Effect of Intermediate Stress on Collapse Behaviour of a Compacted Clayey Silt

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Abstract. There are few experimental results on the influence of the intermediate principal stress on the behaviour of unsaturated soils. Particularly, the effect of intermediate stress on the collapse response of a soil subjected to a suction reduction path has not been studied in depth. This paper describes soaking tests performed in a hollow cylinder device, in which specimens of a compacted clayey silt have been saturated under constant mean and deviatoric stresses but at different intermediate stresses. The descriptions of sample preparation, testing device characteristics, test procedures and interpretation methods are presented. Preliminary analyses of the results seem to indicate that collapse is larger when the intermediate stress coincides with the minor one, i.e. under conventional axi-symmetric triaxial stress state.

Keywords: hollow cylinder, intermediate principal stress, collapse.

1 Introduction

The influence of the intermediate principal stress on the behaviour of saturated soils has been widely studied. On the contrary, studies performed on unsaturated

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soils are still limited due to experimental difficulties, mainly associated with the precise determination of the volume change response. Hoyos (1998) and Matsuoka et al. (2002) used a true triaxial apparatus, whereas Toyota et al. (2001) and Toyota et al. (2004) a hollow cylinder device, to perform tests under constant suction to study the influence of this constitutive stress variable on soil behaviour under three-dimensional stress conditions. The effect of the principal intermediate stress is by no means an academic issue, since it has been taken into account in modeling earthwork constructions (see for instance, Zerfa & Loret, 2003). Despite its importance, the effects of this intermediate stress on collapse response originated during saturation increase are rather unknown.

Particularly, the present work aims at studying the influence of the intermediate principal stress on the collapse response upon soaking of a statically compacted clayey silt tested in a hollow cylinder device.

2 Testing Apparatus and Tested Material

The sample installed in the hollow cylinder apparatus (see for instance, Bilé Serra and Hooker, 2011) features 50 mm of external radius r_0, 30 mm in inner radius r_i, and 200 mm in height H_o. The capacity of the axial load cell and the torque cell are 10 kN and 100 Nm, respectively. The principal stress parameter $b = (\sigma_2-\sigma_3)/(\sigma_1-\sigma_3)$ (Bishop 1966), can be automatically controlled during the tests (σ_i are principal stresses, being σ_1 and σ_3 the major and minor ones). Both the base and top caps have conventional porous discs. Three pressure / volume controllers were used for the application and control of the pressures, as well as for the measurement of the water volume changes. Figure 1 shows a scheme of the stress state of the soil with the definition of the deviatoric stress (q) and a picture of a sample after the test. The procedure to obtain the principal stress values from the applied forces and pressures has been described in Hight et al. (1983).

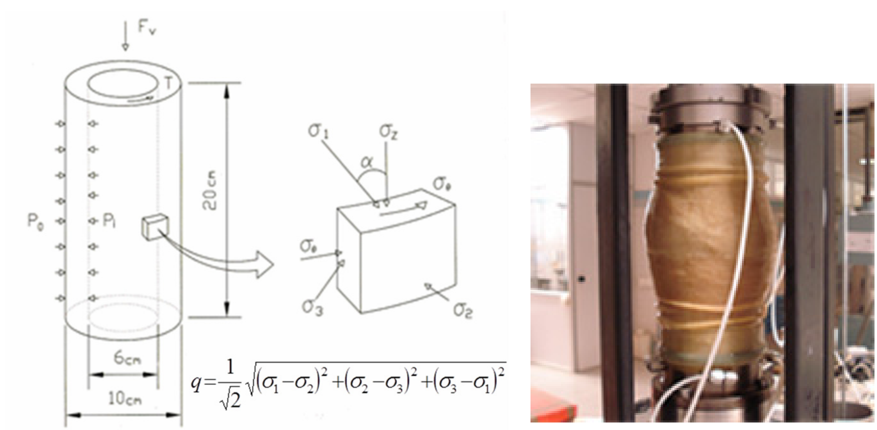

Fig. 1. Stress state in the hollow cylinder device and a picture of a tested specimen.

The soil used is the result of the mixture of two materials: fine sand of Castelldefells (Barcelona) and Barcelona silty clay (w_L = 34%, PI = 18%). The mixing ratio was studied to find a suitable combination of shear strength, water permeability and collapsibility properties. Finally, a mixture of 30% sand and 70% silty clay by dry mass was selected. The mixture with a water content of 4% was statically compacted up to a dry density of (1.55 ± 0.01) Mg/m^3 (void ratio $e \approx 0.74$, degree of saturation $S_r \approx 0.15$).

