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Partial-embedment test on soil-foundation interaction

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ABSTRACT: This paper describes the effects of partial-embedment on soil-foundation interaction by a laboratory test using silicone rubber ground model and a rigid foundation model made of aluminum. A simulation analysis is also performed using two dimensional finite element method (2D FEM) to clarify the availability of the analytical tool.

1 INTRODUCTION

While the effects of the embedment on soil-structure interaction have been investigated in recent years, most of the experimental and theoretical studies have considered the embedded foundation fully surrounded by the side soil (ex. Apsel (1987), Day (1977) and Tanaka (1984)). However in many cases the foundations are not fully embedded and there are few studies of partially embedded foundation (Tassoulas (1983)). Although a forced vibration test is carried out to examine the effects of the partial embedment, the complete information of the soil properties is not known and it is not easy to obtain a foundation input motion even a field test is performed. Therefore, the effects of the partial-embedment on soil-foundation interaction, such as the impedance function of a foundation and the foundation input motion, were studied by laboratory test using silicone rubber whose material properties can be easily controled. The impedance function was obtained by hammering tests and the foundation input motion was evaluated from a series of shaking table tests. A simulation analysis was also worked out by two dimensional finite element method (2D FEM) to clarify the availability of the analytical tool.

2 TEST

2.1 Outline of Test

The ground model and foundation models are shown in Fig. 1. The ground model was made of silicone rubber whose material constants are shown in Table 1.

Table 1. Material constants of ground model.

Young's modulus E(Pa)	Poisson's ratio ν	Density ρ (kg/m³)	Damping ratio h
2.30×10^{6}	0.484	1.24×10^{3}	0.01

The model has a cylindrical shape with diameter of 3.0 m and height of 0.7 m, and has a 0.18 m deep pit at its center. A foundation made of aluminum is 0.3 m square wide and 0.18 m high. The foundation was placed at the center of the pit and it was backfilled by the silicone rubber whose material constants are shown in Table 2.

Table 2. Material constants of backfill.

Young's modulus E(Pa)	Poisson's ratio ν	Density ρ (kg/m³)	Damping ratio h
3.40×10^{5}	0.490	1.00×10^{3}	0.03

Two types of test were carried out. One was the hammering test and the other was the shaking table test. The hammering test was performed to obtain the impedance functions of a massless rigid foundation, and the shaking table test was performed to evaluate the foundation input motions. The impedance functions and the foundation input motions were calculated from measured responses of the foundation as follows:

Impedance function :

$$[[M] - \omega^{-2} [K]]\{\ddot{u}\} = \{f\} \qquad (1)$$

where

- $[M]$: mass matrix of foundation
- $[K]$: impedance function matrix to be obtained
- $\{\ddot{u}\}$: response acceleration vector of foundation by hammering tests
- $\{f\}$: excitation force vector of hammer

Foundation input motion :

$$\{u^*\} = -\omega^2 [K]^{-1} [M]\{u\} + \{u\} \qquad (2)$$

where

- $\{u^*\}$: foundation input motion vector to be obtained
- $\{u\}$: response displacement vector of foundation by shaking table tests

The impedance functions and the foundation input motions were processed using a transient response to eliminate the reflected wave from the bottom boundary (Mita et al. (1989)). Since the transient response uses the data before arrival of the first reflected wave, the impedance functions and the foundation input motions are regarded as those for the half space. The tests were conducted for three different embedment conditions, that is no-embedment, partial-embedment and full-embedment (see Fig. 1) to evaluate the effects of the different embedment condition on a soil-foundation interaction system.

2.2 Impedance function

Fig. 2 shows the impedance functions obtained from the test results and those evaluated by means of a transient response. While the impedance functions of test have many peaks and dips, those of a transient response are smooth. Figs. 3 and 4 show the impedance functions of three different embedment conditions in the direction parallel to the symmetric axis (symmetric direction:X) and in the direction perpendicular to the symmetric axis (antisymmetric direction:Y) respectively. The embedment effects such as increase of the impedance functions are found in the figures. The impedance functions of the partially embedded foundation appear between those of the fully embedded foundation and the no embedment foundation. While difference between the horizontal impedance of the symmetric direction and those of antisymmetric direction is not so significant, the real part of the rocking impedance of the symmetric direction is larger than those of the antisymmetric direction below 30Hz. This is because the constraint effect of partially embedded foundation is larger in the symmetric direction than in the antisymmetric direction.

