UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

PROGRESS IN NEW DESIGNS FOR OUTLET WORKS STILLING BASINS

Hydraulic Laboratory Report No. Hyd.-302

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

DECEMBER 1950

FOREWORD

This paper was originally prepared for the "Fourth Congress on Large Dams" held in New Delhi, India, in January 1951. The format conforms to the requirements set-up by the "International Commission on Large Dams of the World Power Conference." The purpose of the discussion contained in the paper is to answer, in part, Question No. 12, selected by the Executive Meeting of June 29, 1949, in Brussels, Belgium. Question No. 12, to quote directly, is:

"Method for determining maximum flood discharge which may be expected at a dam and for which it should be designed. Selection of type and general arrangement of the temporary or permanent outlets and spillways and determination of their capacities."

The stilling basin designs discussed in this paper were obtained through the joint efforts of the staffs of the Spillway and Outlet Works Section No. 2 and of the Hydraulic Laboratory, both of the Bureau of Reclamation, Department of the Interior in Denver, Colorado.

PROGRESS IN NEW DESIGNS FOR OUTLET WORKS STILLING BASINS

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SUMMARY

The perpetual search for better operating structures at less cost has prompted engineers in the Bureau of Reclamation, Denver, Colorado, to develop new stilling basin designs for outlet works.

The conventional hydraulic jump stilling basin does not provide an economical solution to energy dissipation problems when flow entry is concentrated in a jet from a valve. The length of basin necessary to spread the jet is not useful in dissipating energy and adds to the over-all length and cost of the structure. Outlet works with one of two valves operating require an expensive dividing wall to achieve symmetry of action. When the basin discharges directly into a canal or into a powerhouse tailrace the pulsations in the basin are carried downstream causing objectionable waves and surface disturbances. Solutions to these problems were found in the newly developed designs.

Using hydraulic models, each of the designs was first tested using a conventional basin. Then, taking advantage of local conditions, each design was modified and developed to produce a better performing structure which could be constructed at less cost.

For the Enders Dam basin, a deflector hood was placed to turn the two valve jets downward into a relatively deep pool. The center dividing wall was removed from the basin entirely and the structure was reduced from 175 to 75 feet in length. Improved performance, particularly a quieter water surface was obtained with the shorter, less costly structure.

For the Boysen Dam basin the valves were pointed downward making a deflector hood unnecessary. Using wedge shaped inserts in the basin to protect the valve jets until the entering flow was well submerged, satisfactory performance resulted. Smooth surface flow, negligible erosion of the channel bottom, and general excellent over-all performance characterized this more economical design.

In the Soldier Canyon basin a single valve was used. Here, the jet was protected by a transition hood, until the entering flow reached nearly the bottom of a deep pool. With energy dissipation occurring well below the surface, the water surface in the basin was exceptionally smooth, making it possible to discharge directly into a canal without fear of wave effects on the canal banks.

Although the basins discussed here are designed for specific installations, use of the principles outlined on other outlet works stilling basins will result in improved performance at less cost.

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Discussion of Problem

Most outlet works stilling basins employ an hydraulic jump to obtain the necessary energy dissipation before passing the flow into the lower channel. Although the performance of these basins has in general been considered satisfactory and acceptable, critical examination of the performance and analysis of the basin structure itself has indicated that improved stilling action in a basin of less over-all length would be desirable.

Since the flow usually enters the basin from a tunnel, conduit, or valve, the flow is concentrated into a narrow width. Before a jump can be formed, the flow must be spread laterally. A large percentage of the basin length is thus utilized in preparing the flow to enter the jump and is therefore useless in dissipating energy. It was the desire to eliminate or reduce the length of this part of the structure with a resulting reduction in over-all length and cost of the basin which prompted the Bureau of Reclamation to investigate and develop several new types of stilling structures. In the course of the program, however, other benefits in improved performance and reduced cost were also realized.

Through the combined efforts of the designing engineers and the Hydraulic Laboratory engineers, satisfactory methods for obtaining optimum stilling basin performance without the use of the jump were developed from extensive hydraulic model tests. It was found that the hydraulic jump was not the most satisfactory means for dissipating energy in the outlet works stilling basins. The use of a modified form of the jump or an entirely different method of introducing turbulence into the basin provided more satisfactory energy dissipation in a shorter and less expensive structure. Since the erosion problem in the downstream channel was the same for either type of basin, the modified type was considered more satisfactory because of the extremely smooth water surface which resulted in and downstream from the basin, and because of the more nearly uniform vertical velocity distribution which was evident at the end of the basin. Where waves, surges, and high-velocity surface currents are undesirable, as for example when a basin discharges directly into an unlined canal or stream with soft earth banks, the modified type of energy dissipator proved far superior.

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In each of the three outlet works discussed in this paper, tests were first made on a model stilling basin which was designed to use the hydraulic jump. Full data was taken on the performance and the model was then modified and developed to produce a better performing structure. In each case the structure was also made shorter and other construction economies were effected that would not have been possible had the hydraulic jump basin been used.

The difficulties apparent in the jump basins tested were the aforementioned long transition before the flow entered the jump and the waves and surges in the basin and downstream channel. In addition, however, for an outlet works with two outlets it was found necessary to provide, in effect, two hydraulic jump basins; one for each outlet in order to provide satisfactory performance when only one outlet was operating. With the modified type of energy dissipator it was found possible to eliminate or reduce considerably the length of the dividing wall in the basin.

Examination of the performance of the hydraulic jump basins in general and those shown in Figures 3 and 9, showed that the waves and surges were formed because the inflowing water did not penetrate to the basin floor but rose to the surface of the basin before energy dissipation was complete. Even though a fairly efficient jump was formed, a high-velocity surface current with accompanying waves and surges was evident in the downstream channel. Lengthening the basin would have corrected much of this difficulty, but would have added to the cost of the structure. More satisfactory results were obtained by directing the flow sharply toward and then along the bottom of the basin rather than, in effect, over the tailwater surface. It was necessary to protect the inflowing water with a hood or other device until it was considerably beneath the tailwater surface, since there was a natural tendency for the inflow to rise to the surface and follow the path of least resistance. The inflow was thus protected from being torn apart by induced eddies until it was well submerged. Energy dissipation then occurred in a more orderly and efficient manner.

It is believed that the effectiveness of this method of dissipating energy is due to the small-grain turbulence which is created in the basin. Because the inflow was protected until it was well submerged, the flow when it reached the bottom of the basin still contained sufficient energy to produce many small, efficient, energy-dissipating eddies at the bottom of the basin. Thus, smaller waves and velocity concentrations were evident on the surface.

It has been proven in laboratory tests and also from mathematical considerations that a large number of small-grain eddies are more efficient in dissipating energy than a few large eddies. In some ways the action is analagous to that which occurs when a discharging hose nozzle is submerged in a bucket of water rather than when it is aimed into the bucket from a point above the water surface.

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In each of the first two outlet works discussed, the discharge control consists of two hollow-jet valves placed on the ends of the outlet works conduits. The third outlet works used a pivot valve, which is similar in many respects to a butterfly valve. However, it is believed that a basin utilizing any type of valve or control could be satisfactorily developed from model tests, following the principles outlined in this paper.

The hollow-jet valves, developed from extensive tests by the Bureau of Reclamation, (1)*, (2)* discharge a jet which is annular in cross section. The limits of the jet are very definite in form with little or no flying spray, and the center core, which is air, is adequately ventilated. From a performance standpoint, the annular jet differs from a solid jet mainly in the fact that it has less penetrating power when directed into a pool of water and high-velocity currents quickly rise to the surface of the pool probably because of the relatively great amount of air in the jet. On the other hand, a solid jet provides more penetrating power into a pool of relatively great depth, but is difficult to diffuse over a wide area. Also, less air is carried into the pool. The characteristics of issuing jets are mentioned briefly here because two of the stilling structures were designed for the annular type. The valves are, therefore, an integral part of the stilling structures. The jets from the model hollow-jet valves are shown in several of the accompanying photographs.

DEVELOPMENT OF ENDERS DAM OUTLET WORKS

The outlet works of the Enders Dam, located near Enders, Nebraska, is for the purpose of controlling the release of water for irrigation and flood control. The structure consists of an intake and an 84-inch diameter tunnel through the base of the dam terminating in two 60-inch hollow-jet valves which discharge horizontally into the stilling basin, Figure 1. Irrigation requirements made it necessary to provide a discharge of 1,000 second-feet at a head of 52.5 feet. As a safety measure, however, two valves were installed, one of which operating alone will discharge 930 second-feet at a head of 98.7 feet. The maximum discharge through two valves at the higher head is 1,360 second-feet. Although other discharges and heads were tested, the discussion centers around the maximum flows because they produced the most severe condition in and below the stilling basin.

The stilling basin initially tested was 175 feet long and had a center dividing wall 22 feet high which extended nearly the entire length of the basin, Figure 2. The purpose of the wall was to provide, in effect, a separate stilling basin for each valve when only

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*Numbers in parenthesis refer to bibliography at end.

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one valve was operating. Previous experience with model basins of this type showed that poor operation, due to unsymmetrical flow with only one valve operating, occurred without the wall in place.

The performance of the hydraulic jump structure was found to be acceptable according to minimum standards, and with a longer stilling basin the operation could have been made satisfactory, Figure 3. It was felt, however, that the structure was too long and expensive for the job it had to do. The long basin and the high center dividing wall were items which added greatly to the cost of the structure. It was believed that the basin length could be reduced and the center dividing wall eliminated by using a different approach to the problem of dissipating the energy of the outflowing water. Since much of the basin length was, in effect, wasted because of the long trajectory of the horizontal jet, consideration was first given to tilting the valves downward. To do this meant raising the conduit to keep the valves above water. This was found to be impractical because of diversion requirements and other construction difficulties since the contractor was already at work.

As a substitute for turning the valves downward, a deflector hood was placed downstream from the valves, Figure 4. The center dividing wall was entirely removed and the trajectory curve was modified. Preliminary quick-trial tests on a dozen or more deflectors of various shapes, including straight, concave, and convex; with and without straight and curved lips on the downstream end placed at various heights from the basin bottom, indicated the best shape and location for the deflector hood.

