

## IN-SOIL STIFFNESS OF NON-WOVEN GEOTEXTILE

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**Abstract:** A method for determining the stiffness of geotextile confined in soil is proposed, which interprets the stiffness of geotextile by combining small scale direct shear test and large scale pullout test results. The main idea of the method is to obtain the axial tensile force and tensile strain distribution in geotextile by considering the effect of soil/geotextile interface resistance. The method was successfully applied to determine the stiffness of a non-woven geotextile confined in dense sand. For the case investigated, it shows that in-soil stiffness is much higher than that of in-air case, especially, for tensile strain less than 3% (corresponding to working state of reinforced earth structure), the in-soil stiffness is about 2 to 3 times of in-air data. For determining the design stiffness of geotextile, further research on creep behavior of geotextile is needed.

### INTRODUCTION

Non-woven geotextiles are widely used in geotechnical engineering as reinforcement materials for embankment construction over soft foundation. When considering the strain compatibility, the stiffness of reinforcement is a very important design parameter for a reinforced earth structure because it controls available tensile force. However, due to the non-woven structure, the stiffness of non-woven geotextile is a function of confining pressure and the soil/geotextile interaction. It is generally agreed that the stiffness of the non-woven geotextile will increase under confinement because the increase of friction resistance between fibers and soil/geotextile interaction. McGown et al <sup>(1)</sup> conducted the tension test of geotextile confined in soil, and reported that the in-soil stiffness is much higher than in-air one. However, it seems that the interface resistance between soil and geotextile had not been properly taken into account for interpreting the test results. Palmeira et al <sup>(2)</sup> did the similar test for geotextile confined in soil. Test with a lubrication layer at soil/geotextile interface was also conducted. As pointed out by Palmeira et al, even with lubrication layer, the zero friction between soil and geotextile could not be achieved. Therefore, the data reported also do not represent the true in-soil stiffness of geotextile because during the test the resistance from geotextile itself and from soil/geotextile interface was not separated. For measuring the in-soil stiffness of geotextile, an idea device is that it can apply the same confinement as soil to geotextile, and at the same time, provide shear free condition between geotextile and confining system. At present, this kind of device is not available, and it implies that directly measuring the in-soil stiffness of geotextile is very difficult.

In the case that friction between soil and geotextile can not be eliminated during laboratory test, if (1) the axial force distribution in the geotextile and (2) the corresponding tensile strain variation along the geotextile can be obtained, the in-soil stiffness of geotextile can be easily calculated. In this study, the large scale pullout test and small scale direct shear test (as an element test) are combined to obtain the axial force and tensile strain distribution along geotextile during pullout test. This paper presents the test method and the results for a non-woven geotextile embedded in sand. The implication of the test results on practical application is also discussed.

## METHOD PROPOSED

As just mentioned, the basic idea is to first obtain the axial tensile force and corresponding tensile strain distributions in geotextile using pullout and interface direct shear test results, and then compute the tensile strain and axial force relationship. The methodology used for interpreting the test results is illustrated in Fig. 1.

(1) Tensile strain distribution along geotextile. In this study, the displacement along the geotextile is measured by inextensible wire-LVDT systems during pullout test. If assuming that the displacement variation between two adjacent measurement points is linear, an average tensile strain can be calculated.

(2) Axial tensile force in geotextile. It is assumed that in pullout test, the relative displacement between soil and geotextile is equal to the measured displacement of geotextile. The soil/geotextile interface shear stress/displacement relationship is obtained by small scale direct shear test (insert figure in Fig. 1 (b)). With measured geotextile displacement, the corresponding shear stress can be read from shear stress/displacement relationship. Then, the axial force in geotextile for a given point, can be expressed as:

$$F_i = F_0 - \sum_{i=1}^n 2A_i \tau_i$$

Where  $F_0$  is total applied pullout force,  $F_i$  is the axial force at point  $i$ ,  $A_i$  is the area of  $i$ th interval, and  $\tau_i$  is the average shear stress in  $i$ th interval (Fig. 1 (c)).

With known tensile strain and axial force distribution, the in-soil stiffness of the geotextile can be easily computed. It can be noticed that during pullout test, the tensile strain as well as axial force along the sample is varied. Instead of a continuous curve, for a given total pullout force, several points in tensile strain/axial force plot can be obtained.

