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Study Of The Effect Of Reinforcement Ratio And Height To Width Ratio On Behaviour Of High Strength R.C. Shear Walls

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ABSTRACT: *The high-strength concrete shear wall is widely used because shear wall increased the lateral strength of a structure and have a great effect on stiffness. The using of Fiber reinforced polymer (FRP) in the strengthening is one of the effective method for shear wall strengthening. In this paper Finite Element Method is used to simulate the reinforced concrete Shear wall using 3-D elements. Confined and unconfined shear wall are investigated in the analysis by using ANSYS 12.*
Seventy –two full-scale reinforced concrete model shear walls are analyzed under combined action of a constant axial load and horizontal loading increased loading till failure to study the behavior of high strength reinforced concrete shear wall with confinement. The specimens are classified into Four groups according to height of shear wall and the shape of cross section for Group "1" Height of wall =1100mm and it was I-section cross section and, Group "2" Height of wall=740mm, and the same of cross section of group 1, For Group "3" the cross section shape was Rectangular section and the height of wall equal 1100mm and Group "4" was Rectangular section and the height of wall equal 740mm.Each group divided according to the material of strengthening and variation main flexure reinforcement.
The ultimate load, deflection, mode of failure, crack pattern, stress distribution, ductility and absorption of energy are presented. It is concluded that There is significant increase in strength and ductility of reinforced concrete shear wall because of Fiber Reinforced Polymer (FRP) wrapping. In addition, decreasing the height-to-width ratio caused higher values of the lateral load capacity but on the other hand it has decreasing lateral displacement. -

.***KEYWORDS:*** *-Shear wall, FRP, High strength, Crack Pattern and Finite element*

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I. INTRODUCTION

Reinforced concrete shear walls are considered of topics to which conducted by several studies recently because of the importance of wall to resist the lateral loads due to wind and seismic effects on buildings and provide sufficient ductility and very good lateral drift control which prevent from the undesirable brittle failure against the strong lateral loads, especially during an earthquake. Moreover, strengthening of shear wall are necessary when the shear wall discontinue to provide the required strength and performance under various loads.

Fiber Reinforced Polymer (FRP) wrapping is applied on shear wall to enhance their strength and ductility. FRP is more effective for strengthening than the other traditional techniques because of these properties like lightweight, high stiffness, high strength and good durability of FRP make it an excellent choice for strengthening.

Many experimental studies have been conducted on shear wall Ahmed Abdel Garber (2005) [1], investigated the effects of the height to width ratio, the compressive concrete strength, and the variation of main flexure reinforcement ratio on the behaviour of high strength concrete shear walls he found that significant increasing of the stiffness was observed for short wall, by approximately 20 % more than that of the stiffness of long (HSC) wall. S. Qazi, L. Michel, E. Ferrier (2013) [2], studied the effect of confinement on rectangular reinforcement concrete long shear wall under static load and cyclic load they found that the CFRP strips bonded to the RC-wall panel improved their ultimate load capacity and ductility, and the strips limited the crack propagation to a certain extent and the partial FRP strengthening technique did not deteriorate the capacity of the RC wall to dissipate energy. David T. Lau (2013) [3], presented laboratory testing to study the behaviour of externally-bonded fibre reinforced polymer (FRP) tow sheets for the seismic retrofit of reinforced concrete (RC) shear walls under lateral cyclic load he found that strengthening shear wall with vertical and horizontal FRP sheets increased the flexural and shear strengths, enhance ductility, and increase energy dissipation ability of shear walls. H. El-Sokkary (2013) [4], studied the effect of confinement shear wall with different scheme by using externally CFRP he found different scheme showed different load and deformability capacities due to the nature of crack propagation and the orientation of the applied CFRP sheets. S. Qazi, L. Michel, E. Ferrier (2015) [5], presented an experimental investigation of reinforced concrete short shear wall to study the effect of strengthening on the strength and deformability with negligible variation in RC wall dissipation capacity. They found that the CFRP strengthened wall showed improvement in ultimate load capacity and deformability as compared to control specimen and the bonded CFRP strips performed well in bridging the cracks as the cracks width in CFRP strengthened wall was lesser then that of Control wall.

On the other hand, many analytical studies have been conducted to study the efficiency of concrete shear wall confined with FRP. Also, Davood, Maryam (2012) [6] presented a nonlinear FEM to study the effect of transverse steel reinforcement in boundary element of shear wall and effect of FRP strengthening of boundary element. The model was validated with experiments measures it was observed that increasing transverse steel reinforcement in boundary element decreasing the ultimate displacement at the top of the wall and applying one layer of FRP around boundary elements in the plastic hinge region of shear wall significantly effects on ultimate displacement and ductility of the wall for poor-detailed specimens. A. Delnavaz, M. Hamidnia (2016) [7] ,also performed analytical study by FEM to study the effect of CFRP patterns and number of layers on the loading capacity of shear walls, three different concrete strengths of low, normal and high in 6 different patterns The results are compared with those of similar experimental study for the issue of verification and showed good agreement with the experimental study and it was found that the effect of CFRP in increasing shear wall strength is higher with low strength concretes. increase in the number of layers to more than one layer does not have effect on low concrete, although in concretes with higher strength, increasing the CFRP layers more than one increases the lateral strength. Moreover, Mohammed A. Sakr (2017) [8], carried out a numerical analysis using the finite element method, FEM. The results are compared with those of similar experimental study for the issue of verification. The study investigated several parameters such as, different bracing of CFRP strips and proposed CFRP anchor location he found that the strip configurations were effective on the behaviour of CFRP strengthened RC shear wall.

In this research, non-linear finite element analysis models using ANSYS [12] software of an RC shear wall for strengthening reinforced shear wall with carbon fiber reinforced polymers and Glass fiber reinforced polymers. Firstly, The verification with the pervious similar work, after verification of modelling by laboratory results. Different FRP strips scheme on shear wall were studied. Finally, with the change of FRP types, variation in the main flexural reinforcement and different in height to width ratio, their effect on the lateral loading capacity and the corresponding lateral drift.

II. VERIFICATION MODEL

The experimental investigation of [1] was applied to verify the developed FE model for shear wall using ANSYS 12 software. The control shear wall is cantilever shear wall with I- section, consisted of two flanged walls and a web wall. The web wall was 60 mm in thickness and 400 mm width and its height was variable. Top slab and footing are made rigid enough to prevent lateral distortion (lateral rotation about vertical axis) of the cross-section under lateral load effect and to represent a building floor. The walls divided to two group according to height of wall (Table 1).

