Effects of Uniform Load onExternally Post-tensioning Composite Beams under Multiple Degrees of Shear Connection

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Abstract. Composite beams (steel and concrete) are used widely as the main structural elements in flexure in bridges and buildings. Such structures' design life would be decreased if the loads increased or if environmental deterioration could occur. Such modifications can reduce the strength of these members and therefore need to be considered for replacement or retrofitting. The current study presents an evaluation of the effect of shear connection with its different degrees from partial to full for the composite beams strengthened with post-tensioning tendons. It is known by design that the use of partial shear connection in composite beams requires that the sliding capacitance of the shear connectors shouldn’t be less than the maximum slip so that the composite section can reach the ultimate design load. The degree of shear connection over which the composite section is designed, as well as the span length of the beam, are the most important factors governing the maximum slip limit. This study was performed using numerical modelling by the finite element analysis method to simulate the bending behaviour of composite steel beams under uniform loading cases which were strengthened with three shapes of tendons profiles. The results of two finite element models have been compared with experimental results obtained from previous literature related to the same topic. This comparison was made to ensure the efficiency, effectiveness, and accuracy of the model used, using ANSYS Workbench Software.

Keywords: Partial Interaction; Finite Element Modelling; Composite Beams External; post-tension.

1. Introduction

It is considered one of the most important features of steel and concrete beams because of their attractive capabilities, which make them among the most used elements in construction and building work. Most studies have found its economic and construction effectiveness in many situations and structures [1]. When compared to composite steel beams, post-tensioned steel concrete girders with high-strength external tendons have numerous structural advantages [2]. Ayoub et al. conducted an experimental test programme to examine composite beams. They found that, despite the low cost of the straight tendon, which is why it is usually preferred when strengthening composite beams, the draped tendon was better in terms of amplitude and deflection [3]. As for Chen, he used a full-scale compound beam and strengthened it with external post-tensioned tendons to examine positive moment consequences [4]. The results showed an increase of 49% and 53%, respectively, with regard to the yield load and ultimate resistance, as a result of the inclusion of post-tensile tendons. When the steel section reached the fully plastic state, the maximum moment of the non-strengthened specimens was close to the plastic moment. Regarding the difference between the maximum moment of the strengthened specimens and the yield point is compared, when the yield on the compression flange started, the values vary from 1.03 to 1.11 from the yield moment point [5]. The deflection, yield, and ultimate moments of prestressed composite beams were evaluated using the reduced stiffness approach. The effect of slippage on the yield moment and deflection showed a
significant increase in the prediction accuracy of the analysis. Finally, the pre-stressed continuous steel-concrete composite beams' yield moment may be represented as:

$$M_{yp} = \xi \times M_y$$  \hspace{1cm} (1)

Where $\xi$ : slip coefficient allowed for the pre-stressed continuous steel-concrete composite beam, and $M_y$: Calculated yield moment using transformed section method, which could be obtained from Equation 2.:

$$M_y = W (\varepsilon_i + \varepsilon_y) E_s$$  \hspace{1cm} (2)

Where $W$ is the equivalent section modulus, and $\varepsilon_i$ is the strain at the bottom of the steel induced by the tendon before casting the concrete slab, and $\varepsilon_y$ is the yield strain of the steel beam.

Chen et al. conducted a comparable experimental investigation on pre-stressed continuous steel-concrete composite beams. Chen et al. conducted an experimental comparative study on continuous steel-concrete composite beams that had been pre-stressed [6]. The beam's cracking behaviour and load-bearing capacity were investigated in an experimental context. The final resistance of an externally prestressed composite beam is governed by distortional lateral buckling, local buckling, or a mode that combines these two patterns, according to the researchers’ conclusions. Pre-stressing a continuous composite beam with external tendons also enhanced the degree of internal force and moment redistribution in the beam. One of the most important basic components for studying the behaviour and structural design of the composite beam is the degree of shear connection of the composite section, and it includes the connection between the steel section at its upper flange and the concrete slab. Looking at many buildings and bridges that are structurally composed of composite beams, we find that the partial composite action does exist. This is due to increased loads or as a result of inaccuracies in the implementation of all the components and their connection well, or even the presence of changes in the use of the structure. Despite all of that, most of the previous literature and experimental tests focused on the in the case of the fully shear connected composite beams. Accordingly, the following are points for what this study presents:

- Investigating the impacts of using externally post-tensioned tendons to strengthen whole and partial composite beams.
- Utilizing numerical simulations, investigate the consequences of using straight, triangular, and trapezoidal tendon profiles in full and partial composite action scenarios under uniform loads.
- Due to the complexity of modelling the connection zone between the steel beam and the concrete slab, previous studies did not pay much attention to it. In this study, the welding zone of shear studs was modelled and statistically monitored.

