PROTOTYPE TESTS OF THE HOLLOW-JET VALVE STILLING BASIN, AUXILLIARY JET FLOW GATE, AND GENERAL INSPECTION OF THE HYDRAULIC STRUCTURES AT TRINITY DAM, TRINITY RIVER DIVISION--CENTRAL VALLEY PROJECT, CALIFORNIA

T. J. RHONE, SUPERVISORY HYDRAULIC ENGINEER

TR 2636

INFORMATIONAL ROUTING

Schroeder

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Travel Report #2636

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To: Chief Engineer

Through: Chief Research Scientist
Chief Designing Engineer
Chief, Hydraulics Branch

From: T. J. Rhone, Supervisory Hydraulic Engineer

Subject: Prototype tests of the hollow-jet valve stilling basin, auxiliary jet flow gate, and general inspection of the hydraulic structures at Trinity Dam, Trinity River Division--Central Valley Project, California

Chronology of Travel

I left Denver, Colorado, via commercial airline during the morning and arrived at Redding, California, in the evening of April 28, 1963. Travel between Redding and the Project Construction Engineer's Office at Lewiston, California, was by Government vehicle. On the return trip, I left Redding during the afternoon and arrived at Denver in the evening of May 3, 1963.

Purpose of the Trip

The primary purpose of the trip was to observe the operation of the hollow-jet valve stilling basin and to measure and record the pressure head and air demand fluctuations at the jet flow gate in the auxiliary outlet works. A secondary purpose was to inspect the condition of the morning glory spillway and flip bucket, the auxiliary outlet works discharge tunnel, and the hollow-jet valve stilling basin.

Personnel Contacted

The following personnel of the Project Construction Engineer's Office at Lewiston, California were contacted:

H. E. McInnis, Project Construction Engineer
J. L. Graham, Supervisory Mechanical Engineer

TR 2636

R. W. Tipton, Mechanical Equipment Inspector
T. J. Spicher, Mechanical Engineer
L. J. Sobon, Rotation Engineer
P. W. Merritt, Project Photographer
F. K. Noonan, Photographer

Pertinent Correspondence

1. Letter dated April 22, 1963, to Project Construction Engineer, Lewiston, California, from Chief Engineer, subject, "Hollow-jet valve outlet works stilling basin and morning glory spillway."

2. Teletype TLX-DN-99, dated April 26, 1963.

Hollow-jet Valve Stilling Basin

Introduction.--The outlet works at Trinity Dam consists of two 84-inch hollow-jet valves discharging into a stilling basin developed specifically for this type of valve. The Trinity Dam valves were designed for full open operation at a total head of approximately 315 feet for two-valve operation and 326 feet for single-valve operation. These heads are considerably higher than had been used in any previous hollow-jet valve structure and were beyond the data used for design purposes. Hydraulic model studies were performed to confirm the stilling basin design. Results of these studies are contained in Hydraulic Laboratory Report No. Hyd-439. The observation of the prototype operation was made to determine the effectiveness of the stilling basin and to obtain a model-prototype comparison.

During the operation of the outlet works, Trinity Reservoir was at approximately elevation 2369.8, 0.2 foot below the spillway crest. With the right valve fully closed, the pressure gage in the control house showed 192 psi, or 443.5 feet pf water, equivalent to reservoir elevation 2373.4. The left valve was 3 percent open to provide downstream river flow requirements and the pressure gage reading was 189.5 psi. The pressure gages were located in the bypass piping of the ring follower gates upstream of the hollow-jet valves. The gages were at elevation 1929.87.

Unsymmetrical Operation.--Two conditions with single-valve operation were observed. The first was with the left valve 3 percent open and the second with the left valve 18 percent open. The jet from the 3 percent opening did not penetrate the stilling basin pool; consequently there was extreme surface roughness and turbulence in the basin accompanied with a considerable amount of splash and spray. The surface roughness carried downstream into the river channel, and almost to the far bank. In the river channel there were clockwise eddies on the right side of the basin and counterclockwise eddies on the left side. The eddies on the right side did not carry upstream into the powerplant tailrace.

The jet from the 18 percent opening plunged into the stilling basin pool and formed a very effective hydraulic jump with a considerable amount of surging and boiling. Downstream from the end of the center dividing wall the boil from the jump moved from one side of the basin to the other, but the asymmetry did not carry down beyond the end of the basin. The high point of the jump was about 100 feet upstream from the end of the basin, (90 feet downstream from the valves) the top of the boil averaged about 8 to 10 feet below the top of the side walls. Occasionally the top of the boil surged to within 4 feet of the top of the wall, then rolled upstream until it came in contact with the jet, which caused an extremely high splash that continued to move upstream until it struck against the front of the control house. This action broke several windows in the control house in the past, most of which have been replaced with chicken-wire-reinforced glass.

Symmetrical Operation.--The remainder of the stilling basin observations were made with both valves equally opened. Valve openings of 10-, 25-, 50-, 75- and 100-percent were tested, commencing with the 10 percent opening.

The pressure gage readings for the 10 percent opening were 188 psi upstream of the left valve and 190 psi upstream of the right valve, indicating discharges of 560 cfs and 570 cfs and total heads (pressure head plus velocity head) of 437.1 feet and 441.9 feet, respectively, immediately upstream from the valves.

The jets from the valves did not penetrate the stilling basin pool. There was considerable mist and spray from the jets which combined with the spray from the surface turbulence in the stilling basin and obscured the vision of the stilling action in the pool. When observed from the far bank, Figure 1, the impact of the jets appeared to create waves about 8 feet high in the basin that leveled out to about 5-foot high surges at the end of the basin. The waves were about 6 inches high along the left bank, 1.5 to 2.5 feet high on the bank opposite the stilling basin, and 0.2 foot high in the afterbay. The water surface along the wingwalls at the end of the basin surged from elevation 1898.3 to elevation 1900.2. The tailwater elevation at the powerplant afterbay was 1899.9.

Pressure gage readings for the 25 percent opening were 178 psi for the left valve and 179 psi for the right valve, indicating discharges of 1,380 cfs through each valve at total heads of 430.7 feet and 432.9 feet, respectively.

The stilling action at this gate opening was very effective, Figure 1. The high point of the boil was usually about 90 feet downstream from the valves but occasionally moved upstream about 40 feet. The top of the boil was about 4 feet below the top of the side walls but occasional high surges carried 15 to 20 feet above the walls.

The high surges usually were moving in an upstream direction and impinged on the jet causing a high splash that landed on the front of the control house. Small stones were sometimes seen in the high splashes. Several of these stones have been found in the control house and were reported to be less than 1 inch in diameter. The roughness and turbulence of this jump were confined to the upstream portion of the basin and flow in the downstream 40 feet was comparatively smooth with about a 4-foot surge in the water level.

