PIPING AND EROSION TESTS AT CONNER RUN DAM

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ABSTRACT: Tests are conducted on the filtration characteristics of the chimney drain and on the erodibility of the upstream clay blanket at Conner Run Dam. The test results are discussed and conclusions drawn regarding the potential of compacted clay to erode internally and on the validity of current filter criteria to prevent piping from occurring. The beneficial effects of fly ash in the reservoir to control piping of clay blankets is also evaluated.

INTRODUCTION

During design studies for raising Conner Run Dam, it was discovered that the existing chimney drain did not meet the requirements of current filter criteria. In light of this finding, the filtering characteristics of the chimney drain were investigated by conducting specific filtration tests. This paper describes the tests that were conducted, discusses the test results, and draws conclusions regarding the effects of fly ash in the reservoir on potential piping and erodability of the compacted clay blanket.

CONNER RUN DAM

Conner Run Dam is located about 12 km south of Moundsville, West Virginia, near the Ohio River. The embankment serves to impound fly ash waste pumped in as a slurry at the head of the reservoir from the nearby Mitchell and Kammer power plants. The dam is a zoned earth fill compacted in layers under controlled conditions. A cross section of the existing dam and the proposed raising is shown in Fig. 1. The upstream clay blanket is on a 1V:2H slope and is 9.2-m thick. Thus, the maximum hydraulic gradient at peak flood stage, which corresponds to a reservoir head of 55 m, is approximately 6.

The ranges in particle size distribution of samples from the Kammer boiler slag used in the chimney drain are shown in Fig. 2. According to Sherard and Dunnigan (1985), the D_{15} of the filter should be less than about 0.5–0.6 mm to prevent internal erosion from occurring at concentrated leaks in clay cores of earth dams. A D_{15} size greater than about 0.1 mm was calculated as necessary to avoid potential buildup of pore pressures in the chimney drain. The Kammer boiler slag met the latter criterion but it did not meet the Sherard and Dunnigan filter criterion.

LABORATORY TESTS

Types of Tests

Two types of tests were conducted: (1) Piping tests on intact samples of compacted clay to determine the hydraulic gradient at which piping would

