OBSERVATIONS FROM THE APRIL 20, 2013 LUSHAN COUNTY, YA'AN CITY, SICHUAN PROVINCE, CHINA EARTHQUAKE

Marshall Lew

AMEC Environment & Infrastructure, Inc.
Los Angeles, California

Abstract

The April 20, 2013 Lushan earthquake followed the 2008 Great Wenchuan earthquake by almost five years. Although the rupture also started in the Longmenshan fault zone, the Lushan earthquake is not an aftershock. Although similar damage and disruptions to infrastructure and society occurred, it was of a smaller scale and not unexpected due to the short time for the lessons from Wenchuan to be applied. There were some examples of lessons learned and the strong motion dataset obtained in this event will prove valuable in assessing how effective the actions taken have been. The visual observations were made on May 27 and 28, 2013 in Lushan.

Introduction

On April 20, 2013, at 8:02 am (Beijing Time), an earthquake occurred in Lushan County of Ya'an City in Sichuan Province in southwestern China. The epicenter was located at 30^{o} 17' 02" N and 102^{o} 57' 22" E, about 120 km from the major city of Chengdu; see Figure 1. Ya'an City is a prefecture level city in the western part of Sichuan Province and has a population of about 1.5 million people and is the location of one of China's main centers for the protection of the endangered giant panda. Sichuan Province is known as the "Province of Abundance." The province is a leading agricultural region of China and the province is also very rich in mineral resources, including large natural gas reserves. Sichuan is one of China's major industrial centers and has developed a high technology industrial base in electronics and information technology, machinery and metallurgy, hydropower, pharmaceutical, food and beverage industries. Sichuan is a major center for aerospace and defense industries in China as well as China's space program.

Earthquake Statistics

The China Earthquake Networks Center estimated the surface magnitude of the earthquake at M_s 7.0 while a moment magnitude (M_w) of 6.6 was assigned by the United States Geological Survey. The earthquake focus was relatively shallow at about 12.3 km below the surface. On the China Seismic Intensity Scale (similar to the Modified Mercalli Intensity Scale), the maximum intensity was assigned a value of IX.

The earthquake occurred in the Longmenshan Mountains, where the Longmenshan fault is a zone of active tectonically-related thrust faults that form the boundary between the high Tibetan Plateau to the west and northwest and the Sichuan Basin lowlands to the east and southeast. The mountain front is known for its extremely steep rise from an elevation of about 600 meters in the basin to about 6,500 meters in the mountains over a horizontal distance of about 50 km. The Longmenshan Mountains also hosts the headwaters of many rivers that are tributaries to the Yangtze River.

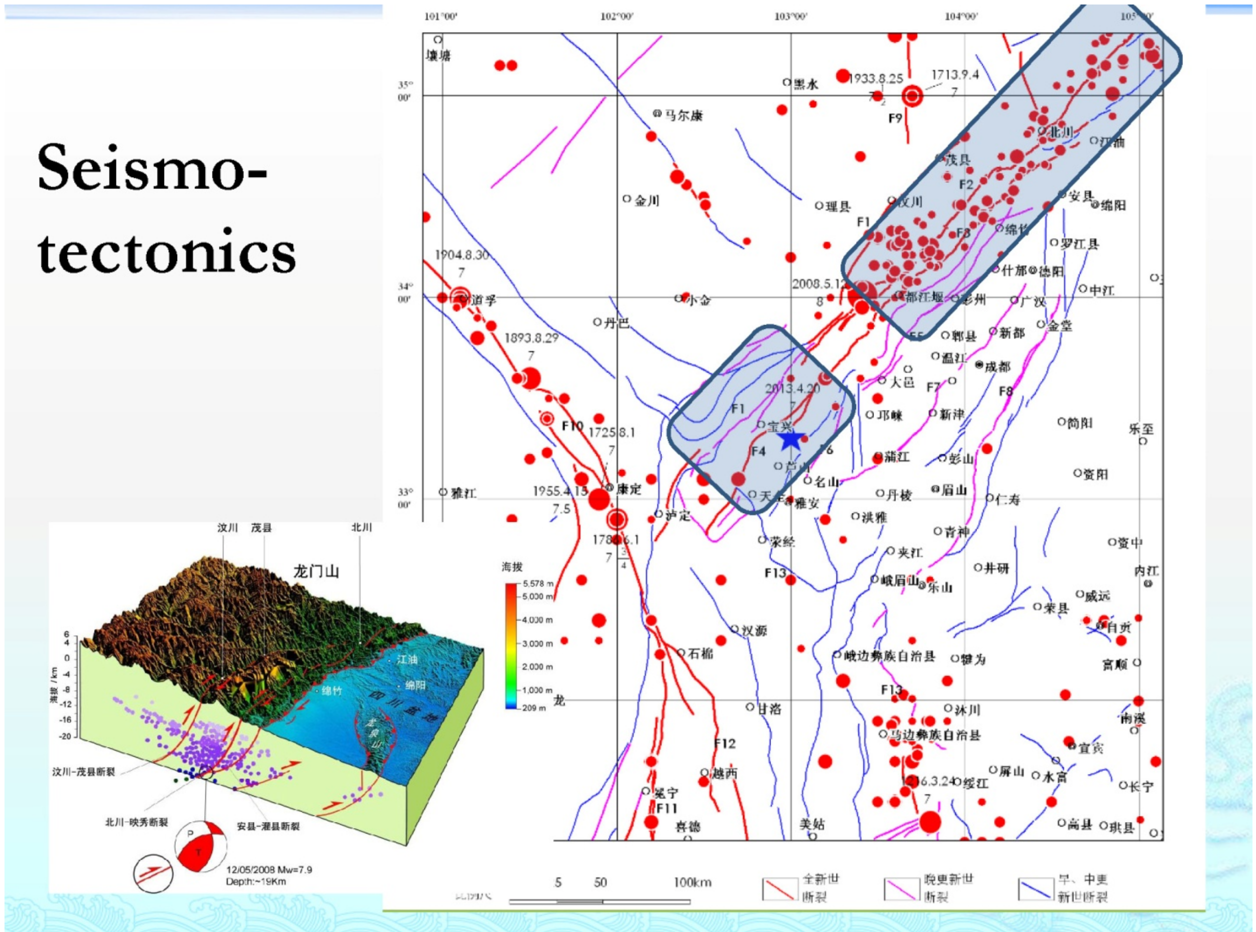

Fig. 1. Location of the Lushan Earthquake; area of 2008 Wenchuan earthquake rupture to the northwest of Lushan. Figure courtesy of Prof. Liu Aiwen of the Institute of Geophysics, China Earthquake Administration.

