New application of pile foundation to reinforced soil structure

Hara, T., Tsuji, S., Yashima, A. and Sawada, K.
Department of Civil Engineering, GifuUniversity,1-1 Yanagido Gifu,Gifu, Japan
Tatta, N.
Technical Department, MAEDA KOSEN CO., LTD., 38-3 Okinunome Harue-cho Sakai, Fukui, Japan

Keywords: reinforced soil structure, pile foundation, dynamic centrifuge model test, numerical simulation

ABSTRACT: This study aims to confirm the effectiveness of applicability of pile foundation to reinforced soil structure by geogrid in order to improve the lateral stability. This paper reports the effectiveness and dynamic interaction between pile and Geo-wall, which are confirmed from a dynamic centrifuge model test (25G), and numerical simulation of the experiment's results by using two-dimensional dynamic FEM analysis with considering three-dimensional effect of pile foundation.

1 INTRODUCTION

High ductility of soil structure reinforced by geogrid is well known and it is also possible to build independent soil structure. The independent reinforced soil structure by geogrid, which is termed "Geo-wall" in this paper, can be applied to earth retaining wall, rockfall protection structure and others, as reasonable one because it can be built by use of existing soil at the construction site.

However, wide Geo-wall with using spread foundation is designed in general, thus the application of Geo-wall to narrow construction site, such as on a slope or beside mountainous road, is too difficult. If pile foundation can be applied to Geo-wall, wide-range narrow width Geo-wall, even though the construction site is on a slope, can be achieved.

Therefore, the application of pile foundation to Geo-wall, which is termed "Piled Geo-wall" in this paper, as shown in Figure 1, has been studied by authors.

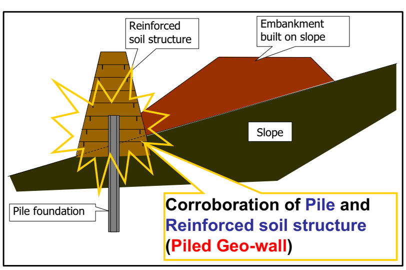


Figure 1. Image of Piled Geo-wall.

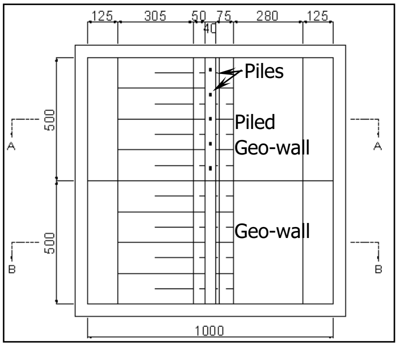
In this study, the effectiveness of applicability of pile foundation to Geo-wall in order to improve the lateral stability was confirmed from a dynamic centrifuge model test (25G). And a numerical simulation was carried out in order to propose a design method of Piled Geo-wall. In the numerical simulation, two-dimensional dynamic FEM analysis with considering three-dimensional effect of pile foundation was adopted from view point of practical design.

2 EFFECTIVENESS OF APPLICABILITY OF PILE FOUNDATION TO GEO-WALL

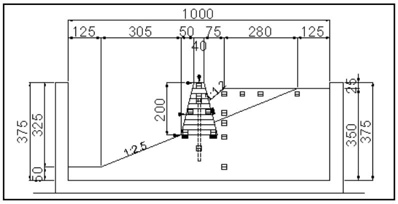
A dynamic centrifuge model test (25G) was carried out to confirm the effectiveness of applicability of pile foundation to Geo-wall, and dynamic interaction between pile and Geo-wall.

