Seismic Rehabilitation of Strengthened Reinforced Concrete Exterior Beam-Column Joints Using FRP Composites

Mohammad Zeynali Moghaddam

[1.] Department of Civil Engineering, Islamic Azad University, Zahedan branch, Zahedan, Iran
yashar709@gmail.com

Abstract: Unsuitable performance of concrete joints are important factors of destruction of concrete structures due to earthquake; thus strengthening and improvement of concrete joints can be a good solution to overcome with these factors. In this research, reinforced concrete joints strengthened with FRP composites are investigated. Also, by ABAQUS software, the effect o fusing different kinds of polymer composites sheets (FRP) with different reinforcing models on bearing capacity and displacement of plastic hinge location at the same time. To do this, at first a concrete connection in ABAQUS software with a CFRP layer is reinforced according to lab specifications and after the comparison of the results of software with the already done lab specimen, validity and precision of the software performance was considered. Then, 58 specimens of reinforced concrete joints were modeled in two states of reinforced and non-reinforced by FRP sheets with different reinforcement models, in addition by considering the effects of length, along fibers, binding and the material of fiber (CFRP-GFRP) were considered and their final bearing capacity was determined. The results reveal that using FRP for shear strengthening and increasing bearing capacity can be a good choice to reinforce and treat the structures. Also, the results show the maximum bearing increasing of reinforced connection according to reinforcement model in all the connection as entirely.
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1. Introduction

Joints play important role in behavior of frame against lateral loads. When bending frame of reinforced concrete is influenced by lateral forces of earthquake, considerable sharing forces are created in its joints, creating these shearing forces is along with many deformations. Thus, the joints of reinforced concrete structures in addition to strength should have adequate ductility [1]. Major effect of joints on their structural behavior was observed after earthquakes of 1989 in Lomaprinta, 1994 Nourtrij, Kube in Japan and Turkey in August 1999. The investigation of damaged structures and the existing reports showed that the main reason of failure of damaged structures in these earthquakes were the failure of their joints.

The first laboratory researches about the behavior of reinforced-concrete beam-column joints in 1960 was done by American Portland cement society. The result of these researches was published in 1967 by Hansen and Conner [2]. In 1982, Ronald, Minhayt and Jirsa as the members of ASCE society, carried out a research about shear strength of reinforced concrete joints [2]. These researchers believed that the existing researches were not adequate to that time to present a value for shear strength of reinforced-concrete connection. In 1983, Ehsani and White published their research about the behavior of external reinforced concrete under seismic load [3]. In 2003, Pantazopoulou and Bonacci in their analysis studies responded some questions about reinforced concrete joints [4]. These researchers by investigating joints mechanic under lateral loads, proposed special formulation for the behavior of joints based on strains, similarity, and stresses equilibrium. In 1992, Ha et al investigated the response of joints made by high strength concrete against forward and return [5]. The study of the behavior of these joints, development of a new attitude for designing them and investigating the attracted energy in them are the major purposes of this research. In 1992, Tesunus et al studied about the seismic behavior of type 2 external joints in which traverse diagonal reinforcement was used in joint core[6]. In 1994, Lou et al in a laboratory research on the joints made with the scale of 1/1, investigated the details of tensile reinforcement in joints of corner of reinforced-concrete frames [7]. In 1994, Cramer and Shahruz investigated the seismic response of corner joints [8]. In this laboratory study, 4 corner joints were studied. The difference of these joints was in the details of connection execution. Scat is one of the researchers who carried out some studies about joints in 1996 to 2000 [9-11]. In 2004, Nahadi et al published an article about analytic solution to find the relation between cohesion and reinforcement s sliding in reinforced concrete joints [12]. In this comprehensive research, to investigate the behavior of reinforcement, the underlying differential equations were written. In 2009, Bing lee et al presented a valuable article about anchorage sliding of reinforcements under cyclic loads [13]. In this paper, an analytical model was presented to express the equation between force- displacement of reinforcement anchored in concrete. In 2010, the recent researches are related to internal joints done by Abdol and Busel [14] and after that at the same year (2010), some experiments were done to assess the joints under seismic loading under cyclic loading by Saloy and Marati and in these experiments, concrete connection with high performance reinforced with FRP were tested and maximum absorbed energy by FRP layers was dependent upon the type and the number of layers [15]. Other researches done about the reinforcement of joints are Bideh et al researches in 1997[16]. This research is published with the title of improving the properties of inductile joints in reinforced-concrete forms. Another method is used today to strengthen reinforced-concrete joints and it is FRP composites. There are various researches about using these materials in strengthening other structural components namely columns, but regarding the FRP- strengthened reinforced concrete joints by there aren't many researches such that the major researches in this regard dates back to 2000. In addition the existing researches are mostly related to Pantlaydez (2008), Moslem and Parvin (17). Moslem carried out many researches in California University about composites [18]. A part of researches of this researcher is about strengthening joints by composites. The major purpose of this research that is done in 2007 is the investigation of flexural strength and ductility of joints reinforced by FRP sheets. Another researcher whose researches about FRP-strengthened joints are more than others is an Iranian researcher and lecturer of Toldedo University in Ohayo city, Parvin. He and his colleagues, Granata, did many researches in this regard [19-20]. Besides these researches, a valuable research about analysis of FRP- strengthened reinforced concrete joints was done by Antonopoulos and Tanazis [21-22]. In this research, an analytic model is presented for FRP-strengthened reinforced concrete joints. By suitable plan of ductile flexural structural joints, failure of structures is avoided and its major reason of their failure is weakness in joints. The designer should design a limited joint area that its dimensions are determined based on the sizes of beam and columns connected to it, this small area receive various forces of beam and column. Thus, a joint should tolerate these forces along with its displacements and transfer them but the design of beam-column joints are difficult for civil engineers [2]. Researchers attempt in recent years is for strengthening to reinforce old buildings and it is for increasing the bearing capacity of reinforced concrete members caused that new solutions are presented in engineering science of treatment of structures that replacing new methods of strengthening to facilitate strengthening and increasing the capacity of structures caused that civil engineers consider FRP system. Most of the researches about strengthening and repair with FRP are focused on beam and columns and here less researches are done about reinforcement concrete joints that compromise the main framework and retaining of reinforced concrete structures against lateral loads and earthquake.