The tailwater elevation at the powerplant was 1901.05. The waves were 1.0 to 2.3 feet high along the left bank, 1.0 to 1.5 feet high on the bank opposite the basin, and 0.3 foot high in the afterbay. The water surface along the wing walls at the end of the basin surged from elevation 1899.3 to 1901.5; the average water level was about 0.3 foot higher on the left side than on the right side. All of the flow beyond the basin moves in a downstream direction; there were no eddy currents in the afterbay or recirculation of the flow along the wing walls.

Pressure gage readings for the 50 percent opening were 146 psi for the left valve and 144 psi for the right valve, indicating discharges of 2,640 cfs and 2,620 cfs at total heads of 410.1 feet and 405.1 feet, respectively.

The jump was very turbulent, in the basin for this operating condition, Figure 2. The toe of the jump (not visible in previous operation) was about 50 feet downstream from the valves, exposing about half of the center dividing wall. The high point of the boil varied from 110 feet to 150 feet downstream from the valves. The high point of the boil varied from 4 to 12 feet below the top of the side walls with an occasional spurt rising about 15 feet above the walls. There was no back splash against the control house but considerable splash passed over the sides of the basin walls. At the end of the basin the water level between the walls varied from 4 to 8 feet higher than the outside tailwater.

The tailwater elevation at the powerplant was 1902.3. The waves were 1.2 to 1.5 feet high along the left bank, 2.0 to 2.3 feet high on the bank opposite the basin, and about 0.4 foot high in the afterbay. During this operation, the combination of the high tailwater and wave action removed the staff gages that were being used to obtain the wave heights on the left bank and on the bank opposite the basin. The latter staff gage had been fastened to a 2-foot-diameter piece of riprap; apparently, the wave action moved this piece of rock, causing it to roll down into the channel. The water surface variation in the afterbay was more in the form of slow surges rather than choppy waves.

Pressure gage readings for the 75 percent openings were 105 psi for the left valve and 104 psi for the right valve, indicating discharges of 3,600 cfs and 3,590 cfs at heads of 378.0 feet and 374.8 feet, respectively.

The hydraulic jump action for this condition was good, Figure 2, but the boil at the end of the jump extended beyond the end of the basin. The toe of the jump varied from 50 to 70 feet downstream of the valves, exposing the full length of the dividing wall at times. The high point of the boil was about 20 feet beyond the end of the basin; making the length of the jump, from the toe to the boil, about 170 feet long. The high point of the boil was usually 4 feet below the top of the sidewalls, but surged about 4 feet above and below this. An occasional splash or spurt in the basin rises 20 to 30 feet in the air. An occasional rock, estimated to be 3 to 4 inches in diameter, was occasionally seen in the boil.

The tailwater elevation at the powerplant was 1903.4. The waves along the left bank were estimated to average about 3.0 to 3.5 feet high with an occasional 5.0-foot high wave. The water surface variation in the afterbay was again in the form of slow surges that varied about 1.2 feet in elevation.

Pressure gage readings for the 100 percent opening were 72 psi for the left valve and 68 psi for the right valve, indicating discharges of 4,350 cfs and 4,270 cfs at heads of 364.2 feet and 347.6 feet, respectively.

The toe of the jump remained fairly constant about 70 feet downstream from the valves, near the end of the center dividing wall. The boil at the end of the jump moved back and forth from the end of the basin to 40 to 60 feet downstream from the end; however, it was predominantly beyond the end of the basin, Figure 3. The top of the boil varied from the top of the side walls to about 6 feet below the top. A secondary boil or surge formed near the end of the basin. Although the formation of this boil was sporadic, it was higher than the downstream boil and usually overtopped the sidewalls. The stilling action was very rough and turbulent, but the turbulence did not extend upstream into the afterbay. The turbulence from the stilling action moved across the channel from the basin and turned downstream. Wave action on the left and opposite bank was estimated to be about the same as during the 75 percent operation. The tailwater elevation in the afterbay averaged about 1903.7; the wave action was in the form of slow surges about 1.2 feet in magnitude.

During the closing cycle, the energy dissipating action in the stilling basin was much more effective than it had been for similar valve openings during the opening cycle. This was no doubt due to the higher tailwater. The surges and splashes still overtopped the sidewalls, but the location of the boil averaged about 20 feet farther upstream and the high point of the boils was about 4 feet long.

Model--Prototype Comparison.--The model investigations were made with 100 percent valve opening for either one- or two-valve operation. At the beginning of the model studies, the design maximum discharge was 3,500 cfs per valve at 260 feet of head for two-valve operation and 4,200 cfs at 380 feet of head for single-valve operation. These values were increased to 3,835 cfs at 315 feet of head and 4,260 cfs at 392 feet of head before the recommended design was evolved.

Comparison of the single-valve operation can be made only in general terms since only 5- and 18-percent valve openings were observed in the prototype. The model studies indicated that for single-valve operation the toe of the jump would be about 70 feet downstream from the valves and the high point of the boil would be about 30 feet farther downstream. In the prototype, the high point of the boil was a little closer to the valves as could be expected for the smaller discharge. The model studies indicated a relatively smooth water surface in the downstream half of the basin with about a 5- to 7-foot surge; the prototype also showed a smooth water surface with a 4-foot surge. The model predicted 2.5-foot high waves in the downstream channel; 6- to 9-inch waves were measured in the prototype. The model showed that 15- to 20-foot high splashes could be expected between the toe of the jump and the high point of the boil; similar splashes occurred in the prototype.

When comparing the maximum discharge operation, consideration should be given to the fact that the prototype valves were discharging a larger quantity than had been used for the model studies. As previously stated, at 100-percent-open the prototype was discharging about 8,600 cfs at 350 to 360 feet of head whereas the maximum model discharge was 7,670 cfs at 315 feet of head. A more comparible comparison would be for the 75-percent-open prototype operation when the discharge was about 7,200 cfs at 375 feet of head.

A maximum operating condition investigated during the model studies was 7,200 cfs at 284 feet of head with tailwater elevations between 1896 and 1910, Figure 4. Water surface profiles with the tailwater at elevation 1902 showed that the toe of the jump would be about 70 feet downstream from the valves and the high point of the boil about 160 feet downstream from the valves, or approximately 30 feet upstream from the end of the basin. The top of the boil was about 10 feet below the top of the sidewalls but there was considerable high splashing between the toe of the jump and the boil. Waves in the downstream channel averaged about 1.5 feet in height.