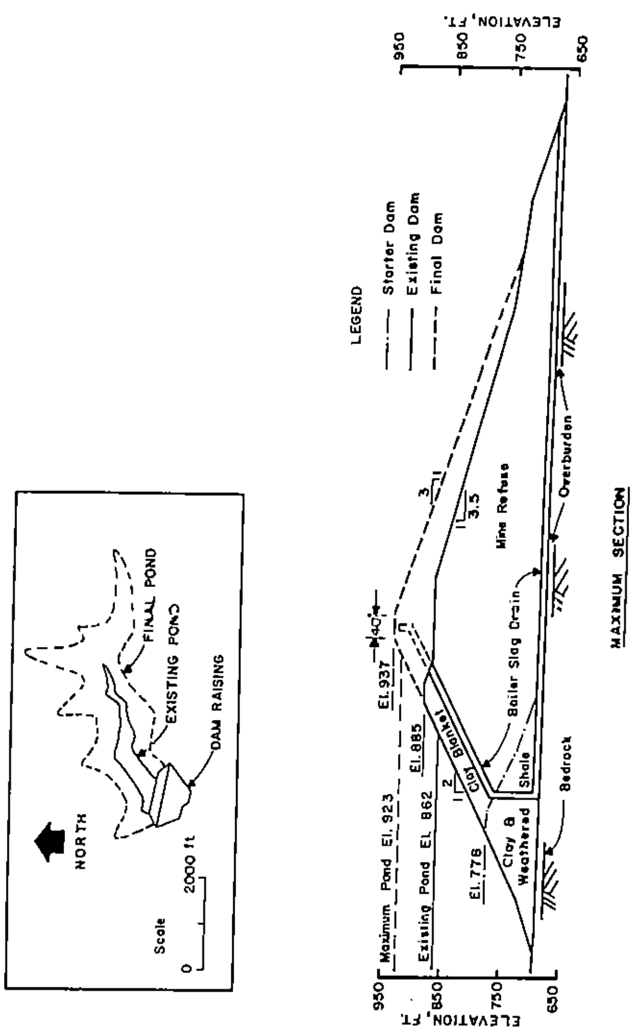

FIG. 1. Cross Section of Conner Run Dam

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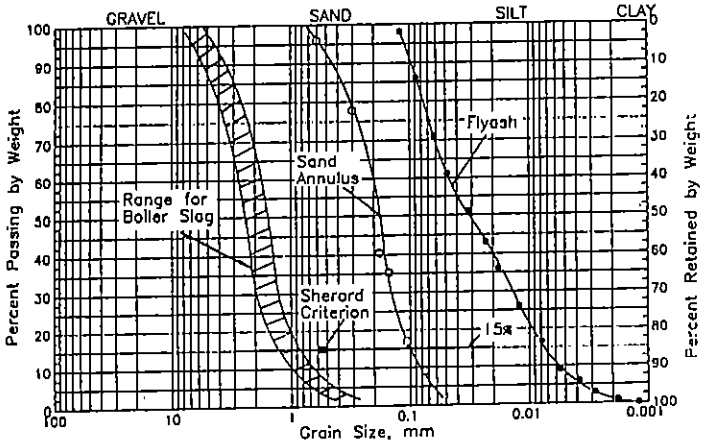

FIG. 2. Particle Size Distribution Curves of Fly Ash and Filter Materials

TABLE 1. Characteristics of Upstream Clay Blanket

Sample number (1)	Test pit (2)	Color (3)	Specific gravity (4)	Liquid limit (5)	Plasticity index (6)
S-3643	18A	Red	2.82	47	50
S-3631	7C	Yellow	2.77	40	16
S-3658	34C	Gray	2.82	37	14

be initiated and, once piping started, if the boiler slag would prevent its progressive development to form concentrated leaks; and (2) pinhole tests to establish whether the boiler slag would arrest internal erosion from progressing if concentrated leaks developed from causes other than piping. If the intact clay liner continued to pipe at hydraulic gradients comparable to the peak value of 6.0 anticipated in the dam, extensive remedial measures would be required. On the other hand, if the boiler slag arrested internal erosion in the pinhole tests, at water pressures corresponding to peak flood stage (about 550 kPa), then remedial measures would not be required.

Characteristics of Upstream Blanket

The upstream clay blanket consisted of compacted weathered shale. Clay samples taken from three test pits had distinct colors. Table 1 shows typical specific gravity and Atterberg limit test results of these samples. In general, the gray clay showed the lowest plasticity and the red clay was the most plastic. The results of standard Proctor tests performed on these clay samples are plotted in Fig. 3.

APPARATUS AND PROCEDURE

Piping Tests

As shown schematically in Fig. 4(*a*), a device was made to hold a compacted clay specimen 15 cm in diameter and 10-cm high. The boiler slag

