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Effect of Post-Tensioned Steel on Girder Structure

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Abstract: This study investigates the flexural behaviour of bonded post-tensioned (BPT) reinforced concrete cantilever girders with different tendon profiles. The ANSYS software analyses the girders using the finite element (FE) approach. Experimental tests are conducted to validate the FE analysis, and the results show satisfactory agreement. The six models considered in the study include configurations with no tendons, two tendons in the middle, two draped points on parabolic tendons at the bottom, and no tendons at the top. The evaluation includes analysing failure loads, deflections, and load-deflection relationships. The findings indicate that the girder with a single-draped tendon profile performs best. Prestressing is an effective and cost-efficient technique for enhancing strength and minimising deflections in reinforced concrete structures.

Keywords: Girder, Post-Tensioning, Finite Element Analysis, Deflection Of Beam.

1. Introduction

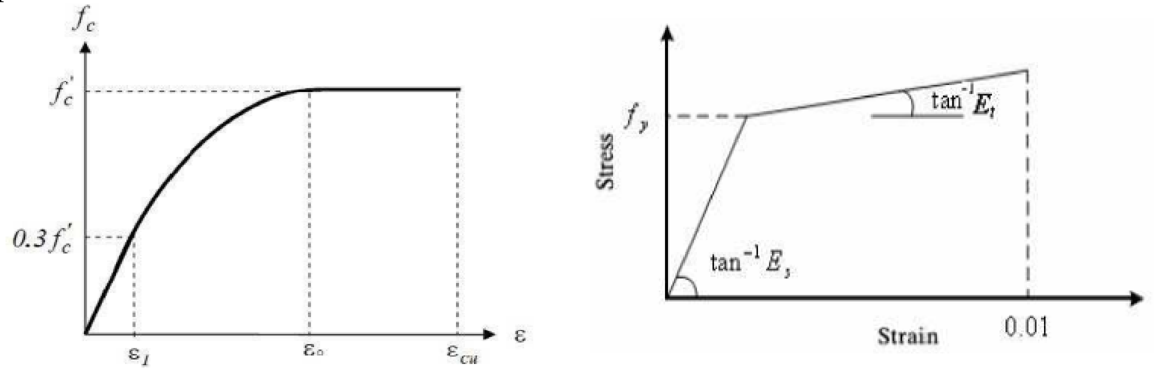
The post-tensioning technique to strengthen structural elements has gained significant popularity in the past two decades. It effectively reduces deflection, enhances stiffness, and improves load-carrying capacity, allowing for more efficient material usage. Various research studies have investigated the effectiveness of this strengthening approach under different types of stresses. A survey conducted by Ayyoub et al. focused on composite beams and concluded that while straight tendon profiles are more cost-effective, draped tendons exhibited better capacity and deflection performance. The authors also found that prestressing a typical composite girder significantly increased the load at which initial yielding occurs and the final total of the beams. Chen presented experimental testing results on a full-scale composite beam reinforced with external post-tensioning tendons. Including post-tensioning tendons substantially improved the yield load and ultimate resistance by approximately 49% and 53%, respectively. The study observed that the maximum moment of non-strengthened specimens nearly reached the plastic moment of the fully plastic steel part. In contrast, the ultimate moment of reinforced models ranged from 1.03 to 1.11 times the yield moment at which the compression flange initiated yielding.

Nie et al. conducted analytical and experimental research on pre-stressed steel-concrete composite beams. They proposed a reduced stiffness approach to calculate pre-stressed composite beams'

**Corresponding author: emran@uthm.edu.my* deflection, yield, and ultimate moment. The study demonstrated that considering slip effects significantly improved the accuracy of analytical predictions for yield moment and deflection. Overall, these studies highlight the effectiveness of post-tensioning in strengthening structural elements, with draped tendon profiles and external post-tensioning tendons proving particularly beneficial in capacity enhancement, deflection reduction, and improved performance under different loading conditions [1].

