

Analysis of Constructive Errors in masonry confined in Highly Seismic Countries and Reinforcement of Walls with Galvanized Mesh

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Abstract. In countries with high seismicity, such as those located in the Pacific belt of fire, great disasters are generated because many houses are not designed to resist seismic forces; this is because they have been built without any professional technical assistance and using low quality materials that make them more vulnerable to an earthquake. In developing countries such as Peru, the problem is recurrent, because more than 80% of homes are self-built, causing construction errors that lead to 70% of these homes have no guarantees to withstand a major earthquake; the importance of solving this problem lies in the need to identify construction errors to study methods of reinforcement. This work investigates 371 houses of confined masonry, the most used construction system in South America, finding as a result that the most important construction error is the structural use of the tubular brick; in view of this, it is proposed to reinforce the walls with a construction system made up of tubular bricks reinforced with galvanized wire mesh to increase resistance and improve ductility.

1 Introduction

Due to the geodynamic behavior of the planet, large earthquakes of different magnitudes occur around the globe [1], generating many disasters. Although a greater disaster would be expected the greater the magnitude of the earthquake, the worst disasters in human history have been caused by earthquakes of lesser magnitude. The world's strongest earthquake on record occurred in Chile in 1960 with a magnitude of 9.5 and caused around 2,000 deaths, while the 2010 Haiti earthquake with a magnitude of less than 7 left 316,000 dead, 350,000 injured and more than 15 million victims [2]. This, it is inferred, is because developing countries do not have ant seismic housing and adequate construction methods and are exposed to a latent seismic hazard. For example, on the Pacific coast, exactly on the central coast of Peru, there is a greater than 70% probability that an earthquake with a magnitude greater than 8.8 Mw will occur in the next 75 years [3].

However, 80% of the houses in this country are built without any professional assistance, causing construction errors [4] and more than 70% of the houses in its capital are not guaranteed to withstand a major earthquake [5]. Faced with this problem, there is a need to identify construction errors that can increase seismic vulnerability in confined masonry houses, structural system present in 43% of houses in Peru and the most used in South America [6].

The studies carried out in places where great disasters by earthquakes occurred, indicate that the main constructive errors causing the collapse of the houses of

confined masonry were: Lack of integrity between walls and floor/ceiling diaphragms in the Gorkha earthquake - Nepal, 2015 [7]; Absence of confining elements, lining of walls and a rigid diaphragm in the Simav earthquake - Turkey, 2011 [8]; Masonry units made with inadequate resistances and permeabilities, Deficiency in the pouring of concrete and in the execution of walls in the Concepción earthquake - Chile, 2010 [9]; Low quality masonry units, Inadequate wall confinement, Absence of mooring beams and of a rigid diaphragm, and Lack and/or Discontinuity of columns in the earthquake of Ica - Peru, 2007 [10, 11]; and Inadequate wall confinement, poorly emptied concrete, Absence of a rigid diaphragm, Low wall density, Vertical discontinuity of walls and large ducts in the slabs in the earthquake of Ancash - Peru, 1970 [11, 12]; and Inadequate wall confinement in the earthquake of Ancash - Peru, 1970 [11, 12].

This research identifies and classifies construction errors and analyzes their impact on confined masonry housing in areas of high seismic risk in a district of Lima, Peru. Then, the reinforcement with galvanized mesh of walls made with tubular bricks to increase their resistance and ductility is proposed as a solution to the most incident error.

2 Methodology

It describes the research process that has been carried out in this work, which includes the area of study, the identification and analysis of construction errors and the proposal for reinforcement.

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2.1 Study area

The investigation was carried out between January and March 2019 in the district of Villa El Salvador de Lima-Peru, which presents a higher seismic risk because it is in a seismic zoning 4 according to Norm E. 030 of Seismic Resistant Design [13]. The study area includes sectors I and III, where 371 consolidated dwellings of 2 to 5 floors built under the confined masonry system were studied.

2.2 Identification of errors

A visual inspection of the dwellings is carried out in the field, equipped with a camera and a data sheet to record the construction errors causing the collapse of the dwellings in previous earthquakes. Then, in cabinet the constructive error of the data sheet is identified by each housing and it is verified with the image of the photograph.

2.3 Error analysis

This analysis was done under 2 modalities: a) quantitative, through a statistical analysis and Pareto Diagram to verify the frequency and accuracy of the most important constructive error, b) qualitative, through the Ishikawa Diagram and Content Analysis to pinpoint the causes, state, methods of prevention and rehabilitation, and solution to constructive errors.

