STUDY OF REINFORCED CONCRETE BUILDINGS DAMAGED DUE TO THE MIYAGIKEN-OKI, JAPAN, EARTHQUAKE OF JUNE 12, 1978

BY

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SYNOPSIS

In this paper, the static and dynamic analyses are carried out three-dimensionally in order to investigate the causes of the damages of two reinforced concrete buildings due to the Miyagiken-Oki Earthquake of 1978. As the results of analyses, it is found that the eccentric location of shear walls is one of the most important causes of the damages.

INTRODUCTION

Several reinforced concrete buildings were damaged beyond repair in Sendai City due to the Miyagiken-Oki Earthquake on the 12th of June, 1978. We select and analyze two buildings of them three-dimensionally, because the eccentricity between the centroids of shear force and rigidity is regarded as one of the important causes of their damages.

OUTLINE OF BUILDINGS AND THEIR DAMAGES

Two reinforced concrete buildings were three-storied office buildings built on diluvial and alluvial fan and supported by piled foundation. They were designed in accordance with the past building code of AIJ.

Building M: This was built in 1970. The plan, section and columns on the 1st story are shown in Fig. 1, 2 and Table 1. In the specification, shear walls were located in Frame 1, 2 and 5. In actual building, however, Frame 5 on the 1st story was an open frame. Therefore, shear walls were located eccentrically on the 1st story. The clear heights of columns in Frame A were short on the 1st story due to concrete block walls.

The compressive strength of concrete dug out was about 170 kg/cm^2.

This building was inclined toward northeast due to shear failure of columns in Frame 5 and A on the 1st story.

Building T: This was built in 1964. The plan, section and columns on the 1st story are shown in Fig. 3, 4 and Table 2. Floor slabs projected over from the column line A or B in E-W direction, and there was no foundation at the tips of the cantilever beams. Shear walls were located only arround a staircase of the north side.

The yield strength of steels dug out were about 2600 kg/cm^2 (22ϕ), 3440 kg/cm^2 (19ϕ) and 5500 kg/cm^2 (9ϕ). The compressive strength of concrete dug out was about 180 kg/cm^2.

The building was inclined toward southeast due to shear failure of columns on the 1st story.

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ANALYSES

It is expected that the eccentric location of shear walls proceeds the torsional rotation of the buildings during earthquake. Two kinds of analyses, therefore, are carried out. One is the analysis taking into consideration of torsional rotation, XYR-Analysis, and the other is the analysis restraining the torsional rotation of the buildings, XY-Analysis.

X-direction is longitudinal direction and Y-direction is transeverse direction of the building.

Assumptions of static analyses are as follows: (1) Beams and columns are idealized into elastic line elements with stiffness at yielding as shown in Fig. 5. Yield hinges occur on the ends when combined end moments of M_X and M_Y reach the yield ellipse shown in Fig. 6. (2) Walls, wall girders and slabs are replaced by braces. When the sum of the horizontal components of the axial force in the braces exceeds the ultimate strength of the walls or wall girders, axial stiffness of the braces become zero. (3) Foundation is supported by pin without rocking and sway due to piles.

Results of static analyses are as follows: The relations between the 1st story shear and story drift are shown in Fig. 7 and 8. In case of suffering horizontal force in Y-direction, the maximum 1st story shears of XYR-Analyses are 0.5 and 0.6 times those of XY-Analyses in Building M and T, respectively, due to the effects of torsional rotation. In case of X-direction, the maximum 1st story shear of Building T is rather shortage, in spite of little torsional rotation.

Assumptions of dynamic analyses are as follows: (1) Structure is idealized as spring-mass system without consideration of rocking and sway. (2) Each floor slab is rigid and movable in its own plane. The stiffness of a particular story is obtained by superposing the individual frame stiffness in the X- and Y-direction. (3) The plane frame stiffness is shear stiffness of its own plane and not effected by perpendicular force and deflection. (4) There are two types of the relations between shear force and drift of the plane frame as shown in Fig. 9. Restoring force characteristics of Type W is applied to the frames including walls and short clear height columns. Type F is applied to other frames. (5) Q_Y and D_Y in Fig. 9 are calculated by the same method as the above mentioned static analyses. (6) As ground motions, both horizontal components recorded at Tōhoku University (Maximum acceleration: 259 gal in N-S direction and 203 gal in E-W) are used simultaneously.