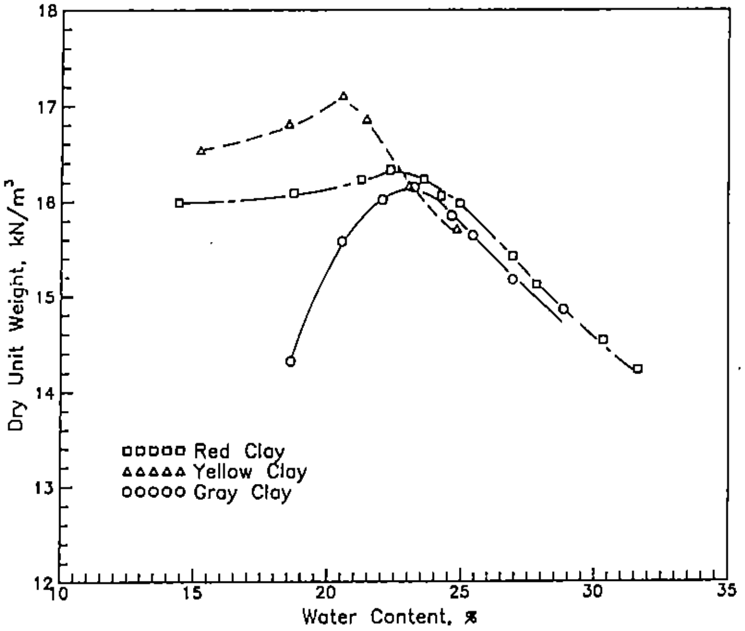

FIG. 3. Results of Standard Proctor Tests on Weathered Clay Shale

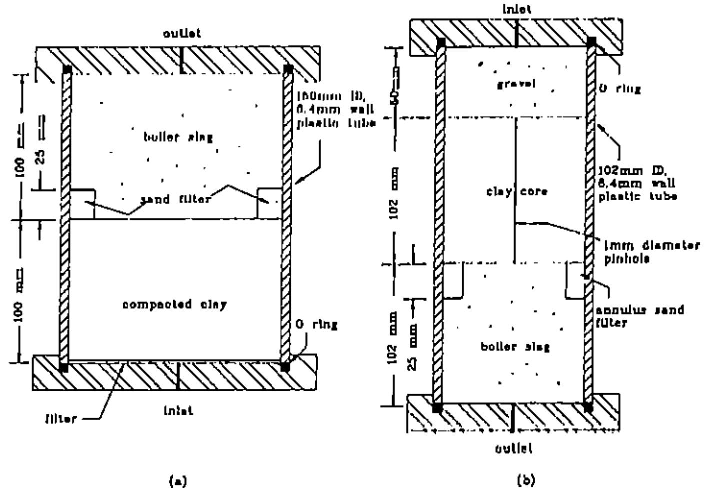

FIG. 4. Schematic Diagrams of Apparatus Used for: (*a*) Piping Tests; (*b*) Pinhole Tests

filter is also 10-cm high. The setup was essentially the same as that of a constant head permeability test. The system was capable of applying high gradients by using air pressure up to 1,000 kPa. A sand annulus filter was placed between the clay specimen and the boiler slag to prevent piping along the cell wall. A uniform fine sand with a D_{15} of 0.1 mm (Fig. 2) was used for this purpose. The boiler slag was compacted to a relative density of about 90% in all the tests, which approximated the average in situ placement density of 16.8 kN/m^3.

Pin-Hole Tests

The design of the pinhole apparatus follows that used by Sherard and Dunnigan (1985). Fig. 4(*b*) shows the dimensions and cross-sectional view of the testing device. The system was set up so that water pressure as high as 700 kPa could be applied and maintained at the inlet. On top of the clay 2 in. of gravel was placed to diffuse the flow of water. An annulus sand filter similar to that in the piping test device was also used in the pinhole apparatus. A 1-mm diameter pinhole was punched through the center of the specimen with an awl.

In all the piping and pinhole tests, the clay was compacted at water contents 1% less than standard Proctor optimum, which corresponded to the average water content obtained from construction control tests and from record samples. In both types of tests, two compaction efforts were utilized in preparing the clay specimens. In the initial tests, the clay was compacted to 95% of the maximum standard Proctor dry density (ASTM D698); in the remaining tests, the clay was compacted to 100% of the standard Proctor maximum density.

TEST RESULTS

Piping Tests

Although piping tests were conducted on intact samples of the three types of clay, the tests concentrated on the weathered gray shale because, due to its lower plasticity, it was found to be more susceptible to piping than the other clays. The essential results of these latter piping tests are given in Table 2. Replicate samples gave similar results. It is evident that increasing the compactive effort from 95% to 100% of standard Proctor resulted in a large increase in the piping resistance of the compacted clay.

A comparison of unit weights and textures of the samples compacted in the laboratory with Shelby tube samples taken from the dam showed that a compaction energy of 100% standard Proctor was representative of field conditions. For these samples a hydraulic gradient of 160 did not induce piping but a gradient of 240 did. Without the fine sand annulus, piping was always initiated and progressed along the cell wall; with the sand annulus, piping always started and remained within the central portion of the clay sample. Thus, the fine sand (Fig. 2) proved to be an excellent filter for the clay blanket materials. Significantly, once piping was initiated, the boiler slag did not prevent progressive erosion from occurring. It was concluded that, although the boiler slag did not act as a filter, seepage through the dam at maximum hydraulic gradients of about 6 would not cause piping in the upstream blanket provided the clay core remained intact.

