Shaking table tests on combined use of EPS and geogrid to improve seismic stability of bridge abutments

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ABSTRACT: In order to study the effects of combined use of EPS (block of expanded polystyrene) and geogrid to improve seismic stability of bridge abutments, a series of 1-g shaking table tests are conducted on a reduced-scale model of a cantilever type bridge abutment and its backfill soil. The test results revealed that, under severe excitation conditions at 700 to 1000 gals, both the base sliding and the tilting of the wall could be reduced by placing geogrid-reinforcement in the backfill soil. In addition, instead of placing the upper geogrid-reinforcement, the base sliding of the wall could be further reduced by replacing partly the backfill soil with blocks of EPS in combination with the use of the middle-height geogrid. Placing EPS blocks above the middle-height geogrid was more effective than placing them below the geogrid. The relative settlement of the backfill soil at the interface with the wall could be also reduced by the combined use of EPS and geogrid.

Keywords: EPS, geogrid, bridge abutment, backfill soil, seismic stability, model test

1 INTRODUCTION

In many of the past large earthquakes in Japan, such the 1995 Hyogoken-Nanbu (Kobe), the 2004 Niigataken-Chuetsu, and the 2011 Off the Pacific Coast of Tohoku (Great East Japan) earthquakes, a significant number of conventional type soil retaining walls suffered severe damage (Tatsuoka et al., 1997, 1998, Koseki et al., 2006a, 2006b & 2012, Koseki, 2012). They include bridge abutments that exhibited considerable residual displacements of the abutment body and large differential settlement at the interface between the abutment body and the backfill soil (Aoki et al., 2003), as typically shown in Figure 1.

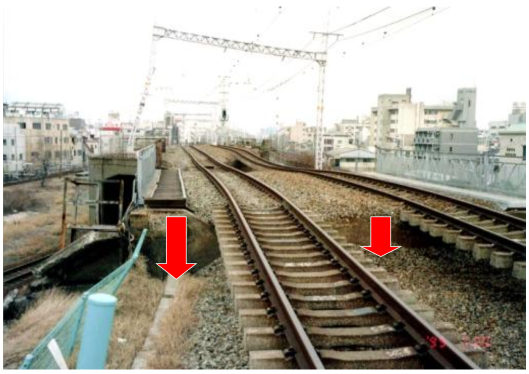


Figure 1. Backfill settlement of railway bridge abutment induced by the 1995 Hyogoken-nanbu earthquake, Japan (Aoki et al. 2003).

Though a variety of aseismic countermeasures have been developed and adapted in practice (Watanabe, et al., 2002, Aoki et al., 2003, Huang, et al., 2006, Tatsuoka et al., 2009 among others), there still is a need for improving effectively and efficiently the seismic stability of bridge abutments, in particular the existing ones.

In view of the above, in order to study the effects of combined use of EPS (block of expanded polystyrene) and geogrid to improve seismic stability of bridge abutments, a series of 1-g shaking table tests are conducted on a reduced-scale model of a cantilever type bridge abutment and its backfill soil. In addition to the high seismic stability of the geogrid-reinforced soil retaining walls, it is expected that the different seismic response characteristics of the abutment body and the geogrid-reinforced backfill soil would be smoothened at their interface by inserting EPS. While referring to the model test results conducted by Zarnani and Bathurst (2007) on single use of EPS as seismic buffers, it is also expected that the deformable EPS would serve as a buffer to prevent excessive mobilization of tensile force in the geogrid at its connection with the abutment body.

2 TEST PROCEDURES

Cross-sections and a typical plan-view of the cantilever type bridge abutment models that were employed in the present study are shown in Figure 2. In total 12 cases of model tests were conducted, while results from 5 cases with different backfill soil conditions as summarized in Table 1 will be reported herein.

