

HYD 272

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EROSION TESTS ON AN EARTH SAMPLE TAKEN
AT ELEVATION 4065.3 ON THE SPILLWAY
CENTERLINE 70 FEET DOWNSTREAM FROM THE
END OF THE PROPOSED SPILLWAY--KEYHOLE DAM--
MISSOURI RIVER BASIN PROJECT

Hydraulic Laboratory Report No. Hyd.-272

RESEARCH AND GEOLOGY DIVISION



BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

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Laboratory Report No. 272
Hydraulic Laboratory
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Subject: Erosion tests on an earth sample taken at elevation 4065.3
on the spillway centerline 70 feet downstream from the end
of the proposed spillway--Keyhole Dam--Missouri River Basin
Project

PURPOSE

To determine the erosion resistance of the above soft layered sandstone when subjected to water velocities of 2 to 19.5 feet per second.

CONCLUSIONS

1. Excessive erosion results at water velocities of 6 feet per second or more when the flow occurs parallel to the horizontal layers of the material and the material is free so that the interlocking between the pieces forming the layers can be broken. The erosion occurs in the form of dislodged pieces being swept away by the water.
2. The harder and nonlayered material at elevation 4064.3 withstands velocities up to 16 feet per second without excessive erosion. Tests at higher velocities could not be made because the specimen was lifted out of the test apparatus by the water and broken.
3. When water strikes the layers of the material in a direction perpendicular to the layer planes, the material has better erosion resistance than given in Conclusion No. 1, and it is not materially damaged by water velocities up to 6 feet per second. Erosion in this case occurs mainly as a gradual wearing away of the pieces comprising the layers.
4. A vertical wall of the material, when constrained on all but the exposed side, resists velocities up to 19.5 feet per second without excessive erosion. Higher velocities could not be obtained with the test apparatus.

INTRODUCTION

Keyhole Dam is an earth-fill structure proposed for construction across the Belle Fourche River about 12 miles northwest of Moorcroft, Wyoming. Extensive model tests have been made in the Hydraulic Laboratory to determine the hydraulic performance of the spillway structure and to determine those design changes required to insure proper operation (Hydraulic Report No. 271). The material used in these model tests to represent the river bed downstream from the spillway scoured to a greater degree and in a different manner than was anticipated on the prototype. Important design decisions depended upon the results of the model tests and it was therefore desirable to find a river bed material which would scour in the model in a manner similar to the scour that will occur in the field. To determine the erosion resistance of the field material, a sample was procured at elevation 4065.3 on the spillway centerline 70 feet downstream from the end of the spillway.

Considerable difficulty was encountered in obtaining the sample due to the poor bond between the many layers of the soft sandstone. After an unsuccessful attempt, a sample was obtained by the following process. A large pit was dug to elevation 4065.3. The pit was then extended 14 inches further down leaving a 21- by 26-inch undisturbed block standing in the middle. Wire mesh was placed around this block and a large wooden crate built around the unit and the space between the crate and the block was filled with plaster. After the plaster had hardened, the constrained sandstone block was cut from the floor of the pit, turned over, and the remaining face covered with wire-reinforced plaster. The bearing, elevation, and location of the block were marked on the crate, and the unit was shipped to the Hydraulic Laboratory in the Denver office.

This report concerns the method of conducting the erosion tests on the field sample and the results obtained from these tests.

DESCRIPTION OF THE SAMPLE

The material was a soft sandstone which was dense, moderately cemented, and arranged in layers containing $3/8$ - to 1-inch thick flat pieces well interlocked but poorly bonded (Figure 2). A 1-1/2-inch thick section of harder and nonlayered sandstone formed the bottom portion of the sample.

