UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC FLUME TESTS USING BENTONITE TO REDUCE SEEPAGE

Hydraulic Laboratory Report No. Hyd.-417

DIVISION OF ENGINEERING LABORATORIES

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HYDRAULIC FLUME TESTS USING BENTONITE TO REDUCE SEEPAGE

INTRODUCTION

The investigations described in this report were performed as a part of the Bureau of Reclamation Lower-cost Canal Lining Program. The testing was done by T. J. Rhone and R. A. Dodge under the direction of E. J. Carlson. The test facilities were located in the Hydraulic Laboratory at the Denver Federal Center near Denver, Colorado.

The phase of the program described in this report was mainly concerned with determining the effectiveness of using dispersed bentonite in flowing water as a means of reducing seepage in two sandy type earth materials.

TEST EQUIPMENT AND PROCEDURE

The tests were performed in a 1-foot-wide, 2-foot-deep, 30-foot-long recirculating flume, Figure 1. Located near the downstream end of the flume was a 6-foot-long section 1-1/2 feet deeper than the remainder of the flume in which the test soil was placed. The seepage outlet was located on the floor of this section and connected to a 1-inch pipe, the outlet of which was at the same elevation as the top of the sand bed. A 15-inch-thick layer of the soil was placed in the test section on top of a gravel-sand reverse filter.

Water was placed in the flume by backfilling through the seepage pipe. This served to remove most of the air from the soil in the test section. Most of the tests were made with the water 1 foot deep over the test section. However, some runs were made in which the depth was either 3/4 of a foot or 1-1/4 feet; the depth being adjusted by a tailgate at the downstream end of the flume. The first tests in each series were made with the water ponded in the flume. After a more or less constant seepage rate had been attained, the pump was turned on and a series of measurements made in which the water was flowing with a velocity of 0.7 foot per second. When a constant seepage rate was reached with the flowing clean water, enough bentonite slurry was added to the flow to provide about a 1 percent bentonite concentration in the water. With the water-bentonite mixture the flume was operated continously for several days and records made of the seepage rate, specific gravity, and temperature of the flume water and the effluent or seepage water, Figure 2.

DESCRIPTION OF TESTS

Four tests are described in this report, two using a fine grain uniform sand and two using a dune sand obtained from the Horse Creek Lateral near Morrill, Nebraska.

Uniform Fine Grain Sand (Run No. 1)

The fine grain sand used in the first tests had a sieve analysis as follows:

Sieve size	Percent passing
No. 16	100
No. 30	95
No. 40	84
No. 50	63
No. 100	7
No. 200	1

The sand was placed over the reverse filter to a depth of 1.25 feet. In addition, a 2-inch layer of the sand was placed on the floor of the flume upstream and downstream from the test section. The flume was backfilled with water through the seepage pipe to a depth of 1 foot.

The initial seepage rate through this test section both in the ponded state and with the water flowing with a velocity of 0.70 foot per second was 18.5 cubic feet per square foot per day* (refer to Figure 2 for a graphical presentation of this test).

The bentonite slurry was prepared by mixing 63 pounds of Volclay (sodium base) bentonite in about 830 pounds of water; this formed a thixotropy that was easily made fluid when placed in the flume water. As soon as the slurry was prepared, it was added to the flume water which resulted in a bentonite concentration of 0.95 percent. Almost immediately the seepage rate began to decline, and within 2-1/2 hours it had dropped to zero. Just before the seepage ceased the bentonite concentration of the seepage water was about 0.1 percent. Inspection of the surface of the sand bed showed that a fine layer of bentonite had been deposited and that this filter cake was responsible for the seepage reduction. When the filter cake was scraped off of the sand bed, the seepage rate increased to about 11.7 cfd.

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*The unit employed for expressing seepage rate from canals is cubic feet per square foot per day. To avoid repetition of this lengthy term, the abbreviation cfd will be used throughout this report to express this unit.

During the following 3 hours the seepage reduced to 7-1/2 cfd. During the same time interval the bentonite concentration of the seepage water increased to about 0.85 percent while the concentration of the flume water had dropped to about 0.92 percent.

During the next 17-hour period the seepage rate further reduced to 4 cfd. At the end of this period, which represented 25 hours of continuous running after the initial introduction of bentonite, a filter cake was again scraped from the sand bed. Immediately the seepage rate increased to 10.5 cfd. At this time the bentonite concentration of the flume water was 0.93 percent and of the seepage water 0.82 percent. For the next 6 hours seepage slowly reduced to 9.5 cfd. When the sand bed was scraped at the end of this period, the seepage rate again increased to 10.25 cfd. The bentonite concentrations of the seepage water and of the flume water were both about 0.9 percent.

