Paper:

Comparison of Behaviors of Non-Engineered Masonry Tubular Block Walls and Solid Engineered Walls

Carlos Zavala, Luis Lavado, Jenny Taira, Lourdes Cardenas, and Miguel Diaz

Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID),
Faculty of Civil Engineering, National University of Engineering (UNI)
Av. Tupac Amaru 1150 Puerta 7 Campus UNI, Lima, Peru
E-mail: czavala@uni.edu.pe

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In Peru, the most commonly used structural system for housing construction is based on confined masonry walls. Solid engineered walls are regulated by the NTE-E070 standard, which lays down a required degree of earthquake resilience. However, around 60% of the population lives in non-engineered houses that use tubular blocks for their walls. This paper presents a comparison of the behaviors of non-engineered tubular block walls and solid engineered walls. Tests were performed on a tubular brick wall by subjecting it to horizontal cyclic loading to examine the effects under a constant axial load of 20 tf. Then, the test results were compared with those for walls in the CISMID Structural Lab database. The resistance of the tubular brick wall in terms of shear stress was found to be relatively low, having an average value of 4 kg/cm^2, while the solid walls can withstand a shear stress in excess of 5.5 kg/cm^2.

Keywords: masonry, tubular brick, solid brick, non-engineered wall, engineered wall

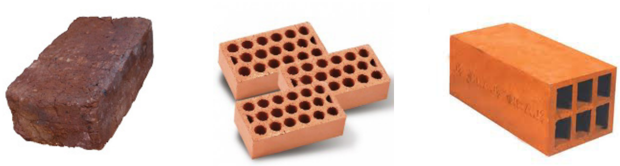

Fig. 1. Handmade, factory-made, and tubular bricks.

Fig. 2. Non-engineered house.

1. Introduction

Masonry buildings first appeared in Peru in the seventeenth century, where most housing had until then been built using adobe or stone. However, the use of this material was a privilege of the rich, the authorities, and wealthy traders. Modern masonry became commonplace in the twentieth century, when it came to be used by the general population. Many people dreamed of a masonry house in the wake of the May 24th, 1940 Lima Earthquake, in which adobe houses collapsed but masonry houses remained standing after the quake. People came to accept that masonry was the stronger material, especially in the case of confined masonry structures. A wall build with bricks confined with concrete elements in their four edges is called confined masonry. Since confined masonry was not so popular at that time, most builders provided a strong support for the roof of a building by using solid handmade bricks. Since then, bricks have evolved, incorporating holes to attain a 25% reduction in the amount of material used. According to Peruvian masonry standard NTE-E070, a standard brick should not exceed this maximum hole area. Then, factory-made bricks appeared and, considering the maximum amount by which the area could be reduced, factories started producing 12-hole bricks. Then, in 1990, 18-hole and 24-hole bricks appeared. All factory-made bricks are standard bricks that conform to the standards. However, due to the high price of these bricks, the population in rapidly expanding regions started to use the bricks intended for partition walls as material for supporting walls, creating non-engineered walls made of tubular brick. **Fig. 1** shows the three kinds of masonry bricks used in the rapidly expanding parts of Peruvian cities. The purpose of our study of the behavior of walls made from tubular bricks was to show how weak these components are, relative to the demands of the Peruvian standards.

One of the problems is the load capacity of tubular brick walls under a lateral load, even though the construction of buildings of up to five stories is permitted by the standards (see **Fig. 2**). These walls are prone to fail abruptly.

One of our aims was to understand the yield level of the confinement elements due to the low strength in shear of the masonry. Confinement, horizontal and vertical concrete elements, will predominant start to work premature on the wall. The relatively low stiffness of such walls in comparison with that of solid walls will be presented. This paper compares the behavior of both kinds of wall: non-engineered walls constructed using tubular bricks and solid engineered walls. A test is presented using cyclic lateral loading under the action of a constant axial load.

2. Test with Tubular Bricks

To investigate the behavior of a tubular brick wall, a series of experiments was performed, with tubular bricks being used to construct a specimen wall.

2.1. Outline of the Specimen

The specimen wall measured 2400 mm long by 2300 mm high and 120 mm thick. The walls have confining reinforced concrete columns at the corners, with each column incorporating four #4 bars with #2 stirrups every 250 mm. **Fig. 3** shows the configuration of the specimen. The specimen was built on a foundation measuring 900 mm by 300 mm.

