STRENGTH AND DEFORMATION CHARACTERISTICS OF LIQUEFIED STABILIZED SOIL REINFORCED BY FIBER MATERIAL PREPARED AT LABORATORY AND FIELD

Hung Quang DUONG1, Yukihiro KOHATA2, Satoshi OMURA3, and Keita OZAKI4

In this study, the difference in triaxial shear property of Liquefied Stabilized Soil (LSS) mixed with fiber material cured in laboratory and at field was investigated. A series of Consolidated–Undrained triaxial compression tests under the conditions at constant strain rate, constant deviator stress (partial creep test), and changed strain rate during monotonic loading have been carried out for both specimens of LSS mixed with fiber material amount of 0 and 20 kg/m³ prepared by trimming LSS retrieved from a model ground by block sampling and cured in laboratory at curing time of 28 and 56 days, respectively. Based on the test results, it was found that the maximum deviator stress, qmax in q–ε curve of LSS mixed with fiber material cured at field tend to be larger than that cured in laboratory, and the brittle property of LSS after the peak in q–ε curve has been improved to ductile property by the addition of fiber material even in field.

KEYWORDS: Liquefied Stabilized Soil, Fiber Material, Cured in Laboratory and at Field, Triaxial Shear Property

1. INTRODUCTION

According to a new study released today by Ministry of Natural Resources and Environment of the Socialist Republic of Vietnam, about 1,000,000 m³ of excavated soil will have to be trucked from construction projects to disposal sites in Hanoi city over the next decade or two. The construction of the first phase of the metro line project alone, for example, will generate some 1,500,000 m³ of excavated soil. The study estimates that it could cost 100 million dollars or more to transport and dispose of these soils depending on the future availability of sites. Another project, the City of Hanoi’s own water and sewer capital program, will produce more than 800,000 m³ between now and the end of the decade. The question of where to put this extracted soil, according to the Ministry, some area surrounding Hanoi city are now restricting or banning the importation of soils. Therefore the excavated soil is becoming an urgent problem of Hanoi city at present.

In Japan, excavated soils generated from construction sites in urban areas are being disposed to landfill as industrial waste in many cases. However, the residual life of the landfill sites is estimated to be 13.6 years in Japan on average, particularly 4.3 years in Tokyo metropolitan area and 14.0 years in Kinki region 1). Then, the effective use of soil generated from construction is an urgent issue. In Japan, since the construction recycling law was established in May 2000, the recycling rate for three target items such as concrete mass, asphalt concrete mass and construction wood waste has been increased. On the other hand, the recycling rate of three items such as mixture construction waste, construction sludge and excavated soil with construction works remained at a low level in 10 years ago. Therefore, the increase of recycling rate for these three items was expected. From this background, "Liquefied Stabilized Soil" (LSS) 2) which is one of the effective methods of using the excavated soil with construction works has become widely. In terms of creating an improved ground by adding and mixing cement stabilizer to the soil material, LSS is classified as slurry based premixed stabilized soil which is one of cement-treated soils. However, the LSS is different from the slurry based premixed stabilized soil 3), 4). Whereas the slurry based premixed stabilized soil is made by homogeneous soil material, the LSS is made by

1) JGS Member, Graduate Student, Muroran Institute of Technology, Muroran, Japan
2) JGS Member, Professor, Muroran Institute of Technology, Muroran, Japan
3) JGS Member, Muroran City Office, Muroran, Japan
4) JGS Member, Graduate Student, Muroran Institute of Technology, Muroran, Japan
excavated soil from construction site, which is inhomogeneous soil material. And the LSS is considered to be carried to long distance by pump and to be filled to empty space. Then, the LSS have the appropriate flow by adjusting the density of soft muddy soil with high moisture content.

It is known that since LSS is one of the cement-treated soils, strength property indicates more brittle behavior when the strength increases as increasing an amount of cement stabilizer. To improve the brittle characteristic of LSS, Kohata et al. 5)~9) have considered on a reinforcement method by mixing crushed waste newspaper as a fiber material into LSS, and carried out a series of unconfined and triaxial compression tests. The results indicated that by the reinforcement effect, the brittle property of LSS mixed with fiber material after the peak in $q-\varepsilon_a$ curve was improved.

