EVALUATION OF DAMAGE OF GEOGRID REINFORCED SOIL WALL BASED ON WALL DISPLACEMENT

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Abstract: Some researchers reported after recent huge earthquakes that the geogrid reinforced soil walls (GRSW) showed high seismic stability and very small displacements. Therefore, the GRSWs are widely used without considerable repair or reconstruction in many cases even after the earthquakes. To assess the necessity of repair or reconstruction, it is needed to evaluate degree of damage of the GRSW. The damage of the GRSW would be evaluated from the surface deformation that is observed from the wall displacement or from the settlement of the crest. In this paper, the evaluation method of the degree of damage of GRSW is proposed. In this method, shear strain of backfill material in the reinforced area is evaluated from the horizontal displacement of the wall and occurrence of the slip line is decided based on the simple plastic theory. Since the past studies show that seismic stability of the GRSW depends upon the pullout resistance between geogrid and backfill material after the generation of slip line in the backfill, seismic stability of the GRSW having slip line in the reinforced area is evaluated from the results of the pullout test. Finally, the validity of the proposed method was verified with results of some centrifuge shaking table tests. The results obtained by the proposed method show good agreement with the test results.

Keywords: centrifuge, geogrid, reinforced soil wall, seismic behaviour

INTRODUCTION

Geogrid reinforced soil walls (GRSW) have showed high seismic stability with limited deformation from past earthquakes. GRSWs are often used without considerable repair or reconstruction after simple inspection, in many cases even after strong earthquakes. For the proper repair or reconstruction, it is necessary to evaluate damage of GRSWs. As the restoration method of the structure should be decided right after the event, the damage must be evaluated by a simple index such as the wall displacement or the crest settlement. Evaluation of damage in GRSWs subjected to earthquake is discussed in this paper based on result of centrifuge tests. The discussion is especially focused on the estimation of slip line formulation by surface displacement.

CENTRIFUGE TILTING AND SHAKING TABLE TESTS

A series of centrifuge tilting and shaking table tests was carried out focusing on the effect of tensile stiffness of geogrid and properties of soils on the seismic performance of GRSWs by Izawa et al. (2002, 2002, 2004). Test cases are summarized in Table 1. Three silica sands having different particle size were used with the relative density of 80%. Model geogrids were made of polycarbonate plates with 0.5 mm or 1mm thickness. The shape of the model geogrid was the same in all cases as shown in Figure 1. Figure 2 shows the schematic diagram of the model GRSW used in both centrifuge tilting and shaking table tests. Five layers of 90mm long geogrids were laid in the backfill at 30mm interval. Five pieces of aluminium plates were used as a model wall and one geogrid was attached to one plate. Some optical targets were set on the surface of the transparent side wall for detailed observation of deformation. Both tilting and shaking table tests were conducted in the centrifugal acceleration of 50G. In the centrifuge tilting table tests, pseudo static horizontal loading usually used in the design was achieved by tilting the model. On the other hand, in the centrifugal shaking table tests, cyclic loading as in the seismic events with frequency of 100Hz, which corresponds to 2Hz in prototype, were applied to the model.

Table 1. Test cases and properties of model geogrids and backfills

	Geogrid			Backfill				Pullout characteristics		
Case	Type	Thickness (mm)	Tensile Stiffness (kN/m)	Type	D_{50}	γ_d (kN/m^3)	ϕ (°)	c_p (kN/m^2)	ϕ_p (°)	$\tan\phi_p/\tan\phi$
CS-T	CS	0.5	197	Toyoura	0.19	15.7	40.4	0.930	21.4	0.451
CS2-T	CS2	1.0	557	Toyoura	0.19	15.7	40.4	7.90	40.5	0.983
CS2-S5				Silica No. 5	0.52	14.5	45.0	16.7	44.5	0.949
CS2-S3				Silica No. 3	1.40	14.8	46.0	30.2	46.1	0.903