The causative fault was attributed to the southwestern segment of the Shuangshi-Daichuan fault of the Longmenshan fault zone by Yueqiao et al. (2013); see Figure 2. The principal rupture plane dipped northwest at about 35 degrees; Xu et al. (2013) has inferred that the earthquake might be related to the ramp activity of the basal detachment zone of the Longmenshan fault zone and not related to the Shuangshi-Daichuan fault because of the distribution of aftershocks as shown in Figure 3. The M_w 7.9 Wenchuan earthquake of May 21, 2008 occurred on the Longmenshan fault zone to the northwest of Lushan. The Lushan earthquake is not considered an aftershock of the Wenchuan event as the Lushan rupture occurred on a portion of the fault zone not ruptured by the prior earthquake.

It was reported that there were more than 203 fatalities and over 11,000 injured from the April 20 earthquake. The casualty numbers are significantly lower than for the 2008 Wenchuan earthquake which had over 87,000 fatalities (dead and missing) with almost 375,000 injured.

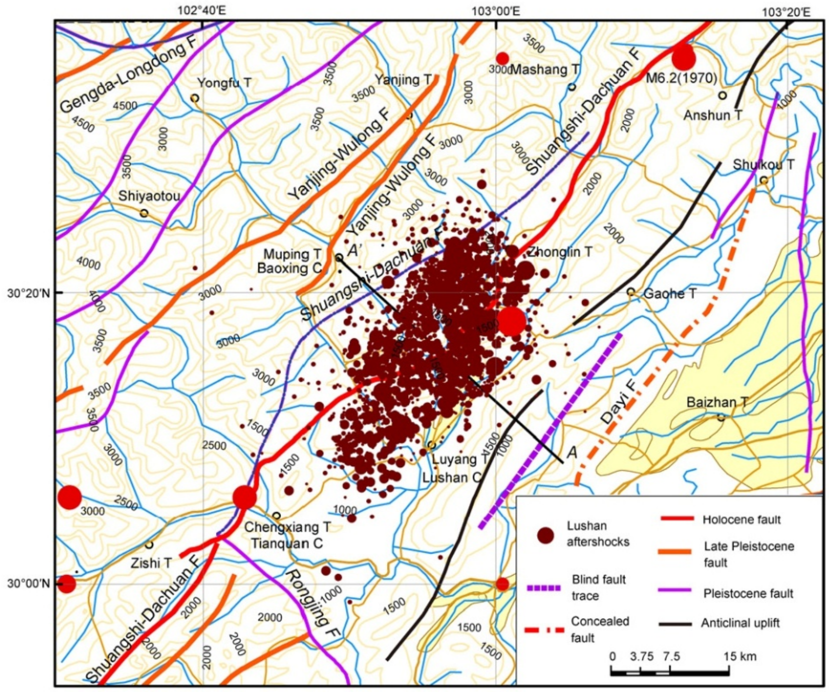

Fig. 2. Spatial Distribution of the Shuangshi-Dachuan fault and aftershocks of the Lushan earthquake from April 20 to 26, 2013 (after Xu et al. 2013)

