A COMPREHENSIVE ANALYSIS OF THE DEVASTATING WENCHUAN EARTHQUAKE OF MAY 12TH 2008

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ABSTRACT :

The Wenchuan earthquake of May 12th 2008 had a magnitude 8.0 on the Richter scale, focal depth of 14 km according to the Chinese Earthquake Administration (CEA). Maximum intensity XI was assigned in the Wenchuan area according to United States Geological Survey (USGS). The powerful earthquake was felt all across China and in parts of neighboring countries such as Thailand, Vietnam and Bangladesh and caused the failure of buildings, bridges and infrastructures in general and severe damage to roads and industrial facilities. Severe damage was caused by landslides which blocked rivers and damaged roads and highways.

The Wenchuan earthquake is one of the strongest in China since three decades. According to the official reports of the Chinese Bureau of Civil Administration statistics, 69,197 fatalities have been confirmed under the debris of collapsed structures as of July 8th, 18,379 were still missing and 374,176 people have been injured.

The aim of this paper is to give an overview of the devastating earthquake. The tectonic structure in the Southwest China is examined, the historical data in the last 100 years are reviewed and the aftershocks characteristics are discussed. A brief comparison between 2008 Wenchuan and 1976 Tangshan earthquake is presented followed by a survey of earthquake damages to civil structures in the affected areas. Lessons to be learnt and have been learnt from the event are proposed in this paper.

KEYWORDS: Wenchuan earthquake, tectonic structure, aftershocks, Tangshan Earthquake, structures damage, historical earthquake.

1. INTRODUCTION

On Monday 12th May 2008, the largest intensity earthquake, magnitude 8.0 on the Richter scale, struck in Eastern Sichuan Province of western China with its epicenter in Wenchuan county at 06:28 UTC (2:28 pm local time), and resulted in the worst natural disaster to impact China in terms of loss of life since the 1976 Tangshan earthquake which killed more than a quarter of a million people. The epicenter of the quake was located 31.0 degrees north latitude and 103.4 degrees east longitude, with a fixed focal depth of 14 km[4] according to the State Seismological Bureau and Chinese Earthquake Administration CEA.

The powerful earthquake was felt all across China and beyond and destroyed numerous communities. Highways, bridges, railways and tunnels into Wenchuan, as well as many other facilities throughout Sichuan, were seriously damaged in the initial shake and its constant aftershocks. Power equipments were destroyed in 244 towns leaving millions people without electricity and, at times, half of Sichuan's mobile communication inoperable[3]. Dams, irrigation canals, other water facilities were also damaged, as well as buildings, including school, hospitals and industrial plants. Severe damage was caused by landslides which dammed rivers and flooded lands upstream. The economic losses remains uncertain but it could reach 400 to 500 billion Yuan[3].

The most immediate concerns after such a disaster are human casualties, injury, and property destruction. As of July 17th, the death toll of China powerful earthquake stood at 69,197 according to the State Council Information Office. This figure will may continue to rise as 18,237 people remain missing, the number of injured stood at

374,176, showing no change since July 2[13]. The majority of casualties occurred in Sichuan Province with at least 15941 fatalities in Wenchuan, 8,605in Beichuan and around 11,098 in Mianzhu city. Qinchuan, Guanyan, Maoxian and Chengdu were also hard hit in terms of fatalities with more than 4,000 reported in each region and around 5,900 deaths have been reported from Shifang and 3,000 people from Dujiangyan. Outside of Sichuan province, Gansu and Shaanxi sustained 365 and 121 fatalities respectively and a small number of 16 fatalities have been reported from Chongqing, Henan, Hubei and Yunnan. Sadly, Some 4,000 children have now been made orphans and millions homeless as a result of the earthquake according to Sichuan provincial civil affairs department[13] and China Bureau of Civil Administration and State Disaster Relief Commission[3].

2. TECTONIC SUMMARY AND HISTORICAL EARTHQUAKE DATA OF SOUTHWEST CHINA

The tectonic structure in the Southwest China earthquake-prone region is very complex and it is much more complicated than the North China region and still only moderately understood. There are a few main faults in this region as shown in figure 1, among them the Longmenshan fault, Mabian fault and Xianshuihe fault[5]. The Sichuan earthquake occurred as the result of motion on a northeast striking reverse fault or thrust fault on the northwestern margin of the Sichuan Basin[14]. The epicenter located in the mountains of the Eastern Margin of Qing-Tibet Plateau at the northwest margin of the Sichuan Basin[1] as shown in figure 2. The earthquake is caused by the collision between two tectonics plates, the Indian plate and the Eurasian plate. China stands on the Eurasian Plate, with the Indian Plate at its south the Indian Plate is driven deeply into the Eurasian Plate at a rate of 5 cm/year. The Qinghai-Tibet Plateau, the highest and widest in the world, is where these two plates overlap.

