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EARTHQUAKE RESPONSE OF REINFORCED CONCRETE WEAK-MODEL STRUCTURES DUE TO DECEMBER 17, 1987 EARTHQUAKE

by

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1. INTRODUCTION

Since August in 1983, earthquake response observations of reinforced concrete weak model structures have been carried out at the Chiba Experimental Field of the Institute of Industrial Science, University of Tokyo. More than one hundred sets of records on acceleration, inter-story displacement and strain of reinforcing bars were obtained by February in 1988. This paper describes the response characteristics due to the December 17, 1987 earthquake, named Chiba Toho-oki Earthquake, which was the most severe since the observation had started.

2. WEAK MODEL STRUCTURES

The model structures are five-story building models which are about 1/4 size of actual structure. Two model structures have been utilized for the observation, one was designed to cause yield hinges at column ends; strong beam-weak column, and the other at beam ends; weak beam-strong column. The design base shear was reduced to about 50% of the real practice in Japan so that the structures could take damage even in moderate earthquake. The dimensions of the model structures are shown in Fig. 1, and column and beam sections are shown in Fig. 2. The location of each structure is shown in Fig. 3.

3. GROUND MOTION

Ground motion of the earthquake was the most intense since the observation had started. Characteristics of the earthquake are summarized in Table 1. Fig. 4 shows the locations of the epicenter of the earthquake and the observation station. The epicenter was located about 45 km Southeast from the observation station and the focal depth was about 60 km. J.M.A. Intensity at Chiba was V and IV at Tokyo. The Richter magnitude was estimated as 6.7. Fig. 5 shows the ground motion recorded at the depth of 1 meter under the ground close to the weak column structure. The peak values were 400 gals in N-S direction, 223 gals in E-W direction and 124 gals in vertical direction. The acceleration response spectra of the ground motion are shown in Fig. 6. The spectra have the extremely high peak in the short period between 0.15 and 0.2 seconds. The peak value for 5% of critical damping reaches 2,000 gals for the N-S component. This peak indicates the predominant period of the ground.

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4. RESPONSE CHARACTERISTICS OF WEAK MODEL STRUCTURE

Both weak model structures have already suffered the damage due to past earthquakes (for example : October 4, 1985 earthquake). The damage of weak column structure was between medium and small, and that of weak beam structure was slight by Japanese classification. However, the weak model structures suffered the severe damage and numbers of cracks occurred due to this earthquake. The foundamental natural periods of the weak model structures became twice as long as the initial elastic periods.

BEHAVIOR OF WEAK COLUMN STRUCTURE

The maximum response base-shear coefficient during the earthquake was 0.19. Fig. 7 shows the crack patterns occurred due to the earthquake. Several flexural cracks at the column ends were observed at each story. The horizontal peak acceleration and maximum inter-story displacement at each floor of weak column structure are shown in Table 2. The maximum acceleration were 260-468 gals at the 1st floor, 388-767 gals at the 3rd floor and 411-591 gals at the roof floor. Fig. 8 shows the time history of the horizontal acceleration records observed at each floor. Fig. 9 shows the distribution of the response displacement and acceleration when the inter-story displacement at the 1st, 3rd or 5th story was maximum, respectively. It is found that the 1st mode shape was predominant in the X direction and the 2nd mode shape was predominant in the Y direction. Consequently the peak acceleration of the intermediate floor were relatively high in the Y direction. The changes of the vibration periods are shown in Table 3. Fig. 10 shows the hysteresis loops of 1st and 2nd story. Because of the damage due to the earthquake, the vibration periods were much longer than before. From Fig. 10, it is recognized that the stiffness degraded and the maximum inter-story displacement exceeded yield point.

BEHAVIOR OF WEAK BEAM STRUCTURE

The maximum response base-shear coefficient during the earthquake was 0.33. Fig. 11 shows the cracks at 3rd floor system. At beam ends at 2nd, 3rd and 4th floor the flexural cracks which penetrated the floor slab were observed. The number of cracks in the X direction was more than that in the Y direction. The horizontal peak acceleration and maximum inter-story displacement are shown in Table 4. The maximum acceleration were 258-285 gals at the 1st floor and 582-705 gals at the roof floor. Fig. 12 shows the time history of the horizontal acceleration records at each floor. Fig. 13 shows the distribution of the response displacement and acceleration. It is recognized that the 1st mode shape was mostly predominant in both X and Y directions. In the X direction the maximum inter-story drift angle reached 1/100 radian at 2nd and 3rd story. It is found that the vibration periods were much longer and the stiffness was much lower than before, as shown in Table 5 and Fig. 14. The stiffness degradation and hysteretic behavior were observed especially in the X direction except at the 5th story. Fig. 14 suggests that the maximum deformation became beyond yield point.

