



Study on horizontal and vertical seismic response model of BWR-type reactor building

Kai Y.⁽¹⁾, Iizuka S.⁽²⁾

(1) Shimizu Corporation, Japan

(2) Nuclear Power Engineering Corporation, Japan

ABSTRACT: An accurate dynamic response analytical model of BWR-type reactor buildings for a set of horizontal and vertical seismic motion is proposed. The model considers the flexibility of the base-mat and spatial configure of the roof truss. The accuracy of the proposed model is examined from the response analysis using the model with a set of horizontal and vertical seismic input motion.

INTRODUCTION

In Japan, vibration models of reactor buildings for horizontal ground motion have been studied and examined through many simulation analyses of forced vibration tests and earthquake observations of actual buildings. Recently vertical vibration models have been also proposed. And now it is possible to establish a reliable horizontal and vertical vibration model on the basis of multi-lumped mass and column element model. However, the vibration models for simultaneous horizontal and vertical input motion have not been so much studied as the single input motion models.

In this paper, the horizontal and vertical seismic response model of a BWR-type reactor building including soil-structure interaction effect is numerically studied, by comparing the dynamic characteristics of (1) multi-stick lumped mass model with a flexible base-mat and grid roof truss model and (2) multi-stick lumped mass model with a rigid base-mat and one beam roof truss model.

ANALYTICAL MODELS AND CONDITIONS

outline of reactor building

A typical BWR Mark-II type reactor building is selected for study, as shown in Fig. 1. The building is mainly made of reinforced concrete and its dimensions are 75.5m high and 80.5m x 81.5m rectangle at the base-mat. The total weight of the building is about 293,000ton. The main seismic structural members of the building are the circular shield wall (SW), the inner box wall (IW) and the outer box wall (OW). The thickness of the walls and the slabs are also

shown in Fig. 1. The roof trusses at the top of the building are made of steel. Main-trusses and sub-trusses are orthogonally arranged in horizontal plane.

The building is assumed to be built on a surface of rock outcrop.

analytical models

The following two horizontal and vertical seismic response models are surveyed here, as shown in Fig. 2.

(1) Multi-stick lumped mass model with a flexible base-mat and grid roof truss model

The building is represented by a three stick model with lumped masses and column elements, which is horizontally divided to three main seismic walls (SW, IW and OW) as shown in Fig. 3. Each seismic wall is modeled by column elements, which have axial, bending moment and shear stiffness, and masses concentrated in every floor levels. Some walls (such as pool girders) connected horizontally between seismic walls are modeled by vertical springs between the walls. Slabs connected horizontally between seismic walls are modeled by horizontal springs between the walls.

Considering the flexibility of the base-mat, the interactive complex soil springs are attached to the bottoms of the three sticks. These springs are obtained by the linearization of the interactive frequency dependent complex soil springs estimated by the theory of elastic half-space wave propagation theory (Tajimi's vibration admittance method).

The roof truss is modeled by a grid-shaped lumped mass model connected at the top of the building and the main and sub trusses are modeled by beam elements. The effect of rotation of the top floor on the response of the roof truss is considered using the rigid beam. The out-of-plane deformation of the flange wall is modeled by the stick model to consider its effect on the response of the roof.

The accuracy of this model has been examined by the comparison the horizontal and vertical response with that of the finite element model.

(2) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss model

Although the flexible base-mat model is accurate, it has much more degree of freedom than the traditional lumped mass beam element model usually used in the seismic design of the Japanese nuclear power plant. Multi-stick lumped mass model with a rigid base-mat and one beam roof truss model is proposed as the simplified model to be used in the seismic design.

The building model is the same with (1), but the base-mat is assumed to be rigid. The soil stiffness, therefore, is represented by a single complex spring which is easy to be computed. The roof truss is modeled in the one beam lumped mass model connected at the top of the building, which represents the main trusses. The effect of the out-of-plane deformation of the flange wall is considered with the horizontal and rotational spring at the end of the truss.

analytical conditions

(1) Material properties of building

The material properties of concrete and steel used are shown in Table 1.

