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Seismic stability of the geogrid-reinforced soil wall combined with soil cement

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ABSTRACT: The new type of geogrid-reinforced soil wall (GRW) combined with soil cement was developed in recent years. The higher stability of GRW was found from the past studies, but so far, little is known about the seismic stability. Therefore, the centrifuge shaking table tests under the centrifugal acceleration of 50 G were carried out to study the behaviour of the new type reinforced wall during earthquake. In the centrifuge tests, the deformation of the wall could be observed by using a CCD camera and image processing system. As a result, GRW combined with soil cement wall exhibited high seismic stability as compared with the conventional GRW and the retaining wall made of soil cement. At the high seismic intensity, however, a tension crack was observed at the top of the soil cement wall. In this case, the generation of tension crack was protected by mixing the short fibers in the soil cement. As a result, the reinforced soil wall showed very high seismic stability.

1 INTRODUCTION

The reinforced soil wall (RSW) method, which is widely used with design flexibility, was developed in recent years. It is considered that the demand for a steep slope is getting higher for the reduction of construction cost by the effective use of site or the reduction of purchase fee and so on. In order to establish the economical and reasonable construction method of the reinforced soil wall, (Ito et al., 2001) developed the new type GRW, whose wall was made of soil cement. Characteristics of this method with the following features:

- A quantity of geogrid can be reduced.
- Construction cost can be restricted by using site waste soil of the site to the soil cement wall.
- The steep slope can be achieved.
- Soils near the wall can be strong.
- The end of the geogrid is not connected to the wall panel.
  … and so on.

In the previous study, it has been reported that stability of the new GRW is sufficient. Since the seismic stability is not known yet and it is important to understand the behavior of the wall during earthquake, a series of centrifuge shaking table tests was conducted to study the seismic stability of the reinforced soil wall combined with soil cement.

2 OUTLINE OF THE TEST

An experimental research program was conducted to study the behaviour of GRW combined with soil cement during earthquake. The centrifuge tests were performed at the geotechnical centrifuge facility in Tokyo Institute of Technology. The Mark 3 centrifuge and 2D-shaker (Takemura et al., 2002) were used.

2.1 *Model geogrid reinforced soil wall*

A typical model soil wall is shown in Figuree 1. The soil cement wall had a height of 200 mm, 10 m in prototype scale when the test is performed at 50 g. Vertical spacing of the reinforcement was also at 20 mm. The length of the reinforcement was 120 mm. The backfill used was air dry Toyoura sand with relative density of 80%. The properties of Toyoura sand are shown in Figure 1.

The soil cement was composed of Toyoura-sand and high early strength Portland cement of 600 N/m^3. The wet density and water content of Toyoura-sand were 16 kN/m^3 and 10% respectively. The curing time was 7 days in order to obtain the unconfined shear strength of q_u = 420 kPa. Vinylon short fibers with length of about 10 mm and thickness of 43 mm which was mixed in the model soil cement wall was the same as used in situ. Ductility of soil cement against the seismic loading can be improve by mixing short fiber.

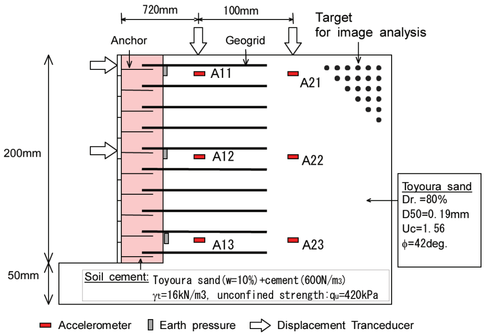

Figure 1. Schematic view of model setup.

Model geogrid was made of polycarbonate with 1 mm in thickness. The schematic view of model geogrid is showed in Figure 2. The holes with a diameter of 10 mm were made at 15 mm interval. Tensile stiffness of geogrid and friction angle between soil and geogrid, which were investigated by tensile test and pullout test respectively, were indicated in Figure 2. They were almost the same as those of the geogrid used in situ. The aluminum panel with 5 mm thickness was used as wall panel.

The test cases were summarized in Figure 3. The reinforced wall of CASE 1 was the conventional GRW which was without soil cement wall. In CASE 2, the soil cement wall was not reinforced with geogrid. The reinforced walls of CASE 3 and 4 were the new GRW combined with soil cement. Anchors in Case 3 were not reached to geogrid and there was non-reinforced area in the soil cement. On the other hand, anchors wer overwrapped with geogrids in Case 4.

