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

7-4-8

INFLUENCE OF BUILDING SHAPE IN HORIZONTAL PLANE ON EARTHQUAKE RESPONSE

Takeru HIROMATSU

Dr.Eng., Chief Reseach Engineer, Takenaka Tech. Reseach Lab., Tokyo, Japan

SUMMARY

Principal axes were found to take an important role by the free vibration tests and measurements of microtremors in the investigation of data of presently a existing 29 story high-rise building. This coupled vibration was extremely strong but the independent parallel and torsional vibration modes were separated by the method presented in this paper. Propriety of use of the free vibration mode in the response analysis was investigated through comparisons between the records of the building. The response analysis results are also presented for the same building where the free vibration mode are subjected to the motion recorded in the lowest story of the building.

INTRODUCTION

Buildings with complex shape in horizontal plane are increasing in number because of building site restrictions and their function and design requirements. In those buildings, the principal axes of vibration modes do not coincide to the frame axes of the builings so that coupling of parallel and torsional vibration modes become significant. Generally seismic design is conducted by assuming those axes coincide. That assumption might cause serious error in some cases of seismic designs. Objectives of this paper are to estimate the influence of principal axes and torsional vibration in the response characteristics of building subjected to a impulse wave and the eight sets of earthquakes.

RESULT OF THE VIBRATION TEST

As shown in Fig.-1, the multi-storied building in which the vibration test was carried out has two, 114.45m towers rising on a base structure with four floors below the ground. One of the towers, which is a hotel, rises in L shape from the ninth floor. Each wing is 61.3m in length. The hotel tower below the ninth floor is triangluar in horizontal shape. The other tower is for office use.

Fig.-2 shows the orbits for predominant frequency obtained from two horizontal components of the microtremor waveforms at each center of gravity in both the rooftop and the ninth floor. These orbits were observed through a narrow-band filter. Each of these orbits shows a comparatively clear, long, elliptical configuration. The long axial direction can be considered to indicate predominant vibration component direction at each vibration frequency. In other words, it can be seen that the natural period and the vibration mode exist only in the principal axes, not in the frame axes.

In order to investigate the vibration behavior of the towers, a wire cable was strung at the top of the towers. The cable was tightened to provide ten tons and then released (Fig.-1). In Fig.-3, the vibration modes are shown in three dimensions for each natural frequency. There are only parallel vibrations in both primary and secondary frequency in the axial direction U. In the axial direction V, however, parallel and torsional vibrations are coupled. This is because the center of gravity of the hotel tower does not coincide with the center of rigidity in the axial direction V.

By locating two sets of vibration sensors on one of the hotel tower floors, vibration motions toward the axial direction V were obtained.

ANALITICAL APPROACH

When the position of the center of gravity is assumed, components of the parallel and torsional vibration waves are separated. Fig.-4 indicates the power spectral density functions of the parallel mode components. When the apparent torsional center coordinates (ρ_1, ρ_2) on the main floors and when the values of two natural frequencies (f_1, f_2) coupled with parallel and torsional vibrations are obtained as shown in Fig.-4, the basic parameters of parallel and torsinal characteristics could be calculated as follows:

Natural frequency of the parallel direction to the vibration mode only;

$$f_V = \frac{\sqrt{(\rho_1 f_1^2 - \rho_2 f_2^2)}}{\sqrt{(\rho_1 - \rho_2)}} \tag{1}$$

Natural frequency of the torsional vibration mode only;

$$f_T = f_1 \cdot f_2 / f_V \tag{2}$$

Eccentric distance;

$$S = \frac{\rho_1 \rho_2 (f_1^2 - f_2^2)}{\rho_1 f_1^2 - \rho_2 f_2^2} \tag{3}$$

Radius of gyration;

$$i_o = \sqrt{(-\rho_1 \cdot \rho_2)} \tag{4}$$

Elastic radius;

$$e_o = i_o \cdot (f_T / f_V) \tag{5}$$

As a result, all the dynamic factors and elements can be obtained. The apparent torsional centers (ρ_1, ρ_2) on the main floors are shown in Table-1. They were obtained using the method outlined above. The positions of rigidity which have been obtained from equation (3) according to the results of the vibration test are indicated by a broken line in Fig.-5. These were compared to the positions of center of rigidity computed statically, which are shown with a chain line in the same figure. A fairly large difference was seen between these two lines. From this result, it is suggested that the rotatoy inertia force must also be considered in addition to rigidites, which are used in static approaches.

