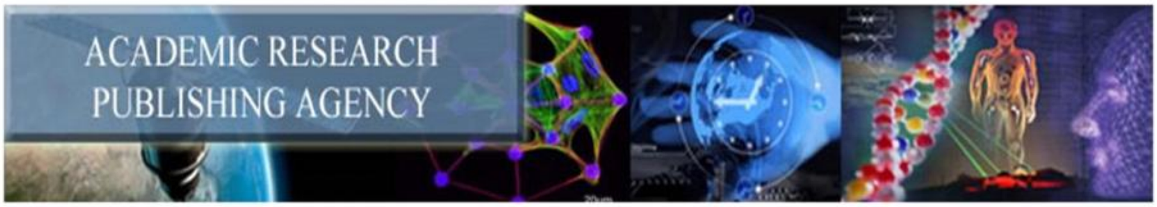

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CALIBRATION OF A FE MODEL OF MASONRY WALL RETROFIT BY CFRP (CARBON FIBER REINFORCED POLYMER)

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ABSTRACT
The recent earthquake in different countries of the world, such as those in Iran (2003), Algeria (2003), India (2001), Turkey (1999) and Vrancea (1997) have shown, particularly masonry walls were damaged. Thus, masonry walls are the most vulnerable elements of buildings when subjected to earthquake loading. Therefore, it is necessary to find practical solutions by study the behavior of these walls, first without and then with retrofitting under monotonic and/or cyclic seismic loading. Presently, many methods are successfully used as reinforcement in masonry retrofitting, such as steelmesh reinforced cement mortar layer, RC tie columns and beams, etc. These traditional methods generally need much time and construction cost, so engineers are trying to find some new methods and materials to solve these problems. By increasing the use of FRP composites in civil engineering, they seem highly essential to be studied.
The purpose of the study is seismic behavior of URM wall and influence of geometric characteristics and arrangement of CFRP laminates on strengthening of masonry walls. The unreinforced and reinforced walls with externally bonded carbon fiber reinforced polymer (CFRP) sheets under cyclic loading have been modeled using the FE software ABAQUS and validated with the experimental data. The results for the different strengthening systems are compared. These comparisons demonstrated the major effectiveness of FRP layers in cross position to increasing the shear performance of URM walls in term of load capacity. four walls have been modeled.

Keywords: *Seismic Strengthening , Masonry Wall, FRP Reinforcement, Finite Element Analysis*

1. INTRODUCTION
Numerous studies have been performed investigating both the static and dynamic response of fiber reinforced polymeric and elastomeric materials used as structural retrofits. Gilstrap, Dolan, and Christensen .[2] evaluated the use of aramid fabric reinforcement for masonry walls. Kevlar fabric was adhered to brick beams that were supported at their ends and loaded to failure with a center point load. Triantafillou.[3] studied the strengthening of unreinforced masonry structures using epoxy-bonded FRP laminates. The effects of FRP reinforcement on masonry strength were examined for out-of-plane bending with axial force, in-plane bending with axial force, and in-plane shear with axial force.In a similar study, Ehsani, Saadatmanesh and Velazquez-Dimas . [4] examined the behavior of retrofitted unreinforced brick masonry walls subjected to cyclic out-of-plane loading. Albert, Elwi, and Cheng . [5] conducted an experimental program to determine the effectiveness of externally applied fiber reinforce polymers in increasing the load carrying capacity of unreinforced masonry subjected to out-of-plane flexural loads. Almusallam, Al-Salloum, and Alsayed .[6] studied the behavior of unreinforced masonry strengthened with fiber reinforced polymer composite materials. Mosallam, Haroun, Almusallam, and Faraig . [7] performed an experimental investigation on the out-of-plane response of reinforced brick walls retrofitted with fiber reinforced polymer composites. Tan and Patoary . [8] investigated the load-deflection response of masonry brick walls strengthened with FRP systems when subjected to transverse loads. In each of these studies, considerable strength was gained through the use of FRP.

