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Comparison of the Ground-Motion Attenuation Relationship Between the Wenchuan, China, Area and the Central and Eastern United States

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Comparison of the Ground-Motion Attenuation Relationship Between the Wenchuan, China, Area and the Central and Eastern United States

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Abstract

An M_w-7.9 earthquake occurred in Wenchuan, China, in 2008, along the Longmenshan Fault, which is located on the western border of the South China stable continental region. A detailed comparison of the Wenchuan ground-motion attenuation relationships with the relationships for the central and eastern United States (also a stable continental region) showed that the ground-motion prediction equation for the Wenchuan area is similar to those for the central and eastern United States. Thus, the strong-motion records from the Wenchuan earthquake can be used for constraining the ground-motion prediction equation and engineering analysis for the central and eastern United States.

Introduction

An earthquake is a natural force that can cause great disaster. For example, the 1556 Shaanxi, China, earthquake killed 830,000 people, the most fatalities in recorded history. More recent earthquakes in Tangshan, China, in 1976 and Haiti in 2010 killed more than 240,000 and 100,000 people, respectively. Earthquakes themselves do not kill people, but building collapses caused by earthquake ground motion do. As shown in Figure 1, strong ground motion generated by the Wenchuan, China, earthquake (M_w 7.9) in 2008 caused a school building collapse that killed many students. On April 6, 2009, building collapses caused by a strong earthquake (M_w 6.3) killed 309 people in L'Aquila, Italy, which led to 6-yr prison sentences for six scientists.

The ground-motion attenuation relationship, also called the ground-motion prediction equation, is a statistical function that determines a median ground-motion parameter from an earthquake

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Figure 1. Strong ground motion from the Wenchuan earthquake caused a classroom building to collapse and killed many students.

(e.g., peak ground acceleration or peak ground velocity). GMPE was originally derived from observations (Campbell, 1981; Joyner and Boore, 1981). For example, Joyner and Boore (1981) developed a GMPE for peak horizontal acceleration from strong-motion records from California. But GMPE's have also been developed from synthetic (simulated) ground motions, which complicates their application.

The next-generation GMPE's for the western United States were developed from a global ground-motion database and synthetic ground motions (Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008). But the development of GMPE's for the central and eastern United States has been hindered by a lack of observations. All the GMPE's for this area were developed either solely from computer models or from computer models and limited observations from small to moderate earthquakes (M ≥ 6.0). For example, Sommerville and others (2001) developed a GMPE from synthetic ground motions based on Green's function simulation. Campbell (2003) developed a GMPE using a hybrid method: transferring the GMPE for the western United States by considering the differences in crustal properties (e.g., thickness and shear-wave velocity) between the two regions. Atkinson and Boore (2006) developed a GMPE from synthetic records based on stochastic finite-fault simulation.

Even in an active region, ground-motion records are limited because earthquakes are rare events, large earthquakes in particular. It is common to use ground-motion records from one tectonic region to develop a GMPE for a similar tectonic region. For example, ground-motion records from active plate boundary regions such as Turkey and Taiwan were used to develop a GMPE for the western United States (Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008). Cramer and Kumar (2003) used ground motions observed from the 2001 Bhuj, India, earthquake (M 7.7) to constrain GMPE's developed for the central and eastern United States.

On May 12, 2008, a large intraplate earthquake (M 7.9) occurred in Wenchuan, China, along the Longmenshan Thrust Belt, which separates the Qinghai-Tibet Plateau from the Sichuan Basin

(Fig. 2). The Wenchuan earthquake caused about 90,000 fatalities and $110 billion in damage (Xie and others, 2009). The main event and aftershocks were recorded by the Chinese National Strong-Motion Observation Network System (Li and others, 2008; Lu and others, 2010; Wang and others, 2010). A preliminary analysis indicated that the strong-motion records from the main shock of the Wenchuan earthquake are in general agreement with ground motion predicted from several GMPE's for the central and eastern United States (Wang and Lu, 2011).

Strong-Motion Data Set

Figure 3 shows the distribution of stations in the National Strong-Motion Observation Network System of China, which recorded the main event and aftershocks of the 2008 Wenchuan earthquake. The ground-motion records from the main shock (M 7.9) and 52 aftershocks with magnitude greater than 5.0 were obtained from the network (China Earthquake Administration, 2008; Li, 2009a, b) for this project (Fig. 4). Table 1 lists the aftershocks with magnitude equal to or greater than 5.0. The

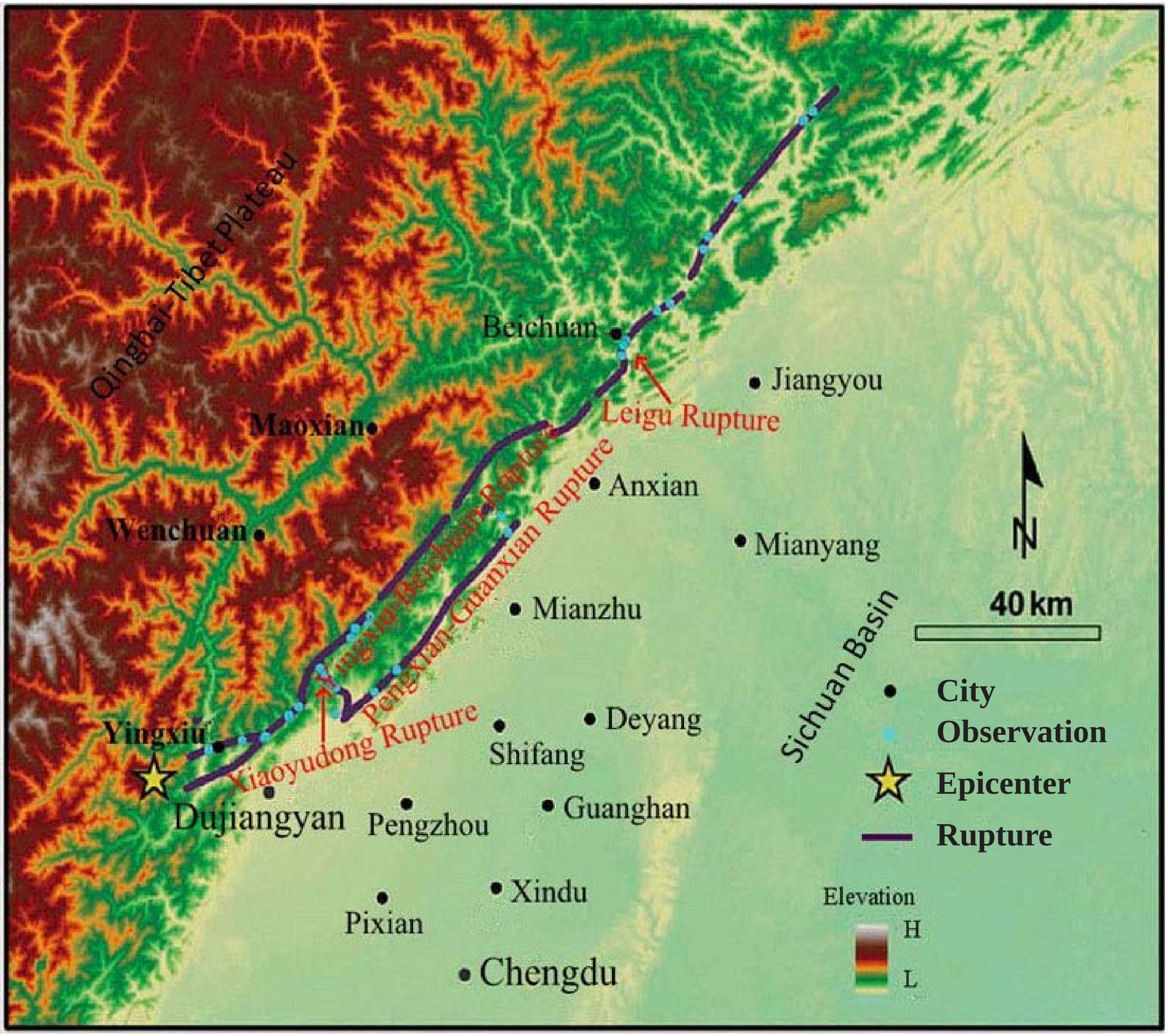


Figure 2. Surface ruptures of the Wenchuan, China, earthquake. Modified from Li and others (2009).

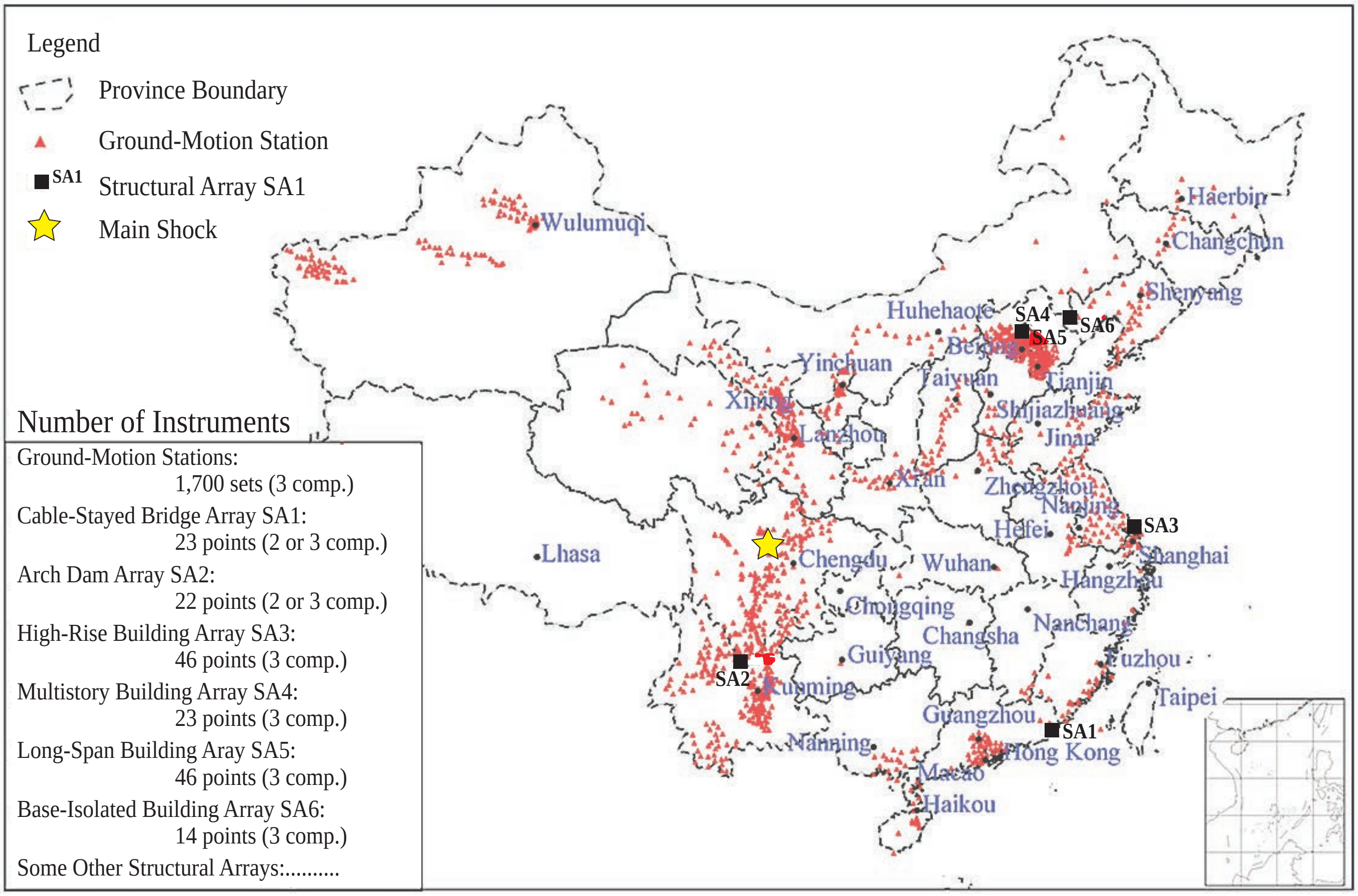


Figure 3. Distribution of stations of the National Strong-Motion Observation Network System of China.

largest aftershock occurred on May 25, 2008, with a magnitude of 6.4. The data were processed and analyzed with SMA, a strong-motion analysis software produced by Kinemetrics Inc. The following equations were used to convert surface magnitudes (M_s) to moment magnitudes (M_w):

$$\log M_0 = 1.5 M_s + 16.1$$

(Purcaru and Berckhemer, 1978) (1)

$$M_w = \tfrac{2}{3}\log M_0 - 10.7$$

(Hanks and Kanamori, 1979). (2)

Table 1 also lists the original M_s and converted M_w.

Main-Shock Ground Motions

A total of 420 stations recorded the main event of the 2008 Wenchuan earthquake. The PGA's recorded at 45 stations exceeded 0.1 g. All the records are digital with a rate of 200 samples per second. Table 2 lists PGA's recorded at seven near-fault stations. The highest PGA, 0.98 g in the east-west direction, was recorded at Wolong station in Wenchuan County. The vertical component at Wolong station was also very high, 0.97 g PGA, almost the same as the horizontal component of the east-west direction. Figures 5 through 7 show the PGA, PGV, and spectral response acceleration at Wolong station. The PGA, PGV, and response accelerations for the main shock are listed in Appendix A.

The 2008 Wenchuan earthquake generated two surface ruptures: a 240-km-long main rupture and a 70-km-long frontal rupture (Fig. 2). The fault is reverse-dipping to the northwest and has left-lateral strike-slip offset with a maximum vertical surface offset of 6.5 m and maximum horizontal surface offset of 5.5 m. The focal depth was about 10 km. The ground-motion records clearly show the characteristics of fault rupture asperity and directivity. Figures 5 and 6 show two strong subevents (shaking) that are consistent with fault rupture asperity and two main ruptures (Fig. 8). The rupture

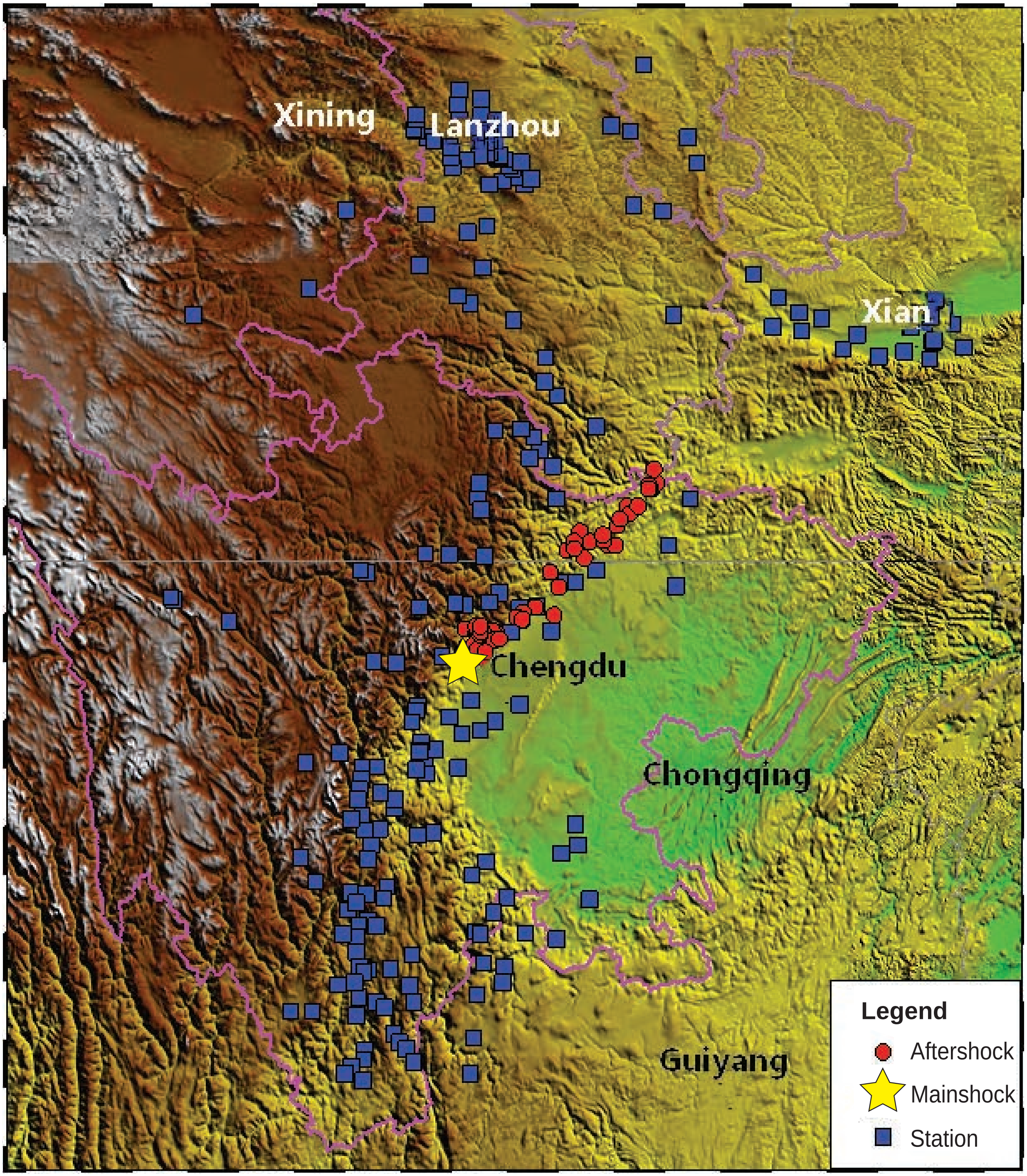


Figure 4. Epicenters of the main shock and aftershocks of the Wenchuan earthquake and locations of stations of the National Strong-Motion Observation Network System of China.

directivity effect on ground motion can be seen clearly in Figure 9. As shown in Figures 8 and 9, the rupture started in the southwest and propagated northeast, resulting in a shorter shaking period in the southwest and longer in the northeast.

Aftershock Ground Motions

A large number of strong-motion measurements were recorded from the aftershocks of the Wenchuan earthquake, including 64 with magnitudes between 5.0 and 6.5 (Table 1). Figure 10

Table 1. Wenchuan earthquake aftershocks with magnitude equal to or greater than 5.0.

Date	*Time*	*Latitude*	*Longitude*	*Focal Depth (km)*	M_s	M_w
Aug. 5, 2008	17:49:16	32.72	105.61	13	6.5	6.5
May 25, 2008	16:21:47	32.55	105.48	14	6.4	6.4
May 12, 2008	14:43:15	31.27	103.82	14	6.3	6.3
May 12, 2008	19:11:01	31.26	103.67	14	6.3	6.3
Aug. 1, 2008	16:32:42	32.02	104.85	14	6.2	6.2
May 13, 2008	15:07:08	30.95	103.42	14	6.1	6.1
May 18, 2008	1:08:24	32.20	105.08	13	6.1	6.1
July 24, 2008	15:09:28	32.76	105.61	10	6.0	6.0
May 16, 2008	13:25:47	31.31	103.45	14	5.9	5.9
May 12, 2008	14:36:39	31.27	103.58	*	5.8	5.8
May 12, 2008	14:54:17	31.26	103.59	13	5.8	5.8
May 12, 2008	15:34:42	31.29	103.77	13	5.8	5.8
May 13, 2008	4:08:49	31.43	104.06	21	5.8	5.8
May 14, 2008	10:54:37	31.34	103.63	16	5.8	5.8
May 27, 2008	16:37:51	32.78	105.70	15	5.7	5.7
July 24, 2008	3:54:43	32.72	105.63	10	5.7	5.7
May 12, 2008	15:01:34	31.45	104.49	13	5.5	5.5
May 12, 2008	16:10:57	31.14	103.60	10	5.5	5.5
May 12, 2008	16:21:40	31.53	104.28	11	5.5	5.5
May 19, 2008	14:06:53	32.47	105.38	14	5.5	5.5
Sept. 12, 2008	1:38:59	32.92	105.67	12	5.5	5.5
May 13, 2008	7:46:18	31.34	103.58	13	5.4	5.4
May 12, 2008	17:42:24	31.48	104.13	14	5.3	5.3
May 27, 2008	16:03:22	32.76	105.65	15	5.3	5.3
May 12, 2008	16:35:05	31.29	103.65	14	5.2	5.2
May 12, 2008	17:06:59	31.16	103.69	10	5.2	5.2
May 12, 2008	17:31:15	31.16	103.56	10	5.2	5.2
May 12, 2008	21:40:53	31.02	103.65	9	5.2	5.2
May 12, 2008	23:05:30	31.20	103.79	17	5.2	5.2
May 13, 2008	4:45:31	31.73	104.55	20	5.2	5.2
May 13, 2008	7:54:46	31.28	103.63	10	5.2	5.2
May 12, 2008	14:41:55	32.10	104.65	*	5.1	5.1
May 12, 2008	16:26:12	31.40	104.12	12	5.1	5.1
May 12, 2008	16:47:23	32.16	105.12	9	5.1	5.1
May 12, 2008	17:30:55	32.15	105.21	8	5.1	5.1
May 12, 2008	22:46:06	32.72	105.64	10	5.1	5.1
May 12, 2008	23:05:36	31.05	103.42	14	5.1	5.1
May 12, 2008	23:28:52	31.10	103.59	10	5.1	5.1
May 13, 2008	1:54:32	31.26	103.62	17	5.1	5.1
May 13, 2008	15:19:16	32.35	105.24	18	5.1	5.1
May 14, 2008	17:26:43	31.41	104.12	10	5.1	5.1

Table 1. Wenchuan earthquake aftershocks with magnitude equal to or greater than 5.0.

