SEISMIC SIMULATION ANALYSIS OF A BWR TYPE REACTOR BUILDING BY SOIL-BUILDING INTERACTION MODEL

by

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SUMMARY

The records of Miyagiken-oki earthquake of June 12, 1978 obtained at the Fukushima Nuclear Power Station site were used for the investigation of soil-building interaction analysis.

Seismic simulation analysis was performed using a soil-building interaction model to examine the adequacy of the analytical method used in current design practice. The results of this simulation analysis showed reasonably good agreement with the recorded ones, and consequently proved that the analytical model was appropriate to evaluate the soil-building interaction effect.

INTRODUCTION

An observation system of earthquake motions at the Fukushima Nuclear Power Station of Tokyo Electric Power Company has been in operation for the past several years. Measuring instruments for the Unit No. 6 are installed on major floor levels of the reactor building and at some soil layers below the base mat level.

The Miyagiken-oki earthquake of June 12, 1978 (magnitude 7.4) occurred off the coast of Miyagi Prefecture (about 130 km north-east of the plant site). Three components (NS, EW, UD) were recorded by each instrument, and the peak acceleration values of each component had been larger than those ever observed at the Unit No. 6.

Seismic simulation analysis was performed using a soil-building interaction model developed by the authors[1], to examine the adequacy of the model in current design practice by comparing the computed results with recorded ones.

OUTLINE OF THE REACTOR BUILDING

The site of Fukushima Nuclear Power Station is located on the coastline facing the Pacific Ocean in Fukushima Prefecture in mid-northern part of the main island of Japan.

A total of six units were already in operation and from them, the Unit No. 6 located on the north end was the subject of this study (See Fig. 1.).

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The reactor building of the Unit No. 6 (a BWR-MARK II type, 1100MWe) is approximately 72.6m high from the bottom of base mat (OP-4.0m) to the top (OP+68.6m).

The building is founded on mudstone at elevation of 17m below the ground level (OP+13.0). The plan dimensions of the building is 68.5m x 68.3m at the lower portion and 45.5m x 42.5m at the upper portion.

The reactor building is made of reinforced concrete and is structurally isolated from the adjacent turbine building and the radwaste building. The turbine building is located on the sea side and Unit No. 5 is placed on the south.

EARTHQUAKE RECORDS

Seismographs are installed in the building and in the soil under the building. Accelerometers of moving coil type are installed to record the horizontal motions of N-S direction and E-W direction and the vertical motion of U-D direction. They are located under the roof (P-1), on the refueling floor (P-2), top of base mat (P-3) and in the soil (P-4) (See Fig. 1).

In this study, the earthquake records of N-S component were investigated. The maximum acceleration values recorded by Miyagiken-oki earthquake are shown in Fig. 2, together with the response analysis results obtained at the design stage using a design earthquake normalized to 180 Gal. According to the comparison between these values, it is seen that design values are approximately ten times larger than the recorded ones. Fig. 3 shows the transfer functions obtained from the analysis of the records by ARM (Auto Regressive Model Fitting). Both the first predominant period and it's modal damping factor found in transfer functions to the base mat tend to be smaller than those to the soil.

ANALYTICAL METHOD

The simulation analyses were performed for evaluating soil-structure interaction effects by using the lumped mass interaction model called "Lattice Model" as shown in Fig. 5, where the building structure is idealized as three vertical cantilevers (the outer, inner and shield walls) with the shear and bending stiffnesses and as the masses lumped at each floor level. Three cantilevers are connected each other by horizontal floor springs. Two displacement degrees of freedom (horizontal translation and rotation) are considered for each mass point of the building (See Fig. 4.).

The plan dimensions of the soil included in the model is 5 x B in parallel direction and B in perpendicular direction (B is width of building base mat). The depth of the model is taken approximately 1.2 times the width of the base mat.

The soil is divided into vertical columns representing "distant soil", "intermediate soil", "near soil" and "sub soil". Each soil column is idealized as a vertical shear beam with lumped masses. Soil columns are interconnected by horizontal springs to consider the interaction of each column. Only horizontal translation degree of freedom is considered for each mass of soil. Rocking springs representing soil reaction against the foundation rotation are attached to the bottom of the building base mat. Modal damping factors are assumed to be proportional to strain energy as suggested by whitman[2]. In order to express the energy dissipation through the boundary of the model, the viscous boundaries are introduced for each side and the bottom of the model shown in Fig. 5. The physical constants and damping factors of the building and the soil are listed in Table 1, which were determined after several trial computation.

