Unsaturated and Saturated Soil-Interface Effect on Shearing Behaviour of Soils

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ABSTRACT: Soil interfaces occur at the contact surfaces between the soils and the engineering constructions, such as retaining wall, foundations, and others, where reciprocal transition of stresses takes place at interfaces. An intrinsic motivation of this work stemmed from observations of problematic behaviour of natural deposited soils and engineered soil during drying-wetting processes due to variations in annual thermal conditions. Soil may experience changes in the state of stress and rearrangements of soil particles under drying and wetting processes. In this paper, shear-interface behaviour of a highly expansive soil was studied under saturated and unsaturated conditions. A modified set up of the traditional direct shear apparatus was employed to conduct the soil-interface tests under water content control. An acrylic square plate was fabricated with two counter-faces, including smooth and spiral-circular grooved surfaces. The shear strength parameters, i.e., friction angles and adhesions, were obtained from the shear failure envelops to examine the impact of interface on shearing behaviour of soil. The experimental results indicate the substantial effect of different interfaces on the shearing behaviour of soils under different initial moisture conditions. In addition, the initial saturation state of soil interface sample appears to have an important effect on the mechanical shearing behaviour.

1 INTRODUCTION

Unsaturated and saturated soil interfaces may occur at the contact surfaces between the soil and the geotechnical structures such as shallow and deep foundations, retaining walls, buried pipes, and slopes. At the soil-interface, a reciprocal transmission of the developed stresses takes place, Miller and Hamid (2007), Hamid and Miller (2009), Manzoli et al. (2018), where may cause variations in the shearing behaviour of the soil, and formation of crack during drying process. However, this may significantly depend on many factors which are mainly related to the initial saturation conditions of the soil, soil structure (i.e., compacted, slurry) and the roughness of the soil-interface as well. In this study, circular plates with two acrylic counter faces (circular bases) were used including smooth and spiral-groove interfaces. At interfaces, when the adhesion between soil and plate is high (i.e. grooved plate with a strong bonding between soil and plate) a relatively small amount of soil mass (for a given thickness) is necessary to develop the horizontal stresses necessary to induce the failure of the soil during shrinkage, Sanchez et al. (2014). On the other hand, if the adhesion between soil and plate decreases, a larger mass of soil is necessary to generate the horizontal stresses needed to develop the vertical cracks. In this case, cracks do not open because no constraint to displacement is imposed by the plate, therefore no tensile stresses develop. The horizontal stresses are compressive in this case. This kind of behaviour has been observed and reported in several works, Nahlawi and Kodikara (2006), Péron et al. (2009a), Kodikara and Choi (2006), Zielinski et al. (2014). For example, Zielinski et al. (2014) conducted a set of drying tests. Soil samples from non-active pulverized kaolin were prepared at specific initial conditions and then placed in a rectangular Perspex mold with the dimensions of (15.9×2.9×1.4 cm) and subjected to air drying at controlled room temperature and relative humidity. A thin film of silicone grease was placed inside each mold in order to reduce the adhesion at boundaries and allow the free shrinkage of the soil. It was observed that under these conditions, the soil sample experienced shrinkage without developing any crack.

Evolution of desiccation-induced cracks is a natural phenomenon occurs due to vaporization of water from the soil into the atmosphere during dried season. In fact, the presence of cracks may cause problematic influence on the hydro-mechanical properties of the soil, that may be detrimental for geotechnical, geo-environmental, and geological applications, such as clay liners, landfill covers, industry waste, Albrecht and Benson (2001), Rodriguez et al. (2007), Tang et al. (2011). The existence of cracks may increase the hydraulic conductivity, Albrecht and Benson (2001), and the compressibility of the soil as well. Under dehydration process, the soil may expose to variations in the physical (i.e., rearrangement of soil particles) and the hydro-mechanical characteristics, and consequently cracks may form. However, the roughness of soil-interface and the initial saturation conditions of the soil should be taken in consideration in interpreting the formation of desiccation cracks in the drying process.

Furthermore, it is important to note that the fine content plays a substantial role in crack formation during drying process. It is reported that the compacted soils with high fine contents experienced higher cracking than those of compacted soils with lower fine contents (Yesiller et al. 2000). Also, for compacted soils, the initial compaction conditions (e.g. water content, dry density and compaction energy) have a significant effect on the hydro-mechanical behaviour during dehydration process.

Research described herein was focused mainly on understanding the effect of different soil-interfaces and initial moisture conditions on variations of shearing behaviour of a high-plastic mixture of 75 % of kaolinite and 25% of bentonite. Modifications on direct shear tests were performed in this research.

The primary objective of this research is to investigate the effect of different interfaces on the shearing behaviour of soils under saturated and unsaturated conditions. Better understanding of the impact of counter-interfaces at different initial conditions introduces new interpretations of crack formation mechanism.