The properties of the element introduced for reinforcement behavior

To introduce longitudinal reinforcements, truss element is used. In this research, to model longitudinal and transverse reinforcements, T3D2 elements are used that are 3D, two nodes element with linear displacements and these elements are embedded in concrete elements and their behavior will be like them. This element is consisted of 3 translational degree of freedom and 3 rotational degree of freedom. Generally, truss element points are constrained in three translational degrees of freedom including (ux, uy, uz) and by this capability, supporting conditions are imposed on the specimens.

2. Modeling of anchorage sliding of rebar and concrete

Rebar sliding inside the concrete and stress change is an important fact that has considerable influence in final period of connection and final results. A good model to consider this influence in modeling limited components of joints is in ABAQUS software, model of defining constraints between concrete and rebar [23]. In this model, beam longitudinal reinforcement (in negative anchor area) in joint area, don't have total cohesion with concrete. Thus, it is necessary that these reinforcements are created in the connection area between nodes except concrete nodes and then the nodes of reinforcements connect to concrete nodes by the required constraints. To do this, in interaction area, embedded region is used. These modes and the required choices to define them are shown in figure (1).

The properties of the introduced element for FRP sheets

In this research, for modeling FRP, S4R element of SHELL elements family and General purpose are used. General purpose four-node shell element can reduce integral points to make the calculations minimum and reduce analysis time. As the effect of transverse shear is considered in this element, it can be used in models with thin and thick structures. This element is consisting of three translation degrees of freedom and three rotational degrees of freedom.

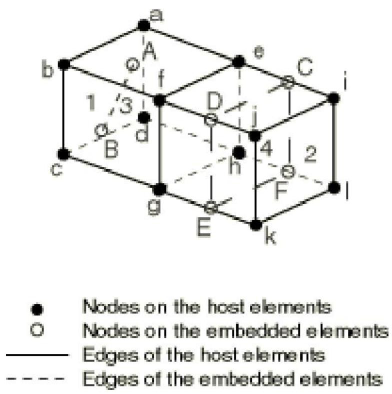


Figure 1- Common nodes to consider constraint

General properties of the built models

The first general property is the material of the substances defined in modeling:

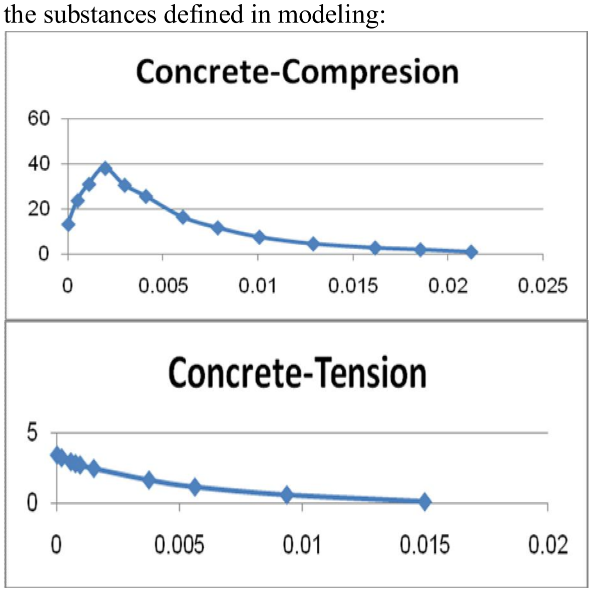


Figure 2- The material of substances used in concrete [23]

The concrete defined in modeling is with the strength of 38 Mpa. The defined reinforcements in the studied models are of two types. Longitudinal reinforcements are of reinforcements with high strength with yield stress 500 Mpa and transverse reinforcements are of normal reinforcements with yield stress 382MPa.

The properties of FRP sheets used for strengthening are considered according to reference [24-25] in table (1). In this research, the sheets used in reinforcement are 3mm thick. The metal sheets used in supports and loading place is made of steel with linear elastic properties and elasticity module 200000 MPa. FRP is modeled by S4R element and in this modeling non- isotropic material ANISO is used. To use FRP in different directions in models, the definition of local axles is used.

Table 1- Mechanical properties of FRP used in reinforcement of the studied specimens [24-25]

The type of material	Poisson ratio	Elasticity module (MPa)	Shear module (MPa)	Strength (MPa)
σ ult(ten)=2493 σ ult(comP)=1318 τ ult (12)=43.3	G_{12}=350 G_{13}=3500 G_{23}=2340	E_1=131600 E_2=8700 E_3=8700	$\nu_{12}=0.33$ $\nu_{13}=0.33$ $\nu_{23}=0.3$	CFRP Laminate
σ ult(ten)=1280 σ ult(comp)=525 τ ult(12)=48.6	G_{12}=5600 G_{13}=5600 G_{23}=3740	E_1=49500 E_2=15900 E_3=15900	$\nu_{12}=0.26$ $\nu_{13}=0.26$ $\nu_{23}=0.3$	GFRP Laminate

Figure 4 shows general view of supporting conditions and loading in this research. In these figures, vertical load as constant values P2 and horizontal load P1as statistics at the end of column till the failure of connection are imposed gradually on the specimen, they are imposed on the model as loading steps and sub steps and they are entered as cyclic chart on ABAQUS software (Figure 3). To avoid stress concentration in supports and load imposing location, steel plates are used.

