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

Mohammad Zeynali Moghaddam

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.

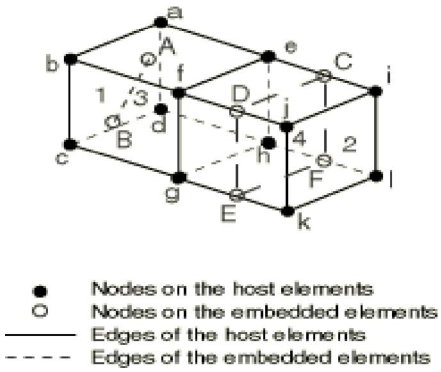


Figure 1- Common nodes to consider constraint

General properties of the built models

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

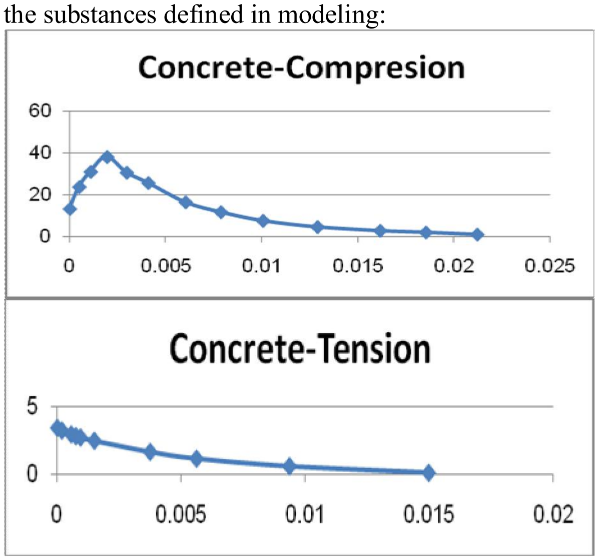


Figure 2- The material of substances used in concrete [23]

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.

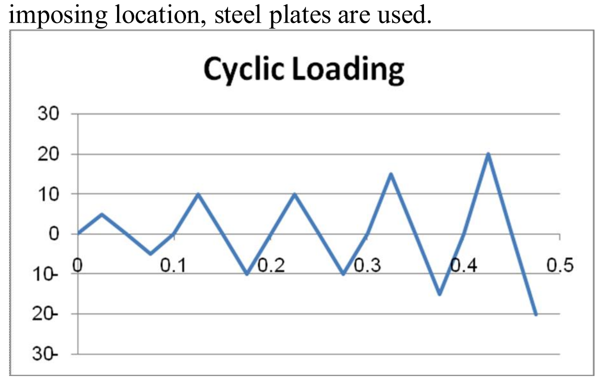


Figure 3- The load imposed on the set in reference point of rigid material [26]

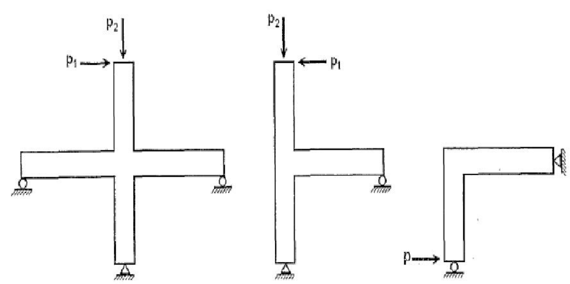


Figure 4- Loading method and support conditions in the modeling

Strengthened specimens of intermediate joints

To name intermediate strengthened joints, C symbol is used. The idea of defining these joints is done based on failure and ductility idea.

Joints: (Type 1 strengthening model of length effect) C_1-C_2

Strengthening method and direction of placement of fibers are shown in figure 5 and naming method is shown in table (2).

