Division of Engineering Laboratories
Hydraulic Laboratory Branch

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

EROSION STUDIES ON SANDSTONE THROUGH WHICH THE GLEN CANYON DAM DIVERSION TUNNELS WILL PASS--GLEN CANYON DAM--COLORADO RIVER STORAGE PROJECT

Hydraulic Laboratory Report No. Hyd-423

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

December 24, 1956

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Commissioner's Office--Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Structures and Equipment Section
December 24, 1956

Laboratory Report No. Hyd-423
Compiled by: W. P. Simmons, Jr.
Checked by: W. E. Wagner
Reviewed by: J. W. Ball
Submitted by: H. M. Martin

Subject: Erosion studies on sandstone through which the Glen Canyon Dam diversion tunnels will pass--Glen Canyon Dam--Colorado River Storage Project

PURPOSE

The purpose of the study was to determine the resistance of the sandstone material at Glen Canyon damsite to erosion by flowing water. This information was obtained for evaluating whether or not lining would be required in the diversion tunnels.

CONCLUSIONS

1. Negligible erosion occurs when clear, sediment-free water flows parallel to, or impinges upon, the sandstone at velocities up to 110 feet per second.

2. Considerable erosion occurs when sediment-laden water impinges upon the sandstone at velocities of 20, 30, and 40 feet per second.

3. Increases in sediment size and sediment concentration increase the amount of erosion produced. Sediment size has a more pronounced effect than concentration.

4. The erosion rate increases rapidly as the flow velocity of the sediment-laden water increases.

5. Appreciable erosion will occur in the diversion tunnels, if they are left unlined, due to the amount and size of sediment moved by the river water which may flow at velocities up to 40 feet per second.

INTRODUCTION

Glen Canyon Dam, which is to be built across the Colorado River in Arizona a few miles downstream from the Utah border, will have two large diversion tunnels 2,500 feet long through its abutments. During early construction of the dam, the entire river flow will pass through these tunnels. Later, when the dam has been raised sufficiently and diversion is no longer necessary, the upstream 1,500 feet of the tunnels will be plugged and abandoned. The downstream 1,000 feet of the tunnels will then be used as parts of the final concrete-lined spillway tunnels. The velocity through the diversion tunnels at the maximum expected river flow will be about 40 feet per second. The canyon walls at the site of the dam are a sandstone of medium strength and fairly uniform grain size.

To assist in determining if lining would be needed to resist excessive erosion in the tunnels during the diversion period studies of the erosion characteristics of the sandstone were requested by the Dams Branch and performed by the Hydraulic Laboratory.

TEST EQUIPMENT AND PROCEDURES

From several 6-inch-diameter core samples of the Glen Canyon sandstone shipped to the Engineering Laboratories for testing, Samples 33-7-126 and 29-8-8 were selected as being most representative of the material in which the tunnels will be constructed. Most of the erosion tests were conducted on Sample 33-7-126, a vertical core which was obtained from the left bank of the river at elevation 3150. A similar core, when tested with an axial load and in a saturated condition, showed a compressive strength of 5,180 psi. Sample 29-8-8 was a horizontal core obtained at elevation 3200 on the left canyon wall and had a compressive strength of about 3,300 psi.

Three series of tests were conducted on Sample 33-7-126. In the first series, sediment-free water from a 0.52- by 1.88-inch rectangular nozzle was passed across the flat end of the sample in a direction approximately parallel to the core surface (Figures 1A and 2A). To assure that the jet was in firm contact with the core surface, the sample was tipped about 1/8 inch to place the downstream end of the surface into the stream. The bedding planes of the sandstone, which were inclined about 30 degrees to the horizontal, were oriented so that the flow tended to enter the seams.

In the second series of tests, clear water from the nozzle was directed downward so as to strike the flat surface at an angle of 25 degrees (Figure 1B). The sample was oriented so that the flow was roughly parallel with the bedding planes.

In the third series, sediment was introduced into the flowing water and the stream struck the flat surface at an angle of 15 degrees (Figure 1D). As in the pervious series, the bedding planes were oriented so that the flow tended to enter the seams.

In each of the test series, the nozzle was mounted on a 6-inch-diameter pipe by a threaded coupling welded to a 6-inch flange (Figure 1C). In the first and second tests, clear water was supplied from the main laboratory pumping system, and the rate of flow was measured with calibrated laboratory venturi meters. In the third series of tests, which used sediment in the water, a separate recirculating system was used (Figure 1D). The flow velocities in this series were determined from pressure measurements taken in the 6-inch pipe 1 diameter upstream from the nozzle.

