Influence of slurry density on strength and deformation property of liquefied stabilized soil reinforced with paper

Tuan Anh Do, Yukihiro Kohata & Masato Sasaki
Graduate Student, Division of Engineering, Muroran Institute of Technology, Japan

ABSTRACT: In Japan, the Liquefied-Stabilized Soil (LSS), which is one of premixing cement treated-soil, has been popular as a recycling method for excavated soil. On the other hand, in current situation in Vietnam, the soils excavated from construction sites are becoming a serious problem. It becomes more and more difficult to find reclamation sites for excavated soil to be disposed. Because of the lack of reclamation sites, it causes the environmental pollution. Therefore, this serious problems can be solved if LSS will be applied in Vietnam. In general, LSS is made based on standard design chart of mixture proportion. Recently, in order to improve more advantages of LSS, there are some suggestions that LSS can be decreased a slurry density to reduced vertical earth pressure. However there is a lack of study on strength and deformation properties of the LSS decreased to slurry density.

In this study, influence of slurry density on strength and deformation properties of LSS reinforced with fiber material was discussed. A series of Consolidated-Undrained triaxial compression tests (CUB tests) have been carried out for LSS reinforced with different fiber content (i.e. 0, 10 kg/m^3) prepared by two slurry densities at curing days of 28 days. Based on the test results, it was found that the strength of LSS prepared by low slurry density decreased, and an effect of reinforcement was seen on strength and deformation of LSS prepared by low slurry density.

Keywords: Liquefied-Stabilized Soil, Strength, Deformation, Triaxial test, Slurry density

1 INTRODUCTION

A huge and growing sinkhole appeared at dawn on November 8, 2016, in downtown Fukuoka city in southern Japan. According to some reports of Japanese media, a ground was collapsed extensively at the subway construction site in front of JR Hakata station and this cave-in in the road was about 30 meters long, 27 meters wide, and 15 meters deep. The cause of this collapse analyzed by geotechnical engineers was considered a consequence of NATM construction method leading to tunnel accident. In order to return a normal life as soon as possible, the restoration in short period was required. The required volume of sinkhole was estimated 7000 m^3 to fill with soil. For conventional backfilling methods, sand produced from mountain or river valleys is easy to be compacted to a degree of compaction prescribed a standard. Then, the conventional backfilling method requires the long construction duration and the ground surface settlement after backfilling also need to be considered. Therefore, the conventional backfilling method could not be adopted. On the other hand, LSS is effective backfilling method for using excavated soil in construction work (Kuno et al. 1997), and LSS should be applied in many backfilling constructions in Japan. Therefore, it is considered that the LSS method should be applied in this restoration work.

On the other hand, in recent years, in Vietnam, more and more cave-ins appear at urban roads, especially in Hanoi and Ho Chi Minh cities. The main reasons of road cave-in at Ha Noi and Ho Chi Minh City are soil loosened during underground infrastructure construction and water leaked from ruptured underground pipelines. The ground under municipal roads is congested with public utility networks supplying electricity, telecommunications services, heating and for drainage. Large underground projects such as subways, commercial facilities, tunnels, etc., are also conducting actively. The roads are often re-excavated freely to install or repair various utility networks, which are managed by different utility providers. In addition, in Vietnam, most backfilling material for construction is obtained from natural sources. Mining of the materials such as sand from river and gravel from mountain has a significant impact on the natural environment and the demand for sand and gravel continues to increase day by day. Thus, it is considered that the application of LSS in Vietnam can solve the aforementioned problems.

The Liquefied-Stabilized Soil, which is made from construction generated soil mixing with water (or muddy water) and cement stabilizer, is one of the cement-treated soil classified as premixing stabilized soil of slurry type (ex., Kohata 2006). The use of soil material in order to produce LSS is not necessarily good quality called excavated soil. In the case of soft soil with high water content, the density of the slurry can be adjusted to appropriate fluidity property. In addition, advantage of LSS has been shown that it can be carried out long distance transportation by pump and pipe systems. However, strength property indicates more brittle behavior when the strength increases as increasing an amount of cement stabilizer. Kohata et al. (2002, 2004, 2007) and Duong et al. (2014) presented a reinforcement method to improve the brittle property of LSS by mixing newspaper as a fiber material into LSS and a series of unconfined and triaxial compression tests have been carried out. The test results showed that the brittle property of LSS mixing fiber material after the peak in stress-strain relations was improved.

From the standard mix proportion design figure published by Ito et al. (2011), Duong et al. (2014) reported about comparison of strength and deformation property of LSS prepared by field and laboratory. The specimens in this study were prepared by following conditions, that is, the bleeding rate was less than 1 %, the content of cement stabilizer was 80 kg/m^3 and the target density of LSS was 1.280 g/cm^3. However, an investigation on the LSS decreased slurry density in order to be reduced vertical earth pressure has been not perform and the study on strength and deformation properties of the LSS decreased a slurry density has not been investigated.