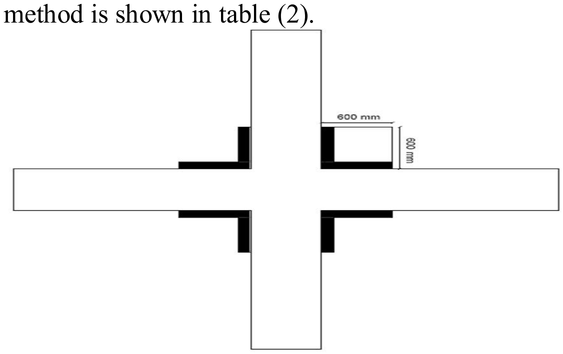


Figure 5- specimen of C_1-C_2 intermediate strengthened joints before and after beam and column wrapping

Table 2- The properties of C_1-C_2 strengthened specimens

Name	C_1	C_2
Type of material	CFRP laminate	CFRP laminate
L(mm)	200	600

Joints: (Type 2 strengthening model of the effect of material of sheets and FRP wrapping) C_3-C_5

Strengthening method and direction of placement of fibers are shown in figure 6. Table 3 shows strengthening properties used in C_3-C_5 specimens.

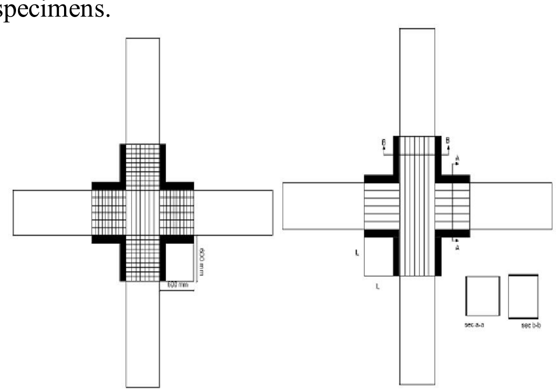


Figure 6- specimen of C_3-C_5 intermediate strengthened joints before and after beam and column wrapping

Table 3- The properties of C_3-C_5 strengthened specimens

Name	C_3	C_4	C_5
Type of material	CFRP laminate	GFRP laminate	CFRP laminate
L(mm)	600	600	600

3. The results of analysis of inner joints specimens

The first result that is investigated in the analysis of inner joints specimens is load-displacement curves of specimens.

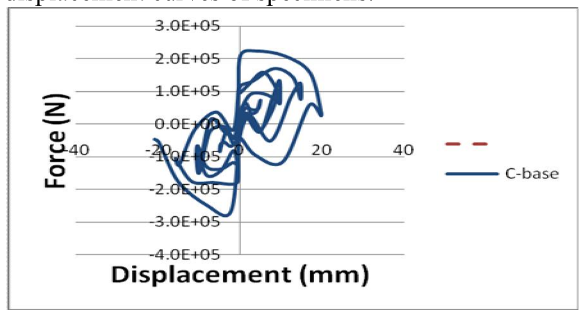


Figure 7- Behavior curve of un-strengthened inner joint

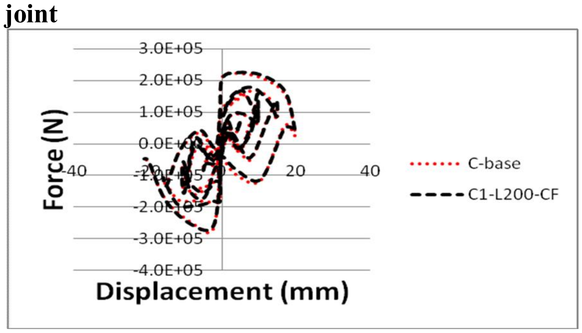


Figure 8- The behavior curve of CFRP - strengthened inner joint with the length of 200 mm

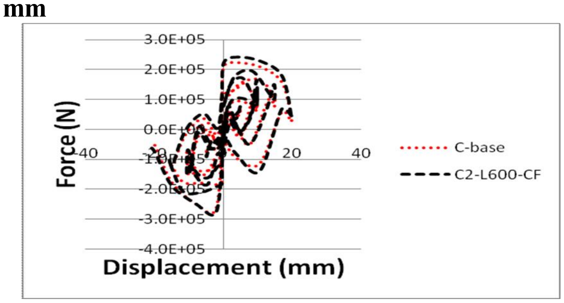


Figure 9- The behavior curve of CFRP - strengthened inner joint with the length of 600 mm

