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FREQUENCY RESPONSE CHARACTERISTICS OF THE RIGID COLUMN TYPE FOUNDATION

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SUMMARY

In design, a foundation assumed to be a single whole of columns called the column type foundation. To obtain fundamental data that would help establish seismic design method for the rigid column type foundation during great earthquake, shaking table test of foundation model with different embedded depth D_f and height of ground surface H were conducted. The results is the followings: 1) as H/D_f increases, the foundation model respond to shaking at their respective natural frequency; 2) a model natural frequency smaller than that of the ground gives rise to a good degree of isolation; 3) as the input acceleration increases, the damping constant increases and thus broadens the frequency range of vibration; 4) the vibration of a model is affected by a phase difference as the input acceleration increases, consequently complicating the vibration mode; 5) the percent reduction of a natural frequency vs. an increased input acceleration tends to be practically equal among the models. We also conducted a modal analysis and verified the nonlinear characteristics of the ground by comparing the results of the modal analysis and those of the bench test.

INTRODUCTION

The 1995 Hyogoken-Nanbu Earthquake damaged many bridges. Since the earthquake, Japanese design standards (e.g. JRA 2002) have incorporated a ductility design method for bridge pier foundations. In designing bridge foundations by the ductility design method, to evaluate the yield strength and the behavior of the foundation when applied large deformation, the nonlinear of the ground resistance and foundations have been considered rationally.

In Japanese design standard, a foundation assumed to be a single whole of columns has been defined as rigid column type foundation including caisson foundations, and steel pipe sheet pile, diaphragm wall foundations. However, the resistance characteristics of the ground surrounding these rigid column type foundations in the event of an earthquake remain unclear, because so few cyclic loading tests have been performed.

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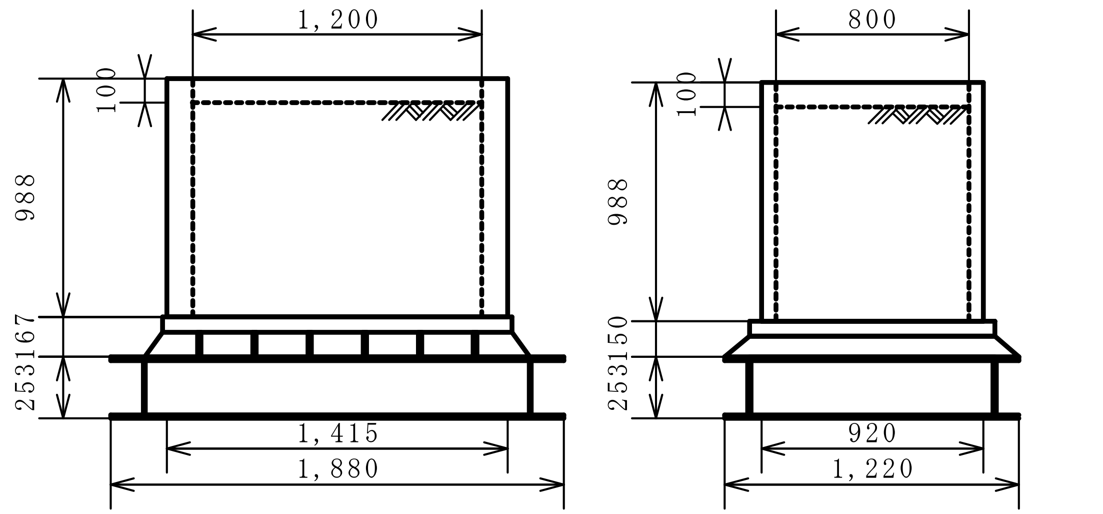