In this study, slurry density of 1.280 g/cm^3 (hereafter called $D\rho_f$ = 100 % LSS) was mixed fiber material amount of 0, 10 kg/m^3. In parallel, slurry density of 1.280 g/cm^3 reduced 5 % (=1.2160 g/cm^3, hereafter called $D\rho_f$= 95 % LSS) and mixed fiber material amount of 0, 10 kg/m^3 and curried out in Laboratory. A series of consolidated undrained triaxial compression tests (CUB tests) were performed on both $D\rho_f$ = 100 % LSS and $D\rho_f$ = 95 % LSS at curing time of 28 days. From test results, the differences in strength and deformation properties of $D\rho_f$ = 100 % LSS and $D\rho_f$ = 95 % LSS were discussed.

2 TEST PROCEDURE

2.1 *Test material*

In this study, NSF-CLAY was used as a homogeneous base material, which was commercially available cohesive soil with very well defined the physical properties clearly. Table 1 shows main physical properties of NSF-CLAY. The Geoset 200 provided by Taiheiyo Cement Co. was used as cement stabilizer. This is special cement stabilizer for soft clay and problematic soil. Newspaper crushed like cotton by a food processor was used as fiber material.

Table 1. Main physical Properties of NSF-CLAY

Density of soil particle, ρ_s (g/cm^3)	2.762
Liquid limit, w_L (%)	60.15
Plastic Limit, w_P (%)	35.69
Plasticity Index, I_P	24.46

2.2 *Mixing method*

There are two LSS mixing methods to be suitable for excavated soil including the slurry type and adjustment slurry type. For the slurry type, water is added suitably to excavated soil to adjust density of slurry, and then cement stabilizer is added and mixed. For adjustment slurry type, water is added to excavated soil, then fine-grained sand or cohesive soil is added in order to adjust density of slurry and after that cement stabilizer is added and mixed. In this study, the LSS of slurry type was selected due to easier procedure.

2.3 *Specimen preparation*

The purpose of this study is to determine influence of slurry density on strength and deformation properties of liquefied stabilized soil reinforced with fiber material. Therefore, density of slurry decided based on the standard mix proportions. In this study, two densities of slurry were made including 1.280 g/cm^3 (Dρ_f = 100 %) and 1.216 g/cm^3 (Dρ_f = 95 %). The content of cement stabilizer used in this study was 80 kg/m^3 after densities of slurry reaching 1.280 g/cm^3 and 1.216 g/cm^3, respectively.

LSS was produced by adding and mixing cement stabilizer into liquefied stabilized soil with hand mixer. In the production process, the determination of the density was performed by measuring the mass of slurry filled into a stainless steel mold of 400 cm^3 called “AE mortar container”. After achieving the desired density, fiber material with amount of 0, 10 kg/m^3 (Pc-0, 10) was added and mixed by hand mixer. In order to determine fluidity of LSS mixed fiber material, the flow test was performed in accordance with JHS A313 - Japan Highway Public Corporation Standard. Moreover, the fresh LSS mixed with fiber material is made to be removed the air inside specimen applying vacuum.

In this study, the fresh LSS mixed fiber material was placed into mold of 5 cm in diameter and 10 cm in height. The top surfaces of specimens were covered by a polymer film and were cured under air humidity and temperature of 20 ± 3 °C. After curing 28 days, the specimens were tested.

3 TEST METHOD

In this study, a couple of Local Deformation Transducer (LDT), which can measure the axial deformation from small strain level without the bedding error due to the compression of loose layers at the top and bottom ends of specimen or filter paper, were set on the diagonally opposite surface of specimen diameter (Goto et al. 1991) as shown in Figure 1. The top and bottom ends of LDT was set between two pseudo-hinged attachments fixed on the surface of rubber membrane at the points which were glued to the specimen to prevent slipping between the membrane and the surface of specimen. When the value of LDT exceeds a measurable range, the axial displacement was used the value of proximity transducer (Gap sensor) and dial gauge by correcting the bedding error. In this test, a digital servo motor was used for the loading device. This device enables to control the axial displacements with high precision, and can ignore backlash when reversing the loading direction. The whole operation of apparatus during test was automatically controlled by a PC software.