ANALYTICAL RESULT

Comparisons of computed and recorded transfer functions are shown in Fig. 6. The computed transfer functions corresponding to the building (P-1/P-3, P-2/P-3) match closely to those of the recorded ones.

According to these results, both have the same first peak frequency of 3.4 Hz and amplification factor of 9.2 and also have the same second peak frequency of 8.2 Hz and amplification factor of 16.

But, there is a little differences between computed and recorded results of transfer functions to the point P-4 in the soil layer (P-1/P-4, P-2/P-4, P-3/P-4) around 4.5 Hz in the frequency domain. Except around 4.5 Hz, both are in reasonably good agreement as a whole.

Dynamic response analyses were conducted in the frequency domain using the transfer function of the model and the Fourier amplification function of the recorded motion at the base mat. These comparison of the response analysis are shown in Figs. 7 and 8.

The maximum response acceleration and acceleration time histories agree closely to recorded ones at each level.

Comparison of acceleration response spectra with 5% damping factor are shown in Fig. 9. It may also be seen that the spectra match the recorded ones closely. The good agreement in these values is an encouraging indication of the analytical procedure used in these studies.

CONCLUSION

The results of the simulation analyses showed reasonably good agreement to the recorded ones with respect to the distribution of maximum acceleration values, acceleration time histories and corresponding response spectra. These results suggest that the lumped mass interaction model used herein is very effective to evaluate the soil-building interaction effects.

With the scarcity of appropriate opportunity to check analytical methods for computing responses of nuclear power plants under strong earthquakes, the records obtained at the Fukushima Nuclear Power Station site of Miyagiken-oki earthquake of June 12, 1978 are very useful in investigating the adequacy of current design practice.

ACKNOWLEDGEMENT

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REFERENCES

1. Tanaka, H. & Nakahara, M., "Investigation of Soil-Building Interaction Behavior of a BWR Plant during Miyagiken-oki Earthquake of 1987", 7th WDEE Sept., 1980
2. Whitman R. V., "Soil-Sturcture Interaction, Seismic Design for Nuclear Power Plants", MIT Press 1970

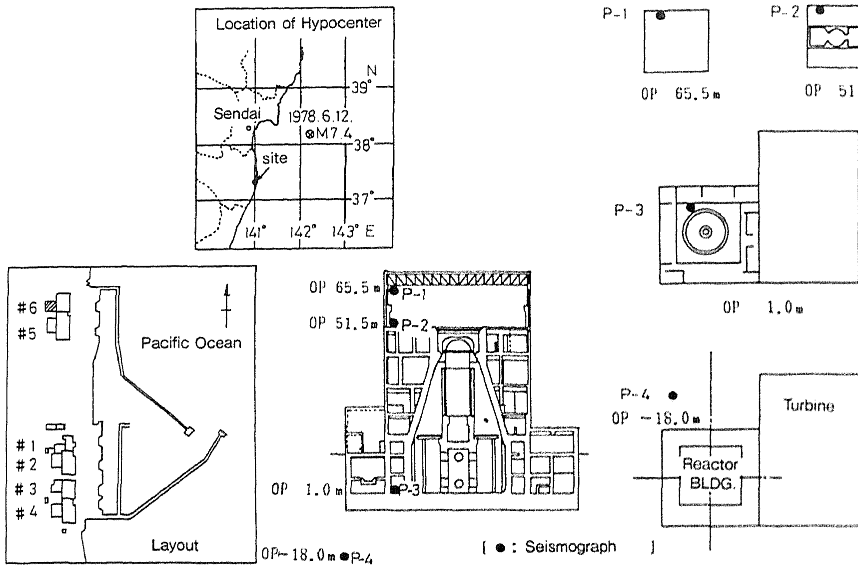


Fig. 1 Location of Hypocenter and Seismograph

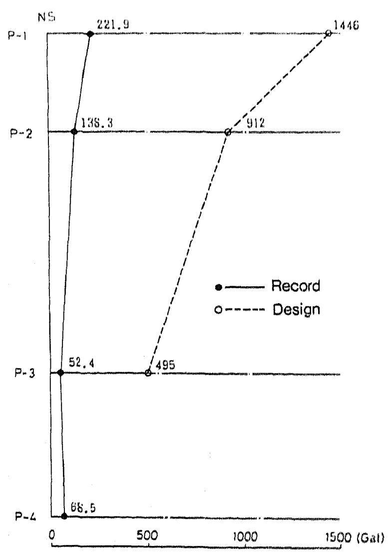


Fig. 2 Maximum Acceleration Values (NS)

