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Seismic performance of back-to-back mechanically stabilized multi-anchor walls

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ABSTRACT: In this study, a series of dynamic centrifuge model tests were carried out to investigate the deformation and failure mechanism of multi-anchor wall (MAW). The back-to-back mechanically stabilized wall (BMSW) were modeled in this study to compare the seismic performance of one single side of MAW. With regard to the seismic behavior at 2.0 m/s^2, the verticalities of facing of both case were only 0.3% which was less than construction management standard. The settlement of top surface of MAW on BMSW was larger than that of single type. This is because BMSW had less area of behind reinforced region which followed to the deformation of reinforced region. The gentler slip surface than active condition was observed, and it crossed another reinforced region on BMSW. It follows from this results that the anchor plate resisted the movement soil mass during earthquake of another side of reinforced region. Therefore, the seismic performance of BMSW is higher than that of single type in high intensity of seismic wave.

1 INTRODUCTION

The reinforced soil structures have been constructed since 1980's in Japan, and they have widespread and developed exponentially (Ochiai, 2007). Incidentally, as generally known, the seismic performance of reinforced soil wall has been high as shown in the disaster investigation after Hyogoken-Nambu earthquake (Tatsuoka et al, 1996) and Niigataken-Chuetsu earthquake (Koseki et al, 2006), Great East Japan earthquake (Kuwano et al, 2014). However, the long service period make such structure degrading compared with original performance, for instance out flow of backfill material gradually, deterioration of drainage facilities, variation of properties by weathering. The variation in performance of the reinforced Multi-anchor Wall subjected to clog of drainage was investigated in order to clarify the unstable mechanism of the MAW (Kobayashi et al, 2012). The damages of reinforced soil structures were also mentioned though these structures have high seismic performance, because of the very high ground water level in the backfill (Miyata, 2014). The seismic performances and deformation mechanisms were investigated in order to approach the performance-based design of reinforced soil wall with high ground water level (Kobayashi et al, 2016). Test results showed that the verticality of facing panel was slight larger than that of no damage condition, in spite of lower relative density; 40% due to 2.0m/s^2 of acceleration.

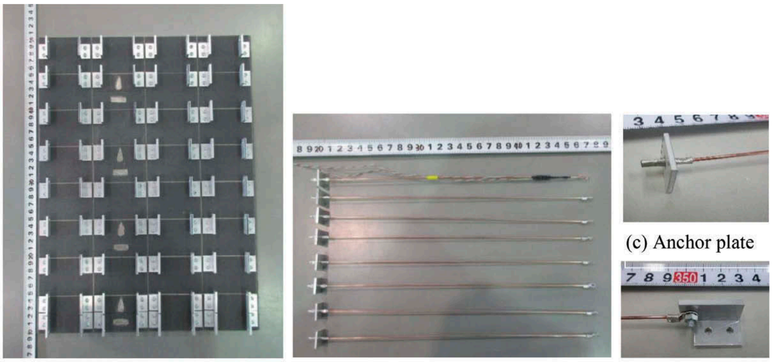
On the bridge abutment, the back-to-back mechanically stabilized walls (BMSW) were often applied. The seismic performance of these type of reinforced soil wall have not been clarified yet. In the present study, dynamic centrifuge model tests were conducted to investigate the deformation and failure mechanism of MAW. Two type of MAW models; one single side of MAW and back-to-back mechanically stabilized MAW, were prepare in these tests. The model was subjected to sinusoidal waves with different amplitudes of acceleration which was increased stepwise of about 2.0 m/s^2 to 10.0 m/s^2 and over.

2 DYNAMIC CENTRIFUGE MODEL TESTS

2.1 *Preparation of model grounds*

Figure 1 shows the model of the wall facing and reinforcement. The facing panels were connected with fixing jig of tie-bar, and it was height of 50mm and width of 73mm, which modelled 1000mm height and 1500mm width of prototype scale. The steel bar of 1.2mm diameter as the tie-bar has a strain gauge placed at 25mm far from facing panel. Anchor plate is 15mm square of aluminum plate. The tie-bars were connected to fixing jig on facing panel.

