# INTRODUCTION AND PRELIMINARY ANALYSIS OF STRONG MOTION RECORDINGS FROM THE 12 MAY 2005 Ms8.0 WENCHUAN EARTHQUAKE OF CHINA*

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**ABSTRACT :**

An Ms8.0 Wenchuan earthquake occurred on the Longmenshan fault belt in Sichuan, China on 12 May 2008. The strong motion recordings of the main shock are obtained from 460 permanent free-field stations and three arrays for topographical effect and structural response observation in the National Strong Motion Observation Network System (NSMONS) of China, and a large numbers of acceleration records from the strong aftershocks occurred were also obtained by permanent free-field stations of the NSMONS and 59 mobile instruments quickly deployed after the main shock. The mobile instruments are specifically deployed to record the strong motions of the strong aftershocks for the purposes of near-fault effect, topographical effect, basin effect and structural response observation. This paper provides a detailed description of the relevant stations and the resultant strong motion measurements of the main shock, and a brief description of the mobile observation. The preliminary analysis of the recordings shows that over 1,400 components of strong motion records are obtained from the main shock. Among the records, there are more than 500 components with peak ground acceleration (PGA) larger than 10 gal, 200 larger than 50 gal, 115 larger than 100 gal, 42 larger than 200 gal, 16 larger than 400 gal, and 7 larger than 600 gal. With the stations of the NSMONS and mobile stations, over 20,000 components of acceleration records were obtained from strong aftershocks. In the aftershock records, the largest PGA has exceeded 800 gal which was recorded in the Qingchuan aftershock on 5 August 2008. Some near-fault properties of recordings are also demonstrated such as large vertical acceleration, rupture directivity effect, fault slip effect, hanging wall effect, basin effect, etc.

**KEYWORDS:** Wenchuan Earthquake, Strong Motion Observation, Mobile Observation, Observation array, Strong Motion Record, Peak Strong Acceleration, Rupture Directivity Effect, Hanging Wall Effect

## 1. INTRODUCTION

The Great Wenchuan Earthquake occurred in Sichuan Province, China at 14:28 on May 12, 2008 (Beijing Time). The surface wave magnitude is Ms8.0. The earthquake epicenter was located at latitude 31.021°N and longitude 103.367°E and the focal depth was 14 km. The associate fault rupture is mainly thrust with strike-slip component. The rupture propagated mainly unilaterally with a main rupture length of about 200 km spreading towards the northeast, accompanied by a small dislocation of less than 1 m at 300 km northeast of the epicenter. The rupture was relatively small to southwest of the epicenter (Chen, et al., 2008). This earthquake generated a 240 km surface rupture along the Beichuan-Yingxiu fault characterized by right-lateral oblique faulting and a 72 km surface rupture along the Guanxian-Jiangyou fault characterized by dip-slip reverse faulting. Maximum vertical and horizontal displacements of 6.2 m and 4.9 m, respectively, were observed

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along the Beichuan-Yingxiu fault, whereas a maximum vertical displacement of 3.5 m occurred along the Guanxian-Jiangyou fault (Xu, et al., 2008). The Wenchuan Earthquake caused very strong shaking in Sichuan, Shanxi and Gansu Provinces. The earthquake was also felt in Beijing, Shanghai, Tianjin, Ningxia, Gansu, Qinghai, Shanxi, Shandong, Hebei, Henan, Anhui, Hubei, Hunan, Chongqing, Guizhou, Yunnan, Inner Mongolia, Guangxi, Tibet, Jiangsu, Zhejiang, Liaoning, Fujian, Taiwan, and Bangkok of Thailand, Hanoi of Vietnam. As of 15 August 2008, a total of 260 aftershocks with magnitude larger than 4.0 had occurred, in which 40 aftershocks are with magnitude larger than 5.0, and 8 aftershocks larger than 6.0. The largest one with a magnitude of 6.4 occurred in Qingchuan on 25 May 2008.

The mainland of China, in number and density of strong-motion observation stations, was seriously behind the United States, Japan, Iran and Mexico before 2000 (Xie, et al.,1982, Gao, et al., 2001, Zhou, 2006, Nozu, 2004). It could not meet the needs of research and engineering constructions in China. In order to change the situation, the nation provided funds to implement the Project of China Digital Strong Motion Observation Network in the National 10th Five-year Plan. The project considered the existing strong-motion stations, seismicity in all regions and cities, and the distribution of major engineering structures. It also considered the research and construction needs and trends. After a five-year construction, the project was completed (Earthquake Disaster Prevention and Mitigation Division of China Earthquake Administration, 2008) and the National Strong Motion Observation Network System (NSMONS) was established, forming a large scale of strong motion observation network in the mainland of China, as shown in Figure 1. The network focuses on regional distribution of permanent stations, seismic intensity stations in major cities for intensity rapid reporting, and special arrays for research purposes. The network is augmented with mobile observations and includes the National Network Center and Regional Network Centers for record recovery, processing and dissemination, network technical support, network management and maintenance.

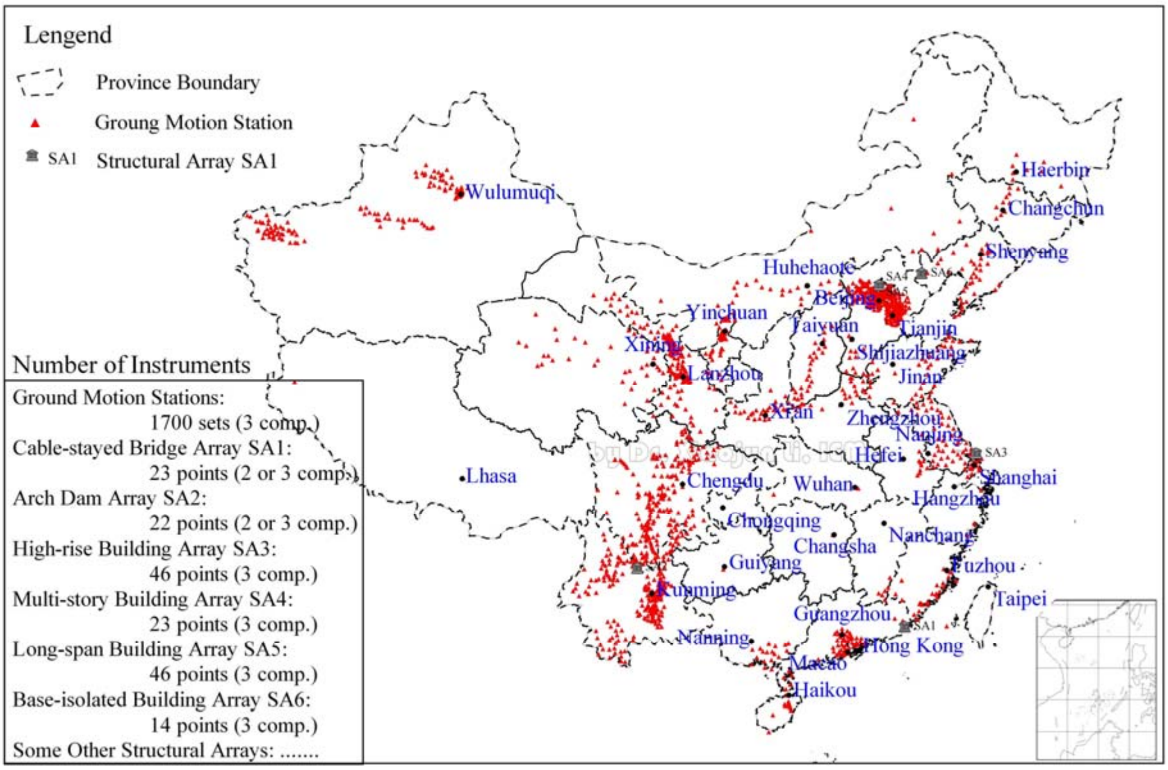



Figure 1. Distribution of stations in the National Strong Motion Observation Network System (NSMONS)

During the Wenchuan Earthquake of May 12, 2008, the network system obtained the records from 460 stations and 3 arrays. After the main shock, 59 mobile instruments were quickly deployed to record ground motions and structural responses from strong aftershocks. A large numbers of aftershock records were obtained. The strong motion records from the main shock and aftershocks will provide basic data for researches on the earthquake ground motion and structural response. In this paper, the strong motion recordings are summarized, and the characteristics are preliminarily analyzed.

