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EFFECT OF TRANSVERSE REINFORCEMENT RATIO ON BEHAVIOR OF A PRESTRESSED BEAMS UNDER TORSION LOADS

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الملخص العربى :

تستخدم الخرسانة سابقة الإجهاد في مجموعة واسعة من المباني والمنشآت الخرسانية، حيث يمكن تحسين أدائها من خلال زيادة بحور الكمرات، وتقليل ابعاد القطاعات الخرسانية، وتوفير المواد مقارنة بالخرسانة المسلحة العادية. وتشمل تطبيقات الخرسانة سابقة الاجهاد المباني الشاهقة، والأبراج السكنية، والاساسات، وهياكل الجسور والسدود، والصوامع والخزانات، والأرصفة الصناعية، والهياكل النووية. في معظم الهياكل الخرسانية، لا يحدث عزوم اللي الخالص بشكل متكرر وعادة ما يكون مصحوبا بقوى الانحناء أو القوى المحورية أو قوى القص. لكن دراسة عزوم اللي مهمة جدا بالنسبة للكمرات سابقة الإجهاد، خاصة تلك المستخدمة في الجسور والكمرات ذات البحور الواسعة المعرضة للأحمال من جانب واحد، على سبيل المثال الجسور المنحنية. ويقدم هذا البحث برنامجا تجريبيا لدراسة تأثير التسليح العرضي على الكمرات الخرسانية سابقة الإجهاد تحت تأثير أحمال عزوم اللي. حيث يتم تحليل سلوك الكمرات قبل وأثناء وبعد الكسر. تم في هذا البحث اختبار أربع عينات من الكمرات سابقة الإجهاد المتماثلة في الأبعاد والخصائص، وكان المتغير هو التسليح العرضي فقط. بعد اجراء الاختبار تم تحليل وتوضيح سلوك الكمرات الاربعة والتي شملت حمل الشرخ الابتدائي وحمل الكسر وزاوية الالتواء ومنحنى الانحراف وتدهور الصلابة واخيرا الممطولية.

ABSTRACT :

Nowadays, prestressed beams are frequently utilized in buildings. When compared with ordinary reinforced concrete, prestressed concrete offers a number of benefits, such as extending the length of beams, decreasing R.C section dimensions, and requiring less material. This study presents an experimental program to investigate the effect of the transverse reinforcement ratio on prestressed concrete beams subjected to torsion loading. Were prestressed beam behavior is examined before, during, and following fracture. Four prestressed specimens (part of PhD) with the same dimensions and features were tested in this study; the only variable was the transverse reinforcement ratio. Following the test, the four beams' behaviors were studied and explained, including the stiffness degradation, twisting angle, torsion moment, crack load and failure load, deflection curve, and finally the displacement ductility.

KEYWORDS : torsion moment; prestressed concrete beams; transverse. reinforcement

1. INTRODUCTION

Prestressed concrete is used in many different types of buildings and civil structures. When compared to ordinary reinforced concrete, it performs better by allowing beams to great span distances, decrease building thickness, and save material. High-rise buildings, residential towers, foundations, bridge and dam structures, silos and tanks, industrial docks, and nuclear structures are among its common applications. Pure torsion is uncommon in most concrete structures; instead, it is typically accompanied by bending, axial, and shear forces. Therefore, for prestressed beams, particularly those used in bridges and beams with wide spans that are subject to loads on one side, like curved bridges, a torsion study is very important.

2. RESEARCH SIGNIFICANCE

This study is important because it fills in a knowledge gap regarding the behavior of post-tensioned reinforced concrete beams under torsion loads. It was investigated how some variables affected the pre-stressed reinforced concrete beams' torsion strength. The transverse reinforcements ratio is one of these parameters. Lastly, a prediction was made regarding the torsion strength of pre-stressed reinforced concrete beams.

