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MODEL AND PROTOTYPE STILLING BASINS

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ABSTRACT

Model and prototype examples of five different stilling basin structures on Bureau of Reclamation projects are presented. Discussed are structures designed without the benefit of hydraulic model studies and in which some deficiency became apparent, those designed on the basis of a model study and in which some deficiency was later discovered, and those designed on the basis of a hydraulic model study and which operated as predicted. The deficiencies encountered in some instances and the measures taken to correct them are described. The unusual features of the various structures are described.

INTRODUCTION

The stilling basin was in existence in natural form long before man began to build dams across streams. Streams have always made use of natural stilling basins throughout their courses to slow the water after it has speeded up through a steep section.

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Stilling basins used by man have varied from the natural pool at the toe of the dam or the end of a spillway channel to the modern, well-proportioned, efficient, architectural structure. Many of these basins ably performed their function of dissipating energy and transforming the higher velocity shooting flow to turbulent flow of non-destructive form, while others failed completely.

Certain relationships must exist between stream velocity, stream thickness, length of pool, and depth of tailwater to have a stilling basin perform its function. When the proper relationship of these factors does not exist, aids such as baffle piers and sills are placed in the basin. The Bureau of Reclamation has made numerous investigations over the years on different basin designs to establish practical, general design procedures.[2/] Basins constructed in accordance with these procedures function as predicted unless some flow characteristic of the design is different from that used in establishing the procedure. Where such differences are encountered, model studies are the most logical approach. In some cases the difference is not obvious to the designer and his structure fails in some way to perform its intended function.

2/ "Hydraulic Design of Stilling Basins" by J. N. Bradley and A. J. Peterka. Journal of the Hydraulics Division, American Society of Civil Engineers. October 1957.

There have been a few instances in past years where a stilling basin constructed without the benefit of a model study has failed to perform properly and a model study was later made to develop some means of correcting the deficiency. Also, there have been deficiencies discovered in prototype structures even though the design was based on the results of a well-planned comprehensive model study. Such cases are rare but do exist. Usually the prototype structure has performed exactly as predicted when the design was based on a comprehensive model study. Five examples will be discussed briefly in this paper.

STRUCTURES HAVING BENEFIT OF MODEL STUDY AFTER CONSTRUCTION

Carter Lake Canal Outlet Works [3/]

The arrangement of the outlet works which supplies water to the Saint Vrain Canal from Carter Lake, a reservoir of the Colorado-Big Thompson Project, near Loveland, Colorado, is typical of outlet works used for earth and rock-fill dams. The outlet is essentially a gate-controlled tunnel passing through the base of

3/ Bureau of Reclamation Hydraulic Laboratory Report HYD 394, "Hydraulic Model Studies of the Outlet Works at Carter Lake Reservoir Dam No. 1. Joining the St. Vrain Canal."

the dam with a special intake structure in the reservoir and a stilling basin at the downstream end near the toe of the dam (Figure 1). In this design two gates are located about midway between the inlet and outlet of the tunnel. The high-velocity discharge from the gates in the Carter Lake outlet structure flows about 400 feet before it emerges into an open-cut channel and enters the stilling basin.

Where the tunnel downstream of the control is quite long, the water is slowed by friction until the depth and velocity are quite different from that immediately downstream of the gates. The stream geometry at the entrance of the stilling basin will depend principally upon the initial velocity at the gates, the length of the flow channel between the gates and the basin, and the roughness of the flow surfaces. The depth-velocity relationship used for a design must be reasonably near the actual conditions if the basin is to perform properly. This requires knowledge of the friction coefficient for the tunnel, or flow channel, downstream of the controls.

At first thought a value of 0.012 to 0.014 for "n" in the Manning formula would seem reasonable. However, there is one factor in particular which makes the usual values for open-channel flow nonapplicable. The boundary layer is substantially destroyed as the flow accelerates through the controls and must redevelop as the flow moves on downstream. This redevelopment of the boundary layer requires a substantial distance which depends on the roughness of the surface and the flow velocity.

The Carter Lake outlet works stilling basin was designed assuming an "n" value of 0.014. The computed velocity of the flow entering the basin using this value of "n" was 39 feet per second. The dimensions of the stilling basin required for the velocity-depth relationship obtained in this manner are shown on Figure 2.

When the field structure was operated, conditions in and downstream of the stilling basin were extremely rough; in fact, the hydraulic jump swept completely from the basin at the design discharge of 625 cfs under a head of 100 feet which was 59 feet below the maximum (Figure 3). Field attempts to make the structure operable by placing a log raft at the end of the basin and adding sand bags to the downstream canal banks failed, so hydraulic model studies were instigated.

The model used to investigate the cause of the deficiency and to develop a remedy was constructed on a scale of 1 to 16 (Figure 4). The model represented the gates, the downstream horseshoe tunnel, the stilling basin and the Parshall measuring flume downstream from the basin. The initial tests on this model verified the prototype action and indicated that the jump would be swept from the basin when the entrance velocity exceeded about 53 feet per second (Figure 5). Since this was much in excess of the velocity used for design, field tests were made to ascertain what velocities would exist in the prototype structure.

It was impossible at the time of the field tests to release large flows, so velocity and depth measurements were made at the prototype tunnel portal for one head and one discharge. The average measured velocity was about 25 feet per second. The apparent value of "n" computed from this velocity and depth measurement was 0.008. The entrance velocity at the basin for maximum discharge was computed to be 58 feet per second when this value of "n" was used. A velocity equivalent to 60 feet per second was used in the model studies to evolve a remedy for the deficiency. Rather tranquil flow was desirable at the end of the basin because the Parshall measuring flume requires uniform tranquil approach flow for best accuracy.

It was desired to retain the general dimensions of the basin and make a minimum of alterations to obtain satisfactory flow conditions. The problem was therefore one of supplying adequate aids within the original basin. After numerous tests were made, involving many combinations of chute blocks, baffle piers and sills, a special design consisting of six hook-shaped piers was determined to be the optimum (Figure 6). Flow entering the measuring flume downstream was still too rough for good flow indication (Figure 7) and further tests were directed toward improving the flow conditions at the flume entrance.

A cover was placed in the channel section between the stilling basin and flume to form what is known as a short tube underpass, or wave suppressor, developed in the Bureau laboratory where rough-operating stilling basins discharge their flow directly into canals. The remedy for keeping the jump in the basin and smoothing out the flow entering the canal appeared very effective on the model (Figures 8 and 9). This fact was later verified by prototype operation (Figure 10).

Tule River Parsnall Flume[4/]

A structure not having the benefit of model studies and found deficient in its performance after being built was the

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4/ Bureau of Reclamation Hydraulic Laboratory Report HYD 406, "Hydraulic Model Studies of Tule River Parshall Flume--Friant-Kern Canal--Central Valley Project."

stilling basin approach channel to the 15-foot Parshall flume which measures releases of water from the Friant-Kern Canal to the Tule River near Porterville, California.

Three 6- by 6-foot slide gates control water releases into this channel which feeds the measuring flume only 40 feet away (Figure 11). The channel is 25 feet wide, about 27 feet long and 17 feet deep. A vertical step up of 7 feet 5 inches at the downstream end of the basin connects to the entrance transition of the flume and forms a boxlike basin between the gates and the flume entrance. This basin was intended to still the flow from the gates before it entered the flume. Tranquil flow in the flume approach at a depth greater than critical is a requisite to accurate flow measurement.

When accurate measurement of water is required by a large structure, such as the 15-foot Parshall flume used in this case, it is the practice to calibrate it in place during the early period of operation by making spot checks of the standard rating table. Such calibrations are particularly important when the setting deviates from the ideal or conventional installation for which standard rating tables are applicable. The comparatively short distance from the stilling basin to the Tule River flume made calibration of this flow measuring structure desirable.

Excessive surging was discovered in the head measuring well when the calibration was begun. For most discharges the water from the partially open gates passed through the bottom portion of the basin, impinged on the step up and rose to the surface in violent turbulent "boils" (Figure 12). This caused excessive surging of the water surface in the head measuring well until the 4-inch opening leading to the well was reduced to 3/4-inch. Although the head in the well was then recordable, surface variations at the staff gage on the wall of the flume near the entrance to the gage well were as much as 0.6 of a foot.

Current meter traverses were made in the flume for several discharges. The difference between the discharge indicated by the standard rating table and the discharge determined from current meter traverses was as much as 39 percent for flows of the order of 200 cfs, 30 percent of the turnout capacity (Figure 13). The inaccuracy was somewhat less for both the higher and lower ranges of discharge. Examination of the stilling basin disclosed a build-up of head sufficient to cause critical flow to occur at the step up for all discharges. This condition caused a higher velocity and a shallower depth in the flume entrance than would have been the case had the flow entered the flume at depths above critical. As a result, the depth registered by the head gage was too small and the quantity of water for this head indicated by the standard head-discharge rating curve was less than that actually passing through the flume. Hydraulic model studies to evolve corrective measures were instigated when the solution to the problem appeared complex.

The model, which was constructed on a scale of 1 to 18, represented a portion of the main canal, the adjacent wasteway and the turnout, including the control gates, stilling basin and measuring flume. Good correlation between model and prototype flow conditions was noted, even to the magnitude of the water surface variation at the staff gage (Table 1).

It was desirable from an economic standpoint to keep any corrective measures within the confines of the existing structure. The problem thus became one of determining what aids, such as baffle piers, slotted walls, and sills could be placed within the basin to assure tranquil, above-critical-depth flow in the flume entrance transition. Various fillets were placed immediately upstream from the 7-foot 5-inch step up to eliminate the abrupt change in cross section of the flow passage. Baffle piers with sills between them were placed on the basin floor near the gates, and slotted walls were placed in the basin near the upstream edges of the floor fillets. An arrangement of these aids to give satisfactory flow in the measuring flume was determined (Figure 14). Eight baffle piers 5 feet high and 18 inches wide with sills 9 inches high and 18 inches long between them were placed 2 feet downstream of the gate head wall. A fillet 15 feet long and 7 feet 5 inches high, with an upslope of about 2 to 1 and a 7-foot 5-inch radius, was placed in the downstream corner of the basin. A slotted wall with twelve 12-inch-wide vertical openings placed on 2-foot centers was tested but was considered optional because of the small improvement in flow it afforded. Variations in water surface at the staff gage were measured for discharges up to and including the maximum of 700 cfs, with and without the slotted wall in place. These variations are given in Table 1.