2.4 Proposed reinforcement of a tubular brick wall

It is proposed to use a material of low cost and of easy access in the market, such is the case of the hexagonal mesh of galvanized wire of $\frac{3}{4}$ " of \varnothing 1 mm, as reinforcement of the walls of 47.5 x 51 cm constructed with tubular bricks of 23 x 11 x 9 cm.

3 Results and validation

3.1 Study area

Figure 1 shows the study area for sectors I (Zone 1) and III (Zone 2). In zone 1 185 confined masonry dwellings were inspected and in zone 2 186 dwellings of the same construction system.

3.2 Identification of errors

Table 1 identifies the construction errors observed in dwelling No. 3 in sector III (Zone 2) and Figure 2 shows the image of this dwelling.

3.3 Analysis of construction errors

3.3.1 Quantitative analysis

a) Statistical analysis

Table 2 presents the statistical analysis carried out, considering the total number of dwellings visited and the percentage frequency by number of floors. It shows that the highest percentage frequency is 48.25% for 2-storey dwellings, followed by 3-storey dwellings with 43.94%.

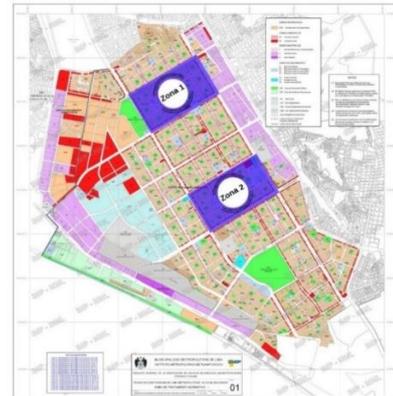


Figure 1. Areas of study in the district of Villa El Salvador.

Table 1. Constructive errors in housing N° 3 of sector III.

Item	Constructive errors
A	Lack of continuity of vertical walls
B	Absence of vertical confinement elements
D	Absence of rigid diaphragm
E	Lack of mooring beams
G	Use of tubular brick for structural purposes



Figure 2. Photograph of housing N° 3 in sector III (Zone 2) of the district of Villa El Salvador.

Table 2. Distribution of dwellings according to the number of floors.

Number of floors	Number of dwellings	Percentage frequency of dwellings
01	0	0.00 %
02	179	48.25 %
03	163	43.94 %
04	27	7.28 %
05	2	0.54 %
TOTAL	371	100.00 %

This shows us that the place of study is mostly made up of 2 and 3-storey houses and they are the ones that present greater dangers in the event of a seismic event.

Table 3 shows the percentage of incidence in the 7 typical errors found in the dwellings. The main error is the use of tubular brick for structural purposes and has an incidence of 96.77%, followed by an inadequate mortar joint between bricks, with an incidence of 91.37%.

Table 3. Constructive errors identified in confined masonry dwellings.

Item	General classification of construction errors		
	Type of construction errors	Number of dwellings	% incidence
A	Lack of continuity of vertical walls	304	81.94 %
B	Absence of vertical confinement elements	313	84.37 %
C	Discontinuity of columns	10	2.70 %
D	Absence of rigid diaphragm	297	80.05 %
E	Lack of mooring beams	205	55.26 %
F	Inadequate mortar joint between bricks	339	91.37 %
G	Use of tubular brick for structural purposes	359	96.77 %

b) Pareto Diagram

Figure 3 shows the number of dwellings and their types of construction errors. It shows that the most important error to be resolved is the "G" which corresponds to the use of tubular brick for structural purposes. After the statistical classification of the constructive errors, an analysis of their hierarchy was carried out to determine the most important errors using Pareto's quality tool.

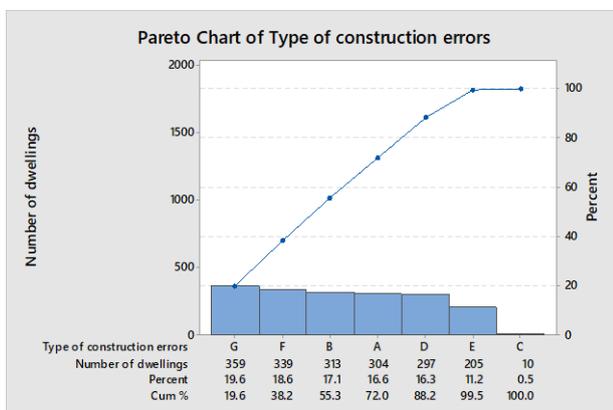


Figure 3. Pareto diagram for construction errors.

3.3.2 Qualitative analysis

a) Ishikawa diagram

Figure 4 shows the causes the use of tubular bricks for structural purposes. The main causes are: work environment, tubular brick, social environment and labor.

