PLEA 2017 EDINBURGH
Design to Thrive

How to provide "Better" rammed-earth buildings to villagers after earthquake in Southwest China - A case study of Ludian Reconstruction project

Xinan Chi[1], Edward Ng[1] and Li Wan[1]

[1] School of Architecture, The Chinese University of Hong Kong, Hong Kong, correspondence email chixinancuhk@gmail.com

Abstract: Rural construction is an important issue in the contemporary development of China given that a growing number of buildings that have been built do not follow traditional culture and the local environment. Significant challenges exist in implementing permanent housing reconstruction programs after the occurrence of earthquakes because of the lack of systematic and effective guidelines in poor the safety of their traditional rammed-earth buildings. However, the price of building materials rapidly increased and exceeded the acceptable budget limit for most local villagers.

Our research team decided to use "local technology, local materials, and local labor" (3L) strategies in the reconstruction project. We improved the traditional rammed-earth technology by using "high science and low technology" theory, which mainly focuses on seismic capacity, thermal comfort, and cost of construction. We built two demonstration projects which made rational use of local materials and technology to rebuild the rural communities, while respecting traditional culture and the autonomy of villagers. The concept of "collaborative construction" not only provided an opportunity for local labor force to learn new skills, but also reduced economic pressure on house construction. The projects will also provide a reference for the local government to formulate rules for reconstruction projects.

Keywords: Better rammed-earth building, after earthquake

Introduction

Ludian County is located between 568 and 3356 m above sea level in Zhaotong Prefecture, Northeast Yunnan. The county has a total area of 1,519 square kilometers, of which 87.9% is characterized by mountains and valleys. This terrain makes transportation inconvenient and impedes the development of the area. Ludian has a low latitude upland monsoon climate. No significant temperature difference exists among the four seasons. Annual average temperature is 12.1 °C, and annual average rainfall is 923.5 mm. The 2014 Ludian earthquake with a moment magnitude of 6.1 struck Ludian County with a focal depth of 12 km on August 3, 2014. The earthquake claimed 617 lives. A total of 112 people were reported missing, and several people were injured. Over 80,900 houses collapsed and 129,100 were severely damaged (BBC 2014). After the earthquake, the challenges of reconstruction work include:

- bad anti-seismic performance of traditional rammed-earth buildings
- significant increase in the price of construction materials
- how to deal with the construction waste of damaged buildings in earthquake
- poor thermal performance of brick-concrete buildings
- lack of local labor

The villagers lost confidence in the performance of traditional rammed-earth buildings. They are now eager to build houses that are anti-seismic, cheap, and comfortable. The following SWOT analysis (Table 1) shows that rammed-earth buildings have a number of advantages in meeting the needs of poor rural areas of Southwest China. Improving the anti-seismic performance and durability of rammed-earth buildings has become a highly important issue for earthquake-prone areas. Mitigation of seismic risk will therefore be possible only when the villagers themselves adopt improved rammed-earth construction systems as an essential part of their own culture.

Table 1. SWOT analysis of rammed-earth building in Southwest China

	Helpful to achieving the objective	Harmful to achieving the objective
Internal attributes of the organization	**Strengths**	**Weaknesses**
	1.local materials 2.good thermal performance 3. regulate indoor humidity 4.low energy consumption and carbon emissions 5.little pollution 6.noise reduction 7.easy to learn 8.low construction cost 9.collaborative construction	1.bad anti-seismic performance 2.poor durability (waterproof/mothproof/moisture proof performance) 3.Non-standard materials 4.Labor-intensive construction
External attributes of the environment	**Opportunities**	**Threats**
	1.new countryside construction 2.the rise of ecological sustainability theory	1.misunderstanding of rammed-earth building- for village and officer 2.how to improve the anti-seismic performance

In collaboration with Professor Emily So of Cambridge University and Professor Bai of the Kunming University of Science and Technology, our team launched a Village Rebuilding Assistance Program in Guangming Village on October 2014. We aim to use “local technology, local materials, and local labor” (3L) strategies to design an anti-seismic building with traditional features at low cost but in an enhanced and comfortable living environment. In addition, we also hope to provide a basis for the local government to formulate reconstruction strategies.

