PRELIMINARY ANALYSIS OF STRONG-MOTION RECORDS OF THE TANGSHAN EARTHQUAKE AND ITS AFTERSHOCKS

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SUMMARY

This paper summarises the general features of the strong-motion observation in the Tangshan earthquake of July 28, 1976 (M=7.8) and its aftershocks. Distributions of stations, epicenters and related seismic parameters are presented. The characteristics of ground motion of the records obtained are analyzed primarily and the effect of focal mechanism parameters, propagation path and local site conditions are discussed.

INTRODUCTION

A destructive earthquake occurred in Tangshan-Fengnan District, Hebei Province, China, on July 28, 1976, at 3:42 a. m. (Beijing time). The magnitude of the main shock is 7.8. The focal depth is 22 km and the epicenter is located in lat. 39.4°N, long. 118°E. Satisfactory records were obtained at five stations of the strong-motion instrumentation network, in North China, during the main shock, two of the stations being located in Beijing, the others in Miyun Reservoir, Fengchung and Hongshan, Hebei Province, respectively. After the main shock, 4 mobile stations were installed immediately in Tangshan Airport, Cement Plant, Lanhe Bridge in Qianan County and Fenghuangshan in Changli County. Instruments used in the above mentioned stations were accelerographs RDZ1-12-66, characteristics of which have been described in Ref. (1). The locations of the network in North China and the mobile stations are shown in Fig. 1.

The seismic activity after the main shock was relatively high. There were 89 aftershocks of magnitude greater than 3 recorded after the installation of mobile stations within half a month. Up to Nov. 15, 1976, a total of 15 earthquake records of magnitude greater than 4, including that of the main shock, were obtained. Distribution of epicenters of these earthquakes is shown in Fig. 2.

During the main shock, records of structural response were obtained also at Beijing Hotel, Miyun Reservoir, Hujialou and Fengchun Railway Bridge Station, in addition to the records of ground motion. Beijing Hotel is a multistory R.C. framed structure, in which the measuring points are shown in Fig. 3. The results of measurement show that the natural period of the structure along the major axis increased from about 1.0 sec. recorded by microtremor measurement before the earthquake to about 1.3 sec during the event. The period along the minor axis also increases from 0.9 sec. to 1.4 sec. Besides, it is found that the horizontal vibration along the minor axis of the top floor was not symmitric and that the movements of measuring points h and i were sometimes opposite in direction, showing that a torsion vibration may be occur in Beijing Hotel.

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Inspection after the earthquake showed that the filled wall of Beijing Hotel was slightly damaged, cracks appeared in the ceiling and damage induced by the pounding of the finishing material along the settlement joint also occurred. Sliding of the facing layer of Bei-River Dam of Miyun Reservoir (64 m in height) occurred below the water level along the dam (Fig. 4). Uncontinuous cracks along the axis of the dam on the facing layer over the water level were formed, totalling 600 m. These two structures were all located in the region of intensity VI, 150 km away from the epicenter approximately. The damage pattern mentioned above was considered in relation with the fact that the low frequency component of the ground motion in the main shock was obvious and the duration of the earthquake motion was rather long.

Based on the strong-motion records obtained during the main shock and aftershocks in the Tangshan earthquake, characteristics of the ground motion and its associated affecting factors are analysed and discussed as follows.

PEAK ACCELERATION OF THE GROUND MOTION

Peak acceleration data In the 15 earthquake records used for analysis, there are altogether 82 traces of accelerograms recorded on 29 measuring points on ground surface. Peak acceleration and related data of the records are given in Table 1. Relations between horizontal component of the peak acceleration and magnitude as well as epicentral distance are shown in Fig. 5. Different symbols are used to denote different magnitudes and data taken from the same earthquake are connected by straight lines. From the figure, it is apparent that there is a trend that peak acceleration increases with the increase of magnitude and decreases with the increase of epicentral distance.

Local site condition Stations situated in Hongshan, Tangshan Cement Plant, Qianan and Changli in Fig. 1 and Table 1 are located on bed rocks (Class I soil), while stations situated in Beijing Hotel, Hujialou, Miyun Reservoir, Fengchun and Tangshan Airport are located on soils of Class II, described in the Chinese aseismic code, and Tianjin Hospital station is located on soil of Class III.

