Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Forced vibration test on a horizontally '+' planned SRC building

Shigeru Miwa, Yasuo Maekawa, Masashi Yamamoto & Baoqi Guan
Tobishima Corporation, Tokyo, Japan

Tadao Minami
Earthquake Research Institute, University of Tokyo, Japan

ABSTRACT: Forced Vibration tests and analyses were performed on a "+" planned steel encased reinforced concrete(SRC) 12-story building which consists of four identical wings connected by link members, in order to get its fundamental vibration properties. As a result, it was found that the torsional behavior caused by connecting each of the two wings with link slabs to form two "L" shaped sub-buildings for user's convenience can be prevented by further connecting the two L's with link braces which have proper rigidity. Vibration modes peculiar to this building were observed, due to the link members, i.e. two link slabs and two link braces, which expand and contract, but it was found that they do not affect seriously the seismic response of the building.

1. INTRODUCTION

Recently, construction of complex-planned high rise buildings are increasing. The architectural demands will still make the shape of buildings more complex, i.e. the growing requirement for better living environment, in terms such as relaxation and comfort, apart from the structural utility concerns. Consequently, it is important to understand the complex dynamic behavior of these buildings for the purpose of seismic design and vibration-proof design.

The authors performed forced vibration tests on a SRC 12-story building which consists of four wings of almost the same shape and dimensions connected by link members to form a "+" shaped plan, and studied its dynamic characteristics as a typical complex-planned building (Miwa et al., 1990 and Nagao et al, 1990). Here the results obtained from the vibration tests are reported, as well as the results obtained from response analyses of a simple 3-dimensional system (Guan et al, 1992).

2. OUTLINE OF THE BUILDING

The building is located on an alluvial lowland formed by Tama River in Kanagawa Pref., Japan. The foundation of the building is cast-in-place concrete piles which are supported by the alluvial basal gravel at GL-22m. The predominant period of the ground is approximately 0.5 sec. (2 Hz), according to microtremor measurements and an analysis of the multiple reflection theory of S waves.

This SRC building has 1 story below ground and 12 stories above ground, with an eaves height of 52.65 m and a total floor area of approximately 97,000 m^2. The plan of the building above ground is the shape of a "+", consisting of four connected wings, as shown in Fig. 1. And there is an atrium at the center of the four wings. The basement is a large structure approximately twice as large as the area of an upper floor, incorporating all of the four wings.

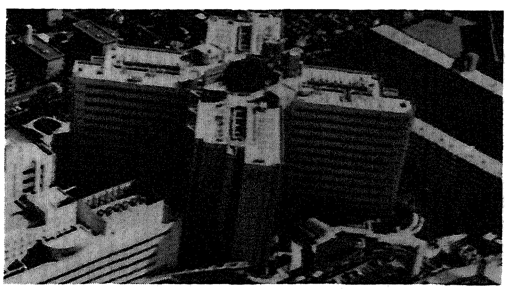

Fig.1 Test building

Fig. 2 shows the plan of the building. It was required to reduce the vibration of the building, because precision instruments were to be installed in the building. Therefore the four wings of the buildings were planned to be connected with link members. Two wings each were functionally connected to form two "L" shaped sub-buildings with the RC link slabs for user's

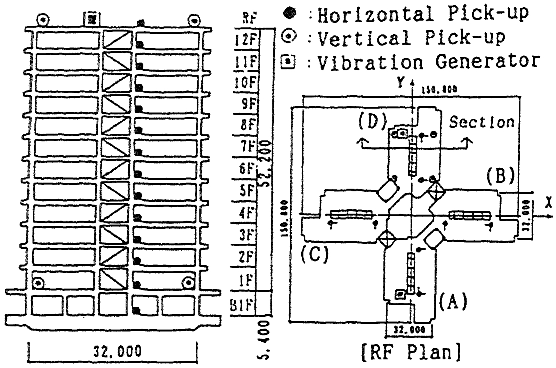

Fig.2 Outline of the building and location of pick-ups

convenience. With the purpose of preventing the torsional behavior caused by eccentricity of "L" shaped sub-building, the two L's were further connected at every two floors to form a "+" with box-section steel braces which were arranged in a shape of an "x" (see Fig. 2).

