Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

7-4-2

STUDIES ON THE ORTHOGONAL EFFECTS IN SEISMIC ANALYSES

Toshihiko HISADA[1], Masamitsu MIYAMURA[2], Satoshi KAN[1] and Yasuyuki HIRAO[3]

[1]Kajima Institute of Construction Technology, Kajima Corporation, Tokyo, Japan
[2]Kobori Research Complex, Kajima Corporation, Tokyo, Japan
[3]Structural Design Division, Kajima Corporation, Tokyo, Japan

SUMMARY

Two studies are carried out in order to investigate the orthogonal effects of structures with regard to the ground motion characteristics and the structural response. One is a statistical study on 75 recorded strong ground motions based on the Two-Dimensional Response Spectrum and Column Axial Force Response Spectrum. The computed mean values of these spectra are 1.3 and 1.7 times larger than that of one-directional input, respectively. The other study is an investigation of the response properties of a typical building subjected to horizontal orthogonal ground motions. The analytical results clarify that the axial forces at the corner columns are about 1.0 - 2.0 times larger than that of one directional input.

INTRODUCTION

It is well known that earthquake ground motions have very complicated orbits in three-dimensional space. In dynamic response analyses, observed acceleration time histories and the response spectra in the N-S and E-W directions are usually used separately for convenience. However, it is noted that observation of past earthquake damage to buildings shows that the corner columns are apt to suffer damage. One of the reasons for this might be considered to be the intricate response due to orthogonal effects. In this paper, two-dimensional response spectrum and column axial force response spectrum are proposed in order to investigate the orthogonal effects, and carried out the analytical study to confirm the orthogonal effects on actual buildings.

TWO-DIMENSIONAL RESPONSE SPECTRUM

The two-dimensional acceleration response spectrum $Sa_{x+y}(T)$ is defined as the maximum of $r(t)$ for t in the form:

$$Sa_{x+y}(T) = r(t)_{max} \qquad \text{for } t \qquad (1)$$

where $r(t)$ is the absolute response acceleration vector obtained from the response of one mass system in the horizontal plan.

As the simple index of orthogonal effect, the ratio $Ra_x(T)$ was defined as follows:

$$Ra_x(T) = Sa_{x+y}(T) \;/\; Sa_x(T),\; Ra_y(T) = Sa_{x+y}(T) \;/\; Sa_y(T) \tag{2}$$

where, $Sa_x(T)$, and $Sa_y(T)$ indicate the response spectrum subjected to one directional input in the x and y directions respectively. Fig.1 shows an example of two-dimensional response spectra for El Centro waves of the Imperial Valley Earthquake of 1940. The response orbits subjected to El Centro waves in a horizontal plane are shown in Fig.2. The circular marks in Fig.2 represent the maximum values, showing the maximum value is not always on one of the two axis.

For the investigation of average properties of observed ground motions, statistical analyses were carried out using 75 strong ground motion records, where maximum accelerations of both components are greater than 100 gal. The basic earthquake parameters such as magnitude and epicentral distance are shown in Table 1. $Ra_x(T)$ obtained from records is shown in Fig.3. Though the values of $Ra_x(T)$ show relatively large variations, the mean values $Ra_x(T)$ show a constant value of about 1.3 through the objective period range. $Ra_y(T)$ is also shown in Fig.4 and the mean is approximately 1.3, similar to Ra_x. In both directions, some of the records, which are obtained in the near field, show relatively large variations in the period range longer than around 1.0 second. This is considered to be the effect of source mechanisms or propogation path. The result of this study is compared with a previous study (Ref.2) as shown in Fig.5. The mean values of this result almost correspond to the previous study.

COLUMN AXIAL FORCE RESPONSE SPECTRUM

A building with a rigid floor with two degrees of freedom and four corner columns is idealized as shown in Fig.6.

