International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988

Strength characteristic of reinforced sand in large scale triaxial compression test

S.Fukushima, Y.Mochizuki & K.Kagawa
Technical Research Division, Fujita Corp., Yokohama, Japan

ABSTRACT: A reinforcing mechanism, strength and deformation characteristics of the reinforced soil have been investigated by a laboratory element test using a small specimen. However, the properties of soil that reinforced with a full scale reinforcing material cannot be studied by the laboratory test as the size of specimen is very small. In this paper, a series of large scale triaxial compression tests were performed in order to investigate the strength and deformation characteristics of sand reinforced with full scale reinforcing materials (geo-grid, nonwoven fabric and metal strip for Terre Armee). The tests were carried out on a dry sand sample, the results were represented by comparing the stress-strain relationship of reinforced sand with that of unreinforced sand.

1 INTRODUCTION

The reinforced soil method reinforces the soil by arranging synthetic textile materials, metallic strip materials, and other materials (reinforcement) than soil having strong resistance to tension in the direction of the soil elongation. Friction generated between soil and reinforcement restrains the soil deformation by elongation and reinforces the ground. This method is now widely applied to construct comparatively small-scale bankings and cuttings. It is expected that the application range of this method will be further expanded, and the reinforced soil method will be applied to higher bankings, longer cuttings and other large-scale soil structures. Up to the present, the reinforcing mechanism and the effect of reinforcement have been examined by the shearing test of soil reinforced principally by model reinforcing materials. For this, the small-type element tests (triaxial compression and plane strain compression tests) with small specimen were used. It is impossible to study the effect of full scale reinforcement with these tests because of the smallness of the specimens. Particularly, to apply the reinforced soil method to construct a large scale soil structure, it is imperative to grasp the reinforcement when it is actually arranged in the ground. This report summarizes the results of experimental studies on the effect of full scale reinforcing materials when they are arranged in the sandy ground at same intervals.

2 TEST METHOD

2.1 Large scale triaxial compression testing system

A large scale triaxial compression testing system used for this study was developed to examine the stress-strain characteristics of the rock material for the rock fill dam. The size of the specimen was 120cm in diameter and 240cm in height. Figure 1 shows the sketch of this testing system. Highly compressed air pressure from a compressor is controlled to a specific level by the regulator. It is applied as lateral pressure to the specimen after being converted to water pressure inside the specimen volume change measuring tank (TA). A hydraulic unit feeds a fixed amount of fluid to the loading cylinder, which presses the loading plunger. The plunger compresses the specimen, and an axial load is applied to specimen. Axial displacement rate is changed by adjusting the flow from the hydraulic unit with the flow control