(2) Material properties of soil

Two kinds of soil conditions are considered as shown in Table 2. One is

shear wave velocity $V_s=500\text{m/s}$ for a soft rock site and the other is $V_s=1000\text{m/s}$ for a hard rock site.

(3) Input ground motion

The input horizontal and vertical motions are artificial waves fitting to smoothed acceleration response spectra, of which the input acceleration time histories (maximum acceleration: horizontal 267.4 Gal, vertical 172.1 Gal) and their acceleration response spectra are shown in Fig. 4.

ANALYTICAL RESULTS

Free vibration analyses and seismic response analyses are conducted for the above models. The tendencies of the analytical results among the models are almost same in each case of two soil conditions. The results for the soil condition of $V_s=500\text{m/s}$ are mainly mentioned hereafter. Typical results are compared as follows;

(1) Fundamental natural period

Fundamental natural periods of vertical (roof truss) and horizontal (soil-structure interaction) vibration mode are compared in Table 3. The fundamental periods of the roof truss are a little different between the grid lumped mass model and the one beam lumped mass model. The difference of the first modal frequency is less than 15%. The fundamental periods of one beam lumped mass model is a little longer than the grid lumped mass model. The fundamental periods of the horizontal vibration mode are almost same between the models. The difference between the models is smaller in the result for the soil condition of $V_s=1000\text{m/s}$. This means the effect of the flexibility of the base-mat becomes smaller in the hard soil site.

(2) Maximum horizontal response acceleration

Maximum horizontal response accelerations (Hor. Acc.) of the models are compared in Fig. 5. The Hor. Acc. of the IW and SW in a rigid base-mat and one beam roof truss model are larger and the Hor. Acc. of the OW are smaller than those in a flexible base-mat and grid roof truss model. The Hor. Acc. of the roof in a rigid base-mat and one beam roof truss model nearly correspond to average values of those in a flexible base-mat and grid roof truss model.

(3) Maximum vertical response acceleration

Maximum vertical response accelerations (Ver. Acc.) of the models are compared in Fig. 6. The Ver. Acc. of the IW in a rigid base-mat and one beam roof truss model are larger and the Ver. Acc. of the OW and SW are smaller than those in a flexible base-mat and grid roof truss model. The Ver. Acc. of the roof in a rigid base-mat and one beam roof truss model nearly correspond to average values of those in a flexible base-mat and grid roof truss model.

(4) Maximum response shear force

Maximum response shear force (Max. Shear) of the models are compared in Fig. 7. The Max. Shear of the IW and SW in a rigid base-mat and one beam roof truss model are larger and the Max. Shear of the OW are smaller than those in a flexible base-mat and grid roof truss model. This is the same tendency which was shown in the result of maximum horizontal response acceleration. The Max. Shear of the roof in a rigid base-mat and one beam roof truss model nearly correspond to the sum of those in a flexible base-mat and grid roof truss model.

(5) Maximum response axial force

Maximum response axial force (Max. Axi.) of the models are compared in Fig. 8. The Max. Axi. of the IW in a rigid base-mat and one beam roof truss

model are larger and the Max. Axi. of the OW are smaller than those in a flexible base-mat and grid roof truss model. This is the same tendency which was shown in the result of maximum vertical response acceleration. The Max. Axi. of the SW in a rigid base-mat and one beam roof truss model are smaller than those in a flexible base-mat and grid roof truss model in the lower story. This is the same tendency which was shown in the result of maximum vertical response acceleration. But the Max. Axi. of the SW in the upper story are larger than those in a flexible base-mat and grid roof truss model.

