DAMAGE OF VILLAGE BUILDINGS IN RECENT YUNNAN EARTHQUAKES

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ABSTRACT

In recent years, several earthquakes occurred in Yunnan province. All of these quakes mainly struck in mountainous countryside. The buildings in these areas are poorly constructed. While some of buildings are strongly damaged, some stand still after these earthquakes. This paper firstly introduced these building damages in Yunnan. The preliminary discussed and some research is presented on the reasons for the damage or undamaged of these buildings. Some principles for earthquake-resistant building construction in high intensity country area are presented in the end.

Keywords: Yunnan Earthquakes, Rural Buildings Damage, Minority Nationality

INTRODUCTION

In 2003, there were 21 destructive earthquakes occurred in the mainland of China. The epicenter of all these earthquakes were located near villages, 2.98 million people were influenced. 319 people died, 2,332 people injured heavily and 4,815 people injured lightly. The collapsed buildings were 3.285 million m², 4.8369 million m² were server damaged, 10.0642 million m² were moderate damaged and 19.095 million m² were slightly damaged. Total economic losses of these disasters reach 4.66 billion yuan RMB. Since the 20th century, destructive earthquake occurred in China amounted to 2,700 times, among which are 560 times magnitude greater than 6 on Richter scale. The earthquake caused damage and certain economic losses only accounted 2 percent, the other destructive earthquakes occurred in rural villages. Yunnan is a mountainous province where the mountainous area accounts for 96%. The 147 basins only occupy the other 4% of the total area. Most basins develops along the active faults, thus 90% of cities are located in the region where the seismic fortification intensity is equal to or higher than 7. Obviously, most earthquakes stroke in mountainous area where living poverty minority nationalities. Through the seismic damage site research and literature review, the living house and its damage under earthquakes are described and discussed in this paper. Some suggestions for rural buildings construction and disaster mitigation measures are presented in the end.

SEISMICITY IN YUNNAN

There were 713 earthquakes of M6.0 from 1900 to 2001 in China, among which 53 earthquakes took place in Yunnan, accounting for 7% of that in China. 12 out of 114 earthquakes of M7.0 happened in

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Yunnan, accounting for 11% of that in China. Especially in the year from 1949 to 2001, there happened 63 earthquakes of M7.0 in China and 8 in Yunnan, accounting for 13%. Sudden death and injury to the local people, heavy economic losses and severe damages of buildings were suffered from these frequent and strong earthquakes in Yunnan (Fei, M.L., et al., 2003).

Until Feb., 1999, the recorded earthquakes are about 610 times which magnitude on the Richter scale is greater than or equal to 5. Among which, there are 552 times of 5.0 ≤ Ms < 6.0; 53 times of 6.0 ≤ Ms < 7.0 and 13 times of 7.0 ≤ Ms < 8.0. The historical epicenter distribution and active faults are described in Fig. 1. It can be easily found that most earthquakes occurred along these active faults. On Sept. 6th, 1833, a strong earthquake measuring 8 on Richter scale occurred on Xiaojiang Fault where 50 kilometers far away from Kunming, was the greatest earthquake in Yunnan recorded history (Ye, L.Y., 2003).

![Seismotectonic Map of Yunnan Region.](image)

**MOUNTAINOUS BUILDINGS AND SEISMIC DAMAGES IN YUNNAN**

Yunnan is a typical agricultural province; nearly 80 percent of peasant’s earning is coming from agriculture. In 2005, the provincial net income per person for peasant family is 2041.8 Yuan RMB, which is only 20% of that in cities. The income for those people living in mountainous region may smaller than this data. In a word, the mountainous minority people in Yunnan province still very poor up to now. Fig.2 shows the living mountains where the “7.22” earthquakes measuring 5.1 on Richter scale this year, form which the hardy living conditions for local people can easily be deciphered.

Since the poverty in mountainous areas, the livings house in these area are mainly built by stones, soils and timber; only a small amount of buildings located in economic developing places are constructed by brick or even reinforced concrete.