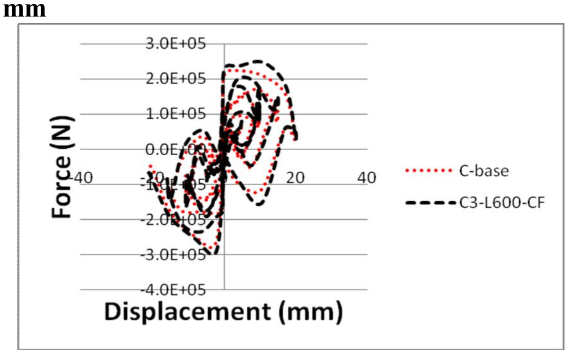


Figure 10- The behavior curve of CFRP - strengthened inner joint with the length of 600 mm

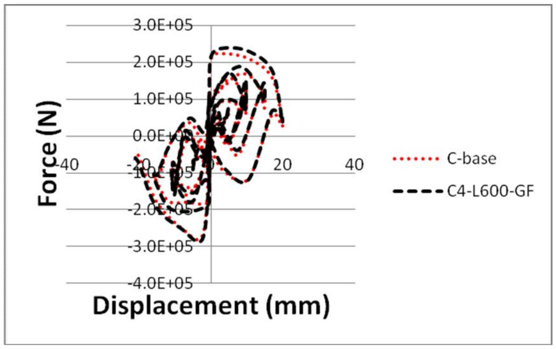


Figure 11- The behavior curve of GFRP - strengthened inner joint with the length of 600 mm

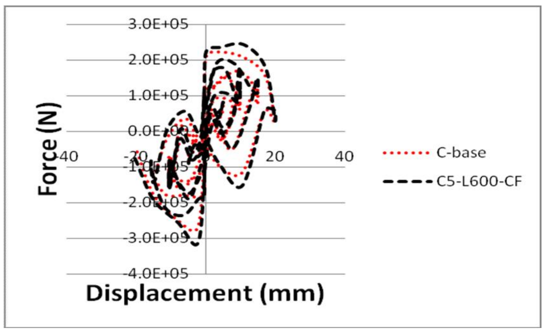


Figure 12- The behavior curve of CFRP - strengthened and FRP wrapping inner joint with the length of 600 mm

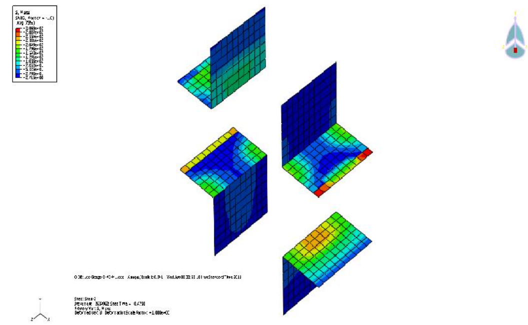
Figure 7 to 12 show these curves for strengthened specimens of carbon and glass as separately beside basis specimen. The summary of analysis results for inner joints specimens is shown in figure 4.

Table 4- The results of non-linear analysis for strengthened inner joints

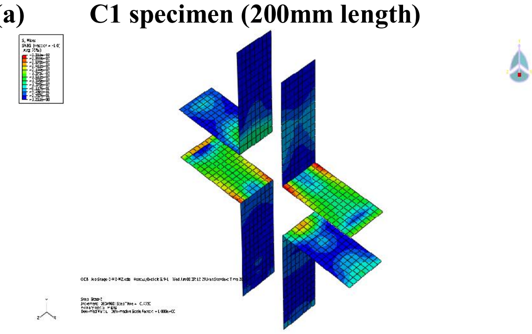
Type of joint	Ultimate load		Ultimate displacement
	value (P) (KN)	Changes (%)	Value (mm)
C-base	270.503	0	3.581
$C_{1\text{-}L200\text{-}CF}$	272.388	0.74	2.385
$C_{2\text{-}L600\text{-}CF}$	280.593	3.70	2.381
$C_{3\text{-}L600\text{-}CF}$	295.357	9.25	2.380
$C_{4\text{-}L600\text{-}GF}$	281.546	4.07	2.382
$C_{5\text{-}L600\text{-}CF}$	315.068	17	2.379