TABLE 1

Approximate Flume Discharge cfs (Proto)	Water Surface Variation at Head Gage (Feet Prototype)				
	Original Structure		Modified Structure		Design With Slotted Wall
	Proto	Model	Proto	Model	Model
250	0.25	0.25	0.10	0.04	0.04
500	.60	.38	.12	.07	.05
630	.60	.54	.11	.09	.07
700	--	.61	--	.09	.05

The slotted wall was not included when the corrective measures were constructed in the prototype. The modified prototype structure was tested to determine the effectiveness of these measures. Their effectiveness can be realized from a comparison of model and prototype conditions for the original and modified structure, Figures 15 and 16, and Figures 12 and 17. Complete photographic records, including motion pictures, were taken and these showed excellent correlation between the model and prototype, even to the water surface variations at the staff gage, Table 1. Current meter measurements showed a maximum deviation from the standard rating table of about 5 percent at a discharge near 450 cfs. The deviations were less both above and below this quantity. The structure is now being operated satisfactorily.

STRUCTURES HAVING BENEFIT
OF MODEL STUDY PRIOR TO CONSTRUCTION

Pump-Turbine By-Pass Valve--Flatiron Power and Pumping Plant[5/]

It is rare that a structure based on comprehensive hydraulic model studies fails in some detail to function as intended. One such case was the stilling basin for the pump-turbine by-pass valve at the Flatiron Power and Pumping Plant of the Colorado-Big Thompson Project near Loveland, Colorado. The discrepancy appeared to be in pressure conditions because cavitation, not predicted by the model, occurred in the prototype.

The pump-turbine unit in the Flatiron plant pumps water from the tailrace into nearby Carter Lake storage reservoir during low-power-demand periods and then uses a part of this pumped water to generate power during high-power-demand periods. The remainder of the stored water is released as needed

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5/ Bureau of Reclamation Hydraulic Laboratory Report HYD 328, "Hydraulic Model Studies of the Stilling Basin for the Pump-Turbine By-Pass Valve at Flatiron Power and Pumping Plant--Colorado-Big Thompson Project."

for irrigation through the Carter Lake outlet works described in the preceding section of this paper. The by-pass valve is attached to a branch in the pump-turbine penstock and serves to release storage water under an approximate head of 300 feet from the reservoir to a feeder canal of the irrigation and storage system farther to the north when the pump-turbine unit cannot be used for that purpose. A schematic arrangement of this system is shown in Figure 18. The stilling basin for this by-pass valve was the subject of a comprehensive model study.

The first design considered was one using a 42-inch hollow-jet valve and a rectangular stilling basin to dissipate the energy in the valve jet and transform it to nondestructive form, Figure 19. The model tests on this arrangement disclosed extremely rough flow conditions in and downstream from the basin for discharges near the design maximum of 500 cfs, (B, Figure 20). It was desired to improve the flow and if possible confine the basin within the limits of the powerplant structure. Since a short effective basin using either a submerged tube or needle valve had been developed for another project, studies were concentrated on obtaining a satisfactory design of this type of basin.

A design evolved from hydraulic model studies was one using a 42-inch tube valve operating submerged at the upstream end of a stilling basin containing a special arrangement of baffles, Figure 21. The valve discharge impinged on a triangular splitter pier, or baffle, which directed the divided flow outward to the walls of the basin. A part of the flow on each side was turned upstream and the remainder on each side turned downstream. The downstream flow was directed to the center of the basin by baffles built in the basin walls. A floor with a passage beneath it allowed circulation of water from the downstream portion of the basin back upstream to the valve. The circulation in this passage helped to keep the subatmospheric pressures in the basin to less than half an atmosphere as recorded by a pressure cell and oscillograph, a value not considered critical.

The flow conditions in this basin were very tranquil compared to those for the unsubmerged hollow-jet valve and rectangular basin, (A, Figure 20). Moreover, the basin with the submerged tube valve was much shorter and could be constructed well within the confines of the powerplant substructure.

It was realized that rapid fluctuations in pressures were likely to occur in this basin and that it might be possible for the pressure to reach vapor pressure momentarily and thus induce cavitation. The pressures at critical points were investigated by a pressure cell and an oscillograph. Variations of as much as 20 feet of water were recorded but pressures lower than 15 feet below atmospheric were not indicated. The design was therefore considered satisfactory and was constructed.

The structure was completed and placed in operation about three years after the model tests were made. The flow conditions at the downstream end of the basin were excellent and as indicated by the model (Figure 22). However, there was considerable noise and vibration. The vibration was of such intensity as to warrant a field study of the structure. The field study was facilitated because piezometers had been installed in locations corresponding to those used in the model and which were believed to cover all the critical points. Pressure tests were made by the writer in the fall of 1954.

An inspection of the flow surfaces disclosed cavitation at several locations. However, all except one of these cavitated areas resulted from local irregularities in the flow surface, the most prominent being the abrupt into-the-flow offset of the concrete surfaces at the edges of the steel lining on the sidewalls upstream of the baffles. The offsets were as much as three-eighths of an inch and cavitation-erosion had resulted on both sides of the basin due to the high velocity water passing over these offsets (Figure 23). These areas were not considered serious because the cavitation could be eliminated by grinding the offsets on very flat bevels.

The cavitation in the ceiling of the passage just downstream and to each side of the center triangular baffle (Figure 25) was considered of a more serious nature. One cavitated area was near two piezometers which registered slightly positive pressures and moderate fluctuations. The pressures were recorded by mercury-filled U-tubes so the fluctuations were dampened. It was reasoned that the piezometers were not properly located to register the lowest and most critical pressures in the area just downstream from the triangular baffle. The pressure distribution pattern was very similar to that obtained from the model.

The abrupt offsets were ground on a bevel of 30:1 and made flush with the metal surface at the joint. Also, facilities were provided to inject compressed air into the basin at the critical points to ascertain the effectiveness of venting behind the triangular baffle. Subsequent tests showed that a decided decrease in the noise and vibration in the structure had been accomplished. The cavitation apparently had not been completely eliminated but the outlet was made operable. The turbulence in the tailrace was changed very little by the venting, Figure 25. The flow was quite smooth and there was no danger to the riprap surfaces of the tailrace. In the past three years the by-pass has not been used.

Soap Lake Siphon Blowoff Structure [6]

A unique stilling basin, termed a vertical stilling well, was developed in 1947 for dissipating the energy in the flow from a 16-inch drainpipe near the low point of the Soap Lake siphon on the Columbia Basin Project irrigation system near the town of Soap Lake, Washington.

The drain structure, or blowoff, was designed to release about 90 cfs under a maximum head of 212 feet and was not intended to operate at partial openings for extended periods because of danger of cavitation at the valve. The design was complicated somewhat because the drain flow from the siphon could not be

[6] Bureau of Reclamation Hydraulic Laboratory Report HYD 277, "Hydraulic Model Studies of the Stilling Well for the Blowoff Structure, Soap Lake (Inverted) Siphon--Columbia Basin Project."

drained directly into nearby Soap Lake where it would dilute the mineral content of this resort attraction. The flow had to be conveyed in an earthen channel about 1-1/2 miles long to Lake Lenore. The earthen channel made it necessary that the flow leaving the structure be tranquil without excessive wave or surge action. Since previous exploratory laboratory tests had indicated that a vertical stilling well could be designed with the siphon drainpipe directed vertically downward to meet these requirements, this type of structure was chosen for development by hydraulic model studies.

The preliminary design well was 6 feet square in cross section and 10 feet deep with respect to the bottom of the trapezoidal conveying channel. The well was placed at the dead end of the channel which had a bottom width of 6 feet and side slopes of 1-1/2 to 1.

The model used for the initial tests on this design was built to a scale of 1 to 4. The model scale was later changed to 1 to 5 when the initial tests indicated the need for a larger prototype well. This new scale was represented by changing the size of the model supply pipe. Later, false walls were placed in the well to represent the smaller preliminary design on the 1 to 5 scale. Operation of the model was mainly at wide-open gate and under variable head, because of the possibility of cavitation of the prototype at partial openings of the 16-inch gate valve.

Extreme turbulence with violent boiling action occurred on the model of the preliminary design, Figure 26. Waves up to 4 feet high prototype were indicated at a point in the channel 15 feet from the well. These tests emphasized the need for some type of aid within the well to increase its effectiveness as a stilling device for the larger discharges.

Numerous aids, in the form of baffle piers, baffle walls, pedestals, shelves, and corner fillets were investigated, Figure 27. Several of these aids showed a definite improvement over the preliminary design. The aids giving the best conditions are shown as G and H on Figure 27. The square well with corner fillets was selected for further study because of the simplicity of construction. Subsequent model tests showed that optimum flow conditions were obtained when corner fillets were placed in a well 7-1/2 feet square and 11 feet deep below the bottom of the channel. In this arrangement the end of the downpipe was 2-1/2 feet from the floor and corner fillets 3 feet 1-1/4 inches wide, about 22 inches high, with lower and upper surfaces sloping back to the corner, were set 12 inches from the floor (H, Figure 27). The flow conditions for this design operating at a head equivalent to about 200 feet and a flow representing 90 cfs are shown on Figure 28. The model indicated that waves in the channel 15 feet from the well would be about 6 inches high for a flow of 75 cfs and about 9 inches high for a flow of 90 cfs. The effectiveness of this design in quieting the water may be visualized by comparing the flow conditions shown in Figures 26 and 28. Later studies with a fluid polariscope model indicated that the fillets were extremely effective in affecting a uniform distribution of the flow rising from the well.

When the prototype structure was completed and placed in operation in 1951, the flow in the stilling well was quite acceptable and in excellent agreement with that indicated by the model (Figures 28 and 29). The design has been used in other installations and a special cavitation-free valve developed for use at the end of the pipe in the bottom of the well.

Boysen Dam Outlet Works Stilling Basin[7/]

The efforts of progressive hydraulic engineers have always been directed toward developing better operating structures at less cost. These efforts have brought about new developments in the hydraulic design of stilling basins for valve-controlled outlet works. The stilling basin used for the outlet works at Boysen Dam of the Missouri River Basin Project near Thermopolis, Wyoming, is one example.

The conventional stilling basin, which depends upon the hydraulic jump for the dissipation of the energy in the inflowing stream, does not provide an economical solution when the inflow is in the form of concentrated jets from valves. The distance required to spread the flow uniformly before it enters the stilling basin is not useful for dissipating energy. This part of the structure adds to the overall length and cost of the stilling basin. The waves and turbulence downstream from such basins are usually objectionable when the discharge empties into a canal or a powerhouse tailrace. Recently developed designs have eliminated most of the objectionable flow conditions found in conventional stilling basins.

