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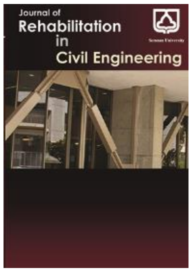

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Studying the influence of Geometric Characteristics and Arrangement of FRP Layers on Rehabilitation of Concrete Shear Walls

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ABSTRACT

During recent years, the use of fiber-reinforced polymers (FRP) as a desirable alternative for improving the behavior of lateral resisting system are known. There are various factors influencing the quality of such kind of rehabilitation. This study aims to investigate the influence of geometric characteristics and arrangement of FRP layers on rehabilitating of concrete shear walls. A few reinforced concrete shear walls with different thickness and arrangement of FRP layers were analyzed by ABAQUS finite element model software, under gravity and lateral loads. The results indicated that the variation of shear wall strength is considerable due to confinement provided by the FRP layers based on the influence of thickness and arrangements. It is seen that, the performance of Chess and Cross layers of FRP are more effective than other arrangements for improving the final strength of reinforced concrete shear wall. It is also observed that, by increasing the FRP thickness, the wall performance against lateral loading will be improved considerably.

1. Introduction

During recent years, the new methodologies have been more considered to limit the structural drift during earthquakes. Reinforced concrete shear walls are the most common lateral load resistant system in the high-rise structures. Very high in-plane stiffness of such systems and their role for redistribution of forces may control drift in the structures very high. These walls not only must provide the structure with enough resistance and stiffness but also they must provide enough ductility to prevent brittle failure particularly under the strong seismic loads [1].

With passing the time, structural damages in past earthquakes and weakness in the old regulations caused improper efficiency of existing structural walls against earthquake. So, most reinforced concrete shear walls in our country and other points through the world required to be improved and strengthened because of various reasons such as changes in the requirements of seismic regulations, weakness in designing or construction, passing the time and influence of environmental destructive factors.

During recent years, FRP composite materials have been more used for rehabilitating and improving the structural elements [2]. High resistance, durability against corrosion, quick and easy installation and their very low weight comparing to traditional materials are the advantages of the FRP material. The prominent properties of such materials caused using them as the first choice for rehabilitation projects of R/C structures. FRP fibers were also used extensively and successfully to improve the behavior of structures. Their very high ratio of strength to weight cause no additional weight to the existing structure when strengthening by such materials comparing to traditional methods (using shotcrete or Ferro cement). Strengthening of the columns and piles with FRP has been more considered. There are fewer studies and works indicating the influence of FRP layers arrangement on deformation capacity under gravity and lateral loads [3]. In this regard, reinforced concrete shear walls are among the elements, less considered in the view of seismic rehabilitation.

Todut et al. presented the results of an experimental program on precast reinforced concrete wall panels (PRCWP). These panels were damaged under cyclic lateral loads and thereafter retrofitted and retested. The experimental program was conceived to analyses the possibilities of using FRP materials for strengthening the PRCWP affected by seismic action [4].

Shadan et al. studied the behavior of squat R/C shear wall strengthened by fiber reinforced polymer using a numerical analysis. They concluded that the behavior of strengthened wall and strengthening scheme strongly depend on the amount of web reinforcement [5].

Woods evaluated the effectiveness of applying FRP sheets to enhance the seismic performance of deficient reinforced concrete shear walls. He confirmed the ability of the FRP retrofitting system to increase in-plane stiffness, flexural strength, ductility and energy dissipation capacity in shear deficient wall specimens [6].

El-Sokkary et al. investigated the behavior of two 8-story cantilevered R/C shear walls rehabilitated using carbon fiber-reinforced polymer (CFRP) composite sheets when subjected to base excitations from a shake table. In their research, the rehabilitation scheme resulted in a reduced wall rotation and lower strain values of the flexural steel rebar at the 6th-story panel [7].

Rezaiefar studied the behavior of FRP-Retrofitted squat shear wall by Finite Element Modeling under cyclic load [8].

Many Researchers evaluated the influence of FRP thickness on seismic performance of rehabilitated shear walls [9-11].

Mohamed et al. represent a new step in using the finite-element method (FEM) as a powerful tool to simulate the seismic behavior of shear walls reinforced with glass-fiber-reinforced polymer (GFRP) reinforcement, which were tested and demonstrated the method’s applicability as a lateral resisting system [12].

