ERODIBILITY AND DURABILITY OF CEMENT-STABILIZED LOAM SOIL

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ABRIDGMENT

A cement-stabilized loam soil (A-4) was used to study the weight loss per unit surface area of samples containing various amounts of cement (i.e., 6, 8, 10, 12, and 14 percent by weight). These samples were subjected to repeated weathering (freeze-thaw or wet-dry cycles). At the end of each treatment cycle, the weight loss caused by brushing or erosion was measured. Erosion tests were carried out in a rotating cylinder apparatus with a chosen speed of 1,060 rpm and a duration of erosion of 2 min. The results show that resistance to weathering and subsequent erosion increases as cement content in the samples increases. It was also observed that a steady state of soil erosion can be achieved in samples containing higher cement contents. A comparison of weight loss caused by brushing and erosion indicates that the brushing procedure, as specified in durability test methods, appears to be more damaging to soil-cement samples than the shear stress generated by the rotating fluid. It is believed that by using the rotating cylinder apparatus, this study has provided a more rational approach to relating the durability test results to erodibility of cement-stabilized soils that are not accounted for in the current soil-cement design criterion.

• DURING the last two decades, there has been increasing use of soil-cement (cement-stabilized soils) to reduce surface erosion and seepage loss in hydraulic structures such as highway drainage ditches, reservoir and channel lining, and earth dam facing. The first 10-year performance of the Bonny reservoir test embankment (1) proved that durable, low-cost slope protection for dam or other earth embankments and linings can be built with natural soils and cement using construction procedures and equipment similar to those used in soil-cement road construction. During the design stage of the Bonny test section, the engineers were confronted with deciding on the amount of cement suitable for different soils for slope protection. There was no information available at that time about the interaction between erosion resistance and weathering of cement-stabilized soils; therefore, it was logical to borrow experience from the road construction industry. Although recognizing that the critical forces experienced by the soil are different in roadway construction than in slope protection, the use of durability tests designed primarily for roads to determine the cement content for the construction of hydraulic structures was not altogether unfounded. Furthermore, to minimize possible risks because of lack of knowledge, 2 and 4 percent more cement were added to the amount determined from durability tests (ASTM D 559-57 and D 560-57) for granular soil and fine-grained soil respectively.

Unfortunately, in almost 25 years since the construction of the Bonny test section, our fundamental knowledge of cement-stabilized soil in hydraulic structure construction has not improved significantly. Information gathered from performance studies is scarce. The absence of any major failure thus far seems to satisfy most engineers

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to adopt the borrowed design criterion permanently. Furthermore, the adequacy of the design criterion was substantiated in a laboratory study (2). However, in design thus far, the more basic factors relating the interaction of stabilized soil, flowing water, and the environment have not been thoroughly studied.

More recently, Akky and Shen (3) studied the erodibility of a cement-stabilized sandy soil. For uncycled samples (subjected to no environmental attack) of low cement contents, they reported that a simple relationship can be established between the 7-day cured unconfined compressive strength and the critical shear stress at which erosion is initiated. Further results (4) indicated that this relationship holds for a variety of soils with low cement contents. For samples subjected to various freeze-thaw cycles, erodibility cannot be related directly to the unconfined compressive strength. Expansion of water in the pore space, which is due to repeated freezing and thawing, causes the soil surface to heave. This weakens the bond strength between cementing particles and consequently reduces the soil's erosion resistance. From the results of their study, Akky and Shen concluded that the alternating weathering and erosion cycle is responsible for the deterioration of cement-stabilized soils and is essential to understanding the interaction of water, stabilized soil, and the environment. This paper gives the results as a part of a continuing study on soil-cement erodibility (i.e., the weight loss of a cement-stabilized soil caused by either erosion in a rotating cylinder or brushing as specified in the standard durability tests. It is hoped that by relating these two types of soil losses a better picture may be obtained to translate the durability test results to erosion resistance of cement-stabilized soils.

EXPERIMENTAL PROGRAM AND TEST RESULTS

The experimental program tested a loam soil for durability and erosion. After each treatment cycle (either freeze-thaw or wet-dry), soil weight loss due to either brushing in the case of durability test samples or erosion in the case of erodibility test samples was recorded.