During the next 18-hour interval the seepage was stopped by closing a valve in the seepage line, but the flow of the flume water continued. At the end of this interval the seepage line was opened and the seepage rate had increased slightly to 10.5 cfd. However, within 2-1/2 hours the seepage dropped to 7.75 cfd. When the sand bed was scraped to remove the filter cake, the seepage rate increased to 11.0 cfd. At this time the bentonite concentration in both the flume water and the seepage water was constant at 0.85 percent.

For the next phase of this test the effective head on the sand bed was reduced to 6 inches by raising the outlet of the seepage line. The seepage rate immediately reduced to 5.5 cfd. During the next 18 hours while the effective head was maintained at 6 inches, the seepage rate gradually dropped to 4.5 cfd. At the end of this period the effective head was increased to 12 inches, resulting in a parallel increase in the seepage rate to 10.8 cfd. Scraping the sand bed to remove the filter cake increased the seepage rate to 11.0 cfd. The bentonite concentration in the flume water and seepage water was about 0.83 percent at this time.

To reform a definite filter cake, additional bentonite slurry was added just upstream from the test section; the seepage rate rapidly dropped to zero. The water was then drained from the flume and the surface of the sand bed, which had a complete filter cake covering it, was dried by heat lamps. When dried, the filter cake had a tendency to curl, Figure 3.

The flume was then filled from the top to a 1-foot depth with tap water, with care being taken to insure that the dried filter cake was not washed. The flume flow was started at a velocity of 0.7 foot per second. The seepage rate at this time was 10.5 cfd, Figure 4. In 2 hours the seepage rate dropped to 9.0 cfd. The sand bed was scraped to remove the filter cake and the seepage rate increased to 14.0 cfd. In the next 2 hours the seepage rate dropped to 12.5 cfd and removal of the filter cake again increased it to 13.5 cfd. During the next 16 hours the seepage rate dropped to zero. Apparently the flowing water was picking up sufficient bentonite from the flume floor and from the pipe to form a dense filter cake. When this filter cake was removed, the seepage rate was 9.0 cfd. During another 24-hour interval the seepage rate again dropped to zero.

The total time that the flume had operated since the bentonite was first added was about 131 hours. It was found that removing the filter cake had probably caused mixing near the surface of some of the filter cake material and test sand. The combination was rather dense. Petrographic tests on sand taken from mid-depth in the test section showed that the sand contained about 0.24 percent montmorillonite by weight.

Uniform Fine Grain Sand (Run No. 2)

For the second test, fresh fine grain sand was placed in the flume on top of a reverse filter and compacted to maximum density. Clear water was placed in the flume by backfilling through the seepage line. At the start of the test the seepage rate was 21 cfd, Figure 5. This rate was comparatively steady for the first 4 hours. Then it started to increase, and after an additional 16-1/2 hours had reached a peak of 24 cfd. At this time a filter cake consisting of rust from the pipe and a small amount of silt began to form on the sand bed, and in 3 hours the seepage was reduced to 11 cfd. The filter cake was scraped from the sand bed and the seepage immediately increased to a rate of 25 cfd. Over the period of the next 3 hours the seepage rate slowly increased to 27 cfd. During the next 2-hour period a slight decrease was noted in the seepage rate, also a slight filter cake was forming on the test section. When this filter cake was removed the seepage rate began to increase. Over the next 17 hours the seepage rate increased to 38 cfd and then started to decrease. Over the next 6 hours the seepage rate fell to 35 cfd, and in 2 more hours had decreased to 31 cfd.

The sand bed was again scraped to remove the filter cake, and in the next 16 hours the seepage rate increased to 45 cfd. After a slight decrease to 43 cfd, the seepage rate increased to 46 cfd. The seepage rate remained constant at this figure for the next 7 hours, at which time the test with the plain water was discontinued. This represented a total of 78 hours' operation, during which period the seepage rate increased from 21 to 46 cfd.

Uniform Fine Grain Sand (Run No. 3)

The bentonite to be added to the flume water was prepared by mixing 60 pounds of Volclay bentonite in about 2,300 pounds of water. The solution was allowed to stand for 3 days before it was placed in the flume. This permitted the material to degrit, or for the coarser bentonite that does not stay in suspension, to settle out.

The degritted bentonite slurry when added to the flume water made an initial concentration of 0.60 percent suspended bentonite. The flume flow was started at a velocity of 0.70 foot per second, and seepage rate measurements and bentonite concentration of the flume water and seepage effluent were obtained in the same manner as in the previous test, Figure 6.

The first seepage measurement was made a short time after the bentonite slurry had been added to the flume water, but a filter cake had formed on the sand bed and the seepage rate was only 6 cfd, and within 2 hours the seepage stopped. The filter cake that had formed on the sand bed differed from those which had formed in the previous test in that it had the appearance of a gel rather than fine clay layer. This gel was easily removed or worked back into suspension by gently stirring the deposits of gel.

