SEISMIC DAMAGE ANALYSIS ON BUILDINGS OF THE NING'ER EARTHQUAKE WITH Ms6.4

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ABSTRACT :

The earthquake mechanism, seismic records, damage index and intensity of the Ning'er earthquake with Ms6.4 are introduced in this paper. Based on the field investigations, damage situations of rural houses and buildings of cities and towns have also been introduced. The failure mechanisms are briefly analyzed. Some seismic fortification measures are proposed.

KEYWORDS: Ning'er earthquake, seismic damage analysis, seismic fortification measure

1. INTRODUCTION

An earthquake with Ms6.4 occurred in Ning'er County, Pu'er City, Yunnan Province, on June 3, 2007 at 5:34 a.m. Beijing time. The epicenter is located at 23°00′N, 101°06′E with focal depth 5 km. The epicenter is in the Taida-Ning'er-Manlian area which is 4-5 km far from the central area of the county and the seismic intensity of the epicenter area is Ⅷ+. Since the earthquake is near to Ning'er County, it is considered as a near-field moderate earthquake right beneath the city. Total area of 1 511 397 m^2 of houses had been collapsed in the towns and villages and the whole destruction area was almost 6 228 135 m^2. 3 were killed and 28 were seriously injured, totally 94 286 families and 403 128 people subjected to earthquake disasters. The disaster area was about 3 890 m^2 and the total direct economic loss was about 1.9 billion Yuan.

The investigation results which were carried out after the earthquake elucidate the main characteristics of this earthquake. Though the casualty is relatively slight, various types of engineering structures are seriously damaged and the economic loss is relatively significant. Obviously, it is similar to the earthquake disasters which were taken place in the United States, Japan, China Taiwan and other developed areas in the 1980s and 1990s. It was found that the same structure buildings exhibited different seismic failure modes because of the complex site conditions. Seismic reinforcement measures were proved to be effective through this earthquake. The buildings which were reinforced or rebuilt according to the seismic reinforcement measures after the Ms6.3 earthquake happened in 1993 in local area mostly remain intact in this earthquake. Through field investigation, problems were found to exist in the aspect of site selection, structural design, quality of materials and construction in present rural and city buildings. In the Code of GBJ11-89, Ning'er's seismic fortification intensity was set as 8 degree (0.2g). The earthquake provides a good opportunity to verify the seismic ability of various types of constructions, to find the seismic weak points of all kinds of structures and to summarize the experiences from earthquake damage.

2. THE MECHANISM OF THE EARTHQUAKE SHOCK

Tectonic background of the earthquake disaster areas shows that the earthquake zone is located at Tanggula-Changdu-Lanping-Simao fold, which is Jinggu-Mengla folding beam in Lanping-Simao foldbelt. The earthquake is located in the Ning'er new tectonic uplift with complex geological structure and strong activity. The regional fault focused in this area, and the most important fracture zone is the Wuliang Mountain fracture zone. Wuliang Mountain fracture zone is formed by three fracture zones. The east branch is Mohei fracture, the central branch is Zhenyuan-Ning'er fracture, and the west branch is Puwen fracture. The fracture zone is spread in the west of Wuliang Mountain, controlled the Mesozoic to early Cenozoic depression of Lanping-Simao, and its new internal tectonic uplift activities since the Miocene. The fracture belongs to the late Pleistocene active fracture, and several strong earthquakes occurred along this fracture in the history. Wuliang Mountain fracture zone is an important active fracture zone which controls the modern uplift. Ning'er earthquake is located in the

Zhenyuan-Ning'er fracture which is in the central branch of Wuliang Mountain foldbelt. As a result of this complex geological background, in the range of earthquake zone (about 50 km), 8 times of Ms 6.0-6.9 earthquakes have been occurred in the last 100 years, the biggest earthquake is the Pu'er Ms 6.8 earthquake occurred on March 15, 1979. On average an earthquake more than Ms 6.0 occurred every 13 years, so it is a very active seismic region. The force to produce crustal movement comes from collision between Indian plate and the diamond-shaped block wedge of the Sichuan-Yunnan plate, along with the clockwise rotation of Baoshan-Pu'er blocks and its internal sub-blocks.

