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## ハノイ市における繊維質材料混合流動化処理土の埋戻し地盤への適用に関する研究

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# Mechanical Properties of Liquefied Stabilized Soil (LSS) Evaluated by Field Testing Method

## 4.1 INTRODUCTION

Based on the laboratory test results in chapter 3, it has been suggested that the application of LSS mixed with fiber material as a backfilling material to construction sites enable to create a ground with the improve ductile characteristic. 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  $E_{P.FWD}$  calculated from the coefficient of subgrade reaction  $K_{P.FWD}$ -value estimated by portable Falling Weight Deflectometer (FWD) tests and tangent Young's modulus  $E_{tan}$  in  $q \sim \varepsilon_a$  relation obtained from consolidated undrained triaxial compression tests (CUB tests) of the backfilling ground reinforced with fiber has been not found.

In Japan, stiffness of unbound pavement layers is evaluated from K value i.e. coefficient of sub grade reaction, obtained from a plate loading test (JRA, 1995). This K value is used in quality control management during execution of these layers. However, a large reaction device is required to perform the plate loading test. Moreover, the location to be tested is restrained for further work for at least one day as the plate loading test require much time. For these reasons, application of  $K_{P.FWD}$  values based on portable FWD tests for construction quality management of unbound pavement layers is attempted in Japan (Tatsumi et. al., 2004; Kamono et. al., 1999). Portable FWD due to its numerous advantages including, portability; simplicity and ease of measurement; and time efficiency in estimating stiffness moduli has gained popularity in recent years (George, 2006)

In this chapter, a model ground was made as presented in chapter 3 by backfilling with LSS reinforced with fiber (an amount of 0 and 20 kg/m<sup>3</sup>, 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  $E_{P,FWD}$  calculated from the measured  $K_{P,FWD}$ -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  $E_{P,FWD}$  and  $E_{tan}$  were discussed and the in-situ compressive stiffness of the backfilling ground reinforced with fiber was evaluated.

## 4.2 TEST PROCEDURE

### 4.2.1 Test material, mixing method and specimen preparation

Test material, mixing method and specimen preparation were presented in chapter 3. After placing, the surface of LSS was covered with a polymer sheet and cured under outdoor condition. After curing time of 28, 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.

### 4.2.2 Test method and equipment

#### 4.2.2.1 Portable FWD test

Schematic of a portable FWD test apparatus is shown in Figure 4.1. 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.

Generally, the stiffness of natural/artificial ground is evaluated by plate load test which calculates  $K_{30}$ -value with 30 cm diameter loading plate from the relation between 1.25 mm displacement and corresponded load strength at static loading. In portable FWD test, loading and displacement

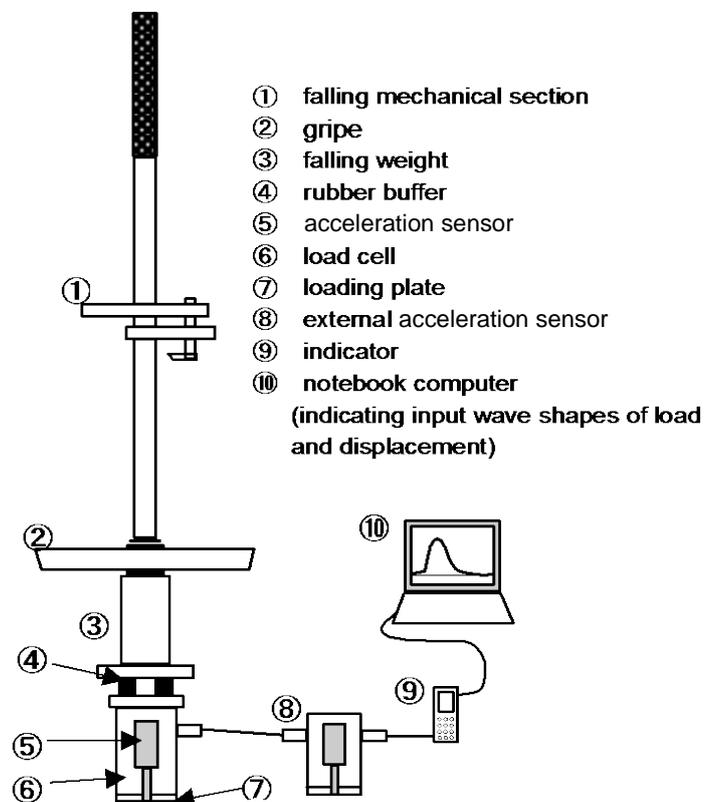


Figure 4.1 Schematic of portable FWD test apparatus

are measured and obtains  $K_{P,FWD}$ -value from its relation. The value evaluates the stiffness of the ground. In this study, the loading plate diameter of the apparatus was 10 cm which was different from that of the plate load test. Therefore, the loading plate diameter was corrected and the  $K_{P,FWD}$ -value at 30 cm loading plate diameter was calculated as following equation (JSCE ed., 2002).

