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AN EXPERIMENTAL STUDY ON ADVANCEMENT OF DAMPING PERFORMANCE OF FOUNDATIONS IN SOFT GROUND PART1 FORCED VIBRATION TESTS OF A FOUNDATION BLOCK CONSTRUCTED ON IMPROVED SOIL MEDIUM

Shinji ISHIMARU
College of Science and Technology, Nihon University, Japan

Yukio SHIMOMURA
Junior College of Nihon University, Japan

Masashi KAWAMURA
College of Industrial Technology, Nihon University, Japan

Yoshio IKEDA*
Taisei Corporation, Japan
Phone: 81-3-5381-5196, Fax: 81-3-3345-8330
E-mail: yosioi@eng.taisei.co.jp

Ippei HATA
Research Institute of Science and Technology, Nihon University, Japan

Hidenori ISHIGAKI
College of Science and Technology Nihon University, Japan

ABSTRACT

Purpose of this study is to enhance attenuation performance of structures that will be constructed in the soft ground area. We conducted material tests to obtain basic properties of the soil cement column. The forced vibration tests then were carried out to acquire dynamic feature of the reinforced concrete block constructed on improved soil mediums. Additional forced vibration tests for various conditions of trenches dug along the block were conducted to obtain fundamental features of damping effect of the side surfaces of the test block.

According to results of the material testing, densities of the soil cement columns were 1.45-1.52 g/cm^3 and the unconfined compressive strengths were 2.4-4.2 times as large as the specified design strength (1 MPa). In comparison of resonance curves by experiments and simulation analysis, simulation analysis results estimated by the hybrid approach were in good agreement with experiment ones for both the X and Y-directions. From the results of the forced vibration test focusing on various condition of the trenches dug along the test block, it was indicated that response of tamping by the rammer decreased compared with that of treading.

Keywords: Damping performance, Soft ground, Soil cement columns, Forced vibration test.

1. INTRODUCTION

As a solution to environmental problems of the earth, the seismic isolation structures play an important role in pervasion of longer lasting structures in quake-prone countries. The author's group has undertaken studies on the feasibility of the seismic base-isolation system constructed on soft ground sites (S. Ishimaru et al., 1999, Y. Shimomura et al, 2001, S. Ishimaru et al, 2004). Purpose of this study is to enhance attenuation performance of structures that will be constructed in the soft ground area. In order to grasp dynamic characteristics of a reinforced concrete block sustained by small-sized soil columns made of soil cement materials and the existing soil layers, forced vibration tests were carried out.

First, we conducted material tests to obtain basic properties of the soil cement column. The forced vibration tests then were carried out to acquire dynamic feature of the reinforced concrete block constructed on improved soil mediums. It is assumed that soil region under the test block is a composite medium consisted of the soil cement columns and existing soil layers. The composite medium is called the improved soil medium. Simulation analyses for the forced vibration tests were also conducted. Finally, additional forced vibration tests for various conditions of trenches dug along the block were conducted to obtain fundamental features of damping effect of the side surfaces of the test block.

2. GROUND CONDITION AT EXPERIMENTAL SITE

Schematic view of the experimental site is shown in Fig.1. The experimental site has been located at a vacant lot on the north of the experimental building (Joint Research Center for Environment Protection & Disaster Prevention City) in the Funabashi campus of Nihon University in Chiba Prefecture, which is near Tokyo in Japan. Soil profile of the test site is illustrated in Fig. 2. Ground surface 2.8m shallower is loamy layer of the Kanto district and partially includes backfilling soil 0.1m deep. Cohesive soil is distributed in the range of G.L.-2.8m to G.L.-3.5m. Tuff fine sand can be seen in the range of G.L.-3.5m to G.L.-5.3m. G.L.-5.3m deeper, silty fine sand and fine sand are distributed. Tips of the improved soil cement columns are located at G.L.-2.8m, where loam and cohesive soil are distributed, and its value of the standard penetration test is five and under.