2. BEHAVIOR OF UNREINFORCED MASONRY BUILDINGS
A variety of factors makes predicting the response of unreinforced masonry buildings during seismic events complicated. Masonry is orthotropic with high strength in compression and often negligible strength in tension. It is also heterogeneous as it is composed of both masonry units (brick or concrete) and mortar. The mechanical properties of the components very greatly depending on the type of construction, location, and time of erection. The masonry tends to have a short elastic period before cracking and subsequent non-linear behavior.
In addition to difficult component properties, the global behavior of masonry buildings under lateral loading is not well understood. The failure modes typically depend on the type of construction, the amount and size of openings, the type of diaphragm (flexible vs. rigid), and how the vertical elements are connected to the diaphragm. It is also highly dependent on the direction of the ground motion, and whether it occurs parallel to the walls (in-plane) or perpendicular to the walls (out-of-plane). The behavior under large loads is highly non-linear and has been assumed

to be brittle, although recent studies have shown that URM buildings can dissipate large amounts of energy after cracking through global rocking and sliding mechanisms (Griffith 2004). This make analyzing and retrofitting URM structures very complex [9].

3. MODELING OF UN-REINFORCEMENT AND REINFORCEMENT MASONRY WALLS

Walls designing in the experiment are Modeled unified (MACRO) and as Isotropic in ABAQUS software [10].Wall section and FRP layer are presented as a solid and a shell respectively and they are deformable . Mechanical specifications that introduced to the software gained from Mechanical specifications of bricks and mortar used in walls under experiment and is determined by the following equation:

$$\sigma_{cw} = 0.538\sigma_{cb} + 0.241\sigma_{cm} \tag{1}$$

Where σ_{cw} is the compressive strength of masonry materials; σ_{cb} is the compressive strength of brick; and σ_{cm} is the compressive strength of mortar [11].Walls material is like damage plastic concrete and tension-compression behavior in plastic zone are listed in table 1. [12]

Table1. results obtained from tensional– compressive axis loading of damage concrete in plastic zone.

Compressive yield stress	Nonlinear strain	Tensile yield stress	Strain cracking
12	0	0.8860	0
14.5	0.0008	0.7250	0.0001
15.8	0.0016	0.5540	0.0003
16.1	0.0024	0.4780	0.0004
15.8	0.0032	0.3980	0.0005
15.1	0.0040	0.2670	0.0008
14.2	0.0048	0.1790	0.001
10.9	0.0072	0.0801	0.002
7.4	0.0100	0.0363	0.003
1.47	0.0200	0.0199	0.005

3.1. Properties Of Masonry Walls Interaction

We define two constraints to identify Properties of interaction between ingredients of model (concrete base , walls body , FRP layer and bars) There is one tie to define kind of contact between walls edge and concrete foundation and also contact between walls body and FR player. There is another tie to calculate contact surface of bars with concrete beam that transfers force. because elastic Module of wall is less than concrete foundation and FRP layer, wall choose as slave surface and concrete foundation and FRP layer as master surface .We use tie for joint in order to limit partial movements between parts and applied an embedded tie to put bars in concrete beam.

3.2. Loading And Exert Boundary Condition Masonry Walls Model

In the way we put load in the experiment , compressive loading put on upper surface of concrete beam on the wall. Compressive force was 98 KN in test , and since unit of compressive load In the software is force per surface so that load degree is 10847 N. fig.1 shows loading limit in ABAQUS software. [13]

To this reason that lower beam in the test is rigid , boundary conditions chooses rigid in this point. [14,15]

