

EXPERIMENTAL RESEARCH ON DEVELOPMENT/DIMINISHING OF ANISOTROPY AND ITS EFFECT ON MECHANICAL BEHAVIOR OF CLAY

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ABSTRACT: Anisotropy refers to the directional dependence of material properties. The knowledge of development/diminishing of anisotropy are very important, to understand the true behavior of naturally deposited soil. The anisotropy of clays and silty clay intimately connected with their structure, which depends on the environmental conditions during which the soil is deposited as well as the stress changes subsequent to deposition. In this paper, triaxial tests were carried out using the vertical and the horizontal extraction specimen of the reconstituted clay and silty clay, for accumulating experimental facts of development of anisotropy during the preliminary consolidation process and the influence of the anisotropy on the shear behavior. Pre-consolidation pressure of 200kPa applied to induced initial anisotropy. Undrained shear triaxial test was performed with different isotropic stresses on clay (50 to 1800kPa) and silty clay (50,300 and 600kPa), and undrained shearing was carried out under constant axial strain rate of 0.0056(mm/min). Vertical sample shows larger peak strength as compared to horizontal, because of the development of anisotropy on the compression side. As the confining pressure increases, the difference between peak strength of vertical and horizontal becomes smaller and smaller which indicate that the anisotropy diminished and intensity ratio decreases. By comparing clay and silty clay, silty clay materials lose their anisotropy at lower confining pressure (600kPa) as compared to clay materials (1800kPa). Therefore, the grain sizes have significant effect on the developing and diminishing of anisotropy. Another important fact observed was, critical state index is decreasing and becomes constant as confining pressure increases.

Keywords: Anisotropy, Clay, Silty Clay, Undrained shear test and Critical state index.

1. INTRODUCTION

Anisotropy refers to the directional dependence of material properties. The anisotropy of clays and silty clay intimately connected with their structure, which depends on the environmental conditions during which the soil is deposited as well as the stress changes subsequent to deposition. Neglecting the anisotropy of soil behavior may lead to highly inaccurate predictions of soil response under loading. In order to know the true behavior of naturally deposited soil, the knowledge of development/diminishing of anisotropy are very important.

Hoque et al. investigated the anisotropy in elastic deformation of granular materials by measuring local strains in both vertical and horizontal direction with static cyclic loading. He found that vertical Young's modulus is greater than horizontal Young's modulus at isotropic stress level [1]. Islam et al. investigated the strength anisotropy in both vertical and horizontal directions by trimming the specimens at different angles so as to obtain the test samples of different orientations, compared to the depositional direction and then subjected to unconfined compression tests and direct

shear tests for both the horizontal and vertical planes from undisturbed clay masses. He concluded that the clay samples collected from different places and different depths showed different coefficients of anisotropy in different laboratory tests [2]. There have been some similar studies related to this research [3-10] and numerous experimental studies on the effects of anisotropy have been conducted focusing on the shear strength, however, there is not much to explain how the anisotropy develops or disappears with ongoing plastic deformation.

In this paper, triaxial compression tests were carried out using the vertical and the horizontal extraction specimen of the reconstituted clay and silty clay sample, for accumulating experimental facts of development of anisotropy during the preliminary consolidation process and the influence of the anisotropy on the shear behavior. Also the comparison of clayey and silty clay and how the grain size affects the development/diminishing of anisotropy were discussed.

2. EXPERIMENTAL WORK

Physical properties and grain size distribution of the clay and silty clay used in the experiment are

shown in Table 1 and Figure 1 respectively. After thorough stirring and degassing at a water content of 1.5 times the liquid limit, we applied pre-consolidation pressure of 200kPa for one week for clay and two days for silty clay.

The method of extracting the sample from the preliminary consolidation tank is the following; specimen pulled out so that the axis was in the vertical direction is vertical specimen and the specimen extracted so that the axis is in the horizontal direction is horizontal specimen, shown below in schematic Figure 2.

