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# The optimum configuration of FRP laminates of coupling shear wall concerning the load capacity

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## Abstract

Using of CFRP carbon sheets because of their high strength, lightness and ease of use have been very expanded in retrofitting concrete members. Including shear walls systems FRP can be used in order to rebuild or maintain the strength of an aged structural member. Repairing, or retrofitting of the intact structural member is conducted to enhance the structural resistance that was deteriorated due to the overloading, construction ignorance and so on. In this study, a model of coupled reinforced shear walls with changing the shape of CFRP fibers arrangement under lateral loading is considered. Then, the effect of coupled concrete compression shear wall resistance vary is investigated on the retrofitting. In all stages, the comparison among the proposed arrangement shape of CFRP fibers are accomplished in terms of lateral load carrying capacity of the specimens. Accordingly, the best form of fiber formation is recommended. Finally, it was concluded that the most optimistic fiber arrangement is fully covered and the next choice is vertically covered FRP arraignment.

***Keywords**: Lateral loading, Coupling shear wall, CFRP, Nonlinear, Carbon fiber.*

## 1. Introduction

Nowadays, fiber reinforced polymer (FRP) is utilized instead of the steel and concrete jackets which was one of the common methods for retrofitting of the steel and concrete structures [1]. Carbon fibers, is a new generation of the high-strength fibers, which due to extraordinary mechanical and electrical properties, has large variety of applications. Composites which made of these fibers are used in various industries such as automobile manufacturing, medical engineering as well as in the construction industries for concrete reinforced buildings, like columns, bridges, tunnels and the other building components.

One technique to retrofit the shear walls is to cover the damage area using the CFRP strips These strips is deploy to enclose the concrete surface, and increase its resistance until it does not decomposed after the curial cracks. Retrofitting the shear wall with CFRP layers increases the ductility and cyclic loading carrying capacity of

the structural member [2-4]. Also for economic reasons, the configuration of fibers should be such that with the least materials used, the most possible strength is produced. The FRP strengthening system can significantly improve the strength, displacement capacities and energy dissipation ability for concrete and masonry walls, however, If sufficient FRP strengthening is applied, the failure can change from a shear dominant mode to a flexural dominant mode. Note that the FRP strengthening would not make a significant difference in the initial stiffness of walls [5-12].Another application of FRP is to increase seismic performance of unreinforced masonry (URM) walls. Experimental research on URM demonstrated that retrofitting of masonry walls by FRP composite laminates can remarkably enhance their in-plane and out-of plane shear carrying capacity [13-15]. Also, the investigations about in-plane seismic behavior of URM walls and in filled RC frames before and after retrofitting using FRP showed that, the materials did not change the

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fundamental frequencies and the initial stiffness of the wall [16, 17]. Nevertheless, the safety measure of this type of the retrofitted structures ought to be assessed in terms of the reliability indices. In doing so, Ghasemi and Nowak proposed a reliability approach to measure the safety condition of the structural components. The benefit of Ghasemi-Nowak [18-20] equation is to determine the safety level of a non-normal limit state function with consideration of the new definition of the safety area in term of convolution theory instead of the joint distribution function. For evaluation of the intended reliability index of structures, there is a need for expression of the optimum safety level, that is called as target reliability. Ghasemi and Nowak [21] and Yanaka et al. [22] proposed several approaches to estimate the target reliability for bridges with respect to the minimization of the cost.

Retrofitting increases the shear walls with carbon fiber resistance subjected to the seismic loads Also, the arrangement of the fiber strips must be in manner that a minimum number and layer of fibers leads to the acceptable resistance level. In this paper, a coupled shear wall, modeled using the ABAQUS software [23], in three-dimensional feature and then quasi-static nonlinear analysis, was used to analyzing it. Then, different modes of CFRP strips, was analyzed on wall and at the end, the results of the various examples were compared.