3. BACKGROUND REVIEW

In the previous Codes, the concrete's resistance to torsion stresses was increased from 0.7 (fc)^0.50 to 0.75 (fc)^0.50 when examining the impact of torsion on prestressed beams. Additionally, the pre-tension stresses were factored in when calculating the longitudinal steel and transverse reinforcement through a factor (θ) of 45 ^{o} for ordinary beams and beams where the tensile stress is less than 40% of the bending reinforcement's tensile strength and equal to 37.50 ^{o} for tensile stresses greater than 40% of the bending reinforcement's tensile strength. Similar to the study of bending moments, shear loads, and axial loads the effect of torsion on prestressed beams has not been given much attention by researchers. However, there are several studies that have studied the torsion of normal beams and prestressed beams. The behavior of segmental box girders with external prestressing under combined shear, moment, and torsion was investigated by **Tarek El-Shafiey et al. (2017).** Five specimens total, split into groups I and II for the experiment, were used. Group I investigated the effects of varying load eccentricity at constant pre-stressing force levels (Pe=0.5Pyps) that resulted in torsion levels (e1=0.05m, e2=0.2m, and e3=0.4m). Group II investigated the effects of various tendon pre-stressing forces at constant applied load eccentricity (e3=0.4m), namely Pe=0.5Pyps, Pe=0.38Pyps, and Pe=0.26Pyps. Following the testing program, it was determined that while the ultimate load and ultimate deflection reduced, the maximum twist increased as the applied force eccentricity was raised to increase the torsion effect. Moreover, the linear stage range, ultimate load, ultimate deflection, and ultimate twist all reduced as the effective prestressing force rose. Therefore, at the nonlinear stage, the prestressing force level has no effect on the torsional and flexural stiffness of the beam. Last, raising the effective prestressing strength level significantly improves the beam's resistance to flexure and torsion and delays shear stress cracking. Also, three hollow beams were examined by **Luís Bernardo * and Cátia Taborda (2020)** and tested till failure. The beams were 5.90 meters long and had a squared cross-section of 0.60 by 0.60 meters. Four wires with a diameter of 1.52 cm that were centered in the cross-section were used to apply external prestressing. For all three beams, the longitudinal reinforcement ratio remained unchanged. After temporary losses, the amount of stress in concrete caused by prestress (fcp) ranged from 0 MPa (beam without prestress) to 3.08 MPa. Tests on the three specimens revealed that longitudinal prestress was useful in delaying cracking and boosting the specimens' resistance to torsion. After cracking, the longitudinal prestress reinforcement begins to function as a regular reinforcement, supporting the internal equilibrium condition of the beams. There is also a lot of research studying the effect of prestressed beams under torsional loads, but we limited ourselves to mentioning the previous two examples in order to move to the next step.

4. EXPERAMENTAL PROGRAM

Four simply supported specimens were tested under load until they failed. The pre-stressing profile, internal reinforcement, support arrangement, and beam geometry of the tested specimens are displayed in Figure 1. The reinforce cages are displayed in Figure 2. All beams generally had an R-section with a cross-sectional area of 150 by 400 mm. Each beam had the same span. Each beam measured 2300 mm in length and supported span measured 1800 mm. For fully pre-stressed beams, pre-stressing seven wire strand has nominal diameters of 15.24 mm was used. The first specimen (B8) has no transverse reinforcement. For specimens (B3), (B9), and (B10) the transverse reinforcements were closed stirrups Y8@200 mm, Y8@143 mm, and Y8@100 mm respectively. The force in strands was 90 kN (Pre-compression stress Pe/A=1.50 MPa) and the average concrete strength for all specimens was 39.5 Mpa. Table 1 displays the specimen classification, and Figure 3 displays reinforcement details for each specimen.

Table 1 : The classification of specimens

Spec.	Bott RFT	Top RFT	Side. RFT	$\boldsymbol{Pe}$(kN)	$\boldsymbol{Pe/A}$ (Mpa)	Trans. RFT
B8	2Y6	2Y6	6T10	90	1.50	--
B3	2Y6	2Y6	6T10	90	1.50	Y8@200
B9	2Y6	2Y6	6T10	90	1.50	Y8@143
B10	2Y6	2Y6	6T10	90	1.50	Y8@100