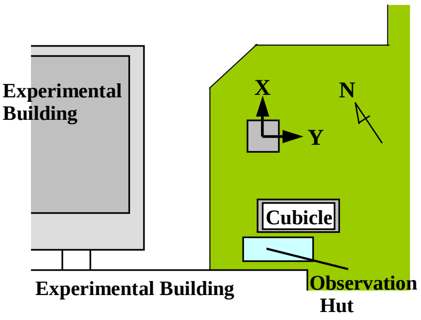


Fig. 1 Schematic view of the experiment site

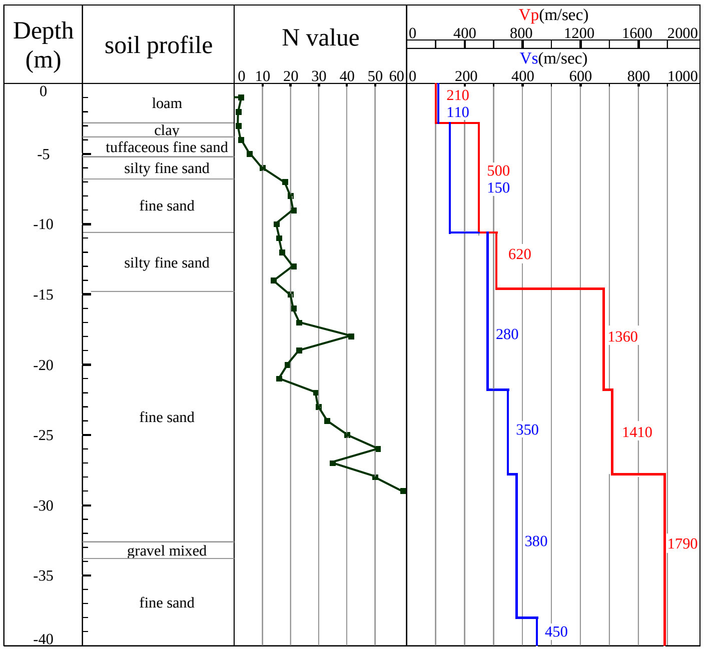


Fig. 2 Soil profile of the test site

3. PRE-ANALYSIS AND DESIGN OF TEST BLOCK

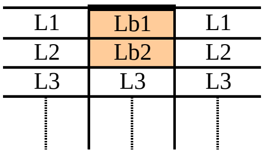
Excitation frequency of an eccentric mass-type vibration generator adopted in these forced vibration tests was in the range of 0.2Hz to 20Hz. In order to put the predominant frequency of the reinforced concrete block within the above frequency range, it was decided that the target predominant frequency of the block would be 10Hz. Pre-analyses were carried out by axisymmetric thin layer method. Soil properties for analyses shown in Table 1 were defined by results of soil surveys and PS logging tests. The volume of the improved soil medium part under the test block was modeled as the Timoskenko Beam that has an equivalent section area of the test block and equivalent properties shown in Table 2. Frequency response analyses of four block models shown in Table 3 were conducted. Here, it was assumed that the Young's modulus of the improved soil column was equal to the specified design strength, 1MPa. Resonance curves of the response acceleration per unit exciting force for the exciting direction on the upper surface of the test block are shown in Fig. 3. In terms of the block height and based on results of the analyses, Model C was selected as the most appropriate specimen. Illustration of the reinforced concrete block specimen constructed on the site is shown in Fig. 4.

Table 1 Soil profile for numerical prediction analysis

Depth (m)	ρ (t/m^3)	Vs (m/s)	Poisson's ratio	Damping ratio	Symbol
1.0	1.4	110	0.311	0.03	L1
2.7	1.4	110	0.311	0.03	L2
5.4	1.6	150	0.451	0.03	L3
10.6	1.7	280	0.372	0.02	L4
14.7	1.7	280	0.478	0.02	L5
21.7	1.7	350	0.465	0.02	L6
27.8	1.8	380	0.461	0.02	L7
38.0	2.0	450	0.466	0.02	L8
45.2	2.0	420	0.461	0.02	L9

Table 2 Soil profile of improved soil medium (Lb)

Symbol	ρ (t/m^3)	Vs (m/s)	Poisson's ratio
Lb1	1.5	129	0.25
Lb2	1.5	129	0.25



L1	Lb1	L1
L2	Lb2	L2
L3	L3	L3

Table 3 Foundation models for prediction analysis

Model	Height h(m)	Width b(m)	Mass (ton)	Moment of inertia (tm^2)	Excitation height (m)
A	0.50	2.4	6.9	3.45	0.80
B	0.75	2.4	10.3	5.45	1.05
C	1.00	2.4	13.8	7.77	1.30
D	1.25	2.4	17.2	10.52	1.55

