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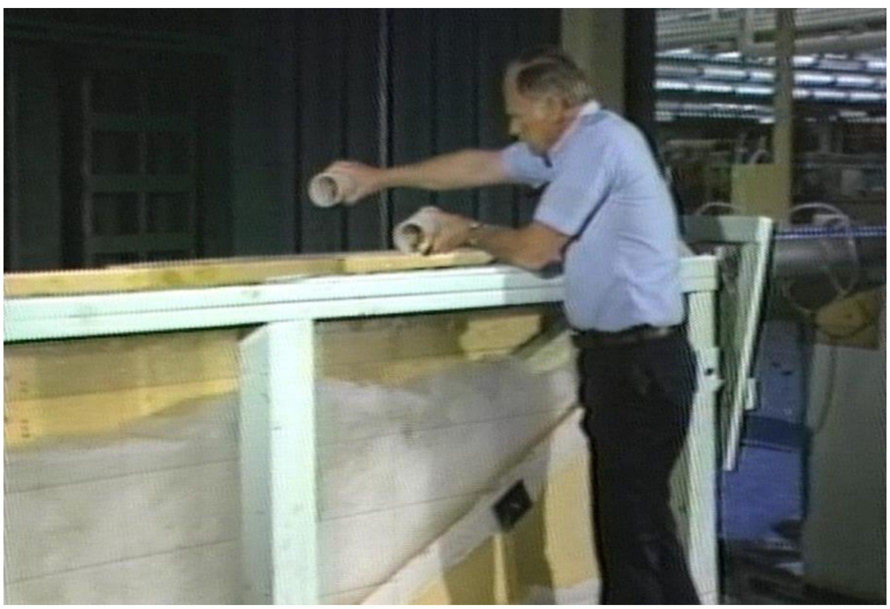
Hydraulic Laboratory Technical Memorandum PAP-1175

Hydraulic Model Study of Abrasion Damage to Mason Dam Outlet Works Stilling Basin

R-90-xx draft research report



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado **1990**

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Hydraulic Model Study of Abrasion Damage to Mason Dam Outlet Works Stilling Basin

R-90-xx draft research report

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Compilation by: Tony L. Wahl

This draft research report was prepared by Eugene Zeigler in the late 1980s but was incomplete at the time of his death. In about 1990 an effort was made to finish the report, but was apparently never completed. The report has been cited on occasion, but could not be located without an official report number. During a review of the 40-year history of studies of abrasion damage in stilling basins, a draft copy of the R-series report labeled R-90-xx was found in data file F-955, along with original photographs for some of the figures. The last marked-up draft of the report is provided here, along with 16 original figures and one figure (Fig. 10) that is representative of what the original figure probably contained. Nine of the originally planned twenty-six figures are still missing.

— Tony Wahl, April 2019

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R-90-XX

HYDRAULIC MODEL STUDY ABRASION DAMAGE - MASON DAM OUTLET WORKS STILLING BASIN

Month 1990

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
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HYDRAULIC MODEL STUDY ABRASION DAMAGE - MASON DAM OUTLET WORKS STILLING BASIN

by

Eugene Zeigler
(??)

Hydraulics Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

Month 1990

/M/

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16. ABSTRACT

A 1:8.25 scale hydraulic model was used to study the abrasion damage problem of high head slide gate outlet works stilling basins. Model tests investigated rock movement inside and downstream from the model stilling basin. For basin operation with less than a 70-percent gate opening, a strong flow current enters at the end of the basin along the invert. Rocks can be drawn into the basin. Because of the downstream rock movement, no sand or gravel should be within 25 feet (7.6 m) of the basin and no 12-inch (0.3-m) and smaller size rock within 15 feet (4.6 m). Rocks of 2-feet (0.6 m) size should withstand basin exit velocities. For basin operation with less than a 50-percent gate openings, rocks were trapped in the basin. Flow currents confined rocks downstream from where the hydraulic jump high-velocity flow leaves the basin floor. The violent turbulence continually "ball mills" the rocks against the basin floor and along the side walls near the basin floor. A rock trap (trench) at the downstream end of the basin prevented flow currents from drawing rocks into the basin. However, when the rock trap is within 1 foot (0.3 m) of being full, it will require rock removal and, therefore, may not be a practical prototype solution to the abrasion damage problem.

Mention Mason Dam and location here somewhere and benefit of study to Reclamation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- hydraulic models/ hydraulic structures/ outlet works/ stilling basins/ abrasion damage/ flow currents/ riprap stability/ slide gates

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The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. 80-1, Stilling Basin Damage Due to Erosion.

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I do not have copies of figures 4, 5, 6, 8, 9, 10, 13, 15, 19, and 24. Will the ones xeroxed change?

PURPOSE

A laboratory investigation was conducted to study hydraulic characteristics related to abrasion damage for outlet works stilling basins where flow enters from high-head slide gates and to test remedial measures to prevent abrasion damage caused by material entering the basin.

INTRODUCTION

Mason Dam is a 173-foot-(metric equiv.?) high rolled-earth- and rock-filled structure located on the Powder River in the east-central region of Oregon. Mason Dam outlet works stilling basin started operation in April 1968 for the release of irrigation water. Rocks entering the Mason Dam outlet works (Baker Project) stilling basin damaged the basin floor. These rocks, moved by the violent turbulent flow, abraded the concrete floor of the basin. The basin was repaired and a chain link fence was built around the basin to prevent rocks being thrown or knocked in by the general public; however, these measures did not prevent the damage from recurring. It was suspected that the surging action of the hydraulic jump was drawing rocks into the basin. To investigate rock movement, underwater divers placed colored rocks downstream from the basin. Although the test results were inconclusive, some rocks had moved out; yet none were found in the basin (equal discharge for both gates).

CONCLUSIONS

- Rocks, once in the stilling basin, stayed in the basin for gate openings of 50 percent or less. Flow currents confined rocks to an area downstream where the high-velocity flow of the hydraulic jump left the basin floor and surged upward toward the water surface.

- The area where the rocks were confined had the most persistent and violent rock movement and, consequently, the most potential for abrasion damage. Rocks moved upstream and downstream, rolling and sliding along the basin floor. Eddies moved rocks in circular paths on the floor and slammed rocks against the side walls.

- Under some operating conditions (Do you want to say **what** operating conditions here?), a strong return flow enters at the downstream end of the basin and can draw rocks into the basin. Because of the danger of being drawn into the basin, no sand or gravel should be within 25 feet (8 m) of the basin, and no 12-inch (0.3-m) and smaller size rock should be within 15 feet (5 m) of the basin.

- Rocks sized 2 feet (0.6 m) should make stable riprap downstream from the stilling basin and should extend at least 15 feet (5 m) from the end sill.

- No rock deposits should be allowed on the end sill because of the danger of being drawn into the basin. Rocks are more susceptible of being drawn into the basin deposited on the end sill than from the downstream topography near the end sill. (last sentence is confusing?!?)

- Rocks can be flushed from the basin. A 750- to 800-ft^{3}s (21- to 23-m^3/s) discharge, operating for 15 minutes, will flush rocks from the basin. However, some (some of these?) rocks may be drawn back into the basin as the gates are closed to a smaller opening.

- A modified end sill, with a rectangular shape, was not superior to the normal dentated end sill.

- A rock trap (rectangular-shaped trench) at the end of the basin prevented rocks from being drawn into the basin. The rock trap will require cleaning when rocks are within 1 foot (0.3 m) from the top.

- Single gate operation drew rocks into the basin more readily (faster?) than balance-and-flow operation from both gates. The model tests were similar to field tests of the prototype.

APPLICATION

Test results of the model study are pertinent to similar stilling basins (long, narrow, and deep stilling basins where flow enters from high-head slide gates) and with similar velocities entering the basin at 90 to 100 ft/s (27 to 30 m/s). The general concept of rocks being trapped in the basin and drawn into the basin by currents of the hydraulic jump should be similar to other hydraulic jump stilling basins.

THE STRUCTURE

The dam has two stilling basins as shown on figure 1. The outlet works stilling basin is on the right, and the spillway stilling basin is on the left. Dimensions of the outlet works stilling basin are shown on figure 2. The basin is divided into two bays by a center wall, and flow enters the basin from two 2-foot 9-inch (838-mm) square high-pressure slide gates.

Conditions of the downstream channel at the end of the basin are shown on figure 3. Some gravel was deposited on the sloping face of the end sill. (Note: the gravel deposit is highest just downstream of the dentate near the centerline of the basin and has the appearance of being drawn upstream toward the basin.) Topography of the downstream channel is shown on figure 4; (need fig. 4) a longitudinal cross section view along the basin centerline is shown on figure 5. (need fig. 5)The basin invert is at elevation 3889 feet (1185.4 m), and the downstream channel bottom is at 3904 feet (1189.9 m). A tailwater depth of 15 feet (4.5 m) is present in the stilling basin without discharge. Most basin operation (fig. 6) (need fig. 6) is with considerably less discharge than the maximum design discharge of 900 ft^3s (25.5 m^3/s); consequently, the hydraulic jump is submerged.

THE MODEL

The 1:8.25 scale model consisted of a tail box, stilling basin, and piping, which is shown on figure 7. In the prototype the outlet works conduit passes beneath the dam, and just upstream from the gate house, a wye branch divides the flow to the two slide gates. Simulation of the prototype piping in the model started just downstream from the wye branch. A head tank was used to reduce turbulence before directing the water into the pipes. The end of these pipes (arrow on fig. 7b) represents the downstream end of the wye branch. The model included the transitions from a circular to square cross section, 30° vertical bends, the upstream gate frames, and the downstream gate frames. The model gate leaves were made of sheet metal, which slid up and down within the gate frames. A trapezoidal shape was soldered to the upstream face of the model gate and duplicated flow surfaces of the prototype gate leaf. Model discharges were measured with Venturi meters in the permanent laboratory supply system.

The model stilling basin was constructed according to the dimensions given on figure 2. Clear plastic was used for the left side of the basin so that flow conditions within the basin could be observed (fig. 7b). A 5-foot (1.5-m) line grid was marked on the plastic to help locate flow conditions.

The general prototype area covered by the model is displayed on figure 4. The backfilled area between outlet works basin and the spillway stilling basin were excluded from the model. Initial tests were conducted with no topography in the tail box. Later, sand was placed in the tail box to form the topography (fig. 4).

TESTING

Flow Conditions

A capability was needed to model test the full range of prototype flow conditions and also a selected range of theoretical flow conditions. The designers furnished the discharge rating for the range of gate openings (fig. 8) (do not have figs. 8, 9, and 10), and tailwater data are given on figure 9. The curve designated "Prototype" is for the actual tailwater acting on Mason Dam outlet works stilling basin. Theoretical tailwater curves were obtained using the hydraulic jump formula.

$$\frac{D_2}{D_1} = 0.5\,(\sqrt{1 + 8F^2} - 1) \qquad (1)$$

Where:

D_2 = depth of flow, downstream basin (conjugate depth)
D_1 = depth of flow entering basin

$$F = \frac{V_1\text{, Froude number}}{\sqrt{gD_1}} \qquad (2)?$$

Where:

V_1 = velocity of flow entering the basin (?)
g = acceleration of gravity

V_1 was velocity leaving the gate (gate discharge divided by gate opening area) and D_1 was the water depth of V_1 acting across the whole bay width instead of the gate width. (V_1 is defined differently??)

Value D_2, conjugate depth, were computed for discharges at a high and low reservoir elevation (fig. 9).

Model tests were made with various gate openings. The prototype discharge and tailwater elevation are given in table 1 for the percent gate openings used in the model tests.

Table 1. - Prototype flow conditions tested in the model (high reservoir elevation 4076 ft (metric?)

