Study on the Damage of Residential Buildings of Jiuzhaigou Tibetan Villages in World Heritage Sites

Hongtao Liu[1], Yibo Feng[2], Yue Fei[3] and Hongyang Yang[4]

[1] Associate Professor, Southwest Jiaotong University, School of Architecture and Design
(Sichuan, Chengdu, 611756, China)

[2] Master, Southwest Jiaotong University, School of Architecture and Design
(Sichuan, Chengdu, 611756, China)

[3] Master, Southwest Jiaotong University, School of Architecture and Design
(Sichuan, Chengdu, 611756, China)

[4] Research Fellow, University of Sydney, Faculty of Architecture Design and Planning
(Sichuan, Chengdu, 611756, China)

Jiuzhaigou, one of the world natural heritage sites in China, was severely damaged by the earthquake in August 2017, and many traditional Tibetan residential buildings in its villages were seriously damaged. This paper takes the damaged Tibetan style residential buildings in Jiuzhaigou villages as research subject. The research methodologies of this paper include 1. the field investigation; 2. analyze the earthquake damage and post-earthquake restoration of the residential buildings; 3. Explore the correlation between local Tibetan traditional building structure, construction characteristics and earthquake damage. Finally, it is expected that the results of this study could be a valuable reference to the conservation and restoration of those vernacular residential buildings with local regional characteristics after earthquakes.

Keywords: *World Natural Heritage; Jiuzhaigou Valley; Earthquake; Post-disaster Restoration*

1. Research Background

On August 8, 2017, a magnitude 7.0 earthquake struck the region near Jiuzhaigou (Fig.1) which is a world natural heritage site in China's sichuan province.

This earthquake was the strongest one of 142 earthquakes happend in the region during 2012-2017. The epicenter of the earthquake is located in a village 5km west of Jiuzhaigou World Heritage Conservation Area. Until August 13，2017, 25 people was killed, 525 injured, 6 were disappeared ,176492 (including passengers) were affected and 73671 houses were damaged in varying degrees (including 76 collapsed)[1)] .

Jiuzhaigou is the main tributary of the Baihe River, the Baihe River flows from west to east from the north of Jiuzhaigou. From south to north, the Zechawa ditch and Rize ditch gather in Nuorilang. After the Zharu ditch meets the Shuzheng ditch in the North, they flow together toward the north and finally into the Baihe River.

Along the river, nine Tibetan villages are distributed in the valley (Fig.2). Since it is located in the border area of Sichuan Basin and Qinghai-Tibet Plateau, Jiuzhaigou village region is the Multi-ethnic mixed

settlements while Tibetan villages as the dominant body. Thus, Jiuzhaigou village region shows unique geographical environment and cultural diversity.

