AIR ENTRAPMENT IN SOIL WITH FINER MATERIAL OVERLAYING A COARSER MATERIAL

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1. INTRODUCTION

The significance of air in soil has been well recognized by geologists and geotechnical engineers for a long period of time. Several authors including Horton (1940), Powers (1934) and Constantz, Herkelrath, & Murphy (1988) have studied the effect of entrapped air on the hydraulic properties of soil. In addition, Sato & Kuwano (2015) studied air entrapment in unsaturated soil. However, they considered a homogeneous soil column containing Edosaki sand. This paper presents a study on air entrapment in fine soil-coarser soil composite with the finer material overlaying the coarser one.

2. MATERIAL, EXPERIMENT SET-UP AND TEST PROCEDURE

The experiment setup (Fig.1a) consisted of a soil column; a water tank containing de-aired water, a pressure gauge, a laser displacement sensor, a manometer, and a Low Capacity Differential Pressure Transducer (LCDPT). The one-dimensional (1-D) soil column (cylinder inner diameter of 50mm and soil height of 200mm) was made of 10mm-thick transparent acrylic plastic. The column was closed at the bottom with a water inlet connected to the de-aired water tank and an air outlet about 100mm from its bottom. The de-aired water was subjected to pressure by a Pressure Gauge. This pressure determined the infiltration rate of the de-aired water into the soil column. As water was infiltrated through the unsaturated soil, soil air was immiscibly displaced upwards (Wang, Feyen, Genuchten, & Nielsen, 1998) and trapped just below the saturated soil layer (Fig.1b). The manometer and LCDPT attached to the side of the soil column measured any pressure increase due to entrapped air. In addition, any change in displacement due to uplift of the saturated layer by the entrapped air was recorded using a laser displacement sensor placed eccentrically above the soil column.

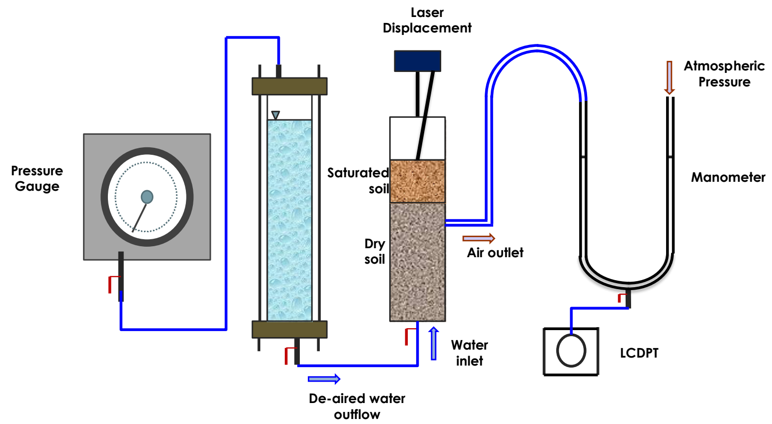

Figure 1a: Experimental set-up

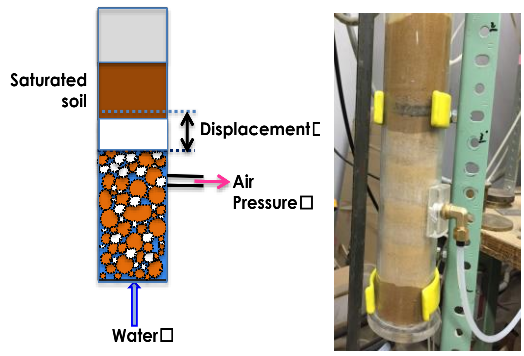

Figure 1b: Entrapped air

2.1. Soil Properties, Sample Preparation and Test Conditions

Two types of soil were used for the experiment, namely: Silica sand no.8 and DL Clay. DL Clay is a non-plastic silt with specific gravity, G_s=2.665; saturated unit weight, γ_{sat}=18.2kN/m^3; void ratio, e=0.920; and mean diameter, D_{50}=0.023mm. Silica sand no.8 has G_s=2.670; maximum dry density, ρ_{max}=1.760; e=1.157; and D_{50}=0.14mm.

2.2. Sample Preparation and Test Conditions

The dry soil was prepared using a free tamping rod in 5 layers each measuring 35mm with a Degree of Compaction, D_c of 80%. The saturated soil was prepared outside the soil column and carefully placed on top of the dry soil ensuring that potential pathways for escape of entrapped air were minimised.
A series of tests was carried out with different rates of infiltration of the de-aired water into the soil column. A control experiment was also conducted with the entire soil column containing only Silica sand no.8 with the de-aired water subjected to 30kPa. For each test, water was infiltrated into the soil column until no further change in displacement was recorded. Table 1 shows the test series considered in this paper.

