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Effect of Using Partial Continuounity by External Post-Tension on The Simple Composite Beams as a Strengthening Technique

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ABSTRACT

Composite steel-concrete beams are used widely in bridge and building construction as the main structural elements in flexure. These structures have a design life and this may be reduced if loads are increased or environmental degradation occurs. Strength of such structure members and thus replacement or retrofitting may need to be considered. One method of retrofitting (stiffening and strengthening) a composite steel-concrete beam is to externally post-tension the beam. The present study focuses on evaluating the effect of adding the external post-tension as a strengthening technique on the simple composite beams. The study was conducted using the finite element program "ANSYS". Nonlinear material models for the components of the composite beam were used in the finite element model. The outcomes got from finite element analysis were confirmed against available experimental results. A broad parametric study was conducted to explore the effect of tendons profiles on flexural behaviour. This covers: load deflection behaviour, converting the simple beam into partially continuous beam, verifying an external post-tensioned simple beam.

1. Introduction

Steel-concrete composite girders have attractive potentials when applied in building construction. It has been found to provide an efficient and economical solution for a wide range of structure types and conditions. Composite steel-concrete beams post-tensioning with high strength external tendons have demonstrated many advantages when compared with plain composite beams like: Increase in ultimate moment capacity of structure, Enlarge the range of elastic behaviour before yielding for the structure with the introduction of internal stresses. The stresses can then oppose the moment generated by the loading. The amount of structural steel used in construction, based on yield strength alone, can be significantly reduced by using high-strength tendons, thereby reducing the cost of construction [5]. Post-tensioning a composite beam can introduce internal stresses into the member cross sections that can be defined for different purposes. Such induced stresses can then counteract the external loads applied on the structure. Post-tensioning can be carried out for simple-span or continuous-span composite beams. In the positive moment region, the steel beam is usually post-tensioning before the concrete is cast because the negative moment induced by post-tensioning may be used to counteract the positive moments caused by the concrete's self-weight. In the negative moment region, the steel beam and concrete deck can also be

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post-tensioning either separately or jointly along the top flange before or after casting of the deck [2] .In this paper, a suitable three-dimensional (3D) FE model is presented to simulate the nonlinear flexural behaviour of steel–concrete composite beams strengthened with externally post-tensioned tendons. The effective post-tensioned force is taken as an initial value that appears in the analysis as initial strain in the link elements used to model the tendons. To verify the accuracy of the developed 3D FE model, comparison between the FE analysis results and previous experimental results is presented. In-depth study of the overall behaviour of the strengthened beam is discussed through the effect of external post-tensioning on deflection and slippage between concrete slab and steel beam. The FE analysis predictions compared well with the test results. It was observed that using externally post-tensioned tendons in the positive moment region increased its ultimate capacity and improved the behaviour of composite concrete–steel beams.

2. FINITE ELEMENT MODEL

The present study utilized the finite element program ANSYS version 14.0 [6] to simulate the behaviour of the composite beam and the stud shear connectors. A three dimensional finite element model was presented to simulate the material non-linear behaviour of the composite beam. The used elements are summarized in the following. The concrete slab was modelled using a three dimensional concrete element (solid 65). The most important aspect of this element is the treatment of the non-linear material properties. In the proposed concrete material model, tension stress, relaxation coefficient, shear transfer for open and closed cracks, and concrete crushing were considered. The steel I-beam was modelled using an eight-node solid element with three degrees of freedom at each node. SOLID185 is used for the three-dimensional modelling of solid structures. Three-dimensional spar elements were used to model the reinforcing bars embedded in the concrete in the longitudinal and the transverse directions. The LINK8 is a spar (or truss) element. The external tendons were modelled using 3D spar elements. Link8 is used to represent the external cable. The interface of the steel flange and the concrete slab was represented by using node-to-node. The purpose of using the contact element between these connected surfaces is to prevent penetration and to ensure physical separation between them as shown in Figure 1. To avoid stress concentration problems at the loading location steel plates are added. This provides a more even stress distribution over the load area. An eight-node solid element with three degrees of freedom at each node is used to represent the shear connector's behaviour to resist the normal force between the concrete and steel beam.

3. MATERIAL MODELING

The main components of the composite section in this study: concrete slab, steel beam, tendons, contact surface and shear connection are modelled with relevant ANSYS elements that are explained in a sequel. A three dimensional element was used to representation the structure.

