

**IMPRESSIONS FROM A FIELD INVESTIGATION OF  
THE WENCHUAN, SICHUAN PROVINCE, EARTHQUAKE  
OF MAY 12, 2008**

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Field Investigation Team

**INTRODUCTION**

A team of earthquake researchers, sponsored by the Earthquake Engineering Research Institute (EERI) and the Geo-Engineering Earthquake Reconnaissance (GEER) Association, carried out a field investigation in conjunction with Chinese colleagues from August 4<sup>th</sup> to 10<sup>th</sup> to document scientific and engineering effects of the devastating earthquake (moment magnitude 7.9 according to the USGS) that occurred in Wenchuan County of Sichuan Province, China, on May 12, 2008. The EERI field investigation was conducted as part of the Learning from Earthquakes Program with funding from the National Science Foundation (NSF).

The EERI-GEER field investigation team was invited by Prof. Zifa Wang, Director of the Institute of Engineering Mechanics-China Earthquake Administration (IEM-CEA), to investigate the effects of the Wenchuan earthquake. During the short period of one week in the field, the EERI-GEER team could only get a small sample of the effects of the great earthquake. Prof. Junwu Dai of the IEM-CEA accompanied the team during the field investigation.

The research team, under the leadership of Dr. Marshall Lew of MACTEC Engineering and Consulting in Los Angeles, California, included experts in structural, lifelines, and geotechnical engineering as well as disaster response and recovery. In addition to Dr. Lew, EERI team members were David Friedman and Dennis Lau of Forell/Elsesser Engineers, Inc., and Laurie Johnson, an urban planning consultant, all of San Francisco, California; Prof. Tricia Wachtendorf of the Disaster Research Center at the University of Delaware in Newark; and Prof. Jian Zhao of the University of Wisconsin at Milwaukee. The GEER team consisted of Prof. David Frost of the Georgia Institute of Technology in Savannah, Prof. J. P. Bardet of the University of Southern California in Los Angeles, and Prof. Tong Qiu of Clarkson University in Potsdam, New York.

This paper presents observations made during the EERI-GEER field investigation in Sichuan Province as well as observations made by other investigators who have visited the earthquake-affected region. Information from other sources have also been incorporated.

**EARTHQUAKE SETTING**

The May 12, 2008 Great Wenchuan Earthquake is the worst earthquake to strike China since the magnitude 7.8 Tangshan event of July 27, 1976 that claimed an estimated 242,000

lives. The May 12 earthquake affected more than 100,000 square miles and about 30 million people. It caused the deaths of 69,226 people (as of August 21, 2008) with 17,923 missing, injured almost 375,000 others, caused almost 1.5 million to be relocated (Xinhua, 2008). The earthquake also caused destruction of more than 216,000 buildings in Sichuan Province, including approximately 6,900 school buildings, whose collapses buried thousands of students and teachers. The location of the May 12, 2008 earthquake and major aftershocks through May 28, 2008 are shown in Figure 1.

