THE INFLUENCE OF SOME ENGINEERING PARAMETERS ON THE EROSION OF SOILS

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An experimental investigation is carried out concerning the effects of engineering parameters on fine soil erosion. The chosen parameters characterize the density and the saturation of the soil. The influence on erosion resistance of energy, density, water content at compaction, and presence of a saturation stage or not are investigated. The soil erosion behavior is evaluated with a Jet Erosion Test device. The interpretation of the performed data is made according to a linear relationship between an excess hydraulic shear stress and the rate of erosion. The effects of the compaction and of the saturation are indicated by the observed variation of the erosion law parameters. The results underline the effects of the soil fabric and the saturation on the soil erodibility.

Key Words : *Erodibility, Jet Erosion Test, Saturation, Water Content, Compaction*

1. INTRODUCTION

From the literature concerning soil erosion, water content is one of the key factors affecting erosion behavior, as is the compaction (Hanson and Hunt[1)]). The objective of this study is to test the influence of these two engineering parameters along with the influence of saturation on the erosion behavior. The coupled water content and energy at the time of compaction defines the primary state of the soil, and the saturation history after compaction defines an altered state for the soil.

A protocol is defined for preparing and testing soil specimens to study the variation of erodibility as a function of the compaction conditions and saturation history. The test results are interpreted using a linear erosion law which represents the erodibility in terms of an erosion rate coefficient and the critical shear stress. The effect of the engineering parameters on the erodibility parameters is presented.

2. EXPERIMENTAL PROTOCOL

(1) Preparation of the specimens

It involves three different operations:

- initial soil preparation;
- compaction;
- curing in one of two environments designed to produce either a saturated specimen or a specimen that can be tested at its original compaction moisture content.

Initially, the soil is air dried, sieved to eliminate material larger than the U.S. No. 4 sieve (A.S.T.M.), and then stockpiled in plastic buckets. Then, the following procedure is used to moisturize the material.

Initial water content is determined for the stockpiled soil. Additional water is added and mixed with the soil to reach a target water content. The soil is placed into a sealed plastic bag, which is then stored in a plastic container with a humidity source for at least 36 h.

Following the initial conditioning of the soil, compacted test specimens are prepared and saturated if desired. The compaction is made in a standard Proctor mould (101.6 mm diameter, 944 cm3, volume) with a standard Proctor plate. Two rammers are used: the “normal” (2.49-kg, 305 mm drop) and the “modified” (4.54-kg, 457 mm drop). The compaction is always made in 3 layers and 25 blows per layer. Water content is determined from uncompacted material. If saturation is required, it is produced in an upward direction under a constant hydraulic gradient of 10 m/m with a permeameter built for a Proctor mould. The specimen is confined to maintain a constant volume during the saturation process. The degree of saturation is evaluated by checking the specimen weight. Samples are kept in the saturation chamber for a minimum of 48 h.

Five different compaction water contents were targeted for each tested soil. After compaction, some specimens were saturated, while others were held at their compaction water content until erosion testing could be performed.

(2) Description of the Jet Erosion Test

The apparatus used to evaluate erodibility is the submerged jet erosion test (JET) device (Hanson and Cook[2)]). It applies a water jet to a submerged soil surface and the scour depth beneath the jet is measured over time. The JET is composed of 3 parts as seen in figure 1.

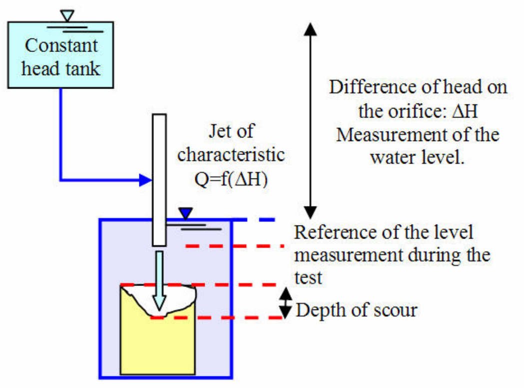

Figure 1 Schematic view of the JET.

