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Bradley

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OUTLET WORKS--HORSETOOTH DAM-- COLORADO-BIG THOMPSON PROJECT, COLORADO

Hydraulic Laboratory Report No. Hyd.-263

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
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FOREWORD

Hydraulic model studies of the outlet works for Horsetooth Dam, Colorado-Big Thompson Project, were conducted in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during the period September 1946 to July 1947.

The final plans, evolved from this study, were developed through the cooperation of the staffs of the Spillway and Outlets No. 2 Section and the Hydraulic Laboratory.

During the course of the model studies Messrs. H. W. Tabor and E. O. Sowers of the Spillways and Outlets No. 2 Section frequently visited the laboratory to observe the model tests and to discuss test results. Messrs. W. H. Nalder, Chief Designing Engineer, and K. B. Keener, Head of the Dams Division, saw the model operate and approved the structure.

These studies were conducted by W. E. Wagner assisted by T. J. Rhone under the direct supervision of A. J. Peterka and J. N. Bradley.

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FLOW IN RECOMMENDED DESIGN

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Branch of Design and Construction
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Hydraulic Laboratory
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Reviewed by: A. J. Peterka

Subject: Hydraulic model studies of the outlet works--Horsetooth Dam--Colorado-Big Thompson Project, Colorado.

SUMMARY

The hydraulic model studies discussed in this report were made to determine the operating characteristics and adequacy of the stilling-basin design for Horsetooth Dam outlet works. The results and recommendations contained herein are based on studies conducted on a 1:24 scale model of the valves, stilling-basin, and a portion of the downstream canal. This report covers investigations and tests made on two separate and distinct plans for the outlet works stilling-basin, designated as Scheme A and Scheme B. For each scheme several different designs were tested and these are designated as Basin No. 2 or 3, etc.

The preliminary design for Scheme A, shown on Figure 3, is the first proposal received from the Spillway and Outlet Works Section No. 2. From tests on this design and on Basins 2-5, shown on Figure 7, the recommended design was evolved. Although the recommended design for Scheme A will operate satisfactorily for all conditions of flow, it is a relatively costly structure. It was apparent that a satisfactory design, using a different approach to the problem, could be developed which would be less costly.

Scheme B, Figure 15, was developed from this idea, using model tests to achieve the recommended design. The resulting structure was found to perform satisfactorily over the entire range of operation and was less costly to construct. Consequently, Scheme B has been accepted for construction in the field.

To avoid confusion in presenting the two studies, this report is divided into two parts. Part I covers the studies, results, and recommendations for the design of Scheme A, and Part II contains the same information for Scheme B.

Scheme A. The stilling-basin of Horsetooth outlet works is designed for a maximum capacity of 1,500 second-feet, which may be released through either one or both of the 72-inch hollow-jet valves. The preliminary design of Scheme A, Figure 7, gave satisfactory performance for the condition with both valves discharging 1,500 second-feet. However, when only one valve was operated at the maximum discharge, major changes in the preliminary design were required to obtain satisfactory stilling-pool operation.

Of the required changes, lengthening the stilling-basin 72 feet from Station 14+58.75 to Station 15+30.75, Figures 3 and 9, was most important. This additional length is necessary to satisfactorily dissipate the energy of the jet before the flow enters the canal when one valve is operating. Together with lengthening the stilling-basin, the center dividing wall was extended 64 feet from Station 14+33.75 to Station 14+97.75 to prevent side eddies from forming in the stilling-basin when only one valve is operating. In addition, better stilling-pool performance was obtained by lowering the stilling-basin floor 2 feet to elevation 5272.

The stilling-pool performance was further improved and better distribution of flow was obtained at the upper end of the hydraulic jump by depressing the valves 5° below the horizontal. The 5° tilt of the valves caused the jets to strike the invert and spread more evenly before entering the stilling-pool proper, Figure 8.

As a means of reducing the height of waves in the stilling-basin and canal, it is recommended that a surface baffle or curtain wall, the bottom of which is at elevation 5285, be installed between the center dividing wall and each training-wall at Station 14+94.75, Figure 9. When one valve is operating at the maximum discharge of 1,500 second-feet, further reduction of the wave heights can be obtained by placing baffle piers in the stilling-basin at Station 13+96.75, Figure 9.

Stilling-pool studies were also made using a vertical step or rise at Station 15+30.75, but no effect, either beneficial or detrimental, on the operation of the stilling-pool or the height of waves in the canal was observed.

Figure 7 shows the six different designs of the stilling-basin which were tested and Figure 9 is a detailed drawing of the recommended design for Scheme A.

Scheme B. Because the cost of the stilling-basin required in Scheme A had increased considerably as a result of the necessary lengthening of the entire structure, immediate attention was given to developing an alternate scheme which would be less costly to construct. It was believed in the laboratory that a satisfactory design could be evolved which eliminated the long, expensive dividing wall between the valves. As a result of discussions between the laboratory and design personnel, the Design Section furnished the laboratory with a preliminary design for Scheme B, Figure 15, on which model studies were made.

Tests on the preliminary design for Scheme B indicated that, although the plan was feasible, changes in the proposed design were necessary to obtain satisfactory performance of the stilling-basin. Excessive splash and high fins formed immediately downstream from the valves where the jets impinged on the 10° slope, Figure 15. Extensive model studies were made to develop the proper slope and profile which would bring the water smoothly into the chute with a minimum of splash. Figure 17 shows the profile evolved from these studies.

The distribution of flow at the downstream end of the horizontal chute where the water drops into the stilling-basin (Figure 15) was satisfactory when two valves were operating. However, when only one valve was discharging, the water concentrated on one side of the chute, causing an unsymmetrical jump in the stilling-basin. To improve this condition the valves were converged 2-1/2° toward the centerline of the chute. Further improvement of the flow distribution was obtained by placing a crown on the horizontal chute from Station 14+14.70 to Station 17+12.47, Figure 17. The crown tended to force more flow toward both training-walls, which helped to stabilize the hydraulic jump in the stilling-basin.

Studies of the stilling-pool performance indicated modifications of the stilling-basin design were necessary to provide a stable jump and reduce to a minimum the height of waves in the canal. A steeper parabolic curve connecting the bottom of the chute with the stilling-basin floor and lowering the stilling-basin floor 3 feet provided a more stable hydraulic jump. The shape and length of the transition from the stilling-basin to the canal was also changed to improve the flow entering the canal. These changes are shown on Figures 15, 16, and 17. The recommended design is shown on Figure 17.

Comprehensive data on the performance of the recommended design was taken from the model to determine the performance characteristics of the structure and also for correlation with similar data to be obtained from the prototype at a later date.

Figures 19 to 27, inclusive, are water surface profiles extending throughout the length of the structure for discharges of 500, 1,000, and 1,500 second-feet passed through one and both valves at the maximum reservoir elevation of 5430 feet and reservoir elevation 5340 feet. Piezometric pressures in critical areas, Figure 28, for the same operating conditions were obtained and are shown in tabular form on Figure 29 and schematically on Figures 30 and 31. Table 2, Page 18, shows the height of waves in the canal which were measured under similar operating conditions and ranges of discharge.

Tests were also made to determine the feasibility and length of a cover or hood required to prevent splash and spray from flying over the training-walls onto the banks. The cover would extend over the width of the structure in critical areas of splash and rest on the training-walls. This phase of the investigation is discussed on Page 16.

PART I--SCHEME A

INTRODUCTION

Horsetooth Reservoir, with a capacity of 146,000 acre-feet, is a part of the Colorado-Big Thompson Project and the major storage reservoir on the eastern slope for storing irrigation water diverted from the western slope through the Alva B. Adams Tunnel. Horsetooth Dam will be one of four earth-fill dams impounding irrigation water in Horsetooth Reservoir approximately 10 miles west of Fort Collins, Colorado, Figures 1 and 2. The Horsetooth Dam will be approximately 1,500 feet long, with a crest elevation of 5440 feet and rising 140 feet above the original ground surface. The maximum water surface of the reservoir will be at elevation 5430.

The principal hydraulic feature of Horsetooth Dam is the outlet works which consists of the outlet conduits, the stilling-basin, and two 72-inch hollow-jet valves for releasing irrigation water through a supply canal to the Cache La Poudre River and thence to existing irrigation systems.

Water from the reservoir will flow through an 8-1/2-foot diameter circular conduit, 354 feet in length, to the gate chamber which encloses two 5 by 5 feet high pressure emergency gates. From the gate chamber the water will pass through two 72-inch steel conduits, 480 feet in length, to the hollow-jet valves and thence to the stilling-basin. The hydraulic model tests discussed in this report were confined to studies of the entry of the jet from the valves into the stilling-basin, the stilling-basin performance, and flow into the canal.

THE 1:24 SCALE MODEL

A model of the outlet works, consisting of a headbox, two 3-inch hollow-jet valves representing the 72-inch prototype valves, the stilling-basin, and a section of the canal, was constructed on a geometric scale of 1:24, as shown in Figure 4. Water was supplied to the headbox from one of the laboratory pumps through a venturi orifice meter for accurate measurement of the water. The valves were attached to two short sections of 3-inch brass pipe leading from the open-top headbox. The stilling-basin was constructed of wood and lined with galvanized sheet metal, while the invert curve, transition leading from the pool to the canal, and the canal were made of neat concrete formed to sheet metal templates. A tailgate was installed at the end of the canal to control the tailwater elevation. Tailwater elevations for various discharges, furnished by the Design Section and used in the model, are shown in Figure 32. Flow through the valves was controlled by the small handwheel incorporated in the valve.

THE INVESTIGATION

The outlet works is so designed that the maximum canal capacity of 1,500 cubic feet per second may be discharged through one or two 72-inch hollow-jet valves at a maximum reservoir elevation of 5430 feet. In addition, the valves are designed to discharge 1,250 cubic feet per second through one valve at reservoir elevation 5401. To assure that the investigation covered all possible conditions, the tests included discharges up to a maximum of 1,500 cubic feet per second through one and two valves.

The preliminary design first received by the laboratory called for a canal with side slopes of 1/4:1, and the model was so constructed. However, before any tests were made the slope of the canal walls was changed to 1-1/4:1. All tests were conducted using a canal with side slopes of 1-1/4:1, and all references made to the preliminary design in this report include a canal with 1-1/4:1 side slopes. Figures 3 and 5a show the preliminary design of the outlet works.

Stilling-basin Studies

Preliminary basin. Initially, the model was constructed according to the preliminary design, Figure 3, and operated with varying discharges from 500 to 1,500 cubic feet per second through one and two valves at a head corresponding to a maximum reservoir elevation of 5430 feet prototype. With both valves equally discharging a total of 1,500 cubic feet per second, Figure 5c, the flow within the stilling-pool appeared satisfactory with the hydraulic jump forming well up on the invert curve and smooth, uniform flow occurred throughout the basin. However, when 1,500 cubic feet per second was discharged through one valve, the hydraulic jump was swept from the basin, Figure 6a, causing high-velocity flow throughout the canal. Test runs with one valve operating were made as follows:

a. A constant discharge of 1,500 cubic feet per second with tailwater elevation above normal and gradually reduced to normal.

b. A constant tailwater at normal elevation with gradually increased discharge to 1,500 cubic feet per second.

In each case the jump was swept out. Under condition a, the jump began to move downstream at a tailwater elevation of 5293, 1 foot above the normal elevation. Under condition b, the jump held momentarily and then gradually moved downstream until it was entirely swept out. These tests indicated the stilling-basin had insufficient depth and was probably too short; but, before concluding that the basin should be made deeper and longer, a costly procedure, other remedies were tested.

Basin No. 2. In an attempt to prevent the jump from being washed out of the basin the sloping floor connecting the bottom of the stilling-basin with the bottom of the canal was replaced with a single step, as shown in Figure 7. Although water remained in the stilling-basin at all discharges and tailwater elevations, it was due to the obstruction of the

flow by the step rather than to the fact that the step was helping to produce an hydraulic jump. This arrangement appeared fairly good for a maximum discharge of 1,500 cubic feet per second through two valves, but when the maximum discharge was put through one valve, the disturbance at the step caused large boils and standing waves in the transition and waves of smaller magnitude (about 2 feet in height) downstream in the canal.

Basin No. 3. From the outset of the experiments, the jet from the valve did not strike the invert curve leading to the stilling-basin. This lack of contact resulted in a concentration of flow in a small area, circular in cross-section. It was felt that a level section of channel of suitable length placed between the valve and the origin of the invert curve would cause the jet to strike the level section, flatten out, and evenly distribute the flow across the width of the trajectory section before reaching the stilling-basin. Computations by the Design Section showed the level section should be 196 feet in length. This design was tested and is illustrated in Figure 7, as Basin No. 3.

With this design the hydraulic jump moved farther upstream on the invert curve, but the jet was unevenly distributed and the flow concentrated near the training-walls. This condition existed regardless of which valve was operated. It was first thought this phenomenon was due to misalinement of the valves, but horizontally shifting the jet toward or away from the center pier did not correct the difficulty.

Basin No. 4. In Basin No. 4 it was believed that the performance of the structure could be improved by tilting the valves downward to obtain greater spreading of the jets before they entered the jump and by lengthening the stilling-basin to provide a greater volume in which energy dissipation could take place. Basin No. 3 was altered by adding 72 feet to the length of the basin and depressing the valves in successive trials to 2-1/2°, 5°, and 7-1/2° below the horizontal. In all cases the angle of depression was varied by placing a shim or dutchman at the base of the valve rather than by bending the approach pipe. From observations of the flow, it was found that a 5° depression gave the best stilling-action in the basin, Figure 8. Although depressing the valves 7-1/2° gave the greatest spread, part of the jet was deflected from the invert curve which caused less effective stilling-action.

After the best angle of depressing the valves had been determined, studies of the stilling-basin were continued. With the longer stilling-basin, Basin No. 4, Figure 7, the maximum flow of 1,500 cubic feet per second through two valves appeared satisfactory within the stilling-basin and the length of the basin was ample. When the maximum discharge was put through one valve, the jump formed about 15 feet downstream from the lower end of the invert curve, indicating the depth of the stilling-pool was insufficient. By raising the tailwater an equivalent of 2 feet prototype above normal, the jump was satisfactory and formed well up on the invert curve.

Basin No. 5. The floor of the stilling-basin was then lowered 4 feet to elevation 5270 and the 0.25 slope at the end of the invert curve was extended downstream until it intersected the level floor of the basin, Basin No. 5, Figure 7. Four feet was considered more than an ample amount to lower the basin, but since raising the floor of the basin to a suitable elevation was a simple operation in comparison to another lowering operation, a floor was constructed which was lower than necessary. Tests run with this design were satisfactory for all conditions of flow, including the action with one valve operating, and there remained to be determined the highest elevation of the stilling-basin floor at which the stilling-pool would function satisfactorily for all flows.

Recommended basin. The proper elevation of the stilling-basin floor was determined by lowering the tailwater and observing the hydraulic jump in the stilling-pool, Basin No. 5. It was found that the tailwater could be lowered as much as 2 feet below normal and still maintain good stilling-action. Consequently, it was decided that the stilling-basin floor could be raised 2 feet to elevation 5272.

When two valves were operating at a maximum discharge of 1,500 cubic feet per second, the length of the stilling-basin appeared too long with the hydraulic jump making use of approximately the upstream two-thirds of the basin, Figure 11a. However, with 1,500 cubic feet per second discharging through one valve, the entire length of the basin was required to fully dissipate the energy of the jet, Figure 11b. It was decided to use this length in the recommended design, Figure 9. Figures 11c and d, and 12a and b show the stilling-basin operation at discharges of 1,000 and 500 second-feet.

Waves in the Canal

During the tests on Scheme A it was apparent that excessively high waves were being generated in the stilling-basin and were traveling downstream into the transition and the downstream canal section. Due to the comparatively smooth concrete lining and the 1-1/4:1 sloping sides of the trapezoidal canal, the waves appeared to magnify after they entered the trapezoidal section until waves from 2.5 to 6 feet in height were measured at the edges of the water surface in the canal, Figures 13c and d.

To find a means of dampening and controlling these wave heights in the canal, several tests were conducted using wood floats, baffle piers, and surface baffles. A wooden float placed in the stilling-basin and attached to the end of the center pier was effective in reducing the wave heights in the canal, but due to the maintenance requirements and difficulty in making it effective for all flows and tailwater elevations, the float method of dampening the waves was abandoned.

Comprehensive tests were also conducted using various combinations of baffle piers at Station 13+96.75, a surface baffle between the center pier and each training-wall at Station 14+94.75, and the effect of placing a

10-foot vertical rise or step at Station 15+30.75 from the stilling-basin floor to the canal bottom elevation of 5282 feet, Figure 9. The results of these tests are shown in Figure 14 where height of waves, as abscissa, are plotted against the elevation of the bottom of the surface baffle (ordinate), for a discharge of 1,500 cubic feet per second through one and two valves under the following conditions:

a. Step and baffle piers removed.

b. Step installed and baffle piers removed.

c. Step removed and baffle piers installed. With the step removed, the transition corresponded to that shown in Figure 9, while Basin No. 2, Figure 7, shows the profile of the transition when the step was installed, except that the basin floor was 2 feet lower.

From visual observations of these tests and a study of the curves in Figure 14 the following conclusions were reached:

a. The use of a 10-foot vertical step had no effect upon the height of waves in the canal when the surface baffle was in place. Compare Figures 12c and d with Figures 11a and b.

b. Installation of baffle piers at Station 13+96.75 reduced the height of waves especially when one valve was discharging 1,500 cubic feet per second. Compare Figure 11b with Figure 13b.

c. The surface baffle considerably reduced the height of the waves for both conditions of one or two valves operating at maximum discharge of 1,500 cubic feet per second, Figures 13a and b, and the optimum elevation of the surface baffle was reached when its bottom was at elevation 5285 feet, Figure 14. Below this elevation the wave heights, with the baffle piers installed, increased when only one valve was discharging.

The choppy water surface and the wave heights in the canal are quite prominent in Figures 13c and d when the baffle piers and the surface baffles were removed.

PART II—SCHEME B

INTRODUCTION

The outlet works stilling-basin, Scheme A, discussed in Part I proved to be undesirable from an economic standpoint. With the intention of developing a less costly plan, Scheme B, shown in Figure 15, was tested. Scheme B differs from Scheme A in that the center dividing wall is eliminated and a long, flat chute is placed between the valves and the stilling-basin. Since the canal below the stilling-basin will be concrete lined, the long chute requires little more concrete per linear foot than the canal itself, and the economy in concrete for Scheme B is found in the smaller required stilling-basin and elimination of the expensive center dividing wall of Scheme A.

THE 1:24 SCALE MODEL

The 1:24 scale model used to test Scheme A was modified where necessary and used in studying Scheme B. The flat chute was placed below the valves and the stilling-basin moved farther downstream. Laboratory space limitations necessitated a shorter canal section in which to study waves, but otherwise the model was essentially the same as that used in the development of Scheme A.

THE INVESTIGATION

Chute Studies—Upper End

In the preliminary design, Scheme B, Figure 15, the valves discharged onto a plane surface inclined upward 10° from the horizontal. The incline was connected by a parabolic curve to the level portion of the chute. In the initial tests it was found this slope was too steep and caused the jets from the valves to deflect and leave the surface of the incline forming a high fin of water in the centers of the jets and inducing considerable spray, some of which splashed over the training-walls, Figure 33a.

To determine the proper slope of the incline an adjustable floor was set in the model in place of the 10° slope. By altering the incline of this floor, slopes for the floor could be determined which gave comparatively smooth flow. From visual observation, using slopes varying from 1° to 10° and connecting curves of different radii, it was found that slopes of 1° 40' and 10°, joined by curves of 80-foot radius, gave the best results, Figure 17. Although the appearance of the flow using this arrangement was satisfactory for all discharges, there was still the possibility that pressures beneath the jet might be unsatisfactory. Piezometers were installed in the model and pressure measurements made. These studies are discussed on Page 15.

Up to this point in the investigation of Scheme B the valves were set to discharge horizontally and parallel to the centerline of the chute. This arrangement produced satisfactory flow distribution throughout the chute when two valves were operating. However, with one valve discharging, there was a tendency for the flow to concentrate on one side of the downstream end of the chute at all discharges which caused an unsymmetrical jump in the stilling-basin, Figure 34a. To improve this condition and to obtain more symmetrical flow at the upper end of the stilling-basin, the valves were turned horizontally toward or away from the centerline of the chute. The valves were tested for a range of angles from a divergence of 2-1/2° to a convergence of 5°. From visual observations it was determined that a convergence of 2-1/2° to 3-1/2° gave the best distribution of flow in the chute with no appreciable difference in operation between the two angles.

The valves were also elevated from 0° to 5°. However, as the angle of elevation was increased, the extent of deflection of the jet and splash also increased. As a result of these tests, it is recommended that each valve converge 2-1/2° on the centerline of the chute and remain horizontal in the vertical plane.

Chute Studies—Lower End

Although the changes described above helped to spread the flow over the width of the chute, several suggested methods were tested for further improving the flow distribution at the end of the chute. Among these were: (a) a small crest or rise in the chute floor before dropping into the stilling-basin; (b) a streamlined pier in the center of the chute to force more flow near the edges of the chute; (c) a submerged pier, triangular in cross-section and 36 feet long, Figure 35d, located in the center of the chute 30 feet upstream from the stilling-basin; and (d) a crown on the chute floor placed throughout the length of the horizontal chute.

Methods (a) and (b) provided no solution for any operating condition. The small crest caused a jump to form in the chute at the lower discharges. While a satisfactory position for the streamlined pier was found for one operating condition, for other operating conditions the position was unsuitable.

The submerged pier forced the flow toward the training-walls and a fairly symmetrical jump formed in the stilling-basin, Figure 35. However, the submerged pier suggested another method of providing the same results—that of placing a crown on the bottom of the chute and throughout its length. The crown consisted of an upward slope, 1/4 inch to 1 foot, extending from each training-wall to the centerline of the chute. The crown was placed only on the flat portion of the chute from Station 13+96.20 to Station 17+30.97, Section c-c, Figure 17. The crown was also desirable in that it will provide drainage for the chute during periods when the outlet works was not operating. Like the submerged pier, the crown served

to force a greater quantity of the flow toward the training-walls and provided a more even distribution of flow at the downstream end of the chute. However, further improvement of the stilling-basin performance was necessary before a satisfactory structure could be recommended.

Preliminary Stilling-basin Studies

Tests were made on eight different designs of the stilling-basin, Figure 16, to investigate the effect of various elevations of the stilling-basin floor and of the canal bottom, the steepness of the parabolic curve connecting the bottom of the chute with the stilling-basin floor, the inclusion or omission of a step or abrupt rise in the downstream end of the stilling-basin, and the shape of transition between the rectangular basin and the trapezoidal canal.

Tests on Basins No. 2, 3, and 4, Figure 16, were made to improve the operation of the preliminary stilling-basin before an adequate valve arrangement and chute entrance were obtained.

The remaining designs, Basins No. 5, 6, 7, and 8, were made with the valve positions and the chute as shown for the recommended basin of Scheme B, Figure 16, which gave a satisfactory flow distribution for all flows at the end of the chute.

Preliminary basin. The operation of the stilling-pool in the preliminary design was, in general, unsatisfactory. The distribution of flow at the end of the chute was poor for all flows, Figure 33. When one valve was discharging 1,500 second-feet, the hydraulic jump was concentrated on one side of the stilling-basin and the opposite side was occupied by a slow eddy. This condition resulted in considerable turbulence and excessive waves in the canal. When both valves were discharging, the stilling-basin performance was improved, but the flow concentrated in the center of the basin with comparatively quiet water along the outer edges of the basin.

Basins No. 2, 3, and 4. Before modifying the valve arrangement and the chute of the preliminary design, an effort was made to improve the stilling-basin performance in spite of the fact that the flow distribution was poor at the downstream end of the chute.

The floor of the stilling-basin was lowered 2 and 4 feet in Basins No. 2 and 3, respectively, and a step was placed at the end of the basin, Figure 16. These changes had no appreciable effect in the basin action, and there was little improvement in the excessive waves and turbulence in the canal.

Basin No. 4 differed from the above designs in that the bottom of the canal was raised 3 feet to elevation 5285 and the stilling-basin floor to 5283 feet, Figure 16. The entire canal was raised 3 feet due to field considerations rather than results of the hydraulic studies. In general, the operation of the stilling-basin was unsatisfactory and worse than the previous tests.

Basin No. 5. Following the above basin studies it was decided little improvement in the stilling-basin performance could be attained until a more uniform distribution of flow was obtained in the chute. Therefore, the chute studies described on Pages 9 and 10 were made at this point of the investigations and the chute results and recommendations contained therein were incorporated in the model.

In addition to the chute changes, a steeper parabolic curve, $y = -\frac{x^2}{50}$, was installed at the upper end of the stilling-basin in place of the original curve, $y = -\frac{x^2}{125}$. This change in the stilling-basin is shown as Basin No. 5, Figure 16. The steeper curve noticeably improved the operation of the stilling-basin. The jet from the chute penetrated more deeply into the stilling-pool, producing a more uniform hydraulic jump. However, due to the deeper penetration of the jet, the appearance of the stilling-action indicated that a deeper pool was required.

Basins No. 6 and 7. The floor of the stilling-basin was then lowered 2 feet to elevation 5281 in Basins No. 6 and 7, Figure 16. Lowering the stilling-basin floor improved the stability of the jump and the action in the stilling-basin was acceptable with either the $y = -\frac{x^2}{50}$ or $y = -\frac{x^2}{125}$ curve installed, Figures 35a and b. However, the steeper curve, $y = -\frac{x^2}{50}$, gave a more stable hydraulic jump and resulted in satisfactory stilling-basin operation for all conditions of discharge. The hydraulic jump formed well up on the curve for both conditions of the maximum discharge of 1,500 cubic feet per second through one or two valves.

With the milder curve, $y = -\frac{x^2}{125}$, and with only one valve discharging, the hydraulic jump was less stable. The instability of the jump was demonstrated by churning the water in the stilling-pool in a circular manner either clockwise or counterclockwise. The jump could be made permanently unsymmetrical in this manner. With the steeper curve installed the jump could not be made unsymmetrical for any flow condition.

To determine the effect of changing the length and shape of the transition a reverse parabolic transition, 60 feet in length, Figure 17, was substituted for the 30-foot straight-line tramsition of the preliminary design. Hydraulically, the 30-foot straight-line transition was an unsatisfactory design for this structure since it was comparatively short and because, by use of this transition, there resulted two distinct breaks in the flow from the stilling-basin to the canal—one at the upstream end of the transition and the other at the point where the transition joins the canal. On the other hand, the reverse parabolic transition was twice as long and was tangent to the rectangular stilling-basin and the trapezoidal canal at the ends of the transition.

The parabolic transition was a definite improvement over the shorter straight-line transition. Waves in the canal were noticeably reduced and the flow throughout the transition was comparatively uniform, Figure 38c.

Basin No. 8. In Basin No. 8 the 4-foot step at the downstream end of the stilling-basin was eliminated and the bottom of the transition sloped from the basin floor to the bottom of the canal. With this change there was very little difference in the height of waves or in the flow through the transition over Design No. 7, but there appeared to be less stability in the hydraulic jump.

Recommended Stilling-basin

In view of the above stilling-basin tests it is recommended that Basin No. 7, Figures 16 and 17, be accepted for construction in the field. This basin includes the steeper parabolic curve, $y = -\frac{x^2}{50}$, a step at the end of the stilling-basin and the reverse parabolic transition from the basin to the canal.

