WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY

MODEL STUDY OF THE OUTLET STRUCTURES FOR THE WAPPAPELLO DAM

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U. S. WATERWAYS EXPERIMENT STATION

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SAINT FRANCIS RIVER PROJECT

THE WAPPAPELLO DAM

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLES

MODEL STUDY OF THE OUTLET STRUCTURES

FOR THE

WAPPAPELLO DAM

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SYLLABUS

1. This memorandum constitutes a final report of the study performed at the U. S. Waterways Experiment Station on a model of the outlet works for the Wappapello Dam. The model was built undistorted to the linear scale ratio, model-to-prototype, of 1 to 25. The general purpose of the model study was to check the hydraulic characteristics of all elements in the design of the outlet works, and to develop means of correcting any uneconomic, unsafe, or undesirable conditions. The results of the study indicated that the basic design of the outlet works was, for the greater part, satisfactory. The single feature of the design offering greatest opportunity for improvement was the stilling basin. The model study indicated that a reduction of 64.5 ft. in the overall length of the stilling basin could be gained by effective combination of apron curvature, wing-wall alignment, and baffle-pier arrangement.

METHODS OF PRESENTING RESULTS AND USE OF TERMS

2. All details concerning the study are described and discussed in the text of this memorandum. Supporting data are as follow:

a. Tables 1 to 14, enumerating the tests and summarizing the test data.

b. Photographs 1 to 63, showing the model during various phases of operation.

c. Plates 1 to 99, presenting the dimensions of the structural features investigated and the data obtained from the tests thereof.

3. To avoid confusion and to permit ready visualization of prototype conditions, all data are presented in prototype equivalents. Throughout the report, the following terms are used as indicated below:

a. Hydraulic jump. Aside from its denotation of the common hydraulic phenomenon, this term denotes a freely formed jump characterized by a nearly vertical surface at the point of transition from sub-critical to super-critical depth.

b. Submerged jump. This term is used with the adverbs "partially" and "completely" to denote conditions wherein excessive tailwater depths tend to drown the jump action. A jump is partially submerged when there is still a distinct transfer from sub-critical to super-critical depth, though the water surface extending from the nappe to the tailwater is nearly level. A jump is completely submerged when it is evidenced only by a boiling action on the surface below the transition, the water surface extending from nappe to tailwater being practically level.

c. Surface roller. This term denotes a standing wave with a curling crest. The formation is similar to that assumed by a wave approaching a beach just before it becomes a breaker.

d. Spray action. This term denotes a nearly vertical dispersion of water resulting from the impingment of a nappe upon a row of baffles as it enters a stilling basin. The phenomenon occurs where the tailwater is of insufficient depth to induce the hydraulic jump.

e. Test. This word denotes an experiment conducted upon a certain arrangement of the elements of the outlet works. Tests are numbered consecutively from the beginning of the study. Where tests are conducted under more than one condition, i.e., discharge, headwater, or tailwater, these conditions are indicated by a number set off from the test number by a hyphen. The types of stilling basins are designated by letters.

f. Conduit. This word denotes the passage for flow from the control gates to the downstream portal of the tunnel.

g. Tunnel. This word denotes that portion of the conduit which is of uniform D-shape and which extends from the transition section to the upstream limit of the stilling basin.

PERSONNEL

4. The model study of the outlet structures for the Wappapello Dam was accomplished in Experiment Section No. 4 of the Hydraulic Laboratory of the U. S. Waterways Experiment Station. Mr. Eugene P. Fortson, Jr., Assistant Engineer, is chief of Experiment Section No. 4. Mr. Fred R. Brown, Junior Engineer, was in direct charge of the model study. Mr. W. G. Gill, Junior Engineering Aide, was the assistant in the operation of the model.

PART I - THE PROTOTYPE AND THE PURPOSE OF THE MODEL STUDY

History of the Study

Initiation and Authority

5. Pertinent facts concerning the history of the model study follow:

   a. Study initiated by the District Engineer, Memphis, Tennessee.

   b. Study authorized by the President, Mississippi River Commission, in the 5th Indorsement, dated November 1, 1937, to a letter to the District Engineer, dated October 11, 1937.

   c. Study accomplished at the U. S. Waterways Experiment Station, Vicksburg, Mississippi, during the period November 1, 1937 to May 16, 1938.

   d. Final report (this report) rendered August 15, 1938.

The Prototype

General Features

6. A major feature of the flood control program for the St. Francis River is the reservoir to be located near Wappapello, Mo. (See Plate 1.) The reservoir will be created by the proposed Wappapello Dam, an earthen embankment containing approximately 2,000,000 cu. yd. of material. (See Plate 2.) The dam will be about a half mile in length and will rise 73 ft. above the general valley floor to El. 416.* The lake at spillway crest elevation of 395 will be about a mile wide and forty miles long, having an area of 23,000 acres and a storage capacity of 625,000 acre-feet. Solid rock underlies the abutting hill to the south,

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*All elevations are referred to the datum of mean Gulf level.

where the control structures will be located.

Spillway

7. A spillway to be located on the south abutment ridge about 1200 ft. from the dam will provide for the passage of extraordinary flood flows from a full reservoir. The spillway will be of concrete founded on rock with a 740-ft. crest width at El. 395 and a discharge capacity of 155,000 c.f.s.

Outlet Structures

8. The outlet structures to be located in the south abutment ridge between the spillway and the dam, will provide a means for controlling the outflow from the reservoir and for conveying this flow to the channel below the dam. The outlet structures will consist of a conservation-pool weir; three control gates; a transition section; a concrete-lined, D-shaped tunnel; and a stilling basin. (See Plate 3.) The design contemplates an outflow rate for these structures of 10,000 c.f.s. at comparatively low heads, which can be increased to 17,000 c.f.s. when the pool is near the spillway crest and all gates are open. The capacity at maximum pool stage of 410 will be about 20,000 c.f.s. Plans include provisions for a 75-kva hydro-electric plant to be installed in a chamber adjacent to the gate tower. This plant will supply power for operating the gates and lighting the dam and operator's quarters.

Purpose of the Model Study

General

9. The general purpose of the model study was to check the hydraulic characteristics of all points in the design of the outlet works,

and to develop means of correcting any uneconomic, unsafe, or undesirable conditions.

Specific Points Involved

10. In accomplishing the purpose of the model study as enunciated above, specific determinations as follow were to be made:

a. The suitability of the structural elements as designed.

b. The improvements in design as might be indicated in the course of the model study.

c. The performance of the outlet works, with a view to establishing the technique for safe and effective operation of the prototype.

11. The model study was to be conducted in accordance with the following criteria:

a. Discharges of 10,000 c.f.s. must be passed for extended periods of operation without damage to stilling basin or outlet channel.

b. A discharge of 17,000 c.f.s. must be passed without endangering the stability of the works.

PART II - TECHNIQUE OF THE MODEL STUDY

Apparatus

12. The experiments were conducted on a model installed in two wooden flumes located on the model floor of the main laboratory building. The water used in the operation of the model was supplied by the circulating system provided for the indoor testing flumes. Flow from the constant-head tank of the circulating system was piped to a weir box whence it passed successively over a measuring weir and through the model to the sump return channel. The tailwater in the stilling basin and exit channel was maintained at any desired depth by means of an adjustable tailgate. (See Photograph 13.) Standard types of hook and point gages were used for measurements of water-surface elevations, while soundings were taken with a specially constructed sounding stick. (See Photograph 14.) Pressures were measured by piezometers located throughout the outlet structures. Nearly all velocity measurements were made with a pitot tube. (See Photograph 15.) Velocities below the measuring range of the pitot tube were determined with a Bentzel tube.

Construction of the Model

General

13. The model of the outlet structures was built undistorted to the linear scale, model-to-prototype, of 1 to 25. In the model, 275 ft. of the approach channel, the outlet structures proper, and 400 ft. of the exit channel below the stilling basin were reproduced. (See Plates

3 and 4, and Photographs 1 to 4.) The tolerances of model fabrications were kept as small as possible, and it is believed that the model was precise in every detail. Parts modeled in wood were treated with waterproofing material before installation; the short time they were in use did not result in any dimensional change.

Approach Channel

14. The approach channel to the intake structure was molded in concrete to female templets. These templets were cut to conform to the shape of channel and overbank area as shown in the data furnished by the District Engineer. Riprapped channel sections and overbank areas were represented in the model by a brushed finish of the cement mortar surface. Those portions of the approach channel which are to be concrete in the prototype were represented by a surface troweled to a smooth finish.

Conservation-pool Weir

15. The counterpart of the conservation-pool weir was a composite structure having each of its elements fabricated from a material best suited for the purpose at hand. (See Photographs 5 and 6.) Thus, the ogee surface of the weir, requiring extreme smoothness and precise shaping, was molded in wax and machined to the ogee curve; the slotted buttresses on the upstream face and the sluices through the weir, having curved and plane surfaces, were modeled in wood; the automatic gates, requiring hinged movement, were made of sheet metal. The weir was so constructed that its location in the approach channel could be easily changed.

Intake Structure

16. All features of the intake structure having to do with its hydraulic performance were incorporated in the model. The piers, trash racks, and curved entrance throats were modeled in wood and waterproofed to prevent expansion. (See Photographs 7 to 9.) The gates and gate guides were a separate unit of carefully machined brass, bolted to the downstream ends of the piers. The intake structure was supported upon a structural-steel base; the base was supported upon a rigid pedestal by four leveling screws. All flow phenomena within the structure could be observed directly through pyralin panels fitted into the left outside pier, the floors of the intake passages, and the downstream walls of the gate chambers.

Transition and Tunnel

17. The construction of the transition and tunnel sections of the conduit was to be such as to permit direct observation of flow. Hence these elements of the structures were molded of transparent pyralin. The division piers within the transition were modeled of treated wood. (See Photographs 10 and 11.)

Stilling Basin

18. The stilling basin, with the exception of the horizontal apron, was molded in cement mortar to female templets. (See Photograph 1.) The horizontal apron, baffle piers, and end sill were modeled in wood. (See Photograph 36.) The baffle piers were mounted on sheet-metal strips nailed to the stilling-basin floor. This construction facilitated the shifting of the piers for successive tests. For the exit channel, male templets cut to conform to soundings in the channel downstream from the stilling basin, were used in molding the

sand bed prior to each scour test.

Theoretical Considerations

19. True dynamic similarity, assuring rigorous reproduction of all hydraulic phenomena, cannot be attained in fluvial models. In practice, however, it is not necessary to reach this perfection. A model study is feasible provided: (a) one of the dynamic forces involved predominates; (b) similitude with respect to the predominating force is attained; and (c) the limitations imposed by the lesser forces are duly considered. In a model of a conduit with its inlet and outlet structures, gravitational and frictional forces are involved. The laws of similitude relating to these forces, discovered by Froude and Reynolds, are not compatible. Froude's Law (gravity), requiring that inertia and gravitational forces bear the same relation in model as in prototype, is applicable to models in which free surfaces exist. Where free surfaces do not exist, statical buoyancy eliminates the action of gravity, and dynamic similitude depends upon the observance of Reynolds' Law (viscosity). This law of similitude requires that the ratio of inertia to internal frictional forces be the same in model and prototype. That the two laws of similitude are incompatible is apparent when it is noted that the Froudian relationship requires a reduction of velocity, prototype to model, whereas the criterion set up by Reynolds demands a velocity increase.

20. In the model of the Wappapello outlet structures, gravity was considered to be predominant among the forces concerned. Similitude with respect to the laws of gravity was attained by selecting a

large scale ratio, model-to-prototype, and making all surfaces of the model very smooth. As scale ratios decrease in magnitude, model surfaces must increase in smoothness. To illustrate this point, assume that the value of Manning's "n" for the concrete surfaces of the tunnel section of the prototype is 0.014 (value for carefully finished concrete). In the case at hand, the linear scale ratio, model-to-prototype, is 1 to 25. With Manning's "n" for prototype and linear scale ratio of the model known, it can be demonstrated that the value of Manning's "n" for the tunnel section of the model should be 0.008. Were a smaller model scale used, the model should be correspondingly smoother. With the materials available (pyralin, wood, etc.) it is possible to build a model having an "n" value of the magnitude of 0.008. A value of "n" of 0.008 has been determined for pyralin conduits of circular, or nearly circular, section. In the case at hand, the average value of "n" as calculated from model tests on the tunnel section was 0.0096. Inasmuch as the present tunnel is of pyralin, the higher value of the coefficient (0.0096 as compared to 0.008) is ascribed to the D-shape of the present section. It is believed that this D-shape would cause the value of "n" for the prototype tunnel to be correspondingly higher than the value of 0.014 mentioned above. Hence, it is believed that similarity of gravity forces was substantially attained in the model.

21. The limitations imposed by the lack of identity of the Reynolds' number in model and prototype operate to invalidate quantitative measurements of flow characteristics in the tunnel flowing full.

The dimensions and intensities of regions of turbulence, cavitation, and eddies are not transferable to the prototype. However, the model indications of the existence of these conditions are believed to be reliable.

22. The quantitative transference of model pressures to the prototype is limited to positive pressures. A negative pressure indicates a tendency for a void to form, and voids in contact with a water surface are relieved by the ebullition of air from the water and formation of water vapor. At low negative pressures this escape of gases from the water into the voids is very slight but increases as the degree of rarefaction, until near zero, absolute pressure, the escape is so rapid that it prevents the occurrence of a perfect vacuum. A model such as that of the Wappapello outlet works cannot simulate this phenomenon known as cavitation. Therefore, the prototype equivalents of negative model pressures become more and more at variance with the true pressures as zero, absolute pressure, is approached. Since the point at which cavitation invalidates the model results is not known, it is necessary to consider negative pressures in a model only qualitatively.

23. The simulation of prototype bed material in a model is not feasible. Hence, the movable-bed portion of the present model was molded in clean sand, and measurements of erosion resulting from flow over this material were considered only qualitatively. Actual depths of scour in the prototype would have to be analyzed in the light of the bottom velocities, and the extent to which the material would be moved by such velocities.

24. The conclusions to be reached from these theoretical considerations are that measurements of discharges, positive pressures, and velocities may be transferred quantitatively to the prototype by means of the scale relationships, and that evidences of turbulence, cavitation, scour, etc., may be considered qualitatively reliable.

25. The relationships for the transference of data from the model to the prototype are given below:

Model Relationships for Scale of 1:25

Dimension	Symbol Prototype	Symbol Model	Symbol Ratio m/p	Relationship
Length	L_n	L_m	ℓ	$\ell = 1/25$
Area	A_n	A_m	a	$a = \ell^2 = 1/625$
Time	T_n	T_m	t	$t = \ell^{1/2} = 1/5$
Velocity	V_n	V_m	v	$v = \ell^{1/2} = 1/5$
Rate of Discharge	Q_n	Q_m	q	$q = \ell^{5/2} = 1/3125$

Theory of Procedure

26. It was believed that the specific determinations, outlined in Paragraph 10 as the purpose of the model study, could be made from tests which involved the following:

a. The relation of the pool elevation in the reservoir to discharge for various combinations of full and partial gate openings. Data on this relation would establish the rating curves and would enable a direct comparison to be made between different gate combinations. Study of these data would indicate best gate operation.

b. The flow conditions throughout the structures. Observation of flow phenomena would show the hydraulic performance of the elements of the structure, revealing eddies, turbulence, and cavitation wherever such existed.

c. The magnitude of pressures throughout the structures. Data as to pressures would establish the hydraulic gradient and indicate the forces acting upon the surfaces of the elements of the structure. Where negative, the pressures would indicate possible tendencies for cavitation. Air pressures measured in the gate vents with these vents sealed would show their action in relieving the vacuums formed behind the gates.

d. Profiles of the water surface in approach and exit channels. Such data on the approach channel would indicate flow lines and the nature of the action below the conservation-pool weir. Such data on the stilling basin would indicate the conformation of the hydraulic jump.

e. The magnitudes of velocities in approach channel, stilling basin, and exit channel. These data would indicate the distribution of flow. Study of the data on bottom velocities in the channel below the stilling basin, together with study of the characteristics of the prototype bed material, would indicate the extent of scour to be expected in the latter.

f. The depth and location of scour below the stilling basin. These data would furnish indications as to the comparative effects of different arrangements of the stilling basin elements. These data would not indicate the absolute depth to which the prototype channel would be scoured.

Method of Operation

Gate Ratings

27. The relation of pool elevation to discharge was determined for every combination of gates at full, half, and three-quarter openings. A complete rating for a gate combination required from three

to six runs. A run consisted of opening the gates in the combination desired and measuring over the inflow weir the rate of flow when the reservoir level reached stability at the selected pool elevation. The head on the weir and the reservoir level were determined by hook gages. (See Plate 4.)

Current Directions

28. Surface currents were traced with confetti, while currents below the surface were defined by dye. The dye was injected into the water through a glass tube at the location and elevation desired.

Water-surface Profiles

29. Elevations of the water surface in the approach channel were measured with a point gage supported on a steel beam. This beam was in turn supported by rails fixed to the flume walls. Profiles of the hydraulic jump in the stilling basin were obtained with the sounding rod along the center line of the structure.

Pressures

30. Pressures were measured in manometers connected by tubes to piezometers. (See Photographs 17 and 18.) These piezometers were installed in various locations throughout the structure, so as to provide a complete record of all pressures. In order to measure the negative air pressures relieved by the gate vents, the vents were sealed and connected to U-tubes.

Scour

31. Prior to beginning a scour test, the sand bed was molded to the configuration of the outlet channel shown in the prototype plans. To obtain the required flow conditions for a test, the outlet channel

was first flooded to prevent unnatural erosion before reaching stability of flow. The desired discharge was then introduced over the weir. As the flow from the tunnel became stabilized the tailgate was adjusted to obtain the required tailwater elevation. A scour test lasted 50 minutes, during which time the bed had become stabilized and all data pertaining to basin action had been recorded. At the conclusion of a test the outlet channel was drained and the sand bed was cross-sectioned. (See Photograph 14.)

Velocities

32. The magnitudes of velocities were determined with pitot or Bentzel tubes. Prior to velocity explorations in the outlet channel, the sand bed was capped with a thin coating of cement mortar to prevent sand particles from fouling the velocity instruments. The fixing of the bed of the outlet channel also insured constant flow conditions over the period necessary to secure all data.

Field Data

33. The dimensions of the model structures were originally in accordance with prototype plans and specifications prepared by the Memphis and Little Rock district offices. Structural changes resulting from model tests are presented on plans incorporated in this report. All discharge and flow data were made in accordance with computations supplied by the district offices.

34. Tailwater depths in the stilling basin tests were based on the computed tailwater curve originally furnished by the Little Rock district office. (See Plate 21.) The sharp break in the curve at about 17,000 c.f.s. is due to backwater caused by the operation of the spillway

PART III - TESTS OF THE OUTLET STRUCTURES

General Procedure

35. The initial tests were conducted on the outlet structures as originally designed. (See Plate 3.) When all features of the original design had been investigated, tests were conducted to determine the effects of various alterations of the elements of the outlet structures. The character of subsequent tests was dictated by the purpose and criteria for the model study. (See Paragraphs 10 and 11.)

36. In presenting the results of the tests, no attempt is made to explain the test data according to the chronological order in which the tests were conducted. Instead, each element of the outlet structures is considered in turn, and all tests conducted thereon are described in detail.

Test Results - Approach Channel

Approach Channel of Basic Design

37. General. The scope of the study of the approach channel embraced conditions obtaining with (a) the conservation-pool weir in place, and (b) the conservation-pool weir removed. The tests comprised velocity determinations and observations of flow phenomena. In the basic design of the approach channel, provision was made for 95.6 ft. of concrete channel upstream from the intake structure. Upstream from this point, the channel was to be riprapped.

38. <u>Conditions without weir.</u> With the conservation-pool weir removed, velocity measurements indicated that, for a discharge of 10,000 c.f.s. with all gates open, the bottom velocities at the upstream edge of the concrete channel averaged 5.3 ft. per sec.; and that these velocities decreased as the discharge increased, becoming too low to measure at a discharge of 15,000 c.f.s. For pool elevations which slightly submerged the crests of the side retaining walls, the surface of the rapidly accelerating flow in the channel became lower than the pool elevation maintained in the relatively quiet areas shoreward of the retaining walls. As a result, the crests of the retaining walls acted as submerged weirs. This submerged-weir action, barely perceptible (Photograph 23) under the conditions described, assumed appreciable proportions with the installation of the conservation-pool weir. Aside from this condition, no other noteworthy phenomena were observed.

39. <u>Conditions with weir.</u> With the conservation-pool weir installed, flow conditions in the approach channel upstream from the weir were largely influenced by the operation of the weir sluices. Velocities on the bed of the riprapped channel ranged from relative quiescence with sluices closed, to a maximum of 6.0 ft. per sec. with all sluices open and pool elevation at weir crest. As regards channel flow downstream from the weir the only noteworthy condition was the submerged-weir action of the side retaining walls. The weir offered an obstruction to flow which considerably intensified this action. (See Photograph 24.)

Approach Channel of Modified Design

40. General. Upon the completion of tests upon the approach channel of basic design, instructions were received from the District Engineer at Memphis to determine the effects of flattening the slope of the face of the hill, where the hill rose from the berm in rear of the side retaining walls. This 1 on 1-1/2 slope was to be flattened to 1 on 2 (map in district office, file 26/20-1). With the flattened slopes, tests indicated no apparent effect upon flow conditions in the approach channel, or on the performance of the outlet structures.

Test Results - Conservation-pool Weir

Conservation-pool Weir of Basic Design

41. General. The function of the conservation-pool weir is to maintain the normal condition of the reservoir with pool at or near El. 355. This condition is desired to provide recreational facilities and a preserve for fish and wild fowl. The conservation-pool weir is to have an ogee crest, and is to be provided with sluices for stream-flow diversion and pool drainage. (See Photographs 5 and 6.) The hydraulic features of the weir were determined from the model study by means of flow observations, water-surface profiles, and pressure measurements.

42. Flow in channel. The effect of the weir upon flow conditions in the channel downstream was confined to discharges ranging downward from 10,000 c.f.s.; submergence of the weir at 10,000 c.f.s. transferred control of the reservoir to the gates. (See Photograph 26.)

Flow from the sluices caused no undesirable conditions except possibly at low rates of flow. A discharge of 1000 c.f.s. produced a surface roller. (See Photograph 27.) The dip in the channel floor below the weir tended to deflect the bottom current more sharply upward. No other effect of this dip was observed. Tests to determine the effect of the weir upon entrance conditions at the intake structure indicated one interesting case. The closure of either side gate or two adjacent gates caused water to pile up on the side of slack flow. The steep drop-down across the front of the pier adjacent to the intake under draft caused a vortex to form next to the pier nose. (See Photograph 25.)

43. Flow over crest. As stated above, the effect of the weir on flow conditions was confined to discharges ranging downward from 10,000 c.f.s. The effect of the weir upon a flow of 10,000 c.f.s. was barely perceptible. With a discharge of 7,500 c.f.s., there was a transformation of flow without a jump. Lower discharges produced a submerged jump. Comparison of the pressure profiles and the profiles of the water surface indicated that the ogee surface of the weir was free of negative pressures at all rates of flow. (See Plates 5 to 7.)

44. Pool elevation-discharge relation. The pool elevation-discharge relation for the conservation-pool weir was investigated at full openings of the control gates. The results indicated that the weir controlled the rate of flow for discharges ranging upward to 10,000 c.f.s. (See Plates 8 and 10.) As to the capacity of the sluices, tests indicated that the maximum discharge with all sluices open and

the pool at the crest of the weir was 5,000 c.f.s. Inasmuch as it was not practicable to simulate in the model the automatic action of the downstream sluice gates, the determination of sluice capacity was subject to error to an unknown extent.

45. Position of the weir. An investigation of flow conditions was made with the conservation-pool weir occupying various positions in the approach channel. The purpose of this investigation was to determine the most desirable weir position. Observation of the traces of dye injected into the flow in the channel revealed that the upstream surface current induced by the hydraulic jump extended downstream 90 ft. from the weir. With the weir in its original position (95.6 ft. upstream from the intake structure) the flow into the gate passages was uniformly downstream. The installation of the weir in positions closer to the intake structure than 95 ft. caused the effects of the hydraulic jump described above to extend into the gate passages.

Removal of Automatic Sluice Gates

46. General. As stated above, facilities for stream-flow diversion and pool drainage are to be supplied by sluices through the conservation-pool weir. These sluices are to be closed by means of concrete stop-logs dropped into slots on the upstream face of the weir structure. In order to insure smooth flow over the weir, the recessed downstream portals of the sluices are to be covered with steel gates which will maintain the ogee surface unbroken. Automatic operation of these gates is to be obtained by hinging at the top, thus permitting them to open under pressure of sluice flow and to

close under pressure of weir flow. Since these automatic gates would be of heavy steel fabrication their omission would result in considerable savings in construction costs. Therefore, tests proposed by the District Engineer were conducted to determine whether or not such omission would set up flow conditions detrimental to the safety or efficiency of the outlet works.

47. Flow conditions. With the automatic gates removed, tests were conducted at discharges of 1,000, 1,500, and 2,500 c.f.s. Since the sluices were nearly submerged at a discharge of 2,500 c.f.s., no investigation was made of conditions at discharges in excess of that rate. Operation at discharges of 1,500 and 2,500 c.f.s. indicated no discernible differences in flow conditions from those which obtained with the gates in place. (See Photographs 28 and 29.) At a flow of 1,000 c.f.s., however, the nappe spilled into the recessed sluice portals. (See Photograph 30.) Tendencies for cavitation were observed at all rates of flow investigated. These tendencies for cavitation were located under the intersections of the crowns of the sluices with the surface of the ogee. (See Photographs 28 to 30.)

Alternates for the Conservation-pool Weir

48. General. A proposal for the elimination of the weir, made during the course of the model study, contemplated the maintenance of the conservation pool by means of removable barriers. These barriers (presumably reinforced steel plates) were to present much the same appearance as vertical-lift gates. In position for low reservoir stages, the barriers would act as sharp-crested weirs in providing

uncontrolled outflow. To permit unobstructed use of the control works, they were to be removed for high reservoir stages. As to the location of the barriers, consideration was given to: (a) the slots of the emergency gates (Alternate A); (b) the upstream face of the intake tower (Alternate B); and (c) a position in the approach channel 33 ft. upstream from the intake tower (Alternate C). The hoisting machinery of the gate house was to be used for removing the barriers if located in the emergency-gate slots; the derrick on the intake tower was to be used if the barriers were located elsewhere. If the barriers were located in the control tower (Alternates A and B), they could be supported by the piers; location in the approach channel (Alternate C) would require special bracing.

49. Alternate A. The installation of the barriers in the emergency-gate slots placed a definite limitation upon flow capacity. Discharges in excess of 1,000 c.f.s. caused the upper surfaces of the nappes to contact the roofs of the gate passages, thereby causing the nappes to become orifice jets. This action reduced the capacity of the works. (See Plate 9.) Observations of flow conditions revealed that the impact of the nappes (or jets) was sustained by the service-gate slots and the floors of the contiguous portions of the transition section. (See Photograph 31.) Turbulence resulting from this impact extended into the tunnel.

50. Alternate B. Although the barriers located at the upstream face of the intake tower exhibited less efficiency than the conservation-pool weir, they passed as much as 10,000 c.f.s. without marked increase in pool elevation. (See Plate 9.) It was noted that nappes

for the higher discharges entered the constricted gate sections with little disturbance. (See Photographs 32 and 34.) With lower discharges, the freely falling nappes struck the floors of the gate passages with full force. The low rate of flow could not in this instance (as at higher discharge) provide a depth of water sufficient to cushion the resulting impact. Also noted at low flows was a tendency for the water surfaces to rise between the nappes and the downstream walls of the barriers. This phenomenon is ascribed to the lack of aeration below the crests of the barriers.

51. Alternate C. A barrier located in the approach channel resulted in discharge characteristics roughly similar to those in Alternate B. (See Plate 9.) Flow conditions were satisfactory in that virtually no turbulence was observed in the inner passages of the intake tower. However, a hydraulic jump which occurred abreast of the piers was attended by turbulence of considerable intensity. (See Photographs 33 and 35.)

Test Results - Intake Structure

Trash Racks

52. General. The basic design of the intake structure called for trash racks across the entrance to the gate passages to insure protection against fouling by debris. The trash racks were to consist of grills of vertical and horizontal members; each member was to be stream-lined to assure minimum obstruction to flow. (See Photograph 4.) The board of consultants decided during the course of model study to omit the trash racks from the design. The model data

previously obtained on the trash racks are presented in this report as a matter of record. The tests of the trash racks were made to determine (a) the effect of such structures upon flow conditions, and (b) the efficacy of such structures in affording protection against fouling by debris.

53. Flow conditions. Flow passed the members of the trash racks smoothly with no discernible turbulence. (See Photograph 19.) The racks had slight effect upon the discharge-stage relation. (See Plate 10.) In order to determine the velocity of flow past the racks, the approach channel immediately upstream was explored with a pitot tube. Velocities ranged from 7 ft. per sec. for a discharge of 10,000 c.f.s. with all gates open to 16.5 ft. per sec. for the same discharge with one gate open.

54. Debris. To study the effect of the racks on debris, sticks were placed in the model approach channel to simulate logs and trees. The racks operated as intended, preventing drift from entering the gate passages. (See Photographs 20 to 22.) When the racks were removed, some of the logs passed through the tunnel into the stilling basin, some were caught in the gate passages, and some remained in front of the intake piled against the piers. The logs that passed into the stilling basin were buffeted about in the hydraulic jump; the tailwater, however, provided depths sufficient to prevent impact of the logs on baffles. The conservation-pool weir had some effect on drift piled against the piers in that it induced an upstream surface current which tended to draw the drift upstream. This upstream current probably reduced the pressure of debris upon the racks.

Piers and Curved Throat Sections

55. General. The investigation of the curved throat sections and the piers of the intake structure comprised observations of flow conditions and measurements of pressures on the surfaces of the elements in question.

56. Flow conditions. It was observed that the rounded noses of the piers effected a quiet division of flow into the gate passages. The curved surfaces of piers and throat sections guided flow to the gates with a complete absence of turbulence and eddies. Tendencies for vibration of the structural elements could not be obtained, inasmuch as the model was designed only to study the hydraulic efficiency of the structures.

57. Pressures. Pressures on the surfaces of piers and throat sections were positive for all discharge conditions. (The locations of piezometers and the magnitudes of pressures are recorded in Tables 4 to 8.

Gates

58. General. The study of the control gates was confined to the determination of ratings with gates in all combinations of full, three-quarter, and half openings. Since it was necessary to fit the gates tightly in their guides to prevent leakage, any tendency for the gates to chatter could not be investigated.

59. Ratings. The capacity of the outlet structures at full openings of all gates with the maximum pool elevation of 410 was practically 20,000 c.f.s. (See Plates 10 to 12 for complete data on gate ratings.) Model discharge curves were found to be in close agreement with computed curves. (See Plate 13.) At partial gate openings, the lips of the gates caused contractions of the jets which tended to

decrease the rate of flow. (See Plate 14 for comparison of partial openings to equivalent clear openings.)

Air Vents

60. General. The air vents for the control gates are to be of the separate-riser type. (See Photograph 16.) Tests of the vents comprised measurements of the negative heads set up in sealed vents for various discharges and gate openings. All observations were made on falling stages with the tunnel flowing full. The negative pressures were measured in U-tubes connected to the sealed vents.

61. Operation. Negative pressures were observed in the U-tubes for all but one condition. Positive pressures were observed when all gates* were fully opened. (See Table 9.) Hence, the vents operated to relieve vacuums behind the gates for all conditions except those mentioned. It was noted that the negative pressures obtaining in the transition with vents sealed kept the tunnel flowing full at low pool elevations.

Power Unit

62. General. The power unit specified in the basic design (Plate 3) was represented in the model schematically, inasmuch as it was not feasible to simulate the turbine with its attendant losses. (See Photograph 12.) A revision in the design of the draft tube, effected during the course of the study, was not made in the model. Calculations were corrected, however, to determine the gross head on the unit in its revised position. Investigation of the power unit comprised (a) observation of flow conditions at the mouth of the draft tube, and (b) determination of the gross head on the unit.

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*For description in this report, the gates are numbered from left to right of an observer facing downstream.

63. <u>Flow conditions</u>. Flow issuing from the draft tube had no appreciable effect upon flow in the tunnel.

64. <u>Gross head</u>. The gross head on the power unit was obtained with all gates open from measurements with piezometers located in the transition section adjacent to the draft tube. As the losses through the penstock and turbine could not be accurately determined, only the gross head on the unit was measured. (Gross head equaled pool elevation minus elevation in piezometer at end of draft tube.) These measurements indicated that the head exceeded 8-1/2 ft. for all rates of flow. (See Plate 15.)

Test Results - Conduit

Transition

65. <u>General</u>. The transition from the gates to the tunnel is to be approximately 70 ft. long, changing gradually from a rectangular section with a net area of 600 sq. ft. to a D-shaped section with an area of 379.8 sq. ft. The two division piers in the transition are to be of such shape as to provide for the gradual merging of flow from the three gates as it enters the tunnel proper. (See Plate 3.) The investigation of the transition consisted of observations of flow phenomena and measurements of pressures upon the surfacesof the confining walls.

66. <u>Flow conditions</u>. Observations of flow through the transition under various conditions revealed that the performance of this element of the outlet structures was generally satisfactory. (See Plates 16 and 17.) With any gate at full opening, flow filled the passage

directly below the gate, but started to drop away from the conduit crown when it reached the ends of the division piers. The operation of two adjacent gates induced a small eddy in the passage from the closed gate.

67. Pressures. A determination was made of the pressures to which the division piers and transition walls were subjected. Nine piezometers were located in the left sides of the division piers and in the right wall of the transition. As the critical area to be considered in the design of the division piers was near the downstream ends where the piers were of least width, the piezometers were located as close to the ends as possible. These piezometers were located 1.5 ft. from the ends of the piers at distances of 2.0, 10.0, and 18.0 ft. above the floor of the transition. Measurements of pressures were made for various gate combinations and discharges. (See Table 10.) The greatest negative pressure of -17.25 ft. of water was measured on a division pier with a pool elevation of 410 and with one outside gate open. This pressure rose gradually to zero as the pool fell in stage. The maximum positive pressure of 52.0 ft. of water was measured on the wall of the transition, with a pool elevation of 410 and with all gates open. As stated above (Paragraph 22) negative pressures produced in the model were subject to error.

Tunnel

68. General. The tunnel section of the conduit is to be 270.0 ft. long. It is to be D-shaped with an approximate diameter of 22.0 ft. and a cross-sectional area of 379.8 sq. ft. The tunnel was examined for performance under various conditions of pool elevation and gate operation. It was also examined for performance when provided

with air vents along its crown. The investigation of the tunnel consisted of observations of flow phenomena and measurements of pressures.

69. Flow conditions - three gates open. With three gates open, at high pool elevations the tunnel flowed full with no discernible disturbance. (See Plate 18.) At low pool elevations, flow from the three gates intermingled immediately below the division piers with some local disturbance, then swept through the tunnel with the water surface undulating through a series of stationary waves.

70. Flow conditions - two gates open. Inasmuch as the performances of Gates 1 and 3 were identical there were but two combinations of two opened gates to be investigated: (a) the inside and one outside gates, and (b) the two outside gates. No difference could be discerned in flow conditions in the tunnel with either combination of two gates open at high pool elevations, the tunnel flowing full with no disturbance. At such pool elevations as caused the tunnel to flow partially full, the discharges from two gates induced spiral flow action in the tunnel. The spiral action set up by two adjacent gates continued around the periphery of the tunnel until broken up by impact upon the tunnel floor. The spiral flow from each of the two outside gates, following counter directions, met mutual destruction at the crown of the tunnel.

71. Flow conditions - one gate open. The flow from one outside gate produced spiral action with attendant turbulence of considerable intensity, while flow from the inside gate proceeded through the tunnel with moderate disturbance.

72. <u>Flow conditions - partial gate opening.</u> The operation of gates at partial openings caused flow conditions in the tunnel which were nearly similar to conditions set up by operation of gates at corresponding full openings. The only difference noted was a tendency for the slightly higher velocities resulting from partial gate openings to increase the turbulence in flow.

73. <u>Pressures.</u> When the tunnel flowed full, the pressure grade line dropped below the crown of the tunnel, thereby indicating the existence of negative pressures. (See Plates 19 and 20, and Table 11.) Air vents placed in the crown of the tunnel removed the negative pressures, but caused fluctuation between full and partial flow. The pressure grade line was raised above the tunnel crown by reducing the area of the tunnel exit by 53.75 sq. ft. However, this expedient caused a decrease in discharge: from 17,700 c.f.s. to 14,500 c.f.s. for a pool elevation at spillway crest; and from 10,000 c.f.s. to 8,800 c.f.s. for a pool elevation of 368.5.

74. <u>Critical pool elevation.</u> The manner of approaching the critical reservoir stage for full tunnel flow determined its position. Such may be perceived from an inspection of the following table, and may be understood from a consideration of the negative pressure operating to maintain the tunnel at full flow on falling stages.

<u>Table 1</u>

<u>Critical Reservoir Stages for Full Flow in Tunnel</u>

Stage	All Gates Open	Gates 1 and 3 Open	Gates 1 and 2 Open
Falling	359	362	365
Rising	366	370	370

When Gates 1 and 2 were discharging under a falling head the transition from full to partial tunnel flow was brought about quickly, because the vacuum was relieved by air drawn through Gate 2. A complete filling of the tunnel was never attained with the full opening of one gate or the three-quarter opening of gates in any combinations.

75. Discharge of 10,000 c.f.s. A discharge of 10,000 c.f.s., with all gates open and on a falling stage, filled the tunnel throughout its length, while the same discharge on a rising stage caused the tunnel to flow less than full in the lower 100-ft. portion. If the latter condition were maintained for an appreciable time the reservoir would slowly increase about 2.5 ft. in stage, thereby causing the tunnel to fill completely. As soon as the tunnel filled the reservoir level would fall slightly, but the tunnel would remain full. This phenomenon demonstrated that the point of filling for the tunnel was reached at a discharge of 10,000 c.f.s., and substantiated indications of the existence of negative pressures in the tunnel.

Test Results - Gate Operation

Methods of Adjustment

76. General. The plan for the control of the reservoir contemplates maintenance of the normal pool by means of the conservation-pool weir. For these normal conditions the gates of the control structure will remain fully opened. When flood flows cause the discharge through the outlet structures to reach 10,000 c.f.s., it is planned to operate the control gates in such manner as to maintain that discharge until the reservoir returns to normal conditions. An investigation

was made on the model to study various methods of gate operation and to determine the adjustments required for a controlled flow of 10,000 c.f.s.

77. Best practice. Information as to operation of the control gates was obtained by manipulating the model gates and observing the resulting flow phenomena. Best practice was in accord with the following procedure:

a. Gates should be closed slowly and symmetrically. Rapid closure of the gates caused a slug of air to be entrapped in the tunnel; the release of this slug at the tunnel portal was attended by violent flow disturbance.

b. Gates should be set so as to provide symmetry of flow. Turbulence was kept at a minimum by operating Gates 1 and 3 when two gates were required, and by adjusting gates to equal openings when partial settings were required.

c. Gates should be operated at full openings in preference to partial openings. Partial gate openings produced free jets which impinged upon the walls of the transition. However, no advantage derived from the use of one fully opened gate instead of two partially opened gates; for turbulence created by the former equalled in disturbance the jet action of the latter.

d. Gates should be operated in the combinations presented in Table 2 for least flow disturbance.

Table 2

Schedule for Gate Operation

Requirements	Gates Open
Discharge of 1 full gate or less	Gate 2 (full) or Gates 1 and 3 (partial)
Discharge of 2 full gates	Gates 1 and 3
Discharge of 3 full gates	Gates 1, 2, and 3

78. Controlled flow of 10,000 c.f.s. The gate adjustments required for the maintenance of a controlled flow of 10,000 c.f.s. at various pool elevations are presented in Table 3. Where several alternate adjustments are possible, they are listed in order of preference for best flow conditions.

Table 3

Gate Adjustment for a Controlled Discharge of 10,000 c.f.s.

Pool Elevation	Preference	Gate Opening in Feet: Gate 1	Gate 2	Gate 3
410.0	a	7.25	7.25	7.25
	b	--	19.00	--
	c	11.00	11.00	--
400.0	a	7.75	7.75	7.75
	b	--	20.00	--
	c	12.00	--	12.00
	d	12.00	12.00	--
395.0	a	8.50	8.50	8.50
	b	12.50	--	12.50
	c	12.50	12.50	--
	d	2.00	20.00	--
390.0	a	9.00	9.00	9.00
	b	13.00	--	13.00
	c	13.00	13.00	--
	d	4.00	20.00	--
380.0	a	10.50	10.50	10.50
	b	15.00	--	15.00
	c	15.00	15.00	--
	d	8.00	20.00	--
370.0	a	20.00	--	20.00
	b	20.00	20.00	--
367.5	c	20.00	20.00	20.00

Test Results - Stilling Basin

Stilling Basin of Basic Design - Type A

79. General. The stilling basin for the outlet works is to be of the jump-action type. The essential elements of the basin are to be (a) an apron shaped to a trajectory curve, (b) a horizontal apron, (c) two rows of stepped baffle piers, (d) a stepped sill, and (e) flared spray and wing walls. (See Plate 22.) The curved apron is to exert pressure on the bottom of the jet issuing from the tunnel, thereby causing this jet to spread. The horizontal apron is to be so located as to insure the formation of the hydraulic jump within the stilling basin at maximum discharge conditions with pool elevation at spillway crest level. The function of the baffle piers is to assist the formation of the hydraulic jump, while the purpose of the sill is to deflect bottom currents upward into the tailwater. The model investigation of the stilling basin of basic design consisted of (a) determinations of the extent of scour, (b) determination of the distribution of velocities, and (c) observations of flow conditions.

80. Scour. Scour tests were conducted at discharges of 19,700, 17,000, 14,550, 10,000, and 4,980 c.f.s. with the tailwater depths corresponding thereto. (See Plate 21.) The results of these tests were characterized by a marked tendency for the bed to be eroded along the bases of the flared wing walls. (See Plates 23, 25, 27, 29, and 31.) The scour produced by a discharge of 19,700 c.f.s. appeared excessive.

81. Velocities. Velocity tests were conducted under the conditions of discharge and tailwater enumerated in Paragraph 80. The results of these tests showed that bottom velocities did not exceed 7 ft. per sec. except during a discharge of 19,700 c.f.s. (See Plates 24, 26, 28, and 30.) Bottom velocities at a discharge of 19,700 c.f.s. reached 12 ft. per sec. Velocity distribution was such as to cause the erosion along the wing walls noted in the scour tests. (See Plate 95.)

82. Flow conditions. The flow conditions in the stilling basin and in the exit channel were investigated at the discharges enumerated in Paragraph 80; the tailwater depth was varied in certain tests in order to determine the characteristics of the hydraulic jump. The results of the investigations revealed that the hydraulic jump was partially submerged to varying degrees for all rates of flow, and appeared to be completed at or near the first row of baffles. (See Plates 32 to 34, and Photographs 36 to 44.) Conditions during a discharge of 19,700 c.f.s. constituted an exception to the above findings. In this case, the tunnel exit portal was submerged by the tailwater, causing the jet from the tunnel to set up a boiling action in the stilling basin. Partial flow through the tunnel, accompanied by tailwater depths above the tunnel crown, caused a jump to form in the tunnel; this condition created great disturbance within the tunnel structure. The jet issuing from the tunnel splashed against the spray walls at discharges in excess of 7500 c.f.s. (See Photograph 54.) The splash rose higher and moved downstream as the discharge increased, reaching a maximum height of 4 ft. at a discharge of 17,000 c.f.s..

Under no conditions did this splash overtop the spray walls. The spray walls were not overtopped by the tailwater until the discharge exceeded 17,000 c.f.s. Eddies existed at the wing walls for all rates of flow. (See Photograph 45.) These eddies attained great proportions at a discharge of 20,000 c.f.s. as they swept back over the stilling-basin berms with velocities as high as 17 ft. per sec.

Components of the Stilling Basin

83. General. Upon the completion of a thorough investigation of the stilling basin of basic design, tests were conducted to determine (a) the best design for the structural elements of the basin, and (b) the most effective and economical arrangement of these elements assuring satisfactory stilling action. Tests were conducted on each alteration of an element of the basin. Thus there existed at all times a previous test with which to compare results, and thereby arrive at a conclusion as to the performance of the item under consideration. Inasmuch as over thirty alterations were tested in a sequence best suited to the experimental routine, no attempt will be made to describe each arrangement in this report. Instead the detailed record is presented in tabular form (Tables 12 and 13), while the discussion deals with the elements in such manner as to bring out the essence of the results of tests conducted thereon.

84. Horizontal apron.

a. Length. Mid-channel scour with the basin of basic design at discharges of 10,000 and 17,000 c.f.s. was of such slight extent as to indicate the feasibility of shortening the horizontal apron. Hence investigation was made of progressive reductions in apron length. The results of this investigation indicated that the horizontal apron could be shortened from the length of 104 ft. called for in the basic design to 73 ft., with no increase in scour (compare Plates 35 and 25, and Plates 36 and 29) and only a moderate increase in velocities over the end sill from a maximum of 4 ft. per sec. to 10 ft. per sec. (Velocities over the end sill were used as an index of basin action in preliminary tests; bottom velocities in the exit channel were always much lower.) The 73-ft. apron was incorporated in the basin design designated Type R. (See Paragraph 89.) The greater stilling effect produced during the course of the model study by efficacious spacing and locating of baffle piers rendered additional shortening of the horizontal apron possible. Thus for the basin design designated Type DD the apron was 53 ft. in length. (See Paragraph 94.) In order to attain satisfactory stilling action with a shortened curved apron, it was found necessary to extend the horizontal apron 15 ft. Thus for the basin design designated Type GG the horizontal apron was 68 ft. long. (See Paragraph 99.)

b. Elevation. Inasmuch as the elevation of the horizontal apron was fixed by conditions of the river channel and the conformation of the rock underlying the site, no study was made with the apron raised or lowered from its original location.

85. Curved apron.

a. Curvature of the apron. The action in a stilling basin is controlled by such interrelated factors as flare of spray walls, inclination of the curved apron, elevation of the horizontal apron, width of the basin, and elevation of the tailwater. Hence, an investigation as to the feasibility of shortening the curved apron in the case at hand was preceded by consideration of the theoretical aspects of such an alteration. The basin was basically designed so as to cause the theoretical depth after jump (D_2)* for a discharge of 17,000 c.f.s. to intersect the tailwater elevation above the intersection of the curved and horizontal aprons. (See Diagram A on Plate 79.) Steepening of the curved apron would create a demand for higher tailwater or a lower elevation of the horizontal apron. (See Diagram B on Plate 79.) Observations of basin action in the model revealed that (1) a good hydraulic jump occurred

*King, H. W., "Handbook of Hydraulics," page 336.

at tailwater depths considerably below the natural depths (3.5 ft. at 17,000 c.f.s.), and (2) that dangerous spray action occurred only after further reduction in tailwater depth. (See Plate 21.) Consideration of the above factors led to the tentative selection of an apron which followed the curve of $X^2 = 500.33Y$, and which theoretically required a lowering of the horizontal apron of 3.5 ft. (See Diagram B on Plate 79.) The results of tests conducted with this apron of steepened curvature showed no undesirable conditions to follow from the alteration. It was therefore incorporated in the basin design designated Type GG. (See Paragraph 99.)

b. Steps in the apron. An investigation was conducted to determine whether or not V-shaped steps (Plate 80) in the curved apron would aid in spreading the flow laterally and contribute to the dissipation of kinetic energy by offering increased resistance to flow. The resultsof scour tests indicated that the steps had practically no effect on conditions in the exit channel. (Compare Plates 96 and 83, and 98 and 87.) A study of flow conditions revealed no tendency of the steps to cause a spreading of flow.*

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*The ineffectiveness of steps in the curved apron of the Wappapello stilling basin is believed to be ascribed to unusually high tailwater. Only a few of the upper steps came into action before the free jet entered the tailwater.

86. Wing walls. As stated above (Paragraph 80), a marked tendency for scour along the wing walls was revealed in the tests of the basin of basic design. Effort was made to reduce this scouring tendency by alterations in the alignment of the wing walls. No improvement was effected with wing walls located at right angles to the spray walls. (Compare Plates 40 and 25.) On the other hand, the tendency for scour was greatly reduced by providing a curved transition (Plate 50) from spray to wing walls. (Compare Plates 41 and 36.)

87. Baffle piers.

a. Spacing. The basic design called for baffle piers 4 ft. wide spaced at 5-ft. intervals. This arrangement provided clear space in the staggered rows of piers through which jets passed unhindered. Reduction in extent of scour was obtained by decreasing the spacing to 4 ft. (Compare Plates 42 and 43.) In addition, velocities over the end sill were reduced from 9 ft. per sec. to 6 ft. per sec.

b. Height. The basic design called for baffle piers 8 ft. high. The results of scour tests of piers 4 ft. high and 6 ft. high (Plate 46) revealed that (1) 4-ft. piers were not as effective as 8-ft. piers (compare Plates 42 and 44); and (2) that 6-ft. piers were equally as effective as 8-ft. piers (compare Plates 57 and 42).

c. Type. Tests were conducted upon baffle piers with vertical, stepped, and sloped faces. (See Plate 46.) The results of these tests indicated that the piers with vertical and stepped faces were practically alike in action, and were slightly superior in action to the piers with sloped faces. (See Plates 47 to 49.)

d. Position. With the curved apron of basic design, the position of the baffle piers produced little effect on scouring tendencies. However, observation tests appeared to indicate that the piers produced best results when located in rows at Stations 29+86 and 30+02. In this location the piers were far enough downstream to be cushioned from excessive impact and yet assist in the creation of the jump at a discharge of 17,000 c.f.s. At a discharge of 10,000 c.f.s., the piers contributed little to the creation of the jump. The full effect of the piers appeared to develop with an interval of 10 ft. between rows. (Compare Plates 69 and 78.) With the curved apron as called for in Type GG design (see Paragraph 99) it was found necessary to move the piers an additional 15 ft. downstream from the toe of the curved apron to obtain the most effective action throughout the range of discharges investigated. A scour test conducted without baffle piers clearly indicated the need for such structures. (Compare Plates 45 and 25.)

88. Sill. The basic design called for a 3-ft. stepped sill on the end of the horizontal apron. (See Plate 3.) The results of scour tests conducted upon stepped sills 4.5 and 6 ft. high revealed that the 3 ft. sill of basic design was the most effective. (Compare Plates 36, 37, and 38.) A test conducted without a sill indicated the need for one. (Compare Plates 39 and 45.)

Stilling Basin of Alternate Design - Type R

89. General. A stilling basin design designated Type R was developed by effecting such improvements in the basic design as were suggested by the tests of the basin elements. (See Plate 50.) The basin of alternate design was subjected to tests similar to those conducted upon the basin of basic design.

90. Scour. Scour tests were conducted at discharges of 19,420, 17,150, 14,500, 10,000, and 5,000 c.f.s. with the tailwater depths corresponding thereto. The results of the tests indicated no tendencies for erosive attack on the bottom of the outlet channel except during a discharge of 19,420 c.f.s. (See Plates 51, 53, 55, 57, and 59.) As in the case of the basic design, a discharge of 20,000 c.f.s. caused excessive scour. In order to determine whether or not high-head discharge caused increased scour, a test was conducted with the pool elevation at spillway crest. No appreciable increase was noted. (Compare Plates 53 and 60.)

91. Velocities. Velocity tests were conducted under discharge and tailwater conditions enumerated in Paragraph 90. The results of the tests showed that bottom velocities did not exceed 5 ft. per sec. for discharges up to 17,000 c.f.s. (See Plates 52, 54, 56 and 58.) Measurements of velocities in transverse sections indicated good distribution of flow. (See Plate 95.)

92. Pressures. An examination was made of pressures on the surfaces of center and outside baffle piers in the first row. (See Plate 61.) This examination was conducted at various rates of flow with corresponding tailwater depths. The results of the tests indicated that positive pressures obtained under all conditions. The maximum pressures were sustained by the risers of the second steps in the piers.

93. Flow conditions. Observation tests revealed flow conditions in the stilling basin to be substantially the same as in the basin of basic design. (See Paragraph 82.)

Stilling Basin of Alternate Design - Type DD

94. General. In order to determine whether or not the basin design designated Type R provided the required performance with minimum dimensions of the structural elements, an investigation was made of a basin identical with Type R in all essentials except length of the horizontal apron. It was found that satisfactory basin action continued to prevail with the apron shortened 20 ft. The design incorporating this shortened apron was designated Type DD. (See Plate 62.) The basin of such design was subjected to tests similar to those conducted upon the Type R basin.

95. Scour. Scour tests were conducted at discharges of 19,620, 17,000, 14,500, 10,000, and 5,000 c.f.s. with the tailwater depths corresponding thereto. The results of the tests demonstrated stilling action for the Type DD basin to be virtually as effective as the action in the Type R basin. (Compare Plates 51 to 59 with Plates 63 to 71.) In order to determine whether or not high-head discharges caused increased scour, a test was conducted with the pool elevation at spillway crest. No appreciable increase was noted. (Compare Plates 65 and 77.)

96. Velocities. Velocity tests were conducted under discharge and tailwater conditions enumerated in Paragraph 95. The results of the tests showed that bottom velocities did not exceed 8 ft. per sec. for discharges up to 17,000 c.f.s. (See Plates 64, 66, 68, and 70.) Velocity distribution was satisfactory. (See Plate 95.)

97. Pressures. As in the investigation of the Type R basin (Paragraph 92), an examination was made of pressures on the surfaces of the baffle piers. This examination indicated that positive pressures obtained, and that the maximum pressures were sustained by the risers of the second steps in the piers. (See Plate 72.) Measurements of pressures on the surface of the horizontal apron revealed little or no reduction of pressure over that due to ordinary tailwater depths. (See Plate 73.)

98. Flow conditions. Observation tests revealed flow conditions in the stilling basin to be substantially the same as those in the basin of basic design. (See Paragraph 82, Plates 74 to 76, and

Photographs 46 to 52.)

<u>Stilling Basin of Alternate Design - Type GG</u>

99. <u>General</u>. Consideration of the possibilities of effecting additional reduction in the dimensions of the stilling basin resulted in the selection of the basin design designated Type GG. (See Plate 80.) The design differed from Type DD only in that it included a curved apron following a sharper trajectory, and a horizontal apron increased in length by 15 ft. (See Paragraph 84.) The sharper trajectory automatically effected a 28.5-ft. reduction in the length of the curved apron. Thus, a 13.5-ft. net reduction in the overall length of the stilling basin was effected. The basin of this alternate design was subjected to tests similar to those conducted on the basin of basic design.

100. <u>Scour</u>. Scour tests were conducted at discharges of 19,550, 17,000, 14,550, 10,000, and 5,000 c.f.s. with the tailwater depths corresponding thereto. The results of the tests revealed that erosion at discharges of 5,000 c.f.s. and 10,000 c.f.s. slightly exceeded that occurring at comparable discharges in the Type DD basin. (Compare Plates 81 and 83 with Plates 63 and 65.) On the other hand, at discharges of 14,500 and 17,000 c.f.s. the scour was less than that occurring in the Type DD basin. (Compare Plates 85 and 87 with Plates 67 and 69.) Asin the case of the basic design, a discharge of 20,000 c.f.s. caused excessive scour. No appreciable increase in scour resulted from high-head operation with pool at spillway crest elevation. (Compare Plates 90 and 83.)

101. Velocities. Velocity tests were conducted under the discharge and tailwater conditions enumerated in Paragraph 100. The results of the tests showed that bottom velocities did not exceed 7.5 ft. per sec. for discharges up to 17,000 c.f.s. (See Plates 82, 84, 86, and 88.) The velocity distribution was satisfactory. (See Plate 95.)

102. Pressures. As in the investigation of the Type R basin, (Paragraph 92) an examination was made of pressures on the surfaces of the baffle piers. This examination indicated that positive pressures obtained, and that the maximum pressures were sustained by the risers of the second steps in the piers. (See Plate 91.) Pressures on the curved apron were positive and were not appreciably reduced under any conditions of flow investigated. (Compare Plates 92 to 94 with Plates 19 and 20.) Pressures on the horizontal apron were substantially the same as those obtaining in the Type DD basin. (See Paragraph 97.)

103. Flow conditions. Observation tests revealed flow conditions in the stilling basin to be substantially the same as in the basin of basic design. (See Paragraph 82 and Plates 92 to 94.) The steepened trajectory of the curved apron produced no discernible differences in flow phenomena. (See Photographs 55 to 62 and Plates 92 to 94.) The locus of the hydraulic jump and the characteristics of the jump action, as influenced by tailwater depth, are shown in Table 14.

Outline of Tests

104. Tabulation. The most important features discussed in the preceding paragraphs are outlined in the tabulation which follows:

Outline of Tests

Component of Outlet Structures Investigated	Purpose of Tests	Test Procedure	Results	Reference
Approach Channel	Study of flow conditions and velocities upstream from intake tower.	Flow conditions observed and velocities measured with Pitot and Bentzel tubes.	Flow conditions satisfactory for all discharges. Velocity of 5.3 ft. per sec. at upstream edge of concrete channel. Discharge = 10,000 c.f.s. Weir in place and sluices open, velocities of 6.0 ft. per sec. recorded.	Paragraphs 37 - 40 Photographs 23 - 24
Conservation-pool weir	Study of flow conditions, water surface, and pressure profiles. Determination of best position of weir in approach channel.	Flow conditions observed, water-surface profiles measured with a point gage, and pressures with piezometers installed in crest. Position of weir determined from observations.	Weir effect confined to flows of 10,000 c.f.s. and below. Jump submerged below flows of 7,500 c.f.s. Surface free of negative pressure. Best location as in basic plans. Removal of automatic steel gates had no effect except for flows below 1,000 c.f.s. Alternates proposed for weir not effective.	Paragraphs 41 - 51 Plates 5 - 10 Photographs 5 and 6, 25, 27, 28 - 35.
Trash Racks	Study of effect of racks on debris.	Effect of racks observed and recorded by means of photographs.	No effect of racks on clear water flow. Practically no effect on pool elevation - discharge relation. Racks prevented drift from entering gate passages.	Paragraphs 52 - 54 Plate 10 Photographs 4,19,20-22.

Outline of Tests

Component of Outlet Structures Investigated	Purpose of Tests	Test Procedure	Results	Reference
Piers and Curved Throat Sections	Study of flow conditions and pressures.	Flow conditions observed and pressures measured by means of piezometers.	Flow past pier noses and through intake tower satisfactory. Pressures were all positive	Paragraphs 55 - 57 Tables 4 - 8
Gates	To rate the gates and determine schedule of gate operation for controlled flow.	Pool elevation and discharge measured by standard methods. Gate operation determined by observation of flow.	Model and computed discharge curves in close agreement. Schedule for gate operation to maintain discharge of 10,000 c.f.s. determined.	Paragraphs 58-59 76-78 Plates 10-14 Tables 2 and 3
Air Vents	Study of vacuums relieved by vents.	Vents sealed and pressures measured by means of U-tubes.	Venting of gates necessary to relieve negative pressures below gates.	Paragraphs 60 - 61 Table 9 Photograph 16
Power Unit	Study of flow conditions at mouth of draft tube. Determination of gross head on unit.	Flow conditions observed and gross head measured with piezometers.	No effect on tunnel flow. Gross head on unit always exceeded 8-1/2 feet.	Paragraphs 62 - 64 Plate 15 Photograph 12

Outline of Tests

Component of Outlet Structures Investigated	Purpose of Tests	Test Procedure	Results	Reference
Transition Section	Study of flow conditions and pressures on ends of division piers.	Flow conditions observed and recorded by means of photographs. Pressures measured with piezometers.	Flow conditions generally satisfactory. Negative pressure on end of division pier for one gate open.	Paragraphs 65 - 67 Plates 16 and 17 Table 10
Tunnel	Study of flow conditions for various gate combinations. Pressures and point of filling determined.	Flow conditions observed and recorded by means of photographs. Pressures measured with piezometers.	Flow conditions generally satisfactory. Pressures in downstream portion of tunnel negative for full tunnel flow. Point of filling at a discharge of 10,000 c.f.s. with all gates open.	Paragraphs 68 - 75 Plates 18-20 Tables 1 and 11
Stilling Basin.	Design of satisfactory basin.	Scour measurements were taken. Bottom velocities obtained with a pitot tube.	Basin designed so that practically no scour and low bottom velocities obtained when basin subjected to flows of 17,000 c.f.s. or below. A discharge of 20,000 c.f.s. was unsafe for any type of basin investigated.	Paragraphs 79 - 103 Plates 21-99 Tables 12-14 Photographs 36 - 63

PART IV - SUMMARY AND CONCLUSIONS

Performance, Adequacy of Design, Etc.

105. There follows a summary of the tests of the outlet structures, together with conclusions to be drawn from these tests:

a. Approach channel. (See Paragraphs 37 to 40.) Flow conditions in the approach channel of basic design were satisfactory. Bottom currents in the channel upstream from the conservation-pool weir were of negligible velocity under normal operating conditions with the sluices through the weir closed. With all sluices open and the pool at weir crest, the bottom currents did not exceed a velocity of 6 ft. per sec.; such currents could have no destructive action upon the rip-rapped channel. Pool stages which slightly submerged the side retaining walls caused these walls to act as submerged weirs. Inasmuch as the crests of the walls were 2 ft. above the rip-rapped berms in their rear, the submerged-weir action could have no destructive effects on these berms.

b. Conservation-pool weir. (See Paragraph 41 to 47.) The conservation-pool weir operated most satisfactorily when located in the position called for in the basic design. In this location flow conditions were satisfactory for all discharges. No effect of the dip below the weir was detected other than a tendency for this depression to deflect the bottom currents more sharply upward. The study of the hydraulic performance of the weir with the automatic sluice gates removed did not reveal any change in the flow approaching the intake structure compared to flow which obtained with the gates in place. Whether or not the removal of the gates would subject the weir structure to destructive forces was not determinable from the model results. Tendencies for cavitation were observed under the intersections of the crowns of sluices and the surface of the ogee. This condition makes necessary a system of vents to supply air to the affected regions in the event that the automatic sluice gates are removed.

c. <u>Alternates for the conservation-pool weir</u>. (See Paragraphs 48 to 51.) While results of tests on alternates for the conservation-pool weir indicated that barriers located in or near the intake tower would (with the exception of Alternate A) operate satisfactorily in maintaining the conservation pool, these results also demonstrated that such barriers would cause increased turbulence in the gate passages. In the model, this turbulence produced no measurable reactions. However, viewed in the light of the fact that the energy scale is equal to the fourth power of the linear scale, this condition is seen to have major prototype potentialities. In this connection it is to be remembered that previous tests of the conservation-pool weir demonstrated that any obstruction must be at least 90 ft. upstream to provide tranquil approach to the intake works. Therefore, it is concluded that any subsititute for the conservation-pool weir located in or near the intake tower will operate to the disadvantage of approach conditions which, with the conservation-pool weir in place, are satisfactory.

d. <u>Intake structures</u>. (See Paragraphs 52 to 64.) The hydraulic performance of the intake structure was satisfactory under all conditions of operation. Pressures were positive throughout the structure. Data as to the performance of certain elements of the intake structure are presented below:

(1) <u>Trash racks</u>. Flow passed the bars of the trash racks smoothly with no discernible turbulence. The racks had slight effect on the capacity of the outlet works. The racks operated as intended, preventing drift from entering the gate passages. The omission of the trash racks enabled debris to pass through the conduit. No undesirable conditions attended this passage of debris.

(2) <u>Air vents</u>. The air vents operated to relieve vacuums behind the control gates for all conditions except full openings of all gates. Hence, the vents perform a necessary function at all partial gate settings and during all gate opening and closing operations.

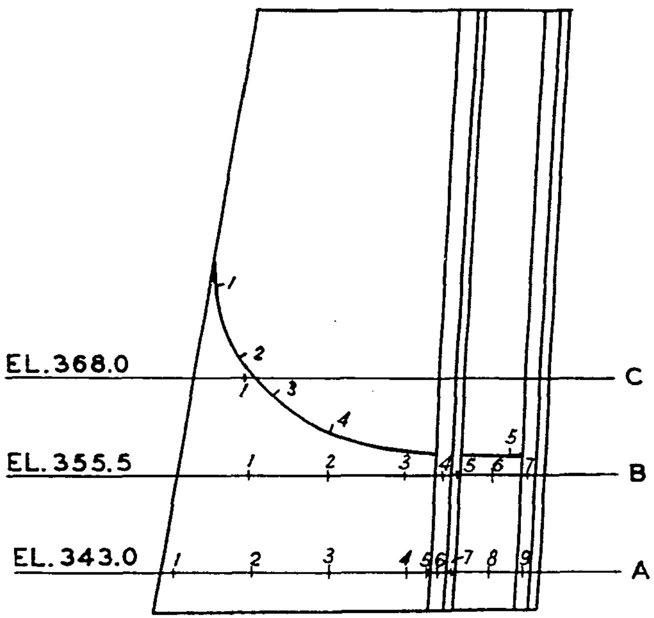
(3) <u>Power unit</u>. The operation of the power unit had no deleterious effect upon the performance of the outlet works. The operating head on the unit exceeded 8-1/2 ft. at all conditions of flow.

TABLES

TABLE 4

MODEL STUDY OF WAPPAPELLO DAM-OUTLET STRUCTURES

PRESSURE READINGS ····· INTAKE STRUCTURE
ONE INSIDE GATE OPEN ····· Q = 10,000 C.F.S.



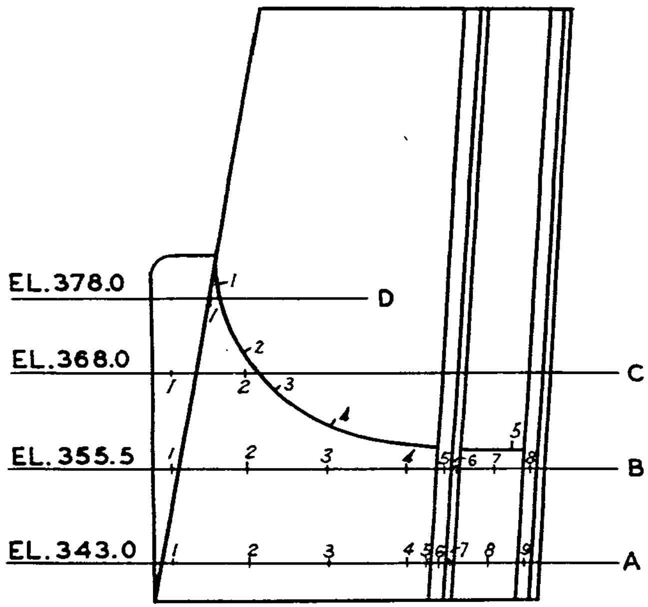
SKETCH OF INSIDE PIER
SHOWING
LOCATION OF GAGES

LEVEL	GAGE NO.	INSIDE PIER
A	1	392.50
	2	394.00
	3	384.25
	4	371.50
	5	365.75
	6	365.25
	7	369.75
	8	361.00
	9	357.00
B	1	395.00
	2	383.75
	3	366.00
	4	—
	5	363.00
	6	357.00
	7	357.75
C	1	398.25
CURVED THROAT	1	401.25
	2	396.50
	3	388.50
	4	369.00
	5	358.50

TABLE 5

MODEL STUDY OF WAPPAPELLO DAM—OUTLET STRUCTURES

PRESSURE READINGS ..... INTAKE STRUCTURE
ONE OUTSIDE GATE OPEN ..... Q = 10,000 C.F.S.