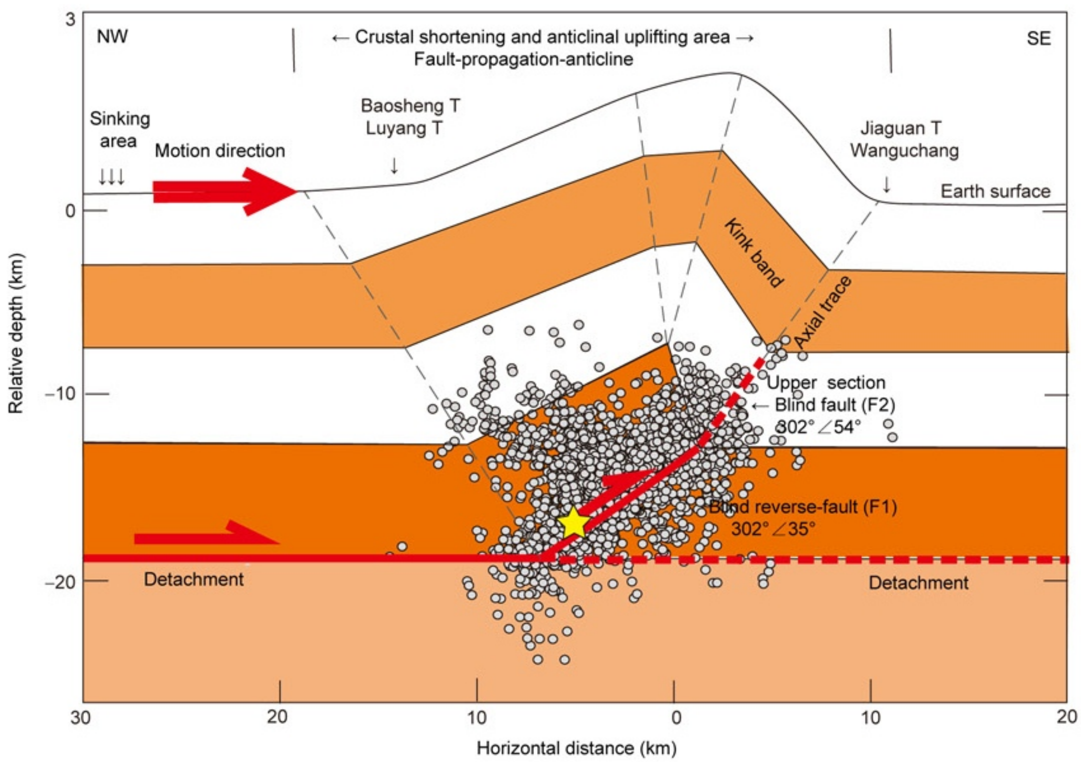

Fig. 3. Cross Section A-A’ showing distribution of aftershocks from April 20 to 26, 2013 (after Xu et al. 2013).

Ground Failures

There have been no reports of evidence of surface fault rupture from the April 20 earthquake. Xu et al. (2013) made field investigations along the Dayi, Shuangshi-Dachuan, Yanjing-Wulong and Gengda-Longdong faults of the southern segment of the Longmenshan thrust belt. Thus the Lushan earthquake appears to have occurred on a blind thrust fault in contrast to the Wenchuan earthquake where there was abundant surface fault rupture. Xu and his colleagues also reported that there were NE- and NW-striking tensional ground fissures, landslides, bedrock collapses and occurrences of liquefaction found on the terraces or floodplains and steep piedmont zones. They also report buckled pavement on a concrete road that indicates local crustal shortening. Xu et al. attribute most of these features to the blind thrust faulting which formed a broad arch, or anticline, which results in crustal shortening and anticlinal uplifting as shown in Figure 3.

Strong Ground Motions

China has a strong motion network of ground instrumentation. This system provided a wealth of information from the Wenchuan earthquake. Some 84 stations recorded ground motions (with three components, two orthogonal horizontal and one vertical) at distances ranging from 27.7 to 769 km from the epicenter of the Lushan earthquake according to the China Strong Motion Networks Center (2013). Of these 84 stations, five stations were located within about 50 km of the source as shown in Figure 4.

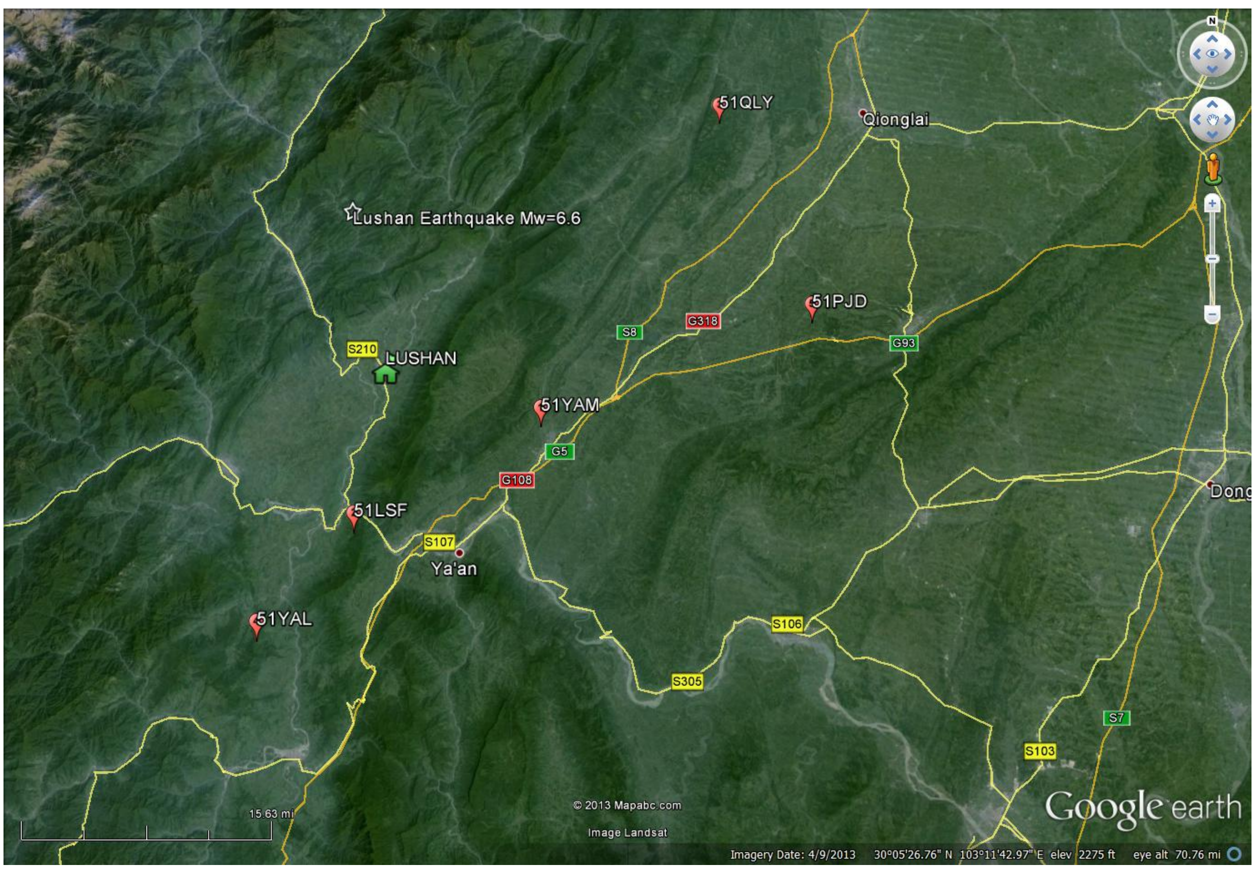

Fig. 4. Locations of five strong motion stations closest to Lushan earthquake source.

