# EVALUATION OF STRUCTURAL PERFORMANCE FOR CONFINED MASONRY WALLS RETROFITTED WITH WIRE MESH AND WITH DISPOSABLE FIBER MATS

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MEE08171

**ABSTRACT**

This study presents a prediction method on structural performance for confined masonry walls and for retrofitting of confined masonry walls by comparison with results of structural test performed at structural laboratory in CISMID UNI-Lima-Peru. The cyclic loading tests on walls were carried out two different kinds of the retrofitted schemes of confined masonry walls: the one is a wire mesh wrapping alternative and the other is the combined materials such as adhesive and disposal mats with different arrangements. On the other hand, the methodology to evaluate structural performance for retrofitted confined masonry wall is suggested. And the accuracy of the prediction method could be verified, and the applicability of this model in analysis is confirmed using pushover analysis.

**Keywords:** Confined masonry wall, retrofit method, structural performance evaluation, analytical model.

## 1. INTRODUCTION

The masonry is one of the materials commonly used around the world. At the time of colonization by Spain, it was the main material used to build the first cities in South America, including Peru. The evolution in construction started with adobe housing, quincha or baharenque, adobe with quincha and actually with clay bricks. Reasons such as low cost, material availability ease of fabrication and durability make this material remains still common throughout years.

In the last decades approximately 70% of housings in Peru were built using masonry walls. Among these 40% has been constructed without reinforcement elements or without structural design. This problem mainly occurs in rural areas or small cities, because those local people build houses valuing only an economical problem and/or are also lack of technical knowledge. This is the reason why many houses in Peru are not following the construction requirements given by the codes. There is always the possibility of severe earthquake occurrence in this area, and such non-engineering buildings without reinforcement are very vulnerable.

Based on the above screen of damages, it is necessary to develop new alternatives aiming at improvement of seismic structural performance. Such systems which improve the safety of the housing and avoid loss of lives should be resistant, durable and with low cost. Started many years ago the development of different techniques that allow the existing masonry buildings to be retrofitted; however in Peru there are only a few comparisons of experimental and analytical simulation studies. For this reason a further development of retrofit technique of masonry buildings is required as a priority issue.

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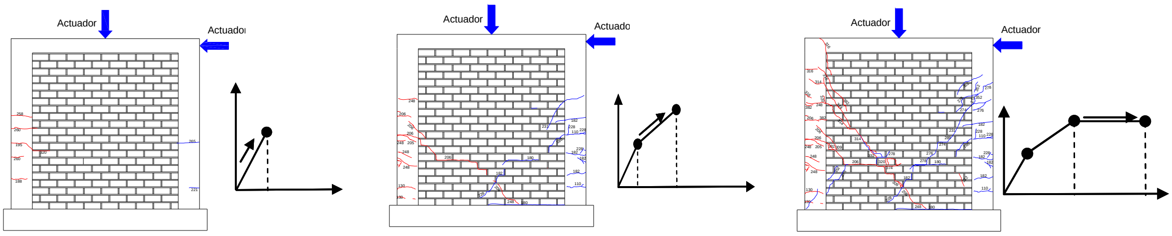
## 2. SUGGESTION OF EMPIRICAL FORMULAS TO PREDICT THE STRUCTURAL PERFORMANCE FOR ORIGINAL CONFINED MASONRY WALLS AND RETROFIT ONE

For the modeling confined masonry wall in the analysis, it is necessary to understand some concepts for the evaluation of walls. The originals confined masonry walls are divided by two components: the masonry wall and RC frame, in order to find individually equations that could evaluate unique points, and then the idealization curve for the originals confined masonry walls is suggested.

### 2.1 Idealization Curve of Original Confined Masonry

For idealization curve, we must know and analyze the process of structural damages on confined masonry walls. Through this investigation, it is possible to understand the behavior of the wall and identify the damage for each structural element.




First cracks | Stiffness degradations | Stiffness and strength degradations.