Scatter of the ground peak acceleration It should be noted in Table 1 and Fig. 2 that the epicenters of earthquakes No. 3 and No. 6 are the same and their magnitudes are pretty close to each other, while both magnitudes and epicenters of earthquakes No. 12 and No. 13 are similar. As records of these two pairs of earthquakes were obtained simultaneously in Qianan and Changli stations, so relative difference of the peak accelerations of each pair of earthquakes recorded in the same station can be computed from nine pairs of data given in Table 1, with 10% in average, 18.7% as the max. and 2.2% as the min. The records mentioned above provide valuable information for study of the scatter of ground peak acceleration and indicate that, if all other conditions, i.e. focal mechanism, propagation path and local site condition are similar, the scatter of peak acceleration on bed rocks would be rather small . As a matter of fact, the variations of the above mentioned three conditions in most strong-motion records is, in general, considerable large. According to the strong-motion records of certain earthquakes in China (2,3,4), in case of similar magnitudes and epicentral distances, variation in each of the above conditions (or factors) would probably induce the change of peak accelerations to 1- 1.5 or even 2 times. Therefore, it can be estimated that in the same earthquake (with similar focal mechanism), the ratio of max. to min. peak acceleration might reach to 4-6 times, and in different earthquakes accompanying with three different conditions, the value of ratio would raise to 8-15 times (even higher). Owing to the high scatter of peak accelerations, how to explain and use the peak acceleration of the ground motion is worthy of further study.

DURATION OF EARTHQUAKE MOTION

Duration of the accelerograms recorded in the main shock are rather long, most of them are over 2 min., some even over 4 min. and more (see Table 1). Based on the physical process of tectonic earthquakes which is much related to earthquake engineering, fault rupture plays an important role in the formation of earthquake. Strong-motion records are the result of the combined effect of all kind of seismic waves with different speeds of propagation, such as body wave, surface wave, reflective and refractive wave. In complete strong-motion record, especially in which P and S waves can be differentiated clearly by a point, there is, generally, a portion having large amplitude behind that point. This portion is called the strong-motion stage in the record. Duration of this portion depends on the time of propagation of fault rupture. If the length of fault is denoted by L (in km) and the speed of propagation of rupture by v, then the duration of the strong-motion stage of an earthquake motion, ts, can be determined by the following formula

$$ts = \frac{L}{V}$$

For example, the main shock of the Tangshan earthquake occurred on a right strike-slip fault which is nearly vertical. The strike of the fault is 30°NE. The fault is a two-way unsymmetric rupture, total length of which is 114 km. with 69 km in the NE branch and 45 km in the SW branch. The average velocity of rupture is 2.7 km/sec (5). For two-way rupture, the longer branch should be taken as the fault length in the above formula, and the duration of the strong-motion stage of the main shock is 25.5 sec. The Ninghe earthquake of Nov. 15, 1976 of magnitude 6.9, occurred on an one-way rupture. The fault length is 43 km, the velocity of rupture is 3.3 km/sec, and its duration then is 13 sec.

Duration of the strong-motion stage which is controlled by the focal parameters represents a period of concentrated release of energy of the earthquake. It plays an important role in the structural response. Therefore this portion of record can be taken as an input in the calculation of structural response.

The portion of the record before the strong-motion stage is called initial stage. If there is no delay or not much delay in the initial stage of recorded P wave which can be estimated, duration of the initial stage can be determined by the focal distance divided by the difference between P and S wave velocity. This relation has been used to deduce the focal distance of the main shock and certain aftershocks. The calculated focal distance is in good agreement with the actual distance. The portion of the record after the strong-motion stage may be called attenuation stage, in which the energy of seismic wave attenuates. Duration of this stage depends on the propagation path, properties of the medium, and the local site condition, etc. Generally, there is no obvious boundary in wave form and amplitude between the attenuation and the strong-motion stage. The length of the attenuation stage can be taken, based on the superimposition of various waves, the effect of surface wave and the purpose of application.

CHARACTERISTICS OF GROUND MOTION AND ITS AFFECTING FACTORS

It is not practical to find out the quantitative relation between characteristics of ground motion and its affecting factors by a limited number of strong-motion records in a series of earthquakes. Therefore, the aim of the following discussion and analysis is only to pay attention on some meaningful results obtained in the Tangshan earthquake.