Date	*Time*	*Latitude*	*Longitude*	*Focal Depth (km)*	M_s	M_w
May 15, 2008	6:10:10	31.21	103.85	10	5.1	5.1
May 12, 2008	17:23:35	32.19	104.92	20	5.0	5.0
May 12, 2008	18:23:39	30.97	103.48	9	5.0	5.0
May 12, 2008	19:33:20	32.55	105.35	16	5.0	5.0
May 17, 2008	0:14:42	31.08	103.69	9	5.0	5.0
May 17, 2008	4:15:21	32.19	104.73	14	5.0	5.0
May 20, 2008	1:52:33	32.26	105.07	15	5.0	5.0
June 8, 2008	18:51:17	31.88	104.45	15	5.0	5.0
Aug. 2, 2008	2:12:17	32.42	105.27	14	5.0	5.0
Aug. 7, 2008	16:15:34	32.12	104.73	15	5.0	5.0
May 12, 2008	15:07:36	32.29	104.80	19	5.0	5.0

* focal depth is unknown

Table 2. PGA's obtained from seven near-fault stations (cm/s/s).

Station	*Fault Distance (km)*	*East-West*	*North-South*	*Vertical*
Wenchuan Wolong	23.7	957.4	655.8	948.1
Mianzhu Qingping	1.4	824.4	802.5	622.9
Shifang Bajiao	4.2	548.9	585.7	632.9
Jiangyou Hanzeng	16.9	519.3	350.1	444.3
Jiangyou EA	25.2	511.8	458.8	198.2
Maoxian Nanxin	24.3	421.1	349.4	352.5
Guanyuan Zengjia	53.5	424.4	410.6	183.3

shows locations of the mobile and permanent strong-motion stations and the epicenters of aftershocks in the Wenchuan area (Li, 2009a, b). The largest aftershock was M 6.5 and occurred on August 5, 2008. Figure 11 shows the accelerations recorded at station Guanyuan Zengjia at an epicentral distance of 47 km. Figure 12 shows the spectral response acceleration at the station.

Station Site Classification

Ground-motion site effect is an important factor that must be considered in the development of a GMPE. Site effect is classified by the average shear-wave velocity of the topsoil. In the United States, site effect is quantified by the average shear-wave velocity of the top 30 m of soils, v_{s30}, and calculated according to the following equation:

$$v_{s30} = \frac{d_0}{\sum_{i=1}^{n} \left(\frac{d_i}{v_{si}}\right)}, \tag{3}$$

where $d_0 = 30$ m, d_i = thickness of the ith soil layer in meters, v_{si} = the shear-wave velocity of the ith soil layer in meters per second, and n = the number of soil layers (Building Seismic Safety Council, 2009). Table 3 lists the National Earthquake Hazard Reduction Program site classifications (Building Seismic Safety Council, 2009).

In China, however, site effect is classified by the average shear-wave velocity of the top 20 m of soil, v_{s20}. Table 4 lists the Chinese site classification (China Architecture and Building Press, 2010). In order to compare the GMPE's between the central and eastern United States and the Wenchuan region, the site classifications of the Wenchuan strong-motion stations were converted to the NEHRP site classification (Table 5) (Lu and others, 2009). Appendix B lists the converted NEHRP site classifications for 217 Wenchuan strong-motion stations.

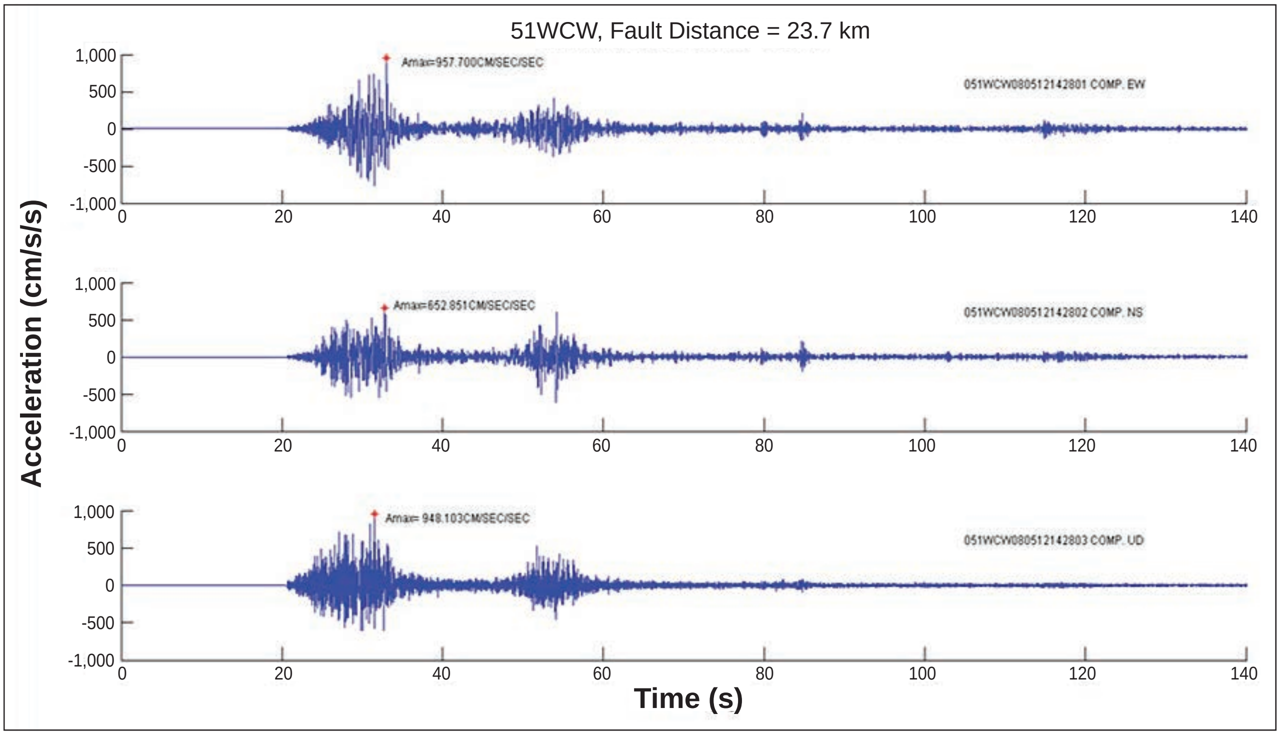


Figure 5. Peak ground acceleration recorded at Wolong station. Top: east-west component. Middle: north-south component. Bottom: vertical component.

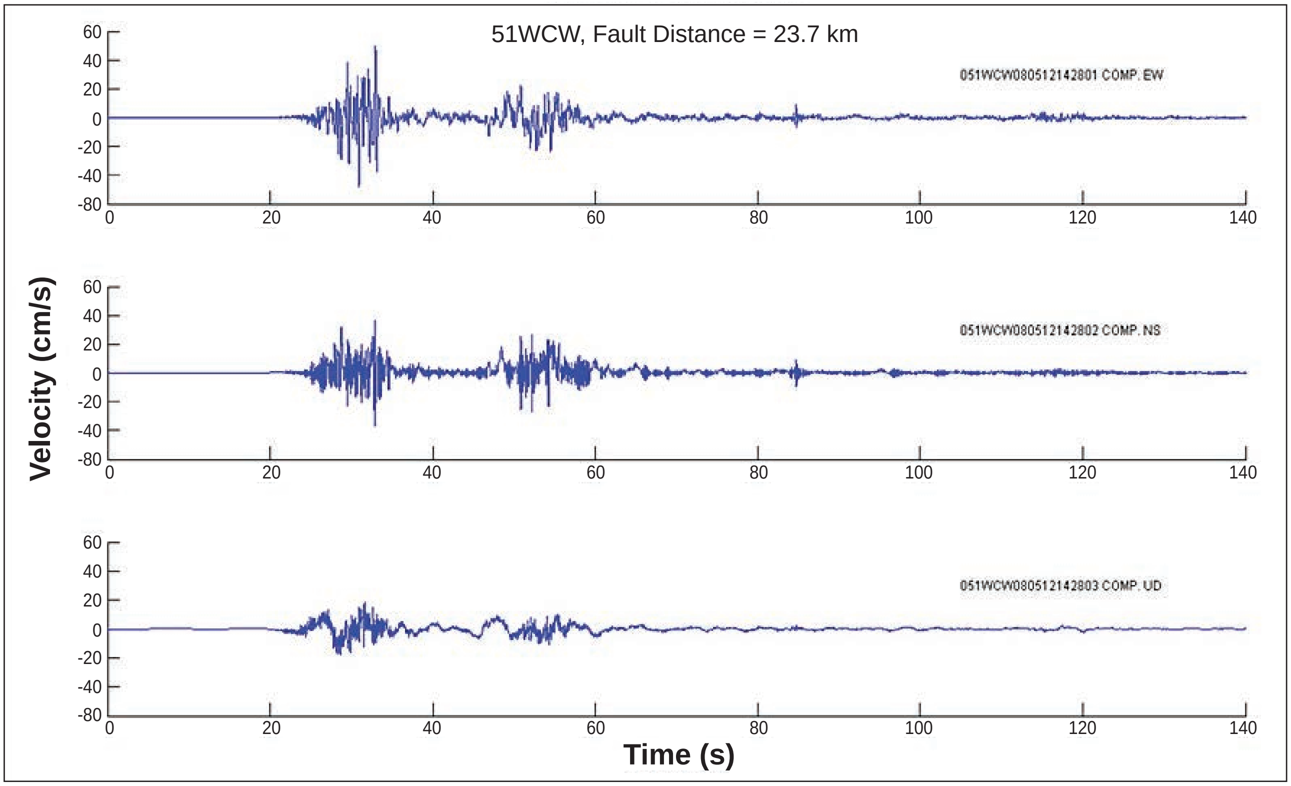


Figure 6. Peak ground velocity recorded at Wolong station. Top: east-west component. Middle: north-south component. Bottom: vertical component.

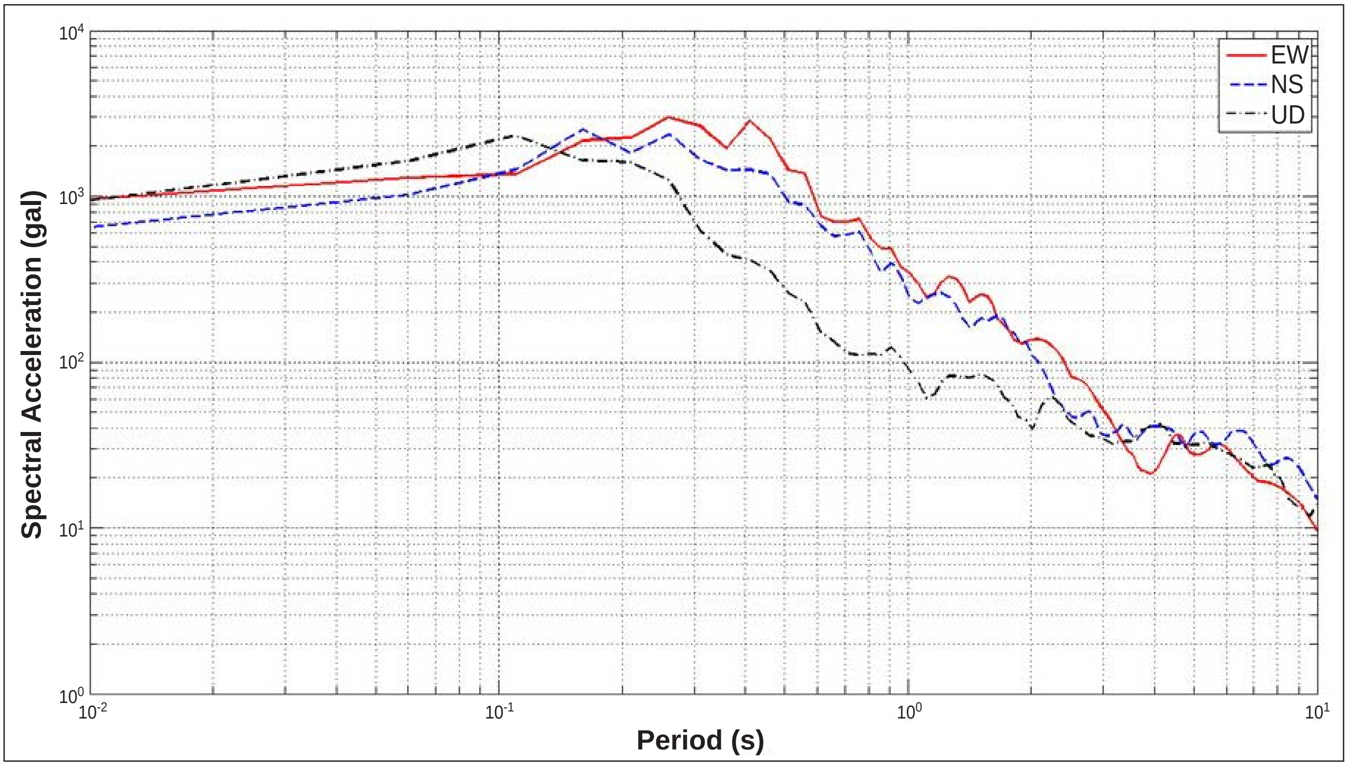


Figure 7. Spectral response acceleration at Wolong station. EW: east-west component. NS: north-south component. UD: vertical component.

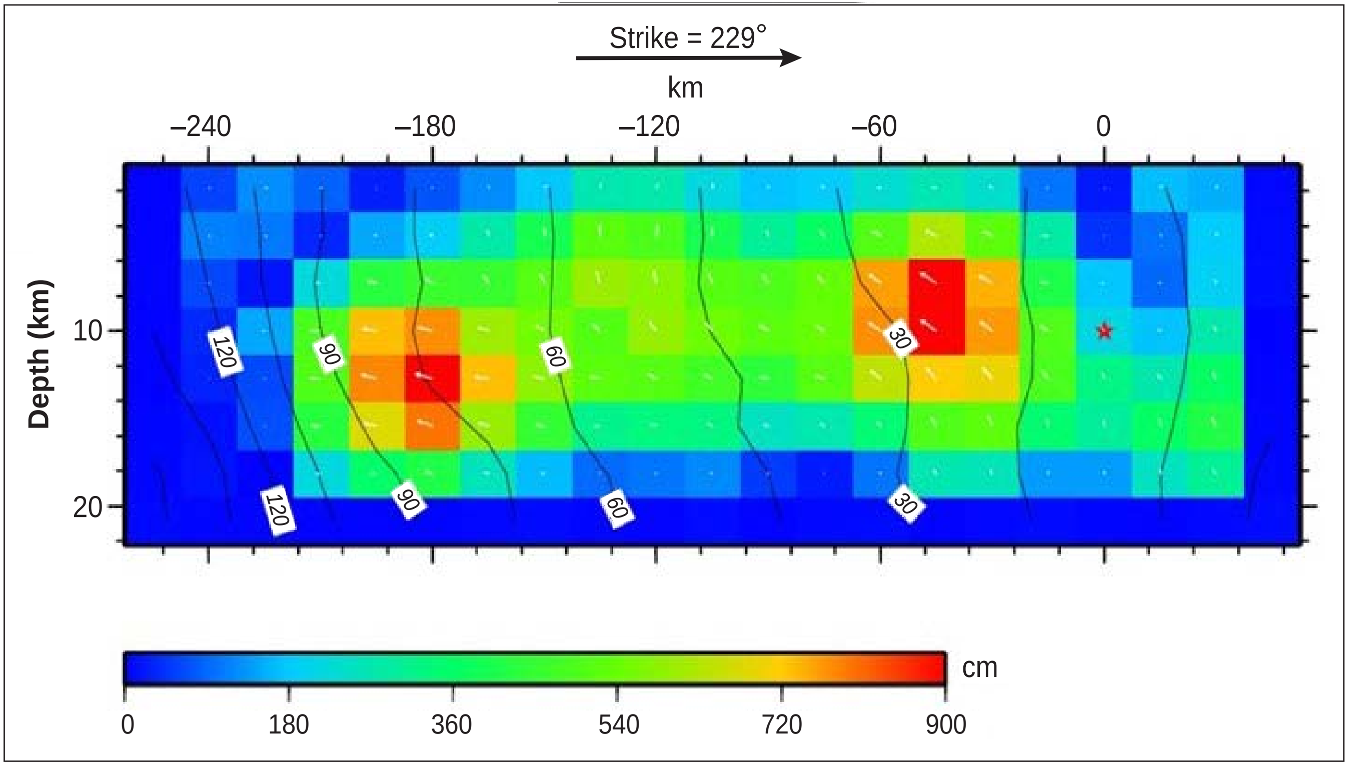


Figure 8. Slip distribution of the Wenchuan earthquake (Ji and Hayes, 2008). The strike direction of the fault plane is indicated by the black arrow and the hypocenter location is denoted by the red star. The slip amplitude is shown in color, and motion direction of the hanging wall relative to the footwall is indicated by white arrows. Contours show the rupture initiation time in seconds.

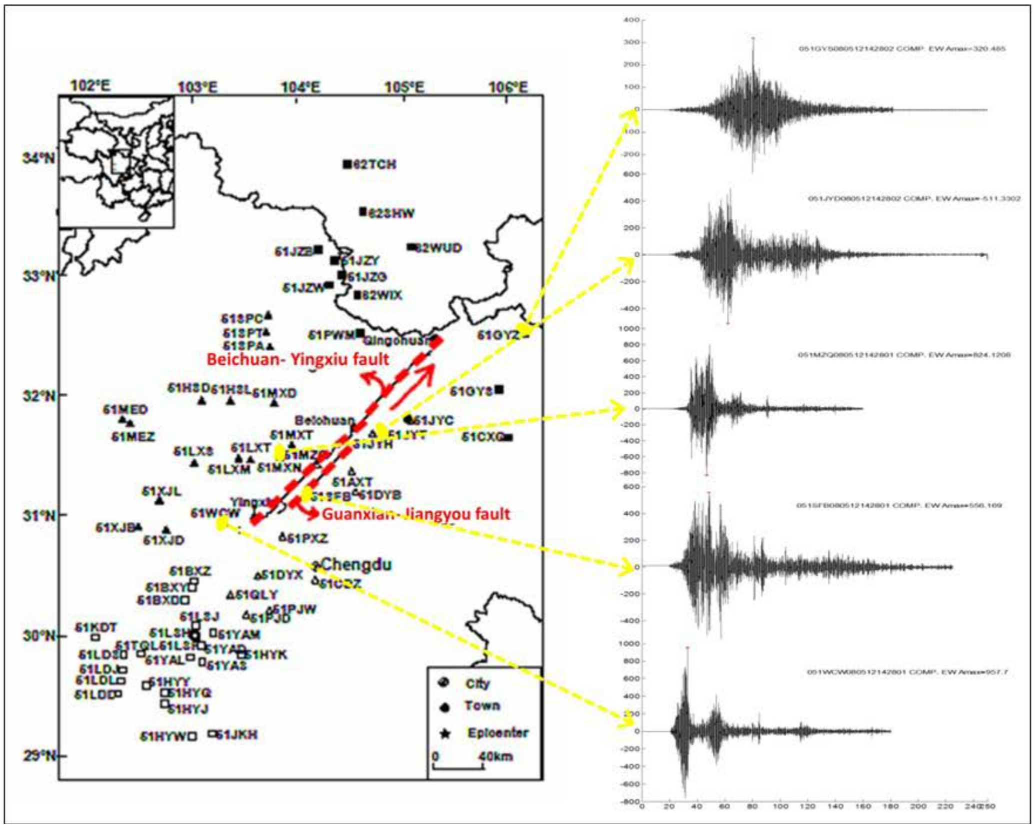


Figure 9. Rupture directivity effect on ground motion during the Wenchuan earthquake.

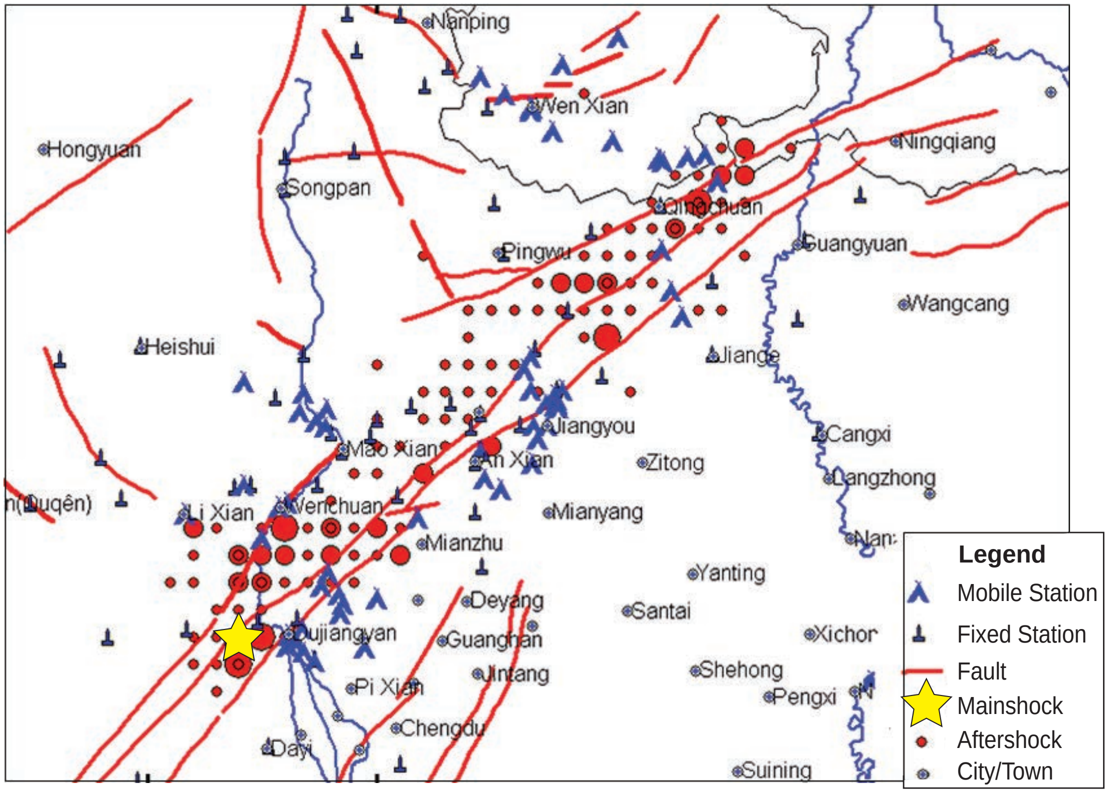


Figure 10. Locations of the mobile and permanent stations and aftershocks in the near-source area.

