Characteristics of engineering damage and human mortality in Mianzhu areas in the great 2008 Wenchuan, Sichuan, earthquake

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ABSTRACT: The great Ms 8.0 Wenchuan earthquake caused huge seismic damage and high casualty in the areas along the Longmenshan fault zone. Mianzhu is a city among those severe damaged areas. Mianzhu city is located near the central Longmenshan fault and crossed by the front range fault, Dujiangyan-anxian fault. After the earthquake occurred, a field team of IEM reached Mianzhu city at the earliest time, and the field survey were carried out. Investigations into the engineering damage and human mortality in Mianzhu show that the seismic intensity attenuates fast with the distance to the fault trace, and it dramatically decreases from X to about VII degree within a distance of about 60 km; Whereas, seismic intensity along the fault trace shows almost no attenuation within the distance of about 20 km in Mianzhu. Except for the effect of site condition, topography and path, this phenomenon may also effected by the rupture direction of the long extended Longmenshan fault and it's front range fault.

KEYWORDS: Wenchuan earthquake; seismic damage; human mortality; seismic intensity; intensity attenuation

1. INTRODUCTION TO THE WENCHUAN EARTHQUAKE

On May 12, 2008, a great earthquake of Ms 8.0 struck southwest China. This catastrophe caused heavy engineering damage and high human casualty in areas along Longmenshan fault. It is reported by the Chinese Ministry of Civil Affairs that the death toll reached 69,226 and the number of missing reduced to 17,923 as of September 4, and the estimated direct economic loss for property (including the infrastructure) is about 845.1 billion RMB. At the earliest time after the earthquake occurs, a field work team of Institute of Engineering Mechanics, China Earthquake Administration, arrived at Mianzhu city on May 13, and During May 13-16, a four day's field investigation in Mianzhu areas was carried out.

Wenchuan earthquake is the greatest earthquake to strike Sichuan province since the 1972 Ms 7.2 Songpan-Pingwu earthquake, and it is the most devastating earthquake in China science the 1976 Tangshan earthquake. The strong ground shaking resulted in almost all kinds of disasters that can be seen in the past earthquakes. Except the engineering damage, like the damage of buildings, lifeline system or infrastructures, the earthquake lead to many kinds of geological and geotechnical disasters, like the surface rupture, quake lake (barrier lake), landslide, debris flow, ground crack, soil liquefactions and etc.

The epicenter of the Ms 8.0 (Mw7.9) earthquake located in Yingxiu town (31.0° N , 103. 4° E) southwest of Wenchuan County (CENC) with a focal depth of 14 km (CENC). And it has a distance about 21km to Dujiangyan, and 75km to capital of Sichuan province Chengdu. Figure 1 shows the location of the epicenter and some cities.

2. FIELD SURVEY OF MIANZHU AREAS

2.1. Overview of Mianzhu City

Mianzhu is a county-level city and located in the northwest of Sichuan basin, with a distance of about 83 km to Chendu, and 60 km to Mianyang city. The shape of Mianzhu area is like a penpoint, with a width of about 42 km in east-west direction and length of 61 km in north-south direction (see Figure1). Because Mianzhu located at the edge of Sichuan basin, the topography of Mianzhu area is significantly different from northwest to southeast. The northwest part of Mianzhu is higher in altitude which extends to Longmen Mountain range and the southeast part is lower in altitude which extended to Chengdu Plain (see Figure1). The total area of Mianzhu

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is 1245.3 km^2, including 21 towns and 157 administrative villages. The population reached 513,9 thousand at the end of year 2007, and the GDP and per capita GDP reached 14.25 billion RMB and 28,862 RMB, respectively.

