EARTHQUAKE RESPONSE ANALYSIS OF 19 STOREY PREFABRICATED REINFORCED CONCRETE FRAME STRUCTURE

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FOREWORD

During Tangshan Earthquake in 1976, the 10th apartment was subjected to an approximately 6 grade shock according to The New China Intensity Scale. A small number of infill light walls cracking from the columns were found at 6-8th stories of the frame structure. The seismograph located in the building recorded several satisfactory curves. This paper was aimed at trying to verify further the dynamic parameters of the structure by means of spectrum analysis of the earthquake records. The study of the response characteristics of this structure subjected to different seismic was presented as well.

BASIC CASE OF THE STRUCTURE

The tower-like building 10th apartment was built in 1973(I). The building area of the typical storey is 575m^2, the height of the building above the ground is approximately 60m. The prefabricated R/C frame structure was used.

The load bearing structure of the building is a R/C frame. Precast R/C piles are used in the foundation. Diagrammatic sketch for response calculation is of 19 stories (Fig. 2.1).

The recording system and mechanical starter were located in the basement, the pick-ups were respectively installed on the floor of the 5th, 10th and the 17th stories, as well as in the basement. There were four observation points altogether (Fig. 2.1). Each observation point has two horizontal pick-ups, respectively recording the two main axial directions (EW and SN), and a perpendicular pick-up.

OBSERVATION RESULTS OF STRONG EARTHQUAKE AND ANALYSIS OF RECORDINGS

1. A brief description of the earthquakes

For the purpose of analysis, three representative ones were selected from among the records obtained at 10th apartment building, listed in Table 4-1. The recorded accelerograms are shown in Fig. 4.1 to Fig. 4.3 and Fig.5 lb. The peak values of every recorded acceleration curve are shown with

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their respective occurring times as listed in Table 4.2. The biggest perpendicular accelerations were approximately one half of the maximum horizontal ones. The structural dynamic amplification factor β , i.e., the proportion of the maximum horizontal accelerations of the 17th story to those at the basement was about 2-3. The duration of the earthquake, and the ratio of occurring time of the maximum acceleration to the duration, all showed increase with the magnitude of the event (Table 4-3).

2. Frequency analysis of earthquake records

The peak values of the response spectra of W02 earthquakes basically occurred within the 0.5-0.6 seconds, while those for W01 and W03 earthquakes occurred in a wider region. The latter also included the long period components within the range of 1.25 second. It is apparent that the higher the magnitude and the longer the epicenter distance, the ground motion may contain more long period components.

Besides, the predominant periods of the environmental microtremors of the ground obtained indoors and outdoors both were o.4 second, but those of the strong ground motion during the earthquake were 0.5-0.6 second, the latter being 1.25-1.5 times of the former. It seems to show that the predominant period of the ground has to do with the amplitude of ground motion as well.

SEISMIC RESPONSE ANALYSIS OF STRUCTURE

1. The formulation of the mathematical model

In the present paper the principal structure was simplified into a multi-degree-of-freedom system, possessing flexure and shear stiffness and the seismic recordings at basement were used as the input ground motion.

(1) The calculation of the structural stiffness is as reference(2)

(2) The determination of the lumped masses
In order to determine the lumped masses at different stories of the building, the total static load, in combination with 80% of live load was taken into consideration.

(3) The choosing of critical damping ratio
Reference was made to the test results of the experimental building and other relevant data, the foundamental mode damping ratio was adopted as following: 5% for the east-west vibration; 3% for south-north vibration.

(4) The input of accelerograms
The horizontal components of seimic waves were put in as the excitation at the bottom of the model for calculation.

2. The analysis of computed results

The computed results as compared with actual earthquake records, in the way of basic frequency and the acceleration amplitude are practically the same. Fig. 5.1b shows a comparasion of the acceleration time histories.

