HYDRAULIC MODEL TESTS OF ROCK MATERIAL IN THE CANYON FERRY DAM SPILLWAY STILLING BASIN

FEBRUARY, 1980

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510.

Memorandum

To : Regional Director, Billings, Montana
Attention: Jim Verzuh, UM-210

From : Chief, Hydraulics Branch

Subject: Hydraulic Model Tests of Rock Material in the Canyon Ferry Dam Spillway Stilling Basin (Your Memorandum Dated February 17, 1978)

The hydraulic model of Canyon Ferry Dam Spillway Stilling Basin was reassembled and tests made. A memorandum report is enclosed.

No movement of the large rock debris occurred in the model stilling basin when testing with the present prototype outlet works operation criteria, i.e., a 57-m^3/s (2000-ft^3/s) discharge equally distributed through all four outlets. For larger discharges, where only spillway releases are made and with equal openings, a 504-m^3/s (17 800-ft^3/s) discharge moved some large rocks. The large rocks were displaced downstream and did not circulate on the basin floor with a continuous abrading action. Another release test with only the large rock debris in the basin showed the large rock could move at a 212-m^3/s (7500-ft^3/s) discharge.

We suggest that the stilling basin be cleaned hydraulically, the same as was done in May 1974. Until such cleaning, discharge into the basin should be held under 198 m^3/s (7000 ft^3/s). Rock entry into the prototype basin since the 1974 cleaning indicates that the model is not duplicating prototype rock movement at the lower discharges. Thus, some rock movement may occur in the basin with the consequent risk of damage. However, we believe this risk is slight because of diver reports about existing damage in the basin. Damage was reported in the 1960's, and since that time the basin has been cleaned twice. The damaged area has been subjected to rock movement and subsequent diver inspections have not reported serious progression of the damaged area. We believe the risk is a reasonable alternative to the large expense to remove the rock material.

Under the research program, "Abrasive Material in Stilling Basins," further tests will be made with the Canyon Ferry model. We plan to test the reported prototype spills where the river outlet gates No. 1 and 4 and spillway radial gates No. 2 and 3 were used.

N. L. King

Enclosure

Copy to: Chief, Division of O&M Technical Services
(with copy of enclosure)

UNITED STATES GOVERNMENT

Memorandum

Memorandum
Denver, Colorado

TO : Chief, Hydraulics Branch

DATE: February 4, 1980

FROM : E. R. Zeigler

SUBJECT: Hydraulic Model Tests of Rock Material in Canyon Ferry Dam Spillway Stilling Basin

BACKGROUND

Canyon Ferry Dam has a combined stilling basin where water enters from either or both the spillway and river outlet works. The stilling basin floor has experienced abrasion damage from rocks in the basin. To determine how the rocks entered the basin and a method of removing the rocks, a hydraulic model study was made (REC-ERC-74-27, December 1974). Model tests showed that when operating the outlet works at a discharge of 85 m^3/s (3000 ft^3/s) or greater, rock material was drawn into the stilling basin. High velocity jets from the outlet works swept along the water surface of the stilling basin and formed a large eddy with a return flow acting along the bottom of the exit channel and stilling basin floor. Rock material was flushed from the model basin when operating only the spillway. The spillway jet plunged to the bottom of the model basin floor, swept through the basin, and removed the rock material.

In 1972, 13 000 m^3 (17 000 yd^3) of rock material were removed from the stilling basin with a clamshell bucket mounted on a platform barge. In 1973, 688 m^3 (900 yd^3) of material had again been drawn into the basin. During 1974 results of the hydraulic model study were used. The spillway operated for 3 hours with a 792-m^3/s (28 000 ft^3/s) discharge, and flushed the rock out of the basin. Thereafter the outlet works discharge was restricted to 85 m^3/s (3 000 ft^3/s) or less to prevent rock from being drawn into the basin. However, in 1977 an underwater inspection revealed rock had again been drawn into the basin. Thus, the model test results appeared inadequate and the outlet works discharge was further restricted to 57 m^3/s (2000 ft^3/s).

During the 1977 underwater diver inspection, some large debris was found in the left bay of the stilling basin, figure 1. Recommendations were that the large debris be removed. However, an estimated cost was $30,000 to $40,000 for a contractor to mobilize and demobilize, and an additional cost for the actual removal of debris. Before preparing a contract for debris removal the UM Region asked if further hydraulic model studies could be made concerning the large debris. The Hydraulics Branch has undertaken a research program "Abrasive Materials in Stilling Basins," and funds were used from this program to reassemble the Canyon Ferry hydraulic model and perform limited testing.

SUMMARY OF HYDRAULIC MODEL TESTS

Following are the questions the region asked about movement of large debris in the stilling basin and results of the model tests:

1. When operating under the present recommended operating procedure (Chief, Water O&M's memorandum dated September 12, 1977), is there any movement of the large boulders and concrete slabs?

