

# Investigation of Damaged Old Buildings of Historic Town in Sichuan Earthquake

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Zhaohua is one of historic towns of Sichuan province in China. On May 12<sup>th</sup> 2008, 232 historic buildings with through type timber frame were damaged in earthquake measuring 8 on Richter scale. The purpose of this report is to study the extent of damage to these historic buildings during the earthquake, and then attempt to find the weak points which these buildings displayed. In China, although a disaster prevention plan was in place for historic towns, mainly this plan focused on fire and did not include practical information on how to reinforce the historic buildings and what should be done during a disaster and post disaster.

**Keywords :** *Sichuan earthquake, historic building, through type timber frame, disaster prevention plan*

## 1. Introduction

On the afternoon of May 12, 2008, an 8.0-magnitude earthquake hit Wenchuan County of Sichuan province in China, a mountainous region in Western China, killing about 69,226 people and leaving over 17,923 missing. Also, some historic towns and historic buildings with traditional and local identities were damaged in this earthquake.

Zhaohua, a historic town, is located in the northeast of Sichuan province, approximately 220 kilometers northeast of epicenter, Wenchuan. The position of Zhaohua is shown in Fig.1. The detailed planning of repairing the Zhaohua historic district was finished under the guidance of National Historic City Research Center of Tongji University from April to October 2006. With this planning the authority of Zhaohua town had taken the corresponding measures for reparation of historic buildings.



Fig.1 Position of Epicenter Wenchuan and Zhaohua Town

In this planning, the historic district area was determined as 29Ha, where 2750 people live (in 2006 statistics). 232 historic buildings, the main structure is through type timber frame, located in this town,

including 41 historic buildings belongs to cultural property units, which were designated by province or municipality, and 191 undesigned historic buildings. In December of 2008, Zhaohua was designated as a Historic and Cultural Famous town by the Chinese government. After the earthquake, we investigated Zhaohua's damaged historic buildings.

The purpose of this report is to find the weak points of the damaged historic buildings with through type timber frame, and provide some useful tips for the reinforcement of the historic district in Sichuan province. Also, some advice would be rendered for improving disaster prevention plan of China. The over arching aim is to preserve local and cultural identities in historic towns.

## 2. Characteristics of Through Type Timber Frame

The buildings with through type timber frame utilize tile roofing. The building structure consists of columns and beams. Through type timber frame consists of three column wooden frames or five column wooden frames. Across the beam through the column under the crossbar is called through type timber frame. Through type timber frame is wearing connection into the overall structure of wood components. The role is to be the connection of beams and columns, ensuring lateral rigidity and stability of the wooden frame.

The characteristics of through type timber frame (Fig.2 and Fig.3):



Fig.2 Wooden Structure of Gable Wall and Perspective in Through Type timber frame



Fig.3 Building under Construction of Through type timber frame House

### 1) Load-bearing system and maintaining structure separately

The wooden structure is also a load-bearing system, columns and horizontal beams are the main load-bearing elements, as are the retaining wall structure, which are flat and flexible to meet different seismic loading requirement. Commonly, substructure, such as walls are composed of mud, adobe, pebble wood, walls, bamboo, which are easy to be found nearby.



Fig.4 Distribution of type timber frame house

## 2) Tenon-and-mortise

It's easy to maintain structural integrity with tenon-and-mortise structure. Generally, joints with tenon-and-mortise in beams and columns absorb more energy, in order to increase structural integrity. The tenon-and-mortise is a kind of light structure, with small seismic loading, good elasticity, ability of deformation and recovery.

## 3) The heavy gable walls with low ability of deformation and recovery

As gable wall is not easy to adopt the deformation, vertical stability has always been weak. The buildings with through type timber frame are distributed in the south of china, especially in Sichuan province, Chongqing city, Yunnan province, Hubei province, and Hunan province. When some old houses in these fields were regenerated or repaired, the owner always kept the main wooden structure.

## 3. Damage Condition

After investigation on 232 damaged historic in Zhaohua, we got the data as follows:

Table 1 Damaged Condition of Historic Buildings

Damage condition	Slightly damaged	Partially damaged	Totally damaged	Total
Numbers				
Damaged Numbers	112	74	46	232
Percentage	48.3%	31.9%	19.8%	100%

We found in our investigation: in 62 buildings with mud wall, the number of totally damaged buildings was 27 and accounts for 43.5%; in 162 buildings with brick wall, the number of totally damaged buildings was 18, accounting for 11.1%, the percentage of totally damaged buildings with mud wall is a significantly higher than damaged buildings with brick wall (Tab 2).

