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Attenuation relations for horizontal peak ground acceleration and response spectrum in northeastern Tibetan Plateau region*

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Abstract

The seismic intensity attenuation relations in northeastern Tibetan Plateau region are established by a regression analysis on isoseismal data. Then the attenuation relations for horizontal peak ground acceleration and short-period response spectrum for western North America are derived based on the database of HUO Jun-rong and strong motion data from recent earthquakes. The attenuation relations of long-period response spectrum for western North America are developed by analyzing the broadband digital seismic recordings of southern California. By integrating the short-period and long-period attenuation relationships, the attenuation relations for horizontal acceleration response spectrum in the period range of 0.04~6 s for western North America are established. The attenuation equation that accounts for the magnitude saturation and near-field saturation of high frequency ground motion is used. Finally the attenuation relations for horizontal peak ground acceleration and response spectrum for the region of northeastern Tibetan Plateau are developed by using the transforming method.

Key words: **attenuation relation**; **response spectrum**; **northeastern Tibetan Plateau**
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Introduction

Developing local attenuation relations of ground motion is one of the key steps in seismic hazard assessment. Because of inadequate strong ground motion records in China, the attenuation relations used in China are usually developed by using the transforming method (Hu, Zhang, 1983; HU, ZHANG, 1984). To use this method, we need to have both the attenuation relation of seismic intensity for the studied region and the attenuation relations of seismic intensity and ground motions for the reference region. At present, many seismic hazard assessment works in China have used the attenuation relations developed by HUO (1989), or transformed from the attenuation relations for ground motions of western North America given by HUO (1989). These relations need to be modified owing to the following reasons:

1) When developing the attenuation relations of ground motions for western North America, HUO (1989) used the strong motion data recorded before 1986. After 1986 several strong earthquakes, including the 1989 Loma Prieta earthquake, 1992 Landers earthquake, 1994 Northridge earthquake and 1999 Hector Mine earthquake, occurred in western North America. Many strong

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motion records were acquired during these earthquakes. By adding these records to the database we can have a better magnitude-distance distribution so as to improve the reliability of the attenuation relations for predicting ground motions from large magnitude earthquakes and in near field. So it is necessary to modify the attenuation relations for ground motion in western North America by using the new ground motion data set.

2) The period of response spectrum in the state standard *Code for Seismic Design of Building* (GB50011-2001) issued in 2001 has been extended to 6 s (Ministry of Construction of China, 2001). Consequently, for the work of seismic safety evaluation of engineering sites we need to extend the period of attenuation relation of response spectrum to 6 s. Nevertheless, the records that HUO (1989) used to develop the attenuation relations of acceleration response spectrum for western North America are analog records. This kind of records has significant long-period errors and needs to be high-pass filtered to correct the errors. Even though the correction procedure is applied, the longest usable period for analog records is only around 3 s (Trifunac, Todorovska, 2001). Thus the attenuation curve of acceleration response spectrum in long-period range for large magnitude earthquakes descends too fast, and even faster than that for small magnitude earthquakes. This is inconsistent with the fact that strong motions of large earthquakes have more long-period components. The reason for the inconsistency may be that the correction to analog records has lost some long-period components. The attenuation curve of acceleration response spectrum in long-period range for small magnitude in long distance does not descend. This is because the errors dominate in the long-period range. So it is necessary to use the new records, which have reliable long-period components, as the database.

3) High frequency ground motions show the phenomena of magnitude saturation and near-field saturation (HU, 1988). This must be considered properly in the attenuation model. The attenuation model in China used by HUO (1989) is the type II model, which accounts for the near-field saturation but fails to manifest the magnitude saturation. The seismicity in the region of northeastern Tibetan Plateau is very high, so the attenuation model should be modified to account for the magnitude saturation.

In this paper the attenuation relation of seismic intensity for northeastern Tibetan Plateau region is developed first. The western North America is taken as the reference region. The empirical attenuation relation for the acceleration response spectrum in short period for the western North America is then developed based on the database including the strong motion records acquired in recent strong earthquakes. The attenuation relation in long-period range is built up based on the southern California digital broadband records (YU, 2002). By integrating the attenuation relations of response spectrum in the short and long period range an attenuation relation for the acceleration response spectrum in the period range of 0.04~6 s is established. Finally, the attenuation relations for horizontal peak ground acceleration and response spectrum for the region of northeastern Tibetan Plateau, with consideration of the magnitude and near-source saturation, are deduced by using the transforming method.

