J. Civil Eng. Mater.App. 2017 (December); 1 (3): 125-136

Journal of Civil Engineering and Materials Application
Journal home page: http://journals.lexispublisher.com/jcema

Received: 21 October 2017 • Accepted: 27 December 2017

Research

doi: 10.15412/J.JCEMA.12010305

Improvement of Out-of-Plane Behavior of Masonry Walls Using FRP Fibers

Seyed vahid Seyed naghavi*, Ahmad Maleki

Department of Civil Engineering, Maragheh Branch, Islamic Azad University, Maragheh, Iran

*Correspondence should be addressed to Seyed vahid Seyed naghavi, Department of Civil Engineering, Maragheh Branch, Islamic Azad University, Maragheh, Iran; Tell: +989144211833; Fax: +989144211833; Email: vahidnagavi@ymail.com.

ABSTRACT

In this research, the finite element modeling method as well as retrofitting of the masonry materials panel under the out-of-plane load was investigated by FRP composite using Abaqus software. In this study, a 1800-mm × 1800-mm wall was placed under an out-of-plane load and then reinforced using FRP sheets. The fibers were placed on the wall in two groups of CFRP and GFRP in four different ways. The wall was placed under a 60 kN out-of-plate load and the modeling results in Abaqus software showed that the wall reinforced with GFRP in Y-shape has 67% maximum performance improvement relative to other layouts, followed by the wall reinforced with CFRP sheet in X-shape with 66%. It is recommended to use these two layouts and fibers in construction.

Key words: Out-of-plane behavior, Masonry walls, FRP fibers, Von Mises, Performance improvements.

Journal of Civil Engineering and Materials Application is published by *Lexis Publisher*; Journal p-ISSN xxxx-xxxx; Journal e-ISSN 2588-2880.

1. INTRODUCTION

The buildings with non-reinforced masonry materials form a wide range of buildings. The statistics of mortality and destruction of buildings shows that masonry buildings have had the most damages from earthquakes (1-5). In addition, these buildings did not have a proper seismic behavior that most likely was due to the lack of proper ductility characteristic. The only structural elements of these buildings are brick shear walls that play the role of gravity and lateral load, which is why the techniques of restoration and reinforcing of walls, as well as the testing of actual samples and scale models, have attracted the attention of the researchers (6-9). The first studies were conducted on reinforcing the masonry wall with FRP fiber in 1994 to 1998 (10-12). Strap et al. (13) studied the out-of-plane FRP-reinforced masonry walls. In this study, they concluded that, in addition to using FRP sheets, they could significantly increase the resistance of the in-plane and out-of-plane masonry walls. When the panel is reinforced, the theory of reinforced concrete bending or reinforced masonry materials can be used to predict the wall's strength. Dimas et al. (14) examined the unprotected walls of non-reinforced masonry walls with FRP sheets under the out-of-plane load. In the presented paper, the behavior of the walls is expressed in three basic steps: the formation of the first visible cracks in the bed, the first separation between the FRP and the wall, and the failure model. In a laboratory study by Sayari (15), seven masonry walls reinforced with a variety of FRP sheets, with different settings and a combination of them on a large scale were made. In this study, walls of different thickness, applied by a simple rack on the four edges on one side and on the other side of the wall, uniformly loaded with an airbag on the wall surface. Now in this study, we investigated the behavior of FRP-reinforced masonry walls under out-of-plane force by modeling in Abaqus software to improve the out-of-plane behavior of the walls.

2. MATERIALS AND METHODS

In order to investigate and find out about the reinforcement of a masonry wall with FRP, a brick wall model with 1350 * 1350 mm dimension and 112.5 mm thickness was used. The wall is reinforced in 8 different modes with GFRP and CFRP sheets and analyzed under the compressive force up to 60 kN / m^2 in the Abaqus software (16), and the results were obtained including changes in the base cut, changes in the amount the maximum displacement outside the wall and the energy absorbed by the wall as well as the plastic strain curvature, which indicates the cracking of the wall, has been investigated.

3. MATERIALS OF REINFORCED POLYMER FIBERS

In this study, two different types of reinforced polymer fibers have been used, the specifications of them are as follows (Table 1 and Table 2): GFRP material with a width of 680 mm and a thickness of 0.135 mm (Figure 1).

Figure 1. GFRP sheet to strengthen the wall

Table 1. Mechanical properties of GFRP materials

Technical data		
The following test results were obtained in laboratory conditions at 20′C and 4% relative humidity		
S&P 90/10	**S&P 50/50**	**Physical properties**
White	White	Color
680 mm width	680 mm width	Size
2.6 kg/cm³	2.6kg/cm³	Fiber density
350 g/cm²	350 g/cm²	Sheet weight
0.135 mm	0.135 mm	Thickness for design (weight/density)
	67 mm²	Cross section for design*
20-30%	20-30%	Fiber content vt
50 m rolls	50 m rolls	Delivery
>64 kN/mm²	>65kN/mm²	**Mechanical properties**
>2000 N/mm²	>2000N/mm²	Modulus of elasticity E_{cu}
2.8%	2.8%	Ultimate elongation εcu
	17kN	Tensile force 0.4% elongation
		* based upon 1000 mm sheet width

CFRP materials with a width of 50 mm and a thickness of 1.2 mm (Figure 2).

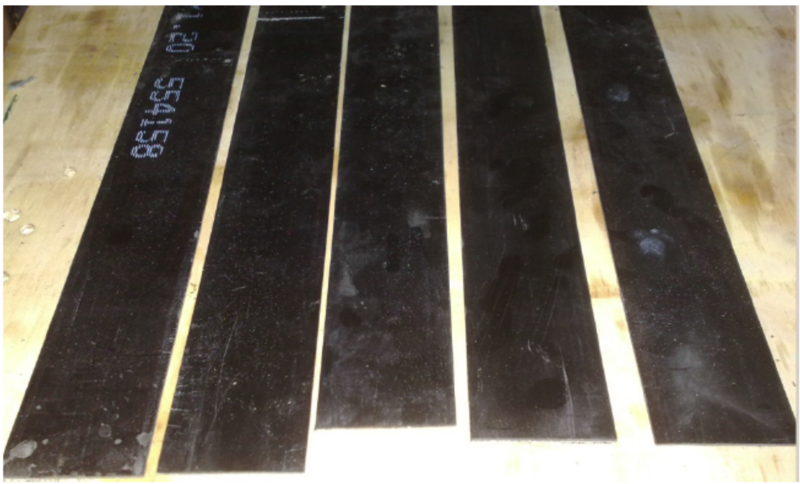


Figure 2. CFRP sheet to strengthen the wall

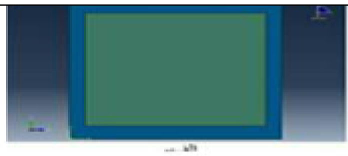
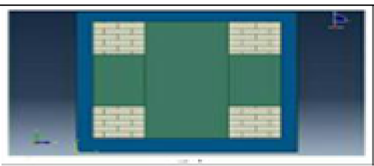
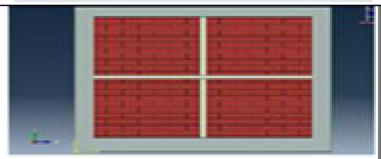
Table 2. Mechanical properties of CFRP materials