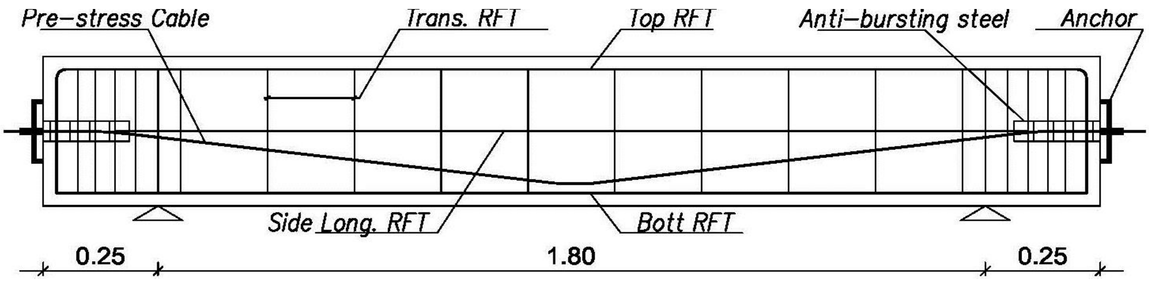


Figure 1: Details of reinforcement for four specimens

Figure 2: Reinforcement cages

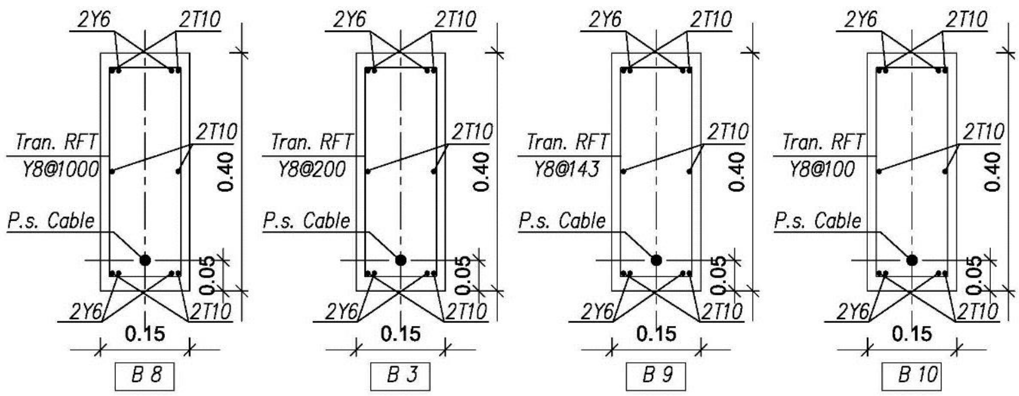
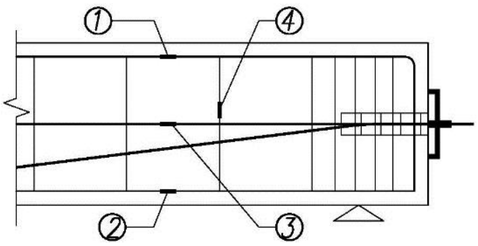


Figure 3: Details of reinforcement for all specimens.

For the cubes that were tested, the average compressive strength of the concrete was 39.50 N/mm^2. In this study, two different types of steel reinforcement were used. High tensile steel has a yield strength of 578 MPa, while normal mild steel has a yield strength of 334 MPa. High-grade steel strands with seven separate wires each made up the pre-stressing strands. For fully pre-stressed specimens, the strand diameter is 15.24. The strands' ultimate tensile strength of 1990 MPa was demonstrated through laboratory testing. Using electrical strain gauges (model KFGS-10-120-C1-11L1M2R), steel strains were measured. The electrical resistance of the gauge was 119.6±0.40%-ohm, its gauge factor was 2.09±1.0%, its transverse sensitivity ratio was 0.1±0.2%, and its gauge length was 10.0

mm. The configuration of the steel strain gauges for the specimens is displayed in Figure 4. The first strain was placed on the upper side longitudinal bar. The second was placed on the longitudinal bar on the lower side. In the stirrup's branch mid-shear span was the third position, and on the mid-side longitudinal sidebar was the final position. All specimens were tested in the R.C. laboratory of the civil engineering department at Al-Azhar University under a continuous static load using a hydraulic jack fixed on the steel frame. As shown in Figure 5, the specimens were loaded using a static load applied 45 cm from the specimen's face on a steel cantilever.