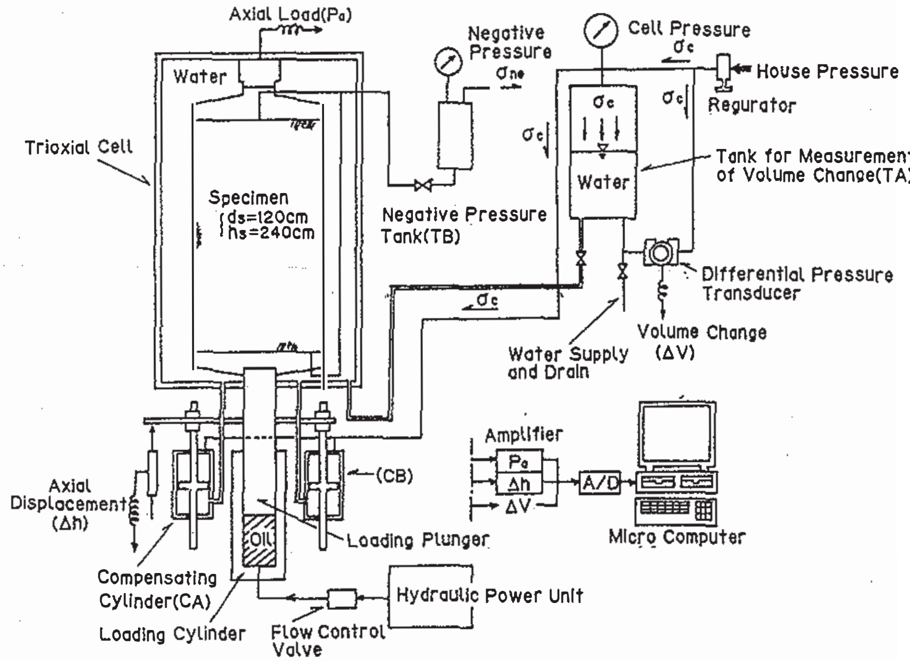


Figure 1.Ultra-large triaxial compression test

valve. The axial displacement rate was determined at ε_a=0.3%/min in this test program. The volume change of the specimen was obtained by measuring the water level inside the tank (TA) with a differential pressure transducer. The water equivalent to the volume change of specimen was led to this TA from inside the triaxial cell. If the loading plunger intrudes into the triaxial cell, the water equivalent to the volume of intrusion enters the compensating cylinders (CA and CB) having one half of the section of the loading plunger. This stops the flow of the water from the triaxial cell to the tank TA due to the intrusion of the loading plunger, allowing the water equivalent to the volume change of the specimen to flow in and out. The top and bottom ends of the specimen were set so that these end faces would become the principal stress plane. Friction was eliminated by adhering a rubber sheet of 0.5mm to the cap and pedestal with silicon sealant, then inserting silicon grease and placing another rubber sheet as shown in Figure 2.

2.2 Preparation of specimen

The sample used for the test was Toyoura sand (Gs=2.64, e_{max}=0.977, e_{min}=0.605).

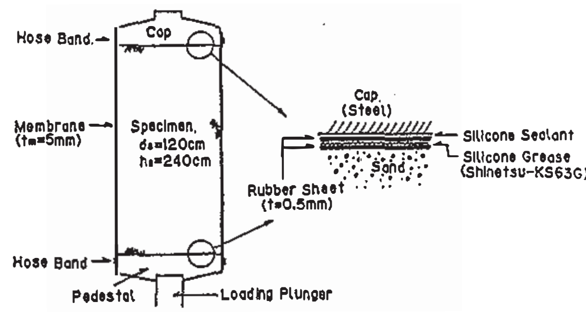


Figure 2.Specimen end face condition

The following describes how the specimen was prepared. A loosely packed specimen was obtained by allowing the sand in air dry state to drop freely through a multi-layered screen (four layered combination of 9.54, 4.76, 4.76, and 4.76mm from the top respectively) from the height of approximately 80cm (air pluviating method). The void ratio of specimen was approximately e=0.84-0.88 (Dr=34%). A densely packed specimen was prepared by the air pluviating method like the loosely packed specimen, then vibration was applied by a vibrator to every sand layer of 60cm. The void ratio of specimen

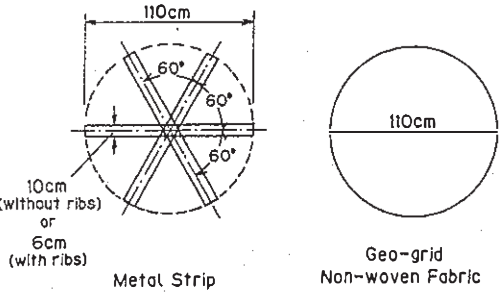


Figure 3 (a). Forms of reinforcement and their dimensions

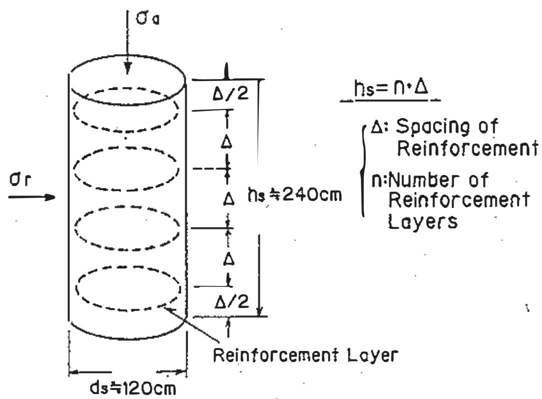


Figure 3 (b). Arrangement of reinforcement inside the specimen

was approximately e=0.68-0.70 (Dr=70%). The reinforcements used for the test are the following three types. They are actually applied to construction sites. Figure 3 shows the reinforcement layers inside the specimen.

