Determination of soil strength parameters from unconfined compression testing on partially saturated soils

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Abstract

The unconfined compression test is used in most geotechnical studies to determine soil strength parameters. This test is recommended for fine cohesive soils with a degree of saturation of more than 90%. It has been observed that such conditions, especially the latter, seldom occur and the shear strength of partially saturated soils is underestimated when a null friction component ($\phi=0°$) and a cohesion value equal to half the axial compression stress at failure are assumed ($c= \frac{1}{2} q_u$). Mathematical expressions are determined in this article in order to determine both the value of the internal friction angle "ϕ" and that of cohesion "c" from the Mohr's circle corresponding to the stress conditions of the unconfined test, a comparative analysis of slope stability is carried out for both cohesive soils and soils with cohesion and friction.

Cálculo de los parámetros de resistencia del terreno a base de pruebas de compresión en terrenos parcialmente saturados

Sinopsis

La prueba de compresión simple se usa en la gran mayoría de los estudios geotécnicos para establecer los parámetros de resistencia del suelo. Esa prueba se recomienda primordialmente para suelos cohesivos y con un grado de saturación de más del 90%. Se ha observado, sin embargo, que dichas condiciones, especialmente la segunda, no se cumplen a menudo por lo que se subestima la capacidad de resistencia a esfuerzos cortantes en suelos parcialmente saturados al presumir un componente de fricción con un valor nulo (ϕ=0°) y un valor de cohesión igual a la mitad del esfuerzo de falla en compresión (c= ½ q_u). En este artículo se deducen expresiones matemáticas para calcular tanto el valor del ángulo de fricción interna "ϕ" como el de la cohesión "c" a partir del círculo de Mohr correspondiente al estado de esfuerzos de la prueba de compresión simple y se establecen comparaciones entre resultados de análisis de estabilidad de un talud considerando tanto suelo puramente cohesivo como uno con cohesión y fricción.

Introduction

The standard penetration test (SPT) is the most widely used sub-soil exploration and sampling method in Puerto Rico and unconfined compression testing is performed on fine soil samples obtained through SPT to estimate soil strength parameters. This procedure is rather conservative because among other things, the following reasons:

1. Lack of confining stresses on the sample
2. Rate of load application
3. Disregard of the frictional portion of the soil's capability to develop shear strength

Mathematical expressions can be derived from the Mohr's circle (fig.1) corresponding to the stress conditions of the unconfined test to evaluate both the cohesive and frictional portions of the soil's shear strength to deal with point number 3 above.

Theoretical failure surface for a sample subjected to axial compression should be at an angle of 45 degrees with respect to the horizontal plane. However, the author has observed during testing at the geotechnical engineering lab at PUPR that samples that have either low degrees of saturation or coarse soils present show failure surfaces at angles slightly larger than 45 degrees. This analysis of the stress state for such situation can be analyzed provided the axial stress at failure, q_u, and the angle of shear failure surface, α, to determine mathematical expressions to obtain the internal friction angle, ϕ° and the cohesion, c (units of "q_u").

Because the actual surface angle is doubled when plotting at Mohr's circle (figure 1), and the shear envelope is tangent to the circle at failure, the stress situation can be represented as follows:

The internal friction angle, ϕ°

$$\beta + 2\alpha = 180° - \phi \tag{1}$$

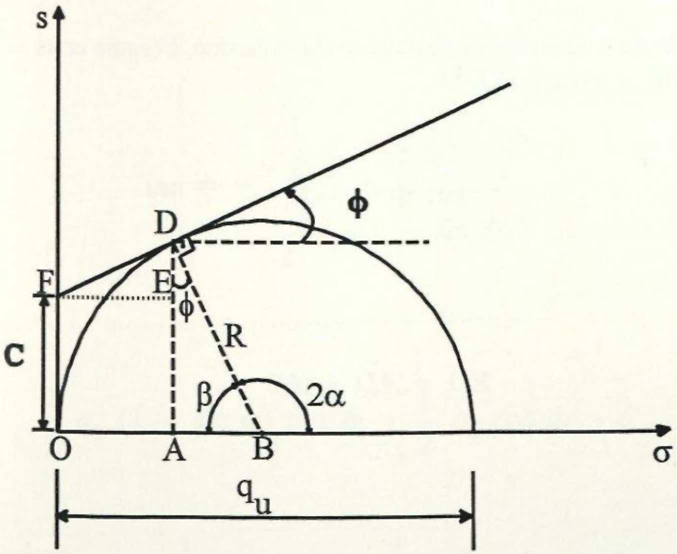

Figure 1. Mohr's circle for the stress situation of unconfined compression therefore, solving for ϕ

$$\therefore\ 90° - \phi' + 2\alpha = 180° \tag{3}$$

$$\phi = 2\alpha - 90° \tag{4}$$

For saturated cohesive soils, $\phi = 0°$,

$$0 = 2\alpha - 90° \tag{5}$$

and $\alpha = 45°$ (minimum value).

