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Effects of reinforcement stiffness on deformation of rein-forced soil structures under small cyclic loading

Effets de la rigidité des armatures sur la déformation des structures en terre armée sous faibles chargements cycliques

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ABSTRACT
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 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, scaled models of reinforced soil pier were tested with cyclic loading. The total amount of the reinforcement was changed to see its effects on the deformation of the structure due to small amplitude cyclic loading. The elastic modulus of a reinforced soil structure against cyclic loading with a small amplitude is not clearly affected by the total stiffness of the reinforcement. The stress level dependency of the elastic modulus of the backfill material is much more effective. Most of the residual deformation during cyclic loading is due to creep deformation which is caused by high average stress level during the cyclic loading procedures, rather than accumulation of plastic strain generated by each loading cycle. The residual deformation can be restrained to a smaller level when the total stiffness of the reinforcement is higher.

RÉSUMÉ
Lorsqu'une structure en terre armée est utilisée pour supporter un ouvrage lourd et important avec une sévère limite en déformation, il est essentiel de limiter sa déformation face aux charges cycliques de service comme face aux charges lourdes pouvant entraîner la ruine. Dans les cas de piles ou de culées de pont en terre armée, supportant des autoroutes ou des voies ferrées, un très grand nombre de chargements cycliques, de relativement faible amplitude, est appliqué et la déformation résiduelle au cours de chaque cycle peut s'accumuler jusqu'à un niveau dangereux. Dans cette étude, des modèles réduits de piles en terre armée ont été testés sous chargement cyclique. Le nombre total d'armatures a été changé pour observer leurs effets sur la déformation de la structure sous chargement cyclique de faible amplitude. Le module élastique d'une structure en terre armée, mesuré lors des chargements cycliques de faible amplitude, n'est pas clairement influencé par la rigidité totale des armatures. La dépendance du module élastique du matériau de remblai avec le niveau de contrainte est bien plus claire. La majeure partie de la déformation résiduelle au cours des chargements cycliques est due au fluage, qui est provoqué par le niveau moyen élevé des contraintes au cours des chargements cycliques, plutôt qu'à l'accumulation de déformation plastique générée par chaque cycle. La déformation résiduelle peut être contenue à un niveau plus faible lorsque la rigidité totale des armatures est plus élevée.

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 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, scaled models of reinforced soil pier were tested with cyclic loading. The total amount of the reinforcement was changed to see its effects on the deformation of the structure due to small amplitude cyclic loading. The elastic modulus of a reinforced soil structure against cyclic loading with a small amplitude was also observed.

2 MODELS AND INSTRUMENTATION

Fig.1 shows the outline of the models. The height of the model was 600 mm, and the cross-section was 300 mm x 300 mm excluding the model of sandbag. Two kinds of well graded gravels were used for the backfill soil (Fig. 2). The 'fine gravel' has parameters of D_{max} = 5 mm, D_{50} = 1.82 mm, Uc = 3.04, e_{max} = 0.986, e_{min} = 0.481, and was compacted to dry density of $?_d$ = 1.79 g/cm^3 (Dr = 90 %). The 'coarse gravel' was prepared by adding coarse particles with diameter of 10 to 19 mm to the fien gravel, to have parameters of D_{max} = 20 mm, D_{50} = 4.7 mm, Uc = 5.85, and was compacted to $?_d$ = 1.91 g/cm^3.

Three kinds of reinforcement were used (Fig. 3). Type A is a polyester grid available in the market, whose opening is 10 mm, nominal rapture strength is 39.2 kN/m, and stiffness is 507 kN/m under a strain rate of 1 %/min. Type B is prepared by cutting the strands of Type A to have a half stiffness. Type C is an alminium grid, whose opening is 10 mm and stiffness is estimated to be 16400 kN/m, 32 times higher than Type A.