2.1 *Dynamic centrifuge test model*

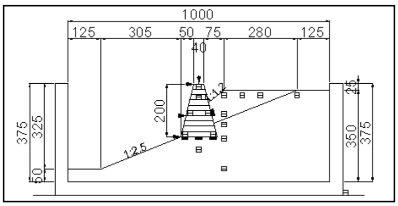
In this test, two Geo-walls, piled Geo-wall and normal one (without pile), as a countermeasure to restrict deformation during earthquake of road embankment built on slope were modeled in a steel box compartmentalized in two space, as shown in Figure 2, and the differences of the seismic responses of road embankment, Geo-walls, geogrid and pile foundation in the two models were compared. The measurements are shown in Figure 2(b) and 2(c), and Table 1 and Table 2 show the geotechnical and the structural parameters adopted in this test.



(a) top view.



(b) A-A section.



(c) B-B section.

unit: mm

Displacement meter
Earth pressure meter
Acceleration meter

Figure 2. Experiment model (1/25 scale model).

Table 1. Geotechnical parameters*

	Elastic modulus kPa	Cohesion kPa	Internal friction angle Deg.
Slope	3.26×10^5	55	0
Embankment	3.0×10^4	0	40
Geo-wall	3.0×10^4	0	40

Table 2. Structural parameters*

	Elastic modulus kPa	sectional area m^2/m	Moment of inertia m^4
Pile	2.0×10^8	4.79×10^{-3}	2.04×10^{-4}
Geogrid	8.0×10^5	1.0×10^{-3}	-

* converted value to actual scale

Where, the Geogrid that has equivalent initial elastic modulus to actual geogrid, which is converted by EA, as shown in Figure 3, was adopted. Geo-walls were built at every step as same as actual execution as shown in Figure 4. Furthermore, longitudinal additional geogrid, in particular, were installed at every layer, as shown in Figure 5, in order to transmit the load to pile from Geo-wall body smoothly. Figure 6 shows input earthquake wave in this test.

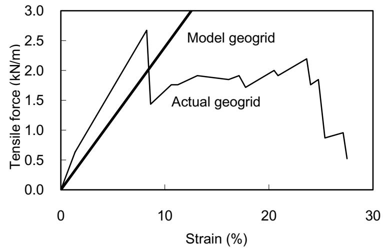


Figure 3. Tensile stiffness of geogrid.

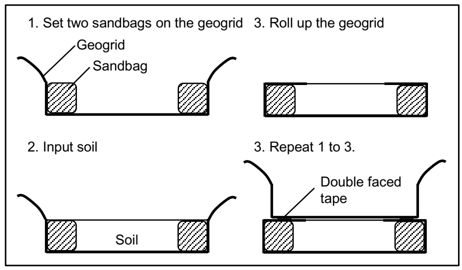


Figure 4. Procedure for building Geo-wall.

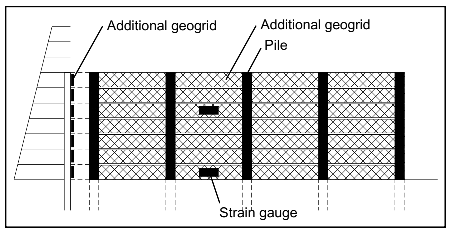


Figure 5. Additional geogrid to unify piles and Geo-wall.

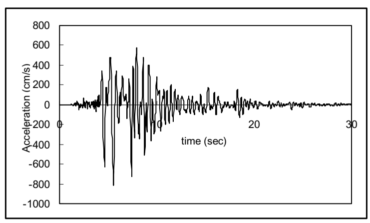


Figure 6. Input wave

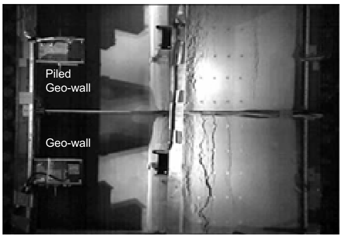
2.2 *Results*

2.2.1 *Effectiveness of pile foundation*

Photograph 1 shows the state of road surface after shaking. And residual deformation of the Geo-walls, transition of earth pressure on the back of the Geo-walls, and distribution of the strain in depth occurring in the pile are shown in Figure 7 to Figure 9, respectively. According to the results, the effectiveness of the application of the pile to Geo-wall was confirmed as follows;

a. The load of embankment was transmitted to the piles from the view point of strain occurring in the piles as shown in Figure 9.
b. As the above result, the Piled Geo-wall received larger earth pressure than the normal one without pile as shown in Figure 8.
c. And, the residual displacement of the Piled Geo-wall is smaller than the normal one without pile as shown in Figure 7.

