Investigation and Analysis of Sustainability of New Seismic Rammed Earth Buildings in Jinning County, Yunnan Province

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Abstract. With the promotion of "green building" and the concept of sustainable development, rammed earth architecture is receiving increasing attention. In this study, a practical study was conducted to critically assess whether the new rammed earth buildings in Dabaiyi Village, a demonstration site in Jinning County, Yunnan Province, whether meet the needs of local residents, whether they are environmental friendly and have good sustainability. The survey found that the modern rammed earth architecture in Jinning County is sustainable, even though it has deficiencies in team building, owner communication and floor plan layout.

Keywords: Rammed Earth Building, Improvement, Sustainability, Environmental friendliness.

1. Introduction

1.1 Research Background

Rammed earth building is made by ramming earth layer by layer between the templates with rammed earth tools. As an ancient architectural form with a long history, it is the crystallization of human civilization[1]. The supporting project of "One village" in Jinning County introduced the modern rammed earth optimization mechanism in the construction of Dabaiyi Village in Jinning County, determined the implementation of 3 households in the first phase, and solved the basic housing problem. In December 2017, the pilot project of rammed Earth dwellings in Dabaiyi Village was completed. This paper takes the project as an example to analyze the production process and technology of the new seismic rammed earth building, and to investigate whether the rammed earth building is environmental friendly.

1.2 Current status of domestic and international research

In the 1970s, Europe, America and other developed countries carried out systematic theoretical research on modern rammed earth architecture, and the scientific research results have been at the forefront of international research. A huge amount of research results have been applied to the construction of modern rammed earth buildings. Peter Walker et al.[2] provided a detailed explanation of the main structural measures in modern rammed earth construction, including wall foundations and joints, and used a large amount of data analysis to provide a strong guide to the practical construction of modern rammed earth. "Modern earth buildings - Materials, engineering, construction and applications" is a book edited by the British academic Matthew R. Hall et al[3]. It systematically analysed national codes, construction techniques, material properties and other relevant aspects of rammed earth construction, and also presented experimental data analysis from the structural and seismic point of view, as well as the latest research results from other countries, providing a theoretical basis for subsequent research work. British scholars Daniela Ciancio and Christopher[4] carried out an experimental study of traditional ramming techniques and obtained data that was compared and analysed scientific measures on material improvement, as well as providing a theoretical basis for subsequent construction measures.

In China, Zhou Jian[5] combed through the data of domestic papers on rammed earth architecture in the past decade, and the results showed that domestic research on rammed earth architecture mainly

focused on traditional architecture and regional culture, which accounted for 57.1%, with very little research on modern rammed earth architecture.

In recent years, due to the international environment, research into modern rammed earth techniques has gradually deepened. Chinese experts have combined advanced foreign techniques to develop rammed earth construction techniques suitable for rural areas in China. Teams from several universities have constructed many rammed earth projects of great scientific value for China. In northwest China, Xi'an University of Architecture and Technology has a wealth of research in the field of rammed earth. The construction team, headed by Professor Mu Jun, implemented a post-disaster reconstruction project for the village of Macha in northwest China, and the construction project has served as a model in China, while Professor Mu Jun has also been committed to the promotion of modern rammed earth technology in China. In southwest China, Professor Bai Wenfeng and his team at Kunming University of Technology and Science have developed four functional raw soil materials for the modification of raw soil materials in Yunnan. Meanwhile, in the post-earthquake reconstruction project for Guangming Village in Ludian, Yunnan, in collaboration with the Chinese University of Hong Kong, the theories and techniques applied during the project have also served as a clear demonstration for subsequent rammed earth construction in poor rural areas of Yunnan.

1.3 Aim

A survey and analysis of new earthquake-resistant rammed earth buildings in Jinning County, Yunnan Province, is carried out to find out whether the construction projects are environmental friendly and whether they are sustainable.

2. Research Methodology

2.1 Qualitative research——Interviews

Interviews can take three forms: unstructured, structured and semi-structured[6]. Structured interviews were used for this interview. The interviews were based on the techniques used in the construction of the new rammed earth dwellings. The artisans were asked questions in response to the issues raised and the answers were written down. The research site is located in the village of Dabaiyi, Jinning County, and the interviews were conducted with the artisans involved in the construction. The purpose of the interviews was to understand the construction process of the new earthquake-resistant rammed earth houses, to analyse the process of making the new rammed earth walls, and to refer the actual situation to the literature to investigate whether the actual construction process matched with the literature findings, whether there was an impact on the environment during the construction process and whether it was conducive to sustainable development.