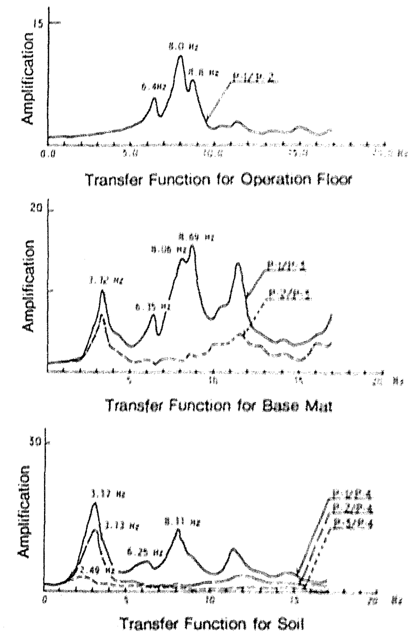


Fig. 3 Transfer Function of the Record

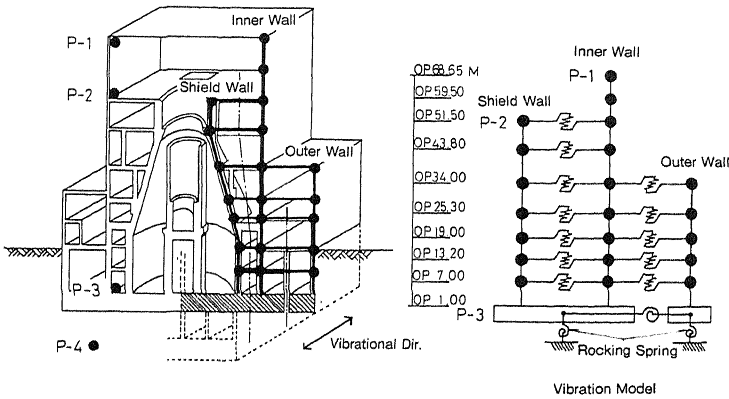


Fig. 4 Building Model

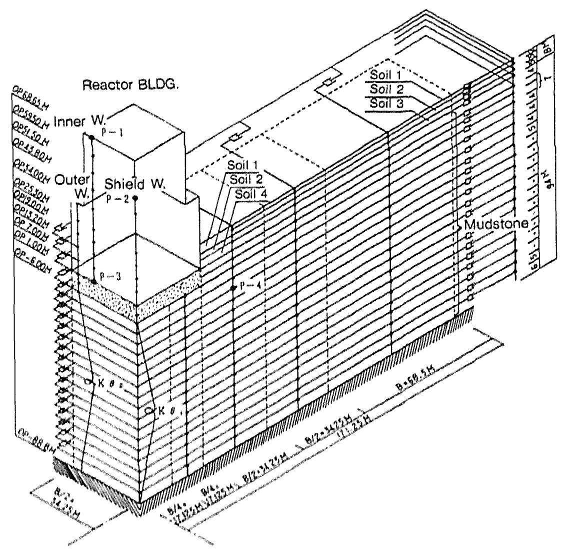


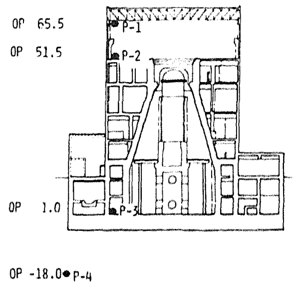
Fig. 5 Soil-Building Interaction Model

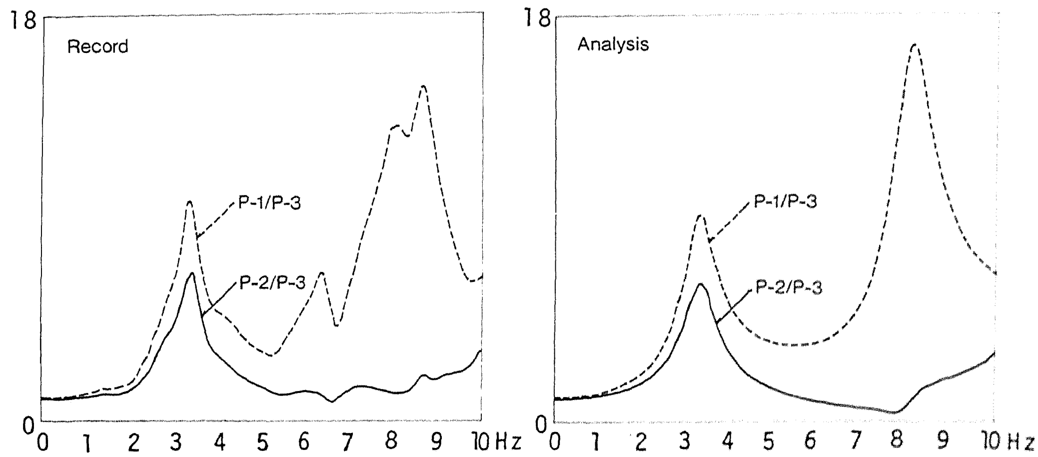
Table. 1 Physical Constant and Damping Ratio

Soil					
	V_s m/s	G t/cm²	ν	ρ t/m³	h
Soil 1	120	0.250	0.294	1.7	0.10
