ATTENUATION RELATION OF GROUND MOTION IN NORTHERN CHINA

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SUMMARY

The strong ground motion recordings recorded in northern China are analysed to obtain the attenuation relations valid for $4 \leqslant M \leqslant 6.5$, $R \leqslant 100$:

$$PGA = 0.1548 \exp(0.5442\, M)(R+8)^{-1.002}$$

$$PGV = 0.142 \exp(1.371\, M)(R+2)^{-1.286}$$

where M is magnitude, R, epicentral distance in km, PGA and PGV are in g and cm/sec respectively.

Western North America data and those together with the northern China data are also analysed in the same way as for the northern China data only. These results differ not markedly from each other. The results are also compared with the existing attenuation relations. The fairly good agreement suggests the possible use of western North America attenuation relations in northern China.

INTRODUCTION

Emperical prediction of strong ground motion is a very important matter in earthquake engineering. The site of important structures such as nuclear power plants and dams has to be investigated specially to determine the quantitative vibratory ground motion to be used in aseismic design. The attenuation relation of ground motion plays an important role in the determination of the strong ground motion parameters of the design basis earthquake.

Publications of attenuation curves for peak ground motion are numerous. Among them the most famous and widely quoted are: Schnabel and Seed (Ref.1), Nuttli (Ref.2), Trifunac (Ref.3), Trifunac and Brady (Ref.4), Ambraseys (Ref. 5), McGuire (Ref.6) and Boore et al (Ref.7). Recently Joyner and Boore (Ref.8), Campbell (Ref.9) and Battis (Ref.10) published new attenuation relations including the data from some new strong motion recordings. Joyner and Boore treated the data carefully to avoid possible bias. They used the regression method which decouples the determination of magnitude dependence from the determination of distance dependence. Boore and Joyner (Ref.11) reviewed the empirical prediction of ground motion and discussed the adequacy of magnitude independent shape of attenuation curve. Bolt and Abrahamson (Ref.12) illustrated the possible overwhelming contribution of data at considerable distances from the source to the behavior of very near field rela-

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tion. They proposed a new fitting procedure and reanalysed the Joyner, Boore and Porcella data. However, their results at near fault region for the $7.0 \leq M \leq 7.7$ set are inconsistent with physical consideration, perhaps due to the insufficient data in that region.

Attenuation relations have local characteristics. Whether the empirical prediction in other regions can be used must be checked by the local data. The purpose of the present paper is to find out the attenuation relation of strong ground motion from the limited available data in northern China where the number of recorded acceleragrams surpasses other regions of mainland China.

ATTENUATION RELATION IN NORTHERN CHINA

The strong ground motion recordings studied in this paper came from the aftershocks of 1975 Haicheng earthquake, 1976 Tangshan earthquake and its aftershocks. Most of the records came from the Haicheng aftershocks. The records are also too heavily concentrated in the small peak ground accelerations. To avoid the bias of using too many records of one set of events in one region and the possibility of too much contribution of far field data to the near field large peak ground accelerations, we exclude recordings with peak acceleration less than 0.05 g. Because attenuation law is mainly concerned in the site investigation for important structures which are usually designed to sustain much stronger motion in seismic area, peak ground acceleration less than 0.05 g is unimportant. According to Liu et al (Ref.13) peak ground acceleration of 0.05 g corresponds to intensity VI in Chinese Intensity Scale which is essentially equivalent to MMI. This is also unimportant for aseismic design of ordinary structures.

The Chinese recordings considered in this paper are listed in table 1. The 19 PGA and 17 PGV listed are the larger of the two horizontal components. They are not necessarily of the same direction. The following attenuation relations are attained by means of simple linear regression. This does not mean that we prefer the simple linear regression to other fitting procedure, or prefer the simple form of attenuation relation to other forms. We only considered that the small data set seems justifying the simple attenuation relation and regression method.

$$PGA = 0.1548 \exp(0.5442\,M)\,(R+8)^{-1.002} \qquad (1)$$

$$PGV = 0.142 \exp(1.371\,M)\,(R+2)^{-1.286} \qquad (2)$$

where M is moment magnitude, when the seismic moment is not available, $M = M_L$ for $M < 6.0$, $M = M_S$ for $M \geq 6.0$. R is the epicentral distance in km, PGA and PGV are in g and cm/sec respectively. Equations (1) and (2) are valid for $4 \leq M \leq 6.5$, $R \leq 100$ km.

