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Effect of soil nails in repairing damaged reinforced soil walls

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ABSTRACT: It is known that reinforced soil walls have higher earthquake resistance compared to conventional retaining walls. However, it is reported that some reinforced soil walls were damaged by large earthquakes such as the 2011 Great East Japan Earthquake. Geogrid reinforced soil walls (GRSW) usually use only geogrids as reinforcing members. But if it is thought that the stability of the damaged GRSW is not enough with only geogrids after the earthquake and the damaged GRSW needs to be repaired, it is expected to add the soil nails afterwards. To investigate the effect of soil nails in repairing damaged geogrid reinforced soil walls (GRSWs), a series of model shaking table tests on GRSWs was carried out to simulate earthquake damage by the first shaking, repair with soil nails, and the second shaking to estimate seismic stability of the repaired GRSW. The results showed that the seismic resistance of the damaged GRSW was improved by adding soil nails. The effectiveness of adding soil nails in improving seismic resistance was found to depend on the length of the soil nails and the degree of damage to the GRSW. Soil nails which were longer than geogrids suppressed the formation of vertical shear plane behind the geogrid reinforced zone. Therefore, seismic stability of the damaged GRSW increased by long soil nails.

1 INTRODUCTION

Geogrid reinforced soil walls (GRSWs) are recognized to have high seismic stability. However, it is reported that some reinforced soil walls were damaged by large earthquakes such as the 2011 Great East Japan Earthquake with M_W=9.0. After the 2011 earthquake, 1,595 reinforced soil walls in the area of 5+ in the JMA seismic intensity, which is almost equivalent to 8+ in the MM scale, were investigated. According to the damage statistics of the reinforced soil walls, the ultimate limit state was less than 1%, and more than 90% of the walls showed no damage, though seismic motion was much higher than the design value in a wide area and the impact of tsunami was not considered in the design (Kuwano et al., 2014; Miyata, 2014). Although the walls did not collapse completely, wall deformations of significant amounts were observed in the recent large earthquakes. Stability of damaged GRSWs against the next big event is unknown. It is necessary to evaluate the extent of their damage to assess the necessity of repairing or reconstructing them. Wall inclination was proposed to be a good index to evaluate the extent of GRSW damage through a series of laboratory model tests (Izawa and Kuwano, 2011).

Geogrid reinforced soil walls (GRSW) usually use only geogrids as a reinforcing material. But if it is thought that stability of GRSW is not enough with only geogrids, or when the damaged GRSW needs to be repaired, it is expected to add the soil nails. In this paper, a series of shaking table tests on GRSWs into which soil nails were incorporated is reported.

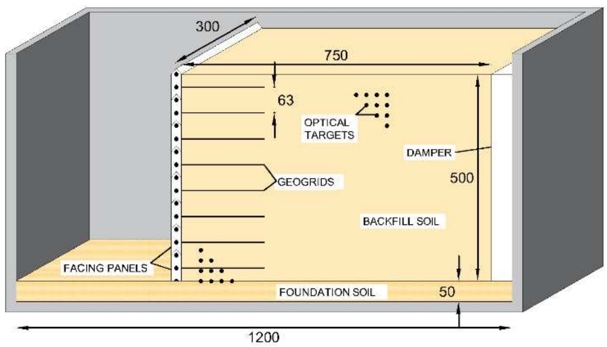

Figure 1. Layout of the model wall.

2 OUTLINE OF THE TESTS

A typical layout of model wall is shown in Figure 1. The dimensions of the models were 750 mm in length, 300 mm in width, and 500 mm in height. The wall

