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Characterization of the relationship soil density and simple compression resistance of silty soils

Caracterización de la relación entre la densidad y la resistencia a la compresión simple de limos

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Abstract

The unconfined compressive strength of soils is closely related to the shear strength that soil particles show in a material sample subjected to stress states where there are no lateral restrictions to stabilize the geotechnical structure. It is known that the resistance of a soil depends on its density and the type of soil. In engineering practice, it is highly desirable to have information in the form of empirical relationships that correlate readily and cheaply obtainable data for soil strength. This article presents an experimental study on materials subjected to compression without confinement and that leads to an empirical proposal that relates the density of a soil with the relationship it exhibits to simple compression.

Simple compression, Empirical relations, Density

Resumen

La resistencia a la compresión no confinada de los suelos está íntimamente relacionada con la resistencia al esfuerzo cortante que ofrecen las partículas de suelo en una muestra de material sujeta a estados de esfuerzo donde no existen restricciones laterales que estabilicen la estructura geotécnica. Es reconocido que la resistencia de un suelo depende de su densidad y del tipo de suelo. En la práctica ingenieril es altamente deseable contar con información en forma de relaciones empíricas que correlacionen datos obtenibles de manera rápida y económica para obtener la resistencia del suelo. En este artículo se presenta un estudio experimental sobre materiales sometidos a compresión sin confinamiento y que derivan en una propuesta empírica que relaciona la densidad de un suelo con la relación que exhibe a la compresión simple.

Compresión Simple, Relación empírica, Densidad

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Introduction

Shear resistance is the fundamental property of soils that is taken into account when designing any geotechnical structure (Rojas *et al*., 2011). A typical experimental observation of soils as construction materials, is that the strength to shear stresses of these materials depends on the confinement stress to which they are subjected (Alonso *et al*., 1990).

To represent this property, the usual convention in soil mechanics is to express the vertical compression stresses with the notation σ_1, as well as the horizontal compression stresses with the notation σ_3. Therefore, the shear stress resistance for a soil sample subjected to a horizontal confining stress σ_3 is expressed by Equation (1):

$$\tau = \sigma_3 \tan\phi + c \quad (1)$$

Where τ is the shear strength exhibited by the soil, ϕ is the friction angle and c is known as cohesion, which is a parameter that depends on moisture conditions.

Under field conditions in which geotechnical structures are not confined, the condition $\sigma_3 = 0$ is met. This state of stress is known as "unconfined" and is present in a variety of geotechnical schemes. Such is the case of vertical cuts in excavations without casings or lateral retention structures. In such a case, the strength of the structure made with soil will depend exclusively on the strength to shear stress quantified as cohesion (Lu *et al*., 2017):

$$\tau = c \quad (2)$$

Therefore, Equation (2) allows identifying the shear strength of soils under unconfined conditions. As can be seen in the Mohr's circle corresponding to the stress state in unconfined compression conditions (Figure 1), this implies that the shear strength in “unconfined” conditions can be evaluated as $\tau = c = \sigma_1/2$. In this case, the stress σ_1 is known as the deviator stress q and has the same value as σ_1.

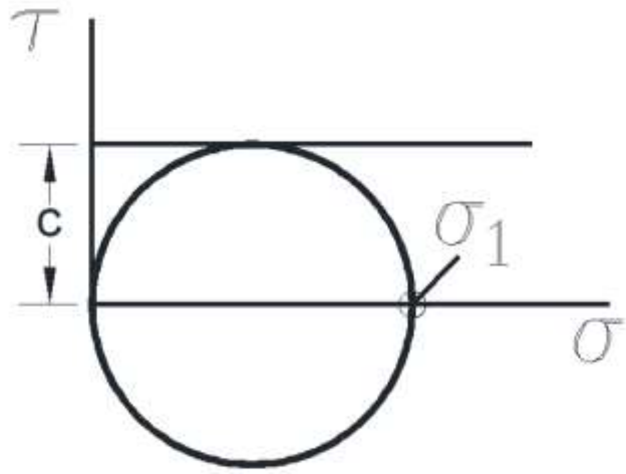

Figure 1 Mohr’s circle corresponding to an unconfined stress state

It is fundamental to recognize the role that soil density plays in the value that Equation (2) takes. Experimental reports on laboratory soils make it possible to identify that the parameters to describe shear strength of the soils (Equation (1)) is a function of the density of the materials (Rojas *et al*., 2017). Laboratory tests reported by Futai and Almeida (2005) evaluate the strength parameters of a soil deposit at different depths of a residual soil. Here the different values of ϕ and c parameters for different densities are exhibited. That is, as confirmed by the more agglutinated the soil particles are, the greater the strength to shear stress.

