International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
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Functions and effects of reinforcing materials in earth reinforcement

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ABSTRACT: When reinforcing materials are deposited in embankment or slope, not only the deformation conditions of soil but also the direction of reinforcing materials in soil influence the functions and effects of reinforcing materials. A new versatile shear test apparatus, which is developed in order to examine the reinforcing mechanism in soil, can demonstrate various types of strain conditions. In this paper, the usefulness and properties of this test apparatus are examined, and the results of simple shear test for sand specimen reinforced with two types of reinforcing materials are described.

1 INTRODUCTION

It is very important to clarify the reinforcing functions, material properties of reinforcement and interaction mechanism between soil and reinforcing materials for both slope reinforced with grouted steel bar and embankment reinforced with metal strips or geotextiles (Hayashi 1985).
Besides, these data are needed for the purpose of establishing the design method of earth reinforcement. Many researchers have studied this subject (Jewell 1987, Tokue 1982), and it has become a common knowledge that the effects of the reinforcement in slope and embankment are influenced by the deformation conditions of soil and the direction of insert angle of reinforcing materials against slip surface.
In this paper, a new versatile shear test apparatus, whose specimen size is larger than that of the standard shear test apparatus, is developed in order to examine the reinforcing mechanism in sand. This apparatus can demonstrate various types of strain conditions such as uniform and nonuniform strain distributions.
The purpose of this paper is to examine the functions and effects of different types of reinforcing materials in sand using this new apparatus. Here, the effective insert direction of reinforcing materials in soil and the reinforcing effects when the reinforcing materials are subjected to tensile and compressive forces are discussed using test results.

2 VERSATILE SHEAR TEST APPARATUS

2.1 Problems of using the standard direct shear test for reinforced soil

To examine the characteristics of reinforced soil, the test apparatus such as triaxial, torsional, direct shear and model test are generally used. Although direct shear test apparatus is most often used for examining the influence of the direction of reinforcing materials on earth reinforcement, the following problems are often generated:

1. It has been indicated that the strain condition in the specimen is by no means uniform as shown in Fig.1, so the functions of reinforcements in such strain condition are complicated.
2. The reinforcing materials deposited plurally are not in the same deformation conditions.
3. Vertical stress by rigid board is not uniformly loaded on the specimen in the ordinary case, much more in the case of deposited reinforcing materials, where the stress distribution is very complex.

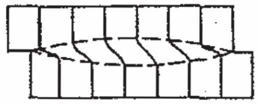


Fig.1 Deformation of specimen in direct shear test.

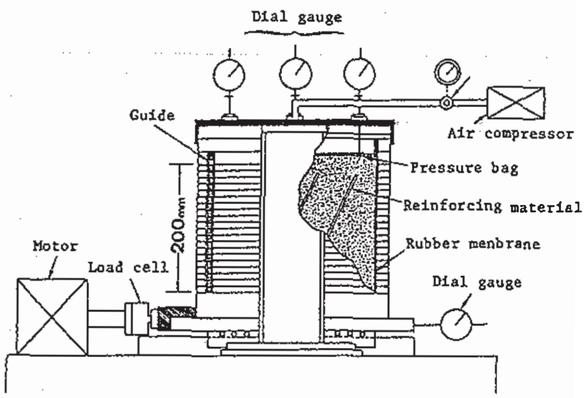


Fig.2 Versatile shear test apparatus.

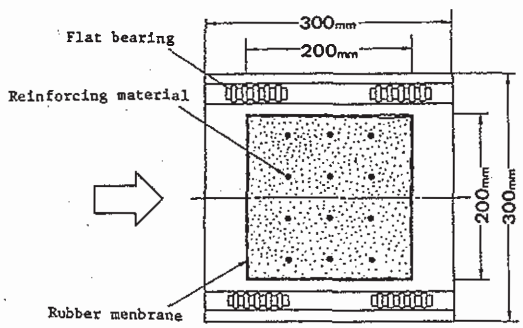


Fig.3 Plan of test apparatus.