The model ground of one single side wall and BMSW of MAW are shown in Figures 2 and 3 respectively. The length of reinforcement and its arrangement, total height of wall are similar each other, but the back side of reinforced region of left one is different. In this study, the dynamic centrifuge model tests conducted at 20G acceleration field, therefore the model scale is 1/20. To measure the lateral earth pressure behind facing and at the border of reinforced region and the vertical earth pressure, thin pressure gauges were placed at the position shown in these figures as EPW and EPH, EPV respectively. The potentiometers; DV, and the laser displacement gauges; DH, were located at the top of the soil wall and the front side of facing in order to record the deformation of model ground. The backfill was constructed by air pluviation to achieve the relative density 70% of Tohoku silica sand No.7. Figure 4 shows the photographs of both case of model ground.



(a) Facing panel (b) Tie-bar (c) Anchor plate (d) Fixing jig

Figure 1. Model of the facing and reinforcement

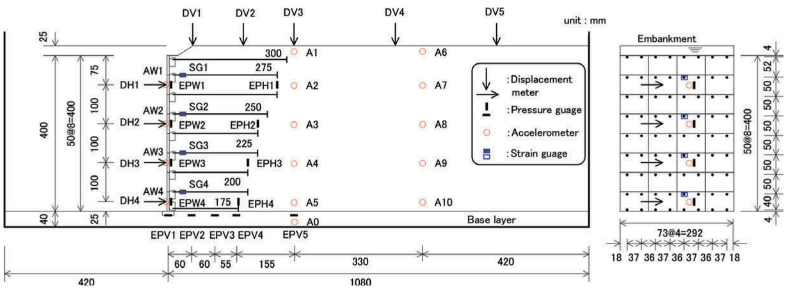


Figure 2. Test setup of one single side of MAW (Case1)

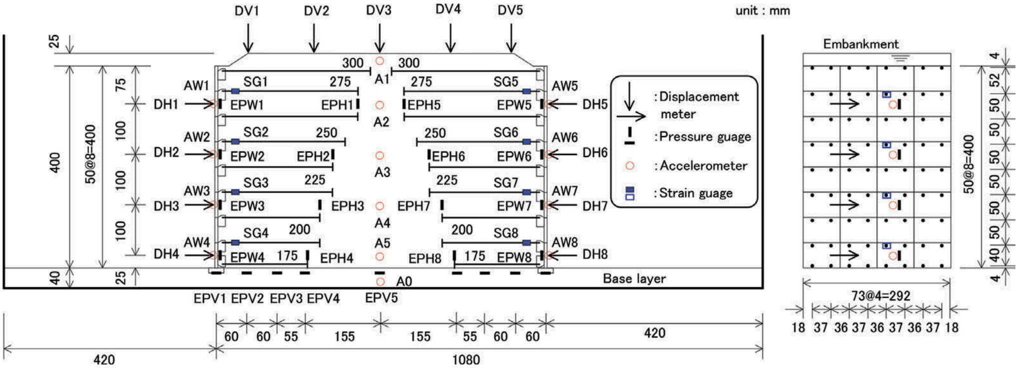
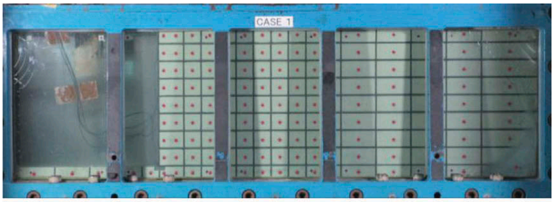


Figure 3. Test setup of BMSW of MAW (Case2)



(a) Case1

(b) Case2

Figure 4. Completed model ground

2.2 *Test conditions*

Table 1 shows test conditions in this study. During each tests, the model was subjected to sinusoidal waves with different amplitudes of acceleration which was increased stepwise of about 2.0 m/s^2 as shown in Table 1, and constant frequency of 2 Hz, duration 10 seconds in prototype scale respectively.

