DYNAMIC PROPERTIES AND EARTHQUAKE RESPONSE OF A 9 STORY REINFORCED CONCRETE BUILDING

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SYNOPSIS

The dynamic properties of an actual 9 story reinforced concrete building with shear walls are investigated by forced vibration tests and earthquake response measurements. The results on the natural periods, damping and vibration shapes are presented. The building is analysed as the torsional vibration model and the calculated periods are compared with the experimental ones.

INTRODUCTION

It is one of the most important problems in earthquake engineering to study the dynamic properties and earthquake response of actual buildings. Especially the dynamic behavior of relatively low reinforced concrete buildings is very complex and difficult to analyse due to the unknown factors involved in the behavior of shear walls, the effect of foundation rocking, the inelastic behavior of structure and soil, and so on. This paper describes on the dynamic experiments and analysis of the building which houses the civil engineering and architecture department of Tohoku University, Sendai.

DESCRIPTION OF THE BUILDING

The building of the civil engineering and architecture department was completed in 1969. The plan and the section are shown in Fig. 1. It is of steel reinforced concrete construction. The main part is 9 storied and the 2 storied parts are attached both in the north and the south sides. The location of shear walls is symmetrical in the transverse direction but unsymmetrical in the longitudinal direction as shown in Fig. 1. Foundations are of individual footing type. Subsoil under the building is gravelly loam and concrete piles of 12m length are used.

The structural design was done in accordance with the Japanese Building Code and the seismic coefficient of 0.18 was adopted.

FORCED VIBRATION TESTS

Forced vibration tests using eccentric mass vibration exciter were conducted in 1969, 1970 and 1971. The exciter was located on the roof floor and the resonance curves were obtained. The first, torsional and second modes of vibration were observed. The torsional mode was seen both for the transverse (more significant) and the longitudinal excitations. Table 1 shows the periods obtained from the peaks of resonance curves. From the comparison of the results of the successive three years, the periods seem to be elongated as the years pass. The effect of excitation level is seen. An example of the resonance curve and the vibration shapes is shown in Fig. 2.

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Damping factor obtained from resonance curve is about 2.5 % in average for both directions.

Foundation rocking was measured in 1971 test. Fig. 3 shows the vibration shapes of shear walls. The ratio of rocking displacement to the total displacement in the experiment is about 40 % as shown in the figure.

EARTHQUAKE RESPONSE MEASUREMENTS

The SMAC type and the electromagnetic type accelerographs are installed in the building as shown in Fig. 1. Earthquake response observation has been continued since 1969. An example of the acceleration records is shown in Fig. 4. The average of the ratios between the maximum accelerations at the each floor and the first floor for the seventeen records from 1969 to 1970 are shown in Table 2.

Natural periods of the building can be determined from the spectral analysis of response records. Figs. 5 and 6 show an example of the power spectral density function and the transfer function. Table 3 shows the periods obtained from the peaks of the spectral densities and transfer functions for the three kinds of earthquake having different intensity. Periods from spectral peaks seem to correspond with those of the first, torsional and second modes obtained from forced vibration tests. It is interesting that the values of the period differ apparently according to the intensity of earthquake. This will suggest the non-linearity of structure and soil due to the deformation level.

ANALYSIS OF THE DYNAMIC PROPERTIES OF THE BUILDING

The building is modeled by a 9 story elastic torsional vibration system with 27 degrees of freedom and the dynamic properties are calculated. Stiffness of each shear wall is evaluated as plane frame with rigid zones considering bending and shear deformations, taking into account the resistance of adjacent beams in plane, the effect of perpendicular wall and the foundation rocking. The coefficient of subgrade reaction of 30 kg/cm^3 is assumed as the ground stiffness including pile stiffness, which is determined considering the observed rocking ratio in the experiment. The factor for the effect of secondary structural elements is considered to interprete the difference between the calculated and the observed periods. The calculated periods are shown in Table 4 for the four cases. The general tendency of the experimentally obtained periods could be explained by the analysis. However, the difference between the periods from the calculation and from the experiment seems larger in the longitudinal direction than in the transverse direction.

CONCLUSIONS

Several conclusions can be deduced as follows.

1. Difference in the periods according to the deformation level is observed. Variation in the periods due to the age of the building is seen.
2. Natural periods obtained from the analysis of measured earthquake response correspond with those from the forced vibration tests.
3. Natural periods from the experiments could be interpreted by the dynamic analysis of the building as the torsional vibration model.

