

Research on Safety Evaluation and Sustainable Conservation Strategy of Tunbao Buildings--An example of residential buildings in Benzhai, Anshun, Guizhou

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Abstract. Tunbao architecture is a combination of defensive and residential architecture of Ming Dynasty, and is an important material substrate of Tunbao culture. With the accelerated pace of urbanization, the population of Anshun Tunbao has moved out, aging has increased and natural catalysis has led to the dilapidation and decay of the dwelling architecture, which lacks certain conservation measures. This paper takes Anshun Tunbao residential buildings in Guizhou as an example, and summarizes the development of residential buildings in this village through literature and field research, and summarizes the current problems of preservation. The results of this study are presented in the form of a graded "point-to-point" conservation strategy, which is intended to provide a theoretical reference for the conservation and restoration of historical buildings in the Han ethnic area of Guizhou.

1 Introduction

1.1 Historical Development Background

The eight fortresses of Yunfeng in Guizhou were built in the early Ming Dynasty, and are the most complete surviving village complexes in Guizhou. During Zhu Yuanzhang's time, he controlled the southwestern region with the "guardhouse cantonment system", and the Anshun Prefectural Records said, "The cantonment fortresses were all transferred to the north and conquered the south by Hongwu's thorns", and many guardhouses were established in Guizhou from the fourth to the thirtieth years of Hongwu. The ancient architecture of Anshun Yunshan Tun is composed of dwellings, temples and theater buildings in Yunshan Tun and this village. With the reduction of war and the reform of military policy, the role of Tunbao as a military camp gradually diminished, and many Tunbao were transformed from military tunnels to civilian and commercial tunnels^[1]. The cottage studied in this paper is located in Qiyangqiao Township, Xixiu District, Anshun, and was built in the late Qing Dynasty. It was relocated by rich families from the surrounding areas and was listed as the fifth batch of national key cultural relics protection units in 2001.

1.2 Explanation of architectural space background

The traditional architecture of this fortress is mainly made of wood and stone structures, among which the wood structure is mainly a pierced structure. The topography of the Anshun area is fragmented, and there is less land available for large area construction, so one courtyard is the common form of the fortress dwelling architecture, and there are two types of courtyards: the triple courtyard and the quadruple courtyard. The triple courtyard consists of the main house and the east and west wings on both sides, while the remaining side is enclosed by a wall, building a complete defense system by taking advantage of the original terrain. After a long period of use, some of the traditional buildings have fallen into disrepair, and some of the damaged building elements have gradually developed into dangerous ones. The dwellings of this fortress are an important substrate for the continuity and vitality of the Tunbao culture, which is limited by the historical and geographical development pattern, as well as the continuous migration of the population to earn a living, resulting in the migration of the architectural texture and the hollowing out of the dwelling units, and the lack of financial support and the contradiction of the people's use of the building functions, resulting in the lack of conservation methods. Therefore, this paper hopes to summarize the strategies for the conservation and restoration of salvaged historical buildings based on the

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evaluation of architectural safety, and to continue their ethnicity, local characteristics and cultural development.

2 The existing problems of the residential buildings in this cottage are summarized

2.1 Damage to the main components

2.1.1 Column bases and their damage

The pillar bases of this cottage are generally arranged under the pillars at the entrance and exit of the main façade and the gable corridor of the main house, except for the pillars near the entrance and exit passages, where no pillar bases are set, and the pillars are placed directly on the stone slabs or the floor. The pillar bases are mainly of drum type, flat drum octagonal type, quadrilateral type and other forms [2]. It was found that the pillar bases used in this cottage mainly have two problems: weathering and misalignment of the pillar bases. One is that after a long period of use, the surface of most of the pillar bases has begun to weather (Figure 2-1-1), and the pillars above the higher size of the flat drum octagonal and quadrangular pillar bases are less damaged, while the protective effect of the smaller size and height of the stone pillar bases is heavier than that of the pillars above the higher size pillar bases.