The erosion produced in the tests with clear water was very small and no measurements of the removed material were made. Considerable erosion occurred during the tests made with sediment-laden water, and the material removed was measured volumetrically by placing the core sample in a graduated container and measuring the quantity of mercury required to fill the container before and after a test. The difference in the amount of mercury required before and after the test was equal to the volume of sandstone eroded. The amount and size of the sediment in the flow were determined from samples drawn from the nozzle jet by a pitot-type sampling tube at 1/2-hour intervals. About 30 liters of sediment-laden water were collected in a graduated container with a conical bottom which terminated in a removable glass tip. The sediment settled into this tip, and after the water was drained off, the tip was removed and the sediment volume measured and expressed in parts sediment per million parts water. The combined sediment deposits from all of the samples taken during a test were then dried and passed through various standard screens or sieves. The amount of material retained on each screen was weighed, expressed in percent of the total sample, and this percent value plotted to produce a standard sieve analysis curve (Figure 6).

RESULTS

Sediment-free water

Very little material was removed from Sample 33-7-126 during the tests with clear water and with the flow parallel to the core surface. A 4-hour test at 20 feet per second, followed by a 25-1/2-hour test at 40 feet per second, produced negligible erosion. An additional 16-hour test at 58 feet per second, and a 7-1/2-hour test at 72 feet per second produced barely detectable erosion (Figure 2B). Similarly, only negligible erosion was detected on Sample 29-8-8 after a 13-hour test at 40 feet per second (Figure 3B).

The samples were then subjected to the more severe tests in which water impinged on the flat surfaces at a 25 degree angle (Figure 1B). Sample 33-7-126 showed practically no additional erosion after a 4-hour test with a velocity of 40 feet per second and a 28-hour test with a velocity of 72 feet per second. When the flow velocity was increased to 110 feet per second, noticeable erosion occurred in 10 hours of operation (Figure 2C). Sample 29-8-8 showed practically no erosion following the impinging test with a velocity of 72 feet per second for 24 hours (Figure 3C).

Sediment-laden water

The Colorado River normally carries a heavy load of sediment and this abrasive mixture could be expected to produce more erosion than clear water. Tests were therefore made with sediment in the flowing water and the jet was directed onto the core surface at a 15 degree angle.

In the first tests with sediment-laden water, the sediment consisted of ordinary commercial sand having a mean diameter of 0.40 mm (Figure 6A). In a 4-hour test with a stream velocity of 20 feet per second, 5.2 cc of sandstone material were worn from the surface of Sample 33-7-126 (Figure 4A). The eroded portion of the sample was then trimmed to a fresh surface. A test was made with a velocity of 30 feet per second and 38.1 cc of sandstone were removed in 4 hours (Figure 4B). In a similar 4-hour test with a velocity of 40 feet per second, 52.5 cc of sandstone were removed (Figure 4C). The sediment loads were 214, 911 and 632 ppm, respectively, and the sediment sizes are shown in Figure 6A.

The size of the sediment particles was believed to have an important effect upon the rate of erosion, and samples of the actual bedload material at the dam site were requested for use in the final tests. While these samples were being procured and shipped, tests were made using a fine, uniform sand that was available in the laboratory at the time, and had a mean diameter of 0.22 mm. A noticeable but fairly small amount of sandstone was removed in a 4-hour test with a flow velocity of 20 feet per second. In a 4-hour test at 30 feet per second, 3.0 centimeters were removed while in a 4-hour test at 40 feet per second 25.5 centimeters were removed (Figures 5A, 5B, and 5C). Sediment concentrations were 1,220, 2,010, and 2,370 ppm, respectively, and the sediment sizes are shown in Figure 6B.

Upon receipt of the samples of bedload material from the dam site, it was found that the samples were remarkably similar to the fine sand used in the laboratory tests (Figure 6B). This similarity was so close that tests using the field samples were judged unnecessary, and the test program was terminated.

A review of the erosion produced by the two sizes of sediment in flowing water showed that at each test velocity the erosion was much greater when coarse sand was used, even though the concentration of coarse sand was less than the concentration of fine sand. The effect of velocity is clearly shown in Figure 4 where a smaller sediment concentration in a higher velocity stream (Figure 4C) produced more erosion than a larger concentration of the same size material in a slower stream (Figure 4B). Similar action is shown in Figures 5B and C where the higher velocity stream with only a slightly larger sediment concentration produced many times the erosion of the slower stream. The tests were not extensive enough to evaluate the effect of different concentrations of the same size sediment, but it seems only logical that large sediment concentrations would produce more erosion than smaller concentrations.

