K26/6

Response Behavior of Base-Isolated Structures

H. MORISHITA
Tokyo Electric Power Company, Tokyo, Japan
T. TAKADA, T. WATANABE, Y. TOGARI
Ohsaki Research Institute, Inc., Tokyo, Japan

1. INTRODUCTION

A base-isolation technique is possibly an effective measure to drastically reduce the seismic force and to improve the safety of nuclear building facilities. The applicability and feasibility of the technique is now being studied in nuclear industry. However, the response behavior and the ultimate state of the base-isolated buildings are quite different from those of ordinary ones. Therefore, a great care has to be taken in a design stage from various aspect point of view.

In particular, the response of such buildings is tuned into the range of the long period to expect the reduction effect of the seismic force and is usually nonlinear even within a design level to reduce the excessive drift. The ultimate state, on the other hand, can be considered to be tensile-shear failure of the laminated rubber of the isolation devices at the edge of the base-mat due primarily to the horizontal seismic force and to the induced overturning moment when the laminated rubber bearings are adopted as the base-isolation devices.

Thus, this paper, primarily focusing on the earthquake ground motions which have extremely large uncertainty, will investigate the effects of the seismic motions on the structural response. The effects of non-stationarity and multi-dimensionality of the seismic motions on the response behavior are of great interest in this study.

2. NON-STATIONARITY OF EARTHQUAKE MOTIONS

2.1 Objective

First of all, the non-stationarity of the seismic motions is studied. The surface wave as well as the body wave must be taken into account when considering the design-based response spectra for the base-isolated buildings since the base-isolation devices are usually tuned from 1.0 to 4.0 seconds. The dispersive property of the surface waves might be significant for the long period nonlinear structural systems.

However, current other studies often use artificial ground motions which do not reflect such property of the surface waves, but define rather large response spectra due to the large uncertainty of the long-period range (say, 1 to 10 seconds) of earthquake motions. The larger seismic force leads to the more conservative design, and it may sacrifice the feasibility of the base-isolated buildings.

In this context, the uncertainty of the long-period range of earthquake motions must be reduced as possible. For this purpose, the sensitivity of the nature of the long-period components of earthquake motions to the structural response is examined below.

2.2 Generation of non-stationary motions with dispersive property

To generate the artificial ground motions which have the non-stationarity similar to the surface waves, a dispersion curve is utilized. The concept of the generation technique of these ground motions is illustrated in Fig. 1. It is assumed here that the generated waves require the following two condition,

1) the waves fit the target response spectrum as specified in Fig. 2,
2) the waves propagate on the surface from the base point to a certain distance D with the phase velocity which exhibits dispersive property as shown in Fig. 3

Although the above first condition guarantees that the maximum response of a linear system with 5% of critical damping is equal to the magnitude of the target response spectrum, of major interest is the tendency of the response of a nonlinear system like the base-isolated buildings. The dispersed waves with random phase angles which can meet the above requirements are generated and are used in the ensuing nonlinear response analyses. Note that the two-layer ground model is determined so as to make the dispersion characteristics more significant in the period range of interest.