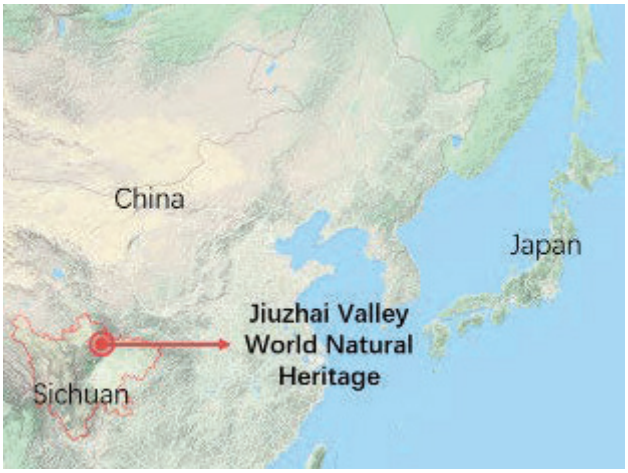

Fig. 1 Jiuzhai Vally Location

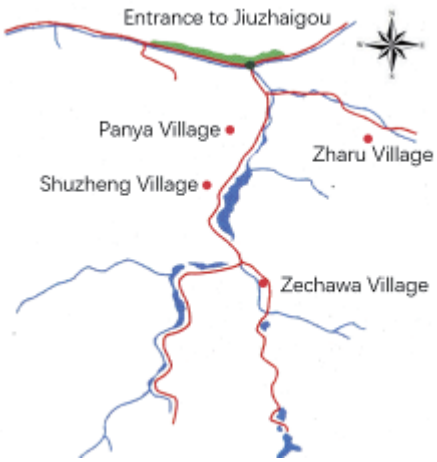

Fig. 2 Village Distribution

2. Jiuzhai Valley Residential Building Style

The reason why the world natural heritage site's name is called "Jiuzhaigou" ("Jiu" in Chinese means nine) is that there are nine traditional Tibetan villages distributed in the ditch. More than 2000 years ago, Jiuzhaigou region was the settlement area of Anduo Tibetan which is one of the three major branches of Tibetans. Thus, those villages in Jiuzhaigou are the physical evidences of Anduo Tibetan's developmental history. Naturally, these villages are of great historical heritage values.[2)]

Most of the traditional residential buildings in Jiuzhaigou were built based on natural terrain, and the volumes of those buildings were small.The type of structures of those buildings mainly includes wood structure, brick structure, earth and wood structure, brick and wood structure etc.As for the interiors in those traditional residential buildings, Tibetan architectural symbols were existed. Also, facades were decorated with traditional Tibetan color paintings or Tibetan wooden symbols. In the spare space of villages, many Buddhism pagodas and prayer flags were estabulished which deeply shapes the distinctive traditional style and features of the villages.[3)]

In recent years, during the development of local tourism and post-disaster restoration, these traditional elements are gradually disappearing. Through the field researches of the four villages (Shuzheng, Panya, Zharu and Zechawa), all investigated buildings were divided into 3 types based on the analysis of 5 elements (1. the time of construction; 2. building's stories; 3. building's structure type; 4. roof form and material; 5. elevation modeling and material):

(1) Style one: good style

The buildings in this style category were mainly built in the 1980s and 1990s, mostly with 2-3 stories. The buildings are mainly made of earth and wood structures, stone and wood structures, brick and wood structures. The roofs of those buildings were mainly slope roofs covered with small green tile. The facades were consisted of wooden door frames and window frame, Tibetan painting, wood veneer material and a small amount of carving (Fig.3)

(2) Style two: general style

The buildings in this style category were mainly built in the late 1990s to the early 20th century, and most of them are 2-4 stories. The buildings are mainly brick structure or framework dwellings. The roofs were covered with small green tiles, color steel plate slope roof, the facade is mostly red paint-based sand wall surface, no painting, the overall style is simple, doors and windows were nearly modern transformed (Fig.4)

(3) Style three: poor style

The buildings in this style category were mainly built around 2010, most of them were 1-4 stories, made of brick structure or framework structure. The roofs were slope roof or flat roof covered by cement or color steel. Facades were nearly made of modern style doors and windows, and a few decorative abstract Tibetan patterns. The building materials of this style were mainly various types of tile veneers, and a small part of them use the fair-faced concrete (Fig.5). Based on field surveys, the overall current situation of the 4 villages' building styles is shown in Table 1 and Table 2:

The Panya village shows the best current situation in building style, which has the highest proportion (reached 89%) of building style one (Good style); While the Shuzheng village shows the largest number (29 buildings) of building style one (Good style). And the Zharu village shows the highest proportion (67%) of the style two (General style), while the Zechawa village has the most buildings (32 buildings) in the style two (General style). As for the Style three (Poor style), Shuzheng village shows the highest proportion (18%) and the most buildings (13 buildings).