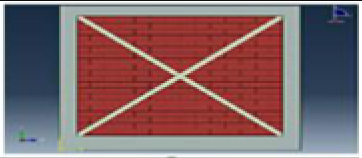
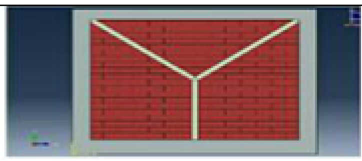
Technical data		
Physical parameters		
Composition	Carbon fiber reinforced laminate in epoxy resin matrix	
Color	Black	
Fiber content v_f	70%	
Density	1.7 g/cm^3	
Temperature resistance T_{GM}	100-130°C	
Thickness	1.2 mm and 1.4 mm standard	
Width	10, 50, 80, 90, 100, and 120 mm standard Other widths available on request	
Mechanical properties		
	Grade 150	**200**
Elastic modulus E_f	> 165 kN/mm^2	>210 kN/mm^2
Characteristic elastic modulus E_{fk}	150 kN/mm^2	200 kN/mm^2
Tensile strength f	2800-3000 N/mm^2	2400-2600 N/mm^2
Characteristic tensile strength f_{fk} (where f_{fk} = f- 2s)		2500 N/mm^2

4. LAYING FRP SHEETS ON THE WALL

FRP sheets are placed on the wall in 8 modes (Table 3):

Table 3. Models reviewed in this research

Row	model name	Model	Description
1	w 1	whole wall reinforced with CFRP	
2	w 2	wall reinforced in crossover with CFRP sheet	
3	w 3	walls reinforced diagonally with CFRP sheet	
4	W 4	wall reinforced in Y-shape with CFRP sheet	
5	w 5	whole wall reinforced with GFRP	
6	w 6	wall reinforced in crossover with GFRP sheet	

7	w 7	wall reinforced diagonally with GFRP sheet	
8	w 8	Wall reinforced in Y-shape with GFRP sheet	

In order to investigate the out-of-plane behavior of the wall, a compressive of 60 kN was applied to the wall surface and the out-of-plane displacement of the wall as well as the strain of brick plastics was calculated by the Abacus software indicating the cracking location, and then compared to the different models. Von Mises' relationship was used to study the tension formed in the wall components (Table 4).

Table 4. Von Mises yield criterion for the different stress conditions

von Mises Equations	Boundary Conditions	State of Stress
$\sigma_v = \sqrt{\frac{1}{2}[(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2+6(\sigma_{12}^2+\sigma_{23}^2+\sigma_{31}^2)]}$	No restrictions	General
$\sigma_v = \sqrt{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]}$	$\sigma_{12}=\sigma_{31}=\sigma_{23}=0$	Principal stresses
$\sigma_v = \sqrt{\sigma_{11}^2+\sigma_{11}\sigma_{22}+\sigma_{22}^2+3\sigma_{12}^2}$	$\sigma_3=0$ $\sigma_{31}=\sigma_{23}=0$	General plane stress
$\sigma_v = \sqrt{\sigma_1^2+\sigma_1\sigma_2+\sigma_2^2}$	$\sigma_3=0$ $\sigma_{12}=\sigma_{31}=\sigma_{23}=0$	Principal plane stress
$\sigma_v = \sqrt{3}\,\lvert\sigma_{12}\rvert$	$\sigma_1=\sigma_2=\sigma_3=0$ $\sigma_{31}=\sigma_{23}=0$	Pure shear
$\sigma_v = \sigma_1$	$\sigma_2=\sigma_3=0$ $\sigma_{12}=\sigma_{31}=\sigma_{23}=0$	Uniaxial

Notes:
• Subscript 1,2,3 can be repiacd with x, y, z, or any orthogonal coordinate system
• Shear stress is denoted here as σij : in practice, it is alw denoted as τij.

In Figure 3, the model under test is shown schematically. As shown here, for the wall from each side with a thickness of 13.5 mm, a support has been considered, with the gap between the two supports being 1530 mm. (1800-2*13.5=1530).

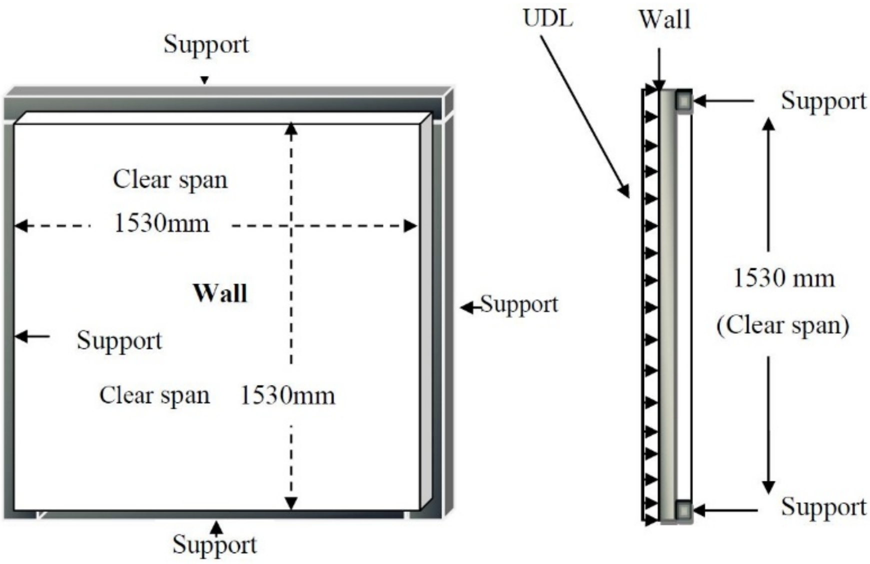


Figure 3. Schematic view of the wall and supports

According to the above sample, the model is presented in Abacus software as described in Figure 4.

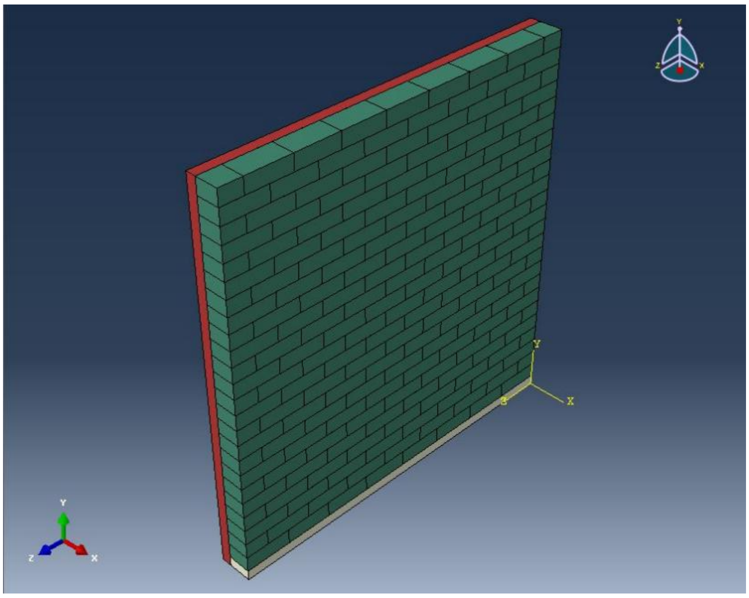


Figure 4. Wall View in Abacus Software

5. DEFINITION OF LOADS AND SUPPORTING CONDITIONS

At this stage, firstly, the supporting conditions are defined, and then the load caused by the weight of the components in gravity and the compressive force of 10 kN / m 2 applied to the wall surface Figure 5, Figure 6 and Figure 7.