The erosive stress applied by the jet is adjusted by varying the pressure head applied to the nozzle, and the initial distance of the nozzle to the soil-water interface.

3. METHOD OF INTERPRETATION

(1) The erosion law

Erodibility can be modelled with an erosive law whose parameters are determined from the experimental data (the scour depth [J] versus time). Stein and Nett[3)] and Hanson and Cook[2)] propose a linear relationship between the hydraulic excess shear stress $\tau - \tau_c$ and the rate of erosion $\dot{\varepsilon}$:

$$\frac{dJ}{dt} = \dot{\varepsilon} = k_d * (\tau - \tau_C) \qquad (1)$$

The erosion law is built on 2 parameters, an erosion coefficient k_d [m3/(N·s)],and a critical shear stress τ_C [Pa].

(2) Description of the jet hydrodynamics

Shear stresses applied during a test are estimated from an analysis of the jet hydrodynamics on the centerline. The water velocity U_0 [m/s] is deduced from the head difference ΔH [m] applied on the nozzle.

$$U_0 = \sqrt{2 * g * \Delta H} \qquad (2)$$

Diffusion of the jet causes the water velocity U at the soil-water interface to be inversely proportional to the distance J from the nozzle, for distances greater than the length of the potential core of the jet, J_P.

$$\frac{U}{U_0} = \frac{J_p}{J}, J > J_P \qquad (3)$$
$$J_P = 6{,}2 * d_0$$

with d_0 [m] : nozzle diameter.

Then, the water velocity U is related to the shear stress with the Chezy equation (equation 4).

$$\tau = C_f * \rho * U^2 \qquad (4)$$
$$C_f = 0{,}00416$$

(3) Back analysis of the experimental data

By rewriting our equation of erosion using equation 1, 3 and, using the notion of the equilibrium depth ($\tau = \tau_C$ (no erosion)), a nondimensional equation is built for $J > J_P$ (equation 5).

$$t = T_R \left(-J^* \Big|_{J_i^*}^{J^*} + \frac{1}{2} Ln\left(\frac{1+J^*}{1-J^*}\right) \Big|_{J_i^*}^{J^*} \right) \qquad (5)$$

with $T_R = \dfrac{J_e}{k_d \ \tau_C} \quad J^* = \dfrac{J}{J_e}$.

To correlate our experimental data set with the theoretical development, a two-step method is used. First, the depth of equilibrium Je is obtained by using the Blaisdell[4)] analysis. The value is used to estimate the critical shear stress by analyzing the hydraulic conditions that would exist at this equilibrium depth (equation 3). Second, the k_d value is adjusted to fit the experimental time series of scour depths to the nondimensional model (equation 4).

(4) The experimental conditions

An initial elevation of the jet orifice is set at a distance J(0) > Jp and this elevation is maintained throughout the test. Therefore during the test, as scour of the soil beneath the jet increases with time, the distance from the jet orifice and soil surface increases. This initial distance and the pressure head applied to the nozzle are set prior to testing to produce a desired initial stress in accordance with equations (2) and (4). The pressure head was typically kept between 75 and 150 cm (30 to 60 inches). Once a head was chosen, it was kept constant during the duration of the test. The rates of erosion produced led to test durations ranging from 10 min to 4 h.

4. TESTED SOILS AND RESULTS

(1) Soil description

The two soils chosen for the tests are clayey soils. They were classified according to the Unified Soil Classification[5)] (L.L. : Liquid Limit, P.I. : Plastic Index). One soil is a CL-ML (P.I.=4, L.L.=21) named P2, the other is a CL (P.I.=15, L.L.=31) soil named P3. The main difference between these 2 soils is the amount of clay.

The compaction curves obtained for P2 are presented in figure 2. The optimum water content for standard Proctor compaction is roughly 11.5% - 12% with a density of 1900 kg/m3. Concerning P3 (refer figure 3), the optimal water content is 13.7% for a dry density of 1860 kg/m3.

