Experimental Evaluation of Seismic Behavior of Quincha Walls from the Historical Centre of Lima – Peru.

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SUMMARY:
The historic centre of Lima, declared world heritage in 1988, has buildings constructed during the Spanish Viceroyalty and the Republican era; have a high value related to history, architecture, artistic and ancient technology.

The most common buildings were houses that consist of two or three stories buildings, the first story constructed of adobe masonry and the second and third of quincha walls. The quincha system is composed by posts and beams of timber, filled with cross linked cane and mud plaster.

This paper presents the results of an experimental program consisting of cyclic horizontal shear test of twelve full scale walls that reproduce the original typologies of quincha system from the historical centre of Lima. Numerical values of mechanical properties were obtained for properly modelling the seismic response of this ancient construction system and the results will be useful for assessment and retrofitting strategies for improving the seismic performance.

Keywords: Experimental evaluation, seismic behaviour, historic building.

1. INTRODUCTION

In the colonial era the houses in Lima were two-story buildings, constructed with adobe or firebrick masonry; but it changed after the houses were seriously damaged by strong earthquakes during the sixteenth and seventeenth century. In 1699, the Viceroy Conde de la Monclova ordered to replace the constructive system in the second floors by a lighter system. Thereafter, instead building with adobe blocks or firebricks, they must build the second floors with “quincha”, a constructive system that uses timber, cane and mud.

After that, the reconstruction and the construction of the houses were done using quincha in the second floor and maintaining the first floor in the original material. Due its good behavior facing earthquakes, the quincha system continued to be used during the Republic era.

This work was developed within the framework of The Seismic Retrofitting Project (SRP), which is held in partnership with the Getty Conservation Institute (GCI) and the Pontificia Universidad Católica el Perú (PUCP). Also University of Bath from England and the Ministry of Culture of Peru participate in the Project.

The SRP has two fundamental goals: on the one hand, to design retrofitting techniques using local materials and expertise and, in the other hand, to develop methodologies to structural assessment, in both cases for earthen historic structures in Peru.

The Hotel Comercio was taken as a prototype because it is located in the Historic Centre of Lima and is a representative sample of traditional construction system in Lima. The testing specimens reproduce the construction system, including dimensions, joints and details of the quincha walls from the Hotel Comercio.

2. CONSTRUCTION TECHNIQUES

Despite its general pattern, there are several typologies of quincha walls in the historic centre of Lima. The general pattern consists in a series of vertical timber posts connected together by a top and a bottom beam. The quincha walls are usually settled on the first floor adobe walls and there is no special connection between them.

The quincha walls vary in the type of stiffeners, which can be timber diagonals that run through along the wall height or timber struts that are located in the bottom of the wall, between the posts. In both cases the walls are filled with cross linked cane and mud. The final plaster is composed by an additional layer of mud and another of gypsum.

The Hotel Comercio is a three floor building. The first floor was constructed of adobe walls, while the second and the third are constituted of quincha walls.

The second floor quincha walls from the Hotel Comercio consist in vertical timber posts, with square section of 0.10 x 0.10 m, spaced between 0.60 m to 1 m. The posts are supported by a bottom beam and a top beam, with similar sections to the posts. The connections between the posts and the beams are “mortise and tenon” type. The posts have cylinder shape pins at each end. The pins are inserted to the drilled holes in the upper and lower beams. Also it have stiffeners called “citaras”, they have 0.70 to 0.90 height and consist in short struts nailed between posts and the bottom beams and fulfilled with adobe blocks or bricks seated with mud mortar.

The third floor quincha walls from the Hotel Comercio consist in vertical timber posts, the dimension of the post are 0.08 x 0.06 m, with variable separation, ranging between 0.60 m to 1 m. As in the second floor, the posts are supported by a bottom and a top beams. The connections between posts and beams are the “mortise and tenon” type. In this case, the stiffeners consist of a timber diagonal, which is nailed to the posts and the top and bottom beams.

In the second and third floor, the vertical posts of the quincha walls have horizontal holes to pass cane and the spaces between posts are filled with interlaced vertical cane. The cane is covered by mud with straw. There is a mud layer that covers the entire wall and finally a thin layer of gypsum plaster.

