ジャケット式基礎の地震時挙動に関する研究（その２）—単杭の動的遠心模型実験の数値シミュレーション—

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ABSTRACT: It is believed that a dynamic analysis is urgently required to provide more reliable numerical method for the evaluation of a full system, which includes foundation, super structure and ground, during a huge earthquake which often happens in Japan and Taiwan. Therefore, in order to conduct a dynamic analysis of different pile foundations, a numerical code DGPILE-3D (Zhang et al., 2000) has been developed. The validity of the computer program has been verified in some case studies. In this paper, a centrifugal model test of pile foundation is simulated. In the calculation, the parameters of soil involved in tij model (Nakai, 1989) are firstly calibrated by centrifugal vibration tests of sandy ground only. Then, model tests of a pile foundation with single pile are simulated using the same parameters of the constitutive model for the soil, which was calibrated in the first step. The results of the simulation are in good agreement with the corresponding experimental results.

Key word: dynamic analysis, pile foundation, 3D-FEM, centrifugal model test

INTRODUCTION

Seismically loaded piles are designed to withstand not only the inertial forces generated from the oscillation of the super structure but also the deformations of a ground caused by the passage of seismic waves through the surrounding soil. It is pointed out that structural researchers always tend to use a too simplified model dealing with ground, and geotechnical researchers tend to use a too simplified model dealing with super structures.

It is believed, however, that a dynamic analysis is urgently required to provide more reliable simulations for the evaluation of a full system, which includes foundation, super structure and ground, especially in the earthquake zones such as Japan and Taiwan. Unfortunately, dealing with the full system with a dynamic analysis is usually thought to be difficult when the nonlinearity of both soil and structure must be taken into account. A few studies have been done in this field through both experiments and numerical analyses.

Kimura and Zhang (2000) conducted a series of static and dynamic 3-D elastoplastic finite element analyses on a simplified sway-rocking model (S-R model) and on a full system to investigate the dynamic behavior of group-pile foundation during earthquake. Zhang et al. (2000) simulated numerically a field test of a real-scale 2-pile foundation subjected to lateral cyclic loading up to ultimate state with a 3-D elastoplastic finite element analysis, taking into consideration the influence of different constitutive models adopted for soils.

In this paper, the authors conducted a series of calculation by DGPILE-3D to simulate the centrifugal model tests described in the Part II of the same paper.

NUMERICAL SIMULATION

In the calculation, two kinds of physical models are considered. One is the physical model that is consisted of soil only, in which the densities of the ground are 1.43 and 1.58 respectively. The other physical model is a full system that consists of a single pile and a pier and a ground. The cases of the calculation conducted in this paper are listed in Figure 1. The calculations are performed to simulate not only the behavior of the ground only but also the behavior of the single pile foundations and the super structure. In order to investigate the influence of the ground, two kinds of ground with the densities of 1.43 and 1.58, are considered, as shown in Figure 1.

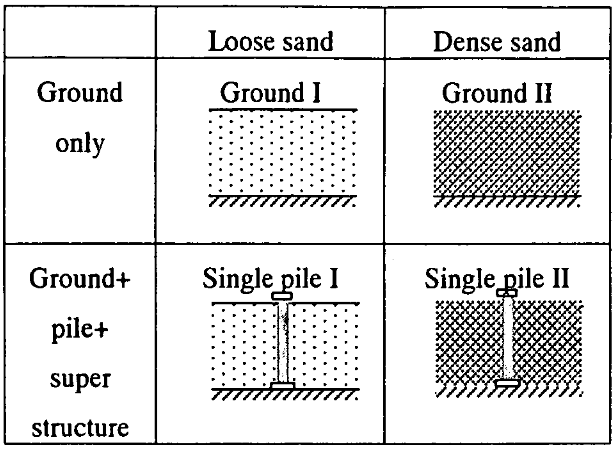

Figure 1 Cases of numerical calculation

Figure 2 shows the layout of the shear box in the centrifugal model tests for the cases of ground only. The information about the centrifuge model tests is described in detail in the Part I of the same paper.

Figure 3 shows the finite element mesh adopted in the analysis. The size of the ground is 23.0 m in length, 11.0 m in thickness, and 16.6 m in height. The number of the node and 8-node isoparametric element are 2290 and 1764 respectively. The finite element mesh here is expressed in a prototype scale. The input earthquake wave is the same one as used in the centrifugal model tests (see the Part I of the same paper).