For comparison, the in-air tension test of geotextile was also conducted. Both without any restriction to necking, a phenomenon that the sample reduces the width with the increase of tensile strain, and under plane strain condition (without necking) were conducted. The reason for conducting tension test under plane strain condition is that during pullout test due to confinement of soil, the geotextile almost did not show necking. The detailed test program as well as the test results will be described in following section.

## TEST PROGRAM AND RESULTS

First the material used in the test will be explained, followed by the discussion of three type test, namely, direct shear test, pullout test and in-air tension test, and corresponding results.

### Material Used

Soil used was a river sand. The sand was air dried first, then passed the 2 mm sieve to eliminate the larger particles because for direct shear test, the sample size is small. The grain size distribution of the sand is shown in Fig. 2. The average particle size,  $D_{50}$ , is 0.7 mm and coefficient of uniformity,

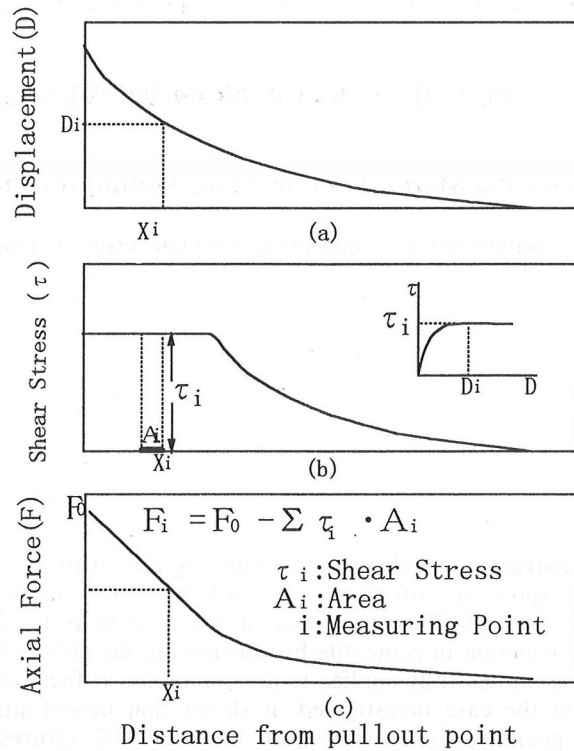


Fig. 1 The method of getting axial tensile force in geotextile

$C_u$ , is 2.25. The maximum void ratio is 1.02 and minimum one is 0.56. Two relative density, 50% (loose) and 80% (dense), were considered in the test.

The geotextile used is a non-woven polypropylene material with a unit weight of 200 g/m<sup>2</sup> and thickness of 2 mm. The tension strength provided by manufacture is 500 N per 50 mm width.

### Direct Shear Test

A direct shear device has been modified to test the soil/geotextile interface behavior. The test set-up is illustrated in Fig. 3. The lower shear box has a diameter of 60 mm and contains 10 mm thick sand. The upper shear box has been replaced by a rough plate with geotextile fixed on it. The geotextile was fixed on four sides of the plate and in addition, glue was applied between geotextile and plate to prevent relative movement between geotextile and the plate. It can be noticed from Fig. 3 that the sand in lower box was set slightly higher than surrounding plate (about 0.5 mm) to avoid the friction between upper and lower plate. The test was conducted under displacement control with constant vertical pressure. The test conditions are summarized in Table 1.

