Mechanical properties of unsaturated soil in small strain range

Student: Tran Tuan Khanh

Advisor: Asso. Prof. Hirofumi Toyota.

I. Introduction:

Small strain of soil is a great importance in various geotechnical engineering practice, where pre-failure ground deformations are considered. The strain levels in the ground under working condition are usually less than about 0.1% (Burland, 1989). This situation has brought out the importance of precise evaluation of stress-strain relationships and stiffness of soil at small strain to analyze the small deformation of ground. It is necessary to ensure that reliable measurement of strain is accurately smaller than 0.01%.

However, many researchers (Atkinson, 1993; Scholey et al, 1995; etc.) pointed out that the used of dial gauge mounted externally in conventional test introduces many errors while the measurement of small strain is considered. Therefore, it is necessary to employ a local instrumentation to measure for strain of soil sample in small strain range.

The purpose of this study is to investigate the mechanical properties of unsaturated soil in small strain range using a local gauge. The objectives of this study will be focused on 3 points:

** Strain-dependency of stiffness.*

** Comparison of stress-strain relationship obtained by conventional and local strain measurement.*

** Suction –dependency of stiffness on unsaturated soil*

II. Apparatus and materials:

To evaluate the stiffness behaviors of soil in small strain range, where the stiffness is varied nonlinearly, the proximity transducers are employed to measure strain locally using a triaxial apparatus (Fig.1) on unsaturated Yoneyama sandy silt, the physical properties of this material are presented in Table.1.

Table 1. Physical properties of Yoneyama sandy silt

ρ_s (g/cm^3)	w_L (%)	w_P (%)	I_P (%)	Clay (%)	Silt (%)	Sand (%)
2.73	52.4	32.6	19.8	15.9	43.1	41.0

An improvement apparatus using proximeter gives a most advantage during operation due to its flexible characteristic, which was unavailable in the other local gauges such as LVDT, LDT and inclinometer., etc. Since proximeters were mounted internally, the distance between target and sensor could be re-adjusted through adjustment screws, after consolidation or dehydration process has been finished. This advantage could not apply for the other local gauges, because another ones are mounted directly on specimen, while a proximeter is a non-contacting type of measuring instrumentation, which used only small target attached to specimen.

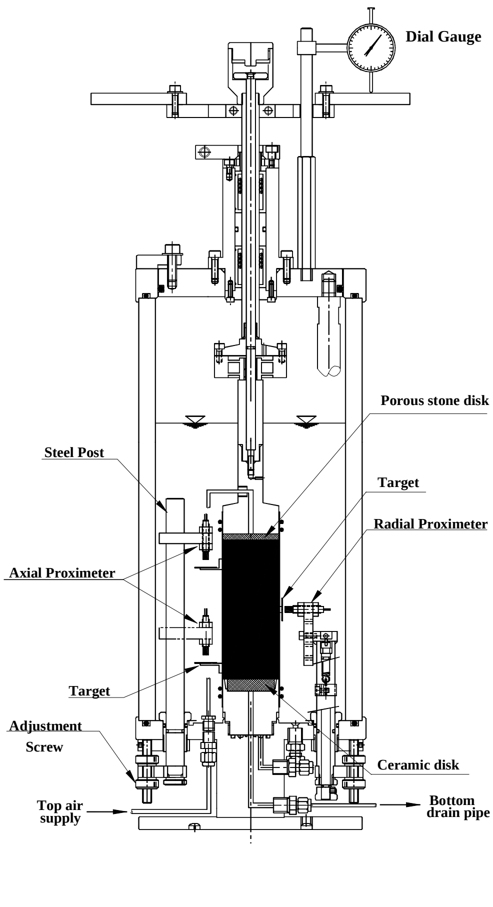

Fig. 1 An improvement apparatus

A series of tests was conducted in the conditions of matric suction constant (CS) in the order of 100, 200,400 and 600 kPa, where drainage is perfectly allowed. These experimental results were analyzed and compared with the similar testing condition on saturated soil.