This study was performed using numerical modelling by the finite element modelling method to simulate the behaviour of composite steel beams under uniform loading cases which were strengthened with three shapes of tendons profiles [7]. The components of the composite beams used in the study were represented in the finite element model using nonlinear materials models. By reviewing the available previous experimental literature, a verification process was made to ensure the efficiency, effectiveness and accuracy of the model used [8], [9]. The study of the structural behaviour due to the effects of using different degrees of shear connection between the concrete slab and the steel section is the main objective of the parametric study, in addition to strengthening these beams with external tendons after tensioning. The moment-deflection behaviour, steel beam moment-bottom flange stress, the slip-deflection relation, and modes of failure are all covered by these parameters. The basis of the structural behaviour and design concerns of composite beams depends mainly on the degree of shear connection between the concrete slab and the steel section. It was discovered that using a partial shear connection allows for a better match between the load applied to the composite beams and the moment of resistance because it reduces the number of connectors used, as well as the benefits of using the post-tension system externally as a strengthening system. A three-dimensional model of finite elements was developed in this work using the ANSYS software to simulate concrete and steel composite beams with external post-tensioning tendons. The degree of contact has also been changed, and the beams are loaded with
distributed loads throughout their entire span. To simulate the behaviour of these tendons during the initial loading process, the effective tensile force was considered and was taken as an initial value that appears as the initial stress in the corresponding components. [10] and [11]. The degree of shear connection was changed to four degrees of shear connection, ranging from 40% to a complete shear connection, by adjusting the number of shear connectors.

2. Material Modelling
The purpose of material modelling is to arrive at a model that can represent the inelastic behaviour of composite steel-concrete beams. The finite element program ANSYS provides a model for the damaged plasticity of the elements represented by it when combined with the tensile elasticity and isotropic stress. Also, for modelling all types of structures that use the same principles of damaged plasticity and so it was used in this study. The choice of the proper elements for modelling different composite beam components necessitates a thorough understanding of each component’s geometric form and material properties. It was also essential to understand how each element interacted with the elements around it. ANSYS provides a collection of elements that address all of these requirements. In the modelling stage, Figure 1 depicted the composite beam cross-section and the elements included.

| Component of the beam                | Element used | Properties of the element |
|--------------------------------------|--------------|---------------------------|
| R.C. slab                            | SOLID65      | 8 nodes Brick element     |
| Steel section                        | SHELL181     | 4 nodes Shell element     |
| Shear studs                          | SOLID45      | 8 nodes Brick element     |
| Slab reinforcement and tendons        | LINK8        | 2 nodes 3D-link element   |
| Steel section-slab interface         | COMBINE39    | Unidirectional spring element |
|                                      | CONTAC178    | Contact element           |

2.1. Concrete Modeling
For concrete, homogenous and initially isotropic properties were assumed. For ANSYS [12] as an input, for concrete under compression, the uniaxial stress-strain relationship is necessary [13]. A 9-point continuous curve was used to produce the relationship between stress on the vertical axis and strain on the horizontal axis for the modelled beams, as shown in Figure 2. To simulate concrete, the Solid 65
element was used. There are eight nodes in this element, each with translations in the X, Y, and Z directions this element has three degrees of freedom. This element can plastically deform, crack, and crush in three orthogonal directions. One of the most important aspects of this element is the consideration of the mechanical properties of non-linear materials. It also takes into account the characteristic parameters of concrete such as compressive stresses, relaxation coefficients, tensile stresses and shear transfer coefficients for closed and open cracks.

2.2. Steel -section Modeling
Considering that there is well knowledge of the mechanical properties of steel, the stress and compression behaviours in stress and strain can be considered consistently. The I-beam steel's elastic modulus and yield stress are based on the parameters of the structural materials listed in Table 1. With six degrees of freedom for each of the four nodes of each element, SHELL181 (Shell element) was the suitable finite element to simulate steel section components [14]–[16]. Steel beam components were modelled using the bilinear isotropic plasticity model. For this model to work, Young’s modulus coefficient, Poison’s ratio value, yield stress value, and plastic tangent modulus must all be defined. The steel beams' Young’s modulus coefficient and Poison’s ratio value were 210 GPa and 0.3, respectively.

