LESSONS LEARNED USING LABORATORY JET METHOD TO MEASURE SOIL ERODIBILITY OF COMPACTED SOILS

G. J. Hanson, S. L. Hunt

ABSTRACT. *Overtopping, internal erosion, and piping are the main causes of accidents and failures of embankments for dams, lagoons, and levees. A key parameter in the failure of these structures is the erodibility of the soil materials used in construction of the embankments. The soil materials are typically constructed based on compaction specifications. The jet erosion test (JET) has been developed to study the erosion characteristics of soil materials. A laboratory version of this apparatus is described in this article and is used in this study to investigate the effects of compaction on erodibility. Two approaches for determining compaction specifications are also compared and discussed. Soil samples, 944 cm^3, were prepared at different compaction water contents and compaction efforts, and tested using the JET method. Erodibility was observed to vary by several orders of magnitude dependent on the soil gradation and plasticity, and the compaction effort and water content. The findings indicate the resistance to erosion for a given soil can be improved considering the following: compaction near optimum water content creates a structure most resistant to erosion; higher compaction effort at a given water content increases erosion resistance; and soil properties including, texture and plasticity, influence erosion resistance as much or more than compaction factors. The findings also indicate the usefulness for erodibility testing of embankment materials to aid in determining the optimal compaction specifications for a given soil.*

Keywords. *Submerged JET, Erodibility, Compaction, Specifications, Critical stress, Detachment.*

Overtopping, internal erosion, and piping are the main causes of accidents and failures of embankments for dams, lagoons, and levees. The recent earthen embankment failures in New Orleans, Hawaii, and California point out the importance of this topic. Overtopping a cohesive embankment results in erosion that has been described as a four-stage process (Hanson et al., 2005a) resulting in failure of the embankment. This four-stage process is the basis for the development of SIMplified Breach Analysis (SIMBA), a computational research tool of the breach process of earthen embankments caused by overtopping (Temple et al., 2005). Embankment material erodibility has been identified as a key material parameter for use in the computational model for predicting erosion during all four stages of the breach process (Hanson et al., 2005b). Wan and Fell (2004) also identified erodibility as a key material property in describing piping and internal erosion of earthen embankments.

The stress-based detachment equation is the fundamental equation used in characterizing erodibility for embankment overtopping (Temple et al., 2005) and internal erosion (Wan and Fell, 2004) for these studies.

$$\dot{\varepsilon} = k_d(\tau_e - \tau_c) \quad (1)$$

with

$$\tau_e = \gamma dS \quad (2)$$

and

- $\dot{\varepsilon}$ = the erosion rate in volume per unit area per unit time,
- k_d = a detachment rate coefficient,
- τ_e = the hydraulically applied boundary stress,
- τ_c = the critical stress required to initiate detachment for the material,
- γ = the unit weight of water,
- d = the normal depth of flow on the slope (computed by Manning's equation), and
- S = embankment slope (sine of the angle of the slope with horizontal).

Erosion rate relations of this general form have been used by numerous investigators (Hutchinson, 1972; Foster et al., 1977; Dillaha and Beasley, 1983; Temple, 1985; Hanson, 1989; Stein and Nett, 1997; Wan and Fell, 2004).

Research conducted by Smerdon and Beasley (1959), Kamphius and Hall (1983), Hanson (1996), and Briaud et al. (2001) has explored the relationship between soil erosion resistance parameters like k_d or τ_c to soil index parameters such as plasticity index or percent clay. This research has shown, however, that erosion of cohesive soils is a complex system dependent on many parameters. Few simple relationships between measured soil index properties and the erosion resistance parameters have been obtained. Determination of erodibility requires testing of specific soils and conditions. Several methods are available for testing the erodibility of soils. Wan and Fell (2004) break these methods up into six categories: 1) flume tests, 2) jet erosion tests (JET), 3)

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rotating cylinder tests, 4) soil dispersion tests, 5) hole or crack tests, and 6) erosion function apparatus. The most dependable method of testing to determine erodibility is a large open channel flow test with the soil of interest forming the entire bed. This testing procedure, however, poses many problems, particularly if the material to be tested is a native streambed material. It is impossible to move that bed to a large open channel flume without disturbing the structure of the soil. Even for materials that are to be disturbed and remolded through compaction for construction purposes, justifying the expense of a large open channel test is difficult. Therefore, a method of testing these materials in the laboratory as well as *in situ* is needed. A JET has been developed for measuring erodibility of soils both in the field and laboratory (Hanson and Cook, 2004). A laboratory version of the JET can be used to test soil samples as small as 10 cm in diameter. The JET can be used to determine both k_d and τ_c.

Researchers have found that the nature and magnitude of compaction used to construct the embankment significantly affects the rate of erosion during embankment overtopping and breach (Hahn et al., 2000; Fell et al., 2003; Hassan et al., 2004). Hahn et al. (2000) observed increases in headcut migration rates of 50 times on three embankment overtopping tests compacted at equivalent efforts for different material types and compaction water contents. Fell et al. (2003) noted that based on a study of cases of piping and internal erosion failures that compaction density and water content were included in the factors that influence progression of erosion. Hassan et al. (2004) observed that increases in compaction effort and water content for the same soil material increased the erosion resistance of small embankment flume tests significantly. These studies point out the significance of soil properties and compaction in determining timing and rate of cohesive embankment erosion.