Table 1. Test conditions of this study.

Test series	Phase of excitation	Acceleration of shaking table (m/s^2)
Case 1	1	2.052
	2	3.97
	3	5.78
	4	7.61
	5	9.30 Appeared the slip surface
	6	10.40 Slid along the clear slip surface
Case 2	1	2.03
	2	3.95
	3	5.88
	4	7.76
	5	9.32
	6	10.76
	7	13.26

3 SEISMIC PERFORMANCE OF MAW

3.1 *Seismic performance of MAW during level 1 earthquake motion*

Shaking phase 1 means the level 1 earthquake motion in Japan; Japan Meteorological Agency seismic intensity scale is about '5-upper'. Figures 5 and 6 shows the photographs of model ground after shaking phase 1. According to these photographs, swelling of wall facing in each test cases cannot recognized. To discuss the point of difference of deformation between case 1 and case 2, Figure 7 shows the horizontal displacement measured by DH1 and DH5, which targeted at the second facing panel from top surface, during shaking tests of both test case. The maximum verticality of one single side of MAW is calculated as 0.28 %, and this value can be classified as no damage condition. It indicates that the seismic performance of MAW is high even though BMSW, which verticality are 0.12% of left

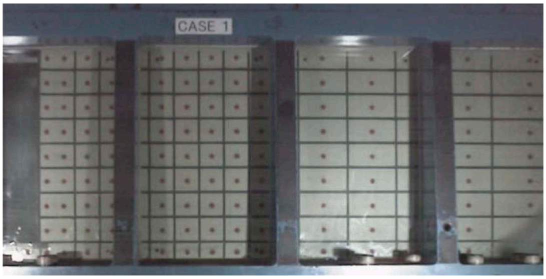


Figure 5. Model ground after shaking (Case 1)

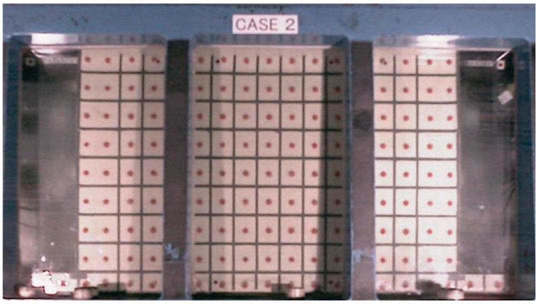


Figure 6. Model ground after shaking (Case 2)

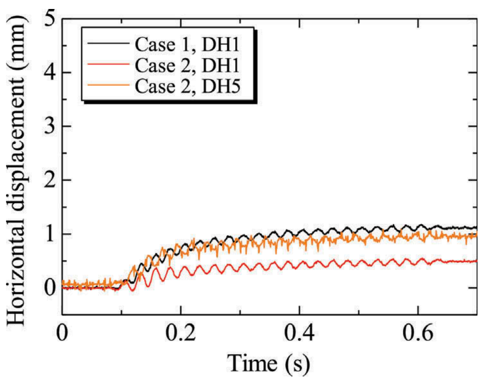


Figure 7. Horizontal displacement during shaking

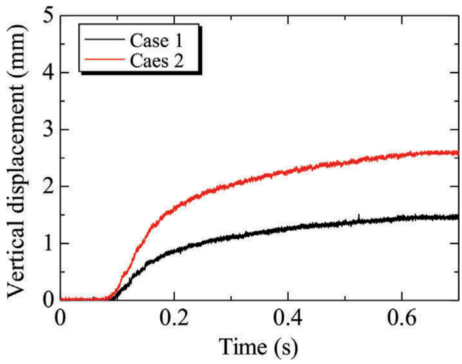


Figure 8. Vertical displacement of top surface

side and 0.23% of right side. However, the total separation of top of wall facing of BMSW was 1.42mm. This value is larger than that of case 1; 1.1 mm. According to the Figure 8 which shows the vertical displacement at the top surface measured by DV3, larger displacement in case 2 were observed compared with case 1, because the residual deformation of the reinforced region accumulated opposite direction each other. This is a characteristic seismic behavior of BMSW.

