Earthquake Response Characteristics of a Base-Isolated Reactor Building with Eccentricities of Superstructure

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1. INTRODUCTION

In designing a conventional non-isolated reactor building, it is always required to pay attention to the location of shear walls and the distribution of the weights to suppress torsional response under an earthquake. Due to this requirement, equipment cannot be freely arranged in the building, and the volume of the building has been larger than that actually needed. However, if the isolation devices are used, even in the case of a building with eccentricity, it may be oscillated only in the direction of excitation, and moreover, the acceleration response could be drastically reduced (Miyamoto et al, 1987).

In this paper, the torsional response behaviors of such building are discussed qualitatively and quantitatively, subjected to a severe ground motion. From numerical examples, it is concluded that the natural frequency of torsional motion depends on the arrangement of the isolation devices, and base-isolation system is effective to reduce the torsional response by decoupling the torsional stiffness of the devices from the lateral stiffness.

2. ANALYTICAL CONDITIONS

2-1. Analytical Model

A reactor building is modeled as a three-dimensional, two-lumped mass model which consists of a rigid basemat, superstructural slab and shear walls. Two eccentric types of superstructures are considered in this study, as shown in Fig. 1. The differences in both types are their eccentricity directions. The base-isolation devices, which are composed of laminated rubber bearings and steel dampers, are idealized as MSS (Multi-Shear-Spring) models (Fig. 2). They are effective in modeling bi-lateral coupled nonlinear system (Wada and Kinoshita, 1985). The restoring force characteristics of the isolatoion devices are set to be bi-linear (Fig. 3).

2-2. Torsional Stiffness of Isolation Devices

To investigate the torsional response, it is necessary to accurately estimate the torsional stiffness of the isolation devices. This is closely related to the arrangement of the devices, especially dampers. In designing a base-isolated structure, the rubber bearings should be arranged in proportion to the dead loads of the superstructure. On the other hand, the dampers may be arranged freely. Typical cases of the arrangements and their torsional to lateral modal period ratios are shown in Table 1.

2-3. Seismic Input

An artificial seismic wave is simulated using Osaki spectrum(Osaki, 1979). The wave is set for high seismic intensity zone ($M=7.0$, $\Delta=20km$) and has the same phase characteristics as El Centro (NS ; 1940). Fig. 4 shows the acceleration time history(max ; 267 Gal) and the corresponding velocity response spectrum. In this analysis, the amplitude is magnified to show 400 Gal as maximum.

2-4. Analytical Cases

The nonlinear earthquake response analyses are carried out in the time domain by direct integration using Newmark β method. The ratio of torsional modal period to lateral one of the isolation devices, and the natural modal period of the superstructure are taken as the indicators to discuss the coupling effects on the dynamic behaviors.(Table 2). The fundamental lateral period of the isolation devices is fixed at 1 sec.

2-5. Comparison between Elastic and Elasto-Plastic Model for Devices

For the typical cases, the results for elastic models are compared with those for elasto-plastic models (Fig. 5).

Using the elasto-plastic model, the response in the excited direction is reduced due to the stiffness degradation and hysteretic damping effects. This characteristics is common regardless eccentricity direction (Fig. 5-1,2).

However, each model makes much difference in torsional response characteristics, although both elastic and elasto-plastic models show rigid-body behavior. Torsional displacement is estimated by the product of the torsional angle and the half width of the basemat (Fig. 5-3,4).

Even after 25 sec. , at which seismic input motion ceases, the elasto-plastic model continues to show resonance phenomena with the period of 1 sec. Therefore, it cannot be expected to reduce the torsional response by plastic deformation.

3. ANALYTICAL RESULTS

3-1. Natural Mode Characteristics

Nomal modes are shown in Fig. 6 for one of the eccentric structures with the elastic devices. For fixed-base, torsional motion is excited and its center is located on the main axis of structural stiffness. On the other hand, base-isolated structure oscillates only in the translational mode along the main axis, and the torsional mode is negligibly small.

3-2. Response Characteristics

In each case shown in Table 2, the responses of the isolated buildings are estimated by the Fourier amplitude spectra (Fig. 7). They express the responses both in the directions of lateral excitation and torsion.

The responses in the excited direction are the same regardless the torsional isolating period. As the superstructure becomes more flexible, the response grows by the coupled effects with the lateral stiffness of the isolation devices. That also results in increase of the structural magnification factor.