2. Materials and Methods

The material properties play a crucial role in ANSYS modelling. When modelling concrete in tension, its stress-strain relationship is similar to elasticity until it reaches a higher tensile strength. The concrete begins to crack at that point, and its strength decreases continuously until it reaches zero. For concrete compression, a multi-linear stress-strain relationship is used based on the research conducted by [2-4]. Additionally, reinforcing steel bars are considered using a bilinear stress-strain relationship as in Table 1. In this study, the steel bars are assumed to only carry axial force due to their thinness, while the strands are treated as a multilinear isotropic material. The model used in this study aims to predict concrete material failure, considering both crushing and cracking failure modes. To define substantial loss, input parameters such as ultimate uniaxial tensile and compressive strength are required. Table 1 lists some basic mechanical properties of materials to fabricate girders. ANSYS finite element software is used to model the beam, as in Figure 2. It shows a single unit of girder box. In the actual application, this girder is connected to form a series of girders, as in Figure 3 and Figure 4, which reveal the finite element model of the beam. In this work, each girder unit is firmly bonded to each other, and no separation is assumed to occur.



(a) (b)

Figure 1 (a) Stress-strain relation of concrete, and (b) Bi-linear relation of concrete.

Table 1 Elastic mechanical properties of concrete, steel, and strand.

Description	Concrete	Steel	Strand
Ultimate Compressive Stress (MPa)	30		
Ultimate Tensile Strength (MPa)	3.8		
Modulus of Elasticity (GPa)	30	200	206.3
Poisson ratio	0.2	0.3	0.3
Yield Strength (MPa)		400	1741

Boundary conditions are applied using loads and supports to ensure a unique solution. For roller supports, all nodes along the middle line of the support have a constraint value of zero in both the Y and X directions. In hinge supports, all nodes along the central line of the support have a constraint value of zero in both directions as well. To simulate the behaviour of the girder under increasing loads, steel plates are placed on the top face of the girder, and nodal forces are gradually applied until failure occurs. Figure 5 shows the type of loading used transversely on the girders. The analysis considers three load instances and six different tendon profiles for the post-tensioning girder. These profiles consist of one draped point, two draped points, and three straight tendons positioned at the girder's bottom, middle, and top. The different load cases applied to the girder up to failure are shown in Figure 6.

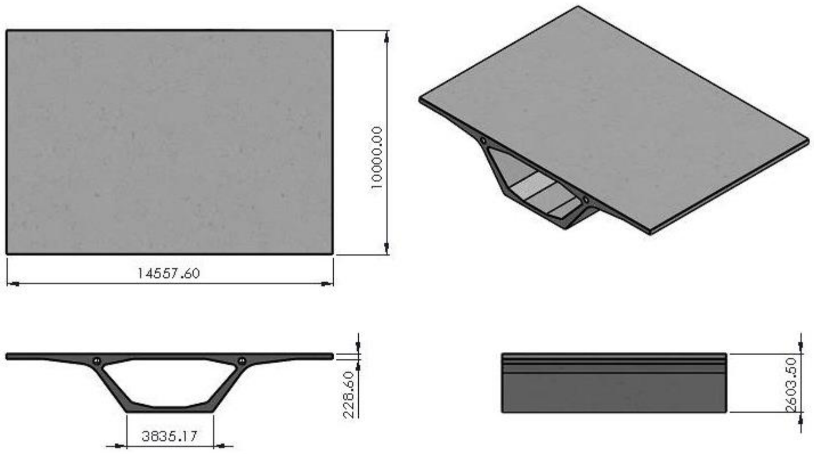


Figure 2 Cross section of Box Girder.

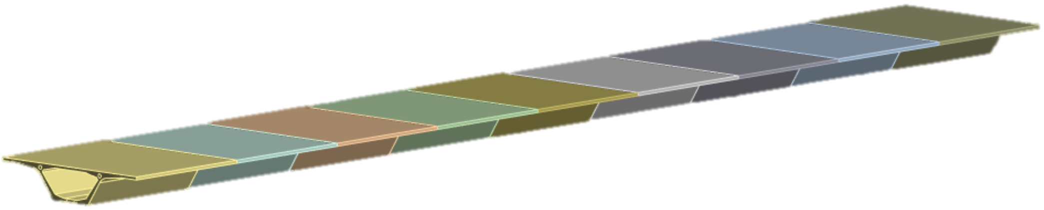


Figure 3 CAD model of girder connected in a series.

