EL-Shihy et al., J Material Sci Eng 2017, 6:2
DOI: 10.4172/2169-0022.1000318

Journal of Material Sciences & Engineering

Research Article Open Access

Effect of Partial Shear Connection on Strengthened Composite Beams with Externally Post-Tension Tendons

EL-Shihy AM[1], Shabaan HF[1], Al-Kader HM[1] and Hassanin AI[2*]

[1]*Faculty of Engineering, Zagazig University, Zagazig, Egypt*
[2]*Faculty of Engineering, Egyptian Russian University, Cairo, Egypt*

Abstract

Composite steel-concrete beams are used widely in bridges and buildings 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 could happen. These changes may reduce the design life and strength of such members and thus replacement or retrofitting may need to be considered. The present study focuses on evaluating the effect of partial shear connection on strengthen composite beams with externally post-tension tendons. Using three dimensional F.E. modeling it's able to simulate the overall flexural behavior of composite beams which are strengthen with many shapes of tendons profiles. A fundamental point for the structural behavior and design of composite beams is the level of connection and interaction between the steel section and the concrete slab. The use of partial connection provides the opportunity to achieve a better match of applied and resisting moment and some economy in the provision of connectors, taking into account the demonstrated advantages of externally post tension system like: Increase in ultimate moment capacity of structure, Enlarge the range of elastic behavior before yielding for the structure with the introduction of internal stresses.

Keywords: Finite element; Nonlinear; Post-tensioning; Composite beams; Deflection; ANSYS 14.0

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 composite beams like: Increase in ultimate moment capacity of structure, Enlarge the range of elastic behavior before yielding for the structure with the introduction of internal stresses [1]. 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 partial shear connection on strengthen composite beams with externally post-tension tendons. This covers: moment deflection behavior, slip-deflection, and moment-bottom flange stress in the steel beam. A fundamental point for the structural behavior and design of composite beams is the level of connection and interaction between the steel section and the concrete slab. The use of partial shear connection provides the opportunity to achieve a better match of applied and resisting moment and some economy in the provision of connectors, taking into account the demonstrated advantages of externally post tension system like: Increase in ultimate moment capacity of structure, Enlarge the range of elastic behavior before yielding for the structure with the introduction of internal stresses. In this paper, a three-dimensional (3D) FE model is presented to simulate the nonlinear behavior of steel–concrete composite beams strengthened with externally post-tensioned tendons under many degrees of shear connection. 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 and degrees of shear connection are ranging from 40% to more than 100% (by means of varying the number of shear connectors). To verify the accuracy of the developed 3D FE model, comparison between the FE analysis results and previous experimental results was carried out in a previous study [2], which shows a good agreement in moment, slip and deflection.

Finite Element Model

The present study utilized the finite element program ANSYS version 14.0 [3] 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 steel I-beam was modeled using an eight-node solid element with three degrees of freedom at each node. SOLID 185 is used for the three-dimensional modeling 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 LINK 8 is a spar (or truss) element. The concrete slab was modeled 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. 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 and shear force between the concrete and steel beam. The external tendons were modeled 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

***Corresponding author:** Hassanin AI, Assistant Lecturer, Faculty of Engineering, Egyptian Russian University, Cairo, Egypt, Tel: 00201027554176; E-mail: Ahmed_eng8028@yahoo.com

Received January 08, 2017; **Accepted** January 21, 2017; **Published** January 31, 2017

Citation: EL-Shihy AM, Shabaan HF, Al-Kader HM, Hassanin AI (2017) Effect of Partial Shear Connection on Strengthened Composite Beams with Externally Post-Tension Tendons. J Material Sci Eng 6: 318. doi: 10.4172/2169-0022.1000318

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 locations steel plates are added, this provides a more even stress distribution over the load area.

Material Modeling

In this study ANSYS finite element program is used. The element damaged plasticity model in ANSYS provides a general capability for modeling all types of structures using concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of the composite steel- concrete beams. The choice of the appropriate elements for the modeling of different composite beam parts requires good understanding of the geometrical shape and material properties of each part. Also, the connectivity of each element with the adjacent elements had to be considered. ANSYS has an element library which covers all these requirements.