Figure 36 contains photographs of the model of the recommended structure with no flow and Figures 37 to 46 are similar views of the recommended design for discharges of 500, 1,000, and 1,500 second-feet through one and two valves at reservoir elevations of 5430 and 5340 feet. Figures 19 to 27 are complete water surface profiles for the recommended design for the same discharges and operating conditions.

No studies were made employing baffle piers since satisfactory stilling-basin performance was obtained without their use.

The various basin designs studied are shown in detail in Figure 16, and a tabulation of the results of the tests on the different designs is presented in Table 1.

Height of waves in the canal. For the purpose of correlating the relationship between the height of waves in the model with those of the prototype, model wave heights for the recommended design were obtained for discharges of 1,500 1,000, and 500 cubic feet per second through one and two valves at reservoir elevations of 5430 and 5340 feet. These results are shown in Table 2. The height of waves shown in the tabulation is the difference in feet between the elevations of the maximum crest and the minimum trough of the waves over a time period of about 1 minute. The wave heights were obtained in the canal near the water's edge by means of a point gage located at Station 19+50.

Hydraulic jump at the valves. Since the chute approach immediately downstream from the valves is lower in elevation than the main chute, a hydraulic jump forms at the valves for the lower ranges of discharges and reservoir elevations, Figure 45a. Model tests for a range of discharges

were made to determine the reservoir elevations at which a jump forms at the valves and at which the jump sweeps out. Results of these tests for the recommended design are shown below:

Q	Two valves discharging		One valve discharging	
	Reservoir elevations when jump forms (Reservoir elevation falling)	Reservoir elevation when jump sweeps out (Reservoir elevation rising)	Reservoir elevation when jump forms (Reservoir elevation falling)	Reservoir elevation when jump sweeps out (Reservoir elevation rising)
500	5344	5434***	5327	5346
800	5329	5377	No jump at 5331*	5335**
1000	5324	5362	No jump at 5350*	5350**
1500	No jump at 5328*	5343**	No jump at 5430*	5430**

*Lowest reservoir elevation which will provide the given discharge with the valve(s) 100 percent open.

**Reservoir elevation required to sweep out a jump which was forced to form at the valves by temporarily placing an obstruction in the chute.

***This elevation is 4 feet above the maximum reservoir.

To illustrate the use and significance of the above table, two hypothetical examples are cited. Assume that it is required to release a constant discharge of 500 second-feet through the outlet works and the reservoir pool is at elevation 5346 feet or higher. The 500 second-feet can be released through one or two valves and no jump will form at the valves. Now suppose the reservoir pool begins to fall. If two valves are equally discharging the 500 second-feet, a jump will form when the reservoir drops to 5344 feet. However, if the 500 second-feet is released through one valve, the reservoir must drop to elevation 5327 feet before a jump will form. Now assume that the reservoir begins to rise. The jump will remain in, when one valve is discharging, until reservoir elevation 5346 feet is reached; but, if two valves are being used, the reservoir must rise to elevation 5434 (or 4 feet above maximum pool) before the jump is swept out.

As another example, assume that it is required to release the maximum canal capacity of 1,500 second-feet. The lowest reservoir elevation at which 1,500 second-feet can be released is 5328 feet. Both valves must be fully open at this head to provide the required discharge and no jump will form at the valves. However, if an obstruction is placed in the

chute until the water backs up to the valves and the obstruction is then removed, a jump will form and remain in until the reservoir pool rises to elevation 5343 feet.

To release 1,500 second-feet through one valve the reservoir must be at the maximum elevation, 5430 feet. Under these conditions a jump will not form and, if artificially forced to form by an obstruction, the jump will be swept out.

The above reservoir elevations at which the jump formed were determined by adjusting the hollow-jet valve or valves for a constant discharge and allowing the reservoir water surface to drop. When water just began to fall back toward the valves, the reservoir elevation, shown in the table, was recorded. In a similar manner but with the water surface in the reservoir rising slowly, the reservoir elevation at which the jump began to sweep from the chute approach was noted.

The above data must be considered approximate only because of the higher relative friction losses in the model. Another consideration is the fact that the model conduit upstream from the valves could be constructed to represent prototype losses only for one discharge; in this case the maximum discharge of 1,500 cubic feet per second through two valves. For a discharge of 1,500 cubic feet per second through one valve or for any lower discharges, the model pipe losses no longer represent prototype losses and slight inconsistencies between model and prototype may exist.

Pressures. Pressures on the floor of the recommended design in the region where the jets strike the invert and on the parabolic curve at the stilling-basin entrance were measured for a range of discharges and reservoir elevations, Figure 28. The greatest negative pressure recorded was for one valve discharging 1,500 cubic feet per second at maximum reservoir elevation and was 2.3 feet of water (prototype) below atmospheric pressure at Piezometer 29. Another low pressure area at the upper end of the chute was in the region of Piezometers 8 to 11, inclusive, Figures 29 and 30.

Pressure measurements, made on the parabolic curve at the entrance to the stilling-basin, Figure 31, were all above atmospheric for the recommended design except for Piezometers 49 and 60. The lowest negative pressure at these points was minus 0.25 foot of water.

No effort was made to increase any of the above pressures by changing the profile, since the lowest pressure recorded on the model was well above the cavitation range.

Splash tests. The model indicated in the final stages of the study that some provision should be made to prevent the splash which occurred downstream from the valves from passing over the training-walls near the upper end of the chute and at the stilling-basin entrance. A series of tests, using an adjustable cover extending across the chute and resting on each training-wall, were made to determine the length and location of a cover, or hood, required to minimize this splash.

The location and extent of the splash was determined by placing on edge a plywood sheet 8 feet long and 3-1/2 feet high over the right training-wall. By use of reference lines painted on the board indicating elevation and station, the location and maximum height of the splash was measured for the various covers tested, Figures 47 and 48.

Results of these tests indicated that the greatest splash occurred immediately downstream from the valves when only one valve was operating, Figure 47. To eliminate nearly all the splash, a hood, 68 feet in length and extending from Station 13+52 to Station 14+20 is required, Figure 48. Results of tests using shorter covers in various locations are also shown in Figure 48.

At the stilling-basin the greatest splash occurred with one valve operating and extended from Station 17+27 to Station 17+87. A cover, 60 feet in length and extending downstream from Station 17+27, is required to eliminate this splash.

Certain limitations should be observed in applying the above data to predict the amount of splash which will occur in the prototype. While splash will definitely occur in the prototype at points indicated by the model, the splash may cover a larger relative area in the prototype and also may occur in places not indicated by the model. The above data were taken only to appraise the extent of the splash and to obtain an estimate of the length of cover required to reduce it.

Method of prototype operation. It is recommended that, whenever possible, water be released from the reservoir through the outlet works by equally opening both valves. Although the stilling-basin performed satisfactorily when one valve was discharging, the model clearly indicated that, for any discharge, the water was more evenly distributed across the width of the chute and a more stable and uniform jump formed in the stilling-basin when each valve was discharging an equal amount of water. Also, the height of waves in the canal, Table 2, Page 18, and the amount of splash, Figure 47, was materially less. Since the crown, discussed on Pages 10 and 11, was not constructed in the chute of the prototype structure, it is more important than ever that the recommended operating procedure be followed.

Table 1

INVESTIGATION OF STILLING-BASIN--SCHEME B

Design	Equation of curve	Elevation of floor	Height of step	Type of transition	Elevation of canal bottom	Stilling-pool operation
Preliminary basin	$y = -\frac{x^2}{125}$	5282	None	30-foot straight-line	5282	Unsymmetrical jump and partially swept out. Excessive waves in canal.
Basin No. 2	$y = -\frac{x^2}{125}$	5278	4 feet	30-foot straight-line	5282	Unsymmetrical jump but well up on curve. Excessive waves and turbulence.
Basin No. 3	$y = -\frac{x^2}{125}$	5280	2 feet	30-foot straight-line	5282	No appreciable change over Basin No. 2. Jump did not sweep out when canal tailwater was lowered.
Basin No. 4	$y = -\frac{x^2}{125}$	5283	2 feet	30-foot straight-line	5285	Less symmetry in jump. General operation unsatisfactory and worse than previous tests.
Basin No. 5	$y = -\frac{x^2}{50}$	5283	2 feet	30-foot straight-line	5285	Operation improved. Steeper curve gave a more even jump.
Basin No. 6	$y = -\frac{x^2}{125}$	5281	4 feet	60-foot reverse parabolic	5285	Satisfactory appearance but jump unstable with one valve operating. Parabolic transition was vast improvement.
Basin No. 7 (recommended basin)	$y = -\frac{x^2}{50}$	5281	4 feet	60-foot reverse parabolic	5285	Good operation when one or two valves discharging. Stable jump. Minimum waves in canal.
Basin No. 8	$y = -\frac{x^2}{50}$	5281	Sloping floor at transition	60-foot reverse parabolic	5285	Satisfactory operation but less stability and symmetry in jump.

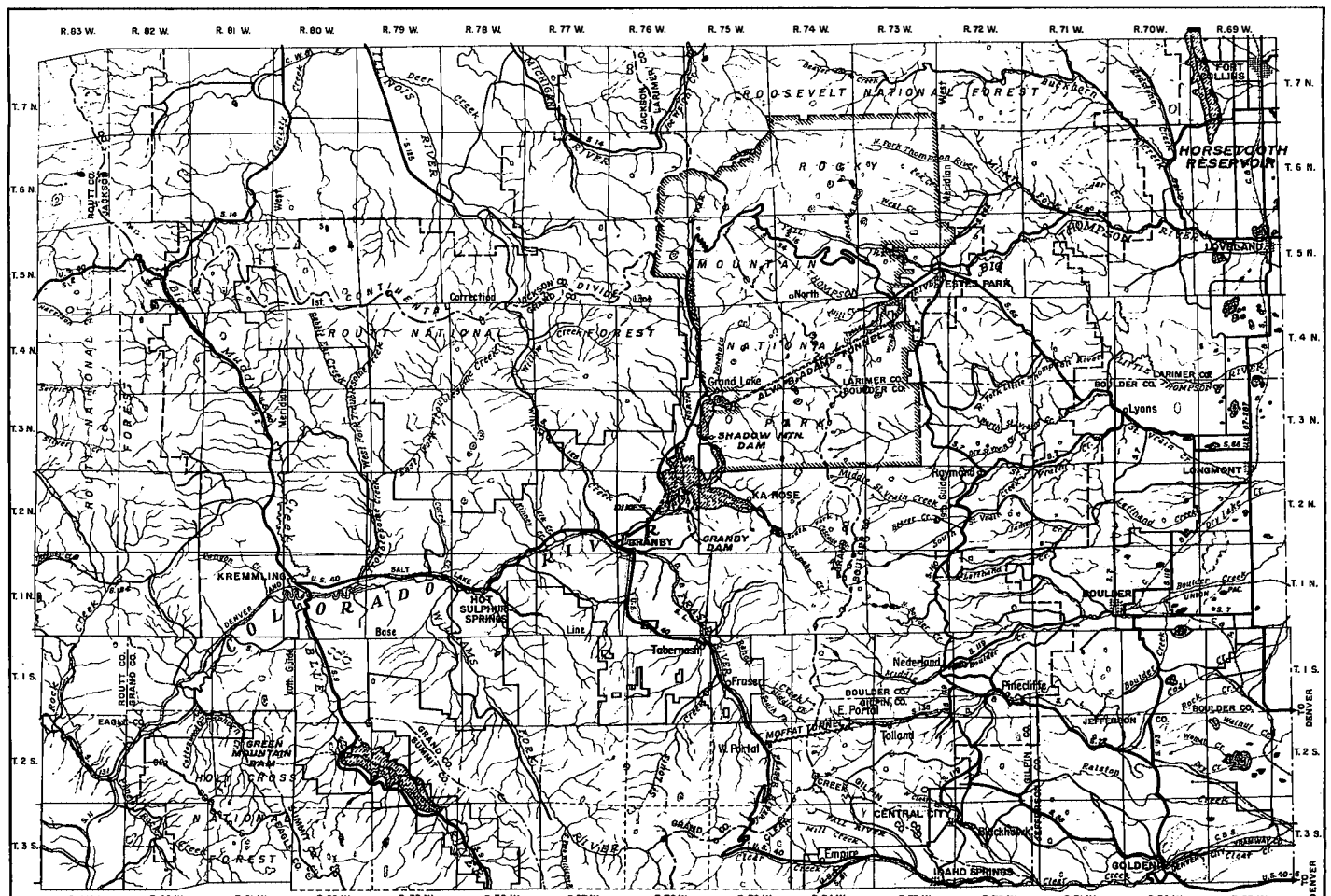
Table 2

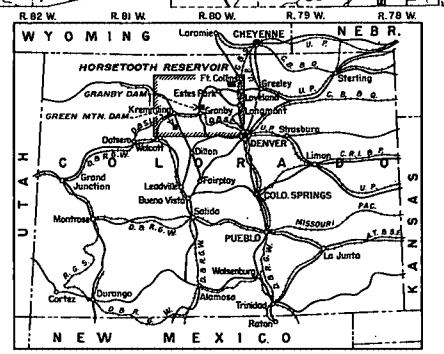
HEIGHT OF WAVES—RECOMMENDED DESIGN

Discharge*	Reservoir elevation in feet	Valve(s) operating	Wave heights** in feet—prototype
1,500	5430	Right and left	0.86
1,500	5430	Right	1.10
1,500	5340	Right and left	0.62
1,000	5430	Right and left	0.67
1,000	5430	Right	0.72
1,000	5340	Right and left	0.60
500	5430	Right and left	0.36
500	5430	Right	0.31
500	5340	Right and left	0.34
500	5340	Right	0.38

*Discharge in cubic feet per second—prototype.

**Waves measured in canal at Station 19+50.





INDEX MAP

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO BIG THOMPSON PROJECT - COLO.

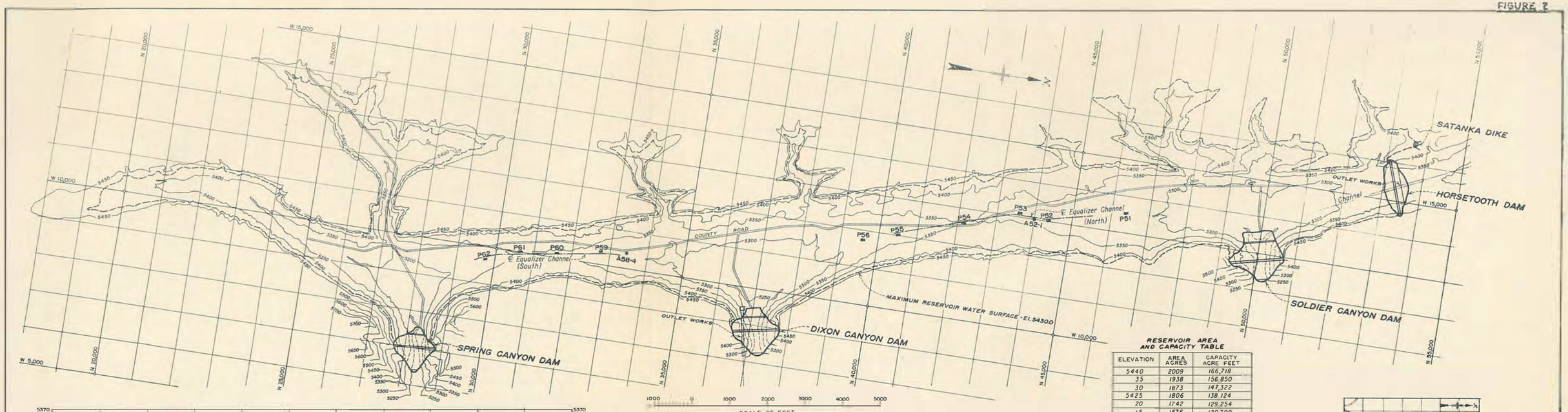
HORSETOOTH RESERVOIR

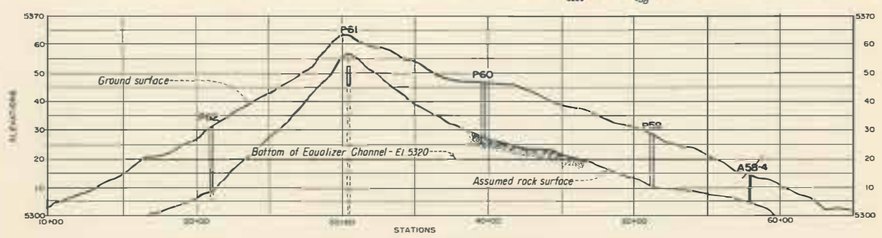
LOCATION MAP

DRAWN C.A.M. SUBMITTED T.M. Meyer
TRACED R.E. Hub — V.F.S. RECOMMENDED W.H. Holder
CHECKED R.E.O. APPROVED Walter R. Young CHIEF ENGINEER
DENVER, COLORADO, FEB. 27, 1946 245-D-2640

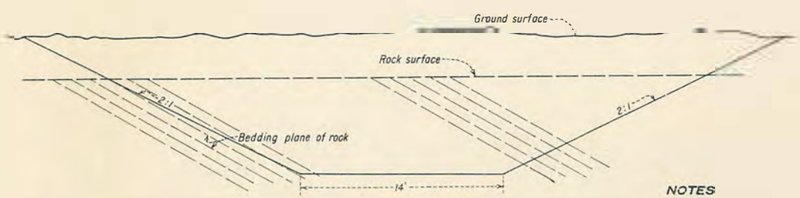
FIGURE 1

FIGURE 3

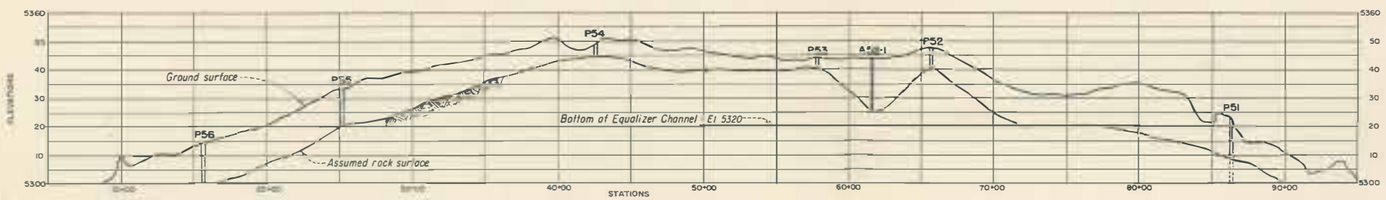




PROFILE ON ℄ SOUTH CHANNEL



CROSS SECTION OF CHANNEL



PROFILE ON ℄ NORTH CHANNEL

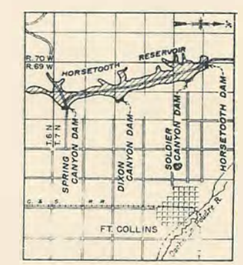
NOTES

P57 Indicates Test Pit

A-56-1 Indicates Auger Hole

RESERVOIR AREA AND CAPACITY TABLE

ELEVATION	AREA ACRES	CAPACITY ACRE FEET
5440	2009	166,718
35	1938	156,850
30	1873	147,322
5425	1806	138,124
20	1742	129,254
15	1676	120,709
10	1625	112,456
05	1569	104,471
5400	1513	96,761
95	1457	89,386
90	1399	82,246
85	1343	75,449
80	1282	68,885
5375	1222	62,624
70	1162	56,659
65	1107	50,987
60	1045	45,607
55	977	40,549
5350	913	35,825
45	837	31,445
40	757	27,460
35	700	23,814
30	635	20,475
5325	580	17,437
20	525	14,675
15	471	12,184
10	419	9,959
05	372	7,982
5300	322	6,247
95	270	4,768
90	220	3,544
85	176	2,555
80	132	784
5275	96	1,183
70	75	754
65	47	448
60	30	255
55	19	132
5250	11	58
45	4	19
40	1	5
5235	0.3	1



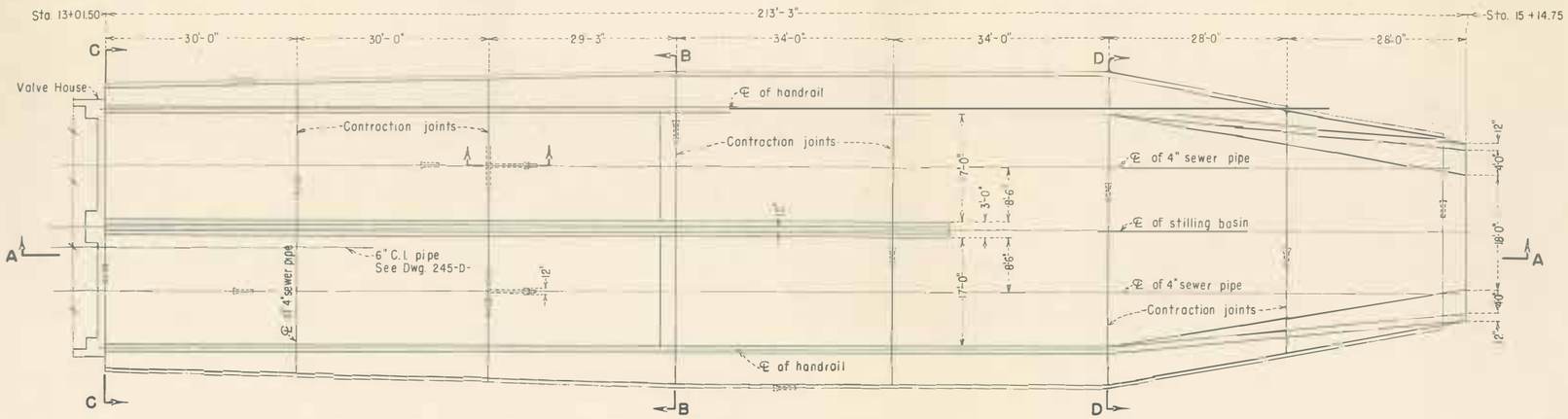
LOCATION MAP

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO BIG THOMPSON PROJECT - COLO.

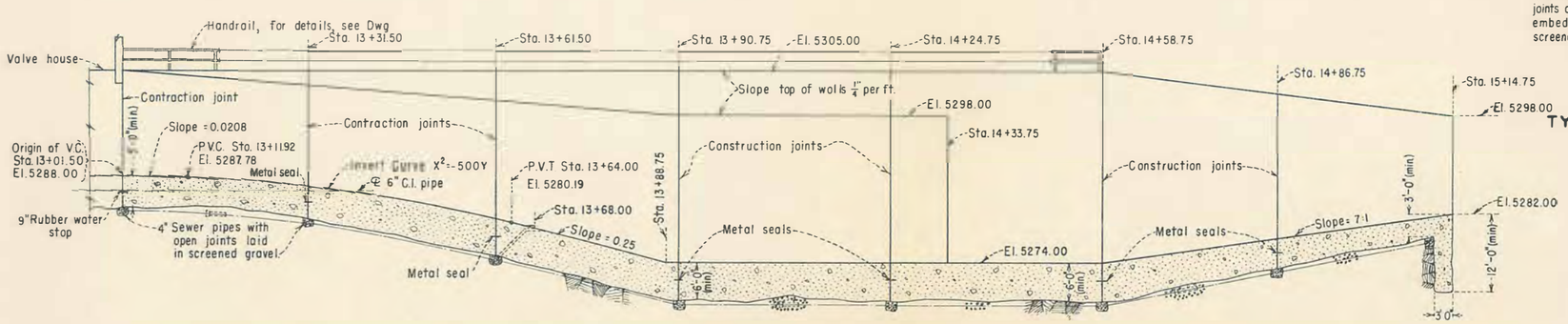
HORSETOOTH RESERVOIR

GENERAL MAP OF RESERVOIR AREA

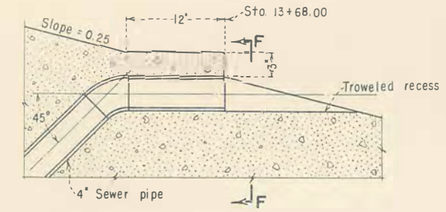
TITLE T.W. Steiner
DRAWN
DATE
CHECKED H.E.B. & R.
SCALE
DRAWING NO. 265-D-2641



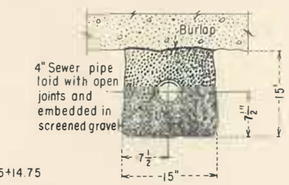
PLAN



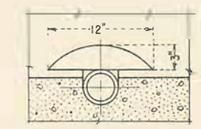
SECTION A-A



SECTION E-E



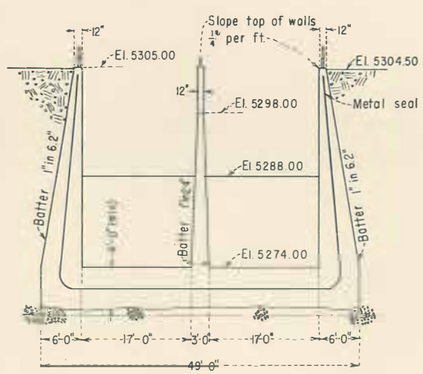
TYPICAL DRAIN DETAIL



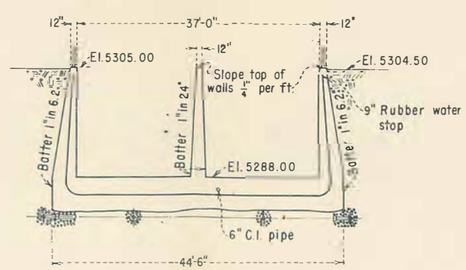
SECTION F-F

NOTES

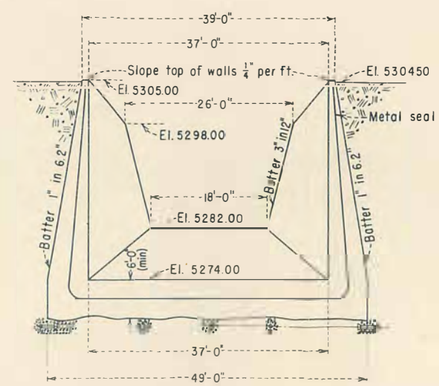
Chamfer all exposed corners 3/4" unless otherwise noted.



SECTION B-B



SECTION C-C



SECTION D-D

0 5 10 15 20
SCALE IN FEET

REFERENCE DRAWINGS

PLAN AND SECTIONS	245-D-2893
VALVE HOUSE SUB-STRUCTURE-CONCRETE OUTLINE	245-D-
STILLING BASIN- REINFORCEMENT	245-D
STILLING BASIN-HANDRAIL	245-D
CONDUIT DRAIN	245-D

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT- COLO.