Answer - No movement of the large debris occurred for a 57-m^3/s (2 000 ft^3/s) discharge. The discharge was equally distributed through all four outlets.

2. At what spillway discharge would there be movement of these large debris?

Answer - With 1036 m^3 (1355 yd^3) of rock material in the model stilling basin, six 0.6-m (2-ft) diameter rocks and both concrete slabs moved at 504-m^3/s (17 800-ft^3/s) discharge. However, should the large debris rest upon the bare stilling basin floor (without the 1036 m^3 (1355 yd^3) of rock) movement can occur at lower discharges. In this case one 0.6-m (2-ft) diameter rock moved at a 212-m^3/s (7500-ft^3/s) discharge, and six 0.6-m (2-ft) diameter rocks moved and one concrete slab moved slightly at a 311-m^3/s (11 000-ft^3/s) discharge.

3. What spillway discharge would be required to remove these large rocks and concrete slabs from the spillway?

Answer - Three 0.6-m (2-ft) diameter rocks were swept out of the basin at a 702-m^3/s (24 800-ft^3/s) discharge. Eleven 0.6-m (2-ft) diameter rocks and the 1-m (3-ft) diameter rock were swept out of the basin at a 744-m^3/s (26 300-ft^3/s) discharge. The two concrete slabs were not removed from the basin but were deposited in the remnants of the pumping plant cofferdam at the left downstream end of the basin.

THE HYDRAULIC MODEL TESTS

The scale of the hydraulic model was 1:48, and the model was the same as figure 1 of REC-ERC-74-27. However, when rebuilding the model provisions were not made for water flow from either the powerplant or pumping plant. Before each test series the prototype gravel deposit, figure 1, was placed in the model stilling basin, figure 2. The identification of large debris in the model was: the concrete slabs by their shape, the 1-m (3-ft) diameter rock was painted yellow, and the twelve 0.6-m (2-ft) diameter rocks were painted red.

The first test was directed toward question 1. Only the outlet works operated with a total discharge of 57 m^3/s (2000 ft^3/s), and the discharge was equally distributed among the four gates. None of the large debris moved and no notable erosion occurred in the sand deposit in the model stilling basin.

The second test series was directed toward questions 2 and 3. Only the spillway operated and with an equal discharge through each of the four gates. The gate opening was the vertical distance between the gate seat, elevation 1147.7 m (3765.5 ft), and the bottom of the gate. For this test series the reservoir water surface elevation was 1152 m (3780 ft), and the gate openings were progressively increased. The gate openings tested were 0.6, 0.8, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, and 2.7 m (2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, and 9.0 ft) and also uncontrolled flow. Each gate opening operated in the model for a period of 2 hours prototype time. Afterwards a sketch was made showing location of the deposit in the stilling basin. When making the sketch, a frame, with strings that formed a grid, was placed over the model basin. The sketches provided a more accurate location of the deposit in the stilling basin than the photographs. Note in figure 1 the sketch grid is 6.1 m (20 ft), starts from the inner left wall of the stilling basin, and progresses upstream and downstream from station 2+74. Sketches of the deposit for some gate openings are shown in figures 3 and 4, and photographs in figures 5 and 6.

With the initial 0.6-m (2-ft) gate opening erosion occurred at the upstream area of the deposit, figure 3a. The eroded material moved a short distance downstream and resettled upon the deposit. Thus, thickness of the deposit increased at the upstream edge. In the central area of the left bay a portion of the deposit moved upstream. Note in figure 3a that erosion occurred further downstream near the sidewalls and center walls of the stilling basin. The combination of alinement of the spillway gates and outlet works produced less erosive force at the central bay area. Piers on the spillway were 2 m (6 ft) thick and caused a space between gate-controlled flows entering the basin. The 1.2-m (4-ft) thick center basin wall nullified the spacing effect and eyebrows of the outlet works tunnels amplified the spacing effect. Thus, erosive force across the basin was not uniform.

With the 0.8-m (2.5-ft) gate opening the thicker leading edge of the deposit moved downstream and covered the large debris (with exception of the 1-m (3-ft) diameter rock). As gate openings increased further downstream movement of the deposit occurred. With the 1.2-m (4-ft) gate openings three of the 0.6-m (2-ft) diameter rocks were uncovered, and with the 1.5-m (5-ft) gate opening six 0.6-m (2-ft) diameter rocks and both concrete slabs moved, figure 3b. Note in figure 3b results of the nonuniform erosion; large debris rocks in the central bay area had not moved. At the 2.1-m (7-ft) gate opening three 0.6-m (2-ft) diameter rocks were removed from the basin and at the 2.7-m (9-ft) gate opening all but one 0.6-m (2-ft) diameter rock had been removed, figure 4.