A simulation analysis of an actual earthquake response recorded in the hotel tower was made using all the dynamic factors and elements regarding parallel and torsional vibration in the same tower. The solid lines in Fig.-6 represent the waves observed on the 28th and 9th floors. The broken lines show the simulation waves. It can be seen that the results observed on both floors coincide.

Eventually, data provited by the vibration tests and the analysis data concerning the dynamic properties of this structure were inputted with a high degree of precision into computers. Then, this coupled vibration is found extremely strong by the separation of the independent parallel and tortional vibration modes through the method mentioned above equations.

EARTHQUAKE RESPONSE ANALYSIS

The input motions were inpulse wave and eight sets of recorded earthquakes as shown in Table-2. In several input motions, a strong directionality for long periods of over one second was recognized.

The left side of Fig.-7 indicates the maximum response of the building due to the recorded earthquake (5), i.e. HACHINOHE earthquake, for example. Upper side and lower side of this figure show the displacement response at the roof floor and shear force at 1-st floor respectively. And right side of this figure shows the two-dimensional response orbit of one-mass system in time domain at each mode of the building. As shown this figure, when changing the direction of the input motion and orientation of the building, the maximum response depends upon the main directionality at each mode period of thebuilding in the input earthquake motion.

Then, a response ratio was defined by dividing the largest value of response amount with the smallest response. As shown in Fig.-8,the ordinary response value evaluation scale i.e. displacement, velocity, acceleration, shear force and over turning moment did not show a considerable difference in its response ratio under the input motions. Subsequently a horizontal two-dimensional response analyses were performed for the impulse waves and eight sets of seismic motions using the free vibration mode that was derived from test measurements. It may be concluded through these analyses that the largest and the smallest response ratio for any direction of the input motions against the building orientation was 1.4 on average.

It was also found in Fig.-9 that the influence of torsional vibration to the maximum earthquake response increased 20-40 percent in addition to the above ratio.

CONCLUSIONS

The natural vibration mode and their corresponding natural period exist only in the direction of the principal axes for any the building shape in horizontal plane. It is shown by the analyses and the experiments that the coupling movements of torsional vibration might cause difference of 80 percent in the maximum response for any direction on the horizontal plane in connection with the direction of the input motions subjected.

ACKNOWLEDGMENTS

The author wishes to express their appreciation to Dr. H.Kobayashi, Emeritus Professor, and Dr. K.Seo, Associate Professor of Tokyo Insititute of Technology, for their helpful suggestions. The vibration test was carried out by Takenaka Corporation and Shimizu Corporation, the author also thanks to the concerned members.

REFERENCES

1. Hiromatsu, T., "Regression Analysis on Response Curves of Forced Vibration Tests and Its Error Estimation Due to Microtremors," Proc.,6 WCEE, (1977).
2. Rosman, R., "Buckling and Vibrations of Spatial Building Structures," Eng. Struct. VOL.3, No.4, (1981).
3. Tso, W. K., "Torsional Provision of Building Cords," Can. J. Civ. Eng., VOL.9, No.1, (1982)

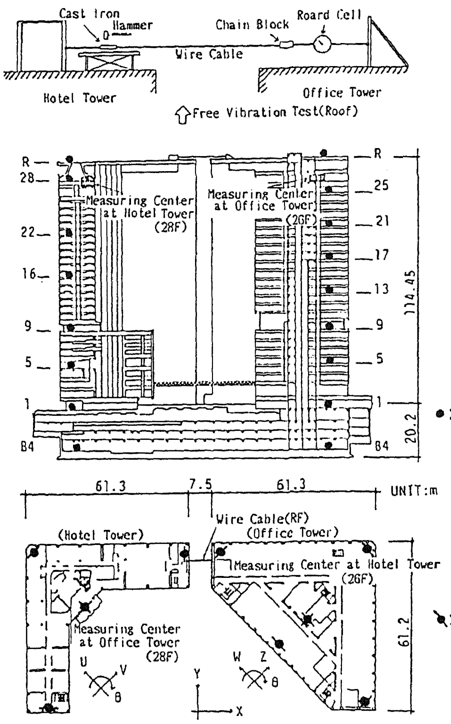

Fig.-1

SECTION AND PLAN OF THE BLDG., AND FREE VIBRATION TEST.