5. CONCLUDING REMARKS

(1) The response during the earthquake were greatest since the observation had started.
(2) Yielding of reinforcing bars and formation of yield mechanism were confirmed by the observation.
(3) The observed behavior due to the earthquake showed good agreement with that of the estimated yield hinge mechanism.

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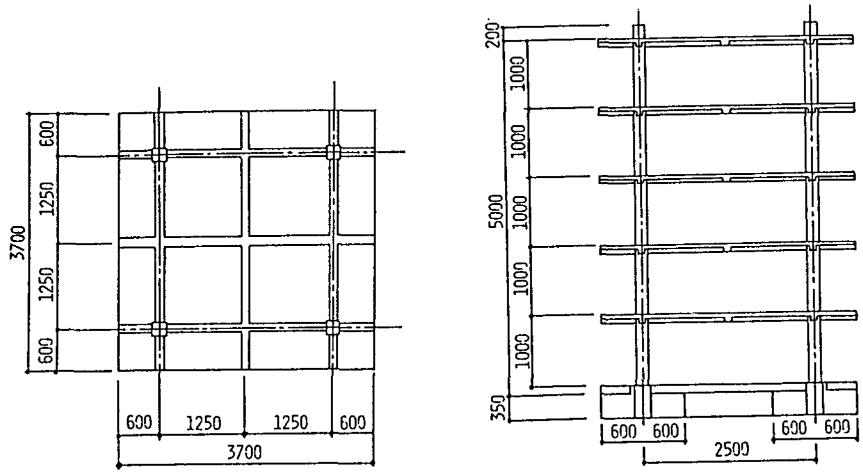


Plan unit : mm Elevation

Fig. 1 Plan and Elevation of Weak Model Structure

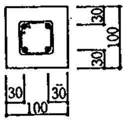
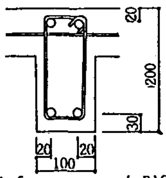
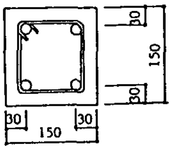
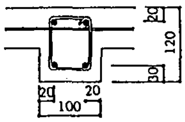
	Column Section	Beam Section
Weak Column Structure	 Reinforcement : 4-D6(SD30) Hoop: 2φ @30(SR24)	 Reinforcement : 4-D10(SD30) Stirrup: 2φ @30(SR24)
Weak Beam Structure	 Reinforcement : 4-D10(SD30) Hoop: 2φ @30(SR24)	 Reinforcement : 4-D6(SD30) Stirrup: 2φ @30(SR24)