Table 1: Test Specimens of Ahmed Abdel Garber (2005)

Specimens Name	Height	Reinforcement Ratio
HL-1	1100	2.26%
HL-2	1100	3.39%
HS-1	740	2.26%
HS-2	740	3.39%

In this paper, the following are the assumptions made for FE model of RC shear wall to provide reasonably good simulations for the complex behavior:

- Concrete and steel are modelled as isotropic and homogeneous materials.
- Poisson’s ratio is considered constant throughout the loading history.
- Steel is considered an elastic-perfectly plastic material and identical in tension and compression.
- Bond between concrete and steel reinforcement is assumed perfect.

The results from ANSYS showed that there is agreement between ANSYS results and the experimental findings as shown in Figure 1.

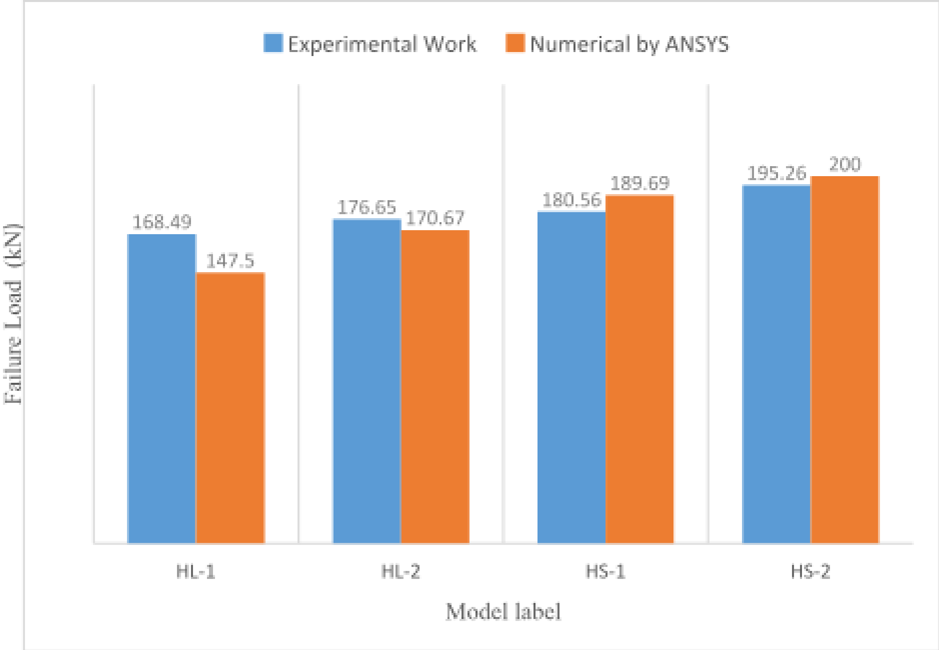

Figure 1: Comparisons between Experimental Tests and ANSYS Results

III. PROGRAMME STUDY

Finite Element Method is used to simulate the reinforced concrete Shear wall using 3-D elements. Seventy –two full scale reinforced concrete model shear walls are analyzed under combined action of a constant axial load and horizontal loading increased till failure. Finite element analysis is carried out to simulate 4 groups of reinforced concrete Shear wall. the model label consists of 4 parts as shown in Figure 2

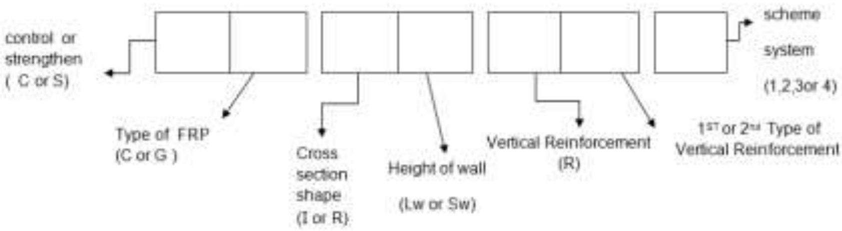

Figure 2: Labelling Scheme

GROUP (1) consist of eighteen I-section shear wall models (Table 2). These shear wall have the same cross sectional area (640 cm2) and same height 1100mm as shown in Figure 3.With the same concrete characteristic strength (FCU= 73 N/mm2) .Two types of vertical main reinforcement are used (6ϕ10) and (6ϕ12) .Each type contains 2 series varied in the type of FRP [CFRP (SikaWrap® Hex 113C) and GFRP (SikaWrap® Hex 106G)] Each series consists of 5 models (unconfined, confined with 250mm height around the web , with 250mm height around the section , confined with 500mm height around the web, , confined with 500mm height around the section as shown in Figure 4.

GROUP (2): The models of this group are the same as the models in group (1) with different height. Where h=740 mm in the current group.

GROUP (3): consist of eighteen Rectangular section shear wall models (Table 3). These shear wall have the same cross sectional area (600 cm2) and same height 1100mm as shown in Figure5. With the same concrete characteristic strength (FCU= 73 N/mm2). Two types of vertical main reinforcement are used (6ϕ10) and (6ϕ12). Each type contains 2 series varied in the type of FRP [CFRP (SikaWrap® Hex 113C) and GFRP (SikaWrap® Hex 106G)] Each series consists of 5 models (unconfined, confined with 250mm height around the web, with 250mm height around the section, confined with 500mm height around the web, confined with 500mm height around the section as shown in Figure 6.

GROUP (4): The models of this group are the same as the models in group (3) with different height. Where h=740 mm in the current group.