Table 2 Damaged Condition of Historic Buildings with Different Materials

Type of historic building	Totally damaged		Partially damaged		Slightly damaged		Total	
	number	percentage	number	percentage	number	percentage	number	percentage
Mud building	27	43.5%	16	25.8%	19	30.7%	62	100%
Brick building	18	11.1%	67	41.4%	77	47.5%	162	100%
Wooden building	1	25.0%	1	25.0%	2	50.0%	4	100%
Total	46		84		98		228	

※ 4 masonry historic buildings (for tourism) were slightly damaged.

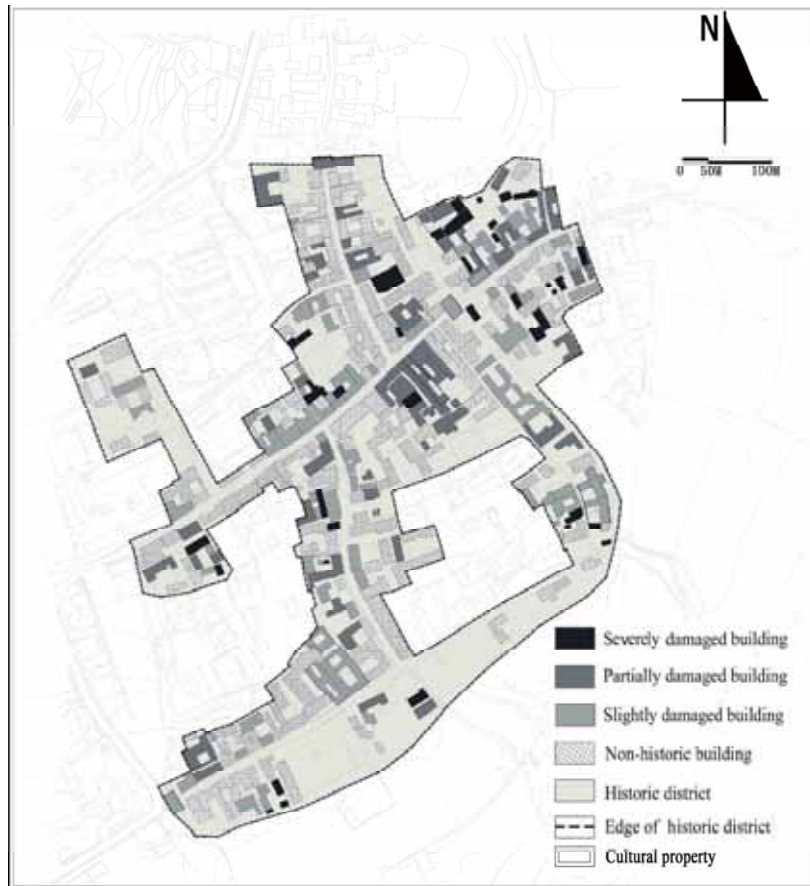


Fig.5 Damage Condition of Historic Buildings

#### 4. Analysis on Damaged Historic buildings

The classification of damaged condition has been shown in Tab 3.

Table 3. Damaged Position of Historic Buildings

Damaged position \ Damaged condition		Slightly damaged	Partially damaged	Totally damaged
		Roof	<p>Tile of the roof Tile fell down with quake ( fig 6 and fig 7)</p> <p>Ridge of the roof Ridge of the roof broken (fig. 8)</p>	
Roof Structure		Few structures damaged, and most of them were all right (fig. 9)	Some structures damaged, others were all right (fig.10)	Most of structure were damaged and collapsed (fig. 11)
Wall		<p>Few cracks occurred on the surface (fig.12 and fig.13)</p> <p>Materials on the surface of wall foot fell down (fig.15)</p>	Wall inclination (fig.16)	Most of wall collapsed, particularly the mud wall(Fig.17, Fig.18 and Fig.19)

※ few means 5%, some means 30% and most means 50%.

### Roof surface damage

Roofs damage during seismic action is a very common. Damage is depicted with the loosening of the tiles, the tiles move individually, not as a cohesive unit and fail, resulting in areas of the roofing tiles falling. All roofs experienced damage in varying degrees (Fig.6 and Fig.7). During construction the tiles were attached to the rafter without the use of fixture and bond. Thus, when the quake happened, the tiles easily fell down. The long semi-circular tiles that sit at the apex of the roof (Fig.6), upon construction, are not adhered with a bonding material. Subsequently upon seismic action of the tiles and structure below the tiles break away and fall.



Fig.6. Most of Tiles Fell Down



Fig.7. Few of Tiles Fell Down



Fig.8. Ridge of the Roof Broken

### Structural roof damage

From observations taken of structural roof damage, we found a high percentage of rotten wood, reducing the structural integrity of the wooden supports. Rafters carry the loading of the roof tiles. Rafter members are generally light and thin. When there is damage to the wood it's not easy to restore and change with its high position, and limited access. In the quake, rotten wood easily fails and tiles fall down.



