

# DETERMINATION OF DISPERSIVE CLAY SOIL ERODIBILITY BY USING A PHYSICAL TEST

Thomas M. Petry, University of Texas at Arlington; and  
T. Allan Haliburton, Oklahoma State University

This paper introduces a new, physical, test method for identification of dispersive clay soil behavior. The significance of this form of internal erosion and the need for such a test are discussed. An analysis of dispersive clay soil behavior is included as a base for understanding the physical erosion test. The theoretical background, apparatus, and process of the proposed physical erosion test are presented. Data for average percentage of erosion were determined during 142 tests on 18 samples of varied properties. Physical erosion test results are correlated with those determined by a chemical property method and the method of plotting soil chemical data on a graph that has empirically derived zones of dispersive clay soil behavior (6). Correlations achieved are significant. We concluded that dispersive clay soil behavior depends on the particular combination of chemical, physical, and mineralogical properties of the soil. The physical erosion test and the erosion device used are shown to provide the measure of dispersive clay soil erodibility needed by soils engineers to predict accurate field behavior.

•DISPERSIVE clay soil phenomena were first noted by agronomists over 100 years ago. They encountered problems of piping (channelization) in clay soils normally thought to be immune to internal erosion. More recently, soil scientists were able to identify the causes of this internal erosion as the self-dispersion of clay particles into water available in soil voids and subsequent removal of these suspended clay particles from the soil by normal groundwater movement.

Soils engineers in North Dakota, Illinois, Mississippi, the southwestern United States, Australia, Israel (i.e., the Negev), and Venezuela have become acquainted with serious damage occurring in earth structures of dispersive clay soil within the last two decades. The destructive effects of this phenomenon of internal erosion on transportation structures in the western United States were described by Parker and Jenne (4) in 1967. In 1968, Bell (1) reported on the extensive dispersive clay soil erosion in the Badlands of North Dakota and its importance as a factor influencing construction of transportation structures. The investigators have found that serious piping erosion occurs in both cut and fill embankments.

Because of the desire to design and construct both safe and stable structures of earth, including dispersive clay soils, soils engineers and soil scientists have studied the dispersive clay phenomenon. Their research has been directed to finding a method for identifying dispersive clay soil erodibility so that they are able to predict the field behavior of these problem soils. These procedures range from qualitative tests of the self-dispersion of clay soils to the more quantitative tests that use soil chemistry properties to identify dispersive clay soil erodibility.

The difficulties associated with use of these previously proposed methods are two-fold. First, and most important, the results obtained from the use of these methods are effectively qualitative so that accurate prediction of field behavior is not possible. Second, those methods that offer the more quantitative results are based on soil

chemistry properties not understood by most soils engineers. A physical test to determine internal erodibility of these problem soils was needed so that the measure of dispersive clay erodibility needed by soils engineers using an easily understood and accepted test method could be provided.

## ANALYSIS OF DISPERSIVE CLAY SOIL BEHAVIOR

The behavior of dispersive clay soil, like that of all clay soils, is a result of the particular physicochemical environment within and surrounding it. There are several factors in this environment that must be present for a clay soil to exhibit the dispersive clay soil phenomenon of internal erosion.

First, there must be a disequilibrium of clay particles and water in the soil mass. This occurs when the chemical environment surrounding certain clay particles is such that they will disperse out of the soil mass and into available pore water if their physical surroundings permit. Many researchers of dispersive clay behavior have noted that either or both illite and smectite minerals must be present in the soil-clay ratio for clay particle dispersion to take place. Moreover, an inordinate quantity of sodium cations, as compared to the total quantity of other cations surrounding the clay particles, causes dispersion of the particles. Methods for determination of dispersive clay behavior based on soil chemical properties use some measure of the percentage of the sodium cation concentration to predict dispersion. These methods ignore all other factors affecting dispersive clay soil erosion.