(1) Geo-grid: Grid-type material made of polypropylene. Applied in sliced disk form with a diameter of 110cm. (Tenser SS-2, grid knot dimensions: 28X40mm)

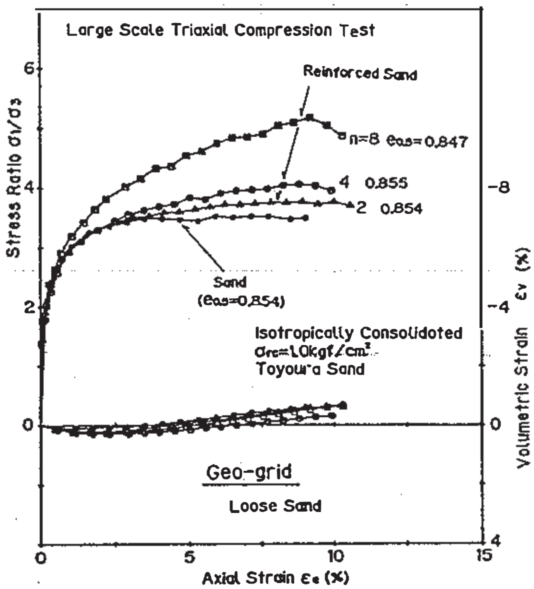
(2) Nonwoven fabric: Fabric-type material made of continuous long filament of 100% polypropylene. Applied in cut circular form with diameter of 110cm. (Toughnel construction matting U-90G)

(3) Strip material: Metal strip materials used for Terre Armee method (without rib, 10cm wide and with rib, 6cm wide). Material was cut in lengths of 110cm, and 3 pieces were crossed at the center to form a layer.

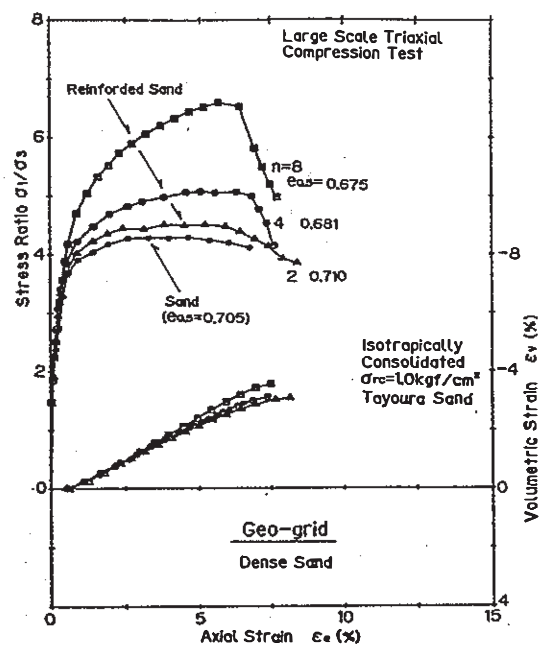
Reinforced specimen was constructed as follows. A sand was prepared as described above. Reinforcement was arranged, as shown in Figure 3(b), horizontally and at equal intervals (reinforcement intervals: Δ). Here the relation between the number of reinforcement is shown by $h_s = n \cdot \Delta$.

3 TEST RESULTS

Figure 4(a) and (b) show the relationship between the stress ratio and deformation of sand reinforced by the geo-grids in varied layer number of n=2, 4, and 8. Figure 5 and 6 show the same relationship of sand reinforced by nonwoven fabric and strip material (with rib) respectively. These figures show that the greater the number of reinforcement layers or the narrower the intervals, the greater the effect of reinforcement. Of the three types of materials, geo-grid reinforced sand was particularly characteristic. It had the greatest reinforcing effect among the three, but the stress ratio sharply dropped after the shearing deformation advanced to certain extent. This trend appeared stronger with the specimen having the greater number of reinforcement layers. The sharp drop of the stress ratio is thought to be attributed to the rupture of geo-grids. Figure 4(a) and (b) show that the axial deformation at the sharp drop of the stress ratio-deformation curve varies by the sand density or the denser the density of specimen, the smaller the deformation. Judging from these facts, when the ground is reinforced using geo-grids, it is necessary to consider the deformation when the rupture of the reinforcing materials occurs. Figures 7(a) and (b) show the maximum stress ratios obtained from Figures 4, 5, and 6, which are replotted against the number of reinforcement layers to investigate their effect. The ordinates of these figures represent the rate of increase of the maximum stress ratio by the reinforcing material. They also show the scale of the angle of internal friction (cohesive component C=0) with reinforcements. These figures show that with the increase of the number of reinforcing layers the effect of reinforcement sharply increases, and that the difference of effect becomes greater by the types of reinforcements. However, considering the fact that the reinforcing materials are generally arranged at intervals of 70-100cm in actual reinforced ground, Figure 7(a) shows that there is almost no difference of reinforcing effect