1 – Top long RFT strain

2 – Bottom long RFT strain

3 – Mid. long RFT strain

4 – Transverse RFT strain

Figure4 : Arrangement of the steel strain gauges for the specimens

Figure 5: Experimental setup

5. EXPERIMENTAL RESULTS AND DISCUSSION

The results obtained from the experimental tests are torsional Moments –deflection, Torsional Moments-twisting angle curve, Stiffness degradation and displacement ductility. Figure 6 shows crack patterns at failure of the specimen (B8).In the figure, it was noted that the crack as a result of the load on the specimen was accidental, due to the lack of transverse reinforcements. The first crack was observed on both sides at a load of 31 kN. The primary crack in this sample occurred then the primary crack increased with the appearance of other minor cracks. For specimen (B8) the peak load was 40 kN was obtained at 1.50 mm deflection. Figure 7shows crack patterns at the failure of the specimen (B3). The first crack was observed at the front left side at a load of 32.0 kN, which was close to specimen (B8). The primary crack in this sample occurred and increased with the appearance of other cracks. The peak load for the specimen (B3) was 47.53 kN and it was obtained at 4.48 mm deflection. Comparing with the specimen (B8), it is clear that the peak load of Specimen (B3) was higher than that of Specimens (B8) by 18.82%. Figure 8 shows crack patterns at the failure of the specimen (B9). The first crack was observed at the front right side at a load of 34 kN, which was higher than that of the specimen (B8) by about 9.70% and close to the specimen (B3). The primary crack in this sample occurred then increased with the appearance of other cracks. The initial cracks were observed at 1.60 mm deflection. The peak load for the specimen (B9) was 54.98 kN and it was obtained at 4.40 mm deflection. It was noted that the peak load of Specimen (B9) was higher than Specimens (B8) and (B3) by 37.45% and 15.67% respectively. Figure 9 shows crack patterns at the failure of the specimen (B10). The first crack was observed at the front left side at a load of 40 kN, which was higher than that of the specimen (B8), specimen (B3) and (B9). The primary crack in this specimen occurred then the primary crack increased with the appearance of other cracks. The initial cracks were observed at 0.97 mm deflection. The peak load for the specimen (B10) was 59.20 kN and it was obtained at 4.68 mm deflection. The peak load of Specimen (B10) was higher than that of Specimens (B8), (B3) and (B9) by 29.73%, 21.21%, and 7.04% respectively.

Figure 6: Crack patterns at failure of specimen (B8)

Figure 7: Crack patterns at failure of specimen (B3)

Figure 8: Crack patterns at the failure of specimen (B9)

Figure 9: Crack patterns at failure of specimen (B10)

From the previous peak loads for the four specimens, the relationship between torsional moments and the corresponding deflection was drawn as shown in Figure 10. It is clear that the increase in the transverse reinforcement ratio increases the peak load. Whereas, when adding closed stirrups Y8@200 mm, Y8@143 mm, and Y8@100 as a transverse reinforcement, the maximum failure load was increased by 18.83%, 37.45%, and 48.00% respectively. Also, the peak torsional moment for four specimens was 9.00 kN.m, 10.69 kN.m, 12.37 kN.m, and 13.32 kN.m respectively.

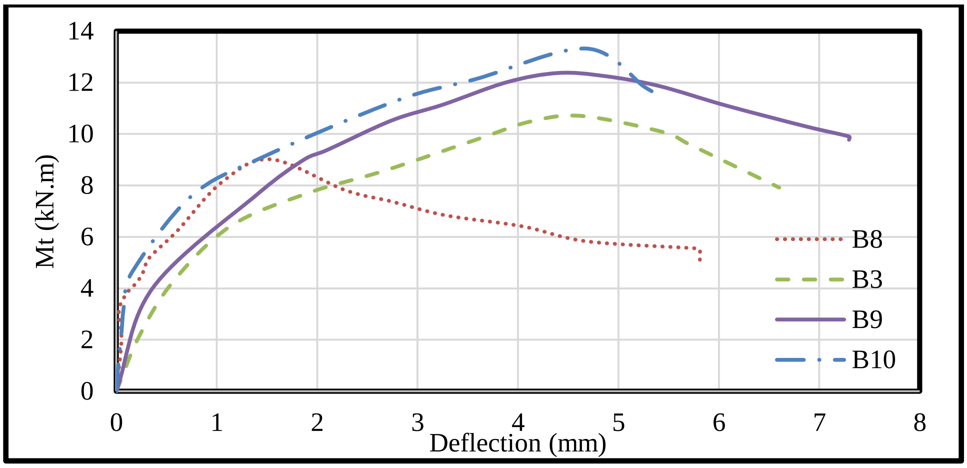


Figure 10: - Torsional Moments – deflection curve of tested specimens.