3. OUTLINE OF THE TESTS

A series of forced vibration tests (step and sweeping excitations) in X-, Y-, and torsional directions, free vibration tests by stopping the vibration generators, and microtremor measurement were performed to get the dynamic characteristics of whole building by using a pair of synchronized vibration generators which were set on the roofs of A and D wing.

In order to catch the complex behavior of the building, displacement was measured at 47 points simultaneously with high-sensitive pickups. The pickups were laid out intensively on every floor of the D wing, which was selected as the standard wing. The pickups were also set on a few floors of the other wings to catch the inter-wing behavior.

The resonance curves were gotten by adjusting the amplitude of displacement, which is obtained from the test, at each frequency in relation to equalized vibration forces. The phases of the measurement points were judged as "same" or "opposite" at the moment of the peak amplitudes of the standard measurement point.

4. TEST RESULTS

This report centers around the results of the step excitation test in the X-direction. The results of the other test agreed with those of the test in the X-direction. The X- and Y-axes herein refer to the directions of excitation that cross at a right angle. The building is almost symmetrical in relation to the axes which cross the X- and Y- axes at 45°. These axes are referred to as X'- and Y'-axes.

4.1 Resonance Curve and Vibration Modes of D wing

The resonance curve by the X-excitation on the roof of the D wing is shown in Fig. 3. At 1.3Hz - 1.7Hz and 3Hz tall peaks appeared. The vibration modes of the D wing at the main peaks of the resonance curve are shown in Fig. 4. At peak frequencies lower than 4.0 Hz, the modes were fundamental mode both in the excitation direction and the direction at 90°. At frequencies of over 5.0 Hz the secondary modes appeared, i.e. opposite phases of vibration were observed on the roof and the middle floor. However, the displacement amplitudes were small at these frequencies.

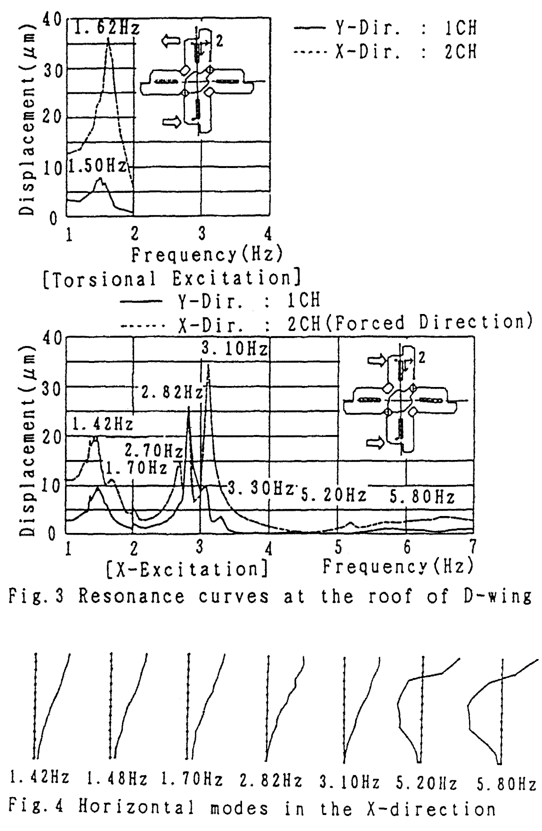

Fig.3 Resonance curves at the roof of D-wing

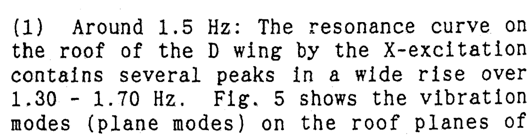

Fig.4 Horizontal modes in the X-direction

4.2 Inter-Wing Behavior

(1) Around 1.5 Hz: The resonance curve on the roof of the D wing by the X-excitation contains several peaks in a wide rise over 1.30 - 1.70 Hz. Fig. 5 shows the vibration modes (plane modes) on the roof planes of

four wings to examine the inter-wing behavior. At 1.42 Hz all wings moved linearly along the Y'-axis almost in the same phase, and the vibration translated along the X'-axis at 1.70 Hz. These are the natural mode of the whole building along the Y'-axis and X'-axis respectively.