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 [2]. The simplified stress–strain curve for each beam model was constructed from nine points connected by curved lines, as shown in Figures 2 and 3.

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.

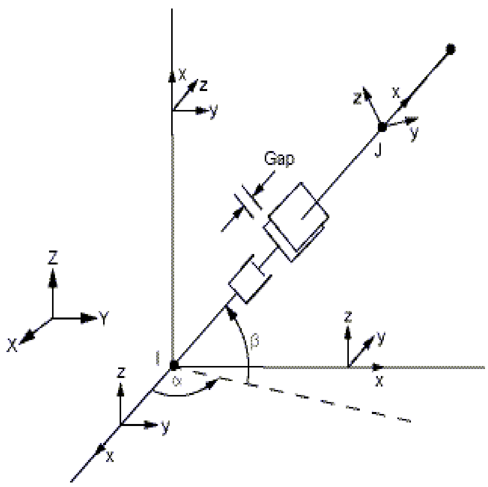

Figure 1: ANSYS contact element (Contact178).

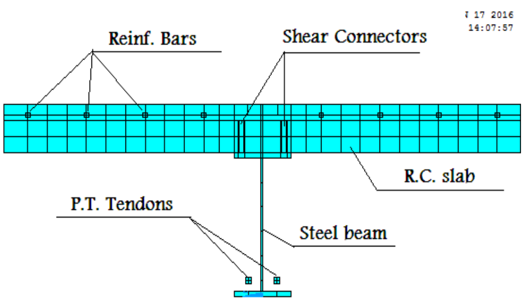

Figure 2: Meshing of composite beam cross-section.

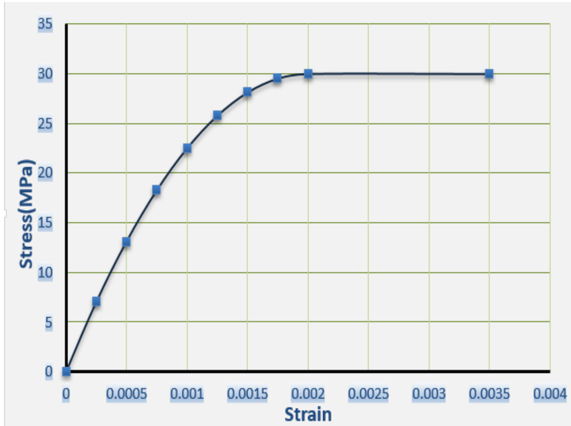

Figure 3: Stress - Strain curve for concrete.

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.

Analyses and Discussion

Verification analysis process

The finite element for this analysis is a simple model under axial point loading. For the purposes of this model, the Static analysis type is utilized. The Restart command is utilized to restart an analysis after the initial run or load step has been completed. The solution control (Sol'n Controls) command dictates the use of a non-linear solution for the finite element model.

Verification results

The goal of the comparison of the FE model and the experimental models Chen [4] and Abdel Aziz [5] is to ensure that the elements, material properties, real constants and convergence criteria are adequate to model the response of the member and verify the accuracy of the FE Model.

It can be seen that many cracks appeared at the studs' locations owing to the longitudinal shear that occurred through the concrete slab. Also, many cracks appeared at the loading location where maximum beam moment and maximum compressive stress in the concrete slab occurred as shown in Figure 4.

The FE-deformed shape for model two (A.Aziz) resulting from the effect of externally applied loads, slippage between concrete slab and top steel flange and increasing of stresses in the bottom steel flange have been observed as shown in Figure 5.

Verified model one (Chen)

The mid span Moment- Deflection curve of the externally post tensioned simple composite beam obtained from the finite element analysis using ANSYS computer program (version 14.0) was compared with corresponding experimental results [6,7].

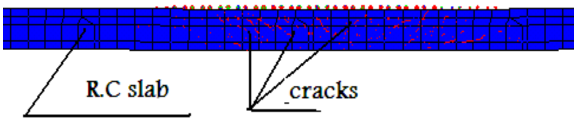

Figure 4: Cracks shape in R.C slab at final loading (at failure).

