# Evaluation of A Retrofit Solution Used for Concrete Masonry Walls with Large Openings Using FEM Nonlinear Analysis

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**SUMMARY:**
This paper deals with the modeling of existing unreinforced concrete block walls with finite elements and evaluation of a proposed retrofit solutions used in practice. The objectives of developing the analytical model were prediction of inelastic response of the walls with the openings and the study of the effect of the retrofit solution for seismic upgrading of the existing walls. Concrete core technique was employed for wall retrofit of the different models. To study of in-plane behavior of the walls the models were verified with the test results obtained from the similar walls studied in previous works and calibrated to present the identical inelastic load-deformation response of the tested specimens. Nonlinear push over analysis was performed on the models to study the capacity of the walls up to 4% drifts. As results, the inelastic response was compared in different studied walls. Lateral resistance capacity, initial stiffness and the mode of failure of the walls were presented and the effect of the retrofit solution on the behavior of the existing masonry walls with large openings was evaluated.

*Keywords: Unreinforced masonry walls, opening, push over analysis, seismic retrofit, failure mode.*

## 1. INTRODUCTION

Masonry structures are one of the important portion of the construction in many countries. They are still used for construction in Iran, Turkey, Greece and many European and South American countries. Masonry materials are relatively cheap construction of this type of buildings is easy and does not need special expertise.

Masonry walls are used as shear walls, partitions and infill walls in framed structures and are subjected to in-plane and/or out-of plane forces during earthquakes. Many studies, including experimental and analytical research, have been performed to investigate the behaviour of the masonry walls and evaluate the performance of various retrofit techniques for seismic retrofitting of the existing walls. A series of tests were conducted in University of California at Berkeley between 1976 and 1979 to determine the maximum capacity of the one storey masonry buildings against earthquake [1]. Different masonry houses with various configuration of the openings were tested on shake table and many suggestions were presented for improvement of the masonry buildings. In 80's decade, UNDP initiated and performed an extensive research program and studied the collapse mechanism and modes of failure of these structural systems [2]. Gambarotta and Lagomarsino developed a model for analysing and designing the shear masonry walls based on mechanical characteristics of the bricks and mortar obtained in experimental works [3]. Schneider and his coleagues performed a series of tests on infill unreinforced masonry walls in steel frames and investigated the effect of the openings, their size and location on the earthquake demands [4]. Bendeti conducted extensive shake table tests in Greece and Italy on two storey masonry houses for seismic evaluation of existing non-engineering buildings and study the application of retrofit methods [5]. Galano and Gusella [6], Paquette and Bruneau [7] and many other researchers have investigated on masonry buildings and studied their performance. For analyzing, seismic evaluation and retrofitting many standards, codes and guidelines have been presented. BIA (Brick Industry Asociation) offereed some technical points for masonry design for lateral forces [9,8]. FEMA (Federal Imergency Managemet Agency) provided technical guidelines for seismic evaluation and rehabilitation [10,11]. IBC (International Building Code) has a provision for masonry buildings [12] and there are many references that describe the behaviour of these buildings and present the concept of modeling, evaluation and design of masonry buildings [13].

In this paper in-plane behaviour of unreinforced concrete masonry block walls is sturdies and the capability of a proposed technique for seismic retrofit the walls is investigated. The studied analytical models are including the walls with no opening and the walls with different layout of openings, all with the same overall dimensions. The walls with different configurations were retrofitted with the suggested technique and the response parameters of the models are compared.

## 2. RETROFIT SULOTION

The center core technique was proposed as retrofit solution for seismic upgrading the concrete masonry walls. The center core system consists of placing vertical reinforcement into the masonry cells and splicing it with rebar dowels anchored to its foundation. This retrofit increases the integrity and resistance of the masonry wall out-of-plane. Typical masonry wall studied in this paper and the proposed retrofit elements layout are shown in Fig. 1. The application of the construction began by sawcutting one continuous vertical slot of 50mm width off the face shells along the full height of the URM wall. Vertical slots were cut every 1200mm along the length of the wall. For each vertical slot, a hole was drilled into the foundation at an angle with respect to the vertical axis (full vertical drilling was not possible due to the spacing provided by the vertical slot being too narrow for the drilling equipment). Rebar dowels 750mm long were anchored 150mm into the foundation using HILTI-HIT Re500 epoxy. One vertical rebar was then placed into each vertical cavity made in the URM wall and spliced with the rebar dowel anchors. A wood cover was placed over each vertical slot and nailed onto the masonry wall allowing filling the cavity with concrete grout (Ventura, Motamedi and Centeno, 2011).

