Earthq Eng & Eng Vib (2008) 7:225-234 **DOI**: 10.1007/s11803-008-0856-1

A preliminary report on the Great Wenchuan Earthquake

Wang Zifa†

Institute of Engineering Mechanics, China Earthquake Administration, Harbin 150080, China

Abstract: The May 12, 2008 Great Wenchuan Earthquake has resulted in more than 68,858 deaths and losses in the hundreds of billions RMB as of May 30, 2008, and these numbers will undoubtedly increase as more information becomes available on the extent of the event. Immediately after the earthquake, the China Earthquake Administration (CEA) responded quickly by sending teams of experts to the affected region, eventually including over 60 staff members from the Institute of Engineering Mechanics (IEM). This paper reports preliminary information that has been gathered in the first 18 days after the event, covering seismicity, search and rescue efforts, observed ground motions, and damage and loss estimates. The extensive field investigation has revealed a number of valuable findings that could be useful in improving research in earthquake engineering in the future. Once again, this earthquake has shown that the vertical component of ground motion is as significant as horizontal ground motions in the near-source area. Finally, note that as more information is gathered, the numbers reported in this paper will need to be adjusted accordingly.

Keywords: Wenchuan Earthquake; field investigation; ground motions; vertical acceleration

1 Introduction

On May 12, 2008 at exactly 14:28:01, a huge earthquake with a magnitude 8 on the Richter scale occurred in the Wenchuan area of the Sichuan Province in China, causing tens of thousands of deaths and hundreds of billions RMB in losses, making it the worst earthquake event to occur in China since the *M*7.8 Tangshan Earthquake in 1976. The event occurred along the Longmen fault, which has an up bound magnitude of 7.3 for potential seismic sources on the zonation map in China. In 1933, a magnitude 7.5 earthquake occurred in the same area at a place called Diexi. In 1976, two earthquakes, both with magnitudes of 7.2, occurred in the Songpan area within one week, resulting in a death toll of over 800. The fault where the Great Wenchuan Earthquake occurred is located at the southern part of the famous south-north seismic belt in China, and no precursor information was observed by the newly completed China Geophysical and Geochemical Network. It appeared to be a totally unexpected event, that resulted in tremendous losses of life and property and caused huge social disruptions. The major features of this event are summarized as follows:

Correspondence to: Wang Zifa, Institute of Engineering Mechanics, China Earthquake Administration, 9 Xuefu Road, Harbin 150080, China
Tel: 86-451-86652629
E-mail: zifa@iem.ac.cn
†Professor

Supported by: Partially the Project 2007CB714205 of the National Basic Research Program of China
Received May 24, 2008; **Accepted** May 30, 2008

(1) The earthquake had an extremely high intensity over a large affected area with sustained impact. The epicentral intensity for this earthquake is XI on Chinese Intensity Scale. The affected area includes the provinces of Sichuan, Gansu and Shanaxi, and the Chongqing Municipal area. It consists of 417 counties in 16 provinces and municipals with an area of more than 440,000 km^2 and a total of population of 45.61 million, which is so large that close to half of China was impacted. More than 15 million rooms collapsed during the earthquake. Eighteen days have passed since the occurrence of the earthquake, however, millions of people in the affected area are still living under a continuing threat that includes several potential geological disasters.

(2) The earthquake happened in a densely populated mountain region, where there is a history of strong earthquakes. From the historical record, a total of eight earthquakes with magnitudes larger than *M*7 occurred within 200 km of the epicenter of the present event, the largest being the 1933 *M*7.5 Diexi Earthquake in Mao County, Sichuan Province. As of May 27, 2008, a total of 8,668 aftershocks have occurred after the main event. The earthquake disaster has been accompanied by many other geological disasters, such as landslide, mud-rock flow and "quake lakes", formed by landslide-induced reservoirs. Due to the occurrence of the earthquake in a mountainous area, a large number of places had landslides and rock slides that blocked the entrance to many heavily damage areas, significantly hampering search and rescue efforts and contributing to the large number of deaths and injuries.