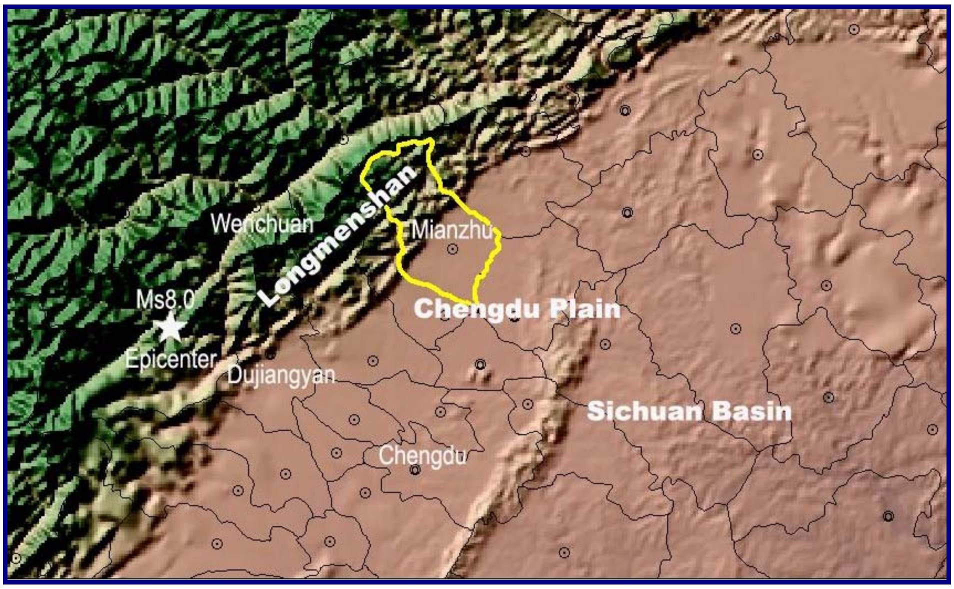

Fig.1 Location of Mianzhu areas to the epicenter

2.2. Investigation Point Distribution

The field survey was carried out at the earliest time after the earthquake occurred. In the investigation, almost all the areas of Mianzhu were covered by our field survey except the Qingping and Tianchi town because of the road broken due to the numerous landslides. Considering the difference of structure types included by city and towns, investigation sites are classified into two types. One type of site is the city level site, Mianzhi city.

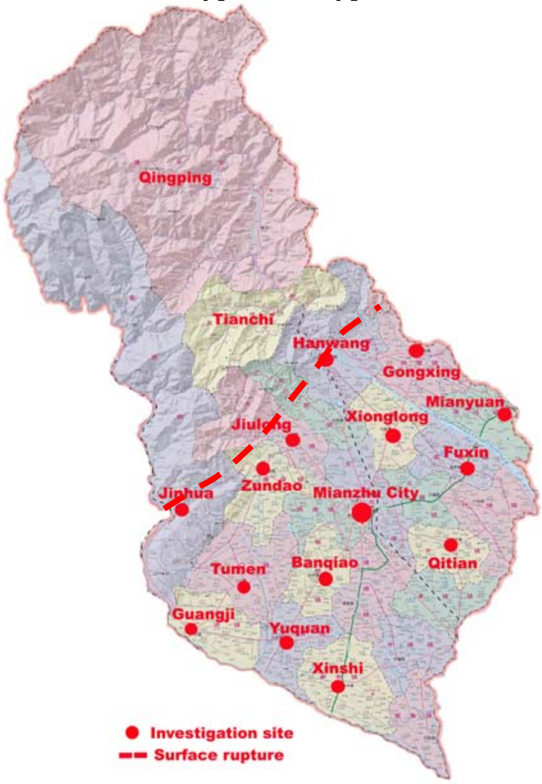

Fig.2 Sketch map of investigated points in Mianzhu

Another type is the surrounding towns and villages which have fewer structure types than that included by Mianzhu city. Figure 2 shows the investigated city and towns, where the bigger red point denotes Mianzhu city, while the smaller red points represent those investigated town and villages.