Table 1 Physical properties of soil.

Description	Clay	Silty-clay
Liquid Limit w_L (%)	81.4	45.82
Plastic Limit w_p (%)	43.7	25.37
Plasticity index I_p	37.7	20.44
G_s (g/cm ³)	2.65	2.65

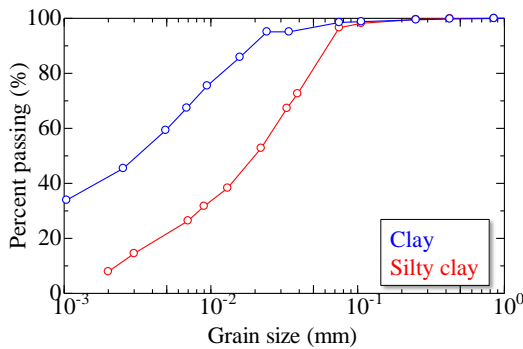


Fig.1 Grain size distributions

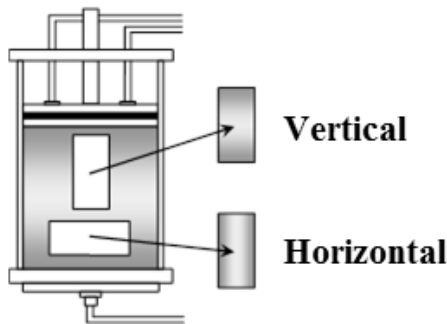


Fig.2 Extracting Vertical and Horizontal Specimen

By extracting the reconstituted sample from different directions, samples with different initial anisotropy were prepared. Five types of isotropic stresses of 50, 100, 300, 600, 1800 kPa were applied on clay and three isotropic stressed of 50, 300 and 600kPa were applied on silty clay. Both clay and silty clay were isotopically consolidated for 24hours. The saturation values B-value of each sample were confirmed to be 0.96 or higher. After isotropic consolidation, undrained shearing was carried out under constant axial strain rate of 0.0056(mm/min) for clay and 0.0112(mm/min) for silty clay. These axial strain rate were considered to be slow enough to maintain element behavior (the distribution of excess pore water pressure inside the specimen is uniform) during shearing

2.1 Development/Diminishing of Anisotropy in Clay

Figures 3 to 7 shows the stress-strain relationship and effective stress path of vertical and horizontal specimen with different confining pressures of clay, 50 to 1800kPa respectively. Isotropic stresses of 50kPa and 100kPa are considered to be in fully remolded and overconsolidated conditions because the pre-consolidation pressure was 200kPa and, the isotropic stresses of 300kPa and above are considered to be in fully remolded and normal consolidated condition.

In all specimens, the effective stress is constant when the axial strain reaches 20%, so it is considered that the specimen reached a critical state. In the case of the normal consolidated condition, the effective stress path exhibits typical behavior with an increasing of q with decreasing of p' .

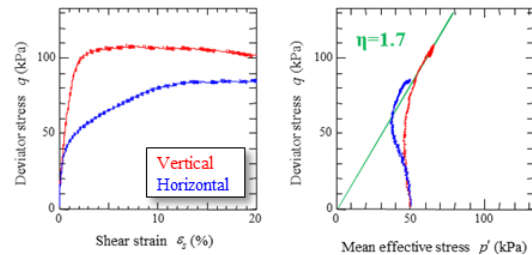


Fig.3 Confining pressure 50kPa (clay)

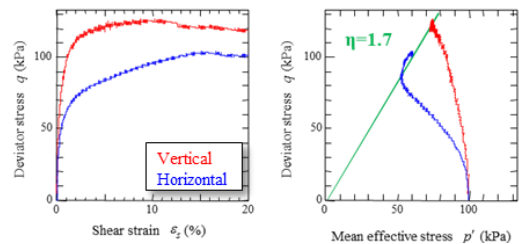


Fig.4 Confining pressure 100kPa (clay)

