NUMERICAL STUDY OF THE BENDING BEHAVIOR OF THE CONCRETE BEAMS STRENGTHENED WITH CARBON FIBER LAYERS

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Abstract

Recently, FRP layers have attracted attentions significantly due to the ratio of resistance to high weight, resistance against corrosion, chemicals and fatigue arising out of loading, and easy installation, they are used for the repair and reconstruction of structures especially concrete ones.

In this paper, we study the results of the analysis carried out 2 and 3 dimensionally and based on finite element method for the bending strength of reinforced concrete beams, whose tension surface is strengthened using CFRP layers. For introduction of concrete materials to software, a nonlinear model with nonlinear stress-strain curves as well as possibility of cracking and crushing were used. To introduce steel into the said software, a bilinear relation was employed, and carbon fiber layers made of materials with the properties of composites are used for modeling. The graphs of load-dislocation illustrated based on the results of ANSYS software show that the responses of those non-crushed areas of strengthened samples are almost similar to those of control groups, but when strengthened beams are cracked, they behave in a more hardening manner, in such a way that after yield of steels, the strengthened beams harden more and more. At this stage, if fiber layers are not separated from the beams, the resistance of such beams increases by 30 to 120 percent, and its unusual upper limit is due to the utilization of low percent of cross section of tension steel used for the modeling of samples. In this paper, the comparison of the behavior of the samples modeled numerically with that of the laboratory studies shows that the results of the modeled beams conform to those of the laboratory ones in such a way that error percent between the final resistance of the laboratory studies and that of numerical model is only from 3 to 9.

Keywords: FRP fibers, Bending Resistance, Finite Element, Carbon Fiber Layers, Ductility

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1. Introduction

The technology of using FRP sheets was firstly introduced by the Federal Laboratory of Swiss in 1984 (1). FRP layers, whose weight is twenty percent of those of steel layers, are two to ten times more resistant than steel layers. This characteristic caused these fibers to be used in different industries. The abovementioned fibers have been used for many years in the industry of aircraft manufacture and space travel. However, the high price of this type of fiber restricted its application in construction industry in the past. Nowadays, the mass production of this material has reduced its price, and it is more cost-saving to use such fibers, which are resistant to corrosion, chemicals, and fatigue. Moreover they decrease required time for repair works, since they can be installed very fast.

Considering that the technique of strengthening has been developed from middle of 1990s, fewer researches have pursued to study behavior of these fiber layers. In 1995, Chajes and Januszka (2) studied the shear resistance of T-beams strengthened with fiberglass and aramid layers. In this laboratory research, 12 concrete beams were used, among which 8 beams were strengthened using FRP layers to enhance their shear resistance. The beams were loaded until they fractured, and it was cleared that the resistance of the strengthened beams was increased by 60 to 150 percent. In 1999, Ross & Jerome (3) conducted a laboratory research to study the bending strength of the beams reinforced with FRP layers. In this research, 24 beams, whose bending strength was low, were strengthened with FRP layers, and 6 different ratios of steel surface were studied. The results of these experiment were analyzed manually. In general, it was observed that the bending resistance of beams was increased by 30 to 120 percent. However, strengthening of beams causes reduction in their formability up to 40 percent. In 2001, Grace (4) provided a paper on the strengthening of negative bending moments. For this purpose, he studied two groups of beams I and II to research shear and bending strength respectively. The studies showed that the use of FRP fibers may increase the strength of group I by 29 percent and the strength of group II by 40 percent in comparison to their control samples. In 2003, Brena and Bramblett (5) investigated the increase in the bending strength of the reinforced concrete. They strengthened beams with 4 different patterns using FRP. The purpose of this research was to determine the best pattern of fibers attached to concrete beams to increase their strength. The results indicated that the increase in the contact surface of fibers and concrete may not be an important factor for separation of concrete from fibers. For such a separation, it is required to attach vertical and continuous links to beam web. Moreover, the use of such links causes that brittle fracture changes to ductile one.