## 2. STRONG MOTION OBSERVATIONS IN THE WENCHUAN EARTHQUAKE

The NSMONS began trial operation in early 2007 and entered formal operations in March 2008. Just two months later, the network system obtained over 1,400 components of strong motion records from the main shock of the Wenchuan Earthquake, including records from 460 stations in 17 provinces, municipalities and autonomous regions and 1 array for topographical effect observation in Sichuan province and 2 temporary arrays for structural response observation in Kunming mobile observatory. After the main shock, mobile instruments were deployed at over 70 locations in the hardest hit areas to record motions of strong aftershocks. Over 20,000 components of acceleration records from the strong aftershocks occurred before August 15, 2008 were also obtained by permanent stations of the NSMONS and the mobile instruments deployed.

Locations of the free-field stations for main shock recordings are shown in Fig. 2. Figure 3 shows the distribution of the stations in local area including a part of Sichuan, Shanxi and Gansu provinces. Figure 2 shows that the relatively dense stations with strong-motion records are located in Xi'an city and its surrounding areas in the Xi'an basin. After the main shock, experts of the strong-motion group in the China Earthquake Administration (CEA) quickly deployed 59 mobile instruments to observe motions of strong aftershocks at over 70 observation points in the near fault areas. These mobile stations were constantly relocated based on the distribution of aftershocks and the trend forecast in order to capture more strong motion records. Figure 4 shows the location of the mobile observation points for strong aftershocks.

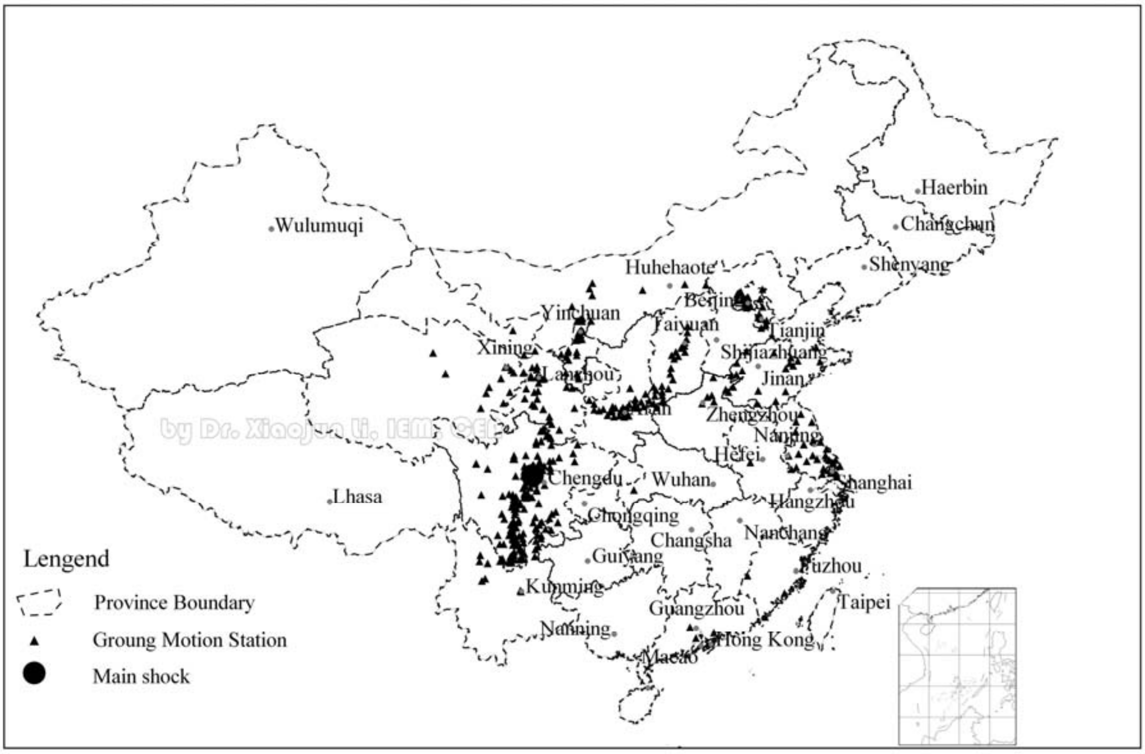



Figure 2. Locations of the strong motion observation stations that recorded ground motions from the main shock of the Wenchuan Earthquake

Among the records from the main shock, there are more than 500 components with PGA larger than 10 gal, 200 larger than 50 gal, 115 larger than 100 gal, 42 larger than 200 gal, 16 larger than 400 gal, and 7 larger than 600 gal. With the stations of the NSMONS and mobile stations, over 20,000 components of acceleration records were obtained from strong aftershocks before 15 August 2008. In the aftershock records, the largest PGA exceeds 800 gal which was recorded in the Qingchuan aftershock on 5 August 2008.

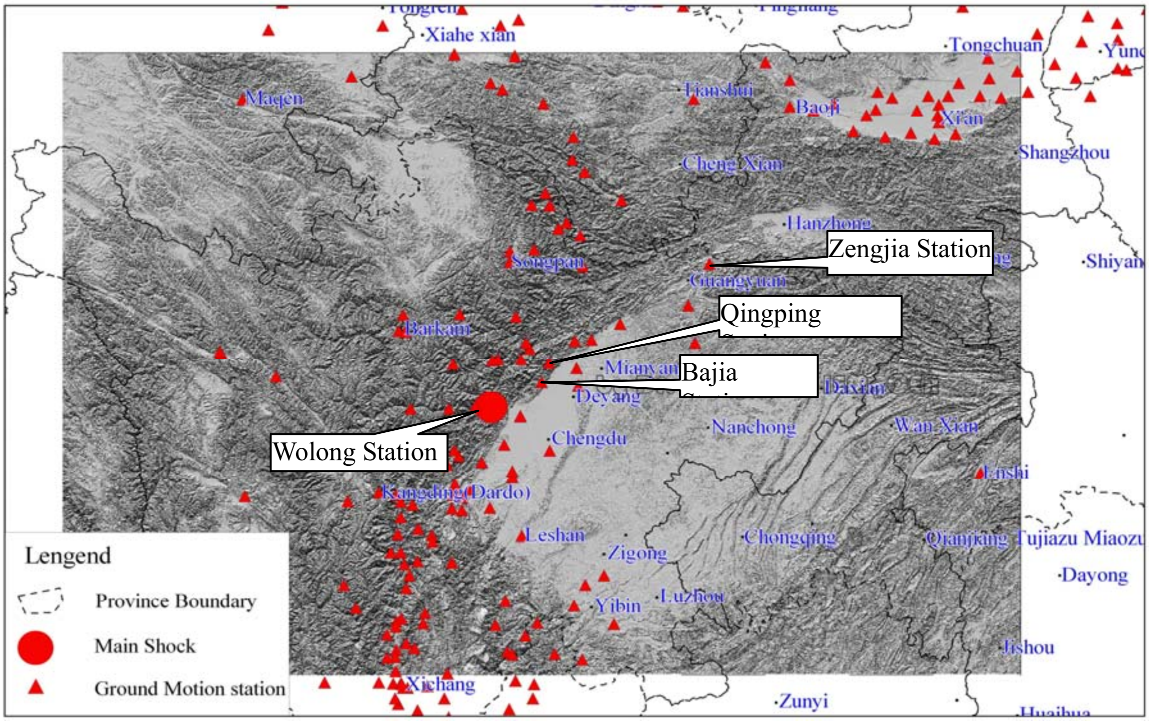



Figure 3. Distribution of the strong motion observation stations that recorded ground motions from the main shock of the Wenchuan Earthquake in the fault surrounding area

