EXPERIMENTAL BEHAVIOR OF ADOBE AND RAMMED EARTH WALL OF RURAL HOUSES USED IN YUNNAN PROVINCE

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ABSTRACT :

Experimental study on the behavior of adobe and rammed earth wall of rural houses used in Yunnan Province is put forward in this paper. The experiments include compression, shear and bending test of single adobe and adobe block, and geotechnical test of used soil, and uniaxial lateral loading test of rammed earth and reinforced rammed earth wall specimens. The mechanical properties of the specimens are obtained through test. Furthermore, characteristics of adobe and rammed earth wall used in Yunnan Province's rural houses are concluded. Finally, proposals to improve the load carrying capacity of adobe and rammed earth wall are presented.

KYWORDS: adobe wall, rammed earth wall, experiment, mechanical properties, rural house, Yunnan

1. INTRODUCTION

For the advantages of the raw soil building, such as available local materials, adaptation to local conditions, simple technology, low cost and good thermal insulation properties, it is widely constructed in the majority of towns and villages in western China, especially in the remote mountain areas. According to statistics, there are currently in China more than 100 million populations living in the raw soil houses. However, previous earthquakes have demonstrated that the rural houses (mainly include raw soil houses) are easier to be damaged under an earthquake. To ensure the safety of life and property in village buildings, it is necessary to study and improve the seismic performance of rural houses. Therefore, Chinese Government started the Rural House Earthquake Safety Project (RHESP) from the year of 2006 to improve rural houses' seismic carrying capacity. Yunnan Provincial Government formally started the project from March of 2007, and Yunnan Province's Construction Department entrust our laboratory to do experiments on typical raw soil wall of rural houses used in Yunnan Province. From Mar. to Oct. of 2007, series tests of adobe and rammed earth wall were done in the Institute of Earthquake Engineering of Kunming University of Science and Technology. The test and research will offer a technological support for the RHESP and formulation of the code for seismic design of rural buildings.

2. TEST OUTLINE

2.1. Test of Single Adobe and Mud

2.1.1 Specimens

The adobes of test were from Luquan County, Yunnan Province, which were made by local craftsman, using local skill and local materials. The size of an adobe was about 300 mm × 160mm × 80mm. As the adobes were taken from an old house, there were great differences in quality. Almost every adobe block had cracks and flaws, and their sizes were slightly different. The mean moisture content of adobe block is 4.01% in the test.

The clay of mud was from Songming County, Yunnan Province, the slurry was made by local artisans in the laboratory. The size of the test slurry block is 70.5 mm × 70.5mm × 70.5mm, six blocks in a group and totally five groups. The test blocks of each group were made of the same mud, and were shaped in the prefabricated cube wooden moulds. The test blocks were laid on the wood backing plate as soon as they demoulded, and conserved for 30 days under natural conditions.

The strength test method of adobe and mud is designed in reference to "Test Method for the Bricks of Building Walls" (GB/T2524-2003) and "Test Method for Key Properties of Constructional Mortar" (JGJ70-90).

It is defined the direction along the adobe's long edge as the length of size, direction along the short edge of the adobe as the width, height of the adobe as the thickness. The stand press is along the length direction of the adobe, the lie press is along the width direction, and the flat press is along the thickness direction.

2.1.2 Test Method

By using of a 100 kN-load jack, vertical force was applied on the single adobe and the slurry block. The basement and loading equipments were self-designed according to the test condition (shown in Figure 2-6). For the purpose of uniform compression, 20 mm thick steel plates were chose as the loading plate. Four dial indicators (range 50 mm, precision of 0.01 mm) were used for measuring vertical displacements. The layout of test points is shown in Figure 2 and 3.

Fig. 2 Compression device

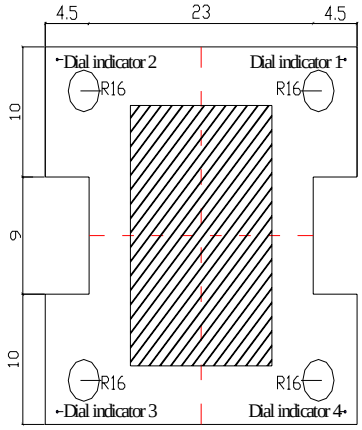

Fig. 3 Specimen and test points arrangement (unit: mm)

Fig. 4 Bending test device

Fig. 5 Single-shearing test

Fig. 6 Double-shearing test

2.1.3 Results

The results of single-adobe test and the compression strength of the mud are shown in Table 1.