The loam soil (A-4) used in this study was a local soil known as Yolo loam (35 percent sand, 55 percent silt, and 10 percent clay). Based on standard AASHTO compaction, the optimum water content was approximately 17 percent and the corresponding maximum dry density was 1.74 grams/cm^3. Commercially available Type II cement was used to mix with the soil. Five cement content levels were used in sample preparation: 6, 8, 10, 12, and 14 percent by dry weight of the soil. Durability test samples were compacted according to the standard procedure, whereas erosion samples were compacted by kneading in two layers in a 7.62-cm-diameter by 8.76-cm-high steel mold. All samples were compacted to a dry density of 1.74 grams/cm^3 at a molding water content of about 17 percent. For samples scheduled for the erosion test, a 1.90-cm hole was drilled axially along the length of the sample. All samples were then cured in the moisture room for 7 days (95 percent humidity and 22 C) before specified tests were performed.

The freeze-thaw and wet-dry durability tests were carried out according to the standard methods (ASTM D 559-57 and D 560-57). Erosion tests were performed after each cycle of treatment. A detailed description of the testing apparatus and procedure is given by Akky (5). Figure 1 shows an overall view of the testing apparatus. A fixed rotating speed of 1,060 rpm was chosen in this study; it is equivalent to a shear stress of approximately 0.8 grams/cm^2 acting on the surface of the sample. The erosion cycle was set for 2 min, which, according to previous experience, is sufficient to cause the erodible surface material to separate from the rest of the sample.

The weight loss per unit surface area after each erosion cycle is shown for wet-dry (Fig. 2) and freeze-thaw (Fig. 3) samples. Samples having higher cement contents underwent a total of 18 treatment cycles. For these samples the amount of weight loss per unit surface area remained more or less constant in the last few cycles indicating that the steady state of erosion loss is reached under the given set of testing parameters. In all cases the resistance to weathering (treatment cycles) and subsequent erosion increases as the cement content increases. The 6 percent wet-dry sample and the 6, 8, and 10 percent freeze-thaw samples showed excessive soil loss, and testing of those samples was discontinued before the completion of 18 cycles.

Figure 1. Erosion apparatus.

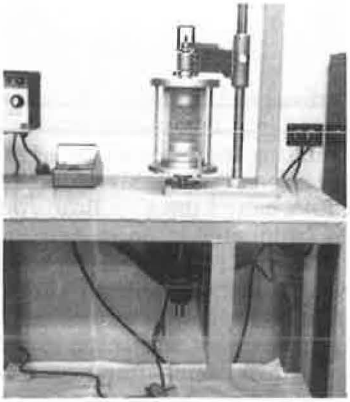


Figure 2. Erosion test results—wet-dry cycles.

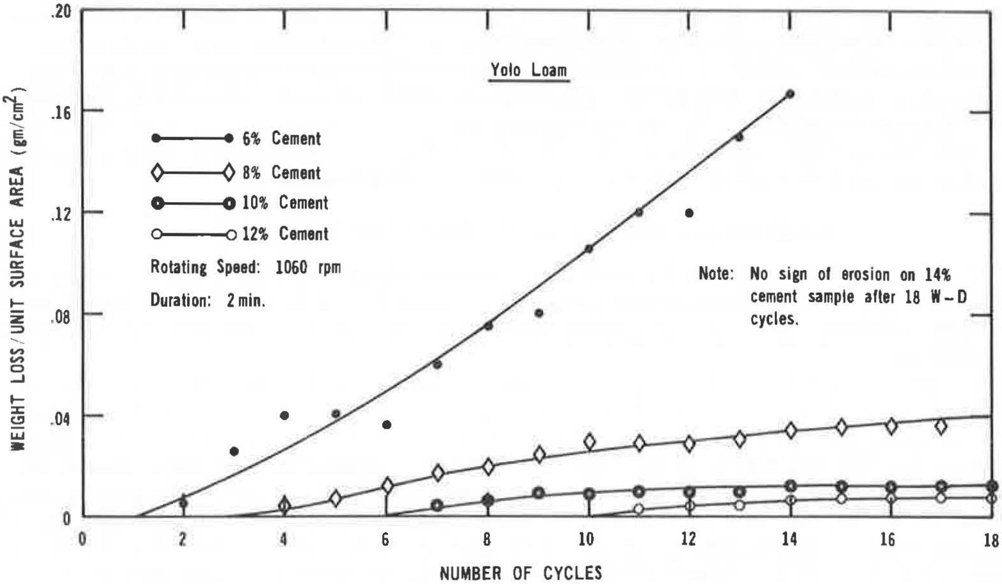


Figure 3. Erosion test results—freeze-thaw cycles.