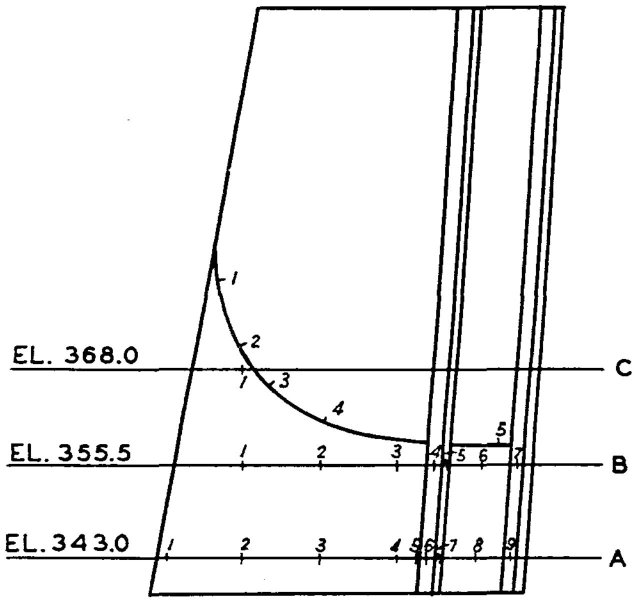
SKETCH OF PIERS
SHOWING
LOCATION OF GAGES

LEVEL	GAGE NO.	OUTSIDE PIER	INSIDE PIER
A	1	399.25	390.00
	2	393.00	393.50
	3	383.00	364.25
	4	370.50	369.00
	5	365.00	363.75
	6	364.25	363.50
	7	368.00	365.75
	8	362.50	360.00
	9	358.00	357.00
B	1	399.25	392.50
	2	394.00	379.50
	3	381.00	362.25
	4	368.00	363.00
	5	363.00	364.75
	6	363.75	356.75
	7	355.50	357.00
	8	358.00	
C	1	400.00	397.00
	2	397.00	—
D	1	401.00	—
CURVED THROAT	1	395.00	395.00
	2	391.00	391.00
	3	383.50	383.50
	4	365.75	365.75
	5	361.25	361.25

TABLE 6

MODEL STUDY OF WAPPAPELLO DAM-OUTLET STRUCTURES

PRESSURE READINGS THROUGHOUT THE INTAKE STRUCTURE ALL GATES OPEN



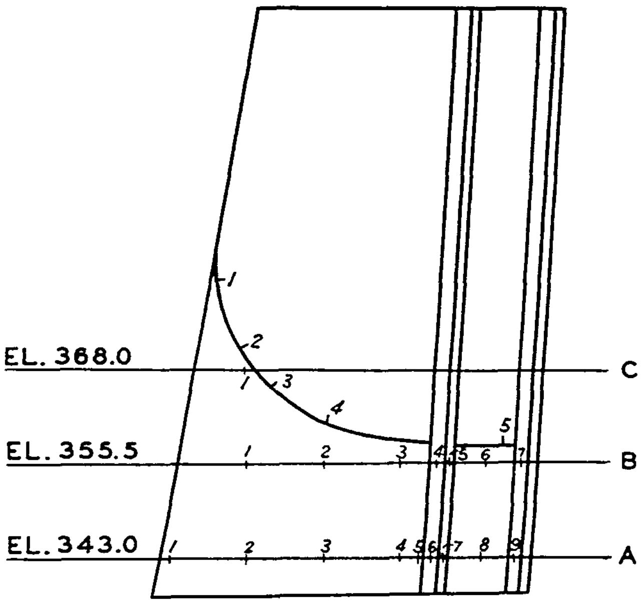
SKETCH OF INTERIOR PIER
(INTERIOR SIDE)
SHOWING
LOCATION OF GAGES

LEVEL	GAGE NO.	DISCHARGE			
		17,000 C.f.S.	14,500 C.f.S.	10,000 C.f.S.	7,500 C.f.S.
A	1	389.50	380.00	366.75	361.75
	2	389.00	379.50	366.50	361.75
	3	386.00	376.75	365.00	360.50
	4	381.25	374.00	364.25	360.50
	5	379.75	372.50	363.50	360.00
	6	379.50	372.50	363.50	360.00
	7	381.50	373.75	363.00	359.50
	8	378.25	372.00	363.25	360.00
	9	377.25	371.00	363.00	360.00
B	1	389.25	380.00	367.00	361.75
	2	385.50	377.00	366.00	361.25
	3	379.25	372.50	363.75	360.50
	4	—	—	—	—
	5	380.00	373.25	364.00	360.50
	6	376.25	370.50	363.00	360.00
	7	377.25	371.00	359.50	360.25
C	1	390.25	381.00	—	—
CURVED THROAT	1	391.25	—	—	—
	2	389.25	382.00	—	—
	3	386.00	378.50	367.00	—
	4	380.00	373.75	365.25	—
	5	377.00	372.25	362.50	359.75

TABLE 7

MODEL STUDY OF WAPPAPELLO DAM-OUTLET STRUCTURES

PRESSURE READINGS THROUGHOUT THE INTAKE STRUCTURE
ALL GATES OPEN



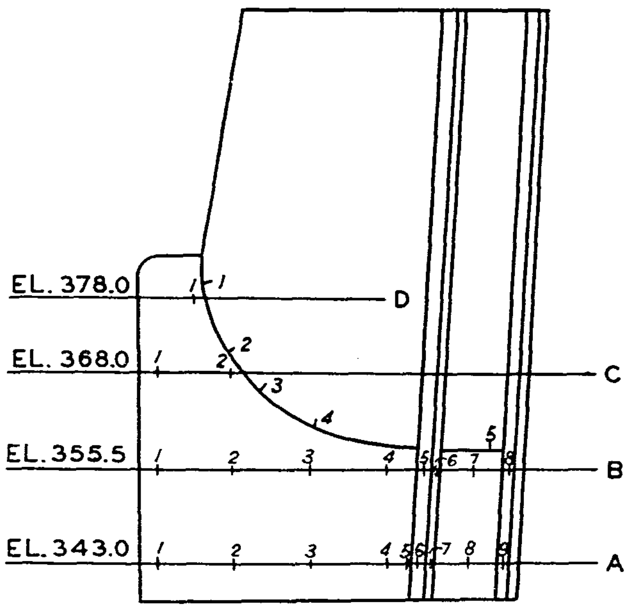
SKETCH OF INTERIOR PIER
(EXTERIOR SIDE)
SHOWING
LOCATION OF GAGES

LEVEL	GAGE NO.	DISCHARGE			
		17,000 C.F.S.	14,500 C.F.S.	10,000 C.F.S.	7,500 C.F.S.
A	1	390.25	380.50	367.00	362.00
	2	389.25	379.50	366.75	361.75
	3	388.50	377.00	366.25	361.50
	4	381.25	374.00	364.25	360.50
	5	379.75	372.75	363.75	360.25
	6	379.50	372.75	363.75	360.25
	7	380.75	373.00	363.75	360.25
	8	378.75	372.25	363.50	360.00
	9	377.50	371.50	363.50	360.00
B	1	389.25	380.00	367.00	361.75
	2	384.75	376.75	366.00	361.25
	3	379.25	372.50	363.75	360.50
	4	379.25	372.50	363.75	360.25
	5	381.00	373.25	364.25	361.00
	6	375.75	371.25	363.25	360.00
	7	377.50	371.25	363.50	360.00
C	1	390.50	381.00	—	—
CURVED THROAT	1	391.00	381.25	—	—
	2	389.25	380.25	—	—
	3	386.50	377.75	367.25	—
	4	380.25	373.25	364.50	—
	5	378.25	370.75	363.25	360.00

TABLE 8

MODEL STUDY OF WAPPAPELLO DAM-OUTLET STRUCTURES

PRESSURE READINGS THROUGHOUT THE INTAKE STRUCTURE
ALL GATES OPEN



SKETCH OF OUTSIDE PIERS
SHOWING
LOCATION OF GAGES

LEVEL	GAGE NO.	DISCHARGE			
		17,000 C.F.S.	14,500 C.F.S.	10,000 C.F.S.	7,500 C.F.S.
A	1	390.25	380.25	367.00	361.75
	2	388.75	379.25	366.50	361.50
	3	385.50	377.00	365.50	361.25
	4	381.25	374.00	364.25	360.50
	5	379.75	373.00	363.50	360.25
	6	379.75	373.00	363.50	360.25
	7	382.50	373.75	364.00	360.50
	8	379.00	372.25	363.25	360.00
	9	378.25	371.50	363.00	360.00
B	1	390.75	380.75	367.00	362.00
	2	389.00	379.75	366.75	361.75
	3	384.25	376.50	365.75	361.50
	4	380.00	373.25	364.00	360.75
	5	379.00	372.25	363.50	360.25
	6	380.75	373.50	364.00	360.50
	7	377.50	371.00	362.75	360.00
	8	377.50	371.25	363.25	360.00
C	1	391.00	380.75	—	—
	2	390.50	380.75	—	—
D	1	391.50	381.00	—	—
CURVED THROAT	1	391.00	381.25	—	—
	2	389.25	380.25	—	—
	3	386.50	377.75	367.25	—
	4	380.25	373.25	364.50	—
	5	378.25	370.75	363.25	360.00

Table 9

Model Study of Wappapello Dam - Outlet Structures

Study of Effect of Air Vents

Pool Elevation	Gate No. 1 Open			Gate No. 2 Open		Gates No. 1 and 2 Open			Gates No. 1 and 3 Open		Gates No. 1, 2, and 3 Open	
	Vent 1	Vent 2	Vent 3	Vents 1 & 3	Vent 2	Vent 1	Vent 2	Vent 3	Vents 1 & 3	Vent 2	Vents 1 & 3	Vent 2
Full Gate Openings												
410.0	0.0	0.0	0.0	0.0	0.0	7.0	-2.0	7.2	6.5	—	29.7	25.5
400.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	5.0	3.0	9.0	22.5	20.2
395.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	5.0	2.0	7.0	19.5	18.2
390.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	3.0	1.5	5.0	15.0	15.5
380.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	2.0	1.0	3.5	0.0	10.0
370.0	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	1.2	0.0	1.5	0.0	4.7
Three-Quarter Gate Openings												
410.0	-44.0*	-28.5	-26.5	-33.0	-35.0*	-28.5	-32.5	-17.0	-27.0	-23.0	0.0	0.0
400.0	-38.0*	-28.0	-26.0	-30.0	-27.7	-25.0	-28.5	-16.0	-24.0	-19.0	0.0	0.0
395.0	-32.0	-27.0	-24.0	-25.0	-25.0	-23.0	-26.5	-14.2	-21.0	-17.5	0.0	0.0
390.0	-26.0	-21.0	-20.0	-20.0	-22.0	-19.7	-22.5	-11.7	-17.0	-15.0	0.0	0.0
380.0	- 8.0	- 8.0	- 7.0			- 6.2	- 6.2	- 5.5	- 4.0	- 4.0	0.0	0.0
370.0	0.0	0.0	0.0	0.0	0.0	- 2.2	- 2.2	- 1.7	0.0	0.0	0.0	0.0
Half Gate Openings												
410.0	0.0	0.0	0.0	0.0	0.0	-42.0*	-34.0	-33.0	-36.0*	-36.0*	-33.0	-30.0
400.0	0.0	0.0	0.0	0.0	0.0	-35.0*	-29.0	-29.0	-31.5	-31.5	-30.0	-25.0
395.0	0.0	0.0	0.0	0.0	0.0	-32.0	-26.0	-25.0	-27.5	-27.5	-26.0	-21.0
390.0	0.0	0.0	0.0	0.0	0.0	-28.0	-25.0	-25.0	-22.0	-22.0	-21.0	-18.0
380.0	0.0	0.0	0.0	0.0	0.0	-21.0	-19.0	-16.0	-17.0	-17.0	-17.5	-15.0
370.0	0.0	0.0	0.0	0.0	0.0	- 7.0	- 7.0	- 7.0	- 6.0	- 6.0	- 9.0	- 9.0

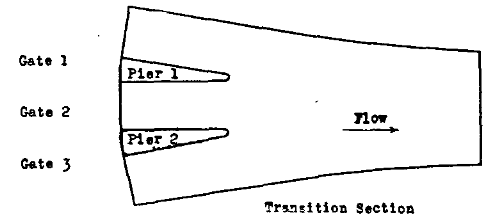
Note: All pressures are recorded in prototype feet of water.
*Recorded for purpose of comparison only; obviously impossible for pressures to exceed 34 ft. of water. (See Paragraph 22.)

Table 10

Model Study Wappapello Dam - Outlet Structures

Pressure in Feet of Water on the Ends of the Division Piers and Sides of the Inlet Transition Section.

Discharge	Pool Elevation	Gate 1 Open						Discharge	Reservoir Stage	Gate 2 Open		
		Pier 1			Wall of Transition					Pier 1 or 2		
		Upper	Middle	Lower	Upper	Middle	Lower			Upper	Middle	Lower
11,100	410	---	-17.25	-14.25	0.25	4.50	12.75	11,100	410	---	-16.00	-9.25
9,800	400	---	-13.00	-10.25	0.50	4.75	13.25	9,800	400	---	-14.00	-6.75
9,200	395	---	-11.75	-8.75	1.00	4.75	13.25	9,200	395	---	-12.50	-5.25
8,500	390	---	-10.00	-7.75	0.75	5.00	13.25	8,500	390	---	-11.25	-4.25
7,100	380	---	-6.75	-4.25	1.00	4.75	13.50	7,100	380	---	-7.75	-2.00
5,400	370	---	-3.00	-0.50	0.75	4.75	13.50	5,400	370	---	-3.50	0.00
3,300	360	---	-0.75	-0.25	0.75	1.50	10.25	3,300	360	---	-0.50	0.25
1,200	350	---	0.00	0.00	---	---	6.00	1,200	350	---	---	0.25



Transition Section

Discharge	Pool Elevation	Gates 1 and 2 Open																						
		Pier 1						Pier 2						Wall of Transition										
		Left Side			Right Side			Left Side			Right Side			Left Side			Right Side							
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower					
19,100	410	10.25	15.50	20.00	---	5.50	18.25	---	5.50	18.25	9.5	18.50	27.25	14.75	23.25	32.50	4.00	16.00	24.50					
17,800	400	8.00	14.50	20.00	---	5.25	18.00	---	5.25	18.00	8.5	16.50	25.75	12.00	20.00	29.75	3.50	15.50	24.50					
16,800	395	7.25	13.75	19.25	---	6.25	17.75	---	6.25	17.75	7.5	15.50	24.75	11.00	19.00	28.75	3.00	15.00	24.50					
15,800	390	7.00	12.00	19.00	---	6.75	17.75	---	6.75	17.75	7.0	15.00	23.75	9.50	18.00	27.50	3.00	14.00	24.50					
13,200	380	4.75	11.50	18.50	---	7.25	16.75	---	7.25	16.75	5.5	13.50	21.75	6.00	14.50	23.75	1.50	12.50	24.50					
9,800	370	3.50	11.0	16.00	---	8.00	17.00	---	8.00	17.00	3.5	12.50	19.75	3.50	12.00	21.25	1.50	10.50	24.50					
5,800	360	1.50	4.0	12.25	---	2.00	10.00	---	2.00	10.00	---	5.50	12.75	----	9.50	18.75	---	3.50	12.25					
1,200	350	---	---	5.50	---	---	4.00	---	---	4.00	---	---	4.75	----	----	6.75	---	----	5.25					

Discharge	Pool Elevation	Gates 1 and 3 Open																	
		Pier 1						Pier 2						Wall of Transition					
		Left Side			Right Side			Left Side			Right Side			Left Side			Right Side		
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
19,100	410	7.75	11.50	19.50	9.50	20.00	29.50	9.50	20.00	29.50	7.75	11.50	19.50	12.00	20.50	29.75	12.00	20.50	29.75
17,800	400	7.00	10.50	18.00	8.50	19.00	27.75	8.50	19.00	27.75	7.00	10.75	18.00	10.00	18.50	27.75	10.00	18.50	27.75
16,800	395	6.50	10.00	17.75	8.00	18.00	26.75	8.00	18.00	26.75	6.50	10.00	17.75	8.50	17.00	26.25	8.50	17.00	26.25
15,800	390	5.50	9.75	17.75	6.75	16.25	25.00	6.75	16.25	25.00	5.50	9.75	17.75	7.50	16.00	25.25	7.50	16.00	25.25
13,200	380	3.50	9.50	16.75	5.00	13.50	22.25	5.00	13.50	22.25	3.50	9.50	16.75	5.00	13.50	22.75	5.00	13.50	22.75
9,800	370	2.50	9.50	16.75	3.25	11.25	20.00	3.25	11.25	20.00	2.50	9.50	16.75	2.50	11.00	20.25	2.50	11.00	20.25
5,800	360	---	2.75	10.25	---	3.50	12.25	---	3.50	12.25	---	2.75	10.25	---	3.00	12.25	---	3.00	12.25
1,200	350	---	---	3.75	---	---	5.00	---	---	5.00	---	---	3.75	---	---	5.25	---	---	5.25

Discharge	Pool Elevation	Gates 1, 2 and 3 Open																	
		Pier 1						Pier 2						Wall of Transition					
		Left Side			Right Side			Left Side			Right Side			Left Side			Right Side		
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
20,000	410	31.00	39.00	46.75	28.50	39.00	48.25	28.50	39.00	48.25	31.00	39.00	46.75	34.25	42.75	52.00	34.25	42.75	52.00
18,600	400	26.50	34.50	41.25	26.00	35.00	43.25	26.00	35.00	43.25	26.50	34.50	41.25	28.00	36.50	45.75	28.00	36.50	45.75
17,600	395	24.00	31.75	38.75	23.00	31.00	39.75	23.00	31.00	39.75	24.00	31.75	38.75	25.00	33.50	42.75	25.00	33.50	42.75
16,500	390	21.00	29.00	35.75	21.50	28.00	36.75	21.50	28.00	36.75	21.00	29.00	35.75	21.00	30.50	39.75	21.00	30.50	39.75
14,200	380	15.50	23.50	30.75	17.00	22.00	30.75	17.00	22.00	30.75	15.50	23.50	30.75	15.50	24.00	33.25	15.50	24.00	33.25
10,900	370	9.00	16.75	25.25	10.50	15.25	24.00	10.50	15.25	24.00	9.00	16.75	25.25	9.50	18.00	27.25	9.50	18.00	27.25
6,600	360	3.75	12.00	20.25	5.50	11.50	20.00	5.50	11.50	20.00	3.75	12.00	20.25	3.00	11.50	20.75	3.00	11.50	20.75
2,700	350	---	3.50	12.00	---	2.50	11.25	---	2.50	11.25	---	3.50	12.00	---	1.75	11.00	---	1.75	11.00

Note: All pressures were obtained from piezometers located in the right wall of the transition section and left sides of the division piers. The piezometers were 1.5 ft. from the ends of the division piers and located above the base of the transition section at distances of 2, 10, and 18 ft. The pressures are recorded in prototype feet of water.

Table 11

Model Study of Wappapello Dam - Outlet Structures

Piezometer Readings in Tunnel

Gage		A	B	C	D
Station		25+60	26+52	27+39	28+09
Elev. Top of Tunnel		358.1	357.74	357.38	357.09
Discharge	Pool Elev.		Gates 1, 2, and 3 Open		
19,550	407.00	363.50	359.50	358.00	355.00
17,000	392.00	359.00	356.25	354.25	352.50
14,500	382.00	357.75	356.00	354.75	353.00
12,000	374.00	357.00	355.25	354.75	353.50
10,000	368.50	356.50	355.75	355.00	354.00
7,500	362.50	356.25	355.75	355.00	354.75
			Gates 1 and 2 Open		
19,700	413.40	364.50	360.00	358.50	354.50
17,000	395.50	358.75	355.50	354.75	352.25
14,500	385.00	358.25	356.25	355.00	353.50
12,000	376.75	357.75	356.75	355.75	354.50
10,000	370.75	357.25	356.50	355.75	355.00
			Gates 1 and 3 Open		
19,700	413.40	364.00	360.00	359.00	355.00
17,000	395.50	358.00	355.25	354.25	351.75
14,500	385.00	357.00	355.50	354.50	352.50
12,000	376.75	356.50	355.25	354.75	353.25
10,000	370.75	356.00	355.50	355.25	354.25

Note: Readings obtained with full tunnel flow.

TABLE 12

Model Study of Wappapello Dam - Outlet Structures

Types of Stilling Basins Investigated in the Model Study

Type of Basin	No. of Tests	Location of end of Apron	Location of End Sill	Height of End Sill	Location of Baffle Piers Row 1	Location of Baffle Piers Row 2	Height of Baffle Piers Row 1	Height of Baffle Piers Row 2	Type of Wing Walls	Remarks
A	5	30+60.0	30+56.0	3.0 ft.	29+76.0	30+01.0	8 ft.	8 ft.	Flared	Basic design.
B	1	30+60.0	----	---	----	----	----	----	Flared	No baffle piers or end sill on apron.
C	1	30+60.0	30+56.0	3.0	----	----	----	----	Flared	No baffle piers on apron.
D	1	30+60.0	30+56.0	3.0	----	30+01.0	----	8 ft.	Flared	One row of baffle piers used.
E	1	30+60.0	30+56.0	3.0	29+76.0	30+01.0	8	8	Right Angle	Wing walls at right angles to center line of basin
F	1	30+09.0	30+05.0	3.0	29+76.0	----	8	----	Flared	starting at end sill.
G	1	30+09.0	30+05.0	3.0	29+62.0	29+80.0	8	8	Flared	
H	1	30+09.0	30+05.0	3.0	29+58.0	29+76.0	8	8	Flared	
I	1	30+09.0	30+15.0	3.0	29+58.0	29+76.0	8	8	Flared	
J	2	30+29.0	30+25.0	3.0	29+61.0	29+79.0	8	8	Flared	
K	2	30+29.0	30+23.0	4.5	29+61.0	29+79.0	8	8	Flared	
L	1	30+29.0	30+21.0	6.0	29+61.0	29+79.0	8	8	Flared	
M	1	30+29.0	30+25.0	3.0	29+61.0	29+79.0	8	8	Rounded	Wing walls rounded on 30 ft. radius starting at end
N	2	30+29.0	30+25.0	3.0	29+86.0	30+04.0	8	8	Rounded	sill.
O	1	30+29.0	30+25.0	3.0	29+86.0	30+04.0	8	8	Rounded	No baffle piers next to spray walls in rear row.
P	1	30+29.0	30+25.0	3.0	29+86.0	30+04.0	8	8	Rounded	Baffle piers spaced at 4 ft. intervals in all follow-
Q	1	30+29.0	30+25.0	3.0	29+90.0	30+06.0	4	4	Rounded	ing tests unless otherwise stated.
R	6	30+29.0	30+25.0	3.0	29+86.0	30+02.0	6	6	Rounded	
S	1	30+29.0	30+25.0	3.0	29+86.0	30+02.0	4	4	Rounded	
T	1	30+29.0	30+25.0	3.0	29+76.0	29+92.0	6	6	Rounded	
U	1	30+29.0	30+25.0	3.0	29+66.0	29+82.0	6	6	Rounded	
V	1	30+29.0	30+25.0	3.0	29+81.0	29+97.0	6	6	Rounded	
W	1	30+29.0	30+25.0	3.0	29+86.0	30+02.0	6	6	Rounded	Vertical upstream face on baffle piers.
X	1	30+29.0	30+25.0	3.0	29+86.0	30+02.0	6	6	Rounded	Sloping upstream face on baffle piers.
Y	1	30+29.0	30+25.0	3.0	29+86.0	30+02.0	6	6	Rounded	Three steps on upstream face of baffle piers.
Z	1	30+19.0	30+15.0	3.0	29+61.0	29+75.0	8	8	Rounded	Baffle piers spaced at 5 ft. intervals.
AA	1	30+24.0	30+20.0	3.0	29+86.0	30+02.0	6	6	Rounded	
BB	1	30+19.0	30+15.0	3.0	29+81.0	29+97.0	6	6	Rounded	
CC	1	30+14.0	30+10.0	3.0	29+76.0	29+92.0	6	6	Rounded	
DD	6	30+09.0	30+05.0	3.0	29+71.0	29+87.0	6	6	Rounded	
EE	1	30+09.0	30+05.0	3.0	29+66.0	29+82.0	6	6	Rounded	
FF	1	30+09.0	30+05.0	3.0	29+76.0	29+92.0	6	6	Rounded	
KK	1	30+09.0	30+05.0	3.0	29+61.0	29+87.0	6	6	Rounded	Baffle pier rows spaced farther apart.
GG	8	29+95.5	29+91.5	3.0	29+57.5	29+73.5	6	6	Rounded	In all following tests, the slope of the apron
HH	2	30+09.0	30+05.0	3.0	29+71.0	29+87.0	6	6	Rounded	follows the trajectory curve of $X^2 = 497Y$.
JJ	2	29+95.5	29+91.5	3.0	29+42.5	29+58.5	6	6	Rounded	

Table 13

Model Study of Wappapello Dam - Outlet Structures

Summary of Scour Tests

Type Basin	Test No.	Discharge c.f.s.	Scour End of Apron: Max. Scour Elev.	Scour End of Apron: Aver. Scour Elev.	Scour in Channel: Max. Scour Elev.	Scour in Channel: Dist. from end of apron	Scour at Wing Walls: Left Wall Max. Scour Elev.	Scour at Wing Walls: Right Wall Max. Scour Elev.
A	3	10,000	321.0	321.0	321.0	—	318.0	319.0
	4	4,980	321.0	321.0	321.0	—	321.0	321.0
	7	14,550	319.0	320.0	320.0	12 ft.	316.0	317.0
	31	17,000	318.5	320.0	319.0	20 ft.	315.0	314.5
	37	19,700	315.0	317.0	312.0	25 ft.	317.0	316.0
B	34	10,070	313.5	315.0	313.0	21 ft.	311.0	311.0
C	35	10,000	320.0	320.5	316.0	18 ft.	317.0	317.0
D	36	10,000	320.5	321.0	319.0	10 ft.	319.0	318.0
E	38	10,000	319.0	320.0	320.0	5 ft.	319.0	318.0
F	39	10,000	317.5	320.5	318.5	21 ft.	315.0	314.5
G	40	10,000	320.0	320.5	320.0	12 ft.	319.5	319.0
H	41	10,000	320.0	321.0	320.0	12 ft.	319.5	319.0
I	42	10,000	320.0	320.5	320.0	12 ft.	320.0	320.0
J	43-1	10,000	320.5	321.0	320.0	11 ft.	320.0	320.5
	43-2	17,000	318.0	320.0	320.0	12 ft.	316.0	315.0
K	45-1	10,000	322.0	322.5	322.0	8 ft.	321.0	321.5
	45-2	17,000	318.0	322.0	320.0	21 ft.	317.0	315.0
L	47	17,000	318.0	323.0	322.0	21 ft.	317.0	316.0
M	48	17,000	318.0	320.0	319.0	21 ft.	317.5	317.0
N	49-1	16,890	319.0	320.5	319.5	20 ft.	318.5	318.0
	49-2	10,000	320.0	320.5	319.5	11 ft.	320.0	319.5
O	50	17,000	320.0	320.5	318.5	11 ft.	319.0	318.5
P	51	17,000	320.0	321.0	319.5	11 ft.	320.0	320.0
Q	52	17,000	319.0	319.5	317.5	31 ft.	316.0	317.0
R	53	17,150	320.5	321.0	320.5	11 ft.	319.0	320.0
	58	5,000	320.5	321.0	321.0	—	320.5	320.0
	59	10,000	320.0	321.0	320.5	11 ft.	320.0	319.5
	60	14,500	320.0	321.0	320.0	21 ft.	320.0	319.0
	61	19,420	312.0	313.0	308.0	41 ft.	311.0	316.0
	64*	10,000	319.0	320.5	320.5	11 ft.	318.0	317.5
S	54	17,000	319.0	319.5	317.5	21 ft.	316.5	317.0
T	55	17,000	319.5	321.0	320.5	21 ft.	318.0	319.0
U	56	17,000	319.0	321.0	320.0	21 ft.	317.0	318.0
V	57	17,000	320.0	321.0	320.5	21 ft.	318.5	319.0
W	69	17,000	320.5	320.5	320.0	31 ft.	319.0	318.5
X	70	17,020	320.0	320.5	319.5	21 ft.	318.5	318.5
Y	71	17,000	320.5	320.5	320.0	11 ft.	319.0	319.0
Z	72	17,000	316.0	319.0	318.0	21 ft.	315.5	315.0
AA	73	17,000	320.5	320.5	320.5	5 ft.	319.0	320.0
BB	74	17,000	321.0	321.0	320.0	15 ft.	319.0	319.0
DD	77	17,000	320.5	320.5	319.5	11 ft.	318.5	319.0
	80	5,000	320.5	320.5	320.5	6 ft.	320.0	320.0
	81	10,000	320.5	320.5	320.5	11 ft.	320.0	320.0
	82	14,500	320.5	320.5	319.5	11 ft.	319.0	319.0
	83*	10,000	320.0	320.5	320.0	21 ft.	319.0	319.0
	84	19,620	311.0	315.0	310.0	46 ft.	309.0	318.0
EE	78	17,000	319.5	320.0	319.5	11 ft.	317.0	318.0
FF	79	17,000	320.0	320.5	320.0	11 ft.	320.0	320.0
KK	88	17,000	318.5	319.5	318.0	11 ft.	317.0	318.5
GG	104	5,000	321.0	321.0	320.5	5 ft.	320.0	320.5
	105	10,000	320.5	320.5	319.5	15 ft.	320.0	320.0
	106	14,500	321.0	321.0	320.0	15 ft.	319.0	319.0
	107	17,000	321.0	321.0	320.0	5 ft.	319.0	319.0
	108*	10,000	320.5	321.0	320.0	15 ft.	318.0	319.0
	109	19,550	311.0	315.0	305.0	50 ft.	312.0	314.0
	112**	10,000	320.5	320.5	319.5	15 ft.	320.0	320.0
	113**	17,000	321.0	321.0	321.0	3 ft.	320.0	321.0
HH	98	17,000	321.0	321.0	321.0	11 ft.	319.0	320.5
	99	10,000	320.5	320.5	319.5	11 ft.	320.0	320.0
JJ	101	17,000	321.0	321.0	320.5	15 ft.	317.0	319.0
	103	10,000	320.0	320.5	319.5	15 ft.	317.5	318.5

*Scour pattern obtained with pool at elevation 395.
**Basin slope stepped.

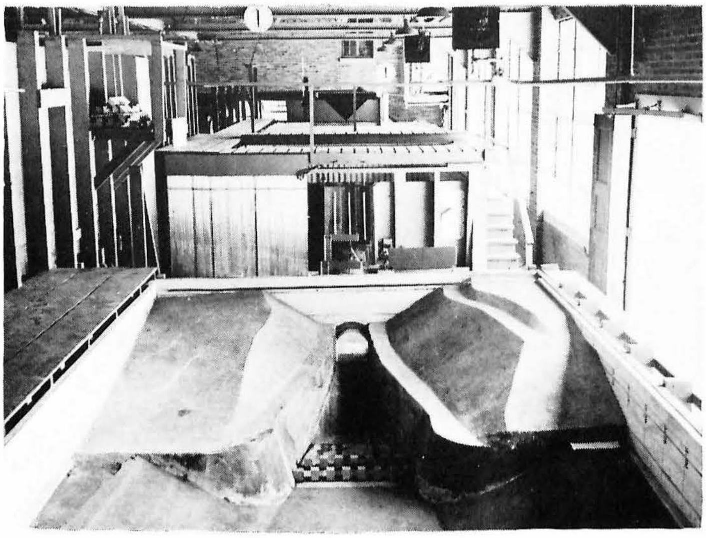
Table 14

Model Study of Wappapello Dam - Outlet Structures

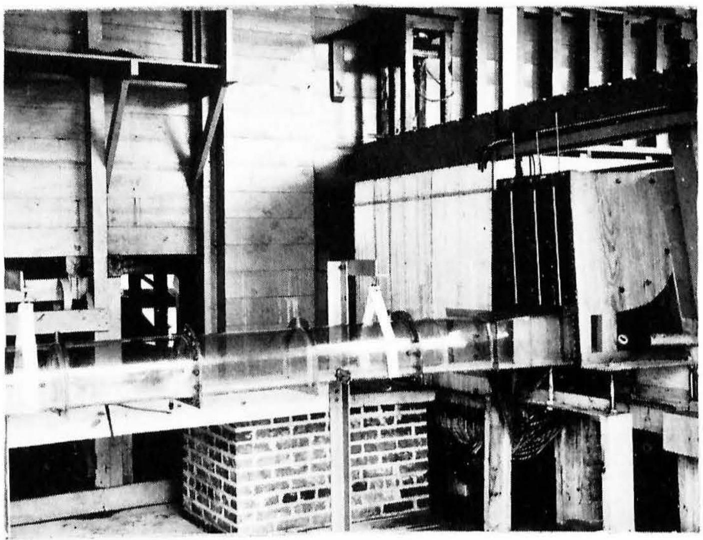
Nature of Stilling-Basin Action and Locus of the Hydraulic Jump

Discharge	5,000 c. f. s.			10,000 c. f. s.			14,500 c. f. s.		
Pool Elevation	395	377	357	395	380	368.5	395	386	382
Gate Adjustment	Gate 2 Open 12 ft.	Gates 1 & 3 Open 8 ft.	Gates 1, 2, &3 Open 20 ft.	Gates 1 & 3 Open 12-1/2ft	Gates 1 & 3 Open 15 ft.	Gates 1, 2, & 3 Open 20 ft.	Gates 1, 2, & 3 Open 12 ft.	Gates 1, 2, & 3 Open 15 ft.	Gates 1, 2, & 3 Open 20 ft.
Description of Basin Action	T.W. El.	T.W. El.	T.W. El.	T.W. El.	T.W. El.	T.W. El.	T.W. El.	T.W. El.	T.W. El.
Spray induced by first row of baffle piers.	332	331	330	337	337	336	341	340	340
Perfect hydraulic jump at toe of curved apron.	335	335	335	343	342	340	345	345	345
Partially submerged jump at point halfway down curved apron.	350	349	345	355	355	352	359	357	357
Partially submerged jump at exit portal of tunnel.	358	357	357	362	361	361	365	364	363
Surface roller at	353	349	—	350	350	353	353	353	355

PHOTOGRAPHS

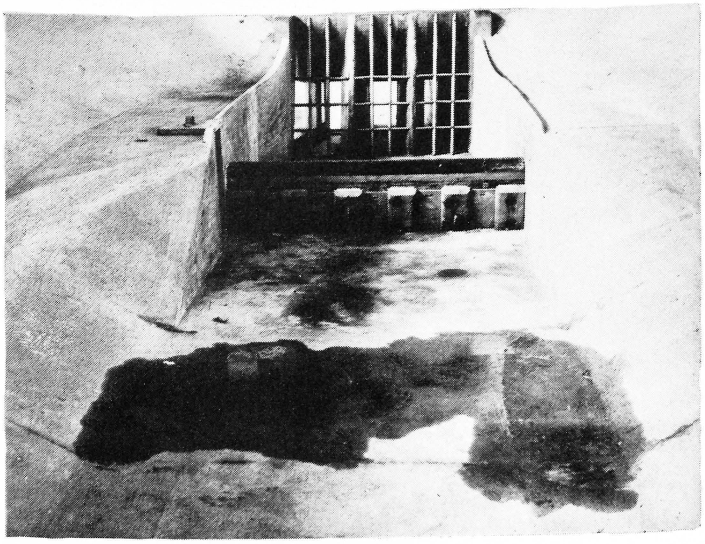


Photograph 1. Upstream view of the model.



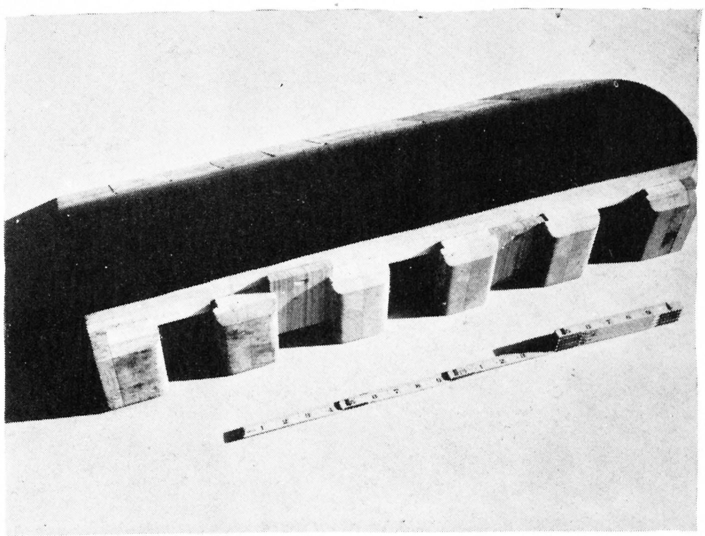
Photograph 2. View of the tunnel and intake tower.

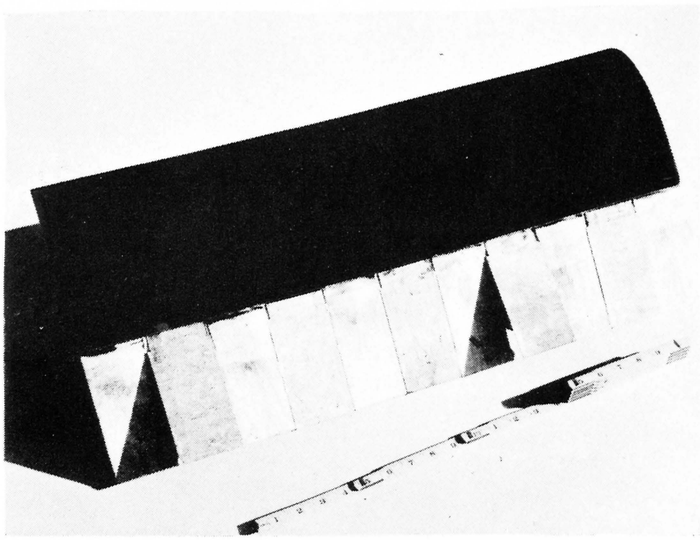
Photograph 3. Downstream view of the model.



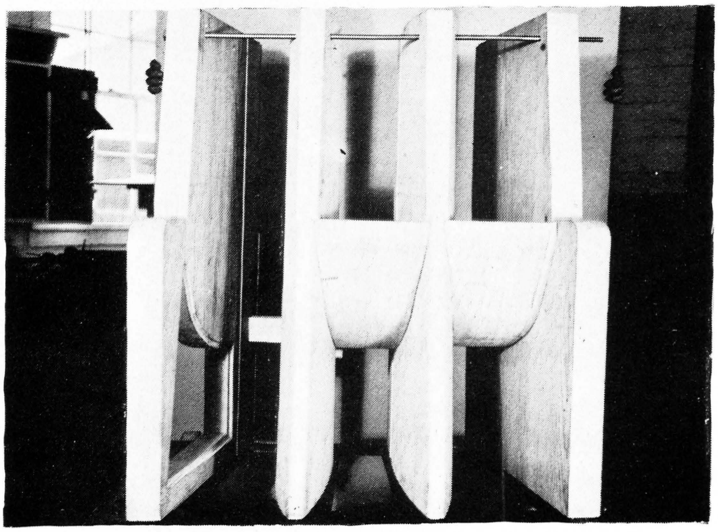
Photograph 4. Downstream view of the approach channel and intake tower.

Photograph 5. View of upstream face of conservation-pool weir.



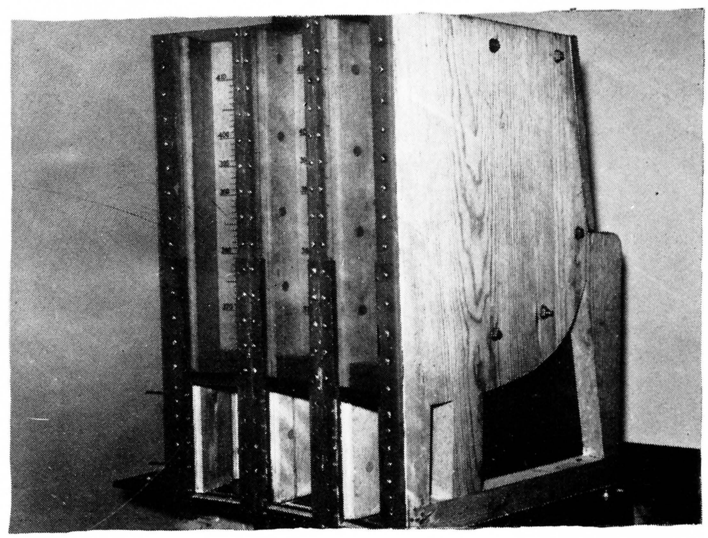


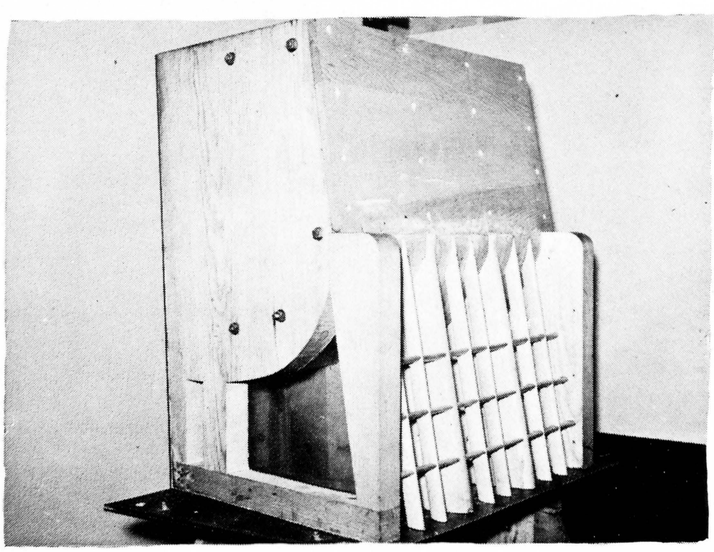
Photograph 6. View of downstream face of conservation-pool weir.



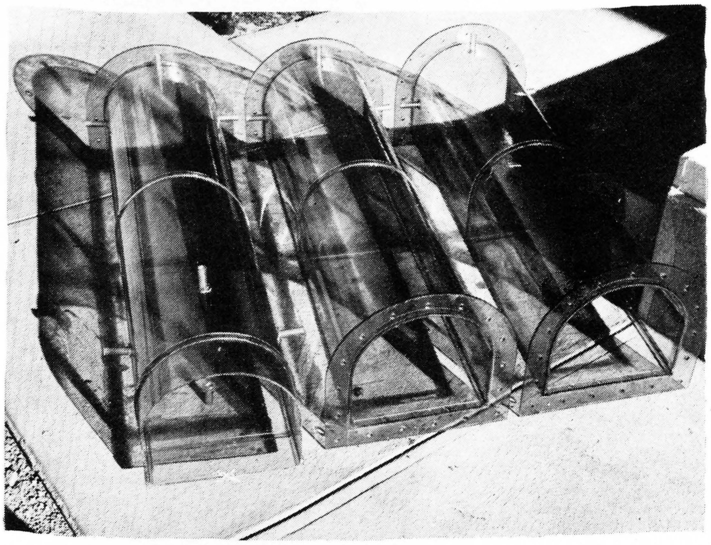
Photograph 7. View of the upstream face of the partially completed intake tower.

Photograph 8. View of the downstream face of the intake tower.

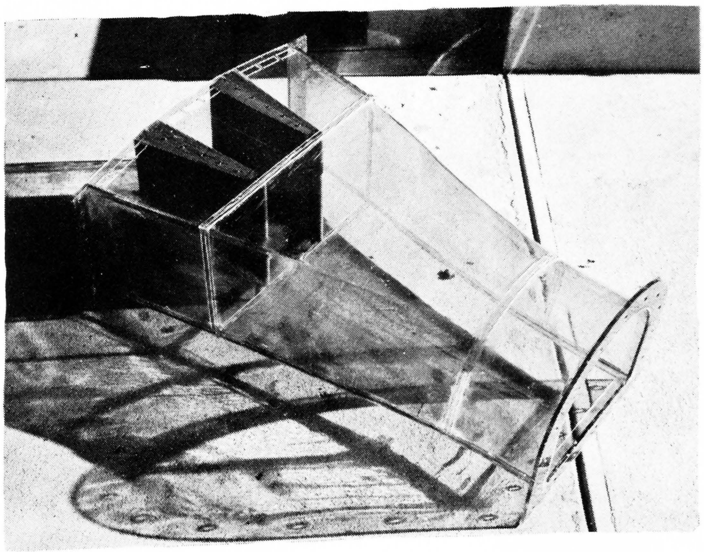




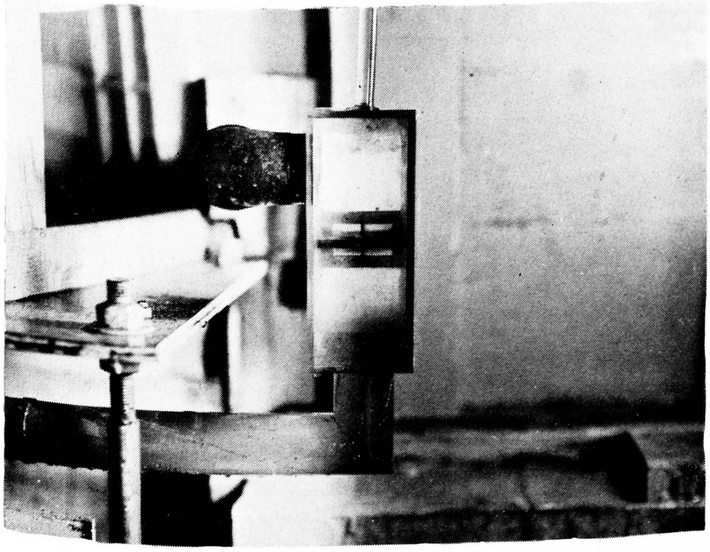
Photograph 9. View of the upstream face and side of the intake tower.



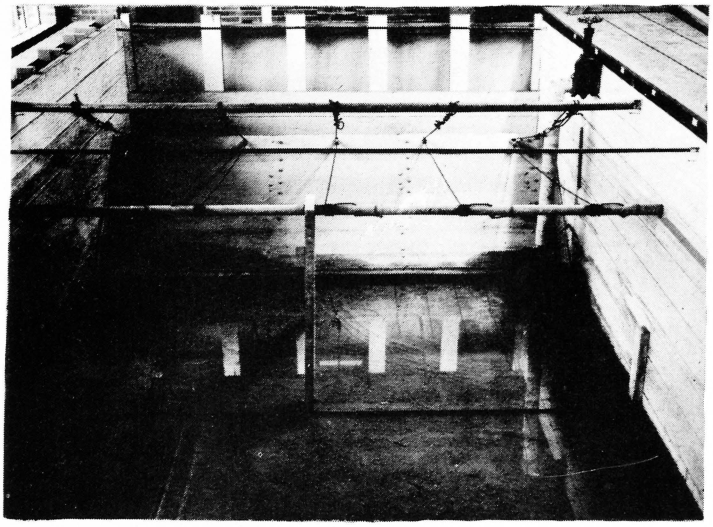
Photograph 10. View of the pyralin tunnel sections.



Photograph 11. View of the pyralin transition section.

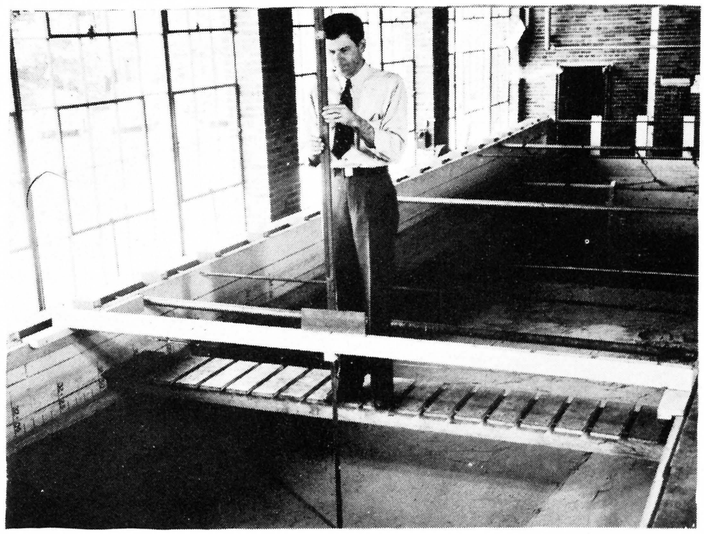


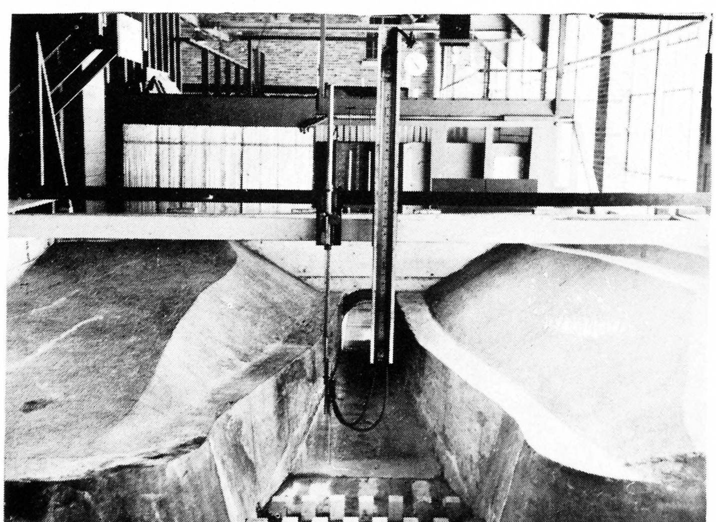
Photograph 12. View of the power unit.



Photograph 13. View of the tailgate.

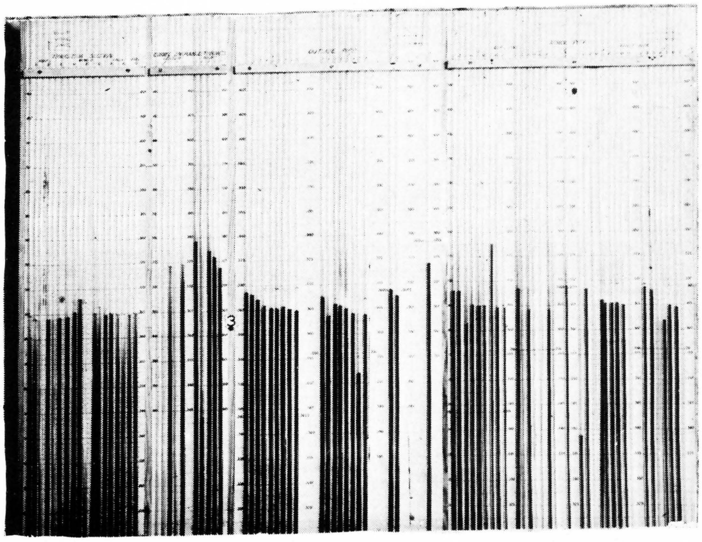
Photograph 14. View of the sounding stick.



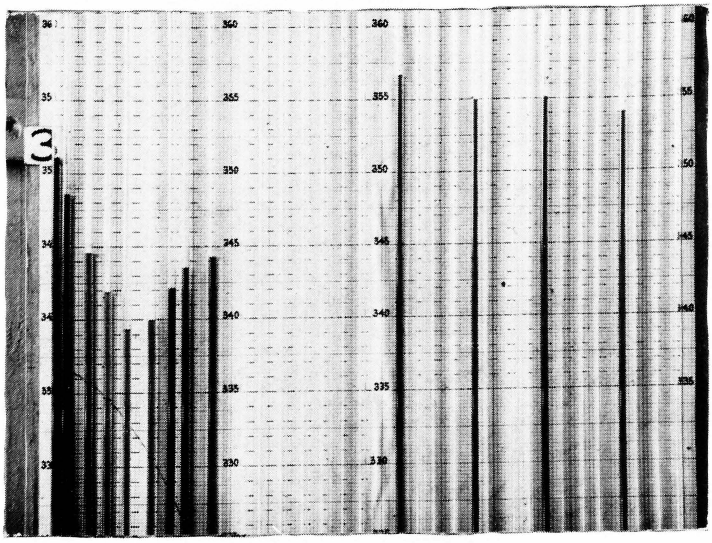


Photograph 15. View of the pitot tube.

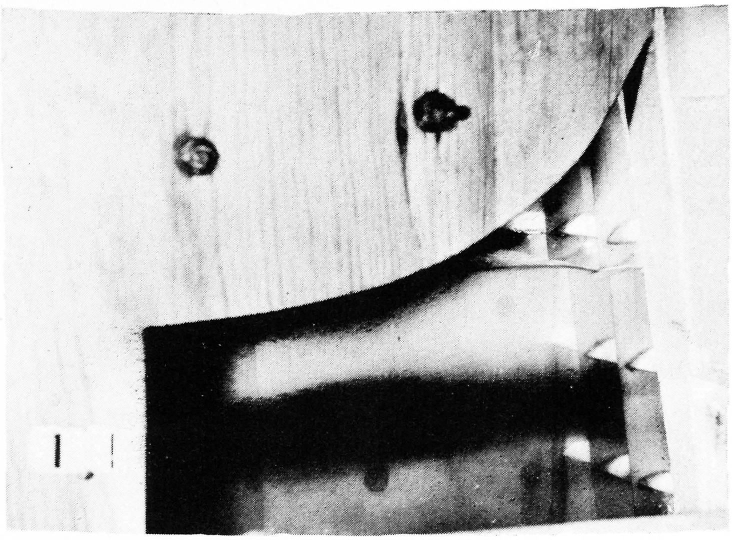
Photograph 16. View of the air vents downstream from the service gates.



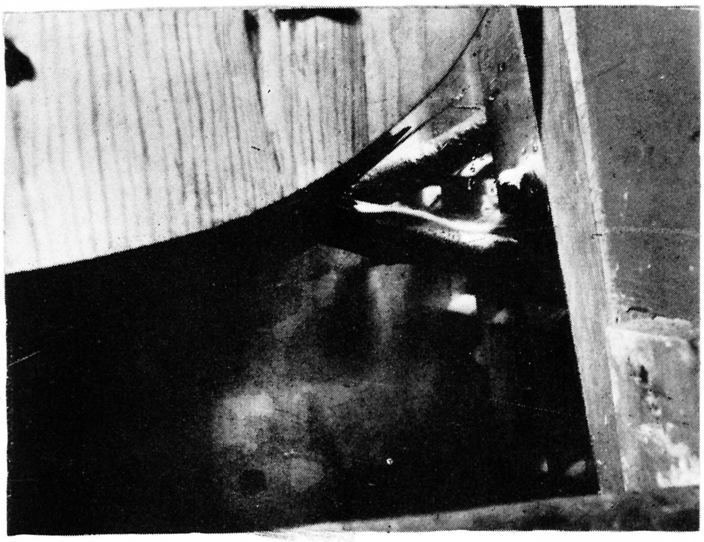
Photograph 17. View of the manometer bank for the gages of the intake tower and transition section.



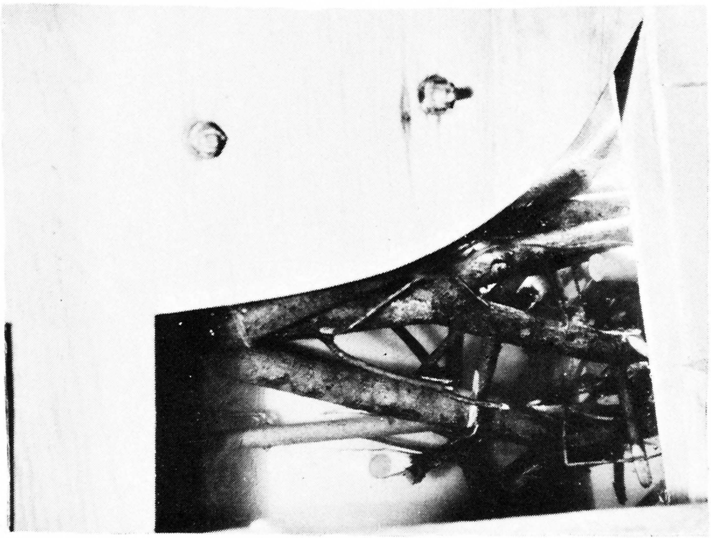
Photograph 18. View of the manometer bank for the gages of the tunnel and stilling basin.



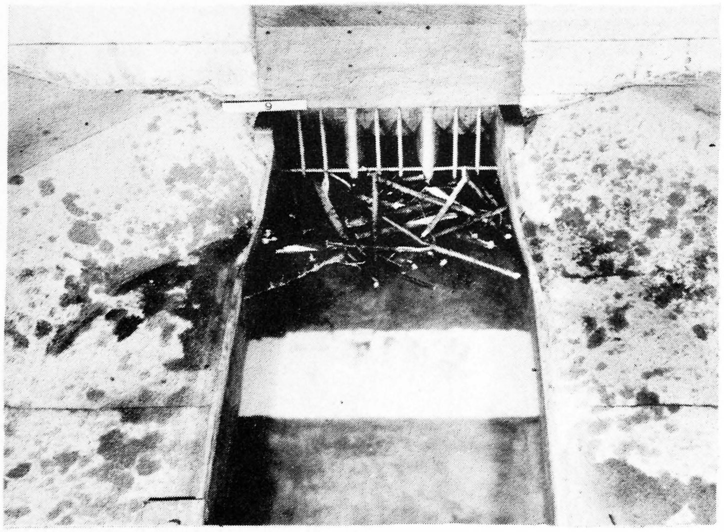
Photograph 19. Side view of the intake tower showing effect of trash racks on clear water flow. Discharge = 7,500 c.f.s.



Photograph 20. Side view of drift caught in trash racks. Discharge = 7,500 c.f.s.

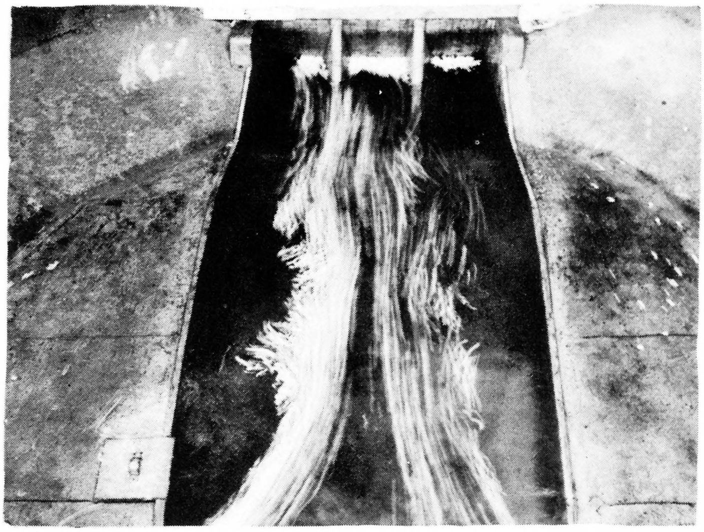


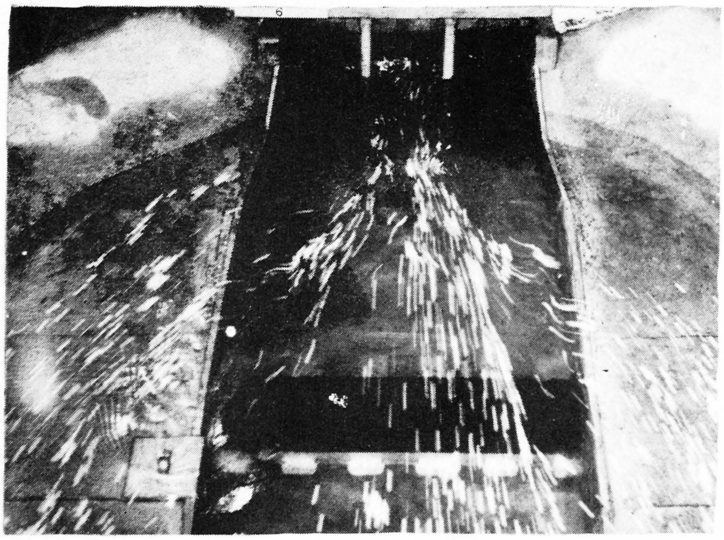
Photograph 21. Side view of drift caught in the intake tower. Discharge = 7,500 c.f.s.



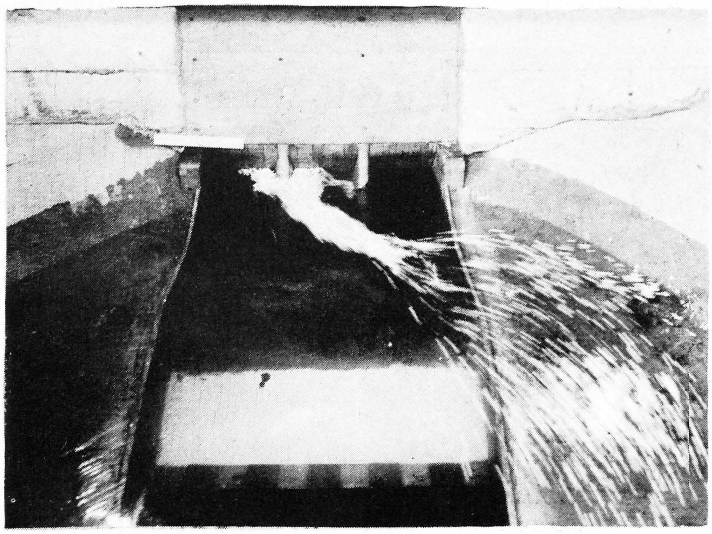
Photograph 22. View looking downstream showing trash piled against the intake tower.

Photograph 23. View of approach channel looking downstream showing flow over the side retaining walls. Conservation-pool weir removed. Discharge = 10,000 c.f.s.



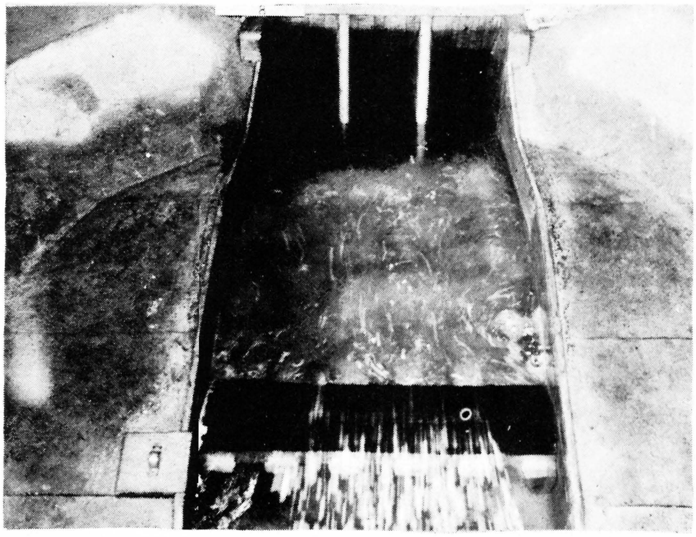


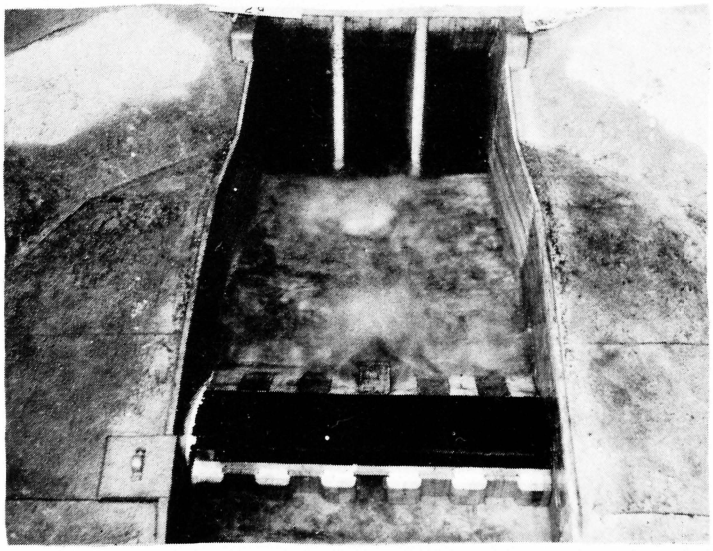
Photograph 24. View of approach channel looking downstream showing flow over the side retaining walls. Conservation-pool weir in place. Discharge = 10,000 c.f.s.



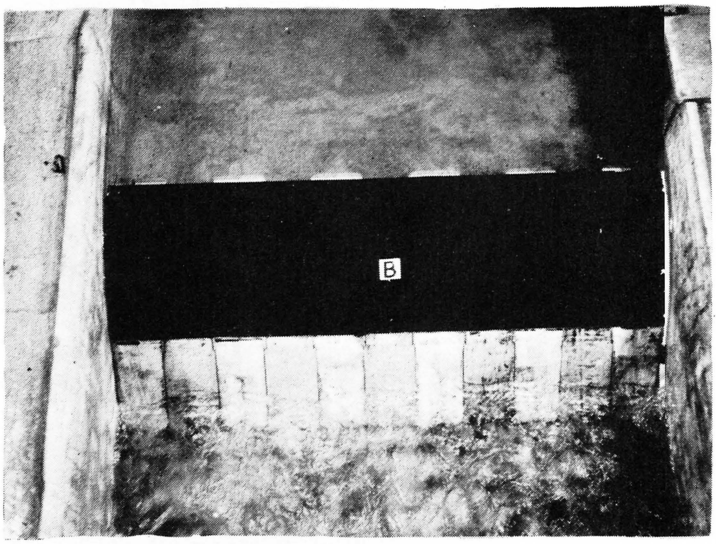
Photograph 25. View looking downstream showing the vortex next to a pier nose. Discharge = 10,000 c.f.s. Gates 1 and 2 open.

Photograph 26. View looking downstream of flow over the conservation-pool weir. Discharge = 5,000 c.f.s.

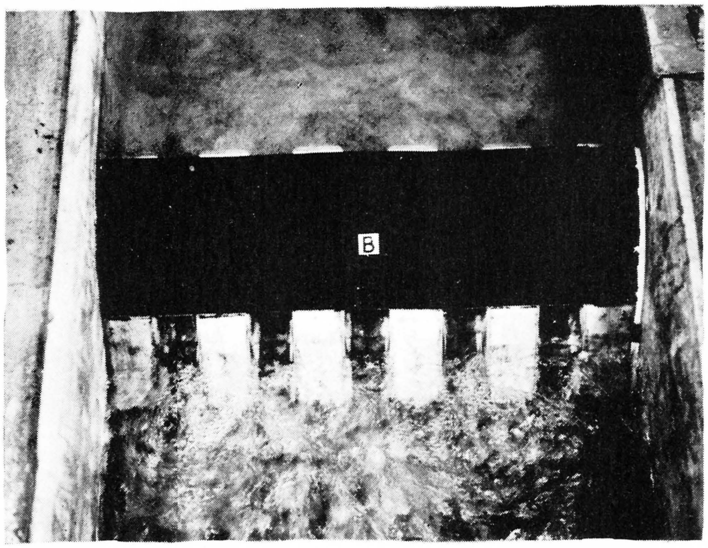




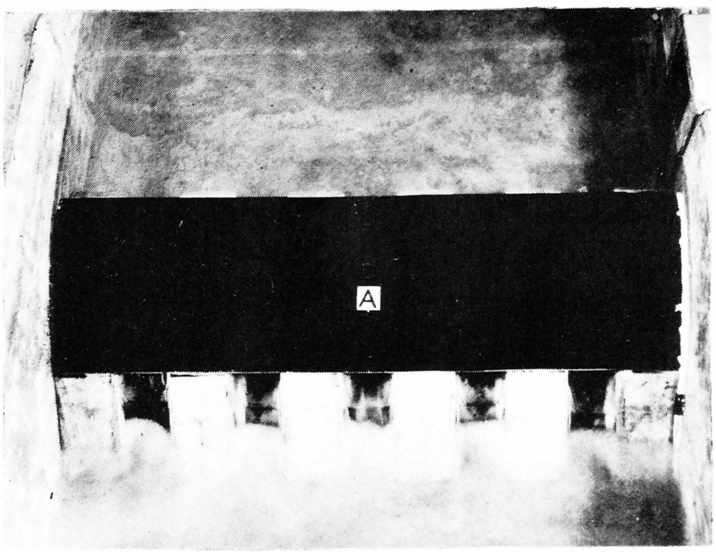
Photograph 27. View looking downstream showing the surface roller caused by the discharge from a sluice through the weir. Discharge = 1,000 c.f.s.



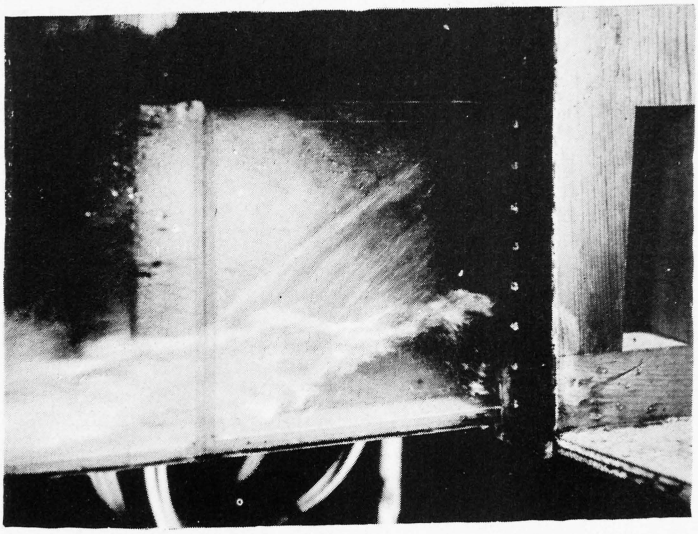
Photograph 28. View looking upstream of flow over the conservation-pool weir. Automatic sluice gates in place. Discharge = 1,500 c.f.s.



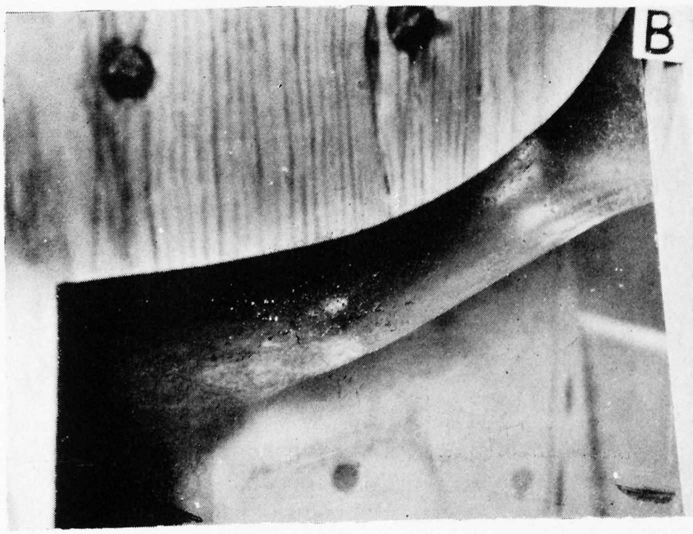
Photograph 29. View looking upstream of flow over the conservation-pool weir. Automatic sluice gates removed. Discharge = 1,500 c.f.s.



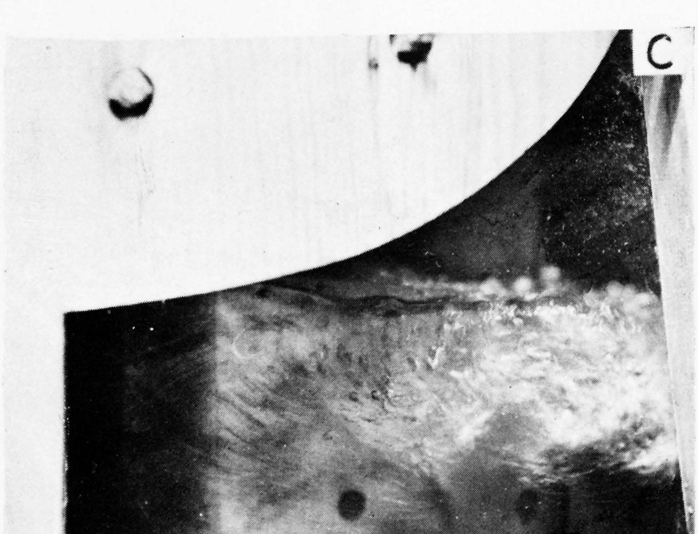
Photograph 30. View looking upstream of flow over the conservation-pool weir. Automatic sluice gates removed. Discharge = 1,000 c.f.s.