Summary

A summary of the test results with clear, sediment-free water is presented in Table 1. A similar summary of the test results with sediment-laden water is presented in Table 2.

Table 1

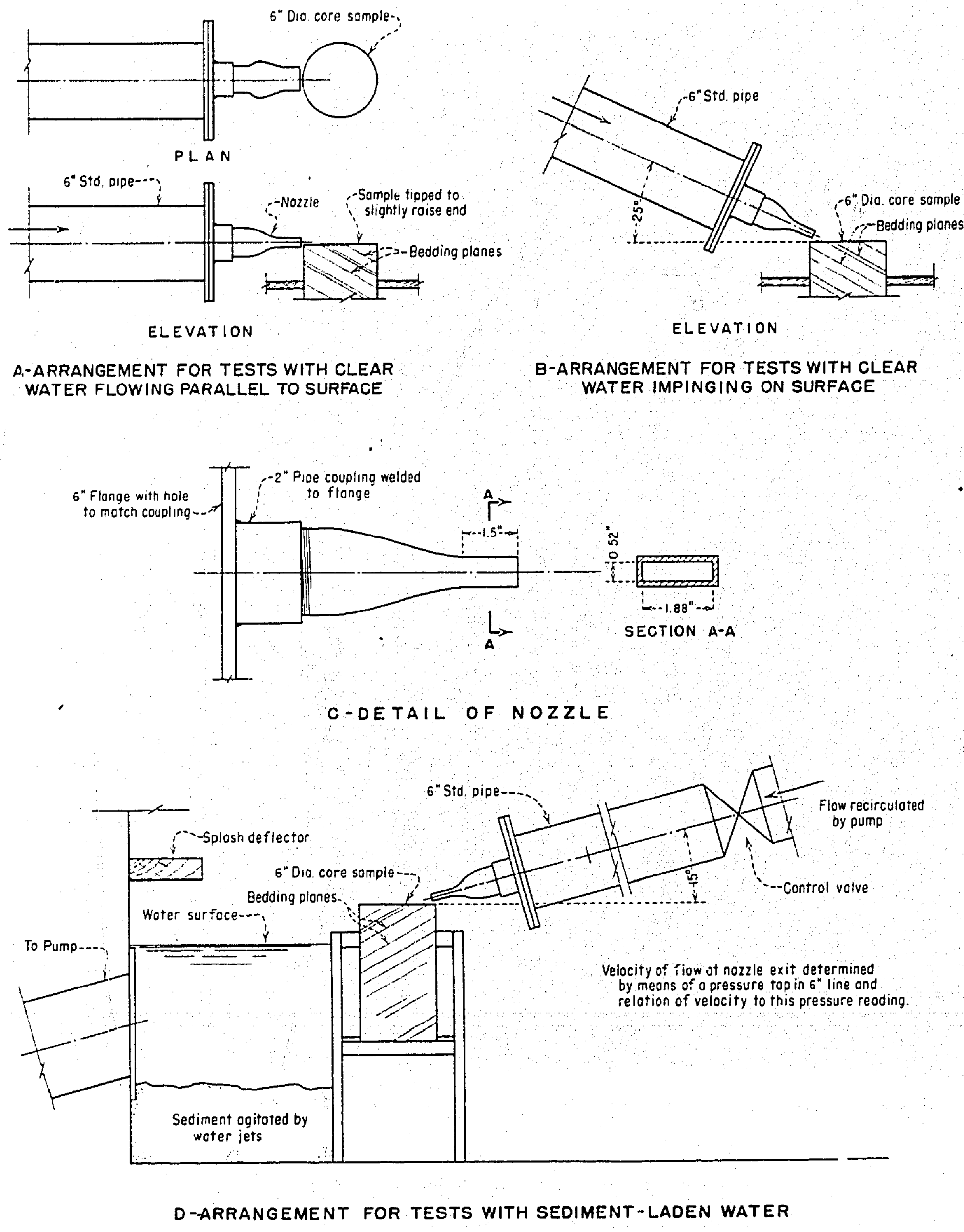
CLEAR, SEDIMENT-FREE WATER

Type of flow	Comments
Parallel to surface	Barely detectable erosion with velocities 20 to 72 fps.
Impinging at 25°	Very slight erosion at velocities 20 to 72 fps. Noticeable erosion at velocities of about 110 fps.

