Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Prediction of deformation of retaining walls of geosynthetic-reinforced soil under large earthquakes

Fujii, T.
Geo-Environmental Engineering Division, Fukken Co., Ltd., Japan

Izawa, J.
Tokyo Institute of Technology, Japan

Kuwano, J.
Saitama University, Japan

Ishihara, M.
Public Works Research Institute, Japan

Nakane, A.
Tekken Corporation, Japan

Keywords: finite element method (FEM), dynamic centrifuge model test, large earthquake, reinforced-soil retaining walls, deformation

ABSTRACT: The authors of the present study turned their attention to the finite element method (FEM) which has been remarkably progressing in recent years in the fields of seismic-response and other analyses and made a basic study of whether or not the FEM was applicable to the estimation of deformation of reinforced-soil retaining walls under large-scale earthquakes. The result of a dynamic centrifuge model test of high reliability was chosen and a model wall was constructed for seismic response analysis by the FEM. The comparison between the result of the test and that of the analysis showed that the FEM was promising as a tool for the estimation of deformation of reinforced-soil retaining walls under large-scale earthquakes.

1 INTRODUCTION

With the Hyogoken Nanbu Earthquake as a turning point, design guidelines and standards began to adopt the two-stage design method[3] and a design method allowing for deformation to a certain extent for large-scale earthquake motion (level-2 earthquake motion) with a recurrence period over the service life of retaining walls is being developed. On the other hand, the seismic coefficient method has been used so far for the aseismic design of reinforced-soil retaining walls; accordingly, the stability of retaining walls can be estimated, but their deformation cannot be estimated. Under the circumstances, the authors of the present study turned their attention to the FEM progressing in various fields and made a basic study of whether or not the FEM was applicable to the estimation of deformation of reinforced-soil retaining walls under large-scale earthquakes.

2 OUTLINE OF DYNAMIC CENTRIFUGE MODEL TEST

The result of the dynamic centrifuge model test conducted at the Tokyo Institute of Technology was chosen as a benchmark for the comparison to the result of FEM analysis.

Vertical reinforced-soil model walls of the height of 150 mm and the relative density of 80% were made of dry Toyoura sand by the midair-drop method for the test. Reinforcements 90 mm long were laid at intervals of 30 mm. Figure 1 shows the configuration of the model wall and the arrangement of sensors. The test was conducted under various conditions after the centrifugal acceleration reached 50 G. In this study, the results of 13 test cases of Table 1 were compared with the results of the analysis. The details of the dynamic centrifuge model test were described in one of the references.

3 TWO-DIMENSIONAL SEISMIC RESPONSE ANALYSIS BY FEM

3.1 *Method of analysis and parameters used for analysis*

The FLIP developed by the Port and Harbor Research Institute of the former Ministry of Transport was used for the FEM analysis. The FLIP is a program for two-dimensional seismic response analysis of the conditions of plane strain base on the effective stress method.

In this study, a multi-spring model was used to represent the stress-strain relation of soil. Models of

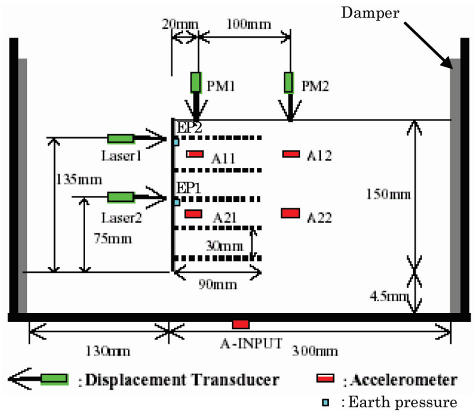

Figure 1. Model of retaining wall of reinforced soil for dynamic centrifuge model test.

Table 1. Test cases compared with results of analysis.

	Waveform	Frequency	Amplitude	Number of cycles
Case 1-1	sin	100 Hz	0.3 mm	20
Case 1-2	sin	100 Hz	0.6 mm	20
Case 1-3	sin	100 Hz	1.0 mm	20
Case 2-1	kobe	1	0.3 mm	1
Case 2-2	kobe	1	0.6 mm	1
Case 2-3	kobe	1	1.0 mm	1
Case 2-4	kobe	1	1.2 mm	1
Case 2-5	kobe	1/2	1.2 mm	1
Case 3-1	kushiro	1	0.3 mm	1
Case 3-2	kushiro	1	0.6 mm	1
Case 3-3	kushiro	1	1.0 mm	1
Case 3-4	kushiro	1	1.2 mm	1
Case 3-5	kushiro	1/2	1.0 mm	1

*Frequency of irregular wave
1: Same as real wave, 1/2: Half of real wave

geogrids and wall-face material were made of linear-beam elements. A model of the interface between the geogrids and soil was made of joint elements.

The parameters used in the analysis are shown in Tables 2 and 3.