A summary of the peak ground motions recorded at the five closest strong motion stations is given in Table 1. Figure 5 shows plots of the acceleration-time histories recorded at the five stations. The acceleration values were uncorrected.

Table 1. Uncorrected Peak ground accelerations recorded at the five closest strong motion stations (after China Strong Motion Networks Center 2013)

Station ID	Station name	Longitude (degrees E)	Latitude (degrees N)	Distance (km)	Direction	Acceleration (cm/sec^2)
51YAM	Mingshan	103.1	30.1	27.7	EW	-400.705
					NS	349.850
					Up	105.102
51LSF	Lushan	102.9	30.0	32.6	EW	387.410
					NS	356.989
					Up	-267.381
51QLY	Qionglai	103.3	30.4	28.2	EW	270.461
					NS	315.486
					Up	111.231
51YAL	Yingjing	102.8	29.9	50.4[a]	EW	-400.705
					NS	349.850
					Up	105.102
51PJD	Pujiang	103.4	30.2	40.8	EW	153.581
					NS	-184.318
					Up	-103.518

[a] As reported by CSMNC; distance appears to be incorrect and may be about 40 km.

Unfortunately, there was no instrumentation in Lushan town, which is approximately 18 km from the epicenter. Considering the strong motion data from the closest stations which are at greater distances, it would be reasonable to estimate the maximum ground accelerations in Lushan to be greater than 0.4g or even 0.5g.

The preliminary report by CSMNC has been published to the world wide web and was accessed at http://csmnc.net/selnewxjx1.asp?id=797.

Landslides and Rockslides

As in the Wenchuan earthquake, there were many landslides and rockslides in the mountainous terrain (see Figure 6). As the terrain in the Longmenshan Mountains is generally very steep, these slides often damaged and blocked roads that were in canyons, along rivers and on the sides of the slopes. Although the earthquake did not occur during the rainy season, precipitation is common in the mountains and landslides and rockslides occur often even in the absence of strong ground shaking. Slides were also observed to have obstructed rivers; there was early concern about a barrier lake formed on the Yuxi River in Mingshan County (IFRC, 2013). It was not uncommon to encounter huge boulders being dislodged from the steep mountainous slopes. It was reported that portions of Baoxing, further into the mountains than Lushan, were isolated by landslides and rescue teams were unable to get there for 33 hours (Xinhuanet 2013). During the emergency and recovery period, traffic had to be regulated where most roads were restricted to one-way traffic only as shown on Figure 7; this resulted in long round-trips as circuitous routes were required to return to the starting point.

