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Partial embedment effects on soil-structure interaction

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ABSTRACT: In order to clarify the effect of partial embedment on soil-structure interaction, forced vibration tests on large-scale model were performed. In this paper, the test results are investigated. The test model simulates a PWR-type reactor building. The sinusoidal forced vibration tests were performed with the different embedment conditions, namely non-embedment, one-side embedment and two-sides embedment.

From the test results, it is shown that the enlargement of embedment area increases dynamic soil stiffness and radiation damping, and the effects of embedment toward the exciting direction are greater than those of side embedment. Even partial embedment is effective in changing the vibration characteristics of the superstructure.

1. INTRODUCTION

The effect of dynamic soil-structure interaction plays an important role on the behavior of reactor buildings during earthquakes. A reactor building in Japan is partially or sometimes mostly embedded in the ground. Therefore, it is important to know how this affects the vibration characteristics of a reactor building relating to seismic safety.

In order to evaluate the embedment effect on dynamic soil-structure interaction, the large-scale model forced vibration tests have been performed (Izumi et al. 1991).

This paper describes the test results on the effect of partial embedment. The large-scale model forced vibration tests were carried out on three different embedment conditions (non-embedment, one-side embedment, two-sides embedment). The general view of the test model is shown in Fig.1. Test data on the vibration characteristics of the test models, the dynamic soil impedance, the earth pressure at the bottom of the foundation and along the side wall were obtained.

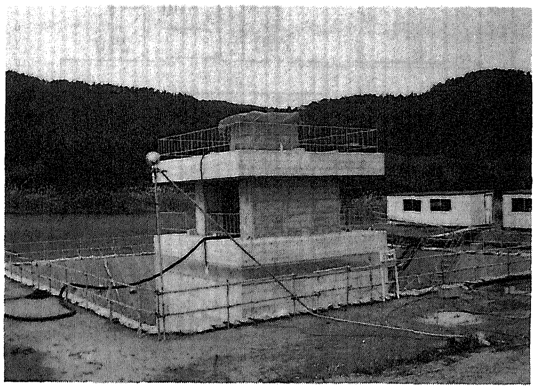


Fig.1 Test Model

2. TEST CONDITIONS

2.1 *Test Model*

The test model was constructed taking into account the non-dimensional frequency, the relative weights of each part, and the mode shape of the PWR-type reactor buildings constructed in Japan. Fig.2 shows the shape of test model. The test model is a RC structure with an 8m square foundation. The total height is 10m and the weight is 920ton. Three different embedment conditions were tested: 1) non-embedment (Test C1), 2) one-side embedment of the foundation (Test C2), and 3) two-sides embedment of the foundation (Test C3). Fig.3 shows the test conditions. The test model was constructed on the field after excavating the ground to 5m depth. Lateral sides of the backfill were supported by sandbags to keep off the landslide.

2.2 *Soil Condition*

Shear wave velocity of the soil was 320-440m/s below the foundation bottom, and was