7/ Bureau of Reclamation Hydraulic Laboratory Report HYD 283, "Hydraulic Model Studies of the Outlet Works, Boysen Dam, Missouri River Basin Project."

The stilling basin for the Boysen outlet works employs downward-tilted hollow-jet valves with converging chute training walls extending from the valves to the upstream end of the stilling section of the basin. The converging walls transform the valve streams from cylindrical hollow jets to rectangular jets as they enter the stilling section of the basin. This convergence and change in shape causes the jets to penetrate the tail water and remain submerged as the energy is dissipated in turbulence. Outward offsets at the ends of the chute training walls assist in improving the flow distribution within the basin and thus increase the effectiveness of the basin. An upward sloped sill near the end of the basin deflects any currents off the bottom of the flow channel as they move from the end of the basin. The turbulent flow within the stilling section of the basin is not a true hydraulic jump. Because the action is similar to a hydraulic jump, it has been termed a modified jump.

The hollow-jet valve is a special control developed for unsubmerged operation, Figure 30. A cone-like regulating element moves upstream against the flow to close this valve. The cone directs the flow outward along the inner surface of a bell-shaped body which discharges the water in the form of a cylindrical, hollow jet. The hollow-jet valve received its name from this characteristic.

Two hollow-jet valves placed side by side, 15 feet apart, and tilted downward were used for the Boysen outlets. The preliminary design which employed the hydraulic jump for the dissipation of energy had an overall length of 117 feet. The valves were tilted downward 15 degrees, Figure 31. The flow in the 1 to 16 scale model outlet structure was rough with high surface velocities, Figure 32. Also, excessive erosion occurred in the movable-bed channel downstream indicating poorly developed stilling action. A much longer stilling basin, or stilling aids, such as baffle piers and sills, would have been required to obtain the desired tranquil flow. However, a longer basin could not be constructed within the confines of the powerhouse. Baffle piers, sills, deflectors and other appurtenances were used to affect a shortening of the basin but little success was achieved until converging training walls were placed on the chute section downstream from the valves, Figure 33. The combination of these walls and the downward tilt of the valves at an angle of 24 degrees induced a finer grained turbulence and more uniform velocity distribution than had previously been obtained. Flow in the movable-bed channel downstream was without excessive turbulence; the erosion was slight; and no objectionable pressures were detected. The turbulence is shown in Figure 34, and the conditions downstream are shown in Figure 35. The dividing wall insured satisfactory operation at all heads, discharges, and valve opening combinations. Details of the prototype basin which could be contained well within the confines of the powerhouse are shown on Figure 33.

Field observations were made in 1956. The prototype structure operated as smoothly and satisfactorily as the model indicated, Figures 36 and 37.

The excellent hydraulic characteristics of the now-termed hollow-jet valve stilling basin, its relatively low cost, and its comparatively short length, led to a general research program to obtain data that could be used in determining the basin proportions for all valve sizes, heads, and discharges. The program was very fruitful and design graphs and instructions have been prepared.[8/] This is just one of several developments made in recent years.

8/ Bureau of Reclamation Hydraulic Laboratory Report HYD 446, "The Hollow-Jet Valve Stilling Basin."

Summary

Stilling basins are important, necessary features of modern hydraulic structures. This is true whether the heads be high or low, whether the water quantities be large or small, or whether the project be simple or complex. In all cases, it is necessary to change the energy contained in the high-velocity flow to nondestructive form before releasing it to continue its prescribed course downstream.

The initial as well as the operating cost of stilling basins has always been of prime importance. The initial cost is government principally by size which in turn is dependent upon efficiency. The operating cost is governed by how well and trouble-free a structure performs its function. The model and prototype examples of stilling basins cited in this paper are proof that hydraulic model studies are profitable and reliable in developing designs which meet these requirements.

Experienced, progressive hydraulic engineers have made outstanding progress in improving the operation and reducing the cost of stilling basins. Some of the work cited in this paper is representative of the progress made. The vertical stilling well and hollow-jet valve stilling basin are typical examples.

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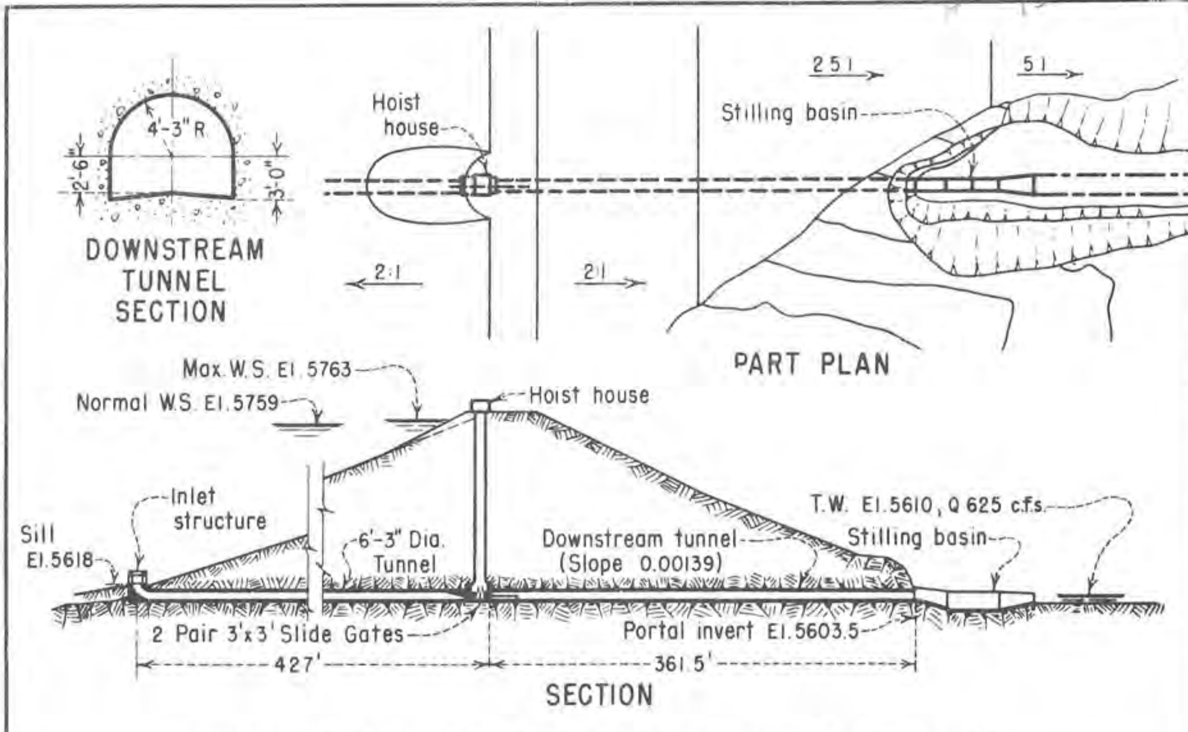