After the filter cake had been removed, the seepage rate increased to 22.5 cfd. During this initial 6-hour period the bentonite concentration in the flume water had reduced from 0.60 to 0.55 percent, while the concentration of the effluent increased from zero to 0.20 percent.

During the next 44 hours the seepage rate decreased from 22.5 cfd to 4 cfd. This reduction was rapid at first. In the first 5 hours it dropped to 12.5 cfd, and in the next 39 hours it dropped to 4 cfd. In this same time interval the bentonite concentration of the flume water decreased from 0.55 to 0.38 percent, and the bentonite concentration of the effluent increased to 0.50 percent in the first 2 hours and then slowly decreased to 0.36 percent.

At the end of a total of 47 hours' operation the filter cake was again removed and the seepage immediately increased to 22 cfd. This also increased the bentonite concentration of the effluent to 0.43 percent and of the flume water to 0.40 percent. During the next 6 hours the seepage rate slowly decreased to about 19.5 cfd. The bentonite concentration of both the flume water and seepage effluent stabilized at 0.40 percent.

The flume flow was continued for an additional 88 hours with the valve in the seepage line closed. The reason for this was to determine if the bentonite mixture that had penetrated the test section would flocculate under quiescent conditions and fill the voids in the sand. At the end of this period the valve was reopened and the seepage rate was found to be 20 cfd, a slight increase. The bentonite concentration of both the flume water and the seepage effluent had decreased to 0.31 percent. Immediately after opening the valve the seepage rate began to decline, and after 25 hours it had dropped to 13.5 cfd. The bentonite concentration of both the flume water and seepage effluent was constant at about 0.30 percent during this period.

During both of the above tests the temperature of the flume water was maintained between 27° and 31° C. The effluent temperature usually averaged about 2° lower than that of the flume water.

Summary

In the two tests with the fine grain sand and bentonite in the flume water the initial seepage rates were 18.5 cfd in the first test and 21.5 cfd in the second test.

In the first test the bentonite slurry was added to the flume water without degritting, and it soon caused a filter cake to form on the sand beds, which stopped the seepage. The filter cake could be removed by scraping the sand bed, and after removing, the seepage rate always increased.

During the 77-hour run of this test, the seepage rate showed an overall reduction from the initial 18.5 cfd to 11 cfd.

Petrographic tests made on sand removed from mid-depth in the test bed showed that it contained 0.24 percent bentonite.

In the second test the flume operated 78 hours with the clear water before the bentonite slurry was added, and in that period the seepage rate increased to 46 cfd. The run with the plain water was similar to the previous runs in that periodically, the seepage rate decreased and when the sufrace of the test section was scraped the seepage rate returned to its former rate. With the plain water the filter cake was made up of rust particles from the pipe and fine sediment particles picked up from the flume floor by the flow. These particles were then deposited on the test section by the action of the seepage flow.

The bentonite slurry for the second test was allowed to stand 72 hours for degritting before it was added to the flume flow. Although the solution was degritted, a filter cake formed on the test bed, but it was in the fórm of a gel that was easily worked back into solution. Even so, the first and largest seepage reading after the bentonite was added was 22 cfd. In the 168-hour test period this seepage rate showed an overall reduction to 13.5 cfd.

Chemical tests to determine the bentonite concentration in the sand at various depths showed that only 0.001 percent bentonite remained in the surface sand and only 1 inch below the surface this concentration had dropped to 0.00004 percent. At 2-1/2 inches below the surface there was no bentonite remaining in the sand.

Horse Creek Lateral Sand (Run No. 1)

The sieve analysis of the Horse Creek Lateral sand is as follows:

Sieve size	Percent passing
No. 16	100
No. 30	99
No. 40	93
No. 50	87
No. 100	41
No. 200	12

The mechanical analysis of this material indicated that it would form a denser section than the uniform grain laboratory sand and the test runs confirmed this.

The soil was placed in the test section in 2-inch layers, each layer being tamped so as to attain near maximum compaction. The water surface was brought up to operating level by slowly backfilling through the seepage line.

The initial seepage rate through this material was only 0.5 cfd. This rate was fairly constant for 26 hours, during which the flume water was flowing at a velocity of 0.7 foot per second.

The bentonite slurry was allowed to degrit for 48 hours before it was added to the flume water. By the time the bentonite slurry was thoroughly mixed into the flume water, a thin layer of gel had formed on the sand bed. This layer was easily worked back into suspension by gently rubbing the surface of the gel. The bentonite concentration of the flume water was about 1 percent during this period. As soon as the gel layer had been removed the seepage rate increased to 1.9 cfd.

During the subsequent 24-hour period the seepage rate slowly decreased to 0.6 cfd. In the same time interval the bentonite concentration of the flume water dropped to 0.9 percent and the gel layer reformed on the test bed.