INCLINATION OF THE WALL AT FAILURE SUBJECTED TO PSEUDO STATIC LOADING

Figure 3 shows the relationships between horizontal displacement at the top of the model GRSW and horizontal seismic coefficient, $k_h = \tan\eta$ where η is the tilting angle. In all the cases, the horizontal displacement increased gradually with tilting and finally sudden failure due to sliding occurred. However, overturning failure was observed in the case of CS2-S3. In addition, effects of tensile stiffness of the geogrid and properties of soil can be seen in the figure. Figure 4 shows the vertical distributions of the horizontal displacement of the model observed in centrifuge tilting table tests. These were obtained from displacements of the optical targets. In these figures, it is thought that horizontal displacement

of the bottom target and gradient indicate sliding displacement and shear deformation respectively. From this point of view, these figures clearly show that shear deformation at lower part of the reinforced area was significant. Consequently, inclinations of the bottom facing panel are plotted against the horizontal seismic coefficient in Figure 5. Here, the inclination of the bottom panel "θ" is defined as $\theta = d_p/H_p$, where d_p and H_p indicate the horizontal displacement of the bottom facing panel and the height of the facing panel. Horizontal seismic coefficients at failure are also indicated in Figure 5. This figure clearly shows that the model GRSWs failed when the inclination of the bottom facing panel reached to about 3.0%. Figure 6 shows distributions of maximum shear strain before failure in CS-T, CS2-T and CS2-S5. The model GRSWs failed immediately after slip line generated in the reinforced area. On the other hand, the model of CS2-S3 did not show clear slip line and failed due to overturning.

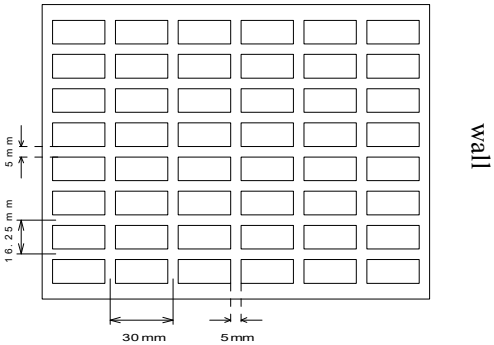

Figure 1. Shape of the model geogrid

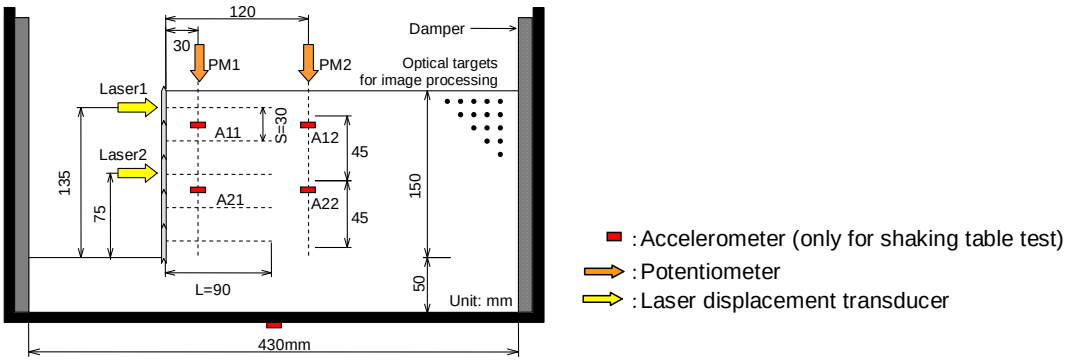

Figure 2. Schematic view of the model GRSW

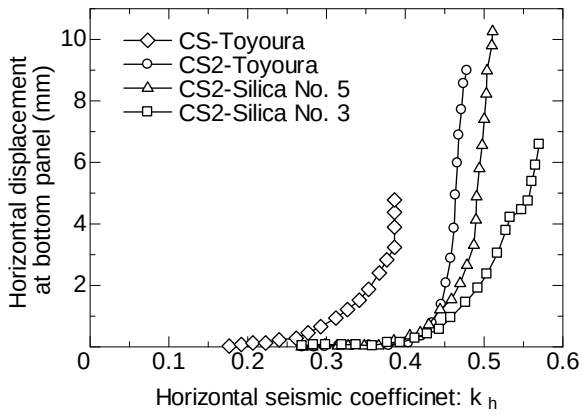

Figure 3. Horizontal displacements at the top of the model GRSW vs. horizontal seismic coefficient