The construction was done in such a way as to replicate, as closely as possible, the actual environment of a construction site. To that end, the wall was built up to half of its full height on one day, with the remainder being completed on the following day. After masonry wall is completed, confined elements reinforce bars are set, to finally put the concrete on site. The three stages of the construction are presented in **Fig. 4**.

2.2. Loading Test

For the test, four jacks were installed to apply a load to the wall. An axial load equivalent to 20 tf could be applied, thus simulating the load applied by four stories bearing down on the wall.

During the test, an axial load was applied at the beginning of the loading process and, after reaching 20 tf, the load was kept constant throughout the duration of the experiment. To simulate a lateral load like that imposed by an earthquake, cyclic loading with controlled displacement was applied to the specimen. **Fig. 5** shows a plot of the cyclic displacement applied to the wall. The displacement was applied using a new hydraulic jack system provided by JICA as part of the SATREPS project. This jack system had a capacity of 500 kN and a stroke of 400 mm.

As shown in **Fig. 6**, transducers were installed to measure the displacement at different points on the walls. The sensors were installed diagonally, vertically, and horizontally in order to reproduce the displacement in all directions. To measure the strains, strain gauges were glued to the surfaces of the concrete and the reinforcing bars. All of the sensors and gauges were connected to a scanning box and a Tokyo Sokki TDS 530 data logger.

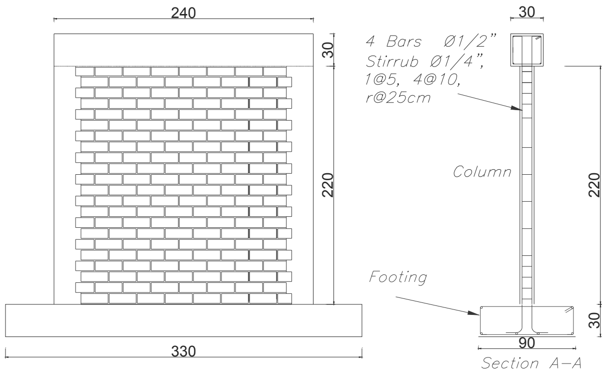

Fig. 3. Specimen wall.

Fig. 4. Three stages of specimen construction.

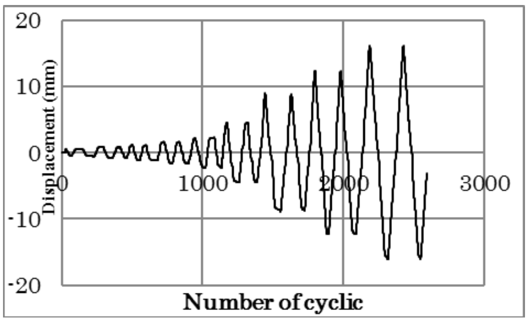

Fig. 5. Cyclic displacement.

The test setup of the specimen is shown in **Fig. 7**. To apply the axial load, two jacks were installed vertically. Another two jacks were used to simultaneously apply a lateral load. Strain gauges were also installed to investigate the yielding of the reinforcing bars at each corner of the confinement elements.

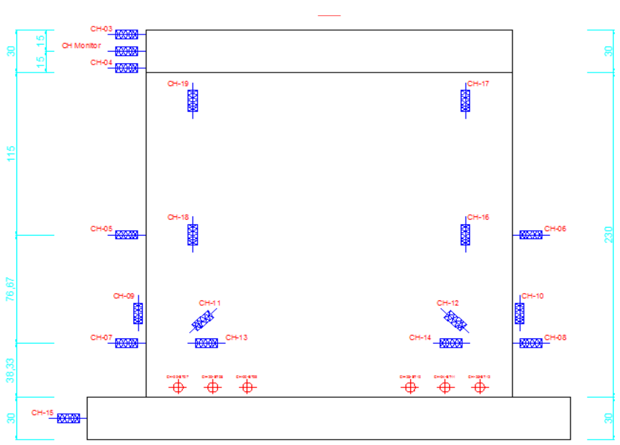

Fig. 6. Locations of displacement transducers.

Fig. 7. Test setup for masonry wall test.

3. Test Results and Comparison

3.1. Test Results

To compare the results of the test with those of previous experiments, the CISMID Structural Lab database of experiments, generated as part of the SATREPS project, was used. For comparison with the test results (WALL-SP-01), four walls were selected: one built with handmade tubular bricks (M-ART), one built using factory-made tubular bricks (M-IND), one built using solid handmade bricks (WALL-C2-HM), and finally one built using factory-made bricks (WALL-C2-FM).