FIGURE 1. CARTER LAKE TUNNEL OUTLET WORKS

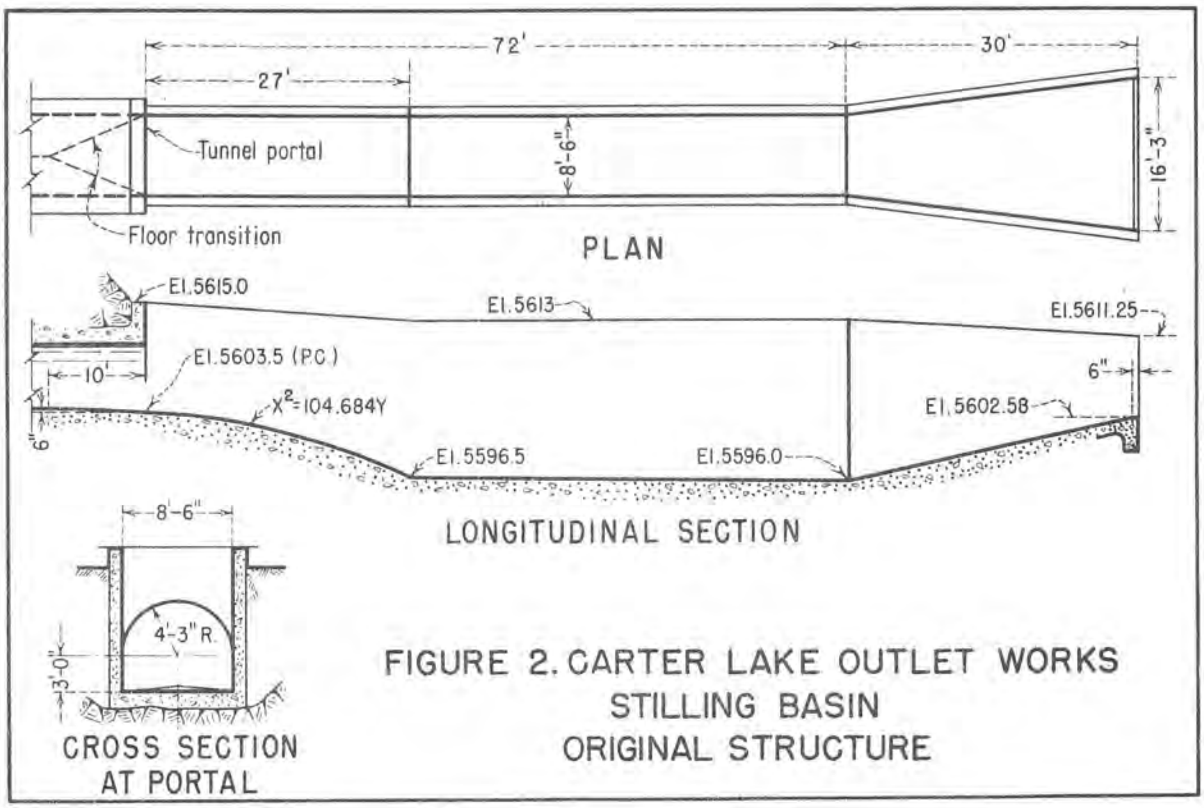

FIGURE 2. CARTER LAKE OUTLET WORKS
STILLING BASIN
ORIGINAL STRUCTURE

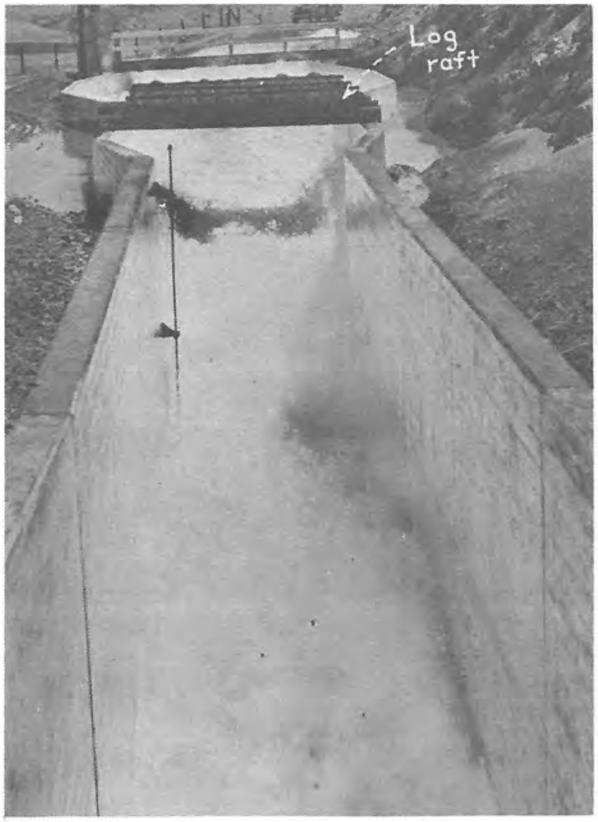

Figure 3. Carter Lake Outlet Works--Original Structure--Jump Swept from Stilling Basin--625 cfs.

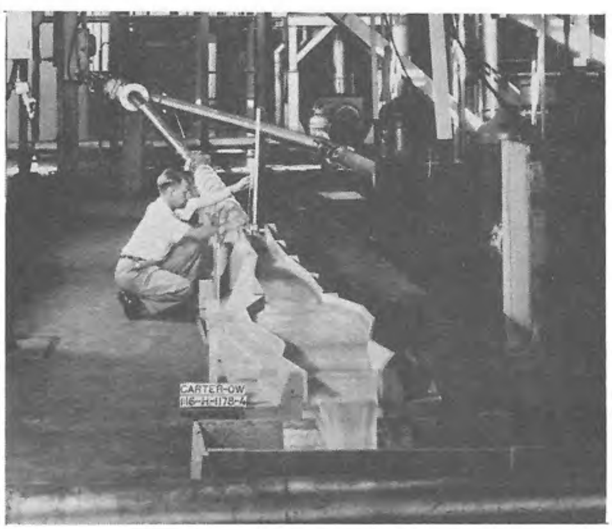

Figure 4. Model of Carter Lake Outlet Works--Scale 1 to 16.

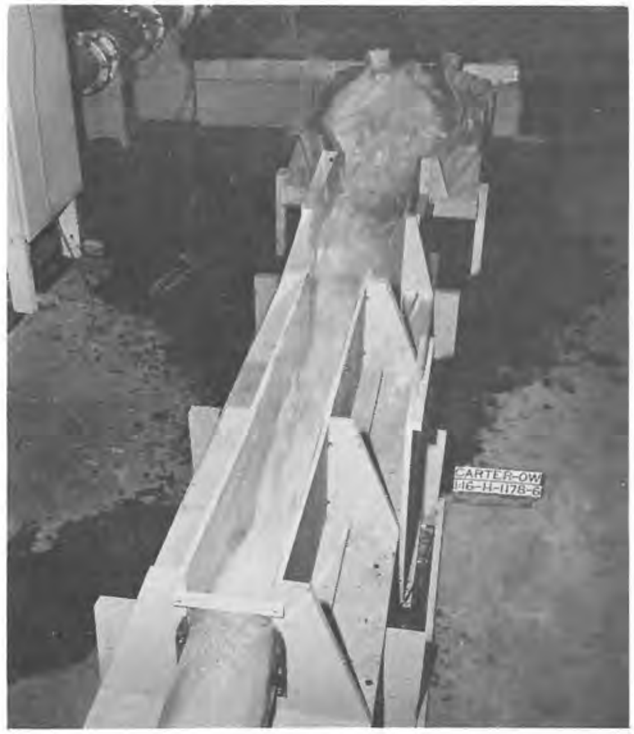

Figure 5. Carter Lake Outlet Works Model--Jump Swept from Stilling Basin--625 cfs.

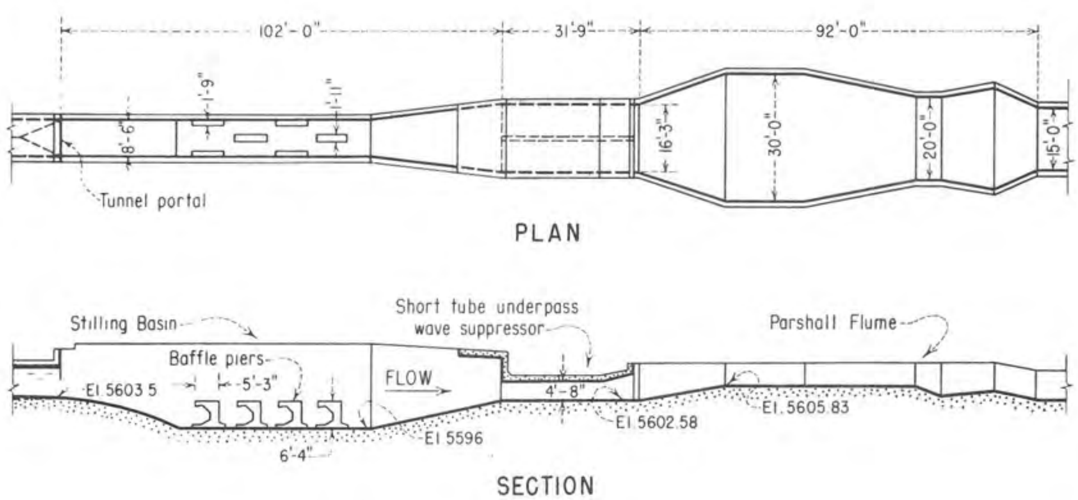

FIGURE 6. CARTER LAKE OUTLET WORKS STILLING BASIN AND MEASURING FLUME. MODIFIED STRUCTURE

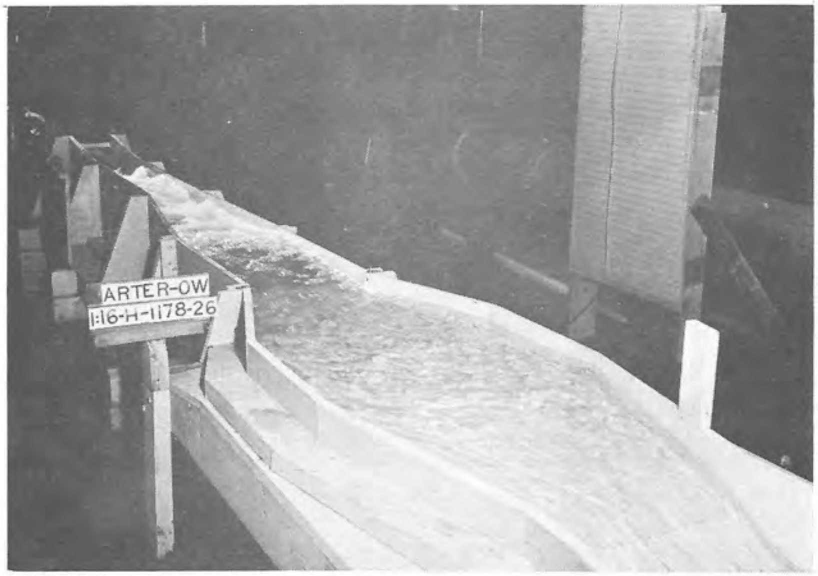

Figure 7. Carter Lake Outlet Works Model--Modified Stilling Basin--625 cfs.

Figure 8. Carter Lake Outlet Works Model--Modified Stilling Basin with Wave Suppressor--625 cfs.

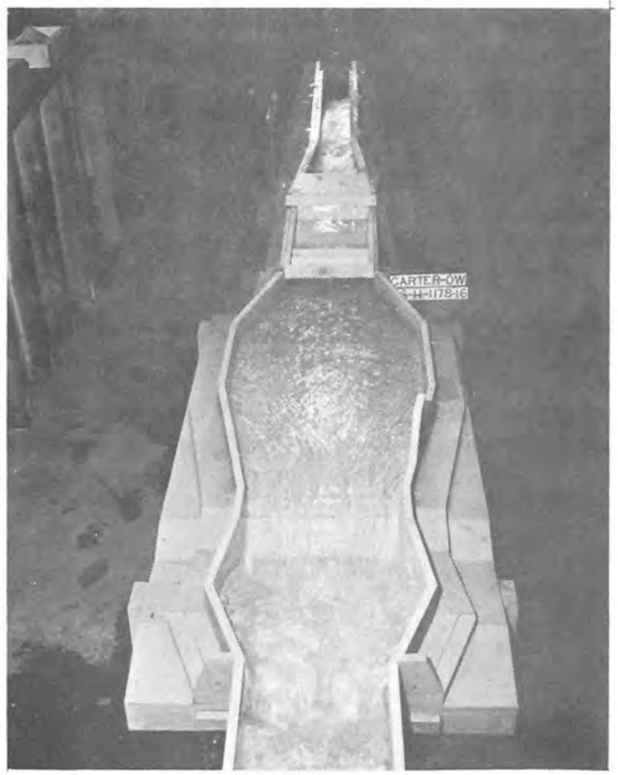

Figure 9. Carter Lake Outlet Works Model--Modified Stilling Basin, Parshall Flume and Wave Suppressor--625 cfs.