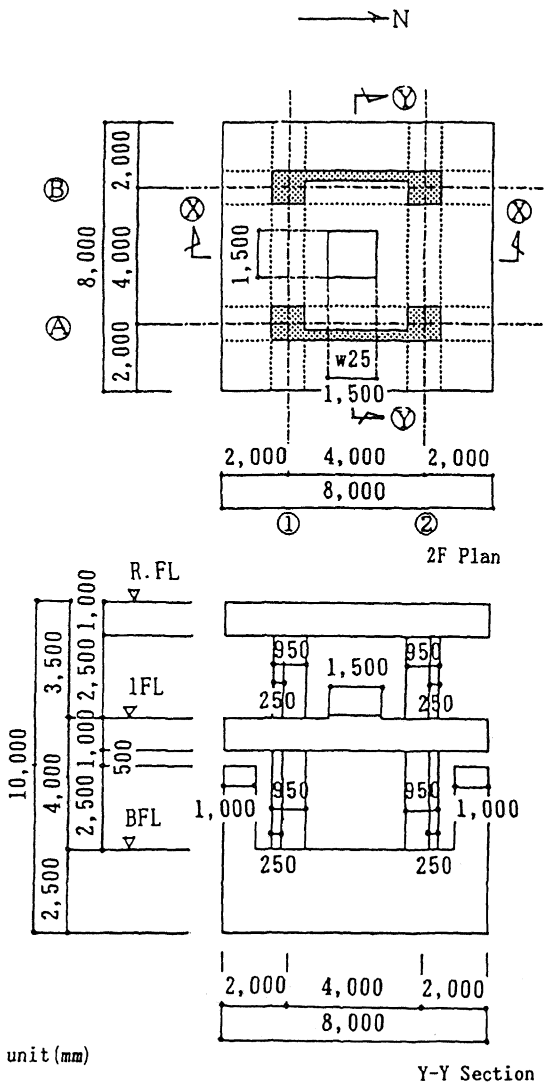


Fig.2 Shape of Test Model

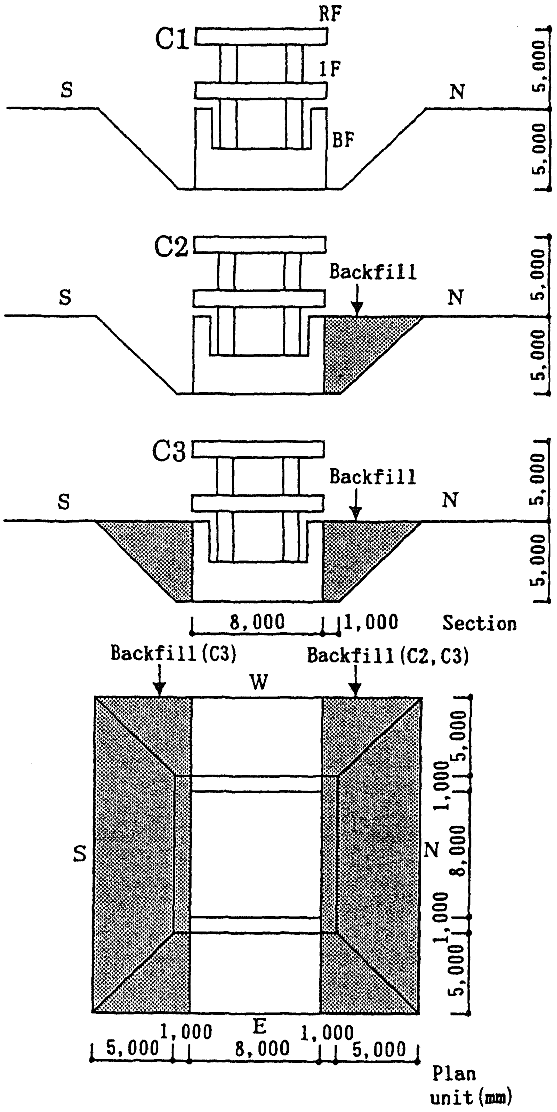


Fig.3 Test Conditions

greater than 920m/s at the layer 8m deeper than the foundation bottom. These description of soil properties were confirmed by the boring examination, the PS logging of the supporting and surrounding ground, and the elastic wave test on the ground surface. Backfill soil was compacted every 15cm layer to control its property as the same condition of density ($1.78g/cm^3$) and shear wave velocity (130m/s).

2.3 *Test Method*

In the tests, sinusoidal vibration was applied using an exciter placed on either the center of the top floor (RF-excitation) or the center of the base mat floor (BF-excitation). As for the exciting direction, horizontal NS (embedment toward exciting direction) and EW (side embedment) excitation tests were performed. For each test, the excitation moment was appropriately examined so that the dynamic characteristics of the structure and soil were in linear range. The response amplitude and phase lag from the exciting force were measured at selected observation points under steady state. The items measured were the displacement of various parts of the models, and the dynamic earth pressure at the bottom of the foundation and along the side wall.The displacement of the test model were measured by displacement transducers. The dynamic earth pressure were obtained by earth pressure gauges.

