New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
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Development of rational design method for the geogrid reinforced soil wall combined with soil cement and its application

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ABSTRACT: A geogrid reinforced soil wall (GSW) combined with soil cement was recently developed and the application of this method has been used increasingly. From the results of the past centrifuge shaking table tests, it is clearly shown the effectiveness of the GSW to increase seismic stability. This current research was then continued to study the effect of the arrangement of geogrid and soil cement wall in order to develop a new rational design method of GSW for practical use in the real construction site. To achieve this target, a series of centrifuge shaking table teats were then carried out. Results show that even if the size of the width of the cement wall was reduced remaining only 2/3 of the full width but the seismic stability of the GSW is still the same and effect of the length of geogrid laid at the upper part of the wall plays the higher important role to the seismic stability than that of in the lower part. Based on these two results, the new design concept was developed. It was shown in details in this paper about the new design method and an example of case study in Japan using this new design concept to reduce the length of geogrid and the width of soil cement.

1 GENERAL INSTRUCTIONS

Geogrid reinforced soil wall (GSW) method 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 a new type GSW, whose wall was made of soil cement as shown in Figure 1. Saito et al. studied seismic behavior of the wall and indicated that it showed higher seismic stability than GSW with only divided panel type wall. In this paper, it is focused on arrangement of soil cement wall and geogrid for more rational design. For that purpose, centrifuge shaking table tests were conducted in order to investigate both static and seismic stability of this method with shorter width of soil cement wall or length of geogrid because arrangement of soil cement wall and gaogrid are determined by evaluation of seismic stability. Finally, case histories, which were designed by new rational method, are reported.

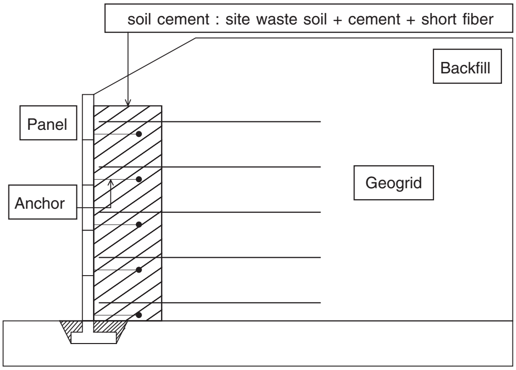


Figure 1. Schematic view of the reiforced soil wall combined with soil cement.

2 OUTLINE OF THE TEST

2.1 *Model GSW*

A typical model soil wall is shown in Figure 2 and Photograph 1. The soil cement wall had a height of 200 mm, 10 m in prototype scale when the test is

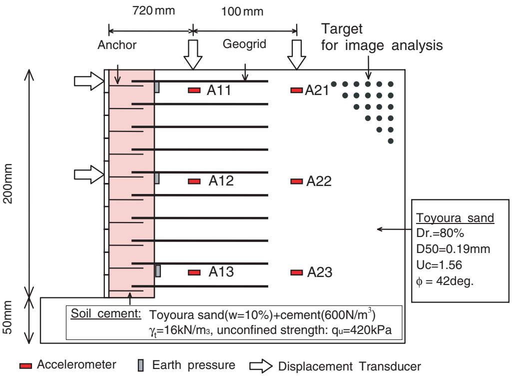


Figure 2. Schematic view of model setup.

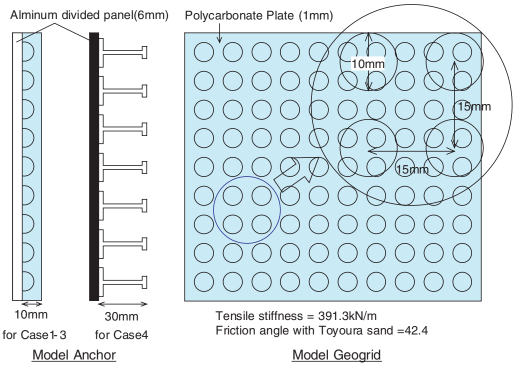


Figure 3. Details of model geogrid and anchor.