2.3. Shear Connectors Modeling
In the design of concrete-steel composite structures, the head shear stud is an essential element in the design process as it is the most used in horizontal shear and vertical uplifting forces. By reviewing the previous literature, the element SOLID 45 was selected for use in modelling the shear connection behaviour. The use of this element presented with a normal force between the concrete and the steel beam. This element consists of eight solid nodes, each with three degrees of freedom, to simulate shear connections. They are also classified as stiff or flexible based on the distribution of shear forces and the functional relationship between strength and deformation [14]–[16]. Shear forces are resisted by shearing through the front side of rigid shear connectors, and deformation is minimal in the region of ultimate strength. Stronger concentrated stresses in the surrounding concrete is also produced by this type of conductor, which results in either concrete failure or weld failure. The relationship of the used stud (shear load-slippage curve) in terms of force-deflection curve was considered by using the table of real constants of springs [6]. Ollgaard et al. established a constitutive relationship for the headed studs[17] and then widely used by other researches can be considered (Aribert and Labib [18], Abdel Aziz [8], Johnson and Molenstra [13]).

2.4. Reinforcement Bars and External Post-tension Tendons Modeling
Regarding the modelling and selection of elements used in post-tensioning tendons and steel bars, it should be borne in mind that post-tensioning tendons and steel bars have several important geometric properties, such as being long and slender in most cases. Thus, it would be better and safer to assume that they are capable of transmitting only axial forces and no other forms of loads. This relationship in this paper is considered equal in terms of tension. Accordingly, the use of the Link 8 element to represent the strings and armature bars was the most appropriate choice in this case. This element is characterised as a three-dimensional mast as it has two nodes in each of the nodal directions X, Y, and Z, and three degrees of freedom translations are supported by this element. The plus here is that this element can deform into a plastic form too.

2.5. Beam-Slab Interface Modeling
Modelling the area between the steel section upper flange and concrete slab is an important stage in making the numerical model of the tested composite beam work as close as possible to reality. Accordingly, and by evaluating the elements available in the software program, two-noded elements (gab elements called Contact 178) were used, as these elements contain the following features: The element has two nodes, each with three degrees of freedom, and also contains translations in the three directions X, Y, and Z. The plus of this element is its ability to support normal directional pressure in Coulomb friction in both the transverse and tangential directions [7].
The second stage of contact area modelling is to keep the interacting surfaces physically separated and avoid penetration. Therefore, it was resorted to determining the value of the natural stiffness $K$ as relative to the stiffness of the contacting surface, and it was considered the weakest stiffness for the surface in contact with the concrete slab and the steel flange. The following well-known formula has been used, it takes into account the properties of the connected surfaces in order to avoid penetration and maintain physical separation:

$$K = \frac{EA}{L}$$

Where:
- $E$: Adjacent element Young's modulus.
- $A$: Area of the adjacent element.
- $L$: Element thickness.

![Figure 2](image1.png)

**Figure 2.** (a) Concrete stress - strain curve
(b) Composite beam components stress – strain curves.
3. Analysis and Discussion

3.1. Assumptions of the Analysis
The study's analytical assumptions are as follows:
* The concrete-to-reinforcement bond was considered to be perfect.
* Throughout the loading, Poisson's ratio was considered to be constant.
* Time-dependent nonlinearities such as creep, shrinkage, and temperature change are not considered in this study.
* The compressive strength of a concrete cylinder, $f_c'$, was supposed to be equal to $(0.8 \ f_{cu})$.

The developed F.E. model in this study, which depends mainly on the finite element analysis method and the loading method, is the static axial distributed load along the span of the composite beam. There are some options that must be mentioned and taken into consideration before entering the solution stage, which are as follows: After the initial run or download phase, the Restart command was used to restart the analysis. The solution control (Sol'n Controls) order was also set so that the solution method used in the analysis process was non-linear.

3.2. Verification Results
The objective of comparing the FE model with Chen [9] and Abdel Aziz [8] experimental results is in order to confirm the conformity of the geometry of the used elements, the properties of the materials, the real constants and the convergence criteria to ensure their sufficiency to simulate the composite beam's response and validate the accuracy of the Finite Element model.

