Seismic Simulation Analysis of a Nuclear Reactor Building Using Observed Earthquake Records

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1. Introduction

In this paper, to verify the effectiveness of dynamic response analysis technique, simulation analyses using observed records of five different earthquakes are performed for the reactor building of Unit 6 of the Fukushima Daiichi Nuclear Power Plant.

A sway-rocking model(SR model) with embedment effect is adopted for the analyses. The model properties of the structure and soil springs are estimated by using the results of the forced vibration test. The soil properties are estimated by referring to the observed records of free field and the soil test data. The flow of the process for establishing the model properties is shown in Fig.1.

2. Modeling of Reactor Building

The superstructure of reactor building is modeled by a lumped mass system considering bending and shear deformations. Each mass is assumed to be located at the floor level and connected by vertical beam elements which represent the bending-shear stiffness of earthquake-resistant walls, which are composed of the shield wall(S/W), the inner box wall(I/B), and the outer box wall(O/B), and by horizontal shear spring elements which represent the shear stiffness of floor slabs. Properties of masses, beams and springs are initially determined by the design drawings and specifications. Then, they are modified by referring to results of the forced vibration test.

3. Modeling of Soil-Structure Interaction

The effect of soil-structure interaction(SSI) is evaluated by an SR model which can take into consideration the effect of embedment. That is, SSI is modeled by base soil springs and side soil springs. The base soil springs are determined by the wave propagation theory(Tajimi,1958, Sato,1983), and the side soil springs are determined by the Novak's theory(Novak,1978). The properties of the soil springs are modified by comparing the horizontal-rotational soil spring properties computed by the analysis model with those computed by the results of the forced vibration test.

4. Modeling of Soil

The soil properties of the free field are determined by the results of soil testings, and the damping ratios are set through the simulation analysis of earthquake observation based on the one-dimensional wave propagation theory. The soil properties used in the analyses are shown in Table 1.

5. Simulation Analysis of Forced Vibration Test

The analysis model for the forced vibration test is shown in Fig.2. The building, in order to evaluate the dynamic properties during the forced vibration test in detail , is modeled by lumped mass system with masses indicating out-of-plane vibration of I/B higher than the refueling floor at OP 51.5m. The effect of SSI is evaluated by the horizontal-rotational side soil springs, and sway-rocking base soil springs.

The analysis results of resonance curves of displacements at the refueling floor and basemat, when an excitation force of 1 ton is applied at the refueling floor of the S/W, are shown in Fig.3 comparing with test results. These figures show that the agreement of the analysis to the test data is very good up to about 10 Hz in the resonance curves.

6. Simulation Analysis of Earthquake Response

The earthquakes of which maximum acceleration at the basemat was over twenty gals and free field records were also obtained are selected for analysis. Five earthquakes were selected from those observed from 1978 to April 1987. The epicenters were ①East Off Kanto(Jul.23,1982), ②East Coast of Southern Tohoku(Jul.2,1983), ③East Off Southern Tohoku (Dec.19,1984), and ④,⑤East Off Fukushima Prefecture(Aug.12,1985 and Oct.14,1986) as shown in Fig.4. The location of seismographs are shown in Fig.5.

The analysis model is shown in Fig.6. The effect of SSI is evaluated by horizontal side soil springs and sway-rocking base soil springs. The basic concept of the seismic response analysis technique using an SR model with embedment effect(Nakai,1985) is shown in Fig.7. The ground motions recorded in free field are used as input motions. In calculating input motions to an SR model, the effect of excavation is taken into account in an approximate way by applying a shear force, which is calculated by the one-dimensional wave propagation theory, at the basemat. And the input motions at the side springs are calculated by the one-dimensional wave propagation theory also. The analysis is carried out in frequency domain because of the frequency dependence of soil springs.

An example of results obtained by using the East Off Kanto earthquake(July 23, 1982, JMA magnitude 7.0, focal depth 30km, epicentral distance 159km) are shown in Fig.8 to compare with the observed results. It is shown that seismic analysis results by the model modified by referring to the results of the forced vibration test agree well with observed results.

Finally, the calculated maximum acceleration responses of the building for five earthquakes are compared in Fig.9 with observed ones. The mean value of the ratios of the theory and observation is 1.07, and the standard deviation(SD) is 0.212. It is shown that analysis results agree well with observed ones for all five earthquakes.

7. Conclusions

Seismic simulation analyses of the nuclear reactor building using observed records of five different earthquakes were performed. It is shown that calculated results agree quite well with observed ones once analysis model is tuned to fit the data of the forced vibration test.