The progress of the reconstruction project

First Demonstration Building

Before the initiation of the design work, the team conducted a series of survey and investigation in the village to identify an appropriate solution. We then chose a family for the first demonstration building in Guangming village. The owner is a woman with two children and their living condition was poor. We designed a main house with rammed-earth and a kitchen with adobe brick (Figure 1-2). The project started in November 2014 and was completed in February 2015.

Before construction, the villagers were required to spend half a month to sieve and moisten the soil of the damaged building. The foundation of the main house and kitchen was a C15 rubble concrete structure with cement: sand: stone: water proportion of 50:124:221:33. After five to seven days of maintaining the foundation, villagers started to construct the main house. The ϕ8 steel bars are embedded every 1200mm in the wall especially in the corner and both sides of the window which are weak in the structure. Steel bars inside the wall became an important part of an effective anti-seismic design because the bars connect the foundation and enhance the integrity of the houses. We changed the components of the wall (soil: sand: cement: grass: fibre proportion of 100:100:7:0.2:0.2) to increase the stability of the walls (Norton 1997). The use of local materials solved the construction waste problems of damaged buildings after earthquakes. Some concrete belts were added into the wall to improve structural integrity and avoid vertical cracking. To promote efficiency in this project, we used electrical rammed tools that were improved according to local manual technology. Several kinds of rammed heads were provided to fit the different parts of the wall. After the rammed-earth work, villagers spent four days building the C20 cast-in-place concrete floor and one month for the second floor and roof construction (Figure 3-10).

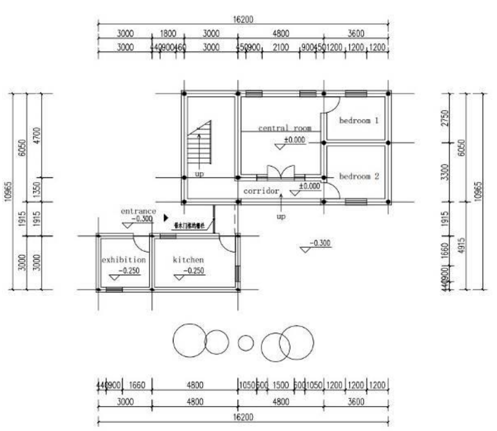


Figure 1. First floor plan

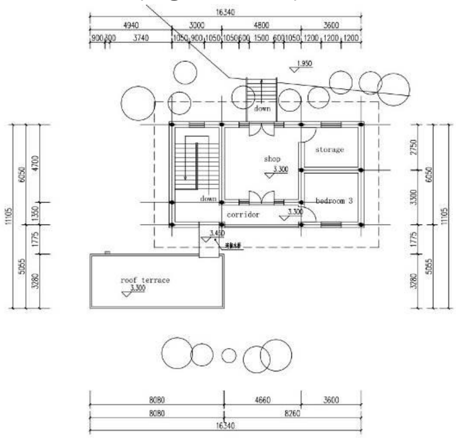


Figure 2. Second floor plan

Figure 3- 10. Main structure construction

Shaking Table Test

To verify the improved technology we used in the reconstruction project, a shaking table test on a single-layered rammed-earth house pilot project was conducted in Kunming University of Science and Technology (Figure 11). The EL-Centro and Ludian earthquakes were used to simulate the conditions in the test. The sequence of the shaking table test included two selected earthquake acceleration records with peak values of 0.1, 0.22, 0.4, and 0.62 g. After the test, only several small cracks could be observed on the rammed-earth wall (Figure 12) (YNEERI 2015). Result shows that the seismic performance of the rammed-earth building significantly improved and can meet local seismic codes.

Figure 11. Rammed-earth model   Figure 12. The state of model after test

Second Demonstration Building

After a summary of the first building, the second demonstration building was built for an aged couple who lived in a tent after the earthquake. The second demonstration building was aimed to validate the systematic construction process and high building performance of the innovative rammed-earth building system. Within the limited land, the design was integrated with living and semi-outdoor spaces to provide a comfortable and artistic living environment for the aged couple. Double-glazed windows and insulated roof are used to improve the thermal performance of the building.

To improve seismic performance, the components of the wall were improved using a soil, sand, cement, grass and fibre proportions of 100:100:5:0.2:0.2 to ensure the stability of the wall. The concrete belts were hidden in the wall so that the earth facade could be integrated. The quality of the building materials, rammed tools and formwork was improved. The project started in December 2015 and was completed on April 2016 (Figure 13-19).

