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Behavior of Post Tensioned Simply Supported Deep Beams

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ملخص البحث:

تم فى هذا البحث عرض وتحليل النتائج لمجموعة من الكمرات الخرسانية المسلحة العميقة سابقة الاجهاد بسيطة الارتكاز ذات حمل مركز فى منتصف البحر وذلك بعمل تجربة معملية ومقارنت نتائجها بالنتائج باستخدام معادلات التصميم من الكود المصري (ECP203-2007).المتغيرات التى تم دراستها هى نوع صلب سبق الاجهاد المستخدم (صلب متماسك او غير متماسك) وتغيرنسبة الحديد المطلوب لمقاومة القص في الكمرات , اي نسبة حديد القص الرأسى (ρ_{VL})الى القص الافقى(ρ_{HZ}) من 0% الى 100% .

Abstract

This paper presents the contribution of post tensioning cables to the reinforcement of the deep beam. An experimental program is carried out for five simply supported post tensioned deep beams with 1300 mm effective span, height of 500 mm and a width of 220 mm. The specimens were designed according to the Egyptian Code of Practice ECP203-2007. Change in post tensioned system (bonded or unbounded) and different ratio of vertical stirrups to side pars various from 0% to 100% from the required shear reinforcement of the deep beams is also studied. These beams are exposed to vertical concentrated load at mid span of each beam. The load was increased gradually till failure. Then discussion on results compared to codes predicted values are presented. The crack patterns for all concrete specimens were also observed.

1. Introduction

Deep beam is a beam having large depth/thickness ratio and shear span depth ratio. Because the geometry of deep beams, their behavior is different from slender beam. The strain or stress distribution across the depth is no longer a straight line, and the variation is mainly dependent on the aspect ratio of the beam. Deep beams have many useful applications for both residential and commercial building structures such as transfer girders, transfer caps of high-rise buildings and as part of lateral load resisting system (Outriggers)…etc.

2. Deep beam definition:

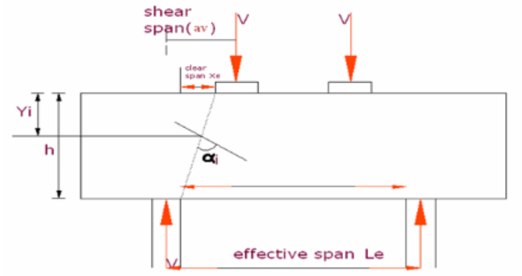

Figure 1 - Geometry of Simple Deep Beam

According to (ECP 203-2007) [1], Deep beams are characterized as beams whose effective span to depth ratios conforming to: $L/d \leq 4$ Where: d = the effective depth of the section and L = the effective span of the beam. According to (ACI Committee 318-14) [2] Deep beams are members that are loaded on one face and supported on the opposite face such that strut-like compression elements can develop between the loads and supports and that satisfy A or B

- **A.** Clear span doesn't exceed four times the overall member depth (h).
- **B.** Concentrated loads exist within a distance (2h) from the face of the support.

The shear strength of concrete deep beams was predicted by numerical methods according to (ECP 203-2007). In this paper, five post-tensioned concrete deep beams subjected to vertical concentrated load at mid span has been considered.

3. Experimental program

3.1 Sample configuration

All five tested post-tensioned deep beams share same dimensions; specimens with an effective span of 1300 mm, width of 220 mm and a height of 500 mm as shown in **Figure 2**. Specimens also share same top and bottom reinforcement and straight tendons shape with 3 numbers of 0.5" strands as shown in **Figure 3 & Figure 4.**