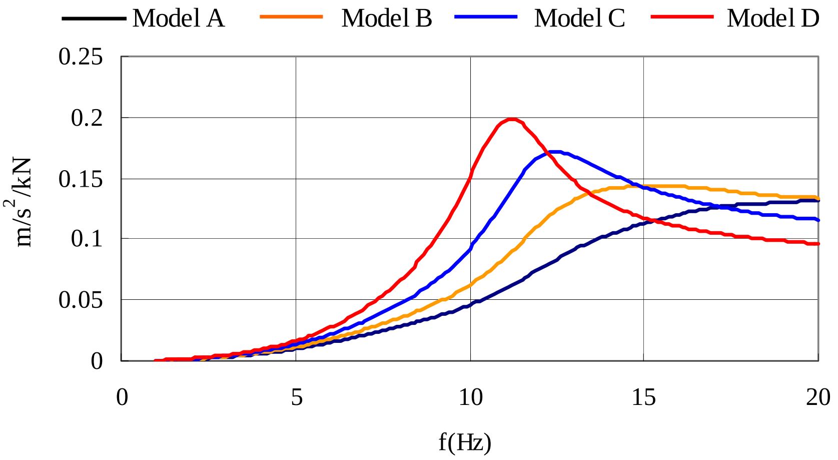


Fig. 3 Resonance curves of horizontal acceleration of upper surface of block

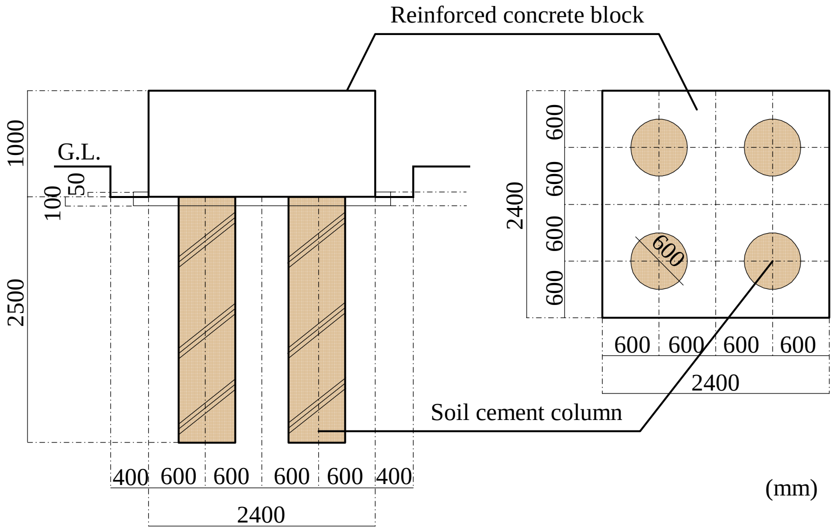


Fig. 4 Foundation block on improved soil medium

4. MATERIAL TESTING OF IMPROVED SOIL MEDIUM

Two core rods, which had 90mm in diameter and 2.5m in length, were obtained from a soil cement column of the material age of 28 days. The core rod was then cut as specimens of 180mm lengths for material experiments. Fig. 5 shows stress-strain curves of the core samples of the soil cement column that were the highest and the lowest deformation moduli (E_{50}) among all of specimens (22 samples). The maximum values of stresses meant the unconfined compressive strength. Further, inclinations of the deformation modulus (E_{50max}, E_{50min}, the mean value and standard deviation σ) are also illustrated in Fig. 5. The deformation moduli of all the specimens were 839-1755MPa. The unconfined compressive strengths of all the specimens became 2.5-4.6 times as large as the specified design strength, 1MPa. Density and the unconfined compressive strength distributions against depth are shown in Fig. 6. The densities distributed uniformly against variations of the depth and were in the range of 1.45 to 1.52g/cm^3.