In figure 5 the thicker upstream portion of the deposit can be seen, and some of the large rocks. Again, note the furthermost upstream location of the deposit was the central area of each bay. This feature was consistent for all gate openings, and some back-and-forth movement of the model sand occurred in the central area. Even a 2.7-m (9-ft) gate opening with an 894-m^3/s (31 600-ft^3/s) discharge did not remove the deposit from the center bay area, figures 4b and 6. Free flow operation at 1013 m^3/s (35 800 ft^3/s) discharge left the deposit nearly the same as shown in figure 6.

With the previous test series, the manner of progressively operating with larger gate openings could influence what discharges moved the large debris. The eroding material covered the large debris, sheltering it from being moved. If the prototype stilling basin operated in a different manner, possibly gravel would not be available to embed the large debris. Therefore, the preceding test series was repeated, but with only the large debris in the model stilling basin. As noted in the answer to question No. 2, the large debris moved at a lower discharge. Also, test results were similar to those of the previous test series; large debris closest to the wall was the first to move.

During May 1974, the prototype spillway discharged 798 m^3/s (28 200 ft^3/s) for 3 hours. Larger discharges or longer operation times would probably cause excessive downstream riverbank damage, and thus model test conditions greater than these prototype conditions are probably unrealistic. Therefore, a model erosion test was made with prototype conditions of 790-m^3/s (28 000-ft^3/s) spillway discharge, 3-hour operation time, and at a 1156-m (3794-ft) reservoir water surface elevation. Test results are shown in figure 7. Considerable erosion occurred in the model stilling basin during the first hour, figure 7b. Afterwards, the sand remaining in the model stilling basin was collected and measured. There were 260 m^3 (340 yd^3) in the left bay and 180 m^3 (240 yd^3) in the right bay. In the left bay sand was removed from the rock of the pumping plant cofferdam and included in the measurement.

MODELING MOVEMENT OF GRAVEL AND ROCK IN THE STILLING BASIN

Sediment modeling is not as accurate as modeling flow over a spillway to obtain a discharge - reservoir elevation curve. Generally, sediment modeling is more qualitative than quantitative. For example, different alternatives of a design are tested and compared, then the alternative with the best test results is considered qualitatively better than the other alternatives.

One aid in sediment modeling is the verification test. Prototype flow conditions with measured sedimentation data are tested in the model. If model sedimentation data compare favorably to the prototype, then the model has been verified. In REC-ERC-74-27 two verification tests were made: (1) sequential operation of the outlet works, spillway, and outlet works with corresponding discharges of 170, 226, and 170 m^3/s (6,000, 8,000, and 6,000 ft^3/s), and (2) a cleaning test with a spillway discharge of 798 m^3/s (28 200 ft^3/s). Verification (2) appeared more accurate than verification (1).

Recommendations made in REC-ERC-74-27 were followed in prototype operations. The outlet works discharge was restricted to 85 m^3/s (3,000 ft^3/s) or less. However, after 3 years operation, rock and gravel had been drawn into the stilling basin. In reviewing REC-ERC-74-27, it was noted that the 85 m^3/s (3,000 ft^3/s discharge was designated as the limiting discharge. A 113 m/s (4,000 ft^3/s) discharge drew material into the basin, and an 85 m^3/s (3,000 ft^3/s) discharge test resulted "in very little movement of riverbed material into the stilling basin, figure 8."

Events of the preceding two paragraphs can be interpreted that the model was only partially successful in duplicating prototype action. The model was successful at tests with the higher discharges. However, with low discharges on the verge of sediment movement, gravel movement prevailed more in the prototype than in the model.

CONSIDERATIONS CONCERNING ROCK MATERIAL IN THE STILLING BASIN

Previous model-prototype experience indicates model test results may be inaccurate at the lower discharges. The large debris present in the spillway basin may move at different discharges than stated in the memorandum. One cannot be assured of prototype operation just on the verge of large debris movement.

How critical is removal of the large debris? The model tests were unable to resolve at what point unacceptable damage will occure to the stilling basin. However, consideration of past basin experience may provide some helpful information. During the 1960's, underwater divers noted damage to the stilling basin (exposed rebars). In 1972 rock material was mechanically removed from the basin, and afterwards more rock material entered. In 1974 rock material was hydraulically removed, and more material again entered the basin. Since the initial discovery of the exposed rebars no serious progression of the damage has been reported, although some movement of the rock material has occurred in the basin. Additionally, the outlet works discharge has been restricted, which should allow for lower velocity eddy currents in the basin. Past experience provides some argument for a "wait and see" attitude toward initiating expensive mechanical removal of rock material from the stilling basin.

