Geosynthetics, J. Kuwano & J. Koseki (eds)

Effects of reinforcement stiffness on deformation of reinforced soil structures under cyclic and sustained load

Uchimura, T. & Nguyen, C.-A.
Department of Civil Engineering, University of Tokyo, Japan

Keywords: reinforced soil, deformation, sustained load, cyclic load, viscosity

ABSTRACT: When a reinforced soil structure is used for supporting a heavy important structure with a severe limit of deformation, it is essential to restrain its deformation against cyclic live load as well as heavy sustained dead load. In this study, triaxial specimens of reinforced sand were tested with cyclic and creep (sustained) loading, with various stiffness and amount of reinforcement. The quasi-elastic Young's modulus of a reinforced soil structure under cyclic loading with small amplitude is not affected by the total stiffness of the reinforcement at all. The Young's modulus was just the same as that of unreinforced sand. This suggests that the properties of the backfill material, not of the reinforcement, are essential to improve the Young's modulus of the reinforced soil structures. On the other hand, the residual deformation due to cyclic loading and the creep deformation due to sustained loading in the vertical direction are clearly restrained by stiffer and larger number of reinforced layers. Based on the test results above, the roles of reinforcement in the deformation of the reinforced soil structures are discussed.

1 INTRODUCTION

When a reinforced soil structure is used for supporting a heavy important structure with a severe limit of deformation, it is quite essential to restrain its deformation against cyclic live load as well as heavy sustained dead load. In cases of reinforced soil pier and abutments supporting bridges for railway or highway, a huge number of cyclic loads with relatively small amplitude is applied, and the residual deformation may accumulate to a harmful level. In this study, triaxial specimens of reinforced sand were tested with cyclic and sustained loading.

The stiffness and the number of layer of the reinforcement were changed to see their effects on the deformation of the structure due to small amplitude cyclic loading and sustained loading.

The roles of reinforcement in the deformation of the reinforced soil structures are discussed based on the test results.

2 TESTING METHOD

Rectangular triaxial specimens (Figure 1; 78 mm × 78 mm × 200 mmH) of air dried Toyoura Sand (Gs = 2.65; e_{max} = 0. 977; e_{min} = 0.597; D_{50} = 0.2 mm; Uc = 1.44) were tested. Thier vertical and horizontal strains were precisely measured by using LDTs (local displacement transducers). The sand was sedimented by air pluviation with multiple sieves to be a uniform relative density of Dr = 93%. The specimens are unreinforced or reinforced with geogrid (polyester; opening is 10 mm; nominal rapture strength is 39.2 kN/m; tensile strain at rapture is 22%; and stiffness is 507 kN/m under a strain rate of 1%/min) or metal grid (aluminium; opening is 10 mm; width of member is 3 mm; thickness is 1 mm; and stiffness is estimated to be 16400 kN/m) (Figure 2). The stiffness of the metal grid is 32 times larger than that of the geogrid.

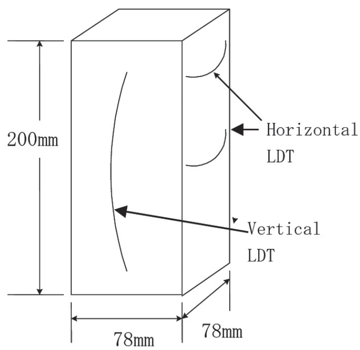


Figure 1. Configuration of triaxial specimens.

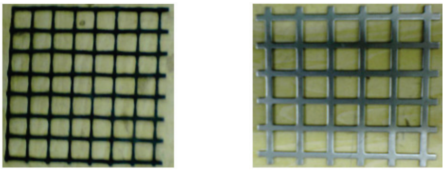


Figure 2. Reinforcement: (a) geogrid; (b) metal grid.

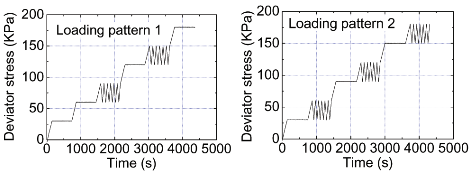


Figure 3. Loading patterns for the specimens: (a) Pattern 1; (b) Pattern 2.

Further, number of reinforcement layers was also changed as 3, 5, 7 and 9. Thus, specimens with various stiffness and amount of reinforcement were compared.

Two loading patterns of the deviator stress as shown in Figure 3 were applied to the specimen, while the horizontal confining pressure was kept constant of 40 kPa. The loading patterns consist of 10 minutes of creep (sustained) loading and 6 cycles of cyclic loading with double stress amplitude of 30 kPa. As each cycles of the cyclic loading takes 100 seconds, the 6 cycles takes 10 minutes, which is the same as the creep loading. The creep and cyclic loading were applied alternatively, with different order for each loading patterns. This is to eliminate the effects of difference of each specimen on comparing their behaviours during creep and cyclic loading.