The connections between two orthogonal quincha walls are of two types. When two posts are adjacent, they are tied with strips of cow leather, commonly called “tiento”. In the case that two walls share a single post, the connection between both walls is given by the upper and bottom beams. The upper beams are joined together to a half lapped joint, and have holes or “mortises” to insert the “tenons” from the post. The same applies to the bottom joints.

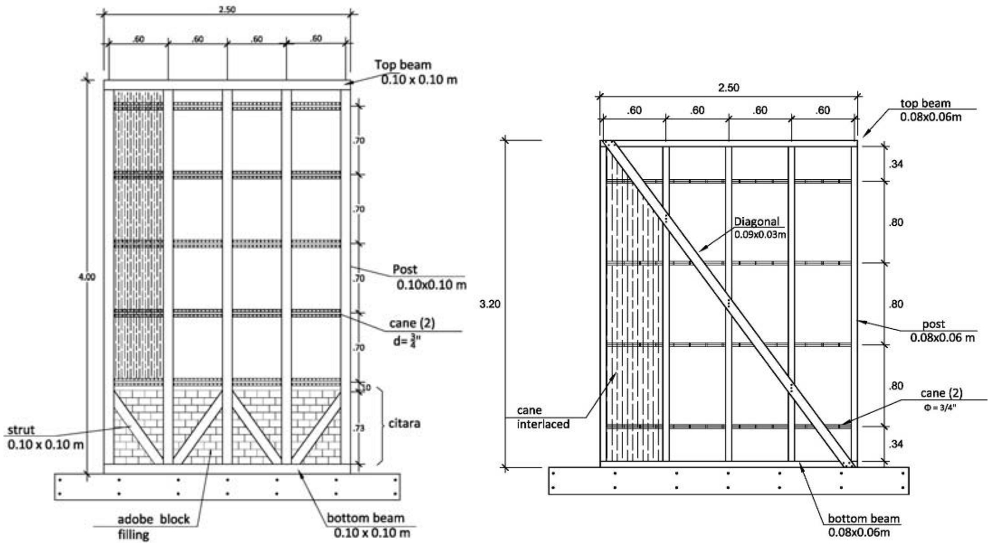
The structural system of floors and roof consist on the timber rafters connected to the upper beam of the quincha walls by nails. Over the rafters a timber boards are placed, and a layer of soil. In the case of the inter floors, also have a timber floor.

3. DESCRIPTION OF SPECIMENS

Twelve quincha walls were constructed reproducing two typologies: 1) 6 with “citara” and 2) 6 with diagonal. The first type corresponds to the second floor of the Hotel Comercio and the second type corresponds to third floor.

The walls with “citara” are 4.00 m high and the walls with diagonal are 3.20 high. All specimens are 2.50 m long (see Figure 1).

In all cases, the junctions between the posts and the beams are the tenon and mortise type (see Figure 2), while the bracing conformed by the diagonals and struts are nailed. As the original walls, the specimens were fulfilled by cane and mud. Furthermore, mud layer covers the entire wall.



a) (b)

Figure 1. Quincha wall specimens: (a) with “citara”; (b) with diagonal.

Figure 2. Typical mortise and tenon joint.

4. TESTING

Twelve quincha walls are tested to lateral cyclic load. Six of them have “citara” and the other six have diagonals.

The quincha walls testing consisted in four cyclical phases with maximum displacement of ± 25 mm, ± 50 mm, ± 100 mm and ± 140 mm. In some cases, the load application system was modifies to increase the number of phases to five cycles, the first four cycles were the same, and the fifth cycle was +300 mm displacement, only in one direction.

4.1 Walls with Citara

From the six specimens with “citara”, two were tested without vertical load (MA1 and MA2), and the other four (MA3, MA4, MA5 and MA6) with vertical load of 4 Ton and 8 ton corresponding respectively to the load on a perimeter wall and to an internal wall from the second floor of the Hotel Comercio. That walls support the weight of the third floor walls, the roof and the inter floor (See Table 1).