3.2.1. Verified Model One (Chen) [9]
Using the obtained results from the numerical analysis, the mean-range deviation curve of the moments was deduced in order to compare them with the experimental results and to match their validity and reality. The F.E. analysis was consistent with the experimental data over the whole range of behaviour, as shown by the Moment – deflection curve. In the linear stage, the response of the model was in compatible with the curve deduced from the results and experimental data, and as the curve shifted from linear to non-linear form, the composite beam began to enter the yield stage. It was noticed that the hardness of the finite element model was slightly higher than that of the experimental model, after reaching the yield stage. This is due to the discrepancy in the shear stud behaviour between the experimental models and the finite element model, as illustrated in Figure 3.

![Figure 3. Moment-Deflection curve at mid-span.](image-url)
3.2.2. Verified Model Two (A.Aziz) [8]

Figure 4 shows the result of the comparison of the mid-span loading-def. curves for experimental composite beams and the curve derived from finite element analysis using ANSYS software. The two curves show a close correspondence between the experimental result and the analysis of the finite element over the whole behaviour range. For the linear range in particular, the two beams behaved similarly; their trends were nearly identical, with a slight variation at maximum deflection. This difference is since the experimental beam was continuously loaded until failure.

Regarding the slip between the top flange of the steel section and the concrete slab, Figure 5 shows that finite element analyses are largely consistent with the experimental data. Table 1 lists verified and modelled composite beams material properties.

![Figure 4. Load-Deflection Curve.](image1)

![Figure 5. Concrete-Steel slippage Value.](image2)
Table 1. Verified and modelled composite beams material properties

|                           | Post-tensioning Tendons | Concrete | Steel I-beam |
|---------------------------|-------------------------|----------|--------------|
|                           | Beam f_y (MPa) | f_u (MPa) | A_p (mm^2) | F(kN) | f_c (MPa) | f_y (MPa) | f_u (MPa) | Web | Flange |
| Chen                      | 1,680       | 1,860     | 137.4      | 112.6 | 35        | 327.7    | 492.6     | 593.6 |
| A.Aziz                    |            |           |            | 40    |           | 260      | 372       | 361  |
| Ref. Model                | 1,680       | 1,860     | 137.4      | 112.6 | 35        | 327.7    | 492.6     | 593.6 |

4. Parametric Study

For composite beam behaviour and design, the degree of interaction between the steel section and the R.C. slab is important. A "full shear connection" is a connection between two components that can completely withstand the forces that are applied to it [19]. Despite the fact that this is the most common case, the expansion of the use of composite beams in the construction of buildings and structures during the past two decades has led to the emergence of a number of cases where it is not possible to withstand all the loads applied to the beam (partial shear connection occurs). In such cases, the shear failure will occur in the connection, most likely before the other components of the beam reach their failure point [20], [21]. Using the verified model, Chen [9], on twelve newly created models based on the layouts of external tendons used in composite beams and the degree of shear connection under uniform loads, the parametric study that was conducted divided the tested models into the following (C-S: when the tendon profile is straight, C-T: when the tendon profile is triangle, and C-P: when the tendon profile is trapezoidal). Regarding to modifying the shear connection degrees on the modelled beams, in the ranges of 40 to 100 percent, was investigated by increasing or decreasing the number of shear connections utilised in the model ((C-X 40) for 40 percent, (C-X 60) for 60 percent, (C-X 80) for 80 percent, and (C-X 100) for 100 percent. The parametric analysis utilised an un-strengthened beam with a full degree of shear connection as a reference beam against which the changes in the behaviour of the modelled beams were measured. The material and geometrical properties of the modelled composite beams are shown in Figures 6 and 7, while the material and geometrical properties of the modelled composite beams are summarised in Table 2.

Figure 6. Cross section for the used model
Figure 7. Geometry of the used models: (a) for (C-S), (b) for (C-T), and (c) for (C-P)

Table 2. Geometrical properties for the modeled composite beams

| Beam      | C-S Group | C-T Group | C-P Group |
|-----------|-----------|-----------|-----------|
| No. of studs | 16        | *         | *         | *         |
|           | 13        | *         | *         | *         |
|           | 10        | *         | *         | *         |
|           | 7         | *         | *         | *         |
| Spacing   | 187.5     | *         | *         | *         |
| between   | 230.7     | *         | *         | *         |
| studs (mm) | 300       | *         | *         | *         |
|           | 428.5     | *         | *         | *         |
| % of he to hs |          | 10%       | 40%       | 40%       |
| profile of the Tendon (mm) | Start   | 30 Mid 30 Straight | Start   | 105 Mid 30 Triangle | Start | 105 Mid 30 Trapezoidal |
|           | End 30    |           |           |           | End 30 |           |

Where:

$h_e$: The high related to the position of the tendons.