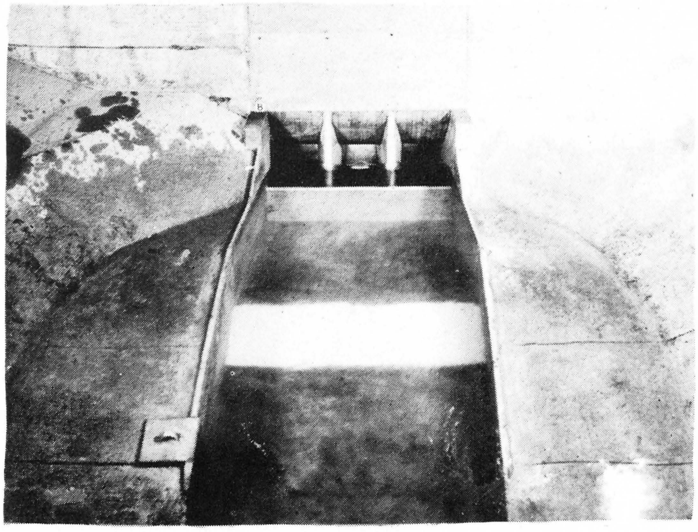
Photograph 31. View showing flow behind the weir. Alternate A. Discharge = 2,500 c.f.s.



Photograph 32. View showing flow behind the weir. Alternate B. Discharge = 7,500 c.f.s.

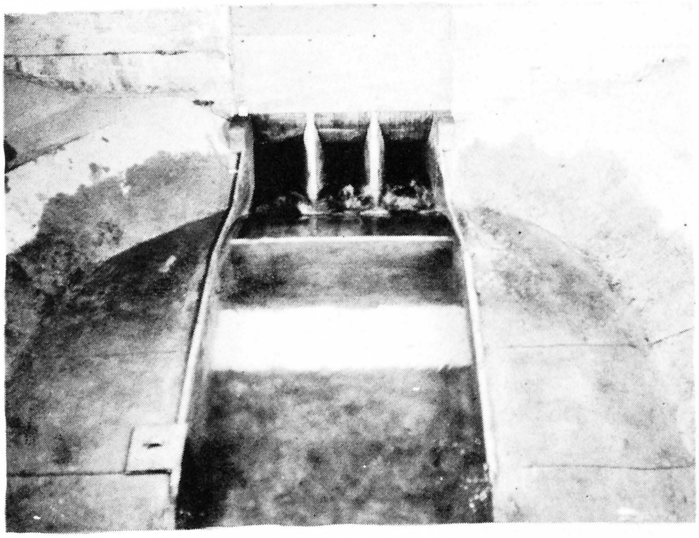


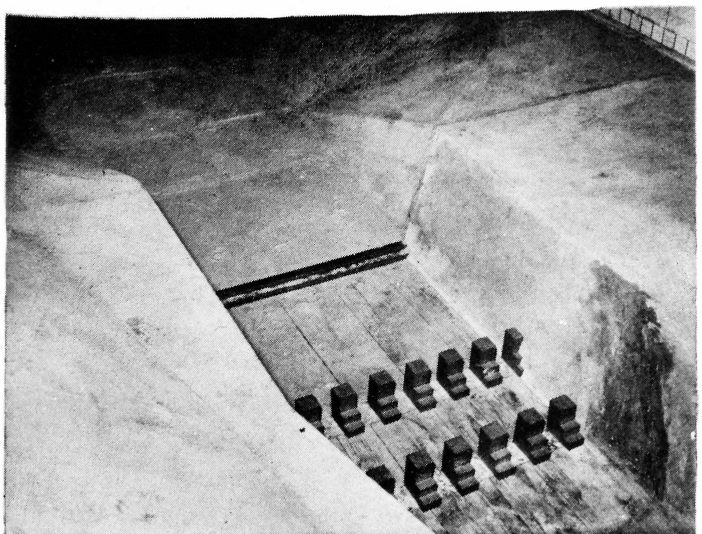
Photograph 33. View showing flow behind the weir. Alternate C. Discharge = 7,500 c.f.s.



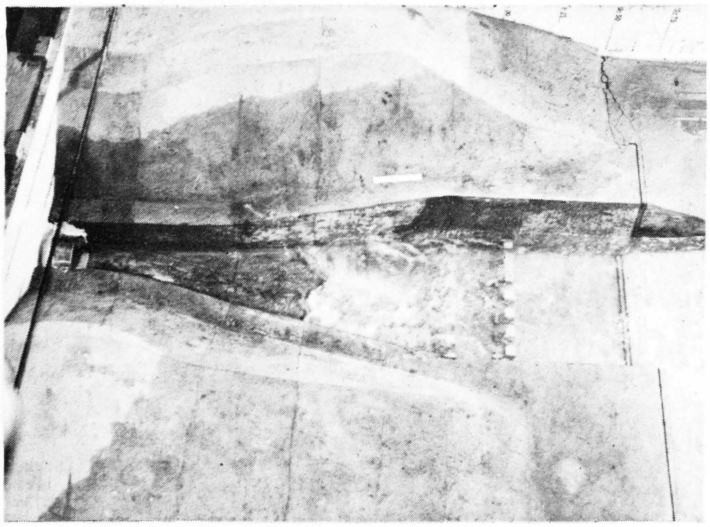
Photograph 34. View looking downstream showing flow over the weir. Alternate B. Discharge = 7,500 c.f.s.

Photograph 35. View looking downstream showing flow over the weir. Alternate C. Discharge = 7,500 c.f.s.

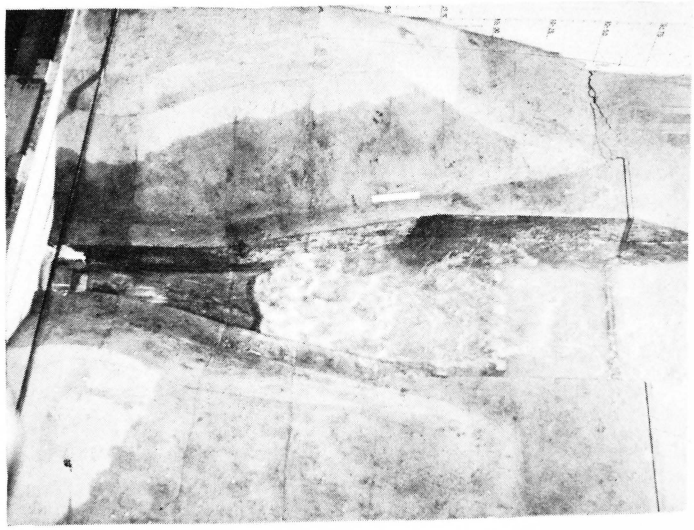




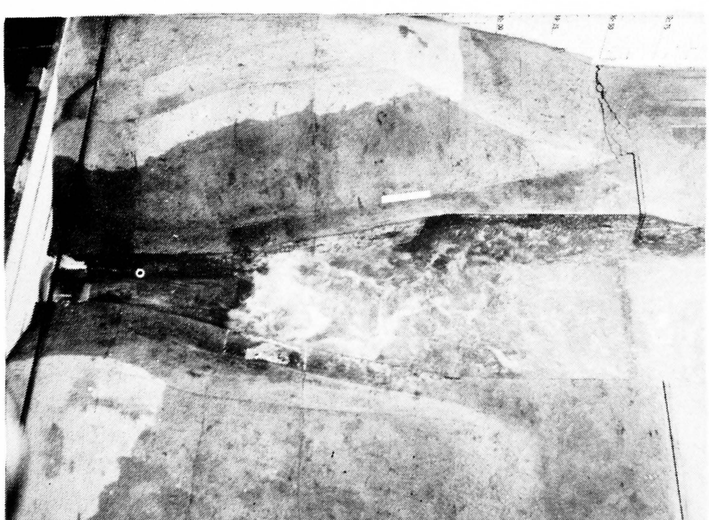
Photograph 36. View of the stilling basin showing baffle blocks and end sill. Basic design.



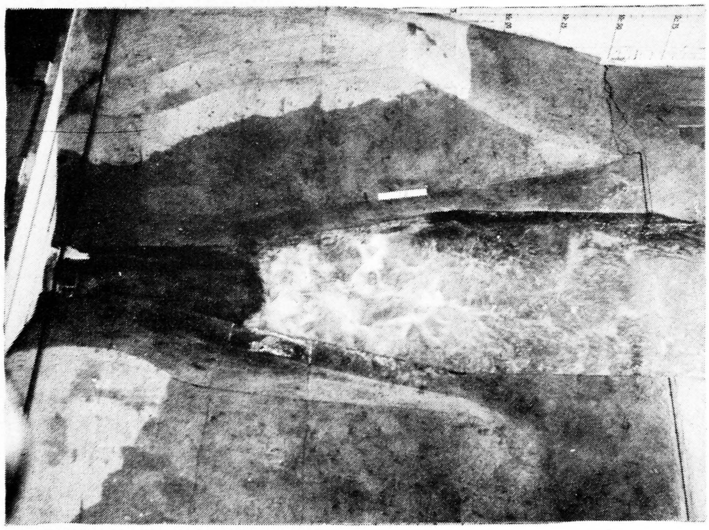
Photograph 37. Basic design
H.W. = 349.0 T.W. = 334.4
Q = 2,500 c.f.s.



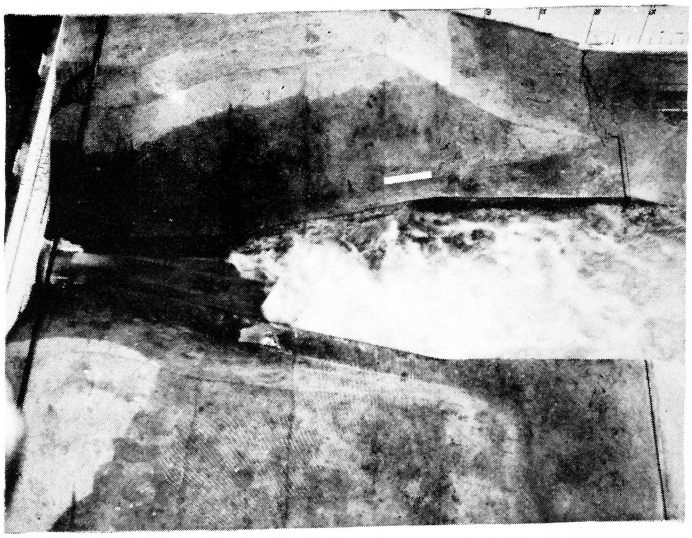
Photograph 38. Basic design
H.W. = 356.5 T.W. = 340.0
Q = 4,980 c.f.s.



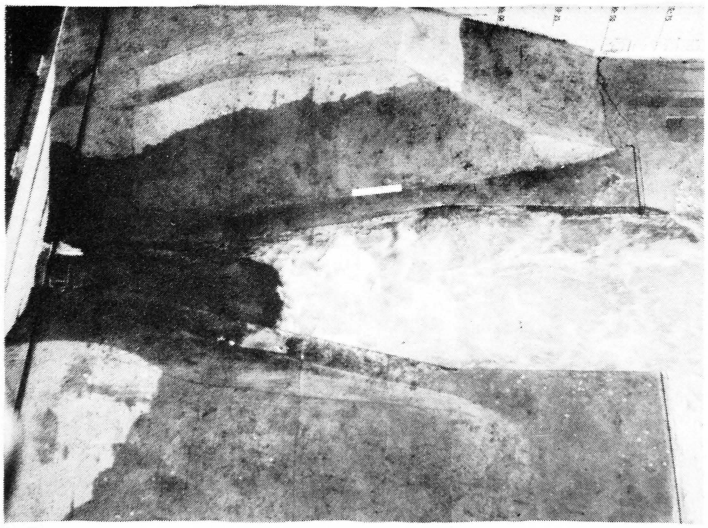
Photograph 39. Basic design
H.W. = 362.0 T.W. = 344.2
Q = 7,480 c.f.s.



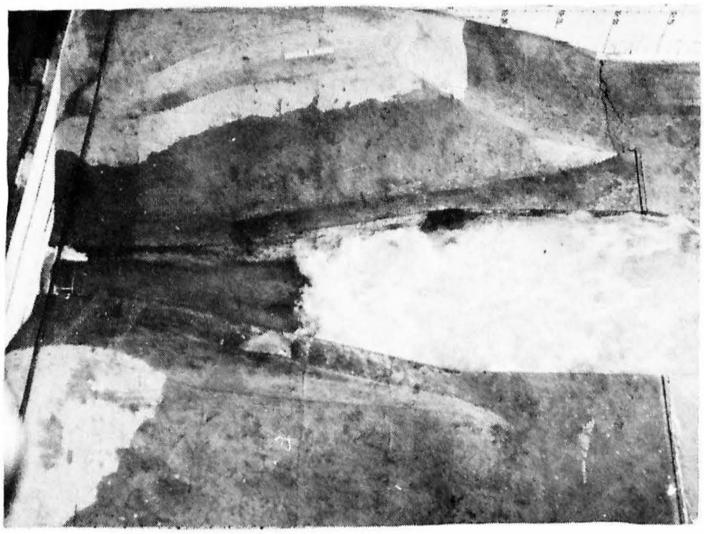
Photograph 40. Basic design
H.W. = 367.7 T.W. = 347.0
Q = 10,000 c.f.s.



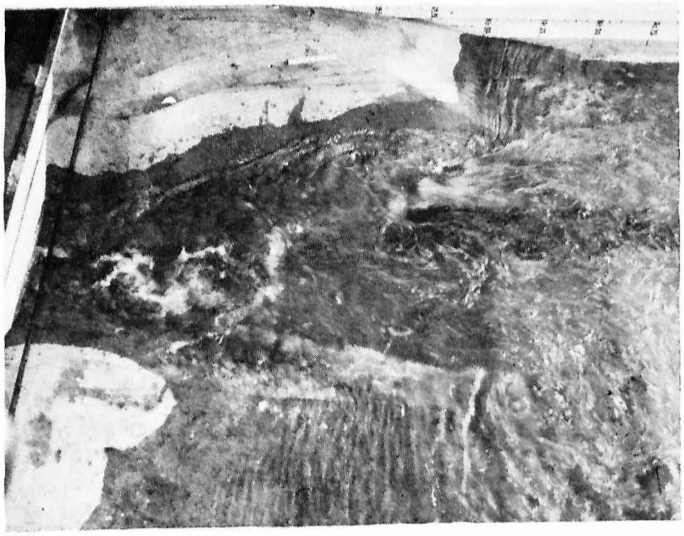
Photograph 41. Basic design
H.W. = 401.4 T.W. = 347.0
Q = 10,000 c.f.s.
Gate 1 open



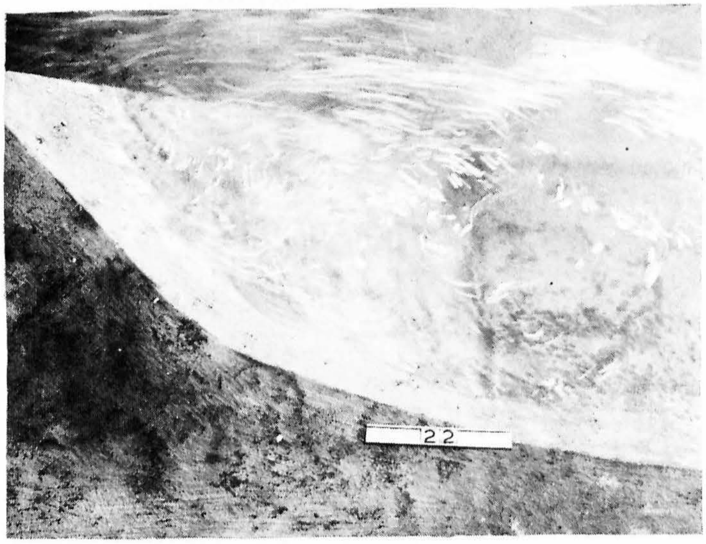
Photograph 42. Basic design
H.W. = 381.3 T.W. = 350.0
Q = 14,550 c.f.s.



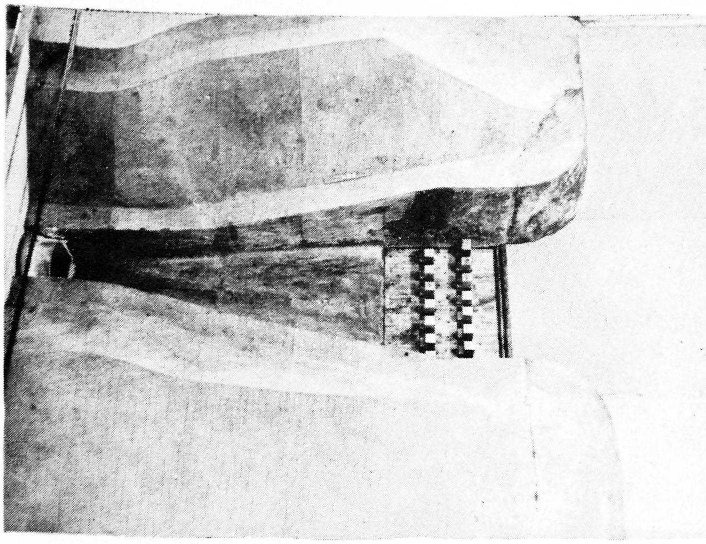
Photograph 43. Basic design
H.W. = 391.0 T.W. = 350.4
Q = 17,000 c.f.s.



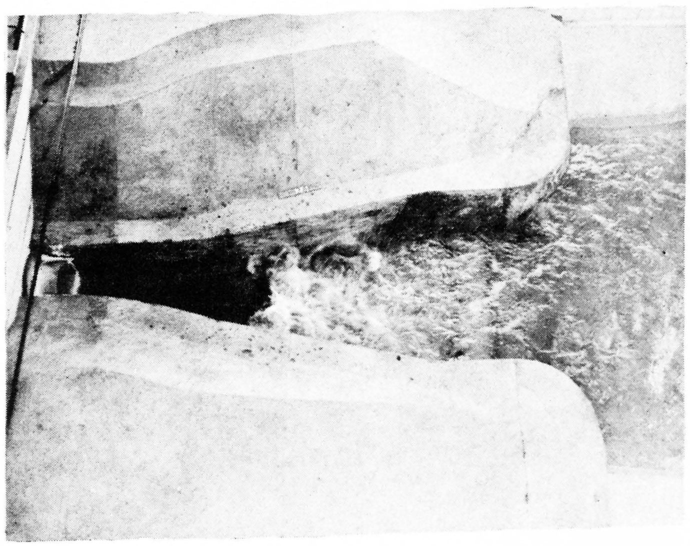
Photograph 44. Basic design
H.W. = 410.0 T.W. = 369.0
Q = 20,000 c.f.s.



Photograph 45. View showing the eddy at right wing wall. Basic design.

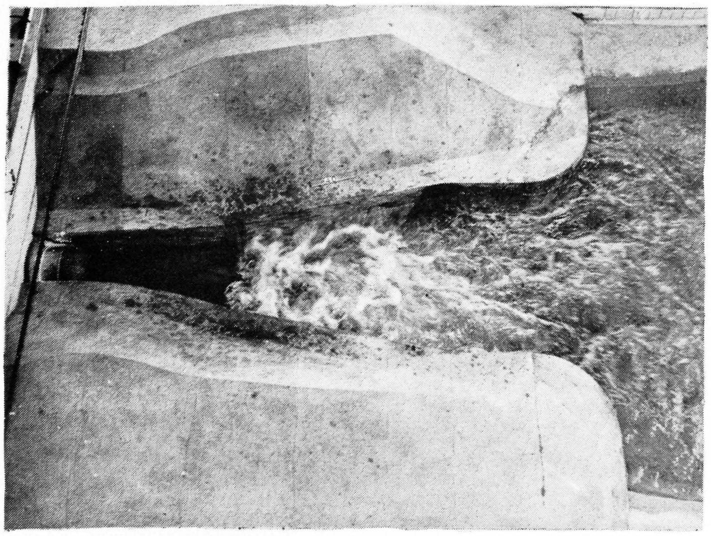


Photograph 46. Basin type DD.
View of the dry bed.



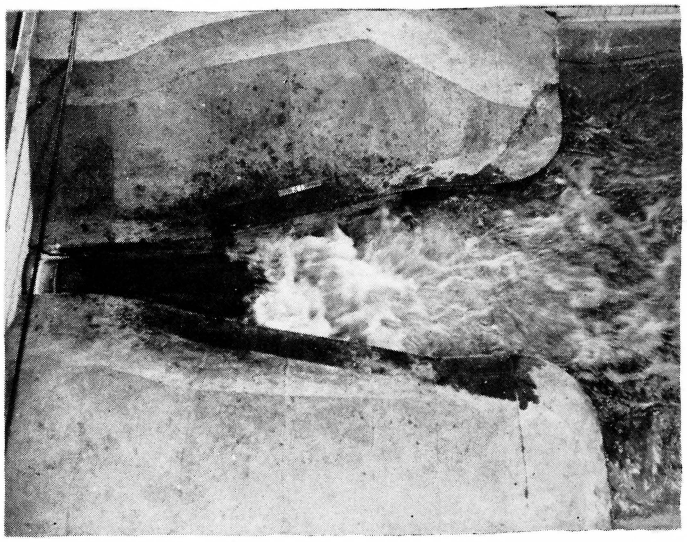
Photograph 47. Basin type DD.
H.W. = 356.6 T.W. = 340.2
Q = 5,000 c.f.s.

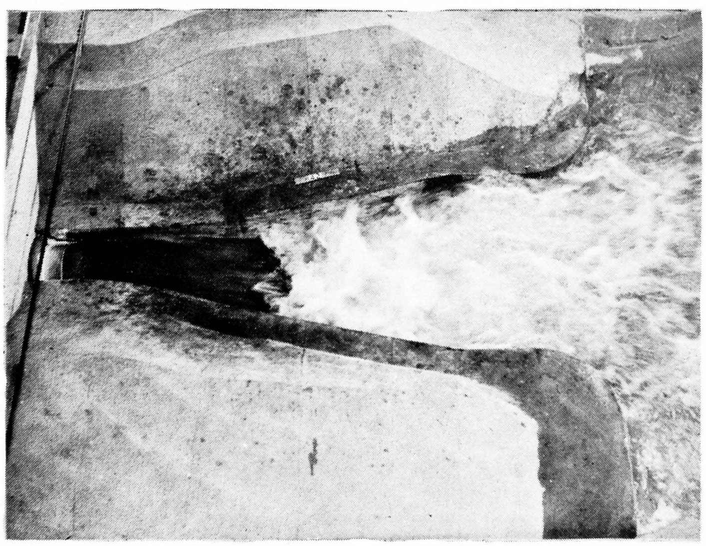
Photograph 48. Basin type DD.
H.W. = 362.0 T.W. = 344.2
Q = 7,500 c.f.s.



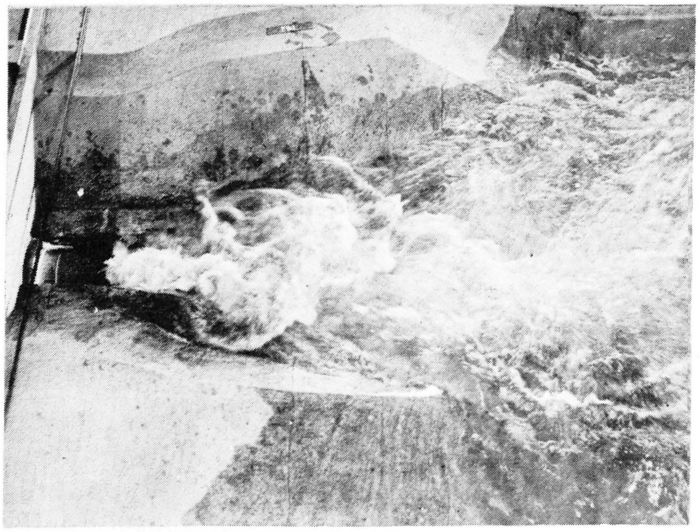
Photograph 49. Basin type DD.
H.W. = 367.7 T.W. = 347.0
Q = 10,000 c.f.s.

Photograph 50. Basin type DD.
H.W. = 381.3 T.W. = 349.5
Q = 14,500 c.f.s.

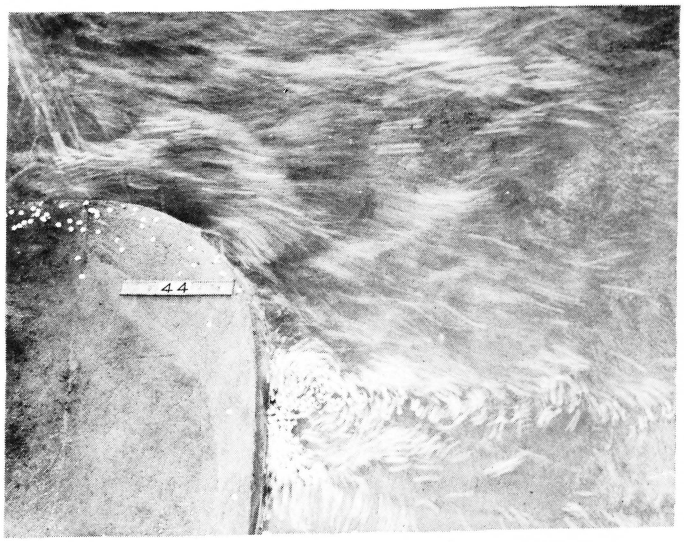




Photograph 51. Basin type DD.
H.W. = 391.0 T.W. = 350.4
Q = 17,000 c.f.s.

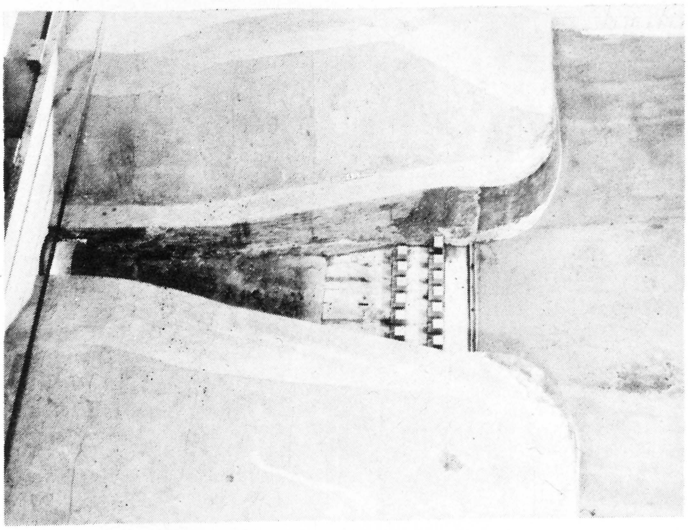


Photograph 52. Basin type DD.
H.W. = 405.2 T.W. = 366.0
Q = 19,620 c.f.s.

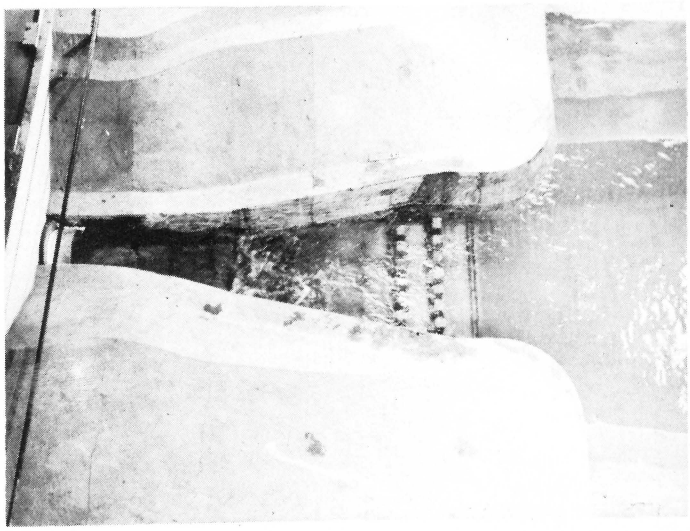


Photograph 53. View showing eddy at rounded wing wall. Radius at top of wall = 30 ft.

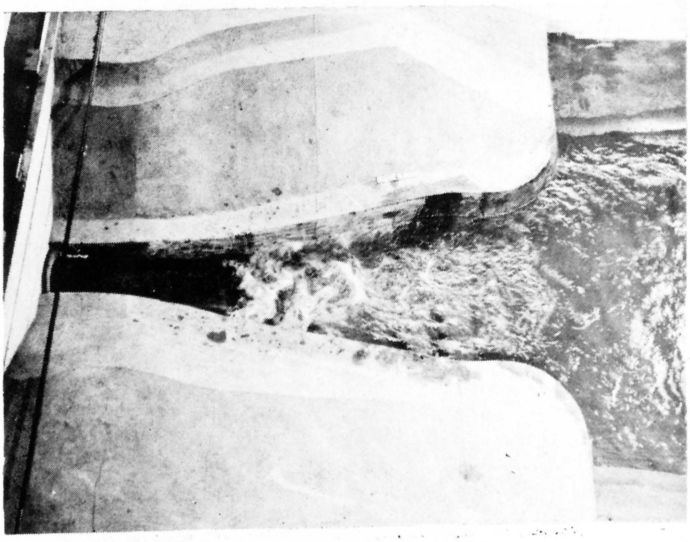
Photograph 54. View showing splash on spray walls for a discharge of 10,000 c.f.s.



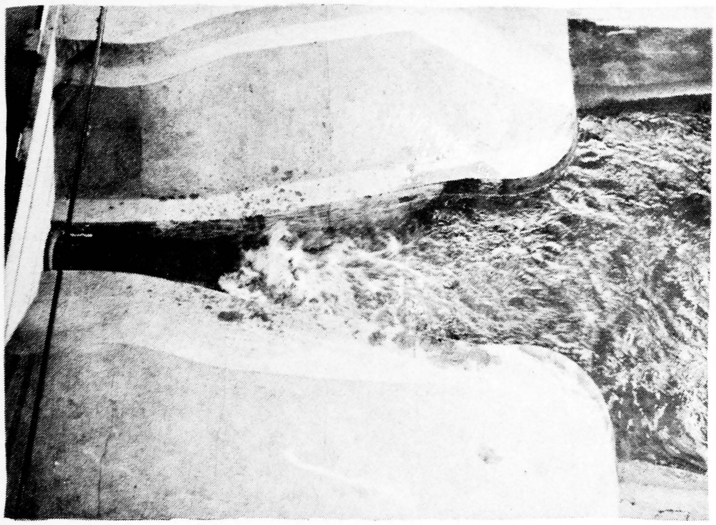
Photograph 55. Basin type GG.
View of dry bed.



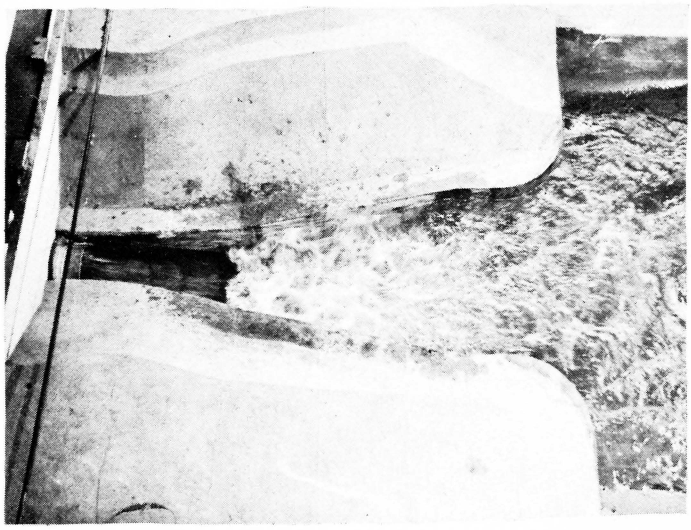
Photograph 56. Basin type GG.
H.W. = 349.0 T.W. = 334.0
Q = 2,500 c.f.s.



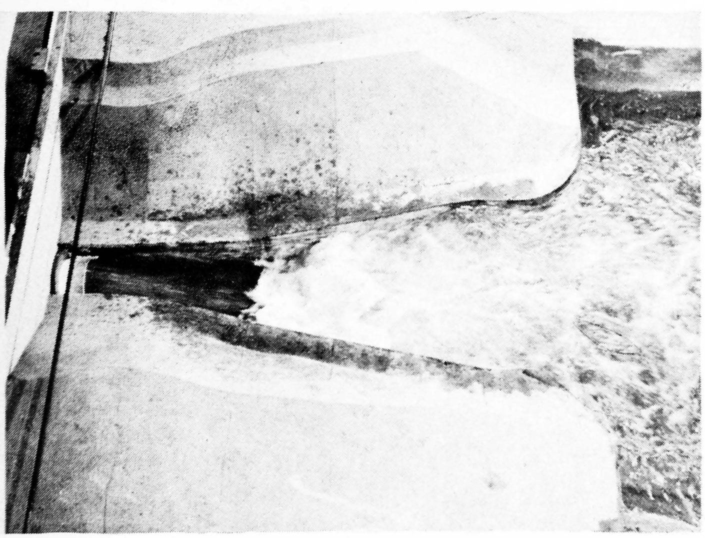
Photograph 57. Basin type GG.
H.W. = 356.5 T.W. = 340.2
Q = 5,000 c.f.s.



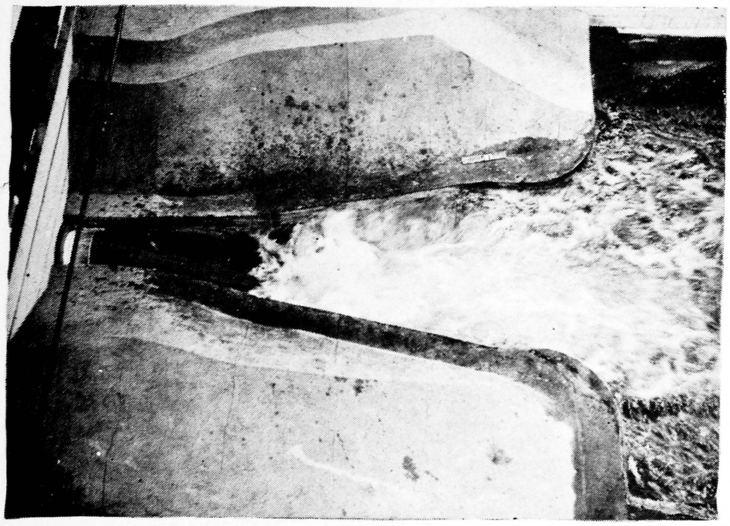
Photograph 58. Basin type GG.
H.W. = 362.5 T.W. = 344.0
Q = 7,500 c.f.s.



Photograph 59. Basin type GG.
H.W. = 367.5 T.W. = 347.0
Q = 10,000 c.f.s.

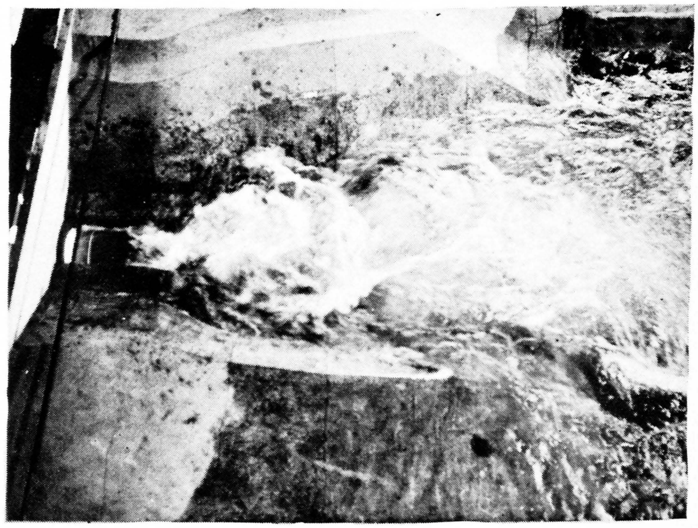


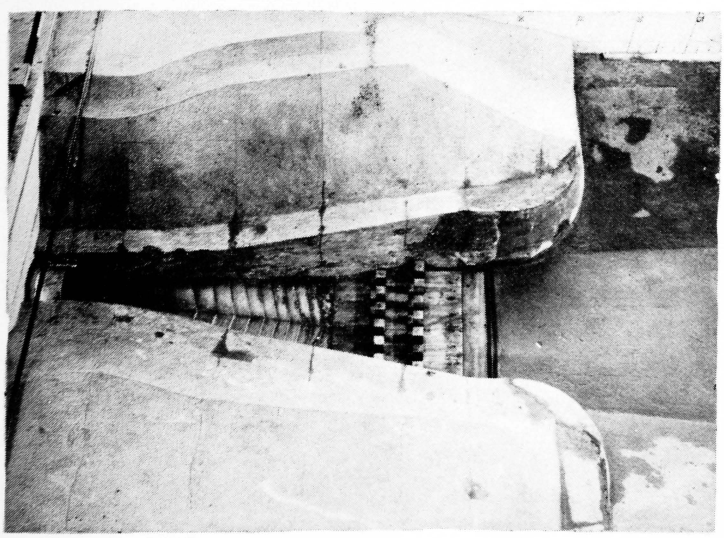
Photograph 60. Basin type GG.
H.W. = 381.3 T.W. = 350.0
Q = 14,500 c.f.s.



Photograph 61. Basin type GG.
H.W. = 391.0 T.W. = 350.4
Q = 17,000 c.f.s.

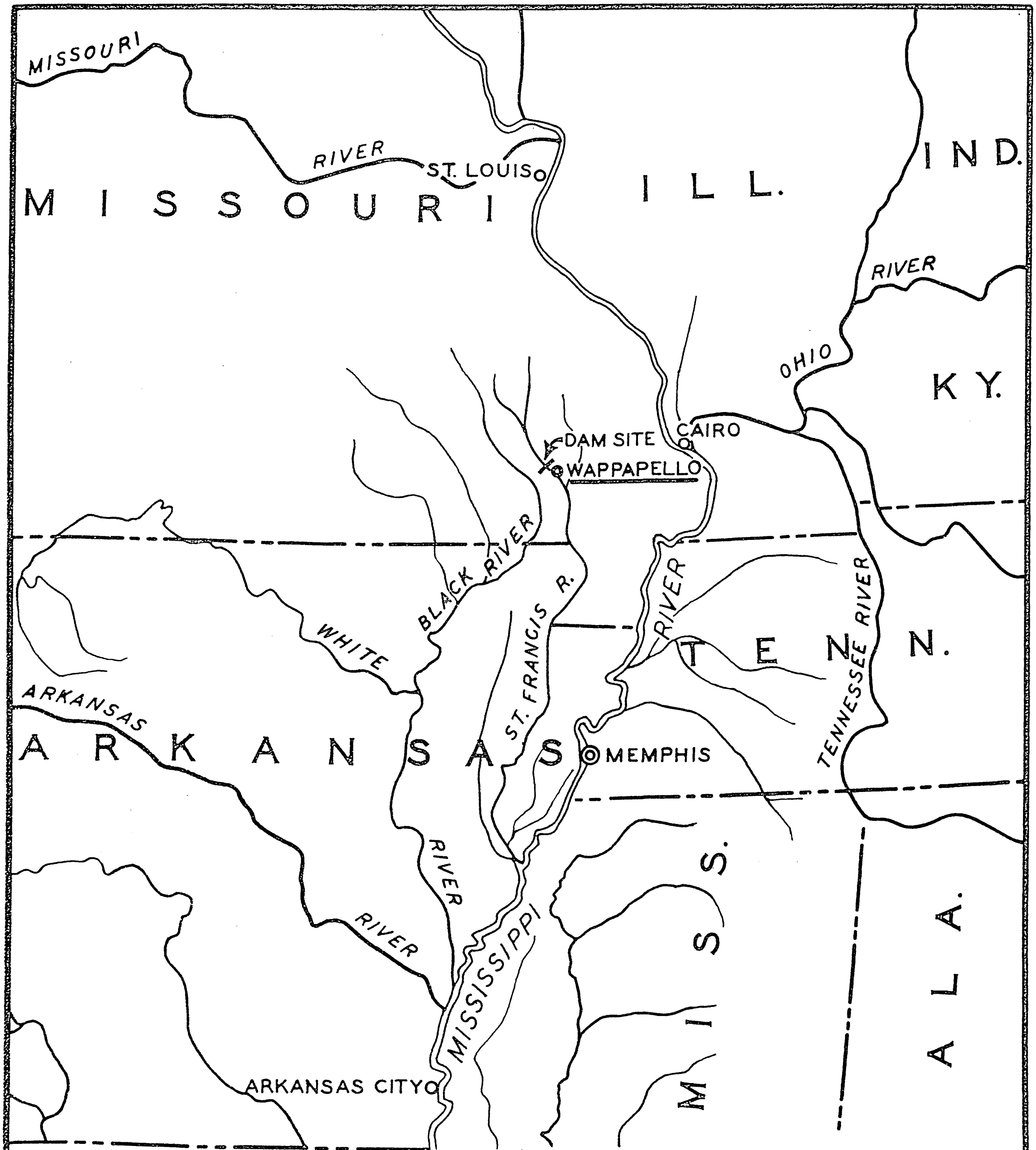
Photograph 62. Basin type GG.
H.W. = 406.1 T.W. = 366.0
Q = 19,700 c.f.s.





Photograph 63. View showing steps on type GG basin design.

PLATES

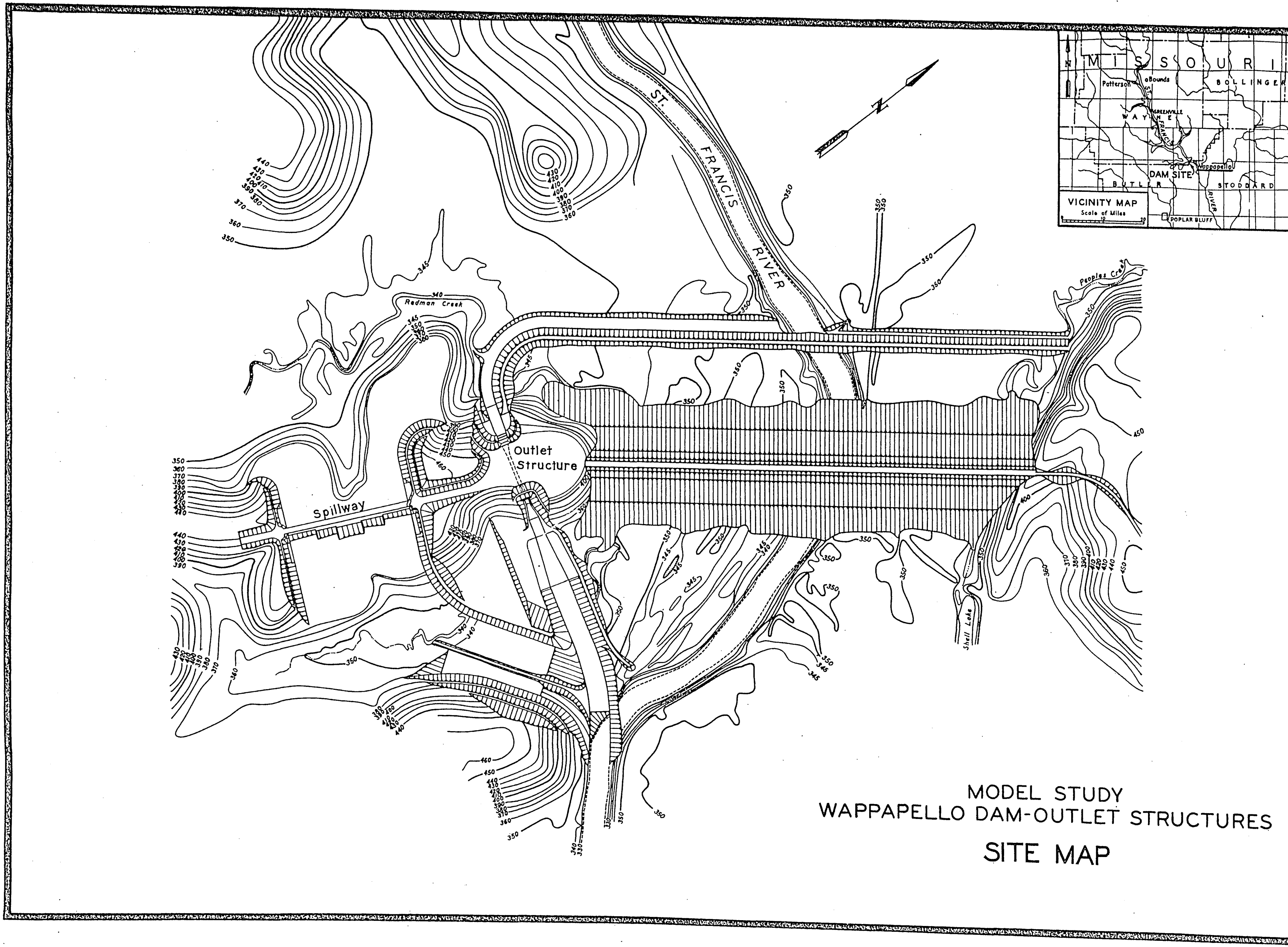


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

LOCATION MAP

SCALE
60 30 0 60 MI.
1 IN. = 60 MI.

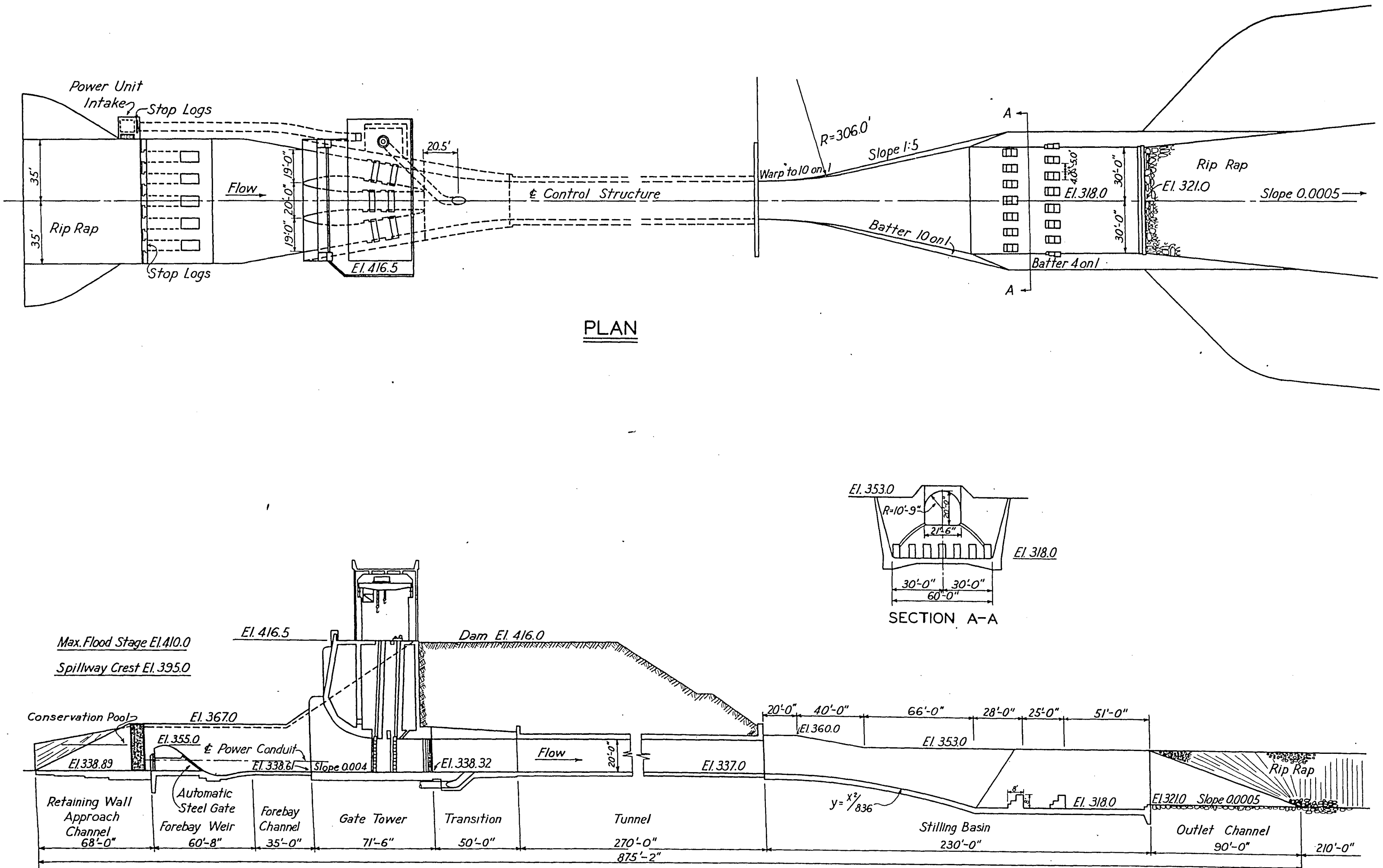
PLATE 1



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

SITE MAP

PLATE 2



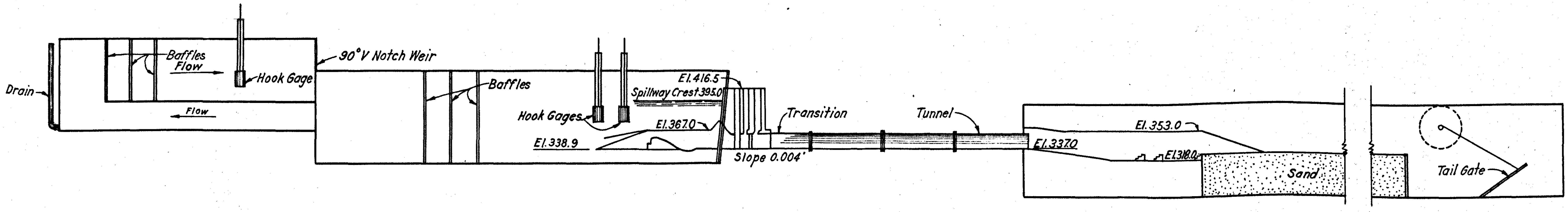
PROFILE ON ℄ CONTROL STRUCTURE

MODEL STUDY

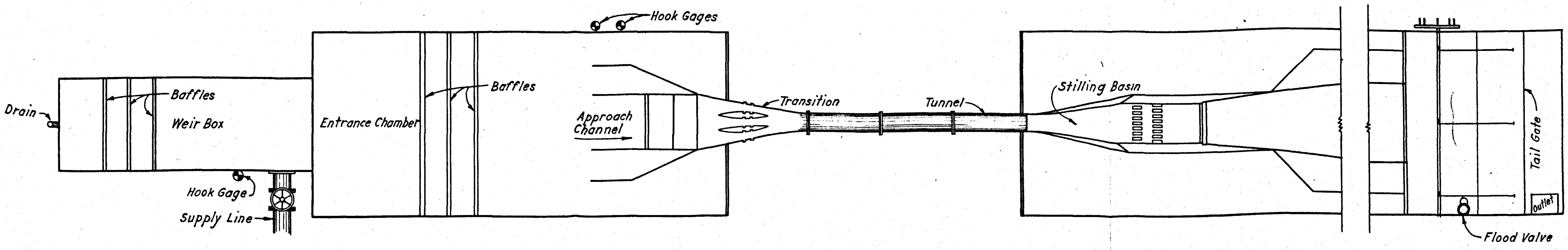
WAPPAPELLO DAM-OUTLET STRUCTURES

BASIC DESIGN

PLATE 3



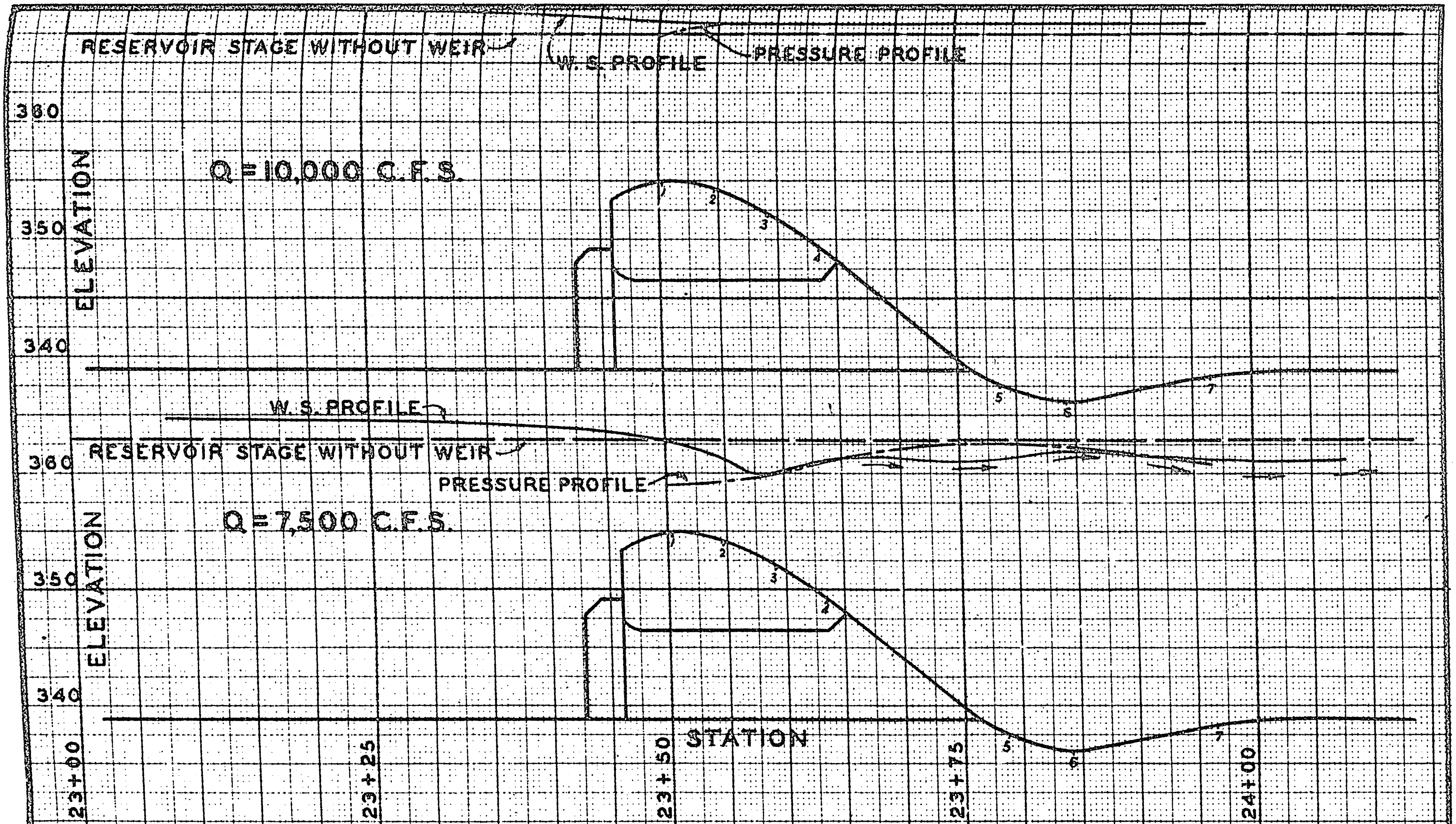
LONGITUDINAL SECTION



PLAN

MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

MODEL AND FLUME



MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
OVER THE CONSERVATION WEIR

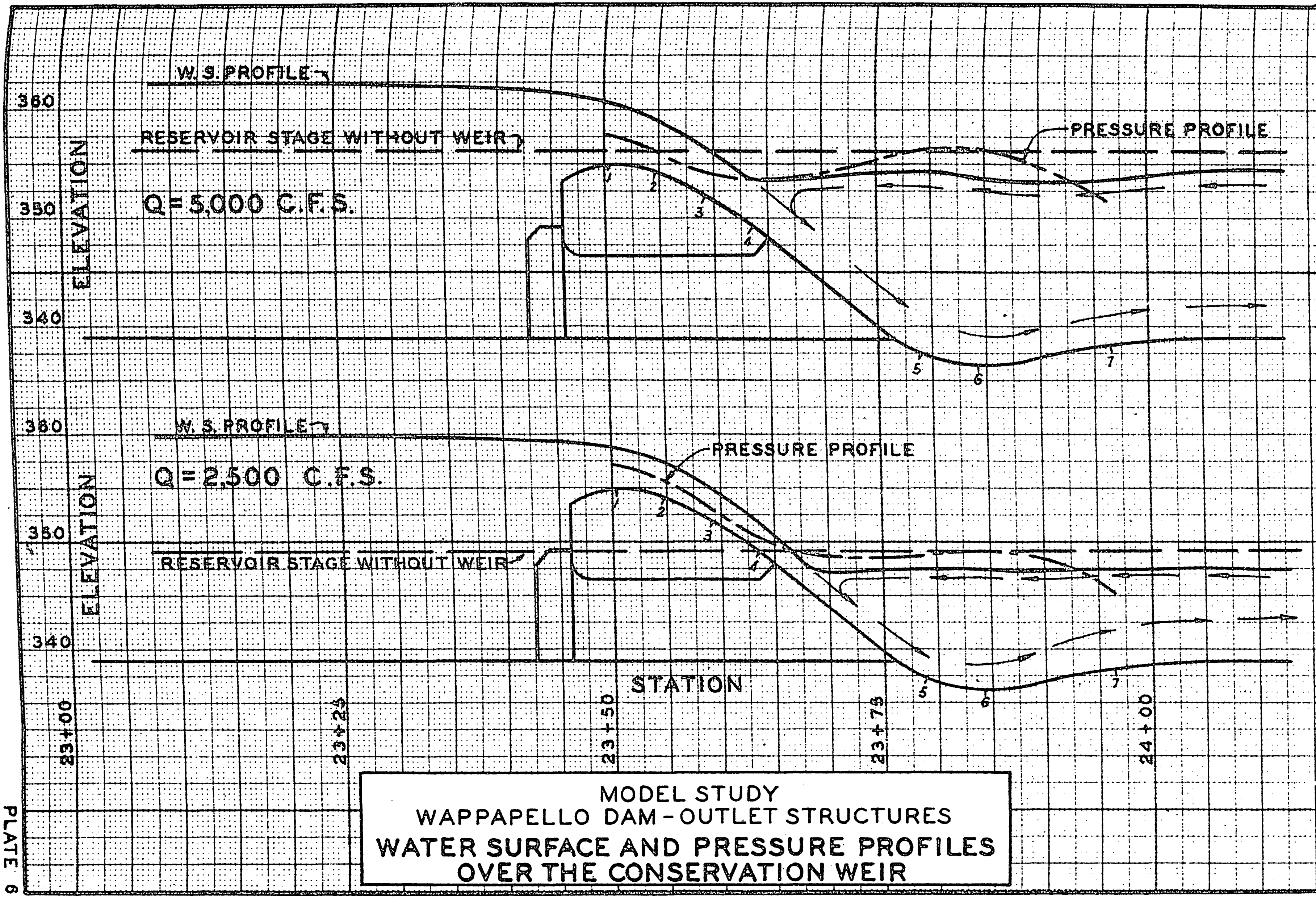
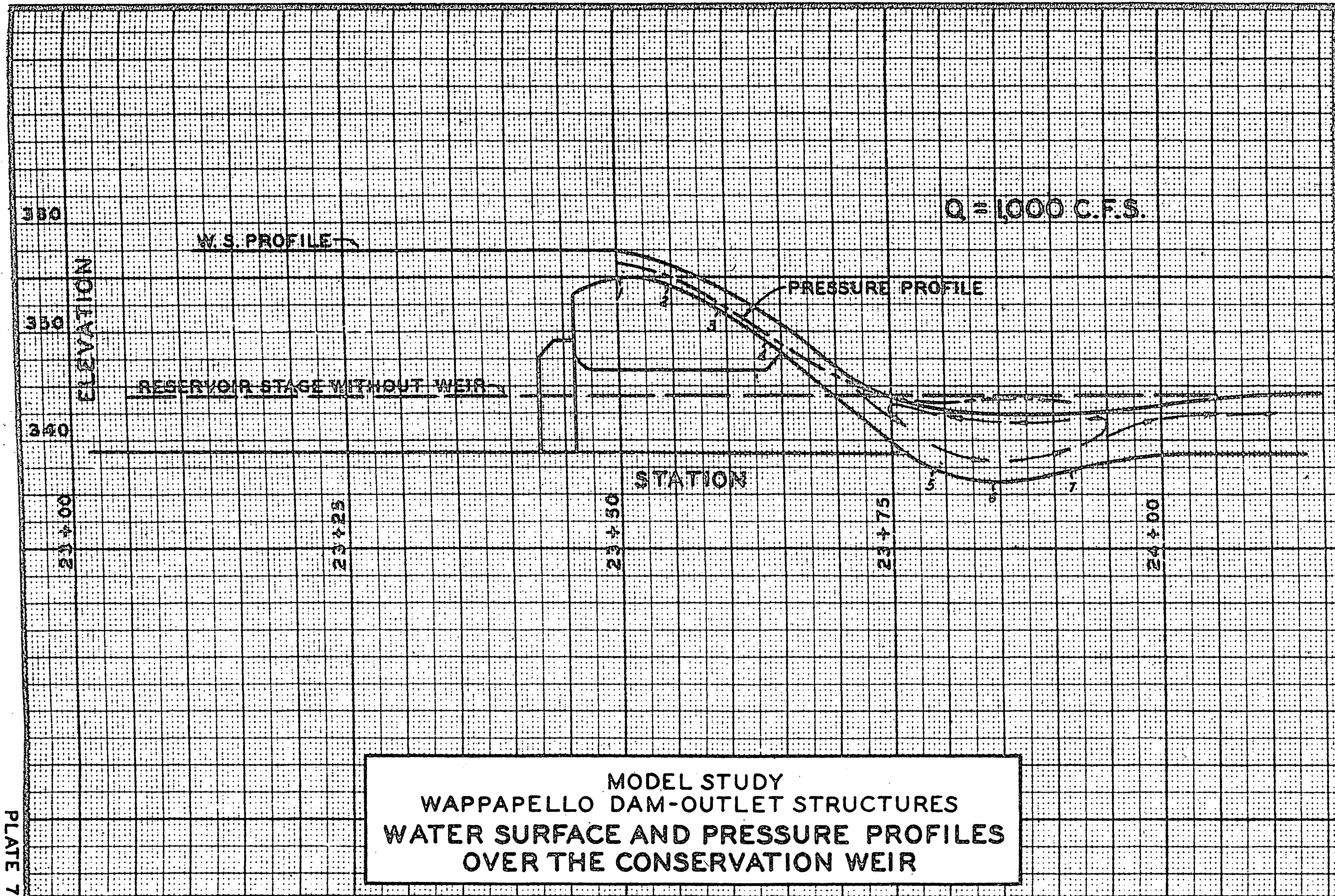
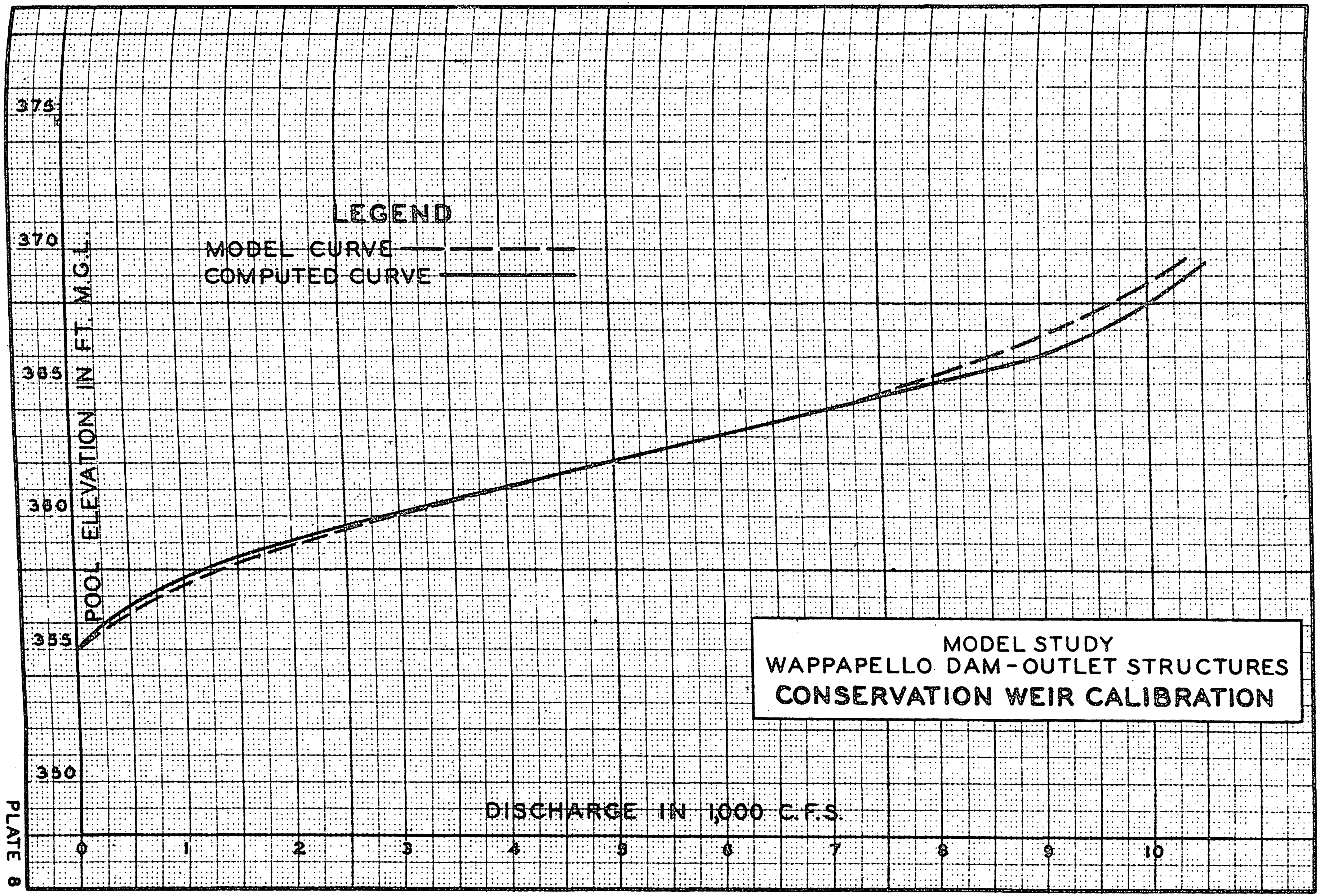

W. S. PROFILE
RESERVOIR STAGE WITHOUT WEIR
PRESSURE PROFILE
Q = 5,000 C.F.S.
ELEVATION
360
350
340
1
2
3
4
5
6
7
W. S. PROFILE
PRESSURE PROFILE
Q = 2,500 C.F.S.
RESERVOIR STAGE WITHOUT WEIR
ELEVATION
360
350
340
STATION
23+00
23+25
23+50
23+75
24+00
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
OVER THE CONSERVATION WEIR

PLATE 6



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
OVER THE CONSERVATION WEIR

PLATE 7


LEGEND
MODEL CURVE
COMPUTED CURVE
POOL ELEVATION IN FT. M.G.L.
375
370
365
360
355
350
DISCHARGE IN 1,000 C.F.S.
0
1
2
3
4
5
6
7
8
9
10
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
CONSERVATION WEIR CALIBRATION