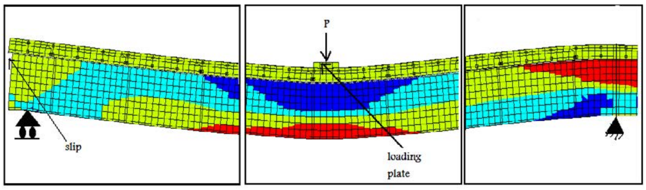

Figure 5: Deformed shape at final loading (at failure).

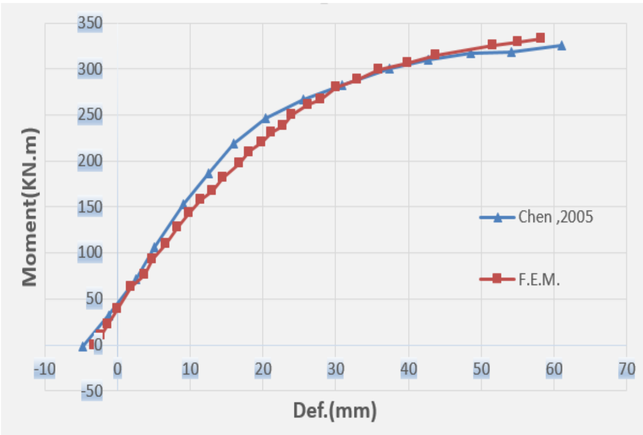

Figure 6: Mid-span Moment-Deflection curve.

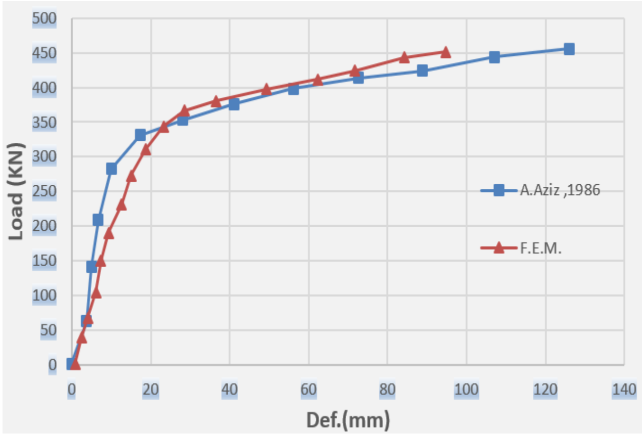

Figure 7: Load-Deflection Curve.

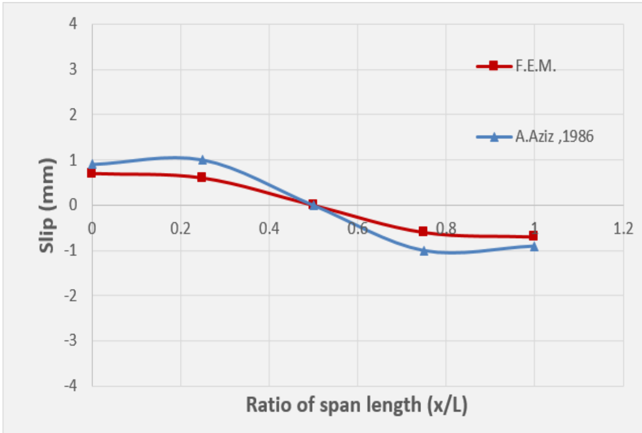

Figure 8: Concrete-Steel slippage Value.

In general, it can be noted from the Moment - Deflection curve that the finite element analyses is agree well with the experimental results throughout the entire range of behavior. In the linear range, the FE moment–deflection response coincides with that from the experimental results. When the moment–deflection curve transitioned from linear to nonlinear, the yielding of the beam started. After this point, the stiffness of the FE model was slightly higher than the experimental beam owing to the difference in behavior of the shear connector between the experimental and theoretical model as shown in Figure 6.

Verified model two (A.Aziz)

Load-mid-span deflection curve of the simply supported composite beam obtained from the finite element analysis using ANSYS computer program (version 14.0) was compared with corresponding experimental data as shown in Figure 7.