However, an investigation on LSS mixed with fiber material placed in-situ has been not performed, and then, the difference of strength and deformation property is not found well between a specimen retrieved by block sampling at in-situ ground and a specimen prepared in laboratory.

In this study, a model ground was made by backfilling with LSS mixed with fiber material (an amount of 0, 20 kg/m$^3$, respectively) into three pits constructed at the test field in campus. In parallel, the specimens of same batch were also molded and cured in laboratory. A series of consolidated undrained triaxial compression tests (CUB tests) were performed on both specimens prepared by trimming LSS retrieved from the model ground by block sampling (hereafter called in-situ LSS) and cured in laboratory (hereafter called indoor LSS) at the same curing time (28 and 56 days, respectively). The specimen was isotropically consolidated under the effective confined pressure of 98 kPa, and then, the specimen was sheared by triaxial compression under the condition at constant axial strain rate, constant deviator stress (partial creep), and changed strain rate during monotonic loading. Based on the test results, the difference in strength and deformation property of indoor LSS and in-situ LSS was discussed.

2. TEST PROCEDURE

(1) Test materials
In this study, NSF-CLAY was used as a base material. The physical properties are shown in Table 1. The cement stabilizer was used a special cement type, namely Geoset 200 made by Taiheiyo Cement Co. The fiber material was used crushed newspaper.

Table 1. Physical Properties of NSF-CLAY

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of particle $\rho_p$ (g/cm$^3$)</td>
<td>2.762</td>
</tr>
<tr>
<td>Liquid limit $W_L$ (%)</td>
<td>60.15</td>
</tr>
<tr>
<td>Plastic Limit $W_p$ (%)</td>
<td>35.69</td>
</tr>
<tr>
<td>Plasticity Index $I_p$</td>
<td>24.46</td>
</tr>
</tbody>
</table>

(2) Mixing method
In general, there are two LSS mixing methods used for excavated soil containing a large quality of fine particles, which are slurry type and adjustment slurry type. In this study, the slurry type was used due to easier preparation. In this method, water was added moderately to soil for adjusting density of slurry, then the cement stabilizer was added and mixed.

A series of mixing tests were carried out by changing density of slurry and amount of cement stabilizer. The bleeding rate, flow value and unconfined compressive strength were determined by soil tests for each of LSS at curing time of 28 days. The values thus obtained were to present a standard mix proportion for this study.

(3) Specimen preparation
Based on the standard mix proportion design figure 8), in this study, 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$^3$.

LSS was prepared by mixing cement stabilizer into slurry in a hand mixer. The density test was performed by measuring the mass of slurry filled into a stainless steel container of 400 cm$^3$ called “AE mortar container”. After obtaining the target density, the fiber material was added to and mixed carefully by hand mixer. The flow test was conducted in accordance with JHS A313 – Japan Highway Public Corporation Standard “Testing Method for Air Mortar and Air Milk, 1.2 cylinder sample” in order to determine the liquidity of LSS. To make the model ground, the fresh LSS mixed with fiber material amount of 0, 20 kg/m$^3$, respectively then was poured into three pits constructed at the test field in campus, as shown in Figure 1.

Before pouring, a nonwoven geotextile filter was set on to prevent seepage of LSS to original ground. After placing, the surface of LSS was covered with a polymer sheet and cured under outdoor condition. In parallel, the fresh LSS was also placed into
mould of 5 cm in diameter and 10 cm in height, the top surface of the specimens was covered with a polymer film and were cured under air humidity and indoor temperature of 20±3°C. After curing time of 28 and 56 days, both the specimens prepared by trimming LSS retrieved from the model ground by block sampling method (in-situ LSS) and cured in laboratory (indoor LSS) were subjected to CUB tests.

(4) Test method and equipment
The outline of apparatus for triaxial compression tests is shown in Figure 2. To avoid the effect of bedding error caused by loose layers at the top and bottom ends of specimen, a pair of Local Deformation Transducer (LDTs) \(^{10}\) was set at the diagonally opposite ends of specimen diameter to measure axial strain. The top and bottom ends of LDT was pinched between two pseudo-hinged attachments fixed on the surface of rubber membrane at the points which were glued to the specimen to alleviate 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, which enables to control the axial displacements with high precision, and can ignore backlash when reversing the loading direction, was used for the loading device. The whole operation of apparatus during test was automatically controlled by a PC software.