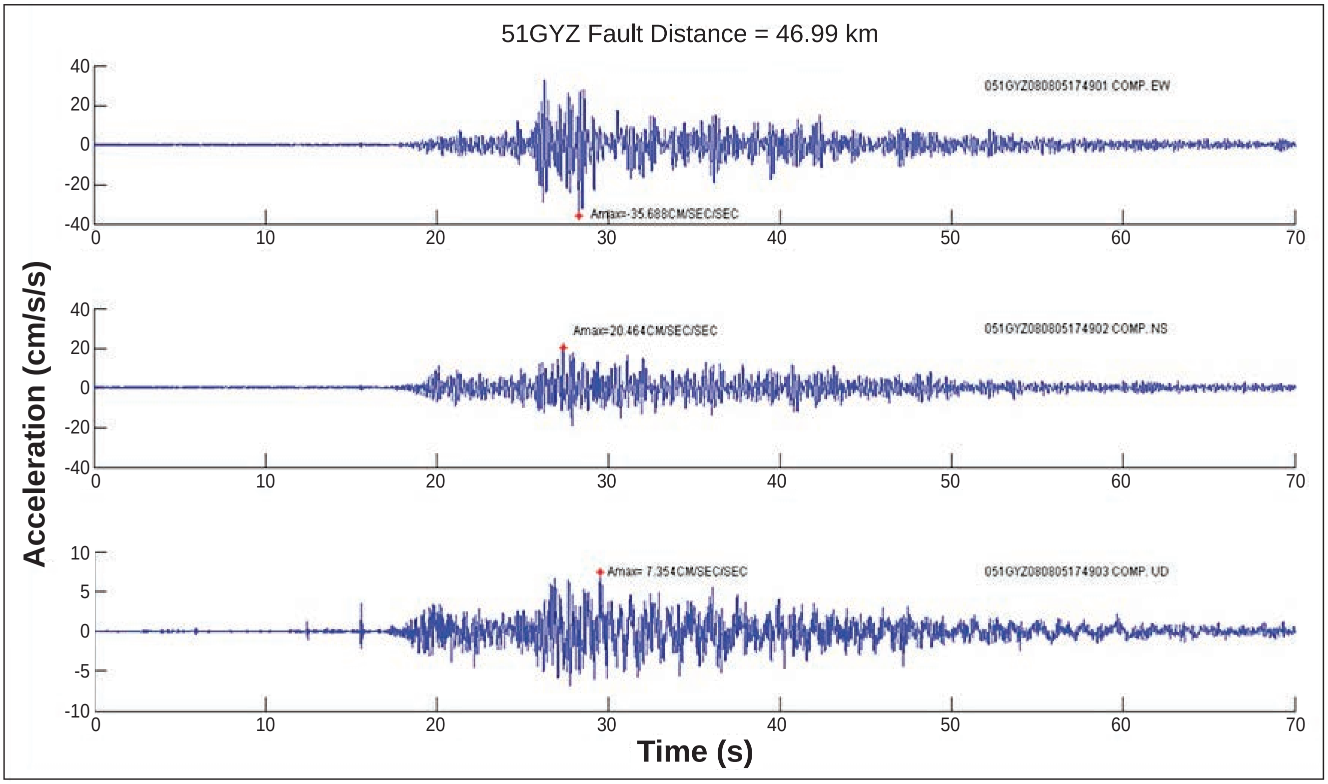


Figure 11. Peak ground acceleration recorded at station Guanyuan Zengjia. Top: east-west component. Middle: north-south component. Bottom: vertical component.

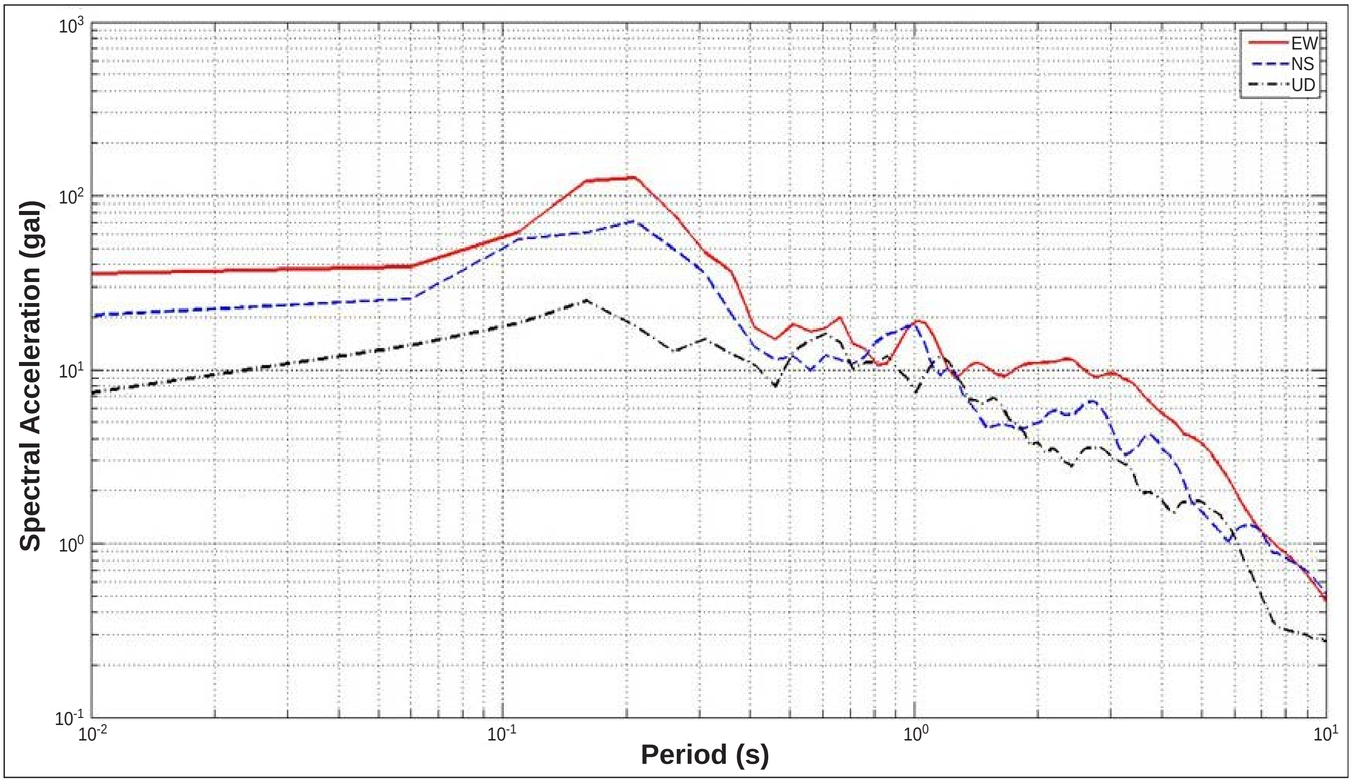


Figure 12. Spectral response acceleration at station Guanyuan Zengjia. EW: east-west component. NS: north-south component. UD: vertical component.

Table 3. NEHRP site classifications (Building Seismic Safety Council, 2009).

NEHRP Category	*Description*	*Mean Shear-Wave Velocity to 30 m*
A	hard rock	> 1,500 m/s
B	firm to hard rock	760–1,500 m/s
C	dense soil, soft rock	360–760 m/s
D	stiff soil	180–360 m/s
E	soft clays	< 180 m/s
F	special study soils (e.g., liquefiable soils, sensitive clays, organic soils, soft clays > 36 m thick)	

Table 4. Chinese site classifications (China Architecture and Building Press, 2010). Note: h is overburden thickness (m).

The shear-wave velocity for rock or equivalent shear-wave velocity for soil (m/s)	*Site Classifications*				
	I_0	I_1	*II*	*III*	*IV*
$v_{s20} > 800$	0				
$800 \geq v_{s20} > 500$		0			
$500 \geq v_{s20} > 250$		h < 5 m	h ≥ 5 m		
$250 \geq v_{s20} > 150$		h < 3 m	h = 3–5 m	h > 50 m	
$v_{s20} \leq 150$		h < 3 m	h = 3–15 m	h = 15–80 m	h > 50 m

Table 5. Comparison of site classifications between China and the United States. From Lu and others (2009). Note: h is overburden thickness (m).

Classification Standard	*Site Classifications*				
U.S.	*v_{s30} < 180 m/s*	*180–360 m/s*	*360–760 m/s*	*760–1,500 m/s*	*> 1,500 m/s*
	E	D	C	B	A
China	I (h < 3)	I (h < 3)	I (h < 5)		
	II (3 < h < 15)		II (h ≥ 5)		
		II (3 < h < 5)			
	III (15 < h < 80)				I (h = 0)
		III (h ≥ 50)			
	IV (h > 80)				
	soft soil	mid-soft soil	mid-hard soil	hard soil or bedrock	
	$v_{s20} \leq 150$ m/s	150–250 m/s	250–500 m/s	≥ 500 m/s	

Ground-Motion Prediction Equation

In general, a GMPE predicts a ground-motion value (e.g., PGA or PGV) using earthquake magnitude, source-to-site distance, fault mechanism (i.e., normal, reverse, or strike-slip), and site condition (e.g., hard rock and soft soil) and is expressed as

$$\log(Y) = f(M, R) + f(F) + f(S) + E, \qquad (4)$$

where Y is a ground-motion parameter (e.g., PGA, PGV, or response spectral acceleration [PSA]), $f(M,R)$ is a function of earthquake magnitude and source-to-site distance, $f(F)$ is a correction factor for the fault mechanism, $f(S)$ is a site correction factor, and E is random error (uncertainty), which is assumed to have a normal distribution and is quantified by a standard deviation, σ. For example, Joyner and Boore (1981) developed a GMPE for predicting peak horizontal velocity (V in meters per second) based on ground-motion records from California as

$$\log(V) = -0.67 + 0.0489M - \log(R) + 0.17S + 0.22P, \quad (5)$$

where M is moment magnitude, $R=(d^2+4.0^2)^{1/2}$, d is the closest distance to the surface projection of the fault rupture in kilometers, S is the site correction factor (0 for rock and 1 for soil), and P is the uncertainty term (0 for the 50th percentile and 1 for the 84th percentile). Boore and Atkinson (2008), Campbell and Bozorgnia (2008), and Chiou and Youngs (2008), for example, used more than 15 constants to describe their GMPE's.

GMPE for the Wenchuan Region

The ground-motion records from the Wenchuan main shock and aftershocks have been used to develop GMPE's for the Wenchuan area. Li and others (2008) and Wang and others (2010) developed GMPE's for an M 7.9 earthquake from the strong-motion records of the Wenchuan main shock. Wang and others (2010) derived a GMPE for PGA and PGV:

$$ln(Y) = a_0 + a_1 \ln(R_{rup} + a_2) + a_3 \ln(V_{s30}) + a_4 R_{rup}, \quad (6)$$

where a_0, a_1, a_2, a_3, and a_4 are the regression coefficients, R_{rup} is the distance to the fault rupture in kilometers, and V_{s30} is the average shear-wave velocity of the top 30 m of soil. Kang and Jin (2009) also developed a GMPE for PGA and PGV using broadband velocity records from 27 stations on bedrock from 105 aftershocks with magnitude M 4.0 to 6.4 for the Sichuan Basin:

$$\ln(Y) = a + bM + (c + dM)\ln(R + 10), \quad (7)$$

where a, b, c, and d are regression coefficients and R is the epicentral distance in kilometers.

We used a simple function for predicting PGA, PGV, and PSA at different periods:

$$\log(Y) = c_1 + c_2 M + c_3 \log(R + R_0) + E, \quad (8)$$

where c_1, c_2, and c_3 are regression coefficients, R is the shortest distance to the fault rupture, R_0 is the near-source distance in kilometers, and E is random error. The ground motion is saturated near the source for earthquakes with magnitude of M 6.5 or greater. In other words, at near-source distance, ground-motion values will not increase with magnitude for earthquakes greater than M 6.5 (Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008). We determined that R_0 is a function of magnitude and has the values listed in Table 6.

The two-step method (Joyner and Boore, 1981; Boore and Atkinson, 2008) was used in regression analysis for the strong-motion data from the main shock and aftershocks. Equation 7 yields:

$$\log(Y) = a + c_3 \log(R + R_0) + E, \quad (9)$$

where

$$a = c_1 + c_2 M. \quad (10)$$

First, we performed regression analysis on equation 9 using the observed ground-motion values and fault distances to obtain coefficients a and c_3. Then, we performed regression analysis on equation 10 using the magnitudes and coefficient a to obtain coefficients c_1 and c_2. Table 7 lists the regression results for PGA, PGV, and PSA with different periods.

Figures 13 through 15 show the predicted median PGA, 0.2 s PSA, and 1.0 s PSA, and observed values, respectively. The magnitudes of the aftershocks were binned according to Table 8 and regression analysis was performed for each magnitude bin. Figures 16 and 17 show the predicted median PGA and PGV for each magnitude bin and observed values from the Wenchuan aftershocks.

GMPE for the Central and Eastern United States

Many GMPE's have been developed for the central and eastern United States. For example, seven GMPE's were used in the 2008 national seismic hazard mapping project (Petersen and others, 2008), including those by Frankel and others (1996), Toro and others (1997), Somerville and others (2001), Silva and others (2002), Campbell (2003), Tavakoli and Pezeshk (2005), and Atkinson and

Table 6. Magnitude and corresponding saturation distance.

Magnitude	6.5	7.0	7.5	8.0
R_0 (km)	5.0	7.5	10.0	15.0

Table 7. Regression coefficients for the main shock and aftershocks of the Wenchuan earthquake.

Period	c_1	c_2	c_3	σ
PGV	–0.259	0.316	–0.856	0.305
PGA	1.698	0.343	–1.180	0.315
0.020	1.702	0.345	–1.165	0.327
0.030	1.746	0.349	–1.173	0.245
0.040	1.890	0.353	–1.154	0.345
0.050	1.819	0.329	–1.153	0.311
0.075	1.901	0.339	–1.134	0.332
0.100	2.125	0.321	–1.150	0.323
0.150	1.864	0.359	–1.135	0.331
0.200	1.602	0.398	–1.120	0.344
0.250	1.426	0.409	–1.095	0.320
0.300	1.250	0.420	–1.069	0.319
0.400	0.898	0.442	–1.018	0.322
0.500	0.546	0.463	–0.967	0.287
0.750	–0.333	0.518	–0.839	0.213
1.000	–1.063	0.574	–0.852	0.214
1.500	–0.965	0.576	–0.966	0.318
2.000	–0.717	0.580	–1.201	0.335
3.000	–0.718	0.556	–1.186	0.323
4.000	–0.779	0.539	–1.136	0.322
5.000	–0.842	0.491	–1.005	0.332
7.500	–1.005	0.495	–1.010	0.310
10.000	–1.167	0.499	–1.123	0.320

Boore (2006). All the GMPE's for the central and eastern United States were developed from numerical simulations of ground motion or statistical analysis with or without constraints from limited ground-motion records of small to moderate earthquakes (<M 6.0). They can be separated into four methods: stochastic point-source, stochastic finite-fault, Green's function, and hybrid empirical.

Stochastic Point-Source Method. This method uses a stochastic representation of the ground motion that is simulated from a seismological model of the single source spectrum and wave propagation. In this approach, synthetic ground motions are first generated from computer simulations for earthquakes with a magnitude range of M 5 to 8, a range of source parameters (e.g., stress drop), and a range of distances. Then, ground-motion parameters are obtained from the synthetic ground motions and used to develop a GMPE. Several GMPE's have been developed with this method, including those by Frankel and others (1996), Toro and others (1997), and Silva and others (2002). We selected the Silva and others (2002) GMPE with the double corner and a near-source saturation term for comparison with the observations from the Wenchuan earthquake. Silva and others (2002) used the following functional form:

$$\ln y = c_1 + c_2 M + (c_6 + c_7 M) \times \ln(R + e^{c4}) + c_{10}(M-6)^2, \quad (11)$$

where c_1, c_2, c_4, c_6, c_7, and c_{10} are the regression coefficients. Figure 18 shows median PGA curves on hard rock for M 5.5, 6.5, and 7.5 predicted by the GMPE of Silva and others (2002) for a double corner model with near-source saturation.

Stochastic Finite-Fault Method. The Wenchuan earthquake demonstrated that large earthquakes cannot be represented by a single-point-source

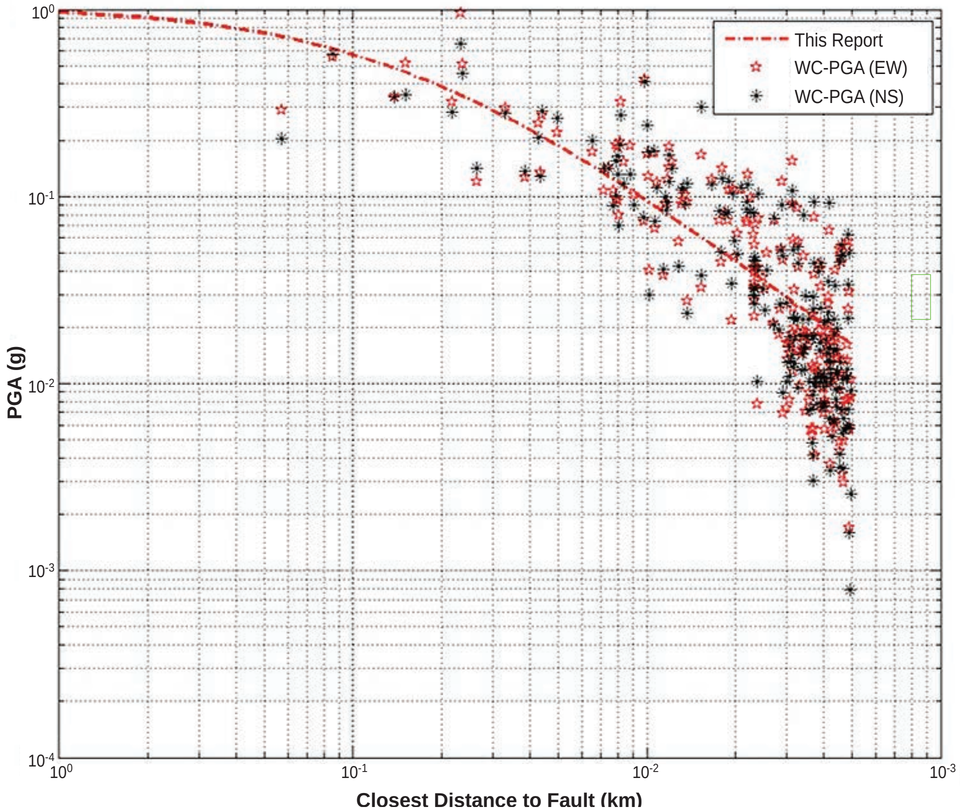


Figure 13. Median PGA attenuation relation of the Wenchuan main-shock recordings.

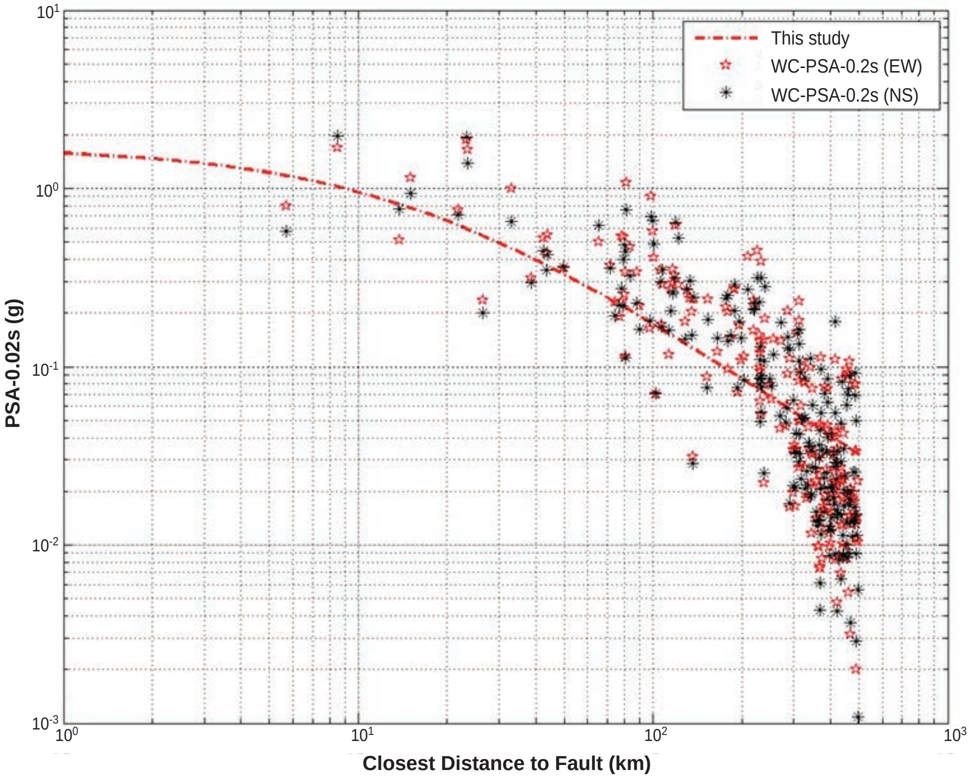


Figure 14. Median PSA attenuation relation of the Wenchuan main-shock recordings at 0.2 s.