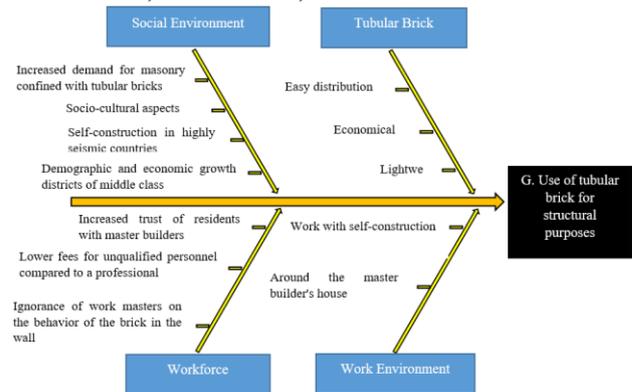


Figure 4. Cause - effect diagram for the most critical error.

b) Content analysis

A. Lack of continuity of vertical walls

Figure 5 shows that vertical loads are not transmitted directly to the ground, this generates cutting forces in the cantilevers as there is no support between slabs. Standard E.070 [13] indicates that confined masonry walls must be continuous because they perform a structural function of support and transmission of vertical loads. Standard [14] considers a confined wall to be structural when it is continuous from the foundation to its upper level.



Figure 5. Discontinuity of walls in masonry dwellings.

B. Absence of vertical confinement elements

Figure 6 shows the non-confined walls at both ends, which have minimal resistance to lateral and oscillatory loads; and as their shear forces are more intense for the brick wall, the chances of failure and collapse increase. Confinement columns must be placed at the ends of structural walls, at intersections with other structural walls and in intermediate places at distances not greater than 35 times the effective wall thickness, 1.5 times the vertical distance between horizontal confinement elements or 4 meters [15]. Moreover, confined masonry walls may in no case have an unconfined length greater than 25 times their thickness [16].

C. Discontinuity of columns

Figure 7 shows that vertical loads are not adequately transmitted to the ground, generating a punching effect on the beams. Standard E.070 [13] requires the continuity of the columns. Confinement columns must be continuous from the foundation to the top of the wall and may be fabricated before or after the wall is erected [16].



Figure 6. Absence of vertical confinement elements.



Figure 7. Column discontinuity in confined masonry dwellings.

D. Absence of rigid diaphragm

Figure 8 shows that the structural elements in the ends (columns or walls) do not receive the lateral loads, this generates unequal deformations. Standard [16] indicates the placement of horizontal confinement beams at the end of the wall and at vertical free distances not exceeding 25 times the thickness of the wall.



Figure 8. Absence of rigid diaphragm.

E. Lack of mooring beams

Figure 9 shows that the wall does not act as a whole, since it is not braced at its four ends (columns and beams). Standard E.070 [13] requires the complete confinement of masonry walls in order to increase the ductility of the system and reduce its fragility. The mooring beams must be placed at the level of the foundation, at the level of the mezzanine system and at the level of the deck level [15].



Figure 9. Lack of mooring beams.

F. Inadequate mortar joint between bricks

In Figure 10 (Right) you can see the separation between masonry units by the lack of connection of the brick with the mortar, this prevents the wall from responding evenly as a block. The thickness of the joint according to E.070 [13] must be a minimum of 10 mm and a maximum of 15 mm. Standard [14] indicates that if mechanized manufacturing units are used, the thickness of horizontal joints shall not exceed 12 mm if horizontal reinforcement is placed in the joints, nor 10 mm without horizontal reinforcement; if artisanal manufacturing pieces are used, the thickness of joints shall not exceed 15 mm; the minimum thickness shall always be 6 mm to ensure a good connection between bricks.



Figure 10. Inadequate mortar joint (Left) and absence of mortar (Right) between bricks.

G. Use of tubular brick for structural purposes

Figure 11 shows the wall made with a brick of low resistance and with many holes, which in the presence of a seismic movement do not support the loads of compression and traction, and the collapse of the wall occurs. For dwellings between 1 and 3 floors in seismic zones greater than 3, the use of solid industrial brick or alveolar brick filled with concrete is obligatory according to standard E.030 [13]. Tubular bricks with horizontal

voids are accepted for confined masonry if their strength exceeds 3 MPa [15].

In view of the above, a technical data sheet is drawn up on a construction error. Table 4 shows about the error in the use of tubular brick for structural purposes, elaborated based on the field work and the cabinet carried out.



Figure 11. Tubular brick in a structural wall.

Table 4. Procedure for qualitative analysis of one of the constructive errors.

