# EFFECTIVE RETROFIT PLANNING FOR MASONRY HOUSING USING STEEL MESH

**Daniel Felipe ESCALANTE MARINO*** **Supervisor: Dr. AZUHATA Tatsuya** **

**ABSTRACT**

The city of Lima located on the coasts of the ocean and belonging to the ring of fire of the Pacific; It has a high probability of a high intensity earthquake, in Lima lives a third of the population of Peru, due to the high concentration of people, low-rise housing and low cost are very common, the 70% of the houses in Lima are of masonry. The seismic code recommends buildings with this system and gives us values of their results to be able to use them. The Pandereta brick is a type of masonry that was created for partitions for rooms because they are lightweight and low cost.
Some people of low-income use these bricks to build their homes, some of which are self-built without engineering because those materials are not adequate to resist an earthquake.
The retrofitting of masonry walls of homes is a method which is rarely used due to the high price in the structural evaluation. In this research, experimental wall data is used, and the typical distribution of a two-level house is used.
To obtain better values, three models were analyzed. The first analysis one is the housing without retrofitting; the second analysis is with all walls retrofitted and the third is in the housing with 50% of the total walls retrofitted. With three points we interpolate the percentage of retrofitting of the house.

**Keywords:** Masonry housing, performance point, retrofitting, and steel mesh.

## 1. INTRODUCTION

In the years of 1966 and 1974, Lima was the scene of great earthquakes where it destroyed more than 50% of houses and 500 people lost their lives. Today the population has increased five times more since the 70's. While the masonry housing in Peru began their construction in the 80's and the 90's, it grew without control extending all around the capital.
Many seismologists predict that an earthquake of 8.5 MW in the coming years would destroy almost all of these homes. The central government together with universities and research centers are investigating and developing methods to strengthen these homes so that they can resist the coming earthquake.

Figure 1. Typical masonry housing in the surroundings of the city of Lima.

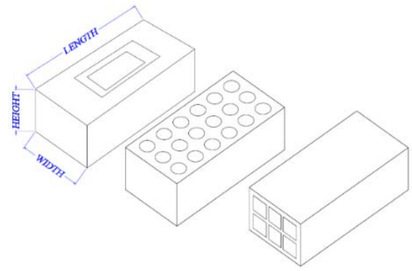


Figure 2. Types of masonry brick units: solid brick, King Kong brick and tubular brick.

* Japan-Peru center of earthquake engineering research and disaster mitigation, Peru.
* * Chief research engineer, Building Research Institute, Japan.

## 1.1. Objectives

- To improve non-engineering and self-construction masonry houses by applying steel mesh method as shown in Figure 3.
- Reduce damages in the homes of masonry in the city of Lima produced by the earthquake.

Figure 3. Coatings of steel mesh with mortar.

# 2. INTRODUCTION MASONRY WALLS IN LIMA-PERU

## 2.1. Masonry homes

Generally, masonry housings are of confined walls, which means that the wall is first constructed, leaving some grooves in each of ends the Wall. Then the steel of the two columns is placed at the ends of the Wall, while concrete is placed posteriorly and the beam is finally constructed.

The masonry of Lima presents mainly three types of brick: (1) Pandereta brick, commonly known as tubular with horizontal hole. This brick presents a low cost and also has a very low weight. That is why many houses use these bricks. (2) Industrial solid is known as King Kong of 18 holes, because they present 18 holes oriented vertically. These types of units are used in the first floor. (3) the solid bricks are hand-made, completely solid bricks made manually, these bricks are found in the walls of the first floor.

## 2.2. Previous studies

The laboratory of structures of the Japan-Peru center of earthquake engineering research and disaster mitigation (CISMID) together with the National Training Service of the Industrialization of Construction (SENCICO) belonging to the central government tested masonry walls in real scale of solid handmade bricks and Pandereta bricks (known as tubular brick) in the years 2016-2017.