(3) Most buildings in the severely affected region had a relatively low level of earthquake resistance. Wenchuan

County, the epicenter of this event, is one of China's four ethnic minority counties that is predominantly settled by the Qiangzu people. The Qiangzu minority population in the region is 29,000, which is close to 27% of the total population in Wenchuan County. The typical buildings used by the Qiangzu people are built with stone masonry walls or rammed earth, which have very low seismic resistance. The affected region was subjected to an intensity of 10 to 11, which was much higher than specified by the building design codes for Wenchuan. Therefore, a great number of buildings collapsed or were damaged, especially near the epicenter.

(4) The relief work is very difficult, especially with the frequent aftershocks. Serious geological hazards caused by the earthquake further aggravated the difficulty of the relief work and amplified the losses. Most of the heavily-hit zones are located in the mountain or valley areas, where access is inconvenient. Additionally, due to transportation and communication interruptions, the river blockade and the bad weather, the rescuers, relief supplies, vehicles and heavy equipment could not immediately reach the areas of greatest need. Thousands of mud-rock flows and landslides were created after each big aftershock. Rocks have plugged the Qingshui River and its branch, the Hongshi River, forming 34 quake lakes. This forced the relocation of an additional million people, on top of the five million people who have already moved. Meanwhile, the roads were blocked, which disrupted traffic and the potential collapse of the damaged buildings further aggravated the problem. Among the 34 quake lakes, Tangjia Mountain is the largest, with a water volume of 171 million cubic meters and a water depth of 64.37m in the dam as of May 30, 2008. It is threatening Mianyang city, which has a population of 1.3 million. As of May 30, 2008, about 200,000 people have been relocated to safer places to allow for water discharge when the spillway is completed.

This preliminary report describes search and rescue efforts, seismicity, observed ground motion, damage to different types of buildings and constructions, and loss estimation.

2 Search and rescue efforts

The response of the Chinese government, related agencies and institutes has been unprecedented. Less than two hours after the event, Premier WEN Jiabao went to the affected area and stayed in the region for the first five days to lead the search and rescue efforts. The entire country, including the armed police and the People's Liberation Army of China, has been mobilized for the search and rescue efforts. The China International Search and Rescue team, the famous team that was dispatched to countries such as Iran, Indonesia, and Pakistan for international search and rescue efforts, responded quickly by arriving at the scene within hours after the tragic event. International search and rescue teams from countries such as Japan, Russia, US, South Korea and Singapore were welcome to join the field efforts and Chinese Taiwan sent its teams to the area within a few days after the event.

Through collaborative efforts from different fronts, many people were rescued. As of May 30, 2008, close to 84,000 people had been rescued and more than 15 million were sent to safe places. A lady was rescued from within the ruins of a building more than 215 hours after the event, making her the longest survivor to be freed from the ruins. The progressive variation of the casualty numbers reported as of May 30, 2008 is shown in Fig.1, which also includes the variation of the number of missing people. As of May 30, 2008, the total number of deaths was 68,858, the number of injured people was 366,586, and the number missing was 18,618. As shown in Fig.1, starting May 26, 2008, both the numbers of injured and dead became relatively stable with only slight increases. The number of missing people showed a corresponding decrease, as reported in the media. The distribution of casualties in the Sichuan region as recently reported is plotted in Fig.2. Note that as the death number for the Aba Autonomous Administration was reported for the entire region, the relevant symbol in Fig.2 is located approximately in the center of the Administration's entire region. The same is true for most other counties. Of course, the casualties depend upon not only the seismic intensity but also local conditions, such as the earthquake resistance of the buildings and the local soil conditions.

As search and rescue efforts progress, more and more attention has been paid to distributing aid and improving basic living needs such as housing, drinking water and food, etc., which have been transported to the earthquake affected areas at an unprecedented speed.