3. STRONG MOTION RECORDS

A total of 22 strong motion network stations had obtained the main shock records. Except for the Jinggu station which is built on the site of bedrock, other stations are built on the site of soil layer. Figure 1 shows the distribution of network stations in the seismic region. Table 1 shows the records of main shock's acceleration. The data were recorded by 4 network stations. According to Table 1, from the near epicenter to far, the four stations are Dehua, Zhengxing, Mengxian and Manxiba, respectively. The maximum time difference between recorded trigger times was nearly 5s. The maximum acceleration peak value recorded was 431.2cm/s^2. The peak value decayed very quickly with the distance increase from epicenter to record point, but the main shock duration time increased nearly two or three times.

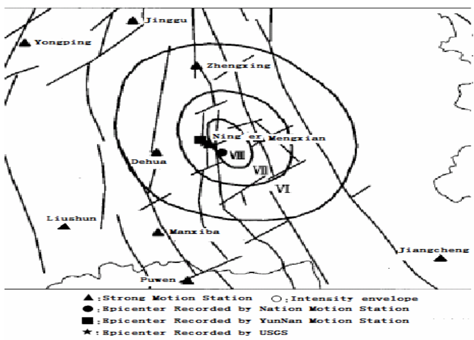

Fig. 1 Distribution of network stations in the seismic region

Table 1 Brief information of the acceleration records of the Ms 6.4 Ninger earthquake

Data Title	Activation Time	Position of Station		Acceleration Peak		
		N latitude	E longitude	NS	UD	WE
Dehua_AJ001	2007－06－03 05:34:40	23.001 9	100.8836	431.2(3.99)	157.4(4.80)	267.0(4.25)
Zhengxing_AM003	2007－06－03 05:34:43	23.330 6	100.9642	－404.9(7.35)	102.6(12.77)	211.3(8.01)
Mengxian_AT001	2007－06－03 05:34:42	23.052 5	101.2066	－121.8(8.66)	53.8(7.30)	－157.7(7.23)
Manxiba_CL002	2007－06－03 05:34:45	25.075 1	102.7342	－58.4(12.19)	23.7(16.58)	49.7(12.74)

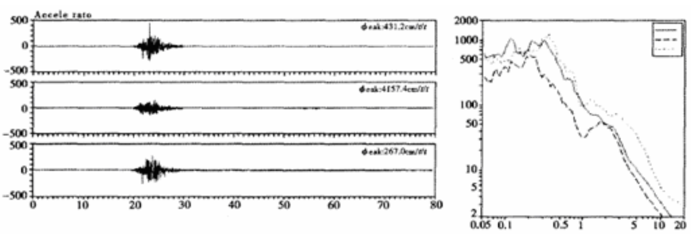

Fig. 2 Dehua_AJ001 acceleration history record and its response spectrum of Ning'er Ms6.4 Earthquake

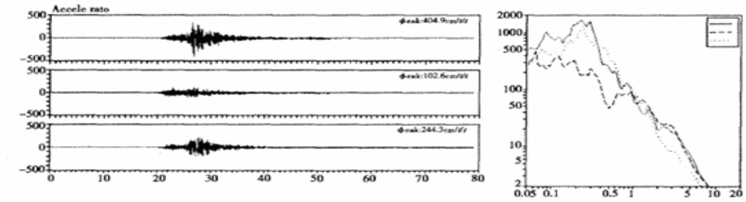

Fig. 3 Zhengxing_AM003 acceleration history record and its response spectrum of Ning'er Ms6.4 Earthquake