HORSETOOTH DAM

OUTLET WORKS

STILLING BASIN - CONCRETE OUTLINE
SCHEME A

DRAWN D.B.T. SUBMITTED
TRACED E.W. RECOMMENDED
CHECKED APPROVED ASS'T CHIEF ENGINEER
DENVER, COLORADO, 245-D-3005

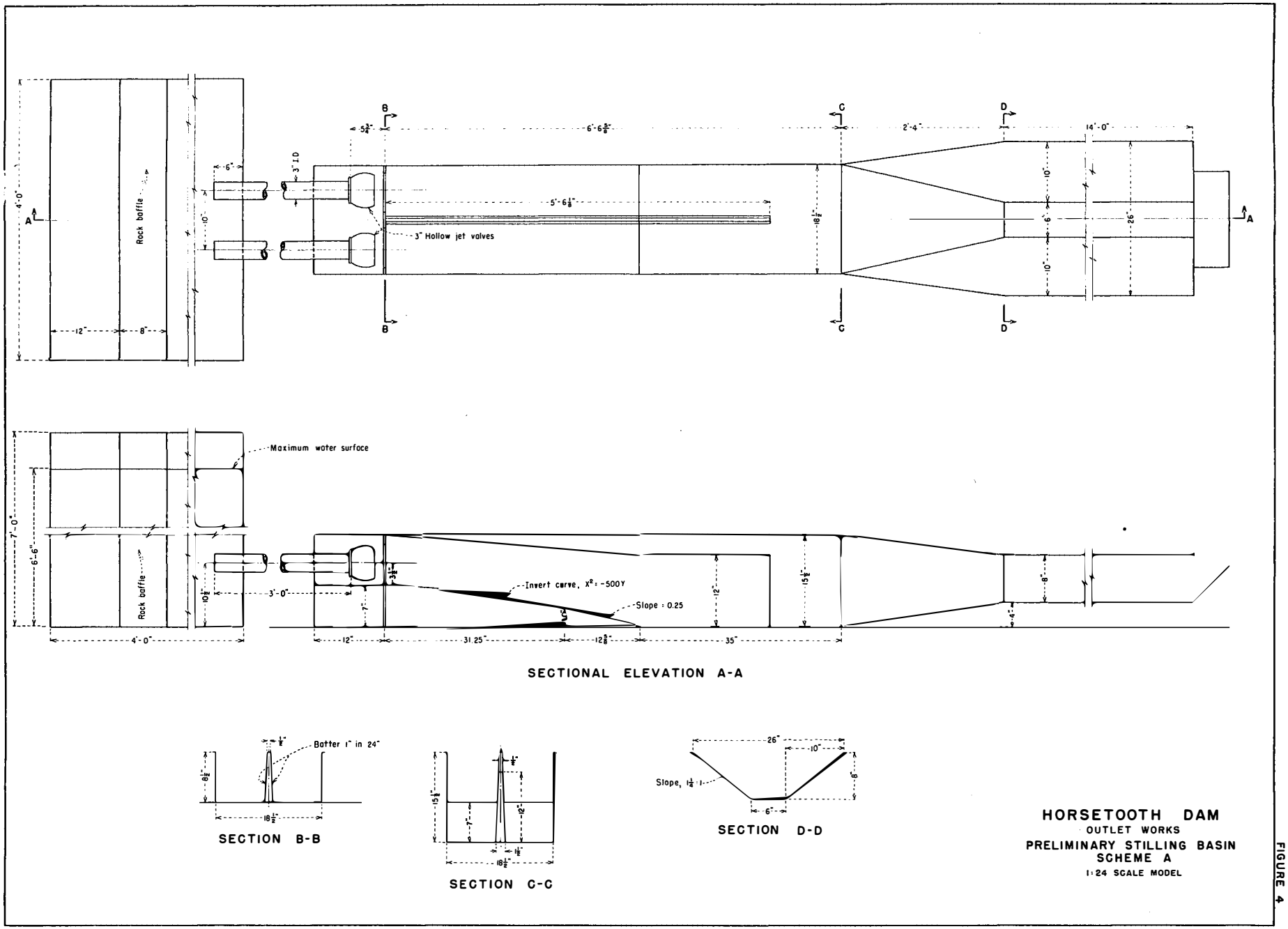

Rock baffle
3" Hollow jet valves
3" I.D.
Maximum water surface
Invert curve, X² = -500Y
Slope = 0.25
SECTIONAL ELEVATION A-A
Batter 1" in 24"
SECTION B-B
SECTION C-C
Slope, 1/4 : 1
SECTION D-D
HORSETOOTH DAM
OUTLET WORKS
PRELIMINARY STILLING BASIN
SCHEME A
1:24 SCALE MODEL

FIGURE 4

FIGURE 5

A. The model

B. Two valves discharging 2500 second-feet

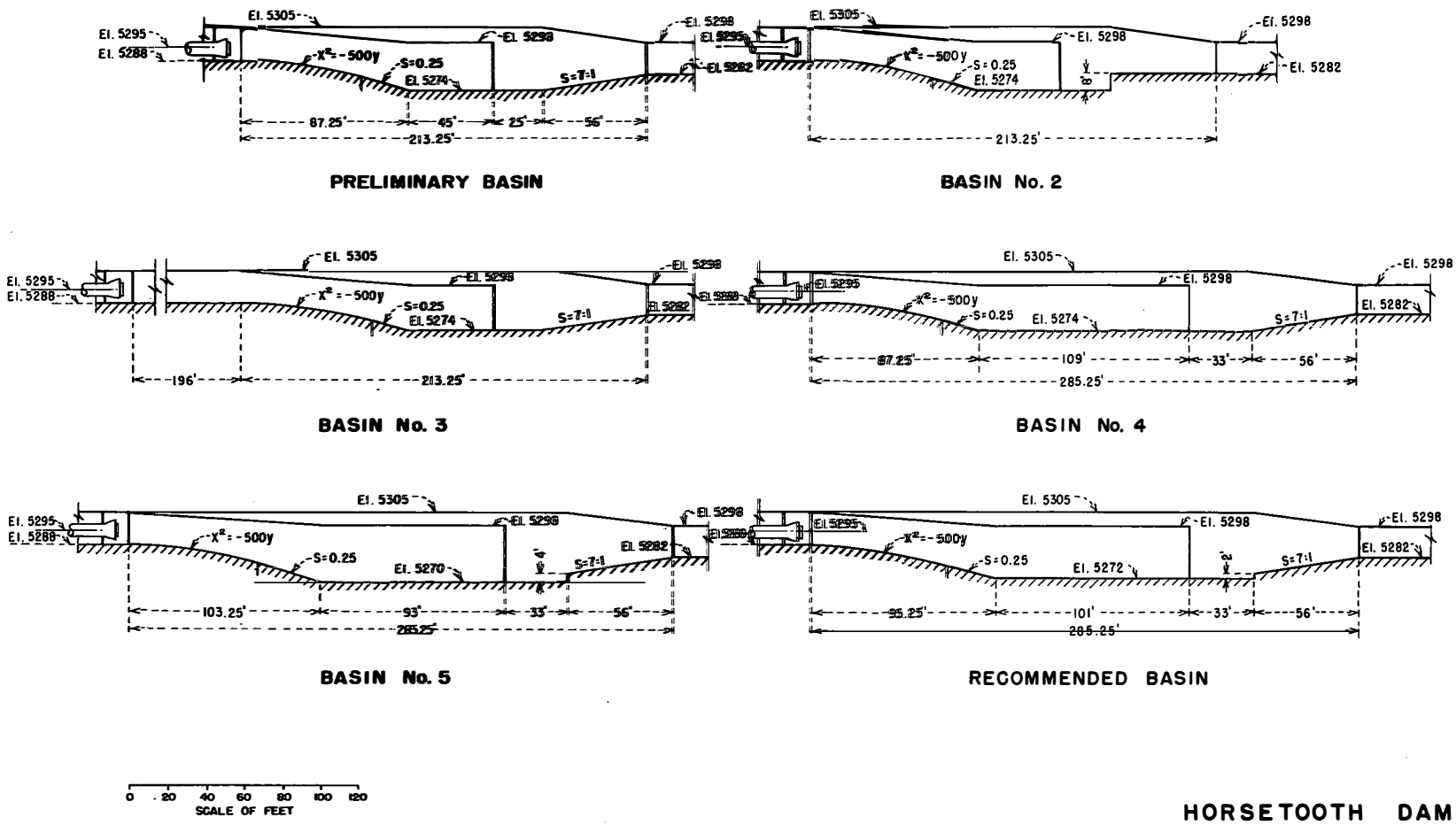
C. Both valves discharging 1500 second-feet

HORSETOOTH DAM OUTLET WORKS
Preliminary Stilling-basin
1:24 Scale Model
SCHEME A

A. Left valve discharging 1500 second-feet. Jump sweeps out

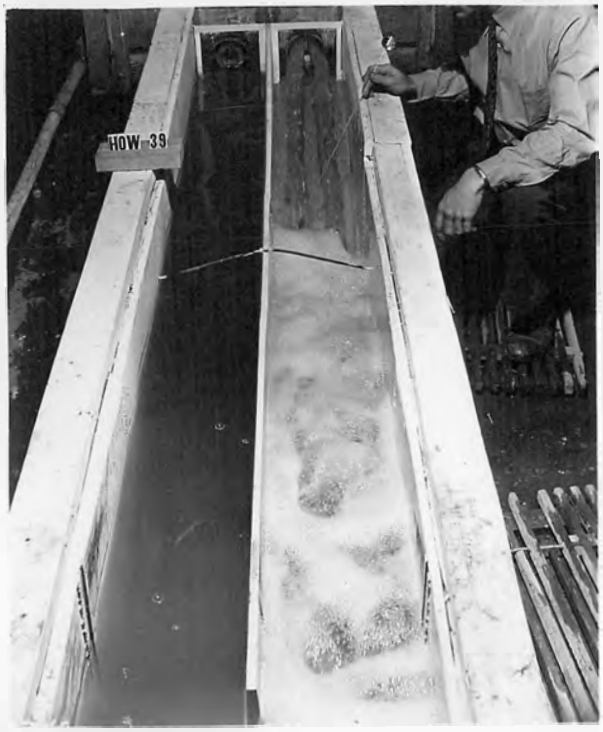
B. Left valve discharging 1000 second-feet

HORSETOOTH DAM OUTLET WORKS
Preliminary Stilling-basin
1:24 Scale Model
SCHEME A

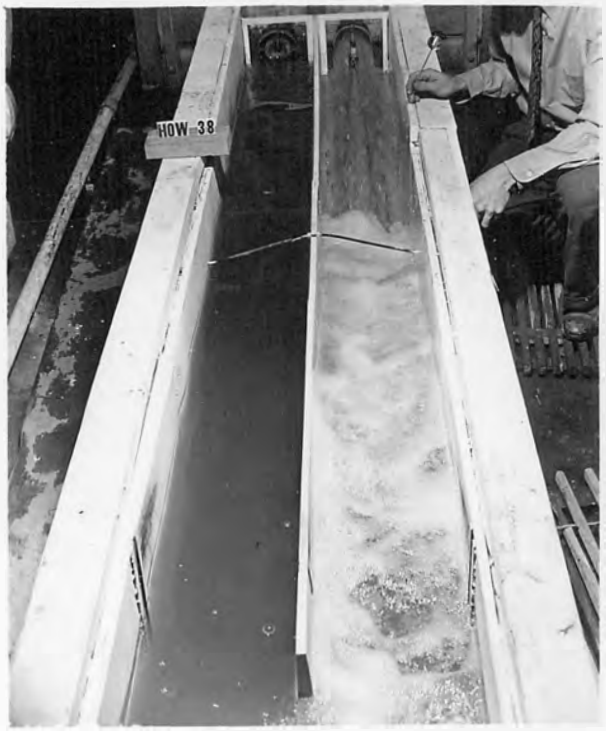


HORSETOOTH DAM
OUTLET WORKS
STILLING BASIN DESIGNS
SCHEME A
1:24 SCALE MODEL

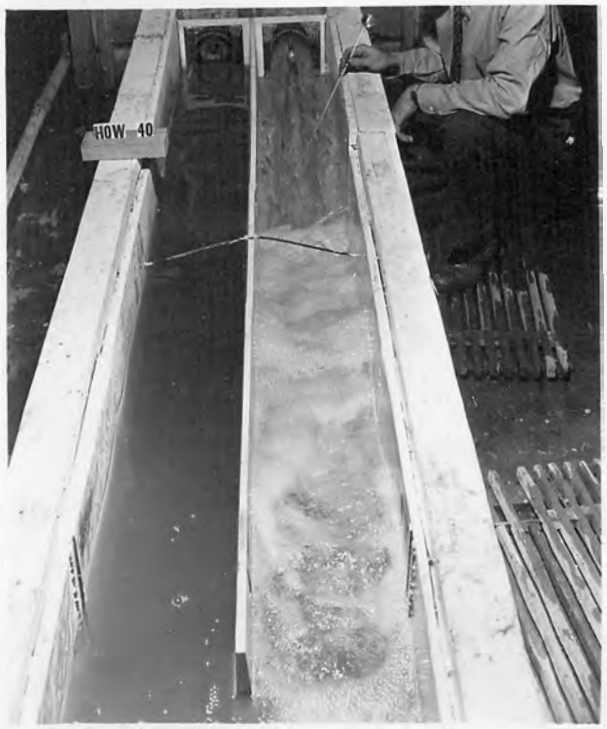
FIGURE No. 7



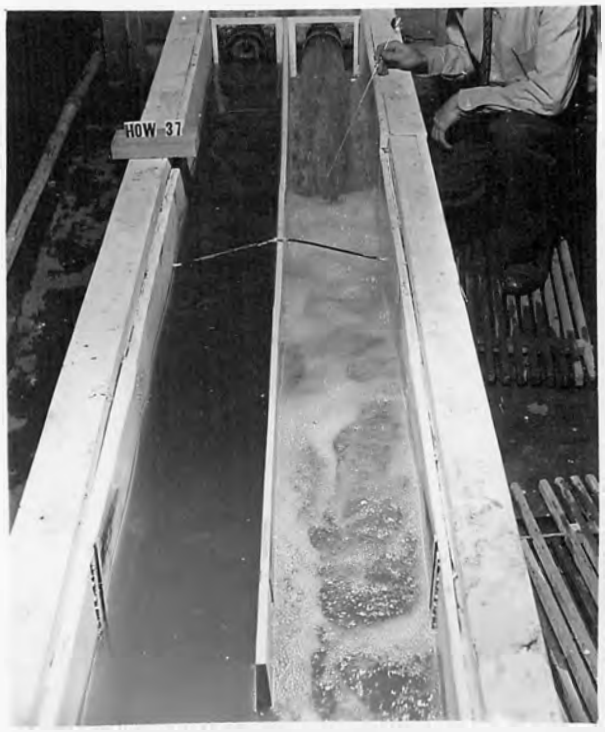
A. Valve horizontal



B. Valve depressed $2\frac{1}{2}^{\circ}$ below horizontal

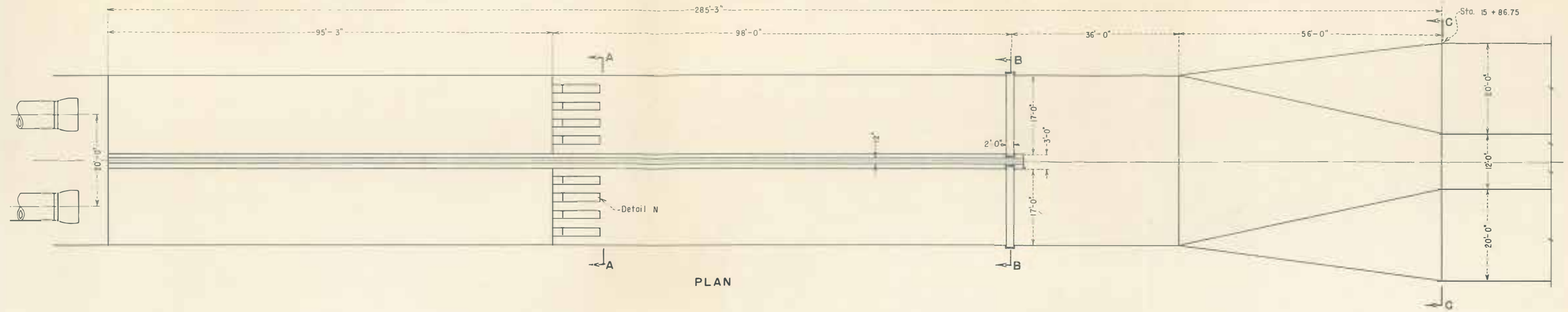


C. Valve depressed 5°

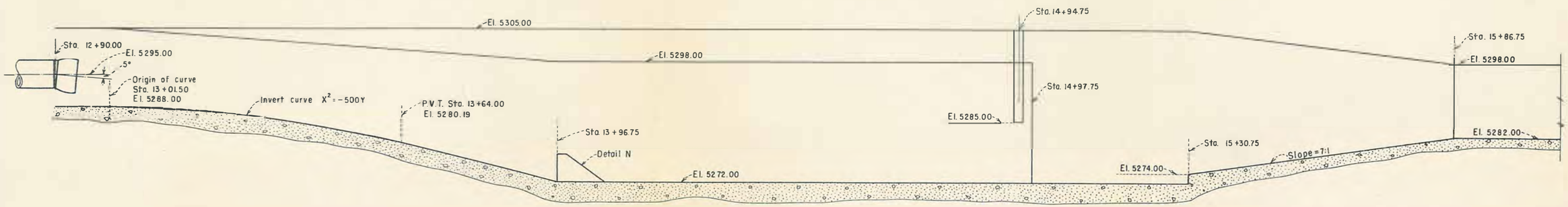


D. Valve depressed $7\frac{1}{2}^{\circ}$

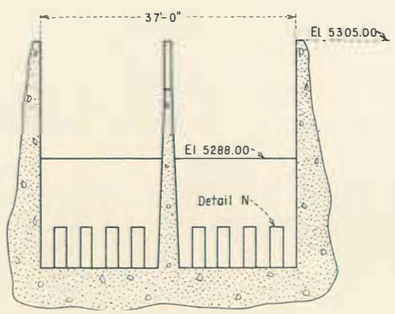
HORSETOOTH DAM OUTLET WORKS
Stilling-basin Operation with Valves Depressed at Various Angles
Discharge = 1500 second-feet 1:24 Scale Model
SCHEME A