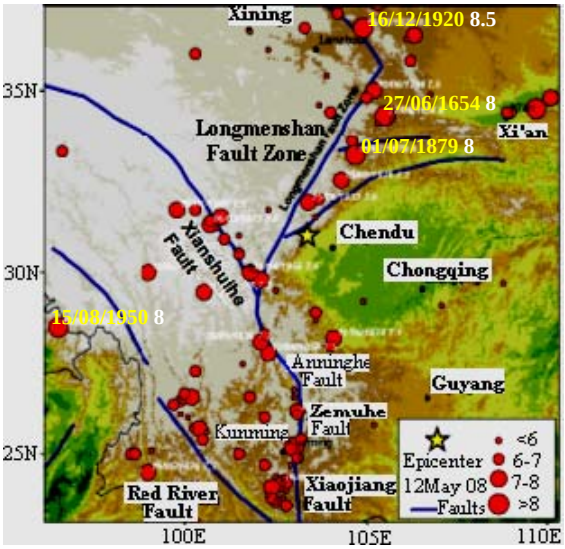


Figure 1 Seismicity and faulting in the eastern Tibetan plateau region, magnitudes 7.0 and greater labeled, (British Geological Survey)[1].

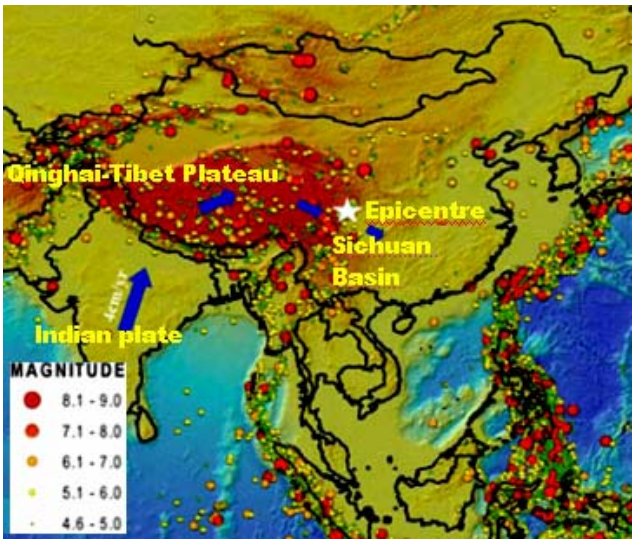


Figure 2 Map showing the location of the 2008 Sichuan earthquake and the northerly motion of India and the resulting easterly motion of Tibet[2].

Wenchuan, a small county in west Sichuan, is located in Longmen Mountain area. This time, the Indian plate simply squeezed northeastward against the Eurasian plate resulting in a continuous accumulation of a massive amount of energy. The force was made even greater because it hit the Longmen Mountain fault, causing it to dislocate and rupture. The blue arrows in figure 2 show the northerly motion of India and the resulting easterly motion of Tibet and the size of the arrows indicates the relative speed of plate motion.

In the last 100 years, more than 14 big earthquakes of a magnitude greater than 5 happened in Longmen Mountain. Among these big earthquakes, thousands of small tremors have shaken this area almost every day. Table 1 presents the destructive earthquakes within the past century centered within 300 km of the May 12, 2008 earthquake according to Sichuan Seismic Data Assembly; figure 3 shows the epicentre distribution of last 100 years events in Southwest China according to CEA.

Table 1 Destructive earthquakes within the past century centered close to Sichuan Province: Ms>=6.0 (Sichuan Seismic Data Assembly)

Date	North Latitude	East longitude	Magnitude	Region
2001.02.23	2921	10104	6.0	Yajiang
1989.09.22	3133	10223	6.6	Xiaojin Suoluo
1989.04.16	2956	09915	6.7	Batang Bachong
1982.06.16	3150	09951	6.0	Ganzi Zake
1981.01.24	3100	10110	6.9	Daofu Goupu
1976.11.07	2729	10106	6.7	Yanyuan, Ninglang
1976.08.16	3242	10406	7.2	Songpan Pingwu
1975.01.15	2926	10148	6.2	Kangting nine dragons
1973.02.06	31.5	100.4	7.9	Luhuo
1955.09.23	26.6	101.8	6.75	Huili Yu
1955.04.14	30.0	101.8	7.5	Kangting Zheduo Tang
1935.12.18	28.7	103.2	6.0	Mabian
1933.08.25	32.0	103.7	7.5	Diexi

