

INVESTIGATION OF SOIL-BUILDING INTERACTION BEHAVIOR OF  
A BWR PLANT DURING MIYAGIKEN-OKI EARTHQUAKE OF 1978

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SYNOPSIS

Simulation analyses were performed of the acceleration records obtained at a BWR plant building during Miyagiken-oki earthquake of June 12, 1978. Acceleration record in the ground approximately 40m below the building was used as the input motion to the soil-building interaction model. The computed building responses were compared with the recorded acceleration time histories. The maximum accelerations, acceleration time histories and their response spectra at each level of the building were agreed very well. Recorded motions were simulated by a lumped mass soil-building interaction model with damping ratio similar to the values commonly used for the building and higher damping values for soil.

INTRODUCTION

In the earthquake resistant design of a nuclear power plant, it is very important to evaluate adequately the soil building interaction, since the reactor building is usually a very rigid structure and its dynamic behavior during an earthquake is influenced by the interaction with surrounding soil. Considerable amount of theoretical and experimental investigations have been undertaken to-date, in the field of soil building interaction study. However, since moderately large earthquake records obtained at nuclear power plants are very limited, the investigation of the analytical method comparing with actual acceleration records as described herein should be very valuable to assure the adequacy of the method of earthquake response analysis. On June 12, 1978 a strong earthquake of Magnitude 7.4 occurred off coast of Miyagi prefecture in northern Honshu, the main island of Japan (Fig. 1). The earthquake caused considerable damage to buildings and urban systems in and around Sendai city, located near the epicenter.

Acceleration records were obtained at Unit No.1 of Fukushima nuclear power station located 100km south of Sendai city. There was no damage to the nuclear plant. The maximum acceleration recorded at the basement floor was approximately 80 gal. Simulation analyses were performed to investigate the dynamic behavior and damping characteristics of the reactor building-soil interaction system.

OUTLINE OF THE REACTOR BUILDING

The site of Fukushima nuclear power station is located on the coastline facing the Pacific Ocean. The ground level of the site was prepared to 10m above sea level by excavation of a hill originally about 35m in height. The Unit No.1, a BWR plant, 460MWe output, was completed in 1970 and started commercial operation in 1971. The reactor building is approximately 58m high from the bottom of basement mat to the top. The building is founded on mudstone at elevation -4m which is 14m below the ground level (see Fig. 1). The

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plan dimensions of the building is about 42m square at lower portion and 42m x 31m at upper portion.

The building is made of reinforced concrete from the basement to the 5th floor (the refueling floor) and of structural steel with metal siding above the refueling floor. The reactor building is structurally isolated from adjacent turbine building and radwaste building. The total weight of the reactor building including equipments is approximately 70,000 tons.

#### EARTHQUAKE RECORDS

Seismographs were installed in the building and in the soil under the building. Accelerometers of moving coil type were installed to record the horizontal motion of N-S direction parallel to the coastline. The acceleration records used for the simulation analyses were obtained from the seismographs AH-1~AH-4 and AH-10 as shown in Fig. 1 below. The earthquake records and the analysis of small earthquake recorded earlier have been reported in previous paper (Ref. 1).

#### METHOD OF ANALYSIS

##### (1) Mathematical Model

Simulation analyses were performed using the soil-building interaction model as shown in Fig. 2, where the mass of the building is lumped in each floor level, and building structure is idealized as two vertical cantilevers having the shear and bending stiffness equivalent to outer and inner wall. Two cantilevers are interconnected by horizontal floor springs. Two degrees of freedom, horizontal translation and rotation are considered for each mass point of the building.

The plan dimensions of the soil included in the model is  $4.5B$  ( $B$  is width of building foundation) in parallel direction and  $1.5B$  in orthogonal direction to the earthquake ground motion. The soil is divided into vertical columns representing distant soil, intermediate soil, near soil, adjacent soil and soil under the building. Each soil columns are idealized as lumped mass vertical shear beam. Soil columns are interconnected by horizontal springs to include the interaction of each column. Rocking springs equivalent to soil reaction to the foundation rotation are attached to the building foundation. Only horizontal translation is considered for each mass point of soil.