## 2. Modeling

### 2. 1. Concrete modeling

For modeling, the shear walls concrete, the elements SOLID C3D8R, the three-dimensional cube 8-node element, are used. In this study, 15.5 MPa concrete was used, and h/Ratio is 1.5.Concrete compressive behavior was described by EN1992 [24] relations in Eq. (1) through (4). Tensile strength of concrete up to the maximum tensile stress, fctm, is calculated from Eq. (5). Equation (6) shows both the elastic parts for fctm and the damage plasticity region of concrete from Wang and Hsu relations [25]

$$\sigma_c = f_{cm}\frac{k\eta - \eta^2}{1 + (k-2)\eta} \qquad (1)$$

$$k = 1.05E_{cm}\frac{\varepsilon_{c1}}{f_{cm}} \quad , \quad \eta = \frac{\varepsilon_c}{\varepsilon_{c1}} \qquad (2)$$

$$E_{cm} = 22(0.1f_{cm})^{0.3} \qquad (3)$$

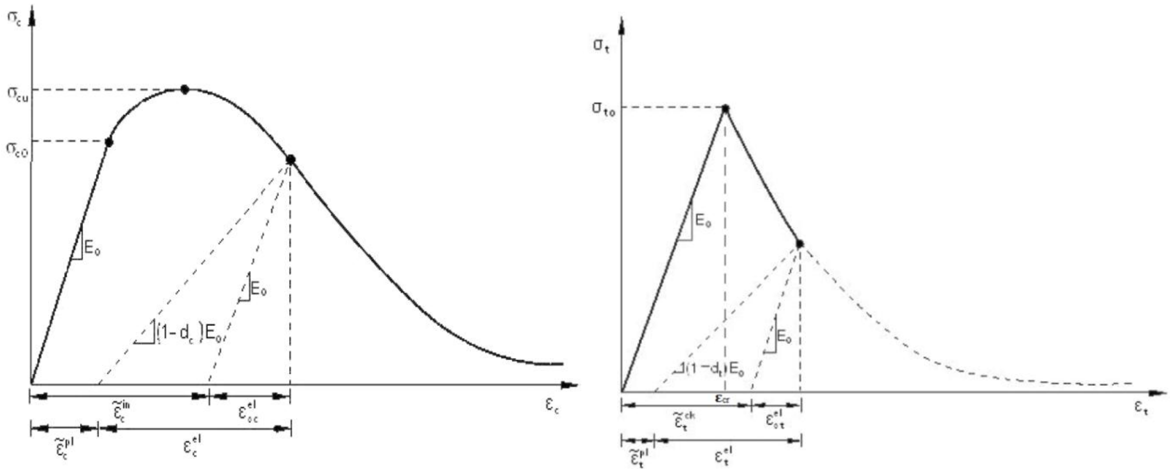
$$\varepsilon_{c1} = 0.7(f_{cm})^{0.31} \qquad (4)$$

$$f_{ctm} = 0.3f_{ck}^{(2/3)} \qquad (5)$$

$$\begin{aligned} \sigma_t &= E_c\varepsilon_t && if \quad \varepsilon_t \le \varepsilon_{cr} \\ \sigma_t &= f_{cm}\left(\frac{\varepsilon_{cr}}{\varepsilon_t}\right) && if \quad \varepsilon_t > \varepsilon_{cr} \end{aligned} \qquad (6)$$

The governing constitutive equation of concrete which is illustrated the stress and strain behavior of the concrete is related to the specimen test results in laboratory. Accordingly, the concrete's behavior for tension and compression have been separately `

Figure 1 shows the stress-strain curve concrete under compression and tensile load. The exact behavior of concrete under tension and strain were separately modeled with plastic damage method which is called concrete damage plasticity (CDP) in ABAQUS, Which is the one of the best methods of modeling the behavior of the concrete subjected to the tensile and pressure loading. Diagram of Figure 2, shows the behavior of the considered concrete. The shear walls geometry is shown in Figure 3.



(a) (b)

Figure 1. (a) Concrete compressive behavior (b) tensile behavior [26]