Percent gate opening	Discharge for two gates		Tailwater elevation	
	m^3/s	ft^3/s	m	ft
10	3.48	123	1190.7	3906.4
20	6.94	245	1190.9	3907.2
30	9.83	347	1191.0	3907.4
40	13.0	460	1191.1	3907.8
50	16.0	565	1191.2	3908.2
60	19.0	671	1191.3	3908.5
70	21.8	768	1191.4	3908.7
80	24.5	864	1191.5	3909.0
90	27.4	968	1191.6	3909.4
100	30.4	1075	1191.7	3909.7

Rock Movement Characteristics Within the Stilling Basin

Tests were made to study characteristics of rock movement within the stilling basin and were of a preliminary nature to gain basic knowledge about this type of stilling basin. To allow for a wider range of flow test conditions (especially tailwater elevation), the downstream topography was not in place. Hence, flow conditions with the theoretical hydraulic jump tailwater elevation could be tested. If the prototype topography was in place, tailwater depths less than 15 feet (4.6 m) could not be obtained (figs. 4, 5, and 9)

Various size rocks were used in these model tests. In this section of the report, rock sizes are given in prototype dimensions. Prototype rock size, geometrically scaling with the 8.25 model scale, are listed in table 2.

Table 2. - Prototype rock sizes

Size classification	Diameter	
	mm	in
A	50	2
B yellow	100	4
C	200	8
D red	300	12

Rock movement in the model stilling basin was affected by hydraulic flow characteristics in the basin similar to a hydraulic jump (fig. 10). A high-velocity jet exits from the gate, travels down the chute, and along the basin floor. Some distance downstream the high-velocity flow leaves the basin floor and moves upward causing a turbulent boil at the water surface. The distance the high-velocity flow travels along the floor varies with discharge (fig. 11). For low discharges, smaller gate openings, the jet leaves the basin floor further upstream (fig. 11e). Flow conditions of a hydraulic jump are very turbulent with considerable surging. Thus for a given discharge, the point where the jet leaves the basin floor also varies (figs. 11b and 11c).

The location of the most persistent rock movement (fig. 10) was the area where the high-velocity flow leaves the basin floor. As flow fluctuations occurred, the rocks surged upstream and downstream, rolling and sliding along the basin floor. Furthermore, the rocks moved in circular paths on the floor and hit the sidewalls. Frequently vortexlike eddies, formed with the axis vertical to the floor, cause rotational currents acting on the basin floor (arrow on fig. 12). The presence of the eddy is displayed by the ropelike concentration of air bubbles, which collects in the central core of the eddy. The location of persistent rock movement defined the area of maximum abrasion potential in the stilling basin and was designated the abrasive action area.

Tests were made to see how the location of the abrasive action area varied with respect to gate openings. For a given discharge, the extent of the upstream and downstream movement was observed and noted on a sketch (fig. 10). The motion occurred over a somewhat general area and determining the location was dependent upon judgment of the observer. A judgment was made locating the prevalent rock movement - the circles on figure 10. An additional judgment was made locating the limits of the extreme upstream and downstream rock movement - the X's on figure 10. A compilation of these locations versus discharges is given on figure 13. (need fig. 13)

All rock sizes tested readily moved in the area of abrasive action. However, rocks lifted above the basin floor varied with rock size. Strength of the upsurging was slightly greater for larger gate openings than for the smaller gate openings. At the 50-percent gate opening, the 2-inch (50-mm) rocks could be lifted almost to the water surface, and then, depending upon the rock location within turbulent boil, either move upstream or downstream. The 4-inch (100-mm) rocks were often lifted 5 feet (1.5 m) above the floor, periodically lifted 10 feet (3.0 m), and occasionally 15 feet (4.6 m). The 8-inch (200-mm) rocks were now and then lifted 5 feet (1.5 m) above the floor and in rare instances 10 feet. The 12-inch (300-mm) rocks were occasionally lifted 1 to 3 feet (0.3 to 1.0 m) above the floor. Figure 14 shows alignment of rocks lifted above the basin floor.

Flow currents confined the rocks to the abrasive action area. An explanation of these confining currents is presented on figure 15. (need fig. 15) As the high-velocity jet leaves the basin floor, the shearing action moves adjoining downstream water upward. Water removed by shearing action is replaced by the current designated "Return flow" on figure 15. The presence of the "Return flow" current in the model is shown on figure 16. Dye was injected near the stilling basin floor and the "Return flow" current carried the dye upstream (to the right). Rocks lifted by upsurging flow settled back down to the basin floor, and the "Return flow" current moved these rocks back upstream to the abrasive action area. Rocks placed in the model basin upstream of the abrasive action area were moved downstream to the abrasion area. (Note: on fig. 15, flow currents on the basin floor, both upstream and downstream from the abrasive area, are directed toward this critical area.) The grouping of rocks on figure 14c demonstrate the confining effect of these flow currents to hold rocks in the abrasive action area.

Five tests were made to obtain some qualitative measure of flushing action for various gate openings. A given number of rocks were placed in the basin, and the model operated for 1 hour. Subsequently, the rocks that remained in the basin were counted. Pertinent data is listed in tables 3 and 4.

Table 3. - Rocks placed in the model basin (half in each bay).

Rock size in	Rock size mm	No.
2	50	80
4	100	20
8	200	10
12	300	4

Table 4. - Number of rocks flushed from the model basin.

Gate opening	Rock size 2 in (50 mm)	4 in (100 mm)	8 in (200 mm)	12 in (300 mm)
40 percent	32	None	None	None
50 percent	All	5	None	None
50 percent	45	None	None	None
(theoretical tailwater elevation)				
60 percent	All	19	8	3
70 percent	All	All	All	All
(rocks flushed in 10 minutes, model time - 70-percent gate opening)				

Rock removal was affected by rock size. Smaller rocks were removed at a lower discharge than the larger rocks. The smaller rocks were lifted more above the basin floor and carried downstream. The rocks settled downstream of the basin or on the end sill. Rocks deposited on the end sill either moved upstream into the basin or rolled down the back incline of the end sill and into the tail box. Large rocks did not lift above the basin floor, but rolled back and forth. When the abrasion action area was close enough to the end sill, the rocks rolled out of the basin. Removal was dependent on whether the large rocks hit the upstream face of the dentates or rolled between the dentates, and also, whether the momentum was sufficient to roll the rocks up the inclined plane between the dentates to the downward sloping portion of the end sill.

One concern was that drowning of the hydraulic jump created by the high tailwater may have been a major factor causing abrasion damage to the prototype stilling basin. (Note: on fig. 6, the actual operating discharges are considerably less than the maximum basin discharge of 900 ft^3/s (metric?). Thus for irrigation discharges (especially low ones), the prototype tailwater elevation was much higher than the corresponding theoretical conjugate depth tailwater elevation (fig. 9). The hydraulic jump was drowned and possibly kept the rocks from being flushed out of the basin. For a 30-percent gate opening, the model was operated at the prototype tailwater elevation 3907.4 feet (1191.0 m) with rocks in the basin. At this point, the tailwater elevation was lowered to the theoretical elevation of 3899.9 feet (1188.7 m). The location of the abrasive action area did not change, and the flushing action did not improve. For comparison purposes, a flushing test was made with a 50-percent gate opening and theoretical tailwater elevation of 3902.4 feet (metric?) (fig. 10). The flushing action was less than for the prototype tailwater elevation 3908.2 feet (metric?). These tests indicate that the prototype tailwater, which is higher than the theoretical conjugate depth, does not adversely affect the ability of the stilling basin to flush out the rocks.

Topography in the Model Tail Box

Topography as shown on figure 4 was placed in the model tail box. Permanent and temporary wooden templates were used to form the model topography. The temporary templates were for a 45-foot (13.7-m) prototype distance downstream from the stilling basin and were removed prior to model operation. The permanent templates were used for the major portion of the model tail box and were present during model operation. Trial and error operations were done to obtain a suitable material for the model topography. Pit run sand quickly eroded in the model (fig. 17) and left the permanent templates exposed. Hence, gravel 3/8 to 1-1/2 inches (9.5 to 38 mm) was placed in the model tail box, except for an area immediately downstream from the stilling basin (fig. 18).

Erosion tests were made with different size materials placed in the erodible area of interest downstream from the stilling basin (table 5). A given test condition would start with a small gate opening where erosion did not occur. The gate openings then were progressively increased. When describing the model tests in the following pages, rock sizes are given in model dimensions.

Table 5. - Particle size of materials placed in the model tail box

Do you want shaded numbers in decimels to be consistent?

Designation	Model size		Prototype size	
	mm	in	mm	in
Sand	0.15-4.75	0.006-0.19	1.2-39.2	0.05-1.5
Pea gravel	6.3-7.9	1/4-5/16	52-65	2.1-2.6
3/4-in rock	11-19	7/16-3/4	90-160	3.6-6.2
1-in rock	25-38	1-1-1/2	210-315	8.2-12.4
2-in rock	50-64	2-2-1/2	420-520	16.5-20.6
No. 16-No. 18 sieve size	1.2-2.4	0.047-0.094	9.9-19.8	0.39-0.78
No. 8-No. 4 sieve size	2.4-4.8	0.094-0.19	19.8-39.6	0.78-1.6

Initial Erosion Test

This test was conducted to gain information about bed movement for the channel downstream from the stilling basin. Pit run sand was placed for a 30-foot (9-m) prototype distance downstream from the basin.

Erosion was first noticed at the 40-percent gate opening, and the erosion progressed with increased gate openings. With the 60- and 70-percent gate openings, a sand bar formed in the shape of a circular arc at the left side of the basin. At the 90- and 100-percent gate openings, a very pronounced circular sand bar formed on the right side of the basin.

At the 100-percent gate opening, the sand erosion is displayed (fig. 18). A large eddy circulated sand at each side of the basin. The pit run sand is probably not indicative of prototype material downstream from the basin. However, the test results showed an eddy current on each side of the basin.

Size of Rocks Moved Downstream From the Basin

Various materials were tested in the model to determine what size rock would withstand flows from the stilling basin (table 5). Various gravel sizes had been placed near the model stilling basin as shown in configuration A (fig. 19). (need fig. 19)

Three-fourth-inch gravel was placed in the model, and the gravel bed was painted white to help detect rock movement. Displacement of the stones would expose a darker color. No movement of the gravel bed was detected until the 70-percent gate opening. Figure 20 exhibits the condition of the gravel bed after 100 percent gate opening. Most erosion was located near the left portion of the basin and extended 15 feet (4.6 m) downstream from the basin. Stones, which had been moved, were noted 25 feet (7.6 m) from the basin. Also, some stones were moved on the right bank, 20 to 45 feet (6.1 to 13.7 m) downstream from the basin (fig. 20, left side).

One-inch rock was placed in the model near the end sill. The rocks first moved at the 80-percent gate opening. The results of the 100 percent gate opening are shown on figure 21a. Stone movement occurred for a 15-foot (7.6-m) distance downstream from the basin.

Two-inch rock was then tested. After the 100-percent gate opening, the stones were not overturned, as indicated by the white surface on figure 21b. Model tests indicated that 16- to 20-inch (metric?) prototype size rocks did not move.

Material Drawn Into the Basin

Two initial configurations of topography (A and B) near the end sill were tested (fig. 19). Configuration A is the design topography (fig. 2). In spite of years of operation, the deposits may still accumulate near the end sill. (Note: fig. 3 has the deposit of rock and gravel on the end sill.) Configuration B simulates a deposit-type topography.

For configuration A (fig. 19) pit run sand entered the basin at a 40-percent gate opening. The sand at a 70-percent gate opening was effortlessly drawn into the basin. With pea gravel and

3/4-inch (19.5-mm) rock, material was drawn into the basin at the 70-percent gate opening. None of the 1-inch (0.3-m) gravel entered the basin; however, the downstream channel bed did erode.

For configuration B, pit run sand (fines) entered the basin by occasional turbulent eddies at a 20-percent gate opening and freely entered at a 30-percent gate opening. Materials and the gate openings through which they were able to pass are as follows:

- Pea gravel — 50-percent gate opening
- 3/4-inch rock — 60-percent gate opening
- 1-inch rock — 70-percent gate opening
- 2-inch rock — 90-percent gate opening

Model tests indicated flow currents can draw material into the stilling basin. The rocks were flushed out after being drawn into the basin; in some cases (in some cases - ambiguous), however, the action was cyclic with recurring flushing and drawing of rocks into the basin. Configuration B was slightly more susceptible for rocks being drawn into the basin than configuration A. In general, with the deposit topography in configuration B, rocks entered the basin at 10-percent smaller gate openings than for the design topography in configuration A.