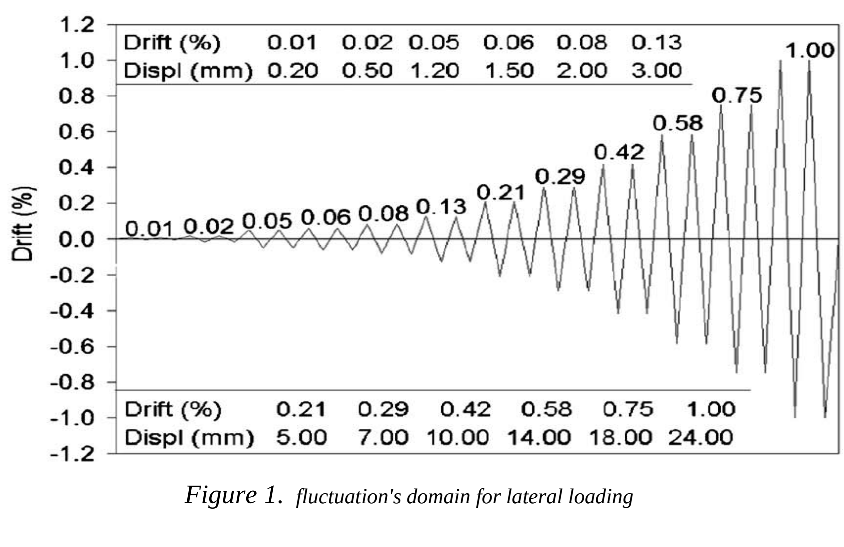


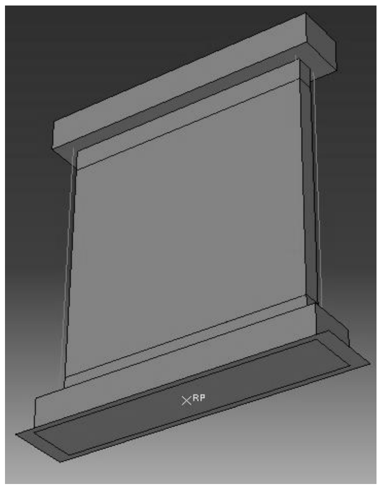
Figure 1. fluctuation's domain for lateral loading

4. TEST MODELING

We testify modeling from comparing hysteresis curve and time – energy curve get of analyzing finite element and curves obtained from experiment.

4.1. Comparing Hysteresis And Time-Energy Curves Ontained From Analysis

Hysteresis curves obtain by displacement of upper concrete beam and base shear's force of lower concrete beam , these points illustrates in figures 2 and 3 .



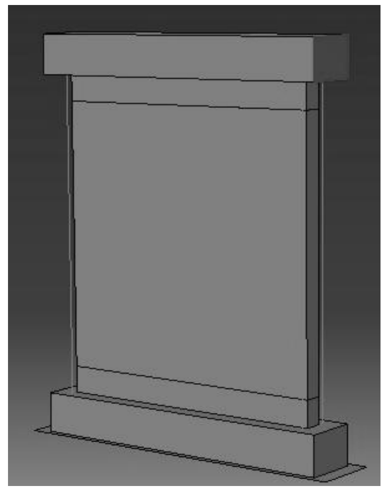
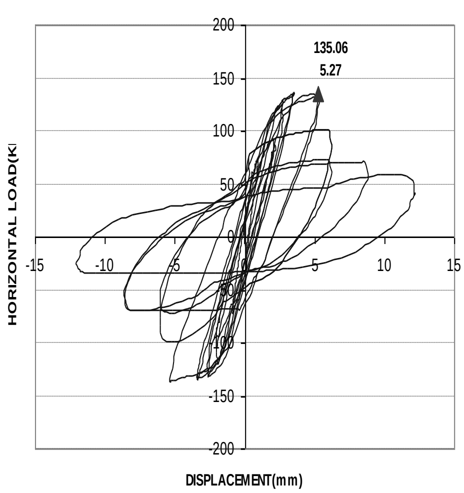