Fig. 3 Good style

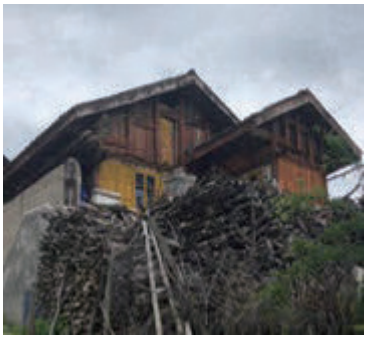

Fig. 4 General Style

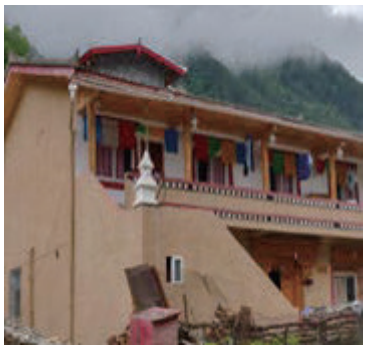

Fig. 5 Poor Style

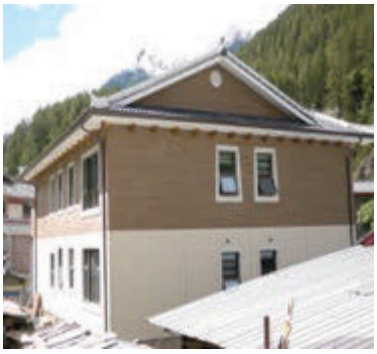

Table 1 Total Number and Proportion of Architectural Styles Investigated

Building style	Style One（Good style）	Style Two（General Style）	Style Three（Poor Style）
Number	76	89	25
Percentage	40%	46.8%	13.2%

Table 2 Number of Each Village Building Style

Building style	Shuzheng Village	Panya Village	Zharu Village	Zechawa Village
Style1	29	24	6	17
Style2	29	3	25	32
Style3	15	0	6	4

Influenced by the development of tourism, commercialization and natural disasters in recent years, the

traditional village style features of Jiuzhaigou were weakened in the restoration of traditional houses: modern materials and designs are constantly changing the fabric of local houses, and the style of the residential buildings in Jiuzhaigou has changed greatly[4]. The traditional building styles of the Tibetan village buildings, which are the core values of the Tibetan village residential buildings in Jiuzhaigou, are gradually missing in the restorations.

3. Statistics on Damage to Buildings in Jiuzhaigou Valley After the Earthquake

(1) Building damage grade after the earthquake

After the "8.8 Jiuzhaigou earthquake" in 2017, village buildings in the area have suffered varying degrees of damage. In the investigation of the buildings, it is found that after decades of development, the structure and materials of buildings in villages have changed.

Thus, this paper divides those buildings into 3 parts based on structure type, namely 1. reinforced concrete frame structure; 2. brick-concrete structure and 3. timber structure. After that, according to the criterion for determining the degree of damage "Technical Guidelines for determining the degree of earthquake damage in rural houses in Sichuan Province", this paper divides all the damage to the village buildings into three levels :1. Slightly damaged; 2. Partially damaged; 3.Fully damaged.

At present, there are residential communities planned in the Jiuzhaigou world natural heritage area, and the those communities consist of 3 administrative villages under the management of the Scenic Area Administration, namely Shuzheng (including Shuzheng village, Zezawa village, and Heijiao Village), Heye (including Heye village, Panya village, Yala Village) and Zharu (including Jianpan village, Rexi village, and Guodu Village). All of these 3 administrative villages are located in Jiuzhaigou valley and directly affected by protection management policies and regulations.

Restricted by natural conditions such as location traffic, the building in high-altitude, remote village houses in the area have been in disrepair for a long time, and the number of residents is small.As the residents mainly concentrated in Shuzheng Village, Heye Village, Zezawa village and Zharu village which are close to the tourist routes or scenic spots, so these four typical villages were selected as the research objects for the post-disaster restoration survey.

(2) Statistics on damage to building

Among the 201 buildings investigated on the spot, 53 buildings were slightly damaged, accounting for 26.4% of the total; 30 buildings were partially damaged, accounting for 14.9%; 12 buildings were fully damaged, accounting for 20.9% (Table 3).