The first reinforcement bars exposed in the prototype basin floor were 30 feet (9 m) downstream from the chute blocks. For abrasion damage to occur at this location, the basin would have to operate at a 20- to 30-percent gate opening (fig. 13). However at these gate openings, trivial material was drawn into the model basin. The model tests did not appear consistent with prototype experience.

The model tests to determine whether material would be drawn into the basin were made over a 15-minute to 1-hour interval. To determine whether the action was time related, additional model tests were made.

Sand (Nos. 16 to 8, table 5) was placed downstream from the basin, deposited on the end sill to represent a 1-foot prototype depth, and midway between configurations A and B on figure 19. The model was then operated with a 20-percent gate opening. During the first 2 hours, the sand movement was insignificant. An occasional eddy would contact the sand surface moving the sand grains. Now and then, two to five grains were drawn into the basin; however, sand deposits did not accumulate in the basin. Apparently the sand grains were flushed from the basin at about the same rate as they were drawn into the basin. The sand movement was random - upstream, downstream, or side to side - over the end sill. After 5 hours operation, the general movement was such that a centralized deposit formed on the end sill. The rate of sand drawn into the basin then increased. Over the next 10 hours, sand deposits slightly increased (fig. 22). Sand was effortlessly drawn into the basin from the tip of the deposit but was also being flushed from the basin. A small amount of sand accumulated downstream from the center wall (fig. 22). Also, a few sand grains were deposited at each corner near the end of the basin where the dentate on the end sill adjoins the side wall.

Larger sand (No. 8 to No. 4, table 5) was placed downstream from the basin with a 1 foot deep deposit on the end sill. The model operated 8 hours with a 40-percent gate opening. No sand grains were drawn into the stilling basin during a 5- to 10-minute observation interval. After the model operated for 8 hours, there were approximately 20 grains of sand in the basin. At the

30-percent gate opening, sand grains were drawn into the basin. However, after 7 hours operation, slightly more than 200 grains were in the basin.

Model tests indicated up to 1-1/2-inch (39-mm) prototype size rocks can be drawn into the stilling basin at relative small gate openings of 20 and 30 percent. The small rocks, once in the basin, can be flushed out. The rocks are not flushed far away from the basin and can eventually be drawn back into the basin. Thus, small rocks should be removed 25 feet (7.6 m) from the end of the stilling basin. Generally, there was not a large quantity of rocks in the basin, but even small rocks banging around in the prototype basin day after day explain progress of floor damage to the prototype stilling basin.

Flushing Rocks From the Stilling Basin

With the downstream topography in the model, another test series was made for flushing rocks from the basin. A given number of rocks were placed in the basin (table 3), and the model operated for 1 hour. The number of rocks flushed from the basin is given in the following table.

Table 6. - Number of rocks flushed from the model basin, downstream topography in model

Gate opening	Rock size			
	2 in (50 mm)	4 in (100 mm)	8 in (200 mm)	12 in (300 mm)
30 percent	3	None	None	None
40 percent	43	None	None	None
50 percent	77	6	None	None
60 percent	All	All	9	3
70 percent	All	All	All	All

(rocks flushed in 5 minutes, model time - 70 percent G.O.)

One remedial measure may be to flush rocks from the stilling basin. At the 70-percent gate opening (high reservoir elevation), rocks were readily flushed from the model basin. Thus, a 750- to 800-ft^3/s (metric equiv.?) discharge operating for 15 minutes should flush rocks up to 12 inches (3.6 m) in size from the prototype stilling basin. However, closing the gates is one prototype operation that cannot be accurately duplicated in the model. As the gates close, the end of the hydraulic jump will move upstream in the stilling basin, and some rocks may be drawn into the stilling basin.

Modified End Sill

A rectangular-shaped end sill was tested (fig. 23a). For configuration A, pit run sand entered the basin at the 40-percent gate opening and pea gravel entered at the 80-percent gate opening. The 3/4-in rock was not drawn into the basin.

For configuration B, small particles of pit run sand entered the basin at the 20-percent gate opening and large particles at 30 percent gate opening. Erosion downstream from the sill is shown on figure 23b. Pea gravel entered the basin at the 60-percent gate opening and 3/4-in (metric equiv.?) gravel at the 70 percent gate opening.

The two end sills, design and rectangular, were compared by material brought into the basin versus gate opening. For pit run sand both end sills were similar. For pea gravel and 3/4-in gravel, the design sill was slightly more susceptible of drawing rocks into the basin than the rectangular sill (10 percent lower gate opening than for the rectangular sill). The modified end sill was not appreciably better than the design end sill.

Rock Trap

A trench, downstream from the stilling basin, was tested as a rock trap (fig. 24). (Need fig. 24) The intent was to prevent rocks from being drawn into the basin.

Various size materials were tested in the model. With pit run sand, a slight amount of sand entered the rock trap at the 40-percent gate opening. More sand entered the rock trap as the gate openings increased. At the 80-percent gate opening, fines evidently were not trapped because fines were observed on the downstream sloping portion of the end sill. With pea gravel, the first rock moved into the trap at a 50-percent gate opening. Pea gravel drawn into the rock trap after the 100-percent gate opening is exhibited on figure 25a. With 3/4-in rock, the gates were 70 percent open before the first rock moved into the trap. A couple of 1-inch rocks moved slightly; none of the rocks were dislodged.

An additional test series was conducted investigating when the rock trap would not effectively trap material. The rock trap was filled with the various size materials and then subjected to flow of 100 percent gate opening. Thus, material eroded from the trap would indicate ineffectiveness of the trap, and the trap would need to be cleaned before material could reach that level. Erosion of the pit run sand is exhibited on figure 25b. The left side had 1-3/4 feet (0.53 m) of erosion, and material was deposited in the middle. Some armoring occurred at each side; the fines were removed, and the larger particles remained. With pea gravel the left side had 1 foot (0.30 m) of erosion and the 3/4-in rock had 1/2 foot (0.15 m) of erosion.

Model tests indicated how the rock trap effectively prevented prototype size rock, 1-in and larger, from being drawn into the basin. The smaller material may not be caught in the trap at the gate openings 80 percent and greater. The rock trap should be cleaned when material is within 1 foot (0.3 m) from the top.

Single Bay Operation

Single bay operation is allowed only under emergency conditions by Reclamation's operating criteria for this type basin. Previous hydraulic model studies showed material could be drawn into the basin with single bay operation at larger gate openings.

A single bay operation field test was proposed. The drowning of the hydraulic jump would be less than with balanced operation and possibly drowning is conducive to drawing material into the basin.

A field test was made with only the left bay operating. Test contingencies allowed an 650-ft^3/s (18.4-m^3/s) discharge for 15 minutes, and then the intended 350-ft^3/s (9.2-m^3/s) discharge operated for 1 hour. The Pacific Northwest Region diving team examined the basin before and after the test. Both corners downstream from the basin were eroded and material had been evoked into the basin (fig. 26a). The divers removed the material from the basin, and another test was made with an 8.5-m^3/s (300-ft^3/s) discharge for 2 hours. Some rocks were drawn into the basin. It was concluded that balanced operation was a superior mode of operation.

A model test was made with only the left bay operating at 650 ft^3/s (metric?) for 5 minutes, then 350-ft^3/s (9.2-m^3/s) discharge operating 20 minutes with No. 8 to No. 4 sand, table 5, downstream of the end sill. Material was drawn into the basin at the 650-ft^3/s and was discharged and deposited in the downstream portion of the right bay. With the 350-ft^3/s (metric?) discharge, the high-velocity flow on the floor occasionally impinged upon the end sill, and other times the flow was deflected upward about 5 feet (1.5 m) downstream from the center wall. Turbulent flow moved material over the end sill and in and out of the left side of the basin. Material swirled around the floor of the left bay downstream from the center wall and collected in a compact pile with circulation of an eddy or at other times spread out. In the right bay there was not much movement of the deposit. Material in the basin and erosion at both downstream sides of the basin are shown on figure 26b.

The model test results were similar to the field test. Although the deposit in the left bay of the model was different than the prototype, the similarity between model and prototype were judged a verification of the model.

PROTOTYPE CHRONOLOGY

- Mason Dam outlet works stilling basin began operating in April 1968.

- In October 1975 during the first underwater examination, divers found extensive damage of the stilling basin floor. Rocks had entered the basin, churned in the turbulent water, and abraded the floor. Most of the damage occurred in the middle portion of the basin, and damage was negligible at the upstream and downstream ends of the basin. The left bay showed more damage than the right bay - left bay, 20 to 24 inches (500 to 600 mm) (with?) maximum concrete removed and right bay, 3 to 4 inches (75 to 100 mm) (with?) maximum concrete removed. The divers found cobbles of 10 to 12 inches (250 to 300 mm) in the left bay and stones of 1 to 2 inches (25 to 50 mm) in the right bay. The basin was repaired in February 1976 using a good quality of concrete after 8 years of operation. A chain link fence was also installed adjacent to the basin in 1976 to block access by people, and preventing rocks from being dropped or thrown into the basin.

- The next underwater examination was made in November 1978. Damage was estimated to be 3 to 4 inches (75 to 100 mm) deep in the left bay (tops of some reinforcement bars exposed, traversing from side to side in the left bay) and an estimated 2 to 3 inches (50 to 75 mm) deep in the right bay. The basin was dewatered and inspected. Damage was caused by rocks which entered the basin, not because of inferior concrete. About 1 yd^3 (3/4 m^3) of rock was removed from the basin. Since the chain link fence prevented people from throwing rocks, it was believed that the hydraulic action brought rocks back into the basin. Surging currents were suspected of drawing rocks in at the downstream end of the basin.

- In 1979, 3 years after the basin had been repaired, basin damage appeared to be progressing rapidly. Frequent underwater diver inspections were made to monitor abrasion damage. At this point, repair of the basin could be made before extensive damage. (Were any repairs made at that time? If not, why not?) In March 1979, eight stations were established for taking abrasion erosion measurements in the left bay. Taking underwater measurements is difficult, and measurement accuracy was believed 0.05 foot (±15 mm). Some abrasion erosion did occur. The erosion could not be quantitatively measured; however, it was detected by a slightly greater exposure of reinforcement bars. During three underwater inspections, (which three?) 0.1 ft^3 of rock was found in the left bay and numerous rocks in the right bay. Rock sizes were 3 inches (75 mm) and smaller with predominate number being smaller. Also, during the 1979 irrigation season, the divers tested rock movement in the channel immediately downstream from the basin. Painted rocks were placed on grid lines. Some rocks did move, but test results were inconclusive for proving rocks were hydraulically drawn into the basin.

- Prior to the 1980 irrigation season, a protective cover was placed on the basin to prevent rock entry by the general public. Wood planks covered the top of the basin. At the downstream end of the basin, the chain link fencing was attached to the planks, hung downward, and were touching the water surface. The cover did prevent some rock entry. Fewer rocks were found in the basin during the 1980 irrigation season. At one inspection visit, two angular rocks - about 2-inch (0.5-m) diameter - were found on the plank cover. For three of the five underwater inspections, rocks were found in the left bay. In the first inspection, three rocks were found - well rounded 1 to 1-1/2 inches (20 to 30 mm); second inspection, 10 rocks - well rounded 1/4 to 1/2 inch (5 to 10 mm) and one angular rock 3/4 to 2-1/2 inches (25 mm); third inspection, several well rounded rocks 3/4 to 2-1/2 inches (15 to 55 mm). Again in 1980, a rock grid was placed downstream from the stilling basin. Some of the rocks did move upstream toward the stilling basin.

- During August 1980, field tests were made to test single bay (gate?) operation. Single **bay** operation provided more discharge to the hydraulic jump, and theoretically the jump should operate with less submergence. (Does single bay and single gate imply the same thing?) Single **bay** operation field tests were conducted for only a short time. Following a 1-hour test and immediate inspection, divers found that rocks had been brought into the basin. Single **bay** operation was not the answer to the abrasion problem. The test results substantiated the Reclamation's operating criteria prohibiting single bay operation.

- Two underwater examinations were made by divers in 1981. On July 17, about six well-rounded rocks, less than 2 inches (50 mm) in diameter, were found in the right bay near the base of the chute blocks. No rocks were found in the left bay. On August 15, five small well-rounded rocks, 3/4 to 1-1/2 inches (20 to 40 mm) in diameter, were found in the left bay. Therefore, in 1980?, more length of reinforcement bars was exposed.