In these early tests it was found that certain deflectors, those that were too steep where the jet impinged or those that did not provide proper clearance between the basin floor and the bottom of the deflector, caused the flow to back up and submerge the valves. Since the valves are not designed for underwater operation, and cavitation within the valve might occur, this condition could not be tolerated. By curving the hood to gradually intercept the normal trajectory from the valves, the tendency for the flow to back up was minimized. Figure 4 shows a comparison between the upper jet trajectory and the curvature of the deflector hood finally adopted.

Proper clearance between the bottom of the hood and the basin floor was determined by trial and in the final design it was found that varying this dimension by as much as 1 foot did not cause a noticeable change in performance.

A major difficulty in obtaining a satisfactory design for the hood was concerned with the lateral distribution of flow when only one valve was operating. When the lower part of the hood was shaped to direct the flow parallel to the basin bottom, the single jet slid out from beneath the hood with very little energy actually dissipated. This caused a high velocity concentration on one side of the basin and

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a return velocity on the other. In addition to poor appearance, erosion of the riverbed downstream from the structure was greater than desired   With the recommended deflector hood in place, however, the flow from one valve was distributed across the entire width of the basin as it left the underwater opening, Figure 5.

The structure, developed to this point, indicated satisfactory performance in every respect. The piezometer pressures were all above atmospheric for the entire range of operating conditions with the highest pressures occurring on the deflector hood. The maximum recorded pressure occurred with one valve operating and was equivalent to 18 feet of water, prototype. This maximum pressure occurred about midway on the deflector. The lowest pressure recorded, 1 foot of water, occurred near the top of the deflector when both valves were operating. These pressures indicated that the total load on the deflector hood was not excessive from a structural viewpoint, and that the lowest pressure was well above the vapor pressure of water, the range where cavitation occurs. The water surface was smooth downstream from the deflector hood for all conditions of flow and caused no appreciable waves in the river channel   Velocities were evenly distributed across the width and depth of the stilling basin, Figure 6, and the erosion of the 100- to 200-mesh sand, used to represent the riverbed material in the prototype, was neglibible.

From an hydraulic viewpoint, the structure was now entirely satisfactory, but it was also evident that the size of the basin could be reduced by making the basin shorter and by elevating the floor at the downstream end. Observations made during the tests indicated that the length need be only 75 feet instead of the 175 feet originally proposed and that the bottom half of the downstream end of the shortened basin, which was not being fully utilized in dissipating energy, could be raised at the downstream end. Thus, the amount of excavation and the height of the basin side walls could be reduced. Tests indicated that these changes produced satisfactory results, but the appearance of the hydraulic action was not as favorable.

Best operation with a raised floor was obtained when the upstream face of the raised portion was crenelated in plan, Figures 1 and 4. Less erosion, lower wave heights, more uniform velocity distribution, and better all-round performance were found for this scheme than for any of the dozen or more other schemes tested which made use of a higher downstream floor. The adopted scheme was believed to provide sufficient protection to the structure itself and to the river bottom and banks below the structure, Figures 5 and 7.

Considerable thought was given to the possibility of erosion of the concrete occurring where the jets strike the deflector. Tests made in the Bureau of Reclamation laboratories have indicated that concrete shows remarkable resistance to the effects of water which

is free of grit. Tests on samples of ordinary concrete only 14 days old with a concentrated jet of water having a velocity of 90 feet per second and aimed directly at the block produced only minor indications of erosion after 240 hours of operation, (3). The jets from the hollow-jet valves will have a maximum velocity of 67 feet per second and will strike the deflector at an angle much less than 90° In addition, particular care in forming and placing the concrete was specified for the deflector face and it is believed that serious erosion of the concrete will not occur. However, if the concrete does erode, provisions have also been made for the installation of a steel liner plate over the affected areas.

DEVELOPMENT OF BOYSEN OUTLET WORKS

The Boysen Outlet Works is part of the Boysen Dam now being constructed on the Big Horn River in central Wyoming about 16 miles south of the town of Thermopolis. The dam is of compacted earth fill and rises 150 feet above the bed of the river. The main spillway, controlled by two 30- by 25-foot radial gates, is located near the right abutment The powerhouse is also located on the right bank and contains two, 7,500-kva generators and turbine units. Because of the economies effected by combining structures, the outlet works is also contained in the powerhouse.

The discharge control on the outlets consists of two 48-inch hollow-jet valves which discharge into a concrete stilling basin adjacent to the turbine draft tubes. Water to one valve is supplied through a 57-inch pressure conduit which is a branch from one of the penstocks. The other valve is connected by a 66-inch line to the reservoir directly. Discharge requirements make it necessary to provide for a maximum flow of 1,200 second-feet at a head of 92.25 feet. One valve will discharge 600 second-feet at the same head. The corresponding outlet velocity at the valves is 68 feet per second.

Although the problems for Enders and Boysen Outlet Works were similar in many respects, there were two outstanding differences which greatly affected the final design of the stilling basin. First, since the Boysen stilling basin is contained in the powerhouse and is located directly beneath the generator room floor, a center dividing wall in the basin was desirable to provide structural support. Secondly, it was possible to depress the valves 24° below horizontal which, in effect, reduced the necessary over-all length of the stilling basin by shortening the trajectory of the jet from the valves to the stilling pool. These differences in the structure influenced the development of the recommended design to a marked degree.

As in the case of the Enders tests, the originally proposed structure used an hydraulic jump to dissipate the energy in the stilling basin, Figure 8. Operation with both one and two valves open indicated that the basin was too short. The effects of the hydraulic jump extended well downstream into the powerhouse tailrace, Figure

9, causing excessive erosion of the riverbed and banks, particularly when only one valve was operating. The remedy appeared to be simple; lengthen the basin. Since this would add to the cost of the structure and necessitate building the structure across a fault, an attempt was made to move the stilling action upstream, using deflector hoods designed to turn the jet downward at a greater angle. Deflectors similar to those tested and described for the Enders Outlet Works were used, one on each side of the dividing wall, with various elevations of the stilling basin floor and heights of opening between the floor and the deflectors. Several of the shapes tested might have been used satisfactorily in the prototype, but because of the presence of the center dividing wall and because the valves were depressed, the deflectors were not as effective as they had been on the Enders Outlet Works. This was due in part to the center wall which prevented the mixing of the two jets under the hood. With one valve operating, the wall prevented spreading of the single jet over the entire basin width, which also resulted in less efficient energy dissipation.

Experiments were then continued without the deflector hoods to determine the most effective profile for the stilling basin floor. The best arrangement is shown in the drawing of Figure 10 and in the photograph of Figure 11 for the maximum discharge. In the photograph it is apparent that the jets from the valves cause a high boil and that the high velocity jet entering the basin is quickly directed to the surface. It is also apparent that the downstream end of the basin is not fully utilized in dissipating energy. Velocity measurements made at the end of the basin confirmed these observations. Surface velocities were found to be several times as high as those just below the surface. The result was to produce undesirable currents and surges in the powerhouse tailrace.

Attempts to smooth out the flow with baffle piers, sills, and other appurtenances met with little success until a pair of inserts, wedge-shaped in plan, were placed parallel to and downstream from the valves. The inserts, shown as the converging walls in Figure 10, provided an opening less than the width of the jet and, in operation, compressed the hollow jet from the sides as it passed between them. The performance of the basin was thus greatly improved. The water-surface profile in the basin becomes almost level and practically the entire volume of the basin became useful in dissipating energy, Figure 12. Surface velocities at the end of the basin were much lower because of the better vertical distribution, while waves and currents in the powerhouse tailrace were negligible, Figure 13. Erosion of the model riverbed at the end of the structure was also negligible.

Pressure measurements made on critical parts of the structure showed that neither excessive nor subatmospheric pressures existed in any part of the structure. The maximum pressure recorded occurred on the floor of the basin and was equivalent to about 15 feet of water, prototype. The minimum pressure occurred on the face of the wedge block and was equal to about 4 feet of water.

The effect of the wedges in obtaining more efficient energy dissipation is not fully understood but the value of these relatively small appurtenances is beyond question. The flow as it passed between the wedges was protected from being torn apart by induced side eddies, and as a result, the original jet penetrated into the basin for a greater depth and length. Combined with this effect, it is believed that the compressing effect of the wedges reduced the quantity of air being carried in the core of the jet. With less air in the basin there was less tendency for the main flow to be carried to the surface by the entrained air, and as pointed out previously, surface disturbances were less in evidence.

Tests made to determine the necessity for the center dividing wall, from an hydraulic point of view, showed that only a short length of wall was needed at the upstream end of the basin. The remainder of the wall is necessary only for structural reasons in this particular case.

DEVELOPMENT OF SOLDIER CANYON DAM OUTLET WORKS

The use of a submerged jet is illustrated in the development of the stilling basin for the Soldier Canyon Dam Outlet Works. Soldier Canyon is part of the Colorado-Big Thompson Project and is one of four earth-fill dams which impound irrigation water in Horsetooth Reservoir, located approximately 10 miles west of Fort Collins, Colorado.

Horsetooth Reservoir has a capacity of 146,000 acre-feet and will store irrigation water diverted from the Colorado River on the western slope of the Continental Divide to the eastern slope through the Alva B. Adams tunnel. The principal hydraulic feature of the Soldier Canyon Dam is the outlet works which consists of a single outlet tunnel equipped with an 18-inch pivot valve at the discharge end to control the amount of flow into the stilling basin, Figure 14. The stilling basin discharges directly into an irrigation canal. Although the maximum discharge, a possible future requirement, into the canal is 99 second-feet, the present required maximum discharge is 60 second-feet. The head on the valve, measured from the reservoir surface to the valve, varies from 117 to 205 feet. The velocity of the issuing jet varies from approximately 60 to 115 feet per second.

Preliminary model tests using a hollow-jet valve with a trajectory curve were made with a conventional hydraulic jump pool, Figure 15. The valve was tilted downward at various angles in order to shorten the trajectory curve and at the same time the elevation of the stilling basin floor was also varied. The most satisfactory basin obtained from these tests performed reasonably well but it was difficult to obtain sufficient spreading of the jet and as a result surges and waves of an undesirable magnitude were formed in the

basin and were carried downstream into the canal. Also, full use of the basin width was difficult to obtain. A longer stilling basin would have been necessary to quiet the water surface sufficiently to make the performance entirely satisfactory. Since the basin was already 111 feet long and since approximately one-half the length of the basin consisted of the trajectory curve, it was felt that better use of the basin length could be realized by using some other method of energy dissipation.