Second, there must be soil mass porosity of sufficient size to allow continuing dispersion of clay particles into pure water and to allow removal of these dispersed clay particles by seepage. This may occur when the soil mass is desiccated and a system of interconnected cracks is present; when the soil consists of aggregates of material that is compacted dry of optimum, rather than discrete particles; or when either of these situations is combined with the presence of constructed or natural fissures in the soil. These systems of pores will promote dispersion and removal of clay particles as long as their size is not markedly reduced by swelling of the soil before significant loss of soil occurs.

Third, water that is relatively pure and in a large enough quantity to provide for clay particle dispersion and that supplies the required hydraulic gradient to cause removal of these particles by seepage must exist. This factor is complicated because the type and quantities of water moving through the soil vary greatly.

Finally, the soil must also have a propensity to exhibit surface erosion. When a surface is available within a soil pipe, loss of material occurs not only by dispersive clay soil action but also by surface sloughing and removal.

The severity of erosion caused by the phenomenon of the dispersive clay soil depends on the combined effects of these environmental factors. The variance of this severity is directly related to the combined physical, mineralogical, and chemical properties of the soil. Because of this fact, those methods for identifying dispersive clay soil erodibility based on less than an analysis that considers all the environmental factors can be only qualitative.

## ENGINEERING CONSIDERATIONS

The need for a physical erosion test to determine the amount of dispersive clay soil or internal erodibility of a soil is based on the desire of soils engineers to predict and correct for detrimental field behavior. The measures taken to use problem soils in earth embankments depend highly on accurate appraisal of soil properties including internal erodibility. It is not sufficient that the general behavior of the soil be known but that a quantitative measure of behavior be available.

In 1972, Sherard, Decker, and Ryker (6) reported on a method they developed for identification of dispersive clay soil erodibility. Of the methods previously proposed for this purpose, this one is most adequate for use by soils engineers. By using test

data from 99 samples of varying physical and chemical properties with known field behavior, they developed a graph of selected soil chemistry data containing zones of soil behavior (Fig. 1). Inasmuch as the zones of behavior associated with this method were developed by observation of field behavior, results obtained may be directly used to predict field behavior, if the field situations under consideration are similar. This method (6), like others previously proposed, is limited in application because it does not consider all factors influencing dispersive clay soil field behavior. However, inasmuch as it represents the most acceptable method for use by soils engineers, it was chosen as a reference method for correlation of test results during development of the physical erosion test, which considers all the environmental factors present in and around the soil.

## PHYSICAL EROSION TEST

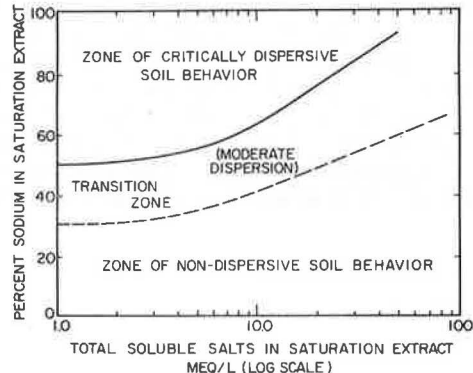
During research recently completed at Oklahoma State University, we developed a physical test for identification of dispersive clay soil erodibility. It was believed that a physical test would provide a most acceptable method for directly studying the reactions of the proposed soil during dispersive clay soil erosion. Thought was directed at making the test accurately assess the one variable of internal erodibility practically and economically. The simplest and most direct approach of field simulation was decided on to accomplish these objectives and to provide results readily transformed into meaningful field behavior. The outcome of the development process was a laboratory test procedure that uses miniaturized equipment to supply a pseudofield environment that promotes dispersive clay soil erosion.