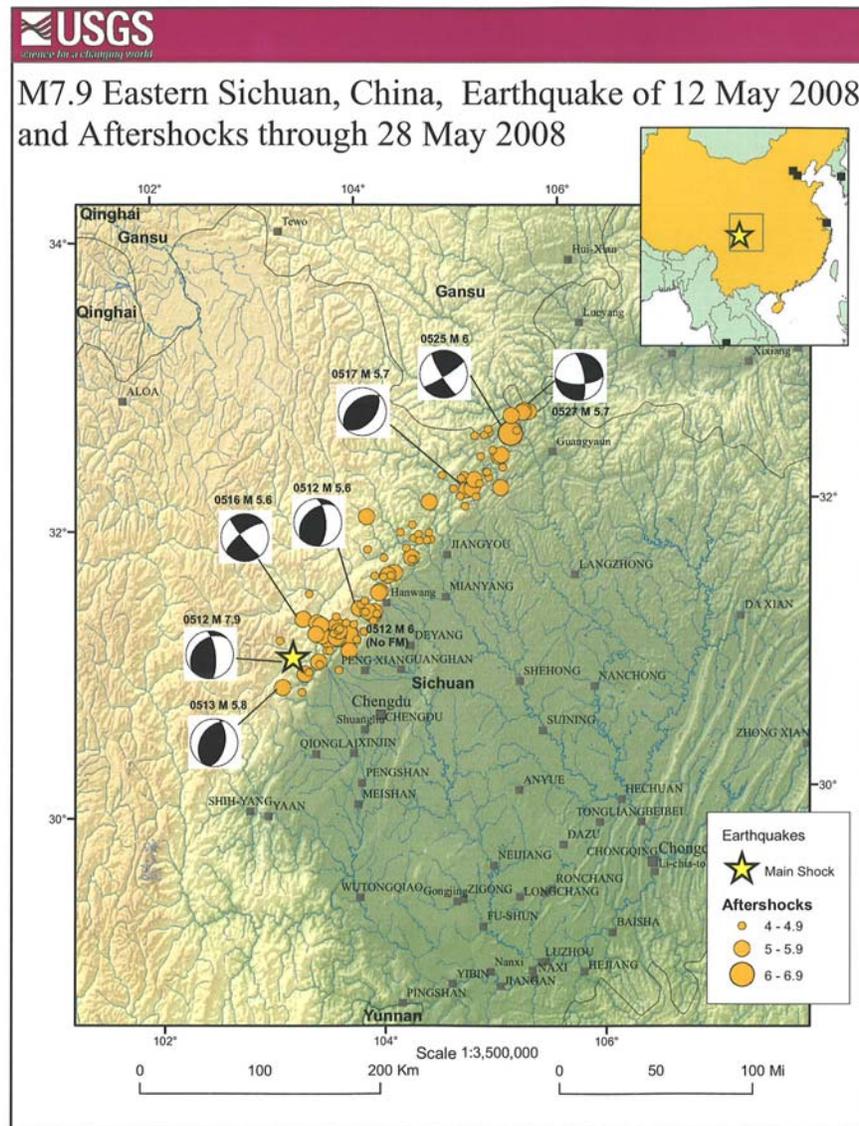


Fig.1 Locations of Wenchuan Earthquake May 12, 2008 Mainshock and Aftershocks through May 28, 2008 (United States Geological Survey, 2008)

The earthquake originated on the Longmenshan fault, a northeastern striking thrust fault that ruptured for almost 300 kilometers. The fault is the result of convergence of crust from the high Tibetan Plateau to the west, against the strong and stable crust block underlying the Sichuan

Basin and southwest China to the east. On a continental scale, the seismicity of central and eastern Asia is a result of northward convergence of the Indian plate against the Eurasian plate. This convergence of the two plates is broadly accommodated by uplift of the Asian highlands and by the motion of crustal material to the east away from the uplifted Tibetan Plateau. Thus India is moving northward pushing into central Asia and pushing Tibet eastward, overriding the Sichuan basin. The tectonic setting is shown in Figure 2. The geology of the Wenchuan earthquake area and the Longmenshan fault zone are shown in Figure 3. A cross section across the Longmenshan fault zone is shown in Figure 4.

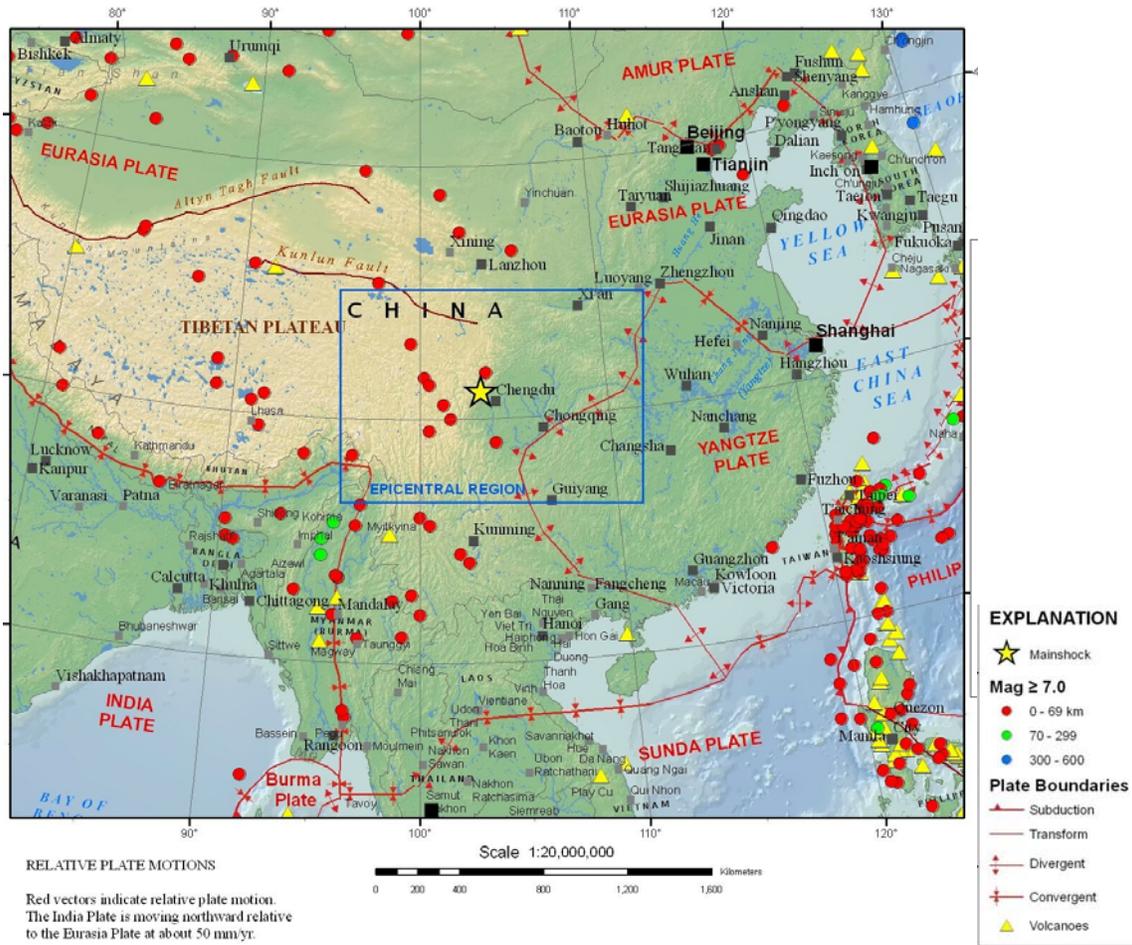


Fig. 2 Tectonic Setting of the Wenchuan Earthquake (United States Geological Survey, 2008)