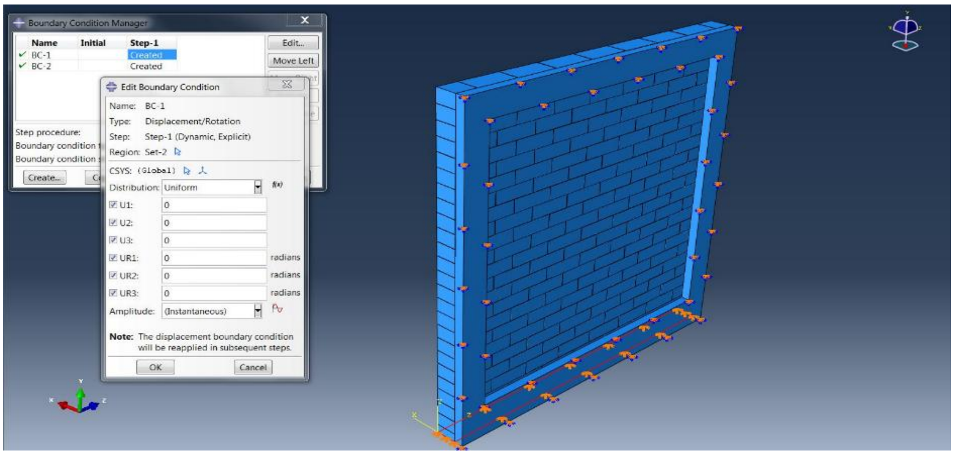


Figure 5. Applying restrained constraint to the wall and supports

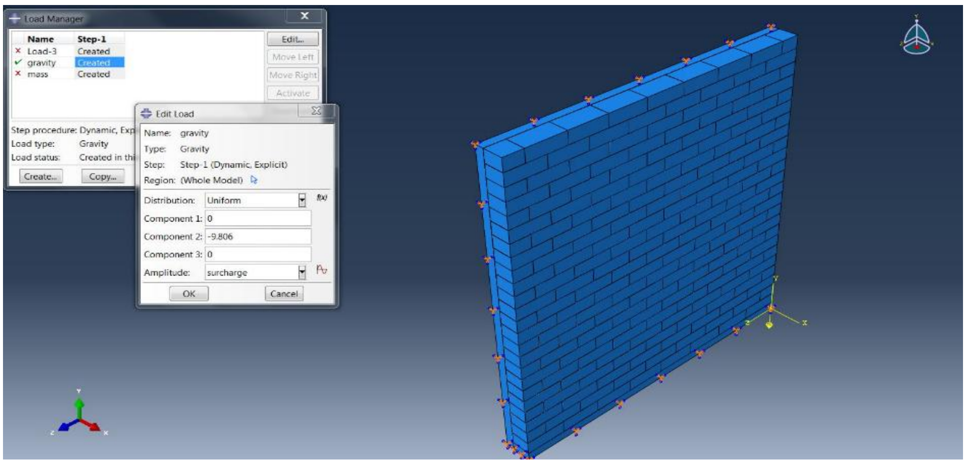


Figure 6. Applying gravitational loads to model

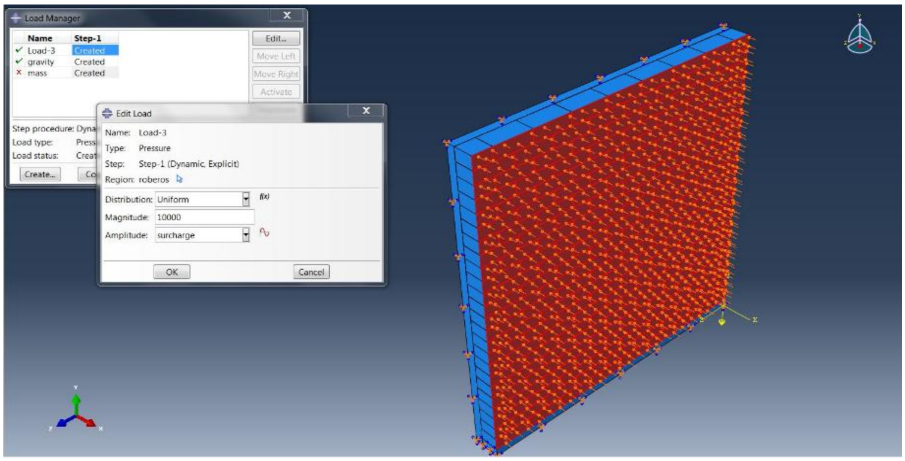


Figure 7. Applying compressive force to the wall surface

6. REVIEW OF LABORATORY STUDY AND VERIFICATION

Considering the experimental results of the construction of a brick wall model at the University of Kingston in England in 2011 by Sayari et al. and observing the amount of out-of-plane displacement of the wall and comparing it with the numerical model (ANSYS software), has led to the difference in the results of the laboratory with the numerical model in determining the out-of-plane displacement of the wall to be very small and less than 1% (Figure 8 and Figure 9).

