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Dynamic reinforcing effect of reinforced sands

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ABSTRACT: A series of dynamic triaxial testing was performed under constant mean confining pressure. The reinforcements with various stiffness and inclined embedding angle were implanted into sand samples. The influence of confining pressure was also investigated. The results showed that, the reinforcing effect was not proportional to the stiffness of the reinforcement and the confining pressure. As the inclined angle of the reinforcement changed, the reinforcing effect would also change.

1 INTRODUCTION

The Reinforced Earth has been developed since 1960. Owing to low cost, easy and fast construction, the reinforced soil structures have been applied widely in geotechnical engineering. However, the published paper deals little with the fundamental dynamic reinforced element. The approaching method and analytic algorithm for dynamic loadings are also lacking.

This study performed a series of dynamical triaxial tests on reinforced sand specimen under constant mean stress state. The sand specimen is reinforced with three different materials: aluminum, plastic, and paper sheets. The reinforcement in the sand core has different stiffness and inclined angle to the horizontal. In other words, this study emphasized the behavior of reinforced sands under cyclic loading.

2 BACKGROUND AND SCOPE OF STUDY

2.1 Dynamic behavior of soil

The dynamic triaxial test on reinforced sand core clarifies the relationship of cyclic hysteretic loop between stress and strain. *Seed* and *Idriss* (1970) suggested that the average slope of hysteretic loop, which is the slope of the line between the highest and lowest acme, showed the soil shear modulus. However, the shear modulus must be modified for dynamic triaxial test, because the hysteretic loop of dynamic triaxial test is axial stress and strain related. Therefore, the slope of hysteretic loops, Young's modulus(E), and shear modulus can be derived by using elasticity theorem:

$$G=\frac{E}{2(1+\upsilon)} \tag{1}$$

$$\gamma=\varepsilon(1+\upsilon) \tag{2}$$

where,

E: Young's modulus
G: shear modulus
γ : shear strain
ε : axial strain
υ: Poission's ratio,

2.2 The influence factors on dynamic shear modulus

Hardin and *Drenevich* (1972) indicated that the amplitude of shear strain (γ), the effective confining pressure (σ_3') , and the void ratio (e) are the major influenced factor on the sand. *Maher* and *Wood*(1990), *Shewbridge* and *Sousa*(1991), pointed out that the dynamic shear modulus of reinforced sand was sensitive to the amplitude of shear strain, effective confining pressure, and the quantity, shape ratio, and stiffness of reinforcement.

3 TEST PROGRAM AND METHOD

3.1 Testing equipment

In this study, the dynamic triaxial testing equipment designed by *C.K. Chan* and *J.P. Mulilis* (U.C. Berkeley), and a cyclic loading and stress controlling device was used. According to *Snell*'s theory, the propagating angle of earthquake waves is nearly perpendicular to the ground surface because of the refraction of multilayer soils. In engineering practice, the ground vibration is generally assumed as induced by horizontal shear waves, and the waves propagate vertically.

When under cyclic shear waves, the *mean normal stress* keeps constant. However, because of the limitation of testing equipment, the mean normal stress can not keep constant when cyclic loading is applied. A nonconstant mean normal stress affects the reinforced sand and induces nonconstant dynamic properties. In this study, the controlled system of testing was reprogrammed to improve this defect.

3.2 Testing material

Ottawa Sand is used in the test, The reinforcement are aluminum sheet, paper sheet, and plastic sheet.

1. Ottawa Sand

Ottawa Sand No-C109 is round shape and quartz is the major mineral. Its properties are shown in Table 1.

2. Reinforcement

The reinforcements is circle, and the diameter is 68 mm. The Young's modulus and the tensile strength are obtained according to ASTM D4595-86 testing specification. These detail properties are presented in Table 2.

Table 1 The properties of Ottawa Sand

Item	Index
Gs	2.66
e_{max}	0.77
e_{min}	0.47
Average size (mm)	0.26
c_u	1.27
Roundness	0.70

Table 2 The properties of reinforcements

Item	aluminum	Plastic	Paper
thickness (mm)	0.5	0.1	0.106
Young's modulus (MPa)	6.01	1.53	0.438
tensile strength (kN/m)	85.23	9.04	3.23

3.3 Testing method

The specimen is 71.2 mm in diameter, 171 mm in height, the relative density Dr is 73%. There are four different confining pressures, 50, 75, 100 and 200 kPa applied on sand cores of medium density in both and dry and undrained conditions.

The sand core is implanted with a layer of reinforcement. The reinforcements inclined at 0, 20, 40, 60, and 90 degrees to the horizontal. The arrangement is shown in Figure 1.