1 Attenuation relation for seismic intensity

1.1 Data

While developing the seismic intensity attenuation relation we should choose the isoseismal data with the magnitude and intensities being independently determined. It implies that only the earthquakes having instrumentally determined magnitude can be used. Following this principle the isoseismal data of 31 earthquakes with M>5.0 in northeastern Tibetan Plateau region are chosen as the database (Department of Earthquake Disaster Prevention, China Seismological Bureau, 1999). In Table 1 the earthquake catalog is listed. Figure 1 shows the distribution of earthquake epicenters.

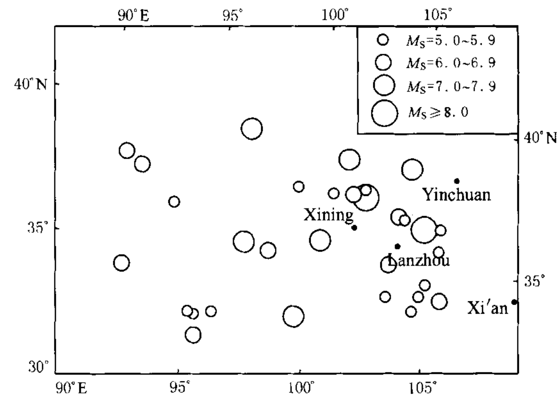

Figure 1 Epicentral distribution of earthquakes used in this study

The number of earthquakes in various magnitude ranges is given in Table 2.

In general, isoseismals are the outer envelopes of corresponding intensities. If the intensity of the inner isoseismal equals to the epicentral intensity, then the area surrounded by the inner isoseismal is the meizoseismal zone, within which the intensity would be saturated. That is, every point in this area has the same intensity. In order to make the attenuation curves meet this condition we add some intensity datum points within the epicentral area. We call this the interpolation of intensities in near field. This procedure is only done when

Table 1 Earthquake catalog used in this study

No.	Date a-mo-d	Epicenter location		M	I_0	Reference region
		φ_N/(°)	λ_E/(°)			
1	1920-12-16	36.70	104.90	$8\frac{1}{2}$	XII	Haiyuan in Ningxia
2	1927-05-23	37.70	102.20	8	XI	Gulang in Gansu
3	1932-12-25	39.70	96.70	7.6	X	Changma of Yumen in Gansu
4	1936-02-07	35.40	103.40	$6\frac{3}{4}$	IX	Southwest Kangle in Gansu
5	1936-08-01	34.20	105.70	6	VIII	South to Tianshui in Gansu
6	1947-03-17	33.30	99.50	7.7		South to Dari in Qinghai
7	1954-02-11	39.00	101.30	$7\frac{1}{4}$	X	Northeast to Shandan in Gansu
8	1954-07-31	38.80	104.20	7	IX	North to Tengger Shamo in Inner Mongolia
9	1959-01-31	37.00	104.00	$5\frac{1}{4}$		Vicinity of Jingtai in Gansu
10	1960-02-03	33.80	104.50	$5\frac{1}{4}$	VI	Zhugqu in Gansu
11	1961-10-01	34.33	104.78	5.7	VII	East to Minxian in Gansu
12	1961-12-04	33.00	95.00	5.9	VII~VIII	Zadoi in Qinghai and its vicinity
13	1962-12-11	34.75	105.05	5.0	VI+	Northwest to Gangu in Gansu
14	1963-04-19	35.70	97.00	7	VIII+	Vicinity of Alanhu in Qinghai
15	1970-12-03	35.93	105.58	5.1	VII+	Xiji in Ningxia
16	1971-03-24	35.50	98.10	6.3	VIII	North to Madoi in Qinghai
17	1971-04-03	32.20	95.40	6.5	IX	Southeast to Zadoi in Qinghai
18	1977-01-02	38.20	91.20	6.4	VIII	Northwest to Mangnai in Qinghai
19	1980-04-18	37.86	99.13	5.2	VI	North to Tianjun in Qinghai
20	1982-04-14	36.71	105.63	5.5	VII	Haiyuan in Ningxia
21	1984-01-06	37.96	102.17	5.3	VI	Northwest to Tianzhu in Gansu
22	1984-02-17	37.74	100.74	5.3	VI	Southeast to Qilian in Qinghai
23	1985-01-16	32.94	95.26	5.2	VII	Xigenda trench of Zadoi in Qinghai
24	1986-04-04	33.11	95.99	5.1	V	Northwest to Yushu in Qinghai
25	1986-08-26	37.78	101.63	6.5	VIII	North to Menyuan in Qinghai
26	1986-12-21	36.72	93.70	5.3	VI	Northwest to Golmud in Qinghai
27	1987-01-08	34.26	103.36	5.8	VII	North to Têwo in Gansu
28	1988-11-05	34.27	91.87	6.8	IX	Southwest to Golmud in Qinghai
29	1990-01-14	37.84	92.00	6.5	VIII	Mangnai in Qinghai
30	1990-04-26	36.06	100.33	7.0	IX	Southwest to Gonghe in Qinghai
31	1990-10-20	37.11	103.72	6.1	VIII	Region between Tianzhu and Jingtai in Gansu