3. TEST RESULTS

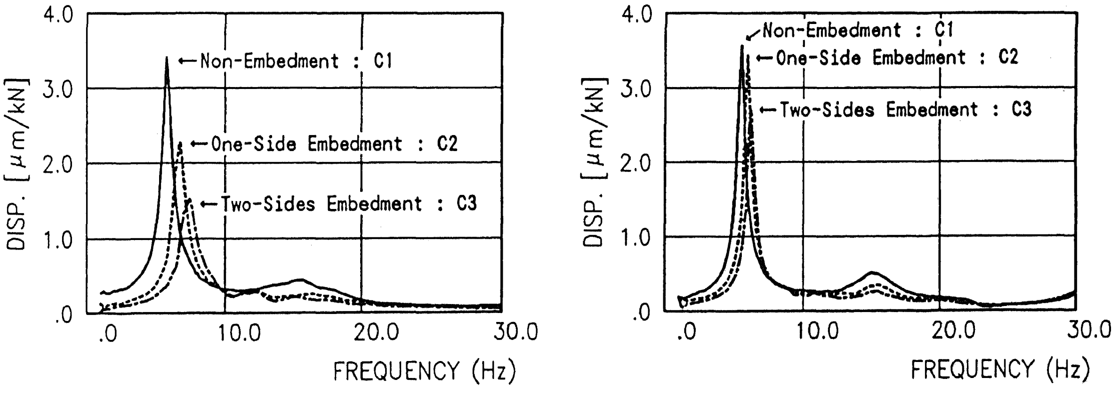
3.1 *Vibration characteristics of test model*

Table 1 shows the natural frequency, damping factor and contribution ratio (swaying, rocking and elastic deformation) at natural frequency. Natural frequencies and damping factors are evaluated by applying regression analysis of a lumped mass system to the resonance curves at the center of the top floor in each test. The enlargement of the backfill area increases the natural frequency. However, the damping factor of one-side embedment (Test C2) is smaller than that of non-embedment (Test C1). The tendency of the dynamic characteristics due to embedment toward the exciting direction (NS-excitation) and side embedment (EW-excitation) are almost same. The reason is that the contribution ratios of each embedment condition are different. Especially, the deformation ratio of the superstructure to the displacement at top floor of one-side embedment (Test C2) is larger than that of non-embedment (Test C1). However, that of two-sides embedment (Test C3) is almost similar to that of one-side embedment (Test C2).

Fig.4 shows the resonance curves at the center of the base bottom, determined from the

Table 1 Dynamic Characteristics at Natural Frequencies

Test	Exciting Location	Exciting Direction	Natural Frequency (Hz)	Damping Factor (%)	Contribution Ratio		
					Swaying (%)	Rocking (%)	Elastic Deformation (%)
C 1	R F	N S	5.9	5.1	17	74	9
		E W	5.5	4.2	11	54	35
	B F	N S	5.9	5.1	17	74	9
C 2	R F	N S	6.85	4.8	15	68	17
		E W	5.9	3.3	10	47	43
	B F	N S	6.85	4.8	15	68	17
		E W	5.9	3.3	10	49	41
C 3	R F	N S	7.5	6.5	15	63	22
		E W	6.15	3.9	10	47	43
	B F	N S	7.5	7.1	15	63	22
		E W	6.15	3.9	10	48	42



(a) NS Excitation (Embedment Toward Exciting Direction)

(b) EW Excitation (Side Embedment)