3 Testing Procedure

The specimen was compacted inside a set of two concentric cylindrical moulds: an inner mould with diameter 60 mm and split up into four parts and an external split mould of 100 mm in diameter. The static compaction was carried out by a hydraulically driven press at a displacement rate of 0.2 mm/min up to a maximum vertical stress around 200 kPa. The assembly of the specimen in the cell was carefully carried out due to the low strength of the mixture. Once the sample was installed, the inner and outer chambers were filled with water. Once the filling was finished, the external pressure was fixed at 10 kPa in the pressure controller to maintain certain confinement on the sample.

To determine the effect of the intermediate principal stress σ_2 on collapse, three tests were performed by changing the value of the parameter b, which was set to 0, 0.5 and 0.8. The tests were carried out by maintaining constant the mean and deviatoric stresses during the saturation stage. The tests started with an isotropic compression stage by applying approximately the same inner and outer chamber pressures up to a maximum mean net stress $p = (\sigma_1+\sigma_2+\sigma_3)/3=200$ kPa under constant water content conditions and atmospheric air pressure. A rate of 2.5 kPa/hour was selected for the application of the external P_o and internal P_i pressures during isotropic compression. After this initial stage, a small increase of deviatoric stress q = 30 kPa was applied before setting the parameter b. Afterwards, the value of q was increased at a rate of 15 kPa/hour up to 200 kPa by maintaining p = 200 kPa and a constant b parameter. Once the target stresses were reached, the samples were soaked under constant stress state by setting a small water pressure at the base. Figure 2 shows the stress paths followed at different b values.

The axial strain ε_z was evaluated directly from the vertical displacements controlled by the stepper motor and the initial height of the sample. Nevertheless, the most important limitation was the lack of local instrumentation in the sample for volumetric strain ε_v measurement. It was necessary to obtain this strain from alternative recorded values (change in sample height ΔH and the volume changes of inner ΔV_i and outer ΔV_0 chambers). The measurement of the final water content and the initial and final dry densities of the sample allowed better assessing volumetric strain measurement.

The evaluation of volumetric ε_v, radial ε_r, and circumferential ε_θ strains need the knowledge of the magnitude of the changes in the internal and external radius u_i and u_o, respectively (see for instance, Hight et al., 1983). These changes can be evaluated from inner and outer chamber volume changes together with height changes:

$$u_i = \Delta r_i = \sqrt{\frac{\pi r_i^2 H_o + \Delta V_i}{\pi(H_o + \Delta H)}} - r_i \;\; ; \;\; u_o = \Delta r_o = \sqrt{\frac{\pi r_o^2 H_o + \Delta V_i - \Delta V_o}{\pi(H_o + \Delta H)}} - r_o \qquad (1)$$

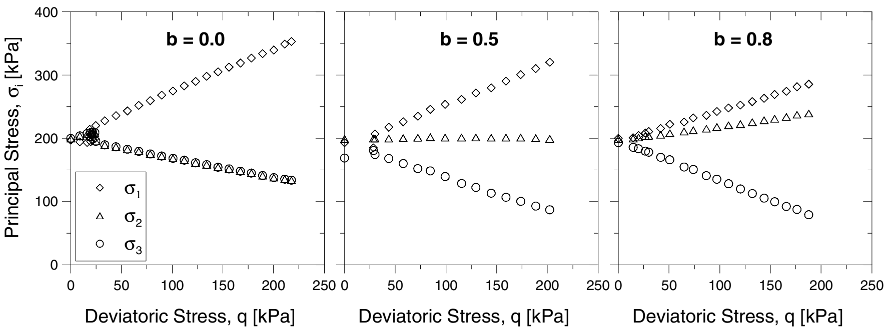

Fig. 2. Principal stress paths followed at different *b* values.

4 Results

The paths in terms of principal strains ε_1, ε_2 and ε_3 followed during the shearing stages are shown in Figure 3. It should be remarked that values of ε_2 changed from negative (expansion) for the case of $b = 0$, to positive (compression) for $b = 0.8$. This behaviour is equivalent to the one observed by Hoyos (1998) in tests performed using a true triaxial equipment.