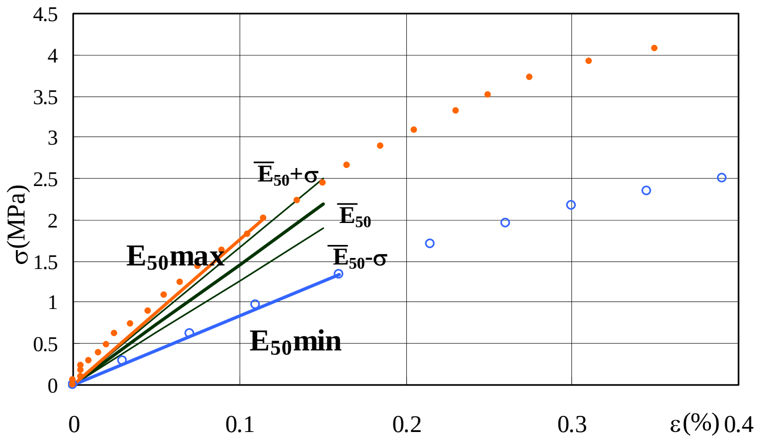


Fig. 5 Stress-strain curves of core samples of soil cement column

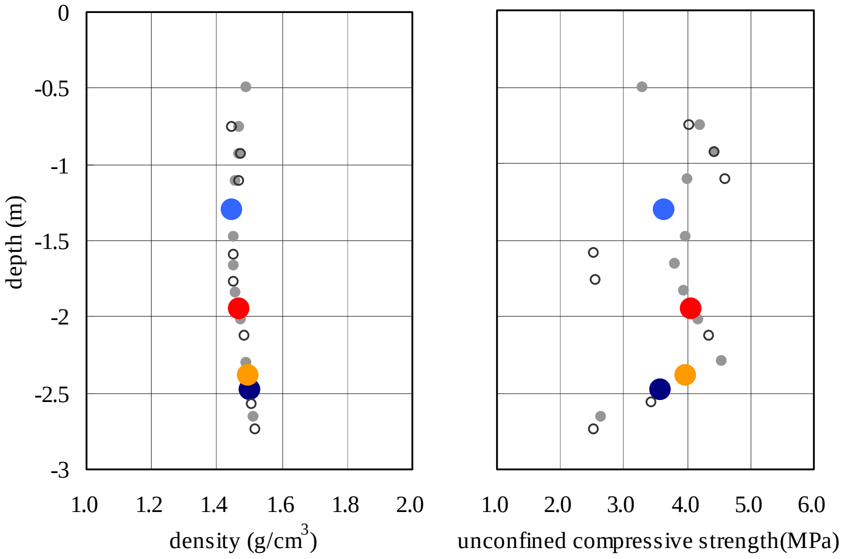


Fig. 6 Density and unconfined compressive strength distributions against depth

5. DYMANIC CHARACTERISTICS OF TEST BLOCK

5.1 Comparison of Test Results and Analysis Results

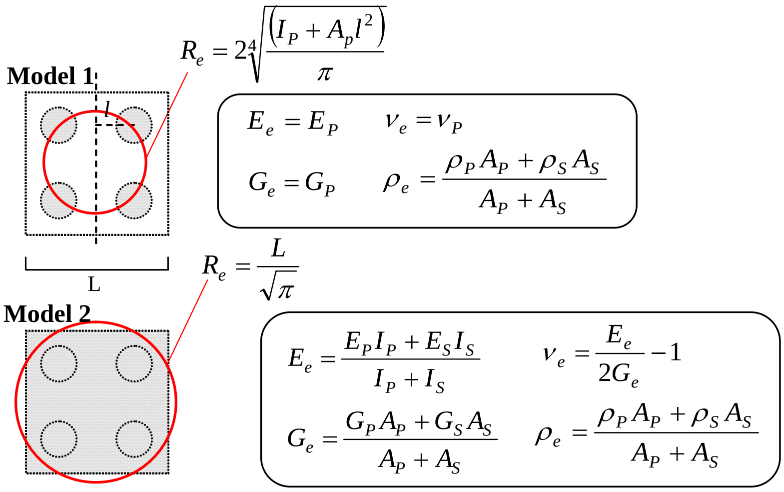
The forced vibration tests were conducted by small and medium sweep excitations that increase exciting frequencies gradually. To obtain the basic dynamic characteristics of the test block, the resonance curves of the block were estimated by measurement data of the small sweep excitation tests where soil surrounding the block assumed to be linear. Taking account of the difference between the core sample strength and the full-scale column strength, the deformation modulus (E_{50}) was defined 0.75 times larger than the core sample strength. Based on the shear wave velocity of the ground surface near the test block obtained by plank hammer techniques, the shear wave velocity of the ground surface 2.8m shallower was set equal to 90m/s.

In analyses, it was assumed that the improved soil medium part under the test block was modeled as a cylinder solid that had an equivalent geometrical moment of inertia of the soil cement columns and equivalent properties of the soil cement columns and the existing soil layers (Model 1). Another model was called Model 2 and it was also a cylinder solid whose section area and properties were equal to the test block and Model 1, respectively. Model 1 and Model 2 are shown in Fig. 7. Simulation analyses of the above both Model 1 and Model 2 were carried out by the axisymmetric thin layer approach. Amplitude and phase functions of the resonance curves of the response acceleration per unit exciting force for the exciting direction on the upper surface of the test block and both models are shown in Fig. 8. Resonance frequencies of the both models were 9.0Hz and 9.7Hz, and both frequencies were corresponded with the resonance frequency of the experiment, 9.3Hz. Amplitudes of the both Model 1 and Model 2 were in an agreement with the experiment ones.

5.2 Analysis Model and Results by Hybrid Method

In Model 1 and Model 2, we assumed that a soil surface level was equal to the bottom of a leveling concrete under the test block. When the test block was constructed, level of side ground surface was higher than the bottom of an excavation of the test block. To take into account such a situation, the three-dimensional analyses were carried out by a hybrid approach. The hybrid approach was that soil near the test block was modeled by point exciting thin layer element, and the test block and the soil cement columns were modeled by FEM model. The hybrid approach is shown in Fig. 9. In the hybrid approach, the soil cement columns were assumed to be a rectangular solid. In the analysis, a foundation of a cubicle (a power transformation vessel) adjacent the test block was also modelled. Analysis and the experiment results for the X-direction and Y-direction are shown in Fig. 10. Simulation results for both directions coincided with the experiment ones.

Actually, there have been adjacent structures including the cubicle near the test block. Therefore existence of these structures might have affected the dynamic characteristics of the test block. This is the cross-interaction effect. To investigate such the effect, another simulation analysis was carried out by the three-dimensional axisymmmetric FEM model. The analysis model is shown in Fig. 11. The properties of adjacent structures are illustrated in Table 4. Resonance curves of the analysis and the experiment for the Y-direction are indicated in Fig. 12. Although the properties of the adjacent structures given in the analysis were not accurate, resonance curves of the analysis represented a peak that could be induced by the adjacent structures.



$$R_e = 2\sqrt[4]{\frac{\left(I_P + A_p l^2\right)}{\pi}}$$

$$E_e = E_P \qquad \nu_e = \nu_P$$

$$G_e = G_P \qquad \rho_e = \frac{\rho_P A_P + \rho_S A_S}{A_P + A_S}$$

$$R_e = \frac{L}{\sqrt{\pi}}$$

$$E_e = \frac{E_P I_P + E_S I_S}{I_P + I_S} \qquad \nu_e = \frac{E_e}{2G_e} - 1$$

$$G_e = \frac{G_P A_P + G_S A_S}{A_P + A_S} \qquad \rho_e = \frac{\rho_P A_P + \rho_S A_S}{A_P + A_S}$$

