A DYNAMIC MODEL TEST AND ANALYSIS OF A STEEL PIPE PILED WELL FOUNDATION

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ABSTRACT

The static mechanical properties of a steel pipe piled well foundation have been studied in the past with few studies about its dynamic characteristics. In present paper, the dynamic characteristics of the steel pipe piled well foundation are investigated by the model tests and FEM calculation. Model tests were performed on a shaking table to estimate the basic characteristics. Based on the results of tests and numerical calculation, it is confirmed that dynamic characteristics of this type of foundation is affected by the relationship of the natural frequency of the foundation, the superstructure and the ground.

KEYWORDS

Steel pipe piled well foundation; Dynamic characteristics; Model test; FEM; Dynamic interaction

INTRODUCTION

A steel pipe piled well foundation is a useful technique for under water and soft ground foundation because of its application to the cofferdam. This kind of foundation shows intermediate characteristics between a caisson and a pile group foundation. The static mechanical properties of a steel pipe piled well foundation have been studied by static load tests and analysis in the past. (Ninagawa et.al., 1972, Yamamoto et.al., 1983, Takeuchi et.al., 1988) However, on account of the complication of the mechanisms, the dynamic characteristics of this foundation have not been researched well. And the standard seismic design have not been established as yet.

The small model test which was made by poly vinyl chloride pipes was carried out. (Uno et.al., 1992, Uno et.al.,1993) From this results, the foundation without the superstructure vibrated at first natural frequency of the ground. However, the effects of superstructure (i.e. mass, inertia force ) were not considered in that tests. In real steel pipe piled well foundation, response characteristics were varied according the relationship between
natural frequency of super structure and that of ground.

This study aims to clarify the dynamic characteristics of the steel pipe piled well foundation with superstructure system using model tests and numerical calculation. To consider the effect of a superstructure under the dynamic response of a foundation, three different rahmen models were placed on the foundation. Model tests were carried out using the shaking table with various amplitude shaking. These tests were analysed by the FEM calculation using FLUSH program. It became clear through model tests and FEM analysis that the dynamic response characteristics of a steel pipe piled well foundation is affected by the relationship between the natural frequency of foundation and superstructure.

MODEL TEST

A small model test was carried out to estimate the basic dynamic characteristics, and the modeling method of steel pipe piled well foundation and soil around the foundation by FEM. In the model test, the law of similarity of the real structure and the model is very important. However, it is difficult to make the foundation model which satisfy the law of similarity because of the complication. Thus, the scale model test is abandoned.

The foundation model, composed of 16 steel pipes (out side diameter, $\phi = 48.6\text{mm}$) and splices of steel pipes (out side diameter, $\phi = 13.8\text{mm}$) and mortar was used in the experiment as shown in Fig.1. The model foundation
is fixed at the bottom of the box filled with sand (average diameter is 1.0mm). The experiment was performed on a shaking table. Accelerations and soil pressures were measured at several points as shown in Fig. 2. Resonance curves of foundation model with or without inside soil were shown in Fig. 3 (a) and (b). These figures show that the resonance frequency of the foundation model is 31.1Hz at 15gal and 30.8Hz at 30gal. To investigate the effect of the superstructure upon the dynamic response of the foundation, a frame rahmen model was placed at the top of the foundation model, three rahmen models TYPE A, B, C were used in the experiment. The natural frequency of TYPE A and C rahmen (22.7Hz and 39.1Hz) are respectively lower and higher than that of the foundation model and TYPE B (30.5Hz) is equal to the foundation model. Table 1 shows the test cases.

**RESULTS OF MODEL TEST**

**Without Superstructure**

Resonance curves of CASE-1 and CASE-2 were shown in Fig. 4 (a) and (b). Here, the accelerations were measured at the top of the foundation model (A00) and ground surface (AG0). Resonance frequencies of CASE-2 which filled soil inside are lower than that of CASE 1. In these figures, it is found that the foundation model vibrated at the resonance frequency of ground. The behaviors are independent of acceleration level and existence of soil inside. In Table 2, the response accelerations of foundation model, inside soil, and ground of CASE-2 are indicated. Response accelerations of foundation model and inside soil are similar. From the test
Fig. 4 Resonance curves of CASE-1 and CASE-2

CASE - 4A

CASE - 4B

CASE - 4C

Fig. 5 Resonance curves of CASE-4
results, a steel pipe piled well foundation without superstructure is observed to vibrate with the soil around the foundation at the resonance frequency of ground. This is because the stiffness of foundation is smaller than that of ground.

