

Comparison between Tests and Analyses for Ground-Foundation Models (Embedment Effect Test on Soil-Structure Interaction)

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1 INTRODUCTION

The laboratory tests were carried out on two ground models made of silicone rubber (hard and soft ground models) and a foundation model made of aluminum in order to confirm the embedment effects on soil-structure interaction system experimentally. The detail of the procedure and the results of the test are described in the companion paper (Shohara et al. 1991). Up till now, the analytical studies on the embedment effect on seismic response of buildings have been performed in recent years and the analysis tools have been used in the seismic design procedure of the nuclear power plant facilities. The embedment effects on soil-structure interaction system are confirmed by the simulation analysis and the verification of analysis tools are investigated through the simulation analysis in this paper.

2 METHOD OF SIMULATION ANALYSIS

The simulation analyses were carried out by three analysis methods: (1) analysis method by means of wave propagation theory (Shohara et al. 1991); (2) Sway-rocking model (S-R model) employing the bottom springs, sway and rocking, obtained by boundary element method (BEM) and the side springs, horizontal and rocking, obtained by Novak et. al (Novak et al. 1985); and (3) axisymmetric finite element method (FEM).

2.1 Analysis method by means of wave propagation theory (Tajimi et al. 1982)

Figure 1 shows the analysis model for the hard ground by means of wave propagation theory. The impedance functions of the half space and the layered half space were calculated. The point-load solution in a thin layered medium was used to solve the problem and the excavated portion of the ground was not taken into consideration. The material properties for the hard ground model used in the analyses are shown in the table 1.

2.2 Sway-rocking model

Figure 6 shows the concept of S-R model for the soft ground and the material properties used in the analysis. The impedance functions of the half space for the half-embedded foundation were calculated. Sway and rocking springs of the half space obtained from BEM were attached at the bottom of the model and the side soil springs evaluated by the Novak's theory (Novak et al. 1985) were added to take the embedment effects into account. The material properties obtained by SMIRT 11 Transactions Vol. K (August 1991) Tokyo, Japan, © 1991

material test results were used except for Poisson's ratio. The Poisson's ratio used for the S-R model was assumed to be 0.49.

2.3 Axisymmetric finite element method

Figures 2 and 7 show the axisymmetric FEM models of the hard and soft ground models respectively. The impedance functions and the foundation input motions were calculated. A square foundation was modelled by a circular foundation with same area. The element size of the axisymmetric FEM model was taken to be smaller than 1/5 of the wave length of the maximum frequency calculated in the analysis. The axisymmetric FEM has a lateral energy transmitting boundary and a viscous boundary or rigid bed rock at the bottom of the model. Since the FEM has a tendency of evaluating the stiffness higher than actual value, the material constant of the ground models were determined beforehand to simulate the ground model tests by axisymmetric FEM. The Poisson's ratio used for the axisymmetric FEM model of the soft ground model was set to be 0.49 to avoid numerical instability. The material constants used in the axisymmetric finite element analysis of two ground models were shown in the table 1 and table 2 respectively.

3 NUMERICAL RESULTS

3.1 Effect of excavated portion of ground

Figures 3 and 4 show the impedance functions of test results and analysis results. The impedance functions of half space were shown in Fig. 3 and those of layered half space were shown in Fig.4. The impedance functions of test results were processed using transient response to eliminate the reflected waves (Mita et al. 1989). The impedance functions of test results for a frequency range lower than 10Hz are fairly small in comparison with those of analysis results due to low S/N ratio in low frequency range of the accelerometer. Although an excavated portion of the ground was not taken into consideration, the results by means of wave propagation theory correspond well to the test results. However, a little difference in the horizontal impedance and in the coupling impedance of the layered half space is seen between the wave propagation theory and the test results or the results of axisymmetric FEM. This difference is probably because of the effect of the excavated portion of the ground.

