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ORIGINAL PAPER

Reconnaissance report on buildings damaged during the Lushan earthquake, April 20, 2013

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Abstract At 8:02 am on April 20, 2013, an earthquake with a magnitude of seven on the Richter scale occurred in Lushan County, Sichuan Province, China. This paper describes the investigation of the damage to buildings in quake-hit areas. By comparison with "5.12" Wenchuan earthquake that occurred in the same region 5 years ago, the damage modes of the buildings have been analyzed. Public buildings, most of which were reconstructed after the Wenchuan earthquake, exhibited a good performance in regard to the main structures. However, severe damages were identified from non-structural elements. The performance of frame structures supported on rubber isolators was examined, and very few cracks from the infilled walls were observed, unlike the other frame structures. Rural housing suffered extensive damage during this earthquake, due to inadequate structural systems for horizontal-force resistance, lack of construction supervision, and insufficient ground treatment, all of which lead to the tragic destruction. Conclusions were given by presenting several suggestions to enhance the seismic behavior of rural housing.

Keywords Earthquake · Field investigation · Building damage · Public buildings · Rural housing

1 Introduction

At 8:02 am on April 20, 2013, an earthquake of 7.0 magnitude on the Richter scale occurred in Lushan County, Sichuan Province, China (latitude 30.0 north, longitude 103.0 east). The

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focal depth of this earthquake was 13 km and the maximum intensity reached the ninth degree on the 12-degree scale. The earthquake epicenter was about 100 km from Chengdu, the biggest city in Southwest China. The intensity map published by the China Seismological Bureau is shown in Fig. 1 (4.20 Lushan Earthquake). The earthquake affected an area of 18,682 km^2 and caused 196 fatalities, 21 people missing, and 11,470 people injured. The direct economic loss was estimated at about 20 billion RMB. Up to 8:00 am on April 22, 2013 aftershocks were recorded, the maximum reaching a magnitude of 5.4.

From Fig. 1, the quake-affected zone is in the northeast direction. The area of the maximum intensity (ninth-degree zone) is 208 km^2 where the long radius and short radius are 11.5 and 5.5 km, respectively. The area of the eighth-degree zone is 1,418 km^2, with a long radius of 29 km and short radius of 17.5 km. For the seventh- and sixth-degree zones, the area of 4,029 and 13,027 km^2 was measured, respectively.

It was reported by the Chinese National Strong Motion Network Center that over 80 stations in Sichuan, Yunnan, Gansu, and Shanxi provinces recorded the ground motions during the "4.20" Lushan earthquake. Among all the recordings, 15 records with ground peak motion (GPA) were greater than 200 gal, and 12 records had GPA between 100 and 200 gal, 6 between 50 and 100 gal to 16 between 25 and 50 gal.

Two stations (named as YAM and LSF), located in the eighth-degree zone in the Minshan district of Yaan and Lushan County (Fig. 2), had GPA records with 400 and 387 gal, respectively. Their acceleration components in the east–west, south–north and the vertical directions, as well as the response spectra are shown in Fig. 3. The response spectra corresponding to the design earthquake level and rare earthquake level at the station zones are drawn in the same figure. Compared with the spectra, the pseudo-acceleration of this earthquake was about three to four times higher than that of a rare earthquake (giant earthquake) in a short period of less than 0.5 s. In the long period, however, it is similar to the level of the design earthquake (medium earthquake). It implies that the Lushan earthquake would affect low story buildings with large stiffness more seriously than the frame system buildings with longer periods. On the other hand, based on the record analysis, it is found that the peak ground velocities (PGV) are of low level by comparing with the PGA, i.e., 13.30 and 13.83 cm/s PGVs for the YAM and LSF stations, respectively. In the Chinese Seismic Intensity Scale (GB/T 17742), a PGV of 13 cm/s is categorized as a seventh-degree zone, whereas a PGA of 400 gal, reaches the ninth-degree zone. It poses a question as to which index, PGA or PGV, is more relevant to represent the earthquake intensity. From the site observations near the stations, the buildings designed for seventh-degree earthquakes were not damaged as severely as those would be expected in a ninth-degree zone. It implies that the PGA is not the best index for representing the effect of earthquakes on buildings, whereas the PGV or other indices should be considered in the next version of the seismic codes.

After the Lushan earthquake, a comprehensive damage investigation of 23 villages/towns of Mingshan, Yucheng, Lushan, Baoxing and Tianquan has been conducted by a reconnaissance team from the Western China Earthquake and Hazards Mitigation Research Centre at Sichuan University. The investigation covers all the ninth-degree zones and partial eighth and seventh-degree zones that have been affected significantly during the earthquake. In this paper, important observations and damage analysis of both public buildings and residential housings are presented according to the reconnaissance assessment. Since most of the areas affected by the Lushan earthquake have suffered the "5.12" Wenchuan earthquake 5 years ago along the Longmenshan Fault, comparisons and discussions between the two seismic events are presented and several suggestions on improving the seismic resistance for local structures are proposed accordingly.

