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VIBRATION TESTS OF SOIL-STRUCTURE INTERACTION USING SILICONE RUBBER SOIL MODEL

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SUMMARY

To make clear experimentally dynamic characteristics of soil-structure interaction, vibration tests using a small-scale model of soil-structure system were conducted. Fifty cases of the vibration tests by a shaking table and a small vibration generater were conducted with consideration of five experimental parameters for soil-structure interaction. The test results are discussed concerning each experimental parameter in this paper. Furthermore the simulation analyses using axi-symmetric FEM are carried out for six fundamental cases. The influence of each experimental parameter is made clear by studying these test results and their analytical ones.

INTRODUCTION

In recent years, forced vibration tests and seismic observations of structures, structure models and fundation blocks in site have been often conducted to investigate experimentally the soil-structure interaction. And these results have been compared with the analytical results which are calculated by various analytical methods.

We conducted the vibration tests on soil-structure interaction using a simplified soil-structure system model of which geometrical and material properties are well-known. The purposes of these tests are to make clear experimentally the dynamic characteristics of soil-structure interaction and to verify various analytical methods about soil-structure interaction. Fifty cases of vibration tests by two exciting methods were conducted with consideration of five experimental parameters for soil-structure interaction. In this paper, we show that test results agree well with analytical results by axi-symmetric FEM and we discuss the influences of each experimental parameter.

SOIL-STRUCTURE SYSTEM MODEL

Fig. 1 shows the cylindrical soil model made of silcone rubber, and it consists of three parts to which hard soil, soft soil and back filling soil are idealyzed. The shape and the dimension are determined to minimize the influence of the finite boundary of the soil model. Table 1 shows material properties of the soil model. Structure models made of steel are also cylindar, as shown in Fig. 1. The diameter of them is determined to minimize the influence of the refrected waves from the shaking table (Ref. 1). Six kinds of model are used, as shown in

Fig. 2. All models are almost the same weight each other.

TEST METHOD

Two kinds of excitation are adapted, namely steady-state test by a shaking table (shaking table test) and forced vibration test by a small vibration generator installed on the top of the structure model (vibration generator test). Fig. 3 shows five experimental parameters concerning soil-structure interaction, and Table 2 shows the experimental parameters in each test model. In these fifty cases of tests, twenty-six cases are shaking table tests and twenty-four cases are vibration generator tests.

ANALYTICAL METHOD

We analyzed six fundamental cases using axi-symmetric FEM and Fig. 4 shows the analytical model composed of 593 elements and 650 nodal points. Table 3 shows the material properties used in analyses. These material properties were obtained from material tests using the test pieces of silicone rubber. For each case of the analysis, different Young's modulus for each part of the soil model was used, because the stiffness of the soil model had been gradually increasing by aging effect during the vibration tests.

TEST RESULTS

In all shaking table tests, the response characteristics at 80 cm away from the center on the soil model are nearly the same. It indicates that the influence of both the soil-structure interaction and the finite boundary of the soil model hardly appear at that point. Therefore this measuring point is chosen as free field motion. Then the shaking table test results are expressed by transfer functions of the response amplitude on the top of the structure to that at 80 cm away from the center on the soil model. On the other hand, the vibration generator test results are expressed by the response amplitude on the top of the structure in unit exciting force. Fig. 5 - Fig. 9 show the test results arranged in consideration of each experimental parameter. These results are as follows;

a) As shown in Fig. 5, the first resonance frequency of the heavier structure model is lower than that of the lighter one and the response of the former is larger than the latter.
b) As shown in Fig. 6, the first resonance frequency of the smaller structure model is lower than that of the larger one and the response of the former is larger than the latter.
c) As shown in FIg. 7, the first resonance frequency of the embedded structure model is higher than that of the without embedment one in both the shaking table tests and the vibration generator tests, however the relations of the reponse between the both tests are different.
d) As shown in Fig. 8, when the larger structure model is adjacent to the smaller one, the larger structure model resonates at about 14 Hz and 18 Hz. These frequencies almost correspond with the first resonance frequencies of the single smaller structure model and that of the larger one respectively. In the case that the distance between the two structure models is short, the adjacent smaller structure model influences the response of the larger one. On the other hand, in the case that the distance is long, the influence of the adjacent structure model is a little. The response of the smaller structure model is independent of the distance and nearly the same as that of the single smaller one.
e) As shown in Fig. 9, when the two structure models are arranged at right angles to the exciting direction, the each response of them is nearly the same as that of the single structure model, but when the structure models are arranged in

paralell with the exciting direction, each response of them is smaller than the case above-mentioned and each first resonance frequency of them is higher than that of the single structure model. This tendency appears more clearly in the shaking table test than in the vibration generator test.