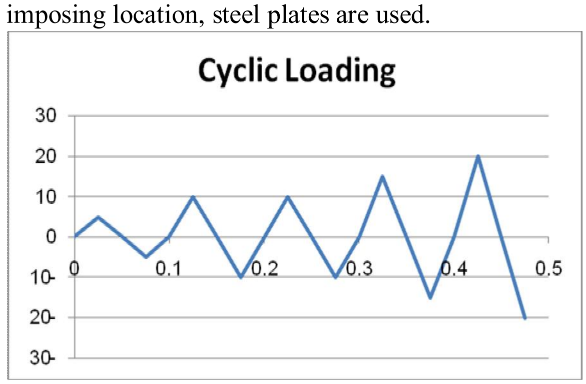


Figure 3- The load imposed on the set in reference point of rigid material [26]

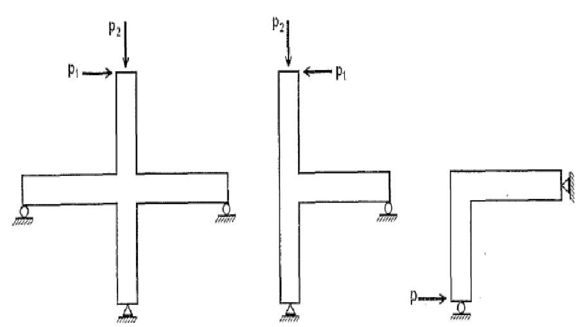


Figure 4- Loading method and support conditions in the modeling

Reinforced specimens of external joints

To name reinforced external joints, we used "E" for simplicity and the subscript indicates the number of joint.

E_1-E_{14} joints: (First type strengthening model)

E_1-E_{14} joints are shown in figure 5, also the method of naming is indicated in table 2. The sheets are used in L form in angle of beam and column in three different lengths. 200 mm length that is the half of measurements of beam and column cross section. The length 400mm that is equal to the dimensions of beam and column cross section and the length 600mm that is near to the required length of regulation for joint region.

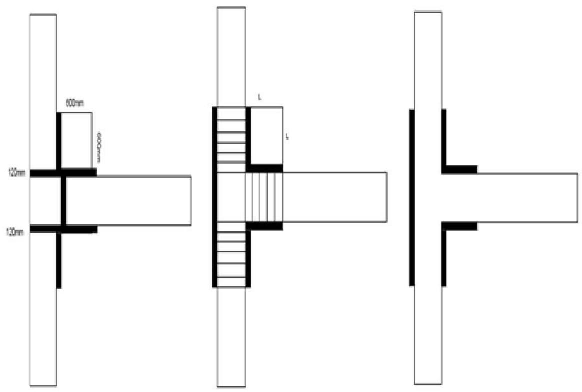


Figure 5- The specimen of strengthened external joints E_1-E_{14}, before and after beam and column wrapping

Table 2- The properties of E_1-E_{14} strengthened specimens

Name	E1, E7	E2. E8	E3, E9	E4, E10	E5, E11	E6, E12
Type of material	CFRP laminate	CFRP laminate	CFRP laminate	GFRP laminate	GFRP laminate	GFRP laminate
L(mm)	200	400	600	200	400	600

Table 3- The properties of E_{22}-E_{33}strengthened specimens

Name	E22, E28	E23. E29	E24, E30	E25, E31	E26, E32	E27, E33
Type of material	CFRP laminate	CFRP laminate	CFRP laminate	GFRP laminate	GFRP laminate	GFRP laminate
L(mm)	200	400	600	200	400	600

E_{15}-E_{21} joints: (Type 2 strengthening model)

Fibers direction is shown in figure 6. It is worth to mention that in E_{21} specimen, we changed the direction of fibers and we investigate its effect in joint performance. In E_{21} specimen, the used sheets are of carbon. It is expected that E_{21} specimen bearing is reduced in comparison with E_{17}, as there is one good solution to avoid extension of cracks after the strengthened length.

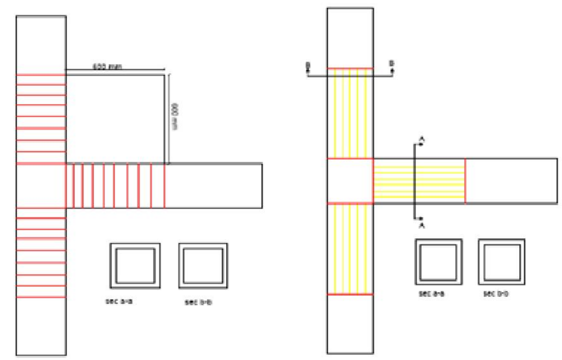


Figure 6- The specimen of E_{15}-E_{21} external strengthened joints

E_{22}-E_{33}joints: (Type 3 strengthening model)

In definition of these specimens, the sheets used in the sides of beam and column are uniform. The reinforcement method and placement of fibers are shown in figure 8. Table 3 shows the properties of reinforcement used in E_{22}-E_{33} specimens.

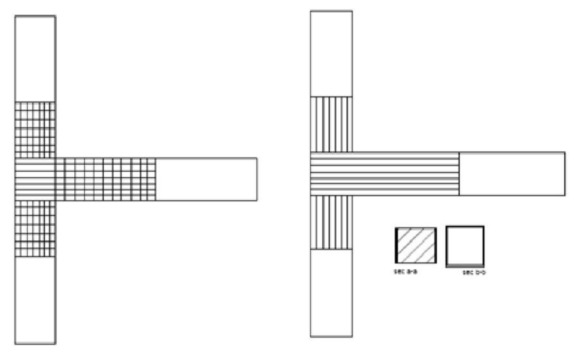


Figure 7- The specimen of strengthened external joints E_{22}-E_{33}, before and after beam and column wrapping

E_{34}-E_{45}joints: (Type 4 strengthening model)

In defining specimens like previous specimens, FRP sheets are used in the sides of beam and column in joint region with this difference that in this case, sheets of beam and column of joint are not uniform and strengthening in beam and column is done separately. It is obvious that this strengthening can be in external frames.

