Form DFC-11
(7-52)
Bureau of Reclamation

INFORMATIONAL ROUTING

AUTHOR

GPO 845867

Memorandum

Denver, Colorado
April 2, 1959

Chief Designing Engineer
Attention: Chief, Dams Branch

Chief, Division of Engineering Laboratories

Hydraulic model studies of Grand Valley Diversion Dam

The purpose of the investigation was to determine the adequacy of several methods of placing riprap at the end of the spillway apron to prevent possible undermining at the downstream end. A minimum model and testing program was necessary because of time and fund limitations.

Most of the design drawings of the structure existed only on microfilm records. Microfilm Nos. 8P94-a, c, d, f, and g were copied and used in designing the model. Drawing No. 8-D-332 was also used.

A 102-foot-wide section of the spillway was modeled to a 1:30 scale ratio and installed in an existing testing flume. A 12-foot-wide pier was placed in the center of the spillway section providing two 45-foot-wide flow passages. In the prototype structure there are six 70-foot-wide spillway bays and one 60-foot-wide sluiceway bay. In order to obtain the most representative scour patterns in the channel, it was decided to place the pier on the center of the spillway rather than use two piers to make one full bay and one or two partial bays. An erodible sand bed was placed downstream from the spillway section to represent a 200-foot-long section of the river channel.

The formal request for model studies indicated that tests should be made to determine the best profile of riprap placement, and the necessary size of the individual stones for a unit discharge of 155 cfs per foot of spillway width which corresponds to a flood of 65,000 cfs. A sketch showing the profiles to be investigated was submitted. Subsequent verbal requests by Mr. C. J. Hoffman expanded the original program to include testing two additional riprap profiles, determining the effect of placing an end sill on the apron, and investigating the adequacy of the above schemes for partial discharges with gate-controlled flow.

The tests are described below giving the discharge, tail water elevation, length of run, and other pertinent information.

The purpose of the initial test was to determine whether the model could duplicate the erosion which had been found below the prototype spillway. If the model could reproduce the known prototype erosion, there would be more confidence in the subsequent corrective measures determined from the studies on the sectional model. For this test the model sand bed downstream from the apron was placed level with the apron at elevation 4774. The model was operated at the maximum discharge (q = 155 cfs) for 1 hour with tail water elevation 4792. The erosion pattern after this test, as shown in Figure 1A, extended to a maximum depth of elevation 4762. This erosion compared favorably with prototype measurements. The deepest erosion in the prototype occurred in the same relative location, but extended to about elevation 4758 4 feet lower than in the model test. From subsequent tests it was concluded that this depth would have occurred in the model with a longer operating period.

For the second test the sand bed was molded so that a 4-foot-thick layer of riprap tilted downstream on a 3:1 slope could be placed on top of the sand bed for 60 feet downstream from the apron. At the end of the apron the top of the riprap was at elevation 4772, 2 feet below the apron surface. The model was operated for 2 hours at the maximum discharge with the tail water elevation at 4792. The model was then unwatered and the riverbed erosion measured and photographed. This procedure was repeated for successively lower tail water elevations 4790, 4788, and 4786 without remolding the bed. Figure 1B shows the erosion after the first 2-hour run. No photographs were obtained for the subsequent runs, but profiles of the riverbed measured after each run indicated that the depth of erosion increased progressively. At the end of the test the riverbed had eroded to elevation 4750 along each side wall and to 4754 at the center of the channel. At the end of the apron the riprap was at elevation 4770, 2 feet lower than at the start of the test. Generally speaking, the riverbed erosion downstream from the riprapped area was an extension of the riprap slope.

For the third test a 4-foot-thick layer of riprap was placed horizontally for 50 feet downstream from the apron and then on a 2:1 slope for 10 feet. The surface of the level section was at elevation 4772. The operating procedure was the same as described for the second test. At the end of the test, the river channel had eroded as shown on Figure 1C. On the left side of the channel, there was very little movement of the riprap. The bed had eroded to about elevation 4750 at the end of the riprap,

and the upstream surface of this erosion followed a 2:1 slope. In the center the bed had eroded to about elevation 4761. On the right side of the channel the riprap moved into the eroded area; however, the end of the apron was protected by the riprap which was still at elevation 4770, Figure 1D. Practically all of the movement of the riprap shown in Figure 1C and 1D occurred during the final 2-hour run with the tail water at elevation 4786.

