Dynamic deformation characteristics for unsaturated soil subjected to suction loading-wetting

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Abstract: Histories of earthquake disasters have reported to civil infrastructures that sever large deformations, and liquefaction can occur in embankment, duke, traffic road basements, and residential land, which are constructed in unsaturated soils. The evaluation of the liquefaction potential cyclic strain accumulation characteristics of fully saturated soil and saturated sandy soils is advantageous. This is a significant suggestion for geotechnical unsaturated engineering and geotechnical earthquake engineering. To provide advantages and useful insights into this crucial subjection. This study focused on the cyclic strain accumulation properties of unsaturated soil and applied the loading to wetting suction changing. Stress-controlled undrained cyclic triaxial tests were conducted for silty soil having uniformity grain size distribution using the developed unsaturated triaxial apparatus. To produce loading-wetting in the suction (i.e., performance of saturation) is close on interpret the disaster and failure by cyclic loading. The cyclic deviatoric stress ratio is presented at failure for both unsaturated and saturated specimens.

Introduction

The investigation reports from many base histories regarding earthquakes worldwide have demonstrated that liquefaction or significant damage induced by earthquakes can occur in both unsaturated soils and saturated loose natural soils. As a result, large ground deformation and slope failures cause severe damage to general infrastructures. However, the evaluation of the liquefaction potential and cyclic strain accumulation characteristics of gravelly soils remains a major challenge in geotechnical earthquake engineering (Pokhrel et al. [1]). In general, it has been proved that many reports and research papers focused on loosely saturated sandy soils and compared with unsaturated condition ground, is quiet poor in experimental works. To measure the matric suction is difficult and time-consuming in standard liquefaction experimental tests or cyclic loading triaxial tests. This study presented the deformations of unsaturated soil in cyclic loading tests that suction controlling is developed to compacted specimens.

Pokhrel et al. [1] reported that stress-controlled undrained cyclic triaxial tests were conducted on sand-gravel mixtures with sand-dominated microstructures by considering varying the gravel content and relative density. Cubrinovski and Stringer [2] experimentally investigated the liquefaction resistance of partially saturated soil experimentally that was of one clean sand and one silty sand collected from a site in Christchurch, where an area severely affected by liquefaction during the 2010–2011 Canterbury earthquakes. A series of cyclic undrained tests were performed on fully and partially saturated and silty sand specimens. Okamura [3] referred to assessments of the liquefaction resistance of clean sand as a current research topic in the field of soil liquefaction. In particular, we focused on the loading history, degree of saturation, partial drainage, and effects of pore pressure generation on liquefaction resistance. Oka et al., [4] examined the stress and strain conditions of cyclic triaxial and simple shear tests for evaluating the liquefaction strength of natural sandy soil. It was emphasis that a strong correlation was observed between the liquefaction strengths obtained from the triaxial and simple shear tests when using the stress invariant ratio.

This study focused on the cyclic strain accumulation properties of unsaturated soil and applied the loading-wetting suction change. Stress-controlled undrained cyclic triaxial tests were conducted for silty soil having uniformity grain size distribution using the developed unsaturated triaxial apparatus. To produce loading-wetting is close on interpret the disaster and failure with actual earthquakes. The presence of the obtained results indicates that the void ratio decreases as the collapsing occurs due to loading-wetting and however the large deformations are accumulated for small lateral confining pressures. Finally, comparison of cyclic deviator stress ratio under large deformation between the unsaturated and saturation conditions.

Soil material

The soil used in this experimental works is a silty soil, which was estimated as non-plastic silty soil. The nonplastic silty soil has been named as DL clay, and experimental tests have been conducted for unsaturated soil mechanics. Before testing, a compaction test described the maximum dry density and the optimum water content are obtained as following; 1.600 Mg/m^3 and 18.8%, respectively. Also, the grain size distribution test result indicated grain size distribution curve that the soil has uniformity distribution. The obtained parameter is a maximum soil particle size of 2.0 mm.