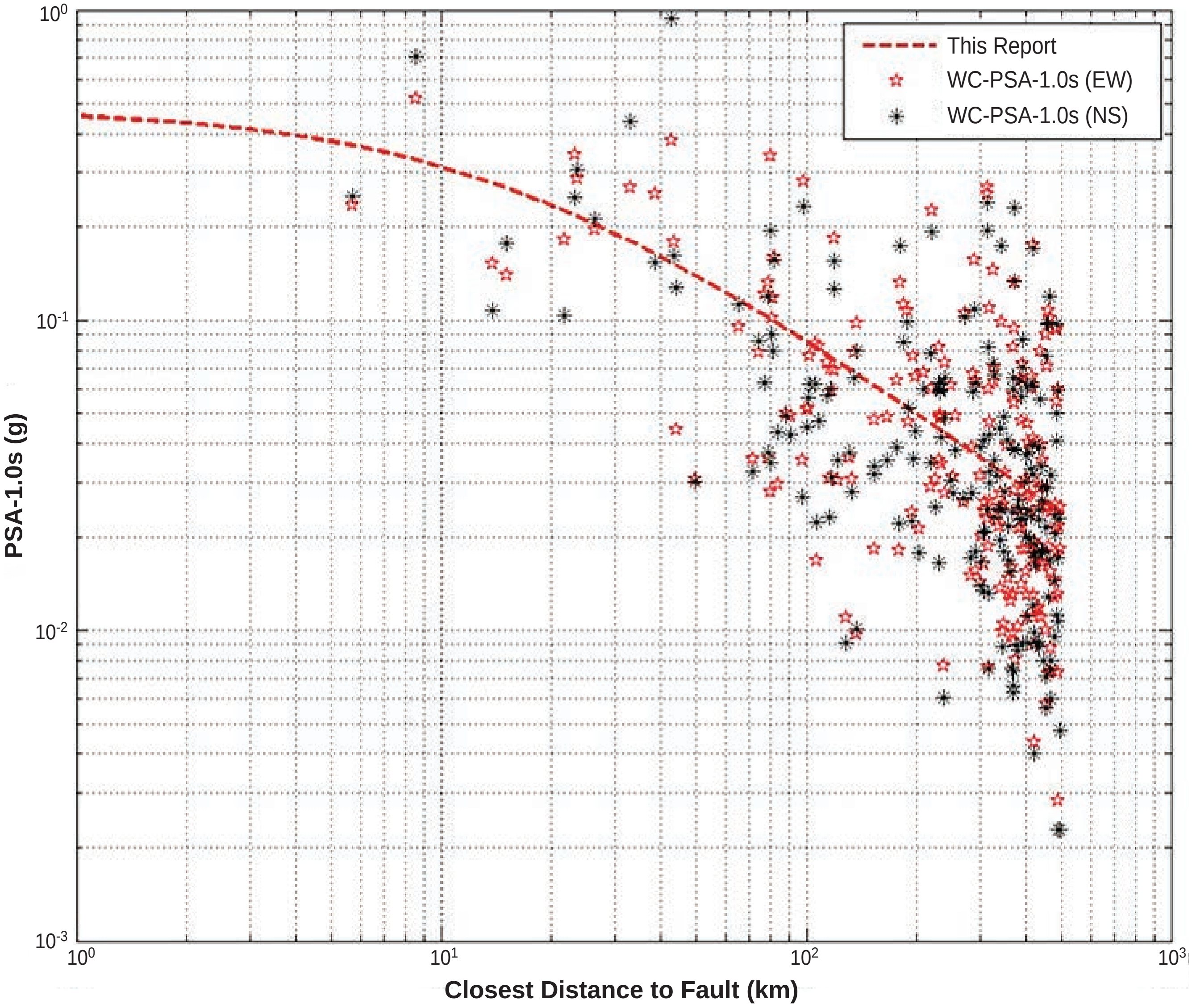


Figure 15. Median PSA attenuation relation of the Wenchuan main-shock recordings at 1.0 s.

model. In order to address this drawback, a finite-fault model was developed to generate synthetic ground motion (Beresnev and Atkinson, 1999). Atkinson and Boore (2006) used the finite-fault model to generate synthetic ground motions and develop GMPE's for the central and eastern United States. Atkinson and Boore (2006) used the following functional form:

$$\log(Y) = c_1 + c_2M + c_3M^2 + (c_4 + c_5M)f_1 + (c_6 + c_7M)f_2 + (c_8 + c_9M)f_0 + c_{10}R_{cd} + S, \qquad (12)$$

Table 8. Aftershock magnitude bins. (The regression is generally not carried out for each magnitude, 5.0, 5.1, 5.2,..,6.5, but over an interval [bin], 5.0 – 5.1, 5.2 – 5.4,…)

Regression magnitude	5.0	5.3	5.6
Moment magnitude bin	$5.0 \leq M_w \leq 5.1$	$5.2 \leq M_w \leq 5.4$	$5.5 \leq M_w \leq 5.7$
Regression magnitude	5.9	6.2	6.5
Moment magnitude bin	$5.8 \leq M_w \leq 6.0$	$6.1 \leq M_w \leq 6.3$	$6.4 \leq M_w \leq 6.5$

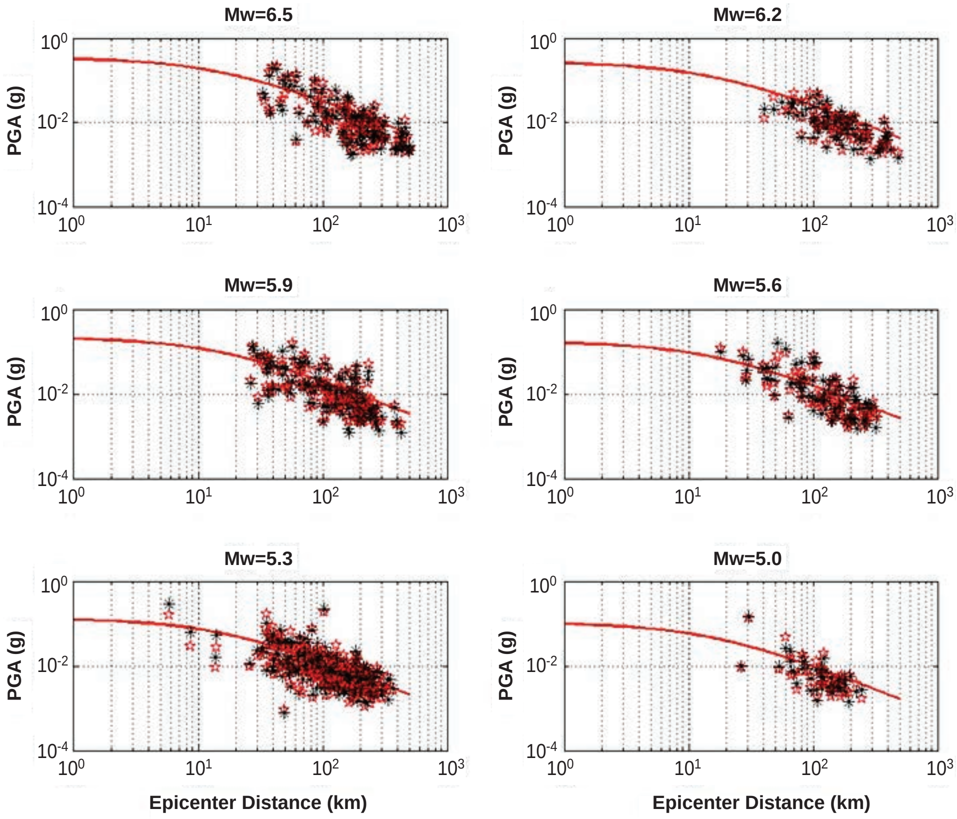


Figure 16. Median PGA attenuation relationships for the Wenchuan aftershocks.

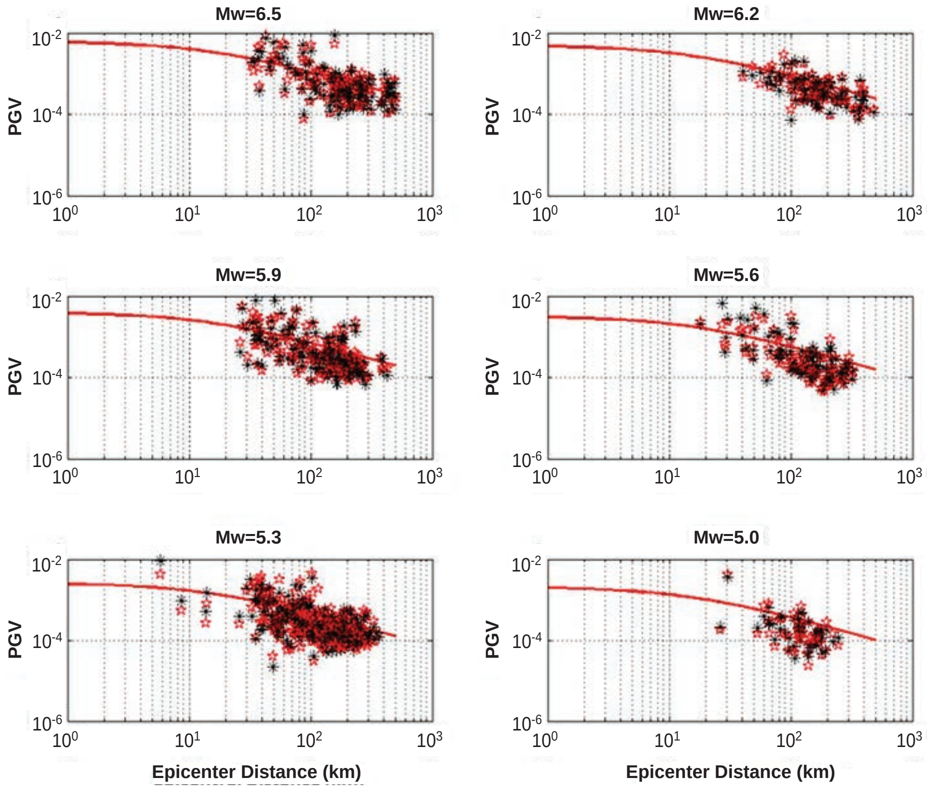


Figure 17. Median PGV attenuation relationships for the Wenchuan aftershocks.

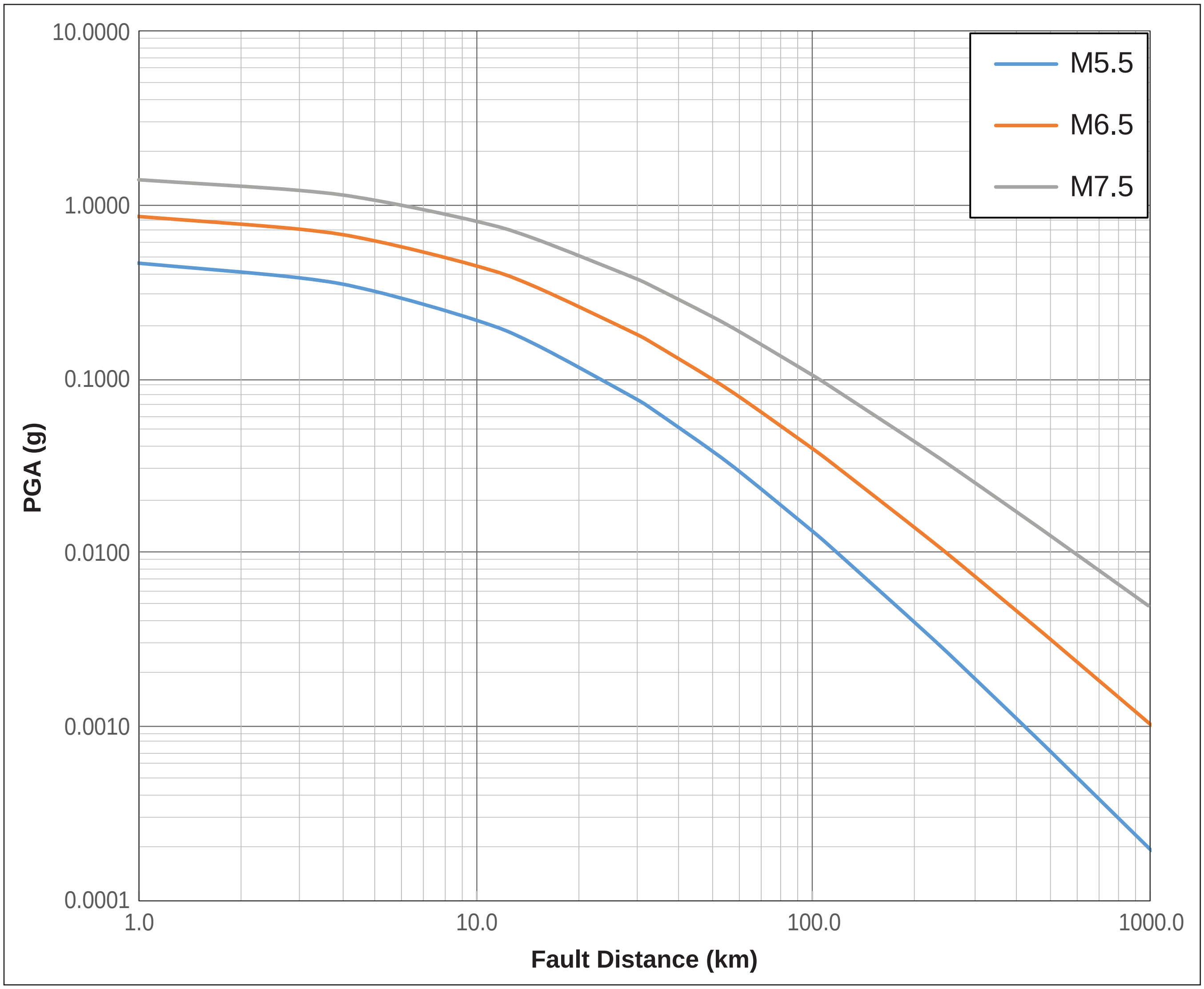


Figure 18. Median PGA curves for hard rock for the double corner model with a near-source saturation of Silva and others, 2002.

where $f_0 = \max\left(\log\left(\frac{R_0}{R_{cd}}\right), 0\right)$, $f_1 = \min(\log R_{cd}, \log R_1)$, $f_2 = \max\left(\log\left(\frac{R_{cd}}{R_2}\right), 0\right)$, $R_0 = 10\,\text{km}$, $R_1 = 70\,\text{km}$, $R_2 = 140\,\text{km}$, R_{cd} = closest distance to the fault rupture in kilometers, and S is site correction factor.

Figure 19 shows the median PGA curves on soft rock for M 5.5, 6.5, and 7.5 predicted by the GMPE of Atkinson and Boore (2006).

Hybrid Empirical Method. In the hybrid empirical method, GMPE is derived by transforming a GMPE from a host region using modification factors determined by the wave propagation characteristics of the host and targeted regions. Campbell (2003) first used this method to derive a GMPE for the central and eastern United States based on the GMPE for the western United States. The modification factors can be developed from different approaches using the seismological parameters in the host and targeted regions. For example, Campbell (2003) used the single-point-source stochastic model to develop the modification factors, whereas Pezeshk and others (2011) used the finite-fault stochastic model to develop the modification factors. For this study, we chose the Pezeshk and others (2011) GMPE for comparison with the oberservations from the Wen-

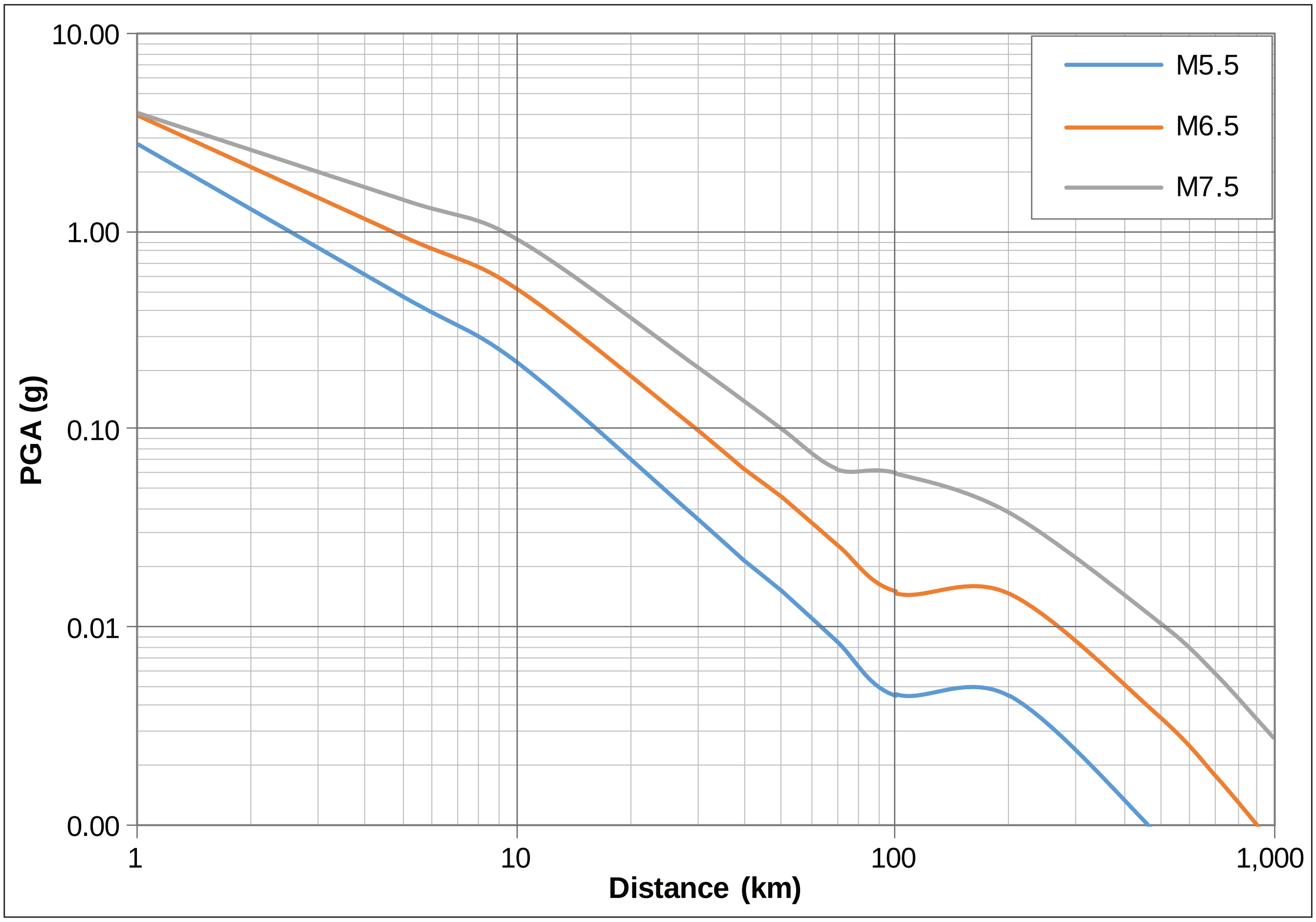


Figure 19. Median PGA curves for soft rock (NEHRP B/C boundary) for M 5.5, 6.5, and 7.5 earthquakes predicted by the GMPE of Atkinson and Boore (2006).

chuan earthquake. Pezeshk and others (2011) used the following functional form:

$$\log(\mathrm{Y}) = c_1 + c_2 M_w + c_3 M^2_w + (c_4 + c_5 M_w) \times \min\{\log(R), \log(70)\} + (c_6 + c_7 M_w) \times \max\left[\min\left\{\log\left(\tfrac{R}{70}\right), \log\left(\tfrac{140}{70}\right)\right\}, 0\right] + (c_8 + c_9 M_w) \times \max\left\{\log\left(\tfrac{\mathrm{R}}{140}\right), 0\right\} + c_{10} R, \qquad (13)$$

where $R = \sqrt{R_{rup} + c_{11}}$ and R_{rup} means the closest distance to the fault rupture in kilometers. Pezeshk and others (2011) determined the uncertainty (σ) as

$$\sigma_{\log(Y)} = \begin{cases} c_{12} M_w + c_{13}, M \leq 7 \\ -6.95 \times 10^{-3} M_w + c_{14}, M > 7. \end{cases} \qquad (14)$$

Figure 20 shows the median PGA curves on hard rock for M 5.5, 6.5, and 7.5 predicted by the GMPE of Pezeshk and others (2011).