Fig.1 Experimental Apparatus

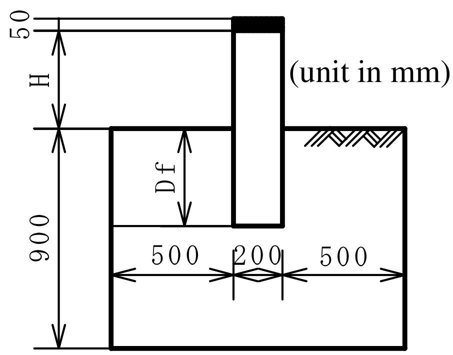


Fig.2 Foundation Model

Table.1 Height from Ground Surface and embedded Depth

	H(mm)	Df(mm)	H/Df
CASE-A	400	400	1.00
B	700	300	2.33
C	700	500	1.40

The objective of this study is to evaluate the dynamic behavior and the resistance characteristics of rigid column type foundation and the ground surrounding them. It also seeks to obtain basic data for establishing a method for designing optimum rigid column type foundation that will resist the forces exerted by major earthquakes. In this study, foundation model with different embedded depth D_f and height from ground surface H were prepared; each was placed in a shear box on the shake table, and the nonlinear response characteristics of the model and ground were examined by varying the input acceleration.

TEST OVERVIEW

Figure 1 shows the test apparatus. As shown in Figure 2, the shear box used in the test is 1200 mm wide, 800 mm long, and 900 mm high. The inside of the side walls are lined with rubber sheets to prevent friction losses between the shear box and the ground caused by shear deformation. The model ground was made by pluviating dry Okagaki sand through air. The shear box is then placed on the shake table and vibrated for 1 minute at an input acceleration of 0.4 G and frequency of 4 Hz to render uniform density. The weight of the ground per unit volume in this test is [γ_d] = 15.7 kN/m^3. Based on physical property data for Okagaki sand obtained in earlier studies, the physical constants of the test ground are estimated that angle of shear resistance is [ϕ]= 42 degrees, and the modulus of deformation is E_{50} = 30

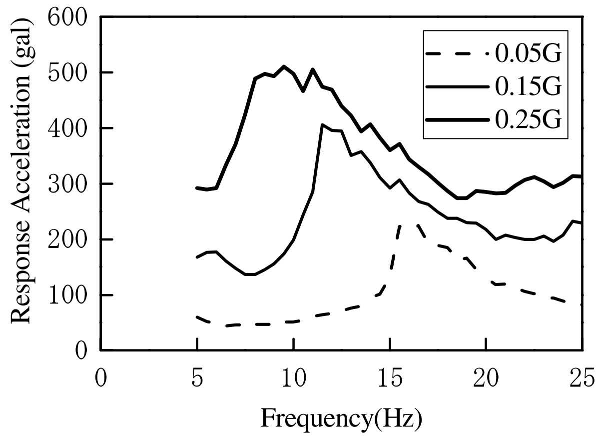


Fig.3 Resonance Curve of Ground

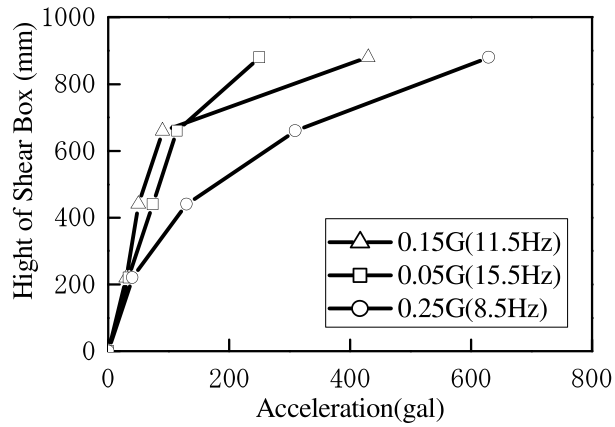


Fig.4 Vibration Mode of Ground

MN/m^2. The foundation model has a square shape of dimensions 200 mm x 200 mm and made of steel.

