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

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Abstract

This paper presents an analytical model to study flexural behavior of reinforced concrete beams strengthened with prestressed carbon fiber reinforced polymer (CFRP) plate by using finite element software (ANSYS 11.0). Eight node brick element (SOLID65 as called in ANSYS) used to model reinforced concrete, four node shell element (SHELL41) used to model prestressed CFRP plate, and two node interface element (CONTAC52) used to model epoxy (bond between reinforced concrete and prestressed CFRP plate). Experimental data of two beams strengthened with prestressed CFRP plate were tested by (Xue *et.al*., 2010) are analyzed to check validating of FE model. An FE Parametric study was performed based on the above model is used to study the effect of prestressed CFRP plate locations, width , and thickness. Then find that used of prestressed CFRP plate on edges increased load carrying capacity of RC beam strengthened with prestressed CFRP plate about 11% than used in center of RC beam.
Keywords: location, prestressed CFRP plate, RC beam, finite element.

الخلاصة

في هذا البحث تم استخدام نموذج تحليلي لدراسة سلوك الانحناء لعتب خرساني مسلح مقوى بـصفائح البـوليمر المـسلحة بألياف الكاربون المسبقة الجهد وذلك باستخدام برنامج تحليل العناصر المحددة (ANSYS V11.0). وقد تم اسـتخدام العناصـر الطابوقية ذات ألثمان عقد (SOLID65 كما يطلق عليه ببرنامج ANSYS) لتمثيل الخرسانة المسلحة، وتم اسـتخدام العناصـر القشرية ذات الأربع عقد لتمثيل صفائح البوليمر المسلحة بألياف الكاربون المسبقة الجهد، وأخيرا تم اسـتخدام العناصـر البينيـة ذات العقدتين لتمثيل الرابط بين الخرسانة المساحة و صفائح البوليمر المسلحة بألياف الكاربون المسبقة الجهد. (CONTAC52) النتائج العملية لعتبان خرسانيان مقويان بصفائح البوليمر المسلحة بألياف الكاربون المسبقة الجهد والمفحوصـة بواسـطة (Xue *et.al.*) تم تحليلها للتأكد من جاهزية البرنامج. كذلك تم عمل دراسة لتقصي أفضل موقع وعرض وسمك صفائح البوليمر المسلحة بالألياف المسبقة الجهد. ووجدت نتائج الدراسة إن استخدام صفائح البوليمر المسلحة بالألياف المسبقة الجهد في حافات العتب تزيد من قابلية التحمل القصوى للعتب بمقدار لا يقل عن ١١% من استخدام صفائح البوليمر المسلحة بالألياف المسبقة الجهد في مركـز العتب.

1. Introduction

In recent years, fiber reinforced polymers (FRP) have been used to increase the capacity of reinforced concrete structural elements. Fiber reinforced polymers are typically comprised of high strength fibers (e.g. carbon and glass) impregnated with an epoxy (often termed the matrix). The addition of these materials can dramatically change the load capacity as well as the failure mechanism of reinforced concrete beams.

Common FRP laminate forms suitable for the strengthening of structural members are sheets and plates. FRP sheets with small nominal thickness could be employed to strengthen the members with irregular surfaces, like seismic strengthening of concrete columns. However, multiple plies of FRP sheets are usually needed to meet the requirements of flexural strengthening of the concrete beams or slabs, which should correspondingly consume extensive labors, and a reduction factor would be introduced for evaluating the effective thickness of multiple FRP plies. Compared with the FRP sheets, FRP plates with relatively large cross-sectional areas could achieve the more effective strengthening effects. And the FRP plate has some stiffness itself which is convenient to the construction in field applications (Lane et.al., 1997). It was found that premature debonding of FRP laminate was the most popular brittle failure mode observed in flexure tests of strengthened beams, and the tensile stresses in FRP laminates were only 10–20% of their ultimate tensile strength as the beams failed (Shahawy, and Beitelman ,1996) So that the FRP laminates usually could not be utilized efficiently in non-prestressed strengthening applications. In the 1990s, some researchers claimed that prestressing the CFRP laminates prior to bonding could be an innovative way to use a higher percentage of the material's tensile strength(Triantafillou et. al.1992; Saadatmannesh, and Ehsani , 1991; Quantrill , and Hollaway , 1998) Several prestressing/anchor systems were developed (Wight et. al. ,2001; El-Hacha et.al. ,2003; Yu et.al. ,2008) and a series of experimental studies on RC beams strengthened with prestressed CFRP sheets or glass fiber-reinforced polymer (GFRP) plates were conducted during the past two decades (Triantafillou et. al.1992; Saadatmannesh, and Ehsani , 1991; Wight et. al. ,2001; El-Hacha et.al. 2001; Wight et. al. ,2003; El-Hacha et.al. ,2004; Yu et.al.,2008; Char et.al., 1994). While studies on RC beams strengthened with prestressed CFRP plates are relatively limited. Garden and Hollaway's research work found that the possible failure modes of RC beams strengthened with prestressed CFRP plates included the compression failure, tension failure, debonding failure and concrete shear failure (Garden, and Hollaway, 1998). Xue et.al. (Xue et.al., 2010) were presented theoretical formulas based on the compatibility of strains and equilibrium of forces to predict the nominal flexural strength of strengthened beams under the three failure modes, (including the compression failure, tension failure and debonding failure)، and a limitation on the tensile strain level developed in the prestressed CFRP plate was proposed as the debonding failure occurred. In addition, the calculation methods for cracking moment, crack width and deflection of strengthened beams were provided with taking into account the contribution of prestressed CFRP plates. Experimental studies on five RC beams strengthened with prestressed CFRP plates and a nonlinear finite element parametric analysis were carried out to verify the proposed theoretical formulas**.**