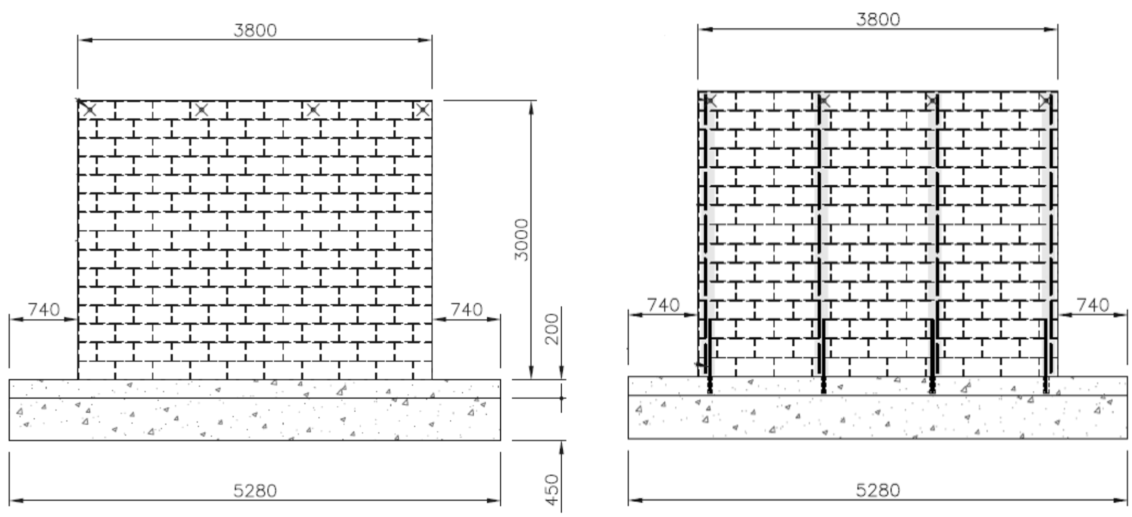
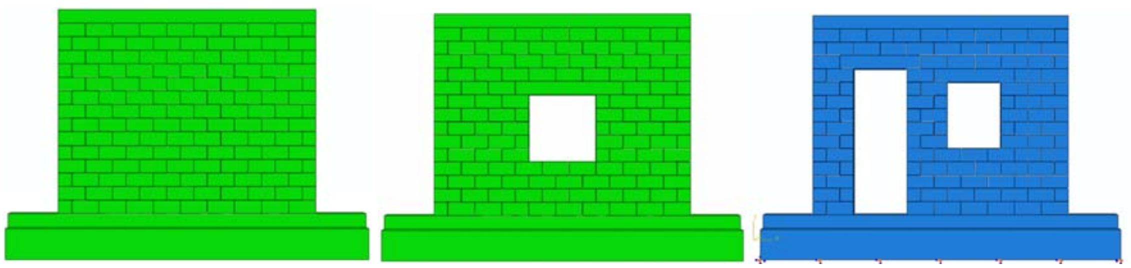