Symbols: P : Soil cement column, S : neighboring soil under foundation block

e : effective property of improved medium as Timoshenko Beam

Fig. 7 Description of Model 1 and Model 2 adopted in simulation analyses

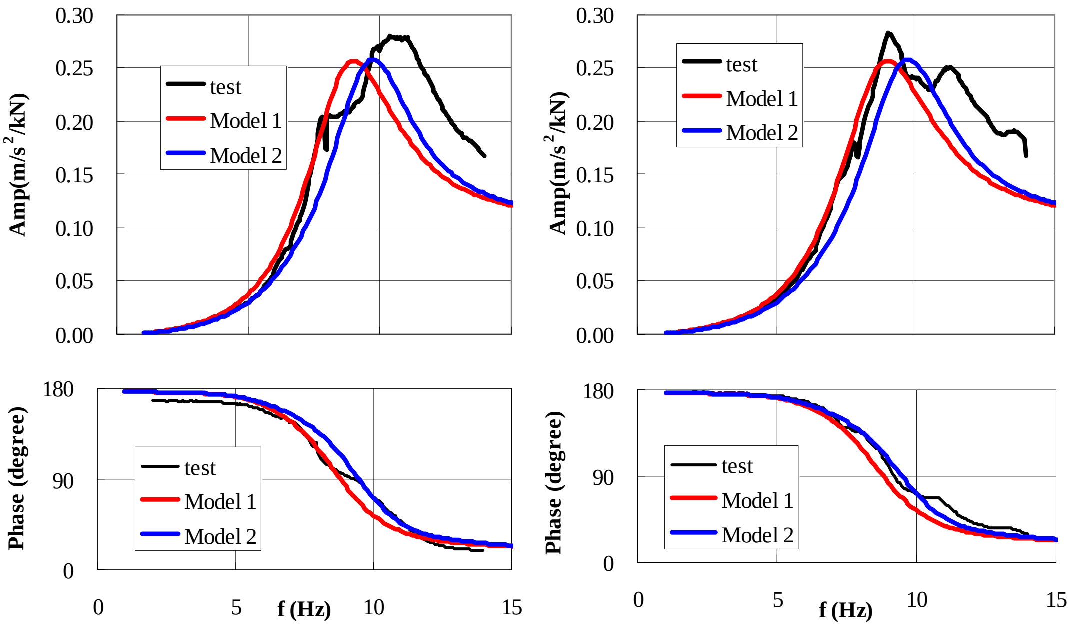


Fig. 8 Comparison of amplitude and phase functions of the resonance curves of the response acceleration per unit exciting force for the exciting direction on the upper surface of the block by Model 1, Model 2 and experiment

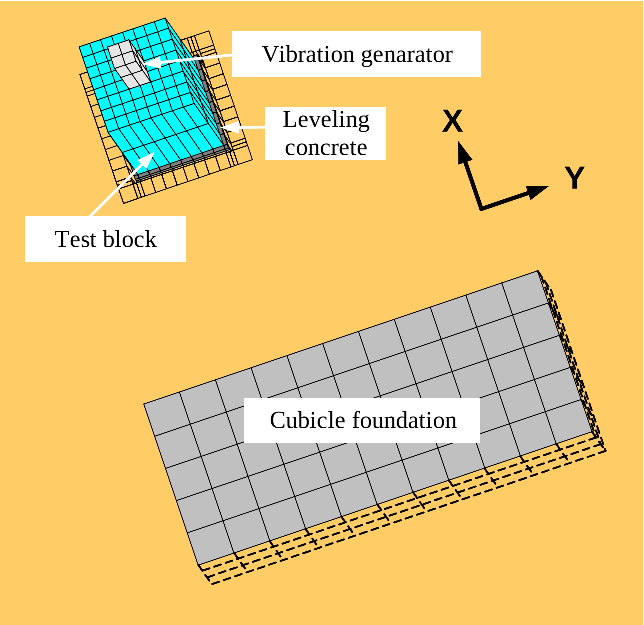


Fig. 9 Models in hybrid approach

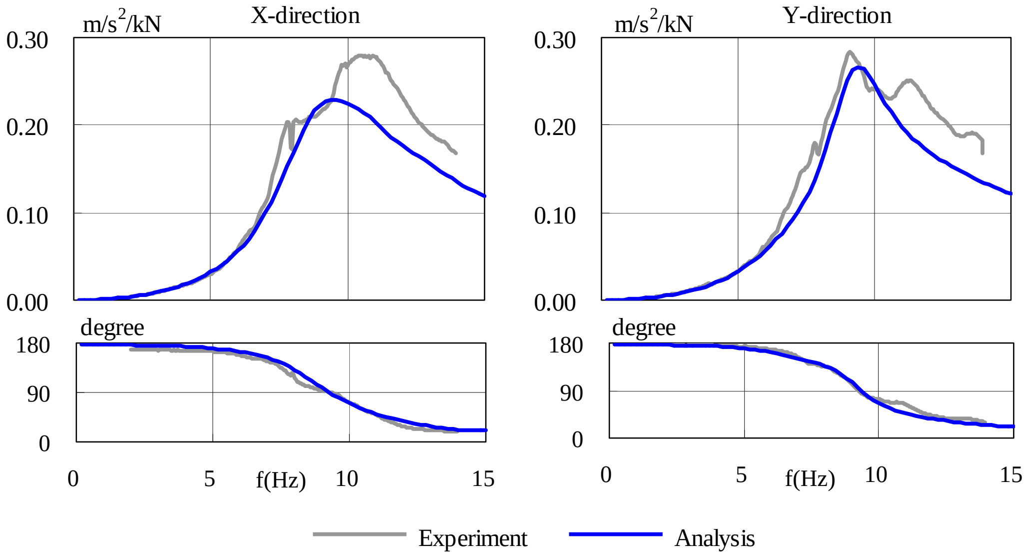


Fig. 10 Comparison of amplitude and phase functions of the resonance curves of the response acceleration per unit exciting force for the exciting direction on the upper surface of the block by hybrid method and experiment

Table 4 Properties of adjacent structures

Depth (m)	Shear wave velocity (m/s)	Density (ton/m^3)	Poisson's ratio	Damping ratio
2.5	1000	1.4	0.2	0.03