The comparable prototype operation was 7,200 cfs at 375 feet of head with the tailwater at elevation 1903.4, Figure 4. The toe of the jump was the same as indicated in the model. However, the boil was about 20 feet beyond the end of the basin, 50 feet farther downstream than in the model, and the top of the boil was usually about 4 feet below the top of the sidewalls. The difference in the location and height of the boil can be attributed to the higher head on the valves creating a higher flow velocity, resulting in a longer hydraulic jump. The larger amount of air entrainment in the prototype hydraulic jump also had some affect on the difference in the appearance of the boil. The waves in the downstream channel were 3.0 to 3.5 feet high, 2.0 feet higher than measured during the model studies. The higher waves were due to part of the hydraulic jump action occurring beyond the confines of the stilling basin.

Auxiliary Outlet Works

In March 1963, air demand measurements were made at the jet flow gate in the auxiliary outlet works. During these tests it was noticed that for gate openings between 30 and 80 percent, there was a pulsation in the pressure head upstream of the gate. The pulsation was accompanied by an audible rhythmic change in the "swishing" sound of the water flowing through the system. It was requested that measurements be made to determine the magnitude and frequency of these pressure head fluctuations to determine whether there were similar fluctuations in the air demand downstream of the jet flow gate, and whether there was any relationship between the air demand and the pressure head fluctuations.

A pressure transducer was connected to the vent valve in the bonnet of the ring follower gate immediately upstream of the jet flow gate to obtain the pressure head measurements. A second transducer was connected to the downstream side of the bonnet of the jet flow gate to measure the change in the air pressure. The leads from the two transducers were connected to separate channels of a two-channel Sanborn recorder so that simultaneous recordings of the pressure fluctuations could be made.

The jet flow gate was opened in 10 percent increments from fully closed to fully open. The pressure fluctuations were recorded during a 2- to 3-minute period. The pressure head fluctuation varied from about 2 feet at the 10 percent and 100 percent openings to 15 feet at the 60 percent opening, Figure 5. The air pressure fluctuations varied from about 0.6 foot at 10 percent opening to a maximum of about 2.5 feet at 40 to 50 percent opening. There was no obvious relationship between the air pressure and pressure head fluctuations except that they both showed the greatest fluctuation in approximately the same range of gate openings.

The air pressure fluctuations had a frequency of about 0.5 to 1.0 major cycles per second, with a secondary cycling of about 20 cycles per second. The minor cycles were less than 0.1 foot of water in magnitude. The pressure head fluctuations were consistent at about 20 to 25 cycles per second. A typical section of the recording is shown on Figure 6.

No intermittent "swishing" noise was noticed at any gate opening during these tests. The operation was quiet except for cavitation crepitation that commenced with the 10 percent opening, reached a peak at the 40 percent opening, and ceased at the 90 percent opening.

Inspection of Structures

The major hydraulic structures at Trinity Dam have operated at large flows for considerable periods of time this year. The inspection was made to determine the extent, if any, of damage to these structures due to the large discharges and heads.

Spillway Tunnel and Flip Bucket.--The morning glory spillway has operated at discharges up to about 7,000 cfs, 30 percent of maximum, for several weeks. Prior to the spillway operation the auxiliary outlet works had operated at maximum discharge, 2,500 cfs, for long periods of time. The auxiliary outlet works discharges into the spillway tunnel; consequently the flip bucket has been subjected to comparatively large flows for several weeks.

The flow surfaces in the flip bucket, the semicircular approach channel, and the tunnel spillway from the tunnel portal to the elbow showed no signs of erosion damage. All of the bug holes have been patched and the offsets at the construction joints have been ground-off to a smooth taper.

The area of river channel downstream from the flip bucket has been severely eroded by the impact of the jet. A hole was eroded along the right side and end of the bucket, Figure 7A. The hole was full of water and its depth could not be determined; however, it did not appear to have undermined the structure. There is an extensive eroded area about 250 feet downstream and to the right of the flip bucket; this hole is 40 feet wide and 70 feet long. From the ground surface to the water surface in the hole is about 12 feet; there was no means of determining how deep the hole extended below the water surface. An even larger eroded area is located about 150 feet directly downstream from the bucket, Figure 7B. This hole was about 50 feet long by 100 feet wide and seemed to be about the same depth as the other eroded area. The impact and flow from the jet has cleared all loose material from the ground in this area as well as having formed the eroded areas. The material from the eroded areas has formed a bar in the river that extends about halfway out into the original channel. The bar is made up of gravel and rock from pea gravel size to about 15-inch-diameter. The bar is about 4 to 5 feet high on the river side.

Morning Glory Spillway Crest.--Light colored streaks were noticed on the upstream and downstream side of the crest axis, Figure 7C. From the dam embankment these streaks appeared to be damaged concrete. However, close examination showed that some misalinements in the crest curve had been ground-off causing the lighter colored areas.

The bug holes in the upper part of the morning glory have been patched; the bug holes on the inside of the crest circle, about 8 or 10 feet below the axis, have not been filled.

There has been some slight movement of the crest pier; the section that sits on the fill has deflected about 1/2 to 3/4 inch to the left; the section that sits on the crest has not moved.

Auxiliary Outlet Works Tunnel.--The protective coating on the steel liner downstream from the jet-flow gate has sustained some cavitation damage. The coating has been removed in strips about an inch wide by 2 to 4 inches long. The uncovered metal in these strips also show some slight pitting but nothing severe.

There are two areas of cavitation damage in the concrete just downstream from the liner on either side of the invert. These areas are about 4 inches wide by 8 inches long by 1/2- to 1-inch deep. There is a similar area of cavitation erosion at the vertical curve just upstream from where the auxiliary outlet works tunnel enters the spillway tunnel. All three of these eroded areas were first reported over a year ago and apparently the damage is not progressing.

There is no evidence of erosion where the flow from the auxiliary outlet works impacts in the spillway tunnel.

Outlet Works Stilling Basin.--The concrete surfaces of the wedges, center dividing wall, sidewalls, and sloping floor in the upstream portion of the basin are in excellent condition and have not been damaged by the extensive operation. The sidewalls in the downstream portion of the basin have been slightly eroded. The damaged area is above the water surface extending about 5 feet upstream from the end of the basin and is less than 1 inch deep. The damage was apparently caused by the abrasive action of small rocks in the hydraulic jump.

The extent of damage to the sidewalls below the water surface or to the floor of the basin could not be determined since the water level was approximately 35 feet above the basin floor and no method was available for making soundings. Subsequent reports from the project have indicated that extensive erosion of the floor has occurred at the downstream end of the basin.