$h_s$: The high of steel I beam section.

4.1. Moment-Slippage Relation

The moment-slippage curves of the modelled beams for the three groups are compared in Figures (8, 9, and 10). The influence of the tendon profile on the composite action of the beams could be evaluated using relative slippage between concrete slab and steel beam [15], [22]. When the effects of changing
degrees of shear interaction on the slippage results were compared, due to their small values, the beam's initial slippage was observed to be undetected. When comparing the straight tendon group's slippage curves, it was discovered that changing the degree of shear of interaction from 40% to 100% lowered the slippage value by 16%, as illustrated in Figure 8. However, between the 40% and 100% degree of shear interaction cases, the decrease percentages for the triangular and trapezoidal tendon groups were 23% and 27%, respectively, as shown in Figures 9 and 10. When the three groups were compared, the straight tendon profile group exhibited a higher maximum slippage value than the triangular and trapezoidal profile groups, according to the findings. This could be attributed to the tendon's straight shape, which, unlike the triangle and trapezoidal profile groups, due to its constant eccentricity. As a result, the post-tensioning stresses are distributed uniformly over the beam.

Figure 8. Slip - Moment curves of Models (C-S40) to (C-S100).

Figure 9. Slip - Moment curves of Models (C-T40) to (C-T100).
4.2. Moment–Deflection Response

The initial upward movement of the modelled beams was shown to be essentially identical for each tendon profile type by comparing the findings of the varied degrees of shear connection in Figures (11, 12, and 13). In all of the cases, the moment-deflection behaviour of the beams was relatively similar. A nonlinear zone is followed by a linear zone, which is then followed by another linear zone until the failure point is reached. As the degree of shear connection increases, it was apparent that the plumpness of the modelled beam curves increased more. Adding to that, the increase in the elastic limit in conjunction with the increase in the maximum moment of the beam due to the existence of composite action. All this increases the composite beam's performance. However, there was a decrease in the ductility of the composite beams when the shear contact was increased.

The maximum moment, elastic limit, and initial stiffness all increased by 62 percent, 39 percent, and 42 percent, respectively, when the shear connection degree was increased from 40 to 100 percent for the first group (Straight tendon profile). However, it resulted in a 12% reduction in maximum deflection. For groups II and III, maximum moment, initial stiffness, and elastic limit improved by 71%, 56%, and 52%, respectively (triangle and trapezoidal tendon profile). The maximum deflection, on the other hand, decreased by 32%.

Some conclusions may be obtained when the results of different groups, such as the straight, triangular, and trapezoidal tendon groups, are compared. Straight and triangular tendon composite beams were shown to be more ductile and load-carrying than trapezoidal tendon composite beams. Straight tendon composite beams, on the other hand, have a lower initial stiffness and elastic limit than triangle and trapezoidal tendon composite beams. The high deformation capacity of the straight-tendon strengthened composite beams is due to the redistribution of shear forces on the remaining studs that have not yet failed. These studs will continue to give extra momentum to keep the composite action, even if it has at this stage become partially and not fully composite action, until the final loading stages. The maximum moment and deflection increased by 12 percent and 44 percent, respectively, when the tendon was changed from a triangle to a trapezoidal profile, in the cases of C-T 100 and C-P100. It's worth noting that when the degree of shear connection increases, the difference in ultimate load between groups II and III decreases. This means that in the case of high degrees of shear connections (more than 80%), the effect on the tendon profile was less significant.
Figure 11. Moment–Deflection curves at mid-span for Models (C-S40) to (C-S100).

Figure 12. Moment–Deflection curves at mid-span for Models (C-T40) to (C-T100).

Figure 13. Moment–Deflection curves at mid-span for Models (C-P40) to (C-P100).
4.3. Deflection - Bottom Flange Stress Relation
The curves shown in Figure 14 compare the ultimate stress at the steel beam bottom flange's mid-span for the different used tendons profiles. It is observed here that the ultimate stress behaviour at the flange is similar to that of the load deformation in the beam. It was also noted that there was an initial negative stress on the lower edge. The reason for this negative stress is the application of the post-tension force during the initial loading stage. The stress values in the triangular tendon were greater than those in the straight and trapezoidal tendons. This was due to the regular distribution of stresses on the tendons in the case of the rectum and trapezoid in the place of maximum torque. On the other hand, the trapezoidal shape proved to give more resistance and maintain the composite action despite the increase in stresses, and this appears in the decrease in the value of the deflection in comparison with other tendons profiles.