##### (2) Evaluation of Soil Stiffness

Soil columns are divided into 5m (partly 4m) elements in vertical direction considering the shear wave velocity. Shear stiffness of vertical shear beams and axial stiffness of horizontal springs per unit are evaluated by the elastic modulus, poisson's ratio and length between mass point. Rocking springs attached to the foundation are evaluated by static 3-dimensional analysis of reactor building and surrounding soil.

##### (3) Damping Values

Different damping values are assigned to concrete, structural steel,

rocking spring, backfill soil, surface layer and mudstone. Modal damping proportional to strain energy were assumed after the method by Biggs & Whitman (Ref. 2). Structural constants of the building and the soil properties are listed in the Table-1, which were all determined after many trial repetitions to obtain the most suitable to simulate the recorded earthquake behaviors. It is noted that soil damping factors of 10~12% are somewhat higher than those adopted in the actual design analysis.

#### RESULTS OF ANALYSIS

##### (1) Eigen Value Analysis

To examine the vibrational characteristics of soil-building interaction model, the eigen values and modal damping ratio are shown in Table-2. Mode shapes of three important mode are shown in Fig. 3. The 1st mode is the fundamental mode of soil with fixed bottom boundary. The 3rd mode is the fundamental mode of the building. The 5th mode corresponds to the whipping of steel structure above refueling floor.

##### (2) Simulation Analysis

The results of time history response analysis are shown in Figs. 4 and 5. The maximum response acceleration agreed closely to recorded acceleration at basement floor, 3rd floor and 5th floor. Computed acceleration time histories at basement floor and 3rd floor show good agreement to recorded accelerations.

Comparison of acceleration response spectra with 5% damping for computed and recorded time histories are shown in Fig. 6. Response spectra agree closely at basement, 3rd floor and 5th floor. Response spectra at roof truss shows good agreement in the frequency range less than 4Hz. The discrepancy of the response spectrum of roof truss in frequency range higher than 4Hz may be due to 3 dimensional effect, torsional vibrations or other local amplifications in the structural components.

#### CONCLUSION

Recorded accelerations are simulated using a lumped mass soil-building interaction model. The adequacy of the analytical method including mathematical model and damping values is demonstrated. The damping values for soil used in the analysis are higher than those from material damping.

#### ACKNOWLEDGEMENT

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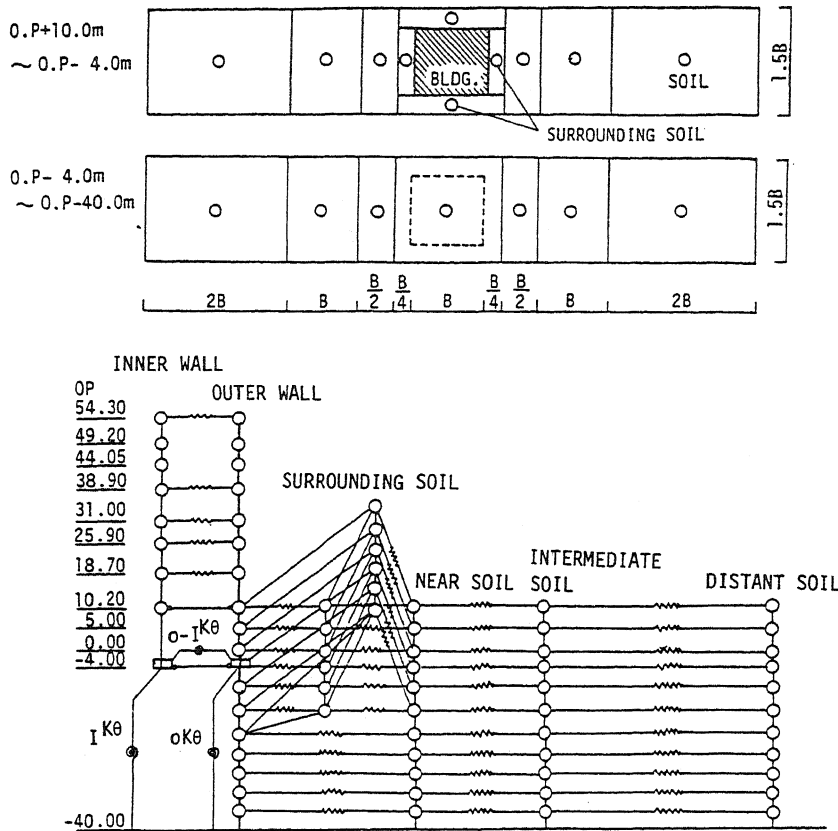