Green’s Function Method. In this method, synthetic ground motions are generated using a Green’s

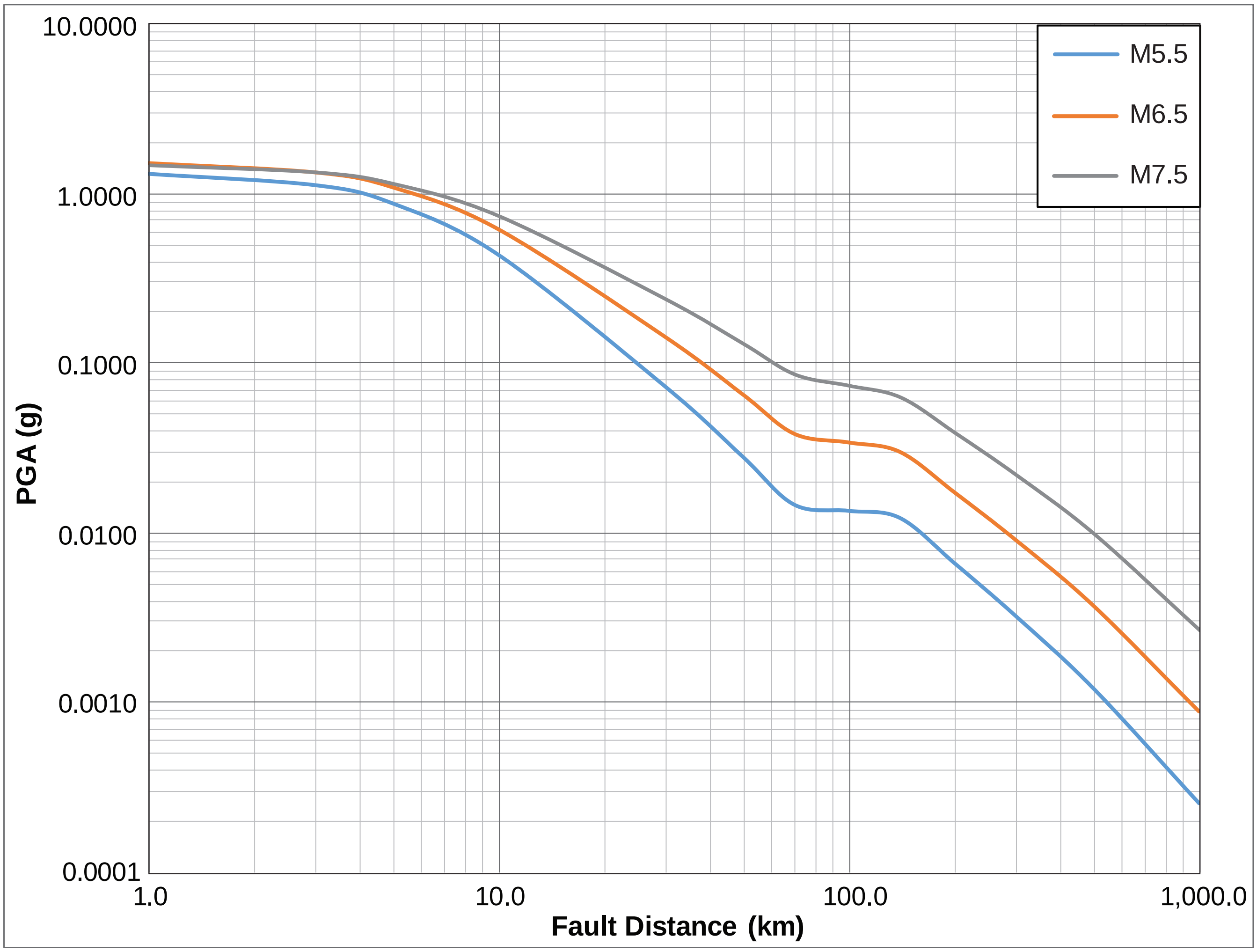


Figure 20. Median PGA curves for hard rock for M 5.5, 6.5, and 7.5 earthquakes predicted by the GMPE of Pezeshk and others (2011).

function and earthquake source-scaling relations. Somerville and others (2001) used this method to develop a GMPE for the central and eastern United States. A large set of synthetic ground motions was generated using a representative crustal-structure model and ranges of source-parameter values consistent with the source-scaling relations; the synthetic ground motions then were used to generate ground-motion attenuation relations for hard-rock conditions in the central and eastern United States (Somerville and others, 2001). Somerville and others (2001) used the following functional form to predict median values:

For $R < R_0$:

$$\ln(Y) = c_1 + c_2(M - m_1) + c_3 \ln(r) + c_4(M - m_1)\ln(r) + c_5 R + c_7(8.5 - M)^2 \tag{15}$$

For $R \geq R_0$:

$$\ln(Y) = c_1 + c_2(M - m_1) + c_3 \ln(r_1) + c_4(M - m_1)\ln(r) + c_5 R + c_6(\ln(r) - \ln(r_1)) + c_7(8.5 - M)^2, \tag{16}$$

where $m_1 = 6.4$, $R_0 = 50$ km, $h = 6$ km, and $r = \sqrt{R^2 + h^2}$; $r_1 = \sqrt{R_0^2 + h^2}$, and R is the Joyner-Boore distance. Figure 21 shows the median PGA curves on hard

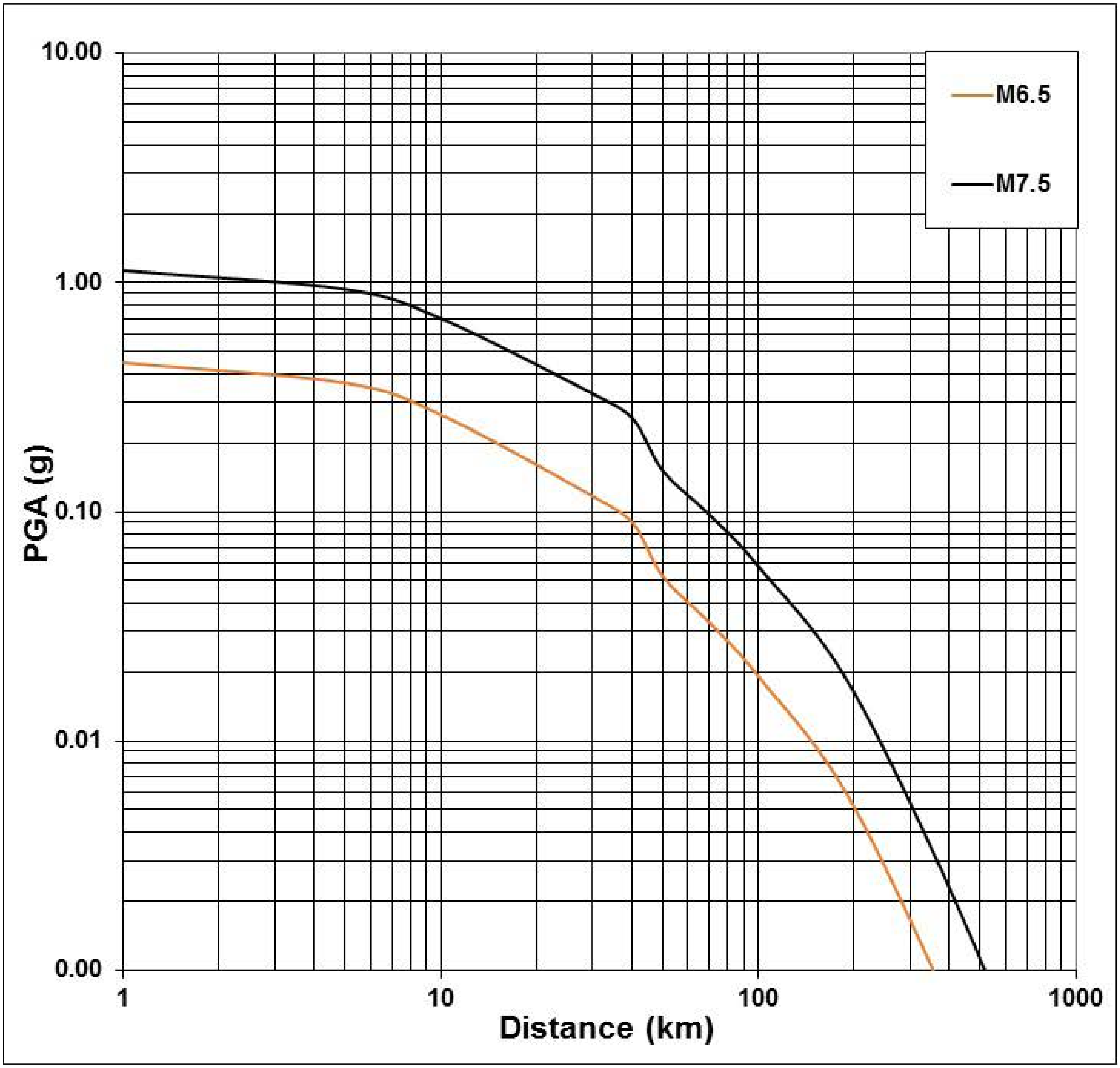


Figure 21. Median PGA curves for hard rock for M 6.5 and 7.5 earthquakes predicted by the GMPE of Somerville and others (2001).

rock for M 6.5 and 7.5 predicted by the GMPE of Somerville and others (2001).

Comparison of Ground-Motion Prediction Equations

The Wenchuan earthquake provided a rich ground-motion data set that could be used to develop a GMPE for a similar seismic-tectonic region. The ground-motion records from the main shock of the Wenchuan earthquake were compared to GMPE's for the western United States (Lu and others, 2010; Wang and others, 2010). The short-period (T<0.5 s) ground motions from the Wenchuan earthquake were consistently higher than the motions predicted by the GMPE's for the western United States, whereas the long-period (T>1.0 s) ground motions for the Wenchuan earthquake were consistently lower than the motions predicted by the GMPE's for the western United States (Lu and others, 2010; Wang and others, 2010).

Therefore, the ground motions from the Wenchuan earthquake are not appropriate for developing a GMPE for interplate regions such as the western United States, coastal California in particular.

The Wenchuan earthquake occurred along the Longmenshan Thrust Belt, which coincides with steep gradients in crustal thickness, ranging from 60 to 65 km in the west to about 40 km in the east (Xu and others, 2008). The Longmenshan Thrust Belt is also the western boundary of the Eastern China stable continental region (Johnston and others, 1994; Wheeler, 2011). A stable continental region is a continent or part of a continent and is defined as a region in which no major tectonism, magmatism, basement metamorphism, or anorogenic intrusion has occurred in the crust since the Early Cretaceous, and no rifting or major extension or transtension since the Paleogene (Johnston and others, 1994). Wheeler (2011) showed that the central and eastern United States and the Wenchuan region both are in stable continental regions (Fig. 22). The two region have similar crustal structures (Mooney and others, 2002; Wang and others, 2003). A preliminary comparison of the GMPE's suggested that the ground-motion data set from the Wenchuan earthquake could be used to develop a GMPE for the central and eastern United States (Wang and Lu, 2011).

A detailed comparison of GMPE's for the central and eastern United States, including those by Somerville and others (2001), Silva and others (2002), Atkinson and Boore (2006), and Pezeshk and others (2011), and the Wenchuan area was made. Figures 23a–c show the predicted median PGA, 0.2 s PSA, and 1.0 s PSA curves for an M 7.5 earthquake in the Wenchuan region and in the central and eastern United States, respectively. Figures 24a–c show the predicted median PGA, 0.2 s PSA, and 1.0 s PSA curves for an M 6.5 earthquake in the Wenchuan region and in the central and eastern United States, respectively. Figures 25a–c show the predicted median PGA curves for an M 7.9 earthquake in the central and eastern United States and the observed PGA's from the main shock of the Wenchuan earthquake.

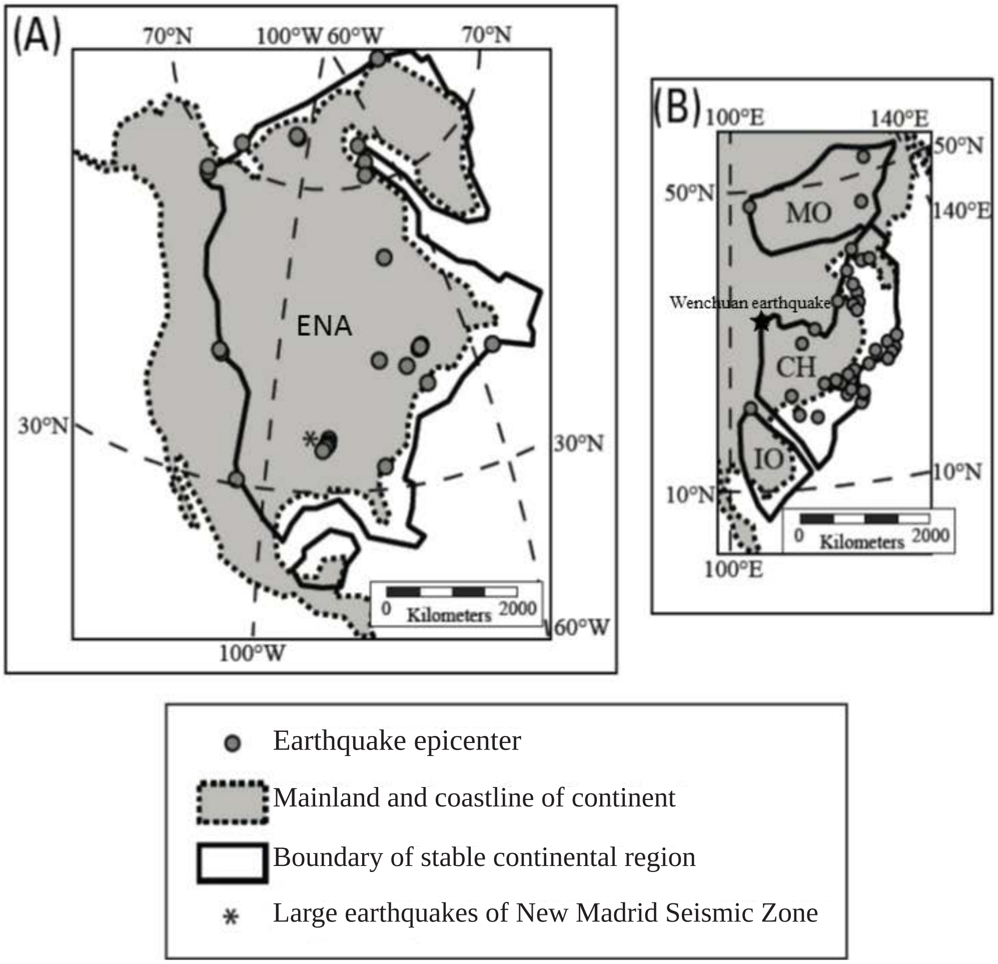
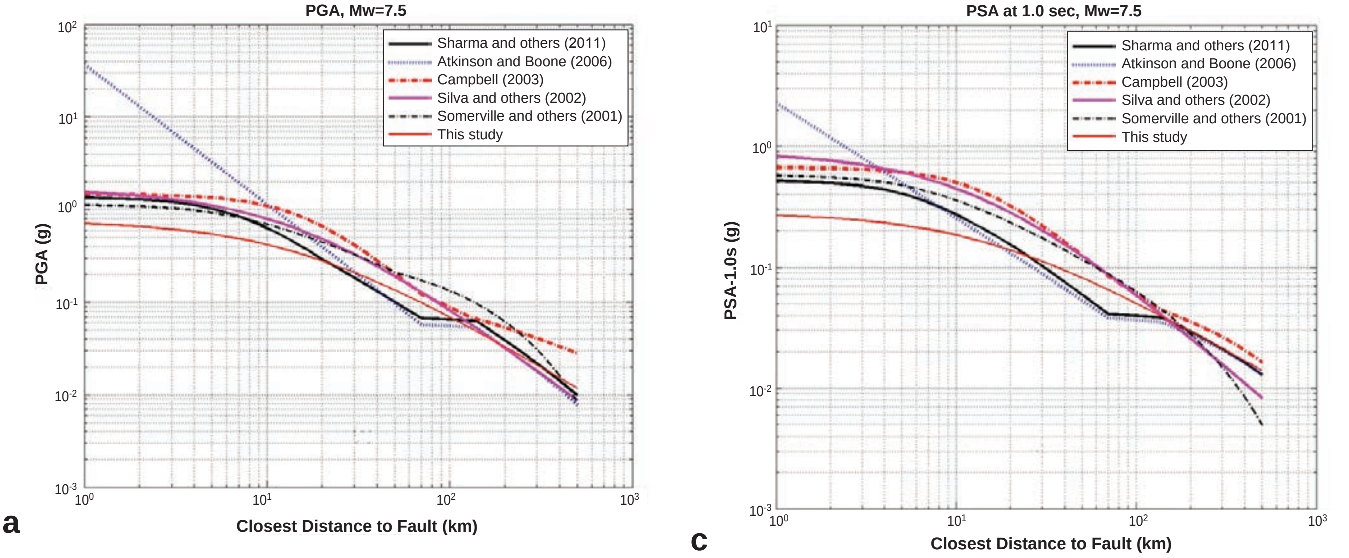


Figure 22. Stable continental regions of North America (A) and South China (B) (modified from R.L. Wheeler, Reassessment of stable continental regions of Southeast Asia: Seismological Research Letters, v. 82, p. 971–983, 2011, © Seismological Society of America). Star: Wenchuan region. ENA: eastern North America stable continental region. CH: Eastern China stable continental region. MO: Mongolia stable continental region. IO: Indochina stable continental region.

Conclusions

It is common practice to use ground-motion records from one seismic-tectonic region to develop a GMPE for a similar seismic-tectonic region. The Wenchuan earthquake occurred along the Longmenshan Thrust Belt, which is the western boundary of the Eastern China stable continental region. The central and eastern United States is also a stable continental region. A detailed comparison of GMPE's for the central and eastern United States, including those by Somerville and others (2001), Silva and others (2002), Atkinson and Boore (2006), and Pezeshk and others (2011), with the Wenchuan area was performed. The results show that the ground-motion attenuations of the central and eastern United States are similar to that of the Wenchuan area. In other words, the GMPE's for the central and estern United States and the Wenchuan area have similar characteristics. Thus, the ground-motion data set obtained from the Wenchuan earthquake can be used to develop a GMPE for the central and eastern United States.



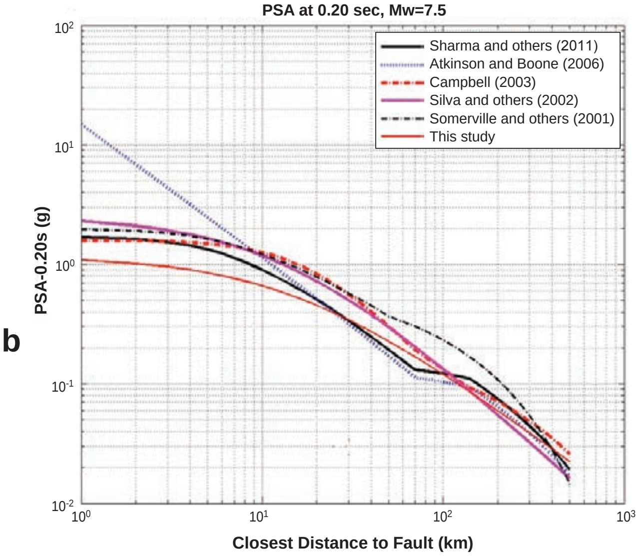
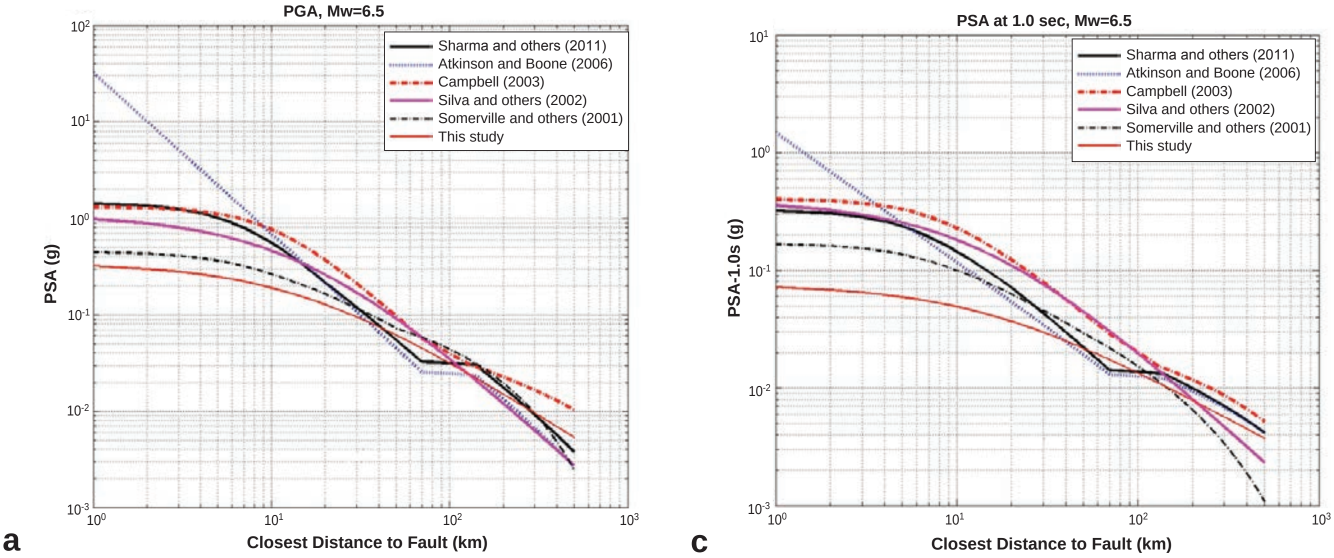


Figure 23. Predicted median PGA (a), 0.2 s PSA (b), and 1.0 s PSA (c) curves for an M 7.5 earthquake in the Wenchuan region and the central and eastern United States.