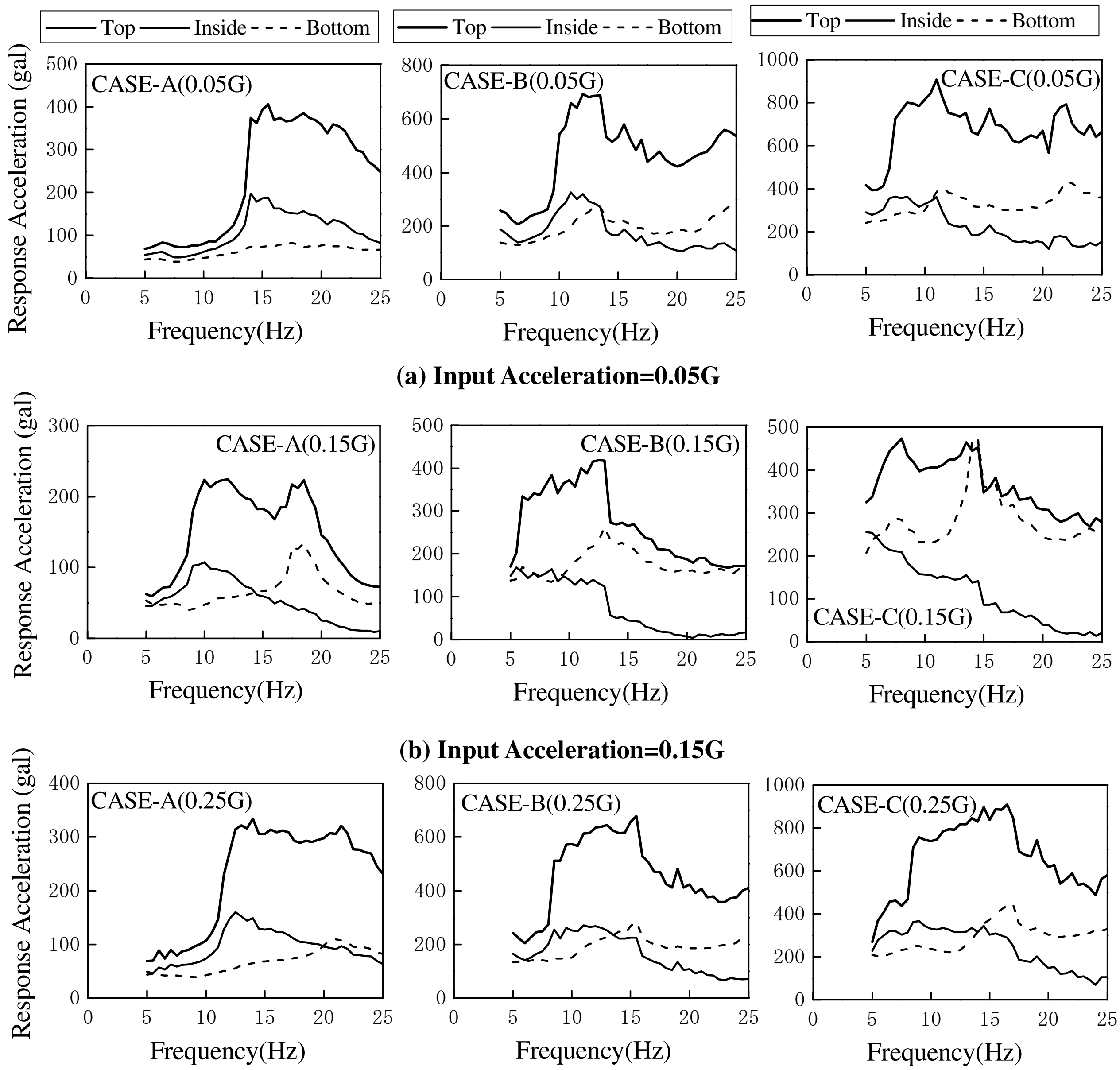
As shown in Table 1, the shaking table test is conducted for 3 separate combinations of embedded depth D_f and height from ground surface H. The foundation model is placed vertically in the center of the shear box. The vibration frequency of the shake table is increased in increments of 0.5 Hz as acceleration is measured. Five measurement positions are selected: on the shake table; at the ground surface 250 mm from the model; and at the top, inside, and bottom of the model. Since the inertial force of the shear box affects the input acceleration of the shake table, adjustments were made to maintain constant acceleration values for all vibration frequencies. Three values are selected for input acceleration: 0.05 G, 0.15 G, and 0.25 G.

TEST RESULTS

Figure 3 shows the resonance curves measured at the surface of the model ground for varying input acceleration values. The ground surface after the test at 0.05 G, 0.15 G, and 0.25 G showed settlement of 12.3 mm, 13.8 mm, and 14.8 mm, respectively, resulting in density changes. The figure also shows that the first resonance frequency of the shear box decreases with input acceleration increases, whereas the damping constant increases in the sequence 0.13, 0.22, and 0.56, respectively.