**Figure 1.** Concrete masonry wall layout and the retrofit solution

## 3. FINITE ELEMENT MODELLING OF THE WALLS

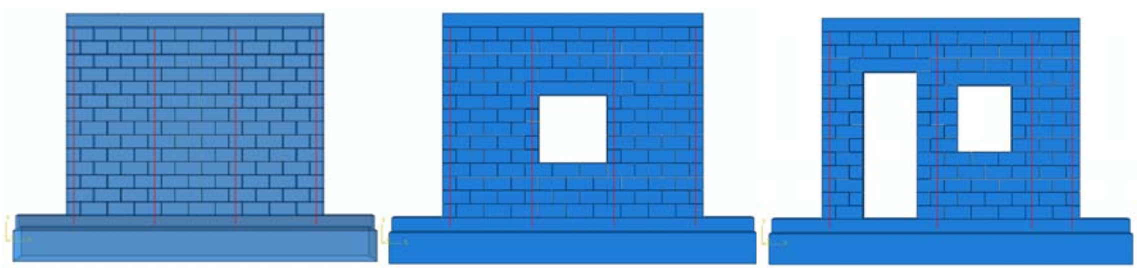
Generally, there are two approaches for finite element modelling of walls: Macro element and Micro element [15]. The macro element approach is based on continues material with equal single properties. In micro element approach, masonry components consisting of block, mortar and interface modelled separately with their related properties [16, 17]. The walls were modelled based on micro element approach. ABAQUS computer software was used to generate the models and nonlinear analysis [20].

All the wall models had 3800 mm length, 3000 mm height and 200 mm wide. Cement blocks had 400x200x200 mm dimension and made up of mortar type S with compression strength of 15 MPa. The wall foundations had 200x200 mm pedestal with compression strength of 56 MPa. Three unreinforced masonry walls were modelled: 1) Model 1: Wall with no opening; 2) Model 2: Wall with one opening, 1000x1000 mm; and 3) Model 3: Wall with two openings, 2200x1000 mm door and 1000x800 mm window. All the unreinforced masonry walls assumed to be retrofitted with the proposed technique and the models were generated. Center core elements were consisting of M15 bars buried in 50x50 mm mortar type S up to top of the wall. Figs. 2 and 3 show finite element models of the unreinforced masonry walls and retrofitted walls, respectively. No extra surcharge was considered for the walls and the walls were subjected to the self-weight gravity load and lateral load at top. Out-of-plane freedom of the walls was restrained but they are free to rotate or move vertically and in-plane direction at top.



(a) (b) (c)

**Figure 2.** Finite element model of the walls: a) Unreinforced masonry wall without opening; b) Unreinforced masonry wall with one opening; c) Unreinforced masonry wall with two openings



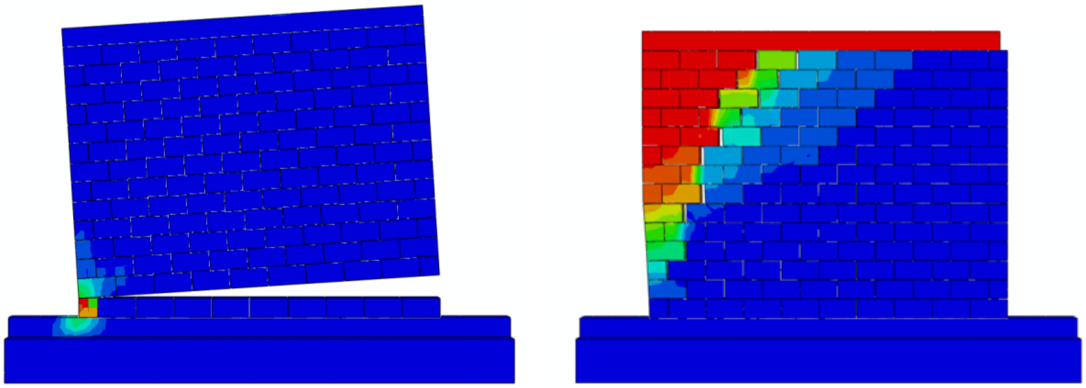
(a) (b) (c)

**Figure 3.** Finite element model of the retrofitted walls: a) Masonry wall without opening; b) Masonry wall with one opening; c) Masonry wall with two openings

The element with 6 surfaces (C3D8R) was used for modelling the blocks. The blocks were assumed to be filled and equivalent properties were considered for the filled blocks. The mortar was not modelled and surface element was used to consider the friction between the blocks. Compression strength of the blocks was defined based on IBC2006 recommendation. Properties of the surface elements were defined as following: 0.65 for friction coefficient, 350 kPa for mortar adhesive, 62 kPa for mortar tensile strength, 10 $N/mm^2$ for shear module of elasticity and 4 $N/mm^2$ for module of elasticity. Defining the surface element let the blocks slide on or separate from the other blocks.