Effect of the variation of focal parameters The prominent feature of the main shock of the Tangshan earthquake is its low stress drop of 6.8 bars in comparison with other earthquakes of the same magnitude (5). Fig. 6 shows the average stress drop in different areas, based on the parameters of aftershocks which occurred in the period between the main shock and the Ninghe earthquake of magnitude 6.9. It is seen from the figure that the stress drop in the vicinity of the epicenter of the main shock and in the south-west areas is rather low, only in the order of several bars, while in the north-east areas, stress drop is as high as 30-34 bars(5). Spectral analysis shows that stress drop may be a sensitive parameter which has effect on the characteristics of frequency spectrum of the ground motion. For example, stress drop in the Ninghe earthquake of Nov. 15, 1976 is considerable low, whereas the spectral values in the low frequency range of the Fourier Spectra, both recorded in Tianjin, Beijing and Fungchun are relatively high (Fig. 7). Inversely, No. 7 earthquake occurred in area where stress drop is high, and the spectral values in high frequency range of the Fourier Spectra of records obtained both in Tangshan, Qianan and Changli are relatively high (Fig. 8). Therefore, it seems that there is certain correlation between stress drop and the frequency of max. spectral value in Fourier Spectrum. Uniformity of stress drop may influence the spectral shape too.

Effect of propagation path The propagation path is composed of factors such as epicentral distance, orientation, physical and mechanical properties of the medium, tectonic structures, etc. The effect of propagation path on ground motion is a very complicated problem. It is shown in Fig. 8 that, although the three stations shown in the figure are on bed rocks, the amplitudes and relative values of Fourier Spectra recorded on these stations are different owing to the difference of propagation paths. Generally, max. spectral value with eignvalue decreases with the increase of epicentral distance, but the amplitude in the low frequency range increases relatively.

Effect of local site condition Local site condition is a sensitive factor affecting the intensity of ground motion, and the shape of Fourier Spectrum and response spectrum.

Variation of local site conditions is the main cause that induces the scatter of the peak acceleration of ground motion. For example, observation of aftershocks of the Haicheng earthquake shows that, with similar magnitude and epicentral distance, the ratio of peak accelerations, recorded on soil layers and bed rocks or on top and bottom of an isolated hill, may amount to 2-3 times (3). In the Tangshan earthquake, when epicentral distance is greater than 50 km, the average ratio of peak accelerations, recorded on soil layers and bedrock, is 2.5, similar to that obtained in the previous ground motion measurements. But, when the epicentral distance is about 35 km, the ratio mentioned above approaches unity.

Fig. 9 shows the Fourier Spectra, both recorded in Tangshan Airport and Cement Plant stations in the same earthquake. All conditions are the same, except the former station is located on soil layer, while the latter on bedrock. It is shown from the figure, that the shapes of Fourier Spectra are obviously different. The spectral value corresponding to frequency of 10 cycle/sec approximately in the Fourier Spectrum recorded on the bed rock is predominent, while those corresponding to the 1-10 cycle/sec. frequency band recorded on soil layer are rather high. This fact indicates that the soil layer has an oppressive effect on spectral value of certain frequencies (such as high frequency) in its Fourier Spectrum, but has magnifying effect on other frequencies, such as low frequency. In the meantime, the dynamic charateristics of soil and bedrock (or earthquake) also play a role in the frequency spectrum.

Curves a, b and c in Fig. 10 show the average values of response spectra recorded on 3 classes of soils in the main shock and aftershocks of the Tangshan earthquake (damping ratio is taken as 0.05). Dynamic amplification factor   is given in Fig. 10 for comparison. It is seen from the figure that the effect of local site condition on response spectrum is obvious, i.e. the higher the   in the long period range, the softer the soil.