Soil 2	180	0.562	0.294	1.7	0.10
Soil 3	270	1.265	0.294	1.7	0.10
Soil 4	380	2.375	0.294	1.7	0.10
Mud Stone	550	5.247	0.480	1.7	0.08

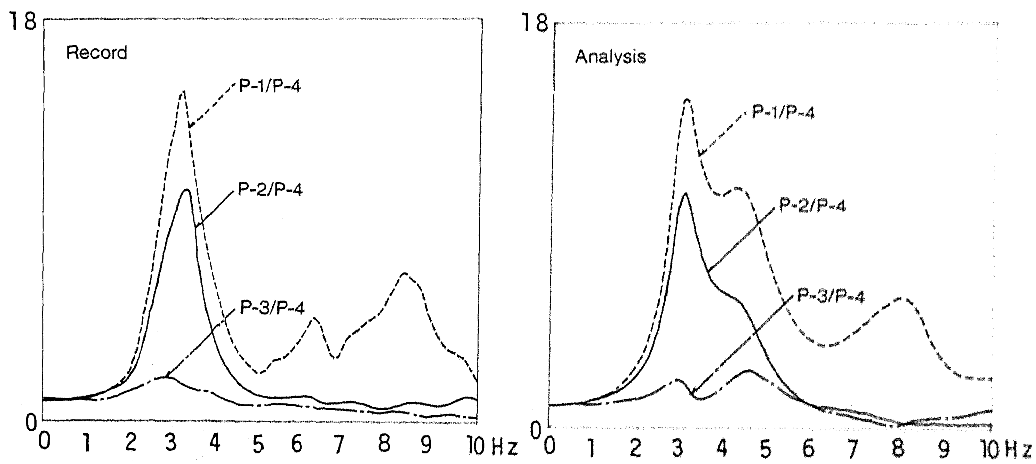
Building			
RC	E	300	t/cm²
	ν	1/6	
	h	0.04	
Rocking Spring	$K\theta_1$	0.906×10^{13}	t·cm/rad
	h_1	0.16	
	$K\theta_2$	0.432×10^{12}	t·cm/rad
	h_2	0.16	

V_s : Velocity of Secondary wave
G : Shear Modulus
E : Young's Modulus
ν : Poisson Ratio
ρ : Unit Density
h : Damping Factor