Table 1 Single-adobe and the mud strength test

Flat compression strength	Lie compression strength	Stand compression strength	Bending strength	Single-shearing strength	Double-shearing strength	Mud compression strength
1.610MPa	0.570MPa	0.472MPa	0.0862MPa	0.200MPa	0.253MPa	2.998MPa

2.2. Compression, Shearing and Bending Test for the Adobe blocks

2.2.1 Specimens

Each of specimens was built with adobes and clay mud. The adobes were from Luquan County in Kunming, which are same as the single-adobe test specimens. The size of an adobe was about 300 mm × 160mm × 80mm.The clay of mud was from Songming County in Kunming. The method of making adobe blocks specimen refer to "Test Method Standard for Masonry Basic Mechanical Properties" (GBJ129-90). The adobe blocks are divided into 3 types as compression, shearing and bending specimens. The size and number of each type of specimens are shown in Table 2. The adobe-laying patterns are shown in Fig.7.

Table 2 Size and number of adobe blocks test specimens

Type of Specimens	Compression		Shearing	Bending	
	Height 600mm	Height 250mm		Slot joint	Straight joint
Size（mm）	300×160×600	300×160×250	300×250×490	290×340×1200	290×290×930
Groups	6	3	6	4	4
Each group numbers	3	3	3	3	3

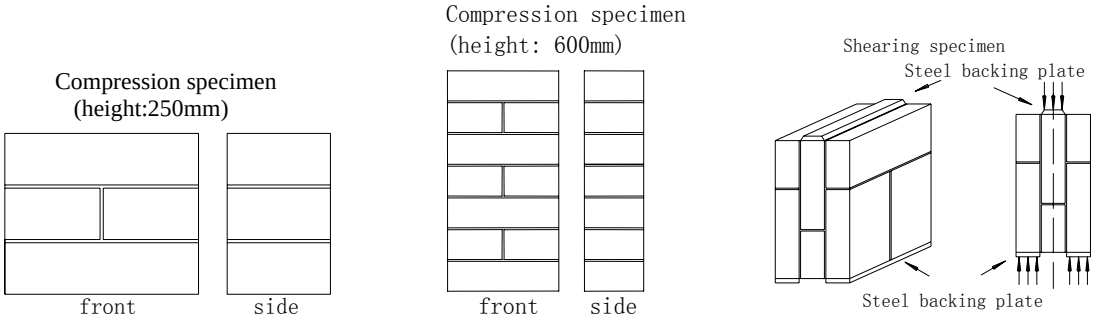

Fig. 7 Adobe blocks laying pattern

2.2.2 Test method

2.2.2.1 Compression test

A hydraulic actuator (ZB-10) of 100-kN capacity was used to apply the load on the adobe blocks for compression, shearing and bending test. The compression test device is shown in Fig. 8.

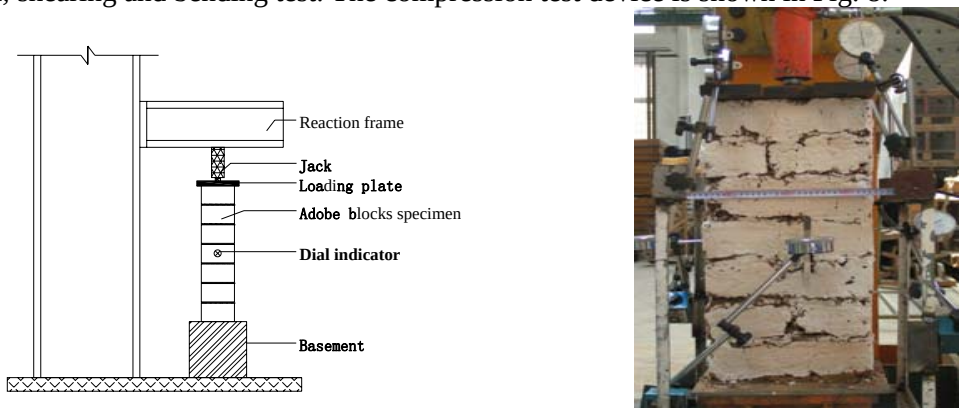

Fig. 8 Adobe blocks compression test device

2.2.2.2 Shearing test

The shearing test device is shown in Fig.9. The sizes of the backing-plate and loading-plate were set according to the supporting surface and loading surface. The center line of specimen should be coincidence with the axis of loading equipment, and the contact between the specimens and the backing plate& loading plate should be closely. Adopting constant rate of loading, and impact should be avoided.