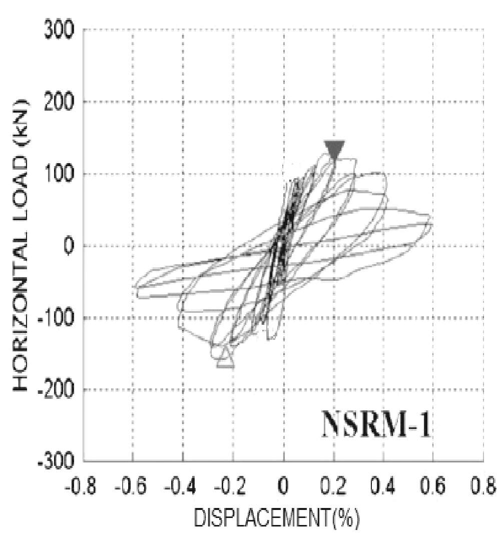
Figure 2. point of base shearing force *Figure 3. point of displacement's control*

Time - energy curve obtains from energy's rate on the total wall in loading period . for to obtain this amount of energy, you should choose ALLKE switch .this option shows wasted energy on total structure when happen plastic deformation.

4.1.1. Simple Masonry Wall (NSRM)

Specification: masonry wall without reinforcement by dimension 2000*1980*140 mm





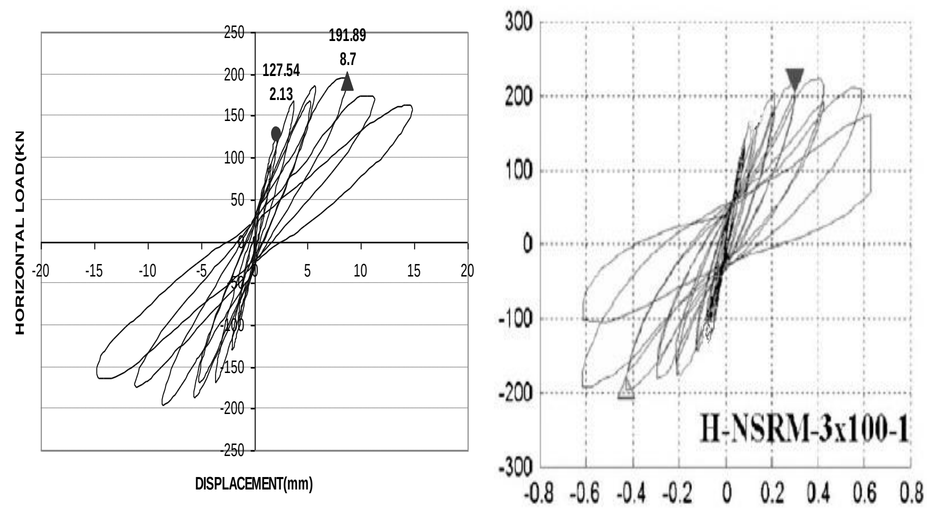
FEA analysis *experimental*

Figure 4. hysteresis curve of un-reinforced masonry wall

In about 5 mm displacement, rate of resistance is 135.06 KN. If we compare this value with 145.90 KN obtained from test we have %7.43 error.

4.1.2. Reinforced Masonry Wall (H-NSRM-3X100-1)

Specification: CFRP bands with 0.13 thick and 100 mm width are located in 3 horizontal rows on each side of the wall.