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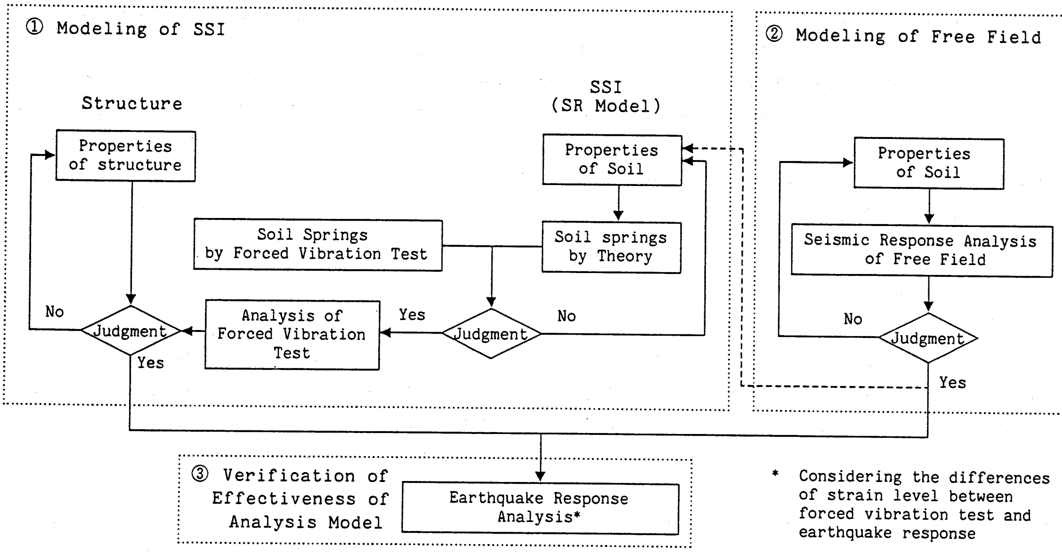


