SOIL EROSION: THE INFLUENCE OF COMPACTION CURVE - APPLICATION ON SILT SOIL USING THE JET EROSION TEST

Van-Nghia Nguyen[1]

Abtract: *The influence of some soil parameters on the erosion of a silty soil, characterized by the erosion coefficient k_D, the critical shear stress τ_c, and the equilibrium erosion depth P_e, is studied. A series of test using the submerged Jet Erosion Tests was carried out to examine the influence of dry density ρ_d, compaction water content w. The results show that at dry side of compaction curve the erosion coefficient and the equilibrium erosion depth decrease when the dry density, the compaction water content, whereas the critical shear stress increases with these parameters. But an inverse relationship is observed at wet side of compaction curve.*

Keywords: Jet Erosion Test (JET), erosion parameter, erosion coefficient, critical shear stress.

1. INTRODUCTION

The erosion phenomenon is an important subject in civil engineering and especially in hydraulic engineering. Erosion phenomena may lead to loss of soil in the fields, scour on the banks of rivers and even, in some cases, to the failure of hydraulic constructions. Quantifying the rate of erosion and the critical shear stress is important for the engineers and scientists because these factors depend on many parameters of the soil. The erosion parameters depend on the properties of the soil, such as the type of soil, the percentage of clay, its mineralogy, as well as the dry density, moisture content, the mineral and ionic composition of the water flowing in the pores.

Previous research has indicated a significant influence of the dry density on soil erosion and the critical shear stress [1], [2], [5]. Lim [10] have shown that the soil structure significantly influenced the erosion resistance of the soil. Furthermore, Hanson and Hunt [7] have shown that the type of soil gave different sensitivities to erosion because the type of soil influences the compactness of the soil.

For estimating the erosion parameters of soil cohesive, several test devices were used: the Hydraulic Flume Test [13], the Erosion Function Apparatus [3], the Rotating Cylinder Test [11], the Jet Erosion Test [2], [6], the Mobile Jet Erodimeter [8], etc... In this work we used the Jet Erosion Test (JET) which was developed at Ecole Centrale Paris. And, concerning the factors which impacted erosion resistance, in this paper we studied in compaction water content, dry density and compaction degree of saturation. The tests were carried out using this improved device. This new JET device allows the change of these parameters to a certain extent, and measure not only the erosion depth in the center of the sample but also the scour profile (see 2.2).

2. SOIL CHARACTERIZATION AND EXPERIMENTAL APPARATUS

2.1. Soil characterization

The soil was a silty soil which was taken in a dike from the south of France. Soil testing ***was performed to determine the soil properties:*** *Atterberg limits (XP CEN ISO/TS 17892-12), particle size distribution (XP CEN ISO/TS 17892-4), Standard Proctor compaction test (NF P94-093). The liquid limit (w_L) ranges from 30 to 35%, the plastic limit (w_P), from 14 to 16%, the plasticity index (I_P), between 13 and 16%, and the methylene blue value, VBS = 1.8, which is consistent with the relatively high soil plasticity. The optimum water content ($\omega_{O\Pi N}$) ισ 17.2%, and the corresponding maximum dry unit ωειγητ $\gamma_{\delta O\Pi N}$ is about 16.8kN/m^3*

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2.2. Experimental apparatus

Following the work of Nguyen et al., [12], the experimental device (Figure 1 to Figure 3) was built at Ecole Centrale Paris (ECP) based on the original apparatus of Hanson and Cook [6]. The apparatus consists of the following parts: acquisition data unit (A), injection cell (B) with angle sensor (E), displacement sensor (F), pressure sensor (G), hydraulic pump (C), reservoir (D), point gauge (H), deflector (I) and Jet tube (J).

The injection cell (B) can rotate around an axis, which allows us to measure the depth of erosion not only in the center of the sample but also in other points on a circle (Figure 5). At its base, in the injection nozzle, the cell is equipped with a rotary valve (or deflector (I), not shown in the photo) that can stop manually the jet very quickly. The injection cell is supplied with water from a constant level reservoir, which can be arranged at different levels on a metal shelf (Figure 1). For constant level, the reservoir D is alimented by a pump C which withdraws water from the immersion reservoir.

A pressure sensor (G) at the top of the column measures the static head actually applied to the jet (when all the valves are open and the valve at the base of the cell is closed). The measurement of pressure is precise to 0.1mm.