Fig. 2 Sections of Column and Beam of Weak Model Structure

Weak Beam Structure Weak Column Structure

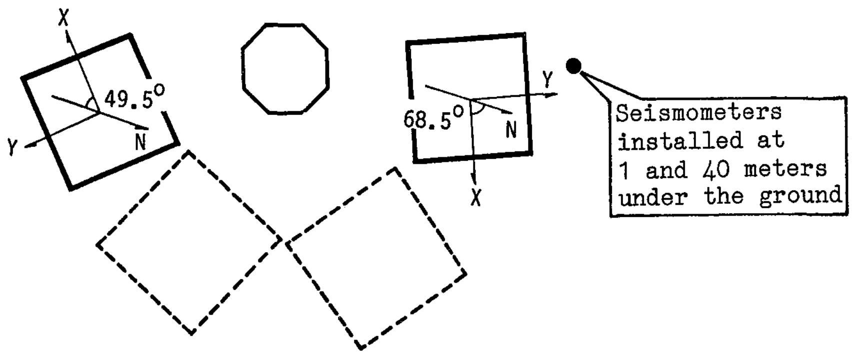


Fig. 3 Layout of Weak Model Structures

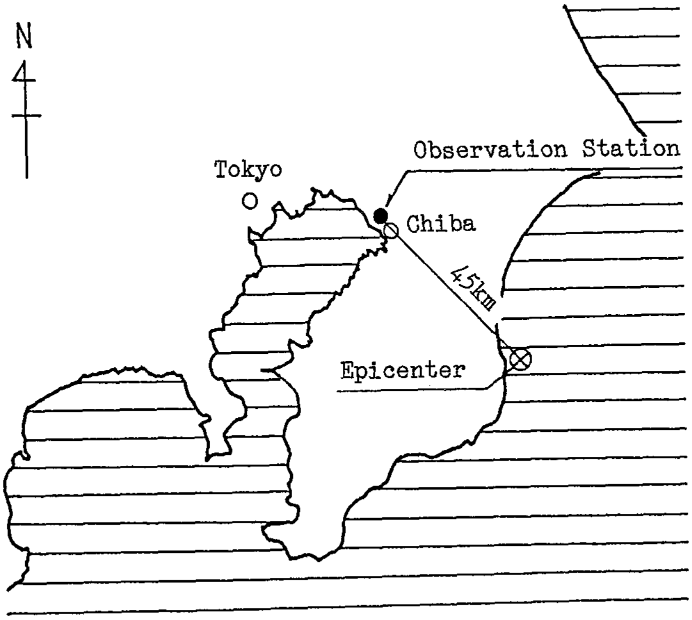


Fig. 4 Locations of Epicenter and Observation Station

Table 1 Characteristics of Earthquake

Date	December 17, 1987
Epicenter	N 35° 21' E 140° 29'
Magnitude	6.7
Forcal Depth	60 km
Epicentral Distance	45 km
JMA Intensity at Chiba	V