Besides, in the siesmic response analysis the calculation of the responses to the EL Centro Earthquake of May 18, 1940 (South-North components) and the earthquake of Sungpan in China S 60° E were carried out for comparasion. The envelops of horizontal displacement and acceleration as well as the horizontal story drift, the story shear and overturning moment were calculated. Under the action of the W01, maximum value of story drift was 0.25 cm, showing that the building vibration caused by earthquake was basically still within the elastic region. Besides, there is a corresponding relationship between the calculated response and damage of the building. For instance, on the 6th to 8th stories, some partition infill walls cracked from the columns. The positions of actual observed damage and the stories undergoing biggest story drift shown by the results of calculation are quite in common with each other (Fig. 5.7)

In order to make it convenient to compare the response values of different earthquakes, the maximum accelerations of every input were readjusted to be equal to each other. Fig. 5.7-5.9 show the envelopes of the response values of all the earthquakes, the maximum accelerations of that were adjusted to $2m/sec^2$. From these figures certain views can be formed.

(1) The effect of the epicenter distance

The epicenter distances W02 and W03 were respectively 96 km and 138 km, the latter being 1.44 times that of the former. The maximum values of the acceleration were almost equal, but their effects on the 10th apartment were considerably different. For example, 1) the story drift, story shear and overturning moment under the effect of W03 were all 2-3 times of the corresponding value caused by W02; 2) from the response value distribution along the height of the building, it was found that the story drift and story shear are heavier at the lower parts in the case of W03, while those were heavier on the upper parts in the case of W02.

(2) Effect of magnitude of earthquake

The epicenter distances of W01 and Wo3 were greater. In the case of these two earthquakes, structural responses were basically due to the first mode vibration. This point can be seen evidently from the ratio of the values of Fourier amplitude spectrum at the first and second frequencies in Table 5-3. Nevertheless, because of the differences in magnitudes and in maximum accelerations and in durations of the two earthquakes, their effects applied to the 10th apartment are also different. When the maximum values of the acceleration were adjusted to be equal, the various response values caused by W01 are still greater than those caused by W03.

If W01 is compared with W02, it will be found that the difference is even greater as for their effects on structure. Even when the greatest value of the acceleration of W01 is lowered to half of the corresponding value of W02, the structural response caused by W01 is still greater than that caused by W02. From this it may be seen that by virtue of the long-period seismic waves, larger and farther earthquake can cause the high building more severe damage than otherwise. If we ignore the effect of the frequency content and the duration of the ground motion and simply scale the peak acceleration of the record of a smaller earthquake to a bigger value and use it as the input function to examine the structural response during high magnitude earthquake, it will apparently be improper.

(3) Soil-structure interaction

According to relevant provision of the U.S. ATC-3-06, when soil-structure interation is taken account of, the seismic load will be reduced(3). From the envelopes of structure response, it is observable that the envelopes of response values to W01 and W03 are greater than those to EL Centro and Sungpan earthquakes. The proportions of the maximum values of story drift δ, shear Q and overturning moment M of the former to those corresponding values of the latter are shown in Table 5-4, the average value changes between 1.53 and 4.62. The fact that there exist between them such great difference is mainly because the former records were gained at the basement of 10th apartment, the last two may be considered to be the ground motion on free field. From the Fourier spectrum curves of these records, it may be noted that in the records obtained at the basement, due to the feedback effect of upper structure on the ground motion, the components which contain the period near to the foundamental period of the structure are obviously magified. This may be the cause which made the structural response larger than others. Therefore it is not always conservative to use the seismic records on free field to calculate the seismic load applied to the upper structure, supposing the ground is perfect rigid (i.e. without considering the soil-structure interaction).

From the above analysis, things which have influence upon the magnitude and state of the structural seismic response are not only the peak acceleration; the frequency contents of the accelerograms, particularly the components which periods near to the foundamental period of structure have significant influence. Therefore, rational selection of input accelerogram is the key for calculation of the structure response as well as for the determination of seismic load.

CONCLUSION

1. Predominant period of the ground of the site, from environmental tremor measurement is 0.4 second, from seismic record analysis is 0.5-0.6 second. The latter is 1.25-1.5 times of the former.