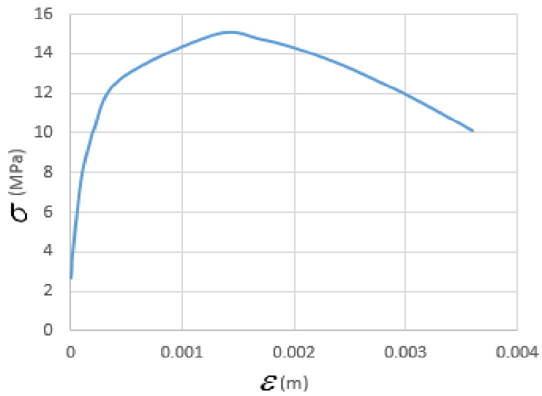



Figure 2. plastic stress-strain behavior of concrete

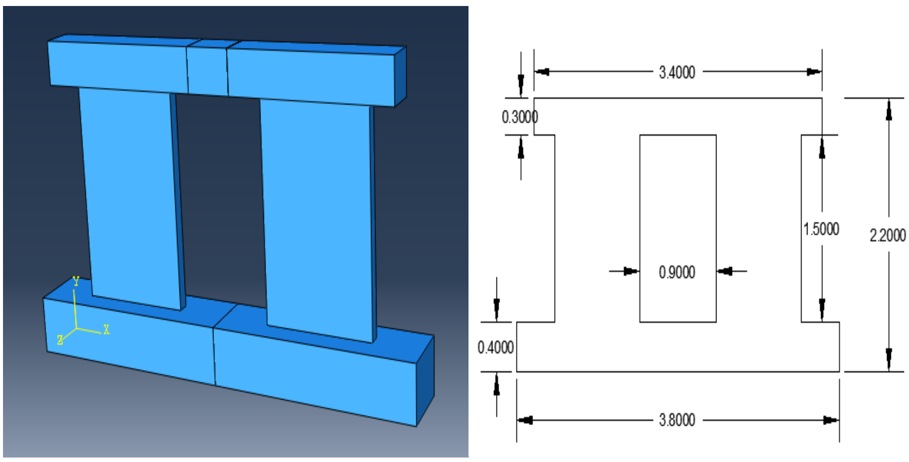
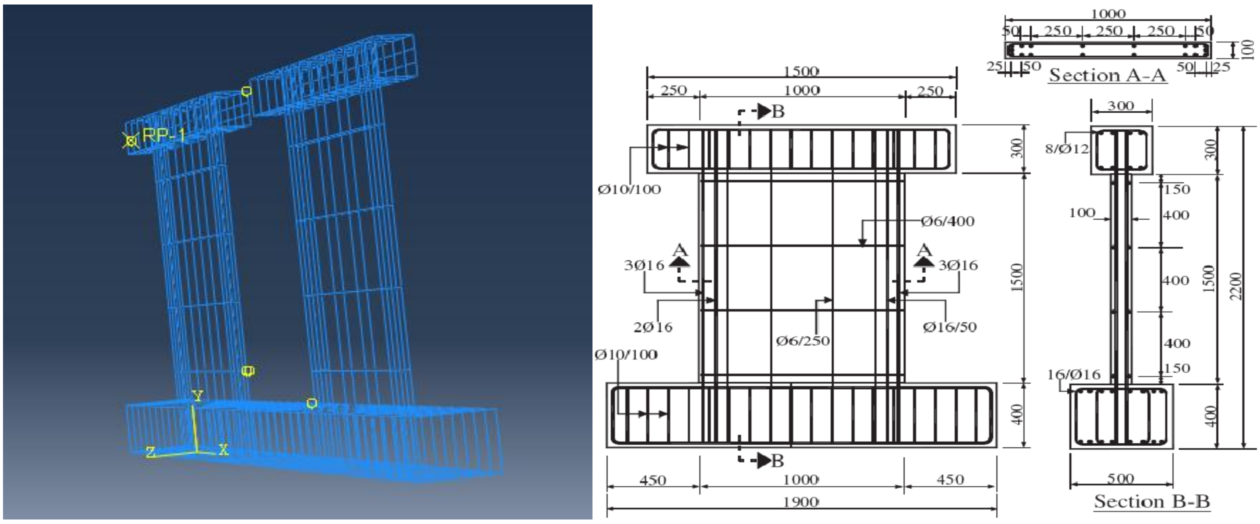



Figure 3. Dimensions of shear walls

### 2.2. Rebars modeling

For modeling bars and stirrups, wire 3D element and planar state were used. The stirrups were modeled in closed rectangle loop. For this reason, all reinforces were defined using elements T3D2. All bars and stirrups after assembly were introduced in MERG form. Then, this rigid body was defined in three-dimensional truss element form, (truss 3D) and all of them were placed together according to the Altin's rebar pattern tests[27], Fig 4 shows the details of rebar based on Altin reserach and the constructed model in ABAQUS software.

To define the behavior of the steel rebars and ties, a bilinear model was used. In this modeling, steel has a linear behavior up to 430 MPa and after this value up to the ultimate stress of 520 MPa, it shows an inelastic behavior. Table 1 shows the characteristics of the steel and Fig. 5 shows bilinear behavior graph of steel, respectively.




(a) (b)

Figure 4. (a) Reinforcement details of test specimens (dimension in mm) [22] (b) Modeling of rebars in ABAQUS.