In practical geotechnical engineering, the use of empirical relationships is recurrent to expedite the proposed solutions to a given problem. These solutions, despite being highly dependent on the type of test and the material to be used, allow the test results to be initially used in immediate applications without the need to resort to an exhaustive experimentation campaign.

This paper presents the relationship between the density and the strength to simple compression that a silty sand material exhibit. Such relationship has been extensively recognized in several research papers such as Sun *et al*. (2007). The subsequent section describes the triaxial compression equipment used for the evaluation of the mechanical properties of the soils that were selected for analysis. Moreover, the way in which they were selected and subjected to simple compression efforts is explained.

Triaxial compression device used in this study

The triaxial compression equipment used in the development of the research is a Triaxial Press with analog triaxial configuration (Figure 2). It is made up of a load frame that is made up of a robust two-column structure, ensuring rigidity for a maximum capacity of 5.1 tons, with a maximum loading speed of 9mm per minute and a maximum deformation of 90mm. It is added with a cell that confines the soil samples within a controlled space. Axial strains are measured with a potentiometric displacement transducer. The force P is transmitted through an external load cell with a capacity of 5.1 tons to apply a vertical axial force $q = P/A$ to a cylindrical soil sample and produce unit strains $\varepsilon = \Delta l/lo$; A is the cross-sectional area to which the stresses q are applied, Δl are the strains in the direction of application of q, and lo is the initial length of the soil sample.

Figure 2 TRIAX 28-WF-4001 Triaxial Press with analog triaxial configuration

The cell and the transducer send signals that are continuously automatically interpreted and recorded, allowing to track the evolution of the axial stress vs. axial deformation.

Classification of the soil used for the investigation

The soil is a highly compressible silt, classified with the notation MH (according to the Unified Soil Classification System (SUCS) (Braja M. Das, 2010)).

Different tests were carried out with different moisture contents, it is sought that the cylindrical soil sample is uniform and that it allows its placement in the compression equipment. From the moisture content variation tests, it is concluded that the best workability results from considering a moisture content of 15%, since in this way the expected manageability and homogeneity conditions are met. Figure 3 shows the material under various moisture conditions.

Figure 1 Upper: MH1 with a 15% moisture content. Central: MH1 with a 20% moisture content. Lower: MH1 with a 30% moisture content.

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Fabrication of cylindrical soil samples

It is proposed to study the behavior to unconfined compression under increasing densities 13 kN/m^3, 15 kN/m^3 and 17 kN/m^3, all of them under a moisture content of 15%. It should be noted that it was not possible to produce material samples at densities lower than 13 kN/m^3 since the structure and integrity of the soil cylinder were compromised since the sample was too fragile. The cylindrical soil specimens were fabricated using the static compaction process by layers, controlling the speed of application of the load (0.5 millimeters per minute) in the triaxial compression device.

This allowed the repeatability of the process thus ruling out uncertainties inherent to manual compaction. The strain rate was established considering that the material will be subject to undrained conditions.

The final cylindrical specimens are 9.5 centimeters high and appertain a diameter of 5 centimeters. The cylindrical mold meets the necessary dimensions, with an internal diameter of 5 cm and a height of 10 cm, which must be greater than the height of the soil cylinder in order to apply pressure and provide density. proposal (Figure 4).

Figure 2 Soil sample after compaction in the used mold

Figure 5 shows the triaxial compression device with the specimen in position before applying the deformation loads.

Figure 3 A soil sample placed in position in the triaxial compression device

Study of unconfined strength

Figure 6 shows the cylindrical samples after failure, that is, once the shear strength has been reached under unconfined compression conditions. It can be noted that there is a tilted failure in each one of them, which confirms the results reported by Lu *et al*., (2009) in the sense that the strength to shear stress evaluated under unconfined conditions implies the mobilization of shear stress producing a defined failure zone associated to them.

Figure 4 Soil samples at different densities **g** driven to failure. Upper: **g** = 13 kN/m^3; Central: **g** = 15 kN/m^3; Right: **g** = 17 kN/m^3

Figure 7, Figure 8 and Figure 9 show the mechanical behavior to strength of samples at different densities. To sequences can be distinguished (solid line and dotted line) which show the evolution of the deformations for two identical samples under the same densities. This was done in order to corroborating the results obtained for a sample. It can be seen that in general the two series of values coincide.