Table 2 Earthquake frequency *N versus* magnitude *M*

M	5.0~5.4	5.5~5.9	6.0~6.4	6.5~6.9	7.0~7.4	7.5~7.9	≥8.0	Total
N	10	4	4	5	4	2	2	31

the epicentral intensity is greater than VII or the semidiameter of the inner isoseismal is greater than 5 km. In addition, in order to represent the characteristic that the far field isoseismals tend to become circles, the radius of felt area is taken as the far field control point. The felt intensity is taken to be the intensity III or IV. This procedure is called the interpolation of intensities in far field (WANG, SHI, 1993).

1.2 Intensity attenuation model and analyzing method

In studying the intensity attenuation the point source model is usually assumed. We adopt the elliptical intensity attenuation model, in which both the major and minor axes of isoseismal around the epicenter region have the same length, while those in moderate epicentral distances are of different length, *i.e.*, there the isoseismals are approximately elliptical. In the model the far distance isoseismals are nearly circular, *i.e.*, the major and minor axes of attenuation curves tend to have equal length due to the diminishing influence of the seismic tectonics. In this paper the combined intensity attenuation model with the long and short isoseismal axis being related (CHEN, LIU, 1989) is used in order to ensure that at the epicentral distance tending to be zero the major and minor axes have equal length, while at moderate distance their lengths are different, and at far distance the two axes remain to have equal length. The attenuation equation of the combined model is

$$I = a + bM + c_1 \lg(R_1 + R_{oa}) + c_2 \lg(R_2 + R_{ob}) + \varepsilon \quad (1)$$

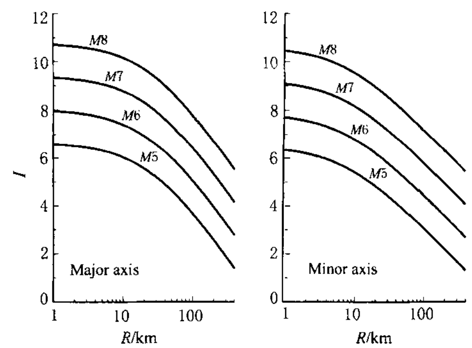

Figure 2 Curves of the intensity attenuation relation for the region of northeastern Tibetan Plateau

where I is intensity; M is magnitude; R_{oa} and R_{ob} are near-field intensity saturation factors in the direction of major and minor axes, respectively; R_1 and R_2 are long and short semi-diameters of the isoseismal with intensity I; a, b, c_1 and c_2 are regression coefficients; and ε is a random variable in regression analysis denoting uncertainties, which is assumed to be of normal distribution with zero mean and standard deviation σ.

1.3 Intensity attenuation relation

According to the above method and data, the intensity attenuation relation (Figure 2) for the region of northeastern Tibetan Plateau is obtained as follows:

$$\begin{aligned} &\text{Major axis} \quad I = 5.774 + 1.376M - 4.287\lg(R+25) \quad \sigma = 0.668 \\ &\text{Minor axis} \quad I = 2.342 + 1.376M - 3.030\lg(R+7) \quad \sigma = 0.668 \end{aligned} \quad (2)$$

2 Attenuation relations of ground motions for western North America

When using the transforming method to develop attenuation relations in China, the attenuation relations for the reference region must be built up first. The western North America is taken as the reference region because there are not only abundant strong ground motion records, but also many intensity data as well. Moreover, the intensity scales used in China and in the United States are approximately equivalent. This has been verified in the work of compiling the new ground motion zoning map of China[①]. Wong, *et al* (2002) also conclude that the characteristics of ground motion attenuation in the western North America are similar to that in North China.