COMPARISON WITH ATTENUATION RELATIONS BASED ON WESTERN NORTH AMERICA DATA

Regressions are also conducted for the western North America data (table 2) and those together with the northern China data. The purpose is to see whether the wealthy attenuation relations based on the western North America data can be used in northern China for the magnitude distance domain not covered by the local data. The answer to this is affirmative as can be seen below. The idea is that if the results based on these three data sets are rather close, we can plausibly use the western North America attenuation relations. Extrapolation is unavoidable in making such predicting, but the authors believe that using western North America attenuation relations is more reasonable than extrapolating directly by using northern China attenuation relations to the M-R domain not covered by the data.

Attenuation relations based on northern China data and western North America data are as following:

$$PGA = 0.2369 \exp(0.679M)(R+12)^{-1.248}$$

$$PGV = 0.1154 \exp(1.345M)(R+2)^{-1.044}$$

Attenuation relations based on western North America data are as following:

$$PGA = 0.192 \exp(0.6383M)(R+10)^{-1.136}$$

$$PGV = 0.4344 \exp(1.056M)(R+2)^{-0.8679}$$

The comparison of these three relations is shown in Fig.1 and Fig.2. The comparison of equations (1) and (2) with Joyner and Boore's and with Campbell's are shown in Fig.3 and Fig.4. The predicted peak ground acceleration by equation (1) is also compared with other attenuation relations as shown in Fig.5. It can be seen that the discrepancy is within the statistical prediction uncertainty in the M-R domain where equations (1) and (2) are valid. However the present attenuation relations predict somewhat larger value than Joyner and Boore's and Campbell's attenuation relations at source distance larger than about 100 km. Whether this is the characteristic of attenuation relation in northern China is suspicious and remains to be testified by more recordings and further investigations. This is more likely due to the lack of exponential attenuation term e^{-bR} in our equation. Efforts have been made to include the exponential attenuation term in our prediction. However, the regression yields negative attenuation either in geometrical spreading or in frictional dissipation term for some northern China data sets. This is of course owing to the insufficient number of recordings and some other effects not considered in the formulation. Thus we are obliged to discard this form of attenuation relation.

CONCLUSIVE REMARKS

Attenuation relations of peak ground acceleration and peak ground velocity for northern China are obtained based on limited available data. These attenuation relations agree well with the attenuation relations based on the extended data by adding to them the western North America data. In the M-R domain well controlled by the data they are also within the reasonable discrepancy in comparison with most of the well known results for other regions. It is recommended to use equations (1) and (2) in northern China for $4 \leqslant M \leqslant 6.5$, $R \leqslant 100$ km. Outside this domain, the use of western North America attenuation relations is preferable to the direct use of equations (1) and (2).

Table 1. Northern China Strong Motion Recordings used in this paper

Earthquake	Date	M	Station	R (km)	PGA (g)	PGV (cm/s)
Haicheng	2,23,1975	4.5	HD-1	17.7	0.051	1.48
			HD-2	17.7	0.098	2.59
			XM-1	10.1	0.190	1.40
			XM-2	10.1	0.151	6.36
	2,15,1975	5.7	HD-2	25.8	0.083	4.57
			HG-1	25.8	0.066	8.02
			HG-2	25.8	0.068	3.79
	2,24,1975	4.8	XN-1	11.8	0.100	2.20
			XM-2	11.8	0.107	2.78
	2,25,1975	4.8	XM-2	24.6	0.058	1.27
	2,26,1975	4.8	PL-2	20.6	0.056	
			PL-3	20.6	0.066	
Tangshan	7,28,1976	7.8	01001	157	0.065	7.50
			01002	153	0.055	5.33
			01003	153	0.089	10.10
	8, 8,1976	5.5	M0203	29	0.050	1.15
	8, 9,1976	5.7	M0203	18	0.140	9.49
	8,31,1976	5.8	M0203	37	0.108	4.50
	11,15,1976	6.9	29001	67	0.149	28.94