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. In the linear range, the two beams behaved similarly; the two trends were parallel to each other with a difference at maximum deflection due to continuounity of loading on the experimental beam till failure [8].

Figure 8 showing the slippage between concrete slab and top flange of the steel beam. It can be noted that the finite element analyses is agree well with the experimental results. Table 1 shows a summary of material properties for the modeled composite beams.

Parametric study

Using the verified model, Chen [4], a parametric study was carried out on three new developed models (A, B and C) according to arrangements of the external tendons applied in composite beams (A) for straight tendon profile, (B) for triangle tendon profile and (C) for trapezoidal tendon profile). An investigation about the effects of changing levels of shear connection in ranges from 40% to more than 100% (by means of varying the number of shear connectors) and varying numbers from (1-1) to (1-5) according to degree of shear connection taken in the model. The case of beam with no post-tension force applied with a fully shear connection had been taken as a reference case. The geometrical characteristics of the used models are shown in Figures 9-11 and a summary of material and section properties for the verified and modeled composite beams are shown in Tables 1 and 2.

Moment-slippage relation: From Figures 12-14, it can be observed that: on decreasing the level of shear connection the system became more flexible, and with reduced in ultimate capacity of moment. The two higher levels (100% and 120%) resulted in very similar curves, in terms of both stiffness and ultimate moment, with the mode of failure being slab crushing at the mid-span of the beam (location of maximum

Model	Post-tensioning Tendons				Concrete	Steel I-beam			
	f_y (MPa)	f_u(MPa)	A_p(mm²)	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
Ref. Model	1,680	1,860	137.4	112.6	35	400	400	480	480

Table 1: Material properties for the verified and modeled composite beams.

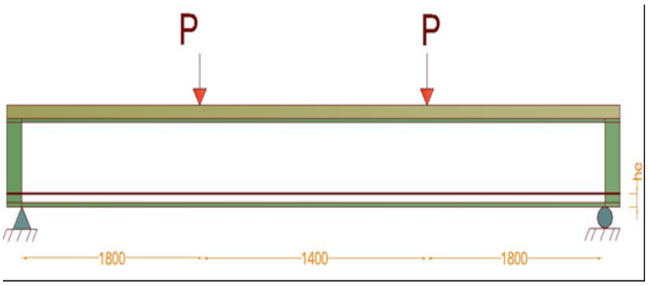

Figure 9: Geometry of Model (A).

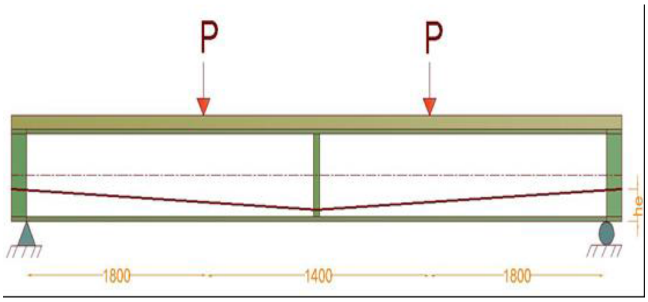

Figure 10: Geometry of Model (B).

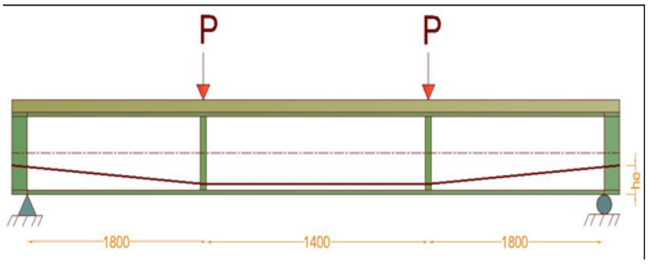

Figure 11: Geometry of Model (C).