The typical mountainous buildings in Yunnan can be divided into four types; they are immature soil structures, timber structures, masonry structures and reinforced concrete structures.
Immature Soil Buildings

Up to now, most buildings in Yunnan mountainous area is built mainly by compacting soil as the load-carrying structure. In some areas, the bamboo was compacted in the soil wall in order to enhance the horizontal connection, as showed in Fig. 3. The upper roof is bearing only by the compacting walls. Most of these buildings in earthquakes are collapsed in the macro epicenter region. The bearing walls always collapsed inside which caused most deaths of people in many earthquakes. During the moderate earthquake measuring 6.2 on the Richter scale hit on the night of July 21, 2003, eight counties including Dayao County were jolted; at least 16 people were killed. 11 people were killed in Ganghe village since the inner collapse of compacting walls. The collapse of this kind of buildings was the first killer in the earthquakes. The collapse of building was showed in Fig. 4 (Liu, B.Y., 2004).
Fig. 5 and 6 shows the damage of these immature soil buildings in Yanjing earthquake measuring 5.1 on Richter scale in Dousha village.

**Timber Buildings**

Timber building is the traditional structure in China. In Yunnan mountainous area, about 60-80 percent of buildings are timber houses (Huang, H.Y., 2005; Meng, P., 2005). The traditional timber house has trough-jointed frame house (Fig. 7), raised-beam frame or well frame (Fig. 8), frame in human shape (Fig. 9 and 10).

![Figure 7. Through-jointed frame house.](image1)

![Figure 8. Well-framed house of Naxi.](image2)

![Figure 9. Bamboo column house of Dai.](image3)

![Figure 10. Stilt house of Jingpo.](image4)

The normal through-jointed wooden frame has five wooden columns, taking strip stone as foundation, the soil billet or compacting soil as curb wall, and clay or asbestos tile roof. Fig. 11 showed the damage of these buildings, five columns were constructed. During the earthquakes, the soil billet curb wall collapsed outside, and the wooden frame stands still. The structure can be simplified as four or three columns. In Fig. 12, the building only had 3 columns to support the whole roof. Since the curb wall may collapsed outside, peoples lived in buildings may escape from sudden death.

In recent years, the curb walls of this through-jointed wooden frame will be clay bricks (Fig. 13) or hollow concrete masonry (Fig. 14). The damage is similar with the outside collapse of walls. During the “7.23” Daoyao earthquake in 2003, the houses in Ganghe village were normal through-jointed wooden frame with five wooden columns. The outer wall collapsed to the outside since the bracing of the columns, that a room fled for life could be provided. Although no death happened, 5 persons were injured and 46 persons were slight wounded. Unfortunately, people constructed with beam-on-wall-direct buildings in the other three villages since the scarcity of economic incomes. 16 persons died since the outer wall collapsed inside during the earthquake.

These buildings may suffer quite damage under seismic intensity of VI, certain severe damage and collapse under seismic intensity of VII, most may damage to the unrepairable extent under seismic intensity of VIII, most collapse under the seismic intensity of IX (Fig.11,12,13,14,15 and 16).
Masonry Buildings

Public buildings such as schools, hospital, and office are often built as masonry buildings. In the point of seismic fortification, the shortcoming of these buildings is that they are constructed with low grade mortar, bad construction quality and narrow walls between windows. The ordinary damages are flaking off powder layer on the wall, cracks of wall, smashed, partially collapse or total collapsed. The oblique cracks may appear near the window or door. The intercross crack may appear on the walls between windows or on the fastigium, the cracks at the bottom floor may severe than that on the upper floor (Fig. 17, 18). The horizontal cracks may appear along the roof or slab, or the upper and bottom section of walls between windows with narrow vertical walls (Fig. 18, 19), some severe damaged wall may collapse. The vertical crack may appear on the connection of walls and column. The outer wall corner may crack or even collapse. The crack in the stair well may severe than that in other rooms (Cheng, D.S., 1991; Lu, Y.K., 2006).

Since located at a mountainous region, buildings were constructed complied with terrain. Civil buildings or schools located at the hilltop, which had two more stories, the top story or the chimney or the cistern at the top story were severely damaged or collapsed. Fig. 20 shows the damage of a school at the hillside.
Some buildings constructed with ring beam and structural columns show good earthquake capability. This experience is proved again and again in the seismic damages.

Figure 17. Damage in Wuding Earthquake, 1995.  
Figure 18. Damage in Wuding Earthquake, 1995.  
Figure 19. Damage in Yanjin Earthquake, 2006.  
Figure 20. Damage in Daoyao Earthquake, 2003.

**Undamaged Buildings or Structure**

Although many buildings were damaged in the earthquakes, they were some buildings and structures undamaged after the earthquake. The bridge in Yanjin earthquake shows no damage since it was designed according to VIII degree of seismic fortification intensity (Fig. 21). Some building in Santai village is undamaged in Daoyao earthquake, while some structures in the similar location were severe damaged (Fig. 22). The undamaged examples like these are very popular in earthquake-stricken area.