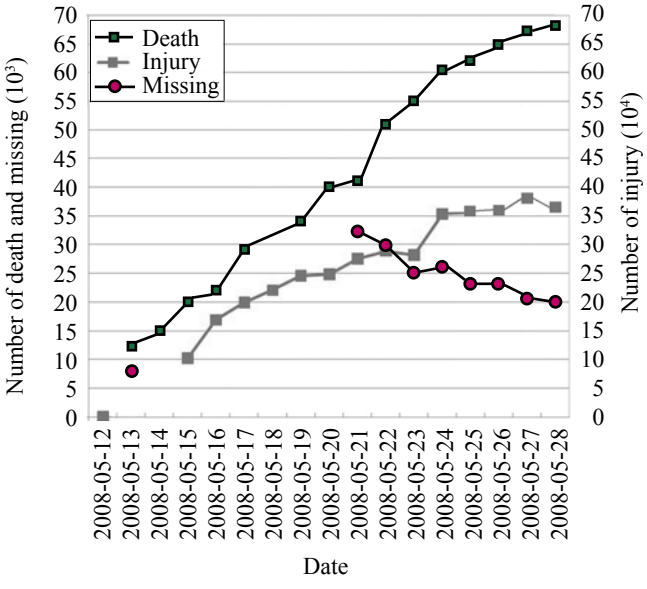

Fig.1 Progressive report of casualties as of May 28, 2008

For many remote villages deep in the mountain areas, bottled water and cups of noodles were dispatched to meet the basic needs of the affected people. Tent production, disease control, and medical help have become the main focus at this time, while reconstruction plans are actively being discussed among many related entities and implementation should begin in the very near future.

From an engineering perspective, repairing the damaged infrastructure facilities, with special attention to reservoirs, power stations and quake lakes, are the major task now as the focus shifts from search and rescue to relief and reconstruction.

In summary, search and rescue efforts have been swift and effective. The entire nation rallied together to contain the challenges brought about by this disastrous earthquake. Many heroic stories arose as people desperately tried to save the lives of others throughout the affected areas. Many teachers, soldiers and construction workers lost their lives in order to save others.

3 Seismicity

The Longmen fault continuously endures pressure from both the Pacific Plate and the Indian Plate, which implies that the area has a high level of seismicity. According to the record in the Songpan-Longmen region there were a total of 35 earthquakes with a magnitude Ms above 5, 16 of them above 6 and 3 of them above 7 during the period 638 to 1983 (Sichuan Province Earthquake Administration, 1983). As a matter of fact, in addition to the 1933 Diexi earthquake, there was another series of earthquakes, the 1976 Songpan earthquake series, which occurred north of Wenchuan at a distance of about 140 km. Note that the 1976 Songpan event was a combination of two *M*7.2 events occurring within the same week, indicating the complexity of the pattern of earthquake occurrence in the area.

As of May 30, 2008, a total of 8,672 aftershocks had been observed, 186 with a magnitude above 4, 28 above 5 and five above 6 (CENC,2008]. Two larger aftershock events occurred, an *M*6.1 on May 13 roughly 24 hours after the main event, and an *M*6.4 on May 25. Figure 3 shows the distribution of aftershocks, including the main shock of the Wenchuan Earthquake, as of May 27, 2008. An interesting trend for the aftershocks is that they seem to be occurring along the fault propagating toward the northeast direction. Recent detailed analysis of the fault mechanism indicates that the rupture of the main event started from the southwestern end of the fault and propagated toward the northeastern end, which correlates well with the distribution of the aftershocks (Xinhuanet, 2008).

4 Observed ground motion

From a researcher's point of view, it was fortunate that the national digital seismic network for strong ground motion observation was completed before the event occurred. There are a few hundred stations in the earthquake affected area, and many recorded valuable information on strong ground motion. Although the recovery work continues on strong ground motion data due to damage to the observation stations and instruments in the heavily damaged area, a good number of records with fairly large peak acceleration values are available. The largest one was observed at Bajiao town in Shifang City as shown in Fig. 4. Note that the peak vertical component of the acceleration is larger than the peak of both the two horizontal components, providing new evidence in the near-source area that vertical components could be larger than the horizontal components. This observation contradicts current seismic design guidelines, where the vertical component