From the recorded acceleration history and acceleration response spectrum which were showed in Dehua_AJ001(Fig.2) and Zhengxing_AM003(Fig.3), NS components of both earthquake motion records all exceeded the acceleration peak value of 400 gal , which is specified as the strong earthquake's input peak acceleration for seismic response analysis in seismic fortification region of 8 intensity(see "Code for seismic design of buildings" (GB50011-2001)) . This is the main reason for which the buildings were damaged more severely in NS direction in the seismic region. However, the other two orthogonal directions' peak accelerations of the ground motion did not reach the peak value specified in the code (which is 0.85 and 0.65 times of peak value of the first direction when the seismic response analysis of two-way and three-way are carried out). So, from the level of seismic motion's peak value, it is almost at the same level or slightly lower than the medium earthquake acceleration of 8 degree (0.2g) in the epicenter. The predominant period of both ground acceleration records were between 0.2~0.4s. As we know, natural period of most 7-story or lower houses are closed to this range. 99% buildings in Ning'er town are lower than 7 stories, so, it is why the buildings in Ning'er were seriously damaged, although the earthquake duration was short.

4. INDEX AND INTENSITY OF EARTHQUAKE DAMAGE

4.1. Index of Earthquake Damage

In the field investigation of Ning'er Ms 6.4 earthquake, we first roughly divided the seismic region into five assessment areas, then modified the scope of the assessment areas according to the obtained earthquake damage index of each sample survey point, and finally, calculated the average damage index of each assessment area. The earthquake damage indexes of each damage grade are listed in Table 2.

Table 2 Damage Index of each damage degree

Damage degree	Destroyed	Serious	Medium	Minor	Basic integrity
Computed value	1	0.7	0.4	0.2	0
Bound	$0.85 \le d_i \le 1$	$0.55 \le d_i < 0.85$	$0.3 \le d_i < 0.55$	$0.3 \le d_i < 0.1$	$0.1 \le d_i < 0$

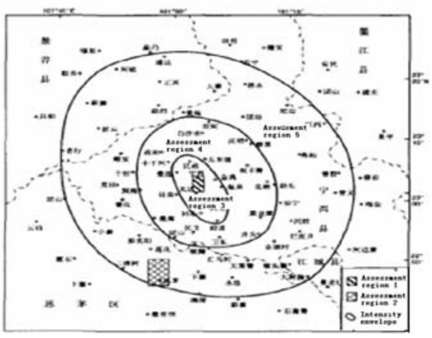

Fig. 4 Map of Ning'er Ms6.4 earthquake assessment area

According to "Earthquake Field Work Part 4: Direct Disaster Damage Assessment" (GB/T 18208.4-2005), brick-wood and earth-wood buildings are classified as simple building, and their damage are classified into three grades, "destroyed", "damaged " and " basically well-remained ", but the damage index value of them is not mentioned. Therefore, in the calculation, the mid-value between "destroyed" & "serious destruction" and "medium" & "minor" according to Table 2 are taken as the "destroyed" and "damaged" index of these two types of building, respectively. The specific values are also taken according to Table 2. Framework and brick-concrete structure buildings are still divided into five damage grades and their damage index values are taken according Table 2. Damage ratio of various types of building at all levels of destruction can be obtained by field investigation. The plan map of the earthquake assessment area is shown in Fig.4, and the assessment results are listed in Table 3-5.