2. Materials Modeling

2.1. Concrete Modeling

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 **(**Hognestad, 1951) *Figure (1*) was used to model concrete

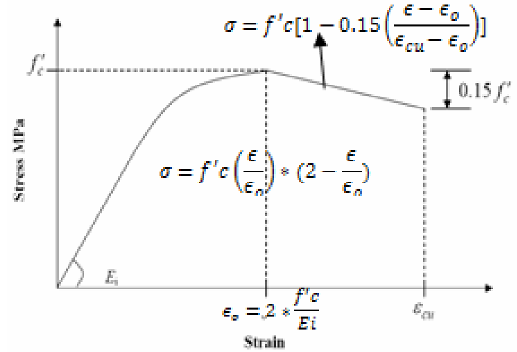


Figure 1 : *Uniaxial stress-strain of concrete in compression(*Hognestad, 1951).

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 (ANSYS, 2006), 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.

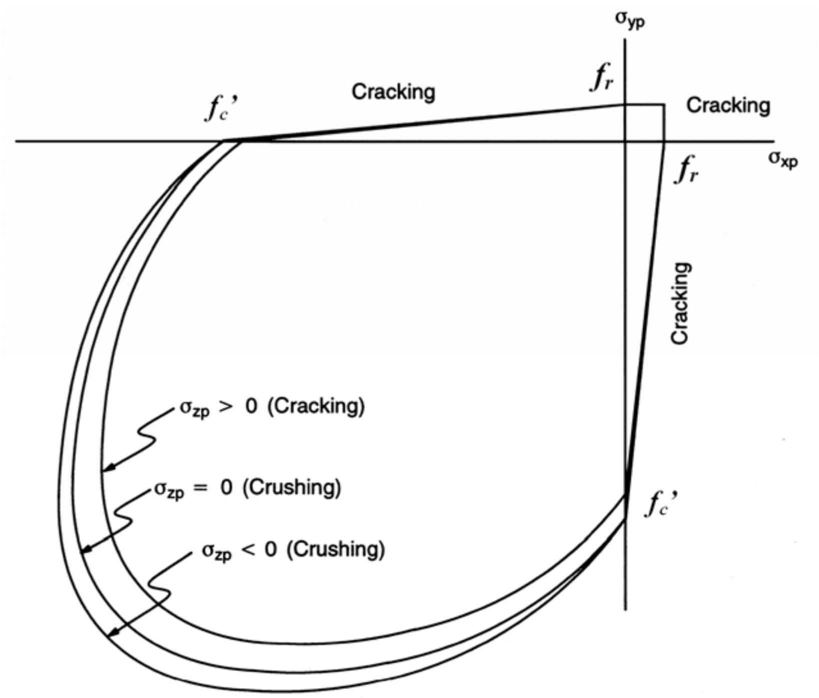


Figure 2: *3D-failure surface for concrete* (ANSYS, 2006).

2.2 Steel Modeling

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).

