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Effect of CFRP Plate Location on Flexural Behavior of RC Beam Strengthened with CFRP Plate

Mohammed Jassam Mohammed Altaee

Civil Engineering, Babylon University
Hillah, Babil, Iraq
Tel.:+96407813518111, E-mail: mohammad_tai2000@yahoo.com

Abstract- Location of CFRP plate, as a mode of failure, is one of the major limitations when using externally bonded carbon fiber reinforced polymer (CFRP) plates in strengthening of RC beams. In this work, mode of CFRP plate location was analytically investigated. A non-linear finite element model is proposed in order to analyze experimental data presented by David et.al.[1]. The eight node brick element (SOLID65 as denoted in ANSYS) is used to model reinforced concrete and four node shell element (SHELL41) is used to represented CFRP plate, bond between concrete and CFRP plate represented by interface element (CONTAC52). The results obtained from analytical study explained that the best location of CFRP is at lower edges of concrete beam.

Keywords - CFRP plate, Flexural, RC beam.

I. Introduction

In recent years, structural engineers started to use Fiber Reinforced Polymer (FRP) as one of the possible techniques to strengthen structural concrete members (slab, beams, and columns). FRP products are attractive materials in strengthening and rehabilitation of structural members due to their high strength to weight ratio, resistance to corrosion, lightweight, and ease of application. There are typically two types of FRP in use: Glass FRP (GFRP) and Carbon FRP (CFRP). For most civil infrastructure engineering applications, CFRP has been identified as the material of choice due to its higher strength compared to GFRP. Flexural strengthening involves bonding CFRP sheets to the soffit of concrete beams to carry the extra tensile force needed for the upgraded member [2].

The use of FRP (Fiber Reinforced Polymer) plates for strengthening and repairing of RC structures represents an interesting alternative to steel plates. FRP materials are lighter than steel. They have a high strength to mass ratio. They are corrosion-resistant and are generally resistant to chemical attacks. This technique has been

Largely investigated especially in Switzerland by [3,4].

Shahawy and Beitelman, [5] presented the results of a study involving the static and fatigue performance of reinforced concrete beams strengthened with externally bonded carbon-fiber-reinforced plastic (CFRP) sheets. The main parameters in the static test study were the concrete compressive strength, the number of CFRP laminates, and the placement of CFRP reinforcement. The static test program showed that the application of CFRP to reinforced concrete beams results in increased strength and enhanced performance. Accelerated fatigue testing was performed on several specimens receiving various amounts of the CFRP lamination system, including one member that was fatigued for over half the expected fatigue life, then rehabilitated with the CFRP, and fatigued again until failure. Comparisons were made for the standard section and equivalent sections with two and three layers of CFRP involving the improvements in fatigue behavior, stiffness, and capacity. The results from the fatigue study indicate that fatigue life of reinforced concrete beams can be significantly extended through the use of externally bonded CFRP laminates.

The increasing of ultimate load capacity ranged from 35 to 73 percent which were registered in strengthened beams, as compared to the control beams. Also, these strengthened beams showed a lower deflection at corresponding loads than the unstrengthened reinforced concrete beam. It was observed that the presence of CFRP plates on the tension face restrained cracking propagation which caused increase in load carrying capacities prior to and beyond the first cracking. The structural ductility of the CFRP strengthened

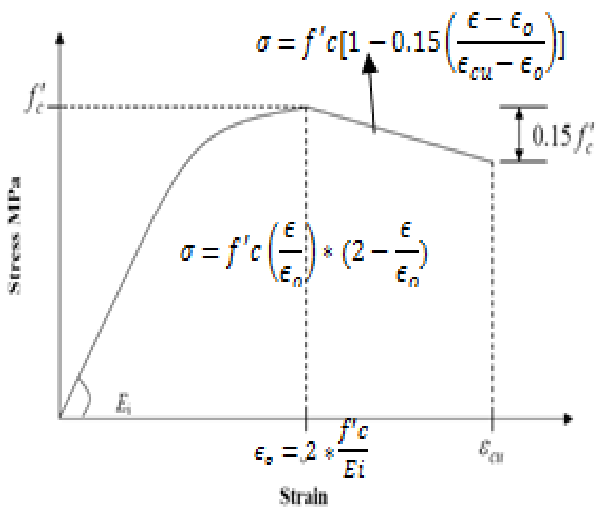
RC beams is very low when compared with the corresponding control specimen. The reduction in ductility ratio is about 30 to 67 percent based on deflection [6].