Compaction is effective in improving engineering properties of earthen materials (Lambe, 1958) including strength, volume change, flexibility, permeability, and erodibility. The normal approach of embankment designers is to determine the engineering properties of soils proposed for use in an embankment from laboratory tests on samples remolded at various degrees of compaction and water contents. By evaluating the resultant properties, designers can select the optimal conditions of compaction that will produce the desired properties in the compacted fill. Clearly, the behavior of the final constructed full-scale embankment may or may not be predicted from the laboratory tests performed. Performing full-scale engineering property tests remains a difficult task that is not often done. Engineers must rely primarily on field-measured water contents and dry densities to verify that an embankment is constructed similarly to the laboratory specimens used for predicting engineering properties. The assumption is that the behavior of the field compacted soil will be the same or can at least be inferred from the laboratory compacted soil if both are compacted at similar water content, similar dry density, and at a given compactive effort.

Earthen embankment dams are typically constructed based on specifications with the purpose of establishing minimum standards of compaction. There are several difficulties in this approach including: 1) laboratory-scale compaction effort can never perfectly match field compaction effort; 2) it is difficult to control field samples to the same level of uniformity as laboratory samples; and 3) the soil fabric created in the laboratory is not necessarily equivalent to the fabric in the field. Nevertheless, laboratory prepared and tested samples continue to be useful for indicating field performance and forming the basis for determining compaction specifications.

A common method for specifying compaction of earth embankments is to require a given degree of compaction (the compacted soil must be at a dry density equal to or higher than the stated percentage of the control compaction test), and within a range of acceptable water contents. Often, small embankments (less than about 20 m high) have acceptable engineering properties if they are compacted to about 95% of Standard Proctor dry density, with the specified water content dependent on the soil type and other site specific conditions. Higher embankments or those built with more highly plastic soils are often specified to be compacted to a higher degree, perhaps 100% of Standard Proctor (ASTM D698A) dry density, to achieve acceptable shear strength. Acceptable water contents are specified in compaction specifications to achieve the engineering properties thought to be most critical by the designer. Water content specifications usually include a range of acceptable water content. An example would be requiring the compacted soils to have a water content in the range of 2% dry of optimum to 3% wet of optimum. If permeability for instance is a primary consideration, specifications will require compaction at higher water contents. Whereas, if shear strength is more important, compaction at lower water content may be required.

Another procedure that has recently been proposed for determining compaction specifications of soil liners and covers (Daniel and Benson, 1990) is based on optimal combinations of dry density and placement water content for permeability performance. Using laboratory permeability tests, an acceptable zone of water contents, and dry unit weights relative to performance tests of laboratory compacted samples (Daniel and Benson, 1990) can be established. This method was developed to determine acceptable zones of compaction for shear strength, shrinkage, and hydraulic conductivity of soil liners and covers. The procedure involves compacting samples in the laboratory over a range of water contents using three compaction efforts. The parameter of interest, such as permeability, is measured for each sample. The values of dry density and water content that result in an acceptable value for the criterion parameter, such as permeability, can then be contoured for lines of equal permeability. The envelope of acceptable values of compacted dry density and water content can then be used in writing a construction specification for that soil. While the primary use of this approach has been in specifying soil compaction for permeability, the method may also have potential in determining acceptable zones of compaction for erodibility resistance of earthen embankments. This method is discussed and proposed by the authors in this paper as a viable approach for specifying embankment compaction based on erodibility performance tests.

The objectives of this study as described in this article are to: 1) conduct jet erosion tests of laboratory compacted samples for two soils over a range of compaction water contents and three compaction efforts; 2) compare erodibility test results for standard laboratory compaction samples to compacted embankment field tests; 3) compare erodibility test results for samples compacted at three compaction efforts for two soils; and 4) contrast the difference of a typical construction specification for material compaction to an acceptable zone specification of erodibility based on JET results.

Experimental Setup

Material Properties and Compaction

Two soil materials were used in the laboratory experiments in this study. They were the same as the soil materials used in embankment breach widening experiments conducted in the USDA Hydraulic Engineering Research Unit's field laboratory (Hunt et al., 2005). Index tests for these two soils were conducted by the NRCS National Design, Construction, and Soil Mechanics Laboratory (Fort Worth, Tex.). The soils will be identified throughout this manuscript as Soil 2 and Soil 3. Index properties of the two samples are summarized in table 1 including: grain size, plasticity index, dispersion, standard compaction maximum dry density γ_{dmax} and the optimum water content WC_{opt}, and soil classification.

Dispersive clays normally deflocculate when exposed to water, opposite of aggregated clays that would remain flocculated in the same soil-water system. Generally, dispersive clays are recognized as highly erosive. ASTM standard D4221 is a qualitative test method that provides an indication of the dispersive nature of the soil material based on the ratio of particles less than 0.005 mm in a soil-water suspension without mechanical agitation and a dispersing agent versus a soil-water suspension with mechanical agitation and dispersing agent. A percent dispersion of 100% would indicate a completely dispersive clay-sized fraction and a value of 0 indicates a completely non-dispersive clay-sized fraction. As can be observed from the percent dispersion results reported in table 1, neither soil is particularly dispersive.