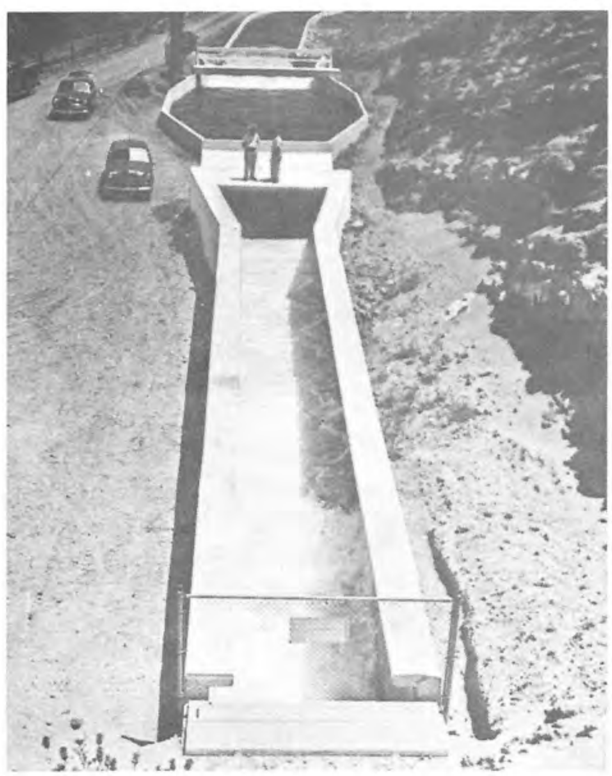

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Figure 10. Carter Lake Outlet Works Stilling Basin and Parshall Flume--Modified Structure--Jump Stays in Stilling Basin--380 cfs.

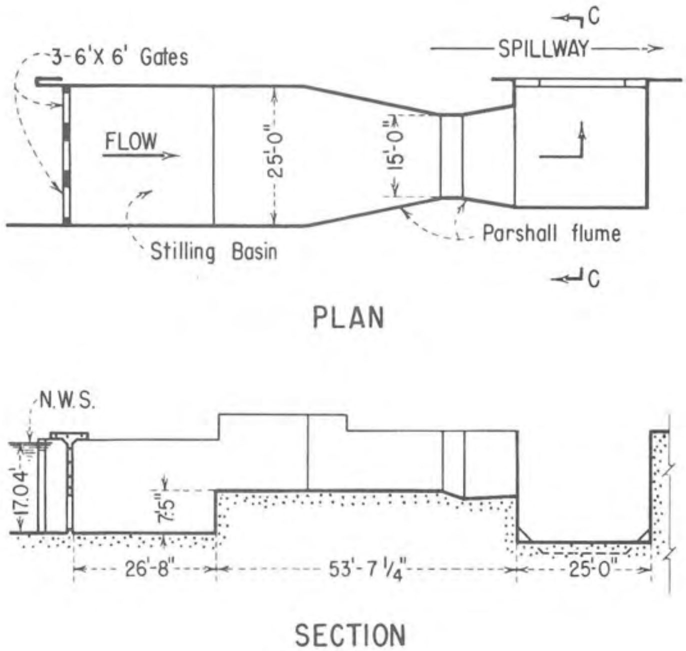

FIGURE 11. TULE RIVER TURNOUT, ORIGINAL STILLING BASIN AND PARSHALL FLUME

Figure 12. Tule River Turnout Stilling Basin--
Turbulent Flow in Original Structure--243 cfs.

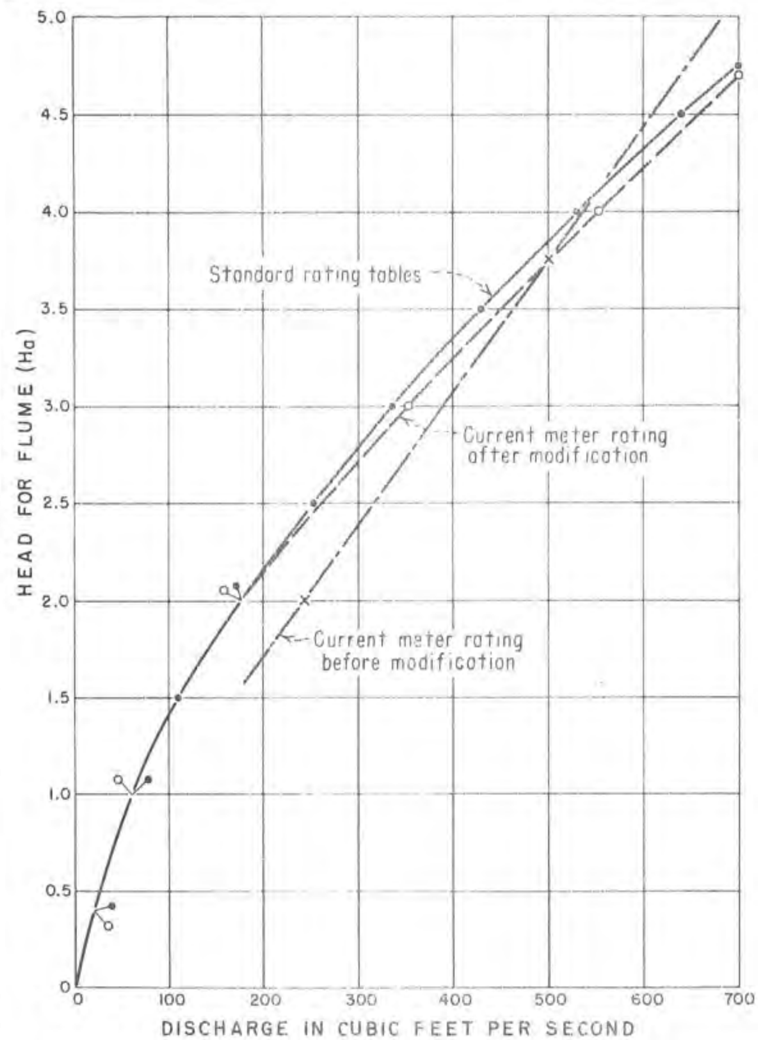

FIGURE 13. DISCHARGE CURVES FOR 15-FOOT PARSHALL FLUME, TULE RIVER TURNOUT

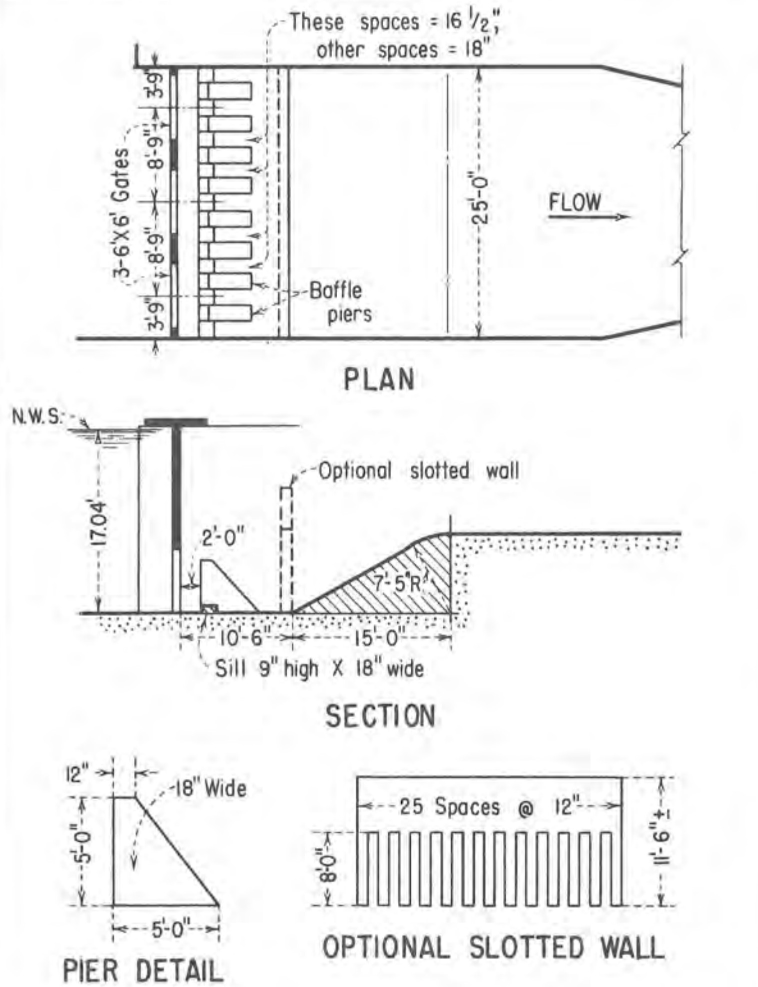

FIGURE 14. TULE RIVER TURNOUT, MODIFIED STILLING BASIN

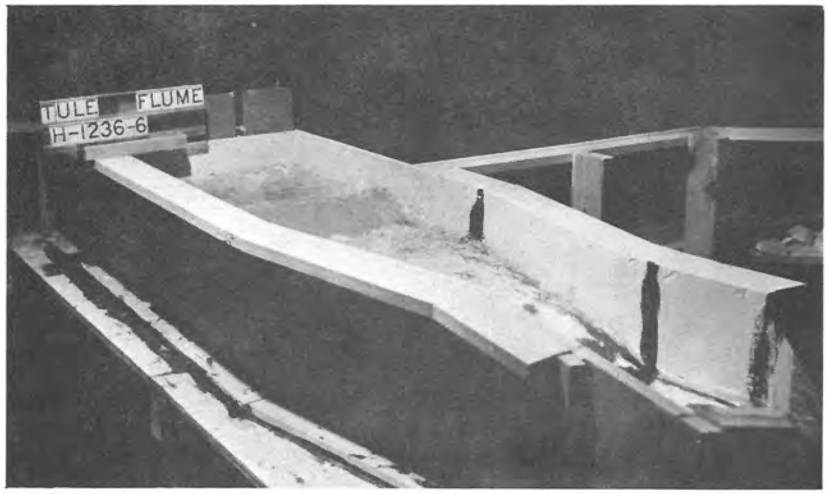

Figure 15. Tule River Turnout Stilling Basin Model--Turbulent Flow in Original Structure--700 cfs.

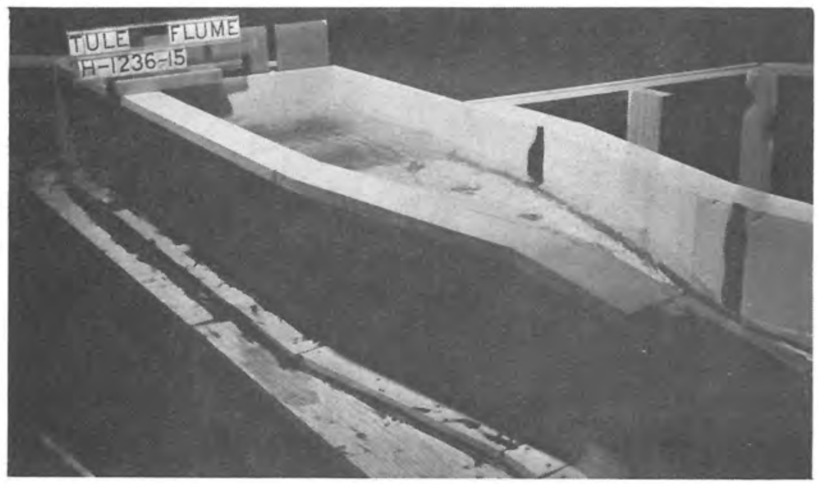

Figure 16. Tule River Turnout Stilling Basin Model--Flow in Modified Structure--700 cfs.