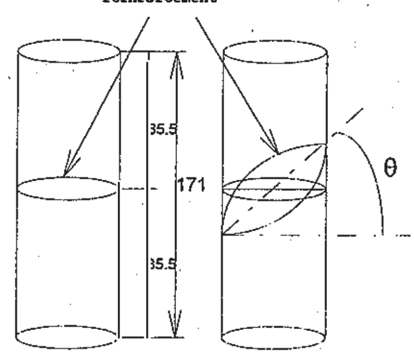

Figure 1 The scheme of the testing specimen (unit:mm)

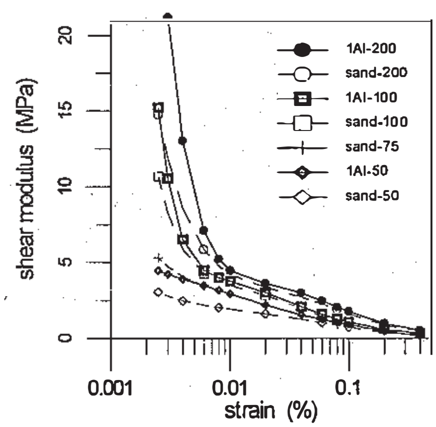

Figure 2 The results of the specimen with and without reinforcement under different strain condition.

4 RESULT ANALYSIS AND DISCUSSION

4.1 The effect of shear strain

The shear modulus decreases as the shear strain is increasing as shown in Figure 2. In the figure, the legends of "1Al-200" represents the specimen reinforced with a layer of aluminum and under 200 Kpa confining pressure condition. The "sand- 200" represents the unreinforced specimen under confining pressure 200 kPa condition.

In addition, the reinforced specimen has higher shear modulus than unreinforced specimen. However, the shear modulus of the reinforced specimen decreases when the shear strain increases. Furthermore, considering *the reinforcing effect* Gr/Gs (Gr represent the shear modulus of reinforced specimen, Gs represent the shear modulus of unreinforced specimen) as shown in Figure 3, the results demonstrate that the reinforcing effect is high at small strain though this effect decreases quickly as the strain cumulated. In addition, the reinforcing effect will be very small at large strain (about 0.05%). Due to reinforcement implanted into sand core, the movement of sand particles are constrained by the reinforcement. The reinforcement forms a cutoff plane in the sand core and distorts the development of the potential shear zone. Hence, the shear modulus of specimen increases. As the strain increases, the soil structure will collapse and become loose progressively. The constrained effect of reinforcement is reduced as the soil structure becomes loose that causes the reinforcing effect of reinforcement decreases significantly.

4.2 The effect of effective confining pressure

The shear modulus of reinforced sand is enhanced as the effective confining pressure rises. In Figure 2, the dash lines show the relationship of shear modulus with strain of unreinforced sand specimen under different confining pressures. The solid lines show the relationship of reinforced specimen. Clearly, the shear modulus increases for both cases when the confining pressure rises. On the other hand, the reinforcing effect (Gr/Gs) is not consistent with the increase of confining pressure (Figure 3). As shown in Figure 3, the reinforceing effect of 50 kPa confining pressure is the highest of all. The reinforcing effect of confining pressure of 200 kPa is about the same as that of 100 kPa confining pressure except at small strains.

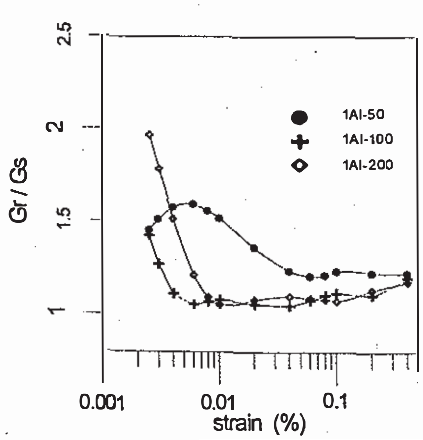

Figure 3 The reinforcing effect of aluminum under different confining pressure.

4.3 The effect of the stiffness of reinforcement

The stiffer reinforcement is, the more rigid of specimen can be formed, and the higher shear modulus is derived.

Figures 4 and 5 show the results of different stiff reinforcements. Aluminum has the highest shear modulus and reinforcing effect. However, the Young's modulus of aluminum is thirteen times the modulus of paper, but the reinforcing effect of aluminum is just about 1.4 times that of paper (Figure-5). It can be concluded that the reinforcing effect of aluminum is not proportional to stiffness.

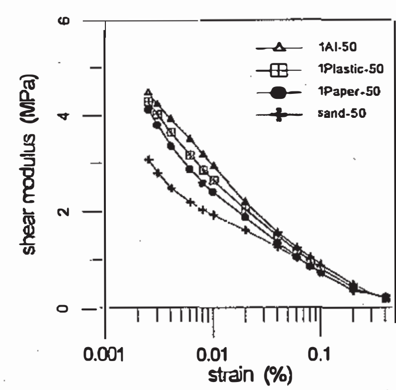

Figure 4 The shear modulus of specimens with different stiffness reinforcements.