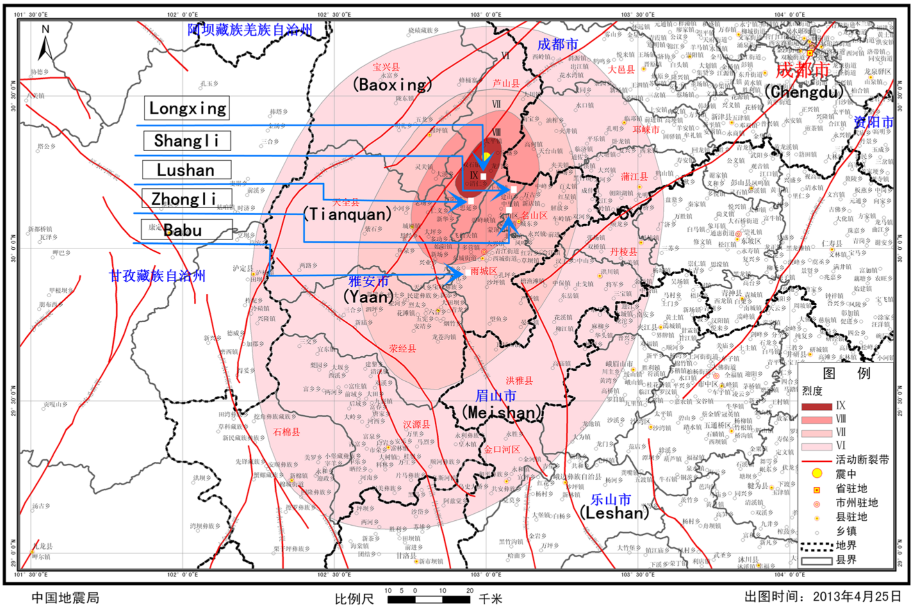

Fig. 1 "4.20" Lushan earthquake intensity map (4.20 Lushan Earthquake)

2 Investigation on public buildings

2.1 Damage to public buildings

Due to the time limit of the reconnaissance activity, discussions on the public buildings in this paper only focus on schools, hospitals, and office buildings. Further studies could be conducted on gyms, cinemas, and other large-span structures. In the China Earthquake Intensity Map, the quake-hit area is categorized as a seventh-degree zone (Basic acceleration of ground motion is 0.1–0.15 g), except Baoxing, which is in the eighth-degree zone (0.2 g). From this point, the worse-hit area (8th- and 9th-degree) suffered greater earthquake impacts than the design earthquake intensity.

The public building structures in this area are primarily made of reinforced concrete frames, with masonry infill, of three to five stories. Most of them were built following the 2010 seismic code (GB50010, GB5003, GB50023) after the Wenchuan earthquake, with good construction quality. Since the Wenchuan earthquake caused severe damage and heavy casualties in school buildings 5 years ago, enhancement has been given for public buildings in the updated seismic codes, i.e., schools and hospitals. Therefore, the reconstructed public buildings generally have good seismic behavior, as proven from the statistical data mentioned in the previous section.

From the site observations, damage still could be identified from some public buildings. It can be concluded as: (1) The main structures were in good condition, no complete or partial collapse occurred, and only cracks at column ends were seen in very few buildings. The design target of "no collapse in rare earthquakes" was achieved. (2) Masonry infill walls were badly damaged. In most public building frames, infilled partitions and external walls cracked extensively or collapsed. These buildings were not able to be used