## 4. ANALYTICAL RESULTS

Deformation and crack pattern of the wall with no opening is shown in Fig. 4. Failure mode of the unreinforced masonry wall and retrofitted masonry wall are shown in Fig. 4(a) and Fig. 4(b), respectively. The unreinforced wall showed rocking motion when subjected to lateral load. Load-deformation response of the unreinforced wall is presented in Fig. 5. The finite element model was compared with a test result to validate the model. Shear failure was observed in the retrofitted wall under lateral loading. Load-deformation response of the retrofitted wall is presented in Fig. 6. The model was calibrated with the experimental results obtained from similar walls.



(a) (b)

**Figure 4.** Deformation and crack pattern of the masonry walls subjected to lateral load: a) Unreinforced wall; b) Retrofitted wall

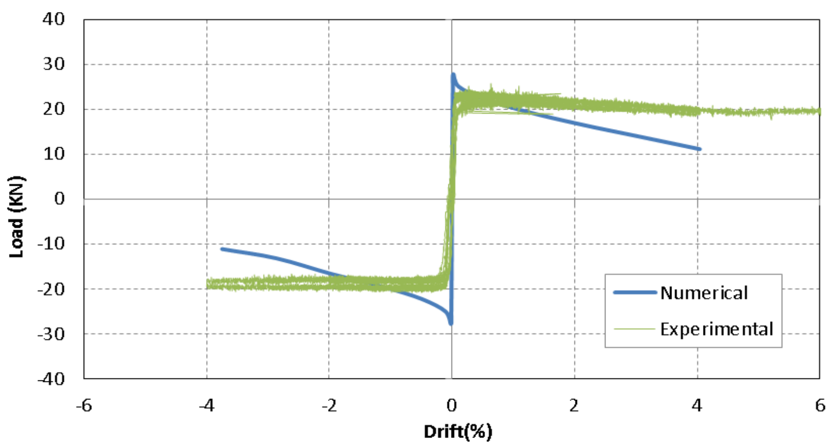



**Figure 5.** Verification of the FE model of the unreinforced masonry wall with experimental results

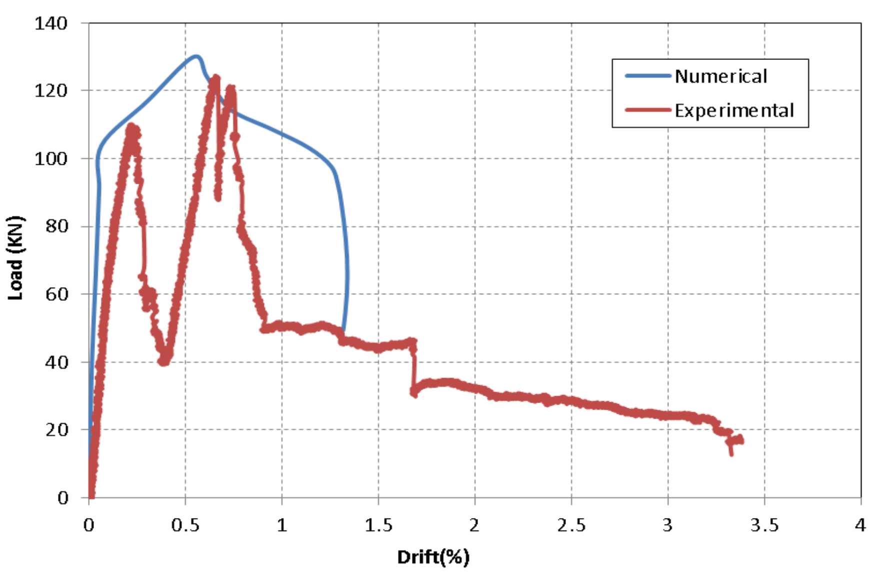
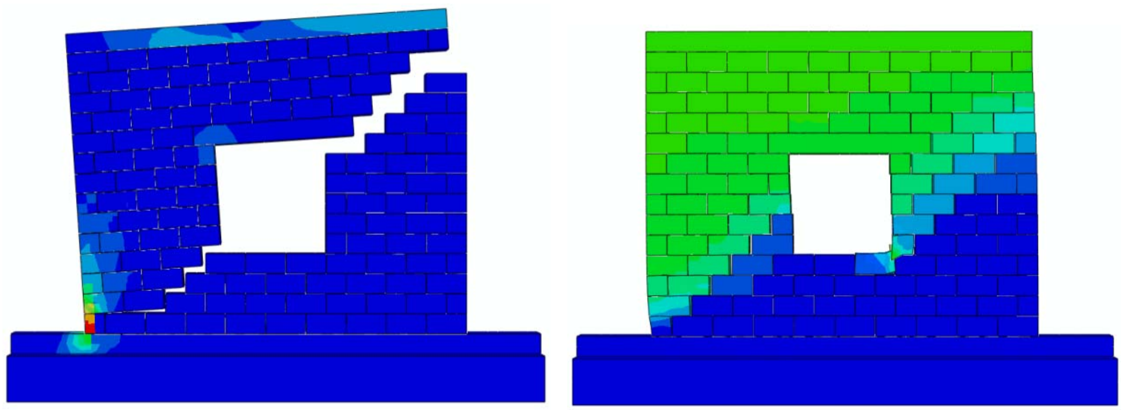