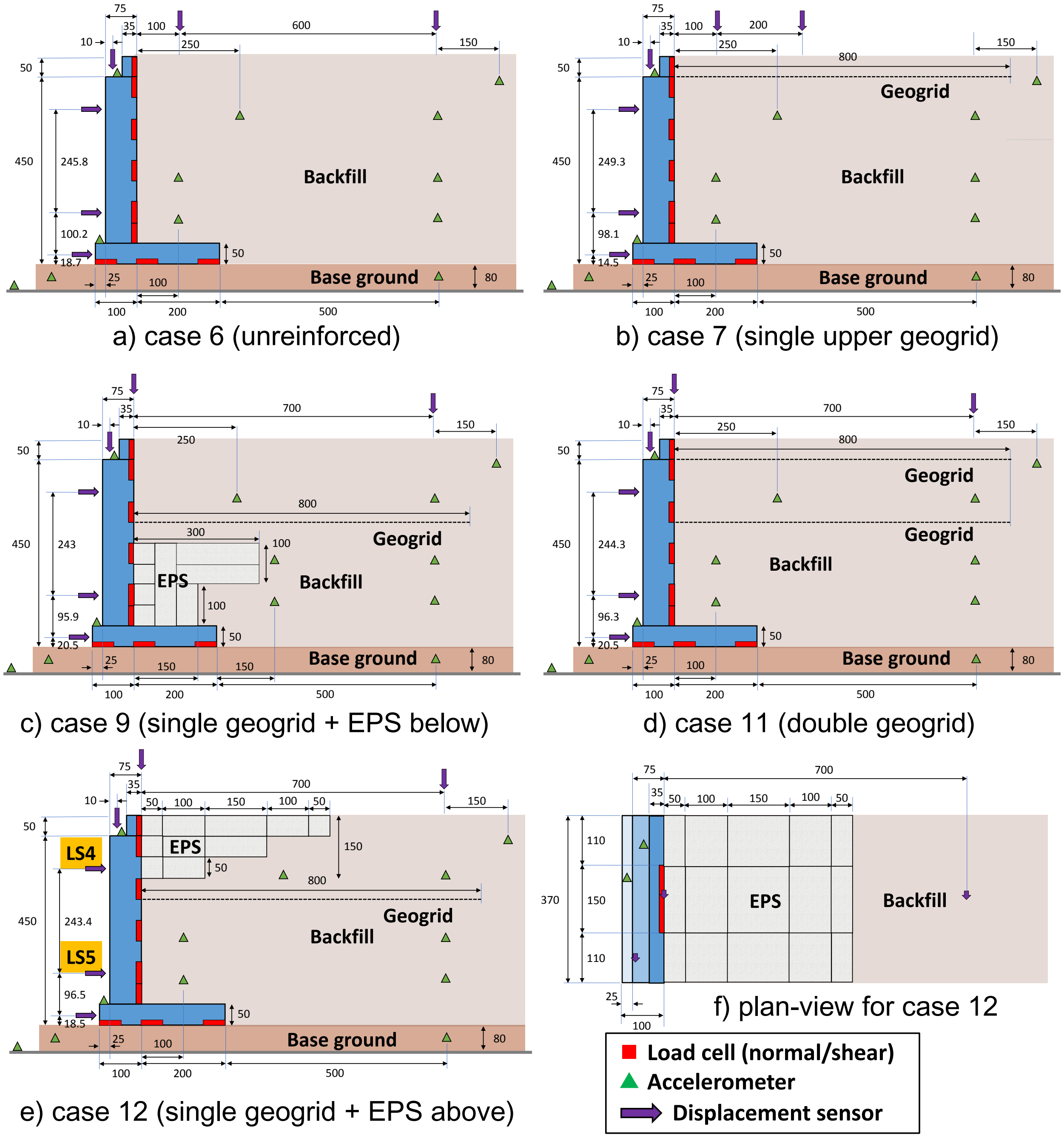


Figure 2. Cross-sections for a) case 6, b) case 7, c) case 9, d) case 11 and e) case 12; and f) plan-view for case 12 (unit in mm).