3.1 Modeling of Concrete

The concrete is assumed to be homogeneous and initially isotropic. The uni-axial stress–strain relationship for concrete in compression is required for ANSYS as an input. The simplified stress–strain curve for each beam model was constructed from nine points connected by curved lines, as shown in Fig. 2.

3.2 Modeling of Steel I-Beam

The mechanical properties of steel are well known so that the stress–strain behaviour in tension and in compression can be assumed typical and identical. Elastic modulus and yield stress for the steel I-beam used in this study follows the design material properties used for the experimental investigation.

3.3 Modeling of Reinforcement and External Post-Tension Tendons

Since the reinforcing bars and post-tensioning cables are normally long and relatively slender, they can generally be assumed to be capable of transmitting axial forces only. This relation is assumed to be identical in tension and in compression.

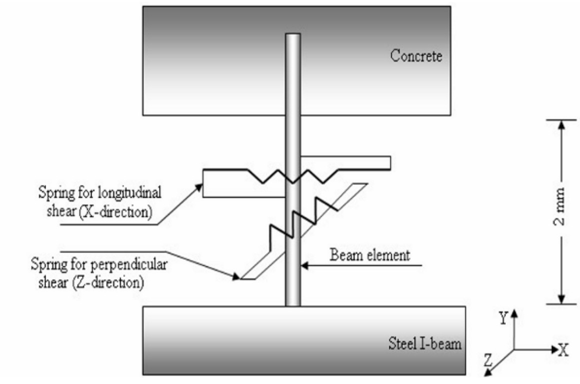

Fig.1: Finite element model for the composite section and the stud shear connector

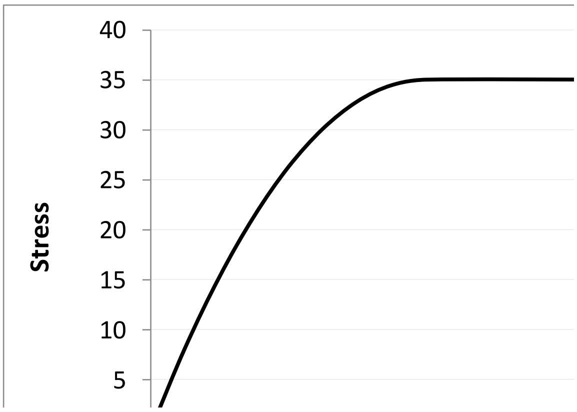

Fig.2: Simplified compressive uni-axial stress- strain curve for concrete

4. Analysis and Discussion

4.1 Verification of Finite Element Model

The accuracies of the proposed Finite Element models were verified by means of experimental data to ensure their validity and degree of accuracy. In this section two different models were analyzed, and the Finite Element model's results were compared with the corresponding experimental data. Table 1 shows a summary of material properties for the modelled composite beams.

The first model is the simply supported composite beam tested by Abdel Aziz (1986).The beam is simply supported with a total length of 5,400 mm and an effective span length 5,000 mm [1]. The beam was characterized by the cross section shown in Figure 3. The beam was loaded symmetrically at one point at the mid - span of the beam. Two rows of 19 mm-diameter by 80-mm-length shear studs were welded to the top flange, with a transverse spacing of 110 mm and a longitudinal spacing of 650 mm. 41% shear connection was achieved in accordance with the experimental study of Abdel Aziz [1]. The concrete slab was reinforced with 10-mm-diameter deformed bars in two orthogonal directions and two levels (top and bottom).

The second model is a composite beam, tested experimentally by Chen (2005) [3], was selected to investigate the behavior of externally post-tensioned concrete–steel composite beams by developing a general analytical approach to predict the ultimate flexural response. The dimensions, details, and profiles of the post-tensioned tendons of the beams studied are illustrated in Figure 4. The beam had a total length of 5,150 mm and was simply supported over a 5,000-mm span.

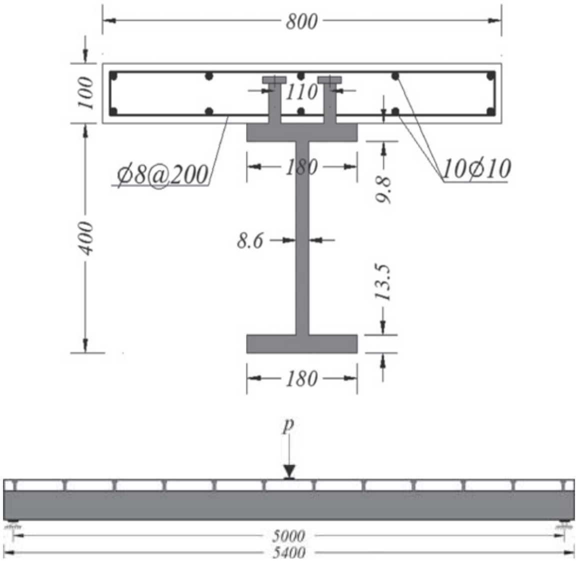

Fig.3: Model (1) The geometrical characteristics of the simply supported composite beam tested by Abdel Aziz (1986) (All dimensions in mm)