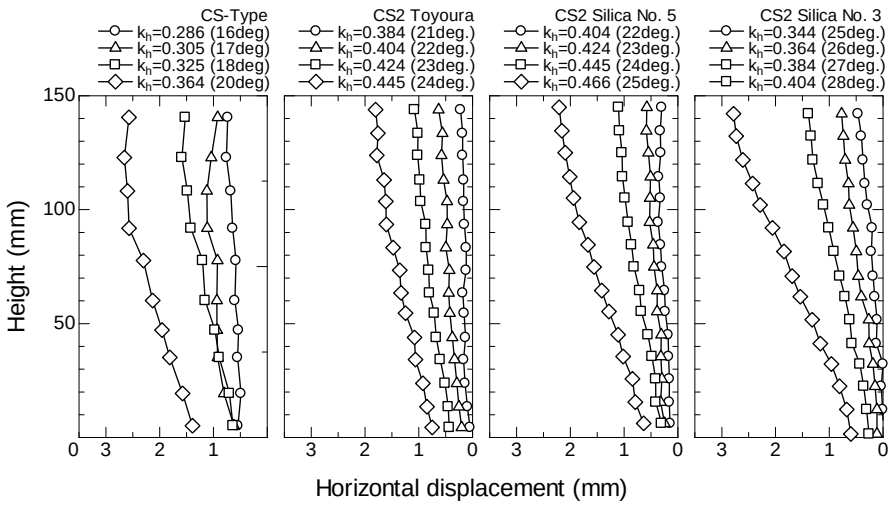

Figure 4. Vertical distributions of the horizontal displacement of the model

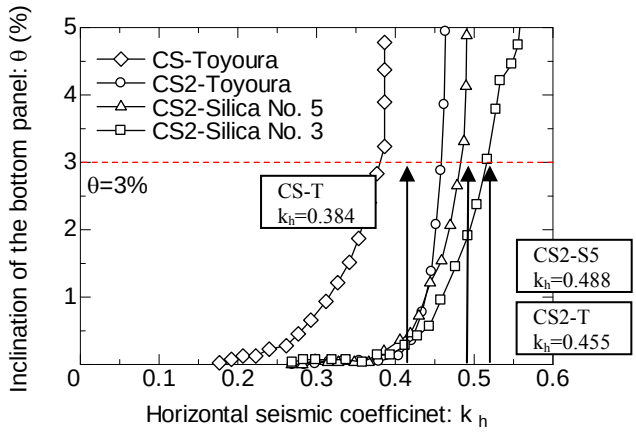

Figure 5. Inclinations of the bottom facing panel vs the horizontal seismic coefficient