Figure 5 shows a comparison between the test results and the results of axisymmetric FEM of the foundation input motions of the half space. The foundation input motions are referred to an average motion of the excavated ground surface. If there was no excavated portion of the ground, the amplitude of the horizontal component should be equal to 1.0 and no rotational component of the foundation input motion should arise. Therefore, the excavated portion of the ground affect the foundation input motion significantly.

3.2 Effect of embedment depth

Figure 8 shows the impedance functions of the half space for no-embedded foundation of the test results and those calculated by the axisymmetric FEM and the BEM. The impedance functions of the tests were also processed to eliminate the reflected wave and had not enough accuracy due to the low S/N ratio in low frequency range of the accelerometer. Although the BEM did not account for the excavated portion of the ground, the analysis results of the axisymmetric FEM and those of the BEM showed good agreement with test results.

Figure 9 shows the impedance functions of the half space for the half-embedded foundation of the test results and those calculated by the S-R model and the axisymmetric FEM. The impedance functions obtained by the S-R model with Novak springs indicate a different tendency from those of the test results. It is

because, according to the Novak's theory, the real part of the impedance functions decrease rapidly when the poisson's ratio is close to 0.5.

By comparing Fig. 8 and Fig. 9, it can be seen that the real part of the impedance functions in lower frequency range increase as the embedment depth increased and that the imaginary part of the impedance functions tends to increase also with embedment depth.

Figures 10 and 11 show the foundation input motions of the half space for the no-embedded foundation and those for the half-embedded foundation respectively. The rotational components are induced by the excavated portion of the ground and the embedment. By comparing Fig. 10 with Fig. 11, it can be seen that the axisymmetric FEM simulates the test results well and that the foundation input motions for half-embedded foundation have smaller amplitude than those for the no-embedded foundation and have a little phase lag in the horizontal component.

4 CONCLUSIONS

The following conclusions can be drawn from comparison between laboratory test results and analysis results.

- (1) The effects of embedment, such as increase in the impedance functions and the rotational component of foundation input motions, were clarified by the simulation analyses and laboratory tests.
- (2) The analysis results of axisymmetric FEM showed good agreement with processed test results by means of the transient response to eliminate the reflected waves and the analysis tools were confirmed experimentally.
- (3) The excavated portion of the soil affected the foundation input motion rather than the impedance function since there was little difference between the impedance functions obtained by wave propagation theory and those obtained by the axisymmetric FEM and the rotational component of the foundation input motions increased significantly.

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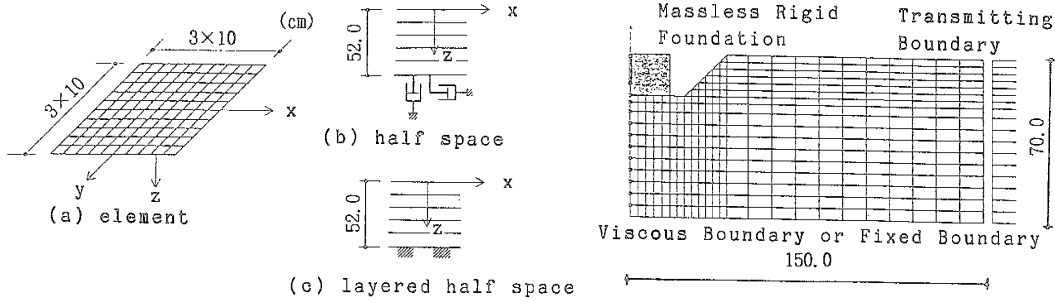


Fig. 1 Analysis Model By means of Wave Propagation Theory Fig.2 Axisymmetric FEM Model (Hard Ground)

Table 1 Material Property Used in Simulation Analysis (Hard Ground)

Young's modulus $E(\text{kg/cm}^2)$	Poisson's ratio ν	Shear wave velocity $V_s (\text{m/sec})$	Density $\rho (\text{g/cm}^3)$	Damping Ratio h
20.3	0.484	23.2	1.24	0.01