The axial force on a column caused by the overturning moment is represented in the x and y directions as follows:

$$\begin{aligned} N_x(t) &= m(\ddot{\delta}_x(t) + \ddot{\alpha}_x(t))H/4L_x \\ N_y(t) &= m(\ddot{\delta}_y(t) + \ddot{\alpha}_y(t))H/4L_y \end{aligned} \tag{3}$$

where $N_x(N_y)$ shows axial force due to ground motion, $\ddot{\alpha}_x(\ddot{\alpha}_y)$ and $\left|\ddot{\delta}_x+\ddot{\alpha}_x(\ddot{\delta}_y + \ddot{\alpha}_y)\right|$ is the absolute response acceleration due to $\ddot{\alpha}_x(\ddot{\alpha}_y)$.

Considering the combination of the sings of the input motions, the column axial force response spectrum $Sn_{x+y}(T)$ is defined in the form:

$$Sn_{x+y}(T) = n'(t)_{max} \qquad \text{for } t \tag{4}$$

where $n'(t) = \left|\ddot{\delta}_x(t) + \ddot{\alpha}_x(t)\right| + \left|\ddot{\delta}_y(t) + \ddot{\alpha}_y(t)\right|$

In the paper, the ratio $Rn_x(T)$ and $Rn_y(T)$ defined as (5) are disucussed.

$$Rn_x(T) = Sn_{x+y}(T)/Sa_x(T),\; Rn_y(T) = Sn_{x+y}(T)/Sa_y(T) \tag{5}$$

Fig.7 shows an example of the column axial force response spectrum $Sn_{x+y}(T)$ for the El Centro wave. Fig.8,9 show $Rn_x(T)$, $Rn_y(T)$ for same 75 data sets as Ra(T). Though these values change depending on the wave properties, their mean values in both directions are about 1.7. It is clear that the column axial force response spectrum $Sn_{x+y}(T)$ is larger than the response spectrum subjected to one-directional input, which suggests that the expected axial forces on a corner column might be larger than that evaluated in one-directional analysis.

RESPONSE OF A TYPICAL BUILDING SUBJECTED TO ORTHOGONAL GROUND MOTIONS

In order to investigate the orthogonal effects on actual buildings,an 8-storied steel building is selected and designed. The building is composed of beams and columns with rigid floors, and have a simple two-by-two span plan as shown in Fig.10. Seismic response analyses subjected to horizontal orthogonal ground motions are carried out in the elastic range in order to study the maximum responses of the column axial force. Analytical conditions are shown in Table 2. The ratios of maximum column axial forces are shown in Fig.11. The ratios change between 1.0-2.0 by the column position, while the ratios show not so significant change through the stories.

CONCLUSION

The ratios $Ra_x(T)$ and $Ra_y(T)$ are computed for the selected 75 strong motion records by the two-dimensional response spectra in comparison with the result of the current one-dimensional spectra. Though the ratios change depending on the characteristics of the frequency content of the ground motions, the mean is approximately 1.3. The column axial force response spectrum is defined and proposed in order to represent the approximate orthogonal effects. When compared with the result of two-dimensional response spectra, the ratio $Rn_x(T)$ derived from the column axial force response spectrum showed rather higher values of around 1.7, which suggests that the effects of the column axial force are significant. Furthermore, the orthogonal effect for column axial force on actual building is investigated by the dynamic response analysis, of which result clarifies that the axial forces at the corner columns are about 1.0-2.0 times those obtained from one directional input. These results suggest the importance of the orthogonal effects in seismic design as well as the absolute values of input ground motions and the design method of structural elements.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. K. Muto, Dr. T. Kobori, and Dr. H. Kanayama for their valuable comments and advice, and to Mr. H. Koshida and Mr. K. Igarashi for their kind participation in the discussion.