(6) Floor response spectrum

Acceleration floor response spectrum (FRS) at EL50.5m (operating floor) of the circular shield wall and FRS at EL70.0m (top) of the inner box wall are compared in Fig. 9 and 10 respectively. The FRS of are compared between the two models. The difference of the floor response spectrum between a flexible base-mat and grid roof truss model and a rigid base-mat and one beam roof truss model is less than 30% at the hard rock site. The difference of the response, however, is more than 30% at the soft rock site.

CONCLUSIONS

An accurate dynamic response analytical model of BWR-type reactor buildings for a set of horizontal and vertical seismic motion is proposed. From the dynamic response analysis using the model, followings are concluded.

The multi-stick lumped mass models with flexible or rigid base-mat can reasonably represent the dynamic characteristics of the building. However, the case of the rigid base-mat tends to give a little greater values than the others.

Regarding the roof model, the one beam lumped mass model is adequate to estimate the maximum response stresses of the main truss. However, the frequency dependent characteristics are estimated better by the grid lumped mass model.

Acknowledgment

This work was carried out as a part of the "Study on advanced design for Light Water Reactor (LWR)" by Nuclear Power Engineering Corporation (NUPEC), under the sponsorships of the Ministry of International Trade and Industry (MITI) of Japan. The sponsorships and the cooperation and valuable suggestion by the members of the Committee on this study are acknowledged.

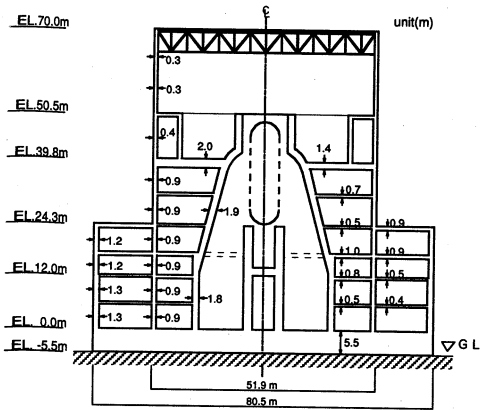


Fig. 1 Reactor Building (BWR Mark-II)

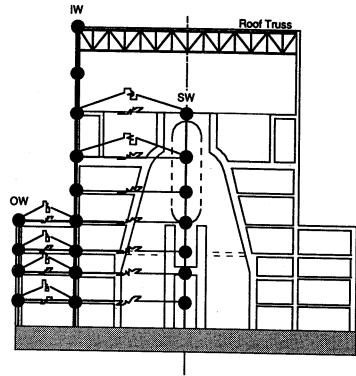
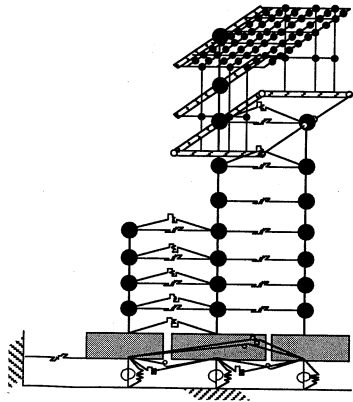
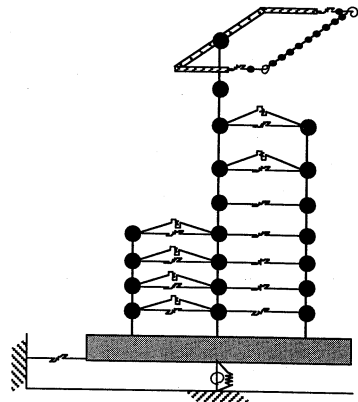


Fig. 3 Multi-Stick Model



(a) Multi-stick lumped mass model with a flexible base-mat and grid roof truss



(b) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.2 Horizontal and vertical simultaneous seismic response analysis models

Table 1 Material properties of building

Material	Concrete	Steel
Strength	300 kg/cm ²	-
Young's modulus	257 t/cm ²	2100 t/cm ²
Poison's ratio	0.167	0.33
Unit weight	2.3 t/m ³	7.85 t/m ³
Damping factor	0.03	0.02

