Mechanical behaviour of unsaturated undisturbed black volcanic ash soil under static and cyclic loading

Kyushu University, Student member, ○ OKRI ASFINO PUTRA
Kyushu University, Fellow member, YASUFUKU Noriyuki
Kyushu University, Regular member, ISHIKURA Ryohei
Kyushu University, Student member, ALOWAYSI Adel
NEXCO West, Regular member, KAWAGUCHI Yuko

1. Introduction

Black volcanic ash soil which is known as Kuro-boku soil in Japan that is a problematic type of soil [1]. Distribution of black volcanic ash soil covers approximately 31% of the total area of Japan, mainly within the volcanic zones [2]. Black volcanic ash soils are generally found near the slope surfaces above the groundwater table which can be generally as an unsaturated zone. Recently Kumamoto earthquake 2016 triggered many slope failures around the Aso area. The black volcanic ash soils and orange-colored pumice deposits are the most common types of soils that experienced failure in the Aso area. Many researchers have studied the volcanic ash soil in Kumamoto slope failures especially the orange-colored pumice [3-4]. However, small attention was given to the shear strength and characteristic of the black volcanic ash soil. In this paper, the shear strength and characteristic of black volcanic ash soil was evaluated. A series of static and cyclic tests using the constant volume direct shear box was performed. Also, for further understanding of the chemical content of the black volcanic ash soil, X-ray fluorescence analysis (XRF) has been done. In order to enhance understanding of the black volcanic ash soil behaviour same as natural condition undisturbed samples were collected and focused on overconsolidated area. Furthermore, to consider the effect of changing the moisture content under precipitation events, saturated samples were tested.

2. Materials and sampling locations

Tests were conducted using undisturbed samples. Samples were collected at the middle and the top of the slope failure zone at the boundaries in Kumamoto slope failure. Samples were collected 1.5 m, from the original surface next to the failures zone boundaries and the cross-section mainly showed the black volcanic ash.

The median grain size D_{50} of black volcanic ash soil is approximately 0.012 mm. Based on that, the black volcanic ash soil can be classified as volcanic cohesive soil type II (VH2) according to the JGS standards. The yield stress in the unsaturated undisturbed sample was 105 kN/m^2 in average. Based on the consolidation test results, the black volcanic ash used in this research is considered as overconsolidated soil. Where the sampling depth is around 1.5 m, thus overburden pressure less than 105 kPa.

3. Methodology

In order to examine the shear strength properties of the black volcanic ash soil, a series of constant volume direct shear box tests were carried out. In a static test for overconsolidated sample, 10 and 50 kPa vertical stress was applied. On the other hand, for normally consolidated sample 200 kPa vertical stress was adopted. Before the shearing start, specimens were consolidated under the designated vertical stress each condition for 1 hour. Then, sheared with the undrained condition up to 7 mm at a shear rate of 0.2 mm/min according to the JGS standards. In order to examine the shear strength of the black volcanic ash soil under the earthquake shakes, a series of cyclic direct shear box test was carried out. The cyclic test under two pattern with displacement 1 mm were adopted. First type of pattern, cyclic one-sided shearing was applied. Where shearing was started from 0.5 mm to 1 mm, from 1 mm moving back to 0 mm and again to 0.5 mm. The total of displacement for one cycle was 2 mm. On the other hand, for the second type of pattern two-sided shearing was conducted. Where shearing was started from 0 mm to 0.5 mm, then from 0.5 mm moving back to -0.5 mm and again to 0 mm. The total of displacement for one cycle was also 2 mm. The schematic diagramof cyclic loading and test program were applied is shown in **Fig. 1.** and Table 1.

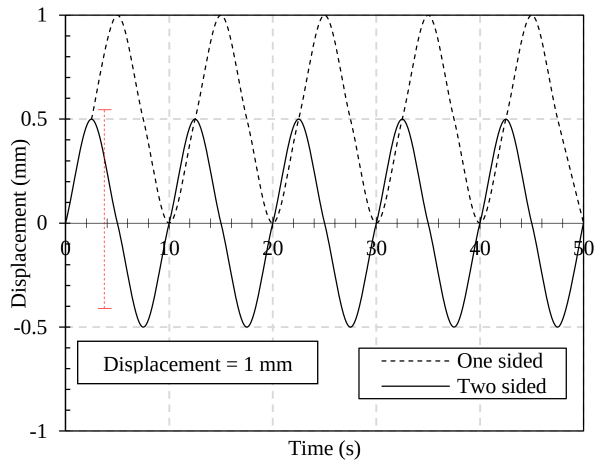

Fig. 1. Schematic of (one-sided and two-sided) cyclic loading.

Table 1. Test program for static and cyclic.

Test ID	Sample	Void Ratio (e_0)	Sr_0 (%)	Initial Suction* (kN/m^2) [5]	Vertical stress (kN/m^2)
Static test					
S01	Unsaturated	4.70	65.5	100	10
S02	Unsaturated	5.16	68.0	100	50
S03	Unsaturated	4.95	72.5	97	200
S04	Saturated	4.60	99.7	0.1	10
S05	Saturated	4.77	99.3	0.1	50
S06	Saturated	4.72	100	0.1	200
One-sided cyclic					
C101	Unsaturated	4.03	67.8	100	50
C102	Unsaturated	4.01	69.5	100	200
C103	Saturated	4.41	99.5	0.1	50
C104	Saturated	4.45	96.8	0.2	200
Two-sided cyclic					
C201	Unsaturated	4.73	74.1	97	50
C202	Unsaturated	4.96	82.9	8	200
C203	Saturated	4.43	100	0.1	50
C204	Saturated	4.77	100	0.1	200