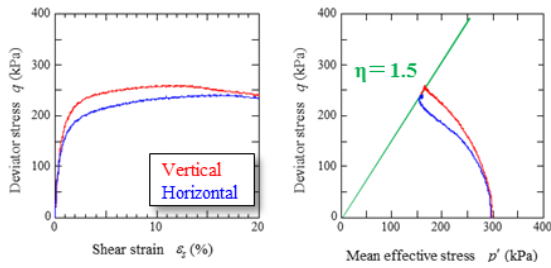


Fig.5 Confining pressure 300kPa (clay)

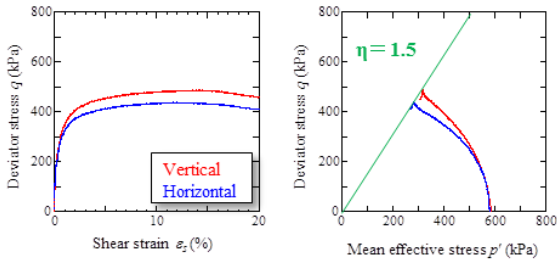


Fig.6 Confining pressure 600kPa (clay)

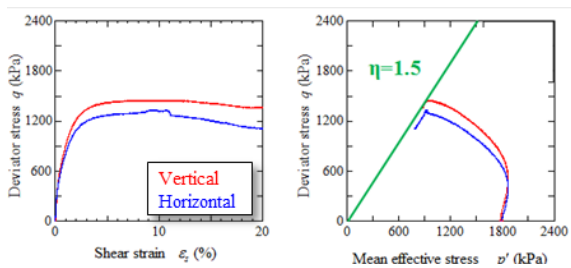


Fig.7 Confining pressure 1800kPa (clay)

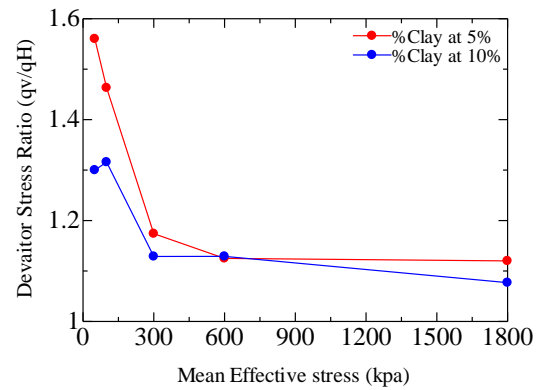


Fig.8 Difference in vertical and horizontal shear strength of clay

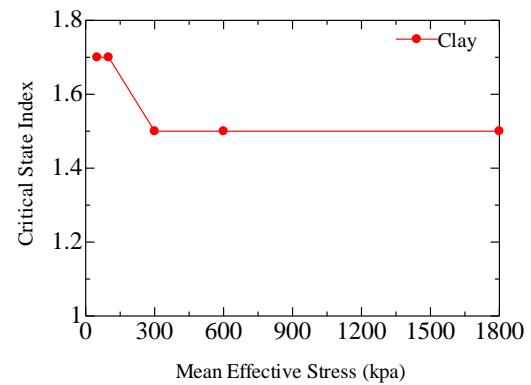


Fig.9 Difference in critical state index of clay

Figure 8 summarizes the difference of shear strength in vertical and horizontal direction at the time of axial strain was 5% and 10% (almost critical state). By comparing the shear/peak strength of samples of clay, it was observed that vertical sample shows larger peak strength as compared to horizontal because of the development of anisotropy on the compression side. As the confining pressure increases, the difference becomes smaller and smaller which indicate that the anisotropy disappears/diminished and intensity ratio decreases.