An angular sensor (E) identifies the position of the center of the sample and the different positions of the depth sensor along a circular arc, the precision of this angular sensor is 0.01^{o}.

A vertical displacement sensor (F) of 20 cm equipped with a stroke extension rod is used to measure the depth of erosion. This sensor does not have a spring, so that the force exerted on the sample is only a function of the (constant) weight of the rod. The precision of this displacement sensor is 0.1mm.

The improvements, compared to the original device developed by Hanson, consist in the possibility of changing the values of real hydraulic head, h_1, depth of immersion in water of the specimen, h_2, and distance between the nozzle of jet and the specimen, h_3 (Figure 7), more accurate measurements, and the acquisition of the erosion profiles as shown in Figure 8. Moreover, it is not necessary to close supply valve, which was operated manually while we measured the depth of erosion and the erosion profiles.

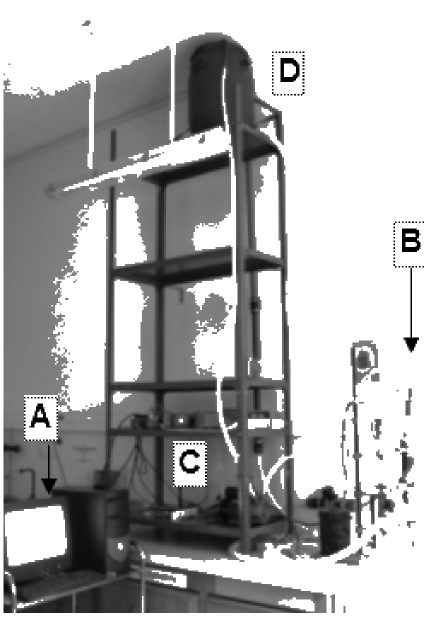

Figure 6: Supply system of jet in closed-circuit

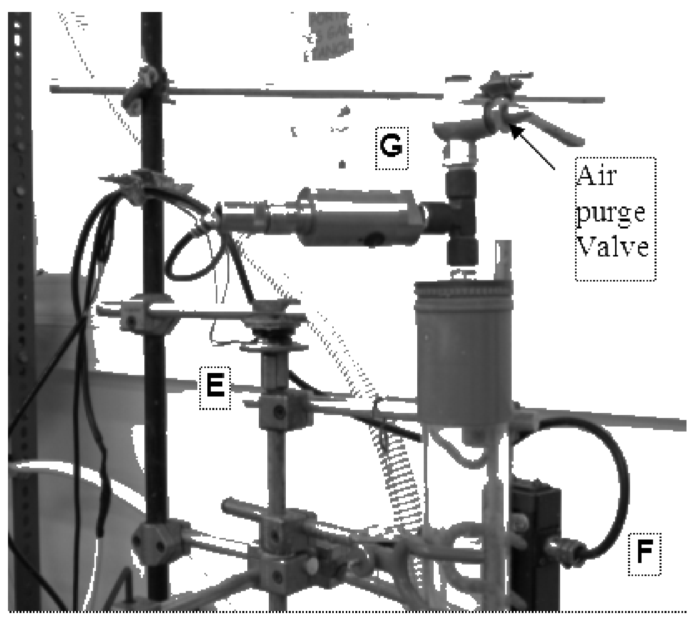

Figure 7: Pressure and angle sensors

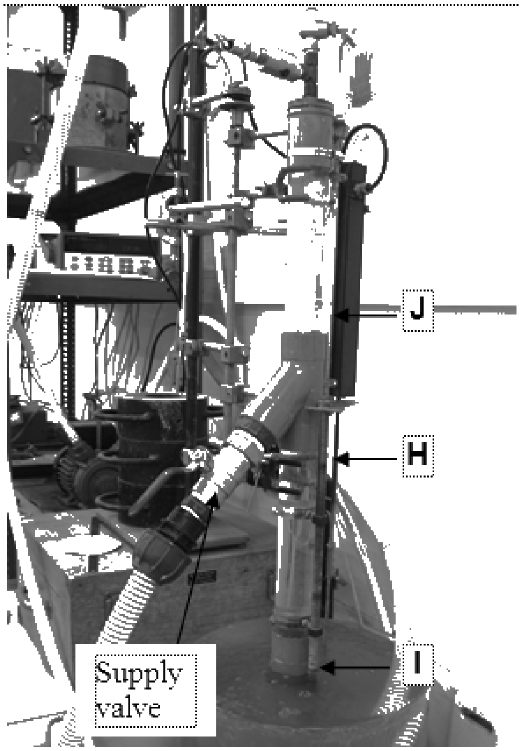

Figure 8: Photo of the injection cell

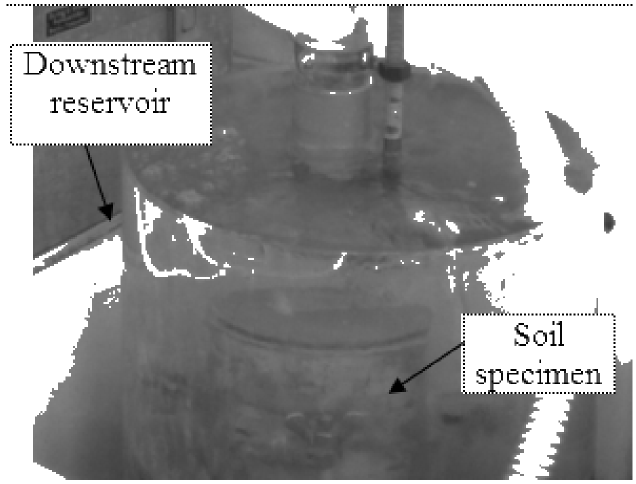

Figure 9: Sample submerged