* Initial suction before shearing

4. Results of static and cyclic (one-sided and two-sided) shearing behaviour

The relationship between the vertical and shear stress for the unsaturated and saturated sample is illustrated in **Fig. 1.** It can be observed that for the normally consolidated condition, the vertical stress increases dramatically till achieving the peak shear stress. Then, slightly decreases regardless of the saturation condition. On the other hand, for the overconsolidated condition both vertical stress and shear stress increases without distinct peak value. The observed behaviour is similar to the clayey soil behaviour under undrained triaxial test [6]. For the overconsolidated sample, the monotonical increases in the vertical stress can be justified to be a result of the pore water pressure reduction under shearing. On the other hand, for the normally consolidated increases in the pore water pressure during shearing leads to decreasing of the vertical stress. The apparent cohesion decreases from 24.6 kN/m^2 under unsaturated condition to 13 kN/m^2 for saturated condition. In addition the apparent friction angle slightly reduced from 35.5° under unsaturated to 35.1° for saturated condition. Finally it can be concluded that the shear strength strongly depend on soil water content, within translate into suction force which contributed to the total shear strength of the soil.

The relationship between the normalized shear stress and number of cyclic in the overconsolidated sample as illustrated in **Fig. 3.** It can be observed on the one sided cyclic that the normalized shear stress value decreases with the increasing number of cyclic. On the other hand for the two-sided cyclic shearing test, the normalized shear stress value is higher than the one-sided cyclic shearing test. It can be seen that the normalized shear stress value increases with the increasing number of cyclic till reaching the maximum value at the 10th cycles (final cycles). This might be justified to be a result increasing of frictional resistance of soils. The obtained results also are in good agreement with two-sided cyclic test direct shear box test results obtained by Cabalar [7]. Finally, It can be concluded that the cyclic shearing pattern and number of cyclic significantly affect the shear stress of soil.

Furthermore, it can be seen the shear stress of unsaturated condition in both cyclic test, it is significantly larger. The obtained results are in good agreement with the shearing behaviour in the static shearing. This can be atributted to the influence of the matric suction contribution in the total shear strength of soils.

5. Chemical content

The chemical content of black volcanic ash soil results SiO_2, Al_2O_3, Fe_2O_3 accounts for as high as about 93%. It is known that these three are the main components of substances called allophane. Single particles of allophane are much smaller than other clay minerals and are extremely porous. The chemical content of the black volcanic ash soil is shown in Table 3.

6. Conclusions

The main conclusions are as follows:

1. Unsaturated sample exhibits a higher the shear strength in comparison to the saturated sample condition both in static and cyclic test.
2. The cyclic shearing pattern direction and number of cyclic significantly affect the shear strength of soil.
3. The chemical content of black volcanic ash soil results SiO_2, Al_2O_3, Fe_2O_3 accounts for as high as about 93%.

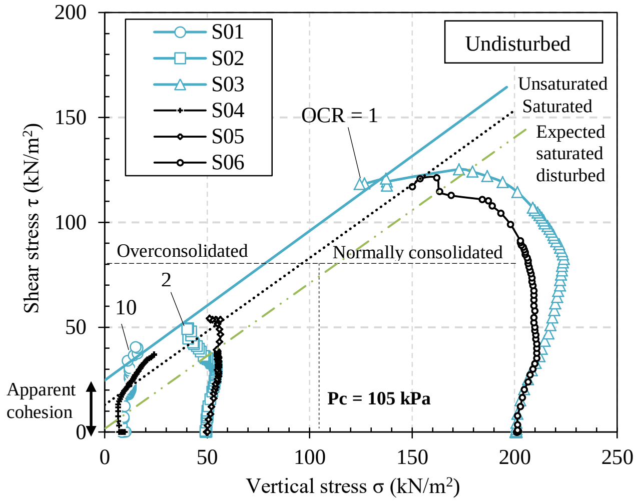

Fig. 2. Stress path static test unsaturated and saturated sample

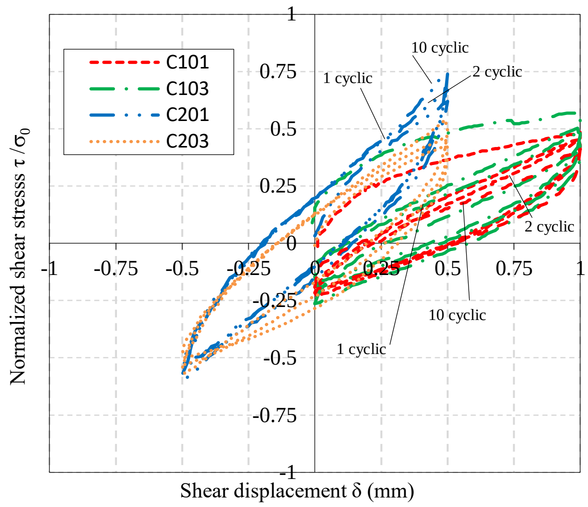

Fig. 3. Cyclic shear stress - displacement behaviour under one-sided and two-sided shearing for the overconsolidated area

Table 3. The chemical content of black volcanic ash soil

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	TiO_2 (%)	K_2O (%)	SO_3, P_2O_5, V_2O_5, S_rO, Z_nO, Cr_2O_3, MnO, MgO, ZrO_2, Br (%)
50.2	28.7	14.4	2.1	1.8	1.0	1.0

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