However, even at 300, 600, and 1800kPa, the same degree of strength difference remains. So it was found that even if we have applied high isotropic consolidation pressure, anisotropy was not completely diminished. Figure 9 summarizes the clayey samples that the critical state index (slope of critical state line) is changing with increasing confining pressure. Also it was observed that, critical state index is decreasing and become constant as confining pressure increases.

2.2 Development/Diminishing of Anisotropy in Silty Clay

Figures 10 to 12 shows the stress-strain relationship and effective stress path of vertical and horizontal specimen with different confining pressures of silty clay at 50 to 600 kPa respectively. Isotropic stress of 50kPa is considered to be in fully remolded and overconsolidated condition. The isotropic stresses of 300kPa and 600kPa are considered to be in fully remolded and normal consolidated condition. In the case of silty clay specimens, unlikely clay specimens, q continues to increase even when the axial strain reaches 20%. Moreover, the effective stress path of the normal consolidated condition turns to an increase of q with increasing of p' after increasing of q with decreasing of p' . Figure 13 summarizes the difference of shear strength in vertical and horizontal direction at the time of axial strain was 5% and 10%. By comparing the shear/peak strength of samples of silty clay, it was observed that vertical sample shows larger peak strength as compared to horizontal because of the development of anisotropy on the compression side. As the confining pressure increases, the difference becomes smaller and smaller which indicate that the

anisotropy disappears/diminished and intensity ratio decreases. Moreover, the anisotropy almost diminished at confining pressure of 600kPa. Compared with the clay specimen in Figure 8, it can understand that anisotropy disappears with small isotropic pressure. Figure 14 summarizes the silty clay samples that the critical state index is changing with increasing confining pressure same as in clayey specimen.

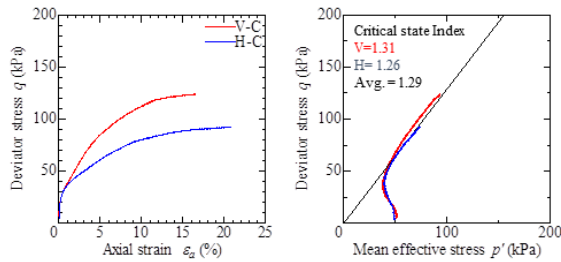


Fig.10 Confining pressure 50kPa (silty clay)

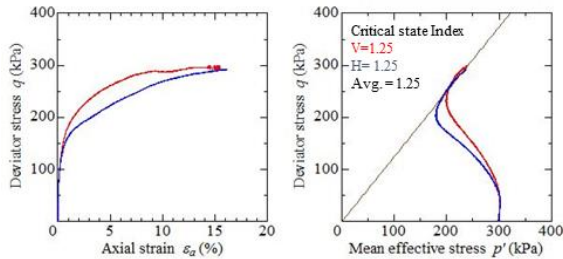


Fig.11 Confining pressure 300kPa (silty clay)

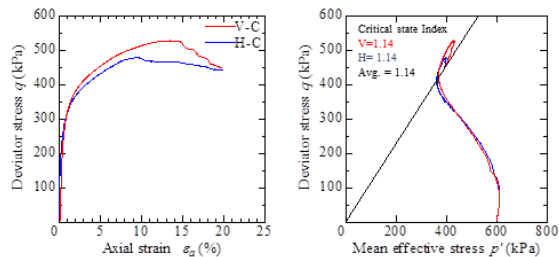


Fig.12 Confining pressure 600kPa (silty clay)