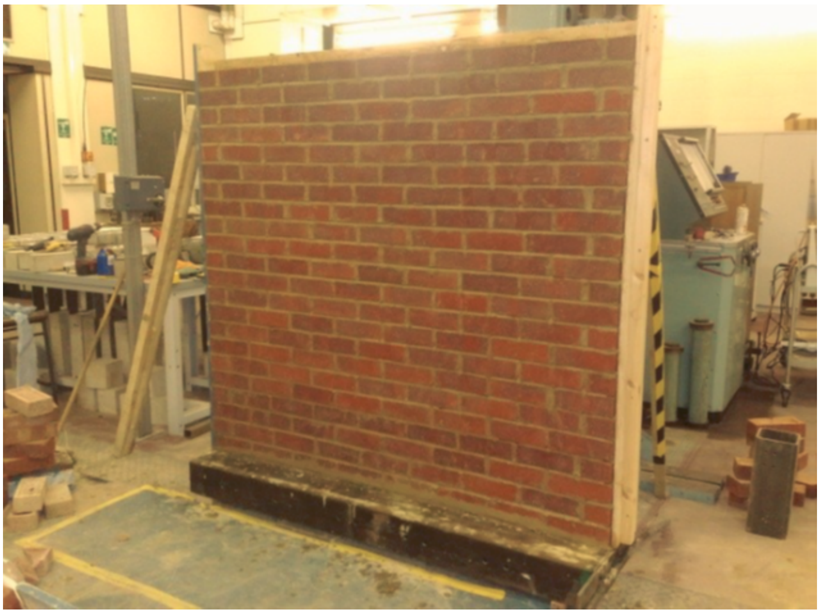


Figure 8. Wall sample tested by Sayari at Kingston University, UK

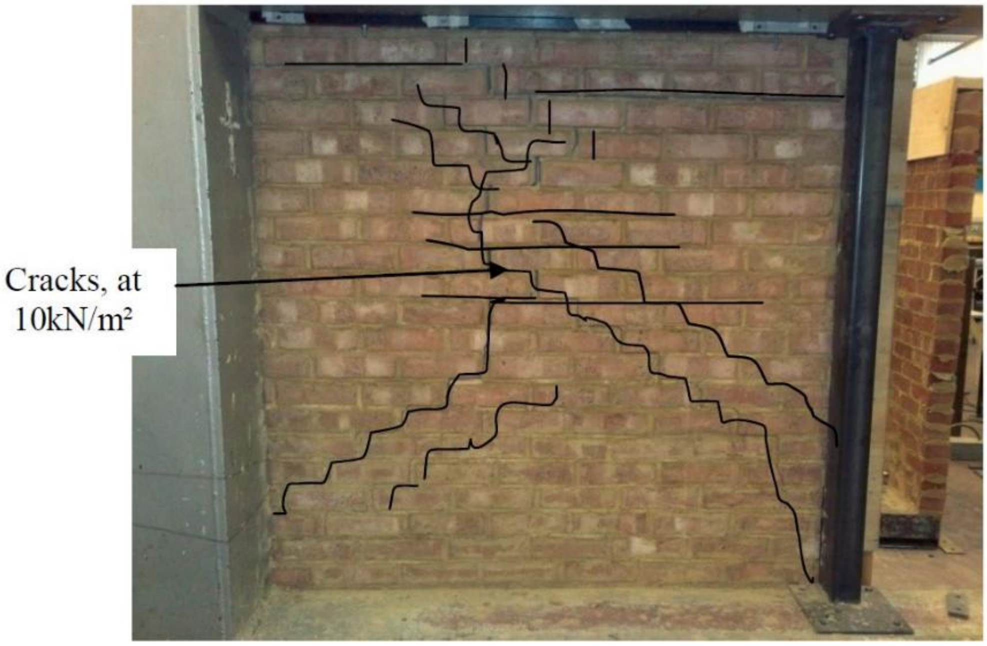


Figure 9. The cracks in the wall tested by Sayari after out-of-plane loading of the wall

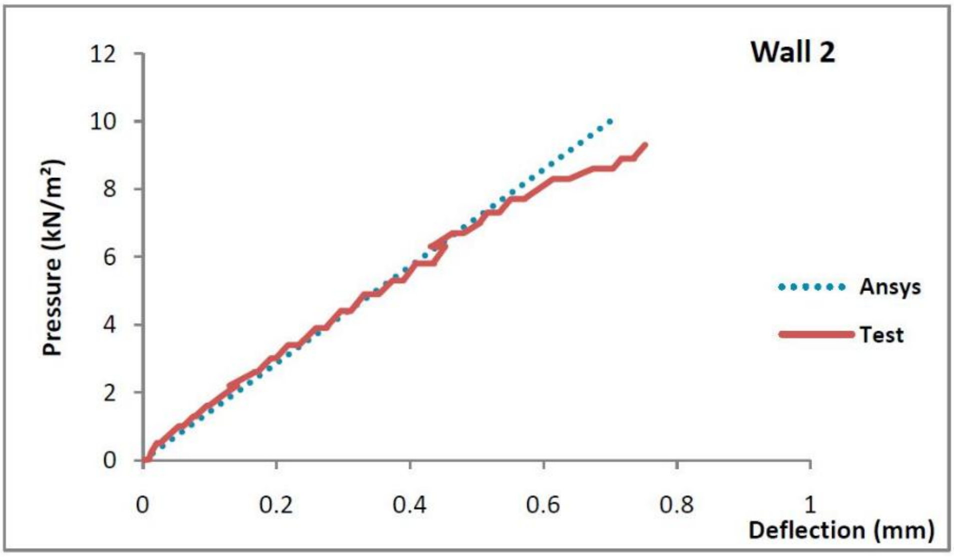


Figure 10. The displacement-force diagram from numerical analysis and experiment

By examining this research, as shown in Figure 10, the results of numerical analysis of finite element are very close to reality.

7. DISCUSSION AND CONCLUSION

After performing finite element analyzes on all models and plotting them to compare the out-of-plane behavior of the wall and the reinforcement performance of the FRP materials, the curves were compared with each other by the CFRP and GFRP sheets below (Figure 11).