3. Results

The first conclusion of the specimen's analysis is load- displacement curves of the specimens. The following figures show some of these curves for strengthened specimens made of carbon and glass separately beside the basis specimen. Viewing load- displacement curves, it is seen that the discussing curves are consisted of some sections that shows joint condition in different cycles of loading. The first section of curves is linear and it shows linear behavior of joint before cracking. The second section of joint behavior curve is linear and this behavior is considered as joint behavior after concrete cracking and before tensile reinforcement's yield of beam. Partial jumps in this part of curve, normally don't lead into complete change in the slope of load-displacement curve of joint and then we observe sudden drop of curve to return and start next cycles. This section is related to non- elastic displacements of beam tensile reinforcements. The summary of results for external joints specimens is shown in table 4. The first issue is the investigation of final load in joints failure moment, the second issue is the final displacement like final load.

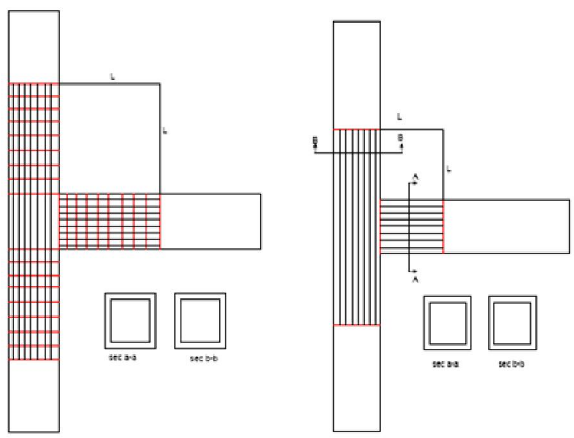


Figure 8- The specimen of strengthened external joints E_{33}-E_{45}, before and after beam and column wrapping

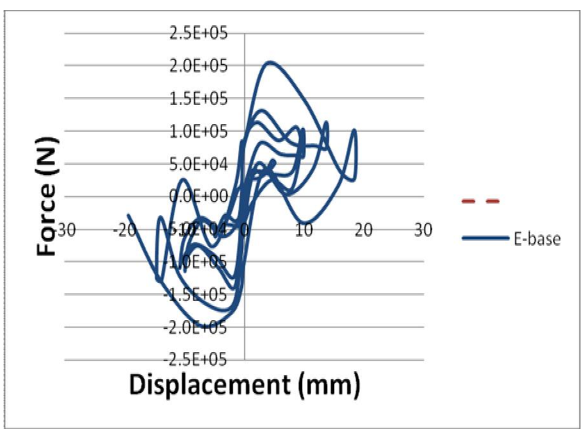


Figure 9- Behavior curve of lateral non-strengthened joint

Strengthening concrete joints according to first type reinforcement model in comparison with the non-strengthened specimen increased the bearing capacity of joint1 to 21%. Also, the maximum increased in final strength in this model is occurred in E_3 specimen that is equal to 248. 917 KN. Behavior curve of these specimens show that stiffness, bearing capacity and final displacement in this strengthening model are improved considerably.

Table 4- non-linear results for strengthened external joints

Type of joint	Final load		Final displacement
	Value (P) (KN)	Changes (%)	Value (mm)
E-base	205.362	0	4.912
$E_{1-L200-CF}$	231.342	13.5	3.610
$E_{2-L400-CF}$	239.885	17.73	3.6
$E_{3-L600-CF}$	248.917	20.9	3.589
$E_{4-L200-GF}$	205.995	1	3.611
$E_{5-L400-GF}$	219.172	6.82	2.608
$E_{6-L600-GF}$	235.627	14.6	3.607
$E_{7-L200-CF}$	259.275	26.3	3.611
$E_{8-L400-CF}$	270.428	31.7	3.607
$E_{9-L600-CF}$	285.277	39.04	3.606
$E_{10-L200-GF}$	251.444	22.43	3.611
$E_{11-L400-GF}$	260.014	26.82	3.609
$E_{12-L600-GF}$	276.769	34.63	3.608
E_{13-CF}	295.008	43.9	3.608
E_{14-GF}	278.168	35.60	3.606
$E_{15-L200-CF}$	235.883	14.6	3.612
$E_{16-L400-CF}$	239.986	17.74	3.611
$E_{17-L600-CF}$	250.710	21.95	3.608
$E_{18-L200-GF}$	229.800	12.09	3.611
$E_{19-L400-GF}$	238.518	16.09	3.609
$E_{20-L600-GF}$	247.877	20.48	3.608
$E_{21-L600-CF}$	222.402	8.29	3.610
$E_{22-L200-CF}$	286.375	39.51	3.609
$E_{23-L400-CF}$	310.743	51.21	3.608
$E_{24-L600-CF}$	339.594	65.36	3.605
$E_{25-L200-GF}$	274.212	33.65	3.610
$E_{26-L400-GF}$	302.683	47.31	3.609
$E_{27-L600-GF}$	328.444	60	3.607
$E_{28-L200-CF}$	324.701	58.04	3.6
$E_{29-L400-CF}$	330.883	60.97	3.585
$E_{30-L600-CF}$	341.411	66	3.568
$E_{31-L200-GF}$	315.209	53.65	3.611
$E_{32-L400-GF}$	328.151	60	3.609
$E_{33-L600-GF}$	336.620	63.9	3.606
$E_{34-L200-CF}$	271.028	32.19	3.610
$E_{35-L400-CF}$	286.522	39.52	3.609
$E_{36-L600-CF}$	304.332	48.29	3.608
$E_{37-L200-GF}$	266.061	29.75	3.610
$E_{38-L400-GF}$	278.917	36.09	3.610
$E_{39-L600-GF}$	289.165	40.97	3.609
$E_{40-L200-CF}$	283.750	38.04	3.610
$E_{41-L400-CF}$	297.458	44.87	3.609
$E_{42-L600-CF}$	319.258	55.61	3.608
$E_{43-L200-GF}$	269.025	31.21	3.610
$E_{44-L400-GF}$	288.903	40.48	3.609
$E_{45-L600-GF}$	306.394	49.26	3.608