Tests 4 and 5 were performed to determine the effectiveness of dumped riprap as channel protection. In Tests 1 to 3 the riprap was assumed to be "placed" on a prepared smooth base, for Tests 4 and 5, the riprap was "dumped" on the existing channel bed. For these tests a level sand bed at elevation 4774 was prepared and the model operated for 1 hour for a discharge of 155 cfs per foot with tail water elevation 4792. This gave an erosion pattern similar to that shown in Figure 1A. Sufficient bed material was then removed at the downstream end of the apron to provide for a 4-foot-thick layer of dumped riprap without exceeding elevation 4772. For Test 4, a 4-foot-thick mat of riprap was dumped for 30 feet downstream from the apron. The model was then operated for 2 hours with a discharge of 155 cfs per foot and tail water at elevation 4792. After the extent of riverbed erosion was determined, the operation was continued with a flow representing 4,200 cfs being discharged through two spillway bays. The tail water elevation for the latter flow was 4779. The flow was controlled by gates so that the reservoir level was the same as for the maximum discharge. The 4,200 cfs flow was used when it was learned that this had been a common operating condition in the prototype, and a trial run in the model indicated that it was as severe a condition as the maximum discharge. This was mainly due to the hydraulic jump being on the apron at the pier and running diagonally downstream across and off of the apron. The effect of the diagonal flow is shown by the riprap pattern in Figure 2B. The edge of the riprap was located directly under the toe of the hydraulic jump. For the fifth test the length of riprap protection was extended to 50 feet. The flow conditions were the same as for Test 4.

The riverbed erosion for these tests is shown on Figures 2A and 2B. The deepest erosion was adjacent to the sidewalls, and was 2 feet deeper when the length of riprap protection was 50 feet than when it was 30 feet. In the center

of the channel the deeper erosion occurred with the 30-foot length of riprap. No explanation can be given for these differences.

The riprap used in all tests had the following gradation; the sizes are given in prototype dimensions:

Percent	Diameter in inches
5	12 - 18
19	18 - 24
47	24 - 36
26	36 - 45
3	45 - 52

The sixth test in this series was to determine the effectiveness of placing a sill on the end of the concrete apron. Only one sill design was tried, but this was considered adequate for determining the effectiveness. The sill was 3 feet high with a 1:1 slope on the upstream face, a 2-foot-wide flat top, and a vertical downstream face. A 2:1 upstream face would have provided better results but, since it was planned to prepare the sill in precast units, it was thought that the thicker section of the 1:1 slope was necessary.

Five runs were made in this test, three with the end sill and two without an end sill. Three flow conditions were represented, one was the maximum flow or unit discharge of 155 cfs per foot of width; the second represented a discharge of 4,200 cfs diverted through two spillway bays with the tail water at elevation 4779; and the third condition represented approximately the same unit flow as the second condition, but in setting the tail water it was assumed that all spillway bays were operating, resulting in a total discharge of 20,000 cfs with the tail water at elevation 4785.

The test procedure was to mold the sand bed to elevation 4774, then operate the model without an end sill for 1 hour under one of the three operating conditions. After the extent of erosion had been determined the sand bed was remolded, the end sill installed, and the model operated for 1 hour at the same discharge. This procedure was repeated for the second and third discharge quantities.

The erosion patterns after these three tests are shown on Figures 2 and 3. The tests showed that the end sill was effective in reducing the erosion at the maximum discharge, Figures 1A and 2D, and at the 20,000-cfs discharge, Figures 3C and 3D. At the 4,200-cfs flow the erosion was deeper with the end sill than

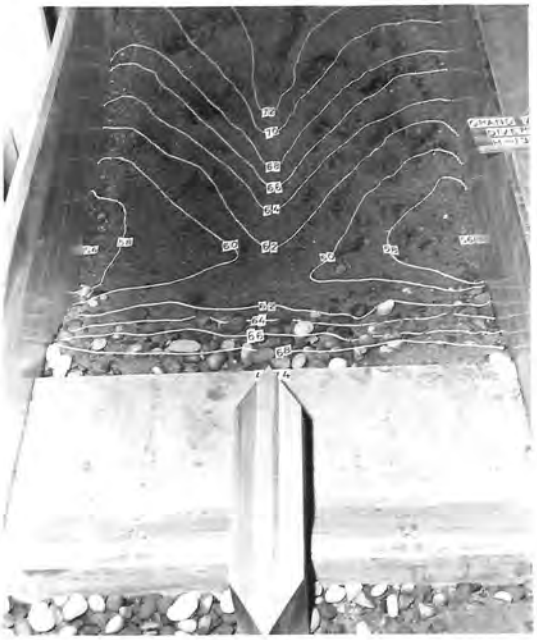
without, Figures 3A and 3B. The reason for this is that with the low flow there was insufficient tail water depth to maintain the hydraulic jump on the apron. Water was thrown over the sill into the riverbed where it caused considerable erosion. Also significant was the more uniform scour pattern that occurred when the sill was in place and a jump occurred on the apron. The sill produced a more uniform distribution of flow leaving the apron.