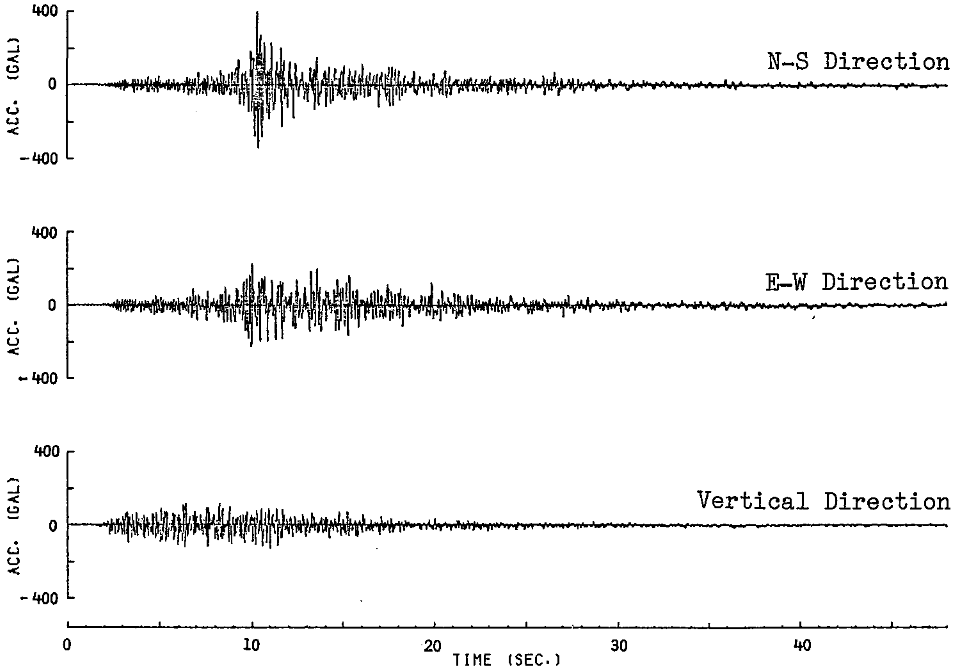


Fig. 5 Time Histories of Acceleration of Ground Motion

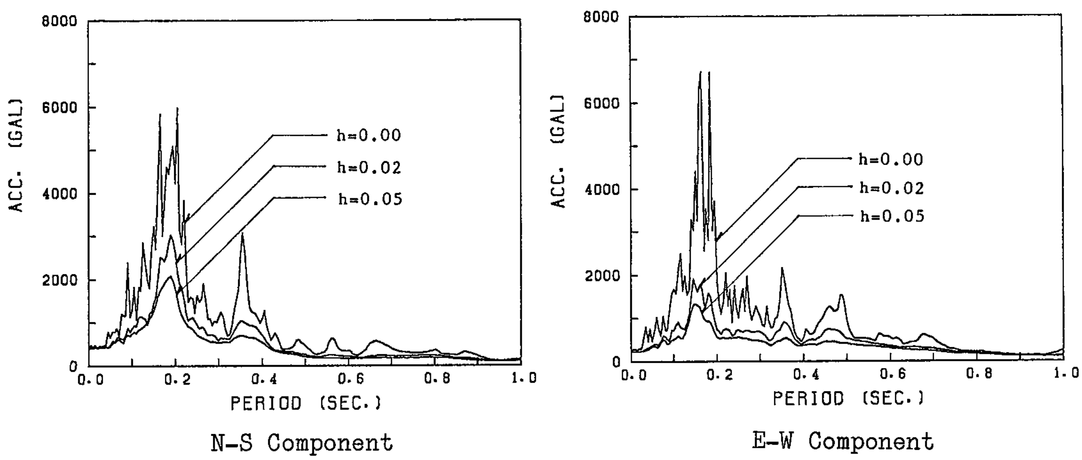


Fig. 6 Response Acceleration Spectra of Ground Motion

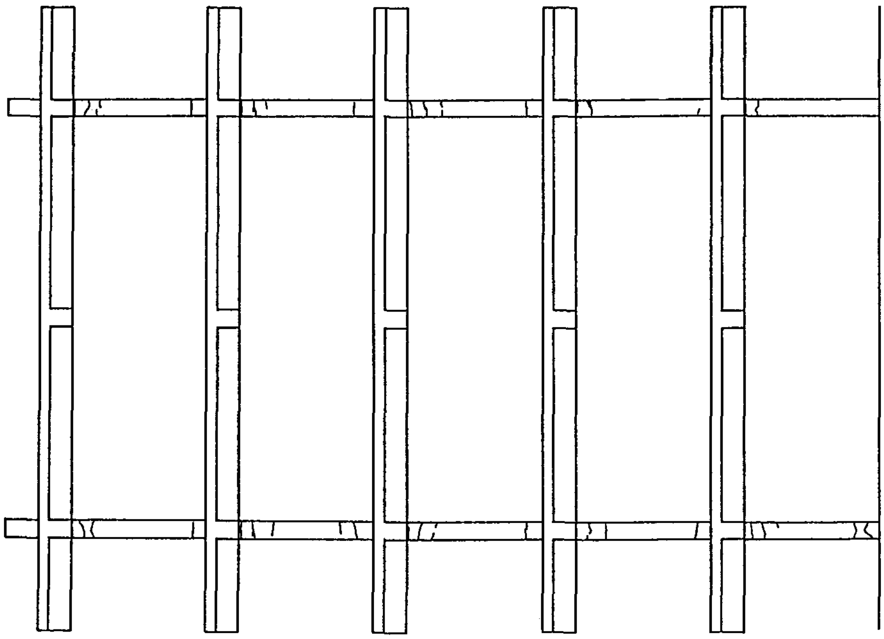


Fig. 7 Crack Patterns of Weak Column Structure

Table 2 Maximum Response of Weak Column Structure

	Dir.	Acceleration (gal)
Roof	X	411
	Y	591
5th	X	299
	Y	313
4th	X	391
	Y	633
3rd	X	388
	Y	767
2nd	X	374
	Y	419
1st	X	260
	Y	468

	Dir.	Inter-story Disp. (cm)	Inter-story Drift Angle (rad.)
5th	X	0.38	1/265
	Y	0.57	1/175
4th	X	0.84	1/120
	Y	0.79	1/125
3rd	X	0.86	1/115
	Y	0.61	1/165
2nd	X	0.86	1/115
	Y	0.69	1/145
1st	X	0.95	1/105
	Y	0.72	1/140

