59.34	45.5 Lt.	714.0	78.0	121.0	122.0	130.0
47	12+62.43	45.5 Lt.	714.0	2.5	-21.5	-38.0	-36.0
48	12+85.50	31.5 Rt.	715.0	25.0	55.0	67.0	75.0
49	12+87.40	31.5 Rt.	716.0	15.7	4.0	-18.5	-21.0
50	12+89.40	31.5 Rt.	714.0	18.3	12.0	-6.0	-8.0
51	12+85.50	Centerline	715.0	18.6	36.5	53.0	73.0
52	12+87.40	"	716.0	17.9	20.0	-9.5	-17.0
53	12+89.40	"	714.0	20.0	25.0	0.5	-4.0
54	12+85.50	31.5 Lt.	715.0	21.8	42.0	52.5	61.0
55	12+87.40	31.5 Lt.	716.0	15.8	8.0	-12.0	-15.0
56	12+89.40	31.5 Lt.	714.0	18.4	13.5	-4.0	-6.5
57	13+13.50	28.0 Rt.	714.5	19.9	28.0	28.5	32.5
58	"	28.0 Rt.	718.0	16.2	26.5	37.0	45.0
59	13+18.00	30.0 Rt.	718.0	16.3	25.5	2.5	-4.0
60	13+21.50	30.0 Rt.	714.5	19.7	27.5	11.5	5.5
61	13+18.00	26.0 Rt.	718.0	16.2	25.7	4.0	-3.5
62	13+21.50	26.0 Rt.	714.5	19.6	27.5	12.5	5.5
63	13+13.50	28.0 Lt.	714.5	19.5	28.1	24.5	31.5
64	"	28.0 Lt.	718.0	16.0	26.0	31.0	40.5
65	13+18.00	26.0 Lt.	718.0	16.0	22.2	10.0	5.0
66	13+21.50	26.0 Lt.	714.5	19.5	26.5	16.0	12.0
67	13+18.00	30.0 Lt.	718.0	16.0	21.8	9.5	6.0
68	13+21.50	30.0 Lt.	714.5	19.5	25.8	16.5	12.5
69	13+85.50	40.0 Rt.	714.5	20.8	28.6	25.0	27.0
70	"	Centerline	714.5	21.2	32.6	27.5	30.5
71	"	40.0 Lt.	714.5	20.7	28.1	24.5	26.0
72	13+90.00	40.0 Rt.	785.0	7.9	13.7	13.0	20.0
73	"	Centerline	785.0	8.7	12.0	14.5	4.0
74	"	40.0 Lt.	785.0	7.6	14.1	14.7	15.5
75	13+95.00	40.0 Rt.	785.0	7.9	13.7	14.5	12.0
76	"	Centerline	785.0	8.1	13.6	15.5	12.5
77	"	40.0 Lt.	785.0	7.7	14.4	15.3	16.5

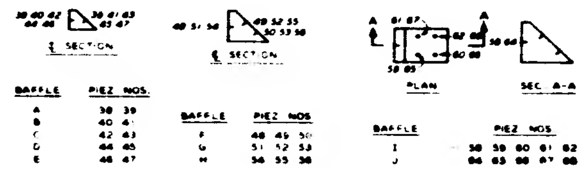
Note: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

TABLE H

PRESSURES – CHUTE AND BAFFLE PLANS O

TEST 24





Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
19	10+01.85	94.6 Rt.	835.5	3.1	6.2	7.6	8.3
20	"	94.6 Lt.	835.5	2.9	5.3	6.0	6.1
21	11+00.00	75.0 Rt.	788.2	1.8	5.1	7.8	10.6
22	"	50.0 Rt.	785.7	3.2	7.7	10.8	13.8
23	"	Centerline	785.7	3.8	6.4	8.5	10.6
24	"	50.0 Lt.	785.7	3.1	6.8	9.4	11.8
25	11+00.00	75.0 Lt.	788.2	1.3	4.1	6.2	8.4
26	11+75.00	65.1 Rt.	750.7	- 0.7	4.4	7.1	9.6
27	"	40.0 Rt.	748.2	3.5	8.0	10.8	13.3
28	"	Centerline	748.2	4.4	6.9	8.7	10.8
29	"	40.0 Lt.	748.2	4.5	8.1	10.3	12.5
30	"	65.1 Lt.	750.7	4.3	9.1	11.2	13.1
31	12+71.04	40.0 Rt.	712.0	24.3	28.2	25.2	31.5
32	"	Centerline	712.0	22.0	25.3	27.5	34.8
33	"	40.0 Lt.	712.0	25.5	26.8	12.0	25.8
34	12+93.00	60.6 Rt.	714.5	19.5	22.7	11.0	10.0
35	"	60.6 Lt.	714.5	19.8	25.9	20.0	16.0
36	13+41.00	60.6 Rt.	714.5	20.9	29.0	26.0	25.0
37	13+41.00	60.6 Lt.	714.5	20.9	28.5	27.0	25.5
38	12+59.24	45.5 Rt.	715.0	73.0	123.0	133.0	135.0
39	12+63.24	45.5 Rt.	715.0	5.0	- 19.0	- 36.0	- 31.0
40	12+59.24	24.5 Rt.	715.0	34.5	117.0	127.0	133.0
41	12+63.24	24.5 Rt.	715.0	13.8	- 19.0	- 31.0	- 27.0
42	12+59.24	3.5 Lt.	715.0	25.5	112.0	125.0	120.0
43	12+63.24	3.5 Lt.	715.0	18.0	- 8.0	- 21.5	- 17.0
44	12+59.24	24.5 Lt.	715.0	33.5	113.0	120.0	120.0
45	12+63.24	24.5 Lt.	715.0	13.0	- 15.0	- 33.0	- 31.0
46	12+59.24	45.5 Lt.	715.0	68.0	115.0	130.0	137.0
47	12+63.24	45.5 Lt.	715.0	6.5	- 11.0	- 30.0	- 32.0

Piezometer				Discharge in c.f.s.			
Number	Stati.	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
48	12+85.50	31.5 Rt.	716.5	21.0	49.5	56.5	68.5
49	12+88.00	31.5 Rt.	718.0	14.8	8.0	- 4.0	-15.0
50	12+91.00	31.5 Rt.	715.0	18.2	16.5	8.0	2.0
51	12+85.50	Centerline	716.5	17.9	36.5	46.5	68.5
52	12+88.00	"	718.0	16.5	18.5	5.0	-11.0
53	12+91.00	"	715.0	19.7	22.5	13.0	4.0
54	12+85.50	31.5 Lt.	716.5	21.0	44.5	46.5	60.5
55	12+88.00	31.5 Lt.	718.0	15.0	13.5	3.0	-10.0
56	12+91.00	31.5 Lt.	715.0	18.4	10.8	11.0	3.0
58	13+13.50	28.0 Rt.	718.0	17.0	30.0	27.0	38.0
59	13+19.50	30.0 Rt.	720.0	14.9	21.5	20.5	6.0
60	13+23.50	30.0 Rt.	716.0	19.0	26.1	25.5	14.0
61	13+19.50	26.0 Rt.	720.0	14.9	21.5	19.5	6.0
62	13+23.50	26.0 Rt.	716.0	19.0	26.1	25.2	13.0
64	13+13.50	28.0 Lt.	718.0	17.1	29.0	29.0	37.0
65	13+19.50	26.0 Lt.	720.0	15.0	21.5	21.0	9.0
66	13+23.50	26.0 Lt.	716.0	19.0	26.1	25.5	16.5
67	13+19.50	30.0 Lt.	720.0	15.0	21.5	20.7	9.5
68	13+23.50	30.0 Lt.	716.0	19.1	26.1	25.7	17.0
69	13+85.00	40.0 Rt.	714.5	21.4	29.3	30.7	26.0
70	"	Centerline	714.5	21.7	31.3	29.5	30.5
71	"	40.0 Lt.	714.5	21.4	28.5	30.3	27.0
72	13+90.00	40.0 Rt.	725.0	8.1	13.4	20.7	15.5
73	"	Centerline	725.0	9.0	13.2	20.9	15.0
74	"	40.0 Lt.	725.0	8.0	14.0	18.4	17.5
75	13+95.00	40.0 Rt.	725.0	8.3	14.1	20.4	16.5
76	"	Centerline	725.0	8.4	14.4	21.5	17.0
77	"	40.0 Lt.	725.0	8.1	14.8	18.0	17.5

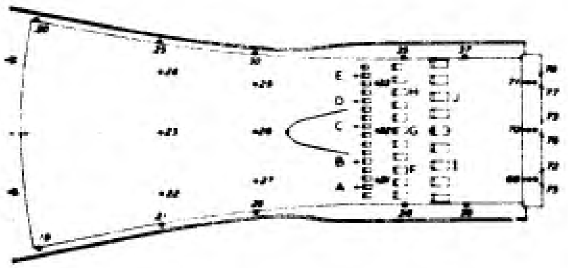
Note: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitati.n is indicated.

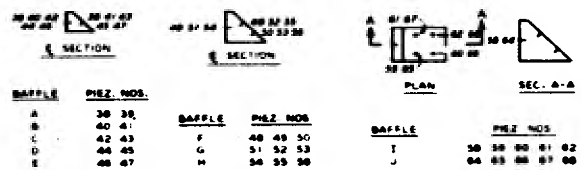
Piezometers 57 and 63 omitted.

TABLE I

PRESSURES - CHUTE AND BAFFLE PLANS P

TEST 25A





Piezometer Number	Piezometer Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	Discharge in c.f.s. 15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
19	10+01.85	94.6 Rt.	835.5	3.0	5.3	6.2	6.3
20	"	94.6 Lt.	835.5	2.5	3.7	3.5	2.4
21	11+00.00	75.0 Rt.	788.2	*	1.5	3.8	6.8
22	"	50.0 Rt.	784.4	2.0	5.7	8.7	11.6
23	"	Centerline	783.2	3.0	5.8	8.1	10.4
24	11+00.00	50.0 Lt.	784.4	2.1	4.9	7.1	9.4
25	"	Centerline	788.2	*	1.8	3.8	6.3
26	11+75.00	65.1 Rt.	750.7	*	4.8	8.3	10.8
27	"	40.0 Rt.	747.9	2.6	5.7	8.1	10.5
28	"	Centerline	747.6	2.4	5.1	7.1	9.3
29	11+75.00	40.0 Lt.	747.9	2.1	4.3	6.1	8.1
30	"	65.1 Lt.	750.7	*	6.9	9.7	12.8
38	12+59.24	45.5 Rt.	715.0	33.0	112.0	124.0	126.0
39	12+63.24	45.5 Rt.	715.0	14.0	- 10.0	- 36.0	- 33.0
40	12+59.24	24.5 Rt.	715.0	63.0	120.0	127.0	133.0
41	12+63.24	24.5 Rt.	715.0	5.5	- 21.0	- 32.0	- 24.0
42	12+59.24	3.5 Lt.	715.0	36.8	65.0	70.0	76.0
43	12+63.24	3.5 Lt.	715.0	59.7	- 7.0	- 10.0	- 2.0
44	12+59.24	24.5 Lt.	715.0	50.5	116.0	118.0	124.0
45	12+63.24	24.5 Lt.	715.0	7.5	- 15.0	- 32.0	- 27.0
46	12+59.24	45.5 Lt.	715.0	27.0	85.0	120.0	128.0
47	12+63.24	45.5 Lt.	715.0	17.0	0.0	- 29.0	- 33.0
48	12+85.50	31.5 Rt.	716.5	30.0	54.5	63.5	77.5
49	12+88.00	31.5 Rt.	718.0	12.5	7.0	- 12.0	- 16.0
50	12+91.00	31.5 Rt.	715.0	17.0	15.5	2.0	- 1.0

Piezometer Number	Piezometer Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	Discharge in c.f.s. 15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
51	12+85.50	Centerline	716.5	22.0	42.5	58.5	76.5
52	12+88.00	"	718.0	15.8	10.0	-10.0	-19.0
53	12+91.00	"	715.0	19.1	18.0	5.0	1.0
54	12+85.50	31.5 Lt.	716.5	25.7	40.5	49.5	59.5
55	12+88.00	31.5 Lt.	718.0	13.5	15.0	- 2.0	-11.0
56	12+91.00	31.5 Lt.	715.0	17.0	13.5	6.0	1.0
58	13+13.50	28.0 Rt.	718.0	20.0	30.0	26.0	33.0
59	13+19.50	30.0 Rt.	720.0	14.5	19.5	11.5	5.0
60	13+25.50	30.0 Rt.	716.0	18.8	24.5	16.0	13.0
61	13+19.50	26.0 Rt.	720.0	14.5	20.0	13.5	6.0
62	13+25.50	26.0 Rt.	716.0	18.5	24.5	20.5	14.0
64	13+13.50	28.0 Lt.	718.0	17.0	25.0	25.0	23.0
65	13+19.50	26.0 Lt.	720.0	15.0	20.8	17.0	8.0
66	13+25.50	26.0 Lt.	716.0	19.2	25.0	21.5	15.5
67	13+19.50	30.0 Lt.	720.0	15.0	20.6	17.0	18.0
68	13+25.50	30.0 Lt.	716.0	19.2	24.7	22.5	16.5
69	13+85.00	40.0 Rt.	714.5	21.1	28.5	27.0	26.0
70	"	Centerline	714.5	21.6	32.0	26.5	32.0
71	"	40.0 Lt.	714.5	21.5	27.5	27.5	26.5
72	13+90.00	40.0 Rt.	725.0	8.1	13.7	17.2	14.0
73	13+90.00	Centerline	725.0	9.0	13.0	16.5	11.0
74	"	40.0 Lt.	725.0	8.0	13.8	17.0	15.5
75	13+95.00	40.0 Rt.	725.0	8.0	14.1	17.5	15.0
76	"	Centerline	725.0	8.7	13.2	17.0	13.5
77	"	40.0 Lt.	725.0	8.0	13.5	17.0	16.0

Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.
* Not in contact with water.

Pressures at Piezometers 31 - 37 were not observed.

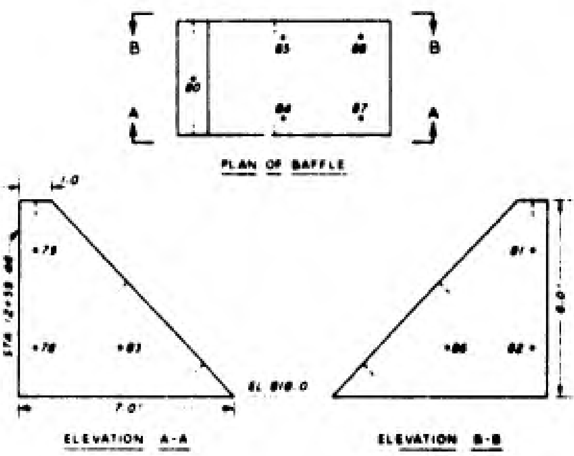
Piezometers 57 and 63 omitted.

TABLE J

PRESSURES ON BAFFLE A

TEST 25A

SEE TABLE I FOR
LOCATION OF BAFFLE A



Piezometer				Discharge in c.f.s.			
Number	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.	15 000	45 000	70 000	95 400
				Head on Piezometer in Feet of Water			
78	18+59.74	47.25 Rt.	713.5	7.8	-67.3	- 84.0	- 82.3
79	18+59.74	47.25 Rt.	716.5	7.0	-63.3	- 75.5	- 80.0
80	18+59.74	45.50 Rt.	718.0	9.6	-30.5	- 43.0	- 40.0
81	18+59.74	43.75 Rt.	716.5	3.0	-84.5	-121.5	-121.5
82	18+59.74	43.75 Rt.	713.5	6.7	-76.5	-113.5	-102.5
83	18+62.49	47.25 Rt.	713.5	15.7	-18.0	- 22.5	- 30.5
84	18+62.74	46.75 Rt.	715.5	13.7	-14.7	- 40.5	- 36.5
85	18+62.74	44.25 Rt.	715.5	14.8	-11.5	- 34.8	- 34.5
86	18+62.49	43.75 Rt.	713.5	14.4	- 4.7	- 25.5	- 15.5
87	18+65.24	46.75 Rt.	713.0	17.0	0.3	- 23.5	- 14.5
88	18+65.24	44.25 Rt.	713.0	18.1	0.0	- 23.3	- 10.5

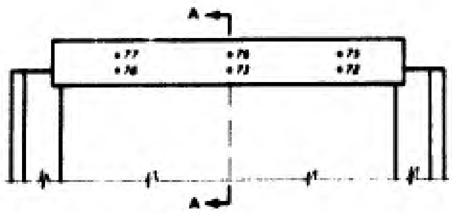
Notes: Piezometers 78 - 88 replace piezometers 38 and 39 in Baffle A - see Table I.

Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

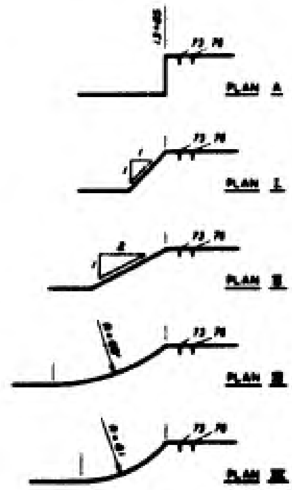
For location of Baffle A see sketch on Table I.

TABLE K

PRESSURES ON END SILLS



PLAN



SECTION A-A

End Sill Plan / Test					A 13 A	I 16 B	II 16 C	III 16 D	IV 16 E	A 13 F	I 16 A	III 16 G	IV 16 F
Piezometer				Discharge in C.F.S.	Without Baffles					With Baffles+			
No.	Station	Transverse Distance in Feet	Elevation in Feet M.S.L.		Head on Piezometer in Feet of Water								
72	13+90.0	40 Ft. Rt.	785.0	50 000	3.5 *	11.5	4.0	3.8	10.5	15.5 *	14.3	18.5	11.5
73	"	Centerline	"		5.5 *	10.8	3.5	3.2	12.0	16.2 *	16.4	18.5	14.0
74	"	40 Ft. Lt.	"		4.5 *	8.0	- 1.0	0.0	10.5	14.5 *	13.3	18.0	12.5
75	13+95.0	40 Ft. Rt.	785.0	50 000	3.5 *	11.5	3.0	5.0	12.8	14.0 *	14.3	18.0	12.5
76	"	Centerline	"		5.5 *	10.8	4.0	8.5	12.0	15.8 *	16.4	18.5	15.0
77	"	40 Ft. Lt.	"		5.0 *	6.0	- 0.5	0.0	10.5	14.5 *	13.4	15.0	13.0
72	13+90.0	40 Ft. Rt.	785.0	70 000	9.3	14.0	- 1.0	8.0	13.5	13.0	9.5	8.0	10.0
73	"	Centerline	"		7.5	12.0	- 3.0	6.8	12.5	13.0	11.0	9.0	10.0
74	"	40 Ft. Lt.	"		5.5	10.5	- 4.0	- 3.5	9.5	14.0	14.6	14.0	14.5
75	13+95.0	40 Ft. Rt.	785.0	70 000	8.5	13.8	- 8.0	8.5	13.8	13.0	13.0	11.5	12.5
76	"	Centerline	"		8.0	12.0	- 3.0	6.8	12.5	15.5	14.0	12.5	13.8
77	"	40 Ft. Lt.	"		9.0	10.8	- 4.0	- 1.5	9.5	14.8	15.5	14.5	14.8
72	13+90.0	40 Ft. Rt.	785.0	95 400	11.0	15.0	-33.0	-45.0	15.5	10.0	5.5	5.0	6.5
73	"	Centerline	"		8.0	14.0	-43.0	-40.0	14.0	9.8	5.0	5.0	3.0
74	"	40 Ft. Lt.	"		4.5	7.0	-38.0	-46.0	7.0	15.8	16.0	16.5	16.0
75	13+95.0	40 Ft. Rt.	785.0	95 400	11.5	15.0	-20.0	-45.0	15.2	12.8	10.5	10.5	10.0
76	"	Centerline	"		8.5	14.0	-31.0	-45.0	14.0	13.5	11.5	11.8	10.5
77	"	40 Ft. Lt.	"		8.0	6.5	-30.0	-19.0	7.0	16.5	16.5	17.0	17.8

Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

+ Baffle Plan I.

* Discharge = 45 000 c.f.s.

TABLE L

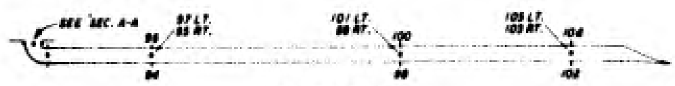
TUNNEL WATER - SURFACE ELEVATIONS

TEST 2A

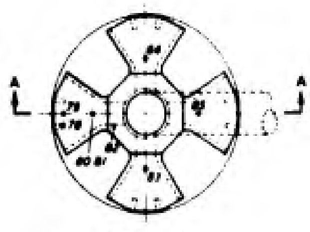
Gate Opening		1/4						1/3			1/2						3/4			Full		
Pool Elevation in Feet M.S.L.		770.5			832.0			832.0			770.5			825.0			770.5			770.5		
Tailwater Elev. in Ft. M.S.L.		780.3			782.5			785.9			782.4			785.1			783.6			785.6		
Discharge in c.f.s.		2000			3720			5000			3700			6130			4750			4750		
Tunnel Station	Invert Elevation in Feet M.S.L.	Height of Water Surface Above Invert in Feet																				
		Left	Right	Mean	Left	Right	Mean	Left	Right	Mean	Left	Right	Mean	Left	Right	Mean	Left	Right	Mean	Left	Right	Mean
6+05	723.5	9.5	9.0	9.2	10.0	11.0	10.5	12.0	11.0	11.5	9.5	9.5	9.5	11.0	11.0	11.0	11.0	12.0	11.5	11.0	10.5	10.8
6+50	723.1	6.0	6.0	6.0	7.0	8.0	7.5	11.0	10.0	10.5	9.0	8.5	8.8	11.0	10.0	10.5	10.0	10.0	10.0	9.0	9.5	9.2
7+00	722.6	5.5	5.5	5.5	8.0	7.0	7.5	9.0	10.0	9.5	8.5	9.0	8.8	9.0	10.0	9.5	10.0	10.0	10.0	9.5	9.5	9.5
7+50	722.1	5.0	7.5	6.2	4.5	10.0	7.2	6.0	12.0	9.0	8.0	11.0	9.5	6.0	14.0	10.0	8.0	12.0	10.0	7.0	12.5	9.8
8+00	721.7	5.5	6.5	6.0	5.5	9.0	7.2	7.5	11.0	9.2	8.5	9.5	9.0	6.5	13.0	9.8	9.5	11.0	10.2	9.5	10.5	10.0
8+50	721.2	5.0	8.0	6.5	6.0	9.0	7.5	7.0	11.0	9.0	7.0	10.5	8.8	8.0	11.5	9.8	8.0	12.5	10.2	8.0	12.0	10.0
9+00	720.8	5.5	7.0	6.2	6.5	10.0	8.2	7.5	11.5	9.5	8.5	9.5	9.0	7.0	13.5	10.2	9.5	11.5	10.5	9.0	11.0	10.0
9+50	720.3	6.0	7.0	6.5	7.0	9.0	8.0	8.0	11.0	9.5	8.0	11.0	9.5	9.5	11.5	10.5	9.0	12.5	10.8	9.0	12.0	10.5
10+00	719.8	7.0	7.0	7.0	9.0	8.5	8.8	11.0	10.5	10.8	10.0	9.0	9.5	10.5	11.0	10.8	11.5	10.5	11.0	11.0	10.0	10.5
10+50	719.4	7.0	7.5	7.2	8.0	10.0	9.0	10.0	10.0	10.0	10.0	10.0	10.0	11.0	10.5	10.8	11.0	12.0	11.5	11.0	12.0	11.5
11+00	718.9	7.0	6.5	6.8	9.0	7.0	8.0	10.5	10.0	10.2	10.0	10.0	10.0	10.5	11.5	11.0	11.0	11.5	11.2	11.0	11.0	11.0
11+50	718.5	6.0	6.0	6.0	8.0	9.0	8.5	9.0	10.0	9.5	9.0	9.0	9.0	11.0	10.0	10.5	10.5	10.5	10.5	10.5	10.5	10.5

TABLE M

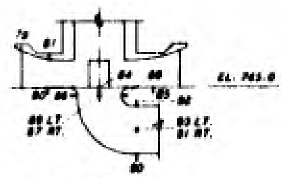
PRESSURES – ORIGINAL TUNNEL DESIGN
TUNNEL VENT CLOSED – TEST 2A



TUNNEL PROJECTED



INTAKE PLAN



SECTION A-A

Gate Opening			1/4	1/2				3/4		Full		
Pool Elevation in Feet M.S.L.			898.2	775.0	830.0	832.0	898.2	770.5	832.0	770.5	831.0	898.2
Tailwater Elevation in Feet M.S.L.			755	753	779	765	778	759	797	765	816	842
Discharge in c.f.s.			4500	4300	6380	7500	7800	6090	10050	6170	10080	10050
Piezometer			Head on Piezometer in Feet of Water									
Number	Station	Elevation in Feet M.S.L.										
78	5+62.50	750.0	107.8	24.5	73.0	73.6	106.5	19.5	78.2	19.5	77.9	104.7
79	5+61.50	756.7	101.2	17.5	72.5	73.2	100.1	13.1	73.0	13.6	71.7	98.4
80	5+72.00	745.0	111.5	28.0	81.1	68.5	107.1	22.0	76.2	21.7	73.5	101.8
81	5+72.00	754.0	102.8	19.3	72.6	72.3	98.8	13.8	67.4	12.6	66.2	92.2
82	5+73.60	749.5	105.5	19.8	69.5	66.3	91.8	9.7	49.2	9.8	50.7	74.5
83	5+90.00	745.0	111.3	27.8	80.5	79.5	106.0	21.7	73.3	21.8	76.0	102.0
84	5+90.00	745.0	111.8	27.7	80.2	72.2	103.4	21.5	74.7	20.7	72.7	98.5
85	6+00.00	745.0	110.6	27.6	79.8	78.1	104.3	20.5	71.6	21.5	74.9	100.7
86	5+82.25	742.5	1.0	2.0	28.8	8.3	27.5	2.0	13.5	2.2	18.5	38.2
87	5+90.00	742.5	-17.0	- 6.9	- 9.0	-33.5	-19.0	- 6.3	0.7	3.4	24.9	45.5
88	5+97.75	742.5	-33.5	-13.0	- 7.5	-27.5	-93.5	-58.5	*	-52.0	*	*
89	5+90.00	742.5	-12.5	- 7.0	2.7	-80.7	- 7.0	- 6.1	- 3.1	- 0.3	16.4	36.0
90	6+03.08	725.5	28.5	16.3	39.8	35.3	33.0	22.4	46.1	22.7	43.3	67.0
91	"	731.2	17.8	0.9	11.5	11.6	30.3	9.5	22.6	10.1	25.0	49.8
92	"	739.0	8.2	- 8.8	- 1.2	-24.8	- 9.5	-14.7	-26.9	-19.3	-44.0	-22.0
93	"	731.2	14.3	- 0.8	4.4	6.2	27.3	5.0	18.9	7.3	19.6	36.3
94	7+11.11	722.5	31.0	14.8	10.0	18.3	36.5	14.9	22.5	15.4	22.7	43.0
95	"	730.2	22.8	6.2	- 1.6	8.1	26.3	5.8	10.0	6.2	10.4	30.3
96	"	738.0	17.0	1.4	----	3.1	21.3	- 0.5	7.1	0.0	7.3	22.0
97	"	730.2	22.1	6.0	----	7.3	24.5	5.3	8.8	5.3	8.1	26.8
98	9+73.46	720.1	30.6	14.8	10.5	12.2	29.9	11.7	10.2	11.9	10.9	29.9
99	"	727.8	22.9	7.1	3.5	5.1	22.0	3.9	4.4	4.1	4.6	21.7
100	"	735.6	----	----	----	- 6.3	13.7	- 4.8	- 6.3	- 4.1	- 5.7	12.9
101	"	727.8	22.7	6.9	1.0	3.4	21.0	3.4	0.5	3.5	1.0	19.4
102	11+47.96	718.5	27.8	11.8	9.8	8.1	25.5	9.5	2.8	9.5	2.9	21.0
103	"	726.2	19.0	3.0	- 1.0	- 2.7	14.2	- 0.2	-11.0	- 0.5	-10.5	6.8
104	"	734.0	----	----	----	- 4.0	9.7	- 4.4	-10.7	- 4.3	-10.8	8.0
105	"	726.2	19.5	3.8	1.8	- 1.2	16.1	1.0	- 7.6	0.8	- 7.7	9.8

Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

* Reading was less than -120 ft. and could not be obtained.

TABLE N

PRESSURES - ORIGINAL TUNNEL DESIGN
TUNNEL VENT OPEN - TEST 2A

SEE TABLE M FOR SKETCH OF PIEZOMETER LOCATIONS

Gate Opening			1/4			1/3	1/2				3/4				Full			
Pool Elevation in Feet M.S.L.			770.5	832.0	858.2	832.0	770.5	805.0	832.0	858.2	770.5	775.0	832.0	858.2	770.5	775.0	832.0	858.2
Tunnel U.S. Elevation in Feet M.S.L.			749	753	757	766	755	778	769	779	764	765	801	821	768	770	840	843
Discharge in c.f.s.			2880	3780	4100	5000	3780	6130	7170	7500	4790	5760	9840	10400	4790	5700	9880	10100
Piezometer			Head on Piezometer in Feet of Water															
Number	Station	Elevation in Feet M.S.L.																
78	5+62.50	750.0	20.5	82.0	108.1	81.5	20.3	74.2	80.5	106.5	20.0	24.4	79.2	105.0	20.0	24.2	79.5	104.8
79	5+61.50	756.7	13.8	75.3	101.4	74.9	13.7	67.6	74.1	100.1	13.4	17.7	72.9	98.8	13.3	17.7	75.2	98.5
80	5+72.00	765.0	25.0	80.0	111.3	84.6	24.2	76.3	81.9	107.0	23.5	27.0	77.5	102.7	25.4	26.8	76.3	102.5
81	5+72.00	754.0	16.2	77.3	103.0	76.0	15.5	67.8	73.5	98.7	14.7	18.0	68.7	93.7	14.4	17.7	69.0	93.0
82	5+79.60	749.5	20.4	80.3	105.5	77.0	17.2	65.0	68.2	91.7	13.9	14.9	51.3	73.8	14.4	15.7	56.8	76.5
83	5+90.00	765.0	25.1	85.8	111.2	84.2	24.0	75.7	81.1	106.0	25.1	26.7	76.8	101.8	25.5	27.0	79.1	102.3
84	5+90.00	765.0	25.0	85.7	111.2	85.5	24.0	75.4	80.7	105.5	25.1	26.6	76.1	101.1	22.7	26.0	76.3	99.0
85	6+08.00	765.0	25.0	85.4	110.5	85.7	25.7	75.0	79.8	104.4	22.4	25.5	72.4	97.7	23.0	26.6	78.0	101.2
86	5+82.25	742.5	- 0.8	6.2	0.5	12.1	6.9	27.3	16.0	28.7	9.8	6.8	17.5	36.7	11.7	9.3	30.5	42.0
87	5+90.00	742.5	- 0.5	-11.0	- 17.5	-15.0	- 3.9	- 3.8	-25.0	- 18.5	5.9	1.5	5.0	22.2	11.7	10.3	36.5	46.0
88	5+97.75	742.5	----	----	- 19.0	- 3.0	- 0.5	- 2.5	-64.5	- 88.5	- 4.5	-31.0	*	*	- 1.1	-13.5	-49.0	*
89	5+90.00	742.5	- 0.5	-21.0	- 20.5	-15.5	- 2.0	2.8	-13.0	- 5.0	6.1	1.0	2.0	17.7	10.6	7.8	29.0	39.0
90	6+03.08	785.5	6.1	13.0	39.0	22.3	17.7	34.5	37.8	54.5	23.3	24.1	47.5	67.3	24.9	22.3	42.5	67.5
91	•	731.2	1.1	1.3	17.8	0.3	4.6	11.6	11.8	30.8	10.8	9.6	25.3	42.8	12.8	8.6	24.8	46.8
92	•	759.0	----	----	9.0	- 2.7	----	----	-15.0	- 8.0	----	- 8.0	-22.0	-10.0	----	----	-19.5	-15.5
93	•	751.2	0.1	- 0.2	14.8	- 2.6	2.0	5.3	10.0	20.3	8.7	7.9	20.8	39.8	11.7	6.8	19.3	38.3
94	7+11.11	732.5	6.3	7.7	31.0	9.5	8.8	10.0	25.3	37.0	10.0	18.2	24.3	42.5	9.9	18.2	30.0	45.0
95	•	730.2	----	----	22.8	----	1.4	----	14.0	28.8	3.3	9.4	12.6	29.3	- 0.2	9.6	19.5	32.8
96	•	758.0	----	----	17.0	----	----	----	8.7	21.8	----	4.0	9.5	27.2	----	3.4	15.3	30.0
97	•	730.2	----	----	22.3	----	1.0	----	11.5	25.3	1.4	6.0	10.3	27.8	- 0.8	7.8	16.1	25.3
98	9+73.46	720.1	6.3	7.9	30.9	9.7	9.2	10.5	17.6	30.4	10.7	15.7	12.9	29.4	10.4	16.2	19.6	31.6
99	•	727.8	----	1.6	25.2	2.4	1.9	2.9	9.6	22.2	3.8	7.9	14.2	21.4	2.5	8.2	11.6	25.4
100	•	753.6	----	----	----	----	----	----	----	12.6	----	----	----	12.8	----	----	3.2	10.9
101	•	727.8	----	----	22.9	0.1	1.8	0.8	8.8	21.2	3.5	7.3	2.2	19.4	2.0	7.7	9.7	20.7
102	11+47.96	716.5	6.8	8.2	28.0	9.5	9.1	9.8	12.2	25.5	10.5	12.0	4.5	21.5	10.3	12.5	11.2	22.0
103	•	726.2	----	- 0.4	18.8	- 0.2	0.3	- 1.0	1.8	14.3	1.2	2.8	- 8.7	7.0	0.9	3.0	- 1.2	8.3
104	•	734.0	----	----	----	----	----	----	----	13.5	----	----	----	8.5	----	----	----	7.5
105	•	726.2	----	0.2	19.6	1.3	3.9	1.8	3.5	16.3	5.6	3.8	- 6.2	10.8	2.0	3.9	1.3	10.8

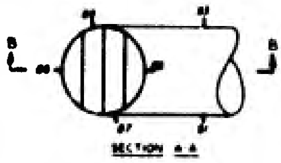
Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

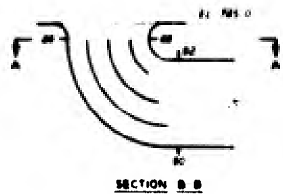
Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

* Reading was less than -120 ft. and could not be obtained.

TABLE O

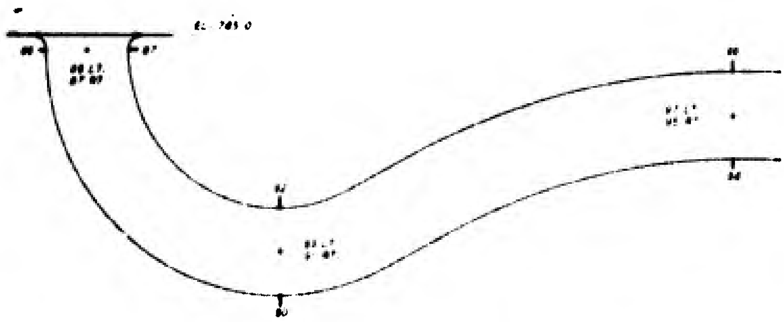
PRESSURES — TUNNEL ELBOW PLANS B AND C





PLAN B ELBOW — TEST 28B♦

Gate Opening			1/4			1/3	1/2			3/4			Full		
Pool Elevation in Feet M.S.L.			770.5	800.0	832.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0
Tunnel U.S. Elev. in Feet M.S.L.			746	748	750	755	750	765	778	764	786	807	767	794	802.0
Discharge in C.F.S.			2820	3090	3930	5000	4000	5600	6840	4990	6600	8350	4990	6800	8350
Piezometer			Head on Piezometer in Feet of Water												
Number	Station	Elevation in Feet M.S.L.													
86	5+80.25	748.5	0.5	-3.0	-5.7	-9.1	-4.4	-0.3	3.7	5.2	14.7	29.5	7.8	18.5	31.6
87	5+90.00	742.5	-2.2	-13.5	-24.5	-20.9	-10.4	-16.7	-17.8	-1.5	12.8	7.5	1.2	10.8	10.4
88	5+87.75	742.5	-0.8	-7.5	-11.3	-11.2	0.9	-1.4	-4.8	-12.5	-26.5	-46.0	-12.0	-27.5	-50.5
89	5+88.00	742.5	-1.1	-6.3	-10.8	-25.1	-10.6	-6.8	-13.8	1.2	0.2	19.2	0.4	21.6	36.3
90	6+03.08	783.5	15.1	16.1	20.5	26.3	13.3	27.3	36.5	23.5	34.1	49.2	28.6	35.6	40.8
91	"	731.2	0.6	1.8	2.6	4.2	3.4	5.6	8.2	6.8	9.6	12.4	6.9	10.9	14.6
92	"	729.0	----	----	----	----	----	----	----	----	----	----	----	----	----
93	"	731.2	0.8	1.6	3.0	5.3	3.1	5.7	8.1	6.8	10.0	13.2	6.6	10.2	14.[illegible]



PLAN C ELBOW — TEST 26♦♦

Gate Opening			1/4			1/3	1/2			3/4			Full		
Pool Elevation in Feet M.S.L.			770.5	800.0	832.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0
Tunnel U.S. Elev. in Feet M.S.L.			746	750	757	759	749	759	765	758	777	799	---	769	816
Discharge in C.F.S.			1900	2800	3990	5000	3060	6050	7500	6250	6550	9850	6530	8810	10650
Piezometer			Head on Piezometer in Feet of Water												
Number	Station	Elevation in Feet M.S.L.													
86	5+80.25	742.5	6.2	-3.0	-7.0	-20.7	-9.0	-15.5	-26.0	-2.7	-2.3	8.5	-3.0	3.5	8.3
87	5+90.00	742.5	3.8	-1.0	-5.0	-12.8	-0.8	-22.5	-31.0	-16.2	-19.2	-19.0	-6.5	-6.0	-4.5
88	5+87.75	742.5	4.5	-0.5	-3.0	-12.5	-0.2	-23.5	-30.5	-20.5	-25.5	-25.5	-14.0	-18.5	-22.8
89	5+90.00	742.5	2.5	-1.0	-5.0	-19.0	-10.5	-13.0	-30.5	-12.3	-14.0	-7.0	-4.3	-0.5	4.2
90	6+56.00	698.8	18.3	21.5	25.2	31.0	35.7	49.2	61.2	47.9	58.7	75.4	49.5	60.7	72.7
91	"	706.5	20.1	14.1	5.5	10.5	21.5	33.0	42.0	36.0	39.5	52.0	35.2	41.3	47.2
92	"	714.2	20.6	14.3	6.3	18.3	21.3	27.0	26.5	22.5	16.5	31.5	26.4	17.8	19.5
93	"	706.5	21.7	14.5	9.5	9.0	28.5	33.0	42.0	34.2	39.6	52.8	35.4	41.5	40.0
94	7+11.11	722.5	10.2	12.2	12.0	13.5	13.9	17.5	22.4	14.2	16.8	27.3	15.3	10.3	21.5
95	"	730.2	2.7	4.0	5.3	7.3	6.7	10.6	16.3	7.3	10.6	21.4	8.0	12.1	15.7
96	"	738.0	----	-1.0	0.5	4.0	1.0	6.0	11.0	1.0	5.5	17.3	2.1	7.3	12.5
97	"	750.2	2.7	4.8	9.1	7.3	6.6	10.2	15.0	6.0	9.4	19.6	7.6	10.4	13.6

Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

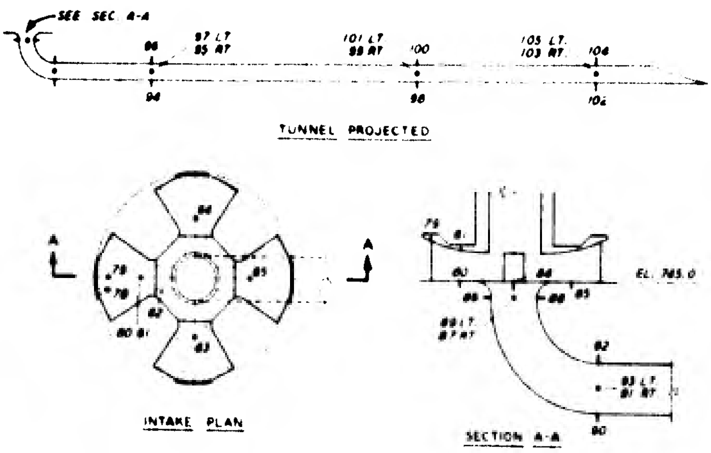
Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

♦ Tunnel Vent open.

♦♦ No Tunnel Vent.

TABLE P

PRESSURES - TUNNEL ELBOW PLAN D
TEST 27



Gate Opening			1/4			0.3	1/2			3/4			Full		
Pool Elevation in Feet M.S.L.			770.5	800.0	832.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0	770.5	800.0	832.0
Tower U.S. Elev. in Feet M.S.L.			----	----	----	744	748	753	758	757	777	797	764	787	810.0
Discharge in C.F.S.			2850	3330	4100	9000	4450	6800	8800	6900	9300	11000	6950	9300	11000
Piezometer			Head on Piezometer in Feet of Water												
Number	Station	Elevation in Feet M.S.L.													
78	5+60.50	770.0	20.5	50.0	81.6	81.3	20.0	48.3	79.2	19.0	47.5	70.2	19.0	47.5	77.6
79	5+64.50	756.7	13.8	45.3	73.0	76.7	13.3	41.8	73.1	12.4	41.3	71.8	12.6	41.1	71.5
80	5+72.00	765.0	25.1	54.1	85.2	84.0	25.3	49.4	78.3	20.8	46.8	74.4	20.4	45.0	72.8
81	5+72.00	754.0	16.5	45.3	76.5	77.5	14.5	41.2	70.5	12.1	38.2	65.9	11.5	36.7	68.0
82	5+72.60	762.5	20.5	49.4	80.5	78.5	17.2	44.5	68.1	10.6	30.6	55.4	10.0	31.1	55.0
83	[illegible]	762.0	25.2	54.0	85.8	83.9	25.2	48.2	77.8	19.7	45.3	72.4	20.6	46.6	74.0
84	[illegible]	760.0	25.0	53.9	84.9	85.5	25.0	48.5	77.0	19.7	45.0	72.5	19.3	44.8	71.1
85	[illegible]	765.0	25.0	53.9	84.8	85.5	25.0	48.7	76.8	19.5	43.5	70.0	20.2	45.6	72.9
86	5+82.85	760.0	-10.0	-21.3	-34.5	-12.5	- 1.0	- 6.0	- 6.5	4.7	15.5	27.0	7.5	20.0	32.4
87	5+90.00	760.0	-11.0	----	----	----	0.4	- 9.2	-14.0	- 0.5	6.0	14.8	2.6	8.0	14.5
88	5+97.75	760.0	----	----	----	----	0.1	- 6.0	-28.5	- 5.0	- 3.0	- 2.8	- 7.5	- 8.0	- 7.5
89	5+90.00	760.0	-10.0	-21.2	-28.0	-16.2	- 2.7	- 5.0	- 9.5	2.0	9.5	19.8	3.8	12.5	21.2
90	6+17.75	704.5	19.2	17.0	16.7	22.0	21.3	27.5	33.5	32.5	42.2	56.5	32.0	47.3	52.2
91	"	712.2	6.4	3.8	3.8	4.6	5.1	6.8	-21.8	26.3	30.3	35.8	26.8	31.0	34.3
92	"	720.0	----	----	----	----	----	4.5	25.0	17.3	12.3	14.8	11.6	10.2	10.9
93	"	712.2	7.0	----	----	----	4.1	7.8	34.8	20.2	33.6	39.1	27.8	33.2	38.4
94	7+11.11	705.6	25.8	10.3	9.9	9.9	27.0	31.4	37.9	29.4	31.0	32.4	29.4	31.1	32.4
95	"	713.3	16.2	----	----	----	20.3	26.2	33.7	25.5	26.6	29.6	25.3	26.7	29.4
96	"	721.1	----	----	----	----	----	10.9	24.9	16.6	20.3	24.2	16.4	20.4	24.7
97	"	713.3	16.1	----	----	2.4	19.1	25.7	29.2	20.8	21.8	22.6	20.8	21.7	22.7
98	9+73.46	708.7	19.6	10.0	10.0	10.0	21.3	21.8	22.3	17.9	13.7	9.4	17.9	13.6	9.6
99	"	716.4	11.6	- 0.1	2.6	- 4.9	11.5	9.6	7.6	5.9	- 1.7	- 9.7	5.8	- 1.5	- 9.4
100	"	724.2	----	----	----	----	----	----	----	3.2	- 0.2	- 4.2	3.5	- 0.1	- 4.2
101	"	716.4	11.9	----	3.6	3.6	13.4	14.1	14.1	10.0	5.9	1.0	10.1	5.8	0.9
102	11+47.96	710.7	17.2	11.8	10.8	10.6	16.1	14.6	12.3	12.1	5.0	- 2.5	12.0	4.9	- 2.6
103	"	718.4	9.3	4.4	3.1	2.3	7.7	5.9	3.1	2.8	- 5.3	-14.5	2.5	- 5.5	-14.2
104	"	726.2	----	----	----	----	----	----	----	- 3.2	-10.0	-17.7	- 3.2	- 9.8	-16.9
105	"	718.4	9.4	4.5	4.0	3.4	7.9	6.4	4.1	3.4	- 4.1	-12.7	3.5	- 4.0	-12.4

Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

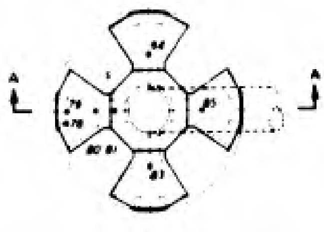
No Tunnel Vent.

