Evaluation of in-situ compressive stiffness of liquefied-stabilized soil reinforced with fiber

Hung Quang Duong i), Yukihiro Kohata ii), Keita Ozaki iii) and Saori Abiru iv)

i) Graduate Student, Division of Engineering, Muroran Institute of Technology, 27-1, Mizumoto, Muroran 050-8585, Japan.
ii) Professor, Division of Engineering, Muroran Institute of Technology, 27-1, Mizumoto, Muroran 050-8585, Japan.
iii) Graduate Student, Division of Engineering, Muroran Institute of Technology, 27-1, Mizumoto, Muroran 050-8585, Japan.
iv) CTI Engineering Co., Ltd., 3-21-1, Nihonbashihamacho, Chuoku, Tokyo, 103-8430, Japan.

ABSTRACT

In this study, evaluation of in-situ compressive stiffness of backfilling ground reinforced with fiber was discussed. A model ground made at the test field by backfilling with Liquefied Stabilized Soil (LSS) reinforced with fiber amount of 0 and 20 kg/m³ was subjected to portable Falling Weight Deflectometer (FWD) tests at curing time of 28, 56 and 84 days, respectively. The stiffness was estimated by Young’s modulus $E_{FWD}$ calculated from $K_{FWD}$-value as the coefficient of subgrade reaction. In parallel, in order to obtain the tangent Young’s modulus $E_{tan}$ in deviator stress and axial strain $(q$–$\varepsilon_a)$ curve, 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 specimens prepared by trimming LSS retrieved from the model ground by block sampling. Based on the test results, the relationship between the $K_{FWD}$-value and $E_{tan}$ was discussed. It is considered that the $K_{FWD}$-value is able to estimate the stiffness of backfilling ground by LSS reinforced with fiber.

Keywords: liquefied stabilized soil, fiber, backfilling ground, in-situ compressive stiffness

1 INTRODUCTION

According to a recent 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, it was reported by Ministry of Environment (2012) that 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. 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) described by Kuno (1997) 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 according to JGS (2005) and Kohata (2006). 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. 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, author’s research group 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 (Kohata et al. (2002, 2007a), Kohata and Tsushima (2004), Ito et al. (2011) and Duong et al. (2014)). The results indicated that the brittle property of LSS mixed with fiber material after the peak in q~εp curve was improved by the reinforcement effect.

However, an evaluation of in-situ compressive stiffness of backfilling ground by LSS reinforced with fiber has been not performed. Moreover, the relationships between the Young’s modulus $E_{PFWD}$ calculated from the coefficient of subgrade reaction $K_{PFWD}$-value estimated by portable FWD tests and tangent Young’s modulus $E_{tan}$ in q~εp relation obtained from consolidated undrained triaxial compression tests (CUB tests) of the backfilling ground reinforced with fiber has not found.

In this study, a model ground was made by backfilling with LSS reinforced with fiber (an amount of 0 and 20 kg/m$^3$, respectively) into two pits constructed at the test field in campus. After curing time of 28, 56 and 84 days, the ground was subjected to the portable FWD test for estimation of the stiffness in term of the $E_{PFWD}$ calculated from the measured $K_{PFWD}$-value. In parallel, in order to obtain the $E_{tan}$, a series of CUB tests were performed on the specimens prepared by trimming LSS retrieved from the model ground by block sampling. The specimens were 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 relationships between the $E_{PFWD}$ and $E_{tan}$ were discussed and the in-situ compressive stiffness of the backfilling ground reinforced with fiber was evaluated.

2 TEST PROCEDURE

2.1 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.

| Physical Properties of NSF-CLAY | Value |
|---------------------------------|-------|
| Density of particle $p_s$ (g/cm$^3$) | 2.762 |
| Liquid limit $W_l$ (%) | 60.15 |
| Plastic Limit $W_p$ (%) | 35.69 |
| Plasticity Index $I_p$ | 24.46 |

Fig. 1. Schematic drawing of pits.

2.2 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.

2.3 Specimen preparation

In this study, based on the standard mix proportion design figure described by Ito et al. (2011), 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 amount of 0 and 20 kg/m$^3$, respectively, then was poured into two pits constructed at the test field in campus, as shown in Figure 1.
56 and 84 days, respectively, the model ground was subjected to portable FWD tests. In parallel, the specimens prepared by trimming LSS retrieved from the model ground by block sampling were subjected to CUB tests.

2.4 Test method and equipment
2.4.1 Portable FWD test

Schematic of a portable FWD test apparatus is shown in Figure 2. The apparatus makes the weight fall freely on its loading plate to apply impact load and measure the displacement caused by the fall at the center of impact load and also at points in radial direction from the center of impact load.