4.2 Walls with Diagonal

From the six specimens with diagonal, two were tested without vertical load (MB1 and MB2), and the other four (MB3, MB4, MB5 and MB6) with vertical load of 1.6 Ton and 3.2 Ton corresponding to the load on a perimeter wall and to an internal wall from the third floor of the Hotel Comercio respectively. These walls support basically the roof weight (See Table 1).

Table 1. Testing plan

ITEM	SPECIMEN	HEIGHT (m)	THICKNESS (m)	TYPOLOGY	VERTICAL LOAD (Ton)	NUMBER OF PHASES
1	MA1	4.00	0.10	WITH CITARA	0	4
2	MA2	4.00	0.10	WITH CITARA	0	5
3	MA3	4.00	0.10	WITH CITARA	4	5
4	MA4	4.00	0.10	WITH CITARA	4	5
5	MA5	4.00	0.10	WITH CITARA	8	5
6	MA6	4.00	0.10	WITH CITARA	8	5
7	MB1	3.20	0.08	WITH DIAGONAL	0	4
8	MB2	3.20	0.08	WITH DIAGONAL	0	4
9	MB3	3.20	0.08	WITH DIAGONAL	1.6	4
10	MB4	3.20	0.08	WITH DIAGONAL	1.6	4
11	MB5	3.20	0.08	WITH DIAGONAL	3.2	5
12	MB6	3.20	0.08	WITH DIAGONAL	3.2	5

5. RESULTS

The results correspond to the twelve quincha walls tested; they are MA1, MA2, MA3, MA4, MA5, MA6, MB1, MB2, MB3, MB4, MB5 y MB6.

5.1 Experimental Behavior of Quincha Walls with “Citara” MA.

The six specimens with “citara” were tested under lateral cyclic test. The specimen MB1 was tested in four phases and the rest walls were tested in five phases, to the fifth phase the load application system was changed to develop a displacement of +300 mm. A typical hysteretic curve is showed in the Figure 3.

Despite the large displacement applied to the walls, the horizontal load did not fall; instead, it continues to increase. It does not reach the maximum capacity of shear strength. Even in the fifth phase, is not observed significant deterioration failures in the connections and the timber elements.
Only the mud, which covers the entire wall, was cracked. The maximum shear load was 10.5 KN, which is related to a distributed force of 4.2 KN/m for +300 mm of displacement, and a drift of 0.075.

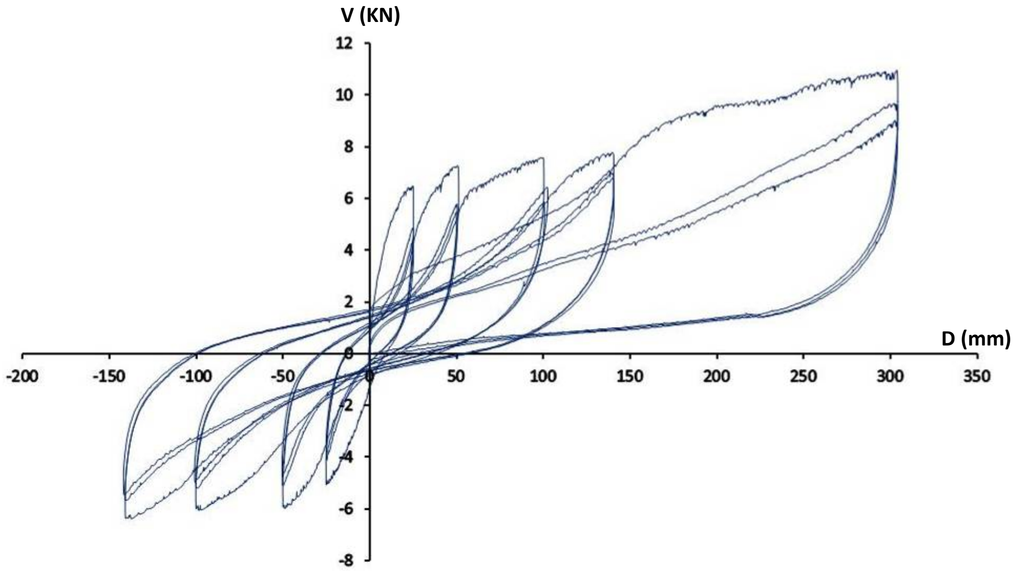


Figure 3. Load – displacement curve. MA2.