2. The natural period of 10th apartment is given in Table 4-4, the foundamental period during earthquake is 1.25 times of that measured from environmental tremor.

3. The calculated acceleration response history curves basically agree with recorded ones, there is a certain corelationship between the calculated response and the damage observed.

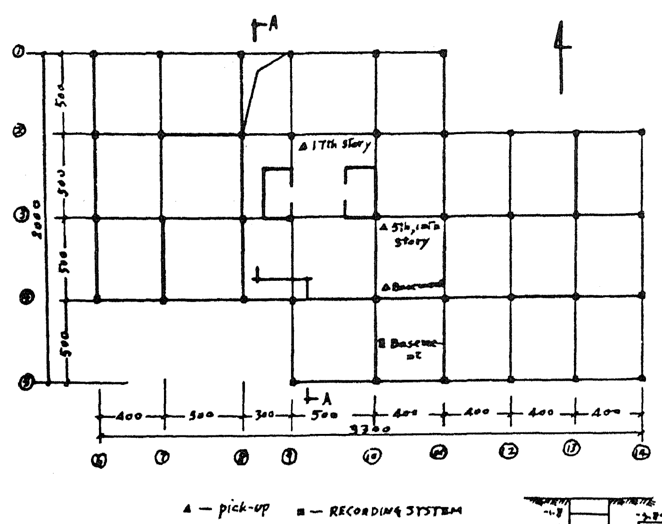
4. The frequency characteristics of the records of W01 and W02 are different, the vibration of 10th apartment excited by them are also quite different, in the former the vibration of foundamental mode shape was predominant, while the latter appeared as a vibration of mode shapes 2 and 3.

REFERENCES

(1) "16-story prefabricated appartment building", Designing Group of the Peking Architectural Planning Institute, Jornal of Architecture, 1974, No. 1.

(2) R. W. Clough, I. P. King and E. L. Wilson, "Sructural Analysis of Multi-story Buildings", Joural of the Structural Division. Proc. ASCE, Vol.90, No. St3, 1964,6.

(3) ATC with the SEAOC (1978), Tetative Provision for the Development of Seismic Regulations for Buildings.