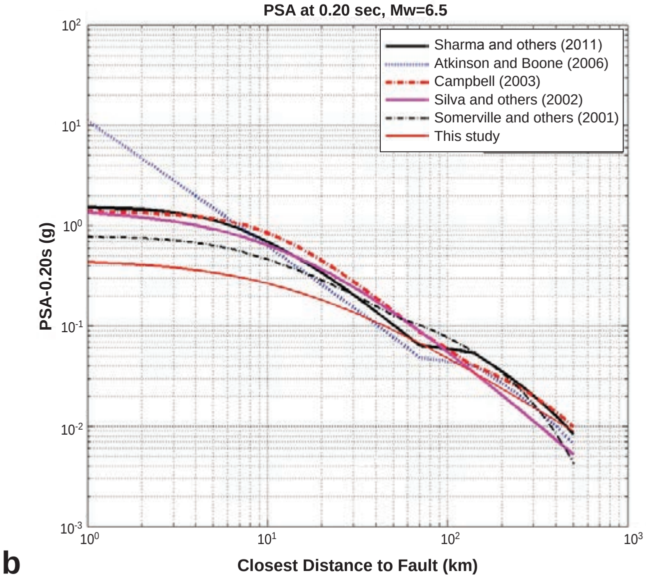
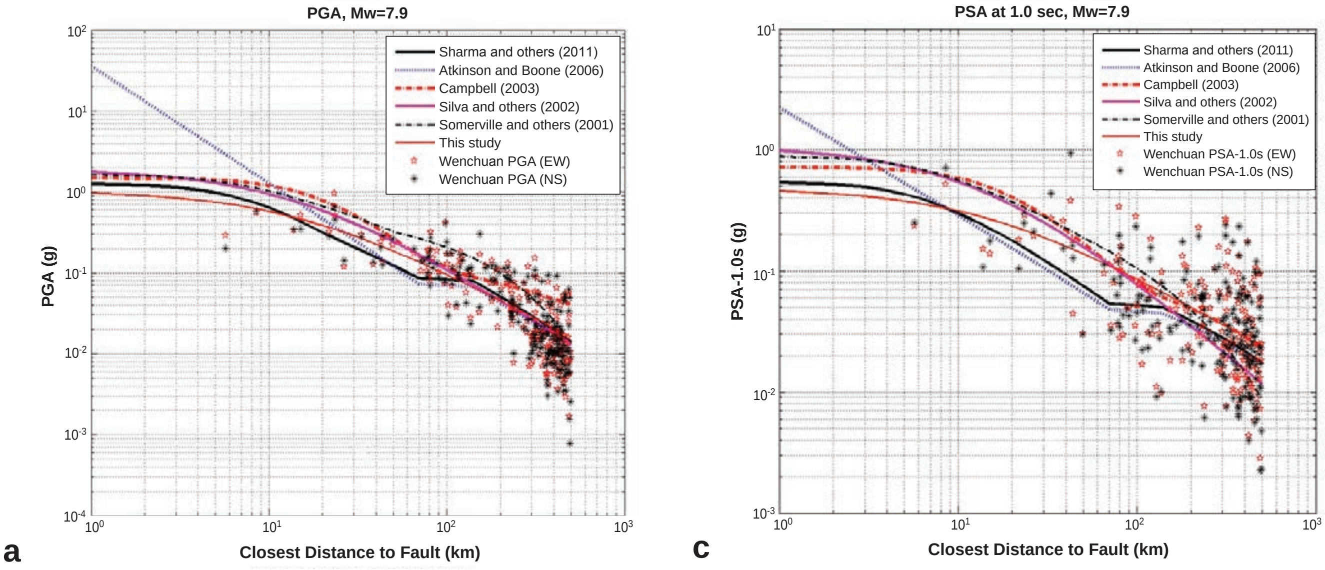


Figure 24. Predicted median PGA (a), 0.2 s PSA (b), and 1.0 s PSA (c) curves for an M 6.5 earthquake in the Wenchuan region and the central and eastern United States.



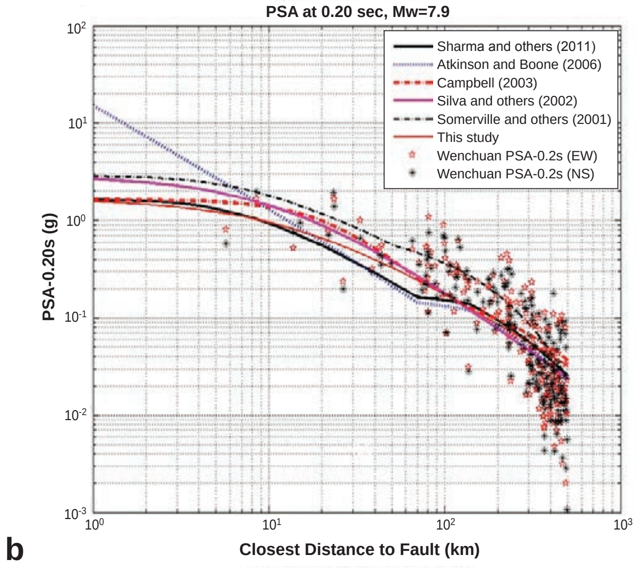


Figure 25. Comparison of ground-motion predictions of this study for the Sichuan Basin and four GMPE's for the central and eastern United States for an M 7.9 earthquake and the observations of the Wenchuan earthquake main shock. (a) PGA, (b) 5 percent damped response spectral acceleration at 0.2 s period, and (c) 5 percent damped response spectral acceleration at 1.0 s period.

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Appendix 1: Recording Data from the Wenchuan M_w 7.9 Earthquake

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Anxian Tashui	AXTS	104.30	31.54	5.70	285.58	177.550	176.020	21.90	27.34	23.19	9.61	14.478	14.755
Baoji	BJ	107.07	34.36	287.13	118.94	88.664	33.989	13.86	11.37	5.13	4.51	4.035	4.505
Bowuguan	BWG	103.73	36.12	416.27	6.99	6.351	4.464	3.85	4.14	3.19	2.89	3.736	3.341
Basong	BS	103.48	35.31	348.34	127.01	17.467	6.552	4.14	4.28	2.06	3.74	1.881	1.403
Butuo EA	BTDZJ	102.80	27.71	370.32	12.07	10.384	9.988	3.96	3.49	2.00	1.98	1.416	1.081
Butuotuojue	BTTJ	102.84	27.55	386.97	9.86	10.09	5.151	1.84	1.66	1.09	0.84	0.726	0.795
Baoxing EA	BXDZJ	102.82	30.37	97.51	72.24	76.549	49.104	3.39	3.16	3.45	0.99	1.199	2.084
Baoxing Minzhi	BXMZ	102.88	30.49	83.62	148.51	114.66	107.28	5.86	6.00	3.55	1.35	1.267	1.764
Baoxing Yanjing	BXYJ	102.90	30.54	78.39	185.98	151.98	90.458	6.50	4.69	4.14	1.49	1.494	2.11
Caotan	CT	108.95	34.40	463.32	54.16	48.101	12.7	16.71	17.26	6.61	14.92	15.329	5.54
Chengdu Zhonghe	CDZH	104.09	30.55	80.42	76.95	69.254	43.199	14.67	9.40	9.06	9.06	5.752	6.135
Changan	CA	108.92	34.03	443.4	17.03	20.169	13.546	4.20	5.95	5.33	4.06	4.071	5.341
Chen Chuangc Chenchuang	CC	107.41	34.32	313.63	89.83	105.47	48.536	22.02	20.93	8.97	8.06	6.785	6.13
Chenjing	CJ	103.46	36.05	421.43	12.03	11.278	7.614	3.08	2.15	2.78	2.75	2.142	2.204
Changning	CN	104.91	28.58	312.09	47.25	14.147	8.178	3.71	2.77	3.51	2.30	2.361	3.818
Cuijiaya	CJY	103.71	36.08	412.99	15.10	14.086	7.098	6.01	5.15	3.10	5.03	4.963	3.182
Changqiqixiangju	CXQXJ	105.93	31.74	118.96	181.03	164.63	68.598	23.49	11.73	8.15	19.99	7.452	5.427
Daguan	DG	103.89	27.74	363.02	5.47	6.481	7.59	1.90	1.70	1.26	1.35	1.31	0.975
Datong	DT	103.36	36.60	481.5	15.71	10.812	7.463	7.18	5.32	3.14	6.92	4.681	3.02
Dangchuang	DC	104.39	34.05	176.35	73.68	82.657	42.424	7.99	6.38	6.36	4.13	4.769	5.532
Dechangnongkeju	DCNKJ	102.17	27.41	421.39	10.43	9.465	6.437	2.25	2.78	1.53	1.00	1.218	0.832
Dingyuan	DY	104.01	35.96	388.73	12.24	14.36	0.003	4.97	4.19	0.00	3.52	3.56	0.001
EA	DZJ	103.86	36.05	403.77	18.05	20.732	11.409	5.07	6.99	4.08	3.38	5.131	3.732
Dongshan	DS	103.59	36.32	442.76	13.71	14.881	11.293	7.27	5.65	4.69	6.40	4.833	4.153
Dawu	DW	100.25	34.48	489.83	1.40	1.489	1.141	1.03	1.08	0.92	1.07	1.059	0.915
Deyang Baima	DYBM	104.46	31.29	38.64	124.29	131.09	84.717	20.58	31.41	28.65	10.14	23.285	20.028
Dayiyinping	DYYP	103.52	30.59	43.47	136.74	125.13	82.158	23.56	15.16	12.41	15.84	6.548	10.775
Er Tong Gongyuan	ETGY	103.83	36.06	405.99	17.02	16.905	9.396	4.23	7.47	4.38	3.32	5.713	4.082

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Fengxiang	FX	107.38	34.50	323.45	76.01	22.753	49.724	23.08	7.80	13.70	19.52	4.943	9.056
Fushubanqiao	FSBQ	104.78	29.13	253.05	31.50	24.492	12.955	4.31	3.33	3.94	3.51	2.832	3.925
Ganyanchi	GYC	105.17	36.39	415.9	25.30	22.814	10.738	6.06	5.17	2.50	3.24	3.832	2.462
Gaoling	GL	109.09	34.53	483.73	52.59	61.358	15.735	13.00	16.86	7.96	13.22	17.56	5.204
Guanxiang	GX	103.85	36.09	408.32	14.02	10.184	6.911	3.12	4.32	3.84	2.11	4.373	3.964
Guyuan	GY	106.17	36.01	390.94	32.23	24.823	15.582	8.62	9.66	4.48	4.84	5.484	3.783
Guanyuan Shijing	GYSJ	105.84	32.15	81.43	315.58	271.67	139.71	17.86	23.08	15.40	11.14	12.711	11.991
Guanyuan Zengjia	GYZJ	106.10	32.62	98.17	415.85	395.8	183.33	23.17	41.00	20.30	12.44	11.146	12.902
Ganzhi	GZ	100.02	31.61	364.78	5.03	4.746	3.875	1.90	1.59	1.54	1.64	1.86	1.456
Ganzixiang	GZX	99.99	31.63	368.33	5.44	3.108	3.633	1.71	1.86	1.39	1.50	1.652	1.401
Haiyuan	HY	105.39	36.33	410.19	20.56	21.352	13.536	11.84	6.54	6.56	10.35	5.6	6.277
Hanji	HJ	102.99	35.49	395.72	9.01	7.558	4.327	2.67	1.93	1.63	1.92	1.427	1.208
Heping	HP	103.98	35.98	391.92	40.66	43.272	24.281	5.57	7.20	5.12	3.68	4.927	2.697
Heqiao	HQ	102.87	36.45	491.86	7.50	9.072	4.593	2.24	1.99	1.77	1.89	1.355	1.723
Hezui	HZ	103.08	36.23	458.96	10.90	6.99	4.557	3.27	1.89	1.30	2.90	1.655	1.208
Kuaili Baiguowan	HLBGW	102.26	26.96	465.82	4.88	5.507	2.907	1.59	0.96	1.25	1.01	0.768	1.051
Kuailiwaibei	HLWB	102.25	26.75	488.55	5.69	5.708	2.911	1.61	0.97	1.13	1.21	0.89	0.997
Kuaili Yundan	HLYD	102.27	27.06	454.85	4.51	4.034	2.582	0.98	0.97	0.82	0.95	0.919	0.865
Henan	HN	101.61	34.74	420.59	3.61	3.45	1.928	1.20	1.81	1.55	1.17	1.702	1.329
Hongcheng	HC	103.38	36.46	466.41	12.01	10.083	0.147	4.91	4.60	0.05	4.53	4.18	0.026
Honggu	HG	103.02	36.27	466.15	6.14	6.135	2.924	3.18	1.48	1.13	3.32	1.529	0.815
Heishuidiban	HSDB	102.98	32.07	90.3	99.86	86.029	50.502	4.87	3.59	4.65	1.72	1.861	2.216
Heishuishuangliusuo	HSSLS	103.26	32.06	71.4	105.38	140.09	106.18	4.11	8.01	4.94	1.95	2.527	3.328
Huxian	HX	108.62	34.11	416.29	65.76	88.974	23.175	18.51	26.42	6.01	15.22	13.235	4.511
Hongya	HY	103.37	29.91	118.84	117.46	138.79	9.999	6.79	10.79	10.00	3.70	3.955	9.994
Hanyuanjiuniang	HYJR	102.62	29.50	188.48	73.28	81.277	45.958	9.19	6.96	3.77	3.00	2.145	1.903
Hanyuanqingxi	HYQX	102.62	29.59	179.83	136.02	121.6	53.39	9.89	8.14	4.15	2.33	2.512	1.81
Hanyuanwusihe	HYWZH	102.89	29.23	203.98	62.28	48.486	33.713	4.99	2.19	2.60	2.03	1.193	6.647
Hanyuanyidong	HYYD	102.45	29.66	184.03	81.03	79.149	37.24	5.88	5.20	2.74	1.45	0.989	0.937
Hezuo	HZ	102.91	34.98	358.78	8.22	10.056	3.634	1.78	2.35	1.60	1.35	2.403	1.771
Jingning	JN	105.77	35.53	327.94	14.36	9.354	12.95	5.20	5.74	5.42	3.28	4.983	5.491

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Jingyang	JY	108.84	34.53	459.18	43.48	55.15	18.677	11.53	10.82	5.71	9.40	10.947	3.516
JinYa	JY	104.10	36.02	392	20.43	10.646	6.162	2.80	1.86	2.37	2.43	1.576	1.885
Jiulong	JL	101.51	29.00	308.2	16.56	12.988	6.381	0.66	0.62	0.67	0.37	0.415	0.506
Junlian	JLIAN	104.52	28.18	332.65	9.67	17.824	6.678	2.09	2.44	1.50	1.65	1.421	1.174
Jiulong Naiju	JLNJ	101.69	28.76	314.91	24.82	21.867	11.737	1.18	1.10	0.60	0.51	0.33	0.415
Jiangyou Chonghua	JYCH	104.99	31.90	33.06	287.86	277.11	175.01	21.98	32.74	17.36	8.82	12.557	10.562
Jiangyou EA	JYDZJ	104.74	31.78	23.5	497.60	446.53	194.13	26.41	34.08	30.08	11.32	22.374	10.845
Jiangyouhanzeng	JYHZ	104.63	31.78	15.05	495.28	343.14	425.05	19.97	29.28	18.76	11.65	19.022	9.918
Jiuzaibaihe	JZBH	104.11	33.33	133.1	93.78	108.94	65.753	4.96	4.05	5.57	2.46	2.067	5.287
Jiuzaiguoyuan	JZGY	104.32	33.12	100.12	165.74	236.69	107.24	8.19	7.67	7.49	3.70	4.055	6.608
Jiuzaiyongfeng	JZGYF	104.25	33.24	115.26	87.53	97.536	63.69	5.66	5.63	5.89	3.48	4.353	5.451
Jiuzaiwujiao	JZWJ	104.21	33.03	100.82	124.92	170.59	82.128	7.61	6.52	5.63	4.12	4.741	5.316
Jiuzaizhangzha	JZZZ	103.81	33.31	153.67	163.06	286.86	112.54	5.36	5.33	3.46	2.62	2.261	2.935
Kangding	KD	101.97	30.06	193.92	21.22	33.336	16.006	1.93	1.64	1.46	1.42	0.717	1.131
Kangdingxiaba	KDXB	101.57	29.96	238.01	7.92	9.845	5.643	1.31	1.20	1.23	0.94	0.695	1.099
Kangle	KL	103.71	35.37	341.44	15.52	14.9	7.712	5.81	5.49	2.90	3.70	4.034	1.721
Lantian	LT	109.32	34.15	489.65	30.00	48.528	12.102	13.31	14.69	4.63	10.98	10.017	3.844
Leibohuangliang	LBHL	103.79	28.45	283.29	24.53	26.093	14.601	3.48	2.48	2.49	2.47	1.923	2.102
Leiboxian EA	LBXDZJ	103.57	28.26	302.22	13.36	12.995	9.651	2.73	1.83	1.93	1.82	1.212	1.575
Ludingdetuo	LDDT	102.18	29.59	209.31	107.33	109.65	54.792	6.18	7.34	2.29	0.90	1.027	0.787
Ludingjiajun	LDJJ	102.21	29.69	198.94	46.64	57.285	34.956	3.23	3.20	1.92	0.81	0.632	0.716
Ludinglengzi	LDLQ	102.23	29.79	189.5	106.81	117.97	45.551	4.73	6.29	2.30	0.94	0.78	0.652
Ludingshuichang	LDSC	102.24	29.91	179.64	43.74	49.659	31.156	2.87	2.26	1.68	1.52	0.724	1.184
Luhuo	LH	100.67	31.39	290.95	6.34	9.684	5.71	1.61	2.32	1.74	1.17	2.021	1.849
Lianta	LT	104.03	35.87	378.54	6.73	7.642	6.815	3.21	2.49	3.37	3.45	2.126	3.189
Lintong	LT	109.19	34.38	486.4	56.29	32.594	18.52	12.22	8.87	4.80	6.75	6.504	3.617
Liujiabao	LJB	103.70	36.11	416.5	15.63	15.045	8.021	6.65	4.50	3.12	5.85	4.067	2.624
Longxian	LX	106.84	34.89	313.01	151.39	89.503	32.352	23.87	15.79	6.79	10.32	6.976	3.281
Lushanfenghe	LSFH	102.91	30.08	116.52	88.54	83.317	48.653	5.23	6.03	4.18	2.44	2.72	3.254
Leshanjinkouhe	LSJKH	103.08	29.25	196.33	108.08	101.87	41.305	7.01	5.33	3.05	1.97	1.235	2.176
Lushanjishengju	LSJSJ	102.93	30.16	107.8	113.81	110.71	59.708	6.47	6.23	5.09	1.93	2.672	2.869