The CUB tests were performed for both in-situ LSS and indoor LSS specimens at curing time of 28 and 56 days, respectively. The saturation of specimen was achieved by the double vacuum pressure method which the de-aired water flowed through specimen under a back pressure of 196 kPa. After isotropically consolidated during 12 hours under the effective confined pressure of 98 kPa, the specimen was sheared by triaxial compression. To investigate the strength and deformation property and the effect of creep on those of LSS mixed with fiber material, two cases of axial strain rate were used in this study as shown in Figure 3 and Figure 4. Case 1 was obtained by applying small unloading/reloading loops under monotonic loading process and axial strain rate of 0.054 %/min (\(\dot{\varepsilon}_0\)). In case 2, creeps (\(\varepsilon\)) were subjected during loading and before a change of constant axial strain rate (\(\varepsilon_0 \rightarrow \varepsilon_0 \rightarrow \varepsilon_0 \rightarrow \varepsilon_0 \rightarrow \varepsilon_0 \rightarrow \varepsilon_0 \)). In addition, the change of axial strain rate was carried out in a range of about \(\dot{\varepsilon}_a = 1 \%\).

3. TEST RESULTS AND DISCUSSION

(1) Relationship between deviator stress and axial strain
Figure 5 and Figure 6 show the relationship between the deviator stress \(q = \sigma_1 - \sigma_3\) and the axial strain \(\varepsilon_a\) in range of 0~2.0 % from the CUB tests under the confining pressure \(\sigma'_c = 98\) kPa for case 1 and case 2 of both indoor LSS and in-situ LSS mixed with fiber material amount of 0, 20 kg/m\(^3\) (Pc-0, 20) at 28 and 56 curing days, respectively. From the figures, as comparing the \(q\)~\(\varepsilon_a\) relation in each test of both 28 and 56 curing days, the maximum deviator stress, \(q_{\text{max}}\) of in-situ LSS specimens substantially tend to be larger than that of indoor LSS ones. It is caused to the factors of curing
environment affecting the cementation into LSS. Then, it is considered that the onset of cementation was accelerated under outdoor curing condition compared to indoor curing condition, because the factors of curing environment humidity and temperature cannot be controlled. In addition, the $q_{\text{max}}$ of both indoor LSS and in-situ LSS at 56 curing days is generally larger than that at 28 curing days. Therefore, it is considered that the strength of LSS mixed with fiber material increases as the increasing of curing time when LSS mixed with fiber material is used as a backfilling material at the sites. It is found from previous researches 5)~9) that by the reinforcement effect, the brittle property of indoor LSS mixed with fiber material after the peak in $q \sim \varepsilon_a$ curve was improved. As shown in Figure 5(b) and Figure 6(b) the brittle property of both indoor LSS and in-situ LSS, Pc-20 after the peak in $q \sim \varepsilon_a$ curves is improved in comparison with pure LSS, Pc-0. For this reason, the application of LSS mixed with fiber material as a backfilling material to construction sites enables to create a ground with the improved ductile characteristic. Figure 5(b) indicates that the $q_{\text{max}}$ of in-situ LSS, Pc-20 is smaller than that of other in-situ LSS, Pc-0. It seems that due to the addition of the fiber material, the cementation was considered to be delayed at early curing time.

(2) Deformation property

a) Definition of Young’s modulus

Figure 7 shows the definitions of various Young’s moduli. The initial Young’s modulus $E_0$ is defined as initial stiffness at small strain of $\varepsilon_a = 0.002\%$ or less. The tangent Young’s modulus $E_{\text{tan}}$ is defined as tangential gradient in $q \sim \varepsilon_a$ curve, it indicates the non-linearity of deformation property in $q \sim \varepsilon_a$ relation. The equivalent Young’s modulus $E_{\text{eq}}$ is obtained from small unloading/reloading loop during monotonic loading. Moreover, the $E_{\text{eq}}$ 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 $q \sim \varepsilon_a$ curve in reloading. The $E_{\text{eq}}$ indicates a changing of damage degree under the shearing 11), 12).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Figure 5. $q \sim \varepsilon_a$ relations at 28 days}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure6.png}
\caption{Figure 6. $q \sim \varepsilon_a$ relations at 56 days}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{Figure 7. Definition of various Young’s moduli}
\end{figure}
Figure 8 shows the relation of $q_{\text{max}}$ and $E_0$ with curing days of in-situ LSS, Pc-0, 20, respectively. The results of in-situ LSS at 84 days with the same test conditions are shown here just for information. The values were obtained from the $q$-$\varepsilon$ curve of the CUB tests under the confining pressure of 98 kPa. From the figure, $E_0$ and $q_{\text{max}}$ of Pc-0 is decreased at 56 days, but overall it tends to increase as at 84 days. In general, increase of the $q_{\text{max}}$ of cement-treated soil with curing days has been known. However, $q_{\text{max}}$ of Pc-20 decrease at 84 days though $E_0$ of one increases. Because the temperature of which the time is close to 84 curing days is below 0°C, it may be due to the effect of frost heave on the strength of specimen. For the reason, it is considered for further study.