The beams were loaded symmetrically at two points to create a pure bending region. Two rows of 16-mm-diameterby 65-mm-length shear studs were welded to the top flange; with a transverse spacing of 76 mm and a longitudinal spacing of 200 mm [3]. Full shear connection was achieved in accordance with BS5400 Part 5 (BSI 1979) [7]. The concrete slab was reinforced with 8-mm-diameter deformed bars in two orthogonal directions. The Post-tensioning tendon's profile was straight and was anchored at the two ends of the beam 30 mm above the tension flange and extended on both sides of the web along the full length of the beam as shown in Figure 4.

4.2 Results and Discussions

The load-mid-span deflection curve of the simply supported composite beam tested by Abdel Aziz, (1986) (model 1) and moment- deflection curve of the externally post tensioned simple composite beam tested by Chen,(2005) (model 2) obtained from the finite element analysis using ANSYS computer program (version 14.0) was compared with corresponding experimental data as shown in Figure 5 for model 1 and Figure 7 for model 2 . In general, it can be noted from the load deflection curve that the finite element analyses is agree well with the experimental result throughout the entire range of behavior. Figure 6 showing the slippage between concrete slab and steel beam validation between finite element model and the corresponding experimental one for (model 1).

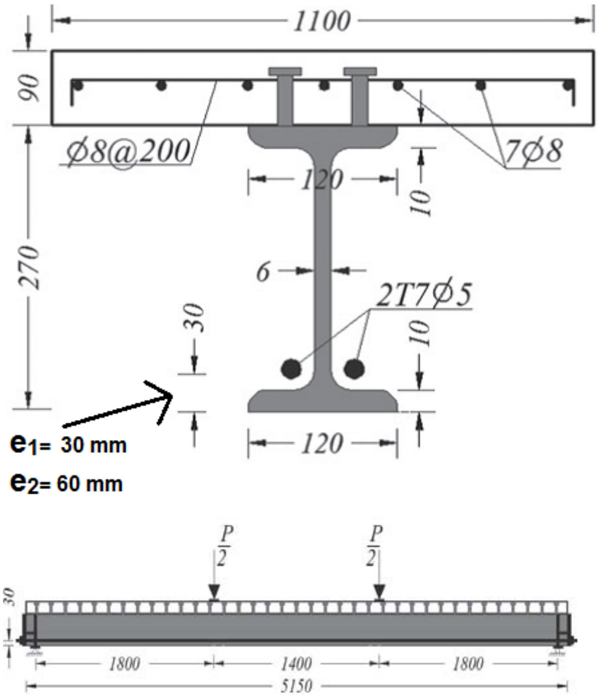

Fig.4: Model (2) the geometrical characteristics of the simply supported composite beam tested by Chen (2005) (All dimensions in mm).

4.3 Parametric study

Using the verified models, A.Aziz and Chen, 2005 a parametric study was carried out on three new developed models. From A.Aziz model an investigation about the effects of 41%& 60% & 80% and 100% degrees of degree of shear connection, along with the effects of converting the simple composite beam into continuous composite one on load capacity and the deflection (model 3).From Chen model an investigation About the effects of the re-arrangement of the tendon profile. Two models(A1 and D1) with a straight tendons using two cases of (e = 30 and 60 mm) respectively ,which (e) is the distance from the bottom flange to the tendon location.The case of beam with no post-tension force applied taken as a reference case. Another two models (B1 and E1) have been developed to study the partially continuounity for Chen model by using atriangle and trapezoidal tendon profile respectively with (e = 30 mm from the top and the bottom flange, as shown in Figure 9 (a and b).

4.3.1 Deflection Response

Figure 8 shows the comparison between the ultimate loads of multi shear connection phases applied to the continuous composite steel-concrete beams and deflection in (mm) .In comparison with the four cases of the simple beam deflection the finite element model show (71.6%) decrease in the mid-span deflection for model 3 .

