INVESTIGATION OF ENGINEERING PROPERTIES OF LIQUEFIED STABILIZED SOIL REINFORCED FIBER MATERIAL

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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. Meanwhile, in Vietnam, the soils excavated from construction sites are considered a serious problem. It becomes more and more difficult to find reclamation sites for disposing excavated soil. Because of the lack of reclamation sites, it causes the environmental pollution. Therefore, this serious problem 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 some samples of fiber-reinforced LSS (at 0,10 kg/m3) prepared by two slurry densities at curing days of 28 days. 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.*

Nghiên cứu các tính chất kỹ thuật của đất ổn định hóa lỏng được gia cố vật liệu sợi

Tóm tắt

Ở Nhật Bản, đất ổn định hóa lỏng (LSS), một trong những loại đất ổn định bằng xi măng, là phương pháp tái chế đất đào tương đối phổ biến. Trong khi đó, ở Việt Nam, đất đào từ các công trình xây dựng đang trở thành một vấn đề nghiêm trọng. Ngày càng khó tìm được các bãi đổ để xử lý đất đào. Do thiếu bãi đổ nên xảy ra tình trạng ô nhiễm môi trường. Do đó, vấn đề nghiêm trọng này có thể được giải quyết nếu LSS sẽ được áp dụng tại Việt Nam. Nói chung, LSS được thực hiện dựa trên thiết kế tiêu chuẩn về tỷ lệ hỗn hợp. Gần đây, để khai thác ưu điểm của LSS, đã có đề xuất nâng cao LSS bằng cách hạ khối lượng riêng bùn để giảm áp lực đất dọc trục. Tuy nhiên, hiện vẫn còn thiếu các công trình nghiên cứu về cường độ và biến dạng của LSS khi khối lượng riêng của bùn. Nghiên cứu này thảo luận về ảnh hưởng khối lượng riêng bùn lên các đặc tính cường độ và biến dạng của LSS được gia cố bằng vật liệu sợi. Một loạt các thí nghiệm nén ba trục cố kết - không thoát nước đã được thực hiện đối với LSS được gia cố với hàm lượng sợi khác nhau (tức là 0,10 kg/m3) với hai khối lượng riêng bùn tại thời gian bảo dưỡng 28 ngày. Kết quả thí nghiệm cho thấy rằng cường độ của LSS được tạo ra bởi khối lượng riêng bùn thấp giảm xuống và ảnh hưởng của đất được gia cố đến cường độ và biến dạng của LSS được chế tạo bởi khối lượng riêng bùn thấp.

Từ khóa: *Đất ổn định hóa lỏng, cường độ, biến dạng, nén ba trục, mật độ bùn.*

1. Introduction

A huge and growing sinkhole had 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 with the sinkhole about 30 meters long, 27 meters wide, and 15 meters deep. By analysis of geotechnical engineers, this collapse was considered as 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. A volume of 7000 m^3 with soil has been filled up into the sinkhole. If conventional backfilling methods were used, sand of mountains or river valleys are easily fill up and compacted as required by standards. However, the conventional backfilling method takes a long construction duration and the ground surface settlement after backfilling also need to be supervised. Therefore, the conventional backfilling method could not be adopted. Meanwhile, LSS is an effective approach for recycling excavated soil for backfilling in construction works [1], that should be applied for backfilling construction and restoration in Japan. The developed recycling technique, called Liquefied Stabilized Soil is a method that excavated soil is thoroughly mixed with muddy water and cementing material and then placed in space where back filling is necessary at site.

At Vietnam, in recent years, more and more cave-ins appear at urban roads, especially in Hanoi and Ho Chi Minh City [2]. The main reasons of this appearance are soil being loosening and washed away by water leaking from ruptured underground pipelines or rainwater seeping down into. And often it happens and extend during underground infrastructure construction, even though the construction has been done the phenomena is still to continue if it is not found timely and treated fully.

The treatment of some problems happened in the ground under municipal roads is congested with public utility networks consisting of water, waste, electricity, gas, and telecommunication systems, underpin the economic, social, and environmental performance of modern life. They are the basic spatial infrastructure grids which, quite literally, provide the fundamental conduits through which modern cities operate. 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. At current, in Vietnam, most backfilling material for construction is mined from natural sources, such as sands from rivers and gravel from mountains. Mining has a significant damage impact on the natural environment. Mining can pollute air and water resources, harm wildlife and habitat, and permanently scar natural landscapes. And the demand for sand and gravel continues to increase in day by day. Thus, the application of LSS in Vietnam is an urgent require as to solve the afore-mentioned problems.