Soil specimen

All soil specimens were statically compacted in a stainless mold, and the prepared sizes were a height of 100 mm and a diameter of 50 mm. It remains that the ratio of 2.0 between height and diameter, and such as standard specification in soil mechanical tests. Processing of

Figure 1: Developed cyclic triaxial triaxial test apparatus.

compaction, compression forces are statically applied by oil-pressure equipment. Before compaction, the soil material regulates various water contents using a spray pump; the water contents are 10 %, 14 %, 17 %, and 20 %. Prepared water contents are the dry and wet sides to achieve an optimum water content of 18.8%.

Apparatus

This study employs the controlling deviator stress for cyclic loading test and prepare some activity as following; measuring axial strain, controlling suction, seepage application without back pressure. The dynamic triaxial apparatus (Fig. 1) is possible to create loading and unloading from 0.01 Hz to 10 Hz, and application of lateral confining pressure up to 1.0 MPa. In addition, when a static compression test is performed, the apparatus.

Test programs

This test program includes some series of measurements of the initial suction, static triaxial compression test for both unsaturated specimens and saturated specimen, and cyclic loading test. The influence of compaction water content on the initial suction was investigated using a microporous membrane technique. The prepared water contents range from 10% to 20%. The static triaxial compression tests were conducted for both the unsaturated and saturated specimens. The deformations and effects of lateral confining pressure for destruction such as liquefaction are considered, and the specimens are statically compacted with four different water contents, which have a height of 100 mm and a diameter of 50 mm. Observation that the lateral confining pressure effort was applied to specimens subjected to high suction under relative humidity of 98% and 75%. The initial deviator stress ratio is variety, end of test is cyclic number of 10 with a loading frequency of 0.1 Hz. The external loading frequency was 0.1 Hz.

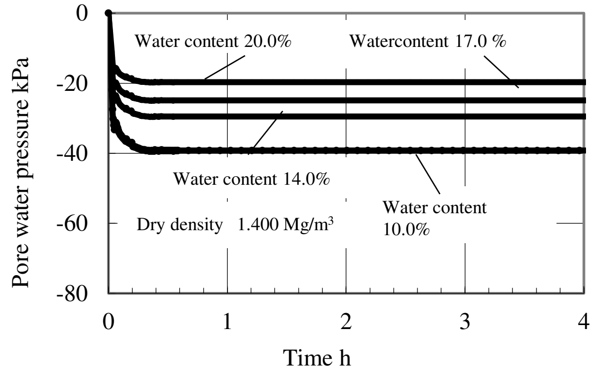

Figure 2: Measurement of pore-water pressures using a micro porous membrane.

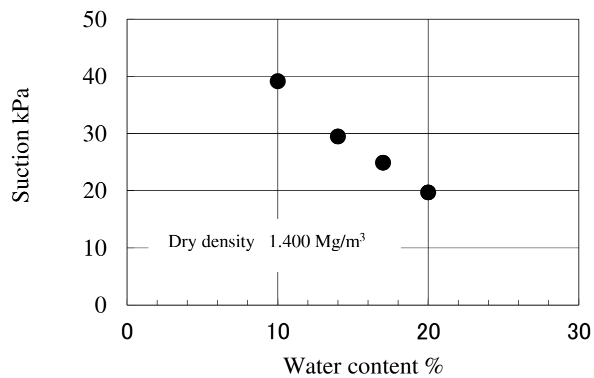

Figure 3: Decreasing of suction measured membrane method with water content.