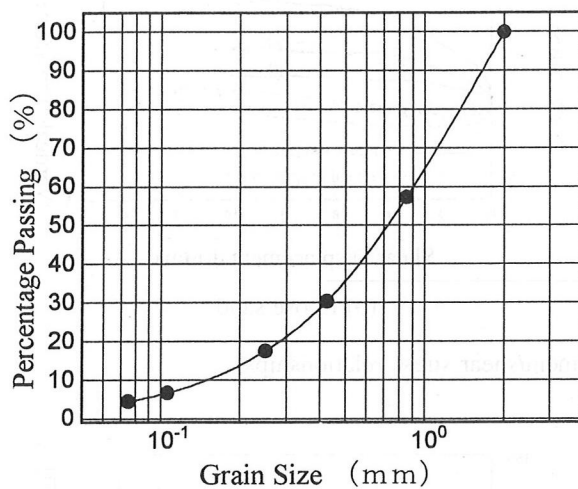


Fig. 2 Grain size distribution

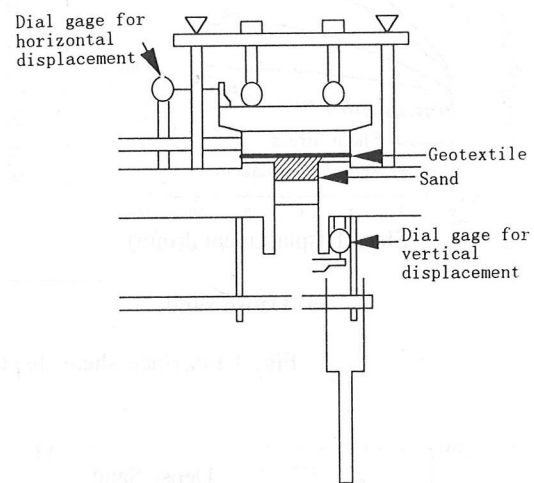


Fig. 3 Set-up of direct shear test

Table 1 Summary of sand/geotextile interface direct shear test

Case	No. of Test	Sand Condition	Vertical Pressure kPa	Displacement Rate (mm/min.)
1	4	Dense	30,60,90,120	0.25
2	3	Loose	30,60,90	0.25

Figures 4 (a) and (b) show the interface shear displacement/shear stress relationship for dense and loose sand cases, respectively. For comparison the shear displacement/shear stress curves for sand is given in Figs. 5 (a) and (b). It can be seen that the interface strength is mobilized by a displacement of about 5 mm which is larger than that for sand itself (about 3 mm). This is because that the re-orientation of geotextile fabric needs larger displacement. Also, for both dense and loose cases, the softening phenomenon was not observed at the interface. It is possibly due to that the shear surface was controlled on a leveled plate where no sand particle rolling over particles occurred. While dense sand shows significant softening behavior (Fig. 5(a)). The interface friction angle is 39.8 and 32.7 degrees for dense and loose conditions, respectively, and is about 3/4 and 9/10 of corresponding internal friction angle of sand.

### Pullout Test

The test was conducted in a large scale pullout box (inner dimension of 1.5 m in length by 0.6 m in width by 0.4 m in height). The test conditions are summarized in Table 2. During pullout test, the

length of geotextile in tension is affected by the density of sand as well as total pullout force. For the geotextile tested, before failure the length in tension is about 100 mm to 300 mm. Using 1 mm/min. pullout rate yields an average strain rate of about 0.7%/min. The displacement along the geotextile is measured by wire-LVDT system, i.e. one end of an inextensible wire is fixed on the geotextile, and another end is connected to a LVDT at outside of the pullout box. The wire was put into a 2 mm diameter plastic tube to prevent the friction resistance between wire and sand. The measuring interval was 50 mm at close to clamp position and 100 mm after 200 mm away from the clamp. Although care was taken to layout the geotextile, for loose sand case, deformation induced by applied vertical pressure had an influence on test results and this point will be discussed further for interpreting the in-soil stiffness of geotextile.