**Figure 6.** Verification of the FE model of the retrofitted wall with the experimental results

As it is shown in Figs. 5 and 6, the proposed retrofit solution increased the lateral capacity of the wall up to 6 times. The shear failure occurred in 1.4% drift.

The behaviour of the walls with opening under lateral loading was investigated using the calibrated FE models. Fig. 7 shows the deformation and crack pattern of the masonry walls with one opening. Failure mode of the unreinforced wall and the retrofitted wall are illustrated in Fif. (a) and Fig.(b), respectively.



(a) (b)

**Figure 7.** Behaviour and crack pattern in the masonry walls with opening subjected to lateral load: a) Unreinforced masonry wall; b) Retrofitted masonry wall

The load-deformation response of the unreinforced wall and retrofitted wall with one opening is presented in Fig. 8. As shown, using retrofit technique increased shear capasity of the wall from 20 kN to 80 kN at 1% drift. Both unreinforced and retrofitted walls showed comparable elastic stiffness.The lateral strength of the unreinforced wall decreased slightly from 25 kN at 0.05% drift to 15 kN at 4% drift whereas the lateral strength of the retrofitted wall increased from 75 kN at 0.25% drift to 85 kN at 2% and then dropped rapidly.

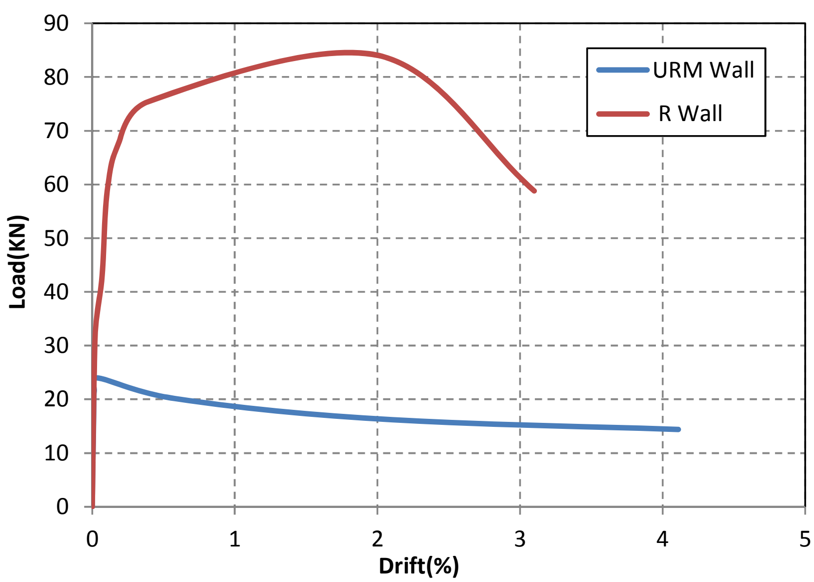
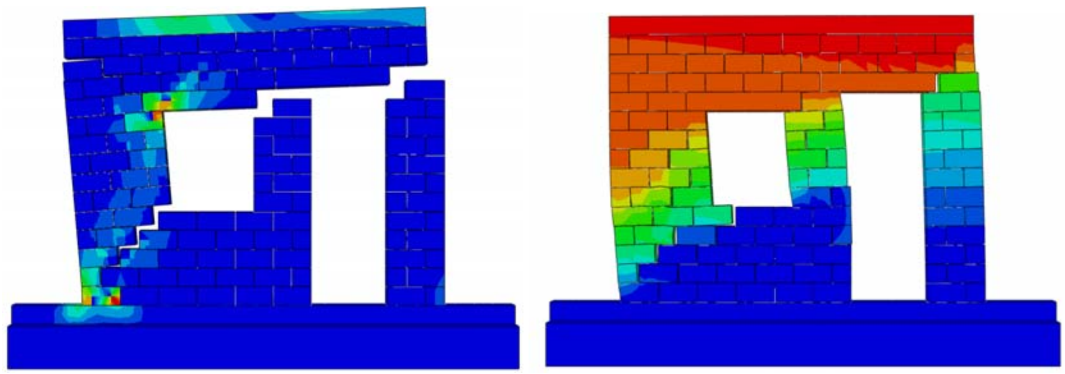