The number of fall at one measurement point was 6 times. The reason is the measurement result at first fall varies due to unstable contact between loading plate and the ground. First fall is regarded as primary fall, so the load and displacement from the second fall are recorded as measurement data and averaged. This was repeated three times to obtain the relationship as shown in Figure 3, and then, the $K_{P,FWD}$-value was calculated using Eq. 1.

The model ground was subjected to the test at curing time of 28, 56 and 84 days, respectively.

2.4.2 CUB test

The outline of apparatus for triaxial compression tests is shown in Figure 4. 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), which is described by Goto et al. (1991), 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 PC software.
The CUB tests were performed for the specimens prepared by trimming LSS retrieved from the model ground by block sampling at curing time of 28, 56 and 84 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 under the two cases of axial strain rate, respectively. Case 1 was obtained by applying small unloading/reloading loops under monotonic loading process and axial strain rate of \( \varepsilon_0 \) %/min. In case 2, creeps were subjected during loading and before a change of constant axial strain rate \( (\varepsilon_0 \rightarrow C \rightarrow \varepsilon_0 \rightarrow C \rightarrow 10\varepsilon_0 \rightarrow C \rightarrow \varepsilon_0) \). In addition, the change of axial strain rate was carried out in a range of about \( \varepsilon_a = 1 \) %.

3 TEST RESULTS AND DISCUSSION

3.1 Effect of curing days on \( K_{P,FWD} \) value

Figure 5 shows the relation of \( K_{P,FWD} \)-value with curing days of the model backfilling ground reinforced with fiber amount of 0 and 20 kg/m\(^3\) (Pc-0 and 20), respectively. The results indicate that the \( K_{P,FWD} \)-values of both Pc-0 and Pc-20 increase with curing time. After 28 days, the values of Pc-20 increase faster by producing the higher values than that of Pc-0 at 56 and 84 days, respectively. Therefore, it is considered that due to the reinforcement effect by the addition of the fiber to LSS, the stiffness of backfilling ground increases as the increasing of curing time when LSS reinforced with fiber is used as a backfilling material at the sites.

3.2 Effect of dry density on \( K_{P,FWD} \) value

Figure 6 shows the relation of \( K_{P,FWD} \)-values with dry density of Pc-0 and 20 at 28, 56 and 84 days, respectively. From the figure, it can be seen that \( K_{P,FWD} \)-values increase with increasing the dry density. Therefore it is considered that besides the effect of curing time and addition of fiber into LSS, the stiffness of backfilling ground is affected by dry density.

3.3 Strain level-dependency of Young’s modulus

Figure 7 shows the strain level-dependency of tangent Young’s modulus \( E_{\tan} \) obtained in \( q~e_a \) relation from CUB tests of Pc-0 and 20 at 28 days and 84 days for case 1 and case 2, respectively. The \( E_{P,FWD} \) values calculated from \( K_{P,FWD} \)-value estimated by portable FWD test are plotted on these figures in correspondence with the strain level. As a comparison at the same strain level, regardless of the curing days, for both Pc-0 and Pc-20, the \( E_{P,FWD} \) shows slightly larger values than \( E_{\tan} \) of both case 1 and case 2. In general, the value of \( E_{\tan} \) and \( E_{30} \) obtained from plate load test at the same strain level has been reported to be approximately equal. In addition, based on the field test results, JSCE (2002) and Kohata and Saratani (2007b) reported that the relationship between the
KP.FWD-value and K30-value calculated by the plate load test for granular soil ground is 2:1. Therefore, in this study, as compared with $E_{\tan}$ values at the same strain level, the $E_{P,FWD}$ estimated from filed test by the portable FWD presented the reasonable values. Consequently, it is considered that the stiffness of backfilling ground by LSS reinforced with or without fiber regardless of curing days can be estimated by KP.FWD-value.

## 4 CONCLUSIONS

In order to evaluate in-situ compressive stiffness of backfilling ground by LSS reinforced with fiber, the portable FWD tests were performed on a model ground at curing time of 28, 56, 84 days. In parallel, the specimens prepared by trimming LSS retrieved from the model ground by block sampling were subjected to CUB tests.

The following conclusions were derived based on test results.

1. The in-situ stiffness of the backfilling ground by LSS increases as the increasing of curing time. Moreover, by the addition of the fiber into LSS, the stiffness is increased faster due to the reinforcement effect.

2. Besides the effect of curing time and addition of fiber into LSS, the stiffness of backfilling ground by LSS is affected by dry density.

3. By comparison with the $E_{\tan}$ value obtained from indoor tests (CUB tests), it is considered that the stiffness of backfilling ground by LSS reinforced with fiber can be estimated by KP.FWD-value obtained from in-situ tests (portable FWD tests).

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