Numerical study on mechanism of dynamic earth pressure on adjacent structures

Hiroyuki Ishihara i), Yasuo Sawamura ii) and Kiyoshi Kishida iii)

i) Graduate student, Department of Civil & Earth Resources Engineering, Kyoto University, C1-4-291, Kyoto 615-8540, Japan.
ii) Assistant professor, Department of Civil & Earth Resources Engineering, Kyoto University, C1-4-583, Kyoto 615-8540, Japan.
iii) Assistant professor, Department of Urban Management, Kyoto University, C1-3-266, Kyoto 615-8540, Japan.

ABSTRACT

Recently, opportunities to construct earth retaining structures nearby other structures have increased due to a variety of construction projects. In these cases, it is considered that the earth pressure on the earth retaining structures greatly changes because of the complicated interaction between the soil and the structures. With regard to the adjacent earth retaining structures, some studies on the set spacing between buildings and the deformation mode of these structures under a static condition have been conducted. However, the mechanism of the dynamic earth pressure on the adjacent earth retaining structures has never been analyzed. In this research, shaking table tests and finite element analyses are carried out to clarify the influence of the set spacing and the deformation mode of adjacent earth retaining structures upon the mechanism of the dynamic earth pressure. The adjacent earth retaining structures in this study are modeled as two walls. As a result, the influence of the set spacing and the deformation mode of adjacent earth retaining structures on the mechanism of the dynamic earth pressure is clarified.

Keywords: finite element method, shaking table test, dynamic earth pressure, adjacent structures

1 INTRODUCTION

Many studies on the earth pressure on earth retaining structures have been conducted. Some researches (Nakai et al., 1985, 1999.) have pointed out that the difference in the deformation mode of the walls causes the difference in the earth pressure distribution. Ishibashi et al. carried out shaking table model experiments with different wall movement modes. It was confirmed that the distribution of dynamic active earth pressure is strongly influenced by the wall movement mode, particularly at a low level of horizontal acceleration, while the effect of the inertial body force becomes dominant at a high level of acceleration. Kodama et al. carried out shaking table tests and a numerical simulation on a nonlinear soil-structure interaction system. It was found that the elasto-viscoplastic mode with the Mohr-Coulomb yield criteria is adequate for simulations of soil behaviour under seismic loading. With regard to adjacent earth retaining structures, some studies (Kikuchi et al., 1995) on the set spacing between buildings and the deformation mode of these structures under a static condition have been conducted. It has been confirmed that the earth pressure is strongly influenced by the relative movement of the neighboring walls.

However, the mechanism of the dynamic earth pressure on adjacent earth retaining structures has never been analyzed. Many researchers have pointed out that the earth pressure on earth retaining structures has never been analyzed. In this research, shaking table tests and finite element analyses are carried out to clarify the influence of the set spacing and the deformation mode of adjacent earth retaining structures upon the mechanism of the dynamic earth pressure. The adjacent earth retaining structures in this study are modeled as two walls. As a result, the influence of the set spacing and the deformation mode of adjacent earth retaining structures on the mechanism of the dynamic earth pressure is clarified.

Keywords: finite element method, shaking table test, dynamic earth pressure, adjacent structures

Table 1. Cases of shaking table test and FEM analysis

| Connection style | L = 120mm | L = 650mm |
|------------------|-----------|-----------|
| Rigid | Case-1 (Rigid) | Case-2 (Rigid) |
| Hinge | Case-1 (Hinge) | Case-2 (Hinge) |

http://doi.org/10.3208/jgssp.JPN-112
been analyzed. In this research, therefore, shaking table tests and finite element analyses are carried out to clarify the influence of the set spacing and the deformation mode of adjacent earth retaining structures on the mechanism of the dynamic earth pressure.