Previous earthquakes have been experienced along the northwestern margin of the Sichuan Basin. On August 25, 1933, a magnitude 7.3 earthquake resulted in over 6,800 deaths with another 2,500 persons perishing later as a result of the failure of a “quake lake” dam caused by an earthquake-induced landslide. The Wenchuan earthquake occurred within the context of long-term uplift and eastward enlargement of the Tibetan plateau; the average recurrence interval of the Wenchuan earthquake has been estimated to be in the general range of 2,000 to 10,000 years by Burchfiel et al. (2008).

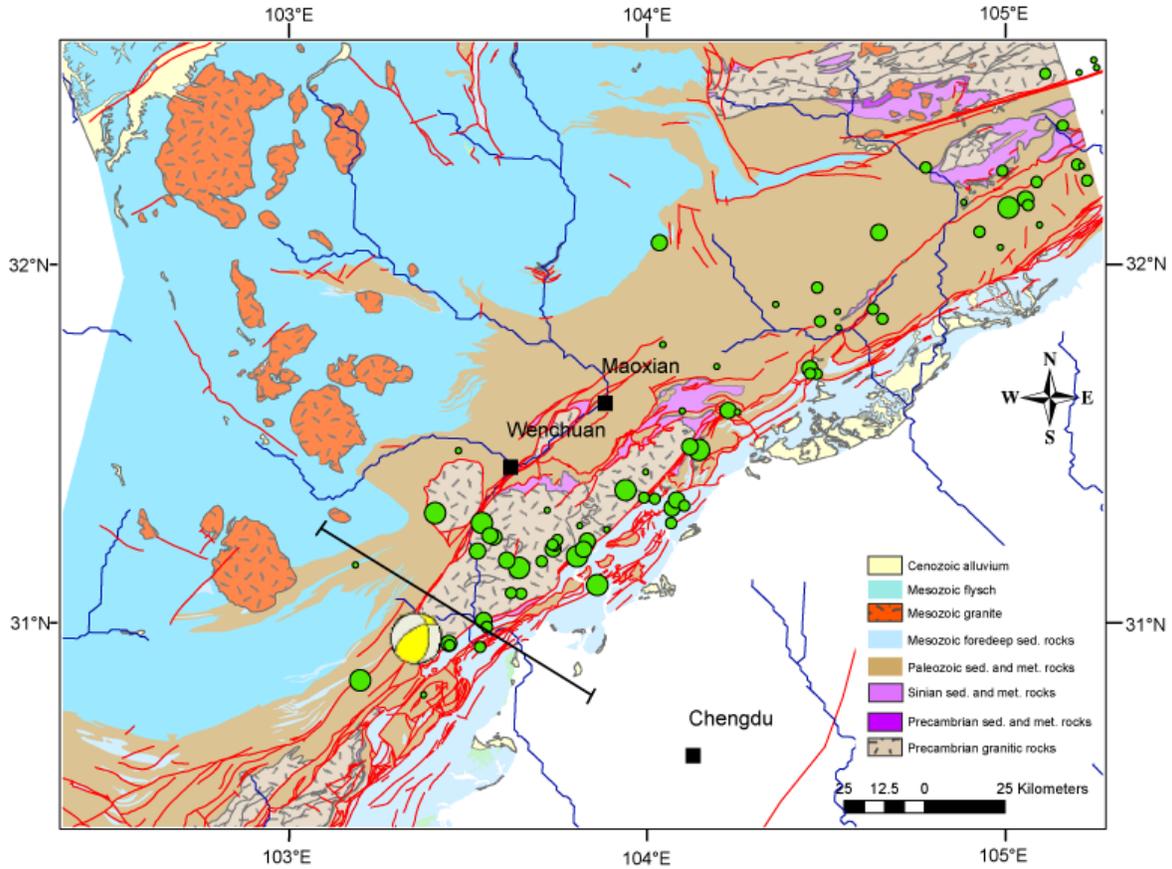


Fig. 3 Geologic Map of the Wenchuan Earthquake Area (Massachusetts Institute of Technology Department of Earth, Atmospheric, and Planetary Sciences, 2008)