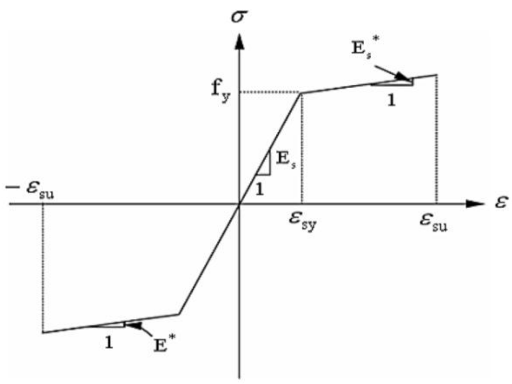



Figure 5. Bilinear behavior of steel.

Table 1. steel bars characteristic

| material | Poison ration | Elasticity module (Mpa) | Yield strength $f_{sy}$ (MPa) | Failure strength $f_{su}$ (MPa) | Density (kg/m$^3$) |
|---|---|---|---|---|---|
| steel | 0.3 | 206800 | 430 | 520 | 7850 |

### 2.3. CFRP Modeling

In order to model the carbon fibers, shell plated elements was used, which can define the properties of CFRP material based on one layer, two layers, and three layers composite lamina. The properties of all fibers are identical and the only difference is based on the layers configuration. For bonding fibers, to the walls, the stronger adhesive was pasted which should be stronger than the strength of CFRP. Therefore, the slip between the concrete, and fiber, has been overlooked. The properties of these fibers were shown in Table 2.

Table 2. propertiesof carbon fibers

| Density (kg/m$^3$) | Elasticity module (Mpa) | Tensile strength (MPa) | Thickness (mm) |
|---|---|---|---|
| 1536 | 231000 | 4100 | 0.12 |

## 3. Detail of strengthening shear wall with carbon fibers

The effect of six different modes of carbon fiber formation on the shear walls was investigated and the arrangement of reinforced samples with CFRP fibers numbered in Table 3 was shown in Figure 6. In all cases, the fibers have a 10 cm width and symmetrically, placed on the wall and the slip between the fibers, and concrete has been overlooked. In sample C-2 the center to center distance of fibers are 20 cm and in sample C-3 the center to center distance of fibers are 15 cm and sample C-4 is the composition of two samples. In samples C-5 and C-6 the angle of fibers relative to the horizon, is coinciding to the diameter of shear walls and the distance from the center to center of the fiber in sample C-6 is 20 cm.

Table 3. Number of samples

| | Strengthening method | Specimen |
|---|---|---|
| 1 | No CFRP | C-0 |
| 2 | Totally covered | C-1 |
| 3 | Simply checkered | C-4 |
| 4 | Simply crossed | C-5 |
| 5 | Horizontally paralleled | C-2 |
| 6 | Vertically paralleled | C-3 |
| 7 | Diagonally checkered | C-6 |

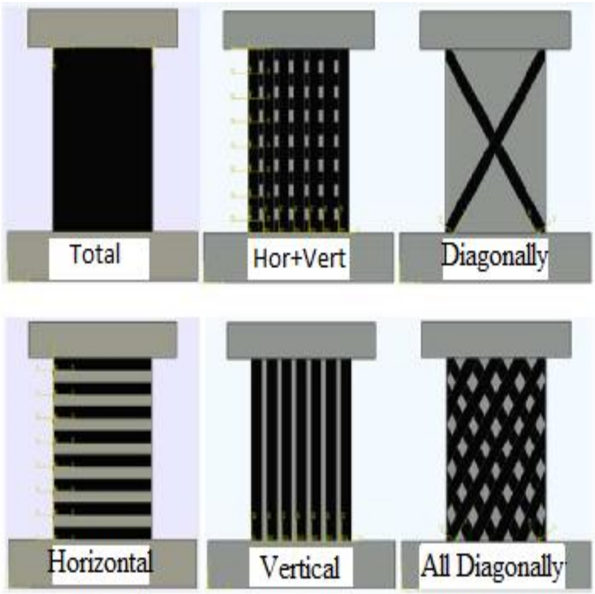



Figure 6. Arrangement of fibers [26]

## 4. Exerting force into shear wall

loading condition, with using the detail of Altin's tests was performed in this way, that the bottom beam shear wall is constantly and completely fixed and is attached into rigid floor. Moreover a hydraulic jack, which is connected to the rigid wall, apply the force to the upper beam of shear wall. Figure7 shows the details of the test.