The soil materials for conducting laboratory JET(s) were taken from the stockpiles that were used in field breach widening tests. The soils were air dried and then passed through a screen with openings equivalent in size to a number 4 sieve (4.75 mm). The soils were then thoroughly mixed with water to achieve the desired water content. The soils were stored for a minimum of 48 h to allow time for the soil particles to hydrate. Samples were compacted at three compaction efforts for each soil over a range of compaction water contents. The soil was compacted in the standard mold described in ASTM D698, with a diameter of 101.6 mm, a height of 116.4 mm, and a capacity of 944 cm^3. The samples were compacted with a manual rammer 50.8 mm in diameter, weighing 2.49 Kg, with each blow consisting of a free fall distance of the rammer of 304.8 mm. The soil was placed and compacted in the mold in three layers. The compaction efforts for Soil 2 included samples prepared at: 1) the standard compaction effort of 25 blows per layer, 2) 16 blows per layer, and 3) 9 blows per layer. The compaction effort for preparing Soil 3 samples included: 1) the standard compaction effort of 25 blows per layer, 2) 9 blows per layer, and 5 blows per layer. The resulting compaction curves for Soil 2 and Soil 3 are shown in figures 1 and 2, respectively. The two

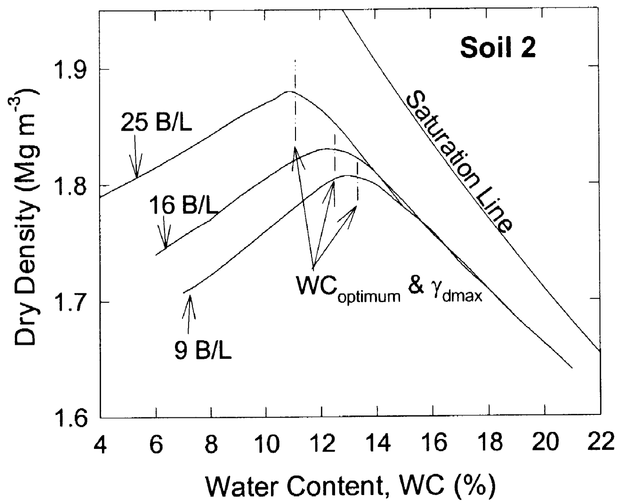

Figure 1. Compaction curves for soil 2 showing blows per layer (B/L) and the optimum water content ($WC_{optimum}$) and maximum dry density (γ_{dmax}).

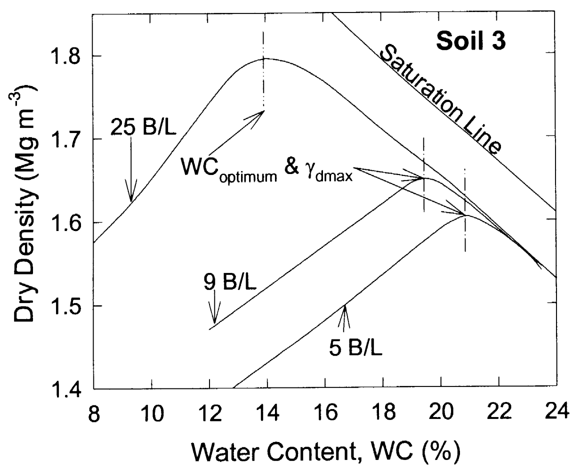

Figure 2. Compaction curves for soil 3 showing blows per layer (B/L) and the optimum water content ($WC_{optimum}$) and maximum dry density (γ_{dmax}).

Table 1. Soil characterization.

	Grain Size[a]					Standard Compaction[d]		
Soil	% Sand > 75 µm	% Fines > 2 µm	% Fines <2 µm	Plasticity Index[b] PI	% Dispersion[c]	γ_{dmax} (Mg-m^{-3})	WC_{opt} (%)	Soil Classification[a]
2	63	31	6	NP[e]	0	1.871	11.0	SM-Silty Sand
3	25	49	26	17	20	1.779	13.9	CL-Lean Clay

ASTM Standards used to measure soil properties:
[a] D2487
[b] D4318
[c] D4221
[d] D698A.
[e] NP – Non Plastic.

lower compaction efforts for each soil were chosen to aid in defining lines of iso-k_d, as explained later, in the area below the standard compaction curve in order to accomplish the previously stated fourth objective.

Erodibility Tests

Laboratory JET Apparatus

The laboratory jet test apparatus consists of a jet tube, nozzle, point gage, and jet submergence tank (fig. 3). The jet tube is made of 50-mm i.d. acrylic tubing with 6.4-mm wall thickness. The jet tube has an 89-mm diameter orifice plate that is 12.7-mm thick with a 6.4-mm diameter rounded opening (nozzle) in the center of the plate. Once a test is started, scour readings are taken with the point gage. The point gage is aligned with the jet nozzle so that the point gage can pass through the nozzle to the bed to read the depth of scour. The point gage diameter is nominally equivalent to the nozzle diameter so that when the point gage rod passes through the nozzle opening, flow is effectively shut off. A deflection plate is attached to the jet tube and is used to deflect the jet, protecting the soil surface, during initial filling of the submergence tank. At test initiation, immediately following submergence of the sample, the deflector plate is rotated out of the way of the jet, allowing direct impingement on the soil surface.