TABLE 2. Results of Piping Tests on Intact Samples of Compacted Gray Shale

Compaction energy (1)	Hydraulic gradient at which piping occurred (2)
95% standard Proctor	> 40 but < 80
100% standard Proctor	> 160 but < 240

Pinhole Tests

At water pressures comparable to those that will be extent in the raised dam (about 550 kPa) internal erosion was immediately initiated in the pinhole tests even for specimens compacted with 100% Proctor energy. Although the differences in plasticity of the three clays were appreciable (Table 1) the differences in erodability were not very noticeable. Thus, while plasticity influenced the susceptibility to piping (removal of soil particles at exit) it did not alter the surface erodability characteristics significantly. The pinhole tests showed that the boiler slag would not arrest internal erosion if a concentrated leak developed. Thus, as it was considered unwise to assume that concentrated leaks would not develop in the clay core of the dam, it appeared that extensive remedial measures would have to be taken.

EFFECT OF FLY ASH IN RESERVOIR

Several potential remedial measures were considered, including dumping bags of bentonite pellets on the upstream face of the dam. This, in turn, indicated the need to ascertain the extent to which the fly ash in the reservoir was in contact with the upstream face of the dam.

Soundings of the elevation of the fly ash surface within the reservoir had been conducted at least once a year for the previous five years. These soundings indicated that the depth to the sediment fly ash surface or, alternately, the depth of clear water, normally varied between 4.5 and 6.0 m in the area of the reservoir immediately upstream of the dam.

Samples of the fly ash were obtained by dragging 5-gal buckets along the fly ash surface near the overflow structure just upstream of the dam. During inspection of the samples in the laboratory, it was observed that the fly ash seemed to be in a comparatively dense state. This raised a question about the actual degree of compactness of the fly ash in the reservoir.

Due to inherent difficulties in sampling fly ash, direct density measurements from undisturbed samples were ruled out. Instead, it was decided to bound the problem by estimating the range in densities of laboratory-prepared specimens. For the lower limit, a 50% fly ash/water suspension by weight, was slowly poured into a 1,000-cc glass cylinder and allowed to settle until the depth of clear water stabilized. The upper limit was determined by vibrating the cylinder for 5 min on a vibratory table. Vibration was repeated twice a day until the depth of clear water stabilized. For comparison, the density of the fly ash in the 5-gal buckets was also measured. The results, which are presented in Table 3, indicate that the fly ash in the reservoir is likely to have a void ratio ranging from 0.6 to 0.7—a relatively loose condition.

The fact that there was only 4.5–6.0 m of clear water in the reservoir at the upstream face of the dam raised questions about the potential for the fly

TABLE 3. Results of Tests to Estimate the Density of Fly Ash in the Reservoir

Sample number (1)	Description (2)	γ_{sat} (kN/m^3) (3)	w (%) (4)	Specific gravity (5)	e (6)
FA-1	Bucket	17.89	24.7	2.28	0.57
FA-2	Bucket	17.78	23.6	—	0.53
FA-3	Bucket	17.90	22.6	—	0.52
FA-4	Minimum γ	16.90	32.1	2.27	0.72
FA-5	Minimum γ	16.69	33.7	—	0.75
FA-6	Maximum γ	18.03	20.9	—	0.47

ash itself to seal concentrated leaks that might develop in the upstream blanket and/or to clog the boiler slag and thereby arrest progressive erosion. Additional pinhole tests were conducted to help answer these questions.

Additional Pinhole Tests

Specimens for additional pinhole tests were first prepared as before except that a 5-cm layer of loose fly ash was placed between the compacted clay and the boiler slag. When full reservoir pressure was applied, the fly ash passed freely through the boiler slag and internal erosion of the clay was almost as fast as before. In a separate test, a loose layer of fly ash was deposited upstream of the compacted clay and a fly ash/water slurry was superimposed on the system under a water head of 80 cm. This procedure simulated the manner in which the fly ash in the reservoir would make contact with the dam. A water pressure of 550 Kpa was then applied for 19 hours. No seepage was observed during this time period. Previously, the flow rate of clean water through the preformed pinhole under the same water head was approximately 30 cc/s. Upon dismantling the apparatus, the pinhole was found to be clogged and only the top 1.5 cm of the compacted clay appeared to be wetted. This result prompted an investigation of the extent to which water had penetrated the upstream blanket on the dam itself.