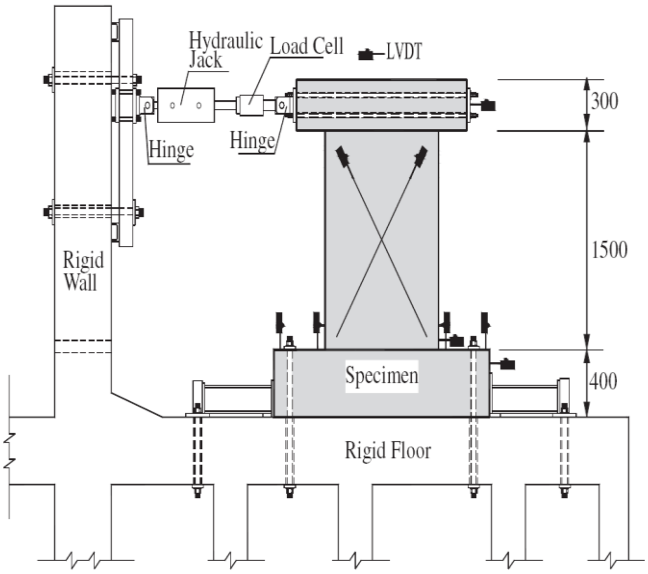



Figure 7. loading condtion [22]

## 5. The results of finite elements analysis of shear walls and the impact of fiber arrangement

With relocation of the upper beam of sample, and fixing the lower bar, the maximum strength of each sample was measured. The maximum resistance of each sample and as well as the increase of samples strength relative to samples without reinforcement was shown, in Table 4. Figure (8), was shown the modeling, meshing, and the tension created in the sample C-2 in Abaqus.

In Figure 9, the curve of drift - force is shown. As can be seen, sample C-1 has the greatest amount of resistance.

