Experimental and Analytical Studies of a Deeply Embedded Reactor Building Model Considering Soil-Building Interaction (Part II)

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Abstract

This paper describes the dynamic characteristics of a deeply embedded reactor building model revealed from the forced vibration tests, earthquake observation and the simulation analyses.

The outline of the whole experimental studies and the vibration test results were discussed in the previous report Part I in 1979, in which authors confirmed that the analytical results obtained using mathematical model of a soil-building interaction system had agreed quite well with the results of the forced vibration tests performed before backfill.

In this paper, the results of simulation of forced vibration tests after backfill are presented, and are compared with those before backfill to investigate the embeddment effects on the dynamic characteristics of a soil-building interaction system.

This system can be represented by a lumped mass model, in which soil medium in the three-dimentional domain with viscous boundary is assumed same as the former case to consider the energy dissipation due to the wave propagation outward the modeled soil domain.

One of the assumptions additionally taken for the backfill is to include the backfilled sand in the analytical model of soil-building system. Another one is that the value of frequency-dependent rocking spring used in the analyses of the forced vibration tests before backfill is multiplied by 1.5 considering an increase in stiffness due to backfill.

The calculated results shows a good agreement with test results in regard to the resonance and phase lag, and the following conclusions are derived from the series of forced vibration tests and simulation analyses.

i) The forced vibration tests before and after backfill and the corresponding analyses indicate that the embeddment affected significantly the dynamic behavior of the building by increasing its restraint and the dissipation of vibration energy to surrounding soil.

ii) The analytical method used in this study provides a practical means to compute the dynamic behavior of a complicated soil-building system including deep embeddment, backfill sand and surrounding soil.

The analytical model proposed so far could simulate fairly well the results of forced vibration tests before and after backfill, but further investigation on earthquake observation records will be necessary to justify the analytical model for the aseismic design of a deeply embedded building.

1. Introduction

This paper describes the experimental studies of a building model to investigate the dynamic characteristics of deeply embedded rigid structures such as a reactor building.

In the previous report (Part I), the outline of whole experimental studies and the experimental results were presented, and the simulation analyses of the result of forced vibration tests before backfill were discussed. It was confirmed that the analytical result obtained using mathematical model of a soil-building interaction system in which soil medium is considered in the three-dimensional domain, agreed considerably well with the experiment.

In this paper, the analyses of vibration test after backfill using the mathematical model in which backfill sand is added to the model before backfill are discussed. In addition, the results of simulation before and after backfill are compared and the effect of backfill is analytically investigated, thus providing useful tools for subsequent analysis of earthquake observation records.

2. Outline of Experimental Results

2.1 Model Building and Test Procedure

The results of vibration tests are mentioned prior to the description of the results of simulation. As shown in Fig. 1, the building is reduced to one fifteenth of the prototype with one basement floor and two stories above the ground, and made of reinforced concrete. The basement and the first story are of bearing wall system and the second story is of relatively soft frame system.

In constructing this model, the soil surface was excavated to a depth of 3 meters having a 45° slope angle and with bottom area of 9X9 meters square. For the vibration tests before backfill, the shaker was set on the second floor approximately one month after the completion of the model construction.

Subsequently, the backfill around the building was made to the ground level with the river sand, evenly compacted with a vibration roller to obtain the uniform density of the sand. The density was measured by means of sand replacement during the backfill and the shear-wave velocity measurement was carried out at the end of backfill. After backfill and then the curing period of approximately 20 days the vibration test was performed.

2.2 Forced Vibration Test Results

In Fig. 2, resonance of each floor of the building, and phase lag against the vibrating force are shown. As to the shaking method, steady state test was done with a constant eccentric moment of 15.5 Kg·cm. The resonance curve is normalized to correspond the shaking force of 1 ton.

The fundamental natural frequency is 10.4 Hz before backfill, while after backfill it increased to 12.3 Hz, and the second peak frequency of 16.5 Hz before backfill disappears after backfill.

The resonance amplitude reduces to approximately a half at the roof floor, and to one forth at the second floor. In other words the restraint effect by the backfill around the building is clearly recognized.

The phase difference of each floor is scarcely seen at the fundamental modal frequency before backfill but after backfill considerably large phase lag is confirmed at the basement at the fundamental frequency of the system.

3. Simulation Analysis of Test Results

3.1 Analytical Model and Assumptions

The model after backfill is shown in Fig. 3. Soil properties shown in Table 1 were obtained by the in-situ measurements of shear wave velocity conducted before the construction of the building and the values were slightly revised for analysis of the test before backfill.