Table 3 damage ratio and index of Assessment region 1&3

Region	Structure	Damage Degree					Index
		Des	Ser	Med	Min	Int	
1	Frame	0	0.03	0.06	0.38	0.52	0.12
	Masonry	0.02	0.12	0.21	0.42	0.23	0.27
	Half-timber	0.25	0	0.70	0	0.05	0.42
	Timber	0.53	0	0.46	0	0.01	0.59
3	Frame	0.09	0.26	0.25	0.27	0.13	0.42
	Masonry	0.02	0.33	0.37	0.20	0.08	0.44
	Half-timber	0.55	0	0.40	0	0.05	0.59
	Timber	0.59	0	0.41	0	0.01	0.62

Table 4 damage ratio and index of Assessment region 2&5

Region	Structure	Damage Degree					Index
		Des	Ser	Med	Min	Int	
2	Frame	0	0	0	0.18	0.82	0.04
	Masonry	0	0	0	0.07	0.93	0.01
	Half-timber	0	0	0.18	0	0.82	0.05
	Timber	0	0	0.11	0	0.89	0.03
5	Frame	0	0	0	0.13	0.87	0.03
	Masonry	0	0	0	0.26	0.74	0.05
	Half-timber	0	0	0.26	0	0.73	0.08
	Timber	0.01	0	0.28	0	0.71	0.09

Table 5 damage ratio and index of Assessment region 4

Region	Structure	Damage Degree					Index
		Des	Ser	Med	Min	Int	
4	Frame	0	0	0.14	0.71	0.15	0.20
	Masonry	0	0	0.18	0.65	0.17	0.20
	Half-timber	0.01	0	0.88	0	0.11	0.27
	Timber	0.18	0	0.49	0	0.33	0.30

4.2. Intensity

According to the earthquake seismic intensity distribution released by the earthquake department (Fig. 5), it is known that the seismic intensity of Ning'er County and its surrounding villages and towns which are located in the epicenter region are 8 degree. Among them, 3 villages, Manlian, Xinping and Taida are abnormal areas at 9 degree.

5. SEISMIC DAMAGE CHARACTERISTICS IN NING'ER EARTHQUAKE

5.1. Damage Analysis on the Timber Structural System

As the rich production of wood in seismic region, wood structure is a very important and major form of the local structures, especially in rural areas. It is mainly composed of brick-wood and earth-wood structures with 1 to 2 floors. Bearing components of brick-wood structures are both enclosure brick walls and wood frames; on the other hand, bearing components of earth-wood structures are enclosure adobe walls and wood frames. Timber structural damages in this earthquake are presented as the following aspects: the enclosure walls totally or partly collapsed; wood frames were almost undeformed or slightly destroyed; most of herringbone roofs were undeformed, only a few of them collapsed; phenomenon of tile-slipping had taken place in the majority of tile roof rural house.

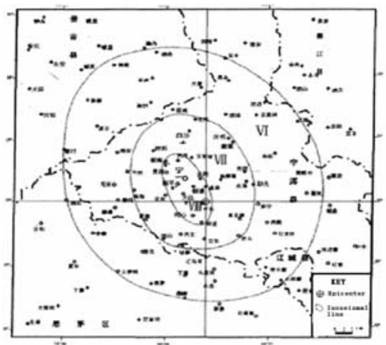

Fig. 5 Intensity distribution map of Ning'er Ms6.4 Earthquake

Mortise joints are used between vertical columns and horizontal beams of Chuandou wooden framework, forming an integral bearing system, and the deformation capacity of mortise joints under the horizontal earthquake action is great, moreover, the mortise joints itself is a dissipative component, therefore, earthquake-resistance abilities of this kind of structure is quite strong. Most wooden frames were basically intact after the earthquake, rabbet of joints were not pulled out, only slight deformation was taken place in the position of column base, and a small number of poor maintenance wooden frames were inclined.

Overall, the earthquake-resistance capacity of brick-wood structures is superior to that of earth-wood structures. Because of the supporting role of frames' bearing part, although most of the walls collapsed, most of them collapsed to the outside, resulting not too much threaten to the people in the houses. It fully demonstrates the nice seismic safety performance of this kind of structure. However, its earthquake-resistance ability is very poor for the lack of reliable links between walls and bearing wooden frames, any slight lateral vibration would cause them collapse, and economy would also suffer great losses. Since the collapse of enclosure walls, this kind of houses losses its function of living and emergency response after a long period of the earthquake. The main damages of wooden structures are focused on the following aspects:

(1) Wooden roof truss collapsed

Such damage was mainly due to the purlins or the girders of roof systems being directly shelved on the adobe walls and the roof truss & walls without reliable links. Furthermore, for the lack of compression strength, concentrated load are applied to the contact side of wall-purlin or wall-girder, vertical cracks are generated in using stage, so it goes against to earthquake-resistance. When the earthquake occurred, not only the roof truss detaches from the bearings on the wall but also the damage of walls can make the roof truss collapsed (shown in Fig. 6).

