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Strong motion observations and recordings from the great Wenchuan Earthquake

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Abstract: The National Strong Motion Observation Network System (NSMONS) of China is briefly introduced in this paper. The NSMONS consists of permanent free-field stations, special observation arrays, mobile observatories and a network management system. During the Wenchuan Earthquake, over 1,400 components of acceleration records were obtained from 460 permanent free-field stations and three arrays for topographical effect and structural response observation in the network system from the main shock, and over 20,000 components of acceleration records from strong aftershocks occurred before August 1, 2008 were also obtained by permanent free-field stations of the NSMONS and 59 mobile instruments quickly deployed after the main shock. The strong motion recordings from the main shock and strong aftershocks are summarized in this paper. In the ground motion recordings, there are over 560 components with peak ground acceleration (PGA) over 10 Gal, the largest being 957.7 Gal. The largest PGA recorded during the aftershock exceeds 300 Gal.

Keywords: Wenchuan Earthquake; strong motion observation network; mobile observation; observation array; strong motion record; PGA

1 Introduction

At 14:28 on May 12, 2008 (Beijing Time), a major earthquake occurred in Wenchuan, Sichuan Province, China. The surface wave magnitude was M_s 8.0. The earthquake epicenter was located at latitude 31.021°N and longitude 103.367°E and the focal depth was 14 km. The associated fault rupture was mainly thrust with a 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 the 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 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, Shannxi and Gansu Provinces. As of August 1, 2008, a total of 244 aftershocks with magnitudes larger than 4.0 had occurred, in which 37 aftershocks had magnitudes larger than 5.0, and 7 aftershocks were larger than 6.0. The largest one occurred on May 25 with a magnitude of 6.4.

During the Wenchuan Earthquake, the NSMONS obtained the main shock records from 460 stations in 17 provinces, municipalities and autonomous regions and an array for topographical effect in Sichuan province and two temporary arrays for structural response in Kunming Mobile Obseratory. Over 20,000 components from strong aftershocks were obtained before August 1, 2008. In this paper, the NSMONS is briefly introduced and the strong motion recordings from the main shock and strong aftershocks are summarized.

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2 NSMONS of China

The goal of strong motion observations from instruments deployed on the earth's surface and near the surface is to study the rupture process of earthquake faulting and the characteristics of near-source ground motions (Xie, *et al*., 1982). Instruments are also installed in structures to measure their responses to earthquake ground motions. The recorded response data may help researchers and engineers to better understand the response and damage characteristics of structures under earthquakes, and provide the basis for future engineering seismic resistant design techniques and disaster mitigation. The mainland of China was seriously behind the United States, Japan, Iran and Mexico in terms of number and density of strong-motion observation stations before 2000 (Gao, *et al*., 2001; Nozu, 2004; Zhou, 2006). In order to change the situation, funding was provided by the central government to implement the Project of China Digital Strong Motion Observation Network as part of the national 10th Five-year Plan from 2000 to 2005. After about a five-year construction period, the project was completed and the NSMONS was established, forming a large scale strong motion observation network in the mainland of China.

The NSMONS includes stations covering the entire mainland, most of which are densely distributed in the Capital Region and some other regions prone to disastrous earthquakes, including Gansu, Yunnan, and Sichuan provinces and Xinjiang Autonomous Region as shown in Fig. 1. The network system includes regionally distributed permanent stations, stations in major cities for rapid reporting of intensity, and special arrays for research purposes. In addition, there are some mobile observatories. The network system consists of 1,154 permanent free-field stations, 12 special observation arrays, 200 mobile instruments and a strong motion observation network management system (Earthquake Disaster Prevention and Mitigation Division, CEA, 2008). The management system, which includes a national center, three regional centers, five centers for rapid reporting of intensity and local centers in all provinces, municipalities and autonomous regions in mainland of China, has been built to ensure record recovery, processing and dissemination, network technical support, network management and maintenance, etc.

Some special arrays, which were deployed for various research purposes, are summarized in Table 1. All stations in the network and all observation points in the special arrays were equipped with international and domestic strong-motion instruments with the most advanced and stable performance to ensure that the network is reliable over the long-term and is able to record high-quality strong-motion data. The main technical specification of the main strong-motion instrumentations used in NSMONS is listed in Table 2.

The network began trial operation in early 2007 and entered formal operations in March 2008. Just two months later, the network system obtained numerous records from the main shock and strong aftershocks of the Wenchuan Earthquake. During its one-year trial run, many strong-motion records were obtained. As of September 2007, more than 3,000 components of acceleration records were obtained. Among these records, 536 components have PGA of larger than 10 Gal. This is equivalent to one-third of the total records obtained in China in the past 30 years and more before

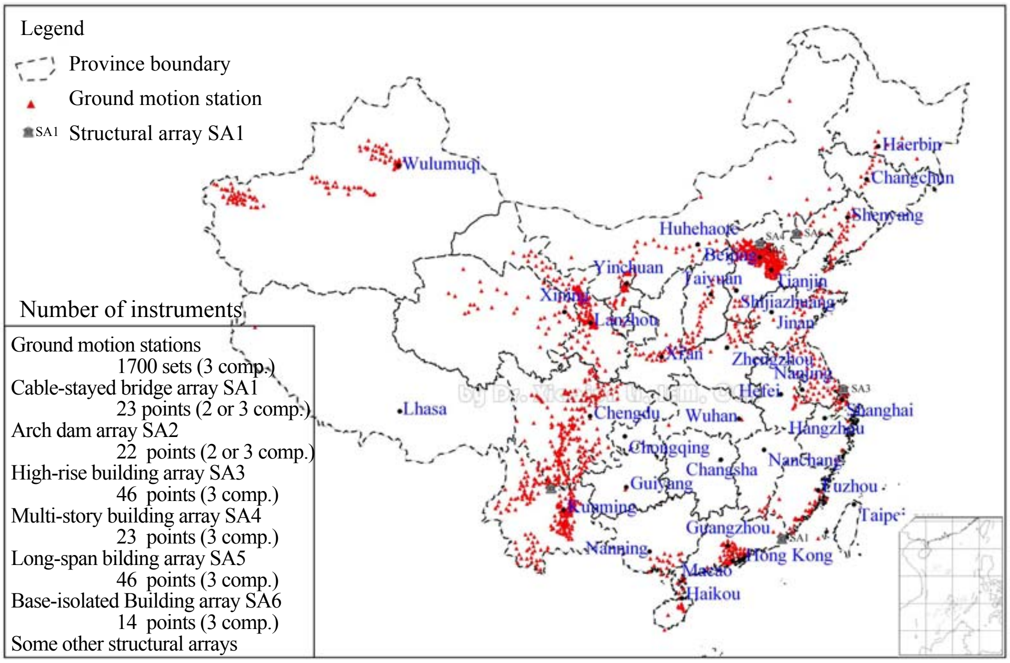

Fig. 1 Distribution of stations of National Strong Motion Observation Network System of China