2.2 *Test procedure*

The centrifuge shaking table tests were performed at the centrifugal acceleration of 50 G. Some sinusoidal input seismic waves were applied to the model reinforced soil wall with gradually increasing amplitude of acceleration. Properties of seismic wave are shown in Figure 4. During the test, displacements,

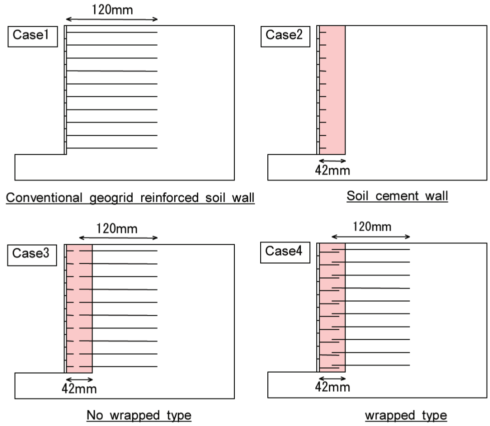

Figure 3. Cross-sections of model walls.

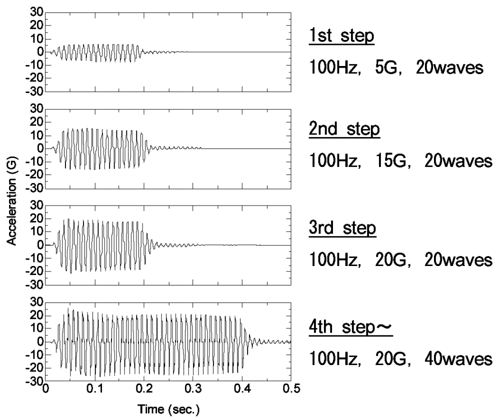

Figure 4. Time histories of input seismic wave.

earth pressures and acceleration responses were measured by some transducer and accelerometers which were shown in Figure 1. Deformation of the model wall was monitored by a CCD camera through the Perspex window of the container. Image analyses were done by using the digital image captured from CCD camera (Tayler et al., 1998).

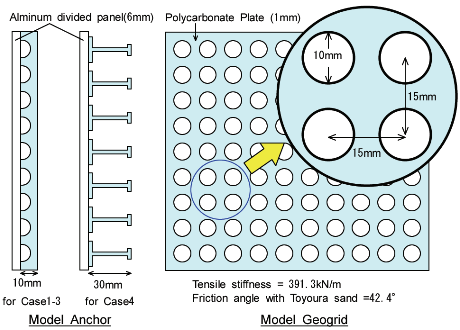

Figure 2. Propeties of model geogrid and anchor.

3 EXPERIMENTAL RESULTS

3.1 *Failure mode*

Figure 5 shows the vectors of displacement and photographs at failure. Since the test CASE 1 was stopped at 4th shaking step, clear failure was not observed. The model wall of CASE 2, which was not reinforced with geogrid, was overturned at the toe of wall at the first shaking. After that, crack was observed from the toe as shown in the photograph and collapsed at the 2nd shaking step (8.8 G, Horizontal seismic

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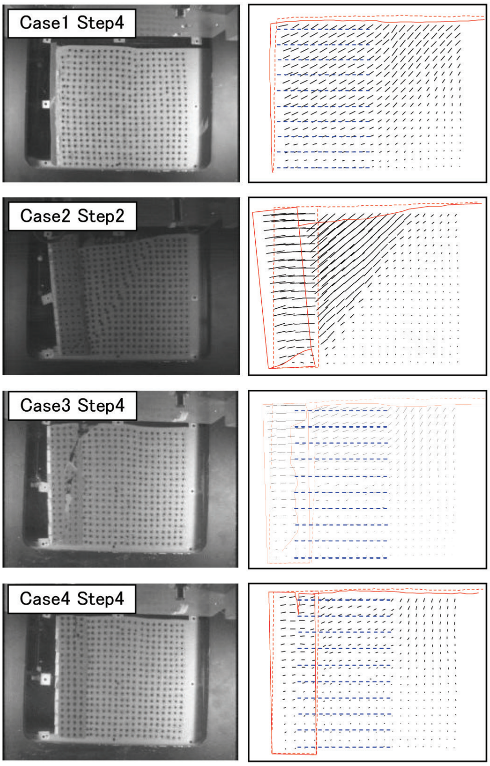
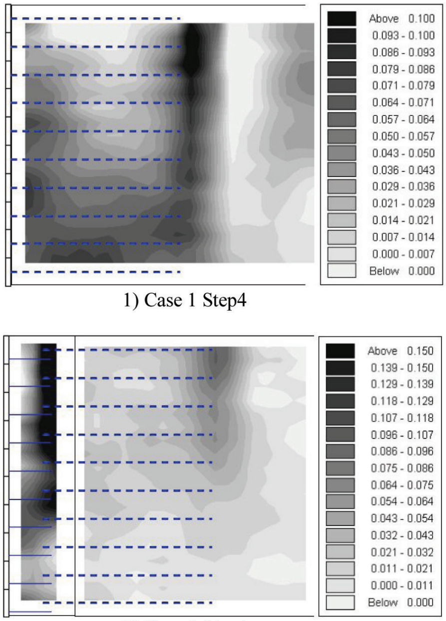


Figure 5. Photographs and displacement vectors at failure.