This paper is focus on the effect of CFRP plate location change more than the effect of CFRP plate numbers.

II. MATERIALS MODELLING:

A. Concrete Modelling

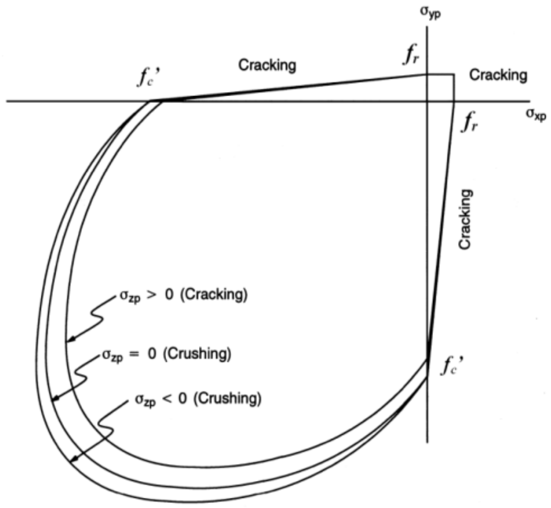
Concrete can behave either as a linear or nonlinear material depending on the nature and the level of the induced stresses. Many experimental studies on the behavior of concrete under uniaxial and multiaxial loading conditions have been performed. The aims of such investigations have been to understand the complex response of concrete for various imposed stress conditions and to provide the necessary data required to develop accurate numerical models for use in nonlinear finite element analysis of concrete structures. In the present analysis Hognestad Model[7] Figure (1) was used to model concrete.



Figure(1) : Uniaxial stress-strain of concrete in compression[7].

In a concrete element, cracking occurs when the principal tensile stress in any direction lies outside the failure surface see figure (2). After cracking, the elastic modulus of the concrete element is set to zero in the direction parallel to the principal tensile stress direction. Crushing occurs when all principal stresses are compressive and lies outside the failure surface; subsequently, the elastic modulus is set to zero in all directions [8], and the element effectively disappears.

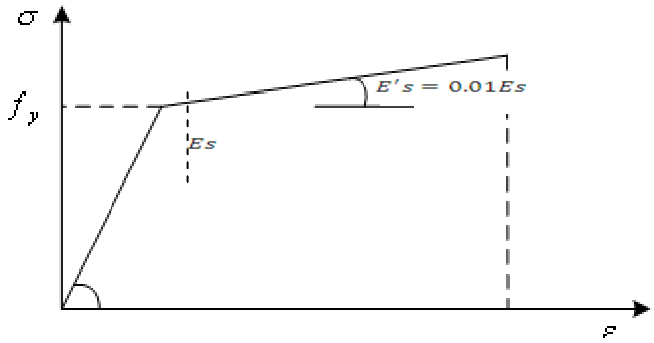
During this study, it was found that if the crushing capability of the concrete is turned on, the finite element beam models fail prematurely. Crushing of the concrete starts to develop in elements located directly under the loads. Subsequently, adjacent concrete elements will crush within several load steps as well, significantly reducing the local stiffness.



Figure(2)- 3D-failure surface for concrete [8].

B. Steel Modelling

Compared to concrete, steel is a much simpler material to represent. Its strain-stress behavior can be assumed to be identical in tension and in compression. A typical uniaxial stress-strain curve for a steel specimen loaded monotonically in tension is shown in figure(3).



Figure(3): Elastio-plastic stress-strain relationships for steel [9]

C. Finite element Modelling:

In this section comparison between experimental results and FE predictions using [8] program are presented. 3-D finite element modelling used in this study to represented full scale simply supported reinforced concrete beam strengthened using carbon fiber reinforced polymer plate have a span length 2.8m (length of beam 3m) and cross-sectional dimensions of (150 *300)mm (Figure (4)) . The main characteristics of the beams and of CFRP plate are listed in table (1)and (2) respectively [1].

TABLE I

THE CHARACTERISTICS OF THE BEAMS [1].

Bea m	Internal steel (mm2)	Concrete strength (MPa)	CFRP plate thickness (mm)
B1	308	38.7	-
B2	308	39.2	1.2
B3	308	38.4	2.4

TABLE II

CHARACTERISTICS OF THE CFRP PLATE [1].