At present many seismic hazard assessment works in China have used the ground motion attenuation relations developed by HUO (1989) or transformed from HUO's ground motion attenuation relations for western North America. The regression approach used in this paper is similar to that in HUO (1989). In this study an empirical attenuation relation for acceleration response spectrum in short period for western North America is worked out based on the database including strong motion records acquired in recent strong earthquakes, and the corresponding attenuation relation in long-period range is developed based on the southern California digital broad-band records. The attenuation model used in this paper can account for the magnitude saturation and near field saturation.

2.1 Data

In this study we have used the analog strong motion records in western North America and the digital broad-band records in southern California for developing the attenuation relations for short and long period response spectrum, respectively.

The analog records include all the records used by HUO (1989) and the records from the 1987 Whittier earthquake, 1989 Loma Prieta earthquake, 1992 Landers earthquake, 1994 Northridge earthquake and other records from some earlier earthquakes. A total of 187 records is used in this study. Two horizontal components of each record are treated as two independent records. The response spectra of absolute acceleration of the all records are calculated in the period range of 0.04~2.0 s (ζ=0.05). Figure 3a shows the distribution of strong motion data.

The amount of our data is about 2 times of that of HUO (1989). The magnitude-distance distribution of the data has been improved. The corresponding epicentral distances for most data are less than 100 km.

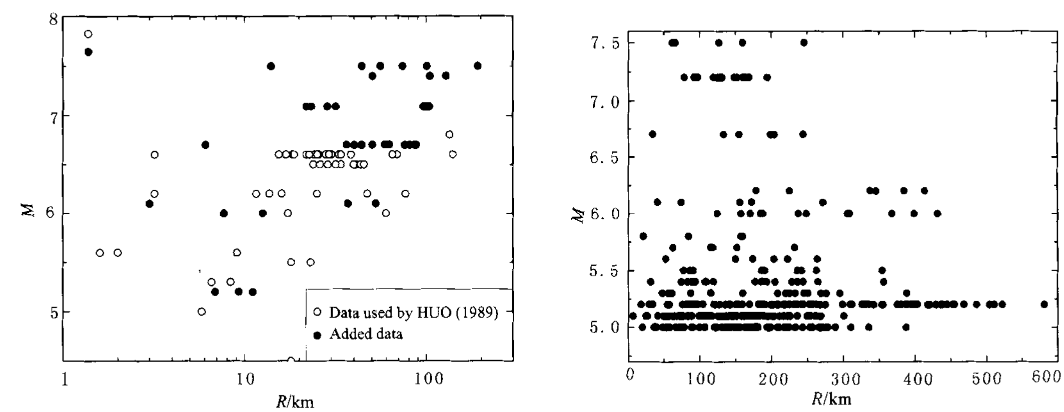

Figure 3 Distribution of strong ground motion data
(a) Analog records; (b) Digital broad-band records

For the attenuation relation of long-period response spectrum, our data come from digital broad-band records, which carry reliable long-period information and are suitable for long-period

① WANG Su-yun, YU Yan-xiang, GAO A-jia. 1999. Development of attenuation relations for ground motion in China. Report No. 95-05-03-04-03, Key Project of China Seismological Bureau during the ninth Five-year Plan.

ground motion studies (YU, 2002; Yu, *et al*, 2000; Hu, Yu, 2000; Yu, Hu, 2001). This kind of data has 754 horizontal records acquired from many strong earthquakes, including the Landers earthquake, Northridge earthquake and Hector Mine earthquake. Figure 3b shows the magnitude-distance distribution of the digital broadband records. For all records the response spectra of absolute acceleration are calculated in the period range of 1.5~6.0 s (ζ=0.05).