Table 2 Material properties of soil

	500 m/s	1000 m/s
Shear wave velocity	500 m/s	1000 m/s
Young's modulus	12.4 t/cm ²	57.1 t/cm ²
Poison's ratio	0.42	0.40
Unit weight	1.7 t/m ³	2.0 t/m ³

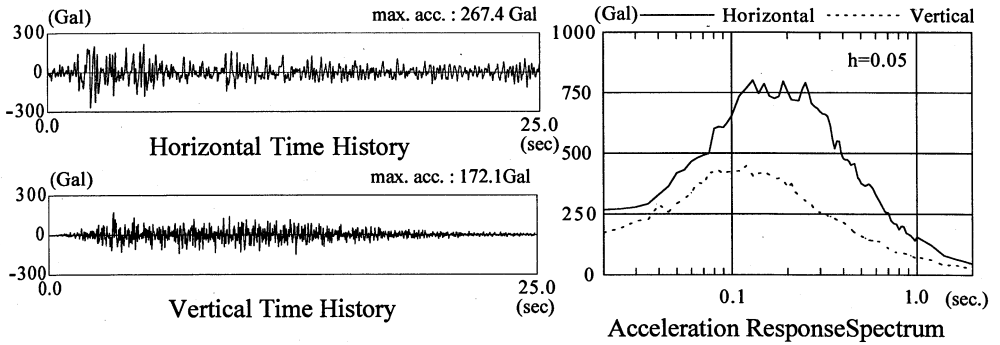
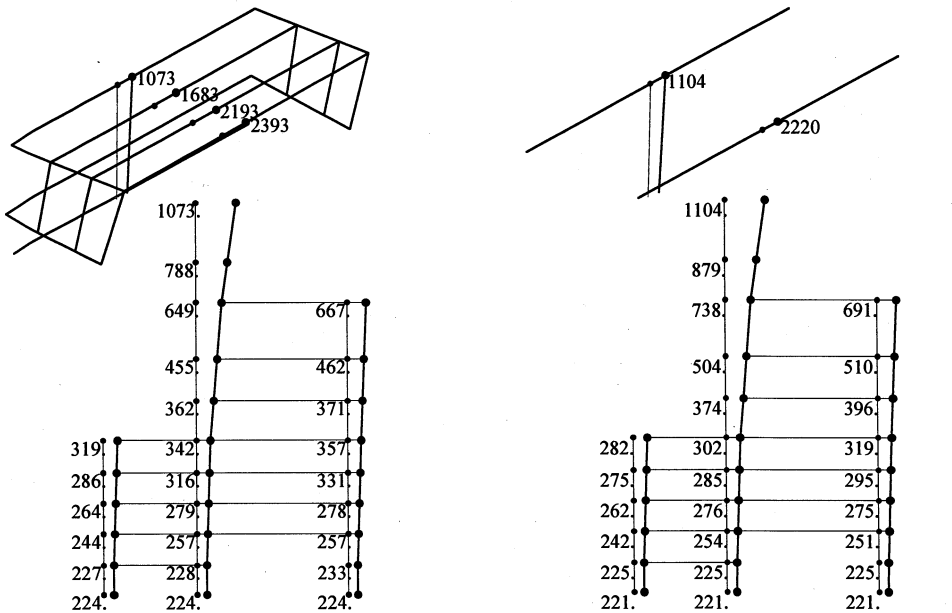


Fig. 4 Input Ground Motion

Table 3 Fundamental natural period (sec)