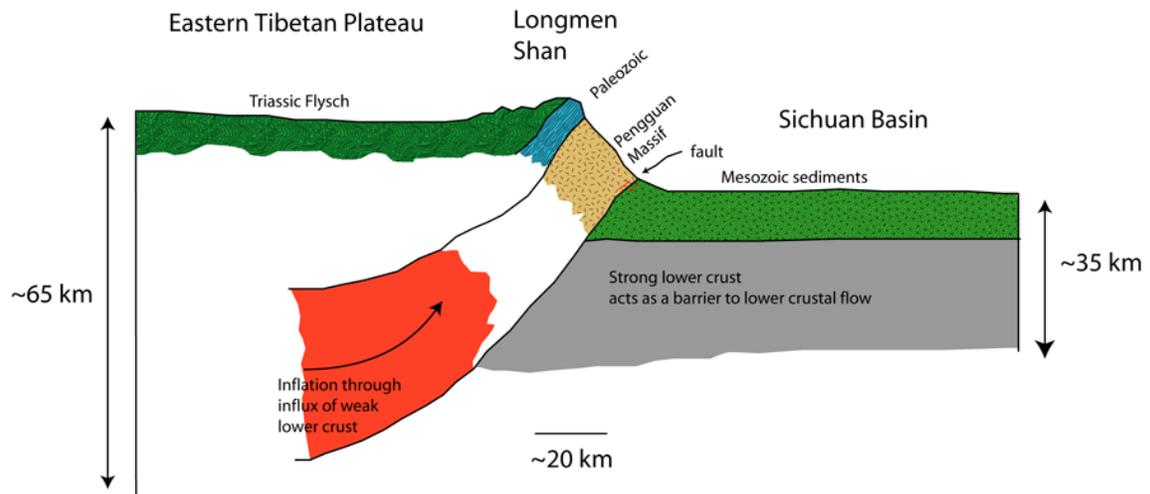


Fig. 4 Cross Section of Longmenshan Fault Zone (Massachusetts Institute of Technology Department of Earth, Atmospheric, and Planetary Sciences, 2008)

Because large earthquakes were rare before the May 12 earthquake, basic design levels in the Sichuan region were established at Intensity VII (Modified Mercalli Scale). School buildings were considered as Category C buildings, which is the same as for regular buildings.

### GROUND MOTIONS

Strong ground motion was measured at about 200 stations established by the China Earthquake Administration. The strong motion time histories have not yet been made available to the research community. Three recordings were shown to the EERI-GEER team during our China investigation. One record was obtained at a distance of 22 km from the epicenter and 1.0 km from the fault had a peak ground acceleration (PGA) of around 957 gal and a duration of nearly 60 seconds. In a recording made 88 km from the epicenter, and 1.0 km from the fault, the PGA was 802 gal and had a strong ground shaking duration of 90 seconds. At 150 km from the epicenter, and 75 km from the fault, a third recording gave a PGA of 550 gal with a strong shaking duration of 150 seconds.

Plots of the PGA contours developed by CEA are shown in Figures 5, 6, and 7 for the north-south, east-west, and vertical components.

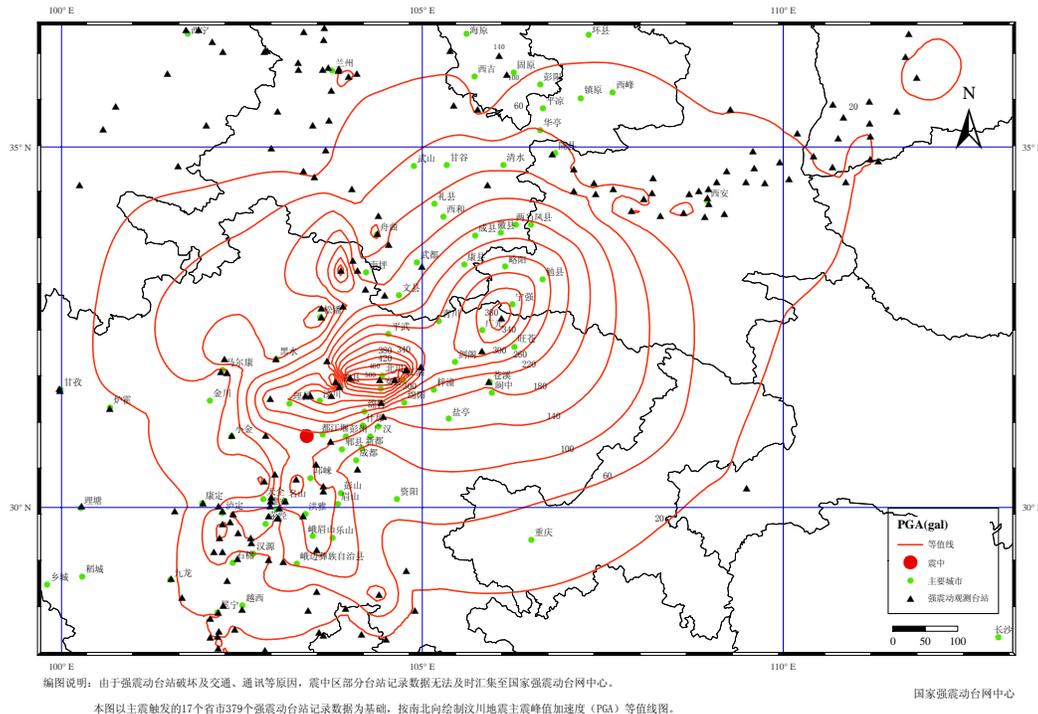


Fig. 5 Distribution of North-South Peak Ground Accelerations (Courtesy of the Institute of Engineering Mechanics-China Earthquake Administration)

