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Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Compressive shear tests of compacted soils wrapped by geosynthetics

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ABSTRACT: This paper discusses the reinforcement effect arising from confining the dilatancy deformation of soils by geosynthetics. A series of compressive shear tests for compacted sandy soils specimens reinforced by geosynthetics is carried out. The major aim of tests is to quantitatively examine the geosynthetic-reinforcement effect arising from confining the dilative deformation of compacted soils during compressive shear. In the test, the initial degree of compaction is changed for each series of sandy soils specimens so that each series has different degree of dilatancy characteristics. Furthermore, a series of conventional elastic F.E. calculations is carried out to extract the effect of dilatancy characteristics of compacted soils on the reinforcement mechanism.

1 INTRODUCTION

This paper aims at discussing the reinforcement mechanism by geosynthetics. The attention is paid to confining effect by the geosynthetics under shearing. The confining effect is interpreted as the mechanical interaction such that the reinforcement works so as to prevent dilative deformation of compacted soils. The authors, in the past, tried to explain the geosynthetic-reinforcement mechanism throughout a series of finite element simulations for full scale in-situ model tests (Ohta, et al., 1997, Iizuka, et al., 2001), in which the soils were modeled as elasto-plastic materials considering dilatancy characteristics of soils (Ohta, et al., 1998, Hirata, et al., 1999). However, in order to heighten the usefulness of such a numerical simulation in the practical design work, the authors realized that the mechanical interaction between soils and reinforcement, that is, the reinforcement mechanism, should be more precisely understood from a viewpoint of mechanical characteristics of soils itself. Then, a series of uniaxial compressive shear tests for compacted sandy soil specimens reinforced by geosynthetics is carried out. Compacted soil specimens (30 cm in diameter and 40 cm in height) are wrapped by geosynthetics. The specimens are laid on the uniaxial loading apparatus and are subjected to compressive shear. The extensive stresses working to the geosynthetics are also measured during shear. The major aim of tests is to quantitatively examine the geosynthetic-reinforcement effect arising from confining the deformation of compacted soils during compressive shear. In the test, the initial degree of compaction is varied for each series of sandy soils specimens so that each series has different degree of deformation characteristics.

2 EXPERIMENTS

2.1 *Materials and test preparation*

The soils used in experiment is Omma sand. The specific gravity of soil particle is 2.74, the grain size distribution is 2% of gravel fraction (2 to 75 mm), 80% of sand fraction (75 *m*m to 2 mm), 11% of silt fraction (5 *m*m to 75 *m*m) and 7 % of clay fraction (less than 5 *m*m). The uniformity coefficient is 21.8 and the maximum grain size is 9.5 mm. The soils of which water content are adjusted to a prescribed value are compacted up to a designated degree of compaction with being wrapped by geosynthetics as shown in Fig.1.

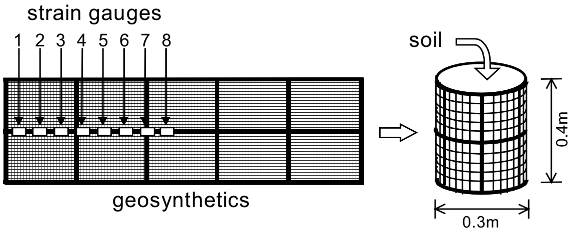


Fig.1 preparation of test specimens

Table 1 prepared specimens

test No	degree of compaction (the number of compaction)x(layers)	water content w (%)	dry density ρ_d (g/cm^3)
2	50x10	18.09	1.526
3	50x10	17.55	1.562
4	50x10	17.34	1.599
5	50x10	17.09	1.539
6	30x6	16.59	1.427
7	30x6	16.98	1.426
8	25x5	16.77	1.454
9	50x10	16.49	1.550