Figure 4 Finite element model of girder.

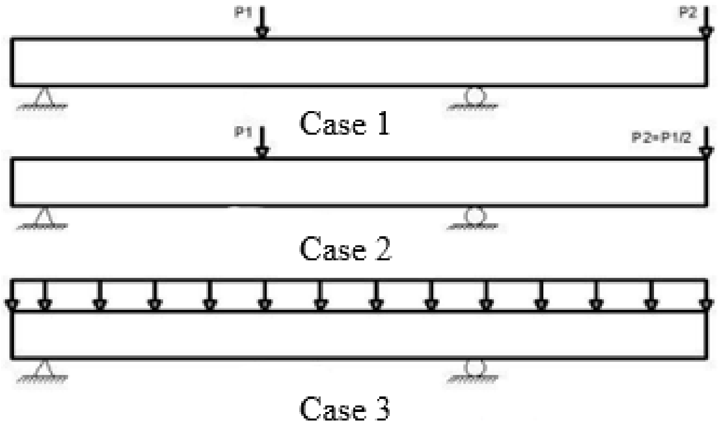
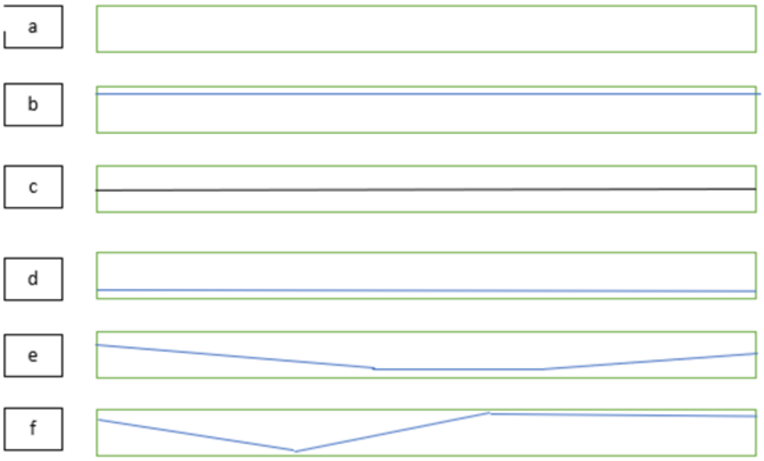


Figure 5 Type of loading applied to the girders.



a-without tendon,
b-tendon at the top,
c-tendon at the middle,
d-tendon at bottom,
e- tendon one draped point,
f- tendon two draped point.

