Experimental Study of Soil-Structure Interaction for Proving the Three Dimensional Thin Layered Element Method (Part 2)

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SUMMARY

The purpose of this paper is to describe the shaking table test results of 1/1000 scale structure-soil model and the simulation analyses using the computer code based on the Thin Layered Element Theory.

In this study, the dynamic characteristics of two soil layers and the structure-soil-structure interaction problems were examined.

The outline of the vibration testing methods and computer code were already presented in the previous report Part 1 in SMIRT 6 (1981).

1) Outline of Test Model:

The size of two soil layers model is 50 cm long and 50 cm wide. An upper layer was made from congealed gelatine and 8 cm thick. A lower layer was made from plywood and 3.2 cm thick. The superstructure was a simplified one mass model made of a metal sheet spring and a metal solid mass. Two superstructure models were produced for the structure-soil-structure interaction study.

2) Results of Tests:

Firstly, the free vibration tests of the structure model and the soil model were carried out. The each fundamental natural frequency of the structure and the soil model obtained from resonance and phase lag curves were 11.0 Hz and 9.0 Hz respectively.

Secondly, the soil-structure interaction tests were conducted using a single structure model and two identical structure models located at an interval of 2 cm. In the structure-soil-structure test, the model was shaken in two directions respectively which were transverse and parallel to the direction aligning two structure models. The resonance and phase lag curves of the single structure model and two identical structure models tests suggested that their dynamic characteristics were nearly equal to each other. Two peaks of 9.0 Hz and 10.4 Hz were observed in the resonance curve of the structure.

3) Results of Simulation Analyses

The analytical method used in this study is based on the Thin Layered Element Theory developed by Dr. Hiroshi Tajimi. In this analytical modeling of two soil layers, the upper layer of congealed gelatine was divided into six thin sublayers and the viscous dashpot boundary evaluated from the rigidity and density of the plywood was placed at the base sublayer. The transfer function and phase lag curves were calculated and these analytical results were in good agreement with those of shaking table tests.

From the shaking table test and the simulation analyses, the following conclusions were drawn.

i) The dynamic amplitude characteristic of two soil layers was influenced by the wave impedance ratio.

ii) The Thin Layered Element Model could simulate fairly well the results of shaking tests.

1. INTRODUCTION

This paper describes the experimental studies of the dynamic characteristics of two soil layers and the structure-soil-structure interaction problems.

In the previous report (Part 1), the outline of preliminarily experimental studies and the computer program were presented. (1) The computational procedure of this computer program is based on the Three Dimensional Thin Layered Element Theory developed by Dr. Hiroshi Tajimi. (2)

2. SHAKING TABLE TEST

2.1 Model of Building and Soil

A reactor building of a PWR plant was reduced to 1/1000 of the prototype. The size the model building and the thickness of the soil model were changed comparing the previous test for the structure-soil-structure test. The structure model was fabricated with a phosphor-bronze plate which was 10.2 mm wide, 0.3 mm thick and 4.5 cm high, a solid metal weighing 16.3 gr, and a wooden foundation. The wooden foundation was 8 cm long and 8 cm wide and 1.2 cm thick. The whole weight of this model building was 63.8 gr. The size of the two soil layers model is 50 cm long and 50 cm wide. An upper layer was made from the congealed gelatine of the weight density 8% and was 8 cm thick. A lower layer was made from plywood and was 3.2 cm thick. The properties of model materials are shown in Table I.

2.2 Test Procedure

Test were performed in four steps as follows:

i) The free vibration test of the structure model.
ii) The shaking table test of the soil model.
iii) The shaking table test of the single-structure-soil interaction.
iv) The shaking table test of the structure-soil-structure interaction.

A small electro-magnetic shaking table was used in the vibrating test. This shaking table could load 40 kg and could vibrate in the range between 0.5 and 100 Hz. The acceleration of the shaking table was controlled to be constant at 10 gals and the vibration frequency range was from 3 Hz to 18 Hz.

In order to measure the displacement of the structure model, a target for a contactless optical displacement meter and wire strain guages were attached to the solid metal and lower plate metal. The relation between the displacement and the measured strain was calibrated and the displacement of the structure model could be estimated correctly.

3. RESULTS OF TEST

From the free vibration test of two structure models, the fundamental natural frequencies and damping ratios were 11.0 Hz, 0.5% (A2-1) and 11.2 Hz, 0.4% (A3-1) respectively.

The transfer and phase lag curves of the soil model test are shown in Fig. 2 and Fig.3. The single peak of the transfer curve was appeared at 9.0 Hz and the phase lag angle was 90° at this frequency. The frequency of 9.0 Hz was considered to be the fundamental natural frequency of the upper soil layer.