The trajectory curve was then removed from the basin and tests were made with the valve tilted downward at various angles and discharging directly into a relatively deep pool. The first tests showed that the jet did not penetrate into the pool sufficiently to produce satisfactory energy dissipation with a smooth water surface. Instead, the jet tended to either ricochet from the tailwater surface at flat angles of entry or penetrate slightly for steeper angles and then rise quickly to the surface of the pool before energy dissipation was completed. In either case the result was a high-velocity current shooting over the surface of the basin and on downstream into the canal.

At this point in the study it was decided to use a pivot valve instead of the hollow-jet because of the economies which could be realized. The pivot valve is similar in performance to a butterfly valve and may be obtained commercially where the hollow-jet valve must be made to order.

The flow emerging from the pivot valve consists of two jets whose characteristics vary considerably with both head and degree of valve opening. Thus, another problem was added to those already described and the fact that the pivot valve jets were concentrated and were difficult to spread added still another feature to the problem. Figure 16 shows the performance resulting from the pivot valve discharging 60 second-feet directly into the stilling basin, the extreme turbulence in the basin, and the rough water surface which extended considerably downstream from the structure. These first tests indicated that a high degree of energy dissipation in the basin would be necessary to prevent damage to the canal downstream from the stilling basin, particularly from waves which caused considerable damage to the model canal banks. Tests on several different schemes for spreading the flow before it entered the stilling basin indicated that a protective hood below the valve would allow the jet to spread and also to penetrate well below the pool surface before it was released into the stilling pool. With this arrangement two objectives were accomplished; first, a uniform shape of jet entering the stilling pool was obtained regardless of the head or valve opening and, secondly, the penetrating power of the jet was increased, which prevented the flow from racing over the tail water surface without appreciable energy loss.

As the development of the structure progressed it became apparent that the hood should be a transition type of nozzle,

completely detached from the valve, which would collect the flow from the valve in a circular opening slightly larger than the valve and release it through a rectangular shaped opening near the bottom of the stilling pool. The valve and the transition nozzle were tilted downward as shown in Figures 17 and 18.

Pressure measuring piezometers installed in areas believed to be critical in the top, bottom, and sides of the hood, shown in Figure 17 indicated that pressures within the hood were neither excessively high nor dangerously low. Thus, cavitation will not occur in the prototype structure because of low pressures induced by faulty design, and it did not require excessive anchorage to hold the nozzle in place. The nozzle was of welded steel construction and was embedded in concrete to reduce the tendency for vibration. Sufficient clearance between the nozzle and the valve was maintained to allow removal of the valve for any reason without interference with the nozzle.

The shape of the nozzle was determined from hydraulic model tests and certain dimensions were found to be critical. The area of the outlet end of the model nozzle was made adjustable to determine the size of opening necessary to prevent the flow from being forced backwards out of the inlet end. The area was found to be dependent to some degree on the depth to which the outlet end was submerged and on the length and tilt of the nozzle itself. By trial a nozzle was developed which was as short as practical and which performed satisfactorily over the entire range of operating conditions; not only those for normal operation but also those for unexpected abnormal conditions. In effect, the nozzle was shaped so that sufficient pressure was developed within it at high heads to spread the flow over the entire nozzle width at the exit and at the same time allow free passage of flow at low heads without backing water out of the inlet end.
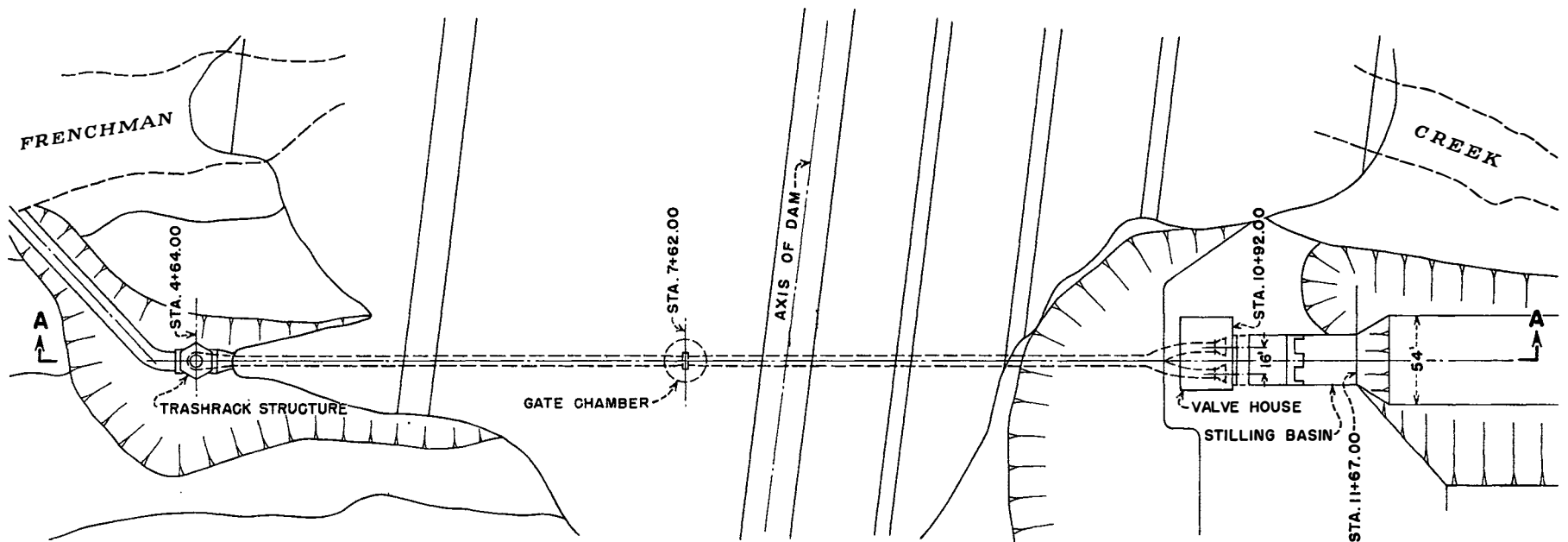
In an early design the nozzle was connected to the valve and vent pipes were installed in the nozzle just downstream from the valve. Excessive air velocities were noted in the vents unless the vents were made quite large. With no air admitted, pressures in the nozzle were below atmospheric and approached the cavitation range. Pressures within the valve also became negative and for these reasons it was considered advisable to construct the nozzle completely independent of the valve. The inlet end of the nozzle was made slightly larger than the inside diameter of the valve to allow for slight inaccuracies in alining the valve and nozzle, and to be certain that flying spray, of which a small amount was visible in the model, would also enter the nozzle. Although a considerable quantity of air was drawn into the nozzle used in the recommended design, it appeared to be less than that required with the nozzle connected to the valve. Quantitative tests were not made, however, but on the basis of relative tests it is believed that the air will enter the prototype structure in a quite and unobjectionable manner.

The operation of the recommended stilling basin shown in Figure 18 was entirely satisfactory. The design discharge of 60 second-feet at maximum head is shown in Figure 19. The side rails used in the basin were found to be useful in several ways. They were found to aid in producing a quiet water surface within the basin which helped to reduce the surface disturbances entering the canal. The rails reduced the wave heights from 3 inches to 2 inches at the upstream end of the canal for the design discharge of 60 second-feet. For 99 second-feet the wave heights were about 8 inches in height but the rails did not reduce the height to any measurable degree. The wave heights were about one-third the height found for the hydraulic jump basin and the hollow-jet valve.
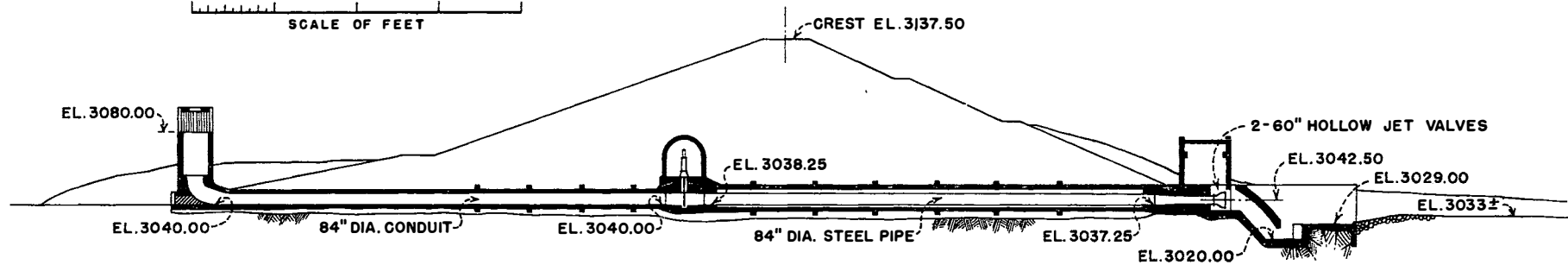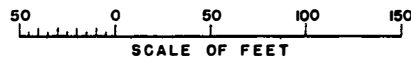
Erosion of the canal bottom was negligible in the model as a result of the almost complete dissipation of excess energy within the basin. The side rails also aided in the dissipation of energy by turning under the boils which attempted to rise to the surface along the basin sidewalls and helped prevent the formation of a high-velocity surface current at the basin exit.