Figure 1: Process of structural damages

a) *Elastic behavior*: The wall keeps elastic behavior until the first cracks are observed on confined masonry walls. When the small displacement is given by the cyclic lateral loading test, the horizontal cracks appears in columns, and the small cracks appear on the wall.
b) *Stiffness degradations*: After the first cracks, there are an increment of the cracking until the initial diagonal cracks appears. Then the confined masonry wall shows a slope post–elastic stiffness. This stiffness has less value than the initial; and then the specimen reaches at maximum strength.
c) *Stiffness and strength degradations:* After the confined masonry walls reach the maximum strength, it keeps constant value until the diagonal cracks penetrate through the RC Frame and the wall fails in shear wall. Then the stiffness decreases with a negative slope with a drastic reduction of the strength.

#### *2.1.1 Idealization Curve of Masonry Wall using Peruvian Code*

***a) Cracking State:*** Peruvian masonry design code for walls defines an elastic shear limit ($V_e$) to prevent the cracks and establish a cracking control. The intention is to avoid the cracks of masonry wall due to moderate earthquake, where $V_e$ is given by the following equation:

$$V_e = 0.55 \cdot V_m$$

Where $V_e$ is the shear force of a wall and $V_m$ is ultimate shear strength associated with the diagonal cracking.
***b) Maximum and Ultimate State*:** The maximum shear strength ($V_m$) of the walls is calculated by the followings formula for the clay bricks.

$$V_m = 0.5 \cdot v'_m \cdot \alpha \cdot t \cdot L + 0.23 \cdot P_g$$

Where $v'_m$ is characteristic resistance of masonry to obtained from diagonal test or parameter can consider empirical values recommended by the Peruvian code for typical kinds of blocks; $\alpha$ is factor reduction ($\alpha$=1), t is thickness, L is length of the wall and Pg is Axial Load.
***c) Idealization Curve:*** Under the prior definitions based on the Peruvian code, an idealization curve is proposed using the relations between the cracking point (55% of *Vm*) and the maximum shear (*Vm*) like figure 2.

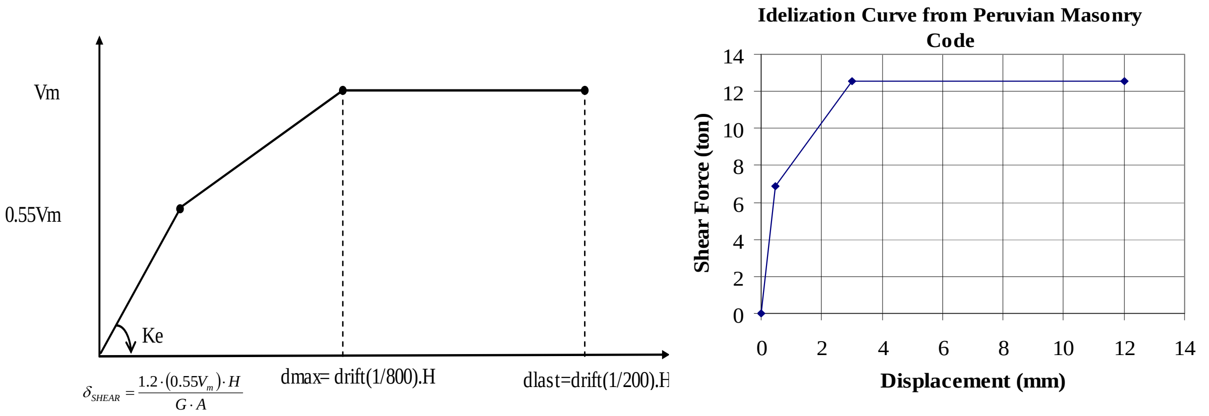



Figure 2: Idealization curve of masonry wall

### *2.1.2 Idealization Curve of RC Frame using Japanese Equations*

For the idealization of the RC Frame that confines the wall, the specifics points of beam and columns were calculated. These calculations are solved by Japanese equations, where the following equations present the flexural cracking moment (Mc) and the yielding moment (My), stiffness ratio of beam and column.