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Lushanxianfeixianguan	LSXFXG	102.92	30.07	116.91	121.26	91.755	46.451	6.36	4.29	3.21	3.44	2.862	2.349
Lintan	LT	103.36	34.67	299.77	7.12	10.453	6.281	1.72	2.17	1.87	1.66	1.686	1.512
Ludian	LD	103.55	27.18	422.18	13.79	13.097	4.88	1.90	1.41	1.21	1.28	0.821	0.803
Lixianmuka	LXMK	103.34	31.57	21.79	308.92	281.9	315.33	18.71	14.71	10.99	4.85	2.58	5.416
Lixianshaba	LXSB	102.91	31.53	49.71	206.17	244.6	207.46	8.30	7.20	8.61	2.39	3.056	3.678
Lixiangtaoping	LXTP	103.45	31.56	13.81	330.25	339.83	374.95	15.86	13.43	11.27	5.83	3.417	5.478
Maolin	ML	103.59	27.62	373.42	4.06	9.082	5.957	1.07	1.25	0.97	1.01	1.169	0.785
Mabiandiban	MBDB	103.53	28.83	238.71	41.83	39.686	18.892	4.50	3.12	3.59	3.14	1.593	2.768
Muchuanlidian	MCLD	103.70	28.96	225.77	96.39	80.425	40.678	5.28	3.67	4.36	3.49	1.805	2.9
Maerkangdiban	MEKDB	102.22	31.90	136.66	26.69	23.475	18.385	1.80	2.15	2.55	1.55	1.792	2.423
Maerkangzuokeji	MEKZKJ	102.29	31.87	128.25	57.75	42.429	32.685	2.08	2.37	2.79	1.27	1.554	2.581
Mianningju	MNJ	102.17	28.55	305.17	14.25	17.605	10.401	2.18	2.42	1.13	1.21	0.963	0.723
Ninhe	MH	102.87	36.33	480.45	13.17	12.079	5.079	5.60	3.66	1.69	5.29	2.779	1.408
MianningCaogu	MNCG	102.29	28.64	290.17	44.76	47.016	14.82	3.55	3.17	1.36	1.37	0.925	0.652
Mianninghuian	MNHA	102.10	28.65	299.23	16.04	26.775	47.937	2.85	3.32	2.23	1.43	1.064	0.685
Mianninghuilong	MNHL	102.07	28.47	318.28	19.49	22.107	8.972	2.21	1.97	1.10	1.05	0.828	0.491
MianningLugu	MNLG	102.20	28.31	327.56	41.11	15.115		3.94	2.71		1.39	0.85	
Mianning Nanshuiwan	MNMSW	102.17	28.20	340.05	18.87	21.547	15.899	3.29	2.73	2.68	1.28	1.37	0.851
Mianningzeyuan	MNZY	102.01	28.23	344.94	17.79	11.783	6.704	1.09	0.85	0.82	0.74	0.448	0.474
Mingshan	MS	103.10	30.09	106.05	162.31	169.32	45.703	8.74	6.60	5.41	6.38	2.306	3.533
Mulan	mulian	103.92	36.35	433.03	15.25	18.063	6.244	5.65	3.83	2.90	3.97	3.458	2.697
Minxian	MX	104.02	34.43	233.56	68.30	43.69	24.677	5.35	4.51	3.83	3.74	2.776	4.078
Maoxiandiban	MXDB	103.85	31.68	0	294.06	300.03	253.43	21.24	18.11	12.84	8.09	6.484	7.658
Maoxiandiexi	MXDX	103.68	32.04	42.59	241.38	202.99	141.36	16.58	30.46	9.13	4.33	7.826	4.314
Maoxian Nanxin	MXNX	103.73	31.58	0	421.67	332.44	499.75	27.52	21.58	18.55	10.47	6.594	6.845
Miyipanlian	MYPL	102.11	26.89	478.23	7.61	10.534	4.83	1.86	1.45	1.22	1.26	1.174	1.088
Miyisalian	MYSL	102.03	26.82	488.43	5.92	5.906	1.909	1.09	0.86	0.28	0.47	0.477	0.299
Mianzhu Qingping	MZQP	104.09	31.52	0	823.11	786.07	484.42	87.80	53.25	33.60	51.63	33.13	14.931
Ningnan	NN	102.76	27.07	441.08	5.45	8.1	4.767	1.63	1.91	1.00	1.06	1.085	0.844
Ningnan Hulukou	NNHLK	102.85	26.94	453.73	4.88	3.438	2.394	0.98	1.37	1.08	0.78	1.063	0.934
Ningnan Laomuhe	NNLMH	102.68	27.14	435.09	5.81	6.06	3.054	1.65	1.08	1.16	1.13	0.926	0.956

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
NNSX	NNSX	102.61	27.22	428.01	4.49	5.177	3.418	1.45	1.62	1.16	1.44	0.953	1.039
Pugeluobinshan	PGLBS	102.41	27.55	398.2	6.97	9.415	4.254	1.29	2.27	1.25	0.82	1.676	1.143
Pugeqiaowo	PGQW	102.50	27.49	401.83	5.82	7.613	3.625	1.74	2.38	1.68	0.95	1.991	1.236
Pingan	PA	103.28	36.17	442.4	14.44	11.255	6.686	3.03	2.60	1.72	2.52	2.152	1.745
Pujiangdaxing	PJDX	103.41	30.25	80.81	191.67	187.06	58.355	13.81	14.45	8.66	6.55	3.511	4.359
Pujiangwuxing	PJWX	103.63	30.29	78.68	93.36	99.454	45.457	15.10	10.13	11.48	11.38	5.135	6.955
Puerzhen	puerzhen	104.16	28.24	314.12	10.51	12.018	8.421	2.29	1.64	1.74	2.07	0.939	1.261
Pingwumuzuo	PWMZ	104.52	32.62	43.85	268.94	273.45	167.84	9.97	17.51	10.57	4.91	8.434	7.395
Pixianzoushishan	PXZSS	103.76	30.91	26.42	115.41	137.99	97.827	17.56	18.03	15.91	11.18	9.795	9.902
Qianling	QL	108.69	34.35	435.04	17.78	21.607	10.106	3.26	6.10	2.44	1.65	3.105	2.353
Qianyang	QY	107.13	34.65	314.1	57.03	51.266	26.272	6.24	6.60	4.46	2.38	4.306	3.883
Qinchuan	QC	103.64	36.66	475.86	7.30	5.775	5.586	3.31	2.75	2.92	2.66	2.665	3.099
Qingshuixiang	QSX	103.39	36.75	495.44	10.45	2.553	0.005	3.45	0.94	0.00	3.01	0.788	0.388
Qingshuiyi	QSY	104.23	35.85	369.78	17.92	17.53	10.358	8.69	5.66	3.99	5.49	3.887	2.318
Qishan	QS	107.65	34.44	342.85	47.00	76.657	37.173	9.09	18.16	9.24	4.87	6.577	4.41
Qiying	QY	106.07	36.27	415.74	28.49	34.616	16.184	8.01	12.53	5.20	5.76	8.197	3.132
Honglaiyouzha	QLYZ	103.26	30.42	65.43	167.42	193.78	54.622	11.67	7.59	8.42	6.50	3.993	4.881
Rongjingshilong	RJSL	102.87	29.89	137.08	91.67	114.83	63.453	6.39	6.17	5.62	2.13	2.657	2.025
Shifangbajiao	SFBJ	103.99	31.28	8.5	544.59	571.96	598.11	58.85	61.30	37.17	20.90	21.669	18.969
Shoushanxiang	SSX	103.91	27.90	345.71	7.09	14.922	13.05	1.76	2.39	2.50	1.51	1.905	1.31
Shuping	SP	103.59	36.32	442.76	7.08	7.447	5.911	4.36	4.17	3.99	4.41	3.657	3.768
Shimiancaoke	SMCK	102.11	29.39	231.14	41.22	29.048	17.069	3.30	2.27	1.33	0.67	0.523	0.652
Shimiancaluo	SMCL	102.34	29.13	239.71	74.13	100.96	34.016	5.40	4.40	2.13	1.48	1.056	0.57
Shimianliziping	SMLZP	102.30	28.99	255.37	48.78	39.807	20.583	2.97	2.72	1.41	1.05	0.615	0.588
Shimianmeiluo	SMML	102.44	29.29	218.73	68.95	82.471	33.982	4.58	4.00	2.40	1.25	0.965	1.05
Shimianwajiao	SMWJ	102.24	29.43	218.55	73.87	92.023	60.145	4.34	4.89	3.03	1.16	1.203	0.773
Shimianxianfeng	SMXF	102.27	29.28	229.97	61.00	79.541	33.08	6.66	4.68	3.23	1.06	1.106	0.635
Songpan	SP	103.60	32.64	102.19	38.86	28.963	23.782	5.05	4.81	5.01	3.06	3.914	4.226
Songpananhong	SPAH	103.64	32.51	87.82	181.63	126.33	85.503	5.63	5.39	4.66	2.86	3.47	3.733
Songpachuanzhushi	SPCZS	103.62	32.78	113.61	37.10	40.189	20.645	5.64	4.86	5.23	3.58	3.012	3.861
Suijiang	SJ	103.94	28.60	269.6	20.84	20.257	10.084	3.38	2.14	1.75	2.32	1.308	1.47

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Shawan	SW	104.53	33.66	130.92	89.22	107.31	56.955	8.54	6.80	7.64	4.35	3.062	4.863
Shuizhu	SZ	103.67	27.94	338.38	14.25	14.209	7.352	2.31	1.52	2.24	1.34	1.176	1.907
Tangyu	TY	107.90	34.13	346.37	18.14	29.644	26.419	3.30	5.95	4.91	2.97	4.937	3.98
Tongren	TR	102.05	35.54	466.27	2.92	3.249	2.203	1.01	1.82	1.47	0.89	2.003	1.618
Tongxin	TX	105.55	37.00	485.91	24.72	22.016	9.3	7.20	5.80	3.19	3.15	4.008	1.347
Tianquanxianlianglu	TQZLL	102.40	29.92	165.89	119.53	113.42	39.898	3.36	3.42	2.13	1.52	1.154	0.803
Tianshui	TS	105.90	34.48	220.55	127.69	114.22	49.769	15.88	14.06	6.61	6.13	5.51	4.76
Tuanzhuang	TZ	103.83	36.44	445.7	12.82	11.035	5.484	4.04	2.59	3.43	3.10	2.545	3.103
Wenchuan Wolong	WCWL	103.18	31.04	23.31	931.80	638.15	858.79	49.58	36.49	18.77	9.25	9.329	9.08
Wudu	WD	104.99	33.35	79.49	181.31	161.24	106.65	16.73	10.94	8.55	5.36	4.637	6.114
Wenxian	WX	104.48	32.95	74.17	108.87	87.713	106.65	9.01	8.66	8.38	6.08	5.55	5.015
Xichangchuanxing	XCCX	102.30	27.87	368.39	22.53	28.507	9.742	5.47	5.58	2.17	1.81	2.653	1.517
Xichanghuangshui	XCHS	102.20	27.59	401.44	8.12	10.277	9.379	2.02	3.00	2.38	0.87	1.111	1.15
Xichanglizhou	XCLZ	102.17	28.05	355.25	15.77	21.382	11.237	3.83	3.11	2.15	1.63	1.47	0.888
Xichangtaihe	XCTH	102.21	27.90	368.9	5.58	8.555	4.002	0.63	0.61	0.61	0.34	0.287	0.28
Xichangxincun	XCXC	102.26	27.85	372.04	37.52	43.087	20.466	4.84	6.21	3.04	3.51	2.427	2.682
Xichangxiaomiao	XCXM	102.24	27.90	367.66	5.61	3.9	3.039	1.56	1.60	1.09	1.09	1.038	0.978
Xichangyoujun	XCYJ	102.15	27.74	387.89	18.54	16.278	7.476	2.87	2.32	1.34	1.50	1.055	0.884
Xichangzhouju	XCZJ	102.25	27.90	367.25	22.99	24.588	13.39	6.18	5.13	3.38	2.59	2.014	1.18
Xideguangming School	XDGMXX	102.41	28.31	318.32	17.35	12.655	8.009	2.17	1.84	1.54	1.35	0.896	1.167
Xidemianshan	XDMS	102.31	28.37	316.42	31.21	16.783	17.222	5.41	2.20	2.00	1.62	0.741	0.922
Xiahaishi	XHS	102.85	36.35	483.5	8.10	6.871	5.167	2.81	2.13	1.38	2.48	1.62	1.181
Xi'an	XA	108.95	34.21	454.29	52.40	42.532	12.974	15.29	19.63	6.03	12.09	13.626	4.551
Xianyang	XY	108.70	34.35	436.02	39.15	49.984	17.838	14.38	13.67	5.53	12.34	11.283	4.236
Xiaokangying	XKY	104.15	35.79	365.93	12.37	17.285	8.831	3.28	3.14	3.20	2.59	2.625	2.237
Xicao	CX	103.64	36.49	458.19	10.36	12.528	8.246	3.27	4.12	3.66	3.16	3.471	3.468
Xigu	XG	103.62	36.08	416.93	19.03	12.755	8.372	4.61	3.93	3.83	4.87	3.185	3.843
Xiji	XJi	105.43	35.58	327.46	56.37	43.267	20.286	8.77	6.93	5.07	3.65	5.235	3.95
Xiying	XY	108.97	34.22	456.77	47.56	47.687	12.294	14.26	20.56	3.41	6.65	12.833	2.266
Xiaojin Diban	XJDB	102.37	30.99	106.86	66.83	71.794	39.699	3.39	3.98	4.06	2.36	2.841	3.825
Xiaojin Dawei	XJDW	102.64	30.97	79.79	90.25	129.85	81.581	4.47	5.79	6.08	3.04	2.768	3.215

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Xinjinlihua	XJLH	103.80	30.38	76.98	106.11	86.473	47.079	12.85	9.46	9.42	7.43	5.245	6.107
Yaandizhentai	YADZT	102.98	29.99	121.61	121.79	138.3	59.089	4.50	5.32	3.70	1.05	0.993	1.25
Yangling	yangling	108.07	34.28	371.16	71.44	90.11	26.944	19.17	26.59	7.80	11.48	18.373	4.596
Yanguoxia	yanguoxia	103.28	36.07	432.6	5.52	6.104	3.686	2.61	1.20	1.65	2.56	1.04	1.314
Yantan	yantan	103.91	36.05	401.85	8.03	7.441	4.431	2.27	3.32	2.82	1.82	3.101	3.16
Yaojie	yaojie	102.88	36.50	496.08	8.98	0.773	0.003	2.27	0.30	0.00	1.72	0.171	1.625
Yaanshaping	YASP	102.99	29.85	135.38	99.32	86.548	32.279	5.67	4.44	3.01	2.88	1.972	2.057
Yibinyongxing	YBYX	104.57	29.04	248.83	35.03	31.337	15.807	4.13	3.51	4.38	3.30	2.725	3.215
Yichezheng	YCZ	103.51	26.82	462.12	3.27	5.188	4.549	1.06	1.21	0.91	0.92	0.82	0.867
Yinshan	YS	103.89	35.83	379.73	12.33	9.553	7.652	3.12	2.96	3.61	2.61	2.405	3.52
Yeliguan	YLG	103.66	34.96	304.75	7.44	11.117	8.356	2.65	2.44	2.54	1.93	2.01	2.272
Yongjing	YJ	103.30	35.97	421.78	10.81	11.42	4.832	2.13	2.01	1.63	1.61	1.829	1.121
Yongshan	YS	103.63	28.23	305.91	15.97	15.161	9.441	2.58	1.41	1.99	1.91	1.068	1.727
Yuexixinmin	YXXM	102.53	28.71	272.07	73.05	75.175	31.903	12.64	12.00	3.50	2.75	2.679	1.188
Yuexizhongsuo	YXZS	102.49	28.59	286.1	51.59	50.819	22.377	7.13	3.64	2.37	1.60	1.305	1.158
Yanyuanjinhe	YYJH	101.95	27.72	398.75	9.30	11.082	7.306	1.51	1.55	1.30	0.84	0.652	0.616
Yanyuanmeiyu	YYMY	101.40	27.45	453.67	9.02	9.2	5.467	3.61	3.11	1.10	1.67	1.146	0.523
Yanyuanweicheng	YYWC	101.65	27.45	440.34	10.86	9.186	6.021	2.37	2.08	1.38	1.08	0.872	0.786
Zigongdixingyingxiang-taizhen0	ZGDXYXTZ0	104.75	29.34	232.26	53.94	46.679	19.349	4.56	4.25	4.00	3.27	2.758	3.566
Zigongdixingyingxiang-taizhen1	ZGDXYXTZ1	104.75	29.34	232.26	22.54	26.225	14.085	4.31	3.90	3.97	3.28	2.803	3.553
Zigongdixingyingxiang-taizhen2	ZGDXYXTZ2	104.75	29.34	232.26	27.15	29.715	15.871	4.17	4.23	3.99	3.33	2.951	3.542
Zigongdixingyingxiang-taizhen3	ZGDXYXTZ3	104.74	29.34	231.6	34.22	32.258	18.725	4.55	4.06	4.04	3.35	2.804	3.523
Zigongdixingyingxiang-taizhen4	ZGDXYXTZ4	104.74	29.34	231.6	31.87	31.931	19.08	4.61	4.13	4.11	3.36	2.791	3.544
Zigongdixingyingxiang-taizhen5	ZGDXYXTZ5	104.74	29.34	231.6	32.37	41.447	17.467	4.63	4.34	4.04	3.41	2.797	3.521
Zigongdixingyingxiang-taizhen6	ZGDXYXTZ6	104.74	29.34	231.6	39.61	41.336	19.732	4.90	4.31	4.11	3.43	2.766	3.537
Zigongdixingyingxiang-taizhen7	ZGDXYXTZ7	104.74	29.34	231.6	38.74	44.769	15.659	4.81	3.96	4.09	3.35	2.571	3.546

Station Name	*Code*	*Location*		*FaultD*	*Acceleration*			*Velocity*			*Displacement*		
		Longitude	*Latitude*		*EW*	*NS*	*UD*	*EW*	*NS*	*UD*	*EW*	*NS*	*UD*
Zhonghe	zhonghe	103.80	36.23	424.85	9.40	10.55	8.405	3.05	3.58	3.56	2.86	3.252	3.538
Zhongpu	zhongpu	103.74	35.79	382.05	11.38	11.08	8.296	3.19	3.71	3.58	2.53	3.317	3.526
Zhongxinxiang	zhongxinxiang	103.63	36.26	434.89	16.10	14.761	8.288	5.30	4.34	3.51	4.35	3.667	3.225
Zhouzhi	zhouzhi	108.32	34.06	383.78	41.92	37.823	33.38	6.93	10.02	4.50	3.97	5.577	3.185
Zhaojuejiefanggou	ZJJFG	102.57	27.88	357.97	8.87	7.103	4.44	2.43	1.67	1.87	2.29	1.566	1.765
ZhaojueQixiangju	ZJQXJ	102.83	28.02	335.89	13.27	11.247	5.316	3.32	1.95	1.28	1.72	1.536	1.064
Zhuoni	ZN	103.51	34.59	282.17	18.53	19.254	9.17	2.18	1.88	1.94	1.45	1.41	1.838
Zhouqu	ZQ	104.38	33.80	152.98	32.20	36.667	22.03	7.14	3.71	5.62	5.57	1.885	5.172

Appendix 2: Geologic Data

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Xiji	30.5	228.7	D (180–370)	195.1	2.0	Mid-hard soil	Loess, $V_{30.45}=375$ m/s
Qingshuiyi	34.0	259.3		202.6	2.0	Mid-soft soil	Mudstone, $V_{34}=560$ m/s
Dingyuan	43.0	265.3		265.3	2.0	Mid-soft soil	Floury soil and conglomerate stratum
Heping	50.0	270.1		221.2	2.0	Mid-soft soil	Floury soil
Minhe	30.0	270.5		215.5	2.0	Mid-soft soil	Loess floury soil and conglomerate stratum
Chenjing	30.0	275.3		229.5	2.0	Mid-soft soil	Rubble, under the buried depth of 25.1 m , $V_{30}=382$ m/s
Cicao	30.0	310.7		243.6	2.0	Mid-hard soil	Rubble,$V_{30}=506$ m/s
Gaolan	30.0	321.7		166.7	2.0	Mid-hard soil	Mudstone, $V_{30}=525$ m/s, unexposed
Tongxin	30.4	341.4		227.6	2.0	Mid-soft soil	$V_{30}=410$ m/s
Ganyanchi	30.0	357.4		317.4	2.0	Mid-hard soil	Loess
Tuanzhuang	30.0	363.3		202.6	2.0	Mid-hard soil	Gravelly sand, $V_{30}=420$ m/s
Jinya	30.0	375.9	B (760–1,500)	269.5	2.0	Mid-hard soil	Conglomerate stratum, unexposed
Guyuan	30.5	394.5		335.4	2.0	Mid-hard soil	Mudstone
Xianyang	30.0	425.2		316.0	2.0	Mid-hard soil	Coarse sand, unexposed
Shuping	30.0	432.8		206.4	2.0	Mid-hard soil	Mudstone, $V_{30}=632$ m/s
Tongren	30.0	450.2		290.2	2.0	Mid-soft soil	Mudstone
Qiying	30.0	460.2		306.8	2.0	Mid-hard soil	Loess, $V_{30.45}=510.3$ m/s
Dawu	31.0	468.4		325.2	2.0	Mid-hard soil	Shale
Xiaokangying	30.0	478.8		266.7	2.0	Mid-soft soil	Conglomerate stratum, $V_{30}=550$ m/s
Henan	30.0	490.2		290.2	2.0	Mid-hard soil	Conglomerate stratum
Pingan	30.0	490.5		280.8	2.0	Mid-soft soil	Mudstone
Qingchuan	30.8	863.5		320.5	2.0	Mid-hard soil	Rubble
Caotian	20.0	210.6		208.1	2.0	Mid-hard soil	Medium sand of 3Q4al, at the depth of 20 m, unexposed
Xichangyoujun	21.0	249.7		216.5	2.0	Mid-hard soil	Intensely weathered mudstone with sandstone, $V_{21}=358$ m/s
Ganzhi	22.0	251.8		357.0	2.0	Mid-hard soil	Loose conglomerate stratum soil, $V_{22}=335$ m/s, unexposed
Yanyuanweicheng	22.5	261.0	D (180–370)	212.6	2.0	Mid-hard soil	Conglomerate stratum sandy clay, $V_{22.5}=420$ m/s, unexposed
Miyisalian	21.0	272.3		237.0	2.0	Mid-hard soil	Strong-weathered conglomerate, $V_{21}=366$ m/s
Butuotuojue	22.3	274.7		235.0	2.0	Mid-hard soil	Gravelly soil, $V_{22.3}=403$ m/s, unexposed,
Dongshan	23.0	274.8		223.7	2.0	Mid-hard soil	Siltstone, under the buried depth of 21.3 m, unexposed