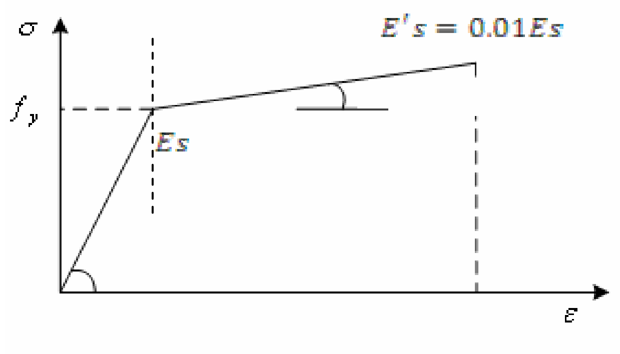


Figure 3: *Elastio-plastic stress-strain relationships for steel*(Xiong, and Zha, 2007)

3. Finite element Modeling

In this section FE method use to predict model by using ANSYS 11.0 (ANSYS, 2006)program. 3-D finite element modeling used in this study to represented full scale simply supported reinforced concrete beam strengthened with prestressed carbon fiber reinforced polymer plates. 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 modeling 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 modeling 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 (4)

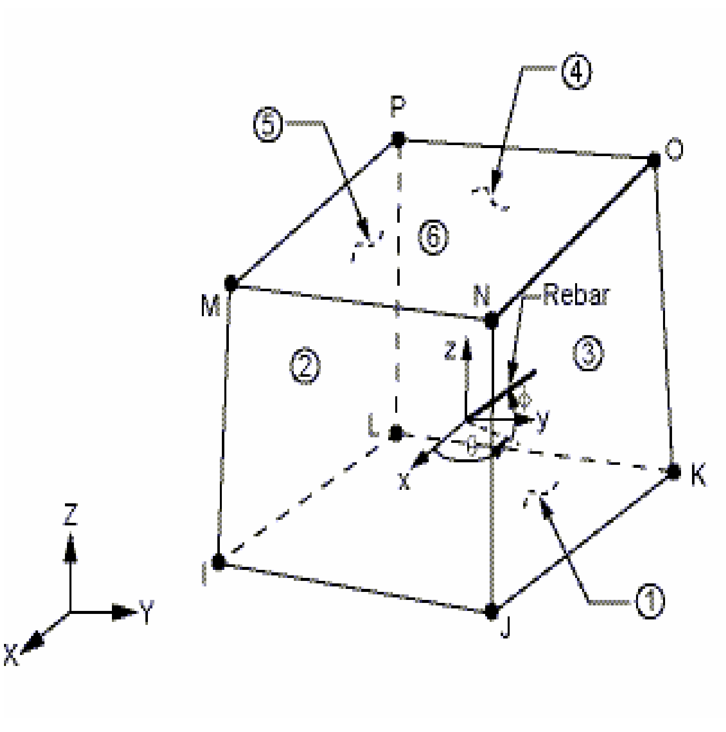


Figure 4: Element Geometry SOLID65 (ANSYS, 2006).

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 (5). 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 element may have variable thickness. 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 to produce a unit normal deflection of the foundation. The elastic foundation capability is bypassed if EFS is less

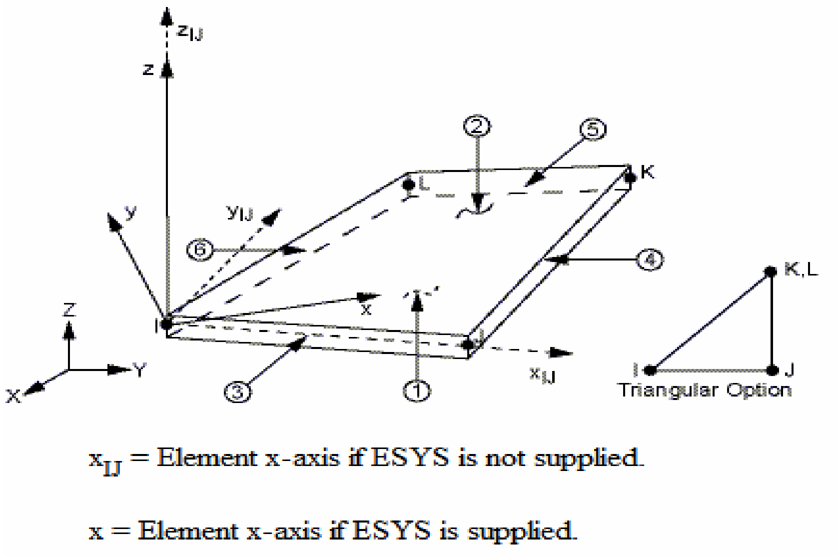


Figure 5: Element Geometry SHELL41(ANSYS, 2006).