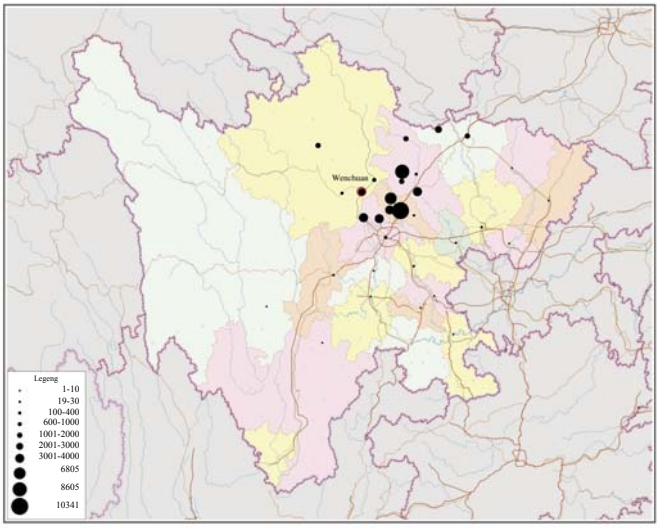

Fig. 2 Distribution of casualties in Sichuan Province as of May 30, 2008

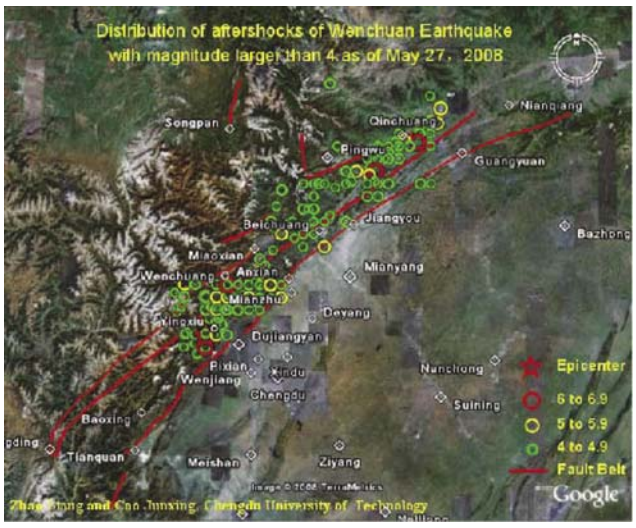

Fig. 3 Distribution of Wenchuan earthquake series as of May 27, 2008 (From Chengdu University of Technology)