Nguyen et al. investigated two lightly reinforced concrete walls experimentally and numerically with an aspect ratio equal to 0.67 (short wall) and 2.5 (slender wall). Different retrofitting strategies have been considered using Carbon-Fiber-Reinforced-Polymer (CFRP) materials. Pushover analyses have been carried out using two advanced numerical approaches for the concrete modeling. 2D and 3D pushover analyses were performed using both approaches [13].

Mosallam et al. presented the results of an experimental study that evaluate the structural performance of reinforced concrete (R/C) shear walls, with different opening geometries strengthened with fiber-reinforced-polymer (FRP) carbon/epoxy composites laminates. Experimental results indicated that the proposed FRP lamination system for R/C shear walls with post-construction openings was successful in enhancing both the strength and ductility of retrofitted walls [14].

Pham et al. investigated the structural behavior and failure modes of fiber-reinforced-polymer (FRP) confined concrete wrapped with different FRP arrangements. A total of twenty four specimens by different wrapping arrangements were cast and tested. They include fully wrapped, partially wrapped and non-uniformly wrapped concrete cylinders [15].

One of the most important issues in rehabilitation of R/C structures by FRP is the arrangement of the FRP on concrete surface in positive and negative bending. The thickness of the FRP is also important in strengthening of R/C buildings [16].

This study investigates the influence of thickness and arrangement of FRP layers for rehabilitating and confinement of wall components by finite element analysis.

This study aims to investigate the behavior of reinforced walls by using finite element software, ABAQUS and then study the strengthening of concrete walls with FRP layers under combination of the lateral and gravity loads. The focus in this study is on the role of arrangement of FRP layers and influence of layers.

2. Methodology

In this study, at first, an experimental specimen of shear wall was modeled by ABAQUS software to ensure the accuracy of numerical modeling results. The non-linear static analysis (pushover analysis) was used in analysis of the specimen. Then the effect of FRP composite sheets on the final capacity of shear wall with various arrangements and thickness of FRP was evaluated in this study.

The FRP layers were investigated in four configurations: horizontal, perpendicular, cross (diagonal) and chess with thicknesses of 1 and 3 mm. The modeled wall is under a combination of gravity and lateral forces to evaluate the influence of FRP sheets arrangement as well as increased number of sheet layers on improving the load-carrying capacity of the wall.

This study used reinforced concrete non-linear finite element analysis approach. Non-linear analyses are powerful analysis for predicting the behavior of reinforced concrete shear wall.

Behavior of the wall is considerably influenced by the height to length ratio. Shear walls with ratio of height to length less than 3 or 2 has shear performance and shear walls with higher ratio of height to length have flexural performance [1]. In this study, the dimension of the wall is 3×2×0.3m. Flexural capacity and curvature flexibility of wall are related to the size and distribution of horizontal and vertical reinforcements in the wall. In all specimens, the wall reinforcements are assumed to be constant making it possible to study the influence of FRP layers individually. In the following, the properties of materials used in the modeling of the specimens, will be presented.

3. Elements Modeling

The plasticity model used in this study is a Damage Plasticity Model using ABAQUS software. The only difference between a plastic damage model and a plasticity model is considering the damage. Concrete damage plasticity theory tries to consider the influence of irreversible damage together with failure mechanism occurs in the concrete under low confining pressures. Damage together with concrete failure mechanism is considered in reducing elastic stiffness [17].

"Concrete Damaged Plasticity Model" developed by Lee & Fenves and Lubliner et al. used for defining the properties of concrete in the software (Behfarnia, 2010). This is a continuous model based on plasticity basically enable to analyze the concrete structures and model the damage in the concrete. This measure indeed considers the tensile and compressive damages of concrete. In this model, two main damage mechanisms are considered, i.e. cracking from tensile and breaking from compression in the concrete materials. The damage level is evaluated by two variables ε_t^{pl} and ε_c^{pl} indicating the failure mechanisms under tensile and compressive loads respectively. ε_t^{pl} and ε_c^{pl} are tensile and compression plastic strains respectively.

ABAQUS finite element software presents three different compositions for analyzing the concrete under a state where a confining pressure applied: cracked concrete in ABAQUS/Standard environment, brittle concrete in ABAQUS/Explicit environment and plastic damaged concrete in ABAQUS/Standard and ABAQUS/Explicit environment. Each model has been considered for designing a plain concrete and reinforced concrete (like other brittle-like materials) in all kinds of structures such as girders, trusses, shells and solid parts.