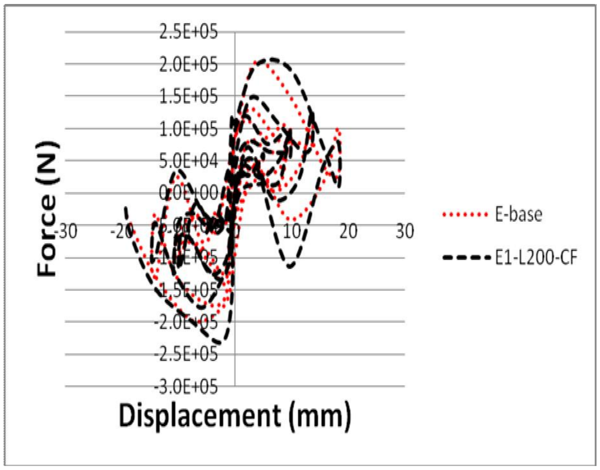


Figure 10- Behavior curve of external joint strengthened by CFRP sheets with the length of 200 mm

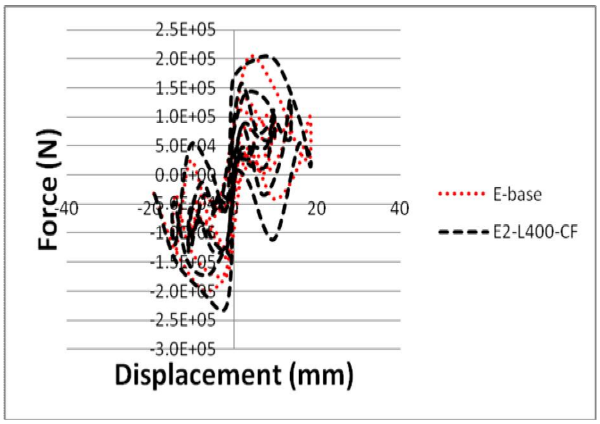


Figure 11- Behavior curve of external joint strengthened by CFRP sheets with the length of 400 mm

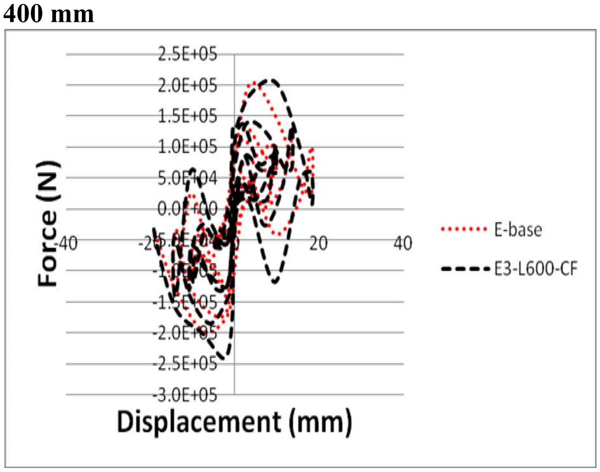


Figure 12- Behavior curve of external joint strengthened by CFRP sheets with the length of 600mm

It is worth to mention that for other specimens we only resort to the investigation of the their results and explain as model by model:

Strengthening concrete joints according to the strengthening model (E7-E14) in comparison with the non-strengthened specimen increases 22 to 43% the bearing capacity of joint. Also the maximum increase in final strength in this model is occurred in E_{13} specimen that is equal to 295008KN. Also, strengthening specimen by FRP strop gives some similar results with FRP wrapping and the only difference is in easy execution of strop to wrapping.

Strengthening concrete joints according to type 2 strengthening model increases 12 to 21% of bearing capacity of joint. Also, the maximum increase in final strength in this model in strengthened specimen with CFRP and the length of 600mm and KN is 250. 710. It is worth to mention that in E_{21} specimen, as it was predicted, due to the fact that direction of fiber despite previous specimens was parallel to shear cracks, we saw weaker performance and less bearing capacity in this specimen.

Strengthening concrete joints according to type 3 strengthening model (E22-E27) increases 33 to 65% of bearing capacity of joint. Also, the maximum increase in final strength in this model in E_{24} model and KN is 339. 594. Behavior curve of these specimens shows that stiffness, bearing capacity and final displacement in this strengthening model are improved considerably.

Strengthening concrete joints according to strengthening model (E28-E33) increases 53 to 66% of bearing capacity of joint. Also, the maximum increase in final strength in this model in strengthened specimen with CFRP at the same time with wrapping with the length of 600mm and its final strength is 341.411KN. Behavior curve of these specimens shows that stiffness, bearing capacity and final displacement in this strengthening model is improved considerably.

Strengthening concrete joints according to type 4 strengthening model in comparison with non-strengthened specimen increases 29 to 49% of bearing capacity of joint. Also, the maximum increase in final strength in this model is occurred in E_{36} model and it is 304.332 KN. Behavior curve of these specimens shows that stiffness, bearing capacity and final displacement in this strengthening model are improved considerably in comparison with the previous model that strengthening is uniformly in all over the beam and column and joint core.

Strengthening concrete joints according to strengthening model (E40-E45) increases 31 to 55% of bearing capacity of joint. It is worth to mention that the results in this model are similar to the strengthening model of the previous type in which strengthening was used in all over the beam and column as entirely with a little difference in final bearing capacity of specimens. Also, the maximum increase in final strength in this model is occurred in E_{42} specimen that is 319.258 KN.