**Figure 8.** Load-deformation response of the unreinforced and retrofitted masonry walls with an opening obtained from push over analysis

The failure mode and deformation of the masonry walls with two openings is shown in Fig. 9. Large deformation and significant cracks were observed in unreinforced masonry wall (Fig. 9(a)) since the retrofitted wall showed less deformation under the same level of lateral load.



(a) (b)

**Figure 9.** Behaviour and crack pattern in the masonry walls with two openings subjected to lateral load: a) Unreinforced masonry wall; b) Retrofitted masonry wall

Load-deformation response of the walls with two openings is showed in Fig. 10. The shear capacity of the wall was increased 5 times using retrofit technique. Unreinforced masonry wall showed about 20 kN lateral strength since the maximum lateral strength of the retrofitted wall was recorded as 110 kN at 0.8% lateral drift. Shear capasity dropped at 0.8% drift rapidly.

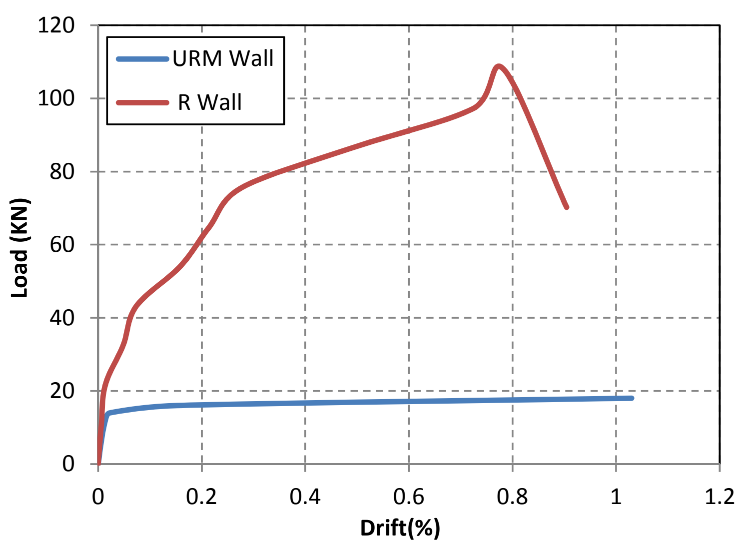



**Figure 10.** Load-deformation response of the unreinforced and retrofitted masonry walls with two openings obtained from push over analysis obtained from push over analysis

Response of the unreinforced wall with no opening (model 1), wall with one opening (model 2) and wall with two openings are presented and compared in Fig. 11. As it is shown, the shear capacity of model 1 is higher than the capacity of mode2 and the shear capacity of model 2 is higher than the model 3. This means, existing the opening reduces the lateral strength of the masonry wall. Model 3, wall with two openings, showed more ductile behaviour than model 1 and model 2.