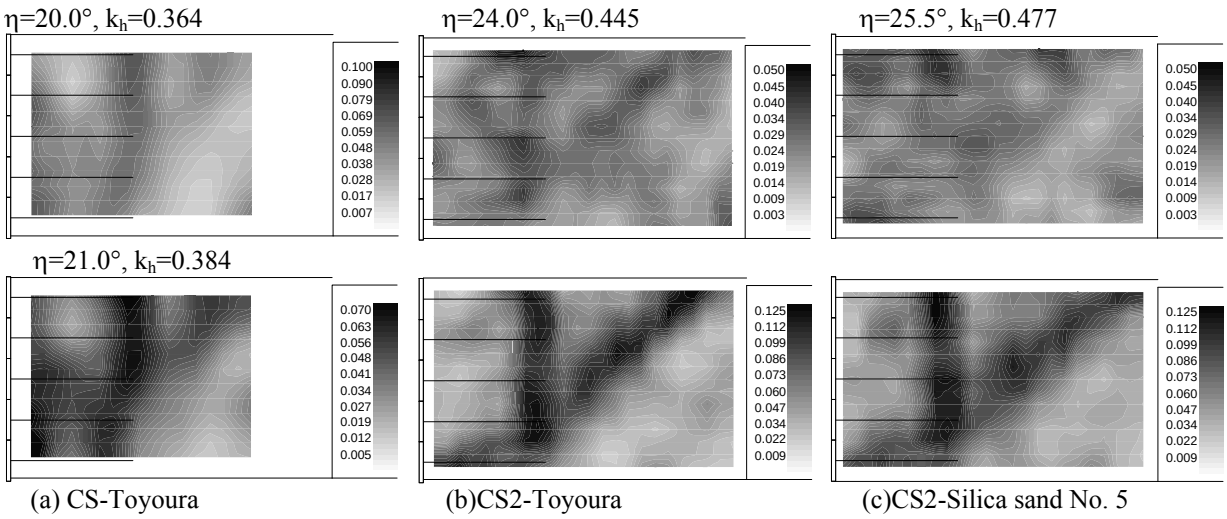

Figure 6. Distributions of maximum shear strain before failure in CS-T, CS2-T and CS2-S5

In summary, the GRSW subjected to pseudo static loading failed due to sliding when the inclination of the wall reached to the particular value and slip line generated. Additionally, the inclination when the slip line appears depends on only the kind of backfill material, since the model of CS-T and CS2-T failed at the same wall inclination. It is considered that such slip line generated when the backfill material reached to failure. Therefore, relationship between inclination of the wall and strain occurred in the backfill will be discussed in the next chapter.

EVALUATION FOR GENERATION OF SLIP LINE

Bransby et al.(1975) proposed the relationship between the inclination of the sheet pile wall and maximum shear strain occurred in the backfill based on the test results as follows.

$$\gamma_{\max} = \frac{2\theta}{\cos\varphi} \qquad (1)$$

where, γ_{max}: maximum shear strain occurred in backfill, θ: inclination of the bottom facing panel and φ: dilatancy angle. Furthermore, it was reported that the proposed equation could give good agreement with test results. Here, it is not easy to obtain the dilatancy angle. Figure 7 shows the relationships between the inclination of the wall and the maximum

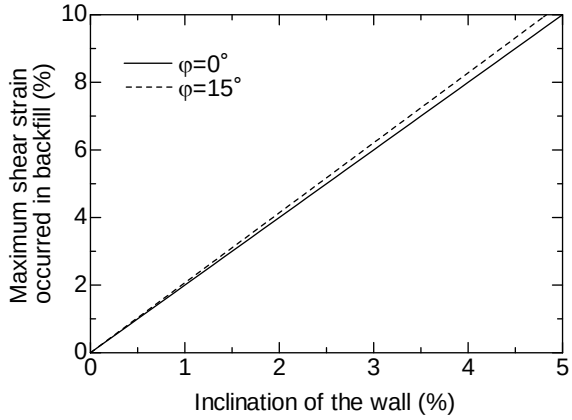

Figure 7. Effect of dilatancy angle on the maximum shear strain occurred in the backfill

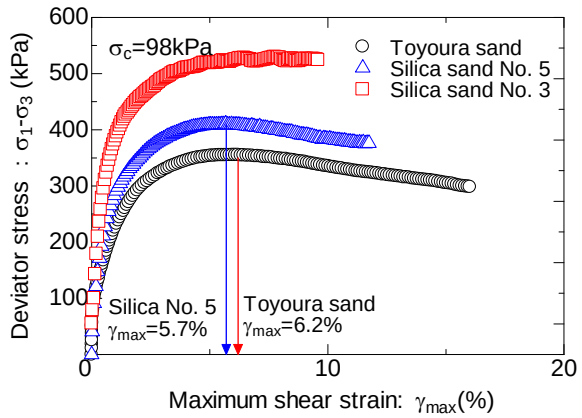

Figure 8. Results of triaxial tests under σ_3=98kPa

shear strain occurred in the backfill calculated by the proposed equation with different dilatancy angle. This figure clearly shows that the effect of dilatancy angle on maximum shear strain is small. Therefore, the proposed equation is simplified as follows.

$$\gamma_{\max} = 2\theta \qquad (2)$$

Above equation is equivalent to the Bolton's equation (Bolton, 1988), which was derived from the test results focused on undrained behaviour of the sheet pile wall. Using equation (2), the maximum shear strain occurred in backfill can be estimated with the wall displacement. As mentioned above, the slip lines generated when the inclination of the model GRSW reached to about 3.0%. That is to say, it can be estimated that maximum shear strain about 6.0% occurred in the backfill of the model GRSWs.