2 FEM ANALYSIS

The difference in basic behaviors between the influence of the set spacing and the deformation mode of adjacent earth retaining structures was confirmed by shaking table tests on the mechanism of the dynamic earth pressure on adjacent earth retaining structures. Figure 1(a) shows a diagrammatic illustration of the experiment. The adjacent earth retaining structures in this study are modeled as two walls. The influence of the set spacing is considered by changing the distance between the two walls. Furthermore, the influence of the deformation mode of the walls is considered by changing the connection style (rigid or hinge) between one of the walls and the bottom of the soil chamber. Dry Toyoura sand (Dw = 0.251 mm, G = 2.64, ϵmax = 0.975 and ϵmin = 0.585) was used throughout the experiment. The average density of 1.61 g/cm³ (relative density = 50%) was achieved by using a sand hopper.

FEM analyses of shaking table tests are carried out to clarify the influence of the set spacing and the deformation mode of adjacent earth retaining structures on the mechanism of the dynamic earth pressure in detail. Figure 1(b) shows one of FEM meshes. Table 1 shows four cases of shaking table tests and FEM analyses. The 2D elasto-plastic FEM analysis is conducted because the experiment is carried out under a plane strain condition. The calculations are all conducted using a FEM code named DBLEAVES (Ye. et al., 2007). One of the simple elasto-plastic models, the "Subloading tij model (Nakai et al., 2004)", is used as the constitutive model for the sand layer. Figure 2 shows the history of the input wave in the FEM analysis. The maximum acceleration is 5.0 m/sec² and the frequency is 4 Hz.

3 RESULTS OF FEM ANALYSIS

In the following, Case-2 (Rigid) is regarded as a normal case because the dynamic interaction between the soil and the structure is small in Case-2 (Rigid). Firstly, it is a look at a comparative study on the influence of the set spacing through Case-2 (Rigid) and Case-1 (Rigid). Secondly, it is a look at a comparative study on the influence of the deformation mode of the walls through Case-2 (Rigid) and Case-2 (Hinge).

3.1 Time history of horizontal earth pressure and the acting position

Figure 3 shows the time history of the horizontal earth pressure on the left wall and the acting position. From the time history of the horizontal earth pressure on the left wall, in the case of a structure with a rigid connection, the phase difference between the input wave and the earth pressure is small. This is because the influence of the inertial force acting on the ground dominates the increase and decrease in earth pressure on the walls. Comparing Case-1 (Rigid) and Case-2 (Rigid), a difference in the maximum and minimum earth pressure levels in Case-2 (Rigid) is larger than that in Case-1 (Rigid). This is because Case-2 (Rigid) has a relatively large volume of the ground, and the inertial force acting on the ground becomes great. On the other hand, in the case of a structure with a hinge connection, the phase difference between the input wave and the earth pressure is large. This is because the influence of not only the inertial force acting on the ground, but also the collapse of the walls, causes the increase and decrease in earth pressure on the walls.

From the time history of the acting position of the horizontal earth pressure on the left wall, the acting
positions in all cases change at 0.08 ~ 0.15 m from the bottom of the wall. Focusing on Case-2 (Rigid), the irregular behavior of the acting position can be seen. This is because the ground of small soil getting covered at the upper wall leaves the wall at a high acceleration level.

3.2 Distribution of lateral stress in ground and earth pressure distribution on left wall

Figure 4 shows distribution of stress in the ground and the earth pressure distribution on the left wall. The times in Figure 4 are 1.25, 1.28, 1.31, 1.34 and 1.37 sec in Figure 2. From the distribution of stress in the ground, it can be seen that the connection style (rigid or hinge) between one of the walls and the bottom of the soil chamber greatly influences the distribution of stress in the ground. Taking a look at 1.31 sec, in Case-2 (Rigid), the lateral stress around 0.15 m from the bottom of the left wall concentrically increases. However, the lateral stress around the right wall is small. This is because the ground deforms toward the left wall and deforms in the direction of separation from the right wall in the case of a structure with a rigid connection. As in Case-1 (Rigid), it can be seen that the trend in Case-2 (Rigid) exists. The earth pressure distribution on left wall shifts in the vicinity of the earth pressure at rest. In Case-2 (Hinge), the lateral stress

![Distribution of lateral stress in ground and earth pressure distribution on left wall](image_url)

Fig. 4. Distribution of lateral stress in ground and earth pressure distribution on left wall
around the bottom of the left wall and the center of the right wall increases at 1.31 sec. As described above, the ground deforms toward the left. Both walls also fall toward the left. Thus, the lateral stress increases around the bottom of the left wall dominated by the small displacement. The lateral stress increases around the center of the right wall in the passive state.