![Figure 14. Deflection-Bottom flange stress relation for fully shear connection models.](image)

4.4. Ratio of Stud Forces and Failure Modes
The degree of shear interaction is an important factor in determining the structural behaviour of the composite beam as a result of a variety of load conditions, and it can be determined based on the concrete slab’s strength, the number, and strength of shear studs, in addition to steel components. The ratio between the shear interaction capacity and the lowest element capacity was used to calculate this value. Figure 15 shows that, despite the assumption that the shear force applied externally was uniform, the slip was irregular over the length of the beam. When X/L becomes close to 0.4, the maximum slip value occurs.

In terms of observed failure modes, the ultimate load was determined for each F.E. model using two boundaries: lower and higher, based on 0.2 percent and 0.35 percent of concrete compressive stresses, respectively. The composite beam failure load exists in this interval between these two boundaries [23]. With the composite beam stud that has been subjected to the higher load reaching its ultimate load capacity, it’s possible that the stud failure point, a third limit condition, has been achieved.

A composite beam's stud failure condition was characterised when the stud failure point was located before the concrete's lower boundary (the corresponding load of the stud failure point was smaller than the lower boundary load). If the stud failure point was after the concrete upper boundary, the mechanism of failure is called R.C. slab crushing. When the stud failure point is between the lower and upper concrete boundaries, the mode of failure for the intermediate condition might be either of them. As a consequence, the proposed finite element model could accurately predict slab crushing and stud failure modes.

It was also possible to reach a third state, known as the stud's point of failure, which occurs when the stud is loaded to its full capacity. If the point of failure was found before the concrete's lower boundary,
the failure mechanism of the beam was considered to be a stud failure. However, if the point is after the concrete slab's upper border, the failure mode considered is a concrete slab crush. On the other hand, if the point falls in the intermediate region, the two cases of failure are equal in probabilities. However, the model used in this study was able to accurately explain the existing failure situation. This is due to the modeling of all composite beam components, including the welding region between the stud and the steel beam's top flange, as shown in Figure 16.

The failure patterns came almost predictably, as the degrees of shear connection were less than 80%, resulting in shear stud failures, especially in the welding area, due to the redistribution of shear forces over the entire section of composite beam, which means an increase in the stresses affecting the stud. In contrast, at the degrees of shear connection greater than 80%, the predominant failure pattern was concrete crush. The presence of strengthening by the post-tension tendons aided the formation of this pattern.

![Figure 15. Stud forces ratio vs. stud relative position](image1)

![Figure 16. Stress distribution and weld failure in shear connectors](image2)
5. Conclusions
The effect of applying uniform loads on composite beams strengthened with various profiles of post-tensioning tendons, in conjunction with decreasing the degree of shear connection to the lowest possible degree allowed by the code, was investigated in the present study. The study resulted in many results and conclusions, the most important of which are here:

1- A good agreement has been reached between the two finite element models presented and the data of the two experimental tests from literature. This demonstrates their accuracy in calculating and predicting the behavior of composite beams under a variety of stresses.

2- If the degree of shear connection changed from the lowest possible degree of 40% to the degree of full shear connection of 100%, this will resulted in a 42 percent rise in the average maximum moment and a considerable reduction in deflection of up to half.

3- The increase in the degree of shear connection also led to a significant improvement in slip with a decrease of approximately 20% and a decrease in the stress of the lower flange of the steel beam by 45 percent.

4- The addition of the external post-tensioning led to an enhancement of the strength of the composite beams, and this was shown by reducing the deflection by 25% and slippage by 11%. This is attributed to the initial camper caused by the external tension on the composite section.

5- By comparing the profiles of tendons used, it was found that the use of the trapezoidal tendon increases the maximum moment capacity more than the other two profiles of tendons (straight and triangle). However, the effect of the profile of the tendon used was not sufficiently evident when shear connection degrees greater than 80% were reached.

6- The failure patterns were not greatly affected by the profile of the used tendon, but the greatest effect was the degree of shear connection, which was able to convert the failure pattern from the stud failure at shear degrees less than 80% to a concrete crush for shear degrees greater than 80%.

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