On the other hand, when the torsional period of the isolating zone equals to the lateral one, the torsional response grows as mentioned in 2-5. Resonance phenomena are observed as the effect of the interaction between the lateral and torsional stiffness. Although it is only in the limited case that the superstructure is very flexible, whose lateral period is 0.4 sec., at the peak, the torsional response shows about 1/4 of the maximum lateral component.

If both periods are separated enough, responses are decoupled. Moreover, as the superstructural stiffness is larger enough than that of the isolation devices, the absolute amplification factor is negligibly small and torsional resonance can be avoided.

3-3. Effects of Superstructural Eccentricity on Torsional Response

It is considered that the torsional response is excited and amplified due to the eccentricity of the superstructural stiffness. In order to estimate this effect, for the typical cases, the accumulated energy curves are indicated in Fig. 8. They are the results obtained from the acceleration response histories for both eccentric types of structure, the lateral period of which is 0.4 sec. They show the rates of energies consumed for the torsional to lateral response.

The torsional rate gradually increases on account of its resonance as shown in Fig. 5-3, 4. In the case of two axis eccentricity, the torsional rate is larger to reach about 20 % compared with 12 % for one axis eccentricity, in spite that there is little difference in the amount of total consumed energy for any type of structure.

4. CONCLUSION

Base-isolation system is very effective for a reactor building with eccentricity to reduce its torsional response. The torsional response is excited only in the case that the torsional modal period of the isolating zone coincides with the lateral modal period and also when the superstructure is flexible.

However, when the dampers are arranged with each rubber pad in a large-scale structure such as a reactor building, the torsional period tends to coincide with the lateral period.

This suggests that the torsional stiffness of the isolation devices should be increased, for instance, by separating the dampers from the rubber pads and locating the dampers along the edges of the building.

5. REFERENCES

Miyamoto, A. et al., Study on Reactor Building using Base-Isolation System, AIJ, Oct.1987

Osaki, Y., "Guideline for Evaluation of Basic Design Earthquake Ground Motions", 1979

Wada, A. and M.Kinoshita, Elastic Plastic Dynamic 3-Dimensional Response Analysis by using a Multiple Shear Spring Model, AIJ, Oct.1985

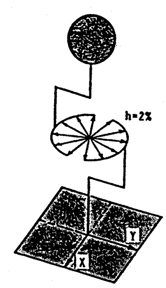


Fig.2 MSS Model

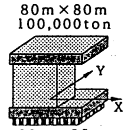
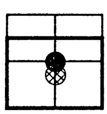
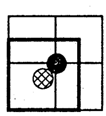
80m×80m 100,000ton  80m×80m 100,000ton	center of gravity ● stiffness ⊗ shear wall — Y X	1 axis eccentricity 	2 axis eccentricity 
eccentric distance (m)	ex	0.0	10.0
	ey	10.0	10.0
eccentric rate	Rex	0.200	0.236
	Rey	0.0	0.236

Fig.1 Analytical Model.

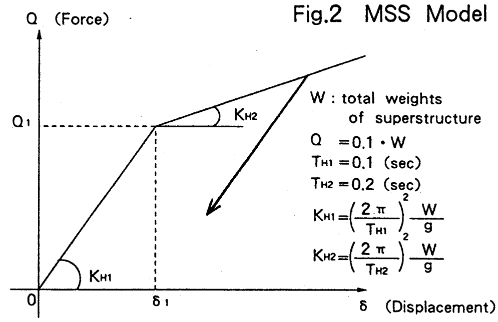
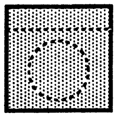
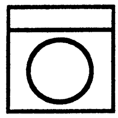
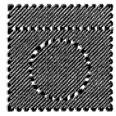
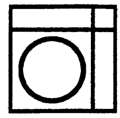


Fig.3 Restoring Force Characteristics

Table 1 Isolating Devices Arrangement
& Torsional／Lateral Period Ratio

arrangement of rubber pads & damper								
	rubber pads	damper	rubber pads	damper	rubber pads	damper	rubber pads	damper
dispersion	○	−	−	−	○	○	−	−
under wall	−	○ (edges)	○	○	−	−	○	○
T_T / T_L	0.76		0.99		1.00		1.00	

T_T : torsional period of isolation devices
T_L : lateral period of isolation devices