E_1-E_{14} joints

Considering the investigation of performance of specimens, it is observed that by the strengthening used in E_1-E_{14} specimens in the form of L, behavior properties of joints such as bearing capacity and final displacement are improved and the results of analysis are shown in table 4. In basis joint, due to the fact that there is weak beam- strong column, critical section is located at the end of beam and is exactly located beside the column. By considering strain of beam tensile reinforcement in this joint, such issue is observed.

By using sheets in form of L, two important influences are created on the behavior of joint. The first important effect is reducing strain of reinforcement in the final section of beam. This effect is similar to the influence of percentage of beam tensile reinforcements. The second effect that placement of composite layers affects the behavior of joint such that, is location change of critical section. Critical section is the section in which the maximum longitudinal reinforcement strain occurs. In these specimens joint failure is occurred still in the beam. By comparing cracking and investigation of tensile reinforcements strain, it is obvious that critical section is occurred for basis connection beside the column and for connecting E2 in strengthening length in the form of L.

Considering behavior curves of figure 13 and the results presented in table 4, it is seen that increasing behavioral properties such as final bearing and final displacement in CFRP-strengthened specimens, were more considerable than GFRP-strengthened specimens.

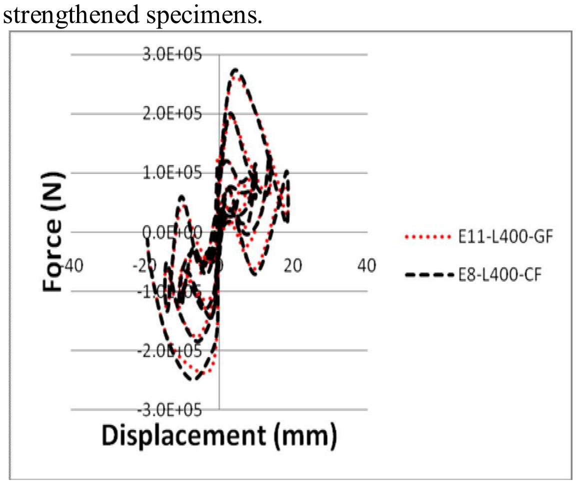
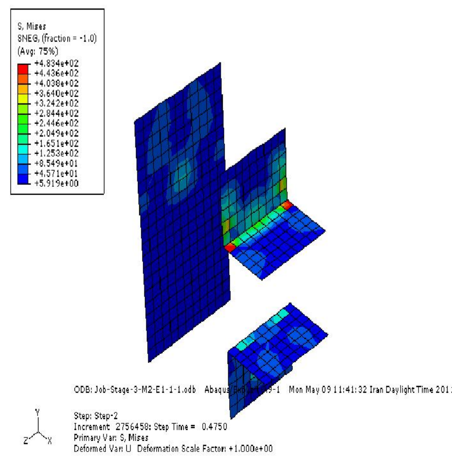
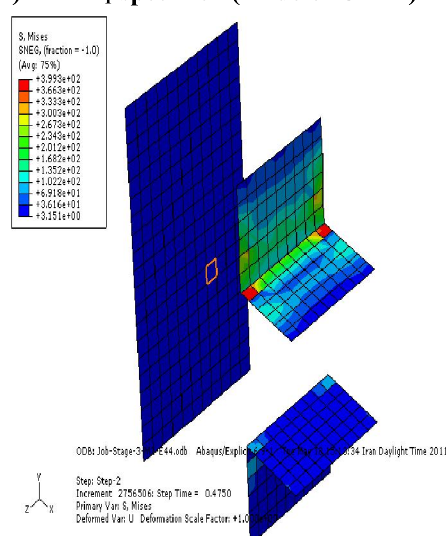


Figure 13- The comparison of the chart of specimen E_8 as strengthened by CFRP sheets and E_{11} specimen by CFRP sheets.

This difference is justified by investigating the stresses created in FRP sheets. Due to the difference in mechanical properties of some sheets of carbon and sheets made of glass, the stress values are different. The major reason of this difference is due to higher elasticity module in the direction of CFRP fibers in comparison with GFRP. For example, in figure 14, the created stresses in FRP sheets in direction of X (beam axle) for E1 specimen in which CFRP sheets are used and E4 specimen in which GFRP sheets are used for strengthening are compared. Considering the stress values in figure 14, it is shown that the created tensile stresses in sheets made of carbon have great values and due to this great number of stress of beam tensile reinforcement beside column are reduced and they have better performance of CFRP-strengthened specimen (E1 specimen) in comparison with GFRP-strengthened specimen (E4 specimen).



(a) E_1 specimen (made of CFRP)



(b) E_4 specimen (made of GFRP)

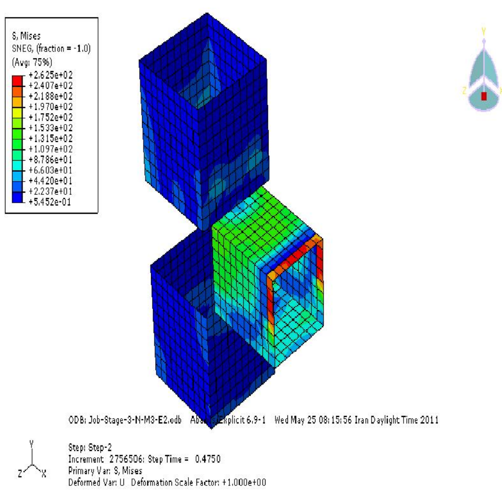
Figure 14- The stressed created in FRP sheets in E_1 and E_4 along beam axle (Mpa).

It is worth to mention that by increasing loading in these specimens, yield region is approached gradually to the edge of column and strain of beam tensile reinforcements is increased on the column and yield region is extended to inside the joint core and by increasing cracking in joint region, joint failure is caused. Considering the drawn curves the results presented in table 4, it is seen that by increasing the length of strengthening of FRP sheets of 200mm to 400mm and 600mm, bearing capacity and final displacement of the specimens are improved.