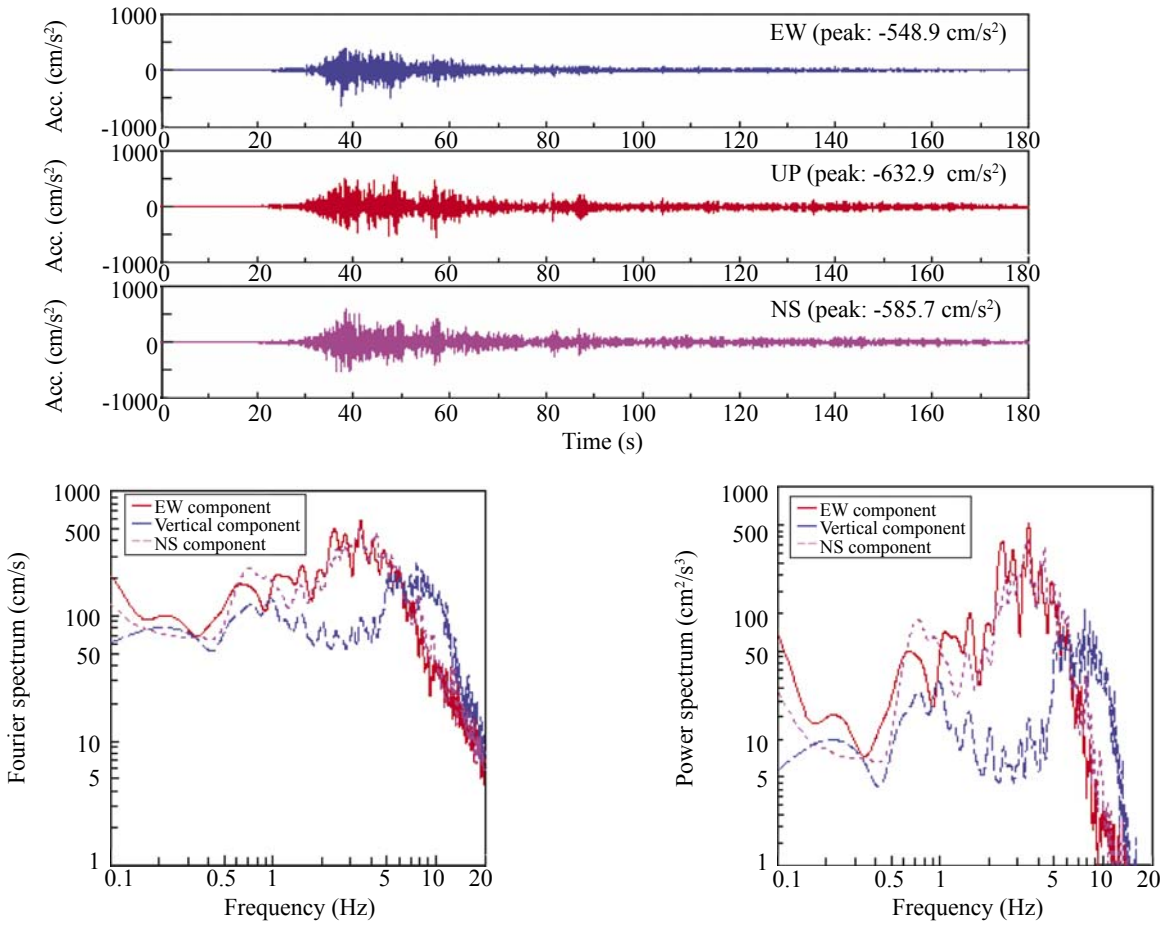

Fig. 4 Acceleration, Fourier and power spectra of Bajiao Station in the Shifang City

is typically assumed to be a third of the horizontal ones. The same trend can be observed at a few other locations and at places as far as Jiuzhaizhuangzhatai station, which is about 250 km from the epicenter and where peak vertical acceleration is close to 300 Gal while both the horizontal ones are less than 200 Gal.

5 Damage and losses

A few hours after the occurrence of the event, the Institute of Engineering Mechanics (IEM), China Earthquake Administration (CEA) sent its first expert team to the field. In the days following the event, and as of May 23, IEM had dispatched six teams of over 60 experts to the impacted area. They worked on different fronts, from search and rescue, loss estimation, and damage survey to structural safety evaluation. The author also went out to the field two days after the event, stayed for an entire week and visited most of the heavily damaged areas, including Beichuan, Shifang, Mianzhu, Pingwu, Anxian, Jiangyou and Dujiangyan.

5.1 Damage

5.1.1 Vulnerability of schools and hospitals

There are many observations from the field. The first is the vulnerability of schools and hospitals. In almost all the cities and towns where there was heavy damage, schools and hospitals were among the worst. The main shock occurred during the day on Monday, and the deaths and injuries basically occurred in crowded public places or regions, i.e., schools, hospitals and office buildings. This tragic fact calls for serious reconsideration of seismic design and construction for buildings of important facilities such as schools and hospitals. Figure 5 shows the complete destruction of four buildings of the Dongqi Middle School in Hanwang town of Mianzhu city, which resulted in hundreds of students losing their lives. It can be seen from the picture that the buildings were totally devastated and did not seem to be designed and/or built according to current seismic design standards.

