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.
Table 1 Material parameters of ground

<table>
<thead>
<tr>
<th>Ground type</th>
<th>Ground I</th>
<th>Ground II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ (g/cm$^3$)</td>
<td>1.43</td>
<td>1.58</td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>$\lambda$ (C$_L$)</td>
<td>0.009</td>
<td>0.009</td>
</tr>
<tr>
<td>$\kappa$ (C$_S$)</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>$m$</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>$c_0$</td>
<td>0.85</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 2 Parameters of single pile (In prototype)

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

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.
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 5 Time history of acceleration of Ground II

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 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.](image)

![Figure 10 Time history of the bending moment of pile in the case of Single pile II.](image)

**CONCLUSION**

A series of three-dimensional dynamic analyses were conducted to simulate the centrifugal model tests on sandy grounds only and a pile foundation-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 DGPL3D and give the users more confidence on its applications in the future.

**REFERENCES**