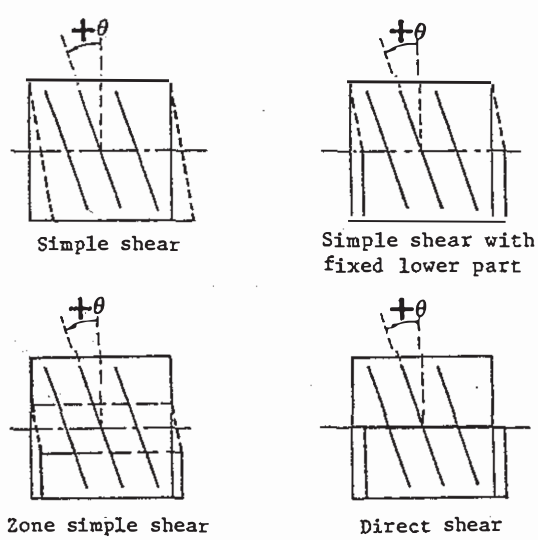


Fig.4 Shear patterns by test apparatus.

4. From the results of model test on reinforcing mechanism using soil bin with bar-type reinforcing materials, it is clarified that the inside reinforcing material is different from the outside one. Therefore more than nine reinforcing bars have to be deposited in the specimen.

2.2 New versatile shear test apparatus

A new versatile shear test apparatus shown in Fig. 2 is developed to overcome the problems described above. The shear box consists of twenty elements made from aluminum. The friction between elements is reduced by flat bearing as shown in Fig. 3, and each element is restrained by four guided pins and rods. The shear box is designed to make the shear deformation uniform. The size of specimen in this apparatus is 200x200x200mm, and the specimen is covered with latex rubber membrane of 0.3mm in thickness.

The top of shear box is fixed by rigid frames, and the shear stress is induced by applying displacement at the bottom. The vertical stress is given by air pressure through rubber pressure bag at the top of shear box.

This shear test apparatus can be demonstrated in several patterns of strain conditions as shown in Fig. 4 by substituting the frames at the top or bottom (or top and bottom) of shear box. This means that the shear box is partially fixed by the frames and induces uniform and nonuniform strain conditions.

3 REINFORCING MATERIALS AND TEST CONDITIONS

The reinforcing materials used in this test are of bar and plane types. The bar-type material is a phosphor bronze bar whose size is 180mm in length and 3mm in diameter. Sand particles are applied on the surface of this bar to develop the skin friction with sand. A group of 4x3 bars is deposited in the sand as shown in Fig. 3. As demonstrated in Fig. 5, the gauges are attached to two bars at the center in group, so that the axial force and the bending moment of these two bars can be measured. On the other hand, the rectangular plane-type material is SS-type polymer grid whose size is 170mmx150mm, and three sheets are deposited in the specimen. All attachments to this material are set up in the same way as in the bar-type material.

The tests are conducted by changing the

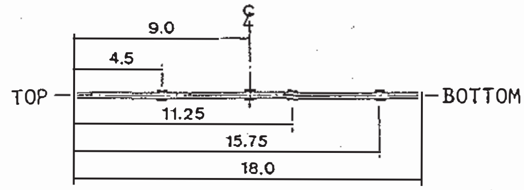


Fig.5 Position of attachment of strain gauge on reinforcing bar (phosphor bronze bar).

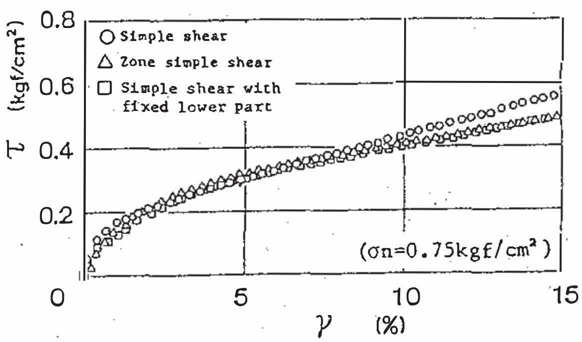


Fig.6 Stress - Strain relationship resulting from simple shear test, zone simple shear test and simple shear test with fixed lower part for unreinforced sand.

direction angle θ of the reinforcing materials from -20° to +20°.