Table 1 Summary of the special arrays arranged in Mainland of China

Special observation arrays	Array number	Number of stations (observation points†)	Location
Near-fault ground motion	1	30	Yunnan province
Ground motion attenuation	2	2×50	Gansu province and the Capital Region
Site effect	2	(2×8)	Yunnan province and Hebei province
Topographical effect	1	8	Sichuan province
Super- high-rise building	1	46	Shanghai city
Multi-story building	1	23	Beijing city
Long-span structure	1	46	Beijing city
Base-isolated building	1	14	Hebei province
Large bridge	1	23	Guangdong province
Large dam	1	21	Sichuan province

Note: † In all arrays for structure response observation, there are tri-axial records for each observation point

Table 2(a) The main technical specification of the data acquisitions adopted in the NSMONS

Data acquisition	Etna	GDQJ-II	MR-2002
Number of channels	3	3	3
Dynamic range	108 dB	120 dB	114 dB
Frequency response	DC –80 Hz	DC –80 Hz	DC –80 Hz
Resolution	18 bit	24 bit	22 bit
Noise	≤ 1 LSB (RMS)	≤ 1 LSB (RMS)	≤ 1 LSB (RMS)
Sampling rate	100, 200, 250 sps	50, 100, 200, 400 sps	50, 100, 200, 500 sps
Input range	±2.5V	±2.5V	±2.5V

Table 2(b) The main technical specification of the sensors adopted in the stations for the ground motion observation of Wenchuan Earthquake

Sensor	ES-T	SLJ-100
Type	Force balance accelerometer	Force balance accelerometer
Full scale range	±2 gn	±2 gn
Bandwidth	DC−200 Hz	DC−80 Hz
Dynamic range	≥155 dB	≥ 120 dB
Noise	≤10^{-7} gn (RMS)	≤10^{-6} gn (RMS)

the founding of the network. The record with the largest PGA of 494.2 gal was obtained from the M_L 4.7 Yanjin, Yunnan Earthquake of June 28, 2006. Prior to the Wenchuan Earthquake, more than 6,000 components of accelerations were obtained, including those from the ground motion attenuation array in Gansu Province. The largest PGA was recorded from the M_S6.4 Puer, Yunnan Earthquake of June 3, 2007. During the Wenchuan Earthquake, over 1,400 components of acceleration records were obtained from the main shock and over 20,000 components from the strong aftershocks were obtained.

3 Strong-motion observations in the Wenchuan Earthquake

During the Wenchuan Earthquake of May 12, 2008, the NSMONS obtained records from 460 stations in 17 provinces, municipalities and autonomous regions and three arrays in Sichuan and Yunnan provinces. 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 areas including parts of Sichuan, Shannxi and Gansu provinces. Figure 2 shows that the relatively dense stations with strong-motion records are located in

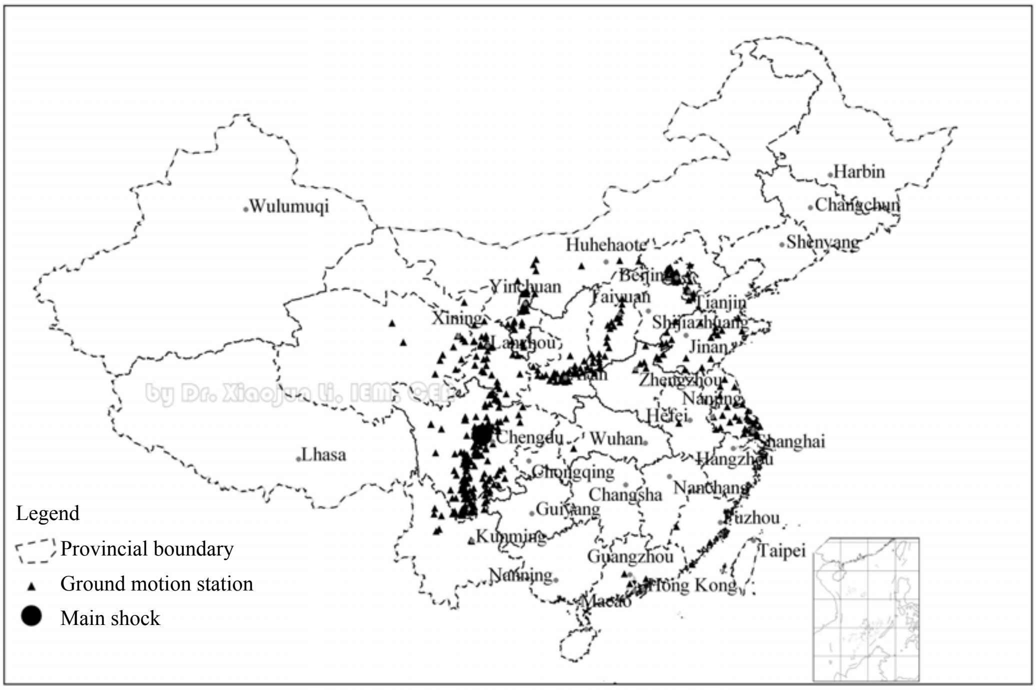

Fig. 2 Locations of the strong motion observation stations that recorded the main shock of the Wenchuan Earthquake