3. BUILDING DAMAGE

Although Mianzhu is about 86 km away from the earthquake epicenter (see figure 1), it is heavily struck. This is because Mianzhu is located near the Beichuan-yingxiu fault which is also called the central Longmeshan Fault, and was crossed by the surface rupture of Dujiangyan-anxian fault (Longmenshan front range fault) in Hanwang town. Seismic damages are concentrated in the junctional zone of mountains and plain, see Figure 1 (Dai *et al.*, 2008; Zhang *et al.*, 2008; Sun *et al.*, 2008). The investigation results show a dramatic decreasing seismic damage in the direction perpendicular to the fault strike, and the seismic intensity decreases from X to near XII quickly in less than 60 km in fault normal direction. Field survey also shows that this earthquake provided long extended surface rupture. It is reported that the rupture trace in the central part of Longmenshan fault reached about 200 km, and the front range fault (Dujiangyan-anxian fault) about 40 to80 km (He *et al.*, 2008; Zhang *et al.*,2008; Chen, 2008; Yao *et al.*, 2008). To illustrate the damage features of different structure styles, we classify buildings into three types, Reinforced Concrete (RC) structure, Masonry-concrete structure and Masonry-timber structure.

3.1 Reinforced Concrete Structure

The Reinforced Concrete (RC) structure, mainly frame structure in Mianzhu, account for less than 1% in area of Mianzhu city (Dai *et al.*, 2008), and most of them located in the relative economically developed urban district and Hanwang town. The RC structures are often used by some buildings like hospital, school, shopping centre, hotel and etc. Figure 3 and 4 provide two examples of the typical damage pattern of RC buildings in Hanwang town. Hanwang town is a bout 13 km to the central Longmenshan fault(Sun *et al.*, 2008) and was crossed by the surface rupture of the front range fault. It is well known that earthquake damages to RC structure are relatively small compared with that of the masonry-concrete and masonry-timber structures. Damages in RC structure are mainly concentrated in shear failure of walls, short-column failure, reinforcement yielding and etc. The below two pictures show the shear crack of bottom walls of an office building and collapse of exterior walls of a three-story cast-in-situ frame structure, respectively.

Fig. 3 Shear crack of the bottom two stories of an office building in Dongfang Steam Turbine Works, Hanwang town, May 15, 2008

Fig. 4 Collapse of the exterior walls of a three-story cast-in-situ RC frame structure in Hanwang town, May 15, 2008

3.2 Masonry-concrete Structure

In this section, the masonry-concrete structures, including brick-concrete and bottom-frame brick-concrete structures, are discussed. According to the statistic results by Dai (2008), about 15% in areas of Mianzhu (including the rural houses) are masonry-concrete structures. These structures are often used by residential buildings, stores and office buildings. As the seismic intensity reached X degree in Hanwang town during the Wenchuan earthquake, which is far beyond the basic seismic fortification intensity (VII). The strong shaking caused heavy damages in the masonry-concrete structures, especially those buildings with poor quality. Figure 5-12 show some badly destroyed buildings in the meizoseismal areas in Mianzhu.

Figure 5 and Figure 6 show a severely destroyed building near the sub-surface rupture (front range fault of Lonmenshan, Dujiangyan-anxian fault) in Hanwang town. Analysis points out that the special damage may be caused by the collision of the adjacent parts of the building and by the change in horizontal stiffness of the building. Figure 7 and 8 provide the pictures of an old residential building and the nearby seismic ruins in Hanwang town, from Figure 7 we can see that the four-story building became a three-story building, and the second story disappeared. Figure 9 and 10 show the pictures of a heavily destroied building which was one of the rather rare standing buildings in Jinhua town. The bottom-frame brick-concrete structures are often used by stores near the street. Figure 11 and 12 provide two typical damage pattern of the bottom-frame structure. Figure 11 shows the collapse of the top story of a bottom-frame building in Zundao town, and Figure 12 shows the inclination of columns of an imitation of ancient building in Jiulong town.