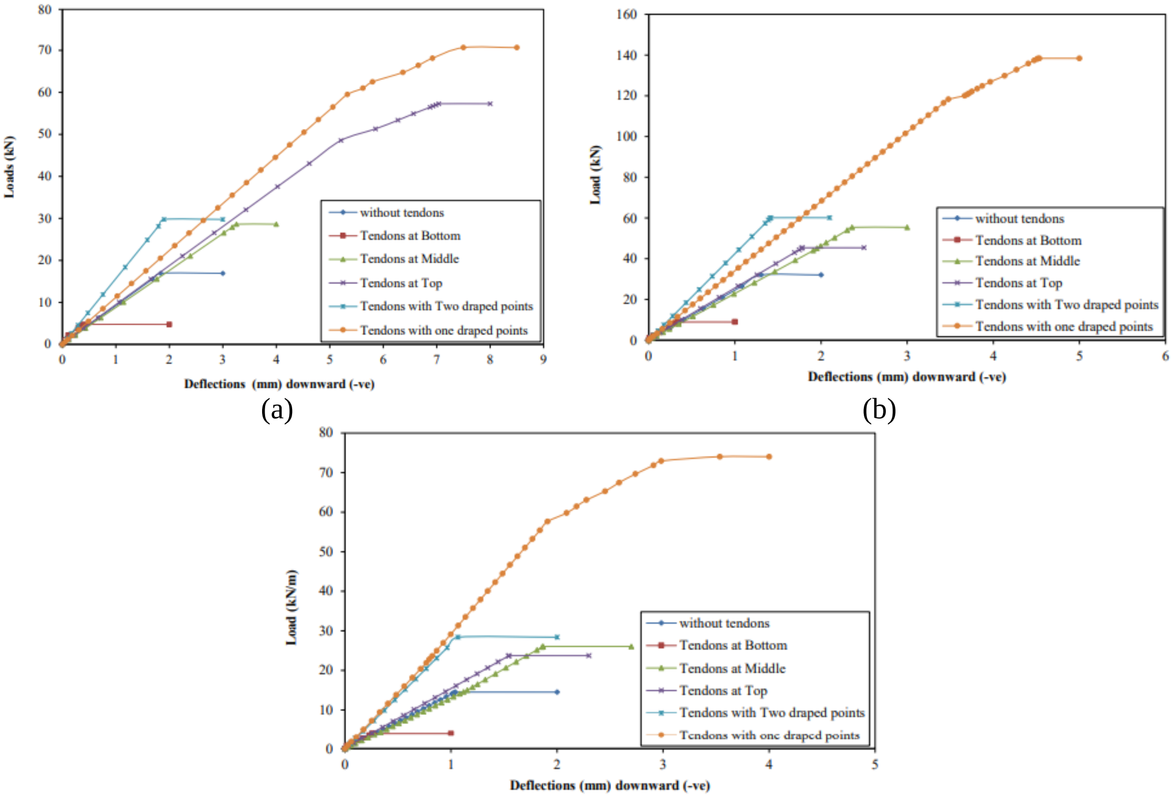
Figure 6 Tendon arrangement along the girder.

3. Results and Discussion

The load-displacement curve represents the relationship between the applied load at the end of the girder and the resulting displacement. This curve provides valuable information about the structural behaviour of the girder and how it responds to different loading conditions.

3.1 Load-displacement Curves at the End of Girder

Figure 7 shows that the load-displacement curves of the girder for all the load cases that were obtained from the FEA demonstrated that compared to girder having a straight tendon profile, those with parabolic tendon profiles had more robust responses and could withstand the maximum load before failing.



(a)

(b)

(c)

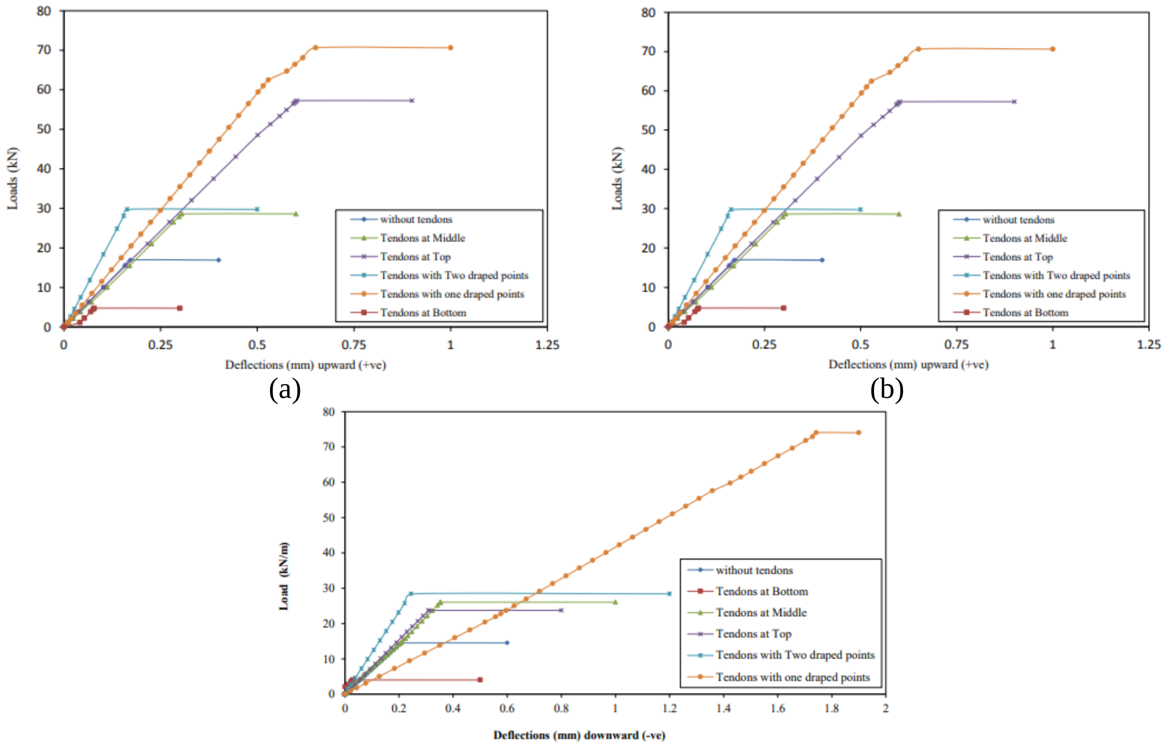
Figure 7 Force-displacement curves of the girder using different tendons, (a) case 1, (b) case 2, and (c) case 3 at the end of the girder.