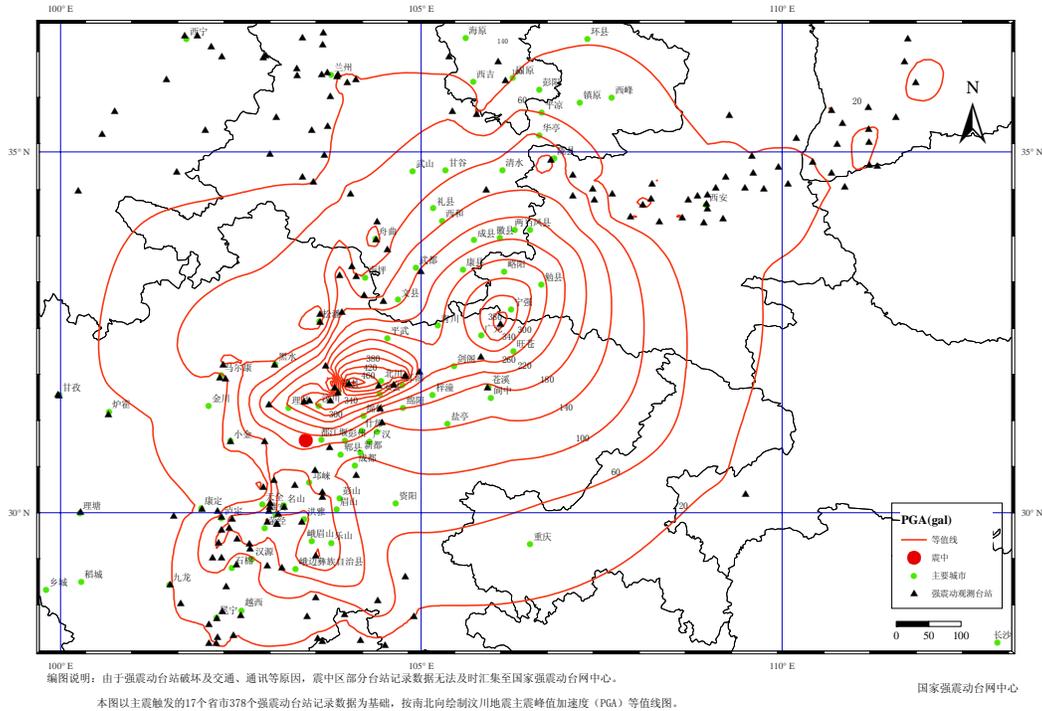


Fig. 6 Distribution of East-West Peak Ground Accelerations (Courtesy of the Institute of Engineering Mechanics-China Earthquake Administration)

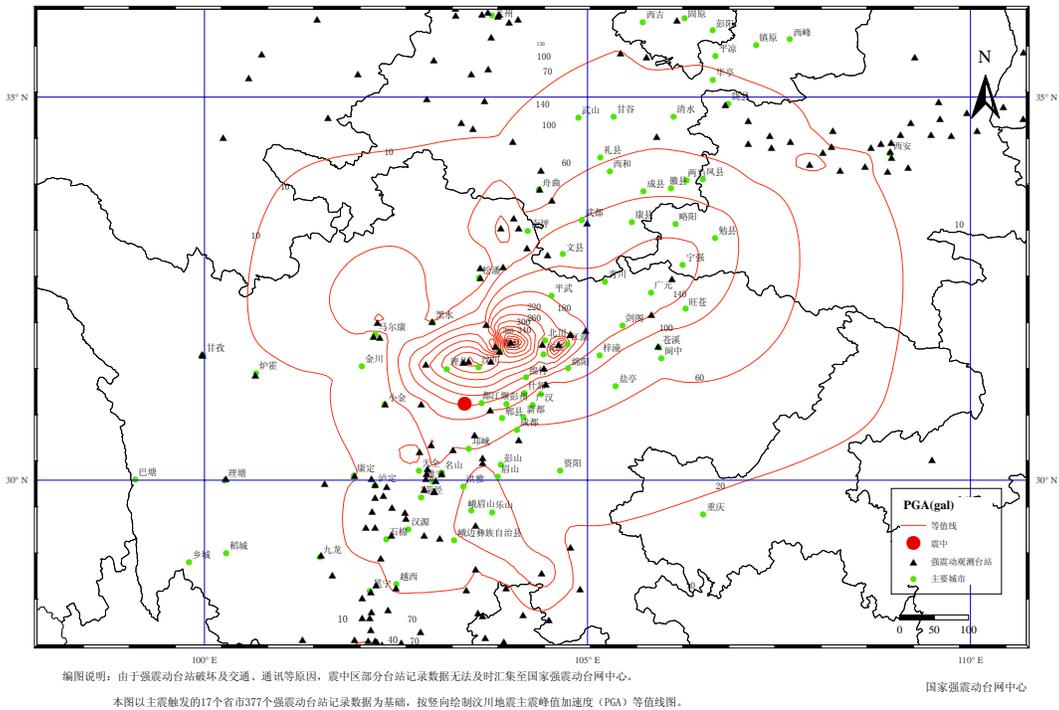


Fig. 7 Distribution of Vertical Peak Ground Accelerations (Courtesy of the Institute of Engineering Mechanics-China Earthquake Administration)