Table 2: Specimens Details for Group 1 and Group 2

Group No.	Shear Wall No.	Cross Section		H (mm)	R.F.T	Strengthening Materials	Scheme
		Flange	Web				
Group 1	C-I-Lw-R1	100*200	400*60	1100	6ϕ10	-----------	
	SG-I-Lw-R1-1					GFRP	1
	SG-I-Lw-R1-2						2
	SG-I-Lw-R1-3						3
	SG-I-Lw-R1-4						4
	SC-I-Lw-R1-1					CFRP	1
	SC-I-Lw-R1-2						2
	SC-I-Lw-R1-3						3
	SC-I-Lw-R1-4						4
	C-I-Lw-R2	100*200	400*60	1100	6ϕ12	--------------	
	SG-I-Lw-R2-1					GFRP	1
	SG-I-Lw-R2-2						2
	SG-I-Lw-R2-3						3
	SG-I-Lw-R2-4						4
	SC-I-Lw-R2-1					CFRP	1
	SC-I-Lw-R2-2						2
	SC-I-Lw-R2-3						3
	SC-I-Lw-R2-4						4
Group 2	Same as of Group 1, but the height of wall (H) is 740 mm						

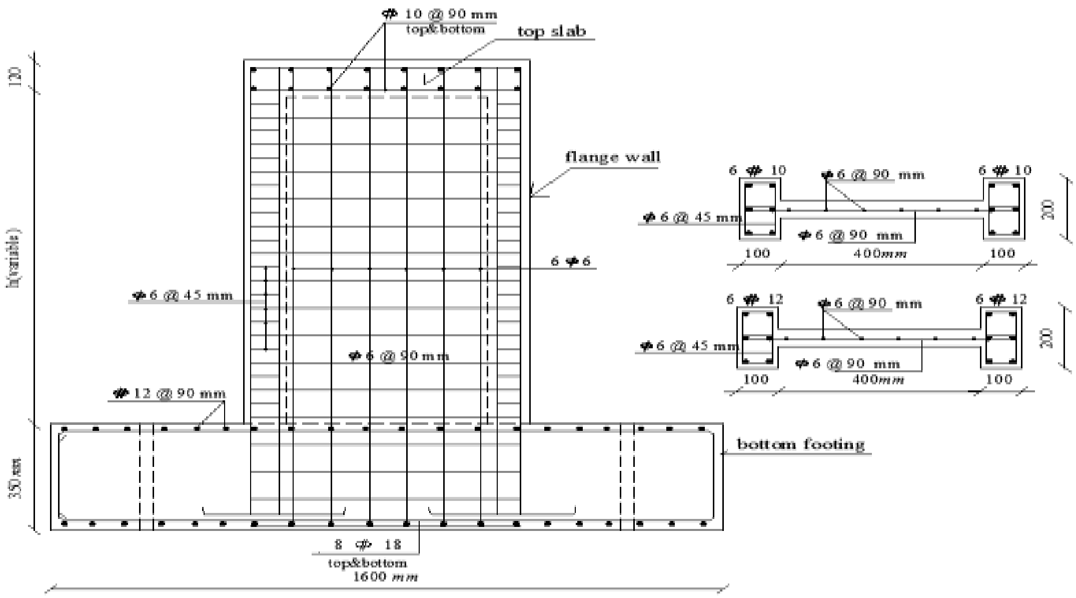

Figure 3: Concrete Dimensions and Reinforcement Details for Group (1) and Group (2)

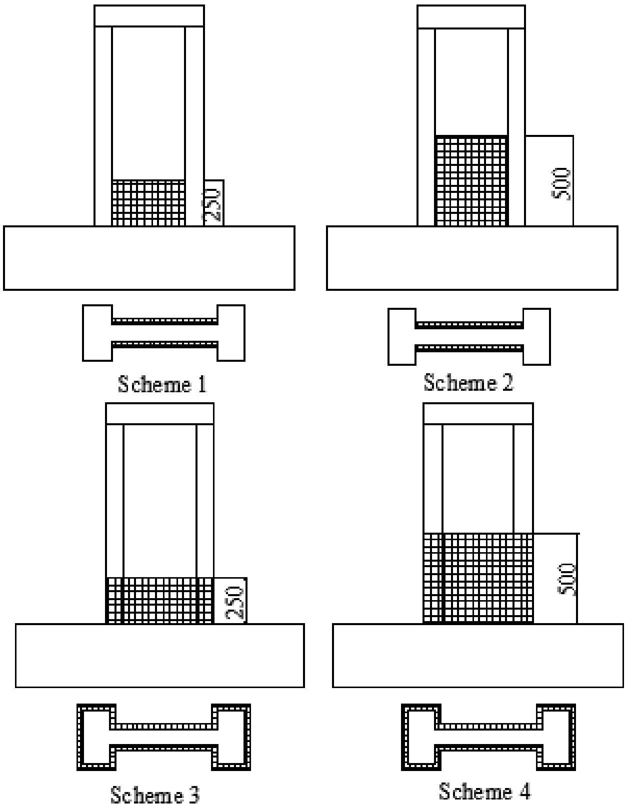

Figure 4: Scheme Types for Strengthening I- Shear Wall

Table 3: Specimen Details for Group 3 and Group 4

Group No.	Shear Wall No.	Cross Section (mm * mm)	H (mm)	R.F.T	Strengthening Materials	Scheme
Group 3	C-R-Lw-R1	600*100	1100	6ϕ10	------------	
	SG-R-Lw-R1-1				GFRP	1
	SG-R-Lw-R1-2					2
	SG-R-Lw-R1-3					3
	SG-R-Lw-R1-4					4
	SC-R-Lw-R1-1				CFRP	1
	SC-R-Lw-R1-2					2
	SC-R-Lw-R1-3					3
	SC-R-Lw-R1-4					4
	C-R-Lw-R2	600*100	1100	6ϕ12	------------	
	SG-R-Lw-R2-1				GFRP	1
	SG-R-Lw-R2-2					2
	SG-R-Lw-R2-3					3
	SG-R-Lw-R2-4					4
	SC-R-Lw-R2-1				CFRP	1
	SC-R-Lw-R2-2					2
	SC-R-Lw-R2-3					3
	SC-R-Lw-R2-4					4
Group 4	Same as of Group 3, but the height of wall (H) is 740 mm					