The CUB tests were performed for both Dρ_f = 95 % LSS and Dρ_f = 100 % LSS specimens at curing time of 28 days. Specimens were saturated by the double suction method which vacuum pressure was

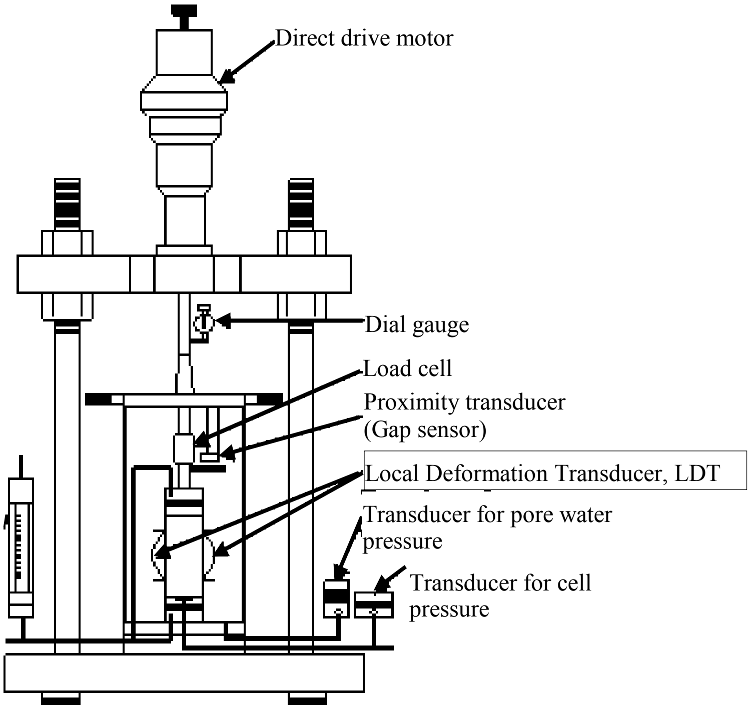

Figure 1. Schematic figure of test apparatus

applied and the de-aired water was flowed through specimen under a back pressure of 196 kPa. And then, undrained triaxial compression test with pore water measurement was performed after isotropic consolidation for 12 hours under the effective confined pressure of 98 kPa. In order to unify with previous studies, small unloading/reloading loops during monotonic loading was applied and axial strain rate was 0.054%/min.

4 TEST RESULTS AND DISCUSSION

4.1 *Relationship between deviator stress and axial strain*

Figure 2 (a) and (b) show the relationship between the deviator stress q (= σ_1 - σ_3) and the axial strain ε_a in range of 0~3.0 % from the CUB tests under the confining pressure σ_c'=98 kPa of both $D\rho_f$ =100% LSS and 95% LSS mixed with fiber material amount of 0,10 kg/m^3(Pc-0,10) at 28 curing days. Although there is not noticeable difference of the maximum deviator stress between Pc-0 and Pc-10 in the case of $D\rho_f$ = 100 % LSS shown in Figure 2(a), and the deviator stress of Pc-10 is not suddenly decreased after the peak stress state compared with Pc-0. Therefore, the brittle property observed in case of specimen without fiber material has been improved by the reinforcement effect of added fiber material as similar to the previous results reported by Kohata et al. (2002, 2004, and 2007) and Kohata (2006). On the other hand, the peak stresses are not clearly in both cases of Pc-0 and Pc-10 of $D\rho_f$ = 95 % LSS shown in Figure 2(b). And, the maximum deviator stress, q_{max} of Pc-10 specimens tend to be larger than that of Pc-0 ones.

As shown in Figure 3(a) and (b), q_{max} of $D\rho_f$ =95 % is smaller than q_{max} of $D\rho_f$ = 100 % for both of Pc-0 and Pc-10. It can be seen that q_{max} of $D\rho_f$=95 % is decreased about 30 to 35% although density of slurry is only decreased 5%. In general, it is known that the strength of sandy soil and cohesive soil is influenced by dry density and water content. On the other hand, based on test results, the strength of liquefied stabilized soil and liquefied stabilized soil mixed fiber material is considered to be greatly influenced by the slurry density.

Figure 4 (a) and (b) show the relationship between the deviator stress q (=σ_1 - σ_3) and the axial strain ε in range of 0~0.5 % for the cases of $D\rho_f$ = 100 % and $D\rho_f$ = 95 % mixed with fiber material of 0, 10 kg/m^3 (Pc-0,Pc=10), respectively. In Figure 4(a), the relationships between q and ε_a before the peak stress are nearly equal and the reinforcement effect of fiber material is not remarkable in the case of $D\rho_f$ = 100 %. However, Figure 4(b) show distinct difference between Pc-0 and Pc-10 in the case of $D\rho_f$ = 95 %. The deviator stress generated during shearing tends to difference from about ε_a = 0.02 % due to the reinforcement effect of fiber material.