Hollow-jet Valves.--Only a cursory examination of the cavitation damage in the hollow-jet valves was made since a detailed inspection was scheduled to be made by a representative of the Mechanical Branch.

The damage to these valves was quite extensive, as previously reported by the Construction Engineer. The cause of all cavitation damage could be traced to misalinements in the flow surfaces. The cavitation damage does not appear to be due to design shortcomings.

Motion Pictures

Motion pictures were obtained during the hollow-jet valves stilling basin tests. In addition, the project photographer made available additional motion pictures of the operation of the morning glory spillway and flip bucket discharging 7,000 cubic feet per second. These movies are on file in the Hydraulics Branch.

Summary and Conclusions

Hollow-jet Valve Stilling Basin.--The hollow-jet valve stilling basin was operated over the full range of valve openings to obtain performance data for model-prototype comparison, Figures 1, 2, and 3. In general, the stilling action in the basin was effective but the turbulence was much more violent than had been experienced in the model. However, it was determined that for 100 percent valve opening the prototype was discharging about 20 percent more flow and at a higher head than had been used in the model studies. This discrepancy is probably due to much lower friction losses in the approach conduits than had been used in the design computations.

The prototype operation for 75 percent valve opening discharged a flow quantity similar to that used for maximum model discharges, although at a higher head. For this operation the model prototype conformity was very good, Figure 4.

Pressure Measurements.--The pressure measurements at the auxiliary outlet works jet flow gate provided a good determination of the magnitude and frequency of the pressure fluctuations, but failed to disclose any relationship between pressure head variation and air demand, Figures 5 and 6.

Inspection of Structures.--The flow surfaces in the crest, tunnel, and flip bucket have not been damaged by spillway discharges up to about 30 percent maximum.

The jet impact area downstream from the flip bucket has been extensively eroded in two areas, Figure 7; one about 100 feet directly downstream, the second about 200 feet downstream and to the right of the bucket. These areas are sufficintly removed from the structure that there is not danger of undermining.

The material from the eroded areas has formed a bar that partially constricts the improved river channel.

Three small areas of cavitation erosion have occurred in the auxiliary outlet works discharge tunnel. However, these areas have not increased in size since they were first reported about a year ago.

Cavitation has removed most of the protective coating from the invert of the downstream portion of the auxiliary outlet works gate frame, but has caused only minor pitting of the metal.

The hollow-jet valves in the outlet works show extensive cavitation damage in the valve body at the needle seat, at the end of the outward flare, and at the downstream end. The cavitation damage does not appear to be due to design shortcomings.

The concrete surfaces in the outlet works stilling basin are in excellent condition except on the sidewalls near the downstream end. In these areas there is slight erosion extending less than 1-inch deep. The extent of damage to the basin floor was not determined; however, subsequent reports from the project have indicated that the floor of the basin near the downstream end has sustained extensive erosion damage.

The riprap of the channel banks downstream from the outlet works basin has not been moved by the extensive operation at large discharges.

TJ Rhone

Enclosure

Copy to: Regional Director, Sacramento, California, Attention: 2-220

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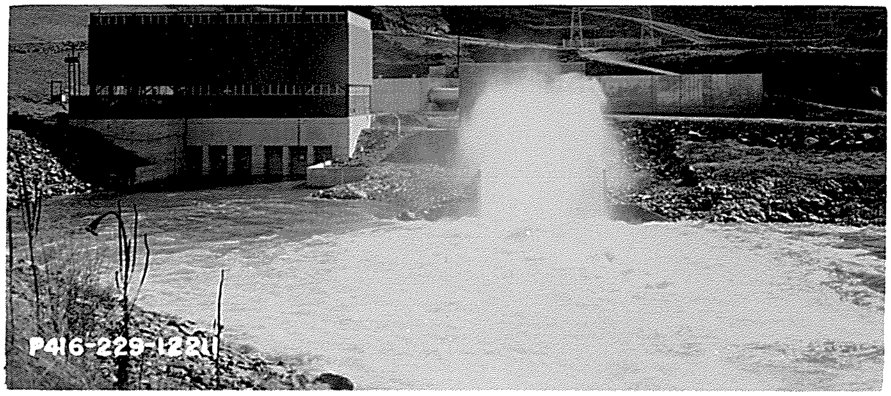
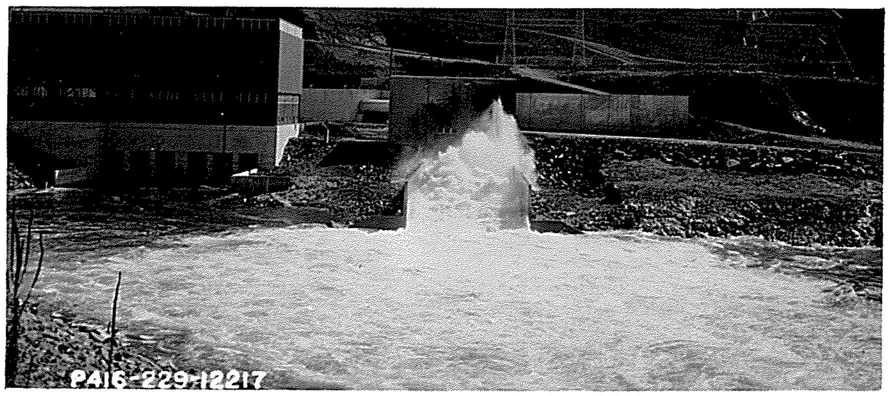
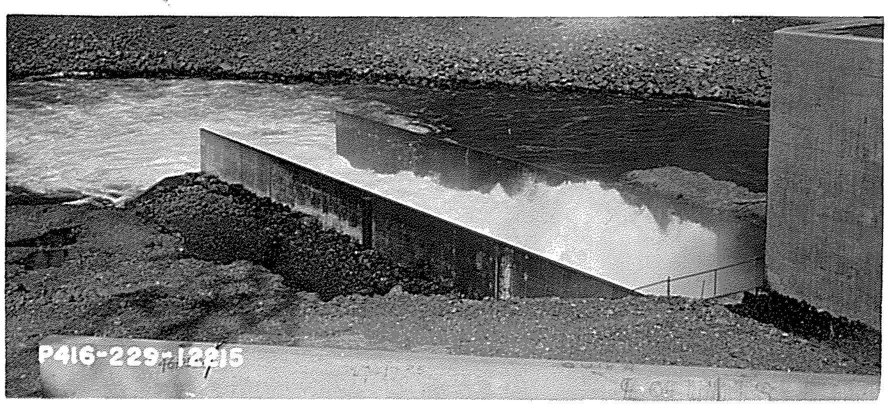
TJRhone:lcr-s