Table 2

SEDIMENT-LADEN WATER

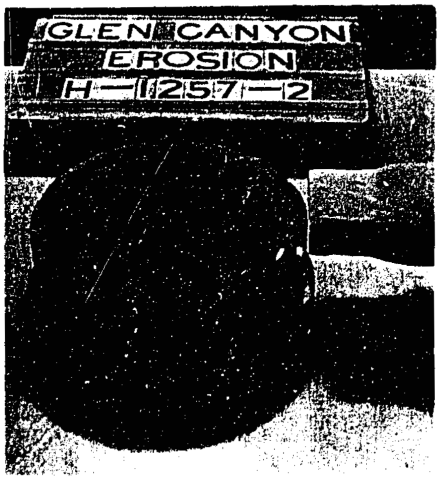
Sediment size	Flow velocity	Concentration	Erosion
Commercial sand Avg. d = 0.40 mm	20 fps	214 ppm	5.2 cc
	30	911	38.1
	40	632	52.5
Fine sand Avg. d = 0.22 mm (similar to sand at dam site)	20	1,220	Slight
	30	2,010	3.0 cc
	40	2,370	25.5



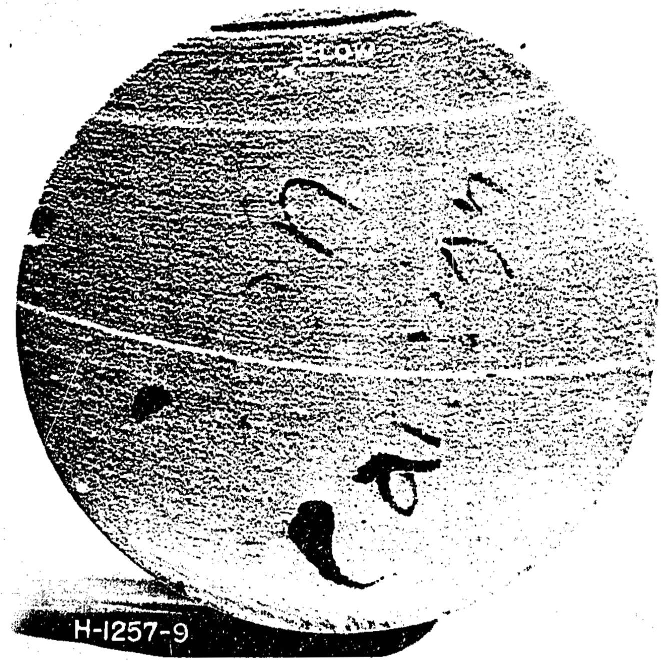
GLEN CANYON SANDSTONE EROSION STUDIES
SCHEMATIC DIAGRAMS OF TEST ARRANGEMENT

556

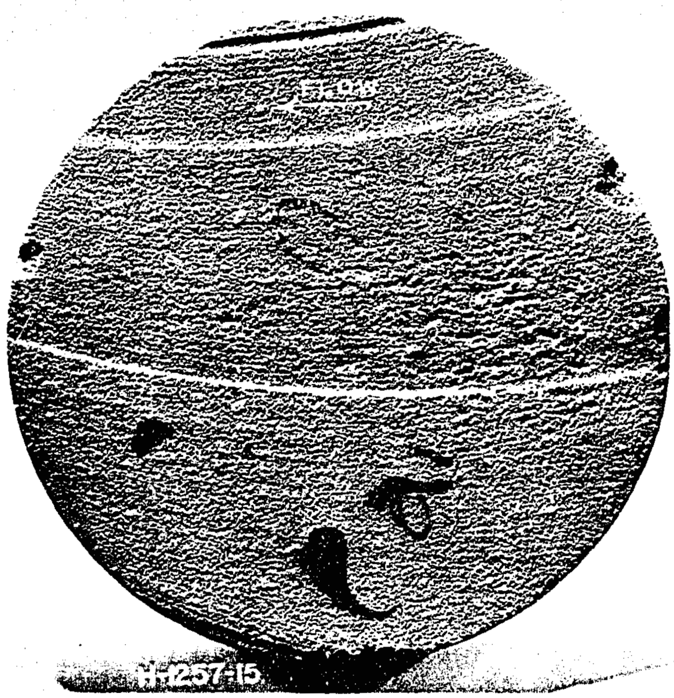
Figure 2
Report Hyd 423



A. Surface before tests



B. Erosion after 4 hrs. at 20 fps, $25\frac{1}{2}$ hrs. at 40 fps, 16 hrs. at 58 fps, and $7\frac{1}{2}$ hrs. at 72 fps with flow parallel to surface.