Table 3 Damaged Condition of Residential Buildings

Damage condition	Slightly damaged	Partially damaged	Fully damaged	Safe	Total
Damaged Numbers	53	30	42	76	201
Percentage	26.4%	14.9%	20.9%	37.8%	100%

In the field survey of the affected buildings, wooden structures suffered most serious damages after earthquakes, 38.5% of all wooden structures were fully damaged. While the number of fully damage

brick-concrete buildings accounted only for 4.7%, and the number of fully damaged buildings of reinforced concrete framework was 0 (the lowest percentage). It is noted that in the order of framework, brick structure and wooden structure, the proportion of buildings in fully damaged (such as collapse, structural damage, and severe damage) were increased and the proportion of buildings in slight damage decreased. (Table 4).

Table 4 Damaged Condition with Different Structure

Structure	Slightly damaged		Partially damaged		Fully damaged		Safe		Total	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Frame	4	15.4%	1	3.8%	0	0%	21	80.8%	26	100%
Brick	15	23.8%	4	6.4%	3	4.7%	41	65.1%	63	100%
Wooden	19	19.8%	23	24%	37	38.5%	17	17.7%	96	100%

According to table 5, there are 41 damaged buildings in Zechawa village, accounting for 77% of the total buildings in the village. Panya village is the most seriously damaged one, accounting for 89%. Except Panya village, the other three villages have the highest proportion of slight damage, while their damaged degree is less than Panya village.

Table 5 Statistics of damage degree of each village building

Village	Slightly damaged	Partially damaged	Fully damaged	Unknown	Total
Shuzheng	16（19%）	12（14%）	11（13%）	45（54%）	39（46%）
Panya	8（30%）	5（19%）	11（40%）	3（11%）	24（89%）
Zharu	9（24%）	4（11%）	8（22%）	16（43%）	21（57%）
Zechawa	20（37%）	9（17%）	12（23%）	12（23%）	41（77%）

(3) Buildings damage

In the survey of four villages, the damaged parts of the buildings were similar in all of the three damage levels. The slightly damaged buildings were mostly roof tiles falling, external wall or soil wall cracking, veneer peeling, fence damage, etc.

In partially damaged buildings, most of them were roof tiles fall inclined structures, collapsed external walls or multiple cracks etc. While in the fully damaged buildings, the external walls of buildings in the four villages are partially or completely collapsed. The details of damaged parts of the buildings under investigation could be found in Table 6.

Table 6 Damaged Position of Residential Buildings with Different Structure

Position	Slightly damaged	Partially damaged	Fully damaged
Roof Structure	Tile fells Fig. 6 Ridge of the Roof Broken Fig. 7		
Wall	Cracks Fig. 8 The Wall Materials Fell Fig. 9	Wall inclination Fig. 10	Most of wall collapsed Fig. 11
Structural framework	Few Structures Damaged Fig. 12	Few Structures Damaged Fig. 13	Most Structures Damaged Fig. 14