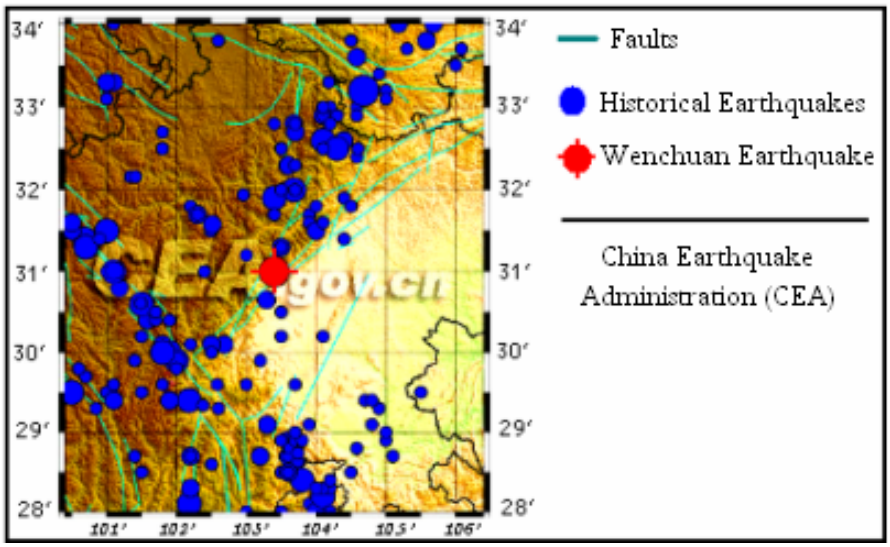


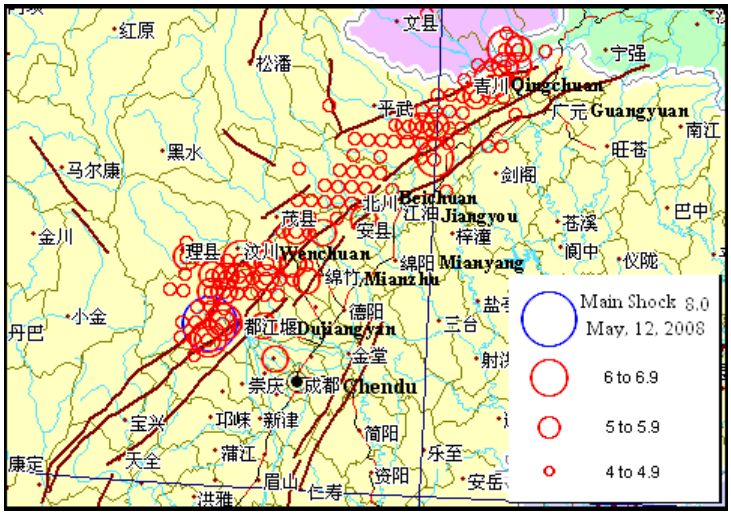
Figure 3 Epicentre distributions of events in Southwest China in the last 100 years, (CEA).

3. AFTERSHOCK CHARACTERISTICS

Although no distinct fore shocks occurred prior to the M_s 8.0 Wenchuan earthquake, there were a lot of aftershocks of high intensity after the earthquake. These aftershocks were distributed in a wide area. According to the China National Seismological Network, Since the main shock occurrence and until July 25, 241 aftershocks of magnitude larger than Ms 4.0 have been recorded, among them 205 with magnitude Ms4.0~4.9, 30 aftershocks with magnitude Ms5.0~5.9, and 6 aftershocks larger than Ms6.0 magnitude. The strongest Ms6.4 aftershock was felt in many parts of the province, including Sichuan's capital Chengdu[4]. The network has located the epicenter of the Ms6.4 tremor at 32.6 degrees north latitude and 105.4 degrees east longitude in Qingchuan county of Guangyuan City, which sits on the northeastern border of Sichuan Province and neighbors Gansu and Shaanxi provinces in northwest China[15].

The aftershocks are distributed along an approx. 300 km long North-East direction as shown in figure 4. As the main shock epicenter is located at the South-West end of the aftershock distribution, the main shock rupture propagated towards the North-East. Figure 5 represents the aftershocks statistical chart according to the Chinese

Earthquake Administration. The regional seismicity over the last 2 years before the main shock does not show any significant earthquake with 2 events of magnitude lowers than 5.2 [6].