From Mohr's circle we can calculate the cohesion, c (same units as "q_u"). For example, at triangle F-E-D

$$\tan \phi = \frac{\overline{ED}}{\overline{FE}} \tag{7}$$

$$ED = \overline{AD} - \overline{AE} \tag{8}$$

$$\overline{AD} = R \cos \phi \ , \ R = \frac{1}{2}\, q_u \ , \ \therefore\ \overline{AD} = \frac{1}{2}\, q_u \cos \phi \tag{9}$$

$$\bar{AE} = c \rightarrow \bar{ED} = \frac{1}{2} q_u \cos \phi - c \tag{10}$$

$$\bar{FE} = \bar{OA} \tag{11}$$

$$\bar{OA} = \bar{OB} - \bar{AB} = \frac{1}{2} q_u - \frac{1}{2} q_u \sin \phi - \frac{1}{2} q_u (1 - \sin \phi) \tag{12}$$

$$\tan \phi = \frac{(\frac{1}{2} q_u \cos \phi) - c}{\frac{1}{2} q_u (1 - \sin \phi)} \tag{13}$$

$$\frac{1}{2} q_u (1 - \sin \phi) \tan \phi = \frac{1}{2} q_u \cos \phi - c \tag{14}$$

solving for c:

$$c = \frac{1}{2} q_u \, [\cos \phi - (1 - \sin \phi) \tan \phi] \tag{15}$$

Calling c_ϕ the expression inside the brackets:

$$c = \frac{1}{2} q_u \, c_\phi \tag{16}$$

where c_ϕ = non - dimensional factor = $f(\phi)$ which can be simplified even further

$$c_\phi = \cos \phi - (1 - \sin \phi) \tan \phi \tag{17}$$

$$c_\phi = \cos \phi - \tan \phi + \sin \phi \tan \phi \tag{18}$$

but, recalling: $\tan \phi = \sin \phi / \cos \phi$

$$c_\phi = \cos \phi - \left(\frac{\sin \phi}{\cos \phi}\right) + \left(\frac{\sin 2\phi}{\cos \nu\phi}\right) \tag{19}$$

$$c_{\phi} = \frac{\cos^2 \phi \; - \; \sin \phi \; + \; \sin^2 \phi}{\cos \phi} \qquad (20)$$

but, recalling that

$$\sin^2 \phi + \cos^2 \phi = 1 \qquad (21)$$

then

$$c_{\phi} = \frac{1 - \sin \phi}{\cos \phi} \qquad (22)$$

For <u>cohesive soils</u> under full saturation conditions: $\phi = 0^{\circ}$

$$c_{\phi} = \frac{1 - \sin 0}{\cos} = 1 \qquad (23)$$

$$c_{\phi} = \frac{1}{2}\, q_u \; * \; c_{\phi} = \frac{1}{2}\, q_u \quad ,OK \qquad (24)$$

Which can be easily verified from figure 2.

Comparison of the results of slope stability analysis: c vs C-ϕ soils.

Determine the slope stability against rotational sliding for the situation that figure 3 shows.

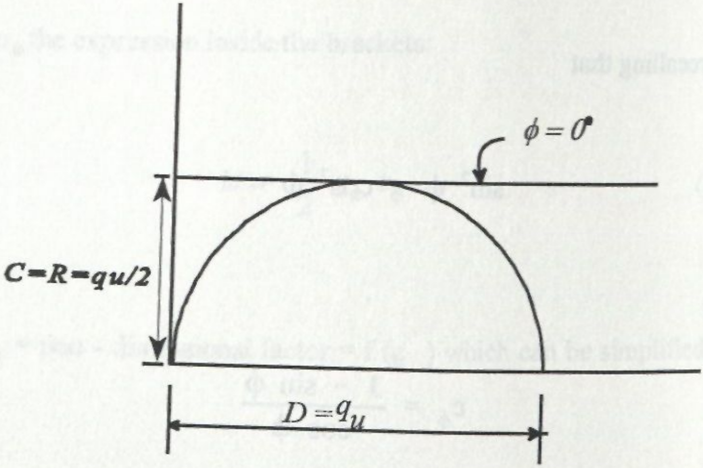

Figure 2. Mohr's circle for unconfined compression testing of "cohesive" soils

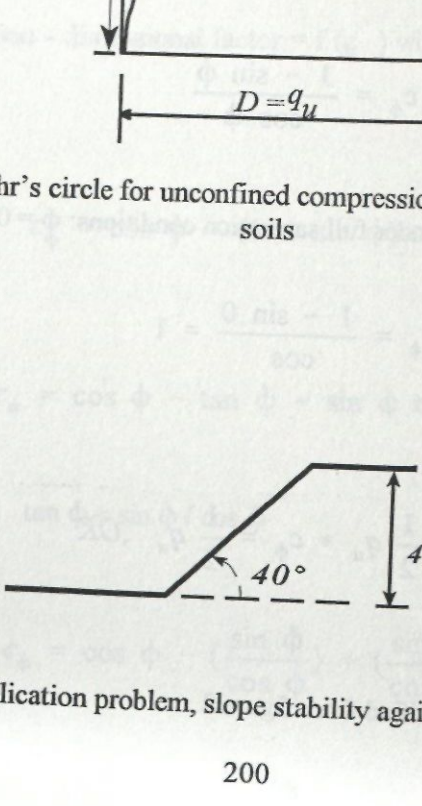

Figure 3. Application problem, slope stability against rotational sliding

The unconfined testing of a sample from the slope yielded the following results:

$$q_u = 2000 \; psf \qquad (25)$$

$$\alpha = 55° \qquad (26)$$

Solution:

If $\phi = 0° \rightarrow$ $c = ½\,(q_u) = ½\,(2000) = 1000$ PSF
If $\phi \neq 0° \rightarrow$ $\phi = 2\alpha - 90° = 2\,(55) - 90 = 20°$

$$c_\phi = \frac{1 - \sin\phi}{\cos\phi} = \frac{1 - \sin 20°}{\cos 20°} = 0.700 \qquad (27)$$

and

$$c = \frac{1}{2}\, q_u\, c_\phi = \frac{1}{2}\,(2000)\,(0.700) = 700 \; PSF \qquad (28)$$

The corresponding factor of safety against rotational sliding can then be computed for both cases with existing software such as MARTAL[1]

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[1] Martínez, José Alfredo, 1994, "MARTAL, Computer program for the Evaluaiton of Rotational Slope Stability for Soils with Cohesion and Friction," PUPR.

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