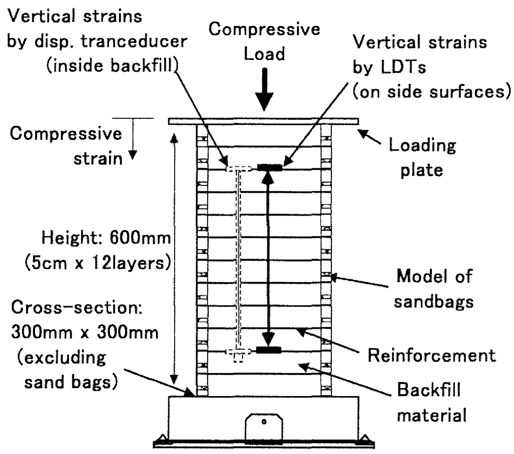


Figure 1. Scaled model of reinforced soil pier.

Polyurethane mat as a model of sandbag with a height of 50 mm was stacked around the periphery of the model in order to prevent spilling out of the backfill (Fig. 4). The mat is soft enough not to affect the vertical stiffness of the model. Alminium plates were inserted in the mat to prevent bending in the lateral direction. The reinforcement was arranged with vertical spacing of 50 mm or 25 mm as shown in Fig. 4.

Models with several amount of reinforcement were tested as listed in Table 1. The 'ratio of total stiffness' means the ratio of (stiffness of each rainforcement layer) times (number of reinforcement layers) compared to that value of 'Single' type model. Triaxial tests on the compacted backfill gravel were conducted for the 'unreinforced' cases with a specimen size of 240 mm x 230 mm x H570 mm and the effective confining pressure of 40kPa.

The vertical strain of the model was measured by three kinds of method. One is to measure the external deformation obtained by LVDT which measures the vertical displacement of the top loading plate. However, the obtained value probaply contains a certain bedding error between the top of the model and the laoding plate. The second method is to measrue the local deformation along the side surface of the model by using LDT (Local Displacement Transducer). LDTs are attached on L-shaped plates inserted to two layers of the model, as shown in Fig. 5. The bedding error at the top of the model can be cancelled by this method. However, the obtained value may not property represent the deformation of the model, because the L-plates are inserted to the side part only, and they may sightly rotate due to the model deformation. The third method is to measure the internal deformation of the model. A small displacement transducer is embedded to the center of the model to measure the deformation of middle eight layers.

An example of the vertical compression the model with 'single reinforcement stiffness' with 'fine gravel backfill' measured by these methods are compared in Fig. 7. The external deformation was larger than the internal deformation. The deformation by LDT is smaller than the internal deformation in this case, but its ratio is different for each model. This is probablly because the arrangement of L-plates for LDT is not the same for each model. Only external and LDT measurement was used for the triaxial tests.

Vertical load was applied to the models and the triaxial specement as shown in Fig. 8. Fifty cycles of cyclic load with double amplitude of 20 kPa was applied at several stress level up to 250 kPa.

Table 1. Total stiffness of reinforcement in the models.

Model type	Half	Single	Double	Metal	Unreinforeced
Reinforcement	Type B	Type A	Type A	Type C	None
Vertical Spacing of Reinforcement	25mm	50mm	50mm	50mm	-
Number of rain-forcement layers	12	12	24	12	-
Total stiffness ratio	0.5	1	2	32	0

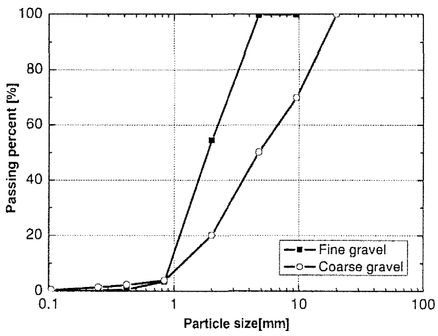


Figure 2. Particle size distribution of backfill soils.