3 TEST RESULTS AND DISCUSSIONS

Figure 4 compares the stress-strain behaviors of the specimens reinforced with various number of geogrid layers loaded with the loading pattern 1. It is obvious that the specimen with larger number of reinforcement layers showed higher stiffness against the large load increment from 0 kPa up to 180 kPa. The difference in the strain at the same stress is larger at higher stress level. Figure 5 compares the stress-strain behaviors of the specimens reinforced with 3 layers of geogrid and metal grid layers respectively, loaded with the loading pattern 1. It is also obvious that the specimen with stiffer reinforcement layers showed higher stiffness. But their difference was not so large, while the difference in the reinforcement stiffness was as large as 32 times.

These facts that larger number of layers and higher stiffness of reinforcement results in higher stiffness of specimen are quite natural. However, Figure 6 shows a fact quite different from our commonsense. Figure 6 compares the equivalent Young's modulus measured at the cyclic loading stages of loading

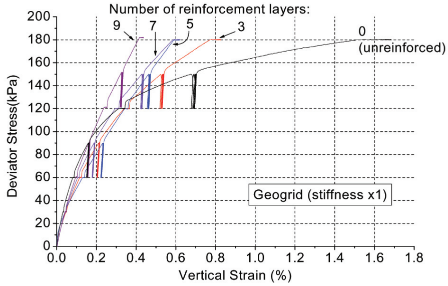


Figure 4. Comparison of stress-strain relationships with various number of reinforcement layers.

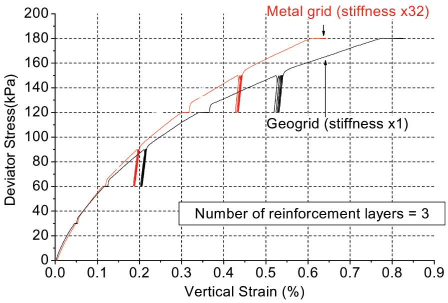


Figure 5. Comparison of stress-strain relationships with different reinforcement stiffness.

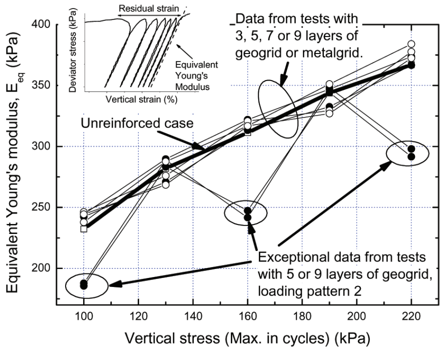


Figure 6. Comparison of equivalent Young's modulus with various number of layer and different stiffness of reinforcement.

patterns 1 and 2, for the specimens with various number of layers and different stiffness of reinforcement, plotted against the maximum vertical stress of each cyclic loading. The equivalent Young's modulus is clearly independent of the number of layer and stiffness of the reinforcement. It is the same as the equivalent Young's modulus of unreinforced sand, which is dependent on the vertical level.

However, this fact does not mean the behaviors of the specimens are independent of reinforcement. Figure 7 compares the Poisson's ratio measured at each cyclic loading, showing that they are dependent

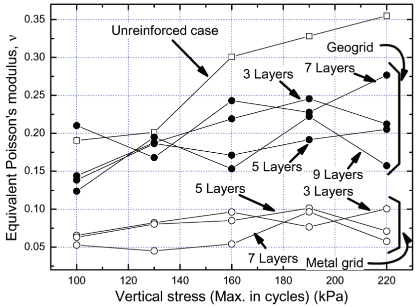


Figure 7. Comparison of equivalent Poisson's ratio with various numbers of layers and different stiffness of reinforcement.

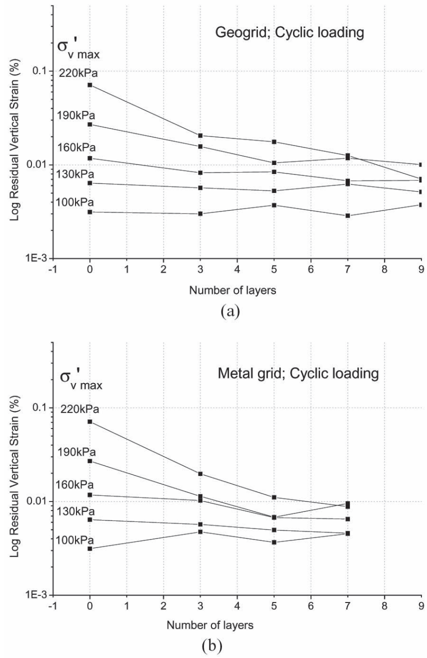


Figure 8. Comparison of residual deformation during cyclic loading at various stress levels with various number of layer of reinforcement: (a) with geogrid; and (b) with metal grid.

on the stiffness of reinforcement. The Poisson's ratio are clearly dependent on the stiffness of the reinforcement, while their relationships with the number of layers are not clear due to variation of data. The specimens with geogrid showed smaller Poisson's ratio than that of the unreinforced specimens, and it was more smaller for the specimens with metal grid. The horizontal deformation was measured by horizontal LDTs placed at the middle height of the specimen, which is the same height as the reinforcement layer in center. Thus, the horizontal strains measured here are near to the extension of the reinforcement layers, and the horizontal strain of the sand between reinforcement layers may be larger.