Densit y	Tensile strength (MPa)	Modulus of elasticity (MPa)
1.6	2400	150000

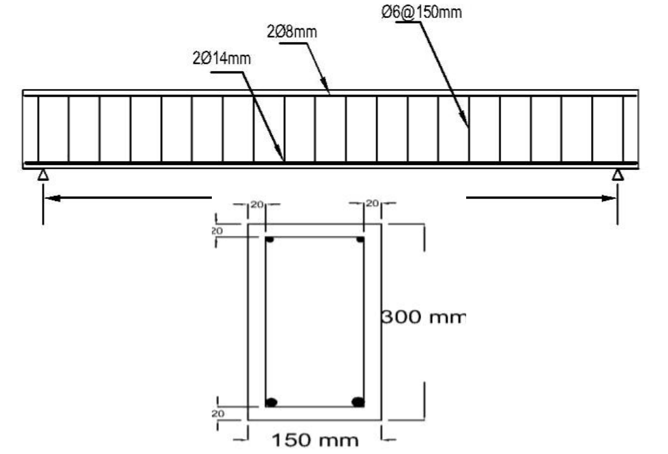


Figure (4): Beams dimensions and reinforcement details [1].

The plate used in strengthened of RC beams has 1.2mm thick and 50mm wide are bonded in one layer of two plate or two layer of two plate as in figure (5). Beam B1 is the reference control beam, and beam B2 is strengthening by one layer of two plates. The other beam B3 is strengthening by two layer two plates. The distribution and length of plates are different from beam to other as shown in figure(5).

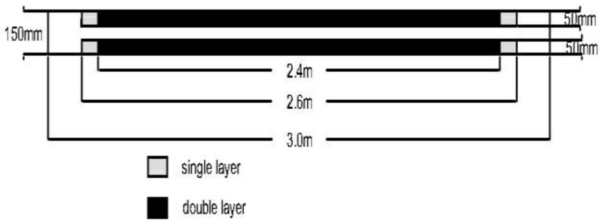


Figure (5): The CFRP plate distribution on Beams[1].

ANSYS program contained many type of the elements, in this study three elements type used to represented materials (concrete ,CFRP plate , and glue) as listed below:

1) SOLID65: (or 3-D reinforced concrete solid) is used for the 3-D modelling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete, while the rebar capability is available for modelling reinforcement behavior. The element is defined by eight nodes having three degrees of freedom at each node: translations of the nodes in x, y, and z-directions. Up to three different rebar specifications may be defined. This 8-node brick element is used, in this study, to simulate the behavior of concrete (i.e. reinforced concrete). The element is defined by eight nodes and by the isotropic material properties. The geometry, node locations, and the coordinate system for this element are shown in Figure (6).

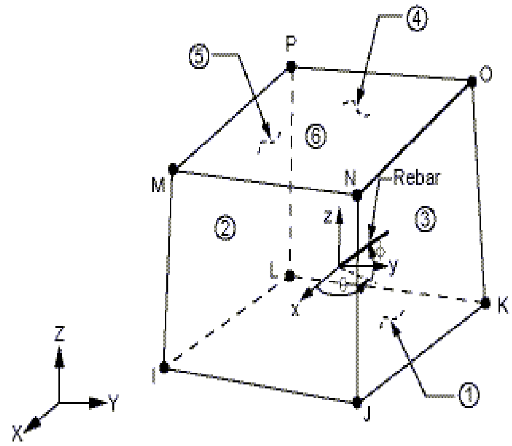


Figure (6): The solid element geometry (SOLID65)[8].

2) SHELL41: is a 3-D element having membrane (in-plane) stiffness but no bending (out-of-plane) stiffness. It is intended for shell structures where bending of the elements is of secondary importance. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.

The geometry, node locations, and the coordinate system for this element are shown in Figure (7). The element is defined by four nodes, four thicknesses, a material direction angle and the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The thickness is assumed to vary smoothly over the area of the element, with the thickness input at the four nodes. If the element has a constant thickness, only one thickness (in any node) need be input. If the thickness is not constant, all four thicknesses must be input (for four nodes). The elastic foundation stiffness (EFS) is defined as the pressure required producing a unit normal deflection of the foundation. The elastic foundation capability is bypassed if EFS is less than, or equal to, zero.