COMPARISON OF TEST RESULTS AND ANALYTICAL RESULTS

Fig. 10 - Fig. 13 show the analytical results compared with the test ones. Unit of longitudinal axis on the resonance curve indicates as the response acceleration in the case of 20 gal excitation of the shaking table test and in the case of unit exciting force of the vibration generator test. Fig. 14 shows the analyzed vibration mode shapes of CASE-G at 10.0 Hz and 14.0 Hz. Some remarkes obtained from the comparison are as follows;

a) Analytical results agree well with test results in all cases.

From shaking table test results -

b) The first resonance frequency of the soil model is about 10 Hz, as shown in Fig. 10, where the shear vibration of the soft soil layer predominates as shown in Fig. 14(a).

c) The second resonance frequency of the soil model is about 14 Hz, as shown in Fig. 10, where the response of central point on the surface of the soil model is the largest and the response of other points become gradually smaller propotion to the distance from center, as shown in Fig. 14(b). In addition, the analytical results using the FEM model with viscous boundary are nearly the same as those using the FEM model with free boundary.

d) In CASE-SR, namely the smaller structure model is installed on the back filling soil, the first resonance frequency of soil-structure system is about 9 Hz. As shown in Fig. 11, the response at this frequency is combined with that of the soil model at about 10 Hz and a large response amplitude appears on the resonance curve.

e) In CASE-SE, namely the smaller structure model is half-embedded in the back filling soil, the first resonance frequency of soil-structure system is about 15 Hz, as shown in Fig. 11.

f) The first resonance frequencies of soil-structure system in CASE-L, namely the larger structure model is installed on the soft soil, and CASE-LG, namely the larger structure model is half-embedded in the back filling soil, appear at about 14 Hz and 17 Hz respectively, however the response of the analytical result at about 10 Hz and 14 Hz in CASE-L is different from that of the test one, as shown in Fig. 12. The disagreement may be caused by the difference of the distribution of the structure weight between the test model and the analytical one.

From the vibration generator test results -

g) In CASE-L and CASE-LG, the analytical results agree with the test ones in the general tendency on the resonance curves as shown in Fig. 13, though these results are slightly different in the resonance frequencies and the response amplitudes.

CONCLUSIONS

We conducted vibration tests on soil-structure interaction using a simplified soil-structure system model. By studying the test results and the analytical results using axi-symmetric FEM, the influences of each experimental parameter for soil-structure interaction are made clear experimentally. Among these experimental parameters, the effect of embedment and the influence of adjacent structure which are considered especially as important problems on soil-structure interaction, are as follows;

<u>Effect of Embedment</u>

a) When the structure is embedded, the stiffness of the soil-structure system increases.

b) The response amplitudes of the embedded structure are smaller than those of the without embedment structure in the vibration generator test. On the other hand, the former is larger than the latter in the shaking table test. This phenomenon may be caused by the reason as follows;
   1) In the vibration generator test, the damping of the soil-structure system is increased by the existence of the back filling soil.
   2) In the shaking table test, as the soil system is wholly excited, the response of the structure is influenced by the characteristics of the soil.

c) The analytical results correspond with the test ones.

Influence of Adjacent Structure

a) The response of the structure which is adjacent to a structure, is different from the response of the single structure.
b) When the distance between the structures is short, the influence of adjacent structure appears clearly.
c) When two structures are arranged in paralell with the exciting direction, the influence of adjacent structure appears clearly.

In future, we intend to verify other analytical methods about soil-structure interaction using these test results and to investigate correspondence between the in-situ test and these tests.