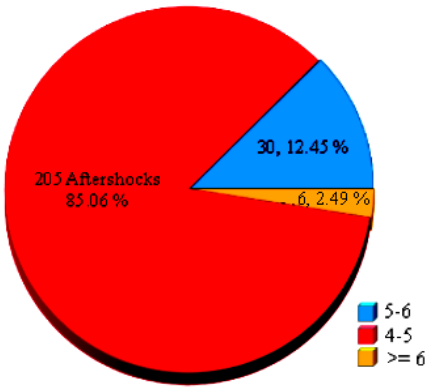


Figure 4 Aftershocks distribution, magnitude => 4.0 (CEA).

Figure 5 Aftershocks statistical chart (CEA).

4. WENCHUAN EARTHQUAKE COMPARED TO TANGSHAN EARTHQUAKE

The strength of Wenchuan earthquake is being compared to the destructive force of the Tangshan earthquake in 1976. Wenchuan earthquake measuring 8.0 on the Richter scale jolted Wenchuan County in northwest part of Sichuan at 2:28 pm on Monday. It has claimed more than 69,186 lives as of June 29th 2008. The tremor lasted two to three minutes, longer than the Tangshan quake. The Tangshan earthquake in the northern Hebei Province in 1976, with 7.6 magnitude, occurred at 3:42 a.m. on July 28, 1976. The earthquake, the deadliest in the twentieth century, leveled the medium-sized industrial city of Tangshan and claimed 242,000 lives.

The Wenchuan earthquake, with its frequent aftershocks, is simply stunning in its power and scale, especially when it is compared with Tangshan earthquake. And comparing the source strength and extent of the fault movement in between the two quakes, Wenchuan's was more than triple that of Tangshan. The Tangshan earthquake has caused more casualties as it took place in the night and the epicenter is directly beneath big cities. But unlike the Tangshan earthquake, the quake in Wenchuan has resulted in massive geological disasters as it occurs in a mountainous area rupturing the mountains and causing extensive landslides.

The Tangshan Earthquake was initiated at a shallow depth 11 km below the city; with the fault rupture of approximate total length of 100 km, while the focal depth of Wenchuan earthquake was 14 km below a mountainous region according to the Chinese Earthquake Administration CEA.

Aftershocks after the Tangshan earthquake lasted for years and were distributed throughout an area approximately 140 km in length and 50 km in width along a northeast trend, indicating the Tangshan fault as the main fault rupture. There were two major aftershocks (or triggered earthquakes). On July 28, 1976 at 6:45 pm local time an Mw 7.0 earthquake struck, centered in Shangjialin Luanxian to the northeast of Tangshan. The second major aftershock of Mw 6.4 struck on November 15, 1976 at 9:53 pm local time centered south of Lutai to the southwest of Tangshan. In all, over 850 aftershocks occurred through the end of 1978[9]. As for Wenchuan earthquake, the aftershocks zone is about 300 km long along the Longmen fracture three times longer than that of Tangshan earthquake. More than 13,000 aftershocks have been monitored in the quake zone, with the strongest reaching 6.4 magnitude on the Richter scale in Qingchuan county of Guangyuan City. Aftershocks are expected to remain for quite a long time.

According to the Chinese Seismic Intensity Scale (approximately consistent with Modified Mercalli Intensity

Scale), maximum intensities exceeded X throughout downtown Tangshan and caused irreparable damage. The estimated intensity contours in the epicentral region of Wenchuan earthquake along the length of the fault ranged from IX to XI on the Modified Mercalli Intensity Scale, just one notch lower than the highest level, based on USGS report[10]. Figure 6 and 7 show the estimated MMI intensity of Tangshan and Wenchuan earthquake respectively.

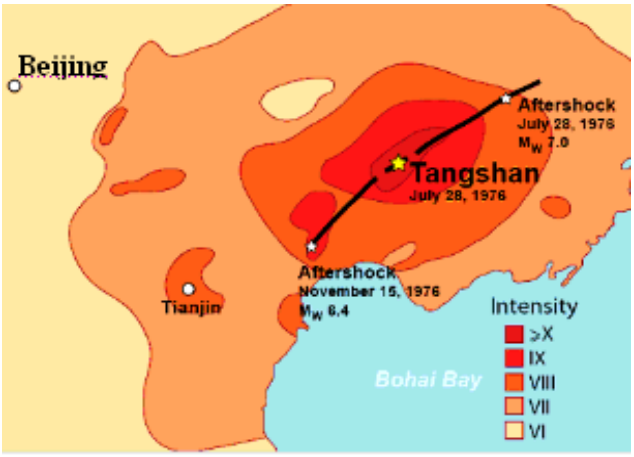


Figure 6 Intensity map of the 1976 Tangshan Earthquake [9].