Fig.9 Few Structures Damaged



Fig.10 Some Structures Damaged



Fig.11 Structures Collapsed

### Connection of the wall and roof

Purlines and beams were connected to the wall without fastening links. The dualities of the movement of the vertical and horizontal members during the quake have not worked in unison, causing failure. Materials act differently during seismic action; together they can work in uncomplimentary ways, causing failure, leading to cracks from these connections.



Fig.12. Few Cracks Occurred on the Wall



Fig.13. Cracks from the Connection of the Wall and Roof



## Wall damage

During the earthquake, the brick and mud load bearing wall failed, structural integrity has been undermined, resulting in partial or complete collapse. Surface materials fell down, significant cracks occurred in the load bearing wall during the seismic action, resulting a failed connection between the walls and the purlines and beams.

During seismic action materials perform differently. Wood is able to absorb the energy, whilst brick and mud cannot. Due to this, the combination of materials worked differently in earthquake, resulting in structural failure (Fig.14).The surface materials on the foot of the wall had been loosened due to precipitation. The already weakened material failed during the earthquake, the surface materials fell away easily (Fig.15). The through type timber frame structurally performed well in the quake due to its lateral stiffness, partial failure occurred resulting in the leaning of gable to one side (Fig.16).



Fig.14. New Wall and Old One Shocked



Fig.15. Materials on the Surface of Wall Foot Fell Down



Fig.16. Wall Inclination

Compared with the wall with only one material, some walls consist of complex materials, such as brick, gravel, mud or earth, collapsed easily. The heavy walls of through type timber frame is not the load-bearing structure, and also collapse easily with less flexible, particularly the mud wall (Fig.17, Fig.18 and Fig.19).



Fig.17. Collapsed Wall



Fig.18. Various Materials in the Wall



Fig.19. Collapsed Mud Wall

## 5. Consideration of Disaster Prevention Plan in Historic Town of China

As we know, a disaster prevention plan is necessary for reducing losses in a disaster. There were some guidelines on disaster prevention in the preservation planning made in 2006, but only specifically for fire, other disasters, such as earthquakes were not including in guidelines. In Infrastructure planning, a lot of investigation and detail has been given regarding the position of fire hydrant, refractory of the historic building, principles of emergency refuge, advice of organizing residents fire, improving residents' awareness of fire prevention and increasing the knowledge of fire fighting equipment and its uses. Whilst this is very important given the high density areas, and high risks of fire (which cause a significant loss of wooden, and wooden composite buildings) earthquake guidelines have not been addressed.

Even though significant planning has been undertaken for fire prevention, there are a number of areas that are still unclear pertaining to fire prevention. For example, detailed information such as; where is the exact position for emergency refuge, which road or roads should be used in emergencies. Methods on how to organize a resident's fire group and improve the dissemination of knowledge throughout the community

would also be of benefit regarding disaster planning.

Regarding standards and principles at a national urban planning level, there are some principles in place for disaster prevention planning of historic towns. It is said fire prevention is the most important in historic districts, and some endangered buildings should be reinforced for seismic damage, but original appearance must not be altered, affecting the authenticity of the building. But in this standard, there is lack of detail regarding how exactly to reinforce the historic building and knowledge pertaining to the weak points for reinforcement.

## 6. Conclusion

(1) The historic buildings made of mud are easy to be damaged compared to other structures. To avoid the collapse of wall, various materials should be changed by one, in order to improve the entirety of the wall, especially for mud wall.

(2) One of weak points is the connection between the beams and purlines to the wall structure. Some historic buildings had been repaired during 2006 and 2007, but during the repair reconstruction no reinforcing was used. Therefore, during the process of recovery for damaged historic buildings, the connection between wooden wall structures, reinforcement is advisable. Additionally utilising different materials could work in harmony and reducing mutual collisions.

(3) Existing disaster planning for the prevention of earthquake disasters, and to reduce the damage made by earthquake is not enough. More than 3 years passed, firstly the Chinese government focused on the reconstruction of big city and resolved some residential problems, and not to make the new disaster prevention planning of historic district.

In order to reduce future loss, in the possibility of a next earthquake disaster, it is necessary to provide some principles and guidelines on how to investigate and subsequently identify structural weak points, and reinforce during cyclic repair work such as in 2006 to 2007. Thus, some method of transmitting knowledge to the owners of the important historic buildings, via perhaps public drills, printed educational pamphlets, local community exhibitions, that identify structural weak points in buildings, and talk of maintenance such as repair of rotten supporting wooden roof member structures, prior to earthquake and post-earthquake.

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