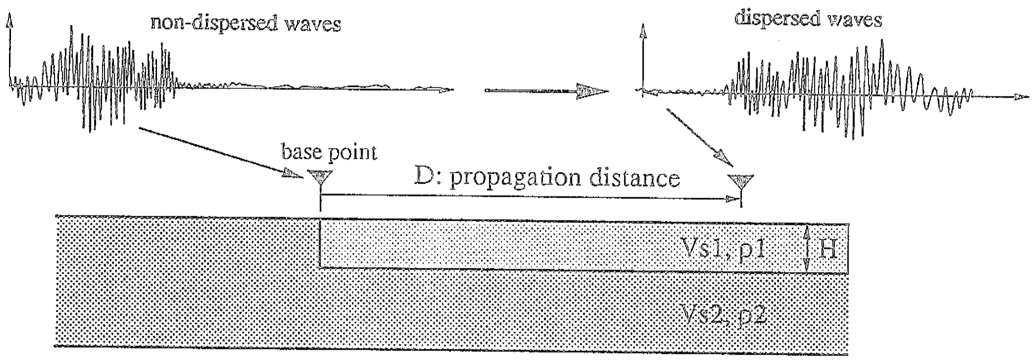

Figure 1 Generation concept of dispersion waves

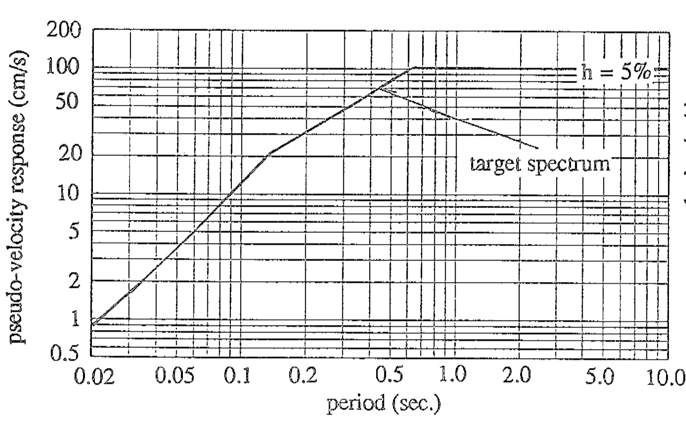

Figure 2 A target response spectrum (5% damping)

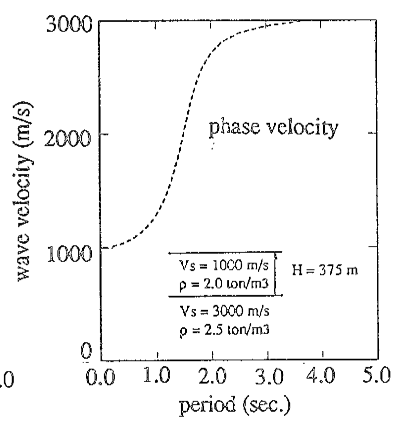

Figure 3 A dispersion curve of a two-layer ground model

2.3 Numerical results and discussions

The Monte Carlo simulation method is adopted to evaluate the statistical nature of the maximum response of the isolation devices. A single degree of freedom system with a bilinear spring (1.0*sec* for the initial period, 2.0*sec* for the second period and 0.05W for the yielding force) and a viscous damper is used to compute the response of the base-isolated buildings.

Figure 4 shows the comparison of the non-stationary spectra of the generated sample waves. The parameter D means the degree of the dispersion of the generated waves, i.e. the large D value implies significant dispersive property of the waves. The waves thus generated are denoted by $D0$, $D50$ and $D100$. For each group of D value, fifty waves with different phase angles are generated. Figure 5 shows the mean square time histories of the fifty generated sample waves when the D value is changed. From this figure, the maximum magnitude of the mean square time histories is getting smaller as the D value becomes larger. Figure 6 plots the response statistics of the SDOF nonlinear system. It can be observed from this figure that the maximum response is slightly reduced when the degree of the dispersion of the input waves becomes large.

As the results, the effect of the dispersion on the maximum response of the base-isolation buildings is not significant.