Figure 4 shows the behaviour of the volumetric strain ε_v for different values of b, both along the shearing and saturation stages, and plotted against the deviatoric stress q. It can be observed that during the deviatoric stress stage, volumetric strains attain values around 2%. The maximum volumetric strain during this shearing stage was measured at $b = 0.5$. On the other hand, during the saturation stage at constant $q = 200$ kPa and $p = 200$ kPa, important collapse strains were recorded along the three soaking tests. Final ε_v values of 14%, 11% and 8% were measured at the end of these soaking stages for values of $b = 0.0$, $b = 0.5$ and $b = 0.8$, respectively. These results indicate that collapse is larger when the intermediate principal stress σ_2 coincides with the minor one σ_3, as in conventional axisymmetric triaxial conditions ($b = 0$; $\sigma_2 = \sigma_3$). As the intermediate principal stress σ_2 tends to σ_1, collapse strains progressively decrease.

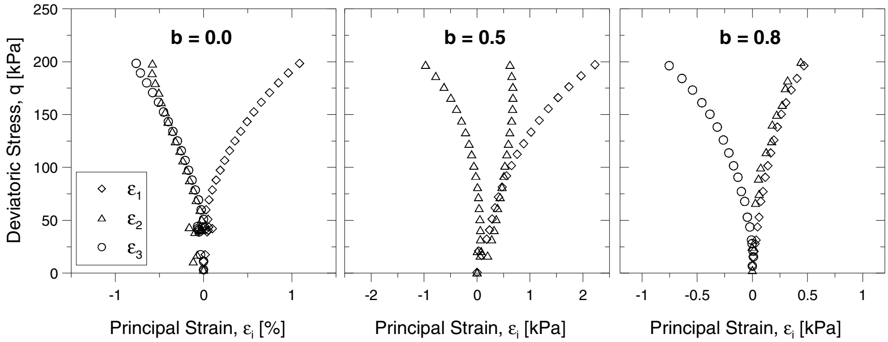

Fig. 3. Principal strain paths followed during the shearing stages for different values of parameter *b*.

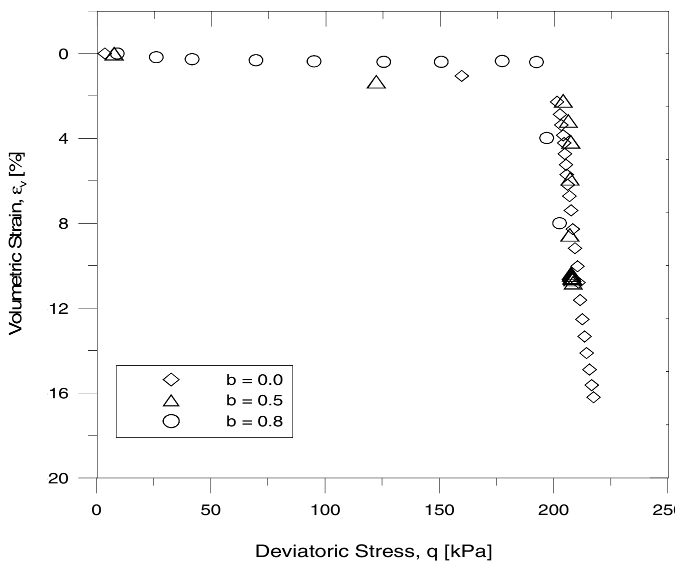

Fig. 4. Volumetric strain versus deviatoric stress for different values of parameter *b* (shearing stage and soaking stage at constant deviatoric and mean net stresses).

5 Conclusions

A laboratory test program was carried out aimed at studying the influence of intermediate principal stress on the collapse behaviour of unsaturated (compacted) clayey silt. A conventional hollow cylinder device can be a suitable equipment to perform these tests, if changes in inner and outer diameters of the specimen are correctly evaluated from volume changes of inner and outer chambers and by taking into account the initial and final dry densities of the material. During shearing, intermediate strain ε_2 changed from negative (expansion) for $b = 0$, to positive (compression) for $b = 0.8$. During this stage, the major principal strain ε_1 remained always positive (compression) independently of the value of b; and the minor principal strain ε_3 always negative (expansion).

Collapse on soaking at constant mean and deviatoric stresses is influenced by the intermediate principal stress σ_2. Test results indicated that collapse was larger when the intermediate principal stress σ_2 coincided with the minor one σ_3, as in conventional axi-symmetric triaxial conditions ($\sigma_2 = \sigma_3$). A progressive and systematic decrease of collapse strain was detected as the intermediate principal stress σ_2 tended to σ_1.

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