Fig. 5, A special destroyed building near the secondary surface rupture in Hanwang town, May 15, 2008

Fig. 6, Partial collapse of the former building (Fig. 5), viewed from the left side, Hanwang town, May 20, 2008 (photograph by Wang Dongming)

Fig. 7, Collapse of the second story of a residential building (the second story was disappeared), Hanwang town, May 15, 2008

Fig. 8, Seismic ruins near the only standing part of the former building (Fig. 7), viewed from the left side, in Hanwang town, May 15, 2008

Fig. 9 A shattered building and fragments in Jinhua town, May 23, 2008

Fig. 10 The former building (Fig. 9), viewed from the right side, Jinhua town, May 23, 2008

Fig. 11 Collapse of the top floor of a bottom-frame building in Zundao town, May 14, 2008

Fig. 12 Inclination of columns of an imitation of ancient building in Jiulong town, May 14, 2008

3.3 Masonry-timber Structure

The masonry-timber or brick-timber buildings and houses are widely used in towns and villages in Mianzhu areas, which account for more than 84% in area of all type of buildings in Mianzhu. Figure 13-16 provide some typical damaged rural houses in towns and villages.

The masonry-timber structure is more vulnerable compared with the RC structure under the earthquake. During the Wenchuan earthquake, thousands of rural houses collapsed, resulting from the badly construction quality and unreasonable structure system. Figure 13 shows a moderate destroyed rural house with severe cracked walls in Mianyuan town. Figure 14 and 15 show the collapsed walls and roof of two rural houses in Zundao town. Figure 16 shows the collapse of walls and wood roof of a rural house in Guangji town as of May 14-16, 2008.

Fig. 13 A moderate destroyed rural house with severe cracked walls, Mianyuan town, May 16, 2008

Fig. 14 Collapse of the front wall of a rural house in Zundao town, May 14, 2008

Fig. 15 Collapse of walls and roof of a rural house in Zundao town, May 14, 2008

Fig. 16 Collapse of walls and wood roof of a rural house in Guangji town, May 14, 2008

4. COMPARISON OF BUILDING COLLAPSE RATIO AND MORTALITY RATIO

To give a general description of structure's performance under the Wenchuan earthquake in different towns in Mianzhu areas. Based on the statistical data, we compared the building collapse ratio and human mortality ratio in different towns we had arrived. And due to the road broken, data in Qingping and Tianchi town are not included.

4.1 Building Collapse Ratio

In this section, we compared the collapse ratio of masonry-timber and masonry-concrete buildings in different places in Mianzhu areas, respectively. The RC structure is not included in this statistical dada as it is not widely used in other towns except the urban district and Hanwang town.

Figure 17 provides the statistical result of some towns and villages. On the one hand, result indicates that the collapse ratio of masonry-timber structure is much higher than that of the masonry-concrete structure, and on the whole, the collapse ratio of masonry-timber structure is about 3 times that of the masonry-concrete structure, except in the most damaged Zundao town that the collapse ratio of masonry-timber structure is about 2 times that of the masonry-concrete structure. On the other hand and more importantly, according to Figure 2, we find that the collapse ratios of the two types of structure decrease quickly with the town's distance to the fault trace, while there is no attenuation along the fault trace.

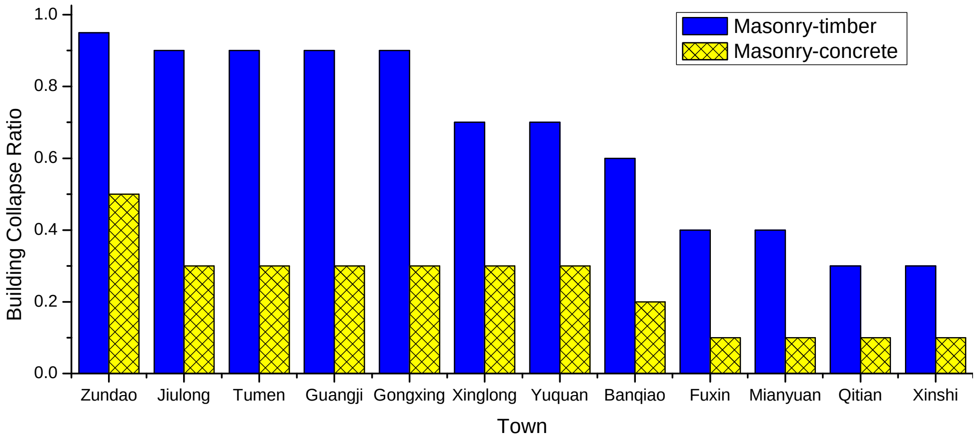

Fig. 17 Comparison of collapse ratio of Masonry-timber and Masonry-concrete buildings in different towns