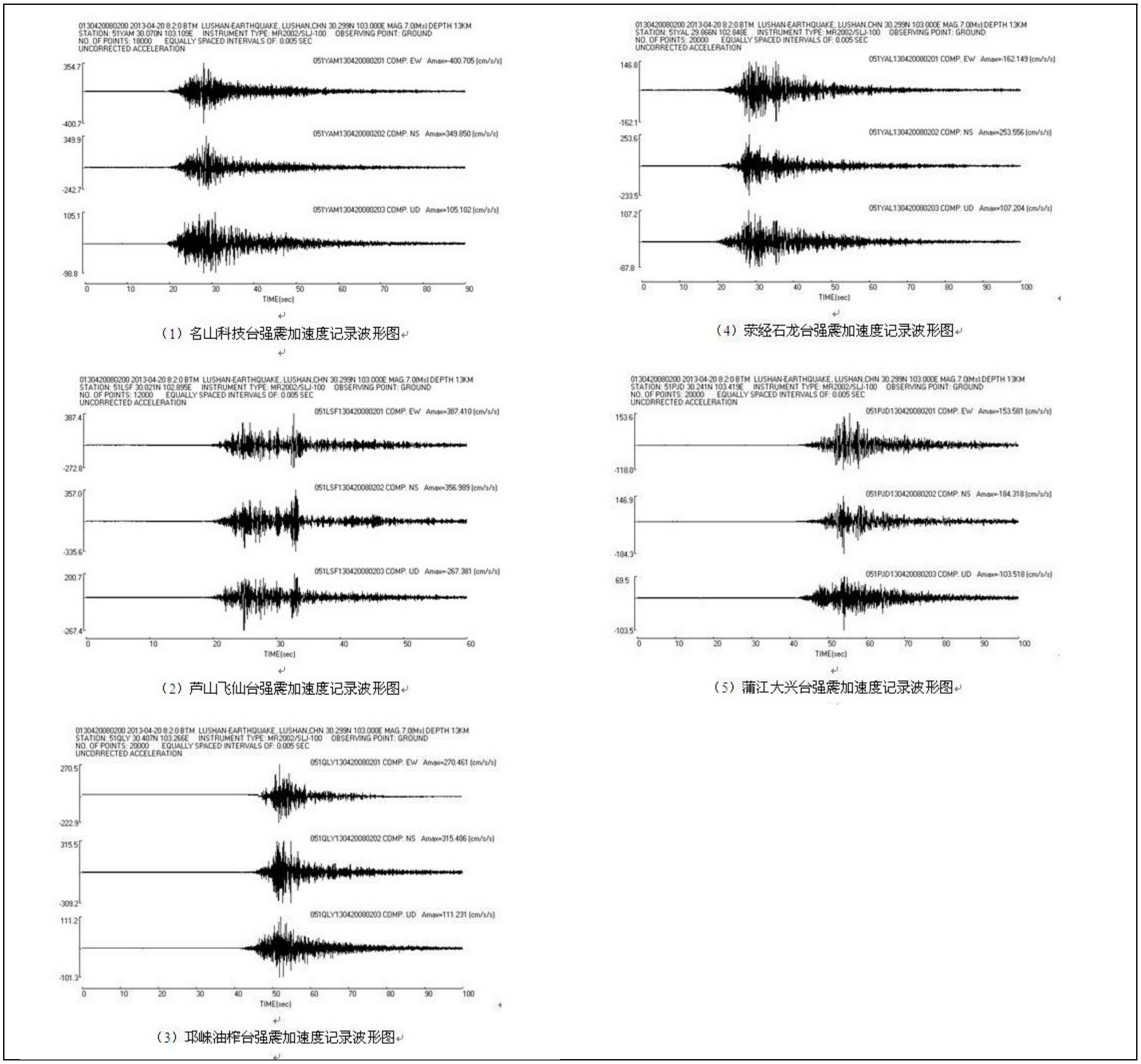

Fig. 5. Acceleration-Time Histories at (1) Station 51YAM, (2) Station 51LSF, (3) Station 51QLY, (4) Station 51YAL and (5) Station 51PJD (after CSMNC 2013).

Fig. 6. Rock and Landslides in Lushan area. Photographs courtesy of Prof. Liu Aiwen.

Structural Performance

From observations in limited portions of Lushan Township, the damages were similar to those observed in the Wenchaun earthquake, although on a smaller scale and much more limited in area. Lushan County has a population of over 110,000 and the main township of Lushan County has a population of about 20,000. According to UNICEF (2013), greater than 90% of the buildings were damaged, while in Baoxing County, to the northwest, greater than 60% of the buildings were damaged. Other seriously affected counties were Yucheng and Tianquan Counties.

As mentioned earlier, the peak ground accelerations in Lushan town are estimated to be in excess of 0.4g or 0.5g. The structures in the old town of Lushan consist of mostly low rise commercial and residential buildings that are typically between two to four stories in height. Typically buildings are constructed with concrete columns and beams with unreinforced brick used as infill and for interior walls; many buildings are also constructed with just brick and mortar.

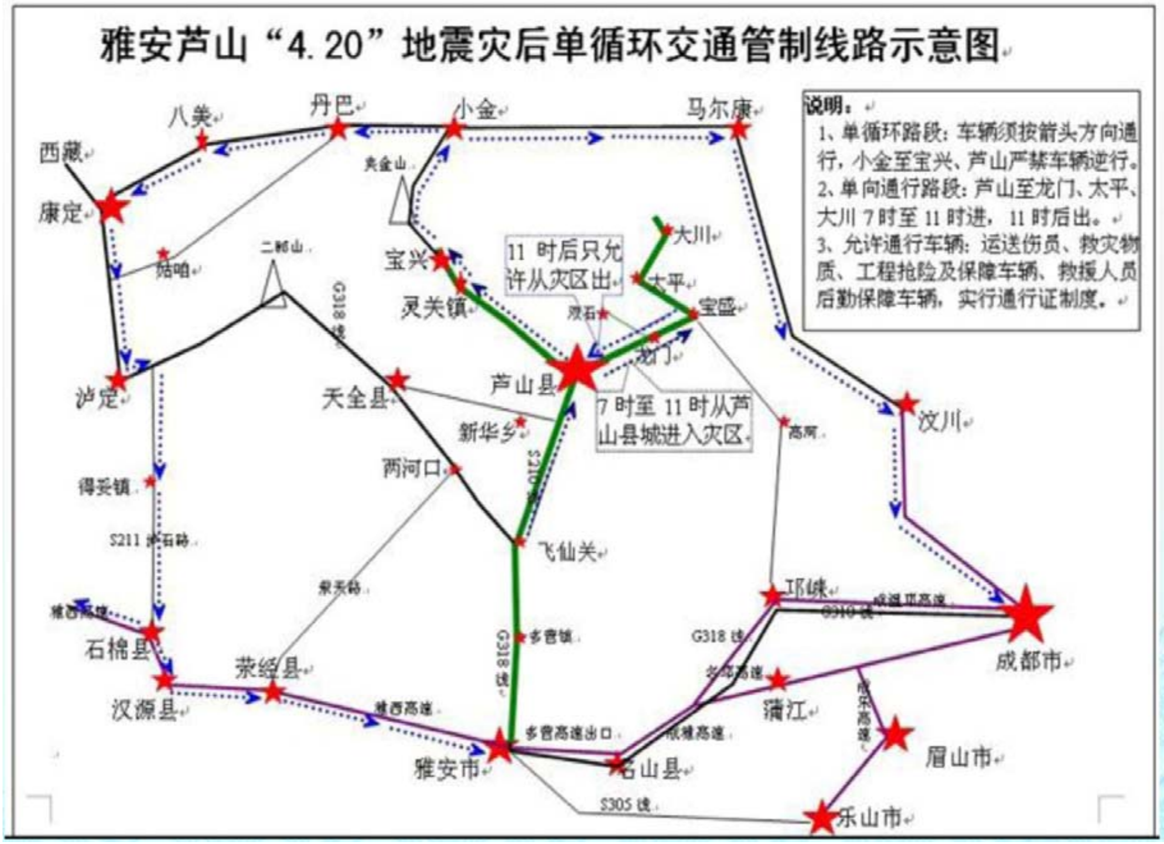

Fig. 7. Traffic control plan for Lushan area implemented after the earthquake due to landslides and rockslides (courtesy of Prof. Liu Aiwen).

Many of these buildings experienced damage, including partial or total collapse; examples of typical damage and partially or completely collapsed buildings are shown in Figures 8 through 11.

Fig. 8. Damage to Lushan County Government Building.

Fig. 9. Debris from collapsed building (Photo by Dr. Craig A. Davis).

Fig. 10. Damaged residential building of brick construction.

Fig. 11. Damaged building with roof collapse.