Table 2. Earthquakes and stations of the western North America recordings used in this paper

Earthquake	Date	Stations
Long Beach	3,11,1933	131, 136, 288
Nevada	1,30,1934	1008
Imperial Valley	5,19,1940	117
Kern County	7,21,1952	135, 283, 475, 1095
Parkfield	6,28,1966	1013, 1014, 1015, 1016, 1097, 1438
Borrego Mtn.	4, 9,1968	117
Lytle Creek	9,12,1970	111, 112, 116, 274, 290, 557
San Fernando	2, 9, 1971	104, 110, 121, 122, 125, 126, 127, 128, 133, 135, 137, 140, 141, 142, 145, 148, 151, 157, 160, 163, 166, 172, 175, 181, 184, 187, 190, 196, 199, 202, 205, 208, 211, 217, 220, 223, 226, 229, 232, 235, 238, 241, 253, 262, 264, 266, 267, 269, 278, 279, 284, 285, 288, 290, 413, 416, 425, 431, 437, 440, 443, 446, 449, 455, 458, 461, 466, 469, 475, 482, 1027, 1052
Sitka, Alaska	7,30,1972	2714
Point Mugu	2, 4,1973	272
Oroville	8, 1,1975	1051, 1291, 1292
Santa Barbara	8,13,1978	106, 283, 885, 5093, 5135, 5137
St. Elias	2,28,1979	2734
Coyote Lake	8, 6,1979	1377, 1408, 1409, 1410, 1411, 1413, 1422, 1445, 1492
Imperial Valley	10,15,1979	117, 286, 412, 723, 931, 942, 952, 955, 958, 1021, 2316, 5028, 5050, 5051, 5052, 5053, 5054, 5055, 5056, 5057, 5058, 5059, 5060, 5061, 5062, 5066, 5115, 5154, 5155, 5165
Livermore Valley	1,24,1980	1219, 1298, 1299, 1308, 1383, 1418
Livermore Valley	1,27,1980	1219, 1308, 1383, 1418, 1510, 1524, 1530, Fagundes Ranch, Morgan Terrace Park

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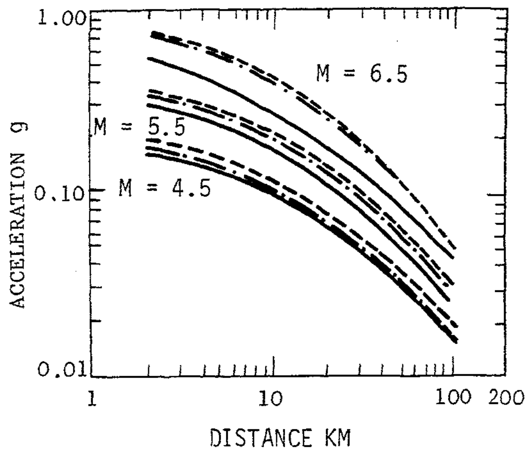

Fig. 1. Comparison of attenuation relations of PGA based on (1) northern China data (solid line) (2) western North America data (dash line) and (3) northern China and western North America data (dash dot line)

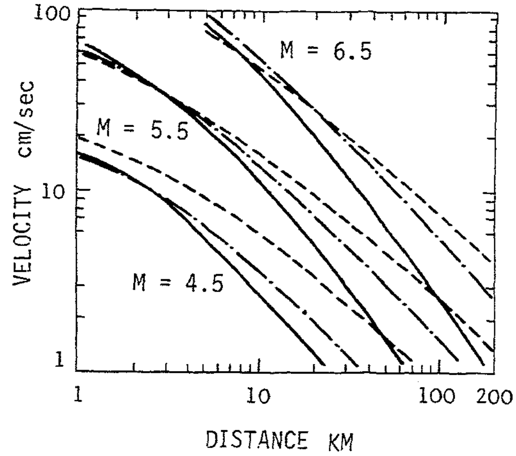

Fig. 2. Comparison of attenuation relations of PGV based on (1) northern China data (solid line) (2) western North America data (dash line) and (3) northern China and western North America data (dash dot line)