AUG 6 1963
NOTED:
John Parmakian
Associate Chief Engineer



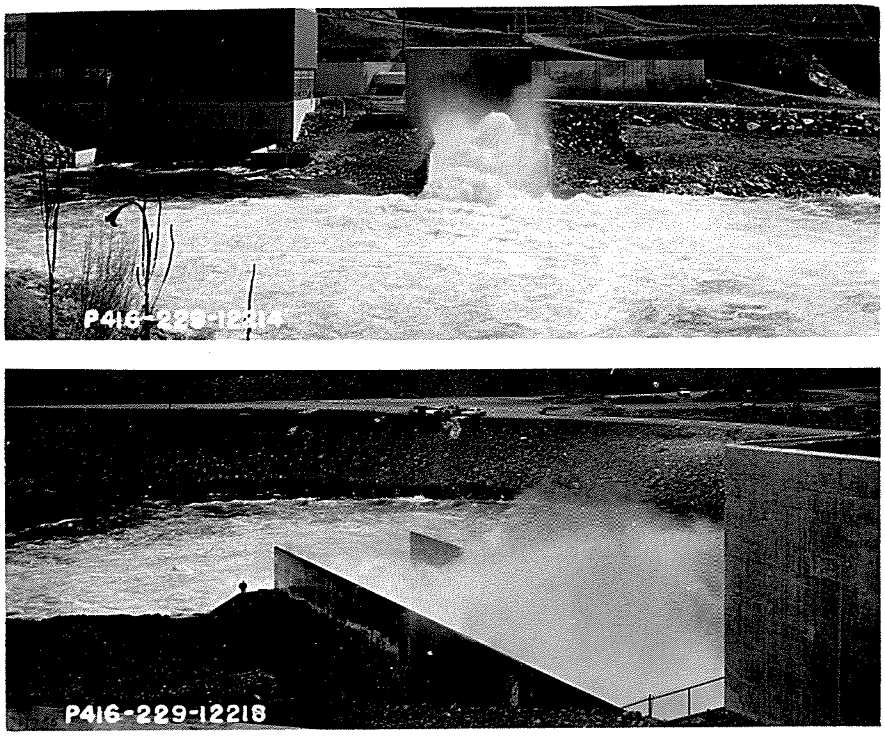
10% Valve opening, Discharge = 1130 cfs, T. W. Elevation = 1899.90