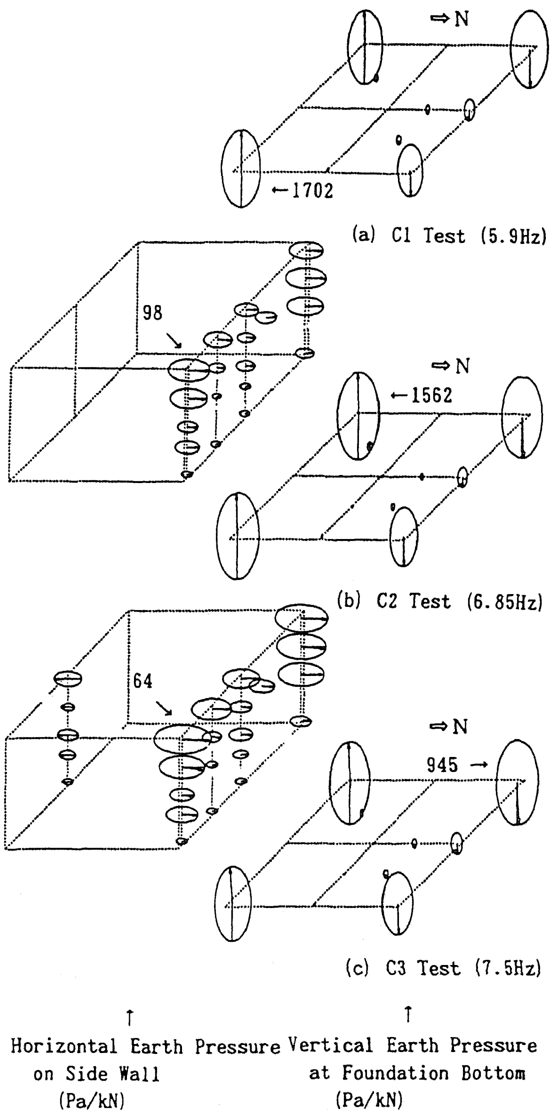
Fig.4 Resonance Curves at Center of Base Bottom (Horizontal Component) test results. The enlargement of the backfill area decreases the peak amplitudes. The tendency of embedment toward the exciting direction is more conspicuous than that of side embedment. From these comparison, it seems that embedment toward the exciting direction is more effective for increasing soil impedance.

3.2 *Dynamic earth pressure*

Fig.5 shows the dynamic earth pressure distribution of each embedment condition at near the natural frequency. The bottom pressure distributions are almost same as of the rigid plate and fundamentally correspond to rocking motion of the foundation in each test. No configurational difference in distribution can be observed between test cases except for vertical earth pressure at foundation bottom of N side (backfill side) in Test C2 (one-side embedment) showing small values. The enlargement of backfill area toward the exciting direction decreases the dynamic earth pressure at the bottom of the foundation and along the side wall.

3.3 *Soil Impedances*

Fig.6 shows the soil impedances (K_H) converted from the test results. The enlargement of the backfill area increases the real and imaginary parts of the soil impedances. Embedment toward the exciting

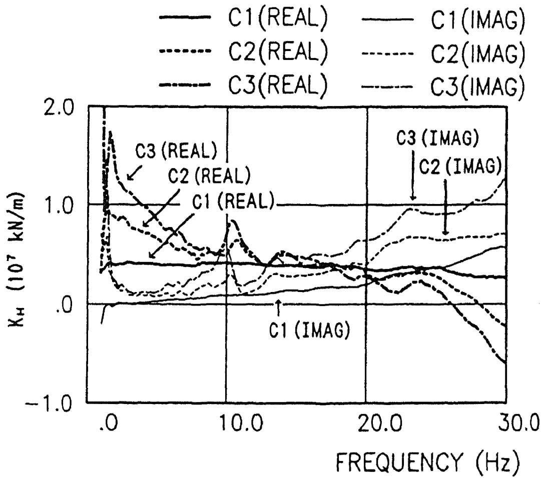


(a) C1 Test (5.9Hz)