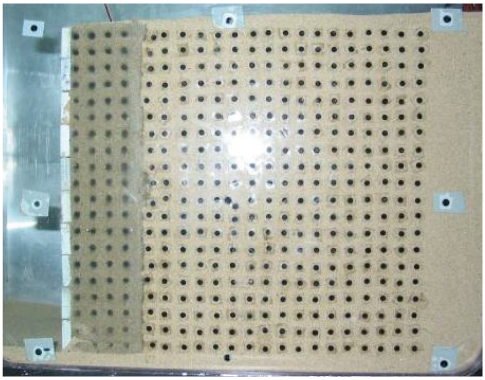


Photo 1. Model of the reinforced soil wall.

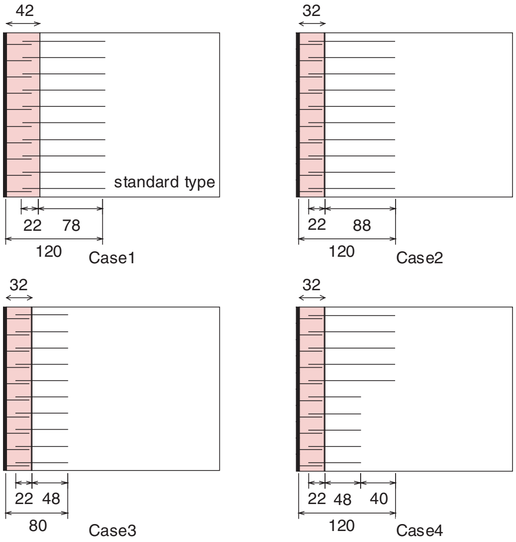


Figure 4. Test cases.

performed at 50 g. Vertical spacing of the reinforcement was also at 20 mm. The backfill used was air dry Toyoura sand with relative density of 80%. The properties of Toyoura sand are shown in Figure 2.

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 diameter of 43∞m 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 improved by mixing short fiber.

Model geogrid was made of polycarbonate with 1 mm in thickness. The schematic view of model geogrid is showed in Figure 3. 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 summarized in Figure 3. 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 shown in Figure 4. Case1 is the standard case and Model of it was designed by using previous design procedure. Model of Case2 had shorter width of soil cement wall as compared with that of Case1. But End of geogrid was the same with Case1. In Case3, length of geogrids was also shorter. According to the past study, not so large strains were not observed in bottom geogrids. Therefore, it seems that length of bottom geogrids may be shorter and length of upper geogrid is more important for stability of GSW. Consequently, model of Case 4 had shorter length of bottom geogrids and usual length of upper ones.

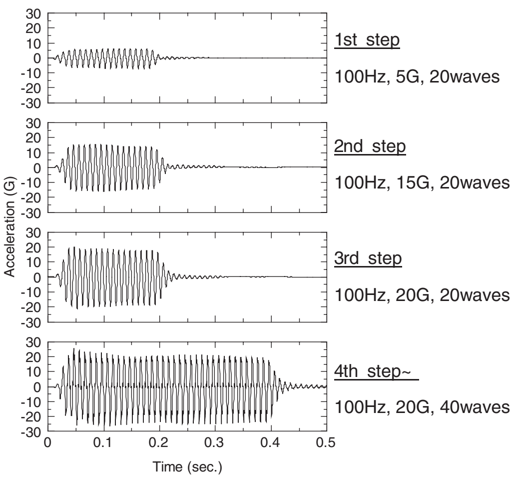


Figure 5. Time histories of input seismic wave.

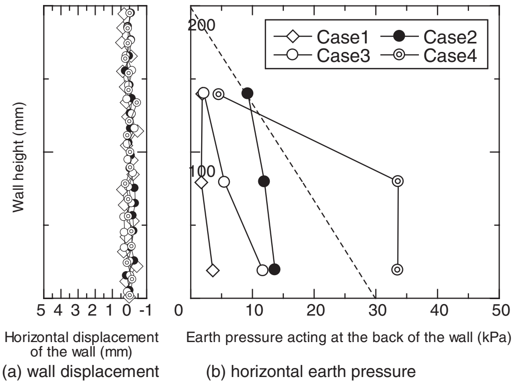
2.2 *Test procedure*

The centrifuge shaking table tests were performed at the centrifugal acceleration of 50G. Some sinusoidal input seismic waves shown were applied to the model reinforced soil wall with gradually increasing amplitude of acceleration. Properties of seismic wave are shown in Figure 5. During the test, displacements, earth pressures and acceleration responses were measured by some transducer and accelerometers which were shown in Figure 2. 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.