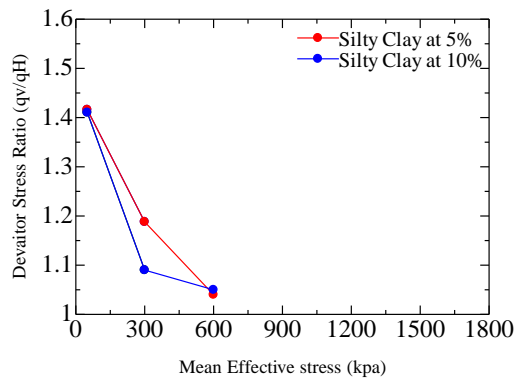


Fig.13 Difference in vertical and horizontal shear strength of silty clay

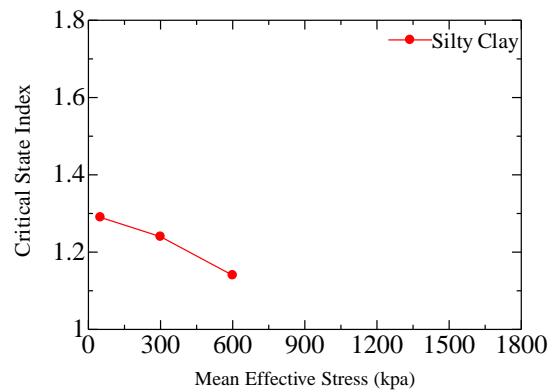


Fig.14 Difference in critical state index of silty clay

3. COMPARISON OF CLAY AND SILTY CLAY

Figure 15 summarizes the clay and silty clay samples, difference in vertical and horizontal shear strength at 5%. Values were taken at 5% because, in case of silty clay sample, localized failure (sudden decrease and discontinuous curve in stress-strain relationship) can be observed after 5% especially within high confining pressure and therefore, it is difficult to recognize as element behavior furthermore.

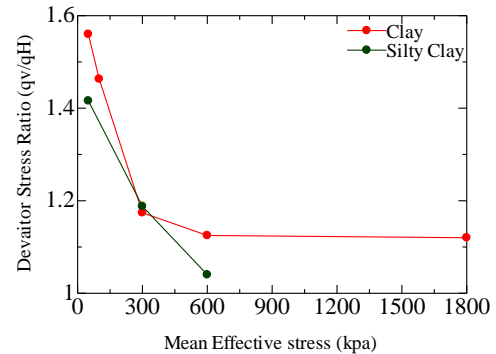


Fig.15 Difference in vertical and horizontal shear strength

As indicated above, both vertical samples shows larger peak strength as compared to horizontal because of the development of anisotropy on the compression side. As the confining pressure increases, the difference becomes smaller and smaller which indicate that the anisotropy disappears/diminished and intensity ratio decreases. It was found that even if we have applied high isotropic consolidation pressure, anisotropy was not completely diminished specially in case of clay soil but in case of silty clay they lose their anisotropy at rapid rate as compared to clayey materials, at confining pressure of 600kPa. So, it is concluded that the grain size has significant effect on the

diminishing of anisotropy, and silty material shows rapid change in anisotropy compared with clay material.

Figure 16 summarizes the clay and silty clay samples changing of critical state index with increasing confining pressure. Comparing clay and silty clay, critical state index is larger for clay material. Another important fact observed that, critical state index is changing with different confining pressure. The critical state index decreases as the anisotropy disappear with an ongoing increase of isotropic pressure.

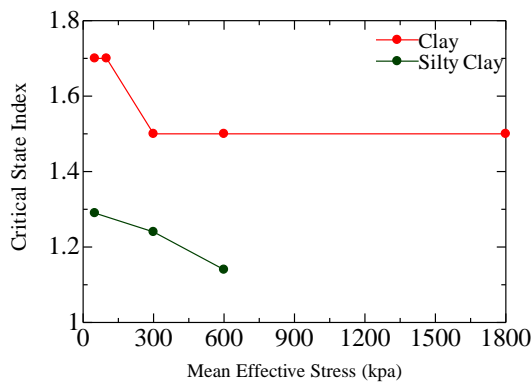


Fig.16 Difference in Critical state Index

To describe the effect of anisotropy in the numerical simulation, the rotational hardening concept [10] was often used. However, when introducing the rotational hardening concept directly to the original Cam clay model that is so-called as the Sekiguchi-Ohta model [11], the critical state index did not change even if the anisotropy develops and disappears. On the other hand, when introducing the rotational hardening concept to the modified Cam clay model, critical state index changes according to the plastic deformation. Figures 17 and 18 show the change of yield surface and critical state line in q - p' plane of Sekiguchi-Ohta model and modified Cam clay model with rotational hardening [12] during undrained shearing respectively. The soil is in the normal consolidated condition, considering only the development of anisotropy.