***<u>Beam</u>***

*Flexural Cracking Moment (Mc):* $Mc = 1.8\cdot\sqrt{\sigma_B}\cdot Ze$ *(1)*

*Yielding Moment (My):* $My = 0.9\cdot At\cdot\sigma_y\cdot d$ *(2)*

***<u>Columns</u>***

*Flexural Cracking Moment (Mc):* $Mc = 1.8\cdot\sqrt{\sigma_B}\cdot Ze + N\cdot D/6$ *(3)*

*Yielding Moment (My):* $Mu = 0.8\cdot at\cdot\sigma_y\cdot D + 0.5\cdot N\cdot D\cdot\left(1-\frac{N}{b\cdot D\cdot Fc}\right)$ *(4)*

***<u>In RC frame:</u>***

*Stiffness Degrading Ratio:* $\alpha = (0.043 + 1.64(Es/Ec)pt + 0.043(a/D) + 0.33no) * (d/D)^2$ *(5)*

*Initial Stiffness(S)* $S = \frac{24EI}{H^3}\left(\frac{1+6\gamma}{4+6\gamma}\right)$ $\gamma = I_B/I_C$ *(6)*

Where: $I_B$: Inertia of Beam $I_C$: Inertia of Column

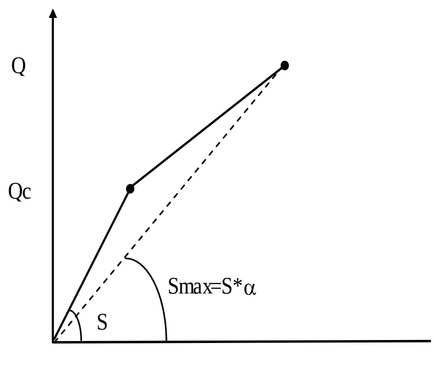



Figure 3: Idealization curve on RC frame

### *2.1.3 Idealization Curve by Combination of Masonry Wall and RC Frame*

To obtain the idealization curve of confined masonry wall, there was some considerations as the behavior and interaction between the RC Frame and masonry wall; at the beginning of the test, both elements simultaneously deformed at the same time, therefore the following figures showed the RC Frame and additionally the masonry wall for analytical model are result of combination, considering the adaptation condition of displacement.

As for the idealization curve of masonry wall, the stiffness in the elastic zone and horizontal capacity cover the majority in the confined wall, comparing to RC Frame. On the other hand, when the masonry wall and RC Frame are idealized as confined masonry wall, this idealization curve has a good accuracy and it can predict the 80% of maximum strength obtained in the test (see Figure 4).

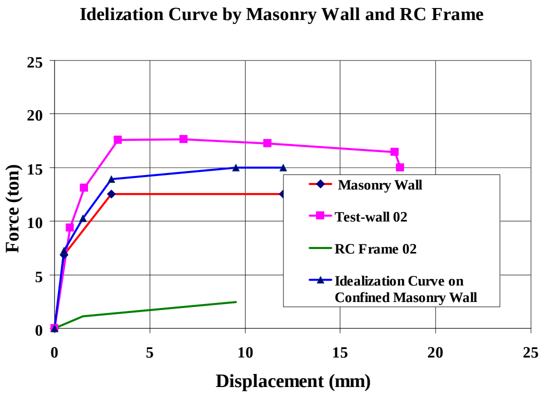



Figure 4: Idealization curve on Masonry wall and RC frame

## 2.2 Idealization Curve of Confined Masonry Wall retrofits with Wire Mesh

For the retrofit of walls, two techniques were used; the first one is commonly used in Peru and is retrofit technique with wire mesh. Another is a new proposal using rice bag with adhesive; both techniques is showed in the below figure (below side is figures showing the specimen retrofitted walls, and above side is figures showing specimen without retrofit) where we can see their effectiveness of retrofit, in all the cases, the specimen with better performance is the specimen retrofitted wall 02, therefore this retrofitted wall will be focused and investigated.