The jet submergence tank is 305 mm in diameter and 305 mm in height, and it is made of 6.4-mm acrylic tubing. The tank is open on the top and accommodates the jet tube and lid which is latched to the tank. During testing excess water flows out through a discharge tube. The water source used was taken directly from Lake Carl Blackwell. This is also the same water used in the outdoor embankment erosion tests. Because there is still a significant amount of research yet to be done on the effects of water chemistry on erodibility, it was considered important in this study to maintain consistency in water sources for comparison purposes.

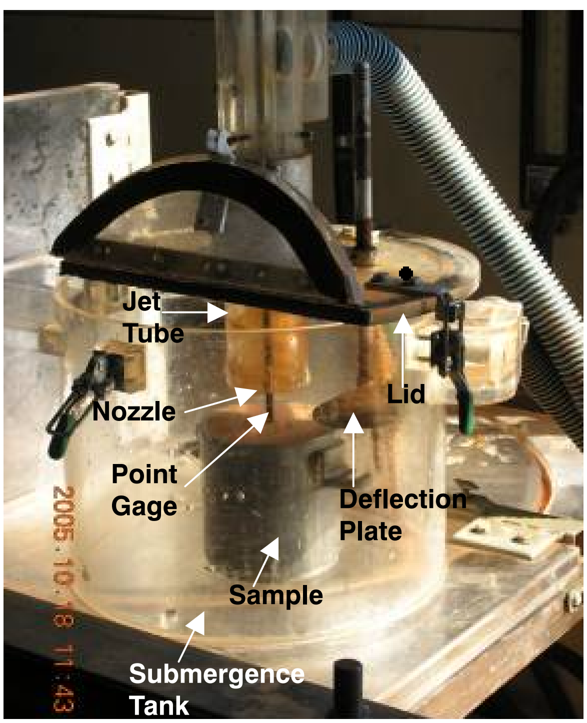

Figure 3. Laboratory JET apparatus. (Note: Detailed plans of apparatus are available from the authors.)

Laboratory JET Procedure and Analysis

Upon completion of compaction of a sample, the top surface of the specimen was trimmed. The specimen was then placed in the submergence tank, centering the mold directly beneath the jet test orifice. The tank was immediately filled, submerging the sample and jet orifice; and jet testing was initiated. The jet orifice is 6.4 mm in diameter and set perpendicular and at a height of 33 mm above the soil surface. The pressure head on the orifice was set at 775 mm. The maximum depth of scour in the mold was monitored using a point gage at set time intervals for a maximum of two hours or to a depth of scour of 116 mm, whichever occurred first. The laboratory JET apparatus, method, and analyses are similar to the field device described by Hanson and Cook (2004).

Field Embankment Testing

Three large-scale outdoor laboratory breach widening tests were conducted at the USDA-ARS Hydraulic Engineering Research Unit, in Stillwater, Oklahoma (Hunt et al., 2005). Widening tests W1 and W2 were conducted using Soil 2, and widening test W3 was conducted using Soil 3. The embankments were 1.3 m in height with a 0.30-m wide notch through the center of the entire height of the embankment (fig. 4). The embankments were constructed in lifts, with a compacted lift thickness of 0.12-m, using a self-propelled vibratory pad-foot roller. Each lift was compacted with two passes of the roller in vibration mode. Tube samples (76.2 mm diameter × 71.4 mm length) were taken from each compacted lift to determine the average compaction density and water content, and percent dry density of the standard compaction dry density (table 2). Water was passed through the notch and the change in width of the notch was monitored during the duration of the test (figs. 5 and 6). The rate of widening and the calculated hydraulic stress were used to determine the erodibility parameter k_d as described in detail by Hunt et al. (2005). They reported values for the erodibility coefficient of tests W1, W2, and W3 were determined to be 1.9, 6.1, and 0.14 $cm^3 N^{-1} s^{-1}$, respectively. These values of k_d are compared in the results section to laboratory JET results for samples prepared at standard compaction effort (ASTM D698A).

Results

Standard Compaction Effort

Examples of scour depth results for Soils 2 and 3 with the standard compaction effort of 25 blows/layer (B/L) are

Table 2. Average compaction water content and dry density.

Embankment Tests	Soil	Compaction Averages: WC[a] (%)	Compaction Averages: γ_d[b] (Mg-m^{-3})	% Standard Compaction of γ_{dmax}
W1	2	12.2	1.802	96.3
W2	2	10.7	1.795	95.9
W3	3	16.2	1.746	98.2

ASTM Standards were used to measure soil properties:
[a] D 2216, and
[b] D 2937.

Figure 4. Embankment widening test showing initial notch width.