4.3.2 Load- Deflection Response

For the analyzed model 3, at failure, the load capacity for 60% shear connection beam was (510 KN) resulting an enhancement of the beam load capacity by about (12.4%), at 80% shear connection model was (616 KN) resulting an enhancement of the beam load capacity by about (21.2 %) and at 100% shear connection it was (585 KN) resulting an enhancement of the beam load capacity by about (14.7%) as shown in Figure 8.

4.3.3 Moment – Deflection Response

From observation of Figure 11 :

For A(1), D(1) :

The F.E.M. parametrice study demonstrate that adding straight post-tensioning to the composite beams significantly increased the yield load and the ultimate moment resistance. It appeared that before the onset of yielding, the internal post-tension forces in the tendons increased proportionally to the load. Afterwards, the internal post-tension forces developed nonlinearly. Using straight externally post-tension tendon in positive moment region of a composite beam increased its ultimate moment capacity by about 62 %.

From observation of Figure 12 :

For B(1) and E(1) :

From this study its observed that by changing the eccentricity of tendons at the anchorage section with a traingl and trapezoidal tendon profile. It appears that the larger the eccentricity of tendons at the anchorage section, the greater the bottom flang stresses. The larger the deflection, the greater slip of the slab and shear connectors moments. Adding post-tensioned tendons to composite beams significantly increases the yield load and the ultimate load. Less deflection can also be achieved using this tendon profile as a strengthening technique.

5. Conclusions

This paper investigates the behaviour of converting simple composite beam into partially continuous one.

1-Good agreement was obtained between the proposed 3D nonlinear FE model and the existing two experimental results selected in this paper. The FE model was effective in predicting and evaluating the behaviour of concrete–steel composite sections.

2-Using externally post-tensioned tendons in composite beams in the positive moment region increased its ultimate capacity by about 106%.

3- In comparison with the four suggested cases of rearrangement of tendon profile, it can be observed that an enhancement in overall behaviour of the beam when trapezoidal tendons are existed more than straight one.

4- The increasing of shear connection degree enhance the ultimate load capacity and deflection response for the continuous composite beams.

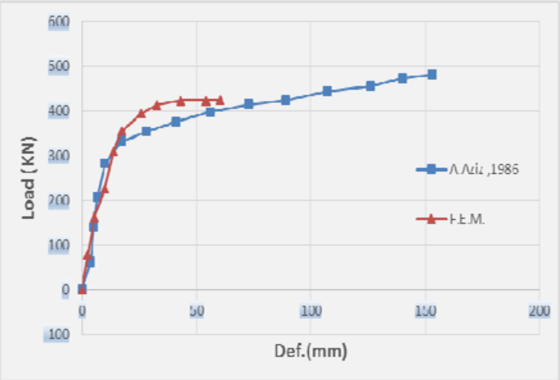

Fig.5: Load-Deflection Curve for (model 1)

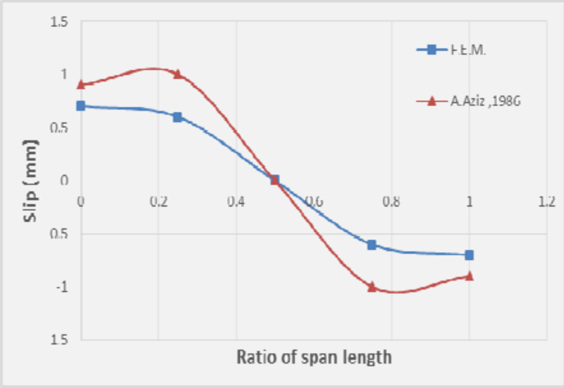

Fig.6: Concrete-Steel slippage Value (model 1)

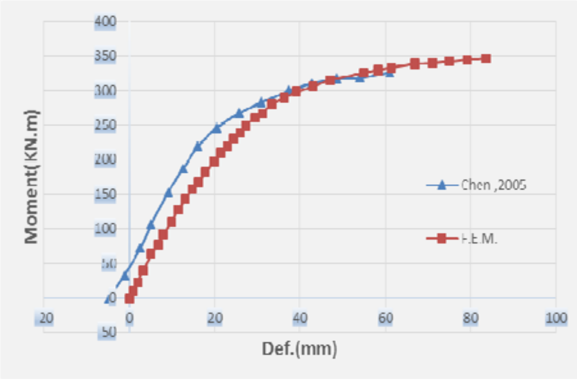

Fig.7: Moment-Deflection Curve for (model 2)