The soil specimen is made of Toyoura Sand, whose properties are uniformity coefficient of 1.7, D_{50} of 0.18mm and specific gravity of 2.64. The specimen is prepared by multiple sieving pluviation method to keep the relative density of 82% constant.

In order to examine the usefulness and properties of this new apparatus, a series of shear tests of both reinforced and unreinforced sand specimens is performed.

4 UNREINFORCED SAND SIMPLE SHEAR TESTS

Figure 6 shows the shear stress-strain relationship of unreinforced sand specimens which are obtained from simple shear test, simple shear test with fixed lower part and zone simple shear test. Shear strain is defined as the ratio of the horizontal displacement of specimen against the height where simple shear deformation occurs. The stress-strain curves of these three tests are closed to each other until shear strain of 15%. The shear stress increases as shear strain increases. The clear peaks of the shear-strain curves do not appear until shear strain of 15%, but the shear stresses settle down at a definite value around shear strain of 30%, as shown in Fig. 7.

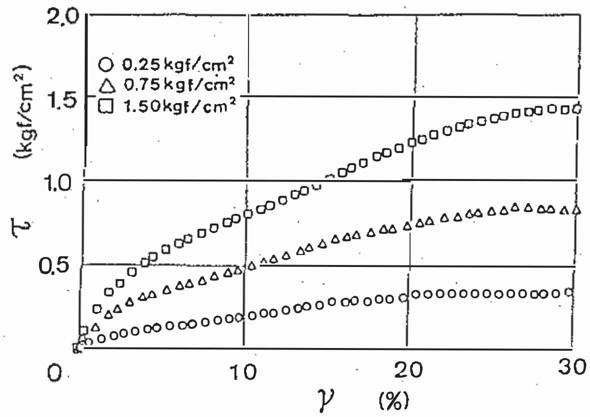


Fig.7 Stress - Strain relationship resulting from simple shear test with fixed lower part for unreinforced sand.

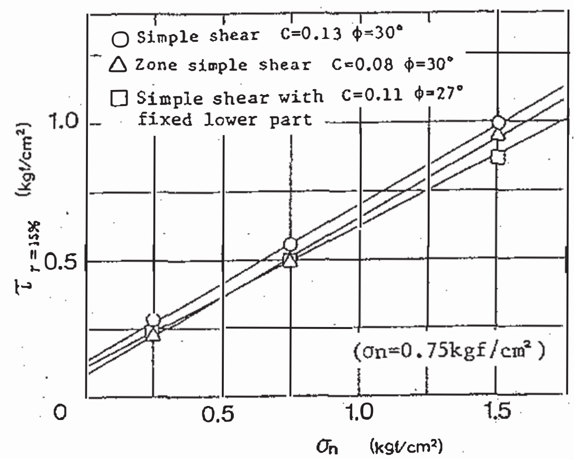
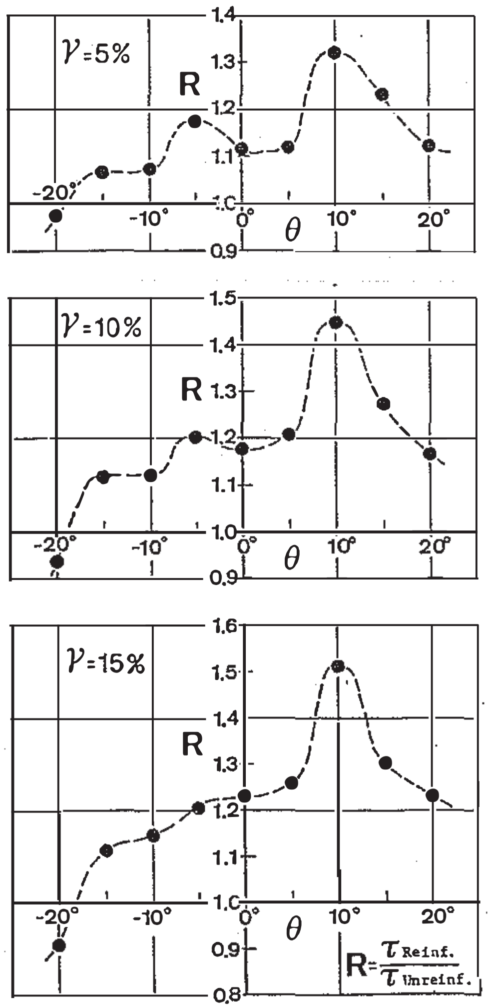


Fig.8 Shear stress - vertical stress relationship from simple shear test results for unreinforced sand.