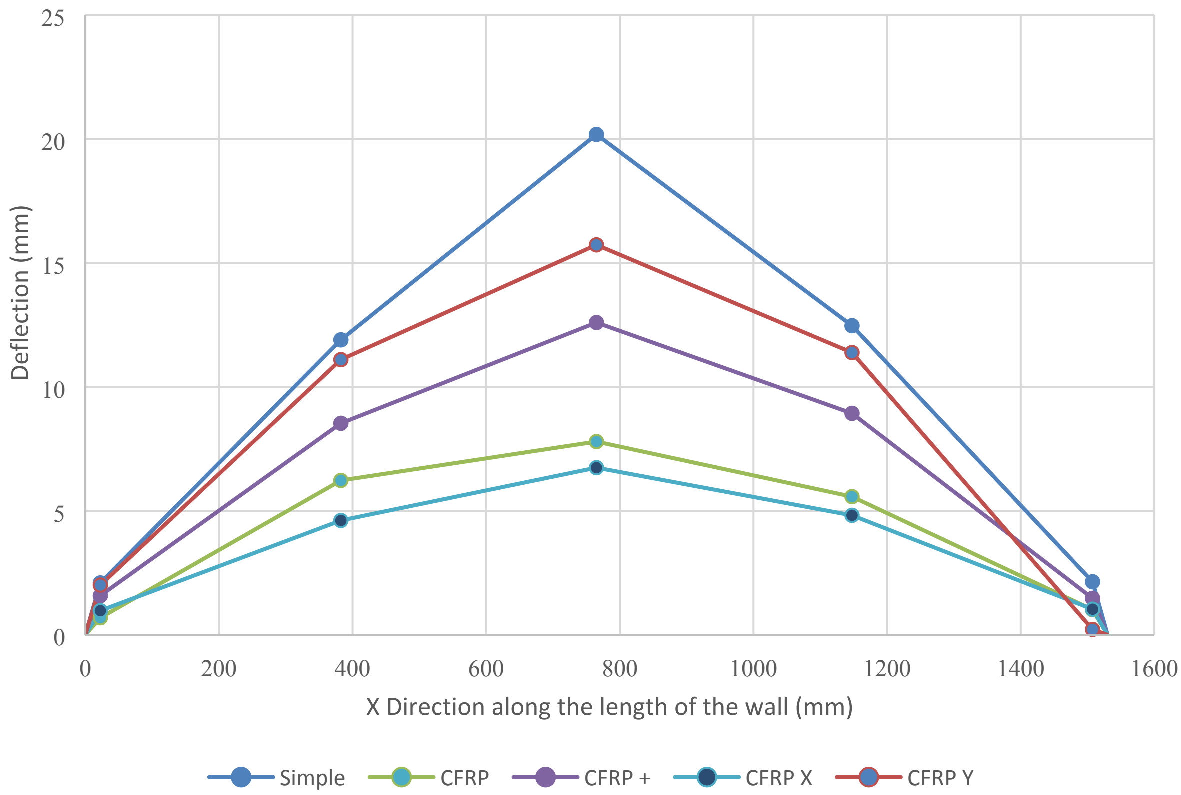


Figure 11. Comparison of displacement curves at horizontal length of the walls reinforced with CFRP

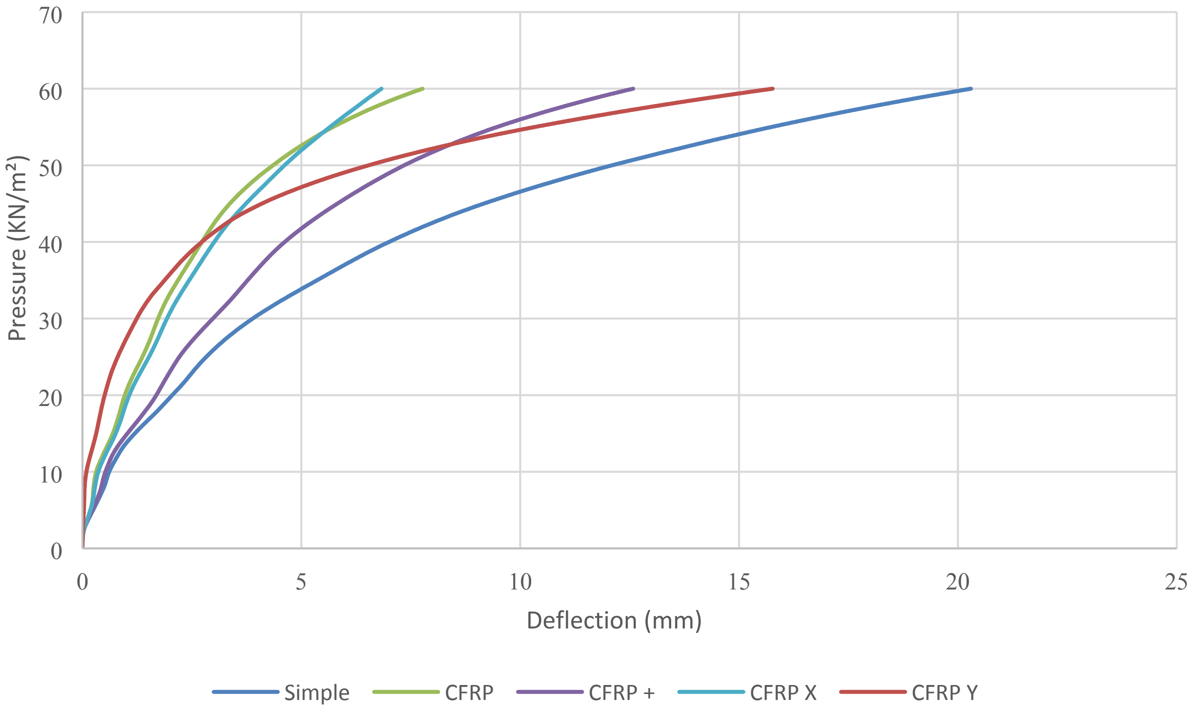


Figure 12. Comparison of force-displacement curves in CFRP-reinforced models

As shown in Figure 12, the curve related to the CFRP-reinforced model in diagonal form with curves of the reinforced model across the entire surface are almost the same and it can be said that due to the saving of the materials, a cross-pattern can be used instead of the total reinforcement to obtain the same resistance. In addition, according to the curve of the Y-shape model, this pattern has higher efficiency than other patterns in walls that are under the influence of less compressive force (up to 40 kN / m 2). With respect to the curves, the performance improvement of the models compared to the non-armed model is as follows:

The entire wall surface is equipped with CFRP fibers ------------------- 65%

CFRP sheets are in the form of a crossover on the wall surface -------- 38%

CFRP sheets are placed in a diagonal form on the wall surface --------- 66%

CFRP sheets are placed on the wall surface in Y-shape form ---------- 21%.

