Geodesy and Geodynamics 2013,4(1):55-60

http://www.jgg09.com
Doi:10.3724/SP.J.1246.2013.01055

Earthquake-resistant performance investigation for rural buildings in Zhongxiang area, China

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Abstract: We carried out a census of the rural residential buildings of Zhongxiang area's 17 towns. Next, we conducted a sample survey in four townships: Huji, Shipai, Zhangji, and Jiuli. According to the census and sample survey data of the rural residence buildings, we evaluated the quality and earthquake-resistant performance of the rural buildings for the various local rural residential structural types. The results showed that there are four main factors affecting the seismic performance of the local rural residences: (1) Foundations are not made appropriately (such as by compaction or some other fill) but are built directly in the farming soil. (2) Seismic measures are not completely implemented. Structure construction measures are not in place at the junction of the vertical and horizontal wall. The vertical wall joints are not the result of the same masonry techniques as the horizontal joints. There are no lintels above the door and window openings, or if there are any, the length of the lintels is less than 240 mm. (3) The brick masonry wall has low strength. The greatest housing wall mortar strength is between *M*0.4-1.5, much lower than the strength of the brick. (4) The building material and construction quality are poor. The quality of the mortar masonry wall is poor. The cracks between the bricks are uneven, even in the seams.

Key words: rural buildings; structure type; seismic precaution; earthquake-resistant performance estimation; earthquake disaster reduction

1 Introduction

The collapse of a house is the main reason for casualties and property losses when a destructive earthquake occurs. The seismic performance of residential buildings is directly related to the safety of people and their property. Vast rural areas, where half of the country's total population lives, account for more than 2/3 of the potential seismic hazard zone, and the majority of the 5 to 6 strong earthquakes have occurred in these areas[1]. Rural buildings account for approximately 85% of the houses that collapsed during the *M*s8.0 Wenchuan earthquake of 12 May 2008[2]. 90% of the houses collapsed during the *M*s7.1 Yushu County earthquake of 14 April 2010.

The huge differences between the seismic capacities of houses in rural areas are a direct result of casualties caused by earthquakes. A single devastating earthquake could cause dozens of people to die in developed countries such as the United States and Japan and could result in the deaths of hundreds or even tens of thousands of people in developing countries. An *M*s6.5 California earthquake in 2003 caused three deaths in the United States. The *M*s7.0 Fukuoka earthquake in 2005 resulted in one death in Japan. In contrast, The *M*s6.8 earthquake in Bam, Iran caused more than 30 thousand deaths and more than 30 thousand injuries in 2003[3]. In 2010, when an *M*s7.0

Received:2012-12-01; Accepted:2012-12-27
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earthquake hit the capital of Haiti, the entire city of Port-au-Prince was in ruins, and the death toll reached 222 500 people.

Seismic fortification management and the capacity to reduce the damage from earthquakes in rural residential buildings are relatively weak in Hubei Province. Therefore, it is imperative and urgent to conduct a rural residential seismic survey and research the countermeasures to reduce earthquake disasters. To improve the overall ability to prevent earthquake disasters in rural areas, we conducted rural residential seismic performance research in Zhongxiang area.

2 The current situation of rural dwellings in Zhongxiang area

2.1 Basic overview

The Zhongxiang area is located in central Hubei Province between the middle the Hanjiang River and the northern end of the Jianghan Plain. Zhongxiang area is a 6-degree seismic fortification zone. There are four seismic records of $Ms5.0$ to $Ms5.5$ earthquakes in the historical record[4] (Tab. 1).

2.2 Investigation content

(1) Basic situation

The population of the village surveyed, the total construction area of rural residences, the number of layers, the height of the construction area, the basic cost, and the rural residential structure type, construction era, and the construction materials.

The building structures types are divided into four categories according to reference [5]: steel and concrete, brick, brick and wood, clay and wood, etc.

The periods of farmhouse construction are mainly divided into four periods: dwellings built before 1960, those built from 1960 to 1980, those built from 1980 to 2000, and those built since 2000.

(2) The geographical location of the village, the seismic intensity status, and the classification of the construction site are surveyed to determine whether they belonged to a favorable location, an adverse lot or a dangerous location. To evaluate the foundation and the basic situation, the foundation is checked for correct handling, the basic form of the dwelling is assessed and the upper structure of the building and its earthquake-resistant features are also checked.

(3) Quality status

We mainly investigate the foundation, load-bearing components (load-bearing walls, beams, columns, etc.), and the degree of non-load-bearing elements damaged. The evaluation results are classified into four categories: intact, largely intact, general damage, and serious damage[6].