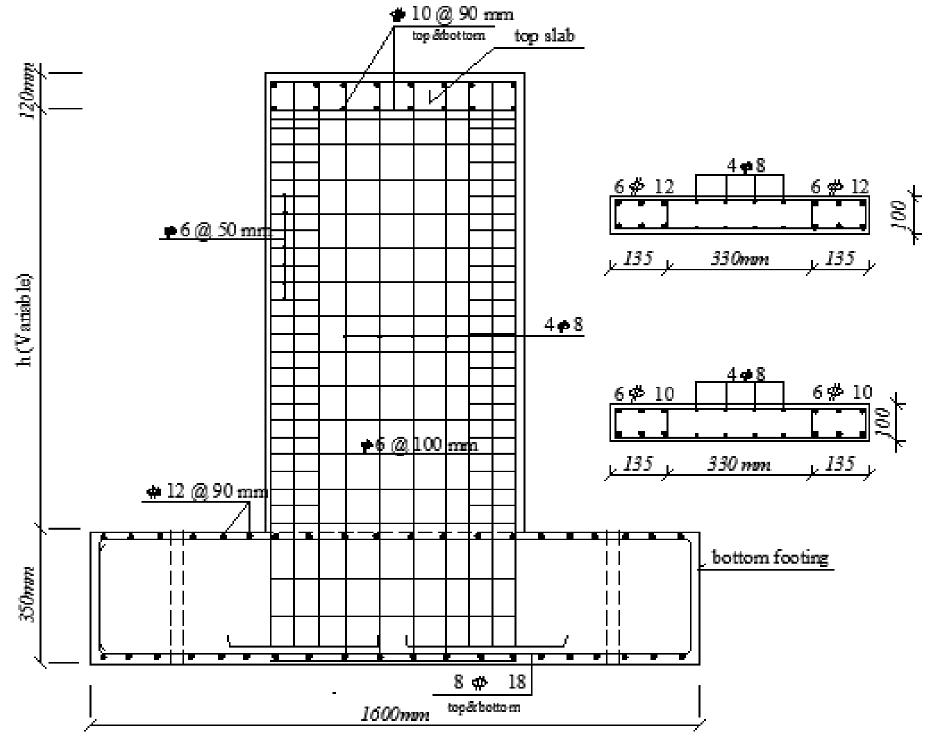

Figure 5: Concrete Dimensions and Reinforcement Details for Group (3) and Group (4)

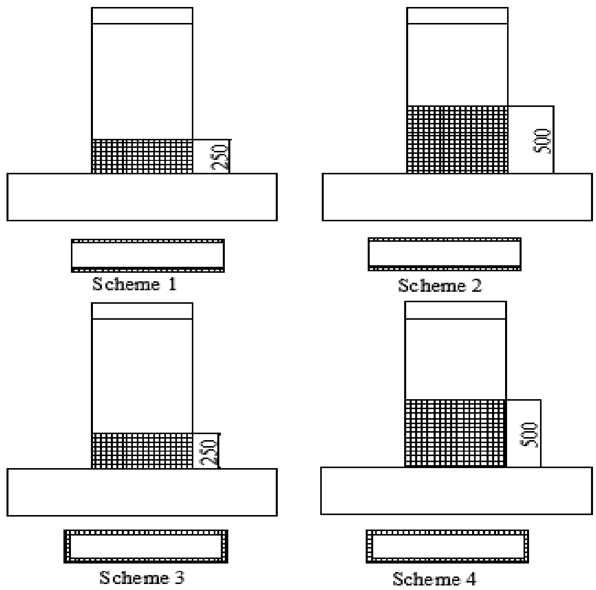

Figure 6: Scheme Types for strengthening Rec. - Shear Wall

3.1 Elements Used for F.E.M Analysis

SOLID65 is used to model the concrete material which is a 3-D modelling of solids with or without reinforcing bars (rebar). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The solid is capable of cracking in tension and crushing in compression.

LINK8 will be used to model reinforcement which is a 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions.

CONTA 174 is used to represent contact and sliding between 3-D "target" surfaces (TARGE170) and a deformable surface, defined by this element. The element is applicable to 3-D structural and coupled field contact analyses. TARGE170 is used to represent various 3-D "target" surfaces for the associated contact elements (CONTA174).

SOLID 46 FRP composites are modelled with 3D layered structural solid elements (SOLID46) having the same number of nodes and degrees of freedom as the concrete elements. The SOLID46 element allows for different material layers with different orientations and orthotropic material properties in each layer.

3.2 ANSYS modelling and meshing

Using the dimensions of each shear wall, a suitable mesh is constructed to simulate the RC shear wall so, the rectangular mesh is recommended [9] to get accurate results from the Solid 65 element, Therefore, the mesh was taken 50x50x50 mm as shown in Figure 7. The Nodes of steel reinforcement element was linking by the nodes of concrete solid element to ensure the perfect bond between materials. the reinforcement modelled in ANSYS as shown in Figure 6. Boundary condition is applied at the bottom face of shear wall foundation is modelled as a hinged support in x, y and z directions (zero displacement on all nodes at y = 0) and the top face of the RC shear wall is free movement.as shown in Figure 6

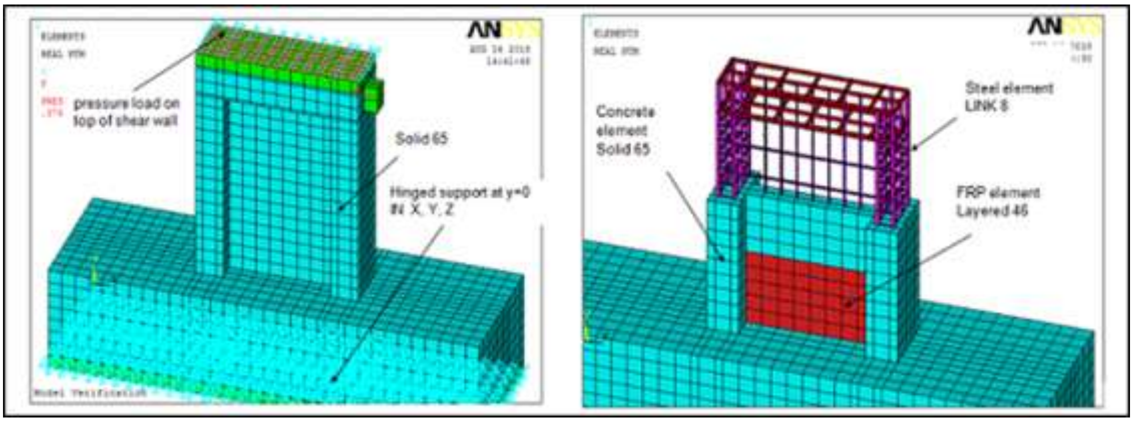

Figure 7: Boundary Conditions and Reinforcement Configuration

- **NUMERICAL ANALYISE RESULTS**

All shear walls are analyzed under combined action of a constant vertical load and horizontal loading increased loading till failure Specimens by using ANSYS. The results are including the failure load and corresponding lateral deflection and stress distribution to study the effect of each parameter on shear wall.