REFERENCES

1. Hisada, T., M. Miyamura, S. Kan and Y. Hirao, "Studies on the Orthogonal Effects in Seismic Analysis" , KICT Report, No.71, Aug.1987
2. Kawashima, K., K. Aizawa, and K. Takahashi, "Effects of Composition of Two Horizontal Components on Attenuation of Maximum Earthquake Ground Motions", proceedings of the J.S.C.E. Jan. 1983 (in Japanese)
3. Kobayashi, H., T. Samano, M Yamauchi, and S. Midorikawa, "Two-Dimensional Horizontal Ground Motions During an Earthquake", Proceedings of the 6th WCEE
4. Matsui, C., S. Morino, and Y. Uchida, "Elasto-Plastic Behavior of Steel Space Frames Subjected to Two-Dimensional Horizontal Force", Transactions of the Architecural Institute of Japan, Nov, 1983(in Japanese)
5. Penzien, J. and M. Watabe, "Characteristics of 3-Dimensional Earthquake Ground Motions", Earth. Eng. and Structural Dynamics. Vol.3,1975
6. Fujiwara, T. and A. Kitahara, "On the a seismic safety of Space Structures under Bi-Directional Ground Motion", Proceedings of the 8th WCEE

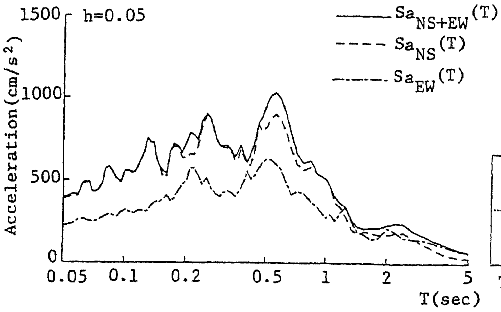


Fig.1 An Example of Two-Dimensional Response Spectra of El Centro Wave

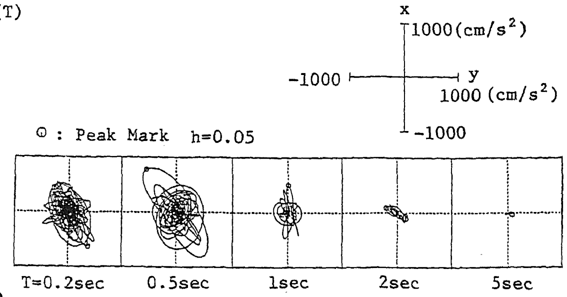
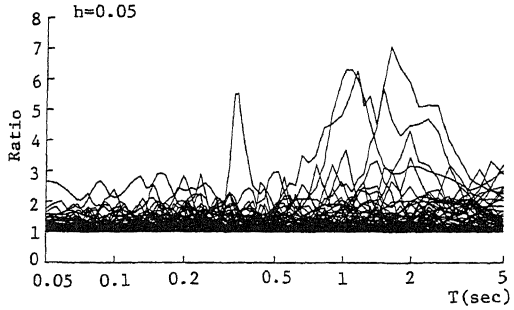
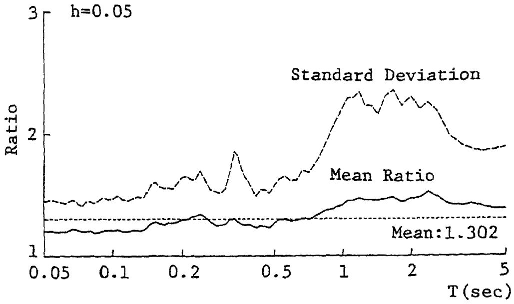