(4) Earthquake-resistant performance estimation

The conclusion is divided into basic compliance requirements, the need for reinforcement and no reinforcement value, for three types of identification based on reference [6].

2.3 Investigation results

In Zhongxiang area, the rural residential buildings are constructed at various distances from each other, and the villages are dispersed. Furthermore, the building structure types are diverse. According to the census and sample survey data of the rural residence buildings in the towns of Huji, Shipai, and Zhangji and the village of Jiuli (Fig. 1), rural residence structure types can be divided into four categories (Tab. 2).

Before 1980, the main structure types were earth and wood, brick and wood, and brick (cottage). The building materials were primarily soil, stone, wood, clay bricks, lime, clay tile, etc. The houses were designed

Table 1 Historical earthquakes in Zhongxiang and the nearby area

No.	Time(yy-mm-dd)	Latitude (°)	Longitude (°)	Magnitude	Reference place names
1	1407	31.2	112.6	5.5	Zhongxiang area, Hubei Province
2	1469-11-13	31.2	112.6	5.5	Zhongxiang area, Hubei Province
3	1603-05-30	31.1	112.7	5	Zhongxiang area, Hubei Province
4	1620-03-05	31.0	112.7	5	Southeast Zhongxiang area, Hubei Province

Table 2 Rural residence statistics of the survey point in Zhongxiang

No.	Survey point	Rural population	Total construction area of arerural residences (m^2)	Construction area ratio (%)			
				Steel and concrete	Brick	Brick and wood	Clay and wood
1	Kedian town	12122	415715	/	12.3	83.2	4.5
2	Shipai town	65688	65688	/	85	15	/
3	Zhangji town	18600	856430	25	40	30	5
4	Jiuli country	12659	66600	/	25	70	5

Figure 1 The administrative zoning map of Zhongxiang area and sample survey points

and constructed by building artisans. The buildings constructed during this period account for 6% of the total houses.

Because the rural economic conditions and quality of life improved between 1980 and 2000, the main structure types used were brick and brick and wood. Multistory brick was mainly used after 1990. The board of the floor (roof) was mostly precast concrete slab. The building materials were mainly clay bricks, steel, cement, sand, gravel, etc. The houses were designed and constructed by building artisans. The buildings constructed during this period account for 86% of the total houses remaining today.

Since 2000, and especially after the 2008 Wenchuan earthquake, the farmers recognized the importance of earthquake disaster reduction, and their awareness increased. The quality requirements of houses also gradually increased. The main structure types since 2000 are brick and concrete and reinforced concrete structures of 2 to 3 layers. The houses are designed and constructed by building artisans. Certain seismic measures have also been taken, such as having layered ring beams and having the four corners reinforced by structural columns. The houses are built through formal planning and are designed in a rural residential village based on seismic safety engineering. They are sanctioned by the government. The buildings built during this period account for 8% of the total houses.

2.4 Existing farmhouse quality status assessment

From the results of the census, 94% of these houses do not have design drawings. They are constructed using traditional experience, and the simple construction of house foundations is based on conventional approaches. Of the surveyed farmhouses, 25% are intact, and 60% are largely intact. The housing walls have a small amount of fine cracks, and the wall plaster has slight hollowing, cracking, and spalling. There are a small amount of brick wall cracks, weathering, corrosion, and mortar joint crisps. Ten percent of the houses are damaged. 5% of the housing walls have cracks, which can cause the roof to leak and result in serious damage to the house. The assessment results are shown in figure 2.

2.5 Estimating the existing farmhouse earthquake-resistant performance

According to the survey results, most of the farmhouses built before 2000 have no ring beams or structural columns. There are vertical cracks in the vertical and horizontal wall junctions. The mortar strength is low, and the weak seismic capacity needs to be strengthened to meet seismic requirements.

Most of the farmhouses built after 2000 have ring beams, structural columns, cast-in-place floor (roof) panels, and a framework structure. These houses are basically in line with seismic requirements. However, parts of these houses are not adequately designed. Seismic measures are not in place, the construction quality is poor, and low strength mortar is used. Rural residences that do not conform to seismic requirements need to be strengthened. The assessment results are shown in figure 3.