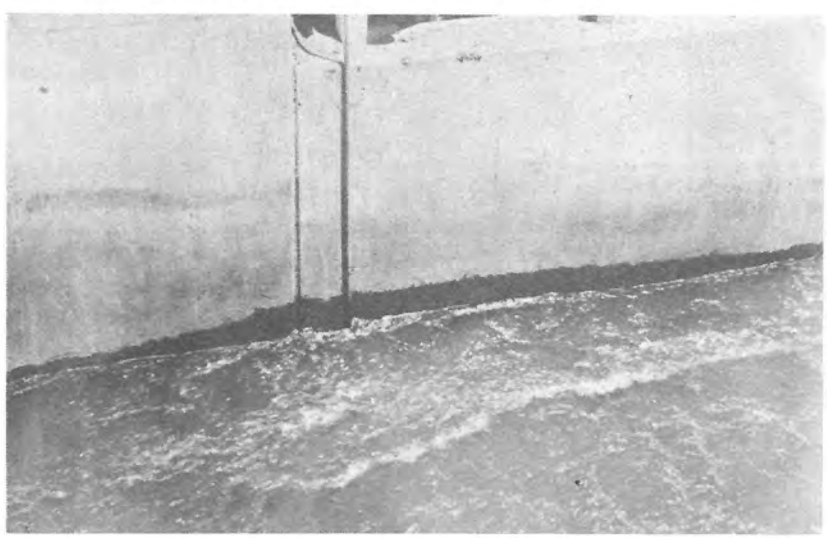

Figure 17. Tule River Turnout Stilling Basin--Flow in Modified Structure--270 cfs.

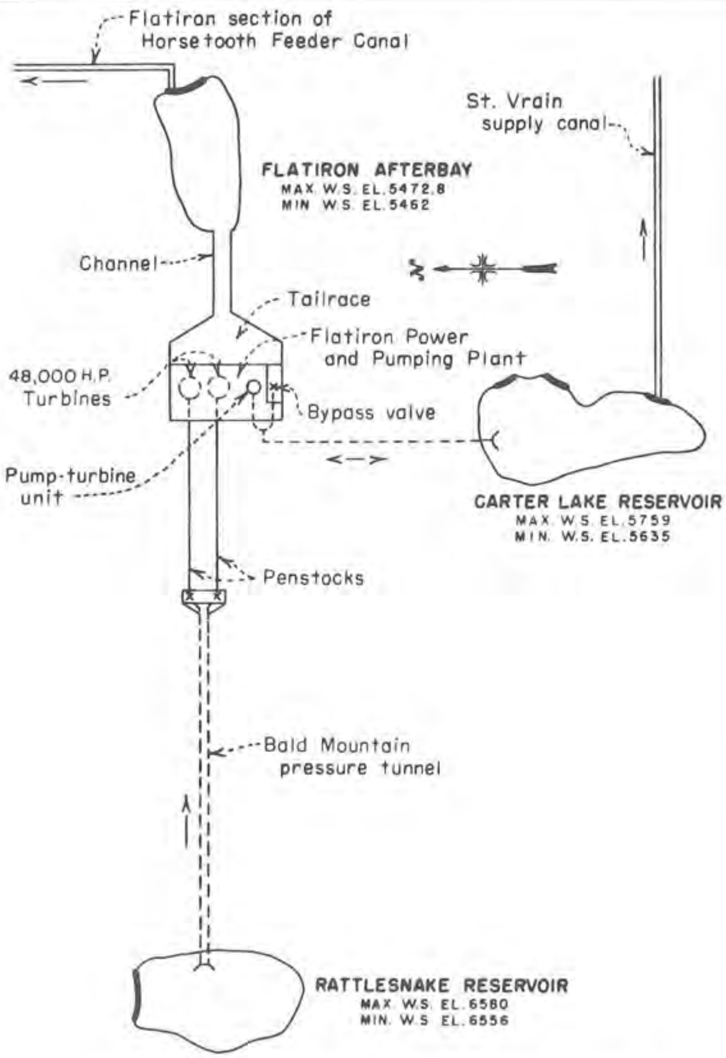

FIGURE 18. FLATIRON POWER AND PUMPING PLANT. SCHEMATIC FLOW DIAGRAM

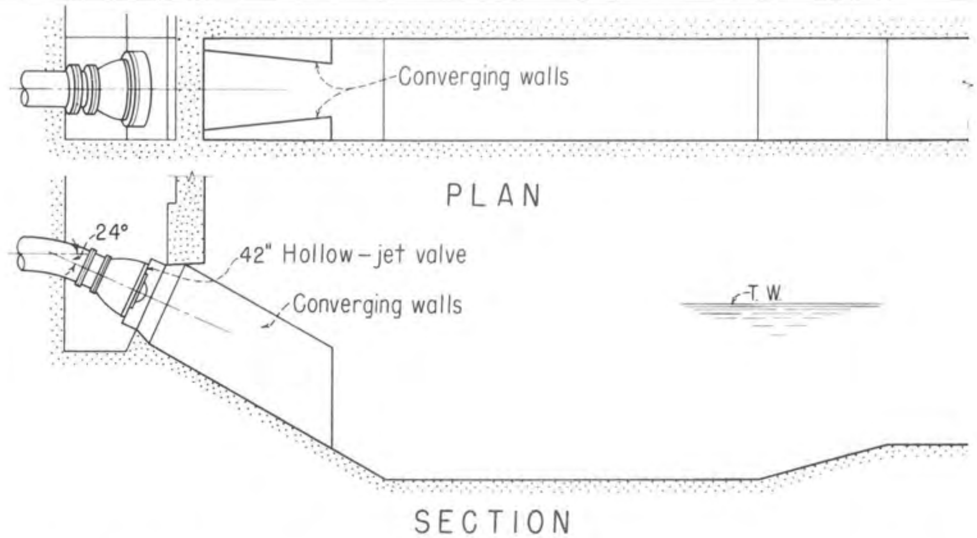

FIGURE 19. FLATIRON POWER AND PUMPING PLANT BYPASS VALVE STILLING BASIN WITH 42-INCH HOLLOW-JET VALVE

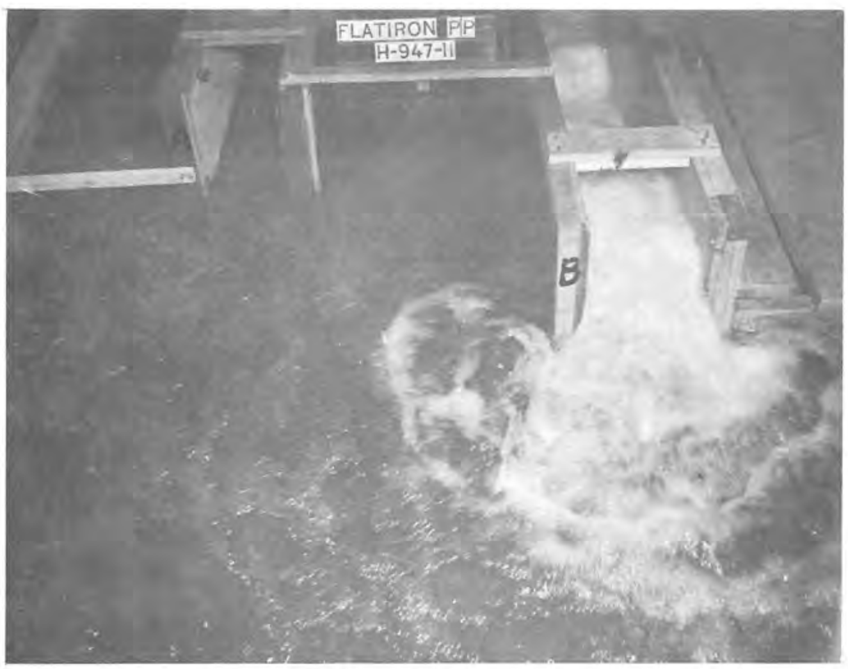

Figure 20. Flatiron Power and Pumping Plant--Comparison of Flow in By-Pass Valve Stilling Basins--500 cfs.

A. 42-inch Submerged Tube Valve

B. 42-inch Hollow-Jet Valve

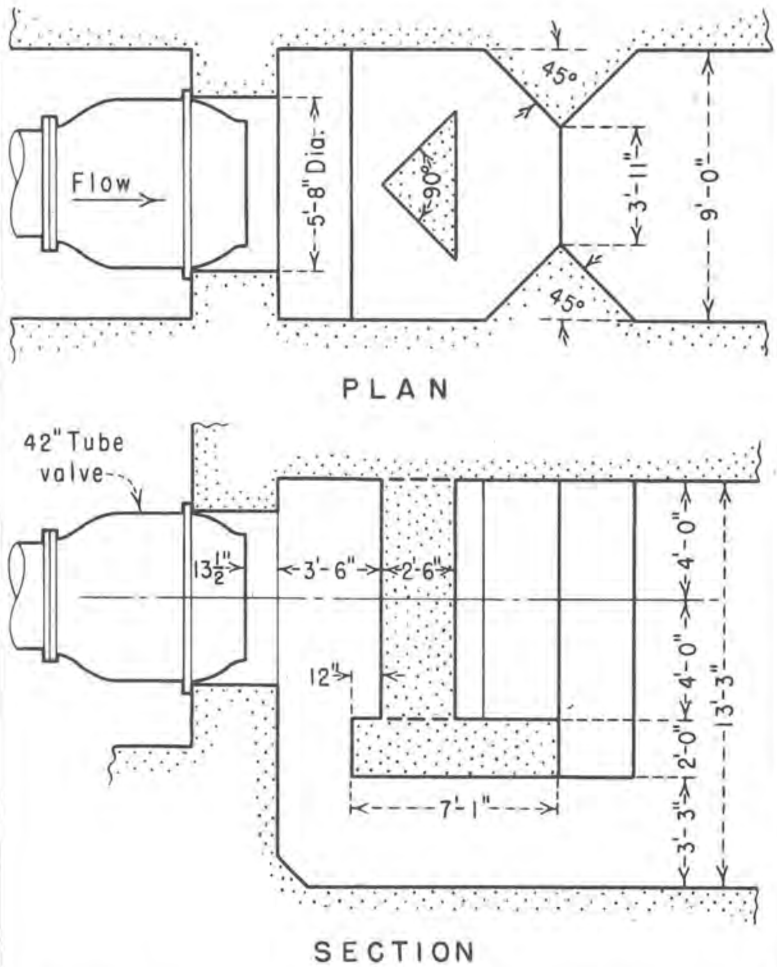

FIGURE 21. FLATIRON POWER AND PUMPING PLANT. BY-PASS VALVE STILLING BASIN WITH 42-INCH TUBE VALVE.