Five elements were needed to complete the field simulation desired, to provide consideration of all the environmental factors, and to accelerate the testing process to make it feasible:

1. A soil mass that would best represent the most internally erodible mass,
2. A water-flow system that would promote possible dispersive clay soil erosion,
3. A chamber that would provide the soil with a controlled environment,
4. A method that accelerated erosion so that laboratory testing of a few hours could simulate months of field behavior, and
5. A system that would provide measurement of loss due to dispersive clay soil erosion.

Each of these elements will be discussed in the following.

Figure 1. Determination of dispersive clay soil behavior (6).





## Soil

The soil chosen for this laboratory simulation was a Harvard-miniature-sized cylinder [diameter = 1.3 in. (3.33 cm), length = 2.80 in. (7.11 cm)] compacted to specifications normally used for field density control by soils engineers. It was believed that with proper control of both density and compaction water these cylinders of soil would well represent the physical soil in the field. Tests were conducted on samples compacted at both standard and modified Proctor specifications by a mechanical device developed at Oklahoma State University. Demineralized distilled water was used to eliminate influences on test results by the chemical properties of compaction water. Finally, to ensure that there would be no variations in test results due to curing before or after compaction, water was added just before compaction, and the specimens were tested immediately following compaction. The product of these efforts was a soil of specified density and water content.

Artificial cracks or holes were drilled longitudinally through the cylinder so that a most internally erodible soil mass could be simulated. Much consideration was given to the development of a system of holes that would provide sufficient space for clay particle dispersion and removal but that would allow natural swelling and sloughing to stop internal erosion loss, as it may in the field. The final configuration (Fig. 2) contains three 0.0125-in. (0.0318-cm) holes evenly spaced throughout the cross section of the cylinder.

## Water-Flow System

The erosion water used for physical erosion testing was distilled water, because of its close resemblance to relatively pure rainwater and because of its availability. A system to control water flow was necessary to minimize the quantities needed and to simulate field conditions. An intermittent flow sequence was adopted to approximate the holding of water in soil voids, the following seepage, and the recharging of the voids. In addition, the internal erosion occurring during constant, slow seepage and during this scheme of intermittent flow was essentially the same. The cycle that best promoted clay particle dispersion into nonmoving water and material removal with fresh-water replenishment had 7 sec of water flow each 6 min. This intermittent flow action was accomplished with timing units that controlled solenoid valves.

## Environmental Chamber

The environmental chamber provided the desired pseudofield environment in which the soil mass could be tested. This most important part of the erosion device is a cell constructed of Lucite, into which the Harvard-miniature-sized cylinder is placed after compaction, slightly compressed to ensure a good soil-cell seal, and then perforated with the longitudinal holes. The completed cell with soil mass is shown in Figure 3. Water enters the top of this enclosure through a 0.25-in. (0.635-cm) tube (outside diameter) and is distributed over the top of the soil. Below the soil cylinder, there is a space for collection of suspension exiting the holes, and below this is a disk of U.S. No. 40 sieve wire, supported by a porous circular plate and a spacer ring. Suspension that passes through the sieve wire collects under this porous disk and exits the cell through a 0.25-in. (0.635-cm) tube. The combination of this environmental chamber, soil mass, and intermittent water-flow system was thought to be capable of best representing the field situation of critical dispersive clay soil erosion.

Figure 2. Longitudinal hole locations.

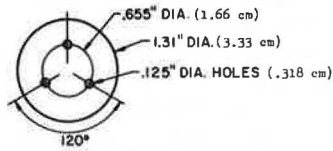


Figure 3. Cross section of assembled erosion device cell with soil cylinder.