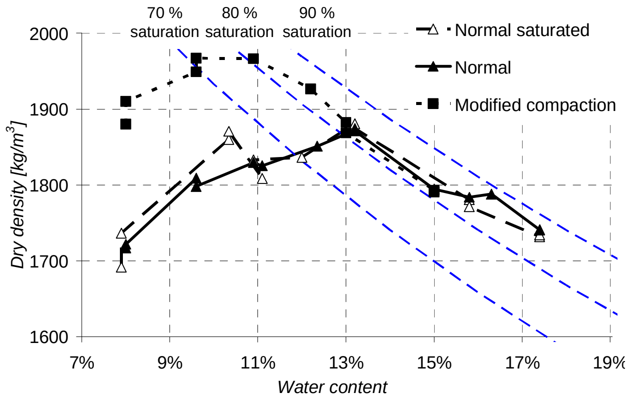

Figure 2 Dry density verswater content at compaction for the P2 soil.

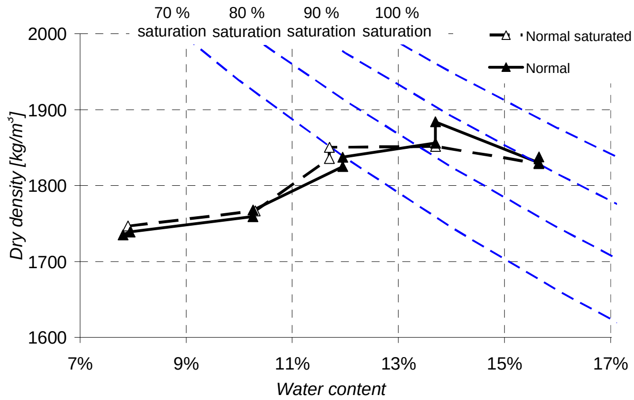

Figure 3 Dry density versus water content at compaction for the P3 soil.

(2) Results concerning the erosion behavior

In table 1, the values corresponding to the minimal erodibility (k_d and τ_C) for the soil P2 and P3 are summarized for a given preparation (water content at compaction, compaction energy and saturation or not). It can be seen that the P3 soil is less erodible in the case of optimal conditions. This can be explained partly by the clay content and the Plasticity Index.

Figures 4, 5, 6 and 7 present the values of the erodibility parameters relative to the value referred in the table 1 for a normal compaction of the soil P2 (k_d ref and τ_C ref). The described parameters are the erosion coefficient and the critical shear stress.

Table 1 Measured erosion law parameters of the different soils at the water content which minimizes the erosion for a given preparation.

Soil	Type of preparation	Water content [%]	k_d [m^3/(N.s)]	τ_c [Pa]
P2	Normal	11.10 - 12	$7.3*10^{-08}$	8
	Normal saturated	12.35	$2.2*10^{-07}$	4
	Modified	9.6 - 10.9	$7.6*10^{-08}$	13
P3	Normal	13.7	$1.9*10^{-08}$	4
	Normal saturated	11.7 -13.7	$1.8*10^{-08}$	23

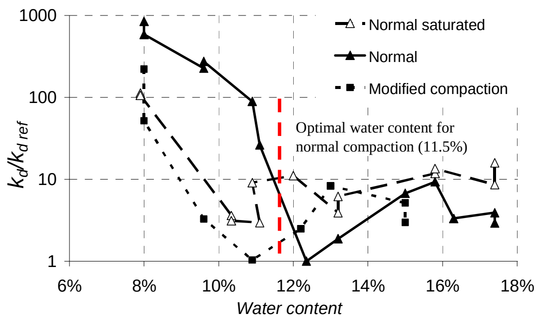

Figure 4 Relative variation of the erosion coefficient k_d for the P2 soil according to the water content at compaction.

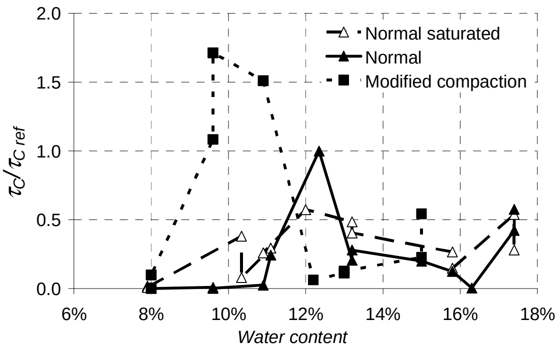

Figure 5 Relative variation of the critical shear stress τ_C for the P2 soil according to the water content at compaction.

