SEISMIC CAPACITY COMPARISON BETWEEN SQUARE AND CIRCULAR PLAN ADOBE CONSTRUCTION

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ABSTRACT

Unreinforced adobe or mud-brick structures have in the past suffered severe damage from seismic forces and have caused a vast number of deaths. However, a number of adobe buildings located in seismic regions have performed well under several seismic events. Most of these traditional buildings' shapes are symmetrical which has significant bearing on the performance of the building during strong earthquakes.

This paper presents an experimental comparison between two symmetrical shapes, i.e., a square and circular model of unreinforced adobe walls. One-third scale models were built and tested using a static tilt test for seismic performance evaluation of both structures. The adobe house models were subjected to a constant acceleration when tilted on a tilt-up table. The lateral component of model weight was used as a parameter to quantify the maximum seismic force for each model. The paper describes the configuration of both specimens and testing method. The results of these comparative experiments indicated a better performance of the circular structure. There are simple and effective solutions for construction of new adobe buildings located in seismic hazard areas which can assist in decreasing damage and death.

Keywords: Adobe construction, mud-brick, earthquake resistance, circular building, tilt table test.

1. INTRODUCTION

Adobe or mud brick construction or sun-dried earth block is one earthen technique that has been known for more than nine thousand years (Minke 2000). However, the earthquake performance of this type construction is poor and has caused a vast number of deaths. The low tensile strength of the earth material is the primary cause of building damage which results in both shear and flexural

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cracking. A high likelihood of serious injuries and loss of life in earthquakes usually accompanies local or general collapse of the adobe structures (E. Leroy Tolles, et al. 2000).

Comprehensive earthquake damage statistics from around the world serve as clear reminders that research to improve the earthquake performance of adobe buildings is urgently needed. On the other hand, there are some historical earthen buildings which had withstood several seismic forces in recent centuries such as the Hakka houses in China, the Bhunga houses in India, the Yomata houses in Malawi, and rammed earth buildings in Argentina. These existing earthen houses used different construction techniques and they were all of a circular shape. Norton (1986) stated that the dimensional proportion of the building is one of the factors likely to lead to building damage during an earthquake. A building of wrong size or shape can be easily damaged by lateral and adulatory motions. Tomaževič (1999) also states that a regular layout in plan is preferred when building adobe buildings in seismic areas. Sufficient seismic behaviour of these existing houses confirmed that it is possible to improve the seismic resistance by considering simple factors such as the architectural configuration. Minke (2001) noted that the shape of the plan might have an influence on its stability in seismic areas and the more compact a plan, the better the stability.

Therefore, this study focuses on the effect of the shapes of unreinforced adobe buildings on earthquake performance. Two compact plans of unreinforced specimens were constructed, one of a square plan and the other of circular plan. Static tilt-table tests were carried out to investigate the failure modes of both structures and their failure mechanism. This research contributes to reducing the vulnerability of adobe houses from earthquake activities in seismic risk areas.

2. CONSTRUCTION DETAILS OF ADOBE TEST WALLS

Two small-scale models (1:3 scale) of adobe structures were built with square and circular plans. The bricks and mortar were made of the same raw material using combinations of raw soil, rice husk and sand with the selected mix of 2:2:1 (Uthai Phat Ra Kun 2004). Bricks were laid in stretcher bond with 10-12 mm thick mortar joints. Compressive strength test was carried out to determine unconfined compressive strength of adobe specimens (Walker & Standards Australia 2002). The average of the unconfined compressive strength was found to be 667 kPa. The tested specimens are all unreinforced. The specifications of two specimens are shown in Table 1.

Table 1: Comparison of small scale adobe models: specifications

Model shape	*Wall thickness (mm)*	*Plan Dimension (m)*	*Wall height (m)*	*Roof load pressure (kN/m²)*	*Total roof load (kN)*	*Total wall load (kN)*
Circular	31	1.2 (Diameter)	0.82	2	2.25	1.56
Rectangular	31	1.2 x 1.2	0.82	2	2.25	1.98

3. STATIC TILT TABLE TESTING

A static tilt-table was set up to evaluate the seismic performance of this type of structure. The static tilt table was constructed with 5 mm steel plate of dimensions 1.5 x 1.5 metres with checker plate floor surface on top. A hydraulic floor jack was installed in order to lift the tilt table with the maximum model load of 2,000 kg.

3.1. The relationship between the static design load and tilt table

In the tilt-table method the structure is subjected to a constant acceleration (due to gravity load) when tilted-up by a tilt table. The horizontal force in this case (*HF*) is equal to the weight of the structure times the sine of the tilt angle as given by the following equation:

$$HF = \sin\theta \times W \quad (1)$$

Figure 1 shows the weight of the model (W) transforming to lateral force (HF) when tilted at θ angle.