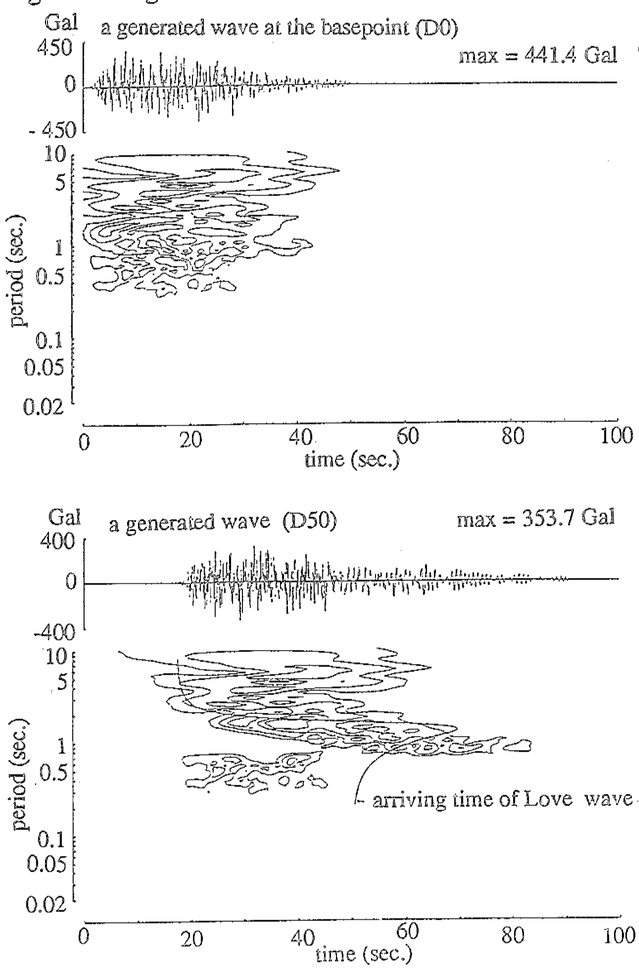

Figure 4 Generated sample waves

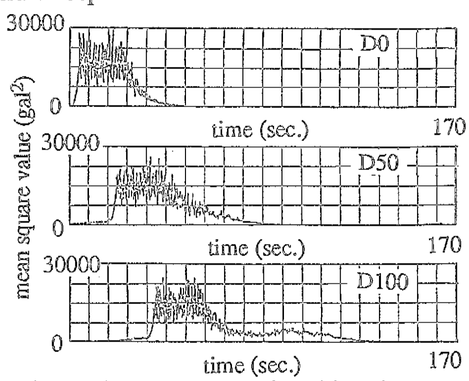

Figure 5 Mean square time histories (fifty samples)

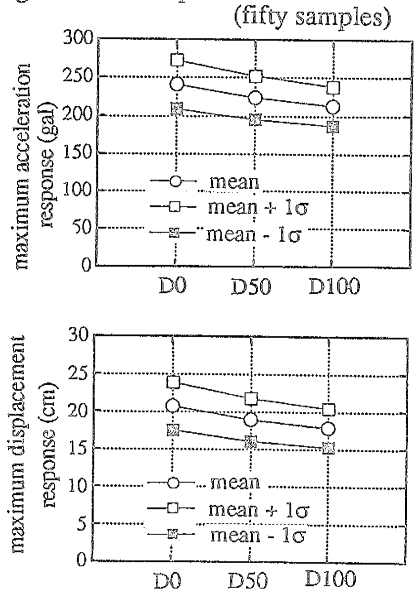

Figure 6 Maximum response versus dispersion of waves

3 MULTI-DIMENSIONALITY OF EARTHQUAKE MOTIONS

3.1 Objective

Regarding the multi-dimensionality (two horizontal and one vertical components) of the seismic motions, the degree of the temporal correlation between any two components is a key parameter. Of great concern is the response of the isolation devices located at the edge of the base-mat, which are subjected not only to horizontal forces in two directions but also to vertical forces. Partially correlated pairs of artificial ground motions with a correlation coefficient $\rho(0 \leq \rho \leq 1.0)$ are generated and are used in the response analysis. Then, the effect of the correlation on the maximum response of the devices is examined.

3.2 Generation of mutually correlated earthquake motions

The partially correlated earthquake motions are assumed to be stationary Gaussian random processes with the power spectrum compatible to the specified target spectrum, as shown in Fig. 2. The two partially correlated random processes can be generated by combining the two statistically independent Gaussian random processes which can easily be generated (Schuëller and Shinozuka 1987). The following two input cases are considered; two horizontal component input, and one horizontal and vertical component input. In the case of the two horizontal motions, keeping the total power of the two motions constant, the correlation property between the two components is changed. In the case of the horizontal and vertical motions, the ratio of the power spectrum of the vertical component to that of the horizontal component is 0.5 for all period range. Again, the correlation property between the two components is changed.

3.3 Numerical results and discussions

The Monte Carlo simulation method is used again in which the random phase angle is assumed. The structural model used in the case of the two horizontal input motions is shown in Fig. 7 (Takizawa 1976). For the case of horizontal and vertical input, the two uncoupled models; the one for the horizontal input and the other for the vertical input, as shown in Fig. 8. The maximum response of the base-isolation devices located at the edge of the base-mat is examined.