- Another underwater examination was made September 25, 1982. Rocks were found scattered on the upstream one-third floor area of the right bay. Sizes ranged from one elongated 3- by 6-inch (75- by 150-mm) rock down to 1/2-inch (12-mm) rocks; most were 1-1/2 to 2 inches (40- to 50-mm) in diameter. The rocks were well rounded to subangular in shape. No rocks were found in the left bay. During the summer operation, some planks had been dislodged, and it was believed many rocks found in the right bay had been dropped through openings between the dislodged planks. Planks covering the left bay were intact. Reinforcement bar exposure on the left bay floor was twice of that in 1981.

- On November 29, 1983, an underwater examination was conducted. Only one 2-inch (50-mm) angular rock was found in the entire structure, which was located in the right bay. Erosion of the concrete floor had not deteriorated much more than it did in 1982.

- On September 22, 1984, another underwater examination was made. Rocks were found only in the left bay; two subangular 4-inch (100-mm) diameter rocks were found about mid-distance between dentate and the splitter wall, and a small pile of well-rounded 1/2- to 1-1/2-inch (12- to 40-mm) rocks in the downstream corner formed by the left wall and dentate. Since 1983, no significant erosion of the floor was evident.

- An additional underwater examination was made on September 19, 1986. Erosion of the concrete floor had progressed since the last examination. In the left bay, some longitudinal reinforcement bars were exposed beneath the transverse reinforcement bars. For the first time, a transverse reinforcement bar was exposed in the right bay. One spot showed where a stone from the concrete aggregate had been plucked out from the floor. (Information for 1986 was obtained by viewing a video tape of the damage.)

(Should the following paragraphs be part of the Conclusions?) I set up the preceding paragraphs differently; I was confused by the setup.

A review of all underwater examination reports indicates that after the basin repair in 1976, concrete floor erosion progressed similar to the previous damage. Most of the damage was in the left bay, and the deep-seated erosion was in the mid-portion of both bays. Previously, the basin operated 8 years before repairs had been made. Currently, the basin has operated 12 years. Covering the basin and/or removing the rocks from the basin by underwater divers has extended basin operation time before requiring repairs.

Few rocks were found in the stilling basin since the 1978 underwater examination, yet exposure of reinforcement bars increased, indicating continued erosion of the concrete floor. The underwater examination reports do not offer enough information to definitely establish that rocks causing the abrasion damage entered the basin only by hydraulic action. From the 1982 report, it is evident that people can still drop rocks into the basin. Therefore, there is still room for speculation of whether rocks can enter the basin only by people, by hydraulic action, or by a combination of both. Cavitation has also been a speculation for the cause of damage to the concrete. Nevertheless, field experience indicates cavitation damage progresses more rapidly than the 12-year operation time of the stilling basin. The divers did see evidence (1986 report (reference?) where high-velocity flow plucked aggregate from the concrete. Although this concrete damage occurred, it probably occurred in combination with abrasion damage. Sand and small pebbles in the turbulent flow abraded the concrete matrix between the larger aggregate particles, which weakened support of the large aggregate against high-velocity flow.

The results of the model tests did not unquestionably confirm the progress of prototype basin damage as described by the underwater examination reports. Model tests did explain the basic mechanism of abrasion damage. The basin flow currents, with rocks within the basin and low discharges, confined the rocks within the basin and the violent turbulent flow continually moved the rocks against the concrete floor. Since the 1978 inspection, the underwater examination reports did not indicate many rocks were found in the basin. Possibly just the few rocks found in the basin caused the abrasion damage. Slow abrasion damage with few rocks found in the basin is described by the last four paragraphs of "Material Drawn into the Basin" section of this report. Is the last sentence necessary?

Original figures. Figures 4-6, 8-9, 13, 15, 19, and 24 were missing from the draft report.

Figure 1. — Stilling basins at Mason Dam, Oregon. The spillway stilling basin is on the left, and the outlet works stilling basin is on the right.

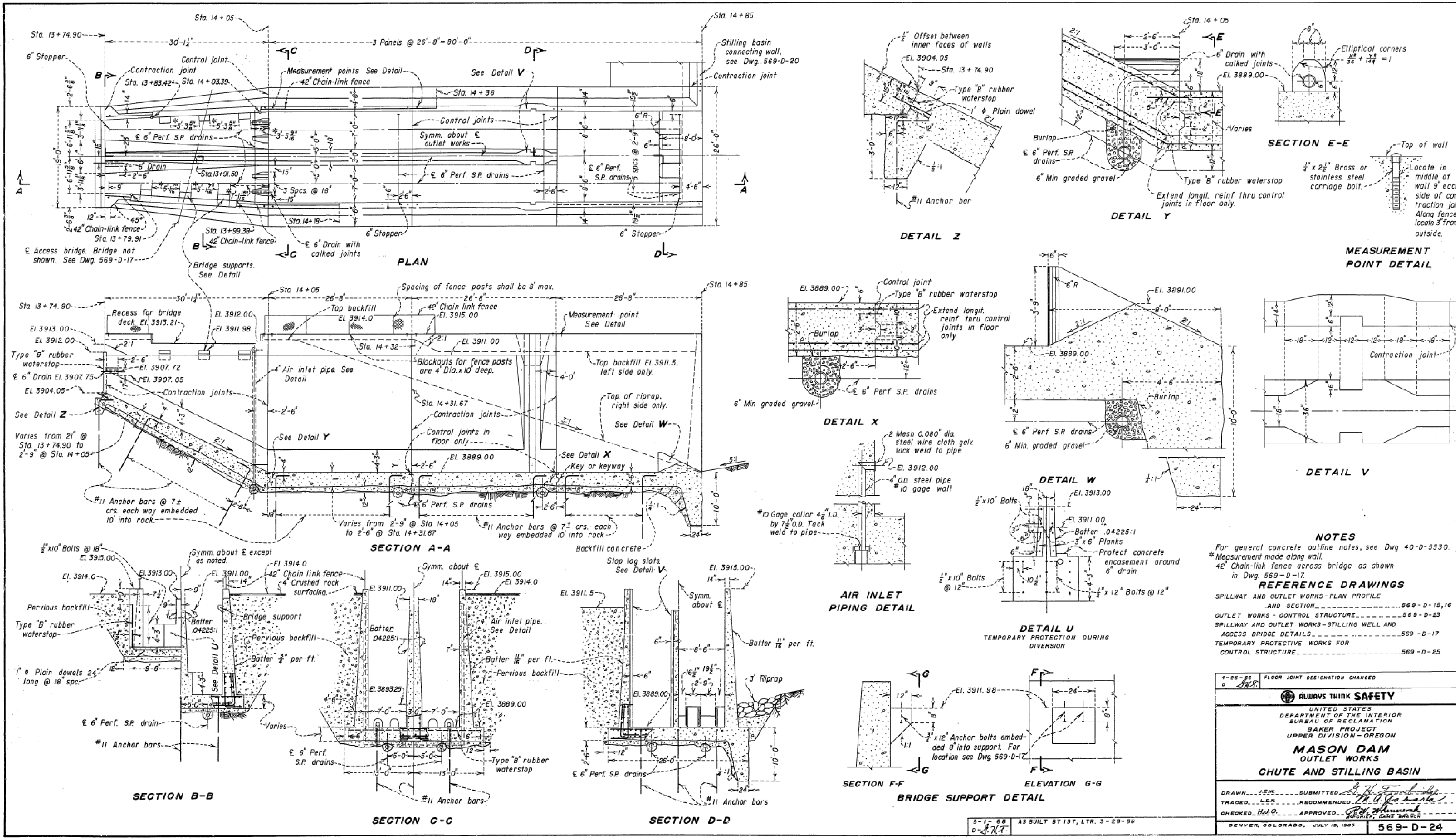
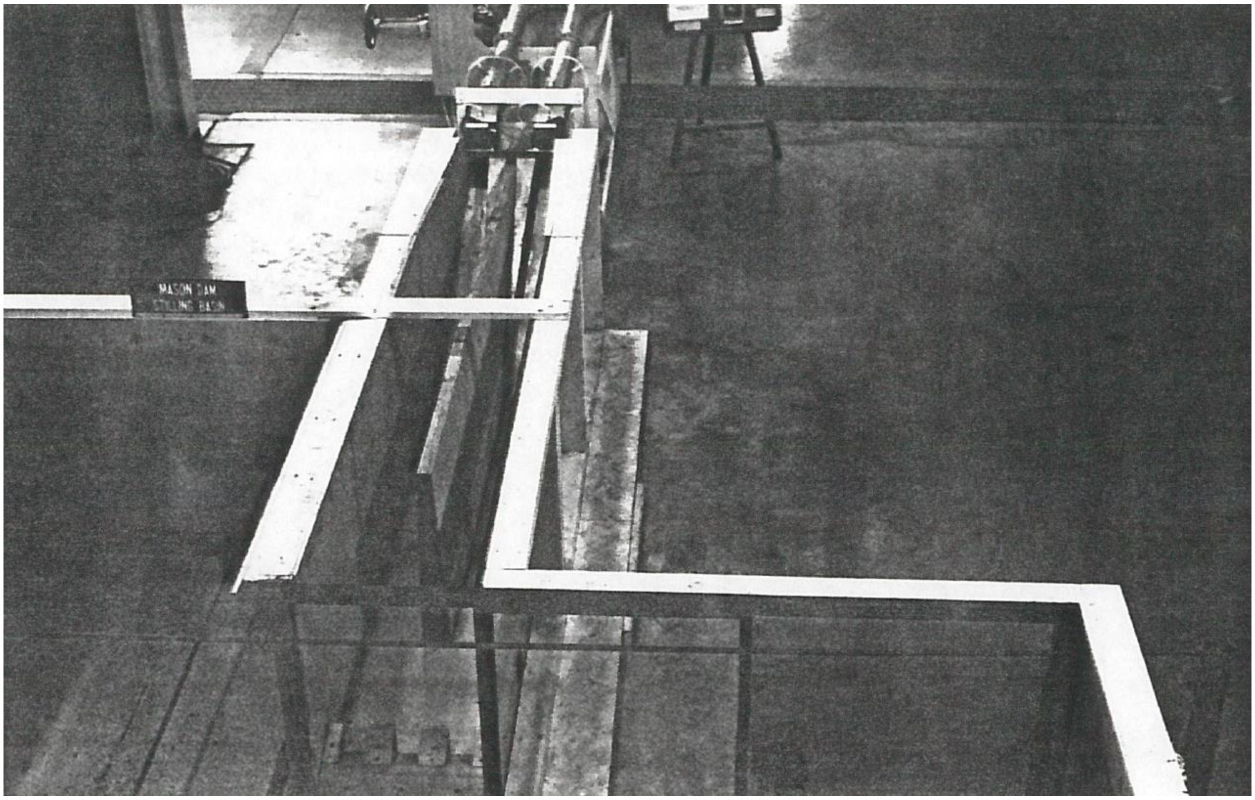
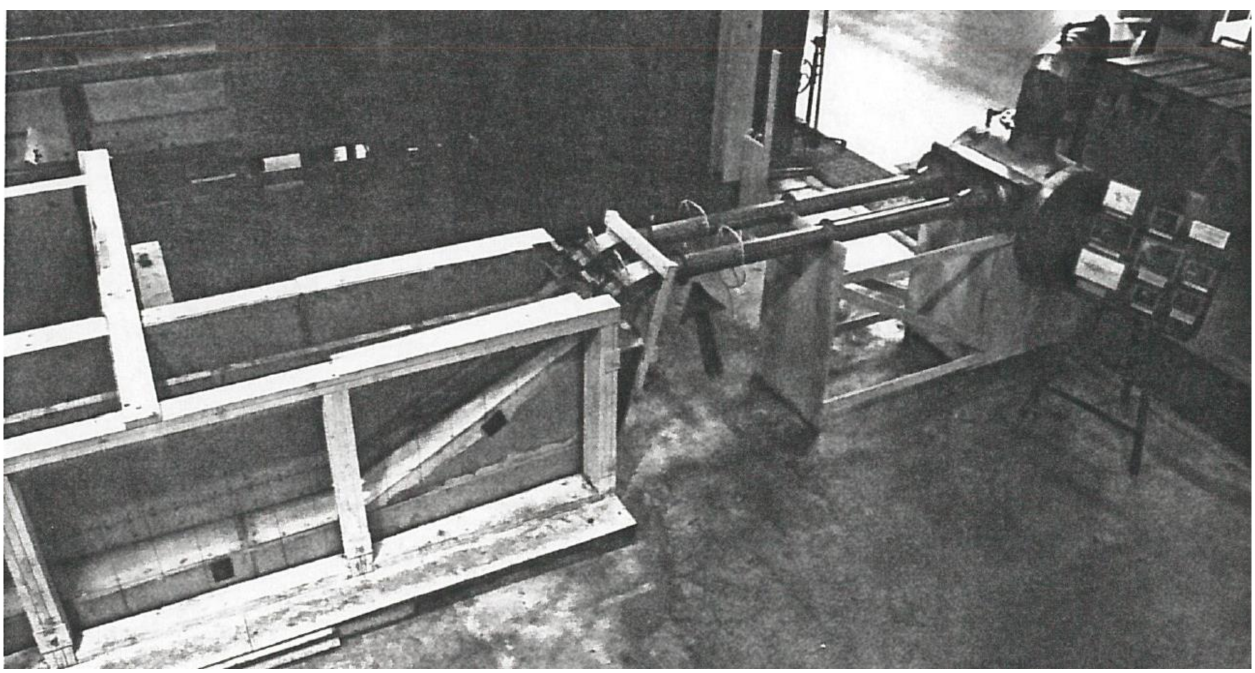


Figure 2. — Original design drawing for Mason Dam outlet works stilling basin.