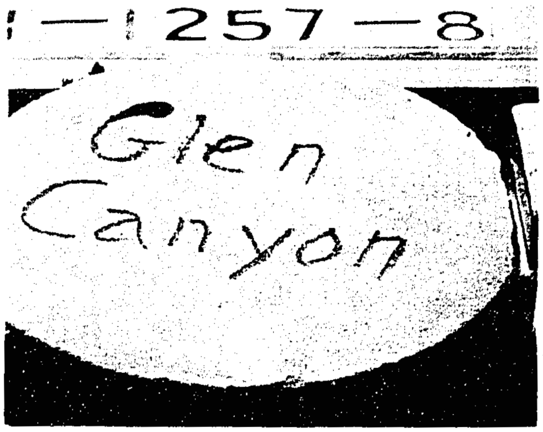


C. Erosion after above tests plus 4 hours. at 40 fps, 28 hrs. at 72 fps, and 10 hrs. at 110 fps, with flow impinging at 25°.

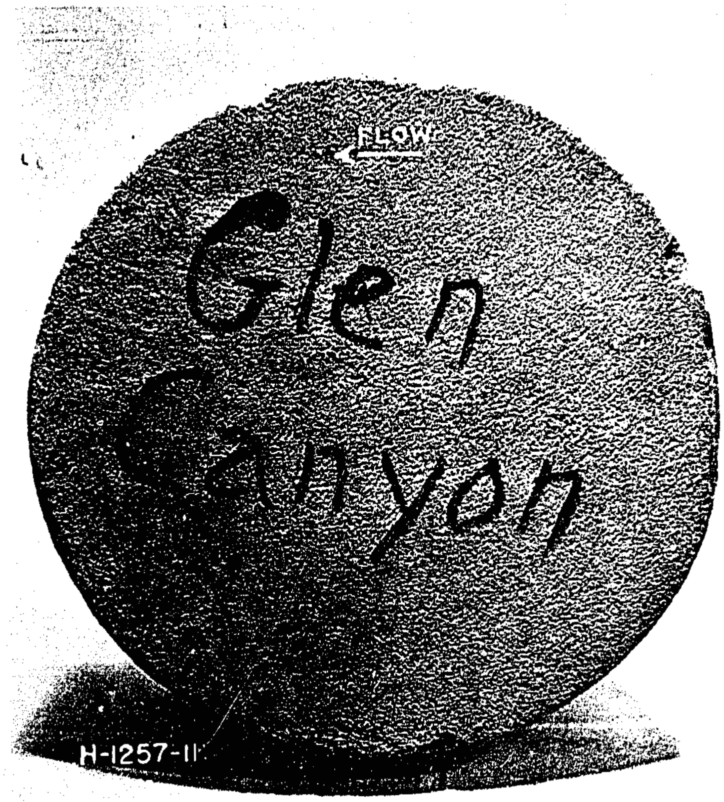
GLEN CANYON SANDSTONE EROSION STUDIES

Erosion With Sediment-Free Water - Sample 33-7-126

Figure 3
Report Hyd 423



A. Surface before tests