APPARATUS AND TEST PROCEDURE

A schematic diagram of the principal erosion test apparatus is shown in Figure 1. Water was supplied through a 6-inch standard pipe and a transition section to the 16-inch wide by 66-inch long test chute. A valve was provided to regulate the discharge and a flow straightener was placed downstream from the valve to insure smooth, straight flow into the test section. The water entered the chute in a uniform stream 2 inches deep, and the slope of the chute was adjusted to maintain this depth over

the full length of the specimen. The velocity of the water over the test specimen was determined by measuring with a Venturi meter the quantity of water flowing, and dividing this quantity by the cross sectional area of the flowing water in the chute of the test rig. The water discharged freely from the end of the chute and was returned to the supply channel by a trough. The floor of the test box was adjustable to permit moving the specimen to keep its top surface level with the chute floor as the material was washed away. To avoid surges and excessive velocities over the specimen when the flow was started, an obstruction was placed across the downstream end of the channel, the chute flooded to a depth of 2 inches, and the control valve slowly opened while the obstruction was removed. A final adjustment of the valve established the desired water velocity over the specimen.

Specimens No. 1 and 2 of the three specimens prepared from the field sample were placed, one at a time, in the test box with the side which was uppermost in the field on top in the box and level with the chute floor. Specimen No. 1 was a 12- by 21-inch piece, 9 inches thick taken from the top of the block sample and was made up of many $\frac{3}{8}$ to 1 inch thick, loosely bonded pieces arranged in horizontal layers (Figure 2). Specimen No. 2 was a 12- by 21-inch piece, 1-1/2 inches thick and consisted of the moderately hard, nonlayered sandstone obtained from the bottom of the sample (elevation 4064.3) (Figure 2). This thin sample was reinforced on the underside for the tests with a 2-inch thick layer of plaster. Specimen No. 3 was a 14- by 21-inch piece, 14 inches thick and the tests conducted on this specimen consisted of discharging water at known velocities from the test chute onto the specimen below, and impinging water at a 15° angle on a vertical face of the material which was constrained in a plaster cast. For the first of these two tests, enough of the plaster cast around the sample was removed to leave one face and the top 6 inches of the material uncovered. The specimen was placed on the floor slightly downstream from the end of the chute and water was allowed to discharge from the end of the chute and fall to the specimen below. Thus, an erosion condition was created roughly similar to that produced by the water discharging from a trajectory spillway. The velocity of the water in the chute was adjusted so that its velocity plus the velocity gained while falling produced the desired final velocity. The second test was conducted on the same specimen by building a new plaster cast over the top and three sides and then placing this specimen in a temporary extension chute at the end of the original chute with the exposed face vertical and at a 15° angle to the chute axis (Figure 3). Water flowed down the chute parallel to the layers, impinged at a 15° angle on the face of the specimen, and discharged freely from the end of the extension chute.

Visual means were used to judge the erosion on the specimens and photographs are attached which show the condition of the specimens at the completion of the tests. At the time of this writing a feasible method of determining the quantity of material removed in the erosion process has not been found. Weight, volume, and collection measurements could not be used because of large changes in moisture content during testing, swelling of certain materials (particularly clay) when water is absorbed, and the lack

of filtering equipment capable of holding the small pieces washed off the specimen and still handling the large quantities of water used. Finally, the size and shape of the specimens tested precludes a close representation of the field erosion conditions. Therefore, the results presented in this report are qualitative only, and use of the laboratory test results to predict field results must be done with care.

The full range of velocities obtainable with the test apparatus was used in the test on the Keyhole specimens, the values ranging from 2 to 19.5 feet per second.

TEST RESULTS

Specimen No. 1

Water was first passed over the specimen at a velocity of 2 feet per second and the loose sand was swept from the top surface almost immediately. At the end of the 30-minute test, the thin pieces which formed the layers were clearly defined (Figure 4a). However, the material within the pieces was sufficiently cemented together that no erosion was visible on them, and the water velocity of 2 feet per second was too low to dislodge them. At 4 feet per second a number of the pieces were swept away with the result that 1 inch of material was removed during the 30-minute test (Figure 4b). At a flow velocity of 6 feet per second, the pieces were swept away almost immediately. As the test progressed, it became necessary to repeatedly raise the specimen in the test box to keep the surface of the material level with the chute floor and within 10 minutes all of the material was removed.

In all cases during the above tests the material was removed in large pieces, and there was little tendency for the sand to wash away by individual sand particles.