3 Factors affecting the seismic performance of rural residences

3.1 The impact of the foundation

There are two main types of foundation. The first is a bad foundation, such as collapsible foundation soil, which does not meet the appropriate ground treatments for housing. The second is a shallow foundation, which does not reinforce or change the fill processing, and is located directly in the farming soil. This foundation is influenced by the temperature and humidity, and the large deformation of the upper load can be observed shortly after the completion of the housing wall cracking caused by the uneven settlement of the foundation, mainly a result of vertical and diagonal cracks in the wall (Fig. 4)[7].

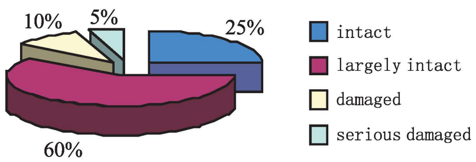

Figure 2 Existing farmhouse quality status assessment results for Zhongxiang area

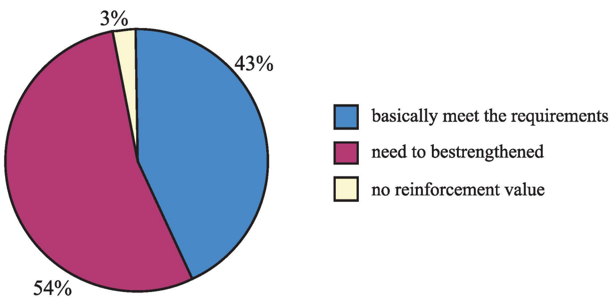

Figure 3 Existing farmhouse earthquake-resistant performance assessment results for Zhongxiang area

Figure 4 Wall vertical crack

3.2 The impact of seismic measures

The wall of the house, floor (house) cover, and the various structural elements between the anchor and the foundation constitute the whole house. They contribute to the structure as a whole, quickly strengthening the stiffness of the space during an earthquake to prevent any structural damage from spreading. Therefore, it is reasonable to take structural construction measures to strengthen the areas between the walls and the floor node connections between the various parts of the building's components. This is very important for improving seismic performance. In this investigation, we found that the structural construction measures of many rural residences are not in place in the junction of the vertical and horizontal walls. The vertical wall joints are not the result of the same masonry technique as the horizontal joints. Therefore, there are large vertical cracks, even through the seams (Fig. 5). There are no lintels above the door and window openings, or if there are any, the length of the lintels is less than 240 mm. Because of this, there are 45-degree cracks in the top of the door and window openings (Fig. 6).

3.3 The impact of wall strength

Given the damage characteristics, the wall strength is the most important factor that affects the seismic properties of the wall. The damage to a wall from an earthquake increased because of the poor quality masonry and the mortar shear strength. The survey results show that the strength of the brick masonry wall is low. The greatest housing wall mortar strength is between $M0.4-1.5$, much lower than the strength of the brick. The bearing capacity of the wall mainly depends on the strength of the mortar when the mortar strength is less than the block strength. The strength of the mortar and the masonry quality are the main factors that affect the wall's shear capacity. Wall shear failure occurs when the wall's shear capacity is exceeded. Evidence of wall shear failure occurs in the form of 45-degree diagonal cracks, cross-diagonal cracks, and mortar joint cracking[8].

Figure 5 Wall junction vertical crack

Figure 6 Wall tilt crack

3.4 The impact of building materials and construction quality

The quality of construction materials, such as brick, cement, sand, and stone, are reinforced to comply with national standards. Construction workers should understand the operating procedures. Erroneous construction methods directly affect the quality of construction, and the construction quality directly affects the quality of the seismic performance of the housing. For shear strength, frictional sliding, crisp crush resistance and compressive strength of multi-story brick houses to improve, they must rely on the quality of construction[9]. Survey results show that the building construction quality is poor. The quality of the mortar masonry wall is poor. The cracks between the bricks are uneven, even in the seams (Fig. 7).

Figure 7 Poor quality of a masonry wall

4 Suggestion

A building's foundation should be properly studied. The soil compaction in layers or dredged first muddy soil, loose silty sand layer, medium-coarse sand, prime soil fill, and compaction in layers must all be taken into account. The housing high aspect ratio and bay should not be too large. A priority cross wall bearing system should be set up. Wall openings and small holes should be minimized. The walls of the connection should be reliable. If possible, the interior and exterior should be constructed with the same masonry techniques. The exterior wall corners and the interior and exterior junctions should be reinforced. Rachel steel should be located on the exterior wall corners and in the interior and exterior junctions. We should note the lap length when the precast hollow slabs are used in the floor and roof. Additional reinforced structural measures are needed between the prefabricated panels and the wall or ring beam.

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