Figure 4 shows the acceleration distribution of the ground obtained with maximum surface acceleration at the resonance frequency. The acceleration plotted here is relative acceleration, which is obtained by subtracting input acceleration from measured acceleration. When input acceleration increases, the acceleration amplification factor of the ground decreases. The ground vibrates most in the region from the surface down to 200 mm.

Figure 5 shows the resonance curves for the models for varying input acceleration. The resonance curve for the top end of the model of CASE-A has approximately the same shape as that of Figure 3 for the ground surface, indicating that the ground and the model vibrate in resonance. In contrast, the shape of the resonance curve for the top end of the model of CASE-B differs markedly from that of Figure 3 for the ground surface, indicating that the model responds to input acceleration by vibrating at its own natural frequency. The response acceleration of the model of CASE-B is smaller than the other cases. Since the first natural frequency for the model of CASE-B is significantly smaller than that of the ground, the model is considered to be in a seismic isolation state. The shape of the resonance curve for the model of CASE-C is approximately the same as that for the ground surface, indicating that the ground and model



(a) Input Acceleration=0.05G

(b) Input Acceleration=0.15G

(c) Input Acceleration=0.25G

Fig.5 Resonance Curve of Model (CASE-A,B,C)

Table.2 The Natural Frequencies(Hz)

	H/Df	1st mode			2nd mode		
		0.05G	0.15G	0.25G	0.05G	0.15G	0.25G
CASE-A	1.00	14.0	11.0	7.5	—	24.0	22.0
CASE-B	2.33	9.0	6.0	4.5	17.5	13.0	10.5
CASE-C	1.40	12.5	8.5	5.5	21.5	15.5	13.0
Ground	—	15.5	11.5	8.0	—	—	—