Strength coefficients obtained from the results at shear strain of 30% in the lower-part-fixed simple shear test have an observed cohesion of 0.12kgf/cm² and an angle of shear resistance of 41°. This result almost agrees with that (c=0.11 kgf/cm², φ=43.7°) of the plane strain compression test.

Figure 8 shows the shear stress plotted against the vertical stress of three shear patterns for unreinforced sand at shear strain of 15%. Results of the three shear patterns have nearly equivalent observed cohesion and angle of shear resistance. These results show that the test apparatus can demonstrate the three types of shear tests with a conservative accuracy.



(σn=0.75kgf/cm²)

Fig.9 Reinforcement ratio (R) - direction of reinforcing material (θ) relationship from simple shear test results for reinforced sand (phosphor bronze bar).

5 REINFORCED SAND SIMPLE SHEAR TESTS

5.1 Reinforced by bar-type material

The simple shear tests of sand reinforced by using phosphor bronze bars are performed by changing the insert direction of reinforcing material, θ , from -20° to $+20^\circ$. Figure 9 shows the relationship between the reinforcing effect (reinforcement ratio : R) and the insert direction of reinforcing material, θ , at strain levels of γ=5, 10 and 15%. Here the new parameter called reinforcement ratio R is defined by the following formula.

$$R = \frac{\text{Shear stress of reinforced specimen: } \tau_{Reinf.}}{\text{Shear stress of unreinforced specimen: } \tau_{Unreinf.}}$$

At the angle of $\theta=-20^\circ$, this ratio R is less than 1.0 for any strain level, so that the reinforcing effect in this case is negligible. For the case of $\theta>-15^\circ$, the ratio R increases as the strain increases, and the direction of reinforcing material which gives the maximum reinforcing effect is about $+10^\circ$. As a whole, the more the angle becomes positive, the higher the reinforcing effect. Also, the increment of reinforcement ratio R, which is about 0.11 ~ 0.20 for the case of $\theta=0^\circ \sim +20^\circ$, is enormously large, while that increment for the case of $\theta=-15^\circ \sim -5^\circ$ is only about 0.02 ~ 0.05. Therefore, when using phosphor bronze bars as reinforcing material, it should be desposited at a positive value of θ .

Figure 10 shows the distributions of axial force of the reinforcing material and Mohr's strain circles at strain levels of 5, 10 and 15% when the reinforcing material is deposited at $\theta=-10^\circ$ and $+10^\circ$. In this figure, the reinforcing material at the position of dotted line moves to the position of solid line as shearing of specimen increases. In the case of $\theta=+10^\circ$, the distribution of the axial force appears in tension in all strain levels and becomes large as shearing increases. As described from the Mohr's strain circle, the reinforcing material is placed in tensile strain region even at small strain range (γ=5%). This means that the distribution of axial force may be explained from this point. On the other hand, when the insert direction of reinforcing material is $\theta=-10^\circ$, the distribution of axial force is in compression in the strain level of γ=5%, and it becomes a tensile force as shearing increases. It is considered that at the beginning of shearing, the reinforcing material is placed in the range of compressive strain in Mohr's strain circle, and by extending the tensile strain range, this material moves gradually into the tensile strain region. In other words, the reinforcing material initially functions as a compressive material and gradually changes to tensile material. In this case, the increase of reinforcement ratio R is realized and the effective reinforcement is performed. From this test, it can be said that the effective direction of reinforcing material is when $\theta>0^\circ$.