Results of dynamic analyses are as follows: The first mode of analyses are shown in Fig. 10. Maximum drifts of the 1st story are shown in Table 3. The results of XYR-Analyses show that Building M rotates remarkably, and the maximum 1st story drifts of Frame 3, 4 and 5 are beyond the yield drift (D_Y). The results of Building T are the same tendency as those of Building M, and the maximum 1st story drifts of Frame A and B are about 2 times the yield drifts in the results of both analyses.

CONCLUSIONS

It is found that the building causes large drift and rotation from the analyses taking into consideration of the torsional rotation. On the aseismic design, it is very important that shear walls should be located so well balanced that the centroids of shear force and rigidity coincide.

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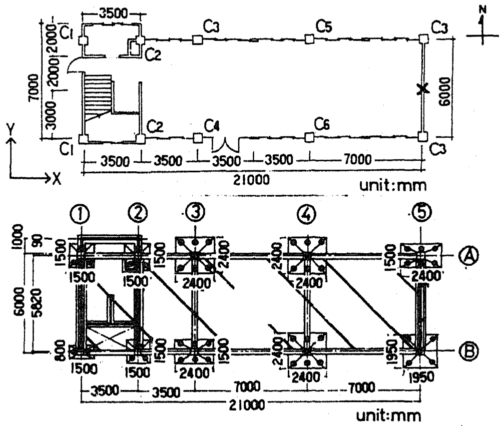


Fig. 1 The 1st floor and foundation plans of Building M

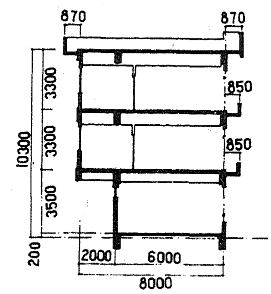


Fig. 2 Section of Building M

Table 1 Column sections on the 1st story of Building M

C1	C2	C3	C4	C5	C6
450×450	450×450	500×500	500×500	500×500	500×500
10-19Φ	12-22Φ	12-25Φ 2-16Φ	10-25Φ 2-16Φ	16-22Φ	14-25Φ 2-16Φ