b) Tangent Young’s modulus $E_{\text{tan}}$

Figure 9 shows the relationship between $E_{\text{tan}}/E_0$ and $q/q_{\text{max}}$ of both indoor LSS and in-situ LSS, Pc-0, 20, respectively at 28 days and 56 days for case 1. The values were obtained from the $q$-$\varepsilon$ curve of the CUB tests under the confining pressure of 98 kPa. In this Figure, reduction rate of $E_{\text{tan}}/E_0$ of indoor LSS and in-situ LSS shows a similar tendency in both Pc-0 and Pc-20 at 28 days and 56 days, respectively. Generally, cement-treated soil has been reported that nonlinearity of stress-strain curve decreases as increasing of curing days \(^3\). However, within this study, a reduction rate of $E_{\text{tan}}/E_0$ of specimens at 56 days is larger than that at 28 days. Therefore, it seems that the nonlinearity increases as increasing of curing time. For this result, it is considered to conduct further works in the coming time.
Figure 10 shows the relationship between $E_{\tan}/E_0$ and $q/q_{\max}$ for case 2. From the figure, it indicates that the $E_{\tan}/E_0$ of both indoor LSS and in-situ LSS temporarily increase significantly immediately after applying a creep and initiating a new constant axial strain rate regardless of the curing days, thereafter, under loading the reduction of $E_{\tan}/E_0$ tends to be larger. Thus, there is a tendency that the rigidity temporarily increases immediately after a creep is given. In addition, the range of indicating $E_{\tan}/E_0$ value of 1.0 tends to be larger in case of Pc-20 as compared with Pc-0. Therefore, it is considered that the range of linear in $q$-$\varepsilon_a$ relation becomes larger by the addition of the fiber material to LSS independent of the curing days. Then, it is found that due to the reinforcement effect by the addition of the fiber material, the linear range in $q$-$\varepsilon_a$ relation of in-situ LSS immediately after creep is increased.

c) Strain level-dependency of tangent Young's modulus, $E_{\tan}$

Figure 11 shows the strain level-dependency of tangent Young's modulus $E_{\tan}$ until the peak in $q$-$\varepsilon_a$ curve of both indoor LSS and in-situ LSS, Pc-0, 20, respectively at 28 days and 56 days for case 1. It is seen that the initial stiffness of in-situ LSS tends to be larger than that of indoor LSS. However, a significant difference in strain level-dependency of $E_{\tan}$ is not found. Figure 12 shows the strain level-dependency of $E_{\tan}$ for case 2. In both indoor LSS and in-situ LSS, even in the range of large shear strain level, $E_{\tan}$ temporarily increase significantly immediately after a creep action. Moreover, in the case of Pc-20, a larger range of $E_{\tan}$ increasing nearly to the initial stiffness is observed. Thus, during loading before the peak in $q$-$\varepsilon_a$ relation, regardless of the curing days, the stiffness of LSS increases immediately after creep, even in the range of large shear strain level. By the addition of the fiber material, due to its reinforcing effect, the range that indicates large stiffness is increased.