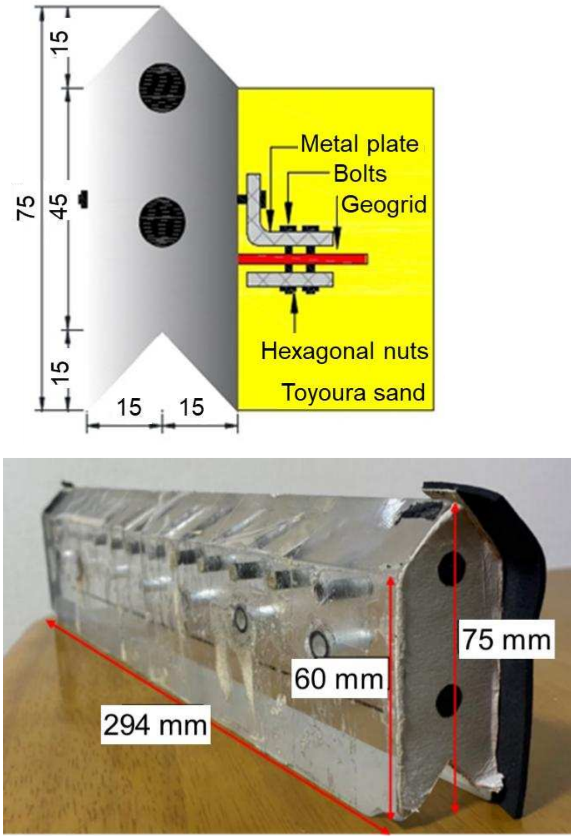

Figure 2. Model facing panel.

Figure 3. Model geogrid and nails fixed to the facing panel.

facing used in the model was made of acrylic panels with wedge-shaped ends, as shown in Figure 2, that allowed rotation at the contacts but restricted any horizontal movement. A model geogrid was fixed on the back of the panel, and two model nails for each panel were inserted to the backfill from the front side through the panel as shown in Figure 3. Toyoura sand (Dr=80%) was used for both backfill and foundation. The model geogrid was made of real geogrid Tensar SS-1 and modified as shown in Figure 3 considering the model size. Pullout friction angle of this geogrid was measured to be 43.2º, which is comparable to the

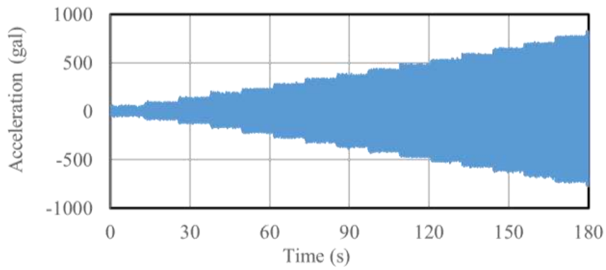

Figure 4. Applied shaking acceleration sequence.

Figure 5. Support in front of facing panels and insertion of soil nails.

geogrid in the real GRSW. 200 mm or 300 mm long screw rods with ϕ5 mm were used for model soil nails as shown in Figure 3. Optical targets were placed within the backfill soil to monitor strain condition by GoPro Hero 7 camera rigidly connected to the front of soil container.

The model walls were subjected to seismic loading in a shaking table using a sinusoidal wave with a frequency of 5 Hz. The amplitude of the wave was increased by 50 gal every 10 seconds as shown in Figure 4 until the walls collapsed completely.

Supports were used when the model GRSW was made to keep the facing panels vertical. But they were also used in the first series of shaking to limit the tilting angle of the wall within the designated value and when the soil nails were inserted before the second series of shaking as shown in Figure 5.

Test conditions are summarized in Table 1. As shown in the notes of the table, all the model GRSWs with the height of 500 mm were reinforced by 200 mm long geogrids (G2). Shaking table tests were conducted in two steps except G2-T0, G2Ns2-T0, and G2Ns3-T0, in which the GRSWs were shaken to collapse completely in the first series of shaking. Soil nails were inserted before the first shaking in G2Ns2-T0 and G2Ns3-T0. In the tests T2 or T4, the walls were shaken to tilt 2% or 4% in the first series of shaking, where 4% wall tilting is serious damage to the GRSW just before the collapse and 2% wall tilting is thought to be medium damage (Izawa and Kuwano, 2011). Supports were fixed in front of the GRSW in the first series of shaking to stop the tilting within the predetermined value of 2% or 4%. After the first shaking, soil nails with the length of 200 mm or 300 mm (Ns2 or Ns3) were inserted as shown in Figure 5. The supports were removed and the second series of shaking was applied until the full collapse to investigate the behaviour and seismic resistance of the repaired GRSW during the following earthquakes.

Table 1. Test cases.