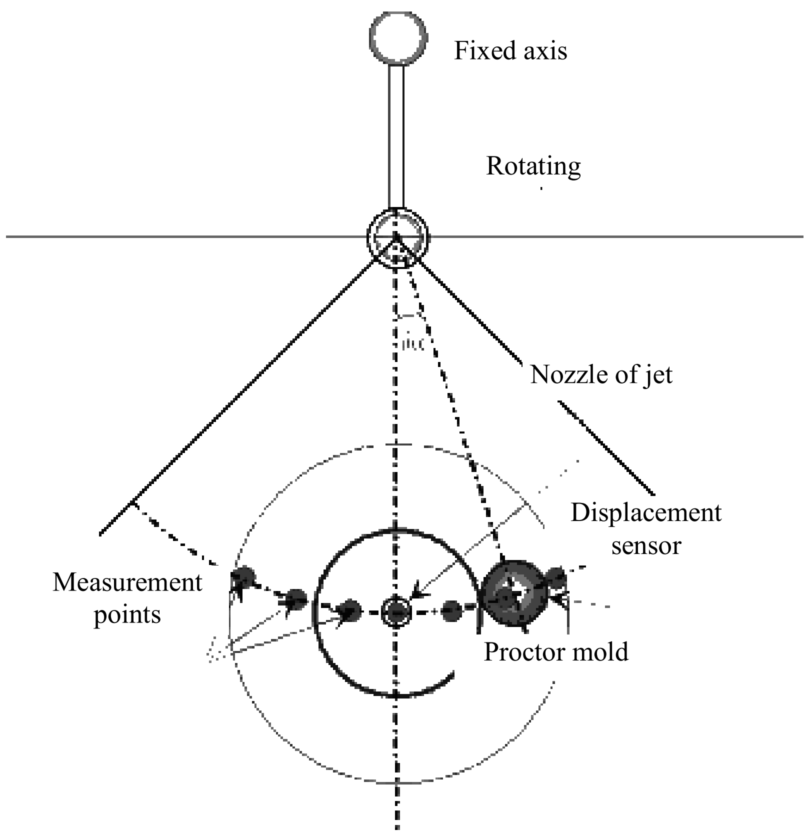

Figure 10: Displacement principle of the injection and measurement devices

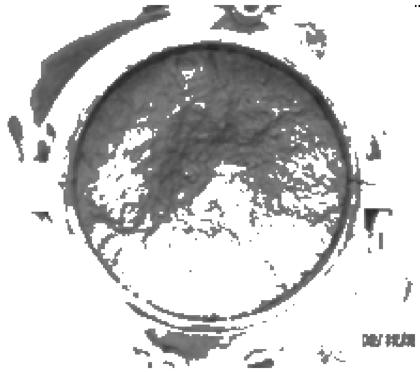

Figure 11: Photo of erosion cone

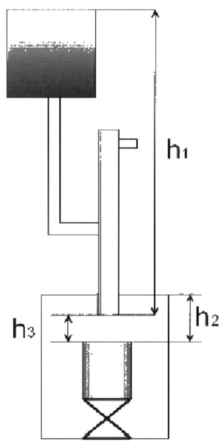

Figure 12: Schematic representation of h_1, h_2, h_3

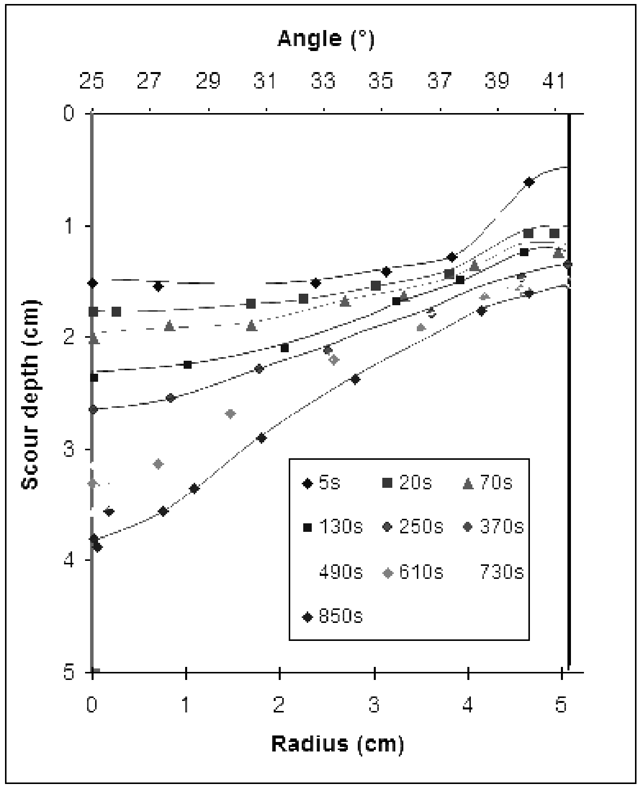

Figure 13: Example of erosion profiles corresponding to different measurement times

3. SAMPLES PREPARATION AND TEST PROCEDURES

3.1. Samples preparation

The soil was dried and crushed, then was sieved to 4 mm. Then, water was added and mixed thoroughly with the soil. Next, the soil is kept in a plastic bag for at least 24 hours to fully hydrate the soil. The samples are compacted statically by a hydraulic press in three layers in a Proctor mold to achieve the desired value of dry density and compaction water content. The values of the gravimetric compaction water content, w, varied from 14% to 20% (w_{OPN} = 17.2%) and the values of the dry density ρ_d, from 1.55 g/cm^3 to 1.75 g/cm^3 (dry unit weight γ_d = 15.21-17.17 kN/m^3).

3.2. Test procedures

The Proctor mold with the sample is placed in a reservoir under the jet (Figure 4), the sample is submerged 10 cm in the downstream reservoir (h_2 = 10 cm), and the jet is centrally located above the sample. The distance between the jet orifice (nozzle) and the initial surface of the sample is h_3 = 5cm. Then the jet is centered with respect to the sample and supply water to the system from the upstream reservoir with a real hydraulic head h_1 = 130 cm corresponding theoretical hydraulic head h_1* = 180 cm which was suitable to this tested soil. Schema representing h_1, h_2 and h_3 is presented on Figure 7.

4. RESULTS AND DISCUSSION

The results in figure from Figure 9 to Figure 11 show the variations of dry density, erosion coefficient, critical shear stress and equilibrium erosion depth P_e as a function of gravimetric compaction water content for the compaction energy corresponding to 25 blows. We find that:

- On the dry side, the equilibrium erosion depth and the coefficient k_D decrease when the compaction water content increases while the shear stress increases with compaction water content, it means that the erosion resistance increases with water content. On the dry side, the water has the effect of lubricating the grains.

- On the wet side, the equilibrium erosion depth and erosion coefficient increase with compaction water content while the shear stress decreases as the compaction water content increases, it means that the erosion resistance decreases with compaction water content. These results are in agreement with the conclusions of previous researchers [2], [5], [7].