（2）Walls collapsed but wooden frames still stood, shown in Fig. 7.

（3）Integral collapse of wooden structure, shown in Fig. 8.

（4）Tile-slipping, shown in Fig. 9.

Fig. 6 Wooden roof truss collapsed

Fig. 7 Walls collapsed & wooden frames standing

Fig. 8 Integral collapse of wooden structure

Fig. 9 Phenomenon of tile-slipping

5.2. Damage Analysis on the Masonry Structural System

Masonry structures are mainly distributed in urban areas, most of them are residential buildings, generally 3-6 floors. During the earthquake, in region of intensity Ⅷ, most walls of masonry structures had obvious cracks, "X"-shape penetrating cracks were seen in some buildings, minority of RC tie columns ruptured and walls dislocated; in region of intensity Ⅶ, most walls had diagonal cracks, part of them were obvious, and "X"-shape penetrating cracks were seen in some individual buildings; in region of intensity Ⅵ, most walls had slight cracks, minority of walls appeared diagonal cracks, only a few walls appeared penetrating cracks.

Based on the investigation, masonry structures which were built in recent years were mostly intact. Obvious damage appeared mostly in the constructions which were built in the 80's and 90's of last century. These buildings were not obviously damaged during the Ms 6.3 earthquake happened on January 27, 1993 in Pu'er(Tongxin Town). Because of no significant damages, they were basically not reinforced, only some repairs were conducted. So the accumulation of damages may be the main reason that caused greater destruction to the buildings. In addition, it is also found that the reasons which caused building damages can also be the followings: uneven settlement of foundation, unreasonable design, low seismic fortification, poor quality of construction, non-standard settlement joint (GB50011-2001), etc. The damages to the masonry structure are in the following aspects:

(1) Diagonal or cross cracks of load-bearing walls

The earthquake made a commonly destruction of the walls, there were different degrees of diagonal-cracks (shown in Fig. 10) and cross-cracks (shown in Fig. 11) appeared on the walls of many masonry structures. Diagonal-cracks are generated because the principal tensile strength of the walls is not enough when the direction of earthquake action is in line with the direction of the wall; then, by the roles of repeated seismic actions, cross-cracks are appeared. The relatively seriously destructed houses were built in 1970s and 1980s, impacted by the backwards of socio-economic and engineering technology then and there, masonry material strength of walls was low, the shear and bending resistance capacity of walls was poor, and the wall's constructional measures were imperfect. For example, space between RC tie columns was large, some houses even hadn't a tie column in the key positions, and there are no tie bars in the walls, resulting in further damages of walls. For example, the official building of YunNan Geology and Mineral Bureau 816 geology team, which is a 5-floor masonry structure built in 1980s, had been seriously damaged. Otherwise, the buildings built after 1990s, which used the construction materials with sufficient strength and adopt more comprehensive constructional measures, suffered slight damages or even basically intact.

Fig.10 Oblique cracks on load-bearing wall

Fig. 11 X cracks on wall between windows

(2) Horizontal cracks of load-bearing walls

The appearance of horizontal cracks located between wall top and beam bottom was mainly due to the non-uniform deformation between the floor and wall. They could not move integrally under the earthquake, so the collision of the floors on the walls caused the horizontal cracks (shown in Fig. 12).