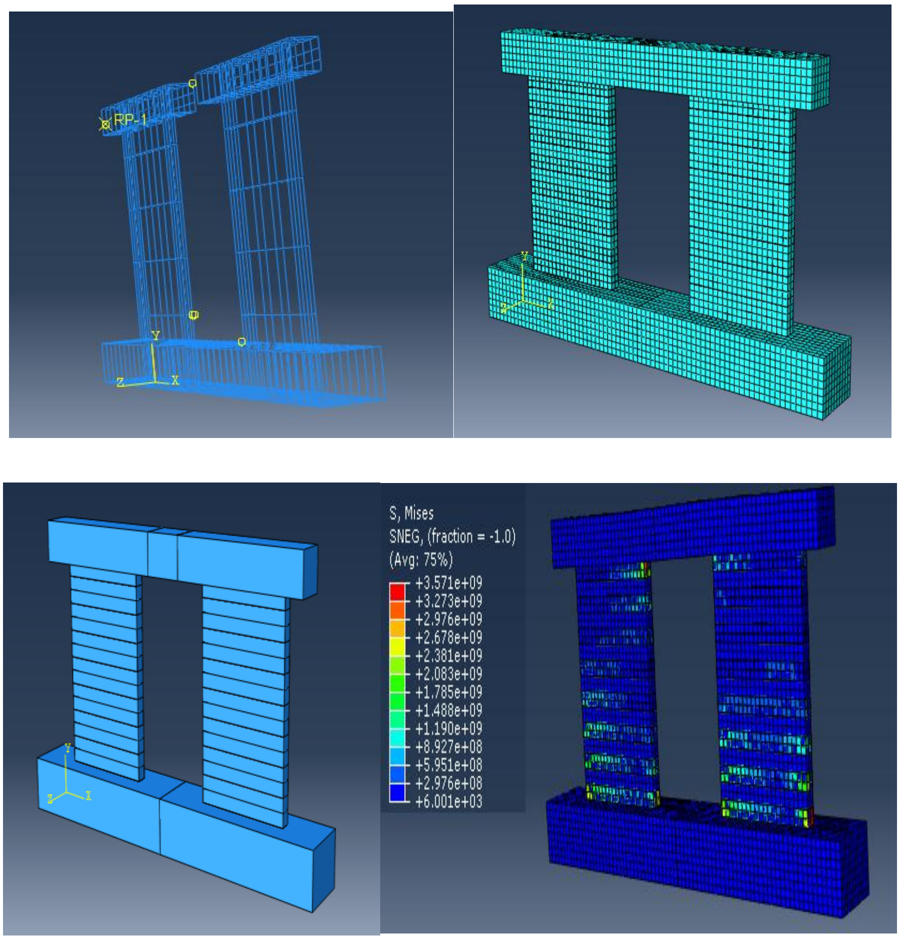



Figure 8. Shear wall modeling, stress, and meshing, in the sample C-2

Table 4. Details of the increasing the samples resistance

| Increasing load (%) | Maximum lateral strength (kN) | Specimen no |
|---|---|---|
| - | 672.691 | C-0 |
| 17.6 | 791.357 | C-1 |
| 7.57 | 723.637 | C-2 |
| 10.4 | 742.843 | C-3 |
| 17.06 | 787.518 | C-4 |
| 3.44 | 695.865 | C-5 |
| 9.83 | 738.822 | C-6 |

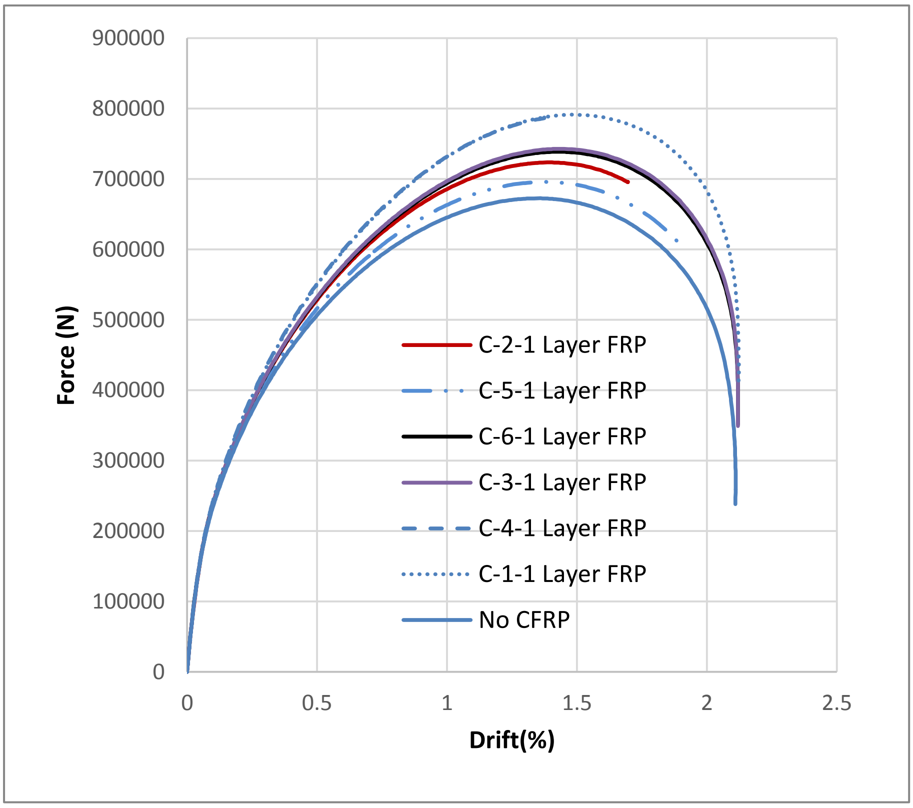



Figure 9. –Force-Drift relationship

As it can be seen, sample C-1 and C-4 can take the maximum amount of force but sample C-1 had further displacement in comparison with the C-4 and with considering that the percentage of FRP coverage, in scenario C-4 is greater than C-1, using from C-1 is more suitable. Specimen C-6 and C-3, are in the second place in terms of force resistance and due to the less coverage of FRP in sample C-3, it is better option. In sample C-2 FRP fibers covered 50% of the wall and its load-bearing is about 723 kN which in comparison with C-3 which its load-bearing is about 742 KN and covered 70 percentage of wall surface, its resistance is well, but its drift percentage is less.

In Fig. 10, force-drift behavior of C-1, C-2, C-3, C-4, C-5, and C-6 specimens using one, two and three layers of CFRP are shown.