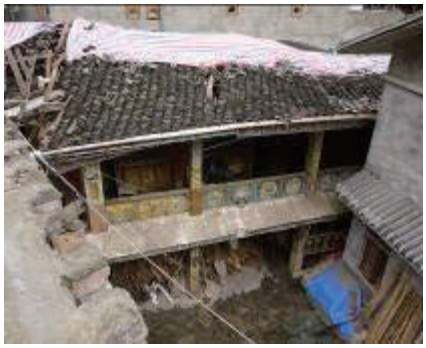

Fig. 6 Tile Fells

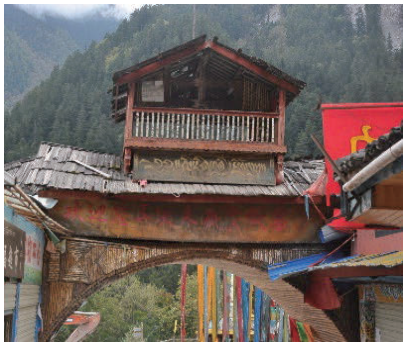

Fig. 7 Ridge of the Roof Broken

Fig. 8 Cracks

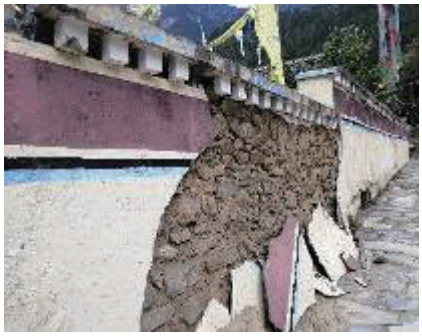

Fig. 9The Wall Materials Fell

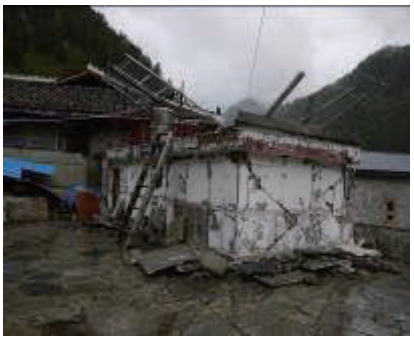

Fig. 10 Wall inclination

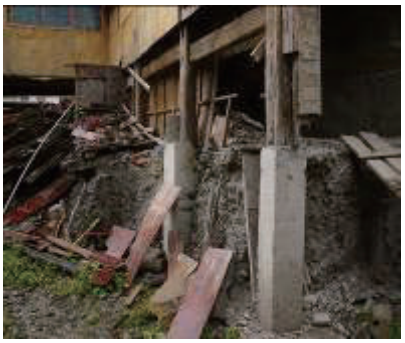

Fig. 11 Most of Wall Collapsed

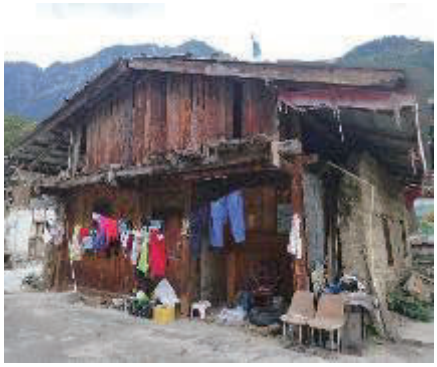

Fig. 12 Few Structures Damaged

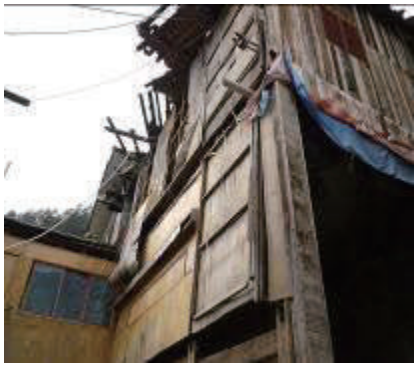

Fig. 13 Few Structures Damaged

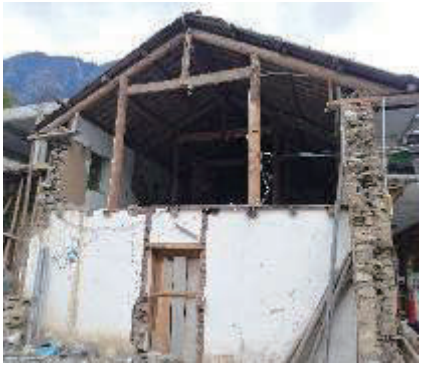

Fig. 14 Most Structures Damaged

4. Post-earthquake building Restoration

In the post-disaster reconstruction of residential buildings in Jiuzhaigou, different measures were taken for different damage degrees. The post-disaster building repair situations of the four villages were nearly similar:

For slightly damaged buildings, the roofs were repaired with new materials like tiles or colored steel plate, and the cracks in the walls are filled with cement mortar and face brick.