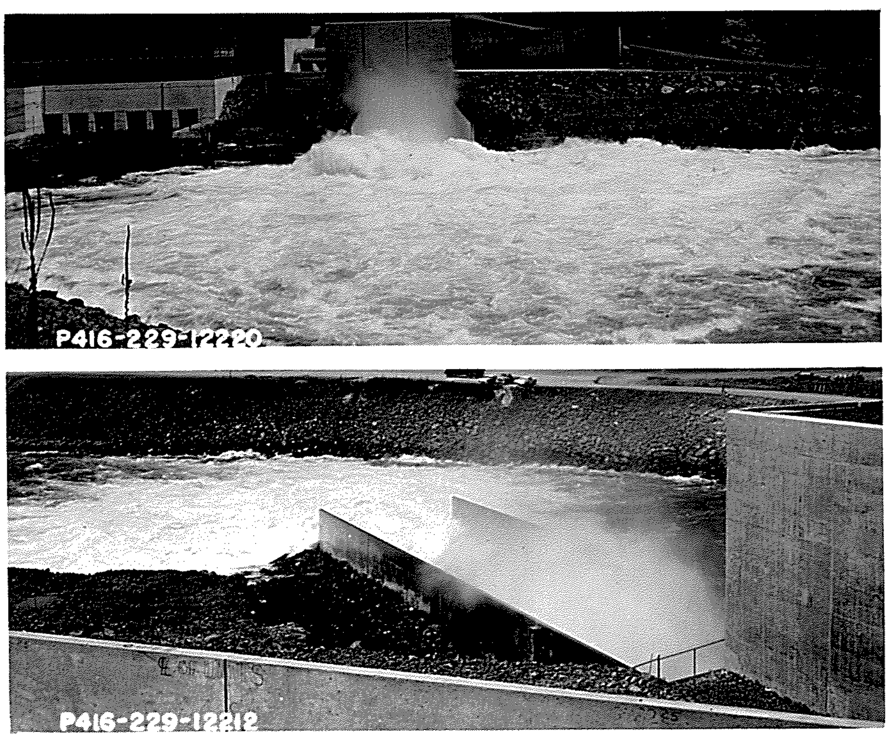


25% Valve opening, Discharge = 2760 cfs, T. W. Elevation = 1901.05

TRINITY DAM OUTLET WORKS
Hollow Jet Valve Stilling Basin
Two Valve Operation

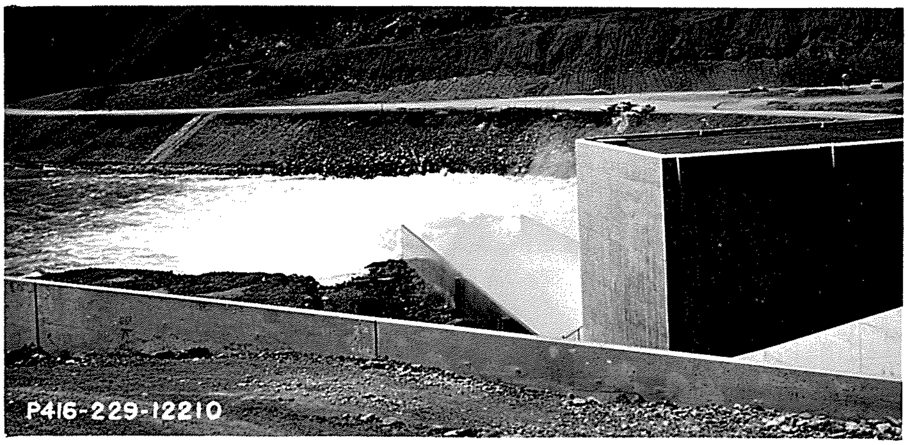


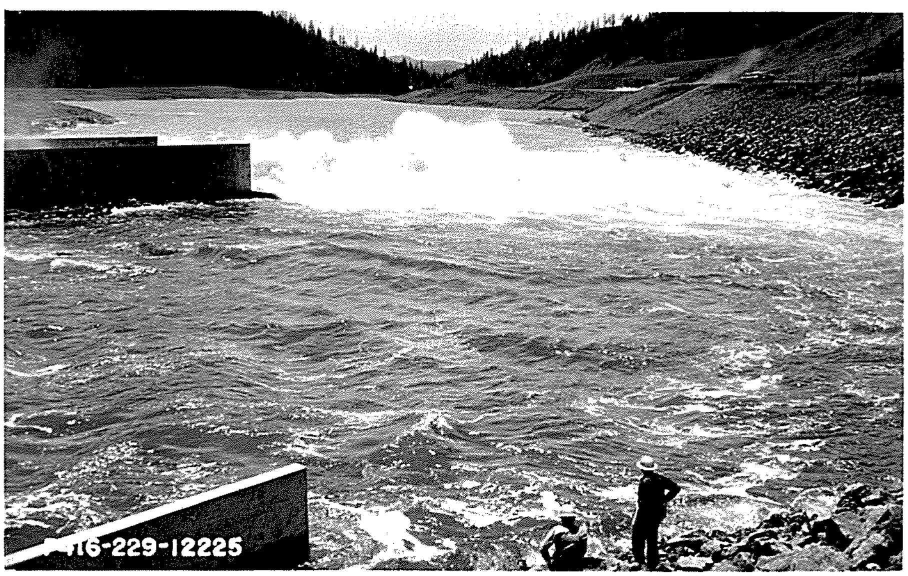
50% Valve opening, Discharge = 5260 cfs, T. W. Elevation = 1902.30