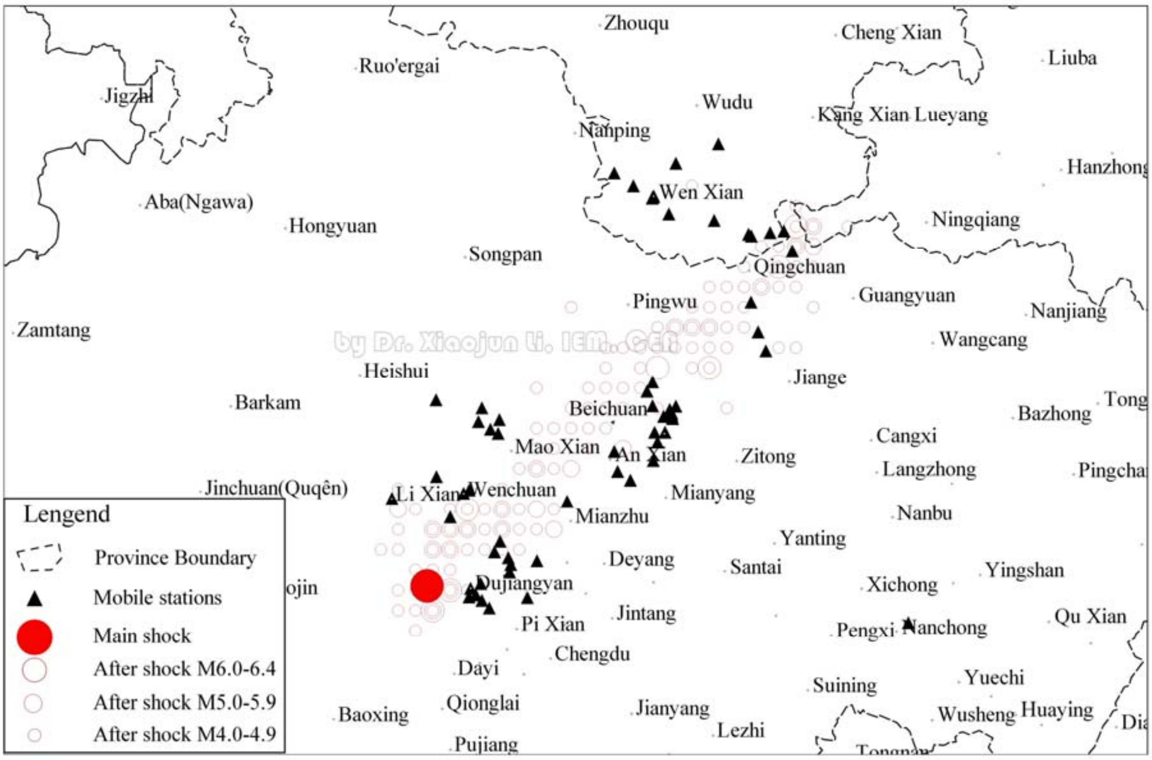



Figure 4. Locations of the mobile observation points for strong aftershocks of the Wenchuan Earthquake

Among the acceleration records from the main shock, the largest PGA was recorded at Wolong station in

Wenchuan County. Location of Wolong station is indicated in Fig. 3, which is near the epicenter and 19 km from the epicenter and 19 km west of the fault. Figure 5 shows the acceleration records, integrated velocities, acceleration response spectra from Wolong station. PGAs recorded in the EW, NS, and UD directions are 957.7 gal, 652.9 gal and 948.1 gal, respectively, and peak velocities are 51.5, 41.7 and 30.4 cm/sec, respectively. Two distinct ruptures separated by about 20 seconds can be seen in the records The Wolong record is followed by the record obtained at Qingping station in Mianzhu City. Location of Qingping station is indicated in Fig. 3, which is near the middle of rupturing fault and about 88 km from the epicenter and only 10 km from the fault. The acceleration records, integrated velocities, and acceleration response spectra from Qingping station are shown in Fig. 6. PGAs recorded in the EW, NS and UD directions are 824.1 gal, 802.7 gal and 622.9 gal, respectively, and peak velocities are 133.0, 65.3 and 39.6 cm/sec, respectively. The third one is recorded from Bajiao station as shown in Fig. 3. The station is also near the middle of rupturing fault and about 67 km from the epicenter and only 20 km from the fault. PGAs recorded in the EW, NS, and UD directions as shown in Fig. 7 are 556.2 gal, 581.6 gal and 633.1 gal, respectively. The Zengjia station in Guanyuan is located near the end of fault rupture and about 314 km from the epicenter and 87 km from the fault, as shown in Figure 3. A large peak acceleration record is also obtained from Zengjia station as shown in Fig. 8. PGAs recorded in the EW, NS, and UD directions are 424.5 gal, 410.5 gal and 183.3 gal, respectively. In the far field, many records were also obtained. Although the epicenter distance of the station is over 1,200 km, the Dongming station in Shandong Province obtained fine recordings from the main shock, as shown in Fig. 9. PGAs in the EW, NS and UD directions are 9.0 gal, 9.8 gal and 2.5 gal, respectively.

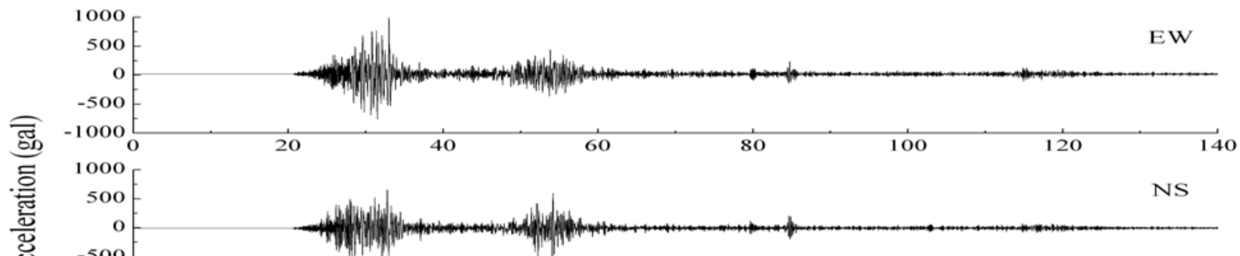
As of August 15, 2008, the largest aftershock was the M6.4 Qingchuan aftershock occurred on May 25, 2008, which is located at latitude 32.6°N and longitude 105.4°E. Acceleration records were obtained at 30 mobile observation stations from the M6.4 Qingchuan aftershock. Figure 10 shows the acceleration records at Linjiaba gas station located at an epicenter distance of about 90 km. PGAs in the EW, NS and UD directions are 58.8 gal, 122.3 gal and 46.2 gal, respectively.