3.2 *Deformation mechanism during earthquake*

Figure 9 shows three photographs from phase 2 to phase 4 with regard to case 1, which observed inflection point of black line behind the lower part of facing panel. On the other hand, 6 photographs are shown in Figure 10 up to phase 7 in the test case 2, and the discontinuous black line in right side of reinforced region was recognized. Comparing the photographs of facing in case 1 with case 2, the different deformation of wall facing are recognized. On the case 1, the leaning to forward of the upper part of facing panels were occurred. In contrast with case 2, the swelling out around middle part of wall facing and caving in the

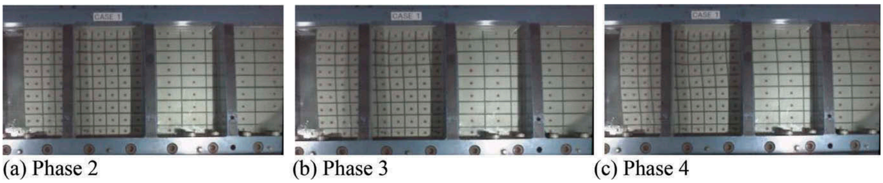


Figure 9. Photographs of model ground after shaking (Case 1)

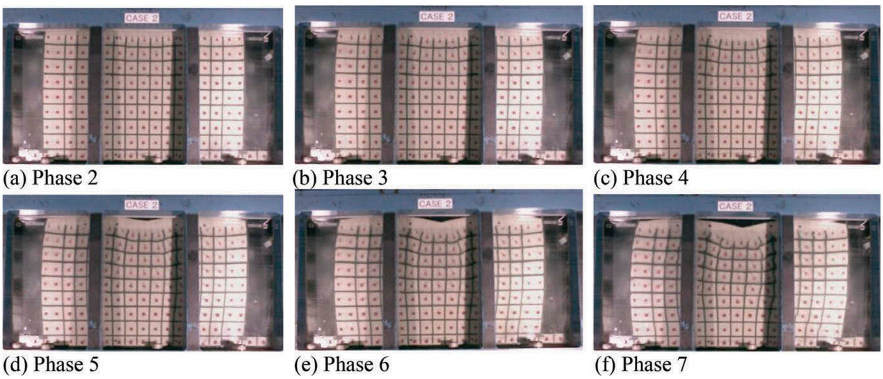


Figure 10. Photographs of model ground after shaking (Case 2)

surface of soil wall were observed. The gentler slip surface than active condition was observed, and it crossed another reinforced region on back-to-back type. It follows from this results that the anchor plate resisted the movement soil mass during earthquake of another side of reinforced region. Therefore, the seismic performance of back-to-back type of MAW is higher than that of single type of MAW in high intensity of seismic wave. Figure 11 shows the horizontal displacement measured by DH1 and 5 at the phase1 to 4 in both test cases. The larger displacements was occurred in case 1 compared with DH5 of case 2. The calculated value of verticalities of MAW are 2.7 % in case 1, and 0.4 % of left side of BMSW and 2.2% of right