Two LVDTs were positioned during the sample test: one below the tested beam's mid-span, and the other below the cantilever at the loading point. A measurement of the angle of rotation is equal to the landing difference between two points divided by the distance between them $(\Delta_2-\Delta_1)$ / L. Figure 11 shows the torsional moment – Rotation curve. The angle of rotation at the peak load was 0.033, 0.065, 0.072, and 0.093 for B8, B3, B9, and B10 respectively. The greater transverse reinforcement ratio leads to an increase in the angle of rotation of the specimen at the maximum failure load, but the rotation angle before yield load for all specimens was close.

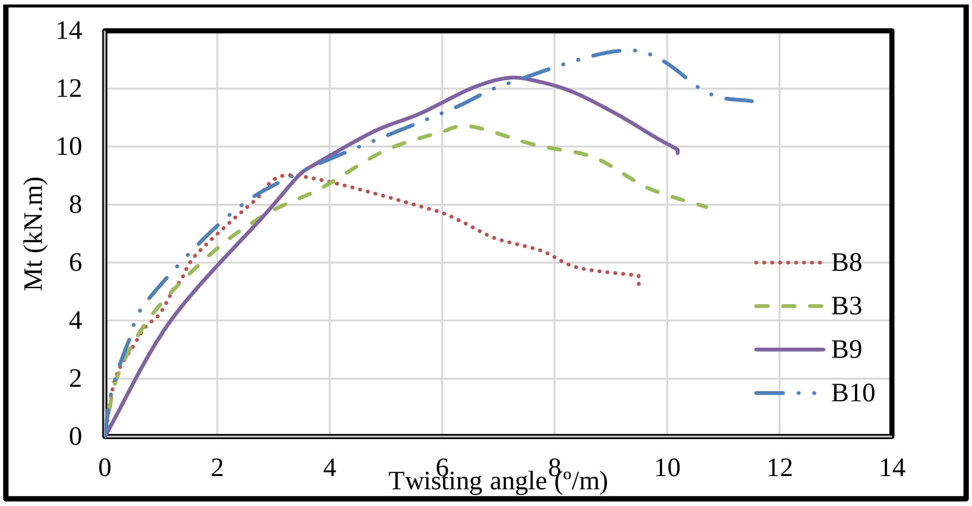


Figure 11: Torsional Moments - twisting angle curve.

Figure 12 shows the stiffness degradation of the four beams during the loading. The stiffness of all beams degrades from cracking to yielding. Also, the stiffness degradation for specimens that had high transverse reinforcement ratio was lower than that had low transverse reinforcement ratio.

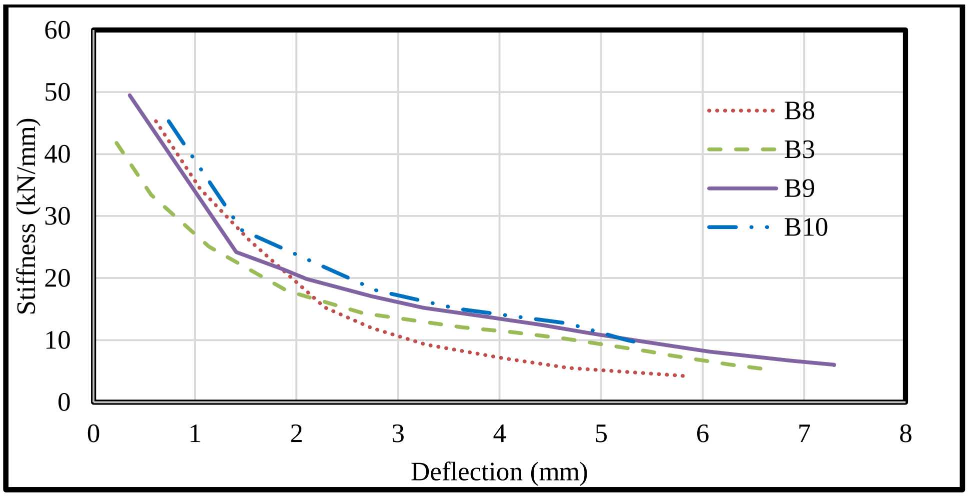


Figure 12: Deflection-Stiffness curve.