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3. M. Niwa, K. Ueno, K. Yahata, and T. Ishibashi, "Fundamental study on Soil-Structure Interaction Part 1, Part 2", Summaries of Techinical Papers of Annual Meeting Architectural Institute of Japan, (October 1987)

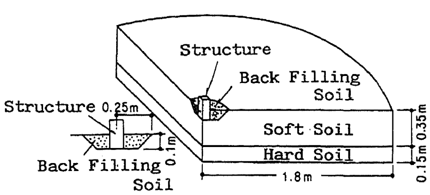


Fig. 1 Soil Model

Table 1 Material Properties of Soil Model

	ρ (g/cm³)	V_s (m/sec)	E (kg/cm²)
Back filling Soil	0.97	6.13	1.10
Soft Soil	1.40	15.8	10.2
Hard Soil	1.69	34.4	60.0

ρ : Gravity
V_s : Shear Wave Velocity
E : Young's Modulus

Size		Large		Small
Dimension		Vibration Generator; 200mm; 112mm	190mm; 112mm	100mm; 112mm
Weight	Light	2845 g	2772 g	2491 g
	Heavy	4023 g	3951 g	3670 g

Fig. 2 Structure Models

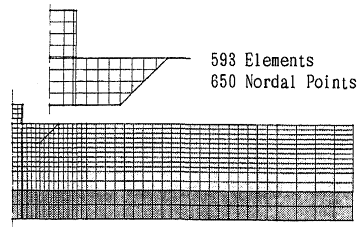


Fig. 4 Analytical Model
by Axi-symmetric FEM

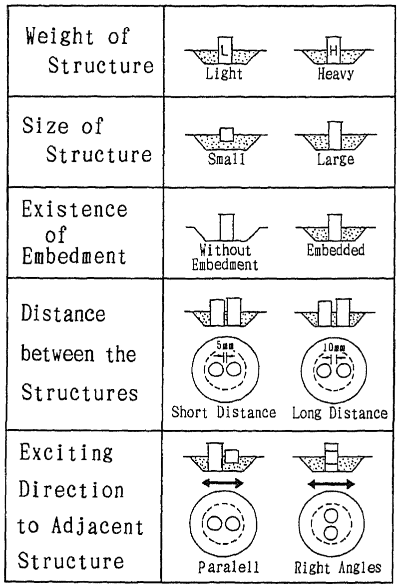


Fig. 3 Experimental Parameters

Table 3 Material Properties used in Analyses

Analysis Case	Exciting Method (S.T.=Shaking Table, V.G.=Vibration Generator)		Back Filling Soil	Soft Soil	Hard Soil
		ρ	0.97	1.40	1.69
		ν	0.48	0.48	0.48
		h	0.05	0.03	0.01
CASE-0	S.T.	Young's Modulus (kg/cm²)	——	10.2	60.0
CASE-G	S.T.		1.06	10.2	60.0
CASE-L	S.T. V.G.		——	10.6	62.4
CASE-LG	S.T. V.G.		1.06	10.6	62.4
CASE-SE	S.T.		1.06	10.4	61.2
CASE-SR	S.T.		1.06	10.2	60.0

ρ : Gravity (g/cm³)
ν : Poisson's Ratio
h : Damping Factor

Table 2 Experimental Parameters in Each Test Model

Parameter / Model	Back Filling Soil		Structure: Weight		Structure: Size		Structure: Embedment		Adjacent Structure: Distance		Adjacent Structure: Exciting Direction	
	Exist	Without	Light	Heavy	Small	Large	Embedded	Without	Short	Long	Paralell	Right Angles
Soil only	○	○	—	—	—	—	—	—	—	—	—	—
Soil-Structure: Single Structure	○	○	○	○	○	○	○	○	—	—	—	—
Soil-Structure: Adjacent Structure	○	—	○	○	○	○	○	—	○	○	○	○