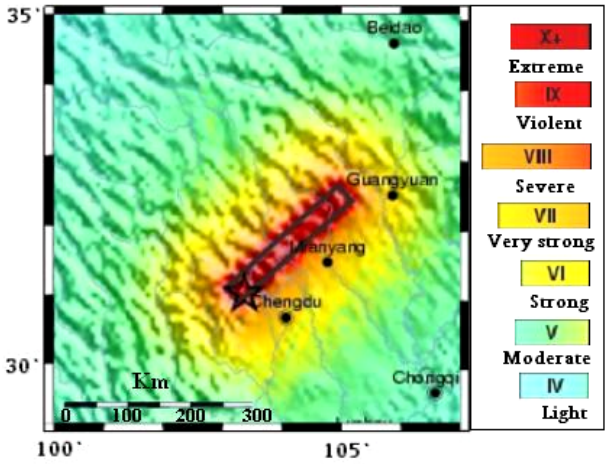


Figure 7 Estimated MMI intensity of 2008 Wenchuan earthquake (USGS).

5. OUTLINE OF EARTHQUAKE DAMAGE TO CIVIL STRUCTURES

The May 12 earthquake leveled many buildings in Wenchuan, Beichuan, Mianzhu, Dujiangyan and Pengzhou in southwest China's Sichuan Province. Heavy damage was experienced not only around the epicentre region but also hundreds of kilometers away. Severe damage has been inflicted on property, industry and infrastructure, and the degree of damage between buildings in disaster area was different. Many of the old buildings that collapsed were adobe and masonry buildings; many of the new buildings that collapsed were concrete and poorly reinforced. The early damage statistics indicate that over 5 million houses collapsed including 6,898 school buildings, and around 21 million houses were damaged by the earthquake, leaving over 5 million people homeless in Sichuan Province and 7 other affected provinces.

Several factors exacerbated the severity of the earthquake, including the shallowness of the hypocenter and the density of the population in the Sichuan region. With dense population comes dense construction. Many buildings in the province toppled completely, the worst of the damage is in Sichuan province with the counties of Wenchuan, Beichuan, Mianyang and Dianjiang particularly badly affected. According to the Seismic Ground Motion Parameter Zonation Map of China, seismic fortification criterion of these quake-affected areas is set at 7 degrees. The intensity of the May 12 destructive quake exceeded the recommended earthquake fortification standards in local building and considered the chief cause of destruction but unqualified building design cannot be excluded too. Buildings in Sichuan may have escaped adherence to codes for a variety of reasons and, but the building collapses shouldn't only attributed to poor construction quality.

Mianyang city: The city of Mianyang saw some of the worst loss of life combined with catastrophic damage. The city is the second largest city in the province with a population of around 600,000, located approximately 160km east southeast of the epicentre, however it lies close to the fault line. Most major buildings including several schools and hospitals have been destroyed in the city. Most of those are still standing look damaged beyond repair. The numerous dams in the area also threaten millions with flooding.

Beichuan County: Beichuan County, in Sichuan, located 50km north of Mianyang and 140 km northeast of the epicentre was one of the worst-affected regions during Wenchuan Earthquake of May 12, 2008. Catastrophic

building collapse was seen in Beichuan County with approximately 80 percent of buildings in the area reported to have collapsed. There were collapsed buildings all along the road to the nearby city of Beichuan. The townships of Qushan and Leigu were hit particularly hard, concrete structures crumbling to rubble under their own weight, or being crushed by landslides.

Wenchuan City: Wenchuan, mountainous area west of Chengdu, is one of the badly hit areas and one of the closest to the epicentre. The earthquake landslides blocked many roads leading to the city and since the town is close to the fault structure itself the damage was very significant. The majority of houses collapsed[11], totally buildings collapse in Wenchuan was more than 25%, nearby Guo Zhupu buildings' collapse rate 30%. In addition, roads leads to Mao County, 213 highways have been toppled. Figure 8 shows the collapsed houses and destroyed traffic line assessment map based on COSMO 1 radar image.

