K03/3

Experimental Studies of Topographical Effect on Ground Motion

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1 INTRODUCTION

When performing seismic design of nuclear facilities that are constructed adjacent to mountainous terrain, it is necessary to take into consideration the topographical effect on ground motions. Many analytical researches concerning topographical irregularity (Wong and Jennings, 1975) have been investigated in the past, however, the majority were restricted to two dimensional investigation. Also, regarding experimental researches (Kasai, et al., 1987), not many examples are available because of the difficulties of experimental technique. This paper describes the topographical effects on ground motions based on shaking table tests which were conducted by using reduced models of simplified mountain topography including the effect of three dimensional aspect. Furthermore, Finite Element Method (FEM), which is often applied when topographical effects are investigated in seismic design, was used for verifying the correlation with the experiment.

2 METHOD OF EXPERIMENT

Four reduced models (hereafter called specimen) are adopted for the shaking table tests as shown in Fig.1. To confirm the basic vibration characteristics of the mountainous topography, the shape of the specimens are simplified. Model 1 is a flat surfaced model which is used as a basic type. Models 2 and 3 are single and twin ridged models which are used to evaluate the fundamental dynamic behavior of two dimensionally idealized topography. Model 4 is composed of three ridges, aiming at the investigation of three dimensional topographical effects through the comparison with the test results of other models. Photo 1 shows the entire view of Model 4. In the present study, the surroundings of the specimen are considered as free boundary, since the assumption of free boundary can better clarify the various conditions and the influence of the boundary can be kept relatively small by making the specimen large.

A silicon rubber, which is low in stiffness and damping, was newly developed for the material of the specimen. The reduced ratios of the principal physical quantities are shown in Table 1. The scale of length is 1/3000 and the time scale is approximately 1/10. The physical properties of the silicon rubber are shown in Table 2 together with those of the assumed site.

The excitation frequency is 2 Hz to 60 Hz, and a stationary excitation with constant amplitude of acceleration is employed. The excitations are in the two horizontal directions, namely, SV (X direction) and SH (Y direction). About 40 accelerometers are installed on and in the specimen.

3 EXPERIMENT RESULTS

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3.1 Two dimensional topographical model

Figs.2 to 5 show response amplifications from 5 to 60 Hz due to unit input motion. The results are shown at the center of the surface of specimen considering the position where the reactor building will be constructed. The response amplifications of Model 1 show the peaks at the 14 Hz, 24 Hz and 33 Hz. These peaks are corresponding to the 2nd, 3rd and 4th natural frequencies of the specimen due to the finite depth of the specimen. The influence of the mountainous topography is indicated by the difference between the Model 1 (solid line) and Models 2 and 3 (broken line). An evaluation is conducted focusing on the results of higher than 20 Hz, because a fundamental frequency of a planning reactor building is approximately 5 Hz which corresponds to 50 Hz in the present shaking table tests, and because a three dimensional behavior of the specimen due to the horizontally finite boundary is recognized in the frequency range lower than 20 Hz.

It is found at response amplifications that the influence of the mountainous topography changes depending on the frequency, and that the influence becomes smaller as the frequency increases. In the case of SV excitation, the influence of mountainous topography in Model 3 is more definite than that in Model 2. In the case of SH excitation, the response amplification of Model 2 is uniformly smaller than that of Model 1 at the center of the specimen.

3.2 Three dimensional topographical model

Model 4 has the configuration composed of Model 2 and Model 3. Therefore, the results of Model 4 at the center of specimen in X and Y direction of excitation are compared with those of corresponding the direction of excitation in Model 2 and Model 3 as shown in Figs.6 and 7. Also, the ratios of response amplification at the center of Models 2 and 3 to Model 4 are shown in Fig.8.

From these results, it is found that the vibration characteristics of Model 4 in X direction are close to those of Model 3 for SV excitation in the whole frequency range. The vibration characteristics of Model 4 in Y direction are close to those of Model 3 for SH excitation in the frequency range lower than around 45 Hz, and close to those of Model 2 for SV excitation higher than 45 Hz. It should be emphasized that the vibration characteristics of Model 4 of both directions of X and Y are almost the same as those of Models 2 and 3 for SV excitation in the frequency range higher than around 45 Hz.