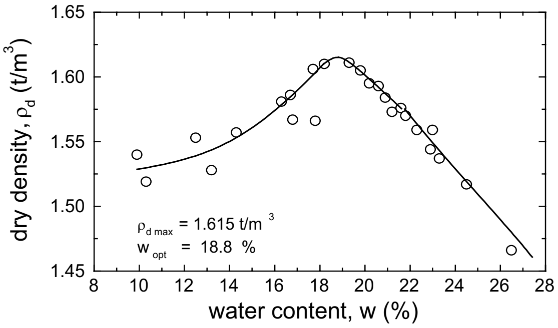


Fig.2 compaction curve of Omma sand

Table 1 summarizes thus prepared compacted soil specimens wrapped by geosynthetics. The compaction curve of Omma sand is given in Fig.2. Some specimens having different degree of compaction (tests 6 to 8 in Table 1) are also prepared to investigate how the dilatancy characteristics of compacted soils influences the reinforcement effect. Herein, in order to measure the extension forces working to geosynthetics, strain gauges are tightly pasted on the geosynthetics as shown in Fig.1. Fig.3 shows the stress-strain relation of geosynthetic material used in the experiment, obtained from uniaxial extension test. The extension strength is 93.9 kN/m, the cross sectional area is $3.2\text{x}10^{-4}$ m^2 and Young's modulus is $4.86\text{x}10^6$ kN/m^2.

2.2 *Shear characteristics of soils used in experiment*

Mechanical properties of soils used in the experiment, that is, compressibility and shear characteristics, were investigated beforehand. A series of shear box tests was carried out for both completely disturbed remolded (loose) samples and compacted undisturbed (dense) samples. Specimen was set in the shear box (6.0 cm in diameter and 2.0 cm in height) and sheared under the condition of constant volume after being consolidated by a designated vertical pressure, *s¢*. Compressibility of remolded (loose) samples is shown in Fig.4 (a) and the effective stress paths under shearing are depicted in Fig.4 (b). The initial water content of each sample is denoted in the figure. Likewise, mechanical properties of compacted undisturbed (dense) samples are shown in Figs.5 (a) and (b) of compressibility and shear characteristics, respectively. When comparing them, it is found that the disturbed samples behave like normally consolidated clays and, on the contrary to it, the compacted undisturbed samples behave like over-consolidated clays.

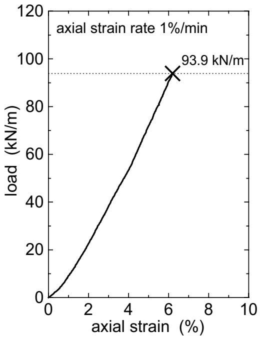
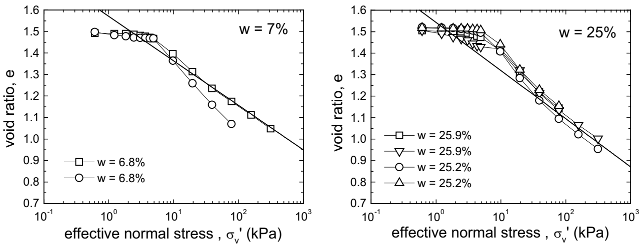


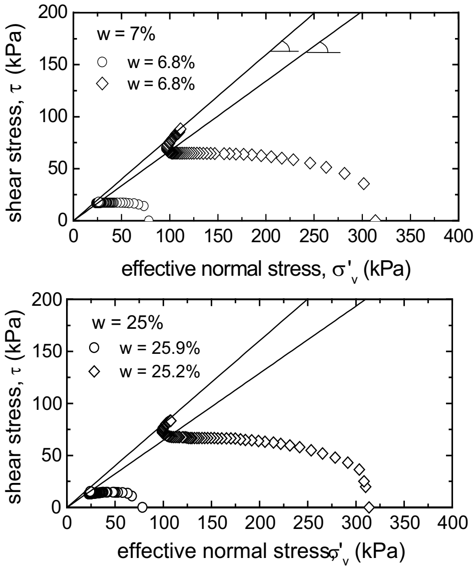
Fig.3 stress-strain relation of geosynthetics

2.3 *Compressive shear test performed*

Omma sandy soil of which water content was adjusted to a prescribed value as summarized in Table 1 is uniformly compacted by rammer of 3.5 kg. Every unit of soils for compaction is 40 to 50 mm in thickness. Thus compacted soil specimen (30 cm in diameter and 40cm in height) wrapped by geosynthetics is laid on the uniaxial loading apparatus as shown in Fig.6 and is subjected to compressive shear. Photos 1 indicate snap shots during the test. In experiment, not only the vertical load applied to the specimen and the vertical displacement but also extensive stresses working to the geosynthetics are measured by strain gauges pasted on the geosynthetics during shear. Note that the compressive shear was carried out at the sufficiently slow rate in order to satisfy the condition that the volume of specimen is changeable (drain condition).