According to the previous researches and the increasing importance of this issue, it is required to study the impacts of these fibers on the strength of beams. Whereas these researches were carried out mostly under laboratory and limited conditions, no numerical model based on finite element has been used to study the performance of fibers (maybe only a linear model or at most 2-D nonlinear models with lesser accuracy had been applied for such studies). In this paper, we aim to provide a fully nonlinear 3-dimensional model of beams and study the fracture criteria for the components of beams to eliminate their defects.

2. The Specifications of Finite Elements

2.1 Modeling of Beams

To study beams, three groups of beams were selected. Each group containing 2 strengthened beams and a control specimen was modeled .Due to complicated behavior of concrete under pressure and tension. ANSYS software was used for modeling .Three dimensional models and many elements with small dimensions were applied to increase the accuracy but they cause augmentation in running time of software.

The concrete made of brittle materials with different tension and pressure behaviors. It exposes elastic behavior until it reaches 25 percent of its final resistance. After reaching final resistance, the graph of strain stress rises moderately (graph 1) and when it arrives at final strain, the concrete is crushed. Under tension state, the concrete is almost elastic (7). To define the concrete, the state of concrete has been elected from the nonlinear library of the software, and the characteristics of the materials (including pressure resistance, elasticity module, Poisson's ratio, etc.) are shown in the table 1. Under tension and pressure the modeled steel, with elasticity module of 200 GPa, is considered to be elastic material. To model steel, bilinear –kinematic state has been used. FRP sheets are made of composites that includes two phases of resin and fiber which are fully different from each other. This fact causes FRP to have orthotropic characteristics with different properties in different directions. To introduce these fiber layers into the software and model them, the materials and equations based on composites were used and the characteristic of such materials (such as number and thickness of layers, module of elasticity, final resistance, etc.), have been applied like the data shown in the following table 1.

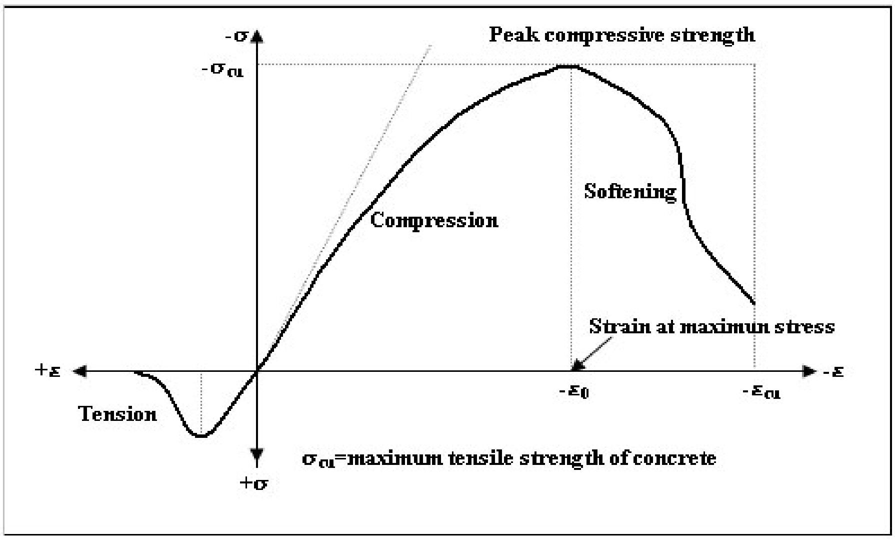


Fig.1 Schematic Graph of the Concrete Stress-Strain

Tab.1 The Specifications of Concrete, Steel, and Carbon Fibers

Concrete				Steel		Fiber Layers							
									Ef (Gpa)				
	Ec (GPa)	Fc (MPa)	nc	gc (KN/m^3)	Es (GPa)	fy (MPa)	Number of Layers	Thickness (mm)	x	Y	z	nf xy	Final Stress (MPa)
Group I	34.5	54.8	0.2	24	200	410	1	0.45	138	4.8	4.8	0.2	2206
Group II	37.8	55.2	0.2	24	200	415	1	1.90	49	4.8	4.8	0.2	690
Group III	25	32	0.2	24	200	420	2	0.52	62	4.8	4.8	0.2	760