Figure 4. Fifth phase of MA5 (d=300 mm)

5.2 Experimental Behavior of Quincha Wall with Diagonals MB

The six specimens with diagonal MB1, MB2, MB3, MB4, M5 and MB6 the behavior was similar. In the first phase of ± 25 mm and the second phase of ± 50 mm, an elastic no lineal behavior with low load loss is showed in the second and third cycle of each phase (See Figure 4).

From the third phase of ± 100 mm (drift = 0.0312) was evident that the diagonal was unpinning. In the four phase (± 125 mm, drift = 0.039) the diagonal was completed detached and the wall began to work without the diagonal influence. At that time, the shear load was resisted by the rest of the structural system, ie, posts, beams, joints and the fulfilled of cane and mud, forming a second line of strength.

Any element specimen observed failures in the elements or connections, except for the diagonal unpinning in the third phase. As expected, the mud was cracked since the first phase. The maximum shear load was 13.5 kN averages corresponding to the distributed load of 5.4 kN/m to a displacement of +60 mm and a drift of 0.093.

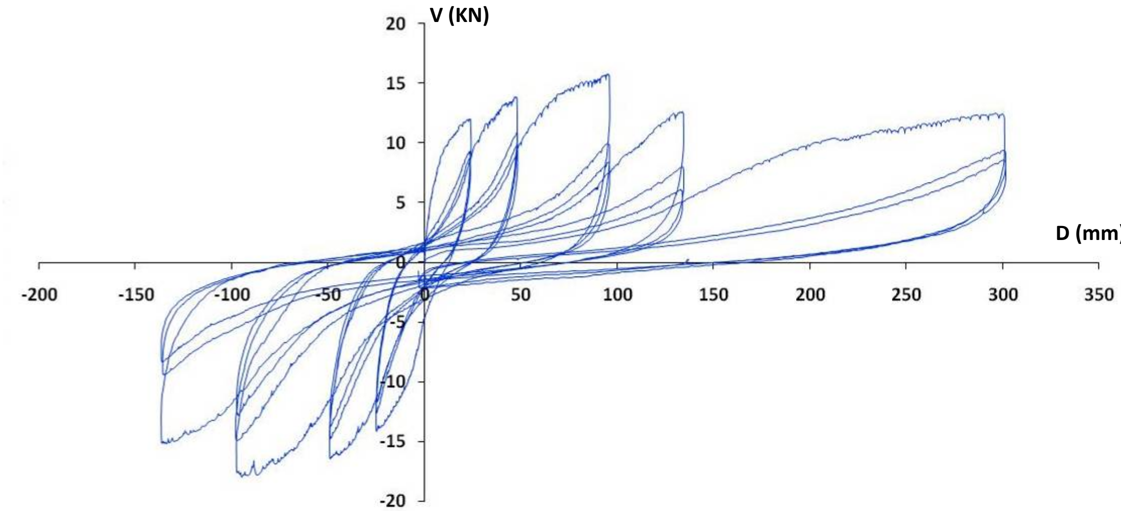


Figure 5. Load – displacement curve. MB5.

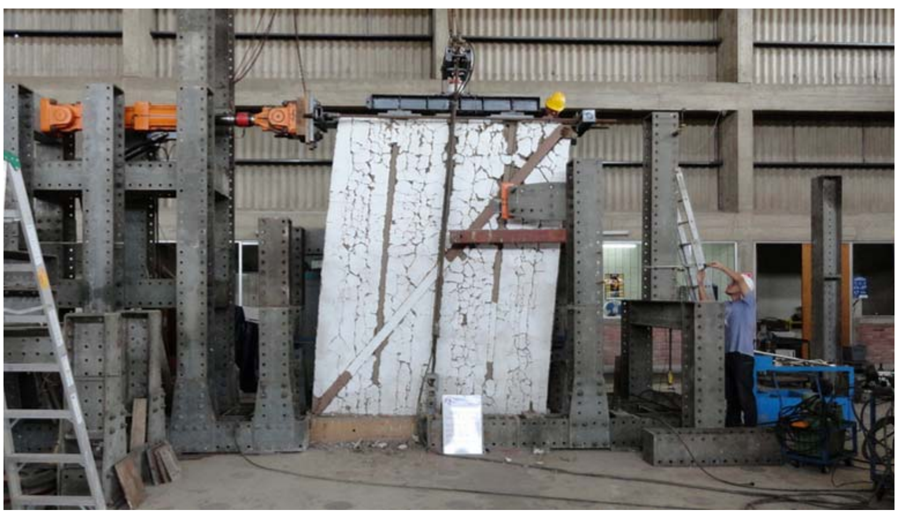


Figure 6. Fifth phase of MB6 (d=300 mm)