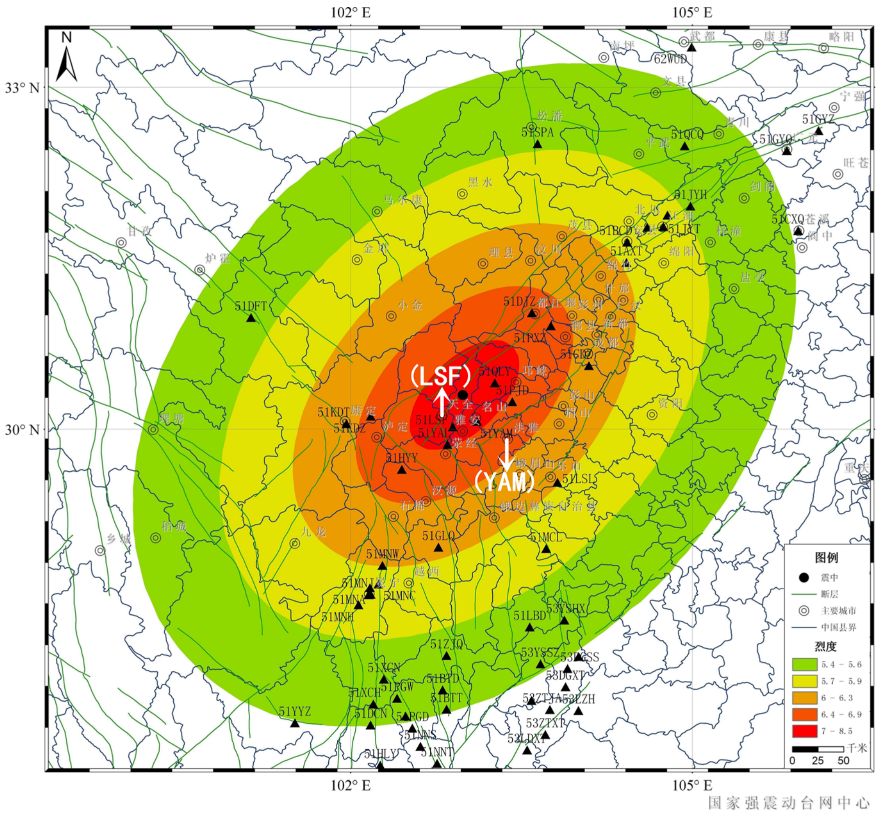

Fig. 2 Locations of LSF and YAM stations in the Lushan area

immediately and must be retrofitted. It is a huge loss for some lifeline buildings, i.e., hospitals. (3) Severe damages were also captured from other non-structural components, i.e., ceilings or roof parapets. There are no specific seismic construction codes for ceilings in China, and the connections attached to the structures were very weak. During this earthquake, ceilings collapsed extensively in schools and hospitals. (4) The collapse of the structure on both sides of the seismic joints can be observed in some buildings with irregular plane shapes which use the seismic joints for separation into regular elements. The damage adjacent to the joints indicated inadequate widths of joints. (5) Most roof towers suffered more serious damage than the main structures. The exterior walls of some towers collapsed, and some structural components cracked severely. (6) The extensive damage of the non-structural components was responsible for the very weak connections that did not met the requirements, i.e., the constructional columns inside the roof parapets indicated that too few were used, there was a lack of strengthened columns inside the infilled walls, and the anchorage length of the rebars inside the constructional columns were insufficient. It can be concluded that with the damage to the frame buildings during the Wenchuan earthquake in the same intensity area, the performances of the frame structures improved significantly and the damage to school buildings decreased. However, the problems in non-structural components, seismic joints, and roof towers are still not solved.

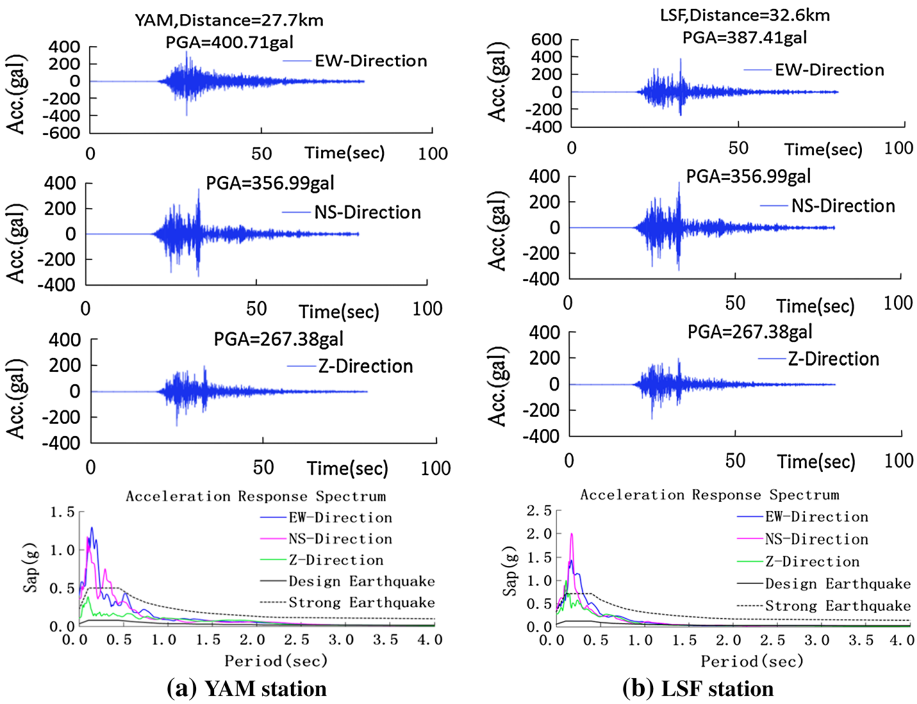

Fig. 3 Acceleration time histories and corresponding spectra. **a** YAM station, **b** LSF station

2.2 Typical cases of damage to public buildings

After the "5.12" Wenchuan earthquake in 2008, a 3-year reconstruction plan has been carried out. In order to solve the funding shortage, the Chinese government created the "aided construction in counterparts" plan and assigned some developed provinces to help counties in the Wenchuan area. Therefore, almost all schools or other public buildings were aid-constructed within a short period. Typical examples of these kinds of buildings were shown as follow.