During cyclic loading, the degradation behavior become more complicated including opening and closing the hair cracks formed before [5]. Experimentally, it has been indicated that by changing the loading direction, the elastic stiffness will be increased. This is one of the important properties of concrete behavior during cyclic loading. The influence of this behavior could be seen when loading changed from tensile to compressive state causing cracks closed and recover the compressive stiffness.

In the modeled specimens, steels were modeled such that they are one-dimensional elements with accurate location. For introducing the constraints between concrete and steel, embedded region constraint used, constraining the degrees of freedom of steel elements to degrees of freedom of concrete elements surrounding it. To avoid numerical instability for completely plastic behavior, there is allocated a small positive value as stress-strain curve slope in the plastic region. Because the plasticity criterion of steel is the Von Mises criterion and steels are modeled as a truss element, it is enough to introduce its uniaxial strain-stress curve based on non-elastic strain. In ABAQUS, concrete and steel behaviors modeled independently and then super-positioned to each other and the interaction between concrete and steel such as inhibitory slip and action are introduced approximately using concrete tensile hardening, as mentioned before. Longitudinal and transverse reinforcements were located in two layers in the wall with concrete cover equal 5 cm.

4. Validation of Modeling

As mentioned before, at first, a reinforced concrete wall has been studied in the experimental researches and its ultimate load capacity was evaluated (using non-linear static analysis or pushover analysis) by ABAQUS finite element software to ensure the accuracy of the results from this software. After ensuring the accuracy of numerical model, the influence of thickness and different arrangements of FRP on ultimate capacity of shear wall under the combination of gravity and lateral loading was studied. The chosen specimen includes one of the shear walls tested under Christian Greifenhagen and Pierino Lestuzzi [18]. The studied model was M3 model (Figure 1) used in ABAQUS software which the properties of material is according to the properties of experimental specimen as indicated in tables (1) and (2). Bi-linear model as well as Von Mises stress criterion was used for modeling of the used steel rebar [18].

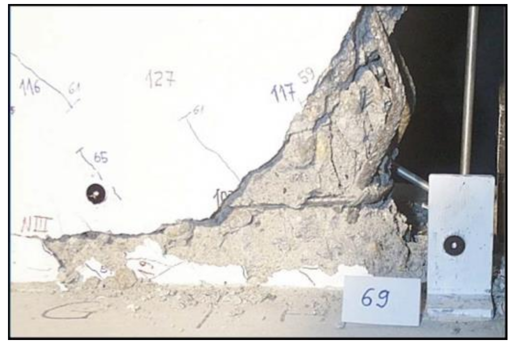

Figure 1. Experimental specimen M3 shear wall [18]

Table 1. Properties of steel used in the modeling and experimental specimen

specimen	Type of reinforcement	Yield stress	Failure stress	Failure strain	Elasticity module	Poison's ratio
M3	Longitudinal reinforcement	504	634	0.11	210000	0.3
	Transverse reinforcement	745	800	0.03	210000	0.3

* All units are based on Mega Pascal.

Table 2. Properties of concrete used in the modeling and experimental specimen

Specimen	Compressive strength, 0.5fc'	0.5fc'	Tensile stress	Compressive plastic strain	Tensile plastic strain
M3	20	10	2.7	0.0035	0.001

* All units are based on Mega Pascal.

Experimental pushover curve obtained by experimental and analytical works are shown in Figure (2) for M3 specimen. As seen, the numerical modeling can accurately predict the experimental results with very good accuracy.

In this research, the point located in the middle of the top cross section of the wall is selected as reference point.

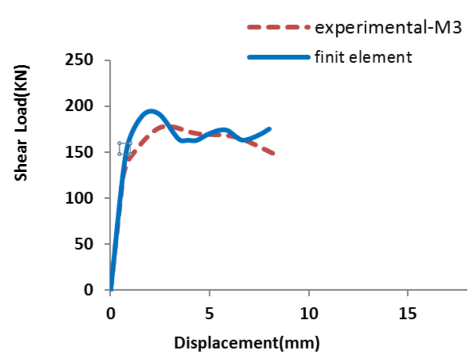

Figure 2.Comparing the results from modeling and experimental specimen

5. Analysis of Shear wall specimens

After ensuring the accuracy of finite element approach for predicting the behavior of shear wall, to study the influence of arrangement and thickness of FRP layers for rehabilitating the shear wall, four different arrangements of FRP layers including horizontal layers, vertical layers, cross layers and chess layers were modeled. FRP fibers were of carbon type. There has been tried that all specimens, have equal area. The FRP layers are used with their properties according to table (3). The walls used in all different FRP arrangements have equal properties. The dimensions of shear wall used include 3m×2m×5cm (L×H×W). Longitudinal and transverse reinforcements were located in two layers in the wall with concrete cover equal to 5cm. Embedded region constraint in ABAQUS software was used to consider the interaction between concrete and longitudinal and transverse reinforcement. Table (4) indicates the specification of reinforcements used in the concrete wall.