It is difficult to explain these results of Figure 6 and 7 by simple elastic deformation theory, but it can be said that the stiffness of reinforced soil structures against small cyclic load (e.g. traffic load) is the same as that of backfill soil, independent of the reinforcement. Thus, it is essential to use well-compacted, high-quality backfill soil, and sometimes improve it by cement-mixing to construct rigid structures. It is also effective to apply high prestress to the backfill as proposed by Uchimura et. al. 2003, because the Young's modulus is dependent on the vertical stress level.

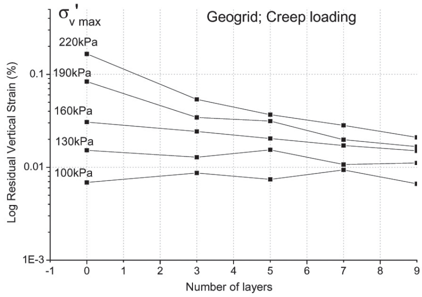
Figure 8 compares the residual deformation during cyclic loading at various stress levels with various numbers of layers of reinforcement. The specimens with larger number of reinforcement layers showed smaller residual strain. This effect of number of layers is significant at higher vertical stress level, while it is negligible at the lowest stress level of 60 kPa. It is also observed that the effect of number of layers are not significant if the number is larger than 7. The specimen with metal grid showed smaller residual strain than that with geogrid, but its difference is not as large as the difference in the stiffness of reinforcement.

Similar trend is observed in the residual deformation during creep (sustained) loading as shown in Figure 9. Thus, it is effective to use larger number of reinforcement layers under high vertical stress conditions to reduce residual deformation of reinforced soil structures due to long-term cyclic loading like traffic load, as well as long-term creep (sustained) loading.

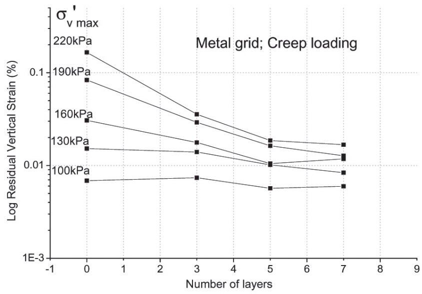
It is also observed from Figures 8 and 9 that the residual creep deformation under sustained load is always larger than the residual deformation due to cyclic loading, if the stiffness and number of layer of reinforcement and the vertical stress level are the same. This is because the vertical stress level of the cyclic loading procedure is defined as the maximum value of the cycles, and the time-average of the vertical stress during the cycles is lower than that, while the time taken for the cyclic loading procedure is the same as that for the sustained loading. If they are compared with the creep deformation under sustained load with stress the same as the minimum value of vertical stress in the cycles, the residual deformation during cyclic loading is larger than the creep deformation under sustained load.

4 SUMMARY

Triaxial specimens of reinforced sand were tested with cyclic and sustained loading, with various stiffness and amount of reinforcement. The quasielastic Young's



(a)



(b)

Figure 9. Comparison of residual deformation during creep (sustained) loading at various stress levels with various number of layer of reinforcement: (a) with geogrid; and (b) with metal grid.

modulus of a reinforced soil structure under cyclic loading with small amplitude is not affected by the total stiffness of the reinforcement at all, but is just the same as that of unreinforced sand. However, the horizontal strain during cyclic loading is clearly affected by the stiffness of reinforcement. These facts suggest that the properties of the backfill material, not of the reinforcement, are essential to improve the Young's modulus of the reinforced soil structures.

The residual deformation due to cyclic loading and the creep deformation due to sustained loading in the vertical direction are clearly restrained by stiffer and larger number of reinforced layers. These effects are significant under higher vertical stress conditions. The specimen with metal grid showed smaller residual strain than that with geogrid, but its difference is not as large as the difference in the stiffness of reinforcement.

REFERENCES

Matsumoto, M. (2004). "Viscous effects on residual strain of sand subjected to cyclic loading", Graduate thesis, University of Tokyo.

Uchimura, T., Tateyama, M., Tanaka, I. and Tatsuoka, F. (2003). Performance of a preloaded-prestressed geogrid-reinforced soil pier for a railway bridge, Soils and Foundations, Vol. 43, No. 6, pp. 155-171.

Uchimura, T., Tatsuoka, F., Hirakawa, D. and Shibata, Y. (2004). Effects of reinforcement stiffness on deformation of reinforced soil structures under creep and cyclic loading, Proceedings of Asian Regional Conferece on Geosynthetics, Seoul, pp. 233-239.

Uchimura, T. and Mizuhashi, M. (2005). Effects of reinforcement stiffness on deformation of reinforced soil structures under small cyclic loading, Proceedings of the 16th ICSMGE, Vol. 3, pp. 1429-1432.