## GEOTECHNICAL OBSERVATIONS

The major geotechnical effects in the Wenchuan earthquake were: the numerous landslides triggered by the mainshock and aftershocks; and the complex fault rupture. Soil liquefaction was not a prominent feature of this earthquake as it was in previous events such as the 1999 Kocaeli, Turkey or Chi-Chi, Taiwan earthquakes.

### Landslides

The Longmenshan Mountains are prone to numerous landslides just due to the topography and steepness of the mountains under normal conditions. The earthquake is reported to have caused almost 10,000 landslides. Some 26 landslides are believed to have volumes exceeding 10 million cubic meters of material. Landslides and rockslides buried villages and towns resulted in numerous fatalities, with two landslides killing about 2,500 persons in the Beichuan area. Landslides near Beichuan also dammed the river and created the Tangjiashan Quake Lake, which was a threat to downstream towns and villages should the landslide mass be breached or overtopped; see Figure 8. The China People's Liberation Army deployed troops to cut channels through the slide to stop the rising water and reduce the risk of a catastrophic failure of the landslide dam and resulting flooding downstream.

Tangjiashan Quake Lake near Beichuan (source: National Survey Bureau)



Fig. 8 Tangjiashan Quake Lake near Beichuan (source: National Survey Bureau)

Figure 9 shows the foot of a landslide that originated from the top of the mountains and buried a village of about 70 persons near Yinchanggou. Figure 10 shows massive rockslides near Shenxigou. Figure 11 shows a typical large rock from a rockslide on a road into the Longmenshan Mountains. Figure 12 shows rockslide damage to a resort hotel in Shenxigou.



Fig. 9 Landslide near Yinchanggou



Fig. 10 Massive rockslides near Shenxigou



Fig. 11 Large rocks on mountain road from rockslide



Fig. 12 Resort hotel damaged by rockslide in Shenxigou

Landslides and rockslides in the Longmenshan Mountains are quite common even without seismic activity due to the steepness of the mountains and heavy rains that occur during the summer months. With continuing aftershock activity and frequent rains, landslides and rockslides are continuing to occur on the mountain roads, often isolating communities and

cutting off vital services and supplies. The continuing landslides and rockslides will also make the recovery more difficult because access to the mountain towns and villages will be hampered. The access to move heavy equipment and material into the more remote areas by road is severely limited by the current conditions.

### Fault Rupture

Fault rupture was prominent in the Longmenshan Mountains as the rupture was about 270 km in length. The fault rupture cut through towns, villages, and roads, causing much damage and havoc in the region. The fault movement was predominantly a reverse thrust in southwestern portion of the rupture, becoming more strike-slip towards the northeast. Fault rupture at Gaoyuan Village, north of Dujiangyan, is shown in Figures 13 and 14; Figure 13 shows about 1 meter of vertical displacement as evident in the concrete roadway and Figure 14 shows the effect of the fault rupture on a brick building nearby.



Fig. 13 Surface fault rupture with 2 meter vertical displacement at Gaoyuan Village



Fig. 14 Surface rupture under brick building at Gaoyuan Village



Fig. 15 Surface fault rupture contributed to failure of Gaoyuan Bridge; north abutment is to the left

The Gaoyuan Bridge, near Gaoyuan Village, is a two lane traffic bridge with north and south abutments and three bents over a river (Figure 15). The bridge suffered the collapse of the second simply supported span (from the north). The thrust fault rupture went through the north (left) abutment of the bridge and caused the approach slab to be thrust over the first span of the bridge. In addition, part of the west wing wall of the abutment collapsed along with some of the fill in the abutment. This apparently caused the passive resistance of the north abutment to be reduced. There was also a failure of the south abutment which showed evidence of yield of the abutment and movement inwards towards the north (as the passive resistance at the north abutment was reduced). This movement of the abutment appears to have caused the spans of the bridge to be pushed northward. The movement was large enough that the second span became unseated at the center bent and fell to the ground below. The other side of the span hit the first bent and caused some bending of the piers.

The fault rupture was reported by CEA to be as much as 5 meters of vertical fault displacement with about 4.5 meters of horizontal fault displacement (Fig. 16). Fault rupture caused collapse of many structures that were constructed over the fault traces; as many of the buildings were of brick construction, total collapse was very common (Fig. 17).



Fig. 16 Surface fault rupture with 5 meter vertical displacement at Shenxigou



Fig. 17 Surface rupture causing total collapse of buildings at Xiaoyudong

Fault rupture also caused damage and collapse of several bridges, including the Xiaoyudong Bridge as shown in Figure 18 and the Baihua Bridge near Yingxiu as shown in Figure 19.