Test case	Wall tilt after the 1st shaking	Reinforcement length (mm)	
		Geogrid	Soil nail
G2-T0	----	200	----
G2Ns2-T0	----	200	200
G2Ns2-T2	2 %	200	200
G2Ns2-T4	4 %	200	200
G2Ns3-T0	----	200	300
G2Ns3-T2	2 %	200	300
G2Ns3-T4	4 %	200	300

G2: 200 mm long geogrid,
Ns2: 200 mm long soil nail, Ns3: 300 mm long soil nail,
T: The wall collapsed in the first series of shaking.
T2: 2% of wall tilt after the first shaking, T4: 4% ditto.

3 RESULTS AND DISCUSSION

Increase of wall tilt with shaking elapsed time is shown in Figure 6 for G2-T0, G2Ns2-T0 and G2Ns2-T0, all of which collapsed by the first shaking. In all three cases, tilt increased rapidly to collapse when it exceeded around 3%. As the vibration of 5Hz increased by 100 gal every 10 seconds, G2-T0 without soil nail collapsed when the amplitude of vibration was about 600 gal. The GRSW with 200 mm soil nails, which were inserted before shaking, collpased at about 700 gal. The GRSW with longer soil nails of 300 mm collapsed for the higher acceleration. This indicates that soil nails inserted to the GRSW even before the damage increased its seismic stability.

Increase of wall tilt with shaking elapsed time is shown in Figure 7 for G2Ns2-T0, G2Ns2-T2 and G2Ns2-T4, all of which 200 mm soil nails were inserted. In G2Ns2-T0, the soil nails were inserted before the first shaking from the vertical facing panels. On the other hand, soil nails were inserted into the GRSWs tilted about 2% or 4% by the first shaking in the test of G2Ns2-T2 or G2Ns2-T4 respectively. Therefore, the wall tilts shown in the figure start from the respective values. As seen in the figure, GRSWs collapsed almost at the same acceleration when the length of soil nail was same

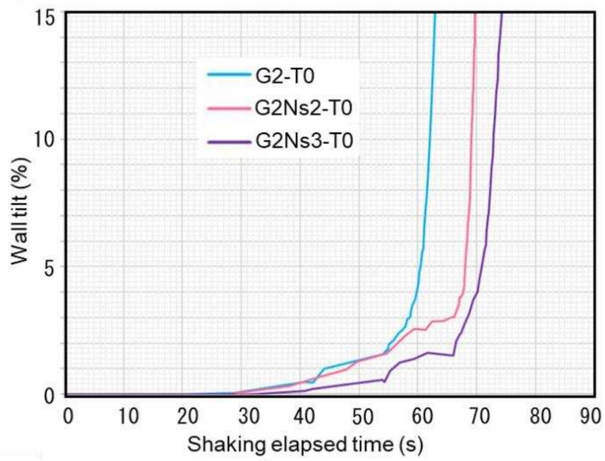

Figure 6. Increase in wall tilt of T0 series with shaking elapsed time.

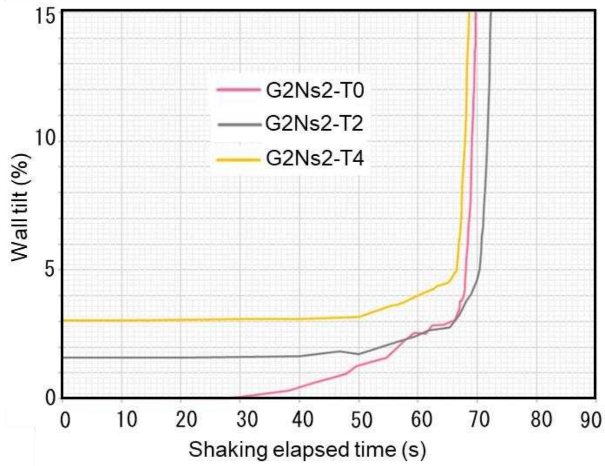

Figure 7. Increase in wall tilt of Ns2 series with shaking elapsed time.