The relationship between q and ε_a in range of 0~0.5 % in the cases of $D\rho_f$ =100 % and the cases of $D\rho_f$ = 95 % mixed with fiber material of 0, 10 kg/m^3 (Pc-0, Pc=10) are shown in Figure 5 (a) and (b), respectively. From these figures, as comparing q~ ε_a relation, although slurry density decreased 5 % from $D\rho_f$ = 100 % to $D\rho_f$ = 95 %, the reduction of q_{max} at axial strain ε_a = 0.5 % was about 30-35 %. However, it is considered that liquefied stabilized soil reinforced with fiber material is more advantageous than application of liquefied stabilized soil in order to be constructed aseismic ground with all things considered from Figures 4(b) and Figures 5.

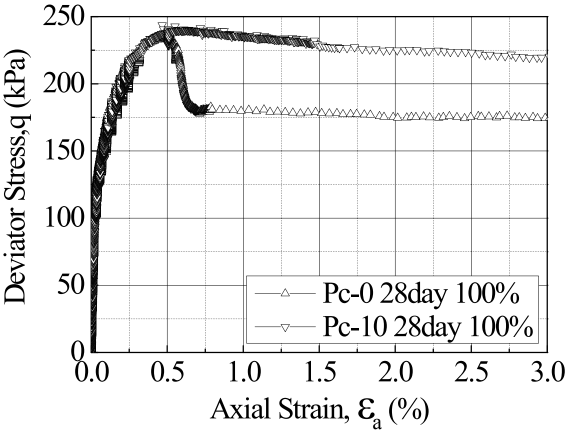

Figure 2. (a) q~ε_a relations of $D\rho_f$ = 100 % at 28 days

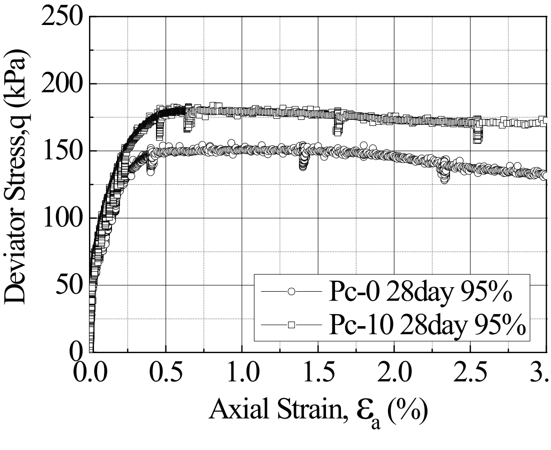

Figure 2. (b) q~ε_a relations of $D\rho_f$ = 95 % at 28 days

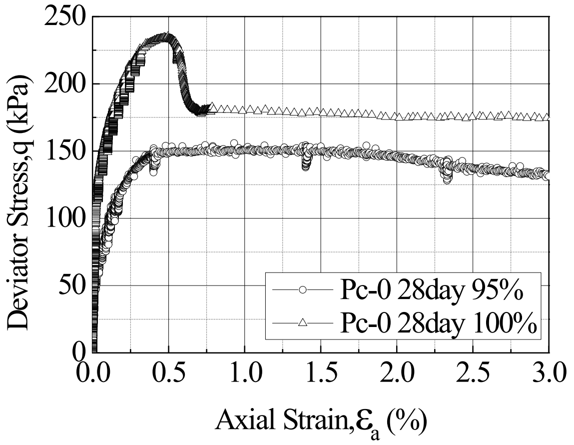

Figure 3. (a) q~ ε_a relations of Pc-0 at 28 days

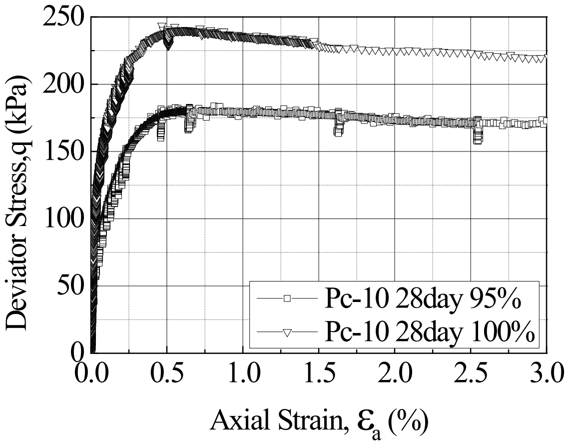

Figure 3. (b) q~ ε_a relations of Pc-10 at 28 days

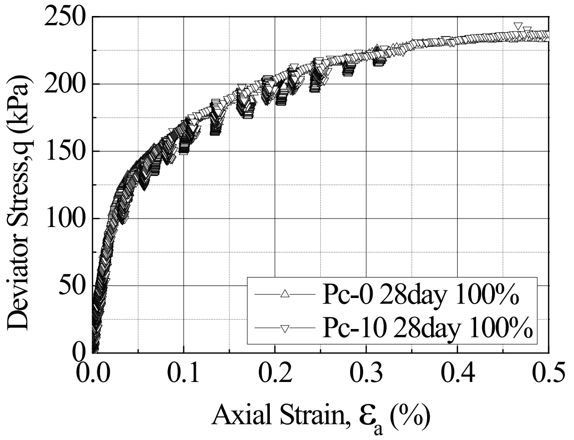