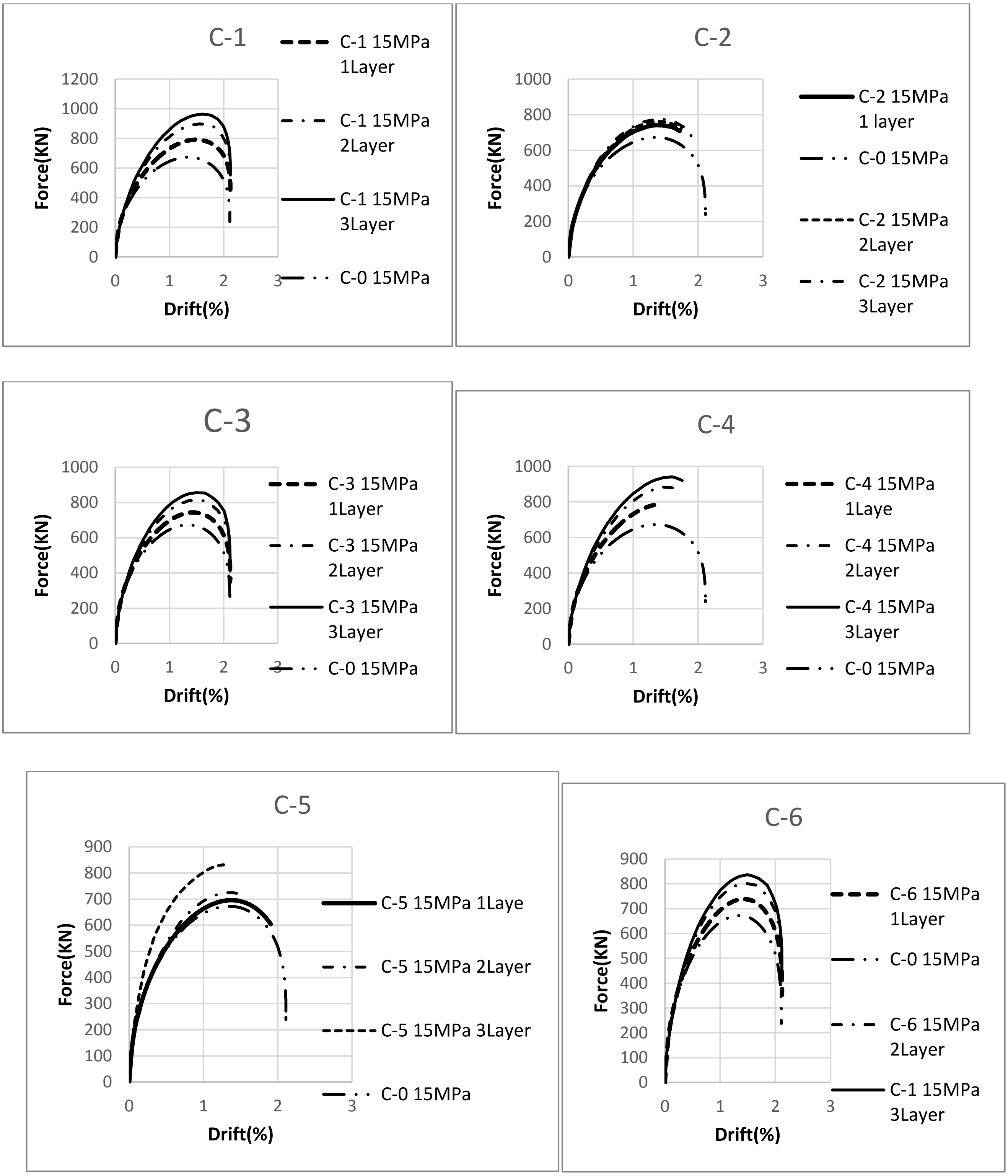



Figure 10. Load- Displacement curve for C-1, C-2, C-3, C-4, C-5, C-6 specimens configuration

## 6. Conclusions

Following presents the outcome of the paper:

1. For retrofitting the lower floors of structure, which require maximum resistance of shear walls, C-1specimen can be concluded as a proper choice.
2. The results show that by increasing the number of FRP layers in C-2, C-4, C-5 specimens declines the drift of the shear walls .
3. Increasing the number of FRP layers leads to the increases of lateral strength of the shear wall.
4. Either with higher aspect ratios or low aspect ratio, usage of CFRP layers does not affect on the primary strength of the shear wall.
5. The checkered pattern is the best CFRP configuration which produces the most increase in shear wall strength. In this case, stresses are distributed throughout the wall and could bear the maximum load capacity. However, this case is not suitable for higher h/L ratios where moment failure is a criterion.

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