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 6. 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.

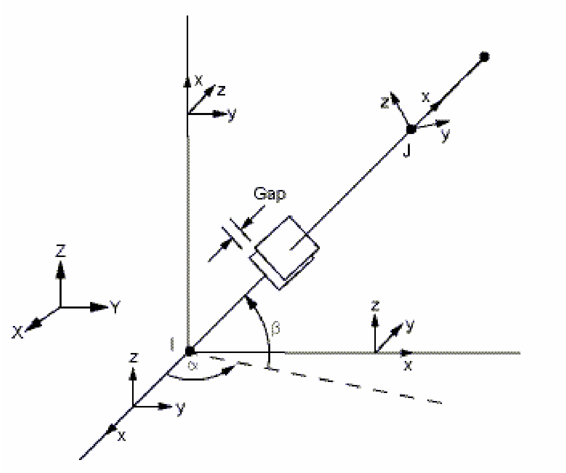


Figure 6:Element geometry CONTAC52(ANSYS, 2006).

4. Results and Discussion

In previous study Xue et.al. (Xue et.al., 2010) presented experimental study : five RC beams strengthened with prestressed CFRP plates were tested in a four-point loading test setup, as depicted in Figure(7). The specimens were 2.7 m long and had a cross-sectional area of 150 * 250 mm. The investigated variables included prestress level and width of the high tensile strength CFRP plates, as well as the tensile reinforcement ratio. Figure(8) shows the beam dimensions and reinforcement details. Details of specimens are listed in Table 1. The CFRP plates had a thickness of 1.4 mm, an ultimate tensile strength of 2500 MPa, and a longitudinal elastic modulus of 150 GPa. Tables 2 and 3 list the mechanical properties of the concrete and reinforcing bars used to construct the beams, respectively

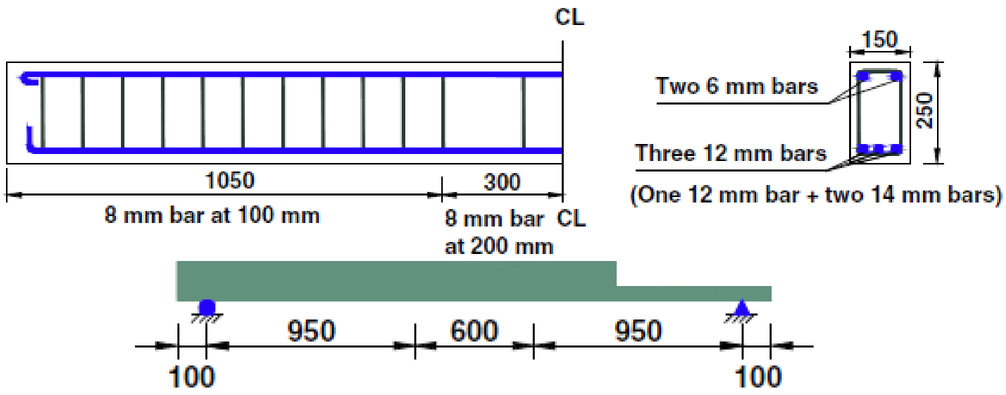


Figure 8: Reinforcement details of the concrete beam specimens (dimensions :mm) (Xue et.al., 2010)

Table1: Details of beam specimens.

Specimen	Steel reinforcement in compression	Steel reinforcement in tension	CFRP plate width (mm)	Effective prestress (MPa)
PC1	2φ6	1φ12+2φ14	50(42.1%)*	1052.0
PC2	2φ6	3φ12	20(50.6%)	1265.4

*The value in parenthesis of the fourth column represent the portion of ultimate tensile strength to which each CFRP plate was prestressed.