III. Experiment results and discussion:

Before the tests on unsaturated soil are performed, the effect of specimen tilting was investigated on saturated soil. To conduct this kind of test, a pair of proximeter was mounted at opposite side of specimen to investigate for the effect of specimen tilting. Fig. 2 and Fig.3 show the results of these tests. There is quite good agreement between two local proximeter measurements. The results demonstrated that the tilting error was not occurred in the case of soft clay.

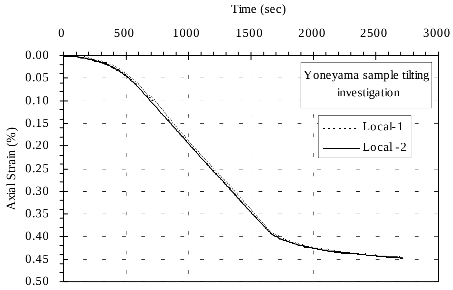

Fig.2 Effect of specimen tilting during consolidation

One more test on saturated sample was conducted, which aimed to inspect the effect of bedding during measurement. In this test a target was attached to the top-cap of apparatus, the other target was attached directly to specimen. The testing result is shown in Fig. 4, it can be seen that the effect of bedding was not occurred during shearing process, because the measurement from top-cap and the measurement from specimen had merged to each other from initial period of loading. This result indicated that the effect of bedding error was not occurred on soft clay sample.

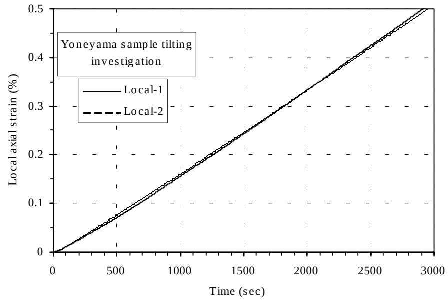

Fig.3 Effect of specimen tilting during shearing

Fig.5 shows the stress-local shear strain, local volumetric- local shear strain relationship for the all tests. The result from saturated Yoneyama sandy silt was also plotted in the same figure as a reference. This figure shows clearly evidence of the effect from suction to the mechanical properties of unsaturated soil.

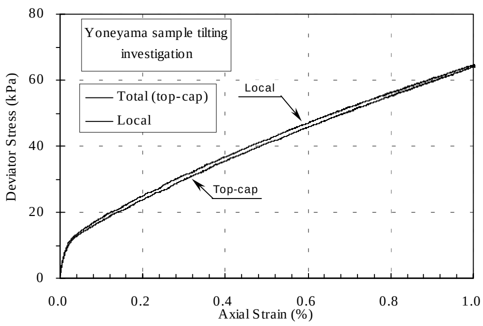

Fig.4 Stress-strain curve in bedding error investigation

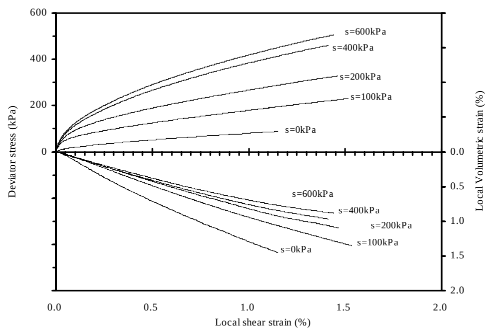

Fig.5 Stress-strain curve for all test under different suction level

The deviator stress increased with an increment of suction, but the behaviors of specimen volume change gave a contradiction. It means that the soil become firmer at higher suction level and at the initial state of strain, the specimens were often being in compression behavior. This figure also indicated that the unsaturated soil always become much stiffer than fully saturates soil in the same consolidation condition.

Fig.6 shows the summarization of the relationship between deviator stress and axial strain for all tests in the range of small strain. In this figure could be seen that, almost the readings from the dial gauge are similar for all tests, only in the under effect of suction 100 kPa, the readings from dial gauge were tended to another direction. This figure indicated that under the effect of incremental suction, the dial gauge did not responses sensitively as proximity transducer in the early state of loading, and it demonstrated for the insufficient of the using of the dial gauge in small strain measurement.