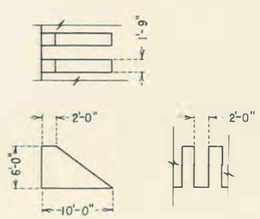
PLAN



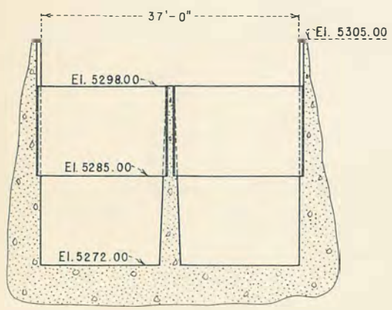
ELEVATION



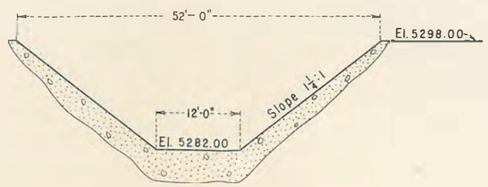
SECTION A-A



DETAIL N

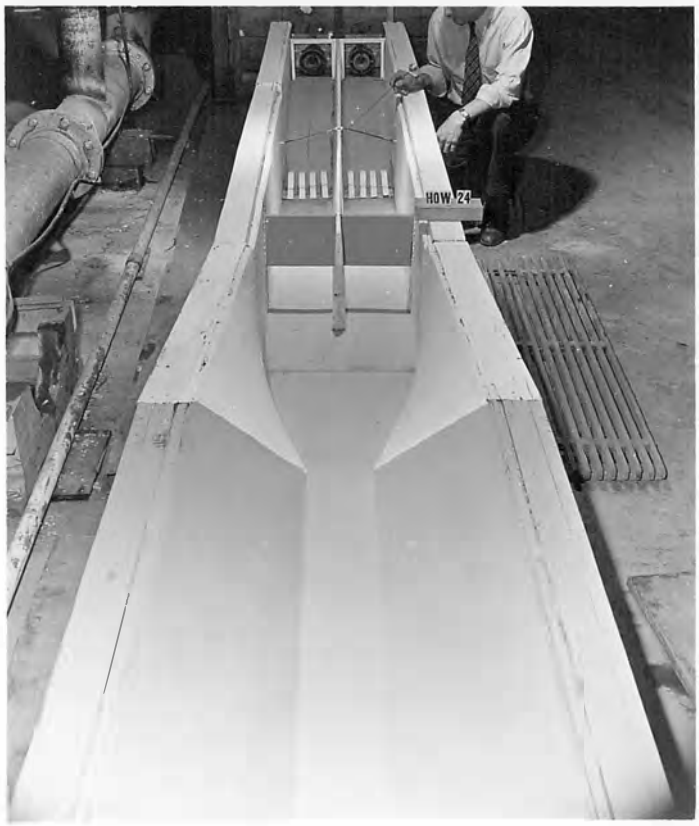


SECTION B-B



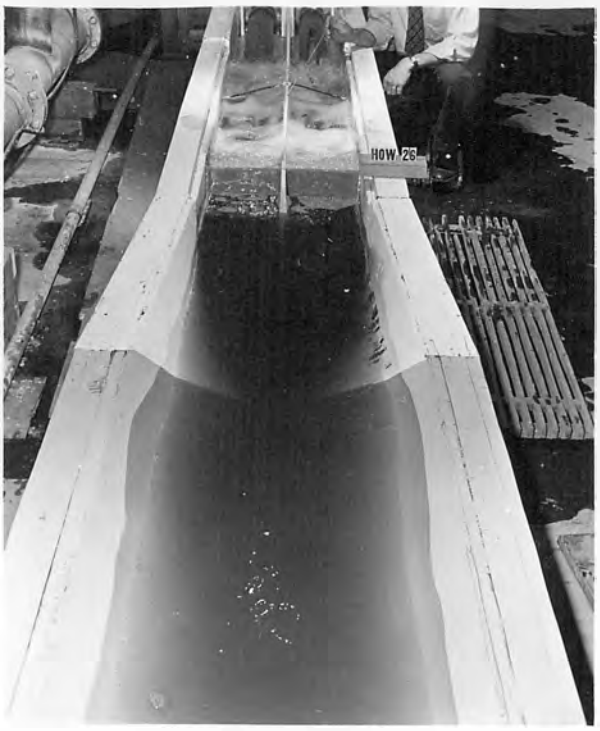
SECTION C-C

HORSETOOTH DAM
OUTLET WORKS
RECOMMENDED STILLING BASIN
SCHEME A
1:24 SCALE MODEL

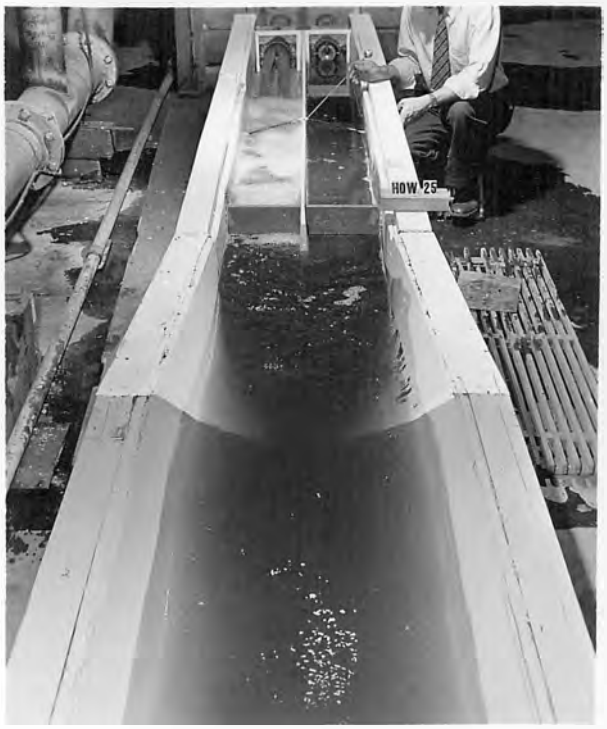


The Model

HORSETOOTH DAM OUTLET WORKS
Recommended Stilling-basin
1:24 Scale Model
SCHEME A

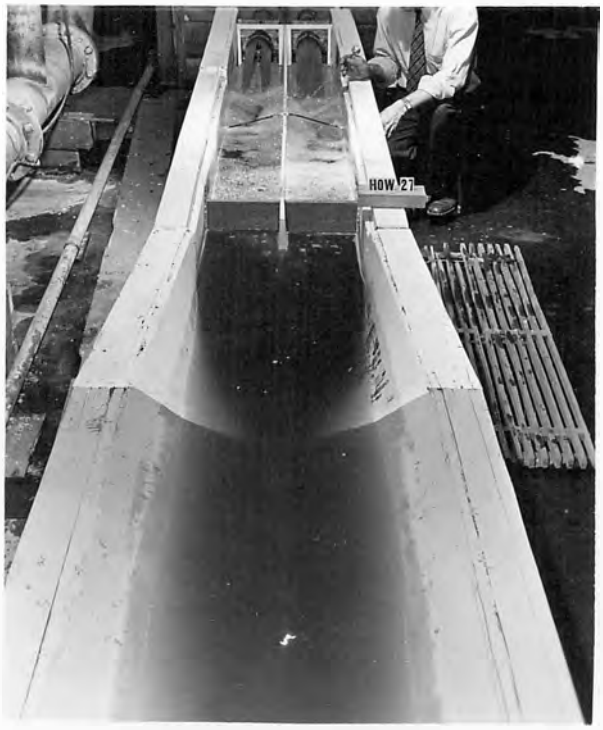


A. Two valves operating

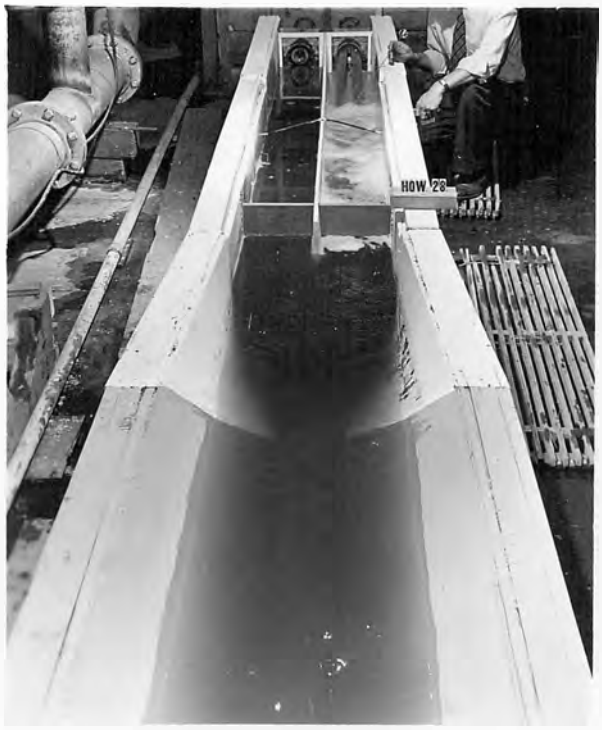


B. Right valve operating

Discharge=1500 second-feet



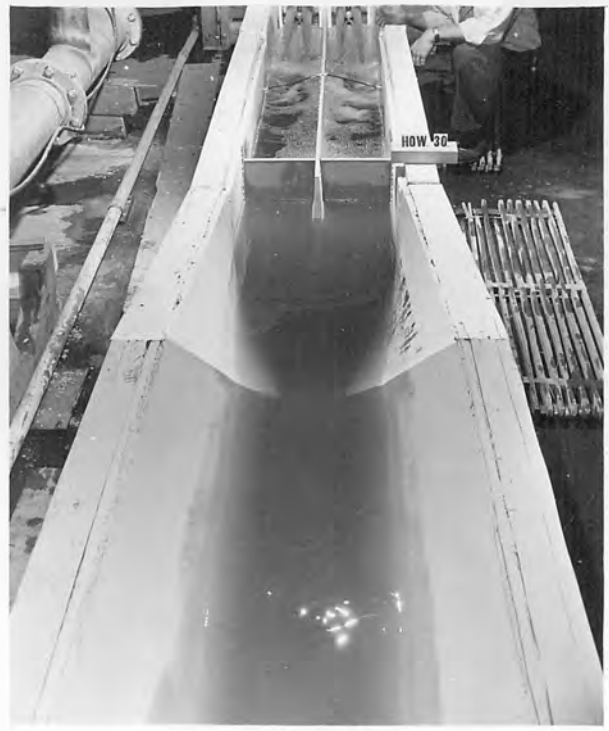
C. Two valves operating



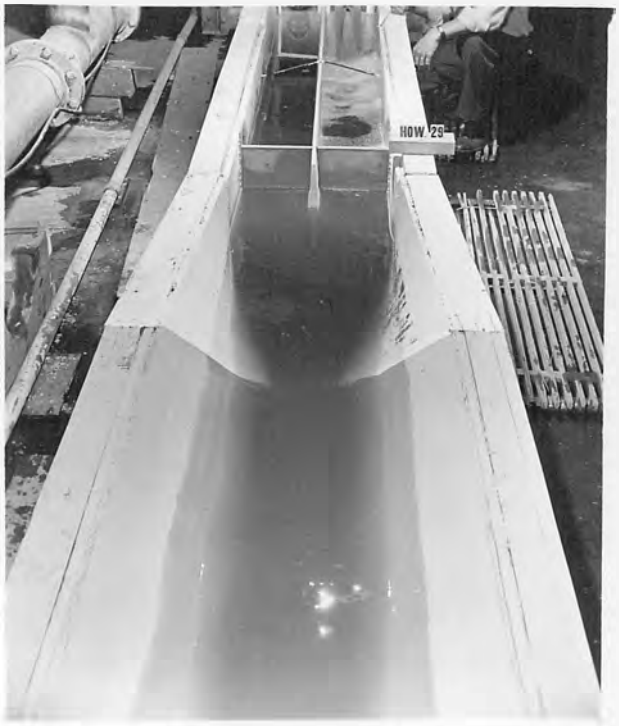
D. Left valve operating

Discharge = 1000 second-feet

HORSETOOTH DAM OUTLET WORKS
Recommended Stilling-basin
1:24 Scale Model
SCHEME A

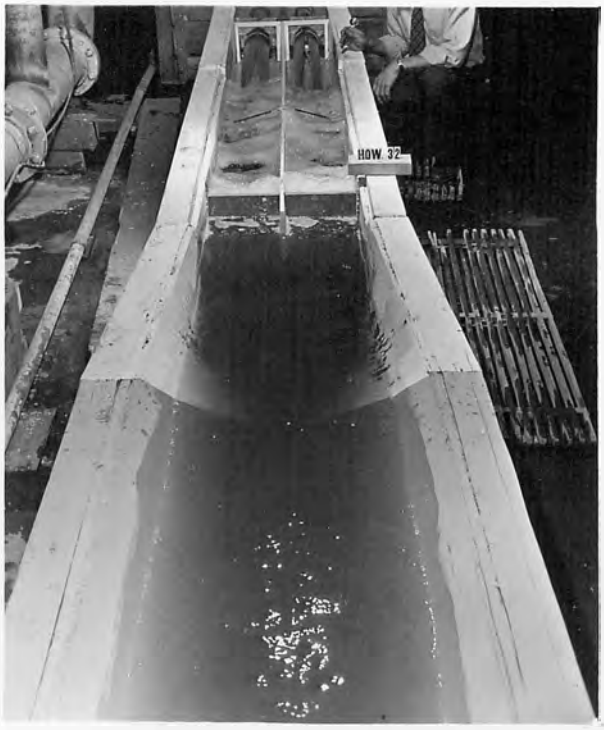


A. Two valves operating



B. Left valve operating

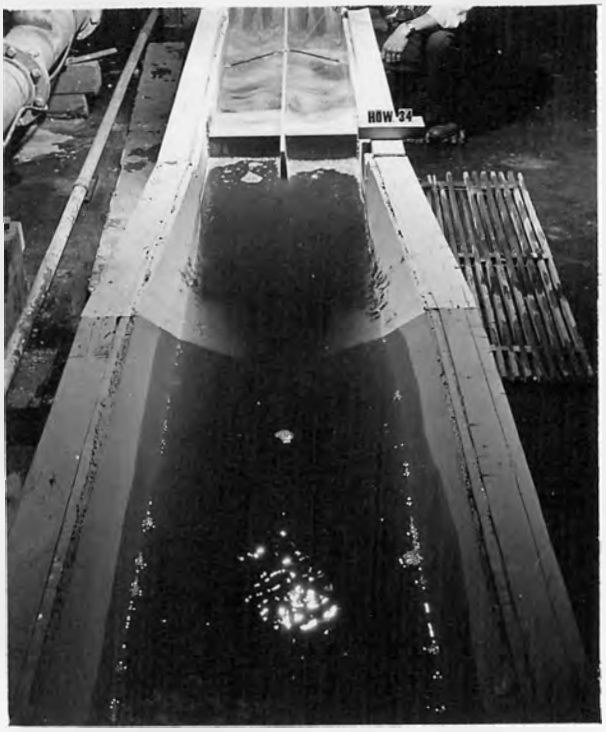
Recommended Stilling-basin
Discharge = 500 second-feet



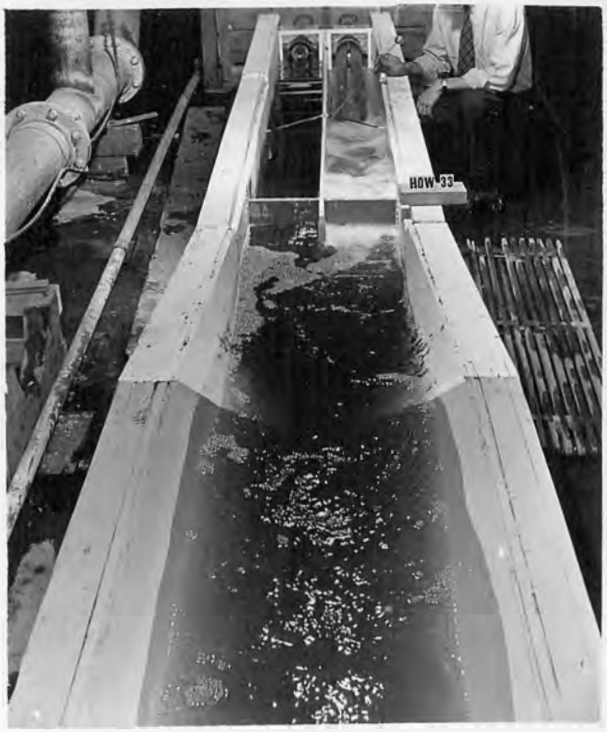
C. Two valves operating

D. Left valve operating

Recommended Stilling-basin with 10-foot step installed
Discharge = 1500 second-feet
HORSETOOTH DAM OUTLET WORKS
1:24 Scale Model
SCHEME A

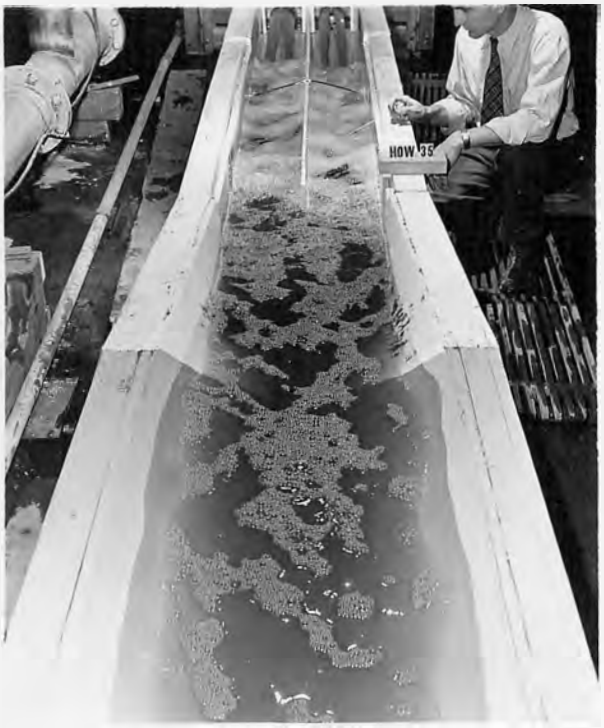


A. Two valves discharging



B. Left valve discharging

Recommended stilling-basin with baffle piers removed
Discharge = 1500 second-feet



C. Two valves discharging

D. Left valve discharging

Recommended stilling-basin with baffle piers and surface
baffle removed. Discharge = 1500 second-feet

HORSETOOTH DAM OUTLET WORKS
1:24 Scale Model
SCHEME A

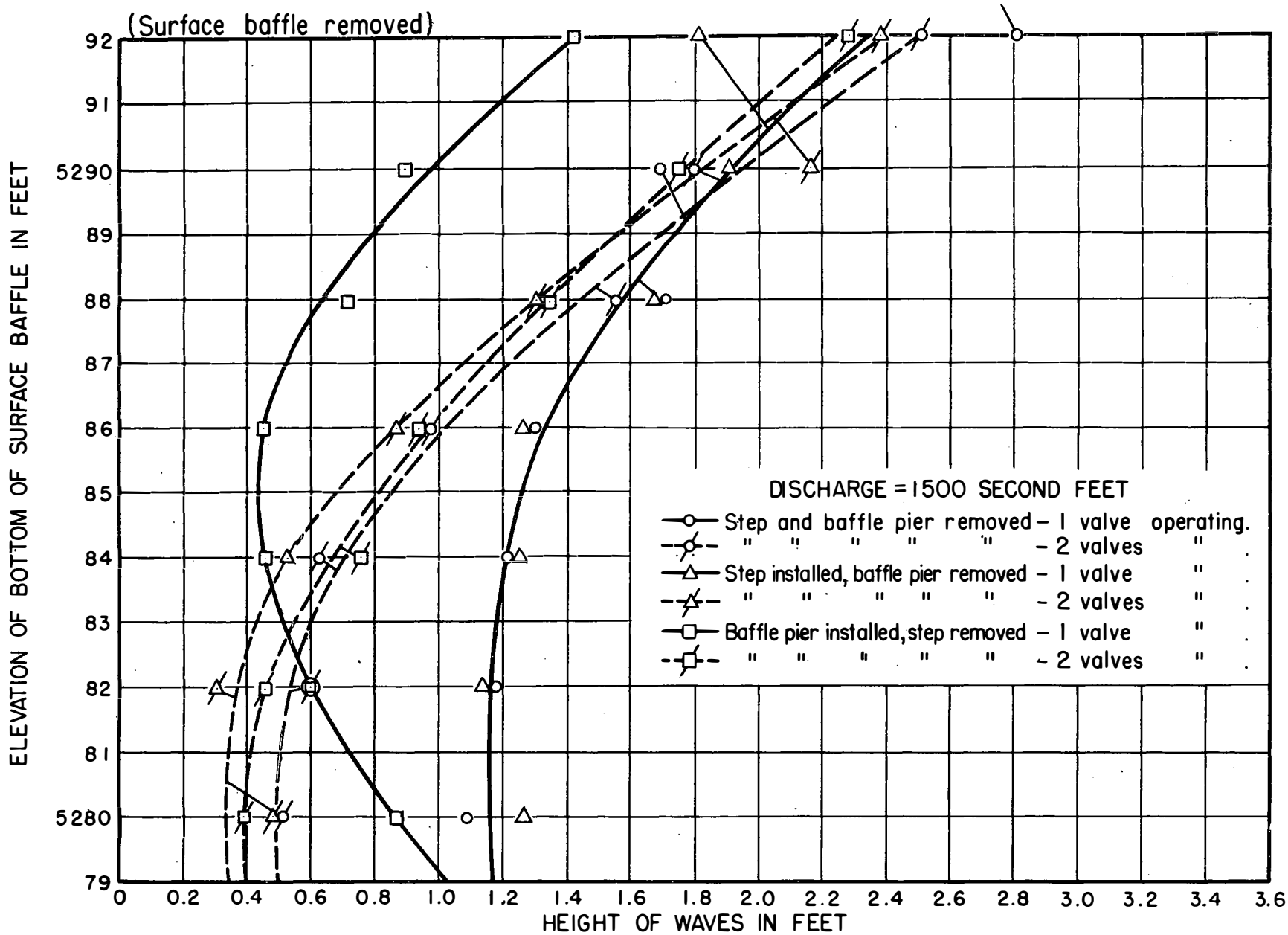
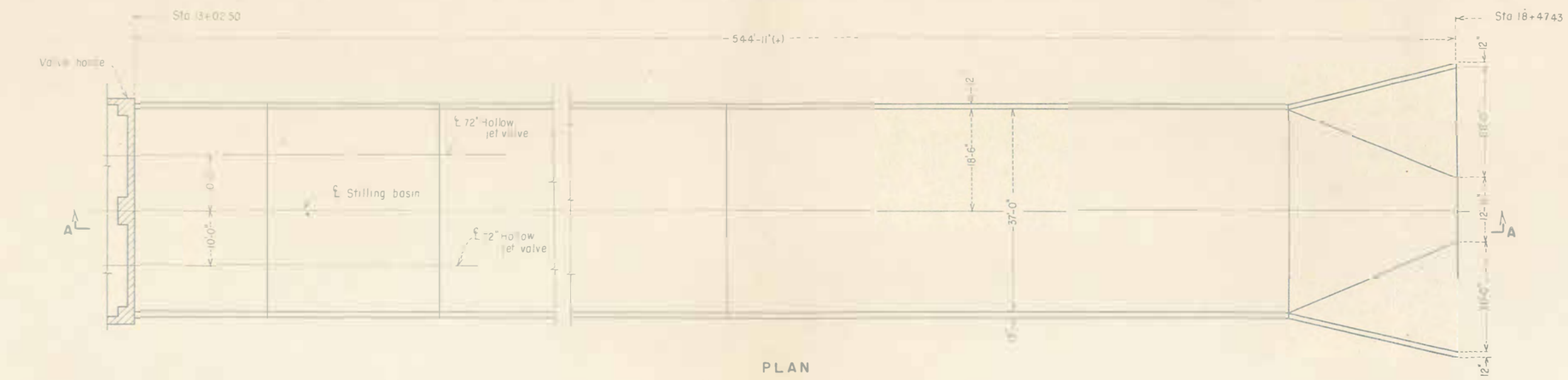


FIGURE 14

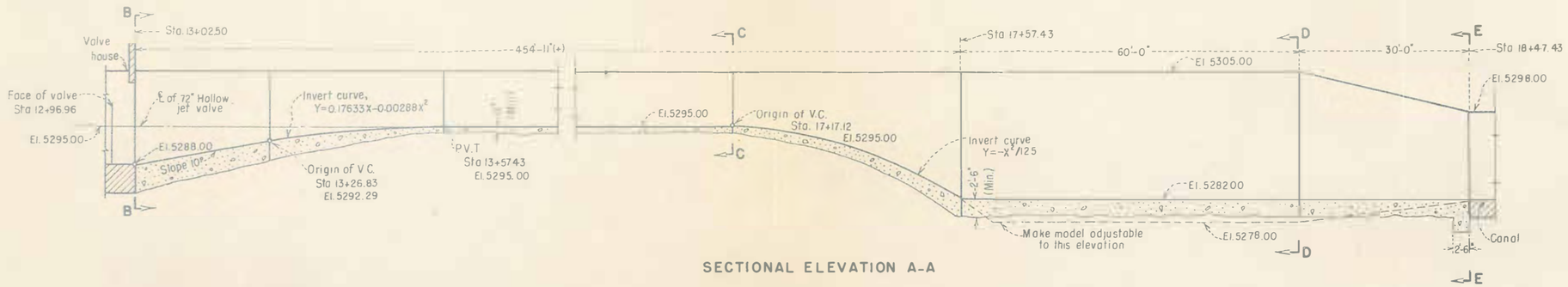
HORSETOOTH DAM – OUTLET WORKS

HEIGHT OF WAVES FOR VARIOUS ELEVATIONS OF BAFFLE

SCHEME A



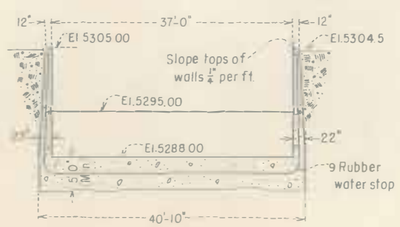
PLAN



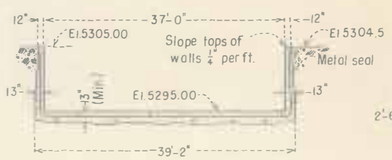
SECTIONAL ELEVATION A-A

NOTE

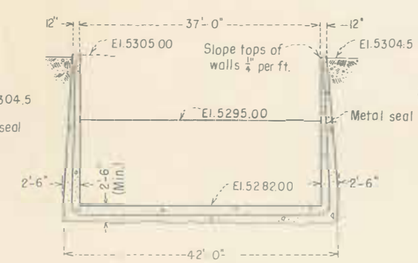
Construction joints not indicated.
All metal seals not shown.



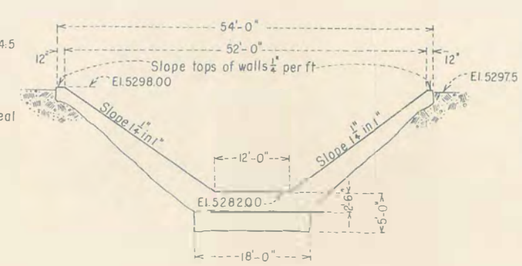
ELEVATION B-B



SECTIONAL ELEVATION C-C

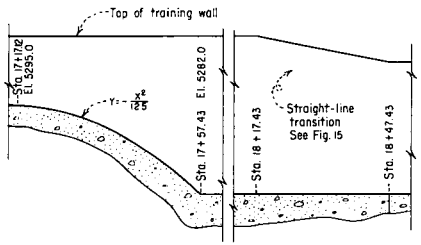


SECTIONAL ELEVATION D-D

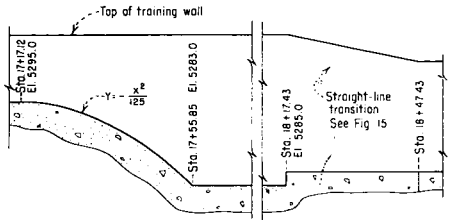


ELEVATION E-E

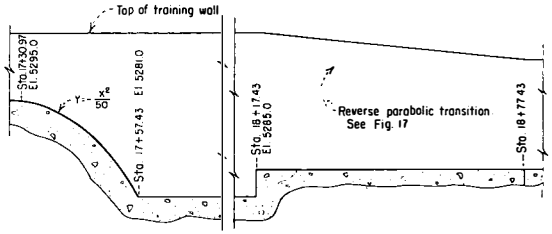
HORSETOOTH DAM
OUTLET WORKS
PRELIMINARY STILLING BASIN
SCHEME B
1:24 SCALE MODEL



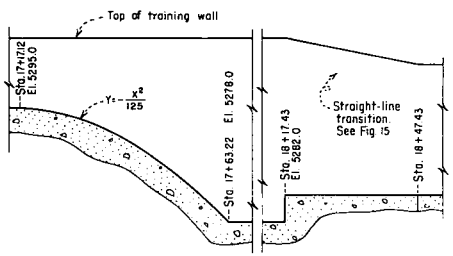
PRELIMINARY BASIN



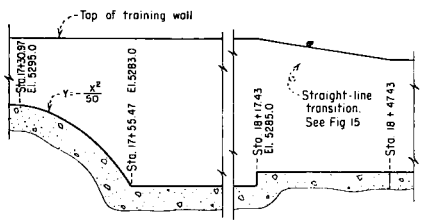
BASIN No. 4



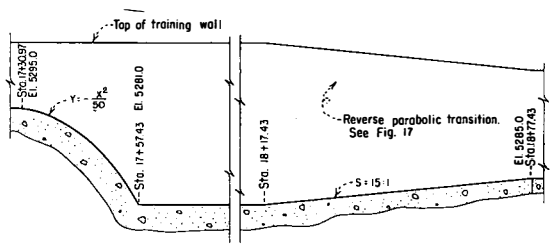
BASIN No. 7 - RECOMMENDED BASIN



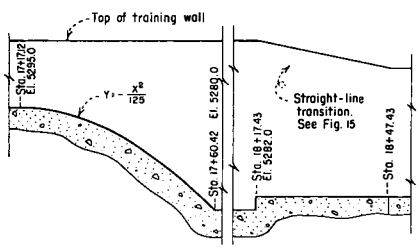
BASIN No. 2



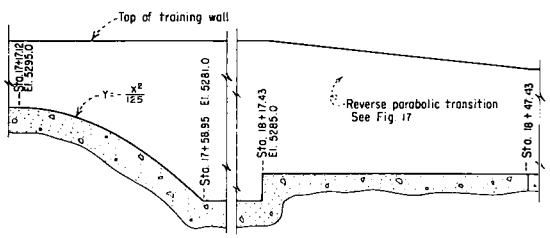
BASIN No. 5'