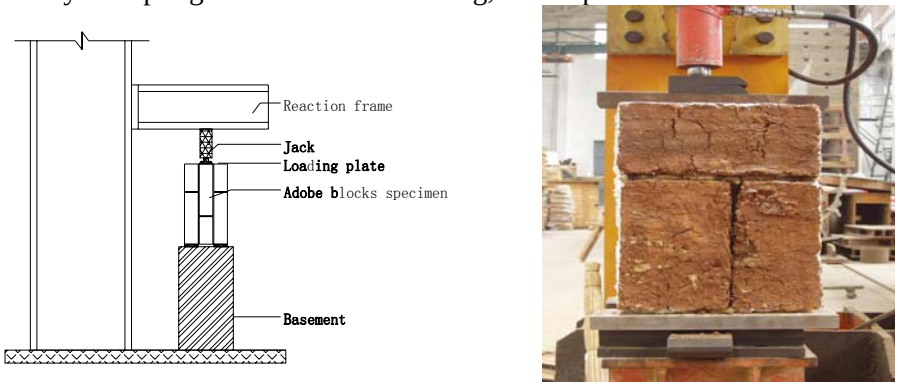

Fig. 9 Adobe blocks shearing test device

2.2.2.3 Bending test device

Because of the bond force between adobe and clay slurry is very low, the adobe blocks specimen's bending

strength can not withstand its self-gravity when the specimen is put horizontally. In this test, the specimen was placed up-standing to bear the load (shown in Fig.10). The devices of bending test were self-designed under the laboratory conditions. When the specimen is being loaded, the bottom of specimen is sliding supported with steel-pipes, and the top is set as free, one side of the specimen is put back on the reaction frame, and another side is loaded by the jack.

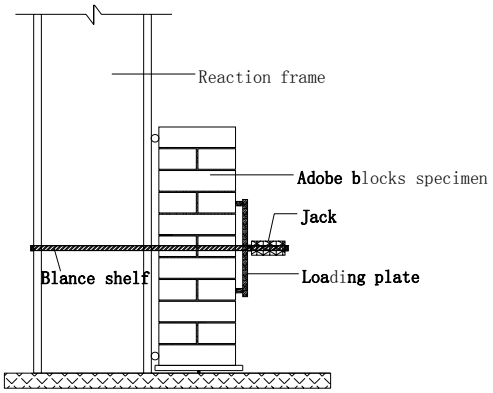

Fig. 10 Adobe blocks bending test device

2.2.3 Results

The 3 types of adobe blocks test results are given in Table 3

Table 3 Adobe blocks test results

Test type		Mean strength（MPa）
Compression	Height: 600mm	0.598
	Height: 250mm	0.617
Shearing		0.0126
Bending	Along the direction of slot joint	0.0862
	Along the direction of straight joint	0.0697

2.3. Rammed Earth Wall Test

2.3.1 Specimens

In order to study the seismic capacity of rammed earth wall, two typical soil samples were chosen, which were taken from Songming County and Luquan County of Kunming city respectively, named as Songming soil and Luquan soil. The fabricating and conserving of specimens were all completed in the laboratory. The method of soil sampling was strictly with reference to the "Soil Mechanics Test Method Standards (GB/T50123-1999)". The water content test, direct shear test, granule analysis test, crucial water content coefficient test, light compaction test and the shrink limit test are all done on the soil samples. The results are listed in Table 4.

Table 4 Basic physical properties of two soil samples

Physical parameter	Songming soil	Luquan soil
Liquid Limit ω_L	42.0%	34.6%
Plasticity Limit ω_P	24.9%	22.7%
Plasticity Index I_P	17.0	11.9
Maximum Dry Density ρ_{dm}	1.61g/cm^3	1.86g/cm^3
Optimum Water Content ω_{op}	21.8%	15.1%
Shrink Limit w_s	13.2%	14.0%
Contraction coefficient λ_n	3.1	31.5

The size of the test rammed earth wall was 1600 mm (length) × 800mm (high) × 400mm (width). The test walls were made by 3 rural craftsmen according to the requirements and scheme of the test. The fabricating processes followed the local traditional practices. Three wall specimens were produced for each soil sample, and

applied to different vertical loads. The vertical load exerted on each wall is shown in Table 5.