Considerations are involved concerning mechanical removal of rock material from the stilling basin, mainly when to clean and how much to clean, as balanced against potential damage and cleaning cost. Initially it was believed Service personnel could inexpensively remove the large debris. Now it appears a private contractor would be needed.

To obtain an economical return of the mobilization expense the whole basin should probably be cleaned. With this large an expense the project may wish to defer mechanical removal as long as possible. An additional consideration would be removal of rock material downstream from the basin that is presently being hydraulically drawn into the basin.

Knowledge is important about presence of the rock material in the stilling basin, movement of the rock material, and abrasion damage occurring to the basin. The project should continue their close surveillance of the rock material so a sound decision can be made conserning removal of the rock material.

Eugene Zeigler

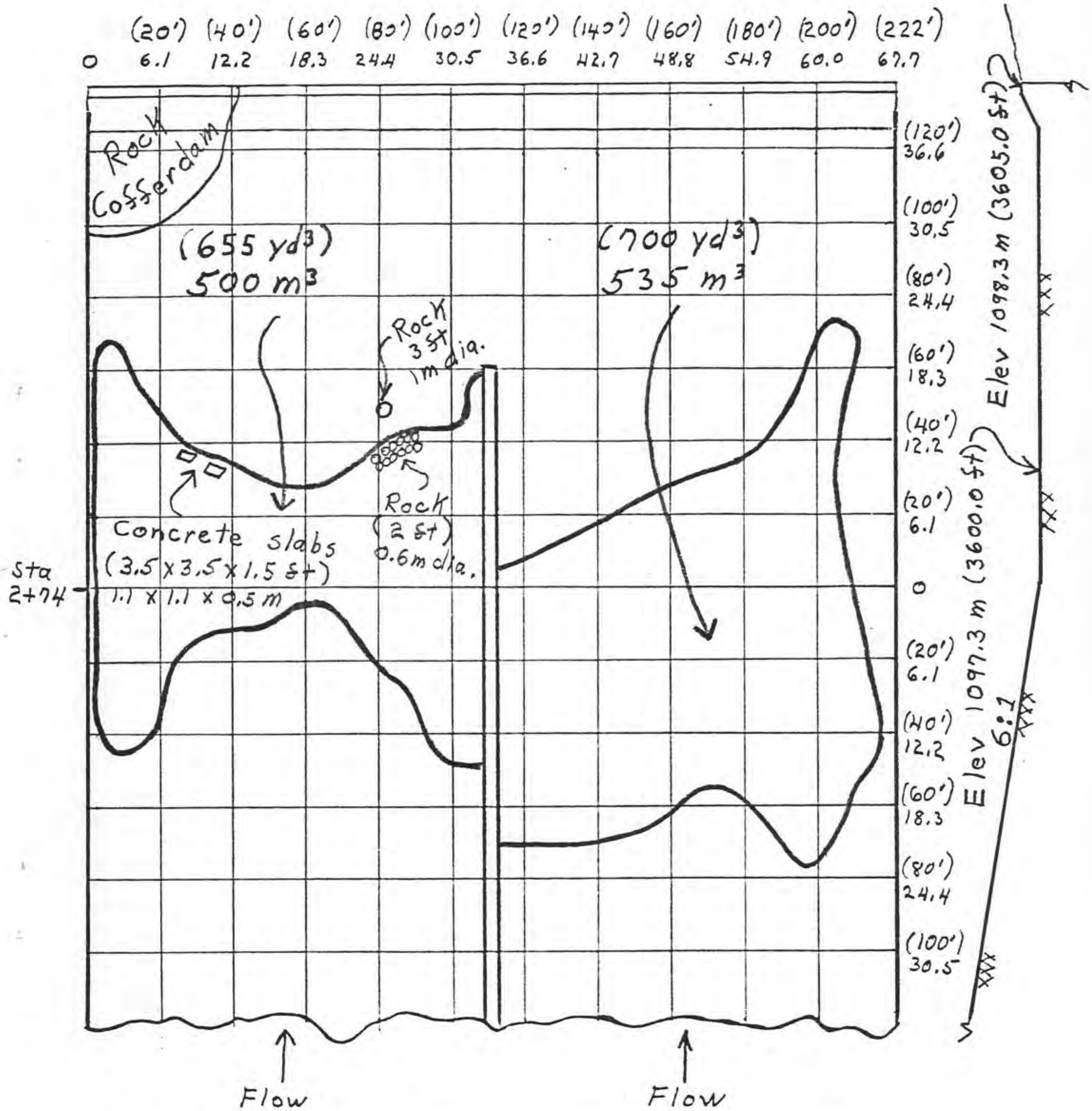
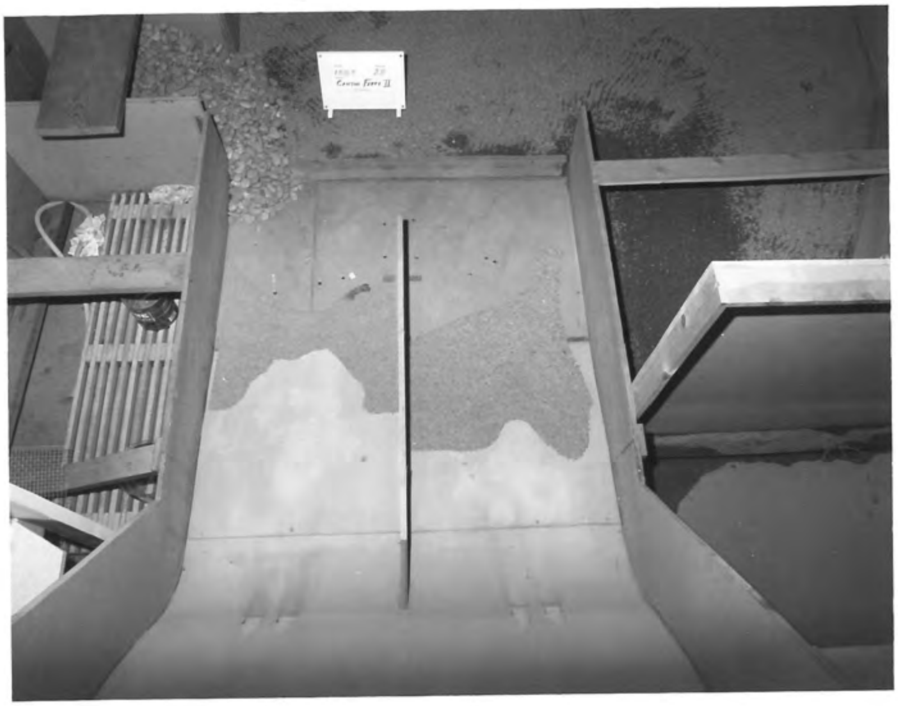