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TABLE I

No	DATE OF EARTHQUAKE	MAGNITUDE M_S	FOCAL DEPTH (KM)	STATION	EPICENTRAL DISTANCE (KM)	LENGTH OF RECORD (SEC.)	PEAK ACCELERATION (g)		
							EW	NS	UD
1	July 28,1976	7.8	22	No.1001	157	150	.0661	.0731	-
				N .1002	153	135	.0564	–	-
				N .1003	153	114	.0791	.0577	.0496
				N .2001	405	138	.0141	.0170	.0104
				No.2002	391	250	–	.0071	.0047
2	July 31,1976	5.6		Mo. 201	38	38	.0338	.0285	.0284
3	Aug. 2,1976	4.7	11	Mo. 203	12	5.4	.0182	.0217	.0087
4	Aug. 3,1976	4.2	5	Mo. 203	7.5	5.4	.0520	.0593	.0186
5	Aug. 3,1976	4.7		Mo. 203	23	8.2	.0216	.0235	.0081
6	Aug. 5,1976	4.2		Mo. 203	12	5.4	.0162	.0240	.0079
7	Aug. 8,1976	5.7	15	Mo. 201	34	5	.0138	.0216	.0113
				Mo. 202	35	30	.0147	.0200	.0122
				Mo. 203	29	11.6	.0451	.0558	.0192
				Mo. 204	54	19	.0121	.0106	.0105
8	Aug. 9,1976	5.9	18	Mo. 201	53	7.8	.0127	.0139	.0080
				Mo. 202	51	19.5	.0048	.0046	.0034
				Mo. 203	18	23.4	.1658	.1805	.0910
				Mo. 204	30	27.4	.0232	.0358	.0311
9	Aug. 15,1976	5.1	12	Mo. 203	13	8	.0412	.0631	.0357
10	Aug. 15,1976	4.9		Mo. 201	20	16	.0224	.0212	.0120
11	Aug. 18,1976	4.5	10	Mo. 202	15	5.4	.0277	.0232	.0099
12	Aug. 31,1976	6.0		Mo. 203	37	22.4	.1123	.1491	.0555
				Mo. 204	44	24.8	.0314	.0360	.0292
13	Aug. 31,1976	6.0		Mo. 203	37	22	.1177	.1212	.0644
				Mo. 204	44	22	.0307	.0306	.0324
14	Sep. 25,1976	5.6		Mo. 203	38	15	.0422	.0364	.0183
15	Nov. 15,1976	6.9	17	No.1001	140	65	.0280	.0393	-
				No.2001	369	64	.0082	.0063	.0039
				No.2901	67	180	.1064	.1499	.0748

Symbols :
No.1001 Beijing Hotel
No.1002 Hujialo, Beijing
No.1003 Miyun Reservoir
No.2001 Fengchun Railway Bridge
No.2002 Hongshan
Mo. 201 Tangshan Airport
Mo. 202 Tangshan Cement Plant
Mo. 203 Qianan Lanhe Bridge
Mo. 204 Changli Fenghuangshan
No.2901 Tianjin Hospital