5.1.2 Vulnerability of buildings in rural areas

The second is the vulnerability of buildings in rural areas. The current design code does not cover buildings in rural areas, making these areas vulnerable when an earthquake occurs. The structures in the countryside without any measures to counter earthquake excitation suffered the worst damage, causing a huge number of casualties as well as an enormous economic loss. Figure 6 shows the complete destruction of a small town called

Yinghua in Shifang City. Almost all the buildings in the town were destroyed, which demonstrates the typical heavy damage to buildings in rural areas. Figure 7 exhibits a similar damage pattern in a small town and remote village in Shifang City where every building in the picture is completely destroyed.

5.1.3 Severity of geotechnical disasters

The third is the severity of geotechnical disasters, such as landslides, mud-rock flow and "quake lakes", formed from landslide-induced reservoirs. After the main shock in the affected areas, many places with potential geological hazards were severely affected by huge landslides, slope collapses and mud-rock flows. This in turn induced the destruction of many constructions and residential buildings that caused a great number of deaths and injuries, and a large number of destroyed infrastructures, including highway and railroad bridges, and communication facilities.

There are mainly three types of geotechnical damage. One is direct damage to engineering structures that sat on top of or beneath the slope. A large portion of the damage in Beichuan County was caused by landslides on the left side and a huge amount of rock slides from the right side as seen from the entrance to the city.

The second is the quake lakes, formed by landslide-induced reservoirs. It is reported that there are 34 landslide-induced reservoirs in the area with the largest one being the Tangjia Mountain quake lake. This lake has a dam height between 82 and 124 m, a total earth-rock volume of 20 million cubic meters and a water volume over 171 million cubic meters as of May 30, 2008. The Tangjia Mountain quake lake (see Fig.8) is a threat to the lower reaches, where counties and cities like Beichuan, Anxian, Shifang, Mianzhou, Pengzhou,and Deyang etc. and some large pre-existing reservoirs and hydraulic power stations are located. For safety purpose a lot of active and positive measures have been taken (http://focus.cnhubei.com/original/200805/t325909.shtml) to reduce the potential risk from the Tangjia Mountain quake lake. For safety purposes, many active and positive measures have been taken (http://focus.cnhubei.com/original/200805/t325909.shtml) to reduce the potential risk from these quake lakes.

The third type of damage is to the transportation

Fig. 5 Complete destruction of four buildings of the Dongqi Middle School in Hanwang Town, Mianzhu City

Fig. 7 Collapsed building in a village located halfway up the mountain in Shifang City

Fig. 6 Complete destruction of Yinghua Town, Shifang City

Fig. 8 Partial view of Tangjia Mountain quake lake

system by the landslides and rock slides. This type of damage not only blocks transportation to the affected area, but also causes direct loss to roads, vehicles and people on the scene. Figure 9 shows rock slides in Beichuan County that completely destroyed the new site of the Beichuan Middle School. Figure 10 shows the trucks smashed and trapped by rolling boulders in Gaochuan of Anxian County. Such phenomena, smashed cars and trucks and casualties, were observed everywhere along the highways. Figure 11 shows the Beichuan county town damaged by a combination of landslide and ground shaking. Figure 12 shows a two story building in Beichuan county town. The top floor was destroyed and thrown to the middle of the street at a distance of more than 15 m apart.

5.1.4 Damage to industrial buildings and infrastructures

Many damaged industrial factories in the affected area were built in the 1960s and 1970s. At that time, less attention was paid in general to the seismic design of buildings and facilities. The Dongfang Steam Turbine Works located in Hanwang town, Mianzhu City with more than 20,000 staff and workers suffered heavy damage. Figure 13 shows some of the damaged buildings of the Dongfang Steam Turbine Works. Note that the building at the rear of the picture did not show any damage from the earthquake because of its strong connections between the beams and columns, further stressing the importance of and need for proper seismic design and construction.

More than 400 bridges were damaged in the affected area, including simply supported beam, steel truss, arch and suspension bridges, etc. Damage seems to be due to a combination of ground surface rupture and strong ground shaking. Some typical bridge damage is shown in Figs. 14 through 18.