With Superstructure

Resonance curve. Resonance curves of rahmen (AP0), top of the foundation (AP1) and ground surface (AG0) at CASE-4 are shown in Fig. 5. Two peaks are occurred in resonance curves of rahmen, the resonance frequency of the rahmen (※) and the ground. On the resonance frequency of rahmen, both the foundation and the ground are vibrated with the inertial force of rahmen. This phenomena is shown clearly at CASE-4A. However, the response acceleration of foundation at the resonance frequency of ground is higher than the response by inertia of rahmen in CASE-4B and CASE-4C. In these tests, test conditions except the resonance frequency of rahmen were the same, thus difference in the response is due to the interaction of rahmen-foundation-ground system frequency characteristics. The similar phenomena was observed in CASE-3.

Vibration mode. Fig. 6 indicates vibration modes of the foundation, the ground and the inside soil in CASE-4. In these figures, the response was normalized by the response at the top of the foundation at resonance frequency of ground. In CASE-4B and CASE-4C, vibration modes at the resonance frequency of ground and rahmen are similar in form, but the response at the resonance frequency of rahmen is very small. However, in
CASE-4A, response of the foundation at the resonance frequency of rahmen is greater than the response of the ground at the resonance frequency of ground, and the vibration mode of foundation at the resonance frequency of rahmen is similar to that of the ground at the resonance frequency of ground. In view of the above mentioned, it is may be happened that the behavior of foundation is affected by the inertia of rahmen and ground vibration when the resonance frequency of rahmen is below that of ground. Fig.7 indicates the phase difference between the rahmen and the top of the foundation. At the resonance frequency of the rahmen, the foundation and the rahmen vibrated at the same phase. However, at the resonance frequency of ground, CASE-4B and CASE-4C vibrated at the same phase, while CASE-4A oscillated with a phase difference of 180 degree. In this case, CASE-4A rahmen and the foundation oscillated at opposite direction, thus the inertial force of the rahmen resists the motion of the foundation.

Soil pressure. The distribution of the soil pressure of the foundation are shown in Table 3. Soil pressure of CASE-4A increased with vibrated at the resonance frequency of rahmen. In CASE-4A, the resonance frequency of rahmen is lower than that of ground and they are very close. Therefore the foundation vibrated not only by the 1st. vibration mode of the ground but also by the inertia force of the rahmen with the same phase.

NUMERICAL ANALYSIS

Analytical model
The foundation, rahmen and ground of CASE-4 were modeled as shown in Fig.8 for FEM calculation. The foundation and rahmen were modeled by beam elements and soil as solid elements. Boundary condition at the bottom was fixed, and at the sides were transmissive. The analysis of model was carried out by using FLUSH program, where three dimensional effect and non-linearity of ground were considered in the calculation. Each pipe that form a well foundation is connected by splice with each other, but not connected rigidly. Therefore, a splice fixity must be estimated for modeling a steel pipe piled well foundation. In this study, a splice fixity was adjusted by the comparison of an observed resonance frequency and FEM eigen value analysis. From this result, a splice fixity of CASE-4 is 0.01.

Analytical results

Fig.9 (a) and (b) shows the response accelerations of the ground, the pile and the inside soil according to the CASE-4A rahmen used. Symbols in this figure represent test results and lines indicate calculation values. Fig.9 (a) represents accelerations under resonance frequency of the ground while the right side shows accelerations under resonance frequency of the rahmen. Close relationship between experiment results and calculated values was obtained, except for the response acceleration of the pile at the resonance frequency of rahmen. This insufficiency would be due to the difference of boundary condition in dynamic test and calculation.
Fig. 10 shows the phase difference of the rahmen and the top of the foundation in CASE-4A. This was calculated by the time history response analysis. Fig. 10 indicates that the rahmen and the foundation oscillated at opposite direction at the frequency region over the resonance frequency of rahmen. This tendency is the same with that of Fig. 7.

CONCLUSION

This study clarified the basic dynamic characteristics of a superstructure, foundation and ground system excited by earthquake. Dynamic response characteristics of a steel pipe piled well foundation are affected by the relationship of the natural frequency of foundation and the superstructure. When the natural frequency of superstructure is below the natural frequency of foundation, the soil pressure of the foundation increased due to the phase difference between the superstructure and the foundation.

REFERENCES