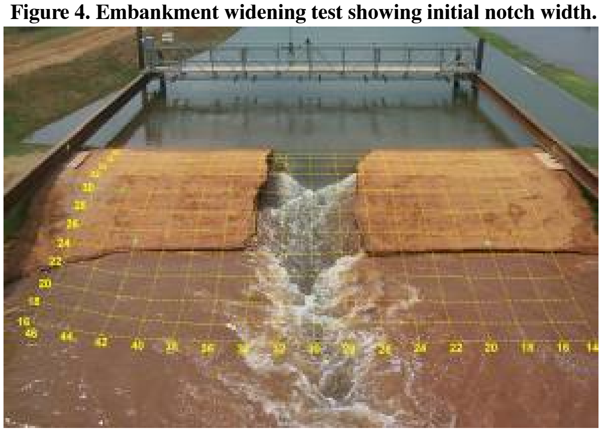

Figure 5. Photographic measurements of erosion width.

shown in figures 7 and 8, respectively. These scour depth results were selected to show the contrast in results caused by changes in water content and changes in soil types. As can be observed from the plot of scour depth versus time, the water content had a significant effect from the driest sample to middle range water content, but it showed less effect from the middle range water content to the wettest sample for each soil. It should be noted that this is over a 4-percentage point change in water content in each case. It can also be observed that the total test for the wettest samples of Soil 2 was 10 min, whereas Soil 3 was 120 min. This indicates the significance of soil texture.

The detachment coefficient k_d and critical stress τ_c values were determined from the JET results using the method described by Hanson and Cook (2004). Hanson and Simon (2001) observed a general relationship between k_d and τ_c of $k_d = 0.2(\tau_c)^{-0.5}$ that also appears to fit the results from these tests (fig. 9). Since the two parameters appear to generally be a function of one another, the discussion of the implications of the results comparing erodibility to compaction will be developed based on the measured values of k_d.

The k_d results from the laboratory compacted samples for Soils 2 and 3 using the standard compaction effort are shown in figures 10 and 11, respectively. The results from the breach widening field tests as reported by Hunt et al. (2005) are also plotted showing a general agreement with the laboratory measurements. This indicates that the laboratory testing can be a useful tool in predicting the erodibility parameters for an embankment sample compacted to the same degree of compaction at a similar water content. The results from the laboratory samples show that k_d varies with the compaction

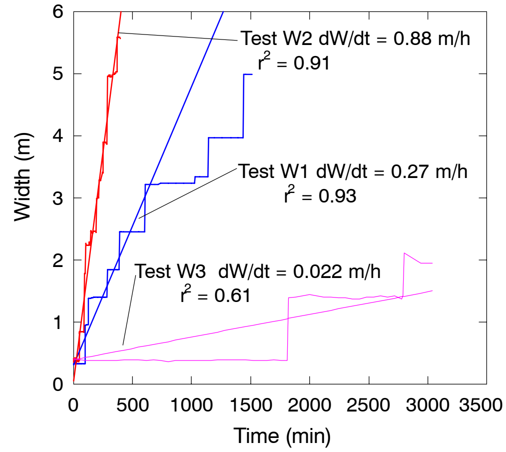

Figure 6. Breach width and widening rate for tests W1, W2, and W3.

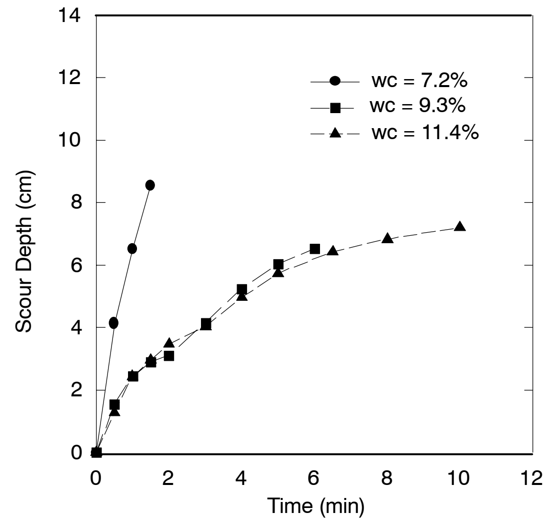

Figure 7. Soil 2 – Scour depth vs. time for standard compaction (25 B/L).

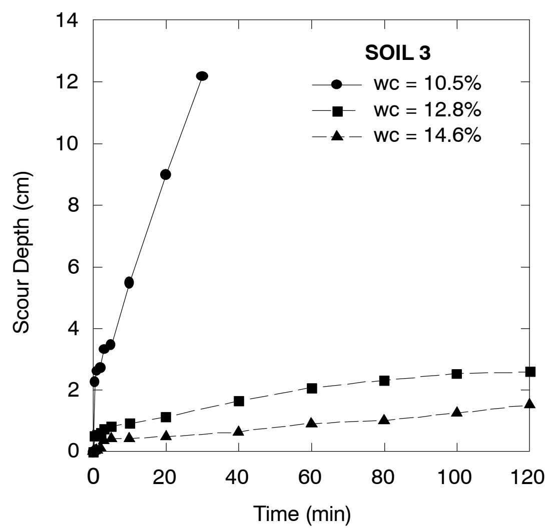

Figure 8. Soil 3 – Scour depth vs. time for standard compaction (25 B/L).

water content for Soils 2 and 3 in similar fashion. The erodibility of samples compacted dry of optimum water content is affected more by changes in water content than samples compacted on the wet side of optimum. For Soil 2, a 2% change in water content changed k_d by two orders of