2.2 Quantitative research——Questionnaires

Questionnaire survey is a data collection method that sends written questionnaires to respondents and obtains the required data through their answers to the questionnaire questions[7]. Through field visits and questionnaires, this study further analyses the situation of modern rammed earth buildings in Jinning County.

2.3 Data collection

This thesis mainly adopts fieldwork research. The field survey method is a method in which the researcher goes into the field to obtain real material about certain groups of people through direct observation and interviews[8].

Questionnaires were used as the main method of this survey and also as an important source of data. Arriving at the research site in person facilitates the conduct of the questionnaire to the target person, and any overly complex questions in the questionnaire can be explained in time to guide the target person, ensuring the authenticity, accuracy and reliability of the findings. At the same time, the

combination with the literature survey method allows for more meaningful research results to be obtained.

3. Research results

3.1 Questionnaires

A resident's questionnaire was used to assess satisfaction with modern rammed earth construction in Jinning County and to investigate the results of modern rammed earth craft practices on four levels: progress, quality, service and other suggestions for improvement. Five valid questionnaires were returned. After sorting out the questionnaire data, this paper selects the two most targeted survey results for analysis.

In the factor of "Evaluation of quality control of raw materials, construction and equipment" , all the owners choose "general". The main reason is that the construction team chooses wooden doors to maintain the characteristics of traditional residential houses, which has poor anti-theft and cannot guarantee the property safety of the owners. Similarly, in order to reflect the characteristics of traditional dwellings, plastering layer is not applied on the walls, so that the natural color of the earth walls can be seen directly. However, the pitted walls are pretty uneven and lack of aesthetics.

In the question about "Is communication with owners sufficient and effective?" , most still select "general". The owners explained that construction drawings were designed in advance, that they can not change the design for indoor layout, can not put forward ideas and any suggestions, and even that the project owner can not accept any adjustment. The communication with designers and managers were both invalid in interior layout after arguing with construction team. There is only one owner who chose "satisfied", due to his elder age. He said he is too old to require more for interior layout. The design scheme of the construction team was followed at that moment under the situation that owners disagreed a lot.

The results show that the satisfaction degree of modern rammed earth building in Dabaiyi of Jinning County is low and the success rate in the construction is insufficient showed by Figure 1.

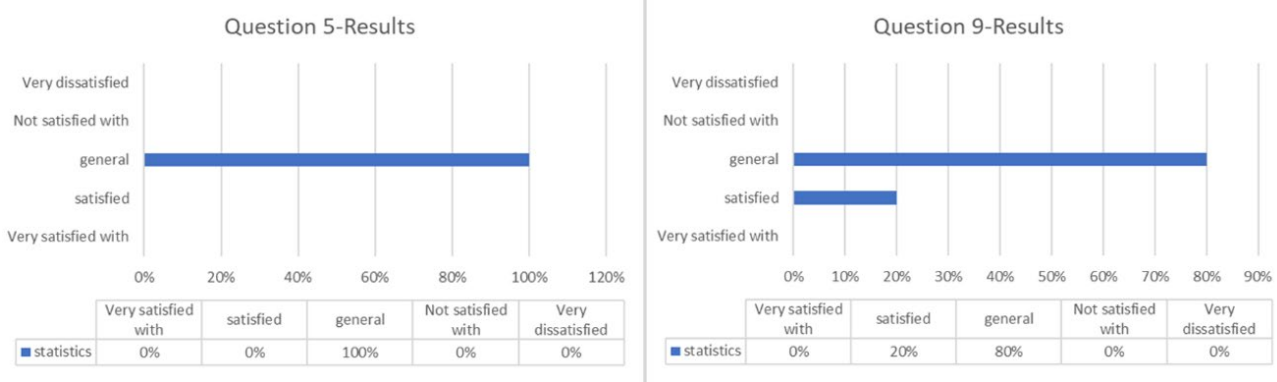


Figure 1. Collated questionnaire data

3.2 Demerit

(1) Design flaws

In the design of the new rammed earth dwellings in Jinning County, the house is divided into three areas for a good symmetry seen by Figure 2. The left and right sides are functional areas, while the middle part is designed with a "semi-enclosed" atrium. The designer thought the space would not only provide an activity area for the owners, but also provide a good cross ventilation. However, the three owners took certain measures to close the courtyard in the middle space when they moved into this house. The owners interviewed that the design brought them a poor and uncomfortable living experience. It is difficult to avoid rural livestock from entering the space and from controlling dust in windy weather.



Figure 2. Enclosed indoor courtyard by the owners

At the same time, the floor plan (see Figure 3） lacked balconies, which made it difficult to install solar panels on the roof. The owners said that this design does not meet their basic needs such as drying farm goods, and the long-term use of electric heaters to get lots of heat water definitely adds their economic burden as an extra cost to the rural family.