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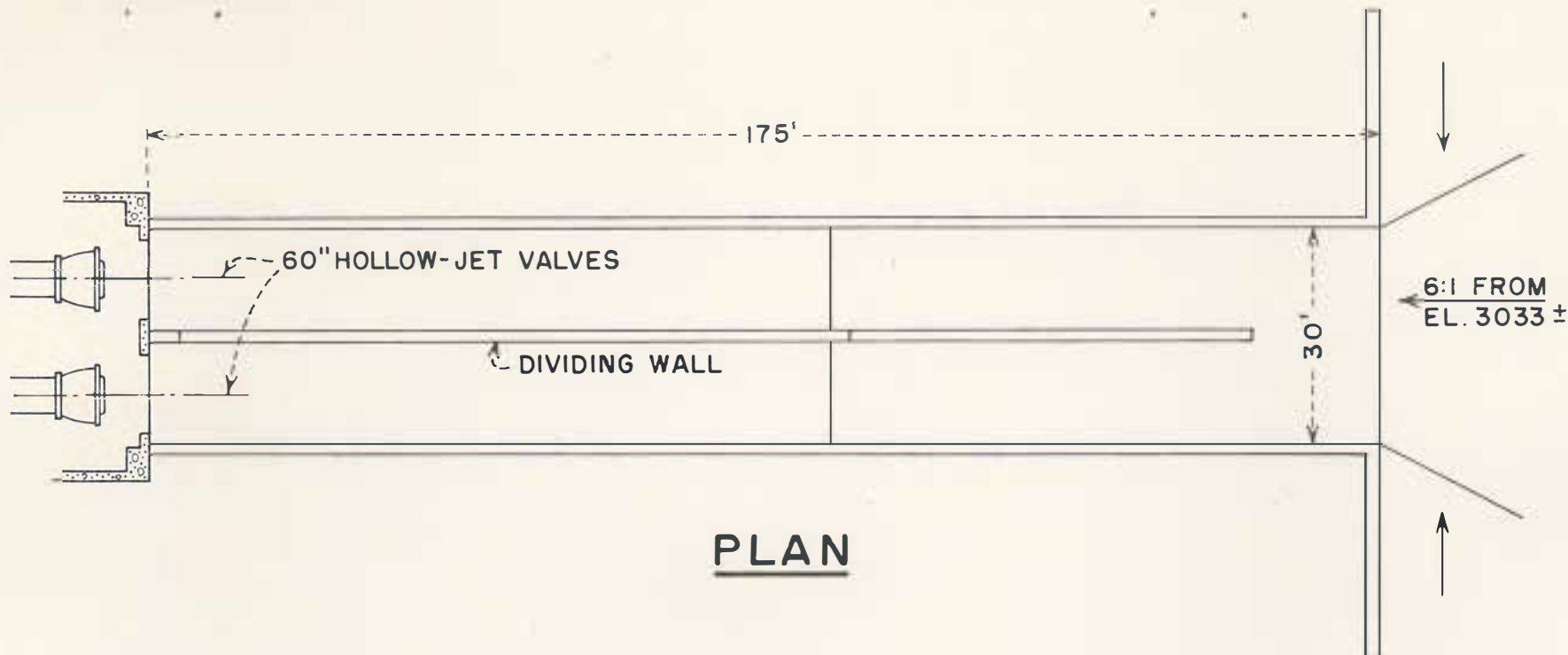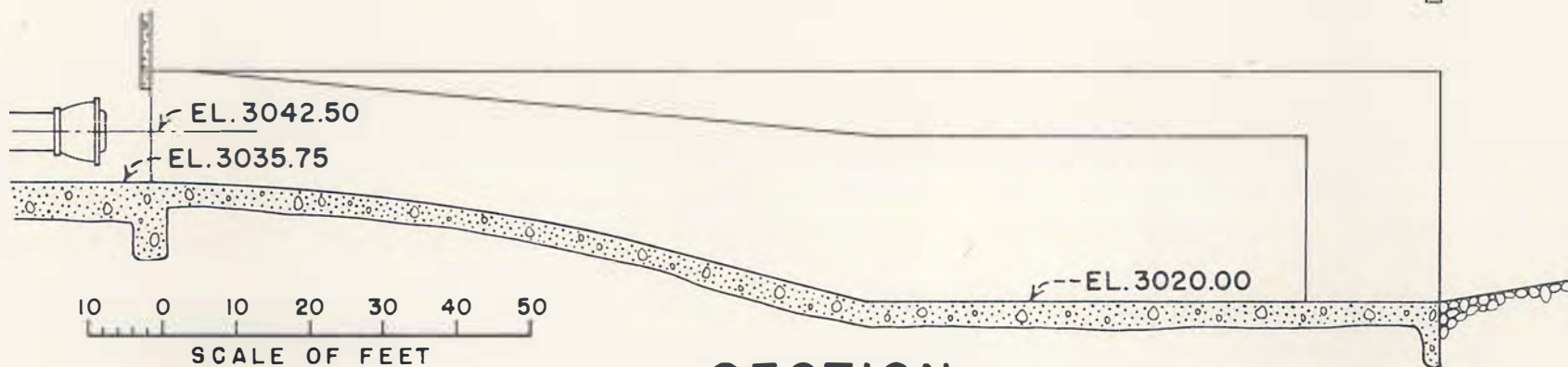3. Materials Laboratory Report No. C-405, Part 2, Bureau of Reclamation, Denver, Colorado.

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PLAN

EL.3080.00

50   0   50   100   150

SCALE OF FEET

CREST EL.3137.50

EL.3040.00   84" DIA. CONDUIT   EL.3040.00   84" DIA. STEEL PIPE   EL.3037.25

EL.3038.25

2-60" HOLLOW JET VALVES

EL.3042.50

EL.3029.00

EL.3033±

EL.3020.00

SECTION A-A

FRENCHMAN

CREEK

STA. 4+64.00

STA. 7+62.00

AXIS OF DAM

STA. 10+92.00

16'

54'

STA. 11+67.00

TRASHRACK STRUCTURE

GATE CHAMBER

VALVE HOUSE

STILLING BASIN

FIGURE 1

ENDERS DAM OUTLET WORKS

GENERAL ARRANGEMENT OF STRUCTURE

175'

60" HOLLOW-JET VALVES

DIVIDING WALL

30'

6:1 FROM
EL. 3033 ±

PLAN

EL. 3042.50

EL. 3035.75

EL. 3020.00
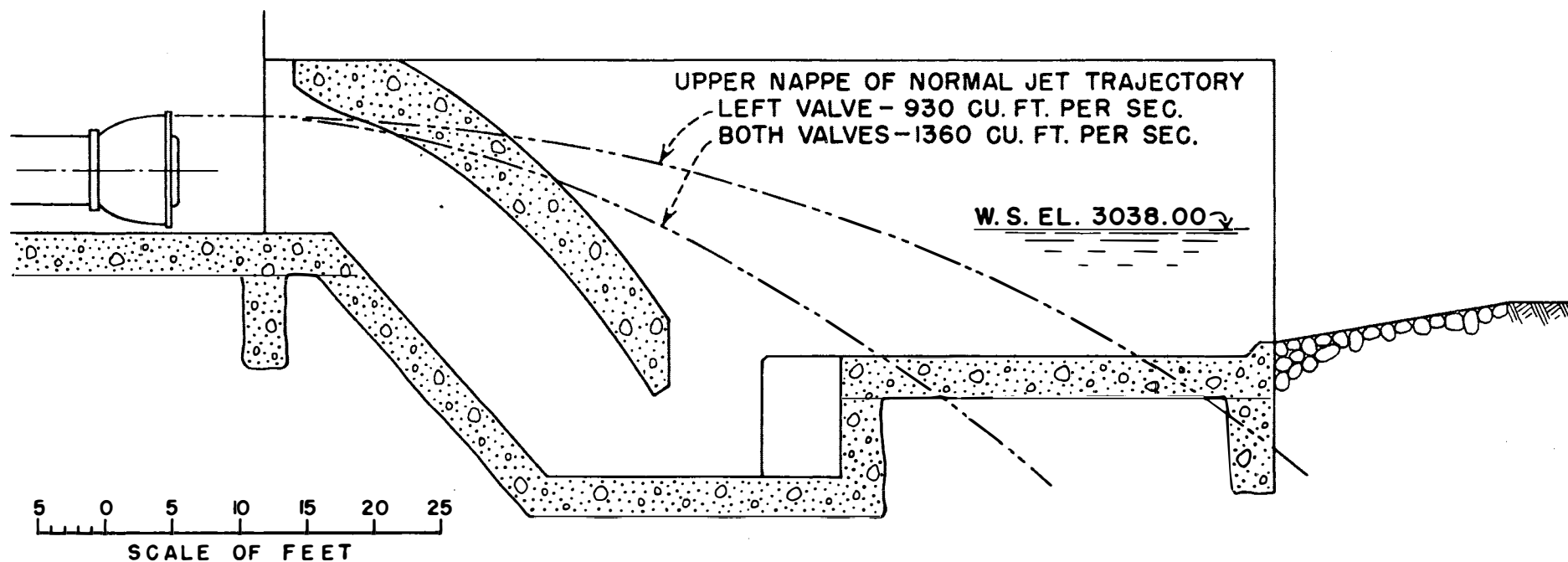
10 0 10 20 30 40 50
SCALE OF FEET

SECTION

FIGURE 2
ENDERS DAM OUTLET WORKS
PRELIMINARY STILLING BASIN

Figure 3
Enders Dam Outlet Works Stilling Basin
Much of the pool length was not useful in dissipating energy
in this hydraulic jump basin. Turbulence extended beyond basin
for lower tailwater elevation.

UPPER NAPPE OF NORMAL JET TRAJECTORY
LEFT VALVE — 930 CU. FT. PER SEC.
BOTH VALVES — 1360 CU. FT. PER SEC.

W. S. EL. 3038.00

5 0 5 10 15 20 25
SCALE OF FEET

FIGURE 4
ENDERS DAM OUTLET WORKS
SECTION ON ℄ OF RECOMMENDED BASIN

Figure 5
Enders Dam Outlet Works Stilling Basin
In the developed design shown, performance is satisfactory
with only one valve operating at maximum head and discharge;
the most critical operating condition.

Figure 6
Enders Dam Outlet Works Stilling Basin
The hood directs the flow to the bottom of the pool where
small-grain turbulence dissipates the energy quickly, at the same
time maintaining a smooth level water surface. Maximum head
and discharge.