HOOP: 9Φ-125@ unit:mm

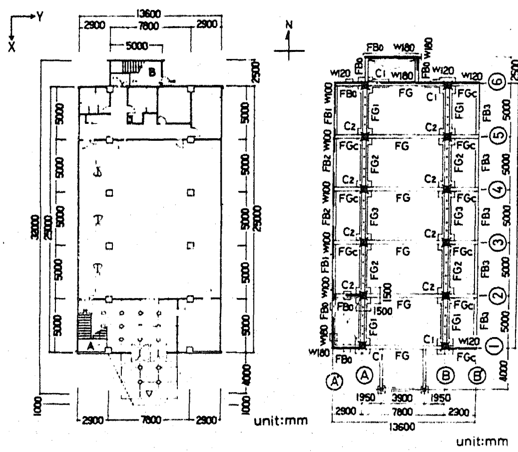


Fig. 3 The 1st floor and foundation plans of Building T

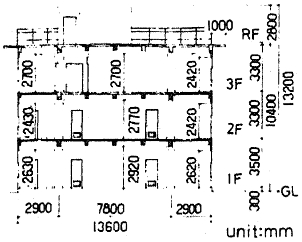


Fig. 4 Section of Building T

Table 2 Column sections on the 1st story of Building T

C1	C2
•4-22Φ •12-19Φ	•12-22Φ •4-19Φ
600 × 600	600 × 600
H-9Φ□150,300	D-9ΦX600

unit:mm

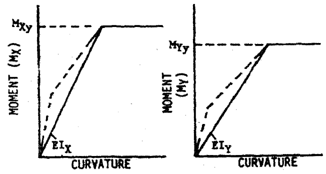


Fig. 5 Moment-curvature relations in static analyses

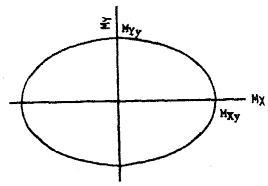


Fig. 6 Yield ellipse in static analyses

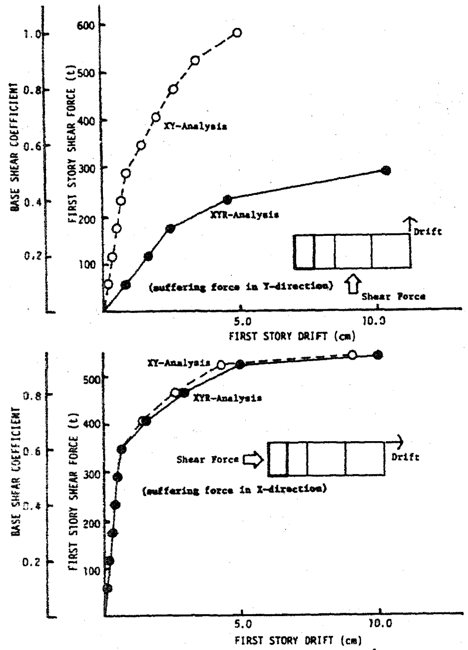


Fig. 7 Relations between the 1st story shear and story drift of Building M

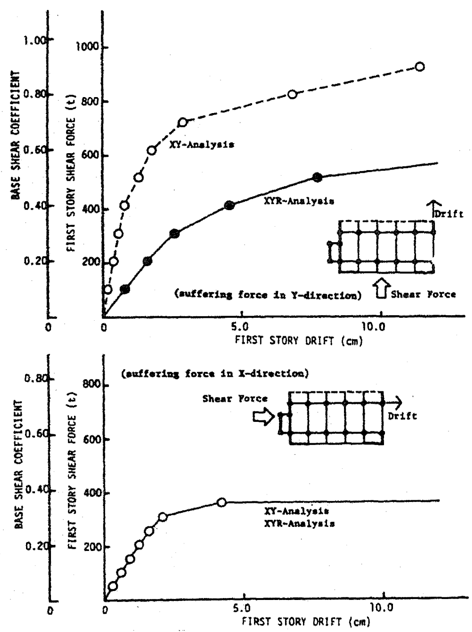


Fig. 8 Relations between the 1st story shear and story drift of Building T

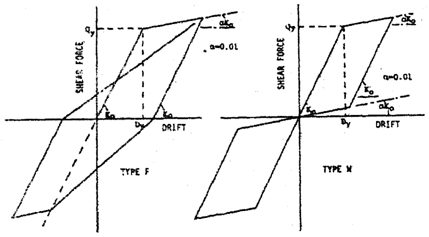
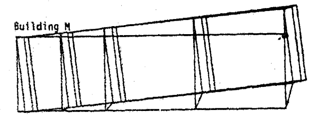
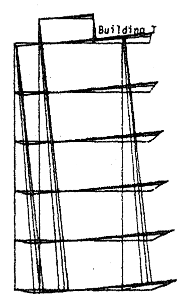


Fig. 9 Types of restoring force characteristics in dynamic analyses

1st mode periods (seconds)

Building M			Building T		
XYR-Anal.	XY-Anal.		XYR-Anal.	XY-Anal.	
	X	Y		X	Y
0.64	0.60	0.40	0.65	0.54	0.45





1st mode shapes of XYR-Analyses

Fig. 10 First mode of analyses

Table 3 The maximum 1st story drifts from dynamic analyses

Building M		Number of Frame						
		A	B	1	2	3	4	5
XY-Analysis	Drift (cm)	0.19	0.19	1.66	1.66	1.66	1.66	1.66
	D.F.	0.75	0.05	0.64	0.49	0.95	0.95	0.69
XYR-Analysis	Drift (cm)	0.25	2.58	0.57	1.46	3.04	6.39	9.78
	D.F.	0.99	0.74	0.22	0.43	1.73	3.64	4.07
Restoring force characteristics		W	F	W	W	F	F	F

Building T		Number of Frame									
		A'	A	B	1	2	3	4	5	6	7
XY-Analysis	Drift (cm)	4.39	4.39	4.39	1.49	1.49	1.49	1.49	1.49	1.49	1.49
	D.F.	0.45	2.09	1.91	0.29	0.56	0.56	0.56	0.56	0.66	0.92
XYR-Analysis	Drift (cm)	3.91	3.91	4.73	6.78	5.48	4.18	2.89	1.67	0.85	0.78
	D.F.	0.40	1.86	2.06	1.34	2.06	1.57	1.09	0.63	0.37	0.48
Restoring force characteristics		W	F	F	F	F	F	F	F	W	W

D.F.; (Maximum drift)/(D_y in Fig. 9), Damping Factor; 5% for 1st mode period