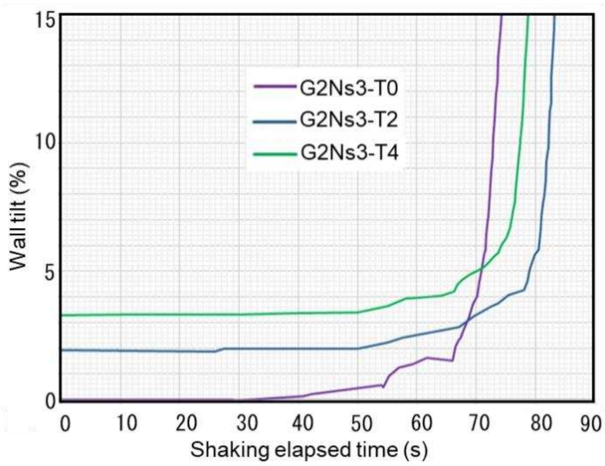

Figure 8. Increase in wall tilt of Ns3 series with shaking elapsed time.

as the length of geogrid.

Increase of wall tilt with shaking elapsed time is shown in Figure 8 for G2Ns3-T0, G2Ns3-T2 and G2Ns3-T4, all of which 300 mm soil nails, longer

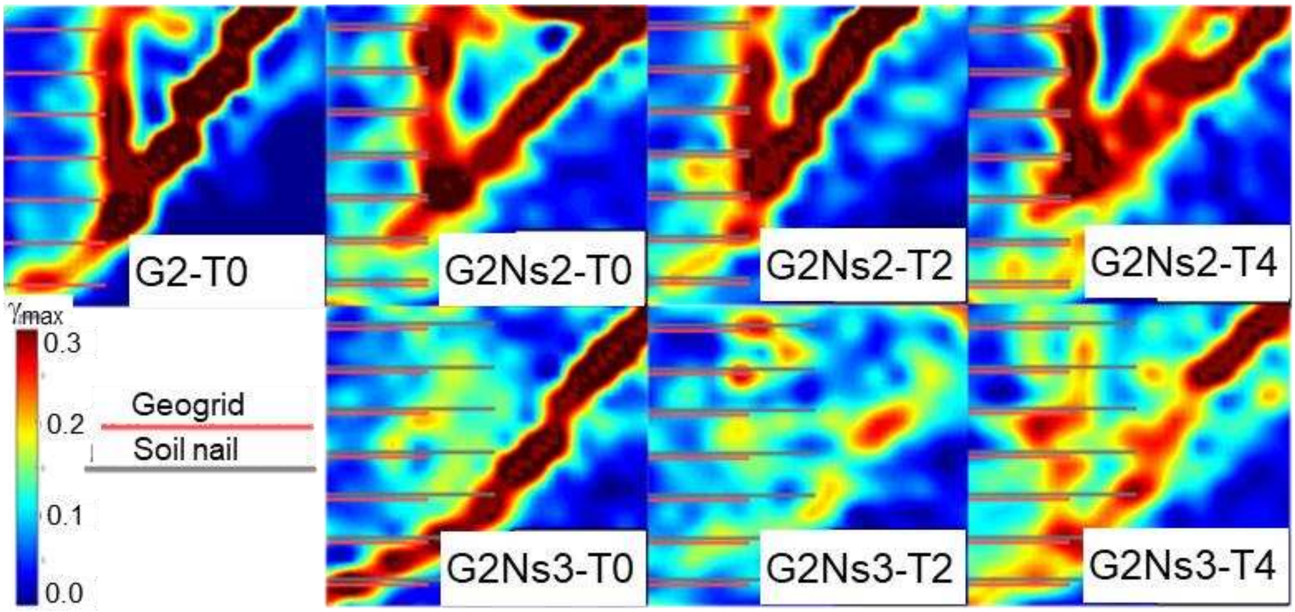

Figure 9. Shear strain distributions just before the collapse of GRSWs.