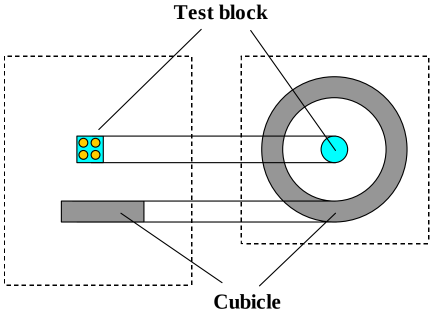


Fig. 11 3-D axisymmetric FEM analysis model

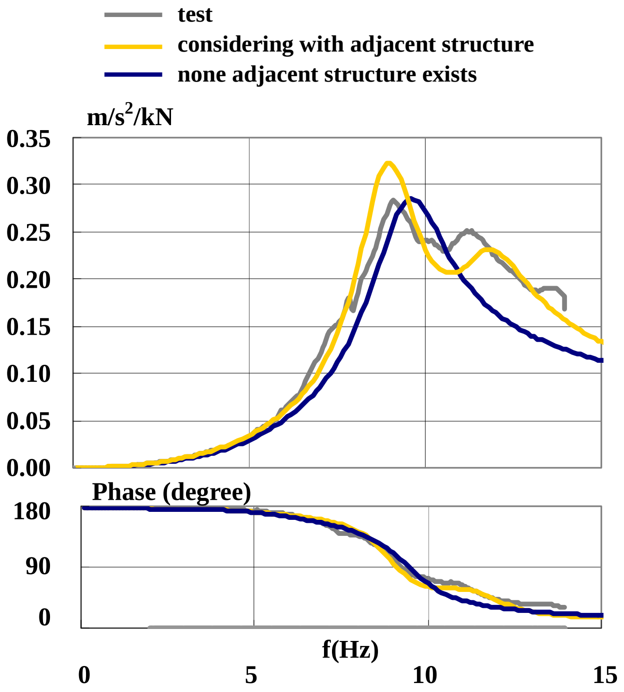


Fig. 12 Comparison of amplitude and phase functions of the resonance curves of the response acceleration per unit exciting force for the Y-direction on the upper surface of the block by 3-D axisymmetric FEM and experiment

6. FORCED VIBRATION TEST FOR CONDITIONS OF TRENCHES DUG ALONG TEST BLOCK

6.1 Forced vibration tests

In order to obtain basic features of attenuation effect on side surface of the test block, forced vibration experiments were carried out under conditions of trenches dug along the test block. A schedule of the forced vibration experiment was planned as follows:

First we dug the trenches along the test block and carried out an experiment to examine influence of existence of the trench (Step 1). Width and depth of the trenches are approximately 0.4m and 0.8m. Then we backfilled the trenches 0.5m deep by the dug soil and trod the soil by 70 kg of a human being (Step 2A). Next we tamped the backfilled soil by a rammer (Step 2B). After Step 2B, we backfilled the trenches by the dug soil until the ground surface level (Step 3A). Finally, we tamped the backfilled soil of Step 3A by the rammer (Step 3B). The schedule of the forced vibration tests is shown in Fig. 13.

Amplitude, phase and coherence functions of the response displacement per unit exciting force for the excitation direction on the upper surface of the test block of Step 1 to Step 3B are illustrated in Fig. 14. According to the coherence curves, it was found that appropriate data were obtained except in low frequency range. As results of experiment data, difference between the amplitude functions for the X-direction and Y-direction could be seen. Resonance frequencies of Step 1 were 8.1 Hz for the X-direction and 8.5 Hz for the Y-direction. Resonance frequencies of Step 3B were 10.4 Hz for the X-direction and 10.0 Hz for the Y-direction. From the results of Step 1 to Step 3B, other peak frequencies of the amplitude curves appeared 7.8 Hz and 9.5 Hz for the X-direction and 7.3 Hz, 8.5 Hz and 11.0 Hz for the Y-direction.

It was revealed that the shallower the depth of the trenches became, the lower the amplitudes of the resonance curves at the peak frequencies became, and the peak frequencies shifted to higher range. Especially, the amplitude of the displacement of Step 3 decreased approximately 60% as compared with that of Step 1. Additionally, effectiveness of tamping by the rammer was confirmed by 10% amplitude reductions of Step 2B and Step 3B compared with these of Step 2A and Step 3A.

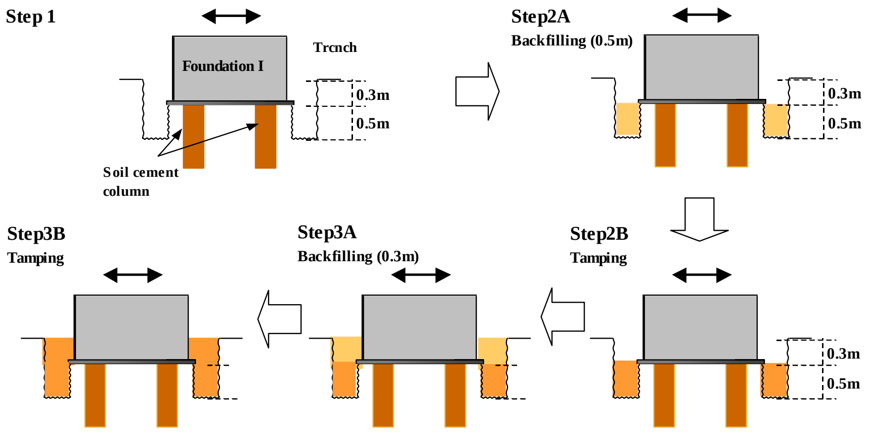


Fig. 13 Schedule of forced vibration tests focusing on various conditions of trenches dug along the test block