(a) Loose sand



(b) Dense sand

Figure 4. Relation between the stress and deformation of sand reinforced by geo-grids

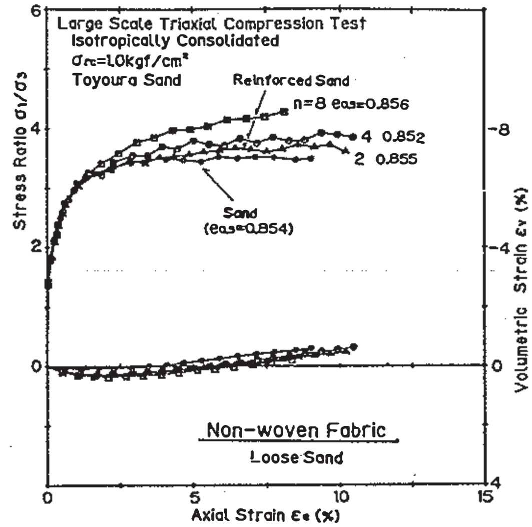


Figure 5. Relation between the stress and deformation of sand reinforced by nonwoven fabric

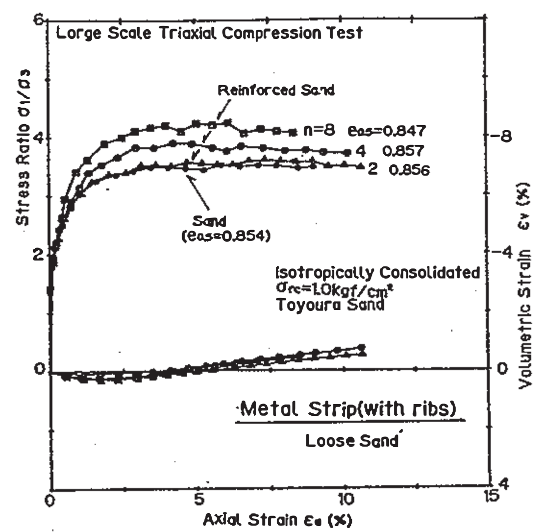
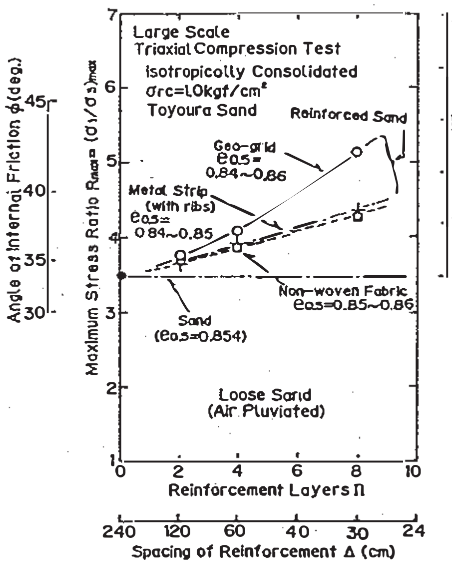
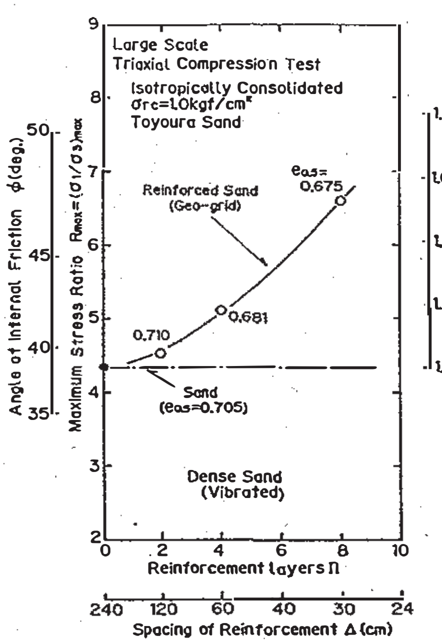