Second, the local occurrence of column base dislocation, column directly resting on the column base, because of uneven settlement and other reasons to produce column base dislocation, coupled with the humid climate and precipitation weather led to water penetration between the column base, accelerating the column tilt, stone softening, reducing its weighing compressive resistance



Figure 2-1-1 Column foundation appears
Source: Author's own photos

2.1.2 The main components of the wooden pile row frame and their damage

The wooden pillars of the traditional building of this fortress are the main vertical load-bearing elements, often arranged in the form of rows of shelves of pierced buildings. Each row of row frame contains round wooden pillars, melon pillars and through square, wooden pillars and through square species connected by mortise and tenon structure, melon pillars and through square are connected by way of slotted plugging. The author sampled and measured at the site, the diameter of the wooden column in the row frame is 150mm and 200mm two specifications, using the specification of the wooden column is thinner, the cross-sectional area of the wooden column are 0.07m² and 0.13m², the diameter of the melon column and the same specification of the wooden column. The whole wooden column is connected with three kinds of members, which are named as the square between the column and the column of the same row frame, the beam located in the second floor plane between the column and the column of the same row frame, and the beam in the floor cover between the row frame and the row frame, the corner column has two directions to connect with other members, the side column has three directions to connect with other members, and the middle column has four directions to connect with other members. The column is connected to the square and the remaining two types of beams and columns by semi-perforated mortise and tenon connections [3]. Meanwhile, the upper part of the melon column bears the load of the roof and is connected to the purlins of the roof, and the lower part transmits the load to the round wooden column by penetrating the square. The melon pillar is a member that transmits the load and bears the load directly.

The research found that the traditional buildings in this cottage generally have wooden pillars with cracked bodies, and the next problem is the rotten bottom of the pillars (Figure 2-1-2). Most of the wooden pillars in this cottage are still in "diseased" working condition, and some of them have reached the level of damage at the point of dilapidation and still have not been properly repaired. The gua pillars and square in the rows of frames have not seen any obvious damage





Figure 2-1-2 Damage to wood column
Source: Author's own photos

2.1.3 Roof cover and its damage

The roof cover of the traditional building of this cottage includes arch ow (see beam), purlins, rafters, and the way of bearing purlins on the pillar head is picking square bearing purlins (Figure 2-1-3), the specification of purlins is about 150mm in diameter, and the section form of purlins is mostly round, but there are also square and other forms. The roof cover is transferred by the purlins on the respective pillars, the purlins rest on the pillars, the golden purlins on the golden pillars are also arranged under the arch ow (see beam) as its middle bearing load members, using a combination of ridge rubbing and arch ow (see beam) way of connection, other pillars and purlins using the chisel excavation sandalwood bowl connection method. The damage of the roof cover of this traditional building is mainly caused by the damage of the roof slate (tiles) and the damage of the sliding purlins (Figure 2-1-3). Damage to the roof slate (tile) often forms a hole in the roof, and sliding purlins cause damage to the rafters and slate (tile) as well.



Figure2-1-3 The stigma purlin bearing method of traditional buildings in Benzhai
Source: Author's own photos

2.2 Damage to the envelope structure

2.2.1 Load-bearing walls and their damage status

The load-bearing walls of traditional buildings in this cottage contain both masonry structures and brick masonry structures. The stone masonry structure is generally built along both sides of the street or the external wall of the village, with a height of 1.8~2.5 m. It is made of small block-shaped stones or large stones piled up (Figure 2-2-1), or a thin ash masonry is laid between the stones, and the masonry method is either ordinary piling or masonry with aesthetic effect, and the choice of stones and the masonry method reflect the economic strength and social status of the Tumbao family. The choice of stone and masonry method reflects the economic strength and social status of the Tumbao family [5]. The masonry also plays a role in overcoming the poor bearing capacity of the weak foundation by virtue of the thickness of the wall. The main problems of cracking and tilting of the masonry walls in this cottage are that the structural damage of the masonry will produce a chain of damage, which is attributed to the way the stone structure is arranged, once the wall has through cracking or tilting beyond the limit will bring safety hazards, the towering hill wall tilts inward, while the street side of the street wall tilts, the direction of tilting is not regular.