Figure 7
Enders Dam Outlet Works Stilling Basin
With the more economical raised downstream floor, crenelated
in plan, performance was less satisfactory than with the lower
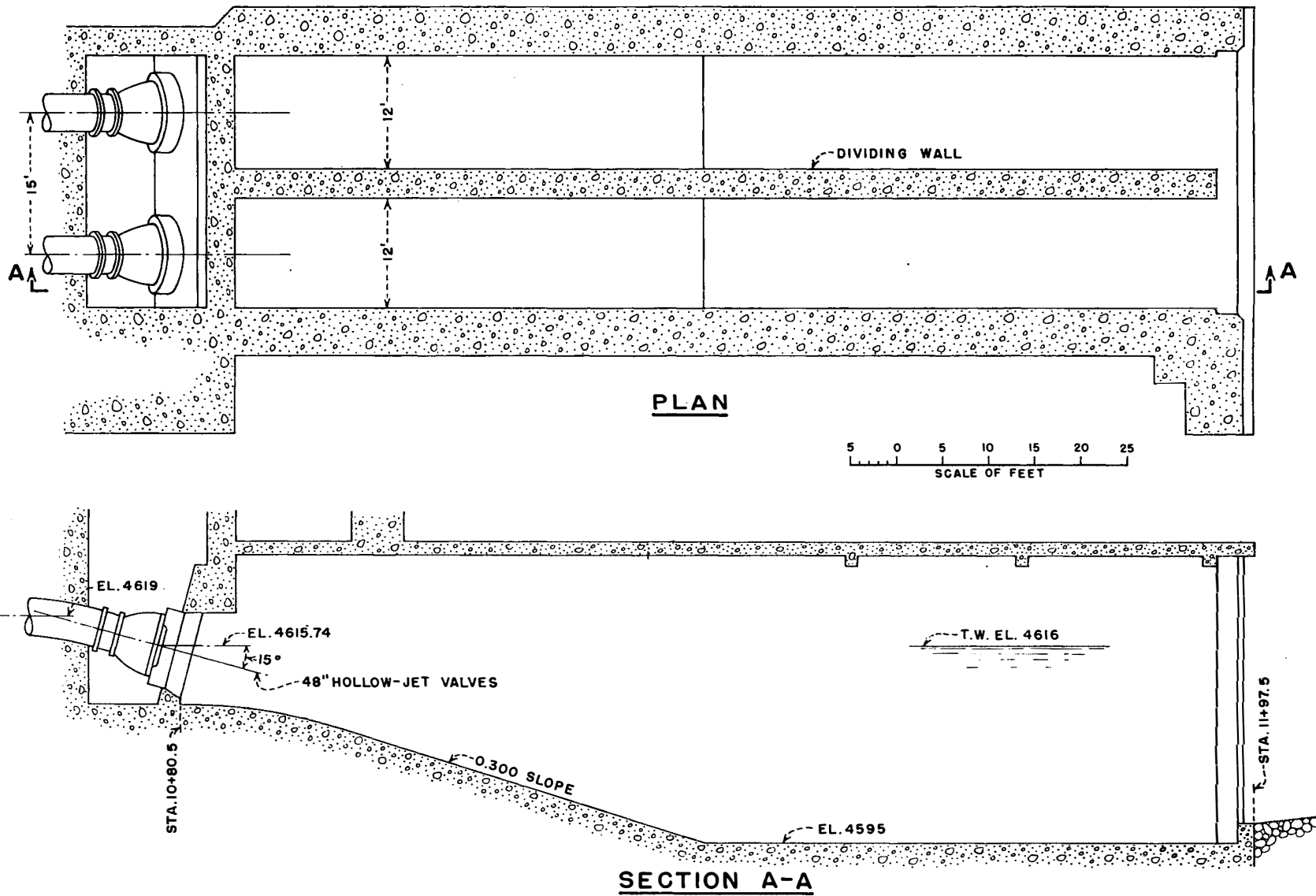floor but was considered adequate.   Maximum head and discharge.

PLAN

5   0   5   10   15   20   25
|ıııılııııl   ı   ı   ı   ı   ı |
SCALE OF FEET

12'

12'

15'

DIVIDING WALL

A

A

EL.4619

EL.4615.74

15°

48"HOLLOW-JET VALVES

T.W. EL. 4616

STA.10+80.5

0.300 SLOPE

EL.4595

STA. 11+97.5

SECTION A-A

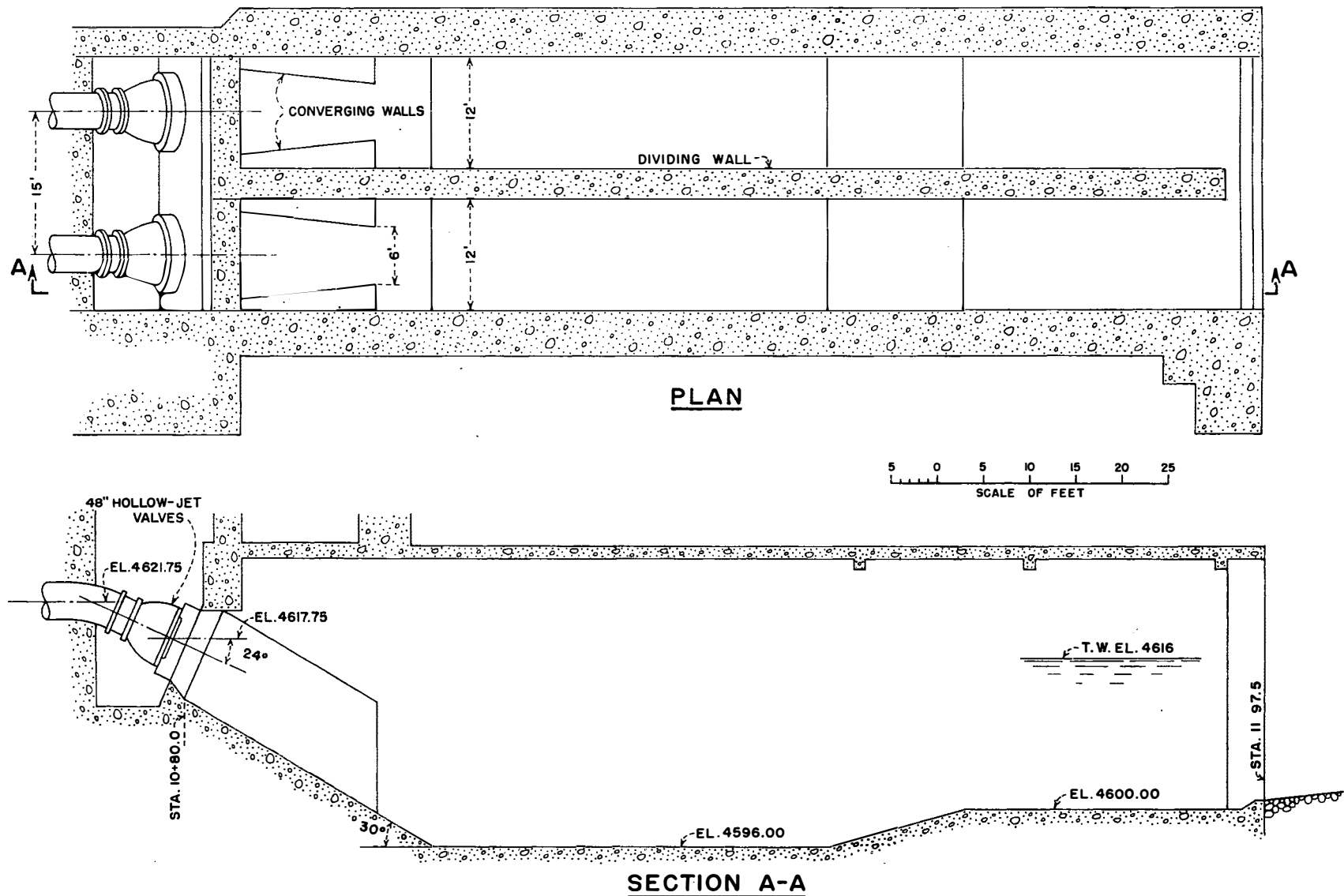FIGURE 8
BOYSEN DAM OUTLET WORKS
PRELIMINARY STILLING BASIN
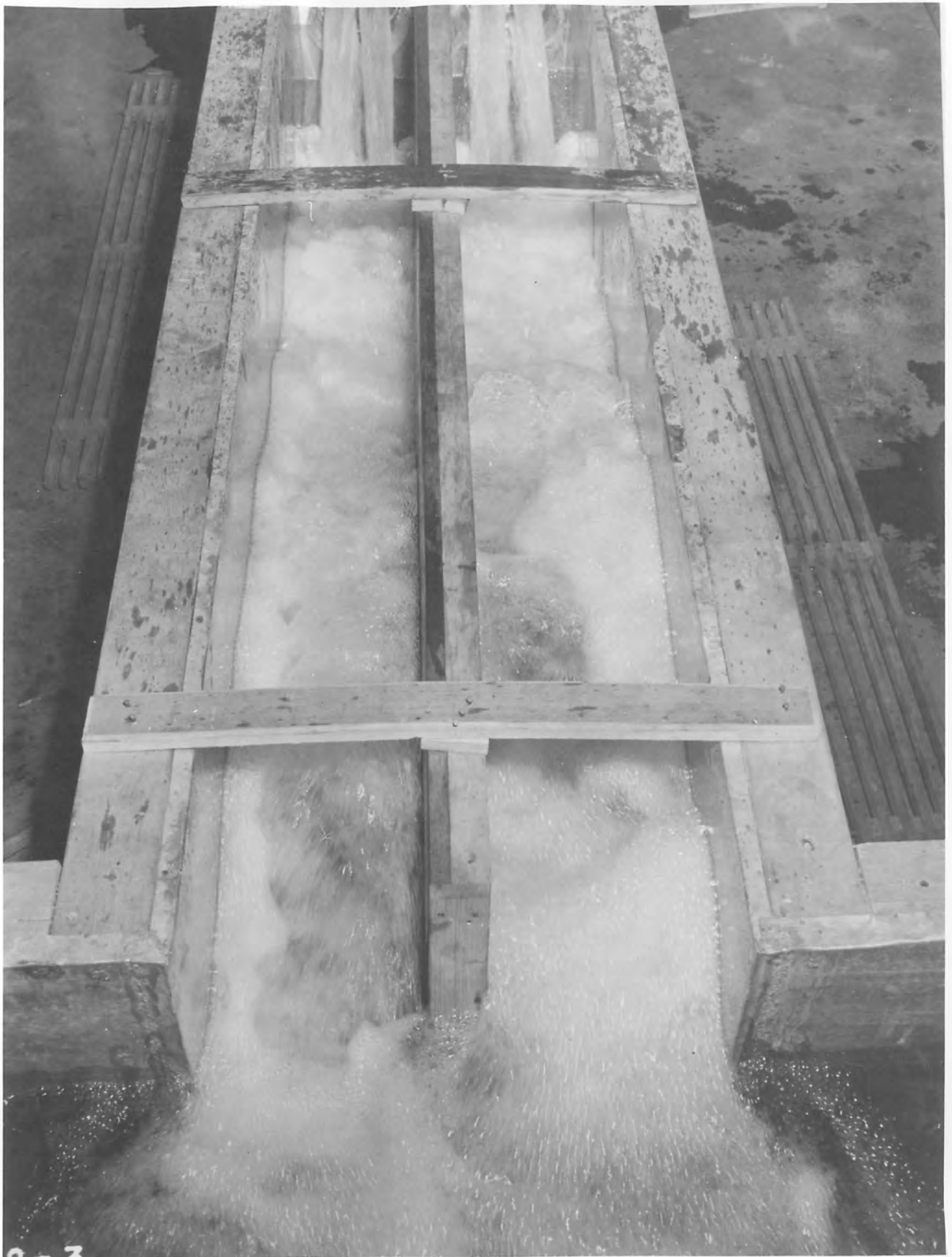
Figure 9
Boysen Dam Outlet Works Stilling Basin
Hydraulic jump stilling basin was too short. Turbulence ex-
tended beyond basin, especially with one valve operating at cor-
respondingly lower tailwater.

