Experimental Studies on Strength and Deformation Characteristics of Unsaturated Clay (II)

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Experimental Studies on Strength and Deformation Characteristics of Unsaturated Clay (Ⅱ)

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Abstract

Strength and deformation characteristics of compacted soils, which are usually under unsaturated condition, are strongly influenced by the moisture content of the soil, while the compaction method might affect these characteristics more directly. In this paper, the influence of moisture content upon the strength and deformation characteristics of unsaturated clays are examined. From the results, followings properties are clarified considering the suction effect : (1) shear strength of specimen become maximum at w_{opt} (w_{opt} : optimum moisture content) condition or slightly drier than w_{opt}, (2) pore pressure occurred in shearing become larger as increasing of the moisture content of specimen, while the volume expansion of specimen become smaller. These results are indispensable to investigate the suction effects of soil, and suggest the importances of moisture content management in soil compaction.

Key Words: Unsaturated clay, Triaxial compression test, Moisture content, Suction effect

Introduction

To design and/or analyze the ground and the soil structures such as irrigation ponds, it is essential to determine the soil parameters by soil tests considering the field conditions. From this point of view, authors have been examined the soil properties experimentally and clarified the strength and deformation characteristics of the soil. In recent studies, we have performed a series of triaxial tests and investigated the fundamental properties of compacted kaolin clay (under unsaturated condition),[1] because many soils near the ground surface and compacted soils constructing soil structures are under unsaturated condition. It is very important to manage soil compaction method in stabilizing the ground and in building the soil structures such as irrigation ponds.

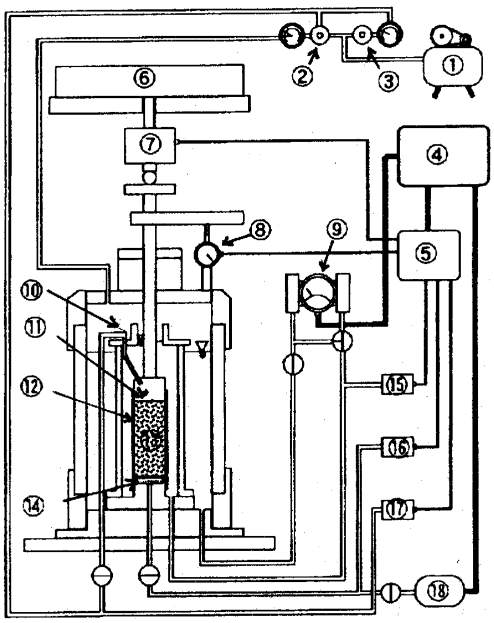
There is some factor influencing upon the strength and deformation characteristics of unsaturated soils.[2] Moisture content is one of the most significant factor affecting the mechanical properties of compacted (unsaturated) soils, while the compaction method might affect more directly. In this paper, series of consolidated-undrained triaxial compression test using compacted (unsaturated) DL-clays are preformed, strength and deformation characteristics of unsaturated soils affecting by moisture content of the specimens are examined, considering the previous results using compacted kaolin clay.[1] Unsaturated soils consist of solid phase (soil particles), liquid phase (pore water) and gas phase (pore air), and the surface tension between pore water and pore air contributes to forming a meniscus and induces a pressure difference (that is, suction). Mechanical behavior of unsaturated soils are strongly influenced by suction, and the suction effects are dominated by the moisture content of specimen. The chief points considered in this studies are the relationships between moisture content and strength, compressibility, volumetric strain, pore water pressure, according to shearing.

Apparatus, Specimen and Testing Procedure

In this study, unsaturated triaxial compression tests were preformed according to the specification defined for 'a cooperative test program of uniaxial and triaxial compression tests on unsaturated soils'[3] which was carried out by the Japanese Geotechnical Society. There were several kind of testing series assorted by consolidating and shearing conditions, ventilated-undrained triaxial shearing tests were performed in this study. The details of testing procedures are referred in above specification. And these conditions are the same as previous study.[1]

Fig.1 shows the unsaturated triaxial compression test apparatus used in this study. The feature of this apparatus compared with conventional triaxial ones (for saturated soils) are : a) inner cell is used to measure the volume change of specimen, b) ceramic disk(air entry value=2.0 kgf/cm^2) is used at the bottom of specimen to measure only the amount of pore water coming in and out, c) glass fiber filter is used only pore air can pass through, d) testing data are automatically recorded by using microcomputer through A/D conversion board. The details are shown in previous paper.[1]

The testing soil used was called DL-clay, which was also used in above 'a cooperative test program of uniaxial and triaxial compression tests on unsaturated soils'.[3] This soil is classified in non-plastic silt, and its specific density (G_s) is about 2.65, the component of particle size distribution is sand=0.1%, silt=90.4%, clay=9.5%. Specimens were prepared to cut a compacted sample in the column 5cm in diameter and 11cm in height. Compaction was carried out in accordance with 'JSF T 711'[4] (the standard of the Japanese Geotechnical Society), the test