2.2 Attenuation model

We have used the equation of attenuation relations of ground motion (HUO, 1989)

$$\lg S_a = C_1 + C_2 M + C_3 M^2 + C_4 \lg[R + C_5 \exp(C_6 M)] \tag{3}$$

where S_a is PGA or response spectral acceleration in cm/s^2; M is magnitude; R is epicentral distance in km; C_1, C_2, C_3, C_4, C_5 and C_6 are regression coefficients.

2.3 Regression analysis and results

The single random variable regression analysis is used in this study. The regression coefficents C_1, C_2, C_3, C_4, C_5 and C_6 are determined by a least squares of the data with $\lg S_a$ being taken as a random variable.

To decouple the magnitude and distance terms, the coefficients C_5 and C_6 in the near field saturation term $C_5\exp(C_6M)$ must be determined first. A two-stage regression approach is applied. When the saturation magnitude is assumed to be M=8, the regression analysis results in the coefficient C_5=1.046 and C_6=0.451.

The attenuation relations of acceleration response spectra in the period range of T=0.04~2.0 s and T=1.5~6.0 s are developed using the analog strong motion records and the digital broad-band records, respectively. By connecting them at the period of T=2.0 s, we thus obtain the attenuation relations for horizontal acceleration response spectra for western North America in the period range of T=0.04~6.0 s. In Table 2 is listed the corresponding coefficients and standard errors σ.

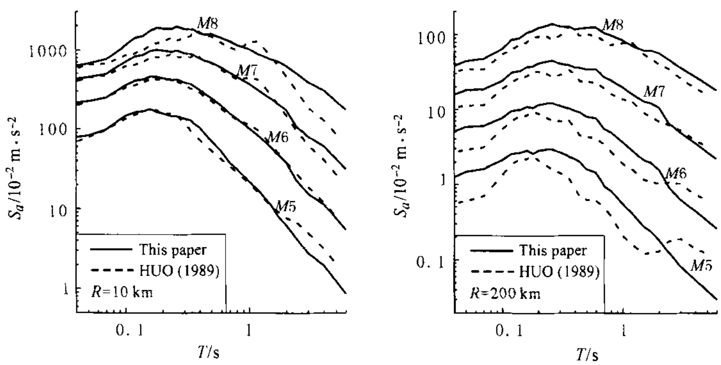

Figure 4 Comparison of the attenuation relations for horizontal acceleration response spectra for western North America developed in this study with that of HUO (1989)

Figure 4 shows the comparison of the developed attenuation relations for horizontal acceleration response spectra for western North America with that of HUO (1989) (R=10 km and 200 km, respectively, M=5, 6, 7, 8). Compared with HUO's attenuation relations, the relations of this paper have been improved significantly in long-period range. In the near field the curves of our long-period response spectra for large earthquakes descend slower than that of HUO (1989). This is consistent with the fact that strong motions of large earthquakes have more long-period components. The up-warp of the attenuation curve for moderate earthquakes in the long-period range no longer exists. This shows that the digital broadband records have high signal-to-noise ratio even in the long-period range.

Table 2 Coefficients of attenuation relations of acceleration response spectra for western North America (ζ=0.05)