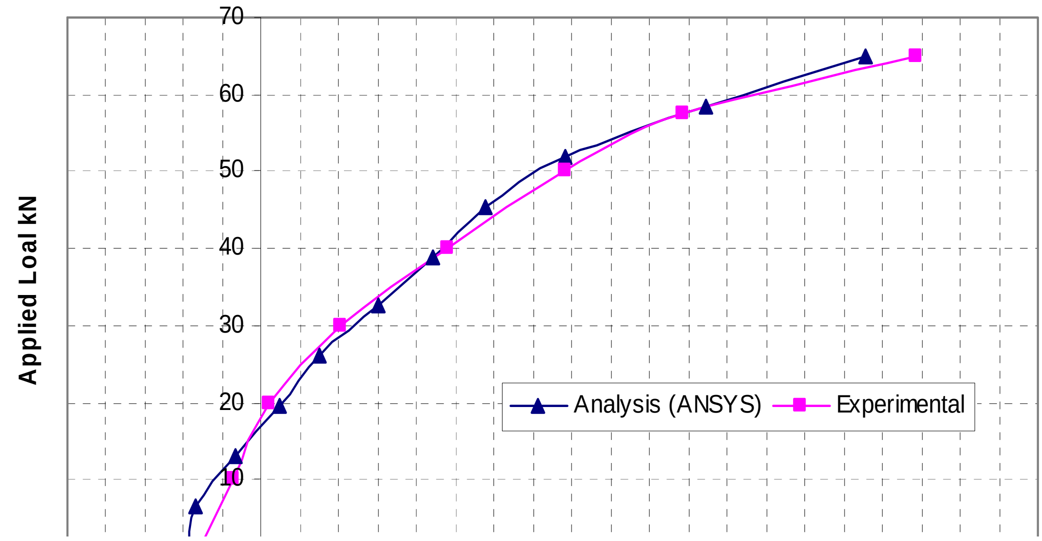
Table2: Mechanical properties of concrete used for beams

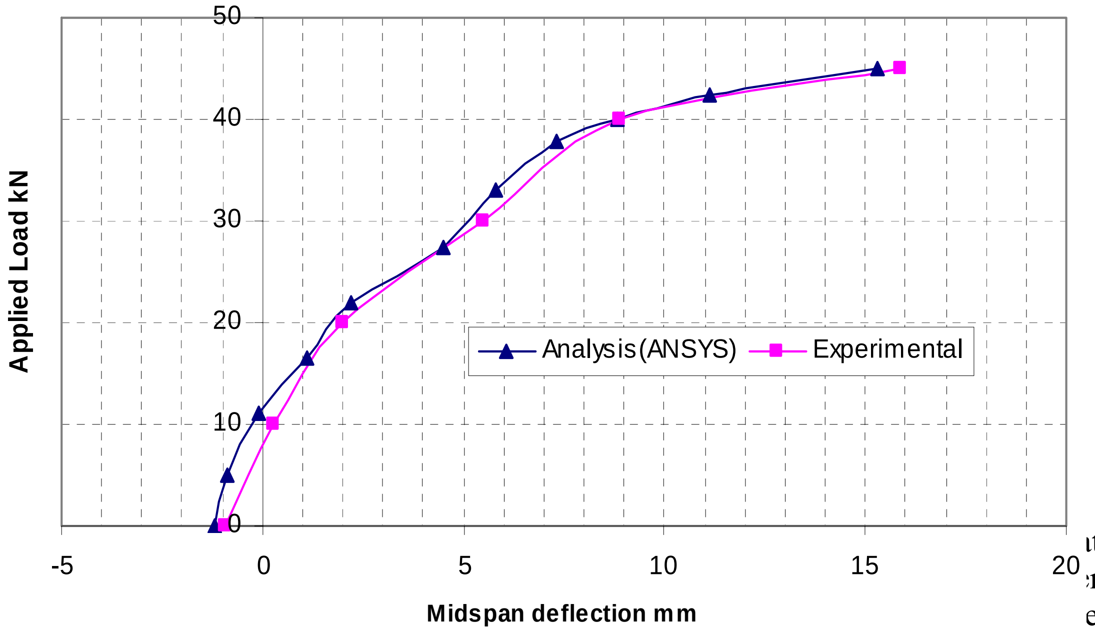
Specimen	Elastic modulus (MPa)	Cubic compressive strength (MPa)	Tensile strength (MPa)
PC1&2	32.5	52.3	3.6

Table3: Mechanical properties of steel reinforcing bars used in concrete beams.

Diameter (mm)	Elastic modulus (MPa)	Yield stress (MPa)	Ultimate stress (MPa)
6	245	500	641
12	145	340	518
14	140	270	450

Figures (9) & (10)plot the experimental curves measured by Xue et.al, (Xue et.al., 2010) and analytical curves for PC1 and PC2 respectively. Comparisons demonstrate that the presented analysis model could in general provide good predictions for the flexural responses of strengthened beams prestressed with CFRP plates under monotonic loading.