Figure 4. (a) q~ ε_a relations of $D\rho_f$ = 100 % at 28 days

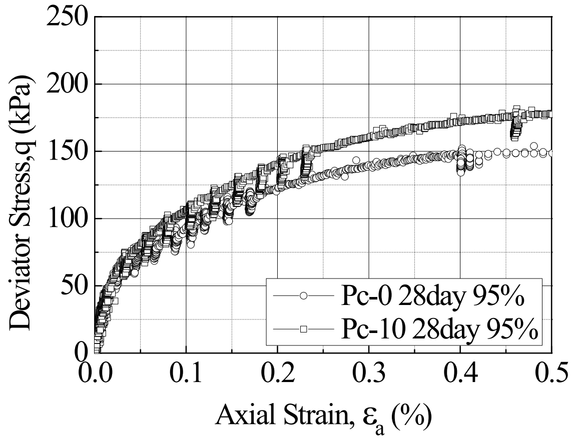

Figure 4. (b) q~ ε_a relations of $D\rho_f$ = 95 % at 28 days

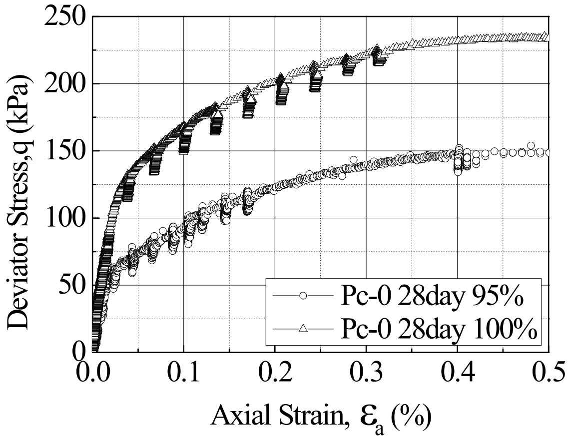

Figure 5. (a) q~ ε_a relations of Pc-0 at 28 days

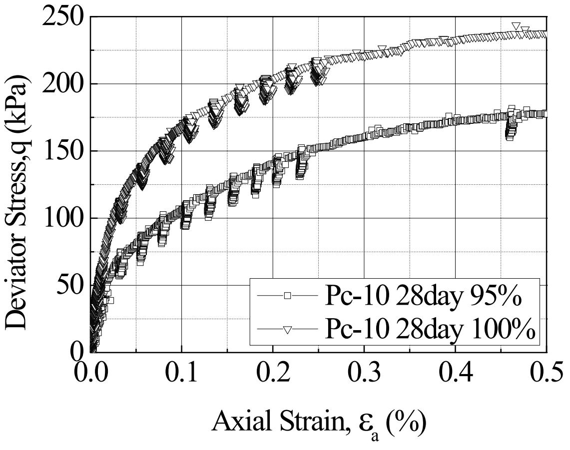

Figure 5. (b) q~ ε_a relations of Pc-10 at 28 days

4.2 *Deformation property*

4.2.1 *Definition of various Young's moduli in this study*

Figure 6 shows the definitions of various Young's moduli. The initial Young's modulus E_0 is defined as initial stiffness at $\varepsilon_a = 0.002$ % or less. The tangent Young's modulus E_{tan} is defined as tangential gradient in q~ ε_a curve, it indicates the non-linearity of deformation property in q~ ε_a relation. The equivalent Young's modulus E_{eq} is obtained from small unloading/reloading loop during monotonic loading. Moreover, the E_{eq} in creep correction is calculated from slope of the lower limit point and the midpoint in line connecting the unloading point and the intersection of q~ ε_a curve in reloading. The E_{eq} indicates a changing of damage degree under the shearing (Kohata et al. (1997, 1999)).