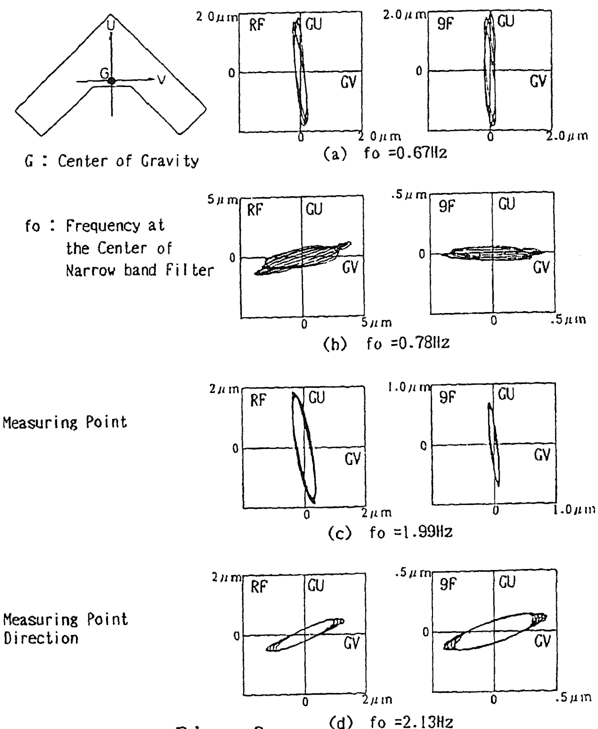

Fig.-2

MICRO-TREMOR ORBITS THROUGH THE NARROW-BAND FILTERS.

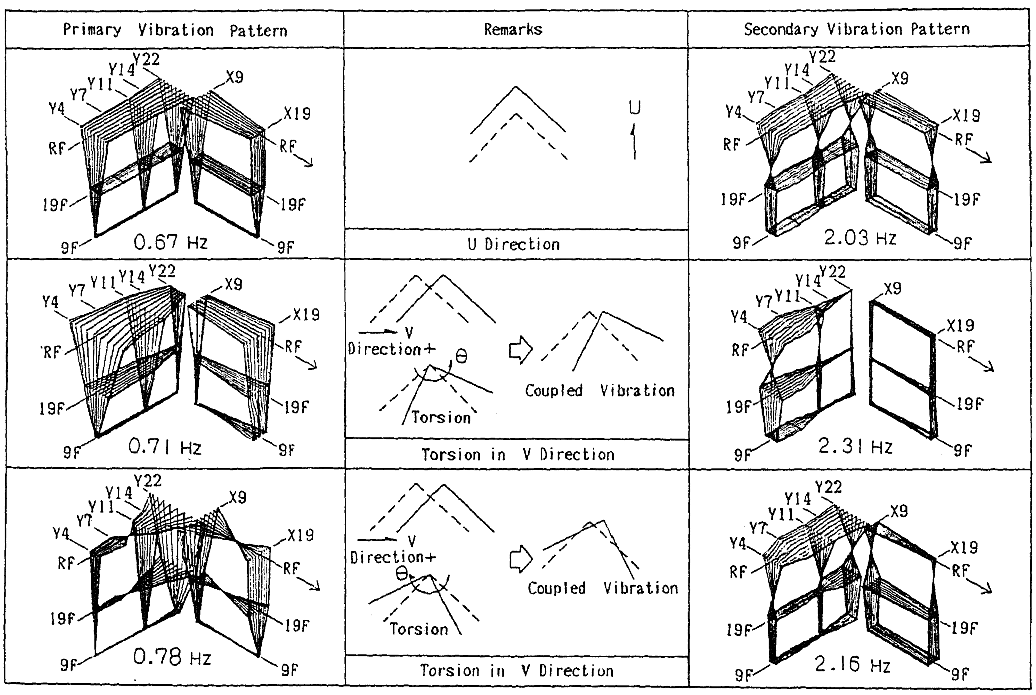

Fig.-3 VIBRATION MODE PATTERN FOR EACH FREQUENCY IN THE TEST.

Table-1 VALUES FOR TORSIONAL CHARACTERISTIC OF THE BUILDING.