FIG.-2 SOIL-BLDG. INTERACTION MODEL

TABLE-1 PROPERTIES

ELEVATION (m)	SOIL				SURROUNDING SOIL				BLDG.	
	$\rho$ t/m <sup>3</sup>	$V_s$ m/s	$\nu$	$h$	$\rho$ t/m <sup>3</sup>	$V_s$ m/s	$\nu$	$h$		
OP 10.0~5.0	1.7	180	0.45	0.10	1.7	160	0.45	0.12	STEEL	E 2100 t/cm <sup>2</sup>
OP 5.0~0.0	1.7	270	0.45	0.10	1.7	240	0.45	0.12		$\nu$ 1/3
OP 0.0~-1.23	1.7	530	0.42	0.10	1.7	320	0.42	0.12		h 0.02
OP -1.23~-40.0									RC	E 235 t/cm <sup>2</sup>
										$\nu$ 1/6
									h 0.05	

$\rho$  ; density ,  $V_s$ ; velocity of shear wave  
 $\nu$ ; poisson's ratio ,  $h$ ; damping ratio ,  $E$ ; young's modulus

TABLE-2 RESULTS OF EIGEN VALUE ANALYSIS

MODE NO	NATURAL PERIOD	PARTICIPATION	MODAL DAMPING	MODE NO	NATURAL PERIOD	PARTICIPATION	MODAL DAMPING
1	0.396 (SEC)	-4.24	10.08 (%)	6	0.163 (SEC)	1.71	11.32 (%)
2	0.322	-1.82	10.15	7	0.159	1.06	10.27
3	0.260	2.46	8.84	8	0.153	0.15	10.47
4	0.210	0.42	8.12	9	0.137	-0.11	10.27
5	0.182	-1.69	6.98	10	0.109	1.35	10.40