Fig.7 shows the relationship between stiffness and overall strain measurement. The stiffness values in this figure were dispersed while using a dial gauge for small strain measurement. The figure illustrated clearly that the dial gauge did not realize a strain smaller than 0.01% and in the range from 0.01% to 0.1% of strain, the stiffness varied with irregular. The stiffness from 0.02% up to 0.1% increased to a peak at strain level about 0.15% in the cases of suction equal to 200 kPa, 400kPa and 600kPa, and then reduced monotonically. But the stiffness in the cases of suction equal to 100kPa and fully saturation only decreased in regular. The abnormal variation of stiffness measured by dial gauge is unreliable when it applies to practice.

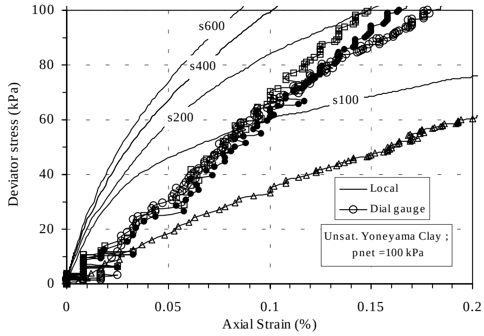

Fig.6 Summarization and comparison in all tests under different suction level

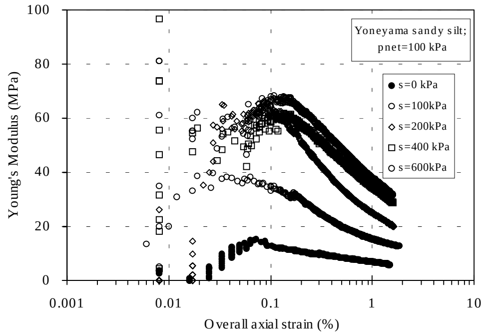

Fig.7 Stiffness- overall axial strain

Fig.8 shows the relationship of Young's modulus versus local axial strain. There is a good arrangement of stiffness correspond with increment of suction, or in the other word, the effect of suction is to increase stiffness in small strain region.

The stiffness in all tests seems to be a constant in the strain level from 0.001% to 0.01%, after that all of them deceased gradually. But in the range of strain larger than 1% the stiffness trends to close to each other included the stiffness of fully saturated soil. This means that it is seem to be merged at similar value and it is not dependent on the effect of suction. However, this phenomenon has not been asserted definitely yet because the behavior of stiffness of soil in the range of large strain are not investigated in this thesis. To affirm for that, the stiffness in wide range of strain should be investigated and more sufficient data should be explored fully for the relationships between stiffness and suction.

Fig.9 shows the stiffness normalized with respect to the relevant saturated E_{sat} value versus matric suction at the lower strain level, where the aim is to find the effect on the stiffness of incremental suction and the variation principle of stiffness under different suction level. This figure shows that the stiffness at difference strain level did not reduce to a unique trend after normalization. At the strain level of 0.1%, stiffness increases of 83.87% as suction varied from 0 to 600 kPa, at the strain level of 0.01% this effect reduce to 71.91%. It can be argued that the effect on Young's modulus of any fixed increment of suction decreases as strain level decreases, and vice verse. However this only be used precisely in the range of strain varied up to 0.1%, after that the effect of suction increment reduced as strain increases.

Fig.10 was plotted in the same axes with Fig.9, but it shows the variation of normalized stiffness at the higher strain level. The variations of stiffness at very larger strain were also plotted in this figure to demonstrate this phenomenon. This figure indicated that the variation of stiffness decreased clearly from the strain level of 0.1%, while strain level increasing.