Dujiangyan City: Dujiangyan is a city with population around 60,000 people, about 50km (32 miles) from the epicenter. In Dujiangyan City (Guan Xian) a hospital and at least 8 schools are reported to have totally collapsed. The worst case is found in Northeast and Centre Dujiangyan with more than 20% of houses were collapsed, while the housing damages in Eastern Dujiangyan are less serious[7]. The collapsed building of Juyuan Middle school, one of the worst cases, is constructed of non-ductile cast-in-place concrete columns and beams, and precast concrete floor planks and the Infilled walls were unreinforced masonry. Juyuan Middle School was built in 1996 which is relatively modern. However, the non-ductile detailing of concrete elements and unreinforced masonry turned out to be the killers. This school had performed very poorly in Wenchuan earthquakes. Figure 9 shows the collapsed houses assessment map based on RS-1 satellite image of May 15th, 2008 and SPOT5 image of August 15th, 2005.

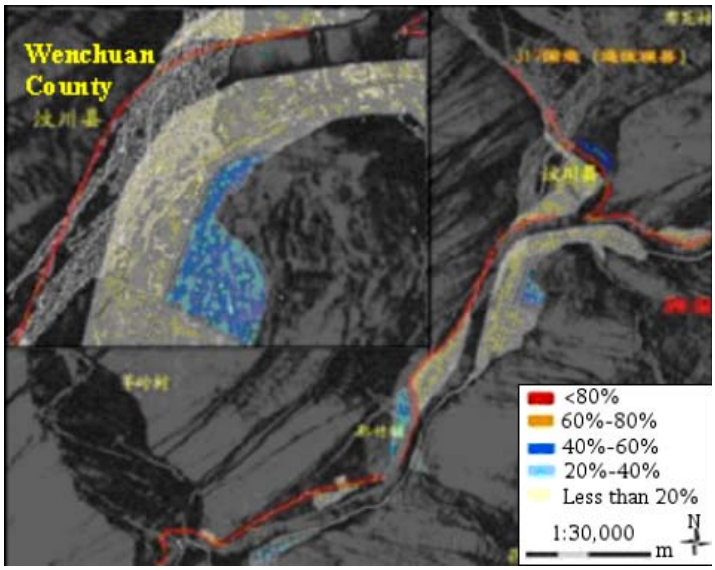


Figure 8 Buildings damage assessment in Wenchuan based on COSMO 1 radar image[11].

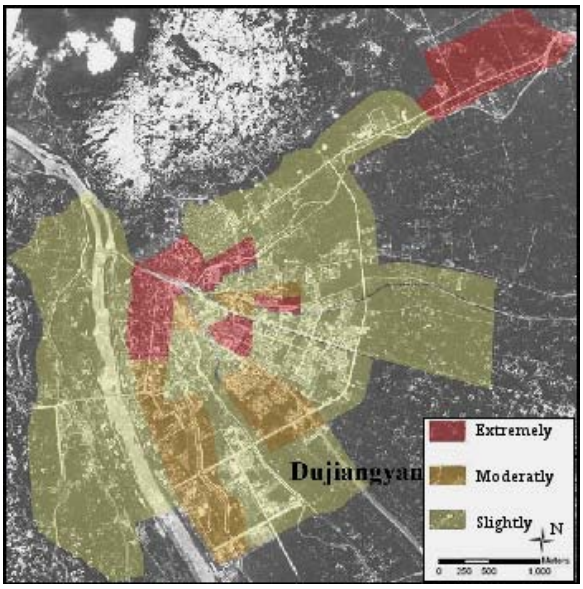


Figure 9 Buildings Damage assessment in Dujiangyan City[12]

Chengdu City: The city of Chengdu, the capital city of Sichuan Province, located approximately 100km from the epicentre has no reports of buildings collapse, however light to moderate damage such as cracks in walls and contents damage had been reported. Buildings in Chengdu have been built in accordance with the seismic fortification criterion – 7 degrees. The urban area withstood the challenge presented by the 8.0-magnitude quake, but those places near the fault zone inevitably faced a lower survival rate.

Pengzhou and Shifang Two chemical plants collapsed in Shifang City, spilling more than 80 tons of toxic liquid ammonia from the site. Figure 10 is a satellite image taken by RS-1 Radar and SPOT 5 satellite data; resident area in Penzhou and Shifang District along Chaping Mountain collapsed seriously; resident area in the

north and west of two capital cities of the two districts collapsed moderately; and resident area around and in the south part of the two districts collapsed slightly[12].

Jiangyou City: The 2008 Wenchuan Earthquake caused lots of houses collapsed and destroyed roads in Jiangyou city as shown in satellite images. Figure 11 shows the collapsed houses and destroyed traffic line assessment map based on ALOS PRISM image on May 18th in Dakang town, Jiangyou city.