A boring drilled into the upstream clay blanket at Conner Run, beginning 30 cm above the water line, was found to be completely dry for its entire length of 11 m. The water contents of Shelby tube samples taken from this boring compared well with the placement water contents, indicating that the clay had not imbibed water in the four years that the reservoir has been at this level. This supports the results of the laboratory tests, which showed that fly ash clogged the pores in the compacted clay, thereby greatly reducing its permeability.

Experiences with Cardinal Dam I

Cardinal Dam I is a fly ash retention facility located near Brilliant, Ohio, approximately 30 mi north of Conner Run Dam. Seepage from the foundation drainage blanket and abutment seeps have been monitored since 1974, when the dam was completed. The reservoir level and seepage losses are plotted as a function of time in Fig. 5. The erratic fluctuations in seepage losses illustrated in this figure indicate that the flow rate is not controlled directly by the total head loss. An explanation of this apparent anomaly is that the fly ash is effectively plugging open joints and other defects in the rock formations along the periphery of the reservoir, thereby greatly reducing the permeability. For example, a stratum of fractured shale is located between elevations 960 and 962. As soon as the reservoir level reached elevation 960 a dramatic increase in flow rate was observed; however, when the reservoir reached elevation 980, the reduction in flow rate was just as dramatic. This is attributed to fly ash in the reservoir reaching the fractured shale stratum and clogging it. Had the reduction in flow rate been due to swelling of the shale, then the seepage losses would not continue to increase from 1981 on, when the reservoir level reached the elevation of the fractured shale, and the sharp reduction in seepage losses would not commence precisely when fly ash in the reservoir reached the fractured shale in 1983.

As there are no highly fractured rock strata in the abutments or reservoir slopes at Conner Run Dam, a dramatic reduction in seepage losses as fly