PLAN

SCALE OF FEET
5 0 5 10 15 20 25

SECTION A-A

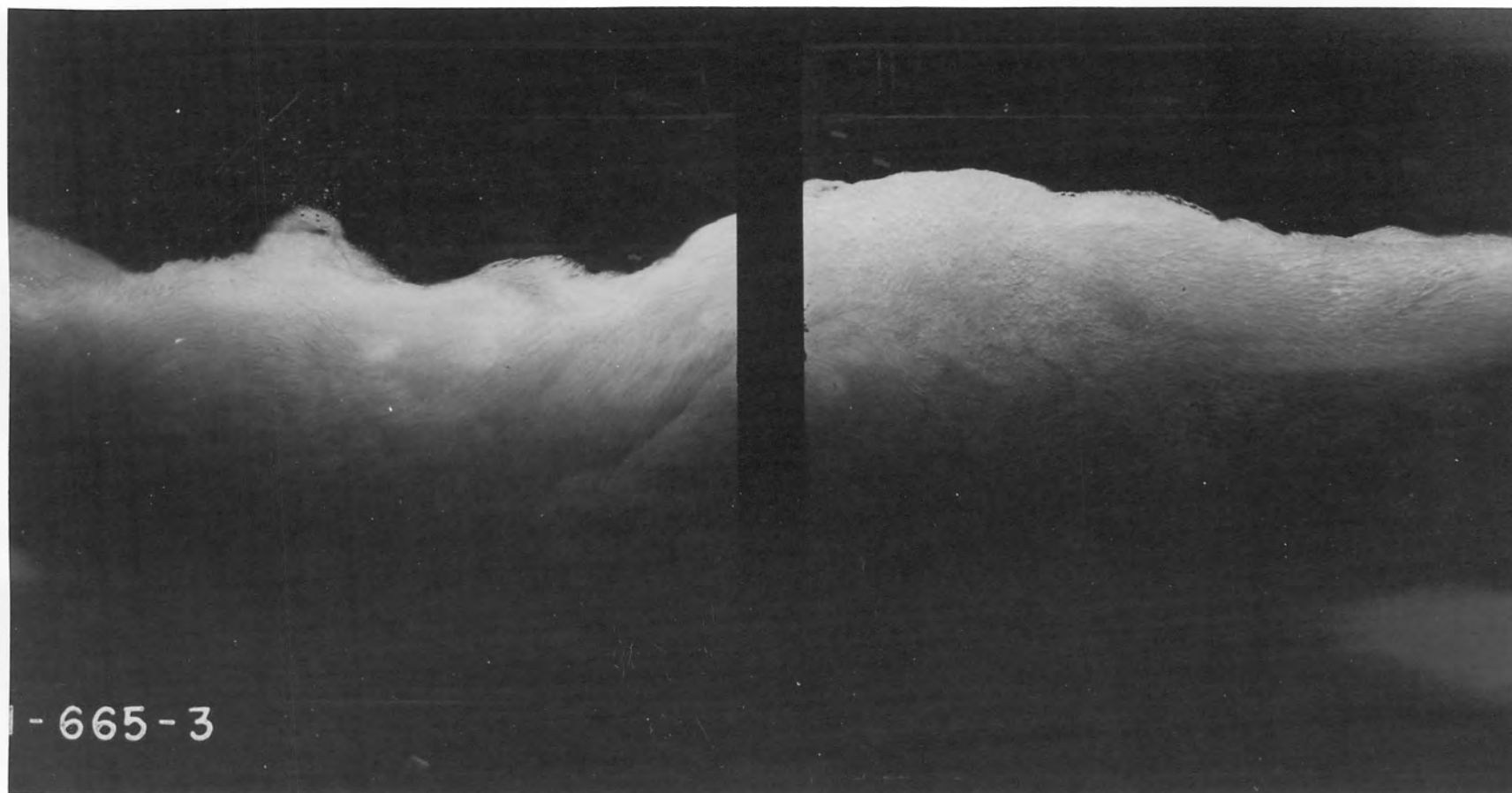FIGURE 10
BOYSEN DAM OUTLET WORKS
RECOMMENDED STILLING BASIN

Figure 11
Boysen Dam Outlet Works Stilling Basin
Partially developed basin shows distinct surface boil and in-
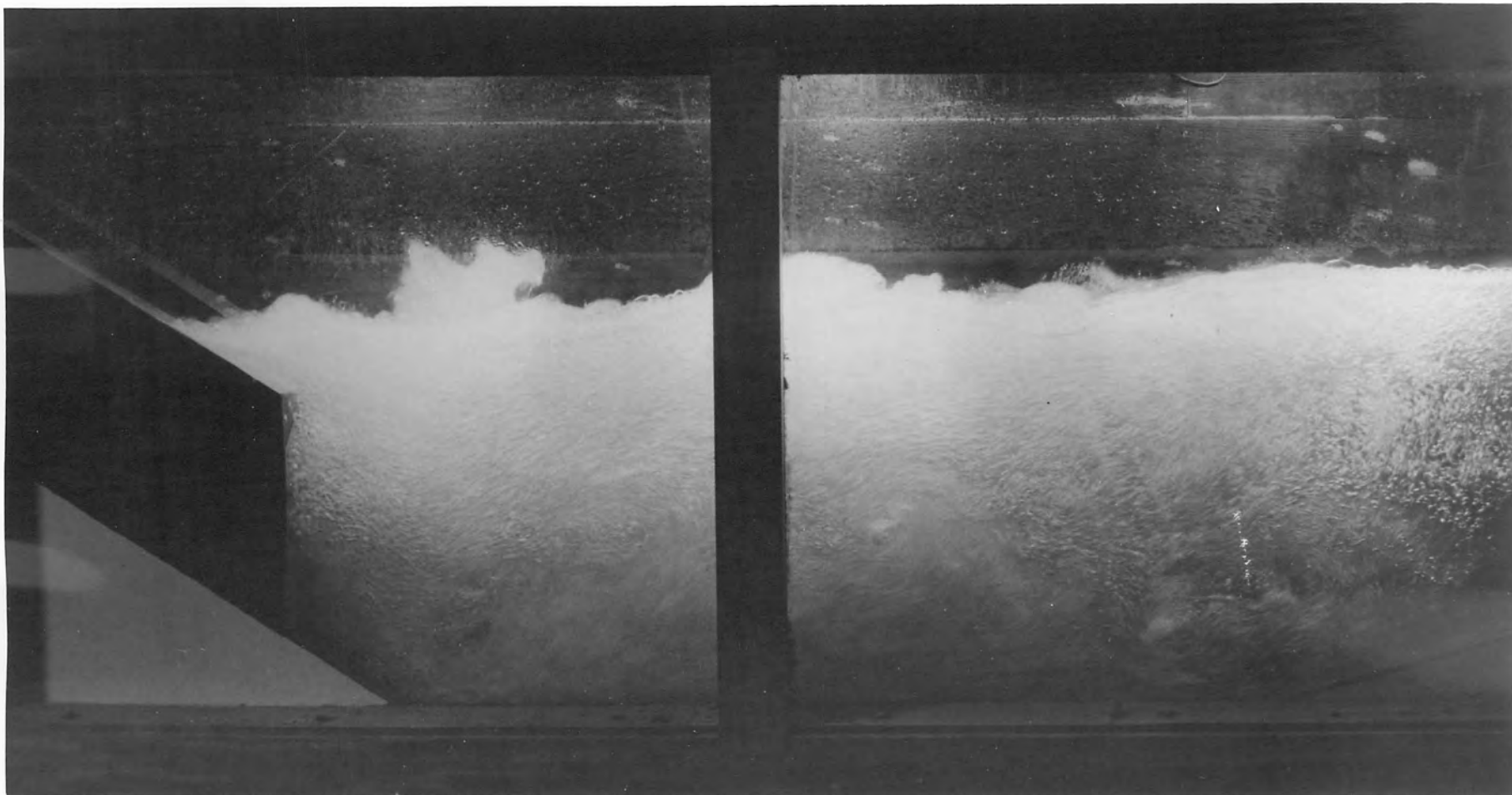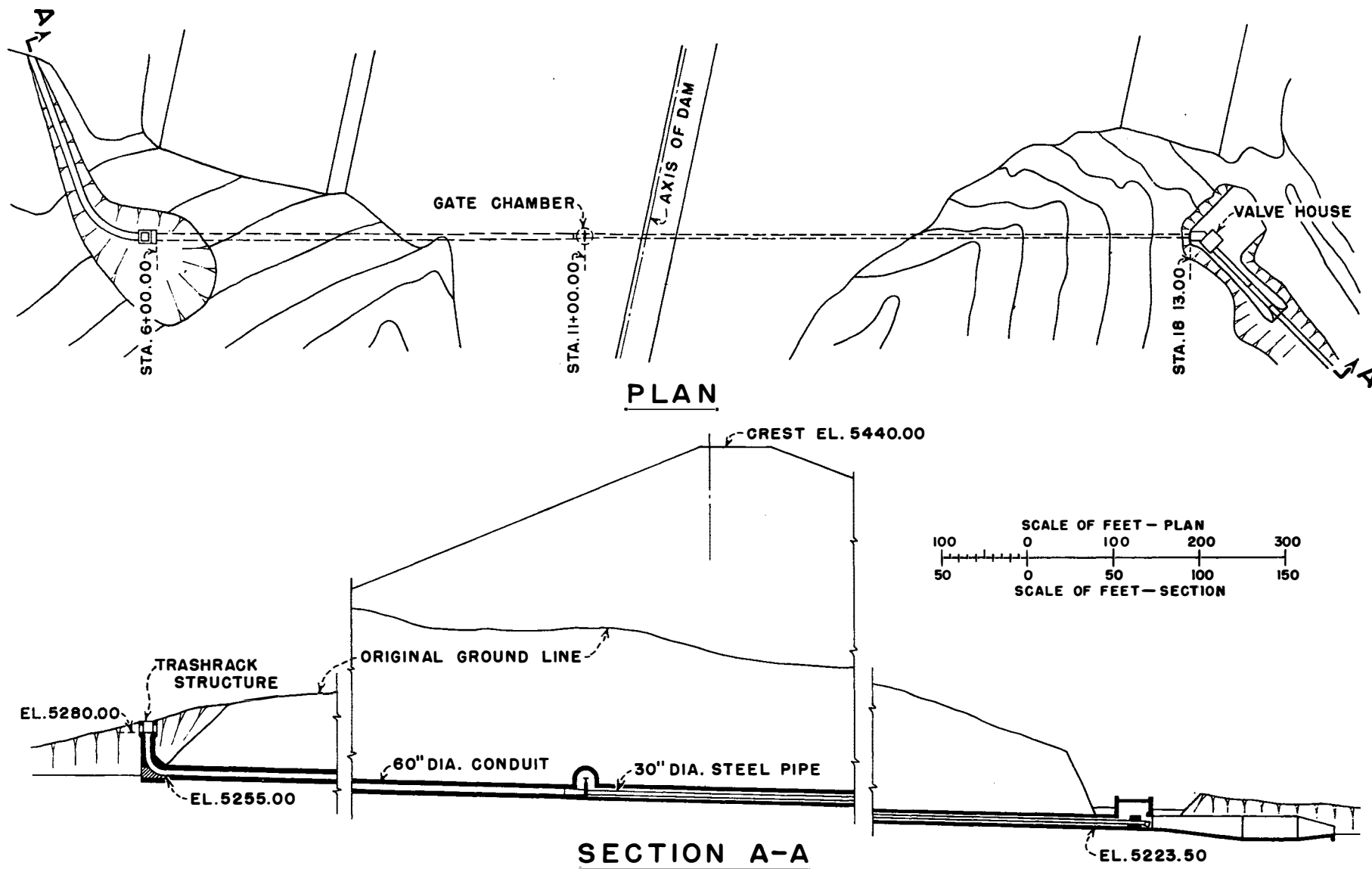efficient use of lower right hand portion of basin.