Fig. 1 Analysis Flow

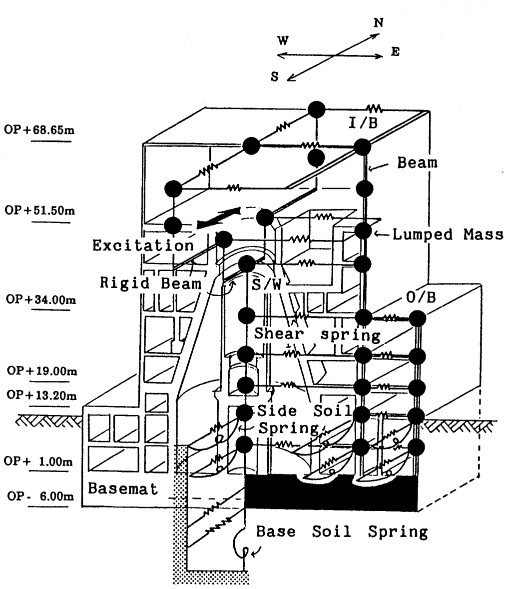


Fig. 2 Analysis Model for Forced Vibration Test

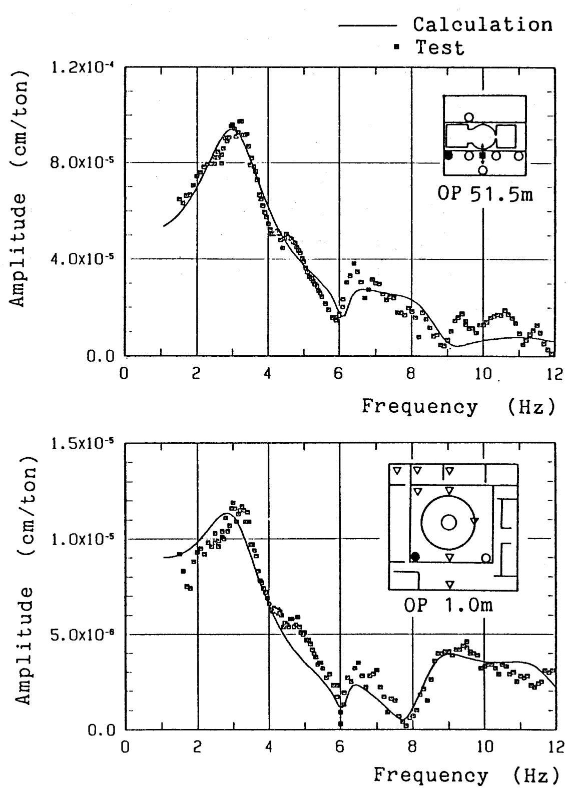


Fig. 3 Comparison of Resonance Curve

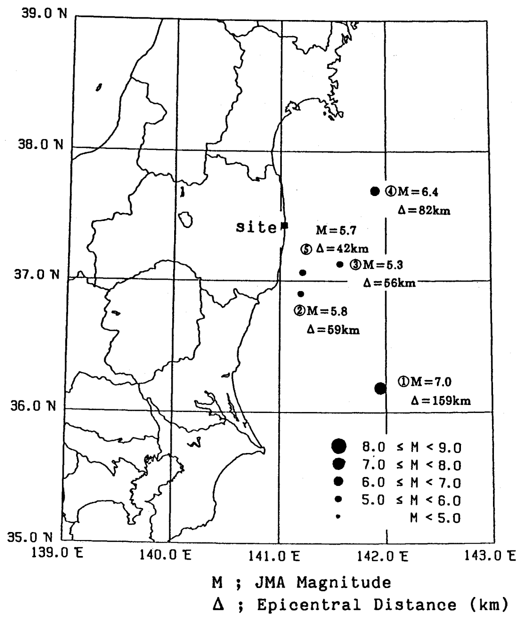


Fig. 4 Epicenters of Earthquakes

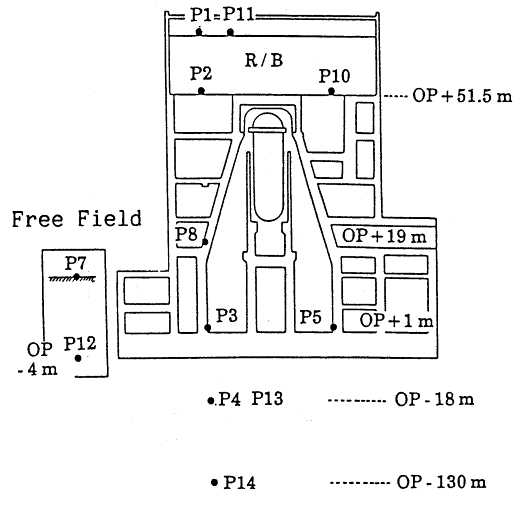


Fig. 5 Location of Seismographs

Table 1 Soil Properties

Depth GL(m)	Unit Weight (t/m^3)	S-wave Velocity (m/s)	Poisson's Ratio	Damping Ratio (%)
0	1.7	120	0.294	10
-2	1.7	180	0.294	10
-5	1.7	270	0.294	10
-8	1.7	360	0.294	10
-12	1.7	550	0.480	3.5