5.2 Comparison between bar-type and plane-type materials

Figure 11 shows the relationship between

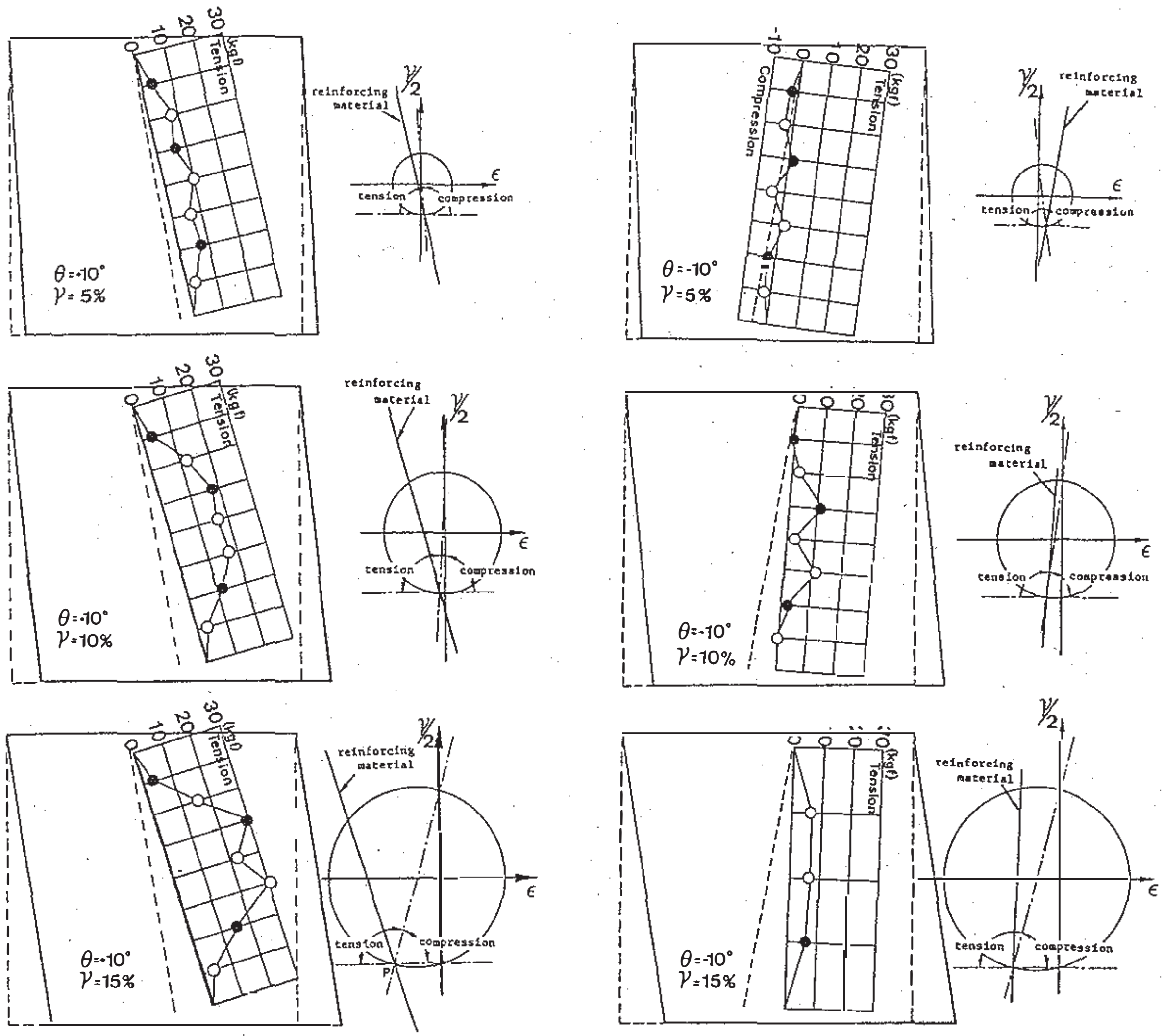


Fig.10 Axial force distributions and Mohr's strain circles (θ=+10°, -10°).