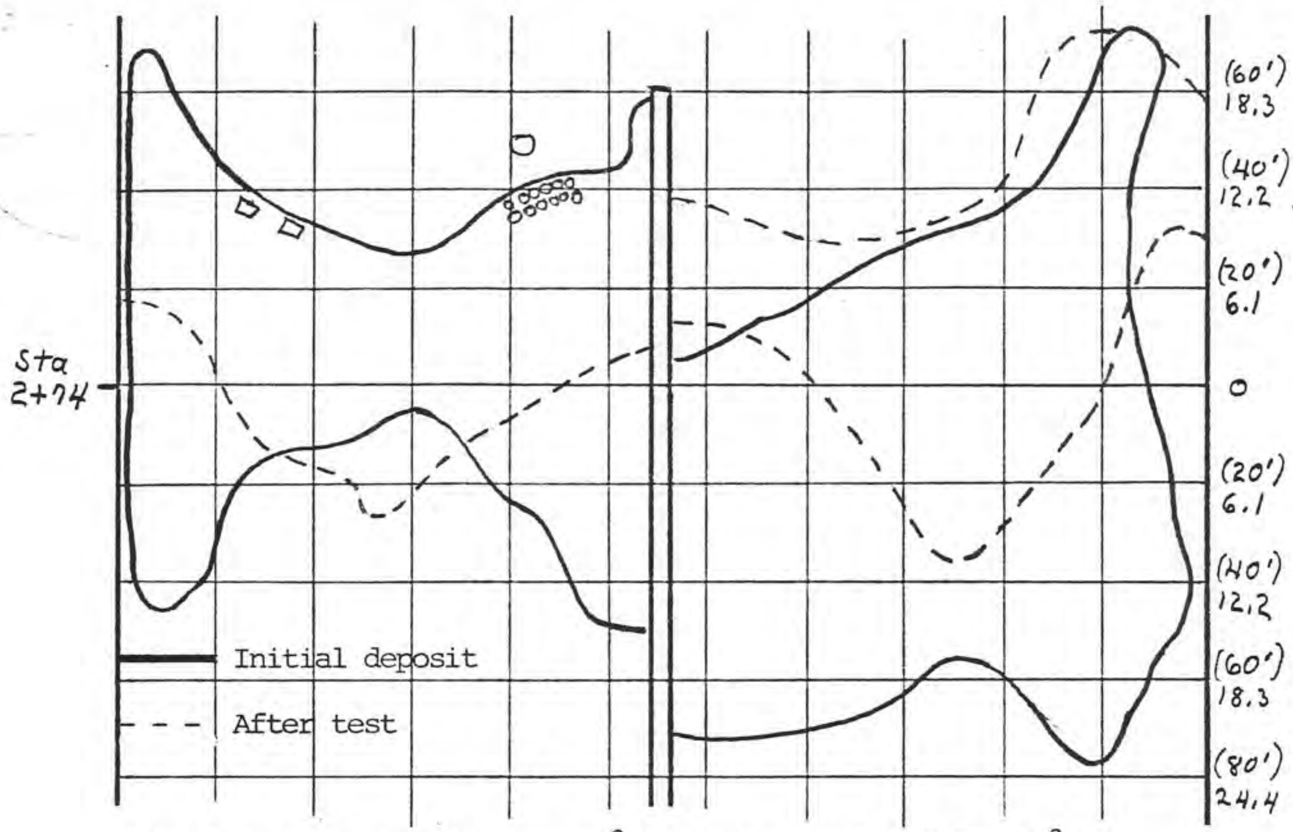
Figure 1. Deposit of rock material in prototype stilling basin.