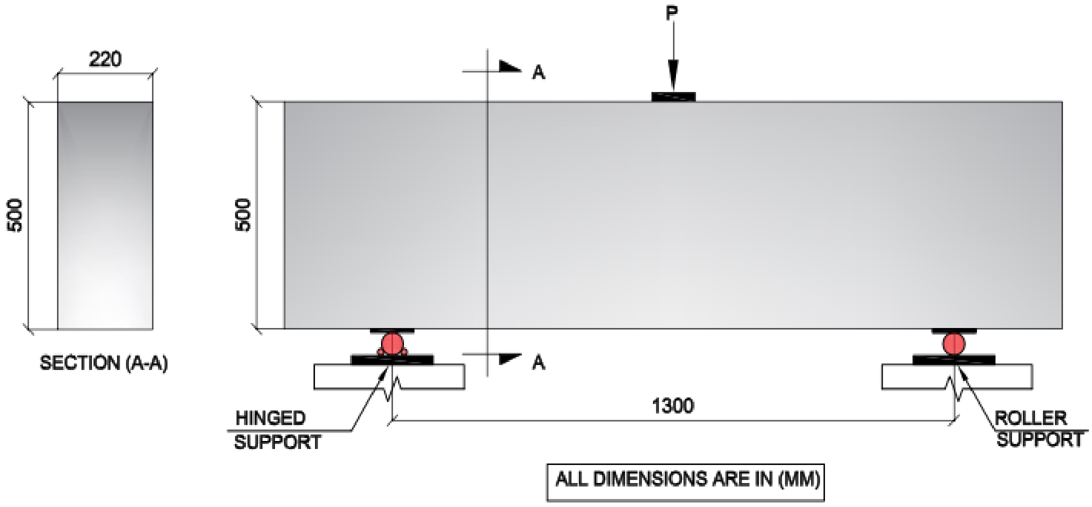

Figure 2 - Specimen dimensions

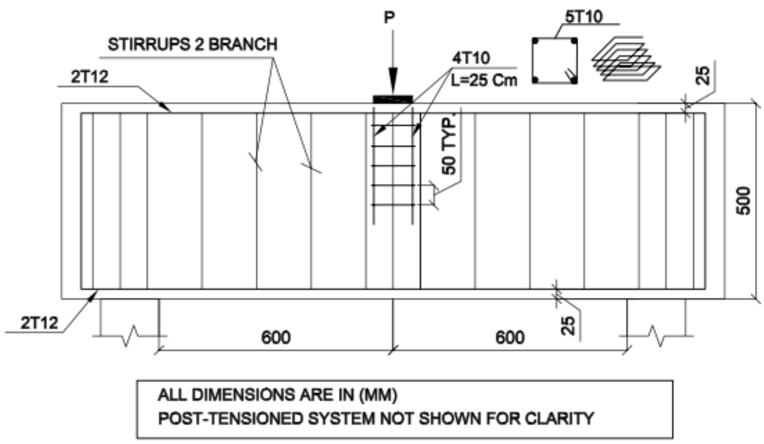

Figure 3 - Reinforcement details of tested specimens

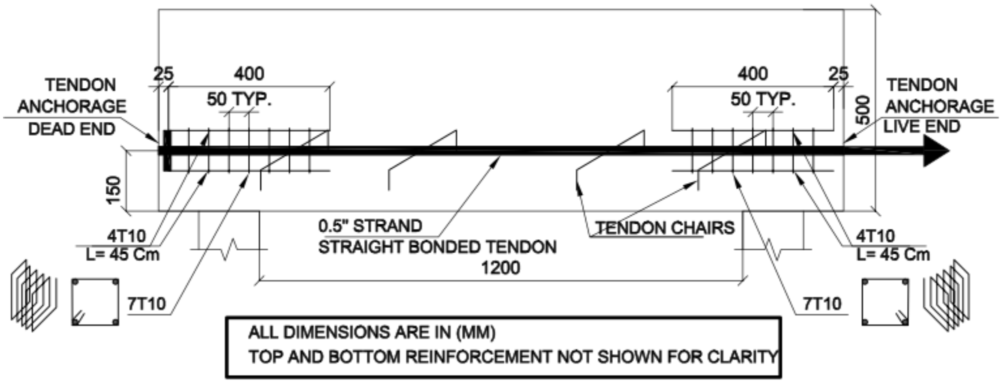

Figure 4 - Post-tensioned details of tested specimens

3.2 Samples parameters

Different parameters and combinations had been used to configure the five specimens to be able to cover some of the studied variables; parameters can be summarized as below:

- Post-tensioned system (Bonded or Un-bonded).
- A varying amount of required shear reinforcement (stirrups and side bars) from 0% to 100%. Each specimen has a unique identification name indicating what parameters values are used in it. Each label has 3 characters as "B11" each character is assigned for one parameter. First character indicates the used Post-tensioned system
  - **B** indicating bonded type.
  - **U** indicating un-bonded type.

Second and third character indicates the used stirrups to side bars ratio.

The used ratio from required shear reinforcement shown in following Table (1)

Table 1- Specimens stirrups to side bars ratio

sample	Vertical Stirrups ratio (ρ_{vL})	Horizontal Side bars ratio (ρ_{HZ})
11	50%	50%
21	75%	25%
10	100%	0%

The description of each beam is summarized as in the following table:

Table 2- Specimen's matrix

Sample number	1	2	3	4	5
Sample name	B11	B21	B10	U11	U10
PT-System	Bonded	Bonded	Bonded	Unbonded	Unbonded
Top RFT	2T12	2T12	2T12	2T12	2T12
Bot. RFT	2T12	2T12	2T12	2T12	2T12
Vertical stirrups	T10@140	T12@135	T12@100	T10@160	T12@110
Middle Horizontal side bars	2T12	2T10	---	2T12	---

3.3 Material Properties:

a) **Concrete:** Concrete mix had been designed to obtain an average cube compressive strength of 40 MPa.

b) **Un-tensioned reinforcement:** High strength steel with grade of 400/600 with elastic Modulus E = 200000 MPa. Two diameters had been used; 10 mm and 12 mm

c) **Post-tensioned reinforcement:** Low-relaxation 7-wire strands with 0.5" diameter conforming to the requirements of ASTM A416[3].

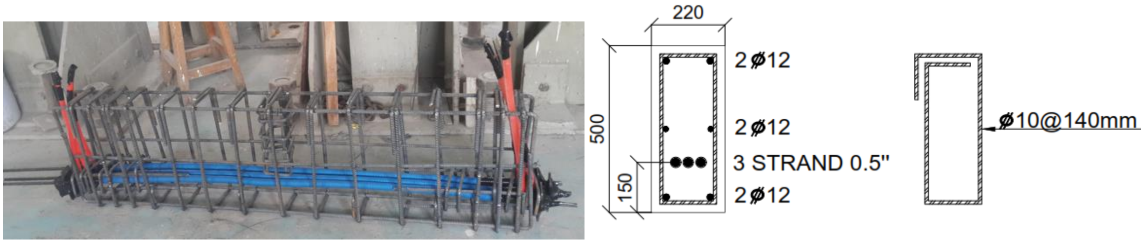

Figure 5 - Sample of reinforcement details for the specimen B11

Figure 6 - Preparation of formwork

Figure 7 - Removing of formwork After 10 Days from casting date

3.4 Procedures of Post-tensioning

Stressing is done using hydraulic jack and a pump with a calibrated pressure gauge as shown in Figure 8. To ensure force existence in full tendon length tendons stressing is monitored by observing the tendon elongation. As soon as stressing process is done, and results had been verified specimens are ready for grouting process to start. Grout mix was designed to produce 28-day cube strength of 35 MPa and seven-day strength of not less than 20 MPa. Grouting is carried out by casting grout mix through the provided grout hoses. Grout is placed to one of duct's hoses and start casting the grout mix into the duct, monitoring the mix to emerge without air pockets from the other hose to ensure full tendon grout without any voids as shown in Figure 9.

Figure 8 - Applying stress on strands

Figure 9 - Applying manual injection to the cable ducts for bonded cables

3.5 Test setup and Loading program

The tested post tensioned (PT) deep beams were simply supported vertically using steel plates rested above rigid steel columns which are fixed in ground and capable of carrying vertical loads at the both ends. Figure 10 shows specimen testing setup components and Loading setup for tested specimens.