(a) transfer function to the base mat



(b) transfer function to the soil

Fig. 6 Comparison of Transfer Function

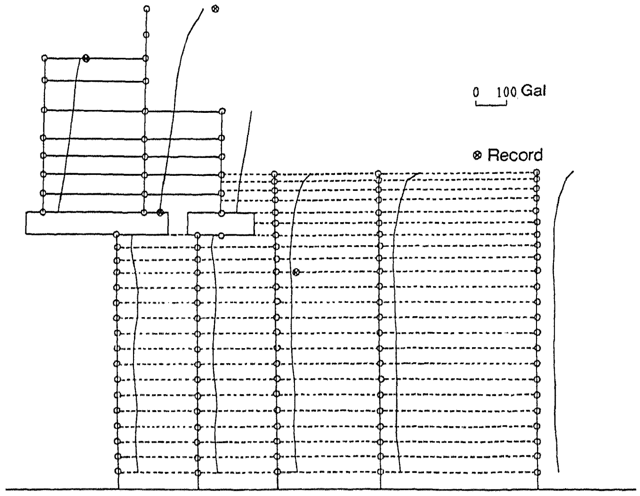


Fig. 7 Distribution of Maximum Acceleration Values

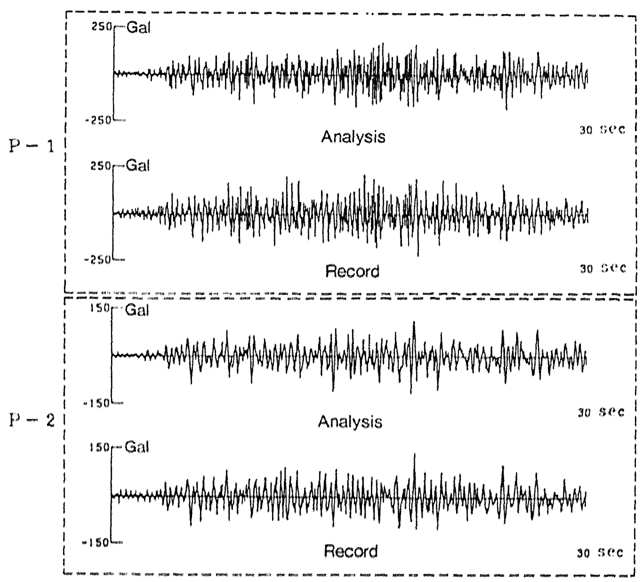


Fig. 8 Comparison of Acceleration Time Histories

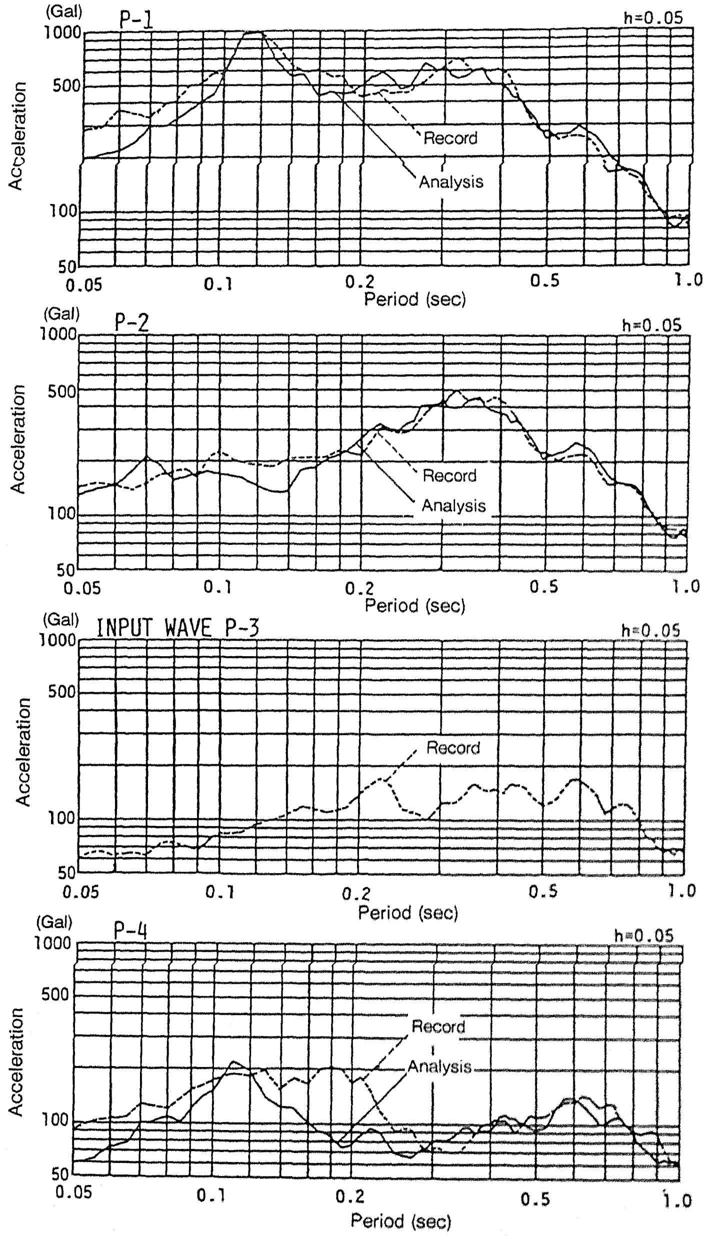


Fig. 9 Comparison of Acceleration Responce Spectra