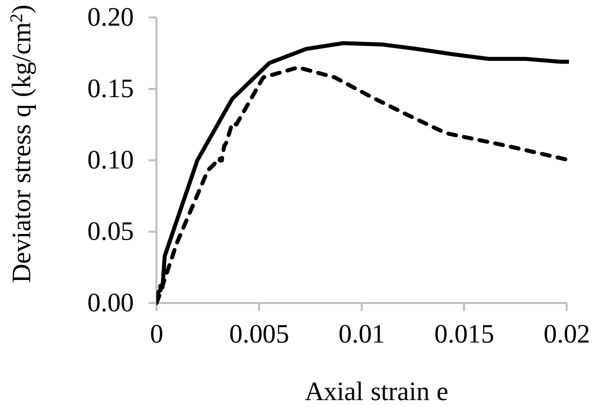

Figure 5 Deviator stress-axial strain relationship for compacted soil samples to $\boldsymbol{\gamma = 13\ kN/m^3}$

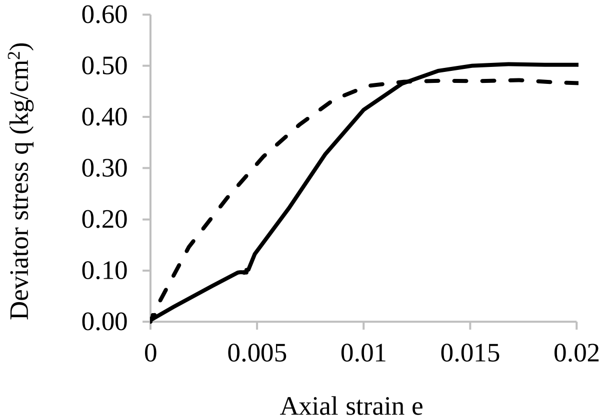

Figure 6 Deviator stress-axial strain relationship for compacted soil samples to $\boldsymbol{\gamma = 15\ kN/m^3}$

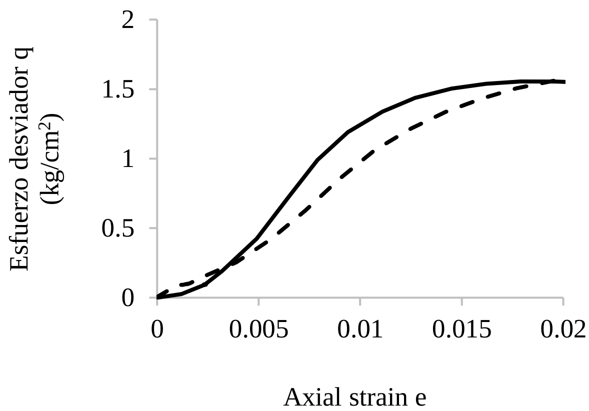

Figura 7 Relación esfuerzo desviador-deformación axial para muestras de suelo compactado a $\boldsymbol{\gamma = 17\ kN/m^3}$

Figure 10 shows the relationship between density and the maximum deviator stress that was sustained. The best fit was retrieved by linear regression, where a clear correlation can be seen between density and unconfined compressive strength, whose equation depicts an exponential nature $q = C_1 e^{C_2}$. It is important to highlight that the tendency of the strength to unconfined compression to decrease, leads to the inference that the material will endure, under the present moisture conditions, shear stresses at densities lower than 7.5 kN/m^3.

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This coincides with the impediment (in the manufacturing stage of cylindrical soil samples), of fabricating cylindrical samples at densities lower than 10 kN/m^3. On the other hand, there is a rapid growth of strength with density.

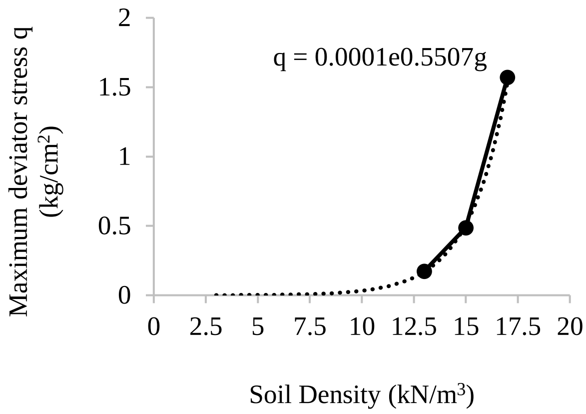

Figura 8 Graphical relationship between soil density and the máximum deviator stress sustained by the samples

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Conclusions

A semi-empirical correlation has been established to relate the density of a silty soil, with its strength in unconfined conditions at constant moisture. This result makes it possible to predict the strength in practical scenarios where geotechnical structures will be subject to unconfined conditions under different densities. The process of fabrication allowed corroborating the results for densities lower than 10 kN/m^3, for which it was not possible to carve the cylindrical soil specimens.

The physical nature of the failure zones in the samples evidences through inclined cracks, the mobilization of shear strength and the consequent strength to these mechanical stresses observed in the soil cylinders that reached the maximum deviator stress.

Future work should consider the behavior of these materials under densities greater than 17 kN/m^3 and at different moisture contents to corroborate the empirical law of variation of material resistance with density.

This empirical law must therefore be calibrated for empirical applications where at least two series of tests must be conducted to calibrate the constants C_1 and C_2 of the linear regression model applicable to these materials.

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