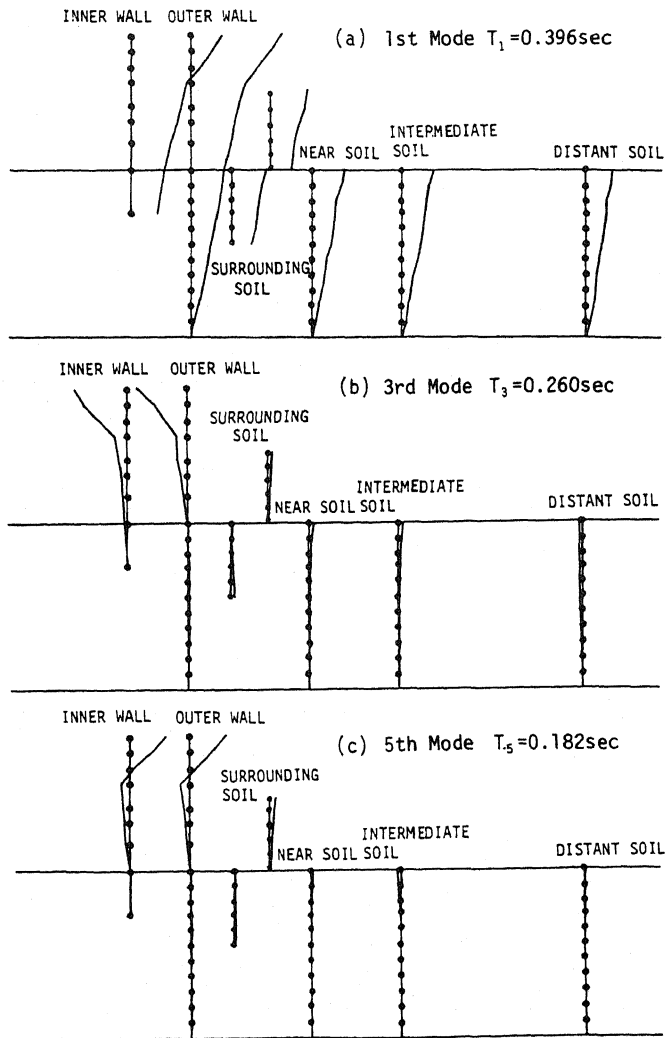


FIG.-3 NATURAL VIBRATION MODE

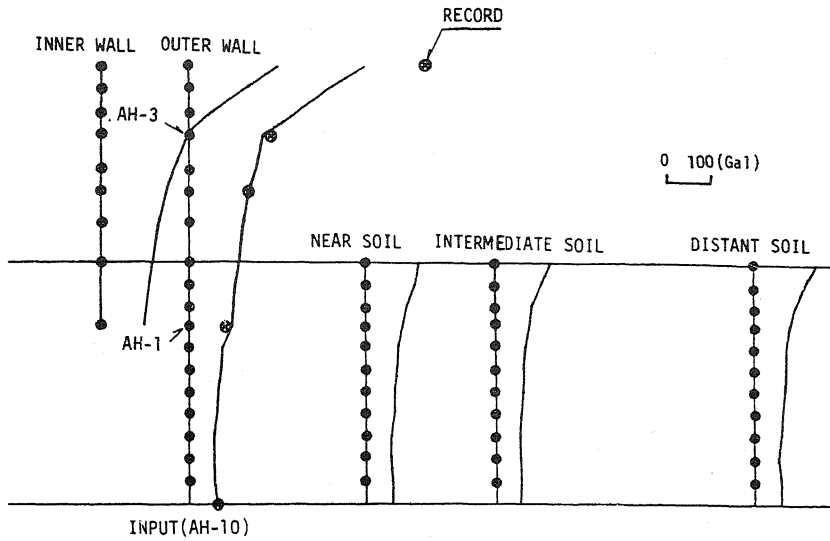


FIG.-4 DISTRIBUTION OF MAX. RESPONSE ACCELERATION