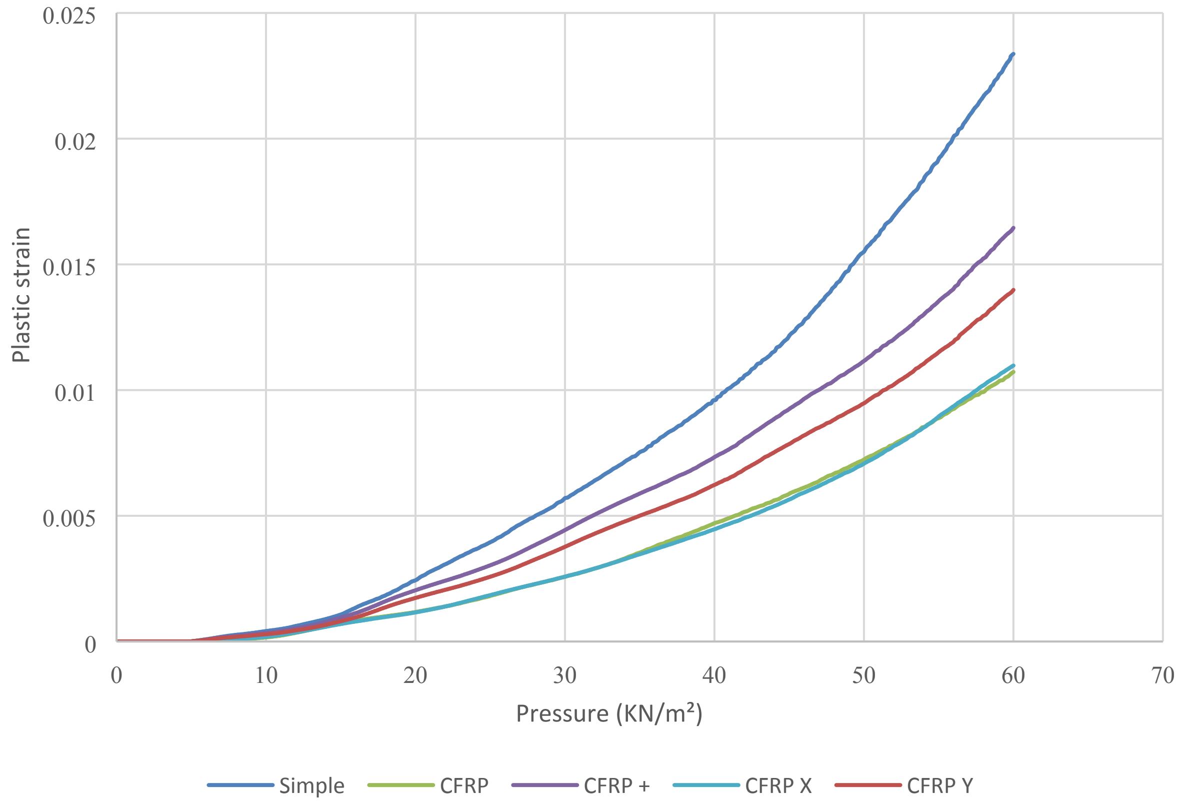


Figure 13. Comparison of plastic strain curves in CFRP-reinforced models

As shown in Figure 13, the strain curve of the CFRP-reinforced model at its entire surface corresponds closely to the curve of the diagonally -reinforced model, and the cracking rate is the same, but the crack may occur in different places in these two models.

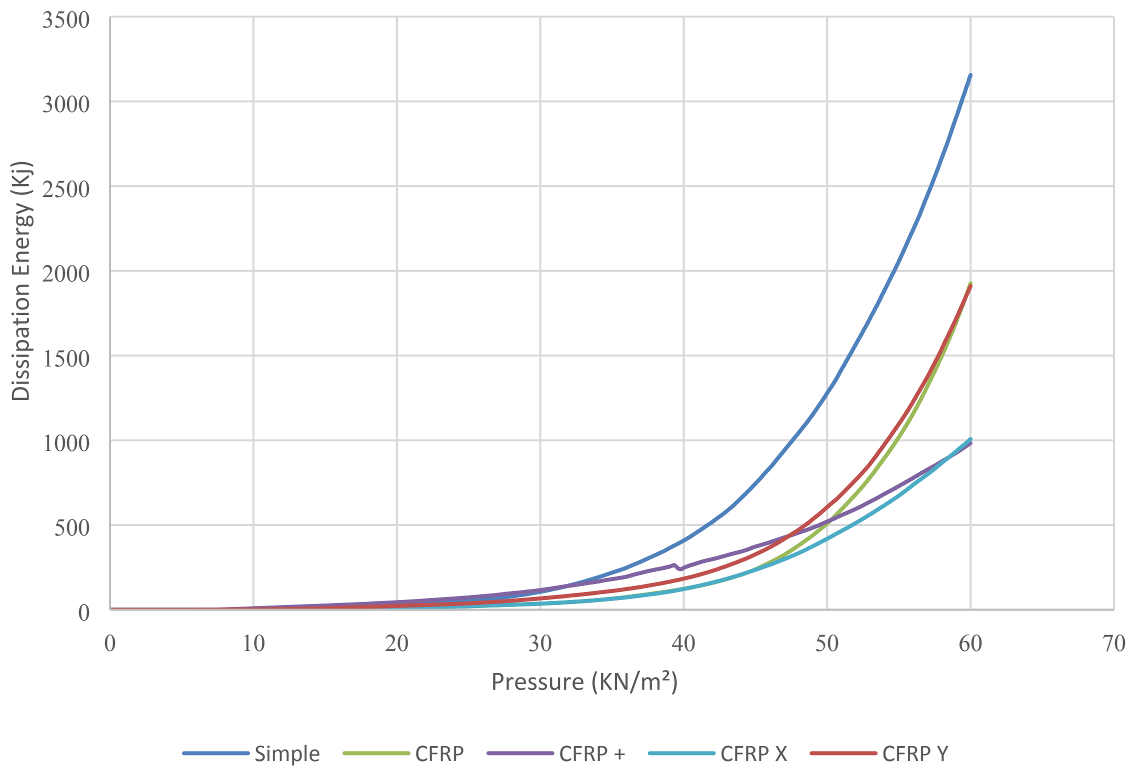


Figure 14. Comparison of energy curves in CFRP-reinforced models

Figure 14 shows that the energy absorbed by the wall-forming bricks in the X-shape reinforcement model is lower than the rest of the models, and much more energy is damped by carbon fiber materials.

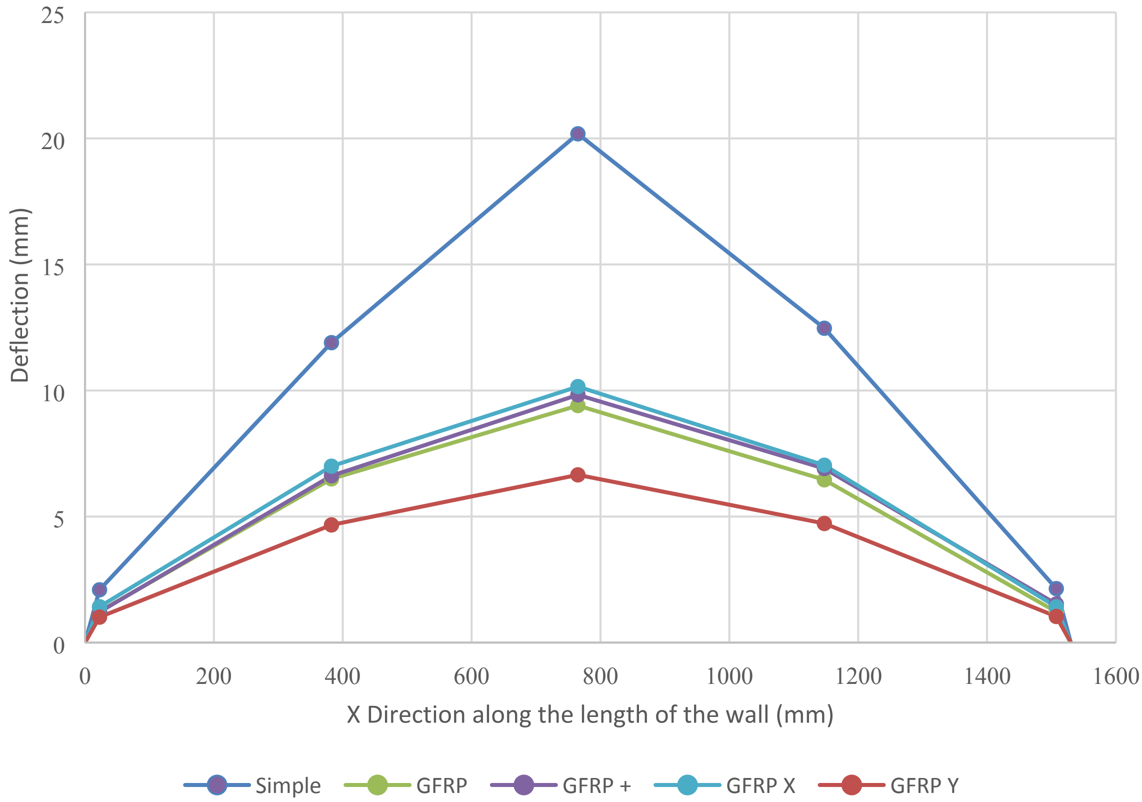


Figure 15. Comparison of displacement curves along the horizontal of the reinforced GFRP wall