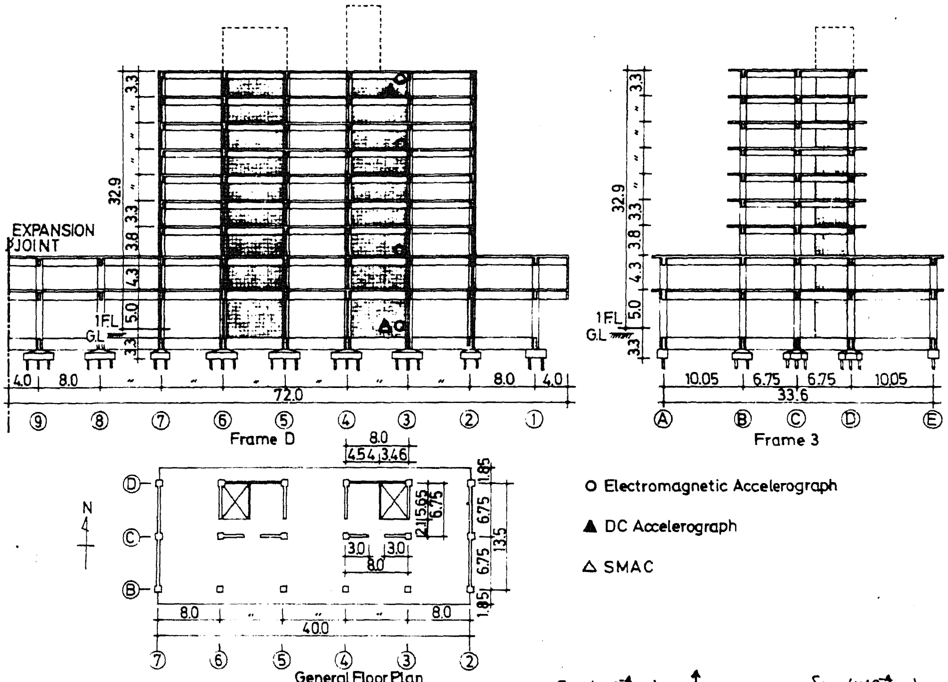

FIG. 1 PLAN AND SECTION OF THE BUILDING

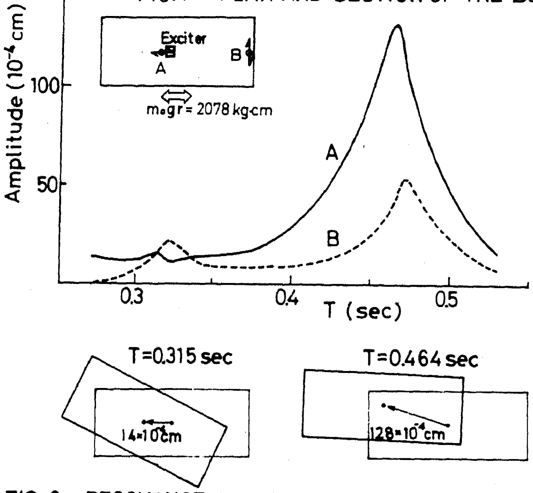

FIG. 2 RESONANCE CURVES AND VIBRATION SHAPES OF THE TOP FLOOR FROM FORCED VIBRATION TEST

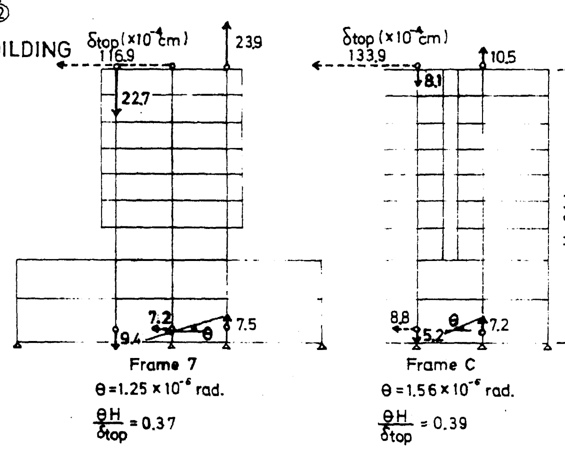

FIG. 3 ROCKING OF SHEAR WALLS IN FORCED VIBRATION TEST ($m \cdot gr$ = 2078 kg-cm)