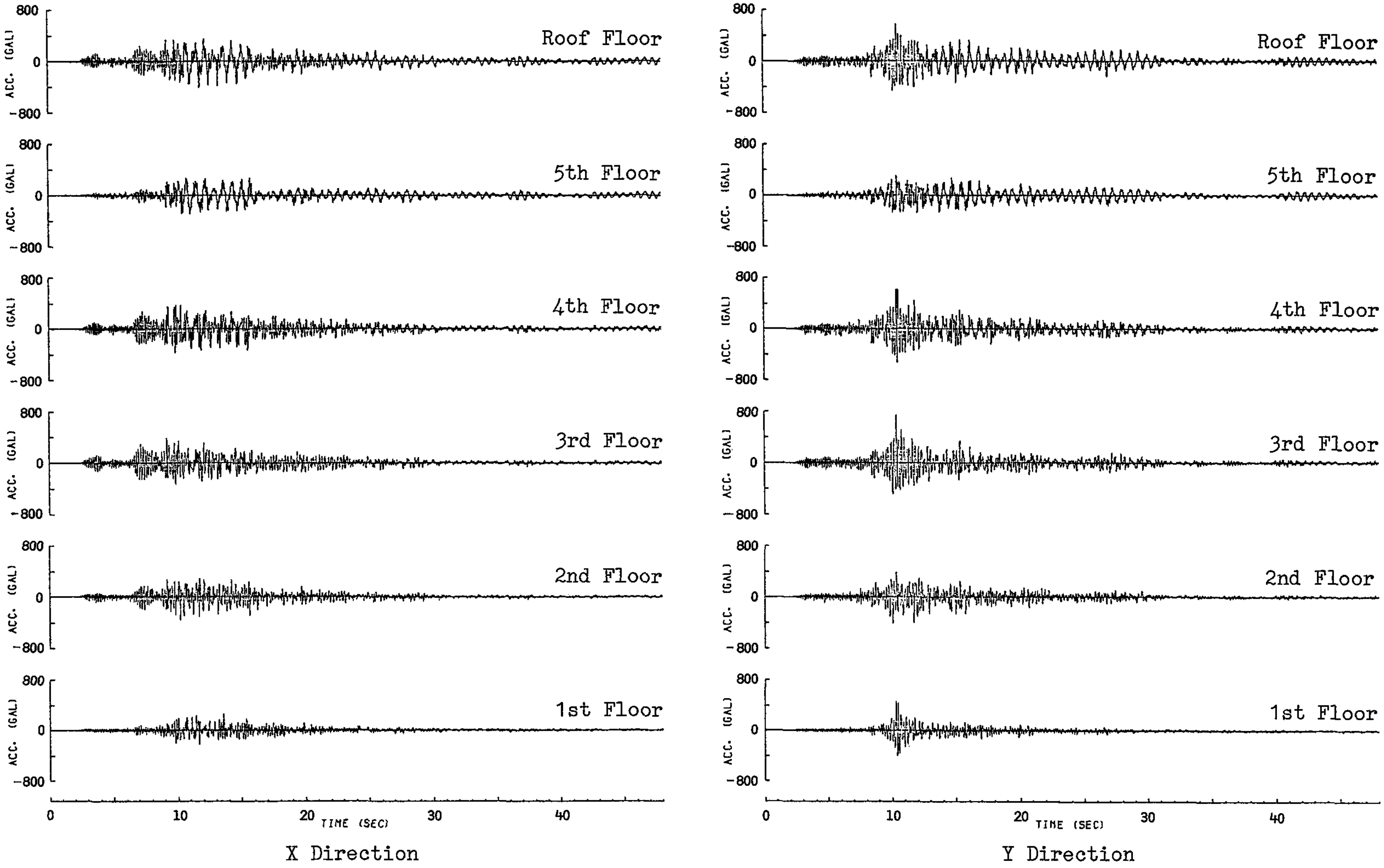


Fig. 8 Time histories of Acceleration of Weak Column Structure

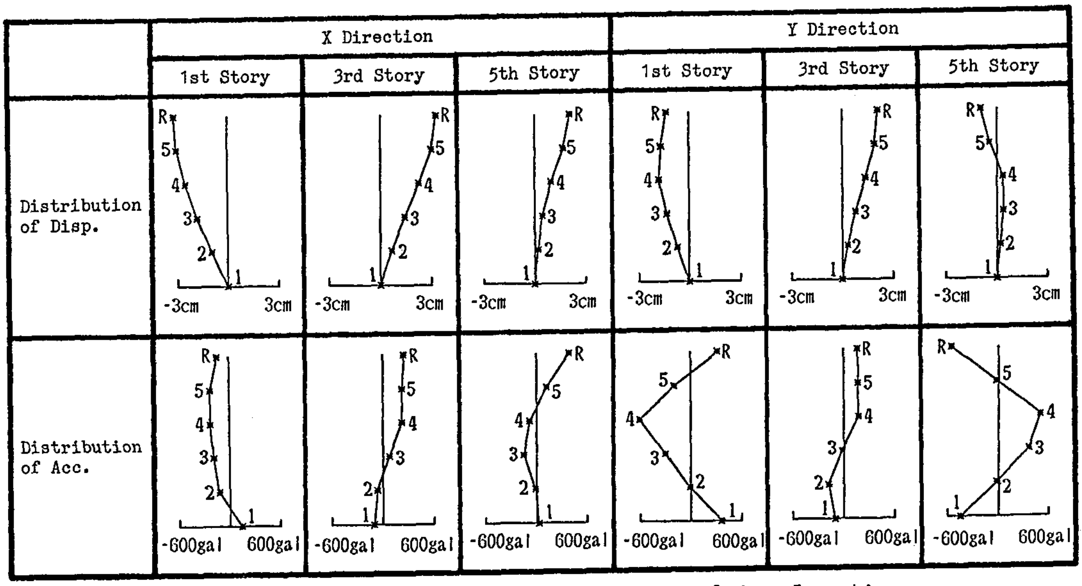


Fig. 9 Distribution of Displacement and Acceleration of Weak Column Sturcture

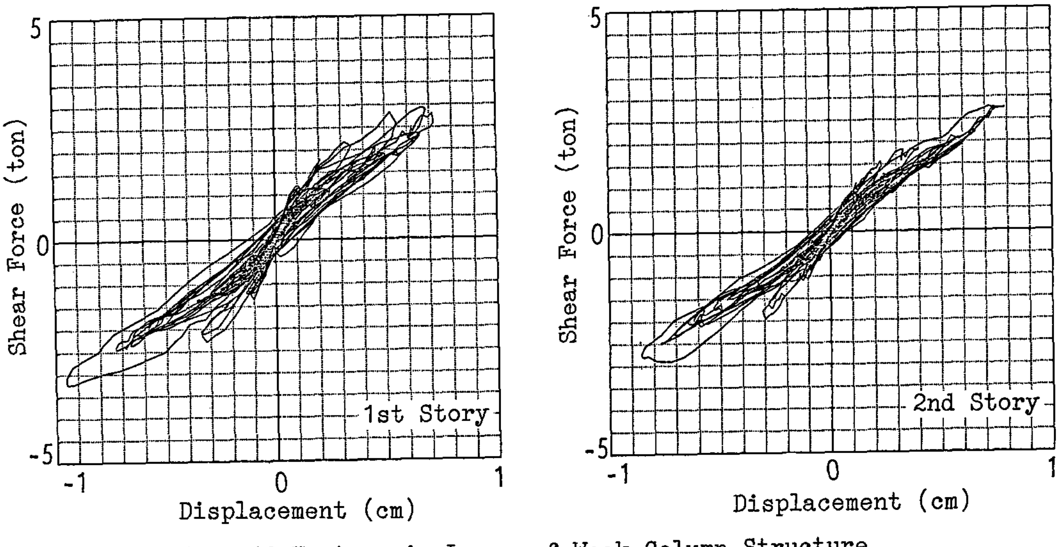


Fig. 10 Hysteresis Loops of Weak Column Structure at 1st and 2nd Story in X Direction

Table 3 Changes of Vibration Period of Weak Column Structure