Story	Center of Torsion (m)		Radius of Gyration io (m)	Elastic Radius eo (m)	Eccentric Distance S (m)	Eccentric Ratio S／io (%)
	ρ1	ρ2				
RF	26.5	−18.5	22.14	22.42	2.138	9.66
28	25.5	−25.0	25.25	25.16	2.437	9.65
22	25.5	−21.0	24.25	24.48	2.346	9.67
16	29.0	−25.0	26.93	27.00	2.608	9.68
9	36.0	−33.5	34.73	34.69	3.358	9.67
5	37.5	−28.0	32.40	32.71	3.135	9.68

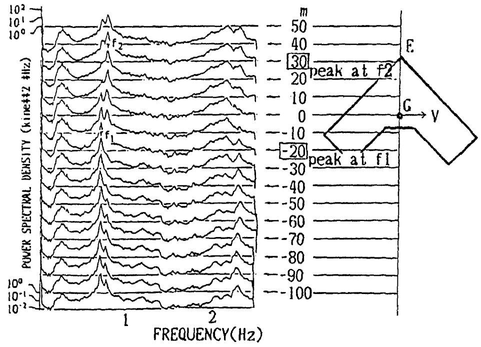

Fig.-4 PARALLEL MOVEMENT ON THE ROOF-FLOOR.

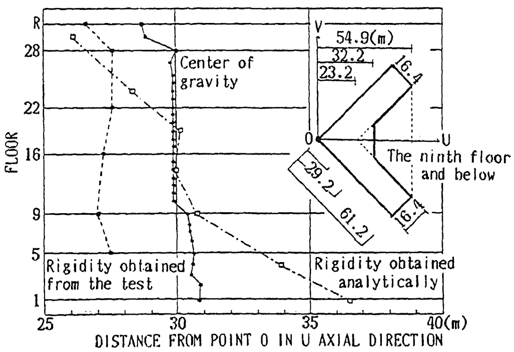

Fig.-5 RIGIDITY CENTER OBTAINED FROM TEST AND ANALYSIS.

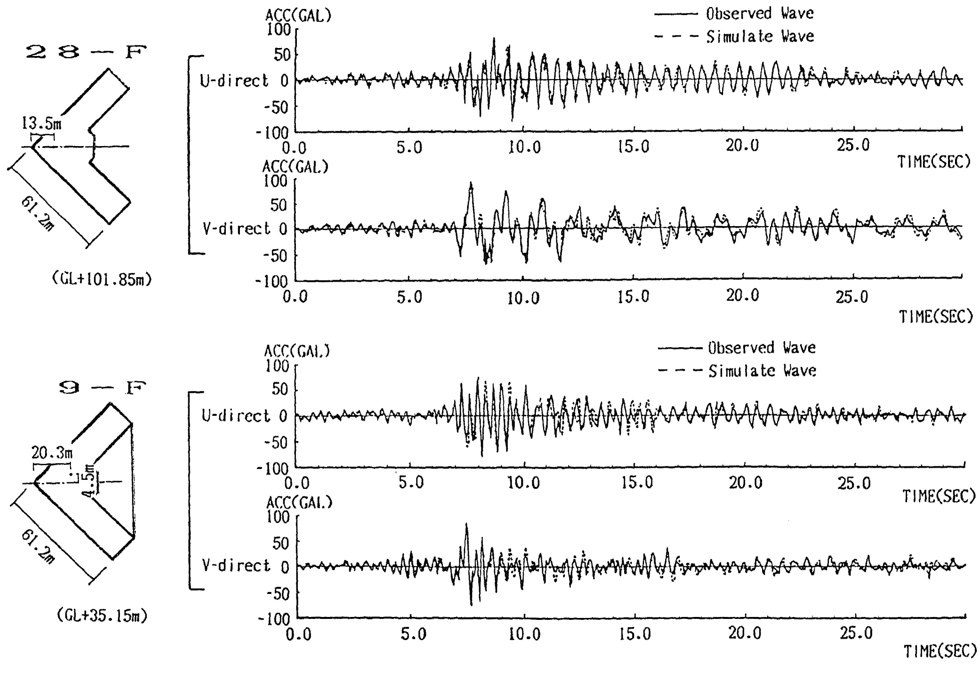

Fig.-6 RESULTS OF OBSERVED AND SIMULATED WAVES.

Table-2 INPUT MOTIONS LIST FOR THE TWO-DIMENSIONAL RESPONSE.