Specimen No. 2

This nonlayered and moderately hard sandstone appeared to have considerable resistance to erosion, and therefore the first test was made using a flow velocity at the specimen of 4 feet per second. No action was noted during the 30-minute test except that the loose sand particles were removed from the top of the specimen soon after the flow was started. The material was somewhat rough and cratered at the completion of the test but was otherwise untouched (Figure 5a). Further 30-minute tests were made using velocities of 8 and 12 feet per second but no noticeable erosion resulted (Figure 5b). Another test was started using a velocity of 16 feet per second, but after 20 minutes the specimen was lifted out of the test apparatus by the water and so severely broken that further tests were discontinued. Examination of the pieces revealed that only slight erosion had occurred, and that the material was capable of withstanding considerably higher velocities without excessive erosion.

Specimen No. 3

The results of the erosion tests conducted on Specimen No. 1 in which the water flowed parallel to the layers of the material indicated that extensive erosion by movement of the pieces forming the layers would result whenever similar flow conditions occur in the field. However, these tests also indicated that the soft sandstone within the individual pieces had fair erosion resistance. Examination of the remaining portion of the field sample (Specimen No. 3) revealed that these pieces were well interlocked, even though the pieces were poorly bonded to each other, and that considerably different erosion could be expected from the plunging flow that would occur from the trajectory bucket on the Keyhole Spillway. To obtain tests with this type of flow, Specimen No. 3 was placed on the floor below and slightly downstream from the end of the chute in a position to receive the water falling from the end of the chute. Tests were then made using velocities of impingement of 4 and 6 feet per second for 10-minute periods (Figures 6a and b). When starting and stopping the flow in these tests, the water struck the exposed upstream edge of the specimen and immediately swept away a number of pieces. These pieces can be seen on the floor in Figure 6b. Little erosion occurred during the periods when the flow was fully established, thereby indicating that the material had moderately good erosion resistance when the pieces were not lifted and carried away by the water.