## 3. DISTRIBUTION OF PEAK GROUND ACCELERATIONS IN THE MAIN SHOCK

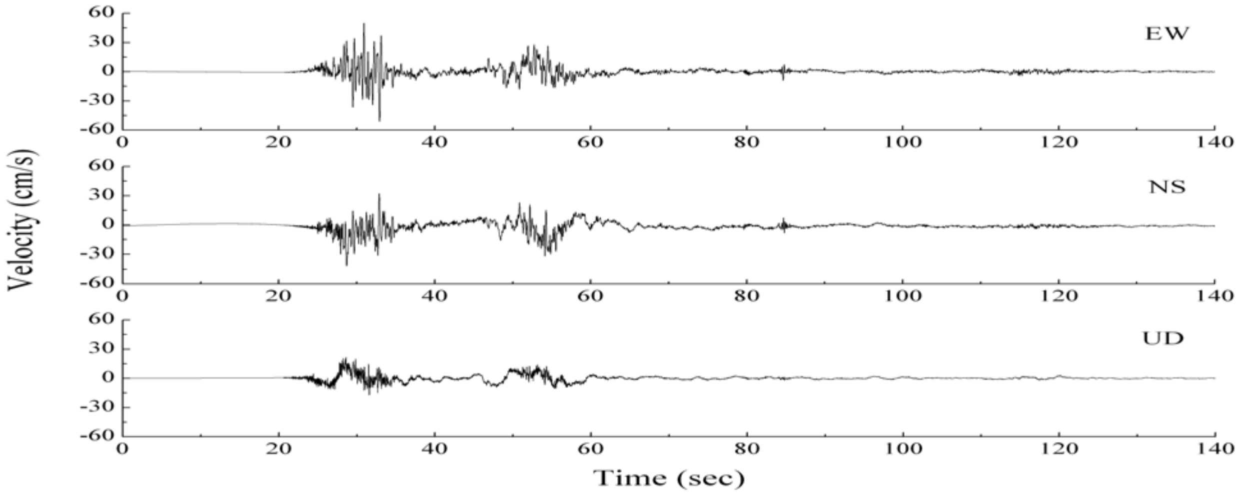
Strong motion records from the main shock were analyzed to understand the distribution of recorded peak accelerations. The peak acceleration values in the EW, NS, and UD directions are shown in Figures 11-13, respectively. The numbers of peak values corresponding to different intensity scales are shown in Table 1. The intervals of PGA values in Table 1 are based on the values for Chinese Seismic Intensity Scale (Chinese National Standard, 1999). Comparisons of peak vertical accelerations with peak horizontal accelerations are shown in Fig. 13.

Table 1 Distribution of peak ground motions of the records from the main shock

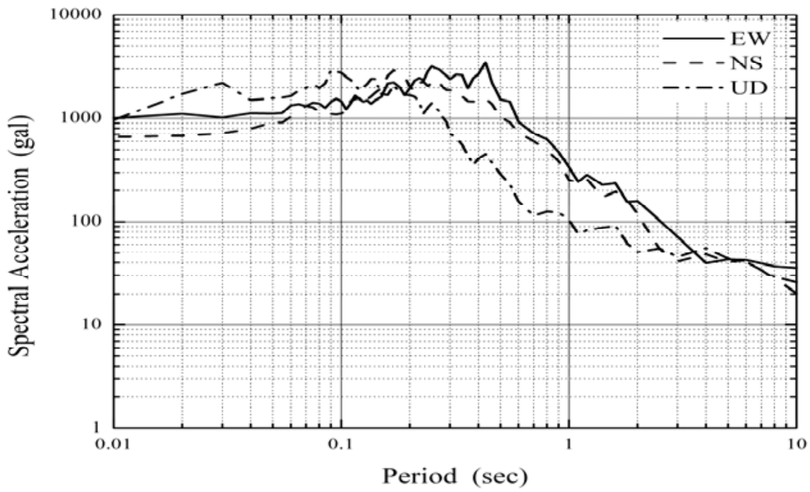
| Chinese Seismic Intensity | <VI | VI | VII | VIII | IX | ≥X |
|---|---|---|---|---|---|---|
| Component (gal) | 10.0-44.9 | 50.0-89.9 | 90.0-177.9 | 178.0-353.9 | 354.0-707.9 | ≥708.0 |
| EW | 104 | 31 | 35 | 14 | 5 | 2 |
| NS | 104 | 28 | 36 | 15 | 4 | 1 |
| UD | 79 | 30 | 12 | 7 | 5 | 1 |
| Total number | 343 | 89 | 83 | 36 | 14 | 4 |



(a) Acceleration records

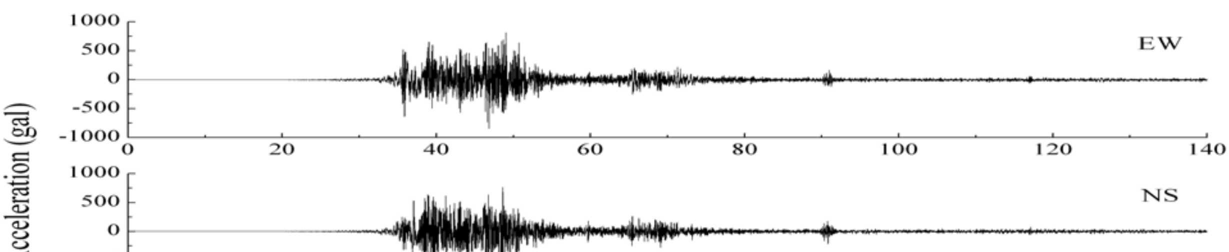



(b) Integrated velocity time-history

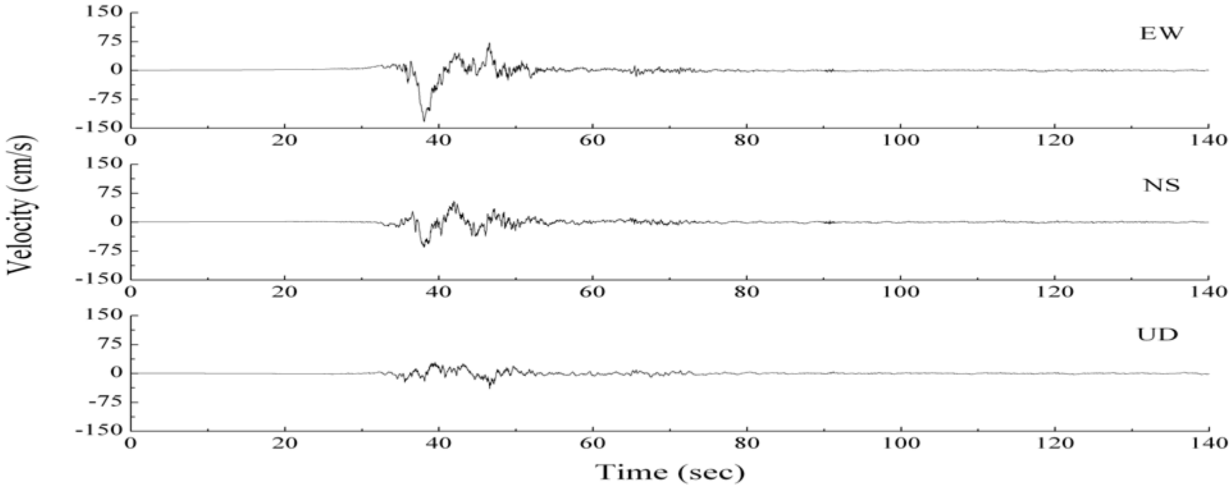



(c) Acceleration response spectra (5% damping)

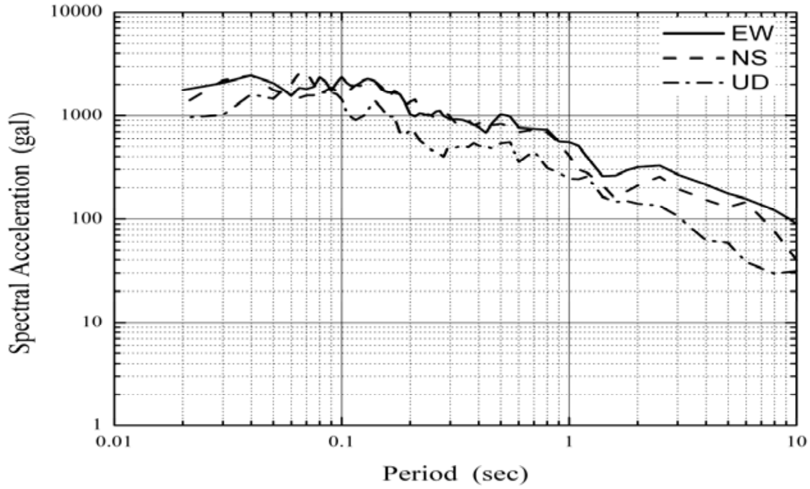
Figure 5. Acceleration records, integrated velocities and acceleration response spectra obtained from Wolong station in Wenchuan during the main shock of May 12, 2008