Figure 3. — Gravel deposit on the end sill of the outlet works stilling basin.



Model tailbox and stilling basin



Stilling basin and outflow piping.

Figure 7. — The model.

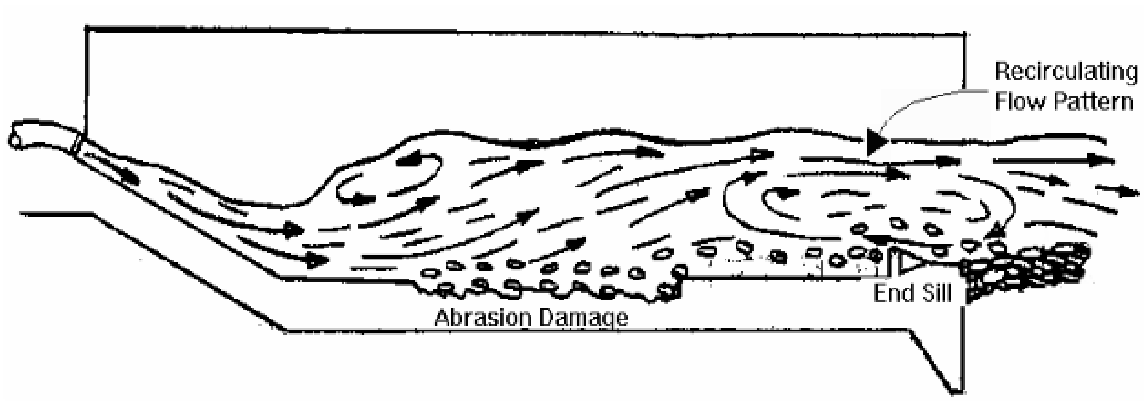
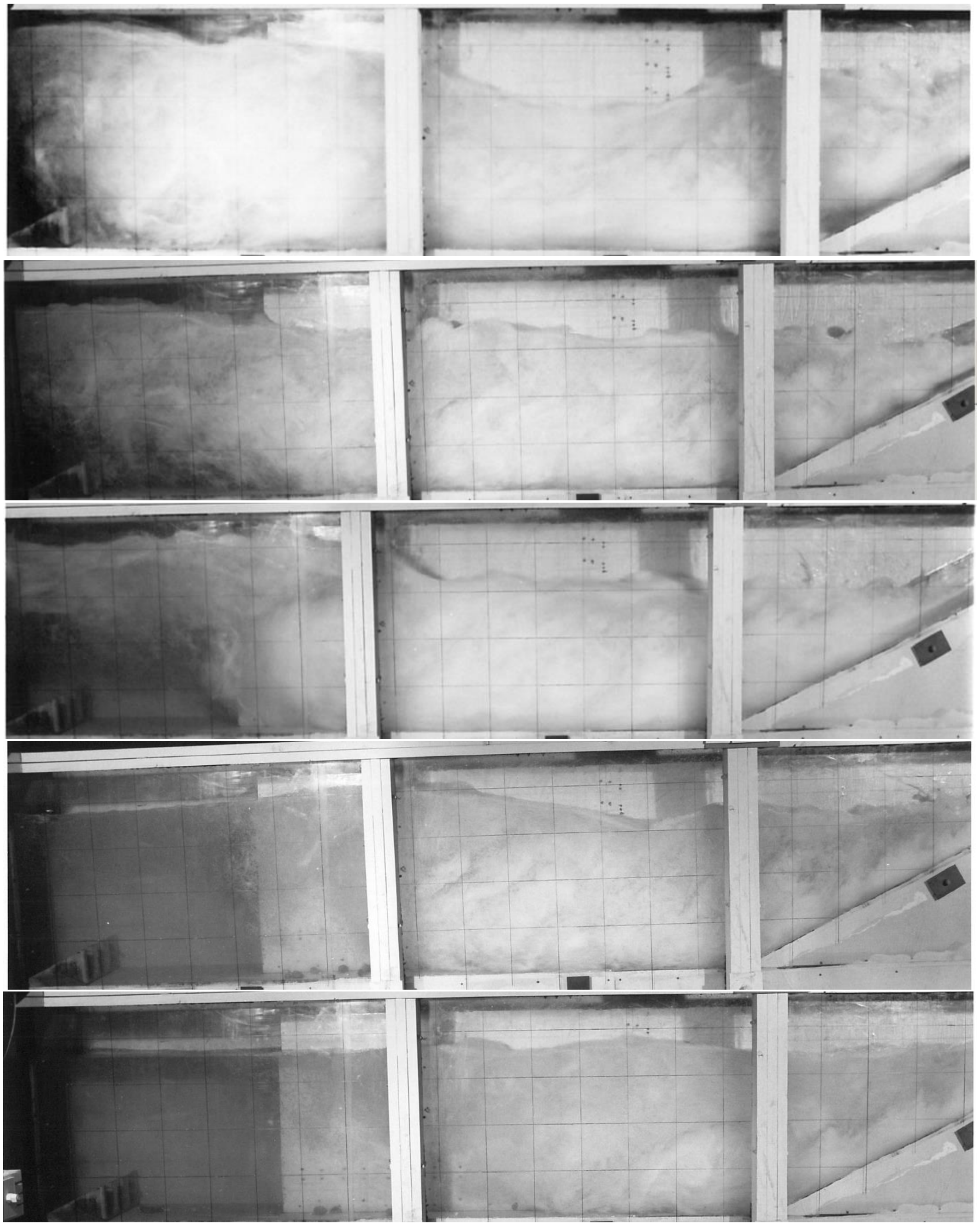


Figure 10. — Schematic of flow in model basin. (Figure was missing from draft report…this image showing something similar is Figure 1 from HL-2005-01).



a)
b)
c)
d)
e)

Figure 11. — Stilling basin flow conditions.

a) 100% gate opening, 30.6 m^3/s (1080 ft^3/s). Photo H-1920-148
b) 60% gate opening, 19.0 m^3/s (670 ft^3/s). Photo H-1920-9
c) 60% gate opening, 19.0 m^3/s (670 ft^3/s). Photo H-1920-14
d) 30% gate opening, 9.8 m^3/s (345 ft^3/s). Photo H-1920-91
e) 20% gate opening, 6.9 m^3/s (245 ft^3/s). Photo H-1920-100

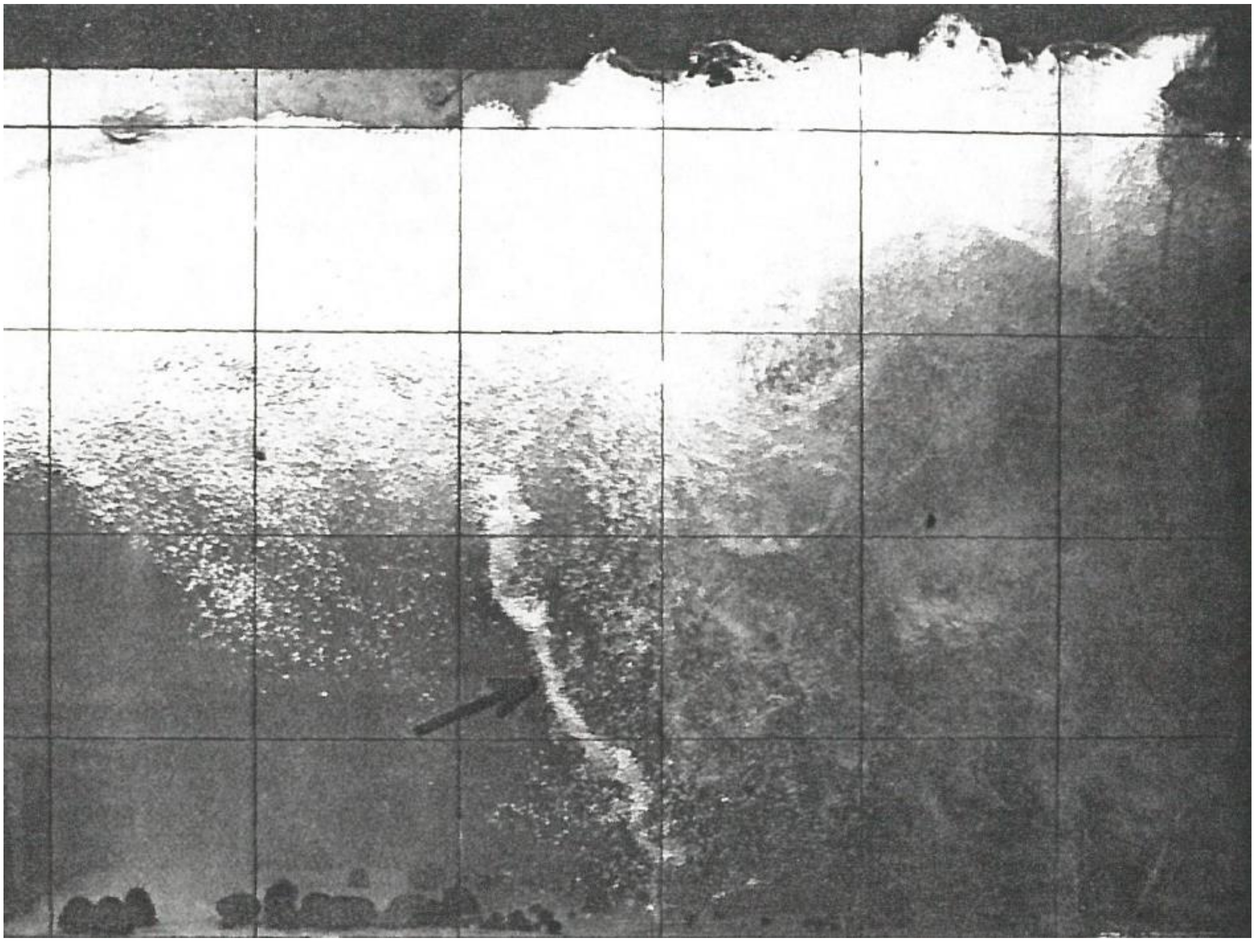
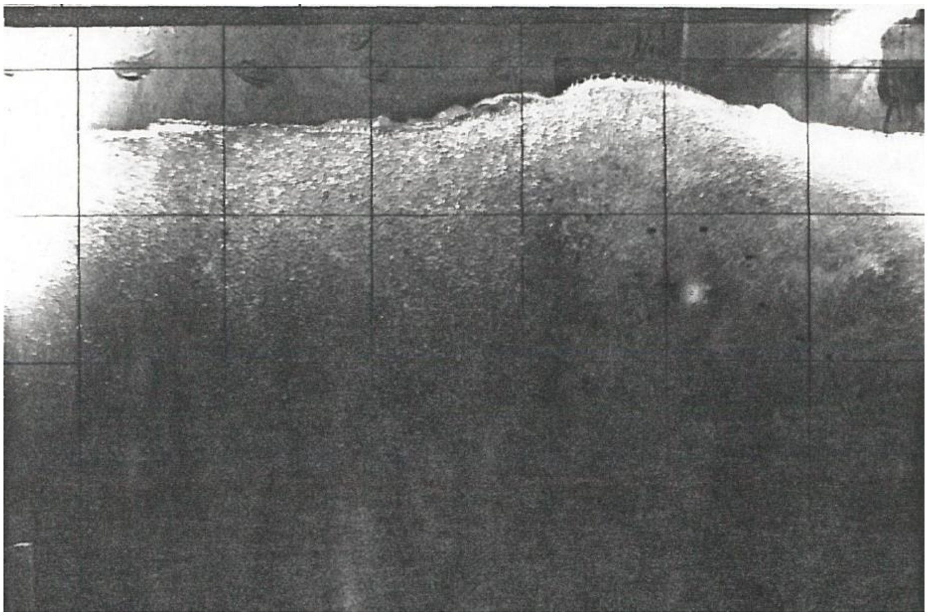
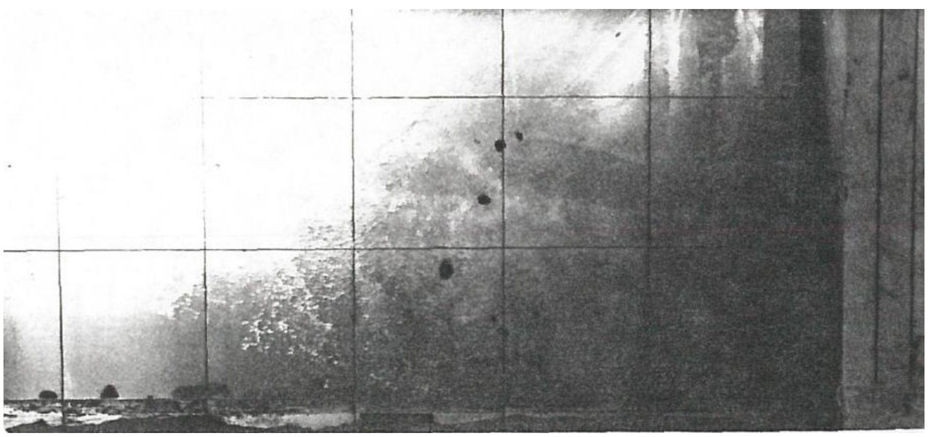