- **Effect of the strengthening scheme**

To study the effect of FRP scheme on strengthening a shear wall, four different scheme on the wall were compared. The following graphs related to load displacement curve for I- section and rectangular section with aspect ratio 1.83 and reinforced by 6ϕ12 in flange and strengthen with CFRP. The maximum specimen lateral strengths are shown in Figure 8 and Figure 9.

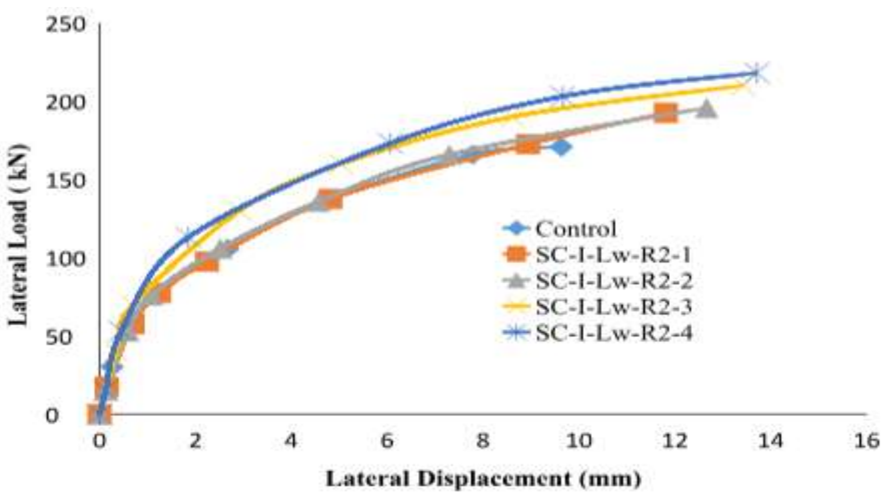

Figure 8: Load-Displacement Curve for I-Section.

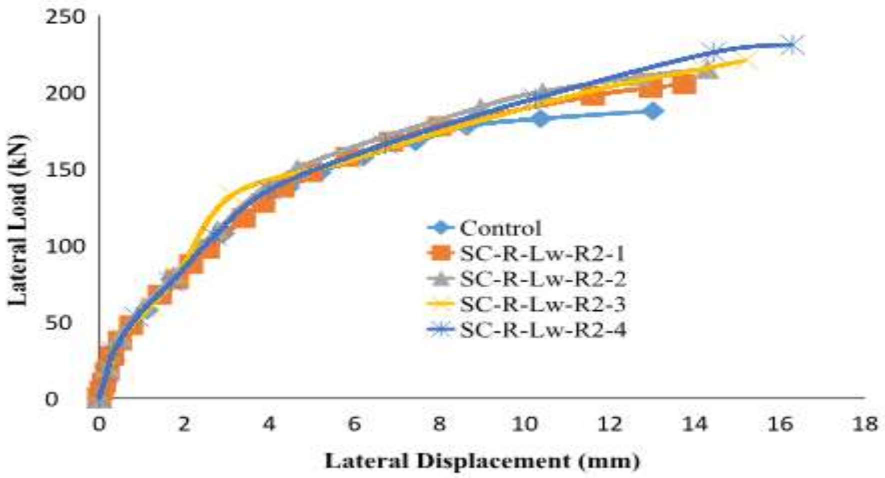

Figure 9: Load-Displacement Curve for Rectangular Section.

The capacities of I-Section shear walls are increased to be 113% and 123% for shear wall strengthening by applying one horizontal layer from Carbon Fiber Reinforced Polymer(CFRP) Sheets with height 250mm with different scheme where the first one is bonded around the web only, and the anther one bonded around all the faces of cross section respectively, when related to the same unconfined shear wall. Moreover, the capacities of I-Section shear wall are increased to be 115% and 127% for shear wall strengthening by applying one horizontal layer from carbon Fiber Reinforced Polymer(CFRP) Sheets with height 500mm.For Rectangular section the lateral strength increased by 109% and 117.67% For first and third scheme where it increased by 114.67% and 129.3% for second and fourth scheme.

Figure 10 and Figure 11 show the stress distribution and failure mode for specimens SC-I-Lw-R2-1 and SC-I-Lw-R2-4 respectively; the two specimens are in group 1 with the same aspect ratio and the same reinforced ratio in flange the change in the scheme it showed that specimens SC-I-Lw-R2-1 diagonal cracks and crushing in concrete in the web above the CFRP sheets and failure load was 192.5KNand for specimens SC-I-Lw-R2-4 the CFRP strips were debonded from the wall surface at tension zone and concrete crushing in flange above CFRP strips the ultimate lateral load was 218.03 Kn