(a) Acceleration records

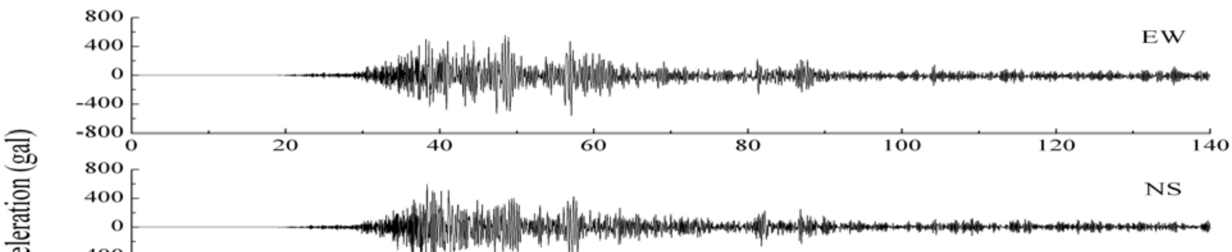



(b) Integrated velocity time-history

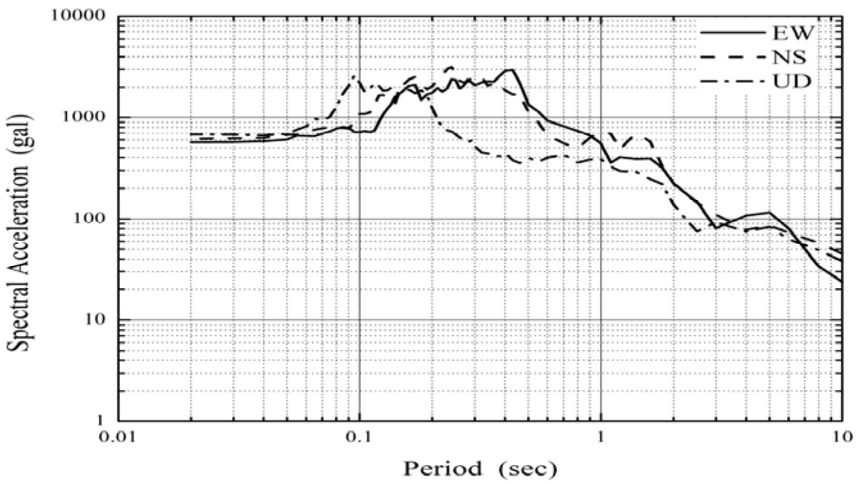



(c) Acceleration response spectra (5% damping)

Figure 6. Acceleration records, integrated velocities and acceleration response spectra obtained from Qingping station in Mianzhu during the main shock of May 12, 200

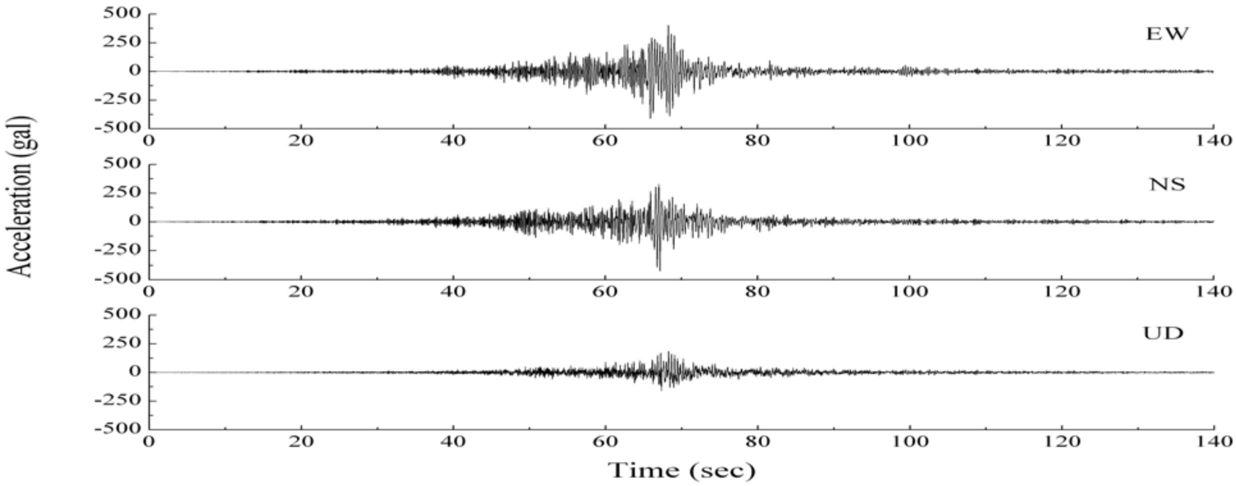


(a) Acceleration records

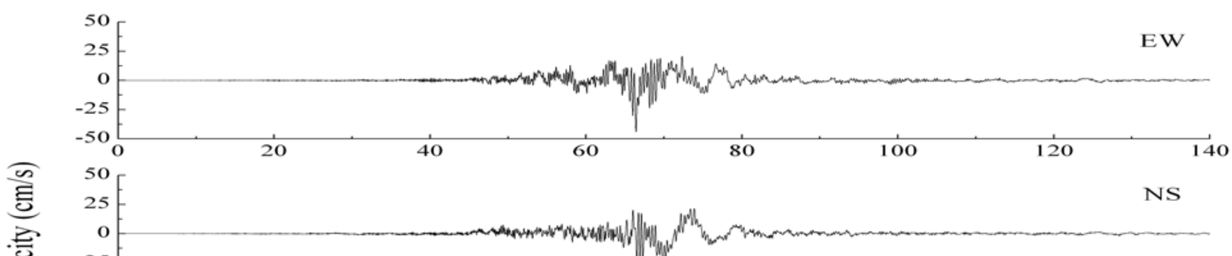



(b) Acceleration response spectra (5% damping)

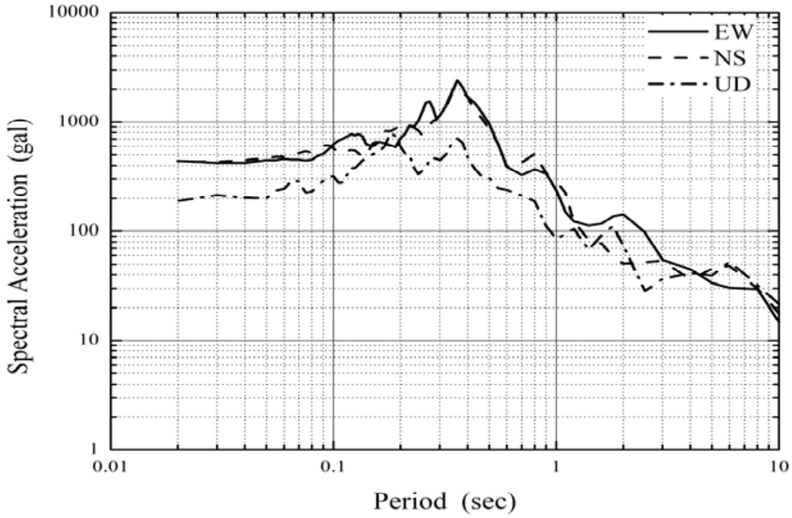
Figure 7. Acceleration records and acceleration response spectra obtained from Bajiao station in Shifang during the main shock of May 12, 2008




(a) Acceleration records



(b) Integrated velocity time-history




(c) Acceleration response spectra (5% damping)

Figure 8. Acceleration records, integrated velocities and acceleration response spectra obtained from Zengjia station in Guanyuan during the main shock of May 12, 2008