Assumptions in the analysis are as follows:

i) Schematic model of a soil-building system is represented by lumped mass system, in which soil medium in the three dimentional domain is taken into account. However, the degree of freedom of displacement is considered to be only in the direction of exciting forces. The effective depth of the soil assumed in the analytical model is to the mudstone layer of which the shear wave velocity becomes 600 m/s.

ii) Structure is replaced by shear-bending beams, and soil springs with shear and axial deformations are considered, thereby treating them as a plane stress problem.

iii) The model of backfill sand consists of three layers as shown in Fig. 4, and the shear-wave velocity obtained by field measurement is shown in the table.

iv) A frequency dependent complex stiffness K_θ & C_θ of rocking spring which connect the foundation slab and bedrock, are taken as 1.5 times the values derived from the test analysis without backfill as shown in Fig. 5, considering the stiffening effect of backfill.

v) In this model, soil medium at the side and bottom boundaries is represented with dashpots, the value of which is expressed as $D = \rho VA$ so as to consider the energy dissipation due to the outward wave propagation.

vi) Damping is assumed to be structural damping, with damping ratios $h = 0.025$ for the building, $h = 0.05$ for soil and $h = 0.10$ for the backfill sand respectively.

3.2 Simulation Results

In Fig. 6, both the resonance and the phase lag curves are shown comparing the simulation results with the test ones. As was clearly seen in Fig. 2, the comparison of the test results before and after backfill shows the considerable differences of resonance and of phase lag curves between the cases with and without the effect of backfill.

It can be said that the analytical results for horizontal components of the displacement on the roof and the second floor and of vertical components at the end of foundation slab, which show large amplitudes, explain well the test results. But considerable differences are seen with respect to the peak amplitude in the ground and surrounding soil. It is because of insufficient accuracy of the simulation, although represented by multi-lumped mass system, to evaluate such far smaller amplitudes in the ground or surrounding soil than on the building floors. This tendency was also seen in the analytical results without backfill.

4. Comparison before and after Backfill

In order to understand the effect of backfill on the dynamic behavior of structures, the analytical results of the test before and after backfill at the major measuring points of the building are compared with respect to the resonance curves and the vibration mode shapes as shown in Fig. 7.

Resulting from a series of tests and analyses before and after backfill, the following remarks are mentioned:

i) The resonance curves and the mode shapes at the peak frequency can be well simulated with a model of the multi-lumped mass structure-soil interaction system.

ii) In the higher order frequency range, the agreement of the simulation and test results in the surrounding soil is not so well compared with on the building itself.

iii) Comparing the simulation results before and after backfill, better agreement with the tests is obtained in the former than in the latter.

5. Conclusion

It is found that the dynamic behavior of soil against the structure can be described fairly well by applying multi-mass system to soil medium. Although the fundamental natural frequency of model soil is around 6.0 Hz, resonance peak does not appear in the analysis. This is thought due to the effect of a modelling of soil as three dimensional and the effect of outward dissipation of wave energy from the boundary.

For the vibration characteristics of deeply embedded structures, it is confirmed from both the test and the analyses that the restraint effect of the backfill sand to the structure and the increase of damping characteristics are remarkable.

After the completion of the vibration tests, an observation of earthquake is performed by installing the seismometers in the building, ground and surrounding soil.

Hereafter, the earthquake record at the structure and in the surrounding soil will be investigated.

REFERENCE

H. Tajimi: Basic Theories on Aseismic Design of Structure (in Japanese), Report of Institute of Industrial Science University of Tokyo, Vol. 8, No. 4, March 1959.

H. Tanaka et al: Experimental and Analytical Studies of a Deeply Embedded Reactor Building Model Considering Soil-Building Interaction (Part I), Transactions of the 5th SMiRT, August 1979.