The initial stress condition of the ground is a gravitational field. The boundary condition of displacement is given as: (a) it is fixed at the bottom in all x, y, z directions; (b) it is fixed at y direction at xoz planes and (c) it is free at yoz planes. In the dynamic analysis, a direct integration method, Newmark-β method, is adopted and the time interval of the integration is 0.01 sec.

The ground is simulated with tij sand model (Nakai, 1989). Table 1 lists the parameters involved in the model. The determination of these soil parameters is mainly based on triaxial compression tests. The detailed description of the determination of these parameters can be referred to corresponding reference (Nakai, 1989). In present case, the model ground is made of Toyoura standard sand. Therefore, most of the parameters involved in tij sand model are available according to the accumulated results. Some parameters, however, are mainly obtained in static loading tests. In dynamic analysis, they should be reviewed again. For this reason, as the first step, the parameters of soil are calibrated based on centrifugal vibration tests on sandy ground only in such a way that the results obtained from the numerical simulation agrees well with the experimental results. Then, model tests of a pile foundation with single pile are simulated using the same parameters that were calibrated in the first step.

Table 1 Material parameters of ground

	Ground I	Ground II		Ground I	Ground II
ρ (g/cm^3)	1.43	1.58	R_f	4.0	4.0
ν	0.30	0.30	λ (C_t)	0.009	0.009
D_f	-0.60	-0.60	κ (C_e)	0.003	0.003
m	0.30	0.30	e_0	0.85	0.68
α	0.80	0.80			

5) Table 2 lists the parameters of the single pile which is made of aluminum. All the values in the table are given in the prototype scale. In the model tests, the pile behaved elastically. Therefore the pile is assumed as elastic material in the calculation.

Table 2 Parameters of single pile (In prototype)

Diameter D= 0.9m
Length L=16.6m
Thickness t= 45mm
EI= 7.842E8 (N-m)

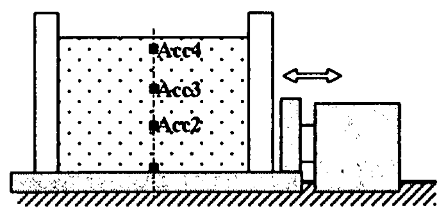

Figure 2 Layout of shear box (Ground only)

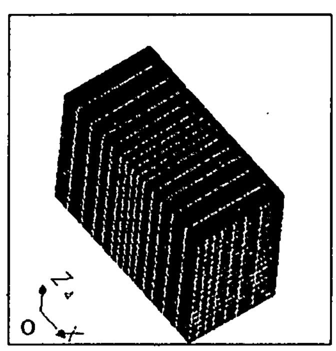

Figure 3 Finite element mesh

RESULTS AND DISCUSSIONS

Figure 4 and figure 5 show the calculation results of Ground I and Ground II respectively. The results obtained from calculation agree well with the results obtained from the tests at the places marked by acc2, acc3 and acc4, which locate at 3.51m, 5.76m and 8.46m beneath the ground surface.

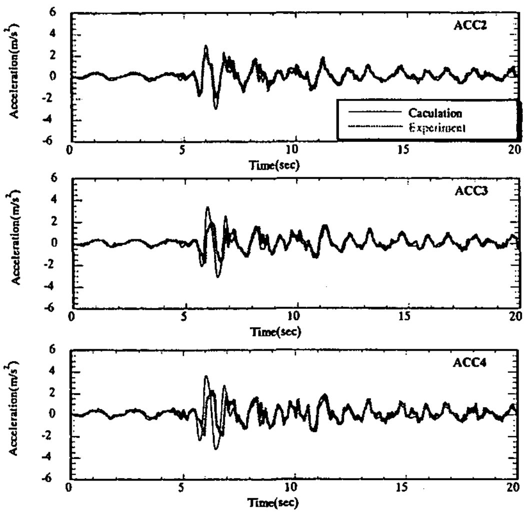

Figure 4 Time history of acceleration of Ground I

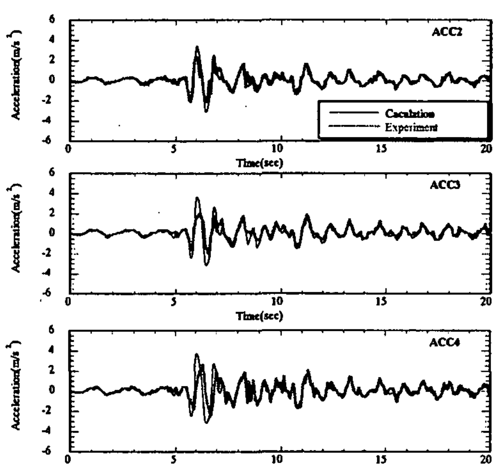

Figure 5 Time history of acceleration of Ground II

After the validity of the numerical simulation for Ground I Ground II is confirmed, the material parameters of the grounds in tij sand model can be determined. Then, the numerical simulation for the cases of Single pile I and Single pile II, in which the same soil parameters as used in the simulations for Ground I and Ground II are adopted.