4 SIMULATION ANALYSIS

4.1 Analysis conditions

A two dimensional FEM analysis is applied in order to clarify the influence of the specimen boundary. In addition, the influence of the mountainous topography is analytically confirmed. The subjects of analysis were the SV and SH excitations to Models 1 to 3.

A FEM analysis model of Model 2 is shown in Fig.9 as one example. The bottom of the model is fixed, and the division of elements were done so that 60 Hz could be transmitted. Also, the value of material properties used for the analysis was obtained from vibration experiment of test pieces that was conducted separately.

4.2 Analysis results

Fig.10 shows the response amplifications obtained by the experiment and its comparison with the analysis. In the frequency range higher 20 Hz the response amplification and resonance frequency of the analysis simulate well with the results of the experiments. In these frequency range it can be seen that the specimen has two dimensional behavior.

Figs.11 to 13 show the response amplification of various points on the specimen surface at two specific frequencies, 20 Hz and 40 Hz.

As regards Model 1 of Fig.11, it is recognized on both results of experiment and analysis that the distribution of response amplitude at 40 Hz becomes uniform because of less influence of boundary compared with that at 20 Hz. This indicates that an influence of boundary decreases to evaluate more easily an effect of mountainous topography as a frequency increases.

Also, with the Models 2 and 3 indicated in Figs.12 and 13, those with higher frequency has better agreement with the experiment and analysis. Regarding the change in response amplification in line with the slope of the hill, a little by little change is noted in the higher frequency of both SV and SH excitations, and with the SV excitation it is very noticeable that the amplitude becomes large at the top of ridge. Also, the response amplifications are more influenced by the excitation direction (SV and SH) than by the shape of topography (Models 2 and 3).

5 CONCLUSIONS

The shaking table experiment was conducted by using specimens of the small-scale topographical model made of silicon rubber in order to evaluate the effect of two and three dimensional mountainous topography on ground motion. Also, the vibration characteristics of the specimen and influence of the boundary were checked by two dimensional FEM analysis, and the influence of the mountainous topography was analytically confirmed. The conclusions are as follows:

(1) From the experiment result of the two dimensional topographical model it is noticed that the influence of mountainous topography changes depending on the frequency and on the location of measurement, and a tendency is seen that an influence decreases as a frequency increases. Also, it is found that the difference of response characteristics between excitation directions SV and SH of each Model is more significant than that between Models 2 and 3 of each excitation direction.

(2) The results of the experiment indicate that it is almost appropriate to simplify a three dimensional topographical model as a SV problem of a two dimensional topography.

(3) The specimen is acting in a two dimensional behavior with the exception of frequency lower than around 20 Hz where the three dimensional behavior of the specimen occurs. And it is confirmed that the two dimensional FEM analyses correspond well with the experimental results of the two dimensional topographical model higher than 20 Hz. Also it is recognized that the influence of the mountainous topography could be evaluated adequately by experiments, because the influence of specimen boundary decreases as a frequency increases.

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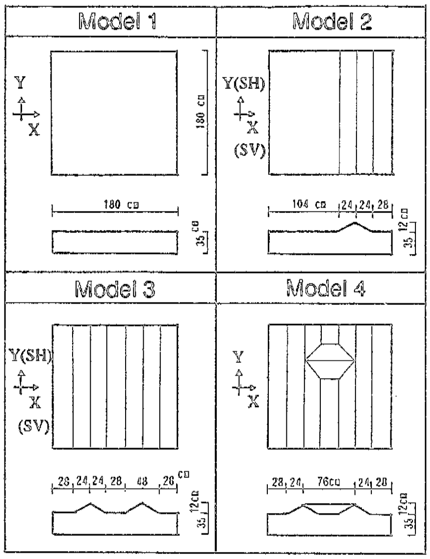