Tab 2 The Dimensions of Beams and Carbon Fiber Layers

Materials	Concrete			Steel			Fiber layers		
	Length (mm)	Width (mm)	Height (mm)	Tension (mm^2)	Pressure (mm^2)	Link	Length (mm)	Width (mm)	Height (mm)
Group I	3040	200	200	259	141	102mm@152mm	2736	200	0.45
Group II	2653	152	254	402	141	#3@102mm	2244	152	1.90
Group III	3200	200	400	402	160	F12@100mm	2600	100	0.52

The dimensions of the modeled beams for groups I, II, and III are 200 x 200 x 3040 mm,254 x 152 x 2652, and 400 x 200 x 3200 mm respectively. The table 2 shows the dimensions order and characteristic of FRP layers for three groups of modeled beams.

The beams are modeled in form of simple support beams. For this purpose, two metal sheets of shell element are used for the supports to prevent the concentration of stress in them. A row of simple supports has been inserted under these sheets. This mechanism lets metal sheets to rotate and prevent the concrete, which is situated on the top of the support to be cracked. The loading system used in this experiment is shown in figure 2 (Table 3 contains support states of the beams).

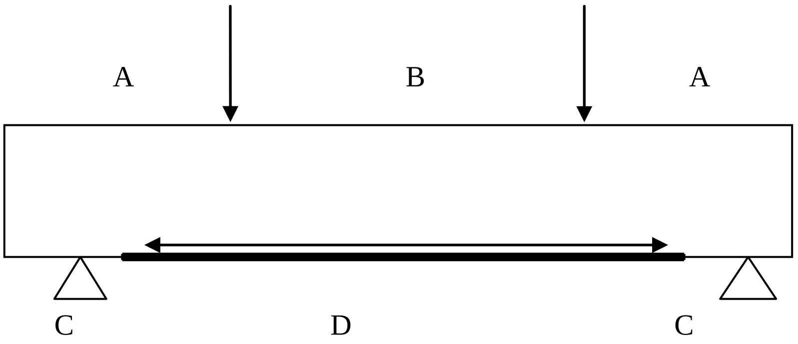
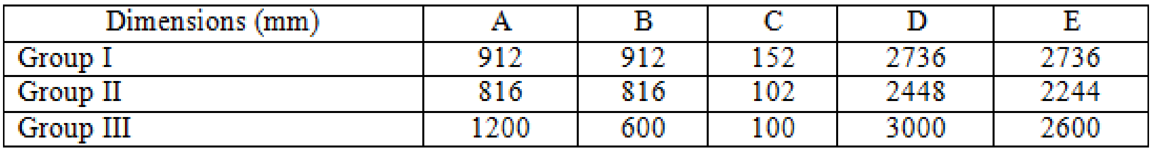


Fig.2 Schematic diagram of the Support Status and Beams' Loading

Tab.3- support state of beams



Dimensions (mm)	A	B	C	D	E
Group I	912	912	152	2736	2736
Group II	816	816	102	2448	2244
Group III	1200	600	100	3000	2600

Nonlinear Analysis

In nonlinear analysis, the loads are applied on different parts called loading steps which are applied respectively. In this paper, the method of Newton – Raphson has been employed for nonlinear analysis. Based on this method, at the end of loading process, the stiffness matrix of structure is formed, and the stresses, and strains are calculated. Then new loading system is ascertained by using calculated stresses. At this stage, if the applied loading and calculated one of the software converge, the next step is taken, otherwise above steps are iterated.