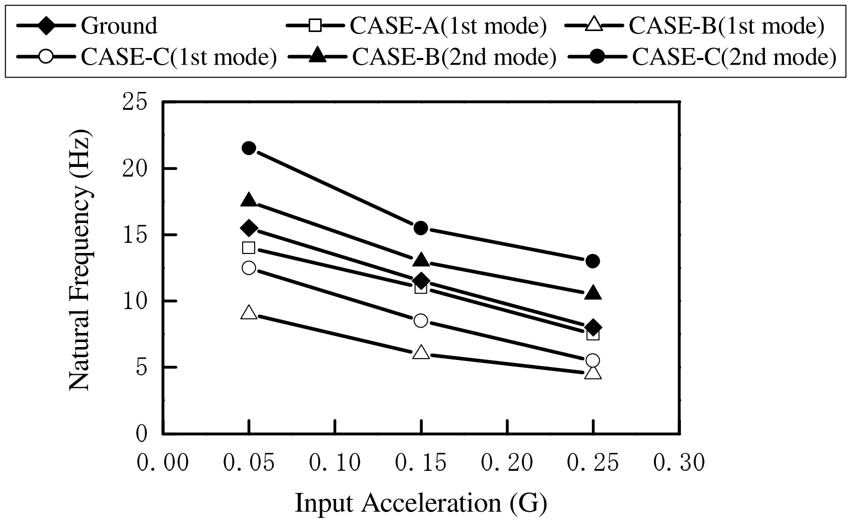


Fig.6 Relation between Input Acceleration and Natural Frequency

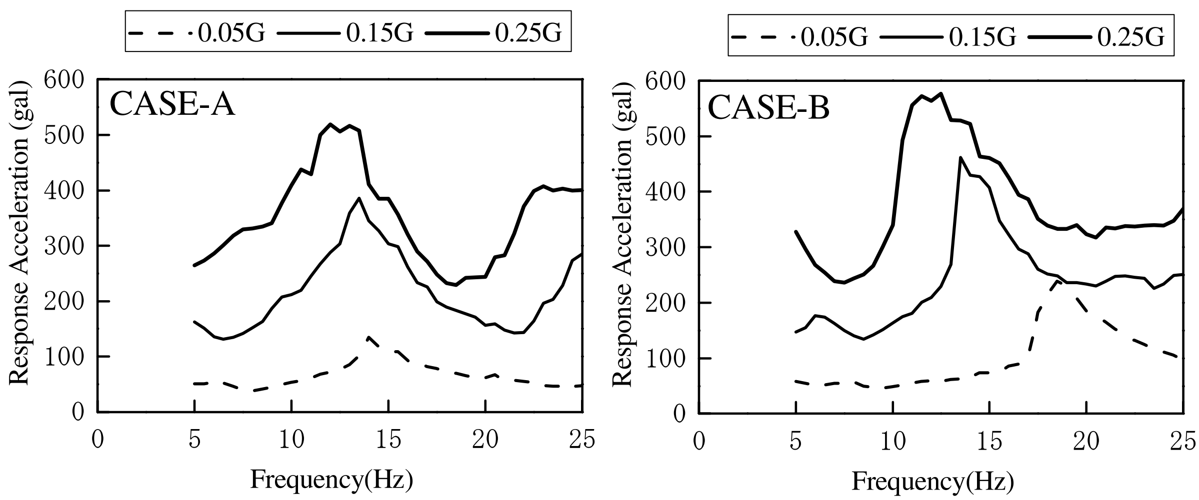


Fig.7 Resonance Curve of Ground

are in resonance, as in CASE-A.

Table 2 shows the natural frequencies obtained from Figure 5. The first and second natural frequencies decrease in all cases as input acceleration increases. The natural frequency of the model is also clearly smaller when the ratio H/D_f is larger.

Figure 6 shows the natural frequency of the model versus input acceleration. The rate of decrease of the natural frequency with respect to the input acceleration is approximately the same in all cases.

Figure 7 shows the resonance curves measured at the ground surface for CASE-A and CASE-B, the differences between which are most in the H/D_f values. Compared to Figure 3, in CASE-A, the resonance curve for the model near the first resonance point is approximately equal to the resonance curve for the ground and slightly higher at the second resonance point. On the other hand, in CASE-B, the inertial force of the model distinctively enhances the peak regarded as corresponding to the second