	Before '87.12.17		'87.12.17 Earthquake
1st	0.4	====>	0.7
2nd	0.20	====>	0.25

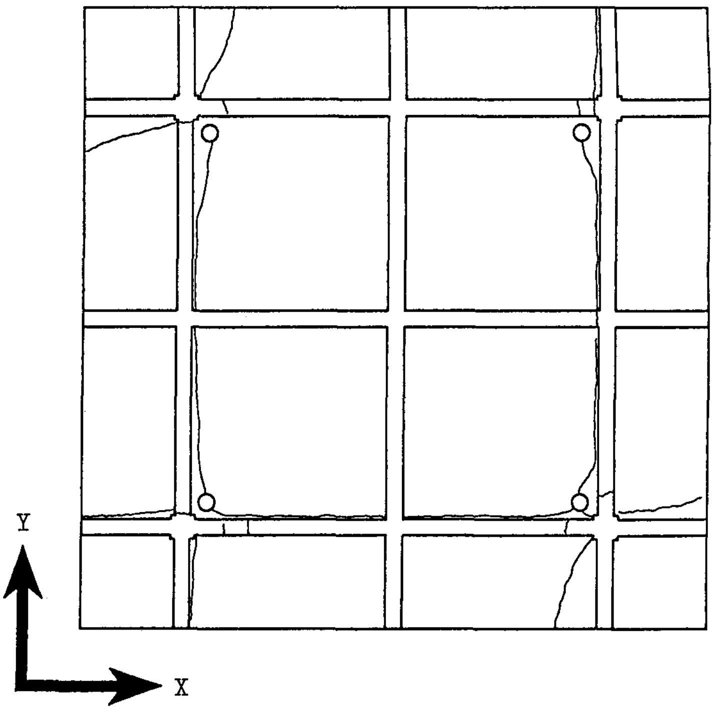


Fig. 11 Crack Patterns of Weak Beam Structure at 3rd Floor System

Table 4 Maximum Response of Weak Beam Structure

	Dir.	Acceleration (gal)
Roof	X	582
	Y	705
5th	X	512
	Y	522
4th	X	488
	Y	208
3rd	X	364
	Y	423
2nd	X	352
	Y	511
1st	X	285
	Y	258