Fig. 18 Surface fault rupture caused damage and collapse of Xiaoyudong Bridge



Fig. 19 Collapse and severe damage of Baihua Bridge at Yingxiu caused by fault rupture

## STRUCTURAL OBSERVATIONS

Brick masonry is the predominant type of construction in Sichuan Province. The two primary building types observed were unreinforced brick bearing wall buildings, particularly in the rural and mountainous areas, and restrained unreinforced brick infill shear wall buildings (also referred to as confined masonry buildings) used in mostly dense urban areas, such as Dujiangyan and Chengdu. Concrete moment frame buildings were present, but were not as numerous as brick buildings in the regions most strongly affected by the earthquake; there are numerous such buildings in Chengdu that were less affected by the earthquake. There were a few wood buildings, but primarily limited to distant rural areas.

The unreinforced brick bearing wall buildings were typically some two to four stories in height with precast hollow core plank floors and roofs which bear on transverse brick walls and longitudinal perimeter walls which may have many openings. As would be expected, this type of building did not perform well in the earthquake as there were many catastrophic collapses as shown in Figure 20.



Fig. 20 Unreinforced brick bearing wall building



Fig. 21 Restrained brick bearing wall building



Fig. 22 Steel reinforcing in brick bearing wall building



Fig. 23 Steel reinforcing and pebble aggregate used in column of brick bearing wall building

Restrained brick bearing wall buildings were typically long rectangular buildings with heights from three to seven stories with precast hollow core plank floors and roofs which bear on reinforced concrete beams spanning to reinforced concrete columns (see Figure 21); there is also a reinforced concrete perimeter ring beam. It was observed that beam stirrups and column ties were typically No. 3 undeformed bars with a fairly wide spacing of 12 inches or greater (Figures 22 and 23). There was no positive connection of floor planks to the bearing beams or perimeter ring beam except by bearing and friction contact. These buildings typically appeared to be stronger in the longitudinal direction than in the transverse direction because the ground floors typically had open storefronts. This type of building had performance that varied from what could be considered “life safe” performance (although there was significant and perhaps unreparable damage) to partial and total collapse. Issues that may have contributed to poor performance include: poor ductile detailing, insufficient concrete cover over reinforcing steel, improper size and shape of aggregate in concrete, quality of cement, and poor quality of brick.

Although not as common in the Longmenshan Mountain region, concrete moment frame buildings appeared to perform much better than the adjacent brick buildings; however, we did not have the opportunity to observe many of these buildings. Although it was observed that some concrete moment frame buildings suffered from weak column/strong beam behavior, there were some buildings that performed remarkably well, even when in close proximity to the fault rupture, such as the newer building constructed in 2007 at the Bailu Middle School and another school building at the middle school in Tongji (see Figures 24 and 25).



Figure 24 Xuankou Middle School building in Bailu with fault rupture in foreground



Figure 25 Tongji Middle School building

It appeared that many of the bridges in the Longmenshan region have bridge spans that are simply supported at the ends, such as the Gaoyuan Bridge shown in Figure 15. A single span of one of the approaches to the tall Minjiang Bridge over the Zipingpu Reservoir became unseated and fell into the lake as shown in Figure 26. There were numerous other reports of bridges having simply supported spans becoming unseated and collapsing. New replacement bridges will need to consider higher seismic input as well as larger displacements. Existing bridges will need to be retrofitted to prevent unseating in future earthquakes and retrofit strategies used in California and the United States may be needed to prevent unseating.

Reports of damage at several bridges indicate that the lateral design for earthquake forces of bridges may not be sufficient given the ground motions of this earthquake. Some bridges had damaged shear keys at the abutments and bent caps when the strongest ground motions were in the transverse direction. Also, the Baihua Bridge had damage to the transverse beams between the piers as well as flexural distress near the base of some of the bent piers.



Fig. 26 Minjiang Bridge crossing over Zipingpu reservoir with one missing span

### **EMERGENCY RESPONSE AND RECOVERY**

The response to the massive earthquake was quick and decisive. Although no country is prepared for a natural disaster of this scale, the response was quickly coordinated by the central China government who mobilized 130,000 soldiers of the People's Liberation Army (PLA) to provide search and rescue, restore access, and maintain order. Other China provinces and major cities sent personnel, equipment and resources to supplement the PLA and local forces. In addition, many private individuals and groups from all over China went to Sichuan Province to offer aid and support. Foreign aid and personnel were also accepted by China, unlike during the 1976 Tangshan earthquake. Undoubtedly there was some confusion on coordination and overlapping of responsibilities, however, the response was considered to be well done by many.

China's 50-member State Council, chaired by Premier Wen Jiabao, quickly established an Earthquake Rescue and Relief Headquarters that has provided most of the overarching principles and priorities for restoring the livelihoods and physical environment of the 51 counties (cities and districts) in the 132,596 square kilometers, disaster-affected region and its 20 million

residents. Three-month targets were established, heavily emphasizing the needs of survivors, as well as an ambitious and comprehensive set of three-year goals to ensure that every family has a house, every household has employment, every person has social and medical care, and that the infrastructure, economy and environment are all improved.