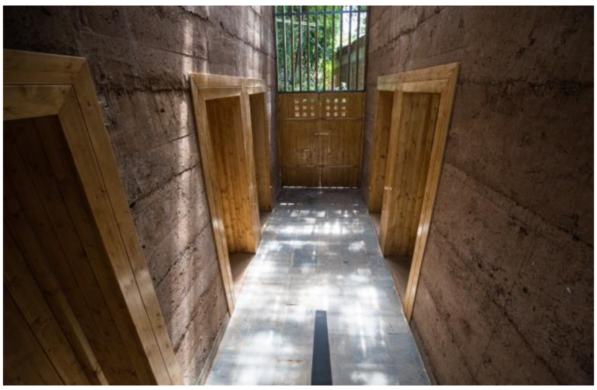
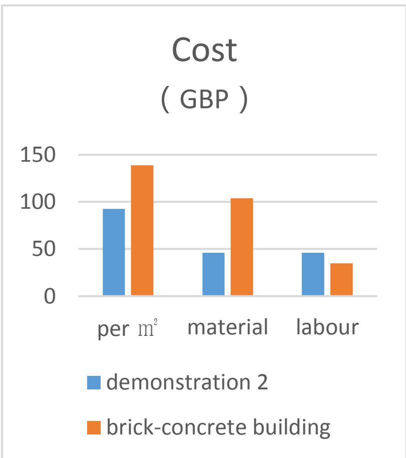


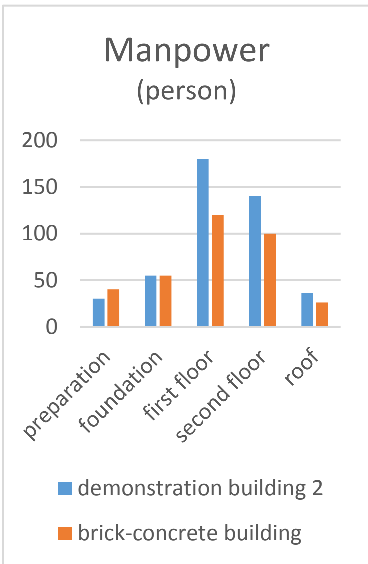
Figure 13-19. Second demonstration rammed-earth building

Performance Evaluation

Cost Analysis

We chose a brick–concrete building with the same area near our second demonstration building in Guangming village to compare the cost of second demonstration building in terms of three aspects: total, material, and labor costs. The details are shown as follows (Figure 20):





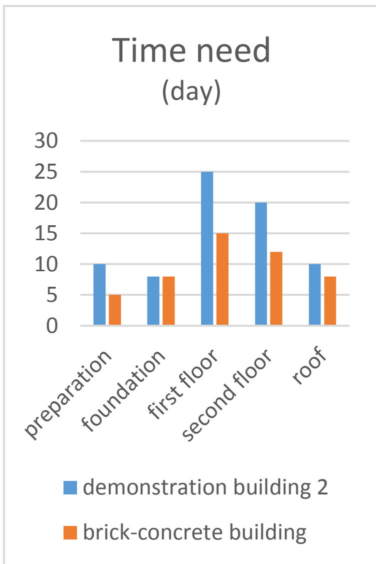


Figure 20-22. Cost, Manpower and Time need analysis

The chart shows that the average cost per square meter of the rammed-earth building is 33% lower than that of the brick–concrete building. This finding indicates the cost advantage of the rammed-earth building. However, the material cost of the rammed-earth building is only 44% of that of the brick–concrete building and the labor cost is 1.3 times. Thus, cost can still be reduced by optimizing manpower during construction. In future projects, we should improve technology in terms of two aspects:

1). Reduce manpower cost by improving the technology to enhance construction efficiency, as well as by encouraging collaborative construction among villagers.

2). Reduce the material cost. The proportion of cement and steel bars can be further reduced based on the results of the shaking table test.