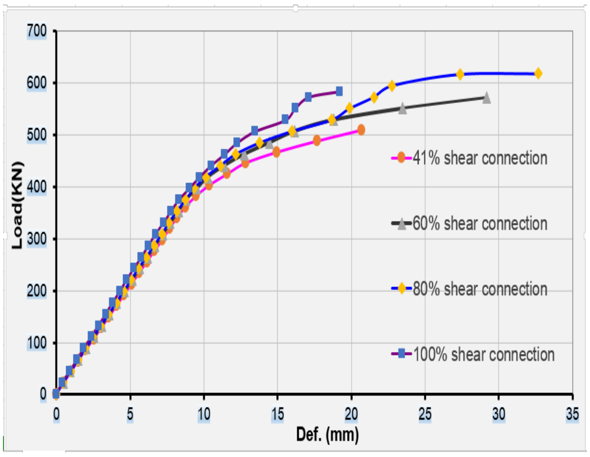

Fig.8: Load-Deflection Curves for different types of shear connection degrees models (model 3).

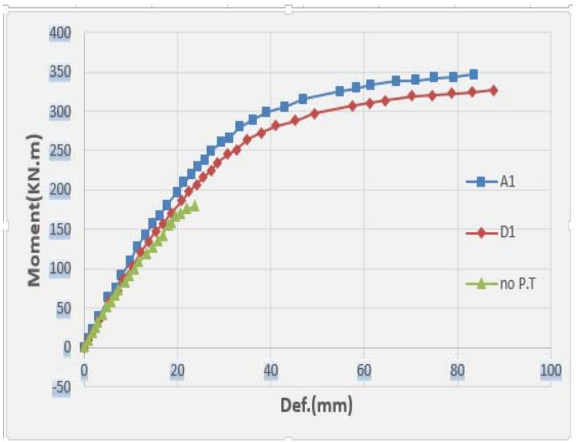

Fig.11: Moment-Deflection Curve for models (A1 and D1)

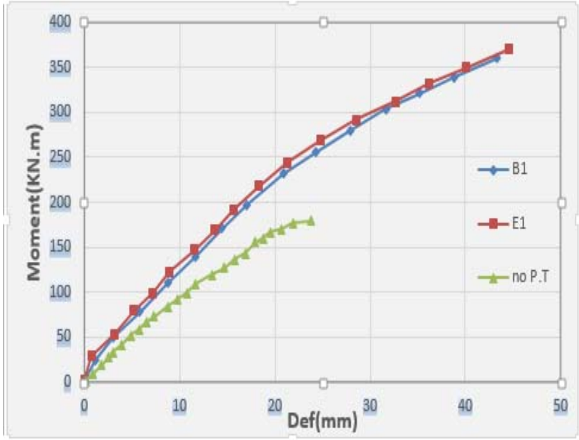

Fig.12: Moment-Deflection Curve for models (B1 and E1)

	Post-tensioning Tendons				Concrete	Steel I-beam			
Model	**f_y (MPa)**	**f_u(MPa)**	**A_p(mm^2)**	**F(kN)**	**f_c(MPa)**	**f_y(MPa)**		**f_u (MPa)**	
						Web	**Flange**	**Web**	**Flange**
Model 1	-	-	-	-	40	260	245	372	361
Model 2	1,680	1,860	137.4	112.6	35	327.7	406.5	492.6	593.6

Table1. Summary of Material Properties for Modelled Composite Beams

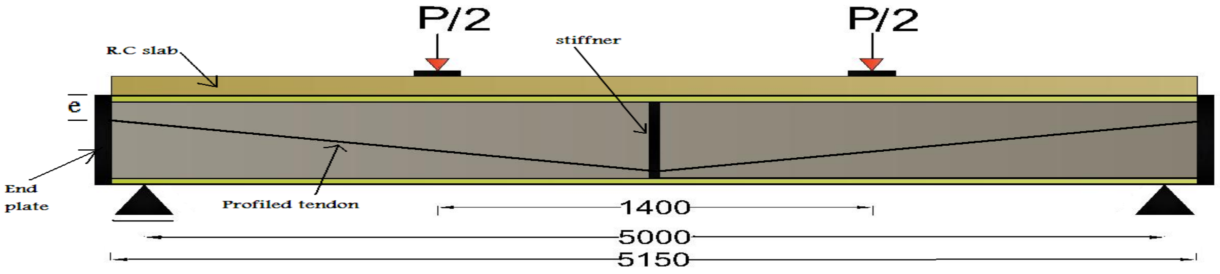

Fig.9 (a): (model 5, case 1)

