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ANALYSIS AND COUNTERMEASURES OF PROBLEMS IN PURE SOIL CONSTRUCTION

take the research and development centre for rural vitalization in Yunnan China as an example

FANG TIAN, WENFENG BAI, LAI ZHOU, XIAOXUE LIU, LI WAN, XINAN CHI, EDWARD NG

[1]The chinese university of HongKong, Hongkong, China
[2] Kunming university of science and technology, Kunming, China

ABSTRACT: Pure soil construction or raw material earthen construction (earthen construction technology without adding chemical stabilizers) is a sustainable construction method with the advantages of having no impact on the environment, low embodied energy and good indoor comfort. Both in China and western countries, this technology has a long history but it has some limitations as well: the construction process is not standardized, durability questioned, not waterproof and so on. Therefore, there are higher requirements for the design and building management in this kind of building, to avoid the occurrence of problems leading to the rework of the project which increases its cost and time limit. This research takes the pure soil construction technology as the research subject, combined with the research and development centre for rural vitalization in Yunnan China. Summarizes and analysis the problems in the process of building. And provides methods of preventing and solving those problems from three aspects, to achieve optimal management and accelerate construction.
KEYWORDS: rammed earth, sustainable development, raw material, Construction and management, contemporary earthen construction

1. INTRODUCTION

Pure soil construction or raw material earthen construction (earthen construction without the addition of chemical stabilisers) is a sustainable construction method with the advantages of low embodied energy, low construction cost and good indoor comfort.[1] Compared with that of modern buildings and even that of modern earth buildings with chemical stabilisers, the environmental performance of pure soil construction is the strongest. This technology has a long history in China and western countries. The most famous example is the Great Wall of China, which was built approximately 2,000 years ago using local materials: rammed earth (RE), stones, baked bricks and wood.[2] However, it has several limitations: the construction is neither standardised, durable nor waterproof. Therefore, the requirements for the design and building management in construction are high to avoid the occurrence of problems that lead to project reworking or safety problems, thus increasing costs and time limits. [3]

2. PROBLEMS IN CONSTRUCTION

2.1 Case background

The research and development centre for rural vitalization(The Terra center) is a research institution for developing rural areas in China with sustainable methods. It also undertakes the training of craftsmen and holding academic conferences and activities. The RE walls of Terra center are built entirely of raw materials without any additives.

Figure 1 Terra center

2.2 Problems in construction

In most studies on earthen buildings, people only focus on investigating building materials and stabilisers, but often ignore the construction process. Moreover, construction problems are poorly analysed and summarised.

The extent of compaction affects the overall load-bearing performance and the texture of the finished surface. Therefore, the management of ramming is one of the most important parts of construction. The following is a summary of the problems in ramming.

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2.2.1 Shrinkage

With the evaporation of moisture in the soil, the RE wall will shrink to a certain extent. Excessive shrinkage will cause extensive cracking. If cracking throughout the wall, then the first defect will affect the overall stability, whereas the second will affect indoor thermal comfort.

Figure 2 Shrinkage

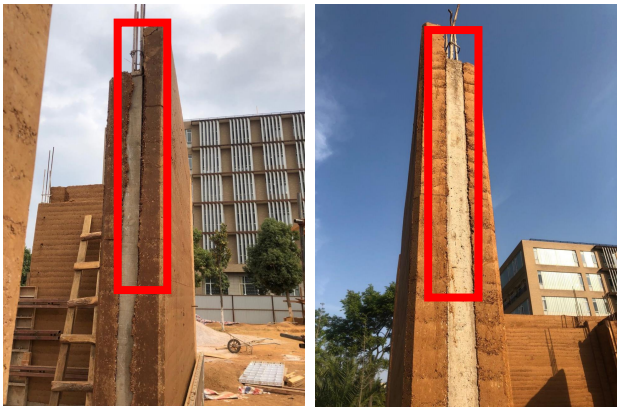


Figure 3 Deviation

2.2.2 Crack

The different physical properties of the soil and water content of the mixture will lead to different degrees of cracking. Cracks will affect the aesthetics of RE and its ability to adjust room temperature. Cracks will also affect the stability of the structure in severe cases.