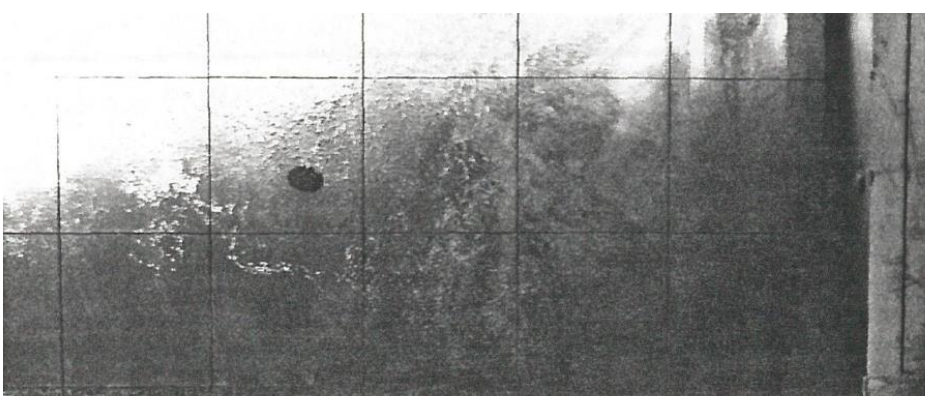
Figure 12. — Eddy with air bubble core. 50% gate opening, discharge = 16.0 m^3/s (565 ft^3/s).



a) 50-mm (2-in.) rocks, 40% gate opening, 13.0 m^3/s (460 ft^3/s)



b) 100-mm (4-in.) and 200-mm (8-in.) rocks, 50% gate opening, 16.0 m^3/s (565 ft^3/s)



c) 300-mm (12-in.) rock, 50% gate opening, 16.0 m^3/s (565 ft^3/s)

Figure 14. — Rocks lifted above the basin floor.

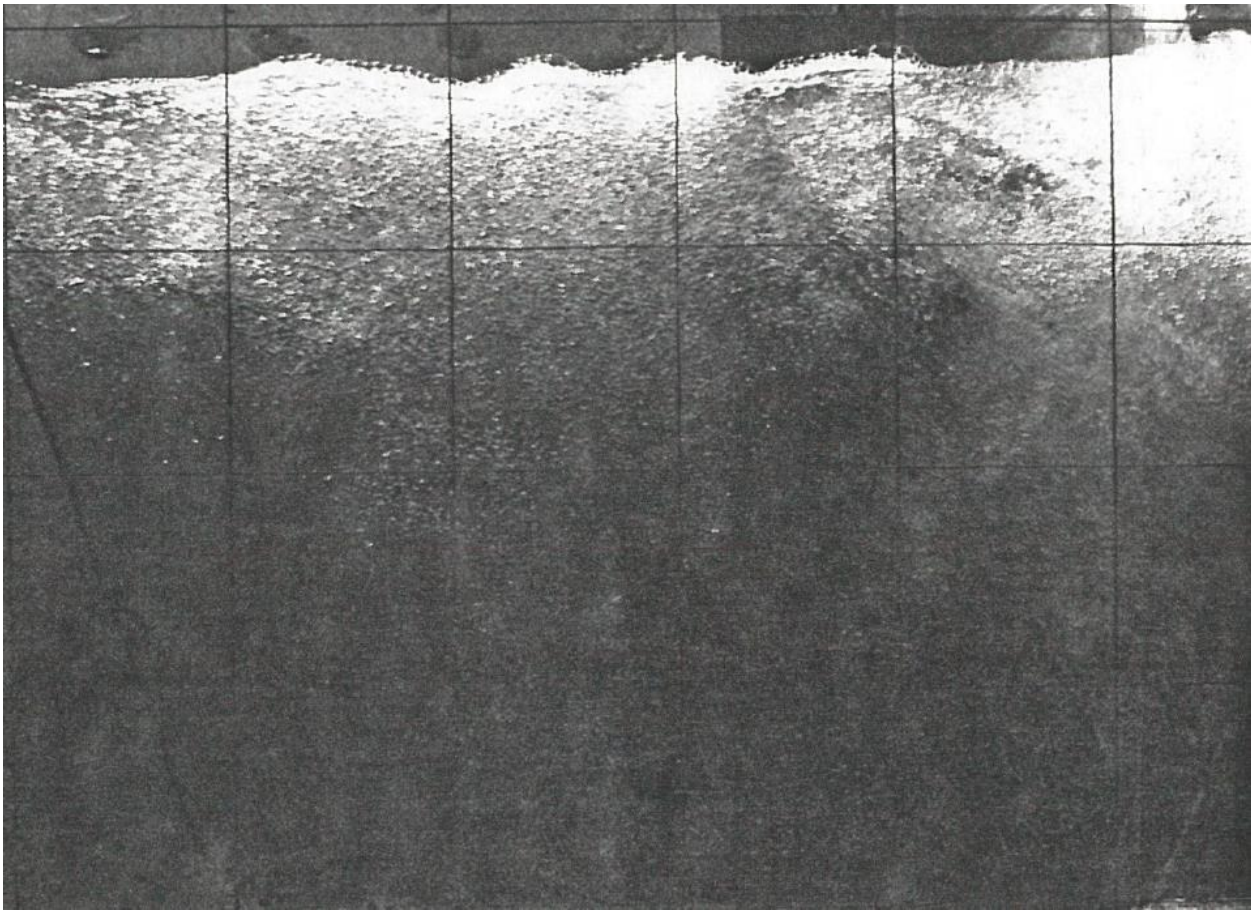


Figure 16. — Dye injected near the end of the stilling basin, 40% gate opening, discharge = 13.0 m^3/s (460 ft^3/s).

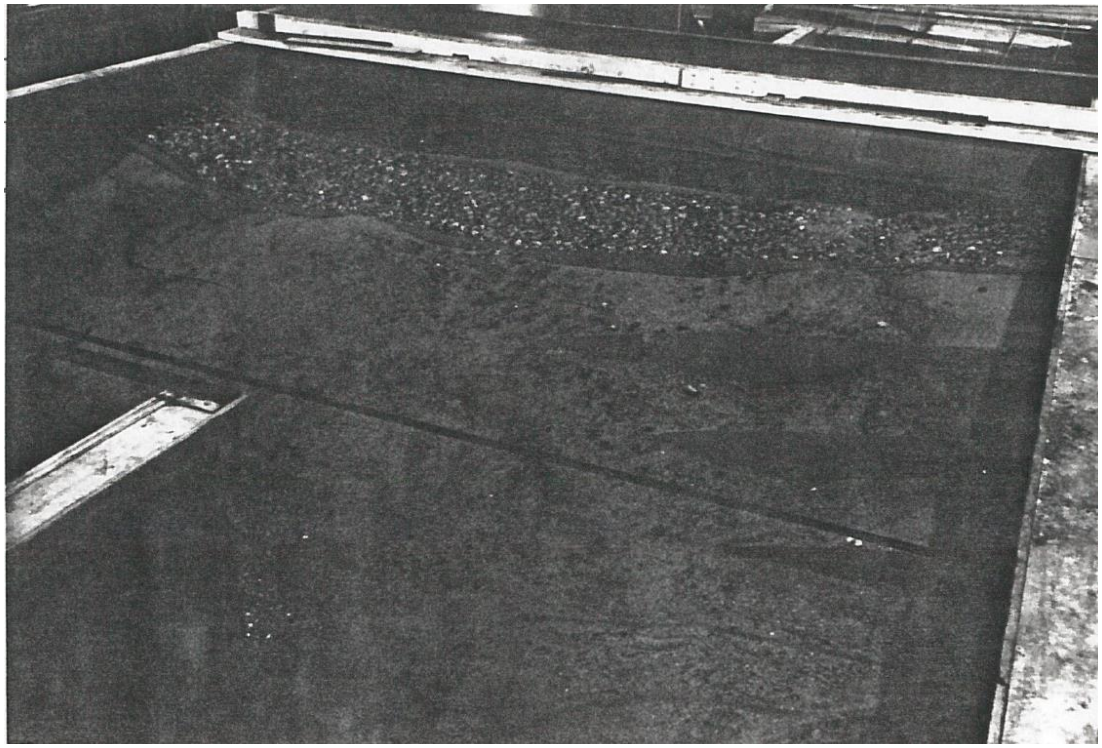


Figure 17. — Unacceptable erosion of model topography.