A Liquefied Stabilized Soil (LSS) is one of a cement-stabilized soil, which is improved the soil properties by the effect of cementation arising in an excavated soil mixed with cement and water by mixing excavated soil with water (or muddy water) and cement acted as a stabilizer. the LSS is different from the slurry based premixed stabilized soil [3]. Whereas the slurry based premixed stabilized soil is made by homogeneous soil material, the

LSS is made by excavated soil from construction site, which is inhomogeneous soil material.

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. 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 [4-7]. 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, comparisons of strength and deformation properties of LSS prepared at field and laboratory have been reported [8]. The specimens in this study were prepared under conditions as following: 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.

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

In this study, slurry density of 1.280 g/cm3 (hereafter called Dρf = 100 % LSS) was mixed fiber material amount of 0, 10 kg/m3. In parallel, slurry density of 1.280 g/cm3 reduced 5 % (=1.2160 g/cm3, hereafter called Dρf= 95 % LSS) and mixed fiber material amount of 0.10 kg/m3 and curried out in Laboratory

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^o 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 [9] 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 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.

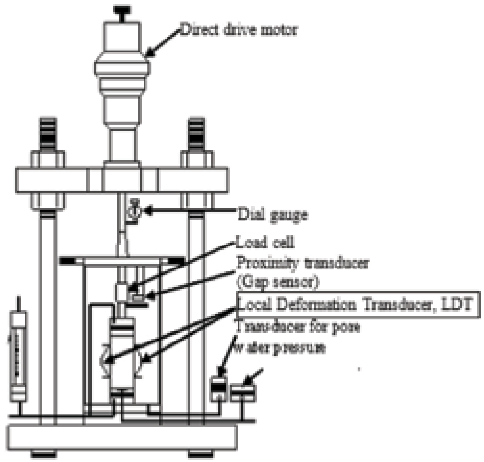

Figure 1. Schematic figure of test apparatus

4. Tesr 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 ($=\sigma_1 - \sigma_3$) 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. [2] [4] [5] [6]. 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.

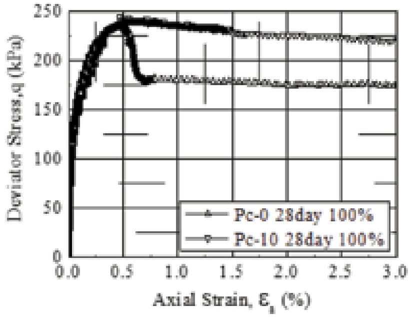

Figure 2. (a) q~ε_a relations of $D\rho_f$ = 100 % at 28 days

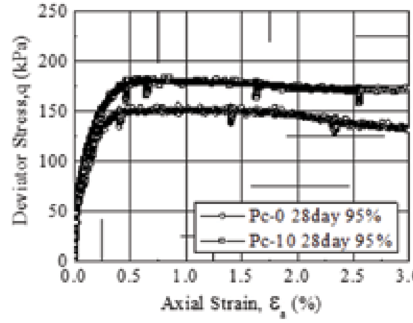

Figure 2. (b) q~ε_a relations of $D\rho_f$ = 95 % at 28 days

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.

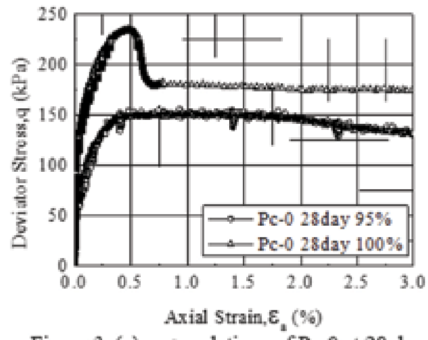

Figure 3. (a) q~ε_a relations of Pc-0 at 28 days

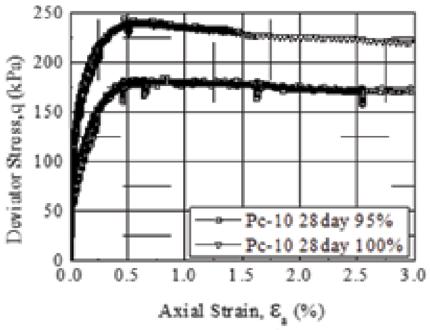

Figure 3. (b) $q \sim \varepsilon_a$ relations of Pc-10 at 28 days

Figure 4 (a) and (b) show the relationship between the deviator stress q ($=\sigma_1 - \sigma_3$) and the axial strain ε_a in range of 0~0.5 % for the cases of Dρf = 100 % and Dρf = 95 % mixed with fiber material of 0, 10 kg/m3 (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 Dρf = 100 %. However, Figure 4 (b) show distinct difference between Pc-0 and Pc-10 in the case of Dρf = 95 %. The deviator stress generated during shearing tends to difference from about ρa = 0.02 % due to the reinforcement effect of fiber material.