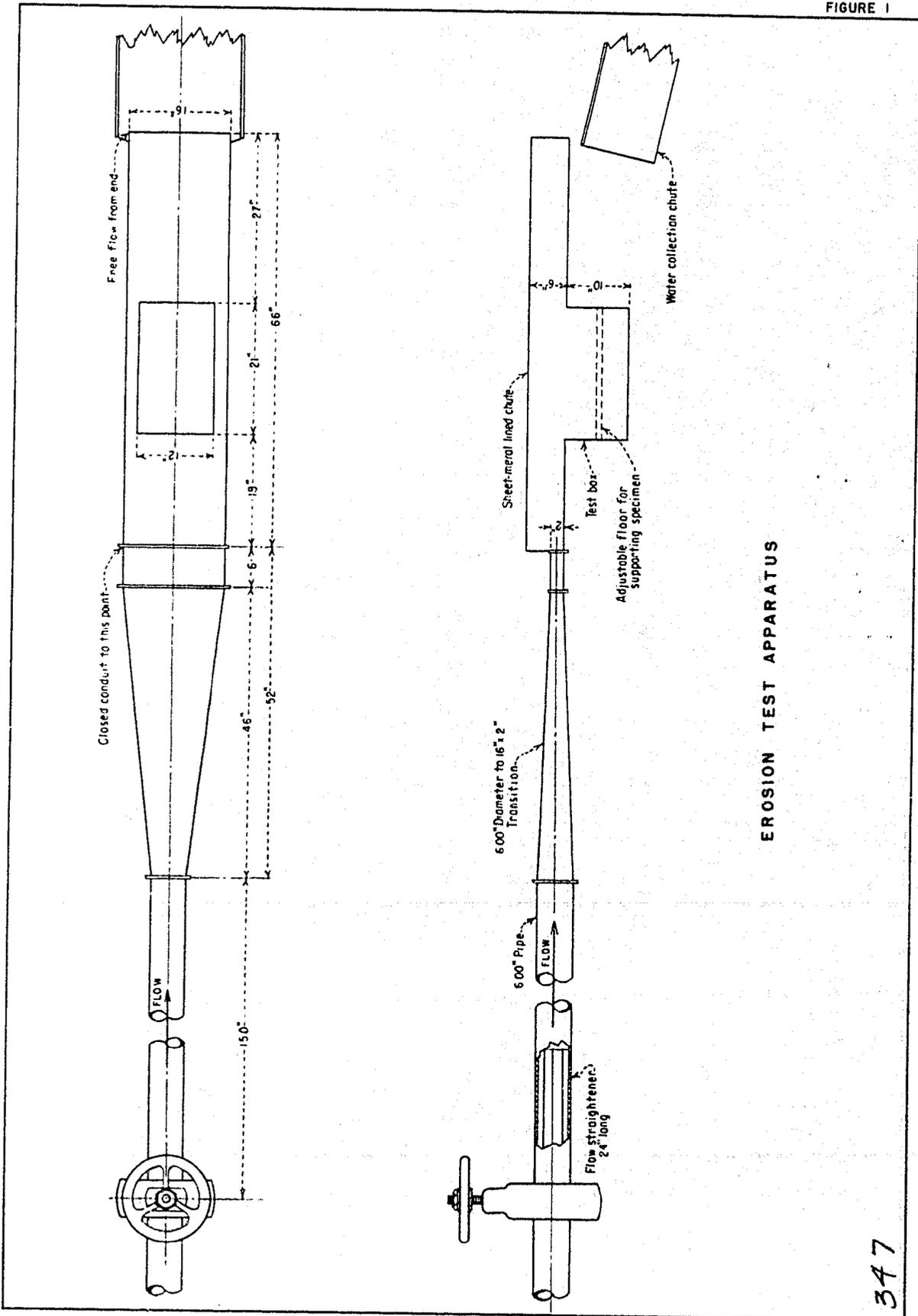
The marked difference in erosion obtained in the tests with water flowing parallel to the layers of the material and in the tests with water striking the layers at an angle made it difficult to estimate the probable erosion in the field. A third type of test was therefore made to obtain a more complete picture of the erosion resistance of the material. The portion of Specimen No. 3 which remained intact during the previous tests was covered with a new plaster cast on all but one side of the block. The specimen was then placed in an extension chute fitted to the downstream end at a 15° angle to the existing test chute (Figure 3). The specimen was oriented with the layers horizontal and with the test face vertical and in the plane of the right wall of the extension chute. Water flowed through the test chute and impinged at a 15° angle on the test face of the specimen (Figure 7a). From there it continued downstream and discharged freely from the end of the extension.