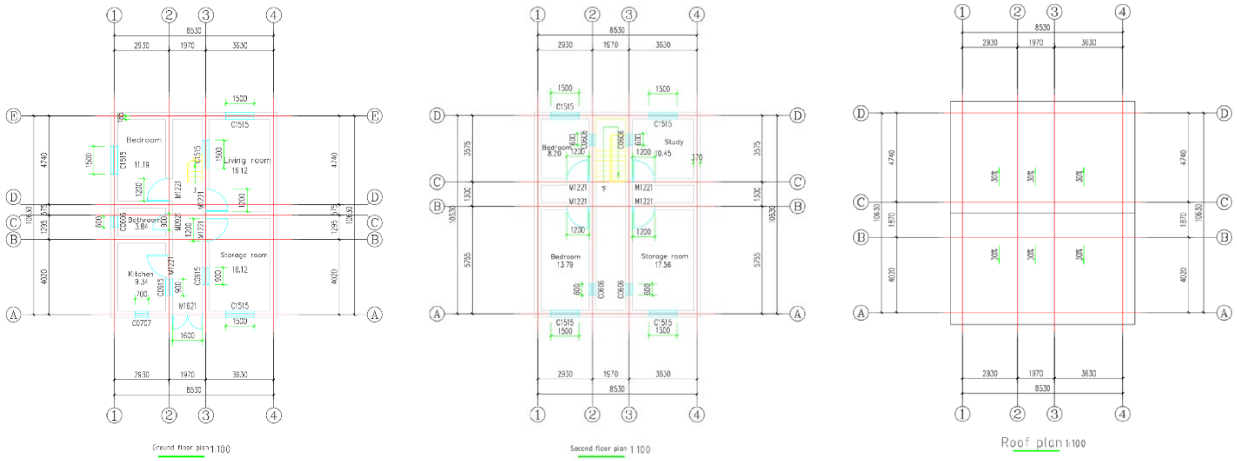


Figure 3. Floor plans of the new residence

(2) Construction defects

The holes created during the formwork support are not tackled after finishing the construction as following Figure 4. In order to ensure the compacted strength of the new seismic rammed earth walls, a new aluminium formwork was used. To ensure that the formwork was held in place without distortion, wall bars were used to hold the formwork in the corresponding place. This resulted in a row of holes left after the wall had been compacted. So far, the holes in the walls are not plugged or covered. It damages the overall appearance of the house and there is a risk of leakage that ants and insects easily enter the indoor rooms from outside through the holes. It is worth pointing out that this is not an inherent flaw in the workmanship, but a lack of details on the part of the construction.



Figure 4. Holes left by the support formwork

3.3 Sustainability analysis

As the earth's energy resources run out, while traditional reinforced concrete buildings generally consume huge energy, raw earth buildings are pursued by architects, due to the advantages of saving energy and material. The raw materials are locally produced so as to reduce the transport costs. At the end of its life cycle, the solid waste can be returned to the ecosystem, making it a sustainable resource. This sustainability merit completely surpass that of modern reinforced concrete buildings. Moreover, raw earth buildings have a good thermal performance, reducing energy consumption for building use. Huang Yan[9] also pointed out that the use of modern rammed earth technology is beneficial for achieving energy savings during the life cycle of construction projects.

As the third batch of national traditional villages, the modern rammed earth optimisation mechanism has been introduced into the construction of Dabaiyi Village in Jinning County. The analysis of the data from the questionnaire survey was able to conclude that the environmental friendliness of rammed earth architecture is recognised by the people. Based on the theoretical research and the content of the structured interviews, the construction process of modern rammed earth buildings in Jinning County has not had a negative impact on the environment, which is in line with the relevant literature. Plus, for the new strategy of adding cement to the local soil material by the construction team, based on relevant research in the area of raw soil material modification, a small amount of raw soil material with added cement does not affect the reclamation properties of the soil.

4. Conclusion

(1) The new earthquake-resistant rammed earth buildings in Jinning County are environmentally friendly and have a good sustainability profile. Modern rammed earth technology is an evolution of traditional rammed earth technology, resulting in a significant improvement in the durability as well as the structural performance of rammed earth buildings, while retaining the traditional green and low-carbon construction methods.

(2) The design of the construction project was unable to meet the needs of the local population and was not successful enough, lacking effective communication between the design team and the owner. Based on the fieldwork, there were some irrational designs which were not able to help the owners to realise their ideal house in their minds. Therefore architects should strengthen field survey and know a lot about the needs of customers.

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