TABLE Q

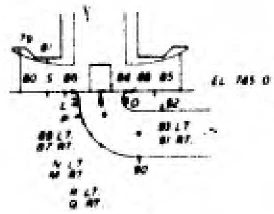
PRESSURES - LIP VENT PLAN A AND TUNNEL VENT PLAN B

TEST 28

TUNNEL PROJECTED



INTAKE PLAN



SECTION A-A

Gate Opening			1/4	1/3		1/2	3/4								Full	
Pool Elevation in Feet M.S.L.			832.0	832.0		832.0	832.0								832.0	
Tower U.S. Elev. in Feet M.S.L.			793	764	765	765	803				807				819	821
Discharge in C.F.S.			3300	5000	5000	7800	9590				8830				10800	9140
Upstream Lip Vent Pipes Downstream Lip Vent Pipes Tunnel Vent			Open Open Open	Open Open Open	Closed Closed Open	Closed Closed Closed	Closed Closed Closed	Open Closed Closed	Closed Open Closed	Open Open Closed	Closed Closed Open	Open Closed Open	Closed Open Open	Open Open Open	Closed Closed Closed	Closed Closed Open
Piezometer			Head on Piezometer in Feet of Water													
Number	Station	Elevation in Feet M.S.L.														
78	5+62.90	750.0	81.8	81.4	81.5	80.6	80.0	79.6	79.8	80.0	80.0	80.1	80.0	80.0	79.2	79.8
79	5+61.90	756.7	75.2	74.9	74.9	74.8	73.6	73.3	73.4	73.5	72.5	72.8	72.5	73.5	73.0	73.4
80	5+72.60	749.0	85.8	84.9	84.9	81.8	79.3	79.0	79.1	79.0	80.0	80.5	80.5	80.0	78.2	80.0
81	5+72.00	754.0	77.1	76.2	76.1	73.3	70.4	70.0	70.1	70.0	71.0	71.5	71.3	71.0	68.5	70.5
82	5+78.29	745.0	77.2	72.5	72.0	59.5	55.8	53.7	56.0	56.0	60.2	60.8	60.9	60.4	52.6	58.7
83	5+90.00	745.0	85.6	84.4	84.2	80.4	77.7	77.5	77.5	77.7	78.6	78.8	78.7	78.5	78.4	78.7
84	5+90.00	745.0	85.5	84.2	84.0	80.1	77.5	77.8	77.5	77.5	78.5	78.7	78.6	78.5	76.1	78.2
85	6+00.00	745.0	85.0	83.8	83.8	79.3	76.0	75.3	75.4	75.7	77.0	77.1	77.0	76.5	75.0	77.3
86	5+82.29	742.5	7.8	19.2	21.2	13.5	24.2	24.3	24.5	25.0	30.5	30.3	30.5	31.3	37.7	45.0
87	5+90.00	742.5	- 9.1	-15.5	-22.5	-30.8	10.5	10.5	9.5	10.1	25.9	25.7	26.0	26.7	17.1	26.5
88	5+37.75	742.5	0.6	0.0	0.0	-63.0	-105.5	-117.5	-115.5	-112.5	-60.0	-60.5	-60.5	-60.5	-119.5	-60.0
89	5+90.00	742.5	- 9.6	-12.0	-15.0	-25.5	18.5	19.7	20.0	19.1	27.0	29.0	28.0	28.5	27.5	39.5
L	5+82.31	741.0	7.0	20.0	22.5	14.5	43.0	40.5	41.8	43.8	47.5	44.5	46.5	46.5	53.5	58.5
M	5+30.10	741.0	- 8.0	-11.5	- 8.2	-13.9	22.0	22.0	21.5	28.0	31.5	32.2	31.6	30.5	38.6	39.2
N	5+90.10	741.0	-10.0	- 5.6	- 4.5	- 8.5	20.0	27.0	20.0	25.3	36.5	36.5	36.5	36.5	38.6	44.0
O	5+90.09	741.0	- 1.0	- 0.7	- 0.5	-96.0	-67.0	-75.0	-75.0	-75.0	-80.2	-27.0	-80.2	-89.7	-86.0	-80.0
P	5+82.98	737.5	11.3	21.7	23.9	19.5	53.3	52.7	52.5	53.7	59.5	56.8	59.0	58.1	63.5	67.3
Q	5+91.17	737.5	6.2	14.8	17.5	3.3	23.7	22.6	22.5	23.5	32.5	31.5	31.8	30.9	28.7	37.5
R	5+91.17	737.5	4.8	25.5	25.7	11.3	30.5	29.8	29.5	30.1	39.5	30.7	39.0	38.0	31.5	48.5
90	6+03.06	723.5	16.8	29.0	30.3	36.5	49.5	43.8	61.2	50.5	48.7	48.0	48.8	48.7	54.0	49.7
91	6+03.06	731.2	1.3	4.8	6.1	9.8	24.8	26.1	26.6	25.9	24.3	24.3	24.8	25.0	30.2	25.1
92	6+11.06	730.9	----	----	----	- 7.4	3.1	7.6	0.6	6.6	----	----	----	----	15.1	----
93	6+03.06	731.2	0.6	2.1	3.2	12.8	29.3	31.6	31.6	30.8	26.8	26.8	26.7	29.7	34.8	28.1
94	7+11.11	722.5	9.3	10.6	10.7	20.0	29.0	29.5	29.7	29.5	31.5	31.5	31.4	31.8	31.5	33.1
95	"	730.2	----	2.0	2.5	13.5	22.5	22.9	23.0	23.0	24.8	25.0	24.8	25.1	25.1	25.5
96	"	730.0	----	----	----	4.2	12.8	13.0	13.2	13.0	15.5	16.0	16.0	15.7	15.0	16.6
97	"	730.2	1.0	0.9	0.5	9.8	17.1	17.5	17.3	17.3	20.8	20.0	19.8	20.0	18.6	21.3
98	9+73.46	780.1	3.4	10.6	10.6	12.5	17.7	17.6	17.6	17.6	20.4	20.4	20.4	20.4	18.2	21.1
99	"	727.8	- 3.0	6.5	- 3.9	- 2.8	- 1.6	- 1.8	- 1.6	- 1.7	1.7	1.7	1.7	1.7	- 2.2	1.6
100	"	735.6	----	----	----	- 4.6	1.1	1.3	1.4	1.4	4.9	5.1	4.9	4.9	1.5	----
101	"	727.8	----	1.2	1.2	2.4	6.4	6.4	6.4	6.9	9.5	9.2	9.9	9.2	6.4	9.8
102	11+47.96	716.5	0.5	9.1	9.0	7.7	10.2	10.0	10.2	10.1	12.1	12.0	12.0	12.0	9.7	11.5
103	"	726.2	1.2	1.2	1.0	- 2.2	- 1.2	- 1.2	- 1.2	- 1.2	1.3	1.3	1.3	1.3	- 2.1	0.2
104	"	734.0	----	----	----	- 7.3	- 5.3	- 5.4	- 5.3	- 5.1	----	----	----	----	- 5.8	----
105	"	726.2	0.5	1.0	0.6	- 2.9	- 1.4	- 1.7	- 1.7	- 1.8	0.8	0.8	0.6	0.5	- 2.5	0.1

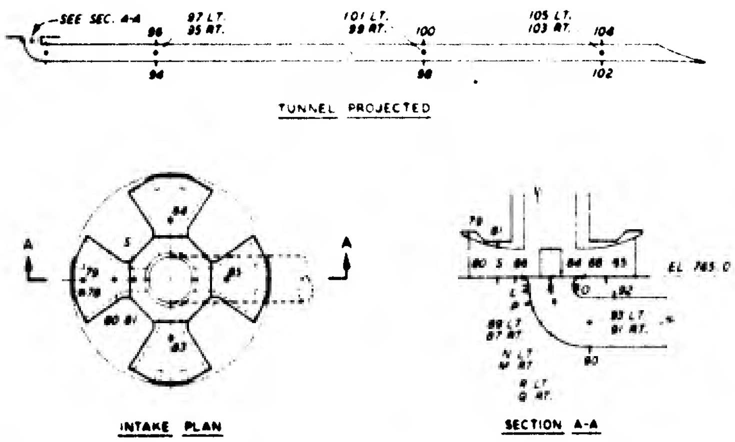
Notes: Negative values greater than approximately -20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

TABLE R

PRESSURES - LIP VENT PLAN B AND TUNNEL VENT PLAN B

FINAL TUNNEL DESIGN - TEST 29



Gate Opening	0.052	0.075	0.113	0.181	0.234	1/4				0.34				0.363	0.456	1/2			
Pool Elevation in Feet M.S.L.	832.0	800.0	770.5	832.0	800.0	832.0				832.0				770.5	800.0	832.0			
Tailwater W.S. Elev. in Feet M.S.L.	----	----	----	753	753	757				765				751	768	764	779	764	765
Discharge in C.F.S.	1000	1000	1000	3000	3000	3940	4000	4020		5000				3000	5000	6620	7000	6600	7700
Lip Vents / Tunnel Vent	Open Open	Open Open	Open Open	Open Open	Open Open	Open Open	Open Closed	Closed Open	Closed Closed	Open Open	Open Closed	Closed Open	Closed Closed	Open Open	Open Open	Open Open	Open Closed	Closed Open	Closed Closed

Piezometer — Head on Piezometer in Feet of Water

Number	Station	Elevation in Feet M.S.L.	0.052	0.075	0.113	0.181	0.234	1/4 O/O	1/4 O/C	1/4 C/O	1/4 C/C	0.34 O/O	0.34 O/C	0.34 C/O	0.34 C/C	0.363	0.456	1/2 O/O	1/2 O/C	1/2 C/O	1/2 C/C
[illegible]	[illegible]	780.0	88.0	30.0	20.5	88.0	30.0	81.5	81.7	81.6	81.5	81.4	81.4	81.5	81.4	20.5	30.0	80.7	80.7	80.8	80.3
[illegible]	[illegible]	774.7	77.3	43.3	13.8	73.3	43.3	73.9	73.2	73.0	73.6	74.9	74.8	74.5	74.9	13.8	43.3	74.4	74.4	76.5	73.9
[illegible]	[illegible]	765.0	87.8	54.0	25.3	82.4	54.4	85.6	85.7	85.6	85.5	84.9	84.7	84.7	84.9	24.9	53.1	83.1	82.7	83.3	81.7
[illegible]	[illegible]	765.0	78.0	46.0	16.5	77.7	45.7	77.1	77.2	77.1	77.1	76.5	76.4	76.5	76.8	16.0	44.5	73.1	74.8	73.3	74.1
[illegible]	[illegible]	765.0	86.5	54.6	25.6	80.9	49.0	76.5	77.7	76.5	76.6	72.6	78.0	78.4	78.6	19.9	42.7	76.7	78.8	77.6	80.2
[illegible]	[illegible]	765.0	87.0	55.0	25.5	86.3	54.3	85.5	85.5	85.4	85.4	84.5	84.4	84.4	84.4	24.7	52.4	82.3	81.8	82.3	80.3
[illegible]	[illegible]	765.0	87.0	55.0	25.3	86.2	54.2	85.3	85.4	85.3	85.2	84.3	84.2	84.2	84.3	24.7	52.2	82.1	81.7	82.2	80.1
[illegible]	[illegible]	765.0	87.0	55.0	25.5	86.0	53.8	84.9	85.0	84.9	84.9	83.7	83.5	83.8	83.8	24.5	51.6	81.1	80.4	81.3	78.9
86	[illegible]	762.5	-3.7	-8.3	-4.5	1.2	2.0	6.1	5.7	6.8	6.9	15.0	14.6	20.7	19.9	2.3	17.2	30.5	19.8	31.0	15.5
87	[illegible]	762.5	-2.0	-0.8	0.3	-1.7	-1.7	-2.4	-2.5	-9.7	-15.0	-1.5	-1.6	-22.0	-22.5	-0.5	-0.2	-0.5	-2.1	-4.0	-89.5
88	5+87.72	762.5	-2.5	-1.0	-0.3	-0.7	0.3	-0.8	-1.0	-0.6	0.0	-2.7	-3.3	0.3	0.3	0.6	0.0	-1.5	-16.5	-2.2	-77.5
89	5+90.60	762.5	-2.0	-1.7	-1.0	-2.2	-1.4	-2.0	-1.9	-17.0	-20.0	-0.3	-0.4	-12.3	-13.2	-0.4	0.8	3.7	-1.9	3.5	-84.8
L	5+86.31	761.0	3.0	2.4	-3.0	1.3	2.5	5.9	6.0	6.9	6.0	15.5	15.0	21.9	20.3	3.2	18.3	38.0	21.5	38.7	16.4
M	5+90.10	761.0	-0.5	0.3	0.4	-1.5	-1.6	-2.3	-2.5	-10.0	-14.9	-0.5	-1.0	-9.3	-11.7	0.3	2.0	8.8	-1.4	14.5	-7.0
N	5+90.10	761.0	-0.8	-0.7	-0.5	-2.0	-1.2	-1.9	-9.4	-15.9	-15.3	1.7	1.4	-7.3	-8.3	1.0	5.5	15.5	4.5	17.0	-6.0
O	5+96.09	761.0	-0.8	-0.4	0.3	-1.0	-0.5	-1.5	-1.8	-1.5	-0.6	-3.2	-3.5	-0.4	-0.5	0.0	-0.7	-2.4	-16.7	-1.8	-49.0
P	5+86.38	737.5	4.6	4.2	3.3	2.8	5.2	9.0	8.9	11.3	10.7	17.9	17.3	23.4	22.1	7.5	22.7	38.5	30.3	38.6	41.0
Q	5+91.17	737.5	0.0	0.0	0.0	-1.2	0.3	0.4	-1.0	7.5	7.5	5.1	4.2	17.0	15.7	3.9	13.3	24.2	11.5	25.7	8.2
R	5+91.17	737.5	-0.3	-0.6	-0.3	1.5	1.0	0.6	1.2	12.0	12.5	7.4	6.0	23.7	22.3	4.0	18.3	33.0	17.2	34.2	14.4
90	6+03.08	753.5	4.5	4.6	5.8	0.7	11.3	14.8	15.1	17.9	17.5	27.3	26.5	30.0	20.9	15.2	27.3	33.5	31.9	39.8	40.7
91	[illegible]	751.8	----	----	----	1.1	1.2	0.5	0.6	1.3	1.3	0.6	0.1	5.8	5.3	2.0	5.2	9.0	-6.6	12.7	15.2
92	[illegible]	750.9	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-16.9	----	-1.9
93	6+03.08	751.8	----	----	----	1.4	1.5	1.2	1.2	0.0	0.0	1.7	1.3	3.1	2.3	1.4	6.3	12.8	-1.5	14.1	10.5
94	7+11.11	788.5	5.7	5.6	5.8	9.1	9.2	9.2	9.2	9.0	9.0	10.5	10.9	10.5	----	9.5	11.6	11.8	22.8	11.8	24.0
95	•	[illegible]	----	----	----	----	----	----	1.2	----	----	2.5	2.3	2.2	2.5	1.8	3.2	3.9	16.8	4.3	16.8
96	•	[illegible]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	8.5	----	7.8
97	•	750.2	----	----	----	0.6	----	0.8	0.9	1.1	1.0	1.1	1.2	0.2	0.2	0.5	1.0	0.3	12.6	0.3	18.7
98	9+73.46	780.1	6.4	5.9	6.1	8.2	8.8	9.2	9.1	9.0	8.9	10.3	10.3	10.0	9.9	9.3	9.9	11.3	17.4	11.3	19.3
99	•	787.8	----	----	----	2.6	1.8	3.3	3.3	3.1	3.1	3.5	3.6	2.5	2.7	2.5	3.6	3.8	9.9	3.8	7.7
100	•	[illegible]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.2
101	•	787.8	----	----	----	----	----	----	----	----	----	1.6	1.5	1.4	1.4	1.2	1.2	2.7	8.9	2.7	6.6
102	11+47.96	718.5	6.7	7.4	7.6	7.7	7.8	8.2	8.2	8.2	8.2	9.0	9.2	8.2	8.3	8.4	9.0	9.1	11.5	9.0	10.6
103	•	[illegible]	----	----	----	0.7	0.5	1.4	1.5	1.3	1.4	1.4	1.6	1.1	1.1	0.9	1.0	1.3	3.8	1.3	2.1
104	•	714.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-3.9
105	•	[illegible]	----	----	----	----	----	0.6	0.6	0.7	0.7	1.5	1.5	1.1	1.1	0.9	0.8	0.9	2.5	0.9	1.6

Notes: Negative values greater than approximately - 20 ft. cannot be interpreted quantitatively -- possibility of cavitation is indicated.

Where no readings are shown, the piezometer openings were not in contact with water or were taking air.

B

		0.34				0.363	0.356	1/2				3/4				Full					
		832.0				770.5	800.0	832.0				832.0				770.5		832.0			
		765				751	768	784	779	784	765	811	808	807	802	768	767	820	816	819	815
4000		5000				3000	500	6680	7000	6600	7700	6840	6700	8700	9560	4900	5000	8700	9130	9000	9580
Closed Open	Closed Closed	Open Open	Open Closed	Closed Open	Closed Closed	Open Open	Open Open	Open Open	Open Closed	Closed Open	Closed Closed	Open Open	Open Closed	Closed Open	Closed Closed	Open Open	Closed Closed	Open Open	Open Closed	Closed Open	Closed Closed
Head on Piezometer in Feet of Water																					
81.6 73.0 82.2 82.6 77.1 76.5 80.4 82.3 84.5	81.5 73.0 82.5 77.1 76.6 80.4 82.8 84.9	81.4 74.9 84.5 76.5 78.0 84.5 84.5 83.7	81.4 74.8 84.7 76.4 78.0 84.4 84.2 83.5	81.5 74.5 84.9 76.5 78.4 84.4 84.8 83.8	81.4 74.9 84.9 76.9 78.6 84.4 84.3 83.8	80.5 13.8 24.9 16.0 19.9 24.7 24.7 24.5	50.0 43.3 33.1 44.5 42.7 50.4 52.2 51.6	80.7 74.4 83.1 73.1 82.7 88.3 82.1 81.1	80.7 74.4 82.7 74.8 82.8 81.8 81.7 80.4	80.8 74.3 73.3 73.3 87.0 88.3 82.2 81.3	80.3 73.2 81.7 74.1 60.2 80.3 80.1 78.9	80.0 73.7 81.2 73.3 65.2 79.8 73.9 78.2	80.0 73.8 81.0 72.8 62.0 79.3 79.5 77.6	79.9 73.6 80.5 78.8 66.7 78.5 72.5 76.5	79.4 73.3 78.5 71.4 54.2 76.6 77.1 74.2	80.0 13.6 45.6 14.8 17.9 25.5 28.3 28.8	80.0 13.6 45.3 14.8 17.9 25.5 28.5 28.7	73.8 73.6 60.0 71.8 60.0 65.3 73.7 70.4	73.4 73.4 73.8 71.1 61.1 73.2 77.9 77.4	73.4 73.3 78.3 71.3 66.3 73.8 77.1 77.7	73.1 73.1 70.1 70.4 67.2 76.3 76.8 75.9
6.8 - 9.7 - 0.6 -17.0	6.9 -15.0 0.0 -20.0	15.0 - 1.5 - 2.7 - 0.3	14.6 - 1.6 - 3.3 - 0.4	20.7 -22.0 0.3 -10.3	13.5 -20.5 0.3 -13.2	2.3 - 0.5 0.6 - 0.4	17.2 - 0.2 0.0 0.8	30.5 - 0.5 - 1.5 3.7	19.8 - 2.1 -16.5 - 1.9	31.0 - 4.0 - 2.2 3.5	15.5 -29.5 -77.5 -24.2	35.5 29.0 - 4.5 29.3	32.0 26.3 -13.3 26.1	32.0 31.8 -30.5 24.0	20.5 7.1 -116.0 7.5	13.9 9.3 - 2.0 12.4	13.5 9.1 - 7.7 11.6	36.0 26.3 -18.0 39.5	40.7 19.0 -33.3 36.6	32.7 22.3 -32.2 34.6	43.1 11.0 -118.5 26.1
6.9 -10.6 -15.5 - 1.5	6.0 -14.5 -15.3 - 6.6	15.5 - 0.5 1.7 - 3.2	15.0 - 1.0 1.4 - 3.5	21.9 - 9.3 - 7.3 - 0.4	20.3 -11.7 - 0.3 - 0.5	3.2 0.3 1.0 0.0	18.3 2.0 5.5 - 0.7	32.0 8.8 15.5 - 2.4	21.5 - 1.4 4.5 -16.7	32.7 14.5 17.0 - 1.8	16.4 - 7.0 - 6.0 -49.0	50.5 37.5 40.0 -10.5	47.8 33.6 36.3 -25.0	40.5 31.2 35.5 -21.5	39.5 13.5 22.0 -79.0	16.3 13.5 15.6 - 1.0	16.0 13.1 14.0 - 2.3	65.7 41.0 50.0 -44.0	59.0 34.7 44.4 -37.5	62.0 38.0 46.3 -20.8	34.3 22.8 33.8 -37.0
11.3 7.5 12.6	10.7 7.5 12.5	17.9 5.1 7.4	17.3 4.2 6.0	25.4 17.0 23.7	22.1 15.7 22.3	7.5 3.5 4.0	22.7 13.3 18.3	38.5 24.2 33.0	30.3 11.5 17.2	38.8 25.7 34.2	21.0 8.2 14.4	63.0 32.0 40.2	61.0 28.3 37.8	60.5 32.0 30.2	52.5 18.8 24.5	25.7 15.5 17.5	23.5 15.2 16.5	70.7 41.0 53.0	66.7 33.0 47.5	71.2 35.5 58.0	60.5 30.0 42.5
17.9 1.3 ---- 0.0	17.5 1.3 ---- 0.0	27.3 0.6 ---- 1.7	26.5 0.1 ---- 1.3	30.0 5.8 ---- 3.1	26.9 5.3 ---- 2.3	15.2 2.0 ---- 1.4	27.3 5.2 ---- 6.3	33.5 9.0 ---- 12.8	31.9 - 6.6 -16.9 - 1.5	39.8 12.7 ---- 14.1	40.7 15.2 - 1.9 10.5	42.5 14.8 ---- 21.3	39.9 10.1 -21.1 17.6	40.5 20.8 ---- 26.8	45.0 19.5 - 1.4 24.3	25.4 11.2 ---- 12.2	25.8 12.0 ---- 13.2	43.0 20.8 ---- 24.8	48.0 16.6 -11.4 28.0	47.3 22.3 ---- 31.3	51.7 25.3 13.1 36.8
9.0 ---- ---- 1.1	9.0 ---- ---- 1.0	10.5 2.5 ---- 1.1	10.5 2.3 ---- 1.2	10.5 2.6 ---- 0.2	---- 2.5 ---- 0.2	9.5 1.2 ---- 0.5	11.8 3.2 ---- 1.0	11.8 3.9 ---- 0.3	22.8 16.8 8.5 12.6	11.8 4.3 ---- 0.3	24.0 16.8 7.2 12.7	9.0 2.8 ---- - 3.2	30.0 24.4 14.4 19.0	30.5 25.0 15.8 19.3	22.5 17.6 6.7 10.3	11.3 4.1 ---- 1.6	11.6 4.5 ---- 1.9	31.2 26.7 16.2 19.8	29.5 25.8 13.7 17.8	32.5 26.6 17.0 20.8	29.9 26.7 14.1 17.8
9.0 3.1 ---- ----	8.9 3.1 ---- ----	10.3 3.5 ---- 1.6	10.3 3.6 ---- 1.5	10.0 2.5 ---- 1.4	9.9 2.7 ---- 1.4	9.3 2.5 ---- 1.2	9.9 3.6 ---- 1.2	11.3 3.2 ---- 2.7	17.4 9.9 ---- 8.9	11.3 3.2 ---- 2.7	15.3 7.7 0.2 6.6	13.4 5.2 ---- 4.2	18.6 11.0 3.9 9.4	19.1 11.5 ---- 9.9	8.9 1.3 - 6.0 - 0.7	12.2 4.6 ---- 4.1	12.4 4.9 ---- 4.3	19.4 11.5 ---- 9.4	16.9 9.5 1.4 7.3	19.9 12.0 ---- 10.0	16.3 8.7 1.0 6.8
8.2 1.3 ---- 0.7	8.2 1.4 ---- 0.7	9.0 1.4 ---- 1.5	9.2 1.6 ---- 1.5	8.8 1.1 ---- 1.1	8.3 1.1 ---- 1.1	8.4 0.9 ---- 0.9	9.0 1.0 ---- 0.8	9.1 1.3 ---- 0.9	11.5 3.2 ---- 2.5	9.0 1.3 ---- 0.9	10.6 2.1 - 3.9 1.6	9.0 0.8 ---- - 0.7	10.5 1.9 - 0.5 0.8	10.5 1.9 ---- 0.5	0.9 - 0.7 -13.5 - 9.9	10.5 2.8 ---- 2.1	10.7 3.0 ---- 2.3	10.7 2.0 ---- 0.1	8.6 0.1 - 3.5 - 2.4	10.6 1.7 ---- - 0.3	8.1 - 1.0 - 5.7 - 2.9

-- possibility of cavitation is indicated.

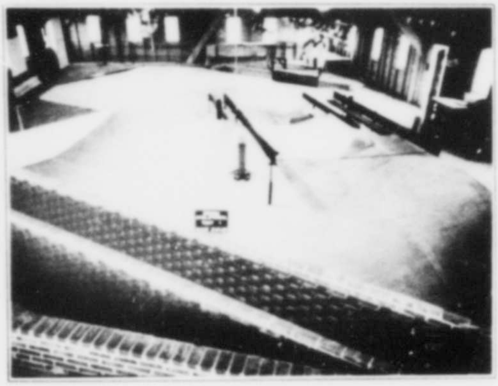
are taking air.

TABLE R

PHOTOGRAPHS

BEST POSSIBLE SCAN

MODEL CONSTRUCTION



Photograph 1

General view of completed model looking downstream from forebay. The steel rails shown were used to carry a movable observation carriage over model.

Photograph 2

General view from tailbay of model constructed according to original design.

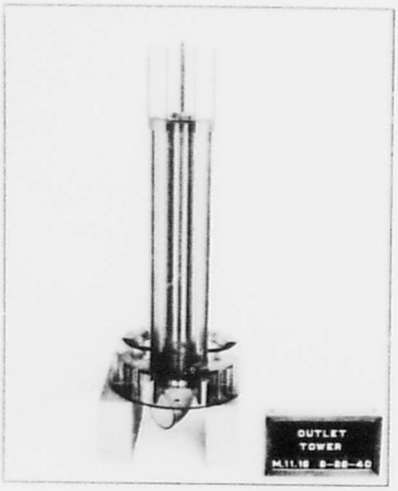
Photograph 3

Partially completed model tailbay. Note metal templets and backfill prior to pouring concrete slab molded to scaled hydrography of the river bed. Spillway construction is shown in lower right foreground.

Photograph 4

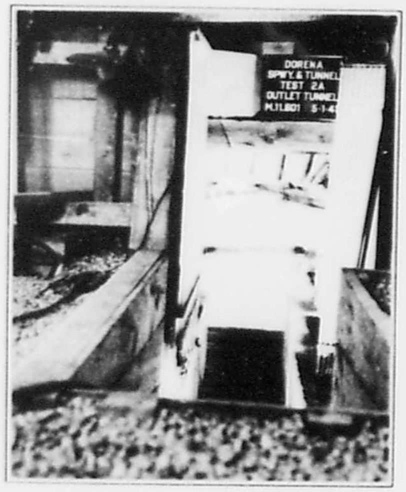
Construction of spillway and stilling basin. Brick baffle wall and section of dam are shown in background.

MODEL CONSTRUCTION



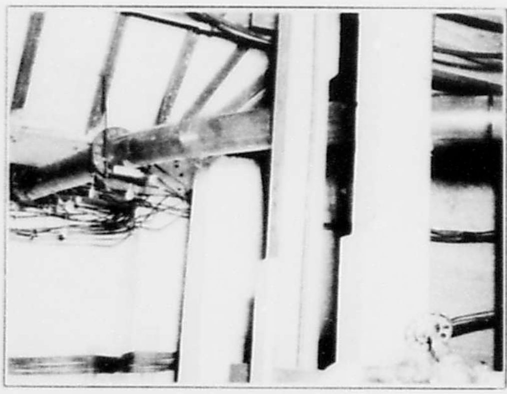
Photograph 5

Pyralin outlet tower with cylinder gate partially open. Trash racks over intake ports are not in place. Plan A elbow is shown beneath cylinder gate.



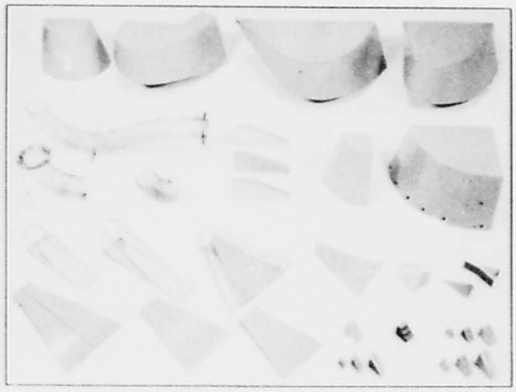
Photograph 6

Inspection gallery underneath model. Note section of outlet tunnel and manometer boards to either side of entrance.



Photograph 7

View of 15.5-ft. outlet tunnel beneath spillway. Note copper tubing leading from piezometer taps to manometer boards.



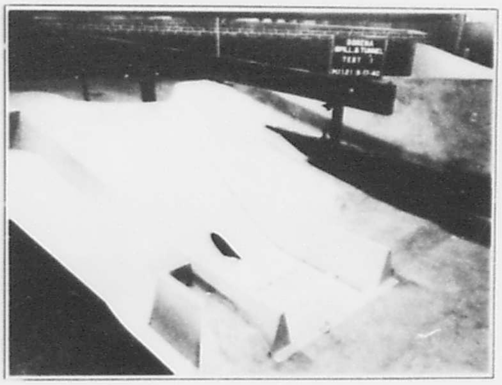
Photograph 8

Some of the modifications of the various features tested, including left abutment plans, tunnel elbows, crest profiles, tunnel outlets, deflector blocks, and baffles.

ORIGINAL SPILLWAY DESIGN

Photograph 9

View of approach apron, right approach wall, left and right abutments, and ogee crest. Note outlet tower at left.

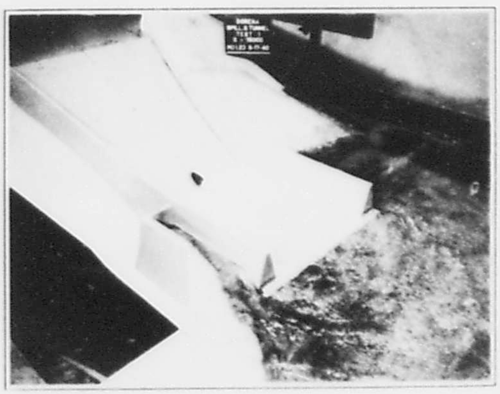


Photograph 10

Looking upstream at spillway chute, tunnel outlet, stilling basin, baffles, and end sill. Note numerous piezometer openings throughout this section.

Photograph 11

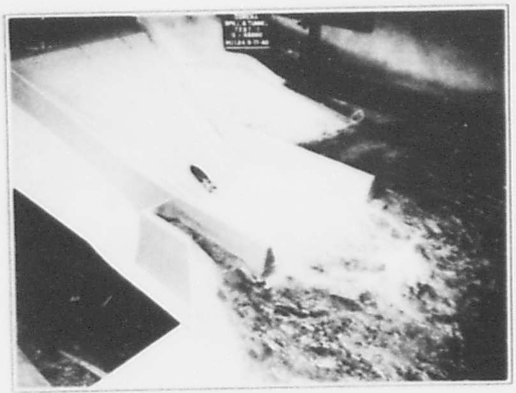
Q = 95 000 c.f.s. Flow over apron and down chute; subsurface currents over apron are shown by dye streaks. Note eddies produced at upstream edge of right approach wall, draw-down around left abutment, and water almost overtopping right sidewall of chute just below crest.



Photograph 12

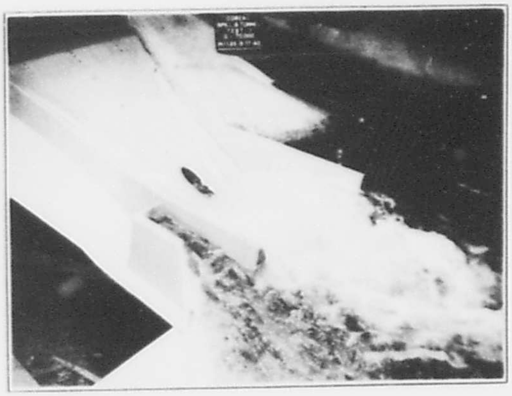
Q = 15 000 c.f.s. Flow conditions down chute and in stilling basin. Note standing waves along chute sidewalls.

ORIGINAL SPILLWAY DESIGN



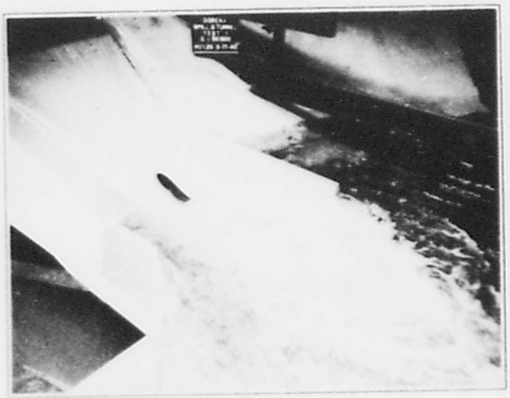
Photograph 13

Q = 45 000 c.f.s. Compare with Photograph 12 and note greater convergence and increased height of standing waves in chute. This discharge was the maximum at which a hydraulic jump occurred in the stilling basin.



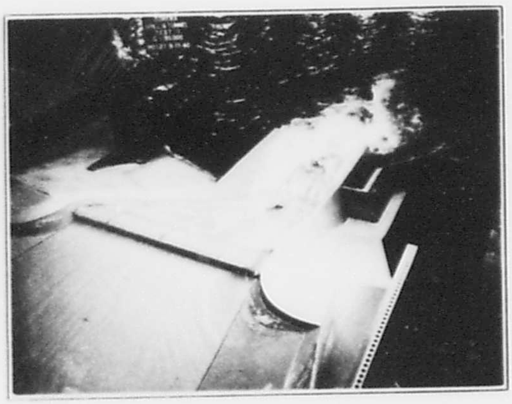
Photograph 14

Q = 70 000 c.f.s. Stilling basin capacity was exceeded and shooting flow occurred over upstream baffles.



Photograph 15

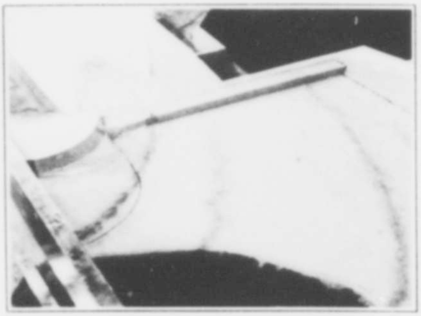
Q = 95 000 c.f.s. High standing waves in chute, and flow shooting over baffles and out of stilling basin.



Photograph 16

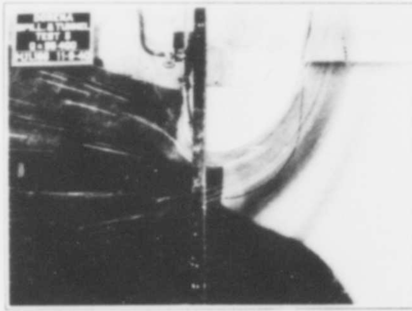
Q = 95 000 c.f.s. Turbulent flow conditions around right abutment, and uneven distribution of flow down right side of chute into stilling basin.

LEFT ABUTMENT PLANS Q = 95,400 C.F.S.



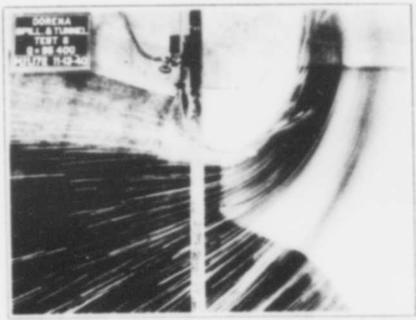
Photograph 17

Plan E: Comparison with Photograph 11 shows that practically no improvement was effected in flow conditions around the left abutment by eliminating the sharp upstream corner of Plan A design.



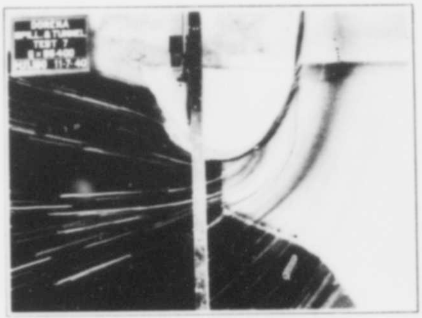
Photograph 18

Plan F: Note smoother flow of water around abutment face than is shown in Photographs 11 and 17.



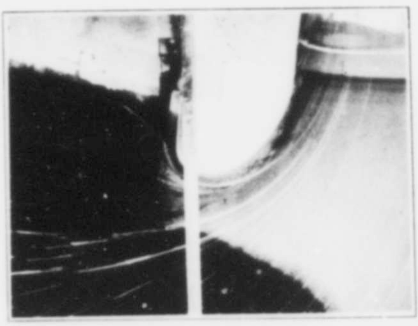
Photograph 19

Plan G: This plan was less effective than Plan F as indicated by small diagonal standing waves that occurred around abutment face.



Photograph 20

Plan H: Note irregular subsurface flow over transition slope as compared with that shown in Photograph 21.



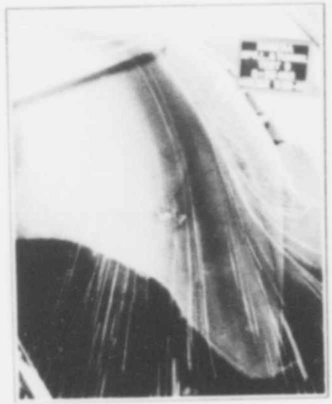
Photograph 21

Plan I: Flow observed around left abutment of final design.

RIGHT APPROACH WALL PLANS Q = 95,400 C.F.S.

Photograph 22

Plan II: Note boils and eddies at upstream corner of wall. Compare with Photograph 16 and note smoother flow along wall just upstream from the crest.



Photograph 23

Plan III: Note reduced area of turbulent wake caused by rounding upstream corner of wall.

Photograph 24

Plan IV: Turbulence along the right approach wall was diminished from that shown in Photographs 22 and 23.

Photograph 25

Plan V: Confetti traces along right approach wall show smoother flow alignment than with Plans I to IV.

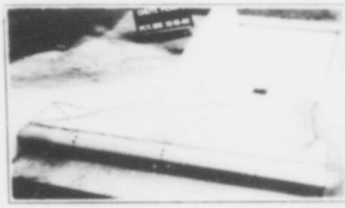
Photograph 26

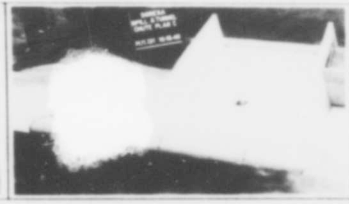
Plan VI: Compare with Photograph 25 and note eddies just upstream and downstream from the corner of the wall.

Photograph 27

Plan VII: Smooth flow along right approach wall of final design. Note that turbulent wake was completely eliminated.

CHUTE PLANS - CONSTRUCTION

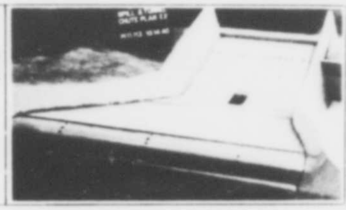

Photograph 28 - Plan B


Photograph 29 - Plan C


Photograph 30 - Plan D


Photograph 31 - Plan E


Photograph 32 - Plan E-1


Photograph 33 - Plan E-2

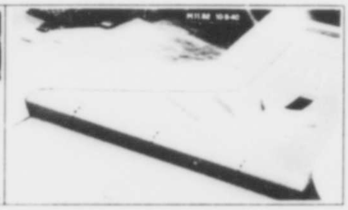

Photograph 34 - Plan E-3


Photograph 35 - Plan F


Photograph 36 - Plan G


Photograph 37 - Plan H

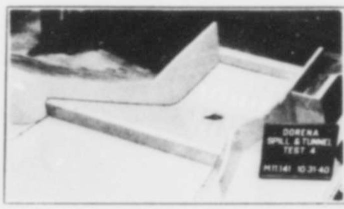

Photograph 38 - Plan I


Photograph 39 - Plan J


Photograph 40 - Plan K


Photograph 41 - Plan L


Photograph 42 - Plan M



Photograph 43 - Plan O


Photograph 44 - Plan P

Notes

1. See Photograph 10 for Chute Plan A.
2. Chute Plan N same as Chute Plan P.

PHOTOGRAPHS 28 - 44

CHUTE PLANS Q = 45,000 C.F.S.

Photograph 45 - Plan B

Photograph 46 - Plan C

Photograph 47 - Plan D

Photograph 48 - Plan E

Photograph 49 - Plan E-1

Photograph 50 - Plan E-2

Photograph 51 - Plan E-3

Photograph 52 - Plan F

Photograph 53 - Plan G

Photograph 54 - Plan H

Photograph 55 - Plan I

Photograph 56 - Plan J

Photograph 57 - Plan K

Photograph 58 - Plan L

Photograph 59 - Plan M

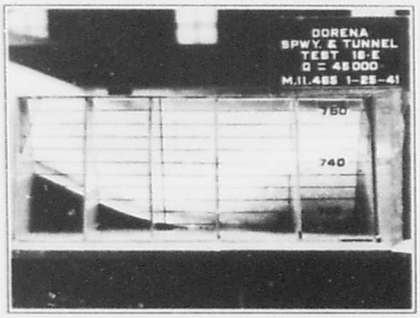
Photograph 60 - Plan O

Photograph 61 - Plan P

Notes

1. See Photograph 13 for Chute Plan A.
2. Chute Plan N same as Chute Plan P.

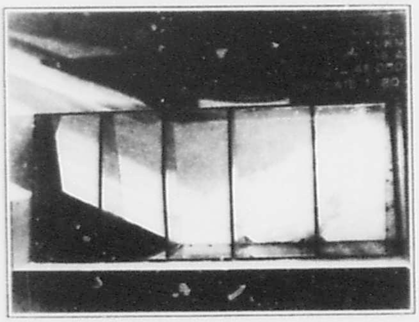
BUCKET PLANS Q = 45,000 C.F.S.



Photograph 62

<u>100-Ft. Radius Bucket with Baffle Plan I</u>

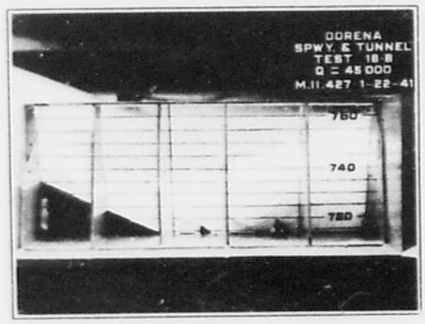
Hydraulic jump in the stilling basin was stable for these conditions.



Photograph 63

<u>Intersecting-Planes Bucket with Baffle Plan I</u>

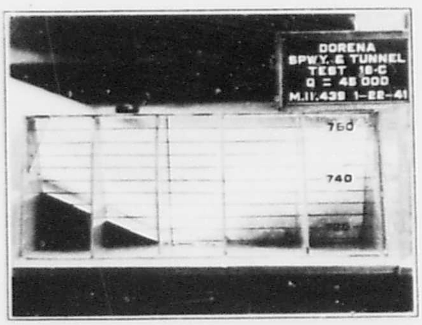
Flow overrode right side of upstream row of baffles.



Photograph 64

<u>Intersecting-Planes Bucket with Baffle Plan M</u>

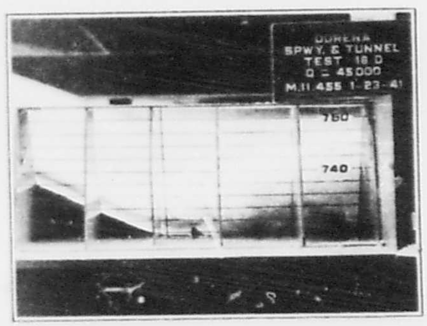
Compare with Photograph 63 and note improvement in stilling basin action effected by moving two rows of baffles upstream.



Photograph 65

<u>50-Ft. Radius Bucket with Baffle Plan I</u>

Comparison with Photograph 63 shows the hydraulic jumps to be similar.



Photograph 66

<u>50-Ft. Radius Bucket with Baffle Plan N</u>

Moving all three rows of baffles upstream stabilized hydraulic jump within the stilling basin.

BAFFLE PLANS Q = 45,000 C.F.S.

Photograph 67 - No Baffles

Photograph 68 - Plan A

Photograph 69 - Plan B

Photograph 70 - Plan C

Photograph 71 - Plan D

Photograph 72 - Plan E

Photograph 73 - Plan F

Photograph 74 - Plan G

Photograph 75 - Plan H

Photograph 76 - Plan I

Photograph 77 - Plan J

Photograph 78 - Plan K

Photograph 79 - Plan L

Photograph 80 - Plan M

Photograph 81 - Plan N

Photograph 82 - Plan O

Photograph 83 - Plan P

Note

Photograph 79: Q = 30 000 c.f.s.

PHOTOGRAPHS 67-83

END SILL PLANS Q = 95,400 C.F.S.

Photograph 84

Plan I: Deflection of stilling basin flow by inclined sill. Note adherence of flow to top of end sill and heavy concentration of flow in center of stilling basin.

Photograph 85

Plan II: Compare with Photograph 84 and note decreased upward deflection of flow over end sill.

Photograph 86

Plan III: Note that deflection of flow is similar to that shown in Photograph 85.

Photograph 87

Plan IV: Compare with Photograph 84 and note similarity of upward flow deflection.

OUTLET WORKS DESIGN

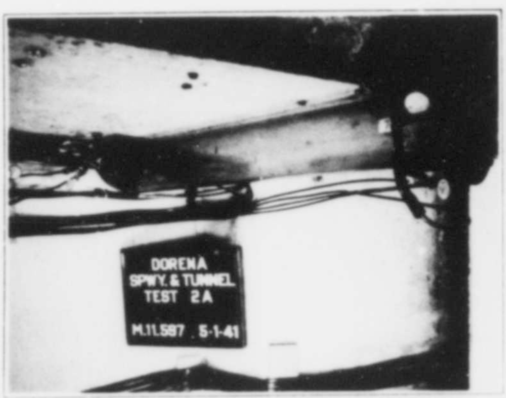
Photograph 88

Pyralin constructed outlet tower showing trash racks over intake ports, 7' x 9' emergency gates, and piezometer connections to top of intake ports. Crank at top of tower was used to operate the cylinder gate.

Photograph 89

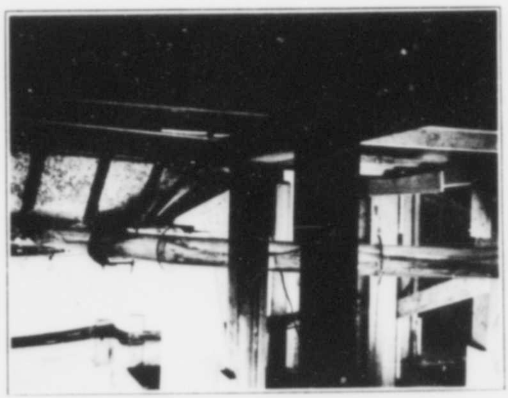
Pool El. 770.5 ft. Q = 4720 c.f.s.
Full Gate Opening

Pattern of flow entering intake ports as indicated by dye streams.



Photograph 90

View of tunnel elbow and section of pyralin tunnel from within the inspection gallery.



Photograph 91

Pool El. 800.0 ft. Q = 3900 c.f.s.
1/3 Gate Opening

Standing waves and superelevation of flow effected by horizontal curvature of the tunnel.

TUNNEL OUTLET PLANS - CONSTRUCTION

Photograph 92 - Plan A

Photograph 93 - Plan B

Photograph 94 - Plan C

Photograph 95 - Plan D

Photograph 96 - Plan E

Photograph 97 - Plan F

Photograph 98 - Plan G

Photograph 99 - Plan H

Photograph 100 - Plan I

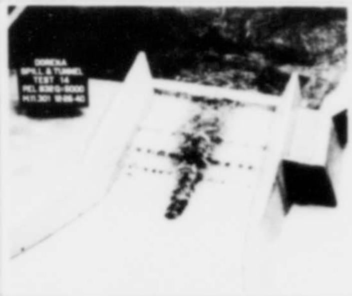
Photograph 101 - Plan J

Photograph 102 - Plan K

PHOTOGRAPHS 92 - 102

TUNNEL OUTLET PLANS Q = 5,000 C.F.S.


Photograph 103 - Plan A


Photograph 104 - Plan B


Photograph 105 - Plan C


Photograph 106 - Plan D

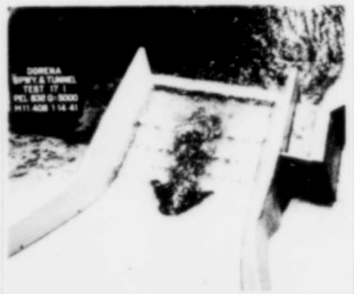

Photograph 107 - Plan E


Photograph 108 - Plan F


Photograph 109 - Plan G


Photograph 110 - Plan H


Photograph 111 - Plan I


Photograph 112 - Plan J


Photograph 113 - Plan K

FINAL SPILLWAY DESIGN

Photograph 114

Q = 45 000 c.f.s. Flow conditions effected by improvements of the final design.

Photograph 115

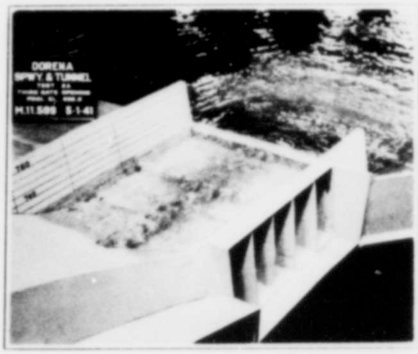
Q = 95 400 c.f.s. Smooth alignment of surface currents around abutments and along right approach wall as shown by confetti traces.

Photograph 116

Q = 55 000 c.f.s. A stabilized jump occurred in the stilling basin at a higher discharge than occurred with the original design (see Photograph 13).

Photograph 117

Q = 95 400 c.f.s. No great improvement was effected in stilling basin action at maximum discharge. Compare with Photographs 15 and 16.

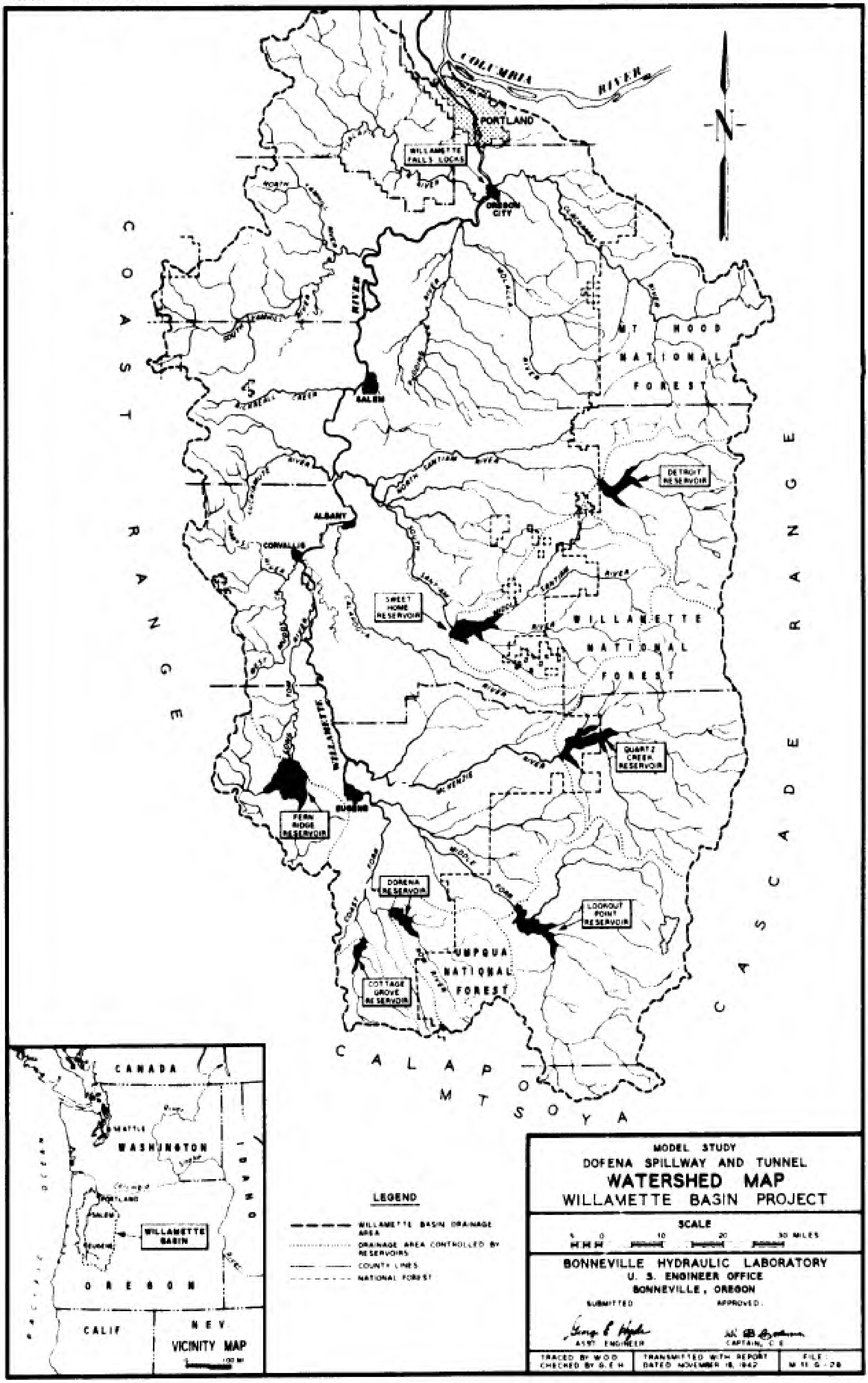


Photograph 118

Pool El. 832.0 ft. Q = 5000 c.f.s.
1/3 Gate Opening

Maximum operating discharge issuing from tunnel into stilling basin.