BASIN No. 8



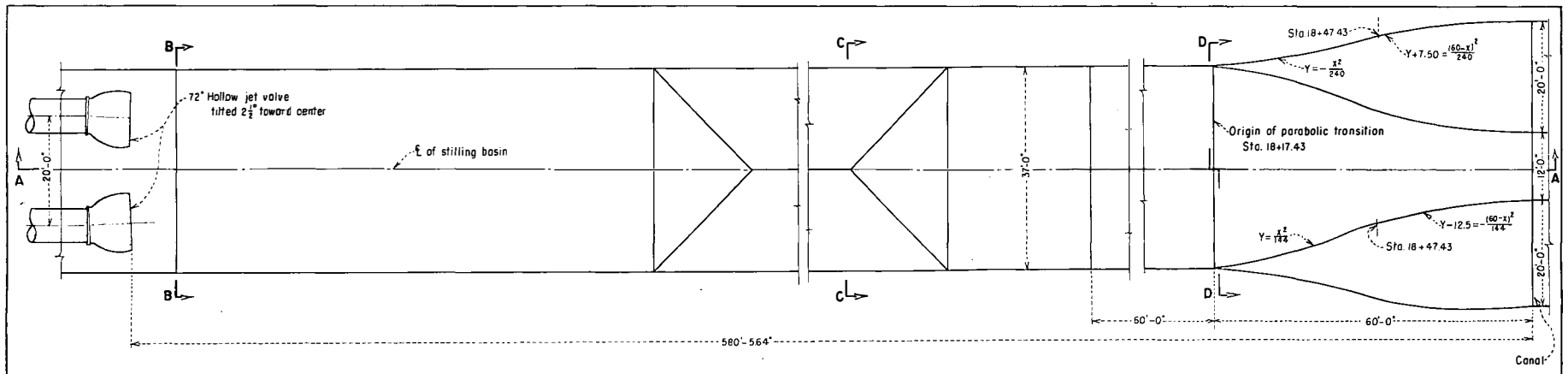
BASIN No. 3



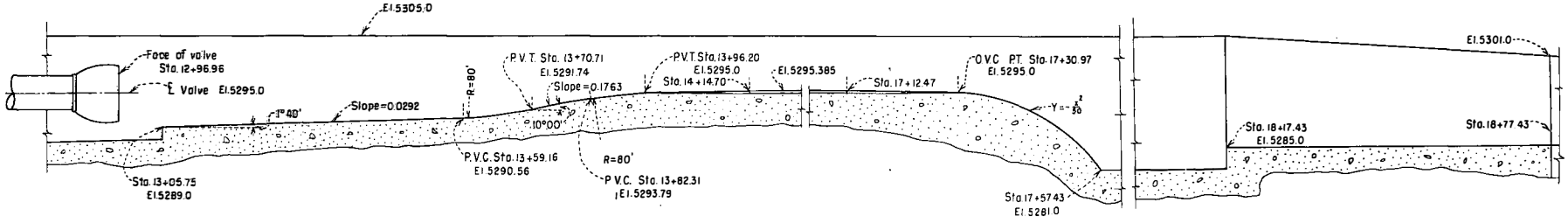
BASIN No. 6

HORSETOOTH DAM
OUTLET WORKS
STILLING BASINS TESTED
SCHEME B
1:24 SCALE MODEL

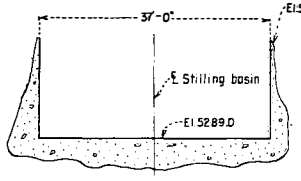
FIGURE 16



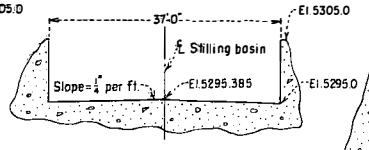
PLAN



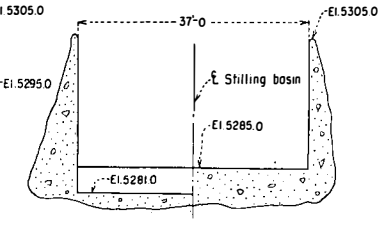
SECTIONAL ELEVATION A-A



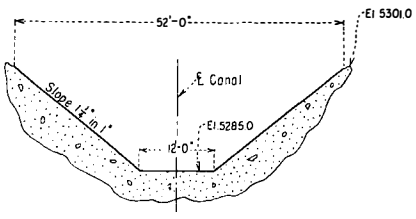
SECTION B-B



SECTION C-C



SECTION D-D

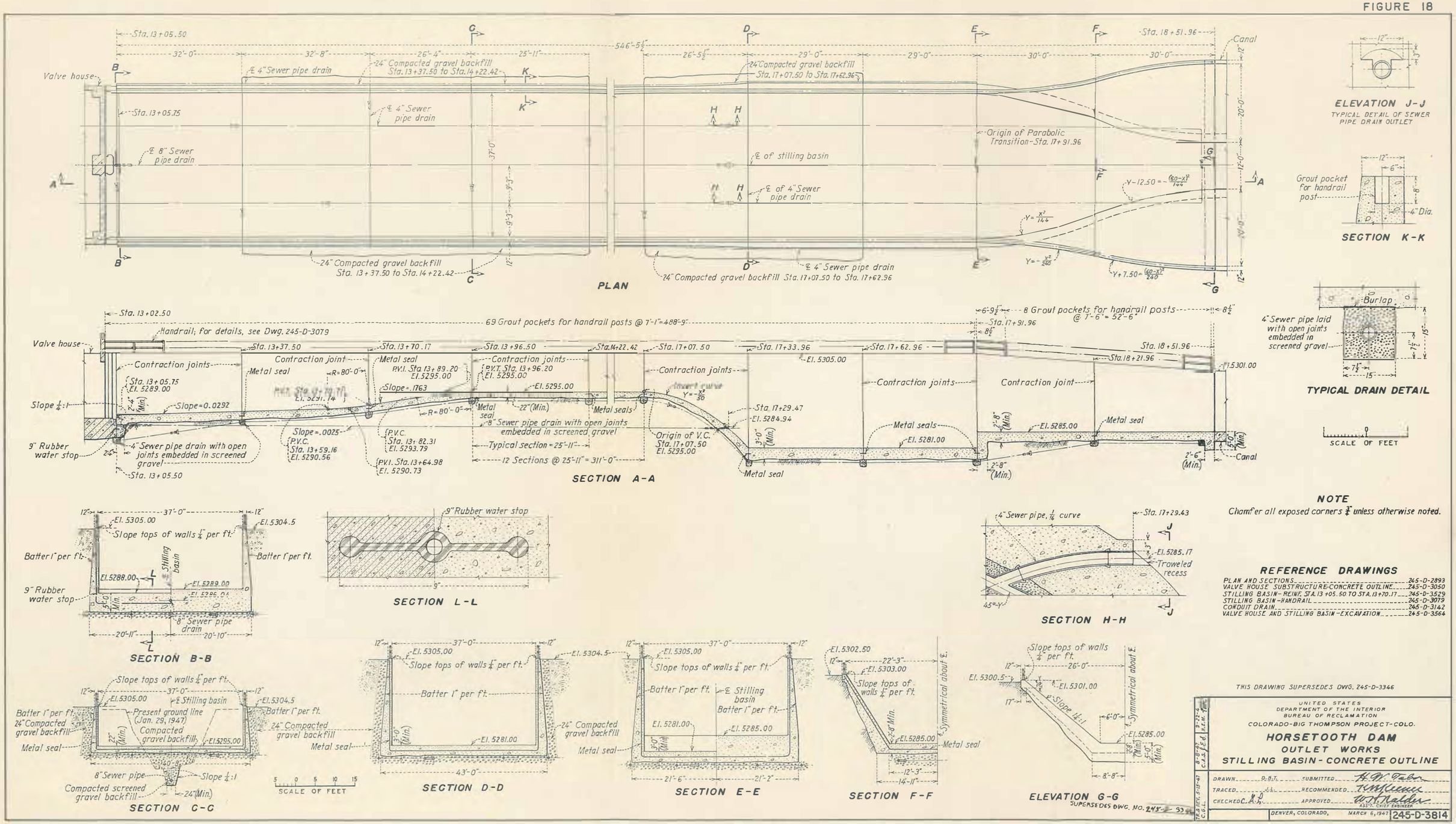


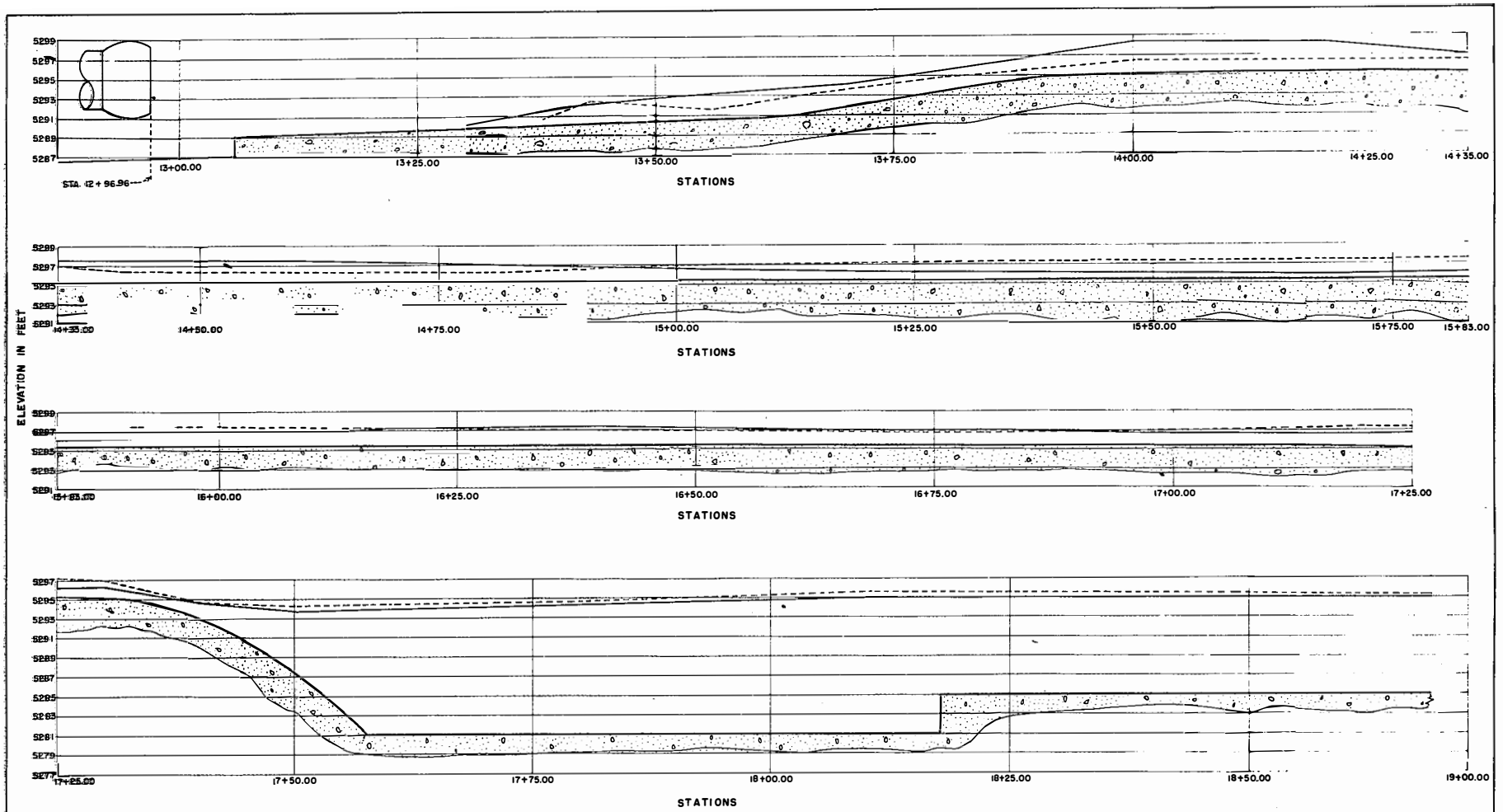
SECTION E-E

5 0 25
SCALE OF FEET

HORSETOOTH DAM
OUTLET WORKS
RECOMMENDED STILLING BASIN
SCHEME B
1:24 SCALE MODEL

FIGURE 17


PLAN
SECTION A-A
ELEVATION J-J
TYPICAL DETAIL OF SEWER PIPE DRAIN OUTLET
SECTION K-K
TYPICAL DRAIN DETAIL
SCALE OF FEET
NOTE
Chamfer all exposed corners 3/4" unless otherwise noted.
REFERENCE DRAWINGS
PLAN AND SECTIONS 245-D-2893
VALVE HOUSE SUBSTRUCTURE-CONCRETE OUTLINE 245-D-3050
STILLING BASIN-REINF. STA. 13+05.50 TO STA. 13+70.17 245-D-3529
STILLING BASIN-HANDRAIL 245-D-3079
CONDUIT DRAIN 245-D-3142
VALVE HOUSE AND STILLING BASIN-EXCAVATION 245-D-3564
SECTION B-B
SECTION L-L
SECTION H-H
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
ELEVATION G-G
SUPERSEDES DWG. NO. 245-D-3346
THIS DRAWING SUPERSEDES DWG. 245-D-3346
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT-COLO.
HORSETOOTH DAM
OUTLET WORKS
STILLING BASIN-CONCRETE OUTLINE
DRAWN D.B.T.
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
ASST. CHIEF ENGINEER
DENVER, COLORADO, MARCH 6, 1947
245-D-3814



EXPLANATION

Along ℄ of chute

Along left and right training walls

SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

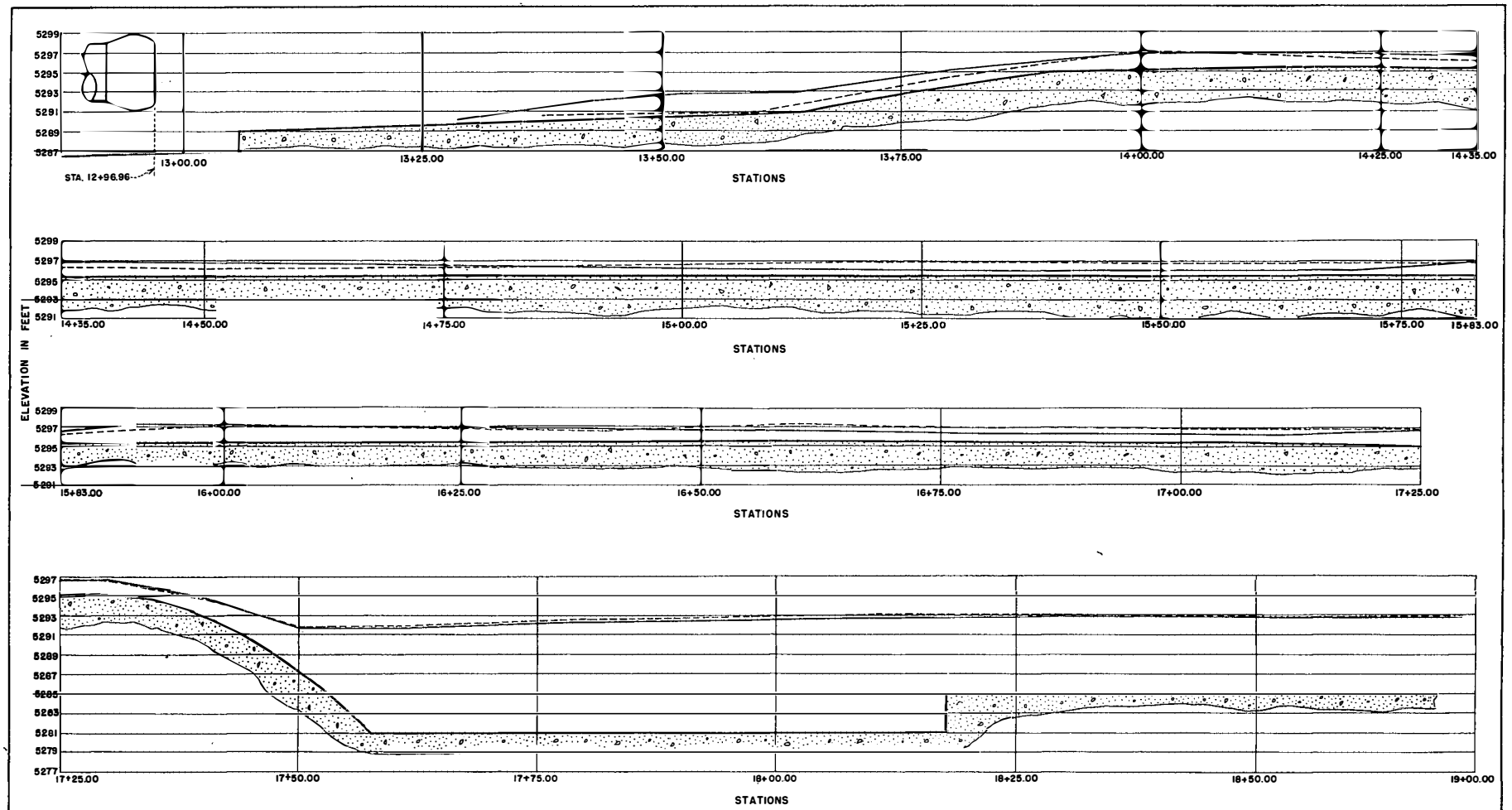
DISCHARGE - 1500 c.f.s. THROUGH TWO VALVES

RESERVOIR ELEVATION - 5430

1:24 SCALE MODEL

SCHEME B

FIGURE 19



EXPLANATION

——— Along ℄ of chute

- - - - - Along left and right training walls.

1 0 5 10 15
SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

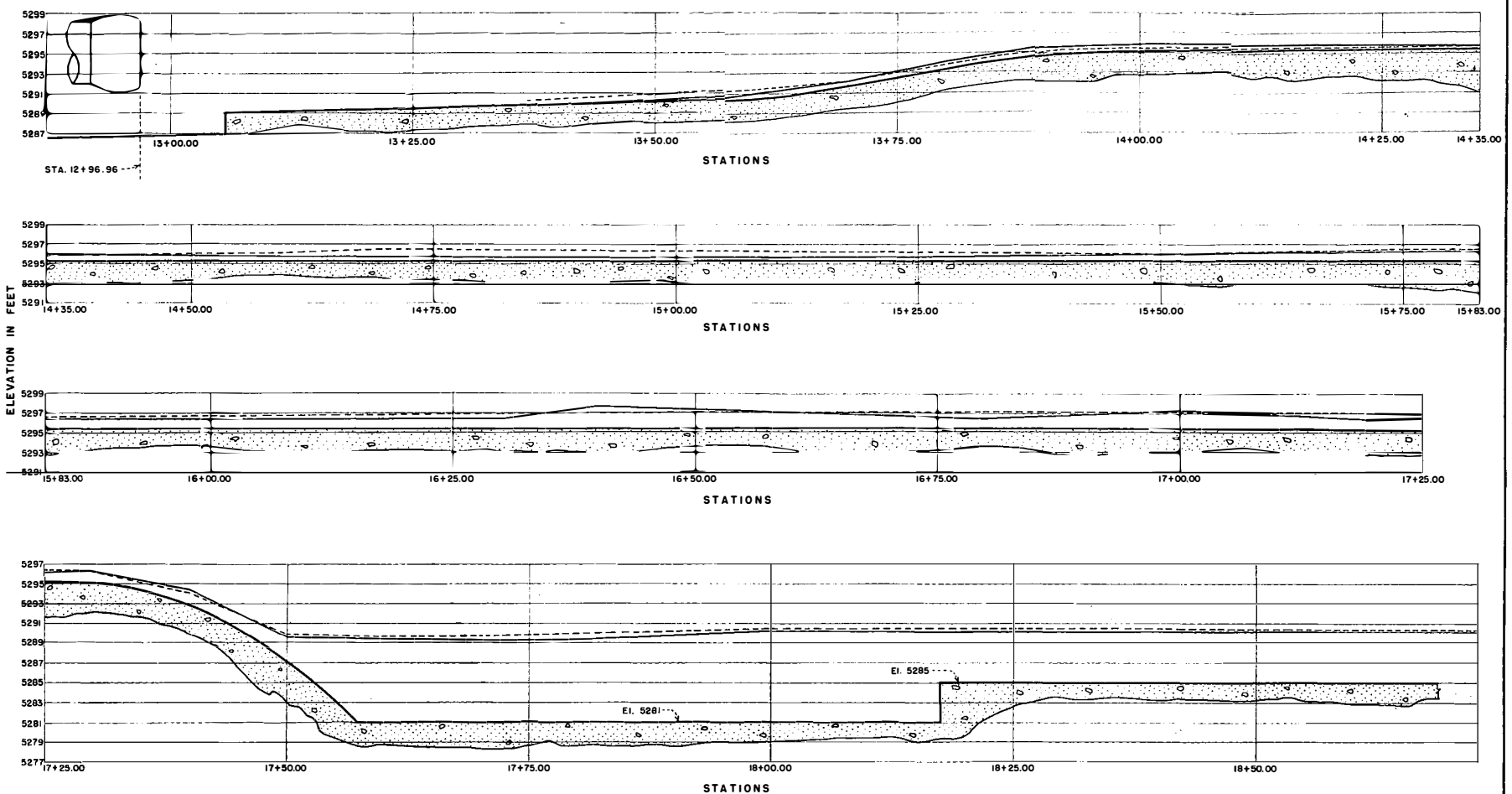
DISCHARGE – 1000 c.f.s. THROUGH TWO VALVES

RESERVOIR ELEVATION – 5430

1:24 SCALE MODEL

SCHEME B

FIGURE 20



EXPLANATION

——— Along ℄ of chute.

- - - - - Along right and left training walls.

1 0 5 10 15
SCALE OF FEET

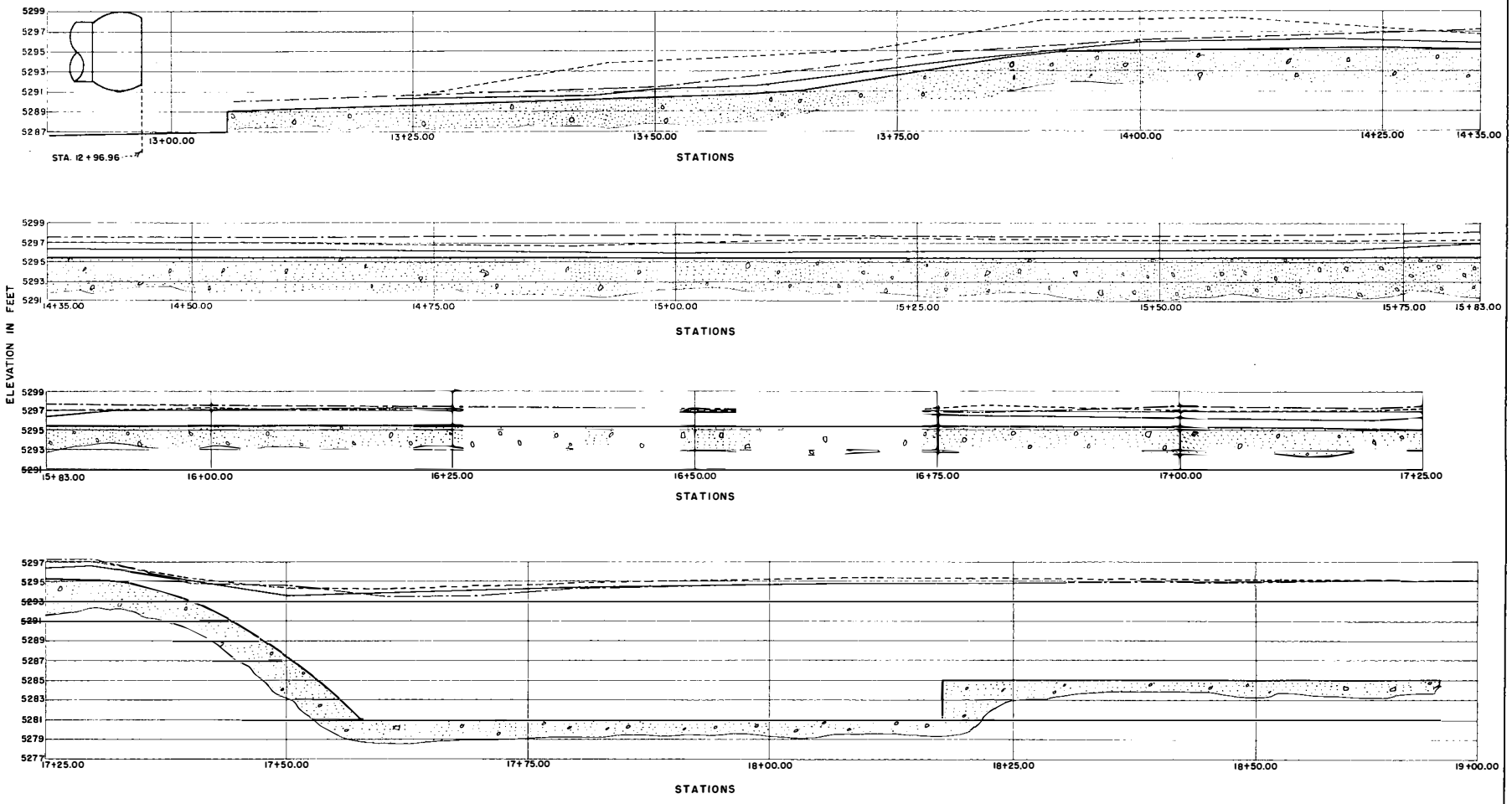
HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

DISCHARGE - 500 c.f.s. THROUGH TWO VALVES
RESERVOIR ELEVATION - 5430
1:24 SCALE MODEL
SCHEME B

FIGURE 21



EXPLANATION

- Along ℄ of chute
- At right training wall
- At left training wall

1 0 5 10 15
SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

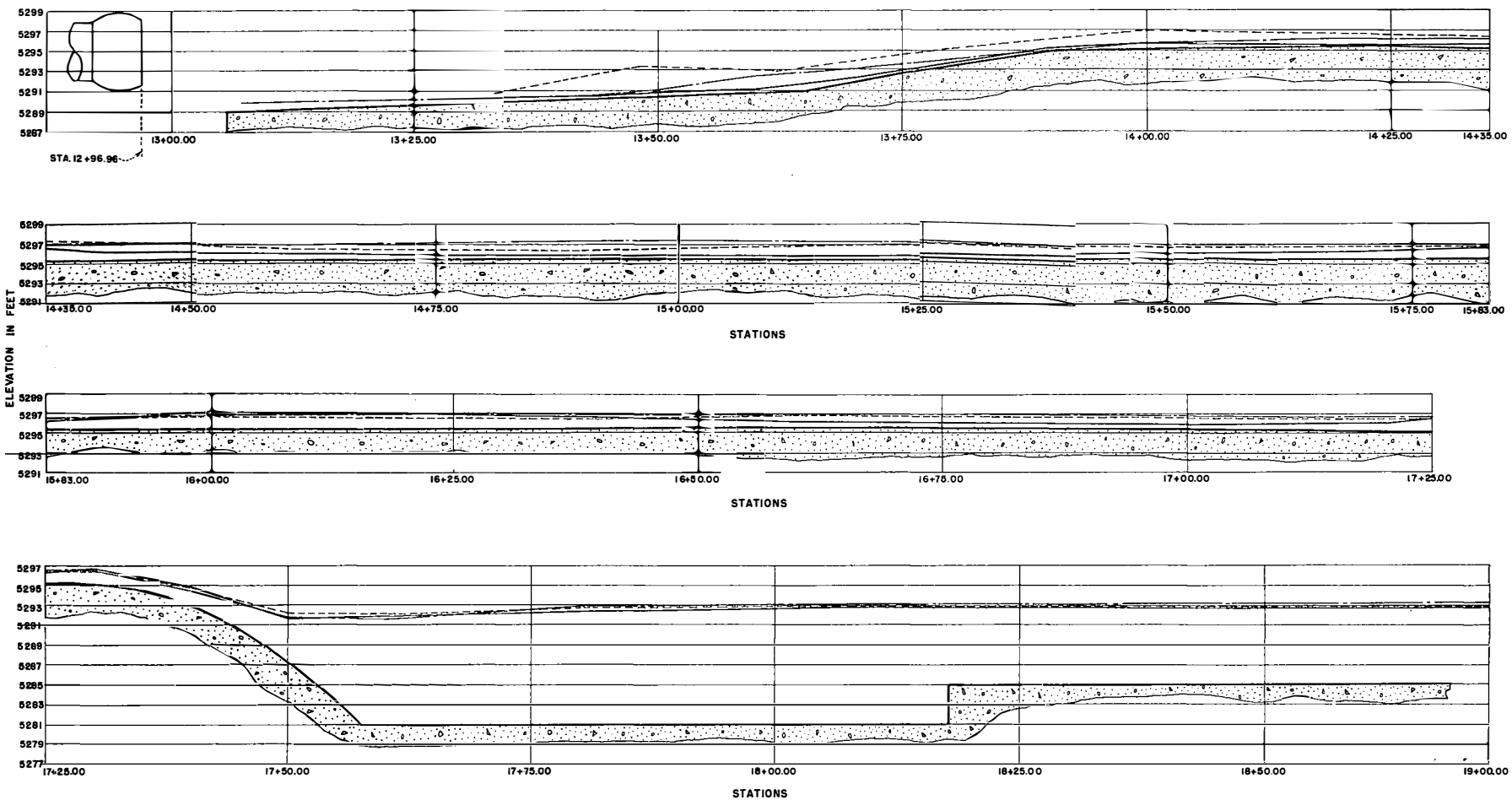
DISCHARGE - 1500 c.f.s. THROUGH RIGHT VALVE

RESERVOIR ELEVATION - 5430

1:24 SCALE MODEL

SCHEME B

FIGURE 22



EXPLANATION

Along ℄ of chute.

At right training wall.

At left training wall.

1 0 5 10 15

SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

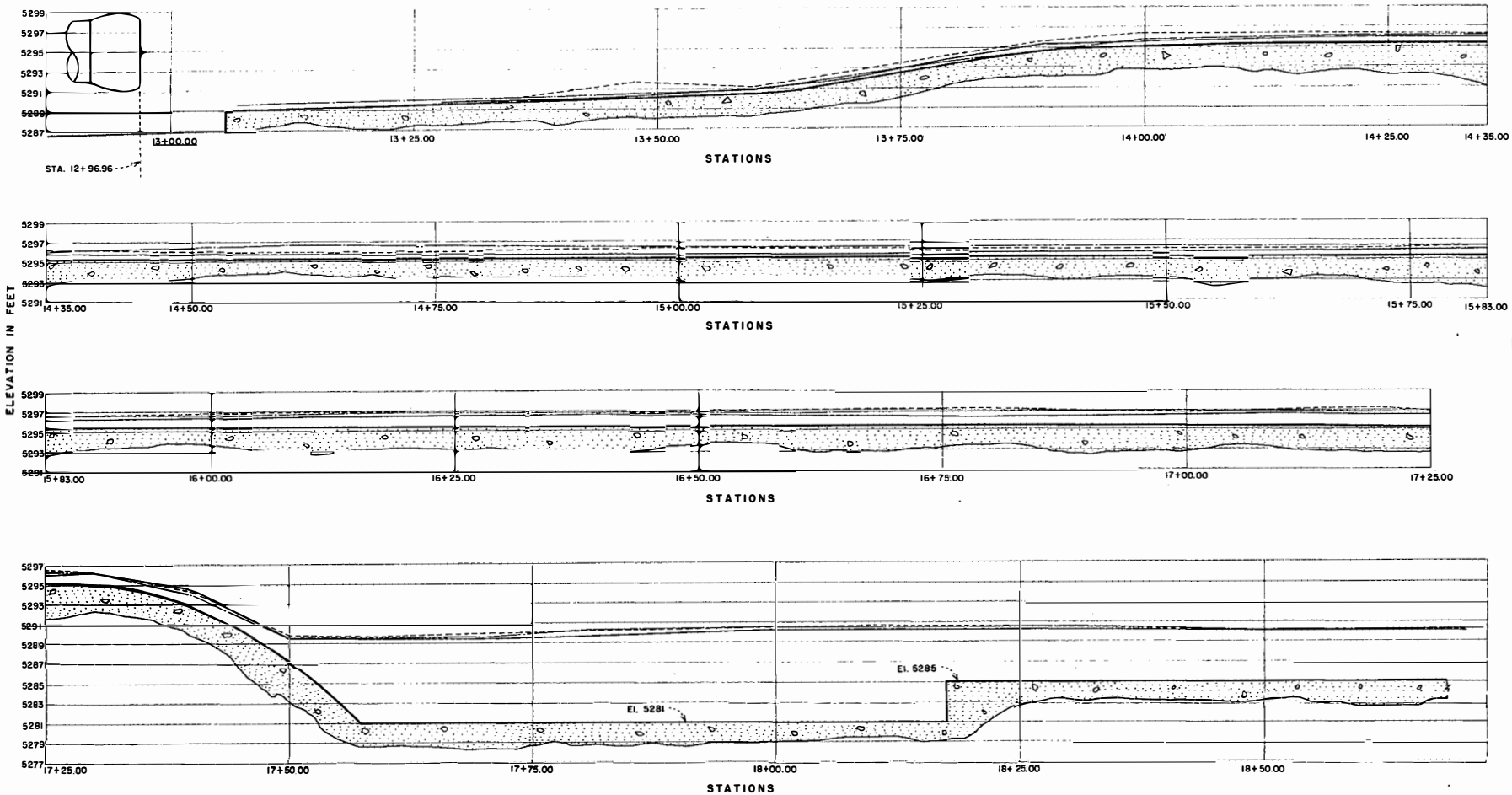
DISCHARGE – 1000 c.f.s. THROUGH RIGHT VALVE

RESERVOIR ELEVATION – 5430

1:24 SCALE MODEL

SCHEME B

FIGURE 23



EXPLANATION

- Along ℄ of chute.
- At right training wall.
- At left training wall.