Table 1 lists the geometrical characteristics of the comparison specimen, where f'_m is the maximum compression stress on the masonry, L is the length, t is the thickness, h is the height, σ_o is the confined axial stress, and N_o is the total axial load applied vertically. It can be seen that the specimen (WALL-SP-1) was subjected to almost double the axial load of the other specimens.

The relationship between the displacement and shear force applied to the walls is shown in **Fig. 8**, where the displacement of wall WALL-SP-1 reaches a maximum of 13.85 mm, corresponding to a maximum drift of 1/160.

The specimens were subjected to different maximum loads, due to differences in the axial confinement and variations in the quality of the materials. For WALL-SP1 and M-ART, shear cracks appeared at basically the same displacement. **Table 2** shows that the maximum load (Q_u) is the lowest of all the measured values, and the displacement at the maximum load ($d_{\max}$) is the smallest. WALL-SP-1 is subjected to more confinement stress and this has a major influence on the displacement. From the table, it is possible to conclude that the confinement will yield before the other walls, due to the low material strength and high axial load on the wall.

Initial cracks appeared in the masonry at a drift of 1/1500, and diagonal cracks started propagating at a drift of 1/1075. Finally, diagonal crack openings appeared at a drift of 1/200 with shedding of the brick surface. The final state of specimen WALL-SP-1 is shown in **Fig. 9**.

The backbone curves of the relationships between the displacements and shear forces are shown in **Fig. 10**. **Table 3** lists the maximum shear stresses, together with the corresponding drifts. It can be seen that the stress for the SP-01 wall is lower because of the action of the strong axial load and the low strength of the material, producing a shear stress of 4.44 kg/cm^2. The M-IND and M-ART walls exhibit the second-lowest level of shear stress among the specimens. Since WALL C2-FM is an engineered wall, it exhibits a higher shear stress.

Also evident is the great difference in the maximum capacity of the engineered wall and that of the M-ART and M-IND walls.

Table 1. Characteristics of comparison specimens.

Specimen	f'_m (kg/cm^2)	L (mm)	t (mm)	h (mm)	σ_o (kg/cm^2)	No (tf)
M-ART	33.20	2500	115	2300	4.13	11.88
M-IND	22.10	2500	115	2300	4.13	11.88
WALL C2-HM	59.26	2200	140	2300	2.76	8.50
WALL C2-FM	70.24	2200	140	2300	2.76	8.50
WALL-SP-1	30.87	2400	120	2300	6.94	20.00

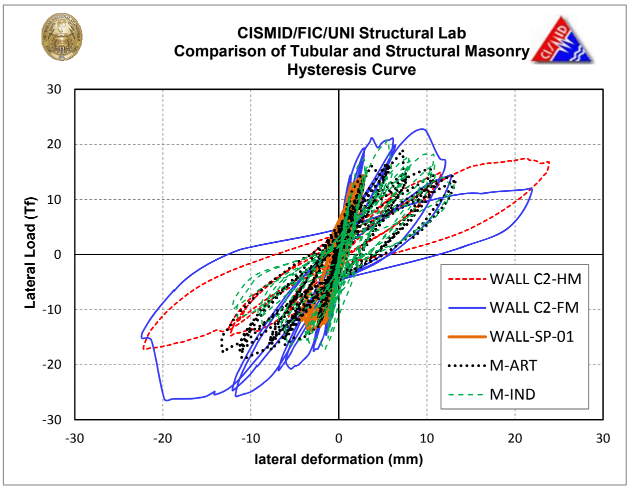

Fig. 8. Hysteresis curves of WALL-SP-1 wall and others.

Table 2. Comparison of test results.

Specimen	Q_u (tf)	$d_{\max}$ (cm)	d_u (cm)	Q_y (tf)	d_y (cm)	Q_c (tf)
M-ART	18.86	0.7242	1.042	14.27	0.2493	9.794
M-IND	20.76	0.5548	1.086	17.23	0.2869	10.659
WALL C2-HM	17.45	2.1340	2.337	14.90	1.1613	9.305
WALL C2-FM	22.79	0.9010	0.901	17.99	0.2708	13.924
WALL-SP-1	13.88	0.3070	1.474	13.34	0.2780	9.617

Fig. 9. Final state of wall (1/150) – WALL-SP-1.