P L A T E S



MODEL STUDY
DOFENA SPILLWAY AND TUNNEL

WATERSHED MAP

WILLAMETTE BASIN PROJECT

SCALE
5 0 10 20 30 MILES

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942	FILE: M 11 G - 28

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

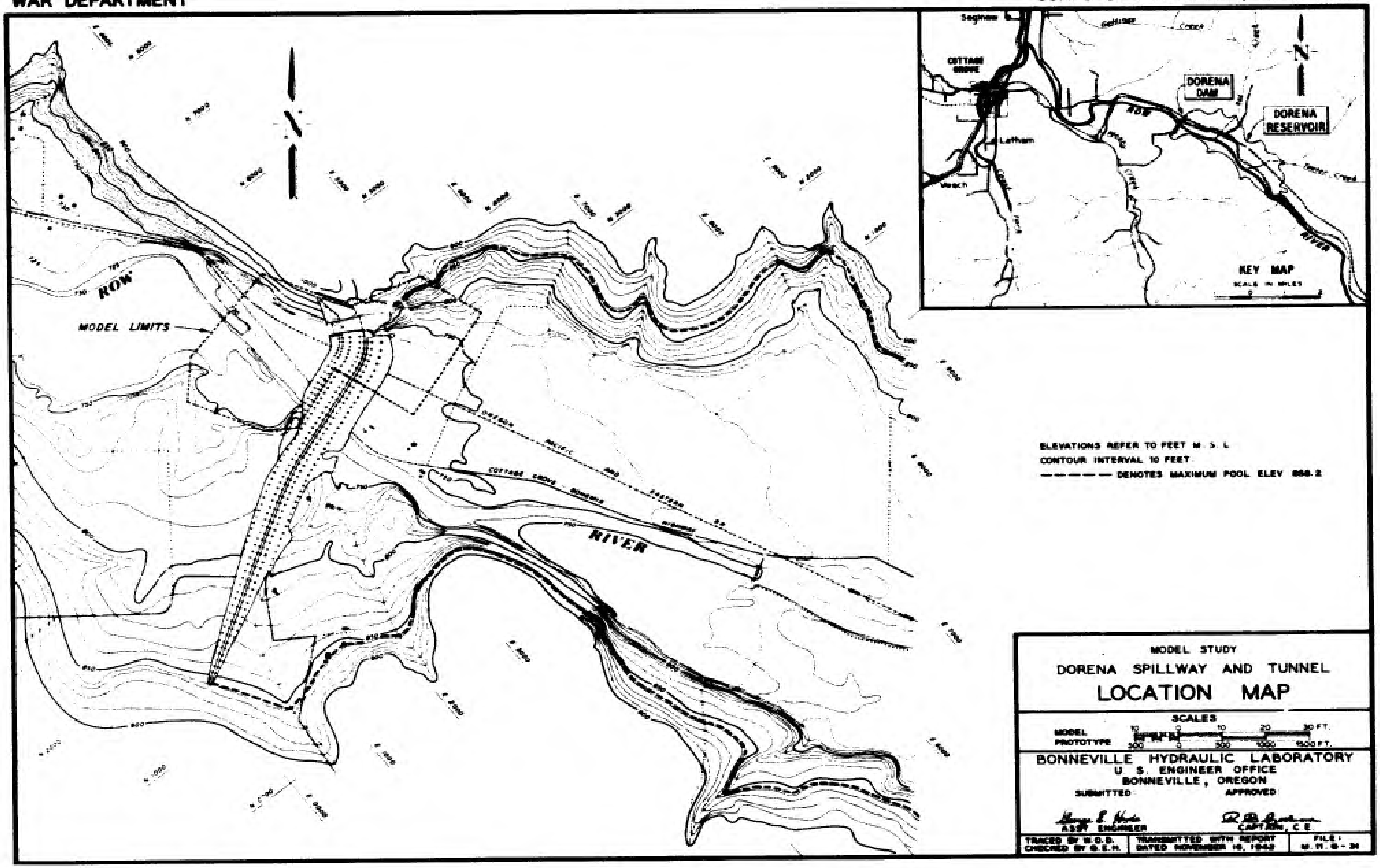
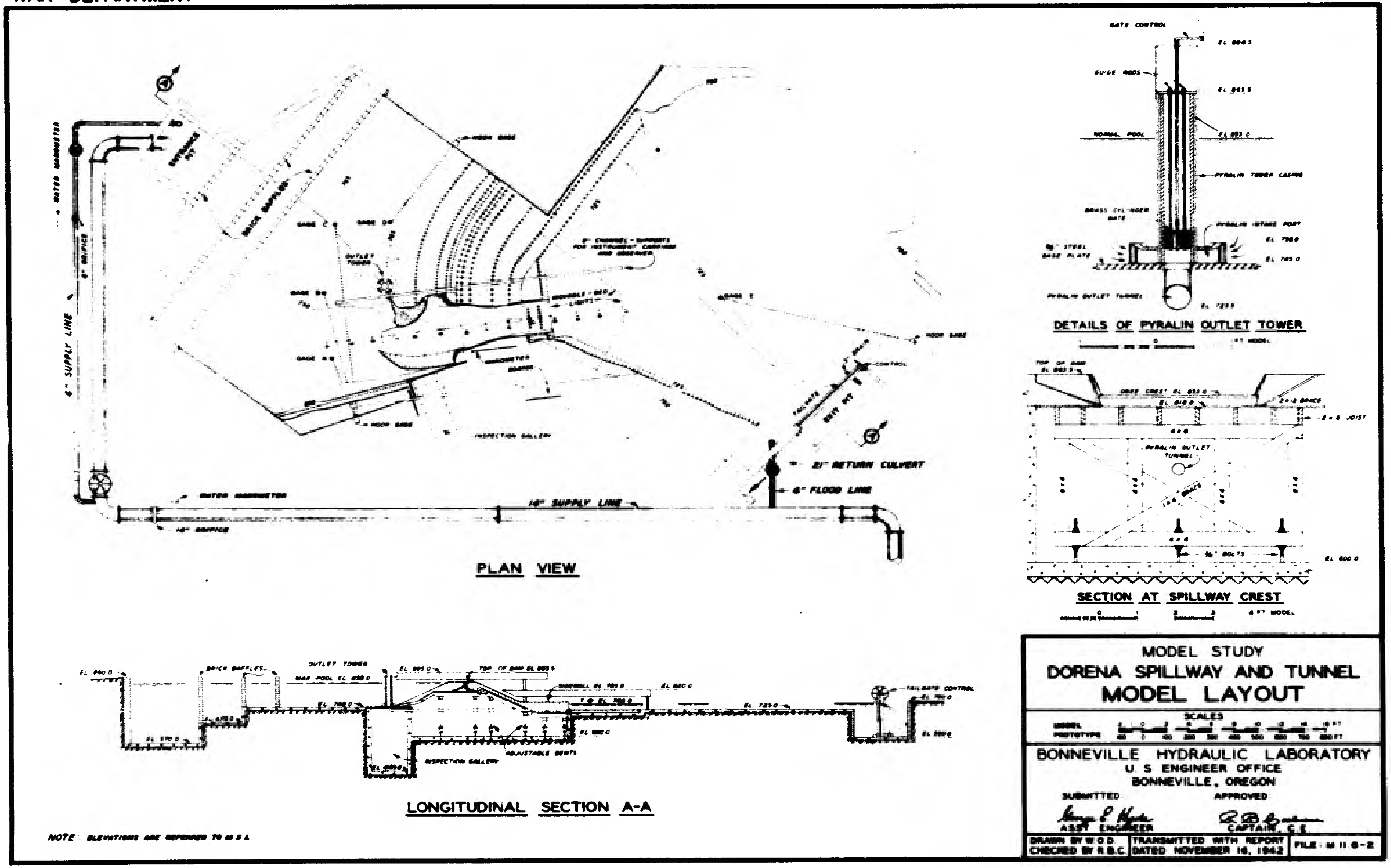
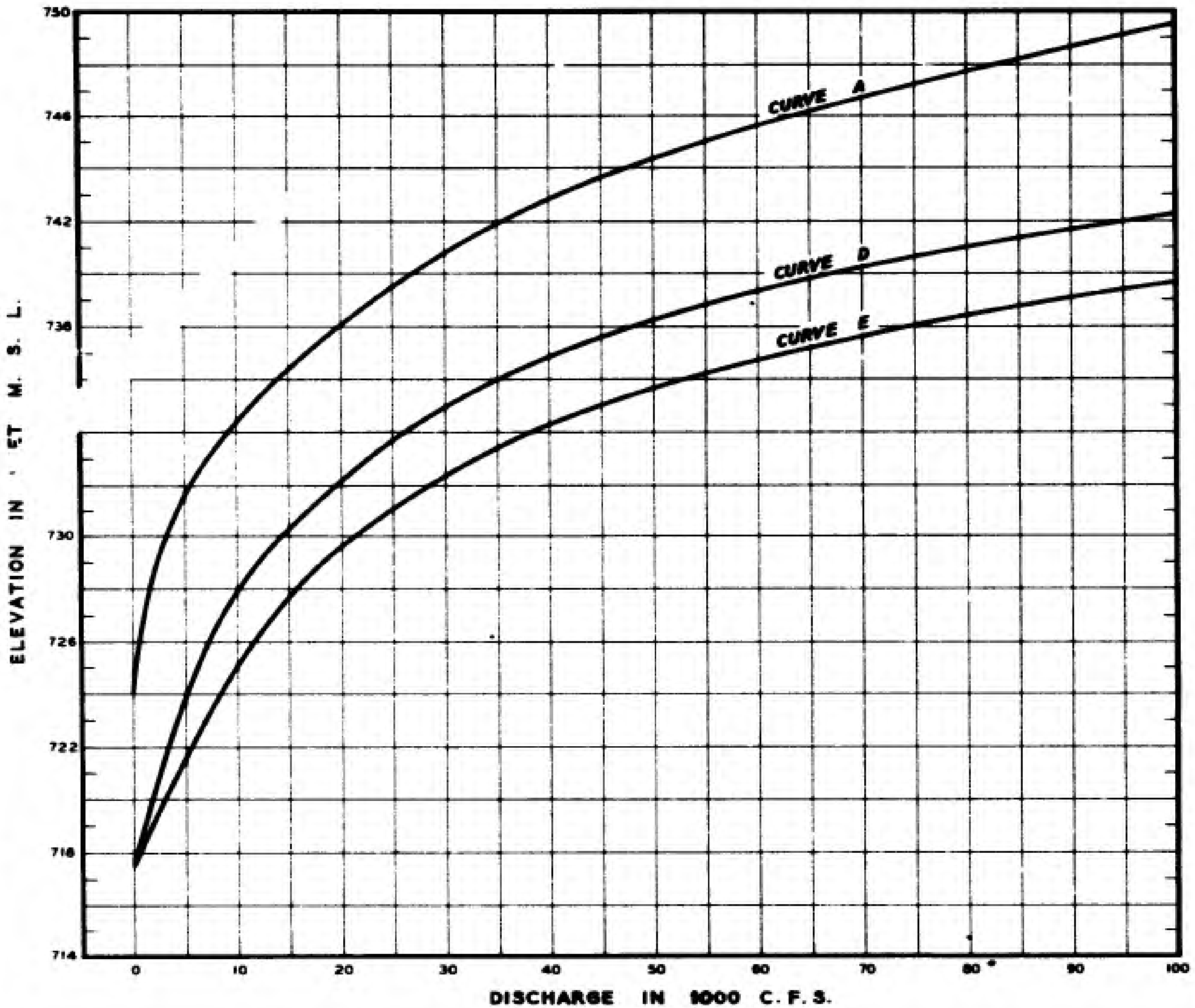


PLATE 2

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY





NOTES

1. DATA FOR CURVE A, NATURAL CONDITIONS AT GAGE 2, TAKEN FROM CHART I ON PORTLAND DISTRICT DRAWING DO-20-3/1-A, REVISED JUNE 17, 1940.
2. DATA FOR CURVE D, MOST PROBABLE CURVE AT GAGE 2 AFTER CONSTRUCTION OF DAM AND APPURTENANCES, TAKEN FROM PORTLAND DISTRICT DRAWING DI-6-7/1, DATED OCTOBER 2, 1940.
3. DATA FOR CURVE E, LOWEST PROBABLE CURVE AT GAGE 2 AFTER CONSTRUCTION OF DAM AND APPURTENANCES, TAKEN FROM PORTLAND DISTRICT DRAWING DI-6-7/1, DATED OCTOBER 2, 1940.
4. THE TAILWATER ELEVATION AT MODEL GAGE E (N 4654, E 3080) AND AT PROTOTYPE GAGE 2 (N 4370.5, E 3140.8) WAS ASSUMED TO BE GEOMETRICALLY SIMILAR.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

TAILWATER RATING CURVES

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY

U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

SUBMITTED: George L. Hyde, ASST ENGINEER

APPROVED: R. B. Cochrane, CAPTAIN, C E

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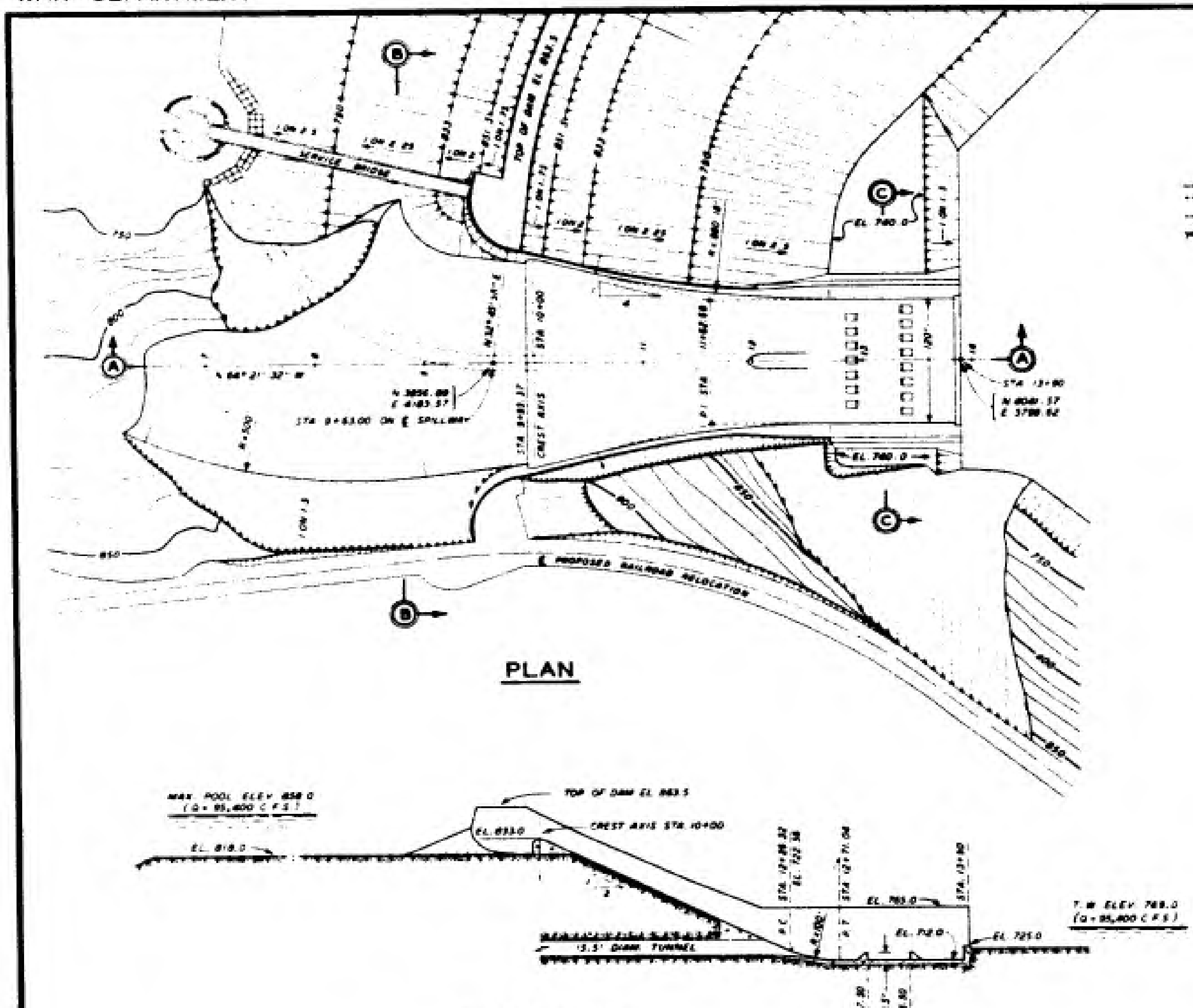
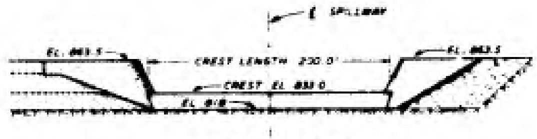
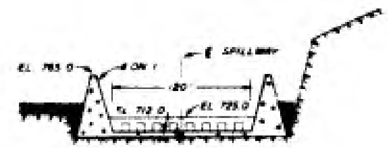


PLAN

SECTION A-A



SECTION B-B



SECTION C-C

NOTES

1. MODEL BASICALLY CONSTRUCTED ACCORDING TO PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.
2. SEE PLATES 7, 13, 25, 37, 38, AND 42 FOR DETAILS OF ORIGINAL SPILLWAY DESIGN.
3. ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
ORIGINAL SPILLWAY DESIGN

SCALES IN FEET
MODEL 1 0 1 2 3 4
PROTOTYPE 50 0 100 200

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER — APPROVED: CAPTAIN, C. E.

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CHECKED BY G.E.H.
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FILE: M. 11. G-30

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

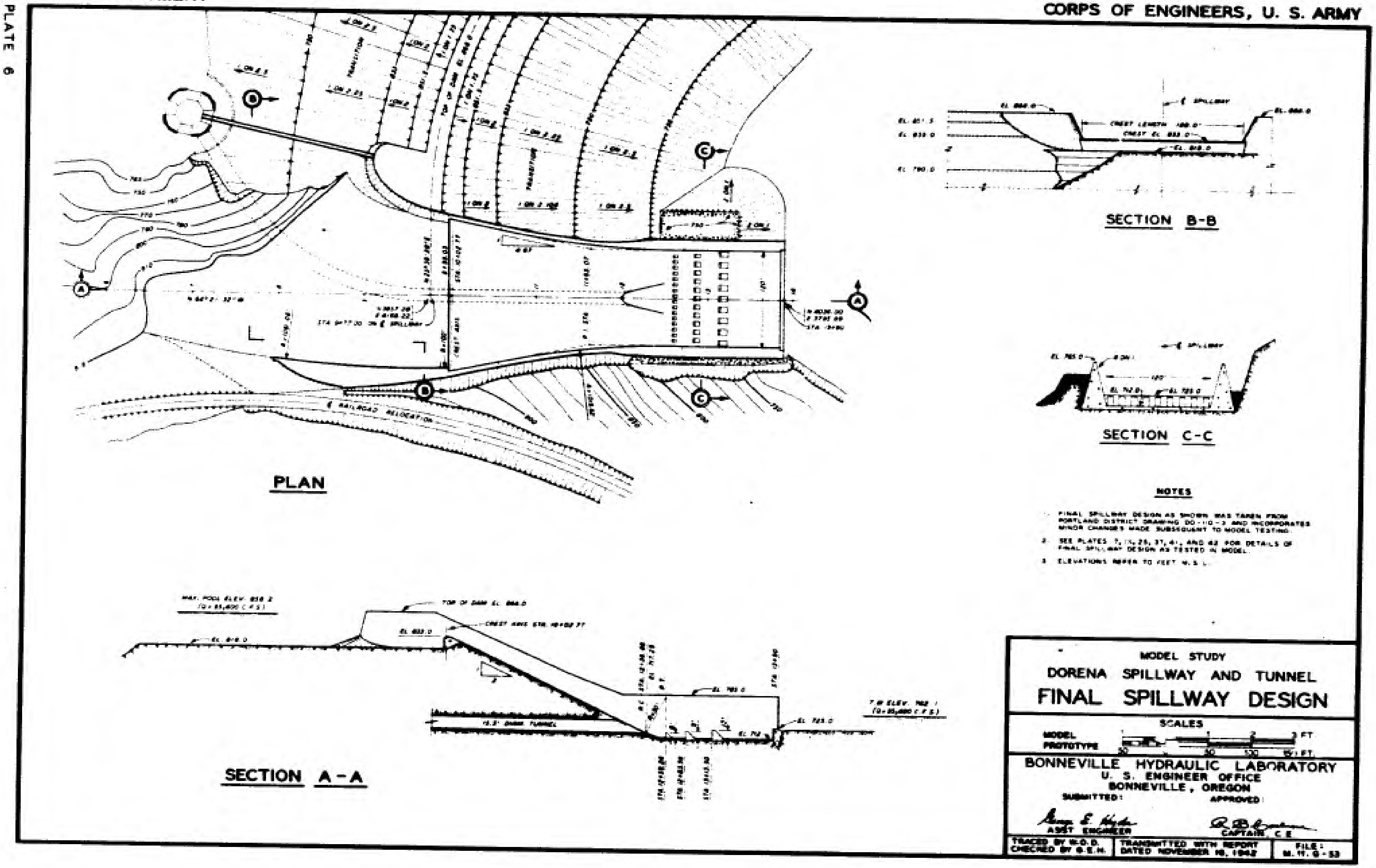
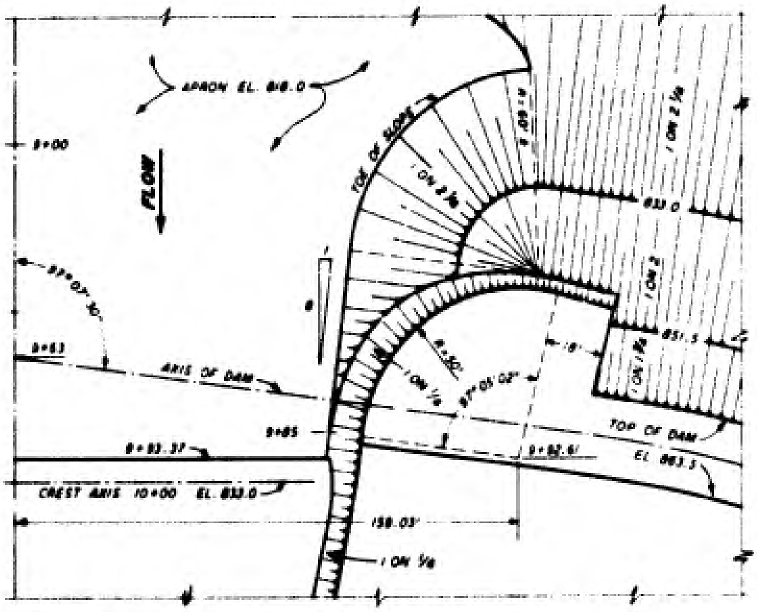
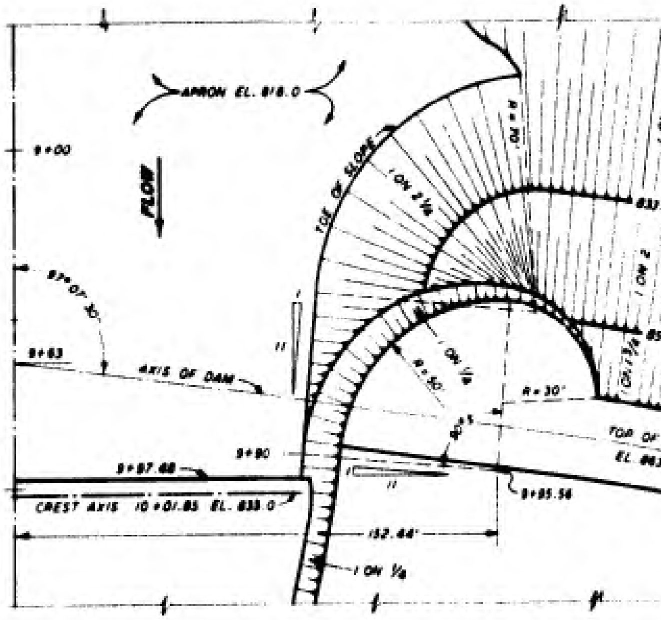


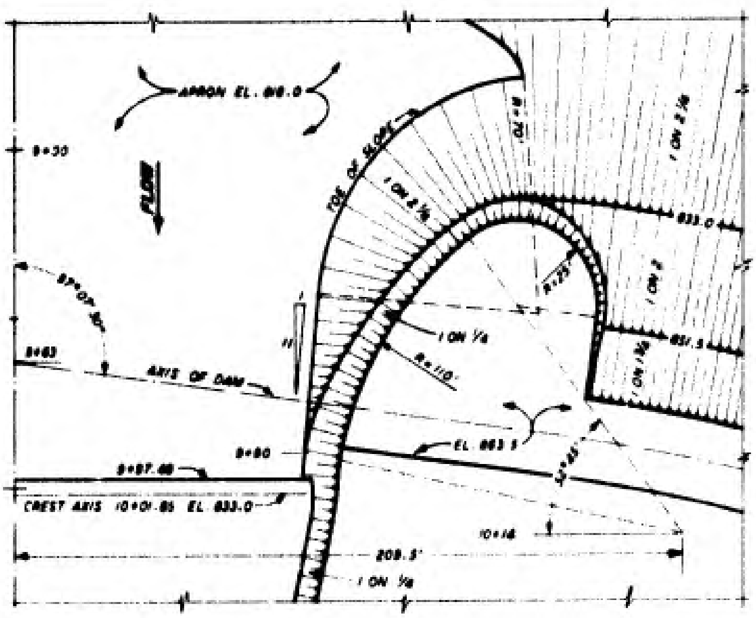
PLATE 6



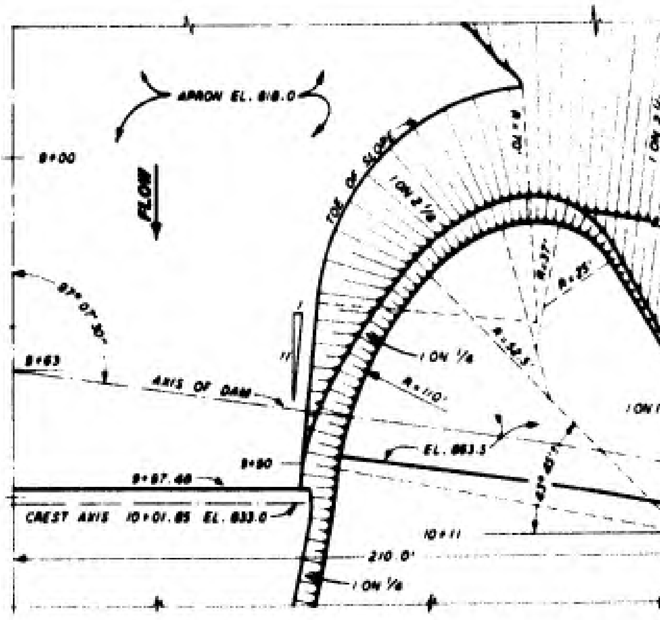
PLAN A



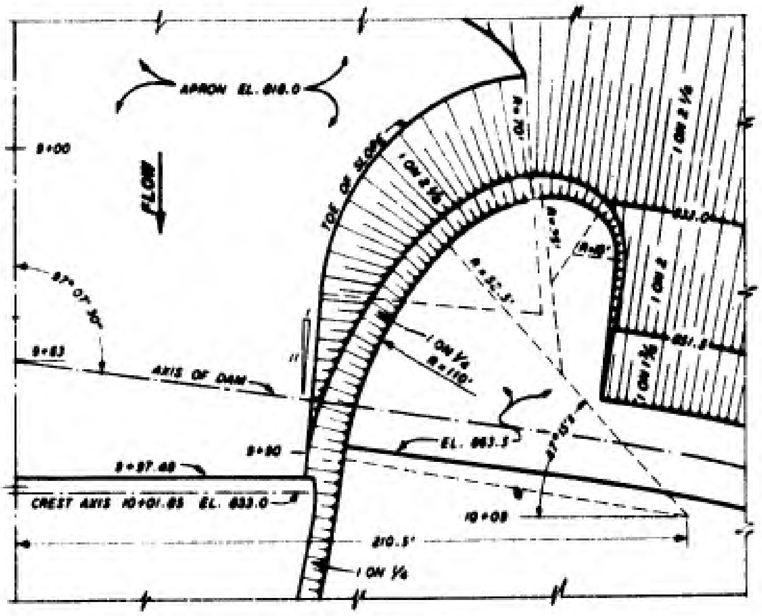
PLAN E



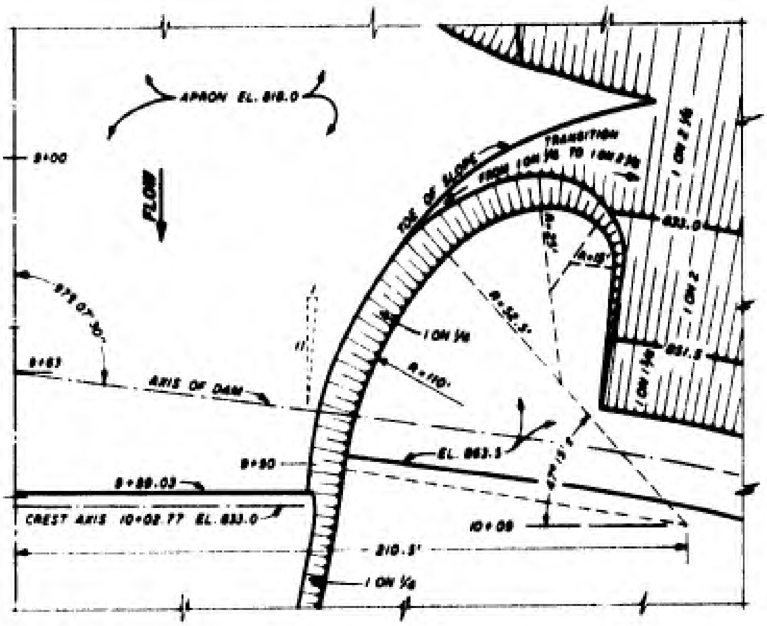
PLAN G



PLAN H



PLAN F



PLAN I

FINAL DESIGN

NOTES

1. PLAN A WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 7, 1940 AND BY SKETCH OF JULY 12, 1940.
2. PLANS B, C, AND D ON PORTLAND DISTRICT DRAWING D1-8-7/1, DATED SEPT. 17, 1940 WERE NOT TESTED.
3. PLAN E WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING D1-8-10/1.
4. PLANS F, G, AND H WERE DEVELOPED EXPERIMENTALLY.
5. PLAN I WAS BUILT ACCORDING TO SKETCH OF DEC. 3, 1940 OF THE PORTLAND DISTRICT OFFICE.
6. ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
LEFT ABUTMENT
PLANS TESTED

SCALES IN FEET
MODEL
PROTOTYPE

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASS'T ENGINEER CAPTAIN, C. E.

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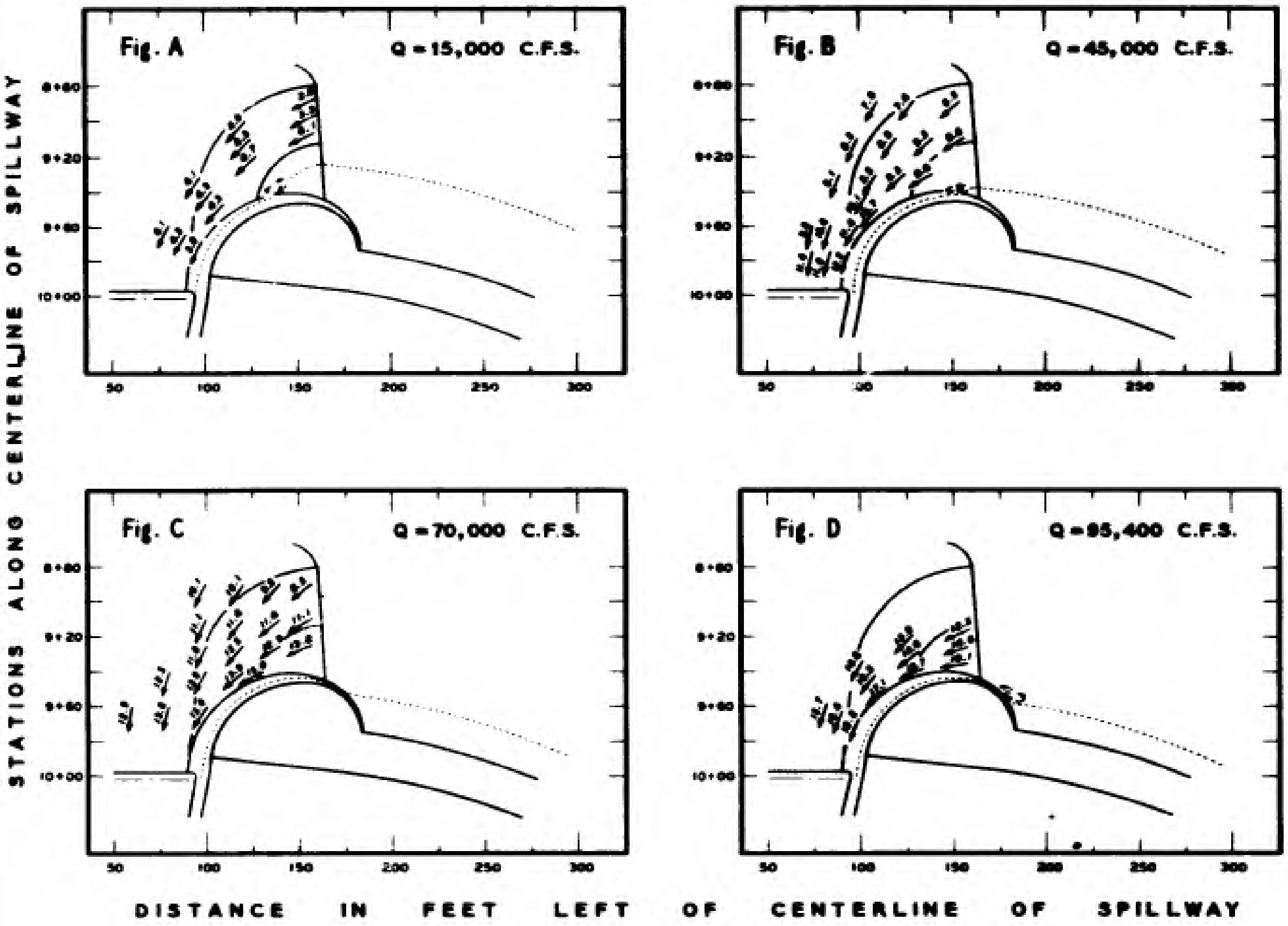

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 4.

CONDITIONS

1. CREST PLAN II.
2. APRON FLOOR ELEVATION 818.0 FT. M. S. L.
3. RIGHT APPROACH WALL PLAN II.

MODEL STUDY
BORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
LEFT ABUTMENT PLAN E

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER

APPROVED: CAPTAIN, C. E.

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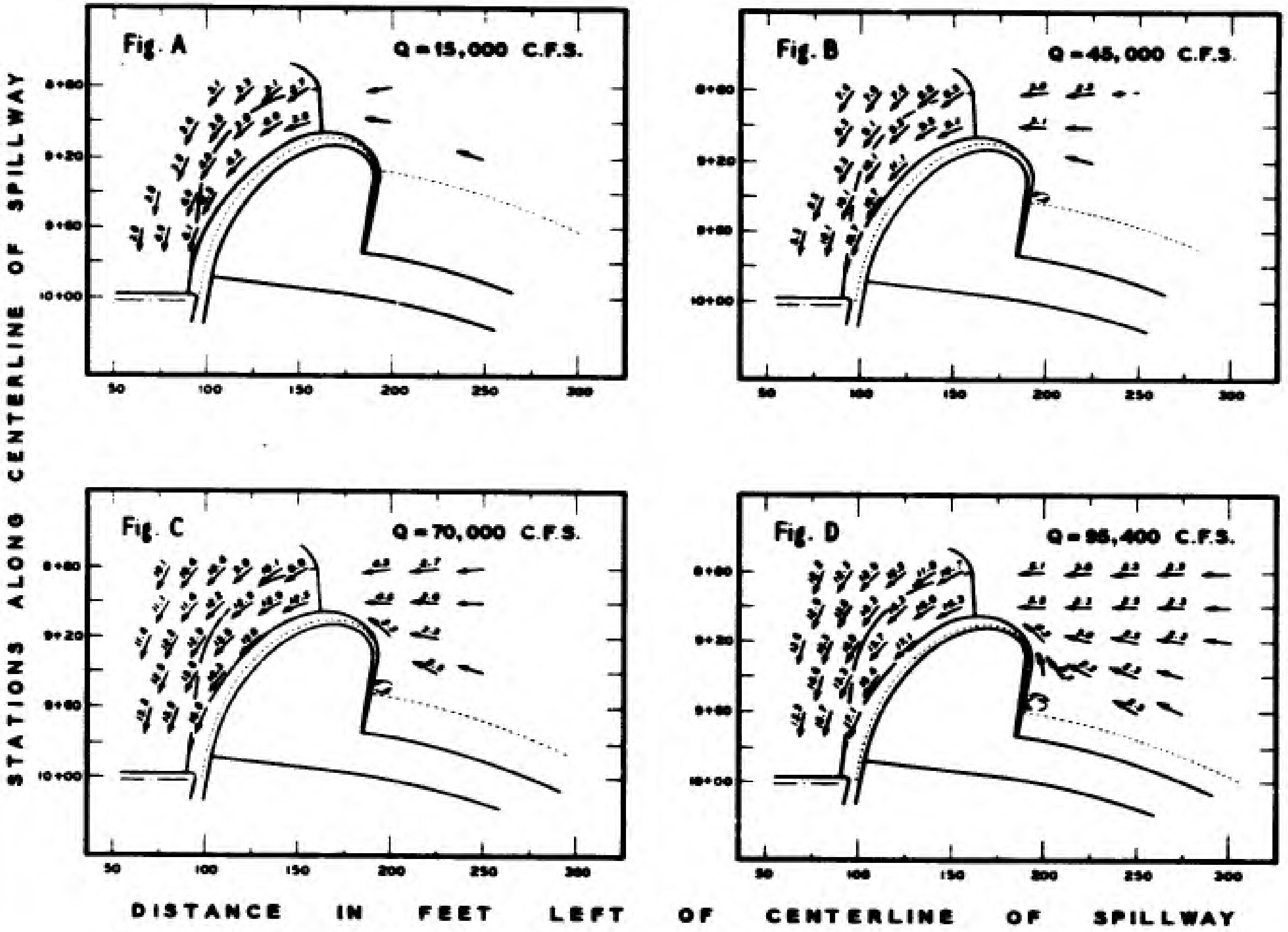

NOTES

1. MODEL VELOCITIES TAKEN WITH GENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 5.

CONDITIONS

1. CREST PLAN II.
2. APRON FLOOR ELEVATION [illegible] FT. M. S. L.
3. RIGHT APPROACH WALL PLAN II.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
LEFT ABUTMENT PLAN F

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George L. Hyde, ASST. ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

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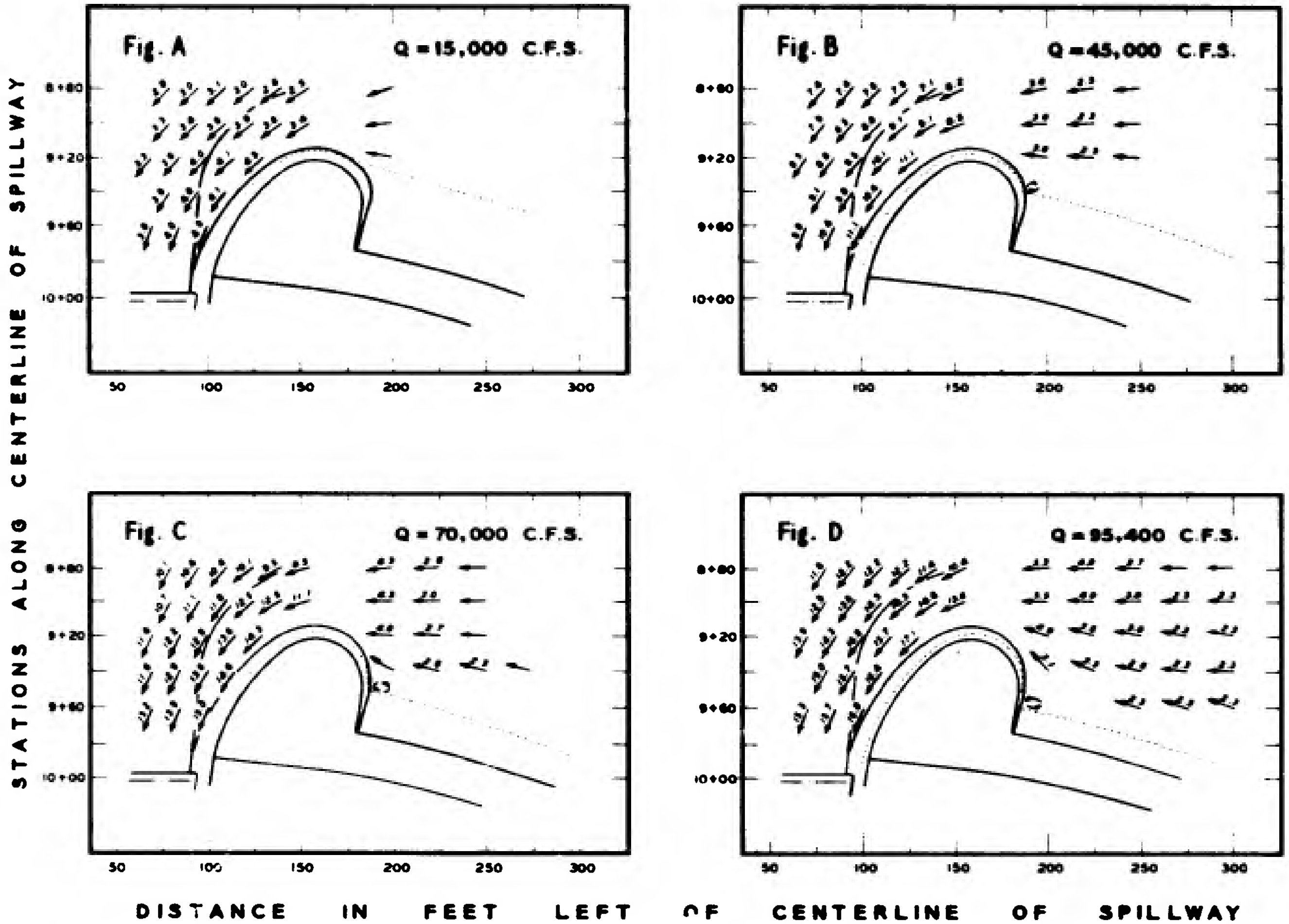

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 6.

CONDITIONS

1. CREST PLAN II.
2. APRON FLOOR ELEVATION 618.0 FT. M. S. L.
3. RIGHT APPROACH WALL PLAN II.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
LEFT ABUTMENT PLAN G

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

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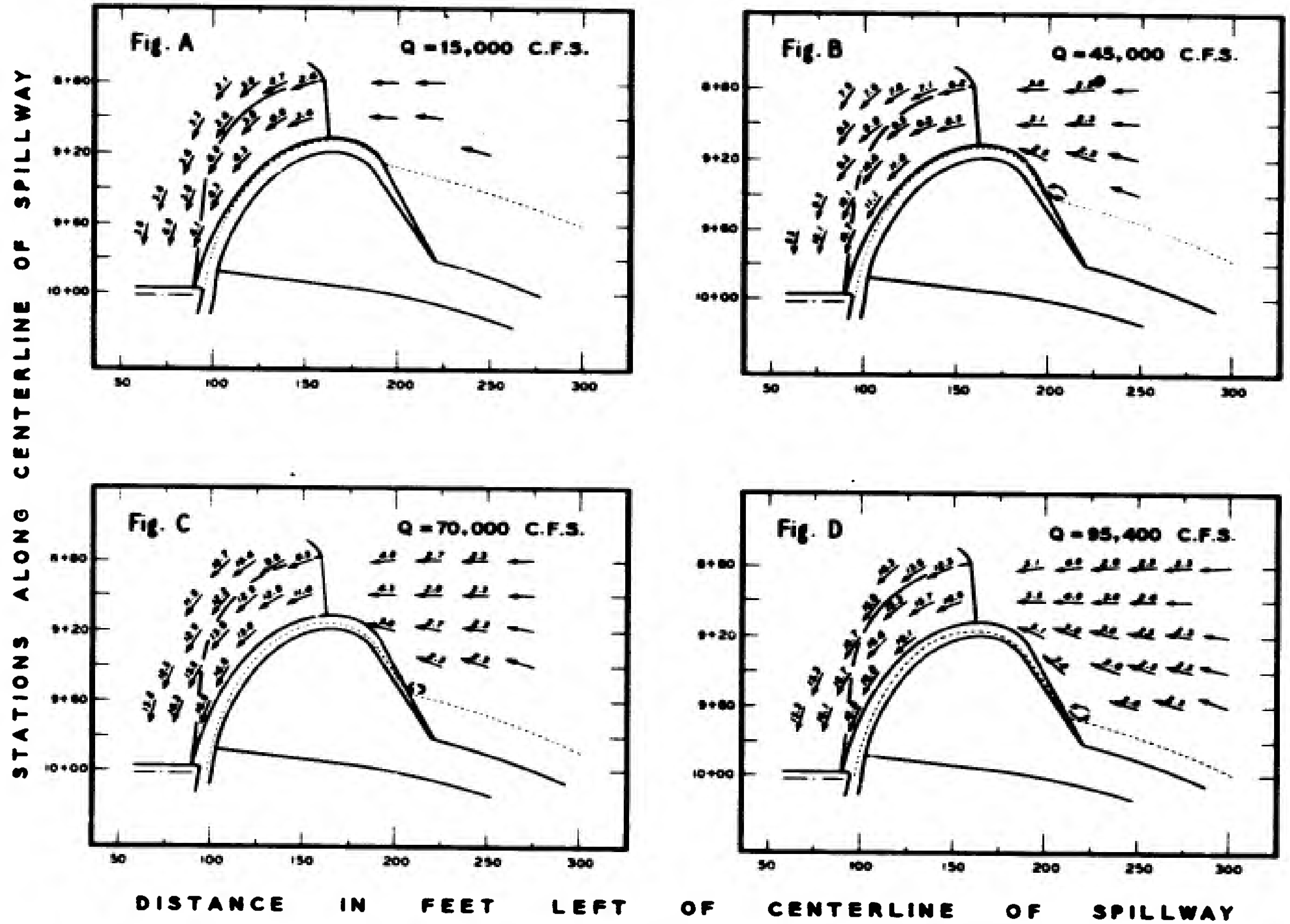

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 7.

CONDITIONS

1. CREST PLAN II.
2. APRON FLOOR ELEVATION 818.0 FT. M. S. L.
3. RIGHT APPROACH WALL PLAN II.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
LEFT ABUTMENT PLAN H

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

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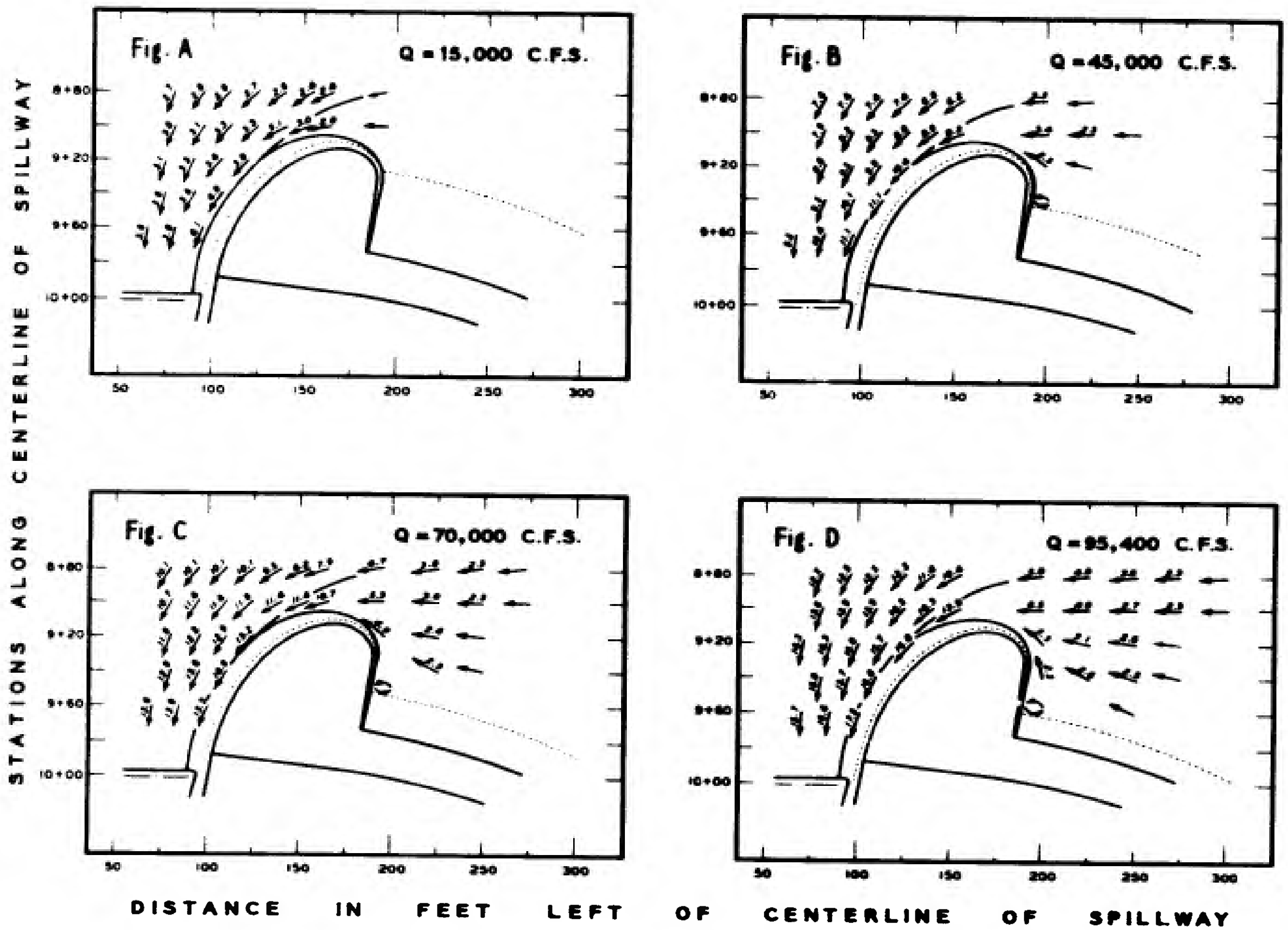

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 11.

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 818.0 FT. M. S. L.
3. RIGHT APPROACH WALL PLAN III.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
LEFT ABUTMENT PLAN I

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: [signature] ASST. ENGINEER

APPROVED: [signature] CAPTAIN, C. E.

TRACED BY W.O.D.
CHECKED BY G.E.H.

TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942

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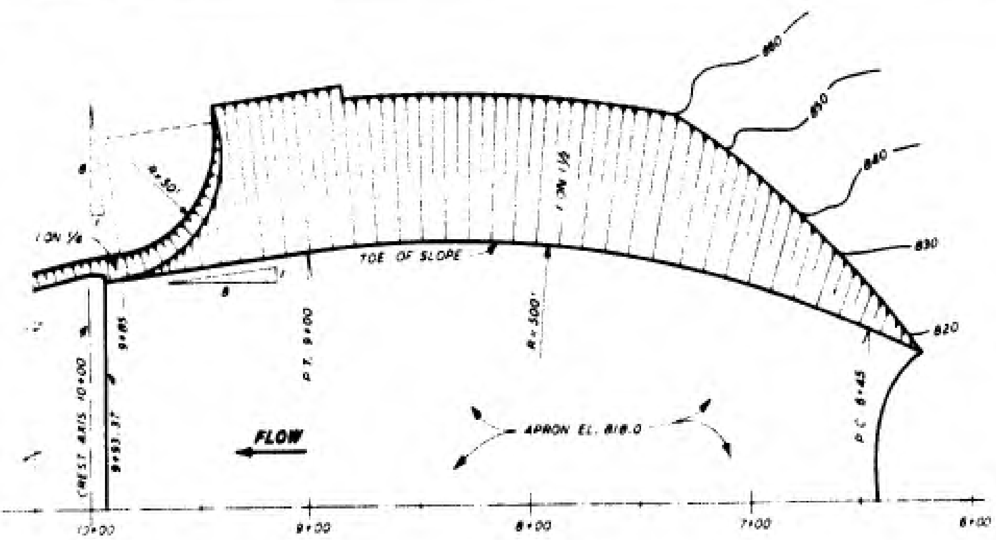
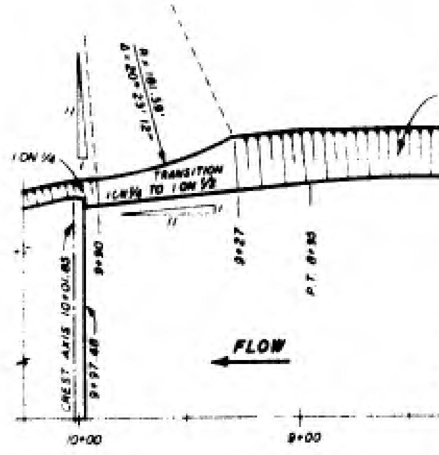
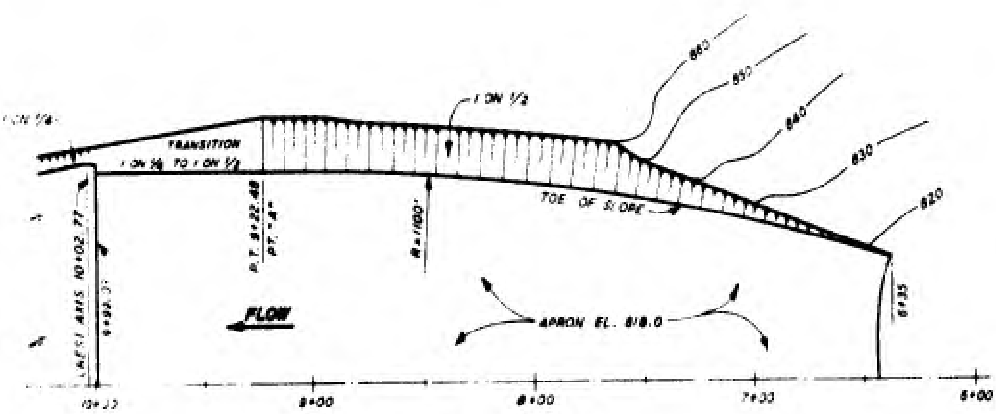


PLAN I





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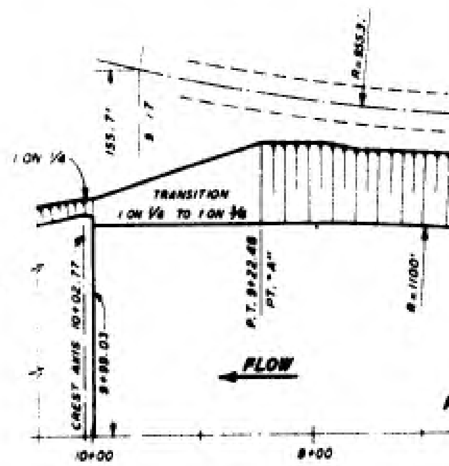
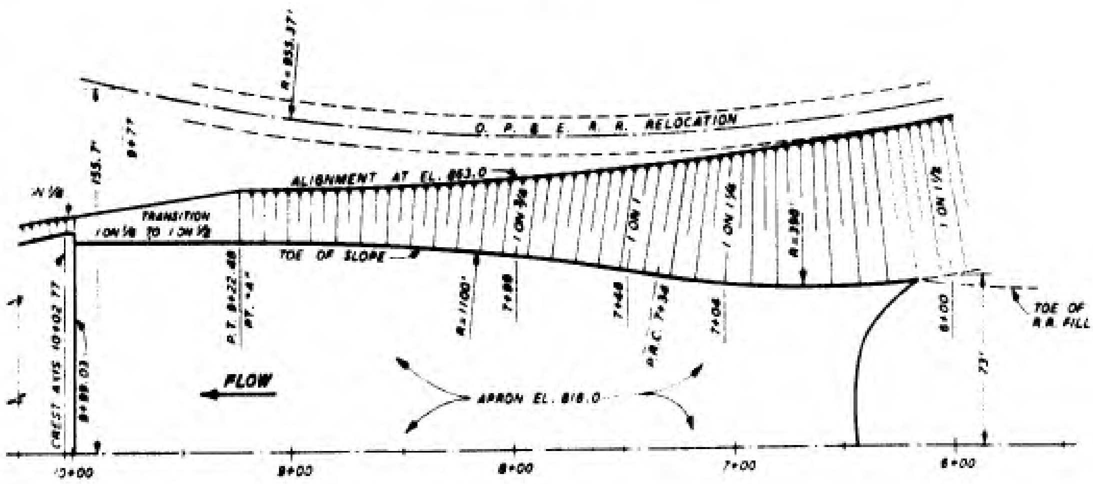
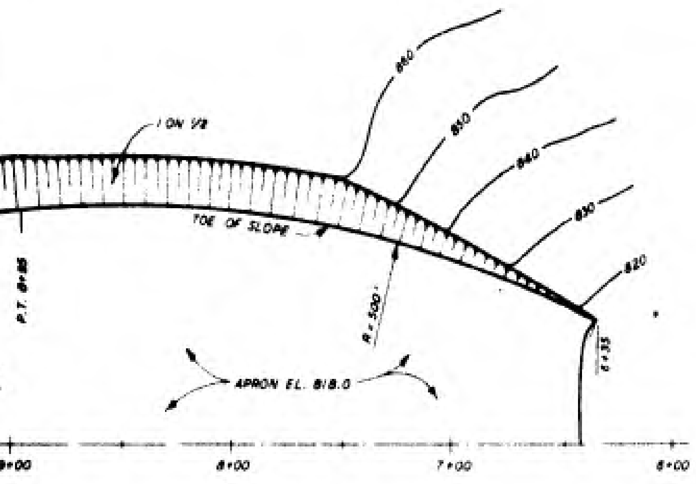


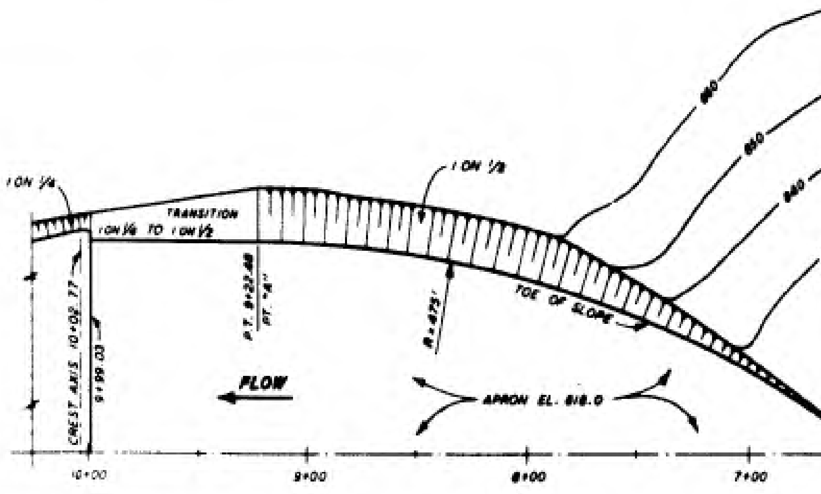


PLAN VII

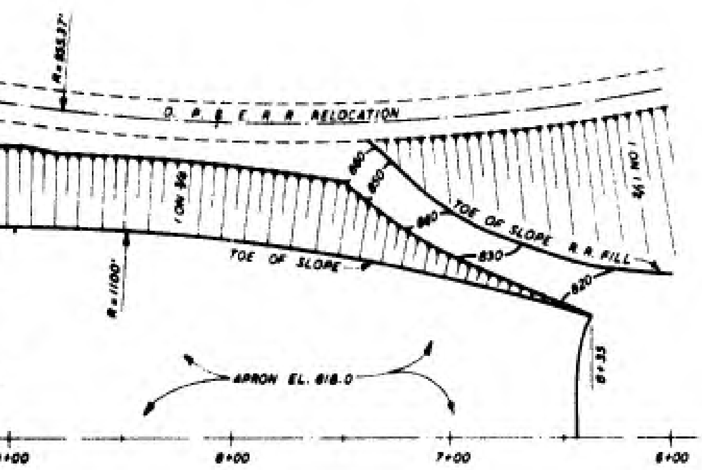
FINAL DESIGN



PLAN II



PLAN III



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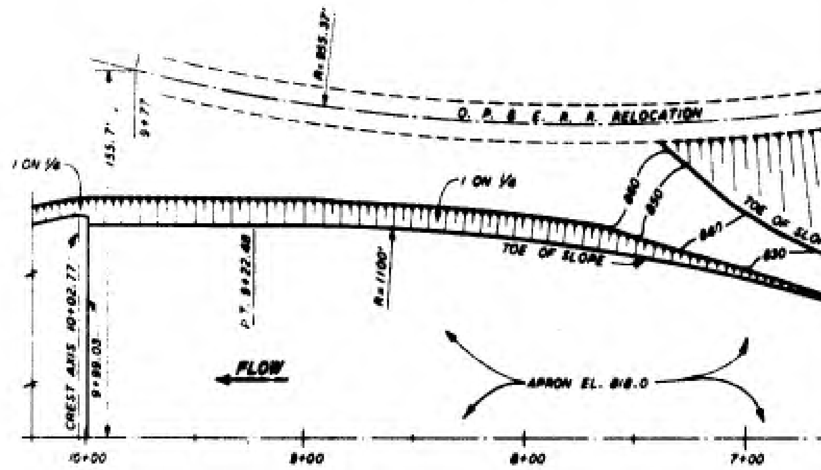
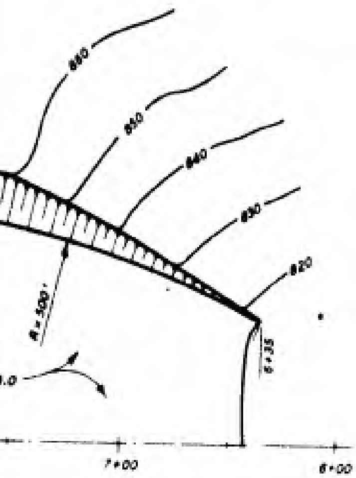


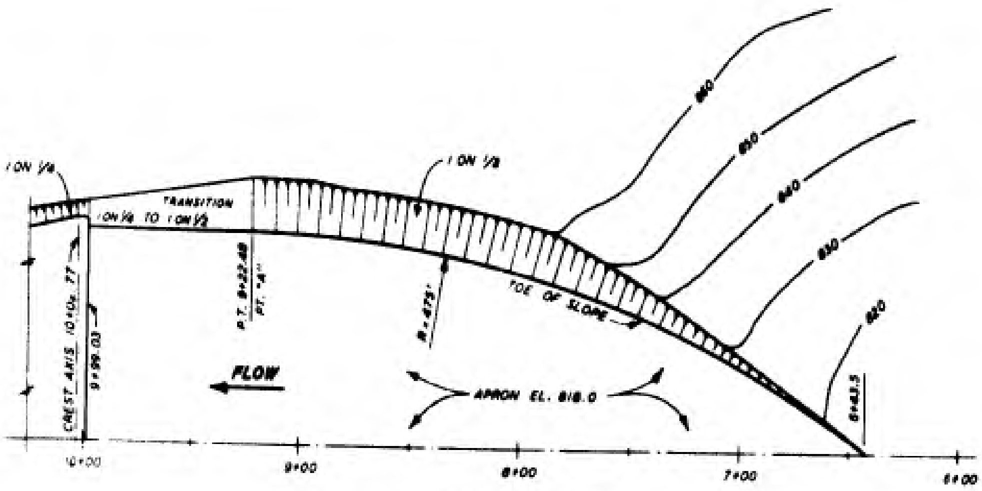
PLAN VI

NOTES

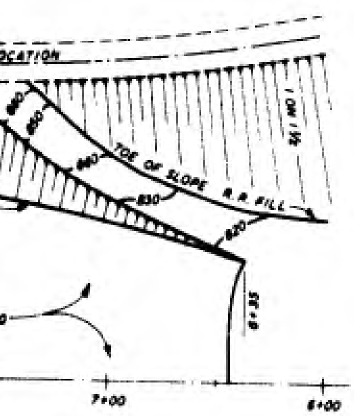
1. PLAN I WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.
2. PLAN II WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING D1-8-10/1.
3. PLAN III WAS A MODIFICATION OF PORTLAND DISTRICT SKETCH, DATED DEC. 3, 1940.
4. PLAN IV WAS A MODIFICATION OF PLANS II AND III.
5. PLAN V WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING D1-7-3/1, DATED FEB. 25, 1941.
6. PLAN VI WAS A MODIFICATION OF PLAN V.
7. PLAN VII WAS DEVELOPED EXPERIMENTALLY.
8. ELEVATIONS REFER TO FEET M. S. L.

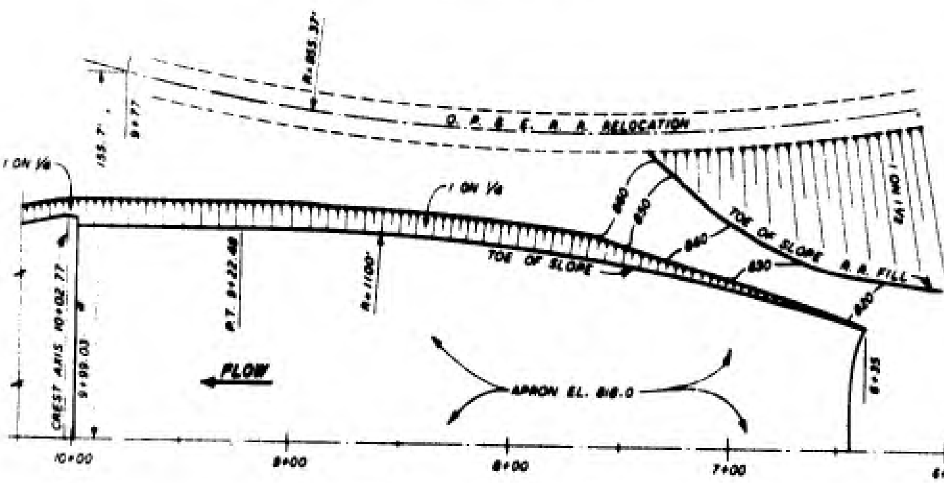
MO
DORENA SPI
RIGHT AP
PLA
SCA
MODEL
PROTOTYPE 50
BONNEVILLE H
U. S. E
BONNE
SUBMITTED:
ASS'T ENGINEER
TRACED BY W.O.D.
CHECKED BY G.E.H.
TRA
DATE





PLAN III





PLAN VI

NOTES

PLAN I WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.

PLAN II WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING D1-8-10/1.

PLAN III WAS A MODIFICATION OF PORTLAND DISTRICT SKETCH, DATED DEC. 3, 1940.

PLAN IV WAS A MODIFICATION OF PLANS II AND III.

PLAN V WAS BUILT ACCORDING TO PORTLAND DISTRICT DRAWING D1-7-3/1, DATED FEB. 25, 1941.

PLAN VI WAS A MODIFICATION OF PLAN V.

PLAN VII WAS DEVELOPED EXPERIMENTALLY

ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
RIGHT APPROACH WALL
PLANS TESTED

SCALES IN FEET
MODEL 1 0 1 2
PROTOTYPE 50 0 50 100

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASS'T. ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

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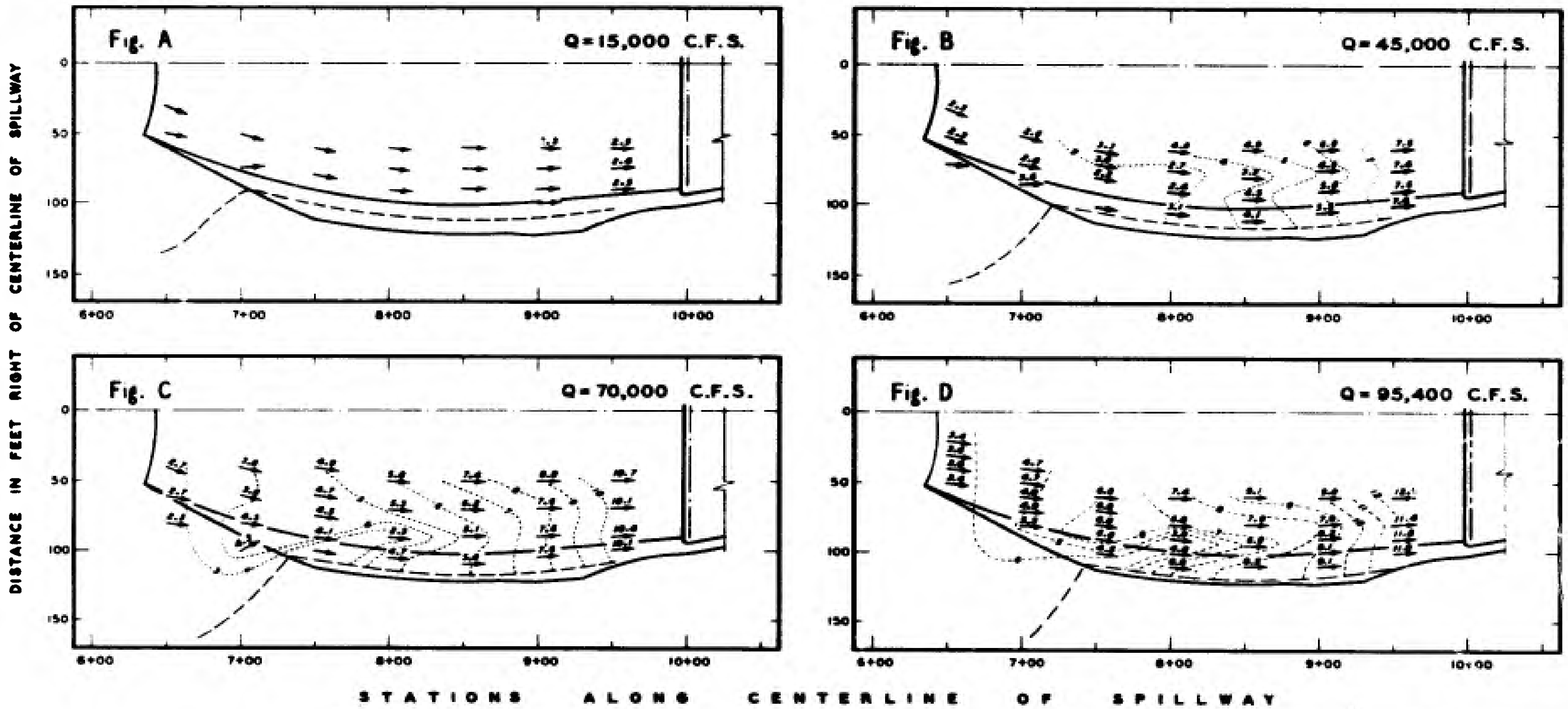


NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 4.

LEGEND

— — — — — EDGE OF WATER.
- - - - - # - - - - - VELOCITY CONTOURS.

CONDITIONS

1. CREST PLAN II.
2. APRON FLOOR ELEVATION 818.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN E.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN II

SCALES AS SHOWN

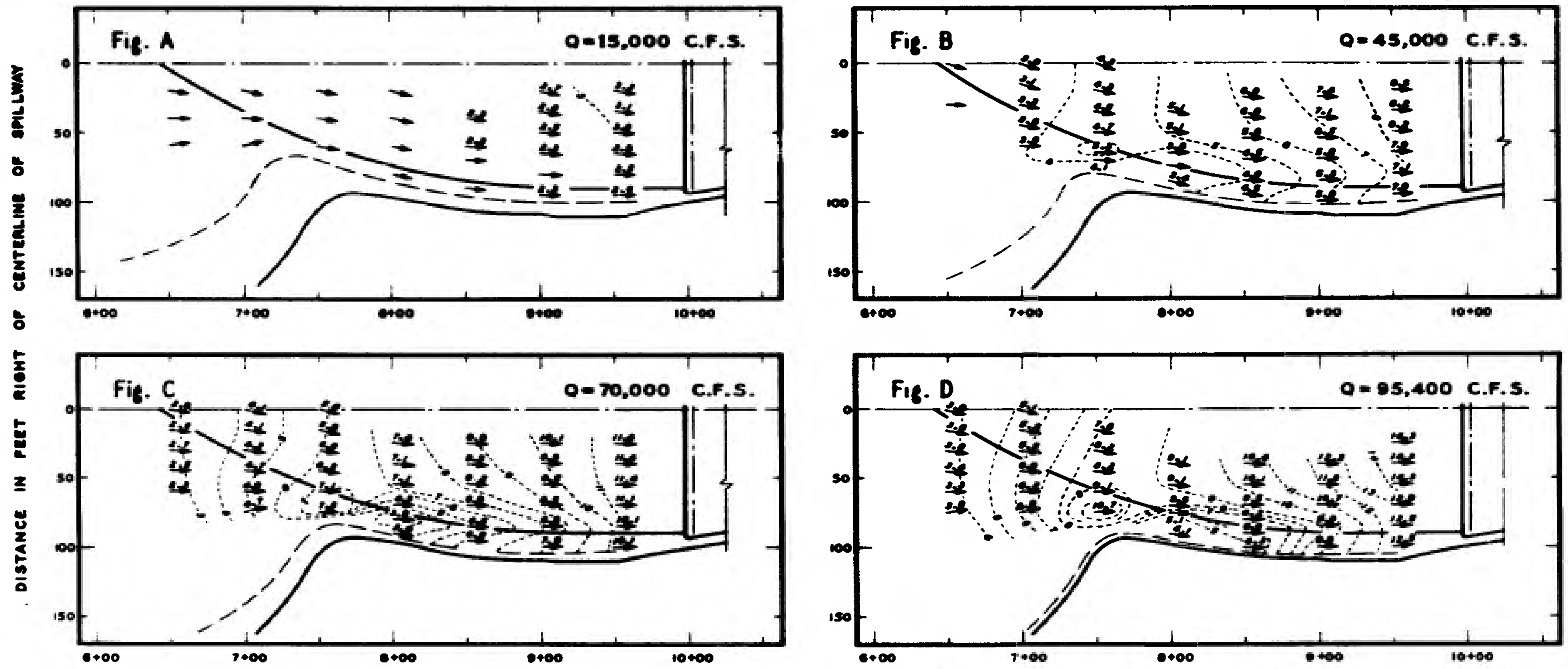
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

TRACED BY G.C.J. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942	FILE: M.11.4-8

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\ V_m)$.
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 9.

LEGEND

— — — — — EDGE OF WATER.

-----2----- VELOCITY CONTOURS.

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 618.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN F.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN III

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

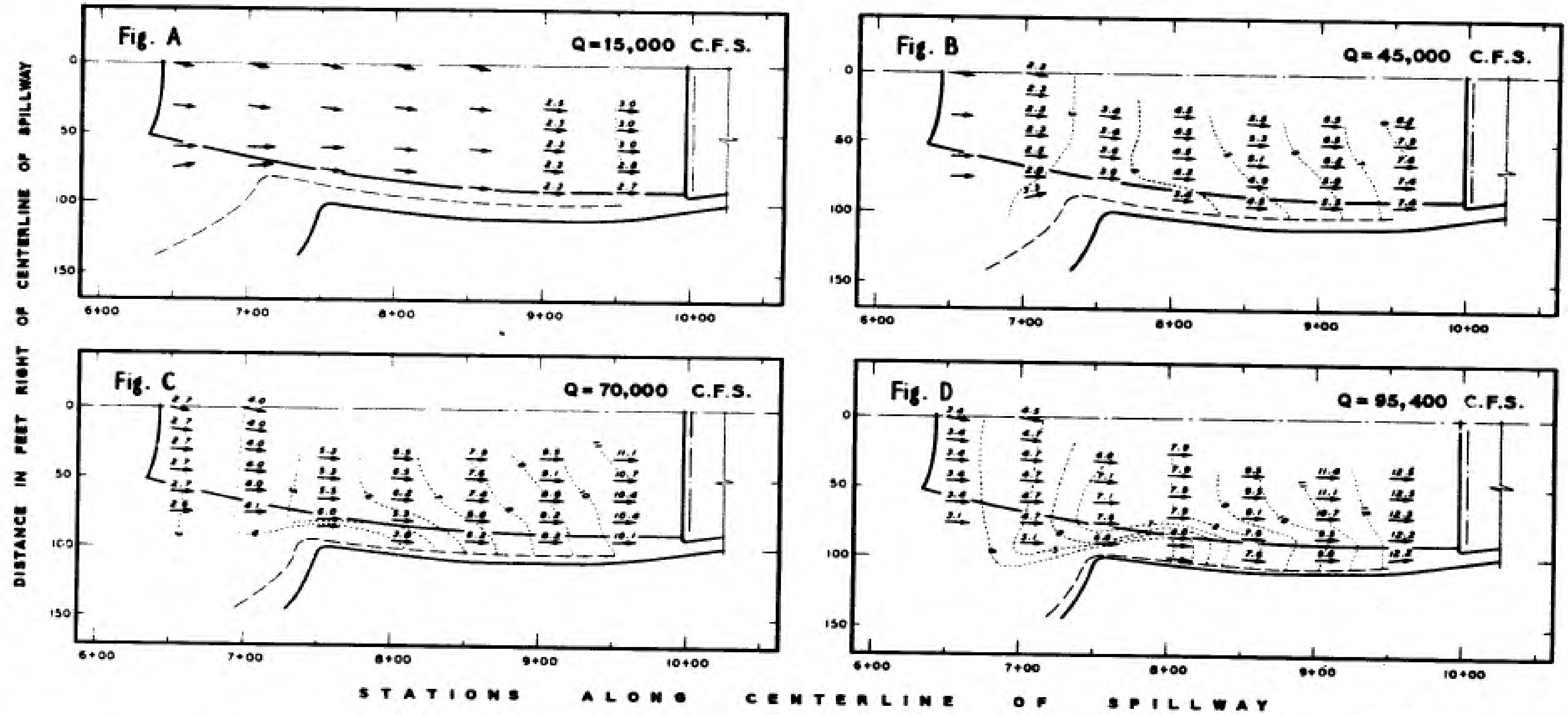
SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: R. B. [illegible], CAPTAIN, C. E.

TRACED BY G.C.J. CHECKED BY G.E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942 | FILE: M.H.-8-3

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\ V_m)$.
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 11.

LEGEND

— — — — EDGE OF WATER

········ 2 ········ VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 818.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN I.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN IX

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: R. B. [illegible], CAPTAIN, C. E.

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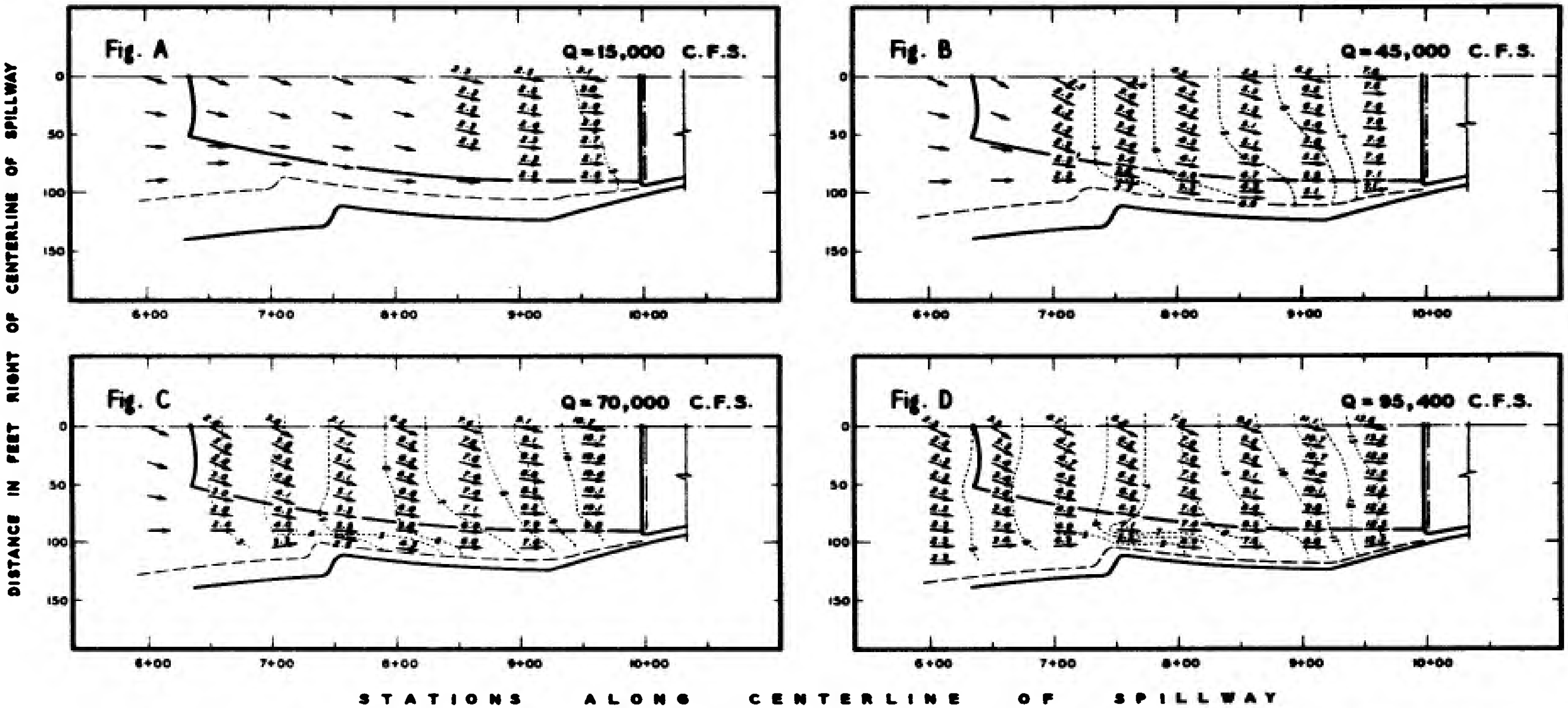
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\ V_m)$.
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 21.

LEGEND

— — — — — EDGE OF WATER

.... 2 .... VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN IX.
2. APRON FLOOR ELEVATION 818.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN I.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN V

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: R. B. ..., CAPTAIN, C. E.

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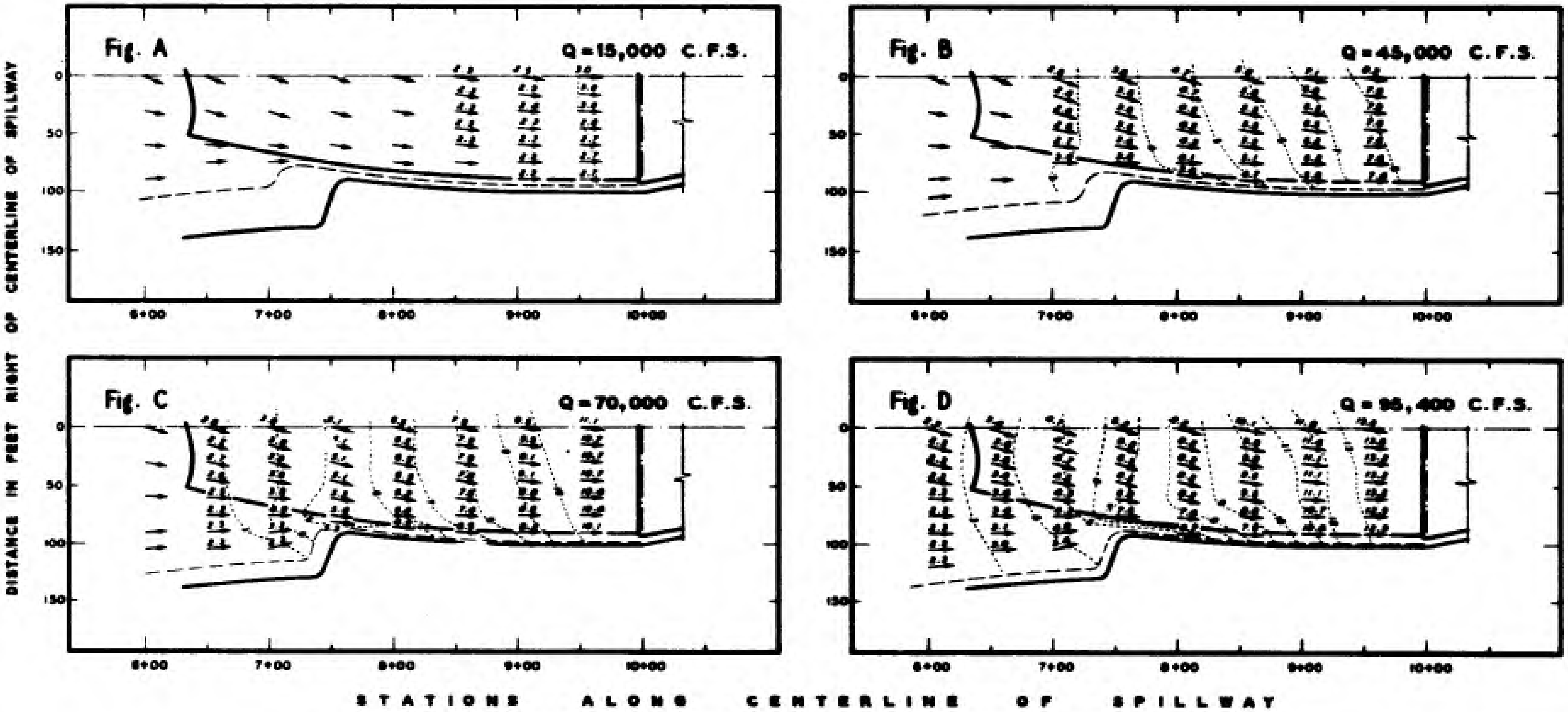

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND
4. DATA TAKEN DURING TEST 22.

LEGEND

— — — — EDGE OF WATER

·········2········· VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 818.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN I.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN VI

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

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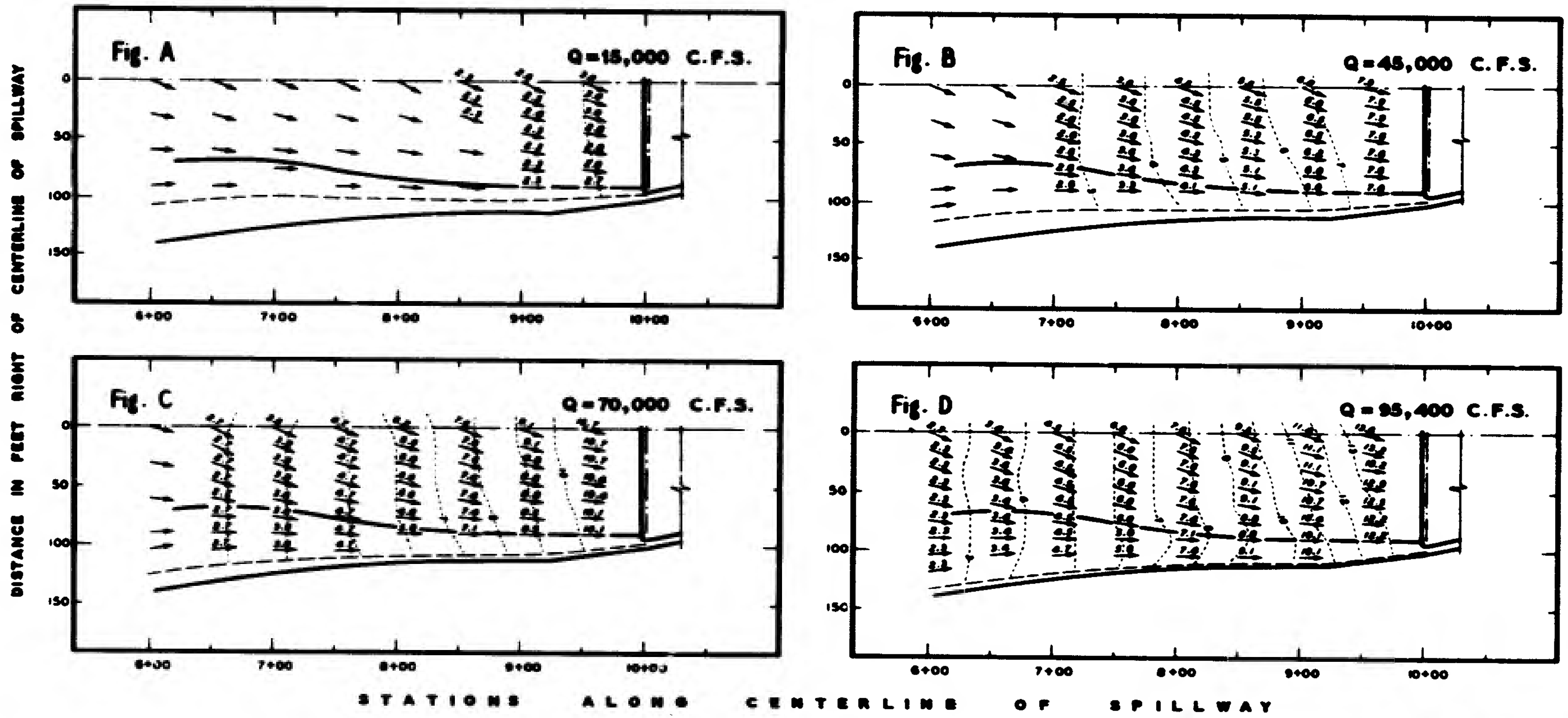
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 23.

LEGEND

— — — — — EDGE OF WATER

.... 2 .... VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN IX.
2. APRON FLOOR ELEVATION 618.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN I.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RIGHT APPROACH WALL PLAN XII

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER

APPROVED: CAPTAIN, C. E.

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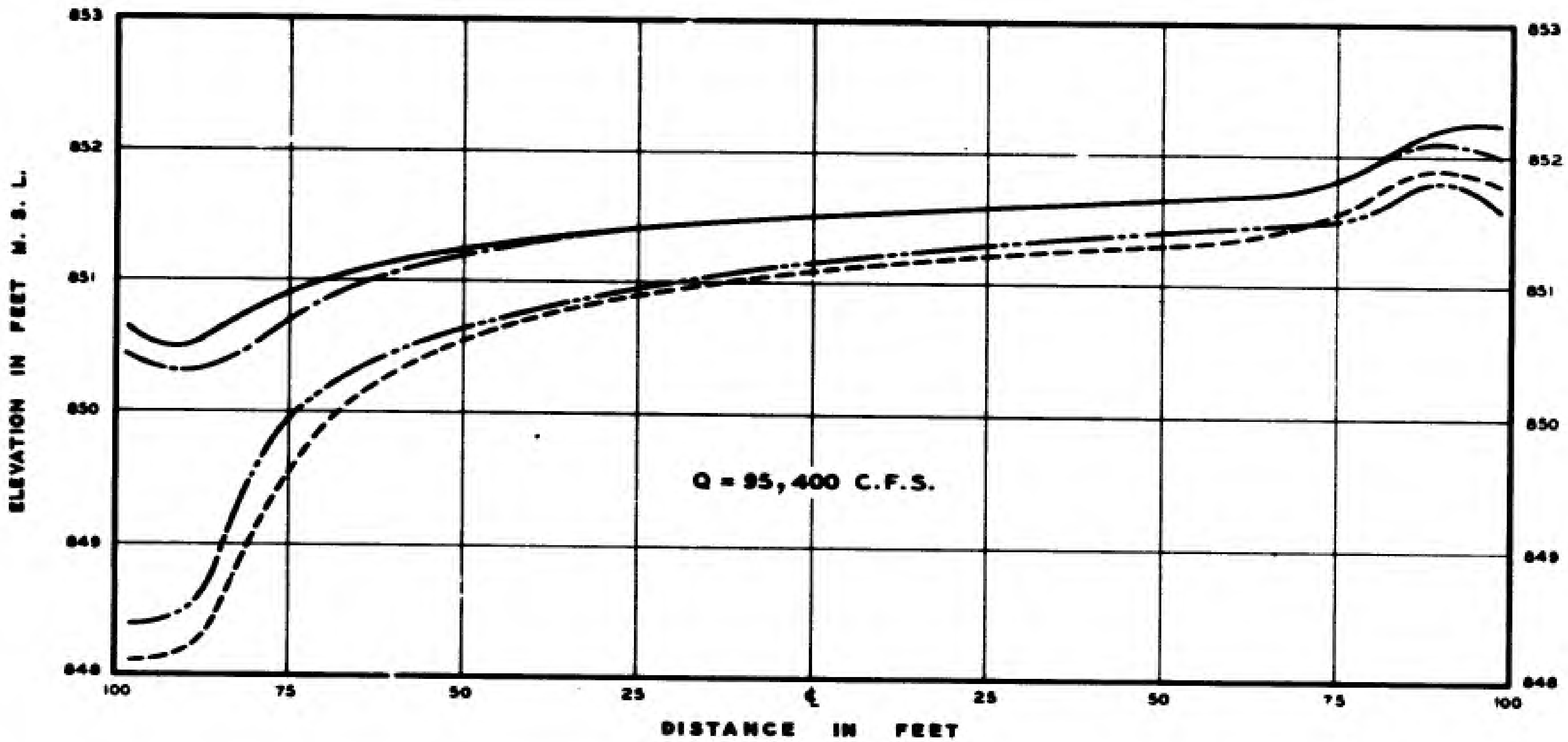
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



LEGEND

- ———— TEST 9
- – – – – TEST 10
- —— - —— TEST 11
- —— - - —— TEST 12

NOTES

1. CROSS SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
2. SIDEWALLS AND CREST NOT SHOWN.
3. SEE TABLE A FOR TESTS CONDITIONS.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
WATER-SURFACE CROSS SECTIONS
SPILLWAY CREST AXIS

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: R. B. ..., CAPTAIN, C. E.

TRACED BY W.O.D.
CHECKED BY G.E.H.

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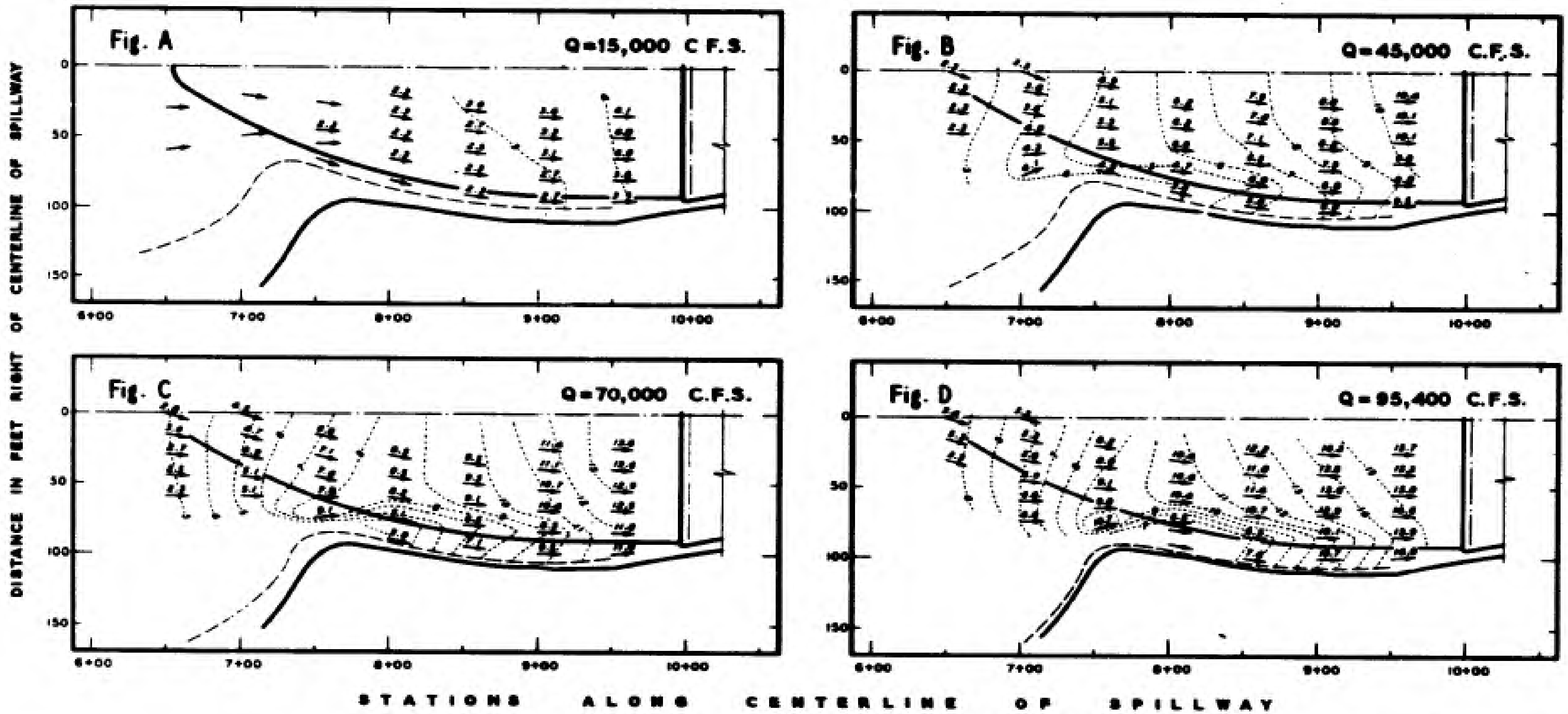
FILE: H.11.6-48



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\ V_m)$.
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 10.

LEGEND

— — — — — EDGE OF WATER

-------8------- VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 623.0 FT. M.S.L.
3. LEFT ABUTMENT PLAN F.
4. RIGHT APPROACH WALL PLAN III.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RAISED APRON FLOOR

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: R.B. Cochran, CAPTAIN, C. E.

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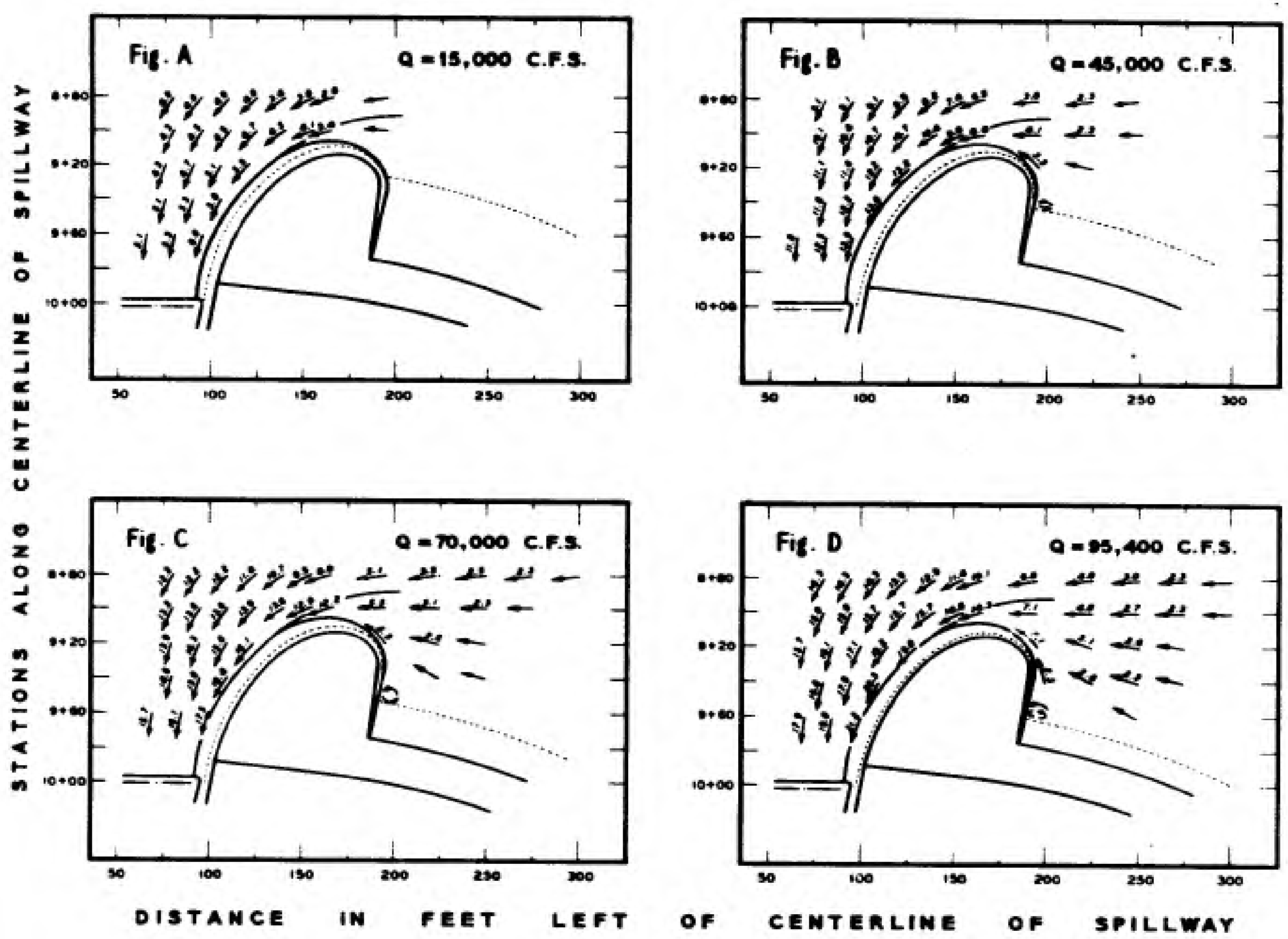
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{30}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 12.