On the figure 4 and 6, it is apparent that the condition of minimum erodibility corresponds to the optimum water content for compaction. On the dry side (water content less than the optimum), the erosion coefficient is 100 times higher than the measured value for the optimum water content. On the wet side (water content higher than the optimum), the erosion coefficient is only 10 times higher than the measured value for the optimum water content. The erosion rate coefficient is quite dependent on the water content at compaction and the compaction energy. The measurements of the critical shear stress show the same evolution (figure 5 and 7).

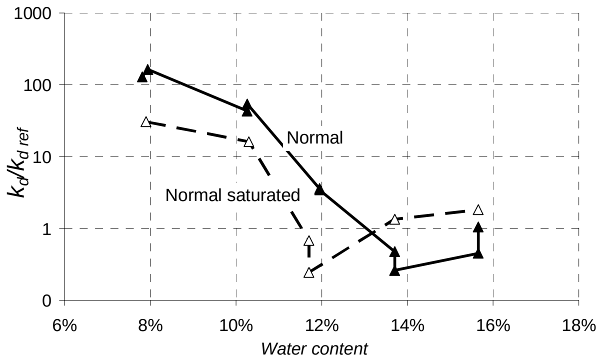

Figure 6 Relative variation of the erosion coefficient kd for the P3 soil according to the water content at compaction.

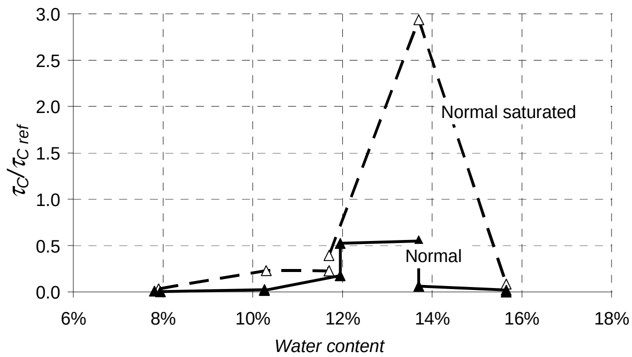

Figure 7 Relative variation of the critical shear stress τ_C for the P3 soil according to the water content at compaction.

The values for the minimal erosion (at optimum water content) are roughly the same for the normal and the modified compaction but the additional compaction energy reduces the optimum water content and shifts the entire erodibility relationship to the left (figure 4 and 5).

Saturation appears to have a similar effect as increased compaction energy by shifting the entire erodibility relationship (i.e. curve) to the left (figure 4 and 6). It also seems to reduce erodibility on the dry side and increase erodibility on the wet side. This phenomenon was also observed for dry side compaction of soil P3.

Moreover the curve representing the erosion coefficient kd, according to the water content seems linked to the curves representing the permeability versus the water content at compaction, presented by Lambe and Whitman[6].

These results seem to underline an effect of the soil fabric that depends on the saturation and on the compaction process. The effectiveness of this compaction can be defined by the dry density, the water in the pores, and the water adsorbed by the clay particles.

It could be concluded from these results that the erodibility is a function of the applied hydraulic stress and the soil fabric. This emphasizes the difficulties of estimating soil erodibility from correlation to engineering parameters without knowledge of the compaction process and saturation history. For clayey soils it appears that understanding the compaction process leads to a better understanding of the erosion process and the behavior of erodibility parameters. The erodibility seems to be linked closely to the fabric of the soil.

5. CONCLUSION

The erodibility of a soil impacted by a jet is the result of the interaction between the water and the fabric of this soil. This study shows the influence of the compaction effort and the saturation (at constant volume) on the soil erodibility.

A remaining work is to establish the same kind of curve with other device to quantify erodibility, as Hole Erosion Test. Moreover, consideration should be given to characterize the length scale of the soil fabric and its impact on the erodibility.

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