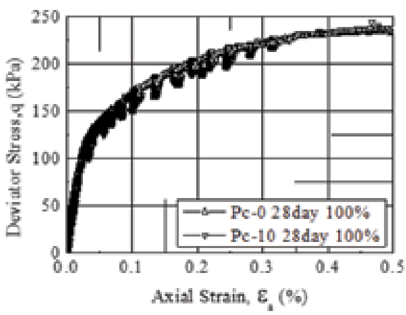

Figure 4. (a) $q \sim \varepsilon_a$ relations of $D\rho_f$ = 100 % at 28 days

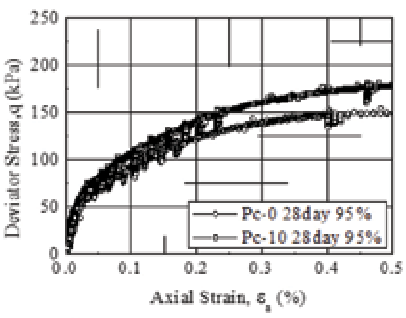

Figure 4. (b) $q \sim \varepsilon_a$ relations of $D\rho_f$ = 95 % at 28 days

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/m³ (Pc-0, Pc=10) are shown in Figure 5 (a) and (b), respectively. From these figures, as comparing $q \sim \varepsilon_a$ relation, although slurry density decreased 5 % from $D\rho_f$ = 100 % to Dρf = 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), Figures 5.

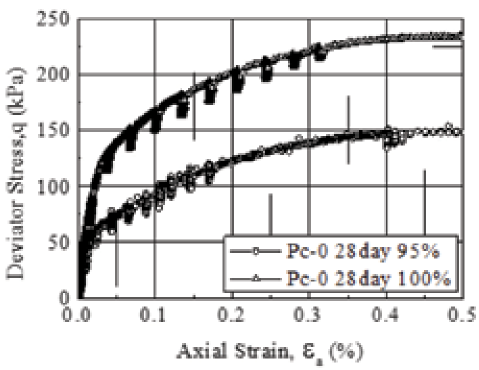

Figure 5. (a) $q \sim \varepsilon_a$ relations of Pc-0 at 28 days

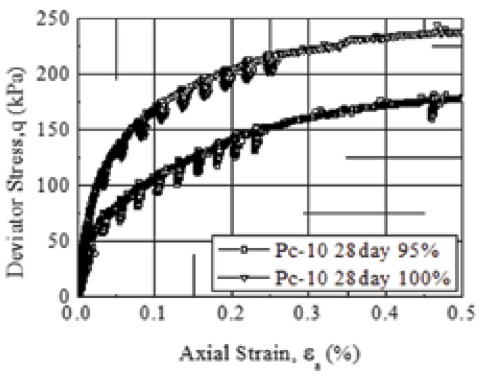

Figure 5. (b) $q \sim \varepsilon_a$ relations of Pc-10 at 28 days

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 ε_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 [4] [5].

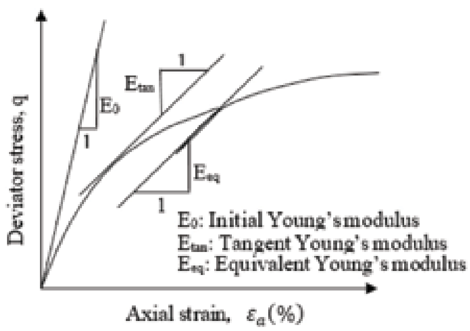

Figure 6. Definition of various Young's moduli

4.2.2. Tangent Young's Modulus Etan

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_a 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.

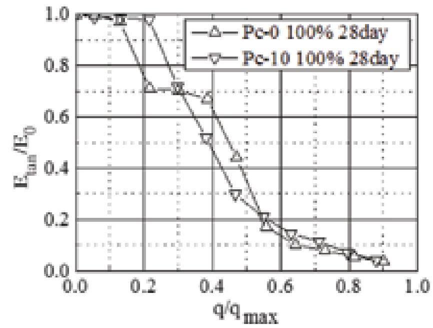

Figure 7 (a). E_{tan}/E_0~q/q_{max} of $D\rho_f$ = 100 % at 28 days

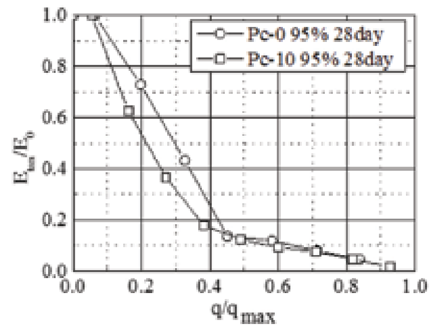

Figure 7 (b). E_{tan}/E_0~q/q_{max} of $D\rho_f$ = 95 % at 28 days

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 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 $q\sim\varepsilon_a$ 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.

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