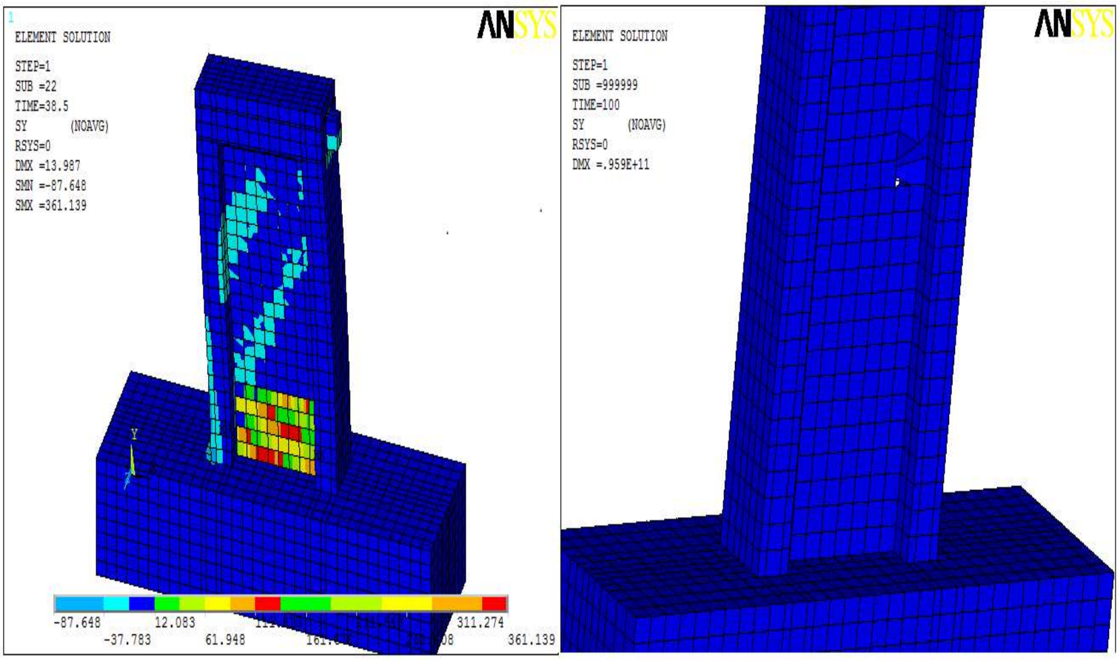

Figure 10: Stresses of Wall at Failure and Deformed Shape SC-I-Lw-R2

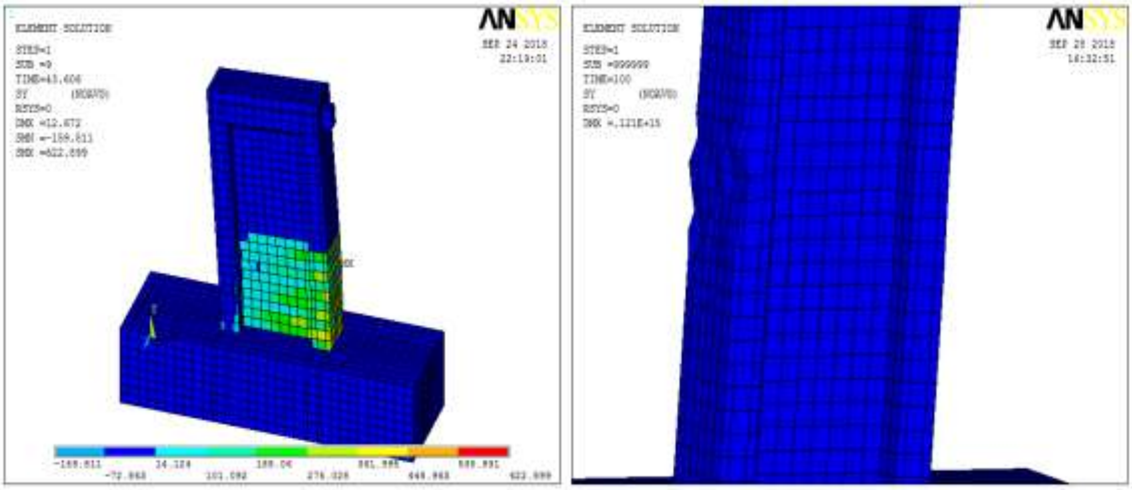

Figure 11: Stresses of Wall at Failure and Deformed Shape SC-I-Lw-R2-4

Figure12 and Figure13, show the stress distribution and failure mode for specimens SC-R-Lw-R2-2 and SC-R-Lw-R2-3 respectively; the two specimens are in group 3 with the same aspect ratio the change in the scheme it showed that specimens SC-R-Lw-R2-2 ruptured in CFRP at the ultimate load 215KN and for specimen SC-R-Lw-R2-3 The ultimate lateral load of specimen was measured 220.625 KN where the CFRP strips were debonded in tension zone and the larger area of crushing concrete.

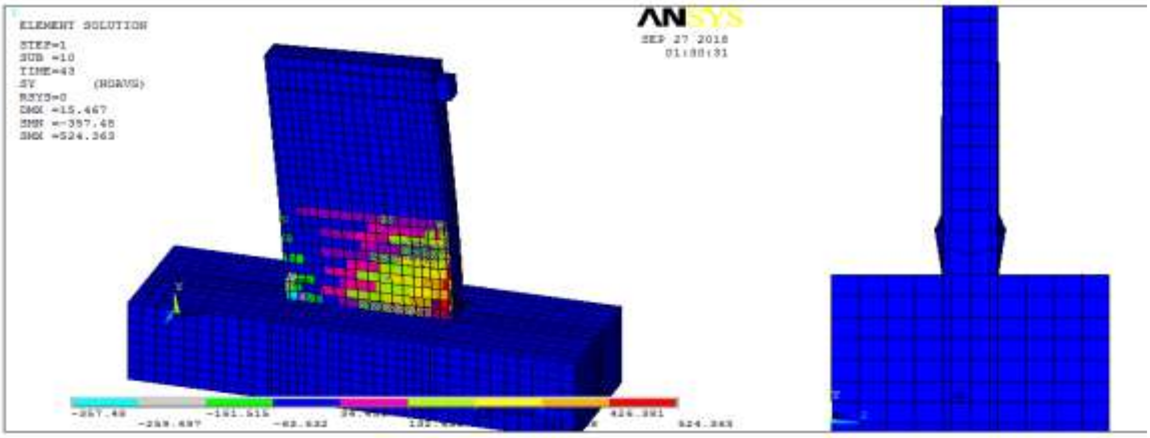

Figure 12: Stresses of Wall at Failure for SC-R-Lw-R2-2

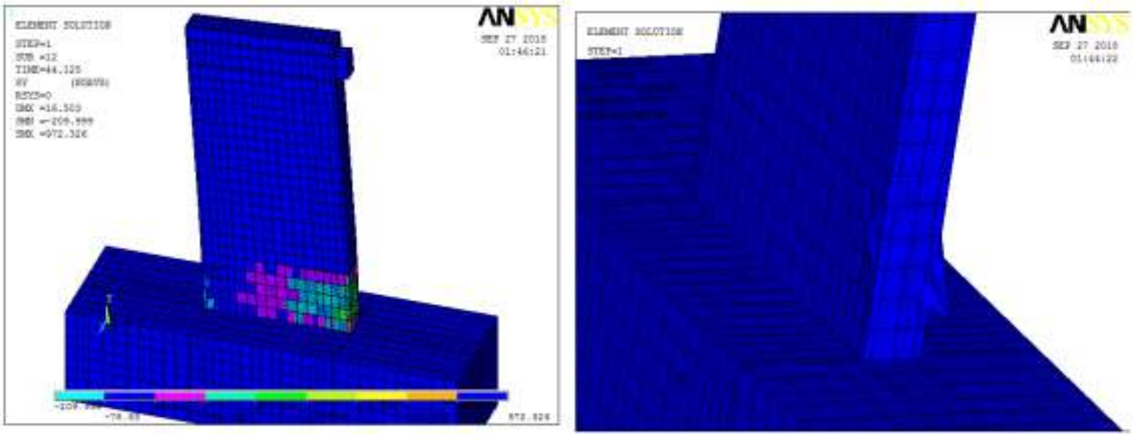

Figure 13: Stresses of Wall at Failure for SC-R-Lw-R2-3

- **Effect of Strengthening Material**

Two different materials are utilized in current study Glass fiber-reinforced polymers and Carbon fiber reinforced polymers Figure 14 shown the load displacement curve for two specimens in group 1 wrapped with the same scheme and it found that It is obvious that the CFRP increased the shear wall capacity more than GFRP, as I-section long wall confined by CFRP increases by 129% when related to the unconfined shear wall but the capacity of I-section long walls confined increases by 122% for shear wall confined by GFRP. The ductility of wall specimens (SC-I-Lw-R1-4) was increasing than the ductility of wall specimens (SG-I-Lw-R1-4) by 18.089% (Table 4). For the wall (SC-I-Lw-R1-4) which confined by using CFRP, the absorption of energy was more by 12.80 % than that of the wall (SG-I-Lw-R1-4) which confined by using GFRP.