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 823.0 FT. M. S. L.
3. RIGHT APPROACH WALL PLAN IX.
4. LEFT ABUTMENT PLAN I.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

VELOCITY OBSERVATIONS

RAISED APRON FLOOR

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY

U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: CAPTAIN, C. E.

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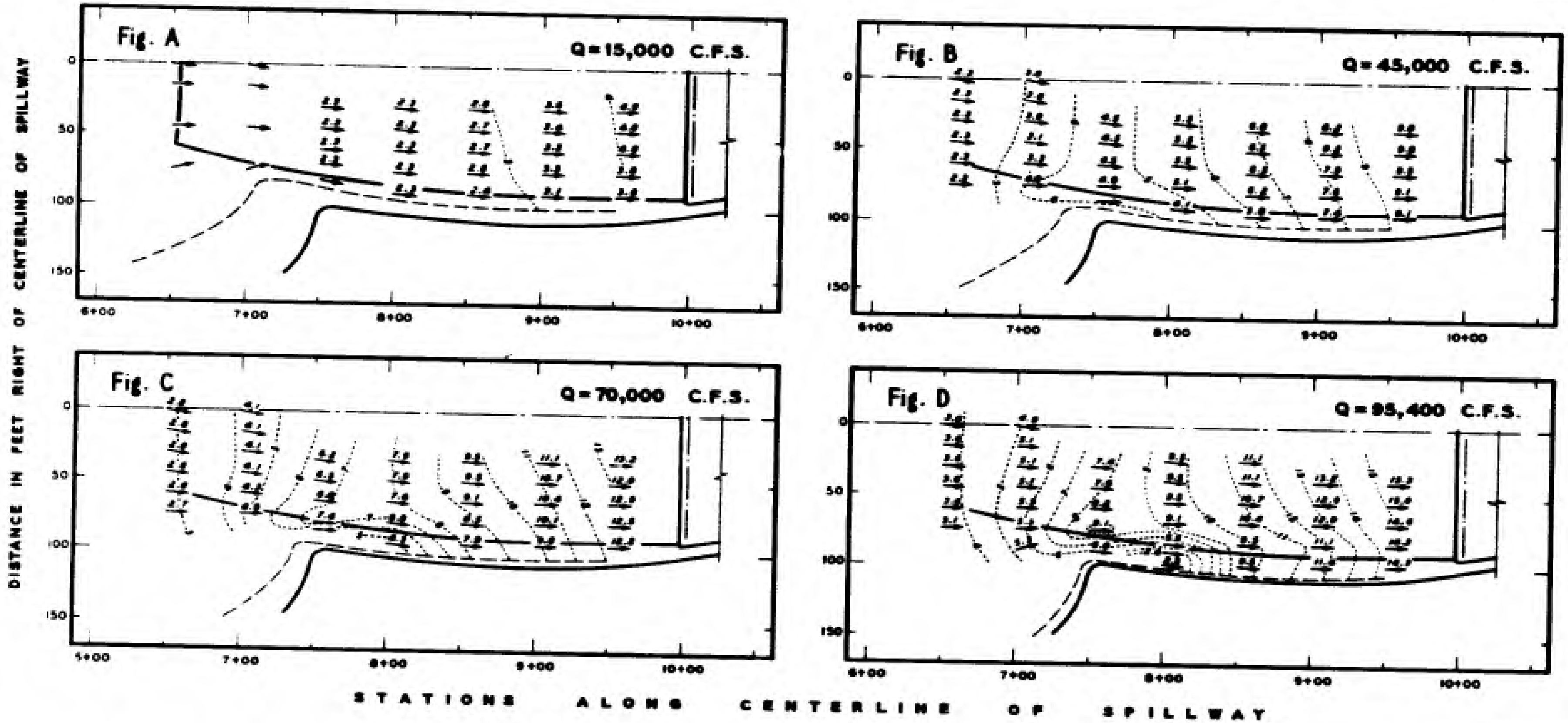
WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DATA TAKEN DURING TEST 12.

LEGEND

— — — — EDGE OF WATER

.......2....... VELOCITY CONTOURS

CONDITIONS

1. CREST PLAN III.
2. APRON FLOOR ELEVATION 623.0 FT. M.S.L.
3. LEFT ABUTMENT. PLAN I.
4. RIGHT APPROACH WALL PLAN III

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
RAISED APRON FLOOR

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

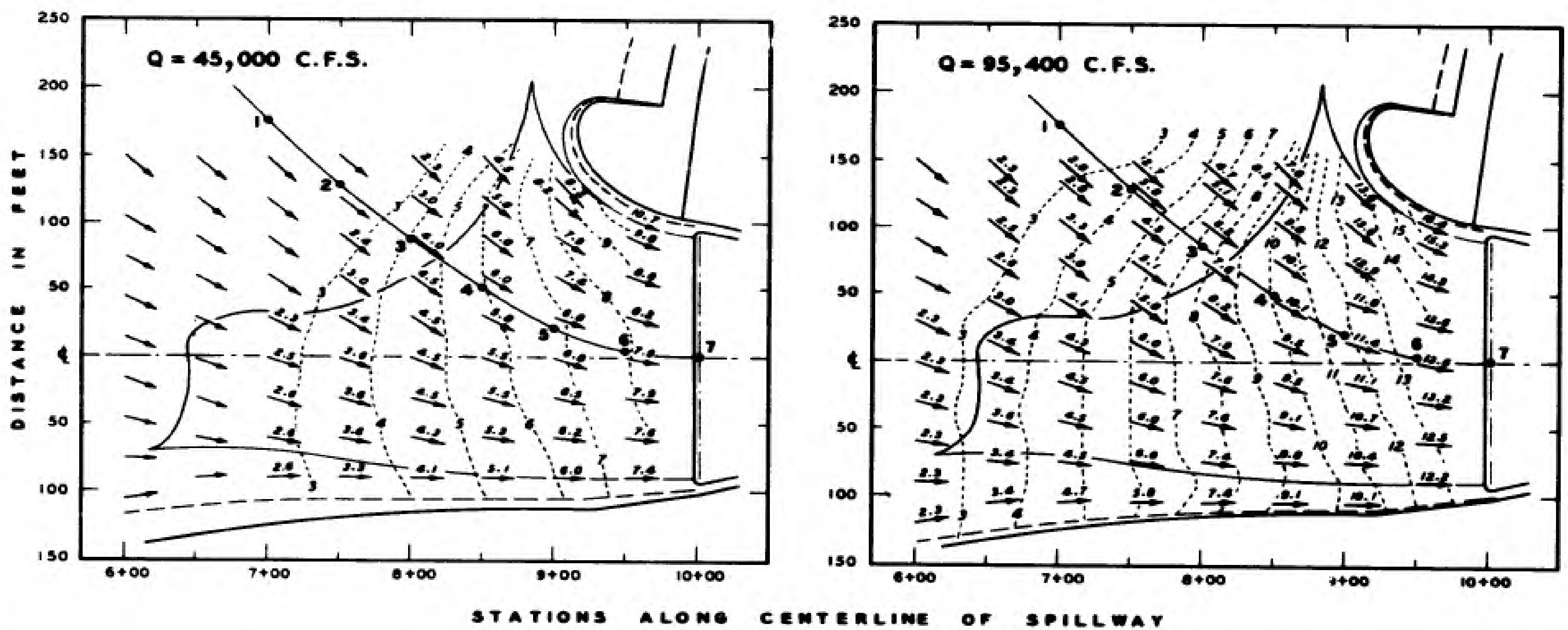
SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

TRACED BY H.G.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: H.11.10-8

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



POINT	POOL ELEVATION FT. - M.S.L.	
	45,000 C.F.S.	95,400 C.F.S.
1	848.5	858.2
2	848.5	858.2
3	848.4	857.7
4	848.1	857.0
5	848.0	856.4
6	847.7	855.6
7	844.3	851.2

NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 5-FOOT DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DOTTED LINE SHOWS WATER'S EDGE.
5. DATA TAKEN DURING TEST 24.
6. APRON FLOOR ELEVATION 810.0 FT. - M.S.L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
APRON FLOOR — FINAL DESIGN

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George L. Hyde, ASST. ENGINEER

APPROVED: R. B. Cochran, CAPTAIN, C. E.

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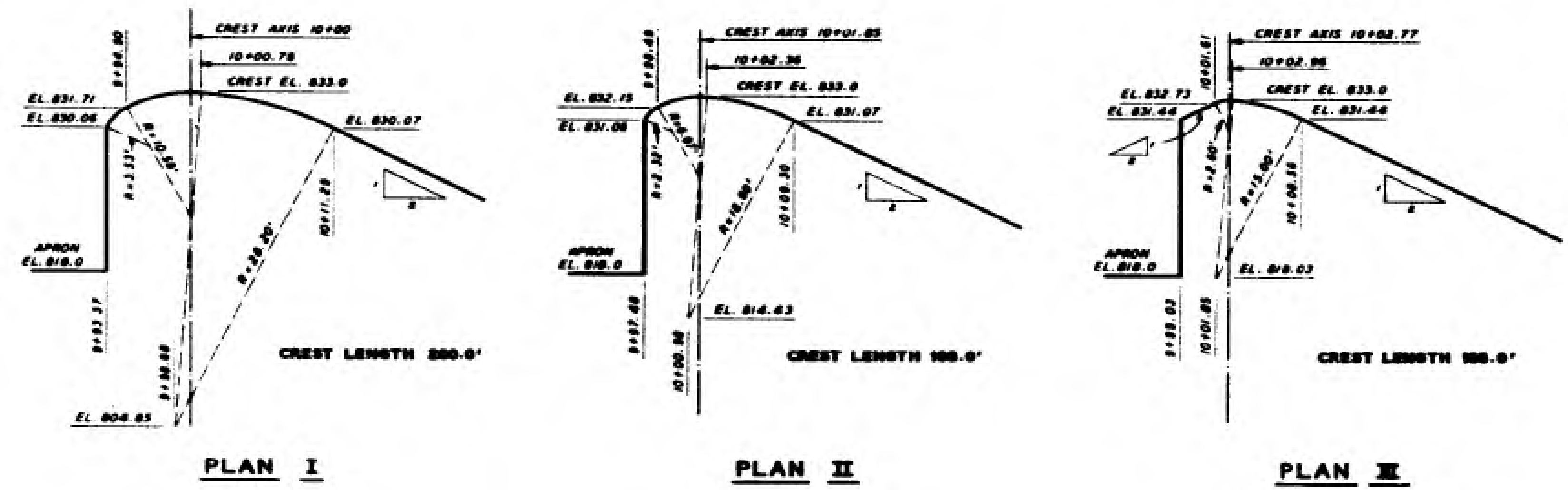

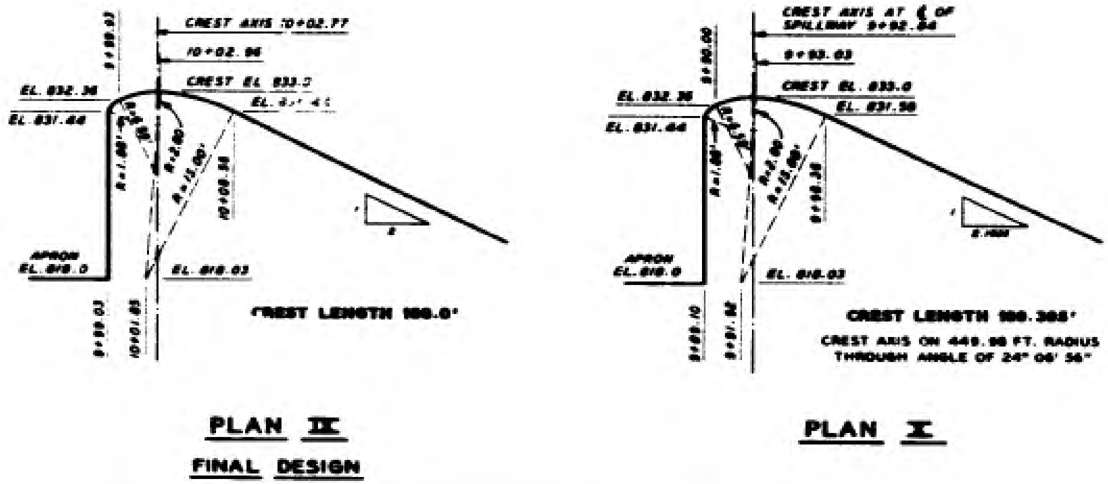

NOTES

1. ALL SECTIONS SHOWN ON CENTERLINE OF SPILLWAY.
2. PLAN I TAKEN FROM PORTLAND DISTRICT DRAWING [illegible], REVISED JUNE 17, 1940.
3. PLAN II TAKEN FROM PORTLAND DISTRICT DRAWING [illegible].
4. PLAN III TAKEN FROM PORTLAND DISTRICT DRAWING [illegible], REVISED NOV. 6, 1940.
5. PLAN IX TAKEN FROM PORTLAND DISTRICT DRAWING [illegible], DATED FEB. 12, 1941.
6. PLAN X WAS SIMILAR TO PLAN IX EXCEPT CREST AXIS WAS ON CURVED ALIGNMENT.
7. ELEVATIONS REFER TO FEET M. S. L.
8. PLANS IV - VIII ON PORTLAND DISTRICT DRAWING [illegible], REVISED NOV. 6, 1940 WERE NOT TESTED.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SPILLWAY CREST
PLANS TESTED

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED:	APPROVED:
[signature] ASST. ENGINEER	[signature] CAPTAIN, C. E.

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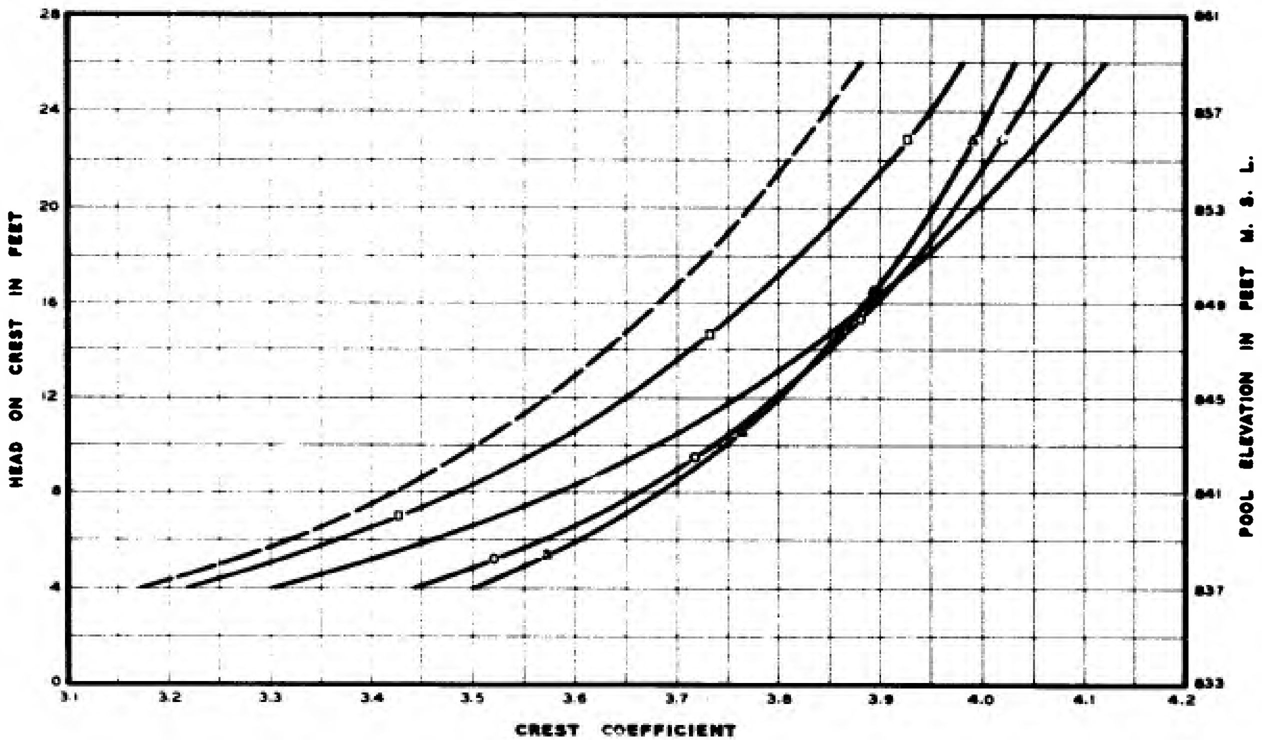

$Q = CLH^{1.5}$
H = POOL ELEV. − 833.0

NOTES

1. REFER TO PLATE 25 FOR DETAILS OF CREST PLANS.
2. COEFFICIENT FORMULAS WERE COMPUTED FROM OBSERVED DATA BY MEANS OF THE METHOD OF LEAST SQUARES.

CREST PLAN	LEGEND	COEFFICIENT FORMULA
I	— — —	$C = 2.732\ H^{0.1077}$
II	—□—	$C = 2.750\ H^{0.1130}$
III	—△—	$C = 3.144\ H^{0.0763}$
IX	———	$C = 2.801\ H^{0.1104}$
X	—○—	$C = 3.038\ H^{0.0886}$

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
CREST COEFFICIENT CURVES
SPILLWAY CREST

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: [signature] ASST. ENGINEER

APPROVED: [signature] CAPTAIN, C. E.

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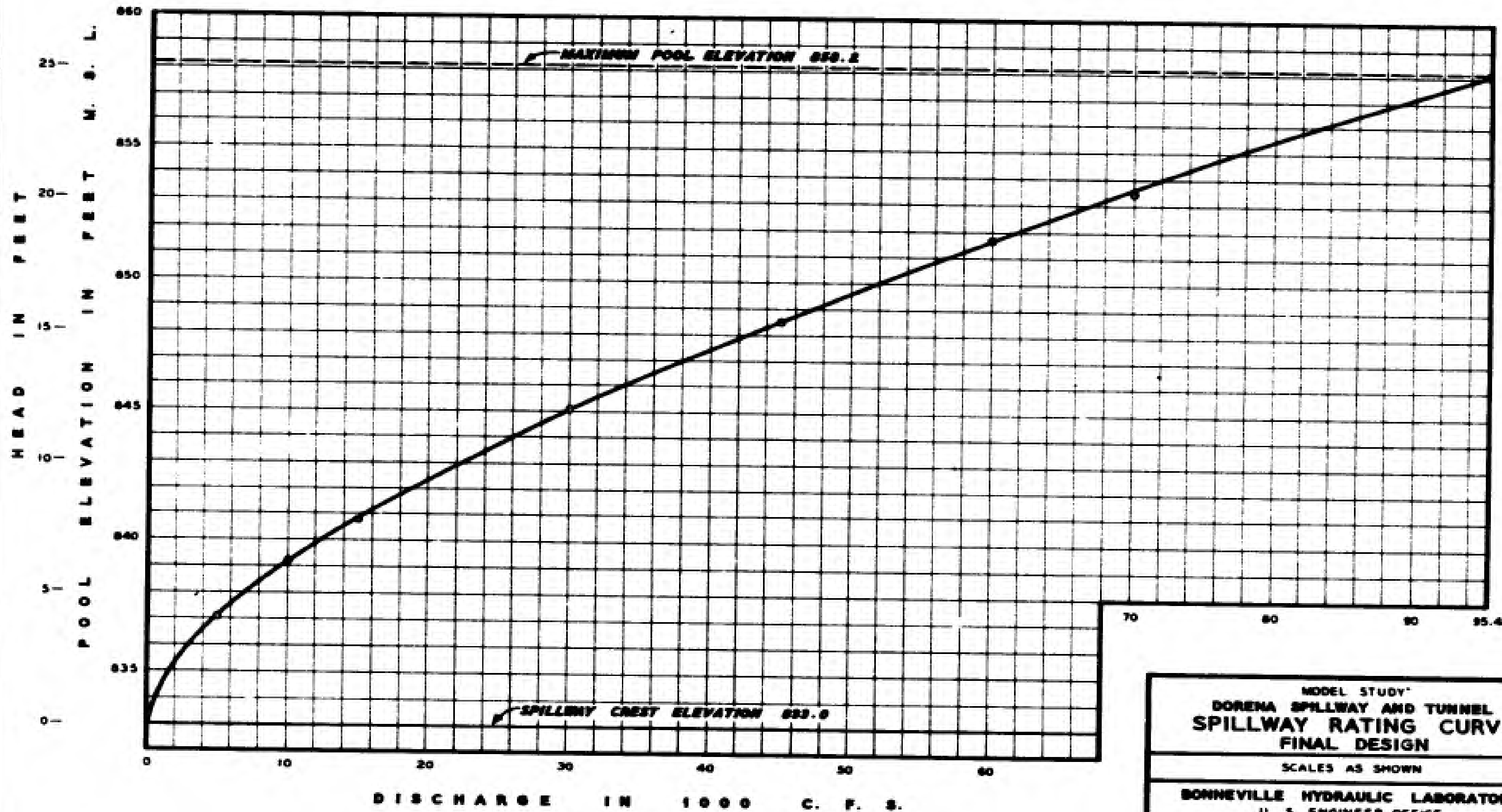


MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SPILLWAY RATING CURVE
FINAL DESIGN

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

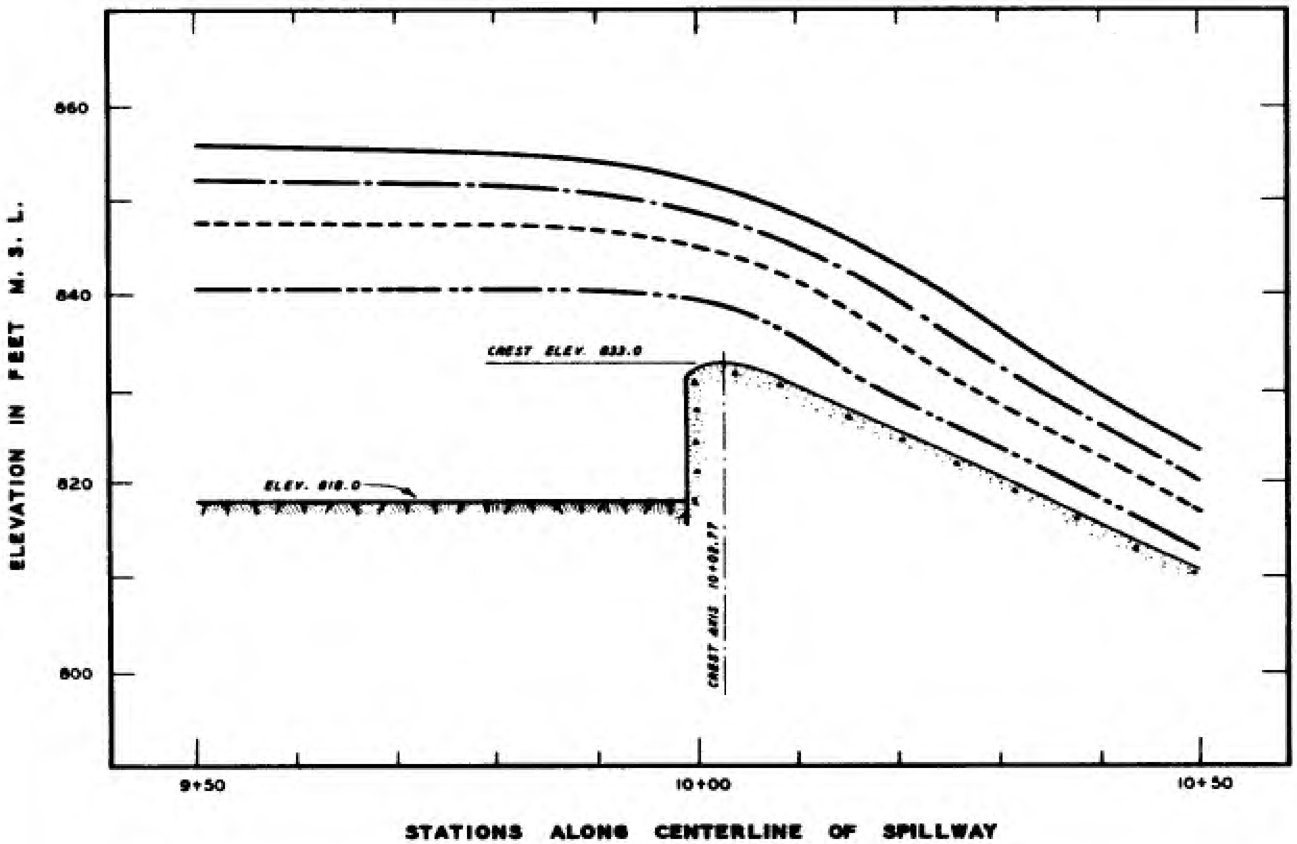
SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: ......, CAPTAIN, C. E.

TRACED BY W. O. S.
CHECKED BY G. E. H.

TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942

FILE: H.11.8-36



NOTES

1. PROFILES ARE SHOWN ON CENTERLINE OF SPILLWAY.
2. DATA SHOWN WERE TAKEN DURING TEST 24.
3. SEE PLATE 25 FOR DETAILS PLAN III CREST.

LEGEND

15,000 C.F.S.
45,000 C.F.S.
70,000 C.F.S.
95,400 C.F.S.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
WATER - SURFACE PROFILES
PLAN III CREST

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. R. [illegible], CAPTAIN, C. E.

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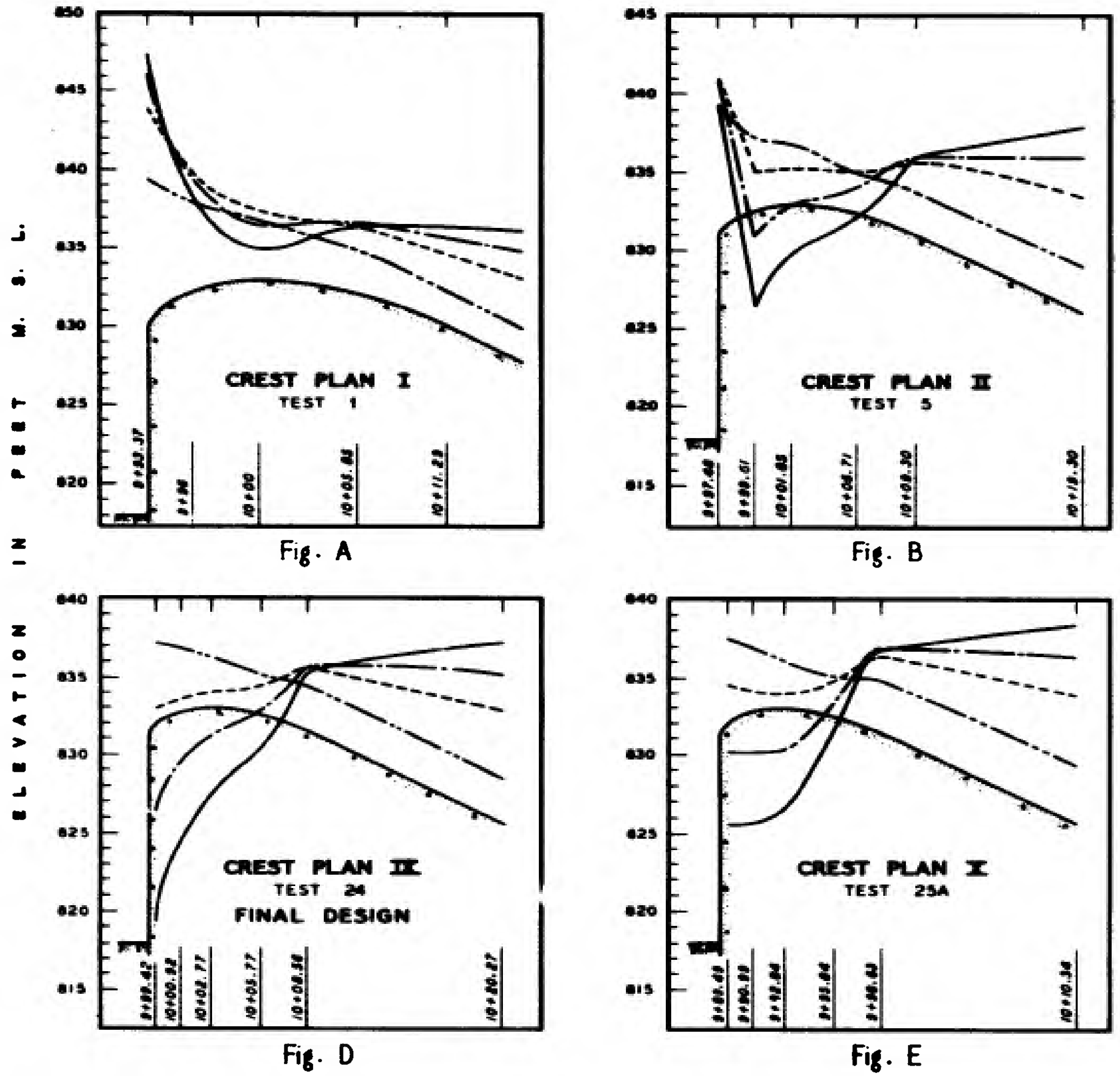


Fig. A

Fig. B

Fig. D

Fig. E

STATIONS ALONG CENTERLINE OF SPILLWAY

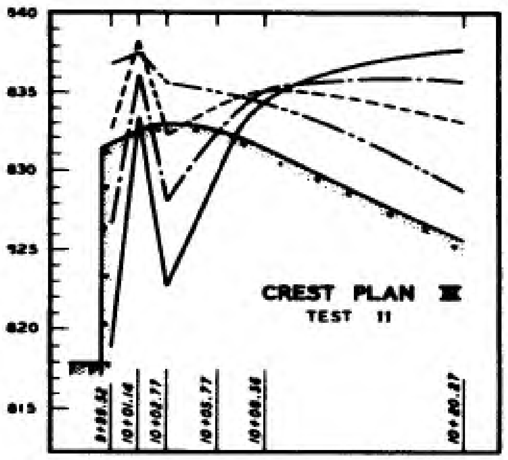


Fig. C

LEGEND

- 15,000 C.F.S.
- 45,000 C.F.S.
- 70,000 C.F.S.
- 95,400 C.F.S. (85,000 C.F.S. FOR PLAN I)

NOTES

1. ALL SECTIONS ARE SHOWN ON CENTERLINE OF SPILLWAY.
2. SEE PLATE 25 FOR DETAILS OF CREST PLANS.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
PRESSURE GRADE LINES
SPILLWAY CREST

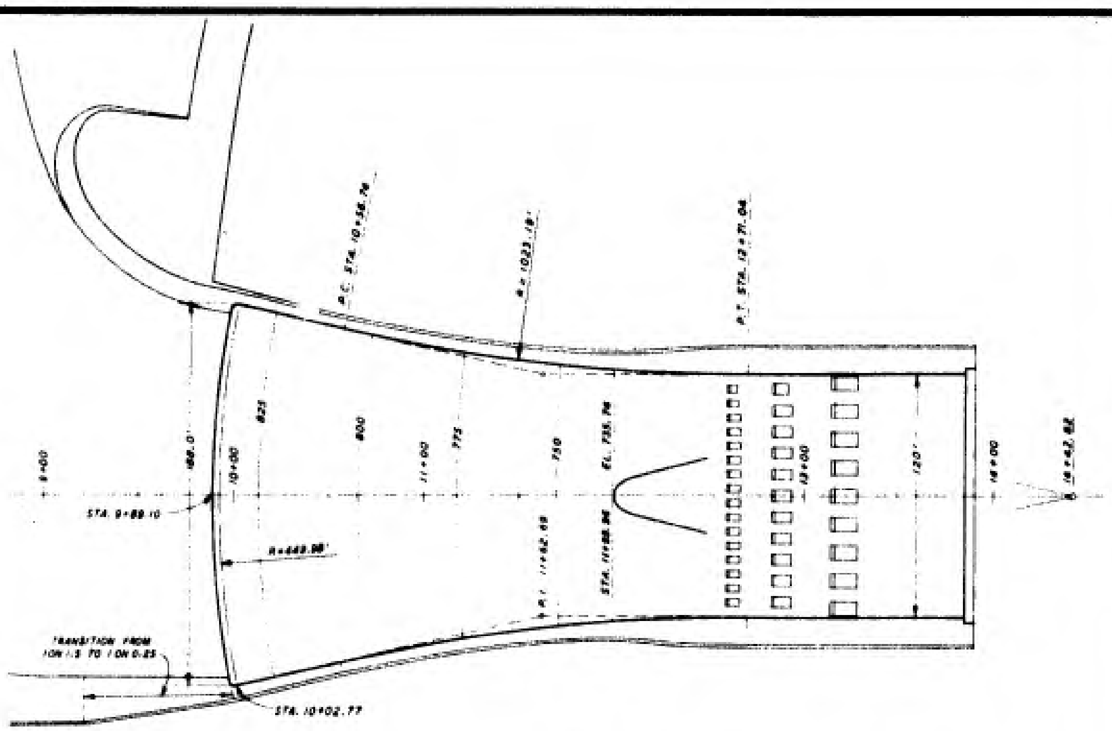
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

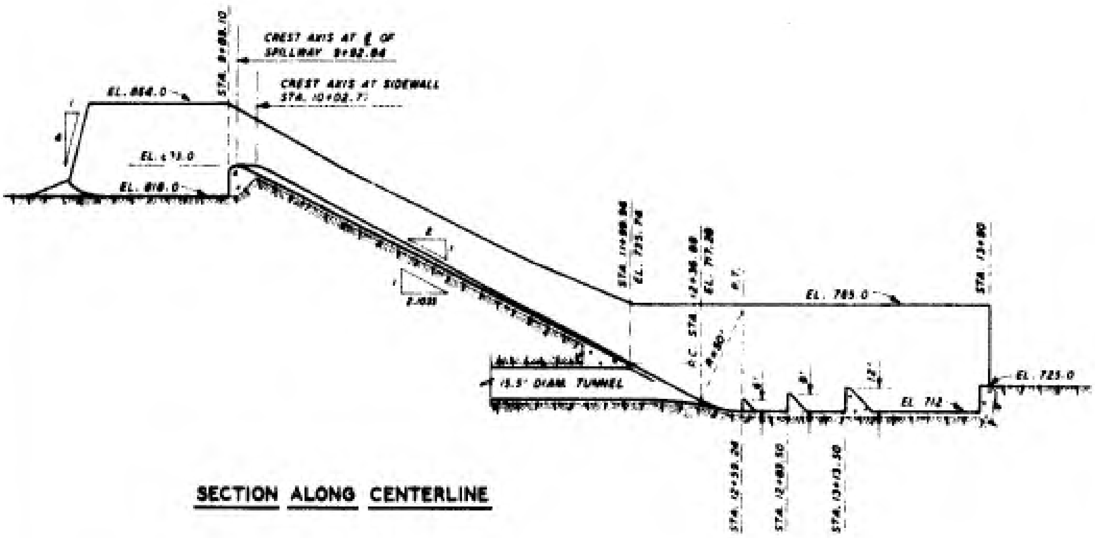
SUBMITTED: ASS'T ENGINEER

APPROVED: CAPTAIN, C. E.

TRACED BY H.O.S. CHECKED BY G.E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942 | FILE: B.H.S-40



PLAN



SECTION ALONG CENTERLINE

NOTES

1. SAME AS FINAL DESIGN EXCEPT FOR CURVED CREST AND RESULTING CONCAVE CHUTE FLOOR DOWNSTREAM TO STA. 11+99.96
2. ELEVATIONS REFER TO FEET M.S.L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
CHUTE PLAN P

SCALES
MODEL 1 0 1 FT.
PROTOTYPE 50 0 50 FT.

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. B. Cochran, CAPTAIN, C. E.

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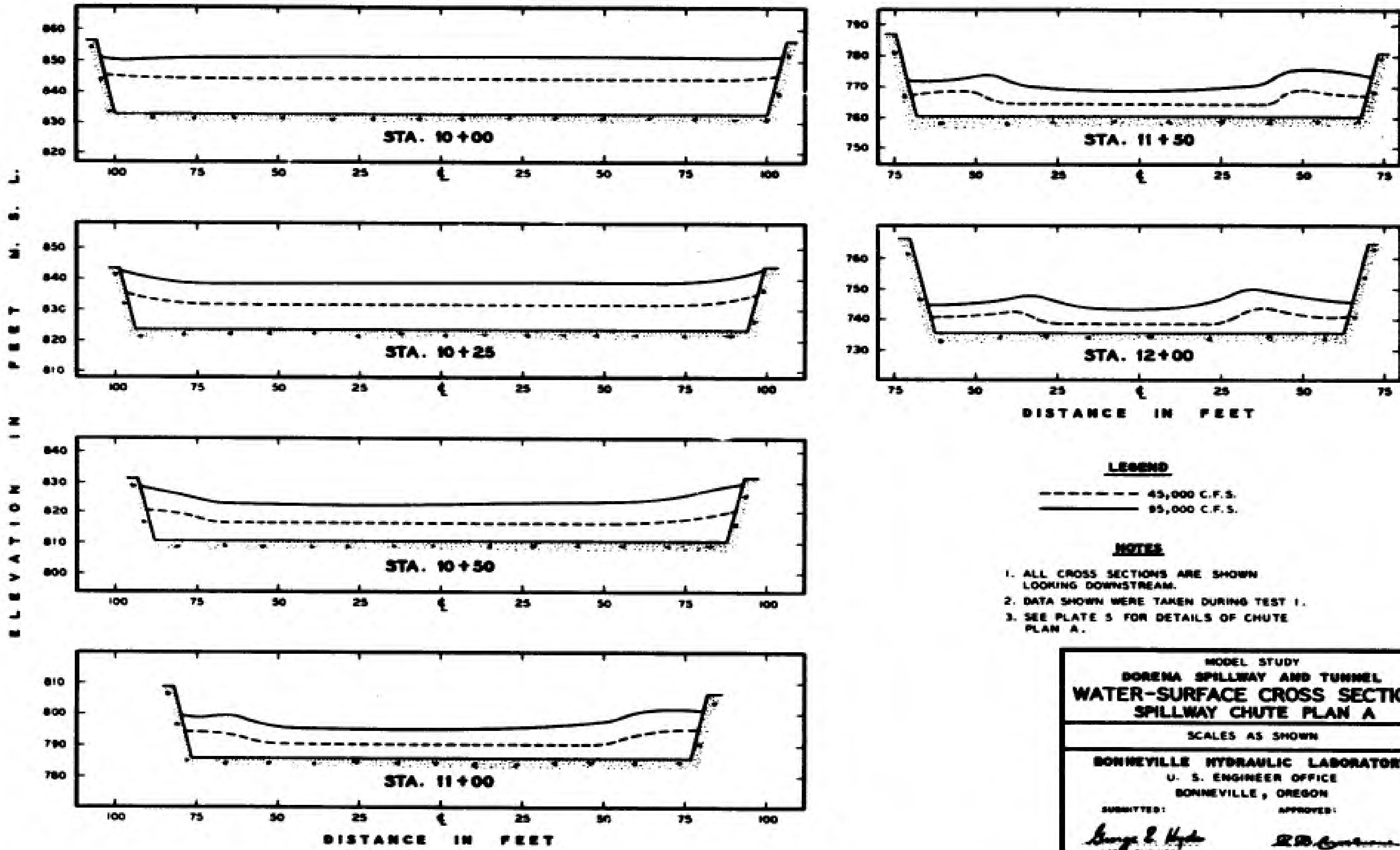

NOTES

1. ALL CROSS SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
2. DATA SHOWN WERE TAKEN DURING TEST 1.
3. SEE PLATE 5 FOR DETAILS OF CHUTE PLAN A.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL

WATER-SURFACE CROSS SECTIONS SPILLWAY CHUTE PLAN A

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASS'T. ENGINEER

APPROVED: [signature], CAPTAIN, C. E.

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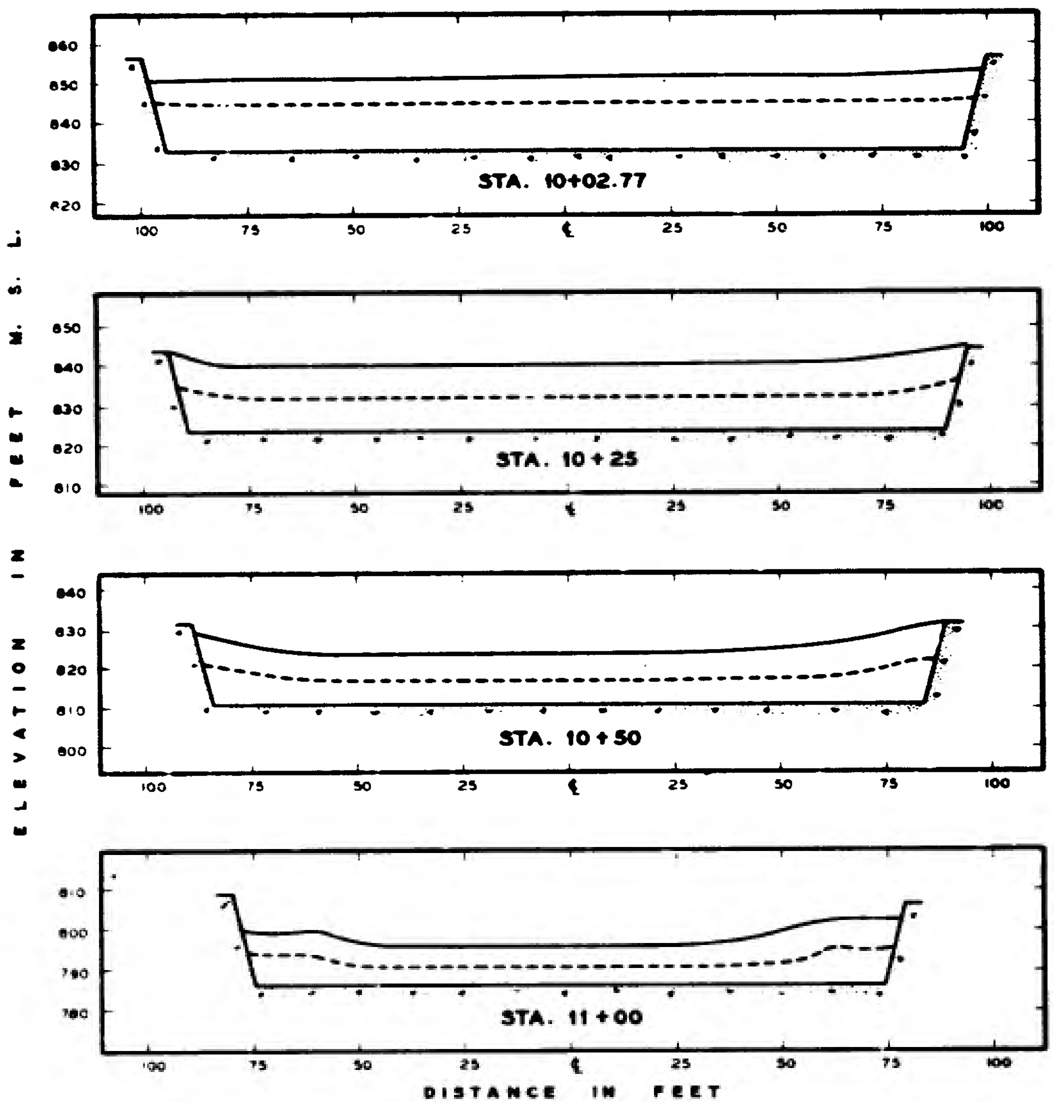
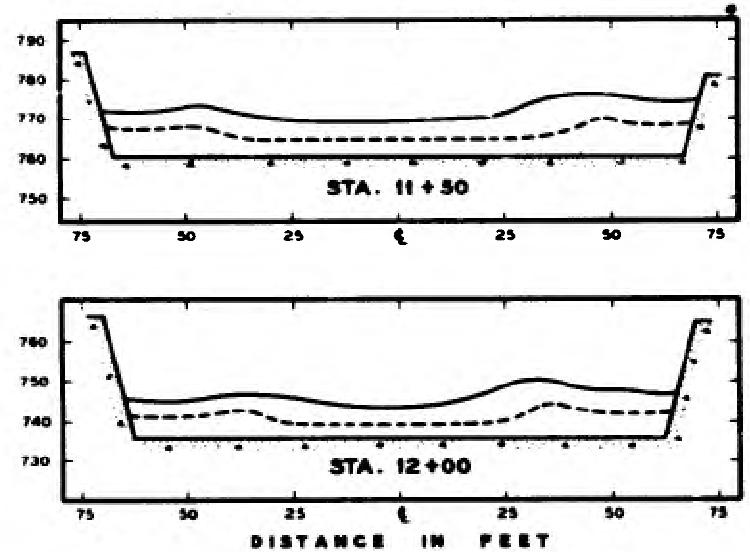




LEGEND

- - - - - - - 45,000 C.F.S.

———————— 95,400 C.F.S.

NOTES

1. ALL CROSS SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
2. DATA AT STA. 10+02.77 WERE TAKEN DURING TEST 23 – ALL OTHER DATA WERE TAKEN DURING TEST 24.
3. SEE PLATE 6 FOR DETAILS OF CHUTE PLAN O.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

WATER-SURFACE CROSS SECTIONS

SPILLWAY CHUTE PLAN O

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY

U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

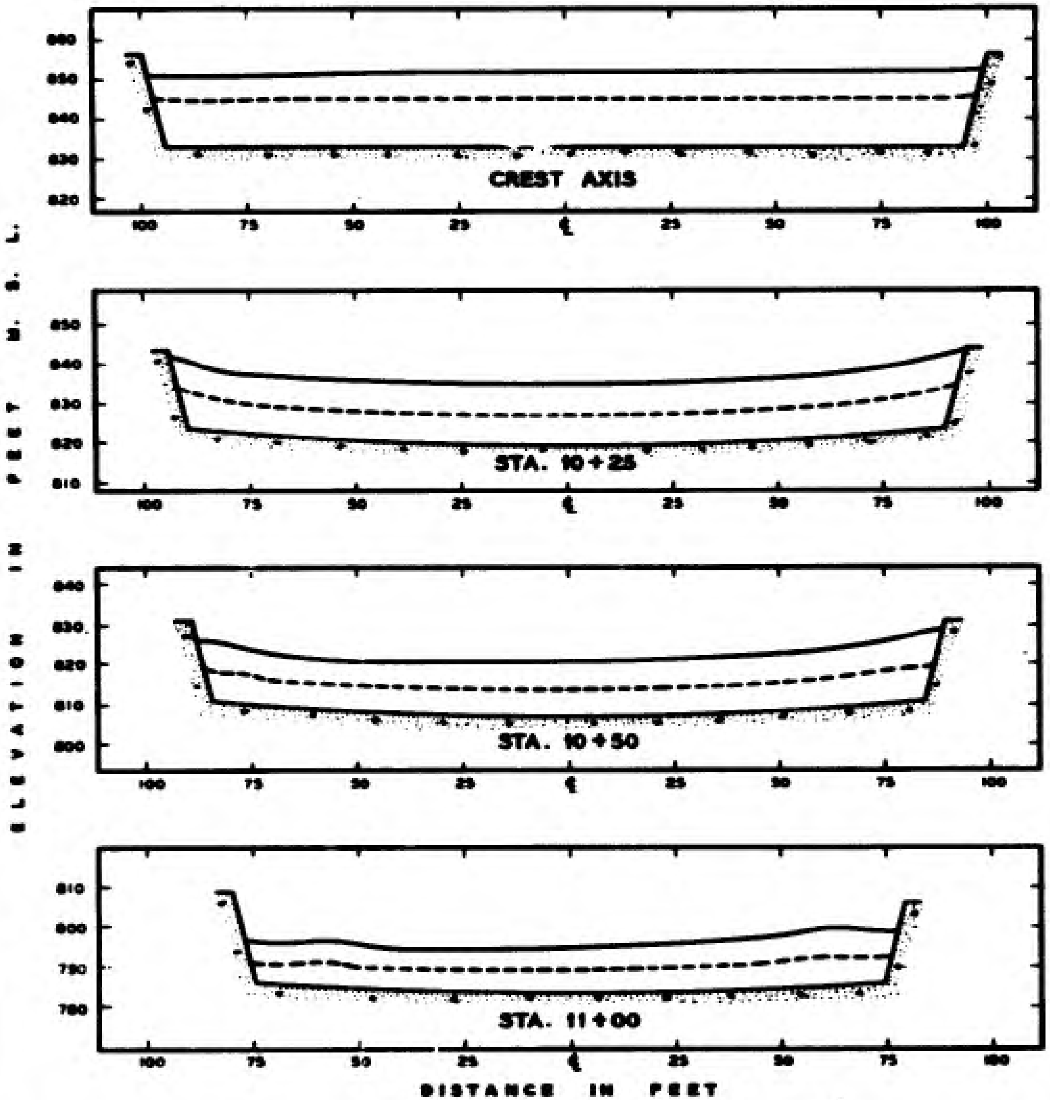
SUBMITTED: George E. Hyde, ASS'T ENGINEER

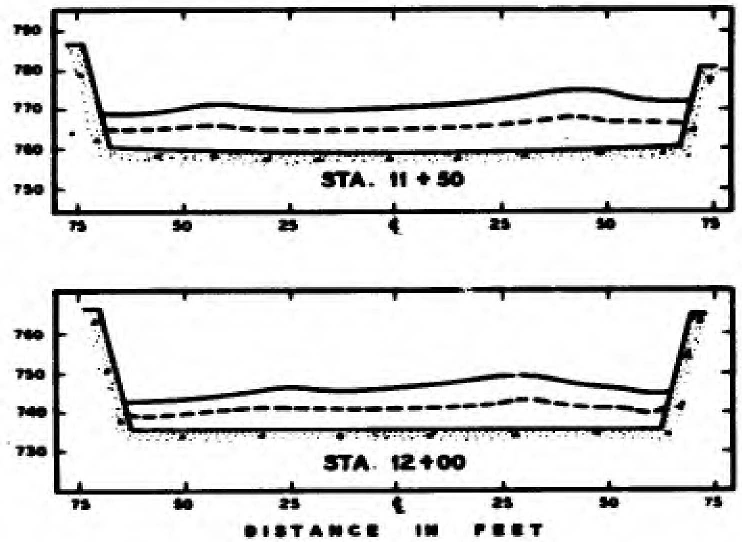
APPROVED: R. B. [signature], CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.11.24-16

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY





LEGEND

- - - - - - - 45,000 C.F.S.

———————— 95,000 C.F.S.