As shown in Fig. 4, the Red Cross school in Longxing Village was aid-constructed by the Hong Kong Red Cross Organization in 2010 and was located in a ninth-degree zone of this earthquake. The teaching building consisted of a four-story main frame structure and a seven-story tower (Fig. 4a). No partition walls were built on the ground floor, and there were classrooms from the second to the fourth floors. Significant damage could be found in the tower, and the hedge on the top two floors collapsed completely. The water tank on the top floor was badly damaged. The partition and exterior walls cracked extensively and collapsed in parts (Fig. 4b). Cracks occurred in the column heads and foots and formed the typical plastic hinges. Damage on the columns of the ground floor was also observed (Fig. 4c). It can be concluded that the huge seismic intensity (ninth degree) could be a factor causing the column damage. However, the damage to the tower was responsible for the whiplash effect. The slender tower had a very weak lateral stiffness that can be easily damaged during the earthquake. This school had the most severe damage in the reconstruction projects covered in the whole investigation activity. Although the main structure

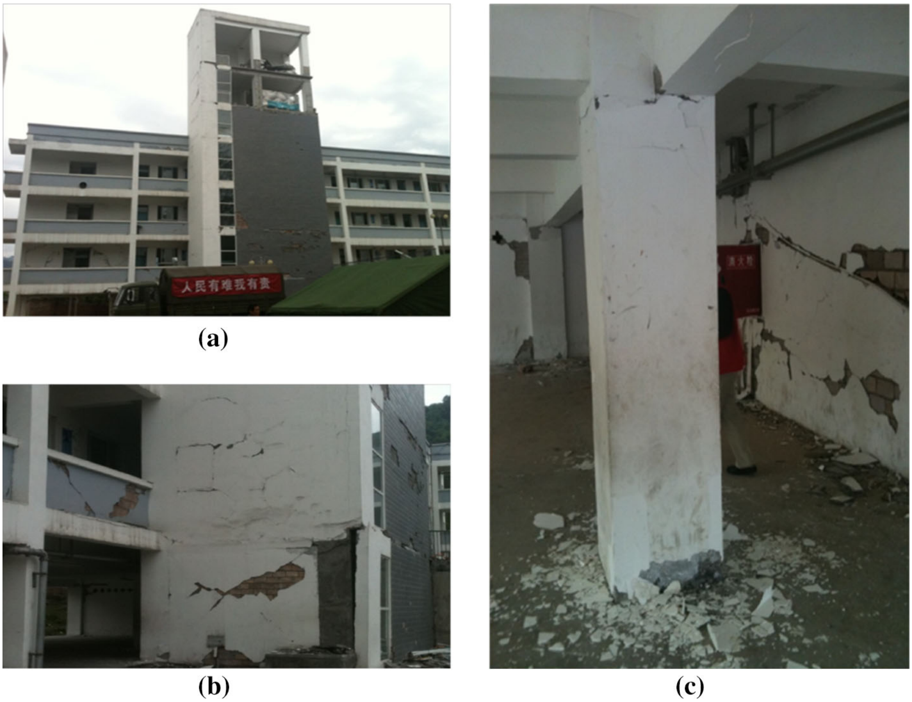

Fig. 4 Red Cross School in Longxing Village

survived, the complete rehabilitation work is needed, and reconstruction is being considered.

The middle school of Lushan is located in a eighth-degree zone and was aid-reconstructed by the Macao Government in May 2012, as shown in Fig. 5. It is primarily composed of a teaching building (10,647 m^2) and a complex building (2,891 m^2). Both are frame structures designed for eighth-degree earthquakes. More than 300 students were having classes on April 20, but fortunately, no injuries were identified. The main structure stayed sound after the earthquake, but the infilled walls were badly damaged (Fig. 5a, b), and the parapets on the roof collapsed completely. It could be explained that the high parapet has inadequate anchorage (Fig. 5c). Besides, the complex building used a roof truss structure and a few members buckled (Fig. 5d).

The Shangli Middle School also located in the eighth-degree zone was expanded after the Wenchuan earthquake (Fig. 6a). The teaching building was constructed in two phases, the left part was a single-span frame which was built in 2004 and designed by following the old codes, while the right part was a two-span frame which was built in 2011. Since a single-span frame structure is prohibited in the updated design code after the Wenchuan earthquake, one more row of columns was required in order to construct a two-span frame in the new part of the building. The old part was damaged badly in that the infilled walls were totally destroyed, and slight structural damage was also found on the columns (Fig. 6b, c, d). In comparison, the new part of the building worked well with only few cracks on the infilled walls (Fig. 6e). As both parts of the same building exhibited distinct contrasts, it indicates that single-span frame structures have poor performance.