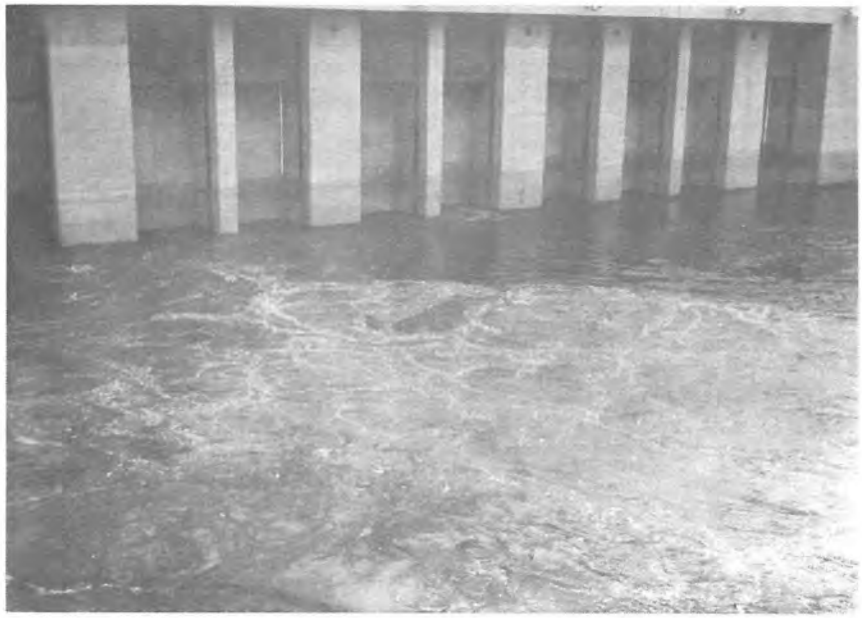

Figure 22. Flatiron Power and Pumping Plant--Flow Conditions in Tailrace Downstream of By-Pass Valve Stilling Basin--Valve Fully Open.

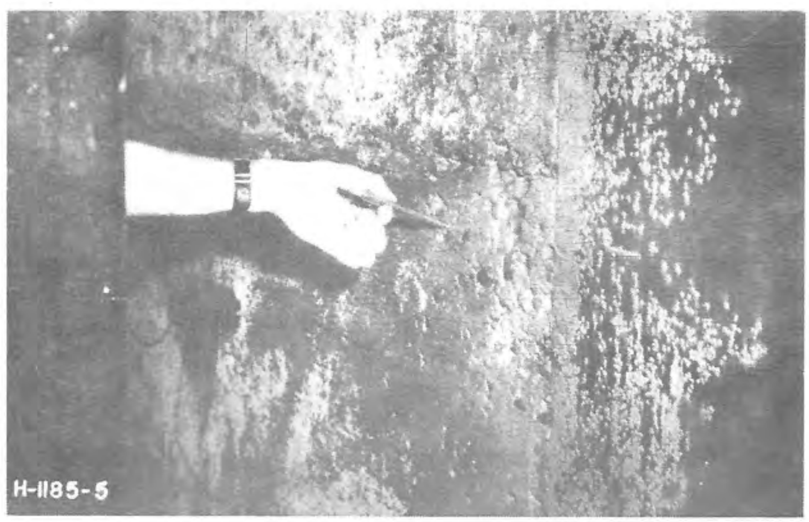

Figure 23. Flatiron Power and Pumping Plant--Cavitation at Into-the-Flow Offset of Concrete Wall in Stilling Basin.

Figure 24. Flatiron Power and Pumping Plant--Cavitation in Coiling of Stilling Basin Downstream of Triangular Baffle.

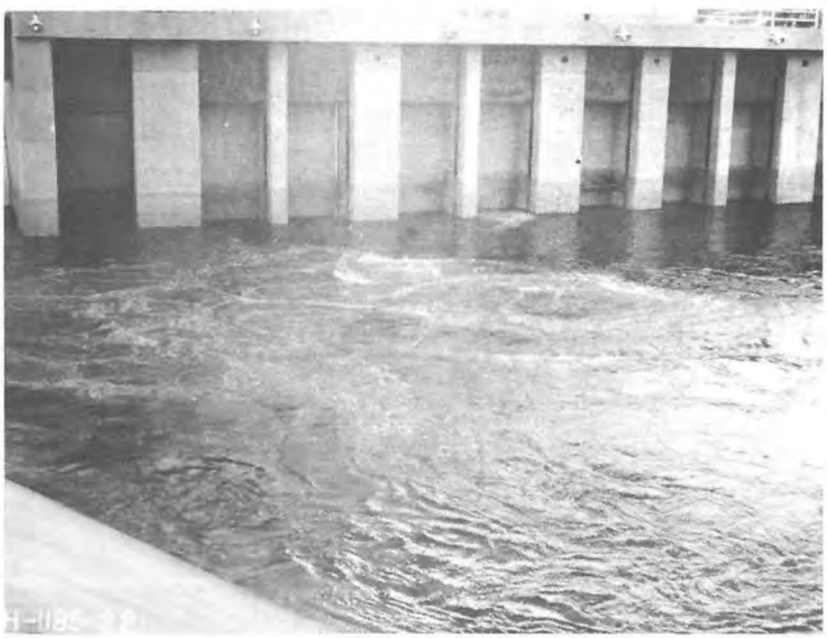

Figure 25. Flatiron Power and Pumping Plant--Flow in Tailrace Downstream of By-Pass Valve Stilling Basin--Air Injected Downstream of Baffle--Valve Fully Open.

Figure 26. Soap Lake Siphon Blowoff--Preliminary
1:5 Scale Model Stilling Well--90 cfs.

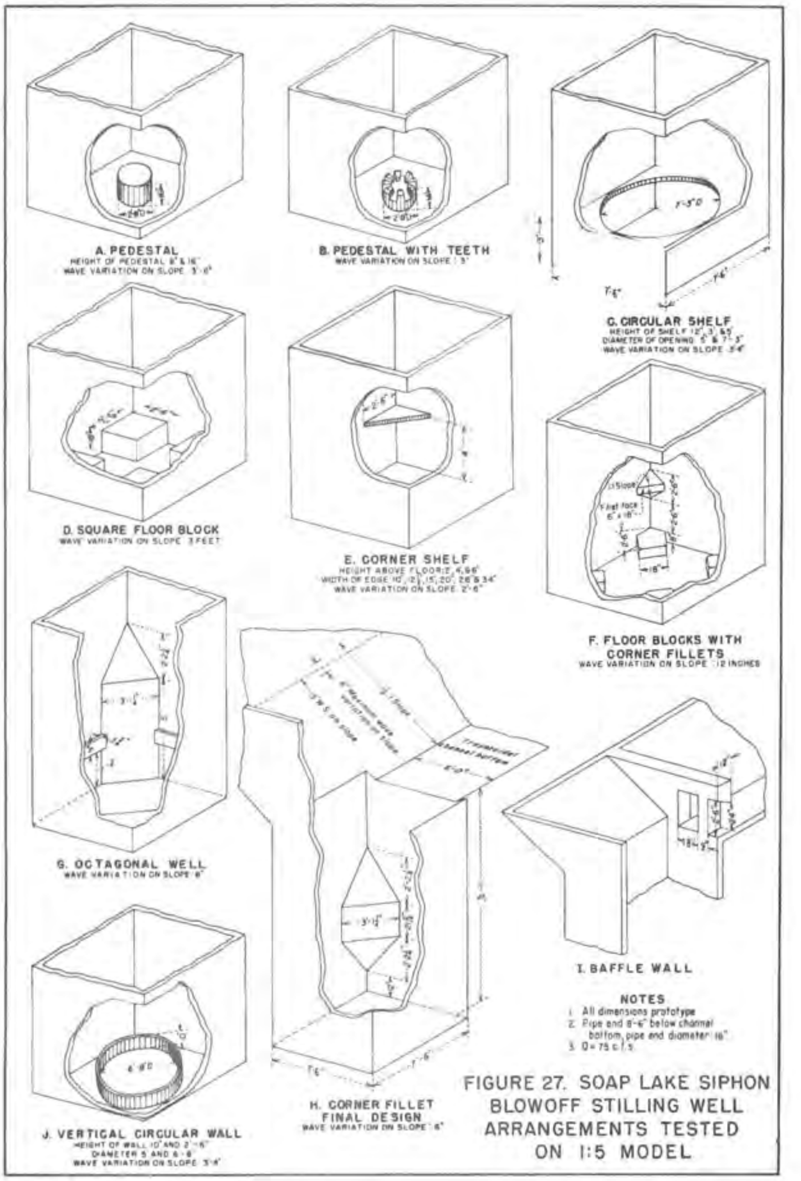

FIGURE 27. SOAP LAKE SIPHON BLOWOFF STILLING WELL ARRANGEMENTS TESTED ON 1:5 MODEL

Figure 28. Soap Lake Siphon Blowoff--Final 1:5 Scale Model Stilling Well--90 cfs.

Figure 29. Soap Lake Siphon Blowoff Stilling Well Discharging About 85 cfs. Under 150-foot Head.