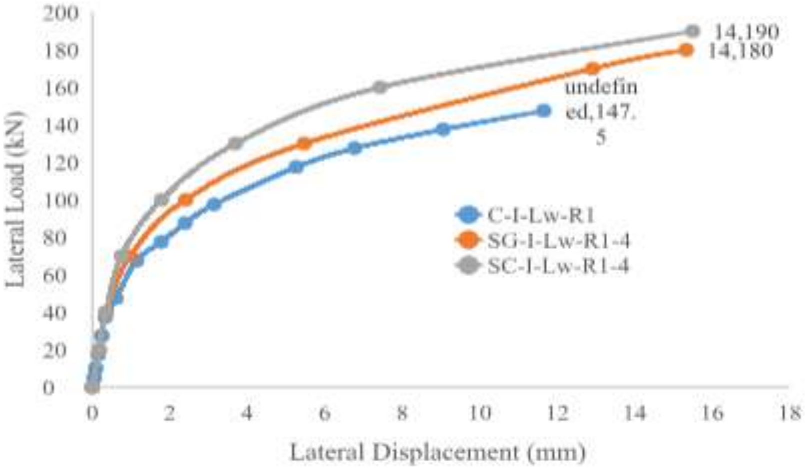

Figure 14: Load-Displacement Curve for I-Section Reinforced by (6ϕ10) Scheme 4

Table 4: FEM Results for Shear Wall

Shear wall (No.)	Ultimate Stage		Ductility Index	Energy Absorption (kN.mm)
	Load (kN)	Lateral Displacement (mm)		
Control	147.5	11.662	3.705	1196.504
SG-I-Lw-R1-4	180	15.338	5.307	1887.22
SC-I-Lw-R1-4	190	15.5	6.267	2128.815

- **Effect of Variation of Main Flexure Reinforcement**

Models in all groups are reinforced by two different types of vertical bars (6ϕ10), (6ϕ12). Figure 15 showed the load displacement curve for two specimens in group 1which strengthened by using GFRP and had the same height-to-width ratio and different steel ratio. It was observed that the increasing of main flexure reinforcement caused the increasing in ultimate lateral load, where the ultimate lateral top deflection of wall SG-I-Lw-R2-2 reinforced by 6ϕ12decreased by than the ultimate lateral top deflection of wall SG-I-Lw-R1-2 reinforced 6ϕ10 as shown in Figure 15. The ductility of SG-I-Lw-R2-2 decreased than the ductility of SG-I-Lw-R1-2

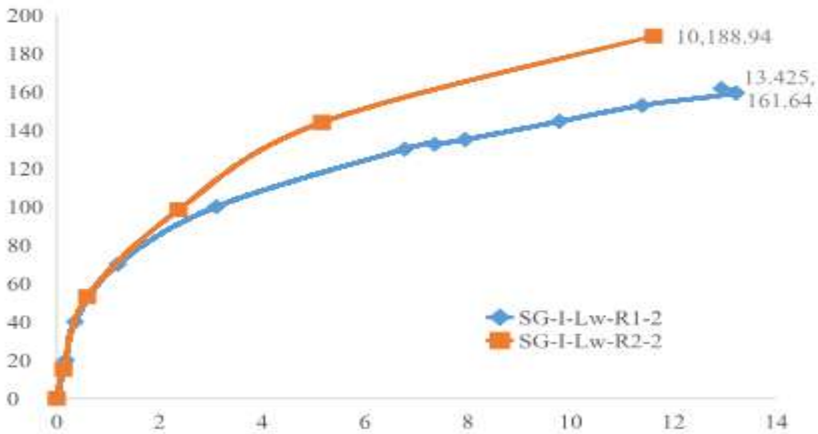

Figure 15: Effect of Variation of Main Flexure Reinforcement for Wall Strengthening by GFRP

Figure 16 showed the load displacement curve for two specimens in group 3 For wall C-R-Lw-R1 and C-R-Lw-R2 Which had the same cross section and the same height and had a different main flexure steel ratio, it is obvious that the wall C-R-Lw-R2 reinforced by (6 ϕ12) the shear wall capacity increased by than the wall C-R-Lw-R1 reinforced by, but the top lateral deflection of wall C-R-Lw-R2 was less than of the deflection of in wall C-R-Lw-R1. Increasing steel ratio decreased the ductility. It was noted also that the increasing of main reinforcement for wall C-R-Sw-R2, caused increasing energy absorption by than C-R-Sw-R1. Figure 17 shows the crack pattern two specimens wall C-R-Lw-R1 and C-R-Lw-R2 respectively it found that less amount of crack occurs in concrete due to increase the reinforcement ratio.