Table 2 Analytical Cases

1 axis eccentricity		torsional period of isolation devices(sec)		
		0.7	1.0	1.4
1st period of super−structure (sec)	0.1	○	○	○
	0.2	○	○	○
	0.4	○	◎	○

lateral period of isolation devices : 1.0sec

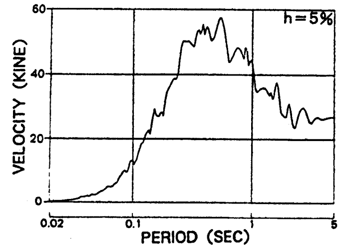


Fig.4−2
Velocity Response Spectrum

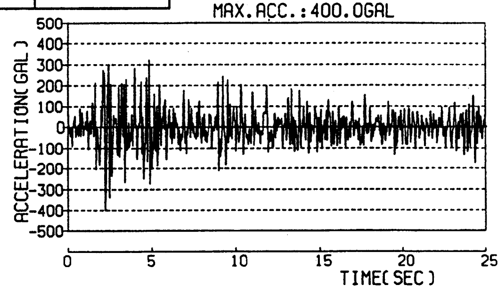


Fig.4−1 Acceleration Time History

Fig.4 Seismic Input Wave

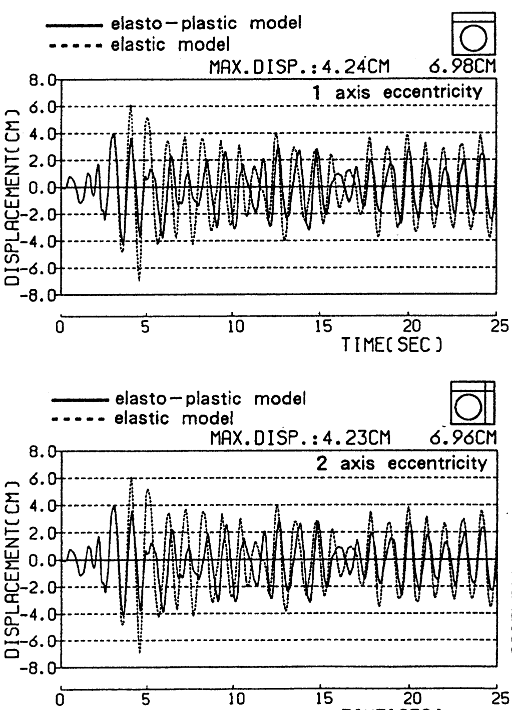


Fig.5−1 Excited Direc.
Displacement Response

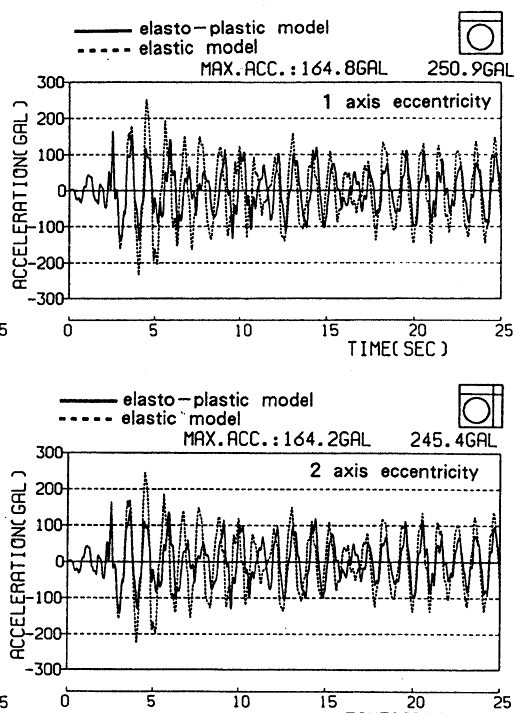
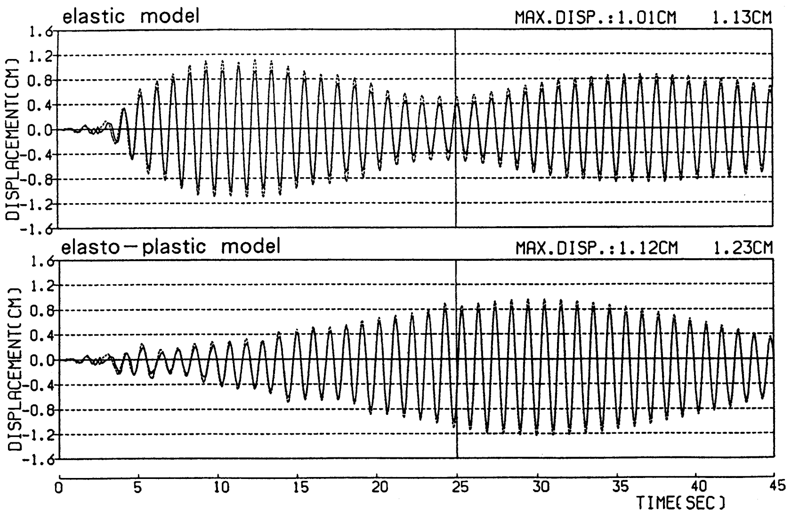