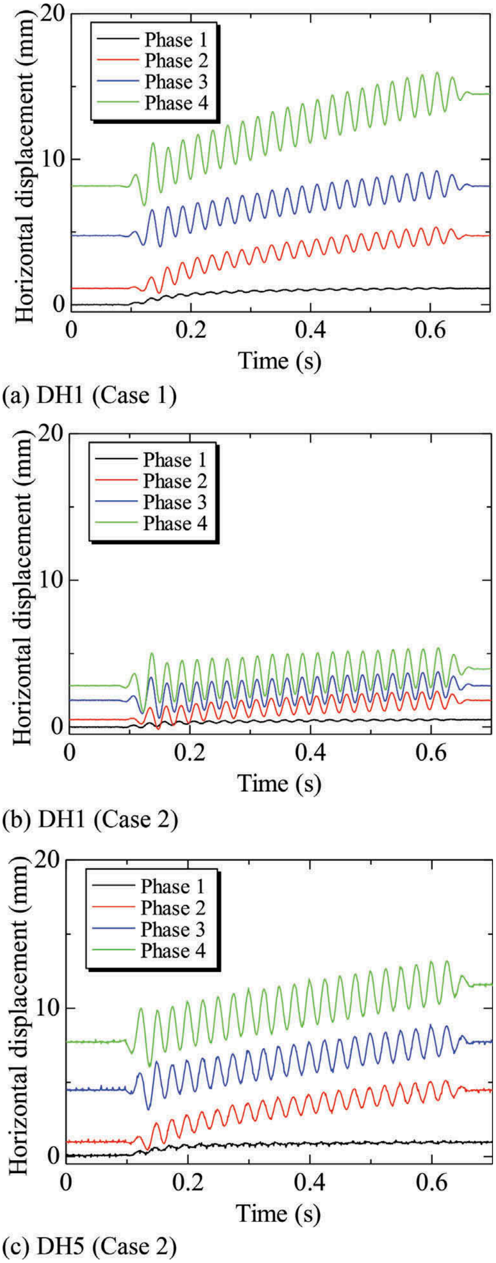


Figure 11. Horizontal displacement of facing panel; DH1 and DH5

one respectively. These values are smaller than the construction management standard; 3.0%. These results show the high seismic performance of MAW even though smaller relative density of backfill than ordinary construction.

It follows from these results that the seismic performance of BSMW will be able to estimate by the ordinary design of one single side one. This is a unique results in this study to develop the applicable site of the multi-anchor wall.

4 CONCLUSION

In the present study, two type of dynamic centrifuge model tests were carried out to investigate the deformation and failure mechanism of MAW. According to the test results, the following conclusions are obtained.

1. The verticality of facing after shaking of 2.0 m/s^2 acceleration was only 0.3 %. This results shows that the seismic performance of MAW is extremely high in spite of smaller degree of density of back fill than ordinary construction.
2. The back-to-back mechanically stabilized wall of MAW has higher seismic performance than ordinary construction, because of the smaller horizontal deformation of facing panel. However, on the BMSW, moving of reinforced region are opposite direction each other made slight lager settlement like cave-in at the center of top surface of soil wall.
3. The gentler slip surface than active condition was observed, and it crossed another reinforced region on BMSW. It follows from this results that the anchor plate resisted the movement soil mass during earthquake of another side of reinforced region.
4. The ordinary design method on one single side of MAW can estimate the performance of BMSW of MAW.

REFERENCES

Kobayashi, M., Miura, K. and Konami, T. 2012. Influence of the drainage in the reinforced soil wall during seepage flow, *Advances in Transportation Geotechnics II*, Balkema, pp.434–439.

Kobayashi, M., Miura, K., Konami, T. and Sato, H. 2016. Effectiveness of drainage pipe to improve seismic stability of multi-anchor wall. *Japanese Geotechnical Society Special Publication*, Vol.4, No.2, pp. 13–16.

Koseki, J., Bathurst, R.J., Güler, E., kuwano, J. and Maugeri, M. 2006. Seismic stability of reinforced soil walls. *Proceedings of the 8th international conference on geosynthetics*. pp.51–77.

Kuwano, J., Miyata, Y. and Koseki, J. 2014. Performance of reinforced soil walls during the 2011 Tohoku earthquake. *Geosynthetics International*. Vol.21, No.3, pp.179–196.

Miyata, Y. 2014. Reinforced soil walls during recent earthquakes in Japan and geo-risk-based design. *Earthquake Geotechnical Engineering Design*. Michele Maugeri and Claudio Soccodato(eds). Springer. pp.343–353.

Ochiai, H. 2007. Earth reinforcement technique as a role of new geotechnical solutions – memory of IS Kyushu. *Proc. of International Symposium on Earth Reinforcement*. pp.3–23.

Tatsuoka, F., Tateyama, M. and Koseki, J. 1996. Performance of soil retaining walls for railway embankments. *Soils and Foundations*. Special Issue of Soils and Foundations. pp. 311–324.