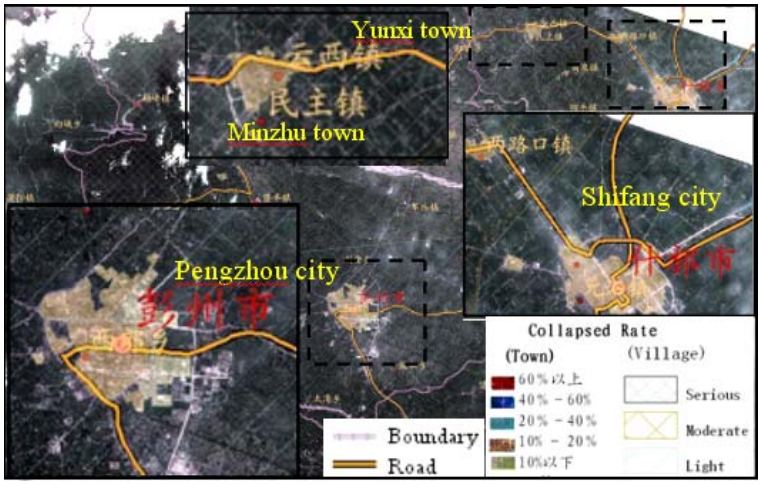


Figure 10 Buildings collapsed in Penzhou and Shifang District based on RS-1 Radar and SPOT 5 satellite image[12].

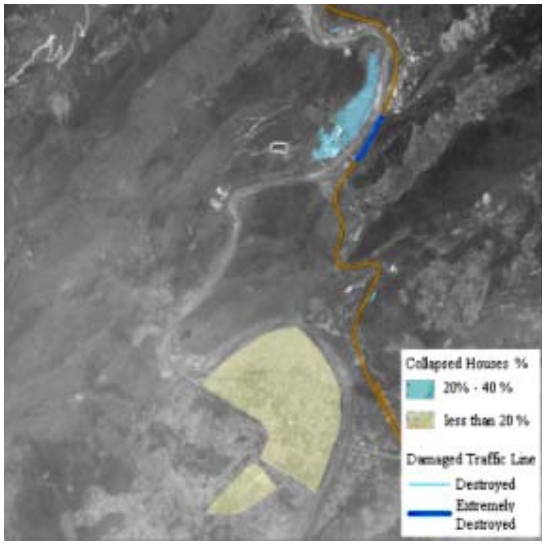


Figure 11 Possible damage to building and infrastructure in Jiangyou City.[12]

Damage to School buildings The issue of collapsed school buildings received most attention from media and authorities. The China Ministry of Housing and Rural Development had ordered local authorities to investigate the school building collapses. The schools collapse during the earthquake caused a huge number of deaths. Thousands school buildings were badly damaged of which about 7,000 were completely destroyed.

Damage to Industry and Infrastructure: Many reservoirs, hydropower stations, dams and water locks were seriously damaged during the earthquake – leading to fear of widespread flooding. Additionally, many factories and mines located in Sichuan province and neighboring Gansu and Chongqing provinces sustained high levels of damage. It is observed that the bridges, reservoirs and dams did not pose any immediate threats to the public as found from the TerraSAR radar image and aerial photos. The nuclear facilities in the area have not been affected by the earthquake. Two facilities in Shifang city had suffered from sulphuric acid and ammonia leak due to aftershocks but the Ministry of Environmental Protection has monitored and controlled the impact in the area and reports suggest that water had not been contaminated. Transport networks in the affected areas were crippled in the immediate aftermath of the earthquake; however the affected railways have quickly resumed operation, allowing aid and relief packages to reach the affected areas. Roads were also severely damaged, both by shaking from the quake and from landslides triggered in the aftermath.

Lost and damaged cultural heritage: Sichuan Province and its neighboring cities contain many well-known cultural heritage buildings which suffered severe damage after the earthquake, among them:

- 150-year-old church in Bailu Town near Pengzhou collapsed.
- Several ancient buildings on Qingcheng Shan in danger of collapsing.
- 2,000-year-old Erwang Temple built to honor Li Bing and his son for their contribution to the construction of Dujiangyan collapsed.
- Bao'en Temple in Pingwu County—one of Sichuan's biggest Buddhist temples—had several walls collapse and its fresco ruined.