Table 1. Backfill soil conditions for five cases of model tests.

Case	Backfill soil conditions	
	Geogrid reinforcement*	EPS**
6	-	-
7	Single layer at upper height	-
9	Single layer at middle height	Below geogrid
11	Double layers at middle and upper heights	-
12	Single layer at middle height	Above geogrid

* With unified length for each layer; L=800 mm.
** With unified total volume per unit width; $V=4.5*10^4$ mm^3/mm.

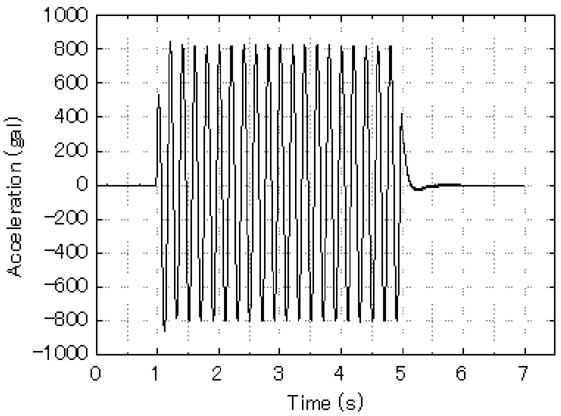


Figure 3. Typical time history of base acceleration.

The models were prepared in a rigid soil container having a length of 260 cm and a width of 37 cm and subjected to several shaking steps of horizontal excitation with a base acceleration consisting of 20 cycles of sinusoidal waves at a frequency of 5Hz, as typically shown in Figure 3. The maximum amplitude of the base acceleration a_{max} was initially set to 100 gals and was increased at an increment of about 100 gals.

The abutment wall was made of aluminum, with a total height of 50 cm and a base length of 35 cm. The average unit weight of the wall was adjusted into 24.6 kN/m^3, while referring to that of reinforced concrete. The horizontal and vertical displacements of the wall were measured with laser-based non-contact type displacement sensors. The normal and shear forces acting on the backface of the wall as well as the bottom of the base were measured by two-component load cells, which will be reported elsewhere.

Air-dried silica sand #7, having e_{max}=1.243; e_{min}=0.743; Gs=2.64; and D_{50}=0.21 mm, was pluviated through air to form a 50 cm-thick backfill soil layer and a 8 cm-thick level subsoil layer at a relative density of 90 %. Several accelerometers to measure the horizontal response were installed in these soil layers and the wall.

As a geogrid model for the reinforcement, a mesh sheet made from polypropylene was used and connected to the wall model in all the relevant cases. It has a nominal aperture size of 0.84 mm and exhibits tensile strengths of 580 N/5cm in the longitudinal direction and 770 N/5cm in the transverse direction.

As an EPS model, a block of expanded polystyrene having a unit weight of 0.20 kN/m^3 was used. In case 9 where the EPS was placed below the geogrid, all the EPS blocks were connected to each other, while in case 12 where the EPS was placed above the geogrid, no internal connection was provided so that each of the EPS blocks would follow the local displacement of surrounding backfill soil.

3 TEST RESULTS

3.1 *Residual displacement of wall*

As typically shown in Figure 4, the horizontal displacement of the wall was measured at two elevations, denoted as LS4 and LS5 in Figure 2. Based on these results, the residual horizontal displacement of the wall at its top and base positions are evaluated and plotted versus the base acceleration in Figures 5a and 5b, respectively. In addition, the residual tilting of the wall was also evaluated and plotted in Figure 5c.

In the early shaking steps up to a base acceleration value of about 600 gals, the residual horizontal displacement and tilting of the wall were not significant for all the cases. When the base acceleration reached 700 gals, however, the wall with unreinforced backfill (case 6) exhibited larger residual horizontal displacement and tilting than the other walls with reinforced backfill.