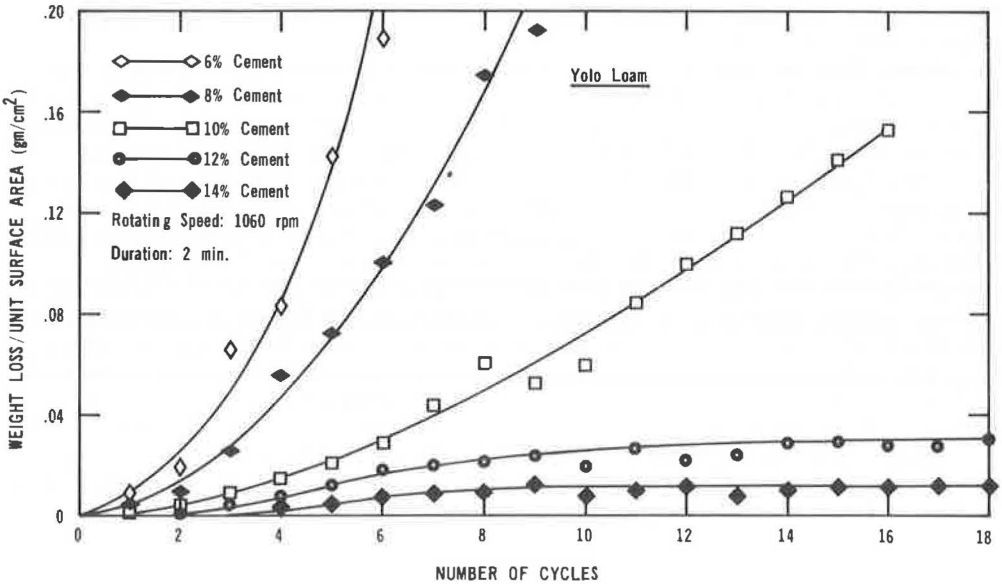


Figure 4. Comparison of soil loss—10 percent.

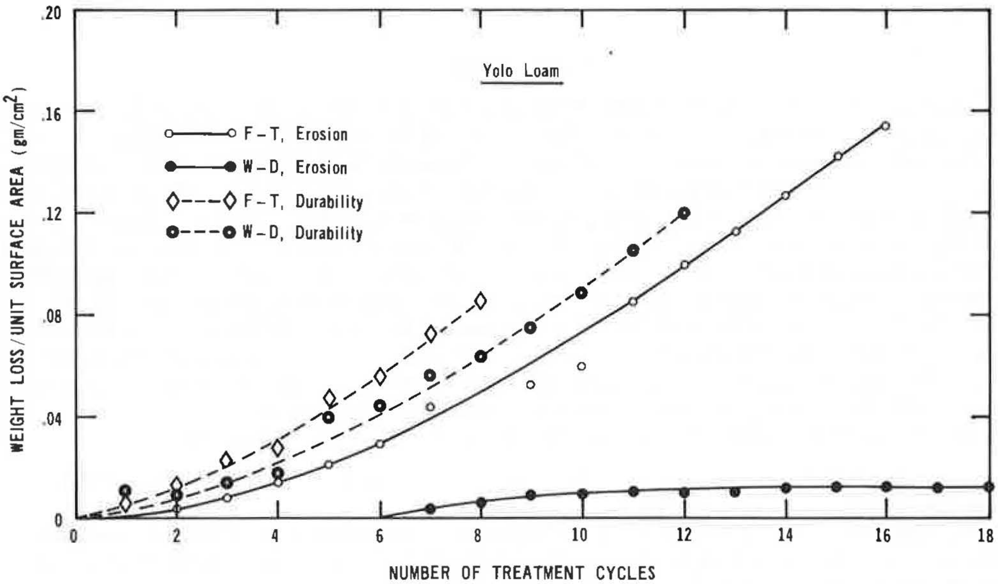
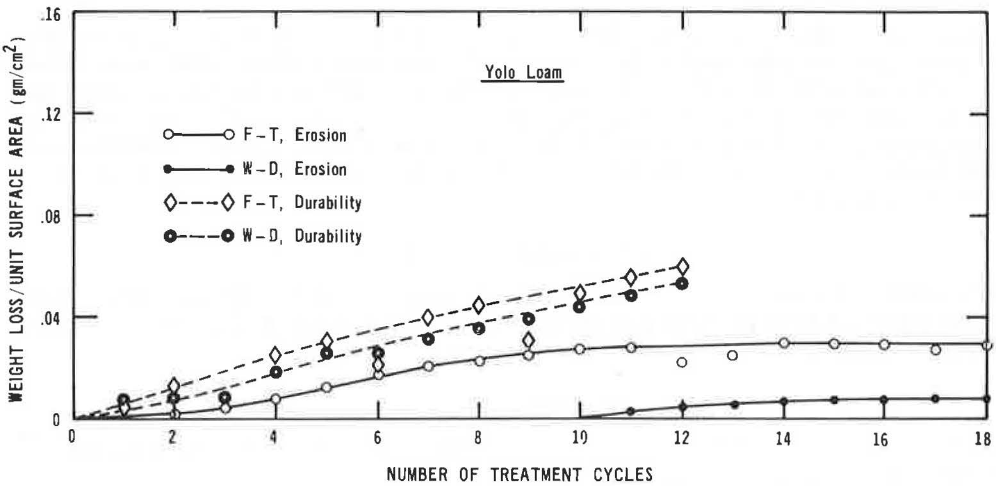