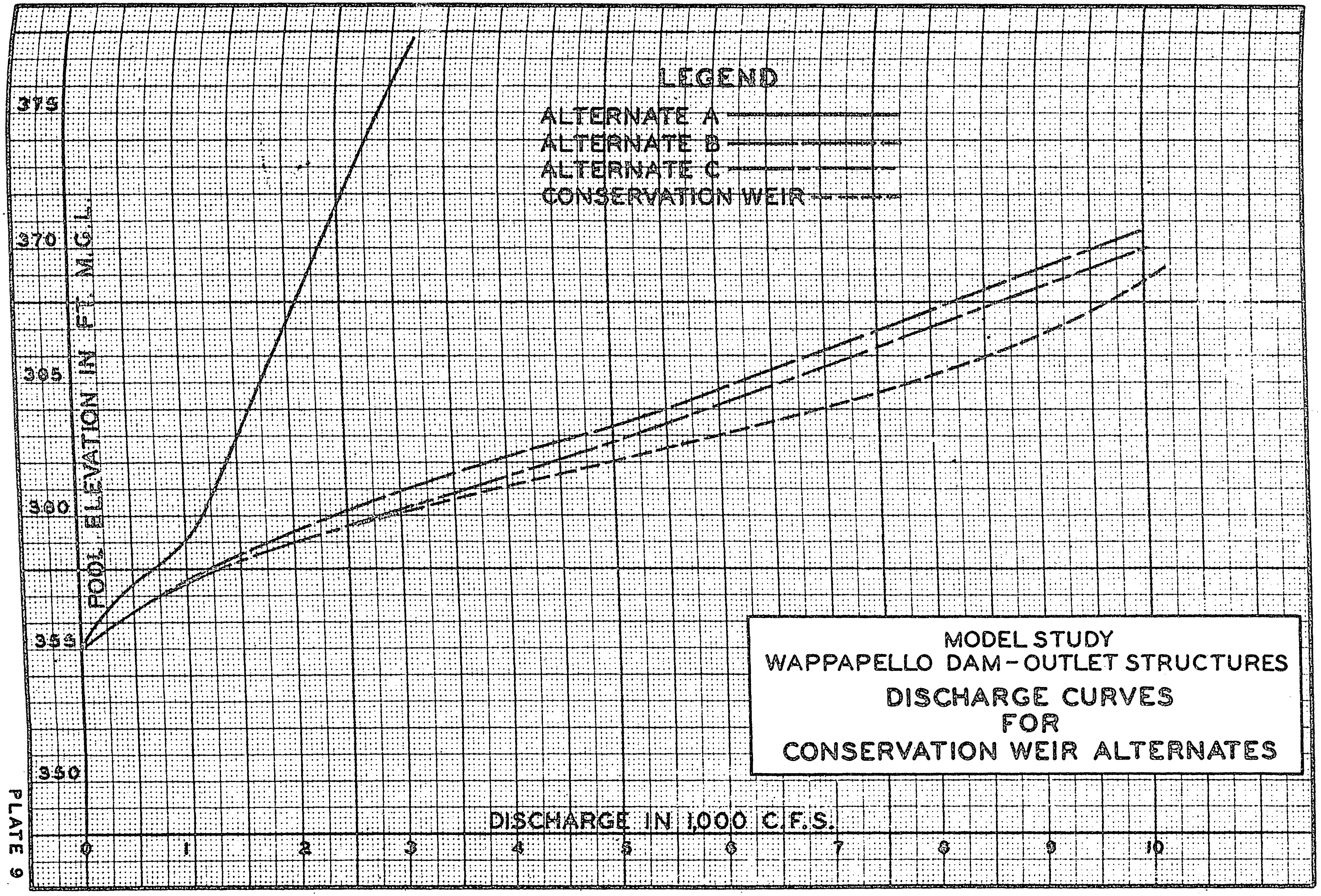
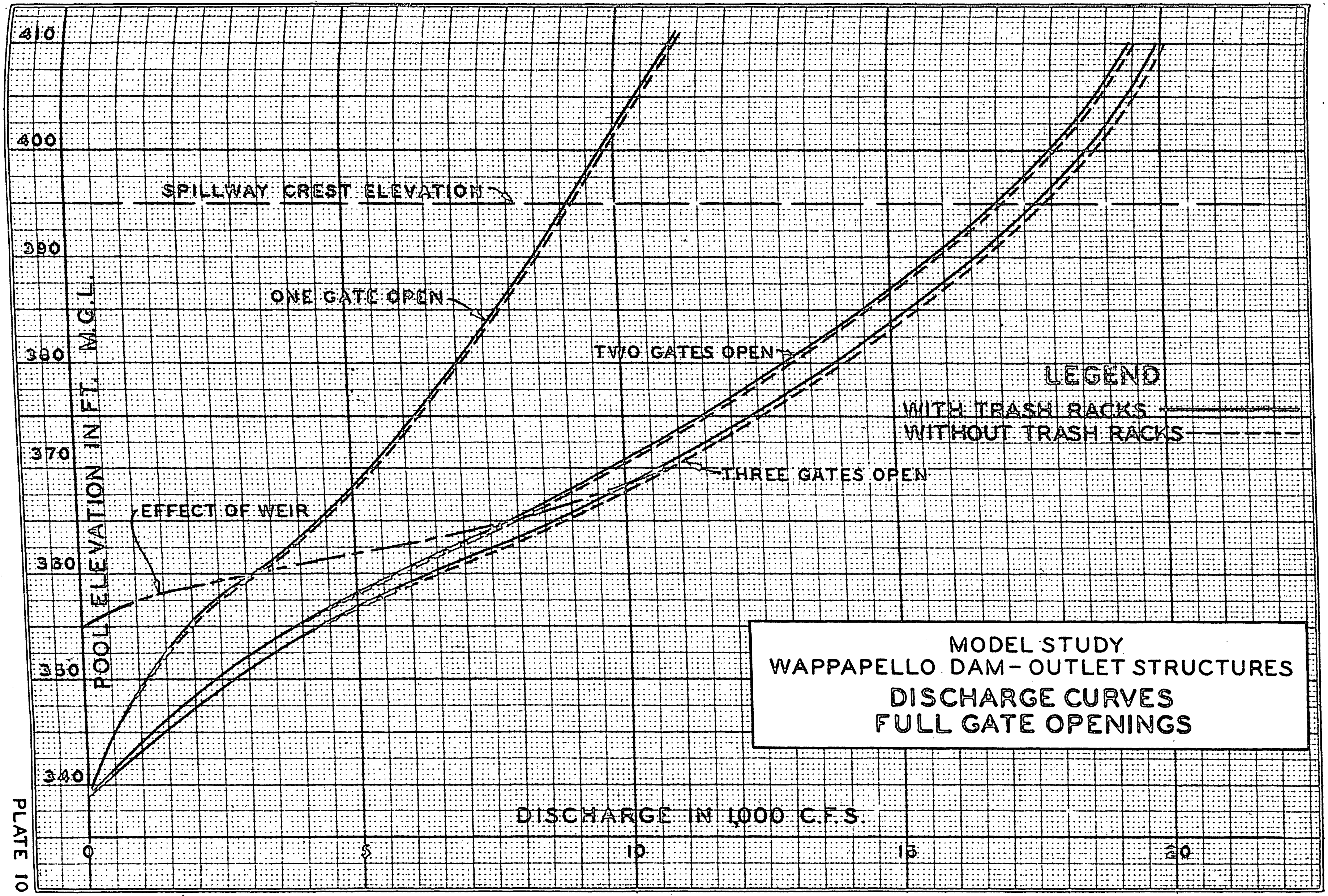
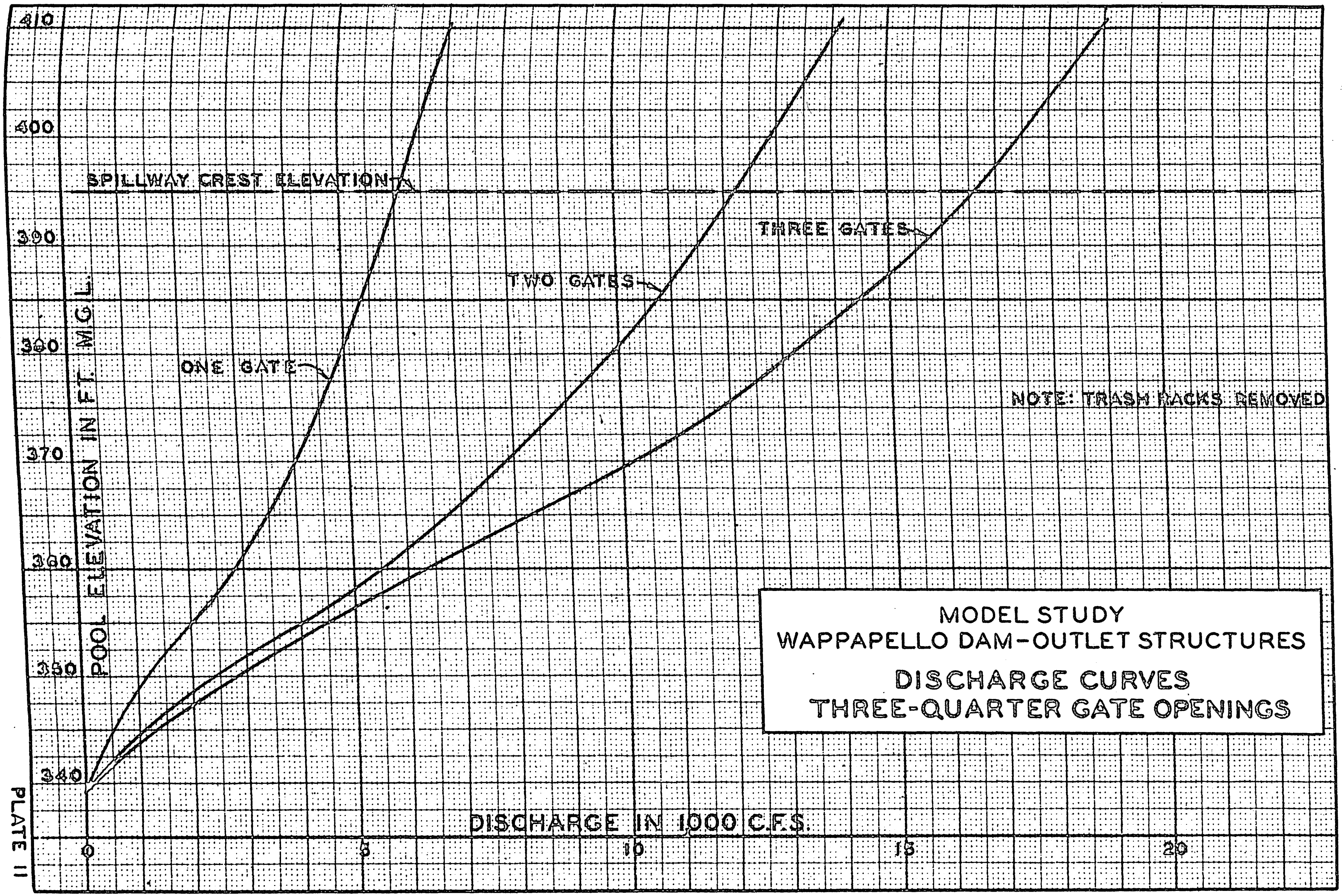

LEGEND
ALTERNATE A
ALTERNATE B
ALTERNATE C
CONSERVATION WEIR
POOL ELEVATION IN FT. M.G.L.
375
370
365
360
355
350
DISCHARGE IN 1,000 C.F.S.
0
1
2
3
4
5
6
7
8
9
10
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
DISCHARGE CURVES
FOR
CONSERVATION WEIR ALTERNATES

PLATE 9


POOL ELEVATION IN FT. M.G.L.
DISCHARGE IN 1000 C.F.S.
410
400
390
380
370
360
350
340
0
5
10
15
20
SPILLWAY CREST ELEVATION
ONE GATE OPEN
TWO GATES OPEN
THREE GATES OPEN
EFFECT OF WEIR
LEGEND
WITH TRASH RACKS
WITHOUT TRASH RACKS
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
DISCHARGE CURVES
FULL GATE OPENINGS



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
DISCHARGE CURVES
THREE-QUARTER GATE OPENINGS

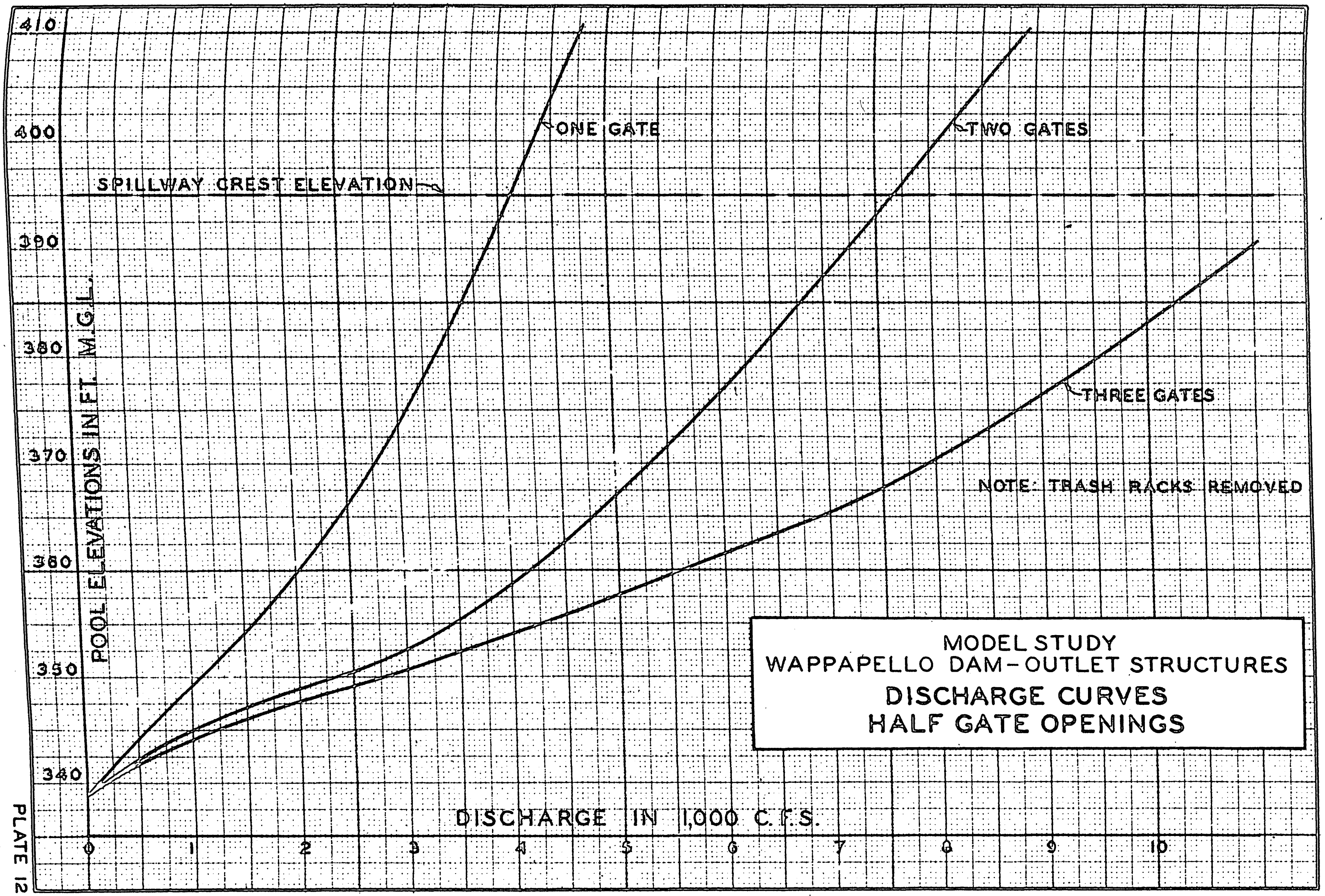
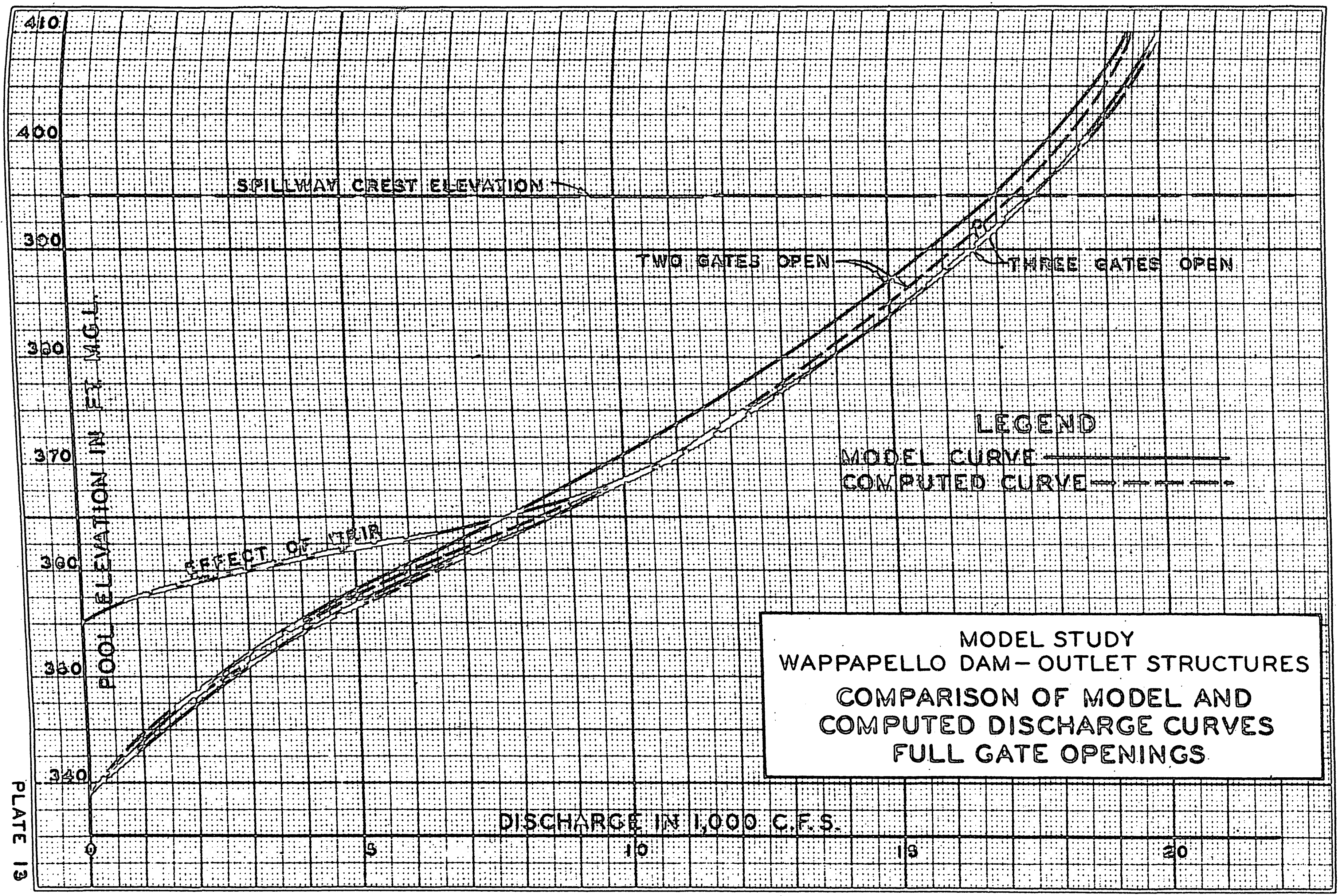

410
400
390
380
370
360
350
340
POOL ELEVATIONS IN FT. M.G.L.
SPILLWAY CREST ELEVATION
ONE GATE
TWO GATES
THREE GATES
NOTE: TRASH RACKS REMOVED
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
DISCHARGE CURVES
HALF GATE OPENINGS
DISCHARGE IN 1,000 C.F.S.
0
1
2
3
4
5
6
7
8
9
10

PLATE 12



MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES
COMPARISON OF MODEL AND
COMPUTED DISCHARGE CURVES
FULL GATE OPENINGS

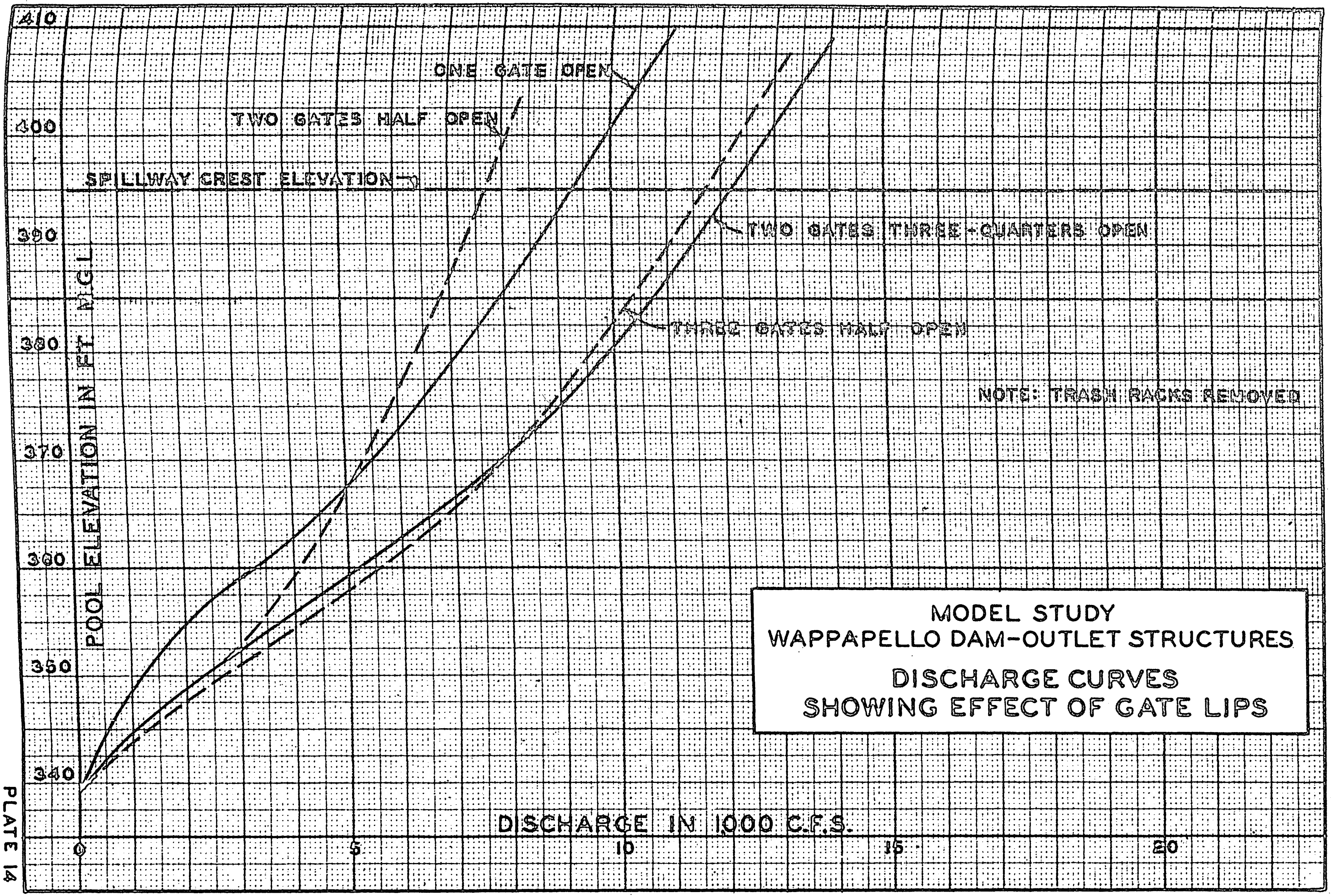
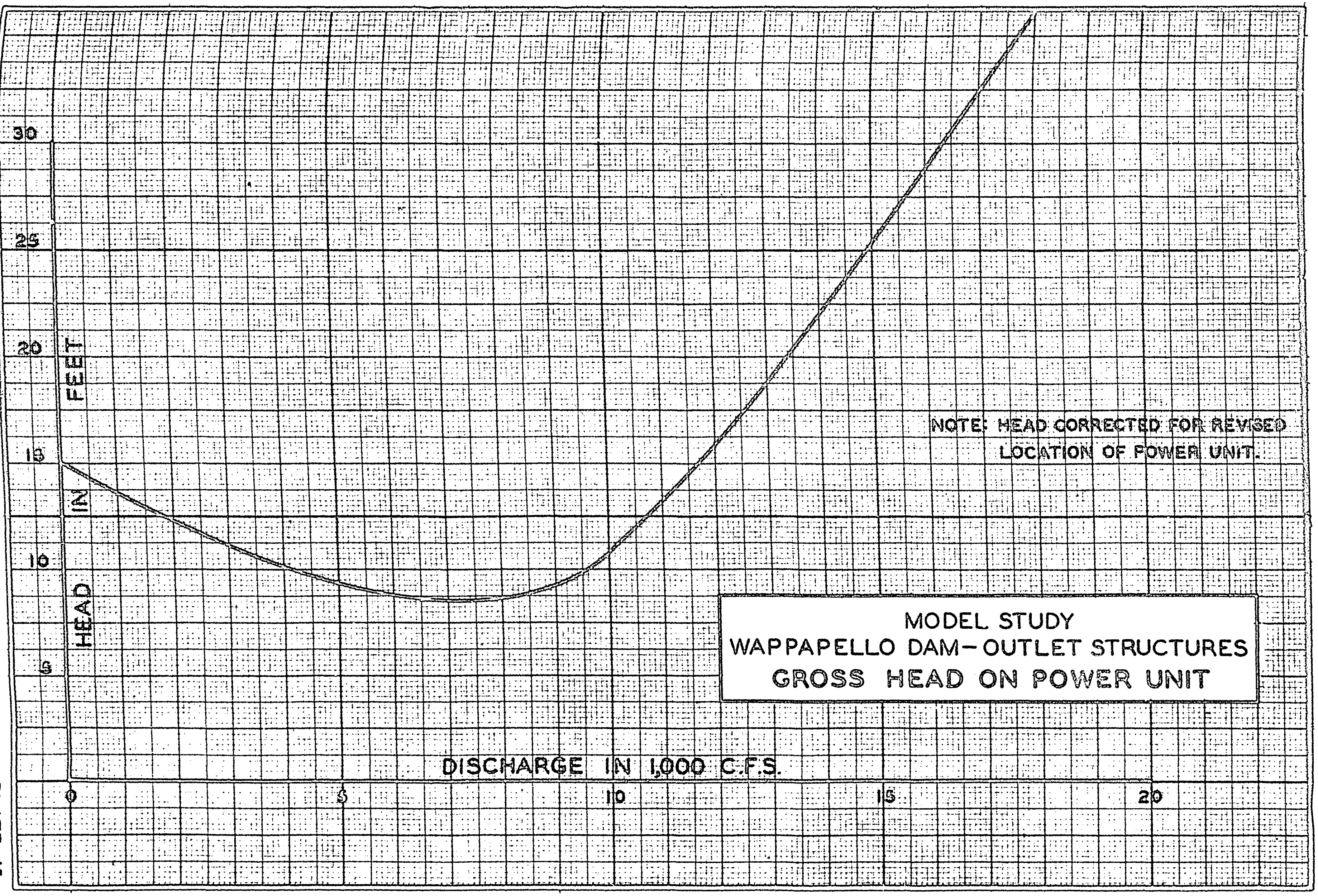
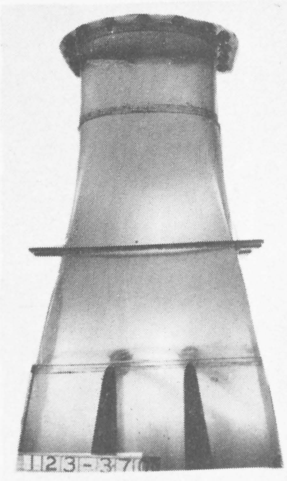

MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
DISCHARGE CURVES
SHOWING EFFECT OF GATE LIPS
POOL ELEVATION IN FT M.G.L.
DISCHARGE IN 1,000 C.F.S.
ONE GATE OPEN
TWO GATES HALF OPEN
SPILLWAY CREST ELEVATION
TWO GATES THREE-QUARTERS OPEN
THREE GATES HALF OPEN
NOTE: TRASH RACKS REMOVED
410
400
390
380
370
360
350
340
0
5
10
15
20

PLATE 14

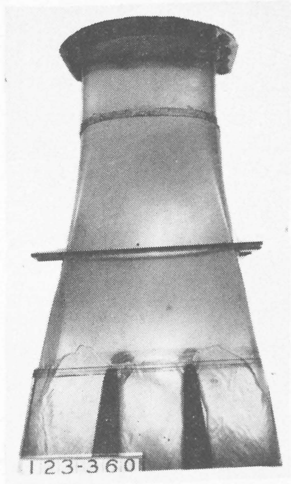


MODEL STUDY
WAPPAPELLO DAM—OUTLET STRUCTURES
GROSS HEAD ON POWER UNIT

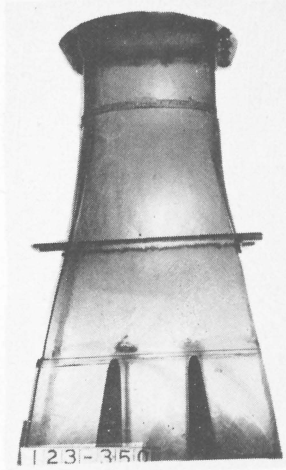
PLATE 15



Reservoir Stage = 370

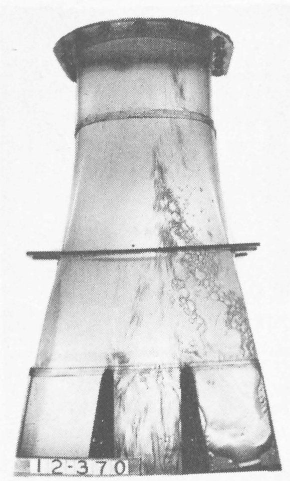


Reservoir Stage = 360

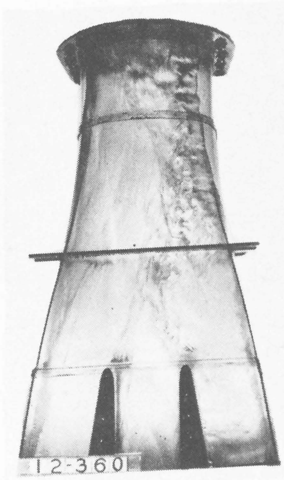


Reservoir Stage = 350

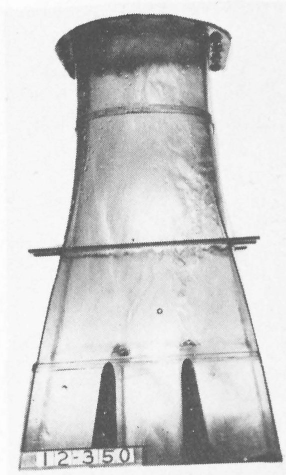
G A T E S 1, 2, AND 3 O P E N



Reservoir Stage = 370

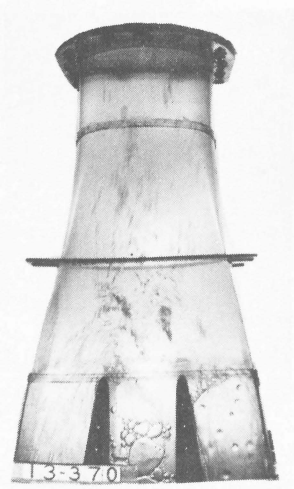


Reservoir Stage = 360

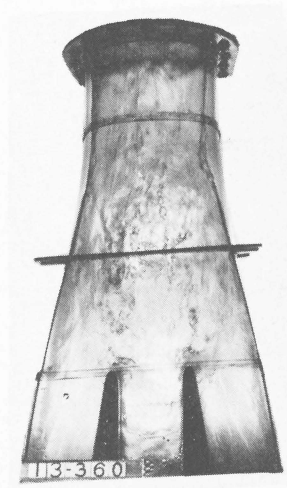


Reservoir Stage = 350

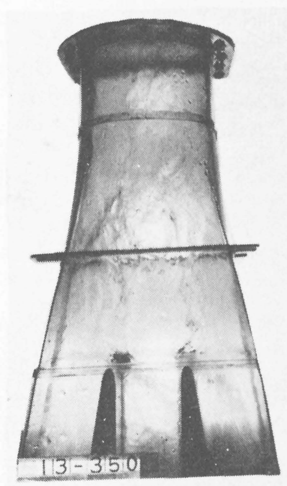
G A T E S 1 A N D 2 O P E N



Reservoir Stage = 370



Reservoir Stage = 360

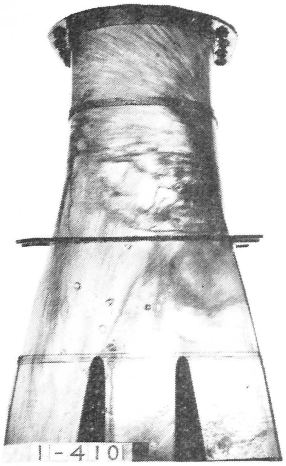


Reservoir Stage = 350

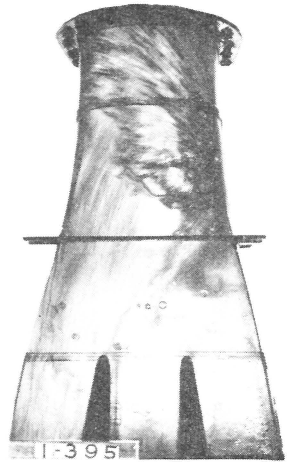
G A T E S 1 A N D 3 O P E N

Model Study
Wappapello Dam--Outlet Structures

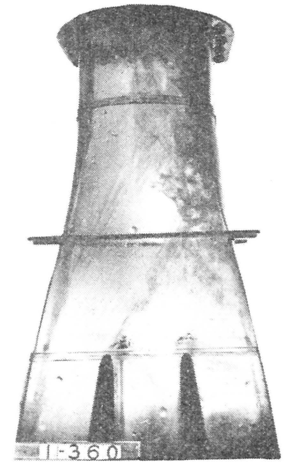
FLOW THROUGH TRANSITION SECTION--FULL GATE OPENINGS



Reservoir Stage = 410

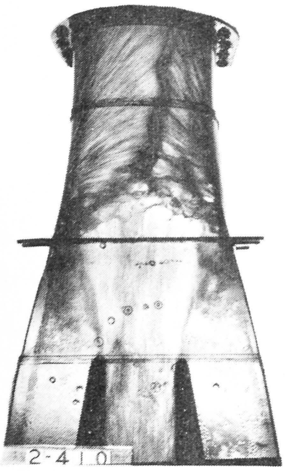


Reservoir Stage = 395

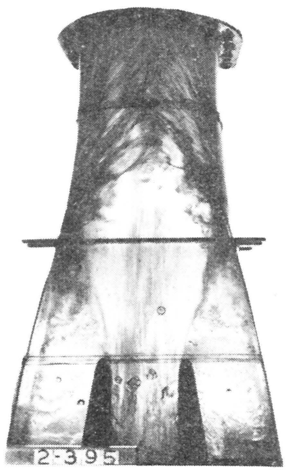


Reservoir Stage = 360

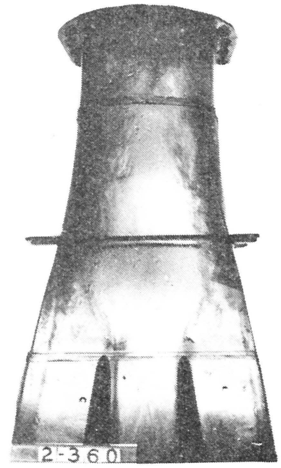
G A T E 1 O P E N



Reservoir Stage = 410



Reservoir Stage = 395

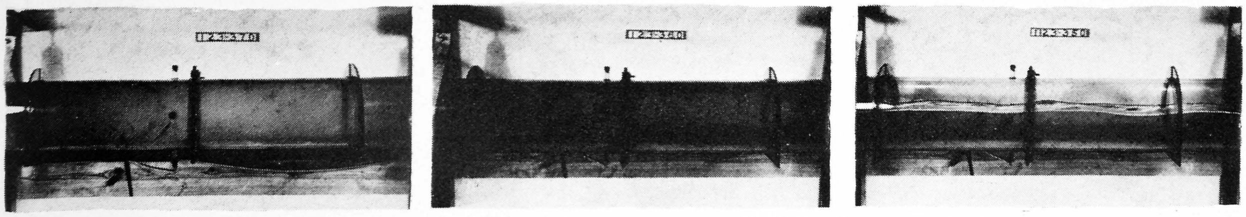


Reservoir Stage = 360

G A T E 2 O P E N

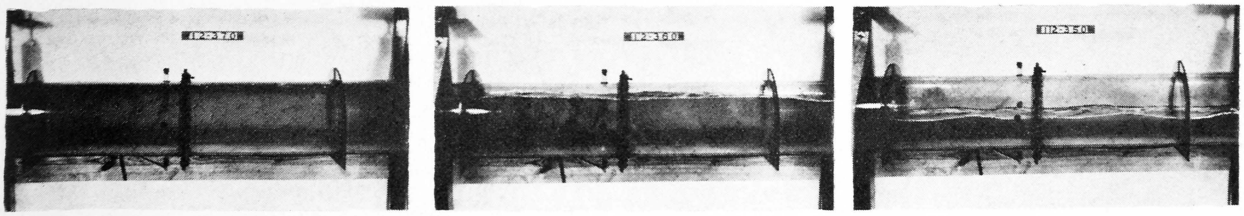
Model Study
Wappapello Dam--Outlet Structures

FLOW THROUGH TRANSITION SECTION--FULL GATE OPENINGS



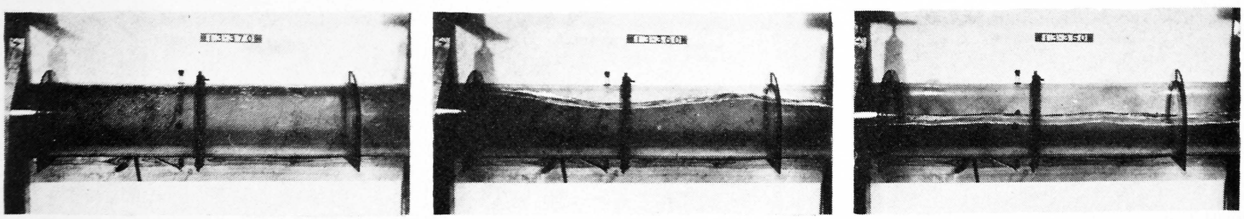
Reservoir Stage = 370 | Reservoir Stage = 360 | Reservoir Stage = 350

G A T E S 1, 2, A N D 3 O P E N



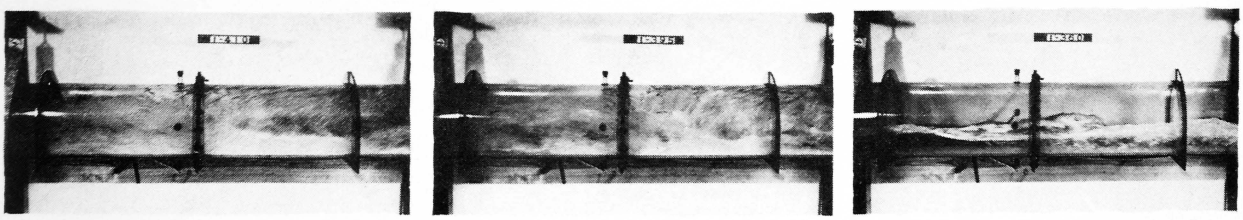
Reservoir Stage = 370 | Reservoir Stage = 360 | Reservoir Stage = 350

G A T E S 1 A N D 2 O P E N



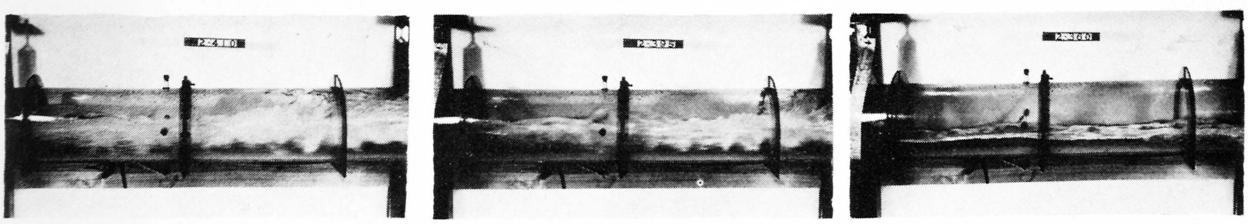
Reservoir Stage = 370 | Reservoir Stage = 360 | Reservoir Stage = 350

G A T E S 1 A N D 3 O P E N



Reservoir Stage = 410 | Reservoir Stage = 395 | Reservoir Stage = 360

G A T E 1 O P E N

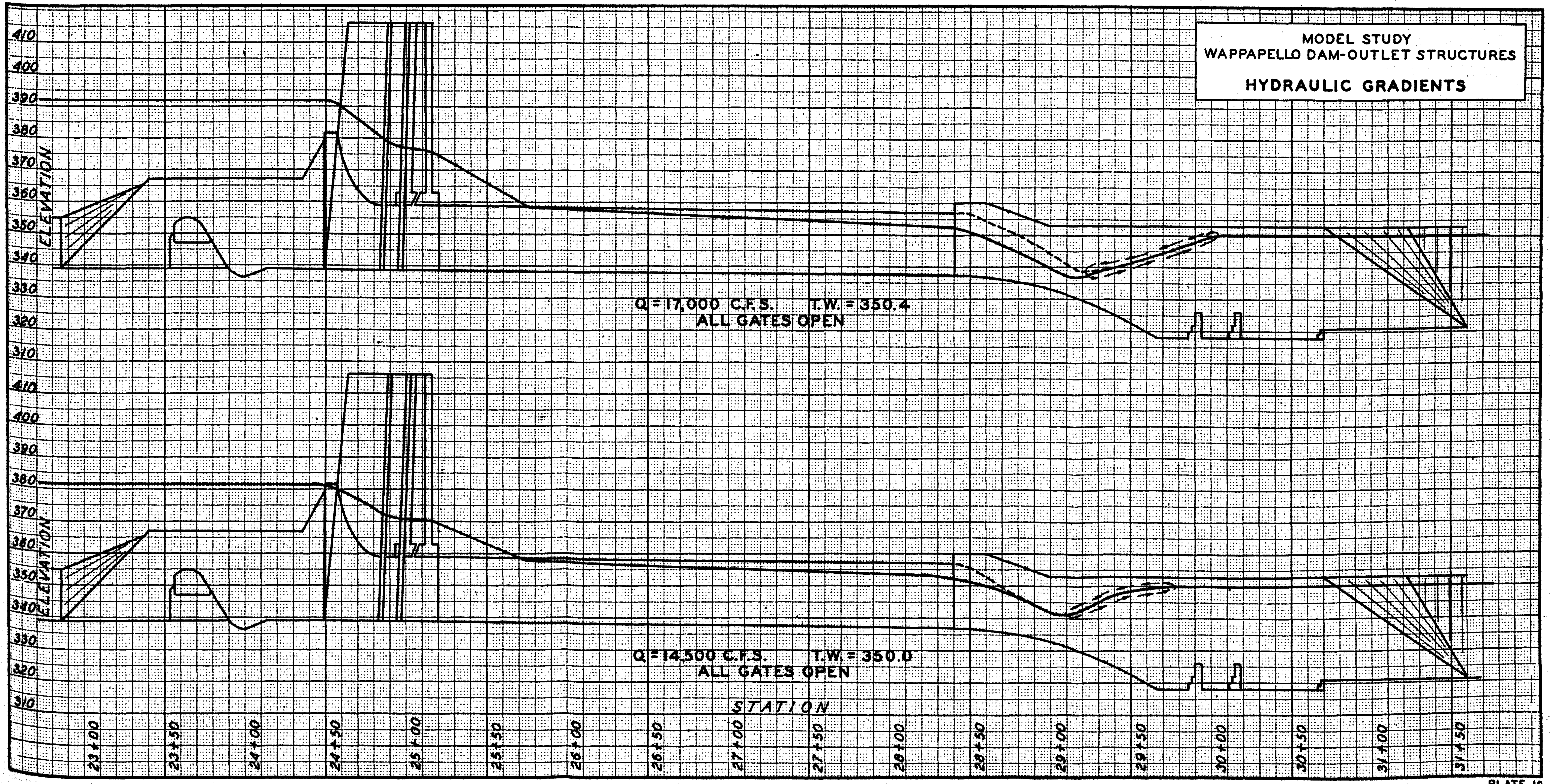


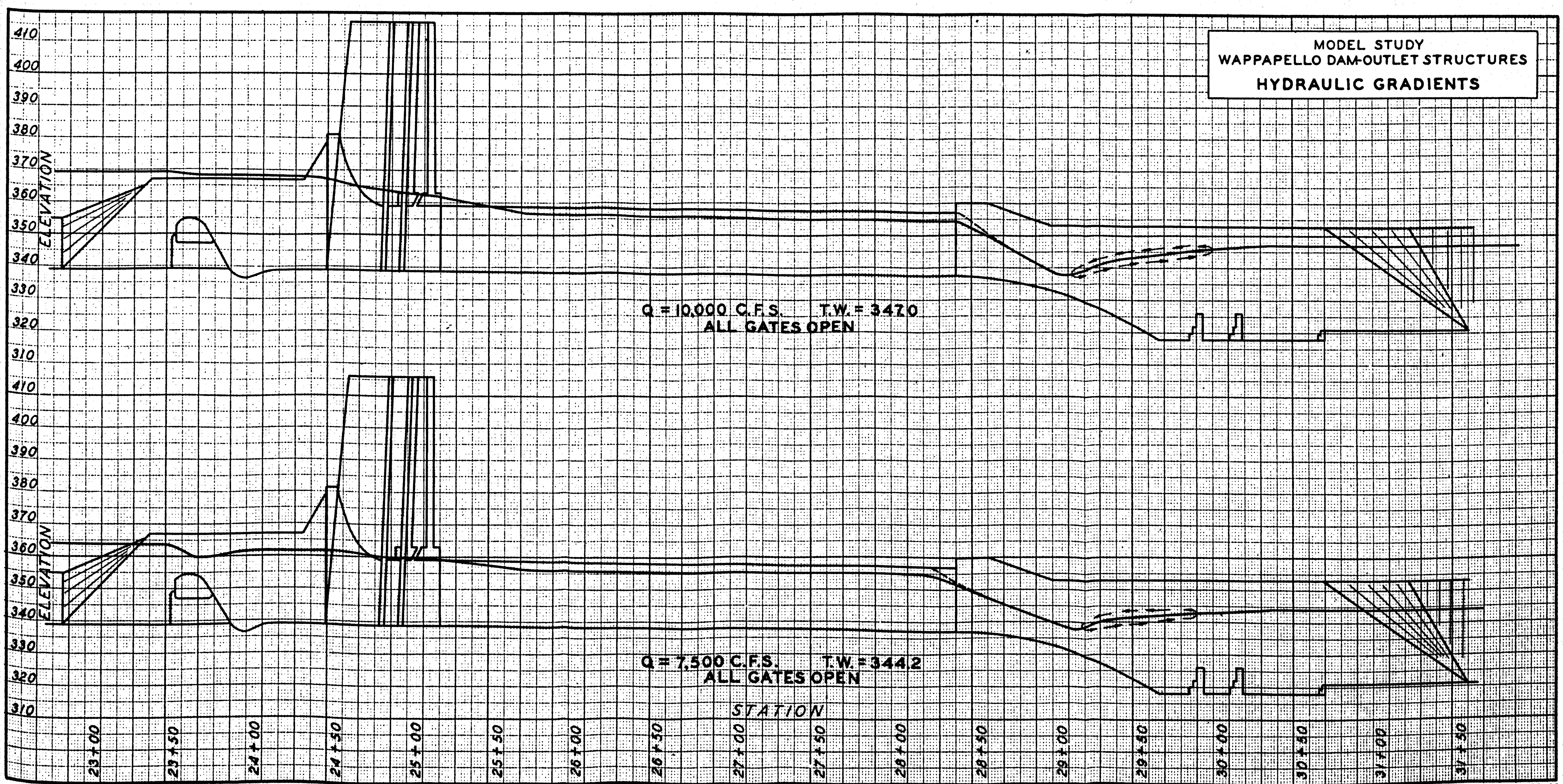
Reservoir Stage = 410 | Reservoir Stage = 395 | Reservoir Stage = 360

G A T E 2 O P E N

Model Study
Wappapello Dam--Outlet Structures

FLOW THROUGH UPSTREAM SECTION OF TUNNEL--FULL GATE OPENINGS


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
HYDRAULIC GRADIENTS
ELEVATION
410
400
390
380
370
360
350
340
330
320
310
Q = 17,000 C.F.S. T.W. = 350.4
ALL GATES OPEN
Q = 14,500 C.F.S. T.W. = 350.0
ALL GATES OPEN
STATION
23+00
23+50
24+00
24+50
25+00
25+50
26+00
26+50
27+00
27+50
28+00
28+50
29+00
29+50
30+00
30+50
31+00
31+50


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
HYDRAULIC GRADIENTS
Q = 10,000 C.F.S. T.W. = 347.0
ALL GATES OPEN
Q = 7,500 C.F.S. T.W. = 344.2
ALL GATES OPEN
ELEVATION
STATION
410
400
390
380
370
360
350
340
330
320
310
23+00
23+50
24+00
24+50
25+00
25+50
26+00
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27+00
27+50
28+00
28+50
29+00
29+50
30+00
30+50
31+00
31+50

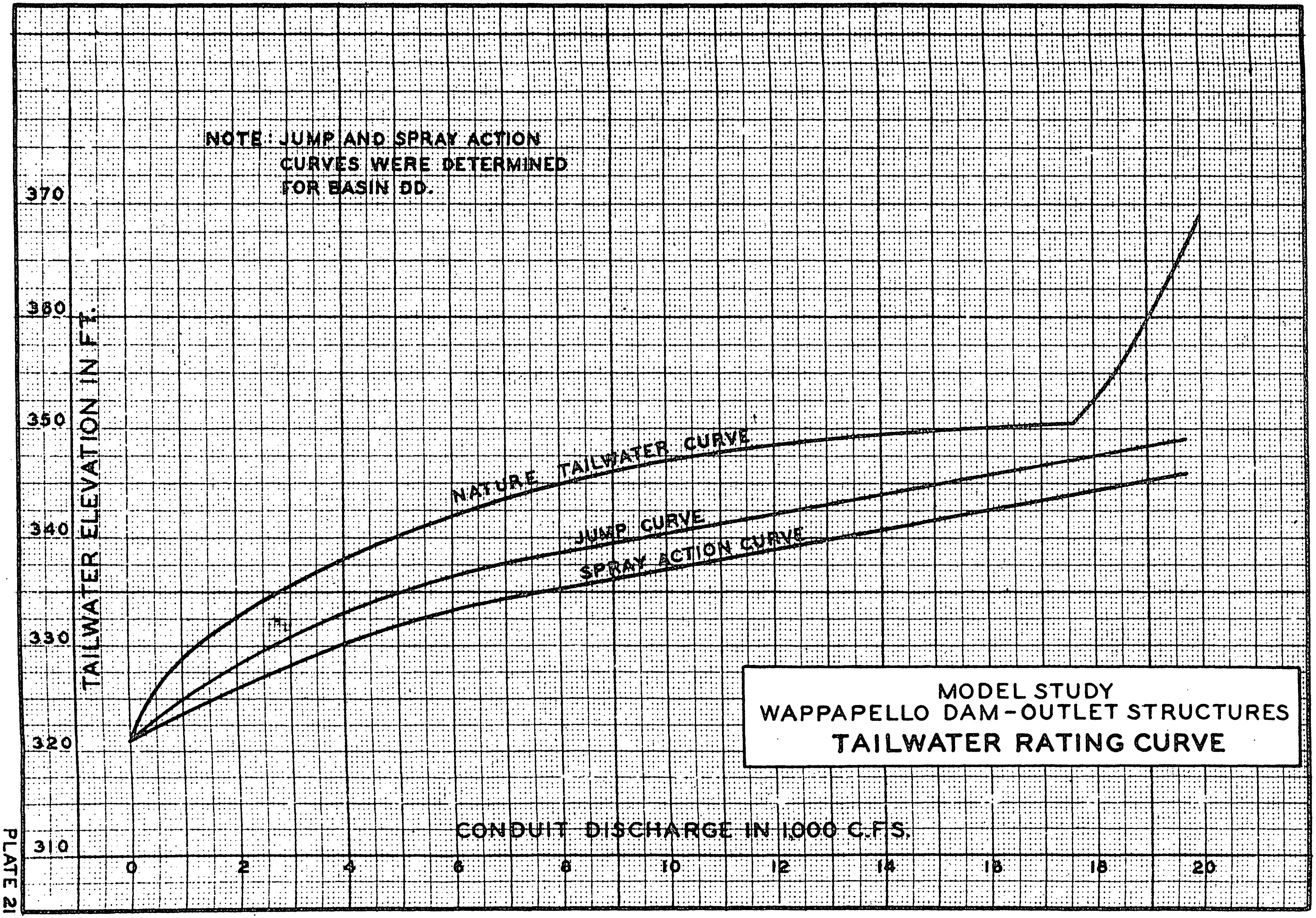
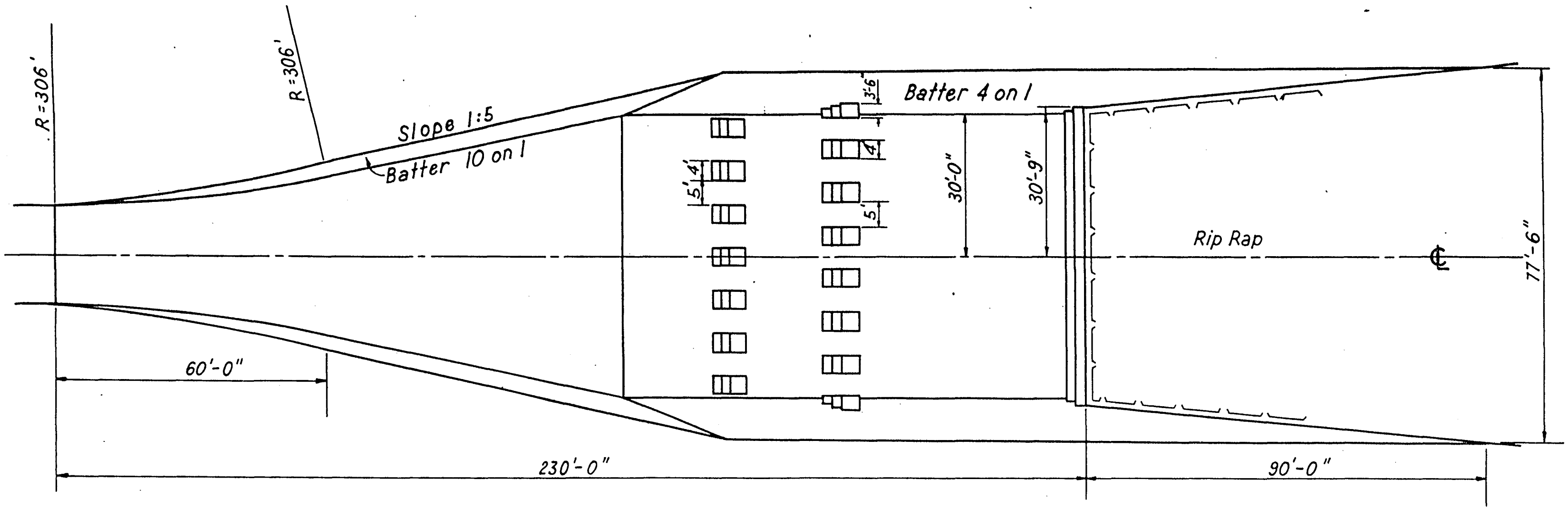
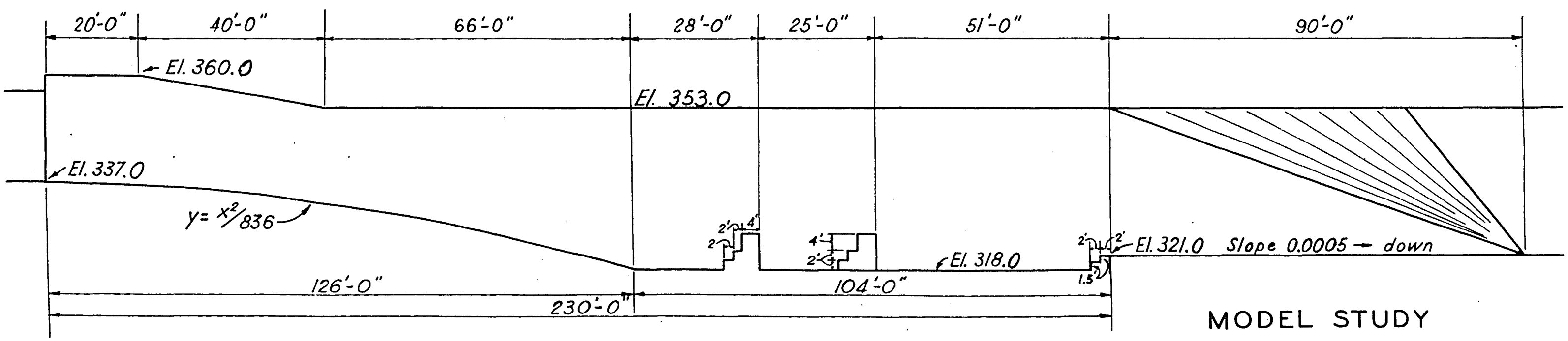

NOTE: JUMP AND SPRAY ACTION
CURVES WERE DETERMINED
FOR BASIN DD.
370
360
350
340
330
320
310
TAILWATER ELEVATION IN FT.
NATURE TAILWATER CURVE
JUMP CURVE
SPRAY ACTION CURVE
0
2
4
6
8
10
12
14
16
18
20
CONDUIT DISCHARGE IN 1,000 C.F.S.
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
TAILWATER RATING CURVE

PLATE 21



PLAN

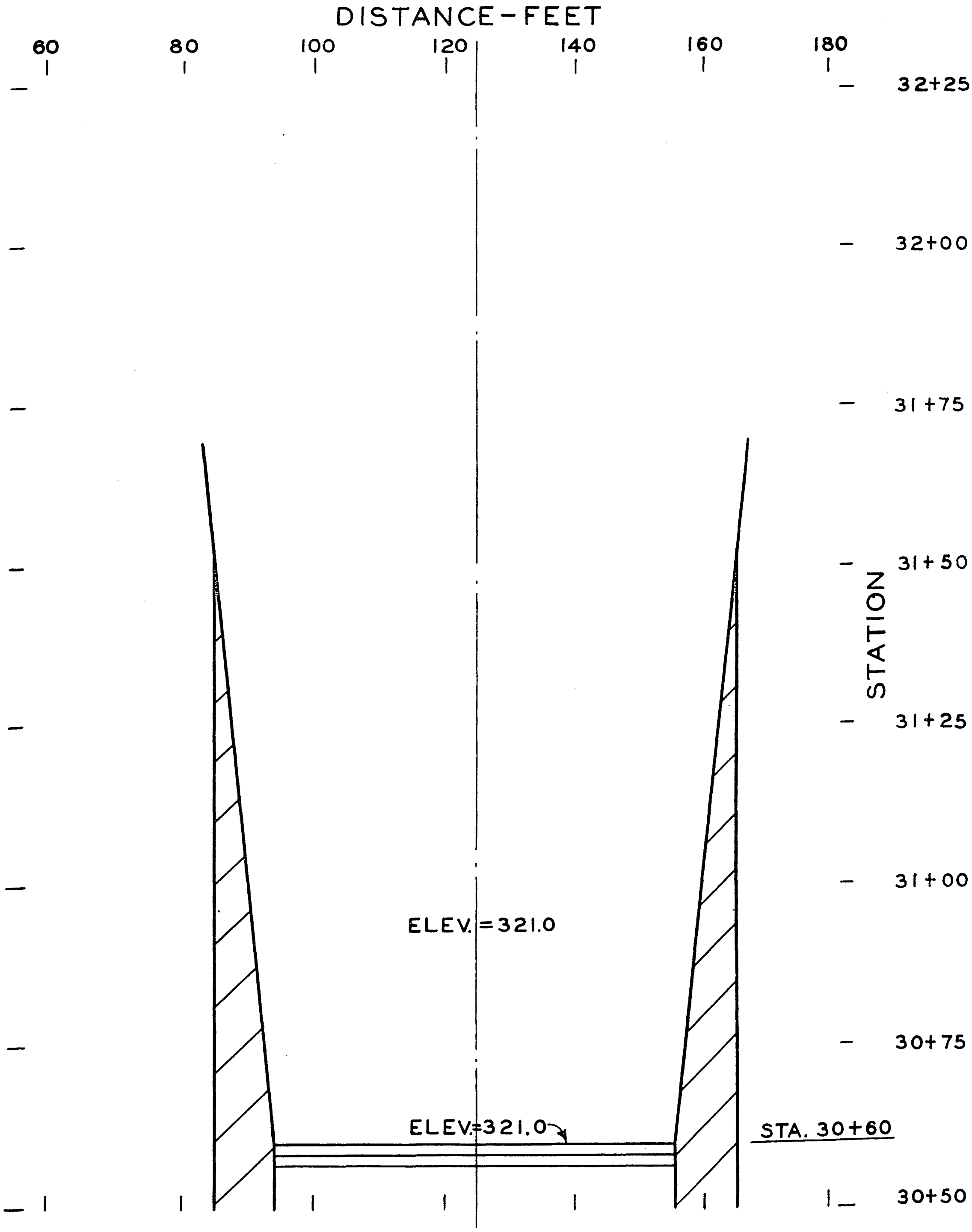


SECTION ALONG ℄

MODEL STUDY

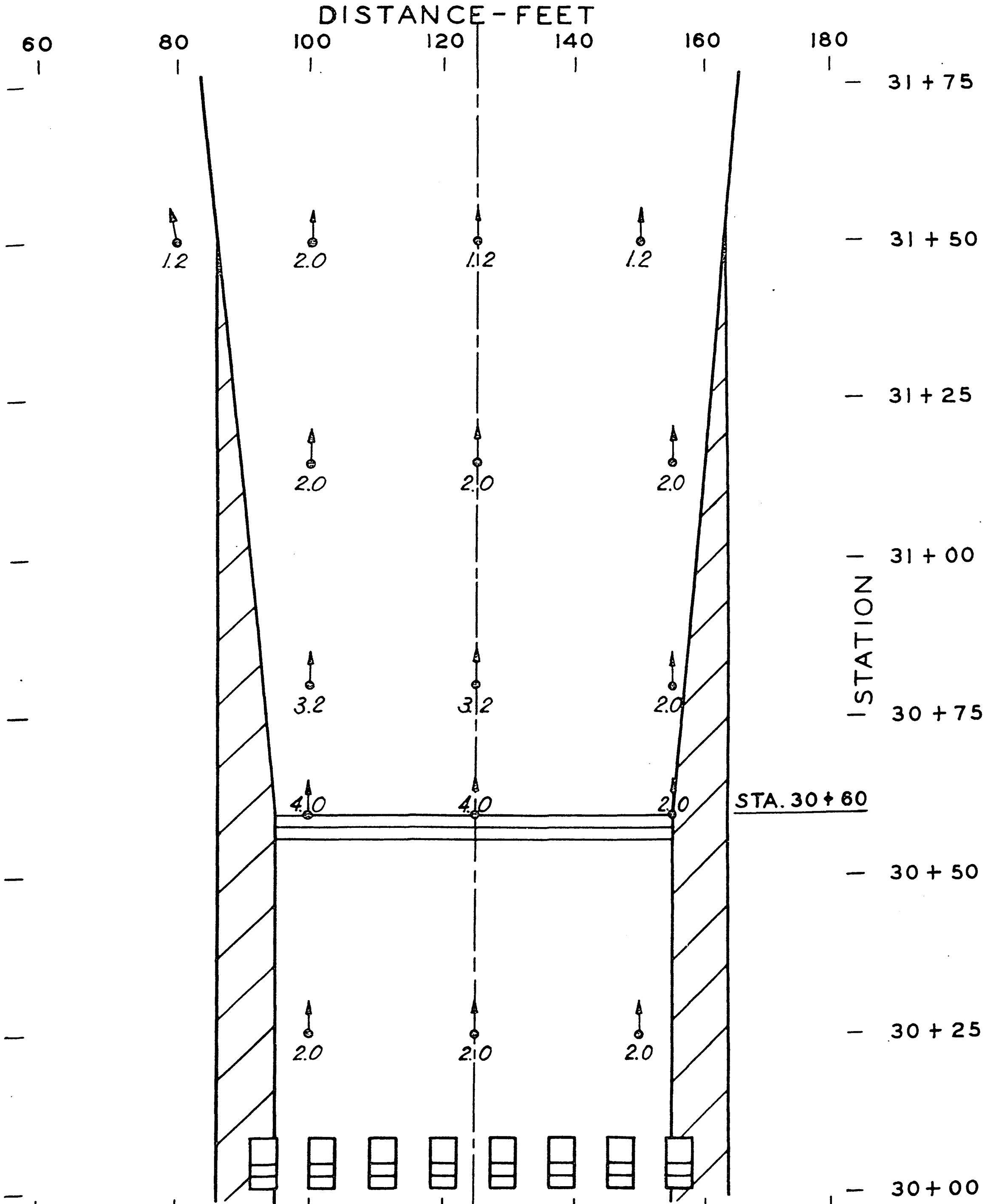
WAPPAPELLO DAM - OUTLET STRUCTURES

STILLING BASIN
BASIC DESIGN



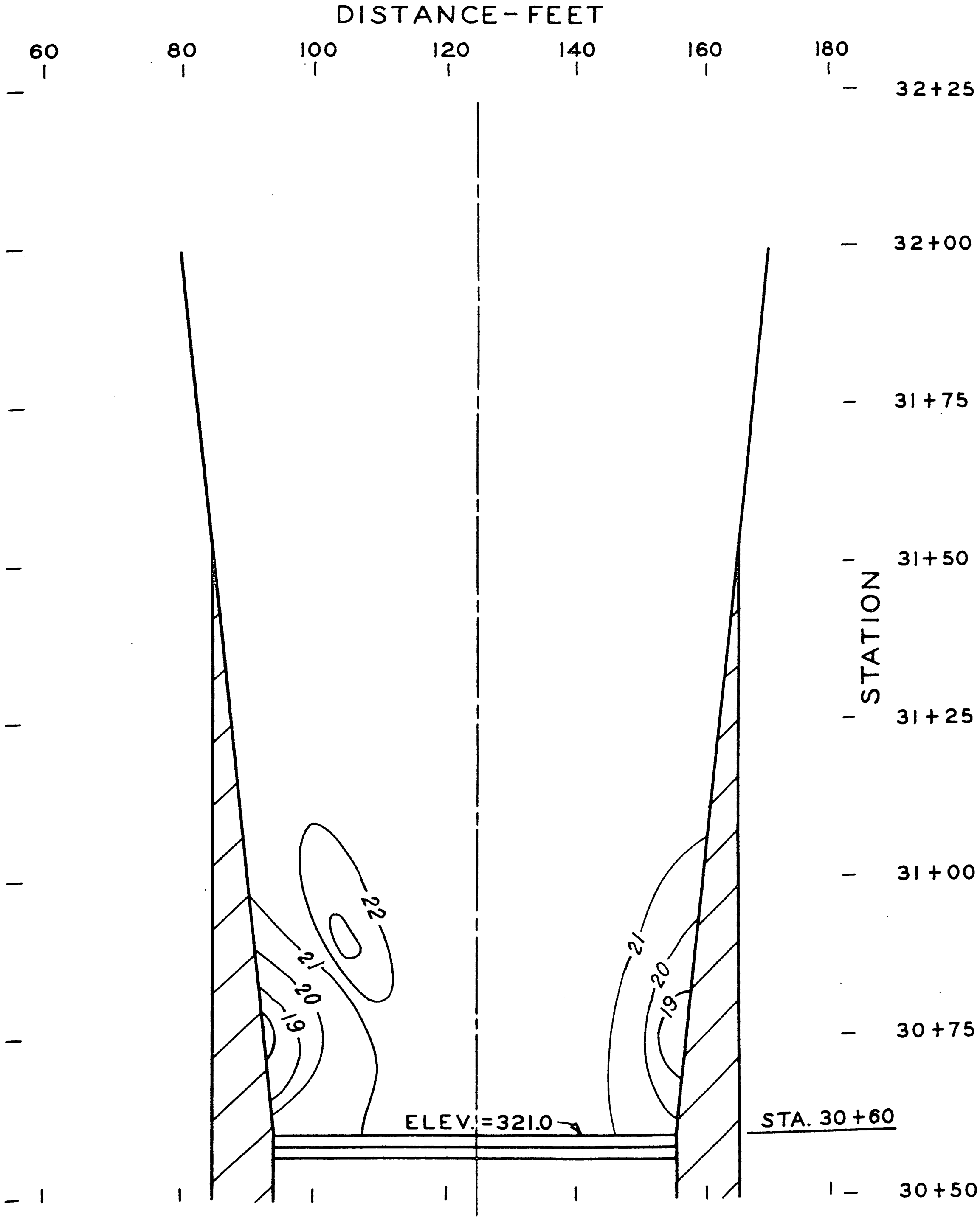
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 4
SCOUR PATTERN
NATURE Q = 4,980 C.F.S.
TAILWATER ELEV. = 340.0
LENGTH OF RUN = 50 MIN.