As soon as the tests were started, it became apparent that the vertical face of the constrained material could withstand considerable battering by the water. The first test was made with a water velocity of 4 feet per second and the only noticeable change in the specimen at the end of the 5-minute run was that the seams between the layers were cleaned out. A second test of 10 minutes' duration was made with a water velocity of 8 feet per second and again the specimen remained practically unchanged. A few small pieces of the material were removed from the disturbed area at the downstream edge of the specimen and only slight erosion was visible at the marks in the face left by cutting tools. Additional 10-minute tests with water velocities of 12, 16, and 19.5 feet per second (the maximum obtainable with the apparatus) were made, and at the end of the tests the specimen showed only moderate wear (Figure 7b). A number of pieces had

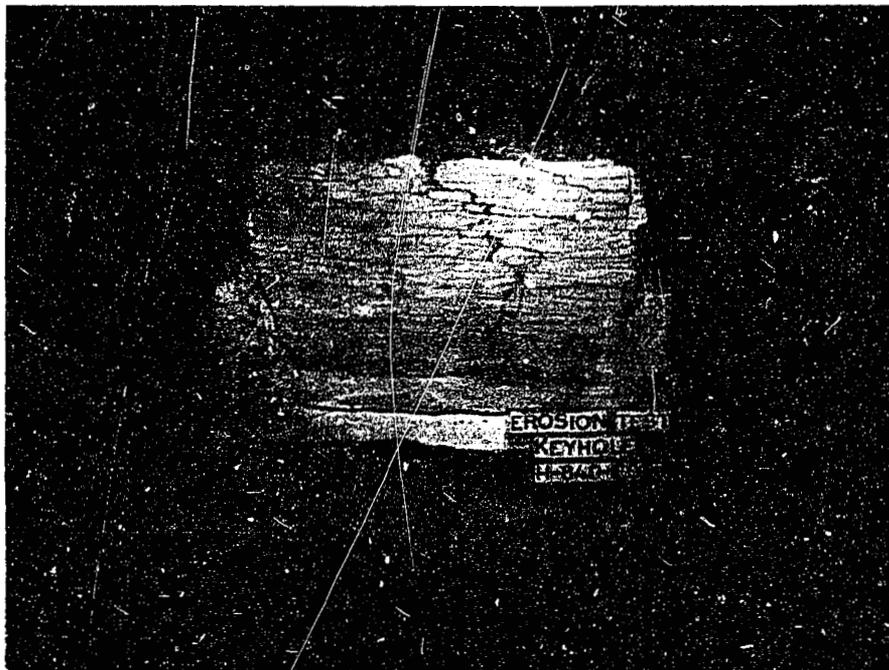
been removed from the disturbed area at the downstream edge of the specimen but otherwise no appreciable damage was incurred.