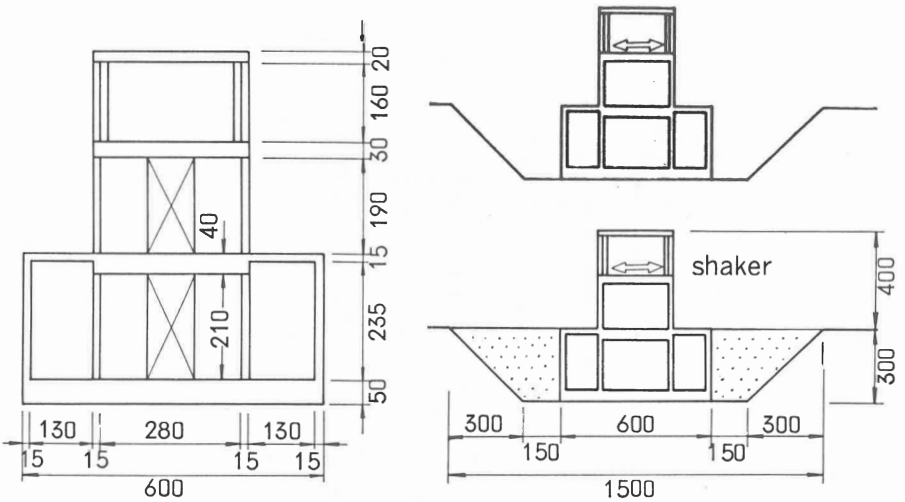


Fig. 1 Model Building and Outline of Tests

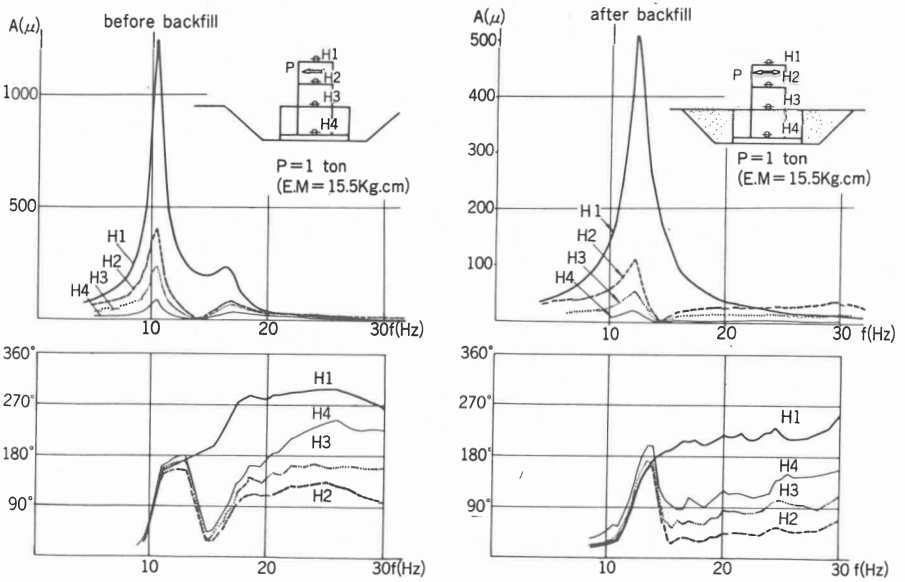


Fig. 2 Results of Vibration Tests before and after Backfill

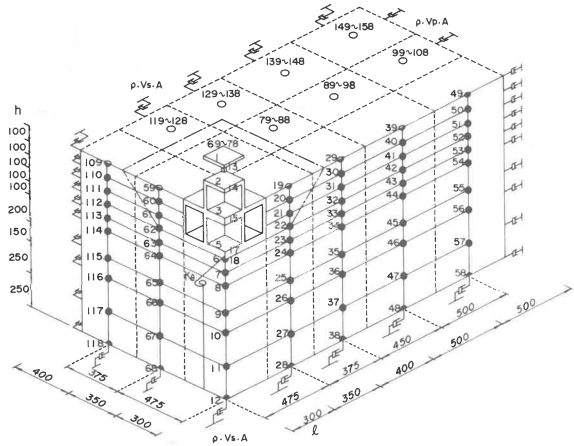
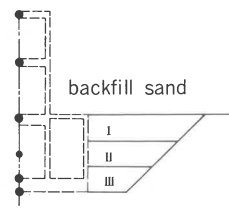


Fig. 3 Simulation Model

Table 1. Data of Soil Profile

in-situ mesurement		analytical data				
Vs (m/sec)	ρ (t/m³)	Vs (m/sec)	G (t/cm²)	ν Poisson's ratio	ρ (t/m³)	H (m)
170	1.5	170	0.442	0.456	1.5	0.5
		170	0.442	0.456	1.5	0.5
190	1.7	180	0.534	0.456	1.6	1.0
		190	0.626	0.444	1.7	1.0
		200	0.694	0.444	1.7	1.0
		300	1.561	0.444	1.7	1.0
250	1.7	320	1.776	0.477	1.7	2.0
400	1.7	400	2.776	0.438	1.7	1.5
320	1.7	320	1.776	0.462	1.7	2.5
		320	1.776	0.462	1.7	2.5
600	1.7	600	6.246	0.418	1.7	2.5
		600	6.245	0.418	1.7	2.5
		600	6.245	0.418	1.7	2.5
430	1.7	430	3.207	0.476	1.7	2.5