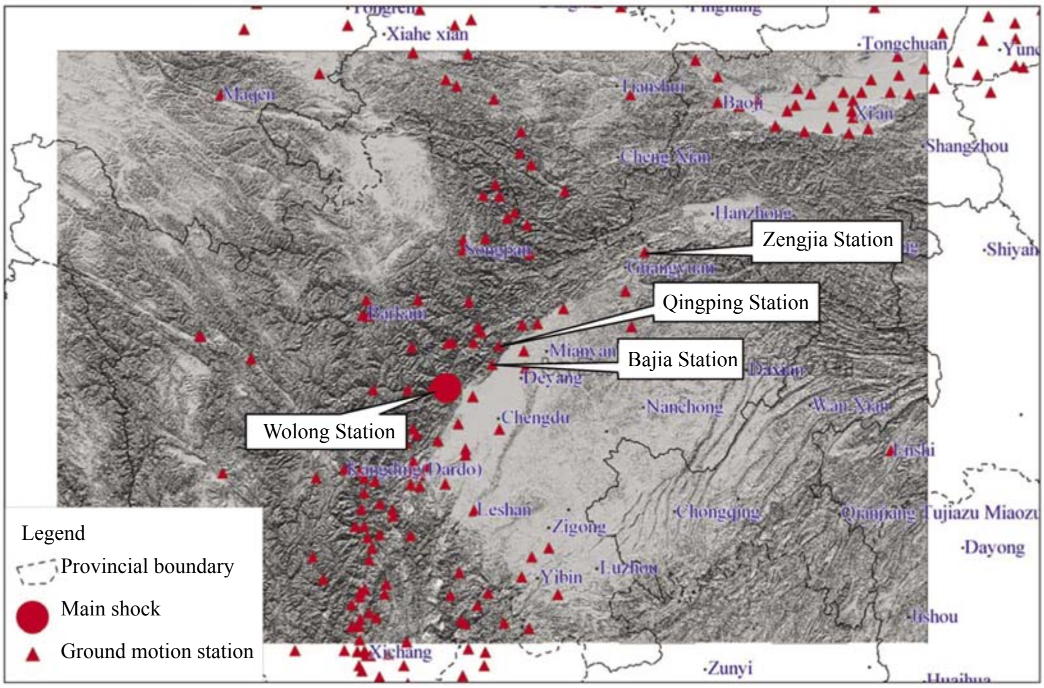

Fig. 3 Distribution of the strong motion observation stations that recorded the main shock of the Wenchuan Earthquake in the fault surrounding area including a part of Sichuan, Shaanxi and Gansu provinces

Xi'an City and its surrounding areas in the Xi'an Basin. After the main shock, experts in the strong-motion group of 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.

Among the records from the main shock, there are more than 560 components with PGA larger than 10

Gal, 226 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. The number of peak values corresponding to different intensity scales are shown in Table 3. The intervals of PGA values in Table 3 are based on the values for Chinese Seismic Intensity Scale (Chinese National Standard, 1999). The intervals in the table correspond to the intensities less than VI, VI, VII, VIII, IX, and larger than X. From the stations of the NSMONS and with the addition of mobile stations, over 20,000 components of acceleration records were obtained from strong aftershocks. In the aftershock records, the largest PGA has exceeded 300 Gal.

Among the acceleration records from the main shock, the largest PGA, shown in Fig. 5 was recorded at Wolong station in Wenchuan County. The location of the Wolong station is shown in Fig. 3. PGAs recorded in the EW, NS, and UD directions are 957.7 Gal, 652.9 Gal and 948.1 Gal, respectively. The Wolong record is followed by the record obtained at Qingping station in Mianzhu City. The location of the Qingping station is shown in Fig. 3. PGAs recorded in the EW, NS and UD directions are 824.1 Gal, 802.7 Gal and 622.9 Gal, respectively. The station is near the middle of the rupturing fault. The acceleration records from the Qingping station are shown in Fig. 6. The third is recorded from Bajiao station as shown in Fig. 3. 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. Another recording shown in Fig. 8 was obtained at the Zengjia station located near the end of fault rupture as shown in Fig. 3. PGAs 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 excellent recordings from the main shock, as shown in

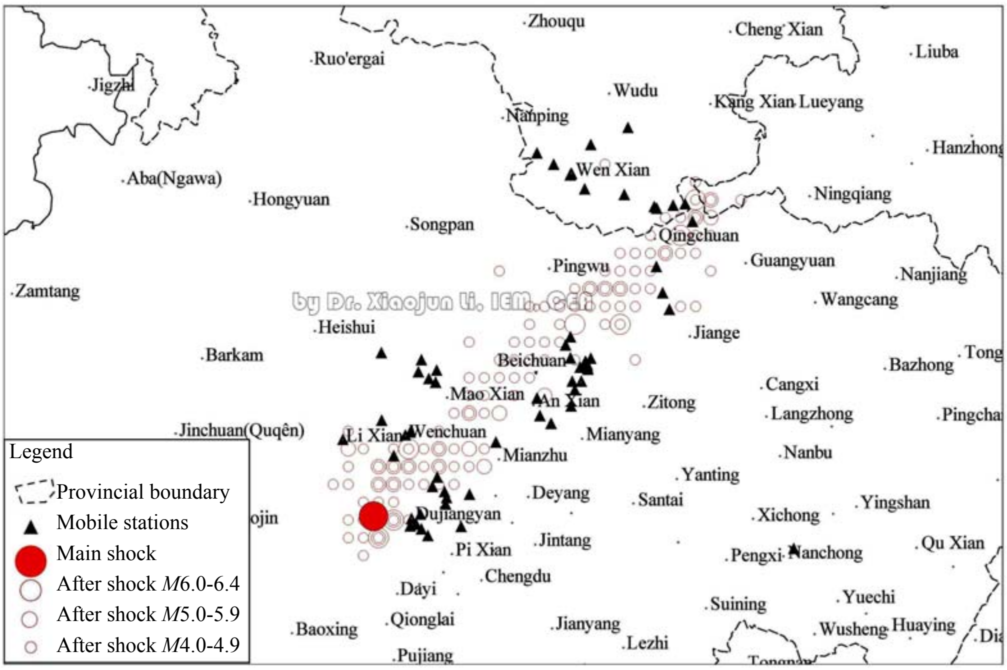

Fig. 4 Locations of the mobile observation points for strong aftershocks of the Wenchuan Earthquake

Table 3 Distribution of peak ground acceleration

Chinese seismic intensity	<VI	VI	VII	VIII	IX	≥X
Component	10.0-49.9 Gal	50.0-89.9 Gal	90.0-177.9 Gal	178.0-353.9 Gal	354.0-707.9 Gal	≥708.0 Gal
EW	124	31	35	14	5	2
NS	133	28	36	15	4	1
UD	86	30	12	7	5	1
Total	343	89	83	36	14	4