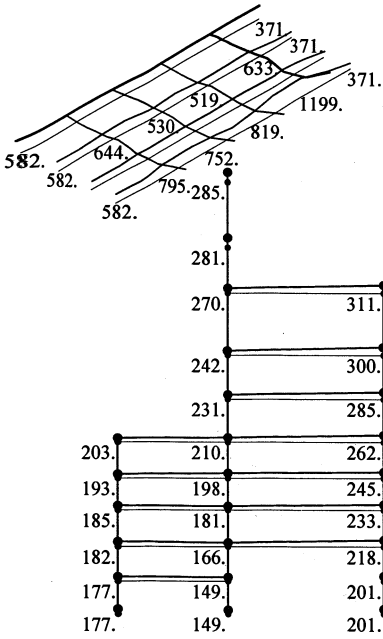
Vs	Mode	Multi-stick lumped mass model with a flexible base-mat and grid roof truss	Multi-stick lumped mass model with a rigid base-mat and one beam roof truss
500m/s	Vertical (Roof)	0.391	0.439
	Horizontal (Soil-Structure)	0.467	0.457
1000m/s	Vertical (Roof)	0.389	0.438
	Horizontal (Soil-Structure)	0.338	0.333



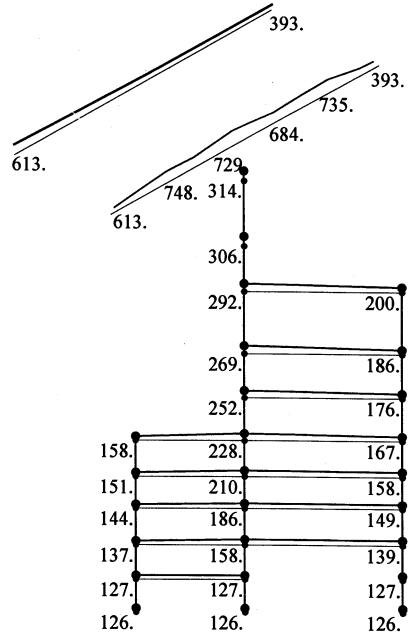
(a) Multi-stick lumped mass model with a flexible base-mat and grid roof truss

(b) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.5 Maximum horizontal response acceleration (Vs=500m/s, Gal)

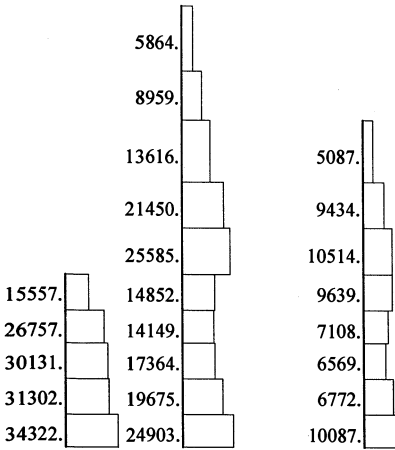
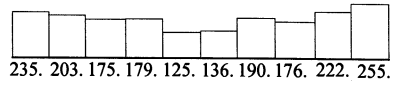
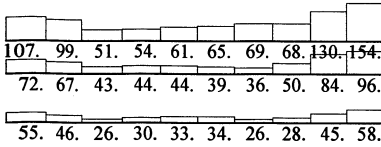


(a) Multi-stick lumped mass model with a flexible base-mat and grid roof truss

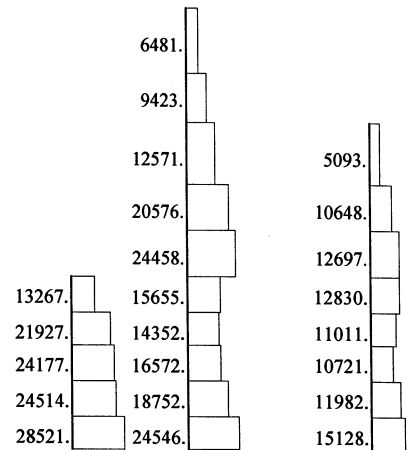


(b) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.6 Maximum vertical response acceleration ($V_s=500\text{m/s}$, Gal)