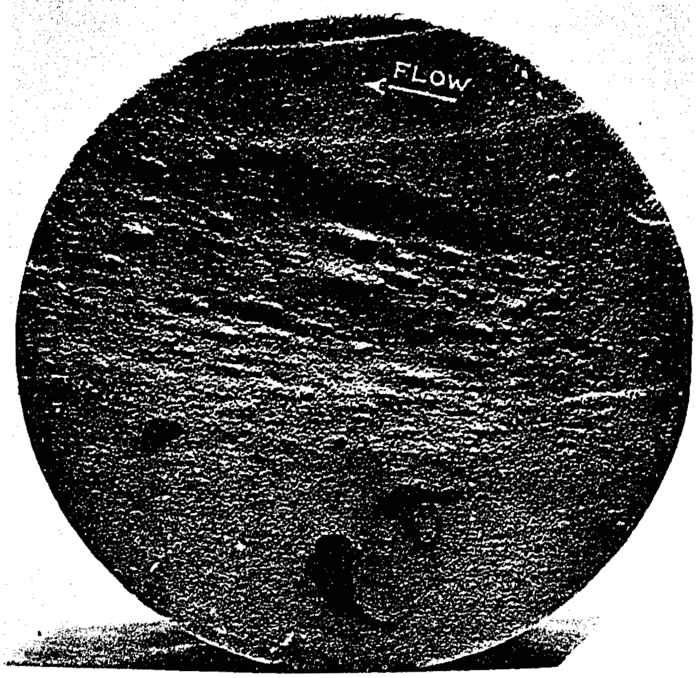


B. Erosion after 13 hours at 40 fps with flow parallel to surface.

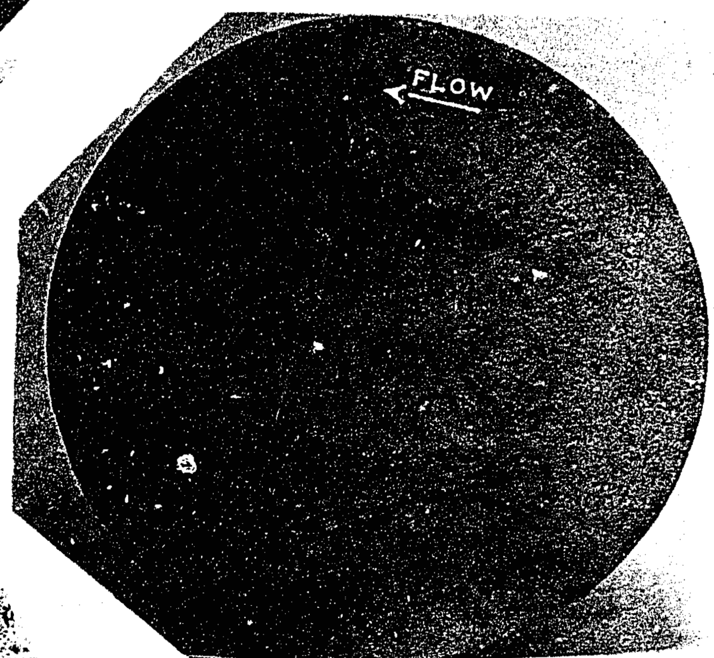
C. Erosion after above test plus 24 hours at 72 fps with flow impinging at 25°.

GLEN CANYON SANDSTONE EROSION STUDIES

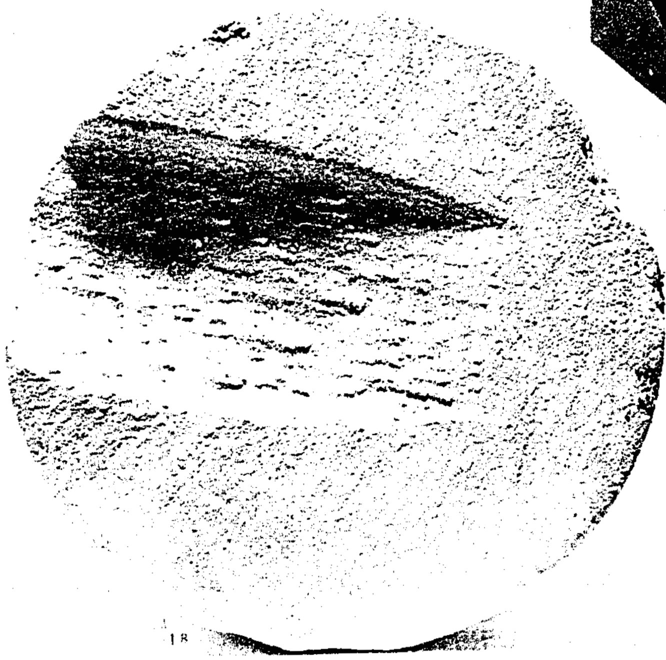
Erosion With Sediment-Free Water - Sample 29-8-8