Since at these frequencies the plane modes and the orbits of measurement points were almost linear, it is considered that the link braces can prevent the torsional behavior caused by "L" shaped sub-building.

The ratio of rocking and swaying were 23% and 12%, respectively. This indicates the influence of soil-structure interaction. The peaks at around 1.5 Hz were not so sharp, because by connecting the four wings which have slightly different natural frequencies, some of the vibration modes were offset by one another, and also because the damping increased due to the radiation damping.

(2) Around 3 Hz: At around 3 Hz there were clear peaks at 2.82 Hz and 3.10 Hz. Peaks were observed also at 2.70 Hz and 3.30 Hz. These modes were classified by plain modes in Fig. 5. it was found that at 2.82 Hz the building moved in the mode in which the A and B wings and the C and D wings rotated as two groups, maintaining the approximate right angle of each group. At 3.10 Hz the building moved in the mode in which the A and C wings and the B and D wings rotated as two groups, maintaining the approximate right angle of each group. In other words, when one of the link members contracted, its counterpart expanded.

The mode at 2.70 Hz was similar to the mode at 2.82 Hz, but there were time lags between the expansion and contraction of corresponding link members. At 3.30 Hz the mode was accompanied by shear deformation within the plane between the two groups of the wings.

Thus, around 3 Hz the wings were found to move in the modes in which the wings rotate in relation to the center of the building, due to the expansion and contraction of the link members (the link braces at 2.70 and 2.82 Hz, the link slabs at 3.10 and 3.30 Hz).

Since these natural modes were excited by the link members, the peaks were clear and the damping factors were small, reflecting the characteristics of the materials. In these modes the swaying was small.

(3) 4 Hz and Above: Only small peaks were found at 5.20 and 5.80 Hz in the X-excitation, and the modes for the D wing were all secondary, as shown in Fig. 4.

4.3 Natural Frequencies of Torsional Excitations

The torsional natural frequency was ob-

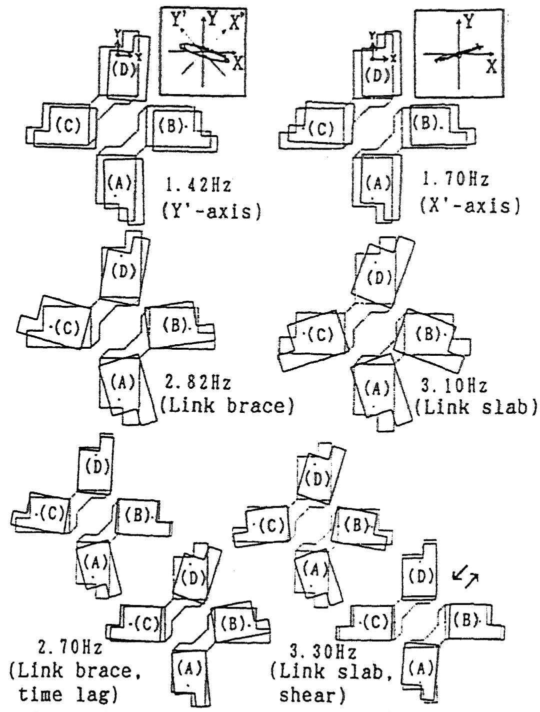

Fig.5 Plane modes on the roof (X-Excitation)

served at 1.62 Hz (Fig. 3). Since the four wings were connected, the building is susceptible to torsional deformation around the vertical axis through the center of the building, and the peaks were clearer than in the X- and Y-excitations. The ratio of the ground torsion to the total torsion was approximately 20% at 1.62 Hz.