CONCLUSIONS AND RECOMMENDATIONS

The model studies showed that riprap of recommended sizes, placed or dumped to a depth of about 4 feet on top of the existing eroded area, will provide adequate protection against undermining of the concrete spillway apron. The riprap should extend for at least 30 feet downstream from the apron, and should consist of well-graded rock with at least 75 percent of the individual pieces being 2 feet or larger in diameter. Under severe operating conditions, the river channel downstream from the riprap may be eroded and cause the riprap to settle and move downstream. To reduce this possibility, it is advisable to distribute the discharge over as many spillway bays as possible. The ideal operating condition would be to use all six bays of the spillway and the sluiceway bay with equal gate openings.

The limited studies performed with this model were not sufficient to determine the best type of end sill for use on the prototype spillway. However, the studies indicated that an end sill would help to protect the apron against undermining by directing flow currents away from the channel bottom. If permanent protection is desired, an end sill should be developed that would be satisfactory under all operating conditions.

A. Erosion after 1-hour of operation. q=155 cfs T. W. Elev. 4792



B. Erosion after 2-hours operation q=155 cfs T. W. Elev. 4792. Rip rap had been placed on a 3:1 slope for 60 ft. downstream from apron.

C.

D.

Erosion after following sequence of operation; q=155 cfs 2 hours at T. W. elev. 4792, 2 hours at T. W. elev. 4790, 2 hours at T. W. elev. 4788, 2 hours at T. W. elev. 4786. Rip rap has been placed horizontally for 50-ft., then on a 2:1 slope for 10-ft.

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A. Erosion after 2-hours operation at q=155 cfs T. W. Elev. 4792, plus 2 hours operation at Q=4200 cfs T. W. elev. 4779. Rip rap had been placed for 30-ft. downstream on top of scour shown in Fig. 1-A.

B. Erosion after 2 hours operation at q=155 cfs T. W. Elev. 4792, plus 2 hours operation at Q=4200 cfs T. W. elev. 4779. Rip rap had been placed for 50-ft. downstream on top of scour shown on Fig. 1-A.

C. River bed before operation. End sill on Apron.

D. Erosion after 1-hour operation q=155 cfs, T. W. elev. 4792. End sill on apron. (Compare with Fig. 1-A.)

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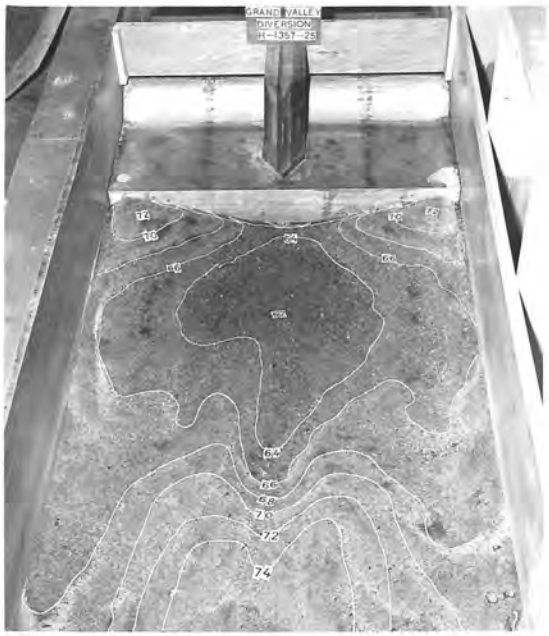

A. Without end sill on apron B. With end sill on apron.
Erosion after 1-hour operation at Q=4200 cfs, T. W. elev. 4779.

C. Without end sill on apron D. With end sill on apron
Erosion after 1-hour operation Q=20,000 cfs T. W. elev. 4785.

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