4.2 Human Mortality Ratio

The human casualty during an earthquake is also an index relating to the seismic damage. But it is difficult to identify the seismic damage intensity merely based on the absolute number of human casualty, because the population varies significantly in different town and villages. In order to view the seismic damage intensity from the aspect of human casualty, the mortality ratio was adopted. Herein we define the mortality ratio as the ratio of the death number caused by the earthquake to the population number of the town. Figure 18 give the normalized mortality ratio of some towns in Mianzhu city. Note that the normalized mortality ratio is adopted because the death number we used here is only a preliminary result as of May 16, and it is still changing with the time. So we use a normalized ratio to show the variation of mortality ratio in different towns. Figure 18 shows the normalized mortality ratio of different towns. From Figure 18 and Figure 2 we find that mortality ratios in areas near the fault trace are bigger, like Jinhua and Hanwang town, whereas they decrease dramatically with the distance to the surface rupture. In general, on the one hand, the mortality ratio decrease fast with distance to the fault trace; on the other hand, the mortality ratio along the rupture trace shows almost no changing in the rupture direction. At last, it is to be noted that although the death toll is a result as of May 16, the increasing in the death number will not be too much. So the small changing will not affect the whole result.

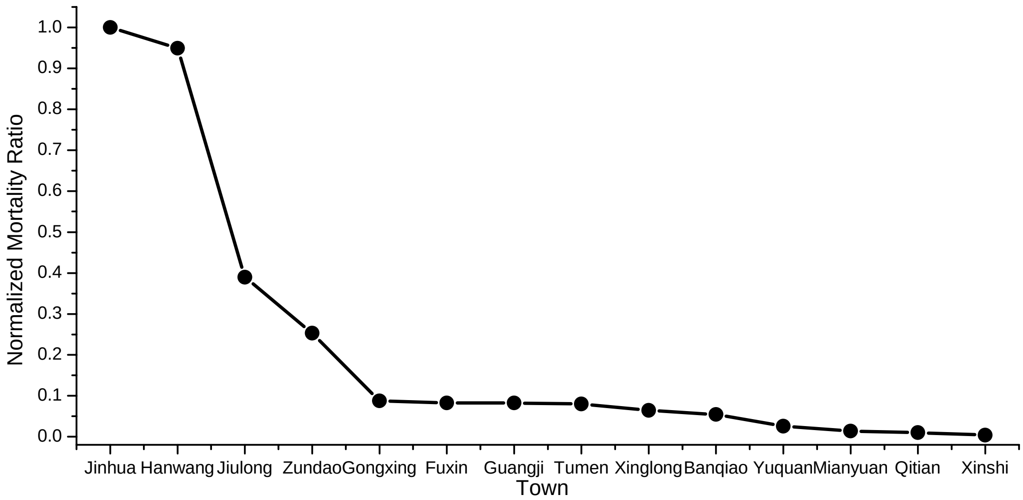

Fig. 18 Comparison of mortality ratio of some towns in Mianzhu city

5. CONCLUSION

Although it is difficult to summarize all the features in seismic damage and human mortality in Mianzhu areas during the great Wenchuan earthquake, still, some preliminary conclusions can be drawn.

1) Seismic damages in Mianzhu areas are heavily affected by the fault geometry and rupture direction. Engineering damages and human casualty are mainly distributed along the Longmenshan fault zone region.
2) Different types of structure have difference performance during the great earthquake. Both masonry-concrete structure and masonry-timber structure show a dramatically decrease of collapse ratio with distance to the fault trace. Whereas, the seismic collapse ratios in along the fault trace direction show almost no changing.
3) Human mortality ratio is another index reflecting the seismic damage and intensity. Similar to the characteristics of building collapse ratio, the normalized mortality ratio decreases fast with distance in direction perpendicular to the fault trace; whereas, it shows no attenuation in the direction parallel to the fault trace.

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