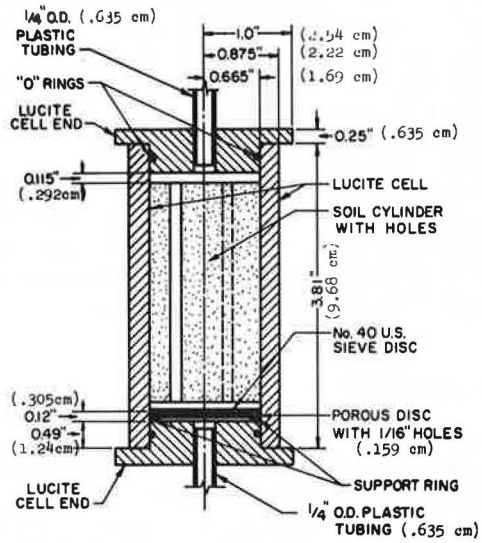


Figure 4. Water-flow system of erosion device.

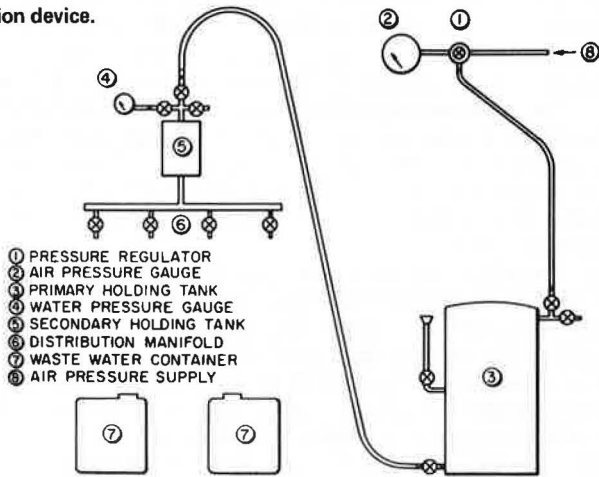
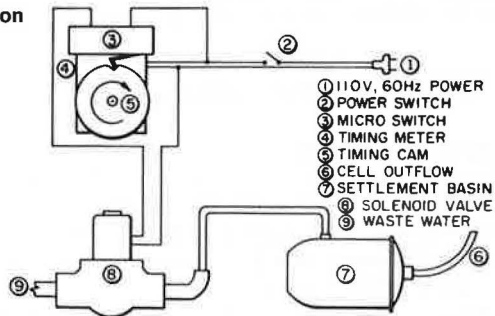


Figure 5. Timing and control system of erosion device.



### Erosion Acceleration

The method chosen to accelerate erosion to simulate months of erosion in hours was pressurization of the water-flow system. This hastened the movement of water into the soil and promoted the dispersion of the clay particles and a breakup of the soil mass. During the development process, several combinations of ways to introduce water into the soil and to pressurize the system were investigated so that the desired results could be achieved. So that maximum water absorption, soil mass breakup, and pseudorealistic soil action could be provided, water had to be introduced under atmospheric pressure and then pressurized to 15 psi (103.4 kPa). This meant that, initially, water entered the soil by normal physical and osmotic movement and that finally it was forced into the total soil to accelerate soil mass breakup and erosion. In addition, the pressurization used was beneficial to the movement of fresh water and soil suspension and to the operation of the solenoid valves.

### Erosion Measurement

The final element for proper operation of the erosion device was some method to ensure that the erosion measured would be mainly that of the dispersive clay soil and only that of the surface, which occurs normally. Inasmuch as the accelerated erosion process used affected both types of erosion in approximately the same way, some device was needed in the test cell to permit, insofar as possible, loss of material by only dispersive clay soil erosion. Aggregates of soil containing flocculated clay particles were structurally coherent even under the flow conditions imposed in the test cells, but aggregates of soil containing dispersive clay particles melted. As a reference for defining coherence or melting of soil aggregates, a sieve was placed below the soil cylinder in the cell. Because of its standard use by soils engineers and relative availability, U.S. No. 40 sieve wire was used. This method of differentiating between aggregate coherence or disintegration proved to be effective and acceptable.

Determination of the length of test needed to observe long-term internal erodibility by using the procedure and apparatus explained was carried out while these elements were studied. It was found that, for soils that had critical internal erodibility, 4 hours was the optimum time.