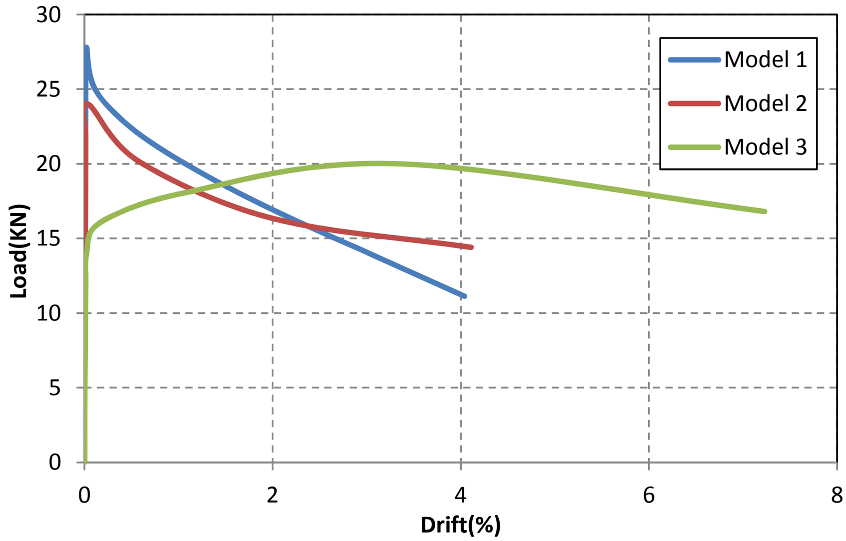



**Figure 11.** FE model of the unreinforced walls: a) Masonry wall without opening; b) Masonry wall with one opening; c) Masonry wall with two openings

The comparison of the retrofitted wall with no opening (model 1), wall with one opening (model 2) and wall with two openings (model 3) is presented in Fig. 12. As shown, the shear capacity of the wall with no opening is larger than the walls with opening. The retrofitted wall with two openings showed larger ductility than the other walls.

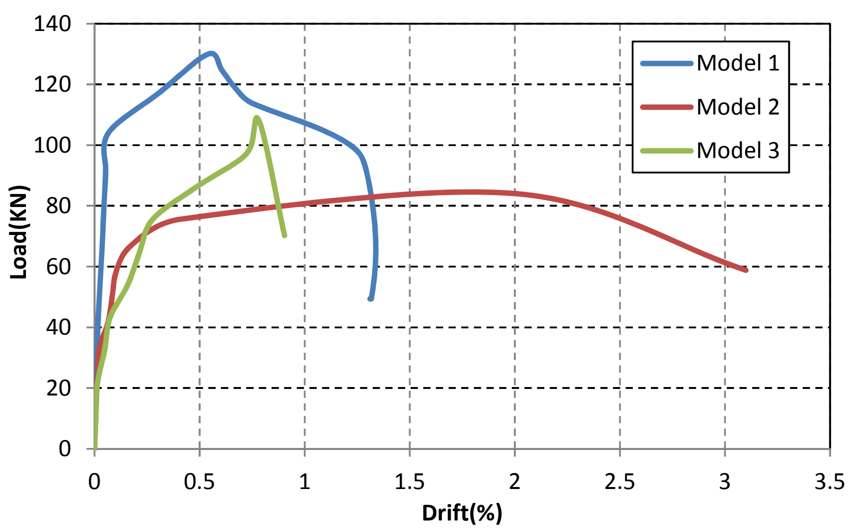



**Figure 12.** FE model of the retrofitted walls: a) Masonry wall without opening; b) Masonry wall with one opening; c) Masonry wall with two openings

The measured response parameters of the masonry wall models due to push over analysis is presented in Table 1. In this table values of elastic stiffness, shear capacity and failure drift are reported and compared between unreinforced walls and retrofitted walls, with no opening, with one opening and with two openings.