Cracks are evaluated and regulated in different countries in accordance with earthen construction codes. Cracks that meet the requirements of those codes will be qualified because they will not cause safety problems. [4] However, given the absence of construction codes in China and that many parts of China are in earthquake zones, the formation of cracks in the earth construction of seismic areas should be strictly controlled in addition to referring to foreign codes.[5]

All cracking problems and locations during construction are summarised. Their causes are then analysed, and solutions to minimise the incidence of cracks are identified. (Table 1)

2.2.3 Deviation

If the mixing is too wet, then the RE wall will deviate from the contact site with the tie column. Deviation will also occur if the formwork is not calibrated in time.

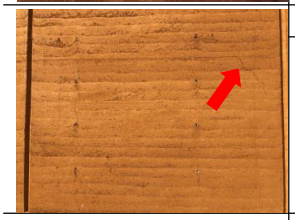
	Location: Around the tie rod of the formwork Cause: Given that the compaction force is uneven, soil around tie rod is not compacted tightly enough
	Location: Lower edge of the formwork Cause: Failure to remove the formwork in time results in uneven shrinkage along the top and bottom of the soil.
	Location: Wall surface Cause: Moisture content of the mixing is too high or too low
	Location: Above the opening Cause: The lintel above the door and window opening is too short or the material bearing capacity is insufficient.
	Location: Cracking due to incorrect operation Cause: Wrong way to use brace or knot on the top
	Location: Temperature difference on the two sides of the wall Cause: Different sunlight intensities on both sides of the wall lead to different degrees of drying and shrinkage

Table 1 Crack analysis

2.2.4 Wall damage

1) Damp

Raw soil buildings are limited in the aspect of waterproofing. Given the failure of waterproofing measures during the rainy season, sustained concentrated water flow will damage the RE wall, resulting in partial destruction, deformation and even collapse.[6] Some specific parts are easily dampened if

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special treatments are not performed. Long-term dampness will also lead to damage. Therefore, detailing design is crucial and always needed for those parts.

All damping problems and locations during the construction process are summarised. Their causes are then analysed. （Table 2）

Location	Causes:
Junction with other materials	Water infiltration is present at the junction of the RE wall and concrete foundation.
Wall crown	The top of the rammed earth wall is the weakest location and will soften if constantly soaked in water.
Windowsill	Rainwater at the edge of rammed earth wall results in partial dampness and damage.

Table 2 Damp analysis

2) Leakage

Given that RE walls made of raw material are not waterproof, prolonged rain or concentrated leakage will lead to damage to RE walls.[7] Water leakage easily occurs where tarps are damaged or where they are connected. The second is the bottom of the RE wall that is easily damaged by the prolonged splashing of water on the ground.

When pouring the concrete floor, the cement slurry pollutes the RE wall along the crevices of the formwork because the concrete is too diluted or the formwork is poorly treated for leakage prevention.

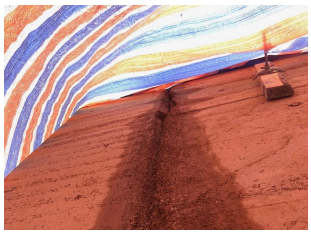


Figure 4 Water leakage

Figure 5 Cement slurry

3) Damage during formwork removal

Figure 6 Formwork removal damage

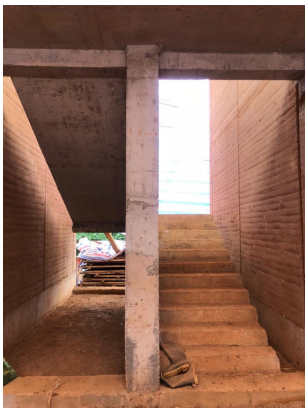
During formwork removal, wet clay is prone to adhering to the formwork and falls off together due to improper operation or the lack of oiling. [8]

3. COUNTERMEASURES

3.1 Design process

The design process involves the moisture-proofing of the bottom and top of the earth wall, the installation of doors and windows, the moisture-proofing of toilets and kitchens and the design of roofs and outer walls in accordance with the local climate.