## 2.3. Calibration of experimental data

The data obtained after the test is processed by filtering values in the experiment. The data obtained from the experiment are displacement and Load, and they form several loops or hysteretic curves. The area formed by these loops is obtained by the damping, and the maximum values are obtained by the rigidity for each distortion.

To verify the good performance of the house, we will use the performance levels according to the seismic code FEMA356 according to the code the levels are classified into three levels of structural performance and two structural performance ranges. See Figure 4 to Figure 6.

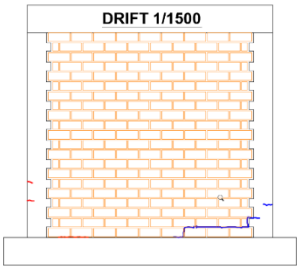


Figure 4. Immediate occupation, cracking initiates in the lower part of the walls.

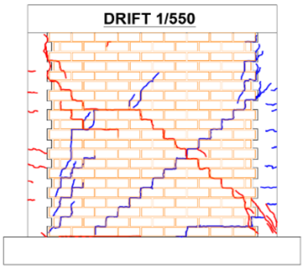


Figure 5. Life safety, in this step the lengths of the diagonal cracks increase.

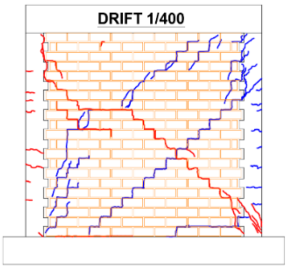


Figure 6. Collapse prevention, increase of the cracks in the diagonal. At the same time the thickness of cracks.

In previous figures, it presents the levels of performance that are going to consider in the studio. For the immediate occupation performance level (IO) is 0.07% of story drift angle, for the life safety performance level (LS) is 0.18% of story drift angle, and for the collapse prevention performance level (CP) is 0.25% of story drift angle is obtained. The Peruvian code specifies a maximum story drift angle for masonry of 0.50%, but this type of material known as Pandereta brick is not recommended to support gravity load or lateral loads.

### 2.4. Retrofitting method for masonry walls

Reinforcement of masonry walls with steel mesh consists of the following steps:

- Cleaning of wall impurities, such as dust, paint, concrete, etc.
- Cut the steel mesh to the suggested size for both sides
- Make perforations to the masonry wall to be able to pass wire of 8mm of diameter to each 45 centimeters of distance between them to each other.
- Place the steel mesh on both sides and fasten them with wires, keeping in mind that the steel mesh must be separated from the wall 0.5 cm
- Prepare a mixture of water with cement and rub against the wall, so that the mortar adheres to the walls.
- Cover the steel mesh with mortar 1: 4 in volume (cement-sand) cover it completely with a maximum thickness of 2.5 centimeters.

## 3. TARGET MODEL

As a typical housing of the city of Lima, the house has an area of 50.8 m2 of two levels, whose model was tested in the CISMID laboratory. In this study we will use the distribution of housing, changing the behavior of masonry walls with non-linear properties of the typical walls used in the district of Lima.

### 3.1. Test of the masonry wall

The tests of masonry walls were carried out to know their non-linear behavior. In this information collection, we will show the curve of masonry walls with and without retrofitting.

Comparison of the story drift vs. load curve of the specimens was tested for the first load (black line) and the second load (red line) of the target distortion of Pandereta brick wall without retrofitting (left) and with retrofitting (right). See Figure 7.