Manpower and Time-need Analysis

The brick–concrete building with the same area was compared with the second demonstration rammed-earth building in terms of manpower and time needed to finish. The Figure 21 and 22 demonstrate that the foundation of the two buildings is almost the same. However, a significant difference was observed in terms of manpower and time needed between the first and second floor construction, which is also reflected in the project cost. The sloped roof of the rammed-earth building is more complicated than the flat roof of the brick–concrete building in terms of structure and construction technology. Thus, more manpower and time were needed to finish the former compared to those of the latter. In terms of construction preparation, sieving and ensuring the moisture of the soil in rammed-earth buildings required more time but did not need considerable manpower. Preparing and transporting the brick and steel bar in the brick–concrete buildings require significant effort but need a short amount of time. Thus, manpower and time needed to finish the brick–concrete buildings can be reduced by optimizing the design and the choice of rammed tools during construction (Taylor and Luther 2014).

Thermal Performance Analysis

Compared with conventional building materials in rural areas, earth materials have outstanding heat storage performance that can provide cooling effect to keep houses cool in summer and warmth in winter. Earth materials can effectively regulate indoor humidity and air quality. The figure 23 shows that the temperature of rammed-earth buildings is warmer than that of brick–concrete buildings in winter and cooler in summer. In comparison, the temperature fluctuation of rammed-earth building is lesser than that of the outdoor temperature of brick–concrete buildings. The figure also shows that the anti-seismic rammed-earth building has outstanding heat storage performance. The temperature of rammed-earth buildings remained low during winter because of the climate in Ludian. Thus, future projects should improve the self-insulation performance of rammed-earth buildings.

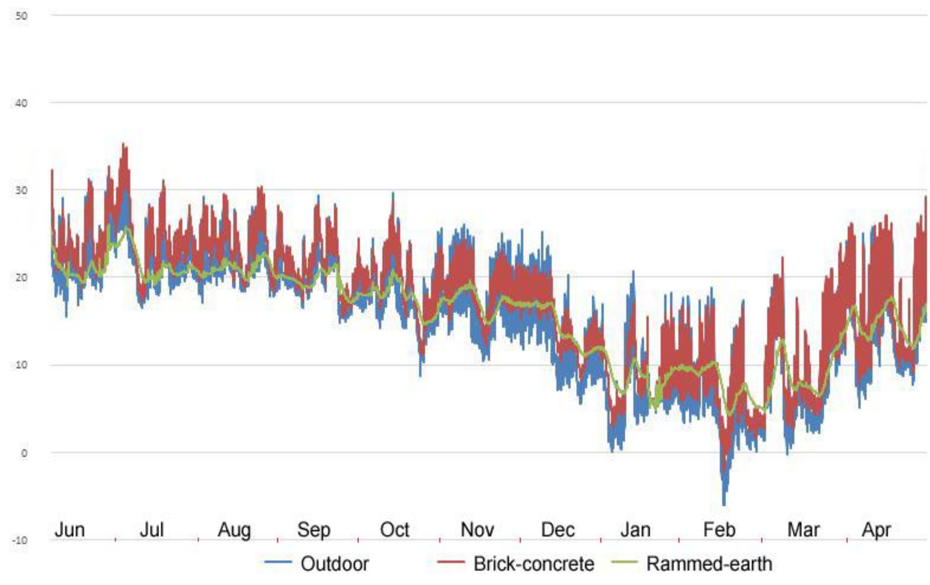
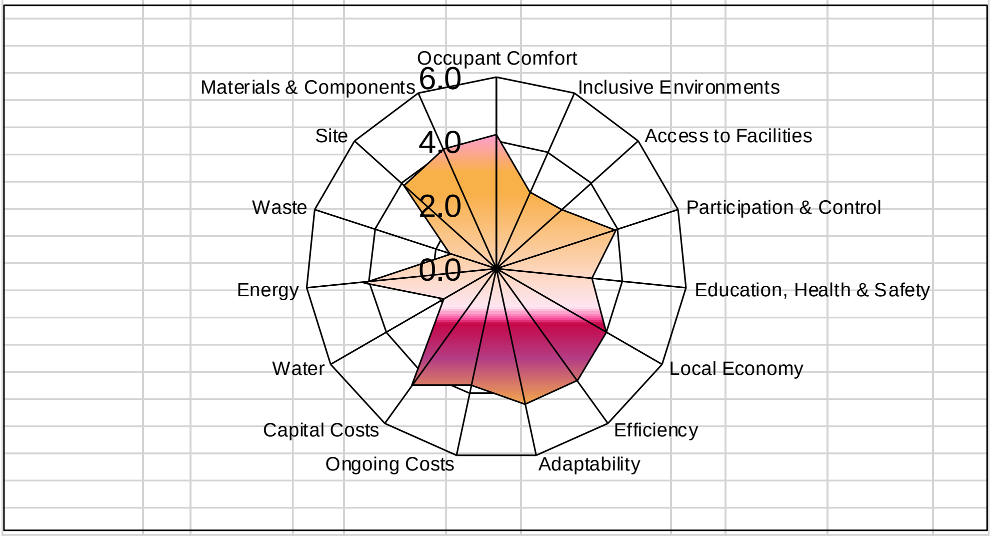