Older buildings clearly did not perform well in this earthquake. Under the older Chinese Building Code, buildings in the Chengdu region were designed for a ground acceleration of 0.10g. There is also an obvious lack of attention to detailing of connections, such as roof anchorage as shown in Figure 11. There is also common use of brick and mortar without adequate reinforcement or confinement as seen in Figure 12.

Fig. 12. Predominantly brick building without adequate reinforcement or confinement; note shear failures in wall at the second story.

After the Wenchuan earthquake, devastated towns like Beichuan and Yingxiu were essentially rebuilt. The new Beichuan town was relocated out of the mountains to a site on the plain. The new Yingxiu town was rebuilt near the old town. Both Beichuan and Yingxiu were essentially rebuilt. In the case of Lushan town, a new town area was constructed (or is in construction) to the south of the old Lushan town; however, the construction is more limited than in Beichuan or Yingxiu, and consists mostly of new government and institutional buildings as shown in Figures 13 and 14.

Fig. 13. Relatively new government building in New Lushan Town.

Fig. 14. Government building under construction in New Lushan Town.

The construction in the New Lushan Town should be governed by the updated seismic design requirements which were increased after the Wenchuan earthquake. It appeared from the exterior that the newer buildings had relatively less damage; however, as seen in Figure 15, the government building was found to be vacated with visible non-structural and minor structural damage. In the interior of the ground floor, ceiling tiles had fallen from a suspended ceiling and non-structural (infilled) walls were observed to be cracked.

(a) Front of Lushan County Building

(b) Damaged exterior tiles removed

(c) Development of hinges at joints

(d) Distress to ceiling tile and light fixtures; damage to non-structural walls. Photo by Dr. Craig A.Davis.

Fig. 15. Vacated Government Affairs Service Center of Lushan County People's Government Building.

There was one residential tower, about 20 stories in height, under construction with the reinforced concrete framing system essentially completed. This was observed from a distance but the construction did not appear to be affected by the earthquake.

The construction practice of using brick infill between beams and columns is quite prevalent in China. Figure 16 shows a new commercial building under construction which used this system; it can be seen that the infill is subject to out of plane failures as there is lack of reinforcement and inadequate confinement.

Fig. 16. New commercial building under construction with damage to brick infill.

One high point in the observations was the Lushan County People's Hospital Outpatient Building which experienced essentially no structural or non-structural damage during the earthquake; see Figure 17. The building is base isolated on 83 rubber bearings that are 500 to 600 mm in diameter (Best News, 2013a). It is reported that the building was completed in May 2012 and entered service in January 2013; there was no structural damage to the building and minimal impact on non-structural elements, glass or contents (Best News, 2013b). It was reported that some latex paint fell off and a few exterior tiles were shed during the earthquake. It was stated that the building was designed for seismic intensity VII, although it may have experience intensity of up to IX. The design and construction of the outpatient building was funded by the Macau SAR government.

Fig. 17. Base-Isolated Lushan County People's Hospital Outpatient Building. Photograph courtesy of Dr. Craig A. Davis.

Despite the seemingly excellent structural and non-structural behavior of the outpatient building, it was reported by Davis (2013) that water lines servicing the building from the outside were damaged because flexible connections were not provided at the isolation interface; electrical service was reportedly interrupted in the earthquake due to the powergrid going down; however, power cables to the building reportedly had sufficient slack across the isolation interface and did not break. It is unknown if the building had a back-up power system. It is questionable if the repairs to the water service have provided the flexible connections needed for a base isolation system.

In contrast to the outpatient building, other buildings at the County People's Hospital had substantial damage to structural and non-structural elements which caused the buildings to be vacated as shown in Figure 18. Although the structural frames appeared to be relatively intact, the infill and non-structural walls consisting of masonry elements sustained substantial damage. Suspended ceiling systems did not perform well as T-bars sometimes broke causing ceiling tiles and light fixtures to be displaced and sometimes falling down or left dangling.

It should be noted that since the earthquake occurred on a Saturday, classes were not in session and no schools were reported to have collapsed (UNICEF China 2013). However, classes in some parts of Lushan County were meeting in tents after the earthquake.

(a) Exterior of Lushan County People's Hospital

(b) Interior or Lushan County People's Hospital

Fig. 18. Lushan County People's Hospital, adjacent to Outpatient Building. Photos by Dr. Craig A. Davis.

Performance of Lifelines

Fig. 19. Temporary above ground water pipe (foreground).

Water service, electrical power, and telecommuni-cations and were interrupted by the earthquake and recovery was still in progress more than one month after the earthquake.

The underground water system was apparently severely damaged and above ground pipes were laid throughout the town providing water service as shown in Figure 19.

It was reported and observed during this visit that there was damage at water treatment facilities. One of these water treatment facilities had structural damage to support buildings and walls, but the treatment tanks did not appear to have any major damage although it appeared that some piping had been replaced. The control buildings were apparently reinforced concrete frame structures with masonry infill. The masonry infill failed in shear and sometimes failed out-of-plane. Repairs to these facilities were being undertaken at the time of visitation about five weeks after the earthquake and appeared to be mostly patching and returning the structures to essentially the pre-earthquake conditions at best; see Figure 20.

(a) Exterior of control building (b) Interior of control building

Fig. 20. Damaged water treatment plant control building in Lushan undergoing earthquake repairs.

Control equipment, storage tanks, and water treatment mixing equipment did not appear to have adequate bracing and some equipment showed evidence of displacement from their initial locations. There was no evidence that these facilities would be retrofitted to provide adequate bracing; see Figure 21.

(a) Inadequately braced chemical tank (b) Unbraced control equipment

Fig. 21. Inadequately or unbraced equipment at Water Treatment Plant.

It was reported that electrical power was lost in large parts of the region, including Lushan and Baoxing, as a result of the earthquake. In May 2013, the ASCE TCLEE team visited the State Grid Corporation of China Jinhua 110kV Transformer Substation which is one of several substations which provide power for the Lushan County region. There was severe damage to the structures and transformers at this facility as shown in Figure 22.