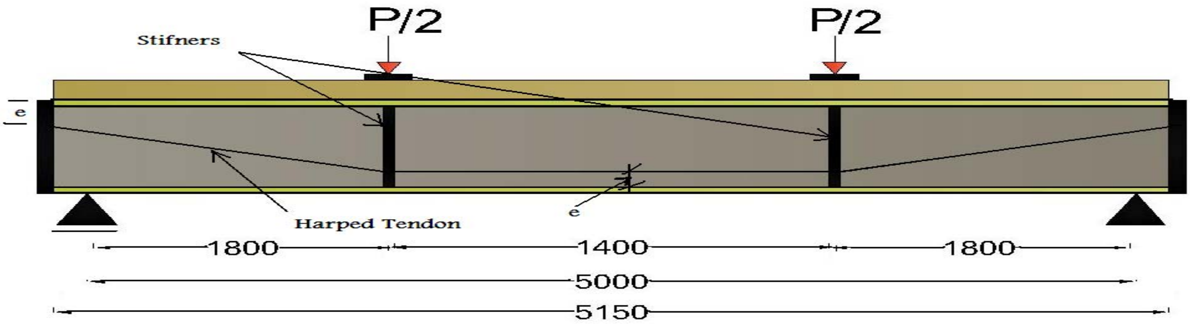

Fig.9 (b): (model 5, case 2)

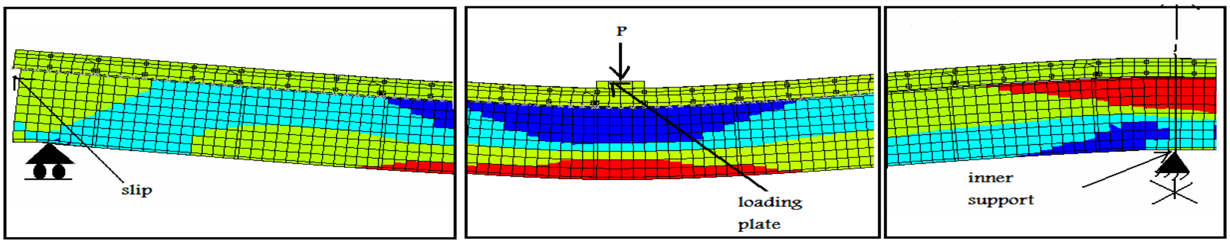

Fig.10: Deformed shape and stress contour of the modelled continuous composite beam (model 3).

5. References

[1] K. Abdel Aziz, "Modélisation et étude expérimental de pouters mixtes acier-béton à connexion partielle ou espacée", Ph.D. Thesis, Institut National des Sciences Appliquées des Rennes, Rennes, France (in French),1986.

[2] B. M. Ayyub, Y. G. Sohn and H. Saadatmanesh, "Prestressed composite girders under positive moment", Journal of Structural Engineering Vol. 116, No. 11 pp. 2931-2951, 1990.

[3] S. Chen and P. Gu, "Load Carrying Capacity of Composite Beams Prestressed With External Tendons Under Positive Moment", Journal of Constructional Steel Research Vol. 61, No. 4 pp. 515-530, 2005.

[4] A. M. El-Shihy, H. M. Fawzy, S. A. A. Mustafa and A. A. El-Zohairy, "Experimental and Numerical Analysis of Composite Beams Strengthened by CFRP Laminates in Hogging Moment Region", Steel and Composite Structures Vol.10, No. 3 pp. 281-295, (2010).

[5] A. A. El-Zohairy, H. Salim, H. F. Shaaban, S. A. A. Mustafa and A. M. El-Shihy, "Finite-Element Modeling of Externally Post-tensioned Composite Beams", Journal of Bridge Engineering Vol. 20, No. 12 10.1061/(ASCE)BE.1943-5592.0000756, (2015).

[6] ANSYS Element Manual, 10th Edition, release 4. 1, Swanson Analysis Systems Inc., Canonsburg, PA, (2008).

[7] R. P. Johnson and N. Molenstra "Partial shear connection in composite beams for buildings", Proceedings of the Institution of Civil Engineers Part 2 Vol. 91, No. 4 pp. 679-704, (1991).

[8] A. M. El-Shihy, H. Shehab El-Din, H. F. Shabaan, S. A. A. Mustafa and S. S. J. Moy, "Partial Interaction in Composite Beams Subjected to Torsion in Sagging Moment Region". Materials and Structures Vol. 45, No. 3 pp. 393-410, (2012).