In the affected area, in addition to bridges, many other types of lifeline engineering structures and facilities suffered damage to different extents. Zipingpu reservoir, one of the largest reservoirs along the Minjiang River, has a rock-fill dam with a concrete cover plate. The dam has a height of 156 m and a length of 663 m. The maximum installed capacity of this hydropower station is 1.112×10^9 m^3. The dam was designed for a seismic intensity of 8. It was said that a settlement of

Fig. 9 Rock slides in Beichuan County

Fig. 11 Beichuan county town damaged by the combination of landslide and ground shaking

Fig. 10 Trucks smashed and trapped by rock slides

Fig. 12 The upper part of a two-story building destroyed and thrown for a distance of more than 15m

Fig.13 Part of the damaged buildings of the Dongfang Steam Turbine Works at Hanwang Town, Mianzhu City

Fig. 16 Damage to a bridge, including a falling deck at the center, at a town in Beichuan County

Fig. 14 Damage to the Yingxiu Bridge caused by the falling of one of the central spans. The bridge is located at the upstream of the Minjiang River at Zipingpu Reservoir

Fig. 17 Xiaoyudong Bridge, two spans near one of the abutments fell down

Fig. 15 A severely damaged railway bridge near Yinghua Town, Shifang City

Fig. 18 A totally collapsed bridge, the only access from Hongbai Town to the mountain area from the Shifang City

73.9 cm and a horizontal displacement of 10 mm along the river direction were observed according to the chief engineer of construction during our survey. A partial view of the dam is shown in Fig.19. Figure 20 shows an overturned train.

5.1.5 Importance of proper seismic design and high-quality construction

Thus far, earthquake damage to different structures and facilities had been described. Even in towns with almost complete destruction, there are always a few building that did not suffer heavy damage. We believe it is valuable to provide some information on the importance of proper seismic design and high-quality construction gained during our survey. It is important to point out that even in cities and towns like Beichuan and Hanwang, where almost every building suffered damage, those that were properly designed and built performed very well during the earthquake and did not completely collapse. Some buildings resisted severe damage and thus exceeded expectations. Figure 21 shows the solo standing building in a small town called Hongbai in Shifang City. Note that almost all the buildings nearby were completely destroyed except this one. During the field investigation, large surface cracks and huge ground displacement was observed near this building. Initial survey by geologic experts proved that there was a fault rupture crossing this town, making it one of the worst hit areas during the earthquake. Detailed investigation of the structure proved that the building was properly designed and built and incorporated recommended seismic design procedures. Figure 22 shows the standing building of the Beichuan Tea Factory in Beichuan county town, another town heavily damaged during this earthquake. Close investigation proved that there was very minor damage to the walls and the structure could be used after only slight repairs. Figure 23 provides a comparison of a building with minor damage and one that was destroyed nearby in the severely affected Beichuan county town. Some low-rise buildings in the mountain area of the severely affected region of Shifang City were found to be only slightly damaged as shown in Figs. 24 and 25.

Fig. 19 Zipingpu Reservoir had slight damage to its dam both on the top and the concrete cover plate of the downstream side

Fig. 21 The only standing building in Hongbai Town, Shifang City

Fig. 20 The train overturned and the railway track slightly deformed at the Yinghua Town, Shifang City

Fig. 22 The office building of Beichuan Tea Factory in Beichuan county town

Fig. 23 Comparison of a building with minor damage and one nearby that was destroyed in the severely affected Beichuan county town

Fig. 24 Some buildings located halfway up the mountain in Shifang City seem to have only minor damage while at the opposite side heavy landslide occurred

Fig. 25 A one-story building located in mountain region in Shifang City has no obvious damage