In the Sekiguchi-Ohta model, the critical state line does not change when anisotropy develops, whereas, in the Modified Cam-clay model, critical state line changes (critical state index increases) as the anisotropy develops. Furthermore, in the case of the Modified Cam Clay model, the phenomenon of increasing q accompanied by an increase in p' in the effective stress path can be reproduced due to the effect of rotational hardening. From this viewpoint, modified Cam clay model can be considered to be more suitable to use as compared to the original Cam clay model in order to represent the work of anisotropy.

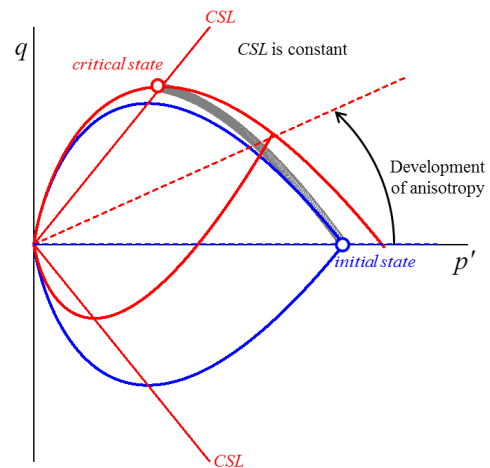


Fig.17 Sekiguchi-Ohta model

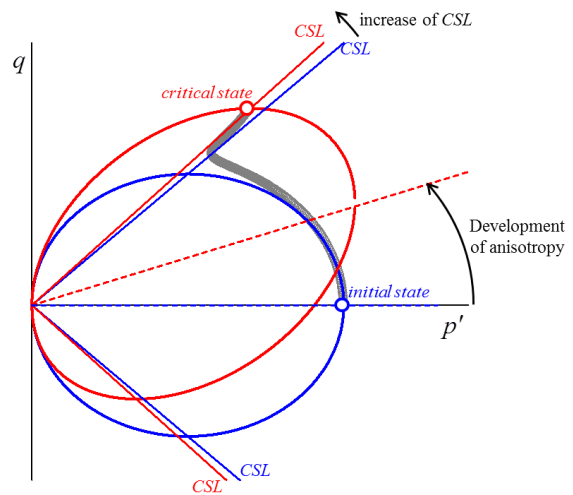


Fig.18 Modified Cam-clay model with rotational hardening

4. CONCLUSION

From a series of experimental results, it is concluded that anisotropy developed in the preliminary consolidation process, and anisotropy disappears due to isotropic consolidation. Nevertheless, it does not completely disappear even under high confining pressure i.e. 1800kPa, especially in case of clay. However, if we compare clay and silty clay soil, silty clay materials lose their anisotropy at lower confining pressure i.e. 600kPa, as compared to clay materials. Therefore, the grain sizes have significant effect on the developing and diminishing of anisotropy.

Another important fact observed was that critical state index (slope of critical state line) is decreasing and become constant as confining pressure increases. Moreover, modified Cam clay model can be considered being more suitable to use as compared to the original Cam clay model in order to represent the

work of anisotropy.

Further experiment will be performed to observe the effect of cyclic shear test to evaluate the development/diminishing of anisotropy. Moreover, based on experimental facts, constitutive model will be validated and add some improvement if necessary.

5. ACKNOWLEDGEMENTS

This research work was supported by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan. I thank Kota Mizukami, my lab member for his kind guidance and help during experimental work.

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