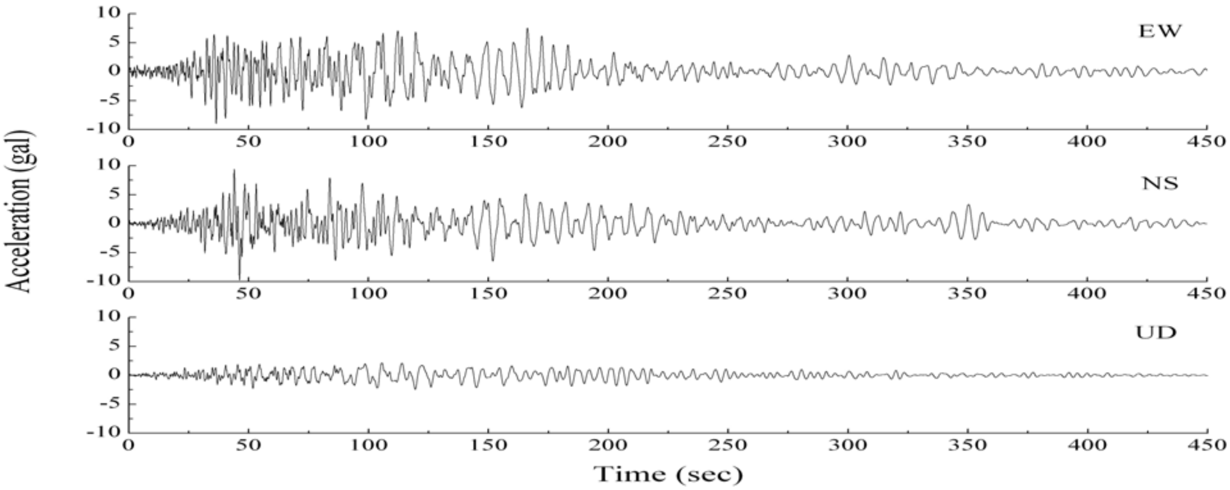



Figure 9. Acceleration records obtained from Dongming station in Shandong province (the epicenter distance is about 1,200 km) during the main shock of May 12, 2008

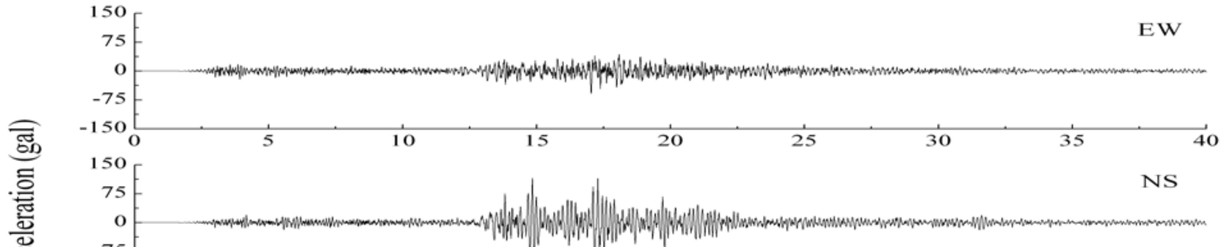


Figure 10. Acceleration records obtained from Linjiaba gas station during the M6.4 aftershock in Qingchuan (the epicenter distance is about 90 km)

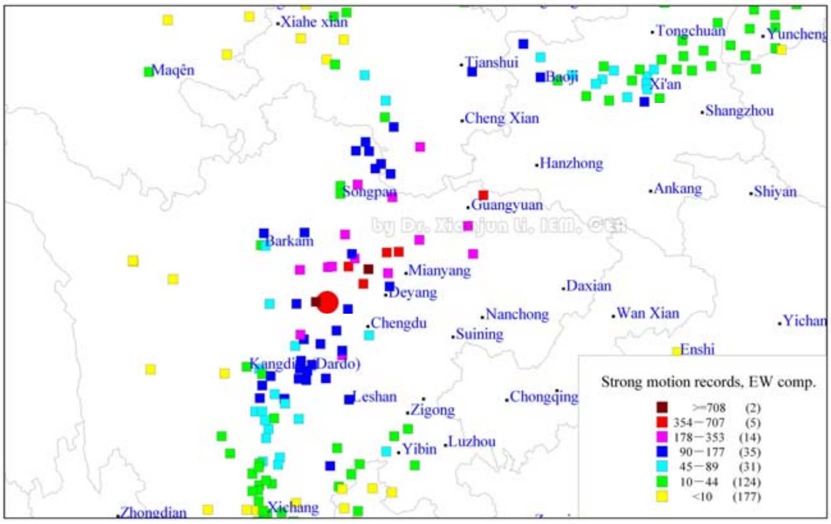



Figure 11. Spatial distribution of PGAs in the EW direction recorded from the main shock of the Wenchuan Earthquake.

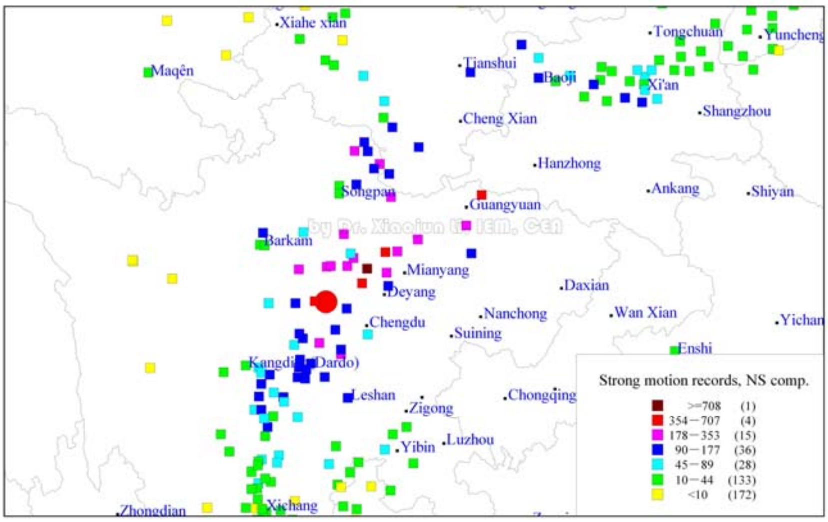



Figure 12. Spatial distribution of PGAs in the NS direction recorded from the main shock of the Wenchuan Earthquake.

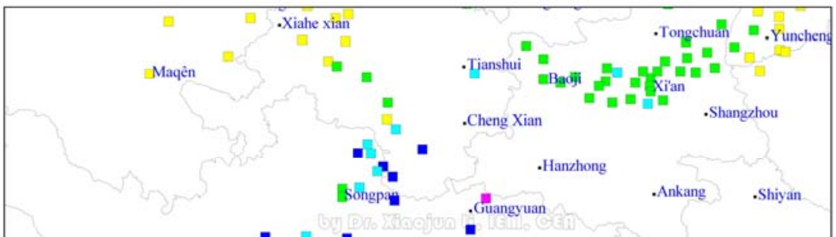


Figure 13. Spatial distribution of PGAs in the vertical (UD) direction recorded from the main shock of the Wenchuan Earthquake..

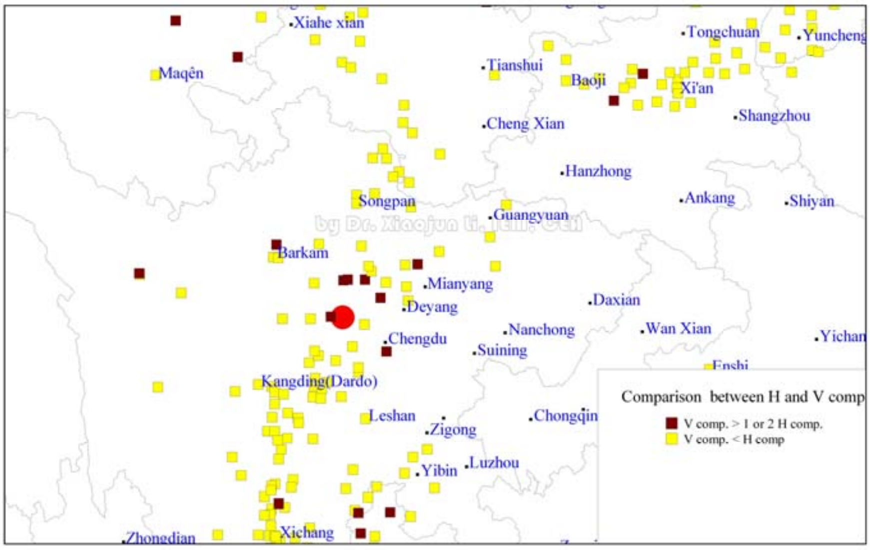



Figure 14. Spatial distribution of the ratios of the vertical PGA and the horizontal PGA recorded from the main shock of the Wenchuan Earthquake.