A. 4 hour test at 20 fps removed 5.2cc of sandstone. Sediment concentration - 214 ppm.



B. 4 hour test at 30 fps removed 38.1cc of sandstone Sediment concentration - 911 ppm.



C. 4 hour test at 40 fps removed 52.5 cc of sandstone Sediment concentration - 632 ppm.

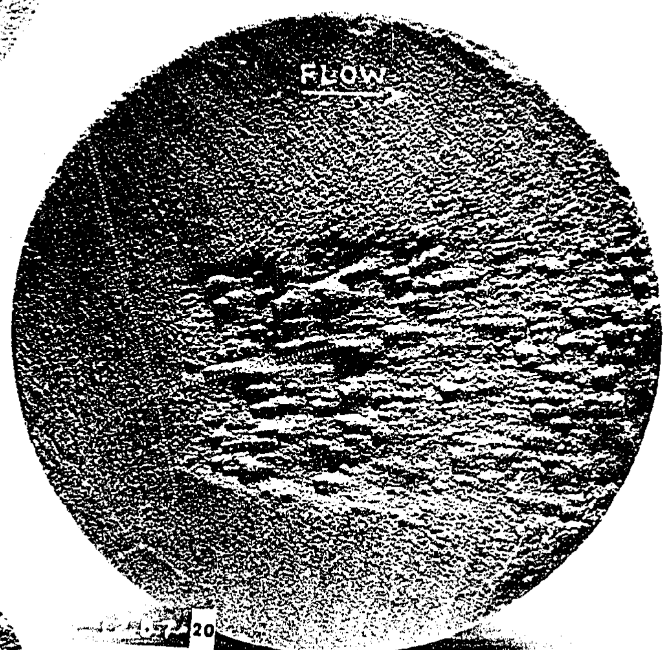
GLEN CANYON SANDSTONE EROSION STUDIES

Erosion With Sediment-Laden Water-Ordinary Commercial Sand

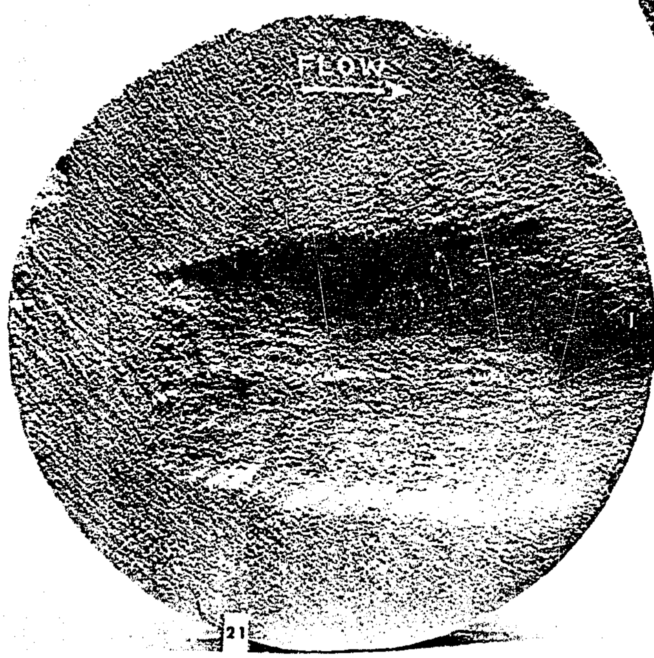
Sample 33-7-126

Figure 5
Report Hyd 423

A. 4 hour test at 20 fps.
produced slight erosion.
Sediment concentration - 1, 220 ppm



B. 4 hour test at 30 fps.