Fig. 1 Type and shape of specimen

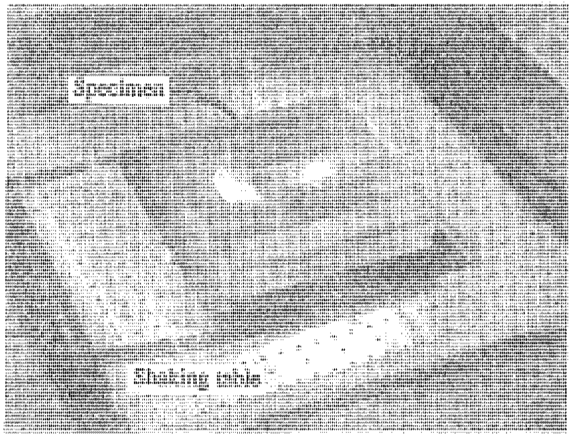


Photo 1 Three dimensional topographical model (Model 4)

Table 1 Reduced ratio of principal physical quantity

Physical quantity	Symbol	Reduced ratio
Length	l	l_p / l_m 3000
Young's modulus	E	E_p / E_m 212000
Density	ρ	ρ_p / ρ_m 2.57
Frequency	f	f_p / f_m 1/10.45

Table 2 Physical properties of specimen and assumed site

	S-wave velocity [m/s]	Density [g/cm^3]	Poisson's ratio	Young's modulus [kg/cm^2]	Damping factor [%]
Specimen	6.73	0.974	0.45	1.307	4.7Hz - 2.56 21.6Hz - 4.20 51.8Hz - 6.48
Assumed site	2000	2.5	0.36	277000	3