Figure 2-2-1 Breakage of wall
Source: Author's own photos

2.2.2 Non-load-bearing walls and their damage characteristics

Non-load-bearing walls of traditional buildings in this cottage include wood-paneled walls, combined walls composed of stone and wood panels, and bamboo-woven walls and bamboo-clad mud walls (Figure 2-2-2), which are important components of the enclosure structure between the two columns of traditional buildings. Plank walls and combination walls are common wall types in traditional buildings in this stronghold and are also widely used in traditional buildings in Guizhou region.



Figure 2-2-2 Types of non-load bearing walls
Source: Author's own photos

Wooden panel wall is a common enclosure structure in this cottage. The plank wall of this cottage is in the form of vertical arrangement, and the wall structure made of about 20mm thick plank and border splicing has good stability. The combination wall located on the second floor of the building is less damaged, and only two pieces of the wall are found to have cracked slabs; however, the combination wall located on the second floor of the building is more seriously damaged, and part of the wall is located on the street side, and two to three adjacent walls have been tilted at the same time, and such walls have become a safety hazard.

The number of bamboo woven walls and bamboo woven sandwich mud walls in this cottage is relatively small compared to the wooden panel walls, but his damage is more serious. Bamboo woven walls are often arranged as partition walls in the second floor interior. The bamboo woven walls as interior partition walls are relatively well preserved, with only some of them showing deformation and decay. However, the large area of bamboo woven sandwich mud wall as an exterior protective wall produces deformation in the middle and lower part of the wall protruding to the outside, the indoor bamboo woven sandwich mud wall has decayed due to humidity and other reasons, the mud and sand filled in the wall appears to fall off locally or in a large area, there is a bending deformation of the wall due to environmental factors.

3 Result

3.1 Classification of building component types

In this paper, the common constituent elements of traditional buildings in this cottage are divided into components according to the parts of foundation, columns, beamworks, floor coverings, masonry walls, roof coverings and enclosure structures, respectively, and the types of components covered above are all superstructure components.

In addition to the above-mentioned components, there are three types of components that are not included in this traditional building, namely, components that are not connected to the main structure, components that are not part of the main structure, and components that have little impact on the structural safety of the building even if they are completely damaged, including doors and windows that have not been evaluated for their needs, movable wooden stairs, railings and handrails, and slate canopies added by users,

3.2 Calculate the overall proportion of dangerous elements of the structure

The proportion of hazardous components is the percentage obtained by dividing the sum of the product of the number of various types of hazardous points and their weights with the sum of the product of the number of various types of components and their weights, and its purpose is to identify and count the hazardous points.

$$r = \frac{\sum_{i=1}^n w_i}{\sum_{j=1}^m w_j} \times 100\% \quad (6)$$

in the formula: n - the total number of components whose safety does not meet the requirements; i - the number of components whose safety does not meet the requirements; w_i - the weight of the i-th component; m - the total number of all components; j - the number of all components; w_j - weight of the jth component.

3.3.2 Determine the weight coefficients of each type of member on each floor relative to this floor

The components to be calculated for the traditional building of this cottage include columns, masonry walls, main beams, secondary beams and floor (roof) panels, among which columns and masonry walls correspond to the two components of columns and walls in the Guidelines and are the components with the largest weights among all calculated components. According to the characteristics of the traditional architecture of Benzai, first of all, the logical order of weight size should be that columns and masonry walls are equally important, columns are important relative to beams or relatively important, main beams are important relative to secondary beams, and floor (roof) panels are the least important. It is worth noting that the division of beams into main beams and secondary beams is based on the characteristics of traditional buildings in Benzai, namely, in the first floor plan, the main beams are perpendicular to the floor cover beams and secondary beams, which are subject to greater forces and are more important than the secondary beams; while the secondary beams parallel to the floor cover beams are subject to reduced forces because of the uniform distribution of the floor cover beams on the floor panels. After the previous analysis, the same logic is adopted in the Dangerous Standard, and the two are different in the division of the project. Therefore, the component weight ratios of traditional buildings in this cottage can use the typical various component weight ratios^[7], as the following table data (Figure 3-3-2)