Figure 5. Comparison of soil loss—12 percent.



Durability test results showed that a minimum of 12 percent cement is required for soil-cement.

CONCLUSIONS

Because the current design of soil-cement slope protection for earth embankments and linings is essentially based on the durability criterion in which erodibility of soil-cement is not being considered, examination and comparison of the results of weight loss due to both brushing and erosion may provide necessary information to relate the durability test results to erosion resistance of cement-stabilized soils. Figures 4 and 5 show typical comparisons of weight loss per unit surface area of the various samples caused by brushing and erosion. These figures indicate that (a) the brushing procedure is more damaging to samples than the shear stress generated by the rotating fluid, and that (b) there is more weight loss due to erosion on freeze-thaw samples than on wet-dry samples. By changing the rotating speed and, to a lesser extent, the time of erosion, the weight loss due to erosion will be different. Therefore, the comparisons are limited to describing the test results obtained from this study.

On the basis of this study the following may be tentatively concluded:

1. By using the rotating cylinder apparatus it is possible to relate soil-cement erodibility to durability test results.
2. Resistance to weathering and subsequent erosion of cement-stabilized soil increases as cement content in the soil samples increases. A steady state of erosion loss is achieved in samples of higher cement contents.
3. For the testing parameters, the brushing procedure used in durability tests caused more severe damage (higher soil loss) to samples than the shear stress generated by the rotating fluid.

Furthermore, there are many other factors that could detrimentally affect the performance of cement-stabilized soils that are not considered in this study—most notably field construction variables such as mixing procedure, compaction control, construction scheduling, interface treatment, and curing method. The use of weight loss comparison caused by brushing and erosion, however, is believed to have provided a more rational approach to realistically relate the durability test results to erodibility of cement-stabilized soils.

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REFERENCES

1. Holtz, W. G., and Walker, F. C. Soil-Cement as Slope Protection for Earth Dams. Proc. ASCE, Vol. 88, No. SM6, Dec. 1962.
2. Nussbaum, P. J., and Colley, B. C. Dam Construction and Facing With Soil-Cement. Portland Cement Association, R&D Ser. 1441, Oct. 1970.
3. Akky, M. R., and Shen, C. K. Erodibility of a Cement-Stabilized Sandy Soil. HRB Spec. Rept. 135, 1973, pp. 20-29.
4. Shen, C. K. Erosion of Cement-Stabilized Soils. Presented at the Soil Erosion Conference-Workshop, 52nd Annual Meeting, Highway Research Board, Jan. 1973.
5. Akky, M. R. The Erodibility of Cement-Stabilized Soils. Univ. of California, Davis, PhD dissertation, 1974.