3.1.1 stairs



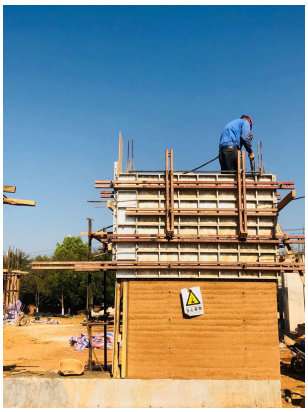


Figure 7 Stairs

Figure 8 Footing

The wall compactness of pure soil is an important condition for ensuring its stability. Thus, drilling and processing after construction should be avoided. The staircase is designed in the form of a cantilevered central slab. The stair lintel is connected to other beams, and the ladder surface of the stairs is not in contact with the RE wall. (Figure 7)

3.1.2 footing and base details

The foundation of the building should have a waterproof layer above the ground to ensure that the RE wall at the bottom will not get wet. The height of the waterproof foundation can be determined in accordance with local weather conditions. (Figure 8)

3.1.3 openings and supports

The openings for door and window is usually reserved from top beam to floor beam, which can facilitate construction. And structural column should be embedded in both sides of the reserved openings to facilitate the installation of doors and Windows. Other forms of windowing shall be designed and constructed in strict accordance with the methods specified in the earth construction manual.[9]

3.1.4 protection given by roofs

Temporary roof protection is required during construction. During roof design, the expansion of the eave depends on the local weather and wind direction. Waterproof structures are required on the tops of RE walls after construction.

3.1.5 Services and fixings

Considering that embedded pipes are not conducive for repair, and leakage will damage the RE wall, all the pipes are not installed through embedding.

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The water supply and drainage piping layout should be fixed using other parts instead of directly making holes in the RE wall. The wires should be installed through the floor slab, floor beam and roof beam.

Figure 9 Drainage

Figure 10 Wires

3.1.6 toilet

A double-layered wall in the toilet must be used to maintain the breathing performance, which is the ability to adjust temperature, of pure earth walls and to ensure that the room can meet reusable water supply and drainage demand and does not suffer from dampness.

Figure 11 Double layer wall

3.2 Construction management

3.2.1 Solution to shrinkage

To predict the degree of shrinkage of the RE wall, a test panel should be fabricated before construction. The test panel is 600 mm high by 1000 mm wide and 350 mm thick. The building method, material and moisture content of the test panel should be exactly the same as those of Terra Centre.(Figure12) The test panel must be checked after surface drying because a newly constructed RE wall is completely different from a wall that has dried out.

Figure 12 test panel

Figure 13'hit and miss'

We used the vertical ramming method to regulate shrinkage. During construction, the order and timing of ramming is monitored, and then the 'hit and miss' approach is adopted.(Figure13) That is, adjacent walls are not rammed at the same time. Every two walls are rammed. The tester then waits until the walls have completely dried and then rams the middle of the walls to minimise shrinkage.

3.2.2 Solution to cracks

Location	Solution
Around the tie rod of the formwork	Ramming should be reinforced around the tie rod and combined with a manual rammer
Lower edge of the formwork	Remove the formwork after ramming
Wall surface	Strictly supervise and control the moisture content of RE materials
Above openings	The sides of the lintel above the door and window openings must be extended by at least 30 cm
Cracks due to incorrect operation	Prohibit the practice of ropes on the top and strictly monitor the strength of the support
Temperature difference on two sides of the wall	Install a sun screen on the sunlit side to balance the drying of each side

Table 3 Solution to cracks

3.2.3 Solution to deviation

Mode		Merit and demerit
Overall frame mode	Merit	Formwork calibration is convenient, and the probability of deviation is low.
	Demerit	All formwork for building is needed, and failure to remove the formwork can lead to cracking.
Vertical frame mode	Merit	Formwork calibration is convenient, and the probability of deviation is low.
	Demerit	The amount of formwork is large, and the junction of two plates must buckle.
Rounds frame mode	Merit	Formwork usage is small, and each plate is fixed firmly
	Demerit	Layer-by-layer formwork calibration is time consuming, and the probability of deviation is increased.

Table 4 Formwork setting mode

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The water content of the mixing should be checked regularly, whereas compactness and load-bearing capacity should be checked through on-site sampling. he installation, calibration and removal of formwork and the correctness of other construction operations should be strictly checked by on-site architects.

If the mixing is excessively wet, then the RE wall will deviate from the contact site with tie column. In this case, the RE wall must be slightly propped on both sides until drying is complete.