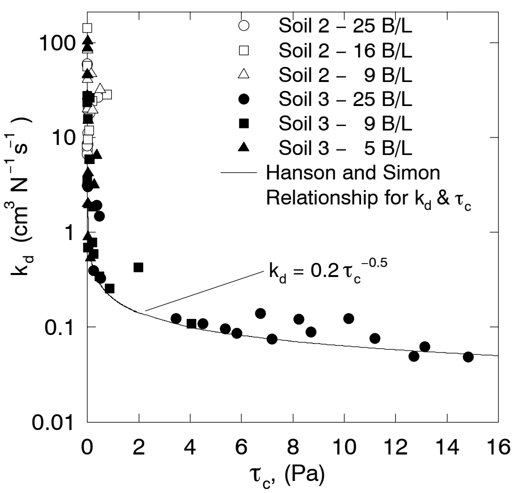

Figure 9. Relationship of k_d vs. τ_c.

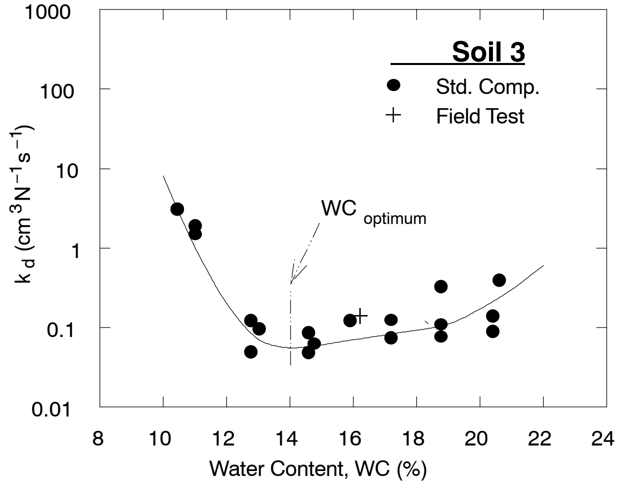

Figure 11. k_d versus molding water content for standard compaction effort of Soil 3.

magnitude on the dry side of optimum, whereas a relatively minor change in the value of k_d occurred for a 2% change on the wet side of optimum. A 2% change in water content resulted in an order of magnitude change in k_d on the dry side of optimum for Soil 3, whereas a 2% change on the wet side results in a relatively minor increase for either soil. Another conclusion that can be reached when considering figures 10 and 11 is that soil texture and plasticity also play an important role in the k_d parameter and the soil's erodibility. There are approximately two orders of magnitude difference in k_d between Soil 2 and Soil 3 when compacted at the optimum water contents at a given compaction effort.

Multiple Compaction Efforts

The variation in k_d with compaction water contents for the three levels of compaction effort for both soils is shown in figures 12 and 13. The resulting curves for each compaction effort coincide at higher compaction water contents and are distinctly separate at lower compaction water contents. Each curve has a point at which k_d is at a minimum. This point occurs at a lower compaction water content for a higher compactive effort. The slope of the curve also becomes steeper on the dry side of optimum with increases in compaction effort. The k_d parameter varies over several orders of magnitude depending on soil texture and plasticity, and compaction effort and water content.

The reason the curves merge at greater compaction water contents is that the compactive energy has less effect at high compaction water contents. The compaction effort is dissipated in the pore pressure generated rather than in affecting particle rearrangement. Water contents wetter than about 4% above optimum compactive effort, do not produce much change in the soil because there is little air remaining in the sample and you are essentially compacting water and soil, both of which are incompressible.

Using the JET results a set of four lines of equal k_d, iso-k_d lines, are constructed for Soil 2 (fig. 14), and Soil 3 (fig. 15) representing curves of equal k_d values plotted on water content (WC) versus dry density γ_d plots. Iso-k_d lines for Soil 2 represent k_d values of 10, 20, 60, and 100 cm^3 N^{-1} s^{-1}. Iso-k_d lines for Soil 3 represent k_d values of 0.1, 0.2, 1.0, and 10 cm^3/N-s.

Comparison of Specification Methods

Even though laboratory-scale compaction can never perfectly duplicate the field scale heavy equipment compaction, laboratory results are used to specify field compaction. Two methods of specification based on laboratory testing as previously described are: 1) the most common compaction specification procedure requires the soil to be compacted to

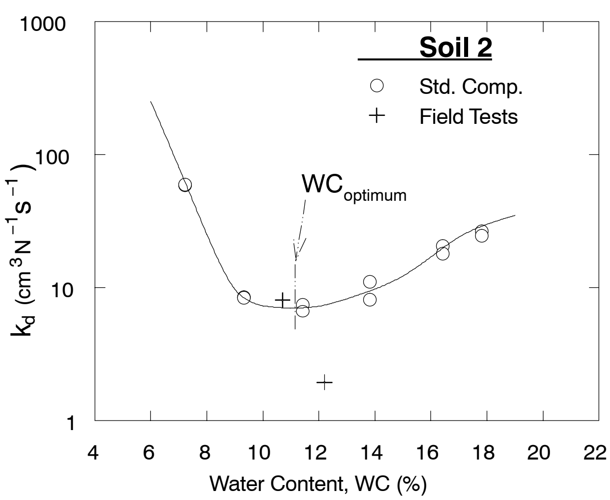

Figure 10. k_d versus molding water content for standard compaction effort of Soil 2.