○ : Test Model

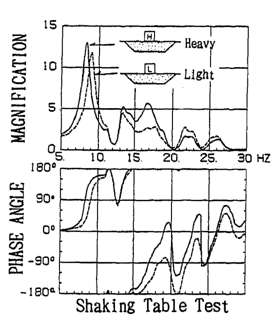


Fig. 5 Comparison of Structure Weight

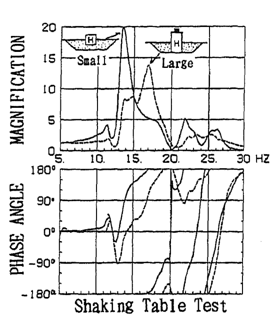


Fig. 6 Comparison of Structure Size

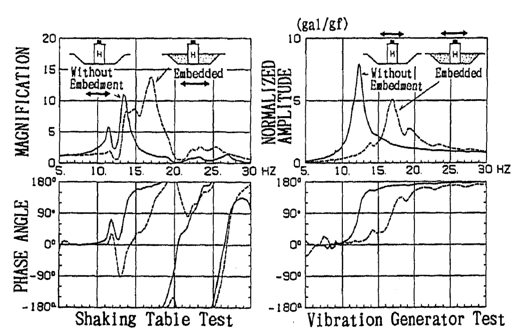


Fig. 7 Comparison of Existence of Embedment

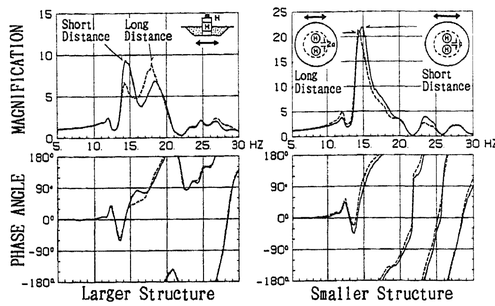


Fig. 8 Comparison of Distance between Structures
(in Shaking Table Test)

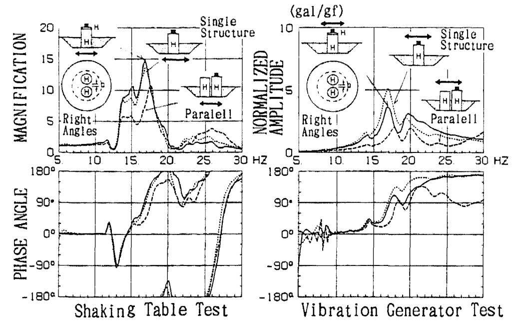


Fig. 9 Comparison of Exciting Direction to Adjacent Structure

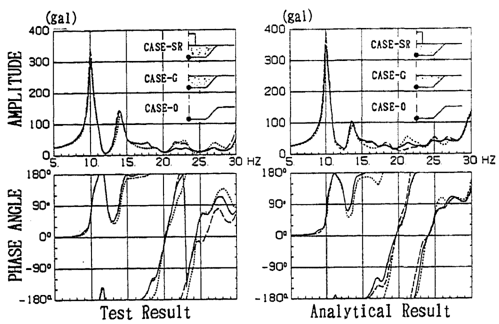


Fig. 10 Comparison of Test Result and Analytical Result
(in Shaking Table Test)

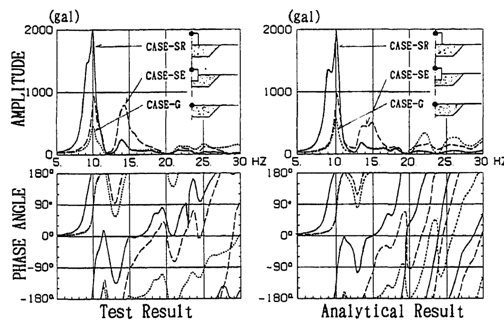


Fig. 11 Comparison of Test Result and Analytical Result
(in Shaking Table Test)

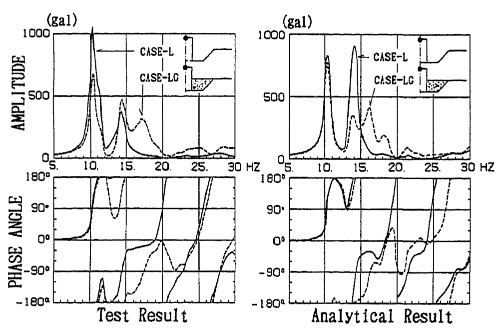


Fig. 12 Comparison of Test Result and Analytcial Result
(in Shaking Table Test)

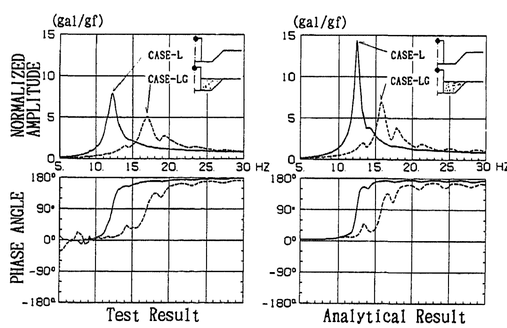
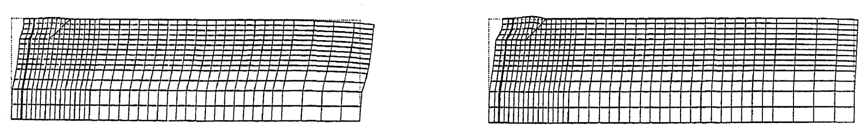


Fig. 13 Comparison of Test Result and Analytical Result
(in Vibration Generator Test)



(a) 10.0 Hz (b) 14.0 Hz

Fig. 14 Vibration Mode Shapes of CASE-G