Fig. 12 Horizontal cracks on load-bearing wall

Fig. 13 Junction crack of walls

(3) Damage on the junction of vertical and horizontal walls

For the earthquake actions on double directions, the stress of vertical and horizontal wall junction is comparatively complicated. Stress concentration is easily to occur, particularly, building constraints on the corner are correspondingly weak, coupled with torsion effects, the junctions are more easily to be damaged (shown in Fig. 13). Concern to the houses which were damaged in the earthquake, it is found that a part of the structures were lack of enough links in the position of vertical and horizontal wall junction, and tie bars and columns were seldom set, which resulted in poor junctions between vertical and horizontal walls. When the earthquake occurred, vertical cracks easily appeared on the junctions, vertical and horizontal walls might be disengaged in severe situations, and the vertical walls might even collapse.

(4) Serious damage of thermal insulating layer on the roof of buildings(shown in Fig. 14)

Most thermal insulating layers on the roof of masonry buildings were seriously damaged for the amplified of earthquake action.

5.3. Damage Analysis on the Reinforced Concrete (RC) Structural System

Compared with other earthquakes occurred in recent years, the damage of RC structures was an important aspect in this earthquake. Its seismic damage performance can be divided into two kinds, one is the damages of load-bearing members such as beams and columns (shown in Fig. 15 and Fig.16); another is the damages of non-load-bearing members such as infill walls (shown in Fig. 17). NS direction is the main shock direction in this earthquake, the structural members' damage in NS direction is more serious than other directions. It is indicated that the trend of structural damages are directly related to the direction of ground movement.

Fig. 14 Damage of thermal insulating layer

Fig. 15 Damage of beam end

Fig. 16 Shear damage of ground floor column

Fig. 17 Damage of filler wall

6. CONCLUSIONS

Through the field investigation which mainly on the seismic damage behavior of each kind of buildings in Ning'er Ms6.4 earthquake, something are worth summarizing as follows for future's construction:

(1) Building design should be accorded to the current codes. Although earthquake is incapable avoid, we can construct buildings properly to obtain the ability to resistant the earthquake loading. From the investigation in the whole areas of Ning'er County, we could find that seismic damage of the buildings, which formally designed, strictly constructed and meeting the code for seismic design, was slight, on the other hand, the seismic damage was serious. It is clear that we should design and construct the building according to the code strictly, fundamentally improve the building's seismic bearing capacity.

(2) Steep slope, easily occurring debris flows and landslide areas should be avoided in site selection. Ning'er County is located in the mountain area, many buildings are built on hillsides and mountain ridges, the seismic loading is usually amplified, and debris flows and landslide are easier to occur in this kind of areas, the safety of the building is not ensured. In the west of Ning'er County there was a huge stone falled from Pu'er Mountain and stopped near the Yuhe village's rural house, and seriously threat the safety of house. When the county will be rebuilt, it should be considered moving village from steep slop and other dangerous hillside to flatland and other safety site. If indeed unable to avoid dangerous site, effective treatment on foundation should be carried out.

(3) Building structures should have uniform mass and rigidity to avoid partially weaken and abrupt change. In the Ning'er earthquake, serious seismic damages were found in certain buildings which were improperly constructed and decorated, such as unduly pursuing large space, changing buildings' main structure, opening big windows, etc.

(4) Vertical earthquake action should be considered in future's structure design. Ning'er earthquake belongs to right beneath city earthquake, the vertical earthquake action was strong, but local engineers seldom considered the vertical earthquake action in their structure design. In future, vertical earthquake action should be properly considered in structure design to avoid the seismic damage from vertical direction.

(5) Construction details should be carefully dealt with. Field investigation found that if construction details, such as cover of reinforcement and concrete pouring quality etc., were not dealt with properly, seismic damage was heavy.

ACKNOWLEDGEMENT

We would express our deeply thanks to the Yunnan Province's Construction Department and Ning'er Construction Bureau and local people to help us to finish this field investigation.

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