The transfer and phase lag curves of the single-structure-soil test are shown in Fig.4 and Fig. 5. Two peaks of the transfer curve were appeared at 9.0 Hz and 10.4 Hz. These frequencies were considered to be the fundamental natural frequency of the soil layer and the structure-soil interaction mode.

In the structure-soil-structure test, two identical structure models were located at an interval of 2 cm and the model was shaken in two directions. The test results of the parallel and transverse direction to the aligning two structure models are shown in Fig.6 - 7 and in Fig.8 - 9 respectively.

4. SIMULATION ANALYSIS OF TEST

4-1 Analysis Model

Fig.1 shows the simulation analysis model of the test, using the Three Dimentional Thin Layered Element. The upper soil of 8 cm in thickness was divided into six thin sublayered and the viscous dashpot boundary which was evaluated from the rigidity and the density of the lower soil of plywood was placed at the bottom of the base sublayer. The radius of inner irregular region was 4.51 cm, which was determined from the equivalent area of the foundation. The superstructure was represented by the lumped mass model. A mass point was made for the foundation and the superstructure was idealized as four mass points.

The properties of model materials used in the analysis were determined by the preliminary test and they are shown in the Table I.

4-2 Results of Analysis

Fig. 2 and Fig. 3 show the transfer and the phase lag curves of the soil model analysis. As for the fundamental natural frequency, the soil model analysis shows an agreement with the results of the test because a peak appears at 9.0 Hz and the phase angle φ is $-\pi/2$ at this frequency. The transfer ratio and the phase, showing some differences in the range of the higher frequencies than the fundamental natural frequency, are generally similar to the results of the test.

Fig. 4 and Fig. 5 show the transfer and the phase lag curves of the single-structure-soil analysis. They show an agreement with the results of the test, because the two peaks in the transfer curve of the single-structure appear at 9.0 Hz and 10.4 Hz and that peak of the soil model appear at 9.0 Hz. As for the phase, the results of the single-structure-soil analysis shows well that the phases of the structure and the soil are the same in the range of 0.0 Hz - 10.4 Hz but in the range of the higher frequencies than 10.4 Hz, both phases are different from each other.

5. CONCLUSION

The dynamic amplitude and phase lag characteristics found in the results of the soil model and the single-structure-soil model test are approximately equal to theoritical values calculated by the computer program based on the Thin Layered Element Method.

The two soil layers model can be simulated fairly well by the viscous dashpot boundary.

The small shaking table test is useful for the fundamental study of the dynamic soil-structure interaction problem.

6. ACKNOWLEDGEMENT

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Table I. Properties of Model Materials

MATERIAL	YOUNG MODULUS E(gr/cm²)	SHEAR MODULUS G (gr/cm²)	SHEAR WAVE VEL Vs(cm/SEC)
GELATINE α : 8 %	261.6	87.2	288.0
PLYWOOD	4.27×10^6	0.712×10^6	2.9×10^4
STEEL METAL	1.4×10^9	0.538×10^9	