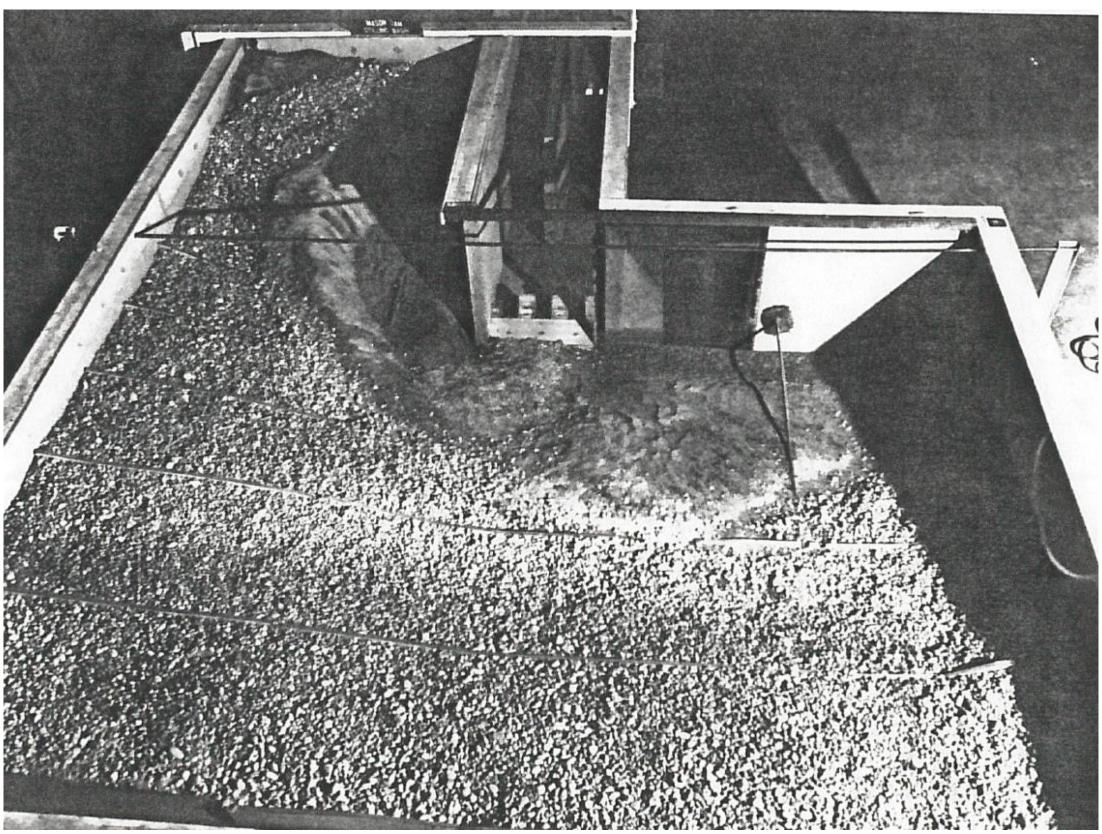


Figure 18. — Major portion of model topography made with gravel.

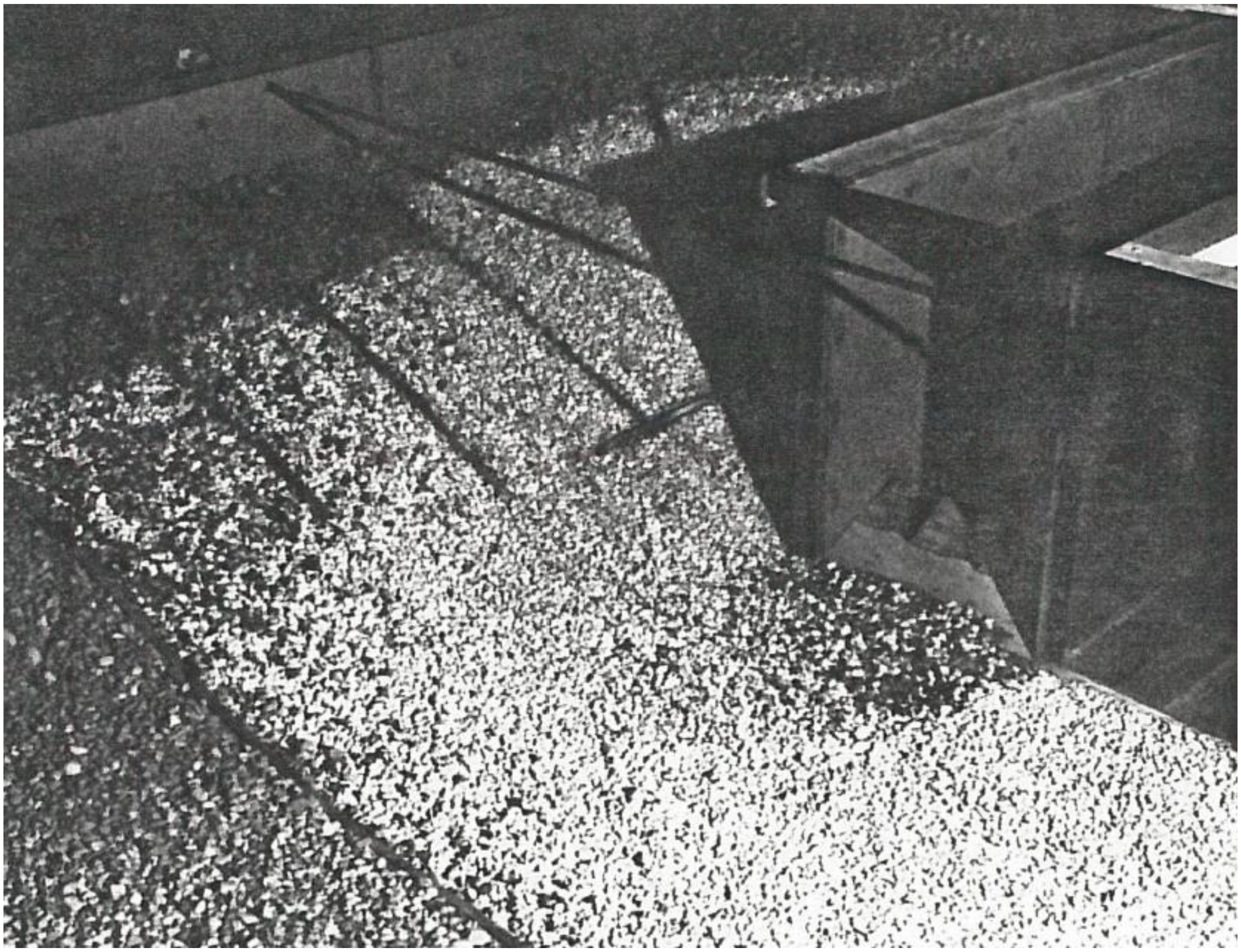
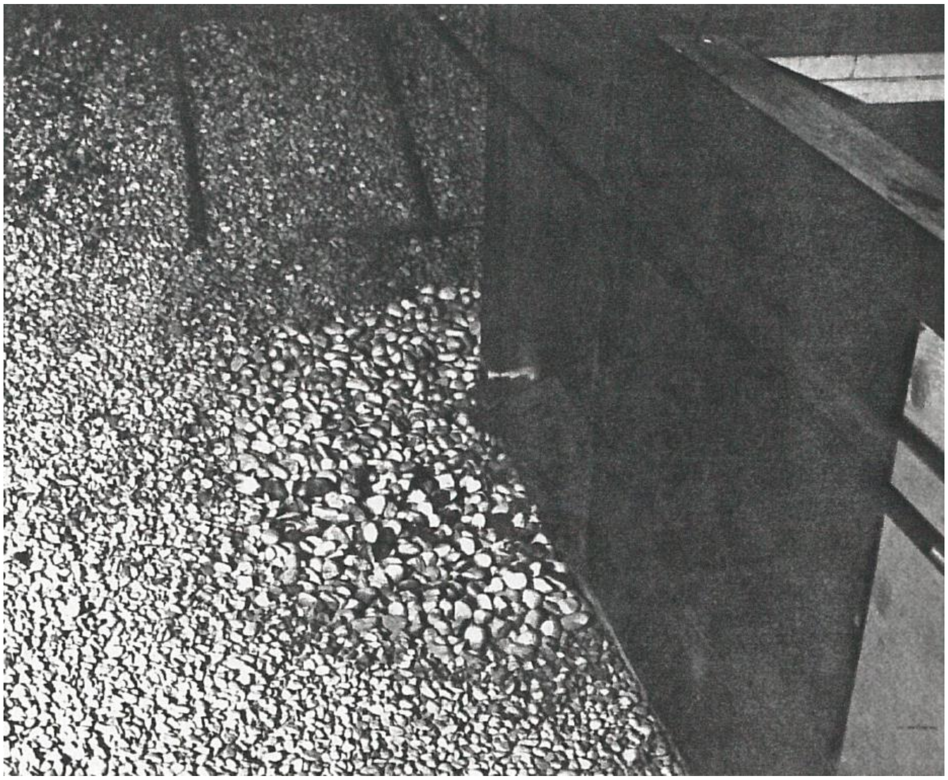
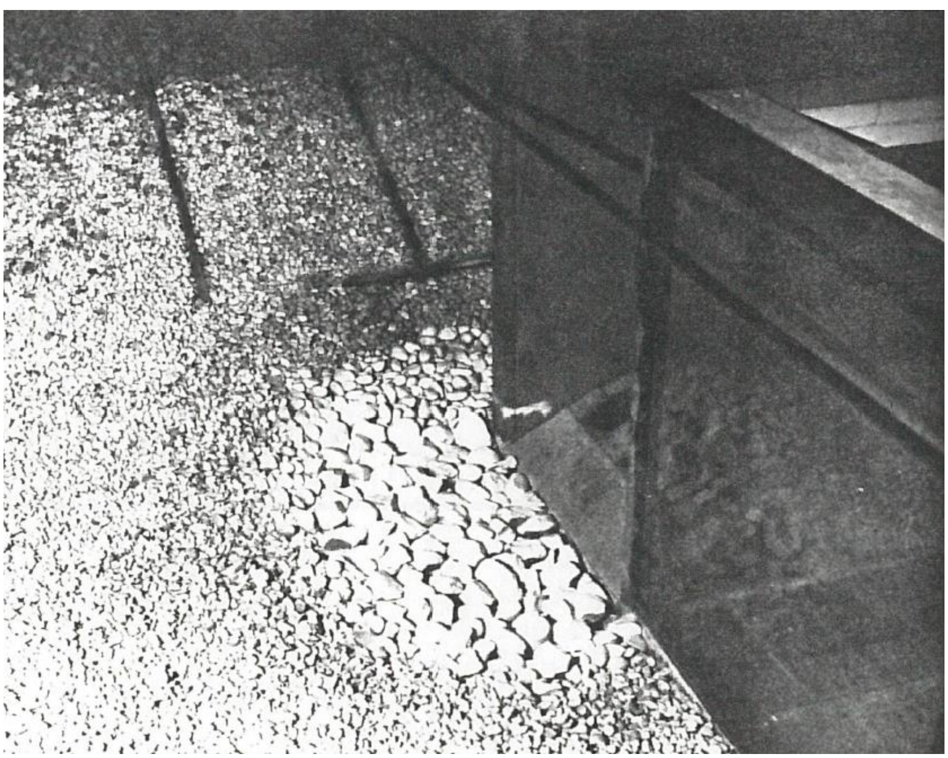


Figure 20. — Gravel bed after 100% gate opening, prototype gravel size 3.5 to 6 inches.



a) Prototype gravel size 8 to 12 inches



b) Prototype gravel size 16 to 21 inches

Figure 21. — Gravel bed after 100% gate opening.