3. The Results of Finite Element modeling

The figures 3 to 5 exhibit dislocation-load diagram for three groups of beams, which include control beams, and strengthened beams. In addition, the results of the finite element model and those of the previous laboratory studies were compared by these graphs.

The graphs of dislocation-load indicate that there is no significant different between control beams and strengthened beams while the beams behave elastically and are not cracked. When the strengthened beams are cracked, the concretes behave in a hardening manner in such a way that when steels yield, the resistance of the strengthened beams of group I to III increases by 30 and 10 percent respectively. When rounded bars yield, the rate of resistance augmentation and dislocation decrement intensifies, in such a way that resistance of samples of group I increases by 120 percent. This increase is because of low application of tensional rounded bars. The resistance of groups II and III increases by 13 to 41 percent. In addition to resistance augmentation, the ductility of the beams attenuate. (ductility of the beams of the group I to III decreases by 48, 52, and 70 percent respectively.)

As it is shown in the following graphs, the results of finite element modeling confirm the results of the laboratory studies to such an extent that there is only 3 to 9 percent of dissimilarity between results of modeling and laboratory results. The results of the numerical modeling including force, dislocation of beams at yielding time of rounded bars and time of final loading have been shown in the table 4 in brief.

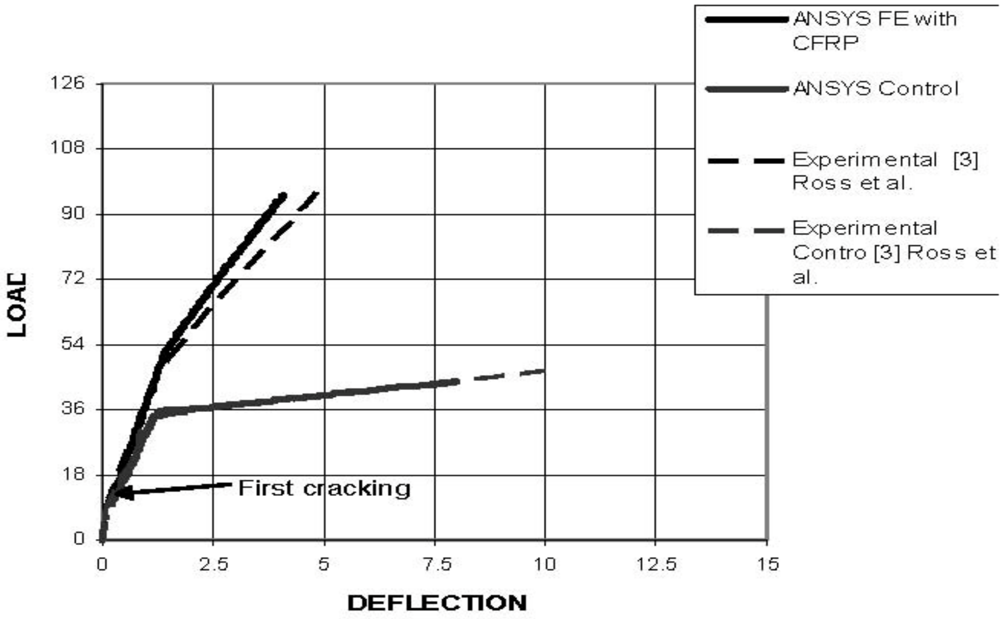


Fig. 3 Graph of Load – Dislocation based on the Laboratory and Finite Element Results of the Beams of Group I