3.2 Load-displacement curves at the middle point of supported parts.

In supported parts, the load-displacement curve at the middle point of the girder can be obtained through analysis, as in Figure 8. The load-displacement curve represents the relationship between the applied load on the girder and the resulting displacement at the middle point. The load-displacement curves at the midpoint of the supported portions of the girder are shown in the figures above for all load cases. It demonstrates that the ultimate load capacity improved with draped tendon profiles compared to other undraped tendon profiles. Straight shapes achieved The lowest nominal resistance before there was no change in stiffness. All the model's girder failures suddenly occurred above supports because of the cantilever effect. The draped tendon profiles were stiffer and more pliable after the yielding point than the straight tendon profiles.

3.3 Deformed shapes with constant applied loads

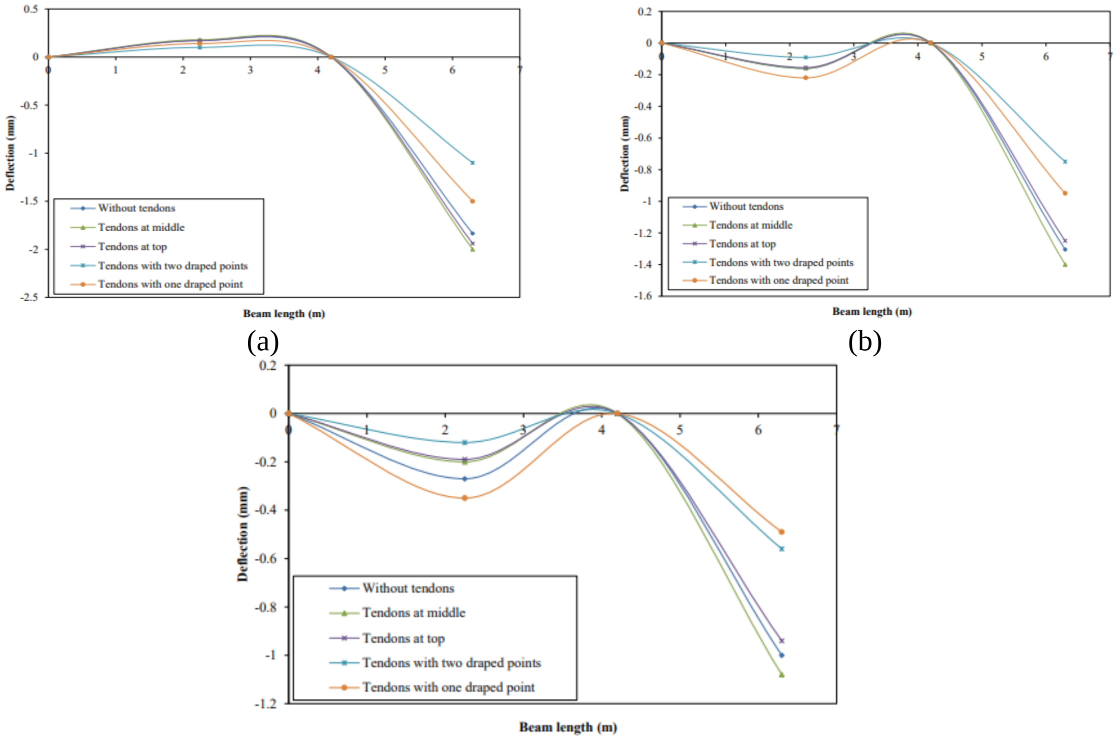
Like a girder, a structure will deform by the material qualities, shape, and boundary conditions when a constant load is applied to it. Software for structural analysis can be used to analyse the distorted shape of the structure, or testing can be used to determine it empirically. The provided figures depict the distorted forms of the girder models under constant applied loads across various load conditions. As the loads incrementally increase, the materials undergo deformation, resulting in the observed shapes. The models can deform elastically and return to their initial girder conditions. Each material follows its respective stress-strain relationship, with the deformation response corresponding to the strain energy characteristic of the material. The parabolic tendon profile allows for more significant deformation without failure than other profiles. Among the profiles, tendons with a single draped point exhibit the highest deformation and displacement levels while demonstrating the highest load-carrying capacity across all load scenarios. This behaviour can be attributed to the similarity in profile shapes, particularly in bending moments, as in Figure 9.