Figure 23. Thermal Performance analysis

Evaluated by Sustainable Building Assessment Tool (SBAT- P) V1

Results show that the demonstration building is classified as Good in the SBAT system (Gibberd 2005). The economic dimension with a 4.2 grade shows that local materials and labor have a number of advantages for poor rural areas. With the participation and control of villagers, they will pay more money for ongoing costs, however, access to facilities and waste and water-recycling, will increase the amount of work done and improve sustained performance. For example, facilities for certain wastes, such as batteries, ink cartridges, fluorescent lamps should be established in the community. Gray water from washing/relatively clean processes also should be recycled and reused.

Table 2. Evaluated by Sustainable Building Assessment Tool (SBAT- P) V1



Social	3.3	Economic	4.2	Environmental	3.1
Overall	3.5	Classification		Good	

Project outcome and future work

The 3L strategy has been used in our reconstruction project. The outcome could be summarized in three aspects. In the environmental dimension, the embodied energy and environmental impact of the houses are minimized. Good thermal and daylight performance guarantee low operating energy consumption.

In the economic dimension, construction and operating costs have been minimized to make it affordable to local residents. The villagers themselves constructed the houses mainly with simple tools. Once skills were transferred, the villagers can easily improve and maintain the houses in the future. They can also utilize this technology as a means of earning their livelihood (WAN 2012).

In the social dimension, local residents were fully engaged in the entire process of reconstruction. Multidisciplinary university resources were fully used to support rural reconstruction. The local government is also involved in learning and practicing this new sustainable method of rural reconstruction. Rammed-earth construction has a long history in China. We protected this kind of construction method and lifestyle by improving its building performance with local materials and a simple strategy.

In subsequent stages, this anti-seismic earth building system will be applied to more rural community reconstruction projects in Yunnan Province, China. The investigation and design of two village reconstruction projects are currently in progress. After a series of practice and research, books and guidelines will be published to systematically document this method and provide a reference for national reconstruction policies and seismic standards for buildings made of earth materials in the future.

Conclusion

The Ludian case study shows that local materials and technology can be used in reconstruction projects, especially in poor rural areas. The project fully respects the traditional culture and autonomy of the local villagers, both of which constitute the core of local community development. The concept of "collaborative construction" not only provided an opportunity for the local labor force to learn new skills, but also reduced the economic pressure on house construction (Chi and Ng 2014).

The 3L strategy emphasizes on the concept of sustainability and focuses on the importance of the locals in poor rural areas. The strategy suggests a self-sufficient, regional character-based model that is suitable for reconstruction in poor rural areas, which have poor transportation and a backward economy. It can also reduce the communities' dependence on external assistance by emphasizing the use of local resource and traditional core values. The 3L strategy can provide a systemic way to further study sustainable reconstruction and community renewal in poor rural areas.

References

BBC. (2014). China earthquake: Troops join race to aid survivors. Retrieved from http://www.bbc.com/news/world-asia-china-28635027

Chi, X., & Ng, E. (2014). Study on the Sustainable Renewal of Poor Rural Communities of Southwest China.

Gibberd, J. (2005). *Assessing sustainable buildings in developing countries–the sustainable building assessment tool (SBAT) and the sustainable building lifecycle (SBL).* Paper presented at the Proceedings of the world sustainable building conference. Tokyo.

Norton, J. (1997). Building with earth. *Building with earth.; Building with earth: a handbook*.

Taylor, P., & Luther, M. (2004). Evaluating rammed earth walls: a case study. *Solar Energy, 76*(1), 79-84.

WAN, L. (2012). *Study of Built Environmental Sustainability Assessment of Poor Rural Areas of Southwest China.* The Chinese University of Hong Kong, Hong Kong.

YNEERI. (2015). *Report of shaking table test: New rammed-earth building*. Retrieved from Kunming University of Science and Technology.