3 TEST RESULTS

3.1 *Stability at centrifugal acceleration of 50G*

Figure 6 shows distributions of horizontal earth pressure acting on soil cement wall and horizontal displacement of wall at centrifugal acceleration of 50G in order to evaluate the stability in ordinary condition. Broken line as shown in Figure 6(b) indicates horizontal earth pressure distribution calculated by using Coulomb's equation. Smallest horizontal earth pressure was observed in Case1, which was designed by past design code and its values were much smaller than that obtained from Coulomb's equation. That is to say, horizontal earth pressure acting on the wall could be reduced by laying geogrids in back fill. In Case 2, whose width of soil cement wall was 10 mm shorter than that of Case1 but end of geogrid was the same as the end of Case1, about 4 times as large horizontal earth pressure as Case1 was measured. It turns out that horizontal earth pressure which acts on the wall becomes large if reinforced area becomes large. On the other hand, in Case3, whose width of soil cement wall and length of geogrids were shortest of all cases, horizontal earth pressure was smaller than that of Case2. The reason is why the soil cement wall in Case3 moved horizontally and stress state in reinforced backfill was active state as compared with in Case1 and 2. But it was not confirmed because difference of horizontal displacement among all cases was not observed. In Case4, whose length of upper and lower geogrids was the same as Case2 and Case3 respectively, movement of the wall was restricted by upper geogrids. But large earth pressure acted on the lower part of the wall due to shortage of geogrids.



(a) wall displacement (b) horizontal earth pressure

Figure 6. Wall displacement and horizontal earth pressure acting on soil cement at centrifugal.

As mentioned above, sufficient stability in ordinary state could be observed in all cases. But earth pressure distribution which acts on a soil cement wall differs greatly by influence of width of the wall or length of geogrids.

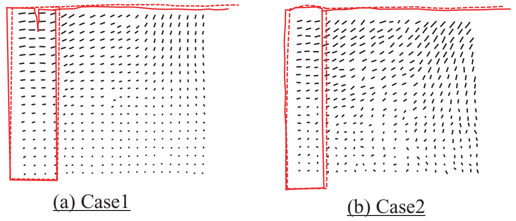
3.2 *Seismic stability*

Figure 7 shows displacement vectors after finishing 4th seismic step of all cases. Although the soil cement wall overturned during shaking, progressive failure was prevented by tensile force of geogrids in all cases.

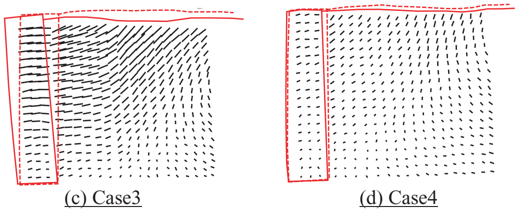
It has been recognized that displacement of reinforced soil wall during earthquake accumulates with shaking in the past studies (Izawa et al. 2002). Therefore, acceleration power is used as index to indicate seismic scale. Acceleration power can consider not only seismic intensity but also duration of shaking and it is calculated by Equation (1).

$$I_E = \int_0^T a^2(t)dt \qquad (1)$$

a : *Input acceleration*
T : *Shaking time*



(a) Case1 (b) Case2



(c) Case3 (d) Case4

Figure 7. Displacement vectors after step 4.

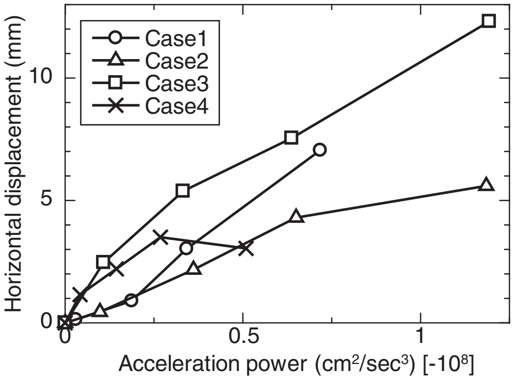


Figure 8. Relationships between horizontal displacement at top of the wall and cumulated acceleration power.