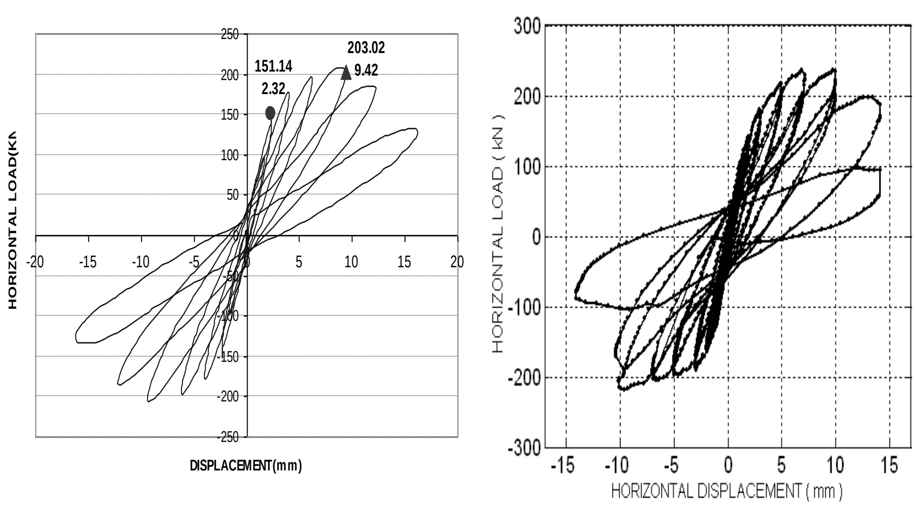
FEA analysis *experimental*

Figure 5. hysteresis curve of reinforced masonry wall with horizontal FRP strips

In about 10 mm displacement, maximum resistance is 191.89 KN that in comparison with result of test (209.9 KN) it has %8.58 error.

4.1.3. Reinforced Masonry Wall (H-NSRM-3X150-1)

Specification: CFRP bands with 0.13 thick and 100 mm width are located in 3 horizontal rows on each side of the wall.



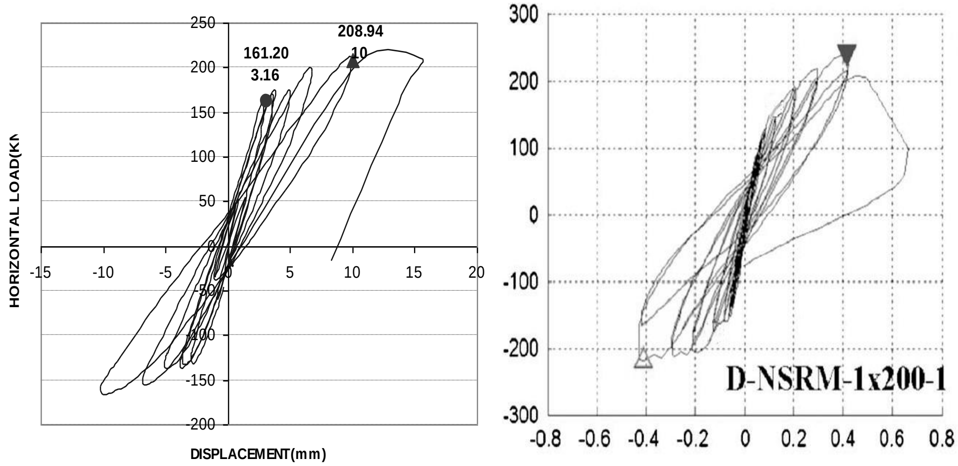
FEA analysis *experimental*

Figure 6. hysteresis curve of reinforced masonry wall with horizontal FRP strips

In about 10 mm displacement, maximum resistance is 203.02 KN that in comparison with result of test (223.70 KN) it has %9.42 error.

4.1.4. Reinforced Masonry Wall (D-NSRM-1X200-1)

Specification: CFRP bands with 0.13 thick and 200 mm width are located diagonal shape on each side of the wall.