C_1-C_2 joints

As it is shown in the investigation of strengthened inner joints specimens, by reinforcement used in C_1-C_2 specimens in L-form, behavioral properties of joints such as bearing capacity and ultimate displacement are improved that results of the analysis are shown in table 4. Critical sections in these joints are transferred to the points after beside the column. For example, the values of stresses in L-shape sheet in tensile section for C1 and C2 specimens are shown in figure 13.

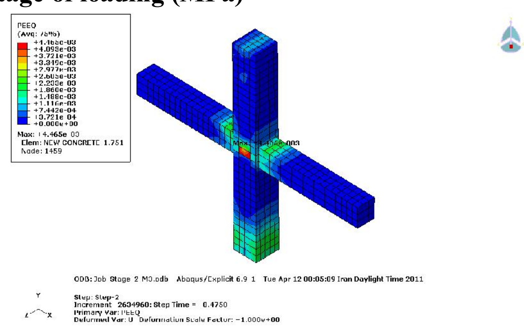


(a) C1 specimen (200mm length)

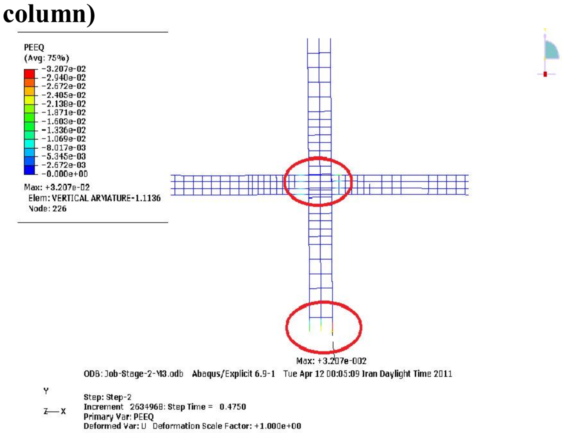


(b) C2 specimen (600mm length)

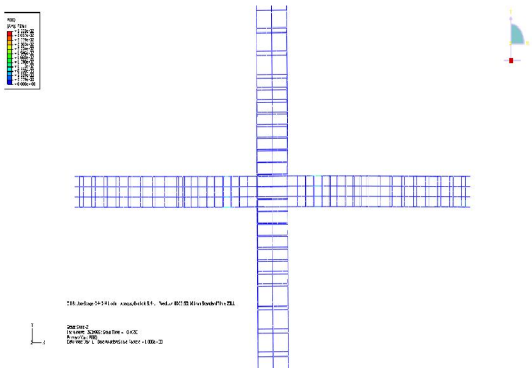
Figure 13- The stresses created in FRP sheets in C1 and C2 specimens along beam axle in final stage of loading (MPa)



(a) Basis specimen (failure in joint core and column)



(b) C1 specimen



(c) C2 specimen

Figure 14- Plastic strain created in basis samples, C1 and C2 specimens in final sub step of loading

For example, figure 14 shows the flowing place of longitudinal reinforcements in C1 and C2 specimens beside basis specimen. By increasing loading in these specimens, yield region is approached gradually to the edge of column and strain of beam tensile reinforcements is increased beside the column and yield region is extended to the inside of joint core and by increasing cracking in joint region leads into joint failure.

Considering the drawn cures and the results presented in table 4, it is shown that by increasing reinforcement length of FRP sheets of 200mm to 600mm, bearing capacity and ultimate displacement are improved.