reinforcement ratio R and direction of reinforcing materials θ, at the strain level of γ=15% for both phosphor bronze bars as bar-type reinforcing material and polymer grids as plane-type reinforcing material. Besides, the relationship between the volumetric strain and shear strain is given in Fig. 12. It is realized from Fig. 11 that the reinforcement ratio R for both cases are different from each other. In the case of negative θ, the ratio R of the plane-type is smaller than that of the bar-type, while in the case of positive θ, it is the opposite. This result is explained by the fact that the dilation for the case of polymer grid is larger than that for the case of phosphor bronze bar regardless of the value of θ, and the confining pressure in soil caused by the side ribs of polymer grid is larger compared with that of phosphor bronze bar shaft. In other words, when polymer grid is placed at the negative value of θ, it reacts with the side ribs, and the ratio R becomes much small compared with that of phosphor bronze bar. On the other hand, as the reinforcing materials are placed at the positive value of θ, the polymer grid functions as a tensile material from the beginning of shearing, and it is considered that the ratio R becomes large, because the confining pressure against soil is high compared with that of phosphor bronze bar.

6 CONCLUSIONS

The main results of this paper are summarized as follows :

1. The new versatile shear test apparatus, which can model various types of strain conditions such as uniform and nonuniform strain distributions, is

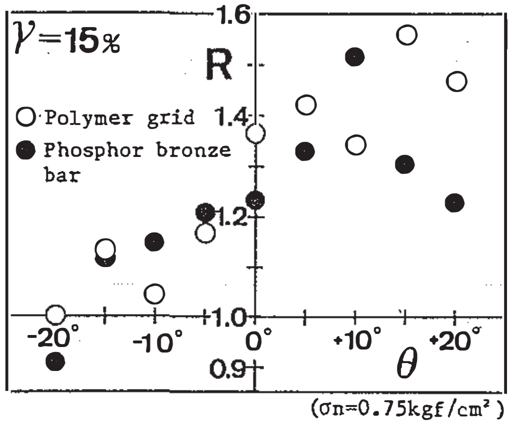


Fig.11 Reinforcing ratio (R)- direction of reinforcing material (θ) reletionship from simple shear test results for reinforced sand.

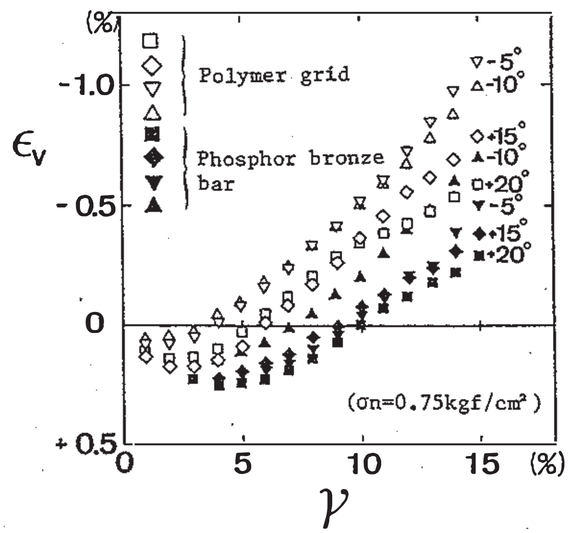


Fig.12 Volumetric strain - shear strain relationship from simple shear test results for reinforced sand(polymer grid and phosphor bronze bar).

introduced. With the results of shear tests shown in unreinforced sand, this apparatus can therefore be useful for many kinds of shear tests of reinforced soil.

2. The effects of reinforcement are depicted when reinforcing material functions as tensile material. On the contrary, they are not expected when reinforcing material operates as compressive material. In the latter case, the strength of reinforced soil goes down sometimes.

3. The reinforcing effect of polymer grids of the plane-type is larger than that of phosphor bronze bars of the bar-type in cases where the reinforcing materials are deposited in the directions of $\theta > 0^\circ$. However the former is smaller than the latter in cases where the reinforcing materials are deposited in the directions of $\theta < 0^\circ$. Hence, it can be considered that the influence of the direction of reinforcing materials on the effect of reinforcement appears clearly in the case of deposited polymer grids rather than in the case of deposited phosphor bronze bars.

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