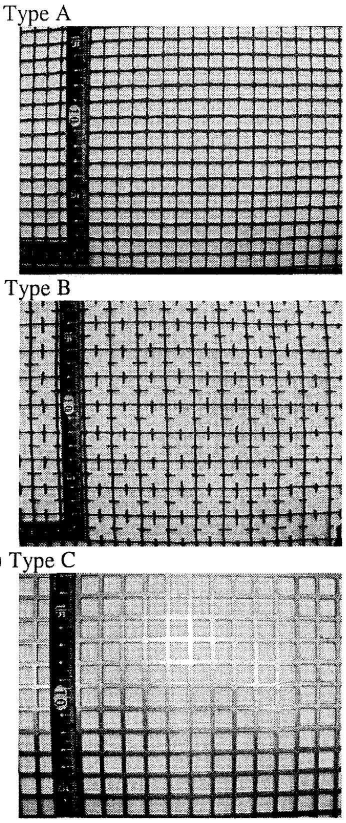


Figure3. Reinforcement for the model

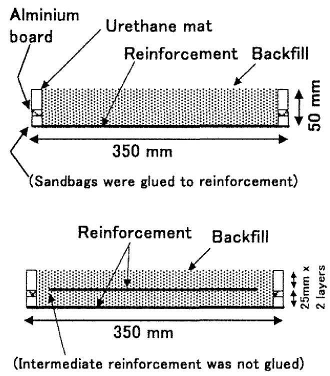


Figure 4. Arrangement of reinforcement and peripheral mat.

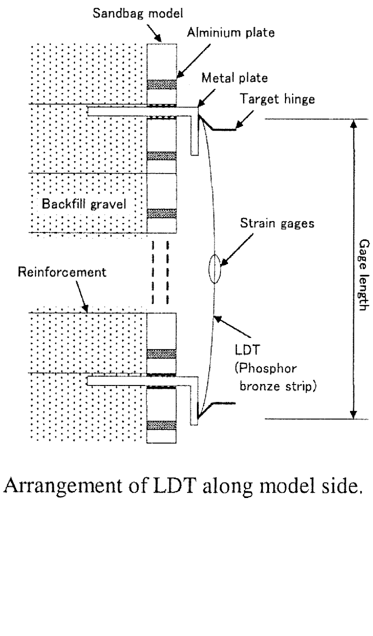


Figure 5. Arrangement of LDT along model side.

membrane, in stead of support by polyurethane mat around the model). This model showed higher stiffnes than the model with single amount of reinforcement and fine gravel supported by polyurethane mat. This suggests that the support with polyurethatne mat is not functioning idealy, and constant and uniform confining pressure in the triaxial tests gives better stability to the model.

On the other hand, the deformation of the models with coarse gravel at the stress level of 250 kPa is not in the order of the total reinforcement stiffness. This is probably due to the difficulty of constructing the models in the same condition with the coarse material.

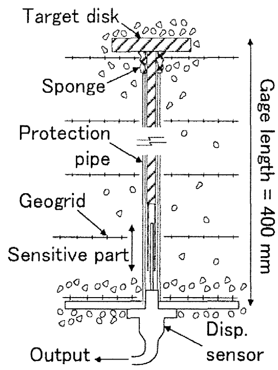


Figure 6. Arrangement of internal displacement transducer.

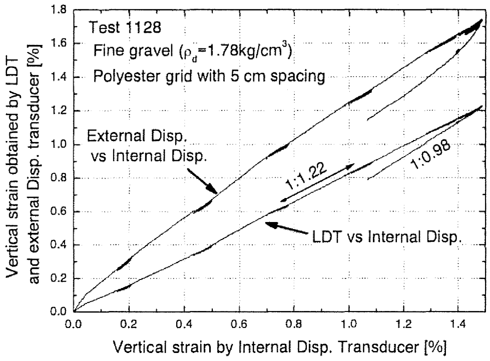


Figure 7. Model compression measured by three method.

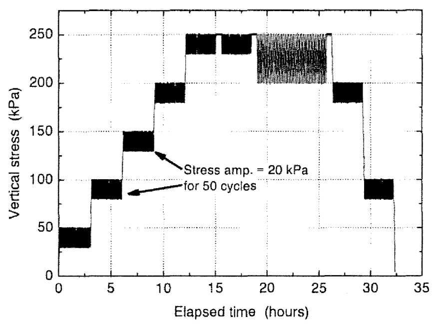


Figure 8. Loading pattern on the models.

3 RESULTS AND DISCUSSIONS

3.1 *Stiffness under loading with a high stress range*

Fig. 9 shows the relashonships between the vertical stress and strain in the models. The vertical strains in the sgiures are measured by internal method for the reinforced soil pier, and by LDT for the triaxial tests. There are some noise included in the strain data for the triaxial unreinforced fine gravel and the model with half stiffness of reinforcement and coarse gravel.