Fig. 5 Lushan Middle School

As shown in Fig. 7, the Lushan People's hospital is primarily composed of an outpatient building complex, an old outpatient building, and a hospitalization building. The three buildings were purposely put together to form a shape of "品", a Chinese character. Among them, the new outpatient building complex (7,995 m^2) was put into use in 2011, and it has seven stories above the ground and one-story underground. The structure is a frame structure and is supported on rubber isolators; in total, 83 isolators were set for the whole building. After experiencing this 7.0 magnitude earthquake, the isolation system showed excellent performance. Only a few cracks were detected on the infilled walls, and the ceiling stayed intact (Fig. 7a, b). Moreover, no medicine fell from any of the medicine cabinets, demonstrating the small displacement of the superstructure. The pipeline system was relatively good, the elevator and the air condition equipment installed on the top floor remained in normal operation. However, the cover on the isolation gutter surrounding the building was damaged, indicating that the building experienced great horizontal displacement on the base isolation floor (Fig. 7c). In the field investigation, some slight damage corresponding to the isolation floor was found, such as cracks in a staircase over the isolation floor, local damage on pipes without flexible joints (Fig. 7d). It exposed problems in the detailed design of the isolation building, as shown in Fig. 8. Infilled walls on the ground floor were badly damaged, and the ceilings collapsed extensively (Fig. 8a, b). In a sharp contrast, the other two adjacent buildings suffered severe damage. In the hospitalization building, cracks were detected in a few columns (Fig. 8c). After the earthquake, patients were moved out from the hospitalization building and lived in temporary tents due to the significant damage in the building. Reconstruction of the building is being considered.

Fig. 6 Shangli Middle School

2.3 Some thoughts about the performance of public buildings

1. The frame structures in eighth- or ninth-degree areas of the Lushan earthquake experienced an earthquake greater than the design level, but still showed good performance and achieved the seismic targets. It proved the validity of enhancing the seismic detailing for public buildings by the Chinese engineering community after the Wenchuan earthquake 2008.
2. Non-structural components in public buildings were severely damaged, even in seventh-degree zones (the design level). No improvement was indicated in the reconstructed buildings after the Wenchuan earthquake. Damage to the infilled walls, parapets, and ceilings could be widely found in the buildings, which brought huge losses and required large funding for retrofitting. Specifically, for some lifeline buildings, such as hospitals, the serious structural damage affected life-saving efforts during the earthquake. Therefore, the non-structural components require great improvement. Analyzing the exposed damage modes, part of the damage was

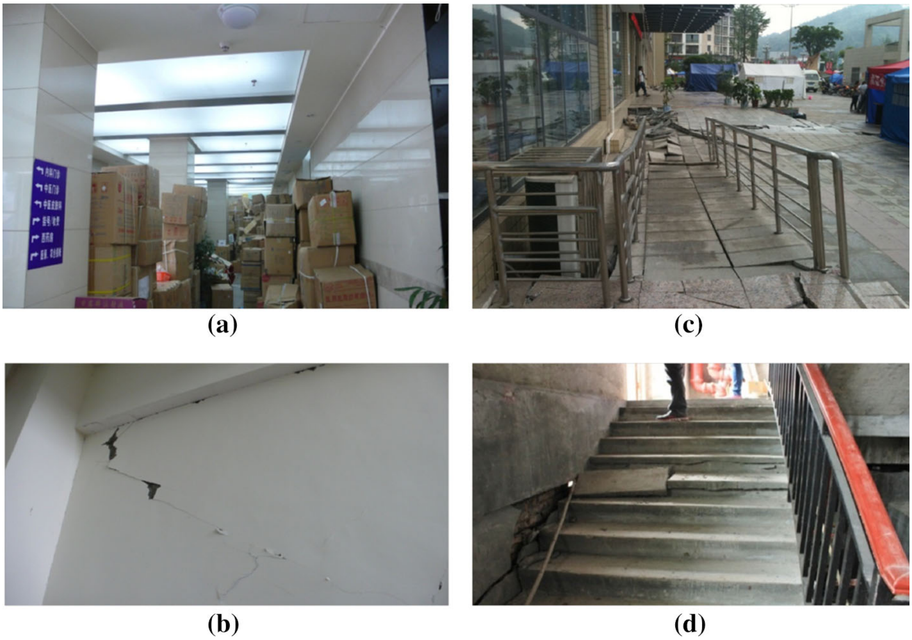

Fig. 7 New outpatient building complex of Lushan Peopole's hospital

Fig. 8 Hospitalization building of Lushan People's hospital

contributed by not strictly conforming to the requirements of the seismic code (GB5011), i.e., lack of detail in connections to the main structure. However, most parts of the damage were due to the inherent vulnerability of the masonry system. Masonry walls do not have adequate deformation ability as frames and easily crack when earthquakes occur. It is necessary to develop some new systems for infills and ceilings to reduce the damage.

3. The new outpatient building demonstrated a good example of an isolated building. It is the first new project to experience a real earthquake of 7.0 magnitude. The design should be applied extensively on schools and hospitals. On the other hand, the detailing of isolated buildings needs to be improved, such as the isolation gutters, flexible pipe joints, and structural members passing through the isolation floor. It is necessary to instruct the owners of isolated buildings how to ensure good maintenance and correct use.

3 Investigations on residential houses

The residential houses in rural regions in China are generally self-built, and lack construction supervision. The structures are made of un-reinforced masonry, confined masonry, masonry and timber or timber and have inadequate seismic resistance. Current houses generally use confined masonry in reinforced columns and beams. During the Wenchuan earthquake in 2008, residential houses suffered the most severe damage and taught the people a great lesson. In 5 years, however, the situation has not changed. As mentioned previously, a total of 205.3 thousand houses were severely damaged in the Lushan earthquake, some of which were newly constructed or even still under construction.

