SHEAR BEHAVIOR OF AN UNSATURATED SOIL-STEEL INTERFACE FROM DIRECT SHEAR TESTS

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ABSTRACT

The interface between an unsaturated soil and a steel plate is a thin layer of soil through which stresses can be transferred from the steel plate to the soil and vice versa. This interface layer exists in numerous geotechnical projects such as pile foundation, soil nail, retaining wall and underground buried pipes etc. In this paper, the behavior of the interface between unsaturated Completely Decomposed Granite (CDG) soil and a steel plate is examined by conducting a series of laboratory experiments, using the modified suction controlled direct shear apparatus. The test results demonstrate the successful implementation of the device. The main observations are described along with the experimental results.

KEYWORDS

CDG Soil, Soil-Steel Interface, Suction, Direct Shear test.

INTRODUCTON

At The Hong Kong Polytechnic University (HKPU), a modified direct shear apparatus (MDSA) was designed and fabricated for the testing of soil and interface. This paper presents: (1) a brief background, (2) testing device; description of the MDSA, (3) testing procedure, (4) result of the direct shear test and discussion, and (5) conclusion.

Background

The presence of air in the soil can be observed in the significant areas of earth surfaces that are considered to be arid, semi arid or extremely arid regions, having low or very low water content and thus rendering the soil to be unsaturated (Fredlund and Rahardjo 1993). The interface is common to various civil engineering projects (e.g. Piles driven through unsaturated soil, buried pipelines etc.), as a variety of materials (such as steel, wood, geotextile, fly-ash etc.) can come in contact with the unsaturated soil(Fleming et al. 2006, Hamid and Miller 2009, Khoury et al., 2010). Generally, the soils in compacted embankment, retaining wall backfill are unsaturated with degree of saturation considerably lower that 100%. It is reported that the interfacial shear resistance of soil greatly depends on the matric suction and net normal stress (Sharma et al. 2007). The behavior of interface governs the design and analysis of some of these soil structure interaction problems (e.g. skin friction along a pile and retaining wall), thus it is important to characterize the interface behavior for improving the design and reliability of these engineering structures.

The present study aims to study the interaction of rough steel–plate with the completely decomposed granite (CDG) soil using the MDSA. A series laboratory tests on soil and soil –interface were conducted under saturated (zero suction) and unsaturated condition, the results of the study are presented and discussed.

A MODIFIED DIRECT SHEAR APPRATUS FOR TESTING UNSATURATED SOIL AND INTERFACE
Testing Apparatus

In MDSA, the suction is controlled by applying a differential air pressure and water pressure to the sample specimen. Briefly , the test apparatus consists of an air pressure chamber, high air entry value porous disc (HAEPD), diffused air volume measuring device DAVI), pressure controlling system, measuring /monitoring devices (eg; two LVDTs, electric volume meter), a pore-water pressure transducer, a load cell, and a personal computer. The details of the test apparatus are described by Hossain and Yin (2010). The air pressure and water pressure in the MDSA is controlled and monitored using pressure regulators and pressure gauge of 1kPa resolution. The air can access the soil specimen through a small opening of 208 mm in the surrounding of the top steel platen. The schematic diagram of the MDSA is shown in Fig 1.