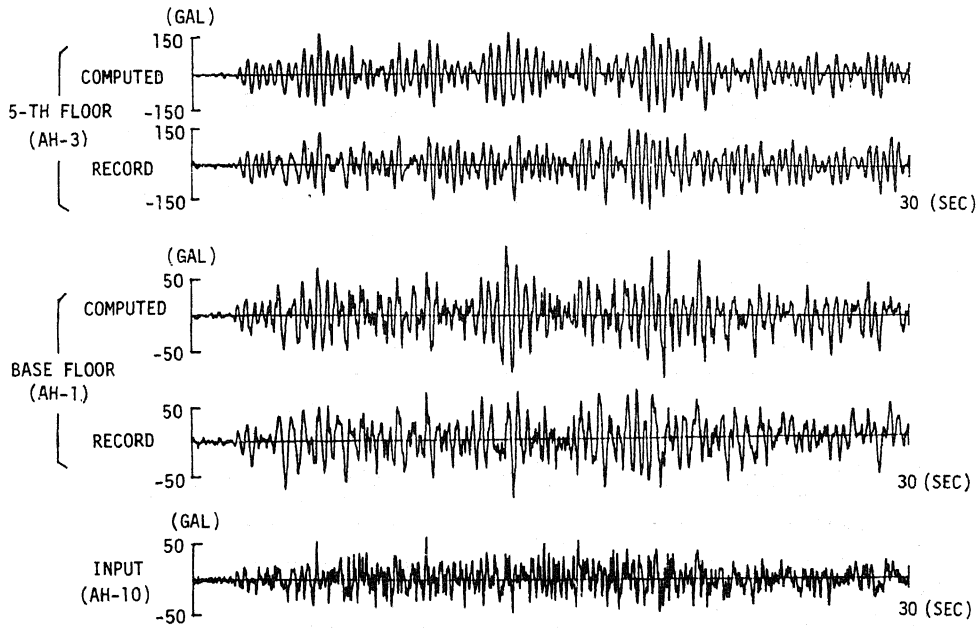


FIG.-5 COMPARISON OF ACCELERATION TIME HISTORY

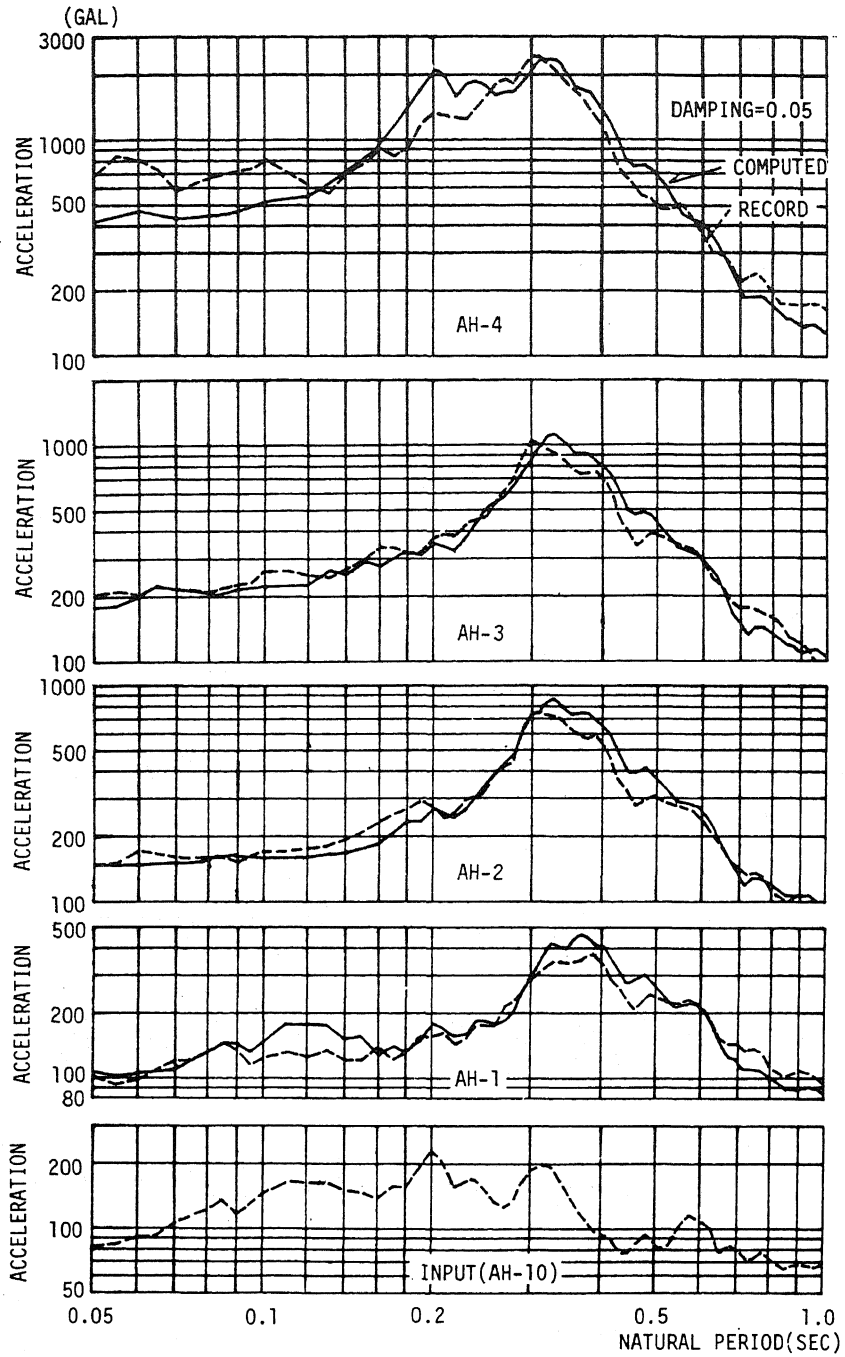


FIG.-6 ACC.RESPONSE SPECTRA