3.2 *Division of elements*

The model wall of Fig. 1 was divided as shown in Fig. 2. The section under 1G was divided.

In both the initial dead-weight analysis and the seismic response analysis, the sides of the wall were considered to be defined by fixed boundaries in horizontal directions and free boundaries in vertical directions and the bottom of the wall was considered to be defined by fixed boundaries in both the horizontal and vertical directions.

3.3 *Flow of analysis*

The banking was made in five steps, and the initial dead-weight analysis was made by analysing the embankment step by step. For the step-by-step analysis, the wall face was considered to be fixed in the horizontal directions so that the wall face would not deform forward under the load of banked soil. After the banking in five steps was completed, the boundary condition on the wall face (fixation in horizontal directions) was removed.

After completing the initial dead-weight analysis, the seismic response analysis was carried out.

Table 2. Soil parameters.

		Foundation	Embankment 1~5
G_{m0}	kN/m^2	110000	110000
σ'_{m0}	kN/m^2	98.0	98.0
m_G	–	0.5	0.5
K_{m0}	kN/m^2	292675	292675
m_K	–	0.5	0.5
ν	–	0.333	0.333
c	kN/m^2	5.0	5.0
φ'_f	degree	42.0	42.0
h_{max}	–	0.24	0.24
ρ	kN/m^3	1.574	1.574
n	–	0.405	0.405

Table 3. Parameters of beam elements.

		Geogrid	Wall-face material
G	kN/m^2	195.0	1.46E+07
ν	–	0.3	0.3
ρ	kN/m^3	1.00E-06	0.52
A	m^2	1.0	4.00E-02
I	m^4	1.00E-06	5.30E-06

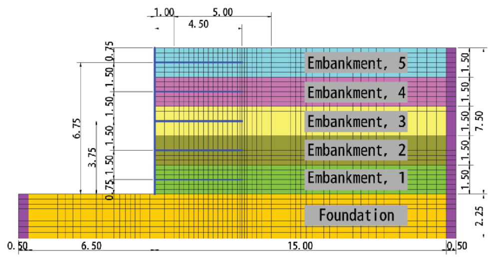

Figure 2. Division of elements.

4 COMPARISON BETWEEN RESULTS OF TEST AND ANALYSIS

The time-series comparison was made of response acceleration, displacement, and earth pressure.

4.1 *Response acceleration*

Figure 3 shows the result of time-series comparison between the response acceleration at the point A22 in the case 2-5 obtained by the centrifuge model test and that obtained by the seismic response analysis. As shown in Fig. 3, the peak values and phases of the

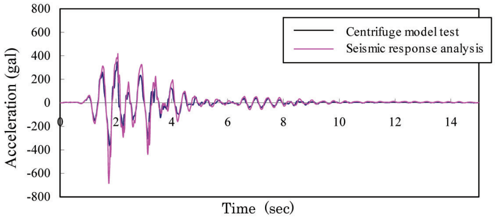

Figure 3. Comparison of response acceleration (Case 2-5).

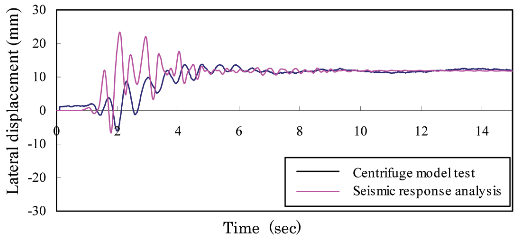

Figure 4. Comparison of lateral displacement (Case 2-5).

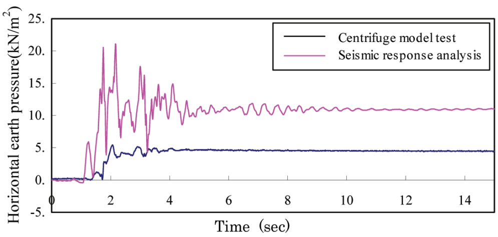

Figure 5. Comparison of horizontal earth pressure behind retaining wall (Case 2-5).

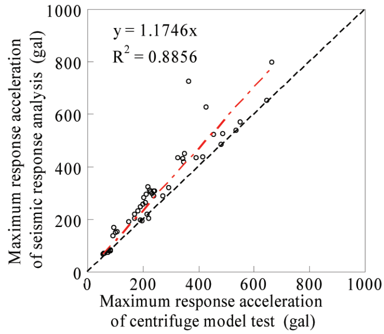

Figure 6. Comparison between maximum response acceleration.

response acceleration obtained by the analysis are relatively consistent with those obtained by the test. Both the regular (sine) and irregular waves showed this tendency.