1 0 5 10 15
SCALE OF FEET

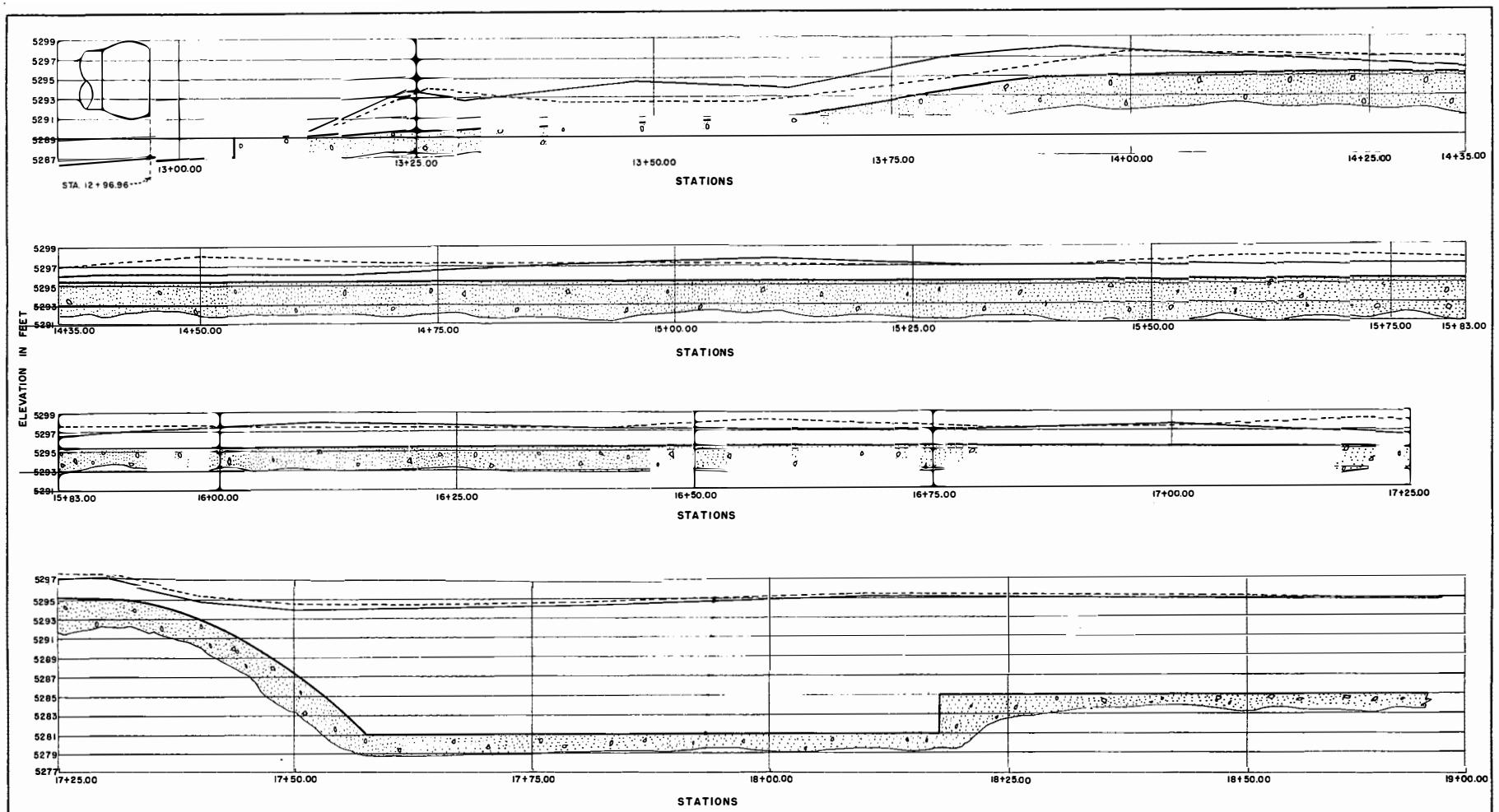
HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

DISCHARGE - 500 c.f.s. THROUGH RIGHT VALVE
RESERVOIR ELEVATION - 5430
1:24 SCALE MODEL
SCHEME B

FIGURE 24



EXPLANATION

Along ℄ of chute

Along left and right training walls

0 5 10 15
SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

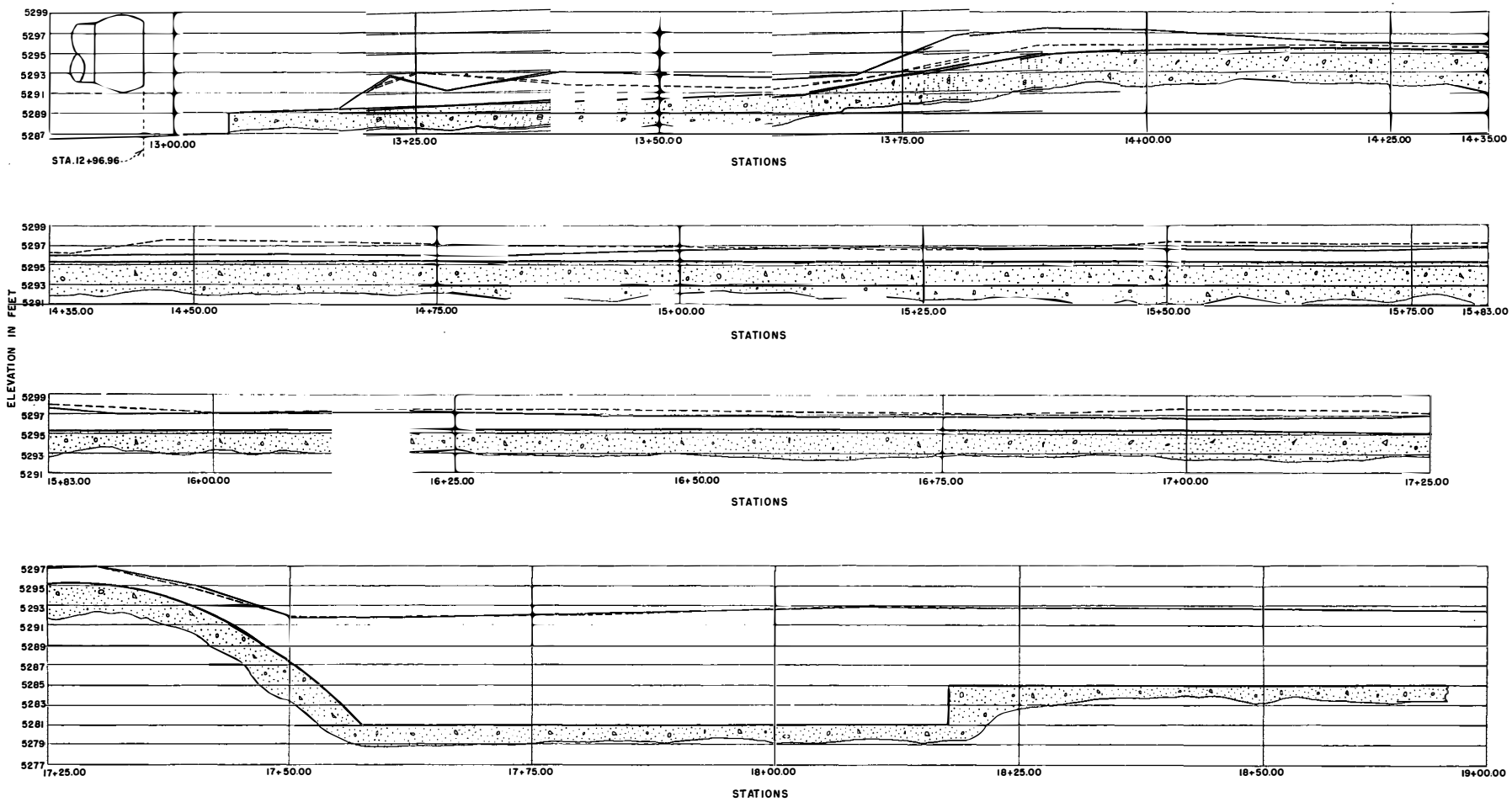
DISCHARGE - 1500 c.f.s. THROUGH TWO VALVES

RESERVOIR ELEVATION - 5340

1:24 SCALE MODEL

SCHEME B

FIGURE 25



EXPLANATION

——— Along ℄ of chute.

- - - - - Along left and right training walls.

1 0 5 10 15
SCALE OF FEET

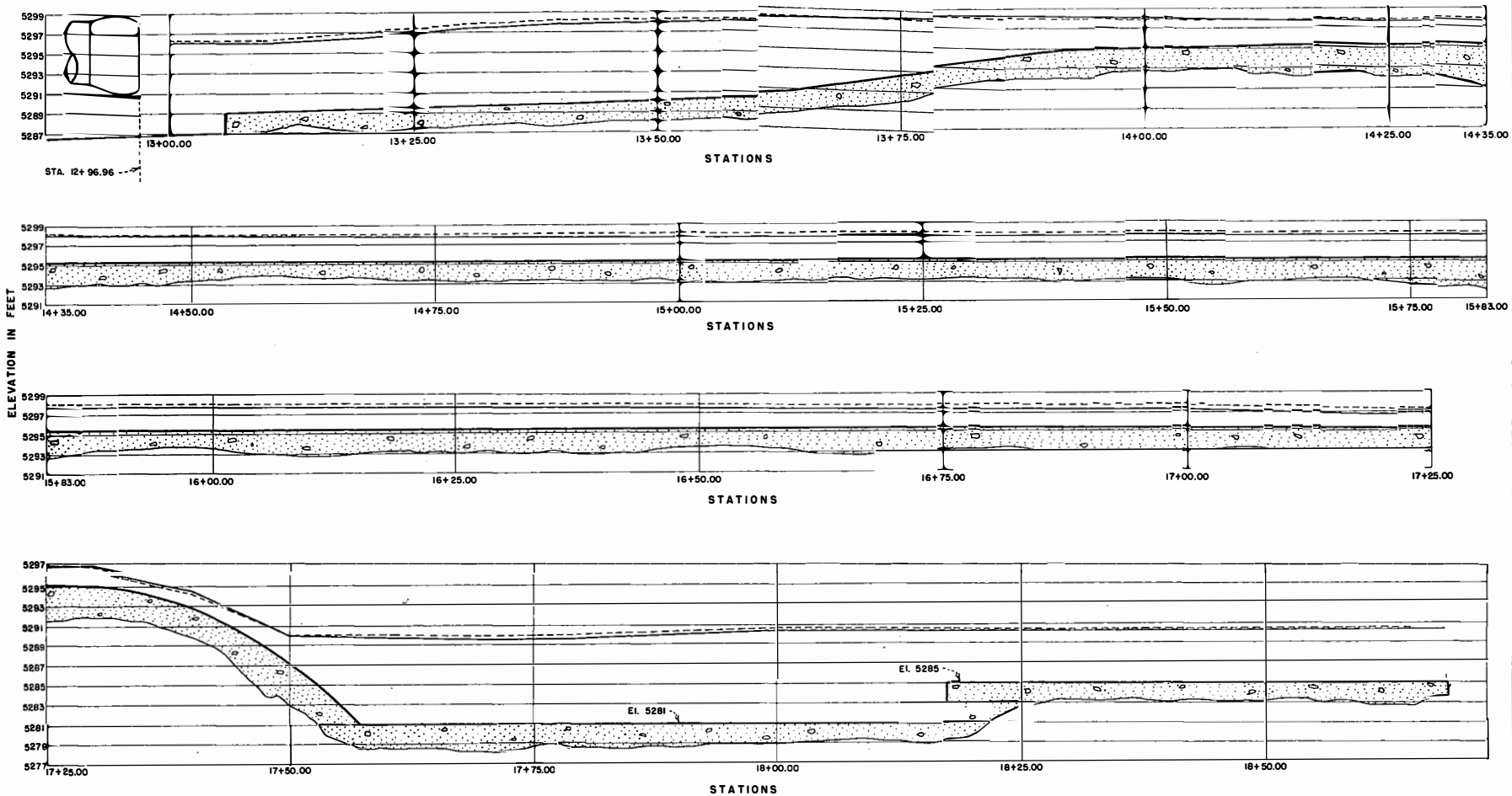
HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

DISCHARGE – 1000 c.f.s. THROUGH TWO VALVES
RESERVOIR ELEVATION – 5340
1:24 SCALE MODEL
SCHEME B

FIGURE 26



EXPLANATION

——— Along ℄ of chute.

- - - - - Along right and left training walls.

1 0 5 10 15

SCALE OF FEET

HORSETOOTH DAM

OUTLET WORKS

WATER SURFACE PROFILES

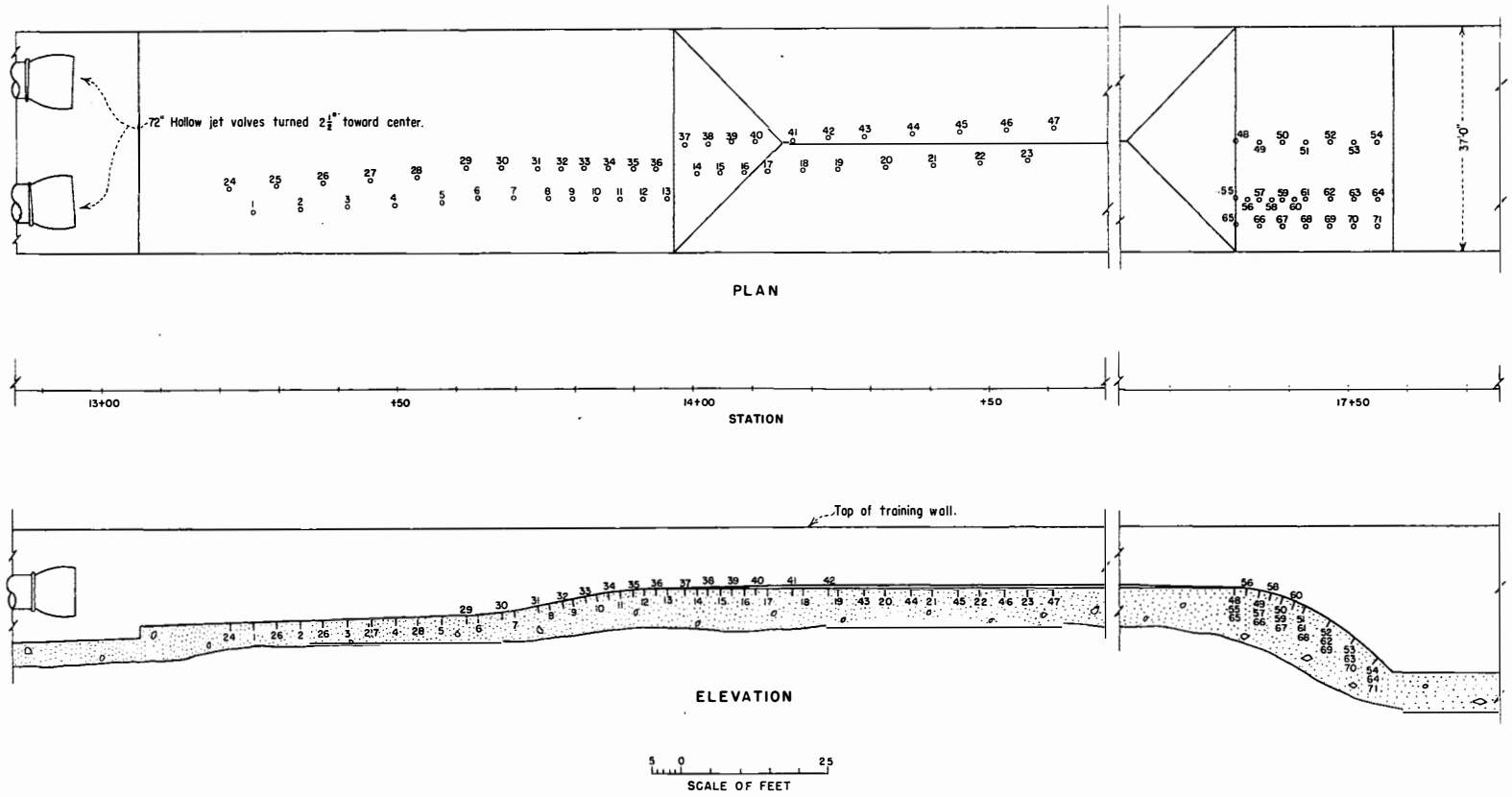
DISCHARGE - 500 c.f.s. THROUGH TWO VALVES

RESERVOIR ELEVATION - 5340

1:24 SCALE MODEL

SCHEME B

FIGURE 27



HORSETOOTH DAM

OUTLET WORKS

LOCATION OF PIEZOMETERS

1:24 SCALE MODEL

SCHEME B

FIGURE 28

HORSETOOTH DAM

OUTLET WORKS

TABULATION OF PIEZOMETRIC PRESSURES IN FEET OF WATER PROTOTYPE

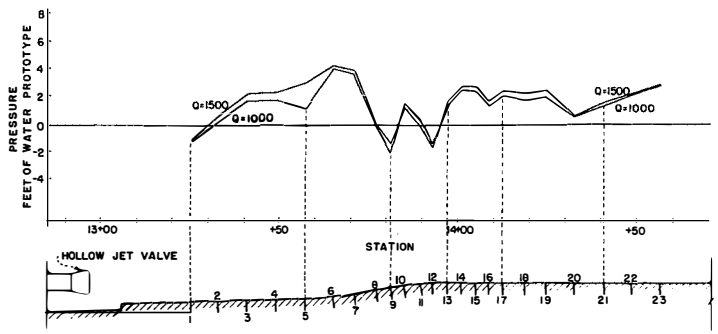
1:24 SCALE MODEL

SCHEME B

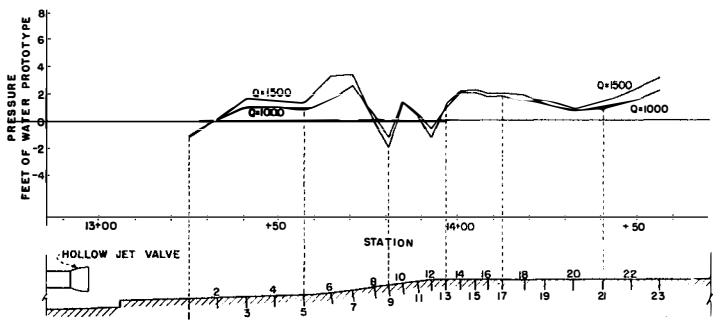
PIEZO-METER NUMBER	RESERVOIR ELEVATION 5430				RESERVOIR ELEVATION 5340	
	RIGHT VALVE Q=1500	BOTH VALVES Q=1500	RIGHT VALVE Q=1000	BOTH VALVES Q=1000	BOTH VALVES Q=1500	BOTH VALVES Q=1000
1	-1.08	-1.25	-1.20	-1.15	-0.55	-1.32
2	0.72	0.12	0.24	0.12	3.96	1.92
3	2.21	1.68	1.63	1.08	1.80	2.11
4	2.23	1.61	1.80	1.08	1.80	1.61
5	2.95	1.32	1.20	0.79	1.80	1.20
6	4.20	3.24	3.96	1.56	2.88	2.71
7	3.84	3.36	3.60	2.59	2.11	1.63
8	0	-0.12	-0.12	0.31	0.36	0.12
9	-1.44	-1.97	-2.16	-1.25	-0.36	-0.84
10	1.20	1.32	1.56	1.32	0.84	0.60
11	0	0.36	0.48	0.48	0.48	0.36
12	-1.80	-1.32	-1.44	-0.65	0.12	0.12
13	1.68	1.20	1.39	0.96	1.20	0.77
14	2.76	2.16	2.52	2.04	1.56	1.13
15	2.76	2.21	2.40	2.04	1.87	1.44
16	1.68	1.73	1.37	1.97	0.72	1.53
17	2.40	1.97	2.04	1.80	1.44	1.32
18	2.28	1.87	1.73	1.32	1.32	1.15
19	2.45	2.16	1.97	1.44	1.32	1.15
20	0.60	0.87	0.56	0.68	0.60	0.48
21	1.56	1.32	1.32	0.84	0.96	0.89
22	2.21	2.11	2.11	1.32	1.01	0.96
23	2.83	3.12	2.69	2.11	1.20	1.08
24	4.08	0.41	0.96	0.96	-1.08	-1.08
25	5.16	4.32	6.17	2.76	2.88	1.92
26	1.80	2.40	2.40	2.28	2.04	2.16
27	-0.12	-0.60	-0.53	-0.24	-0.24	-0.29
28	4.44	2.11	1.97	0.91	0.67	0.48
29	-2.28	-1.44	-1.63	-1.25	2.40	1.25
30	-1.80	-1.00	-1.96	-1.60	3.12	1.15
31	1.56	2.16	1.80	1.27	2.04	1.37
32	4.87	4.16	4.80	2.42	2.47	2.47
33	1.80	1.56	1.80	1.08	2.04	1.99
34	3.36	2.52	2.93	1.56	2.16	1.80
35	0.60	0.48	0.65	0.48	1.32	1.27
36	0.96	0.84	1.20	0.72	1.75	1.68

PIEZO-METER NUMBER	RESERVOIR ELEVATION 5430				RESERVOIR ELEVATION 5340	
	RIGHT VALVE Q=1500	BOTH VALVES Q=1500	RIGHT VALVE Q=1000	BOTH VALVES Q=1000	BOTH VALVES Q=1500	BOTH VALVES Q=1000
37	2.04	1.44	1.80	1.32	2.40	2.16
38	1.92	1.44	1.44	1.32	2.40	2.16
39	1.20	1.08	0.84	1.20	1.92	1.68
40	1.87	1.68	1.25	1.80	1.92	1.56
41	1.73	1.92	1.01	1.73	1.56	1.20
42	1.73	2.40	1.01	1.80	1.32	1.08
43	1.49	2.40	0.96	1.68	1.20	0.96
44	0.48	1.44	0.48	0.96	0.84	0.72
45	1.37	1.80	1.20	1.32	0.84	0.72
46	2.24	2.57	2.04	1.92	0.96	0.84
47	3.84	4.08	3.48	2.88	1.44	1.15
48	0.12	0.12	0.91	0.96	1.20	1.39
49	-0.12	-0.05	0.75	0.80	1.79	1.08
50	0	0	0.48	0.60	0.72	0.96
51	0.12	0.24	0.36	0.48	0.84	0.72
52	2.57	3.00	2.04	1.92	3.36	2.16
53	5.95	6.05	5.04	5.08	6.60	5.31
54	10.50	9.78	9.00	9.00	11.40	9.41
55	0.48	0.48	0.72	0.84	1.56	1.44
56	0.36	0.36	0.60	0.84	1.37	1.32
57	0.24	0.36	0.72	0.84	1.32	1.39
58	0.24	0.24	0.53	0.72	1.15	1.20
59	0	0	0.41	0.60	0.72	0.84
60	-0.24	-0.24	0.24	0.43	0.72	0.72
61	0.19	0.24	0.48	0.67	1.20	0.84
62	1.87	2.16	1.68	1.92	3.12	2.11
63	5.51	5.88	4.92	5.04	6.60	5.28
64	10.50	10.38	9.12	9.00	11.17	9.07
65	1.03	1.08	1.08	1.20	2.16	1.68
66	0.12	0.41	0.70	0.94	1.27	1.08
67	0.24	0.29	0.60	0.72	1.08	0.96
68	0.48	0.60	0.72	0.72	1.39	0.96
69	2.47	2.76	2.04	2.28	3.53	2.16
70	6.12	6.12	5.16	5.40	6.84	5.40
71	10.05	10.08	8.88	8.88	10.75	9.00

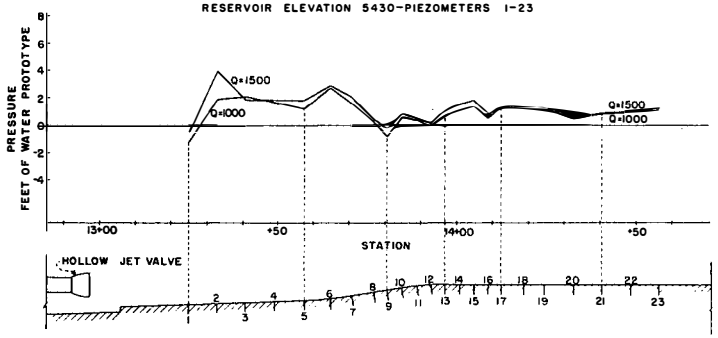
FIGURE 29



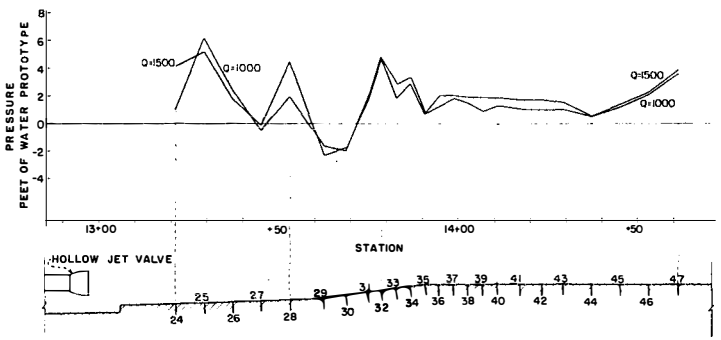
RIGHT VALVE OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 1-23



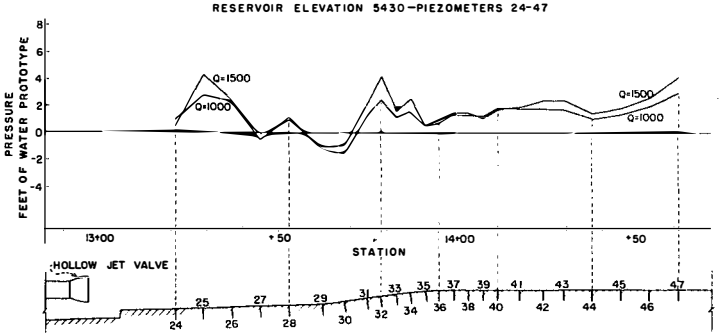
BOTH VALVES OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 1-23