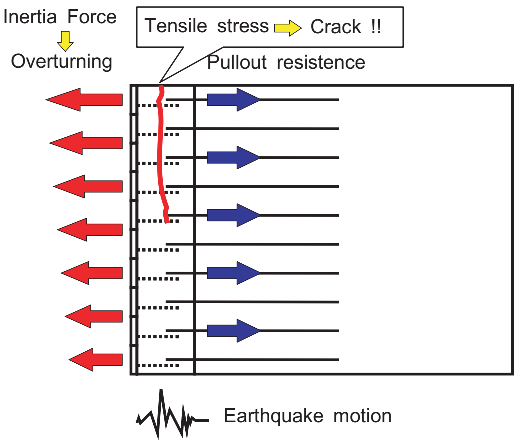
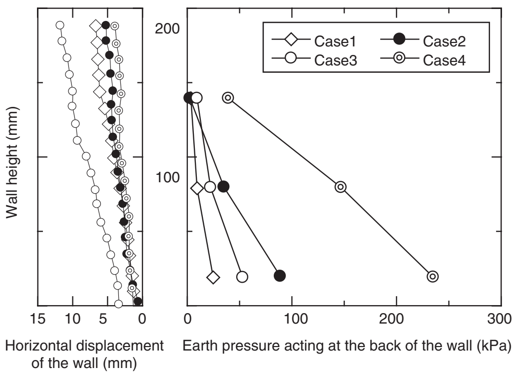


Figure 9. Illustration of generating crack in the soil cement wall.



(a) Wall displacement

(b) Horizontal earth pressure

Figure 10. Wall displacement and horizontal earth pressure acting on soil cement after 4th shaking step.

Figure 8 shows relationships between horizontal displacement at top of the wall and cumulated acceleration power. Almost the same horizontal displacement were observed in Case1 and Case2 until the acceleration power reached about 0.25 × 10^8(cm^2/sec^3). After that, increment of displacement in Case1 was larger than that in Case2 because the soil cement wall cracked at the top of the wall. As shown in Figure 9, tension force occurred in the soil cement wall due to inertia force of the wall and tension force of geogrid to prevent from overturning of the wall during shaking. As a result, the soil cement wall collapsed. On the other hand, such tension crack was not observed in Case2. If the soil cement wall is made small, inertia force of the wall decrease with reduction in weight. Accordingly, large tension force did not occur in the soil cement wall in Case2 and generation of crack could be prevented.

In Case3, the soil cement wall overturned and almost collapsed as shown in Figure 8 due to shortage of geogrid. Such large deformation was not observed in Case4 because length of upper part geogrid was longer and it acted effectively in the prevention from overturning of the wall. But large horizontal earth pressure acted on the wall as shown in Figure 10.

3.3 *Summary*

If the width of soil cement wall is reduced about 20%, the wall has sufficient static and seismic stability. Moreover, generating of a crack in the soil cement wall can be prevented due to reduction of inertia force acting on the wall. On the other hand, length of geogrid is very important for seismic stability of the soil cement wall. Although collapse could be prevented if the length of upper part geogrid was excelled, large horizontal displacement and horizontal earth pressure acting on soil cement wall were observed.

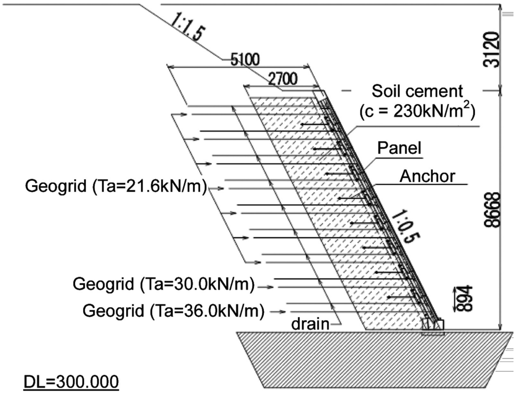


Figure 11. Configuration of Application site 1.

Photo 2. Application site 1.