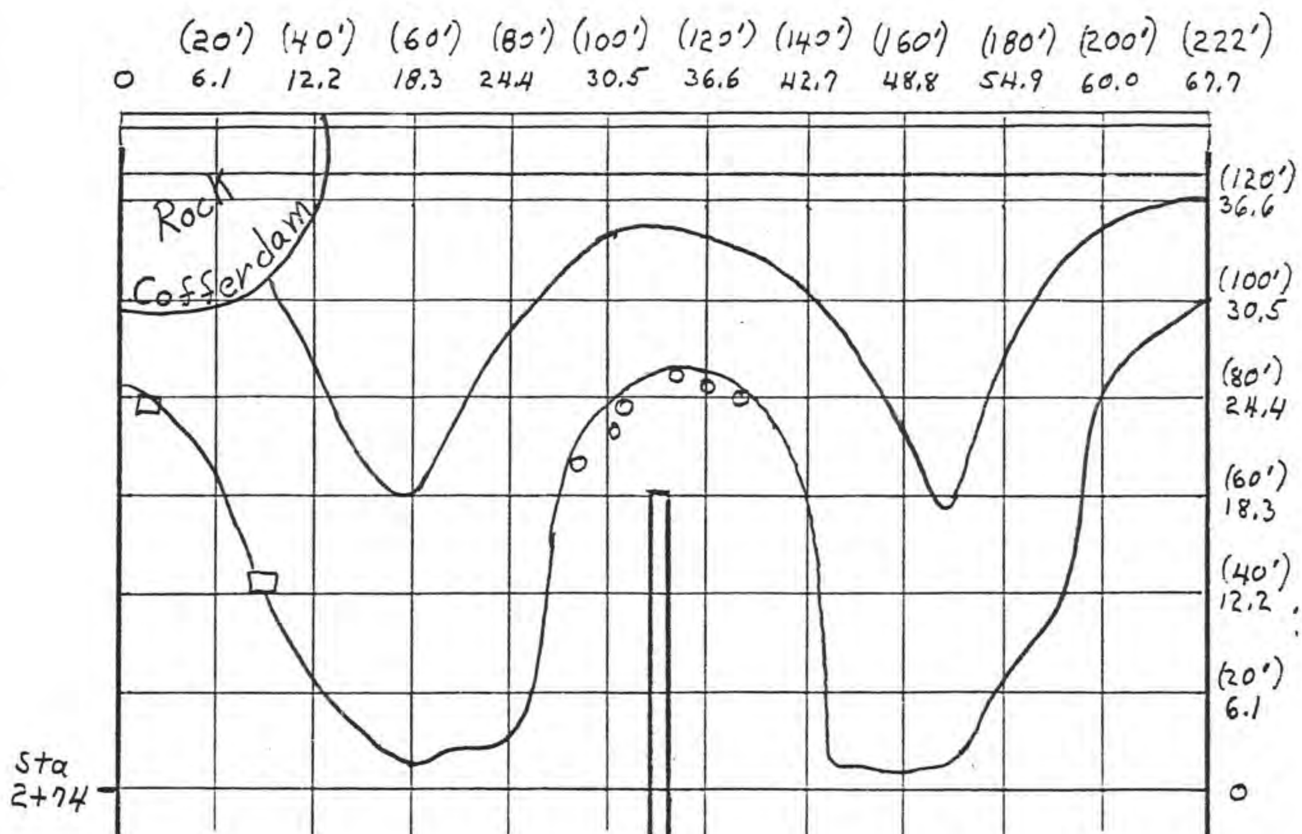
(a) General view

(b) Large debris in left bay

Figure 2. Deposit of rock material in