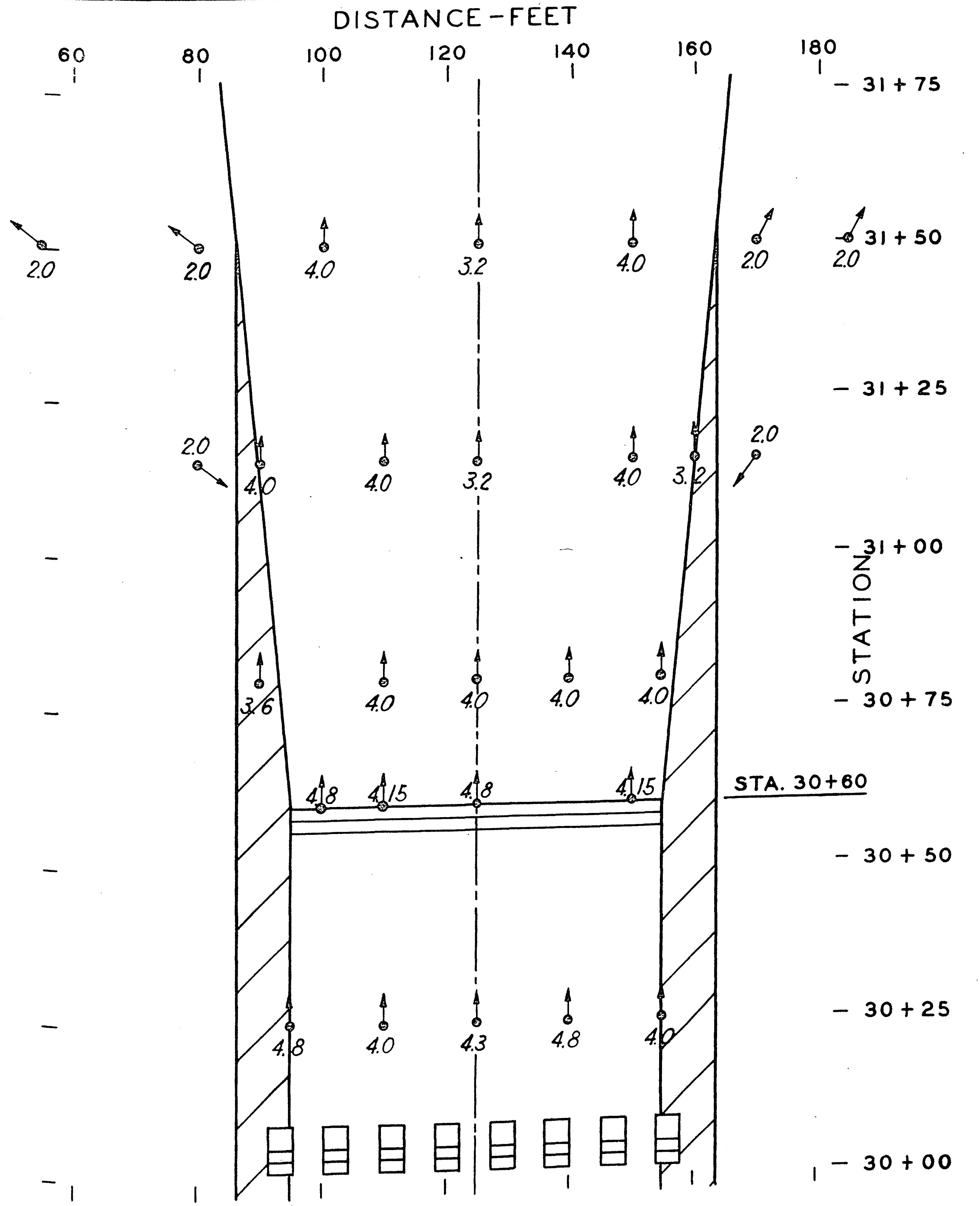
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 4
BOTTOM VELOCITIES
NATURE Q = 4,980 C.F.S.
TAILWATER ELEV. = 340.0



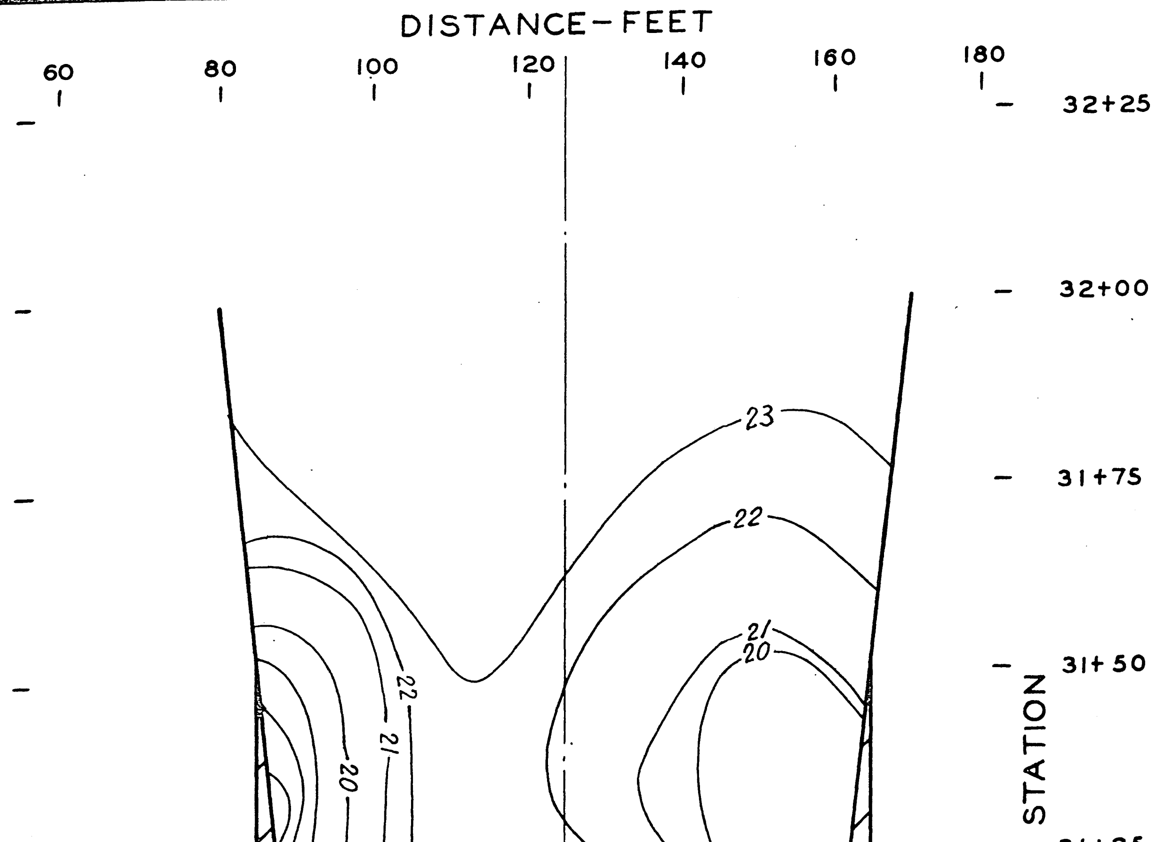
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

TEST NO. 3
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

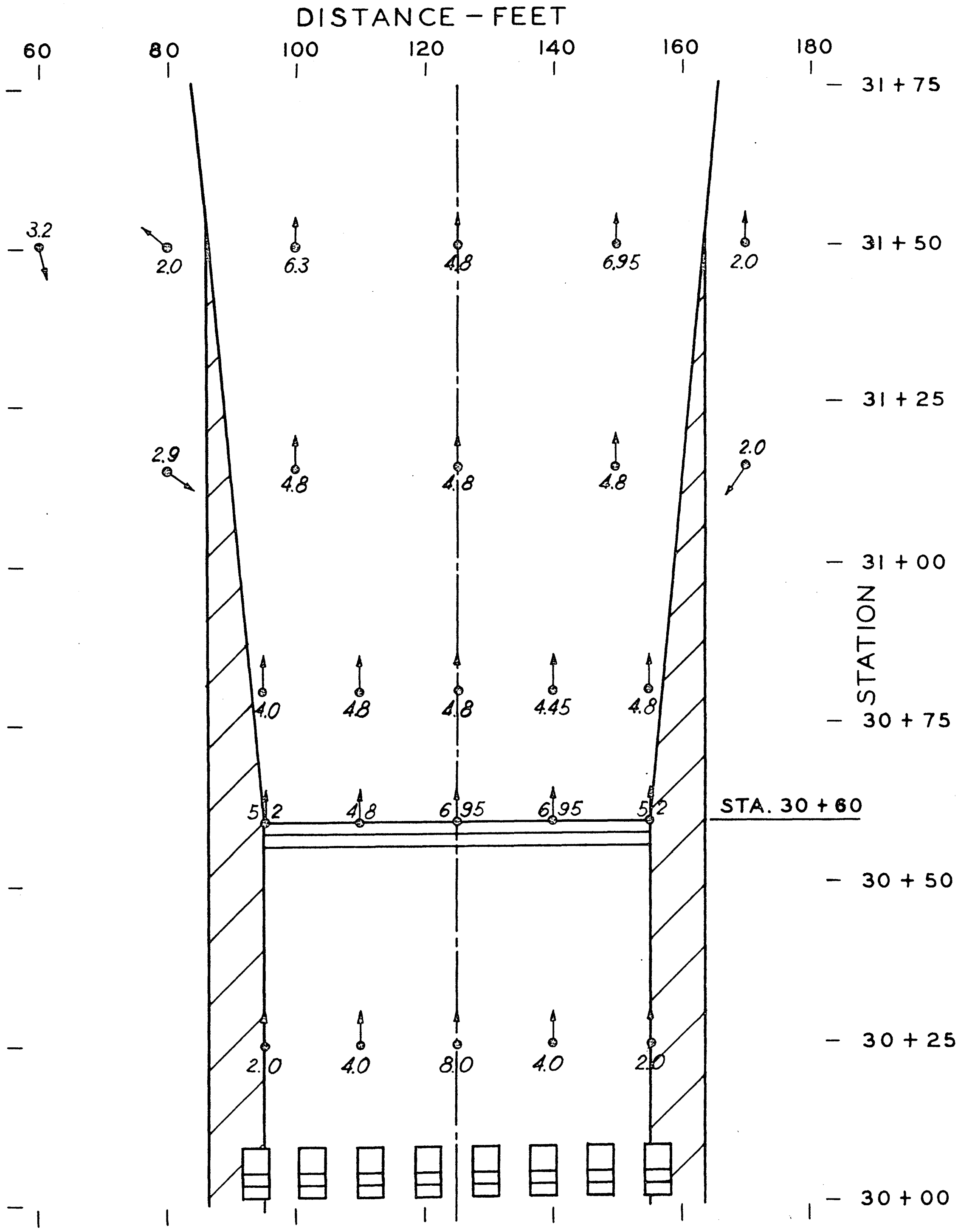
TEST NO. 3
BOTTOM VELOCITIES
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0



MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

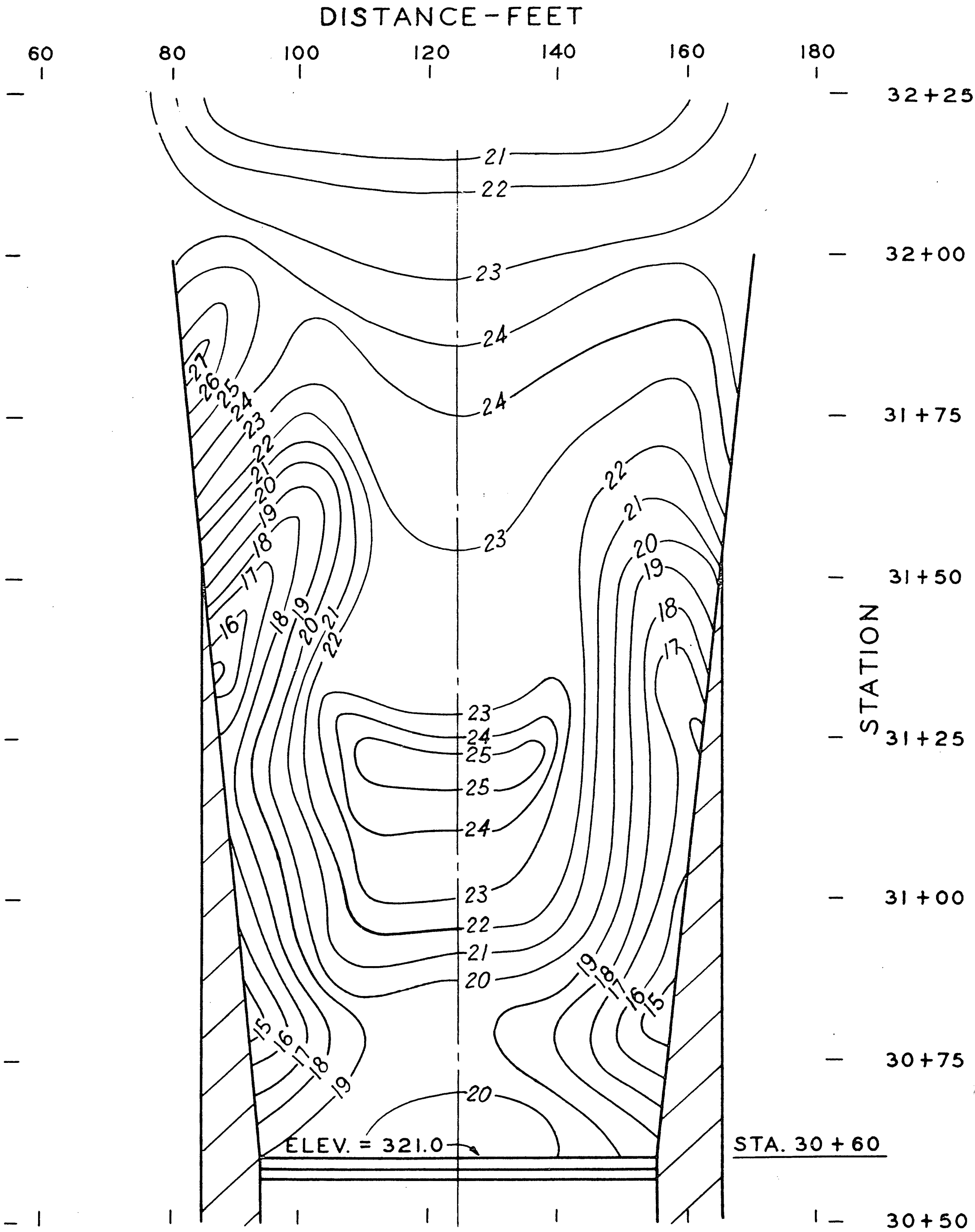
TEST NO. 7
SCOUR PATTERN
NATURE Q = 14,550 C.F.S.
TAILWATER ELEV. = 350.0
LENGTH OF RUN = 50 MIN.

PLATE 27



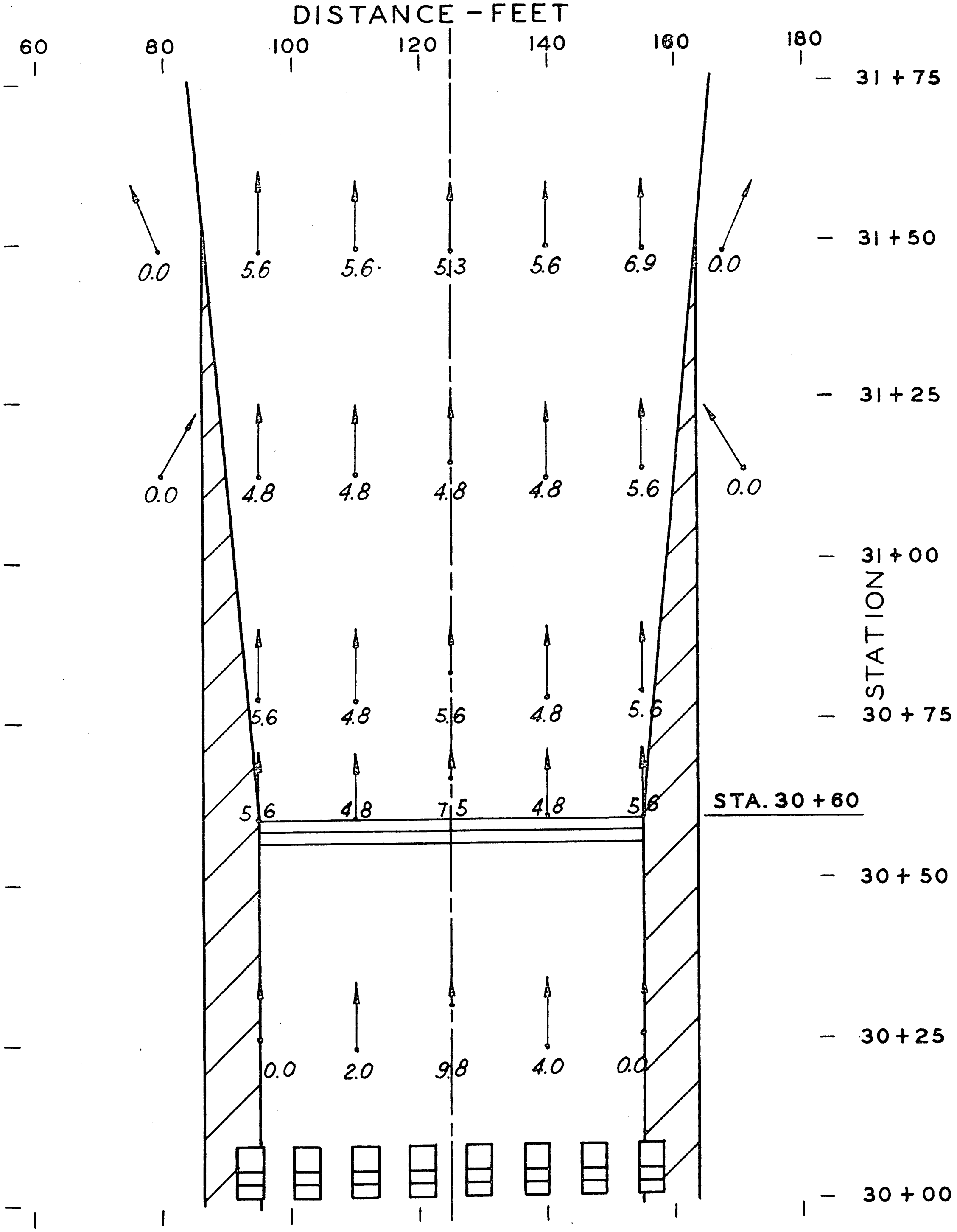
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 7
BOTTOM VELOCITIES
NATURE Q = 14,550 C.F.S.
TAILWATER ELEV. = 350.0



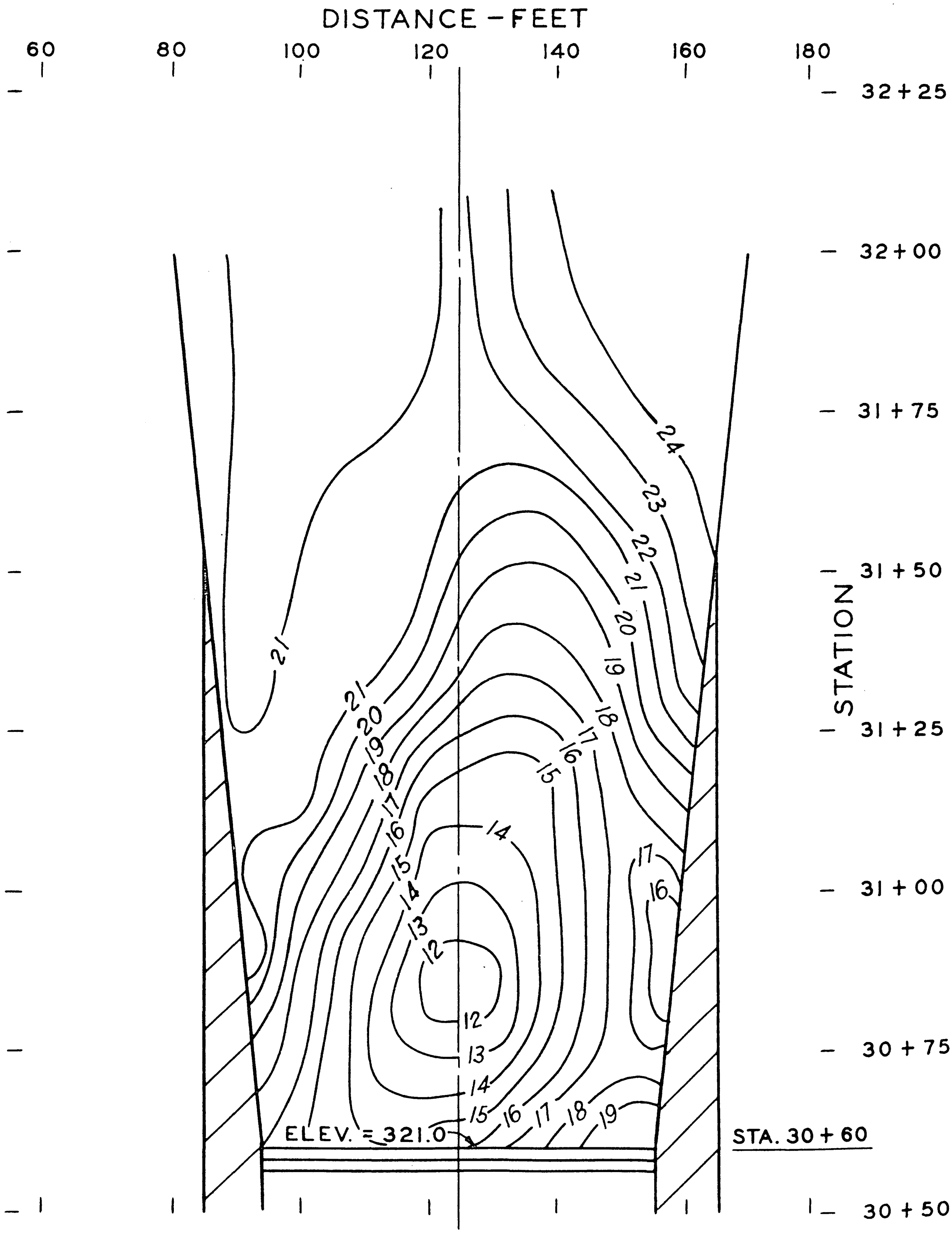
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 31
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



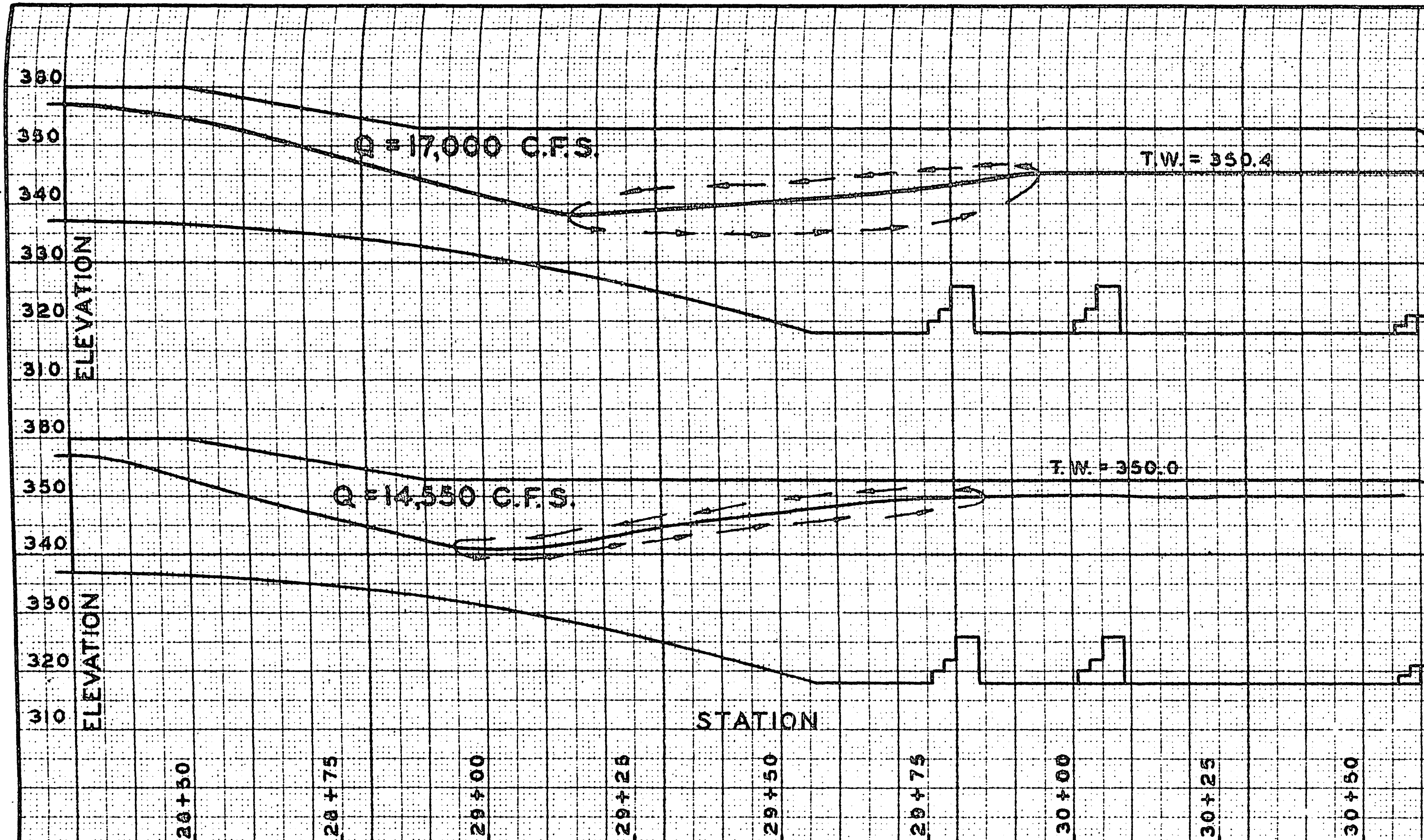
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 31
BOTTOM VELOCITIES
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4

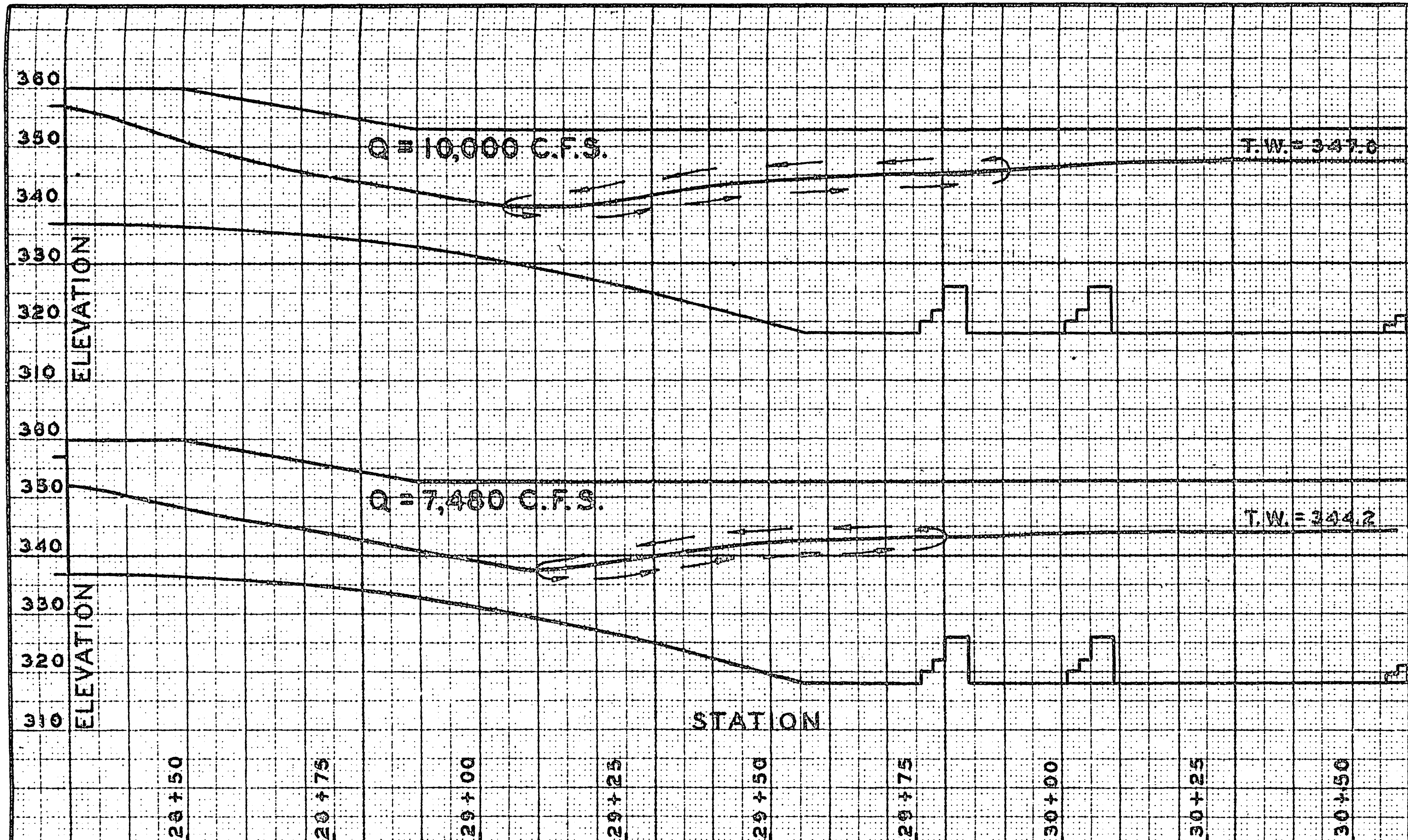


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

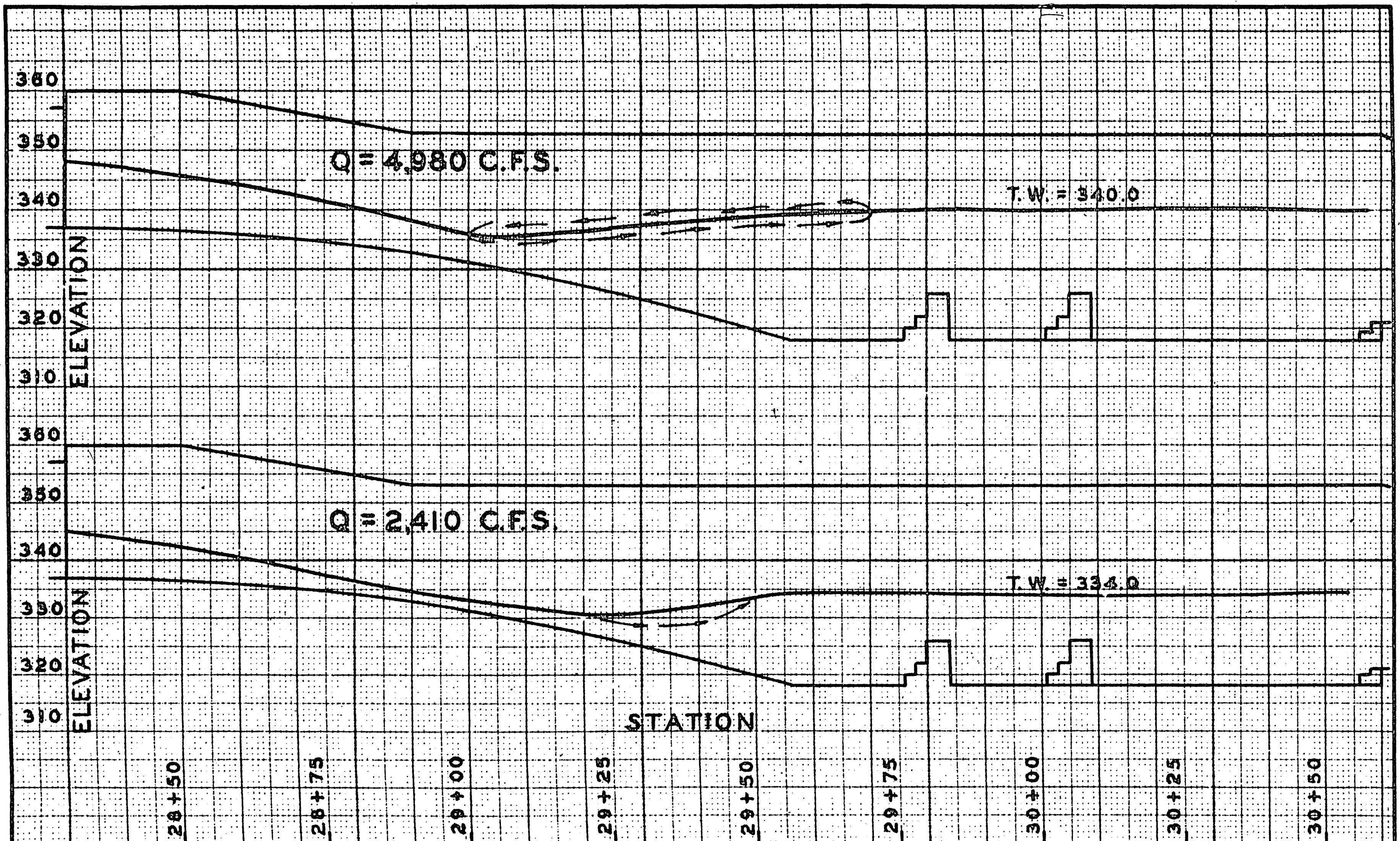
TEST NO. 37
SCOUR PATTERN
NATURE Q = 19,700 C.F.S.
TAILWATER ELEV. = 366.0
LENGTH OF RUN = 50 MIN.



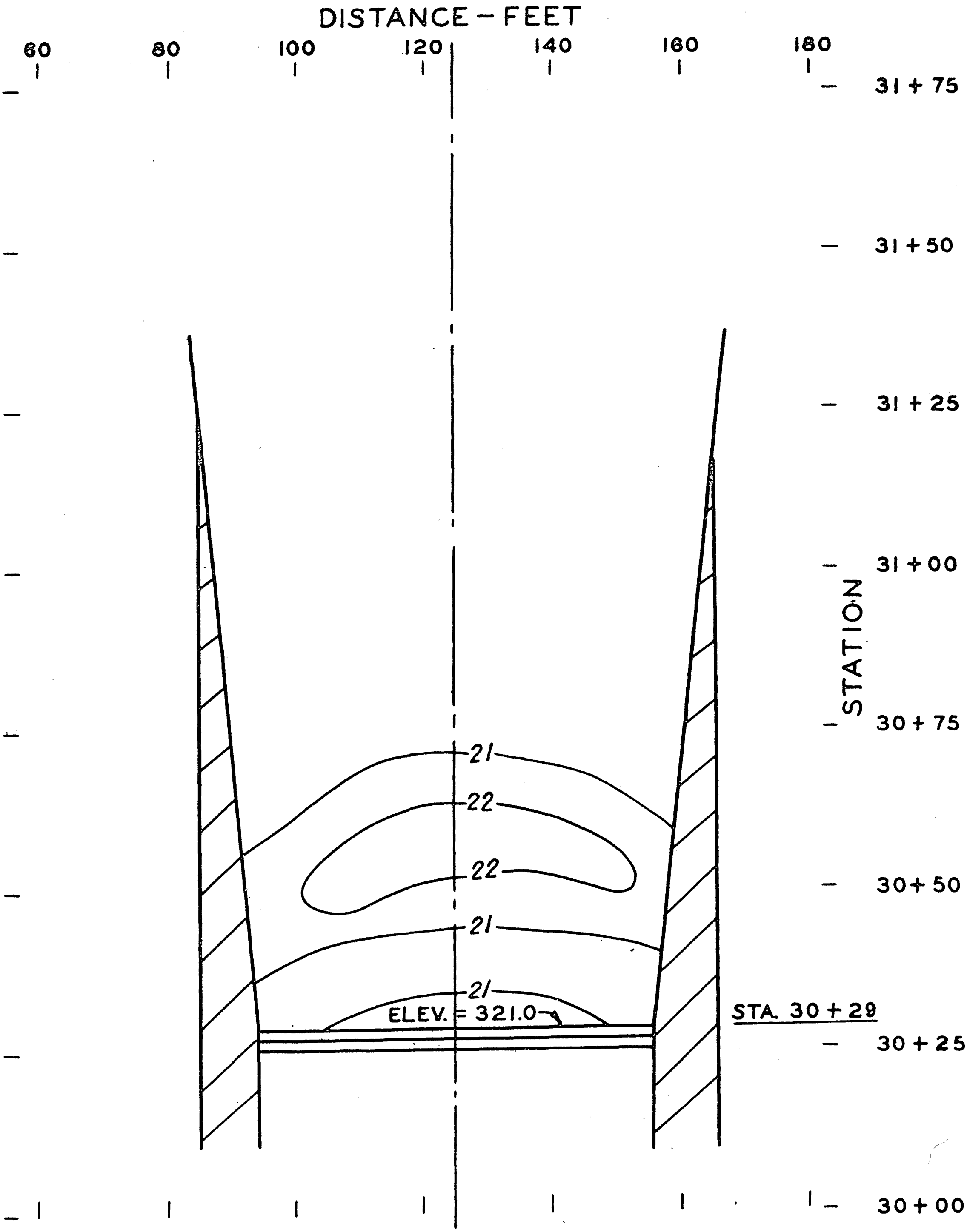
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
WATER-SURFACE PROFILES
BASIC DESIGN



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
WATER-SURFACE PROFILES
BASIC DESIGN

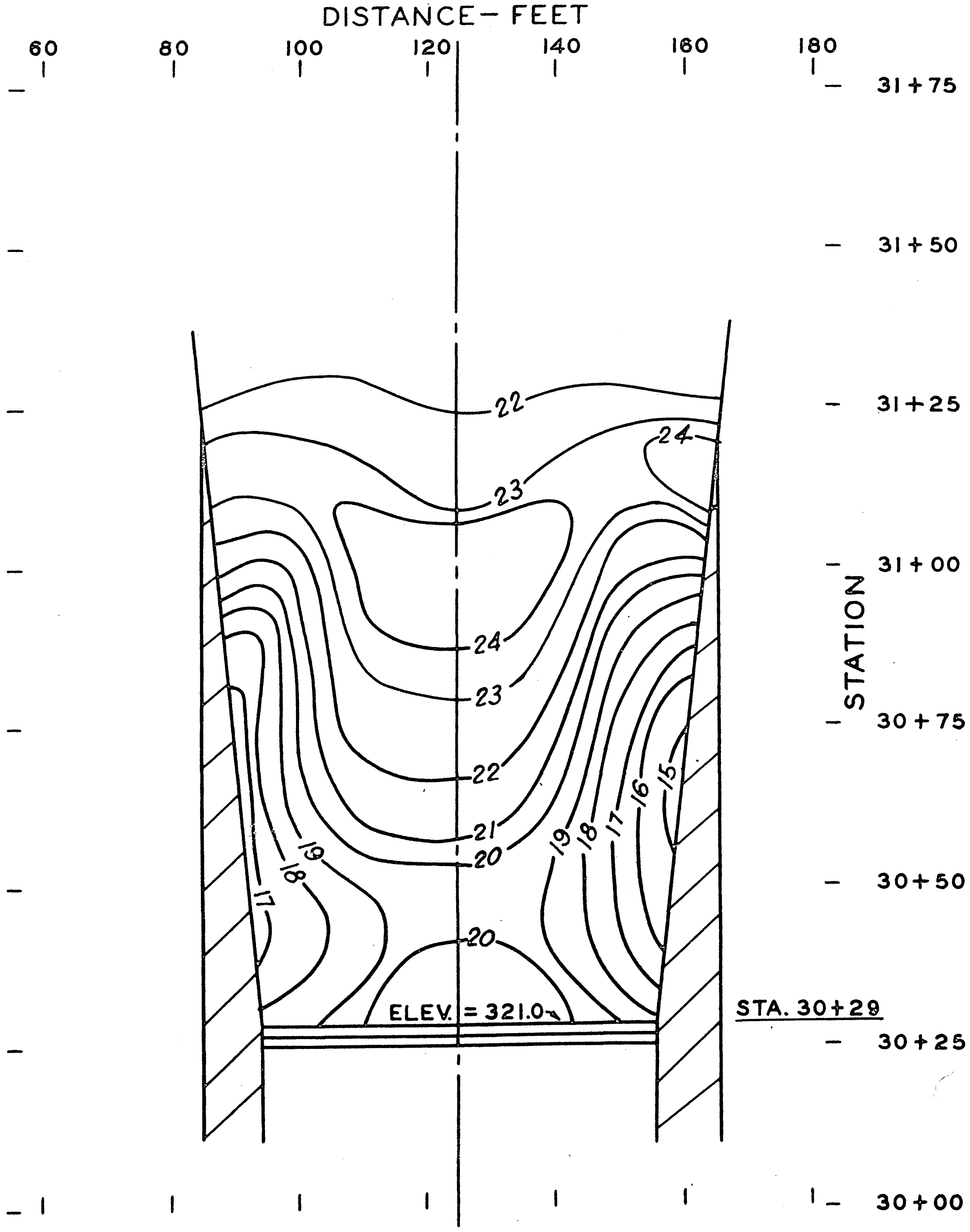


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER-SURFACE PROFILES
BASIC DESIGN



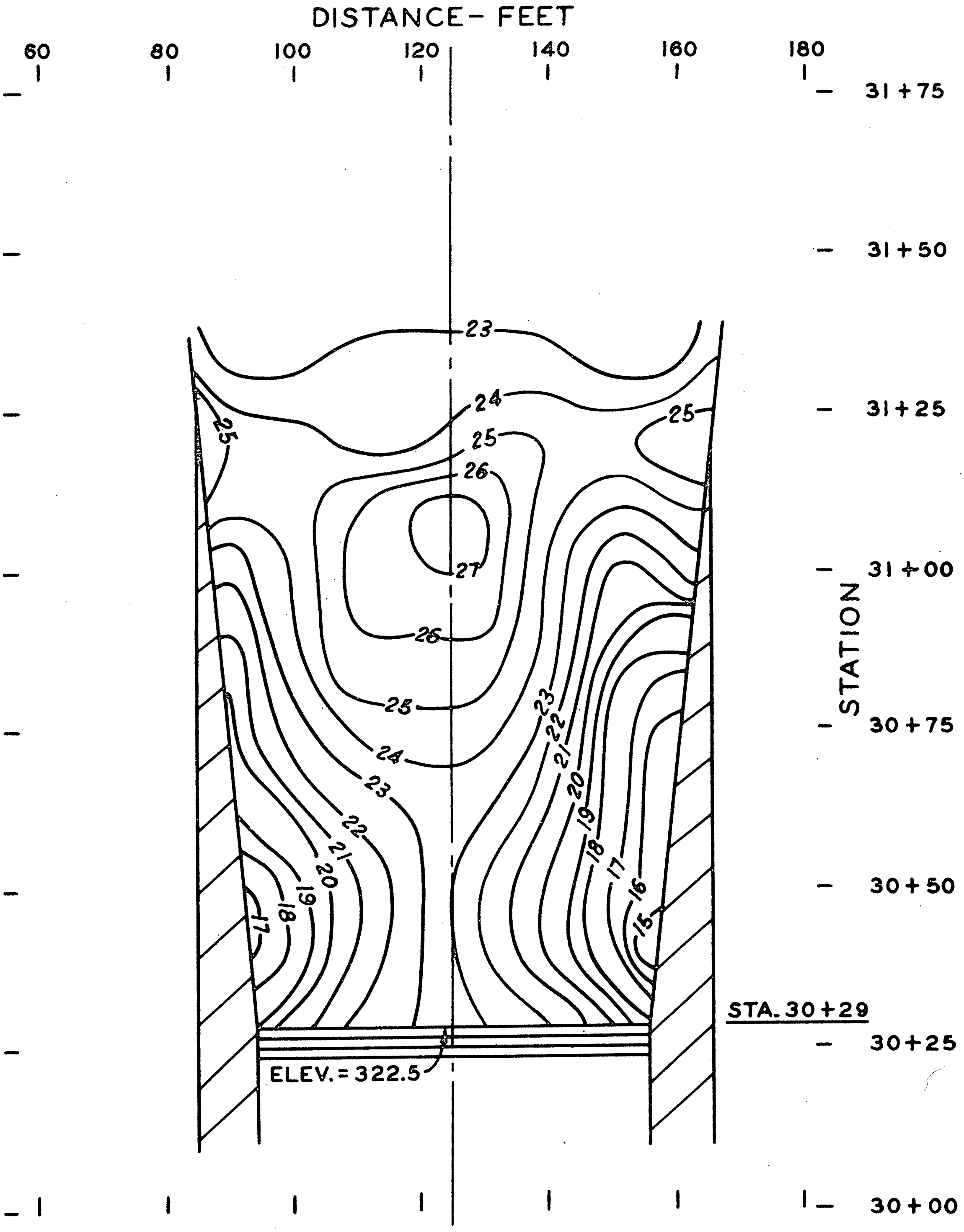
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 43 RUN I
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



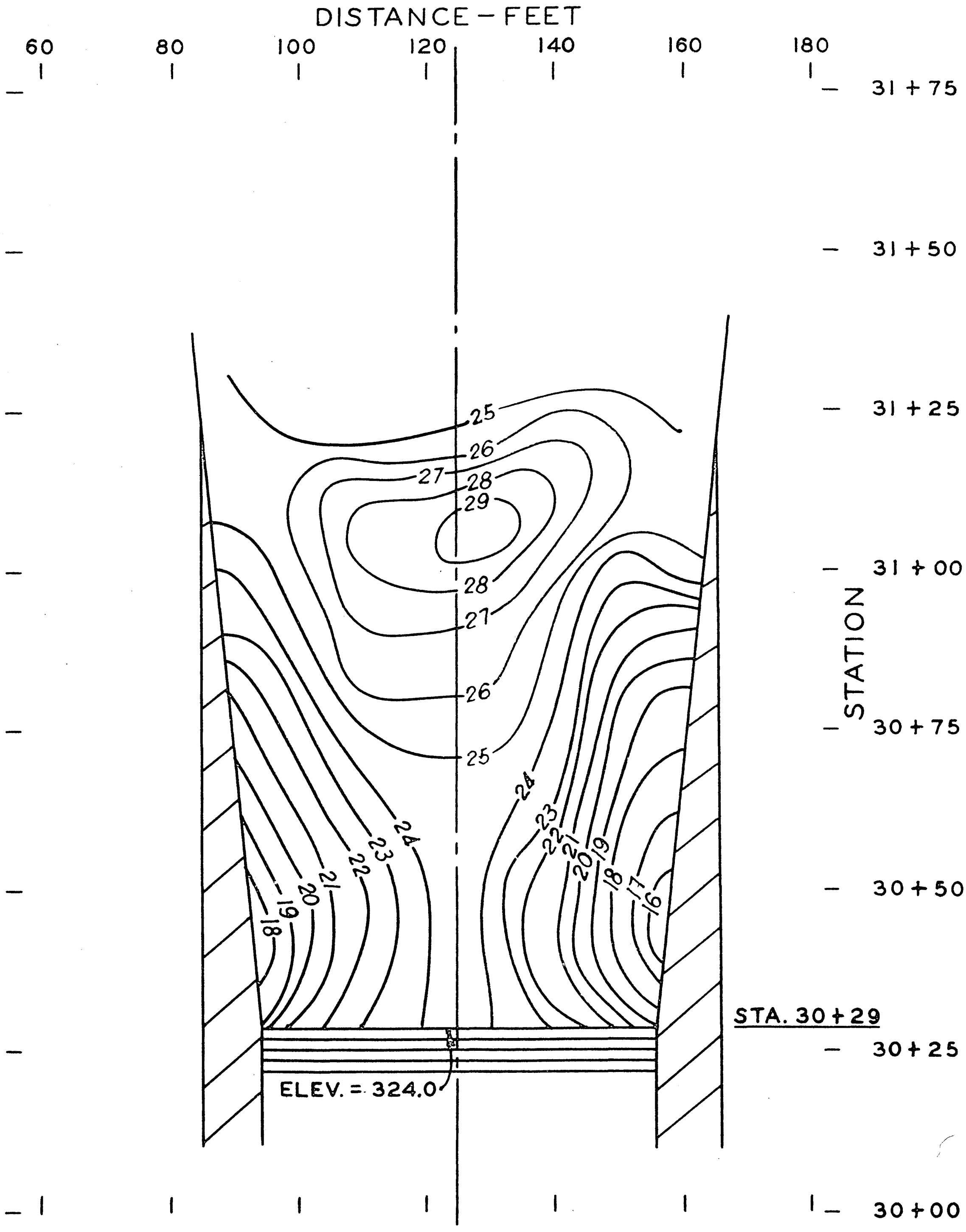
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

TEST NO. 43 RUN II
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



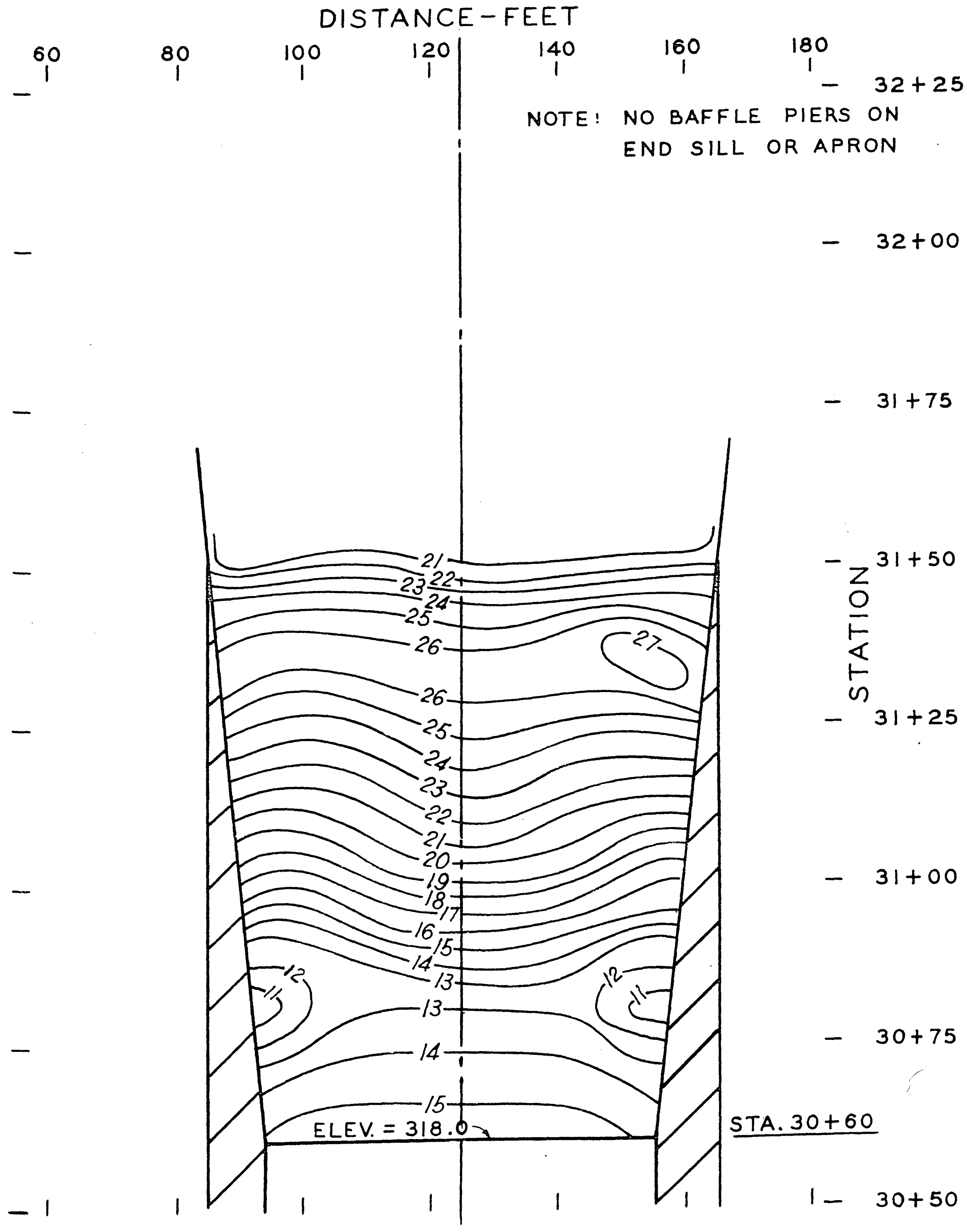
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 45
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



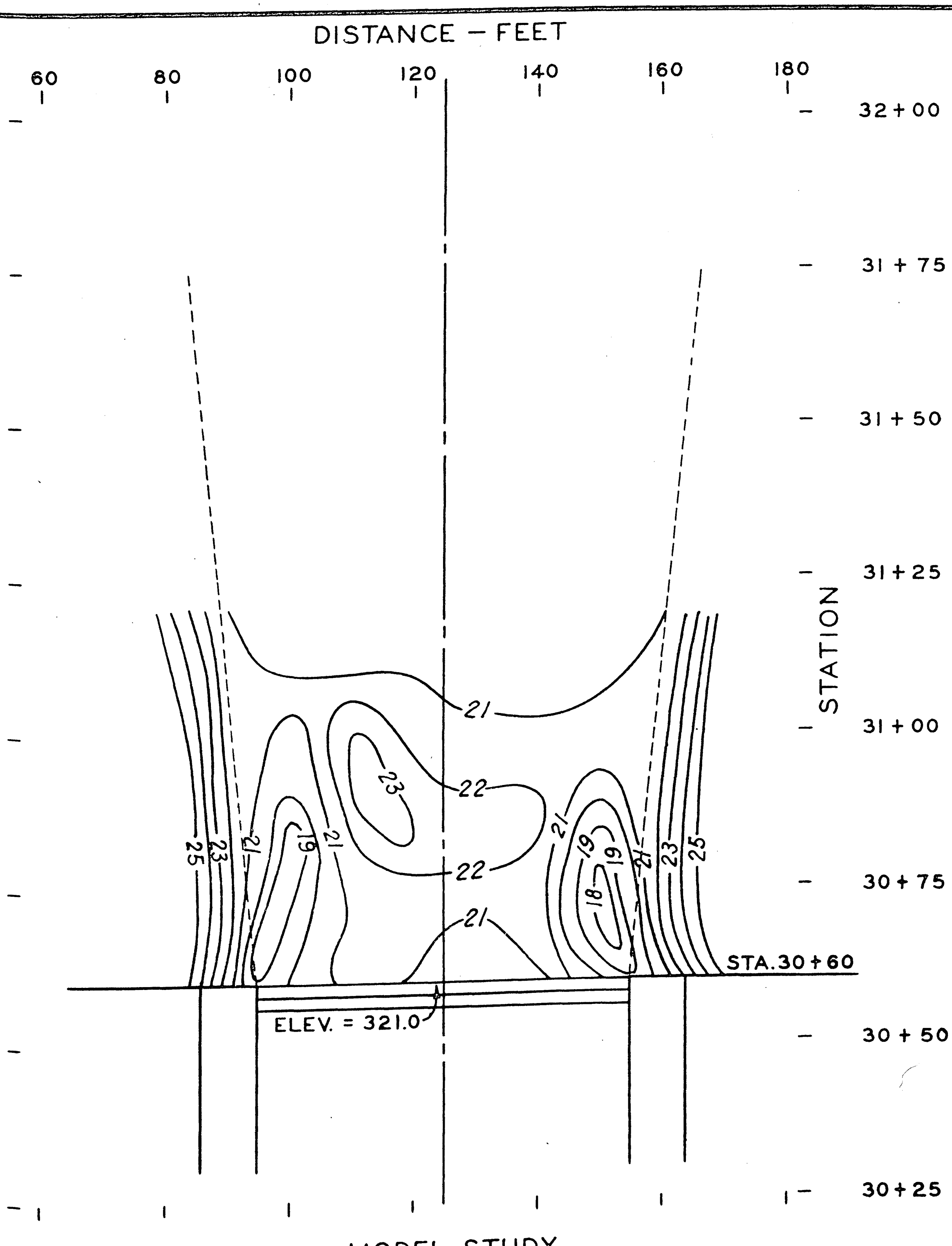
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 47
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



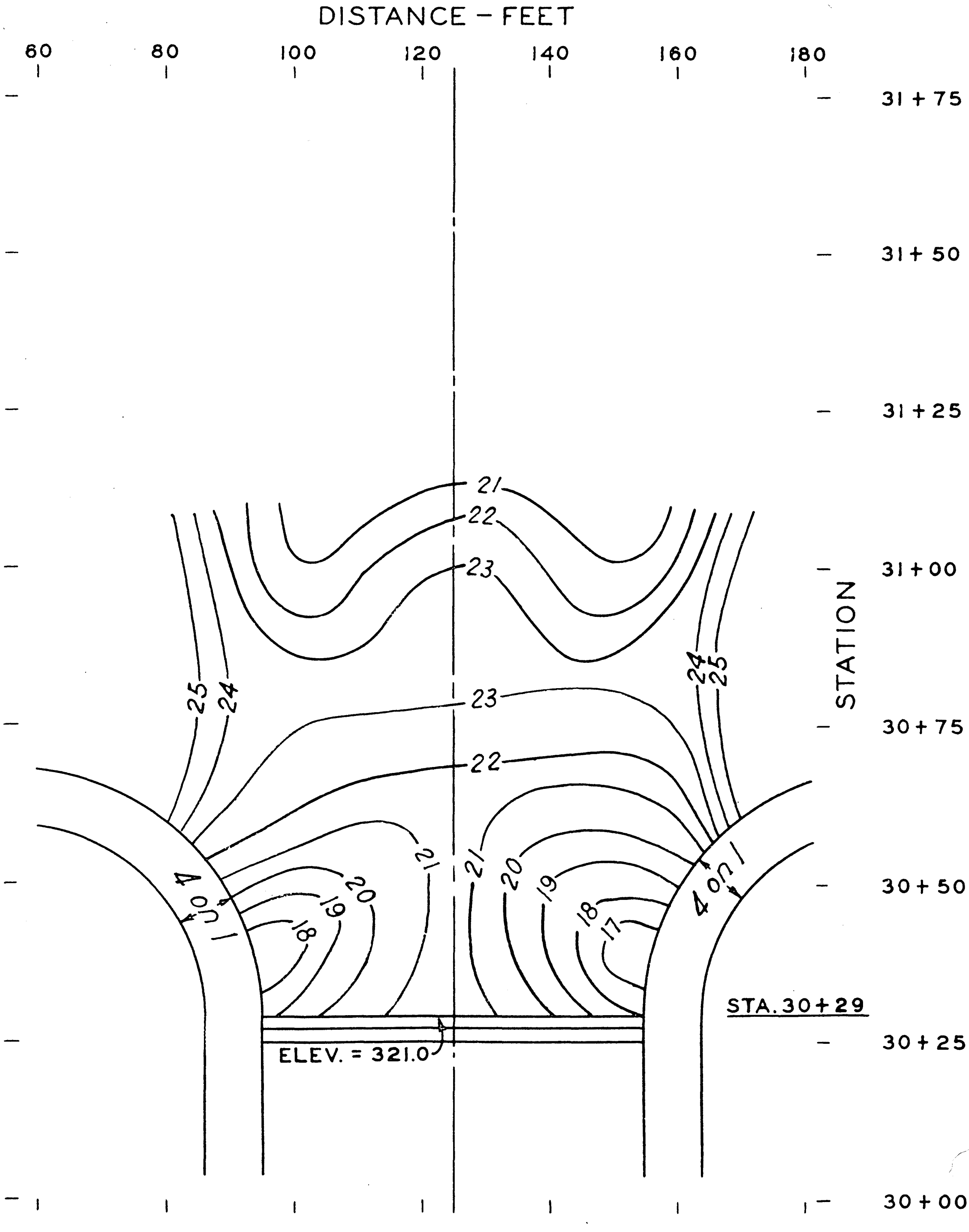
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 34
SCOUR PATTERN
NATURE Q = 10,070 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



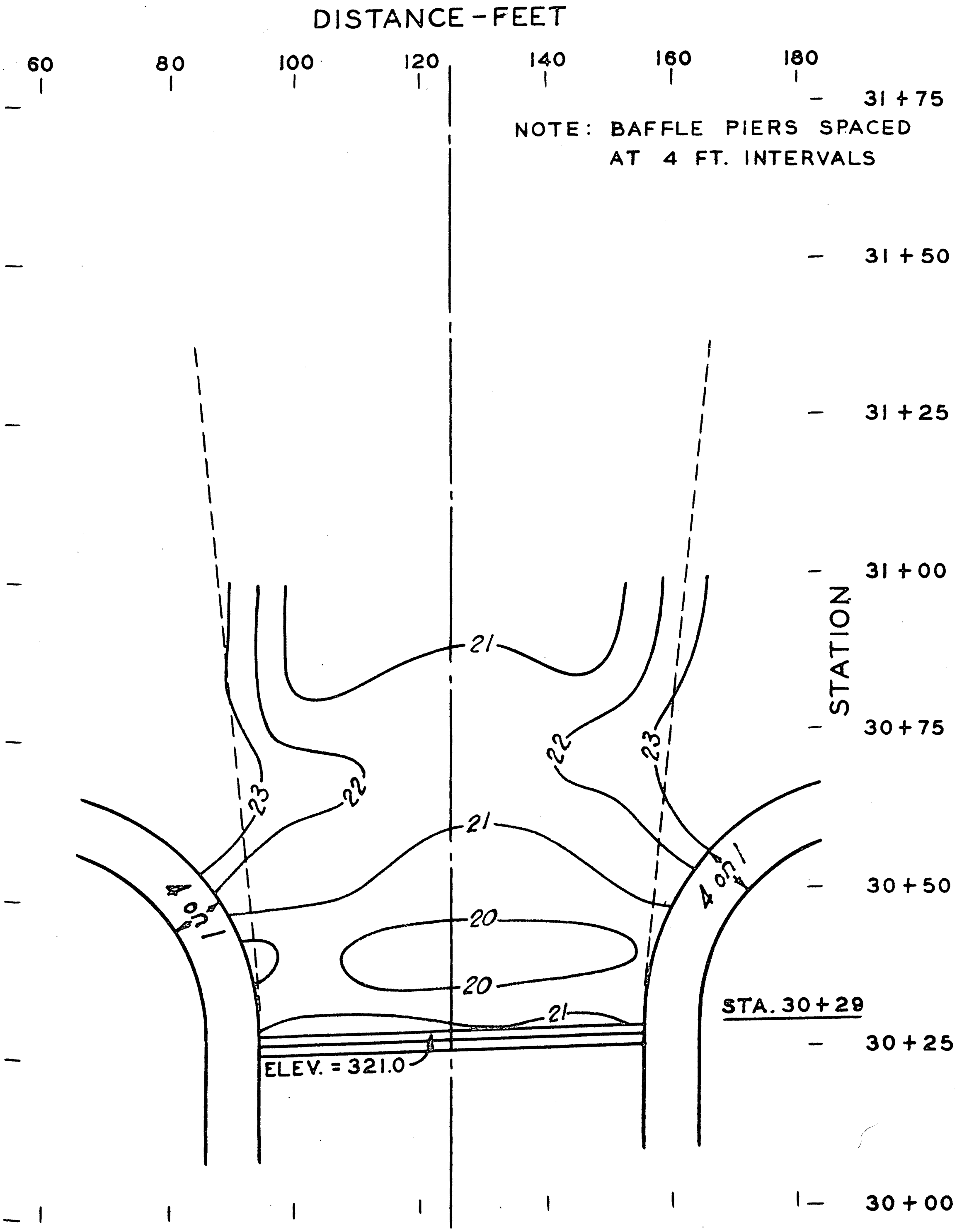
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 38
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



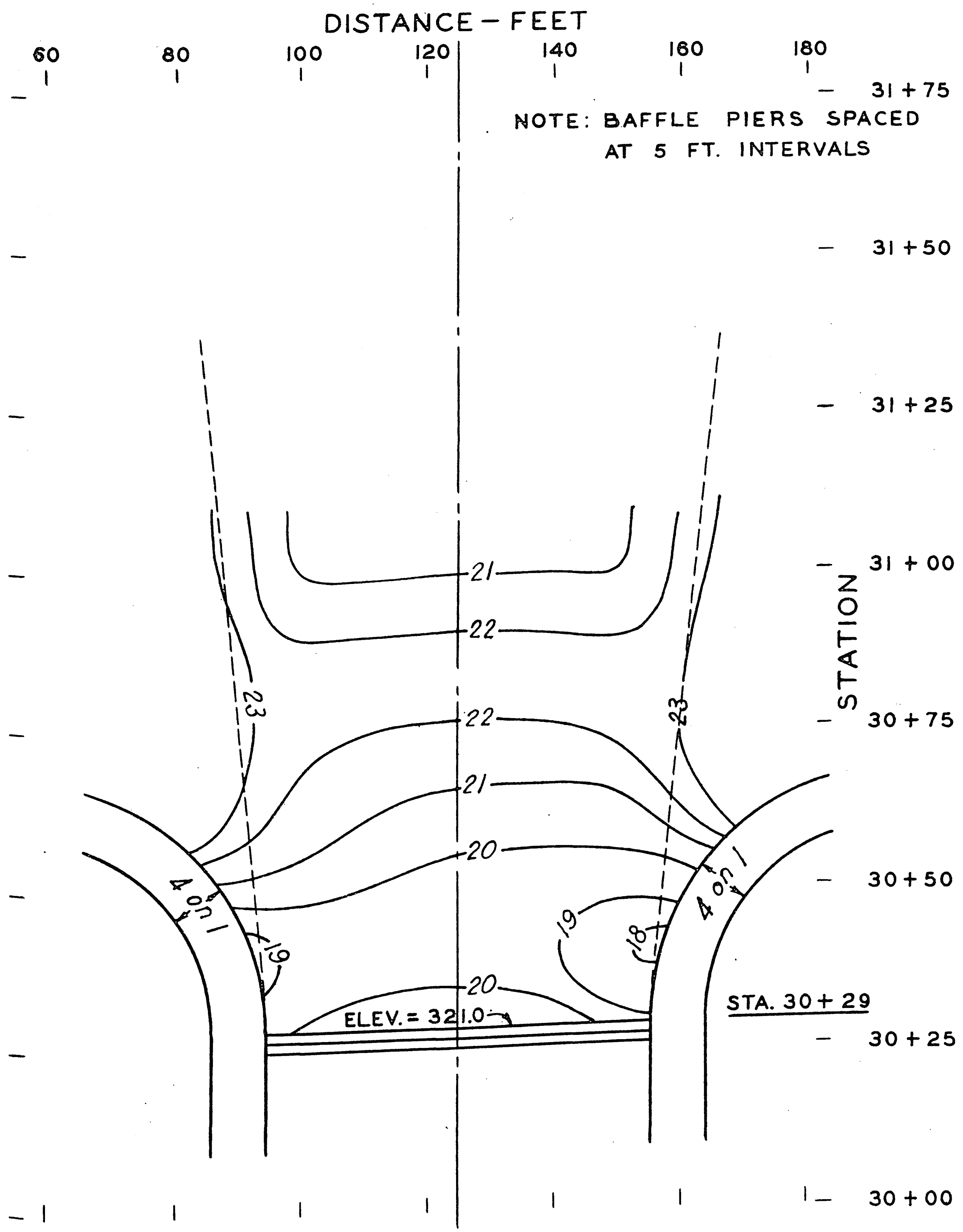
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 48
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



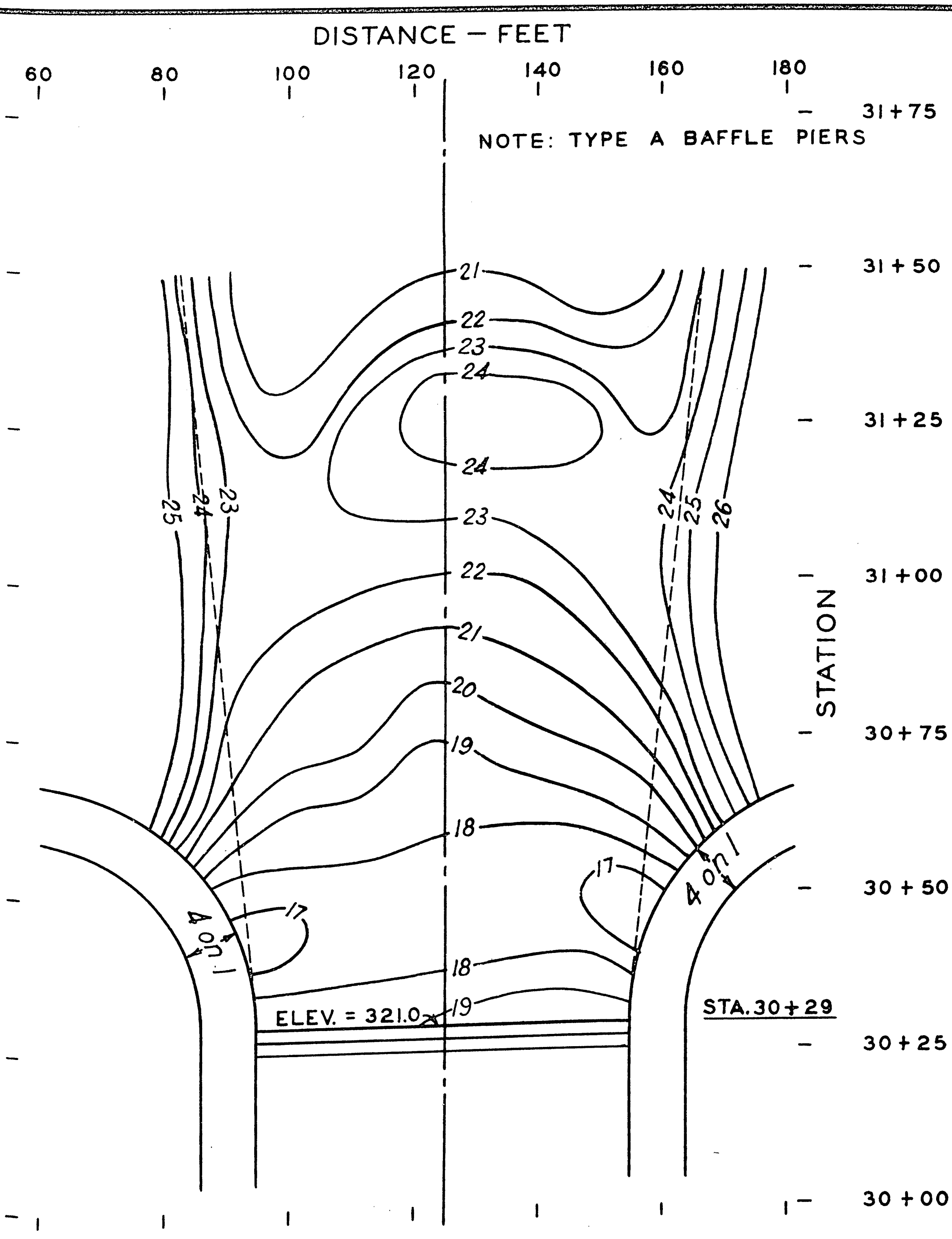
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 51
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



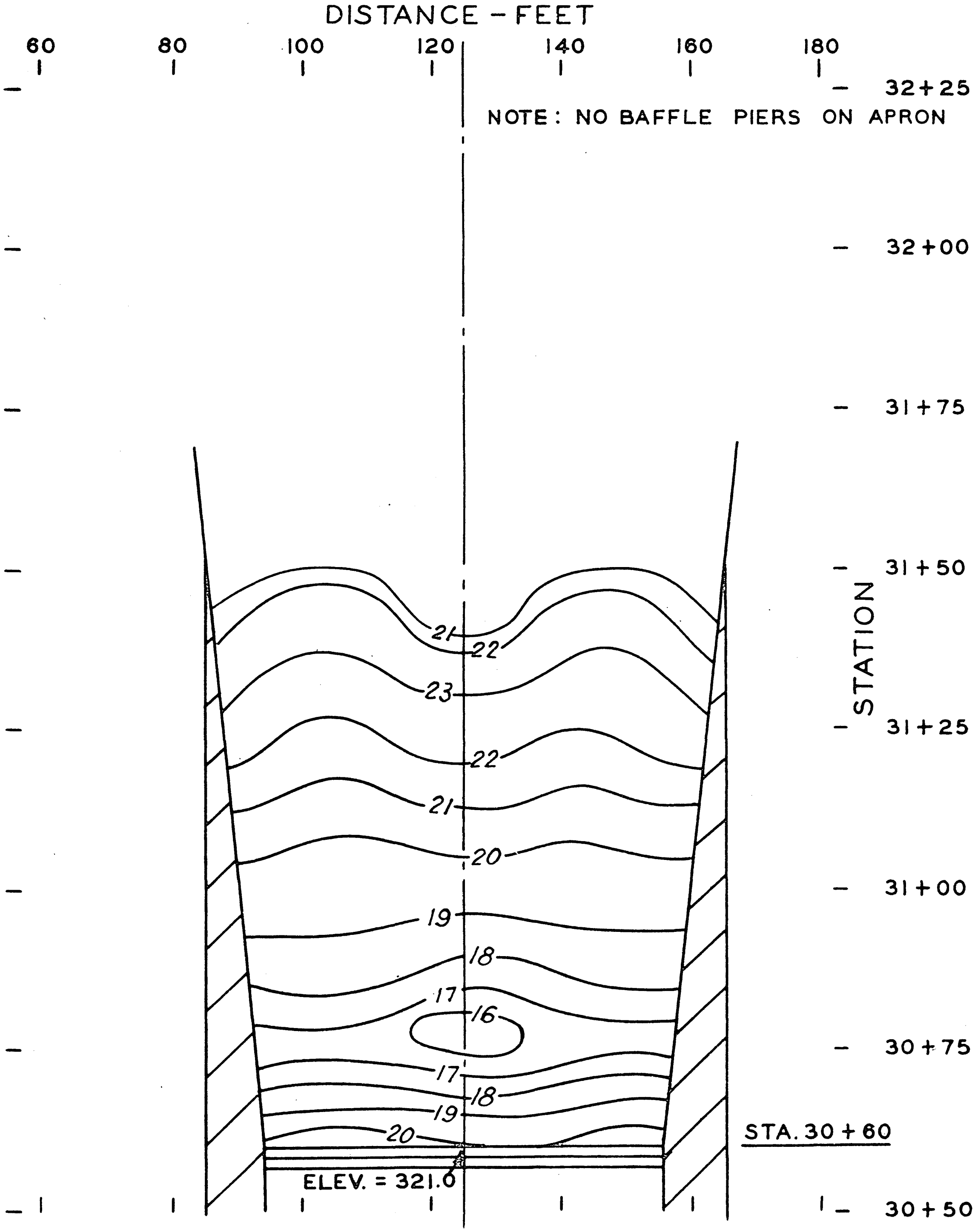
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

TEST NO. 49
SCOUR PATTERN
NATURE Q = 16,890 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



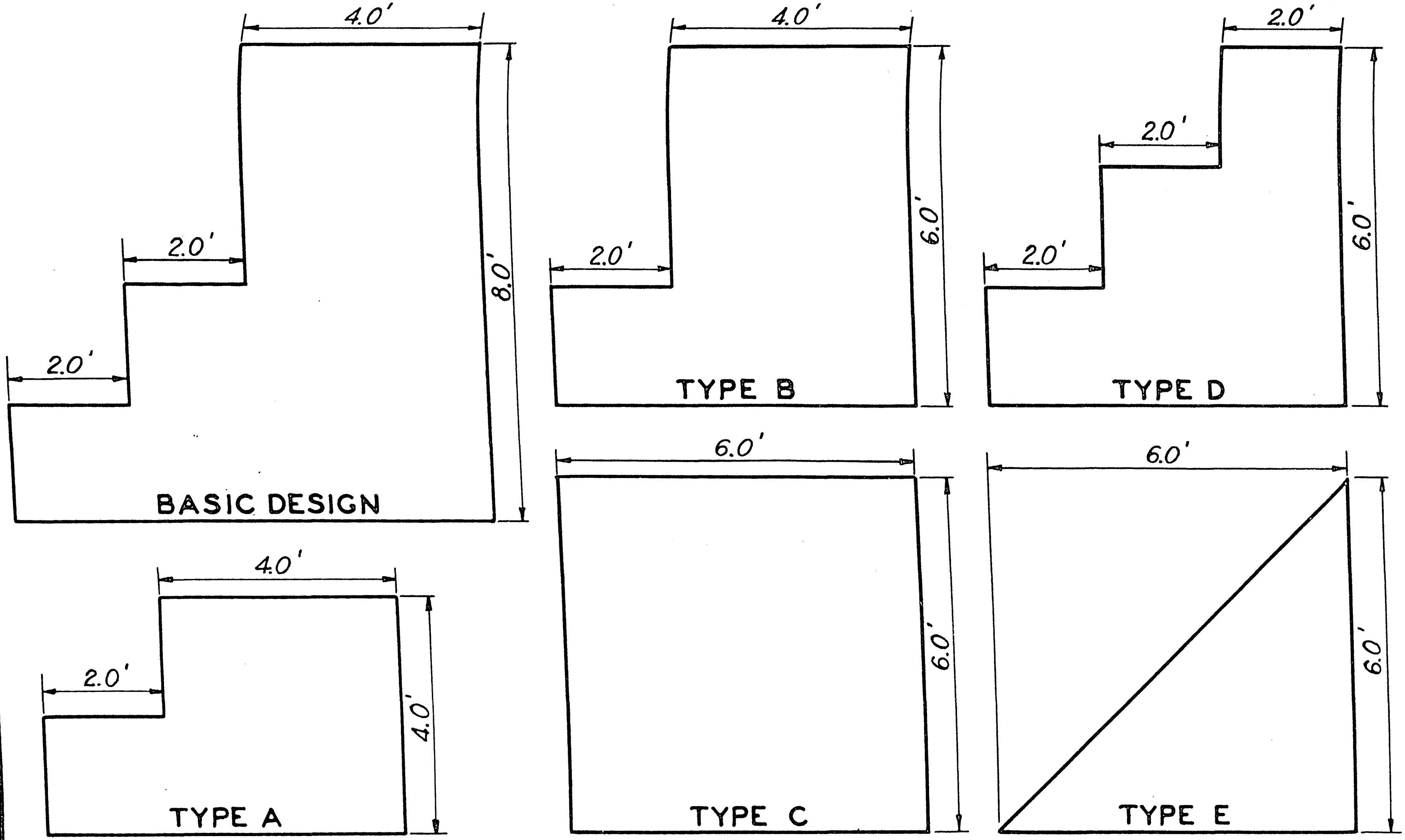
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 54
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.