The above tests completed the erosion test program on the Keyhole earth material field sample, and the investigation was therefore terminated.

FIGURE 1



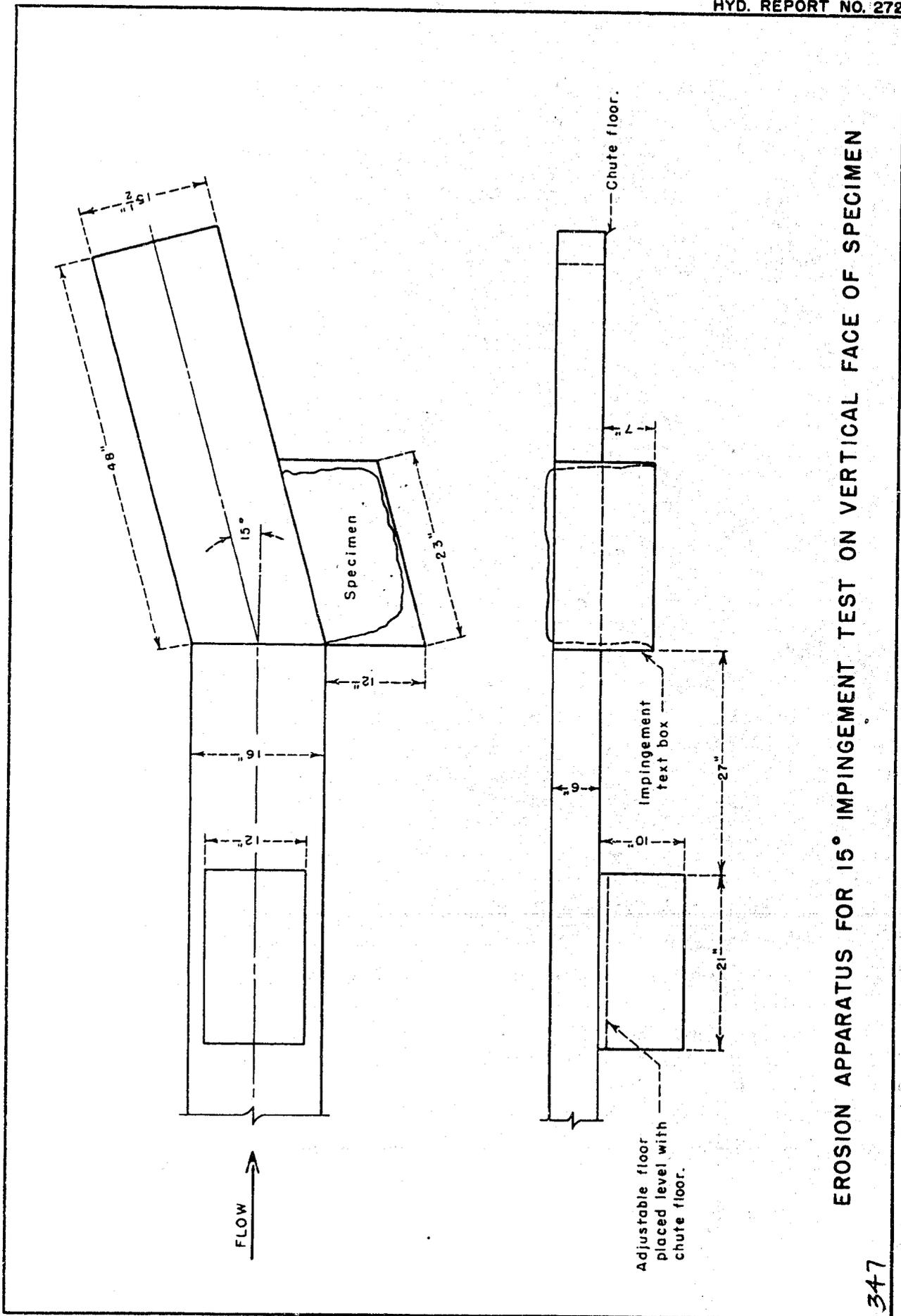
EROSION TEST APPARATUS



The soft sandstone occurred in thin, flat pieces which were well interlocked but formed poorly bonded layers. The bottom 1-1/2 inches was harder and unlayered.

Section Through Block Sample

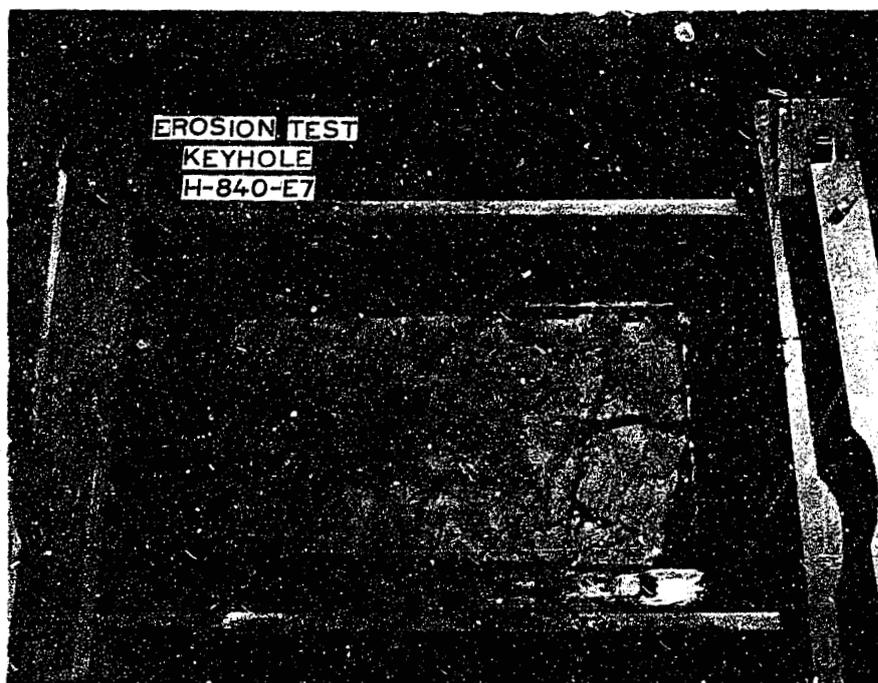
Erosion Tests on Keyhole Damsite Earth Sample