The mechanical properties considered in "Concrete's Damaged Plasticity" are according to table (2) and the mechanical properties of reinforcements used in all walls are the same as table (3).

FRP fibers are carbon type and its properties are the same in all directions. As seen, table (5) indicates the dimensions of fibers (length and width) for all specimens.

It is used the displacement control method as loading in this model. A solid plate on the wall is used for applying the all gravitational loading and lateral displacement controls. Solid sheet equally distributes the forces applied to the wall throughout the width of the wall; this minimizes the possibility of development of diagonal tensile crack. As stated above, loading has been applied in combination of gravity and lateral force to the wall. There has been applied a gravity loading of 408000 N and displacement of 24mm along with the lateral side on the shear wall. When applying the boundary conditions in the base of the wall, all translational and rotational degrees of freedom for nodes in the base of the wall were closed and wall has been modeled like a vertical cantilever beam. Solid eight nodes 3D elements (C3D8R) were used for meshing the concrete parts and truss elements (T3D2) were used for meshing the longitudinal and transverse reinforcements (Table 4). FRP layers were located in both directions of the walls. Non-linear static analysis (pushover analysis) was used for analyzing the modeled specimens.

Table 3. Properties of carbonic FRP layers

FRP properties	Young module	Poisson ratio	Yield stress	Plastic strain
Elastic properties	210000	0.3	-	-
Plastic properties	-	-	2900	0
			3200	0.05

Table 4. Specification of reinforcements used in the wall

Type of reinforcement	Reinforcement	Meshing
Longitudinal reinforcements	Φ10@20 cm	T3D2
Transverse reinforcements	Φ10@20 cm	T3D2

Table 5. Properties of FRP layers in different arrangements

Type of FRP arrangement	Cross	Vertical	Horizontal	Chess
Width	200	140	100	100
Length	3605	2000	3000	2000 & 3000
Number	4	5	5	5 horizontal, 5 vertical

6. Results

Figures (3, 4, 5 and 6) indicate the shear walls with different arrangements of FRP (vertical, horizontal, chess and cross layer respectively). In the next section the results of analysis will be presented.