**Table 2.** Measured response parameters of the masonry wall models under push over analysis

| | | Model 1 | Model 2 | Model 3 |
|---|---|---|---|---|
| Elastic Stiffness(KN/m) | URM Wall | 712.82 | 544.22 | 317.46 |
| | Retrofit Wall | 947.42 | 669.86 | 580.64 |
| Shear Capacity(KN) | URM Wall | 27.8 | 24 | 20 |
| | Retrofit Wall | 130 | 84 | 108 |
| Failure Drift(%) | URM Wall | 4.04 | 4.11 | 3.31 |
| | Retrofit Wall | 1.31 | 3.1 | 0.91 |

## 5. CONCLUSIONS

The inelastic response, crack pattern and shear performance of six masonry wall models without opening and with opening were studied by performing nonlinear static analysis. Important results obtained from this study include:

1- Existing openings in masonry walls, their number and location in the wall have significant effect on stiffness, shear capacity and wall failure. By creating opening and by increasing the number of opening in each wall shear capacity reduced and the failure occurs in lower displacement demand than the wall with no opening.

2- The proposed retrofit solution for concrete masonry walls showed proper performance in decreasing the response of the models and increasing the lateral stiffness and shear capacity. The results obtained from this study confirm that concrete core technique is a suitable solution for seismic retrofit of the unreinforced concrete block walls.

**AKCNOWLEDGEMENT**

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## REFERENCES

Shaking table study of single-story masonry houses 91997), UCB/EERC – 79/25

Design and construction of stone and brick-masonry buildings, (1984), UNDP/UNIDO Project RER/79/015, Vol. 3.

Gambarotta, L., and Lagomarsino, S.( 1997). Damage models for the seismic response of brick masonry shear walls. Part I: The mortar Joint model and its applications. *Journal of Earthquake Engineering and Structural Dynamics* **26:4**,423-439.

Schneider, P., Zagerz, R., and Abrams, P.( 1998). Lateral strength of steel frames with masonry infills having large openings. *Journal of Structural Engineering* **124:8**,896-904.

Benedetti, D., Carydis, P., and Pezzoli, P.(1998).Shaking table tests on 24 simple masonry buildings. *Journal of Earthquake Engineering and Structural Dynamics* **27: 1**,67-90.

Galano, L., and Gusella, V.(1998).Reinforcement of masonry wall subjected to seismic loading using steel x-bracing . *Journal of Structural Engineering* **124: 8**, 886-895.

Paquette, J., and Bruneau, M.(1999).Seismic resistance of full-scale single story brick masonry building specimen. *8th North American Masonry Conference*.

Technical notes on brick construction,(1988), BIA, 24C-revised.

Technical notes on brick construction, (1987), BIA, 39A-revised.

FEMA 274.(1997).NEHRP commentary on the guidelines for seismic rehabilitation of buildings, FEMA, Washington, D. C.

FEMA 356.(2000).Prestandard and commentary for the seismic rehabilitation of buildings, FEMA, Washington, D. C.

International building code (2000), International code council, Falls Church, VA, International Council.

Paulay T., and Priestley, M. J. N. (1992), Seismic design of reinforced concrete and masonry buildings, John

Wiley & Sons, New York.
Ambraseys, N. N., and Meluille, C. P.(1982).A history of Persian earthquakes, Cambridge University..
Lourenco .P.B, " analysis of masonary structures with interface Elements theory and applications " , TNO Building and construction research , Facalty of civil engineering, Delf university of Technology Mineapolis , USA.
E. Dumova-Jovanoska & S. Churilov, C. P.(2009).Calibration of a numerical model for masonry with application to experimental results. *University Ss. Journal of Cyril and Methodius*, *Faculty of Civil Engineering, Skopje, Macedonia*
Ventura, C.E., Motamedi, M. and Centeno, J. (2011). Technical report on laboratory test program, Structural Engineering Guidelines for the performance-based Seismic Retrofit of British Columbia School Buildings, *APEGBC*, Vancouver, BC., Canada.
ABAQUS User Manual (2010).