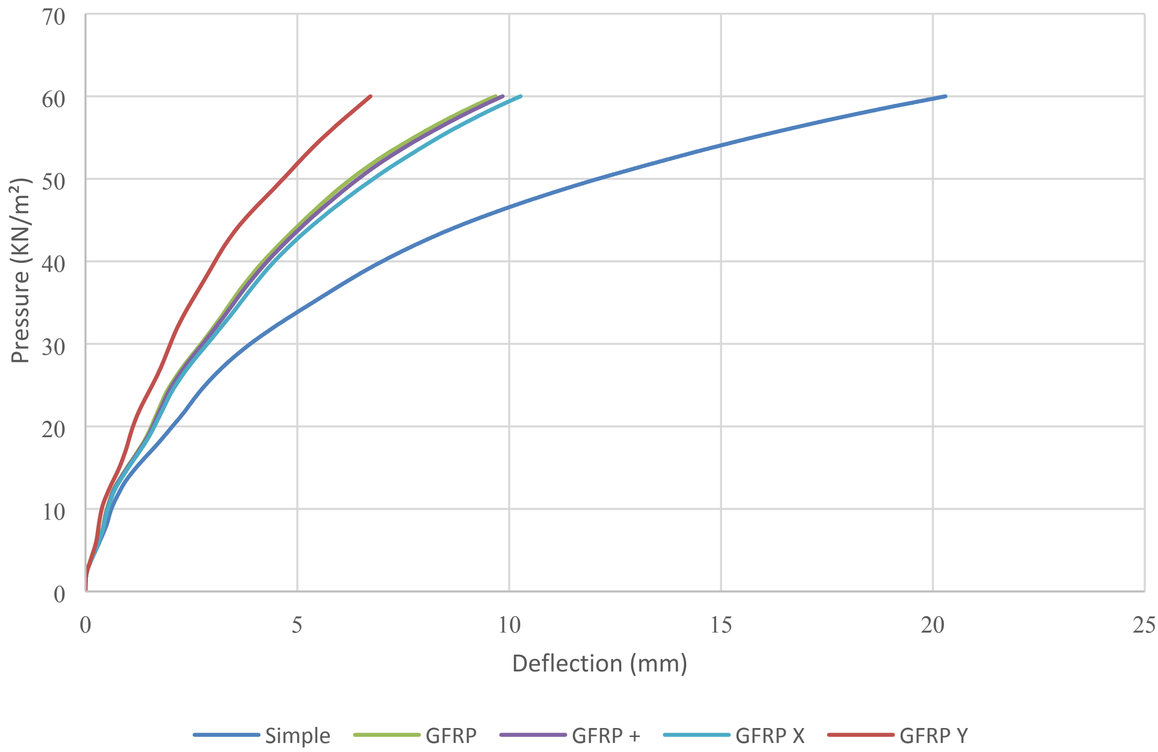


Figure 16. Comparison of force-displacement curves in GFRP-enhanced models

As shown in Figure 15, Figure 16 and Figure 17, the curve of the Y-shaped reinforced with GFRP model has a better performance than other models, and it can be said that due to the saving of materials, Y-shaped pattern can be used and obtained higher resistance, with Attention to curves, performance on improvement of the models compared to the non-reinforced model is as follows:

The entire wall surface is equipped with GFRP sheets ------------------% 52

GFRP sheets are crossover on the wall surface --------------

------------% 51
GFRP sheets are placed on the wall surface in diagonal form --------------% 49
GFRP sheets are placed on the wall surface in Y-shape -----
-----% 67.

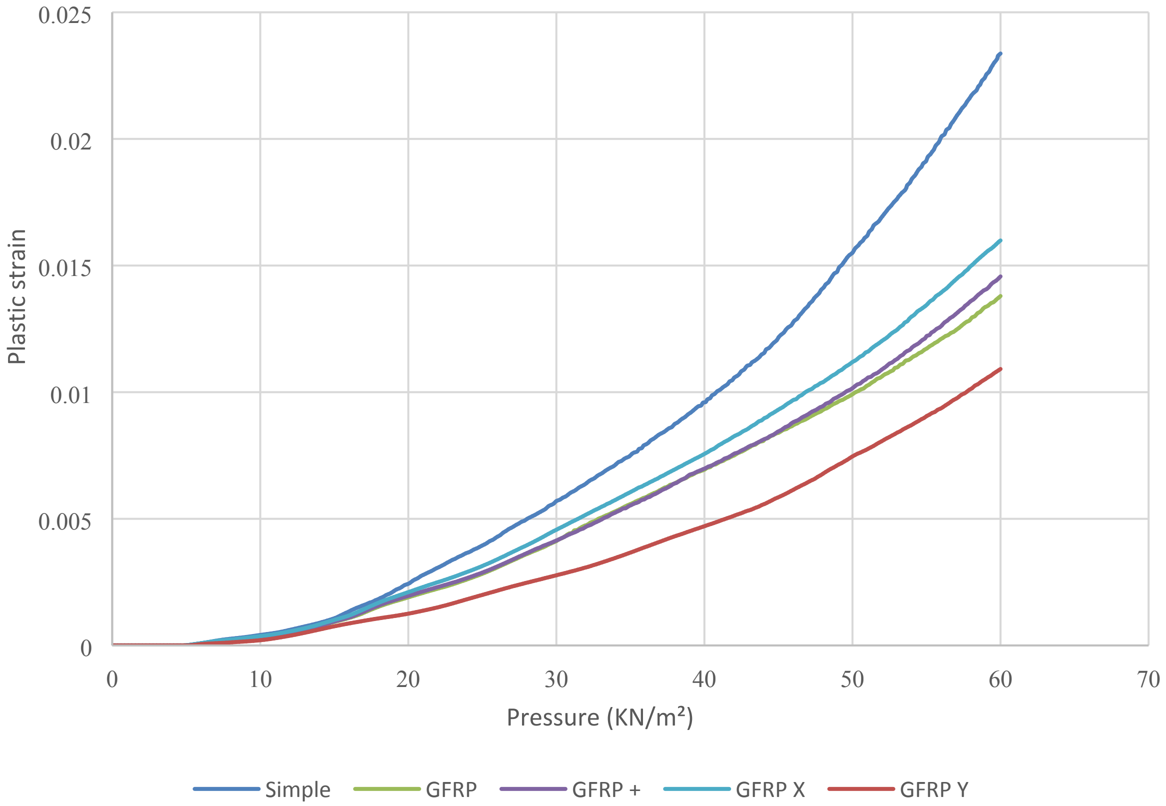


Figure 17. Comparison of plastic strain curves in GFRP-reinforced models

As shown in Figure 17, the strain curve of the GFRP-reinforced model in Y-shaped form is less than the rest of the models, and the rate of cracking in the Y-shape model is lower than the rest.