Figure 12
Boysen Dam Outlet Works Stilling Basin
Developed basin shows nearly level water surface and entire
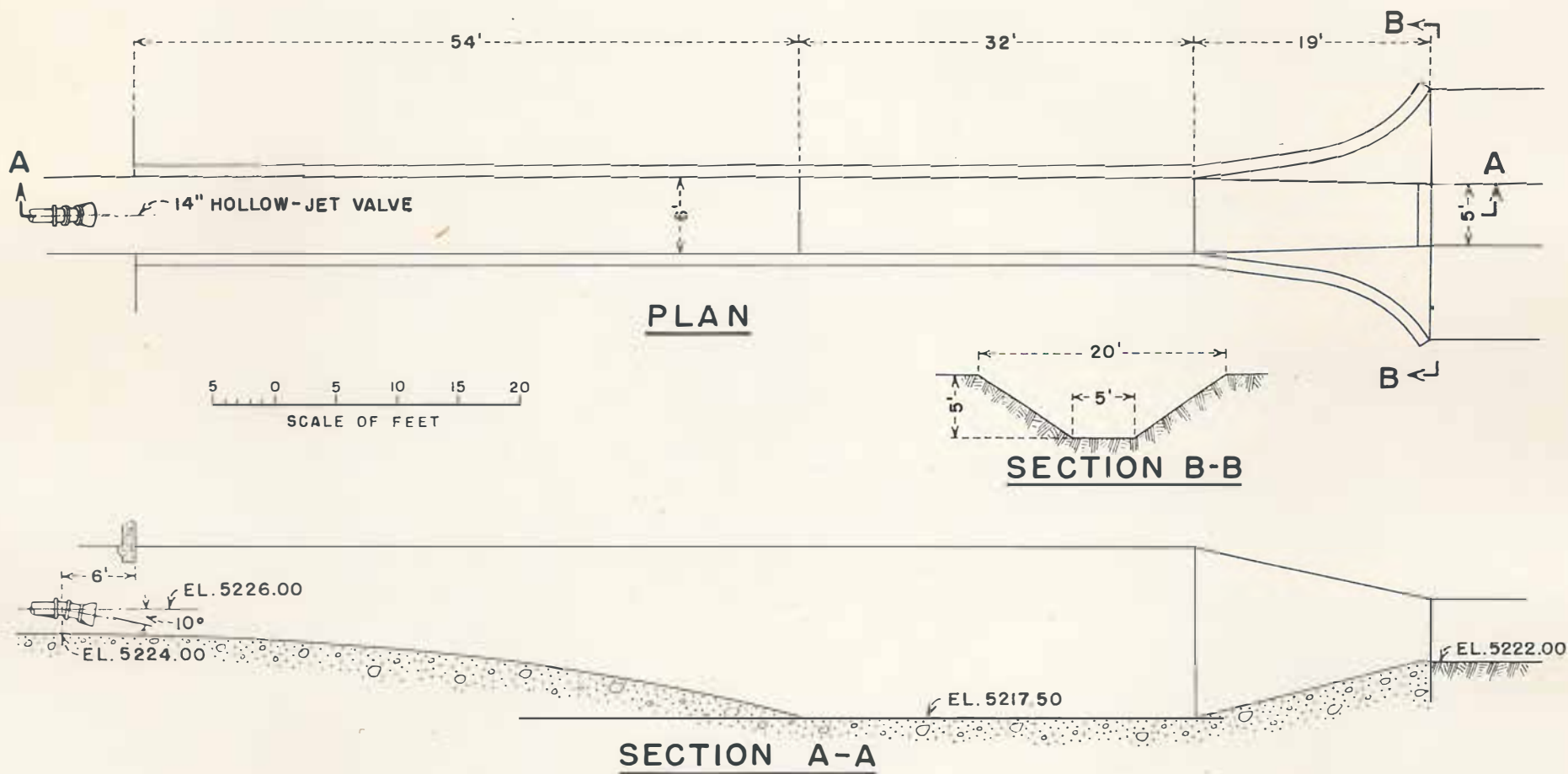basin volume contains small-grain turbulence which aids in dis-
sipating energy.

Figure 13
Boysen Dam Outlet Works Stilling Basin
The recommended basin shows marked improvement over the
hydraulic jump basin. Dissipation of energy is accomplished in
less basin length with less surface disturbance.

PLAN

GATE CHAMBER

AXIS OF DAM

VALVE HOUSE

STA. 6+00.00

STA. 11+00.00

STA. 18 13.00

CREST EL. 5440.00

SCALE OF FEET — PLAN

100	0	100	200	300

50	0	50	100	150

SCALE OF FEET — SECTION

ORIGINAL GROUND LINE

TRASHRACK
STRUCTURE

EL. 5280.00

60" DIA. CONDUIT

30" DIA. STEEL PIPE

EL. 5255.00

SECTION A-A

EL. 5223.50

FIGURE 14
SOLDIER CANYON DAM OUTLET WORKS
GENERAL ARRANGEMENT OF STRUCTURE

PLAN

54'   32'   19'

14" HOLLOW-JET VALVE

B

A

A

B

6'

5'

SECTION B-B

20'

5'

5'

5   0   5   10   15   20
SCALE OF FEET

SECTION A-A

6'