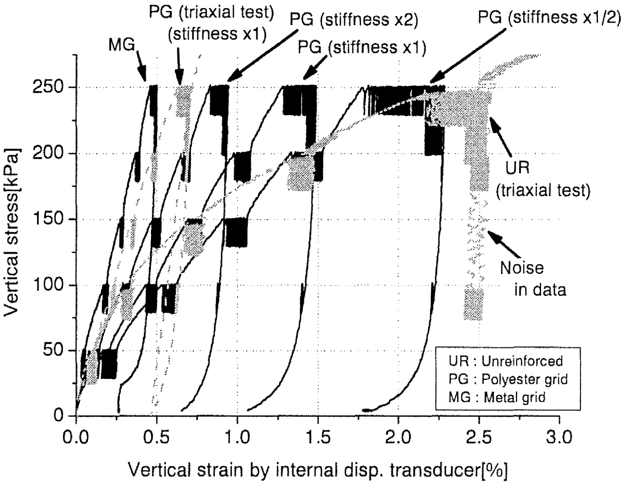
As for the deformation up to the stress level of 250 kPa, the unreinforced specimen showed the largest deformation, and models with stiffer reinforcement showed smaller defroamtion for the cases with fine backfill. However, the stiffness at the initial part of loading is similar to each other, showing that the tension was not yet developed in the reinforcement for this part, and therefore, the reinforcement was not effective.

Fig. 9a also shows an additional test on a model with single amount of reinforcement and fine gravel under triaxial condition (i.e. a constant confining pressure of 40 kPa was applied with

3.2 *Stiffness against small amplitude cyclic loading*

The Young's modulus of the models were obtained from the data at 50 cycles of cyclic loading with double amplitude of 20 kPa under each stress level (Fig. 10). As the resolution of the internal displacement transducer was not enough for the small cyclic strain amplitude, the strain obtained by LDT was corrected by using the ratio between the values by LDT and internal transducer obtained from the loading procedure from 0 kPa up to 250 kP. For example, a ratio of 1:1.22 was used for the test shown in Fig.7. The strain abtained by LDT was used without correction for the case of triaxial tests.

a)



b)

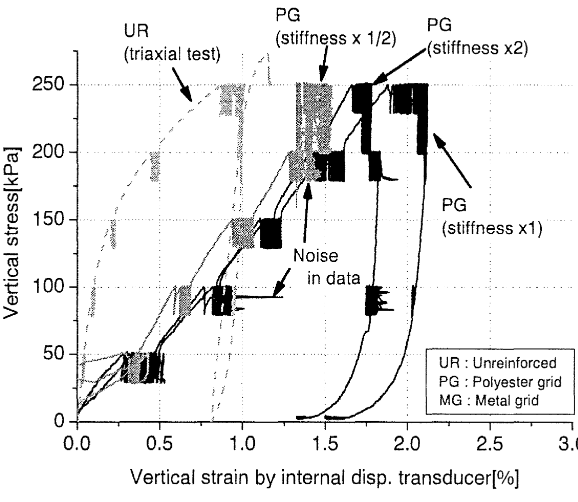


Figure 9. Vertical stress and strain of the models:
a) models with fine gravel; b) models with coarse gravel.

Fig. 11 summarizes the Young's modulus of the each model at each vertical stres level. As for the models, the effect of the total stiffness of the reinforcement on the Young's modulus is small,.while the effect of stress-level dependency of the backfill is much larger. That is, the models showed higher Young's modulus at higher stress conditions. Thus, it is concluded that the stiffness and amount of reinforcement material is not dominant for the stiffness of reinforced soil structures under small amplitude cyclic loading, while the properties of backfill soil is much more important.

As for the triaxial tests without reinforcement, the Young's modulus were much higher than the reinforced models both with the fine and coarse backfill. It may be because of bedding error between the surface of the reinforcement and the backfill material at each layer. It is also found in Fig. 11 that the Young's modulus of the unreinforcement specimens dropped at the higher stress levels. This is pobably because the stress ratio became so high that the specement was damaged when a high vertical stress was applied whitle the lateral confining pressure was constant at 40 kPa. In the case of reinforced models, the lateral confining stress to the backfill increases with the increase in the vertical load, because the tention in the reinforcement also increasesd nearly propotionally to the vertical stress, and thus, the stress ratio to the backfill was almost constant.