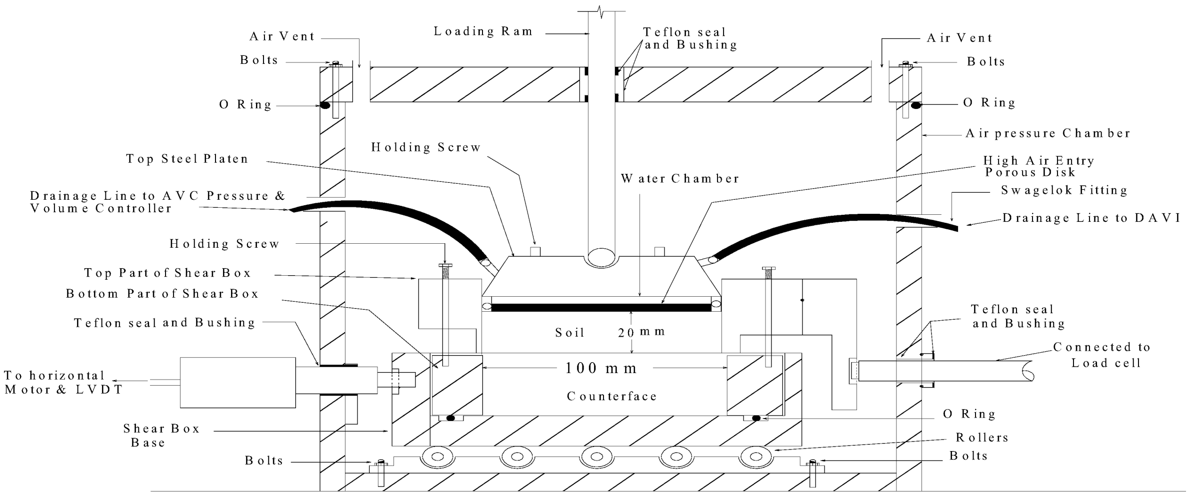

Figure 1 Cross sectional view of the air chamber of MDSA

Test material

(a) Soil

A locally available CDG soil was used in this study; it has wide range of applications in the locality of Hong Kong. The soil is characterized for its basic properties by following the guidelines presented in literature (BS 1337-2; 1990, BSI 1981). The CDG soil has a liquid limit of 31%, plasticity index of 10, specific gravity of 2.58, USCS group symbol of SM. From the standard proctor test, the optimum water content is 13.4 % and the maximum dry density is 1.84Mg/m^3. Table 1 shows the details of particle size distribution test.

(b) Counterface

A rough square stainless steel plate of dimension 100mm by 100mm and thickness of 20mm was used for this study. The normalized surface roughness (R_n) of the steel plate is 10, as defined by Kishida and Usegi (1987).

$$R_n = R_{max} / D_{50} \qquad (1)$$

where, D_{50} is the grain size diameter corresponding to 50% fines.

Table 1 Properties of soil

Soil	CDG
Clay (<0.002mm)(%)	13
Silt (0.002-0.063mm) (%)	34
Sand (0.063-2.0mm) (%)	49
Gravel (2.0mm to 60mm)	4

Sample preparation

The oven dry soil passing through 2mm BS sieve was taken in a mixing bowl and mixed properly by adding 13.4% of water at a constant room temperature (20℃). The mixed soil was then transferred into the shear box and compacted to the desired density (1.75Mg/m^3) by a tamping rod in desired layers (4 layers four layers of 10mm each for soil and two layers of 10mm for soil –interface). Nominally, all the sample specimens used for testing were prepared to the same the dry unit weight and water content.

TEST PROCEDURE

Briefly, the test procedure for interface direct shear consists of three steps (a)saturation of the soil sample, (b) equalization (at constant suction and net normal stress), (c) and drained shearing (at constant suction and net normal stress). The sample was compacted in the shear box and a porous disk was placed on it. Ample amount of water was poured on the porous disk and the sample was allowed to soak for overnight (Gan and Fredlund 1992). It was noted that there was no detectable change in the specimen height. After achieving the saturation, the excess water and the porous plates were removed. The HAEPD was then placed on top of the specimen (HAEPD was completely saturated with di-ionized water prior to the testing). The pre-determined axial load, air pressure and water pressure were applied sequentially to achieve the equalization of the desired matric suction; the equalization was assumed to be complete when the flow of water became negligible. After attaining equalization, the sample specimen was then sheared under drained condition at a constant shearing rate of 0.004mm/min until the desired horizontal displacement was reached. However, it must be noted that the testing of the pure soil was carried out following the guidelines presented by Hossain and Yin (2010).

TEST RESULTS AND DISCUSSION

For analyzing the interface behavior, it is noteworthy to compare the results of soil-steel-interface with the results of a pure soil. Fig. 2 illustrates the variation of normalized vertical displacement (v/H_0) with the horizontal displacement and Fig. 3 shows the variation of shear stress (τ) with the horizontal displacement (u), whereas Fig 4 shows the migration of water from the specimen with the horizontal displacement during the drained shearing. Based on Fig.3, Fig. 4 and Fig. 5, the following important observations are noted.

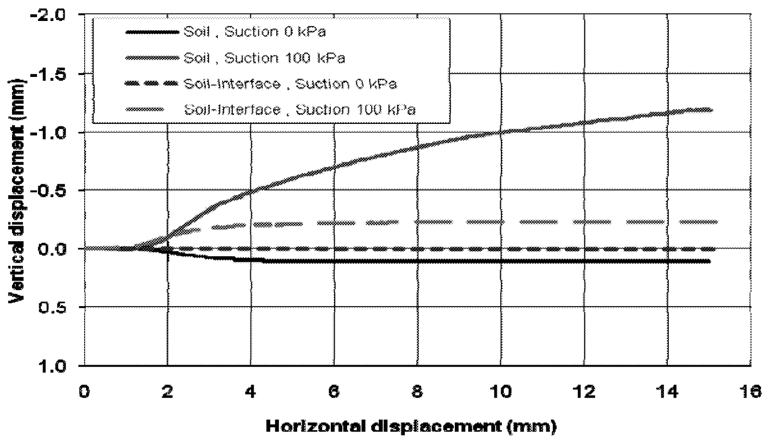

Figure 2 Variation of normalized vertical displacement with Horizontal displacement (u).