$$K_{P,FWD} = (P_{P,FWD,\phi} / \delta_{P,FWD,\phi}) \cdot (\phi_{P,FWD} / \delta_{PLT}) \quad (\text{MN}/\text{m}^3) \quad (4.1)$$

Where:

$P_{P,FWD,\phi}$ : loading stress at displacement  $\delta_{P,FWD,\phi}$

$\delta_{P,FWD,\phi}$ : displacement

$\phi_{P,FWD}$ : loading plate diameter of portable FWD

$\phi_{PLT}$ : loading plate diameter of plate load test on soil for road (30 cm)

Thus, the measurement was conducted to obtain at least three different displacements including 0.417 mm ( $1.25 \text{ mm} \times \phi_{P,FWD} / 30 \text{ cm}$ ) in the middle, by changing weight mass and falling height. One of the displacements would be near 0.417 mm as shown in Figure 4.2.

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 4.2, and then, the  $K_{P,FWD}$ -value was calculated using Equation 4.1.

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

#### 4.2.2.2 CUB test

The outline of apparatus for triaxial compression tests was shown in Figure 3.3 of chapter 3. 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 0.054 %/min ( $\dot{\epsilon}_0$ ). In case 2, creeps ( $C$ ) were subjected during loading and before a change of constant axial strain rate ( $\dot{\epsilon}_0 \rightarrow C \rightarrow \dot{\epsilon}_0 \rightarrow C \rightarrow 10\dot{\epsilon}_0 \rightarrow C \rightarrow \dot{\epsilon}_0$ ). In addition, the change of axial strain rate was carried out in a range of about  $\dot{\epsilon}_a = 1 \%$ .

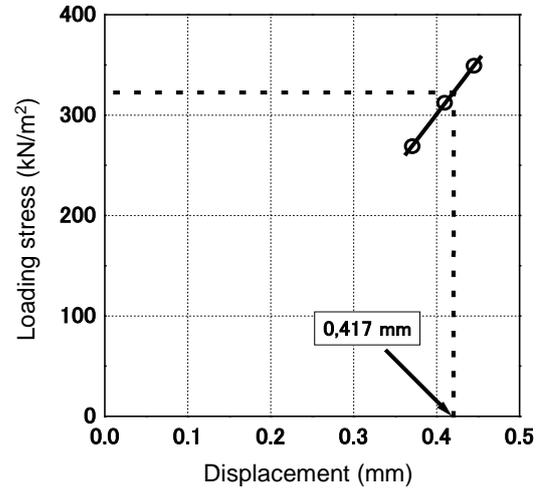


Figure 4.2 An example of displacement and loading stress at one measurement point

### 4.3 TEST RESULTS AND DISCUSSION

#### 4.3.1 Effect of curing days on $K_{P,FWD}$ -value

Figure 4.3 shows the relation of  $K_{P,FWD}$ -values with curing days of the model backfilling ground reinforced with fiber amount of 0 and 20  $\text{kg/m}^3$  (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 the backfilling ground increases as the increasing of curing time when LSS reinforced with fiber is used as a backfilling material at the sites.

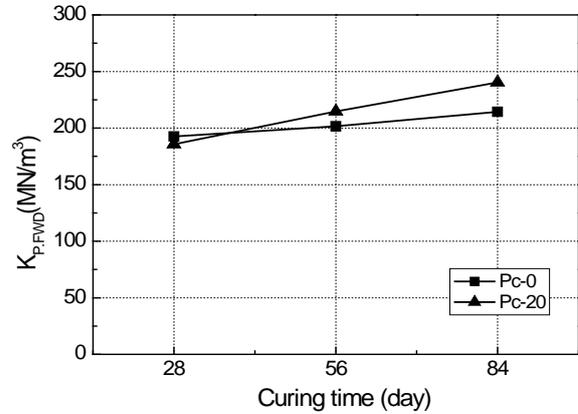


Figure 4.3  $K_{P,FWD}$ -value~curing days relation

#### 4.3.2 Effect of dry density on $K_{P,FWD}$ -value

Figure 4.4 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.