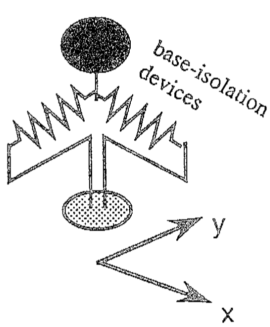

Figure 7 Response model for two horizontal input

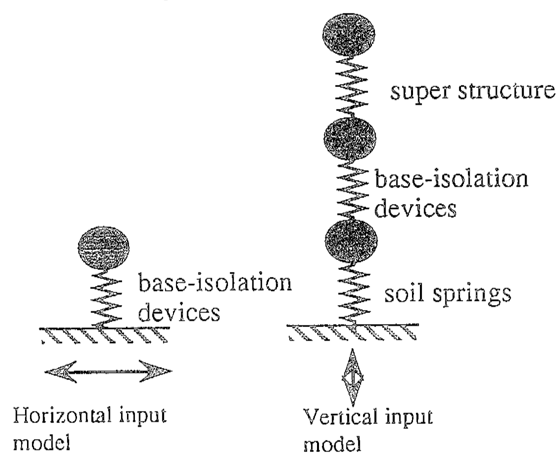

Figure 8 Response model for horizontal and vertical input

Figure 9 shows the change of the maximum value of the vertical stress response of the corner devices. Observed can be the clear tendency that the response subjected to two horizontal seismic input gets smaller as the correlation property becomes smaller. The case which gives the maximum response is the identical two horizontal motions (ρ = 1.0), as is expected.

On the other hand, Fig. 10 shows the sample orbit of the horizontal displacement and the vertical stress responses of the base isolation devices at the edge of the base-mat when the correlation property between the horizontal and vertical components is changed. Figure 11 shows the plot of the maximum vertical stress response versus the correlation coefficient between the horizontal and vertical input. The correlation between one horizontal and vertical components has no influence on the maximum vertical response of the isolation devices. It can be guessed that the horizontal dominant period of the base-isolated buildings is much longer than the vertical one.

Since the response analysis of the buildings subjected to the multiple input is still one of the research topics nowadays and the correlation property of the earthquake ground motions is not well understood, the response analysis is usually done separately in each single direction input in a design. Then, the effect of the multiple input is treated as a problem of the combination of each load effect. Tables 1 and 2 show the comparison of the maximum response predicted by using ordinary load combination methods; a combination of the absolute value of each maximum response (absolute sum) and a combination of the square root value of the sum of the square value of each maximum response (SRSS). For the case of the two horizontal input, the absolute sum value is closer to the exact value that is equal to the sum of the two response time histories, while for the case of the horizontal and vertical input, the SRSS method gives the closer result.

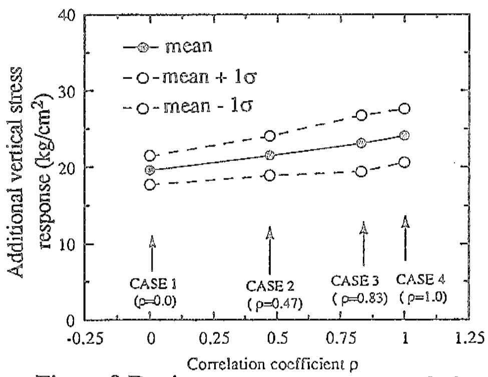

Figure 9 Device response versus correlation of horizontal input

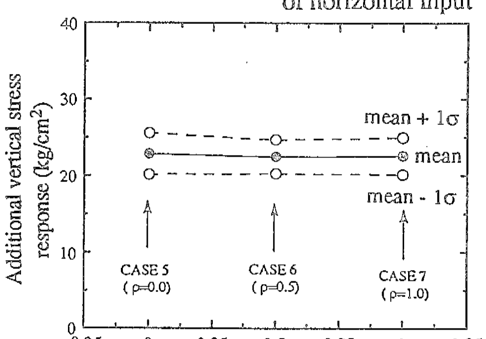

Figure 11 Device response versus correlation between horizontal and vertical input