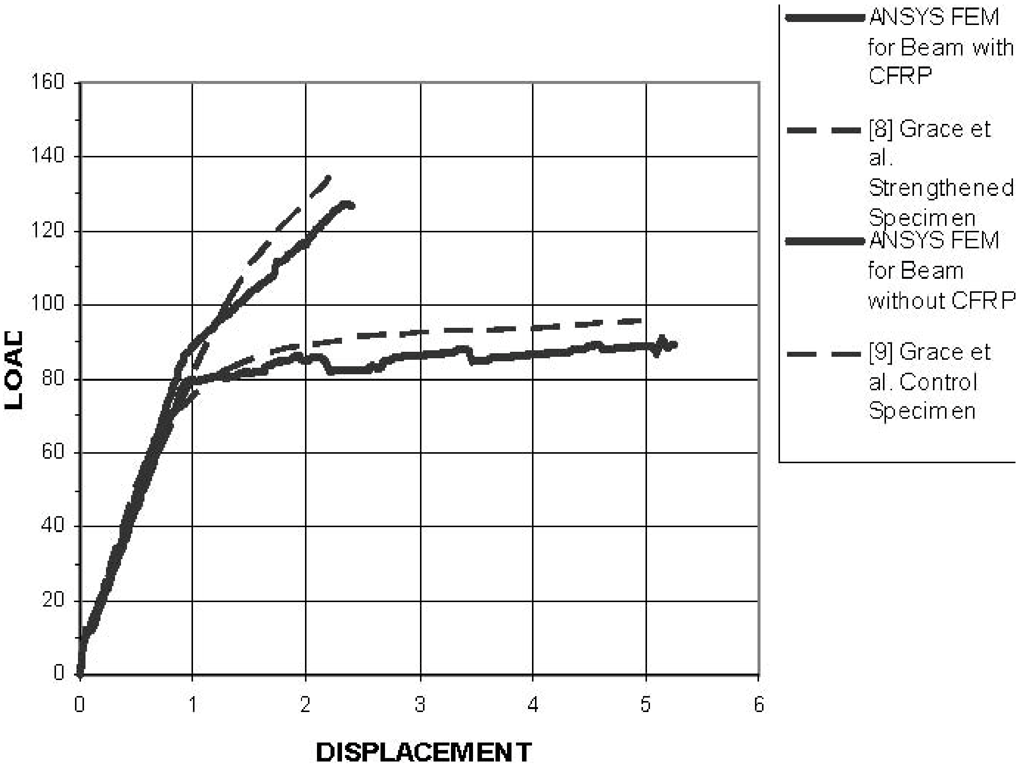


Fig 4 Graph of Load – Dislocation based on the Laboratory and Finite Element Results of Beams of Group II