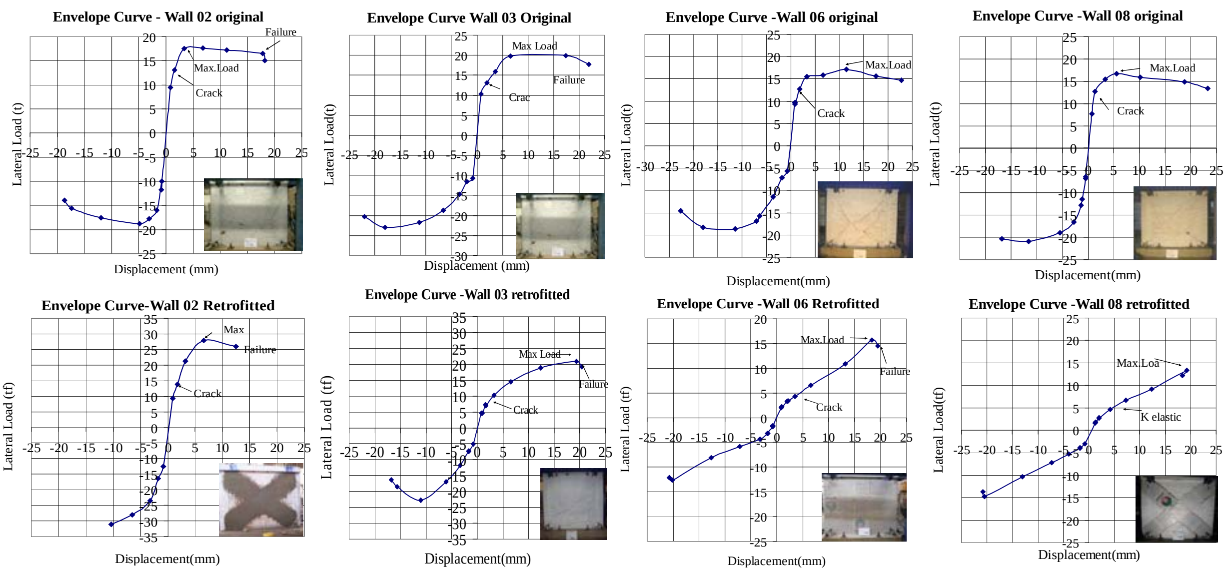



Figure 5: Envelopes with and without retrofits (wire mesh and disposable fiber mats)

### *2.2.1 Idealization Curve of retrofit portion*

The face of specimen retrofitted wall 02 has arrangement as "X" shape using the wire mesh, is removed to repair and the mortar is newly pasted on this part. Therefore the mortar and wire mesh is focused for seismic evaluation of retrofit portion. Both materials are analyzed as bilinear curves, these curves was obtained from mortar and wire mesh test, and idealized using general equation, where the strength is equal to stress of each material and multiplied by section area.

For the retrofit wall, the influence of the portion of the masonry surface removed to replace the retrofit portion (wire mesh and mortar) must be considered. In the case of masonry wall, new idealized curve will be the one of masonry wall (see 2.1.1) considering the difference of wall area, therefore the limits states will be taken into account. This retrofit was only applied in masonry wall zone where had already damaged, the RC Frame has a degrading stiffness and should be considered only the degrading stiffness (see Figure 6).

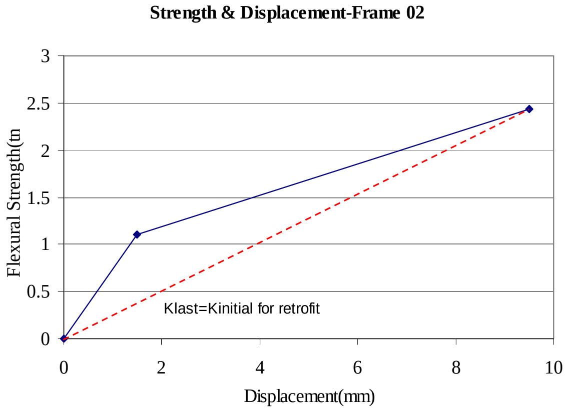



Figure 6: Idealization Curve of RC Frame considering the degrading stiffness

## 2.3 Idealization Curve of Retrofit Confined Masonry Wall

After the computation separately for retrofit portion and new masonry wall and RC frame, then the next step for idealization curve of retrofit wall is combination of all the elements. In the figure 7, the maximum strength of the idealization curve for retrofitted confined masonry wall is represented 80% of test result and the accuracy of this calculation method is generally good. However, there is a room of further investigation in terms of predictions of stiffness, because this investigation was assumed masonry wall without damage and focused only maximum strength.