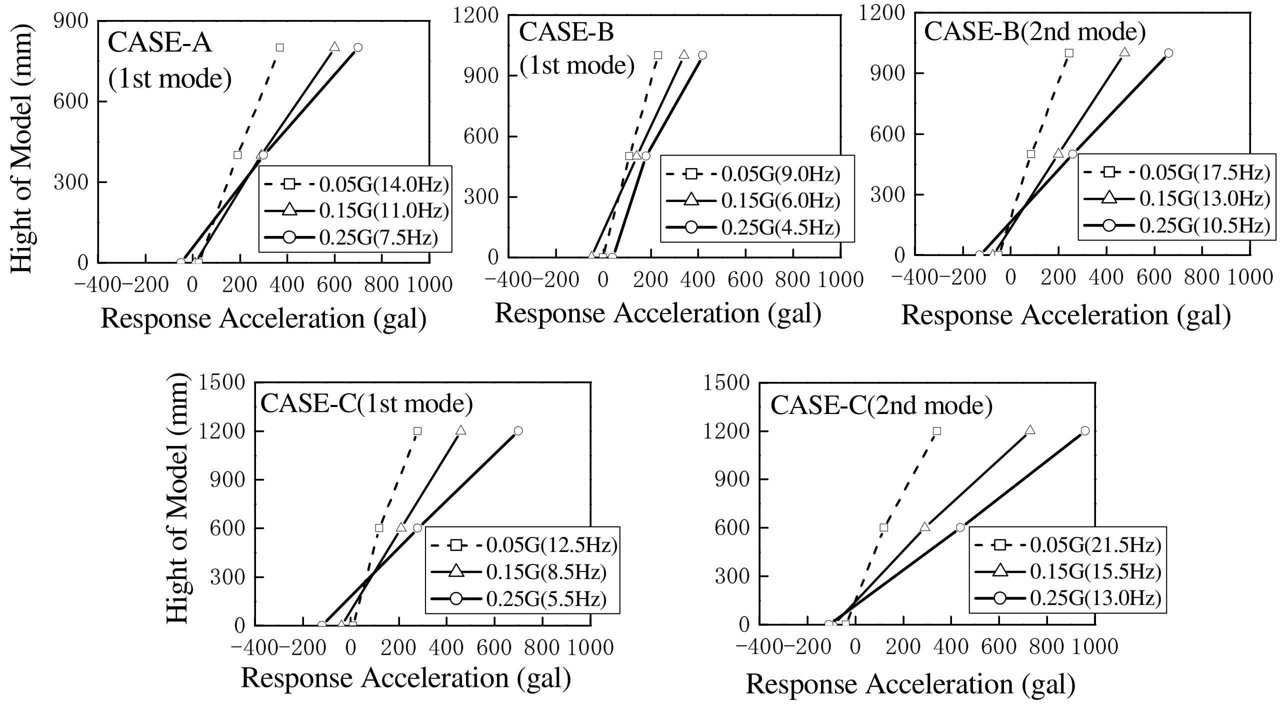


Fig.8 Vibration Mode of Model

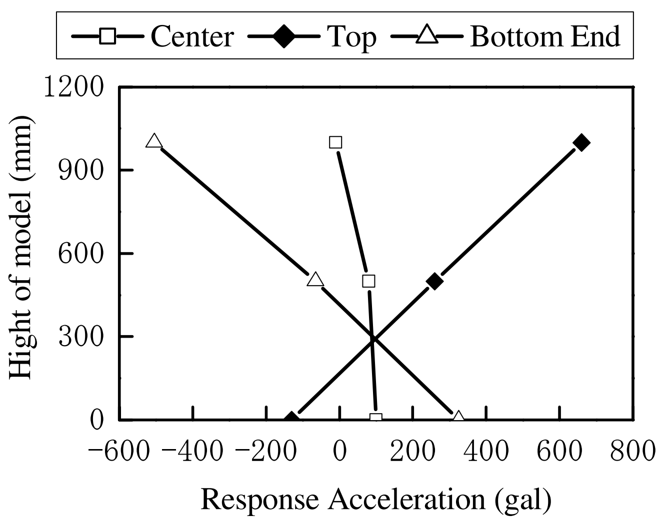


Fig.9 Vibration Modes of 0.25G (CASE-B)

resonance point of the model; response acceleration also increases.

Figure 8 shows the vibration modes of each model corresponding to their natural frequencies. As in Figure 4, indicated acceleration is relative acceleration. The first and second resonance modes are the rocking response modes around the center of rotation at the bottom end of the model.

The second resonance point of CASE-B shown in Figure 5 indicates that response acceleration does not

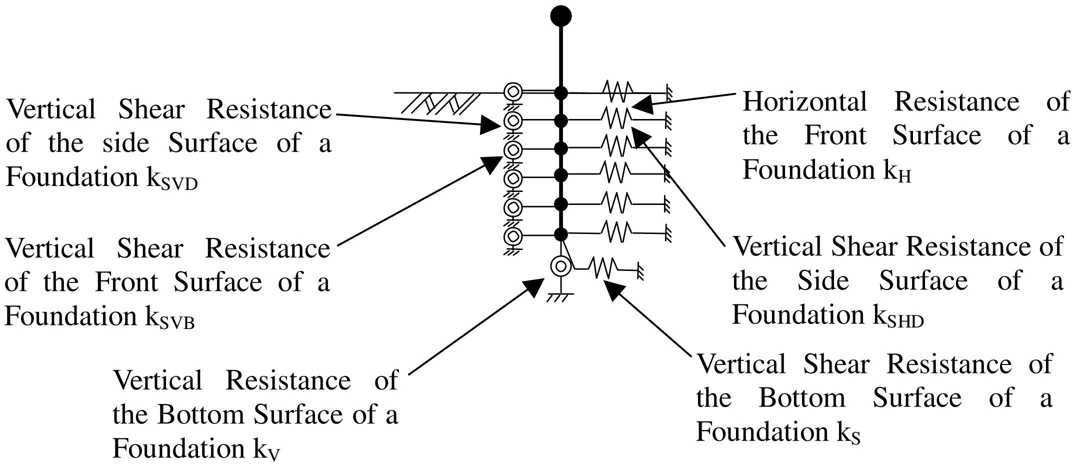


Fig.10 Analysis Model

Table.3 Coefficients of Subgrade Reactions(MN/m^3)

Symbol	Coefficients of Subgrade Reactions	Symbol	Coefficients of Subgrade Reactions
k_H	1084	k_{SHD}	650
k_V	1084	k_{SVB}	325
k_S	325	k_{SVD}	325

depend on input acceleration, and that response acceleration is larger at the bottom end of the model than at the center. Figure 9 shows the vibration modes for the input acceleration of 0.25 G, observed when the response acceleration reaches the maximum at the top end, in the center, and at the bottom end of the model. Due to phase differences, these vibration modes differ from the second vibration mode for CASE-B shown in Figure 8.