4.4 Damping Factor

Table 1 shows the damping factors obtained by half power method from the resonance curve and calculated from logarithmic decrements in the free vibration test. The damping factors for the natural vibrations around 1.5 Hz were apparently large by the influence of soil-structure interaction and dustering of some peaks around 1.5 Hz. The damping factors of the mode in the range between 2.7 Hz and 3.3 Hz were on the small level of 1.0% - 1.5% reflecting the small material damping of link members.

5. POINT LOADING AND EARTHQUAKE RESPONSE ANALYSIS

By modeling this building into a three dimensional shear springs/torsional springs lumped mass system, an eigenvalue analysis, a point loading analysis for simulating the test and a seismic response analysis were

Table 1 Natural frequency and damping factor

Forced Vibration Direction	Natural Frequency (Hz)	Mode	Damping Factor		
			Forced Vibration		Free Vibration
			1ch	2ch	
X	1.42	Y'-axis	-	-	0.017-0.064
	1.70	X'-axis	-	-	-
	2.82	Link brace	0.011	0.009	-
	3.10	Link slab	0.011	0.013	-
			1ch	2ch	
Y	1.50	X'Y'-axis	-	-	0.020-0.064
	2.82	Link brace	0.012	0.012	-
	3.30	Link slab	-	-	-
			1ch	2ch	
Torsion	1.62	Torsion	0.056	0.053	0.020-0.086

performed (Guan et al., 1992). The damping factors were set at 10% at the fundamental modes, taking the radiation damping into account, and at 1.5% for the modes due to link members.

Fig.6 shows the resonance curve obtained from the point loading analysis, in comparison with the test results. This system is considered to be in good conformity with the test results. Seismic response analysis using this system revealed that the vibration modes due to the link members excited by the vibration tests have small effect on the seismic response of the building.

6. CONCLUSION

The dynamic characteristics of this building are much more complicated than those of rectangular-planned buildings. The results of this study are summarized as follows:

(1) The peaks around 1.5 Hz show the fundamental vibration of the building. The natural frequencies are: 1.42 Hz along the Y'-axis, 1.70 Hz along the X'-axis, and 1.62 Hz in the torsional direction.

(2) The peaks around 1.5 Hz were not so sharp, because, by connecting the four wings, the vibration modes of the wings were affected by one another, and also because of energy radiation into the ground.

(3) The modes of the building are nearly straight at around 1.5 Hz. This is due to the effect of the link braces to reduce torsional behavior.

(4) There exists a few modes in the neighborhood of 3.0 Hz, due to the expansion and contraction of the link braces or link slabs, which are peculiar to this building. In these modes, each pair of two sub-buildings connected by the braces or slabs rotates in opposite direction around the center of the four buildings.

(5) According to the response analysis, the modes due to the link members do not affect seriously the seismic response of the building.

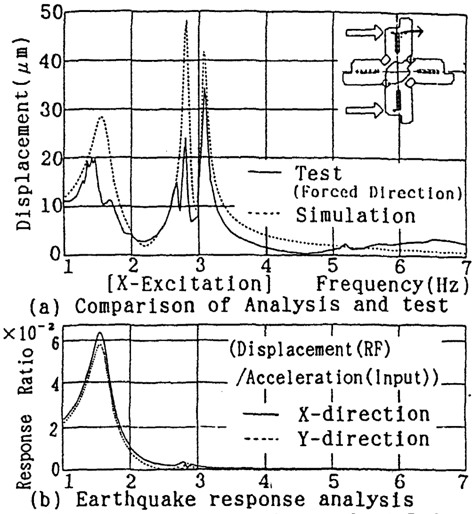

Fig.6 Resonance cure at the roof of Dwing by the analysis

ACKNOWLEDGEMENT

The authors express their gratitude to Prof. Yutakà Matsushima of University of Tsukuba, and Mr. Yoshikazu Kitagawa of the Building Research Institute, Ministry of Construction for their kind advice. The auther also wish to acknowledge Mr. Tadanobu Nagao, and Mr. Shuhei Sudo of Nihon Sekkei Inc., for their cooperation of the tests. This paper is dedicated to the late Mr. Kaio Osada, who advised the authors during the tests.

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