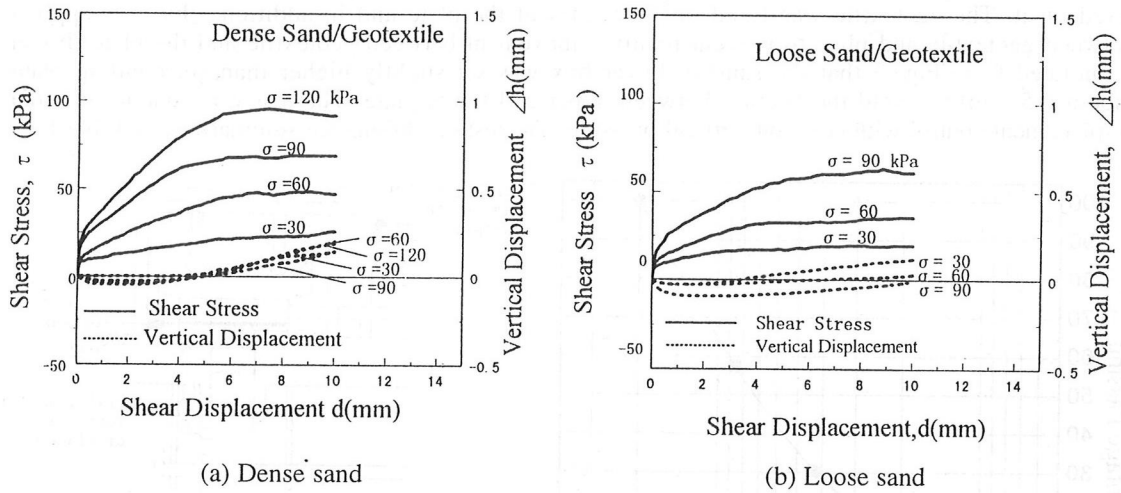


Fig. 4 Interface shear displacement/shear stress relationships

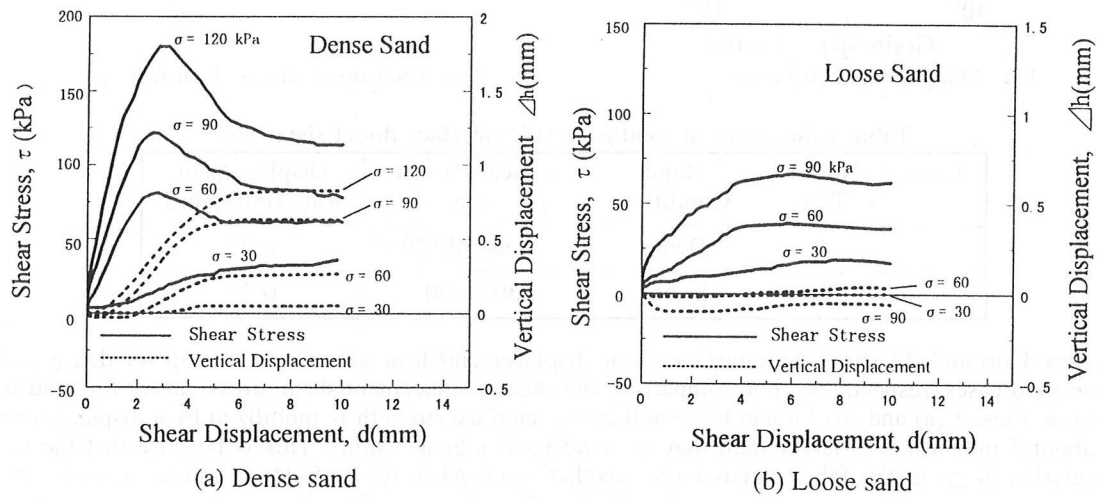


Fig. 5 Shear displacement/shear stress relationships of sand

Table 2 Summary of pullout test conditions

Case	No. of Test	Sand Condition	Size of Geotextile	Vertical Pressure kPa	Pullout Rate (mm/min.)
1	4	Dense	0.36×0.72 m	30,60,90,120	1
2	2	Loose	0.36×0.72 m	30,60	1

The pullout displacement distribution along geotextile is shown in Figs. 6 and 7 for dense and loose sand cases, respectively. These curves and the curves in Figs. 4 will be combined to get the soil/geotextile interface shear stress distribution. The points can be made from Figs. 6 and 7 are: (1) the tensile strain in geotextile is significantly non-uniform, and (2) the higher the vertical pressure, the denser the sand, the shorter the geotextile length in tension. After pullout test, it has been observed by excavating the sand that the geotextile almost did not show necking due to the confinement from soil,