Table, 2 and Figures 13 present the displacement ductility for the test specimen. For specimen (B8) the displacement at peak load was obtained as 1.50 mm, and displacement at yield load was obtained as 1.00 mm. It means that the displacement ductility equals

1.50%. For specimen (B3) the displacement at peak load was obtained as 4.48 mm, and displacement at yield load was obtained as 2.65 mm. It means that the displacement ductility equals 1.70%. For specimen (B9) the displacement at peak load was obtained at 4.40 mm, and displacement at yield load was obtained at 2.55 mm. It means that the displacement ductility equals 1.73%. For specimen (B10) the displacement peak load was obtained at 4.68 mm, and displacement at yield load was obtained at 2.60 mm. It means that the displacement ductility equals 1.80%. So, the displacement ductility of specimens (B3), (B9), and (B10) are 13.33 %, 15.33%, and 20.00% higher than (B8) respectively. From the figure, it is clear that increasing the transverse reinforcement ratio of the beam subjected to torsion leads to an increase in ductility by a small percentage.

Table 2: Ductility displacement of specimens.

Specimen	transverse reinforcement	Yield displacement(mm)	Ultimate displacement(mm)	Ductility index (%)
B8	--	1.00	1.50	1.50
B3	Y8@200	2.65	4.48	1.70
B9	Y8@143	2.55	4.40	1.73
B10	Y8@100	2.60	4.68	1.80

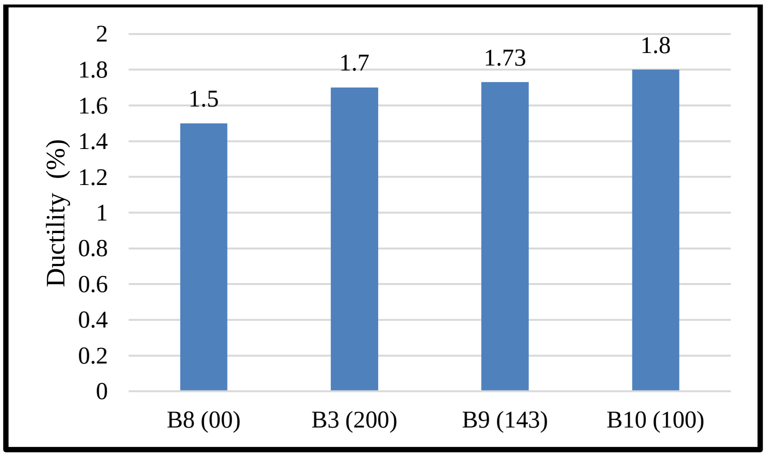


Figure 13: Displacement ductility

CONCLUSIONS

At the end, the following is concluded:

• With the increase of the transverse reinforcement ratio of the pre-stressed specimen subjected to torsion, the maximum failure load increases but the first crack occurs at the same load for all specimens. Whereas, when adding closed stirrups Y8@200 mm, Y8@143 mm, and Y8@100 as a transverse reinforcement, the maximum failure load was increased by 18.83%, 37.45%, and 48.00% respectively.

• It was noted that the transverse reinforcement helps to distribute the cracks, as the specimen without transverse reinforcement had one crack and then increased in width. Unlike other specimens that had transverse reinforcement, several cracks appear on both sides.

• The transverse reinforcement of the specimen improves the stiffness and ductility of the specimen. Whereas, when adding closed stirrups Y8@200 mm, Y8@143 mm, and Y8@100 as a transverse reinforcement, the displacement ductility was increased by 13.33 %, 15.33%, and 20.00% respectively

• Neither longitudinal nor transverse reinforcement alone increase the torsional capacity of a concrete member; however, appropriately arranged, equal proportions of both reinforcements will increase the torsional strength and ductility over that of plain concrete members.

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