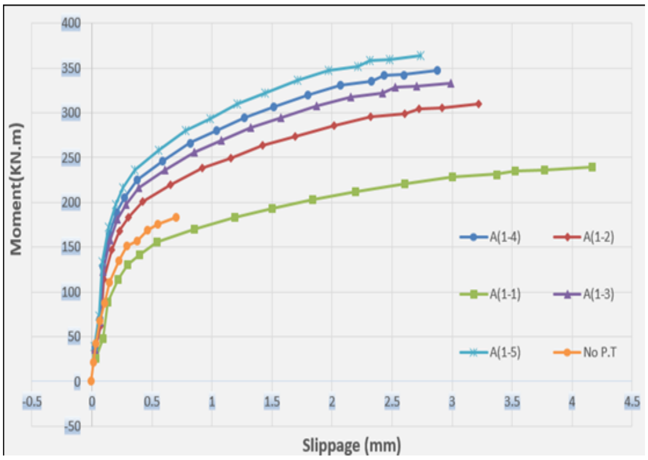

Figure 12: Slip - Moment curves of Models (A1-1) to (A1-5).

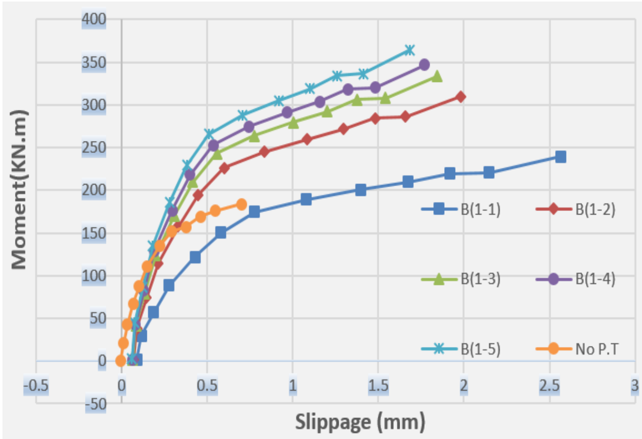

Figure 13: Slip - Moment curves of Models (B1-1) to (B1-5).

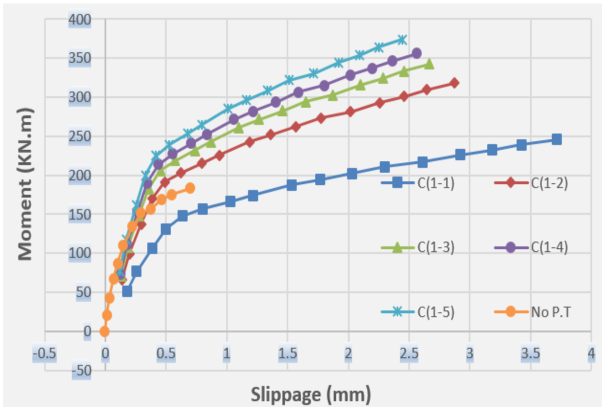

Figure 14: Slip - Moment curves of Models (C1-1) to (C1-5).

bending moment). Regarding level 100%, its mode of failure could be either slab crushing or stud failure due to a separation between R.C slab and steel top flange. As the three lower levels (40%, 60% and 80%) resulted in stud failure, the level 100% was an intermediate level between the two possible modes of failure. The results demonstrate that, therefore, the effects of partial interaction, which are increased by the use of partial shear connection, can be neglected for levels of shear connection above 100%, as no significant improvement in terms of either strength or stiffness of the beam was observed. It was demonstrated that, by decreasing the level of shear connection, the composite system becomes more flexible, with reduced strength and stiffness, mainly for beams with less than 100% degree of shear connection, for which the partial interaction effects are significant and must be taken into account [9].

Moment–deflection response: From Figures 15-17, the Moment–

No.	Model	P.T Force (KN)	h_e (mm)			% shear connection
			Start	Mid	End	
1	A	112.6	30	30	30	40 to 120%
2	B	112.6	105	30	105	40 to 120%
3	C	112.6	105	30	30	40 to 120%

Table 2: Section properties of Models (A, B and C).