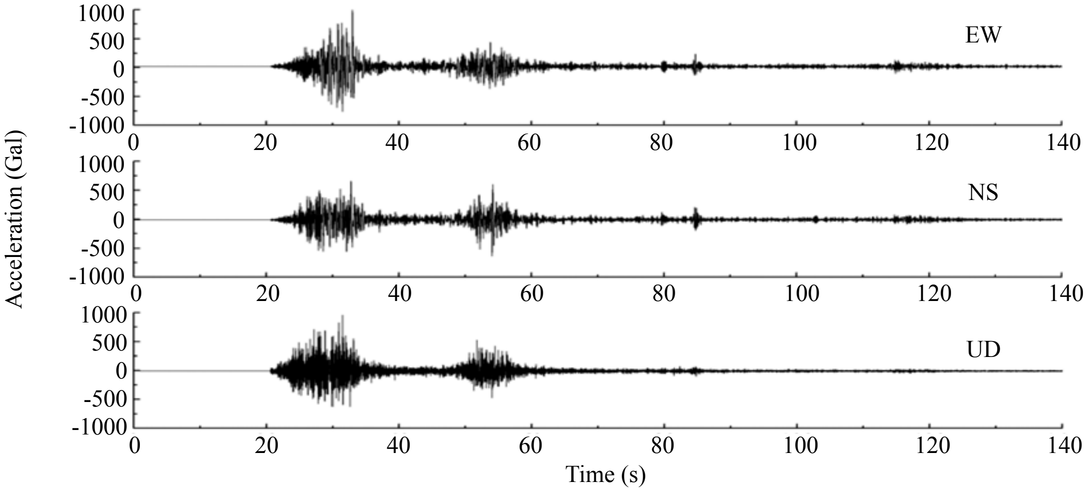

Fig. 5 Acceleration records obtained from Wolong station in Wenchuan during the main shock. Peak accelerations recorded in the EW, SN, and UD directions are 957.7, 652.9 and 948.1 Gal, respectively

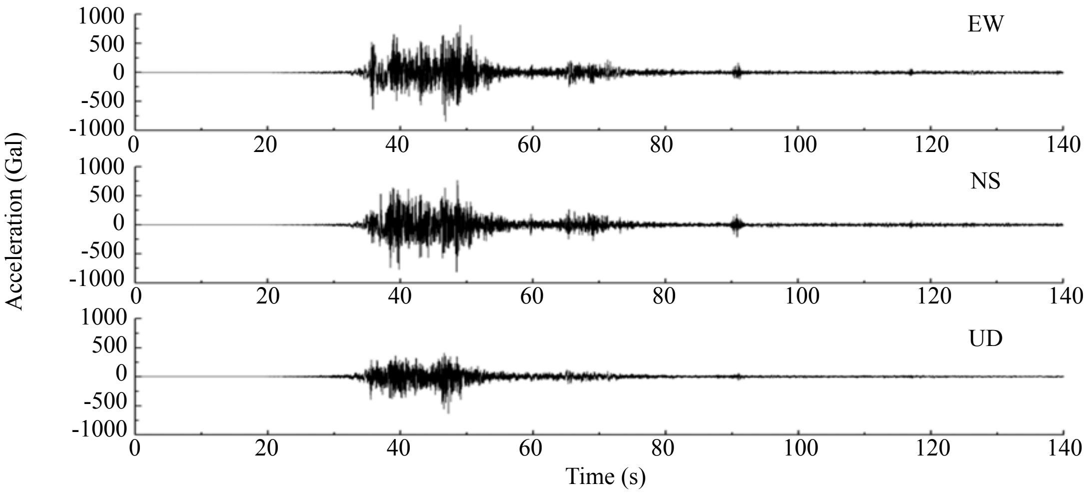

Fig. 6 Acceleration records obtained from Qingping station in Mianzhu during the main shock. Peak accelerations in the EW, NS and UD directions are 824.1, 802.7 and 622.9 Gal, respectively

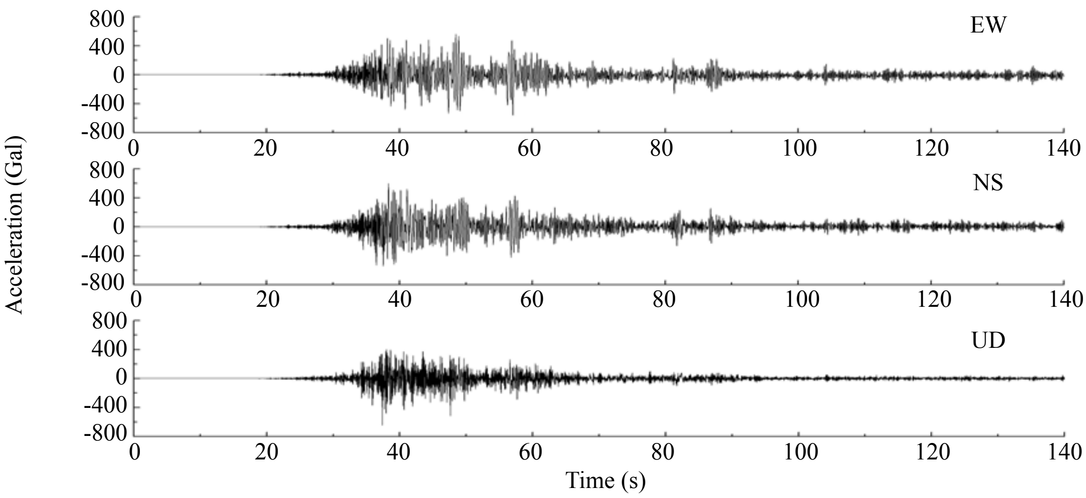

Fig. 7 Acceleration records obtained from Bajiao station in Shifang during the main shock. Peak accelerations in the EW, NS and UD directions are 556.2, 581.6 and 633.1 Gal, respectively

Fig. 9. PGAs in the EW, NS and UD directions are 9.0 Gal, 9.8 Gal and 2.5 Gal, respectively.

Before August 1, 2008, the largest aftershock was the *M*6.4 Qingchuan aftershock that 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 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.

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 with many additional records from more than 10 aftershocks with magnitudes larger than 6.0. The strong-motion records from the Wenchuan Earthquake have greatly expanded the worldwide strong-motion database. In particular, the near-fault records from a magnitude 8.0 earthquake have filled a gap for near-fault records from major earthquakes.

4 Preliminary analysis of records from the main shock

The spatial distribution of the stations that recorded the main shock of the Wenchuan Earthquake can be found in Figs. 2 and 3. Only the epicenter distance of each ground-motion station can be directly estimated from these figures. Since the length of the associated fault rupture is over 240 km in 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