	Velocity	Shear modulus	Poisson's ratio	Unit Weight	depth
	Vs (m/s)	G (t/cm²)	ν	ρr (t/m³)	H (m)
I	100	0.168	0.3	1.65	1.0
II	130	0.285	0.3	1.65	1.0
III	180	0.546	0.3	1.65	1.0

Fig. 4 Data of Backfill Sand

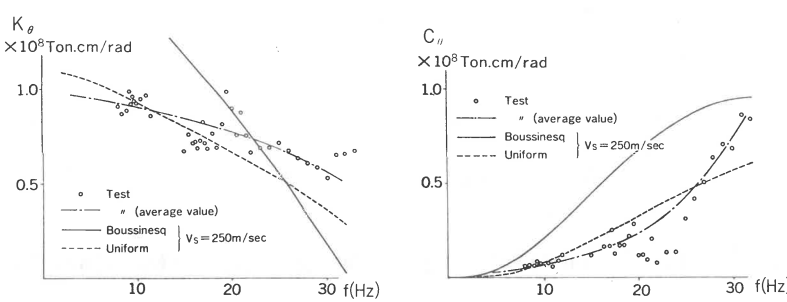


Fig. 5 Complex Stiffness of Rocking Spring

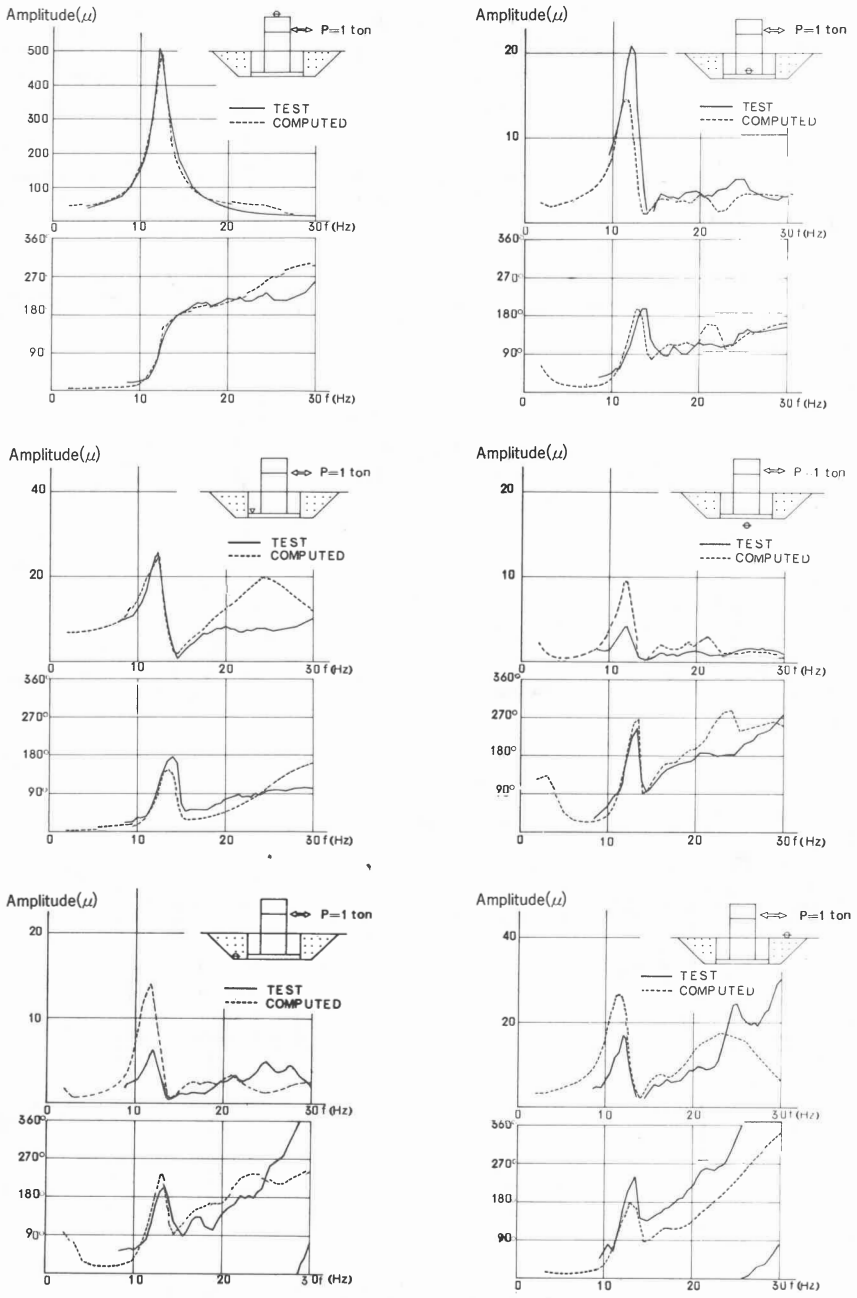


Fig. 6 Comparison of Computed Result with Test after Backfill

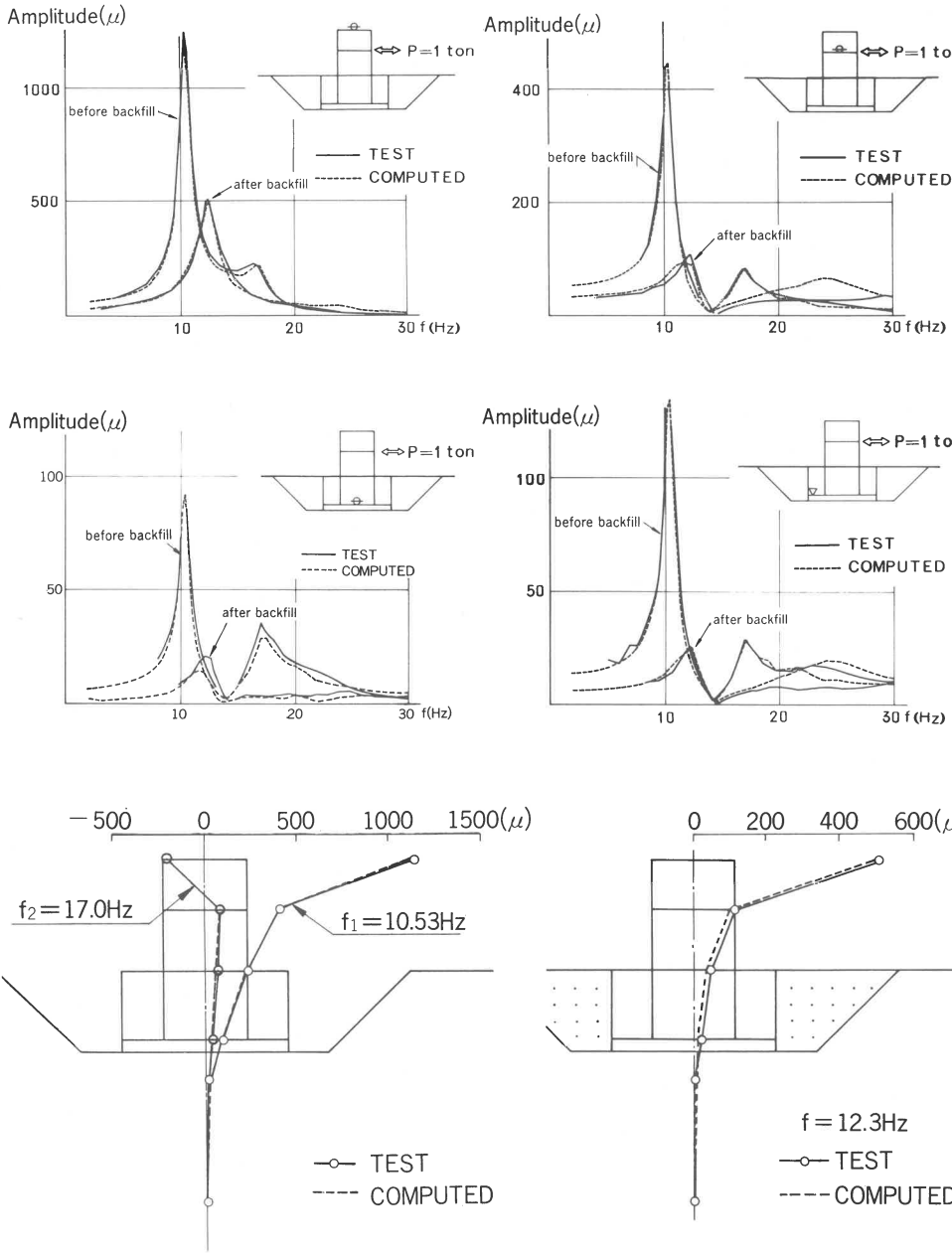


Fig. 7 Comparison before and after Backfill