Figures 2 and 3 show the spatial distribution of the stations recorded from the main shock of the Wenchuan Earthquake, from these two figures only the epicenter distance of each ground motion station can be directly estimated. Because the length of associate fault rupture is over 240 km for the main shock of this event, the fault distance is better than the epicenter distance for understanding and studying the spatial distribution and attenuation of the ground motions. Two kinds of fault distances were calculated separately in this study. The first distance is the distance from the strong motion station to the surface rupture along the Beichuan-Yingxiu fault as shown in Fig. 15. Table 2 shows the numbers of strong motion stations for main shock recordings versus surface rupture distance. The second distance is the distance from the strong motion station to the reference fault of the Wenchuan Earthquake as shown in Fig. 15. Table 3 shows the numbers of strong motion stations for main shock recordings versus reference fault distance. In this study, the reference fault is simply defined as the projection of the energy release center along the fault of the Wenchuan Earthquake. The position of the reference fault is identified by consideration of factors including the distribution of the aftershocks, the focal depth of the main shock, and the dip angle of the Beichuan-Yingxiu fault. The epicenter distance, reference fault distance and surface rupture distance of some of stations mentioned in this paper are listed in

Table4.

The distribution of peak ground accelerations in the Figures 11-14 comparing with the surface rupture and reference fault in the Fig. 15 clearly demonstrates the following characteristics of ground motion from the earthquake, especially for near-fault ground motion (Li, 2001, Wang et al, 2002, Shakal, et al, 2005):

(1) Large peak accelerations are recorded from stations located along the fault, and the distance to the reference fault clearly controls the ground motion attenuation.
(2) Peak accelerations at stations in the fault rupture propagation direction are relatively large, which clearly demonstrates the fault rupture propagation or directivity effect.
(3) In the near-fault records, peak acceleration in the EW direction is in general larger than that in the NS direction.
(4) Peak accelerations at stations on hanging wall of the thrust fault are roughly larger than those from stations on foot wall, which shows hanging wall effect on ground motion.
(5) The area with large accelerations seems to be relatively larger near the northeast segment of the fault than the southwest segment of the fault, which is consistent with the trend in earthquake damages shown in Fig. 16 (Wenchuan Earthquake Damage Assessment Working Group, 2008).
(6) For some near-fault records, the peak vertical acceleration is close to or larger than one or two of the peak horizontal accelerations.
(7) Large velocity pulses of the ground motion appear in some near-fault records, such as those shown in Figures 5, 6 and 8.

In the main shock, strong motion records were obtained from relatively dense stations in Xian area and its surrounding areas in the Xian basin, as shown in Fig. 3. These records will provide more data for studying the basin effects on ground motions.

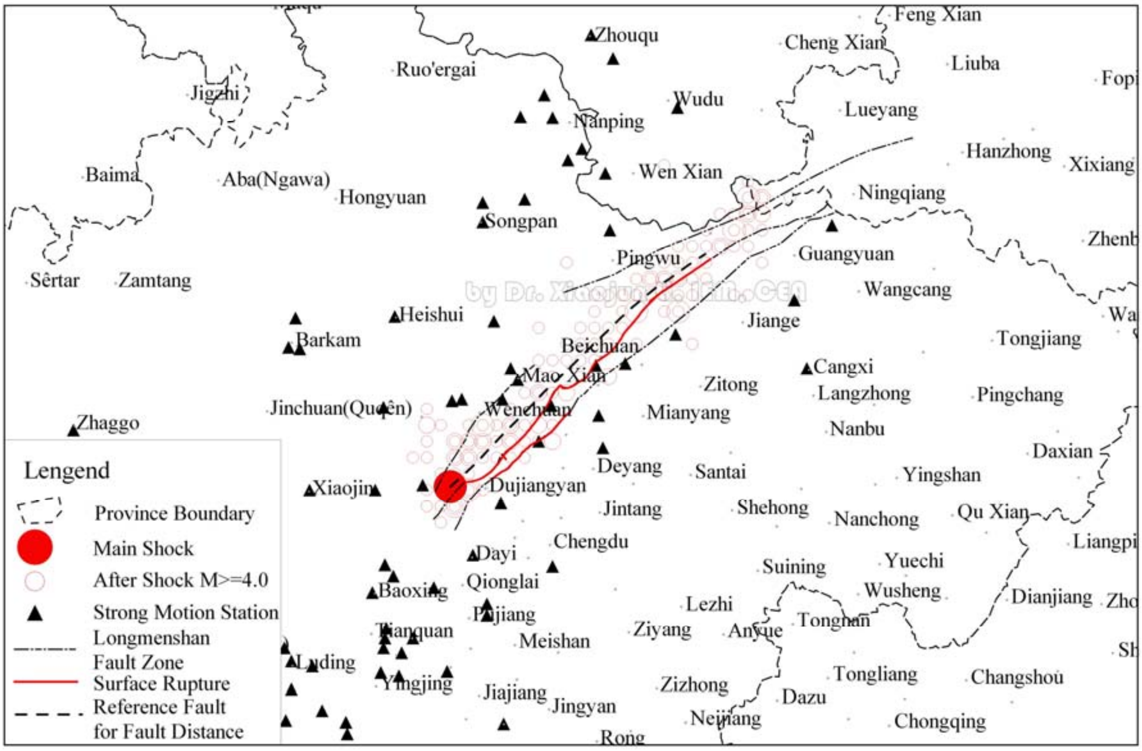



Figure 15. Positions of the surface rupture and reference fault for the Wenchuan Earthquake.

Table 2 Number of strong motion stations providing main shock recordings versus surface rupture distance

| Surface rupture distance (km) | ≤10 | 11-20 | 21-50 | 51-100 | 101-200 | 201-500 |
|---|---|---|---|---|---|---|
| Number of strong motion stations | 3 | 2 | 10 | 17 | 35 | 133 |

Table 3 Number of strong motion stations providing main shock recordings versus reference fault distance

| Reference Fault distance (km) | ≤10 | 11-20 | 21-50 | 51-100 | 101-200 | 201-500 |
|---|---|---|---|---|---|---|
| Number of strong motion stations | 1 | 5 | 7 | 17 | 36 | 133 |

Table 4 Epicenter distance, reference fault distance and surface rupture distance of some stations

| Station | Wolong | Qingping | Bajiao | Zengjia |
|---|---|---|---|---|
| Epicenter distance (km) | 19 | 88 | 67 | 314 |
| Reference Fault distance (km) | 19 | 10 | 20 | 87 |
| surface rupture distance (km) | 23 | 3 | 10 | 86 |

## 4. ATTENUATION OF INTENSITY AND PEAK GROUND ACCELERATIONS

Figure 16 shows the comparison results of horizontal peak ground accelerations and seismic intensities from the main shock of the Wenchuan Earthquake (Wenchuan Earthquake Damage Assessment Working Group, 2008). The comparison results reveal that the seismic intensities investigated are consistent with the trend of the distribution of the horizontal peak ground accelerations recorded, but there is much difference between corresponding intensities of ground motions recorded and the intensities investigated. The most of corresponding intensities of ground motions are larger than the intensities investigated.