75% Valve opening, Discharge = 7190 cfs, T. W. Elevation = 1903.4

TRINITY DAM OUTLET WORKS
Hollow Jet Valve Stilling Basin
Two Valve Operation

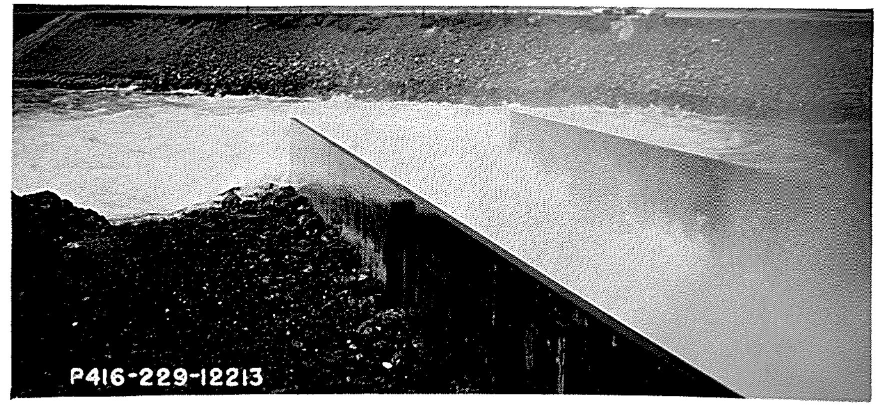


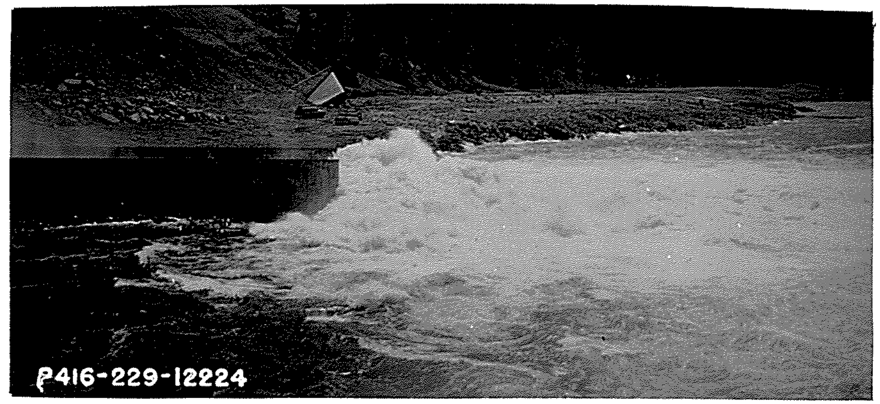


100% Valve opening, Discharge = 8620 cfs, Tailwater Elevation = 1903.7

TRINITY DAM OUTLET WORKS
Hollow Jet Valve Stilling Basin
Two Valve Operation

Discharge = 7670 cfs, Head = 315', Tailwater Elevation = 1903

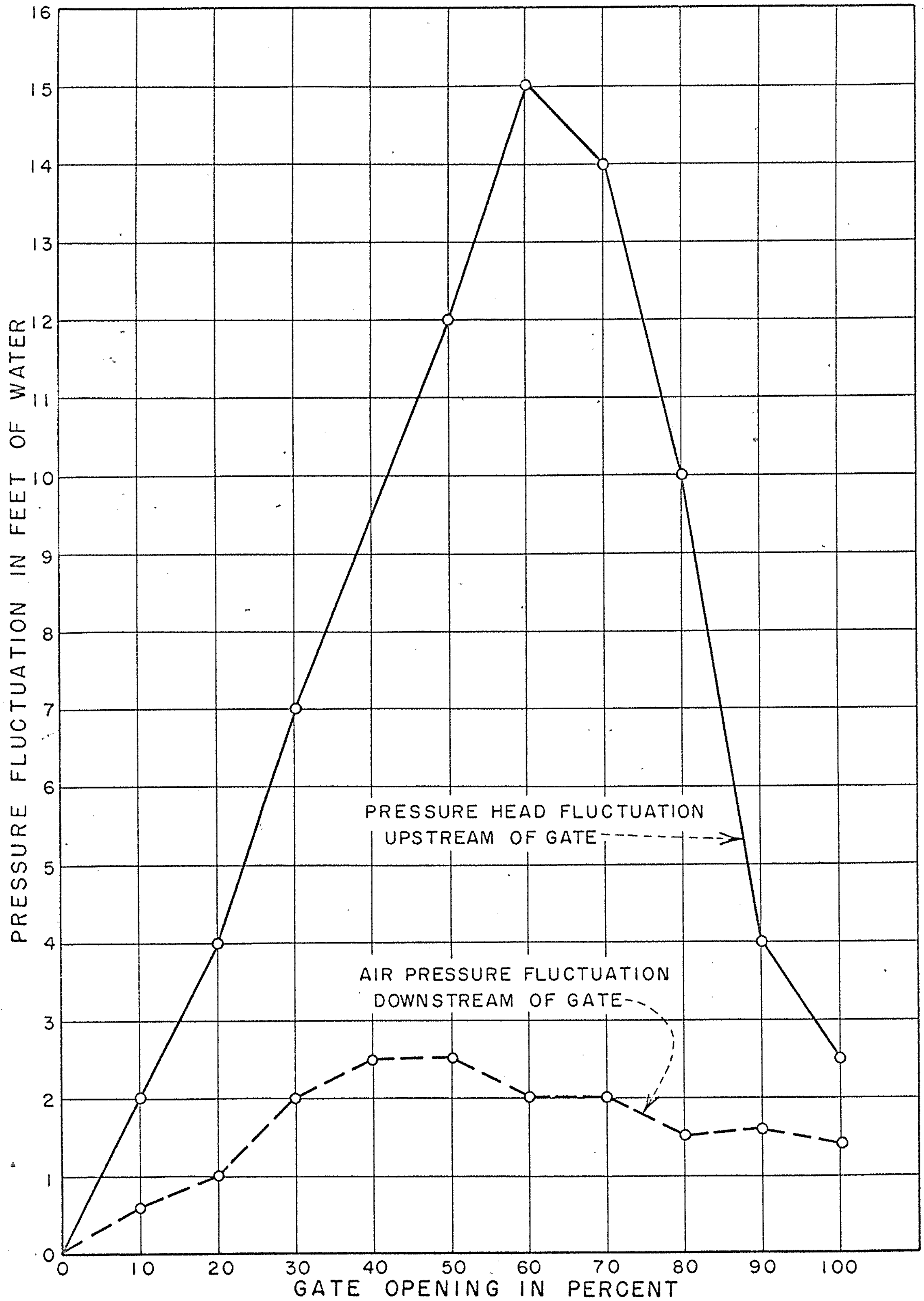




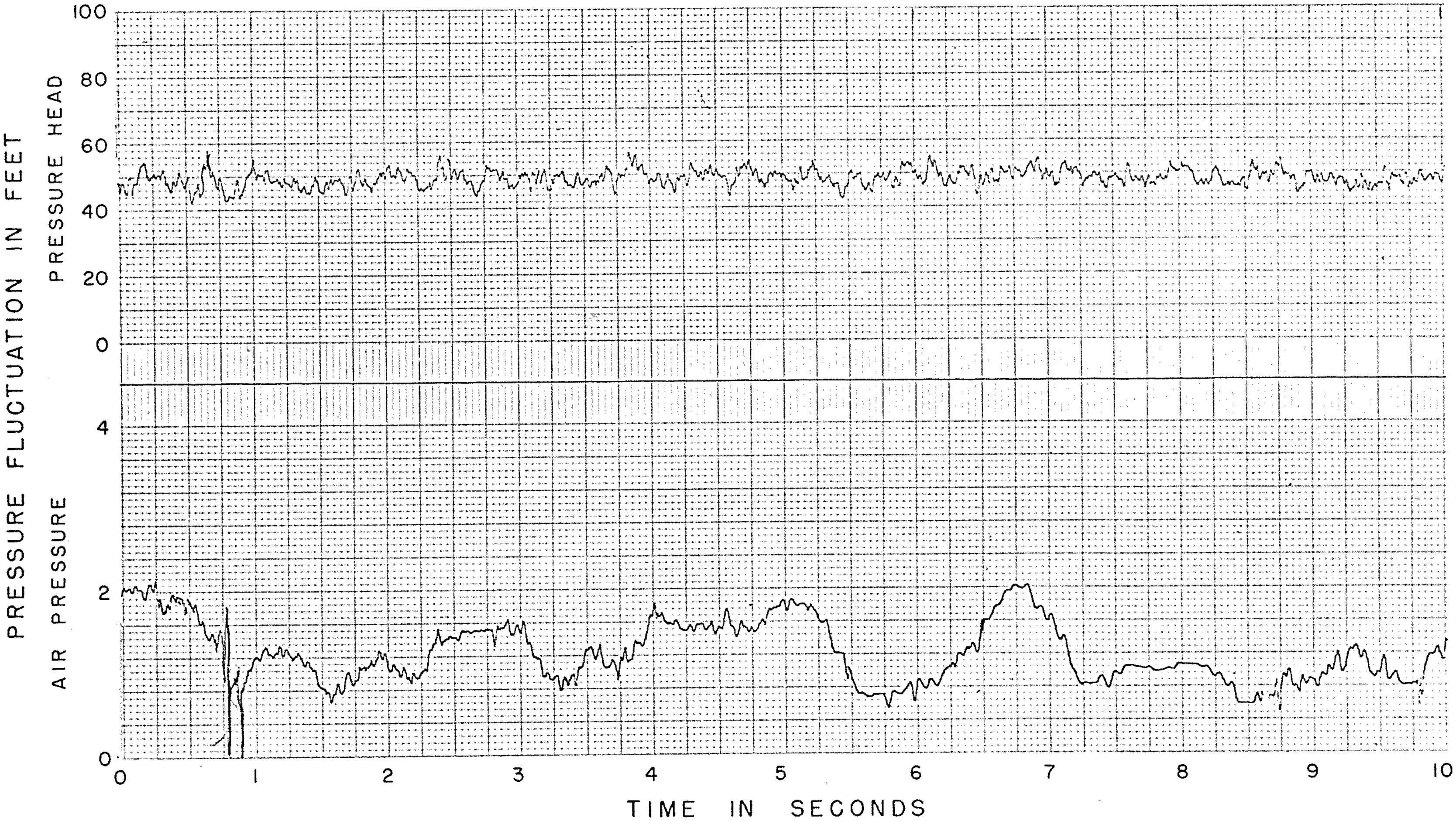
Discharge = 7190 cfs, Head = 375', Tailwater Elevation = 1903.4

TRINITY DAM OUTLET WORKS
Hollow Jet Valve Stilling Basin
Model-Prototype Comparison