① compressor
② cell pressure regulator
③ pore pressure regulator
④ personal computer
⑤ strain amplifier
⑥ axial loading apparatus
⑦ load transducer
⑧ dispalcement transducer
⑨ pressure difference transducer
⑩ inner cell
⑪ glass filter
⑫ rubber membrane
⑬ specimen
⑭ ceramic disk
⑮ cell pressure transducer
⑯ pore water pressure transducer
⑰ pore air pressure transducer
⑱ electric balance

Fig. 1. Overview of unsaturated triaxial conpression test apparatus.

method for soil compaction using rammer. Fig. 2 shows the dry density vs. moisture content relationship obtained, the optimum moisture content : w_{opt} (which can compact soils most densely) are known about 19%. Samples were prepared and compacted in difference moisture content around w_{opt}, and the moisture content and the dry density of specimens used in this

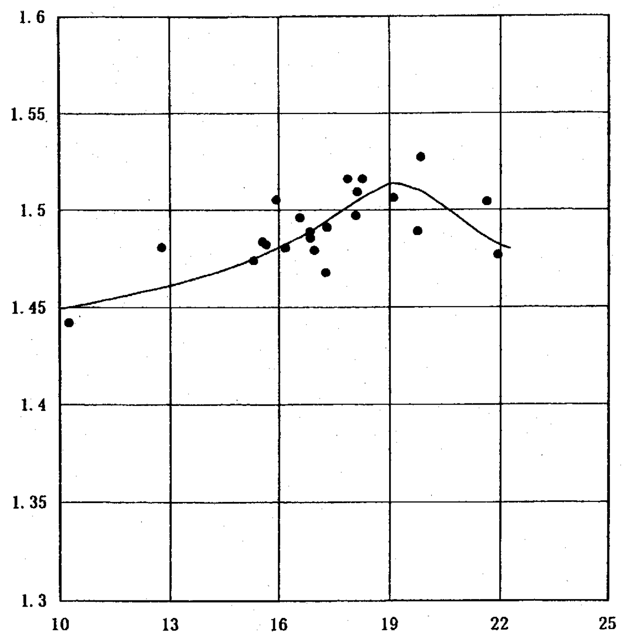


Fig. 2. Compaction curve for DL-clay.

Table 1. Specimen conditions

Specimen No.	1	2	3	4
Water Content Ratio(%)	16.6	18.7	19.8	21.5
Dry Density(g/cm³)	1.53	1.55	1.53	1.49

study are shown in Table 1.

After the specimen is set in triaxial cell and covered with rubber membrane (thickness=0.2mm), initial confining pressure 0.5 kgf/cm² is applied, and the specimen is kept this condition until the volume change of specimen converge to zero. Then the consolidation process is started according to the stress path shown in Fig.3. At the end of this process (consolidation), specimen is isotropically consolidated under the the condition of cell pressure=2.0 kgf/cm² and the pore air pressure=1.0 kgf/cm² (i.e. effective confining pressure=1.0 kgf/cm²).

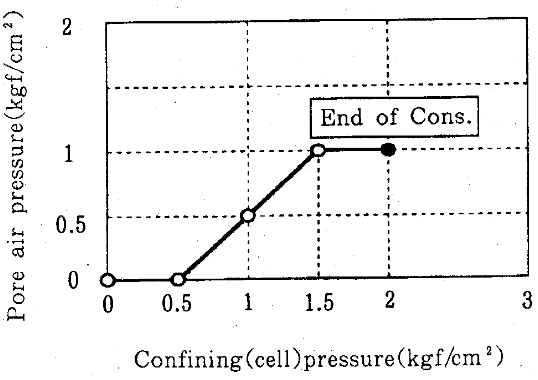


Fig. 3. Stress path for consolidations.

Immediately after the end of consolidation, statical shear is performed. The shear strain rate is 0.06%/min, and specimen is under ventilated-undrained condition.