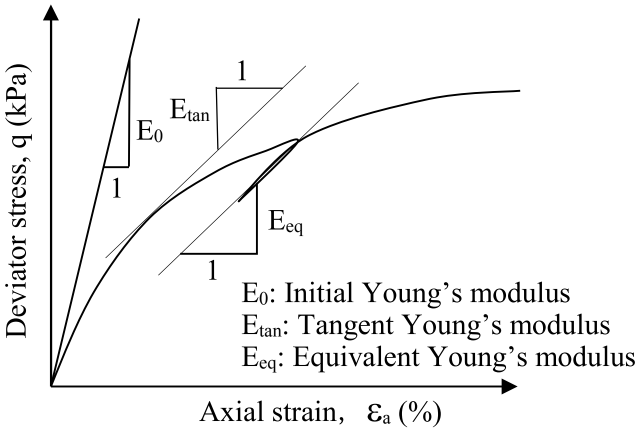

Figure 6. Definition of various Young's moduli

4.2.2 *Tangent Young's Modulus E_{tan}*

Figure 7(a) and (b) show the relationships between E_{tan}/E_0 and q/q_{max} of both $D\rho_f$ = 100 % and $D\rho_f$ = 95 % for Pc-0 and Pc-10 at 28 days. The values of E_{tan} were obtained from the q~ ε curve of the CUB tests under the confining pressure of 98 kPa. The reduction rate of E_{tan}/E_0 of $D\rho_f$ = 100 % and $D\rho_f$ = 95 % shows a similar tendency in both Pc-0 and Pc-10.

In Figure 8(a) and (b), the reduction rate of $D\rho_f$ = 95 % is larger than $D\rho_f$ = 100 % as comparing reduction rate of E_{tan}/E_0 of $D\rho_f$ = 100 % and $D\rho_f$ = 95 %. It is considered that nonlinearity of $D\rho_f$ = 95 % is larger than $D\rho_f$ = 100 %. Therefore, it seems that the nonlinearity increase as decreasing slurry density.

4.2.3 *Equivalent Young's modulus, E_{eq}*

Figure 9(a) and (b) show relationship between E_{eq}/E_0 and q/q_{max} both $D\rho_f$ =100 % and $D\rho_f$ = 95 % for Pc-0 and Pc-10 at 28 days. The values of E_{eq} were obtained from the q~ ε_a curve of the CUB tests under the confining pressure of 98 kPa at small loading/unloading loop during monotonic loading. In general, it has