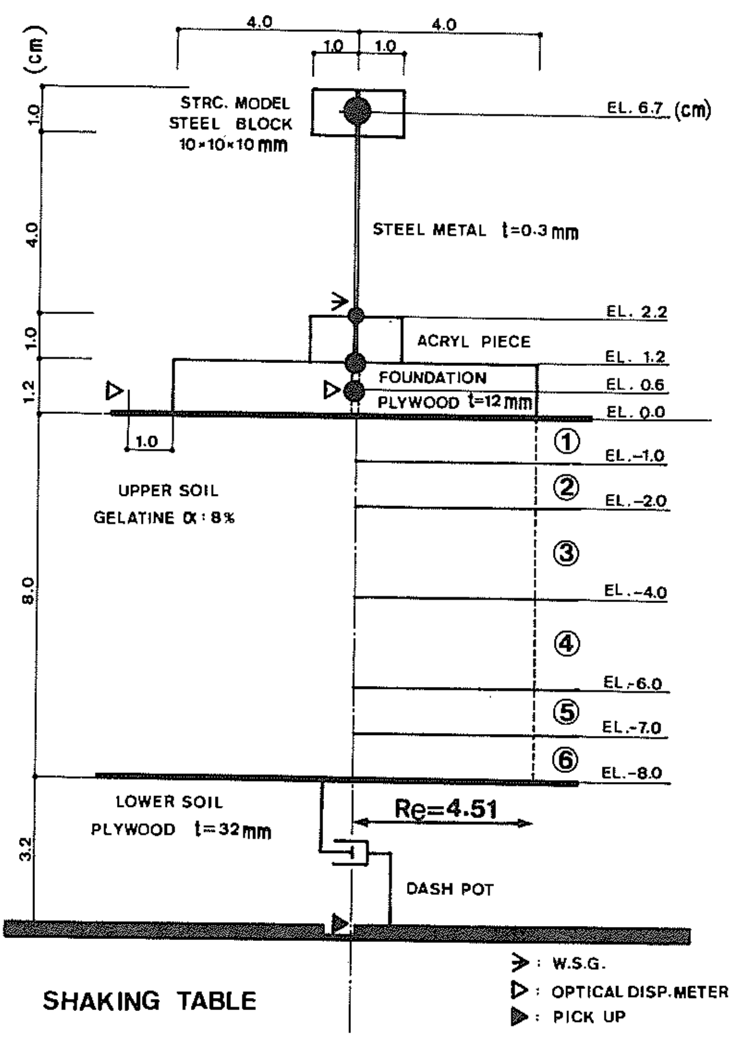

Fig. 1. Soil-Structure Model and Observation Points

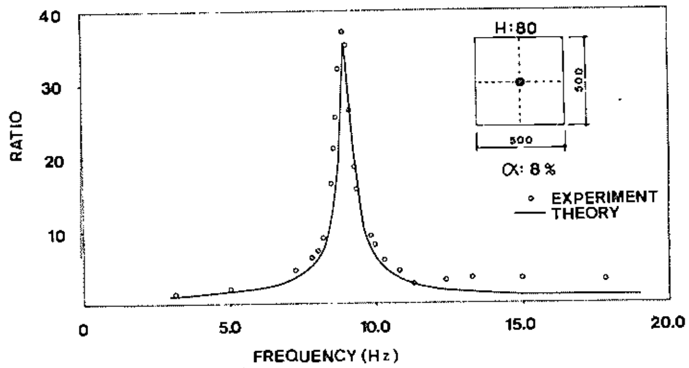

Fig. 2. Transfer Function (Soil)

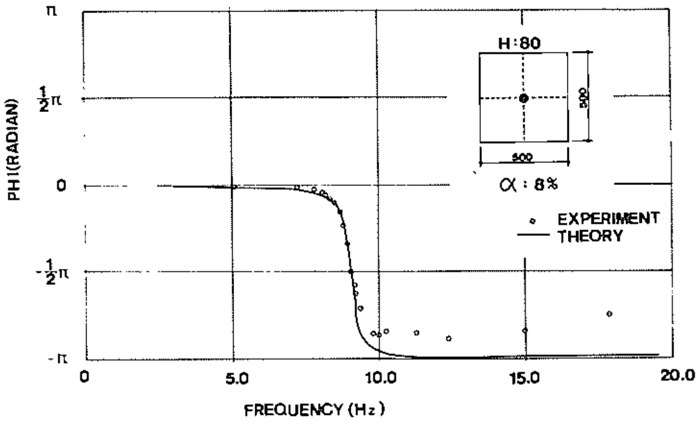

Fig. 3. Phase Lag Curve (Soil)

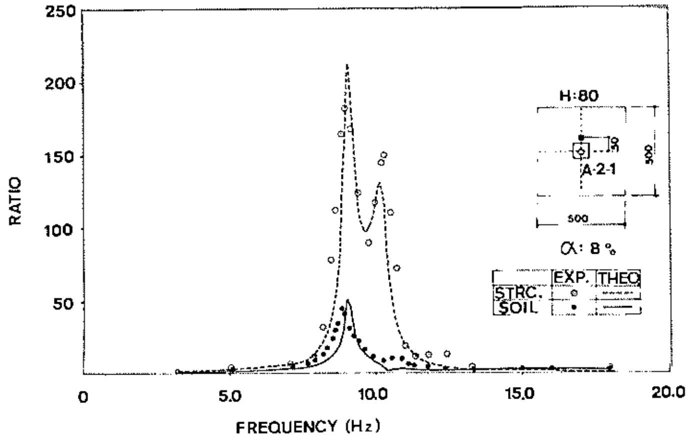

Fig. 4. Transfer Functions (Soil-Structure)