The State Council also took swift legislative action to establish a multi-governmental management framework for the recovery effort. The “Wenchuan Earthquake Disaster Recovery and Reconstruction Act” (passed into law on June 4, 2008) provides the legal basis for various departments and government entities both in and out of the quake-hit region to assist with recovery and reconstruction. The act specifies guiding principles for damage assessment, temporary housing, reconstruction planning, financing, implementation, and management.

A central element of China’s post-disaster management framework is a pairing of affected with unaffected regions to help provide the resources and funds for recovery and reconstruction. The disaster-impacted areas of Sichuan, Gansu and Shaanxi provinces were divided into 24 districts and matched with 24 localities across China. For example, the town of Dujiangyan (within the administrative boundaries of the city of Chengdu) is sponsored by Shanghai. Yingxiu’s sponsor is Guangzhou; Pengzhou’s is Fujian, Mianzhu’s is Jiangsu; and, Anxian’s is Beijing. Each sponsoring locality has been given work tasks, funding and resource assignments as well as timeframes for their completion. Their contributions include provision of staff and human resources, “in kind” support from planning institutes and other agencies within the sponsor region, provision of temporary housing units, and donations and financial support. Banners acknowledging the work of sponsor locations are visible across the disaster-affected region.

As of August 25, the State Council reports that nearly 1.5 million disaster-affected people have been relocated; about 180,000 have been organized to work outside the disaster zone and about 678,000 people have found jobs in their hometowns (Xinhua, 2008). About 92% of the 139,000 damaged business outlet had been reopened; almost 663,000 temporary houses have been constructed and another 2,500 were being installed, and nearly all of the 53,295 km of roads damaged by the earthquake had been restored.

Sponsoring localities have been major suppliers of the temporary housing, and planning institutes from sponsoring localities have volunteered to plan the temporary housing encampments, following the design principles laid out by the central government in the Wenchuan Earthquake Disaster Recovery and Reconstruction Act. Figure 27 shows one temporary shelter in northeastern Dujiangyan. The processes for determining the number of units needed and the site selections are unclear. Local officials described site selections being determined based upon the availability of water, electricity, and access, but less certain about environmental and hazard considerations. Some very large encampments were observed in river floodplains and at the base of steep slopes. Many of the temporary housing encampments include temporary school facilities, such as the elementary school in Yingxiu shown in Figure 28.



Figure 27 Temporary housing in Dujiangyan



Figure 28 Temporary elementary school in Yingxiu

Within a week after the earthquake, the National Development and Reform Commission (NDRC) [China's lead agency for urban plan development], financing and approval, the Ministry of Housing and Urban-rural Development and the disaster-affected provinces established a special team on reconstruction planning to act on the planning principles outlined in the Wenchuan Earthquake Disaster Recovery and Reconstruction Act. Since its founding, the team made dozens of trips to the disaster-affected region collecting the input of local officials and getting input from the disaster-affected residents. A general reconstruction plan, as well as ten specific plans – covering urban systems, rural development, urban-rural housing, infrastructure, public service facilities, productivity distribution and industrial restructuring, market service system, disaster prevention and mitigation, ecological rehabilitation, land utilization, were developed for each of the three, disaster-affected provinces. These, in turn, were incorporated into a comprehensive reconstruction plan that released for public review on August 12. The “State Overall Planning for Post-Wenchuan Earthquake Restoration and Reconstruction” groups the 51 disaster-affected counties into 3 categories – areas suitable for reconstruction, areas suitable for appropriate reconstruction, and ecological reconstruction areas (with future growth limitations) – and sets the rebuilding and funding guidelines for each. The NDRC is currently soliciting feedback on the plan holding outreach workshops with international experts, and setting up special websites for comments at the NDRC, People's Net and China Net.

The recovery effort will be a great challenge, even with China's strong economy. According to Watts (2008), the reconstruction is estimated to have a cost of about 1 trillion yuan (US\$147 billion). This amount is equivalent to one-fifth of the entire tax revenue of China for a single year. This will include providing new homes for 3.9 million refugees, replacing schools and creating jobs for 1 million people.

The infrastructure of the mountains will be a challenge to rebuild based on the geologic and climatic conditions, in addition to the continuing seismic activity. Some massive relocation of the population in the mountains may be required to remove people from the hazards and risks associated with the region. One of the most pressing challenges is in ensuring higher seismic standards and construction quality in the rebuilding. The reconstruction plan calls for higher earthquake-resistance levels of infrastructure construction in the quake-hit regions, especially for schools and hospitals. In rural areas, the reconstruction planning recommends that technicians help advise residents to rebuild safely; but, many villagers are moving ahead and reconstructing

with a variety of traditional and recycled materials, particularly reclaimed bricks. In urban areas, like Dujiangyan, damage assessments are complete. Unsafe buildings have been demolished and buildings that are moderately damaged have had all interior contents, furnishings, doors, windows removed and await repair. But, financing for the repairs has yet to be determined (Iin, 2008). The repairs may be too costly for government to fund alone and too costly for individuals to finance.

### ACKNOWLEDGEMENTS

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