Pushover Testing of Circular Adobe Structure

Watcharin Jinwuth[1,a], Bijan Samali[2,b], and Cynthia Wang[3,c]

[1]Faculty of Architecture, Naresuan University, Thailand.

[2]Faculty of Engineering and Information Technology, University of Technology Sydney, Australia.

[3]Faculty of the Built Environment, The University of New South Wales, Australia.

[a]watcharin_j@hotmail.com, [b]bijan.samali@uts.edu.au, [c]cynthia.wang@unsw.edu.au

Keywords: Mud brick, earth building, Adobe construction, earthquake resistance, circular building, pushover test.

Abstract Many unreinforced adobe or mud-brick structures have in the past suffered severe damage from seismic forces and have caused a vast number of deaths. In contrast, some adobe buildings located in seismic regions have performed well under several seismic events. Researchers noticed that most existing circular adobe houses performed well in withstanding earthquakes even though some did not have any additional ductile reinforcement. This paper presents the investigation of seismic performance of unreinforced circular adobe buildings using static pushover testing. A scaled model (1:3 scale) of adobe circular structure were built and tested by static lateral load and pushed to total collapse. The results presented in the form of capacity curves, are compared with the expected lateral loading obtained from the static tilt testing carried out in earlier research. The outcome of this research can be used to evaluate the existing circular adobe houses and can give design recommendations of suitable configurations for new circular adobe buildings.

Introduction

Adobe or mud brick construction or sun-dried earth block is one earthen technique that has been used for more than nine thousand years [1]. However, the earthquake performance of this type construction is generally 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 cracking. A high likelihood of serious injuries and loss of life in earthquakes usually accompanies local or general collapse of the adobe structures [2]. 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 attacks 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 but they were all of a circular shape. It is noted that some of these existing buildings have reinforced element in their walls.

Based on the previous static tilt table tests for evaluating the earthquake performance of the adobe buildings [3], nine small-scale models (1:3 scale) of adobe structures were built and tested with a variety of configurations and roof loads. In the tilt-up table tests, the adobe house models were subjected to a constant acceleration. The lateral component of model weight was used as a parameter to quantify the maximum seismic force for each model. It was clear from observations that the typical failure mechanism of the circular models in the static tests can be summarized as (Fig. 1): the failure starts from the top of the wall and then rotates about point X' at the bottom of the front wall, the front wall collapses, followed by the rest of the wall [3]. The previous tilt-table test results presented the methodology for predicting the seismic performance of circular adobe buildings by taking moment of all forces in Fig.1 about X', and the predicted failure of the structures can be calculated. This predictive model can be used to evaluate the existing circular adobe houses and gives design recommendations for new circular adobe buildings.

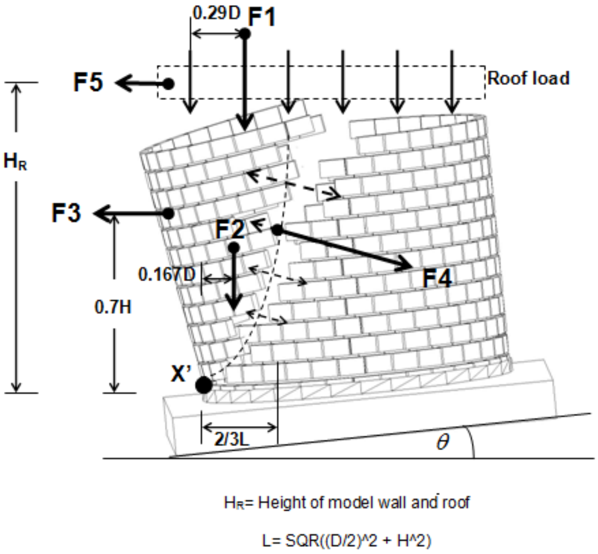

Figure 1: Failure analysis from the tilt table testing of the circular adobe model.