(a) (b)

(c)

Figure 8 Force-displacement curves of the girder using different tendons, (a) case 1, (b) case 2, and (c) case 3 at middle point.



(a) (b)

(c)

Figure 9 Force-displacement curves of the girder using different tendons, (a) case 1, (b) case 2, and (c) case 3 along the beam.

Table 4.1 shows the failure loads and deflections at the end and middle locations of post-tensioned concrete cantilever girders for the three types of loadings. The estimated total deflections include the downward displacement caused by gravity and applied weights and the upward displacement caused by PT forces.

4. Conclusion

In this study, a 3D finite element model is developed to investigate the behaviour of post-tensioned steel on girder structures. Interaction components are utilised to simulate the interaction between the tendon and the concrete, including contact components that maintain the tendon profile during slab deflection and model the behaviour of the grout-tendon bond. An experimental bonded post-tensioned concrete girder from the literature is selected to validate the numerical calculations. The results of both the numerical and experimental analyses exhibit excellent agreement. Using the ANSYS finite element program, this research explores the influence of various factors on the load-deflection response throughout the full range of behaviour. The effects of loading type and tendon profile on the overall behaviour of a post-tensioned concrete cantilever girder are investigated using the established finite element model. It is observed that the girder's tendon profile significantly affects its maximum load capacity. The use of parabolic tendon profiles enhances the maximum load capacity. Compared to girder models with straight tendon profiles, those with a single-draped tendon profile exhibit higher ultimate load capacity and stiffer response. This is because the draped silhouette aligns with the bending moment of the girder, and parabolic shapes have appropriate eccentricity values.

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Table 2 Summary of Failure load and deflection of girder under different load cases.

Load case	Tendon profile	Failure loads (kN)	Mid deflections (mm)	End deflection (mm)
Case 1	Without tendons	17.0	0.171	-1.835
	Tendons at bottom	4.7	0.078	-0.396
	Tendons at middle	28.6	0.304	-3.256
	Tendons at top	57.0	0.601	-0.7039
	Tendon with two draped points	29.7	0.163	-1.899
	Tendons with one draped points	70.6	0.650	-7.501
Case 2	Without tendons	32.0	-0.161	-1.039
	Tendons at bottom	9.0	-0.016	-0.342
	Tendons at middle	55.0	-0.272	-2.354
	Tendons at top	45.0	-0.22	-1.784
	Tendon with two draped points	60.0	-0.175	-1.417
	Tendons with one draped points	138.0	-0.942	-4.534
Case 3	Without tendons	14.5	-0.208	-1.039
	Tendons at bottom	4.0	-0.209	-0.263
	Tendons at middle	26.0	-0.353	-1.868
	Tendons at top	23.7	-0.309	-1.546
	Tendon with two draped points	28.4	-0.243	-1.064
	Tendons with one draped points	74.0	-0.1742	-3.535

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