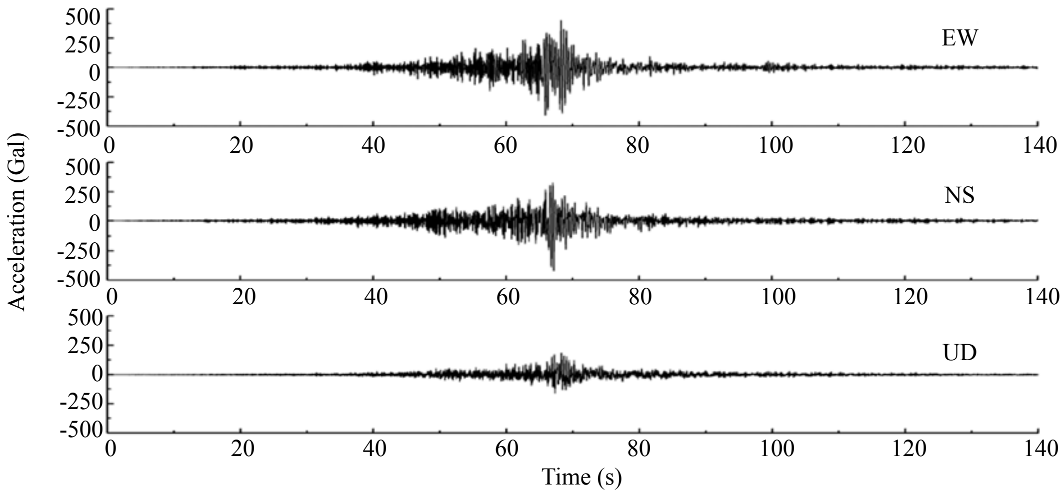

Fig. 8 Acceleration records obtained from Zengjia station in Guanyuan during the main shock. The PGAs in the EW, NS and UD directions are 424.5, 410.5 and 183.3 Gal, respectively

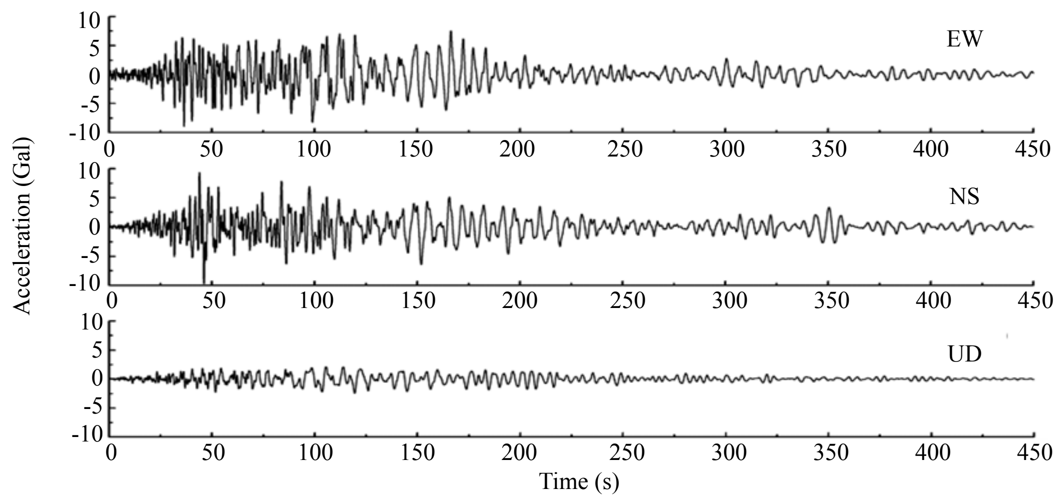

Fig. 9 Acceleration records obtained from Dongming station in Shandong Province during the main shock (the epicenter distance is about 1,200 km). The PGAs in the EW, NS and UD directions are 9.0, 9.8 and 2.5 Gal, respectively

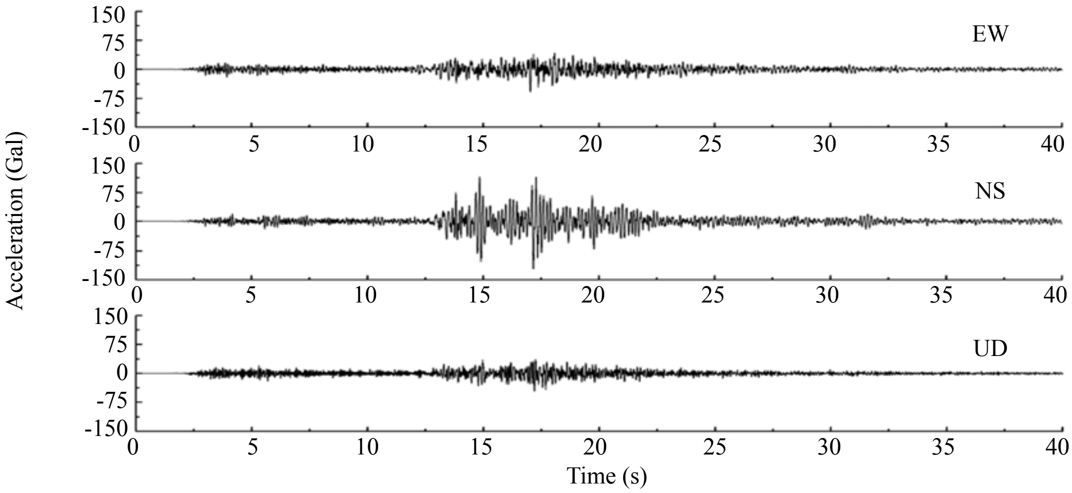

Fig. 10 Acceleration records obtained from Linjiaba gas station during the *M*6.4 aftershock in Qingchuan (the epicenter distance is about 90 km). The PGAs in the EW, NS and UD directions are 58.8, 122.3 and 46.2 Gal, respectively

types 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. 11. Table 4 shows the number of strong motion stations that had 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. 11. Table 5 shows the number of strong motion stations that had 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 considering factors such as 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 the stations mentioned in this paper are listed in Table 6

To demonstrate the distribution of recorded PGAs, a simple analysis was performed on the strong-motion records from the main shock. The PGA values in the EW, NS, and UD directions are shown in Figs. 12, 13, and 14, respectively. The distribution of PGAs in the maps clearly demonstrates some characteristics of the ground motions from the Wenchuan Earthquake,