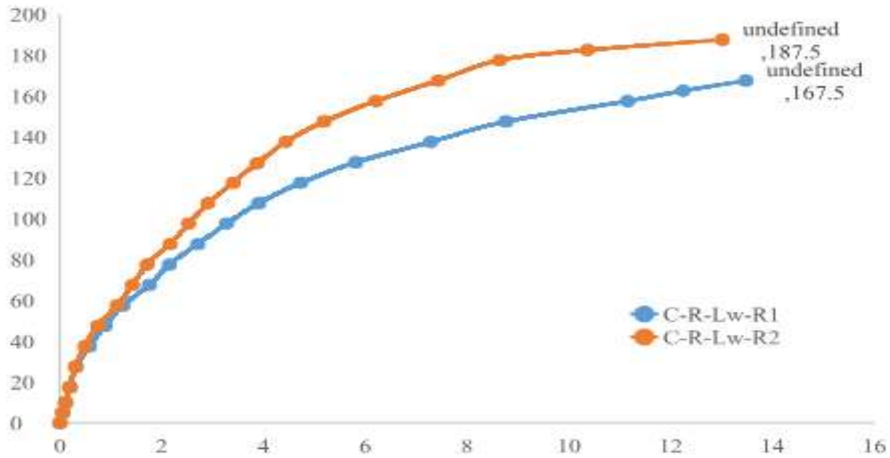

Figure 16: Effect of Variation of Main Flexure Reinforcement for Control Wall without FRP

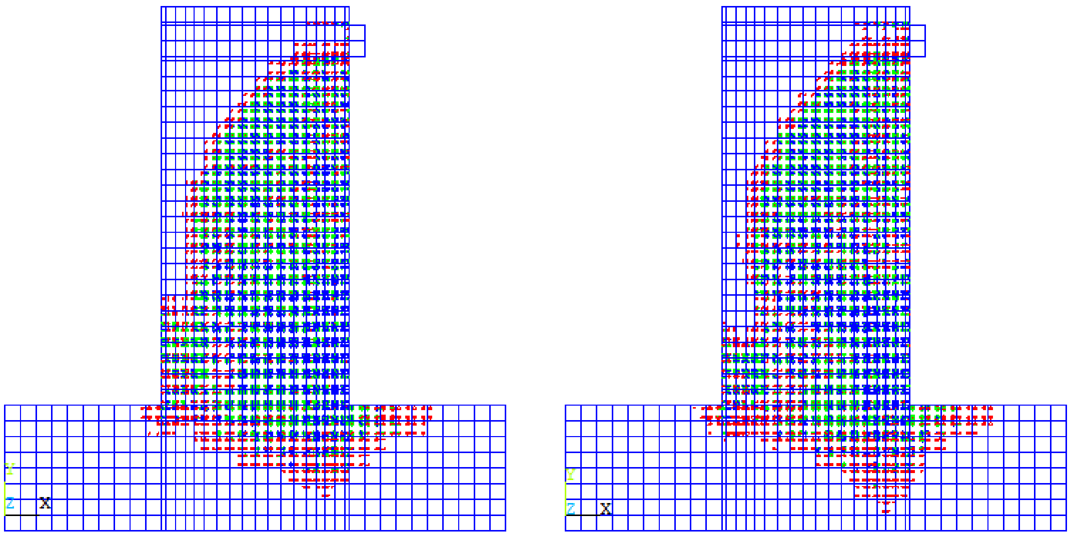

Figure 17: Crack Pattern for Specimens C-R-Lw-R1 and C-R-Lw-R2

- **Effect of Aspect Ratio (Height to Width)**

The Finite Element Models in group (1) which have I-section are the same as those in group (2) in all dimensions and reinforcement details except the shear wall height. Figure18 showed the load – deflection curve in which the height of wall changes from long wall with height 1100mm with aspect ratio 1.83 to short wall with height 740mm with aspect ratio 1.23, it is found that the ultimate carrying lateral load was increased for short wall than the long wall where the lateral top deflection for short wall decreased than that of lateral top deflection of long wall. The height to width ratio effects on the ductility of walls, the ductility of long wall specimens increased than the ductility of short wall specimens. Figure 19 show the deformed shape for short wall and long wall.

Figure 18: Effect of Aspect Ratio for Shear Wall Strengthened by CFRP and Reinforced by 6ϕ10

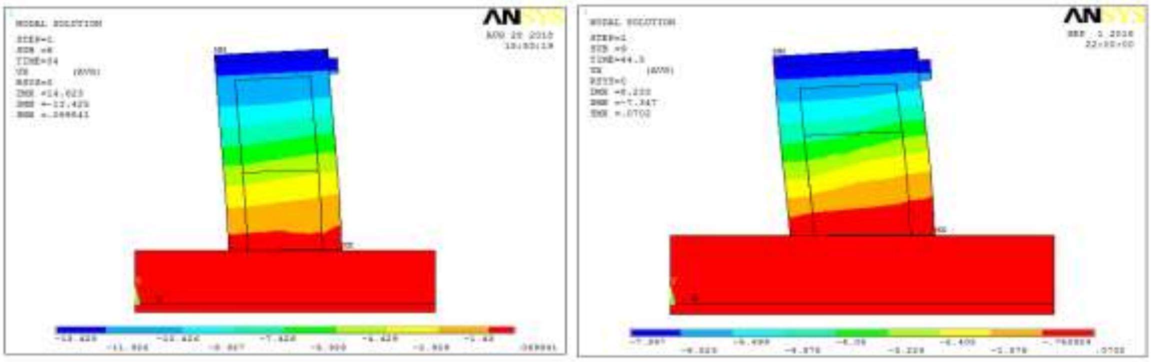

Figure 19: Deformed Shape for Long and Short Shear Wall Strengthened by CFRP and Reinforced by 6ϕ10

III. CONCULESIONS

From this present study, the following conclusions are obtained:

- There is significant increase in strength and ductility of reinforced concrete shear wall because of Fiber Reinforced Polymer (FRP) wrapping
- For I-Section long wall and short wall confined by CFRP the fourth scheme is the best effective scheme the lateral load increased to 127%and 161.5% and lateral displacement increased to142.36%and 182.52% the durability increased to 182.8% and 187.20% and absorption of energy is more by 195.85% and 340.52% when related to unconfined shear wall.
- Fiber Reinforced Polymer (FRP) wrapping is more effective for I-section shear walls than for Rectangular section shear walls
- The Carbon Fiber Reinforced Polymer (CFRP) increased the shear wall capacity more than Glass Fiber Reinforced Polymer (GFRP).
- Strengthening shear wall with Carbon Fiber Reinforced Polymer (CFRP) increasing the ductility index µd than ductility of walls strengthening with Glass Fiber Reinforced Polymer (GFRP).
- Decreasing the height-to-width ratio for I-section shear wall reducing the ductility index µd.
- Decreasing the height-to-width ratio caused higher values of the lateral load capacity but on the other hand it has decreasing lateral displacement.
- Generally, increasing the reinforcement ratio of high – strength shear walls reducing the ductility index µd.
- A significant increasing of the absorption of energy was observed for I –section long wall, which have height-to-width ratio of 1.83 more than that of the absorption of energy of short wall for control wall without FRP.

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