Conclusively, the deformation of the road surface could be reduced as shown in Photograph 1.



Photograph 1. State of road surface after shaking.

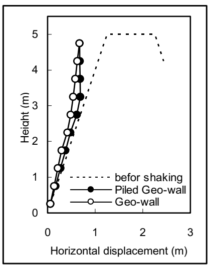


Figure 7. Deformation of Geo-wall.

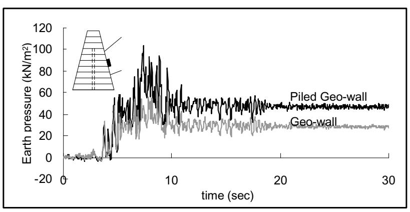


Figure 8. Transition of earth pressure on back of Geo-wall.

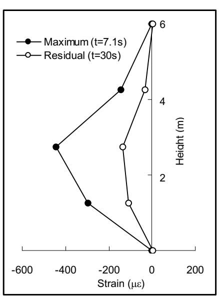


Figure 9. Strain occurring in the pile.

Figure 10 shows the transition of the strain occurring in the longitudinal additional geogrid. According to the result, it was confirmed that the geogrid is effectiveness to transmit the load of the back embankment to the piles through the Geo-wall from the result that large strain occurs in the geogrid.

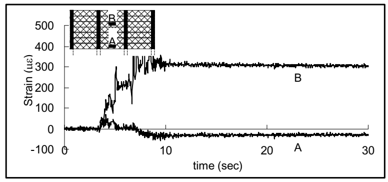


Figure 10. Strain occurring in the additional geogrid.

2.2.2 *Interaction between pile and Geo-wall*

The distribution of the displacements in depth of the pile and the Geo-wall is shown in Figure 11. According to the result, because of high ductility of reinforced soil structure by geogrid, relative deformation between pile and Geo-wall is not small though; it was considered that Geo-wall can transmit the force to pile foundation

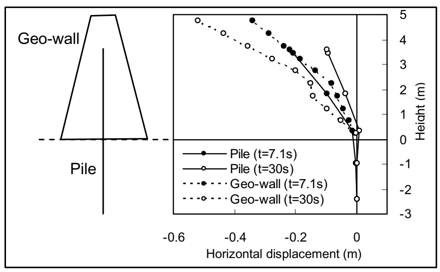


Figure 11. Displacement distribution of pile and Geo-wall.

3 NUMERICAL SIMULATION OF THE TEST

In order to propose a design method of Piled Geo-wall, a numerical simulation of the centrifuge test results was carried out.

3.1 *Simulation model*

From the view point of practical design, two-dimensional elasto-plastic dynamic FEM (Wakai et al. 2004) was adopted for the simulation. Figure 12 shows FEM mesh of the experiment's simulation.

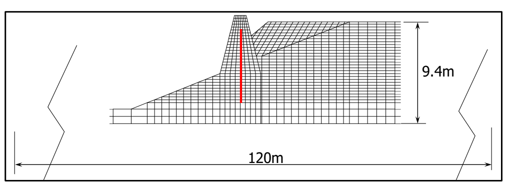
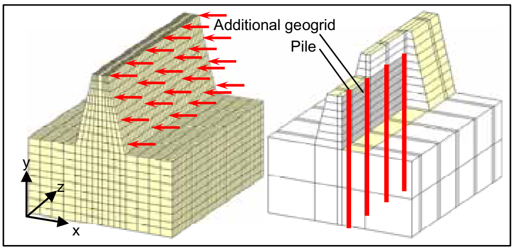


Figure 12. Simulation model.