Table 5 The vertical loads on rammed earth walls

Soil sample	Songming soil (ZQ1 wall)			Luquan soil (ZQ2 wall)		
Number	ZQ1-1	ZQ1-2	ZQ1-3	ZQ2-1	ZQ2-2	ZQ2-3
Test vertical load （MPa)	0.12	0.10	0.07	0.10	0.12	0.07

2.3.2 Test Device

After the fabrication and conservation, the rammed earth wall was lifted and fixed under a reaction frame, applied constant vertical pressure to simulate the real stress produced by the self-gravity of the walls. Uniaxial lateral load act on the test walls through the steel loading cap, the cantilever of loading cap can reduce the overturning moment by lateral force on the far-end. The test adopted step loading schedule, and the test device was shown as Fig. 11.

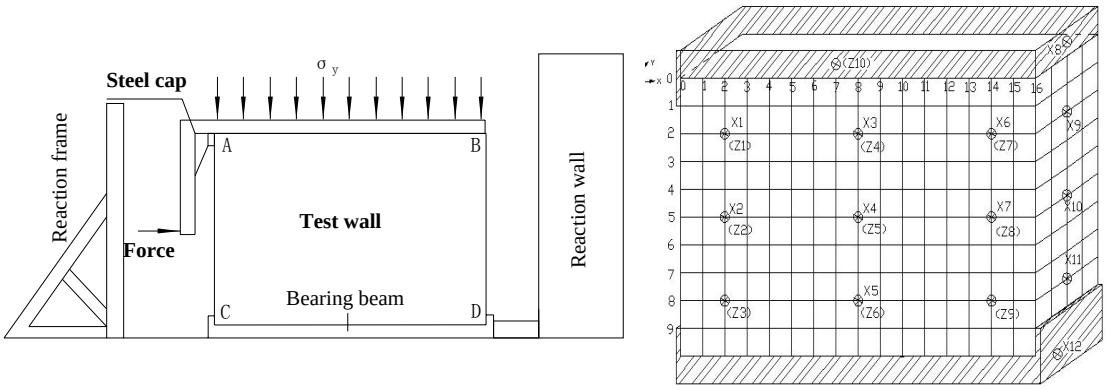

Fig. 11 Rammed earth wall test device and layout of dial indicators

2.3.3 Results

The rammed earth wall test results are given in Table 6.

Table 6 Rammed earth wall test results

No.	Vertical Load (MPa)	Limit lateral load(kN)	Maximum lateral displacement (mm)	Drift angle （%）	Failure mode
ZQ1-1	0.12	58.3	35.37	4.42	ductility
ZQ1-2	0.10	84.6	31.81	3.98	ductility
ZQ1-3	0.07	54.1	21.62	2.70	ductility
ZQ2-1	0.10	33.5	5.60	0.70	brittle, partial collapse
ZQ2-2	0.12	33.5	7.17	0.90	brittle, overall collapse
ZQ2-3	0.07	33.5	7.44	0.93	brittle, partial collapse

2.4. Rammed Earth Wall Reinforcement Test

2.4.1 Specimens

In this paper, a 1/3 scale model wall was adopted. The size of the wall is 1600mm × 800 mm× 300 mm. A total of 5 rammed earth walls were fabricated for the test, one was not reinforced named ZQ1, the other four were reinforced named GW1, GW2, BW1and BW2. The soil of the walls was from Songming County of Kunming City. The steel wire mesh and glass fiber with high tensile strength were used as main reinforcement material, the diameter of steel wire is 1 mm, the spacing of steel wire is 12 mm × 12 mm, and the mesh size of glass fiber is 25 mm. 325# ordinary Portland cement and mountain sand containing clay mud were used to

produce cement mortar. Hot-rolled bars (Φ6) were used as frame to fix the steel wire mesh or the glass fiber mesh. GW1 and GW2 specimens were reinforced with steel wire mesh; BW1 and BW2 specimens were reinforced with glass fiber mesh (shown in Table 7).