2.3 Foundation input motion

Figs. 5 and 6 show the foundation input motions of three different embedment conditions in the symmetric direction and in the antisymmetric direction respectively. The foundation input motions were normalized with respect to the average motion of the excavated ground surface. If there is no excavated portion of the ground or no embedment of the foundation, the horizontal component should be equal to 1.0 and no rotational component should exist. Therefore, the excavated portion of the ground and the embedment of the foundation affect the characteristics of the foundation input motion significantly. Although the embedment condition does not affect the foundation input motion for symmetrical direction, the foundation input motion of the partially embedded foundation is larger than that of the other embedment conditions between 30 Hz and 40 Hz for antisymmetric direction.

3 SIMULATION ANALYSIS

3.1 Model

Fig. 7 shows 2D FEM models used in the simulation analysis for three embedment conditions. The element size of 2D FEM model was selected to be smaller than 1/5 of the shortest wave length considered in the analysis. The 2D FEM model has an lateral energy transmitting boundary along both sides and a viscous boundary at the bottom of the model. Since the FEM tends to overestimate the stiffness, the Young's moduli of the ground model were determined beforehand to simulate the ground model tests. The material constants of the ground model and the backfill used in the simulation analysis are shown in Tables 3 and 4 respectively.

Table 3. Material constants of ground model used in simulation analysis.

Young's modulus E(Pa)	Poisson's ratio ν	Density ρ (kg/m³)	Damping ratio h
1.99×10^6	0.484	1.24×10^3	0.01

Table 4. Material constants of backfill used in simulation analysis.

Young's modulus E(Pa)	Poisson's ratio ν	Density ρ (kg/m³)	Damping ratio h
2.77×10^5	0.490	1.00×10^3	0.034

3.2 Results

The impedance functions and the foundation input motions of the half space in the symmetric direction are shown in Figs. 8 and 9 respectively. The embedment effects indicated in the test results, such as increase in the impedance function and the rotational component of foundation input motion, are also seen in the results of the simulation analysis. Although the embedment condition does not affect the horizontal impedance significantly, the rocking impedance and the coupled impedance increase as the amount of embedment increases, especially for the rocking motion. It was found that the rotational component of foundation input motion is increased by the partial- and the full- embedment and that the foundation input motion depends on frequency significantly.

4 CONCLUSIONS

The following conclusions can be drawn from the laboratory test and the simulation analysis.

1. The effects of embedment, such as increase in the impedance function and the rotational component of foundation input motion, were confirmed by the laboratory test and the simulation analysis.
2. The effects of the partial-embedment were larger in the direction perpendicular to the embedment than in the direction parallel to that.
3. The embedment effects for the full-embedded foundation were larger than those of the no-embedded foundation, and the magnitude of the effects for the partially-embedded foundation appeared between them.

5 ACKNOWLEDGMENTS

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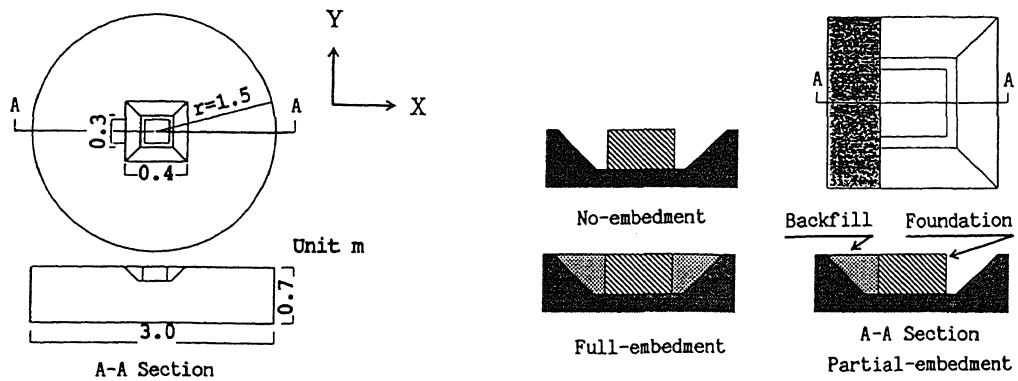