4.2 *Displacement*

Figure 4 shows the result of time-histories comparison between the lateral displacement of the wall face at the height of the laser 2 in the case 2-5 obtained by the centrifuge model test and that obtained by the seismic response analy sis. As shown in Fig. 4, qualitative tendencies such as the increasing tendency of displacement in repetition and the times of occurrence of peaks of displacement ascertained by the analysis are consistence with those ascertained by the test. The absolute values of lateral displacement obtained by the analysis are relatively consistent with those obtained by the test, too. These tendencies were observed in almost all the cases. The vertical displacement of the wall face was tended to be underestimated by the analysis.

4.3 *Horizontal earth pressure behind retaining wall*

Figure 5 shows the result of time-histories comparison between the horizontal earth pressure at the point of EP3 in the case 2-5 obtained by the centrifuge model test and that obtained by the seismic response analysis. As shown in Fig. 5, although the increasing tendency of horizontal earth pressure ascertained by the analysis is relatively consistent with that ascertained by the test, the analysis tended to overestimate the amplitude and absolute value of horizontal earth pressure.

5 APPLICABILITY OF FEM TO ESTIMATION OF DEFORMATION OF RETAINING WALLS UNDER EARTHQUAKES

Figure 6 shows all the values of maximum response acceleration obtained by the dynamic centrifuge model test and the seismic response analysis. As shown in Fig. 6, the correlation between the results of the test and those of the analysis is relatively good, though the values obtained by the analysis tended to be larger by 10-20% than those obtained by the test. Figure 7 show all the values of maximum lateral displacement, respectively, obtained by the dynamic centrifuge model test and the seismic response analysis. As shown in Figs. 7, the correlation between the lateral displacement obtained by the test and that obtained by the analysis are relatively good.

Figure 8 shows all the values of maximum horizontal earth pressure behind the retaining wall obtained by the dynamic centrifuge model test and the seismic response analysis. As shown in Fig. 8, although the correlation between the results of the test and those of the analysis is relatively good, residual horizontal earth pressure showed no correlation and the absolute values of horizontal earth pressure obtained by the analysis were larger by up to 400% than those obtained by the test. The model of the interface between the wall-face material and the soil may have been improper, which may have caused these inconsistencies.

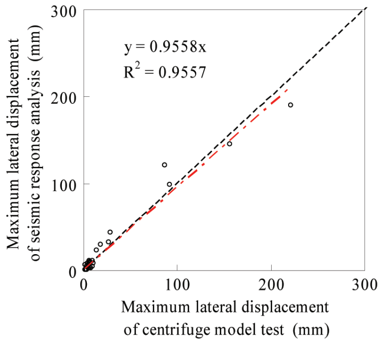

Figure 7. Comparison between maximum lateral displacement.

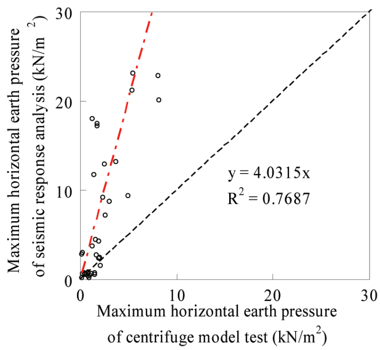

Figure 8. Comparison between maximum values of horizontal earth pressure.

As described above, if various conditions are made clear, the acceleration and displacement of retaining walls of reinforced soil can be estimated by the FEM. Accordingly, the FEM is promising as a tool for the estimation of deformation of reinforced-soil retaining walls under large-scale earthquakes.

6 CONCLUSIONS

The results of the dynamic centrifuge test with models and those of the FEM analysis were compared and the findings are as follows.

- The comparison of histories of response acceleration showed relatively high consistency between the peak values and phases ascertained by the centrifuge model tests and those ascertained by the analysis. This tendency was true of both the regular and irregular waves.
- The comparison of lateral displacement of the front of the reinforced earth wall showed that the qualitative tendencies such as increasing displacement and time of occurrence of peak displacement ascertained by the centrifuge model tests were consistent with those ascertained by the analysis and that the absolute values of lateral displacement ascertained by the centrifuge model tests were relatively consistent with those ascertained by the analysis.
- The comparison of horizontal earth pressure of the ground behind the reinforced earth wall showed that the tendency of increasing horizontal earth pressure ascertained by the centrifuge model test was relatively consistent with that ascertained by the analysis and that the amplitude and absolute values ascertained by the centrifuge model tests were considerably different from those ascertained by the analysis.

Thus, it was ascertained that the finite element method (FEM) was applicable to the prediction of deformation of reinforced-earth retaining walls under large earthquakes.

REFERENCES

Iai, S., Matsunaga, Y. and Kameoka, T. (1992). “Strain space plasticity model for cyclic mobility”, *Soils and Foundations*, Vol. 32, No. 2, pp. 1-15.

Izawa, J., Kuwano, J. and Takahashi, A. (2001). “Effects of properties of geogrids on stability of reinforced embankments under earthquakes”, *Journal of Geosynthetics*, Vol. 16, pp. 37-44.