Table 3-3-2 Table of weight ratio of traditional building components in Benzhai

Floor (roof) panels	secondary beam	Main beam	Column	Masonry walls
1.00	1.76	2.96	5.36	5.36

Source: Drawn according to the Guidelines for Structural Safety Assessment of Modern Historic Buildings

3.3.3 Determine the floor weighting factor

The formula is used to calculate the weight of each floor in the building as a whole. It is noteworthy that some scholars believe that the formula for determining the floor weight coefficient in the Guidelines does not specify that the denominator is $\sum_{j=1}^n j$ or $\sum_{j=1}^n j^2$. And that the influence of the two is completely different, the former has a large difference in the influence coefficient of each floor, especially the basic layer is much higher than the rest of the layers, while the latter is basically from the basic to

the top layer with a regular decreasing. In this paper, according to the denominator $\sum_{j=1}^n j$ Calculation. With the first floor of the traditional building of this fortress as the first floor, the information on the number of floors of the common two-story compound and three- to four-story towers is substituted into the following equation

$$w_j = \frac{n+1-j}{\sum j} \quad (7)$$

The data in the following table were obtained:

Table 3-3-3 floor weight coefficient table

Total number of floors (n)	First tier weightin g factor	Second tier weightin g factor	Third tier weightin g factor	Fourth tier weightin g factor
2	2	0.5	0	0
3	3	1	0.33	0
4	4	1.5	0.67	0.25

Source: Self-drawn by the author

Finally, the weight values of each component of each floor and the numbers in the table of floor weight coefficients are substituted into Equation 6 to calculate the results

4 Protection strategy delineation

4.1 Evaluation of security level

The calculation results obtained are used to determine the component security level according to the determination criteria given in the following table (see Table 4-1).

Table 4-1 Safety level evaluation form for each component

Grading	Judging criteria
a	$r = 0$
b	$0.05 \geq r > 0$
c	$0.30 \geq r > 0.05$
d	$r > 0.30$

Source: 《Guidelines for Structural Safety Assessment of Modern Historic Buildings》

The overall security level is determined on the assessment of the security level of the components. The minimum level of the components is determined by the components and the security level division is indicated by capital letters. When adverse conditions are encountered, it is possible to reduce the original level by one level according to the conditions in the Guidelines.

4.2 Building restoration difficulty determination

Finally, the Guidelines specify the treatment requirements according to the overall safety level, as follows.

Table4-2 Table of processing requirements for various grades of modern historical buildings

Overall security level	Processing requirements
A	No need to handle
B	Very few components require measures
C	A few components require measures
D	Most components require measures

Source: 《Guidelines for Structural Safety Assessment of Modern Historic Buildings》

The impact on the safety of the surrounding buildings can be included in the treatment opinion. The analysis of this factor can reflect the impact of the breakage of certain traditional buildings on the surrounding buildings and residents, as well as on the safety of road pedestrians. Most of the street walls or fences of the traditional buildings in this cottage are masonry walls, and according to the width of the street and the height of the walls, the analysis of the impact on the safety of the surrounding buildings should be carried out. In the same way, according to the characteristics of the traditional building of this fortress with masonry walls underneath and wooden buildings on top, the impact of serious damage of these elements on the safety of the surrounding buildings should also be taken into consideration. In addition, although the walls in the triple compound belong to the structures, when these walls are in danger of toppling, they should be considered as factors affecting the safety of the whole compound, and it is not necessary to calculate the safety level of the structures. It is worth noting that when a traditional building has no impact on the safety of the surrounding buildings, it can be left undescribed, or described as having no impact, and the components that are not seriously damaged and do not affect the aesthetics are included in the daily management of traditional building restoration according to a reasonable traditional building maintenance system.

4.3 Graded protection management of traditional buildings in this cottage

According to the results of safety evaluation, the graded management and protection strategy of traditional buildings in the Village is proposed, and the protection of traditional buildings, the protection of the overall appearance of the Village and the protection of the surrounding environment in the Village are divided into three levels from small to large management scope.