Fig.1 Ground and foundation models

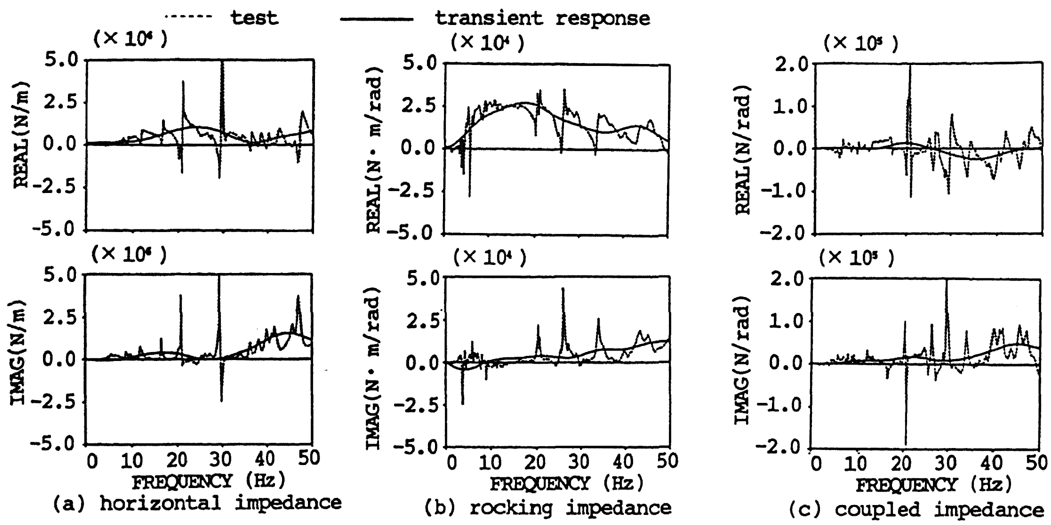

Fig.2 Impedance function obtained from test and transient response

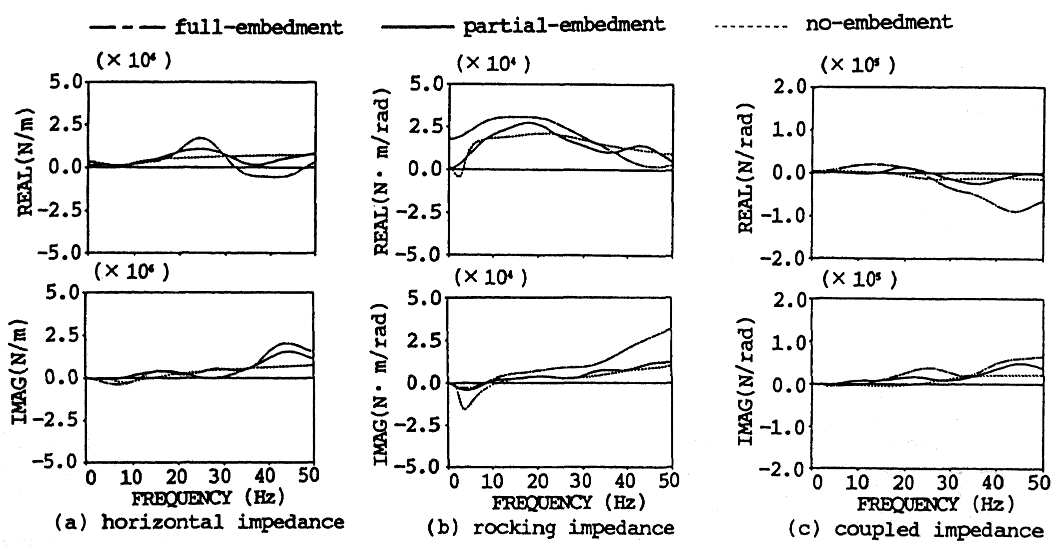

Fig.3 Impedance function of transient response in symmetric direction

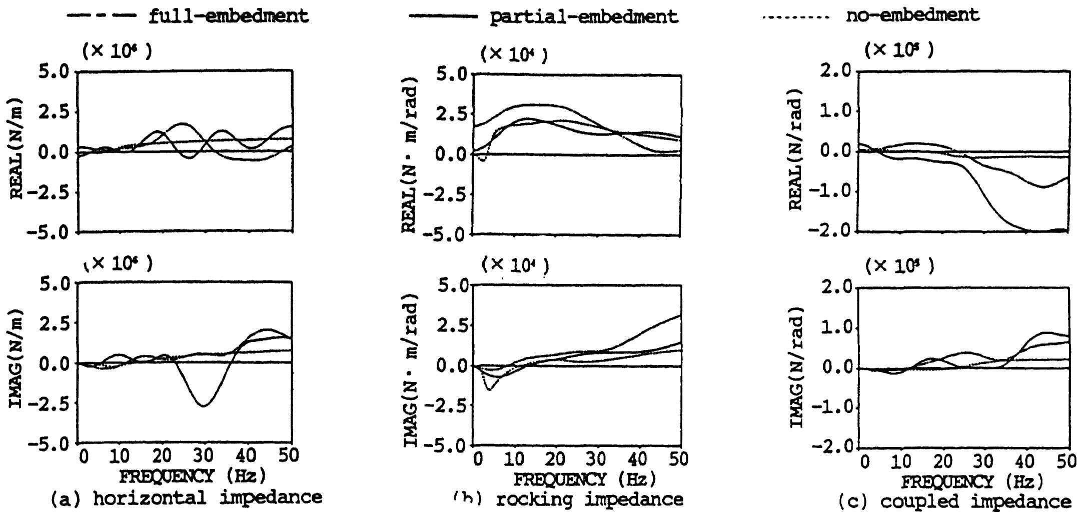