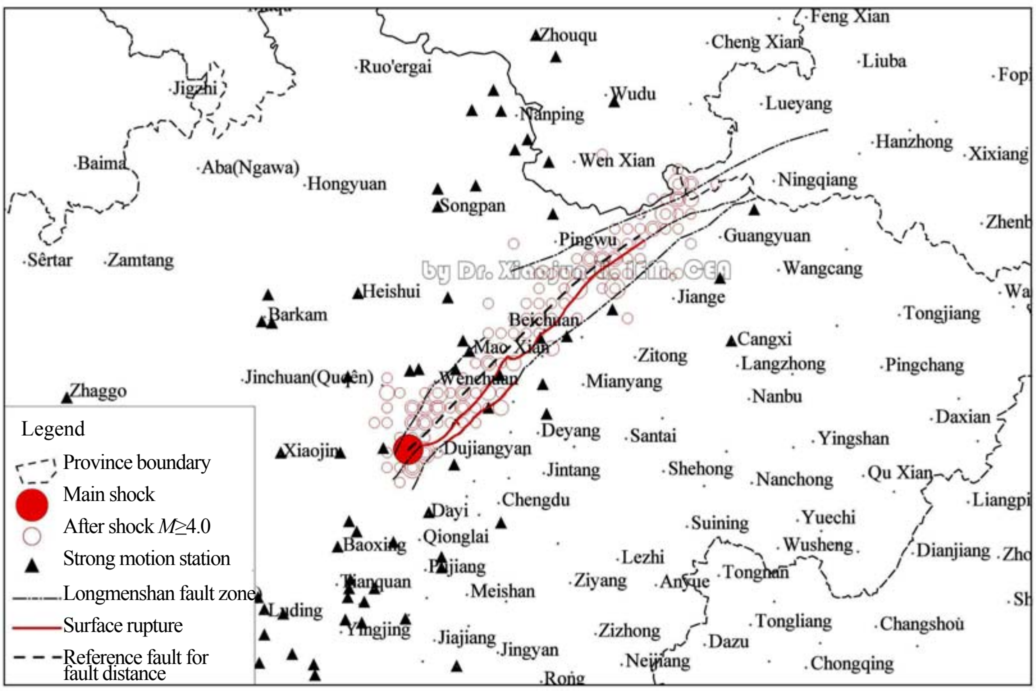

Fig. 11 Positions of the surface rupture and reference fault for the Wenchuan Earthquake

including the special characteristics of near-fault ground motion as observed from other large earthquakes, such as the directivity effect and hanging wall effect (Li, 2001; Wang *et al.*, 2002; Shakal, *et al.*, 2005). Large PGAs from stations located along the fault show that the fault distance dominates the ground-motion attenuation. PGAs are relatively large in the fault rupture propagation direction, and also somewhat larger on the hanging wall. In the near-fault records, the PGA is generally larger in the EW direction than the NS direction. A comparative analysis of the horizontal and vertical components of the main shock records, shown in Fig. 15, shows that the PGA is larger in the vertical direction than in one or two horizontal directions for some near-fault records.

Table 4 Number of strong motion stations for 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 5 Number of strong motion stations for 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 6 Epicenter distance, reference fault distance and surface rupture distance of some stations mentioned in this paper

km

Station	Wolong	Qingping	Bajiao	Zengjia
Epicenter distance	19	88	67	314
Reference fault distance	19	10	20	87
Surface rupture distance	23	3	10	86

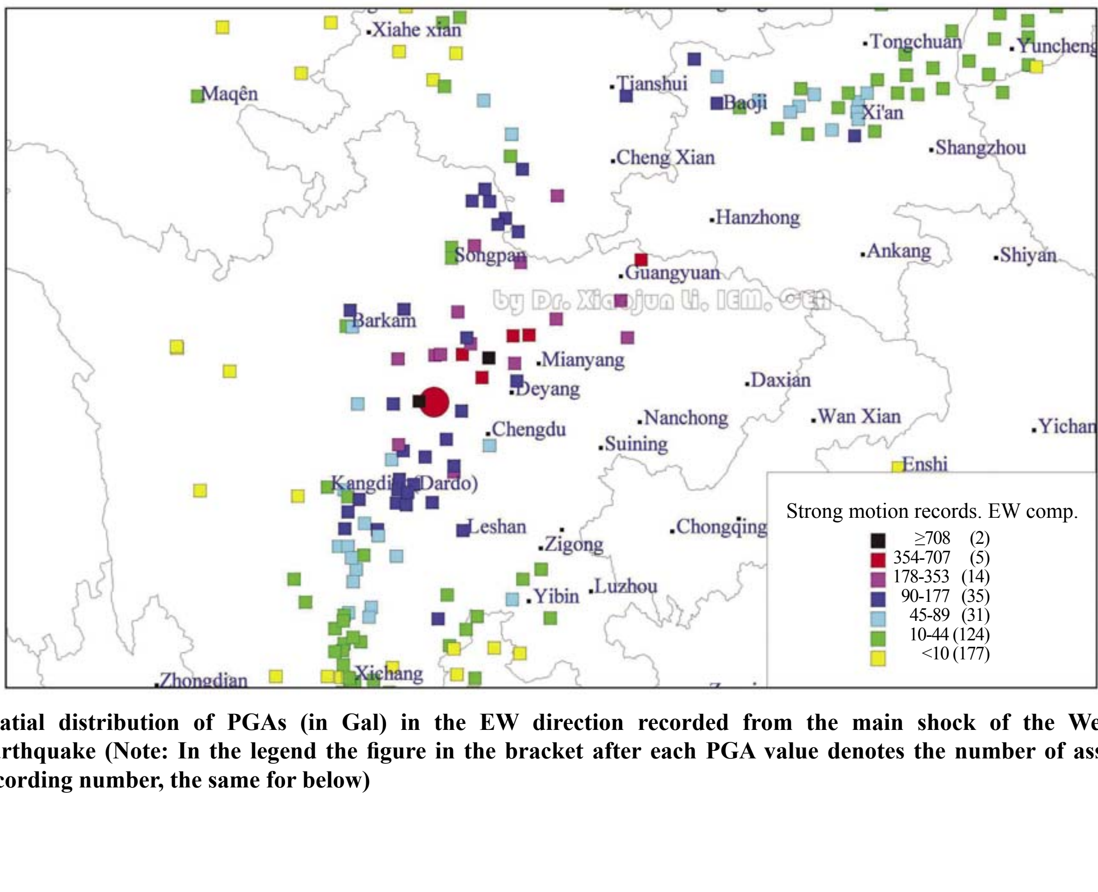

Fig. 12 Spatial distribution of PGAs (in Gal) in the EW direction recorded from the main shock of the Wenchuan Earthquake (Note: In the legend the figure in the bracket after each PGA value denotes the number of associated recording number, the same for below)