The gel layer was removed but apparently some of the gel had penetrated into the sand because the seepage stopped entirely. There was no seepage under this condition for the next 1.5 hours. The water depth on the sand bed was then increased to 1.5 feet; this started the seepage but at the very slow rate of 0.2 cfd. This seepage rate was steady for the next 3 hours.

At the same time the flume flow was stopped and the seepage valve closed in order to pond the test section. After 17 hours of ponding the flume flow was started and the seepage valve opened. For an unknown reason the seepage had increased to almost 4.0 cfd. The seepage remained near this rate for the next 5 hours, and then in the subsequent 3 hours it slowly dropped to about 3.5 cfd.

The sand bed was scraped to remove a gel layer that had formed, and in the next 5 hours the seepage rate dropped to 1.7 cfd.

The flume flow was stopped, and with the seepage valve closed, the test section was ponded for 17 hours. With the flume flow shut off the seepage valve was reopened at the end of this period. The seepage rate was 1.1 cfd. When the flume was started at a velocity of 0.7 foot per second the seepage rate jumped up to 5.5 cfd.

Horse Creek Lateral Sand (Run No. 2)

A new test section was placed in the flume with fresh soil. The water was brought up to operating level by filling from the top instead of backfilling. This was done because attempts to add the water by backfilling through the seepage line had been unsuccessful, probably due to the density of the test section. There was a period of 72 hours before the seepage started. During this time the water had been ponded in the flume rather than flowing. The seepage was very slight at first, the rate being less than 0.03 cfd. The flume was allowed to remain ponded with the seepage valve open for 72 hours. At the end of the time the seepage rate was even smaller so the test was discontinued and the sand removed from the test section.

Horse Creek Lateral Sand (Run No. 3)

The sand from Run No. 2 was allowed to air-dry and an additional 300 pounds of fresh material was thoroughly mixed into it. This reworked sand was placed in the test section with considerably less compaction than had been used in the previous tests.

The flume was filled with clear water by backfilling through the seepage line; this process took 4 days, indicating that the sand bed was quite dense. The water was allowed to stand ponded for 24 hours. At the end of this period, the seepage rate was less than 0.1 cfd. The water was allowed to stand in the flume for 6 days, during which period the seepage rate remained materially the same.

The bentonite slurry was prepared by mixing 78 pounds of Volclay bentonite in 2,700 pounds of water. This slurry was allowed to stand for 4 days before it was mixed with the flume water.

Flow in the flume was started at a velocity of 0.7 foot per second. Similarly, as in Run No. 1, a gel layer formed on the sand bed which was easily worked into suspension. The seepage rate at this time was practically nil and in the next 24 hours showed only a slight increase. The seepage rate at this time was only 0.06 cfd. The bentonite concentration of the flume was 0.7 percent and the seepage effluent was clear, indicating that the bentonite solution had not replaced the clear water in the sand voids. During the subsequent 50-hour period these figures remained substantially the same.

For the next 96-hour period the flume was ponded and the seepage line left open. At the end of this period the seepage rate was still about 0.06 cfd. The bentonite concentration in the flume water was 0.7 percent and the effluent still showed no sign of bentonite.

The flume was allowed to run for the next 10 days with occasional periods of ponding. During this operating period any gel layer in the sand bed was periodically removed. The seepage rates and bentonite concentration of the flume and seepage effluent were regularly obtained. At the end of this period the seepage rate had reduced to about 0.03 cfd. The bentonite concentration was still 0.7 percent and the seepage effluent showed only faint signs of containing bentonite. At this time the testing was discontinued.

Summary

Three separate tests were performed with the Horse Creek Lateral sand. In the first the seepage rate showed an unexplicable tendency to materially increase. In the other two tests the seepage rate was so negligible that no definite results could be obtained.

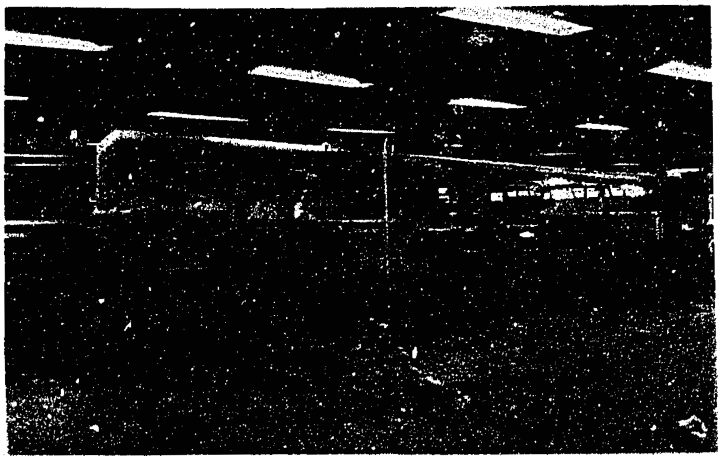
The tests showed that if this earth material was compacted the seepage rate would be very small, probably so small that seepage would not be a problem in a canal constructed of this compacted material.