NOTES

1. ALL CROSS SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
2. DATA SHOWN WERE TAKEN DURING TEST 23A.
3. SEE PLATE 30 FOR DETAILS OF CHUTE PLAN P.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
WATER-SURFACE CROSS SECTIONS
SPILLWAY CHUTE PLAN P

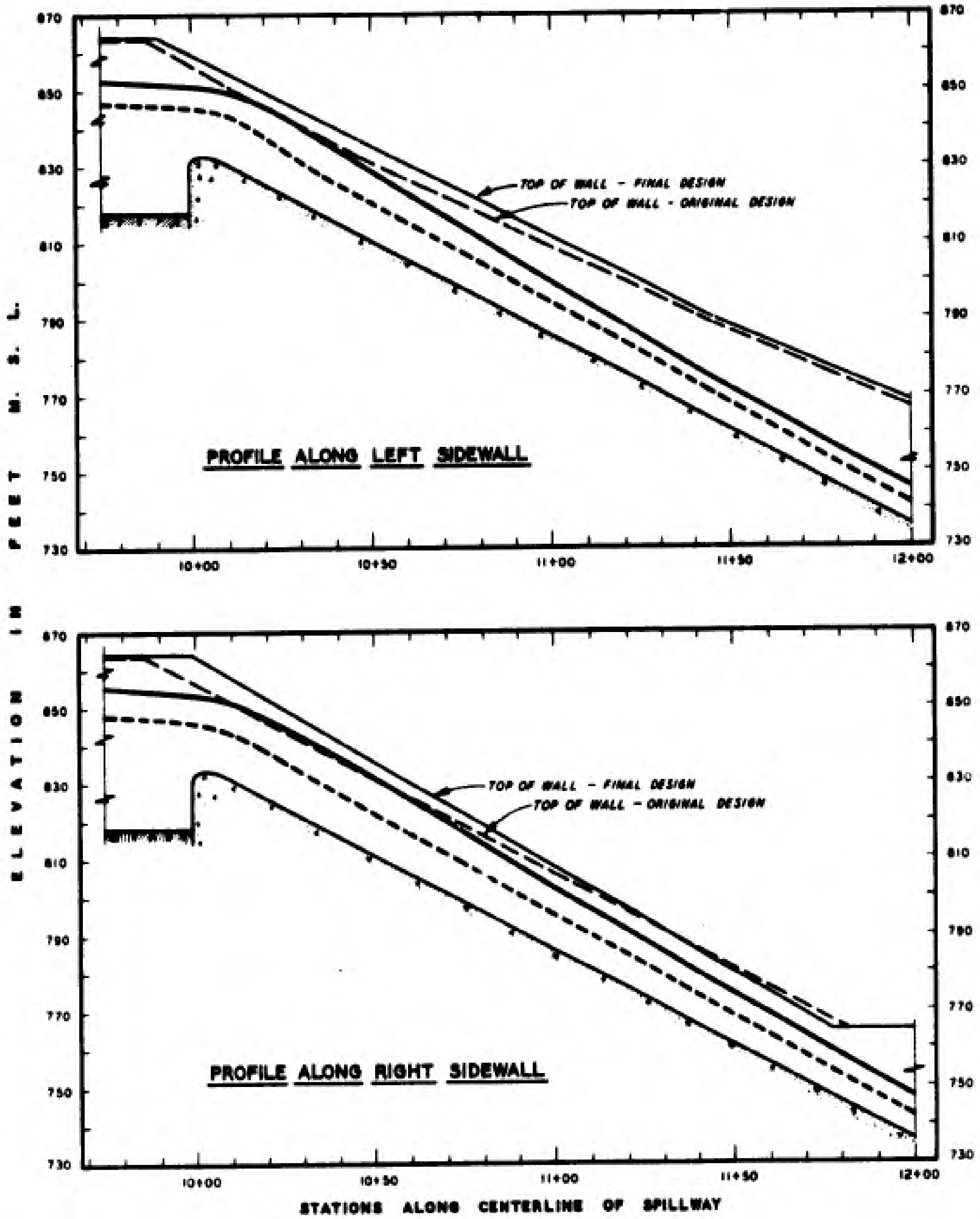
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASS'T. ENGINEER CAPTAIN, C. E.

TRACED BY [illegible] CHECKED BY [illegible] | TRANSMITTED WITH REPORT DATED NOVEMBER [illegible], 1942 | FILE: [illegible]



LEGEND

- - - - - - - - 45,000 C.F.S.
———————— 95,400 C.F.S.

NOTES

1. DATA SHOWN WERE TAKEN DURING TEST 24.
2. PROFILE OF ORIGINAL DESIGN OF SIDEWALLS TAKEN FROM PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.
3. PROFILE OF FINAL DESIGN OF SIDEWALLS TAKEN FROM PORTLAND DISTRICT DRAWING DO-110-3.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
WATER-SURFACE PROFILES
SPILLWAY CHUTE

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST ENGINEER CAPTAIN, C E

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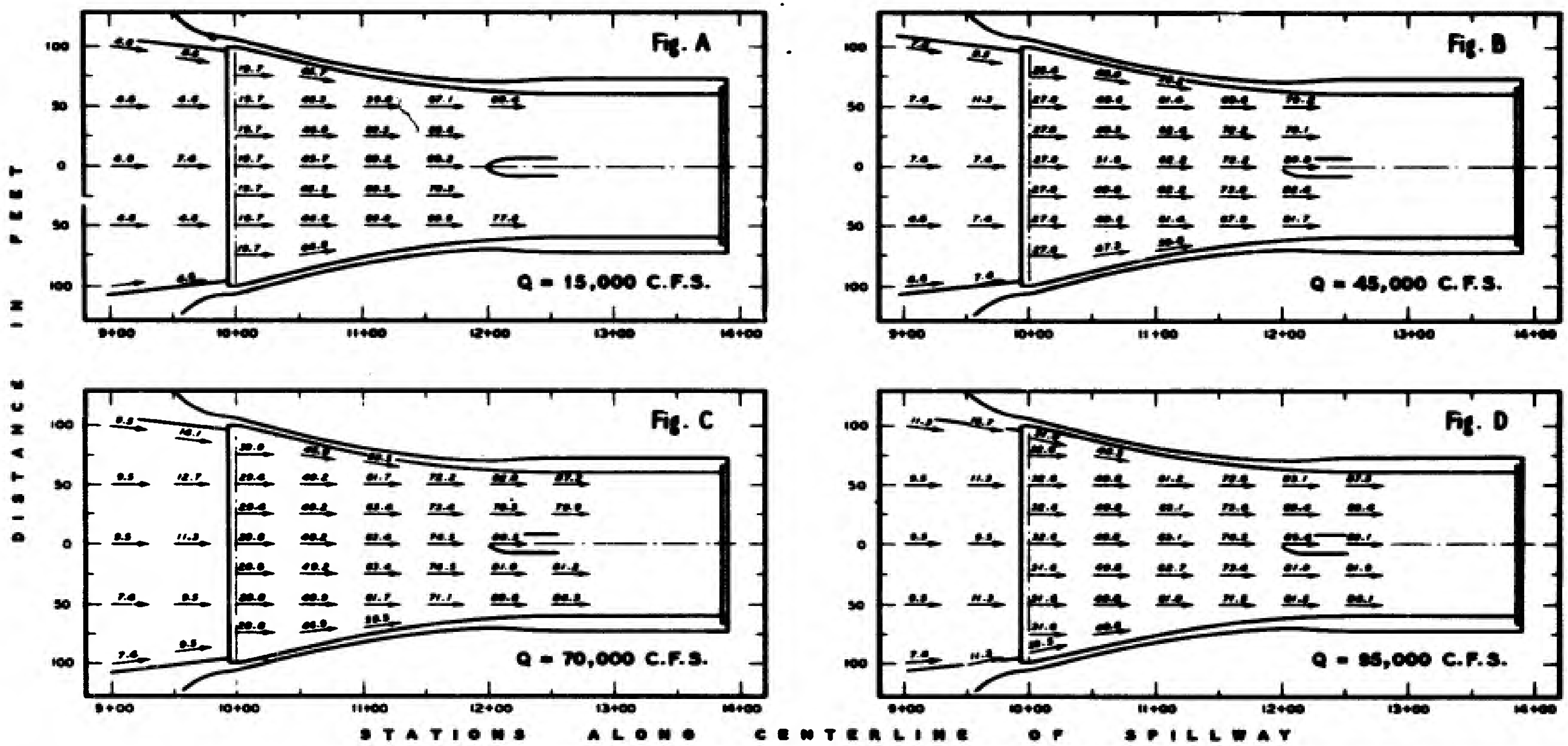


NOTES

1. MODEL VELOCITIES TAKEN WITH PITOT TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\ V_m)$.
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 0.6 DEPTH.
3. DATA SHOWN WERE TAKEN DURING TEST 1.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
SPILLWAY CHUTE PLAN A

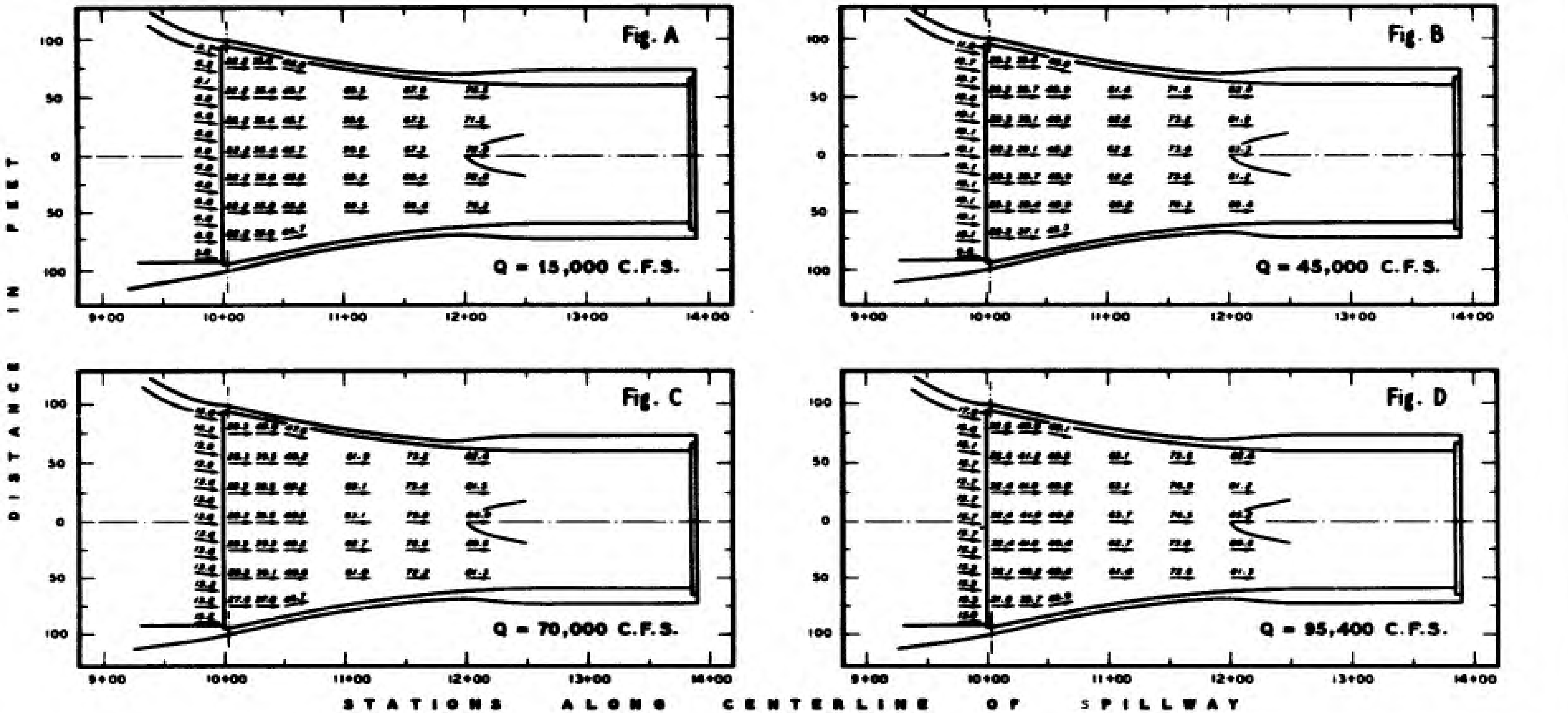
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH PITOT TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{50}\, V_m)$.
2. ALL VELOCITIES ARE SHOWN IN FEET PER SECOND.
3. VELOCITIES AT STATION 9+75 WERE TAKEN AT 5-FOOT DEPTH - ALL OTHER VELOCITIES WERE TAKEN AT 0.6 DEPTH.
4. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
SPILLWAY CHUTE PLAN O

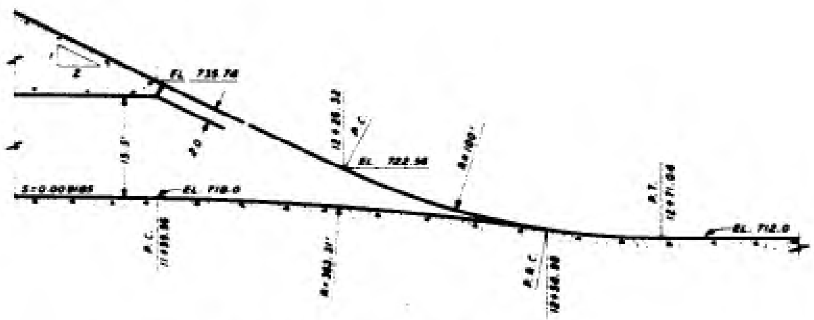
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

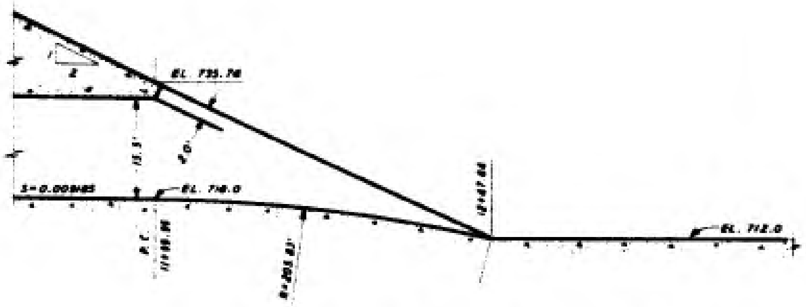
SUBMITTED: APPROVED:

ASST ENGINEER CAPTAIN, C. E.

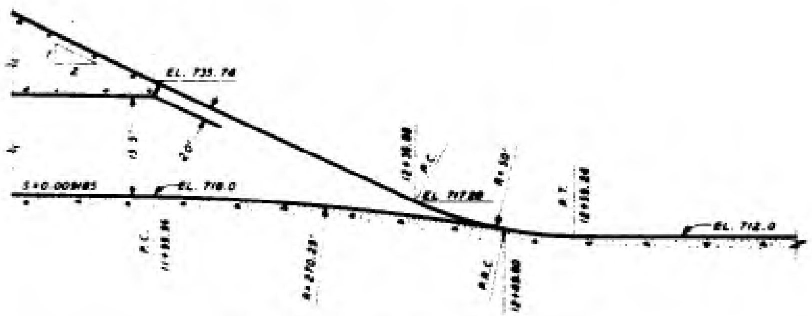
TRACED BY W.O.G. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942	FILE: M.11. 24-19



100-FOOT RADIUS BUCKET



INTERSECTING-PLANES BUCKET



50-FOOT RADIUS BUCKET

FINAL DESIGN

NOTES

1. DETAILS OF 100-FOOT RADIUS BUCKET AS PER PORTLAND DISTRICT DRAWINGS DO-20-2/2A, REVISED JUNE 17, 1940 AND DO-20-2/3A, REVISED JUNE 17, 1940.
2. ELEVATIONS REFER TO FEET M. S. L.
3. SECTIONS ON CENTERLINE OF SPILLWAY.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SPILLWAY BUCKET
PLANS TESTED

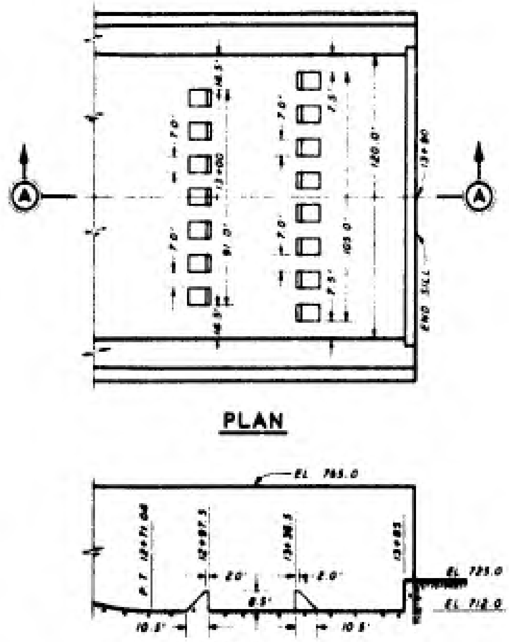
SCALES IN FEET

MODEL	0		0.5			1
PROTOTYPE	0	10	20	30	40	50

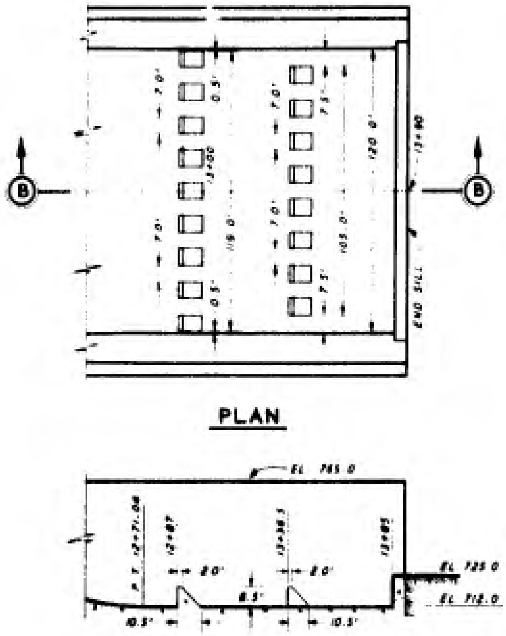
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER
APPROVED: CAPTAIN, C.E.

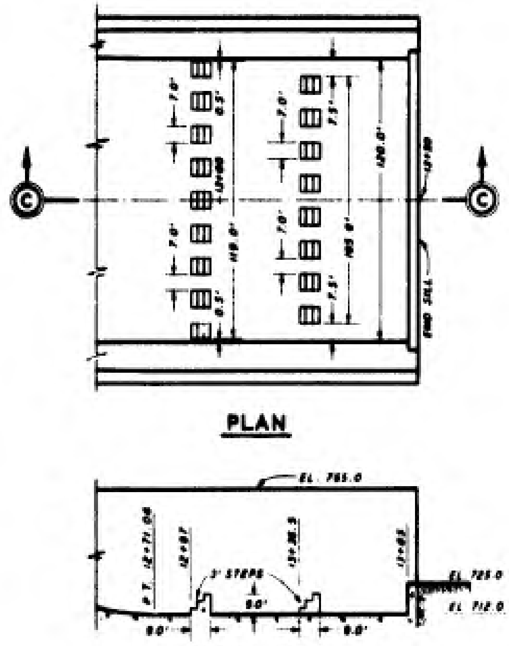
TRACED BY W.O.D. CHECKED BY G.E.H	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.11.6-46



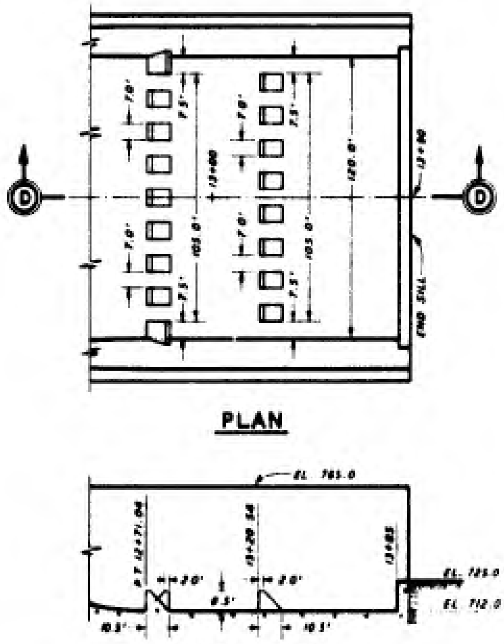
PLAN A BAFFLES



PLAN B BAFFLES



PLAN C BAFFLES



PLAN D BAFFLES

NOTES

1. PLAN A, ORIGINALLY DESIGNED BAFFLES, TAKEN FROM PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.
2. ELEVATIONS REFER TO FEET M. S. L.

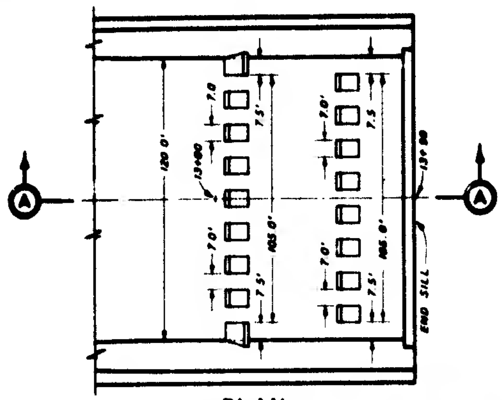
MODEL STUDY
DORENA SPILLWAY AND TUNNEL
BAFFLE ARRANGEMENT
PLANS A, B, C, AND D

SCALES IN FEET
MODEL
PROTOTYPE

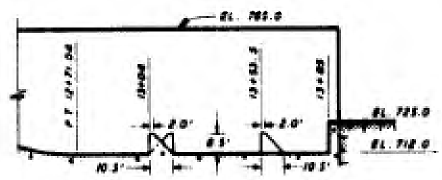
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASS'T ENGINEER
APPROVED: R. B. Cochran, CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942 | FILE: M-11 G-40

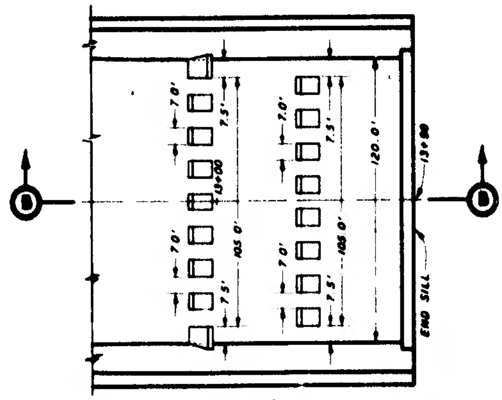


PLAN

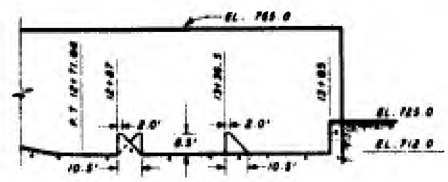


SECTION A-A

PLAN E BAFFLES

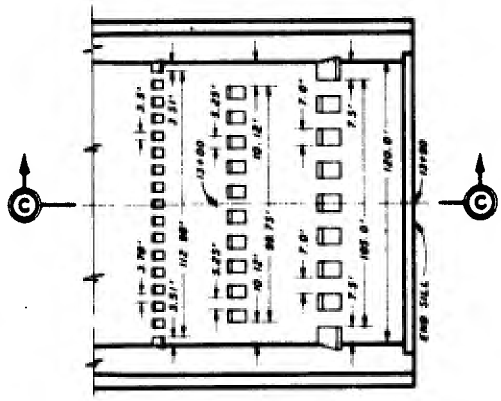


PLAN

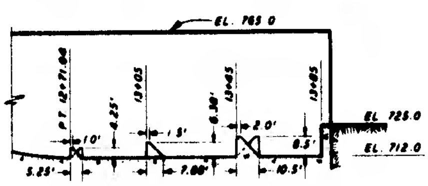


SECTION B-B

PLAN F BAFFLES

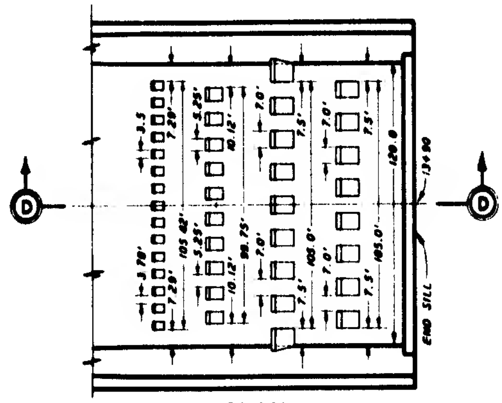


PLAN

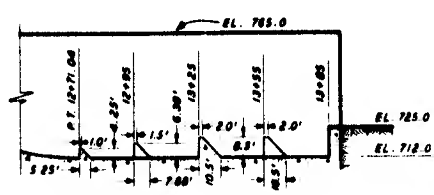


SECTION C-C

PLAN G BAFFLES



PLAN



SECTION D-D

PLAN H BAFFLES

NOTE

ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
BAFFLE ARRANGEMENT
PLANS E, F, G, AND H

SCALES IN FEET

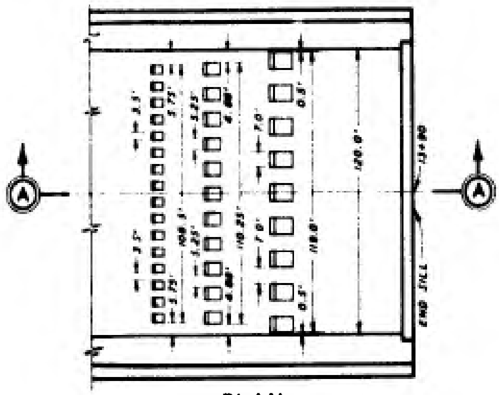
MODEL 1 0 1 2
PROTOTYPE 50 0 50 100

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

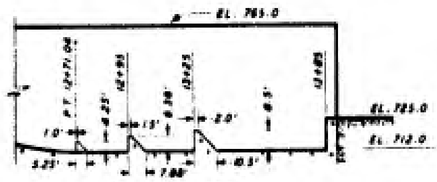
SUBMITTED: APPROVED:

ASS'T. ENGINEER CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942 | FILE: M. 11. G - 41

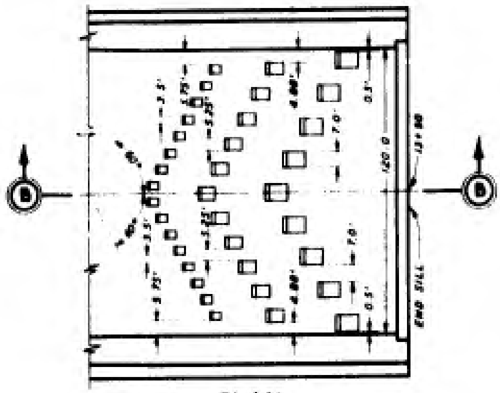


PLAN

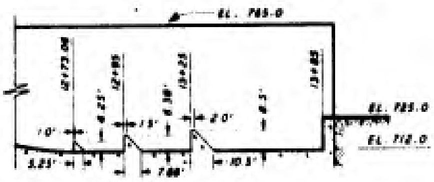


SECTION A-A

PLAN I BAFFLES

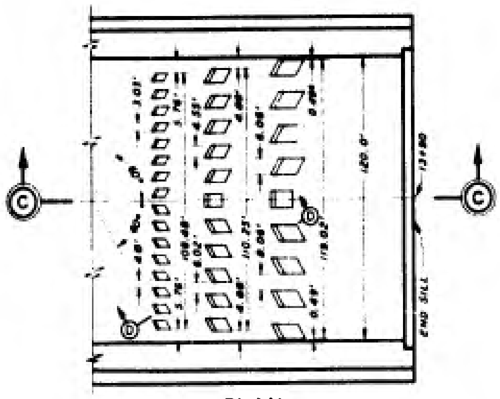


PLAN

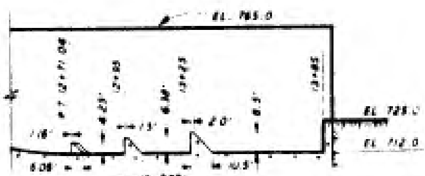


SECTION B-B

PLAN J BAFFLES



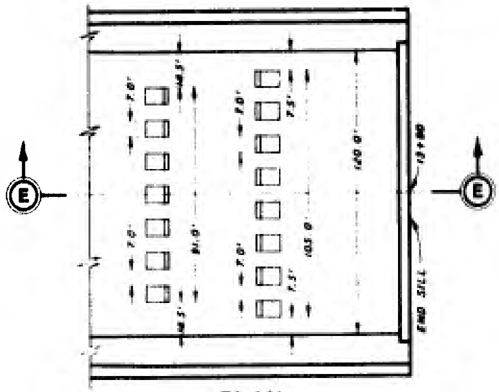
PLAN



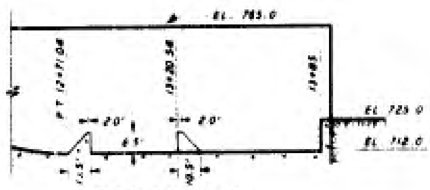
SECTION C-C

SECTION D-D

PLAN K BAFFLES



PLAN



SECTION E-E

PLAN L BAFFLES

NOTE

ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

BAFFLE ARRANGEMENT

PLANS I, J, K, AND L

SCALES IN FEET

MODEL 1 0 2

PROTOTYPE 50 0 50 100

BONNEVILLE HYDRAULIC LABORATORY

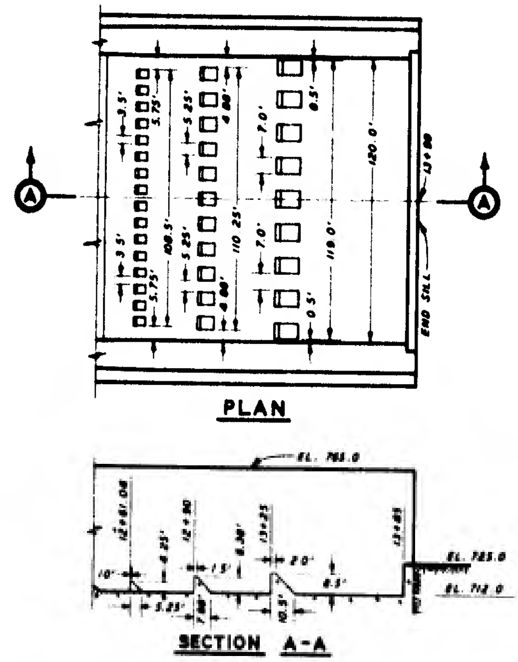
U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

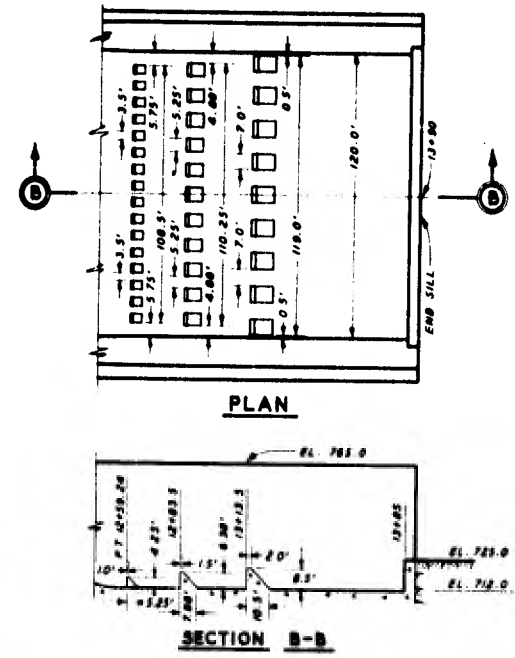
SUBMITTED George E. Hyde ASS'T. ENGINEER

APPROVED R. B. [illegible] CAPTAIN, C. E.

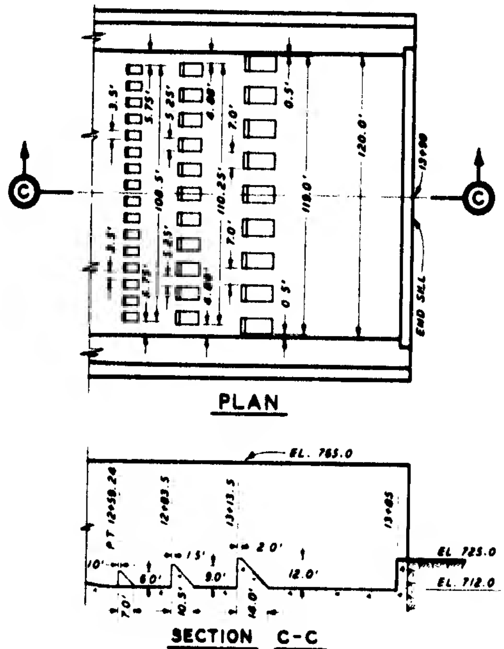
TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942	FILE: M 11 G 42



PLAN M BAFFLES

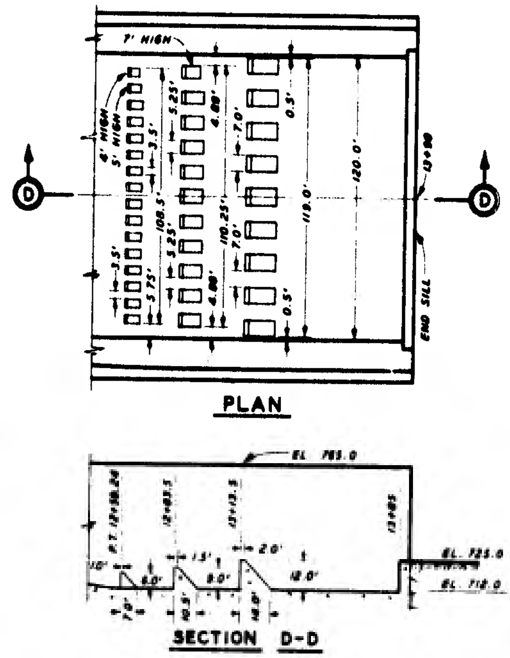


PLAN N BAFFLES



PLAN O BAFFLES

FINAL DESIGN



PLAN P BAFFLES

NOTES

1. ELEVATIONS REFER TO FEET M. S. L.
2. PLAN P BAFFLES WERE DEVELOPED FOR USE WITH CREST PLAN X AND CHUTE PLAN P

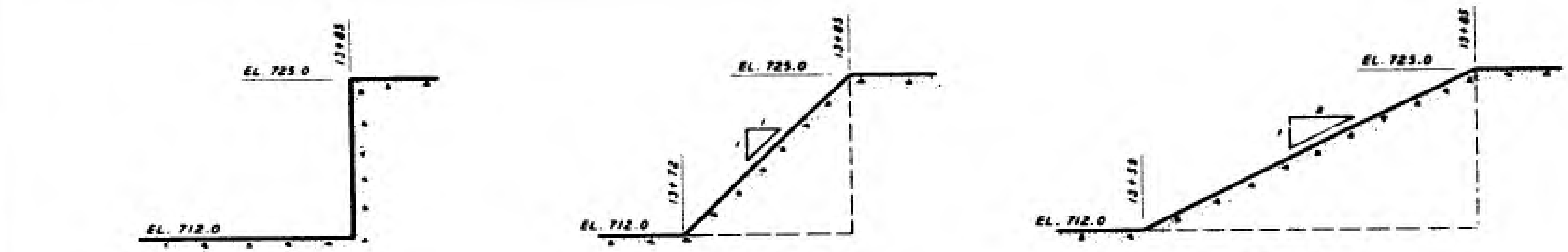
MODEL STUDY
DORENA SPILLWAY AND TUNNEL
BAFFLE ARRANGEMENT
PLANS M, N, O, AND P

SCALES IN FEET
MODEL 0 2
PROTOTYPE 50 0 50 100

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER
APPROVED: CAPTAIN, C. E.

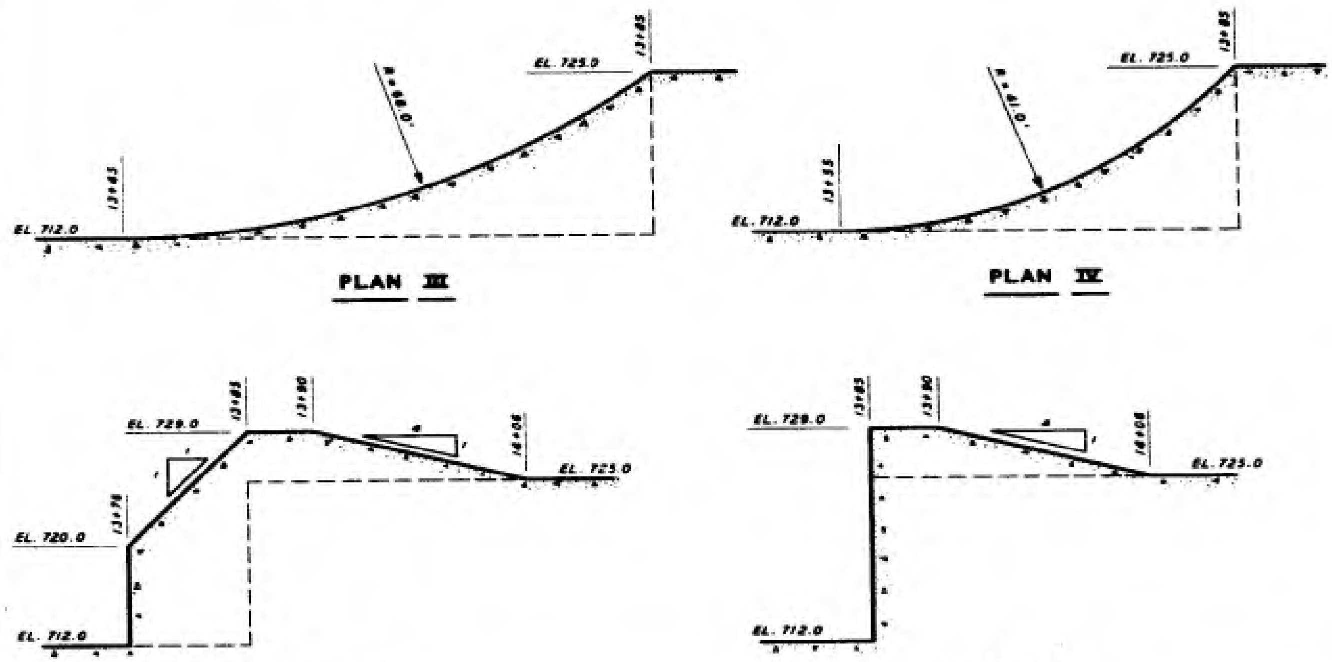
TRACED BY W.O.D. CHECKED BY G.E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942 | FILE: M 11. G-43



PLAN A
FINAL DESIGN

PLAN I

PLAN II



PLAN III

PLAN IV

PLAN V

PLAN VI

NOTES

1. PLAN A, ORIGINAL AND FINAL DESIGN, TAKEN FROM PORTLAND DISTRICT DRAWING DO-20-2/2A, REVISED JUNE 17, 1940.
2. PLANS I TO VI, INCLUSIVE, WERE EXPERIMENTAL DESIGNS.
3. ALL END SILLS EXTENDED THE FULL WIDTH OF THE STILLING BASIN.
4. ELEVATIONS REFER TO FEET M.S.L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
END SILL
PLANS TESTED

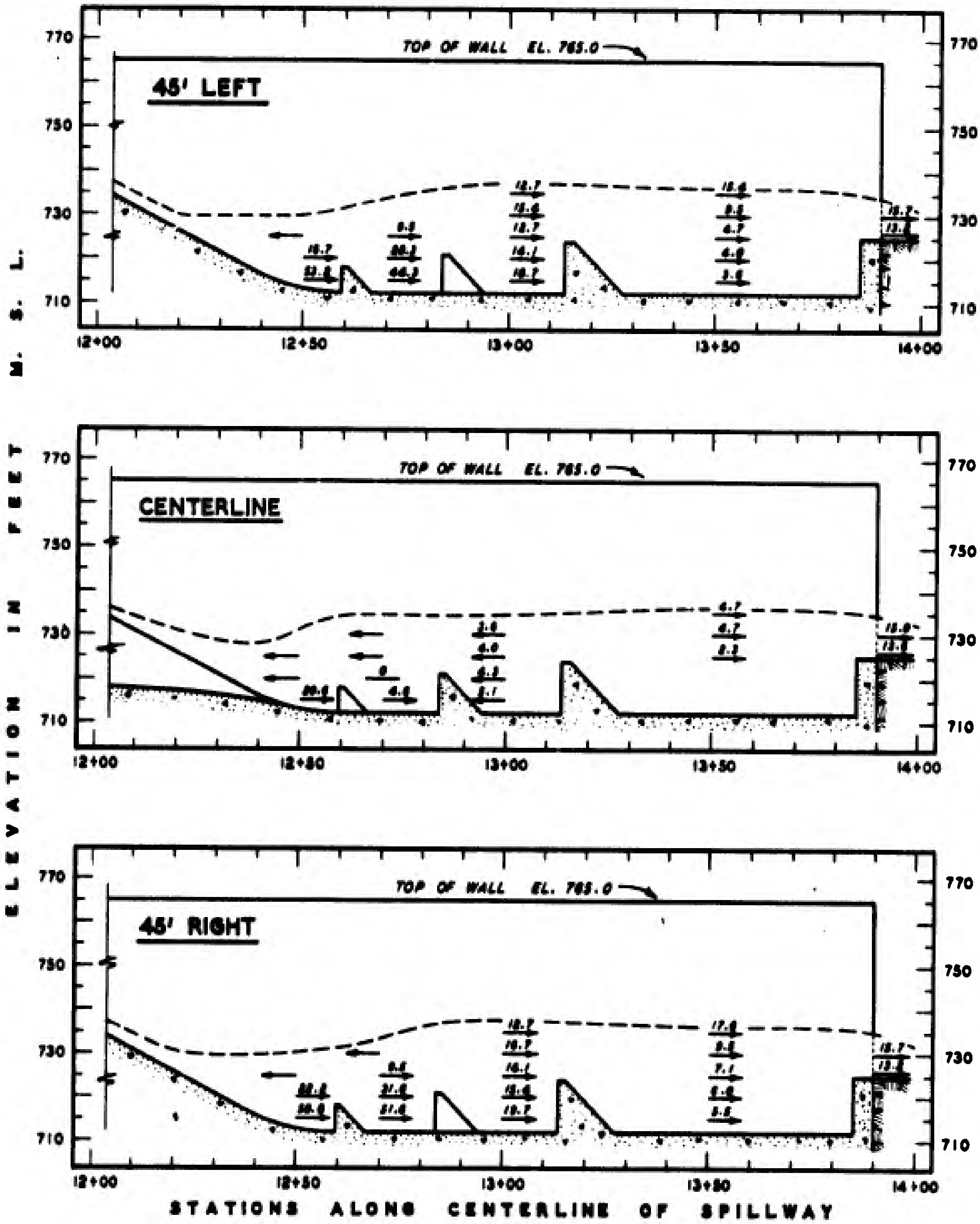
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

TRACED BY W.O.D.
CHECKED BY G.E.H.
TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942
FILE: M. 11. 6-33

Q = 15,000 C.F.S.



NOTES

1. TRANSVERSE DISTANCES SHOWN FOR SECTIONS ARE APPROXIMATE ONLY, AS THE POINTS OF OBSERVATION WERE SHIFTED SLIGHTLY TO AVOID BEING DIRECTLY IN LINE WITH A BAFFLE.
2. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{36}\ V_m)$.
3. BLANK ARROWS DENOTE POINTS AT WHICH VELOCITY MEASUREMENTS COULD NOT BE OBTAINED BECAUSE OF ENTRAINED AIR.
4. ALL VELOCITIES WERE MEASURED IN A HORIZONTAL PLANE.
5. VELOCITIES ARE SHOWN IN FEET PER SECOND.
6. DASHED LINE SHOWS WATER SURFACE.
7. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
STILLING BASIN

SCALES AS SHOWN

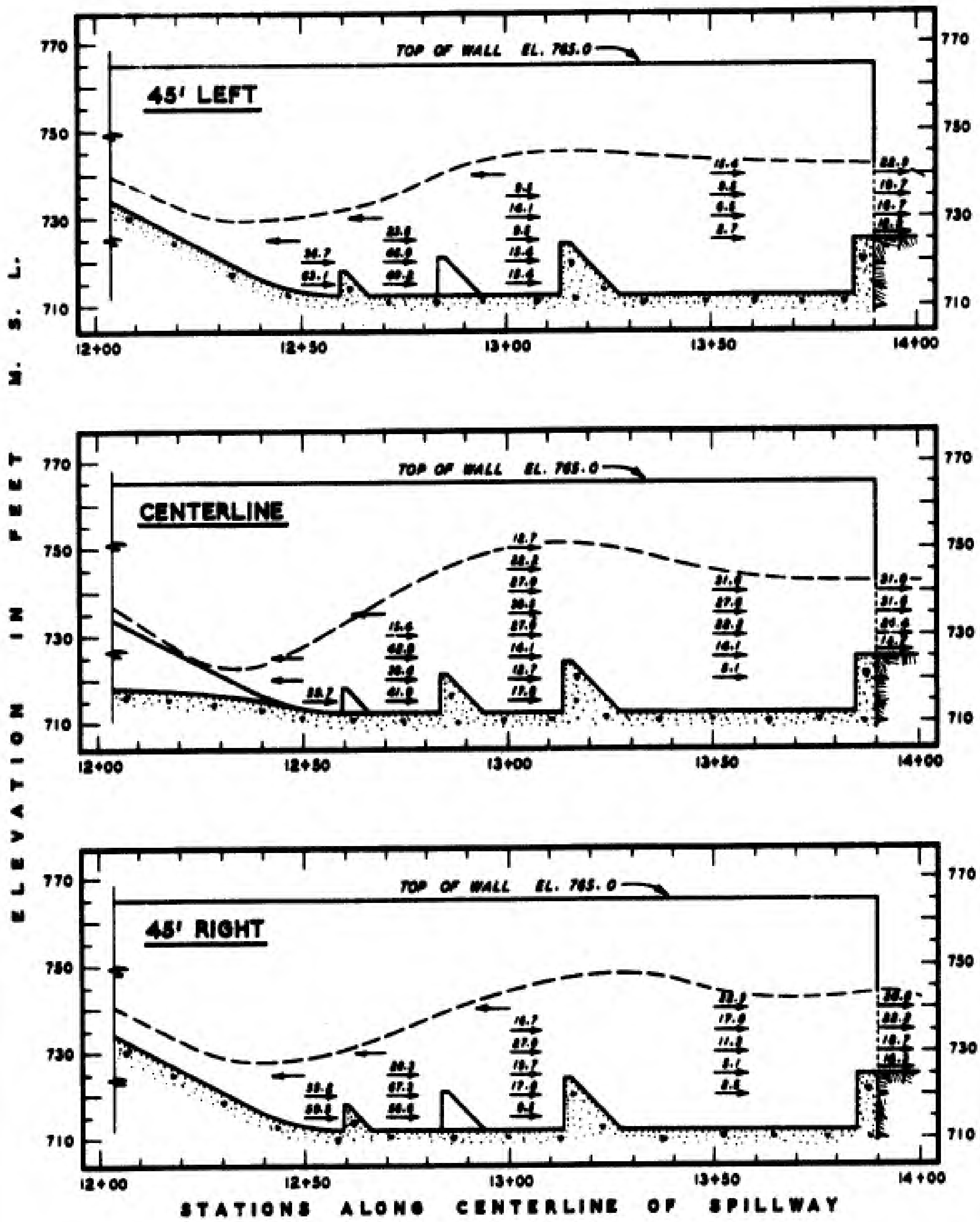
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: [signature] ASST. ENGINEER
APPROVED: [signature] CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.11.24-20

WAR DEPARTMENT | CORPS OF ENGINEERS, U. S. ARMY

Q = 45,000 C.F.S.



NOTES

1. TRANSVERSE DISTANCES SHOWN FOR SECTIONS ARE APPROXIMATE ONLY, AS THE POINTS OF OBSERVATION WERE SHIFTED SLIGHTLY TO AVOID BEING DIRECTLY IN LINE WITH A BAFFLE.
2. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{30}\, V_m)$.
3. BLANK ARROWS DENOTE POINTS AT WHICH VELOCITY MEASUREMENTS COULD NOT BE OBTAINED BECAUSE OF ENTRAINED AIR.
4. ALL VELOCITIES WERE MEASURED IN A HORIZONTAL PLANE.
5. VELOCITIES ARE SHOWN IN FEET PER SECOND.
6. DASHED LINE SHOWS WATER SURFACE.
7. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
STILLING BASIN

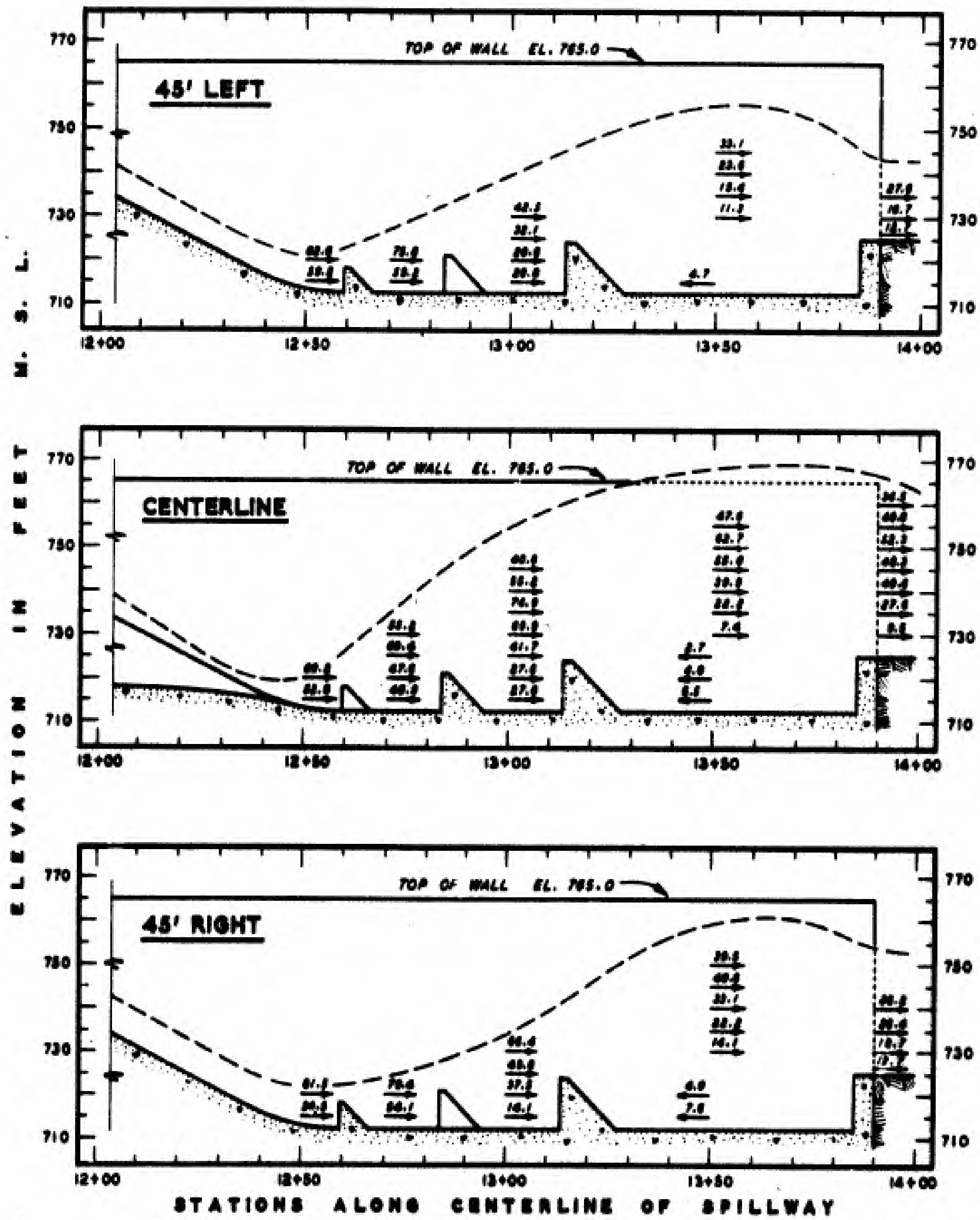
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George L. Hyde, ASST. ENGINEER | APPROVED: R. B. Cochran, CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H. | TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942 | FILE: M.11-84-21

Q = 70,000 C.F.S.