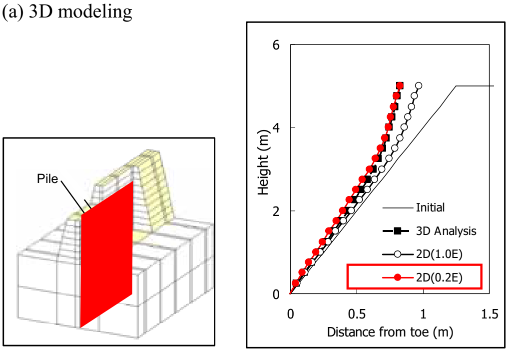
3.2 *Three dimensional effect of pile foundation*

In case of adopting two-dimensional (2D) FEM for design of Piled Geo-wall, three-dimensional (3D) effect of pile for modeling of the piles as a continuous wall in 2D analysis has to be considered. More specifically, the 3D effect can be established by the flexural stiffness of the continuous wall (2D modeling of pile) from the comparison with static 3D and 2D analysis (Hara et al. 2009), which the Geo-wall deformation analyzed by 3D analysis (each pile modeling) can be reproduced by 2D analysis (continuous wall modeling).

Figure 13 shows the example of 3D effect study for the experiment's case. According to the result, 0.2 times of flexural stiffness (EI) of the equivalent continuous wall of the actual piles was established as 3D effect of piles for 2D modeling in this case.



(a) 3D modeling



(b) 2D modeling (c) Geo-wall deformation

Figure 13. An example of 3D effect study.

3.3 *Reproducibility of the design method*

Comparisons of the results obtained from the proposed design method and the experiment, residual deformation of Geo-wall and road surface, maximum deformation and bending moment of the pile, are shown in Figure 14 to 16, respectively. Where, UWLC (Lee 2000) was adopted as an elasto-plastic dynamic FEM design tool. According to the results, the analysed responses comparatively good reproduce the observed ones.

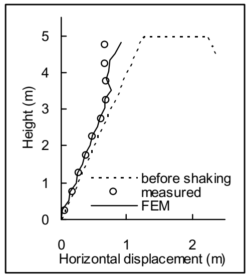


Figure 14. Residual deformation of Geo-wall.

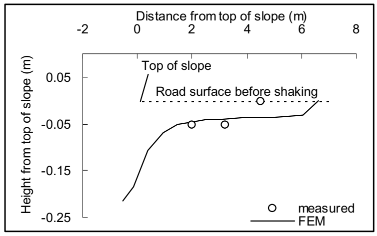
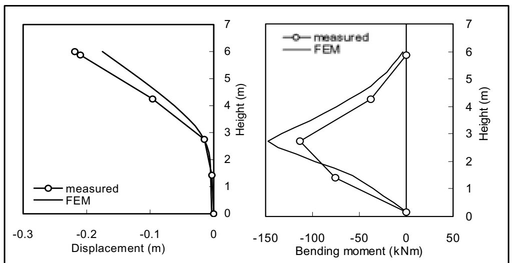


Figure 15. Residual deformation of road surface.



(a) Deformation (b) Bending moment

Figure 16. Maximum deformation and bending moment of pile.

4 CONCLUSION

This paper can be concluded as follows;

- The effectiveness of the applicability of pile foundation to Geo-wall in order to improve the lateral stability was confirmed from a dynamic centrifuge model test (25G).
- The seismic response of Piled Geo-wall can be simulated by 2D FEM analysis.

REFERENCES

Wakai, A. and Ugai, K. 2004, A simple constitutive model for the seismic analysis of slopes and its applications, SOILS AND FOUNDATIONS (Japanese Geotechnical Society) Vol.44 No.4, pp.83-97.

Hara, T., Tsuji, S., Yashima, A., Sawada, K. and Tatta, N. 2009, Dynamic interaction between pile and reinforced soil structure, Proceeding of the International Symposium on Prediction and Simulation Methods for Geohazard Mitigation (IS-Kyoto 2009), pp.457-463