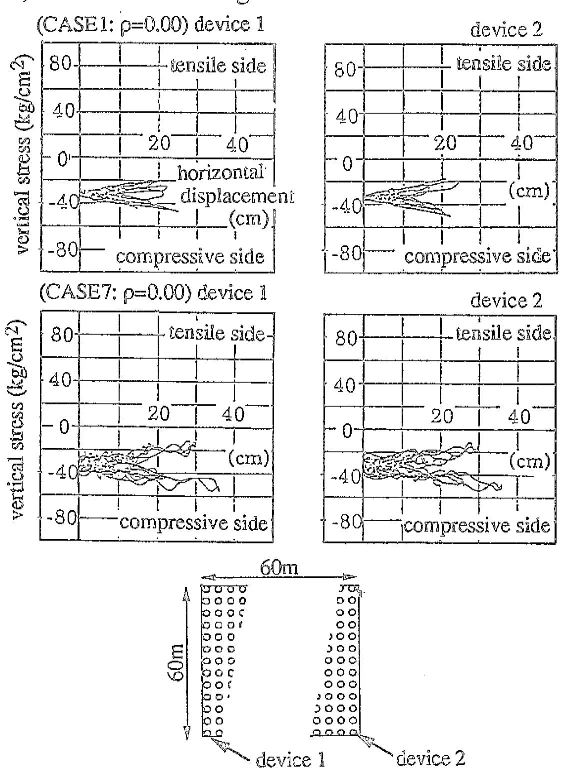

Figure 10 Sample orbits of device response

4 CONCLUSIONS

From the above studies focusing on the non-stationarity and multi-dimensionality of the earthquake motions, the following conclusions are made.

1) the effect of the non-stationarity of the seismic motions is not significant when the seismic motions fit the specified target response spectrum.
2) the effect of the simultaneous input of two horizontal seismic motions on the response is significant and the correlation property of the two components is an important parameter,
3) the effect of the correlation property between the vertical and horizontal seismic inputs on the response is small and it is not necessary to worry about the temporal correlation of the two components.

A rational load combination method should be considered in the future for evaluation of the maximum response of the base-isolation devices.

REFERENCES

Schuëller,G.I. and Shinozuka, M. (1987), Stochastic Methods in Structural Dynamics, Martinus Nijhoff Publishers

Takizawa, H. (1976), Biaxial Effects of Modeling Earthquake Response of R/C Structures, EESD, Vol. 4, pp.523-552

Table 1 Combined load effect for device response (two horizonal input)

Unit(kg/cm^2)

CASE	Correlation coefficient ρ(0)	$\{\lvert\sigma_X(t)+\sigma_Y(t)\rvert\}_{max}$		$\lvert\sigma_{X\,max}\rvert+\lvert\sigma_{Y\,max}\rvert$		$\sqrt{\sigma^2_{X\,max}+\sigma^2_{Y\,max}}$	
		mean	std d	mean	std d	mean	std d
1	0.00	19.6	1.9	21.6	2.5	15.5	1.9
2	0.47	21.5	2.6	22.5	2.2	16.0	1.6
3	0.83	23.1	3.7	24.1	3.7	17.1	2.6
4	1.00	24.1	3.5	24.1	3.6	17.1	2.5

Table 2 Combined load effect for device response (horizonal and vertical input)

Unit(kg/cm^2)

CASE	Correlation coefficient ρ(0)	$\{\lvert\sigma_H(t)+\sigma_V(t)\rvert\}_{max}$		$\lvert\sigma_{H\,max}\rvert+\lvert\sigma_{V\,max}\rvert$		$\sqrt{\sigma^2_{H\,max}+\sigma^2_{V\,max}}$	
		mean	std d	mean	std d	mean	std d
5	0.00	22.9	2.7	27.7	2.7	20.2	2.2
6	0.50	22.5	2.2	27.9	2.4	20.2	1.9
7	1.00	22.6	2.4	27.6	2.7	20.1	2.2