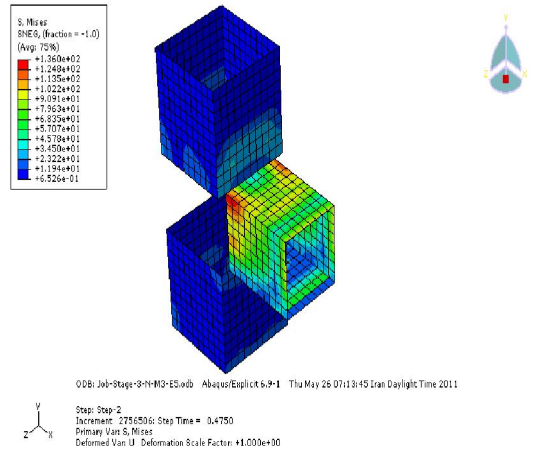
E_{15} and E_{21} joints

In these specimens, due to the presence of strengthening sheets in beam and column as it was seen in E_1-E_{12}, critical section in some of the specimens is not transferred to the region after the column, with this difference that due to avoiding the increase of the depth of cracks created in critical section, in some stages of loading due to using some sheets in two sides of beam, bending displacements of beam around critical section of their similar E_1,E_4 specimens are limited (where only L shape sheets with the length of 200mm are used). This issue is clarified by investigating the stresses created in the sheets used in two sides. For example, figure 15 shows the condition of stresses created in direction of beam axle in FRP sheets in E_{16} and E_{19} specimens.

Thus, as it is shown in load-displacement curves of these specimens, although stiffness and bearing of specimens are increased in comparison with L shape specimens without wrapping (E_1 to E_6) but critical section is created beside the column.



(a) E_{16} specimen



(b) E_{19} specimen

Figure 15- The stresses created in FRP sheets in E_{16} and E_{19} specimens along beam axle (MPa)

As it is shown in figure 16, in this stage of strengthening in E_{16} specimen, direction of fiber is changed and its effect is compared with the similar specimens in the form of hysteresis curves that is shown in the following.

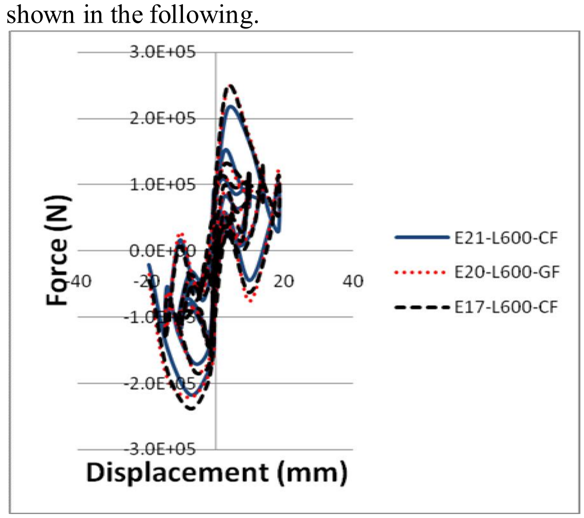
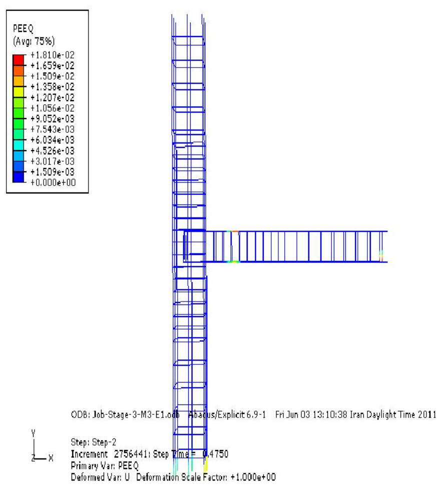


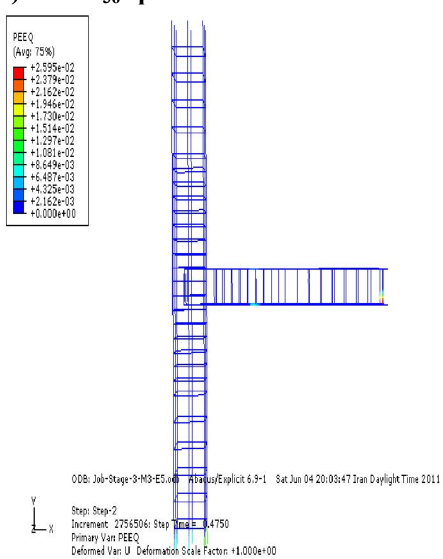
Figure 16- The comparison of E_{17}, E_{20} and E_{21} specimens (The investigation of the effect of material and changing the direction of fiber)

E_{34} and E_{45} joints

The results of analysis in these kinds of joints show that in some stages of loading, we see beam bending displacement around critical section in comparison with previous specimens. These issues are tangible by investigating cracking and strain of reinforcements in these joints (Fig. 17).