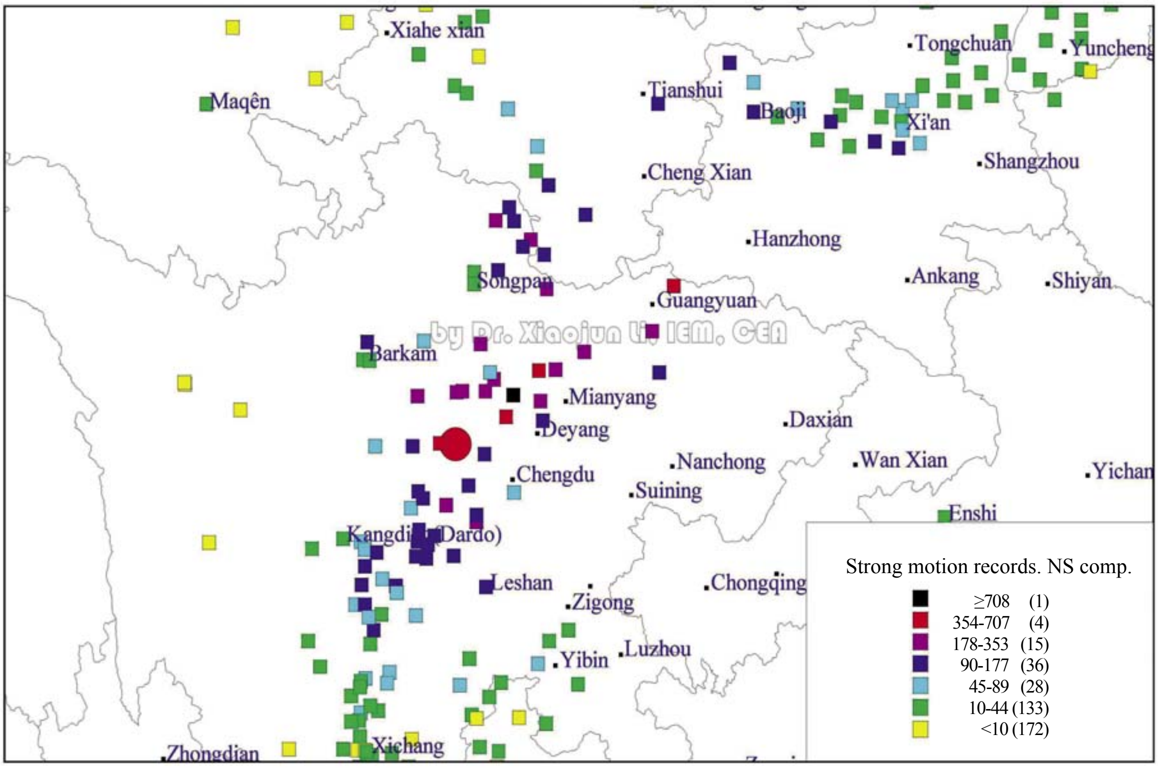

Fig. 13 Spatial distribution of PGAs in the NS direction recorded from the main shock of the Wenchuan Earthquake

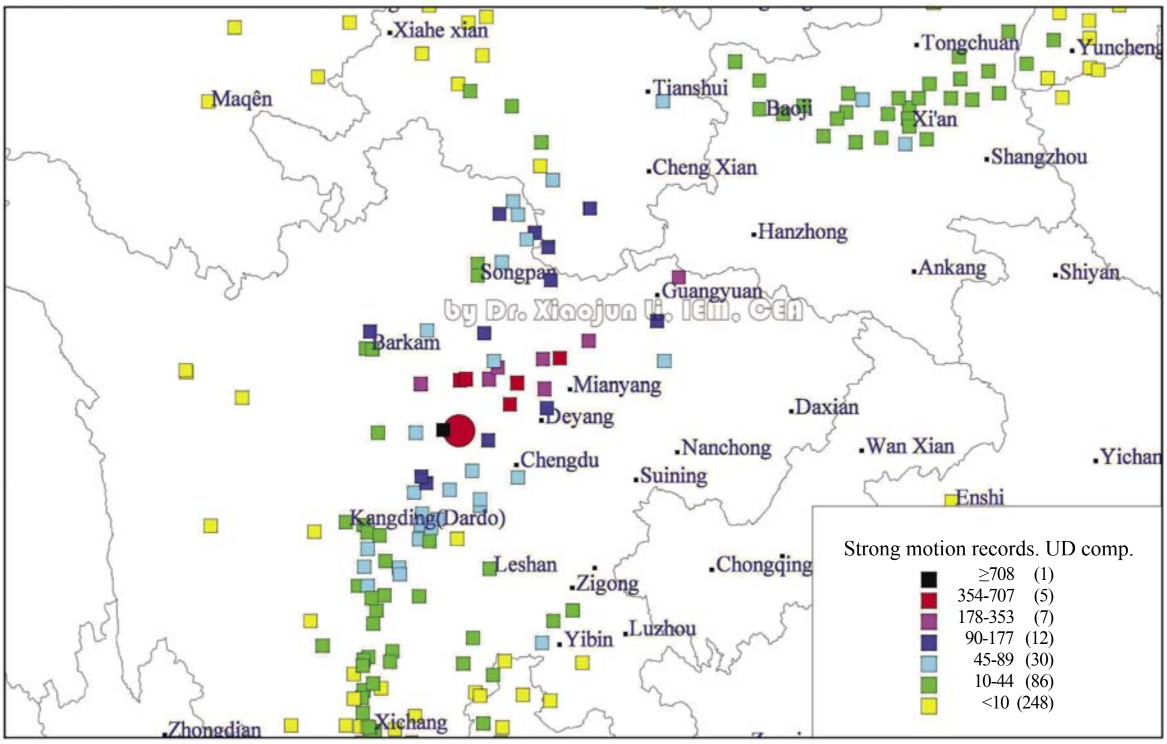

Fig. 14 Spatial distribution of PGAs in the vertical (UD) direction recorded from the main shock of the Wenchuan Earthquake