Fig. 22. Damage at the Jinhua 110kV Transformer Station. Photographs by Dr. Craig A. Davis.

It was also reported that hydropower plants were also affected (Sichuan Provincial People's Government 2013); Figure 23 shows a hydropower plant that was flooded and rendered inoperable at the time of the earthquake. In the mountains, downed power lines were caused by landslides which caused some transmission tower collapses as shown in Figure 24.

Fig. 23. Hydropower plant made inoperable by flooding. (Photograph by Dr. Craig A. Davis)

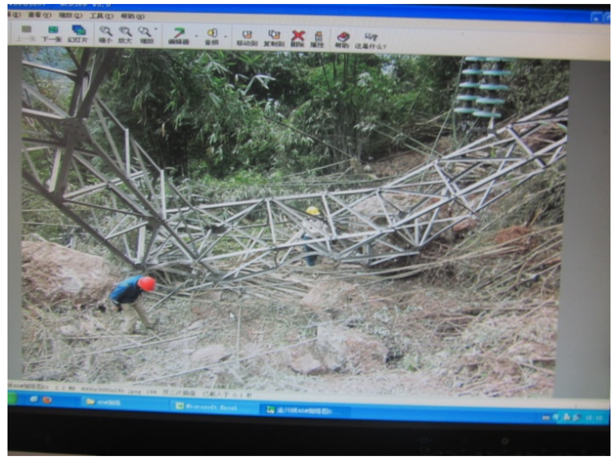

Fig. 24. Transmission tower collapse. (Photograph by Dr. Craig A. Davis)

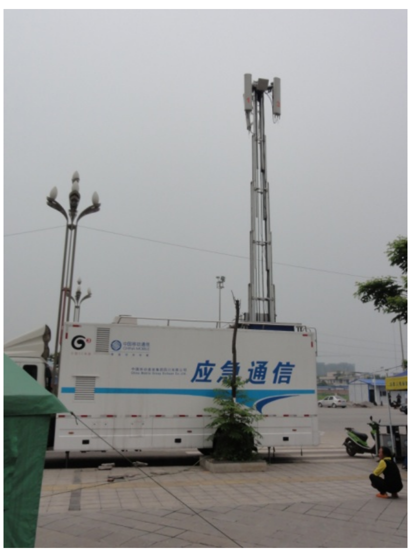

Fig. 25. COW in Lushan Town.

It was reported by Earthquake-Report.com (2013) that electricity was restored to Lushan County on Monday, April 22, two days after the earthquake. Restoration of the power grid to provide electrical service to all the affected counties was accomplished by May 10, 2013 (Newsking.us 2013). Repairs and improvements to the powergrid are on-going.

Mobile telephone service was disrupted by the earthquake. It is reported that China Telecom mobilized teams and equipment from Chongqing to provide service within a few days (Best-news.us, 2013c). As of May 28, mobile phone service in the affected region was still being provided with mobile cell towers, sometimes referred to as COWs or "cell on wheels" as shown in Figure 25.

Emergency Response

The China central government received much criticism during the Wenchuan earthquake for a slow response to the natural disaster. However, in the Lushan earthquake the central government and the People's Liberation Army (PLA) were mobilized within hours (South China Morning Post, 2013). Relief personnel consisted of the military, armed police and central government agencies including personnel from the China Earthquake Administration, the ministries of civil affairs and public security, and government-backed charities. Almost 7,500 PLA soldiers and armed police were sent to the disaster zone the day of the earthquake and 10,000 others were available on standby. The China Air Force used two reconnaissance aircraft from Beijing to take aerial photographs of the earthquake-ravaged area along with five civilian drone aircraft to survey the area. Civilian aircraft were chartered to bring in relief supplies. The Red Cross Society of China rushed supplies from Chengdu to the affected area, including 1,700 tents. A number of non-government organizations (NGOs) also mobilized quickly, but the leads for relief operations were the central and provincial governments. The new Chinese Premier Li Keqiang arrived in Lushan several hours after the earthquake to direct the emergency response and called for an all-out effort to rescue survivors (NTD News 2013). Efforts to rescue people from collapsed buildings in the affected region were hampered because some more remote communities in the mountains were cut off because of blocked roads, collapsed bridges, fallen boulders and landslides.

Long Term Recovery

In July, the State Council issued the “Lushan earthquake restoration and reconstruction plan” (China Meteorological Administration 2013). This plan is to establish and improve the comprehensive emergency response system; this includes: disaster relief; monitoring, early warning and forecasting; and improving disaster prevention emergency planning. The goal is to improve the management of disaster information collection, transmission and processing as well as to promote information integration, intelligent processing and sharing of services for disaster prevention and mitigation. The plan includes an educational component to “popularize the knowledge of disaster prevention and mitigation.” Public awareness of prevention and mitigation are to be improved and disaster emergency drills are included. The plan requires reconstruction of meteorological observation stations and emergency response systems that were damaged. The plan calls for construction of new emergency broadcasting platforms, a national disaster recovery data center, and Sichuan satellite disaster reduction application center.

The plan also states the goal that within three years, every family in the earthquake-hit region will have an apartment, and every family with members capable of working will have a least one job, while living areas in the rebuilt areas will be better than before the earthquake. The funding of the reconstruction plan would come from government fiscal spending, as well as from donations and foreign loans (People’s Daily Online 2013). The cost is for the reconstruction is estimated to be up to 86 billion Yuan ($13.9 billion USD). Companies and individuals participating in post-earthquake reconstruction would receive tax breaks and preferential land and financial measures would be available to support the rebuilding.