removed 3.0cc of sandstone
Sediment concentration-2, 010 ppm.

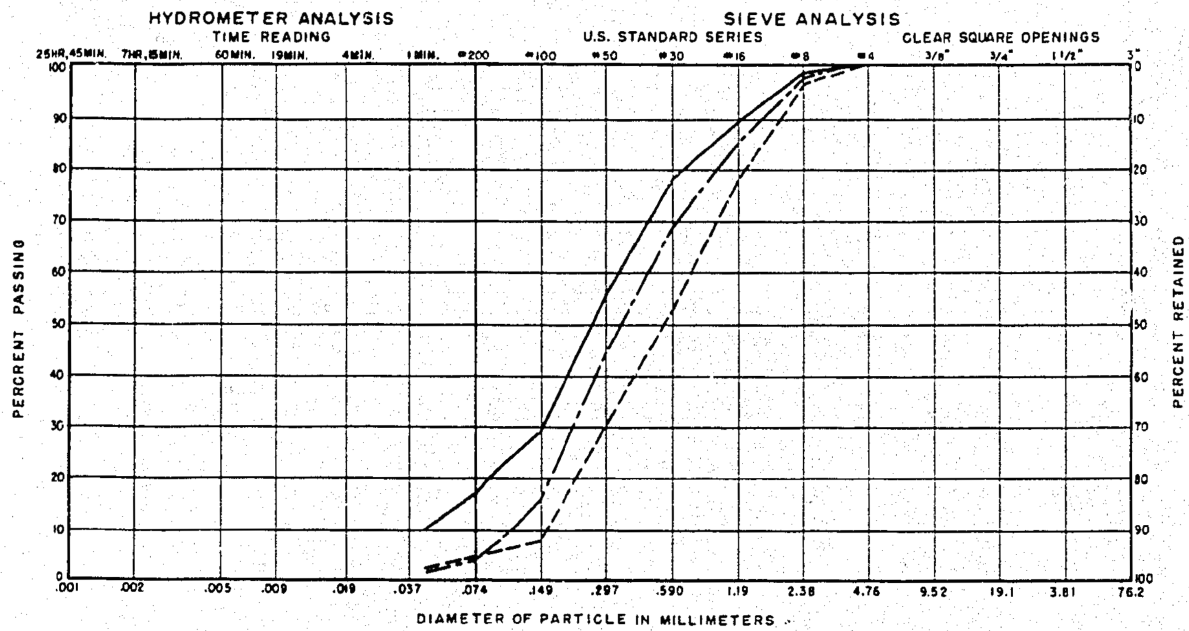


C. 4 hour test at 40 fps removed 25. 5cc of sandstone
Sediment concentration-2, 370 ppm.

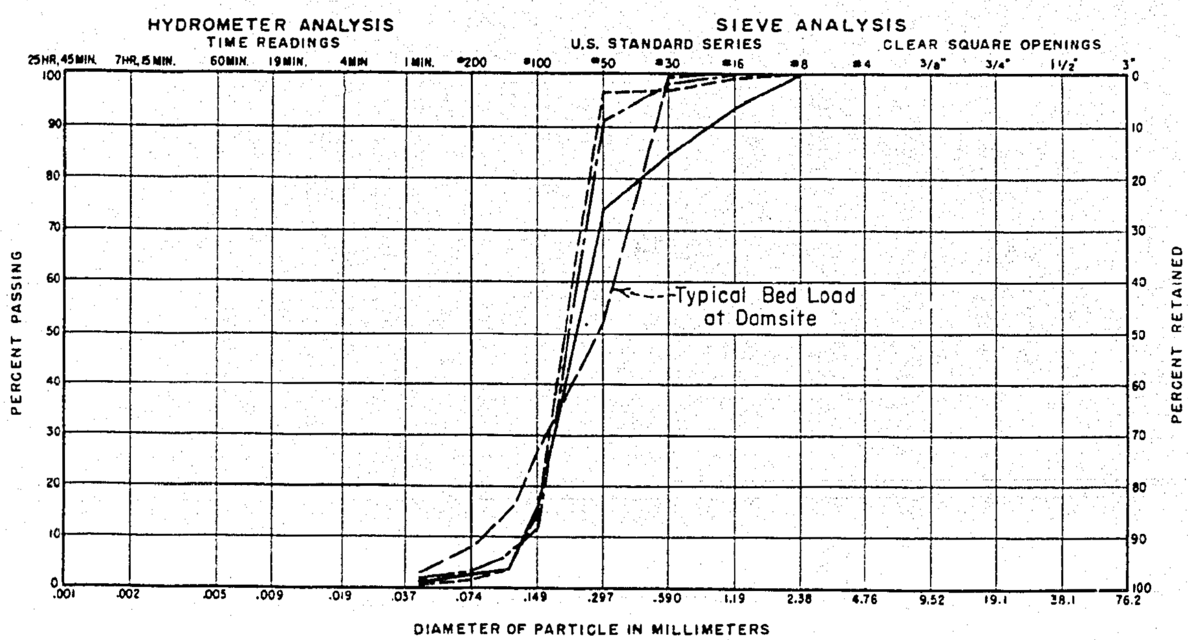
GLEN CANYON SANDSTONE EROSION STUDIES

Erosion With Sediment-Laden Water - Fine Grain Sand
Similar to that at Glen Canyon Damsite

Sample 33-7-126



A - TESTS WITH COMMERCIAL SAND



B - TESTS WITH FINE SAND

Flow velocity 20 fps
Flow velocity 30 fps
Flow velocity 40 fps

GLEN CANYON SANDSTONE EROSION STUDIES

SIEVE ANALYSES OF SEDIMENT COLLECTED DURING TEST RUNS

GPO 843742