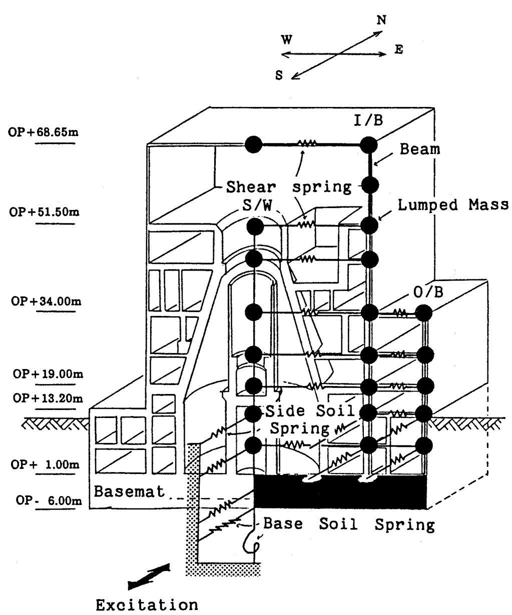


Fig. 6 Analysis Model for Earthquake Response

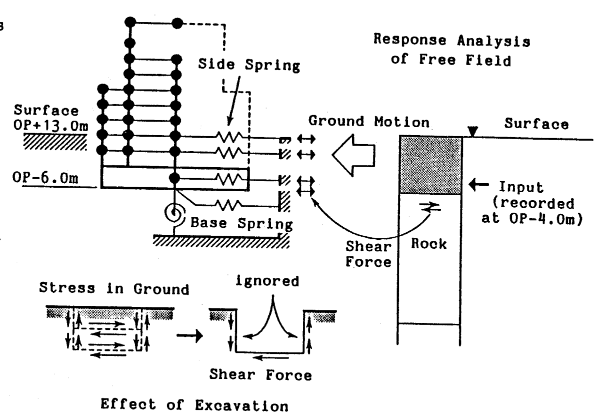
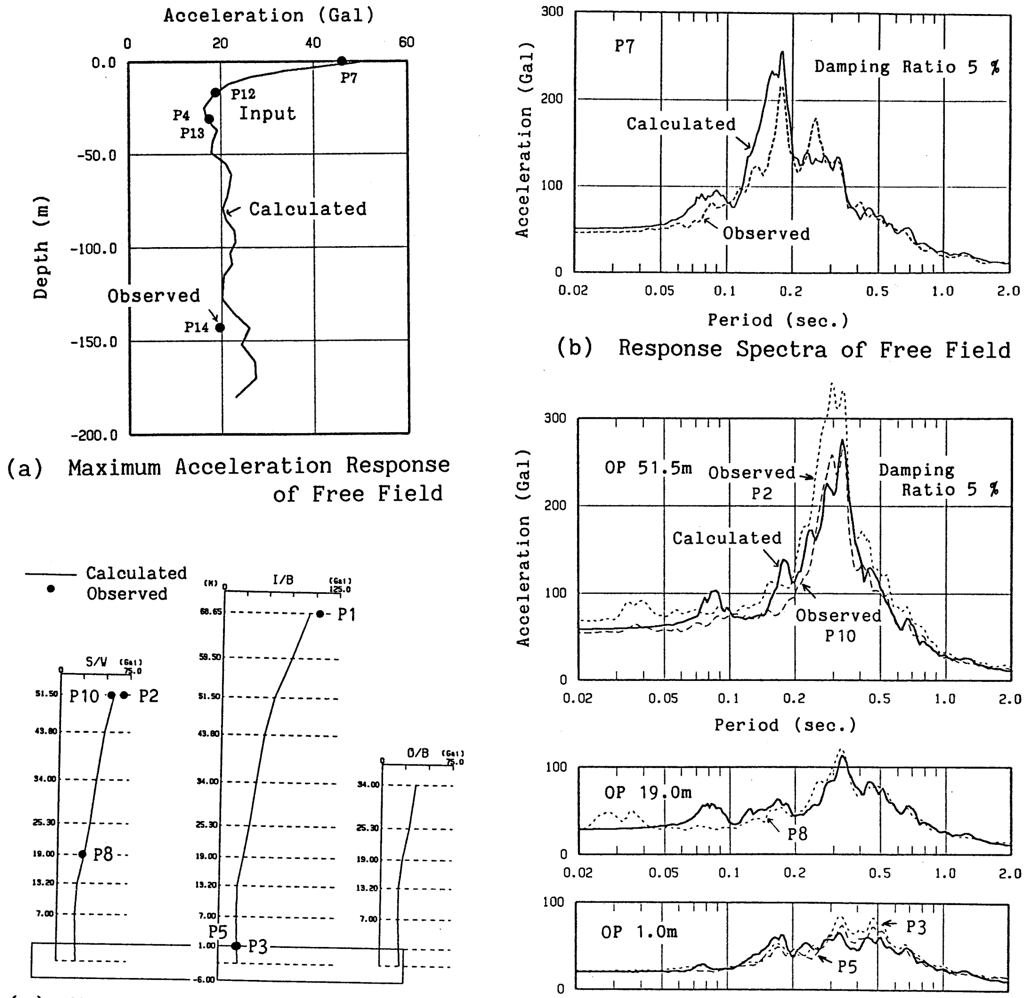


Fig. 7 Analysis Method by SR Model with embedment effect



(a) Maximum Acceleration Response of Free Field

(b) Response Spectra of Free Field

(c) Maximum Acceleration Response of Building

(d) Response Spectra of Building

Fig. 8 Analysis Results of East Off Kanto Earthquake(July 23,1982)

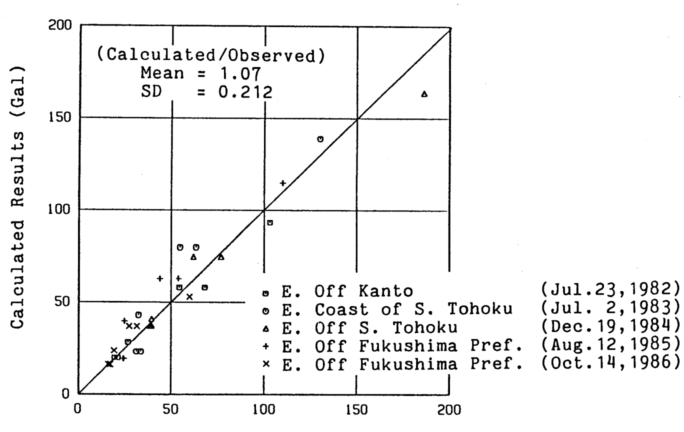


Fig. 9 Comparison of Maximum Acceleration Response of Building