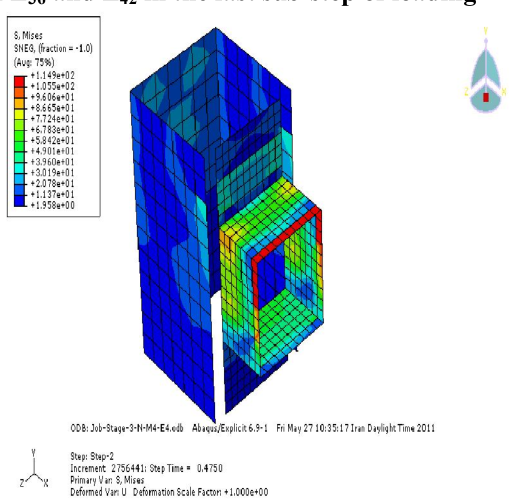


(a) E_{36} specimen

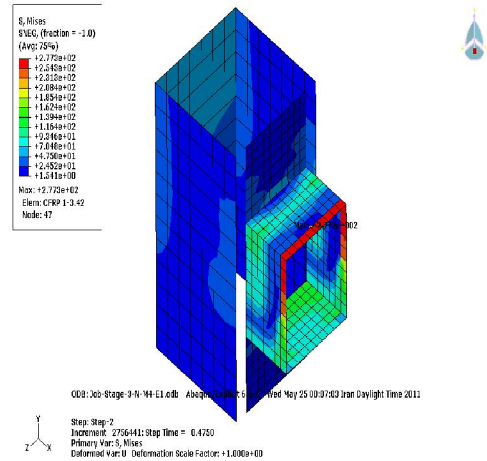


(b) E_{42} specimen

Figure 17- The strain of created plastic in the joint of E_{36} and E_{42} in the last sub-step of loading



(a) E_{34} specimen (made of carbon)



(b) E_{37} specimen (made of glass)

Figure 18- The stresses created in FRP sheets in E_{34} and E_{37} specimens along beam axle (MPa)

Figure 18 shows the condition of stresses in FRP sheets in these specimens. It is seen that carbon sheets attracted more stress in comparison with glass sheets. Also, the condition of flowing longitudinal reinforcements as specimen for $E_{36}$and E_{42} in the final stage of loading in figure 18.

Behavior curve of these specimens shows that stiffness, bearing capacity and final displacement are improved. For example, in figures 19 and 20, load-displacement curves of some specimens are compared that are shown as the followings.

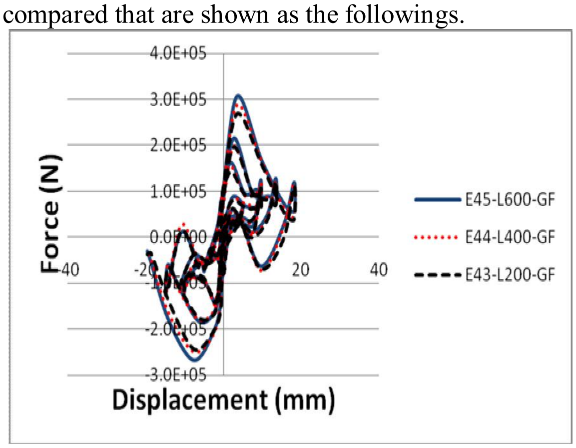


Figure 19- The comparison of the effect of length in E_{43}, E_{44} and E_{45} specimens

Considering the above figures, the change in stiffness of joints is tangible. It is shown that by increasing the length of strengthening of 200 mm to 400 mm and 600 mm, bearing capacity and final displacement of the specimens are improved. While, strengthening specimen is wrapped, this increasing trend is improved. Also, in strengthening with CFRP sheets in comparison with GFRP, more stiffness and bearing are observed.

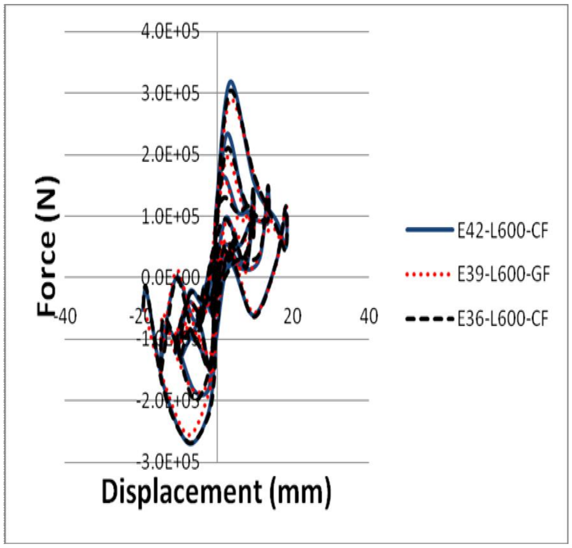


Figure 20- The comparison of the effect of FRP wrapping and length and material of sheet in E_{36}, E_{39} and E_{42} specimens

4. Conclusion

By considering structure component including connecting of a flexural frame and investigating the effects of strengthening by CFRP and GFRP sheets on it we find different results. Of these results we can refer to the increase of bearing capacity of the specimens. In the strengthening in the existing joint in inner frame, to 22% (in E17 specimen) and in external frame to 66% (in E30 specimen) we observed bearing capacity increase in comparison with basis specimen. Also, final displacement at the end of column is increased in strengthened specimens in comparison with basis specimen that according to table 4 to 28% was observed in the existing joints. As it is shown in the investigation of the results of joints analysis, the values of created stresses in the sheets, in CFRP-strengthened specimens are greater than GFRP-strengthened specimens and it is due to the great value of elasticity module of carbon sheets in comparison with glass sheets. Thus, in CFRP-strengthened specimens have better behavior in comparison with GFRP –strengthened specimens. For example, in E22 specimen (CFRP-strengthened sheets) and E25 (GFRP –strengthened specimens) that shape and strengthening length are similar and the only difference is in the material of sheets. Bearing capacity is increased respectively 40% and 33.65 %. It is worth to mention that these conclusions for other specimens are like this.

- By strengthening in basis specimen, increasing trend of stiffness, bearing capacity and final ductility are increased.

The results of this research show that strengthening by fiber composites (FRP) can increase some loads such as cracking and final yield considerably and it is effective in increasing energy loss and opening hysteresis loops.

Corresponding Author:
Mohammad Zeynali Moghaddam
Islamic Azad University,
Zahedan branch
Zahedan
Iran
E-mail: yashar709@gmail.com

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