Effect of Temperature

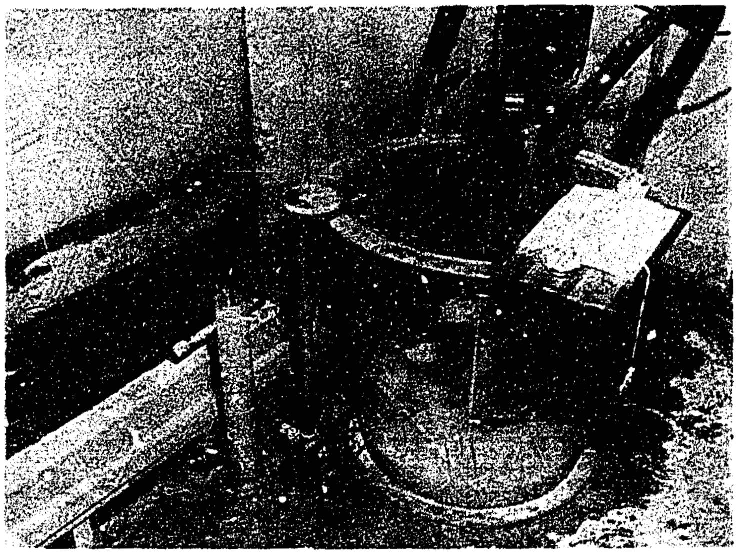
In all tests an attempt was made to correlate the effect of water temperature on the seepage rate. The temperature of the flume water varied from 18° to 45° C. The seepage effluent had the same temperature range with a slight time lag. At no time during the tests was there any obvious relation between the water temperature and seepage rate. However, it was noticed that the amount of dissolved oxygen, and possible air pockets in the test soil, was affected by the water temperature. It would probably be profitable to determine the effect of air pockets on the seepage rate by using a fluid that would not absorb or release oxygen during temperature variation.

CONCLUSIONS

For the particular earth materials used, the tests proved rather conclusively that the bentonite caused a reduction in seepage by forming a filter cake on the surface of the earth material and not by filling the voids at any appreciable depth under the surface. When the filter cake was removed the seepage rate increased to a rate almost as high as it was before the bentonite was added. Removing the filter cake disturbs the soil surface and causes some reduction in the seepage by disturbing the soil grains and possibly mixing some of the bentonite filter cake into the soil surface.



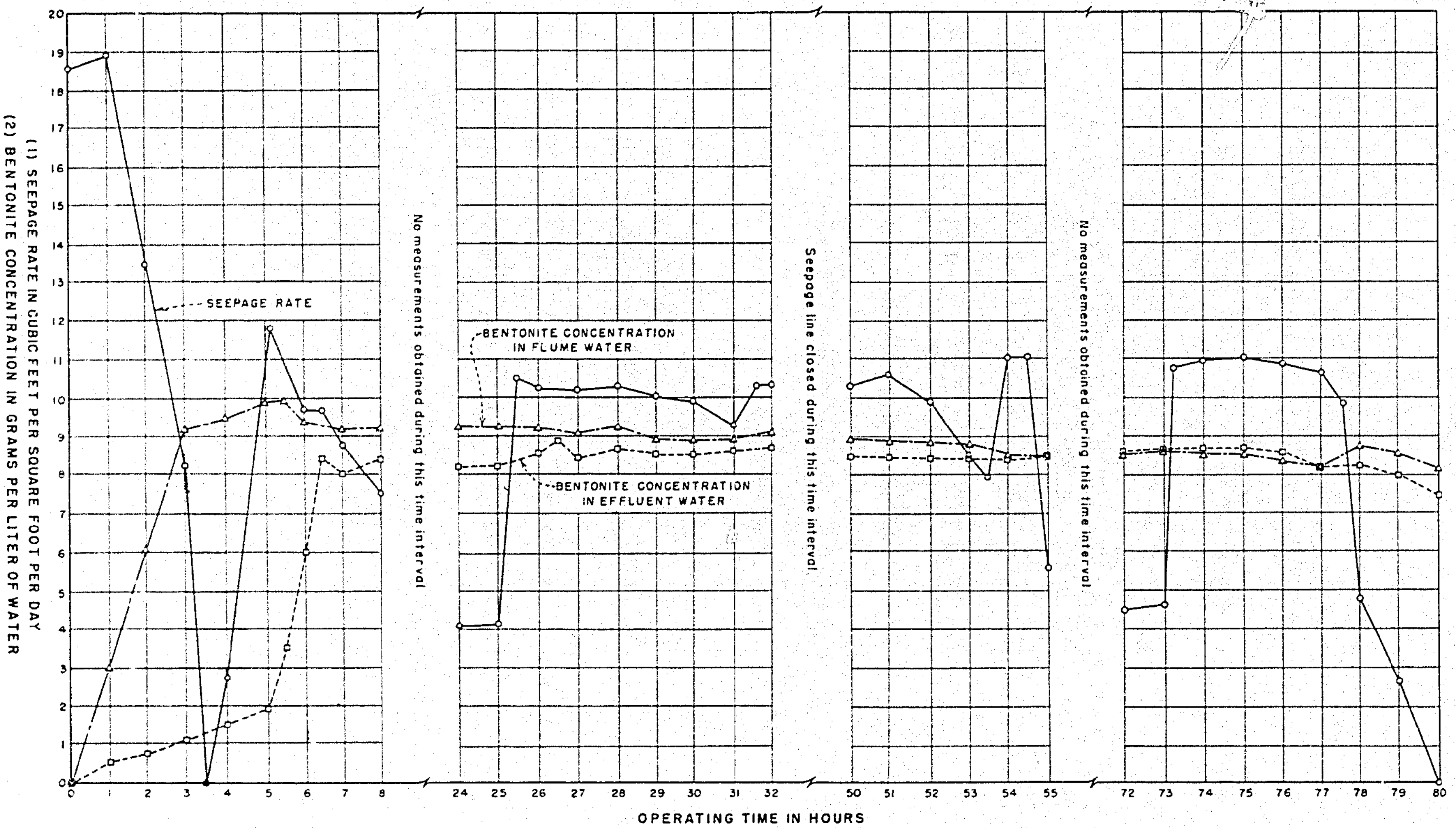
Flume used for tests
Length 30 feet width 1 foot
Soil compartment 6 by 1.5 by 1 feet