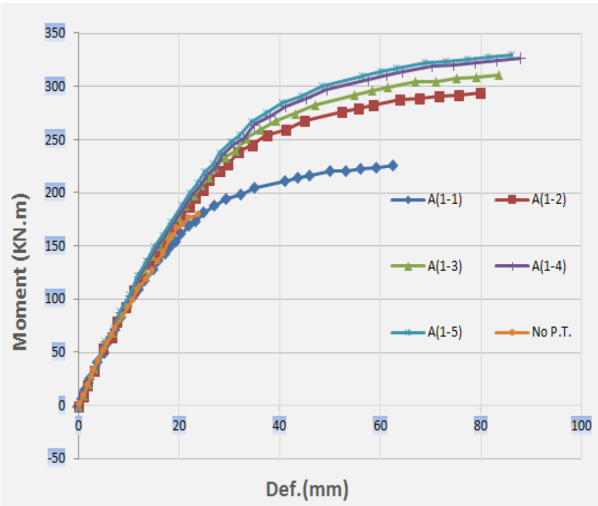

Figure 15: Mid-span Moment–Deflection curves of Models (A1-1) to (A1-5).

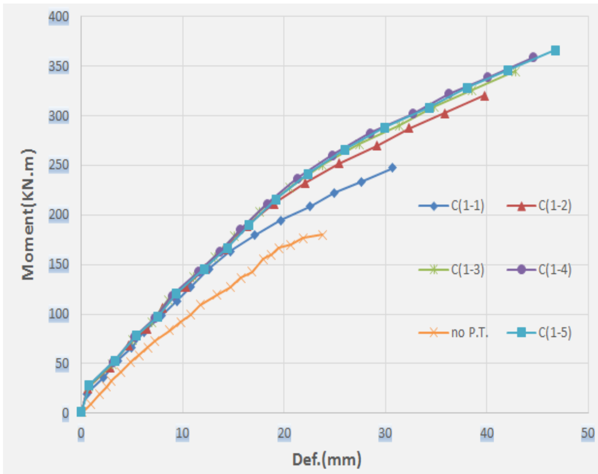

Figure 17: Mid-span Moment–Deflection curves of Models (C1-1) to (C1-5).

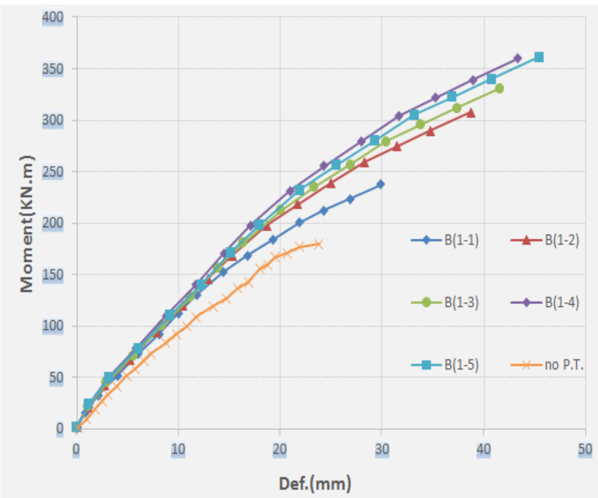

Figure 16: Mid-span Moment–Deflection curves of Models (B1-1) to (B1-5).

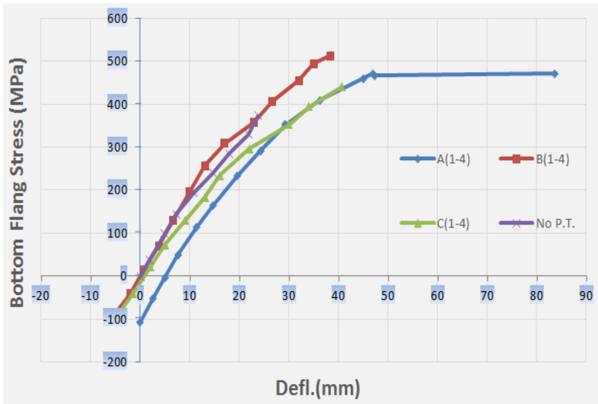

Figure 18: Deflection-Bottom flange stress relation for Models (A1-4), (B1-4) and (C1-4).

mid-span deflection curves for all models and cases (each one having a different level of shear connection). It can be observed that, there was a reduction (comparing to the case of no post-tension) in strength and stiffness at the low levels of shear connections (40%, 60% and 80%). However, the decrease in stiffness did not seem to be as significant as the decrease in the ultimate moment. The two higher levels (100% and 120%) resulted in very similar curves, in terms of both stiffness and ultimate moment; although there were increases in deflection directly proportional to the degree of shear connection.