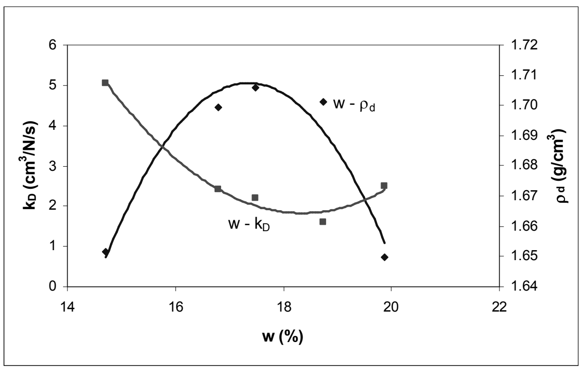

Figure 14: Relationship between the erosion coefficient, k_D, the dry density, ρ_d, and the compaction water content, w, on the compaction curve

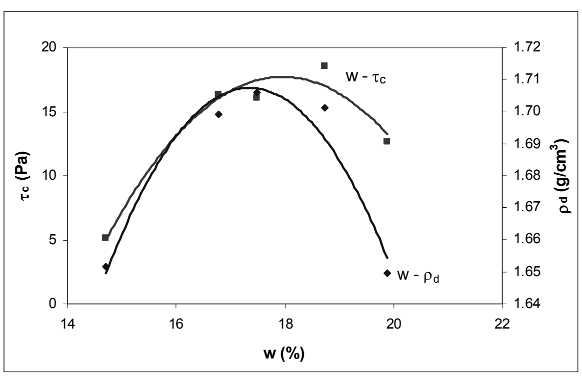

Figure 15: Relationship between the critical shear stress, τ_c , the dry density, ρ_d, and the compaction water content, w, on the compaction curve

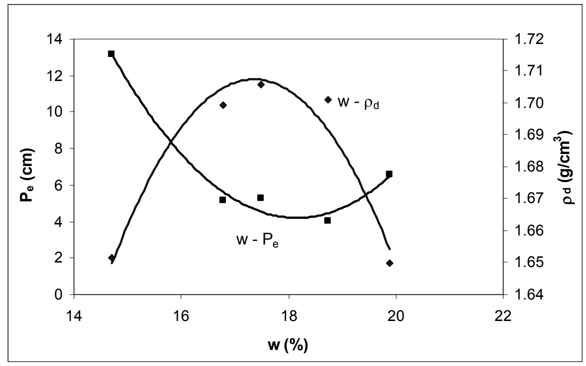

Figure 16: Relationship between the equilibrium erosion depth, P_e, the dry density, ρ_d, and the compaction water content, w, on the compaction curve

At the same dry density, the soil on the wet side is more resistant to erosion than the soil on the dry side because the soil does not have the same fabric on wet and dry sides [9]. On the dry side the soil features an aggregate structure, so the diameters of the inter-aggregate pores are large and inter-aggregate pores are filled with air. Whereas on the wet side, the grains are completely hydrated, the soil has a more homogeneous structure with particles arranged perpendicularly to the direction of loading, the diameter of the inter-aggregate pores are small and the pores are filled with water [4]. Furthermore, it was shown that the soil aggregates break more easily for soil on the wet side when it was immersed in water [14].

In order to get a clearer view of the influence of compaction water content, we plotted the values of k_D, τ_c and P_e as a function of compaction water content for a constant degree of saturation, here, the degree of saturation was determined after compaction. On Figure 12, we observe that the erosion coefficient and equilibrium erosion depth increase whereas the critical shear stress decreases when the compaction water content increases at constant degree of saturation. Relationship between k_D, τ_c and P_e with compaction water content is a power function. We note that, in Figure 12 (b, d), for the small degrees of saturation, the compaction water content influences evidently the erosion coefficient and the equilibrium erosion depth. But when the degree of saturation increases, the compaction water content has a negligible influence on the erosion coefficient and equilibrium erosion depth. In Figure 12c, we note that the critical shear stress decreases when the compaction water content increases at constant degree of saturation and the critical shear stress increases with the degree of saturation.