The final decision concerned the quantity to be measured. This quantity had to be readily applicable for determining field behavior and precise enough to be considered quantitative. Because it was possible to easily determine the initial and final dry weight of soil in the cell, a relationship based on these values was selected. The percentage of erosion was thus defined as the ratio ( $\times 100$ ) of the weight of dry soil lost during the test to the initial dry weight of soil in the cell. This result was found to be directly related to potential internal field erosion.

Other than the erosion device cell shown in Figure 3, two other systems were necessary to complete the erosion device: (a) the water-flow system (Fig. 4) and (b) a system that provided control and timing for the desired intermittent flow (Fig. 5). The complete erosion device used for the physical erosion test is shown in Figure 6.

## TEST RESULTS AND CORRELATIONS

During this research, testing was carried out on 18 different soils of various physical, mineralogical, chemical, and internal erodibility properties, which were native to Oklahoma, Arkansas, Mississippi, and Georgia. Fifteen of these were picked for this study because of their tendencies to exhibit dispersive clay soil erosion in the field. The remaining soils were added to provide a measure of control to this study, because they did not show this tendency.

The engineering properties determined for these soils were not indicative of their internal erodibility. According to plasticity, 15 were CL, 2 were CH, and the Georgia kaolinite was MH. Their textures ranged from almost pure clay, to silty clays, and to sandy clays.

Figure 6. Erosion device used in physical erosion test.

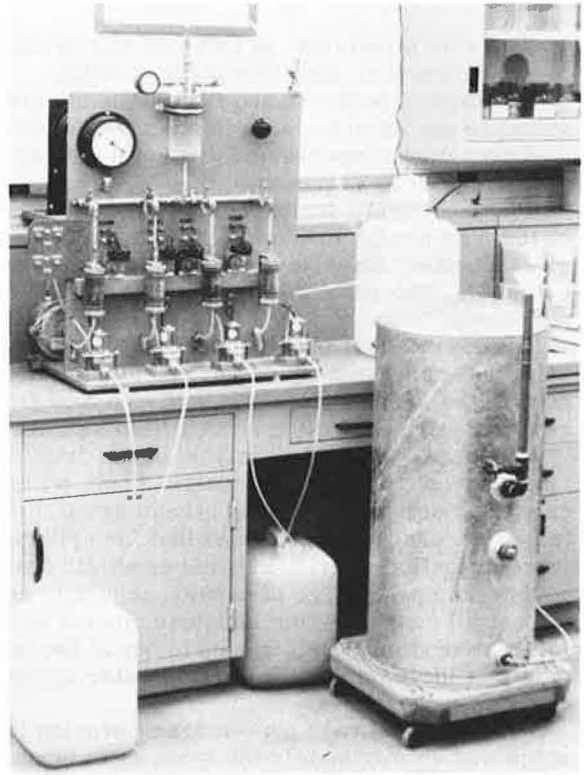


Table 1. Average physical erosion test results.

| Erosion (percent)                        | Sample Number |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--|---------------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|  | 101           | 103 | 103 | 104  | 105  | 106  | 107  | 108  | 109  | 110  | 111  | 112  | 113  | 114  | 115  | 116  | 117  | 118  |
| In standard Proctor compaction specimens | 3.3           | 1.4 | 1.5 | 47.7 | 18.9 | 78.7 | 61.0 | 49.7 | 19.3 | 64.4 | 86.0 | 38.3 | 18.8 | 14.0 | 51.8 | 28.5 | 55.4 | 79.9 |
| In modified Proctor compaction specimens | 5.0           | 6.7 | 2.1 | 43.5 | 30.9 | 33.5 | 70.1 | 32.5 | 30.1 | 60.5 | 75.3 | 32.5 | 14.6 | 15.3 | 35.9 | 33.8 | 61.1 | 71.7 |

Figure 7. Correlation between physical erosion test results and exchangeable sodium percentage (clay).