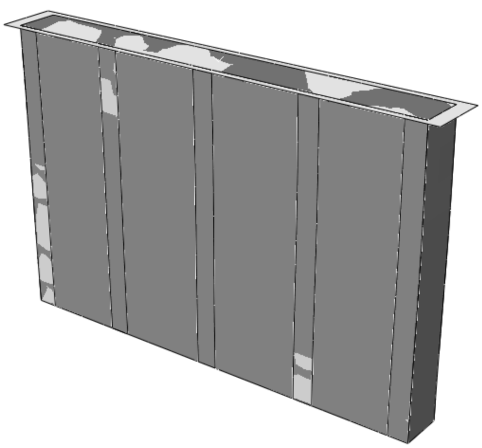

Figure 3. Concrete shear wall with vertical layers

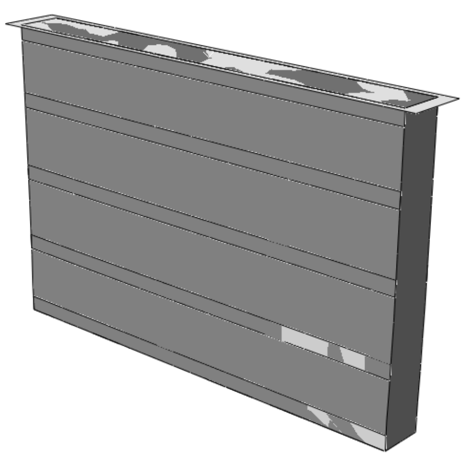

Figure 4. Concrete shear wall with horizontal layers

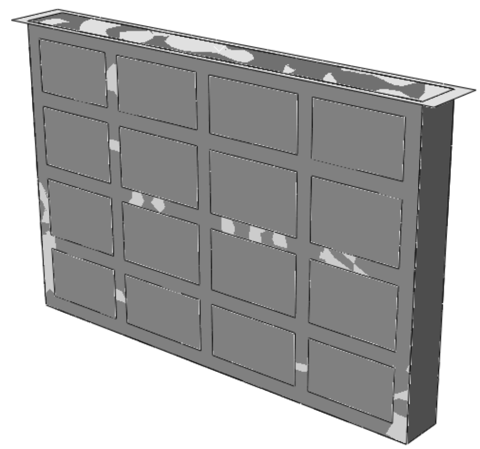

Figure 5. Concrete shear wall with Chess Layers

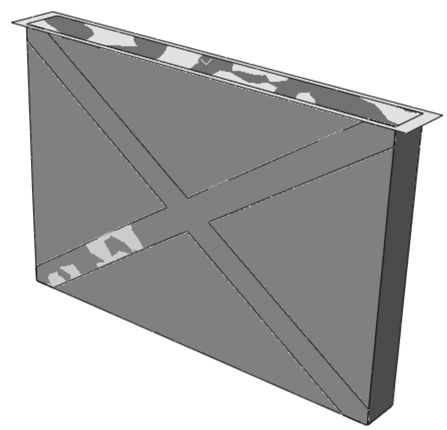

Figure 6. Concrete shear wall with Cross layers

6.1. Studying the influence of the FRP layers arrangements

As stated before, to investigate the influence of arranging the FRP layers on the improvement of strength and ductility of concrete wall, four models of concrete shear wall were compared with different FRP arrangement in diagonal, horizontal, vertical and chess forms. These walls have the same geometrical properties and the properties of the materials are the same, also. The thickness of FRP layers are the same in all walls and the only difference is arrangement in FRP layers. The pushover curve for walls reinforced by horizontal and vertical fibers is more volatile than curve of cross and chess walls. As indicated in figure (7), the walls with chess and cross FRP layers could tolerate higher lateral forces comparing to other rehabilitated walls. Figure (7) shows the result of wall rehabilitation with 1mm thickness. Figure (8) compares different arrangements of FRP layers with thickness of 3mm.

6.2. Studying the influence of FRP layers thickness

FRP layers with thicknesses of 1 and 3 mm were used as a model for studying the effect of thickness of FRP layer on improving the seismic performance of concrete shear wall. Results of this comparison indicate the considerable improvement of ductility and value of maximum lateral forces by doubling the thickness of FRP layer. This comparison indicates the influence of FRP thickness such that by doubling the thickness, the dissipated energy by wall has significantly increased. Figures (9, 10, 11 and 12) indicate the energy absorbed in force-displacement in the walls rehabilitated by FRP layers with thicknesses of 1 and 3mm as well as wall without any FRP layers, therefore the improvement in the performance by increasing in the thickness of wall can be seen.

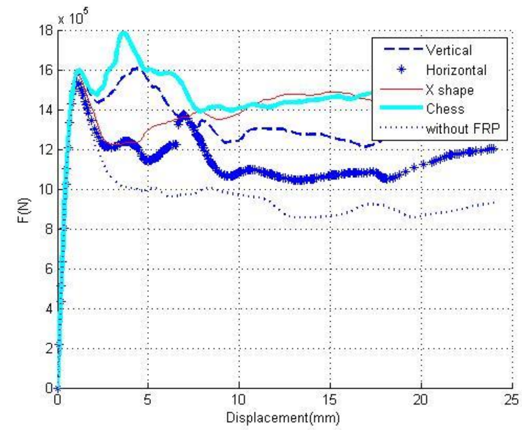

Figure 7. Comparing the results of different FRP arrangements with thickness of 1mm

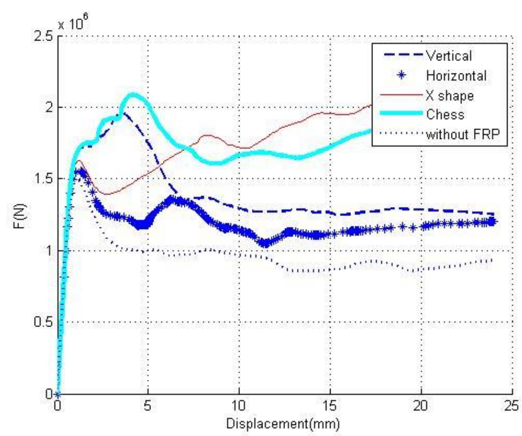

Figure 8. Comparing the results of different FRP arrangements with thickness of 3mm