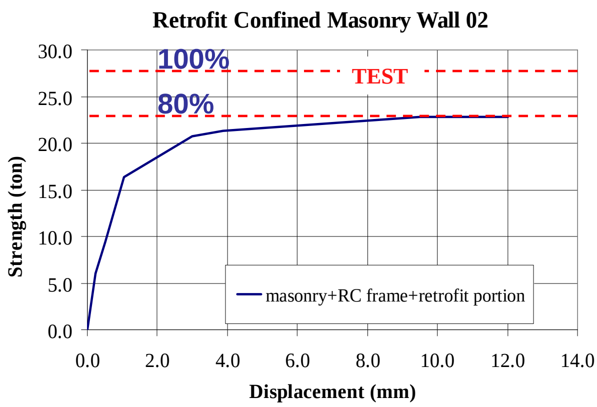



Figure 7: Idealization Curve of Confined Masonry Wall Retrofitted

## 3. INVESTIGATION OF PROPOSED MODEL USING ANALYSIS SOFTWARE

In order to show how to use this wall model in analysis, analytical model is compared to the test results using software "Stera3D"; a nonlinear static analysis for the walls. This confined masonry wall is considered, the RC frame and masonry wall individually. As for both the confined masonry wall and retrofitted one, the accuracy of this method is high and the current analysis model could be useful to express behavior of the wall.

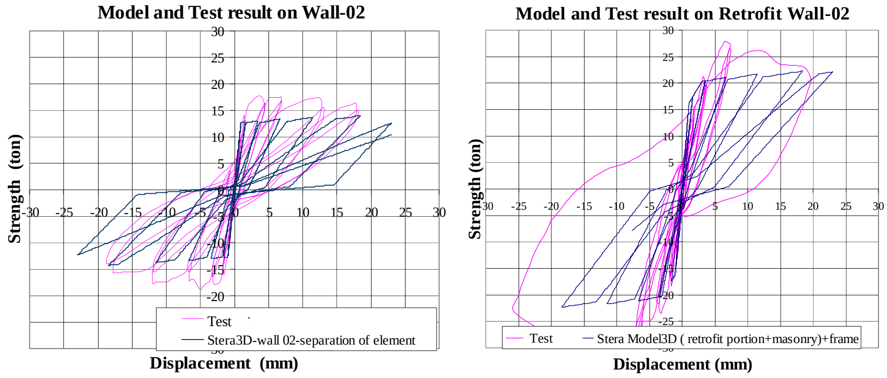



Figure 8: Comparison of idealization Curve to Results
(Left is the Confined Masonry Wall, right is Retrofitted one)

## 4. CONCLUSIONS

- The investigations of the test results for the specimen retrofitted shows that retrofit scheme with the wire mesh is more effective for confined masonry wall.
- The method of idealization by the division of elements (masonry wall, RC frame, and retrofit portion), using Peruvian masonry code and the Japanese equations is suggested
- As a result of comparison the test results to the idealization curve of confined masonry walls, the idealization curve reaches around 80% of maximum strength of the confined masonry wall test and even the stiffness could be quite predicted accurately in the elastic range. The investigation showed that the masonry wall contributes to most horizontal capacity in confined masonry wall.
- As a result of comparison the test results to the idealization curve for retrofitting confined masonry walls, the results of the idealization curve shows a similarity in 80 %of maximum strength of test result.
- Results of the simulations performed with Stera3D have a good agreement in case of the both walls models. The current analysis model could be useful to evaluate the seismic performance of the retrofitted confined masonry wall.

## 5. RECOMMENDATIONS

As for the evaluation of the stiffness for retrofitted confined masonry wall, there is a room of further investigation considering actual repair method. The effect of seismic retrofit by disposable mat must be clear, so it is necessary to carry out the structural test to fail wall part.

## ACKNOWLEDGMENTS

I want to express my deepest gratitude to my adviser and supervisor Dr. Tomohisa MUKAI for his kindly guidance and patience during his teachings and Dr. Carlos Zavala for the confidence he had on me and his support with test data.

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