For partially damaged buildings, the roofs were re-shingled, but the gable, external wall and structural tilt have not yet been dealt with. For fully damaged buildings, such as partial or complete collapse of external walls, people chose to rebuild brick walls, wooden supports, wooden external walls and some have not yet been repaired (Figure 15). Among the surveyed villages, still some differences exist in the repairing of damaged buildings (Table 7):

Table 7 Different repair measures for damaged buildings

Village	Slightly damaged	Partially damaged	Fully damaged
Shuzheng	Cover the roof with tiles, color steel plates and wood board Plastering cement mortar Renovation of enclosure structure	Inclined wall supported by wood Rebuild the outer wall	Build exterior wall with wood Masonry wall
Panya	Filling wall cracks Roof tile laying and joint mending	Cover the damaged collapse part with textile	Wood supported wall Masonry wall
Zharu	Roofing tile Plastering wall	Resurfacing tile Build planks	Masonry wall
Zezhawa	Roof tile Plastering cement mortar	Resurfacing tile Roof covered with battens	Post timber column Rebuilt the inner wall

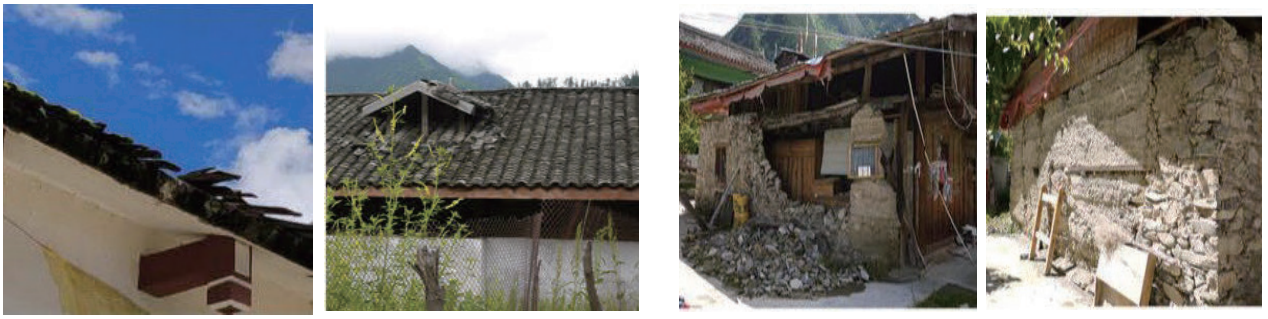

Fig. 15 Comparison of Roof Damage Repair

In the post-earthquake restoration work of world natural heritage site Jiuzhagou, the principle of the restoration was to recover the original traditional features and heritage values. Thus, the restoration of building structure, materials, enclosure structure, etc., were still finished in the traditional way. For examples, some old structures were still restored as earth and wood structures; in the materials' selection of interior environmental restoration, local materials are priorities in order to respect the characteristics of local buildings; as well as retaining traditional architectural symbols in interior or facade. The most important principle in restoration is maintaining traditional residential architectural features, to ensure that their architectural heritage values could be conserved.

5. Conclusion

Traditional architecture in Jiuzhaigou village is an important carrier of local culture and art. In recent years, the rapid development of local tourism caused some damages to the traditional style of local residences. Also, the earthquake disasters in recent years also caused serious damages to local buildings. Through the field investigation, this paper analyzed the data statistics of Jiuzhaigou residential buildings' current situation of styles, damage and restoration of buildings after the earthquake. The investigation reveals that the Jiuzhagou local government's restorations of traditional buildings show great respects to the original structure, functional layout and heritage values of traditional buildings. And their future-oriented implementations could be a valuable reference to the post-disaster restoration of characteristic ethnic buildings in earthquake area in the future. However, in some restoration cases, still many modern materials were used, such as cement mortar and color steel plate. Those restorations disturbed the continuation of the

authenticity of traditional buildings, which caused the overall style of the village buildings develop from unity to chaos.

These problems enlighten us to respect the original style of traditional buildings. Under the clear understanding of the relationship between the local traditional building structure, construction characteristics and earthquake damage, it is necessary to respect the original style of traditional architecture, control and continue the style and trend of residential buildings, preserve the heritage value of the village, and provide scientific guidance for the restorations of the village after the earthquake. Finally, it is expected that the research results will provide useful reference for the protection and restoration of local buildings with regional features after the earthquake.

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