Fig.5−2 Excited Direc.
Acceleration Response

(structural lateral period : 0.4 sec
torsional period of isolation devices : 1.0sec
lateral period of isolation devices : 1.0sec)



structural lateral period : 0.4 sec
torsional period of devices : 1.0sec

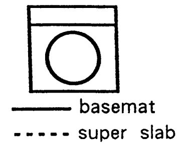
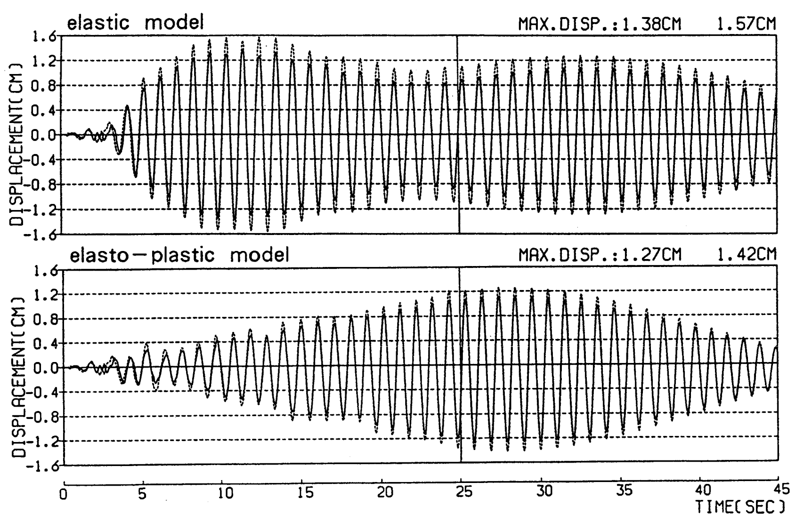
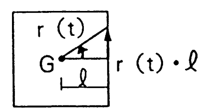


Fig.5−3
Torsional Response
(1 axis eccentricity)





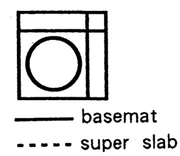
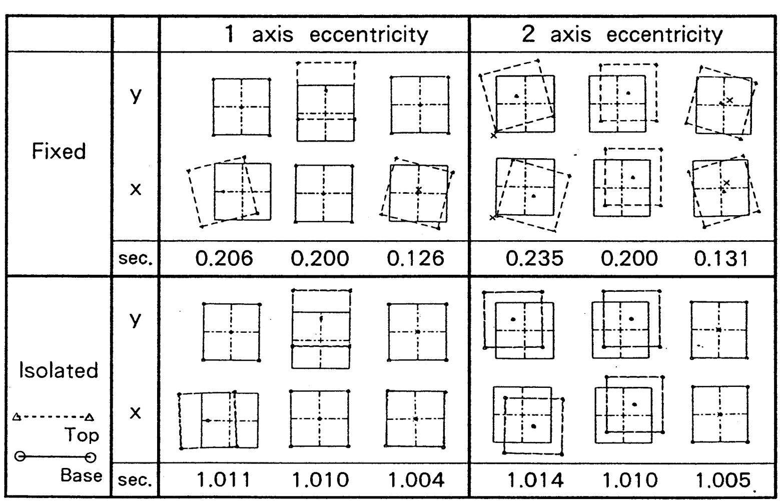


Fig.5−4
Torsional Response
(2 axis eccentricity)