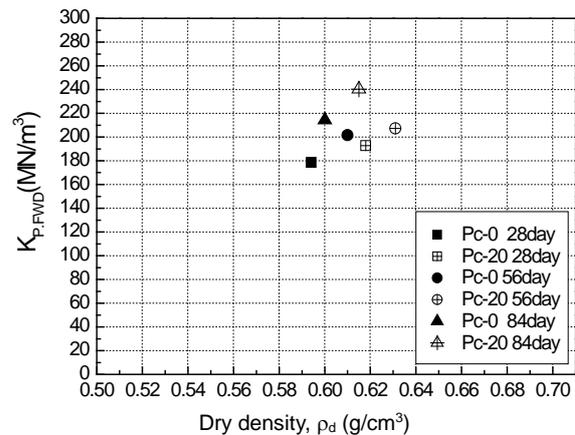


Figure 4.4  $K_{P,FWD}$ -value~dry density relation

#### 4.3.3 Strain level-dependency of Young's modulus

Figure 4.5 shows the strain level-dependency of tangent Young's modulus  $E_{tan}$  obtained in  $q \sim \epsilon_a$  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, the field test results of the past researches revealed that the relationship between the  $K_{P,FWD}$ -value and  $K_{30}$ -value calculated by the plate load test for granular soil ground is

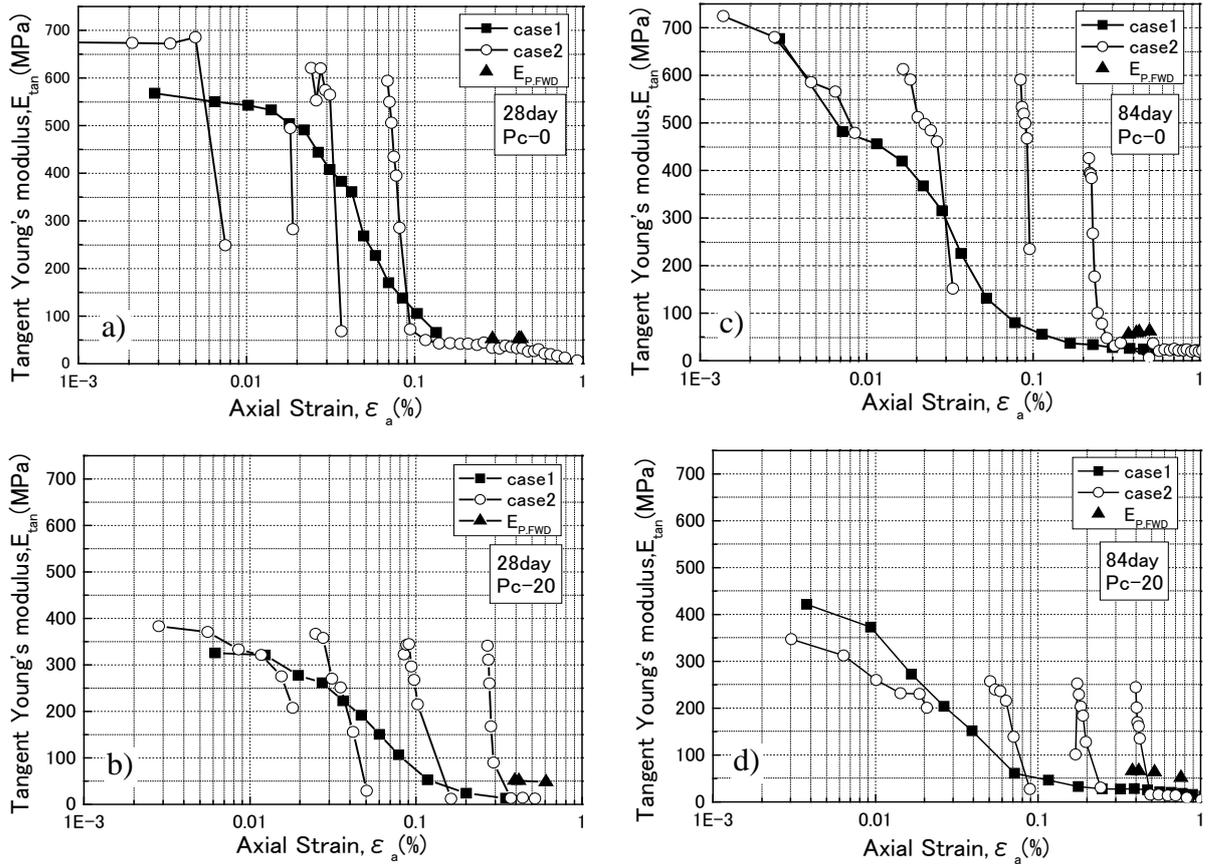


Figure 4.5  $E_{P,FWD}$  and  $E_{tan} \sim \log \varepsilon_a$  relations

2:1 (JSCE ed., 2002; Kohata et al., 2007). 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  $K_{P,FWD}$ -value.

#### 4.4 SUMMARY

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  $K_{PFWD}$ -value obtained from in-situ tests (portable FWD tests).

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