MODAL ANALYSIS

Figure 10 shows the analytical model used for modal analysis of the model. Modal analysis using static young's modulus of deformation (E_{50}=30MN/m^2) was performed. Table 3 shows the coefficient of subgrade reaction used this analytical model. These were calculated based on Japanese design standards (e.g. JRA 2002). In results, the all calculated natural frequency is higher than the experimental one. It is considered that this cause appears effects of non-linearity of the ground as input acceleration increases. Therefore, the averaged ground shear strain investigated by calculated shear deformation from resonance curves of ground shown in Figure 3. Degradations of shear modulus were calculated using these averaged strain of ground based on current study referring to kuribayashi (1975). Figure 11 shows the shear modulus degradations of ground in CASE-A. Experimental and analytical results are compared in Figure 12. In CASE-B, which the embedded depth is the shallowest, the analytical value is approximately equal to the experimental value. On the other hand, the analytical value of other cases is higher than the experimental one. The experimental value is not to agree with analytical value as embedded depth is longer. It is assumed that effects of dynamic interactions between rigid column type model foundations and ground aren't considered.

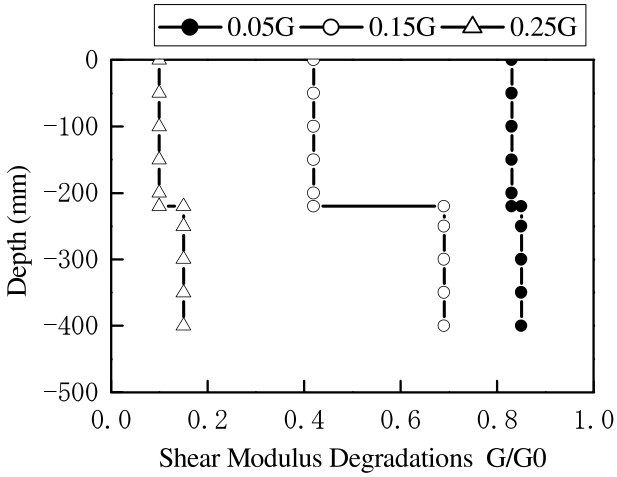


Fig.11 Shear Modulus Degradations of Ground

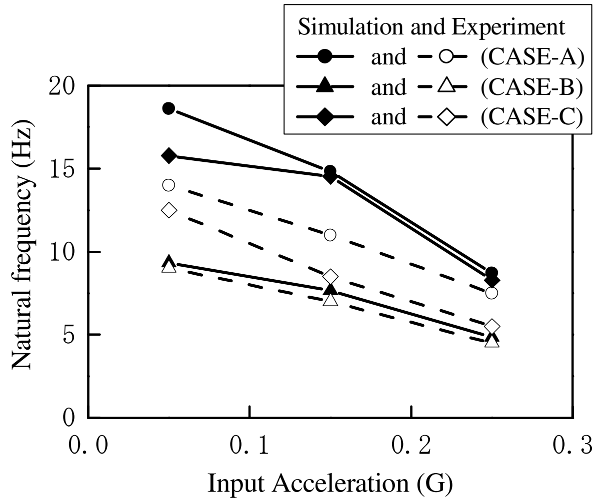


Fig.12 Comparison of Natural Frequencies

CONCLUSIONS

Shaking table tests were conducted for various rigid column type foundations model with different embedded depths and height from ground surface. The following results were obtained:

(1) When input acceleration increases, the rate of decrease of the natural frequencies of the model and the ground are approximately equal.

(2) A seismic isolation effect is observed when the natural frequency of the model is significantly smaller than that of the ground.

(3) When the input acceleration increases, a phase difference affects the vibration of the model, with the emergence of complex vibration modes.

(4) This experimental results agree approximately with analytical value, which was considered effects of non-linearity of the ground.

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