2 MATERIALS AND METHODS

2.1 *Tested soil specimens*

An artificial high plastic mixture consisted of 75% of kaolinite and 25% bentonite was used in this work. The mixture was subjected to classification and physical property tests according to ASTM standards, ASTM (2005): Atterberg limits (ASTM D4318-00) and standard Proctor compaction test (ASTM D69800). The physical characteristics of the mixture are presented in Table 1. Liquid limit (LL) was about 88% while plasticity index (PI) was about 48%. In this work, compacted specimens under saturated and unsaturated conditions were examined. Free (smooth plate) and constrained (spiral-groove plate) shearing tests were performed to study the impact of different restrain conditions on shearing response of soil under saturated and unsaturated states.

Table 1. Physical characteristics and initial conditions of 75% koalinite-25% bentonite mixture

Property	
Liquid limit (%)	88
Plasticity index (%)	48
Specific gravity	2.67
USUC[a] classification	CH
Optimum water content (%)	38.0
Maximum dry unit weight (kN/m^3)	12.16
Saturated-compacted specimen	
Initial water content (%)	63.7[b]-65[c]
Initial dry unit weight (kN/m^3)	11.1[b]-11.16[c]
Initial void ratio	1.36[b] -1.35[c]
Unsaturated-compacted specimens	
Initial water content (%)	42.67
Initial dry unit weight (kN/m^3)	11.40
Initial void ratio	1.29

[a]Unified Soil Classification System, [b] Constrained saturated sample (Groove), [c] Free saturated sample (Smooth)

2.2 *Saturated and unsaturated-interface direct shear testing method*

To investigate the interface effect on the shearing behaviour of the soil, two acrylic counter-surfaces were used. Direct shear tests were conducted on interfaces between a highly-plastic fine-grained soil and two acrylic faces, involving circular-spiral and smooth surfaces. The roughness of smooth surface is considered a negligible value since the surface was lubricated with grease.

Two groups of compacted soil specimens were prepared; each group consisted of one saturated and one unsaturated specimens. Unsaturated-compacted specimen was prepared by mixing thoroughly the mixture with distilled water at the target water content of about 42.67% (4.67% wet of OMC from the standard Proctor test, ASTM D698). Then the soil was stored for 24 hours to promote moisture equilibrium. The soil was then compacted inside the modified direct shear box in two layers to achieve the required dry density of about 11.40 kN/m^3 (94.4% of γ_{dmax} as determined from the standard Proctor test, ASTM D698). Laboratory compaction composed of tamping to achieve approximately uniform application of compaction energy to the top of each layer. For unsaturated samples, the suction measurements were taken by using the chilled mirror dew-point psychrometer (WP4-T), Decagon (1998-2003). For each tested sample, the initial water content was maintained constant during the test by wrapping the surface of the sample with plastic wrap. The weight of the sample was maintained constant, and thus, the matric suctions were controlled during the entire time of the test. The suction measurement was determined at the end of each test. Two unsaturated-compacted samples were examined; one was compacted on smooth plate, the second one on the spiral-groove plate. In this paper, the smooth and the groove-unsaturated compacted samples are referred to (SUC) and (GUC), respectively. The initial degree of saturation and the matric suction were about 0.87 and 1000 kPa, respectively.

On the other hand, two saturated-compacted specimens were prepared to be tested at free and constrained interfaces. The specimens were initially prepared at the same initial conditions (i.e., w = 42.67%, and ρ_d =11.40 kN/m^3) of those of unsaturated-compacted samples. Then the samples were inundated with water and kept for fully saturation or until stop swelling. Then the primary consolidation was achieved, and no significant water dissipation was observed. After that, the sample was sheared. Shearing process was continued until the peak value of the shear force was clearly obtained or no significant change was observed. No pore water pressure measurements were obtained in this work. The degrees of saturation of the samples were calculated (i.e., for SSC, S = 1.3, and for GSC, S = 1.25) to check whether the samples reach to fully saturation or not, if not, the samples were re-inundated. In this paper, smooth and groove-saturated compacted samples are refereed to (SSC) and (GSC).

A conventional direct shear apparatus was employed in this study with a small modification. Identical smooth and spiral-groove counter-faces were used. The only modification made for the direct shear box was by placing an acrylic square plate, fixed by special screws, in between the top and bottom halves of the direct shear box. Figure 1 describes the top and side views of the modified direct shear box in this paper. An acrylic square plate was manufactured with the dimensions of 6 mm of thickness and 88.9 mm of length. The plate was fabricated to have smooth and groove surfaces in each face.