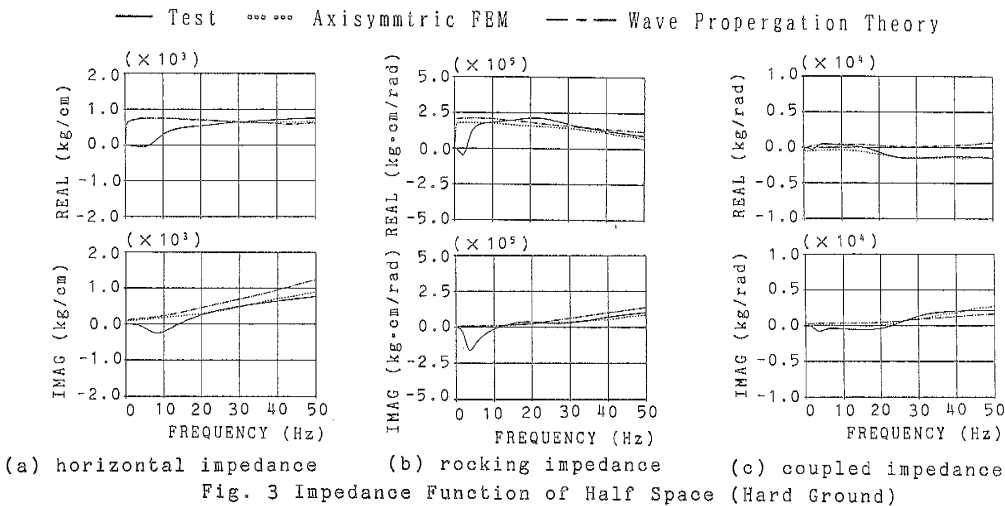


Fig. 3 Impedance Function of Half Space (Hard Ground)

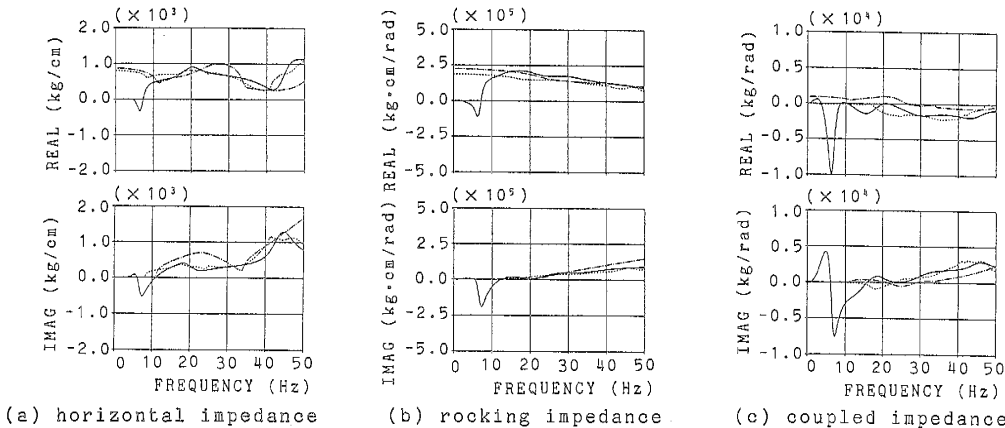


Fig. 4 Impedance Function of Layered Half Space (Hard Ground)