structural lateral period : 0.2 sec
lateral&torsional period of devices : 1.0sec

Fig.6
Comparison of
Nomal Modes

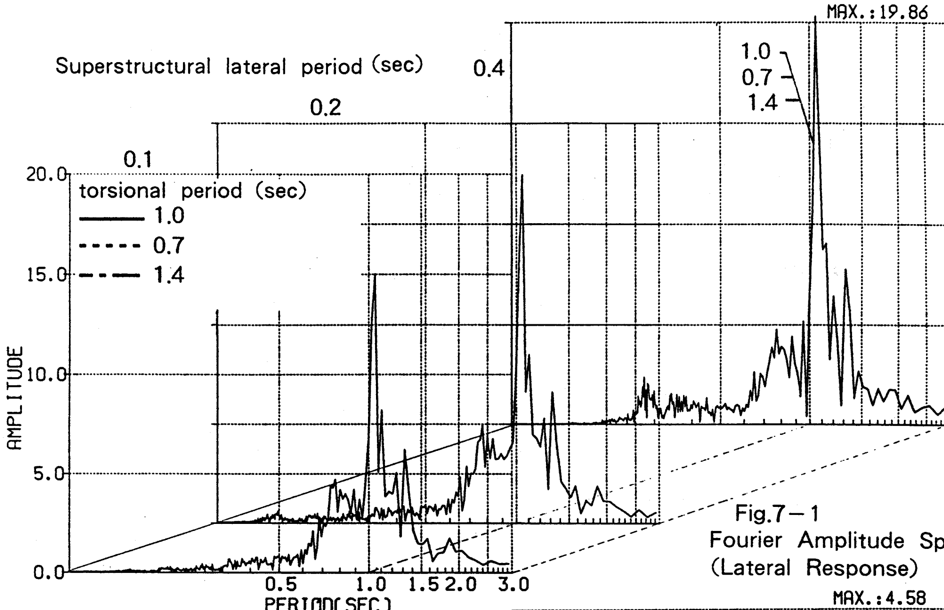


Fig.7−1 Fourier Amplitude Spectra (Lateral Response)

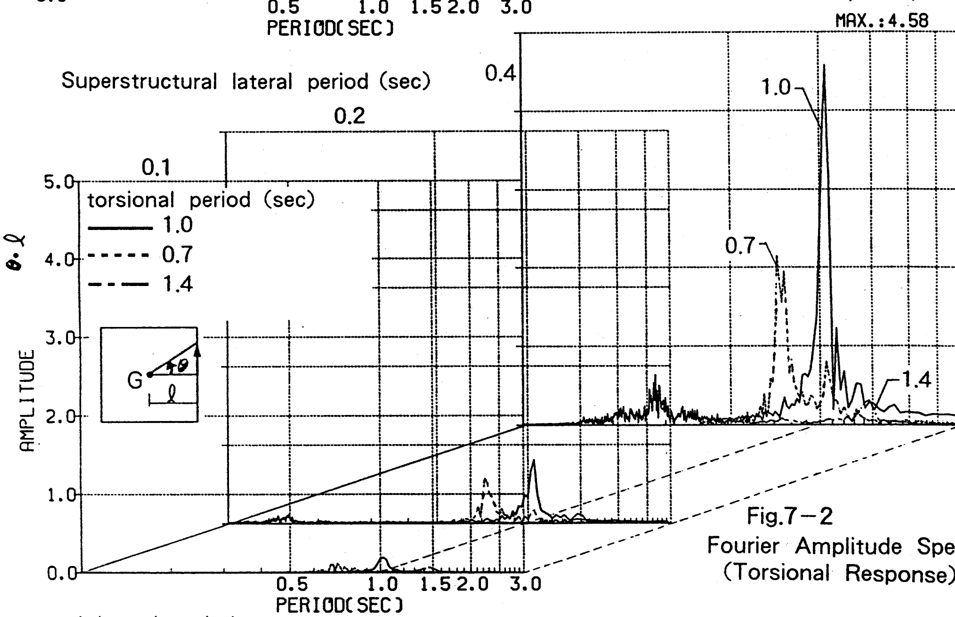


Fig.7−2 Fourier Amplitude Spectra (Torsional Response)

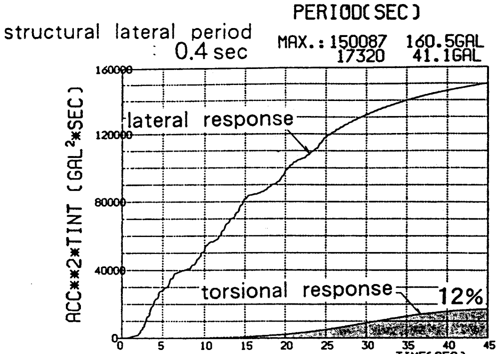


Fig.8−1 Accumulated Energy Curve

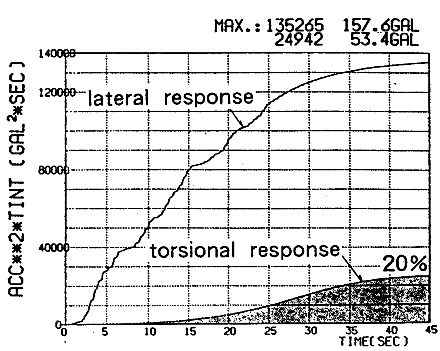


Fig.8−2 Accumulated Energy Curve