In this study, a horizontal displacement rate of 0.018 mm/min was chosen. The main purpose of selecting a slow shear rate was twofold; one to avoid overestimated shear strength parameters (e.g., friction angle, cohesion, and adhesion), second to prevent any changes in pore pressure during shearing for unsaturated samples, Hamid and Miller (2009). Three small different vertical stresses, including 0 kPa, 6.2 kPa, and 15.5 kPa, were selected to define the shear failure envelops of all tested specimens.

3 RESULTS

For all direct shear tests (circular and smooth interfaces), the shear failure envelops in the normal stress (σ_n) and maximum shear stress plane are presented in Figures 2. A comparison between all shear strength parameters is presented in Figures 3.

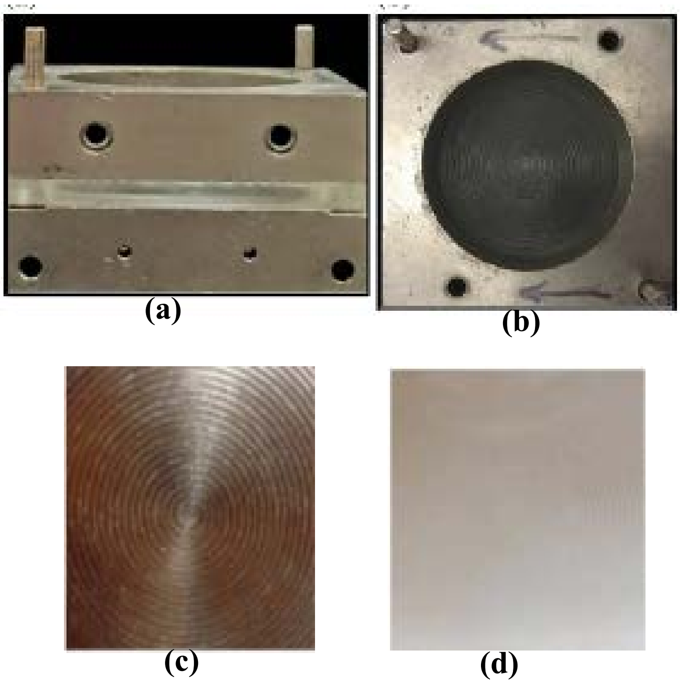

Figure 1. Modified direct shear box for soil-interface testing: a) front view, b) top view; and c) a photo an acrylic fabricated plate with circular-spiral patterns d) plate with smooth face.

For saturated interface direct shear tests, δ’ and ca’ indicate to the interface friction angle and adhesion intercept. Also, for unsaturated samples, δb and cab refer to the unsaturated interface friction angle and interface adhesion, respectively, with respect to matric suction effect.

Results of unsaturated-compacted shear tests showed that the selected value of suction (i.e. S =1MPa) did reveal a considerable impact on the shearing behaviour of soil. Before saturation stage, both saturated and unsaturated compacted samples exhibited similar structures (i.e., fabrics and internal bonding), however, under different initial saturation conditions, different shear strength parameters were obtained. This is largely due to the significant effect of air-water meniscus at shear plane for the case of unsaturated sample. It is known that the matric suction contributes in an increase in the effective stress of the soil, and as the effective stress increases the shear resistance increases, resulting in an increase in the shear strength at the failure plane. Consequently, as shearing process takes place, the compacted sample gained more shear strength than saturated sample, under unsaturated conditions.

It appears that constrained samples (GSC and GUC) experienced higher values of adhesion and interface-friction angle than those of free samples (Table 2). It seems that the constrained samples experienced more shearing resistance at soil-interface than the samples tested at smooth interface with no to negligible shearing resistance.