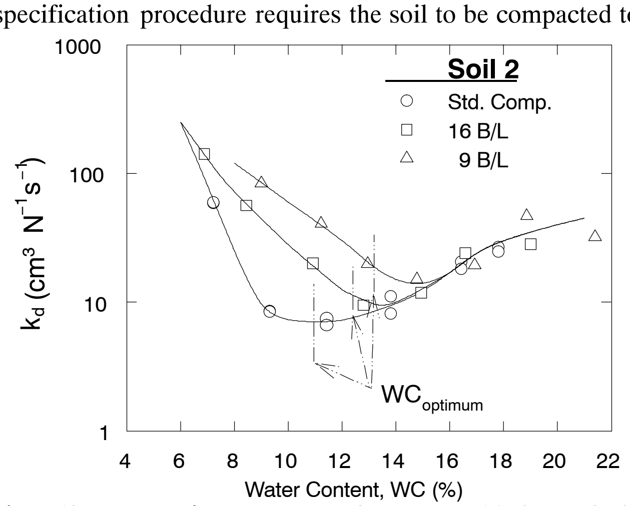

Figure 12. k_d vs. molding water content for standard, 16 B/L, and 9 B/L compaction effort of Soil 2.

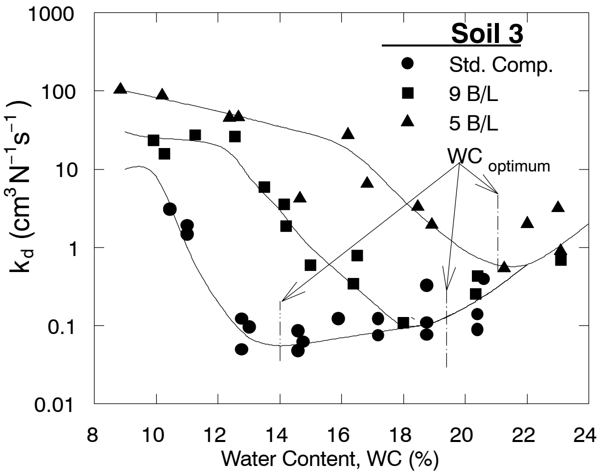

Figure 13. k_d vs. molding water content for standard, 9 B/L, and 5 B/L compaction effort of Soil 3.

a minimum dry density γ_d within a specified range of water content WC; 2) an alternative procedure specifies an acceptable zone of dry densities and water contents based on laboratory test performance, in this case erodibility. A comparison of these two specifications methods based on the test results for Soils 2 and 3 is shown in figures 16 and 17, respectively. A typical current specification approach for method 1 would require a minimum density of 95% of Maximum Standard Compaction dry density γ_{dmax} and a water content range of -2% to +3% of the optimum water content (WC_{opt}). Compaction specifications normally provide conservative values for soil behavior parameters, but it has been recognized that this is not necessarily the case for hydraulic conductivity (Daniel and Benson, 1990). Based on results for Soils 2 and 3 in figures 16 and 17, it is observed that this may not be the case for soil erodibility, either. The lower left area of the acceptable zone for the typical method (method 1) may result in unacceptable erodibilities, depending on design requirements and allowable failure rates.

The proposed method (method 2) requires a determination of an acceptable property performance level in-order to define the acceptable zone. There are two approaches to determining an acceptable performance level. One approach is to set a single value of performance that must be attained by the compacted material regardless of the material. This is typically the approach taken for liners and covers for

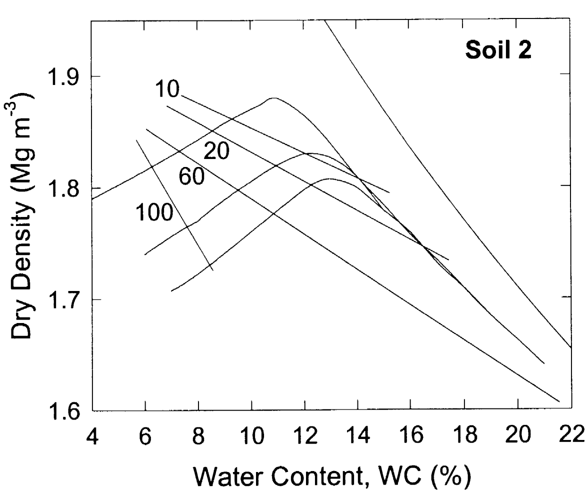

Figure 14. Iso-k_d lines for Soil 2.

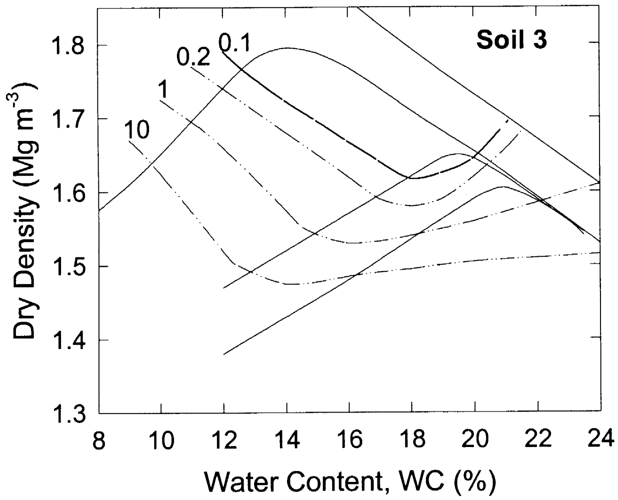

Figure 15. Iso-k_d lines for Soil 3.