Fig.2 Response Orbits of El Centro Wave

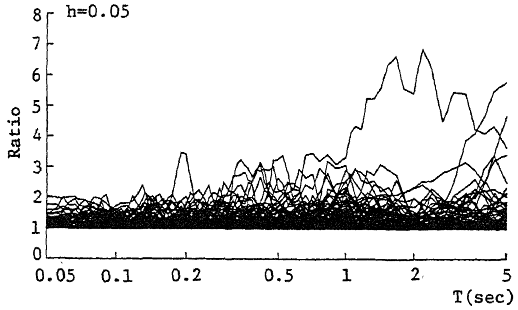


(a) Ratios $Ra_x(T)$

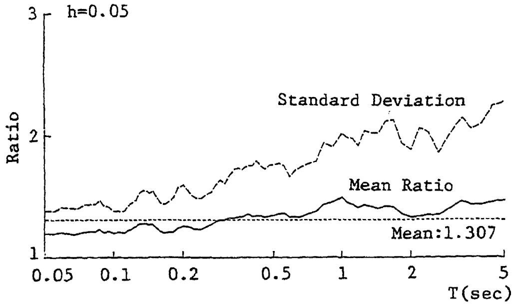


(b) Mean Ratio $Ra_x(T)$

Fig.3 Ratios $Ra_x(T)$ of $Sa_{x+y}(T)$ to $Sa_x(T)$



(a) Ratios $Ra_y(T)$



(b) Mean Ratio $Ra_y(T)$

Fig.4 Ratios $Ra_y(T)$ of $Sa_{x+y}(T)$ to $Sa_y(T)$

Table 1 : Records for Analysis

Categoly	Parametr	Number of Records
Nation	Japan USA	12 63
Magnitude	5.3 ≦ M < 6 6 ≦ M < 7 7 ≦ M < 7.9	8 53 14
Epicentral Distance(km)	2 ≦ Δ < 25 25 ≦ Δ < 50 50 ≦ Δ < 100 100 ≦ Δ < 280	10 47 10 8
Maximum Acceleration (gal)	100 ≦ A < 150 150 ≦ A < 200 200 ≦ A < 1055	43 20 12

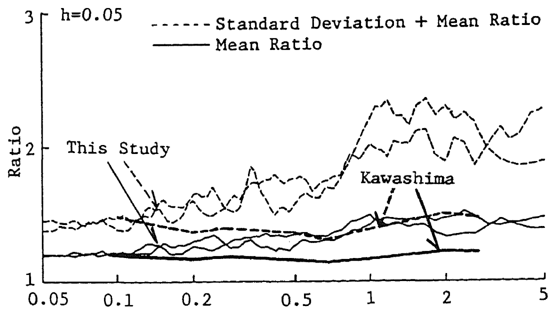


Fig.5 Comparison with Previous Study (Ref.2)

Table 2 : Analytical Condition

1st Natural Period	X Direction : 1.55sec Y Direction : 1.28sec
Input Ground motion	Sumitomo-Seimei in Miyagiken -oki E.Q., 1978 Max.Acc : 255gal(NS), 241gal(EW)
Damping Factor	2%