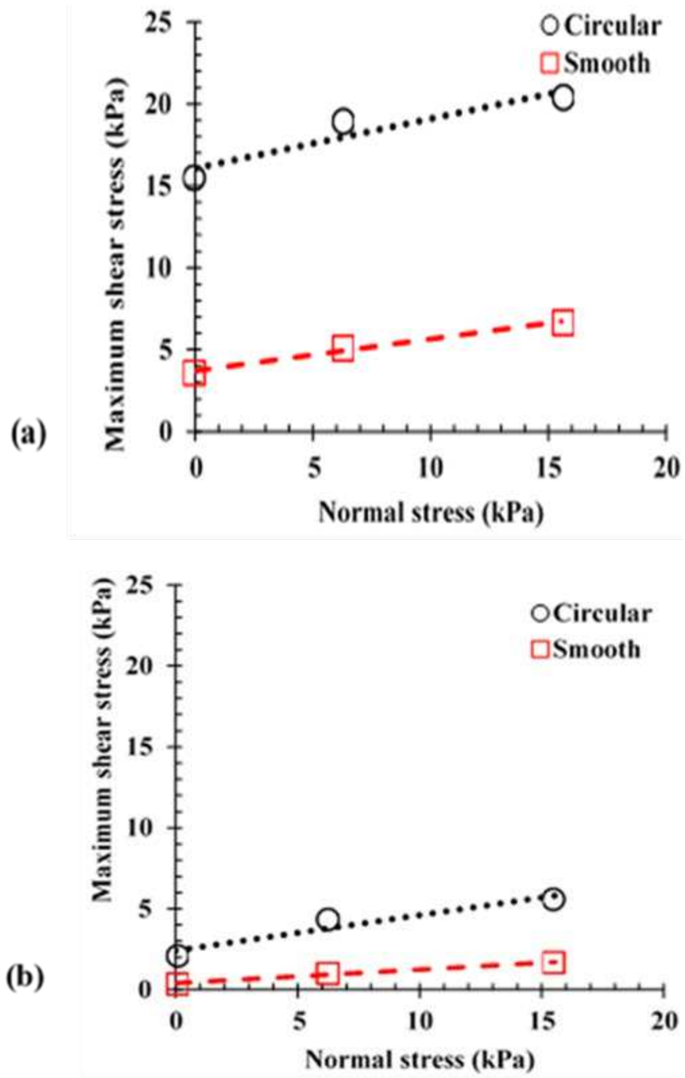

Figure 2. Direct shear-interface results a) Unsaturated-compacted samples, b) Saturated-compacted samples.

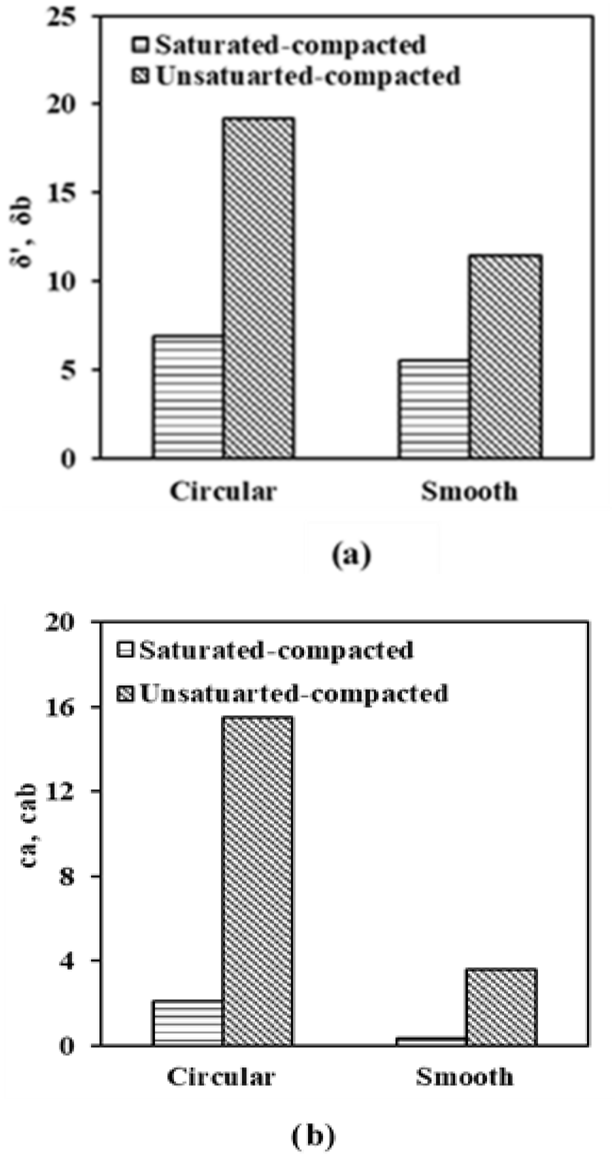

Figure 3. Comparison between circular and smooth-interfaces results; a) Values of interfaces friction angles (δ', δb) determined from shear failure envelopes, and b) Values of adhesion determined from shear failure envelopes.

For the free-interface tests, unsaturated-compacted sample (SUC) experienced higher adhesion and interface-friction angle (cb = 3.59 kPa and ϕb = 11.48o) than those of saturated sample (cb = 0.35 kPa and ϕb = 5.1o). It was highlighted previously that unsaturated samples have more shearing resistance than those of saturated samples and that attributes to large impact of matric suction.

4 CONCLUSIONS

It can be concluded that the type of soil-interface has a large affect on the shearing strengths of soils, where the constrained samples (soil-circular-grooved interface) exhibited more shearing resistance than those of free samples (soil-smooth interface). Also, the interface effect was more pronounced in unsaturated samples than in saturated samples and that attributes to large impact of matric suction of unsaturated ones.

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