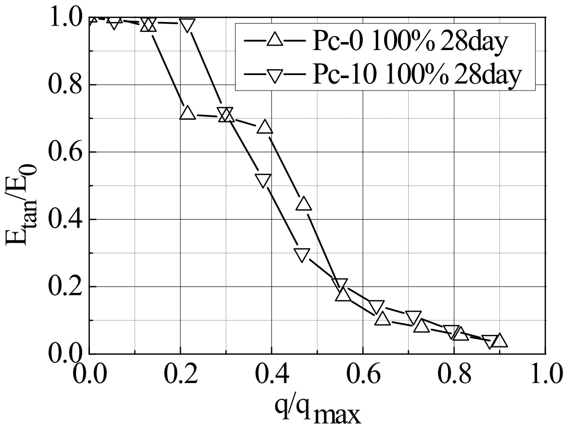

Figure 7 (a). E_{tan}/E_0~q/q_{max} of $D\rho_f$ = 100 % at 28 days

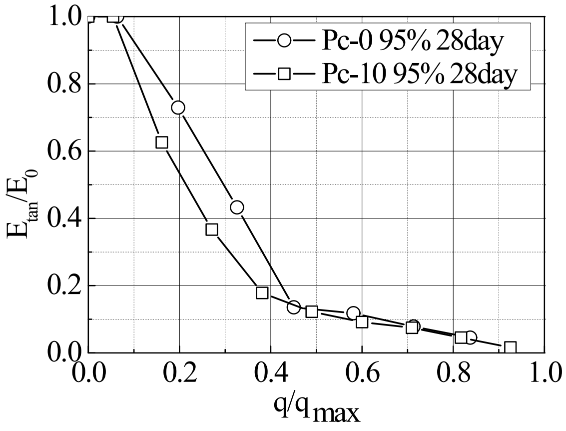

Figure 7 (b). E_{tan}/E_0~q/q_{max} of $D\rho_f$ = 95 % at 28 days

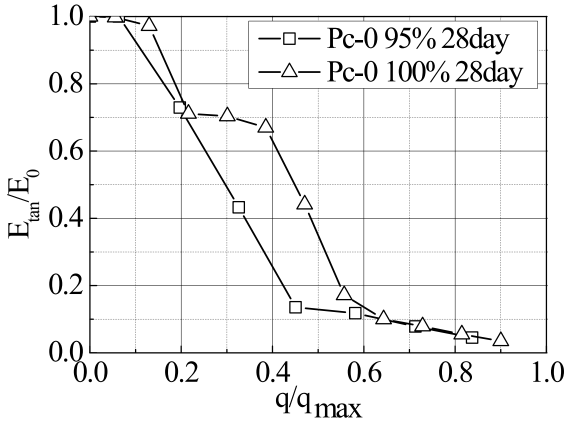

Figure 8 (a). E_{tan}/E_0~q/q_{max} of Pc-0 at 28 days

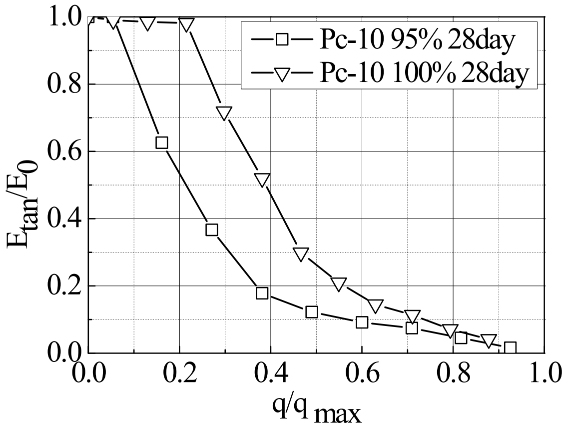

Figure 8 (b). E_{tan}/E_0~q/q_{max} of Pc-10 at 28 days

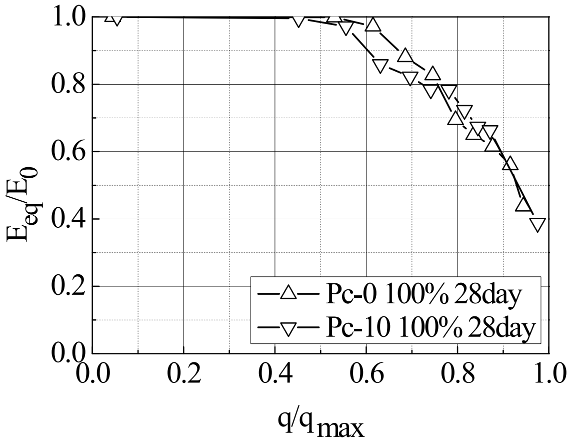

Figure 9 (a). E_{eq}/E_0~q/q_{max} of $D\rho_f$ = 100 % at 28 days

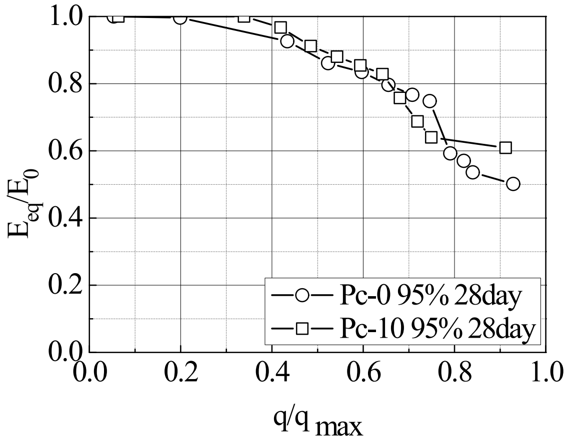

Figure 9 (b). E_{eq}/E_0~q/q_{max} of $D\rho_f$ = 95 %at 28 days

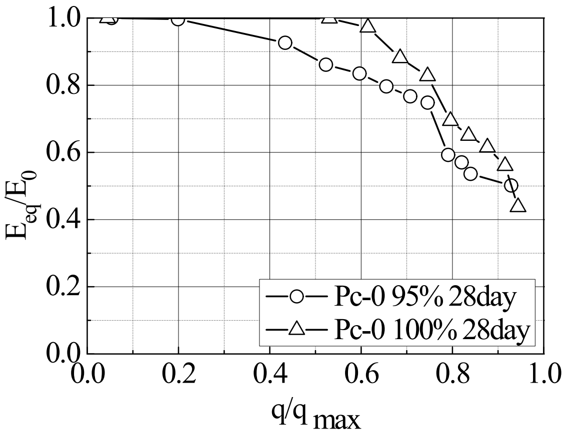

Figure 10 (a). E_{eq}/E_0~q/q_{max} of Pc-0 at 28 days

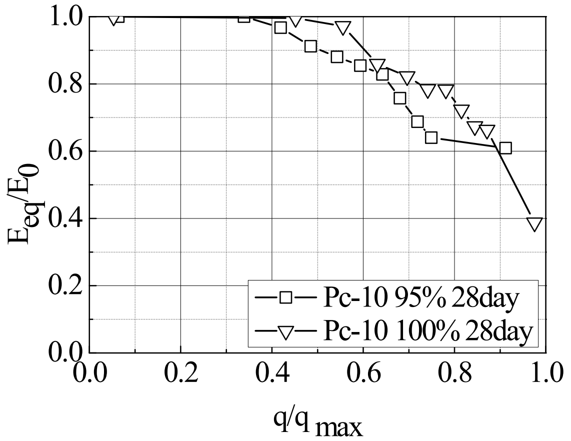

Figure 10 (b). E_{eq}/E_0~q/q_{max} of Pc-10 at 28 days

been reported that initial Young's modulus E_0 of cement-treated soil at small strain is independent of the confining pressure, thus, the E_{eq}/E_0 is considered to be indicative of the change in degree damage during shear. At the initial portion of shear, the soil specimen shows local failure, and finally, the soil specimen is collapsed as the shear band is formed by the strain. This behavior can be explained considering that cementation is broken therefore soil fabric changes and in consequence elastic properties change. There is no significant difference in reduction rate of E_{eq}/E_0 of Pc-0 and Pc-10 in $D\rho_f$ = 100 % and $D\rho_f$ = 95 %. However, it is seen from these figures that the reduction rate of E_{eq}/E_0 of Pc-10 tends to be slightly smaller than that of Pc-0. Thus, LSS reinforced with paper will create the reduction of the local damage caused by shearing.

From Figure 10 (a) and (b), it is seen that the reduction rate of E_{eq}/E_0 of $D\rho_f$ = 95 % tends to be larger than $D\rho_f$ = 100 % as comparing reduction rate E_{eq}/E_0 between $D\rho_f$ = 100 % and $D\rho_f$ = 95 %. Therefore, the reduction of slurry density is suggested to be increased the local damage during shear. In other words, the influence of slurry density on the damage degree caused by shearing is large and it seems that the damage degree tends to be reduced by the addition of fiber material.

5 CONCLUSIONS

In order to investigate influence of slurry density on strength and deformation properties of liquefied stabilized soil reinforced with fiber material, a series of consolidated-undrained triaxial compression tests (CUB tests) was performed under the two conditions of slurry density for specimens cured in laboratory at curing time of 28 days. The following conclusions were derived based on test results.