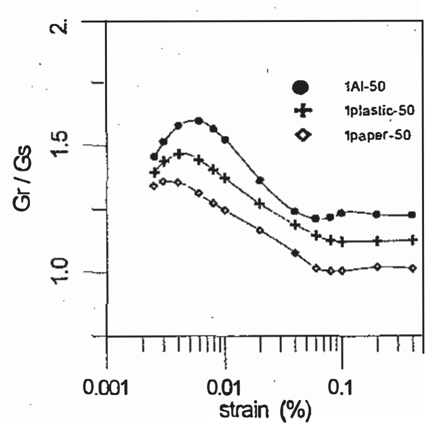

Figure 5 The reinforcing effect of different stiffness reinforcement

4.4 The effect of the inclined angle of reinforcement

As shown in Figure 6, the shear modulus decreases when the inclined angle increases from 0 to 40 degrees. Beyond 40 degrees, the shear modulus will rise up again as the inclined angle increases to 90 degrees. Furthermore, Figure 7 shows the relationship of reinforcing effect versus inclined angle at different strain. As shown in it, no matter whether the strain is small or large , the minimum reinforcing effect is close to about 40 degrees. This result agrees with the results of Jewell(1987). It can also be found that, the reinforcing effect curve is nearly symmetrical to 40 degrees.

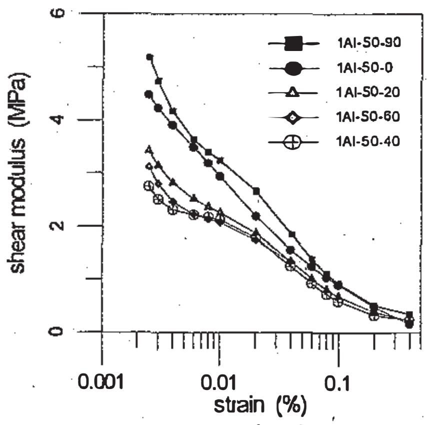

Figure 6 The effect of the inclined angle of the reinforcement under the confining pressure 50 kPa.

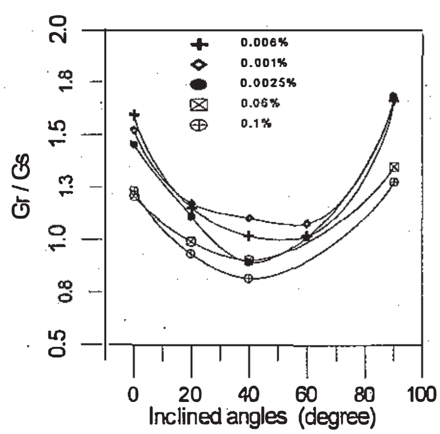

Figure 7 The relationship of reinforcing effect versus inclined angle at different strain.

5 CONCLUSION

1. The shear modulus of reinforced specimen increases with the effective confining pressure (Figure 2). However, the reinforcing effect is more significant under low confining pressure (Figure 3).

2. Since the soil particles are constrained by the reinforcement, and the development of potential shear zone is distorted by the reinforcement, the reinforcing effect will sustain until the soil structure collapses.

3. The stiffer reinforcement implanted will form more rigid specimen. Furthermore, the reinforcing effect is not proportional to the Young's modulus of the reinforcement.

4. While the inclined angle of the reinforcement increases from 0 to 40 degrees, the shear modulus of the specimen decreases progressively. However, as the angle higher than 40 degrees, the shear modulus will rise up again as angle increases. The lowest shear modulus occurs about at the inclined angle of 40 degrees.

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REFERENCES

Hardin, B.O. & Drnevich, V.P. 1972. Shear Modulus and Damping in Soils: Measurement and Parameter Effect. J. Soil Mechanics and Foundations Div., ASCE, 98, SM6, 303-364.

Jewell, R.A. & Worth, C.P. 1987. Direct Shear Tests on Reinforced Sand. Geotechnique, 37, No.1, 53-68.

Maher, M. H., and Woods, R. D. 1990. Dynamic Response of Sand Reinforced with Randomly Distributed Fibers. J. Geotech. Engrg., ASCE, 116(7), 1116-1131.

Schnabel, P. B. et al. 1972. SHAKE- A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites. Report EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley.

Seed, B., & Idriss, I. M. 1970. Soil Moduli and Damping Factors for Dynamic Response Analysis. Report No. EERC 70-10, Earthquake Engrg. Res. Ctr., Berkeley, Calif.

Shewbridge, S. E., & Sousa, J. B. 1991. Dynamic Properties for Reinforced Sand. J. Geotech. Engrg., ASCE, 117(9), 1402-1422.