Figure 4



TRINITY DAM AUXILIARY OUTLET WORKS
PRESSURE FLUCTATION UPSTREAM
AND DOWNSTREAM OF JET FLOW GATE



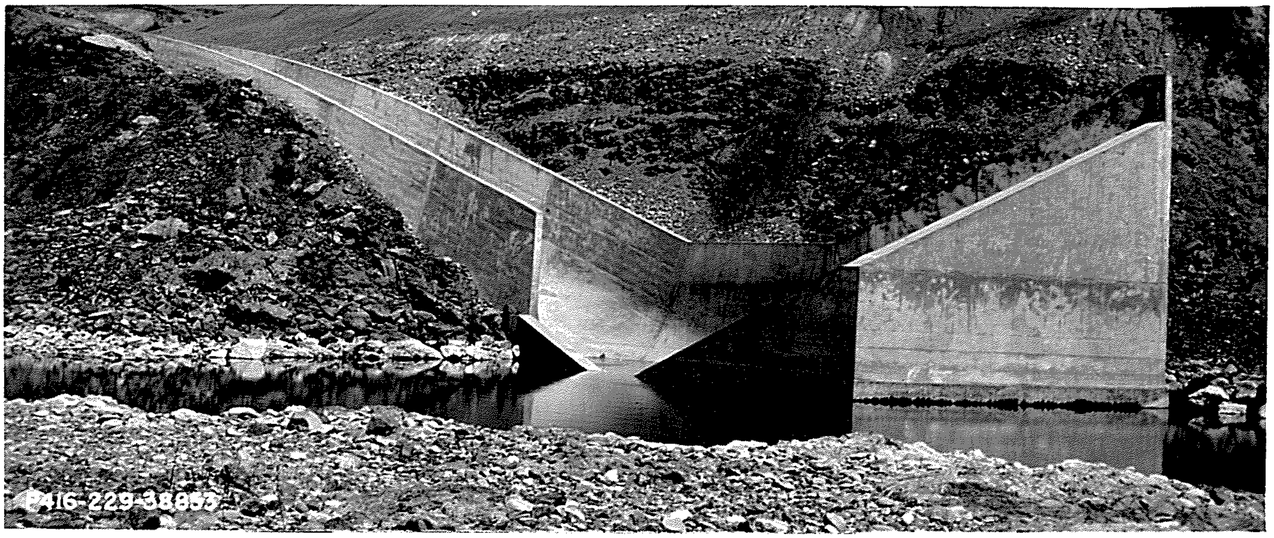
Note: Pressure head fluctuations were measured upstream of gate
Air pressure fluctuations were measured downstream of gate

TRINITY DAM AUXILIARY OUTLET WORKS

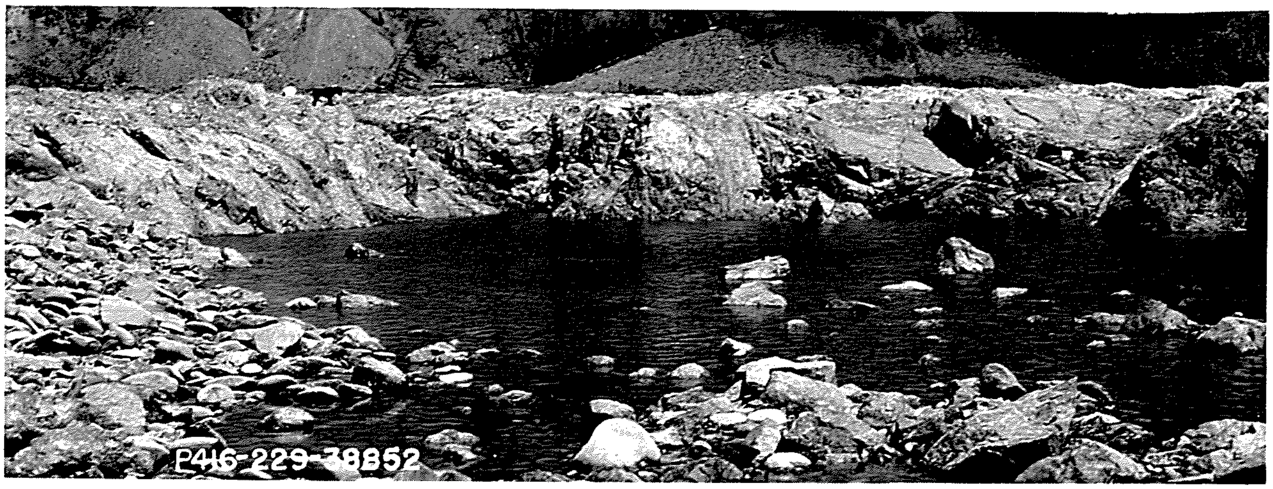
TYPICAL OSCILLOGRAPH RECORDS OF
PRESSURE FLUCTUATIONS AT 60% GATE OPENING

FIGURE 6

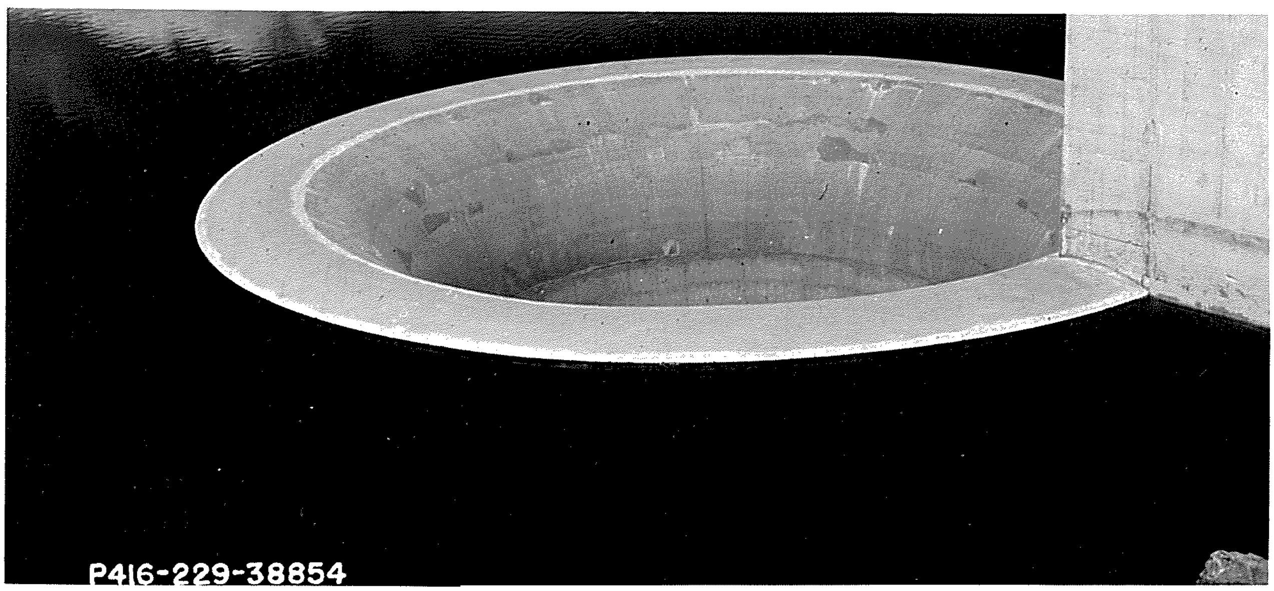
Figure 7



Erosion at side and end of Flip Bucket



Eroded area downstream of Flip Bucket



Morning Glory Spillway

TRINITY DAM SPILLWAY

Morning Glory entrance and eroded areas downstream of Flip Bucket