Three modes of formwork setting are introduced to avoid whole wall deviation, and the second method is adopted in this project. (Table4)

3.2.4 Solution to wall damage

Waterproofing and leakproofing measures should be taken in advance to prevent leakage. Covering the building with a plastic sheet or temporary roofing during construction is a good way to avoid rain erosion. However, a real roof is needed. In addition to providing sufficient eave extension, natural roof drainage should be avoided. The rain will flow back along the bottom of eaves, and in case of strong winds, the rain will erode the exterior walls. Thus, gutters and drains are essential.

When pouring the concrete floor, the cement slurry will pollute the RE wall along the crevices of the formwork because the concrete is too diluted or the formwork is not well treated for leakage prevention. Before pouring concrete, anti-leakage measures should be taken. If slurry leakage has occurred, then the leaked slurry should be cleaned in accordance with the texture of the RE wall after it has dried out.

The following treatments should be emphasised for components that are easily dampened.(Table5)

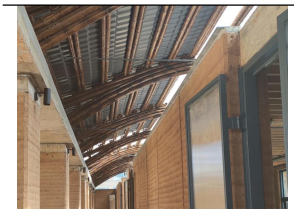
	Location: Junction with concrete Solution: Use a waterproof paintbrush on the foundation, floor and roof
	Location: Wall crown Solution: Use stone or cement to seal the top of the RE wall to ensure stability
	Location: Windowsill Solution: Install a windowsill to expedite rainwater

Table 5 Solution for wall damage

During mould removal, wet clay is prone to adhering to the formwork and falling off together due to improper operation or the lack of oiling. Therefore, the formwork should be cleaned and oiled before ramming to prevent this situation. In addition, the formwork should slide up instead of directly hinging away.

3.3 Training

In accordance with the design guidelines of earthen houses in various countries and regions, workers should be trained in the perception of soil and the construction method to improve their skills and accuracy before the project starts.

Figure 14 Mixing training

Figure 15 Ramming training

3.4 Repair

If wall damage occurs, but does not affect the overall structural safety of the building, then the damaged part can be repaired.

Generally speaking, repair is divided into the following steps: wetting, re-erecting formwork and ramming and removing formwork. During the repair of this project, we found that if the wall is thin (<300 mm), then the whole piece must be removed and re-rammed. The thickness of the damaged wall in this project is 600 mm, and the damaged part is half the thickness. We chose to remove the half part of the damaged wall and re-tamper it. Notably, however, the restoration work must be done with great care because the re-ramming part tends to detach from the original part.

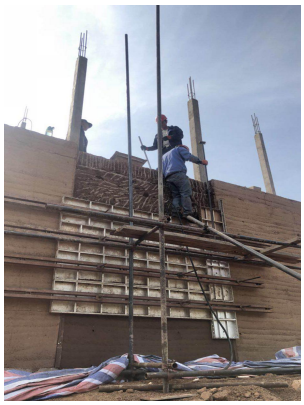


Figure 16 Repair of damaged wall

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4. CONCLUSION

Pure soil construction is a sustainable technology, and modern techniques help increase its strength and regulate its construction practices.

With the dissemination and popularity of sustainable technology and materials in recent years, a growing number of RE buildings are being built worldwide. However, this study finds that:

1) Designers and builders must increase awareness. Although modern techniques and equipment have been used in the construction of modern earth buildings, the design of modern earth buildings is different from that of modern buildings. Therefore, the plan should be discussed with earth experts before construction.
2) Even if the construction is performed by skilled workers, a certain period of construction training is necessary before the construction of raw soil buildings to familiarise workers with the characteristics of materials, construction tools and standard operations.
3) On-site instruction is crucial in the whole construction system. A soil specialist or on-site designer should frequently inspect the site.
4) In addition to optimizing the ratio of materials with different particle sizes in the mixture, we can minimise the disadvantages of earth construction and give full play to its advantages by doing a good job in construction management.

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More importantly, we want to give thanks to Chan Cheung Mun Chung Charitable Fund Ltd and Mr. Chen, the construction sponsor of this project. Given his donation, we can also demonstrate rammed earth houses in many poor rural areas of western China and thus improve the living environment of farmers there.

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