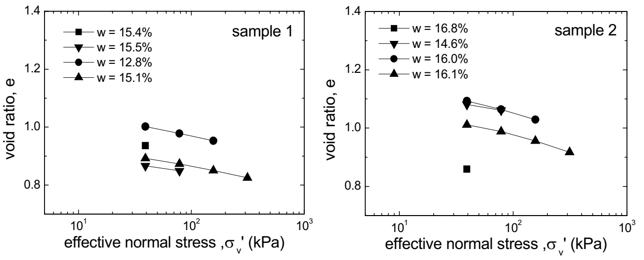


(a) compression properties of disturbed (remolded) specimens

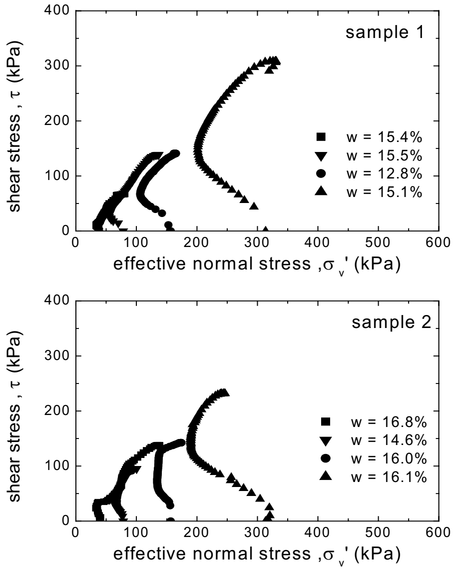


(b) shear properties of disturbed (remolded) specimens

Fig.4 constant volume shear box test for disturbed sample



(a) compression properties of undisturbed compacted specimens



(b) shear properties of undisturbed compacted specimens

Fig. 5 constant volume shear box test for undisturbed sample

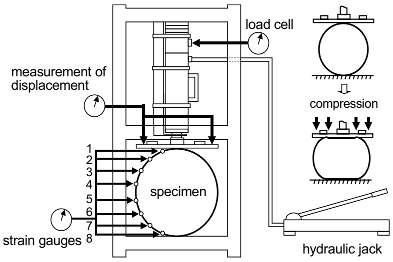


Fig.6 compressive shear

3 EXPERIMENTAL RESULTS

3.1 *Load and displacement*

The load and displacement relations obtained from uniaxial compressive tests are shown in Fig. 7. Relatively higher compacted soil specimens indicated by black symbols (■, ▲, ● and ▼) obviously show higher rigidity than lower compacted soil specimens by white symbols (□, ○ and △). Fig.8 shows extension forces working to the geosynthetics at locations of No.2 and No.4 (see, Fig.6). It can be seen that the extension force working to the geosynthetics gets higher as the initial degree of compaction of soils is higher. Namely, the geosynthetics work more remarkably so as to retrain the deformation of soils, when the soils have higher degree of compaction. It would be concluded that the reinforcement effect by geosynthetics is mobilized relating to the dilatancy characteristics of soils, since well-compacted soils tend to more dilate during shear as can be recognized from Fig.5. Fig.9 shows the distribution of extension force working to the geosynthetics along the circumference of the specimens, when the compressive displacement reaches each of 10, 20, L , 80 cm. It can be seen that the distribution of extension force along the circumference of specimen is almost uniform regardless of the location. Herein, the case of higher initial degree of compaction is represented by test 5 and the case of lower one by test 6, respectively.

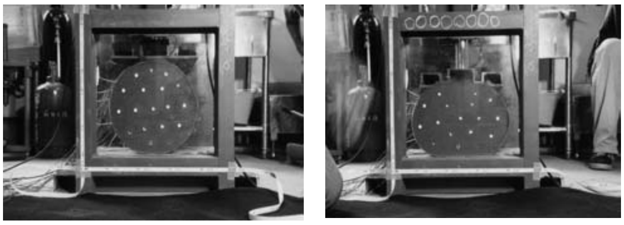
3.2 *Deformation of specimen*

The change of circumference length and the change of cross sectional area during compression are indicated in Fig.10. The circumference length of specimen gradually increases regardless of initial degree of compaction. The cross sectional area of specimen decreases regardless of initial degree of compaction in all of tests.