Description	Image
The walls of the houses do not have elements of confinement and the only ones that are going to support the cyclic loads are the tubular bricks, which are not designed for such purpose.	
State According to standard [15] the degree of performance of a tubular brick wall against an earthquake is in the "LOW" category.	Solution Demolish the walls and reconstruct the elements of the building in accordance with the respective building regulations [11].
Methods of prevention Do not use tubular bricks as load-bearing elements in dwellings.	Methods of rehabilitation Use wall reinforcement techniques such as electro welded wire mesh, galvanized wire mesh, geogrids.

3.4 Proposed reinforcement of a tubular brick wall

3.4.1 Background

Peruvian technical standard E.070 of Masonry [13] indicates that clay tubular bricks may only be used in load-bearing walls in places where the seismic zoning is 1 and a maximum of two floors in a dwelling. However, many confined masonry housing constructions omit this information and misuse this type of brick.

3.4.2 Basis

The proposal is based on experimental researches on reinforcement carried out on walls with geogrids and metal meshes in order to increase the strength and ductility of the reinforced wall [17, 18].

3.4.3 Reinforcement technique

•Description

The tubular brick wall must be confined on both sides with the galvanized wire mesh and covered with 1: 4 dosing mortar (cement: fine sand). The mesh is fixed to the wall with alcayata nails and placed vertically so that the overlaps remain in the same direction. The meshes of both sides of the wall are connected with annealed wire No. 16 by means of a perforation in the wall. 1.5 cm of mortar cover should be considered, and the mesh must be embedded inside the mortar.

•Materials

- 3/4" galvanized wire hexagonal mesh (1 mm in diameter)
- Nail Alcayata 3.0 x 25 mm for concrete
- Annealed wire No. 16
- Type I cement
- Fine sand

Table 5. Unit cost of reinforcement.

Item	Reinforcement of wall with mesh of henhouse					
Performance	m ² /Day	MO	12.00	EQ.	12.00	Cost per m ² S/. 26.61
Description		UND	Squad	Quantity	Price S/.	Partial S/.
Workforce						
Foreman		HH	0.100	0.0667	20.67	1.38
Operator		HH	1.000	0.6667	17.52	11.68
Pawn		HH	0.500	0.3333	13.26	4.42
						17.48
Materials						
Alcayata Nails 3.0 x 25 mm		Kg		0.0220	5.50	0.12
Fine Sand		m ³		0.0236	50.00	1.18
Portland Cement Type I (42.50 Kg)		Bag		0.1190	22.20	2.64
Water		m ³		0.0100	6.00	0.06
Galvanized Hexagonal Wire Mesh 3/4"		Und		1.0526	2.93	3.08
						7.08
Equipment						
Manual tools		%MO		5.0000	17.48	0.87
Aluminum ruler 1" x 4" x 8"		Und		0.0020	3.25	0.01
Metal scaffolding		Day	1.000	0.0833	14.00	1.17
						2.05

•Cost

Table 5 shows the unit cost per m² of the proposal, which is S/. 26.62 (7.88 USD).

•Tests

The tests were carried out in the Materials Resistance laboratory of the Peruvian University of Applied Sciences-Peru, using a Universal Instron model 3382 machine with a maximum test force of 100kN. Simple (axial) compression trials were evaluated for the following cases: Case 1 - Tubular brick wall; Case 2 - Tubular brick wall, reinforced with mesh on one side and covered with 1.5 cm mortar; and Case 3 - Tubular brick wall, reinforced with mesh on both sides and covered with 1.5 cm mortar.

Table 6 shows the axial compressive strength values obtained for each of the cases studied. For case 3 a higher resistance value is obtained, which corresponds to the developed proposal. In addition, the Post-test analysis showed an adhesion of the broken bricks to the reinforcing mesh. Although the bricks were broken, they were held together by the mesh. In this way, the wall had better ductile behavior.

Table 6. Simple compressive strength values of walls made of tubular bricks.

Tests	Simple compressive strength
CASE 01	$f'_m = 10.35 \text{ Kg/cm}^2$ (1.02 MPa)
CASE 02	$f'_m = 15.74 \text{ Kg/cm}^2$ (1.54 MPa)
CASE 03	$f'_m = 15.85 \text{ Kg/cm}^2$ (1.55 MPa)

4 Conclusions

The main construction errors identified in self-built confined masonry dwellings are the use of tubular brick for structural purposes and the inadequate mortar joint between bricks, both of which are not permitted in accordance with international seismic design standards.

The reinforcement proposal developed responds to an increase in strength and ductility in the wall and consists of confining the tubular brick wall on both sides with galvanized wire mesh covered with mortar.

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