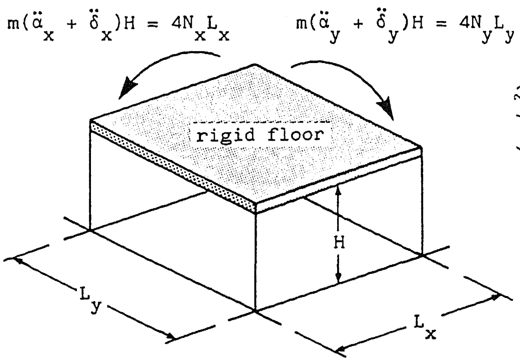


Fig.6 Indealized Model for Column Axial Force Response Spectra

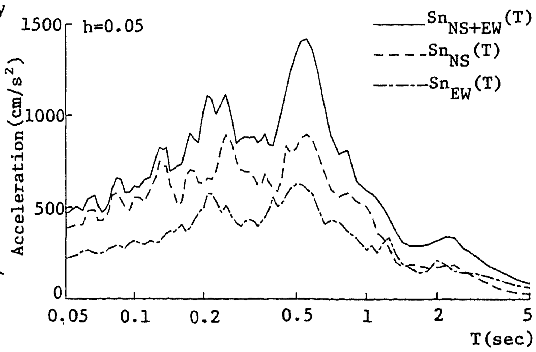
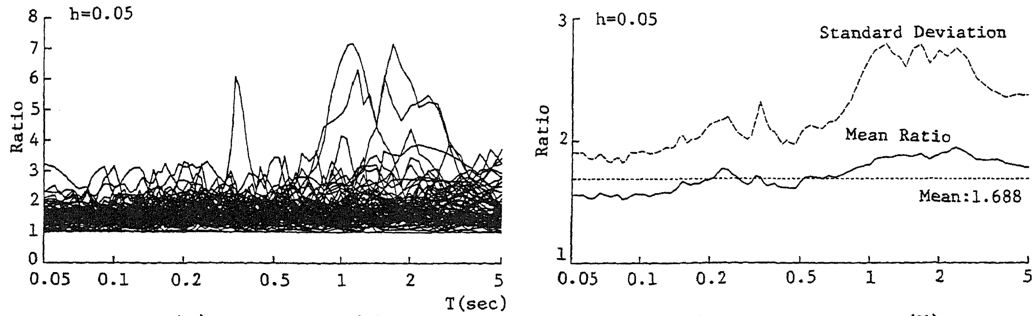
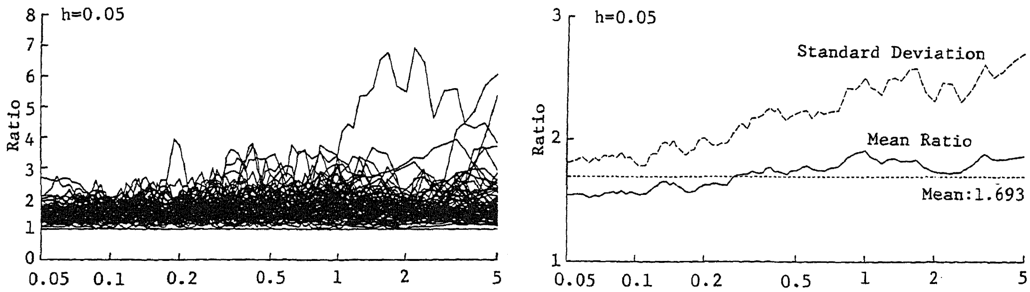


Fig.7 An Example of Column Axial Force Response Spectra of El Centro Wave



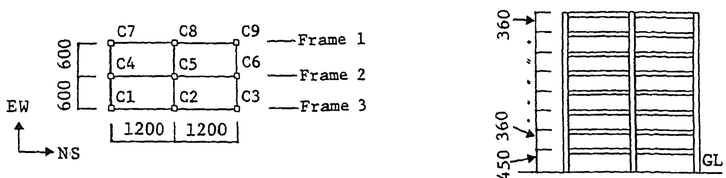
(a) Ratios $Rn_x(T)$ (b) Mean Ratio $Rn_x(T)$

Fig.8 Ratios $Rn_x(T)$ of $Sn_{x+y}(T)$ to $Sn_x(T)$



(a) Ratios $Rn_y(T)$ (b) Mean Ratio $Rn_x(T)$

Fig.9 Ratios $Rn_y(T)$ of $Sn_{x+y}(T)$ to $Sn_y(T)$



(a) Plan (b) Elevation

Fig.10 Plan and Elevation of Typical Building

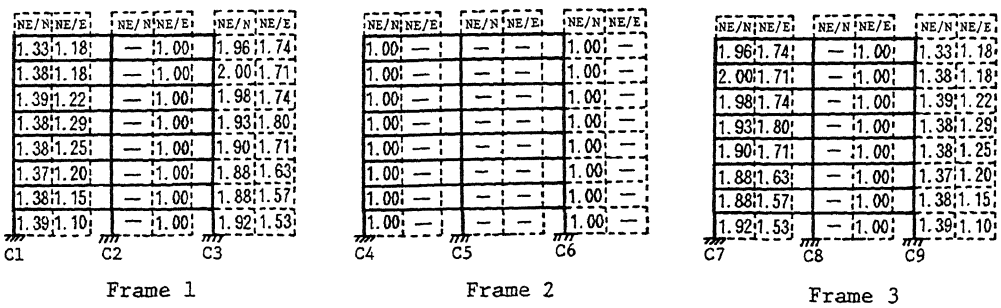


Fig.11 Ratios of Maximum Column Axial Forces in 8-Storied Building Model