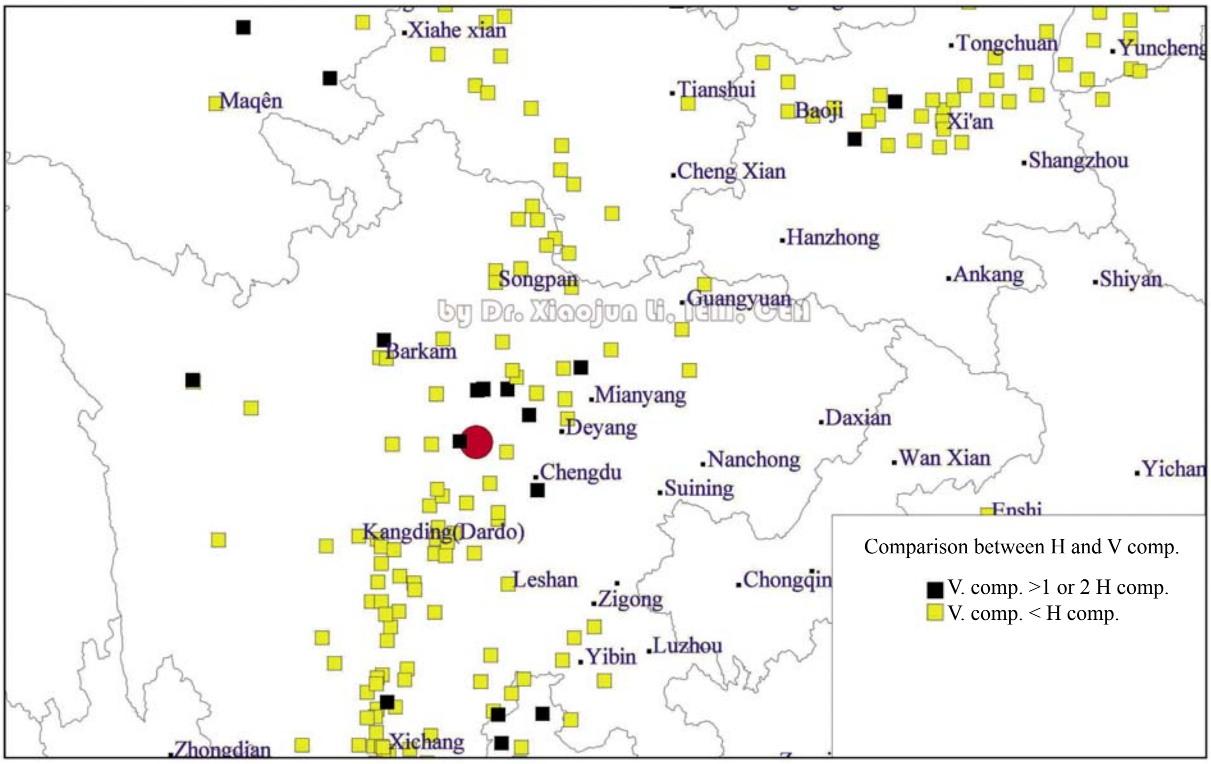

Fig. 15 Comparison of vertical PGAs with horizontal peak ground accelerations recorded from the main shock of the Wenchuan Earthquake

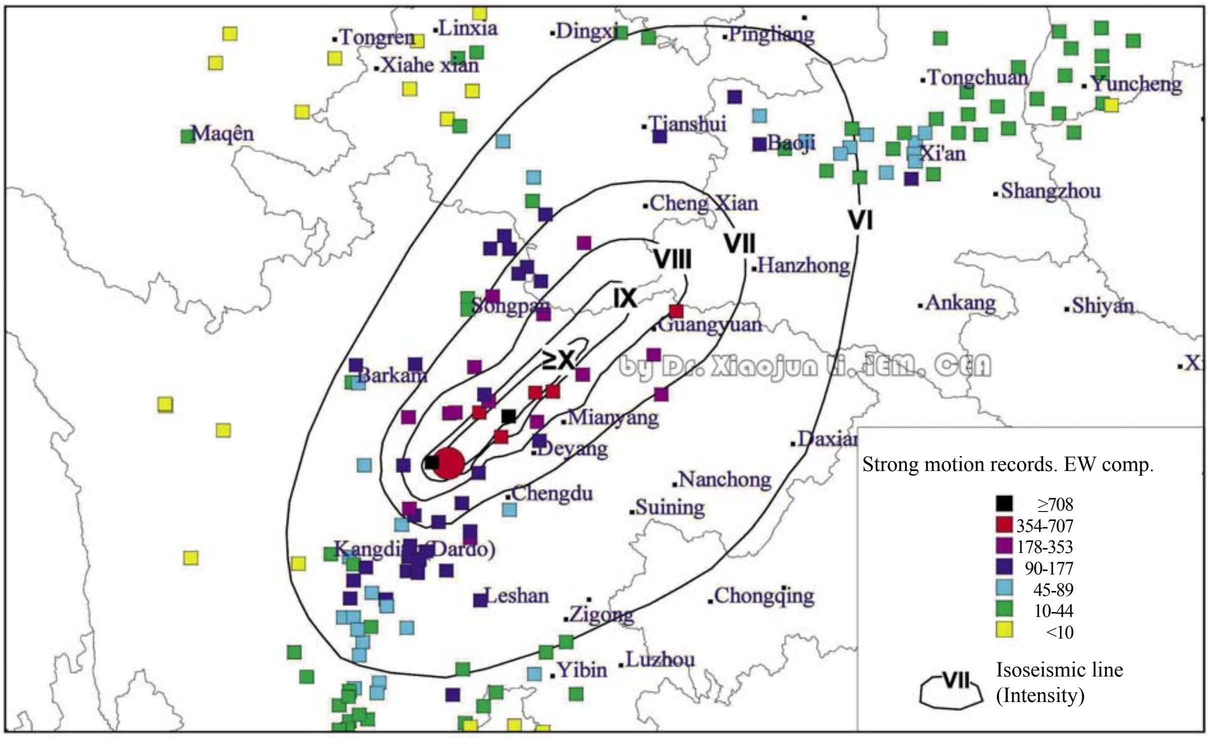

Fig. 16 Comparison of horizontal PGAs (in Gal) with seismic intensities from the main shock of the Wenchuan Earthquake

5 Concluding remarks

This paper introduces the National Strong Motion Observation Network System (NSMONS) of China, whose formal operation started just two months before the Wenchuan earthquake, and summarizes strong motion recordings obtained by the NSMONS from this devastating earthquake. The spatial distribution of the stations that recorded the main shock and the mobile stations that captured the aftershocks are described in detail. During the Wenchuan Earthquake, about 1,200 components of records were obtained from the main shock and over 20,000 components were obtained from the strong aftershocks.

A preliminary analysis of the spatial distribution of PGAs demonstrates that the directivity effect and the hanging wall effect in the near-fault ground motion as observed from past large earthquakes around the world also occurred in the Wenchuan earthquake. PGAs are relatively large in the fault rupture propagation direction, and also roughly larger on hanging wall. In the near-fault records, the PGA is generally larger in the EW direction than the NS direction. A comparative analysis of the horizontal and vertical components of the main shock records displays that the PGA is larger in the vertical direction than in one or two horizontal directions for some near-fault records.

More detailed analyses of the records from both the main shock and strong aftershocks measured from both the free field and structures are being conducted, it is expected that the results will provide critical and important information for future studies.

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The National Strong-Motion Observation Network System of China is managed by the National Strong Motion Observation Center and local strong motion observation centers. Experts from the strong motion observation group in the China Earthquake Administration are in charge of maintenance and operations, data collection, processing, storage and management, and providing Internet data services for the Network. The experts from the Seismological Bureaus of Provinces of Sichuan, Gansu, Shaanxi, etc., and the Institute of Engineering Mechanics made an effort to collect all the recorded data and process them after the main shock of the Wenchuan Earthquake. The authors of the present article are very grateful to the efforts by all the officers and experts who contributed to the success in obtaining the recorded data in the Wenchuan Earthquake.

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