Results and Discussion

Stress-strain relationships

Fig. 4 shows the stress-strain (deviator stress vs. axial strain) relationships of triaxial shearing for DL-clays compacted in different moisture content, as well as the one for kaolin clay. At first, it can be seen about DL-clay that the shear strength is much larger and the peak of stress-strain curve appeared more clearly than kaolin clay. It is because the difference of physical properties, that is to say, DL-clay is silty soil and more brittle (not so much soft) than kaolin clay. Secondary, it is found that maximum shear strength exhibit at the moisture content is about w_{opt} or a little smaller than w_{opt}, while the strength decline suddenly and axial strain at the peak strength tend to be larger as the moisture content increase from w_{opt}. These properties can be considered that the bonding force between soil particles originated in suction effect become maximum at the moisture content is about w_{opt} or a little smaller than w_{opt}, and then decline suddenly. It is generally known that the soil is compacted most dense at w_{opt} condition, and the shear strength become maximum around w_{opt} condition. DL-clay is well adapted for these facts. But it must be careful about the result that the strength decline suddenly when the moisture content is beyond w_{opt}, in practical scene especially. Thirdly, it is found th at residual strength are almost the same (about 4.4 kgf/cm^2) instead of the moisture content. It can be thought that the effect of suction is almost the same in residual state. For this reason, followings are considered. Until the specimen becomes failure, the effect of suction caused by inter-particle meniscus is strongly influenced by the moisture content. After the specimen becomes failure, soil skeleton is disturbed, and the suction effects are independent on the moisture content but dominated by the confining pressure.

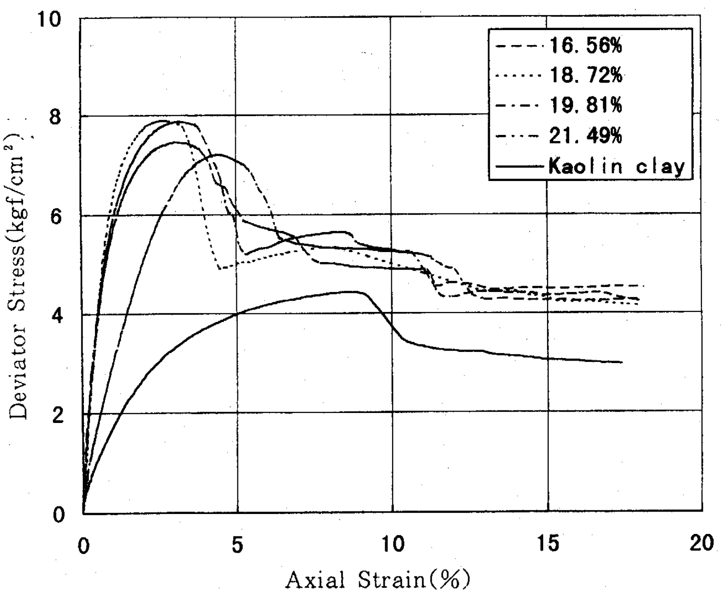


Fig. 4. Deviator stress vs. axial strain relationships.

Behavior of pore water pressure and volumetric strain

Fig. 5 shows the pore water pressure vs. axial strain relationships of triaxial shearing for DL-clays compacted in different moisture content, as well as the one for kaolin clay. It can be seen about DL-clay that the pore water pressure increase with shearing to converge each value, and the value is larger in higher moisture content specimen. These differences of pore water pressure behavior are considered to the effect of suction caused by inter-particle meniscus. As the moisture content of specimens increase, the radius of meniscus become larger and the inter-particle bonding forces (i.e. suction) become smaller. While about kaolin clay, pore water pressure increase only at the beginning of shearing and then decrease to negative value. It is because the difference of physical mechanism concerned with suction generating. That is, soil particles of kaolin are smaller and the radius of inter-particle meniscus are smaller too, then the suction increase and the pore water pressure decrease more remarkably.

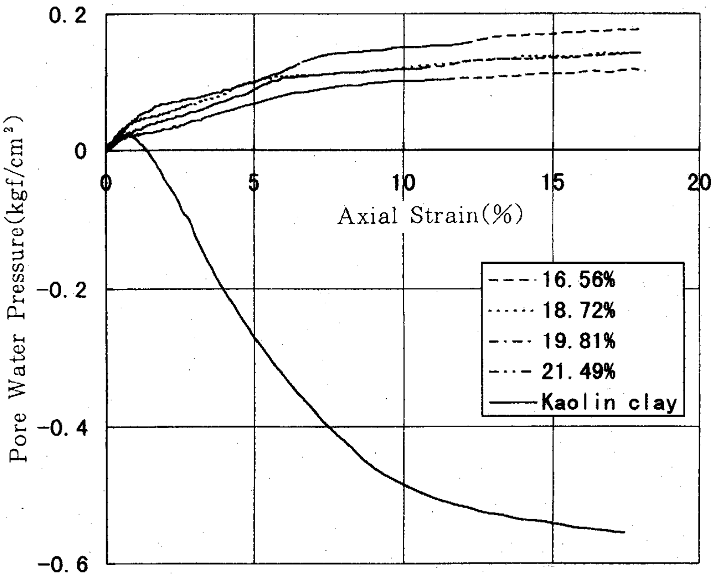


Fig. 5. Pore water pressure vs. axial strain relationships.