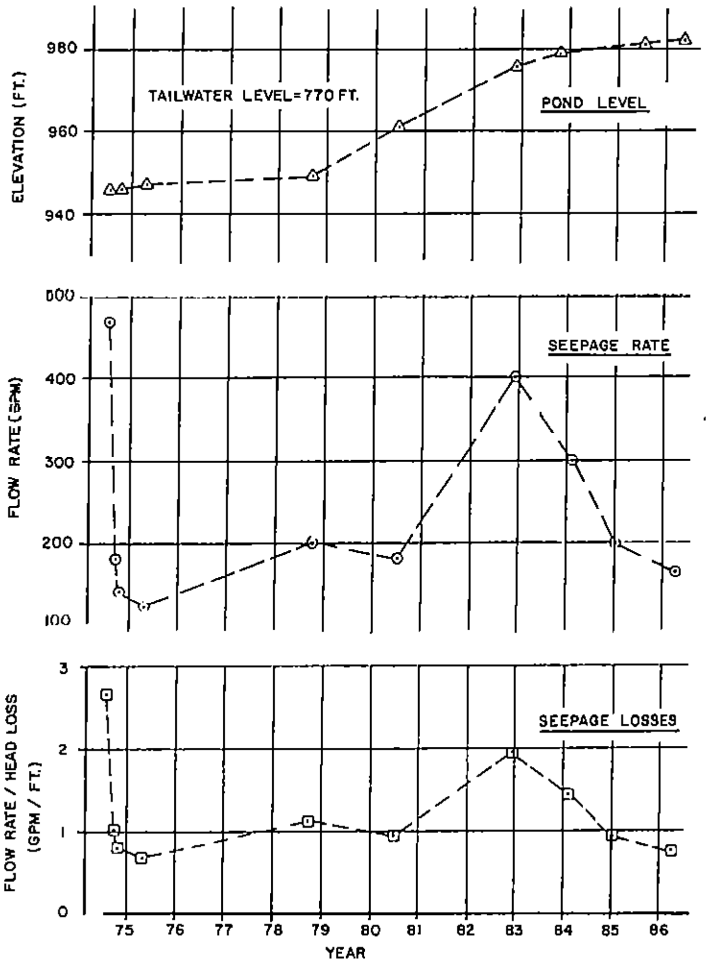

FIG. 5. Pond Level versus Seepage Losses, Cardinal Dam I

ash in the reservoir reached a particular elevation was not observed. However, the general trend is for the flow rate per unit of total head lost to decrease continuously with time. This is further evidence that fly ash in the reservoir is lining the side slopes, thereby effectively controlling the seepage losses.

SUMMARY AND CONCLUSIONS

Based on the test results and on experiences with Cardinal Dam I described herein, the following conclusions are drawn.

1. For the range in plasticities investigated ($13 < PI < 21$), the weathered clay shale with the lowest plasticity was the most susceptible to piping but plasticity had no apparent influence on the resistance to internal erosion.
2. The sand filter, which had a $D_{15} = 0.1$ mm, prevented piping from occurring at the interface between the clay sample and its container at hydraulic gradients (i) in excess of 240. Thus, this sand, which met the Sherard and Dunnigan criterion, proved to be an excellent filter.
3. In an intact condition, the moderately plastic clay core did not pipe until $40 < i < 80$, when the clay was compacted 1% dry of optimum at 95% standard Proctor energy, and until $160 < i < 240$, when the compaction energy was increased to 100% of standard Proctor. This is further evidence that compaction reduces the potential for piping significantly. As the maximum hydraulic gradients across the clay core at Conner Run ≈ 6, there is no danger that piping will develop provided the core remained intact.
4. The D_{15} size of the boiler slag ranged between 0.85 and 3.0 mm while the Sherard and Dunnigan criterion requires it to be less than 0.5:0.6 mm. In the pinhole tests, internal erosion commenced immediately, and was not arrested by the boiler slag filter, at upstream water pressures corresponding to a water head of 55 m (maximum reservoir level). Thus, the prediction that the Kammer boiler slag was too coarse to act as a filter was verified.
5. At the face of the dam, there was not more than 6 m of clear water above the sedimented fly ash surface. At a water head of 55 m, no internal erosion was noted in pinhole tests when the fly ash was placed upstream of the clay core, even after full water pressure was applied for 19 hours. Upon dismantling the apparatus, the pinhole was found to be clogged and only the top 1.5 cm of the clay core was found to be wetted. Thus, the permeability of the fly ash/clay system was more than an order of magnitude smaller when the fly ash was upstream of the compacted clay than when it was downstream.
6. Drilling into and sampling the existing upstream clay blanket at Conner Run Dam from the water line to a depth of 11 m (a vertical height corresponding to the thickness of the inclined blanket) showed the hole to be dry and the water contents of the samples to be comparable to the mean values of the placement water content. This confirmed the results of the laboratory tests, which showed that the fly ash clogged the pores in the compacted clay, thereby greatly reducing its permeability.
7. Monitoring of seepage losses at Cardinal Dam I (about 30 mi north of Conner Run) showed that fly ash in the pond effectively reduced seepage through a stratum of fractured shale in the right abutment. This action is precisely what was observed in the laboratory tests, in which fly ash completely clogged the 1-mm-diameter pinhole and prevented internal erosion from occurring at heads larger than those corresponding to maximum pool level behind the dam.
8. It was concluded that fly ash in the reservoir would effectively control potential concentrated leaks in the clay core of Conner Run Dam. Moreover, the continual reduction in seepage losses at Conner Run, over a service life of 20 years, and the experience at Cardinal I Dam indicate that fly ash also reduced seepage losses through the sides and bottom of the reservoir itself. These latter experiences have important implications in the evaluation of the extent to which leaching of hazardous materials from the fly ash might contaminate the ground water.

ACKNOWLEDGMENT

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APPENDIX. REFERENCE

Sherard, J. L., and Dunnigan, L. P. (1985). "Filters and leakage control in embankment dams." *Proc. Symp. on Seepage and Leakage from Dams and Impoundments*, ASCE, May, 1–30.