4 ELASTIC FINITE ELEMENT ANALYSIS

4.1 *Condition of analysis*

The compressive shear tests are analysed using a simple/ordinary finite element technique. The soils are assumed to be linearly elastic materials that do not have non-linear and irreversible deformation characteristics such as dilatancy characteristics and then, examined is whether the mechanical behaviors of compacted soils reinforced by geosynthetics can be explained or not. The finite element mesh shown in Fig. 11 is employed in the computation. The geosynthetics are modeled by linear elastic bar elements, of which properties are, the young's modulus; $E=4.86\times10^6$ kN/m^2, the cross sectional area; $A=3.20\times10^{-4}$ m^2 and the compression strength $N_f=93.9$ kN/m. In the computation, the bar elements are treated as no resistance materials against axial compression.



(a) initial figure of test (b) displacement of 80 mm

Photo 1. compressive shear test (test 6)

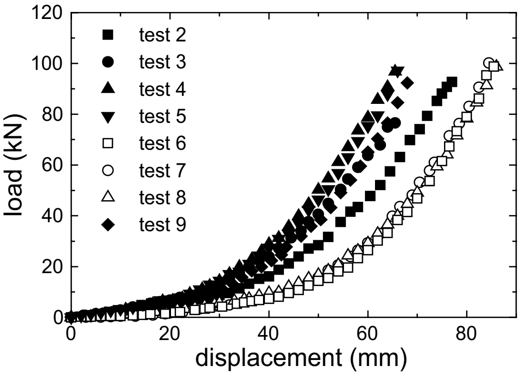


Fig.7 load and displacement relation

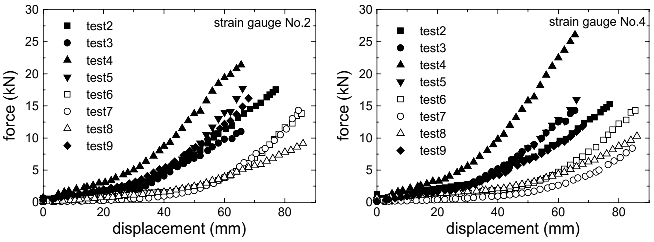


Fig.8 extension force working to geosynthetics with displacement

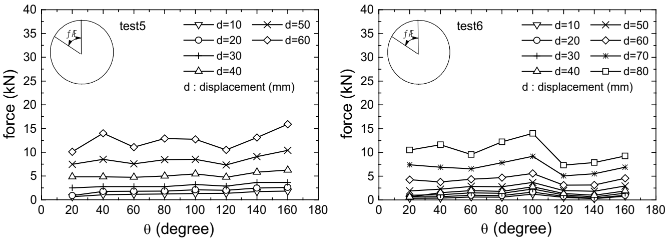
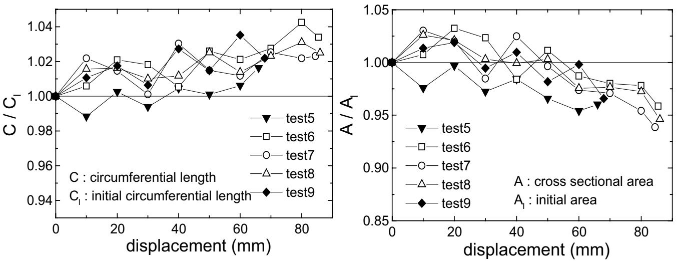