5.3 Comparing Envelopes Curves

To compare the behavior of two types of quincha walls, with different heights, the horizontal force versus horizontal drift was plotted. The horizontal drift was calculated as the horizontal displacement divided by the height.

The quincha walls with diagonal had similar behavior, independently of whether or not they had vertical load. There was a notorious the resistance increase due the presence of the diagonal which provides stiffness to the system. Then there was a marked decrease of the resistance since the diagonal was detached. However, the performance does not correspond to a fragile failure; the wall does not collapse because the rest of the system continues operational.

In the case of the quincha walls with citara, the behavior is quite different, the horizontal load keeps growing, with the increasing the horizontal displacement.

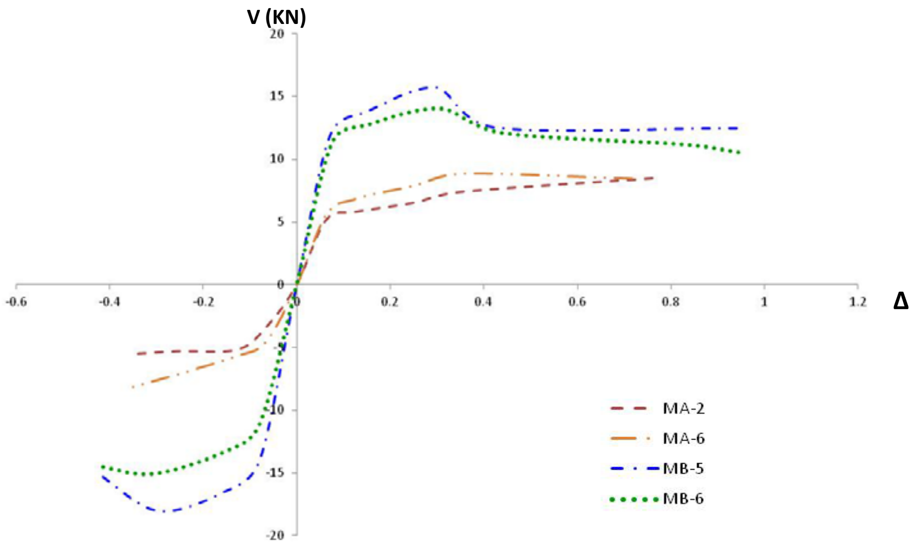


Figure 7. Envelope curves comparison. MA and MB.

6. CONCLUSIONS

The quincha walls reached very high drifts, in order of 0.075 in the case of walls with "citara", and 0.093 in the walls with diagonal. However, there was neither collapse nor significant damage. Therefore, both types of quincha walls showed a larger deformation capacity without major loss of resistance.

In the third phase of the quincha walls with diagonal testing (Dmax = +/- 100 mm) a significant decrease in load capacity is shown, this is due to the nailed joints failure of the diagonal. After this change, the system stabilizes and even develops larger displacement without losing its load capacity. This behavior was possible because the rest of the system (posts, beams, joints and the filling) continued working.

The behavior is quite different in the walls with "citara", because it don't have a strong stiffener, although the "citara" functions as a brace, it works shortening the free length to the posts. The behavior of these walls corresponds to larger deformation without major loss of resistance, similar to the performance of the wall with diagonal from the third phase on. The mortise and tenon joints behave as hinge joint because in spite the larger displacement reached by the system, they don´t fail avoiding the damage in the rest of the elements.

This experimental research demonstrates the excellent seismic behavior of the quincha walls of the historical buildings in Lima.

ACKNOWLEDGEMENT

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