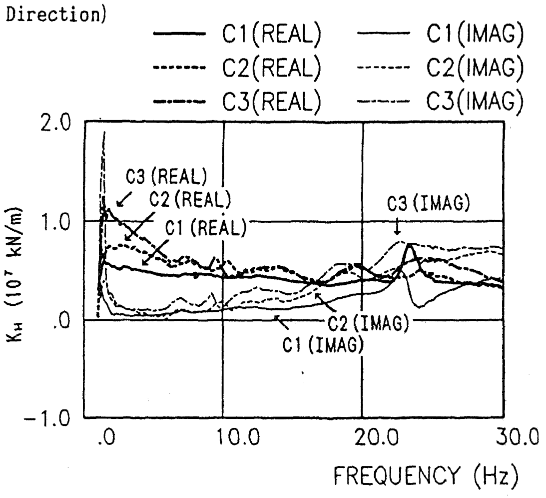
(b) C2 Test (6.85Hz)

(c) C3 Test (7.5Hz)

Fig.5 Distribution of Dynamic Earth Pressure (NS Excitation(Embedment Toward Exciting Direction))

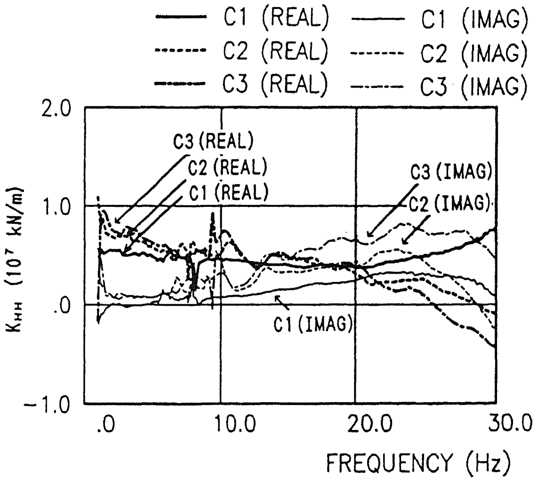


(a) NS Excitation (Embedment Toward Exciting Direction)

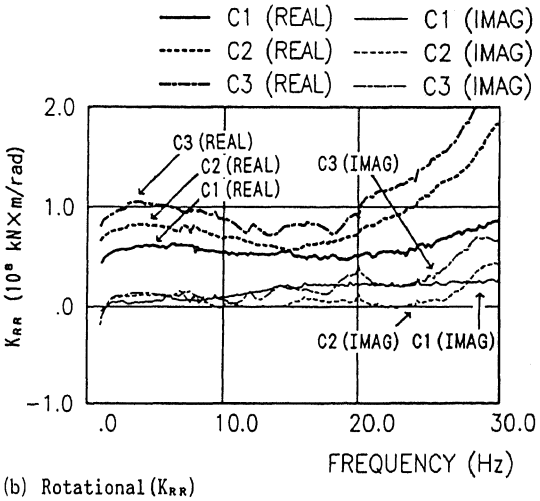


(b) EW Excitation (Side Embedment)

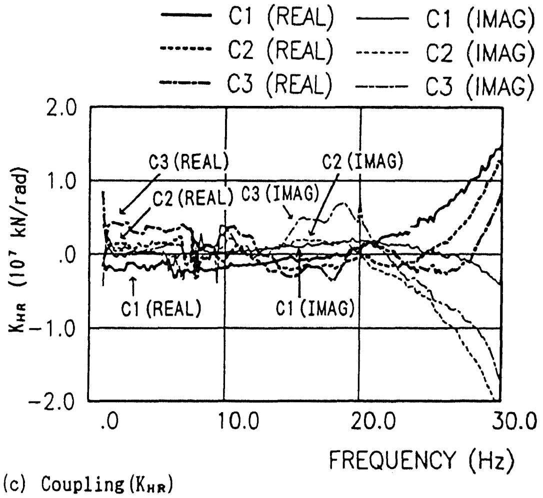
Fig.6 Soil Impedances (K_H)



(a) Horizontal (K_{HH})