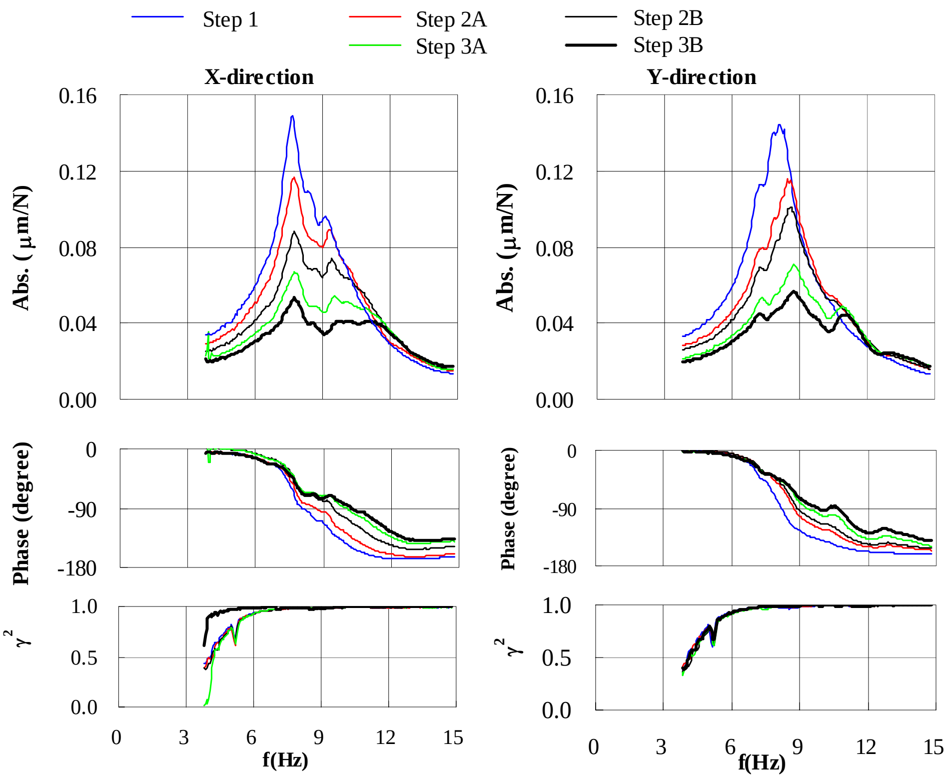


Fig. 14 Comparison of amplitude, phase and coherence functions of the resonance curves of the response displacement per unit exciting force for the exciting direction on the upper surface of the block by experiments

6.2 Simulation Analyses

Furthermore, simulation analyses for the experiment focusing on the trenches dug along the test block were carried out by the three-dimensional axisymmmetric FEM model. Looseness and separation between the backfilled soil in the trenches and the improved soil medium part or soil near the test block were modeled by loose soil regions. The analysis model is shown in Fig. 15. The properties including the loose soil region are given in Table 5. Amplitude and phase functions of the experiment and the simulation analyses of Step 2B and Step 3B are shown in Fig. 16. Although peak frequencies of the amplitude functions obtained by the simulation analyses were different from these by the experiment, resonance frequencies estimated by the simulation analyses were in good agreement with these by the experiment.

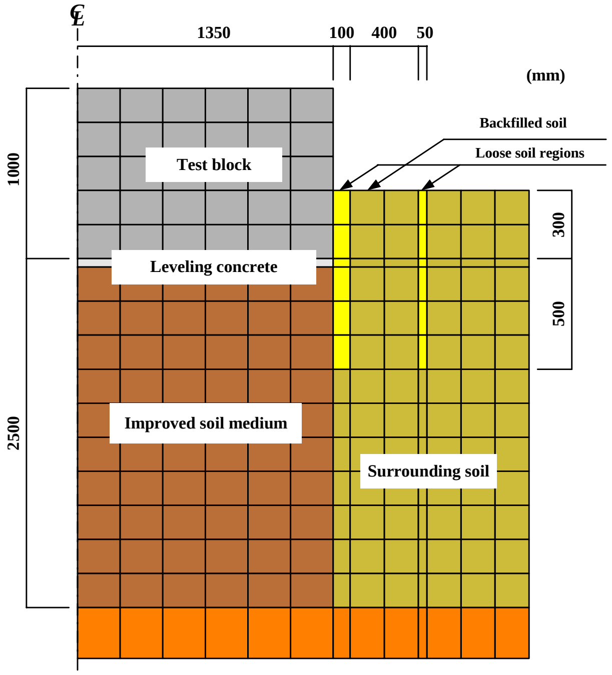


Fig. 15 3-D axisymmetric FEM model taking loose soil regions into account

Table 5 Properties of 3-D axisymmetric FEM model

Material	Shear modulus G (MPa)	S-wave velocity Vs (m/s)	Density ρ (ton/m^3)	Poisson's ratio	Damping ratio
Foundation block			2.4	0.20	0
Leveling concrete			2.4	0.20	0
Loose soil regions	0.000014	0.1	1.4	0.31	0.03
surface subsoil	11.34	90	1.4	0.31	0.03