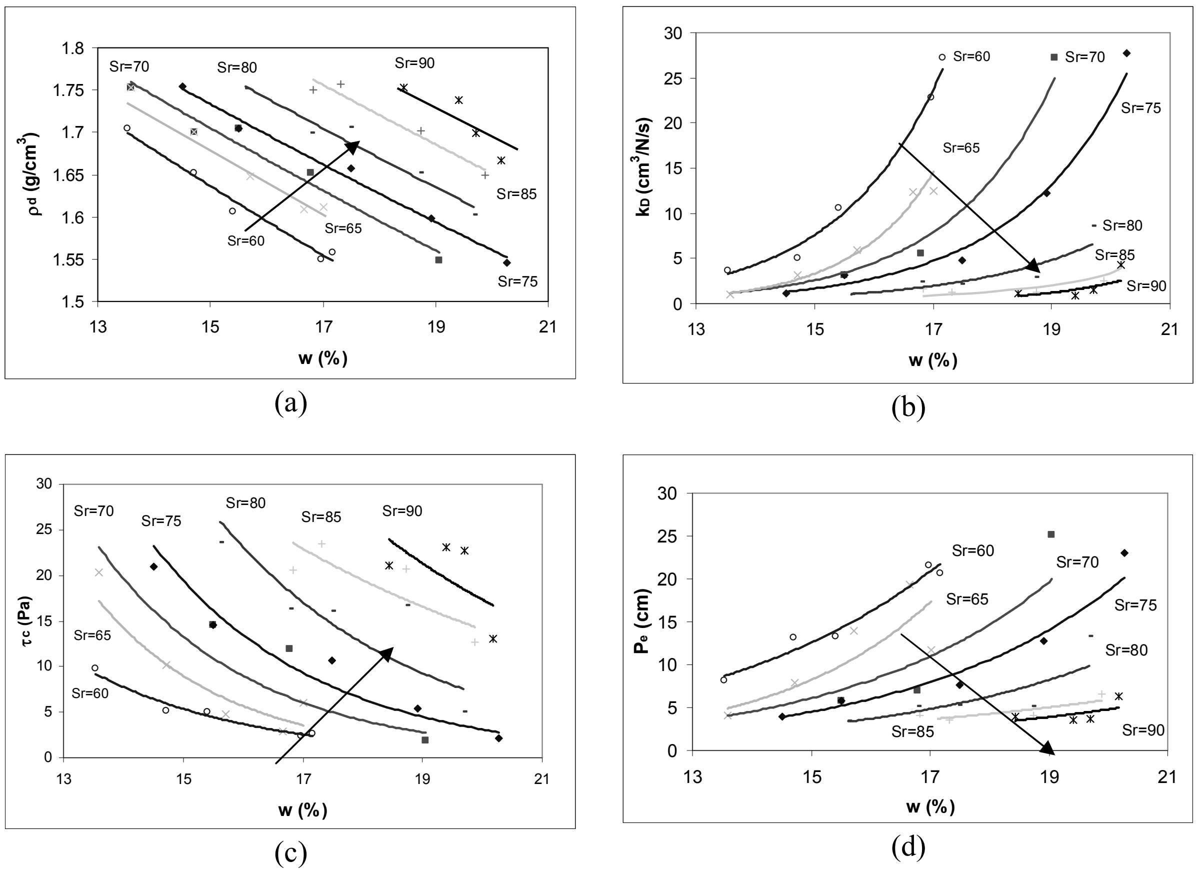

Figure 17: Relationship between the water content, w, the dry density, ρ_d, and the erosion parameters in the case of constant degree of saturation

5. Conclusion

This work presents the result of laboratory tests using an improved Jet Erosion Test device with an impinged jet. These tests highlight the influence of the dry density and the compaction water content on the erosion coefficient, the critical shear stress and the equilibrium erosion depth.

On the dry side of compaction curve, the erosion resistance increases with compaction water content but in other side we found an inverse result. And, at the same dry density, the soil at wet side is more resistant to erosion than one at dry side.

The critical shear stress decreases when the compaction water content increases at constant degree of saturation whereas the erosion coefficient and equilibrium erosion depth increase, it means that the erosion resistance decreases with an increase of compaction water content.

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Tóm tắt:

XÓI MÒN ĐẤT: ẢNH HƯỞNG CỦA ĐƯỜNG CONG ĐẦM NÉN – ỨNG DỤNG CHO ĐẤT Á SÉT KHI SỬ DỤNG THIẾT BỊ JET EROSION TEST

Bài báo nghiên cứu ảnh hưởng của một số thông số của đất đến các thông số xói của đất á sét như hệ số xói k_D, ứng suất giới hạn chống cắt τ_c và độ sâu cân bằng của hố xói P_e. Một loạt mẫu thí nghiệm được thực hiện sử dụng thiết bị Jet Erosion Test để nghiên cứu ảnh hưởng của dung trọng khô ρ_d và độ ẩm đầm nén của đất w. Kết quả cho thấy bên nhánh khô của đường cong đầm nén, hệ só xói và độ sâu cân bằng của hố xói giảm với độ tăng của độ ẩm đầm nén trong khi cường độ chống cắt giới hạn tăng. Nhưng bên phía nhánh ướt kết quả thu được ngược lại so với nhánh khô.

Từ khóa: Jet Erosion Test, thông số xói, hệ số xói, ứng suất giới hạn chống cắt.

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