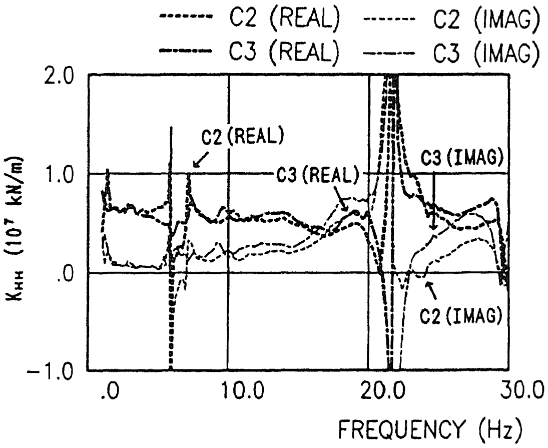


(b) Rotational (K_{RR})

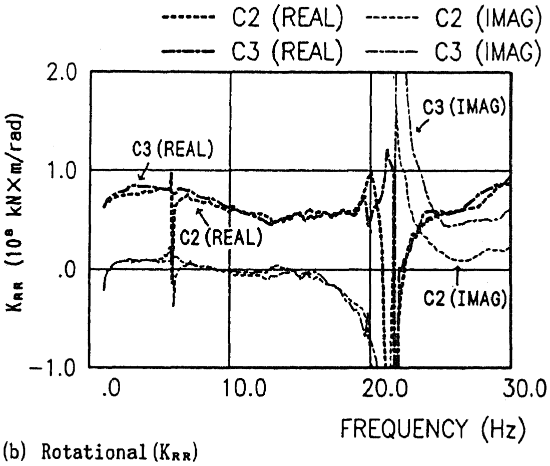


(c) Coupling (K_{HR})

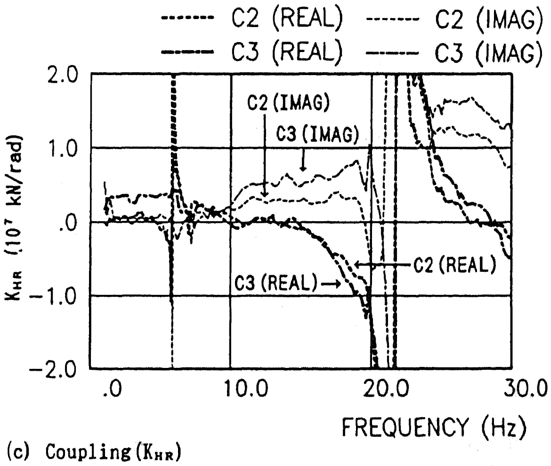
Fig.7 Soil Impedances (K_{HH}, K_{RR}, K_{HR}) of NS Excitation (Embedment Toward Exciting Direction)



(a) Horizontal (K_{HH})



(b) Rotational (K_{RR})



(c) Coupling (K_{HR})

Fig.8 Soil Impedances (K_{HH}, K_{RR}, K_{HR}) of EW Excitation (Side Embedment) direction is more effective in increasing soil impedances than side embedment.

Fig.7 and 8 show the soil impedances (K_{HH}, K_{RR}, K_{HR}). These impedances were converted from the two test results which had different locations of excitation (the top floor, the base mat floor). The enlargement of the backfill area also increases coupling impedances (K_{HR}), therefore, the coupling impedances, especially on two-sides embedment (Test C3), are as effective as the horizontal and rotational impedances.

4. CONCLUSIONS

The effects of partial embedment on soil-structure interaction were investigated using results of the large-scale model forced vibration tests. The following conclusions were drawn:

1. The enlargement of the backfill area increases the real and imaginary parts of the soil impedances. Embedment toward the exciting direction is more effective in increasing soil impedances than the side embedment.
2. The enlargement of the backfill area also increases coupling impedances, therefore, the coupling impedances, especially on two-sides embedment, are as effective as the horizontal and rotational impedances.
3. The contribution ratios of each embedment condition are different. Especially, the deformation ratio of the superstructure to the displacement at top floor of one-side embedment is larger than that of non-embedment. Therefore, the damping factor of one-side embedment is smaller than that of non-embedment.
4. The enlargement of backfill area toward the exciting direction decreases the dynamic earth pressure at the bottom of the foundation and along the side wall.

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