Figure 8 shows relationships between deviator stress and maximum shear strain of Toyoura sand, Silica sand No. 5 and No. 3 obtained from drained tri axial compression tests at the confining pressure of 98kPa, which is almost the same pressure acting on the bottom reinforced area of the model GRSWs under the centrifugal acceleration of 50G. Maximum shear strain was calculated assuming that Poisson's ration of both sands is 0.2. As shown in this figure, the peak deviator stress could be obtained at the maximum shear strain of 6.2% and 5.7% for Toyoura sand and Silica sand No. 5 respectively. That is, it can be considered that the backfill materials failed when the slip line generated and sliding failure occurred in the centrifuge tilting table tests. On the other hand, clear peak value is not shown in Silica sand No. 3.

Therefore, the model of CS2-S3 did not show clear slip line and failed due to overturning.

In summary, maximum shear strain occurred in the backfill of GRSWs can be estimated by using equation (2). When the maximum shear strain reached to the peak value, slip line generates in the reinforced area and sliding failure occurred. Based on this relation, generation of the slip line can be evaluated by using only the horizontal displacement.

VALIDATION FOR RESULTS OF THE CENTRIFUGE SHAKING TABLE TESTS

In the centrifuge shaking table tests, almost the same deformation modes with those of the centrifuge tilting table tests were observed. That is to say, shear deformation of the lower part of the GRSW was significant. Figure 9 shows the relationships between the inclination of the bottom facing panel and cumulated acceleration power. Acceleration power can consider both acceleration and duration of the shaking wave, and it is calculated by the following equation.

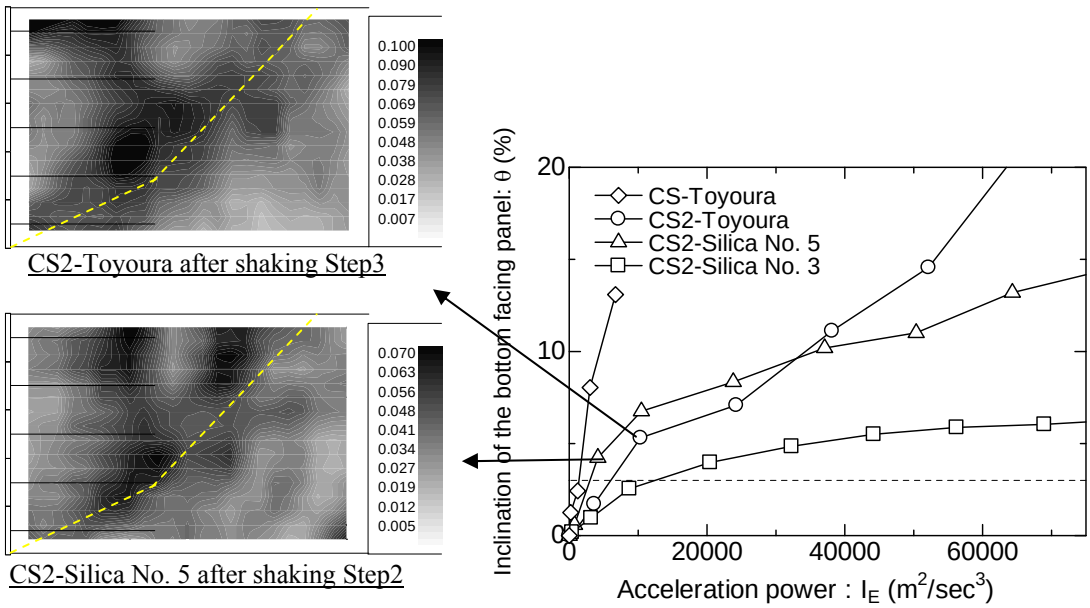

Figure 9. Inclination of the bottom facing panel vs. cumulated acceleration power