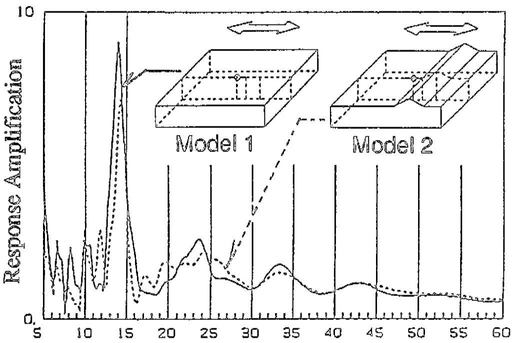


Fig. 2 Experimental response amplification of Models 1 and 2 for SV-excitations

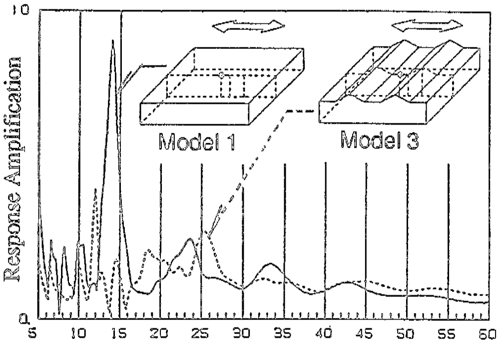


Fig. 3 Experimental response amplification of Models 1 and 3 for SV-excitations

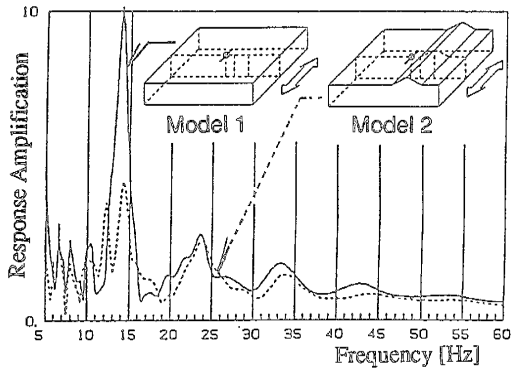


Fig. 4 Experimental response amplification of Models 1 and 2 for SH-excitations

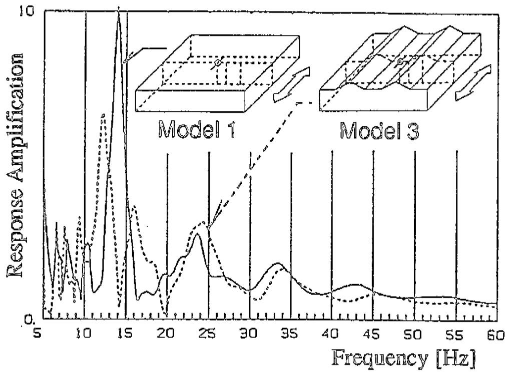


Fig. 5 Experimental response amplification of Models 1 and 3 for SH-excitations

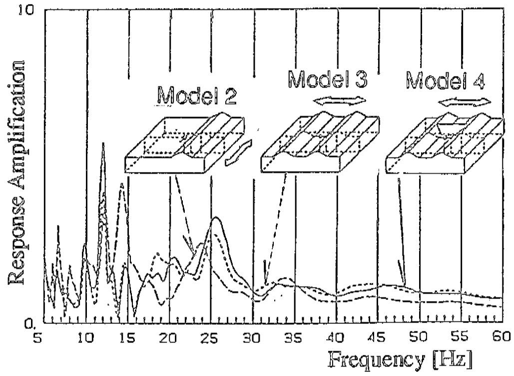


Fig. 6 Comparisons of experimental response amplifications (Model 2 : SH, Model 3 : SV Model 4 : X-direction)

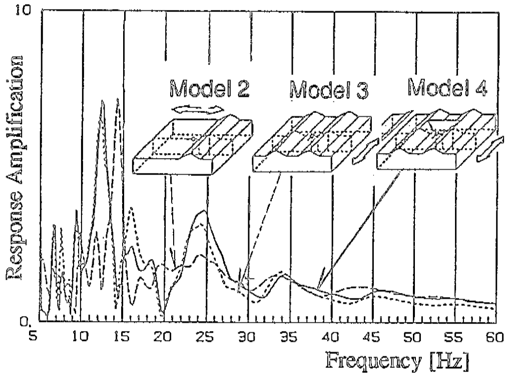
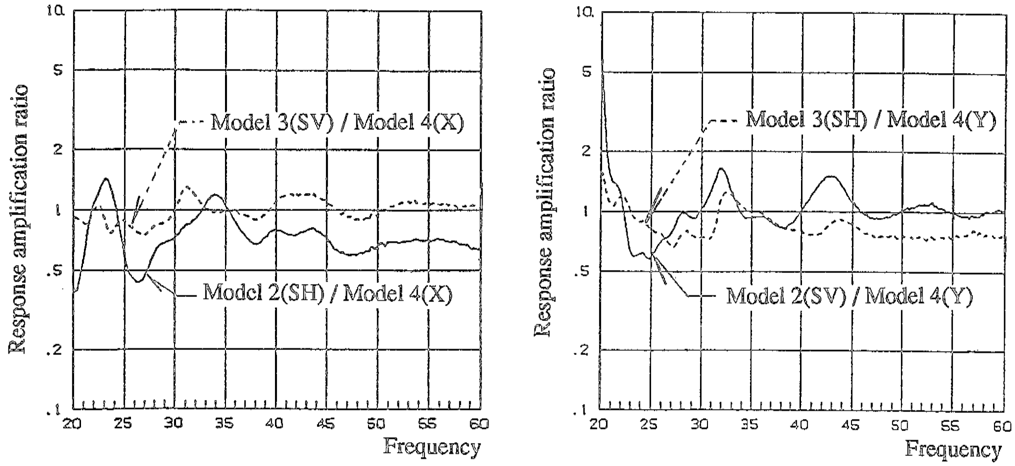


Fig. 7 Comparisons of experimental response amplifications (Model 2 : SV, Model 3 : SH Model 4 : Y-direction)



(a) Model 2(SH) / Model 4(X)
Model 3(SV) / Model 4(X)

(b) Model 2(SV) / Model 4(Y)
Model 3(SH) / Model 4(Y)

Fig. 8 Response amplification ratios for Models 2 and 3 to Model 4

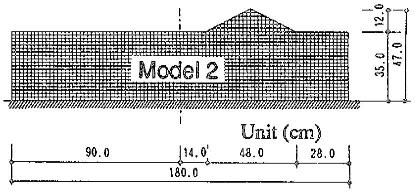


Fig. 9 Analytical model for 2-D FEM (Model 2)