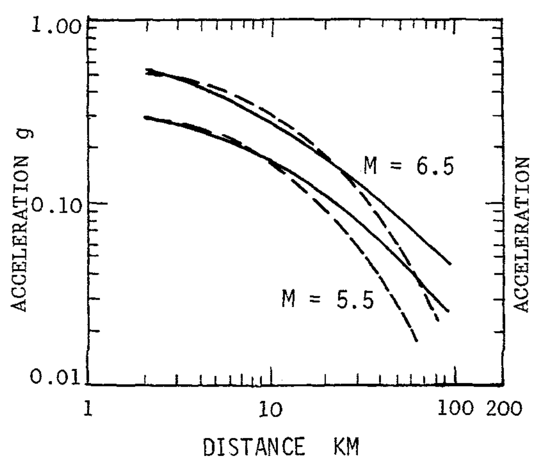

Fig. 3. Comparison of PGA attenuation in northern China (solid line) with Joyner and Boore's result (dash line)

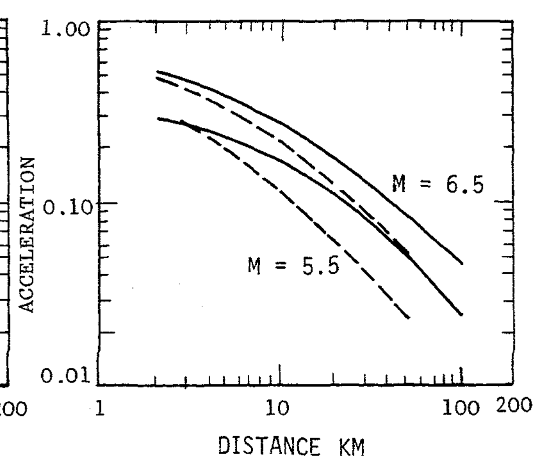

Fig. 4. Comparison of PGA attenuation in northern China (solid line) with Campbell's result (dash line)

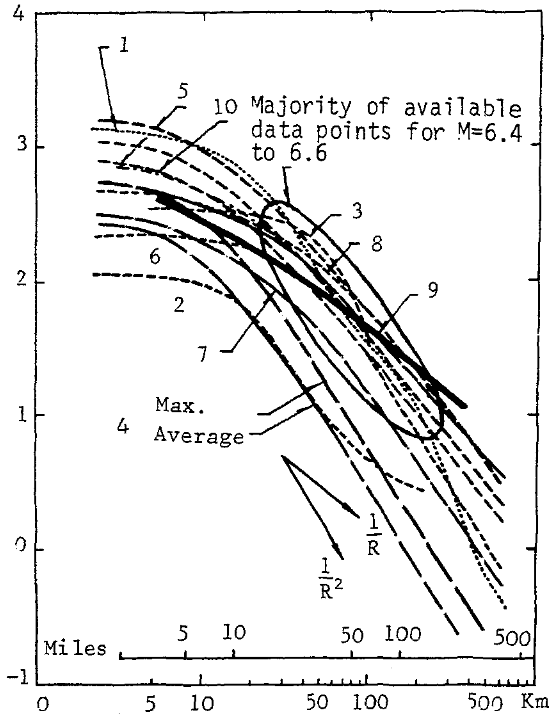

Fig. 5. Comparison of PGA attenuation in northern China (solid line) with other attenuation relations (dash line)

1 - Seed et al (1976); 2 - Gutenberg and Richter (1956);
3 - Housner* (1965); 4 - Blume+ (1965), H=10km;
5 - Kanai* (1966); 6 - Milne and Dovenport (1969);
7 - Esteva** (1970); 8 - Cloud and Perez+ (1971);
9 - Donovan* (1972); 10 - Schnabel and Seed* (1973), M = 6.6.

* - Uses distance to causative fault
** - Uses hypocentral distance
\+ - Uses epicentral distance