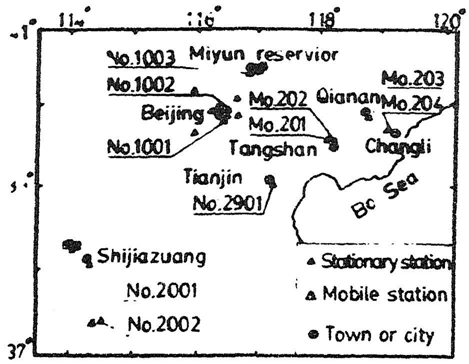

FIG.1 DISTRIBUTION OF STATION

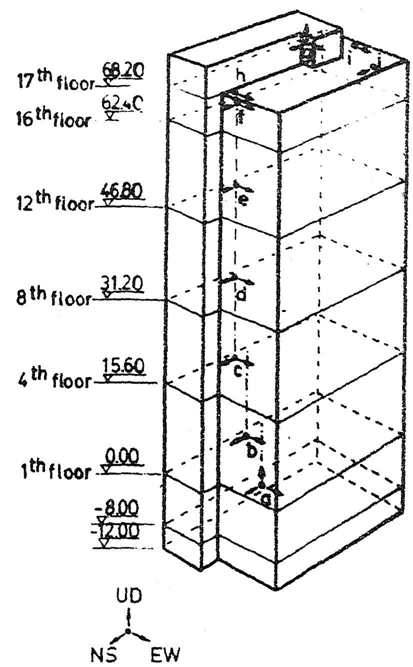

FIG.3 DISTRIBUTION OF MEASUREMENT POINTS IN BEIJING HOTEL

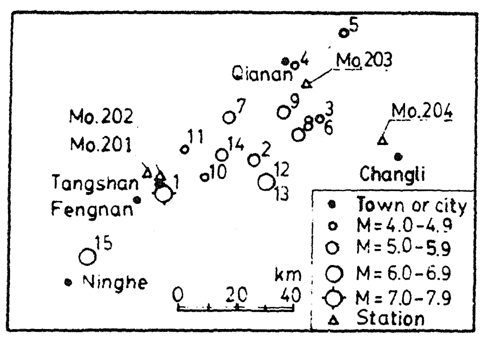

FIG.2 DISTRIBUTION OF EPICENTERS

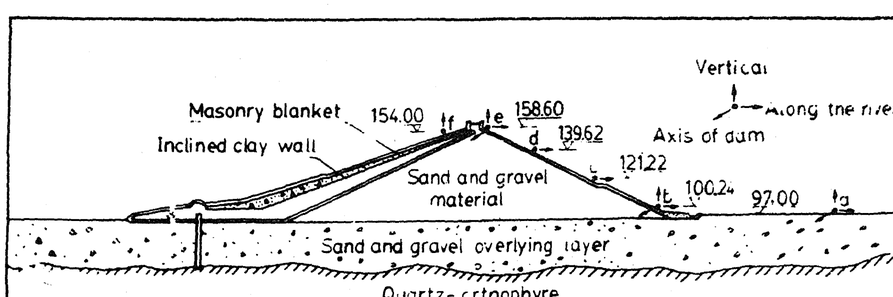

FIG.4 PROFILE OF THE BAI-RIVER MAIN DAM AND DISTRIBUTION OF MEASUREMENT POINTS ON MIYUN RESERVIOR

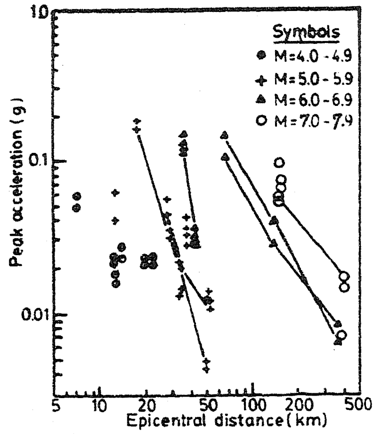

FIG.5 CORRELATION BETWEEN ACCELERATION AND MAGNITUDE AND DISTANCE

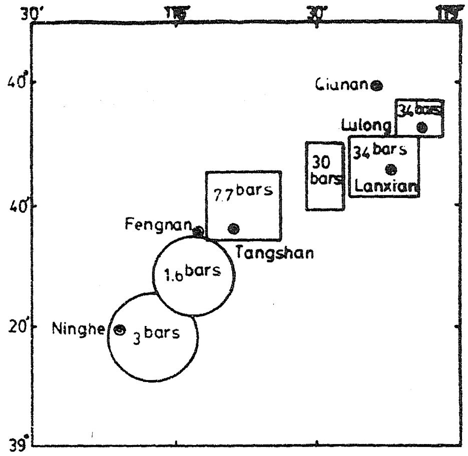

FIG.6 THE REGIONAL DISTRIBUTION OF AVERAGE STRESS DROP

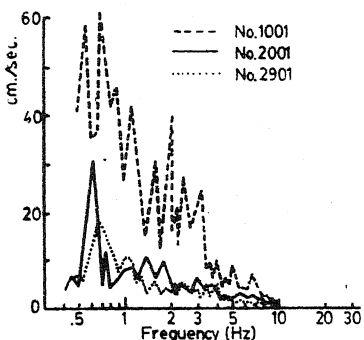

Fig.8 Fourier amplitude spectra for the Ninghe earthquake observed at different stations

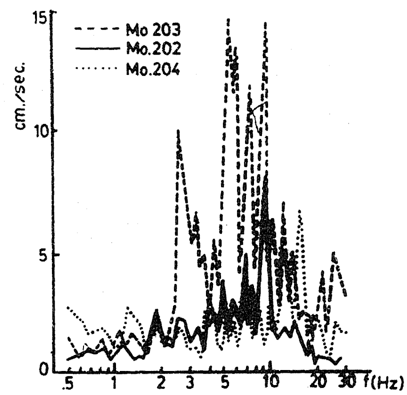

Fig.8 Fourier amplitude spectra for the earthquake No.7 observed at different stations

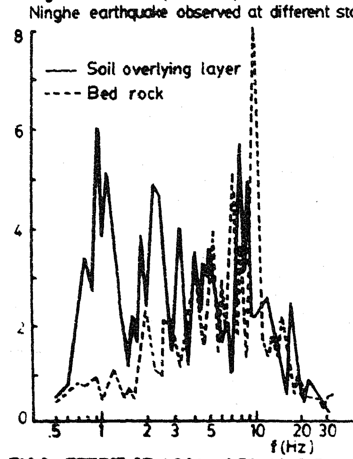

FIG.9 EFFECT OF LOCAL SITE CONDITION ON FOURIER SPECTRA

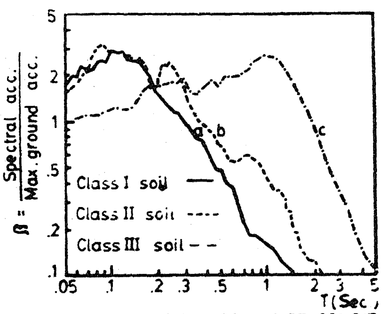

FIG.10 EFFECT OF LOCAL SITE CONDITION ON RESPONSE SPECTRA