Figure 10 – Test setup for tested specimens

Data Acquisition device was used to monitor the data while testing. All instruments (LVDTs, strain gauges and load cell) were connected to an electronic data acquisition system to monitor and recorded the data while testing.

4. Analysis and discussion of experimental results

4.1 Crack Pattern and Failure Mode

The observed behavior under the applied concentrated vertical load for the tested post tensioned deep beams indicated that the first crack was a vertical flexural crack initiated at the middle bottom of the beam web. As the load was increased, the length of this crack increased and additional flexure cracks initiated with different angle, then the widths of these cracks become wider and extended along the depth of the beam. Prior to flexural failure, as shown in the figure 11.

Figure 11 - Flexural cracks pattern

4.2Experimental and Calculated Failure Load

The calculated flexure load capacity calculated by ECP203-2007 design equation had a lower value than the experimental flexure load failure. The summary of the experimental test results is shown in Table 3.

Table 3 - Experimental post tensioned deep beams failure loads verses calculated failure load refer to ECP203-2007 design values

Specimen	Vertical stirrups	Horizontal Bars	$\%\left(\frac{Vl.Stir.}{Hz.Bars}\right)$	Calc. PT Deep Beam failure load (kN)	Exp. PT Deep Beam failure load (kN)	Parameter Tested
B11	T10@140	2T12	1:1	517	544	Control Beam For bonded PT-system
B21	T12@135	2T10	2:1	517	558	---
B10	T12@100	0	1:0	517	534	---
U11	T10@160	2T12	1:1	467	509	Control Beam For unbonded PT-system
U10	T12@110	0	1:0	467	534	---

4.3 Effect of change in ratio of stirrups to horizontal bars:

In post tensioned deep beams B21 first observed crack was a longitudinal crack initiated for at the middle of beam web at load =19 KN, where the cracking loads for the beams B10 was 22 KN, this indicates that decreasing the distance between stirrups tend to increasing cracking load value due to the contribution of stirrups. Flexure failure occurred by initiation of vertical diagonal cracks, the failure load for B21 and B10 was 558 kN and 534 kN, respectively.

4.4 Effect of change in post tensioned system (bonded or unbounded cables) and change in the ratio of stirrups to horizontal bars (Post tensioned deep beams U11 and U10):

It is clear from experiment result that all specimens with bonded post-tensioned system flexure capacity is larger compared to specimens with unbonded post-tensioned system. For U11 first observed crack was a longitudinal crack initiated at the middle of the beam web at load =19 KN, where the cracking loads for the beams U10 was 20 kN, this indicates that decreasing the distance between stirrups tend to increasing cracking load value due to the contribution of stirrups. Flexure failure occurred by initiation of vertical diagonal cracks, the failure load for U11 and U10 was 509 kN and 534 kN, respectively.

4.5 Deformations of Tested Specimens

The load - vertical deflection behavior of post tensioned deep beams B11 – B21 – B10 – U11 and U10 is shown in Figure 12. String potentiometers placed along the web bottom face of the post tensioned deep beams. The deflection behavior at the selected locations indicates that the maximum deflection occurred at the mid span of the post tensioned deep beams due to increasing of load. The maximum vertical deflection for the beams with bonded post tensioned system (B11 – B21 and B10) at mid span of the beam was around 22.9 mm whereas for the beam B11 .The maximum deflection for beams with Un-bonded post tensioned system (U11 and U10) at mid span was around 31.72mm at the failure load whereas for the beams U10 as shown in Figure 12.