— Test ····· Axisymmtric FEM

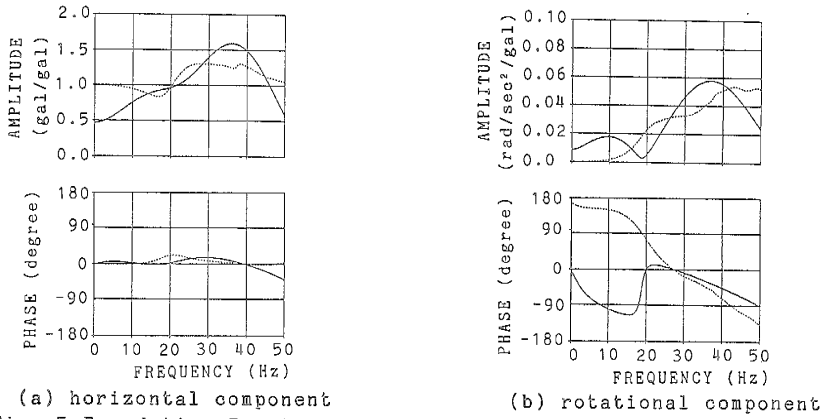
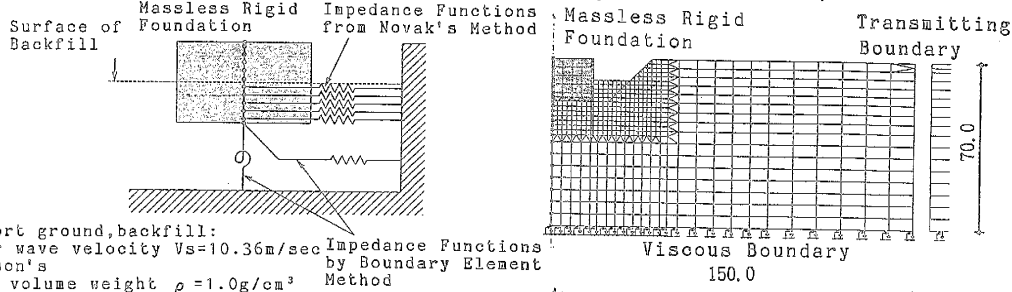


Fig. 5 Foundation Input Motion of Half Space (Hard Ground)



Support ground, backfill:
 Shear wave velocity $V_s = 10.36 \text{ m/sec}$
 Poisson's ratio $\nu = 0.49$
 Unit volume weight $\rho = 1.0 \text{ g/cm}^3$

Impedance Functions by Boundary Element Method
 Massless Rigid Foundation
 Transmitting Boundary
 Viscous Boundary
 150.0
 70.0

Fig. 6 Concept of S-R Model and Material Property Used in Analysis

Fig. 7 Axisymmetric FEM Model (Soft Ground)

Table 2 Material Property Used in Simulation Analysis (Soft Ground)

Young's modulus $E (\text{kg/cm}^2)$	Poisson's ratio ν	Shear wave velocity $V_s (\text{m/sec})$	Density $\rho (\text{g/cm}^3)$	Damping Ratio h
2.82	0.49	9.74	1.0	0.034

— Test ····· Axisymmtric FEM - - - - Bottom Spring of S-R Model (BEM)

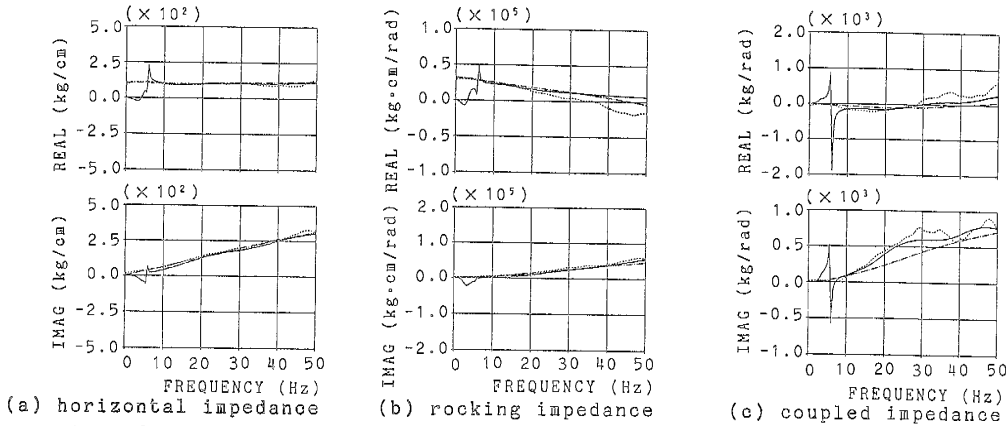


Fig. 8 Impedance Function of No Embedded Foundation (Soft Ground)