No.	Earthquake Date		Max. Acc. (gal)		Duration Time (SEC)	Sampling Time (SEC)	Number of Sampling
			NS	EW			
1	IMPULSE WAVE		1000.	0.0	30.7	0.02	1,500
2	EL CENTRO	1940 5.18.	341.7	210.1	53.5	0.02	2,674
3	TAFT	1952 7.21.	152.7	175.9	54.4	0.02	2,720
4	SENDAI-501	1962 4.30.	50.0	45.0	16.7	0.01	1,670
5	HACHINOHE	1968 5.13.	225.0	182.9	120.0	0.01	12,000
6	SJK/7	1972 2.29.	38.2	47.7	60.0	0.02	3,000
7	TOHOKU UNV	1978 6.12.	258.0	202.7	40.9	0.02	2,048
8	SUMITOMO	1978 6.12.	250.9	240.9	39.0	0.01	3,899
9	OHFUNATO	1978 6.12.	137.6	161.2	58.0	0.01	5,800

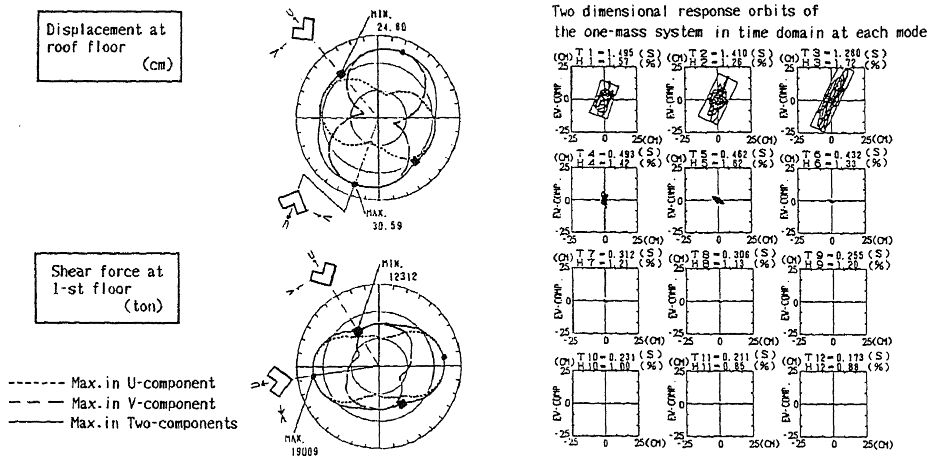

Fig.-7 MAXIMUM RESPONSE OF THE BLDG. AND TIME DOMAIN RESPONSE OF ONE-MASS SYSTEM DUE TO (5) HACHINOHE EARTHQUAKE.

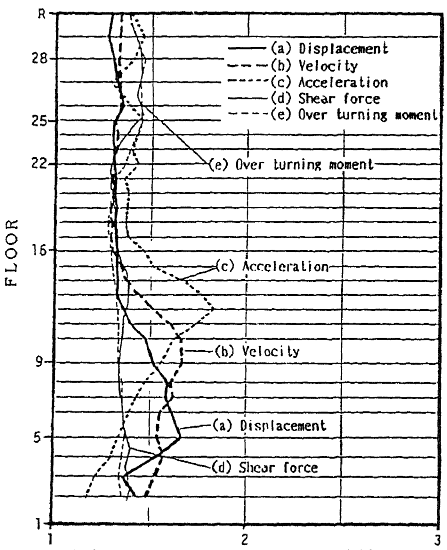

Fig.-8

AVERAGE OF RESPONSE RATIOS DUE TO EIGHT EARTHQUAKES.

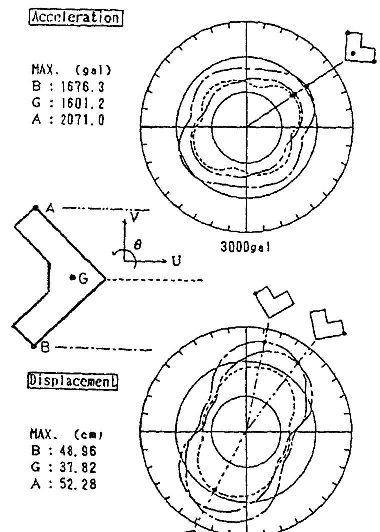

Fig.-9

TORSIONAL RESPONSE DUE TO (5) HACHINOHE EARTHQUAKE.