New design code was developed for the purpose of cost reduction of construction in consideration of test results. In the code, width of soil cement wall can be reduced as compared with past design code because almost the same seismic stability with usual one was shown in the centrifuge model test. In next chapter, two applications, which designed by using new design code, were reported.

4 EXAMPLE OF CASE STUDY

4.1 *Application for reclaimed site*

New rational design method was applied to reclaimed area in Kumamoto prefecture, Japan. Volcanic cohesive soil, which is the peculiar volcanic soil around Mt. Aso area in Kumamoto, was used for soil cement wall. Backfill material is the other sandy soil in order to achieve sufficient fiction between soil and geogrid. Soil properties are shown in Table 1. Height and slope of GSW is 8.7 m and 1:0.5 respectively as shown in Figure 11 and Photograph 2. Moreover, there is embankment with 3.2 m in height above the GSW.

Table 1. Soil properties in application site 1.

	Back fill	Soil cement wall
Specific gravity	2.595	2.632
Natural water content w_n (%)	43.6	58.2
Gradation		
Gravel (%)	38.7	0.2
Sand (%)	43.7	63.6
Silt (%)	14.3	30.9
Clay (%)	3.3	5.3
Maximum dry density ρ_{dmax} (kN/m^3)	11.85	10.70
Optimal water content w_{opt} (%)	39.6	39.5
c_u (kN/m^2)*	27.5	–
ϕ_u (deg.)*	27.2	–

*$\rho = 10.67$ (kN/m^3) at water content $= w_n$

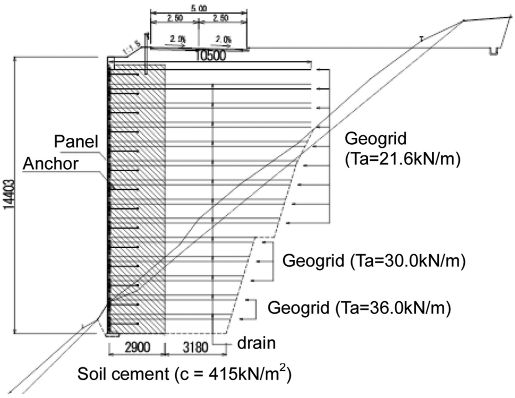


Figure 12. Configuration of Application site 2.

Mixture was determined by unconfined compression test as shown in Table 1. It was conformed that soil cement wall in-situ had the necessary strength. In this site, construction cost could be reduced about 6% because soil cement wall width could decrease from 3.2 m to 2.7 m by using new design code.

4.2 *Application for road embankment*

Second application is at road embankment site also at Kumamoto Prefecture. Maximum height of the wall is over 14m as shown in Figure 12 and Photograph 2. Backfill material is gravelly soil, which was made with crashed weathered rock at the construction site. Properties of backfill soil are shown in Table 2. The same gravelly soil used as Backfill material was also used for soil cement wall. Also at this site, width of the soil cement wall width could make less from 3.4 m

Photo 3. Application site 2.

Table 2. Soil properties in application site 2

		Back fill
Specific gravity		2.814
Natural water content w_n (%)		6.8
Gradation		
	Gravel (%)	92.2
	Sand (%)	5.6
	Silt (%)	2.2
	Clay (%)	
Maximum dry density ρ_{dmax} (kN/m^3)		21.3
Optimal water content w_{opt} (%)		6.2
c_u (kN/m^2)*		60.7
ϕ_u (deg.)*		32.6

*$\rho = 19.17$ (kN/m^3) at water content $= w_n$

to 2.9 m by using new design code. As a result, construction cost could be reduced about 5%. This wall is showing very high stability in spite of a very high perpendicular wall.

5 CONCLUSIONS

Results of centrifuge model tests indicated that the reinforced soil wall combined with soil cement has sufficient stability both in ordinary and seismic state although its soil cement wall width is reduced about 20% as compared with the model designed by past design code. On the basis of results of centrifuge model tests, new design method, which can reduce width of soil cement wall, was made. New design procedure was applied to two construction site at Kumamoto prefecture in Japan. Construction cost could be reduced about 5% in both site by using new design method. Additionally, they show high stability in spite of severe conditions.

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