Fig.9 extension forces along circumference of specimen



(a) change of circumference length (b) change of cross sectional area

Fig.10 change of shape of specimen

4.2 *Results of analysis*

Fig.12 compares load and displacement relation obtained from the experiments with computed ones, in which three values are chosen for the young's modulus of soils as shown in the figure but the poisson's ratio is kept to be 0.33 in all cases of computations. The case of E=6000 kPa seems to explain the load and displacement relation of test 5 (see, Table 2) best of all. Next, investigated are the change of circumference length and the change of cross sectional area of specimen. Fig.13 shows the change of circumference length of the specimen comparing with experimental results. The young's modulus of compacted soils is kept to be 6000 kPa, but the poisson's ratio is varied from 0.2 to 0.499. Only the case of ν =0.499 can explain the experimental fact (test 5). Fig.14 shows the change of cross sectional area of the specimen. All the cases describe the tendency that the experiments show (decrease of cross sectional area with loading). However, taking a look at experimental results more closely (see, Fig.10), in the early stage of compressive loading, the increase of cross sectional area is observed in all cases except for the case of test 5. No computed result can explain it. Thus, throughout linearly elastic finite element simulations, it is found that the experimental facts (changes of circumference length and cross sectional area of the specimen) cannot be explained without assumption of almost incompressibility for compacted soils (ν =0.499). This means that the geosynthetics work so as to restrain the volumetric change of compacted soils, although the compacted soils strongly tend to dilate during shearing as shown in Fig.5 (b).

5 CONCLUDING REMARKS

This paper presents uniaxial compression shear test of cylindrical compacted soil specimens wrapped by geosynthetics. The major aim of the test is to investigate the reinforcement mechanism by geosynthetics. Particularly, the confining effect is discussed. First, the laboratory tests (shear box tests under constant volume) were carried out in order to grasp the mechanical properties of compacted soils beforehand. The compressibility and dilatancy characteristics of compacted soils were quantitatively examined and the similarity in mechanical behaviors between the compacted sandy soils and over-consolidated clays was pointed out. After that, the uniaxial compression shear tests of cylindrical compacted soil specimens wrapped by geosynthetics were performed. And finally the linearly elastic finite element simulations for the tests were carried out. It is found that the experimental facts cannot be explained without assumption of almost incompressibility for compacted soils. This means that the geosynthetics work so as to restrain the volumetric change of compacted soils, although the compacted soils strongly tend to dilate during shearing. This is confining effect by geosynthetics in the reinforcement mechanism.

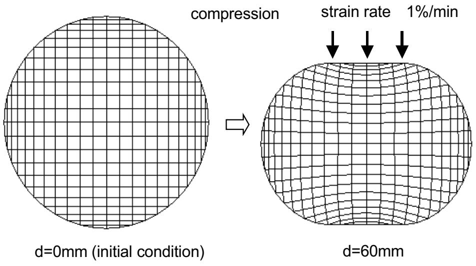


Fig.11 finite element mesh employed

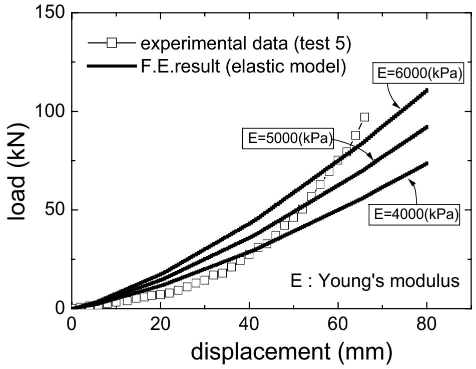


Fig.12 load and displacement relation (comparison with experimental results)

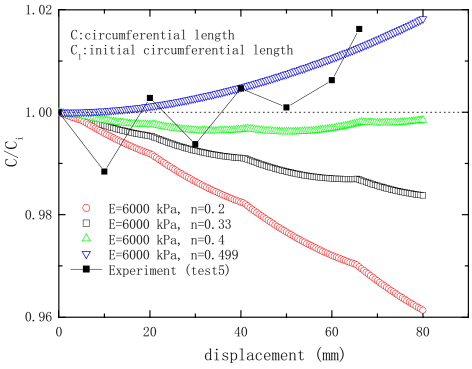


Fig.13 change of circumference length (comparison with experimental results)

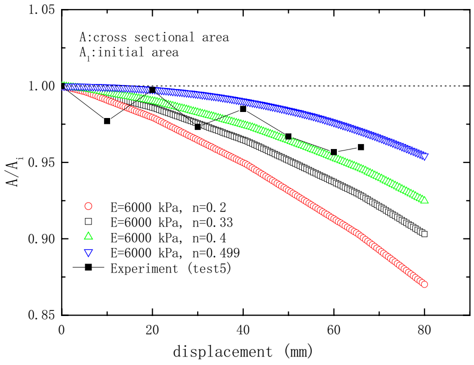


Fig.14 change of cross sectional area (comparison with experimental results)

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