Figure 21. Bridge in Yanjin Earthquake, 2006.  
Figure 22. Building in Daoyao Earthquake, 2003.

SEISMIC DAMAGES ANALYSIS OF MOUNTAINOUS BUILDINGS IN YUNNAN
The seismic damage of mountainous buildings has many reasons. From the upper seismic damage, combined with seismic fortification experience in experiment, the dominating problem for the damage may be as follows.

**Construction Site**

To select a seismic fortification favorable site is a big problem in the construction of a building. Since Yunnan is a mountainous region, many places have developed geology disasters. When the rainy season comes, the geology disasters like landslide and debris flow are frequently reported in newspapers. Fig. 23 is the picture taken at Yanjin Road when we on the way to investigate the seismic damage in Dousha village. Fig. 24 shows that the buildings constructed on the half-dig-half-fill site. In the Yanjing earthquake, 2006, only 8 was killed by house collapse, the other 14 was killed by slungslot along the road.

![Figure 23. Landslide in Yanjin, 2006.](image1) ![Figure 24. Building in Daoyao Earthquake, 2003.](image2)

**Immature Soil Building**

Many in situ seismic damage investigations proved that the immature soil buildings are the first killer to residents. In future construction, this kind building should be forbidden. If it cannot forbid in some bad economic place, the structure should be enforced with bamboo strip or other materials.

**Timber Building**

The situ investigation found that the seismic damage of brick curb wall timber building is rather light than that of compacting soil or soil billet or the mixture of soil billet and brick. The seismic fortification capability of timber building curved with soil is better than immature soil building. The reason for this is that the timber structure functioned as integrity in the earthquake. The brick curved ones are better than immature soil ones. This is because that the brick wall is thinner and lighter than that of soil billet and the construction quality of brick wall is far good than that of soil billet walls.

The popular shortcoming exists in timber buildings curb with brick walls is as follows.

- Rather low grade of mortar. The investigation found that most mortar grade is among M0.4 and M1.5, and the mortar can be smashed by hand. The main crack in earthquake is opened along the mortar lines.
- Infirmity connection of length and breadth walls. The length wall may outside collapse in the earthquake.
- No connection of roof and walls. There is no connection with walls and beam, especially the purline with fastigium which makes the fastigium collapse outside and the collapse of the frame.
- The integrity of buildings is worse. The ring beams and structural columns are rare in seismic region.

**Masonry Buildings**
The severe damage masonry buildings in earthquake were always found that the rather serious problems existed in design and construction process. Those constructed with normal design and strictly constructed according to the design requirement, may suffer slight damage in earthquake. They are many examples of this question.

CONCLUSIONS AND SUGGESTIONS

- Site selection for the town or construction in the earthquake-hit frequently area is very important. In this disaster, the government, schools and relative establishments located at hilltop or hillside, where the earthquake forces would be magnified for the local extruding terrain. Thus, a suggestion for the site selection is that choosing the seismic fortification favorable site and avoiding the seismic fortification dangerous site as construction site. If the buildings must be constructed on the seismic unfavorable site, the corresponding seismic countermeasures should be taking to guarantee the seismic fortification performance of the constructions.
- When constructed in the mountainous regions, the asymmetry site like half-fill-and-half-dig site should be avoided. Under the action of earthquake wave, the upper structure on this site will deform asymmetry and be damaged with ease.
- Though people have some knowledge of earthquake disaster, the speculations in the seismic fortification code are hardly implemented in building construction. Because of the inconvenience of transportation, lower quality of the construction materials, awkward skill of the construction technology and the workers’ shortage of seismic fortification common sense, the existing buildings were feasible to damage in earthquakes. During the earthquake damage investigation, there were some buildings still intact for they had small number of stories. Another suggestion could be draw from these facts is that reducing the maximum height of the structures in this area may compensate for this unfavorable condition.
- The immature soil building should be forbidden in villages. The construction of timber house curbed with compacting soil or soil billet should be enforced by the connection of the whole building.
- The shortcoming pointed in this paper related to timber house curbed with brick walls should be avoided.
- The construction of masonry building should be guided by the local government or some guidelines for construction should be delivered to the construction teams.
- Since 94 percent of land in Yunnan province is mountainous, the construction land is spare resource. The ordinary city or town was constructed with the hill, where the earthquake response will be enlarged. When planning the construction of city or town, the earthquake influence of topography should be considered with the seismic fortification capability of different structures.

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REFERENCES