Seepage outlet from soil compartment with overflow into plastic tank

SEEPAGE REDUCTION TESTS

Using Dispersed Bentonite
Test Equipment



SEEPAGE REDUCTION TESTS
USING DISPERSED BENTONITE
RESULTS FROM TEST 1 - RUN 1

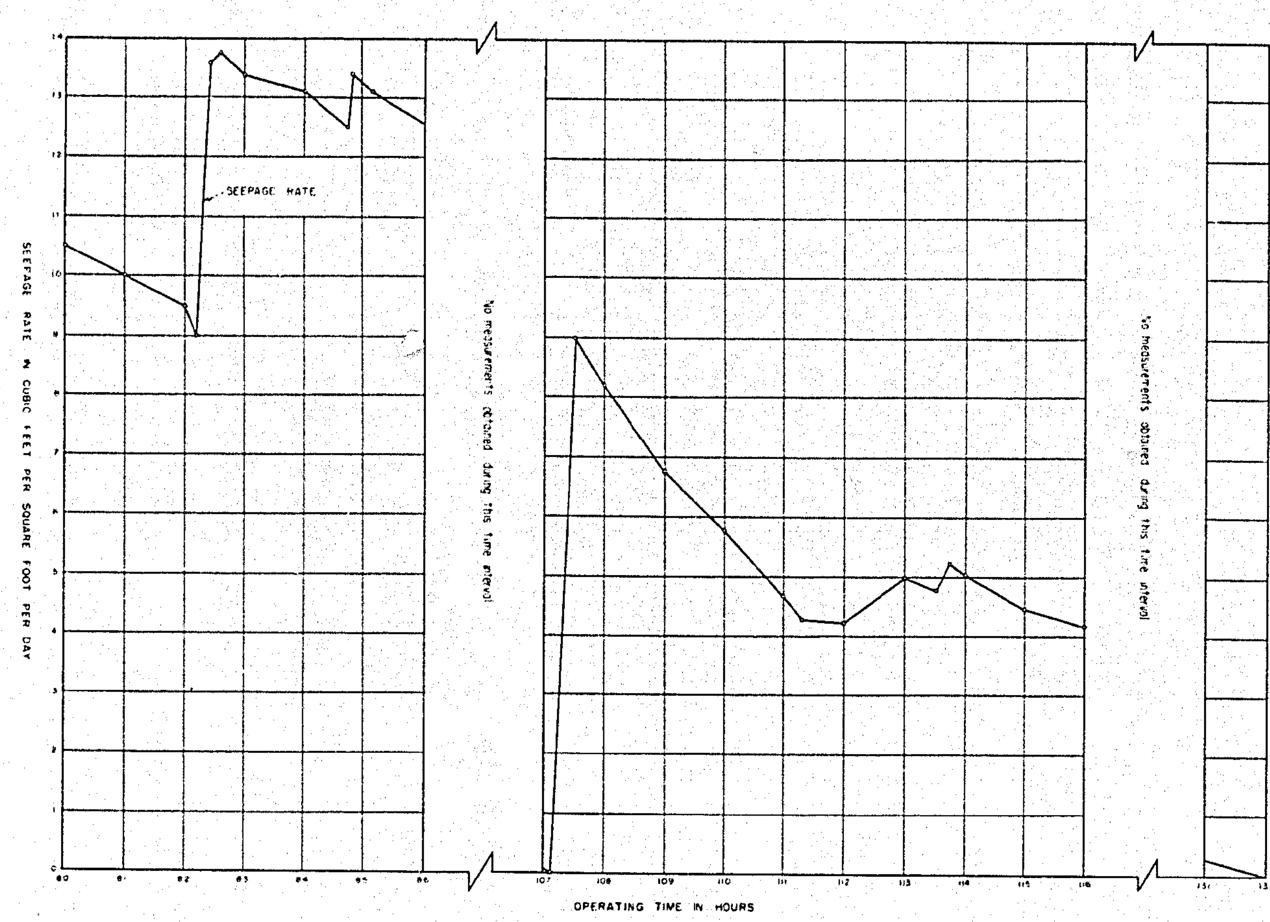
FIGURE 2
REPORT HYD. 417