When the slurry density is slightly decreased from the appropriate slurry density obtained from the standard mix proportion design figure, it is considered that the q_{max} decreased remarkably. In addition, it is seen the local damage caused by shearing even in the case of low slurry density is reduced by the effect of reinforcement on the fiber material.

It seems that the nonlinearity of q~ ε_a relation increase as decreasing slurry density.

The influence of slurry density on the damage degree caused by shearing is large and it seems that the damage degree tends to be reduced by the addition of fiber material.

REFERENCES

Duong, H. Q., Kohata, Y., Omura, S., and Ozaki, K., 2014. Strength and deformation characteristics of liquefied stabilized soil reinforced by fiber material prepared at laboratory and field. Geosynthetic Engineering Journal, Vol.29, pp.33-40.

Goto, S., Tatsuoka, F., Shibuya, S., Kim, Y-S., & Sato, T., 1991. A simple gauge for local small strain measurements in the laboratory. Soils and Foundations, Vol.31, No.1, pp.169-180.

Ito, K., Kohata, Y., & Koyama, Y., 2011. Influence of additive amount of cement solidification agent on mechanical characteristics of Liquefied Stabilized Soil mixed with fibered material. Proc. of the Japanese Geotechnical Society Hokkaido Branch Technical Reports, Vol.51, pp.131-136. (In Japanese)

Kohata, Y., Tatsuoka, F., Wang, L., Jiang, L. G., Hoque, E., & Kodaka, T., 1997. Modelling the non-linear deformation properties of stiff geomaterials. Géotechnique, Vol.47, No.3, pp.563-580.

Kohata, Y., Jiang, L. G., Murata, O., & Tatsuoka, F., 1999. Elastic-properties-based modelling of non-linear deformation characteristics of gravels. Proc. of the second Inter. Symposium on Pre-Failure Deformation Characteristics of Geomaterials, IS-Torino 99, pp.533-539.

Kohata, Y., Fujikawa, T., Ichihara, D., Kanda, M., & Murata, O., 2002. Strength and deformation properties of fibered material mixed in liquefied stabilized soil obtained from uniaxial compression test. Proceeding of the 36th Japan National Conference on Geotechnical Engineering, pp.635-636. (In Japanese)

Kohata, Y., & Tsushima, H., 2004. Effect of fibered material mixing in liquefied stabilized soil on the triaxial shear characteristics. Proceeding of the 39th Japan National Conference on Geotechnical Engineering, pp.721-722.

Kohata, Y., 2006. Mechanical property of liquefied stabilized soil and future issues. Doboku Gakkai Ronbunshuu, F, Vol.62, No.4, pp.618-627. (In Japanese)

Kohata, Y., Ichikawa, M., Nguyen, C. Gia., & Kato, Y., 2007. Study of damage characteristics of liquefied stabilized soil mixed with fibered material due to triaxial shearing. Geosynthetics Engineering Journal, Vol.22, pp.55-62. (In Japanese)

Kuno, G., eds, 1997. Liquefied stabilized soil method-Recycling technology of construction-generated soil and mud. Gihodo publication.