The reconstruction plan also calls for relocation of families currently living in high risk regions that are subject to “geological disasters.” The plan also recognizes the “natural beauty of the landscape and biological diversity of the area.” (This is the habitat of the giant panda.) The plan sets tourism as the priority industry in reconstruction and a significant portion of the rebuilt area will also be a “biological protection zone.” The reconstruction plan includes a comprehensive study of possible natural disasters in quake-affected regions; these include strong rainstorms and severe drought which can cause “potential geological disasters.” An audit plan is also part of the program to assure that reconstruction funds will not be subject to graft and other abuses.

Conclusions

One could easily dismiss the value of the lessons learned from the Lushan earthquake by saying that no new knowledge was gained and that what was seen in this event was déjà vu again. However, with the changes instituted in construction requirements since the Wenchuan earthquake, there is an opportunity to examine what happened and what did not happen as comparisons in behavior are now possible as there are old (pre-Wenchuan) construction nearby the newer (post-Wenchuan) construction. Although the strong motion records stations are not as close to the earthquake source as would be desired, the recordings could be very useful in calibrating the structural performance of old and new construction. The recordings could also be valuable in determining if the changes to the building requirements made after Wenchuan were sufficient or not.

Much can also be learned about the almost immediate Chinese response to the disaster. Hopefully the good things can be applied to emergency response in the United States.

Acknowledgements

Special thanks to Dr. Craig A. Davis, Dr. John Eidinger and Mr. Alex Tang of the ASCE TCLEE Reconnaissance Team for providing the author the opportunity to accompany them on their reconnaissance mission to Lushan County. Greatest appreciation is given to Prof. Liu Aiwen of the Institute of Geophysics, China Earthquake Administration in Beijing, China for providing technical information about the earthquake.

References

Best News (2013a). “Lushan Hospital outpatient building after the earthquake intact.” Accessed on September 7, 2013 at http://www.best-news.us/news-4391701-Photo:-the-Lushan-Hospital-outpatient-building-after-the-earthquake-intact-expert-analysis-isolation-technology.html.

Best News (2013b). “83 rubber bearings dealt with gently from the top-Lushan.” http://www.best-news.us/news-4428683-83-rubber-bearings-dealt-with-gently-from-the-top-Lushan.html.

Best New (2013c). “China Telecom Chongqing rush to the rescue Lushan earthquake zone.” April 29. Accessed on September 8, 2013 at http://www.best-news.us/news-4403072-China-Telecom-Chongqing-rush-to-the-rescue-Lushan-earthquake-zone-rescue-Record.html.

China Meteorological Administration (2013). “Lushan earthquake reconstruction to strengthen disaster monitoring and forecasting.” Accessed on September 9, 2013 at http://www.cma.gov.cn/en/NewsReleases/News/201307/t20130717_220046.html.

China Strong Motion Networks Center (2013). “四川雅安芦山县7.0级地震（第五报）.” [Translated as Lushan County, Ya'an, Sichuan 7.0 earthquake (fifth report)]. Accessed on September 6, 2013 at http://www.csmnc.net/selnewxjx1.asp?id=797.

Earthquake-Report.com (2013). “Deadly earthquake Sichuan (Ya’an), China – Death toll now at 196 dead (21 missing) + April 26 update.” Accessed on September 8, 2013 at http://earthquake-report.com/2013/04/20/very-strong-earthquake-sichuan-china-on-april-20-2013/.

International Federation of Red Cross and Red Crescent Societies [IFRC] (2013). "Disaster relief emergency fund (DREF) – China: Sichuan Lushan Earthquake." April 25.

NTD News (2013). "Difficult rescue efforts in Lushan earthquake epicenter." Accessed on September 9, 2013 at http://www.ntd.tv/en/news/china/20130422/78730-difficult-rescue-efforts-in-lushan-earthquake-epicenter.html.

Newsking.us (2013). "Sichuan – the Lushan earthquake area grid basically returned to the level before the earthquake reconstruction start." Accessed on September 8, 2013 at http://www.newsking.us/news-4465092-Sichuan-the-Lushan-earthquake-area-grid-basically-returned-to-the-level-before-the-earthquake-reconstruction-start.html.

People's Daily Online (2013). "Lushan post-quake work to cost nearly $14b." Accessed on September 9, 2013 at http://english.peopledaily.com.cn/90882/8328007.html

Sichuan Provincial People's Government (2013). "Sichuan provincial government held a second press conference – April 20, 2013." Accessed on September 8, 2013 at http://www.sc.gov.cn/10462/10705/10707/2013/4/20/10257632.shtml.

South China Morning Post (2013). "PLA shows quick response to Lushan earthquake." April 21. Accessed on September 8, 2013 at www.scmp.com/news/china/article/1219509/pla-shows-quick-response-lushan-earthquake.

UNICEF China (2013). "Lushan Earthquake Situation Report #1, 22 April 2013."

Xinhuanet (2013). "Lushan quake prompts disaster preparedness discussion." Accessed on September 8, 2013 at http://news.xinhuanet.com/english/china/2013-04/27/c_124642791.htm.

Xu, X.W., Wen, X.Z, Han, Z.J., Chen, G.H., Li, C.Y., Zheng W.J., Zhang, S.M., Ren, Z.Q., Xu, C., Tan, X.B., Wei., Z.Y., Wang, M.M., Ren, J.J., He, Z.T. and Liang, M.J. (2013). "Lushan Ms7.0 earthquake: A blind reserve-fault event." Chin Sci Bull, 58, doi: 10.1007/s11434-013-5999-4.

Yueqiao, Z., Shuwen, D., Chuntang, H., Jusong, S., Zhonghai, W., Hailong, L., Ping, S., Gang, L. and Jian, L. (2013), "Seismogenic Structure of the April 20, 2013, Lushan Ms7 Earthquake in Sichuan." Acta Geologica Sinica - English Edition, 87: 633–645. doi: 10.1111/1755-6724.12075.