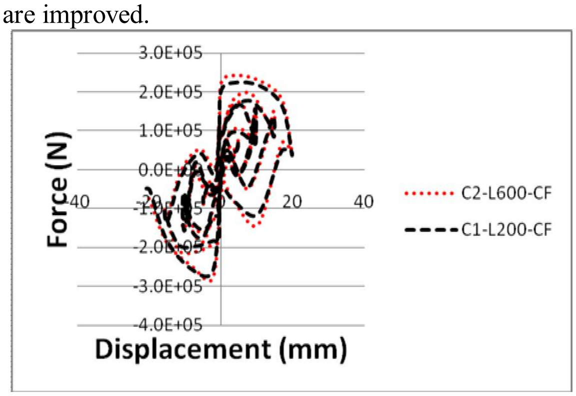
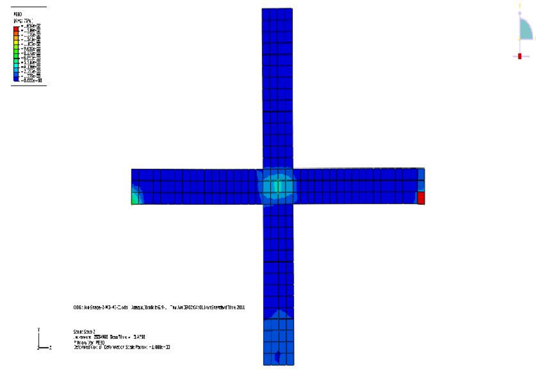


Figure 15- The comparison of length effect in C1 and C2 specimens

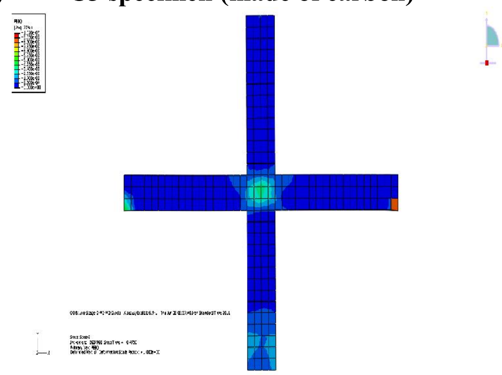
Strengthening concrete joints according to this reinforcement model increases 1 to 4% bearing capacity of joint. Also, the maximum increase in ultimate strength in this model is 272.388 KN.

C_3-C_5 joints

As it is shown, using lateral sheets reduces the depth of cracks in critical section and by this kind of reinforcement, joint failure is postponed and in C_3, C_4 and C_5 specimens we observed more stiffness and bearing capacity in comparison with $C_1$and C_2 specimens. The process of formation of plastic strain and flowing longitudinal reinforcements in this strengthening are shown in figure 16. According to the figure, it is seen that in the final loading sub step, besides critical section, strong cracking is occurred in joint core and in CFRP-strengthened joints, this is seen less. Thus, CFRP-strengthened joints are failed later. Also, figure 17 shows the stresses created in reinforcement sheets. Here it is observed that due to the great value of elasticity module, carbon sheets have more stress than glass sheets and due to this improvement of properties of joints are more in C_3-C_5 joint specimen.

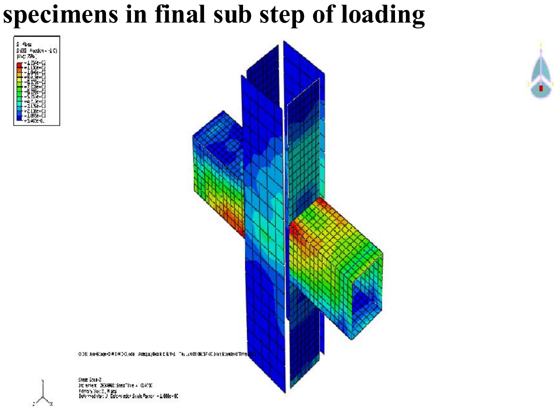


(a) C3 specimen (made of carbon)