Fig.4 Impedance function of transient response in antisymmetric direction

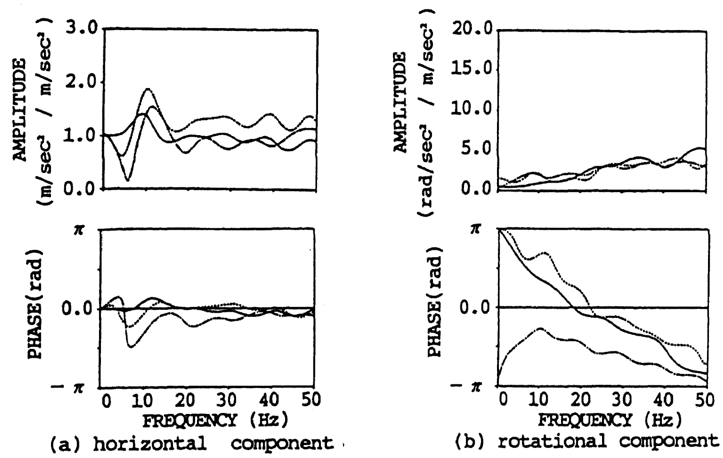

Fig.5 Foundation input motion of transient response in symmetric direction

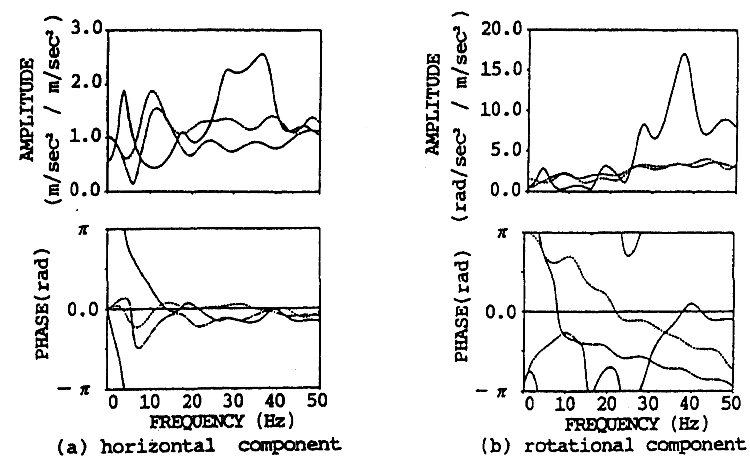

Fig.6 Foundation input motion of transient response in antisymmetric direction