T/s	C_1	C_2	C_3	C_4	C_5	C_6	σ
PGA	−1.276	1.442	−0.067	−1.886	1.046	0.451	0.232
0.04	−0.433	1.175	−0.050	−1.763	1.046	0.451	0.225
0.05	−0.382	1.146	−0.048	−1.714	1.046	0.451	0.226
0.07	0.222	0.990	−0.036	−1.751	1.046	0.451	0.226
0.10	0.825	0.867	−0.026	−1.802	1.046	0.451	0.231
0.12	0.759	0.878	−0.026	−1.760	1.046	0.451	0.251
0.14	0.799	0.869	−0.025	−1.764	1.046	0.451	0.258
0.16	0.799	0.868	−0.024	−1.760	1.046	0.451	0.253
0.18	0.580	0.918	−0.026	−1.770	1.046	0.451	0.259
0.20	0.496	0.915	−0.026	−1.709	1.046	0.451	0.268
0.24	0.370	0.919	−0.026	−1.655	1.046	0.451	0.269
0.26	0.333	0.928	−0.026	−1.660	1.046	0.451	0.276
0.30	0.396	0.903	−0.024	−1.673	1.046	0.451	0.292
0.34	0.365	0.899	−0.023	−1.676	1.046	0.451	0.308
0.36	0.180	0.934	−0.025	−1.661	1.046	0.451	0.318
0.40	0.079	0.945	−0.026	−1.643	1.046	0.451	0.324
0.44	−0.159	0.974	−0.027	−1.609	1.046	0.451	0.331
0.50	−0.553	1.047	−0.030	−1.605	1.046	0.451	0.337
0.60	−0.992	1.103	−0.033	−1.523	1.046	0.451	0.339
0.70	−1.425	1.194	−0.037	−1.570	1.046	0.451	0.340
0.80	−1.603	1.216	−0.038	−1.556	1.046	0.451	0.348
1.00	−2.109	1.306	−0.042	−1.563	1.046	0.451	0.345
1.20	−2.339	1.337	−0.043	−1.576	1.046	0.451	0.338
1.50	−2.770	1.398	−0.045	−1.575	1.046	0.451	0.334
1.70	−3.136	1.425	−0.045	−1.499	1.046	0.451	0.333
2.00	−3.353	1.443	−0.045	−1.495	1.046	0.451	0.329
2.40	−1.828	0.883	0.000	−1.501	1.046	0.451	0.322
3.00	−2.158	0.909	0.000	−1.496	1.046	0.451	0.306
4.00	−2.378	0.929	0.000	−1.521	1.046	0.451	0.307
5.00	−2.697	0.941	0.000	−1.470	1.046	0.451	0.324
6.00	−2.961	0.952	0.000	−1.429	1.046	0.451	0.328

3 Attenuation relations of ground motions for northeastern Tibetan Plateau

3.1 Intensity attenuation relation for the reference region

The intensity attenuation relation for western North America used in this study was developed by Chandra (1979), who used the data of isoseismals from 10 earthquakes in the San Andreas fault zone of California. By applying the relation between magnitude and epicentral intensity of California (Gutenberg, Richter, 1956), the intensity attenuation relation for western North America is expressed as

$$I = 0.514 + 1.500M - 0.00659R - 2.014\lg(R+10) \qquad \sigma = 0.274 \tag{4}$$

where M is magnitude and R is epicentral distance in km.

3.2 Attenuation relations of ground motions for northeastern Tibetan Plateau region

The attenuation relations for horizontal peak acceleration and response spectra for the region of northeastern Tibetan Plateau are deduced from the attenuation relations of ground motions and seismic intensity for western North America and the intensity attenuation relation for northeastern Tibetan Plateau by using the transforming method (Hu, Zhang, 1983; HU, ZHANG, 1984; HU, *et al*, 1996). The attenuation model has accounted for the near field saturation and magnitude saturation. The coefficients of the major axis and minor axis attenuation relations of peak acceleration and response spectra for northeastern Tibetan Plateau region are listed in Table 3 and Table 4, respectively. The standard errors here are the same as original standard errors for the relations in the reference region (HU, 1999).

Table 3 Coefficients of the attenuation relations of acceleration response spectra for northeastern Tibetan Plateau (Along major axis, ζ=0.05)