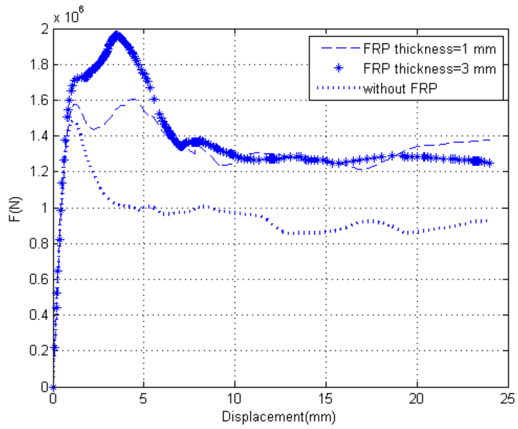

Figure 9. Comparing the results of thicknesses 1 and 3mm with vertical FRP layers

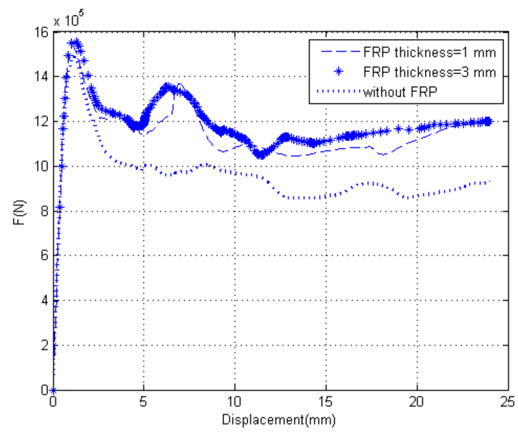

Figure 10. Comparing the results of thicknesses 1 and 3mm with horizontal FRP layers

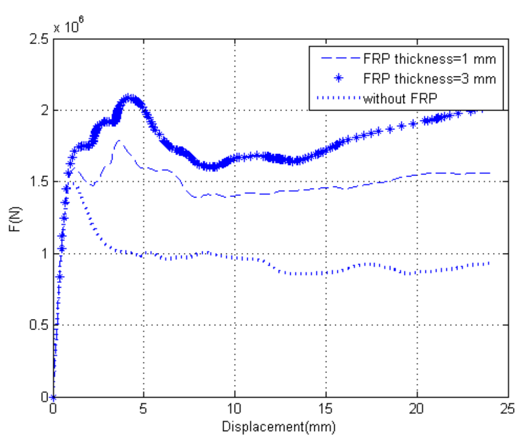

Figure 11. Comparing the results of thicknesses 1 and 3mm with chess FRP layers

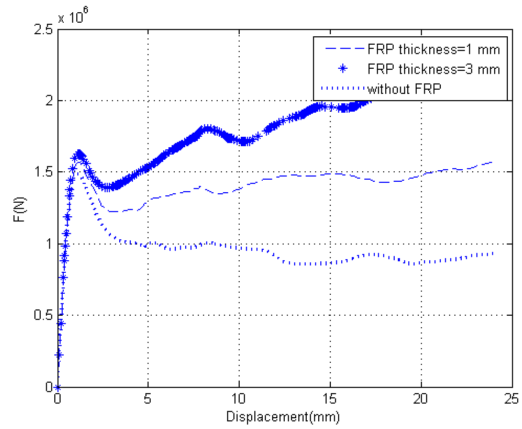

Figure 12. Comparing the results of thicknesses 1 and 3mm with cross FRP layers

7. Conclusion

This study investigated the influence of geometric characteristics and arrangement of FRP layers on seismic performance of reinforced concrete wall. For this purpose a few concrete shear walls rehabilitated with FRP layers homogenously and with a behavior similar to plastic damaged concrete in the compressive and tensile loading were selected. All structural properties of studied walls were completely the same and the differences were thickness and type of arrangement in FRP layers. The influence of these characteristics was studied by comparing the curves from non-linear static analysis. From the studies outlined previously, the following results have also been reached. Obviously, the results obtained from limited studies and it is required further studies for approving them:

FRP stiffness may increase the elastic stiffness, shear capacity and strength in the walls.

Under the equal conditions, it could be seen the influence of cross and chess layers increase the strength comparing to other arrangements.

It could be concluded that FRP horizontal layers have weaker performance for improving the performance of shear wall comparing to other types of arrangement.

Results indicate that using FRP sheet considerably influences the ductile behavior of wall.

It could be also seen that increased number of layers (thickness) may considerably increase the ultimate load, cracking load and wall displacement.

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