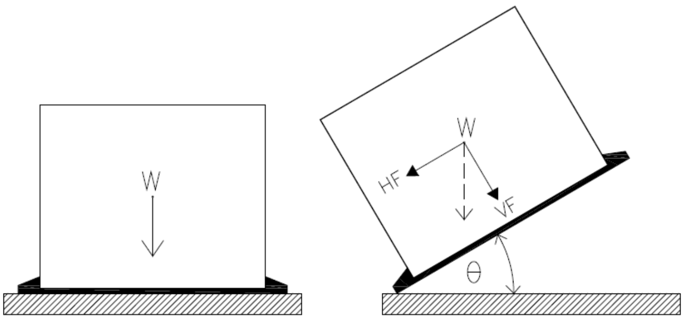

Figure 1: Conceptual scheme of the static testing.

Therefore, the failure angle from the tilt tests can be indicated as the ultimate horizontal force for each model.

3.2. Procedures of the static tilt-table tests

The test began once the constructed specimen was totally dry. The roof cover made from ply wood was installed on which sand bags were placed to reach the required load on the model’s wall. All sand bags were laid in the same direction. The test was recorded by a number of video recorders. The table was slowly and smoothly raised by a hydraulic jack until the adobe model collapsed. The first cracking angle and the angle at which the model totally collapsed were recorded for comparison of the two models’ performance.

Figure 2: Tilting the square specimen and first crack appearing at 25 degrees.

Figure 3: Tilting the circular specimen and first crack appearing at 29 degrees.

Figure 4: The failure modes of the square and circular specimens when tilted further.

4. RESULTS

The results from the tilt-table tests enabled a comparison between square and circular specimens. The first cracking and the complete failure angles are used to calculate the maximum lateral force at each stage. Table 2 and Table 3 give the results of the static tilt-table tests.

Table 2: Results of the square specimen subjected to static tilt testing

	First shear crack	*Complete failure*
Angle (degrees)	20	25
Horizontal force (*HF*)	1.45 kN	1.78 kN
Percentage of the max. horizontal force compared to model own weight	34.3%	42.3%

Table 3: Results of the circular specimen subjected to static tilt testing

	First shear crack	*Complete failure*
Angle (degrees)	29	32
Horizontal force (*HF*)	1.73 kN	2.02 kN
Percentage of the max. horizontal force compare to model own weight	45.4%	53.0%

Tables 2 and 3 demonstrate a comparison between the first cracking angles and the failure angles of both specimens. The results show that the circular adobe structure performed better than the square one with a higher percentage of the horizontal force resistance.

The failure mechanism of the square specimen in the static test was: the vertical corner cracking was induced by shear or tearing stresses and followed by the overturning of the wall panel (Figure 2 and Figure 4). The lack of fixity at the corners allows greater out-of-plane displacement of the wall panels. The top of the wall has a larger response, which causes a greater pounding impact, thus inducing greater stresses that lead to the complete wall failure. For the circular specimen, it was clear from observations that the first shear cracking appeared on the side of the wall, starting from the top edge (Figure 3). The other cracks occurred when the table is tilted further. The model rapidly collapsed when the front part of the wall tended to rotate and separated from the rest of the model (Figure 4). Mauro Sassu (n.d.) stated that the circular floor plan of vernacular buildings offers the best resistance to seismic forces, and a box-shaped building performs poorly with out-of-plane forces and separation at the wall corners. Ole Vanggaard (2003) noted that a circular building has greater static stability due to the shell action of cylindrical wall which has excellent static stability to resist compression force and transfer lateral force.

5. CONCLUSIONS

The static tilt-table testing gives reasonable results when the seismic response of adobe structures is investigated. The result of these comparative experiments indicated a better performance of the circular structures than the square ones. The outcome of these experiments gives simple and effective solutions for construction of new adobe buildings located in seismic areas, and it can help to reduce building damage and death. Further studies of the circular adobe structures on their seismic resistance are being carried out and the results will be published later.

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REFERENCES

E. Leroy Tolles, E.E.K., Frederick A. Webster, William S. Ginell (2000). Seismic Stabilization of Historic Adobe Buildings : Final report of the Getty Seismic Adobe Project, The Getty Conservation Institute, Los Angeles.

Norton, J. & Intermediate Technology Development Group. (1986). Building with earth : a handbook, IT Publications, Rugby, U.K.

Minke, G. (2000). Earth Construction Handbook, Wit press, Bath,UK.

Minke, G. (2001). Construction manual for earthquake-resistant houses built of earth, GATE - BASIN, <http://www.gtz.de/basin>.

Sassu,M. (n.d.). Vernacular Housing Construction, http://www.world-housing.net.

Walker, P. & Standards Australia (2002). The Australian Earth Building Handbook, Standards Australia, Sydney,Australia.

Tomaževič, M. (1999). Earthquake-resistant design of masonry buildings, Imperial College Press.

Uthai Phat Ra Kun, T. (2004) Build house from earth, Fueangfa printing Co.Ltd.

Vanggaard, O. (2003). Clan homes in Fujian, ChinaDwelling.