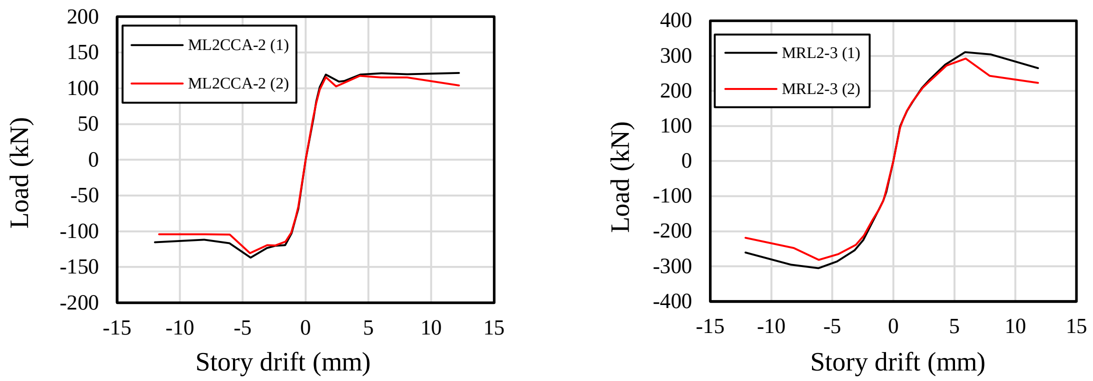


Figure 7. Comparison of the story drift vs. load curve of the specimens tested.

## 4. EVALUATION OF RETROFIT EFFECTS BY CAPACITY SPECTRUM METHOD

### 4.1. Demand curve

To find the demand curve we have to refer to the Peruvian standard of earthquake resistance. Then demand curve is the spectrum of acceleration vs. period expressed in spectral acceleration (Sa) and spectral displacement (Sd).

➢ **Response spectrum reduction factor (Fh)**

Acceleration reduction factor Fh is the response spectrum reduction factor due to the damping effect of the building. Where h is equivalent viscous damping, $\mu$ represents the ductility factor of the building. See the Eq. (1) to Eq. (3).

$$Fh = \frac{1.5}{1 + 10 \cdot h} \quad (1) \qquad h = \gamma \cdot \left(1 - \frac{1}{\sqrt{\mu}}\right) + 0.05 \quad (2) \qquad \mu = \frac{\delta_{max}}{\delta_y} \quad (3)$$

### 4.2. Capacity curve and performance point

From the STERA 3D program, we did obtain the curve of sdx and sfx (shear force vs. story drift). To restrict the maximum displacement, we made use of the Peruvian seismic code, which restricts us the drift for masonry of 0.5%. The limit point is assumed as the starting point, with this point it is determined the performance point assumed, this step is repeated until obtaining a curve of assumed points. Then the assumed point is intersected with the capacity curve to obtain the performance point.

### 4.3. Analysis of masonry housing

For the analysis of the housing, the STERA 3D program was used. The walls of the house were designed with passive damper elements whose data were obtained from the tests. See Figure 8 and Figure 9.

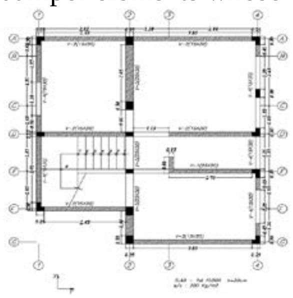

Figure 8. Plans of distribution of the housing.

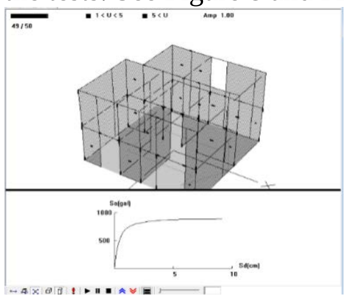

Figure 9. A Mathematical model in STERA 3D.

### 4.4. Analysis results

To know the good behavior of the housing in front of an earthquake we rely on the determination of the performance point, used by many engineers when they retrofit an existing building. For this study it proceeded to determine the performance point of the house for three models: the first is the house without retrofitting, the second model is the one with some walls retrofitted with steel mesh method until it becomes very close to the level of performance (69% retrofitting) and the third model is the building totally retrofitted. See the result in Table 1.