Figure 6 shows the layout of the shear box in the centrifugal model tests for the cases of Single pile I and Single pile II. The comparisons of the responded accelerations obtained from the

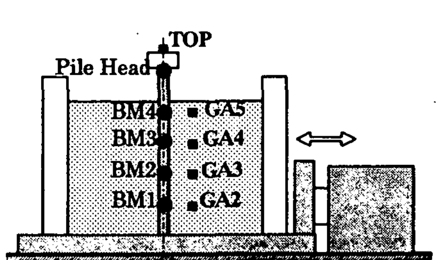

Figure 6 Layout of the shear box in the cases of Single pile I and Single pile II

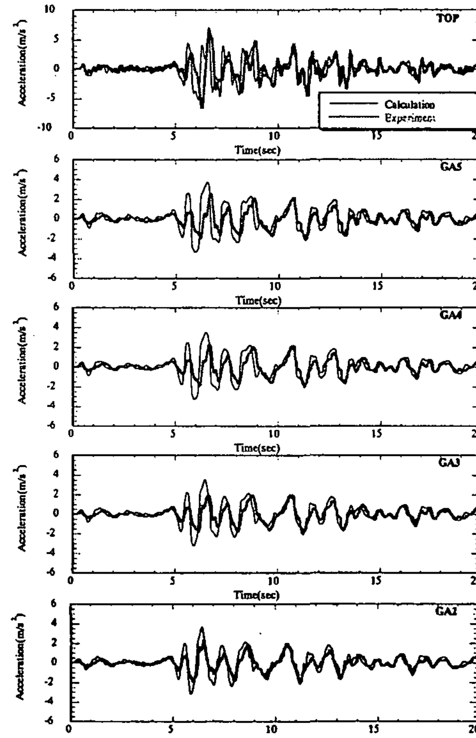

Figure 7 Time history of the acceleration in the case of Single pile I

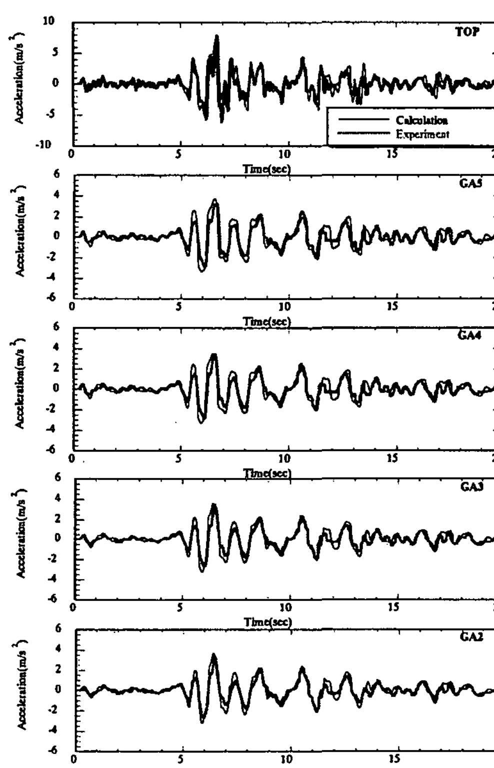

Figure 8 Time history of the acceleration in the case of Single pile II

calculation and the centrifugal model tests are shown in Figure 7 and Figure 8, respectively. In the figures, the positions GA2, GA3, GA4 and GA5 are at the places 1.26m, 3.51m, 5.76m and 8.46m beneath the ground surface, respectively. It is evident that the prediction of the accelerations at all places is quite accurate if compared with the test results.

The comparison of the bending moments in the case of Single pile I is shown in Figure 9, in which the locations of pile head, BM1 to BM4 are given in Figure 5. It can be seen that apart from some difference in the amplitude of the waves, the calculated bending moments at all places agree well with the tested results

The same phenomenon can be observed in the case of Single pile II, as shown in Figure 10. Therefore, it is reasonable to say that present analyses can simulate the centrifugal model tests of a pile foundation-ground-super structure system to an engineering acceptable accuracy.