Deflection-bottom flange stress relation: The Deflection-Bottom flange stress curve was presented in the form of x-y plot where the horizontal axis represents the deflection at mid span point in (mm) and the vertical axis represents the corresponding axial stresses at bottom flange at mid span point in (MPa). Figure 18 shows the Deflection-Bottom flange stress curve for models A (1-4), B (1-4) and C (1-4) as they present the case of full shear connection.

It was demonstrated that: the stresses in the two models B (1-4) and C (1-4) are closed to be matched and the difference increase by increasing the load at (C1-4). This slight difference in the stresses could be explained due to the difference in the region of composite action between (B1-4) and (C1-4). For A (1-4) there was a noticeable difference between it and the other models it was clear in the presence of yielding point and continued increasing in deflection without collapse even after reaching the maximum loading , this difference could be explained due to the straight profile of the post-tension tendon which gives greater ability to withstand stresses [10].

Conclusions

1. When the degree of shear connection decreases along with strengthening the beam by external post-tension tendons:

a. The ultimate load capacity has been found to decreases.

b. A significant increase in the mid span deflection and joint rotation has been clearly observed.

2. When the degree of shear connection is very low (less than 60%), the studs in the negative moment region above supporting points were broken because the maximum slip at the ultimate load had exceeded the slip capacity of the stud shear connectors.

3. The results demonstrate that the effects of partial interaction, which are increased by the use of partial shear connection, can be neglected for levels of shear connection above 100%, as no significant improvement in terms of either strength or stiffness of the beam was observed.

4. The results demonstrate that adding straight tendon in post-tensioning to the simple composite beams increasing the yield load and the ultimate moment resistance by 92.2% comparing to the case of composite beam without post-tensioning.

5. Adding post-tensioned tendons with a triangle and trapezoidal profile to composite beams significantly increases the yield load and the ultimate load by 99.1 and 105.5%, respectively.

References

1. El-Shihy AH, Shaaban HF, Mustafa SA (2015) Finite element modeling of externally post-tensioned composite beams. Journal of Bridge Engineering 45: 393-410.
2. El-Shihy AH, Shaaban HF, Abd-Elkader HM, Hassanin AI (2016) Effect of Using Partial Continuounity by External Post-Tension on The Simple Composite Beams as a Strengthening Technique. The Egyptian International Journal of Engineering Sciences and Technology 19: 305-311.
3. ANSYS Inc. ANSYS (2015) Release 14.0 Documentation.
4. Chen S, Gu P (2005) Load Carrying Capacity of composite Beams Pre Stressed with External Tendons Under Positive Moment. Journal of Constructional Steel Research 61: 515-530.
5. Abdel Aziz K (1986) Numerical modelling and experimental study of composite beams with partial or spaced shear connection.
6. An L, Cederwall K (1994) Push-out Tests on Studs in High Strength and Normal Strength Concrete. Journal of Constructional Steel Research 36: 15-29.
7. Gattesco N, Giuriani E (1996) Experimental Study on Stud Shear Connectors Subjected to Cyclic Loading. Journal of Constructional Steel Research38: 1-21.
8. Mirza O, Uy B (2010) Effects of the Combination of Axial and Shear Loading on the Behaviour of Headed Stud Steel Anchors. Engineering Structures 32: 93-105.
9. Zona A, Ranzi G (2011) Finite element models for nonlinear analysis of steel–concrete composite beams with partial interaction in combined bending and shear. Finite Elements in Analysis and Design 47: 98-118.
10. Qureshi J, Lam D (2012) Behaviour of Headed Shear Stud in Composite Beams with Profiled Metal Decking. Advances in Structural Engineering 15: 1547-1558.