At the shaking steps of 800 to 1000 gals, following trends of behavior could be observed:

– The wall displacement and tilting accumulated further with the unreinforced case, which could be reduced by placing a single layer of geogrid in the backfill soil (case 7). The effect of the geogrid-reinforcement was more significant with the case by using double layers of geogrid (case 11), in reducing the residual tilting of the wall in particular.
– Instead of placing the upper geogrid-reinforcement in case 11, the base sliding of the wall could be further reduced by replacing partly the upper backfill soil with blocks of EPS (case 12) in combination with the use of the middle-height geogrid. On the other hand, placing EPS blocks below the middle-height geogrid (case 9) was less effective than placing them above the geogrid in case 12.

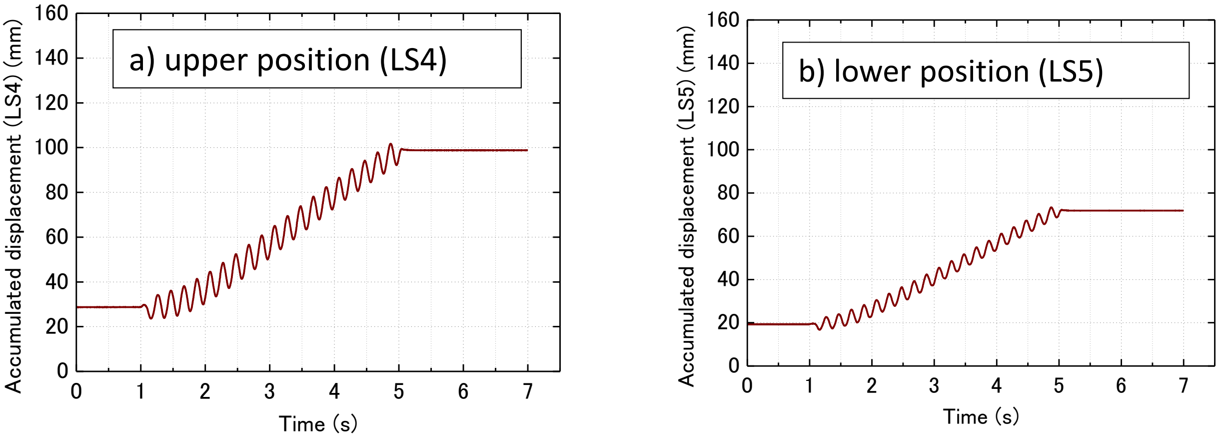


Figure 4. Typical time histories of horizontal wall displacement measured at a) upper and b) lower positions (in case 12 during shaking step of 900 gal).