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Ningnan	21.0	275.7	D (180–370)	305.0	2.0	Mid-hard soil	Gravel sand, $V_{21}=280$ m/s
Ningnansongxin	21.0	275.7		274.0	2.0	Mid-hard soil	Gravel sand, $V_{21}=432$ m/s, unexposed
Shimianwajiao	22.0	280.9		246.0	2.0	Mid-hard soil	Medium dense conglomerate stratum soil, $V_{22}=420$ m/s, unexposed
Ningnanhulukou	21.0	283.2		241.0	2.0	Mid-hard soil	Gravel sand, $V_{21}=280$ m/s
Pugeqiaowo	22.0	283.5		320.0	2.0	Mid-hard soil	Pebble soil, $V_{22}=557$ m/s, unexposed
Dechangnongkeju	22.1	284.0		207.4	2.0	Mid-hard soil	Pebble soil, $V_{22.1}=508$ m/s, unexposed
Miyipanlian	21.0	284.4		210.2	2.0	Mid-hard soil	Gravelly soil, $V_{21}=331$ m/s, unexposed
Xichangchuanxing	22.0	287.0		251.2	2.0	Mid-hard soil	Silty clay, $V_{22}=351$ m/s, unexposed
Lixianmuka	21.0	287.6		261.0	2.0	Mid-soft soil	Pebbly sand, $V_{21}=359$ m/s, unexposed
Maoxiandiexi	21.0	289.2		241.0	2.0	Mid-hard soil	Clay, $V_{21}=358$ m/s, unexposed
Yuexixinmin	22.0	299.8		287.0	2.0	Mid-hard soil	Roundstone, $V_{22}=364$ m/s, unexposed
Hezui	28.0	300.2		221.2	2.0	Mid-soft soil	$V_{28}=530$ m/s, unexposed
Jiuzaiguoyuan	22.0	304.3		271.0	2.0	Mid-hard soil	Dense crushed stone with floury soil, $V_{22}=451$ m/s
Yanyuanmieyu	22.5	304.3		297.0	2.0	Mid-hard soil	Carbon silty clay, $V_{22.46}=376$ m/s
Xichuanglizhou	22.0	307.5		263.6	2.0	Mid-hard soil	Conglomerate stratum at depth of 22 m, unexposed
Ludinglengzi	20.0	308.8		281.0	2.0	Mid-hard soil	Medium dense pebble soil, $V_{20}=420$ m/s, unexposed
Shimianmeiluo	22.0	308.9		279.0	2.0	Mid-hard soil	Micronesia gravel soil at depth of 22 m, unexposed
Shimiancaoke	22.0	309.2		285.0	2.0	Mid-hard soil	Micronesia gravel soil at depth of 22 m, unexposed
Lixianshaba	22.0	310.6		272.0	2.0	Mid-hard soil	Sand pebble, $V_{20.2}=452$ m/s, unexposed
Basong	23.0	311.0		244.9		Mid-soft soil	Mudstone, $V_{23}=530$ m/s, unexposed
Jiulong	15.3	311.2		235.2	2.0	Mid-hard soil	Weathered bedrock and weak-weathered metasandstone, unexposed
Shimianchaluo	22.0	313.3		269.2	2.0	Mid-hard soil	Slightly less dense pebble soil, drilling depth of 22 m, unexposed
Shimianxianfeng	22.0	313.9		283.0	2.0	Mid-hard soil	Medium dense conglomerate stratum, $V_{22}=420$ m/s, unexposed
Lixiantaoping	21.0	317.0		230.9	2.0	Mid-hard soil	Pebbly sand, $V_{21}=424$ m/s, unexposed
Ludingjiajun	22.0	317.1		265.0	2.0	Mid-hard soil	Completely weathered granite, $V_{22}=450$ m/s, unexposed
Haiyuan	25.5	320.1		297.0	2.0	Mid-hard soil	Mudstone, unexposed
Fengxiang	20.0	320.3		230.0	2.0	Mid-soft soil	Silty clay and mild clay at the depth of 20 m
Jiuzaigouyongfeng	22.0	321.9		286.0	2.0	Mid-hard soil	Dense crushed stone with floury soil, $V_{22}=485$ m/s, unexposed
Pujiangwuxing	22.0	322.8		290.0	2.0	Mid-hard soil	Conglomerate stratum , $V_{22}=484$ m/s, unexposed
Luhuo	22.0	323.0		287.0	2.0	Mid-soft soil	Pebble soil containing bleaching, $V_{20}=410$ m/s, unexposed

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Mianninglugu	22.0	323.8	D (180–370)	263.6	2.0	Mid-soft soil	Conglomerate stratum, unexposed
Ningnanlaomuhe	21.0	324.3		305.0	2.0	Mid-hard soil	Gravel soil with clay, V_{21} = 369 m/s, unexposed
Jiuzaibaihe	22.0	326.8		296.0	2.0	Mid-hard soil	Micronesia pebble with floury soil, V_{22} = 465 m/s, unexposed
Xiaojindiban	20.5	330.8		306.0	2.0	Mid-hard soil	Sandy cobble, V_{21} = 430 m/s, unexposed
Xidemianshan	22.0	331.1		233.8	2.0	Mid-hard soil	Compacted gravel pebbles, unexposed
Xichangzhouju	22.0	334.2		243.2	2.0	Mid-hard soil	Medium dense pebbles, unexposed
Hanyuanqingxi	22.4	336.4		291.4		Mid-hard soil	Gravel with rubble, $V_{22.4}$ = 450 m/s, unexposed
Pugeluobinshan	22.0	337.5		320.0	2.0	Mid-hard soil	Boulders soil, V_{22} = 413 m/s, unexposed
Shimianliziping	22.0	340.3		319.0	2.0	Mid-hard soil	Completely weathered granite, V_{20} = 410 m/s, unexposed
Ludingdetuo	22.0	340.9		318.0	2.0	Mid-hard soil	Pebble soil containing bleaching, V_{22} = 410 m/s, unexposed
Heishuidiban	22.0	341.0		243.0		Mid-soft soil	Conglomerate stratum, V_{21} = 496 m/s, unexposed
Mianningnanshuiwan	22.0	342.0		308.5	2.0	Mid-hard soil	Pebbly medium sand layer, unexposed
SongpanAnhong	21.8	342.4		282.0	2.0	Mid-soft soil	Metamorphic feldspathic quartzose sandstone, V_{21} = 473 m/s, unexposed
Xingjinlihua	21.0	343.2		292.0	2.0	Mid-hard soil	Sandy conglomerate stratum, V_{21} = 498 m/s, unexposed
Heqiao	17.0	344.2		2400.7	2.0	Mid-hard soil	Mudstone, unexposed
Ludingshuichang	22.0	345.3		330.0	2.0	Mid-hard soil	Slightly less dense land pebble, $V_{21.9}$ = 350 m/s, unexposed
Zhaojueqixiangju	20.8	345.5		285.8	2.0	Mid-hard soil	Weak-weathered sandstone and mudstone layers, unexposed
Leiboxiandizhenju	13.2	346.0		203.6	2.0	Mid-hard soil	Mid-weak-weathered breccia, unexposed
Jiangyouhanzeng	22.0	346.5		237.0	2.0	Mid-soft soil	Strong weathered limestone, unexposed
Guangyuanshijing	12.2	347.6		202.0	2.0	Mid-soft soil	Weak-weathered mudstone, unexposed
Lantian	20.7	348.2		264.3	2.0	Mid-soft soil	Silty clay and mild clay
Mianninghuilong	22.0	349.1		222.3	2.0	Mid-soft soil	Micronesia dense conglomerate stratum, unexposed
Dayiyingping	22.0	349.8		310.0		Mid-hard soil	Silt quality, powder quality soil, unexposed
Heishuishuangliusuo	21.0	350.0		291.0	2.0	Mid-hard soil	Conglomerate stratum, V_{21} = 227 m/s, unexposed
Zhaojuejiefanggou	22.3	350.0		293.3	2.0	Mid-hard soil	Weak-weathered sand mudstone layers, unexposed
Xideguangmingxiaoxue	22.0	350.7		289.4	2.0	Mid-hard soil	Conglomerate stratum, unexposed
Shifangbajiao	15.2	355.2		232.0	2.0	Mid-hard soil	Weak-weathered rock-fragment sandstone, unexposed
Yuexizhongsuo	22.0	356.7		322.6	2.0	Mid-hard soil	Sand conglomerate stratum, unexposed
Wenchuanwolong	22.1	357.1		295.0	2.0	Mid-hard soil	Phyllite rock, $V_{21.1}$ = 485 m/s, unexposed
Ganzixian	22.0	360.5		357.0	2.0	Mid-hard soil	Loose land pebble, unexposed

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Maerkangzuokeji	22.0	362.9	D (180–370)	284.0	2.0	Mid-soft soil	Metamorphic fine-grained sandstone, $V_{20.15}$=474 m/s, unexposed
Muchuanlidian	22.0	363.7		227.0	2.0	Mid-hard soil	Mudstone, unexposed
Pujiangdaxing	22.0	370.5		318.0	2.0	Mid-hard soil	Conglomerate stratum, V_{22}=464 m/s, unexposed
Anxiantashui	12.8	372.7		191.0	2.0	Mid-soft soil	Weak-weathered silty mudstone
Yanguoxia	17.0	372.8		219.8	2.0	Mid-hard soil	Mudstone, V_{17}=522 m/s, unexposed
Lintong	22.3	373.1		270.5	2.0	Mid-hard soil	Silty clay, $V_{20.8}$=367.39 m/s, unexposed
Songpanchunzhushi	22.0	374.3		314.0	2.0	Mid-soft soil	Carbonaceous slate, V_{21}=473 m/s, unexposed
Mianningzeyuan	22.0	374.8		209.7	2.0	Mid-hard soil	Dense conglomerate stratum, unexposed
Kuailibaiguowan	12.8	376.5		202.0	2.0	Mid-hard soil	Bedrock
Dizhenju	20.0	377.4	C (370–760)	295.2	2.0	Mid-soft soil	Medium sandstone, unexposed
Ertonggongyuan	15.0	378.6		245.4	2.0	Mid-hard soil	Medium sandstone, unexposed
Xichanghuangshui	22.0	385.8		296.6	2.0	Mid-hard soil	Medium dense conglomerate stratum, unexposed
Maoxiannanxin	22.1	386.8		359.0	2.0	Mid-soft soil	Drift gravel, V_{21}=494 m/s, unexposed
Hanyuanwusihe	22.6	387.0		294.0	2.0	Mid-hard soil	Rubble layer, unexposed
Xichangtaihe	18.5	388.6		351.0	2.0	Mid-soft soil	Weak-weathered mudstone with sandstone, unexposed
Yaandizhentai	22.0	393.0		190.0	2.0	Mid-hard soil	Intermediate weathered mudstone, unexposed
Gaoling	22.0	393.5		253.7		Mid-hard soil	Silty clay, unexposed
Guangyuanzengjia	20.0	397.0		226.0		Mid-hard soil	Weak-weathered limestone, unexposed
Yanyuanjinhe	22.0	399.2		204.6	2.0	Mid-hard soil	Feldspathic quartz sandstone, unexposed
Dangchang	17.0	400.2		226.2	2.0	Mid-hard soil	Slabstone, unexposed
Baoxingminzhi	22.0	401.6		220.0	2.0	Mid-hard soil	Weak-weathered calcareous shale, unexposed
Kuailiwaibei	12.9	402.5		268.0	2.0	Mid-hard soil	Weak-weathered pelitic siltstone, unexposed
Jiuzaiwujiao	22.0	402.6		391.0	2.0	Mid-soft soil	Dense conglomerate stratum, unexposed
Pingwumuzuo	22.0	412.0		392.0	2.0	Mid-soft soil	Bedrock and weak-weathered phyllite rock, unexposed
Xichangxinchun	22.0	412.0		303.5	2.0	Mid-hard soil	Silty clay, V_{22}=431 m/s, unexposed
Hanyuanyidong	22.0	414.2		386.6	2.0	Mid-soft soil	Weak-weathered sandstone, unexposed
Jiulongnaiju	22.0	414.6		330.3	2.0	Mid-hard soil	Dense floated conglomerate stratum, unexposed
Kuailiyundian	14.2	414.7		219.0	2.0	Mid-hard soil	Weak-weathered coarse granite
Cuijiaya	24.0	414.8		286.5		Mid-hard soil	Conglomerate stratum, unexposed
Butuodizhenju	22.0	416.8		302.1	2.0	Mid-hard soil	Dense breccia layer, unexposed
Xiahaishi	26.0	425.6		284.5		Mid-soft soil	Mudstone, unexposed

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Yongjing	20.0	430.2	C (370–760)	323.3		Mid-hard soil	Conglomerate stratum, V_{20}=532 m/s, unexposed
Jiangyoudizhentai	10.2	434.6		336.0	2.0	Mid-soft soil	Bedrock
Yaojie	22.0	436.2		344.0	2.0	Mid-hard soil	Mudstone, V_{18}=520 m/s, unexposed
Xigu	24.0	436.4		257.1	2.0	Mid-hard soil	Mudstone, unexposed
Mianningcaogu	22.0	440.0		384.9	2.0	Mid-soft soil	Dense conglomerate stratum, unexposed
Zhonghe	24.0	444.7		233.4	2.0	Mid-hard soil	Sandstone, V23=586m/s, unexposed
Hezuo	18.0	446.5		218.2	2.0	Mid-hard soil	Mudstone, unexposed
Liujiabao	25.0	450.7		281.0		Mid-hard soil	Conglomerate stratum, unexposed
Hanyuanjiuxiang	22.0	451.3		372.1	2.0	Mid-hard soil	Conglomerate stratum, unexposed
Datong	13.5	455.6		314.5	2.0	Mid-hard soil	Mudstone
Honggu	26.0	456.4		229.6	2.0	Mid-hard soil	Mudstone, unexposed
Mianningju	22.0	458.2		343.6	2.0	Mid-soft soil	Dense conglomerate stratum, unexposed
Xiaojindawei	22.2	464.2		305.0	2.0	Mid-hard soil	Sand conglomerate stratum, unexposed
Wudou	20.0	464.2		311.0	2.0	Mid-hard soil	Weak-weathered mudstone with packsand, unexposed
Yingshan	20.0	466.3		285.4	2.0	Mid-hard soil	Sandstone
Jiangyouchonghua	15.0	473.6		355.0	2.0	Mid-soft soil	Bedrock
Yantan	20.0	475.2		216.8	2.0	Mid-hard soil	Mudstone, V_{20}=511 m/s
Kangle	15.0	485.4		230.8	2.0	Mid-soft soil	Mudstone
Qionglaiyouzha	10.5	489.7		216.0	2.0	Mid-hard soil	Bedrock,weak-weathered sandstone
Mianninghuian	22.0	492.2		304.1	2.0	Mid-hard soil	Conglomerate stratum, unexposed
Deyangbaima	10.3	495.6		375.0	2.0	Mid-hard soil	Bedrock
Minxian	22.0	496.2		241.8	2.0	Mid-hard soil	Slate, unexposed
Mianzhuqingping	11.4	508.0		339.0	2.0	Mid-hard soil	Bedrock
Hongcheng	10.0	510.2		242.4	2.0	Mid-soft soil	Mudstone, V_{10}=533 m/s, unexposed
Baoxingyanjing	22.0	515.6		252.0	2.0	Mid-hard soil	Intermediately weathered limestone, unexposed
Tianshui	22.0	516.2		276.2	2.0	Mid-hard soil	Mudstone, V_{22}=540 m/s, unexposed
Qingshuixiang	15.8	530.2		279.2	2.0	Mid-hard soil	Mudstone, $V_{15.8}$=531 m/s
Leshanjinkouhe	22.0	531.2		449.0	2.0	Mid-hard soil	Conglomeratic sand, unexposed
Zhongpu	16.0	541.6		308.9	2.0	Mid-hard soil	Mudstone, V_{16}=512 m/s
Mingshan	22.0	615.0		213.0	2.0	Mid-hard soil	Intermediately weathered mudstone, unexposed
Maerkangdiban	16.8	630.8		243.0	2.0	Mid-hard soil	Weak-weathered phyllite rock, unexposed

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} *(m/s)*	*Classification*	V_{20} *(m/s)*	*Classification*		
Shawan	22.0	635.7	C (370–760)	186.0	2.0	Mid-hard soil	Intermediately weathered argillaceous limestone, unexposed
Yiliguan	12.0	648.2		326.1	2.0	Mid-hard soil	Quartzite, V_{12}=810 m/s
Hanji	28.8	651.7		301.5	2.0	Mid-hard soil	Sandstone
Zhongxinxiang	20.0	659.5		261.9	2.0	Mid-hard soil	Sandstone, V_{20}=522 m/s, unexposed
Lushanxianfeixianguan	9.8	666.2		242.0	2.0	Mid-hard soil	Weak-weathered sandy mudstone, bedrock, unexposed
Yaanshaping	22.0	689.8		226.0	2.0	Mid-hard soil	Intermediately weathered mudstone, bedrock, unexposed
Leibohuangliang	7.2	695.0		114.0	2.0	Mid-soft soil	Weak-weathered Emeishan basalt, unexposed
Changxiqixiangju	22.0	706.6		321.0	2.0	Mid-hard soil	Weak-weathered sandstone, unexposed
Kangdingxiaba	22.0	765.2		252.0	2.0	Mid-soft soil	Slightly less dense conglomerate stratum soil, unexposed
Lushanfenghe	9.8	790.3	B (760–1,500	324.0	2.0	Mid-hard soil	Weak-weathered packsand, bedrock, unexposed
Zhuoni	12.0	801.2		168.8	2.0	Mid-hard soil	Bedrock, slate, V_9=730 m/s, unexposed
Tianquanxianlianglu	22.0	854.1		273.0	2.0	Mid-soft soil	Weak-weathered calcareous shale, unexposed
Lushanjishengju	22.0	862.8		162.0	2.0	Mid-soft soil	Intermediately weathered mudstone, unexposed
Bowuguan	10.0	1519.0		487.8	1.0	Mid-soft soil	Bedrock
Xichangxiaomiao		None					Bedrock
Changan		None					Bedrock
Fushunbanqiao		None					Bedrock
Daguan		None					Bedrock
Jingning		None					Bedrock
Lintan		None					Bedrock
Ludian		None					Bedrock
Miaoxiandiban		None					Bedrock
Puerzhen		None					Bedrock
Beixianzoushishan		None					Bedrock
Songpan		None					Bedrock
Suijiang		None					Bedrock
Tangyu		None					Bedrock
Wenxian		None					Bedrock
Yixingyongxing		None					Bedrock
Shanshan		None					Bedrock
Zixingdixingyingxiangtaizhan1		None					Bedrock

Station	*Borehole Depth (m)*	*NEHRP*		*BG50011-2010*			*Note*
		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Zixingdixingyingxiangtaizhan2		None	B (760–1,500				Bedrock
Zixingdixingyingxiangtaizhan3		None					Bedrock
Zixingdixingyingxiangtaizhan4		None					Bedrock
Zixingdixingyingxiangtaizhan5		None					Bedrock
Zixingdixingyingxiangtaizhan6		None					Bedrock
Zixingdixingyingxiangtaizhan7		None					Bedrock
Zhouqu		None					Bedrock
Chenduzhonghe		None					Bedrock
Qianling	10.0	None			2.0	Mid-hard soil	Silty clay and mild clay, limestone at the bottom of 10 m
Shoushanxiang	2.5	None			2.0	Mid-hard soil	Unweathered limestone
Baoxingdizhenju		None			2.0	Mid-hard soil	
Guanxiang		None			2.0	Mid-soft soil	
Shuizu		None			1.0	Mid-soft soil	
Chenchang		None			2.0	Mid-hard soil	Silty clay and mild clay
Maolin		None			2.0	Mid-hard soil	
Qianyang		None			1.0	Mid-soft soil	Silty clay and mild clay
Xian		None			2.0	Mid-hard soil	Silty clay and mild clay
Xiying		None			2.0	Mid-hard soil	Silty clay and mild clay
Junlian		None			2.0	Mid-hard soil	
Jiuzaizhangzha		None			2.0	Mid-hard soil	
Kangding		None			2.0	Mid-hard soil	
Madadiban		None			2.0	Mid-soft soil	
Qishan		None			2.0	Mid-hard soil	Silty clay and mild clay
Longshan		None			2.0	Mid-hard soil	Silty clay and mild clay
Lianta		None			2.0	Mid-hard soil	
Rongjingshilong		None			2.0	Mid-soft soil	
Yangling		None			2.0	Mid-hard soil	

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		V_{30} (m/s)	*Classification*	*V_{20} (m/s)*	*Classification*		
Yichezhen		None	B (760–1,500		2.0	Mid-soft soil	
Zixingdixingyingxiangtaizhan0		None			2.0	Mid-hard soil	
Hongya		None			2.0	Mid-hard soil	
Zhouzhi		None			2.0	Mid-hard soil	Diluvial gravel
Huxian		None			2.0	Mid-soft soil	Siilty clay and mild clay
Jingyang		None			2.0	Mid-hard soil	Silty clay and mild clay
Changning		None			2.0	Mid-hard soil	
Baoji		None			2.0	Mid-soft soil	Alluvial loess and sandy clay
Shawan	22.0	635.7		186.0	2.0	Mid-hard soil	Intermediary weathered argillaceous limestone,unexposed
Yiliguan	12.0	648.2		326.1	2.0	Mid-hard soil	Quartzite, V12=810m/s
Hanji	28.8	651.7		301.5	2.0	Mid-hard soil	Sandstone
Zhongxinxiang	20.0	659.5		261.9	2.0	Mid-hard soil	Sandstone, V20=522m/s,unexposed
Lushanxianfeixianguan	9.8	666.2		242.0	2.0	Mid-hard soil	Weak-weathered sandy mudstone,bedrock,unexposed
Yaanshaping	22.0	689.8		226.0	2.0	Mid-hard soil	Intermediaryweathered mudstone,Bedrock,unexposed
Leibohuangliang	7.2	695.0		114.0	2.0	Mid-soft soil	Weak-weathered Emeishan basalt,unexposed
Changxiqixiangju	22.0	706.6		321.0	2.0	Mid-hard soil	Weak-weathered sandstone,unexposed
Kangdingxiaba	22.0	765.2		252.0	2.0	Mid-soft soil	Slightly less dense conglomerate stratum soil,unexposed