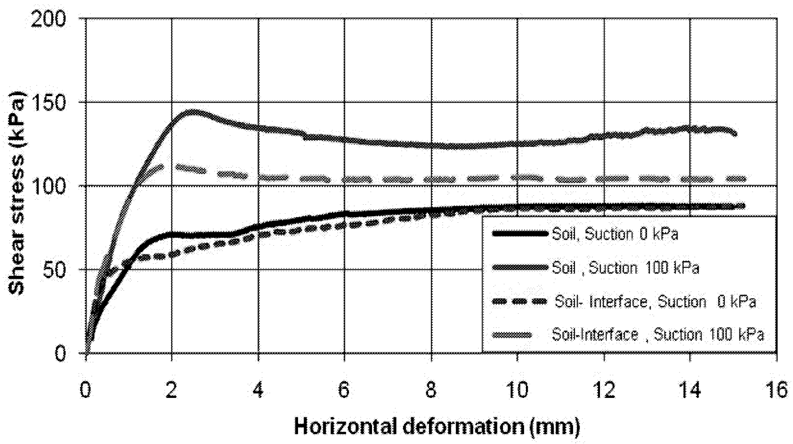

Figure 3 Variation of shear (τ) stress with Horizontal displacement (u)

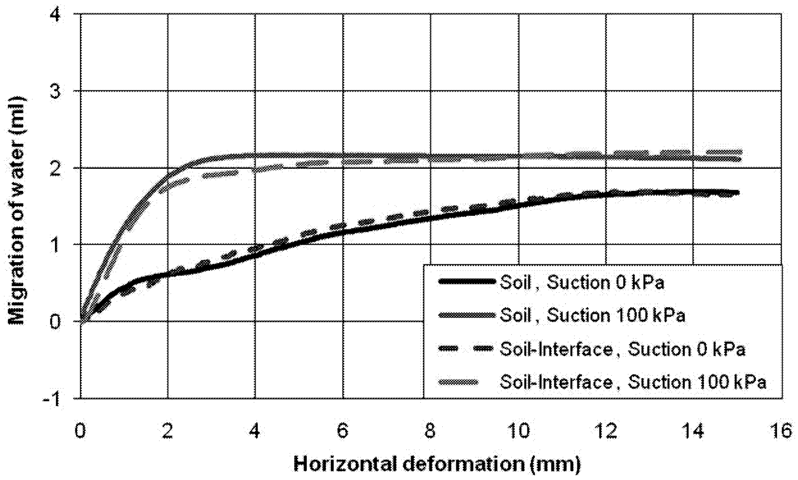

Figure 4 Variation of migration of water with Horizontal displacement (u)

a) The trend of total volume change behavior of both soil and the soil-steel-interface are similar. In case of zero suction, Initial compression behavior can be observed until the peak shear stress is reached. However, matric suction (100 kPa) contributes to the dilation.
b) It is noted that the pure soil dilates more as compared to soil-steel-interface, probably because the pure soil permits the free movement and rearrangement of soil particles.
c) During the undrained shearing at fully saturated condition (zero suction) and matric suction (100 kPa), after reaching the peak shear stress (τ_{max}) the shear stress follows the similar trend of gradual hardening for both soil and soil-steel-interface
d) It is explicitly noted that the matric suction contributes to the increase in τ_{max} for pure soil and soil –steel interface. However the τ_{max} of the soil – steel-interface is lower to pure soil.
e) The flow of water from the soil and soil interface follows a nominally same trend. The quantity of water moving out from saturated sample specimen (both pure soil and soil-steel-interface) is considerably lower in comparison to sample specimen at matric suction (100 kPa).

CONCLUSIONS

This paper describes a simple method to evaluate the interface shear strength of an unsaturated soil and rough steel plate using axis translation technique. The application of MDSA for evaluating the interfacial shear strength is successfully demonstrated. Based on the results obtained from study on the CDG soil, the following conclusions are drawn:

- The shear strength of the soil and soil- steel interface is increase with the matric suction. However, the soil – steel- interface strength is noticeably lower to pure soil.
- The dilation behavior of the soil-steel interface evidently lower in comparison to pure soil, but follows the same trend

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