NOTES

1. TRANSVERSE DISTANCES SHOWN FOR SECTIONS ARE APPROXIMATE ONLY, AS THE POINTS OF OBSERVATION WERE SHIFTED SLIGHTLY TO AVOID BEING DIRECTLY IN LINE WITH A BAFFLE.
2. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\, V_m$).
3. ALL VELOCITIES WERE MEASURED IN A HORIZONTAL PLANE.
4. VELOCITIES ARE SHOWN IN FEET PER SECOND.
5. DASHED LINE SHOWS WATER SURFACE.
6. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
STILLING BASIN

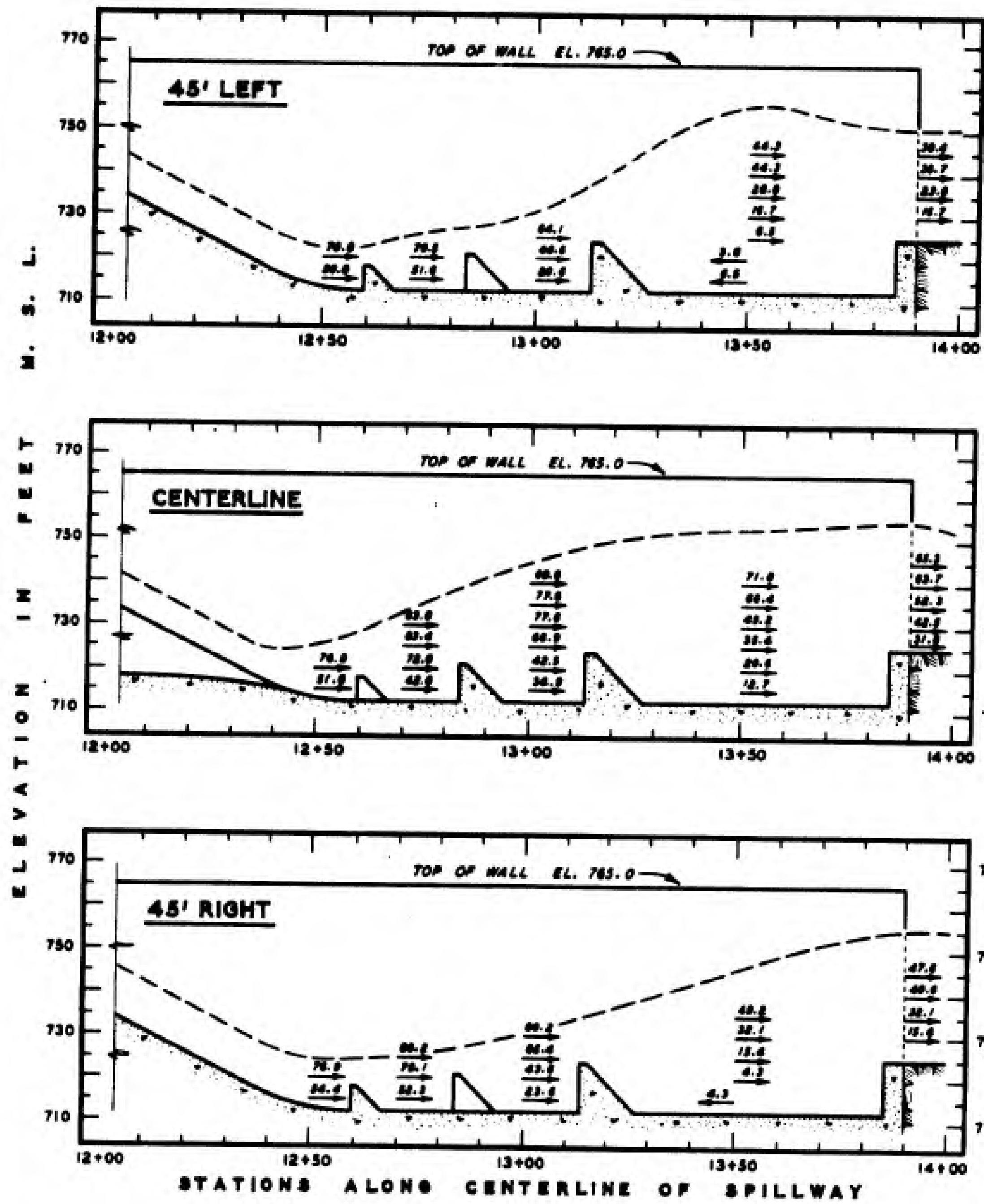
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. B. Cochrane, CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942	FILE: M.11.24-22

Q = 95,400 C.F.S.



NOTES

1. TRANSVERSE DISTANCES SHOWN FOR SECTIONS ARE APPROXIMATE ONLY, AS THE POINTS OF OBSERVATION WERE SHIFTED SLIGHTLY TO AVOID BEING DIRECTLY IN LINE WITH A BAFFLE.
2. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF $(v_p = \sqrt{36}\, v_m)$.
3. ALL VELOCITIES WERE MEASURED IN A HORIZONTAL PLANE.
4. VELOCITIES ARE SHOWN IN FEET PER SECOND.
5. DASHED LINE SHOWS WATER SURFACE.
6. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
STILLING BASIN

SCALES AS SHOWN

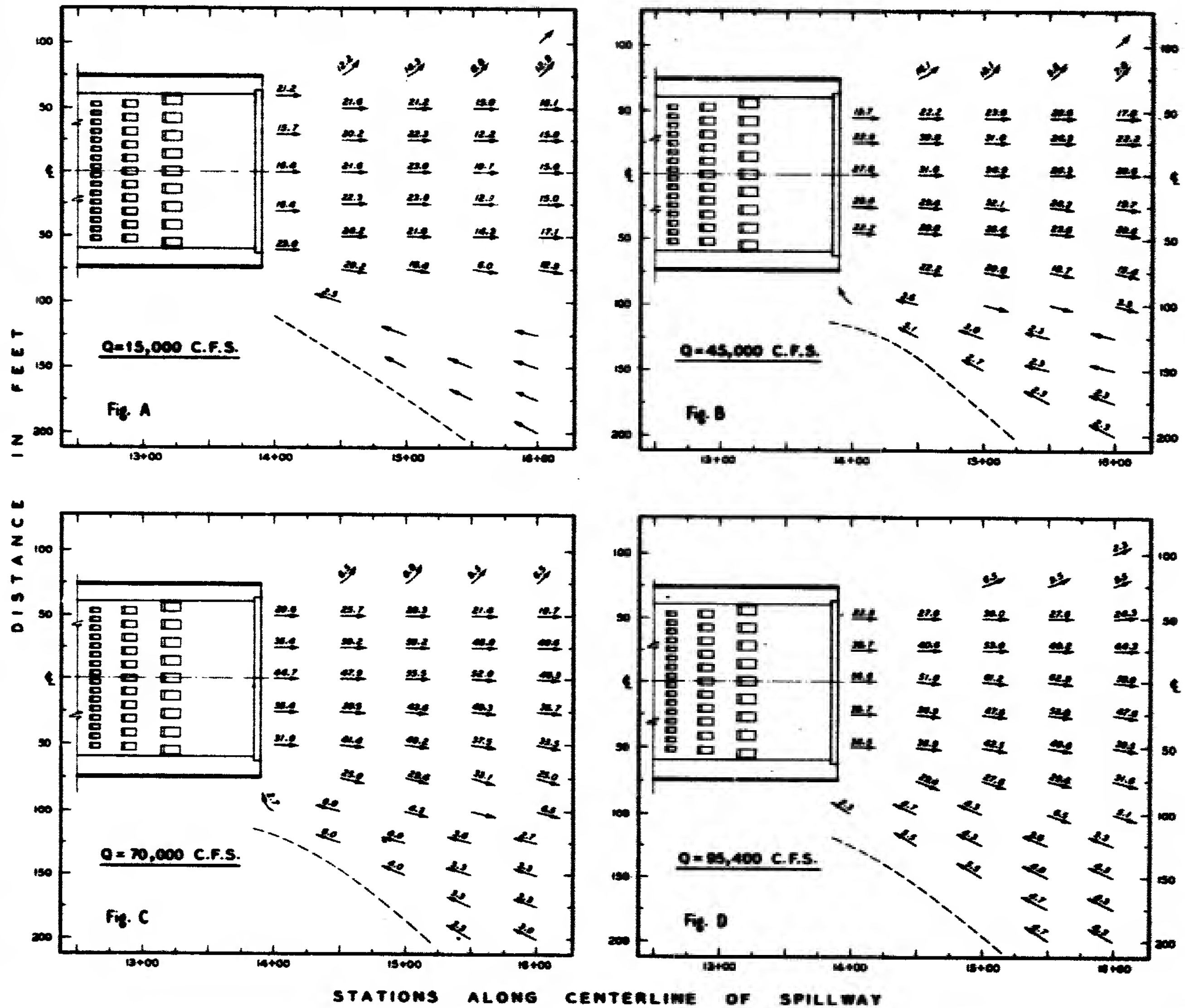
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED:	APPROVED:
George E. Hyde	R. B. [illegible]
ASST. ENGINEER	CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942	FILE: M.11.36-23

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND AT 0.6 DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DASHED LINE SHOWS WATER'S EDGE.
5. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
DOWNSTREAM FROM STILLING BASIN
STATION 14+00 TO STATION 16+00

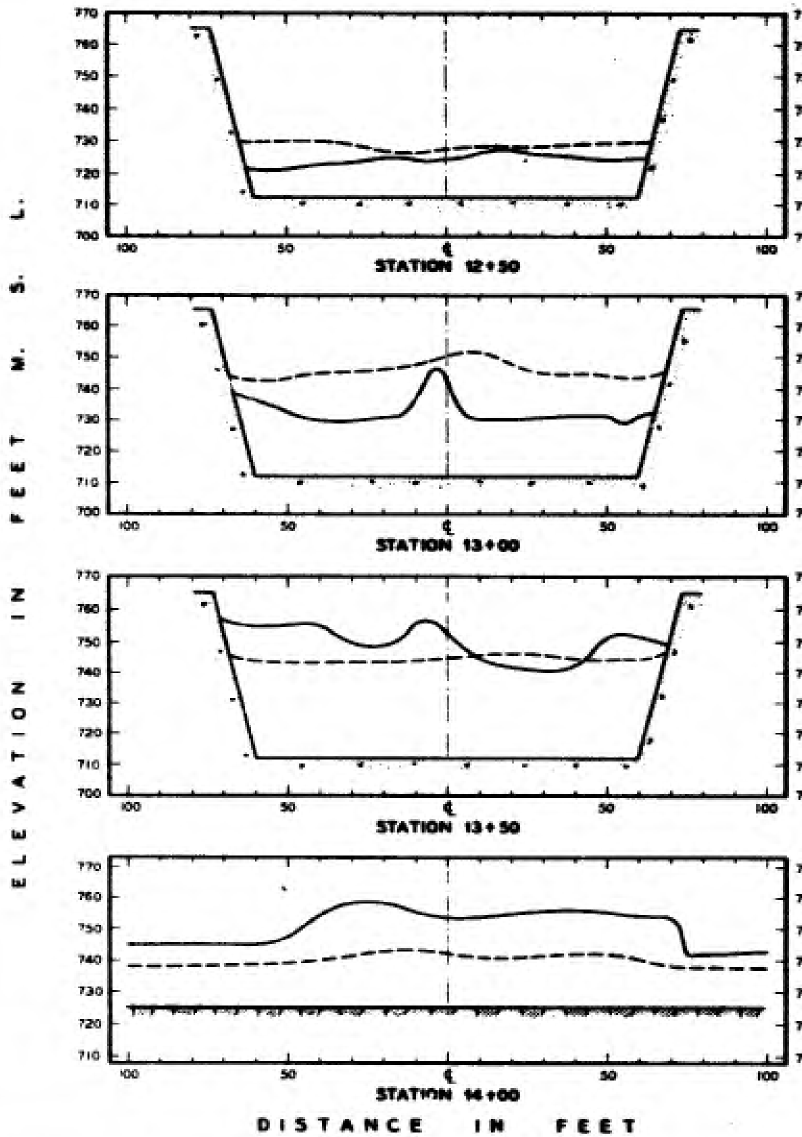
SCALES AS SHOWN

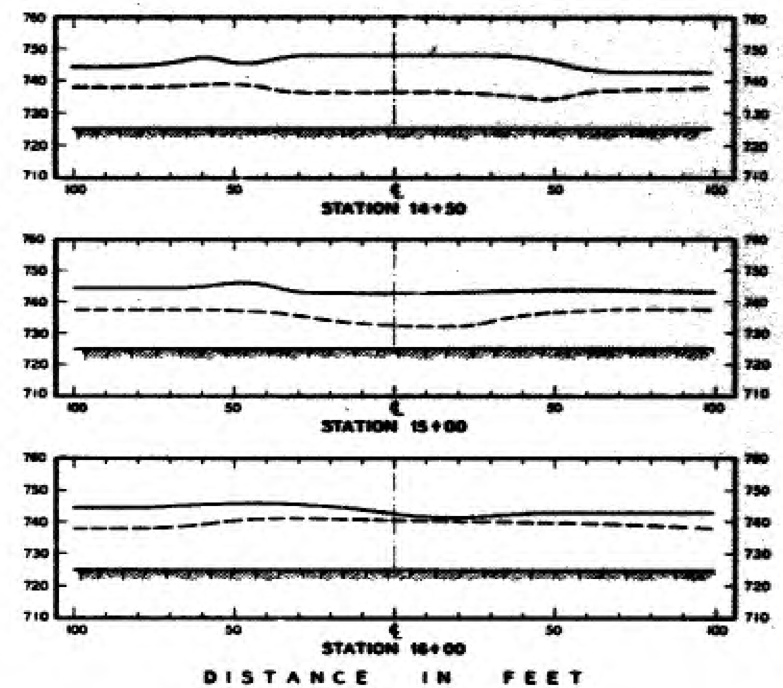
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: [signature] ASST. ENGINEER

APPROVED: [signature] CAPTAIN, C.E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER [illegible], 194[illegible]	FILE: [illegible]





LEGEND

- – – – – 45,000 C.F.S.
- ——— 95,400 C.F.S.

NOTES

1. ALL CROSS SECTIONS ARE SHOWN LOOKING DOWNSTREAM.
2. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
WATER-SURFACE CROSS SECTIONS
STATION 12+50 TO STATION 16+00

SCALES AS SHOWN

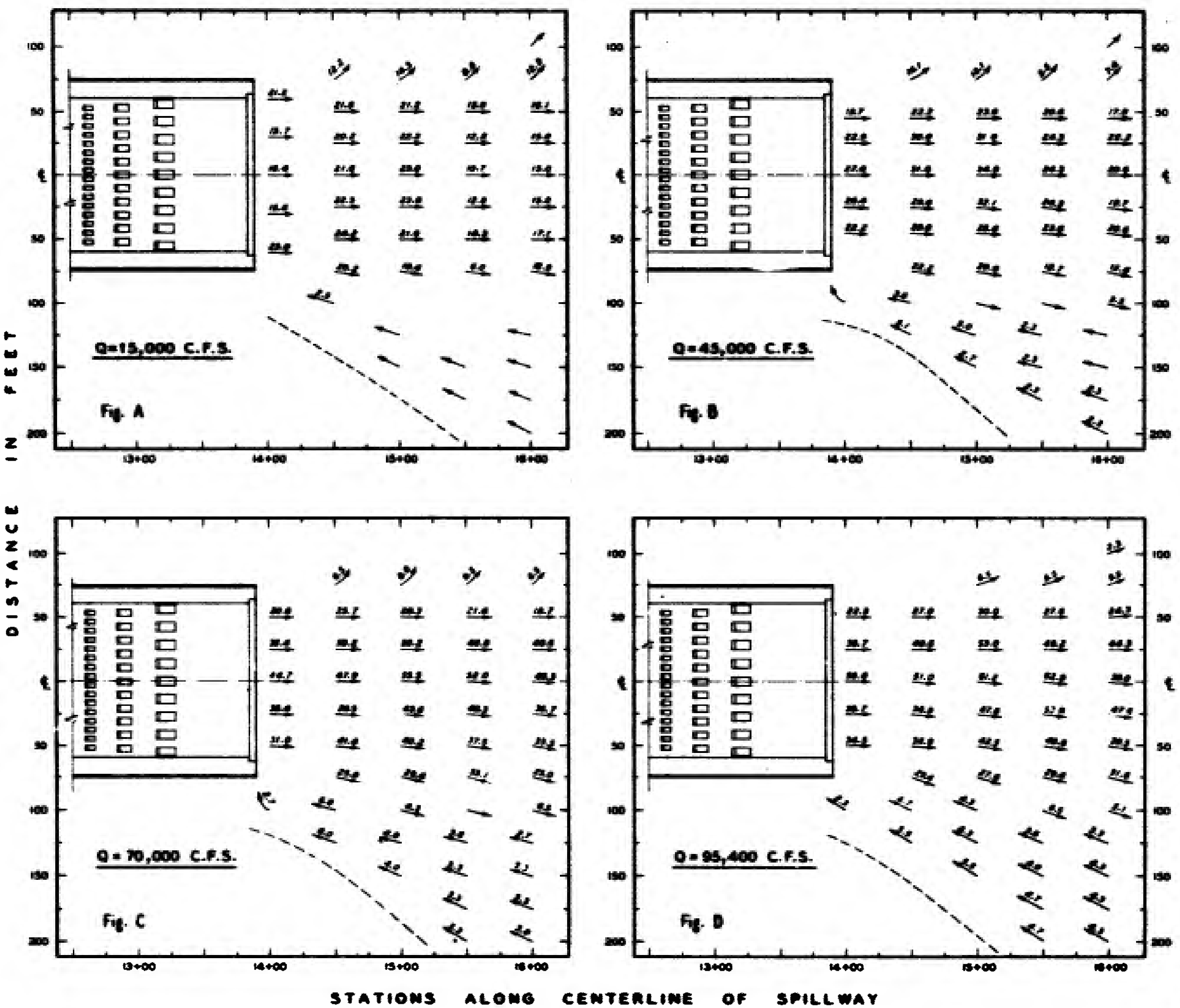
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER — APPROVED: CAPTAIN, C.E.

TRACED BY W.O.D.
CHECKED BY G.L.H.

TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942

FILE: M.H.24-24



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND A. 0.6 DEPTH.
3. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
4. DASHED LINE SHOWS WATER'S EDGE.
5. DATA SHOWN WERE TAKEN DURING TEST 24.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
DOWNSTREAM FROM STILLING BASIN
STATION 14+00 TO STATION 16+00

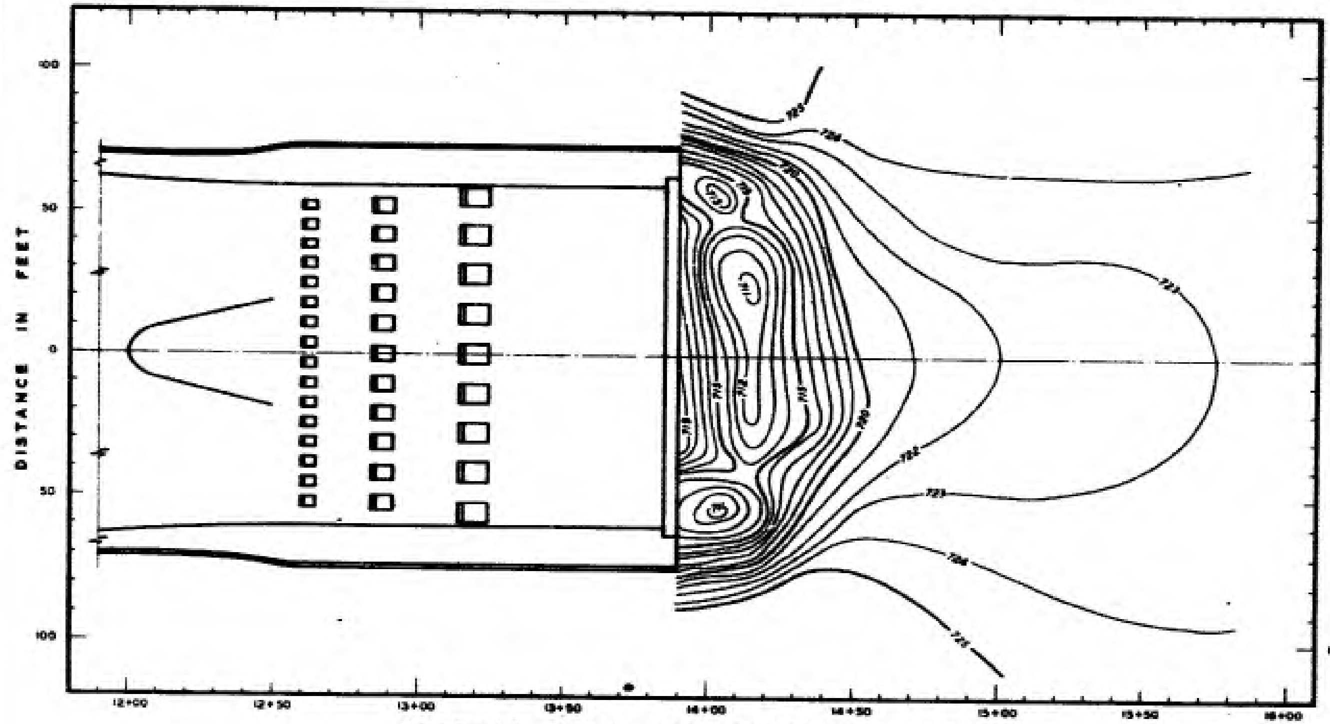
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

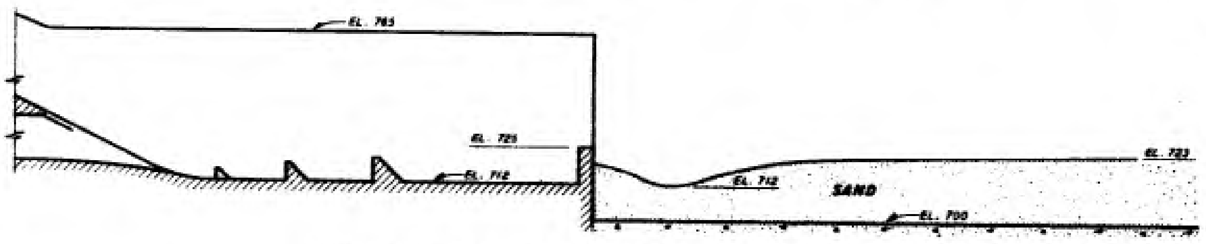
SUBMITTED: ASST. ENGINEER

APPROVED: CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M-11-26-25



STATIONS ALONG CENTERLINE OF SPILLWAY



PROFILE ALONG CENTERLINE OF SPILLWAY

TEST CONDITIONS

TEST NO. 18E
TUNNEL DISCHARGE .... 5000 C.F.S.
LENGTH OF RUN .... 1 HOUR
MOVABLE BED MATERIAL ..... SAND

NOTES

1. THE TOPOGRAPHY OF THE MOVABLE BED WAS MOLDED TO CONFORM TO THAT SHOWN ON PORTLAND DISTRICT DRAWING 01-8-8/1, REVISED OCTOBER 14, 1940.
2. MOVABLE BED MATERIAL AND LENGTH OF RUN ARE GIVEN IN MODEL DIMENSIONS.
3. ELEVATIONS REFER TO FEET M. S. L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
# SCOUR PATTERN
Q = 5,000 C.F.S.

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER

APPROVED: CAPTAIN, C.E.

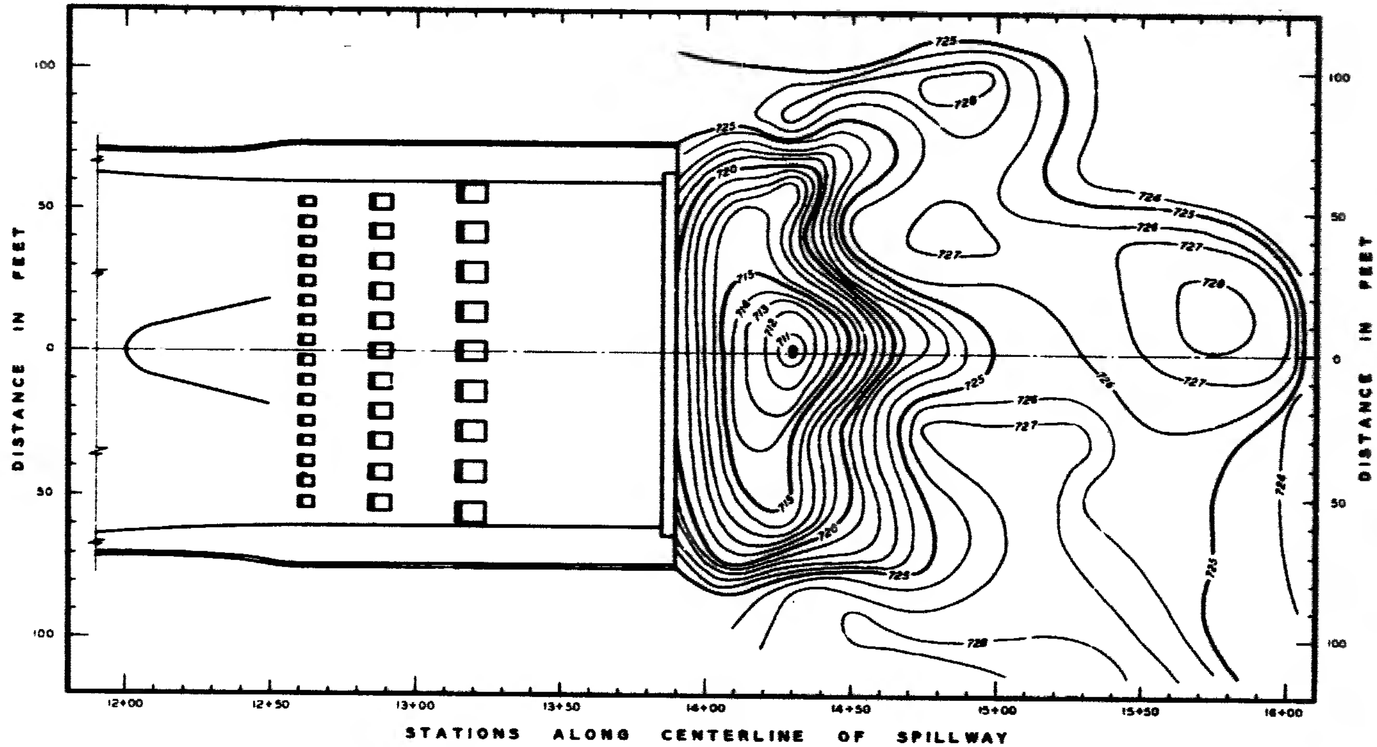
TRACED BY W.O.D.
CHECKED BY G.E.H.

TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942

FILE: M.11.19-10

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

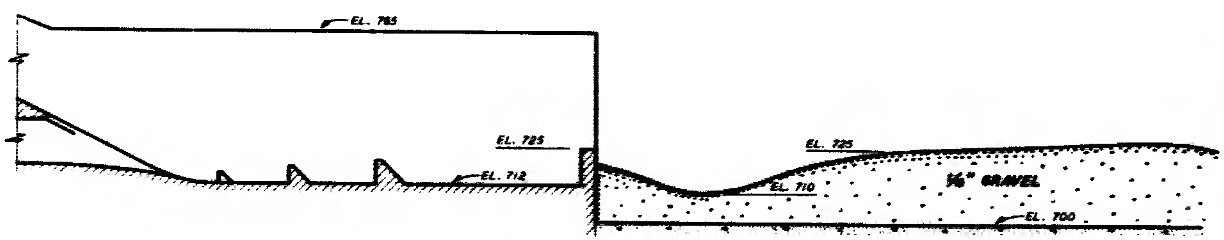


TEST CONDITIONS

TEST NO. ---------------------- 19A
SPILLWAY DISCHARGE -------- 20,000 C.F.S.
LENGTH OF RUN ---------------- 1 HOUR
MOVABLE BED MATERIAL ---- 1/16-INCH GRAVEL

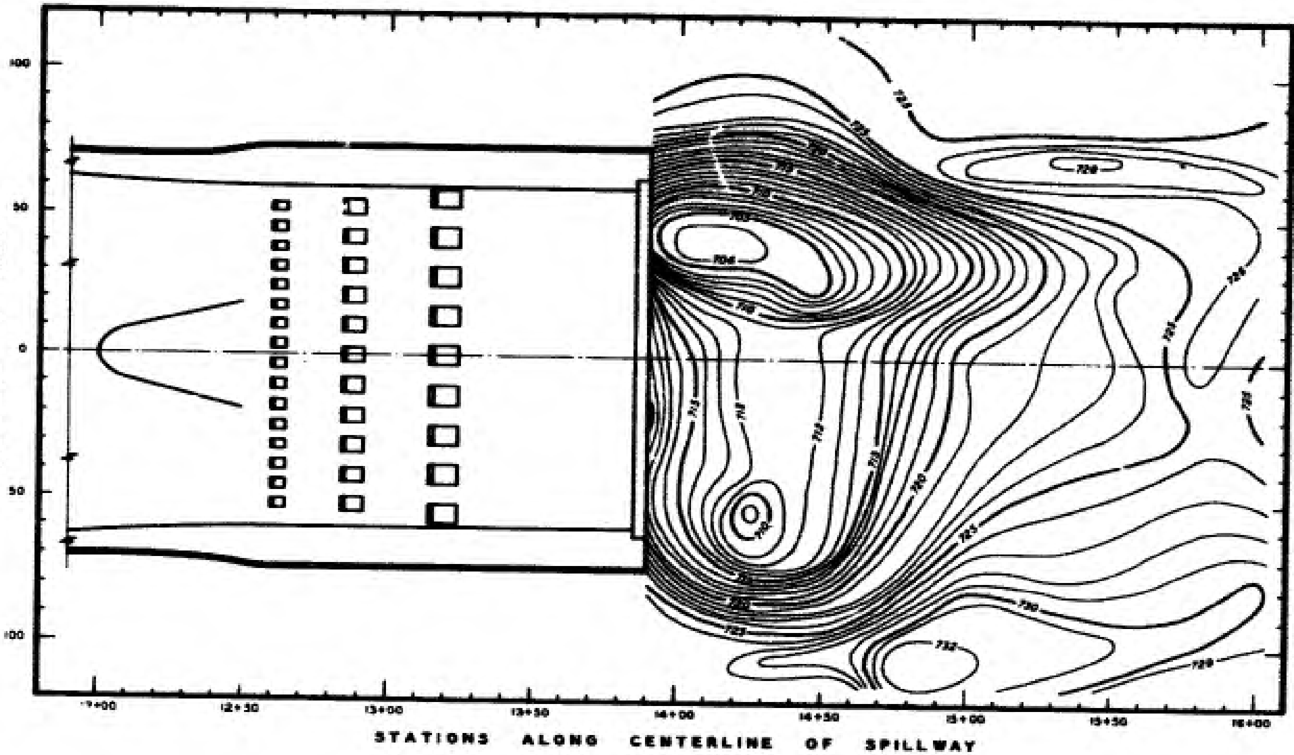
NOTES

1. THE TOPOGRAPHY OF THE MOVABLE BED WAS MOLDED TO CONFORM TO THAT SHOWN ON PORTLAND DISTRICT DRAWING DI-6-5/1, REVISED OCTOBER 16, 1940.
2. MOVABLE BED MATERIAL AND LENGTH OF RUN ARE GIVEN IN MODEL DIMENSIONS.
3. ELEVATIONS REFER TO FEET M. S. L.



PROFILE ALONG CENTERLINE OF SPILLWAY

MODEL STUDY DORENA SPILLWAY AND TUNNEL **SCOUR PATTERN** Q = 20,000 C.F.S.
SCALES AS SHOWN
BONNEVILLE HYDRAULIC LABORATORY U. S. ENGINEER OFFICE BONNEVILLE, OREGON
SUBMITTED: ASS'T ENGINEER — APPROVED: CAPTAIN, C.E.
TRACED BY M.O.D. CHECKED BY G.E.H. — TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942 — FILE: M.11./8-1

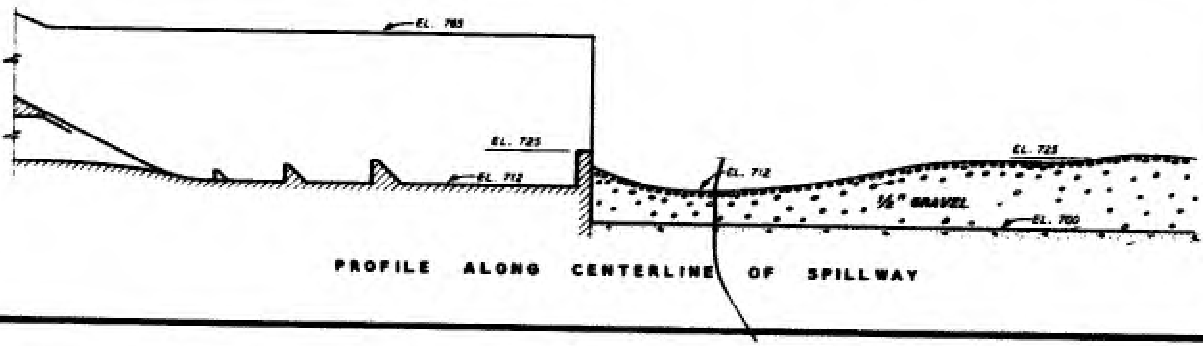


TEST CONDITIONS

TEST NO. 198
SPILLWAY DISCHARGE .... 45,000 C.F.S.
LENGTH OF RUN .... 1 HOUR
MOVABLE BED MATERIAL ---- ½-INCH GRAVEL

NOTES

1. THE TOPOGRAPHY OF THE MOVABLE BED WAS MOLDED TO CONFORM TO THAT SHOWN ON PORTLAND DISTRICT DRAWING DI-8-2/1, REVISED OCTOBER 16, 1940.
2. MOVABLE BED MATERIAL AND LENGTH OF RUN ARE GIVEN IN MODEL DIMENSIONS.
3. ELEVATIONS REFER TO FEET M.S.L.



PROFILE ALONG CENTERLINE OF SPILLWAY

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SCOUR PATTERN
Q = 45,000 C.F.S.

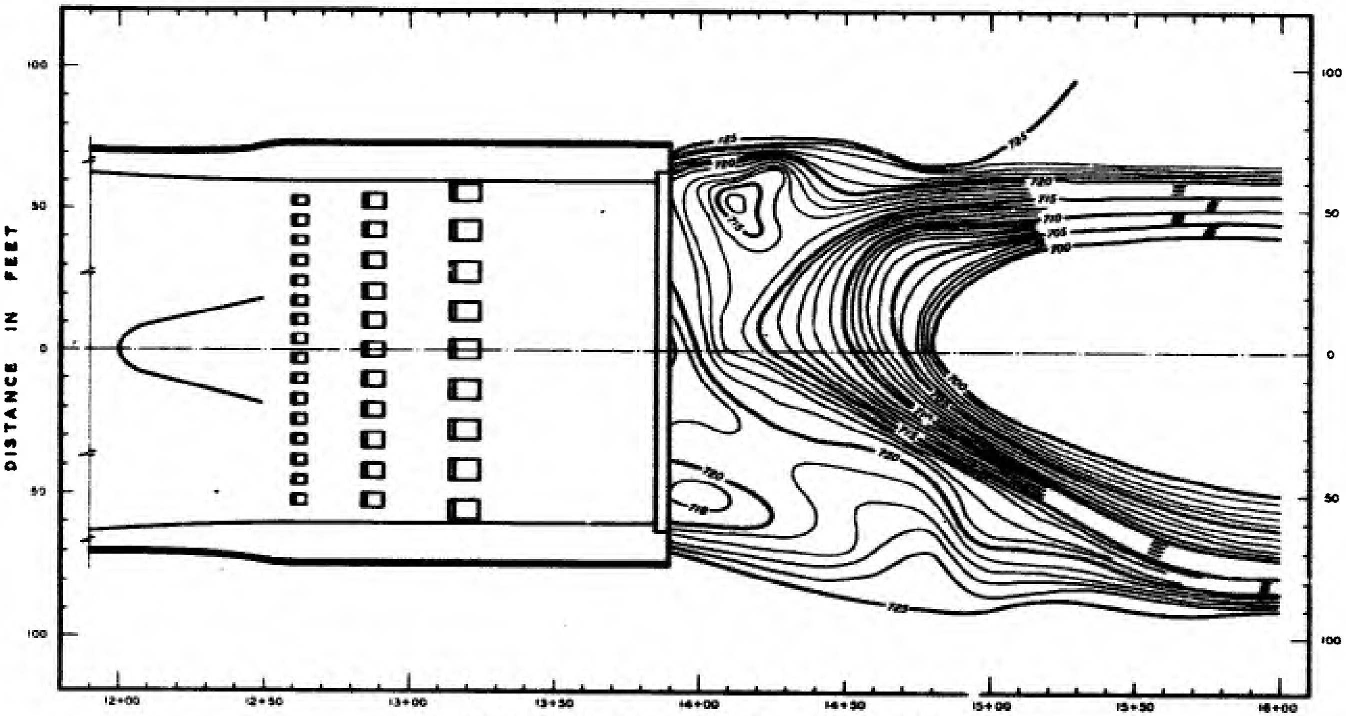
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER

APPROVED: CAPTAIN, C.E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.11.19-12



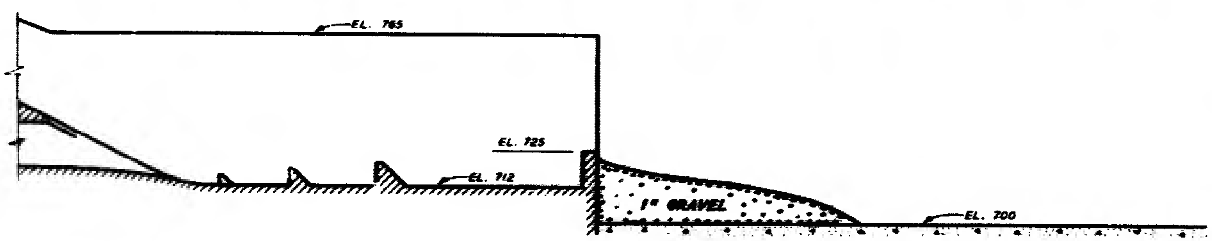
STATIONS ALONG CENTERLINE OF SPILLWAY

TEST CONDITIONS

TEST NO. 190
SPILLWAY DISCHARGE .... 95,400 C.F.S.
LENGTH OF RUN .... 1 HOUR
MOVABLE BED MATERIAL --- 1-INCH GRAVEL

NOTES

1. THE TOPOGRAPHY OF THE MOVABLE BED WAS MOLDED TO CONFORM TO THAT SHOWN ON PORTLAND DISTRICT DRAWING DI-8-9/4, REVISED OCTOBER 14, 1940.
2. MOVABLE BED MATERIAL AND LENGTH OF RUN ARE GIVEN IN MODEL DIMENSIONS.
3. ELEVATIONS REFER TO FEET M. S. L.



PROFILE ALONG CENTERLINE OF SPILLWAY

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SCOUR PATTERN
Q = 95,400 C.F.S.

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

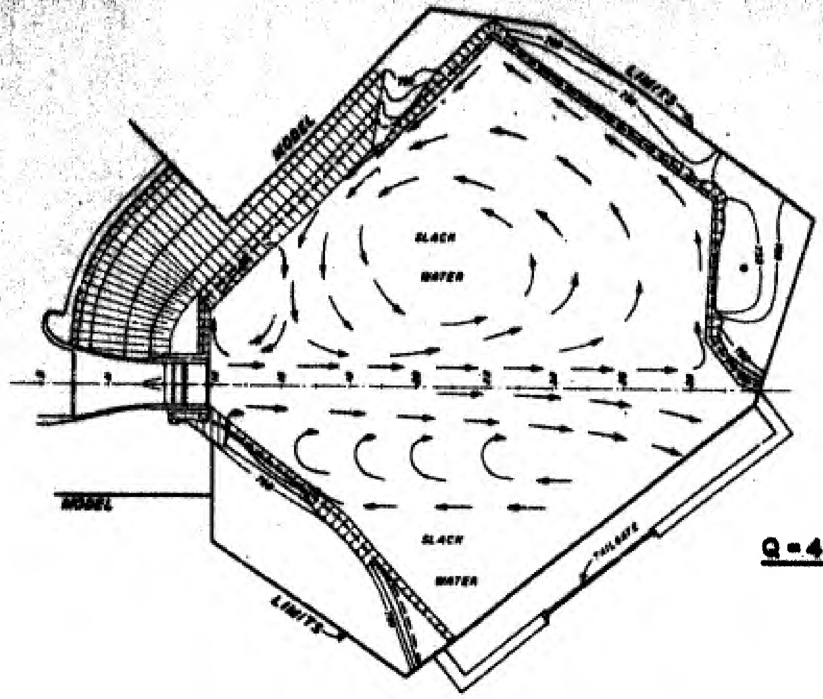
SUBMITTED: George L. Hyde, ASST. ENGINEER

APPROVED: [signature], CAPTAIN, C.E.

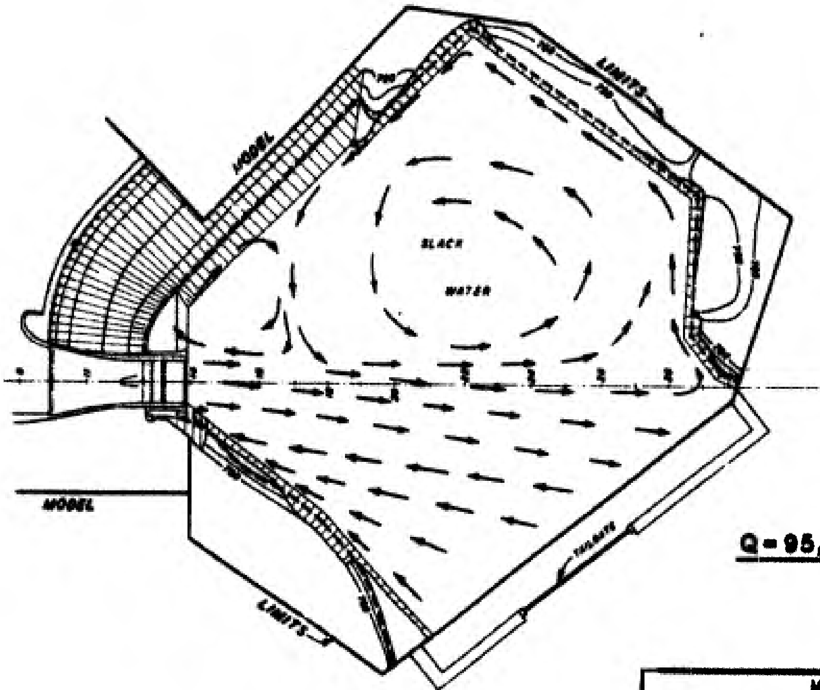
TRACED BY W.O.D.
CHECKED BY G.E.H.

TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942

FILE: M.11.19-13



Q = 45,000 C. F. S.



Q = 95,400 C. F. S.

NOTES

1. SURFACE CURRENT DIRECTIONS WERE PLOTTED FROM DATA TAKEN DURING TEST 20 AND ARE APPROXIMATE ONLY.
2. DASHED LINE SHOWS WATER'S EDGE.
3. ELEVATIONS REFER TO FEET M.S.L.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
SURFACE CURRENTS
TAILBAY

SCALES
MODEL 4 2 0 4 8 12 FT.
PROTOTYPE 200 0 200 400 600 FT.

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

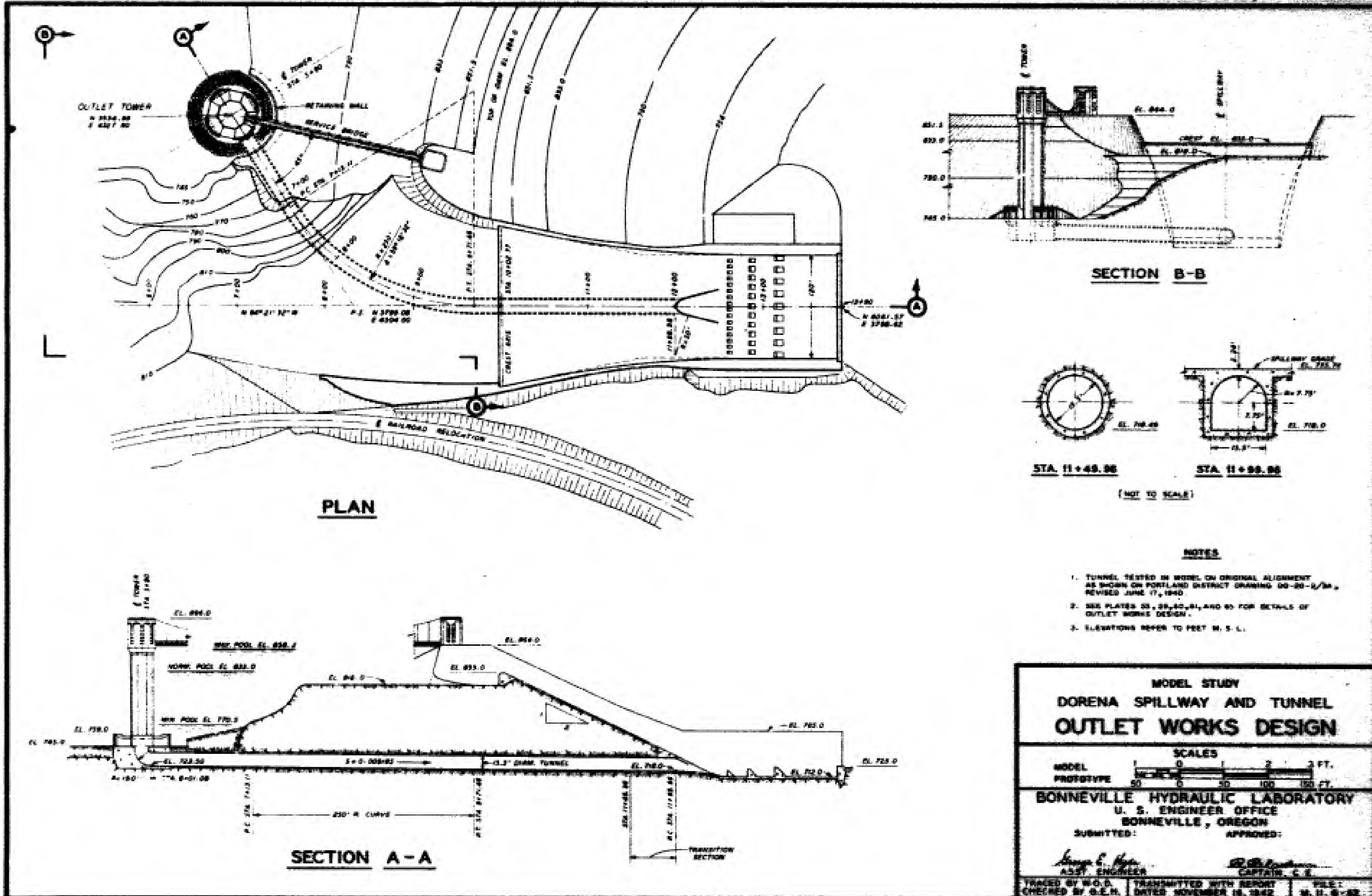
SUBMITTED: APPROVED:

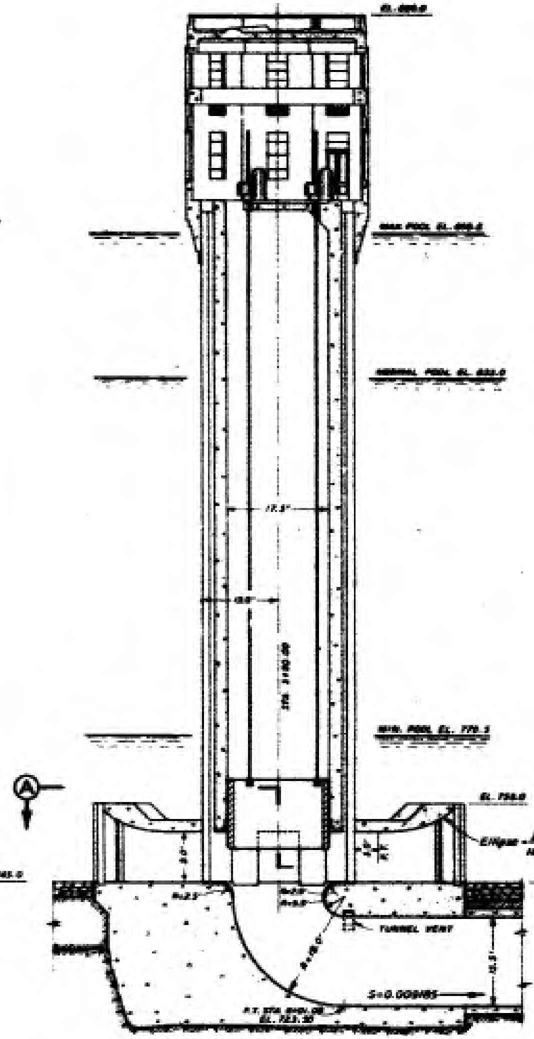
ASS'T ENGINEER CAPTAIN, C.E.