3.3 The relationship between earth pressure and relative displacement

Comparing the case of a structure with a rigid connection and the case of a structure with a hinge connection, the increase and decrease in earth pressure on the left wall in the case of a structure with a hinge connection is more complicated than that in the case of a structure with a rigid connection. This is because the influence of not only the inertial force acting on the ground, but also the collapse of the walls, causes the increase and decrease in earth pressure on the walls. Deformation modes can be classified into four categories by focusing on the inertial force and the relative displacement. Figure 5 shows the four deformation modes and the process followed in Case-2 (Hinge). Figure 6 shows the relationship between earth pressure and relative displacement. The relative displacement (= displacement of top of the wall – displacement of bottom of the wall) shows the collapse of the walls. The vertical axis indicates earth pressure and the horizontal axis indicates relative displacement.

From Figure 6, the graph for the relationship between earth pressure and relative displacement in Case-2 (Hinge) is like a parallelogram. In Mode 1, the ground around the left wall is in the passive state and the direction of the inertial force acting on the ground is right. Firstly, the earth pressure increases by the passive state. Secondly, the inertial force increases. Finally, the earth pressure does not increase. In Mode 2, the ground around the left wall is in the active state and the direction of the inertial force acting on the ground is left. It can be seen that the earth pressure decreases. In Mode 3, the ground around the left wall is in the active state and the direction of the inertial force acting on the ground is right. Firstly, the earth pressure decreases by the active state. Secondly, the inertial force increases. Finally, the earth pressure does not decrease. In Mode 4, the ground around the left wall is in the passive state and the direction of the inertial force acting on the ground is left. It can be seen that the earth pressure increases.

4 CONCLUSIONS

In this research, adjacent earth retaining structures have been modeled as two walls. Shaking table tests and finite element analyses have been carried out to clarify the influence of the set spacing and the deformation mode of two walls on the mechanism of the dynamic earth pressure. The following conclusions can be drawn from the results of this study:

1) In the case of a structure with a rigid connection, the influence of the inertial force acting on the ground dominates the increase and decrease in earth pressure on the walls.
2) In the case of a structure with a hinge connection, it is confirmed that the influence of not only the inertial force acting on the ground, but also the collapse of the walls, causes the increase and decrease in earth pressure on the walls. The increase and decrease in earth pressure on the left wall in the case of a structure with a hinge connection is more complicated than that in the case of a structure with a rigid connection.

REFERENCES

1) Ishibashi, I. and Fanf, Y. (1987): Dynamic Earth Pressures with Different Wall Movement Modes, Soils and Foundations, Vol.27, No.4, pp.11-22.
2) Kikuchi et al. (1995): Dispersion of Earth Pressure in Experiments and Earth Pressure Change due to the Relative Movement of the Neighboring Walls, Technical Note of the Port and Harbour Research Institute Ministry of Transport, No. 811, pp.2-33. (in Japanese)
3) Kodama, N. and Komiya, K. (2010): Model Experiment and Numerical Modelling of Dynamic Soil-Structure Interaction”, Materials with Complex Behaviour, Advanced Structured Materials, Vol. 3, pp. 269-276.
4) Nakai, T. (1985): Finite Element Computations for Active and Passive Earth Pressure Problems of Retaining wall, Soils and Foundations, Vol.25, No.3, pp.98-112.
5) Nakai et. al. (1999): Model tests and Numerical Simulation of braced Excavation in Sandy Ground, Soils and Foundations, Vol.39, No.3, pp.11-12.
6) Nakai, T. and Hinokio, M. (2004): A simple elastoplastic model for normally and over consolidated soils with unified material parameters, Soils and Foundations, Vol.44, No.2, pp.53-70.
7) Ye, B., Ye, G. L., Zhang, F. and Yashima, A. (2007): Experiment and numerical simulation of repeated liquefaction-consolidation of sand, Soils and Foundations, Vol.47, No.3, pp.547-558.