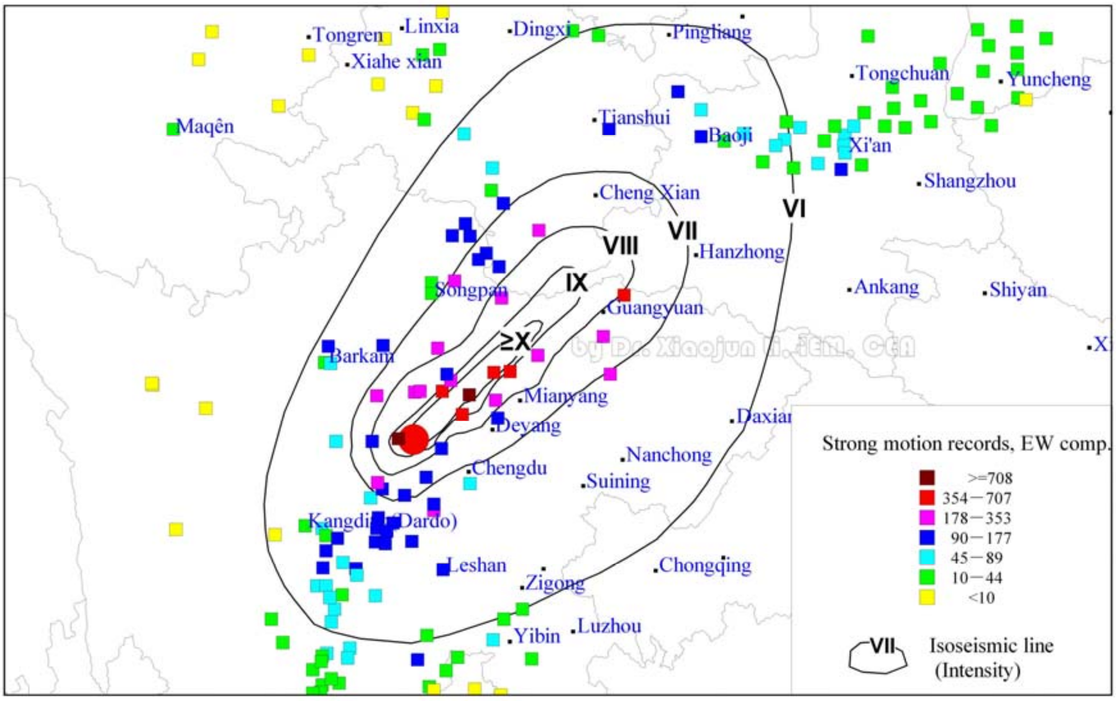



Figure 16. Comparison of horizontal peak ground accelerations with seismic intensities from the main shock of the Wenchuan Earthquake.

Figures 11-13 show that spatial distribution of the peak ground accelerations and demonstrate that the peak ground accelerations decrease very slowly in the fault rupture direction. In order to clearly describe the spatial variation of ground motion in the main shock, it is necessary to study the attenuation of peak ground acceleration. Figure 17 shows the plot of peak ground acceleration for both horizontal components versus the closet distance to the reference fault (log-log). For comparisons, three attenuation relationships including the relationship for California by Sadigh, et al. (1997), the relationship for Japan by Fukushima, et al. (1990), and the relationship for west China by Wang, et al. (2000) are adopted to obtain attenuation curves of peak ground acceleration for a magnitude 8 event, shown in Fig. 17. Considering most of stations recorded the Wenchuan main shock are on hard soil sites or rock sites, the attenuation relationships for rock sites are used in this study.

Some important features of the ground motion from the Wenchuan earthquake may be found in Fig. 17. The peak horizontal ground accelerations of the Wenchuan Earthquake decrease much slower than those from the three attenuation relationships, especially in the fault distance ranging from 100 to 300 km. Some recorded peak values are more than 100 gal even at the fault distance of about 400 km. The peak ground acceleration is highly varied in the fault distance ranging from 100 to 500 km.

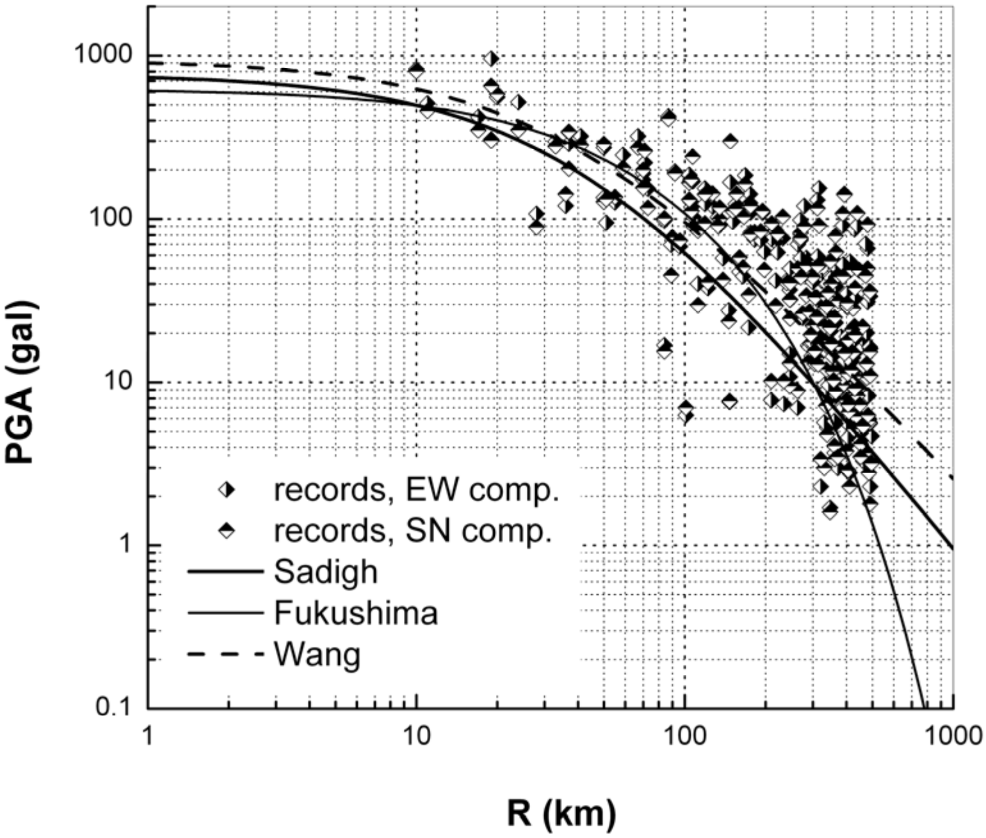



Figure 17. Horizontal peak ground accelerations (PGA) versus fault distance (R) for data from the main shock of May 12, 2008 and three attenuation relationships.

## 5. SUMMARY

This article summarizes the strong motion records from the Wenchuan Earthquake of May 12, 2008 and gives a preliminary analysis of ground motion records. Some characteristics of ground motion for the Wenchuan Earthquake are presented. Analysis of the worldwide strong-motion records indicates that there were about 2,000 records available before 1999. The Chi-Chi earthquake in Taiwan generated over 500 strong-motion records from the main shock and big aftershocks. The strong motion records from the Wenchuan Earthquake have greatly expanded the worldwide strong motion database. In particular, the near-fault records from an magnitude 8.0 have filled the gap for the near-fault records from major earthquakes. The large numbers of records from the main shock and big aftershocks provide basic information for researches on the earthquake and its effects on structures. More detailed study of the records from the main shock and aftershocks will be conducted in the future.

## ACKNOWLEDGEMENT

National Strong Motion Observation Network System of China (NSMONS) is managed by the National Strong Motion Observation Center in the Institute of Engineering Mechanics, China Earthquake Administration (CEA) and local strong motion observation centers. The experts of the strong motion observation group in CEA are in charge of effective maintenance and operations, effective data collection, processing, storage and management, and also to provide Internet data services for the Network. The experts in Seismological Bureaus of Sichuan, Gansu, Shanxi, and other provinces and Institute of Engineering Mechanics made an effort to collect all the recording data and process them after the main shock of Wenchuan earthquake. We are very grateful to the efforts by all relevant officers and experts who contributed to the success in recording data in the Wenchuan Earthquake.

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