EROSION APPARATUS FOR 15° IMPINGEMENT TEST ON VERTICAL FACE OF SPECIMEN



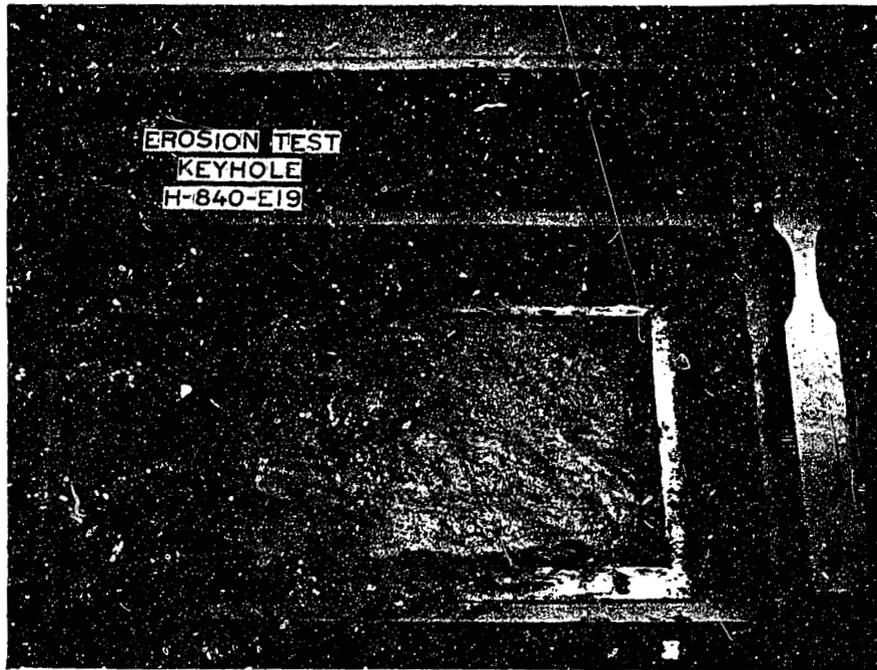
A. Erosion after 30 minutes exposure to a water velocity of 2 feet per second.



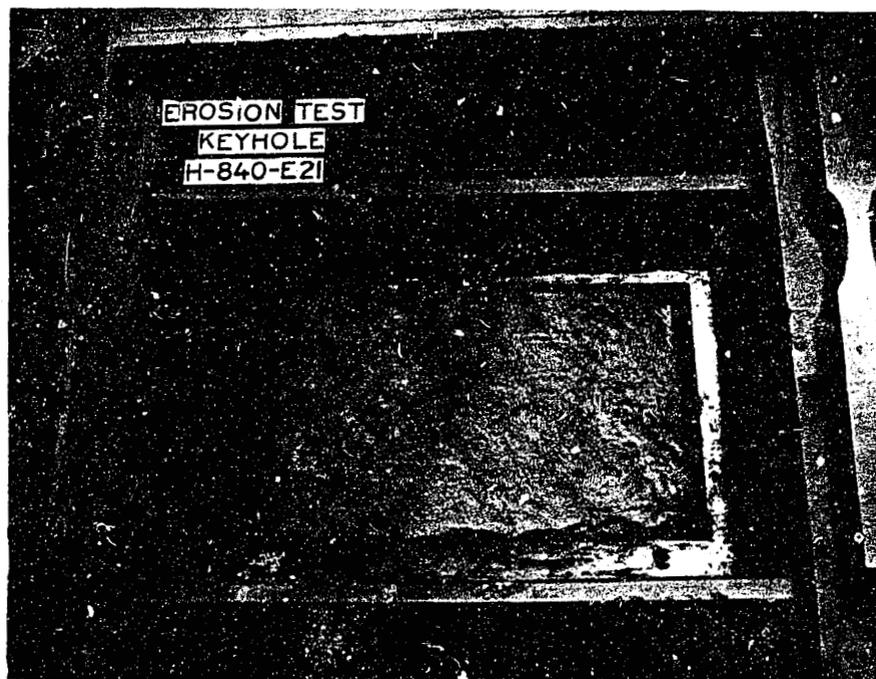
B. Erosion after 30 minutes exposure each to water velocities of 2 and 4 feet per second.