Partially dried bentonite filter cake on test soil

Completely dried bentonite filter cake on test soil

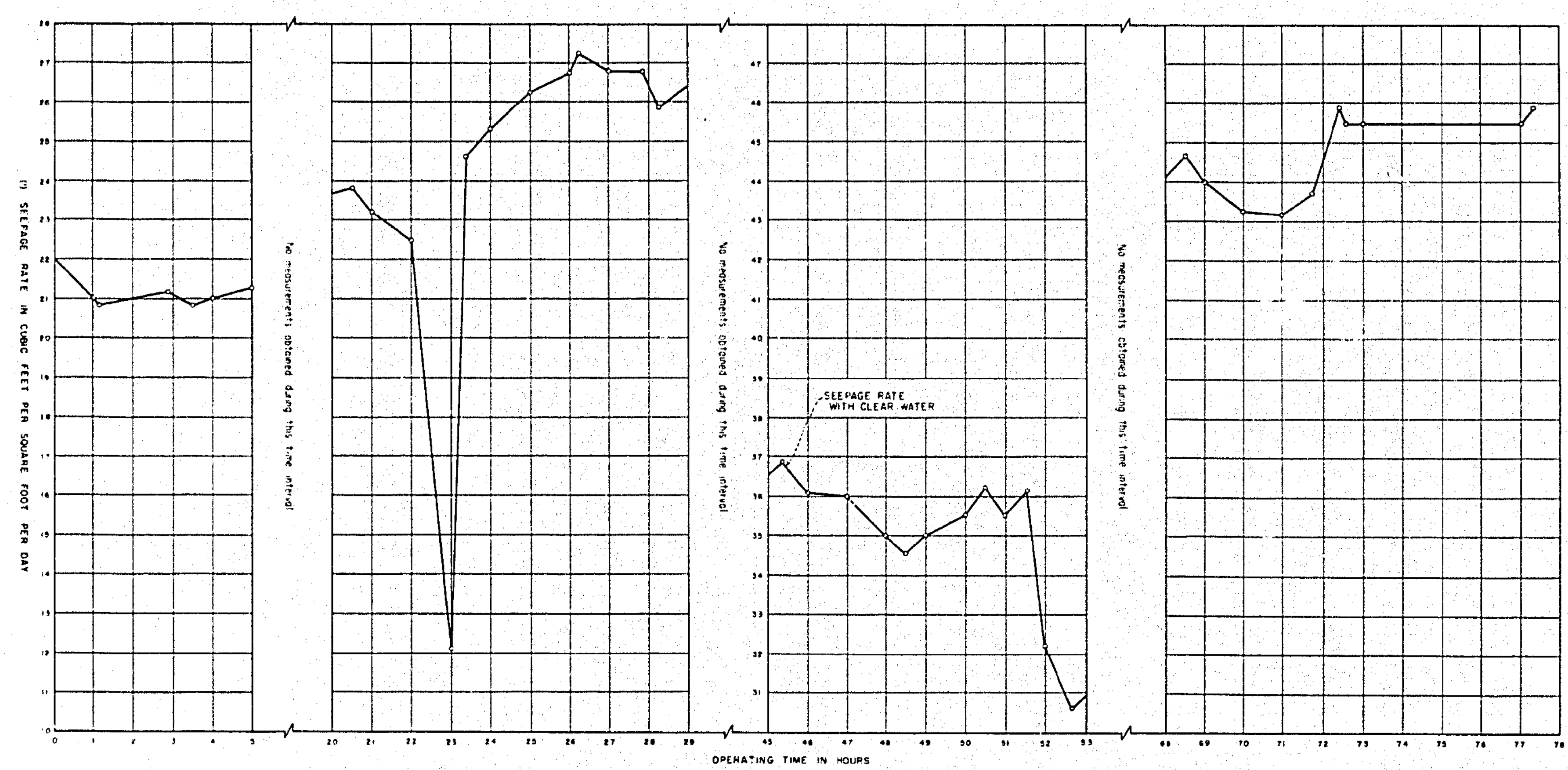
SEEPAGE REDUCTION TESTS

Using Dispersed Bentonite Filter Cake in Test Section



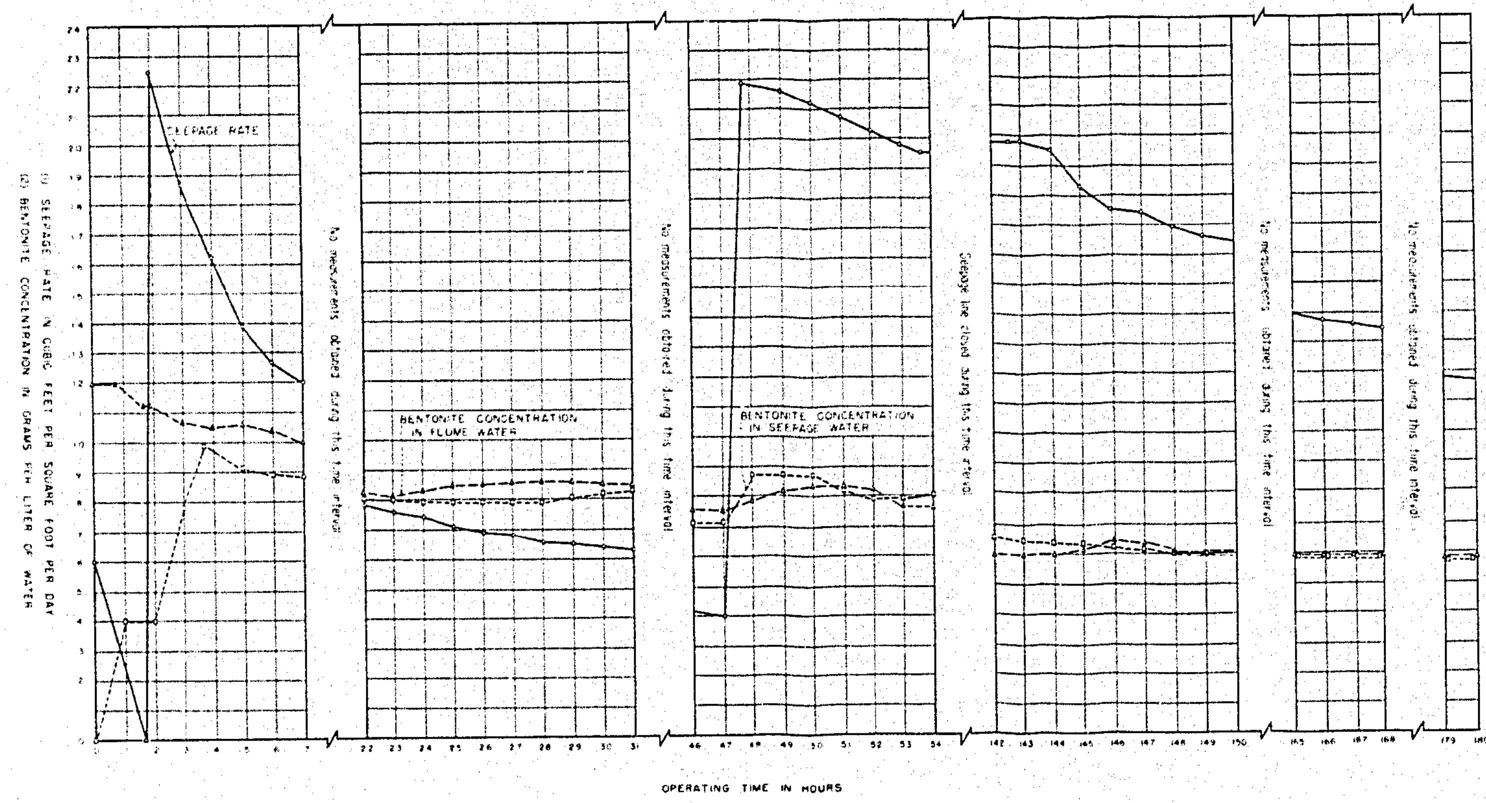
SEEPAGE REDUCTION TESTS
USING DISPERSED BENTONITE
RESULTS FROM TEST 1-RUN 1

FIGURE 4
REPORT HYD 417



SEEPAGE REDUCTION TESTS
USING DISPERSED BENTONITE
RESULTS FROM TEST 1-RUN 2

FIGURE 5
REPORT HYD 417



SEEPAGE REDUCTION TESTS
USING DISPERSED BENTONITE
RESULTS FROM TEST 1-RUN 3

FIGURE 6
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