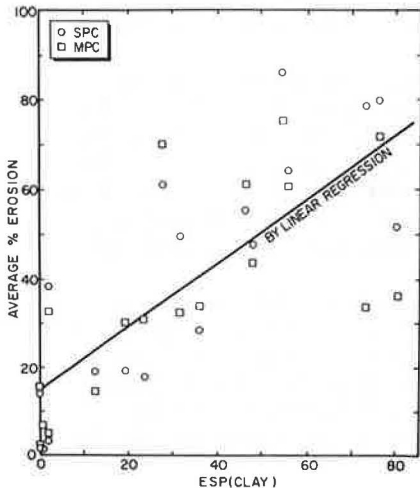
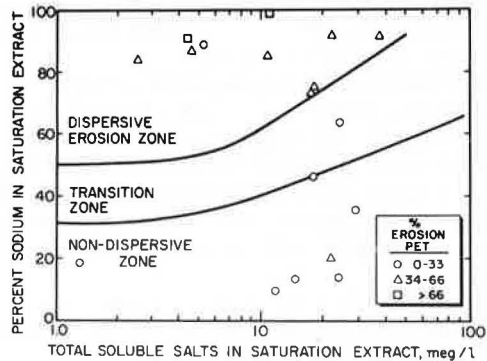


Figure 8. Correlation between physical erosion test results and field behavior determined by chemical properties of saturation extract.





The clay mineralogy of samples was developed by differential thermal analysis, X-ray diffraction, and illite determination. Their clay fractions were found to consist of mixtures of smectite and illite, chlorite and smectite and illite, chlorite and illite, smectite and chlorite, and, in one case, kaolinite.

Laboratory dispersion test results indicated that none of these samples were non-dispersive (0 to 33 percent), that 11 were moderately dispersive (34 to 66 percent), and that 7 were highly dispersive (67 to 100 percent). Soil chemistry testing described 10 of them as nondispersive [exchangeable sodium percentage (ESP) of 0 to 9], 6 of them as moderately dispersive (ESP of 10 to 15) and 2 of them as highly dispersive (ESP of over 16). The results of these qualitative indicators of internal erodibility are not in agreement.

During physical erosion testing, 142 specimens were prepared, 8 from each of the samples except in 2 cases for which material was in short supply. Half of these were compacted with standard and half with modified Proctor efforts. Compaction water contents were controlled so that field soil masses could best be simulated.

Close inspection and analysis of the detailed results obtained during erosion testing revealed several pertinent facts. First, within the limits of water contents tested for each compactive effort, a relatively small difference was found in dry density of the tested cylinders. This means that for cylinders of a sample prepared at each of the two compaction efforts, internal erodibility generally did not depend on dry density. Second, the percentage of erosion generally depended on compaction water content. In almost all cases, as this moisture content increased, the amount of erosion decreased. Internal erodibility is believed to occur because of changes in soil structure as they relate to increases in compaction water content. This agrees directly with the findings of other researchers.

Third, the average percentage of erosion in the standard Proctor compacted specimens was approximately the same as in those specimens compacted by using modified Proctor effort (Table 1). The explanation for this is based on the combination of two factors that influence internal erodibility. Generally, a substantial increase in dry density (e.g., from increased compactive effort) leads to a decreased susceptibility to internal erosion. On the other hand, the lower water contents associated with optimum compaction under increased compaction effort tend to increase erodibility. When both of these influences on behavior of a soil occurred simultaneously, the result was no general change in the average percentage of erosion. Because of the variations of results, it was considered reasonable to average the results found for each type of compaction effort (Table 1).

During analysis of these results, the influence of the physical, mineralogical, and chemical properties on the dispersive clay soil erodibility of each sample was considered. Although the chemical properties of samples largely dominated the action of the soil, both physical and mineralogical properties were determined to be important factors influencing the internal erosion process and, therefore, the behavior of the soil. The erosion device and its use in the physical erosion test were proved acceptable for providing the measure of dispersive clay soil erodibility needed by soils engineers to predict accurate field behavior.