To give an evidence for that, Fig.11 was plotted in a normalized stiffness versus local axial strain. This figure indicated that the effect on Young's modulus of incremental suction reached quickly in the

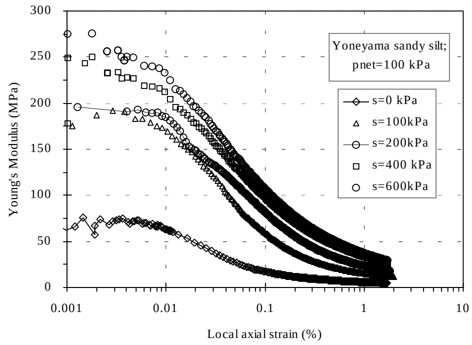

Fig.8 Stiffness-local axial strain

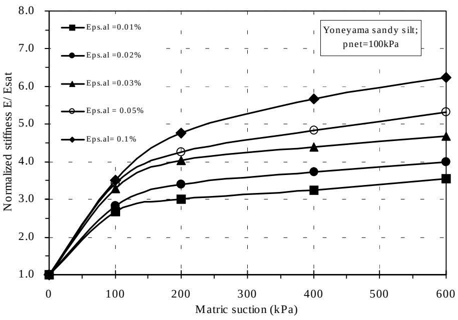

Fig.9 Normalized stiffness-suction in the lower strain level

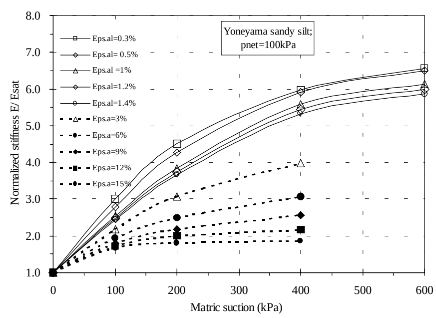

Fig.10 Normalized stiffness-suction in the higher strain level

initial period of shearing state and it was raised up to peak values at strain level of 0.1%. After this the effect of suction increment reduced gradually. At the strain of failure value, the variation of normalized stiffness may be tended to close at the same point, because at this moment the yield point appeared and stiffness decayed rapidly or the specimen was completely failed.

Generally, the effect of suction on stiffness of unsaturated Yoneyama sandy silt were investigated and discussed in this section. The variation of suction has influenced largely to the stiffness of soil such as stiffness increases as a function of matric suction. There is the most effective region on stiffness in relative small value of suction where the air entry value is included.

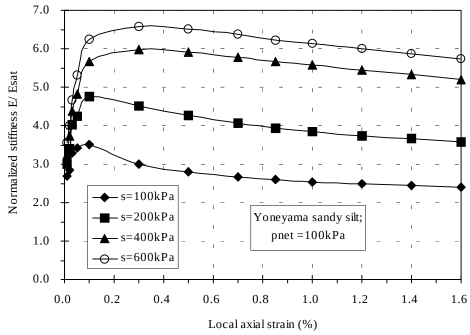

Fig.11 Normalized stiffness-local axial strain

IV. Summarization and conclusion:

The triaxial compression tests were carried out on Yoneyama sandy silt under constant suction condition (CS test) of 100, 200,400 and 600 kPa. All of samples were consolidated at pressure 100 kPa before shearing. The strain rate was controlled until ultimate measurement capable of proximeter (2mm). Finally, the conclusions are made as follows:

1) The dial gauge mounted outside of chamber could not estimate for strain smaller than 0.01% and the conventional measurement using dial gauge usually underestimated the stiffness of soil from about 49.7% to 29.26% at strain level of 0.1%.
2) During shearing process, there is no effect due to specimen tilting in the case of soft clay. The effect of specimen tilting may be occurred in the state before shearing due to a certain random reason. However, the effect of specimen tilting could be eliminated during consolidation process.
3) The effect of system compliance often occurred in a series of test on saturated and unsaturated soft clay, while the effects of bedding were not observed in the all case of soft clay samples.
4) The stiffness of soil increased with suction. Moreover, the stiffness increased rapidly during transition from saturated to unsaturated condition.

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