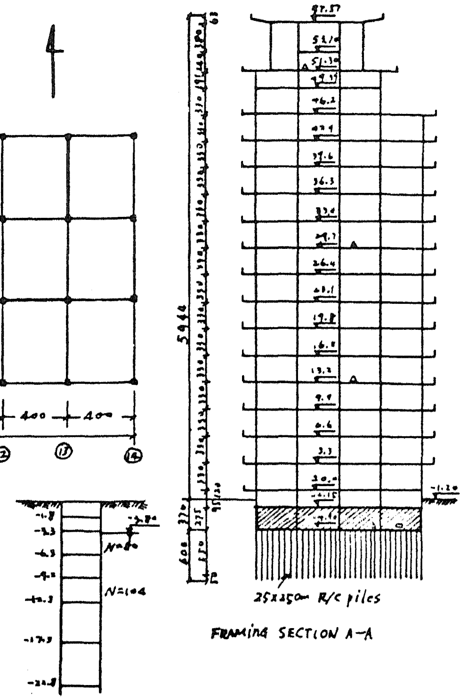


FIG. 2.1. FRAMING PLAN AND FRAMING SECTION AND LAYOUT OF SEISMOGRAPH

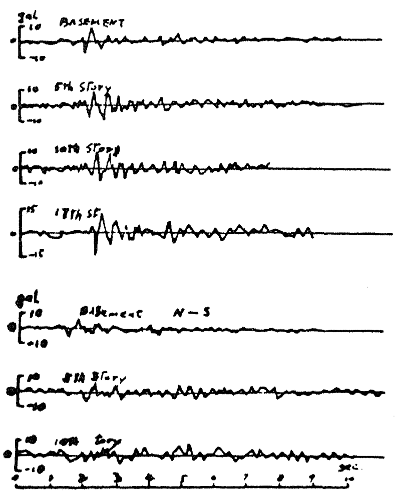


FIG. 4.2. EARTHQUAKE W02

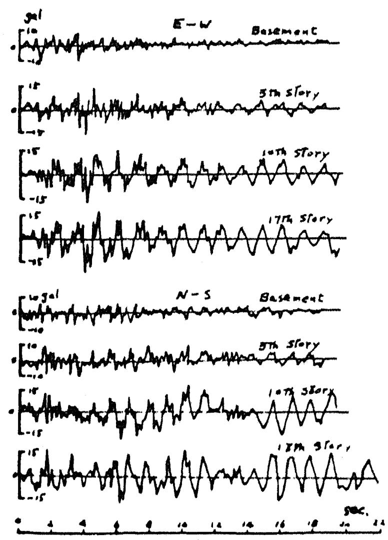


FIG. 4.3. EARTHQUAKE W03

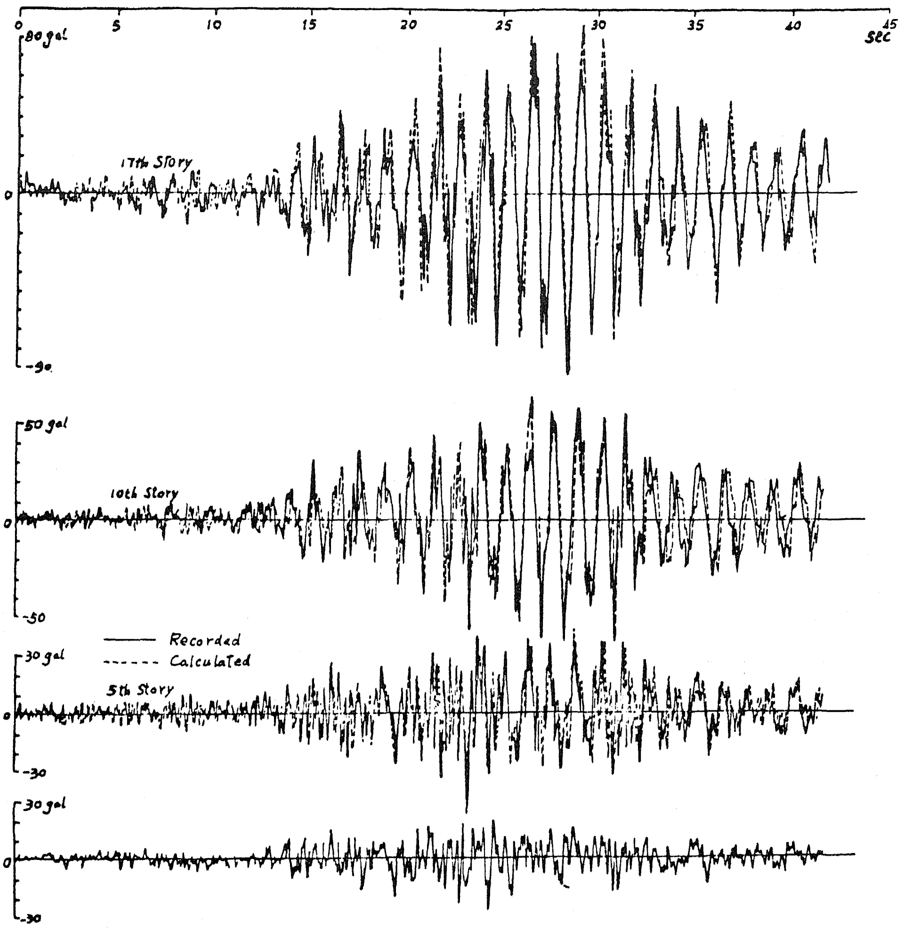


Fig 5.1b. Comparison Between Recorded and Calculated Accelerograms of W01 (EW)