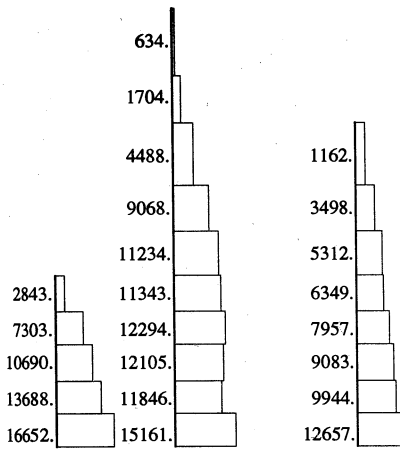


(a) Multi-stick lumped mass model with a flexible base-mat and grid roof truss

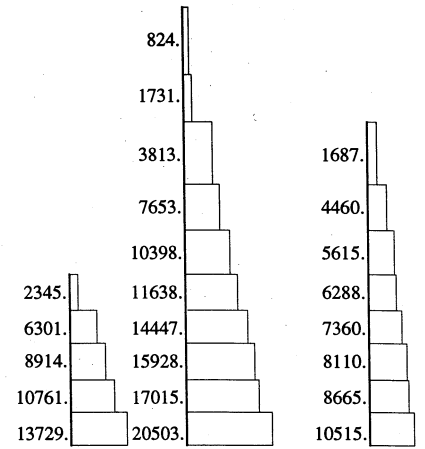


(b) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.7 Maximum response shear force ($V_s=500\text{m/s}$, ton f)

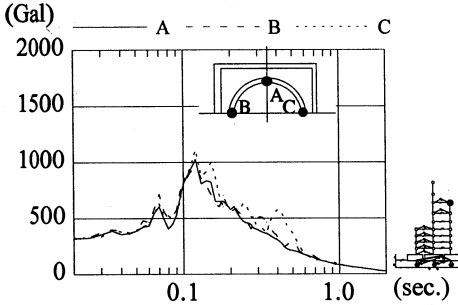


(a) Multi-stick lumped mass model with a flexible base-mat and grid roof truss

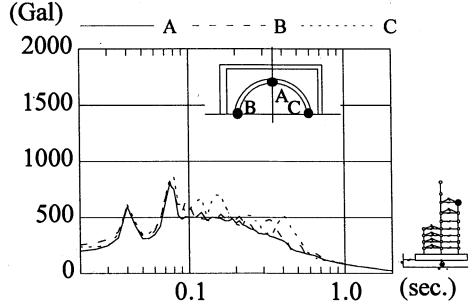


(b) Multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.8 Maximum response axial force ($V_s=500\text{m/s}$, ton f)

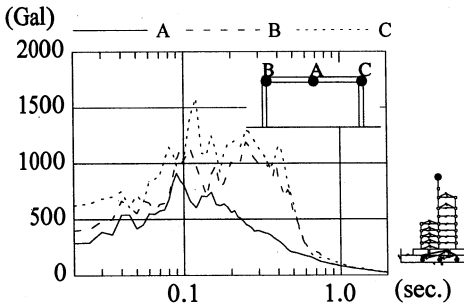


multi-stick lumped mass model with a flexible base-mat and grid roof truss

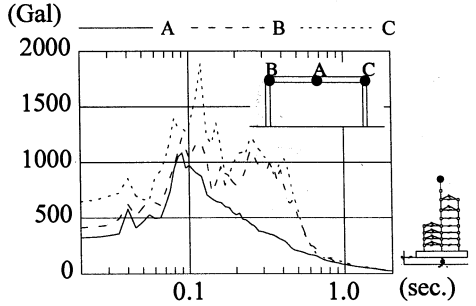


multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.9 Acceleration response spectrum (EL.50.5m-SW, $V_s=500\text{m/s}$)



multi-stick lumped mass model with a flexible base-mat and grid roof truss



multi-stick lumped mass model with a rigid base-mat and one beam roof truss

Fig.10 Acceleration Response Spectrum (EL.70.0m-IW, $V_s=500\text{m/s}$)