After the earthquake, Sichuan University sent a team of 50 staff and students to help in damage assessment for nearly twenty thousand residential houses in 19 towns and villages in Yucheng district, Ya'an city. Yucheng covers an area of 1,067 km^2 and has 320,000 residents. It experienced seventh- and eighth-degree shocks. The team evaluated the structural safety based on "Guidelines for damage assessment of rural housings in Sichuan." There are four categories, 1 (slight damage), 2 (medium damage), 3 (severe damage), and 4 (collapse). Tables 1 and 2 show the typical statistical data of damaged buildings, and it can be seen that almost all the houses suffered damage. The tragic disaster caused thousands of people to become homeless. It is estimated that the reconstruction plan would need funding of 20 billion RMB. China has large rural areas and rural houses without seismic resistance ability will be a significant potential risk in the future.

From the site investigation, the damage modes to rural houses in this earthquake can be concluded as follows.

1. Lack of structural systems for horizontal-force resistance. Since there was no strict design for most self-built houses, the structural columns and beams were arranged only to support the upper floor weight without considering the horizontal-force resistance. Figure 9 shows some typical rural houses, in which the whole structure was supported by the weak frame on the ground floor (Fig. 9a). On the ground floor, there were few lateral walls and no front longitudinal wall, while the back longitudinal wall only had a thickness of 120 mm. The column section was insufficient, only 250 mm $\times$ 250 mm, and caused the weak lateral stiffness (Fig. 9b). The second floor was of masonry structure without or lacking confining columns and ring beams. When the earthquake occurred, either the columns or infill walls on the ground floor cracked or the masonry

Table 1 Percentage of damage to buildings in villages of Zhongli Township (eighth-degree zone)

	Slight damage (%)	Medium damage (%)	Severe damage (%)	Collapse (%)	Percentage of damage
Longquan Village	5	25	60	10	100
Fuxing Village	15	30	50	5	100
Zhongli Village	15	37	45	3	100
Zhengwan Village	40	27	27	1	95
Zhanggou Village	40	27	27	1	95
JIanqiang Village	60	20	9	1	90
Jianxin Village	60	20	9	1	90

Table 2 Percentage of damage to buildings in villages of Babu Township (eighth-degree zone)

	Number of families	Slight damage (%)	Medium damage (%)	Severe damage (%)	Percentage of damage
Fengbu Village	399	232/58.1	129/32.3	38/9.5	100
Lijia Village	324	177/54.6	132/40.7	15/4.6	100
Babu Village	748	420/56.1	292/39.0	36/4.8	100
Shigang Village	412	212/51.5	156/37.9	44/10.7	100

walls on the second floor collapsed (Fig. 9c, d). The confused and poor structural system is the main reason for the severe damage to rural houses.

2. Lack of construction supervision resulted in the poor quality of the self-built houses. The strength of the concrete material generally did not satisfy the design standard, and the amount of rebar was less than many of the designs actually required. The structural members were also of poor strength. Therefore, the reinforced concrete members were destroyed extensively in rural houses during the earthquake (Fig. 10a–d). This is rare in public buildings in big cities.
3. Inadequate ground treatment caused foundation settlement and walls to crack. In Sichuan, rural houses are normally constructed on homesteads, and when encountering soft soil, people often construct houses directly on the natural soil with no special ground treatment. It caused the foundation failure or the damage to the superstructure (GB5007).
4. Inadequate ground treatment caused the foundation settlement and the walls to crack. The majority of the rural areas in Sichuan consist of mountains, where the rural houses are normally constructed, and most of these areas are located in either sloping fields, river valleys, or former farmland. Therefore, the foundation reinforcement treatment in terms of the foundation conditions was not properly considered before the construction of the superstructure (GB5007).
5. The residents were lacking in safety awareness. The seismic capacity of the houses was reduced by adding a floor or attaching side rooms improperly. These side rooms and towers were destroyed extensively during the earthquake.

Fig. 9 Typical rural house structures and consequent damage

4 Discussion

4.1 Comparison with the Wenchuan earthquake along the same fault line

On May 12, 2008, a massive 8-magnitude earthquake hit Wenchuan County, adjacent to Lushan. The focal depth of this earthquake was 15 km, and the maximum intensity reached the eleventh degree on the 12-degree scale. It affected an area of 440,442 km^2 of 900 km length and 600 km width. The Wenchuan earthquake caused 69,197 deaths, 18,341 missing, and 374,171 injured, and it was estimated that about 5.36 million rooms collapsed. The direct economic losses have reached 845.14 billion RMB. Only 5 years later, the Lushan earthquake of 7.0 magnitude occurred in the same zone, causing great concern to researchers. Both earthquakes were 85 km from the epicenter and occurred along the same fault, the Longmenshan Fault, which is of 500 km length and 70 km width and runs along the base of the Longmen Mountains in Sichuan Province in Southwestern China. Motion along this fault is responsible for the uplifting of the mountains relative to the lowlands of the Sichuan Basin to the east. Representing the eastern boundary of the Qinghai-Tibet Plateau, the Longmenshan fault is a border formation between the Bayan Kola block in the Plateau and the South China block in the Eurasian Plate. The Wenchuan earthquake occurred in the middle of Longmenshan fault and the crack length was 330 km, whereas the Lushan earthquake was in the south section of the fault and the crack length was less than 40 km. The distance between the aftershock zones of both quakes was 50 km. The mechanism of both quakes was by upthrusting and the crack directions veer to the