Measurement of initial suction

Each pore-water pressure was measured for the specimens with variations in water contents, and all specimens had a coincident dry density of 1.400 Mg/m^3. Measurement of pore-water pressure conducted through micro-porous membrane during four hours that all pressures indicated negative value and the value had an order with water content of specimens as shown in Fig. 2. Prepared some specimens are put on saturated microporous membrane, is install into a conventional triaxial pedestal. The pedestal connected to the water tube, and the pressure change of the water tube was measured using a pressure sensor. The pore-water pressures showed large changes at the first test time (i.e. till 15 min). At the past hour, the measured pore-water pressure was expected to be stability and have no changing with time. Waer conte gradually decease, the pore water pressure decreases, and the value was 39 kPa. The negative pore-water pressures at the end of the test were plotted with the water contents, as shown in Fig. 3. The minus pore-water pressures are transferred such as matric suction (i.e., later called to suction). Suction decreased with water content, which is a common interpretation in previous works, regardless of the dry density. Alos, it was found that the suction property is a straight line associated with the water content and has a limited water content range.

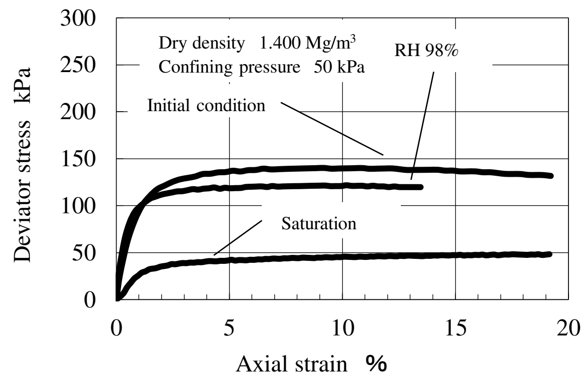

Figure 4: Monotonic compression test results under undrained condition with some suctions.

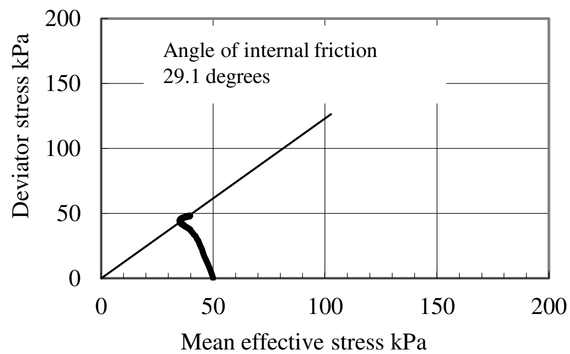

Figure 5: Effective stress path for the specimen subjected to saturation effort under undrain.

Monotonic triaxial test results

This testing program consists of a monotonic triaxial test and cyclic loading triaxial test. Previously, monotonic triaxial compression tests were conducted in which the subjection is to appear the changing of shear resistance among high suction application and saturation effort through compression. Initial condition for specimen is a dry density of 1.400 Mg/m^3 and water content of 17% and the size are a diameter of 5 cm and a height of 10 cm. Stress-strain curves are shown in Fig. 4. The initial compacted specimen and the specimen with a relative humidity of 98% are similar behavior in stress strain curves and deviator stresses are coincident until an axial strain of 1.8%. In the steady state (i.e., changing of deviator stresses is small), the different of deviator stress is nearly 20 kPa. The hydration effort due to a relative humidity of 98% case the reduction shear resistance. Suction reduction decreased the shear strength under unsaturated conditions. Moreover, the compacted unsaturated specimen had a saturation in order to delete suction and measure the maximum deviator stress. Further reduction in shear strength occurs from 140 kPa to 45 kPa in comparison between initial condition and saturation condition. The effective stress path is calculated in order to correct angle of internal friction, as shown in Fig. 5 and the obtained value is 29.1 degrees.

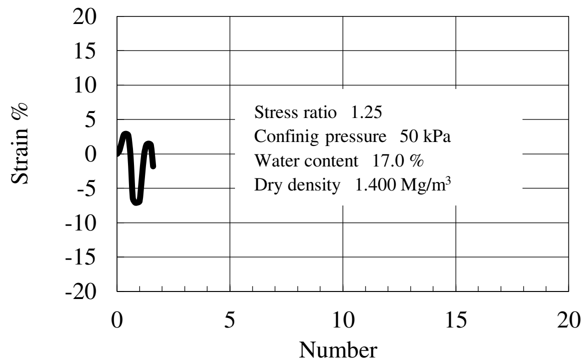

Figure 6: Large deformation due to cyclic for initial compacted specimen .