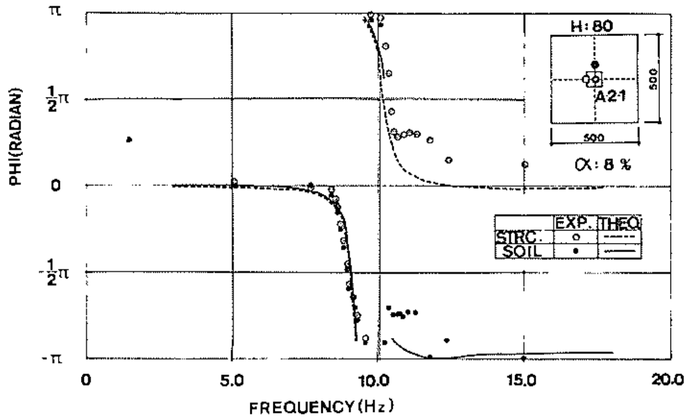

Fig. 5. Phase Lag Curves (Soil-Structure)

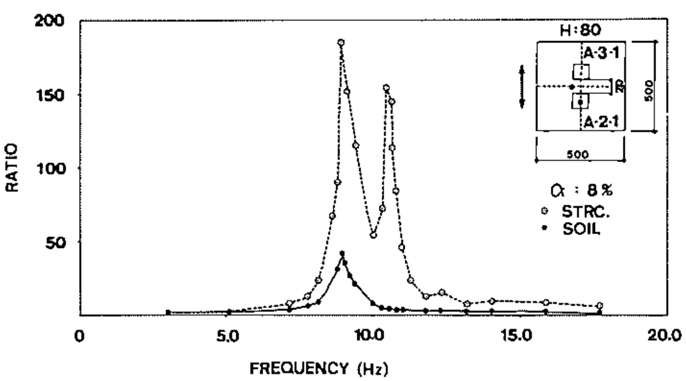

Fig. 6. Transfer Functions (Parallel)

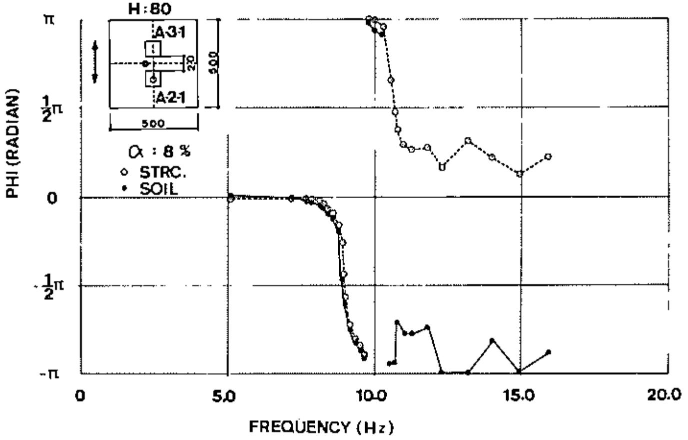

Fig. 7. Phase Lag Curves (Parallel)

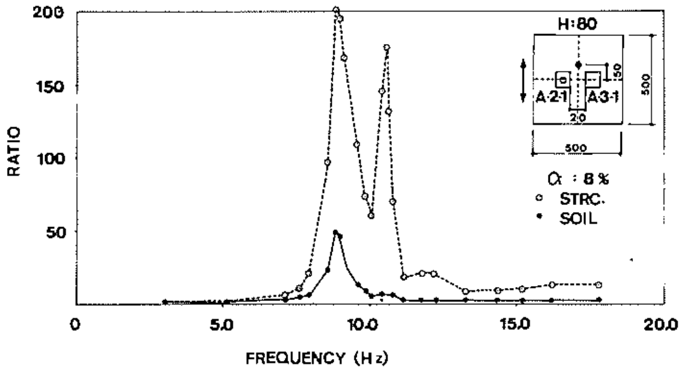

Fig. 8. Transfer Functions (Transverse)

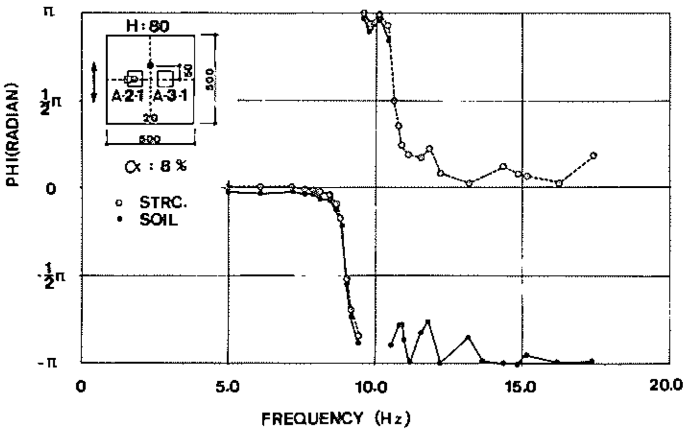

Fig. 9. Phase Lag Curves (Transverse)