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CFRP plate give minimum deflection under same load and in the same time has maximum load capacity. For this purpose many locations of CFRP plate are investigated and with different width and thickness of prestressed CFRP plate as listed in table (4)

Table4: Arrangement of prestressed CFRP plate.

Specimen	Arrangement of CFRP plate number	CFRP plate thickness (mm)	CFRP plate width (mm)	Cross section area of CFRP plate (mm^2)
PC1	A1	1.4	2*25 in edges	70
PC1	A2	0.7	2*50 in edges	70
PC1	A3	0.47	1*150 all	70
PC1	A4	2.8	1*25 in center	70

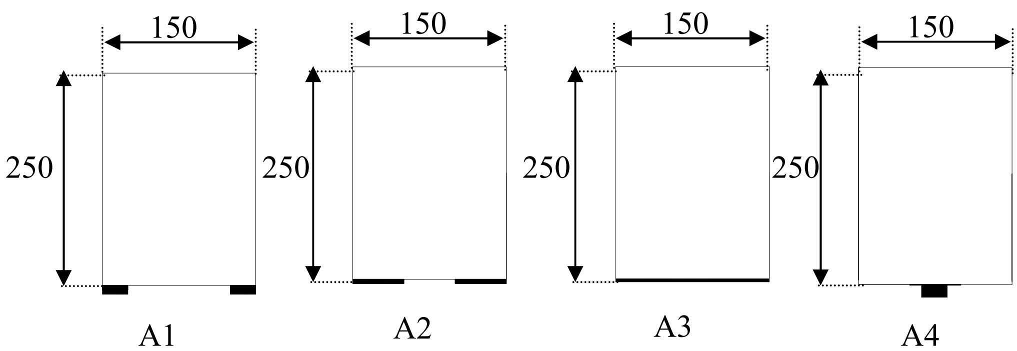
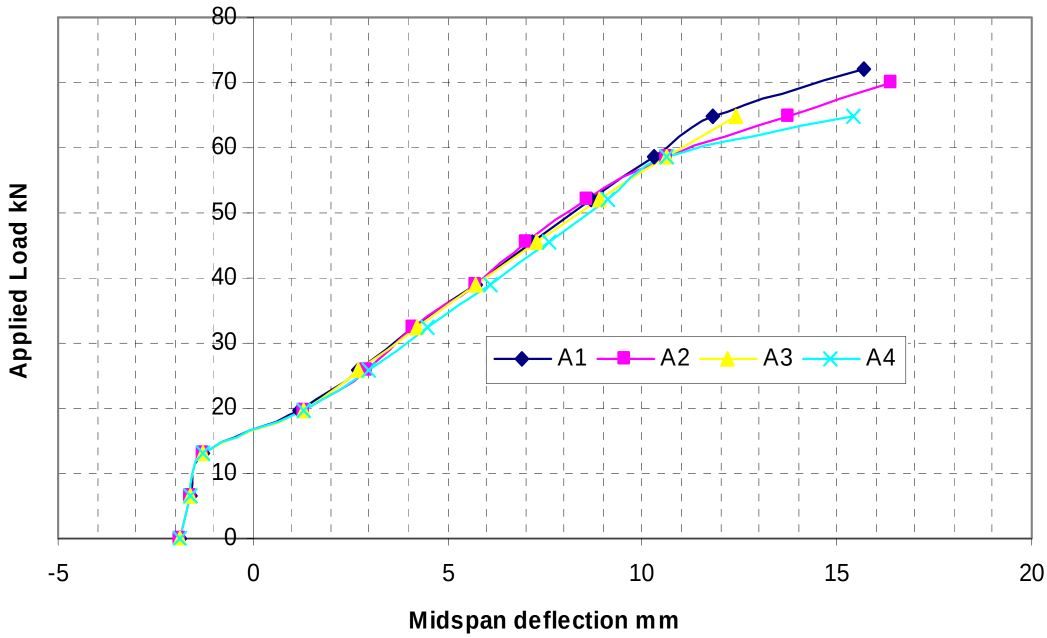


Figure 11: The locations of prestressed CFRP plate.

The results obtained from analysis show that the arrangement type (A1) (prestressed CFRP plate at edges) give maximum stiffness when compared with other types of arrangements by amount reached 11% . The thick layers (1.4 mm) in the edges strength the concentration of stresses at this regions are the reason of the increasing of stiffness in beam (A1).



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2. Results obtained from this study suggest that the best location of prestressed CFRP plates is at the edges of beam.

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