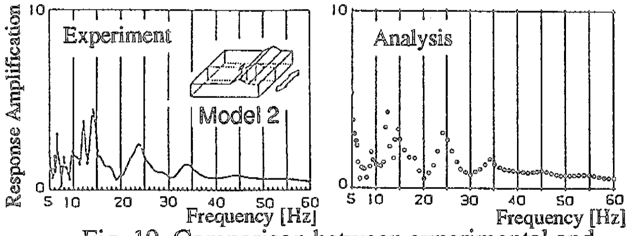
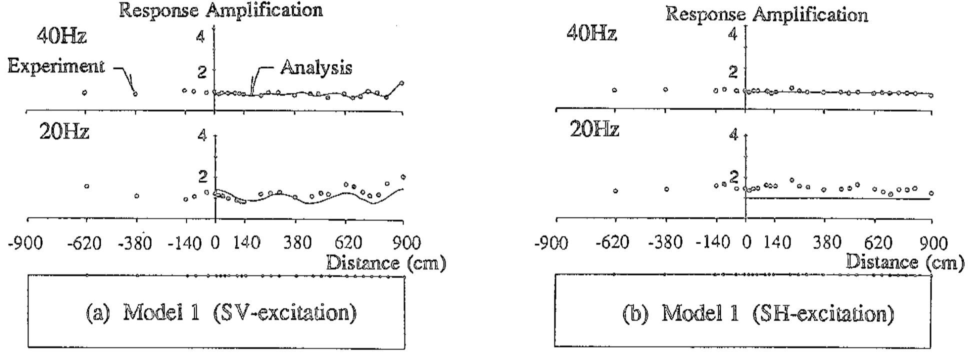


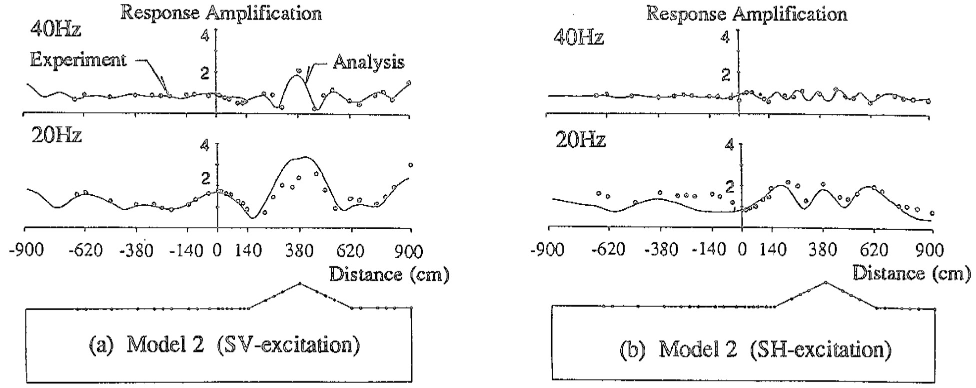
Fig. 10 Comparison between experimental and analytical response amplification



(a) Model 1 (SV-excitation)

(b) Model 1 (SH-excitation)

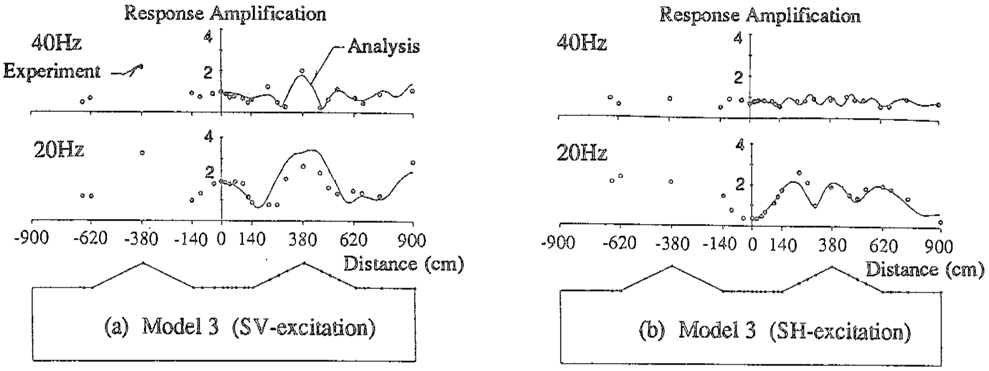
Fig. 11 Comparison between experimental and analytical response amplification for Model 1



(a) Model 2 (SV-excitation)

(b) Model 2 (SH-excitation)

Fig. 12 Comparison between experimental and analytical response amplification for Model 2



(a) Model 3 (SV-excitation)

(b) Model 3 (SH-excitation)

Fig. 13 Comparison between experimental and analytical response amplification for Model 3