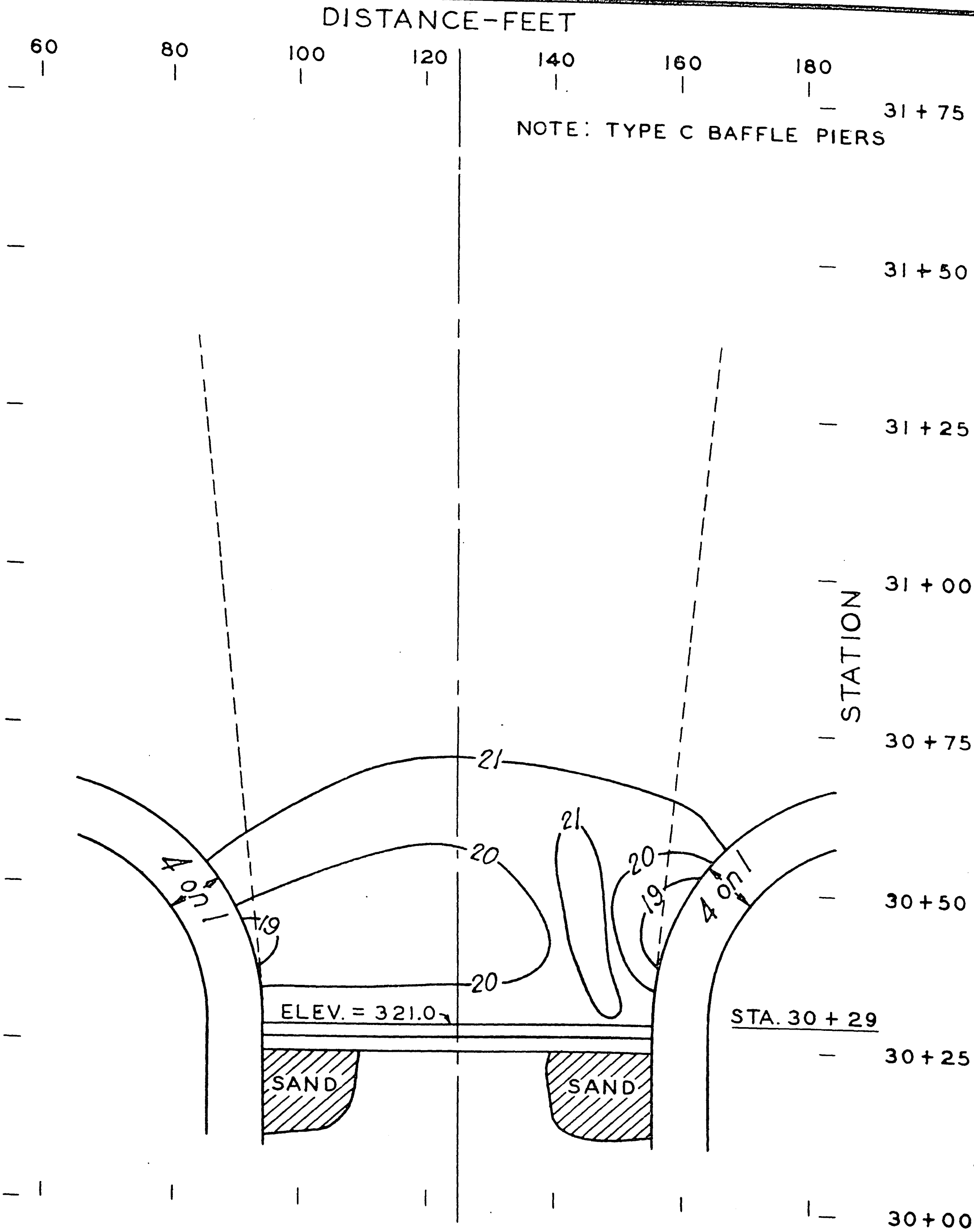


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 35
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.

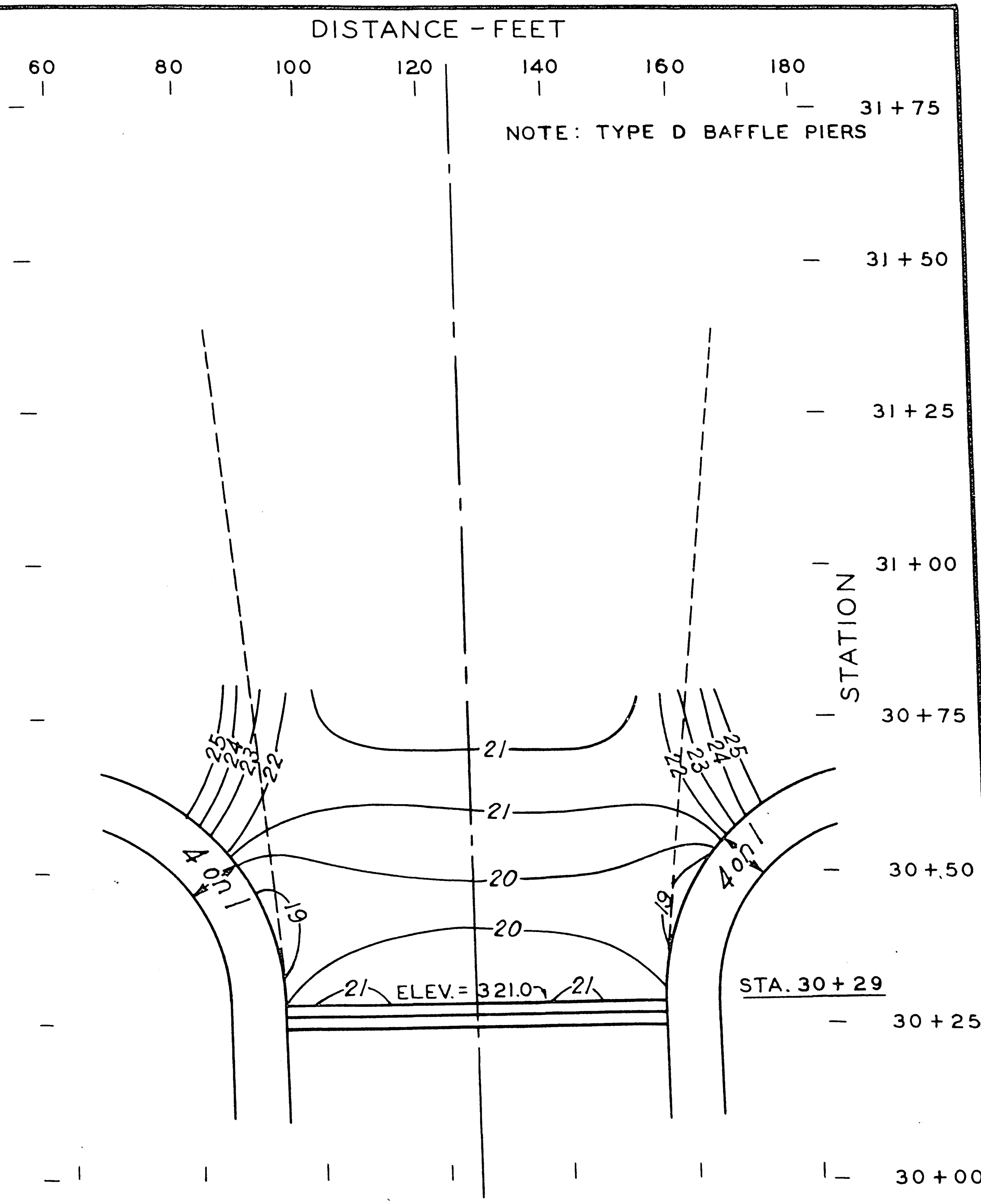


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
TYPES OF BAFFLE PIERS TESTED



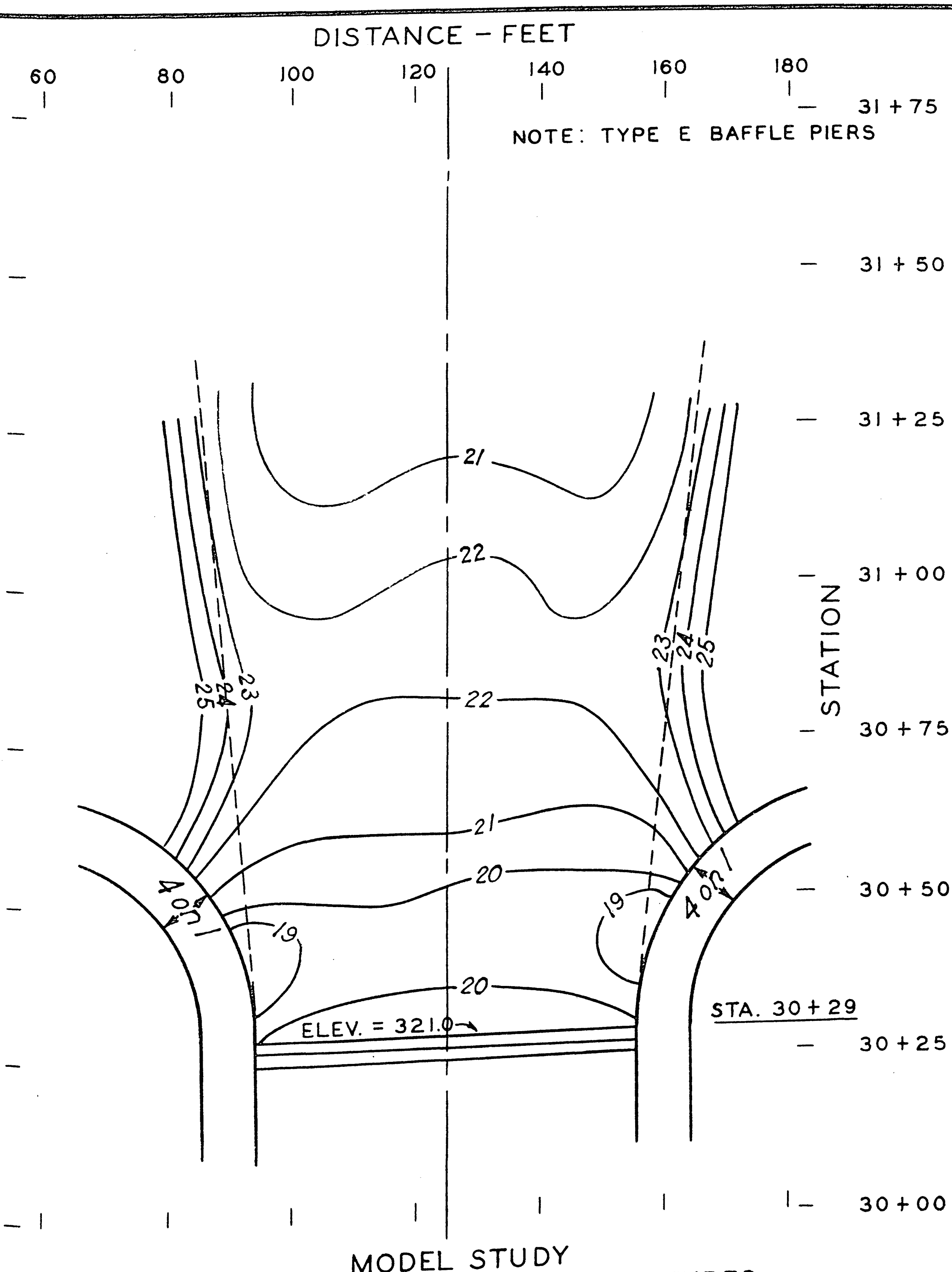
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 69
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



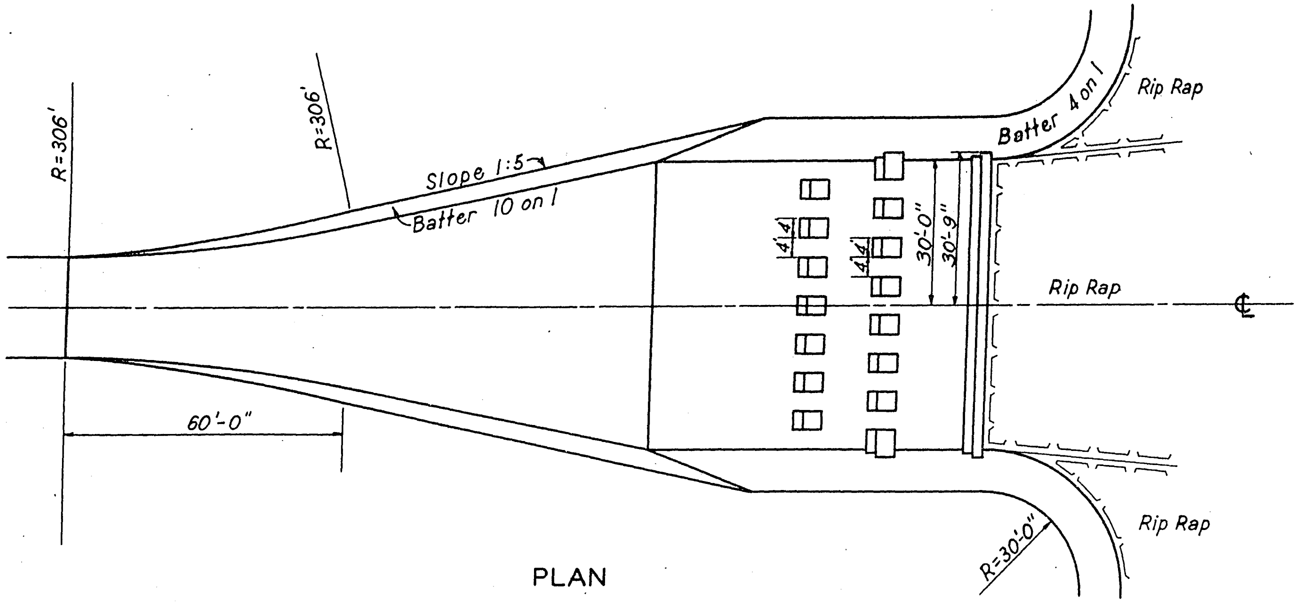
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 71
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.

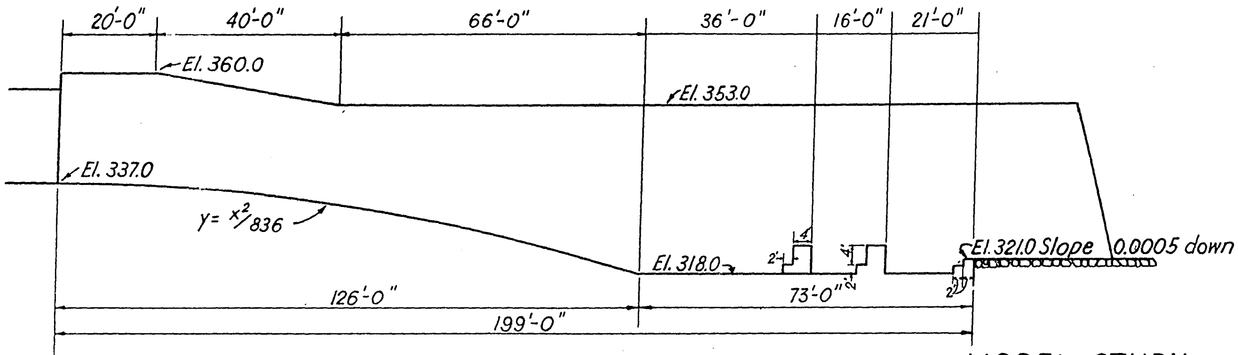


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 70
SCOUR PATTERN
NATURE Q = 17,020 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



PLAN

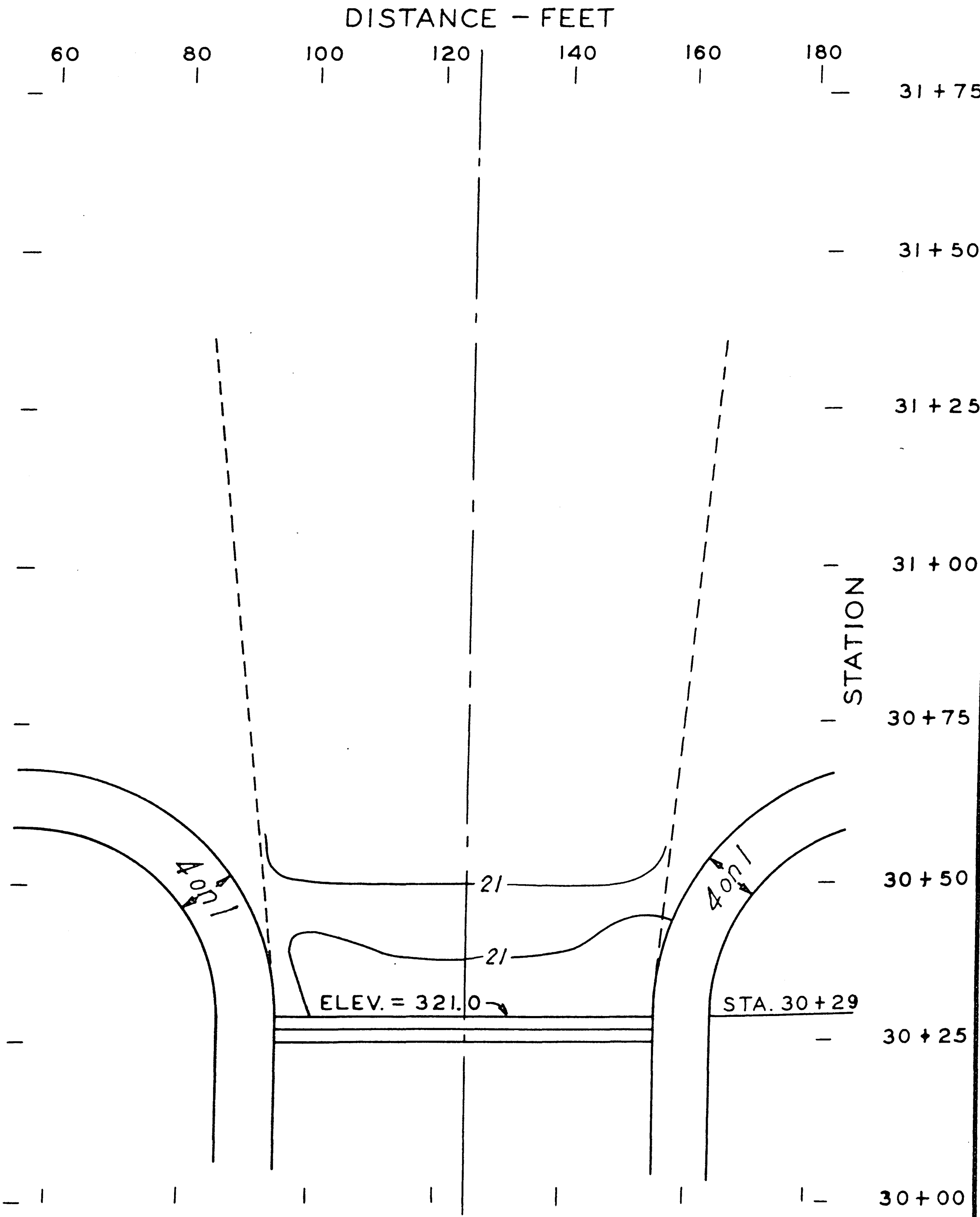


SECTION ALONG ℄

MODEL STUDY

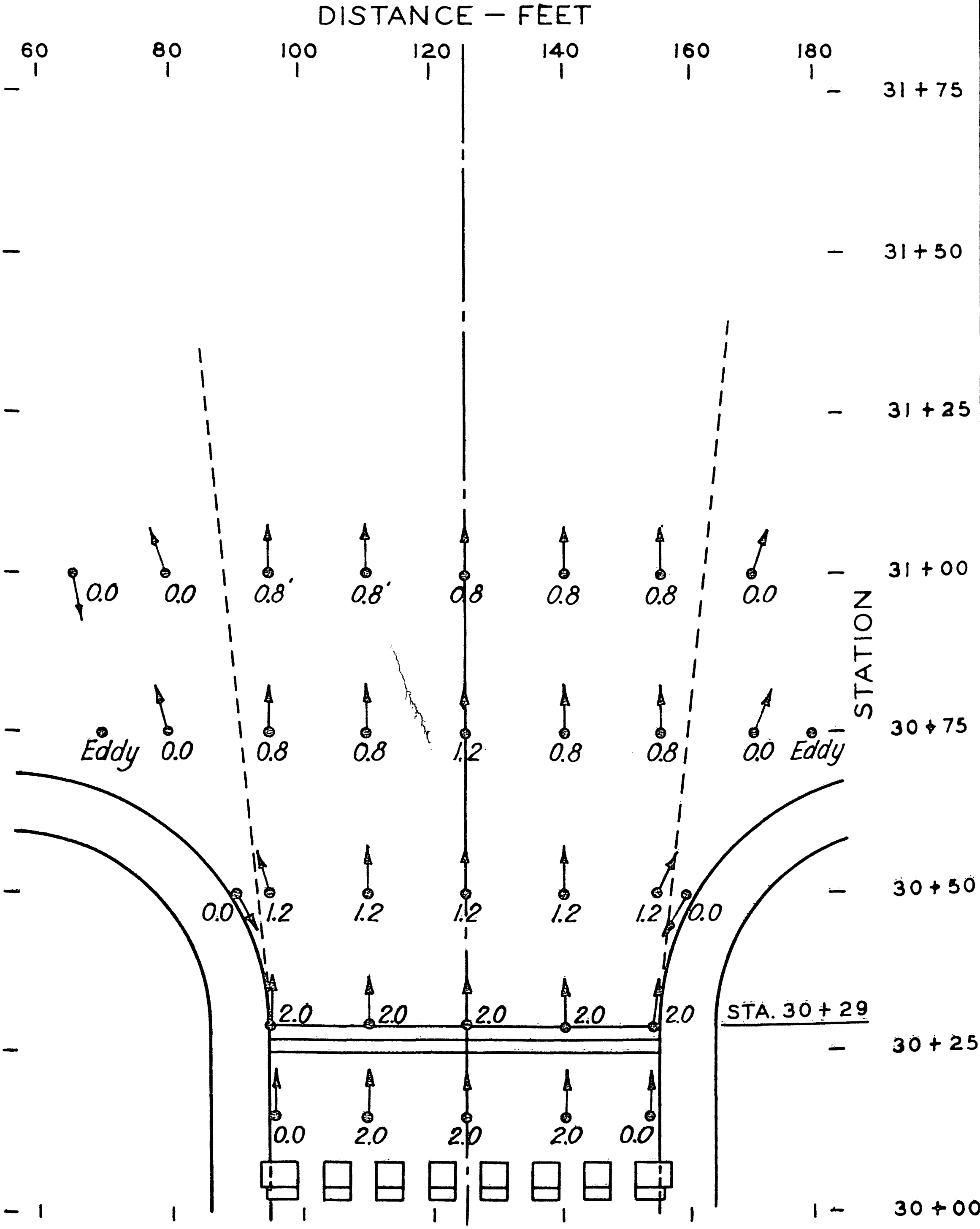
WAPPAPELLO DAM OUTLET STRUCTURES

STILLING BASIN
TYPE R



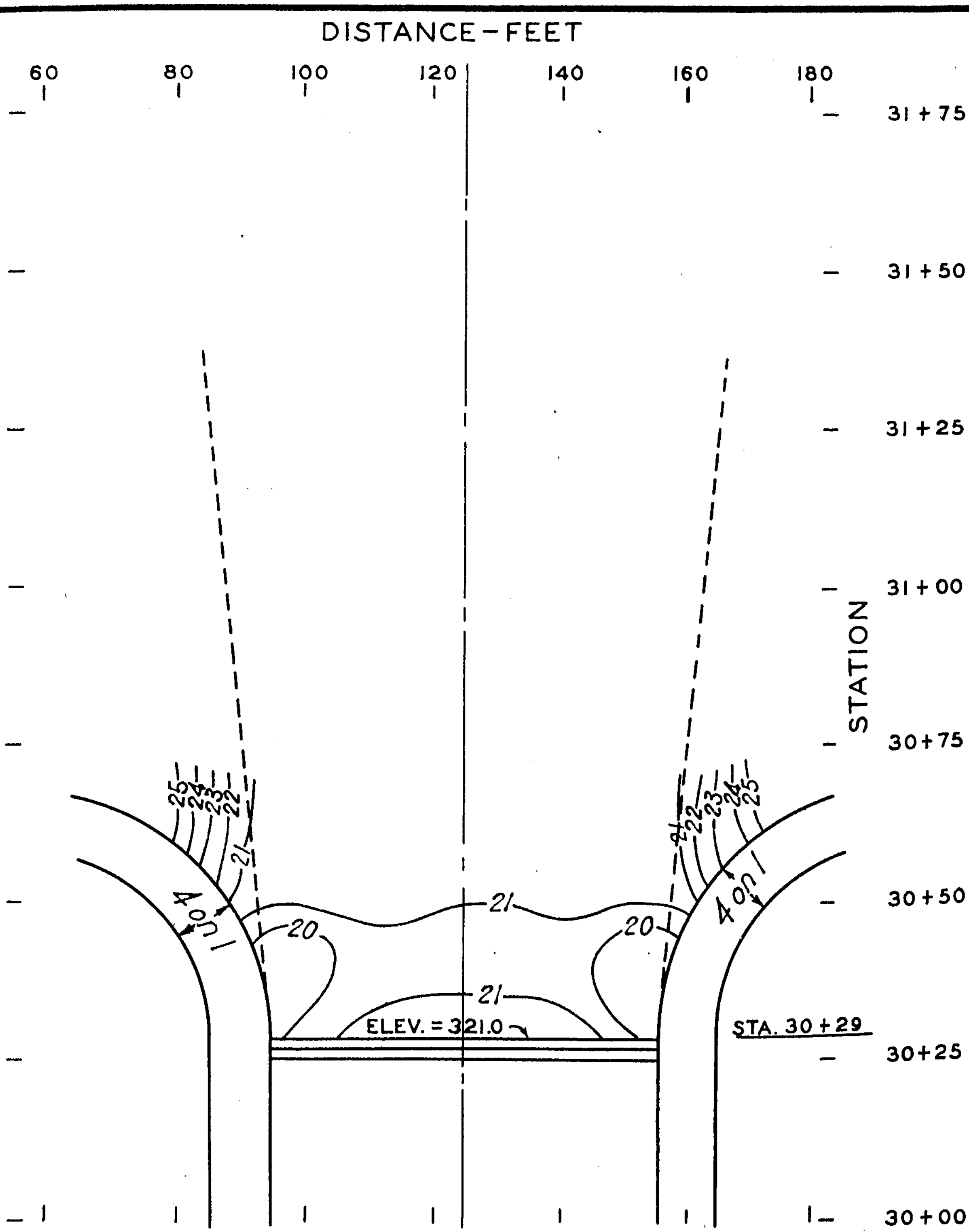
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 58
SCOUR PATTERN
NATURE Q = 5,000 C.F.S.
TAILWATER ELEV. = 340.2
LENGTH OF RUN = 50 MIN.



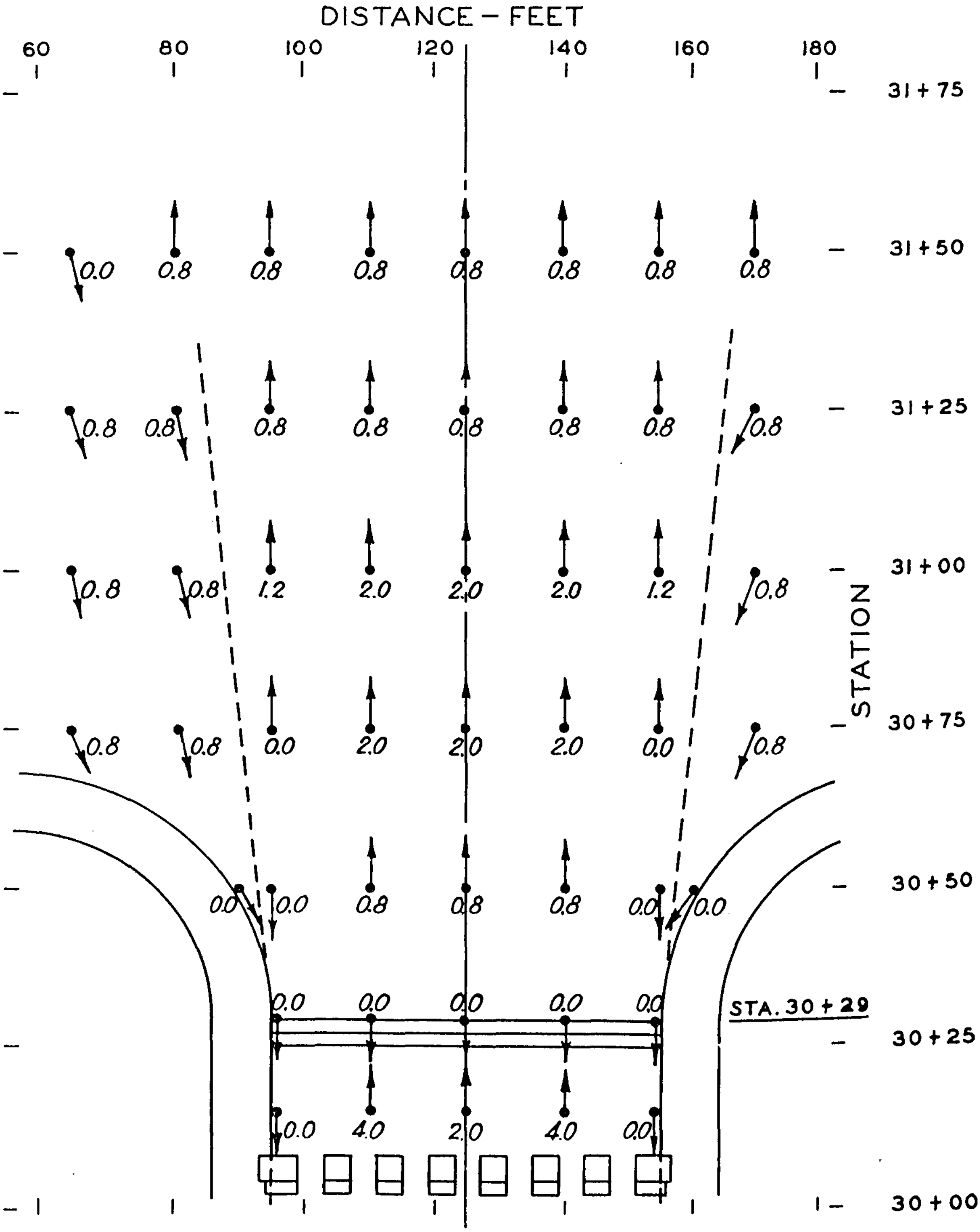
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 58
BOTTOM VELOCITIES
NATURE Q = 5.000 C.F.S.
TAILWATER ELEV. = 340.2



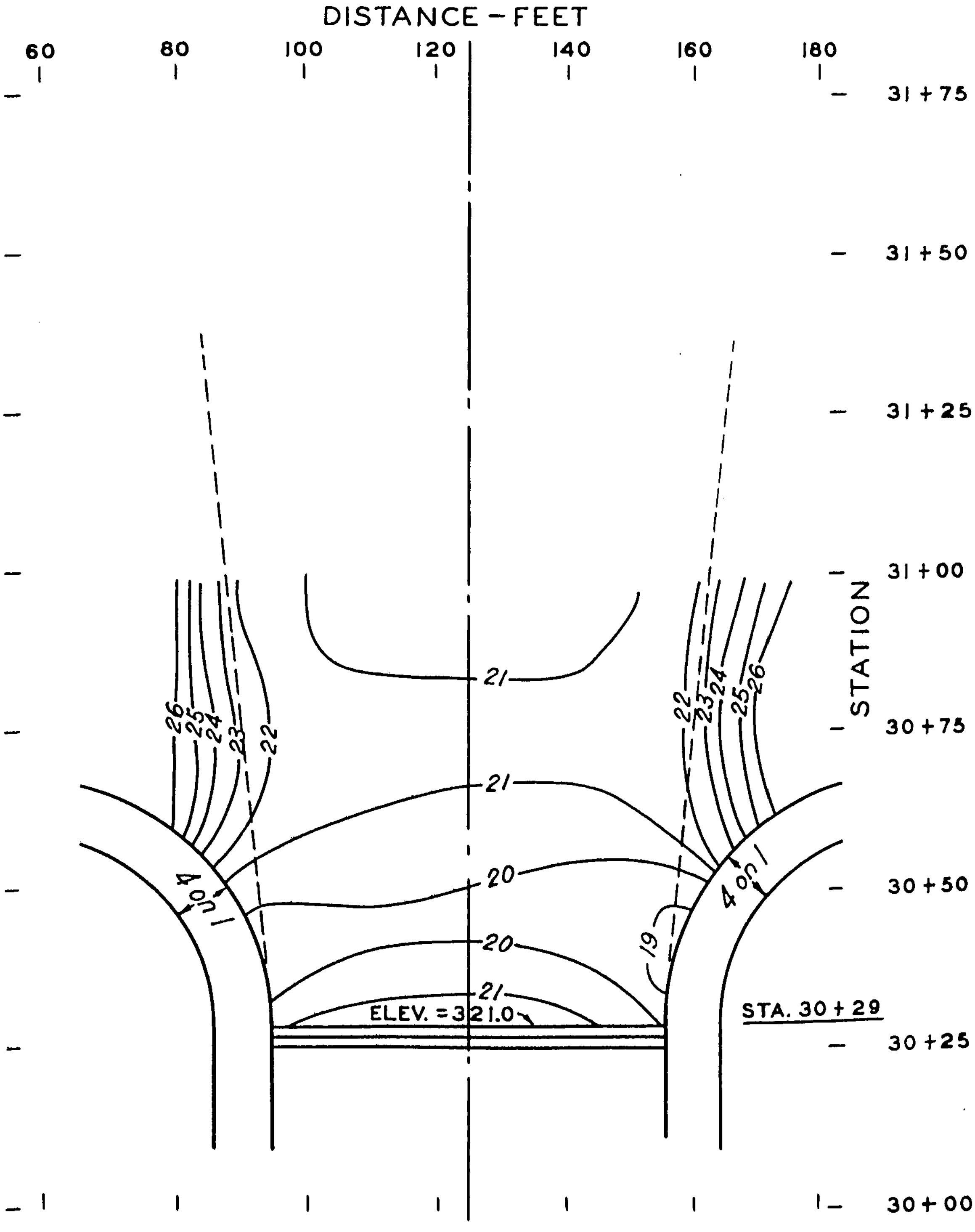
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 59
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



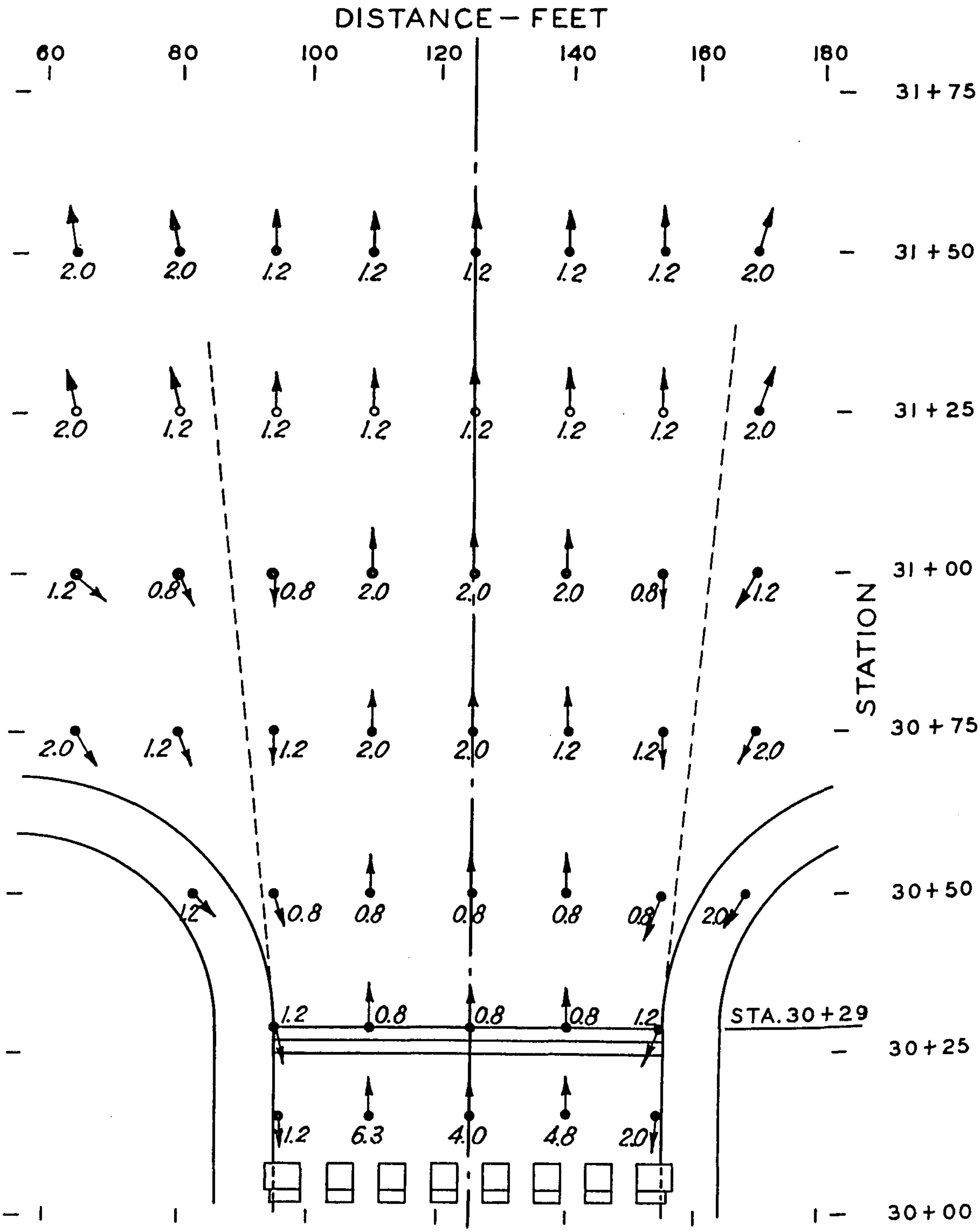
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 59
BOTTOM VELOCITIES
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0



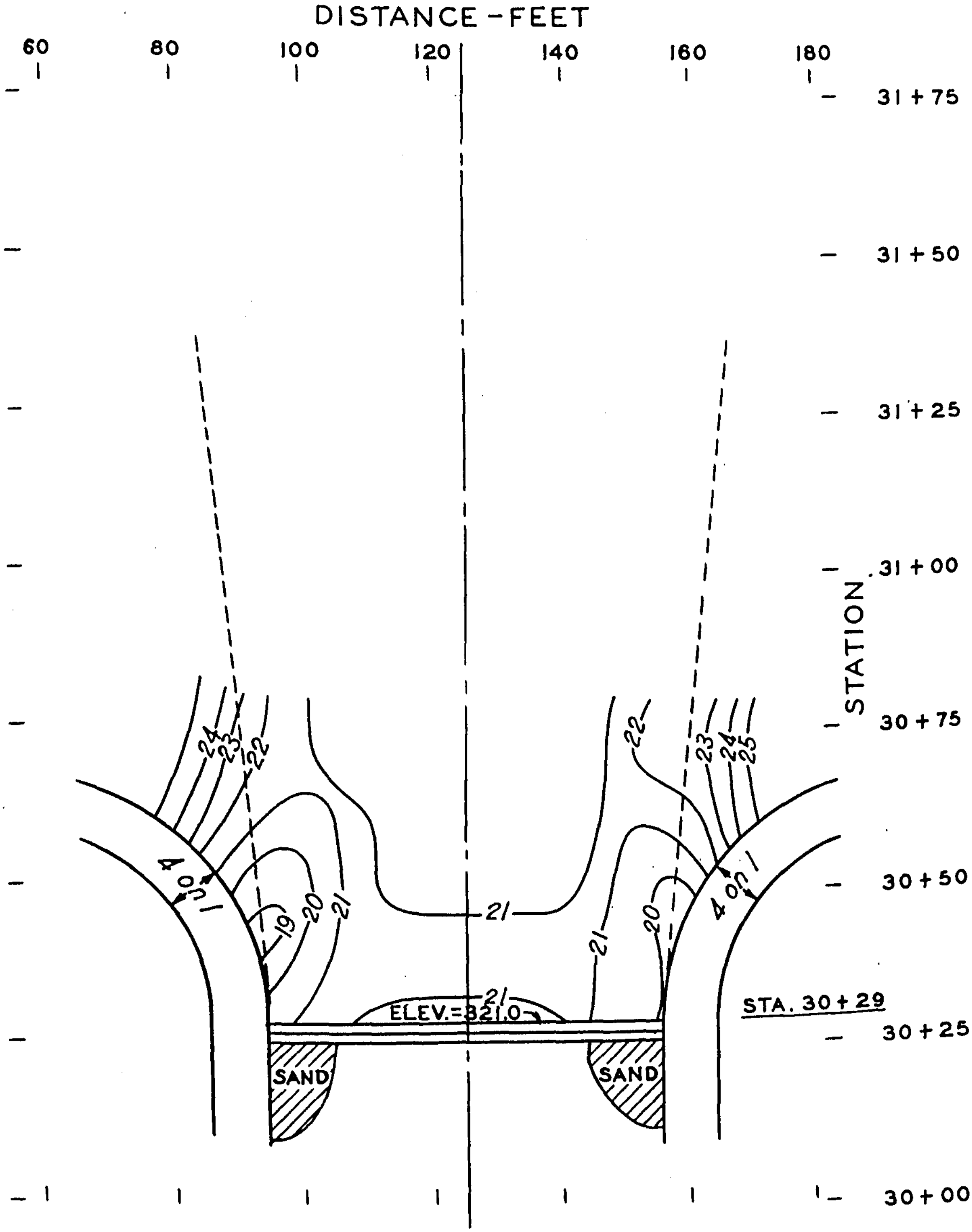
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 60
SCOUR PATTERN
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5
LENGTH OF RUN = 50 MIN.



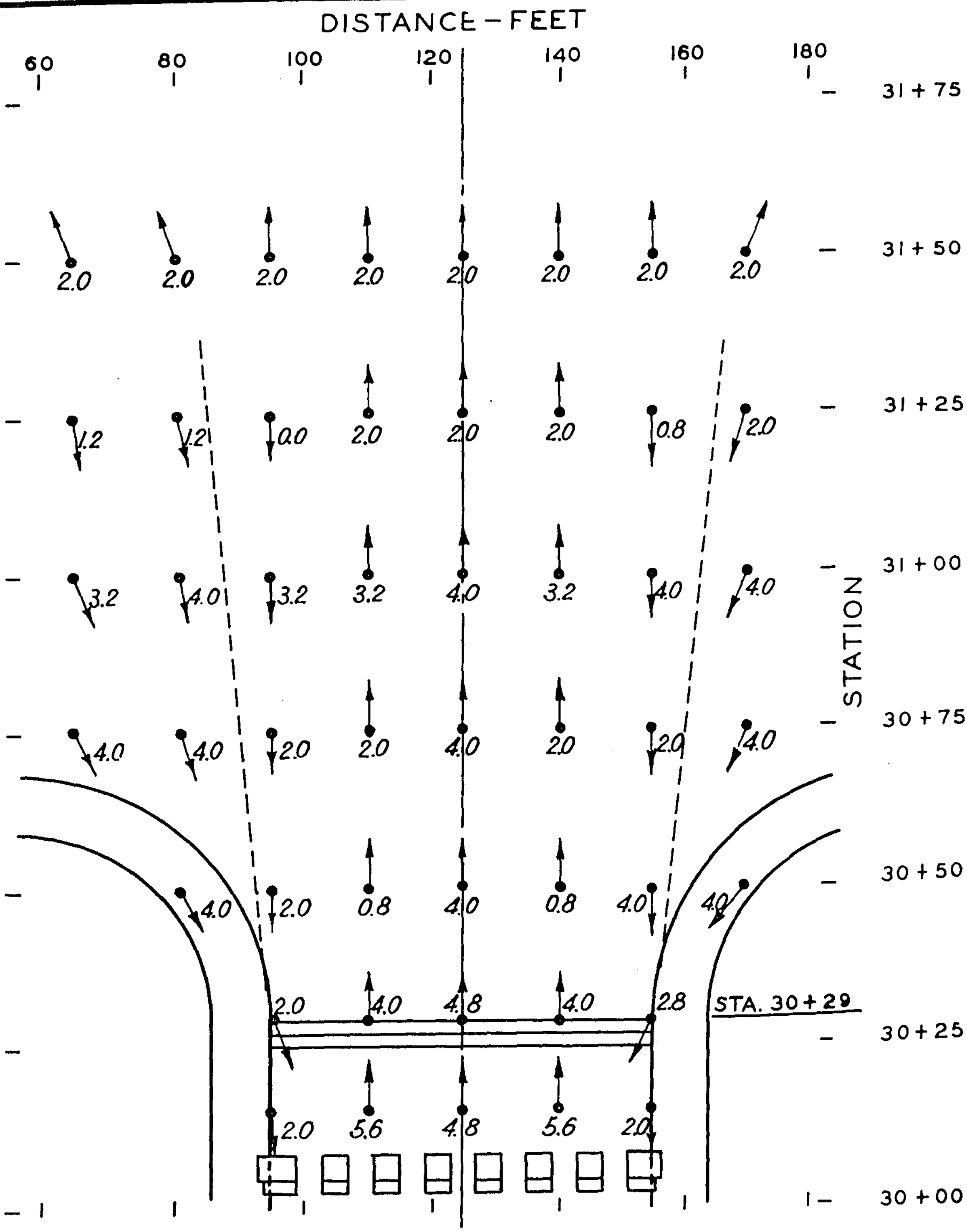
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 60
BOTTOM VELOCITIES
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5



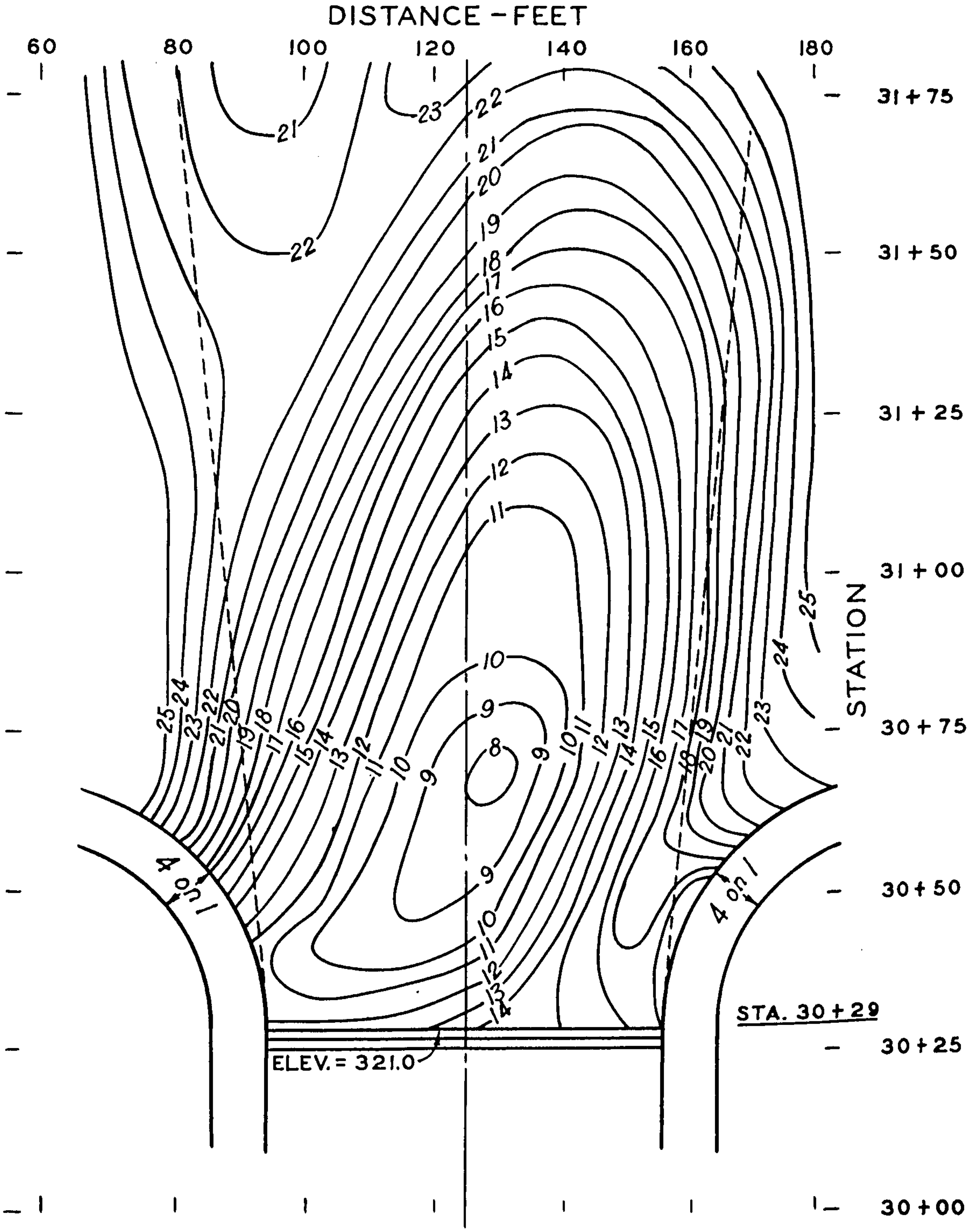
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 53
SCOUR PATTERN
NATURE Q = 17,150 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



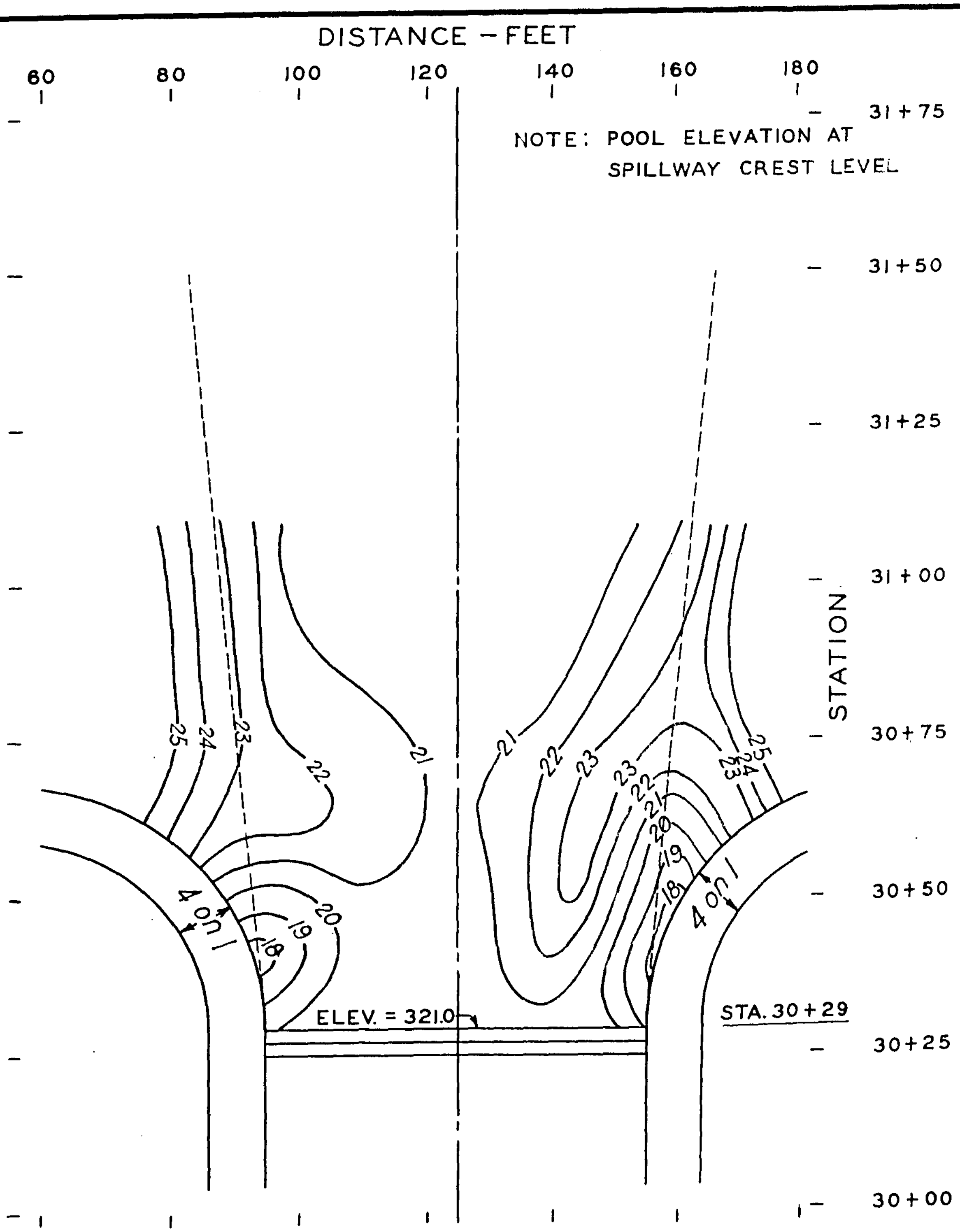
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 53
BOTTOM VELOCITIES
NATURE Q = 17,150 C.F.S.
TAILWATER ELEV. = 350.4



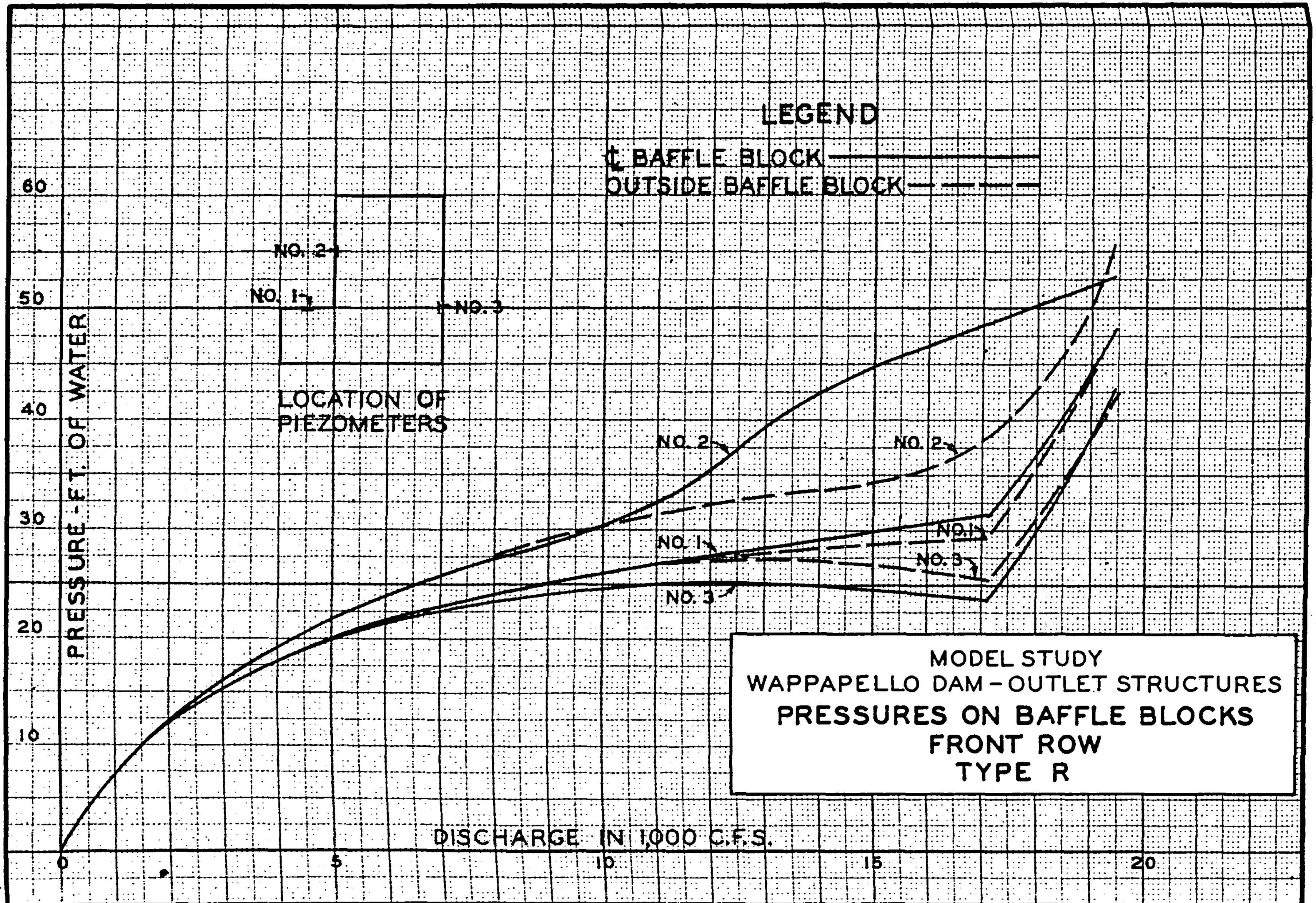
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 61
SCOUR PATTERN
NATURE Q = 19,420 C.F.S.
TAILWATER ELEV. = 366.0
LENGTH OF RUN = 50 MIN.

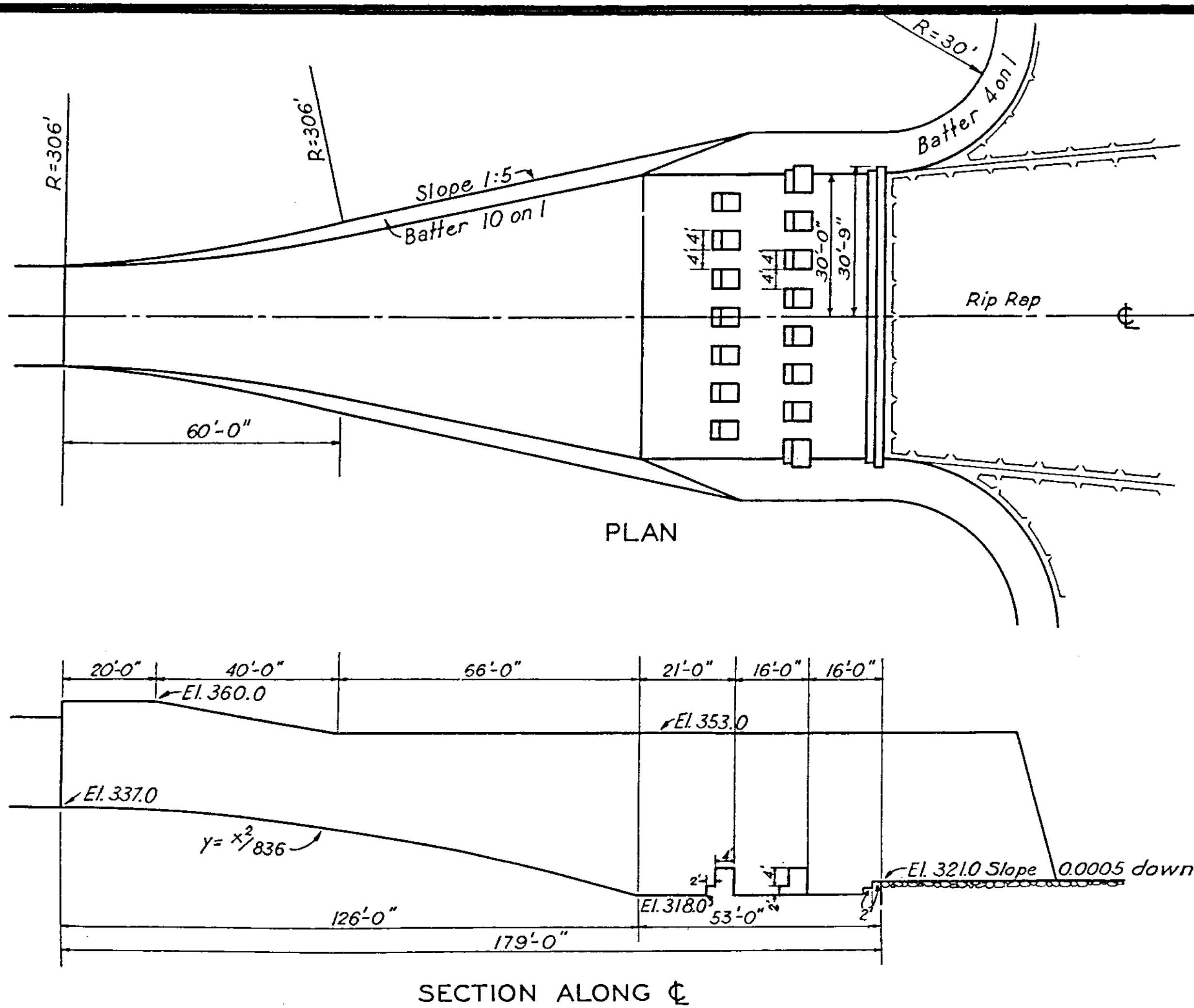


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 64
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.