This paper presents the seismic-resistant evaluation of a circular adobe structure. The static pushover testing was conducted to assess acceptability of the previous tilt table tests' results. Seismic evaluation can be evaluated by a static pushover analysis to determine the predicted seismic force and deformation demands of the structure [4].

Construction of Adobe Wall

A 1:3 scale model of circular adobe wall was constructed and loaded laterally in a pushover test. The bricks and mortar of the model were made of the same raw material using combinations of raw soil, rice husk and sand with the mix ratio of 2:2:1. Bricks were laid in stretcher bond with 10-12 mm thick mortar joints. Compressive strength tests of adobe prisms were carried out to determine unconfined compressive strength of adobe specimens [5]. The average unconfined compressive strength was found to be 816 kPa. The tested model was unreinforced wall. The configuration of circular adobe model was selected from the tilt table tests in previous study [3] to compare with both test results. Table 1 shows the specification of the model.

Table 1: Specification of the circular adobe model

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

Pushover Testing

The pushover test was conducted at the Engineering Laboratory of the University of Technology Sydney. A circular adobe wall was tested to measure its deflection and failure load. The model was placed on the strong floor and fixed its base with bolt fittings to prevent any base movement. Fig. 2 shows the pushover test setup of the circular adobe model. The model was tested by static lateral load and pushed to total collapse. This test is a simple method but it provides some useful information which cannot be obtained from the tilt-table test such as the deformation of the tested wall and the failure loading of the model. The pushover tested results, presented in the form of capacity curves, are compared with the expected lateral loading from the static tilt tests carried out previously.

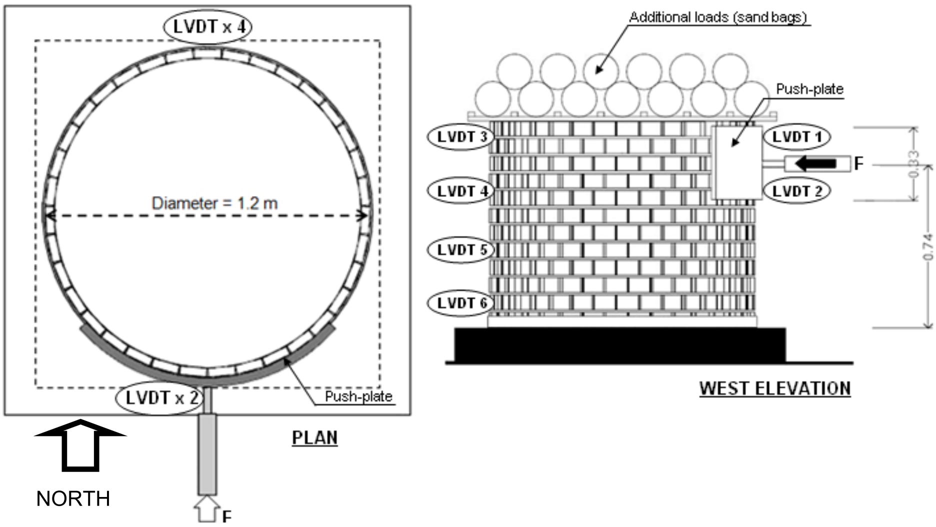

Figure 2: The pushover test setup.

A curve push-plate was constructed with a steel frame and wooden plate. Dimensions for the push-plate were 330mm(H) x 1070mm(W) x 30 mm(T) and located at the south wall of the model. A 200 kN, 300 mm stroke hydraulic-powered jack was mounted to the push-plate in order to applied a lateral load as a uniformly distributed load at one side of the model wall. The jack was attached to a laboratory strong-wall which was used as a reaction point. The jacks provided "*in-plane*" loading conditions to simulate seismic horizontal loads as the static-tilt-table testing. The deflections of the model were measured with the LVDTs (*Linear Variable Differential Transformer*).