EL. 5226.00

10°

EL. 5224.00

EL. 5217.50

EL. 5222.00

FIGURE 15
SOLDIER CANYON DAM OUTLET WORKS
PRELIMINARY HYDRAULIC-JUMP STILLING BASIN

Figure 16
Soldier Canyon Dam Outlet Works Stilling Basin
Extreme turbulence and high velocity surface currents extended into the downstream canal when the pivot valve discharged directly into the stilling basin.
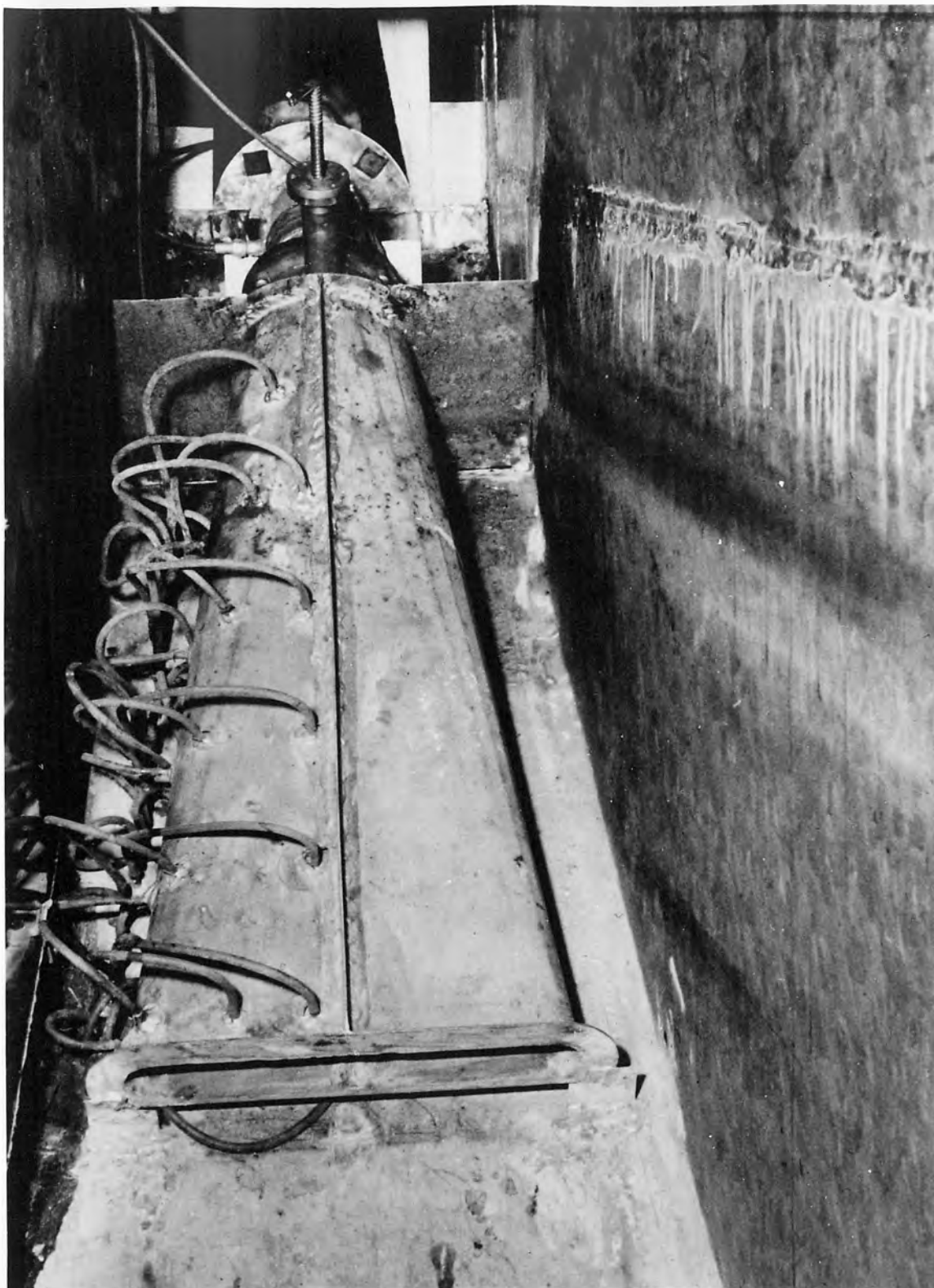
Figure 17
Soldier Canyon Dam Outlet Works Stilling Basin
Hood used to conduct flow from valve toward basin bottom.   Flow
is released well below basin water surface.   Piezometers shown
were used to check pressures inside the hood.

PLAN

5 0 5 10 15 20
SCALE OF FEET

SECTION B-B

CONTROL VALVE
EL.5226.00

EL.5222.20
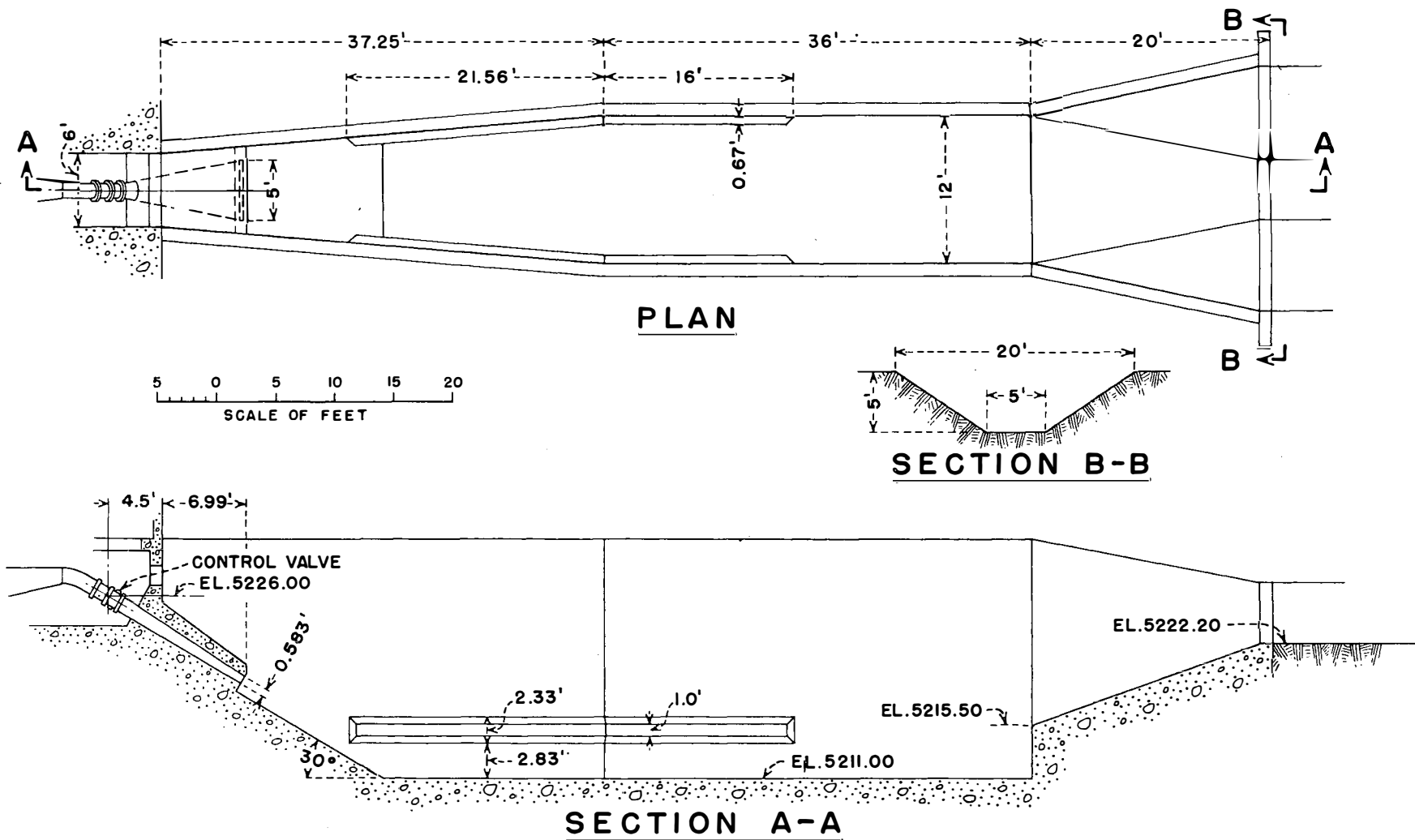
EL.5215.50

EL.5211.00

SECTION A-A

FIGURE 18
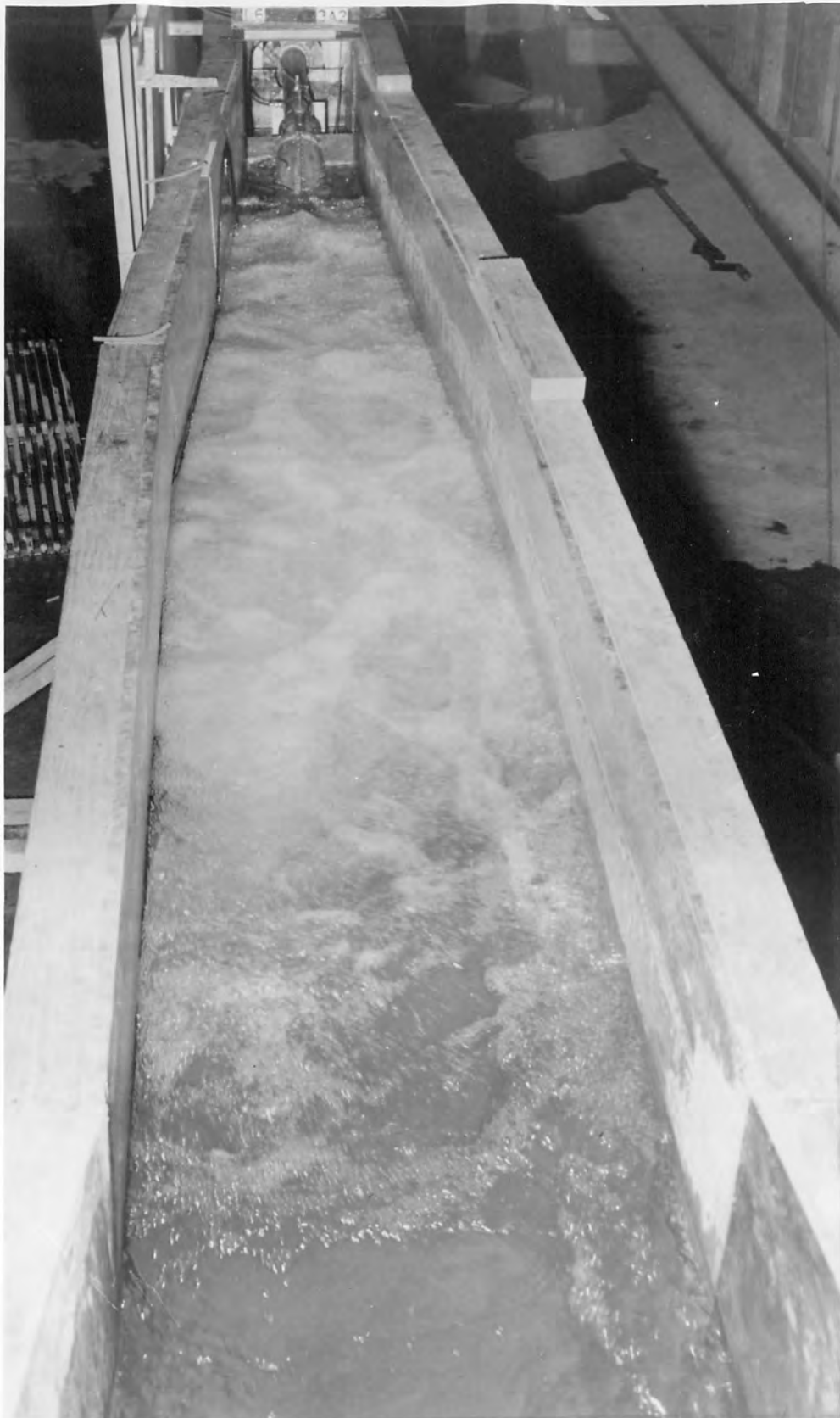SOLDIER CANYON DAM OUTLET WORKS
RECOMMENDED STILLING BASIN

Figure 19
Soldier Canyon Dam Outlet Works Stilling Basin
The recommended stilling basin with the developed hood shows
excellent performance for all operating conditions. Shown is the
present maximum discharge, 60 second-feet at 205 feet of head.