Table 1. Story drift and capacity curve.

| Model | Story drift (cm) | Shear force (kN) | Spectrum displacement (cm) | Spectrum acceleration (gal) |
|---|---|---|---|---|
| 1. Original (0%) | 1.06 | 888.7 | 1.37 | 753.3 |
| 2. Retrofit (69%) | 0.45 | 923.3 | 0.78 | 852.0 |
| 3. Retrofit (100%) | 0.34 | 1007.9 | 0.64 | 896.0 |

### 4.5. Result comparison

The Figure 10 it shows the results of the three analyses, in which the increase in resistance is observed with the increase in the ratio retrofitting. The decrease of the performance point, in which it is observed that after several iterations, the minimum ratio retrofitting was obtained (69%). The blue line represents the minimum displacement according to the ones proposed for this type of masonry (Life safety performance level). See Figure 11.

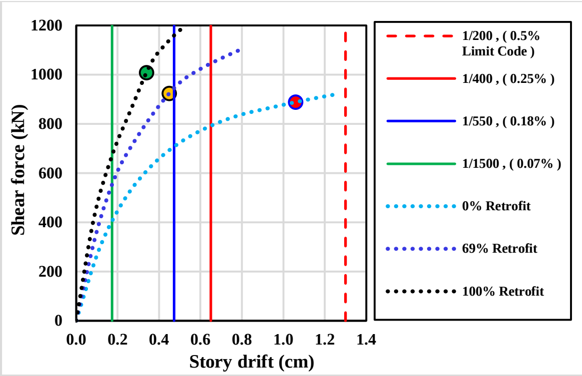


Figure 10. Comparison of performance points of the three analyzed models.

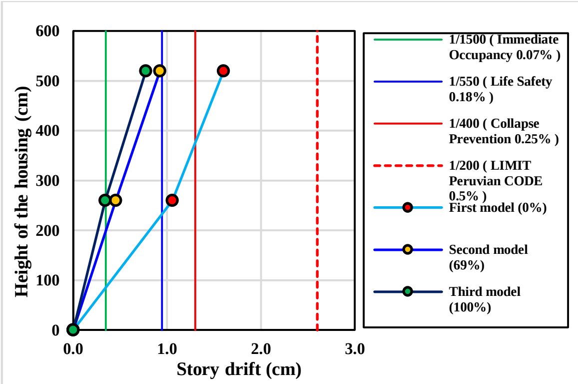


Figure 11. Story drift vs. shear force for the first and second floor.

## 5. EVALUATION OF RETROFIT EFFECTS BY JAPAN BUILDING DISASTER PREVENTION ASSOCIATION (JBDPA) METHOD

Seismic evaluation method uses the Japanese method JBDPA to evaluate old buildings to be able to retrofit. In this method, the seismic demand index should be greater than the seismic index of the structure.

**Seismic demand index $I_{so}$**: The seismic demand index Iso, is calculated with the Eq. (4).
**Seismic index of structure $I_s$**: Seismic performance of the building is represented by Is, the index is evaluated by the following Eq. (5), at each story.

$$I_{so} = E_s \cdot Z \cdot G \cdot U \qquad (4) \qquad\qquad I_s = E_o \cdot S_D \cdot T \qquad (5)$$

**Basic seismic index of structure $E_o$**: The basic seismic index of structure $E_o$, shall be calculated for each story with the following Eq. (6).
**Reduction factor for openings in masonry walls $\lambda_{op}$:** Al-chaar (2002), proposed the reduction factor due to opening that exist in the masonry walls, it can be estimated under the following Eq. (7):

$$E_o = \frac{n+1}{n+i} \cdot (C_w + \alpha_1 \cdot C_c) \cdot F_w \qquad (6) \qquad\qquad \lambda_{op} = 0.6 \cdot (\frac{A_o}{A_w})^2 - 1.6 \cdot \left(\frac{A_o}{A_w}\right) + 1 \qquad (7)$$