Fig.6 shows the volumetric strain vs. axial strain relationships of triaxial shearing for DL-clays compacted in different moisture content, as well as the one for kaolin clay. At first, it is found both DL-clay and kaolin clay, that the specimens are compressing only at the beginning of shearing, and then expanding before the specimens reach the maximum strength state. It is because the effects of dilation that the specimens are expanding instead of the compression test. This characteristic of dilation considered to the effect of the specimen preparation method and the suction. That is to say, the specimens are compacted densely and condensed by the suction, the specimens are hardly possible to be more compressed. Secondary, about the relation between the moisture content and the volumetric strain after specimens are failure, it is found that the higher moisture content specimens are expanding more. The reason can be considered that the effect of suction caused by inter-particle meniscus, as well as the behavior of the pore water pressures. That is, as the moisture content increase, the radius of meniscus become larger and the inter-particle bonding forces (i.e. suction) decrease, then the specimen expand easily.

At last, the difference of volumetric strain behaviors between DL-clay and kaolin clay are considered taking into account for the pore water pressure behaviors. The amount of specim en expansion (decrease of volumetric strain) of DL-clay is almost the same or a bit larger than kaolin clay (cf. Fig. 5). It seem to be inconsistent with the fact that the suction effects are more remarkable (i.e. soil particles bond more strongly) about kaolin clay, in previous section. Properly speaking, kaolin specimens should be more compressed because of the suction effects. But it can be explained from microscopic point of view, that is, soil particles in the specimens tend to be away from each other by the dilating behavior, but the suction caused by inter-particle meniscus prevent from departing soil particles each other. And for kaolin clay, though the radius of the meniscus is smaller, soil particles can dilate (specimens are expanded) more strongly instead of the suction, because the shape of kaolin particles are flat as other general clays are.

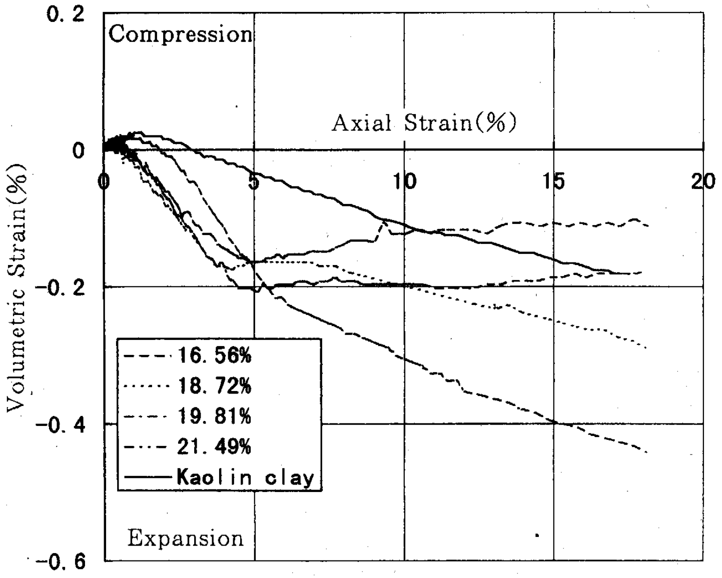


Fig. 6. Volumetric strain vs. axial strain relationships.

Conclusions

Series of consolidated-undrained triaxial compression test using compacted DL-clays are preformed, strength and deformation characteristics of unsaturated soils affecting by moisture content of the specimens are examined, considering the previous results using compacted kaolin clay. Mechanical behavior of unsaturated soils are strongly influenced by suction, and the suction effects are dominated by the moisture content of specimen. As the result, the following conclusions were obtained.

1) Shear strength become maximum at the moisture content is about w_{opt} or a little smaller than w_{opt}, while the strength decline suddenly and axial strain at the peak strength tend to be larger as the moisture content increase from w_{opt}. It is because the bonding force caused by suction become maximum around w_{opt}. So, it must be careful especially in practical scene that the strength decline suddenly when the moisture content is beyond w_{opt}.

2) Pore water pressure increase with shearing to converge each value, and the value is larger in higher moisture content specimen. It is considered that the suction effects become smaller, as the moisture content increase and the radius of meniscus become larger.

3) Specimens are compressing only at the beginning of shearing, and then expanding before the specimens reach the maximum strength state. And the volumetric strain after specimens are failure, the higher moisture content specimens are expanding more. It is because the bonding/confining force caused by suction become weak as the moisture content become higher.

4) The differences of mechanical behaviors between DL-clay and kaolin clay are found to be followings : a) shear strength of DL-clay is much larger and the peak of stress-strain curve appeared more clearly than kaolin clay, b) pore water pressure of DL-clay increase with shearing while decrease to negative value about kaolin clay, c) dilating behavior of DL-clay is more remarkable (specimens are more expanding) than kaolin clay though the shape of kaolin particles are flat.

These results reveal the importance of moisture content management in designing and constructing soil structures and ground, as well as show the fundamental strength and deformation behavior of DL-clay.

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