Specimen No. 1

Erosion Tests on Keyhole Damsite Earth Sample
Flow from Left to Right



A. Erosion after 30 minutes exposure to a water velocity of 4 feet per second.



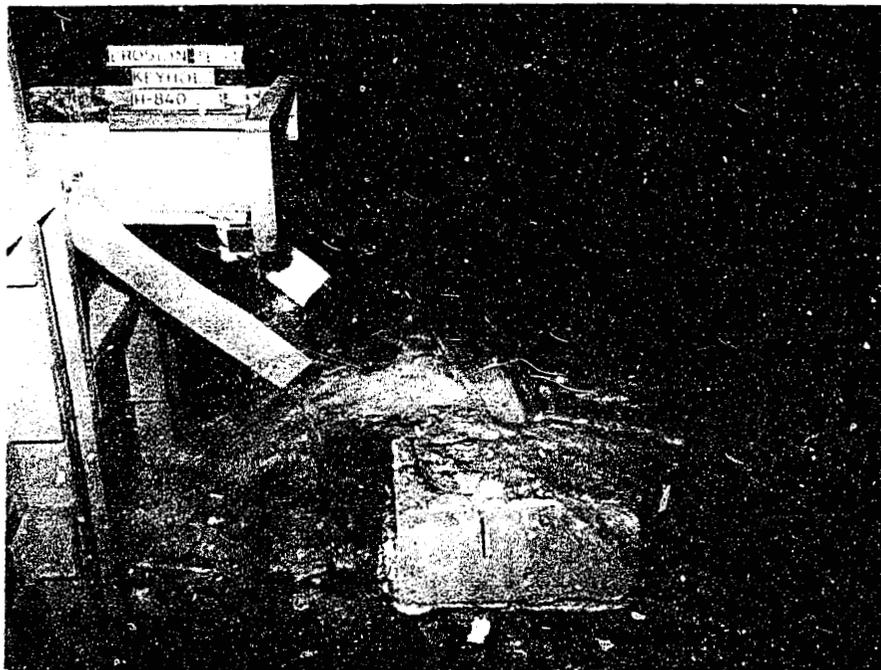
B. Erosion after 30 minutes exposures each to water velocities of 4, 8, and 12 feet per second.

Specimen No. 2

Erosion Tests on Keyhole Damsite Earth Sample
Flow from Left to Right



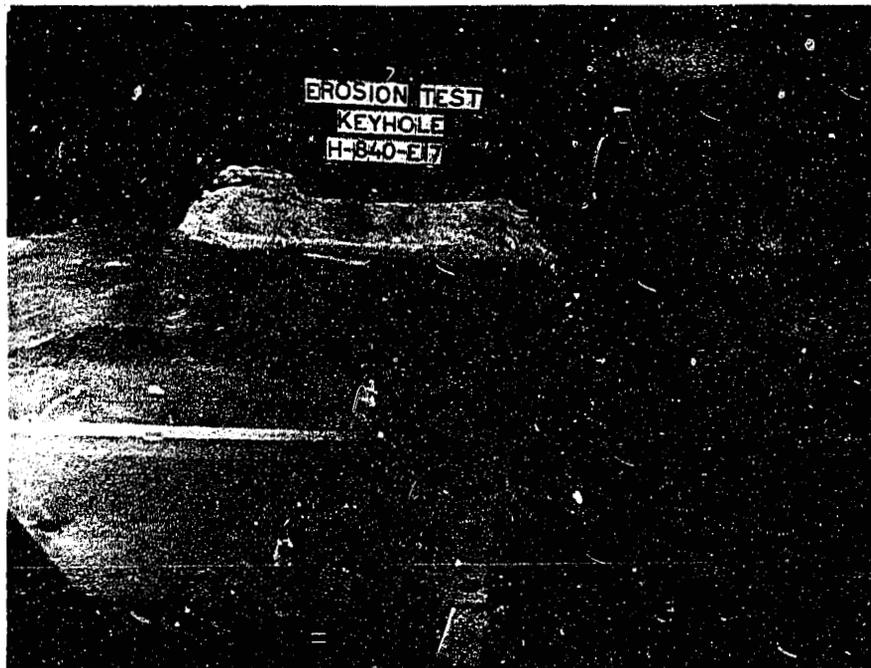
A. Plunging flow striking the specimen at a velocity of 4 feet per second.



B. Plunging flow striking the specimen at a velocity of 6 feet per second. The pieces scattered on the floor were removed while starting and stopping the flow.

Specimen No. 3

Erosion Tests on Keyhole Damsite Earth Sample



- A. Water flowing at a velocity of 12 feet per second impinging at a 15° angle on a vertical face of the plaster-encased specimen. Flow from right to left.



- B. Erosion after a 5 minute exposure to a water velocity of 4 feet per second and 10 minute exposures each to velocities of 8, 12, 16, and 19.5 feet per second.

Specimen No. 3

Erosion Tests on Keyhole Damsite Earth Sample