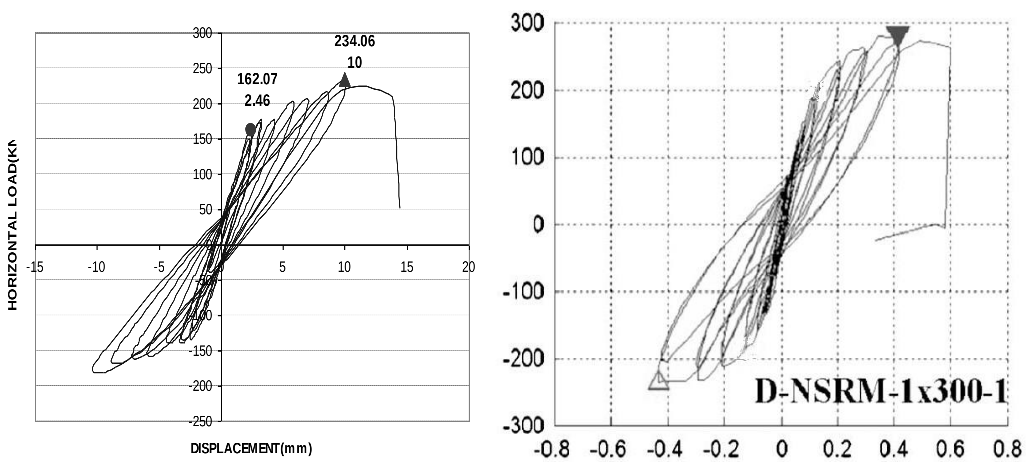
FEA analysis *experimental*

Figure 7. hysteresis curve of reinforced masonry wall with diagonal FRP strips

At approximately 10 mm of lateral displacement, the value resistance is 208.94 and this specimen has %8.99 error in comparison with test result.

4.1.5. Reinforced Masonry Wall (D-NSRM-1X300-1)

Specification: CFRP bands with 0.13 thick and 200 mm width are located diagonal shape on each side of the wall.



FEA analysis *experimental*

Figure 8. hysteresis curve of reinforced masonry wall with diagonal FRP strips

Resistance obtained from this specimen in 10mm displacement was 234.06 KN while this value in test was 259.4KN and there is about %10 error.

Table (2): comparing amounts resistance and displacement obtained from test and analysis

Specimen identification	Retrofitted Pattern	Test Resistance	Displacement in test	Analysis Resistance	Displacement In analysis
NSRM	-----	145.90	5.25	135.06	5.27
H-NSRM-3X100-1	Three horizontal strips	209.90	8.78	191.89	8.70
H-NSRM-3X150-1	Three horizontal strips	223.70	9.77	203.02	9.42
D-NSRM-1X200-1	Three diagonal strips	229.60	9.90	208.94	10
D-NSRM-1X300-1	Three diagonal strips	259.40	10.18	234.06	10

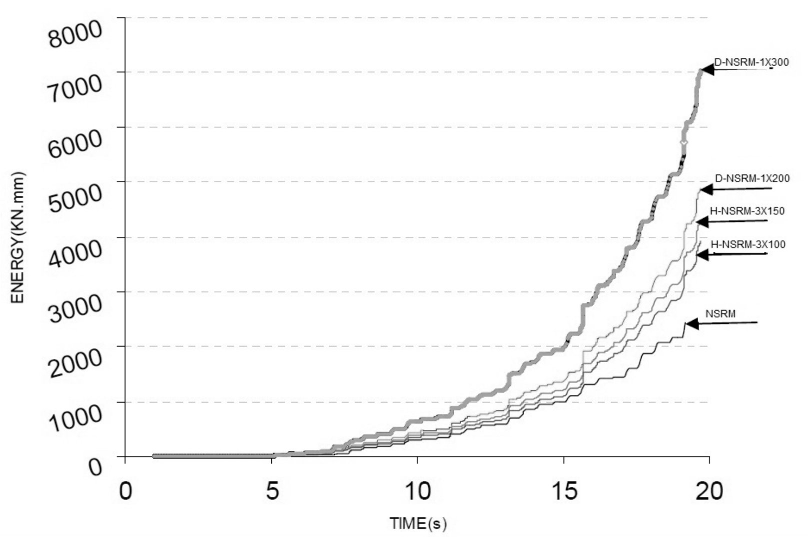


Figure 9 – Energy - time graphs of masonry wall modeled in ABAQUS

5. CONCLUSION

The conclusions are summarized as follows:

1. Applying a concrete damage plasticity model for the retrofitted masonry wall a new and complete finite element model has been developed
2. From comparing hysteresis and time – energy curves obtained from FEA analysis and test we can say that homogeneous theory for masonry wall is a good way in quick modeling .
3. According to the analysis presented, it can be said that Mechanical characteristics of masonry wall that obtained from mechanical specifications of masonry unites and mortar has a good approximation.
4. The increase of the maximum strength and the corresponding displacement in the diagonal retrofitted walls larger than in the horizontally retrofitted walls (see table 2)

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