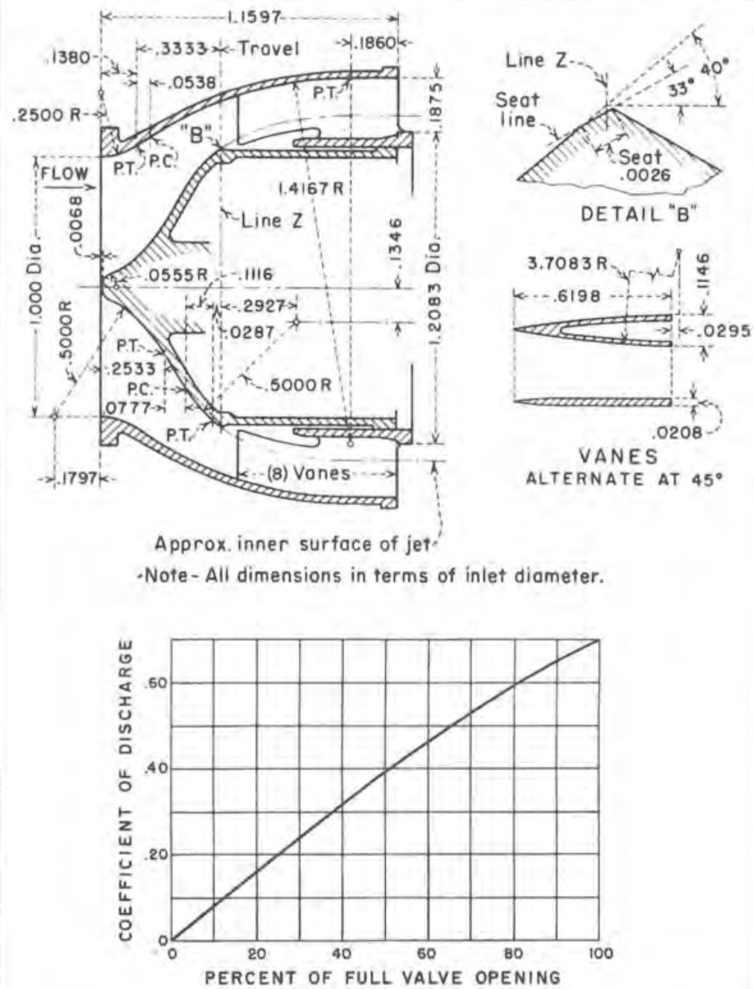

FIGURE 30. HYDRAULIC CHARACTERISTICS AND DIMENSIONS FOR HOLLOW-JET VALVE

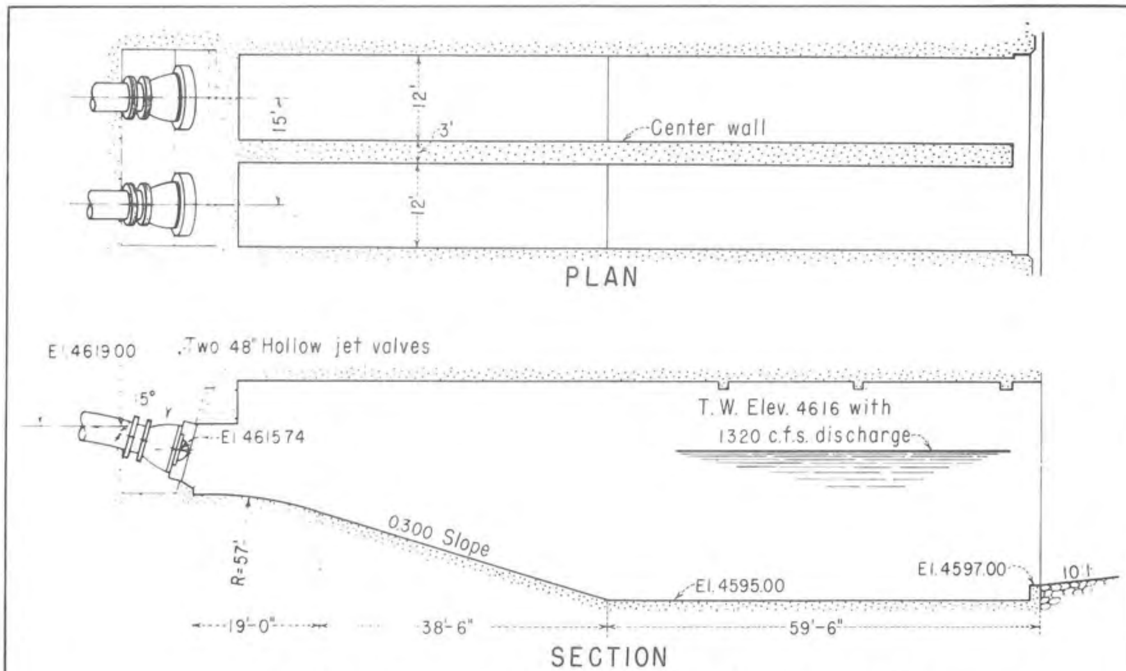

FIGURE 31. HOLLOW-JET VALVE WITH HYDRAULIC JUMP STILLING BASIN

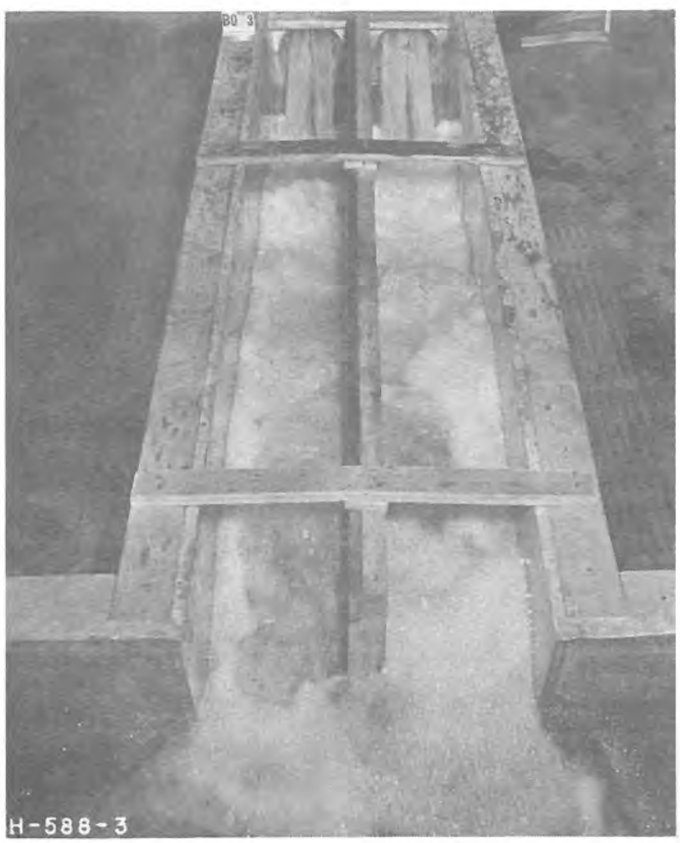

Figure 32. Hollow-Jet Valve Utilizing Hydraulic Jump Stilling Basin.

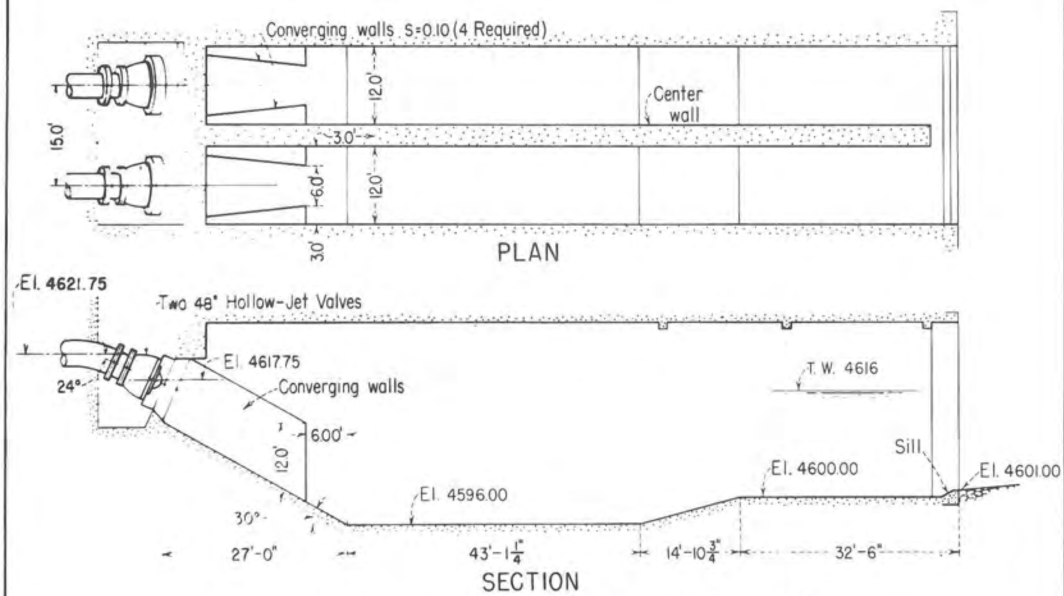

FIGURE 33. HOLLOW-JET VALVE WITH MODIFIED HYDRAULIC JUMP STILLING BASIN (BOYSEN DAM OUTLET WORKS)

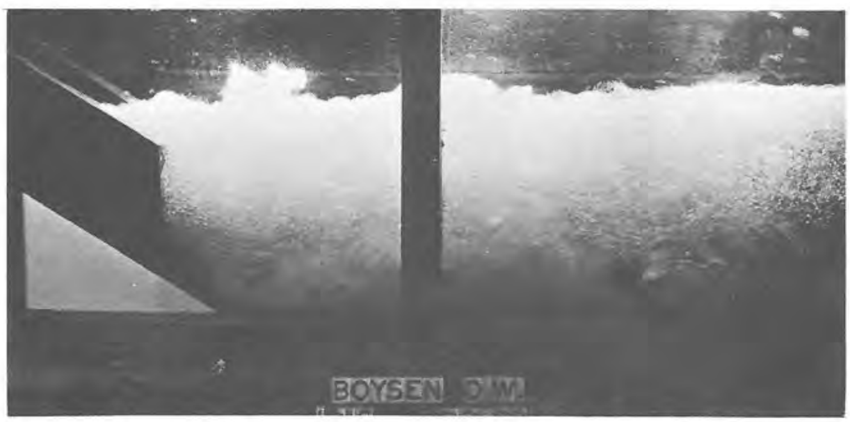

Figure 34. Hollow-Jet Valve Stilling Basin Utilizing Modified Hydraulic Jump Having Fine-grain Turbulence.

Figure 35. Flow Conditions Downstream of Hollow-Jet Valve Stilling Basin Utilizing Modified Hydraulic Jump.

Figure 36. Flow Conditions in Boysen Dam Outlet Works Stilling Basin--730 cfs.

Figure 37. Flow Conditions in Tailrace Downstream of Boysen Dam Outlet Works Stilling Basin--About 1,400 cfs.