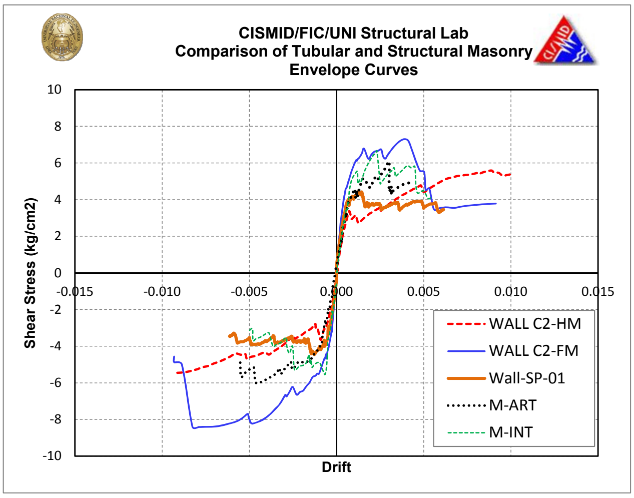

Fig. 10. Comparison of behavior curves.

Table 3. Maximum values from drift-stress curves.

Test	Drift	Max Stress (kg/cm^2)
M-ART	0.0030	6.0433
M-IND	0.0023	6.6529
WALL C2-HM	0.0089	5.5929
WALL C2-FM	0.0039	7.3035
WALL-SP-1	0.0013	4.4479

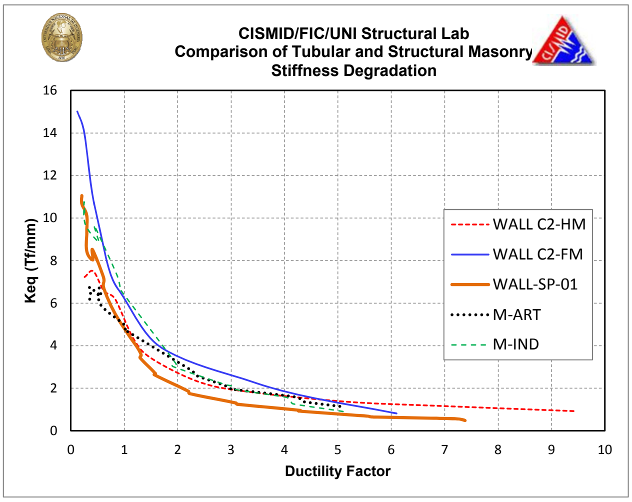

Fig. 11. Comparison of equivalent stiffness relative to ductility factor.

Figure 11 presents a comparison of the equivalent stiffness relative to the ductility factors of the specimens. The engineered walls (WALL C2-FM) exhibit a higher equivalent stiffness while the tubular walls (M-ART, M-IND, WALL-SP-01) have an average stiffness that is around 60% of the initial stiffness of the engineering wall. In all these cases, the tubular brick walls exhibit the lowest levels of stiffness.

4. Conclusions

- In Peru, tubular bricks intended for partition walls are being used for load-bearing walls, despite this being illegal in active seismic zones according to Peruvian standard NTE-E-070. The axial load capacity of tubular brick walls does not satisfy the minimum requirement of the NTE-070 standard.
- A comparison of the cyclic behavior of engineering walls and tubular walls was presented. Four walls were selected for the comparison: one built with handmade tubular bricks (M-ART), one built with factory-made tubular bricks (M-IND), one built using solid handmade bricks (WALL-C2-HM), and one built using factory-made bricks (WALL-C2-FM). The last of these is regarded as being an engineered wall, and exhibits the best backbone curve in the comparison.
- The test results show that the tubular brick walls have the lowest capacity.
- A reduction in the equivalent stiffness is attained more quickly in the case of tubular brick walls. The shedding of the surface of these walls would be dangerous for the inhabitants of housing built using this material.
- The retrofitting of tubular brick walls is required to

avoid the possible collapse of housing built using these materials and techniques.

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Name:
Carlos Zavala

Affiliation:
Researcher, Laboratory of Structures, CISMID
Professor, Faculty of Civil Engineering, National University of Engineering (UNI)

Address:
Los Ishipingos (Ex-Abetos) 245 Dpt. 202, Urb. El Remanso La Molina, Lima 12, Lima, Peru

Brief Career:

1984 Undergraduate Course, Faculty of Civil Engineering, National University of Engineering (UNI), Lima, Peru
1989 Master Course, Graduate School Faculty of Civil Engineering, National University of Engineering (UNI), Lima, Peru
1995 Ph.D., Graduate School of Architecture, University of Tokyo, Japan
2001 Professor, Faculty of Civil Engineering, National University of Engineering, Lima, Peru
2007-2012 Director of Japan Peru Center of Earthquake Engineering Research & Disaster Mitigation CISMID

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Academic Societies & Scientific Organizations:

- Peru Engineering Association (CIP)