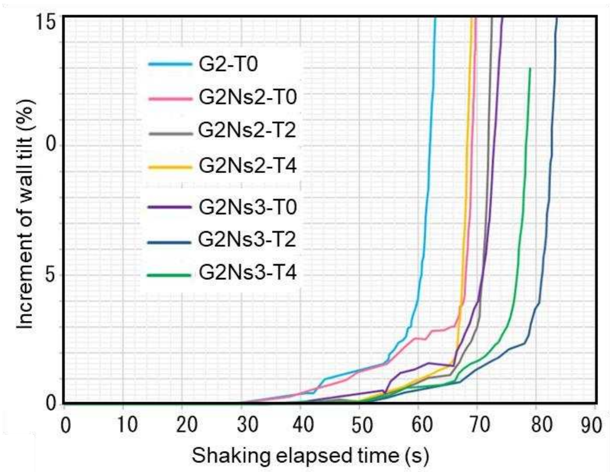

Figure 10. Increment of wall tilt with the shaking elapsed time after the insertion of soil nails.

than 200 mm geogrid, were inserted. Seismic resistance of GRSWs are in the order of G2Ns3-T0 < G2Ns3-T4 < G2Ns3-T2.

Shear strain distributions just before the collapse of GRSWs are shown in Figure 9 for all the test cases. In T0 series, GRSWs without damage were shaken to collapse by the first series shaking. G2Ns2-T0, in which length of the soil nails were the same as that of geogrids, showed vertical shear band at the end of reinforcements. It is similar to G2-T0 in which soil nail was not inserted. However, shear band in the bottom of reinforced area of G2Ns2-T0 was less evident and the shear band for the active slide was gentler as compared with G2-T0. It resulted in higher seismic stability of G2Ns2-T0 than G2-T0. In the case of G2Ns3-T0, 300 mm long soil nails were inserted into the backfill over the 200 mm geogrids. Therefore, a vertical shear band just behind the geogrid was not clearly found and one deep sliding surface was formed.

In Ns2 series, length of soil nails was same as that of geogrids. So the vertical shear bands were formed in all the three cases, though the damage of the wall when soil nails were inserted was different respectively. As the mode of failure was almost same for the three walls, the acceleration to cause collape was almost same as seen in Figure 7.

In Ns3 series, length of soil nails was 300 mm longer than 200 mm of geogrids. It affected formation of shear bands. In the case of G2Ns3-T4, shear bands were already formed when 300 mm soil nails were inserted into the 4% tilted wall over 200 mm geogrids. Therefore, formation of the vertical shear band around the end of geogrids was limited in G2Ns3-T0 and G2Ns3-T2. However, in the case of G2Ns3-T4, shear band was already formed in the 4% tilted wall when soil nails were inserted.

Difference in seismic stability of the tested seven walls is not so obvious in Figures 6 to 8, as the initial values of the wall tilt was different depending on the damage when soil nails were inserted. Figure 10 shows the increment of wall tilt with the shaking elapsed time after the insertion of soil nails. Izawa and Kuwano (2011) reported that the wall tilt reflects the state of backfill and therefore can be an index of damage of GRSW. When the wall tilt is about 3%, shear bands are formed in the backfill and the GRSW is approaching failure. It is seen in Figure 10 that all the GRSWs collapsed at about 3% increment of wall tilt irrespective of the initial damage and soil nail length. Therefore, increment of wall tilt can be an index of extent of damage of repaired GRSW for the following earthquake. It is also seen in Figure 10 that insertion of soil nails into the damaged GRSW increases seismic stability especilly when the length of soil nail is longer than that of geogrid.

4 CONCLUSIONS

When a geogrid reinforced soil wall (GRSW) shows deformation to some extent after an earthquake and its stability is thought to be not sufficient to the next event, it is expected to add the soil nails. In this paper, a series of shaking table tests on GRSWs into which soil nails were inserted is reported.

GRSW into which soil nails are inserted increases seismic stability to the following shaking irrespective of the extent of its damage by the previous shaking.

Effect of soil nails on increasing seismic stability of GRSW depends on the extent of wall damage and length of soil nails. If soi nails longer than geogrids are inserted to GRSW and its damage is moderate, soil nails restrain formation of the vertical shear band at the end of geogrids and increases seismic stability of GRSW.

Stability of the damaged GRSW repaired by soil nails is estimated more properly by the increment of wall tilt after the insertion of soil nails than the toal wall tilt including deformation caused by the first shaking.

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