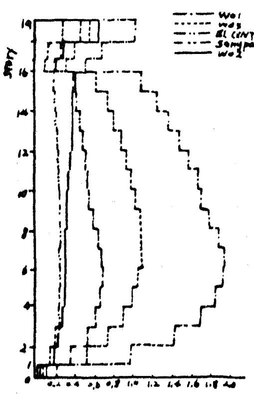


Fig.5.7. Envelops of Drift (cm)

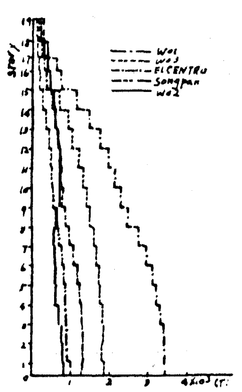


Fig.5.8 Envelopes of Story Shear

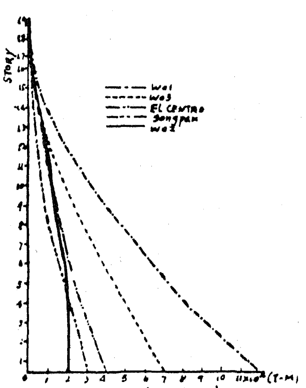


Fig.5.9. Envelopes of overturning moment

Table 4-1

Earthquake No.	Time of occurrence	Magnitude (MS)	Location of epicenter		Focal depth (km)	Epicenter distance (km)	Duration of records (sec)
W 0 1	July 28, 1976	7.1	118° 39'E	39° 50'N	10	190	42
W 0 2	Dec. 2, 1976	5.5	117° 32'E	39° 35'N	23	96	9.5
W 0 3	May 12, 1977	6.3	117° 49'E	39° 18'N	16.5	138	18.6

Table 4-2, The maximum accelerations a_{max} (m/sec^2) and their occuring time t (sec) of accelerograms

Direction	Storey	W 0 1		W 0 2		W 0 3	
		a_{max}	t	a_{max}	t	a_{max}	t
NS	17	0.648	18.17	—	—	0.172	1.752
	basement	0.226	25.29	0.0693	2.33	0.069	4.6
EW	17	0.908	28.5	0.1452	2.34	0.2159	4.016
	basement	0.263	24.57	0.0887	2.23	0.1048	3.76
UD	basement	0.131	17.97	0.039	1.53	0.046	4.145

Table 4-3

Item \ Earthquake No.	W 0 1	W 0 3	W 0 2
Magnitude (MS)	7.1	6.3	5.5
Duration Td (sec)	24	13.1	3.04
Occurring time of the maximum accelerations /Td	0.442	0.265	0.099
Dynamic amplification factor β	3.16	2.28	1.64

Table 4-4, Structural natural periods obtained from earthquake records

Earthquake \ Period (sec)		T_1	T_2	T_3
W 0 1	E W	1.26	0.37	
	N S	1.20	0.33	
W 0 2	E W	1.20	0.37	0.22
	N S	1.22	0.32	
W 0 3	E W	1.26	0.34	0.21
	N S	1.24	0.30	

Table 5-3, Ratio of Fourier amplitude spectrum of 1st and 2nd frequency

Earthquake No. / Direction / Story	W 0 1		W 0 2		W 0 3	
	N S	E W	N S	E W	N S	E W
17	7.23	4.86	—	0.578	5.62	3.26
10	6.07	5.72	1.05	0.354	3.15	3.12
5	2.19	2.07	0.415	0.237	1.53	1.61
basement	1.76	2.15	0.27	0.08	1.1	1.78

Table 5-4

Structure	Response	W 0 1	W 0 1	W 0 3	W 0 3
Direction	quantity	EL CENTRO	Sungpan	EL CENTRO	Sungpan
N S	δ	1.77	5.63	1.48	4.75
	Q	1.65	3.46	1.41	2.94
	M	1.86	3.89	1.48	3.08
E W	δ	2.84	7.46	1.59	4.33
	Q	2.75	3.50	1.48	1.85
	M	2.88	3.79	1.73	2.25
Average		2.29	4.62	1.53	3.20