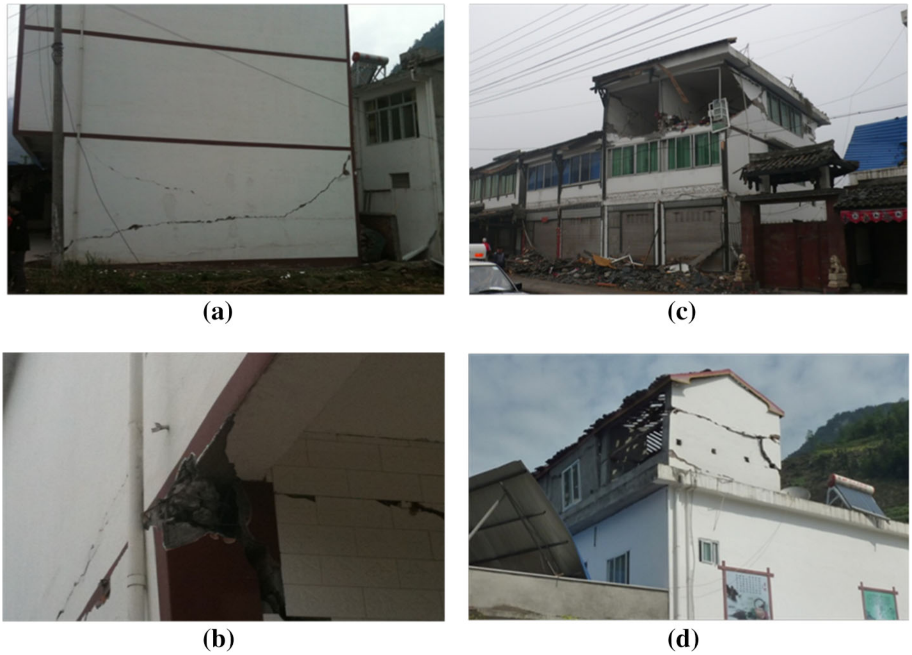

Fig. 10 Damage modes of self-built houses

northeast. However, the devastation of the Lushan earthquake was not as severe as the Wenchuan earthquake since the casualties and economic losses were lower. Most scientists consider the Lushan earthquake to be an independent earthquake along the same fault, and not an aftershock of the Wenchuan earthquake. Some scientists, however, insist that the Lushan earthquake is an aftershock of the Wenchuan earthquake, occurring along the same fault line and in close proximity. The relationship between the two quakes is still a controversial topic in academic circles, even today.

However, in the civil engineering community, there is more interest in the damage to the buildings in the Lushan quake-hit area. The area hit by this earthquake was also hit by the Wenchuan earthquake 5 years earlier, and many buildings suffered serious damage, leading to a reconstruction plan being carried out during the last 5 years. Most public buildings were recently built and were designed, constructed, and supervised according to the new seismic codes (JGJ03). The Lushan earthquake was a real test for the new buildings.

Investigations show that 96.2 % of public buildings could still be used after the earthquake or with partial rehabilitation. Altogether 2,345 buildings with average areas of 387.2 m^2 were evaluated, including schools, hospitals, gymnasiums, and office buildings, and it was found that their main structures remained sound after the earthquake. Among the 2,345 buildings, 45 % of them could be used immediately, 51.2 % needed inspections and rehabilitation, and only 3.8 % were damaged severely. Comparing to the public buildings constructed before the "5.12" Wenchuan earthquake, near 72.3 % of them required repair and rehabilitation, and Lushan County had an even bigger number, 83.8 %. It demonstrates that the seismic behavior of reconstructed public buildings has indeed been enhanced.

Although public buildings exhibited good behavior, self-built houses suffered severe damage. In the worst hit towns, the earthquake caused 49,500 residential housings to be damaged, collapsed, or destroyed. Among them, more than 97.5 % houses in Luyang town were badly damaged or destroyed with no rehabilitation value. Only 2.5 % of the housing remained sound or suffered slight damage. The damage in the Lingguan town of Baoxing was much more severe, with 97.9 % damage and only 2.1 % undamaged. In the villages, the situation was worse. The investigation indicated that the farmhouses in Longmen, Qingreng, Baosheng, Shuangshi, and Taiping were completely destroyed. Among the 177 farmhouses in the Luojia villages of Baoxing, only one single house could be used while the rest were damaged, with no rehabilitation value. In summary, nearly 155,800 farmhouses were destroyed in the whole quake-hit region. The data shows the very poor seismic behavior and inadequate construction detailing for self-built houses in Chinese rural regions.