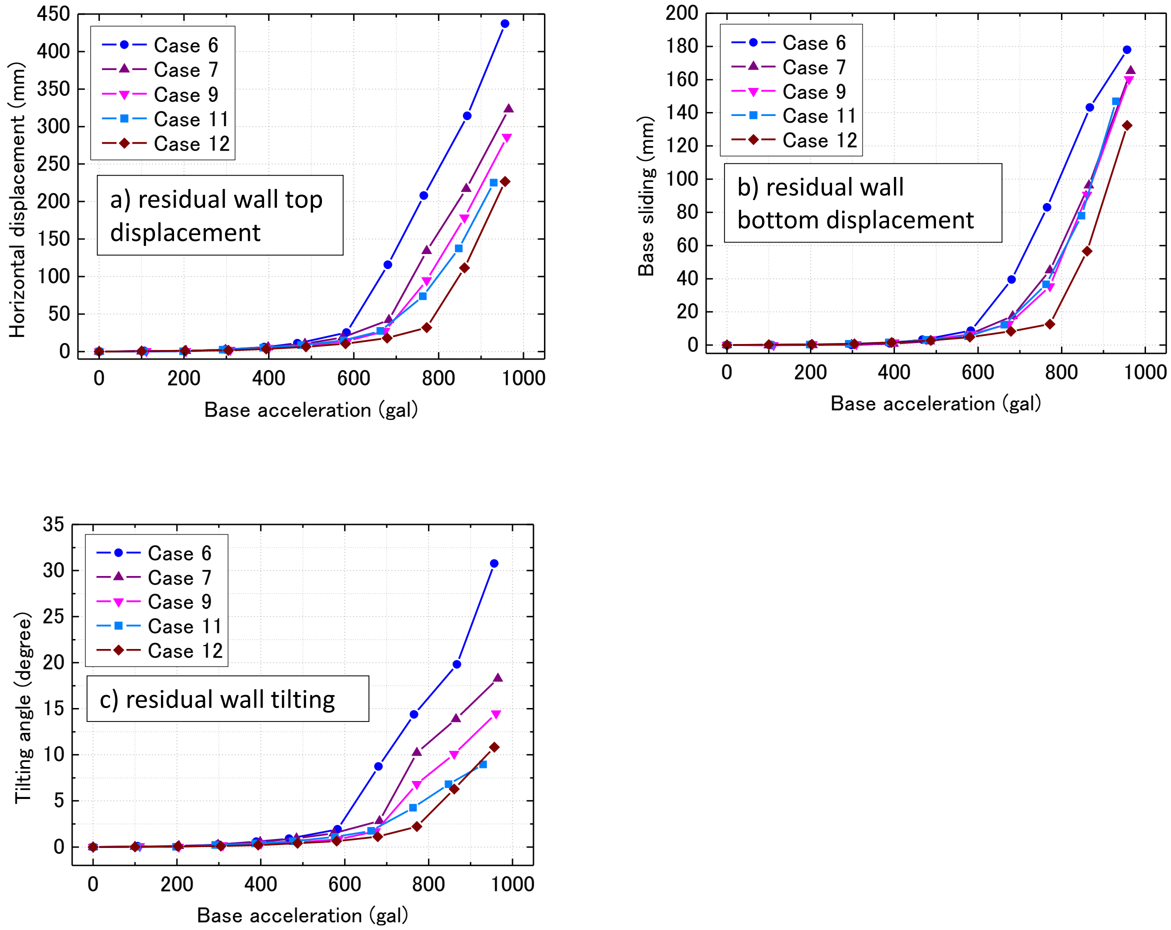


Figure 5. Residual displacements of wall evaluated at a) top and b) bottom positions; and c) residual tilting of wall.

3.2 *Residual settlement of backfill soil relative to wall*

Residual settlements of the backfill soil relative to the wall at their interface at the end of each shaking steps are plotted in Figure 6 versus the residual horizontal displacement of the wall at the middle height of 250 mm above the wall base.

With the unreinforced case (case 6), the relative settlement of the backfill soil was accumulated gradually with the increase in the horizontal displacement of the wall. With the reinforced cases, on the other hand, it could be reduced largely, and the following trends of behavior could be observed:

– Use of double geogrid layers (case 11) was more effective than use of single geogrid layer (case 7) in reducing the relative settlement of the backfill soil.
– The relative settlement of the backfill soil could be further reduced by the combined use of EPS and geogrid (cases 9 and 12).

It should be noted, however, that the EPS blocks in case 12 that were located on the other side of the wall suffered from residual uplift relative to the surrounding backfill soil and separation from each other, as shown in Figure 7. Future studies are required on this issue.

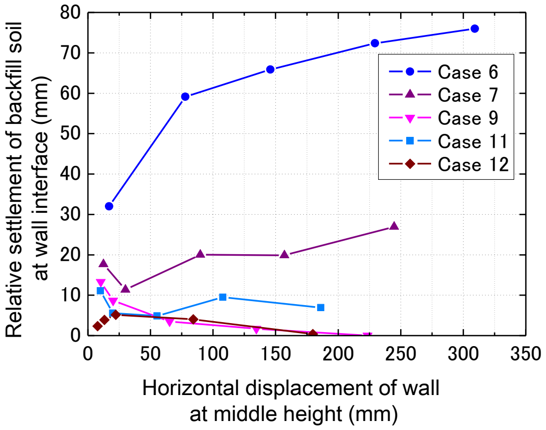


Figure 6. Relationship between horizontal wall displacement at middle height and relative settlement of backfill soil at wall interface.