model stilling basin

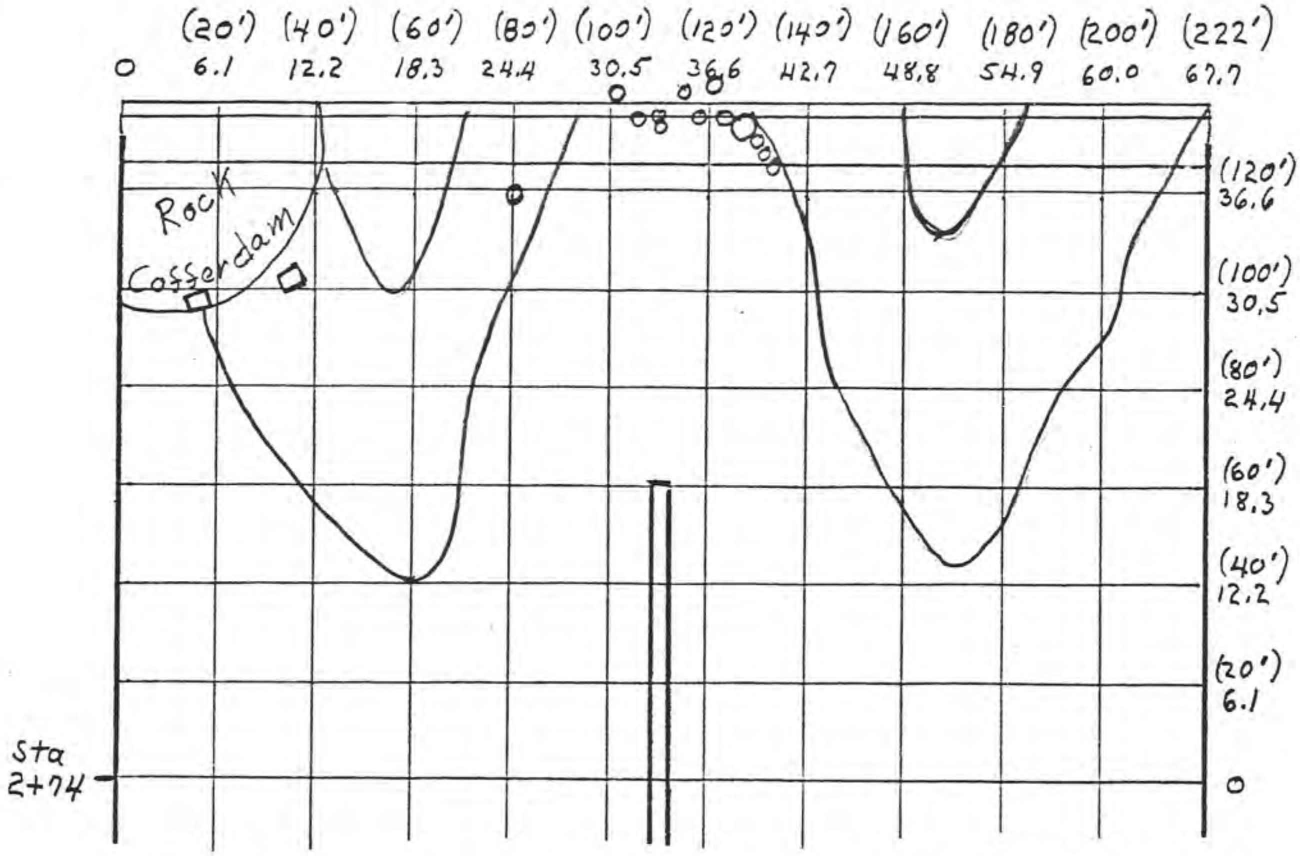


(a) 0.6 m gate opening, 218 m^3/s (2.0 ft G.O., 7,700 ft^3/s)