Deformation for initial specimen

Compacted initial specimen was used for the cyclic loading test that some conditions are as following; lateral confining pressure of 50 kPa, initial cyclic deviator stress ratio of 1.25, and loading frequency of 0.2 Hz. The deformations are shown in Fig. 6 and the specimen approach to destroy at one cyclic application. The end of the cyclic loading test because the specimen was damaged further. In addition, it is possible to make trouble on used apparatus. It is over 7.0% in axial strain on expansion side.

Deformations for various water content

This study considers the influence of water content on cyclic deformations that cyclic test conditions are as following; lateral confining pressure of 20 kPa, initial cyclic deviator stress ratio of 0.15, and loading frequency of 0.2 Hz. The initial cyclic deviator stress ratio is small compare with results in Fig. 6. The prepared water content ranges from 10% to 20%. The compaction water content in specimens has both dry and wet sides because the optimum water content is 17.0% for the soil material used in this study. Each deformation is described in Figs. from 7 to 10, until the cyclic number is eight. It is further important to compare cyclic deformation with the occurrence of deviator stress changes. All axial strains progress into compression side that all specimens prevent the destroy in the cyclic test. The magnitude of deviator axial strains at the end of the test that are influenced by the water content and deviator axial strains grow according to the water content. The deviator axial strain was 0.21% at a water content of 10%, and the deviator axial strain is 0.54% when water content of 20%.

Deformation for high suctions

The specimens were subjected to high suction promoted by the vapor pressure technique with selected relative humidity of 98% and 75%, such as suction of 2.8 MPa and 39 MPa. The applied lateral confining pressure are variety that are 20 kPa, 50 kPa and 500 kPa. The initial deviator stress ratios were 1.30 and 0.15, respectively. In the case of a relative humidity of 98%, the deviator axial strain is shown in Fig. 11, indicating that the specimen experiences failure on the expansion side. The specimens with

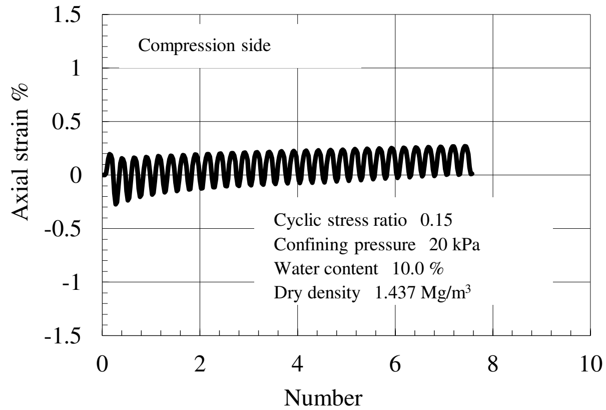

Figure 7: Small deformations by cyclic behavior for water content of 10%.

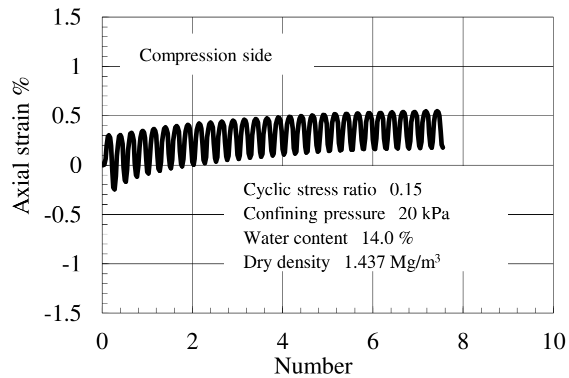

Figure 8: Cyclic compression sider deformations for water content of 14%.