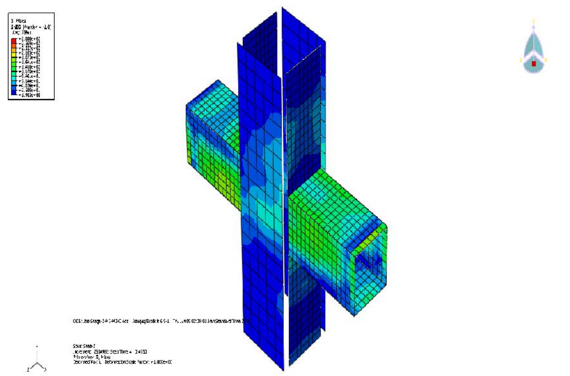


(b) C3 specimen (made of glass)

Figure 16- Plastic strain created in C1 and C2 specimens in final sub step of loading



(a) C4 specimen (made of carbon)



(b) C5 specimen (made of glass)

Figure 17- The stresses created in FRP sheets in C4 and C5 specimens along beam axle in final stage of loading (MPa)

As it is shown, by changing the material of sheets and wrapping joint, bearing capacity and ultimate displacement of specimens are improved. Also, in strengthening by CFRP sheets more stiffness and bearing are observed in comparison with GFRP.

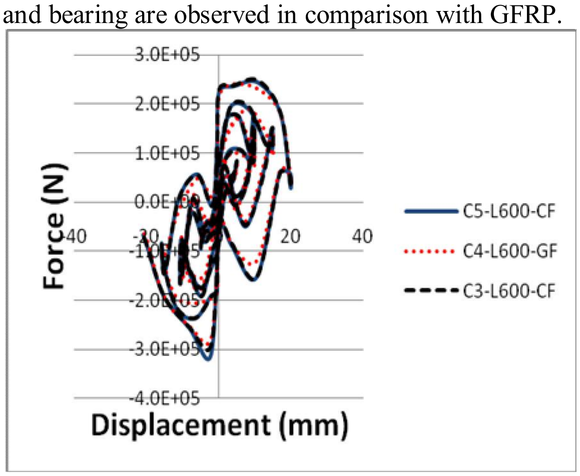


Figure 18- The comparison of FRP wrapping C_5 and C_4 ,effect and material of sheet in C_3 specimens

Strengthening concrete joints according to this reinforcement model increase 5 to 17% bearing capacity of joint. Also, the maximum increase in ultimate strength in this model is 315.068 KN. Also, as it is shown in figure 19, in CFRP and GFRP-strengthened reinforced concrete, in the specimens with CFRP, bearing capacity trend is consistent with increasing length. The following charts show the behavior of these reinforcement models to each other.

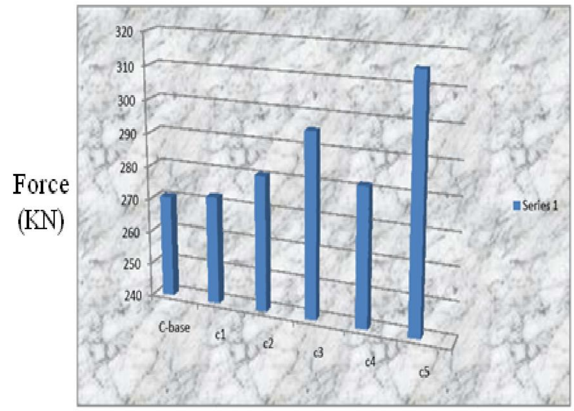


Figure 19- Comparing specimen in CFRP and GFRP-strengthened intermediate joint and FRP wrapping

4. Conclusion

The results of FRP-strengthened inner joints analysis

Regarding the results of intermediate joints, we can refer to the improvement of bearing capacity to 9% (in C3 specimen) and to 17% in external frame (in C5 specimen), also ultimate displacement to 33.56% (in C5 specimen) is increased. Regarding the material of reinforcement, in CFRP-strengthened specimens, bearing capacity and ultimate displacement increase were considerable in comparison with GFRP-strengthened specimens.

- By strengthening in basis specimen, increasing trend of stiffness, bearing capacity and ultimate displacement are increased.
- The results of this research show that strengthening by fiber composites (FRP)can increase some loads such as cracking, yield and ultimate 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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