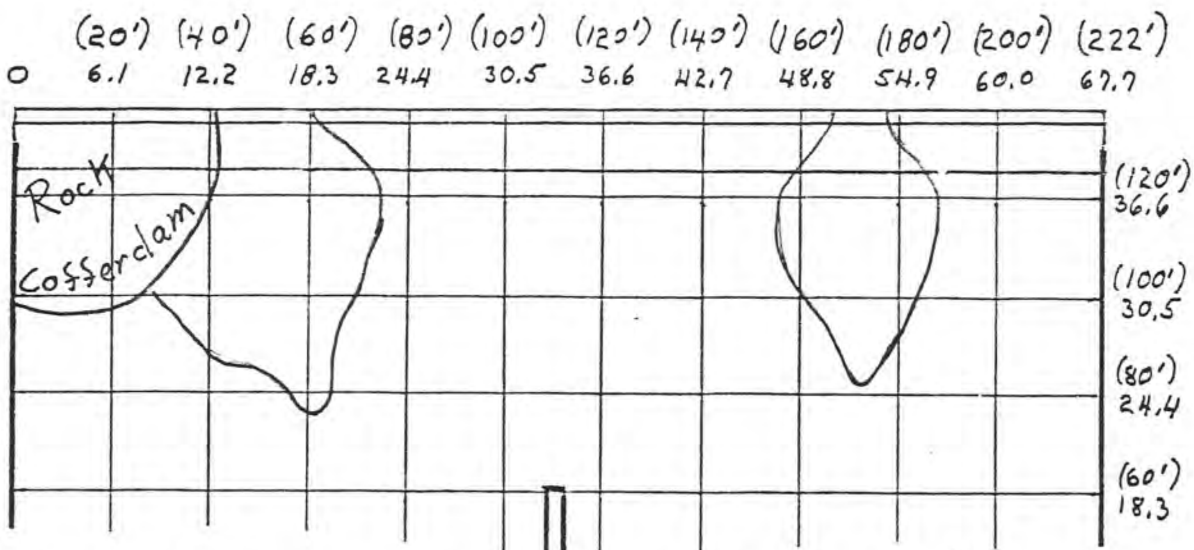


(b) 1.5 m gate opening, 504 m^3/s (5.0 ft G.O., 17,800 ft^3/s)

Figure 3. Sketches of model deposit for spillway tests



(a) 2.1 m gate opening, 702 m^3/s (7.0 ft G.O., 24,800 ft^3/s)



(b) 2.7 m gate opening, 894 m^3/s (9.0 ft G.O., 31,600 ft^3/s)

Figure 4. Sketches of model deposit for spillway tests.

(a) General view.

(b) Some of the large rocks which have moved.

Figure 5. Model deposit for spillway test with 1.8 m gate opening and 600 m^3/s (6.0 ft G.O., 21,200 ft^3/s).

(a) General view.

(b) Most of the large rocks have been removed from the basin

Figure 6. Model deposit for spillway test with 2.7 m gate opening and 894 m^3/s (9.0 ft G.O., 31,600 ft^3/s).

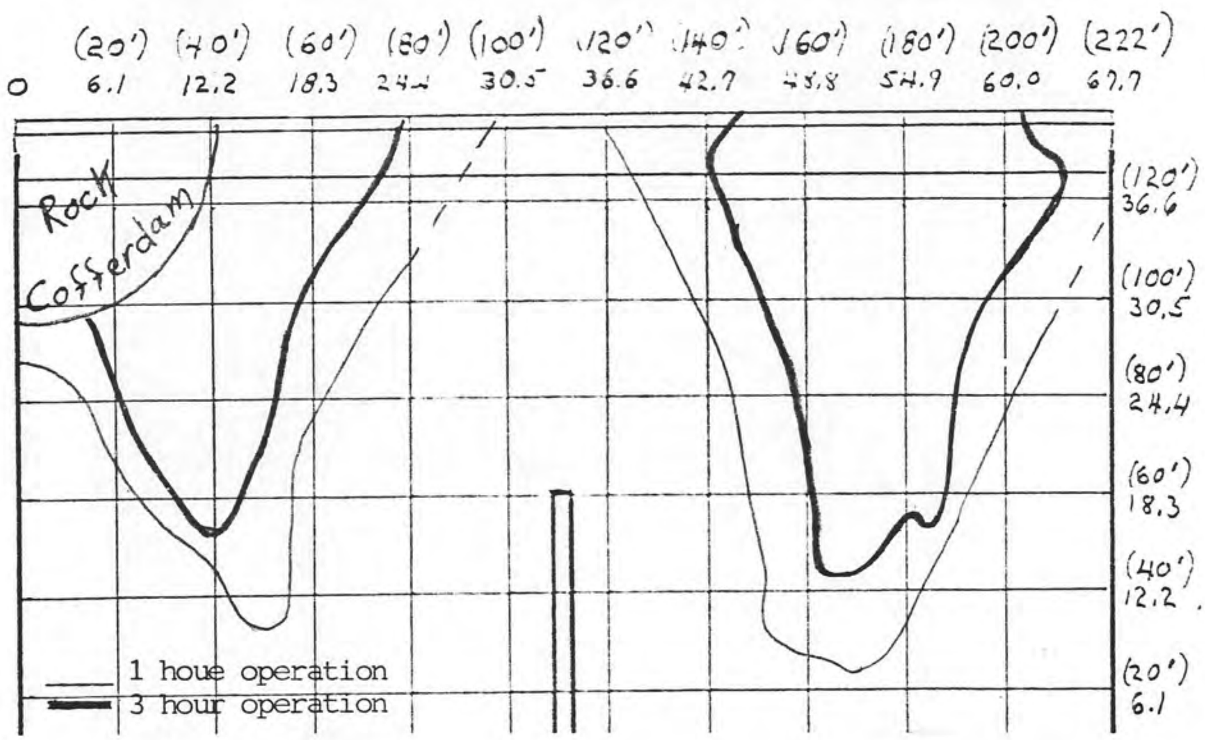


Figure 7. Model deposit for spillway test with 792 m^3/s (28,000 ft^3/s) discharge and 3 hour prototype time operation.