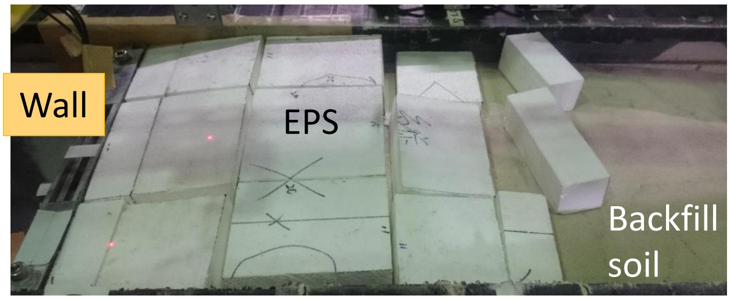


Figure 7. Top-view of EPS blocks in case 12 after shaking step of 900 gal

3.3 *Formation of failure planes in backfill soil*

Figure 8 shows the side-views of the wall, backfill soil and subsoil for case 12 after the shaking steps of 800 gal and 900 gal. After the shaking step of 800 gal, two failure planes became visible in the backfill soil. They developed further during the shaking step of 900 gal, which was accompanied by relatively large accumulation of wall displacements (Figures 4 and 5).

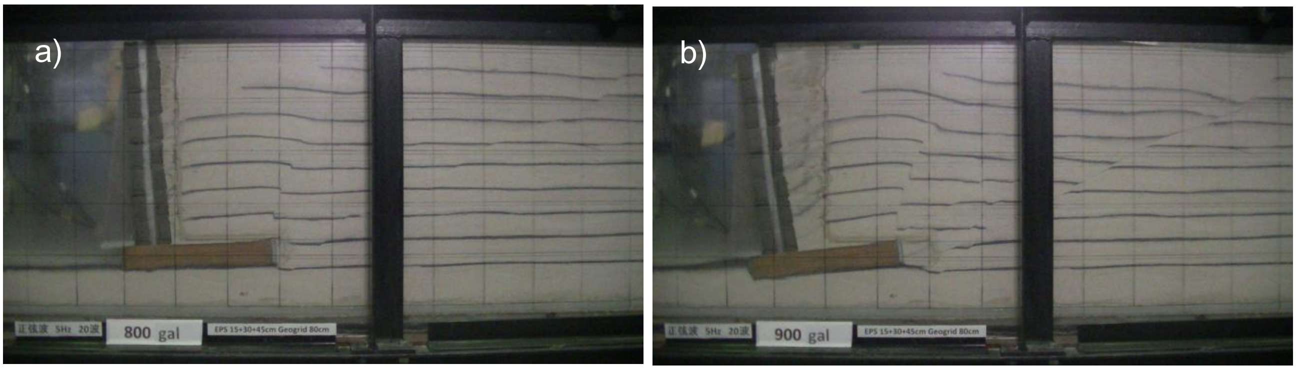


Figure 8. Side-views of model for case 12 after shaking steps of a) 800 gal and b) 900 gal.

Figure 9 shows the side-views for other cases after the shaking step of 800 gal, where the accumulated wall displacements for these cases were comparable to or larger than those for case 12 after the shaking step of 900 gal. The angle of the deepest failure plane measured from the horizontal direction was largest in case 6 with unreinforced backfill, which was slightly reduced by placing a geogrid at upper height of the backfill in case 7. It was largely reduced by placing a geogrid at middle height in cases 9 and 11 (as well as in case 12 as shown in Figure 8), suggesting that the geogrid was effective in preventing the formation of failure plane passing through the geogrid.