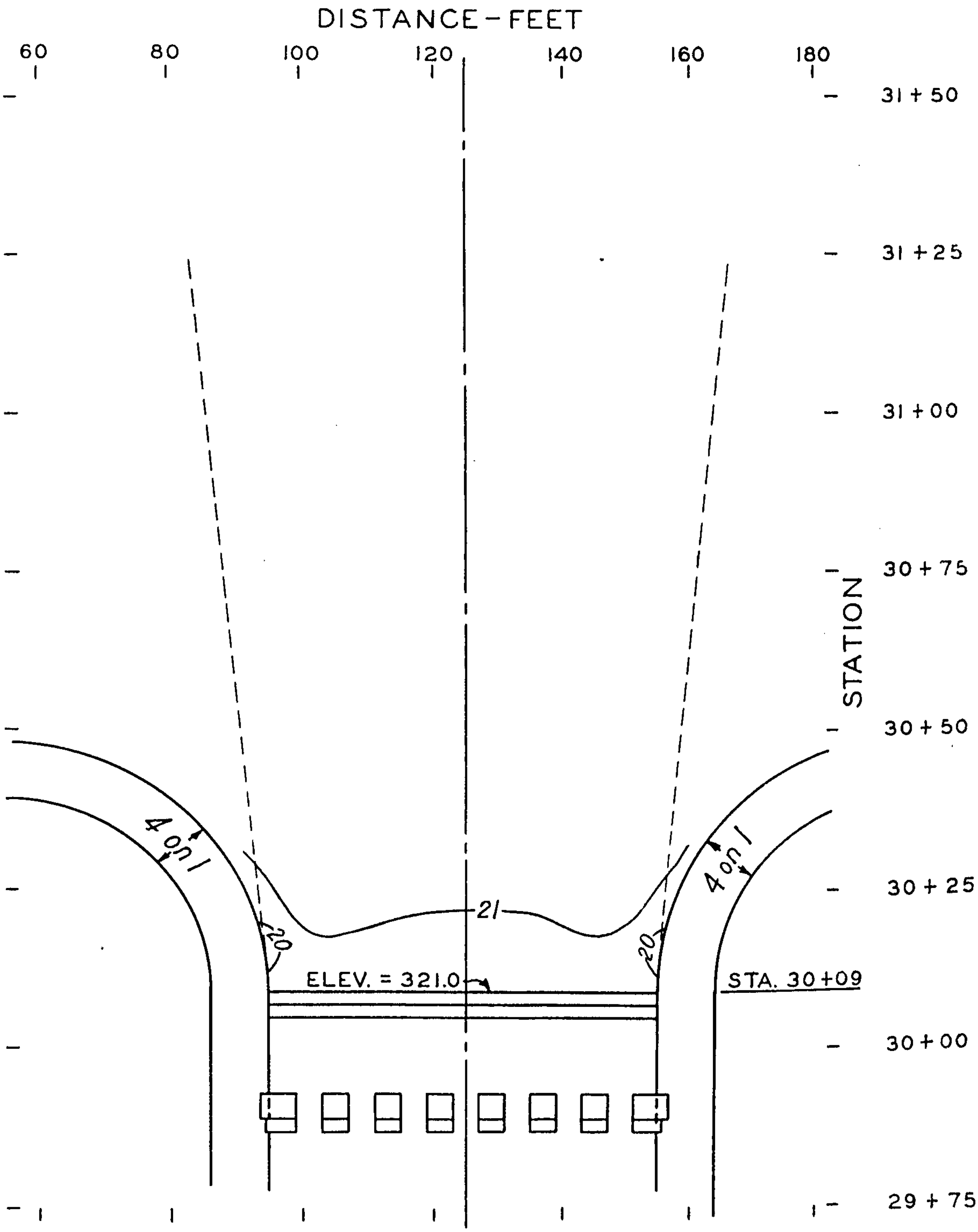


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
PRESSURES ON BAFFLE BLOCKS
FRONT ROW
TYPE R



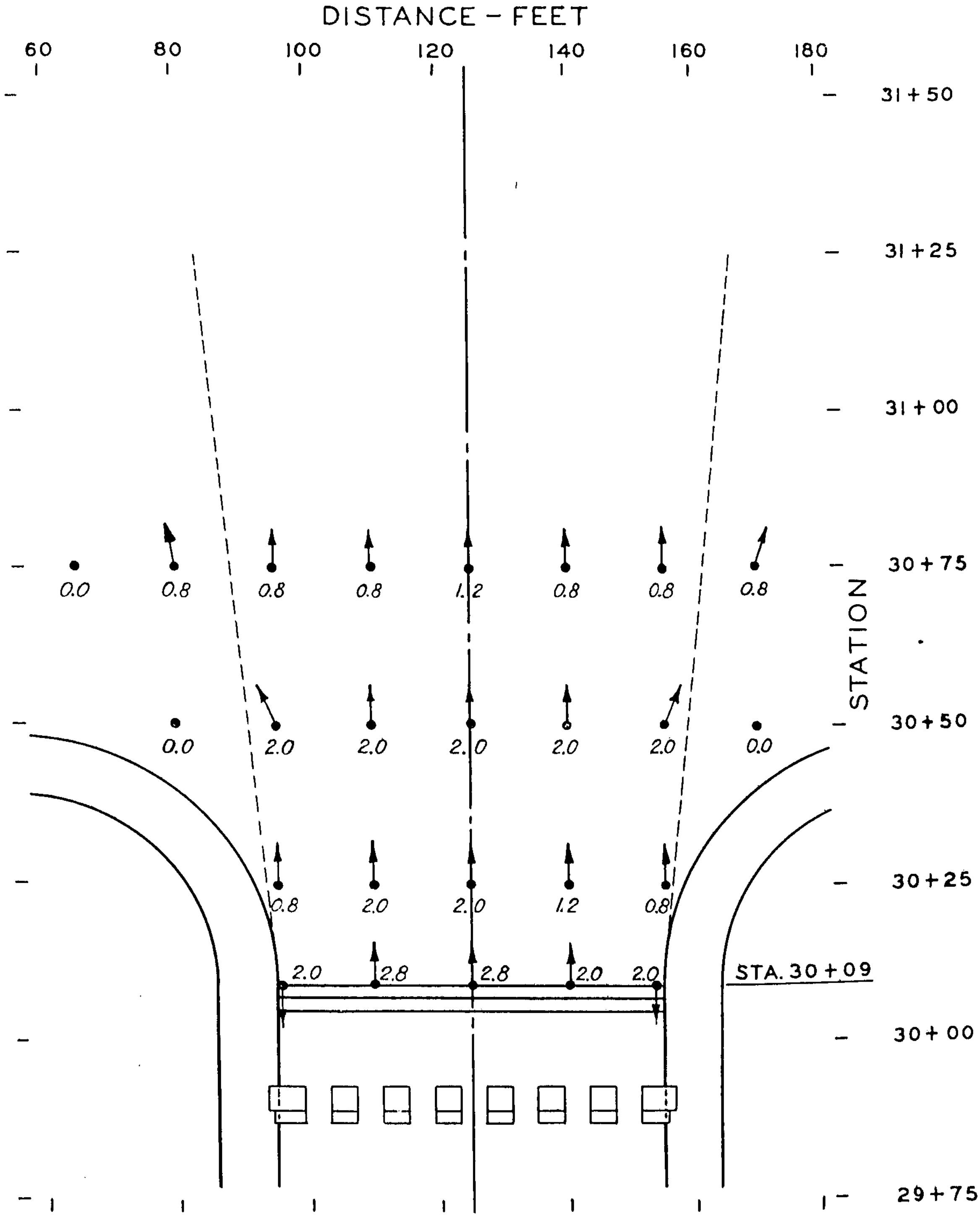
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

STILLING BASIN
TYPE DD



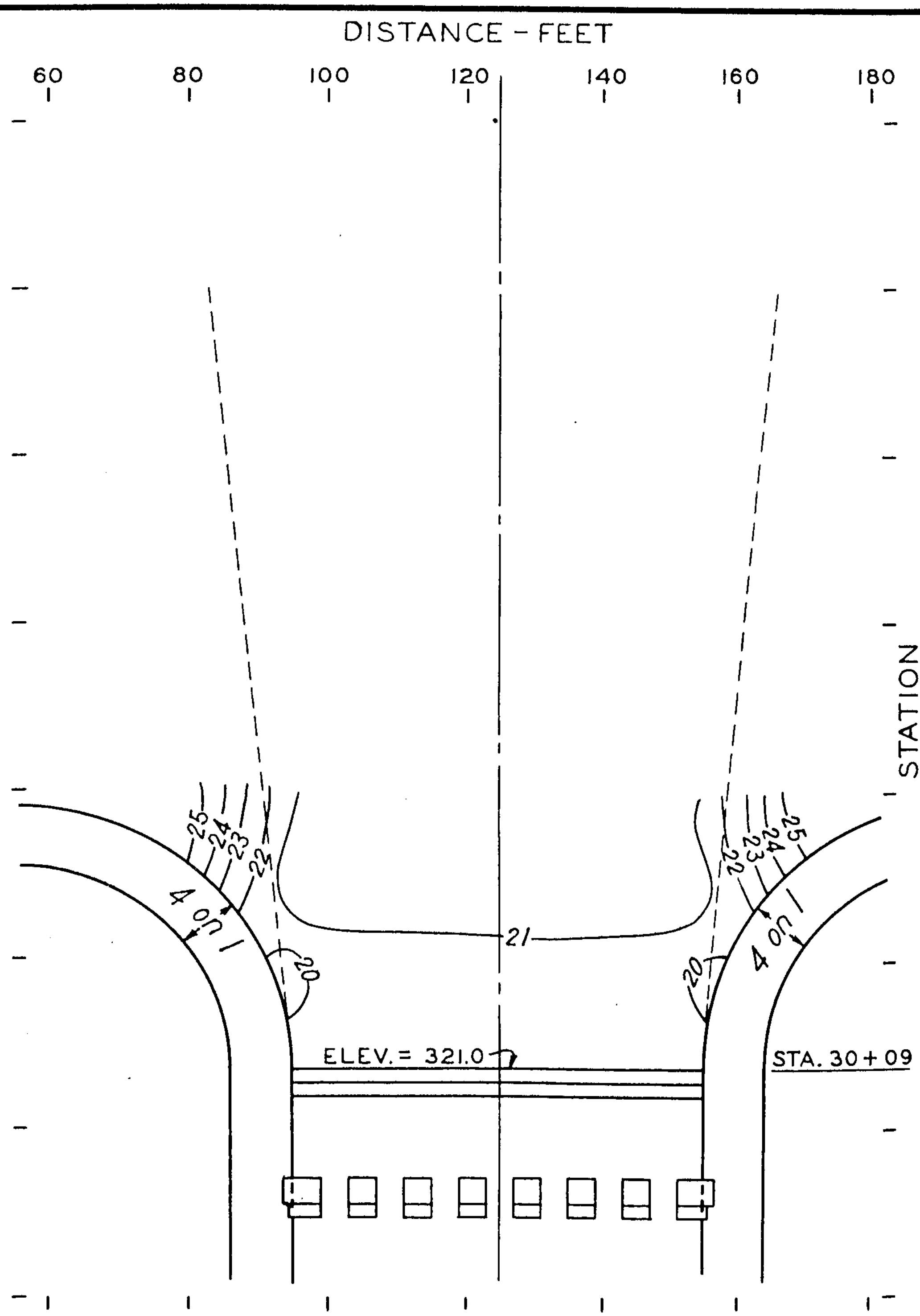
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 80
SCOUR PATTERN
NATURE Q = 5,000 C.F.S.
TAILWATER ELEV. = 340.2
LENGTH OF RUN = 50 MIN.



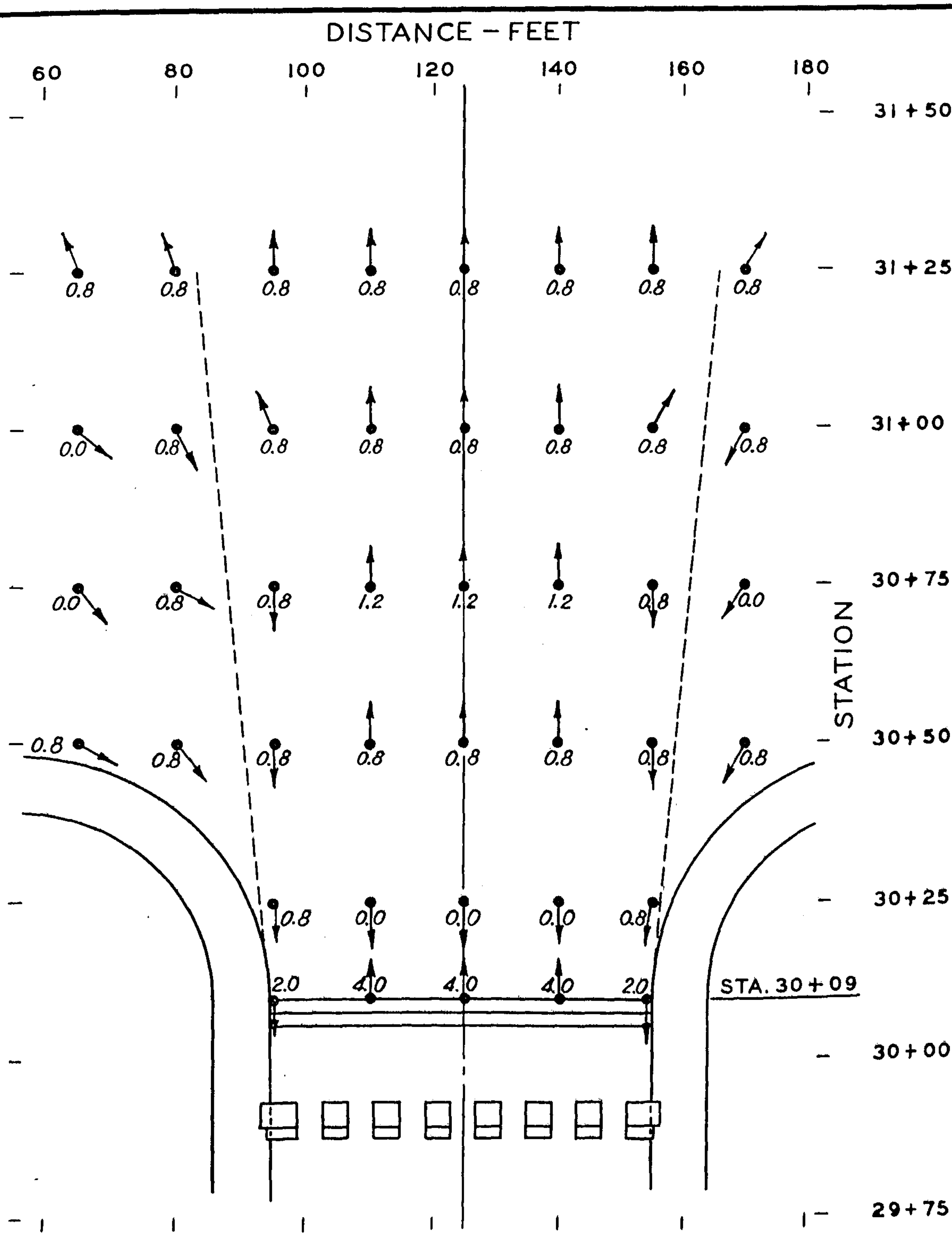
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 80
BOTTOM VELOCITIES
NATURE Q = 5,000 C.F.S.
TAILWATER ELEV. = 340.2



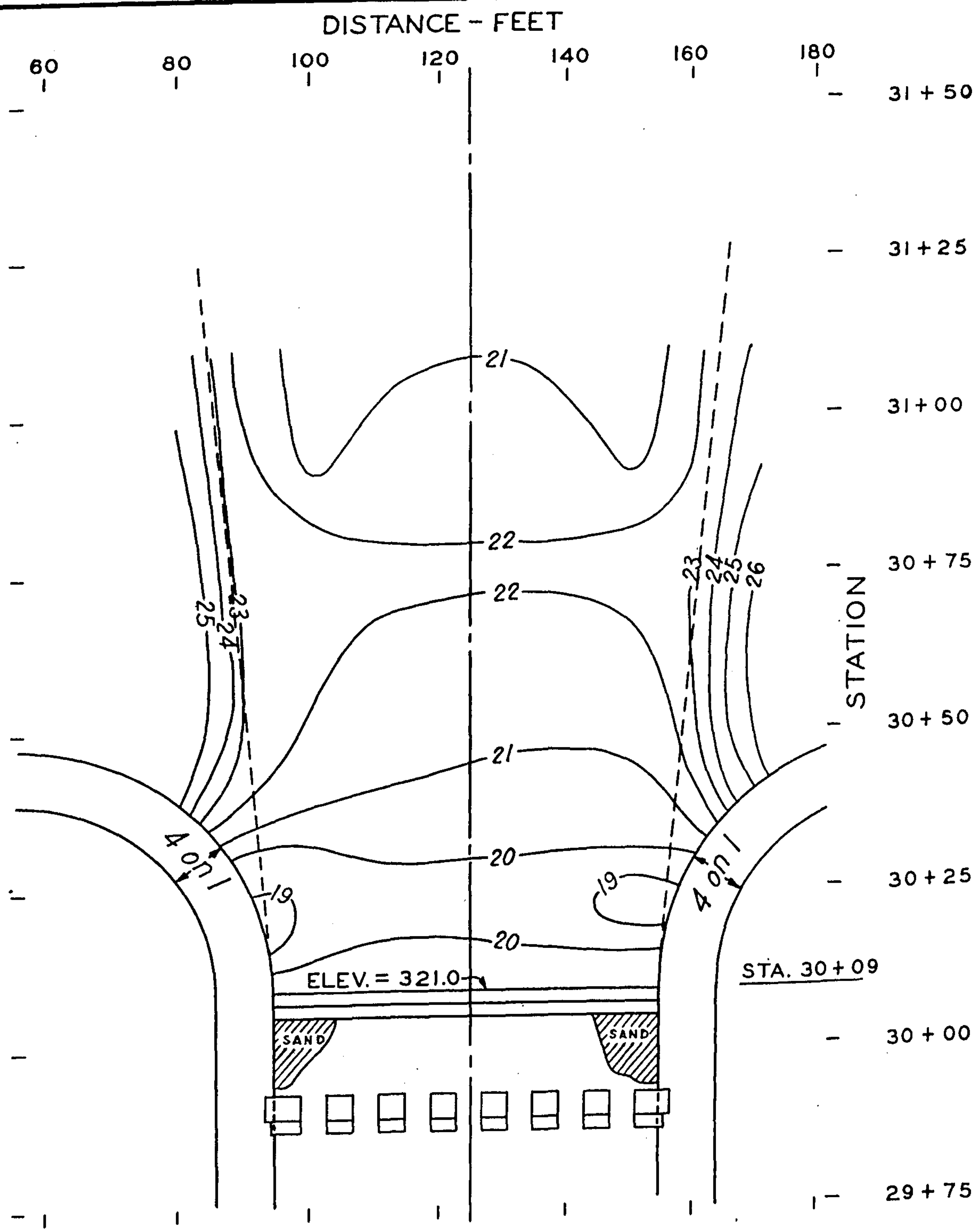
MODEL STUDY
WAPPAPELLO DAM—OUTLET STRUCTURES

TEST NO. 81
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



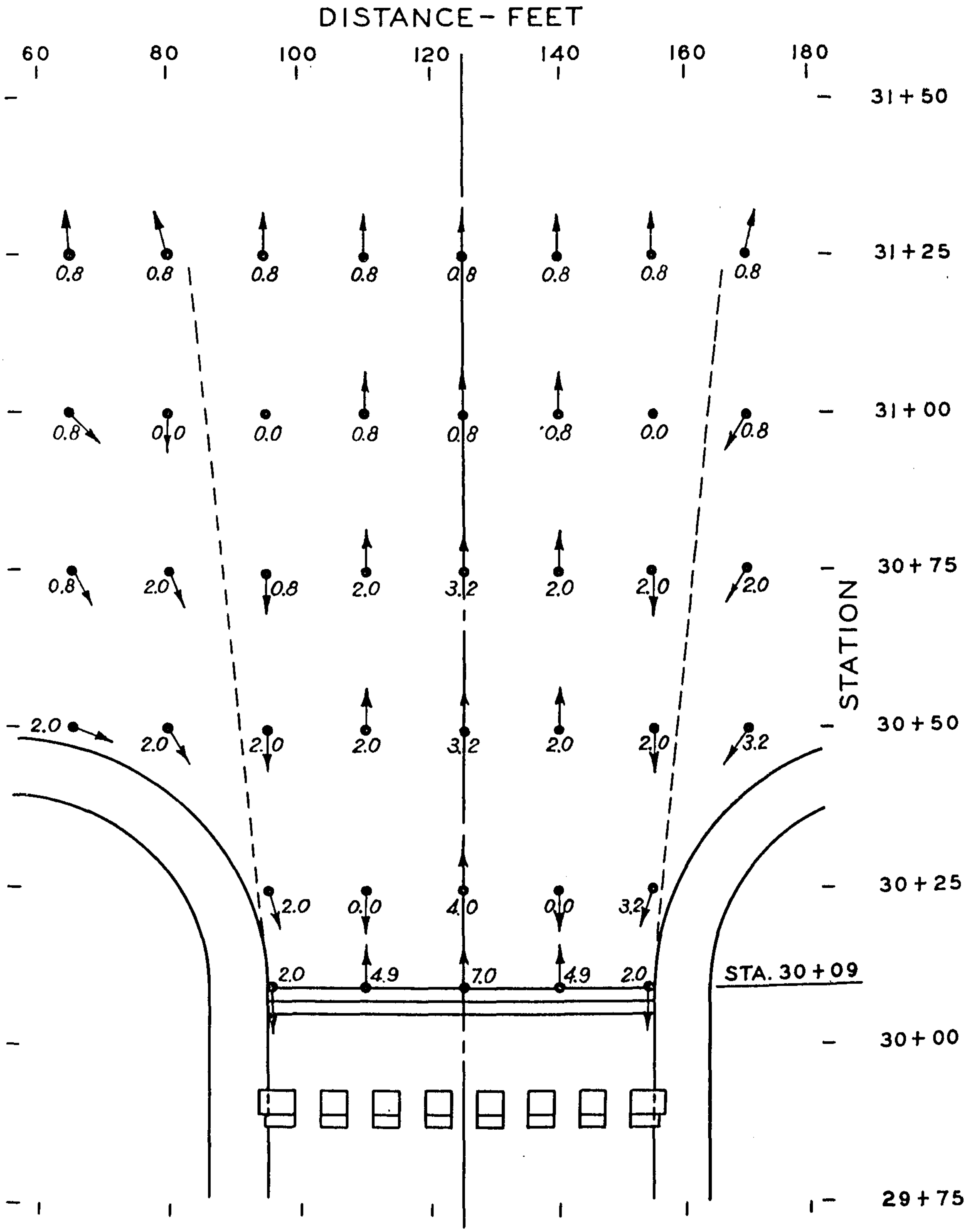
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 81
BOTTOM VELOCITIES
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0



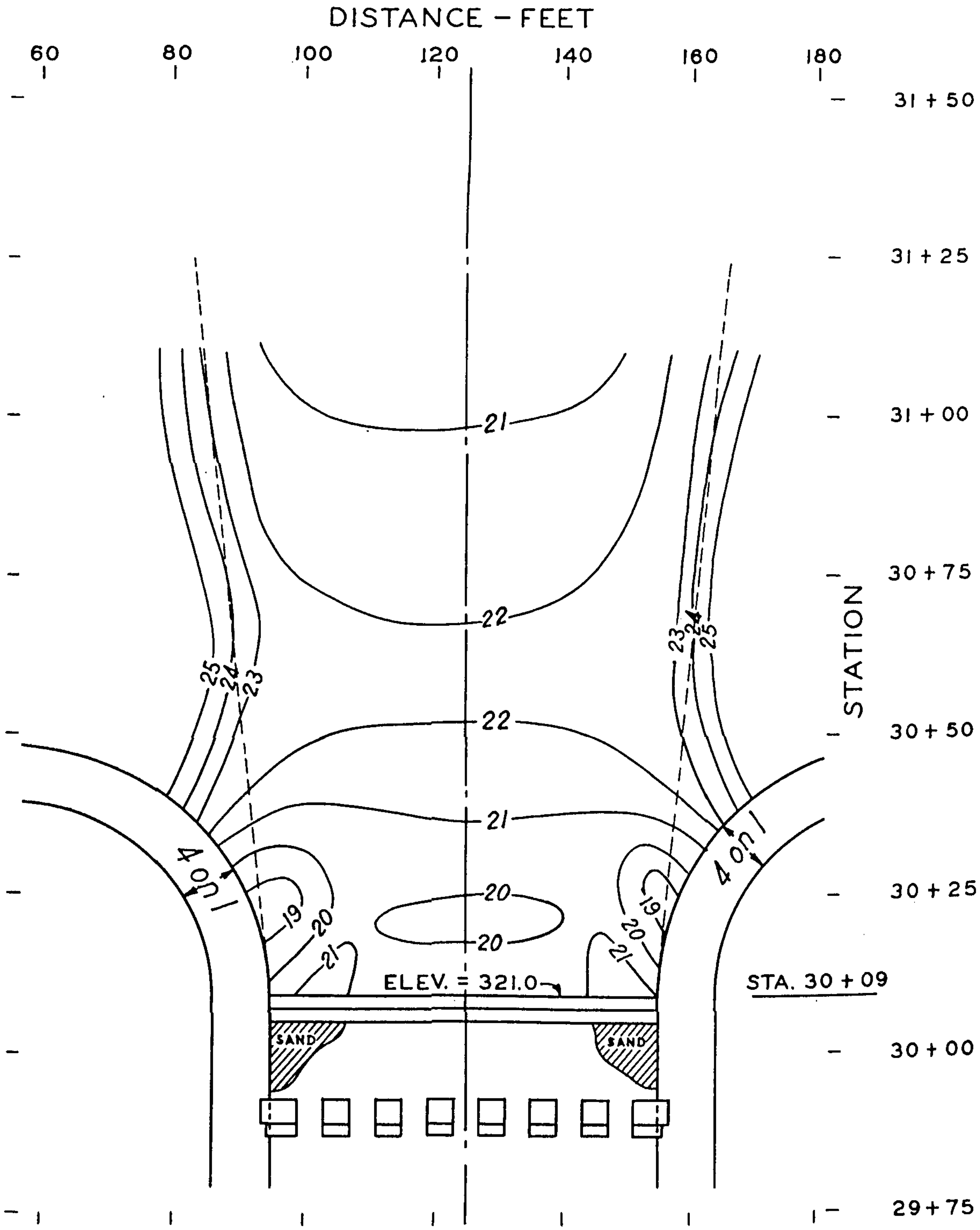
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES

TEST NO. 82
SCOUR PATTERN
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5
LENGTH OF RUN = 50 MIN.



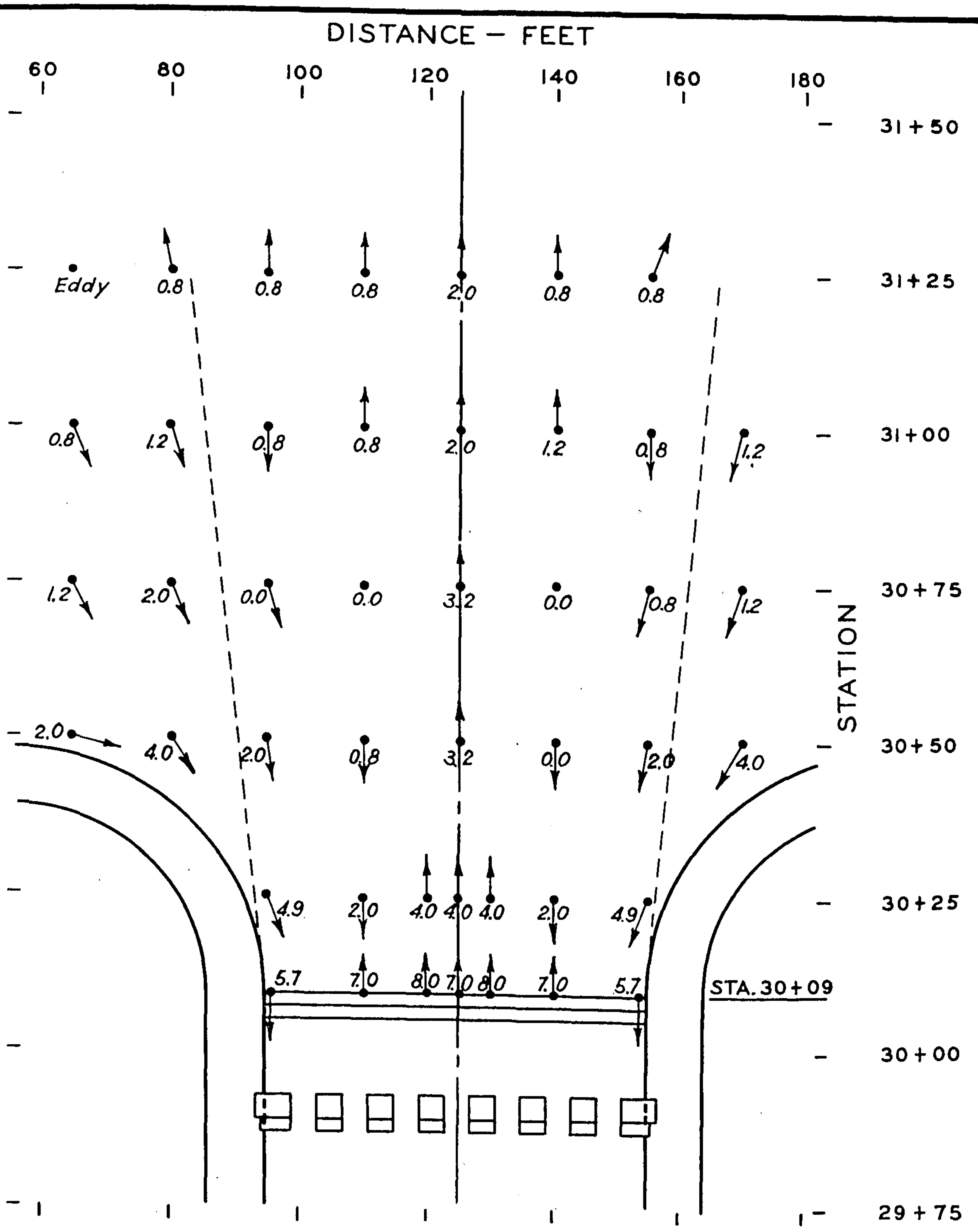
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 82
BOTTOM VELOCITIES
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5



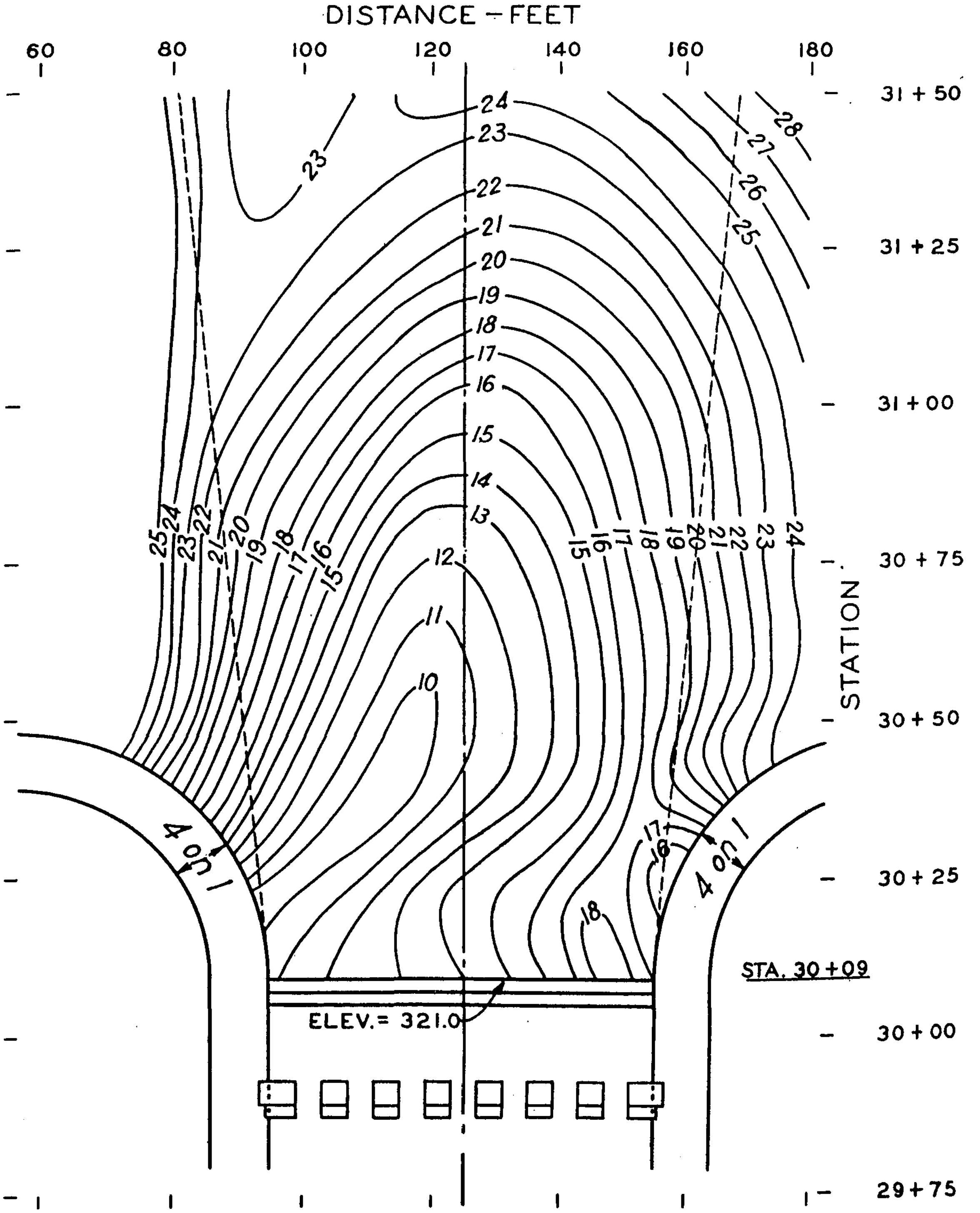
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 77
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



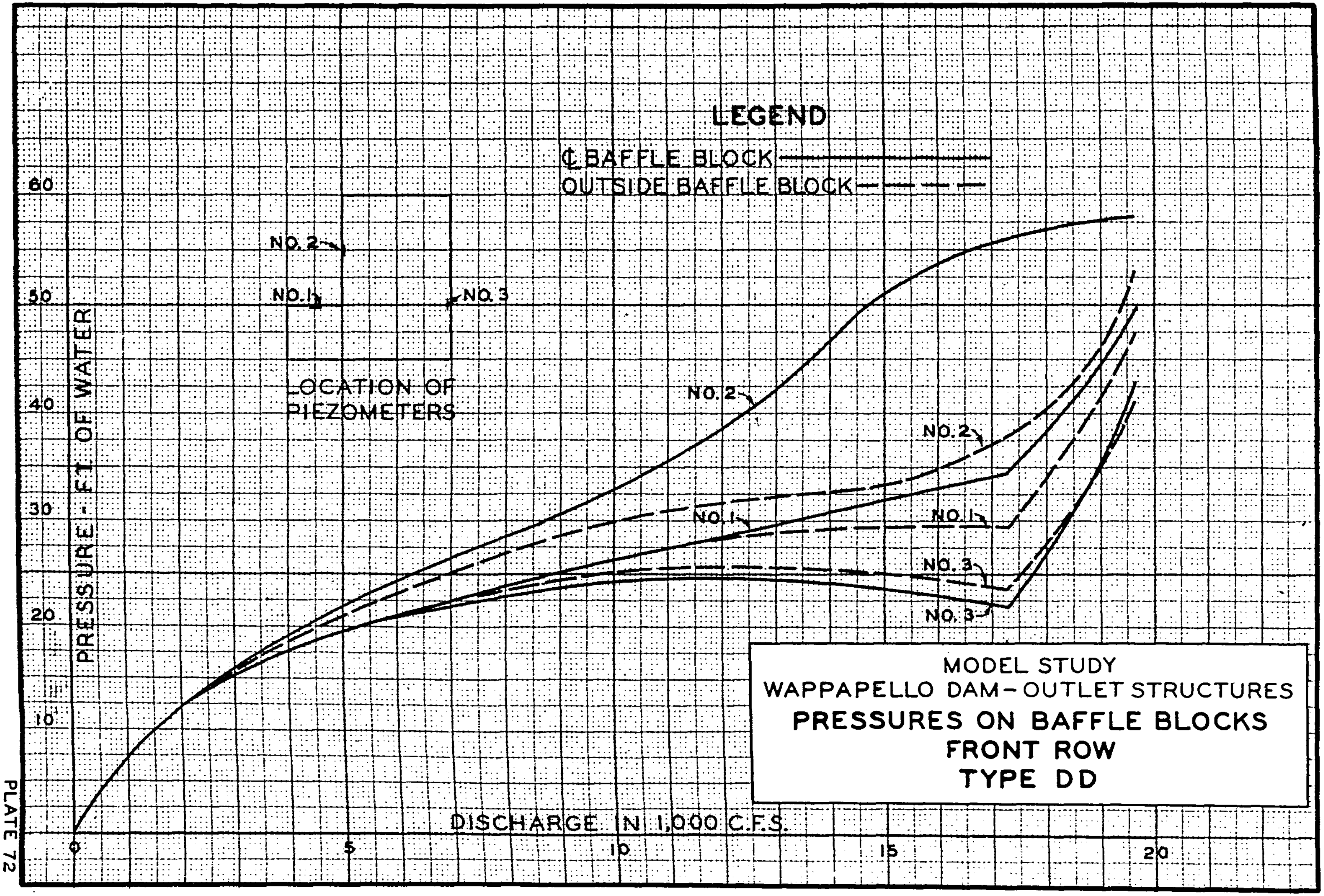
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 77
BOTTOM VELOCITIES
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4

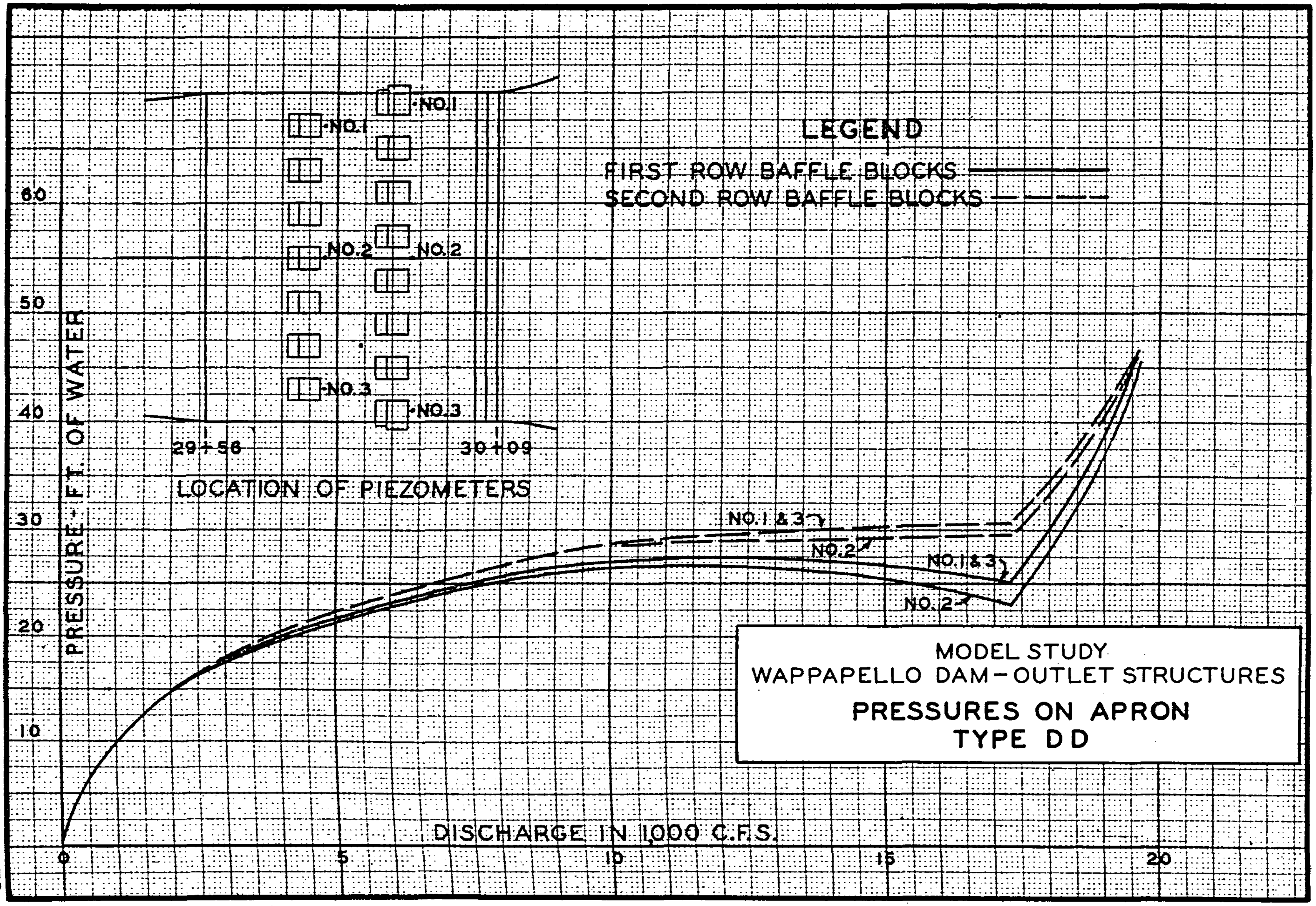


MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

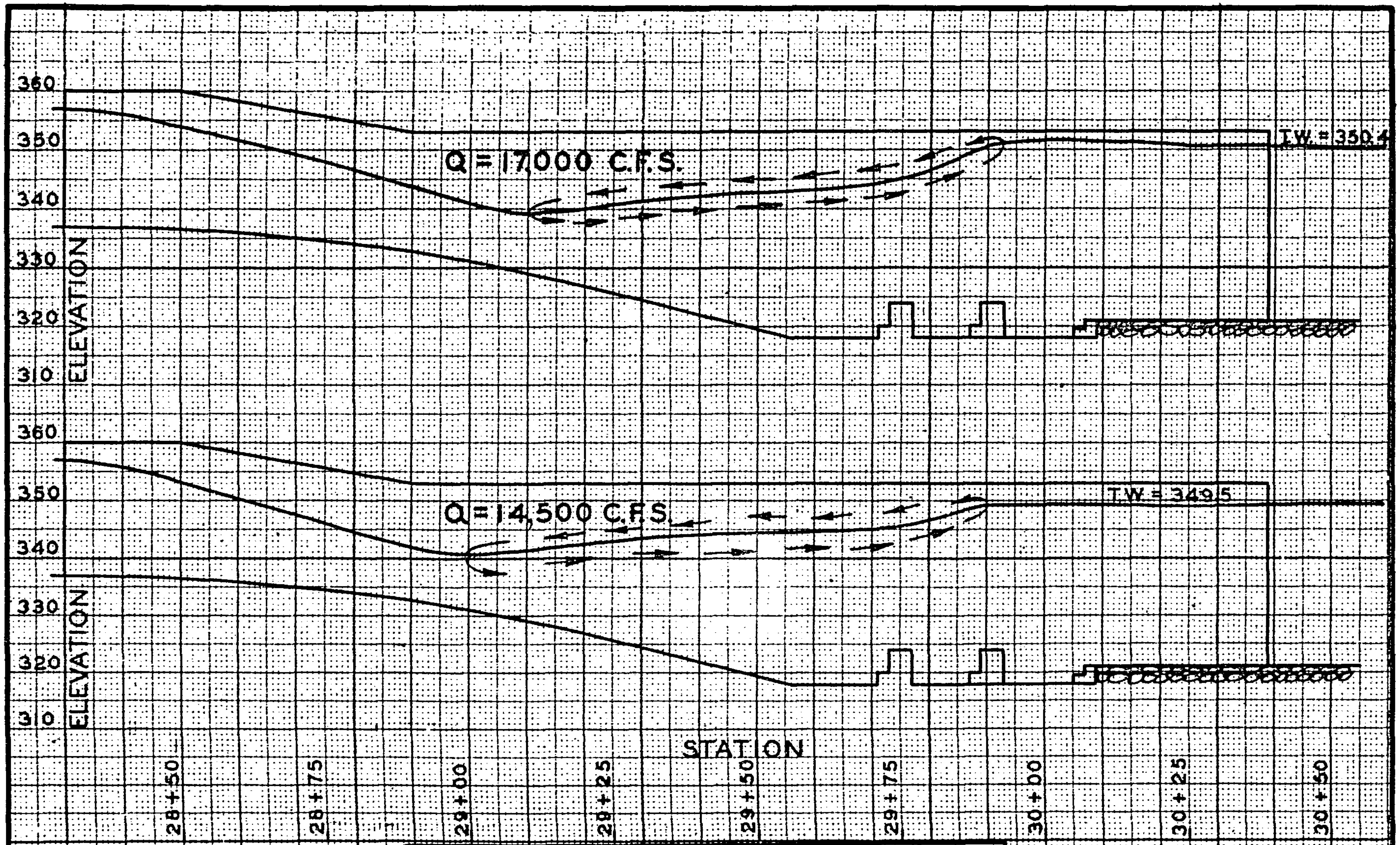
TEST NO. 84
SCOUR PATTERN
NATURE Q = 19,620 C.F.S.
TAILWATER ELEV. = 366.0
LENGTH OF RUN = 50 MIN.



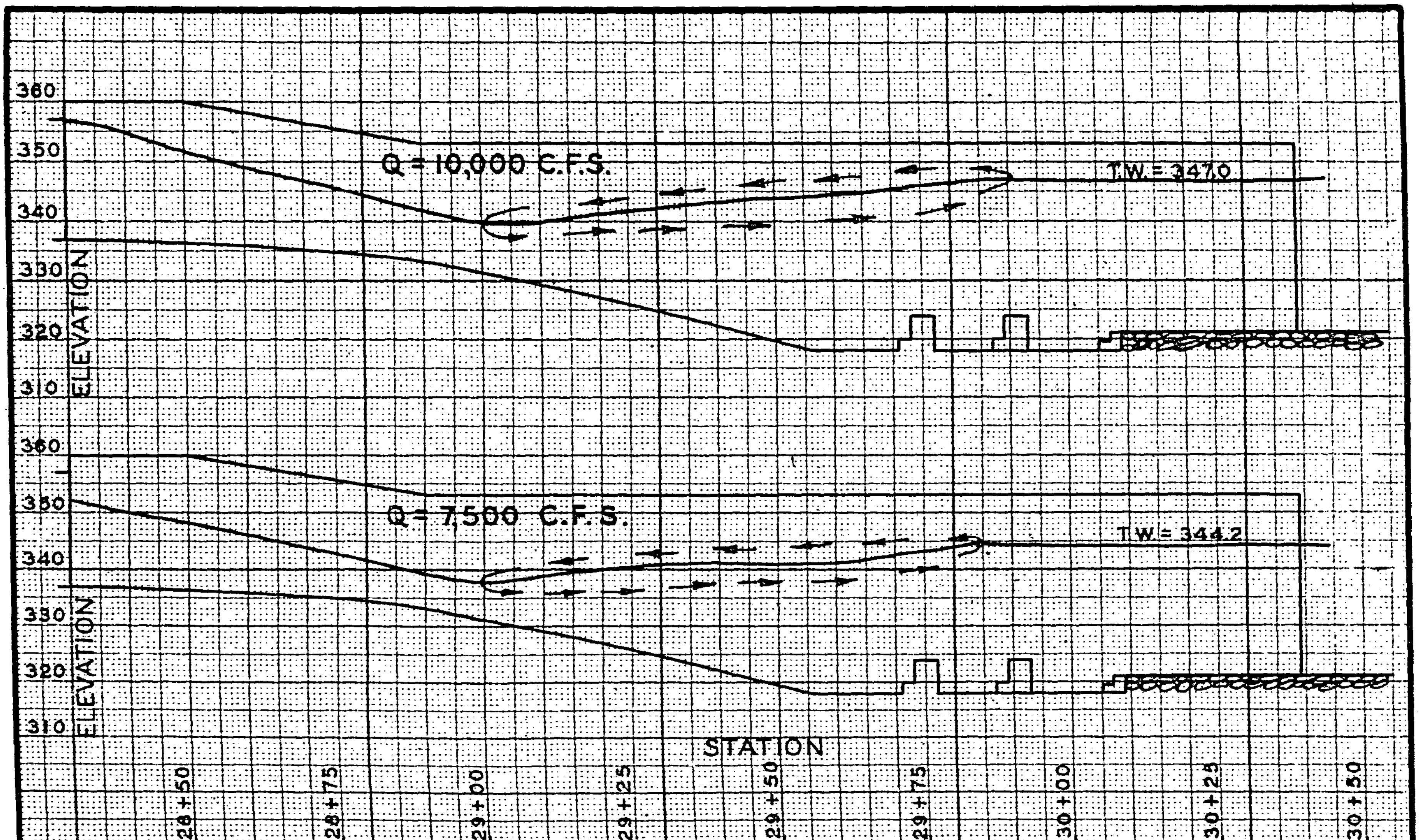
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES
PRESSURES ON BAFFLE BLOCKS
FRONT ROW
TYPE DD



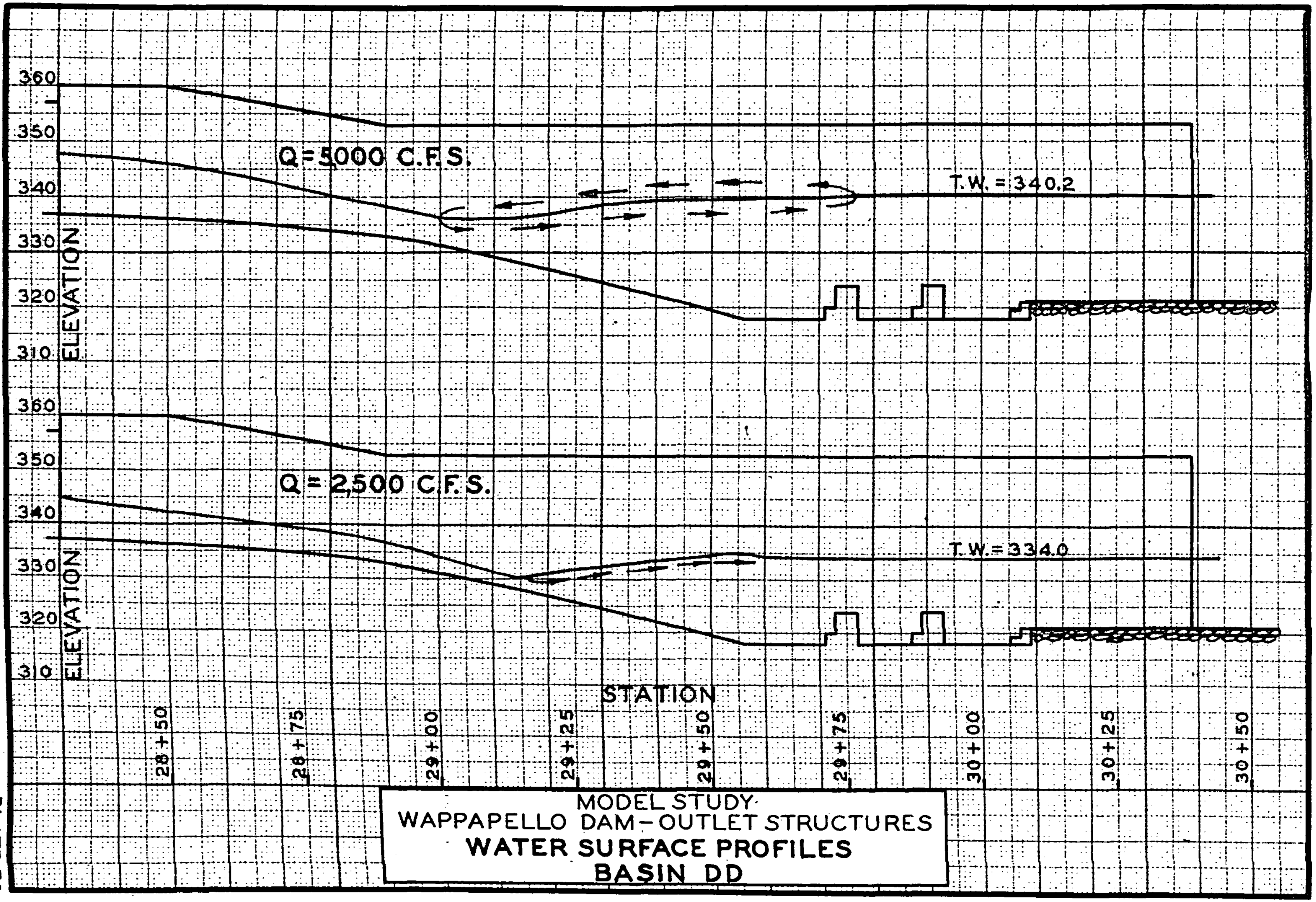
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES
PRESSURES ON APRON
TYPE DD



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
WATER SURFACE PROFILES
BASIN DD

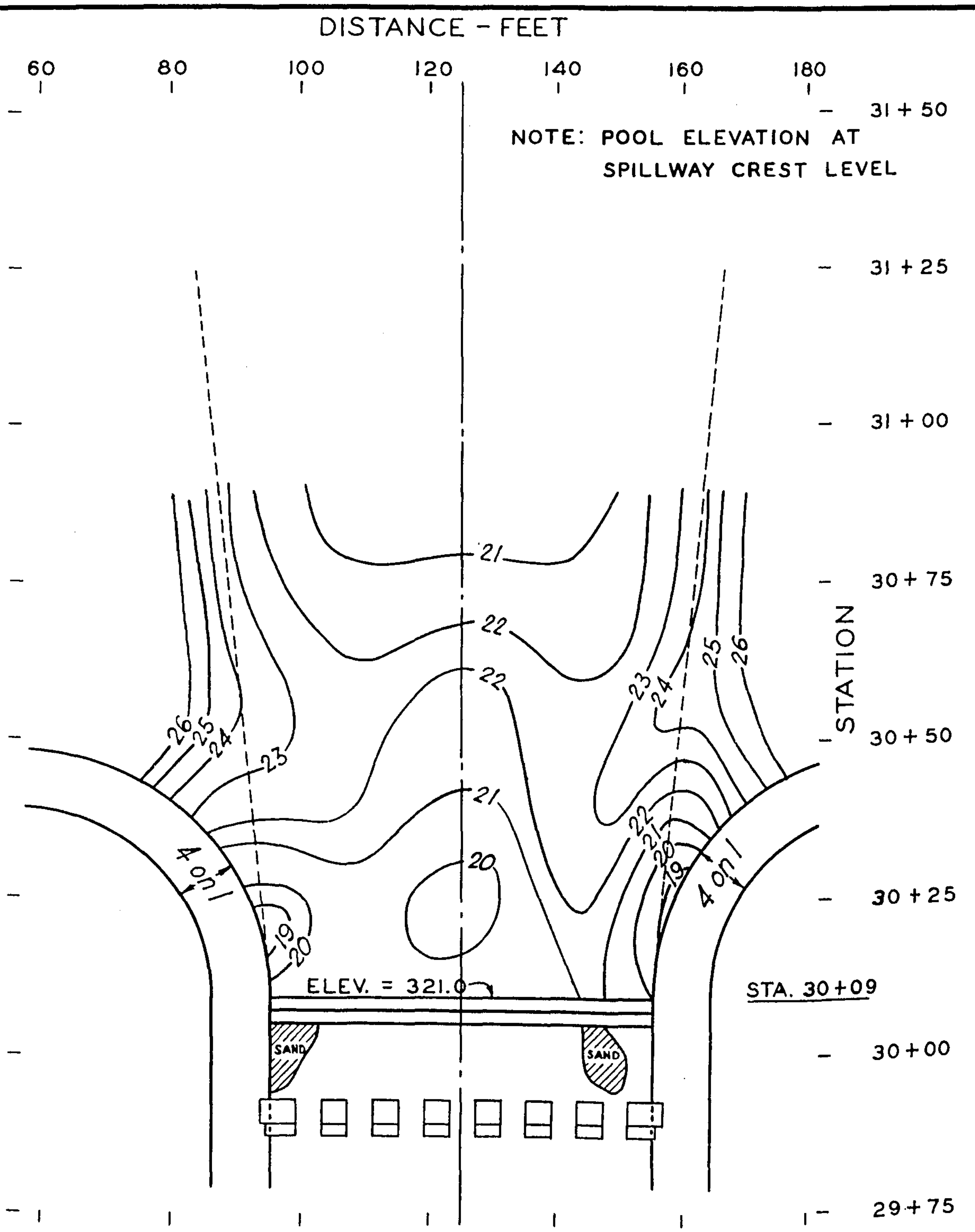


MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES
WATER SURFACE PROFILES
BASIN DD



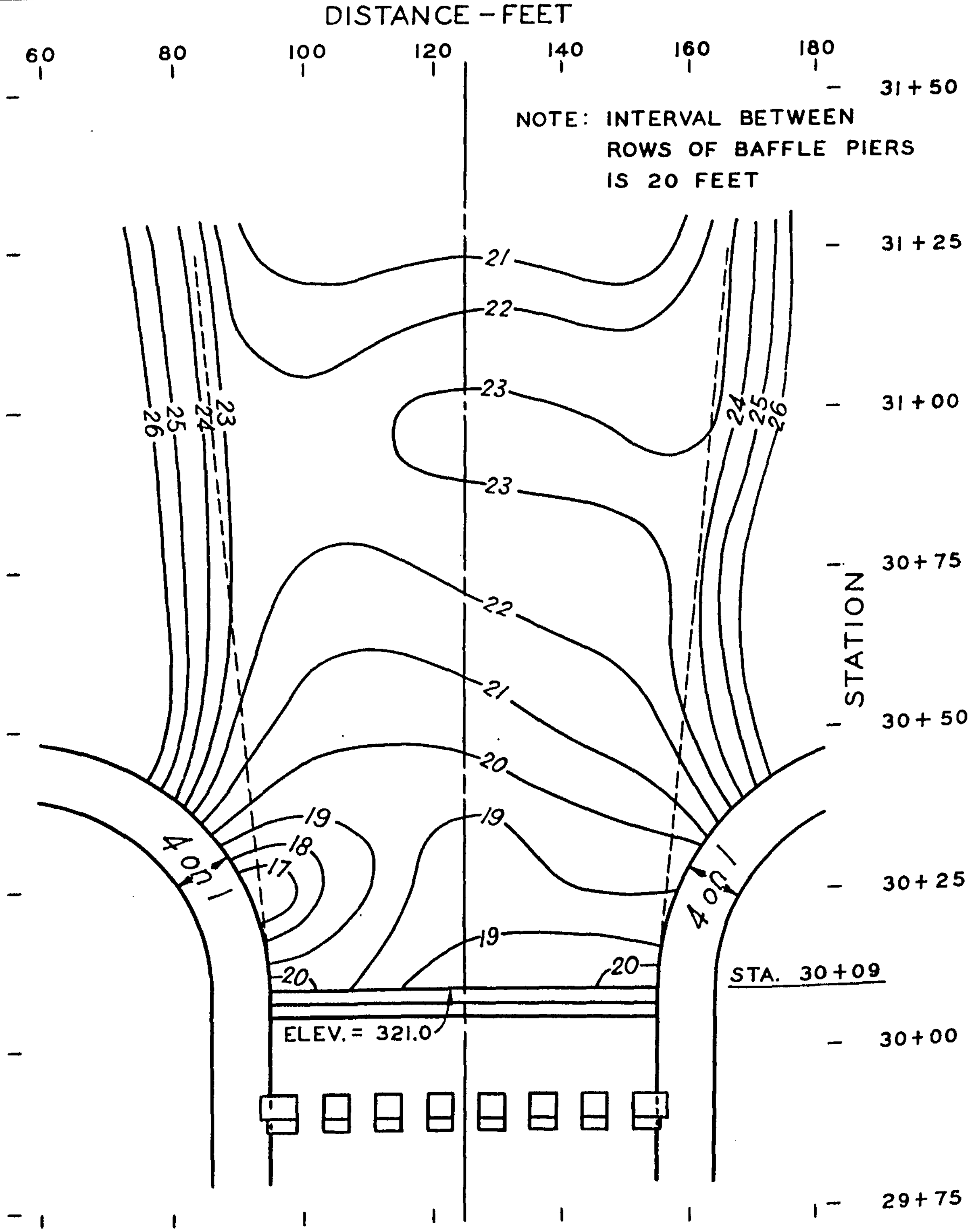
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
WATER SURFACE PROFILES
BASIN DD

PLATE 76



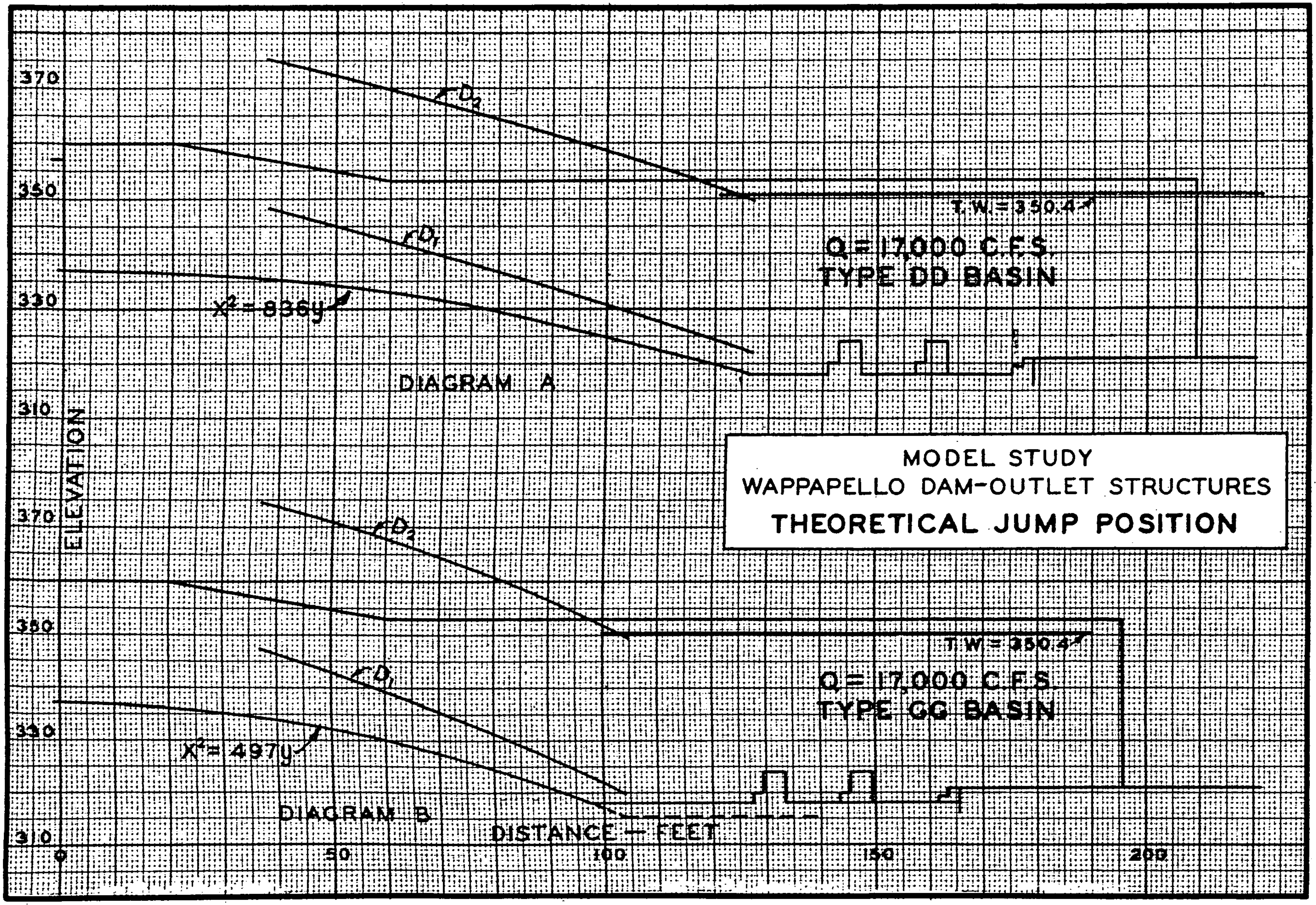
MODEL STUDY
WAPPAPELLO DAM–OUTLET STRUCTURES

TEST NO. 83
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.

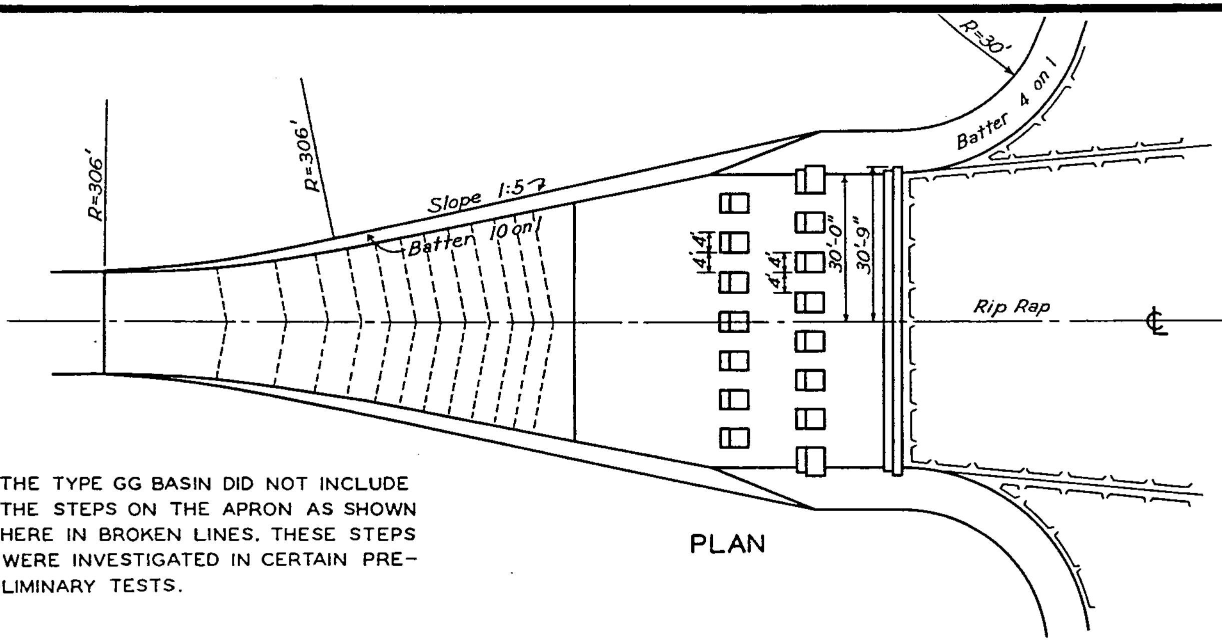


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 88
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.

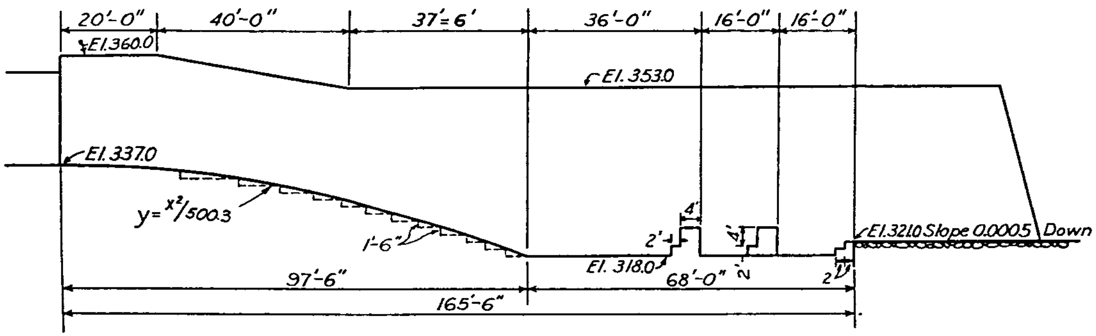


MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
THEORETICAL JUMP POSITION
ELEVATION
370
350
330
310
D2
D1
X2 = 836y
T.W. = 350.4
Q = 17,000 C.F.S.
TYPE DD BASIN
DIAGRAM A
X2 = 497y
Q = 17,000 C.F.S.
TYPE GG BASIN
DIAGRAM B
DISTANCE — FEET
0
50
100
150
200



NOTE: THE TYPE GG BASIN DID NOT INCLUDE THE STEPS ON THE APRON AS SHOWN HERE IN BROKEN LINES. THESE STEPS WERE INVESTIGATED IN CERTAIN PRELIMINARY TESTS.