Among the previously proposed methods for identification of dispersive clay soil erodibility, those believed most practical and useful by soils engineers were included in this research. Of these, two are of significant interest: (a) an indicator (i.e., ESP) of the surrounding chemical environment and of the exchange of clay particles and (b) the method developed by Sherard, Decker, and Ryker (6), which was previously discussed. Indications of dispersive clay soil erodibility as determined by the physical erosion test were correlated with those found by using these previously proposed methods of identification.

The modified ESP method is, in actuality, a previously proposed method of identification modified to better indicate the chemical environment of the clay particle. ESP is the percentage of the exchange complex of a clay soil that is taken up by sodium cations. Although we believed this was a fair indicator of clay particle dispersibility, it was decided that it could be significantly improved if it were related to the clay fraction rather than the whole soil. The method chosen was to amplify the ESP to the



ESP (clay) by dividing it by the decimal equivalent of the percentage of clay in the soil. The result is an indicator of the chemical environment of the clay particle, the constituent part of the soil mass that disperses.

The correlation between the average percentage of erosion achieved by using the physical erosion test and the respective sample ESP (clay) results is shown in Figure 7. There are two points plotted for each sample, one representing the average of results for cylinders compacted at each standard and modified Proctor effort. Linear regression was used to determine what relationship existed. The line shown intercepts the percentage-of-erosion axis at 14.7, which indicates that internal erosion depends on surface erosion potential. This line is inclined from the horizontal axis at about 35.5 deg, which shows that the internal erosion measured depends on the chemical environment surrounding the clay particle. The coefficient  $R^2$  is 0.58, indicating that the majority of changes in measured erodibility may be due to changes in ESP (clay). Figure 7 shows the influence of all factors that affect internal erodibility, including physical and mineralogical properties. The correlation (Fig. 7) is significant and clearly indicates the validity of the physical erosion test.

$$\text{ESP}(\text{clay}) = \frac{\text{ESP}}{\% \text{ clay}/100}$$

Correlation of the identified erodibility by the physical erosion test and by the method proposed by Sherard, Decker, and Ryker (6) was also successful. Physical erosion test results were arbitrarily divided into groups of 0 to 33 percent, 34 to 66 percent, and 67 to 100 percent so that the percentage of erosion could be related to the zones of behavior. The appropriate chemical properties of the samples tested were plotted on the reference graph by using symbols for these groups. The resulting correlations are shown in Figure 8.

The correlation in Figure 8 is significant. Six of the eight samples with erosion from 0 to 33 percent had chemical data that were plotted in or below the transition zone. The sample from this group in the dispersive erosion zone had an average percentage of erosion of 31 percent and was a soil that evidently had physical properties that significantly reduced its erodibility. The group of eight samples that had 34 to 66 percent average erosion were all in the dispersive erosion zone except one. This nondispersive sample had an average erosion of 35 percent and was a soil known for its critical surface erosion potential. Finally, the chemical data of the two samples that had greater than 66 percent average erosion were plotted highest in the dispersive erosion zone. The results of the analysis of this correlation indicate the validity and acceptability of the physical erosion test.

## CONCLUSIONS

The internal erosion phenomenon of dispersive clay soil has become a factor that must be considered during design and construction of earth embankments in many places in the world. So that the internal erodibility of a soil mass may be adequately assessed, all physical, mineralogical, and chemical properties must be considered. The simplest and most logical way to do this is with a physical test such as the physical erosion test. The findings of the analyses of correlations indicate that the physical erosion test is a significant addition to previously proposed methods. If it is applied by using a well thought-out program of sampling, it supplies a quantitative result that may be used to assess the combined effects of physical, mineralogical, and chemical properties on dispersive clay soil erosion potential and to predict field behavior.

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