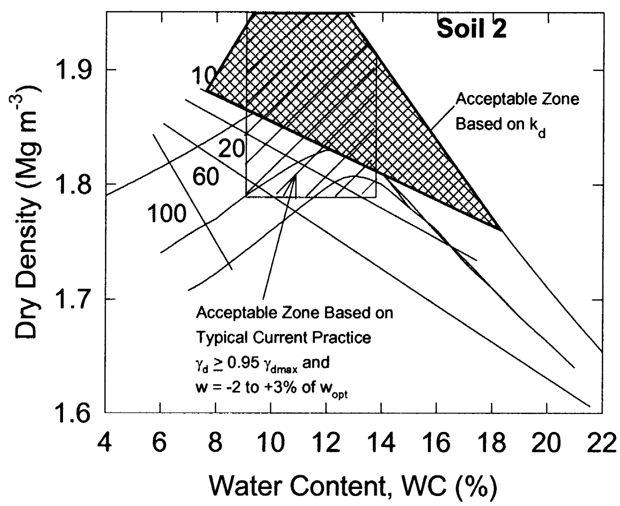

Figure 16. Acceptable zone of compaction for Soil 2 based on typical current specifications and measured k_d.

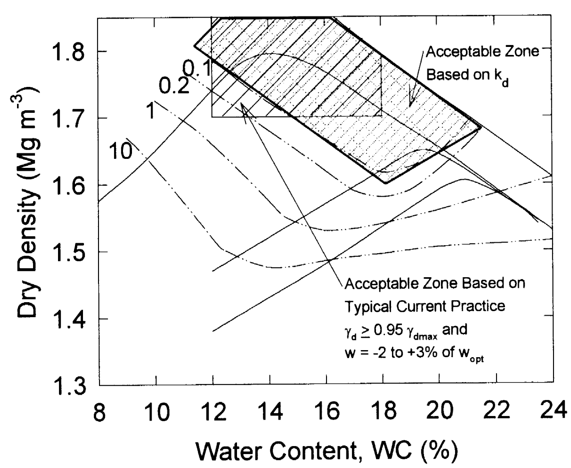

Figure 17. Acceptable zone of compaction for Soil 3 based on typical current specifications and measured k_d.

municipal and hazardous waste containment, with a requirement, for example, of achieving hydraulic conductivity values that are $\leq 1 \times 10^{-9}$ m s^{-1}. The other approach is to set a value of performance that is determined to be attainable and optimum for a given material and compaction conditions. The latter approach is taken here for purposes of comparison and discussion between methods 1 and 2. Based on k_d values for Soil 2 (figs. 12 and 14) an acceptable level of erodibility could be set at $k_d \leq 10$ cm^3 N^{-1} s^{-1}. This results in an acceptable zone as depicted in figure 16. This type of approach would end up with tighter specifications than method 1 but would also reduce the potential erodibility. Based on k_d values for Soil 3 (figs. 13 and 15) an acceptable level of erodibility could be set at a level of $k_d \leq 0.1$ cm^3 N^{-1} s^{-1}. This results in an acceptable zone as depicted in figure 17. This would end up with tighter specifications than method 1 for lower water contents but would provide a wider range of acceptable densities at higher water contents. Acceptable levels of erodibility would also have to be balanced with acceptable levels of strength, shrink swell, and hydraulic conductivity.

Summary and Conclusions

The results from the series of laboratory JET(s) on Soil 2 and Soil 3 showed that: 1) soil texture and plasticity are important parameters in determining erodibility and 2) compaction water content and compaction effort play a major role in determining erodibility as well. The detachment parameter k_d, as an indicator of erodibility, was observed to vary over several orders of magnitude for various combinations of soil type, water content, and compaction effort. This indicates the importance of measuring this parameter to determine anticipated performance and compaction specifications for constructed embankments. Soil texture and plasticity is an important parameter in determining erodibility but the erodibility of a poorly compacted CL material can approach that of a well compacted SM material. Values of k_d measured in laboratory JET(s) agreed well with values determined from field embankment erosion tests on breach widening.

Conducting laboratory tests on compacted samples may be helpful in determining compaction specifications to obtain desirable values of erodibility parameters. This will allow predicting rates of embankment failure as part of design. Two methods of compaction specifications were examined and compared to JET results in this study. The methods were: 1) a typical standard specification based on a minimum γ_d and a range of w, and 2) a specification based on a zone of acceptable performance of erodibility for a range of γ_d and WC. Contrasting the two methods indicates that method 2 may result in tighter or looser specifications, depending on the established value of maximum permissible erodibility. Since method 2 is actually based on performance measurements it may be desirable for certain applications. The other point of consideration is that erodibility is not the only performance parameter of interest. Therefore, acceptable zones of compaction need to also be taken into account for other performance parameters (i.e. strength, shrinkage, and conductivity). Detailed plans of the laboratory JET apparatus are available from the authors.

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