4.3.1 The first level: restoration and protection of single structure techniques of buildings

On the basis of the safety rating of the traditional architecture of this cottage based on the results of safety evaluation, planned batch protection and restoration will be carried out respecting the principles of wholeness, originality and dynamic development. We will emphasize the restoration and preservation of the building structure and construction techniques, and will not reconstruct the remaining buildings, and will strengthen the management

and maintenance of the pillar bases, doors and windows, carvings of decorative parts and frescoes of the traditional buildings as key protection parts. The repair of the roof cover and roof slate (tiles), doors and windows, non-load-bearing envelope walls, wooden stairs, etc., the anti-corrosion and insect prevention measures of wooden structures, and the repair of other unforeseen damages are considered as regular maintenance works, and the regular maintenance works can take one year as the maintenance cycle for the traditional buildings with the safety level of A, B and C without serious damage.

4.3.2 Second level: overall protection of architectural style and appearance

The focus of the second level village overall style and appearance protection is that not only should new buildings and local random demolition be controlled, but also the architectural street pattern should be controlled on the basis of not changing the original building layout structure, building exterior texture and color, and increasing the accessibility of the street. The main components of the traditional buildings of this cottage that are partially destroyed, such as the reinforcement of cracked columns and cracked masonry walls, as well as the village walls and gates that are common to the traditional buildings of this cottage, should also be included in the maintenance and inspection of the public living equipment of this cottage as a key maintenance project to ensure that the new construction of municipal projects in the historical heritage complex does not affect their safe use.

4.3.3 Level 3: Synergistic protection with the surrounding environment

The management of the third level should take rivers and mountains as the management objects, and its focus is to protect the environment in the area of this fortress, and to manage and punish them according to the relevant laws and regulations, especially it should prohibit malicious damage to the environment caused by man, and consciously protect and supervise the surrounding natural environment of this fortress through villagers' self-government and other forms.

5 Conclusion

Based on the current situation of deterioration and poor protection of historical dwelling buildings in remote areas, this paper has conducted a detailed review of the historical formation and background of Anshun Benzhai. After researching and summarizing the construction techniques of the dwelling buildings in this village, and reviewing the current problems of the pillar bases, wooden pile rows, roof covers and walls in the enclosure structure, the damage is mostly caused by the penetration of natural rainfall and humid environment as well as the wear and tear of historical use over time, and based on the current problems, the proportion of dangerous components is evaluated, and the safety weight of the floors is divided

and counted, and the single building is proposed according to the hierarchy. The three-level protection strategy of single building protection, overall architectural style and surrounding environment is proposed according to the hierarchy, thus providing a theoretical evaluation of the current situation and safety of the residential buildings in this village.

References

1. Zhou Zhengxu, Li Jingting, Qian Yun. Characteristics and value analysis of the cultural landscape of Anshun Tunbao settlement in Guizhou[J]. *Guizhou Ethnic Studies*, 2019, 40(05):56-61.
2. Li Meijun, Luo Fajin, Bai Xinxiang. Study on the form of stone column bases of Ciyun Temple in Qingyan Ancient Town, Guizhou Province [J]. *Sichuan Architectural Science Research*, 2014, 40(02):284-286.
3. Dong Chunying. Mechanical properties and experimental study of mortise and tenon joints in wooden structures of ancient buildings [D]. Xi'an University of Architecture and Technology, 2010.
4. Liu Chengwei. Research on the reinforcement technology of structural members of wooden houses in villages and towns [D]. Huazhong University of Science and Technology, 2011.
5. Chen Shunxiang. Study on the Social and Spatial Patterns of Tunbao Settlements in Guizhou [D]. Tianjin University, 2005.
6. Wang Xuan, Wang Biao. Discussion on the safety assessment of modern historical buildings [J]. *Chinese and foreign architecture*, 2017(08):193-194.
7. Zhong Xingrun. Research on safety evaluation of existing housing buildings and its management [D]. Xi'an University of Architecture and Technology, 2010.