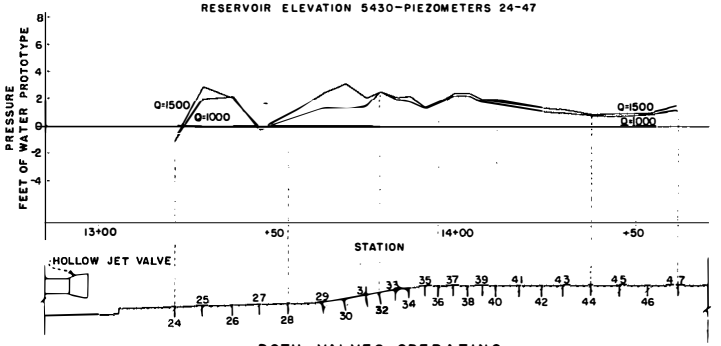
BOTH VALVES OPERATING
RESERVOIR ELEVATION 5340—PIEZOMETERS 1-23



RIGHT VALVE OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 24-47



BOTH VALVES OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 24-47

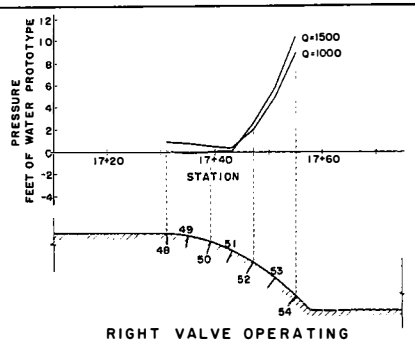


BOTH VALVES OPERATING
RESERVOIR ELEVATION 5340—PIEZOMETERS 24-47

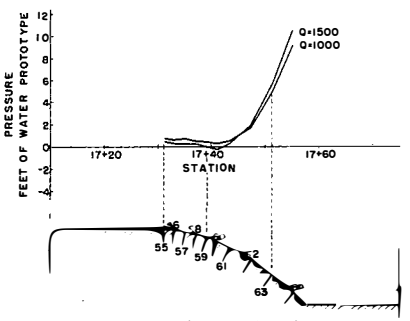
0 2 4 6 8 VERTICAL
0 10 20 30 HORIZONTAL
SCALES
PRESSURE DIAGRAMS

HORSETOOTH DAM
OUTLET WORKS
PIEZOMETRIC PRESSURES
ALONG INVERT BELOW VALVES
1:24 SCALE MODEL
SCHEME B

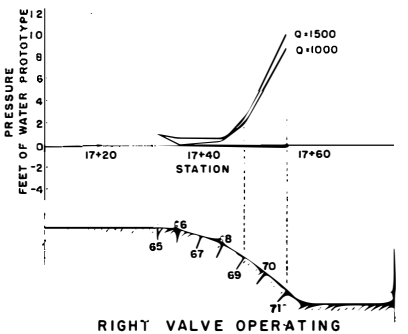
FIGURE 30



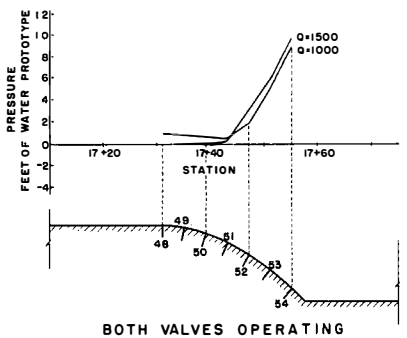
RIGHT VALVE OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 48-54



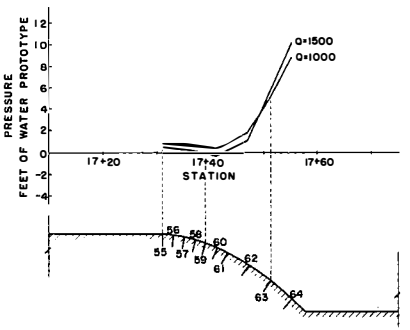
RIGHT VALVE OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 55-64



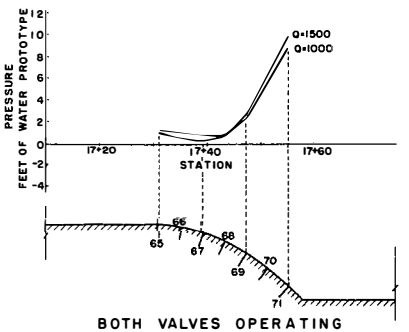
RIGHT VALVE OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 65-71



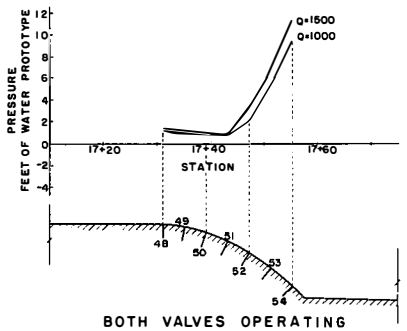
BOTH VALVES OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 48-54



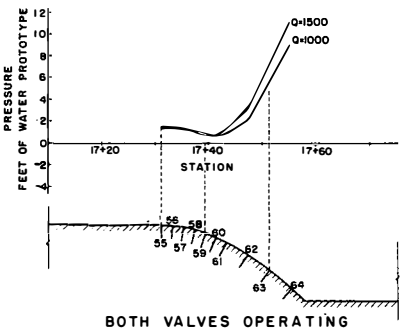
BOTH VALVES OPERATING
RESERVOIR ELEVATION 5430—PIEZOMETERS 55-64



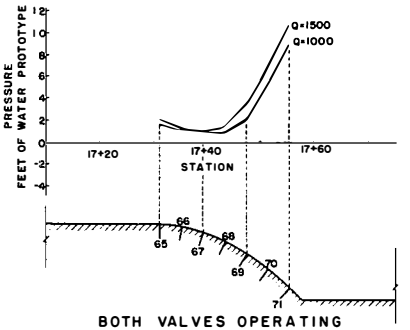
BOTH VALVES OPERATING
RESERVOIR ELEVATION 5430-PIEZOMETERS 65-71



BOTH VALVES OPERATING
RESERVOIR ELEVATION 5340—PIEZOMETERS 48-54



BOTH VALVES OPERATING
RESERVOIR ELEVATION 5340-PIEZOMETERS 55-64



BOTH VALVES OPERATING
RESERVOIR ELEVATION 5340-PIEZOMETERS 65-71

0 2 4 6 8 10 VERTICAL
0 5 10 15 20 HORIZONTAL
SCALES
PRESSURE DIAGRAMS

HORSETOOTH DAM
OUTLET WORKS
PIEZOMETRIC PRESSURES
ALONG PARABOLIC CURVE AT STILLING BASIN
1:24 SCALE MODEL
SCHEME B

FIGURE 31

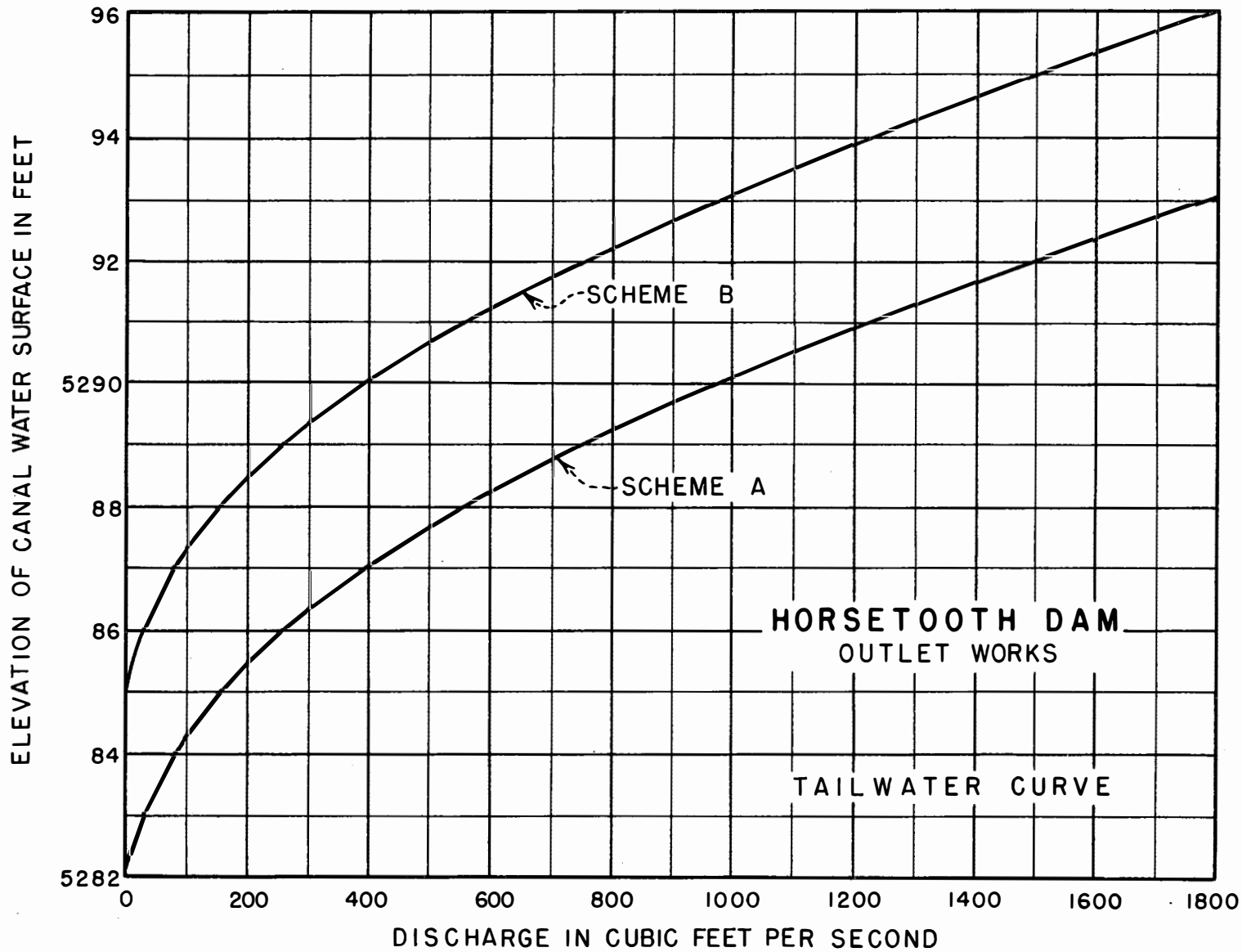
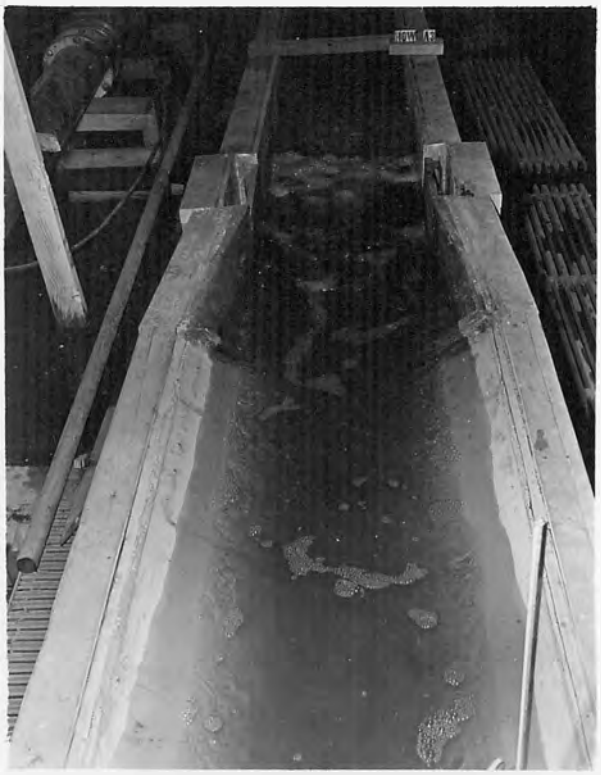
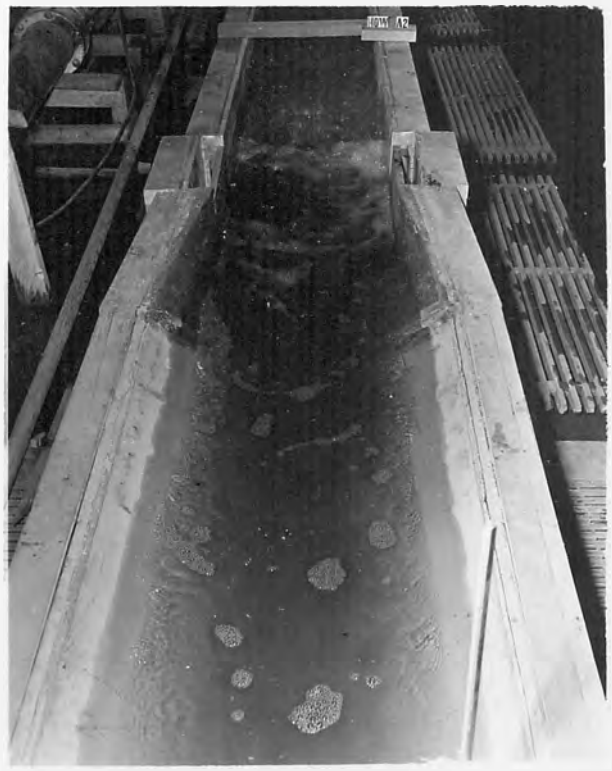

96
94
92
5290
88
86
84
5282
0
200
400
600
800
1000
1200
1400
1600
1800
ELEVATION OF CANAL WATER SURFACE IN FEET
DISCHARGE IN CUBIC FEET PER SECOND
SCHEME B
SCHEME A
HORSETOOTH DAM
OUTLET WORKS
TAILWATER CURVE

FIGURE 32

A. Flow at valve



B. Stilling-pool operation
Both valves operating

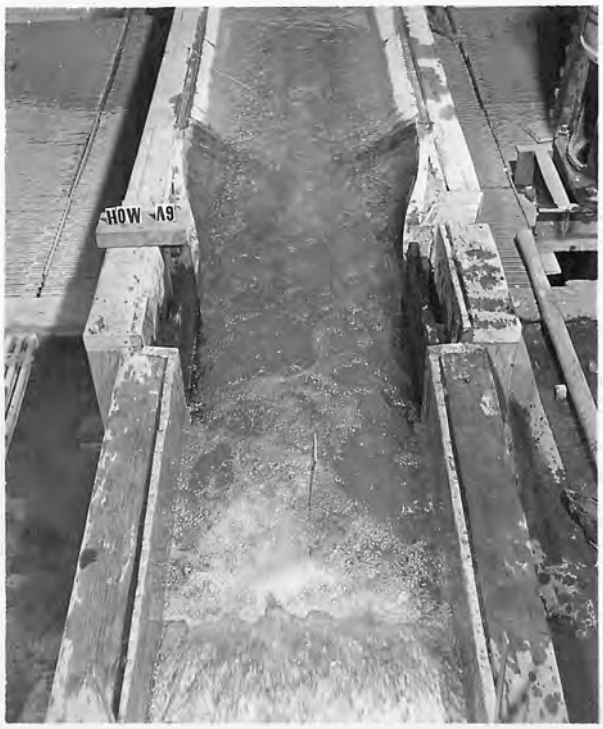


C. Stilling-pool operation
Left valve operating

HORSETOOTH DAM OUTLET WORKS
Preliminary Design
Discharge = 1500 second-feet
1:24 Scale Model
SCHEME B

A. Basin No. 6 with basin floor at Elev. 5281'.

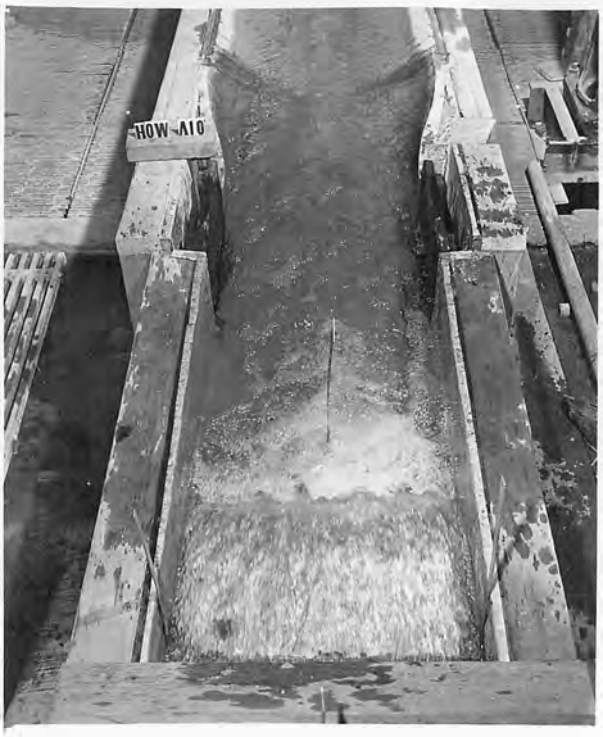
B. Basin No. 6 with basin floor at Elev. 5283'.



C. Basin No. 7 with basin floor at Elev. 5281'.

D. Basin No. 7 with basin floor at Elev. 5283'.

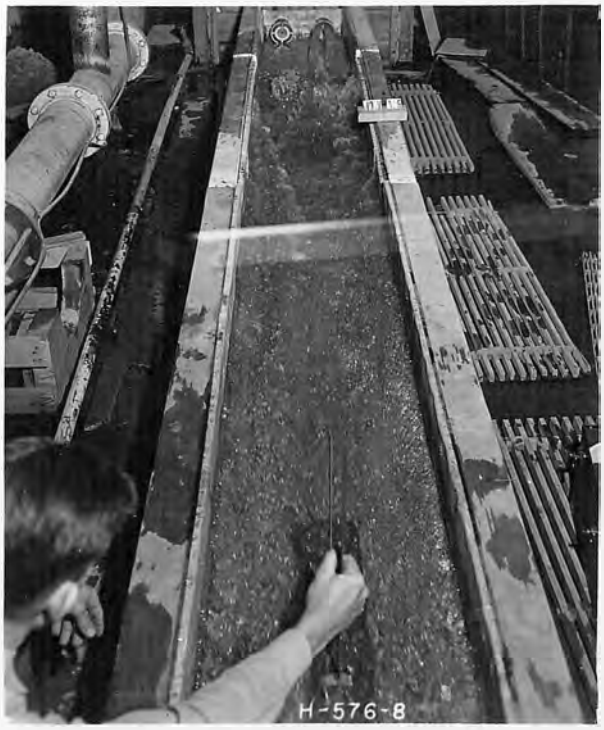
HORSETOOTH DAM OUTLET WORKS
Stilling-pool operation--Basin Nos. 6 and 7
Discharge = 1500 second-feet through left valve
1:24 Scale Model
SCHEME B



A. Basin No. 7. (Steep parabolic curve installed)

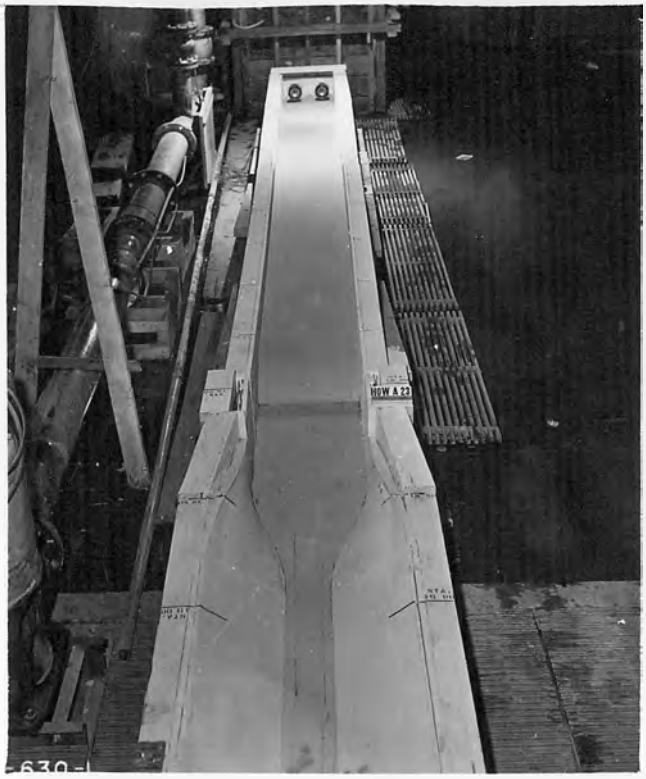
B. Basin No. 6 (Mild parabolic curve installed)

C. Basin No. 6 with Basin floor at Elev. 5283'.

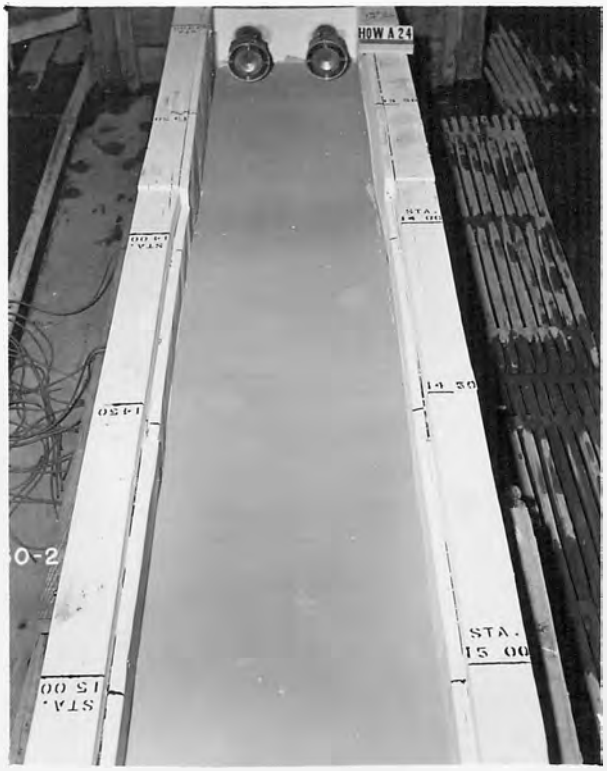


D. Flow in chute

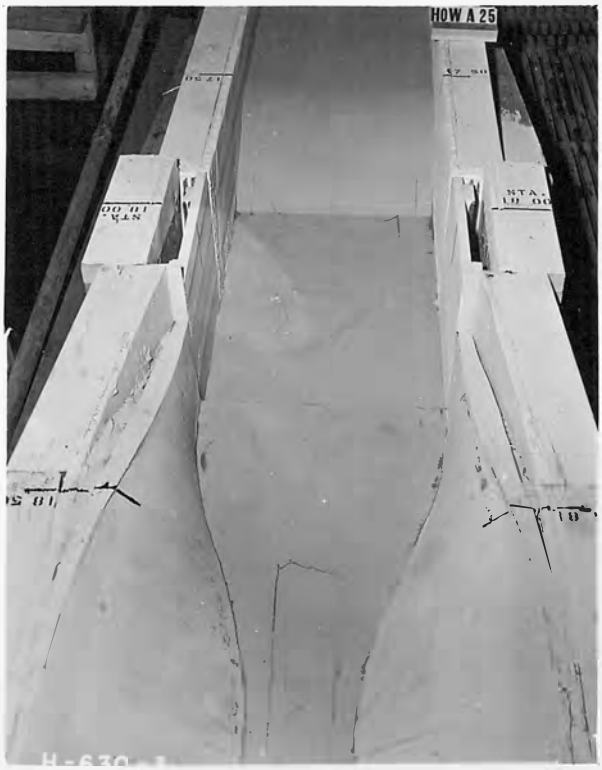
HORSETOOTH DAM OUTLET WORKS
Stilling-pool operation with submerged pier installed on chute
Discharge = 1500 second-feet through left valve
1:24 Scale Model
SCHEME B



A. The Model

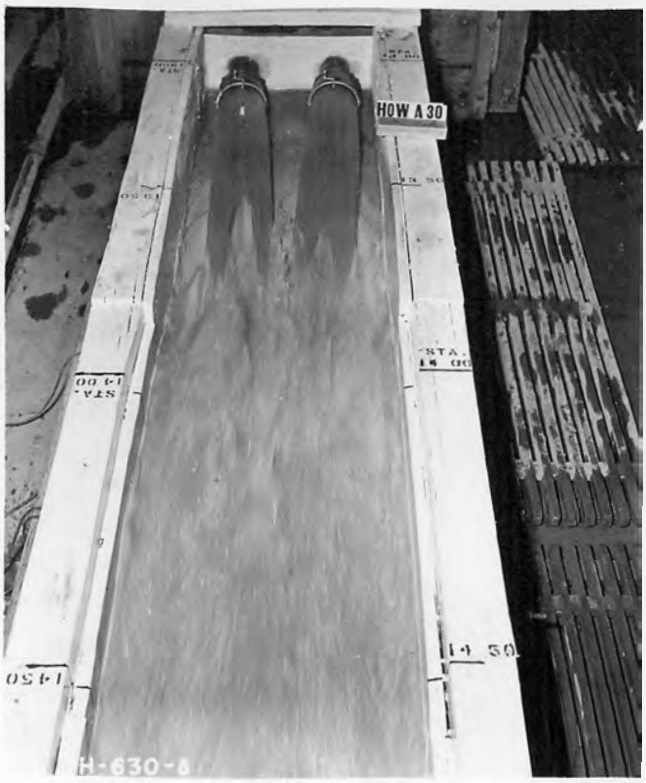


B. Valves and upper end of chute

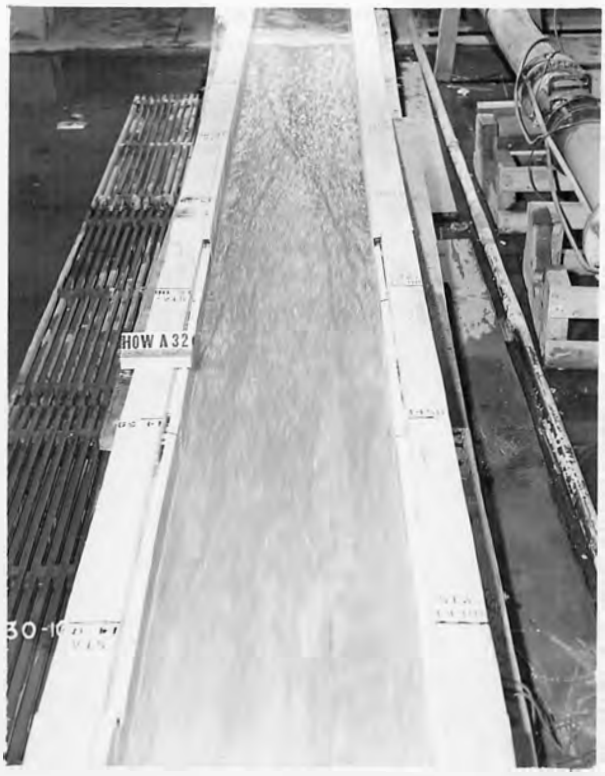


C. Stilling-basin

HORSETOOTH DAM OUTLET WORKS
Recommended Design
1:24 Scale Model
SCHEME B



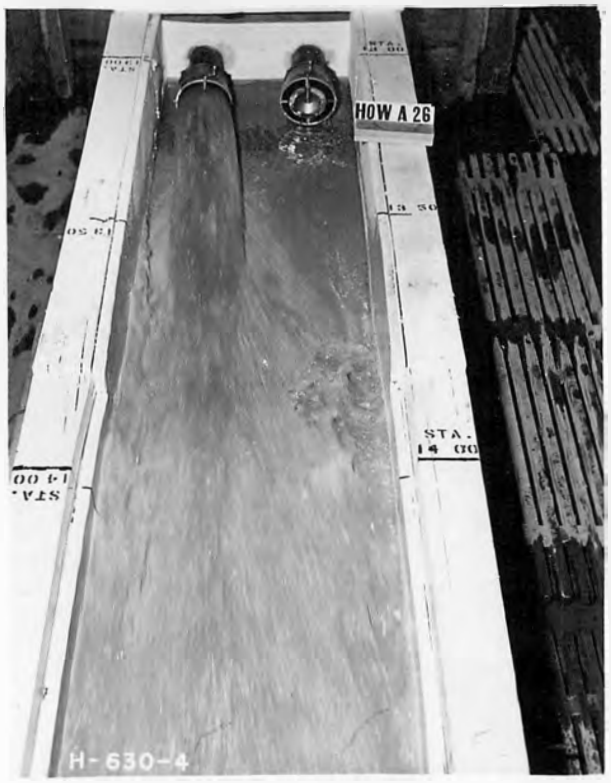
A. Flow at valves



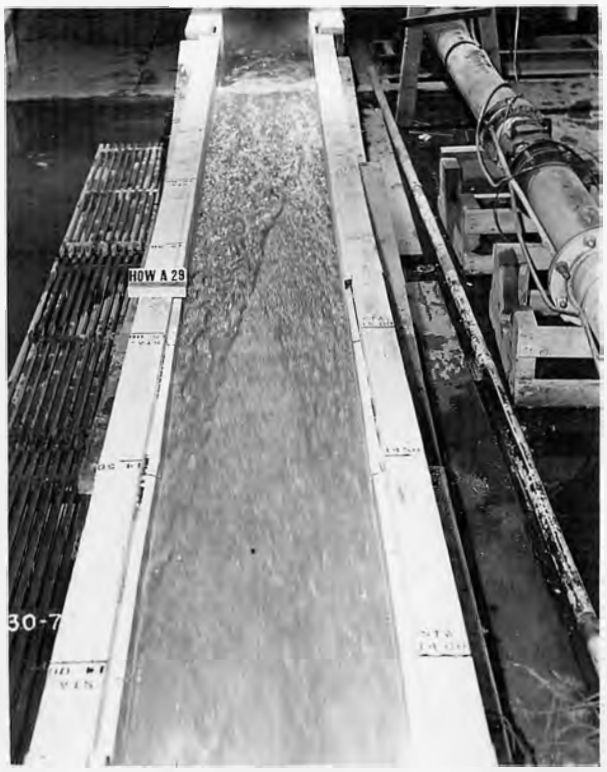
B. Flow in chute--looking downstream

C. Stilling-pool operation--looking upstream

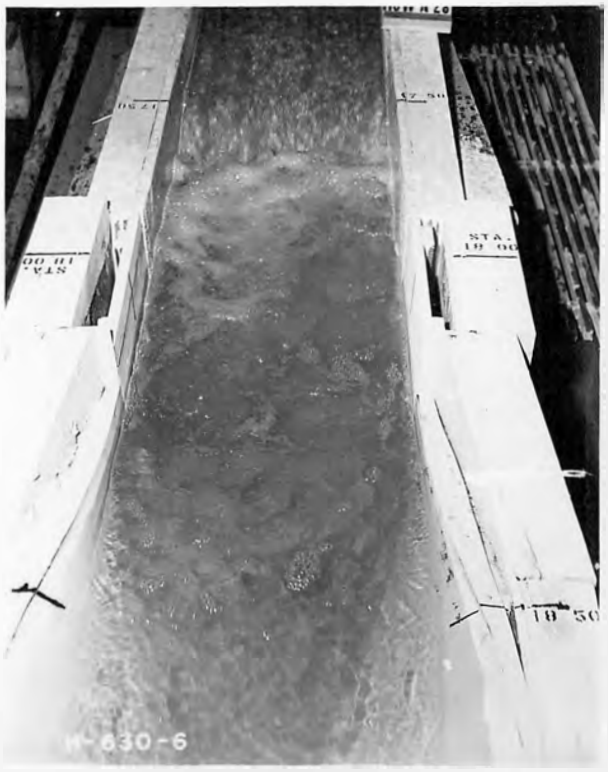
HORSETOOTH DAM OUTLET WORKS
Both valves discharging 1500 second-feet--Res. Elev. 5430
Recommended Design--1:24 Scale Model
SCHEME B