TRACED BY W.O.D. CHECKED BY G.S.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942	FILE: M.11.G-88

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

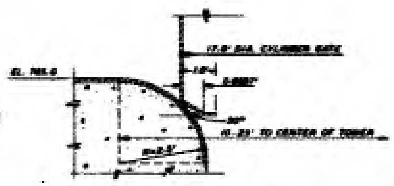




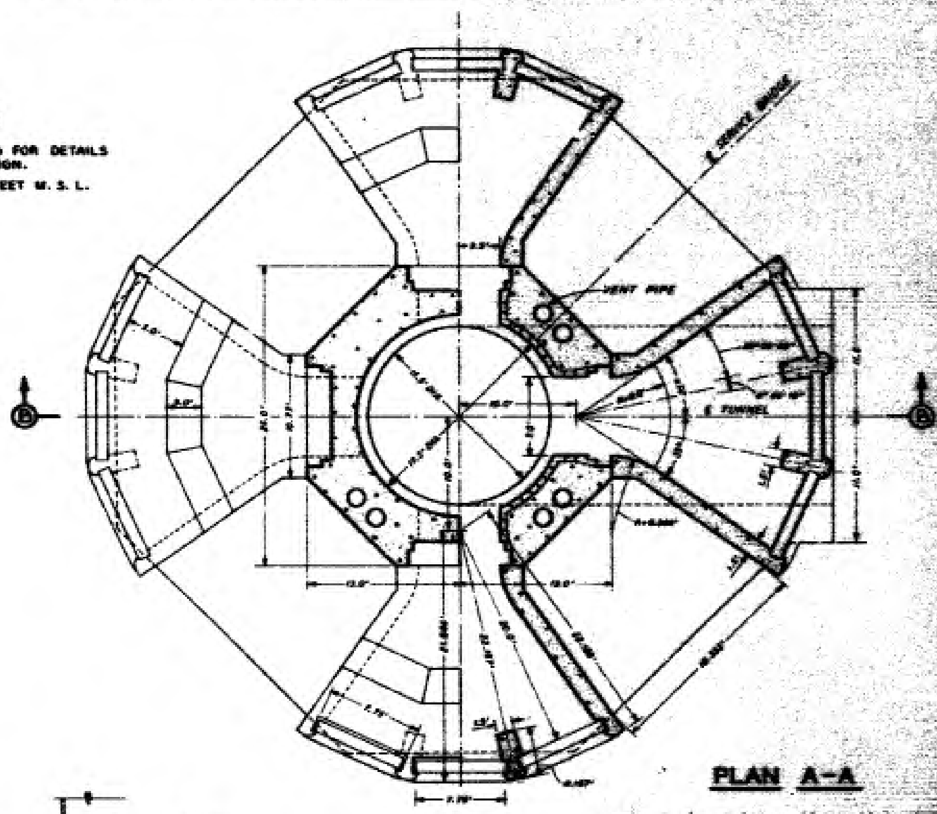
SECTION B-B

NOTES

1. SEE PLATES 59 AND 65 FOR DETAILS OF TUNNEL ELBOW DESIGN.
2. ELEVATIONS REFER TO FEET M. S. L.



DETAILS OF GATE SEAL



PLAN A-A

MODEL STUDY
DORENA SPILLWAY AND TUNNEL

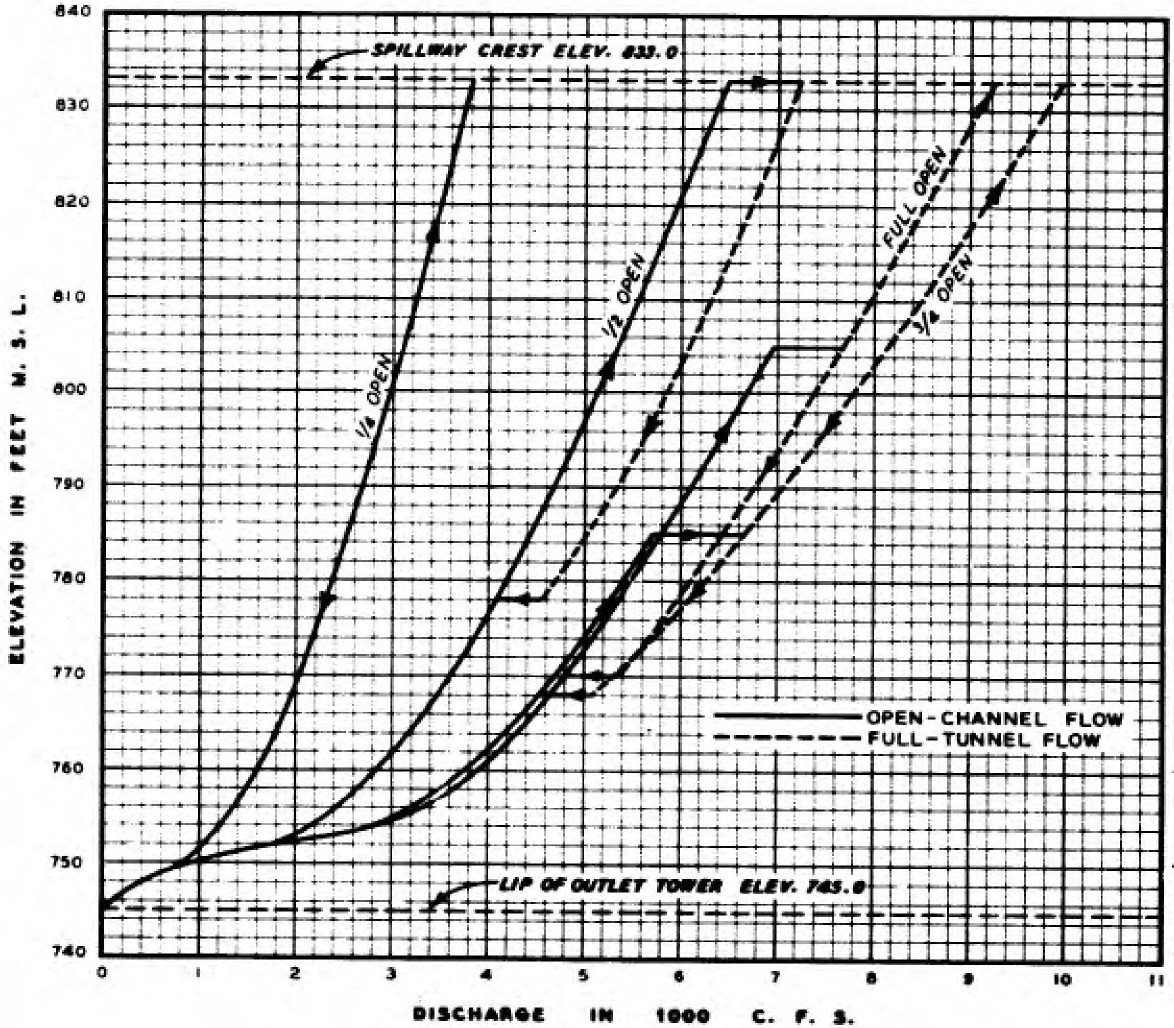
OUTLET TOWER DESIGN

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: ASST. ENGINEER
APPROVED: CAPTAIN, C. E.

TRACED BY H.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942	FILE:



NOTES

1. ARROWS INDICATE RISING OR FALLING POOL ELEVATION.
2. DATA TAKEN DURING TEST 2A.

CONDITIONS

1. TUNNEL VENT OPEN.
2. TAILWATER ELEVATION REGULATED ACCORDING TO CURVE D ON PLATE 4.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL RATING CURVES
ORIGINAL DESIGN

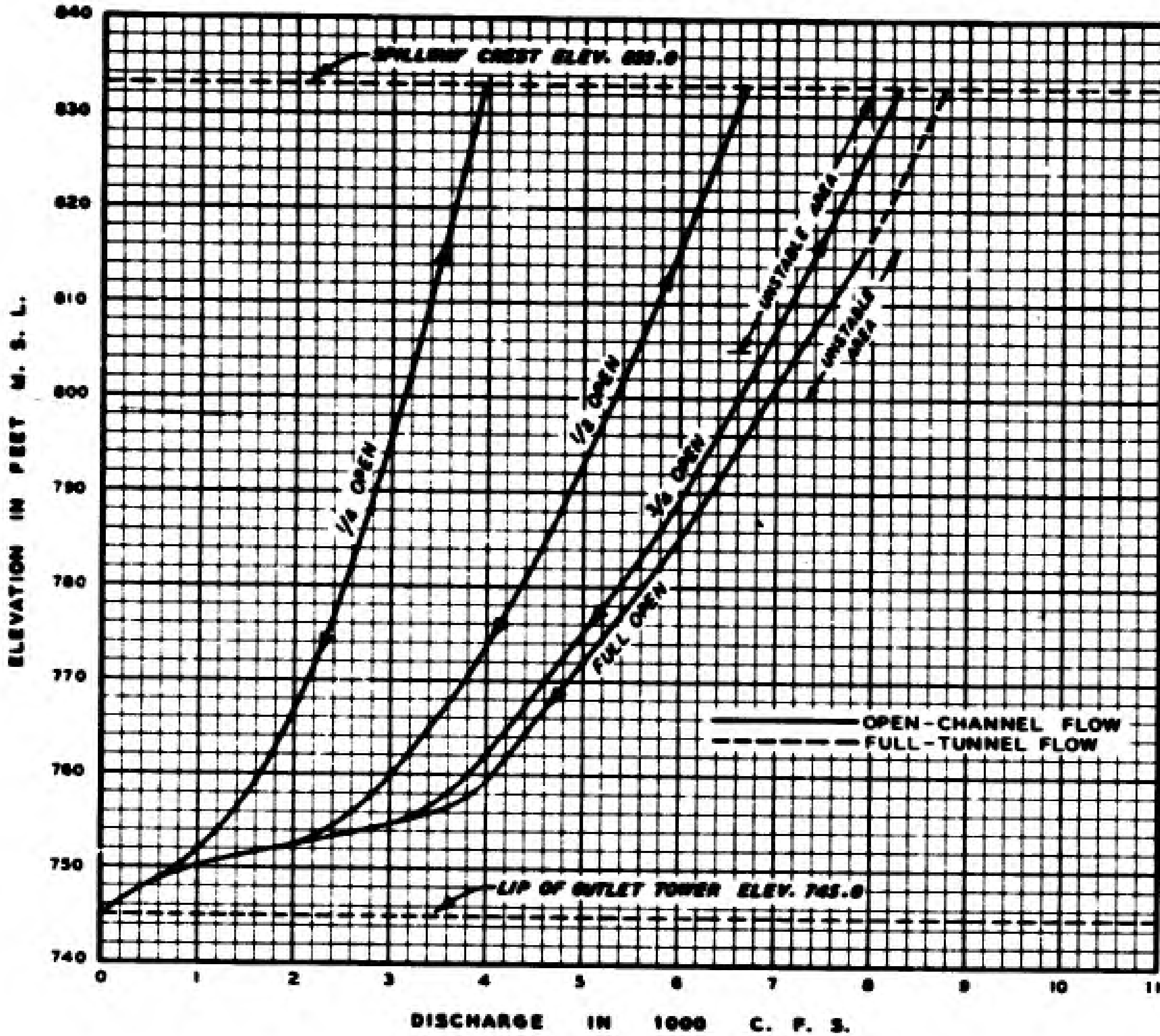
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

TRACED BY H.G.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.H.2A-16



NOTES

1. ARROWS INDICATE RISING OR FALLING POOL ELEVATION.
2. DATA TAKEN DURING TEST 20.

CONDITIONS

1. LIP AND TUNNEL VENTS OPEN.
2. TAILWATER ELEVATION REGULATED ACCORDING TO CURVE B ON PLATE 4.

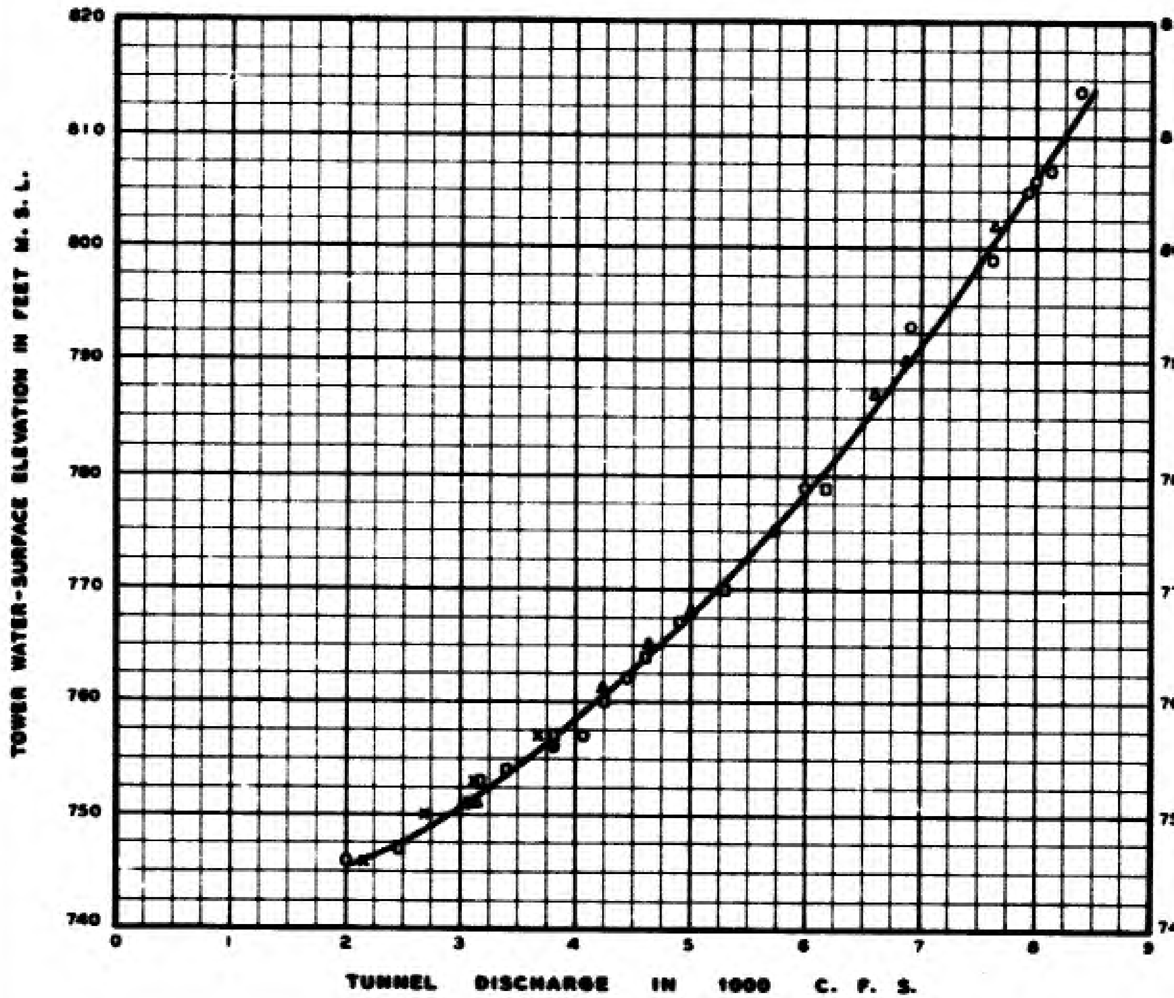
MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL RATING CURVES
FINAL DESIGN

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: R. B. [illegible], CAPTAIN, C. E.

TRACED BY W.G.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: H.H.28-4



NOTE

1. DATA TAKEN DURING TEST 29.

CONDITIONS

1. LIP AND TUNNEL VENTS OPEN.
2. TAILWATER ELEVATION REGULATED ACCORDING TO CURVE D ON PLATE 4.

LEGEND

x ----- ¼ GATE OPENING
□ ----- ½ GATE OPENING
△ ----- ¾ GATE OPENING
○ ----- FULL GATE OPENING

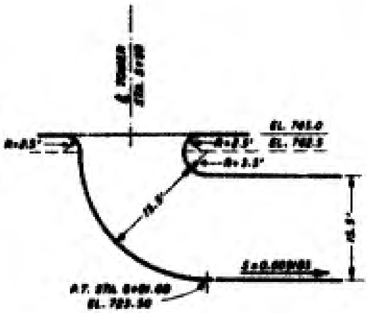
MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL DISCHARGE vs TOWER WATER-SURFACE ELEVATION FINAL DESIGN

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George E. Hyde, ASST. ENGINEER
APPROVED: CAPTAIN, C. E.

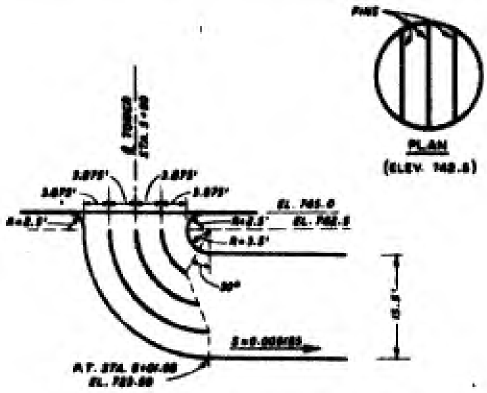
TRACED BY W.O.S. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M.H.29-8



ELEVATION

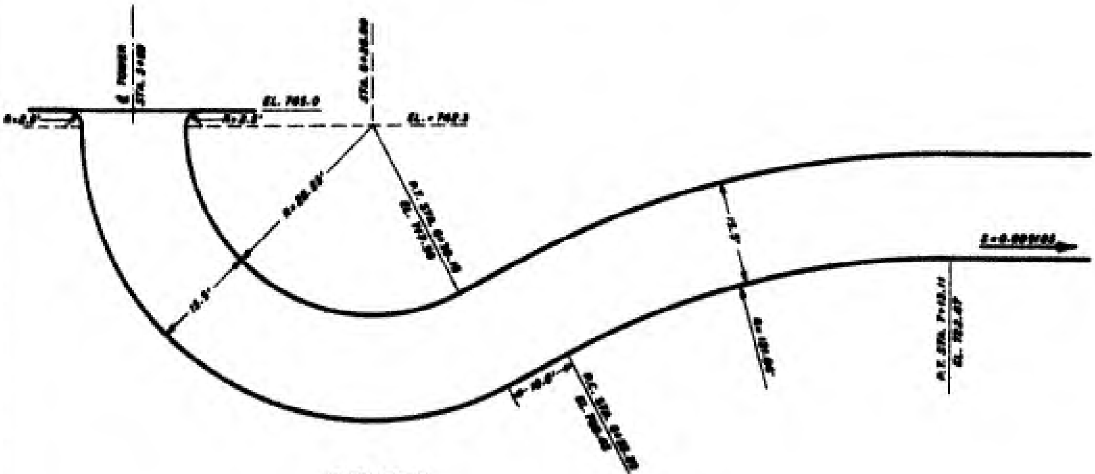
PLAN A ELBOW

FINAL DESIGN



ELEVATION

PLAN B ELBOW

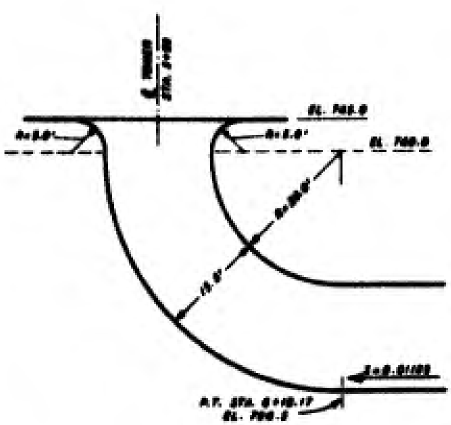


ELEVATION

PLAN C ELBOW

NOTES

1. PLAN A, ORIGINAL AND FINAL ELBOW DESIGN, TAKEN FROM PORTLAND DISTRICT DRAWING DO-20-2/3A, REVISED JUNE 17, 1940.
2. ELEVATIONS REFER TO FEET M. S. L.
3. PLANS B, C, AND D WERE EXPERIMENTAL DESIGNS.



ELEVATION

PLAN D ELBOW

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL ELBOWS
PLANS TESTED

SCALES IN FEET

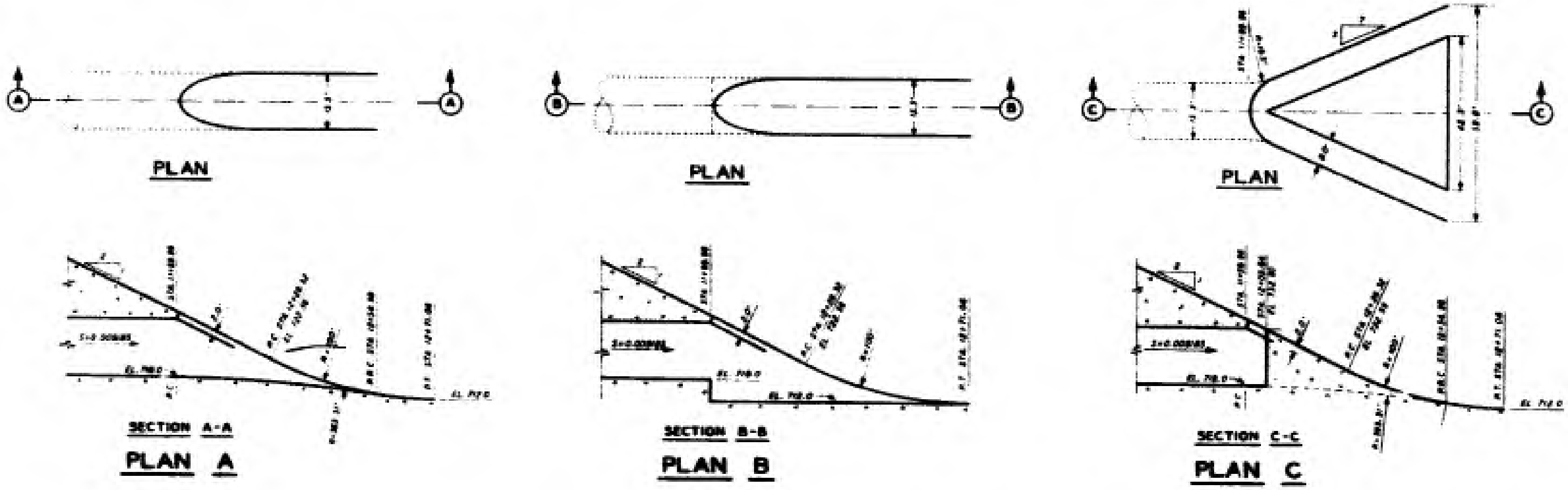
MODEL 0 0.5 1
PROTOTYPE 0 10 20 30 40 50

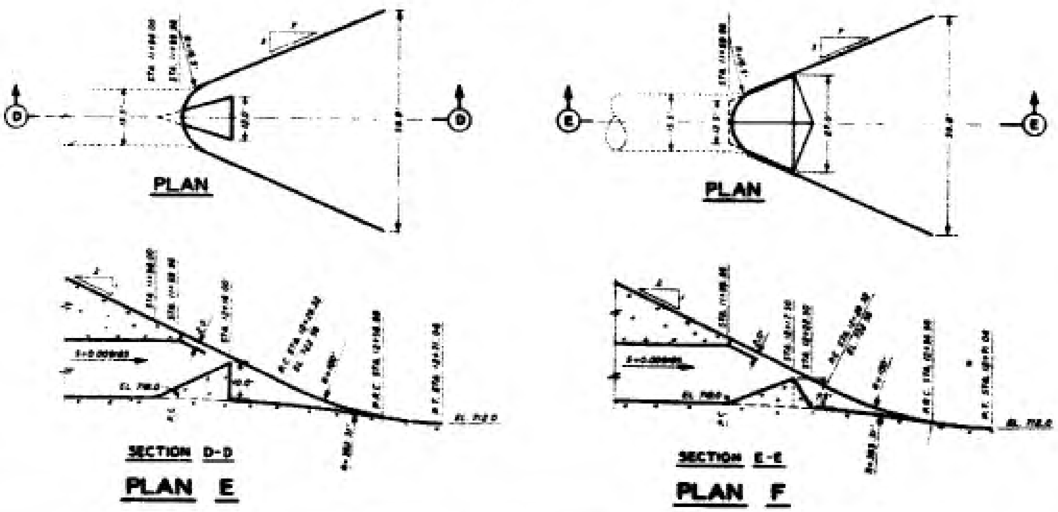
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASS'T. ENGINEER CAPTAIN, C.E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: M. 11-6-30





NOTES

1. PLAN D SAME AS PLAN C, EXCEPT WITHOUT DEFLECTOR BLOCK.
2. PLAN A, ORIGINALLY-DESIGNED TUNNEL OUTLET, TAKEN FROM PORTLAND DISTRICT DRAWING DO-20-3/24, REVISED JUNE 17, 1940.
3. ELEVATIONS REFER TO FEET M. S. L.
4. PLAN B TAKEN FROM PORTLAND DISTRICT DRAWING [illegible], RECEIVED DECEMBER [illegible], 1940.
5. PLANS C, D, E, AND F WERE DEVELOPED EXPERIMENTALLY.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL OUTLET
PLANS A, B, C, E, AND F

SCALES

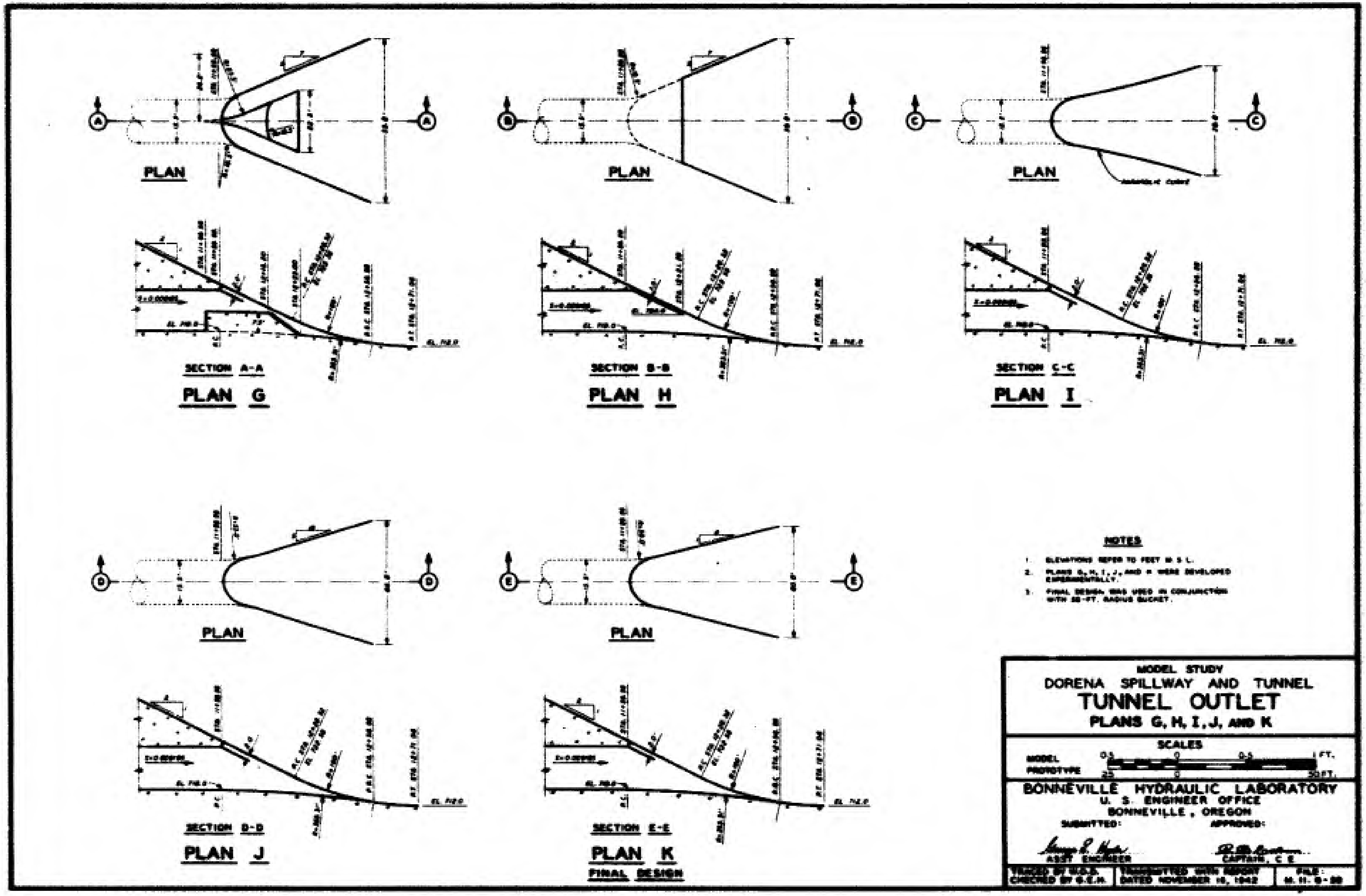
MODEL 0.5 0 0.5 1 FT.
PROTOTYPE 25 0 50 FT.

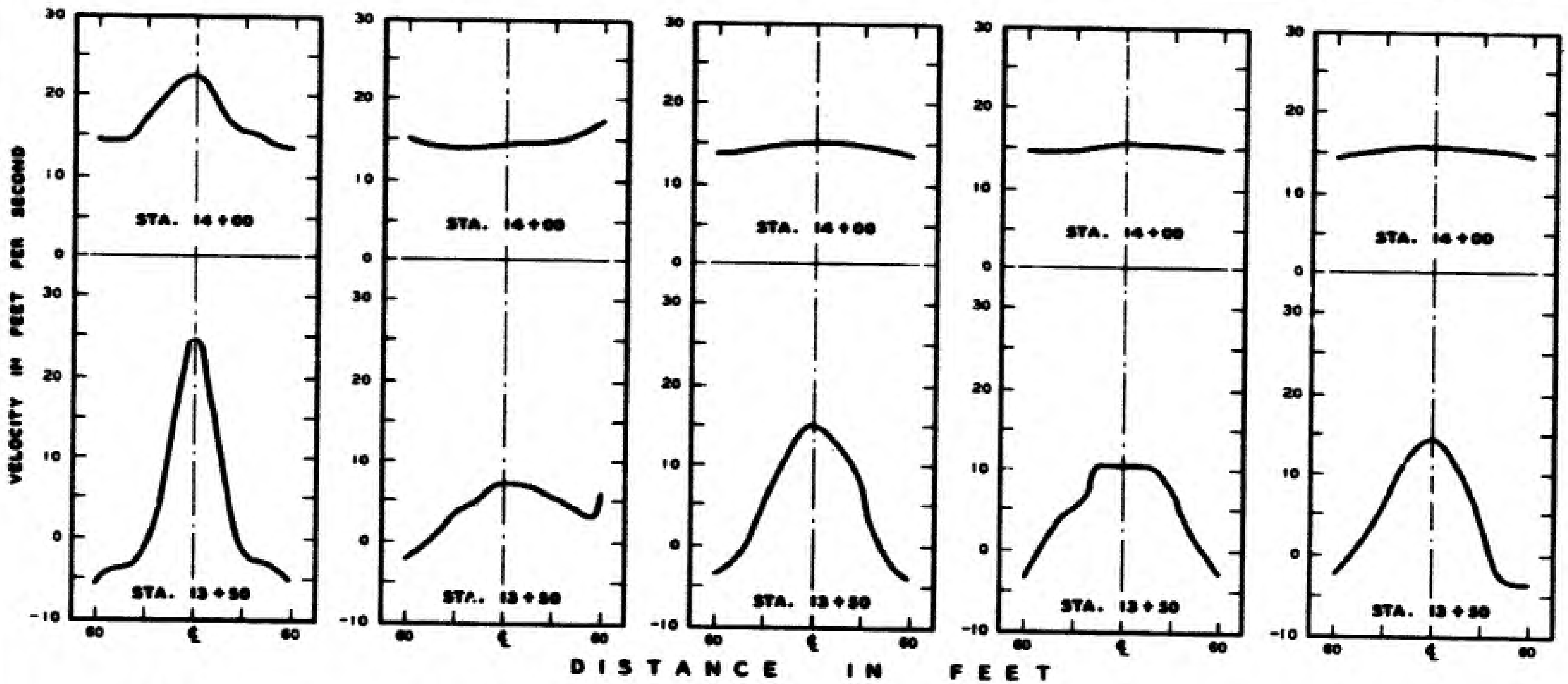
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER CAPTAIN, C. E.

TRACED BY W.D.D. CHECKED BY G.E.H	TRANSMITTED WITH REPORT DATED NOVEMBER 18, 1942	FILE: M. 11. G-37


PLAN
SECTION A-A
PLAN G
PLAN
SECTION B-B
PLAN H
PLAN
SECTION C-C
PLAN I
PLAN
SECTION D-D
PLAN J
PLAN
SECTION E-E
PLAN K
FINAL DESIGN
NOTES
1. ELEVATIONS REFER TO FEET M. S. L.
2. PLANS G, H, I, J, AND K WERE DEVELOPED EXPERIMENTALLY.
3. FINAL DESIGN WAS USED IN CONJUNCTION WITH 25-FT. RADIUS BUCKET.
MODEL STUDY
DORENA SPILLWAY AND TUNNEL
TUNNEL OUTLET
PLANS G, H, I, J, AND K
SCALES
MODEL 0.5 0 0.5 1 FT.
PROTOTYPE 25 0 50 FT.
BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON
SUBMITTED:
APPROVED:
ASS'T ENGINEER
CAPTAIN, C.E.
TRACED BY W.D.S.
CHECKED BY G.E.H.
TRANSMITTED WITH REPORT DATED NOVEMBER 16, 1942
FILE: M. 11. 9-20



PLAN A   PLAN C   PLAN D   PLAN E   PLAN F

NOTES

1. ALL VELOCITY OBSERVATIONS WERE TAKEN FOR A TUNNEL DISCHARGE OF 5000 C.F.S. WITH THE POOL AT ELEV. [illegible] FEET M.S.L.
2. MODEL VELOCITIES WERE TAKEN WITH [illegible] TUBE AND CONVERTED TO PROTOTYPE VALUES OF ([illegible]).
3. VELOCITIES AT STA. 13+50 WERE TAKEN AT 5-FOOT DEPTH, VELOCITIES AT STA. 14+00 WERE TAKEN AT 0.6 DEPTH.
4. NEGATIVE VELOCITIES DENOTE FLOW UPSTREAM.
5. NO DATA TAKEN WITH PLAN B – SIMILAR TO VELOCITY OBSERVATIONS OF PLAN A.
6. DATA TAKEN DURING TEST 17.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
TUNNEL OUTLET
PLANS A, C, D, E, AND F

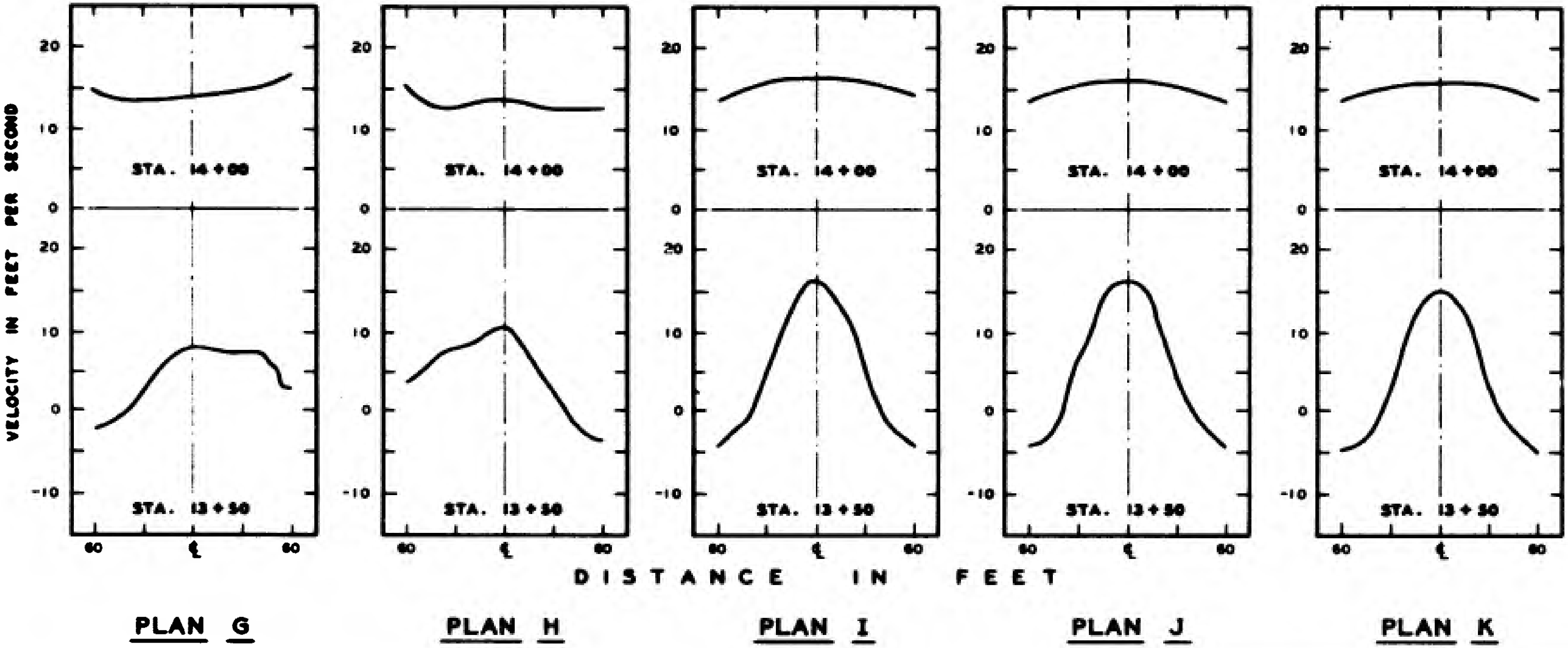
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: APPROVED:

ASST. ENGINEER   CAPTAIN, C. E.

TRACED BY W.O.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: B.H. 17-3



NOTES

1. ALL VELOCITY OBSERVATIONS WERE TAKEN FOR A TUNNEL DISCHARGE OF 5000 C.F.S. WITH THE POOL AT ELEV. 832.0 FEET M.S.L.
2. MODEL VELOCITIES WERE TAKEN WITH BENTZEL TUBE AND CONVERTED TO PROTOTYPE VALUES OF $(V_p = \sqrt{25}\, V_m)$.
3. VELOCITIES AT STA. 13+50 WERE TAKEN AT 5-FOOT DEPTH; VELOCITIES AT STA. 14+00 WERE TAKEN AT 0.6 DEPTH.
4. NEGATIVE VELOCITIES DENOTE FLOW UPSTREAM.
5. DATA TAKEN DURING TEST 17 AND 18E.

MODEL STUDY
DORENA SPILLWAY AND TUNNEL
VELOCITY OBSERVATIONS
TUNNEL OUTLET
PLANS G, H, I, J, AND K

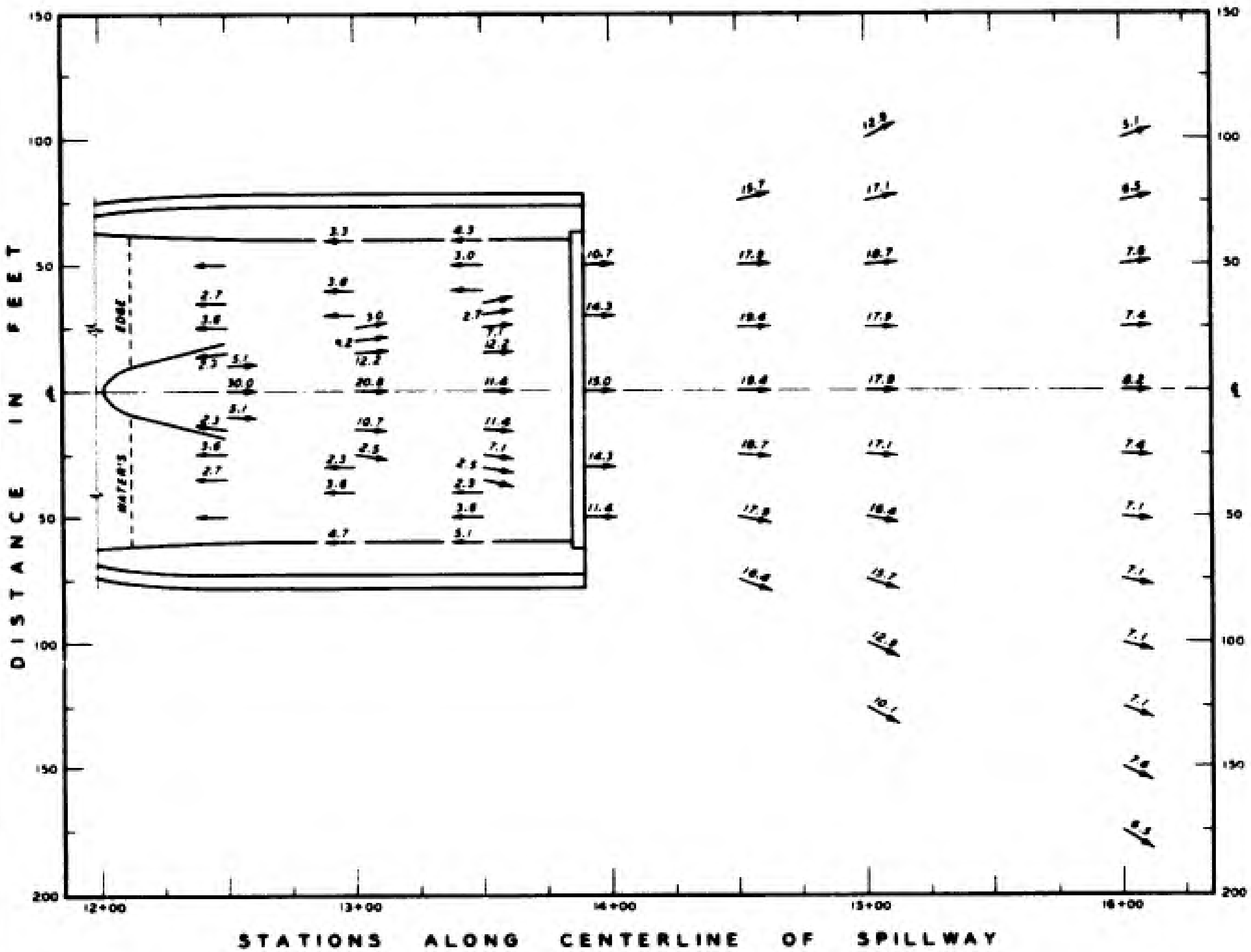
SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY
U. S. ENGINEER OFFICE
BONNEVILLE, OREGON

SUBMITTED: George R. Hyde, ASST. ENGINEER

APPROVED: R. D. [illegible], CAPTAIN, C. E.

TRACED BY W.G.D. CHECKED BY G.E.H.	TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942	FILE: H.11.17-6



NOTES

1. MODEL VELOCITIES TAKEN WITH BENTZEL AND PITOT TUBES AND CONVERTED TO PROTOTYPE VALUES OF ($V_p = \sqrt{50}\ V_m$).
2. VELOCITIES ARE SHOWN IN FEET PER SECOND.
3. FROM STA. 12+50 TO STA. 13+50, INCLUSIVE, VELOCITIES WERE MEASURED AT 5-FOOT DEPTH; ALL OTHER OBSERVATIONS WERE MADE AT 0.6 DEPTH.
4. BLANK ARROWS DENOTE VELOCITIES OF LESS THAN 2.0 FEET PER SECOND.
5. DATA TAKEN DURING TEST 2A.

CONDITIONS

1. Q = 5000 C.F.S.
2. GATE OPENING = 1/3
3. POOL ELEV. = 832.0 FT. M.S.L.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

VELOCITY OBSERVATIONS

TUNNEL DISCHARGE

SCALES AS SHOWN

BONNEVILLE HYDRAULIC LABORATORY

U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

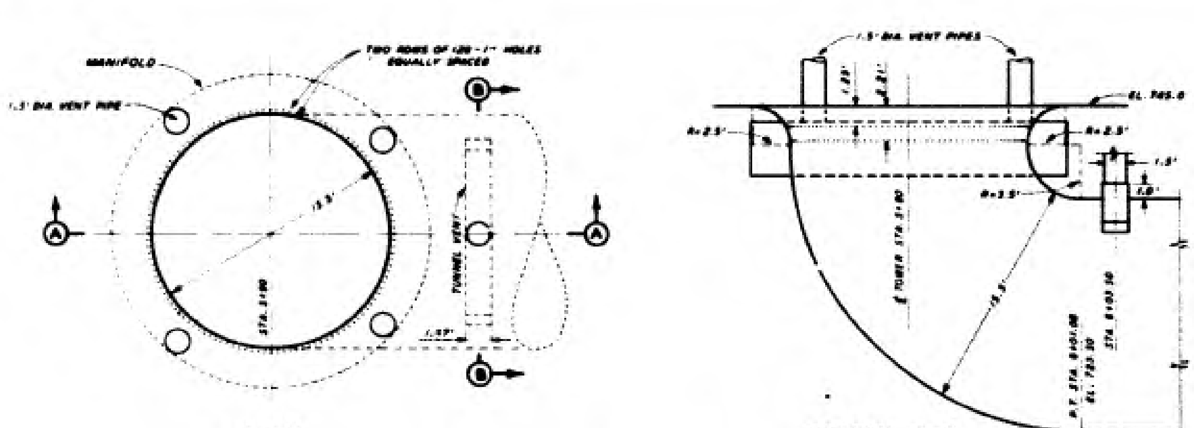
SUBMITTED: George E. Hyde, ASS'T ENGINEER

APPROVED: CAPTAIN, C. E.

TRACED BY [illegible]
CHECKED BY [illegible]

TRANSMITTED WITH REPORT DATED NOVEMBER [illegible], 1942

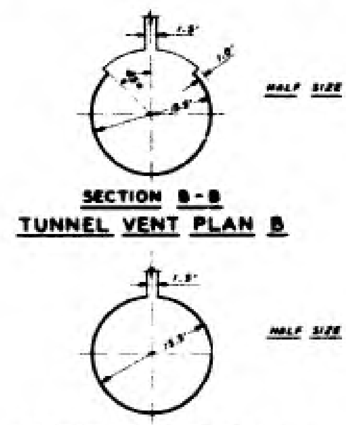
FILE: [illegible]



PLAN

SECTION A-A

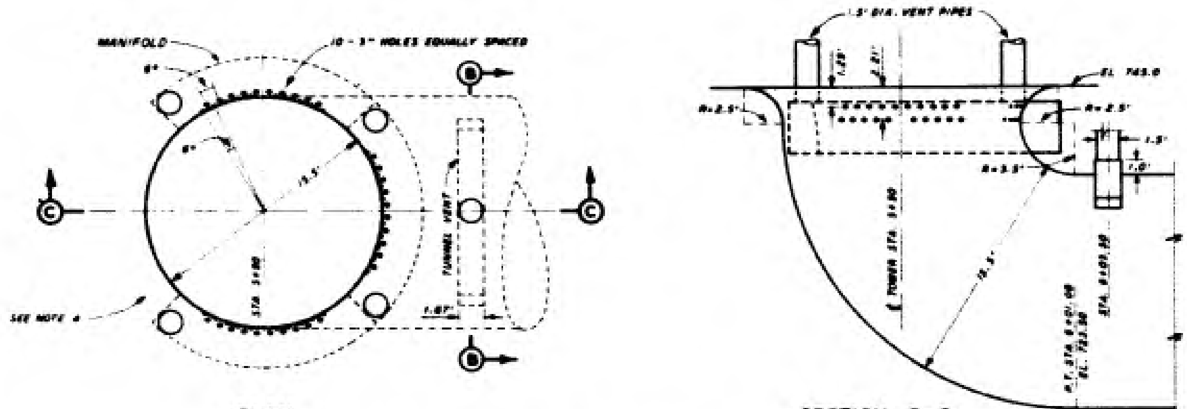
LIP VENT PLAN A - TUNNEL VENT PLAN B



SECTION B-B

TUNNEL VENT PLAN B

TUNNEL VENT PLAN A



PLAN

SECTION C-C

LIP VENT PLAN B - TUNNEL VENT PLAN B

FINAL DESIGN

NOTES

1. ALL FEATURES OF TUNNEL WITH THE EXCEPTION OF THE VENTING SYSTEMS AND OUTLET REMAINED AS ORIGINALLY DESIGNED.
2. ELEVATIONS REFER TO FEET M.S.L.
3. LIP VENT PLAN A AND TUNNEL VENT PLAN B TAKEN FROM PORTLAND DISTRICT SKETCH RECEIVED AUGUST 28, 1941; TUNNEL VENT PLAN A IS THE ORIGINAL DESIGN.
4. UPSTREAM MANIFOLD SECTION WAS RECOMMENDED FOR FINAL PROTOTYPE DESIGN.

MODEL STUDY

DORENA SPILLWAY AND TUNNEL

AIR VENTS

PLANS TESTED

SCALES

MODEL 0 0.1 0.2 0.3 0.4 FT.

PROTOTYPE 0 5 10 15 20 FT.

BONNEVILLE HYDRAULIC LABORATORY

U. S. ENGINEER OFFICE

BONNEVILLE, OREGON

SUBMITTED: ASST ENGINEER

APPROVED: CAPTAIN, C. E.

TRACED BY W.O.D.
CHECKED BY G.E.H.

TRANSMITTED WITH REPORT DATED NOVEMBER 10, 1942

FILE: M.11.6-61

A P P E N D I X

APPENDIX

There is presented herewith a list of the 37 preliminary reports on the results of tests made during the Model Study of the Spillway and Tunnel for Dorena Dam. These reports were forwarded to the Portland District Engineer during the period of September 21, 1940 and November 14, 1941 by the Bonneville Hydraulic Laboratory. To simplify the following list, no attempt has been made to correlate the reports with the project features tested as this may be done by reference to Table A in this final report.

Test	Date of Preliminary Report
1	Sept. 21, Oct. 17 and 31, 1940
2	Oct. 5 and 17, 1940
2A	May 29, and Aug. 9, 1941
3	Oct. 18, and Nov. 9, 1940
4	Nov. 29, 1940
5	Dec. 10, 1940
6	Dec. 10, 1940
7	Dec. 10, 1940
8	Dec. 16, 1940
9	Dec. 27, 1940
10	Dec. 31, 1940
11	Jan. 15, and Feb. 7, 1941
12	Jan. 30, 1941
13	Feb. 13, 1941
14	Feb. 14, 1941
15	Feb. 15, 1941

Test	Date of Preliminary Report
16	Feb. 28, 1941
17	March 6, 1941
18	March 10, and June 9, 1941
19	March 21, 1941
20	Feb. 13, and April 2, 1941
21	April 4, 1941
22	April 11, 1941
23	April 12, 1941
24	May 29, June 9, July 18, and Sept. 30, 1941
25	May 29, June 9, and Aug. 29, 1941
26	June 19, 1941
27	Aug. 14, 1941
28	Oct. 29, 1941
29	Oct. 29, and Nov. 14, 1941