Figure 6. Relation between the stress and deformation of sand reinforced by strips

by the type of material, or nominal if any, in these intervals. The effect of reinforcement arranged in the ground at the intervals of 70-100cm is 10 to 20 % by the increment of the maximum stress ratio. This value is equivalent to 3-4 degrees by the angle of internal friction. Figure 8 shows the angle of internal friction (or the maximum stress ratio) of the tests conducted with the specimen reinforced with n=4 layers of geo-grids and strip material (with rib) under varying the confining pressure σ_{rc}. This figure shows that the relationship between the reinforcing effect and confining pressure differs between the geo-grids and strip materials. In other words, the reinforcing effect $\Delta\phi$ by the strip material remains almost constant irrespective of confining pressure, it becomes greater in the sand reinforced by geo-grids as the confining pressure becomes lower. This is thought to be caused by the difference of reinforcing mechanism between the two materials. That is, strip materials are effective in adding a fixed angle of friction to sands. On the other hand, geo-grids shows greater effect in the lower confining pressure range where the dilatancy of sand is strong. Therefore, the interlocking effect between the geo-grids and sand is thought to play an important role. Furthermore, the geo-grids increases its reinforcing effect as the confining pressure decreases. Its effect tends to become smaller than that of strip



(a) Loose sand



(b) Dense sand

Figure 7. Relation between the number of reinforcing layers and their effect

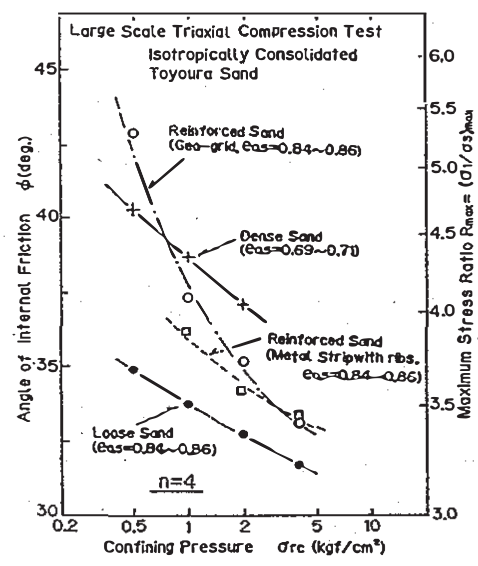
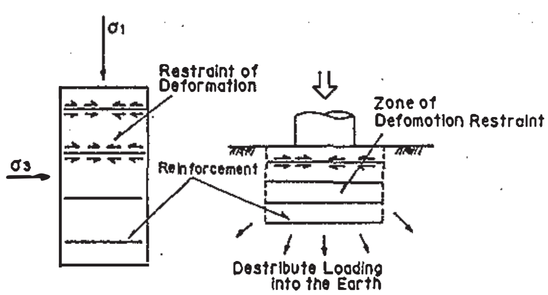


Figure 8. Relation between reinforcing effect and confining pressure

materials if the confining pressure increases. This indicates that this material is suitable for the construction of soil structures like embankments of considerably low height.

4 SUMMARY

Conventionally,the reinforcing mechanism and effect of the reinforcement material for sand reinforced with various materials were studied by the element tests with small specimens. The restriction of small-dimension specimen obliged the use of model reinforcing materials. This report has investigated, by experiments, the effect of actual reinforcement as arranged inside the sandy ground at likely intervals through the ultra large triaxial compression tests using large specimens. The descriptions so far made are confined only to the effect of soil deformation restraint by the reinforcing materials (deformation restraint by the friction that generated between soil and reinforcement), which has clear boundary conditions that can be examined by element tests (figure 9(a)). The effect of reinforcing materials in actually reinforced ground have, in addition to the above mentioned deformation restraint effect, another effect which disperses the load widely to the adjacent ground through the unification of portions which were subjected to the deformation restraint by the reinforcing materials (Figure 9(b)). The stress dispersion effect is determined by the boundary conditions of individual structures. The future problem would be how to incorporate this effect into the design for more rational construction of the reinforced ground.



(a) Deformation restraint effect (b) Deformation restraint effect and load dispersion effect

Figure 9. Effect of reinforcement

REFERENCE

1)F.Tatsuoka,K.Kondo,G.Miki,O.Haibara, E.Hamada,T.Sato 1983. Fundamental study on tensile reinforcing of sand. Tsuchi-to-Kiso vol.31 No.9:11-19(in Japanese)

2)Japanese society of soil mechanics and foundation engineering 1986. Reinforced soil method. Part 2, Fundamentals of reinforcing mechanism and design of reinforced soil method:25-168(in Japanese)