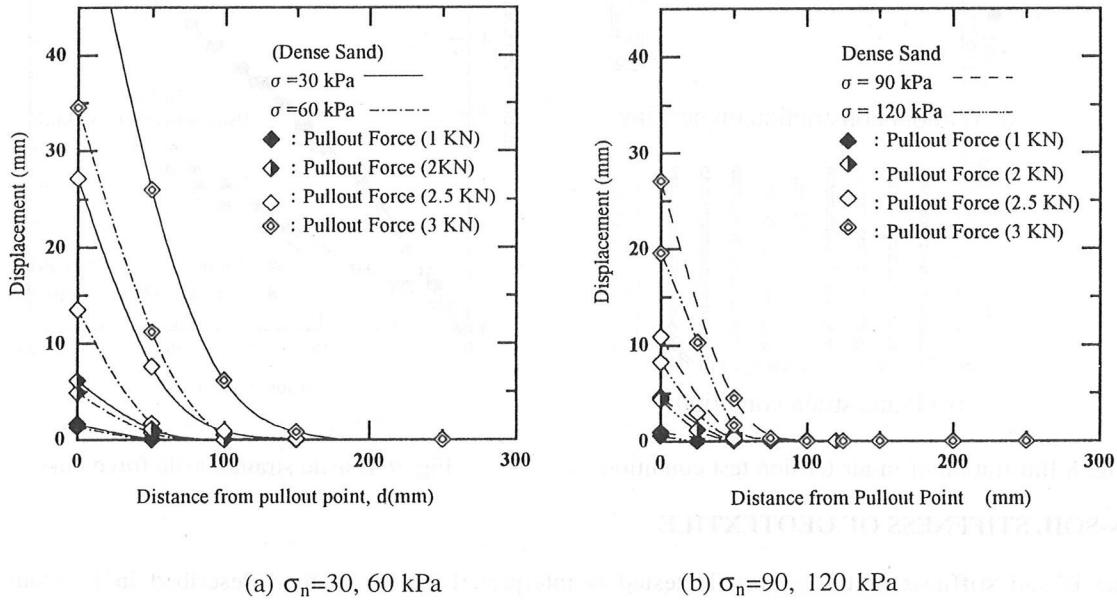


Fig. 6 Pullout displacement distribution along geotextile with dense sand

### Tension Test for Geotextile

The in-air tension test was also conducted by using pullout test equipment with adding a clamp at back of the box. The sample used had a width of 0.36 m and length of 0.72 m. The strain rate was 0.7%/min. and 1.4%/min., which is comparable with pullout test condition. In order to avoid the non-uniformity near the clamp, the strain was measured at middle part of the sample by wire-LVDT system. For the plane strain tension test, the necking was restricted by wooden bar and small screw system<sup>(3)</sup>. One set of the restriction system consists of two pieces of 380 mm in length, 20 mm in width and 2 mm in thickness wooden bar, which was placed on both side of geotextile and connected by small screws which punches through the geotextile. Totally 8 set were used with an interval of 90 mm. Figure 8 illustrates the in-air tension test condition and the necking restriction system.

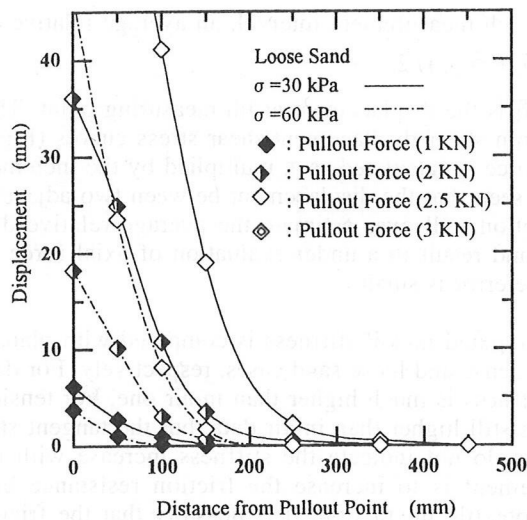


Fig. 7 Pullout displacement distribution along geotextile with loose sand



The tensile strain versus axial tensile force curves are presented in Fig. 9. It clearly indicates that the plane strain case results in a higher stiffness and less strain rate dependence than without restriction case. The plane strain tension curve will be used to compare with in-soil data.