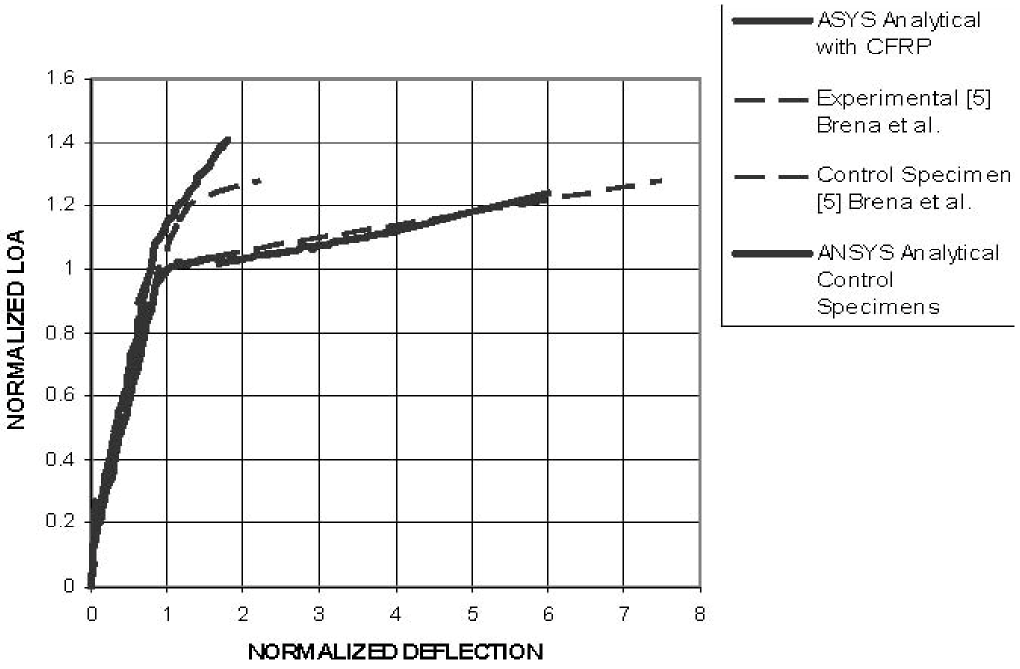


Figure 5 – Graph of Load – Dislocation based on the Laboratory and Finite Element Results of Group III

Table 4- The Results of Force and Dislocation for the Modeled Beams of Group I, II, and III

	Yield		Final		Increase in Resistance (%)	Increase in Ductility (%)	Difference Between Numerical method and Laboratory one (%)
	Dislocation (mm)	Force (KN)	Dislocation (mm)	Force (KN)			
Group I	1.23	45.19	4.1	95.38	120	- 48	3
Group II	1.03	90	2.4	126.7	41	- 52	6
Group III	1.18	1.10	1.8	1.4	13	- 70	9

4. Conclusion

In this paper, the impacts of carbon fiber layers on ductility and bending strength of concrete beams has been investigated and following results were achieved:

The attachment of a thin layer of FRP sheets to the tension surface of concrete beams increases considerably the resistance of these beams. The results of modeling display that if no separation happens between fiber and tension surface of the beams, the resistance of the beams of group I (with high percent of tension steel) and group III(with low percent of tensions steel) increases by 120 percent and 13 percent respectively. Such a difference in resistance augmentation of beams is due to the difference of steel surface, type and thickness of fiber, etc. (9). Moreover, the results demonstrate that the ductility of the strengthened beams were attenuated (48 percent decrement for group I, till 70 percent for group III).

The comparison of the results of finite element modeling with those of the laboratory studies indicates that the results of both types of study fully conform in such a way that only less than 9 percent difference was observed between the forces arising out of two methods.

5. References

[1] Teng J. F., Chen J. F., Smith S. T. & Lam L., FRP-Strengthened RC Structures, *JohnWiley & Sons*, England,1988: p 245.

[2] Chajes M., Januszka T. & Mertz D., Shear Strengthening of Reinforced Concrete Beams Using Externally Applied Composite Fabrics, *ACI Structural Journal*, 1995, Vol. 92: pp. 295- 303.

[3] Ross A., Jerome M. & Tedesco J., Strengthening of Reinforced Concrete Beams with Externally Bonded Composite Laminates, *ACI Structural Journal*, 1999, Vol. 96: pp. 212-220.

[4] Grace N., Strengthening of Negative Moment Region of Reinforced Concrete Beams Using Carbon Fiber-Reinforced Polymer Strips, *ACI Structural Journal*, 2001, Vol. 98:pp.347-358.

[5] Brena S, Bramblett R. & Wood S., Increasing Flexural Capacity of Reinforced Concrete Beams Using Carbon Fiber-Reinforced Polymer Composites, *ACI Structural Journal*, 2003, Vol. 100: pp.36-46.

[6] ANSYS, ANSYS User Manual Revision 5.4, *ANSYS, Inc.*, Canonsburg, Pennsylvania,1998.

[7] Bangash M., Concrete and Concrete Structures, Numerical Modeling and Application, *Elsevier Science Publishers Ltd.*, London, England, 1989.

[8] Grace N., Abdel-sayed G. & Ragheb F., Strengthening of Concrete Beams Using Innovative Ductile Fiber-Reinforced Polymer Fabric, *ACI Structural Journal*, 2002, Vol. 99:pp. 692-699.