T/s	C_1	C_2	C_3	C_4	C_5	C_6	σ
PGA	0.617	1.163	−0.046	−2.207	1.694	0.446	0.232
0.04	1.208	0.952	−0.033	−2.056	1.694	0.446	0.225
0.05	1.196	0.941	−0.033	−2.002	1.694	0.446	0.226
0.07	1.656	0.826	−0.024	−2.037	1.694	0.446	0.226
0.10	2.207	0.731	−0.016	−2.090	1.694	0.446	0.231
0.12	2.115	0.749	−0.017	−2.047	1.694	0.446	0.251
0.14	2.145	0.745	−0.016	−2.052	1.694	0.446	0.258
0.16	2.131	0.750	−0.016	−2.050	1.694	0.446	0.253
0.18	1.946	0.797	−0.018	−2.068	1.694	0.446	0.259
0.20	1.829	0.798	−0.018	−2.001	1.694	0.446	0.268
0.24	1.657	0.809	−0.019	−1.944	1.694	0.446	0.269
0.26	1.645	0.815	−0.019	−1.952	1.694	0.446	0.276
0.30	1.693	0.796	−0.017	−1.965	1.694	0.446	0.292
0.34	1.657	0.796	−0.017	−1.970	1.694	0.446	0.308
0.36	1.490	0.826	−0.018	−1.957	1.694	0.446	0.318
0.40	1.390	0.835	−0.019	−1.937	1.694	0.446	0.324
0.44	1.153	0.864	−0.020	−1.905	1.694	0.446	0.331
0.50	0.804	0.930	−0.023	−1.911	1.694	0.446	0.337
0.60	0.365	0.982	−0.026	−1.828	1.694	0.446	0.339
0.70	0.011	1.063	−0.029	−1.890	1.694	0.446	0.340
0.80	−0.160	1.083	−0.030	−1.877	1.694	0.446	0.348
1.00	−0.606	1.164	−0.033	−1.896	1.694	0.446	0.345
1.20	−0.811	1.192	−0.034	−1.915	1.694	0.446	0.338
1.50	−1.204	1.249	−0.036	−1.923	1.694	0.446	0.334
1.70	−1.585	1.279	−0.037	−1.848	1.694	0.446	0.333
2.00	−1.792	1.298	−0.037	−1.848	1.694	0.446	0.329
2.40	−0.603	0.840	0.000	−1.840	1.694	0.446	0.322
3.00	−0.912	0.864	0.000	−1.841	1.694	0.446	0.306
4.00	−1.107	0.883	0.000	−1.873	1.694	0.446	0.307
5.00	−1.432	0.894	0.000	−1.821	1.694	0.446	0.324
6.00	−1.699	0.904	0.000	−1.780	1.694	0.446	0.328

The attenuation curves of the peak acceleration and the response spectra for the region of northeastern Tibetan Plateau are shown in Figure 5 and Figure 6, respectively.

4 Conclusions

In this paper, the attenuation relations for horizontal peak ground acceleration and response spectra for the region of northeastern Tibetan Plateau are developed using the transforming approach. The intensity attenuation relation for northeastern Tibetan Plateau region is built up first. The western North America is taken as the reference region. The empirical attenuation relations for acceleration response spectra in short period for western North America are then developed

Table 4 Coefficients of the attenuation relations of acceleration response spectra in northeastern Tibetan Plateau (Along minor axis, ζ=0.05)

T/s	C_1	C_2	C_3	C_4	C_5	C_6	σ
PGA	-0.644	1.080	-0.043	-1.626	0.255	0.570	0.232
0.04	-0.005	0.884	-0.031	-1.515	0.255	0.570	0.225
0.05	0.016	0.872	-0.030	-1.475	0.255	0.570	0.226
0.07	0.477	0.757	-0.021	-1.501	0.255	0.570	0.226
0.10	0.941	0.674	-0.015	-1.540	0.255	0.570	0.231
0.12	0.870	0.695	-0.016	-1.509	0.255	0.570	0.251
0.14	0.894	0.691	-0.015	-1.513	0.255	0.570	0.258
0.16	0.878	0.699	-0.015	-1.511	0.255	0.570	0.253
0.18	0.680	0.745	-0.017	-1.524	0.255	0.570	0.259
0.20	0.603	0.748	-0.017	-1.475	0.255	0.570	0.268
0.24	0.484	0.758	-0.018	-1.433	0.255	0.570	0.269
0.26	0.447	0.768	-0.018	-1.438	0.255	0.570	0.276
0.30	0.484	0.749	-0.016	-1.448	0.255	0.570	0.292
0.34	0.442	0.750	-0.016	-1.452	0.255	0.570	0.308
0.36	0.284	0.780	-0.017	-1.442	0.255	0.570	0.318
0.40	0.197	0.789	-0.018	-1.428	0.255	0.570	0.324
0.44	-0.020	0.819	-0.019	-1.404	0.255	0.570	0.331
0.50	-0.374	0.885	-0.022	-1.408	0.255	0.570	0.337
0.60	-0.762	0.939	-0.025	-1.346	0.255	0.570	0.339
0.70	-1.153	1.017	-0.028	-1.392	0.255	0.570	0.340
0.80	-1.316	1.038	-0.029	-1.383	0.255	0.570	0.348
1.00	-1.773	1.118	-0.032	-1.396	0.255	0.570	0.345
1.20	-1.990	1.147	-0.033	-1.410	0.255	0.570	0.338
1.50	-2.390	1.204	-0.035	-1.416	0.255	0.570	0.334
1.70	-2.727	1.236	-0.036	-1.360	0.255	0.570	0.333
2.00	-2.935	1.255	-0.036	-1.361	0.255	0.570	0.329
2.40	-1.770	0.807	0.000	-1.355	0.255	0.570	0.322
3.00	-2.080	0.831	0.000	-1.355	0.255	0.570	0.306
4.00	-2.296	0.850	0.000	-1.379	0.255	0.570	0.307
5.00	-2.587	0.862	0.000	-1.340	0.255	0.570	0.324
6.00	-2.828	0.872	0.000	-1.309	0.255	0.570	0.328