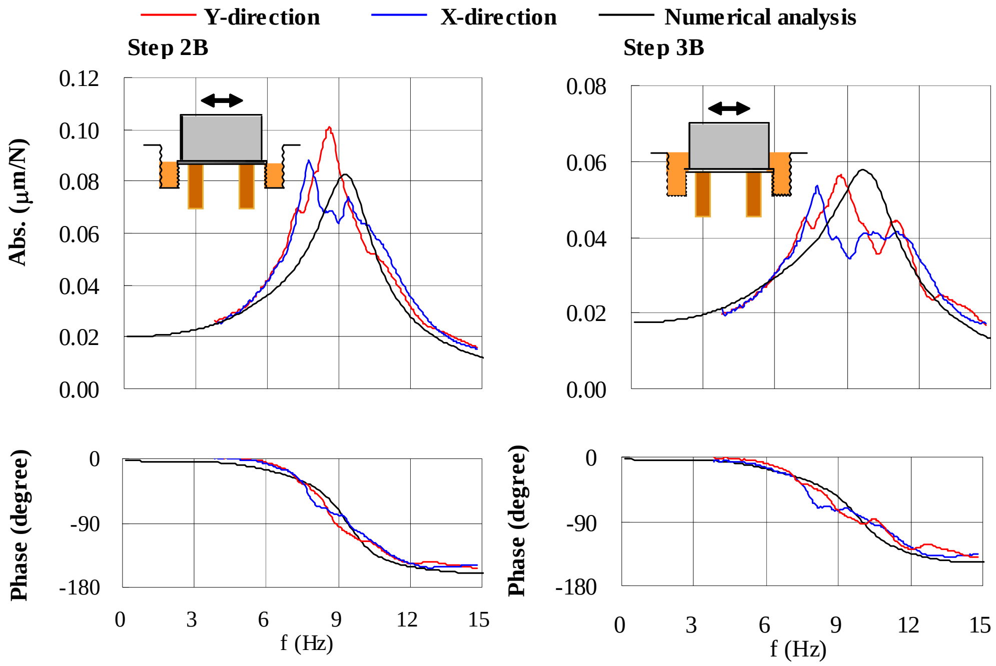


Fig. 16 Amplitude and phase functions of experiment and simulation analyses of Step 2B and Step 3B

7. CONCLUSIONS

In this study, first we conducted the material testing of the soil cement columns to obtain basic material property data. Next, forced vibration tests of the test block set up on the improved soil medium part and their simulation analyses were carried out. Then we also conducted forced vibration tests focusing on various conditions of trenches dug along the test block and their simulation analyses.

Main knowledge obtained from this study was follows:

(1) According to results of the material testing, densities of the soil cement columns were 1.45-1.52 g/cm^3 and the unconfined compressive strengths were 2.4-4.2 times as large as the specified design strength (1 MPa).

(2) In the simulation analyses difference between the core sample strength and the full-scale column strength was taken into account and shear wave velocity obtained by the plank hammer techniques was adopted. Therefore, results of the simulation analyses were in better agreement with the experiment ones.

(3) The hybrid method, which dealt with the test block and soil near the block as FEM model, and surrounding soil as the point exciting thin layer element, could represent the results of the experiment in the both directions.

(4) From the results of the forced vibration test focusing on various condition of the trenches dug along the test block, it was indicated that response of tamping by the rammer decreased 10% compared with that of treading.

(5) Simulation analyses, which took account of the backfilled soil into the trenches dug along the test block, coincided well with the experiment ones.

In our companion paper (Ishimaru et al., 2005), we have described forced vibration tests and simulation analyses that have dealt with a material medium possessing high damping and mitigation performance.

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REFERENCES

1. S. Ishimaru, T. Niiya, K. Morikawa, T. Uotsu, S. Yamazaki, A. Yoshida, Y. Shimomura, K. Ohshima, (1999), "A feasibility study for seismic isolation by use of a soil-pile-structure system, Part 1 - Part 3." Summary of Technical Papers of Annual Meeting Architectural Institute of Japan, Vol.B-2, pp.653-658, (in Japanese).
2. Y. Shimomura, K. Ohshima, S. Ishimaru, T. Niiya, (2001), "A study of dynamic interaction of soil and pile with non-uniform section." Proceedings of 12th World Conference on Earthquake Engineering, Auckland, New Zealand. Paper No.875.
3. S. Ishimaru, I. Hata, Y. Shimomura, Y. Ikeda, H. Ishigaki, Y. Ogushi, (2004), "A feasibility study of new type seismic isolation – composed system of piles covered by pipes and dampers with partial soil improvement –" Proceedings of 13th World Conference on Earthquake Engineering, Paper No.2204.
4. S. Ishimaru, Y. Shimomura, M. Kawamura, Y. Ikeda, I. Hata, S. Miwa, (2005), "An experimental study on advancement of damping performance of foundations in soft ground, Part 2 Experiment focusing on damping and antivibration performance of side surface of foundation blocks." 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18), K13-2 (to be published).