Keywords: Entrapped Air, Air Pressure, Infiltration Rate, Displacement, Unsaturated soil, Impermeable 1
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Table 1: Test Conditions

Test Series	Saturated layer Soil type	Unsaturated layer soil type	Pressure of infiltrating water (kPa)	Saturated layer thickness (mm)	Unsaturated layer thickness (mm)
SIL8-30	Silica Sand No. 8	Silica Sand No. 8	30	25	175
DLSIL-10	DL Clay	Silica Sand No. 8	10	25	175
DLSIL-20	DL Clay	Silica Sand No. 8	20	25	175
DLSIL-30	DL Clay	Silica Sand No. 8	30	25	175

3. TEST RESULTS AND DISCUSSION

Changes in displacement and air pressure below the saturated DL Clay layer were measured as water infiltrated into the sand. In the SIL8-30 test (Fig. 2a), no significant air pressure and displacement were observed due to absence of entrapped air. However, in the DLSIL tests, air was entrapped below the saturated DL clay layer (with low air permeability). Generally, air pressure rose uniformly and proportionally with water inflow. The DLSIL-30 test attained its maximum air pressure at the lowest value of water inflow; after which the air pressure decreased. This drop could have been due to compression of the air phase as more air got entrapped. The early peaking of DLSIL-30 implies that the rate of development of entrapped air pressure is directly proportional to the water infiltration rate. Due to dimension limitation of the test apparatus, water could not be infiltrated until peaking of the DLSIL-10 and DLSIL-20 tests.
Displacement of the saturated soil layer increased with higher entrapped air pressure (Fig. 2b). The rate of change in displacement was highest in DLSIL-30 because of faster rate of entrapped air development. From Fig. 2b (DLSIL-10), the air pressure corresponding to the start of rapid change of displacement is about 0.44kPa. Using Equation 1, the theoretical air pressure (P_{th-d}) required to cause significant displacement was estimated as 0.46kPa. This value is approximately equal to the experimental one implying a near correlation of experiment data with theoretical predictions. The DLSIL-20 and DLSIL-30 test results, however, are not consistent with theoretical predictions. Fig. 2c further shows that the change in displacement with water inflow is identical for DLSIL-20 and DLSIL-30 – slightly deviating from DLSIL-10. This trend is comparable with the air pressure-displacement behavior for the test series.

$$P_{th-d}(kPa) = \frac{\gamma_{sat} \times V_{sat}}{A_{sat}} \qquad (1)$$

where, γ_{sat}: saturated unit weight of upper (saturated) layer (kN/m^3), V_{sat}: total volume of saturated layer (m^3), A_{sat}: area of interface between saturated layer and unsaturated layer of soil (m^2)

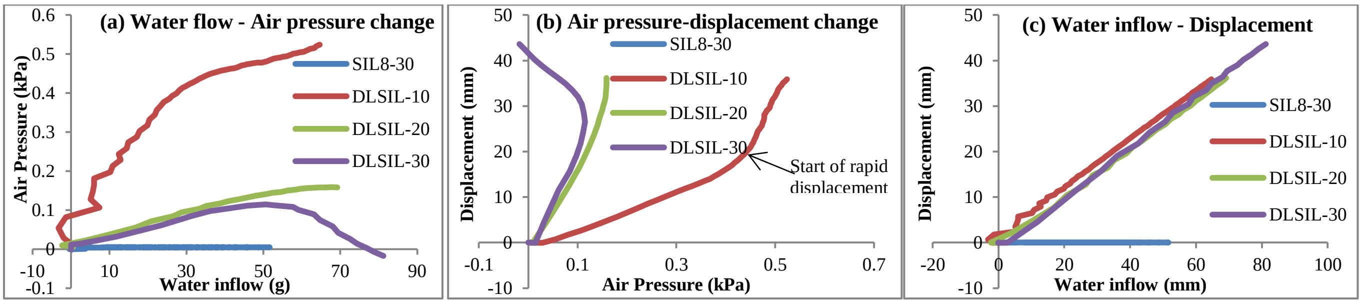

Figure 2: (a) Water inflow- Air Pressure; (b) Air Pressure-Displacement curves; (c) Water inflow-Displacement

4. CONCLUSIONS

From the experimental results, the following conclusions were deduced:

1. Air was entrapped in the experiments with a saturated layer of DL clay overlaying Silica Sand No.8. Although silica sand 8 is considerably a fine material, no air was entrapped when the soil specimen was entirely made of this sand. This suggests that fines content of the saturated layer is not the governing factor for air entrapment and ground failure. However, it should not be ruled out as one of the influencing parameters.
2. As the infiltration rate of water through the soil was increased, the rate of entrapped air development within the soil also increased. Subsequently, a higher rate of change of displacement due to entrapped air was also observed.
3. The deviation of DLSIL-20 and DLSIL-30 tests from anticipated theoretical behavior suggests that higher infiltration rates may misestimate the air pressure and displacement values for soils with relatively low water permeability. This hypothesis should be confirmed by increasing the infiltration rate beyond the values presented in this paper; and experiments using coarser sand for the unsaturated layer.

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