A. Flow at valve

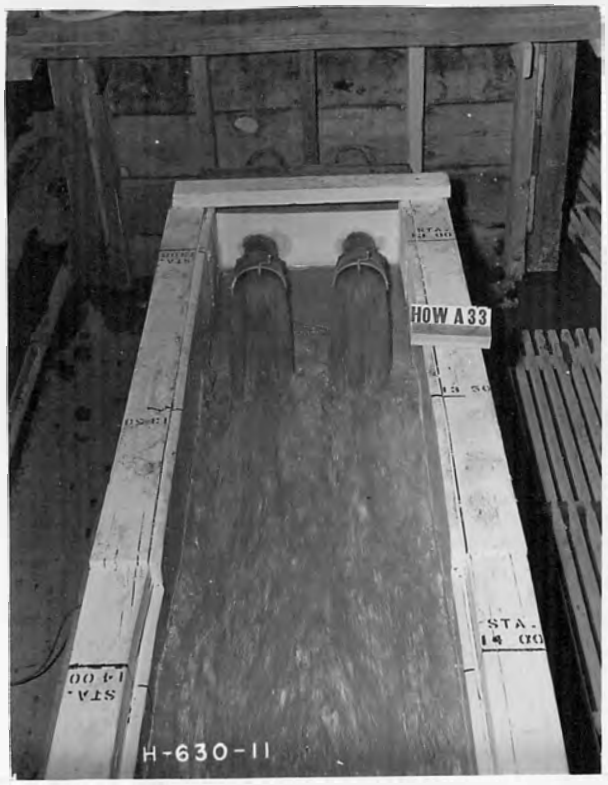


B. Flow in chute--looking downstream

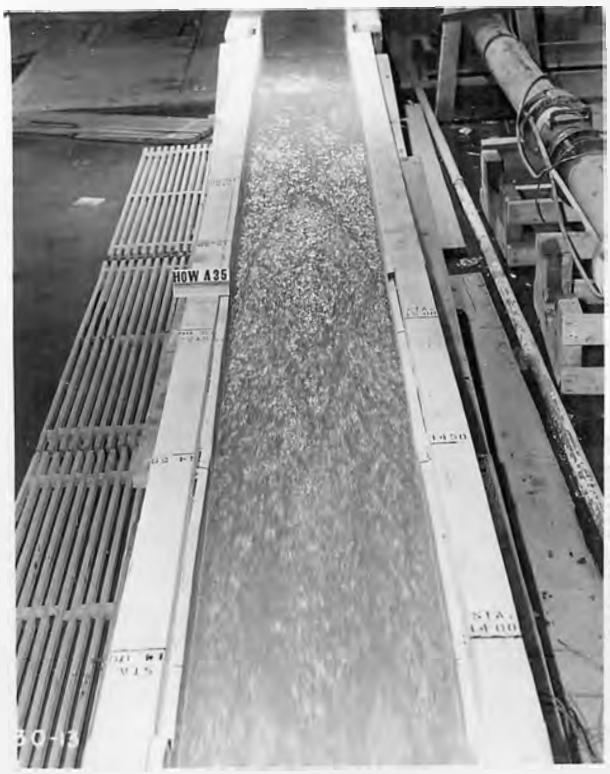


C. Stilling-pool operation--looking upstream

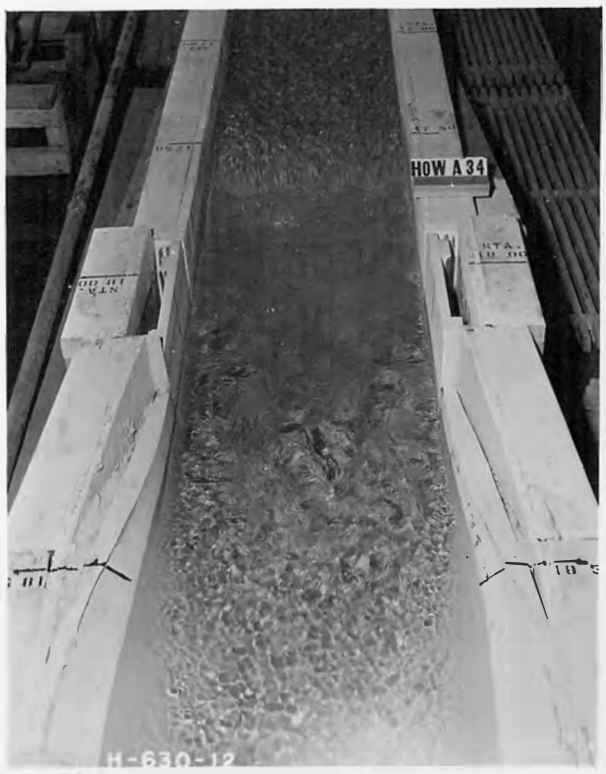
HORSETOOTH DAM OUTLET WORKS
Right valve discharging 1500 second-feet--Res. Elev. 5430'.
Recommended Design--1:24 Scale Model
SCHEME B



A. Flow at valves

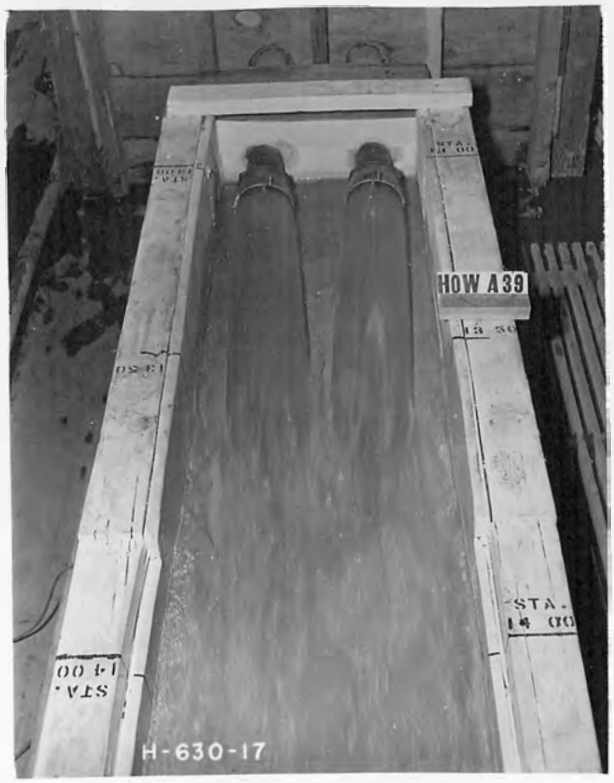


B. Flow in chute--looking downstream

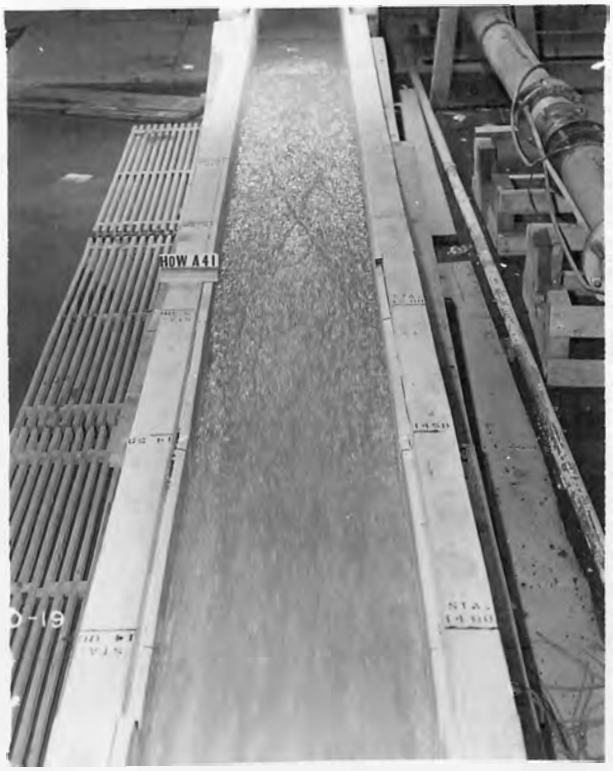


C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Both valves discharging 1500 second-feet--Res. Elev. 5340'
Recommended Design--1:24 Scale Model
SCHEME B



A. Flow at valves

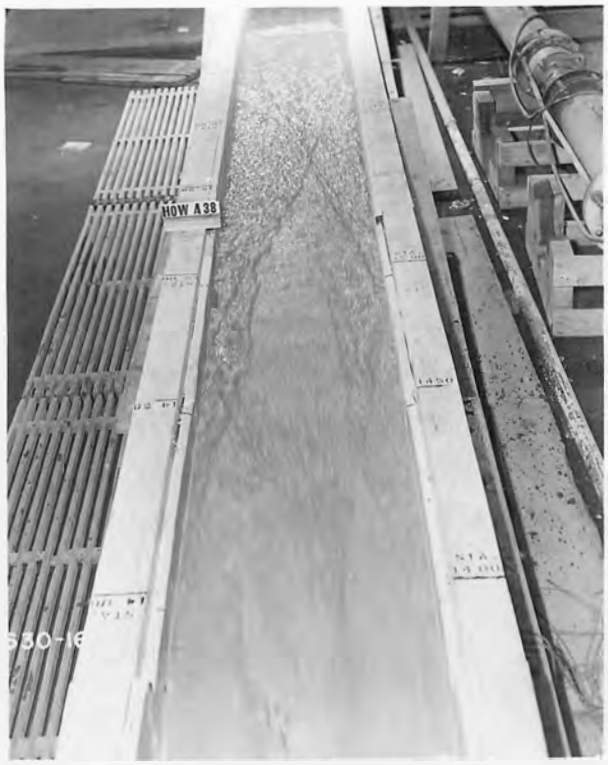


B. Flow in chute--looking downstream

C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Both valves discharging 1000 second-feet--Res. Elev. 5430'
Recommended Design--1:24 Scale Model
SCHEME B

A. Flow at valve

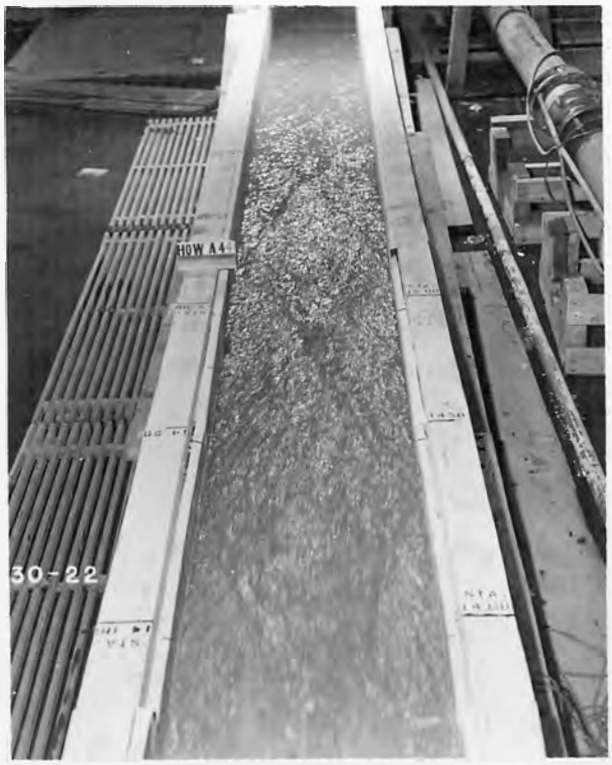


B. Flow in chute--looking downstream

C. Stilling-pool operation looking upstream

HORSETOOTH DAM OUTLET WORKS
Right valve discharging 1000 second-feet--Res. Elev. 5430'
Recommended Design--1:24 Scale Model
SCHEME B

A. Flow at valves

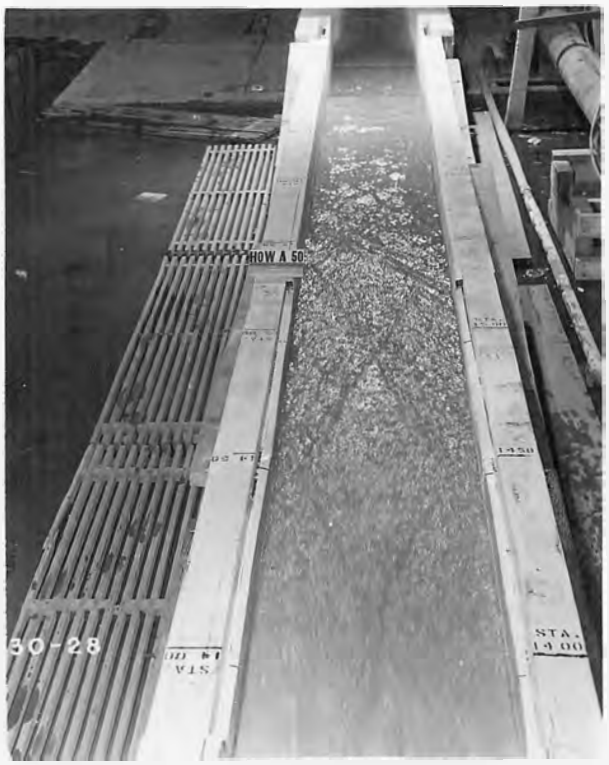


B. Flow in chute--looking downstream

C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Both valves discharging 1000 second-feet--Res. Elev. 5340'
Recommended Design--1:24 Scale Model
SCHEME B

A. Flow at valves

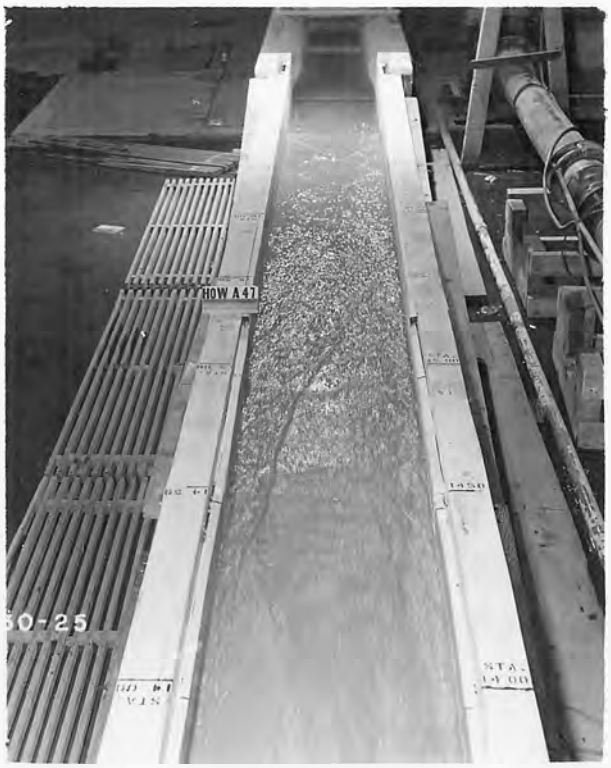


B. Flow in chute--looking downstream

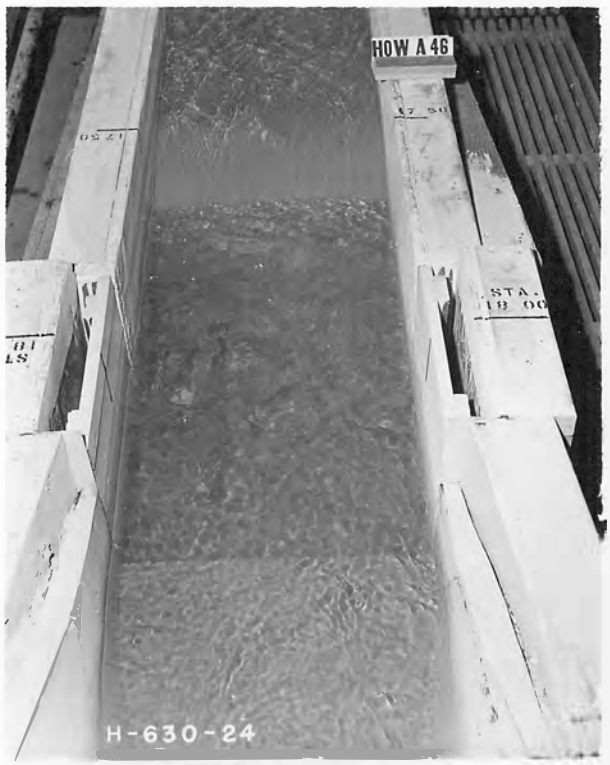
C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Both valves discharging 500 second-feet--Res. Elev. 5430'
Recommended Design--1:24 Scale Model
SCHEME B

A. Flow at valve



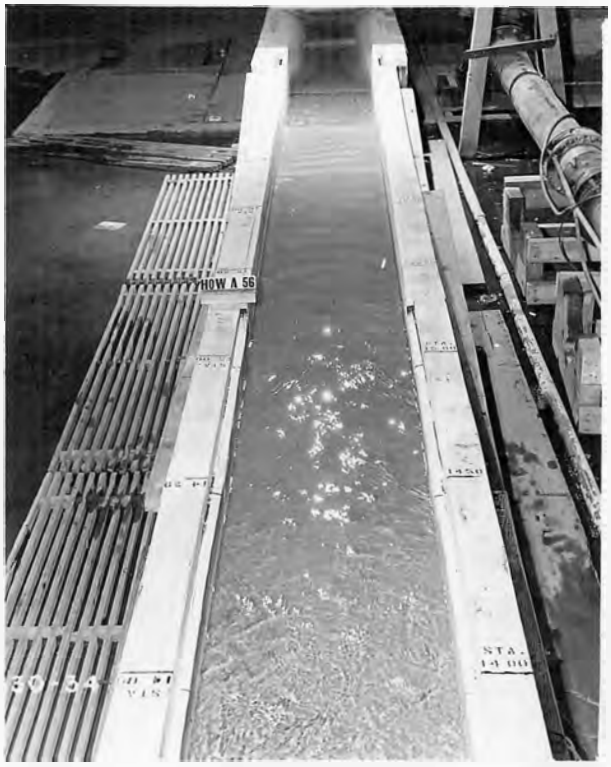
B. Flow in chute--looking downstream



C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Right valve discharging 500 second-feet--Res. Elev. 5430'
Recommended Design--1:24 Scale Model
SCHEME B

A. Flow at valves



B. Flow in chute--looking downstream

C. Stilling-pool operation--looking upstream

HORSETOOTH DAM OUTLET WORKS
Both valves discharging 500 second-feet--Res. Elev. 5340'
Recommended Design--1:24 Scale Model
SCHEME B

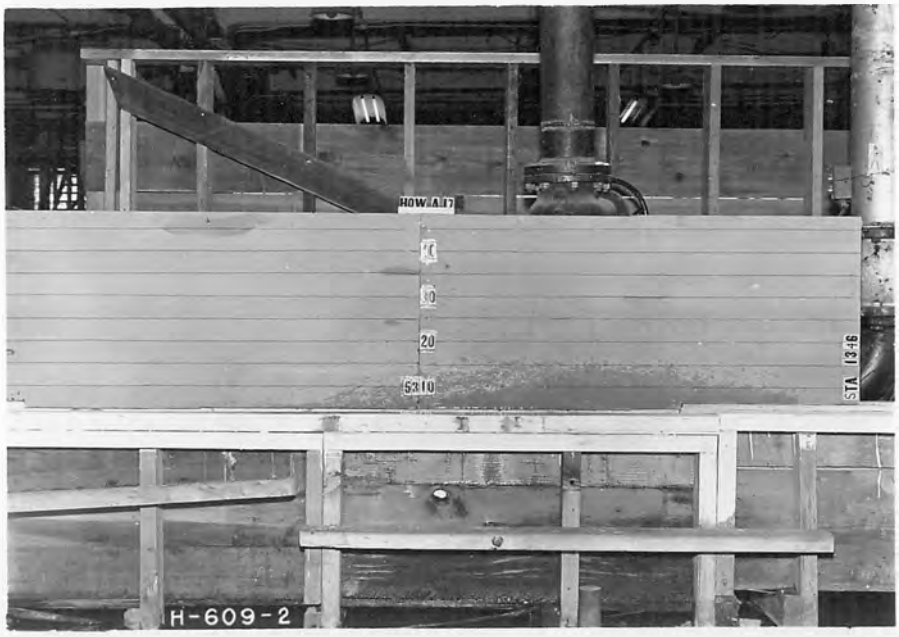
A. Flow at valve

B. Flow in chute--looking downstream

C. Stilling-pool operation--looking upstream

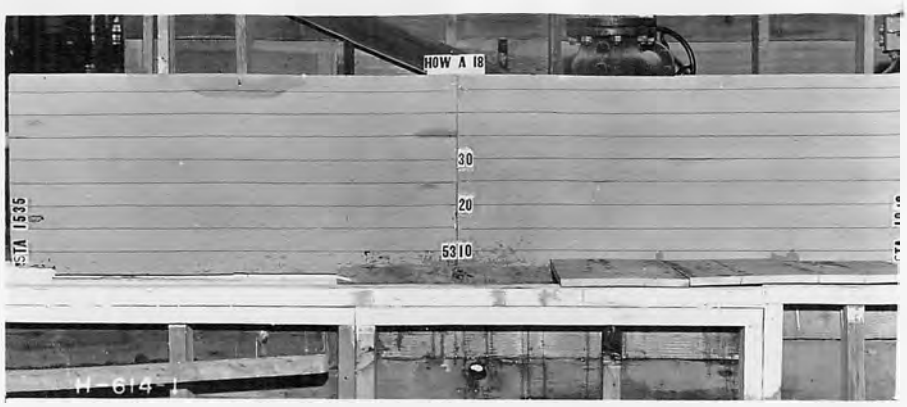
HORSETOOTH DAM OUTLET WORKS
Right valve discharging 500 second-feet--Res. Elev.5340'
Recommended Design--1:24 Scale Model
SCHEME B

A. Extent of splash below valves after left valve discharged 1500 second-feet for 7.5 hours (prototype).



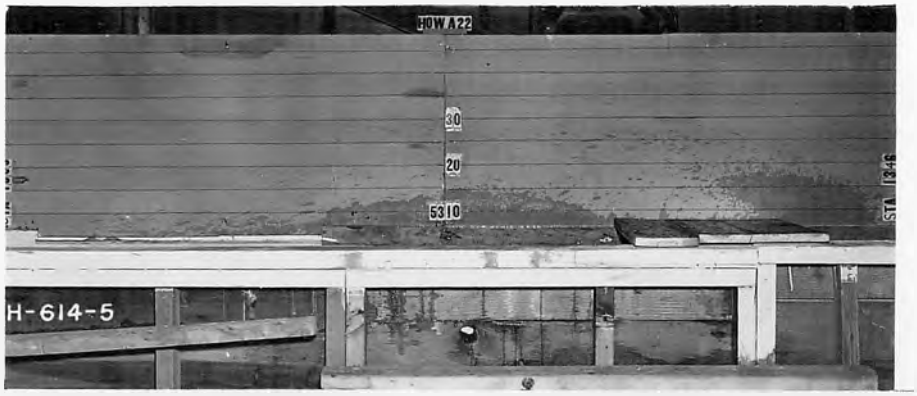
B. Extent of splash below valves after both valves discharged 1500 second-feet for 7.5 hours (prototype).

HORSETOOTH DAM OUTLET WORKS
1:24 Scale Model
Recommended Design
SCHEME B



A. 68-foot cover. Splash pattern after 5-hours (prototype) operation.

B. 57-foot cover. Splash pattern after $7\frac{1}{2}$ hours (prototype) operation.



C. 35-foot cover. Splash pattern after 5-hours (prototype) operation.

HORSETOOTH DAM OUTLET WORKS
Extent of Splash using Various Lengths of Covers
Discharge = 1500 second-feet through left valve
1:24 Scale Model
SCHEME B