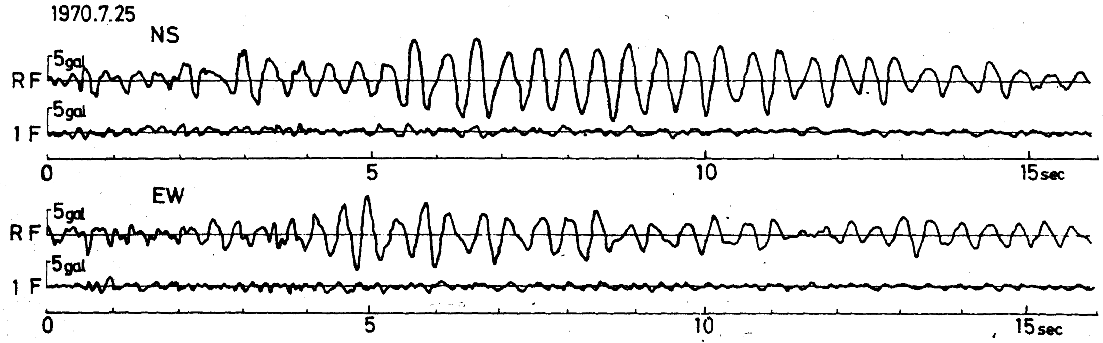

FIG.4 ACCELERATION RECORDS

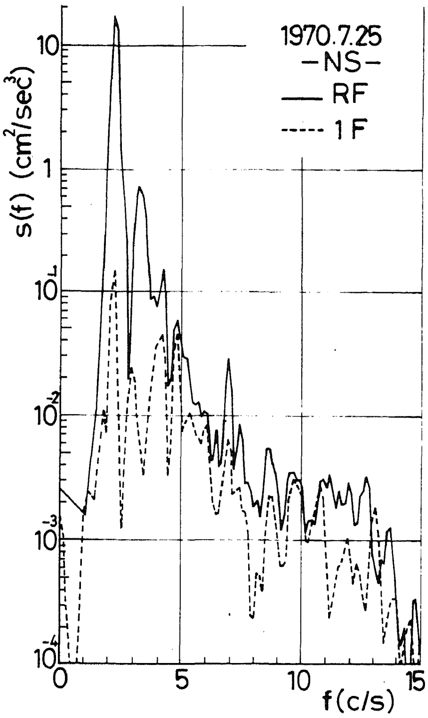

FIG.5 POWER SPECTRAL DENSITIES

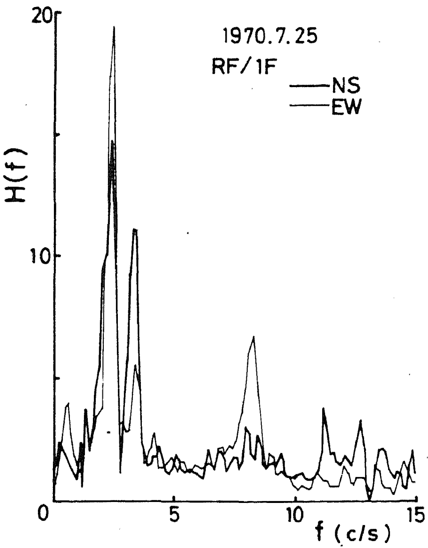

FIG.6 TRANSFER FUNCTIONS

TABLE 1 NATURAL PERIODS FROM FORCED VIBRATION TESTS

Year	Eccentric Moment (kg.cm)	Longitudinal Excitation T_1 (sec)	Longitudinal Excitation T_t (sec)	Longitudinal Excitation T_2 (sec)	Transverse Excitation T_1 (sec)	Transverse Excitation T_t (sec)	Transverse Excitation T_2 (sec)
1969	721	0.408	——	0.127	0.438	0.284	——
	1002	0.412	——	0.124	0.438	0.287	0.136
1970	742	0.443	——	——	0.460	0.305	0.150 0.108
	6022	——	——	——	0.463	0.308	——
1971	789	——	——	——	0.472	0.317	0.115
	2078	0.458	0.310	0.160	0.476	0.320	——
	6022	0.477	——	——	0.480	0.320	——

T_1=1st mode period
T_2=2nd mode period
T_t=torsional mode period

TABLE 2 ACC. RATIO OF EACH FLOOR TO THE FIRST FLOOR

	3F/1F	7F/1F	RF/1F
Maximum	2.0	4.2	6.6
Minimum	0.3	1.0	1.6
Average	1.4	2.7	4.1

Average of 17 earthquakes from 1969 to 1970

TABLE 3 PERIODS FROM POWER SPECTRAL DENSITIES AND TRANSFER FUNCTIONS

Earthquake		Predominant Periods (sec) T_1 H(f)	T_1 S(f)	T_t H(f)	T_t S(f)	T_2 H(f)	T_2 S(f)	Max. Acc. at Top Floor (gal)	Magnitude	Intensity* Scale (Sendai)
70.7.25	NS	0.42	0.47	0.31	0.32	0.13	0.15	8	4.1	I
	EW	0.42	0.42	0.30	0.30	0.12	0.15	7		
70.9.14	NS	0.44	0.50	0.33	0.33	0.14	0.16	100	6 2	IV
	EW	0.47	0.50	0.33	0.33	0.14	0.17	111		
70.10.16	NS	0.44	0.47	0.33	0.32	0.14	0.15	52	6 2	II
	EW	0.47	0.47	0.32	0.32	0.14	0.17	44		

H(f): Transfer Function
S(f): Power Spectral Density

NS : Transverse Direction
EW : Longitudinal Direction

* Japan Meteorological Agency

TABLE 4 NATURAL PERIODS FROM ANALYTICAL STUDY

* Dominant Mode Shape

	Assumed Ground Stiffness (kg/cm³)	Factor for Secondary Elements	Longitudinal*(X) (sec) 1st	2nd	3rd	Transverse*(Y) (sec) 1st	2nd	3rd	Torsional* (sec) 1st	2nd	3rd
Case 1	∞	1.0(X,Y)	0.497	0.163	0.093	0.429	0.144	0.079	0.315	0.124	0.064
Case 2	30	1.0(X,Y)	0.573	0.173	0.094	0.485	0.153	0.080	0.355	0.127	0.064
Case 3	30	1.2(X,Y)	0.525	0.159	0.085	0.448	0.141	0.073	0.327	0.117	0.058
Case 4	30	1.5(X),1.2(Y)	0.485	0.148	0.078	0.448	0.137	0.073	0.325	0.115	0.057