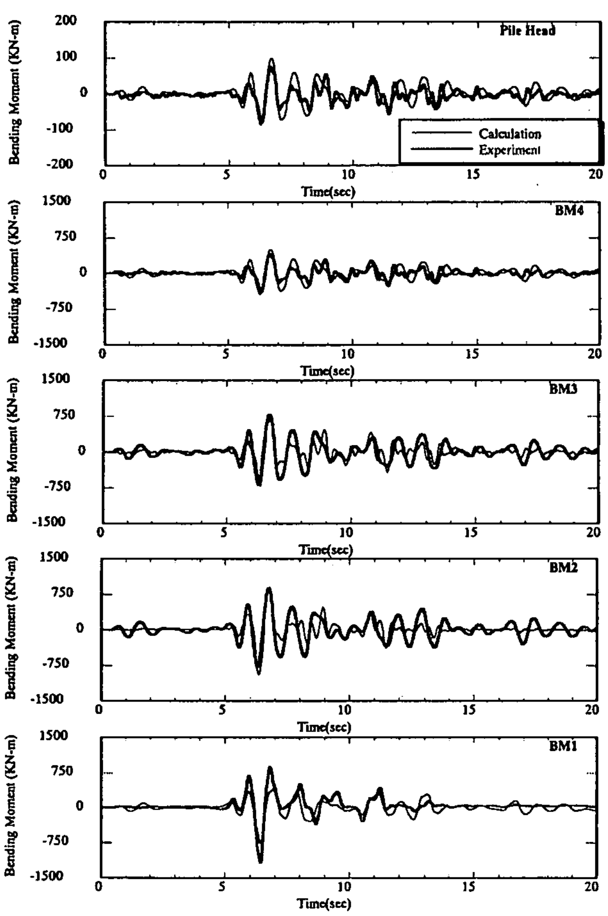

Figure 9 Time history of the bending moment of pile in the case of Single pile I.

CONCLUSION

A series of three-dimensional dynamic analyses were conducted to simulate the centrifugal model tests on sandy grounds only and a pile foundation-

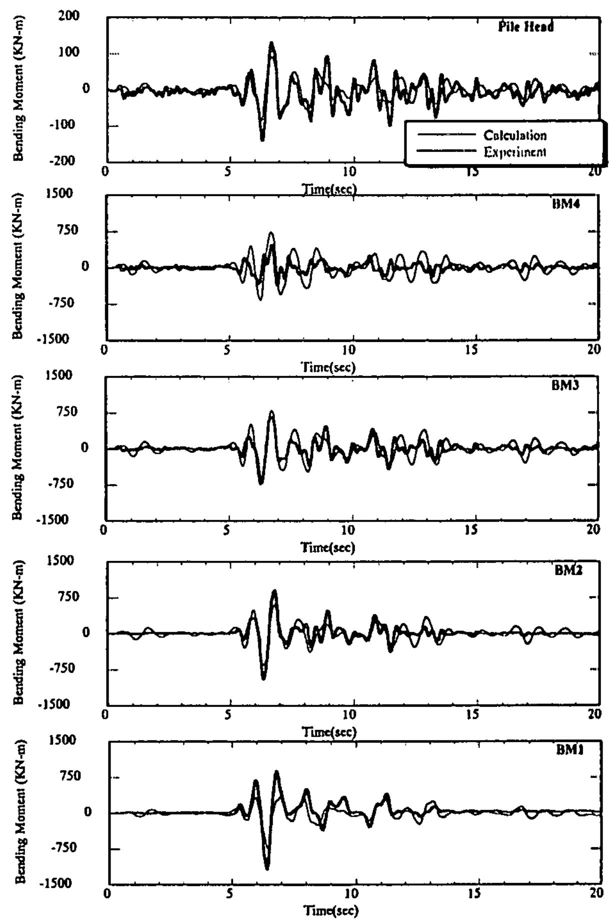

Figure 10 Time history of the bending moment of pile in the case of Single pile II.

ground-super structure system. It is found that in either the cases of dense sand and loose sand, the analytical results obtained from the present analyses agree well with the test results both in the responded accelerations and the bending moments that measured in the model tests. The good agreements between the calculated and experimental results prove the applicability of DGPILE3D and give the users more confidence on its applications in the future.

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