	Dir.	Inter-story Disp. (cm)	Inter-story Drift Angle (rad.)
5th	X	0.17	1/590
	Y	0.20	1/500
4th	X	0.63	1/160
	Y	0.51	1/195
3rd	X	0.99	1/100
	Y	0.72	1/140
2nd	X	1.01	1/100
	Y	0.65	1/155
1st	X	0.65	1/155
	Y	0.36	1/280

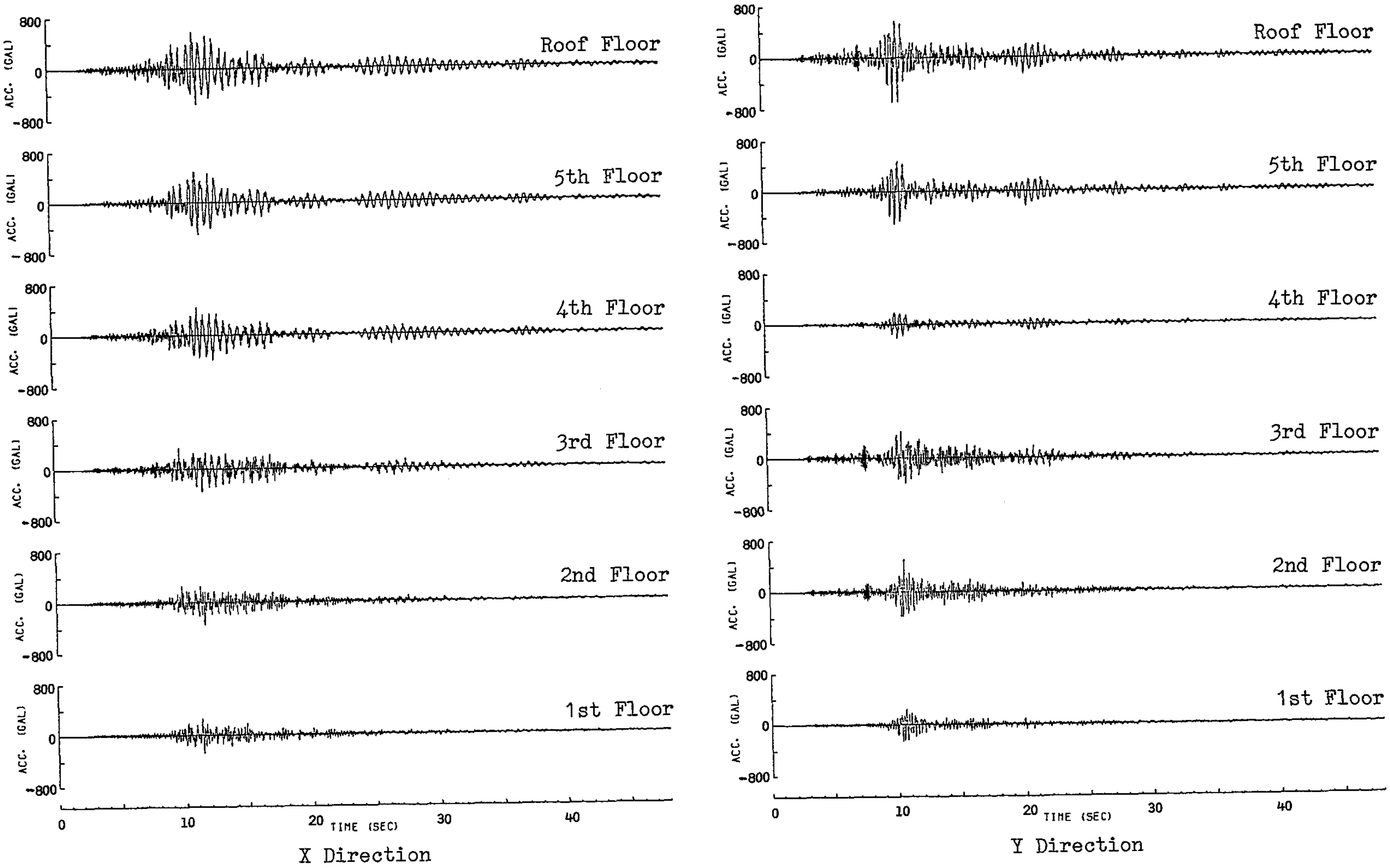


Fig. 12 Time Histories of Acceleration of Weak Beam Structure

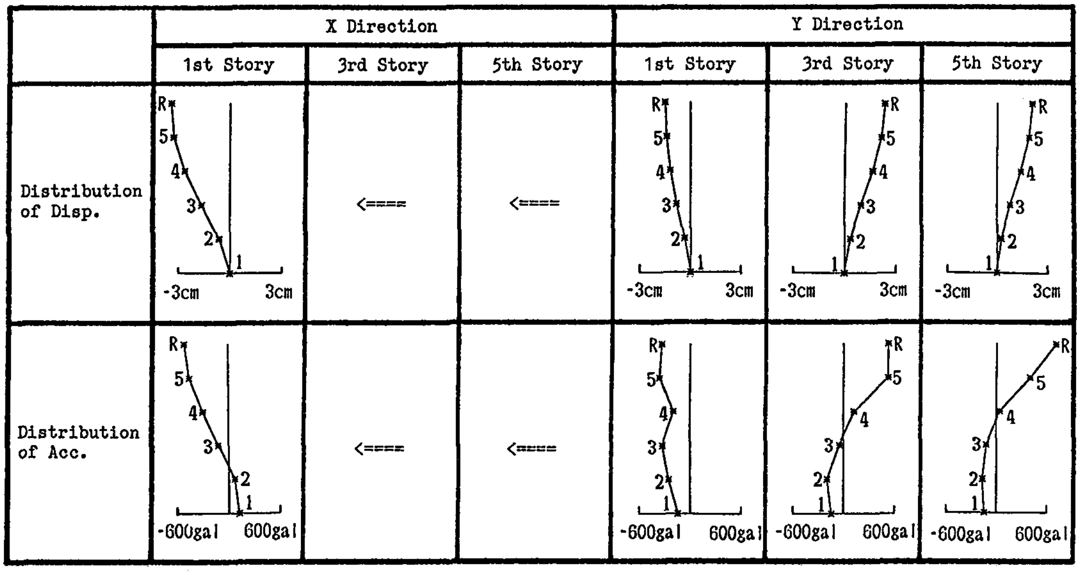