2) Case 4 Step4

Figure 6. Distribution of shear strain: γ_{vh}.

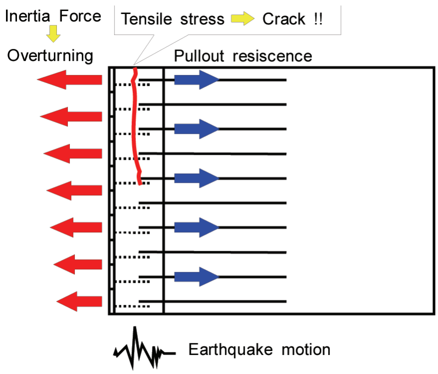


Figure 7. Crack generation in soil cement wall.

coefficient: kh = 0.176). In CASE 3, whose wall was made with soil cement, deformation was much smaller at the 1st and 2nd shaking step as compared with CASE 1 and 2. But the crack appeared in the vertical direction through the soil cement wall at the 4th shaking step (22.9G, kh = 0.458, number of waves: 20) as shown in Figure 5. Figure 7 explains how to generate the crack in the soil cement wall. During the shaking, the inertia force on the soil cement wall made the wall overturned, and the tension force was induced in the geogrid to resist the overturning of the wall. Two forces, which were the inertia force and the tension force from geogrid, acted in the opposite direction.

Therefore, the tension force was induced in the soil cement wall and the tension crack appeared. Crack was observed also at the shaking step 4 in CASE 4. But it was not through the soil cement wall and restricted at the top area as compared with that of CASE 4, because the anchors reached to the geogrids in the soil cement and increase of crack was protected.

Figure 6 (1) and (2) show the distribution of shear strain, which were obtained from image analysis. Shear strain concentrated at the bottom of reinforced area, although the mode reinforced soil wall was not collapsed. On the contrary in Case 4, shear deformation of reinforced area was rather uniform and concentration of strain was not appeared. Same distribution of shear strain was observed in Case 3. That is to say, concentration of strain can be protected by using soil cement wall.

3.2 *Deformation behavior*

Generally, the maximum input acceleration is usually used as a parameter, which indicates the seismic intensity, but effects of the shaking duration cannot be considered. Therefore, as the parameter indicating the seismic power, the acceleration power was determined below:

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

a : Input acceleration
T : Shaking time

Deformation of each case was compared by using the acceleration power. Fiugre 8 shows the relationships between cumulative lateral displacement, which was determined form the displacement of the target at the top of the soil wall, and acceleration power. The broken line indicates the acceleration power which was calculated from the record of Hyogo-ken-nambu Earthquake and Kushiro Earthquake. Horizontal displacement of Case 1 was larger than those of Case 3 and 4 because shear strain of Case 1 was concentrated at the bottom of reinforced area. Cracks appeared in the soil cement wall at the 4th shaking step in also Case 3 and 4. But displacement of the wall in Case 3 was almost twice as large as that in Case 4. It was because the crack of Case 3 run through the whole soil cement wall. These results clearly show that GRW combined with soil cement has a high seismic stability.

4 CONCLUSIONS

This study has explored the seismic stability of reinforced soil wall combined with soil cement. The conclusions obtained from this study are as below.

- In the cases of the new type reinforced soil wall, the tension crack in the soil cement wall was observed by two forces, which were the inertia force and the reinforced force. However, before crack appeared, the new type of reinforced soil wall showed the higher seismic stability as compared with the conventional geogrid reinforced wall. It was because the concentration of shear strain in the reinforced backfill soil area could be restricted.
- By extending the anchors to the edge of the geogrids, increase of crack was protected. As a result, deformation could be restricted and the higher seismic stability could be obtained. On the basis of the result, the anchors extend to the panel without connection in a present design code.

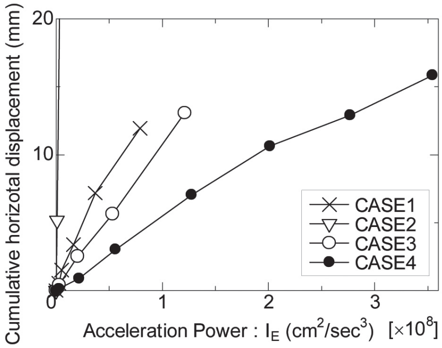


Figure 8. Relationships between horizaontal displacement and acceleration power.

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