based on the database including the strong motion records acquired in recent strong earthquakes. The attenuation relations in long-period range are derived based on the southern California digital broad-band records. By integrating the attenuation relations of response spectra in the short and long period range the attenuation relations of acceleration response spectra in the period range of 0.04~6 s are established. Finally, the attenuation relations for horizontal peak ground acceleration and response spectra for the region of northeastern Tibetan Plateau, with consideration of the magnitude and near-source saturation, are deduced by using the transforming approach. The attenuation relations thus developed can be used in the seismic safety evaluation of engineering sites and seismic micro-zoning.

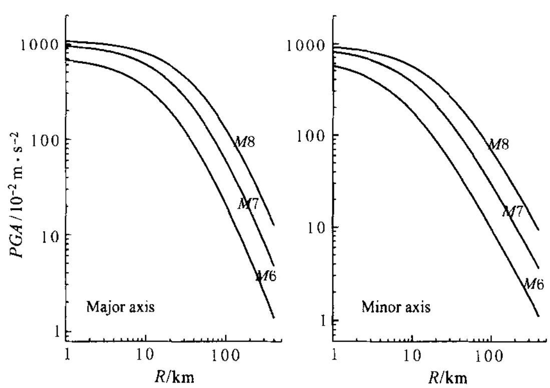

Figure 5 Attenuation curves of peak acceleration for northeastern Tibetan Plateau

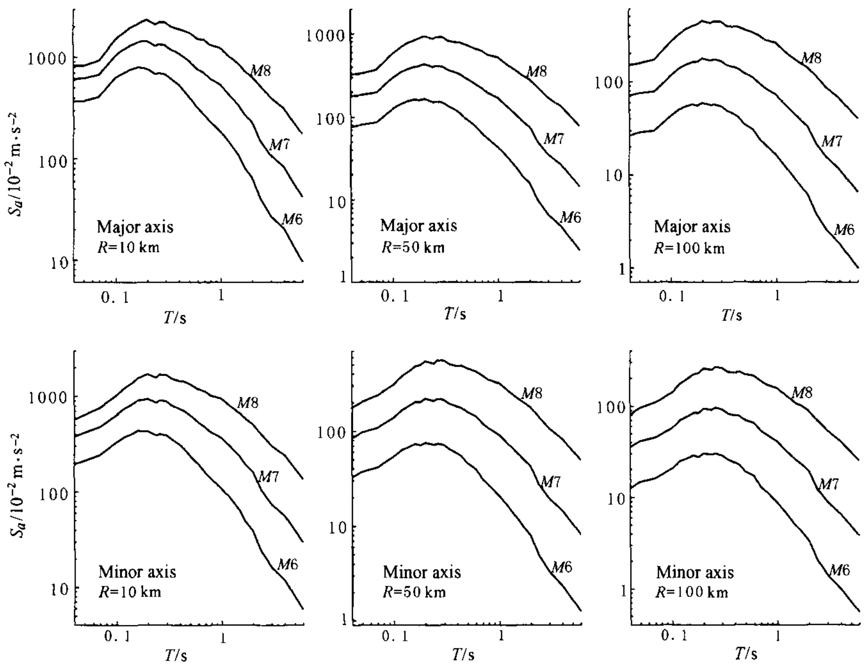

Figure 6 Attenuation curves of acceleration response spectrum for northeastern Tibetan Plateau

Because of the inadequate strong ground motion records in our country, the transforming method is still the main approach to develop the attenuation relations for ground motions in China. Nevertheless, the empirical relations are deduced directly from the observational data, and then should be more suitable to the reality. By accumulating strong motion data and developing new analysis method, more reliable attenuation relations may be established in the future.

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