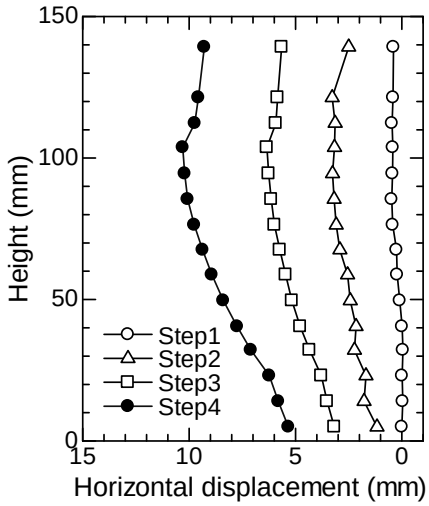

Figure 10. Vertical distributions of the horizontal displacement in the centrifuge shaking table test CS2-T

$$I_E = \int_0^T a^2(t)dt \qquad (3)$$

where, T: Duration of time (sec), a: input acceleration (m/s^2).

In CS2-T and CS2-S5, the inclinations of the bottom facing panel exceeded 3.0% at the shaking step 3 and 2 respectively. Maximum shear strain distributions are also indicated in Figure 9. As shown in these figures, slip lines generated at the shaking step 3 and 2 although they were not so clear than those of the centrifuge tilting table tests. This result clearly shows that the criteria for evaluating the generation of slip line, as indicated in equation (2), can be applied to the GRSWs subjected to earthquake.

In the centrifuge shaking table tests, the model GRSWs did not collapse even after the slip lines occurred. Figure 10 shows the vertical distributions of the horizontal displacement of CS2-T. In the case, the slip line generated at the shaking step 3. As shown in this figure, sliding displacement was much larger than the horizontal displacement due to shear deformation at the shaking step 4. This means that sliding displacement is significant after slip line generated. Amount of such sliding displacement depended on pullout resistance of the geogrid cutting through the slip line. Therefore, the horizontal displacement in CS2-T was larger than that of CS2-S5 after the slip line occurred as shown in Figure, since the pullout resistance of CS2-S5 was larger than that of CS2-T as indicated in Table 1.

CONCLUSIONS

This paper describes evaluation of damage in geogrid reinforced soil walls based on results of centrifuge tilting and shaking table tests. Especially, generation of slip line in the reinforced area was focused on. A slip line generates in the reinforced area when the maximum shear strain of the backfill reaches to their peak value. The maximum shear strain occurred in the backfill can be estimated by the following equation.

$$\gamma_{\max} = 2\theta$$

Inclination of the bottom facing panel can be calculated by the horizontal displacement of the panel. That is, generation of the slip line can be estimated by only the horizontal displacement of the GRSW. The GRSW maintains its adequate stability due to the pullout resistance of the geogrid after slip line formation. However, after the formation of the slip line, the sliding displacement along the slip line is getting significant. Such sliding displacement depends on the pullout resistance of the geogrid.

REFERENCES

Bolton, M. D. and Powrie, W. 1988. Behaviour of diaphragm walls in clay prior to collapse, Geotechnique, Vol. 38, No. 2, pp. 167-189.

Bransby, P. L. and Milligan, G. W. E. 1975 Soil deformations near cantilever sheet pile walls, Geotechnique, Vol. 25, No. 2, pp. 175-195

Izawa, J., Kuwano, J, & Ishihama, Y. 2004. Centrifuge Tilting and Shaking Table Tests on the RSW with Different Soils, Proc. of the 3rd Asian Regional Conference on Geosynthetics, pp. 803-810.

Izawa, J., Kuwano, J. & Takahashi, A. 2002. Centrifuge tilting and Shaking table tests on reinforced soil wall, Proc of 7th International Conference on Geosynthetics,pp. 229-232.

Izawa, J., Kuwano, J. & Takahashi, A. 2002 Befavior of steep geogrid-reinforced embankments in centrifuge tilting tests, Proc. of Physical Modelling in Geotechnics, pp.993- 998.