Table 7 Rammed earth wall reinforcement test specimens

No.	Average thickness of cement mortar （mm）	Reinforcement method	Specimen Size （mm）	Vertical load （MPa）
GW1	15	Method A: Ferro-cement mortar surface reinforcement	1600× 800× 300	0.1
GW2	17			
BW1	14	Method B: Glass fiber cement mortar surface reinforcement		
BW2	13			

2.4.2 Test Device

To ensure that the uniform vertical load can apply on the wall, the vertical load is applied by two jacks with a distribution girder. Uniaxial lateral load act on the test walls is same as that of rammed earth wall test, and the test device was shown as Fig. 12.

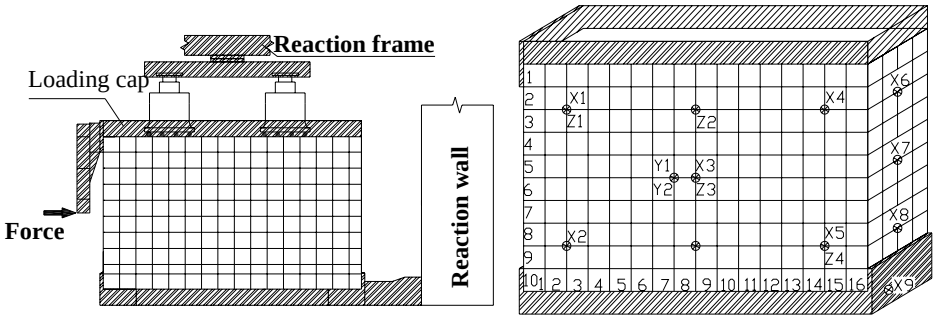

Fig. 12 Rammed earth wall reinforcement test device and layout of dial indicators

2.4.3 Results

Table 7 Rammed earth wall reinforcement test results

Type	No.	Vertical load （MPa）	Limit load （kN）	Limit displacement (mm)	Cracking load （kN）	Limit stiffness (kN/cm)	Ultimate strength increase ratio
Unreinforced	ZQ1	0.1	41.6	21.82	33	19.11	/
Ferro-cement mortar surface reinforcement	GW1		70.9	25.09	—	28.26	70.4%
	GW2		79.4	23.2	—	34.22	90.8%
Glass fiber cement mortar surface reinforcement	BW1		63	21.08	—	29.88	51.4%
	BW2		58.3	20.57	—	28.34	40.1%

3. CONCLUSIONS

The behavior of adobe and rammed earth wall of rural houses in Yunnan Province was experimentally studied in this paper. From a series of tests, it can be concluded as following:

1. The flat compression strength of single adobe is the highest, the lie compression strength is lower, and the stand compression strength is the lowest. The flat compression strength is about 3 times higher than the stand compression strength. Because of the incompact characteristics and unavoidable desiccation crack of adobe, the bending strength of single adobe is comparatively low. The test results showed that single and double shearing strength of adobe were almost in same level, that is to say the adobe can uniformly bear shear loading. Clay mud always decides the bearing capability of the adobe wall, it should be important to improve the bond strength in future research. As the test results shown, the compression strength of slurry cube is only 3.0 MPa.
2. Compression test of adobe blocks show that the adobe blocks have a ductility failure model, immediately collapse will not happen when specimen appeared slight cracks. It is also show that the bond strength of clay mud is the key factor to affect the shearing and bending strength, failure surface were always found in the position of mud-adobe joint in the test. So, adobe wall is not suitable for bending members.
3. The test revealed that, the shearing capacity of rammed earth wall made of Luquan soil is extremely poor. So, such kind of soil is not suitable for construction of buildings. Compare to the masonry walls and concrete walls, the bearing capacity of rammed earth walls is relatively low, but their ductility is better.
4. The bearing capacity of steel wire mesh reinforced walls has increased 70.4%and 90.8% compared to the walls without reinforcement, indicating obvious reinforcing effect. The deformation resistance capacity of steel wire mesh reinforced walls is significantly increased under uniaxial lateral load. The bearing capacity of glass fiber reinforced walls has increased 51.4%and 40.1% compared to the walls without reinforcement. The strength of glass fiber wasn't fully exerted in this test.

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