4.2 Suggestions on improving the seismic capacity of self-built housing in rural areas

The recent large earthquakes that occurred in western China, including the Wenchuan earthquake in 2008, Yushu earthquake in 2010, Lushan earthquake in 2012, and the Dingxi earthquake, indicating that the main causes of many casualties and extensive loss of property were the collapsing and damage of self-built housing in rural areas. Even though the local people have seen the destructive results from past earthquake experiences, the safety problem of self-built housing has still not been resolved due to both economic and social factors. In Sichuan Province, for example, there are approximately 45 million rural population and 14 million households. Apart from the 15 million reconstructed housing after "5.12" Wenchuan earthquake and the 0.8 million newly constructed housing near Chengdu City, the rest 11.7 million houses still remain unprotected. The evaluation of the current state of rural housing demonstrates that more than 70 % (8 million) of rural housing has shown a weak seismic capacity, which cannot meet the basic requirements of current seismic codes and badly needs reinforcement and reconstruction.

With the development of the Chinese economy, more investment and attention should be paid on housing quality. To nip the future damage caused by an earthquake in the bud, the government should spend more money to improve the safety of rural housing, rather than spending a lot of money on reconstruction and disaster relief. To improve the safety performance of rural housing in Sichuan, several suggestions are introduced as follows:

1. Develop a comprehensive database and system for rural housing construction safety assessment evaluation. The building conditions should be categorized into two types, (1) no need to be reinforced and (2) need to be reinforced. For type (2), it could be specifically divided into: (a) worth to be reinforced (b) not worth to be reinforced, thus providing a basis for scientific decision-making.
2. The government should introduce supporting policies and provide subsidies to encourage farmers to reinforce their existing housing by themselves, following the seismic codes. Many countries that experienced only small losses during earthquakes have devoted a lot of attention on strengthening the existing residential housing. Sendai area in Japan, for example, experienced almost no building collapses during the east Japan earthquakes in 2010 due to the continuous self-reinforcement of existing structures (actually 90 % of the damage was from the tsunami). After the Kobe earthquake in 1995, the government increased investments on encouraging residents to reinforce their housing and provided about 1/3 subsidies for those who followed the standard reinforcement rules. Therefore, after 20 years of effort, the buildings' seismic performance in this area has been gradually improved, and they are now able to endure major earthquakes.

3. Strengthen the rules and detailing in quality control for self-built housing; establish a simple and operational construction supervision system for rural housing. In Chinese rural regions, the key issue causing poor seismic performance for residential housing is the lack of control in construction. Farmers build their houses by hiring unprofessional workers due to financial limit. Two ways could be proposed to solve this issue. Firstly, the department of planning and construction in the county should adopt the national homeland geological disaster assessment report to choose possible locations of rural settlements. Further, the township government can determine the specific construction points. Secondly, the township government should establish a construction supervision team, hiring a professional engineering supervision agency to conduct quality control and provide technical guidance for rural housing construction. Additionally, a uniform and compulsory procedure should be introduced, such as "declaration of owners-review and assigning engineering supervision–completion and acceptance," like the construction quality control system in the cities.
4. Increase the safety awareness of farmers. Use the previous collapse and damage cases to advocate farmers to improve their safety awareness of earthquakes, and inform them of the rationale behind the seismic construction code to protect their own properties and lives. Also, the government could assign relevant institutes to (1) carry out comparison research between reinforced housing and un-reinforced housing; (2) visually display the different seismic capacities of engineered and non-engineered buildings using the shaking table tests; (3) make straightforward videos and brochures to help in improving the safety awareness of farmers and leading them to reconstruct and reinforce the existing structures; and (4) provide technical training to help farmers to better understand quality control and the required standards for rural housing construction.
5. Put efforts into developing new rural housing systems by the use of new integrated techniques, aiming at decreasing costs, saving energy, enduring the seismic intensity, and applying modern industrial production methods. The traditional residential construction mode should be changed by introducing sustainability and energy efficient concepts as well as the idea of using precast structures. With factory precasting, small residential buildings can avoid many on-site assemblies to ensure the construction quality. Therefore, the seismic capacity and energy-saving performance can be improved fundamentally. Ultimately, it improves farmer's economic and social benefits.

5 Conclusions

After the "512 Wenchuan earthquake" that occurred in May 2008, the seismic design standards for Lushan country and its surrounding regions have been improved, and subsequent reconstruction projects have also been designed and constructed in accordance with the updated codes. During the Lushan earthquake, the structural components of most public buildings experienced slight damage, showing good seismic performance. However, even in seventh-degree zones, significant damage was captured in many non-structural components, such as the masonry infilled walls, ceilings and roof parapets. This extensive non-structural damage not only increased the possibility of casualties during the earthquake, but also increased the maintenance costs afterward. Therefore, more attention should be put on the design and construction of the non-structural components. Similar with the Wenchuan earthquake, due to the lack of design guidance and construction supervision, the self-built residential houses suffered the most severe damage. Therefore, it is highly recommended to provide farmers with basic training to improve their seismic awareness, and further, promoting new construction techniques with energy-saving, environmental protection and logical economical features that are more suitable and applicable for rural housing.

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