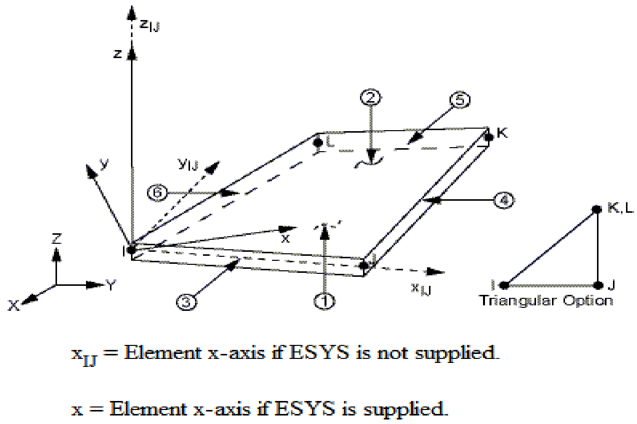


Figure (7): The shell element geometry(SHELL41)[8].

3) CONTAC52: is represents two surfaces which may maintain or break physical contact and may slide relative to each other. The element is capable of supporting only compression in the direction normal to the surfaces and shear (Coulomb friction) in the tangential direction. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions as shown in figure (8). The element may be initially preloaded in the normal direction or it may be given a gap specification. A specified stiffness acts in the normal and tangential directions when the gap is closed and not sliding, the element is defined by two nodes.

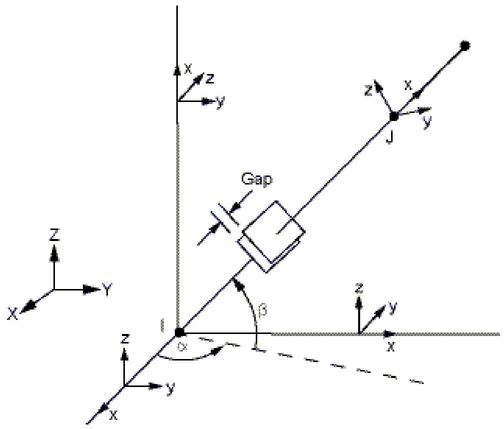


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Figure (8) the contact element geometry (CONTAC52)[8].

III. Discussion of Results:

A. Strengthened beams with one and two layers in the same location:

A total one beam strengthened with one layer of CFRP plate, and the other one beam strengthened with two layers. The load- deflection curves for strengthened beams experimental [1], analytical (full bond) and analytical (partial bond) are shown in Fig. (9) and Fig. (10). The result obtained from this model show good agreement with experimental result provided by [1].

From experimental result the strengthening of beam with two layers of CFRP plate increased ultimate load about 12 % from ultimate load of beam strengthened with one layer of CFRP plate.

The FE results show that the full and partial bond are closed in the beams strengthened by one layer of CFRP but there is absence different between them in beams strengthened by two layers of CFRP , this different due to more epoxy surfaces in the two layers CFRP beams (concrete - CFRP and CFRP- CFRP) than one layer CFRP beams.

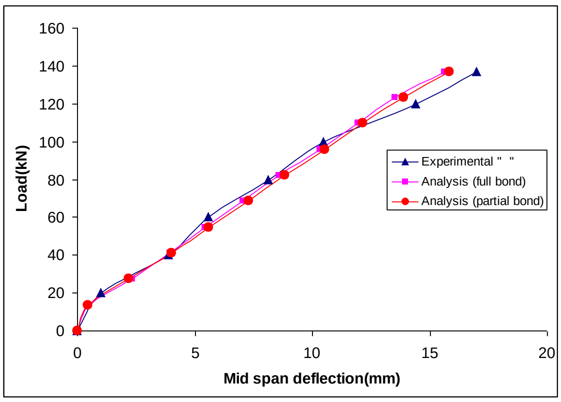


Fig.(9) :One layer CFRP beams load – deflection curve.

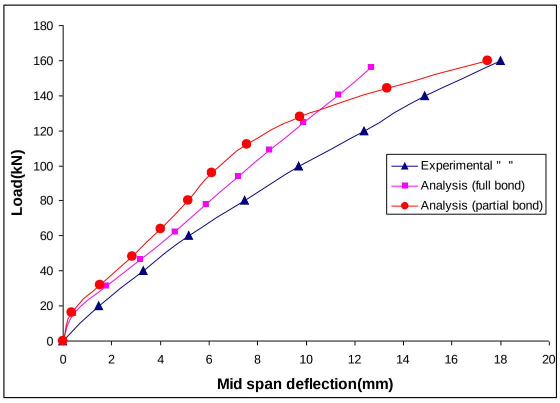


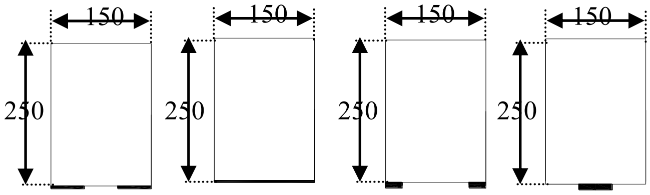
Fig.(10): Two layers CFRP beams load – deflection curve.