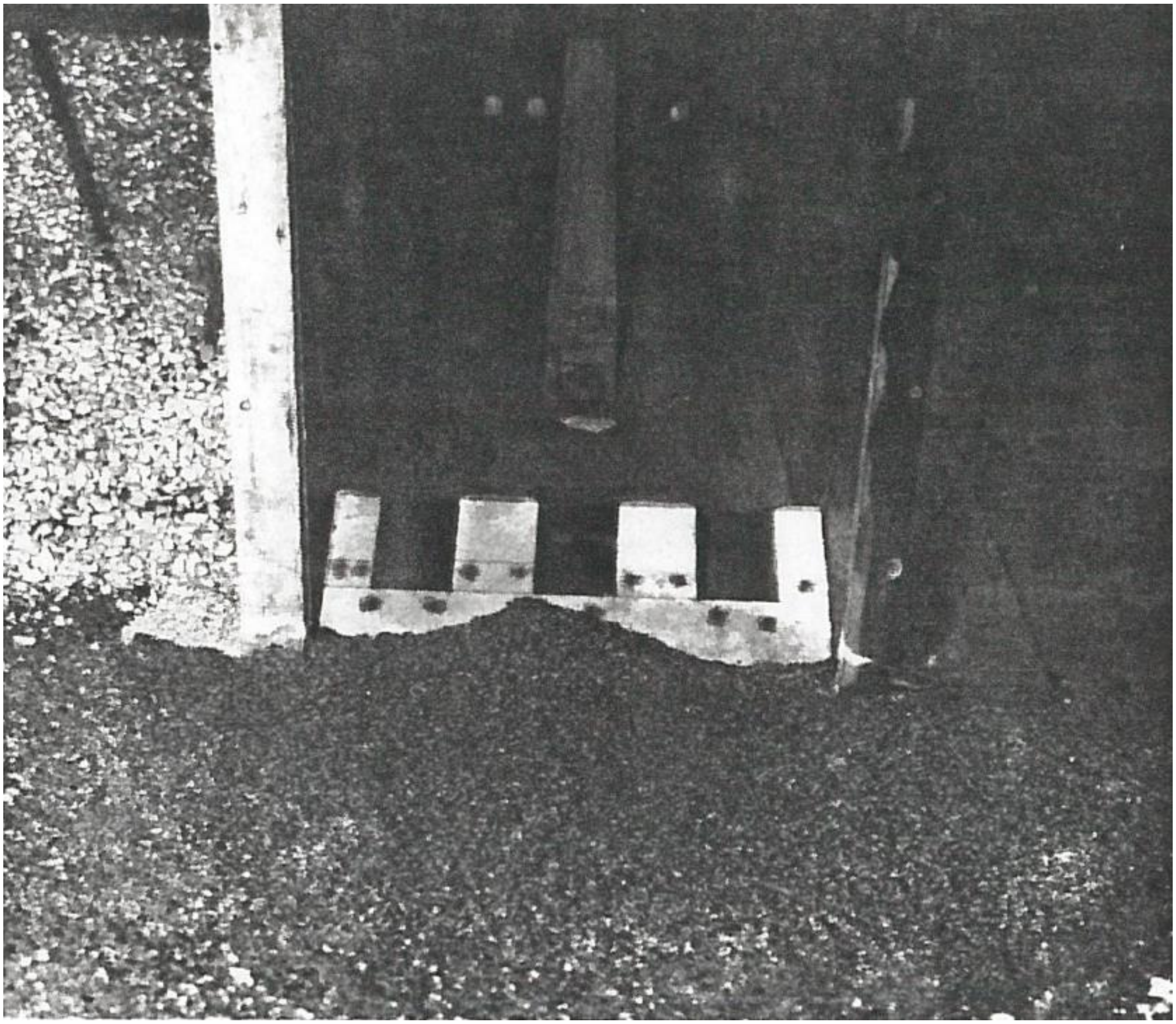
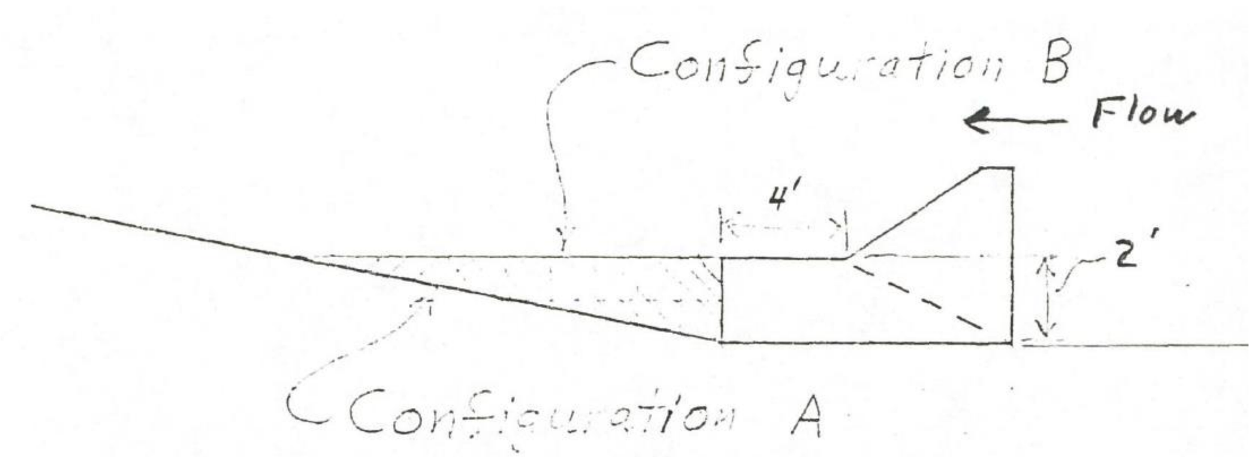
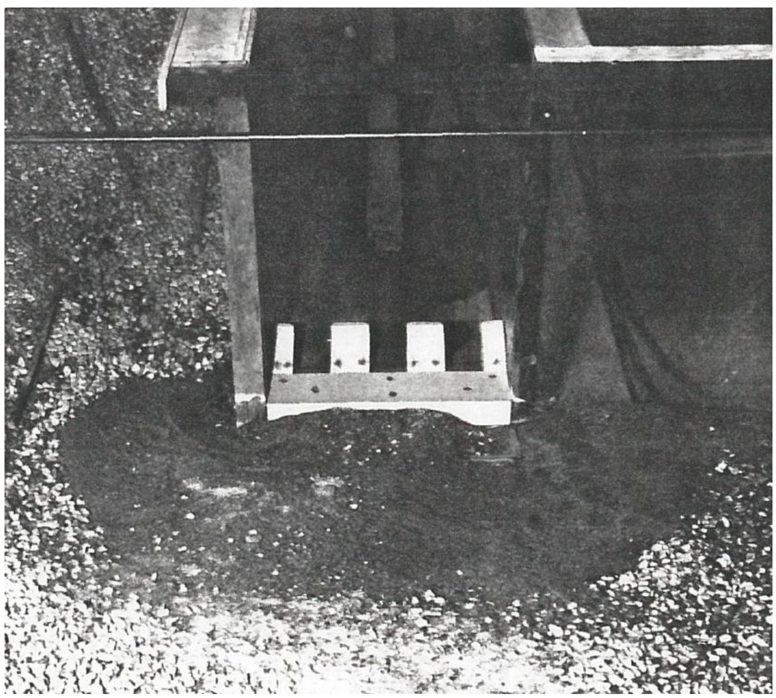


Figure 22. — Sand deposit on end sill, #8 to #16 sand, 15 hours operation at 20% gate opening.

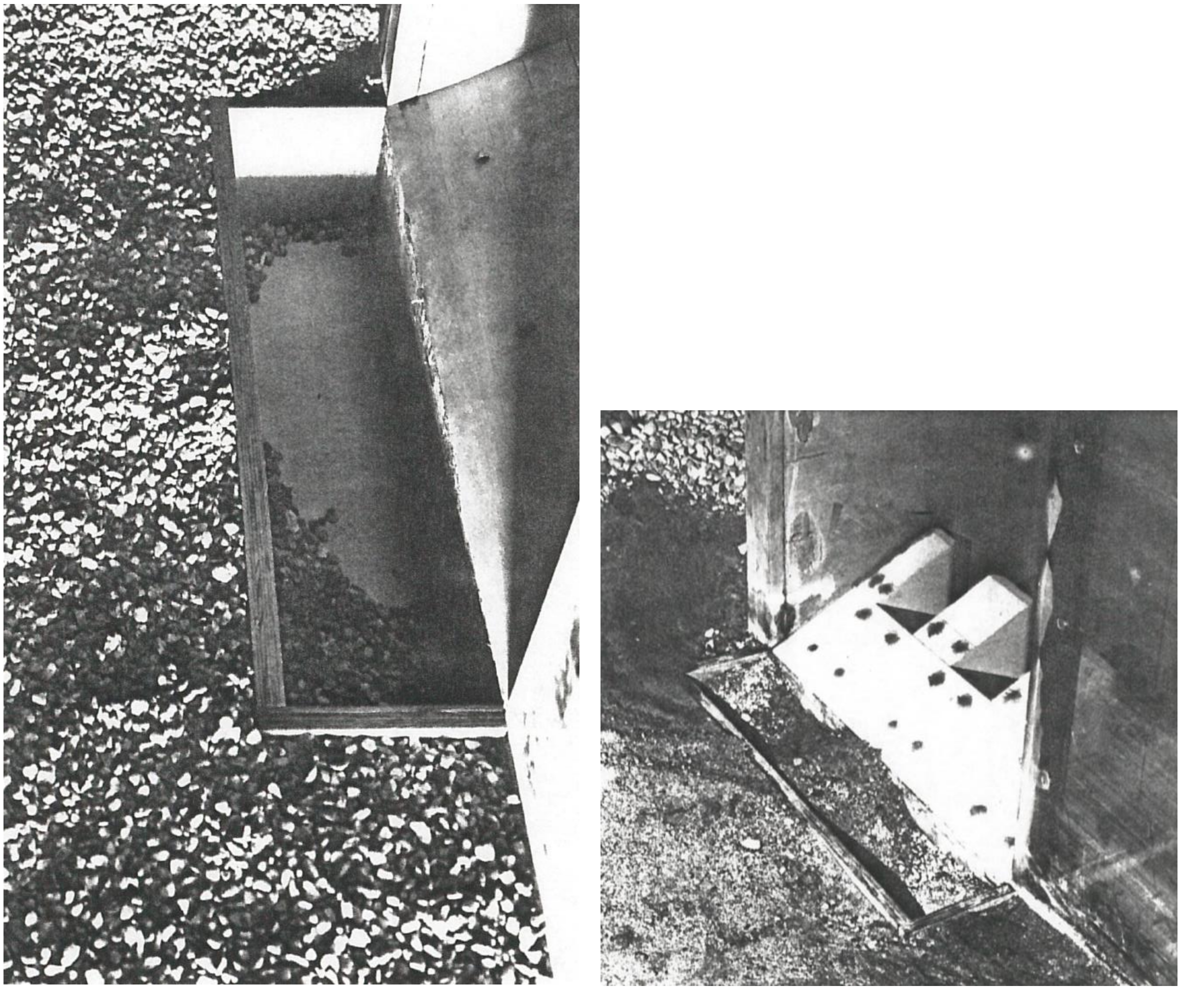


a) Two configurations of end sill topography that were tested.



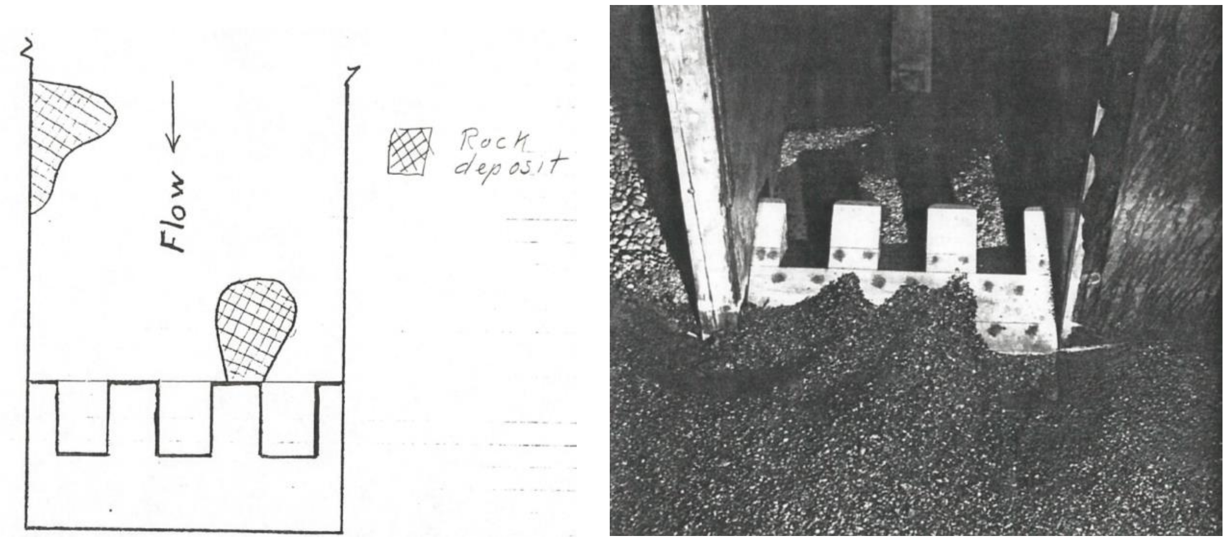
b) Erosion after 1 hour model operation, 100% gate opening, configuration B.

Figure 23. — Modified end sill.



(a) (b)

Figure 25. — Rock trap in model after operating at a 100% gate opening. a) Rocks were captured by rock trap and were not drawing into the stilling basin. b) Erosion from the rock trap. (Before the test, the model rock trap was filled with pit run sand.) The rock trap will require cleaning before material accumulates to within 0.3 m (1 ft) of the top.



(A) (B)

Figure 26. — Operations test results for single (left) bay. A) Results of field test. B) Results of model test.