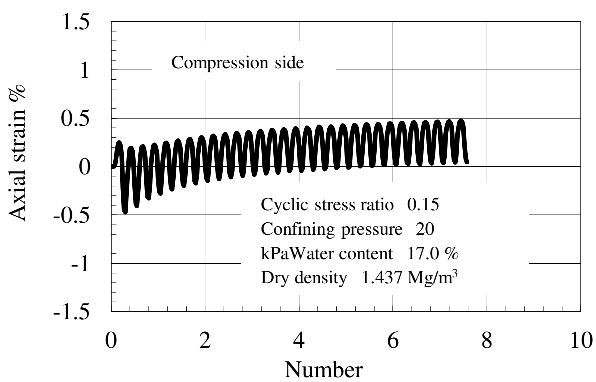

Figure 9: Remaining of compression side cyclic deformations for water content of 17%.

relative humidity of 75%, two different lateral confining pressures of 20 kPa and 500 kPa were applied, and a large lateral confining pressure prevented failure and made rather small

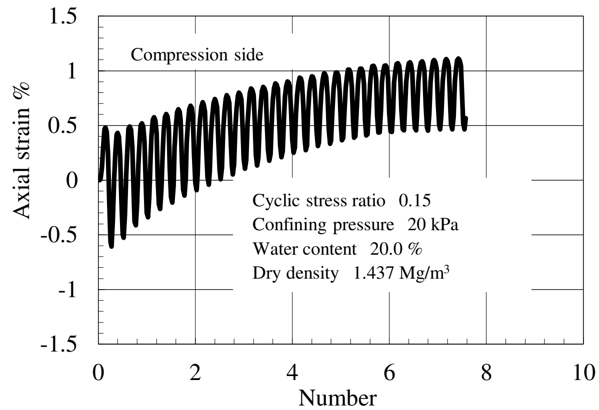

Figure 10: Processing of cyclic behavior for water content of 20%.

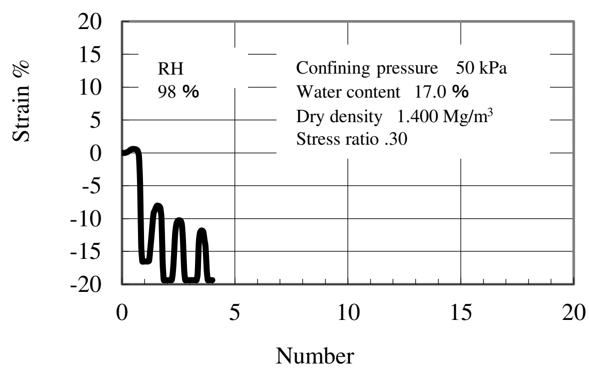

Figure 11: Large deformation at expansion side for RH 98%.

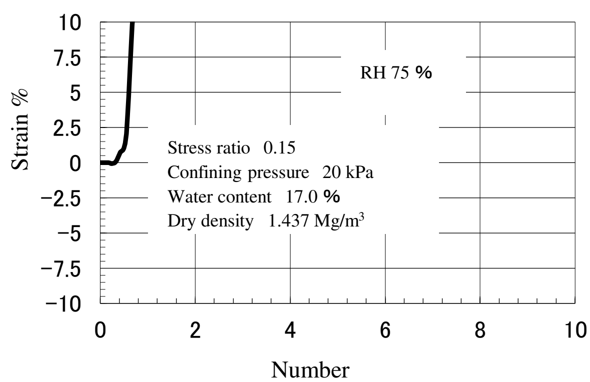

Figure 12: Completely destroy by one cyclic loading for RH 75%.

deformations as shown in Figs. 12 and 13. The measured axial strain was less than 0.2% for a lateral confining pressure of 500 kPa and deviator stress ration of 0.15.