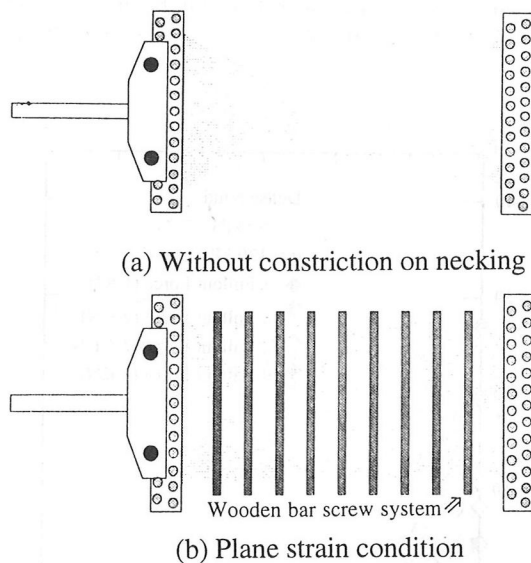


Fig. 8 Illustration of in-air tension test condition

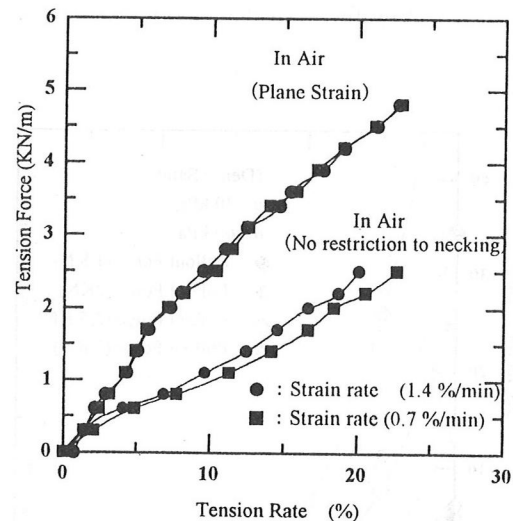


Fig. 9 Tensile strain/tensile force curves

### IN-SOIL STIFFNESS OF GEOTEXTILE

The in-soil stiffness of the geotextile tested is interpreted by the method described in previous section. In actual calculation, following factors are considered.

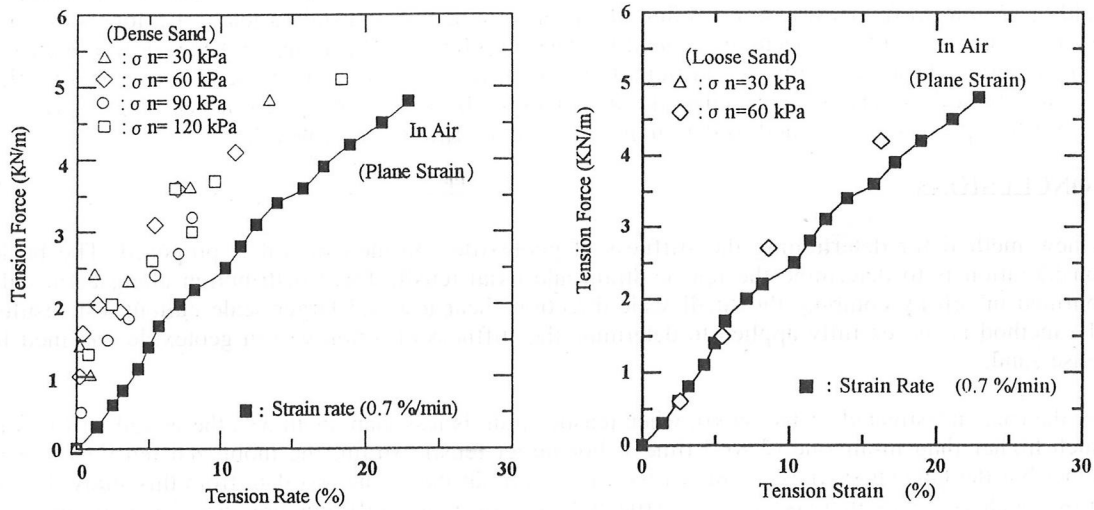
(1) The coordinate of each measuring point is up-dated to consider the increase of interface shear area between two adjacent measuring points. For a point adjacent to clamp, with increase of pullout displacement, it will be pulled out from soil. This factor is also considered in calculating the interface shear force.

(2) In each measurement interval, an average relative displacement  $\delta_{av}$  is calculated as:

$$\delta_{av} = (\delta_i + \delta_{i+1}) / 2$$

where  $\delta_i$  is the displacement at  $i$ th measuring point. Then the incremental interface shear stress,  $\tau_i$ , is read from shear displacement/shear stress curves (Fig. 4) corresponding to  $\delta_{av}$ , and the incremental shear force is calculated as  $\tau_i$  multiplied by the incremental interface area,  $2A_i$ . From Figs. 6 and 7, it can be seen that the displacement between two adjacent measuring points is not linear and the linear assumption will over estimate the average relative displacement and therefore, the interface shear force, and result in a under-evaluation of axial force in geotextile. However, with an interval of 50 mm, the error is small.