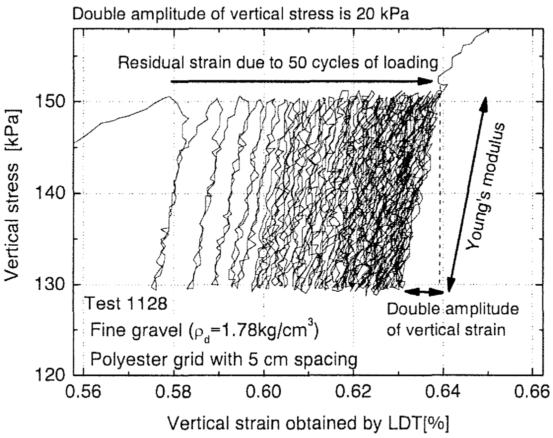


Figure 10. Example of stress-strain relations at cyclic loading.

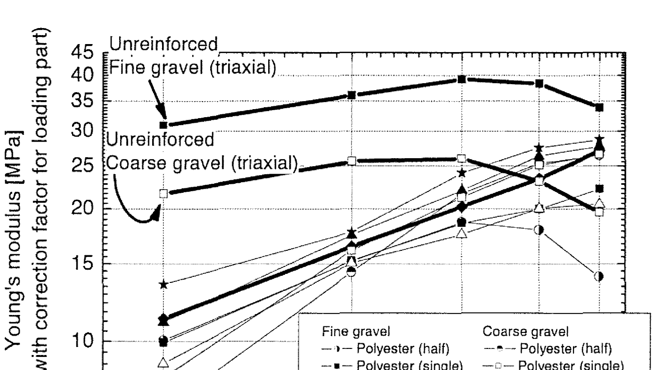


Figure 11. Summary of Young's modulus of the models.

3.3 *Residual strain due to cyclic loading*

Fig. 12 summarizes the residual deformation versus the strain amplitude due to 50 cycles of cyclic loading at each stress level. It was expected that the residual deformation becomes larger for cyclic loading with larger strain amplitude. The data for the cases with lower stress level as 50 kPa agrees with this assumption. However, for the cases with higher stress level as 250 kPa, the residual deformation is much different, although the strain amplitude was similar for each model. The residual deformation was smaller for the model with higher total reinforcement stiffness. On the other hand, comparing at different stress level for the same model, it is clear that the residual deformation becomes larger at the higher stress level. These facts suggest that behaviours of the residual deformation of reinforced soil structures are similar to that of creep deformation, which is highly related to the stress level rather than the effect of cyclic deformation. The creep deformation is more effectively restrained by the reinforcement with larger amount and higher stiffness.

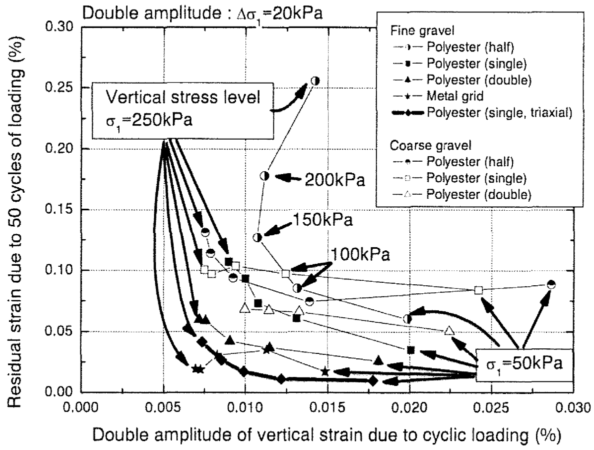


Figure 12. Residual deformation vs. strain amplitude at cyclic loading.

4 CONCLUSION

The elastic modulus of a reinforced soil structure against cyclic loading with a small amplitude is not clearly affected by the total stiffness of the reinforcement. The stress level dependency of the elastic modulus of the backfill material is much more effective. Most of the residual deformation during cyclic loading is due to creep deformation which is caused by high average stress level during the cyclic loading procedures, rather than accumulation of plastic strain generated by each loading cycle. The residual deformation can be restrained to a smaller level when the total stiffness of the reinforcement is higher.

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