The results obtained from analytical study of beam strengthened by one layer of CFRP plate show that the partial bond give a good agreement with experimental result with error value not more than(3%), when the full bond analytical has error value not more then (5%), then in this study the term of analytical refers to partial bond only.

But in case of beam strengthened with two layers of CFRP plate the partial bond give a good agreement with experimental with error not more than (7%) and for full bond an error not more (11%) .

B. Strengthened beams with one layer in the different locations:

The locations of CFRP plate are different from the beam to other with the same CFRP plate cross section area (of 150mm layer, 50mm layer center and 250mm layer beams The arrangement of CFRP plate is shown in figure (11).



Figure(11) The different locations of CFRP plate in beam with same cross section area.

The load- deflection curves for analytical strengthened beams with different locations are shown in Fig. (12). The locations of CFRP plate are different from the beam to other with the same CFRP plate cross section area (of 150mm layer, 50mm layer center and 250mm layer beams present a similar behaviour, but the 50mm in edges beam load is increased of 16 % over other beams.

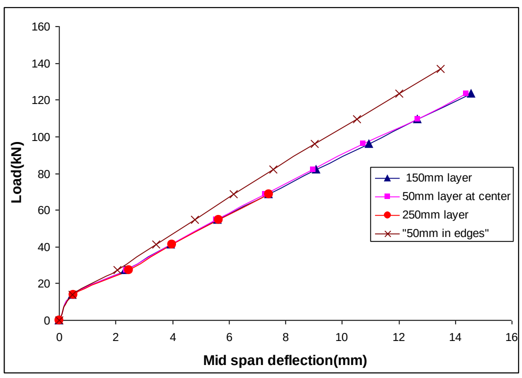


Fig.(12): The different locations CFRP beams load – deflection curve.

IV. CONCLUSION:

1.The results obtained from analytical study explained that the best location of CFRP plate in strengthened beam is at edges .

2.The location of CFRP plate is more effect than the number of CFRP plate layers on the flexural behavior of RC beam.

3.The present nonlinear finite element model is a powerful tool and it can be provide the researchers with a lot of important information that cannot be supplied by the experimental test.

REFERENCES:

[1]David ,E., Ragneau ,E., and Bodin ,F.,"Experimental analysis of flexural behaviour of externally bonded CFRP reinforced concrete structures" Materials and Structures journal, Vol. 36, May 2003, pp 238-241.

[2] R.A. Hawileha, M. Naser a, W. Zaidan a, H.A. Rasheed ' Modeling of insulated CFRP-strengthened reinforced concrete T-beam exposed to fire' Engineering Structures journal , 2009 (31),p: 3072_3079.

[3] Meier, U., 'Strengthening of structures using carbon fiber/epoxy composites', Construction and Building Materials (6) (1995) 341-351.

[4] Kaiser, H., 'Behaviour of reinforced concrete elements strengthened using carbon fiber reinforced plastics', Doctoral Thesis, Eidgen6ssischen Technischen Hochschule (ETH) Ziirich (1989) (in German).

[5] Shahawy, M. and Beitelman, T.E., "Static and fatigue performance of RC beams strengthened with CFRP laminates", Journal of Structural Engineering (ASCE), Vol.125, No.6, June, 1999, pp.613-621.

[6] Shadhan, K., K.,'Behaviour of reinforced concrete beams strengthened with CFRP laminates', PhD Thesis, University of Babylon(2008) , Iraq.

[7] Hognestad, E. "A Study of Combined Bending and Axial Load in Reinforced Concrete Members", University of Illinois Engineering Experiment Station, Bullenit Series No.399, Bullenit No.1, 1951

[8] ANSYS, "ANSYS Help", Release 11.0, Copyright 2006.

[9] Xiong, D., and Zha, X., "A numerical Investigation on the Behavior of Concrete Filled Steel Tubular Columns under Initial Stresses", journal of Construction Steel Research, Vol63, 2007, pp599-611.