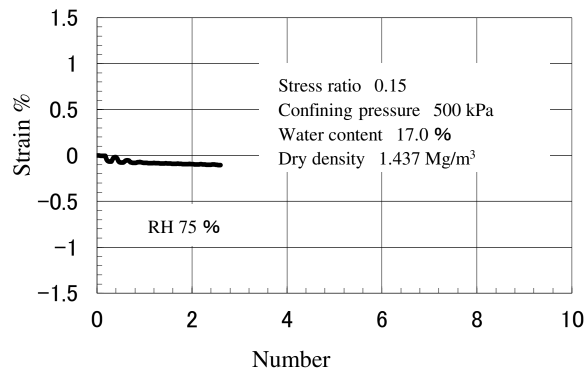

Figure 13: Extremely small deformations for RH 75% with confining pressure of 500 kPa.

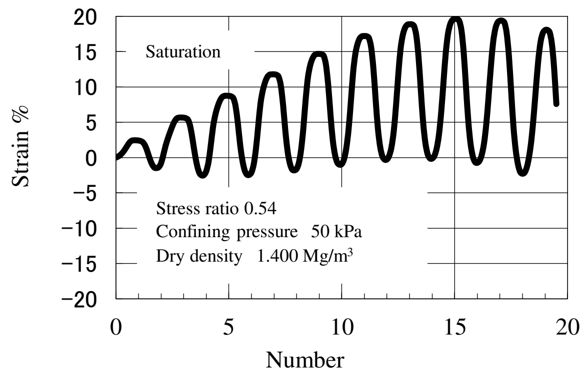

Figure 14: Developed cyclic behavior due to saturation compare to unsaturated condition.

Deformation for saturated specimen

Seepage flow through the specimen is applied as wetting, in which the subjection is the removal of suction in the void structure. The obtained deformation property is absolutely different from the result of the unsaturated specimens, as shown in Fig. 14. The saturated specimen had a failure with few cyclic loadings with further deformations remaining and was over 10% under axial strain.

Liquefaction resistance curve

This study identifies cyclic loading failures that are similar to liquefaction resistance curves for saturated sand. The cyclic deviator stress ratios are plotted with the number of cyclic loadings for both the unsaturated and saturated specimens, as shown in Fig. 15. The relationship between the number of cyclic loadings and the cyclic deviator stress ratio is a significant factor to interpret the resistance cyclic properties, which is necessary to saturated soil liquefaction resistance.

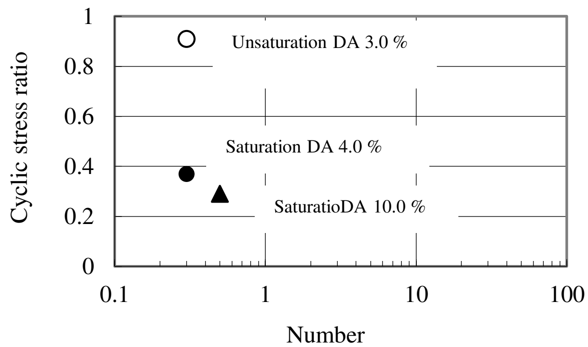

Figure 15: Definition of cyclic loading resistance including unsaturated -saturated conditions.

This paper prepares Fig. 15 in order to consider the cyclic loading properties of unsaturated soil. Geotechnical engineers often required results like those shown in Fig. 15. It was found that the unsaturated specimen maintains high resistance compared to the saturated specimen and that saturation induces a large reduction in the cyclic loading resistance.

Conclusions

The obtained summaries are provided as followings: Measured suction indicated using a microporous membrane, which decreases with increasing water content. The shear strength of compacted unsaturated soil reflects changes and reductions due to both suction and saturation performance. Cyclic deformations were measured using unsaturated specimens with variety of water content, which caused equilibrium with different suction values. The deformations grew under cyclic loading when the water content was larger. The application of high suction was possible to induce the quiet different cyclic deformation.

References

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