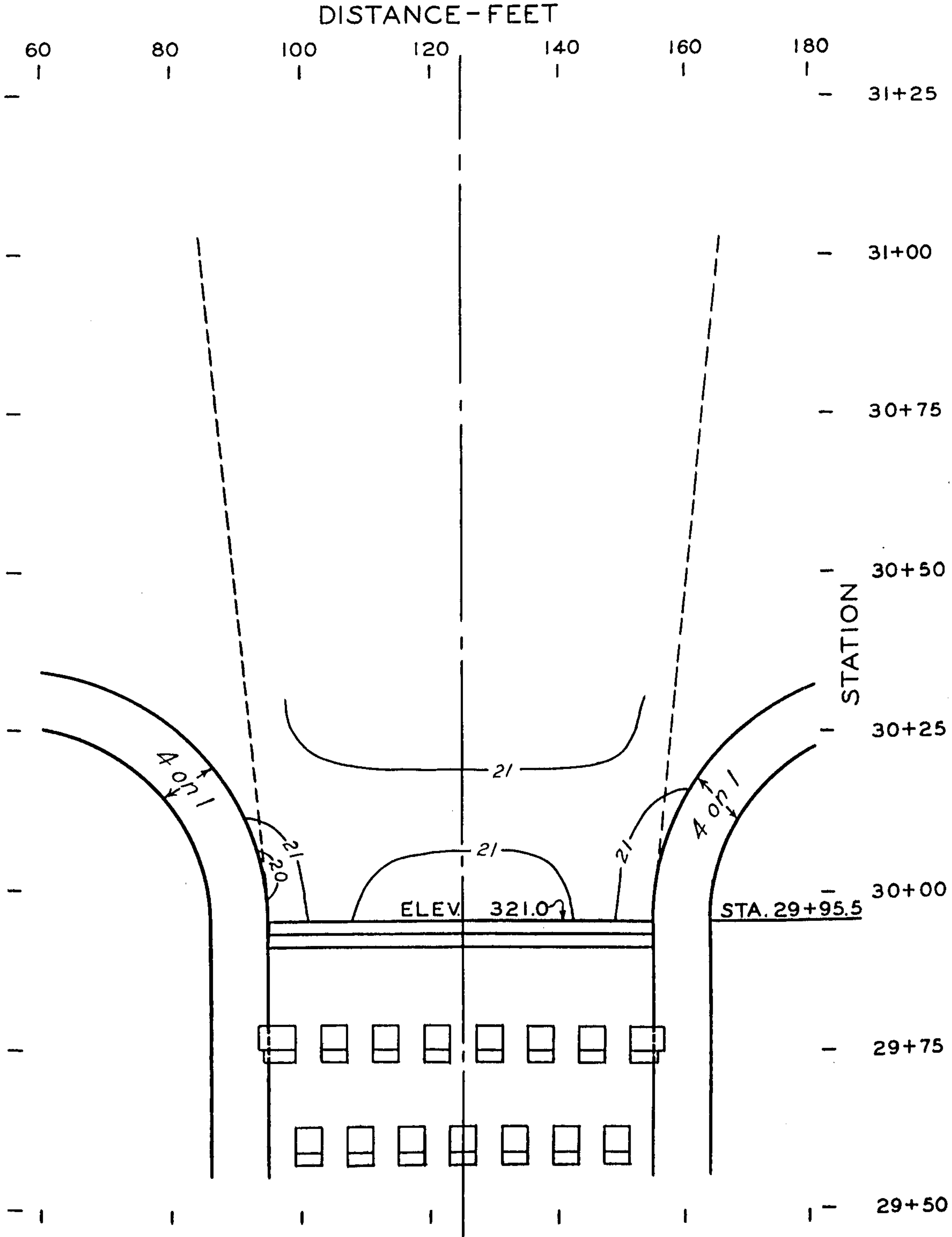
PLAN



SECTION ALONG ℄

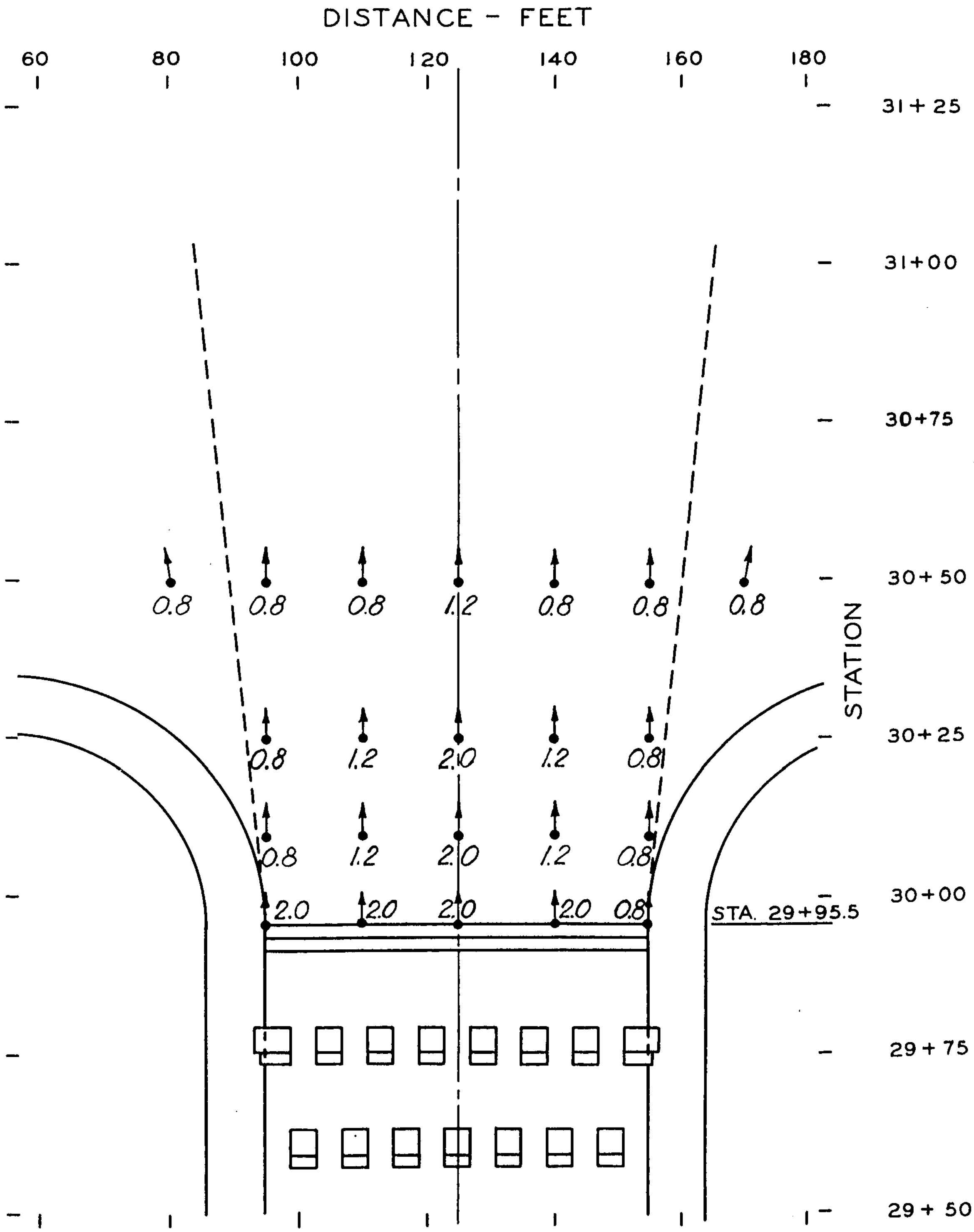
MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

STILLING BASIN
TYPE GG



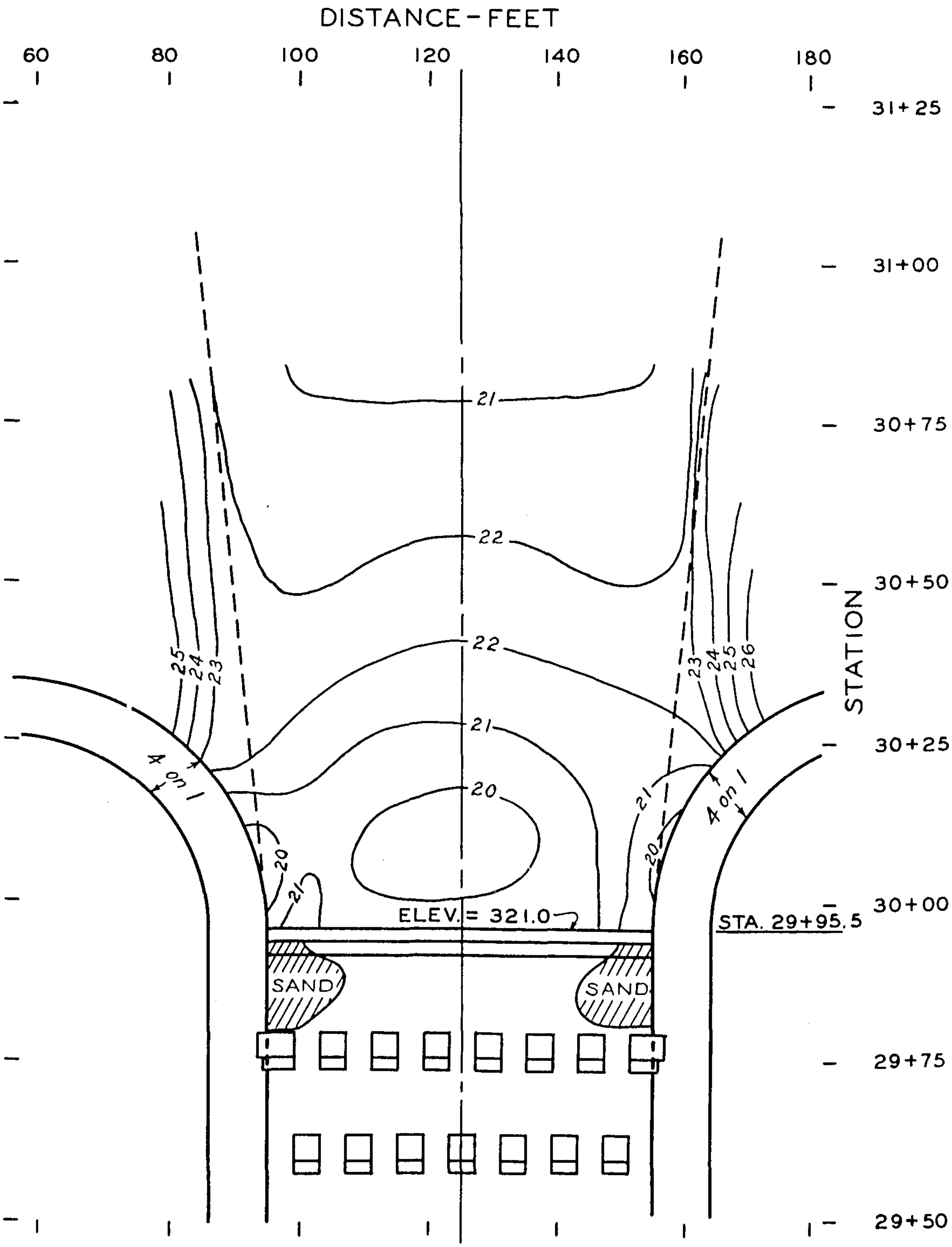
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURE

TEST NO. 104
SCOUR PATTERN
NATURE Q = 5,000 C.F.S.
TAILWATER ELEV.=340.2
LENGTH OF RUN = 50 MIN.



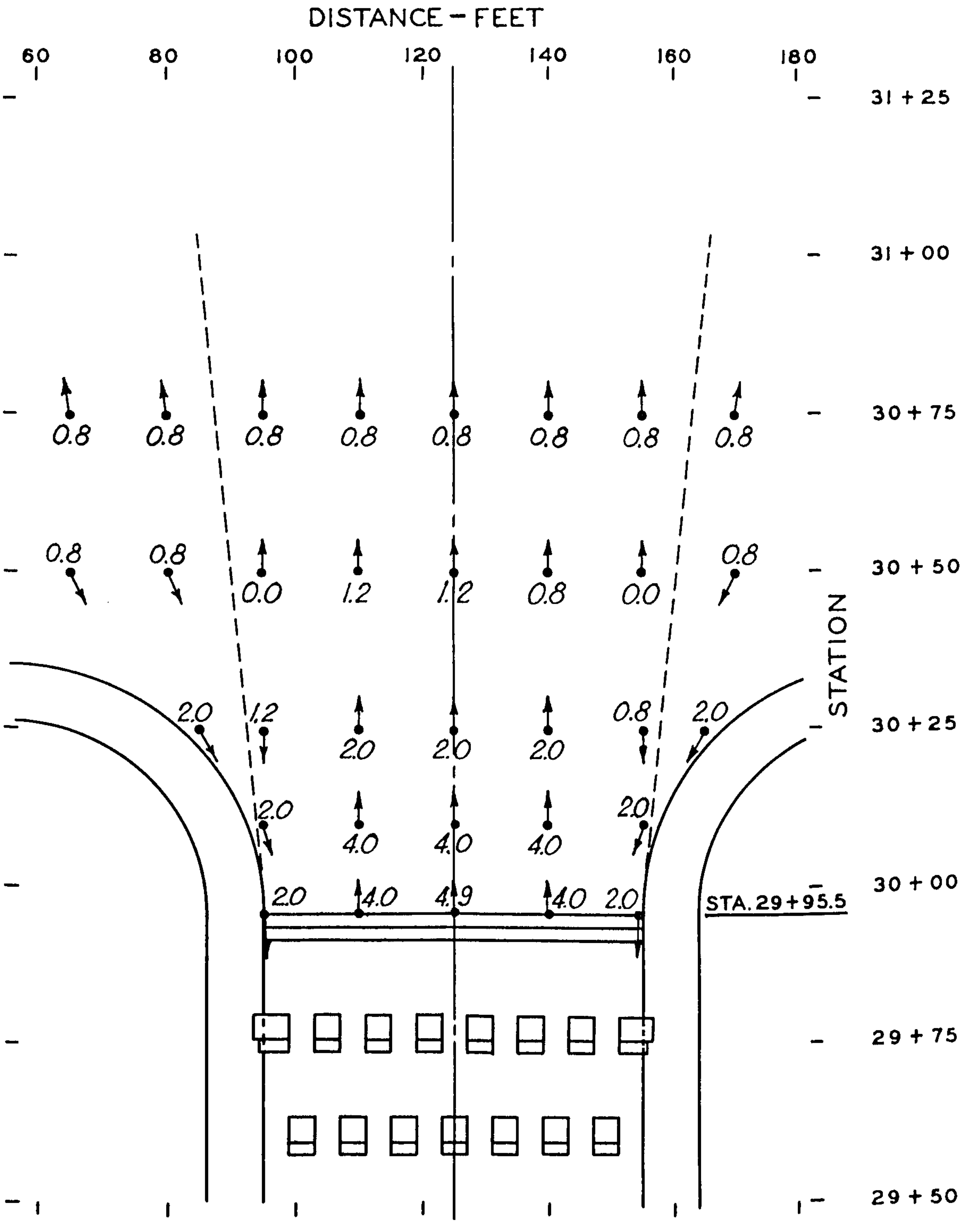
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 104
BOTTOM VELOCITIES
NATURE Q = 5,000 C.F.S.
TAILWATER ELEV. = 340.2



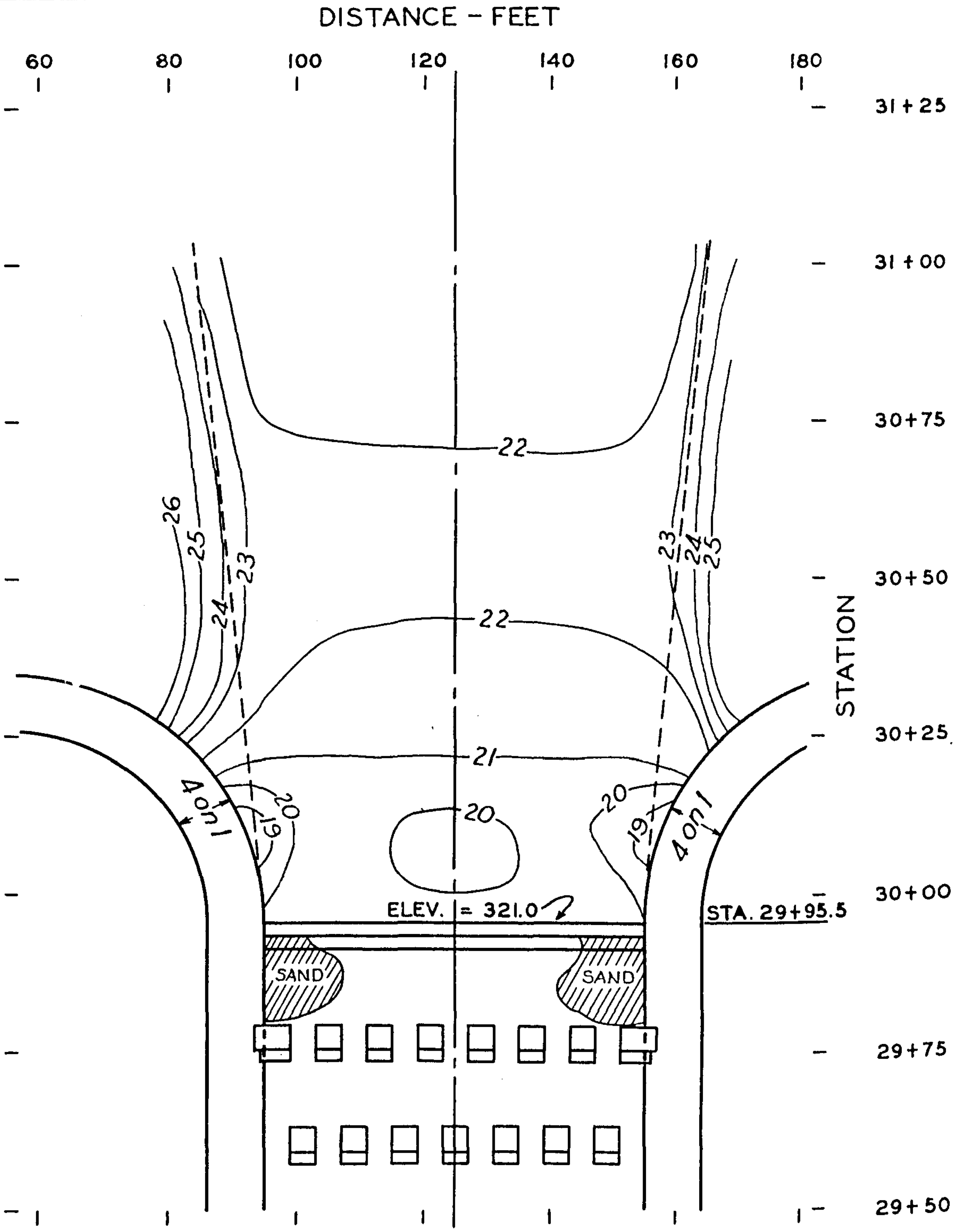
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURE

TEST NO. 105
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV.=347.0
LENGTH OF RUN = 50 MIN.



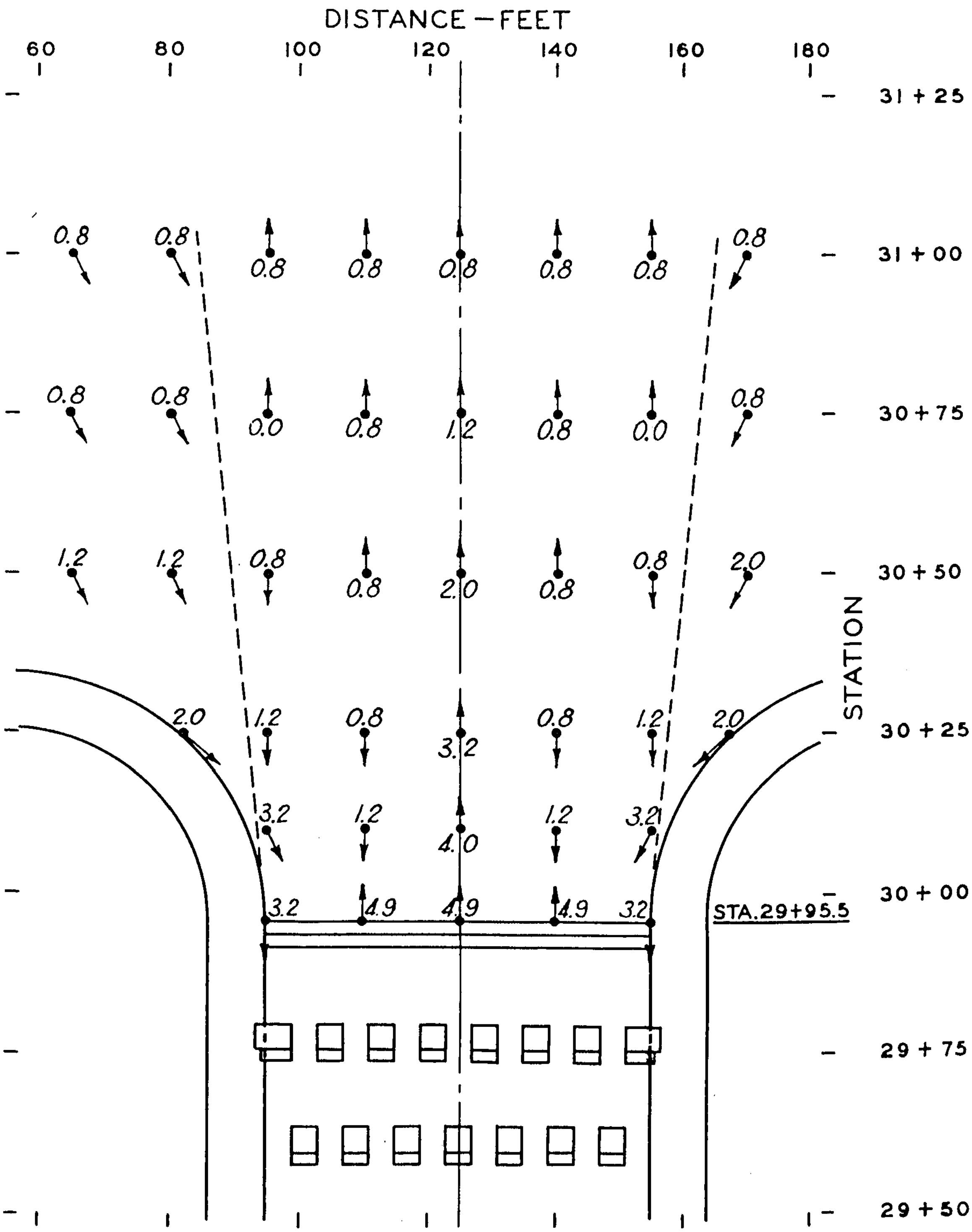
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 105
BOTTOM VELOCITIES
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0



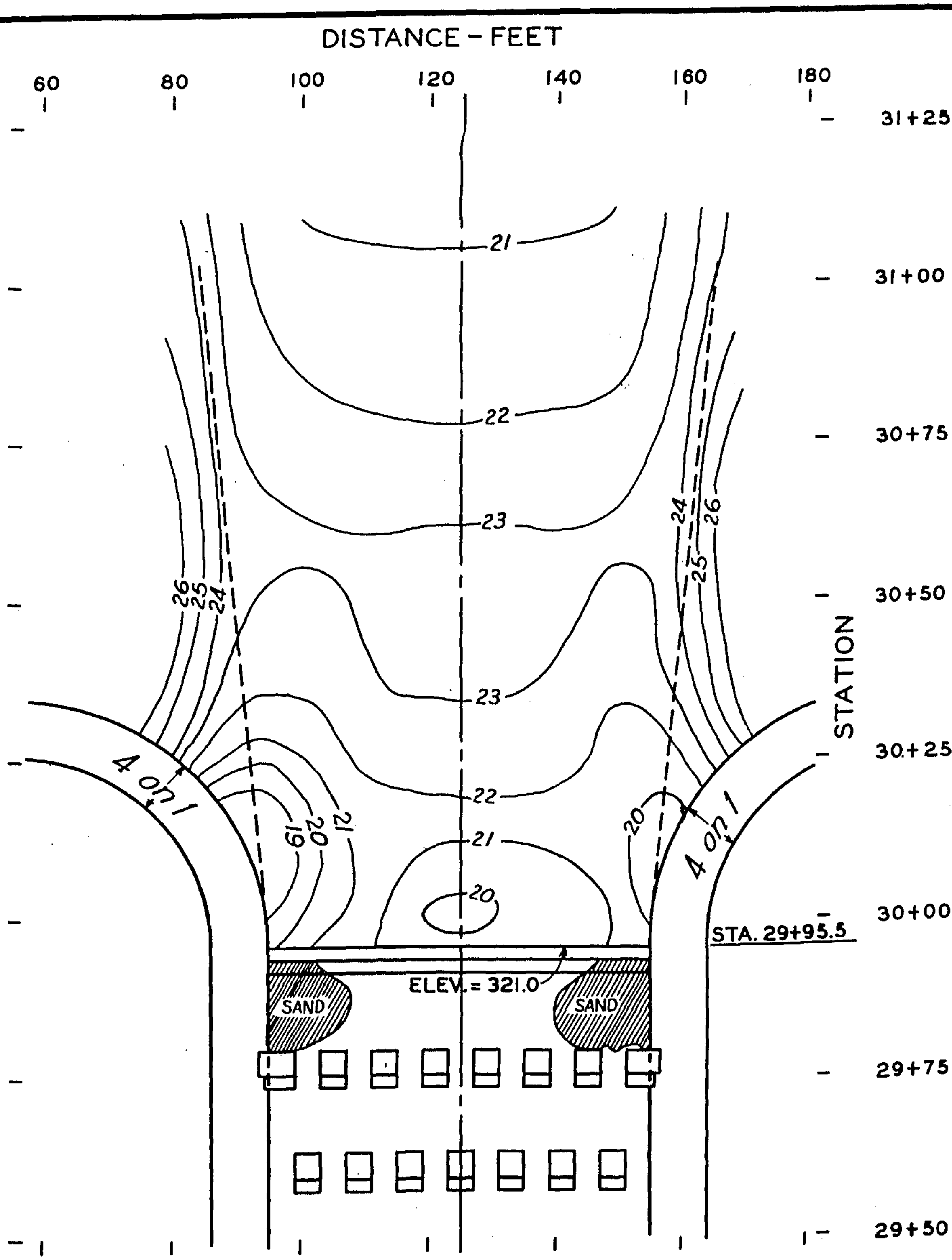
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 106
SCOUR PATTERN
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5
LENGTH OF RUN = 50 MIN.



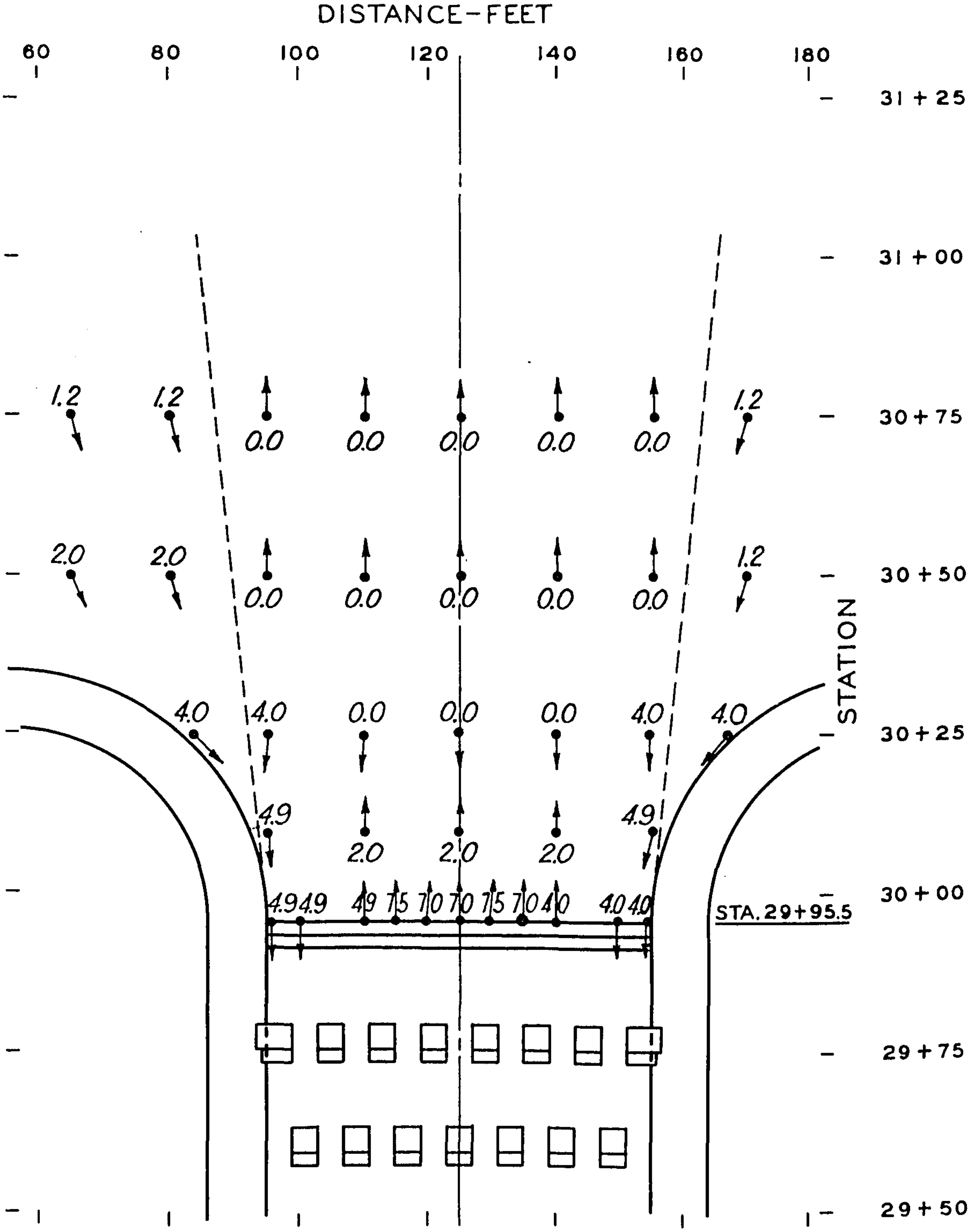
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 106
BOTTOM VELOCITIES
NATURE Q = 14,500 C.F.S.
TAILWATER ELEV. = 349.5



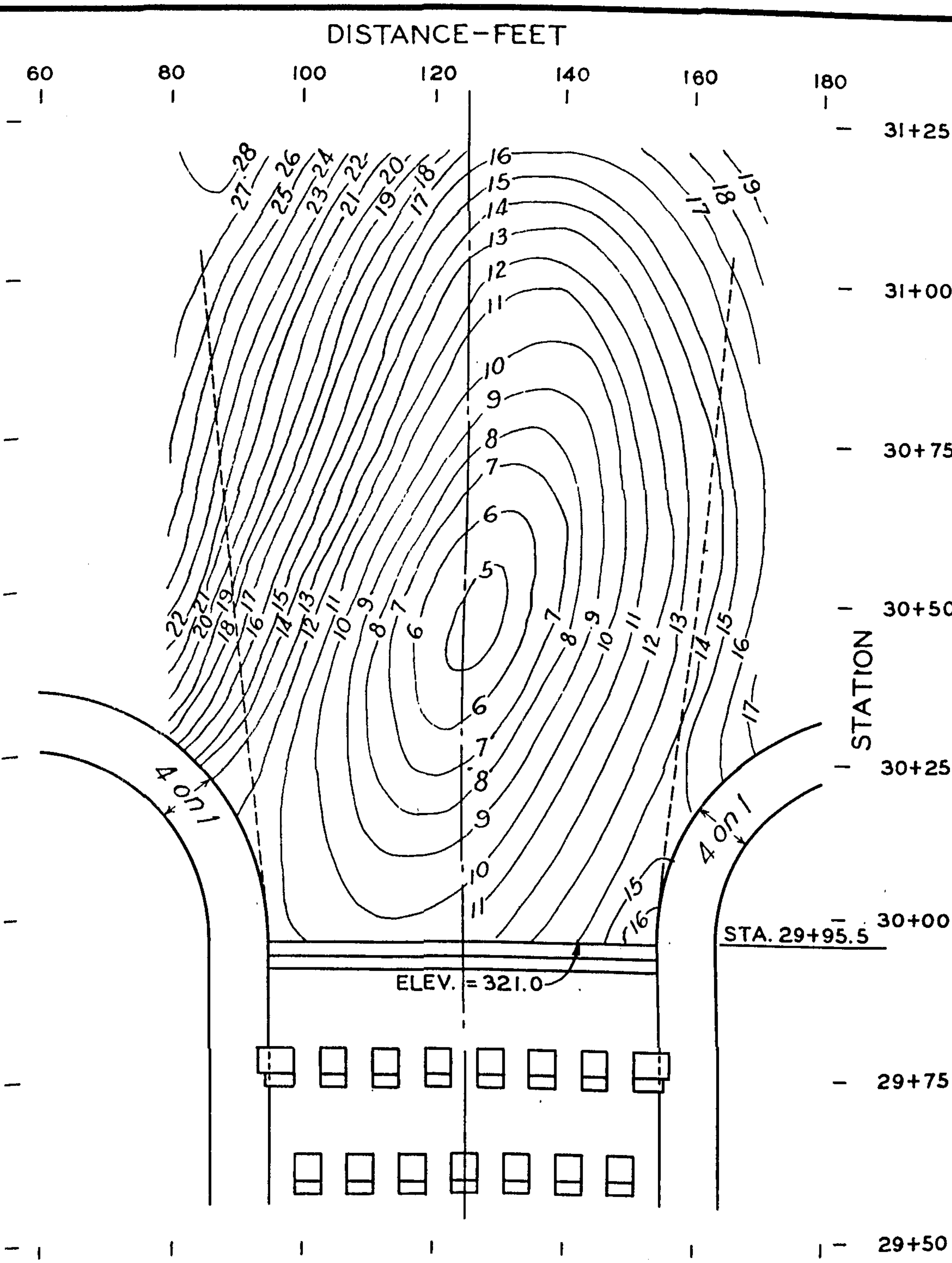
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 107
SCOUR PATTERN
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4
LENGTH OF RUN = 50 MIN.



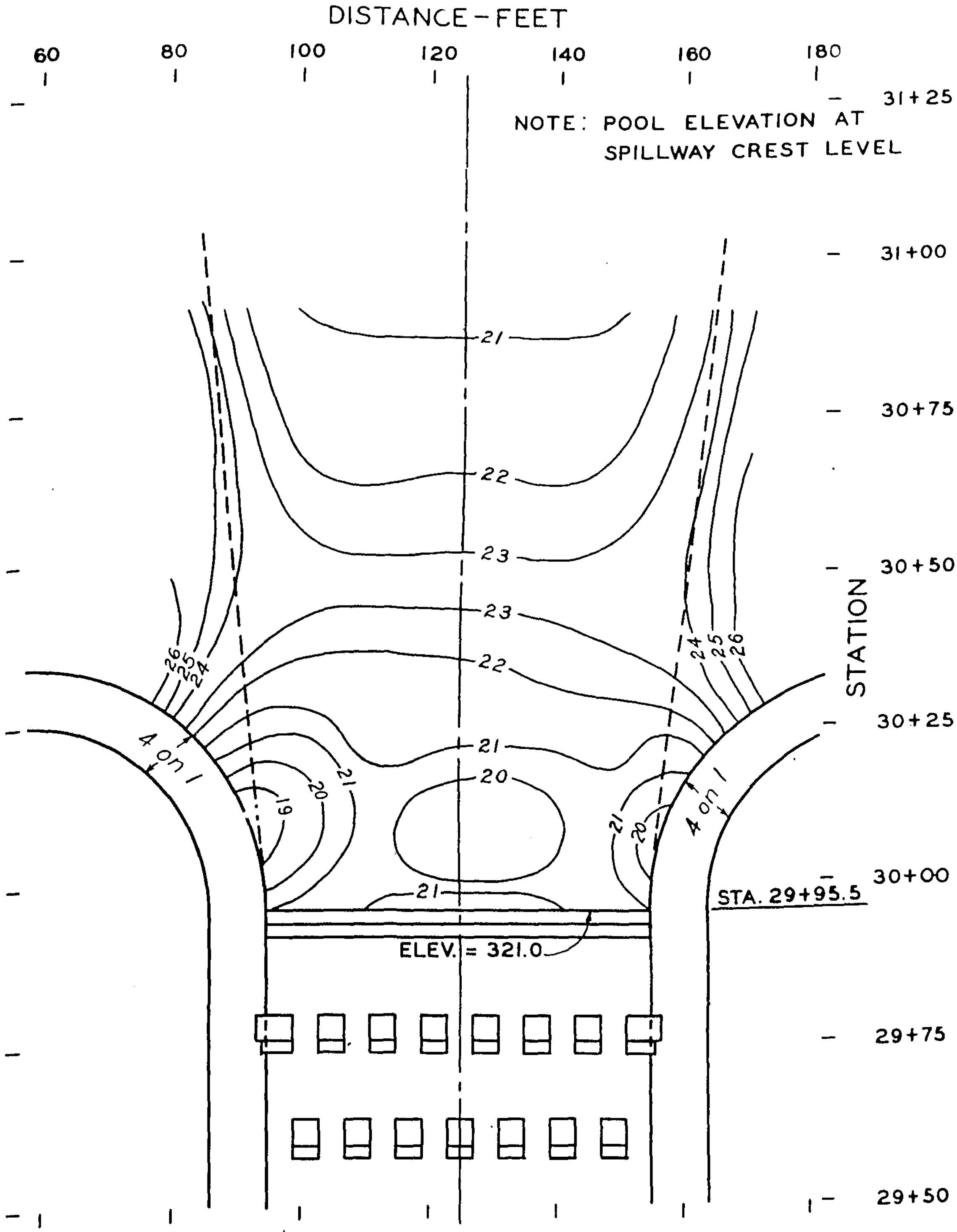
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 107
BOTTOM VELOCITIES
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4



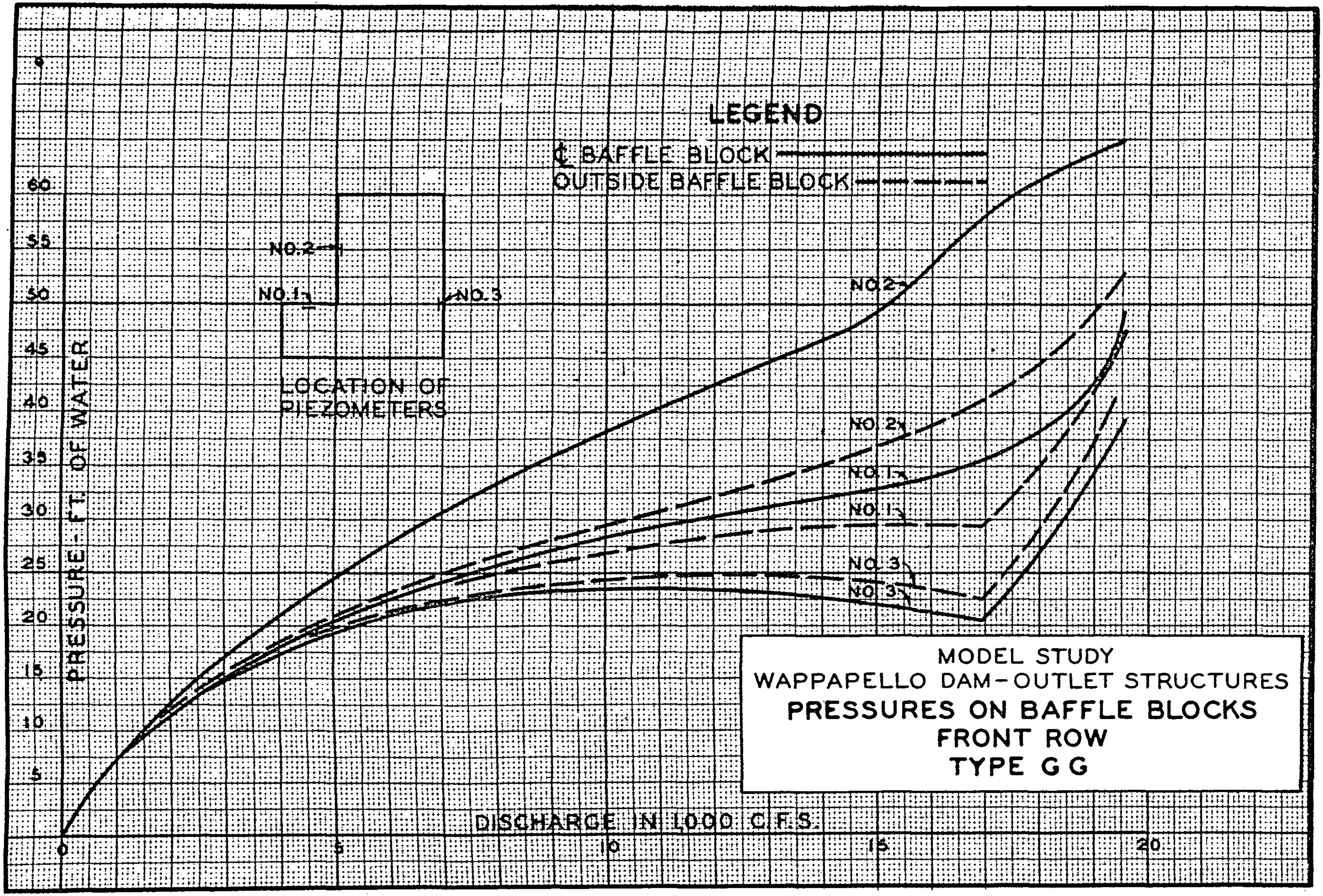
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 109
SCOUR PATTERN
NATURE Q = 19,550 C.F.S.
TAILWATER ELEV. = 366.0
LENGTH OF RUN = 50 MIN.



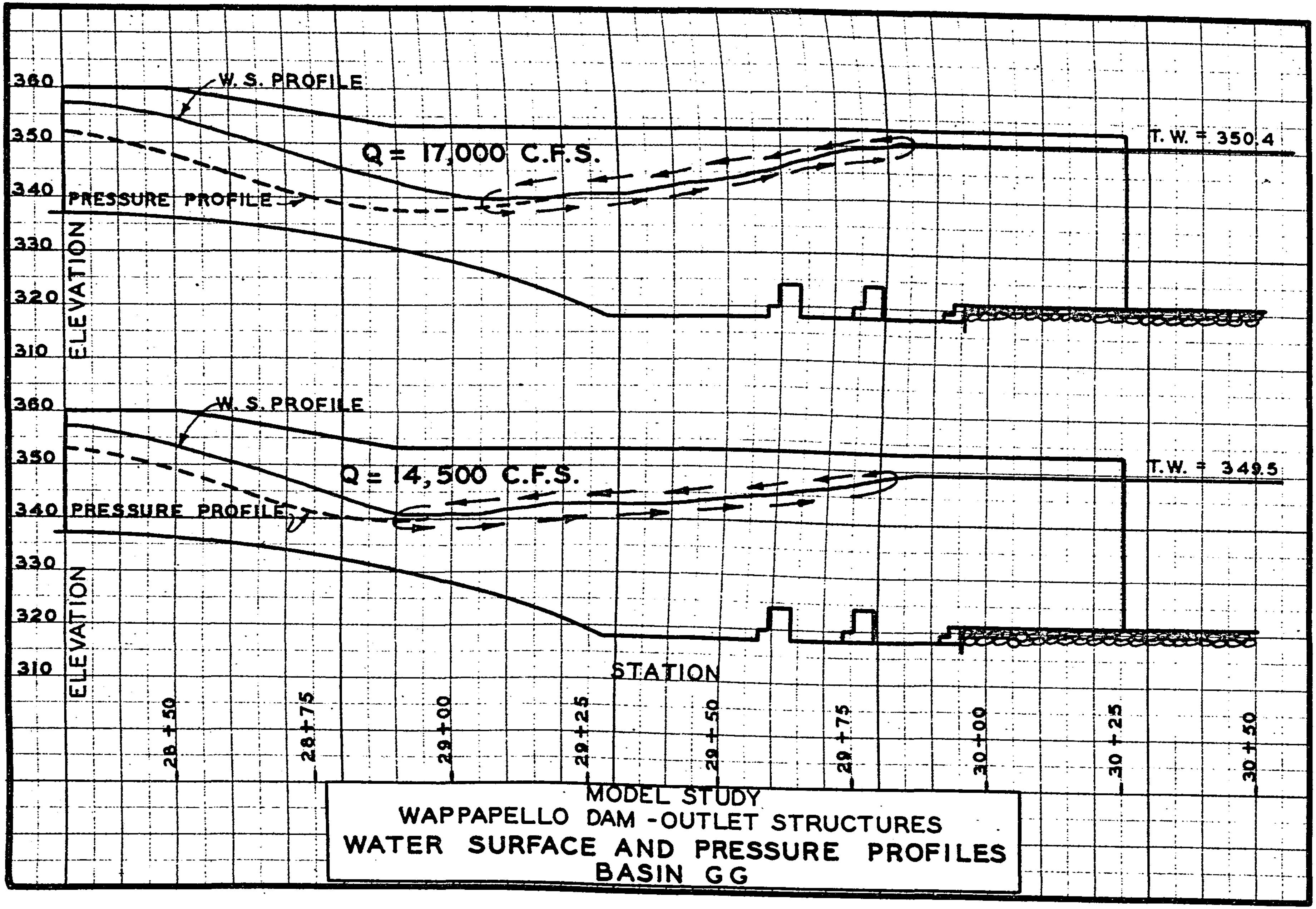
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURE

TEST NO.108
SCOUR PATTERN
NATURE Q= 10,000 C.F.S
TAILWATER ELEV.=347.0
LENGTH OF RUN = 50 MIN.

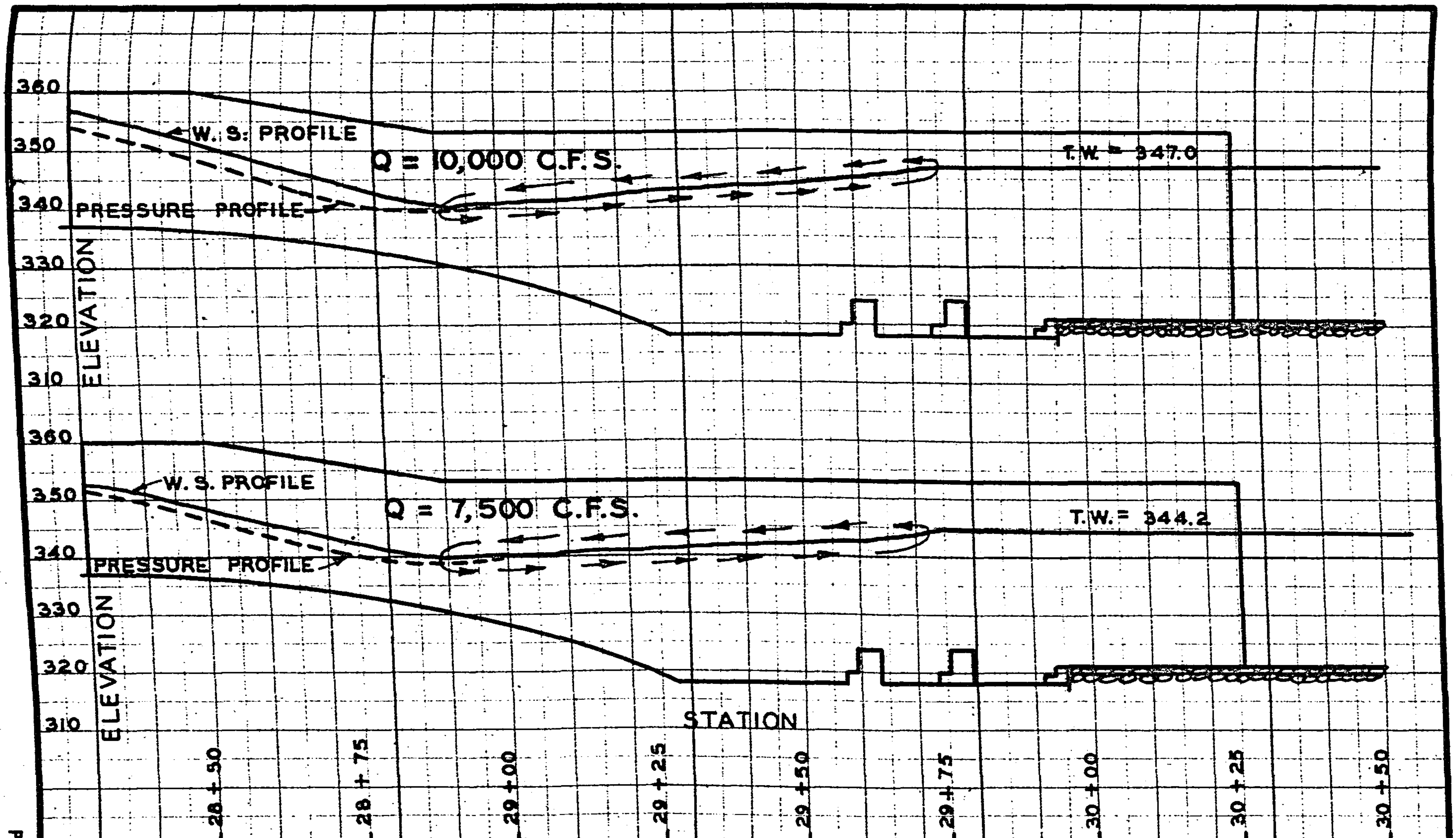


LEGEND
℄ BAFFLE BLOCK
OUTSIDE BAFFLE BLOCK
NO.2
NO.1
NO.3
LOCATION OF PIEZOMETERS
NO.2
NO.2
NO.1
NO.1
NO.3
NO.3
PRESSURE - FT. OF WATER
DISCHARGE IN 1000 C.F.S.
0
5
10
15
20
25
30
35
40
45
50
55
60
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES
PRESSURES ON BAFFLE BLOCKS
FRONT ROW
TYPE G G

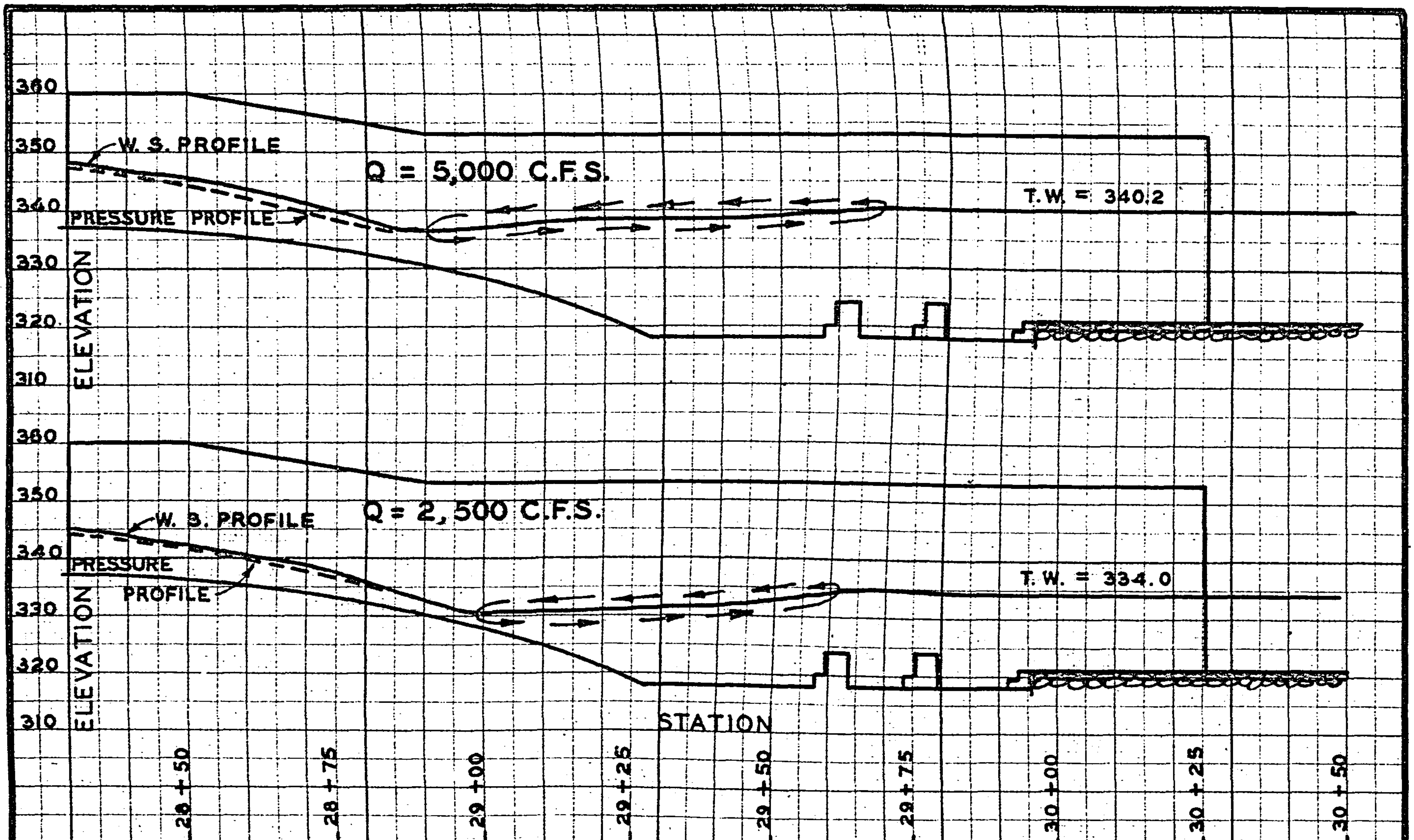
PLATE 91



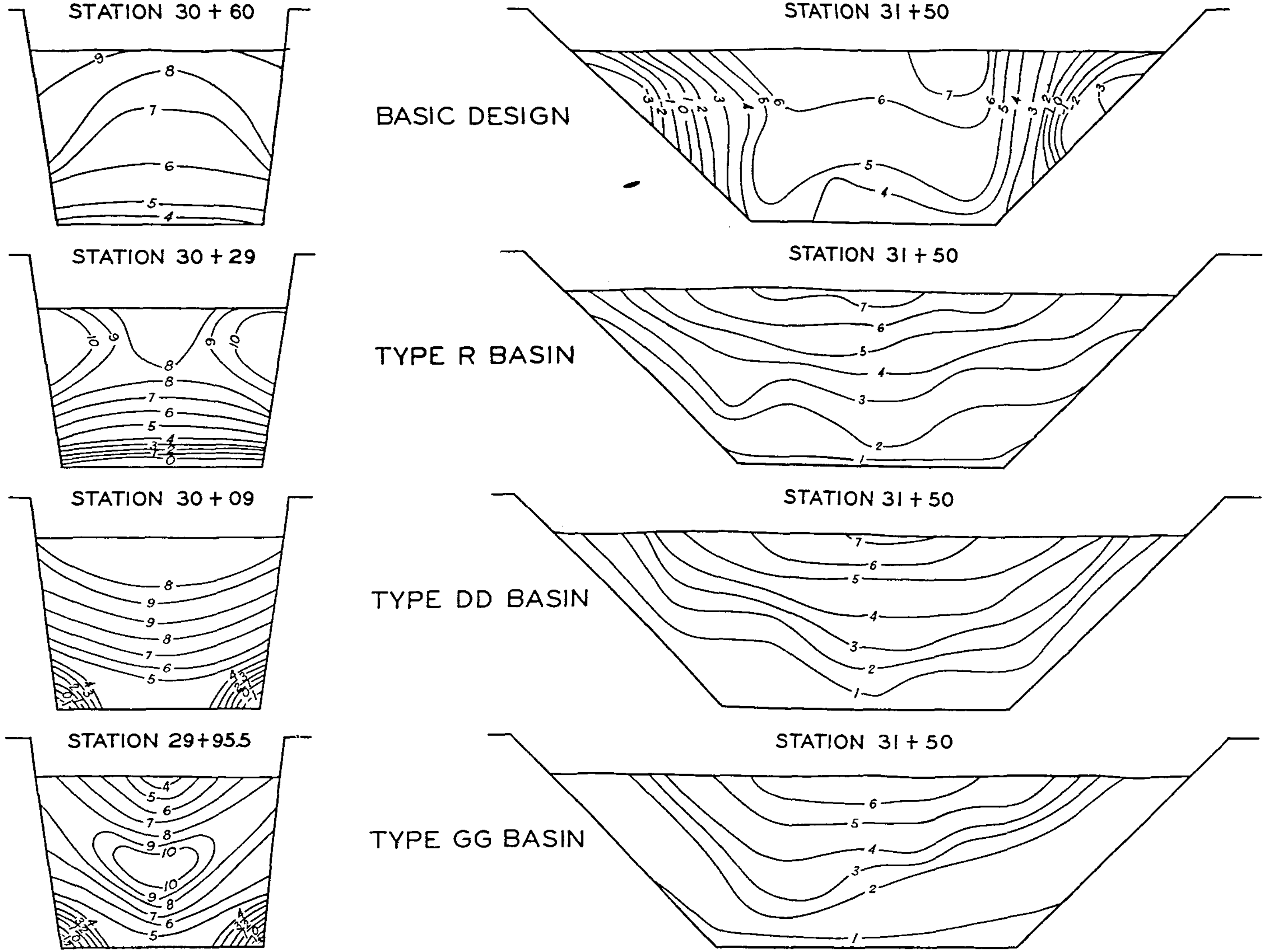
MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
BASIN GG



MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
BASIN G G

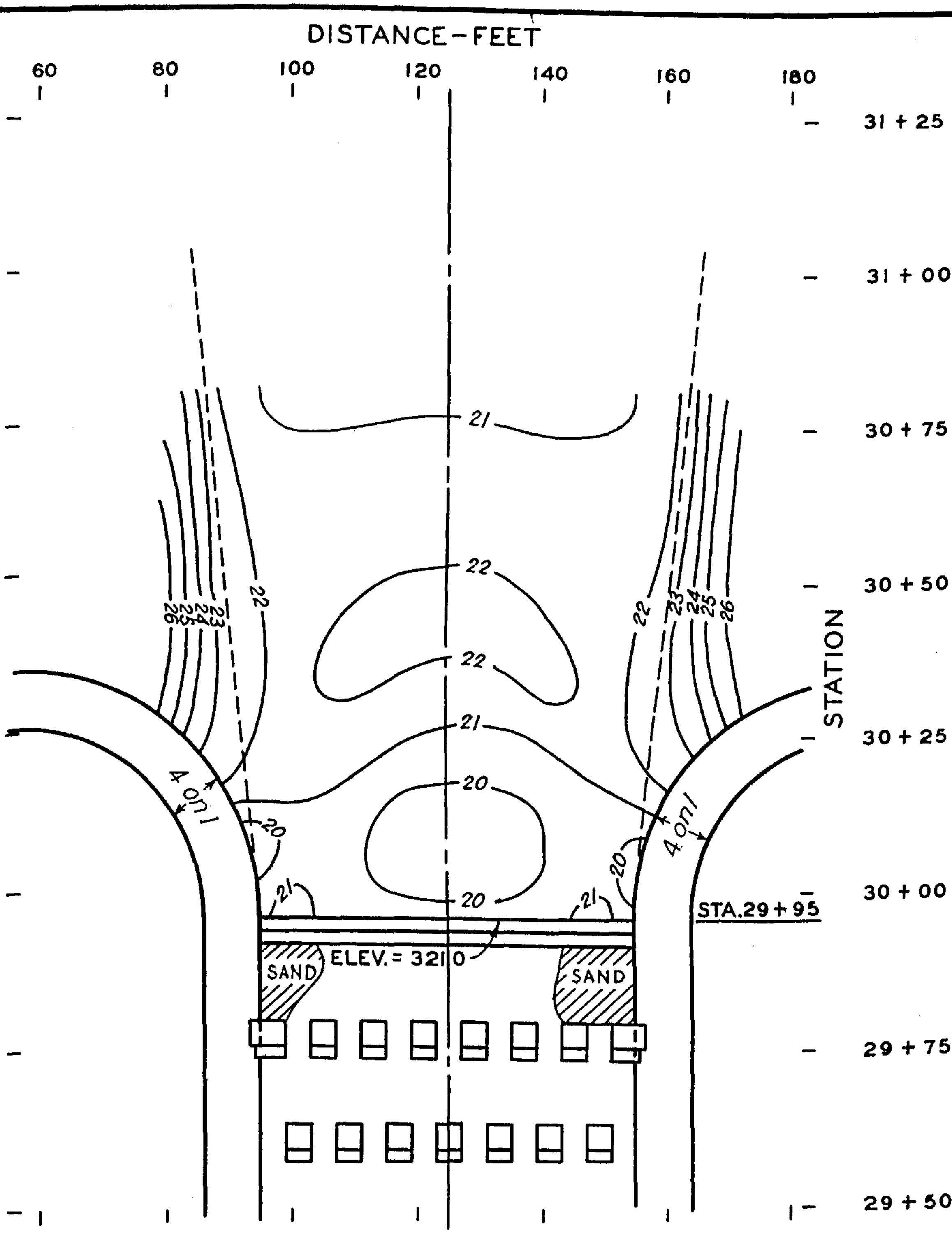


MODEL STUDY
WAPPAPELLO DAM - OUTLET STRUCTURES
WATER SURFACE AND PRESSURE PROFILES
BASIN G G



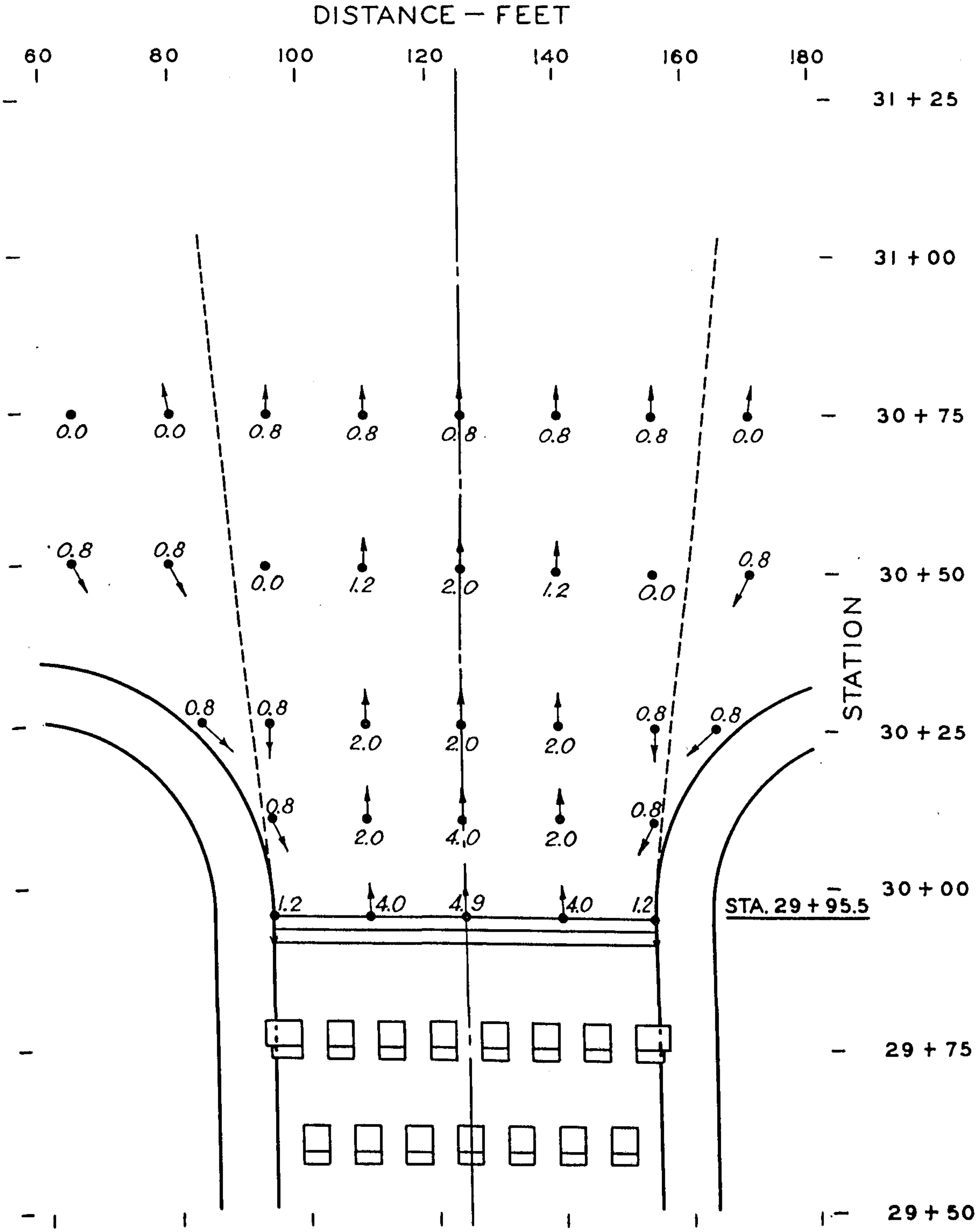
MODEL STUDY
WAPPAPELLO DAM OUTLET STRUCTURES
VELOCITY DISTRIBUTION
NATURE Q = 10,000 C.F.S.

PLATE 95



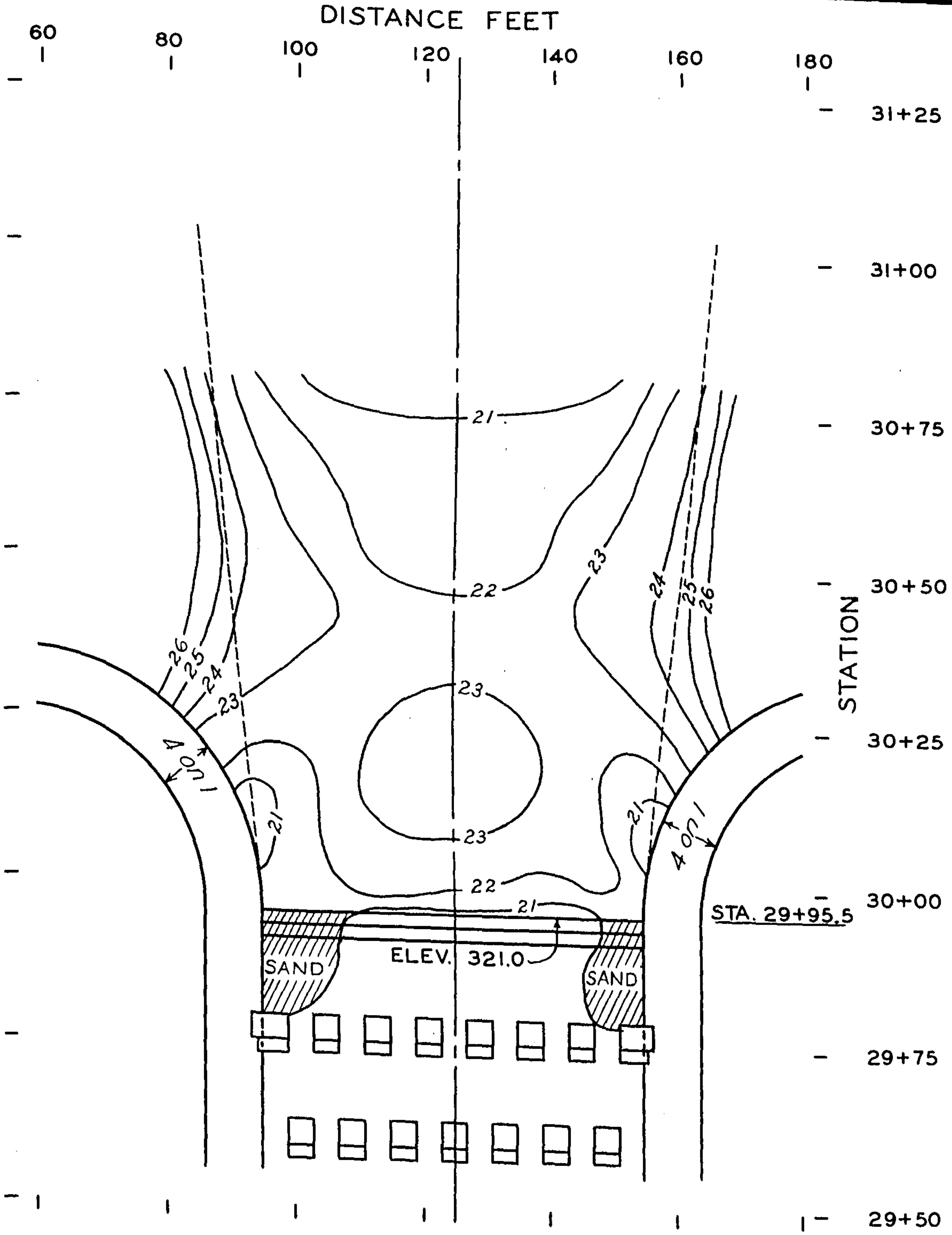
MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURES

TEST NO. 112
SCOUR PATTERN
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0
LENGTH OF RUN = 50 MIN.



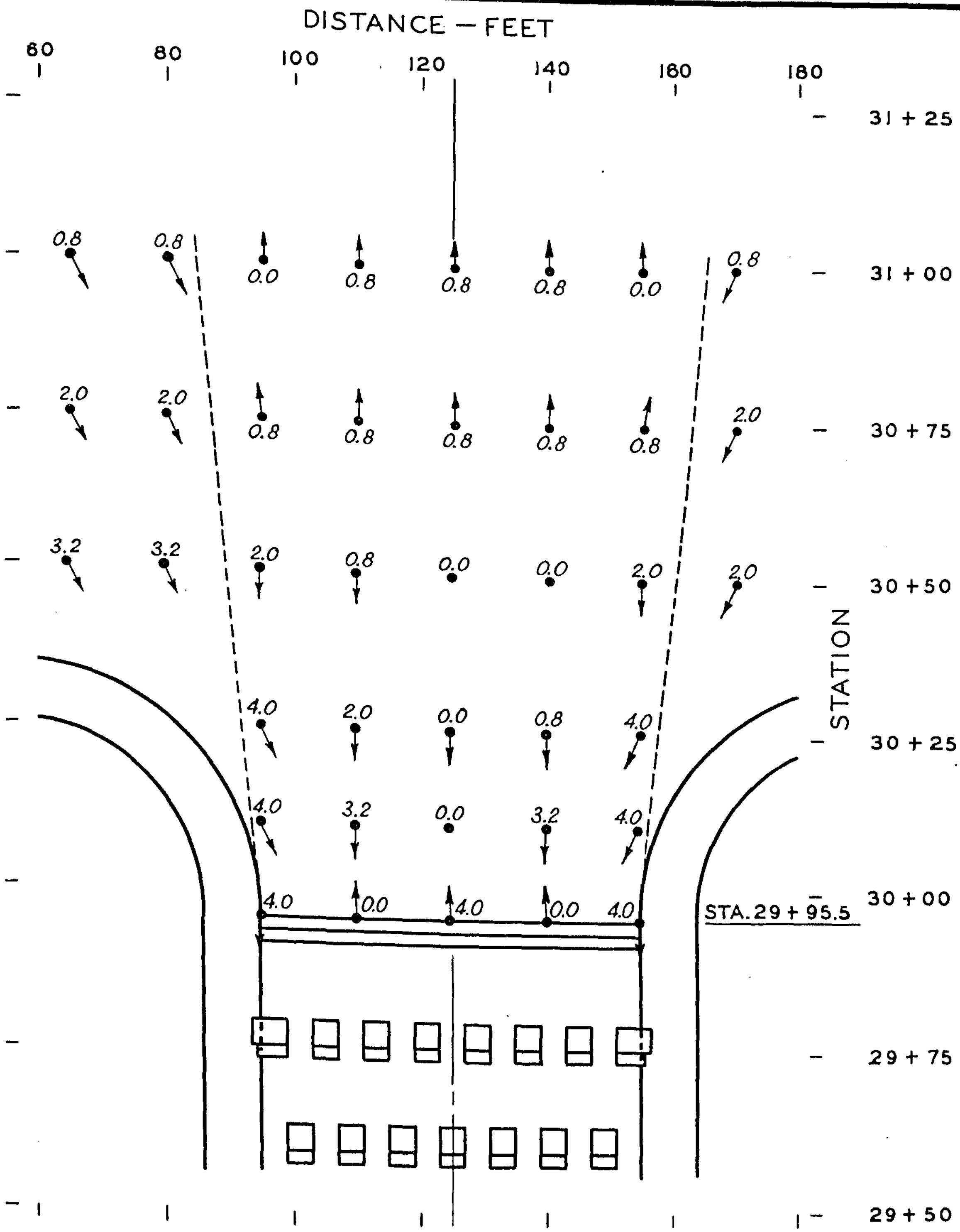
MODEL STUDY
WAPPAPELLO DAM—OUTLET STRUCTURES

TEST NO. 112
BOTTOM VELOCITIES
NATURE Q = 10,000 C.F.S.
TAILWATER ELEV. = 347.0



MODEL STUDY
WAPPAPELLO DAM-OUTLET STRUCTURE

TEST NO. 113
SCOUR PATTERN
NATURE Q = 17.000 C.F.S.
TAILWATER ELEV.= 350.4
LENGTH OF RUN = 50 MIN.



MODEL STUDY
WAPPAPELLO DAM – OUTLET STRUCTURES

TEST NO. 113
BOTTOM VELOCITIES
NATURE Q = 17,000 C.F.S.
TAILWATER ELEV. = 350.4