5.2 Loss estimation

Immediately after the event, RMS and IEM, using a model co-developed for China earthquake loss estimation, calculated a rough number to indicate the severity of the event (Zifa Wang *et al.,* 2008). The estimated ground-up direct property loss was 98 billion RMB without including losses from basic infrastructure systems such as lifelines. The potential death toll was evaluated to be between 18,000 and 34,000. As more information on damage and casualties was reported to the media, it is now clear that this initial estimation of casualties was far below the current number, which is about 68,858 as of May 30, 2008. The composition of low performance rural and old structures in the overall building inventory severely impacted the estimation of the casualties as well as the loss number for structures and it is expected that as more information is gathered on the inventory, a better estimate will be possible. The final official numbers on losses and casualties will probably not be available for a few more weeks, but from the scattered information obtained thus far from local governments and our survey, the estimate of 98 billion RMB for losses to residential, commercial and industrial building properties seems to be lower than the initial estimate from the field. Recent news reports puts the estimate for property loss at anywhere between 150-500 billion RMB including the loss of infrastructure. In any event, the extent of the disaster's severity is very clear regardless of the final value of property loss.

6 Concluding remarks

At this point in the time, it is difficult to summarize the lessons learned from the Great Wenchuan Earthquake, although the author has tried to accurately record observations from the field. Detailed field investigation will follow as soon as the search and rescue efforts stabilize. The detailed field investigations will reveal more on the earthquake occurrence mechanism and new patterns of earthquake damage. IEM has formed a very large team in the field and it is expected that new findings will come out as the study and field survey on the earthquake and its effects continues. While high expectations are put on subsequent studies of various aspects of earthquake damage from this Great Wenchuan Earthquake, the initial revelations from the field survey have already provided a good amount of information for further study and consideration. The poor performance of rural structures, the bad performance of most school buildings, the lack of earthquake resistance seen in old structures, the higher peak value of vertical components in ground motion, the widespread problem of landslides and rock slides, the importance of infrastructure especially the transportation system, and the problem of quake lakes are all important findings, hard lessons, and future subjects for both earthquake engineers and government officers who work in the earthquake hazard

reduction arena. Although the swift national response for search and rescue efforts and strong and continuous donations have helped to mitigate the extreme consequences of this earthquake disaster, there is much more for us to do in the future. This report will only serve as a preliminary overview provided within days of the earthquake occurrence, and thorough thinking with serious critical reading is always welcome and will only help the author to refine the knowledge on this tragic event.

Acknowledgement

The author wishes to thank the field team from IEM that provided strong support in assembling the information presented herein. Special thanks to Profs. LIN Junqi, YUAN Yifan, LI Xiaojun, SUN Beitou, DAI Junwu, GUO Xun, and to Mr. LI Yigang and LU Yongkun etc. for providing pictures taken in the field; to Profs. YU Haiying, WEN Ruizhi and ZHOU Zhenghua for sharing their ground motion pictures; to Profs. QI Xiaozhai and XIONG Jianguo for their efforts to get this report included in this publication on a fast track; to Miss CHEN Yan for her efforts to accumulate valuable information about this event; and to Mr. HU Chunfeng for his suggestions and encouragement. The author is indebted to Prof. XIONG Jianguo for his continuous attention to this article and without his contribution, there would be no report. The author also thanks Prof. CAO Junxing of Chengdu University of Technology and China Institute of Geo-Environment Monitoring for generously sharing valuable pictures. Note also that many statistics and facts included herein are from the news media and there is no way to list all these contributors; however, but the author is equally indebted to them for their contributions. The field survey is partially supported by Project 2007CB714205 of the National Basic Research Program of China.

References

China Earthquake National Center (CENC) 2008, "National Earthquake Network Center Data," http://www.58919.com/512dz.html.

Sichuan Province Earthquake Administration (1983), *1933 Diexi Earthquake*, Sichuan Science and Technology Press, Chengdou, Sichuan.

Xinhua Agency Net (2008), "China Geological Survey Administration (CGSA): Preliminary Conclusions of Causes of the Great Wenchuan Earthquake," May 18, 2008, http://news.xinhuanet.com/newscenter/2008-05/18/content_8200448.htl.

Wang Zifa, Dong Weimin, Mortgat C and Rahnama M (2008), Earthquake Risk Modeling and Its Application in China, *Proc. 5th International Conference on Urban Earthquake Engineering*, Tokyo, Japan, pp.509-512.