- The 32-meter, 12-story landmark Ming Dynasty pagoda in Langzhong County, Nanchong, broke in half.
- Roofs of some buildings at Dufu Caotang are broken and some walls cracked.
- In the Jinsha Ruins Museum in Chengdu a small number of ancient pots in the No. 2 Exhibition Hall of the museum were smashed.
- Sanxingdui Museum in Guangyuan, which was constructed to withstand a magnitude-8.0 earthquake, had broken walls, damaged exterior ruins and 20 sets of 3,000 to 4,000-year-old ceramic utensils shattered to pieces.
- 4,228 cultural relics (the first shipment of 25,000) were transferred from Mianyang Museum to Sanxingdui Museum in anticipation of flooding in the area

On May 14th 2008, Chongqing university of Chian has dispatched a team to the disaster area to survey the jolted regions of the 2008 Sichuan Earthquake. The team is composed of Professor Li Yingmin, the head of Disaster Reduction Department in the College of Civil Engineering, his colleagues and the graduate candidates group. The survey is well prepared to be published in due time. Their survey shows that the distribution of damage to civil buildings during the Wenchuan earthquake is related to the distance from the epicenter, geological and site conditions, types of building structures, quality of construction, etc. The damage degrees of buildings according to this survey can be divided into six categories based on damage to the whole building as follows:

- Completely collapsed: Whole buildings leveled to the ground, or several upper stories of the building collapsed, or most of the building collapsed with a small part remaining.
- Collapsed: All exterior walls nearly collapsed, or the top story of buildings with a timber roof mostly collapsed, or the load-bearing structure partly collapsed.
- Seriously damaged: This type of building can only be used after major repairs. The main part of the building structure seriously damaged; walls cracked and shifted, were offset or loosened, parts of the corner fell down, part of the exterior wall fell or individual walls or panels collapsed.
- Moderately damaged: This type of building can still be used after local repairs or strengthening. Apparent cracks occurred on the main part of the building structure or at several connections; filled walls and attached buildings were seriously damaged or even collapsed.
- Slightly damaged: The buildings that suffered slight damage can be used continuously and only minor repair is required. Non-main part of the building structure obviously damaged; small cracks and constructional cracks occurred on a few walls and panels, obvious cracks occasionally occurred on individual walls but most of the walls were not damaged.
- Basically intact: A few non-main parts of the building structure were slightly damaged, individual doors or window openings, wall corners, brick arches and extruding parts of the building had occasional small cracks on otherwise intact buildings.

6. CONCLUSION

The earthquake provides important lessons that have been taught repeatedly by past earthquakes because the earthquake generated many data, engineers and researchers investigated the disaster area and many industrial and modern cities were in the shaken region. Data recovered from this earthquake will doubtless contribute to the future understanding of the Southwest China earthquakes. One of the most important lessons and significant findings of this earthquake is that the Longmen mountain fault would be identified more precisely. Also, the strong motion records will help interpret the behavior of the different buildings in different parts of the province. The 2008 Wenchuan earthquake highlighted the following:

- In Chendu City, the capital of Sichuan Province, buildings designed according to the modern code requirements performed well during the earthquake, with little structural damage. This event had shed some light in the parameters currently used in the region for the estimation of attenuation laws and seismic requirements of the buildings code, so it necessary for engineers to improve the seismic requirements in the building code and their implementation with reference to the fact that similar or much stronger ground shaking may occur in future earthquakes.

- Older buildings not designed according to “modern” code requirements performed less well and buildings constructed before there were requirements in the building code exhibited dangerous weaknesses. If an appropriate retrofit program is not undertaken there will be many collapsed buildings.
- The impact had to be borne by all levels of society as well as by the government. The fast recuperation must be partly credited to national and international relief organization. The state official organizations must recognize that strong earthquakes will come and that the region should be prepared to respond appropriately.
- Major facilities and buildings had not been instrumented and, therefore, it is not known what motions and stresses these structures underwent.
- All bridges and civil structures have to be checked and retrofitted as required so as to remain functional and prevent collapse. Retrofit of old pre-code buildings is strongly needed and Investigations should be made of the seismic resistance of buildings that were constructed in the early decades of the seismic requirements in the code. The se effect of the deficiencies should be determined and structures should be strengthened as required.
- The Disaster relief activities in dealing with the problem of artificial lakes caused by landslides and orderly evacuation of a very large population, adoption of orphans, etc., must be studied by Disaster Management administrators and mitigation plans.
- The Chinese government has performed the disaster recovery measures quite well, so the effort of the community and the government for the post disaster relief has to be commended.
- Inspection of construction quality should be stressed, and firm policy and design guide lines for the construction of schools and residential buildings need to be adopted.

There are many valuable information and newly data, generated during the May 12th Wenchuan earthquake, to study earthquakes and to improve future seismic design codes throughout the world. It will be important now to use the Wenchuan earthquake experience as a base to set sound standards for the relief and recovery measures and construction of buildings and other infrastructures.

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