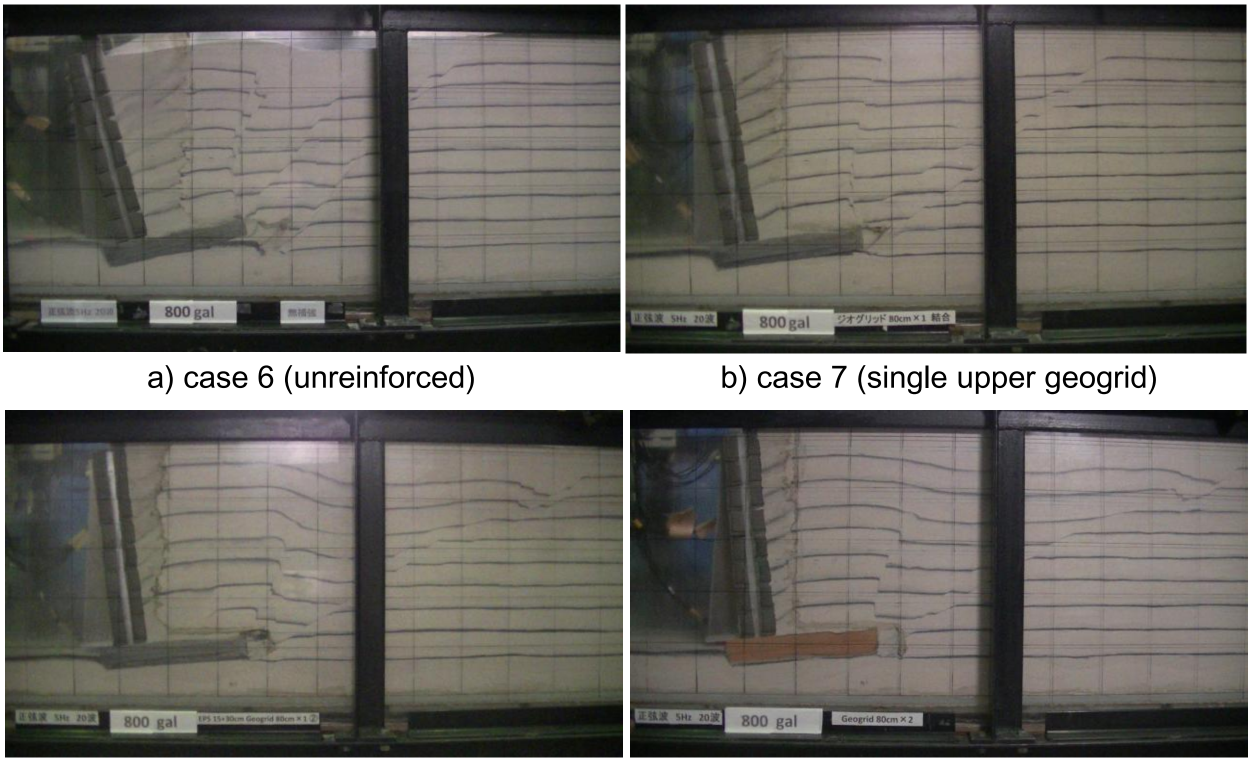
4 SUMMARY

The results from the shaking table tests can be summarized as follows:

– Under severe excitation conditions at 700 to 1000 gals, both the base sliding and the tilting of the wall could be reduced by placing geogrid-reinforcement in the backfill soil. It was effective in preventing the formation of failure plane passing through the geogrid.
– Instead of placing the upper geogrid-reinforcement, the base sliding of the wall could be further reduced by replacing partly the backfill soil with blocks of EPS in combination with the use of the mid-

dle-height geogrid. Placing EPS blocks above the middle-height geogrid was more effective than placing them below the geogrid.

– The relative settlement of the backfill soil at the interface with the wall could be also reduced by the combined use of EPS and geogrid.



a) case 6 (unreinforced) b) case 7 (single upper geogrid)

c) case 9 (single geogrid + EPS below) d) case 11 (double geogrid)

Figure 9. Side-views of models after shaking step of 800 gal for a) case 6, b) case 7, c) case 9 and d) case 11.

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