**Strength index of masonry $C$**: The strength index C in the first level screening procedure shall be calculated approximately using the cross-sectional areas of walls and columns as follows. See Eq. (8) and Eq. (9).

$$Cw = \frac{\beta_m \cdot v'_m \cdot L_w \cdot t_w \cdot \lambda_{op}}{\sum W} \qquad (8) \qquad\qquad Cc = \frac{\beta_c \cdot \tau_c \cdot A_c}{\sum W} \qquad (9)$$

Table 2. Seismic index of structure $I_s$ − Seismic demand index $I_{so}$ , checking and required strength ΔQu.

| | Is | Iso | Check | Weight (kN) | Is | ΔIs (Iso - Is) | ΔQu (kN) |
|---|---|---|---|---|---|---|---|
| 2nd story | 0.852 | 0.80 | **Retrofit NOT requited** | 356 | 0.852 | 0 | 0 |
| 1st story | 0.551 | 0.80 | **Retrofit required** | 712 | 0.551 | 0.249 | 177.28 |

## 6. CONCLUSIONS

The behavior of the Pandereta masonry (tubular) is very brittle. At the beginning it has high resistance, then the resistance decreases rapidly, releasing small pieces of bricks which is dangerous for the residents. It is recommended to retrofit these types of walls with any other mesh to avoid risks of collapse.

Based on the results presented in the tests, Maximum load on the housing without retrofitting wall was 136 kN, and a displacement of 4.4 mm and in the case of the housing with a retrofitted wall is 310 kN and its displacement is 5.9 mm, it can be concluded that it is necessary to do a retrofitting to the houses that present this type of bricks to increase the resistance in front of an earthquake.

As the tubular brick is very brittle, its behavior is very different from bricks specified by the seismic code, we verified it by comparing the tests of the unit, piles, and prism.

| Test | Unit f'b (MPa | Piles f'm (MPa) | Prism v'm (MPa) |
|---|---|---|---|
| **NTE-070 Masonry** | 5.4 (100%) | 3.40 (100%) | 0.50 (100%) |
| **Test (tubular brick)** | 3.6 (67%) | 0.92 (27%) | 0.37 (74%) |

The percentage of retrofitting of the capacity spectrum method is bigger than the result of the JBDPA method. To improve the results, it would be better to carry out more tests.

X-X (Capacity spectrum method)

$$\frac{11.75 * 100}{16.70} \cong 69\%$$

X-X (JBDPA method)

$$\frac{8.00 * 100}{16.70} \cong 48\%$$


## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. Tatsuya AZUHATA, for the support I received throughout this particular learning process as a thesis advisor.

I would also like to thank the Japanese government through GRIPS, IISEE and BRI and all its staff for the opportunity to open the doors of the world and to grow intellectually and above all personally. I would like to express my gratitude to JICA for giving me a chance to follow this course by financial supporting.

I thank the doctors, engineers, and friends of the CISMID for the opportunity they gave me to apply for the scholarship and to support me in many things since I joined CISMID. I always feel the support in many aspects.

I thank my family and friends who are always present anywhere in the world using their calls, messages, likes and viewed on social networks.


## REFERENCES


Japan Building Disaster Prevention Association (JBDPA), 2001, Standard for Seismic Evaluation of Existing Reinforced Concrete Building. Guidelines for seismic retrofit of Existing Reinforced Concrete Building.

Saito, T., 2017. STERA 3D (ver.9.6) Technical Manual. Toyohashi: Toyohashi University of Technology.

Web site: Japan-Peru center for earthquake engineering Research and disaster Mitigation CISMID - National University of Engineering (UNI), http://www.cismid-uni.org

Zavala, C., Lavado, L., Taira, J., Cardenas, L. and Diaz, M.," Comparison of behaviors of non-engineering masonry Tubular block walls and solid engineering walls," Journal of disaster research Vol. 9 Dec.2014, Peru.