The computed in-soil stiffness is compared with plane strain in-air tension curve in Figs. 10 (a) and (b) for dense and loose sand cases, respectively. For dense case, at small strain (less than 3%), the in-soil stiffness is much higher than in-air one. For tension strain larger than 3%, the mobilized tension force is still higher than in-air data, but the tangent stiffness is almost the same as in-air case. Also, the data do not indicate the stiffness increase with increase of confining pressure. The effects of confinement is to increase the friction resistance between fibers which form the geotextile and soil/geotextile interaction. It is possibly that the friction between fibers is limited and not increase with confining pressure significantly. Also, it can be considered that after certain tensile strain, the amount of relative movement between fibers might be reduced. For a given sand state, the increase of confining pressure seems mainly increase the interface shear stress. For loose sand case, the in-soil data almost laid on the in-air curve (Fig. 10(b)), and the possible reasons are as follows.



(a) Dense sand

(b) Loose sand

Fig. 10 Comparison of in-soil stiffness with in-air one

(1) Increase the density of loose sand under vertical pressure. In small scale direct shear test, after apply vertical pressure, the density of sand might be increased because the sample thickness is only 10 mm. Then the interface shear stress will be over-estimated. This reasoning is partially supported by the data in Fig. 4(b), where the interface strength increase for vertical pressure increased from 60 to 90 kPa is much larger than that of from 30 to 60 kPa, which implies the density of sample might be increased due to higher vertical pressure. When the interface shear stress is over estimated, the axial force in geotextile will be under-evaluated.

(2) Non-uniform vertical stress distribution on soil/geotextile interface during pullout test. To eliminate the front wall effect of pullout box, a 200 mm sleeve with 50 mm slot opening is fixed on the front wall. If the soil is deformable, even with a uniform vertical pressure applied at top, the stress distribution on geotextile will be non-uniform. The pressure on the sleeve will be much high than average and the pressure on geotextile adjacent to sleeve will be lower than average. For dense case, the sand was well compacted and for vertical pressure tested, the deformation of the sand might be very limited and not had significant effect on vertical pressure distribution. Loose sand might be deformed under pressure and which will reduce the vertical pressure on the geotextile near the sleeve. In the analysis, the applied average pressure was used, and which means the over estimation of interface shear stress again. It can be said that the data reported for loose sand case may not represent the actual situation. Fortunately, for a reinforced earth structure, normally the soil is well compacted (dense case), and the method proposed in this study is useful.

From above comparison, following comments can be made regarding the design stiffness of geotextile.

(1) The stiffness of geotextile confined in soil is much higher than that determined by in-air tension test. Considering the strain compatibility, for a structure over clay foundation, the mobilized tensile strain before structure failure will be less than 3 to 5% (4)(5). In this strain range, for the case investigated, the in-soil stiffness is 2 to 3 times of in-air one under plane strain condition. However, it is not as high as the data reported in the literature which might not properly take into account the effect of interface shear stress. The stiffness increase also implies the increase of mobilized tensile force in geotextile. The test data from this study indicate that if using a limiting strain of 5%, the corresponding tensile force is about 2.7 kN/m, which is about 27% of the tension strength provided by manufacture.

(2) The tests were conducted for a strain rate of 0.7 - 1.4%/min., it is much lower than the quality control test conducted by manufacture (about 20 - 50%/min), but may be higher than tension rate in field condition. In field working condition, the geotextile needs to sustain a load for a long time and creep is most possibly to occur in geotextile. The mobilized stiffness in field may lower than the values obtained in laboratory condition. Further research on the creep behavior of geotextile confined in soil is needed. Especially, the information about the field performance of geotextile is needed for specifying a method to determine the design stiffness of geotextile.

## CONCLUSIONS

A new method for determining the stiffness of geotextile confined in soil is proposed. The basic consideration is to determine the tensile strain and axial tensile force distribution along geotextile confined in soil by combing the small scale direction shear test and larger scale pullout test results. The method is successfully applied to determine the stiffness of a non-woven geotextile confined in dense sand.

For the case investigated (dense sand), when tensile strain is less than about 3%, the in-soil stiffness is much higher than in-air one (2 to 3 times). For larger tensile strain, the mobilized tensile force is higher but the tangent stiffness is almost the same as in-air case. The test data from this study do not show much stiffness increase of geotextile with increase of confining pressure for a given sand condition.

For specifying a way of determining a design stiffness of geotextile, further investigation on in-soil creep behavior of geotextile is needed. On this aspect, the field performance data is desirable.

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