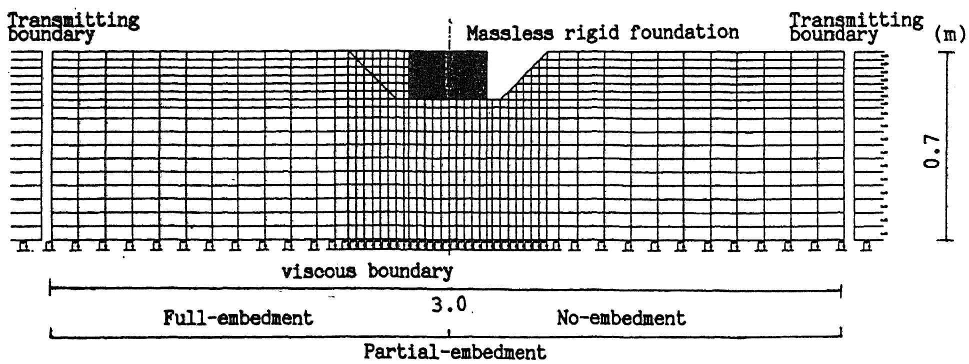

Fig.7 Three 2D FEM model used in simulation analysis

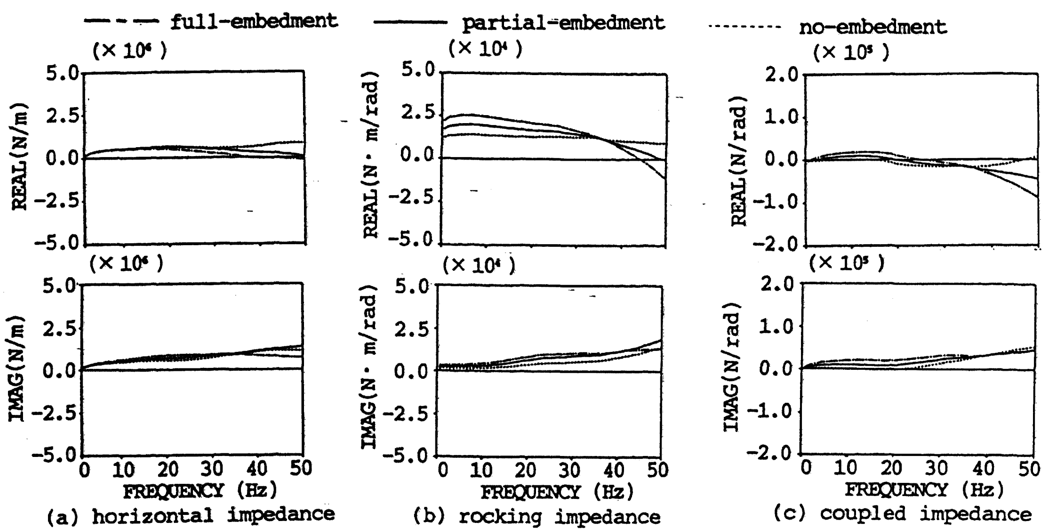

Fig.8 Impedance function of simulation analysis in symmetric direction

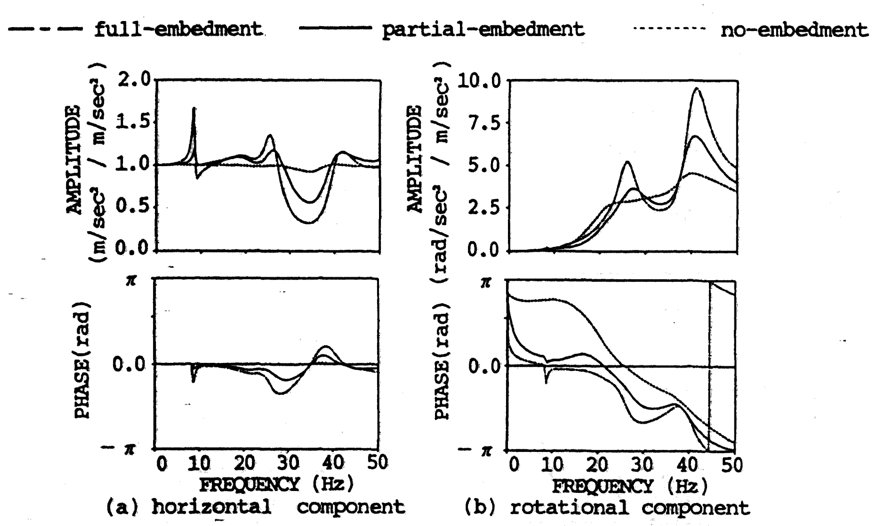

Fig.9 Foundation input motion of simulation analysis in symmetric direction