Test Result

From observations during the test, the first visible shear cracking occurred in the west and east sides of the model wall when the push-loading reached 1.87 kN with about 2.2 mm of displacement. The top part of the wall appeared to crack first. More cracking occurred in the both sides when the load reached 1.90 kN. Finally, the critical failure cracking occurred at a load of 2.05 kN with approximately 5.5 mm of the maximum displacement. In the tilt-table test, cracking was firstly appeared when the horizontal load reached 1.85 kN, and the total failure occurred at the load of 2.02 kN [3]. The outcome from the pushover test confirmed the reliability of the tilt table test on predicting the structure's seismic behaviour [3]. Fig. 3 shows the model after the pushover test.

Figure 3: Failure crack patterns of the circular adobe wall.

The load-displacement curves measured from the test is given in Fig. 4. The curves show the non-linear relationship of the push-force and the deflection of the wall. The non-linear performance starts from early stage of loading till its failure.

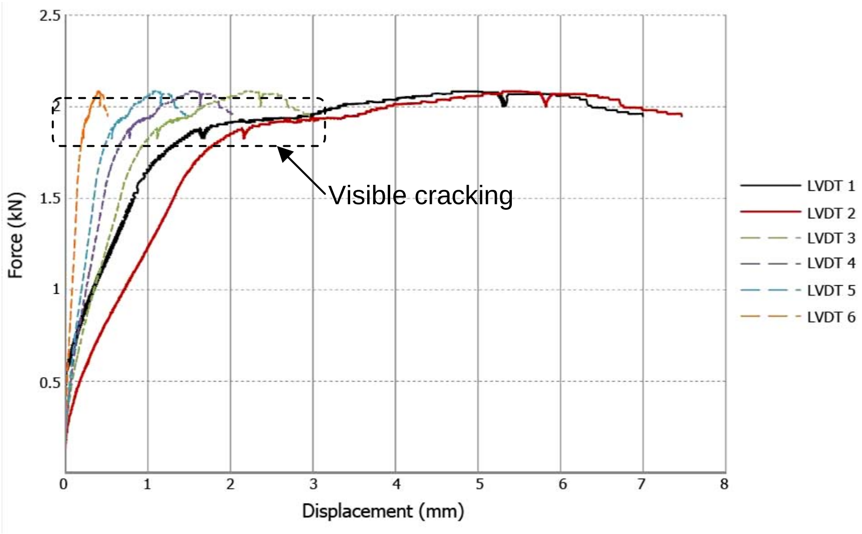

Figure 4: Load-Displacement graph of the pushover-test result.

The pushover curves show that the south wall of the model, where the push plate is located, displaced more than the north wall of the model. It also indicates that the top part of the south wall had less displacement than the middle part, and the reason may be that the push plate was not square to the wall. However, the results from the LVDTs number 1 and 2, located at the north wall of the model, showed that the model wall was subject to shear failure for the reason that there was more displacement at the top part than the middle and the bottom part, respectively.

Conclusion

The pushover test's result confirmed the reliability of the previous tilt table tests. It also provided detailed information for the seismic behaviour of circular adobe model at relatively low cost and in a short time frame compared to dynamic testing methods. Therefore, it is reasonable to use the simple methodology to evaluate the seismic resistance of circular adobe structures. The outcome of this research can be used to evaluate the existing circular adobe houses and can give design recommendations of suitable configurations for new circular adobe buildings. This research contributes to reducing the vulnerability of adobe houses from earthquake activities.

Acknowledgements

The authors would like to thank the UTS technicians for their support to the pushover testing and the Thai government for financial support for this research project.

References

[1] Minke, G. 2000, *Earth Construction Handbook*, Wit press, Bath,UK.

[2] 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.

[3] Jinwuth, W., Samali, B., Heathcote, K. & Wang, C. 2010, '*A Study into the earthquake resistance of circular adobe buildings using static tilt tests*', paper presented to the 2010 AEES Conference, Perth, 26-28 November.

[4] Krawinkler, H. 1998, 'Pros and cons of a pushover analysis for seismic performance evaluation', *Engineering Structures*, vol. 20, no. 4-6, pp. 452-64.

[5] Walker, P. & Standards Australia 2002, *The Australian Earth Building Handbook*, Standards Australia, Sydney,Australia.