d) Equivalent Young’s modulus, $E_{eq}$

Figure 13 shows the relationship between $E_{eq}/E_0$ and $q/q_{\max}$ of both indoor LSS and in-situ LSS, Pc-0, 20, respectively at 28 days and 56 days. The values were obtained from the $q$-$\varepsilon_a$ curve of the CUB tests under the confining pressure of 98 kPa. In general, it has been reported that Young’s modulus of cement-treated soil at small strain is independent of the confining pressure, thus, the $E_{eq}/E_0$ is considered indicating the change of damage degree under shearing. At first stage, the shearing cause soil specimen to break locally, and finally the soil specimen is entirely destroyed as the shear band is formed by the accumulation of the local destructions. This is considered that the cementation or microstructure between particles of the soil is damaged, and then such damages cause the changes of elasticity. It is seen from the figure in the case of indoor LSS that overall the reduction rate of $E_{eq}/E_0$ of Pc-20 tends to be smaller than that of Pc-0. Thus, the fiber material inside specimen is suggested mitigating the local damage caused by shearing. However, in the case of in-situ LSS, the reduction rate of $E_{eq}/E_0$ of Pc-20 at 56 curing days is
large. It is probably due to the influence of the disturbance at the time of sampling and curing environment, which causes remarkably damage for the sample under shearing. For this result, it is considered to conduct further works in the coming time.

4. CONCLUSIONS

In order to evaluate the strength and deformation properties of Liquefied Stabilized Soil mixed with fiber material cured in laboratory and at field, a series of consolidated-undrained triaxial compression tests was performed under the two conditions of axial strain rate for both specimens retrieved from the model ground by block sampling and cured in laboratory at curing time of 28 and 56 days.

The following conclusions were derived based on test results.

1. Within this study, the maximum deviator stress, \( q_{\text{max}} \) in \( q-\varepsilon_q \) curve of LSS mixed with fiber material cured at field substantially tend to be larger than that cured in laboratory. Moreover, by the addition of the fiber material, the brittle property of LSS cured in field after the peak is improved.

2. The \( E_{\text{eq}}/E_0 \sim q/q_{\text{max}} \) relation of both LSS cured in laboratory and at field shows relatively similar tendency. In addition, the nonlinearity in \( q-\varepsilon_q \) relation of LSS due to its reinforcing effect is weakened.

3. It is considered that the linear region on \( q-\varepsilon_q \) relation increases immediately after creep due to reinforcing effect when the fiber material is mixed in LSS prepared at field.

4. It is suggested that the application of LSS mixed with fiber material as a backfilling material to construction sites enables to create a ground with the improved ductile characteristic, although it needs to conduct more study.

ACKNOWLEDGMENTS

The authors express deep gratitude to Ms. Abiru Saori (formerly undergraduate student of Muroran Institute of Technology) for her cooperation in experimental works, to Mr. Yamamoto Kenichi (Dorokogyo Co., Ltd) for the excavation of test pits, to Mr. Kaji Shin (Ueyama Drilling Industry Co., Ltd) for the block sampling.

The second author is grateful for funding awarded by the Japan Ministry of Education, Culture, Sports, Science and Technology (Grant-in-Aid for Scientific Research (C) No. 23560586).

REFERENCES


7) Kohata, Y., Ichikawa, M., Nguyen, C. Giang., and Kato, Y. (2007): Study of damage characteristics of liquefied stabilized soil mixed with fibered material due to triaxial...
室内及び原位置で作製された繊維材混合流動化処理土の強度・変形特性

Hung Quang DUONG・木幡行宏・大村知史・尾崎敬太

本研究では、繊維材混合流動化処理土の室内・原位置作製供試体による力学特性の比較、検討を行った。原位置作製試料は、大学構内に作製したピットに、繊維材をそれぞれ、0, 20 kg/m³で添加した繊維材混合流動化処理土をピットに埋戻して養生された。実験は、ピットからブロックサンプリングにて採取した原位置養生供試体、及び原位置作製試料と同じバッチで室内養生された供試体に対し、98 kPaの等方応力条件下で、単調載荷、載荷中に応力持続載荷（クリープ）を行った場合の圧密非排水三軸圧縮試験（CUB試験）を実施した。室内及び原位置で作製された供試体のq-εa関係を比較すると、28日、56日養生ともに、原位置養生供試体のqmaxが室内養生供試体のqmaxに比べ、概ね大きくなる傾向にあること、また、原位置養生供試体においても、繊維材を混合するとピーク後の脆性の性質が改善されることが分かった。

キーワード：流動化処理土, 繊維材, 室内養生, 原位置養生, 三軸せん断特性