Fig. 13 Distribution of Displacement and Acceleration of Weak Beam Structure

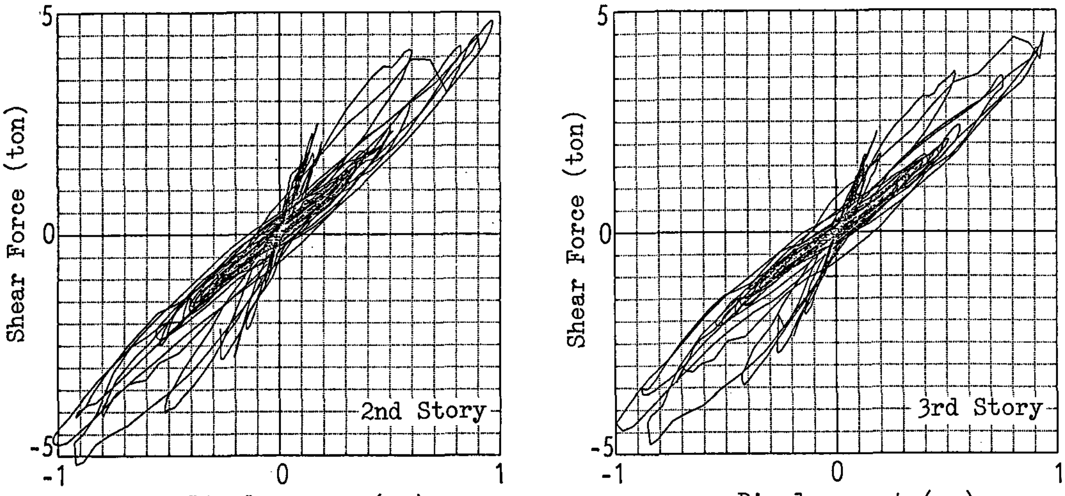


Fig. 14 Hysteresis Loops of Weak Beam Structure at 2nd and 3rd Story in X Direction

Table 5 Changes of Vibration Period of Weak Beam Structure

	Before '87.12.17		'87.12.17 Earthquake
1st	0.3	====>	0.5
2nd	0.09	====>	0.10