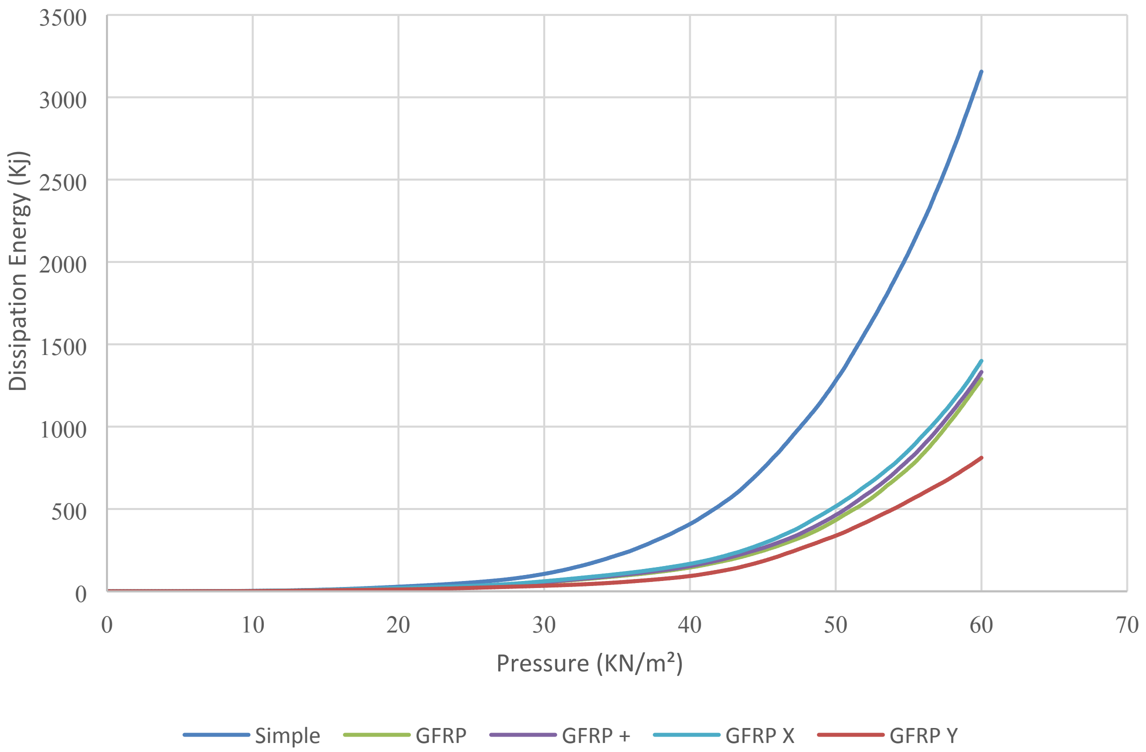


Figure 18. Comparison of Energy Curves in Models reinforced by GFRP

Figure 18 shows that the energy absorbed by the wall-forming bricks in the Y-shaped reinforcement model is lower than the rest of the models, and much more energy is damped by carbon fiber materials.

Table 5. Performance comparison table of outside wall of masonry building materials

67.00%	GFRP sheets are Y-shaped on the wall surface
66.00%	CFRP sheets are diagonal on the wall surface
65.00%	All surface of the wall is equipped with CFRP fibers
52.00%	All surface of the wall is equipped with GFRP fibers
51.00%	GFRP sheets are crossover on the wall surface
49.00%	GFRP sheets are diagonal on the wall surface
38.00%	CFRP sheets are crossover on the wall surface
21.00%	CFRP sheets are Y-shaped on the wall surface

Regarding the improvement in the performance of the walls, as shown in Table 5, the wall with GFRP-reinforced Y-shaped walls on the surface of the wall has a maximum performance improvement, and the CFRP reinforced wall in Y-shape on the surface of the wall has had the minimum performance improvement.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

Not mentioned any acknowledgment by authors.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

REFERENCES

1. Glass RI, Urrutia JJ, Sibony S, Smith H, Garcia B, Rizzo L. Earthquake injuries related to housing in a Guatemalan village. Science. 1977;197(4304):638-43.
2. Penna A, Morandi P, Rota M, Manzini CF, Da Porto F, Magenes G. Performance of masonry buildings during the Emilia 2012 earthquake. Bulletin of Earthquake Engineering. 2014;12(5):2255-73.
3. Karimzadeh S, Miyajima M, Hassanzadeh R, Amiraslanzadeh R, Kamel B. A GIS-based seismic hazard, building vulnerability and human loss assessment for the earthquake scenario in Tabriz. Soil Dynamics and Earthquake Engineering. 2014;66:263-80.
4. Langenbach R. The earthquake resistant vernacular architecture in the Himalayas. Seismic retrofitting: Learning from vernacular architecture. 2015:83-92.
5. Altunışık AC, Genç AF. Earthquake response of heavily damaged historical masonry mosques after restoration. Natural Hazards and Earth System Sciences. 2017;17(10):1811.
6. Corradi M, Borri A, Vignoli A. Experimental study on the determination of strength of masonry walls. Construction and building materials. 2003;17(5):325-37.
7. Corradi M, Borri A, Castori G, Sisti R. Shear strengthening of wall panels through jacketing with cement mortar reinforced by GFRP grids. Composites Part B: Engineering. 2014;64:33-42.
8. Almeida C, Guedes JP, Arêde A, Costa C, Costa A. Physical characterization and compression tests of one leaf stone masonry walls. Construction and Building Materials. 2012;30:188-97.
9. Borri A, Castori G, Corradi M, Speranzini E. Shear behavior of unreinforced and reinforced masonry panels subjected to in situ diagonal compression tests. Construction and Building Materials. 2011;25(12):4403-14.
10. Triantafillou TC. Composites: a new possibility for the shear strengthening of concrete, masonry and wood. Composites science and technology. 1998;58(8):1285-95.
11. Hamid AA, Mahmoud A, El Magd SA, editors. Strengthening and repair of unreinforced masonry structures: state-of-the-art. Proc, 10th Int Brick and Block Masonry Conf; 1994.
12. Ehsani M, Saadatmanesh H, Al-Saidy A. Shear behavior of URM retrofitted with FRP overlays. Journal of composites for construction. 1997;1(1):17-25.
13. Gilstrap JM, Dolan CW. Out-of-plane bending of FRP-reinforced masonry walls. Composites science and technology. 1998;58(8):1277-84.
14. Velazquez-Dimas J, Ehsani M. Modeling out-of-plane behavior of URM walls retrofitted with fiber composites. Journal of Composites for Construction. 2000;4(4):172-81.
15. Sayari A. Improving the out-of-plane flexural behaviour of the FRP strengthened masonry walls: Kingston University; 2011.
16. Ozturk UE, Anlas G. Finite element analysis of expanded polystyrene foam under multiple compressive loading and unloading. Materials & Design. 2011;32(2):773-80.