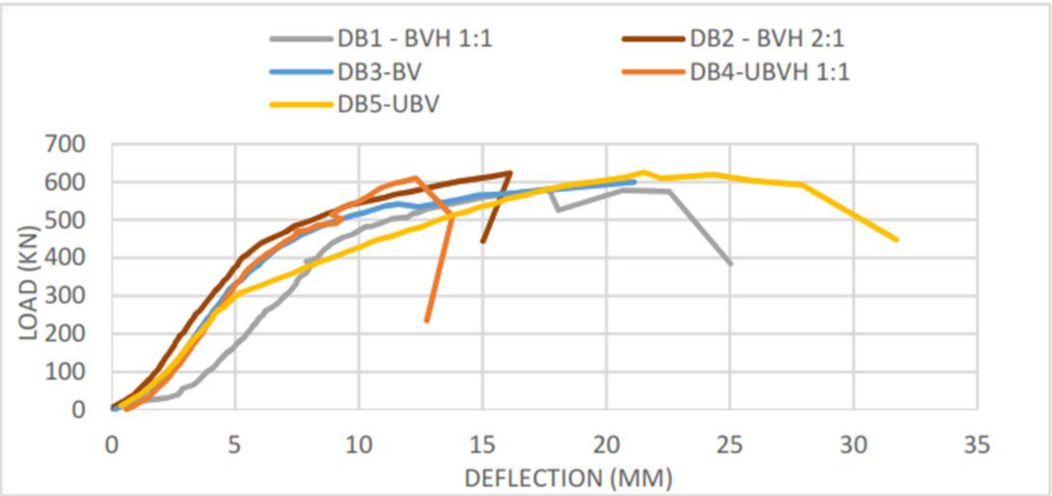

Figure 12 - Load versus mid span vertical deflection for all tested specimens

4.6 Strain of Steel bars of tested specimens

The strain of steel bars for all the tested specimens was recorded with load increment and up-till specimens' failure. Figure 13 show the load versus steel bars strains at mid-span (ε_1) for all tested post tensioned deep beams. These figures are used to determine the yielding loads of beams when yielding strain of steel bars is reached. The yield strains of the bottom steel bars, based on laboratory tests, are measured for all tested beams. Yielding of the bottom steel bars was initiated at the mid span for all tested post tensioned deep beams as shown by the schematic view in Figure 13.

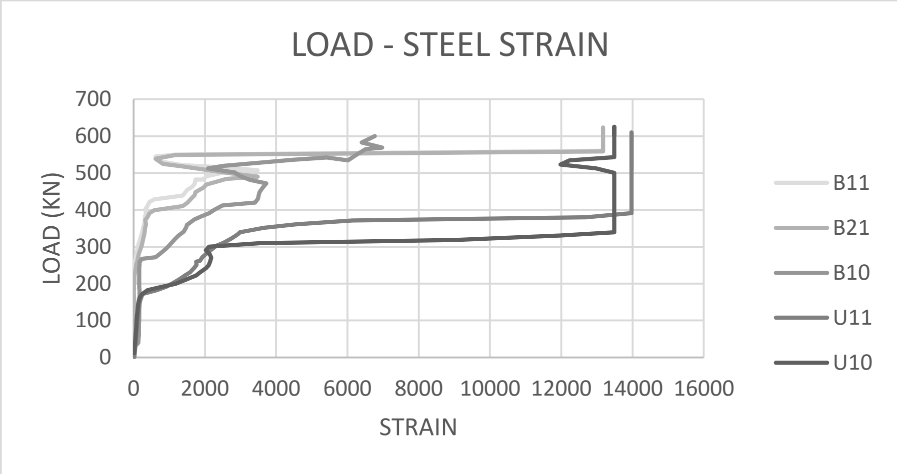

Figure 13 - Load versus steel strain for all tested specimens

4.7 Strain of post tensioned cables of Tested Specimens

The strain of post tensioned cables for all the tested specimens were recorded with load increment and up-till specimens' failure. Figure 14 shows the load versus post tensioned cables strains at mid-span (ε_1) for all tested post tensioned deep beams. These figures are used to determine the yielding loads of beams when yielding strain of steel bars is reached. The yield strains of the post tensioned cables, based on laboratory tests, are measured for all tested post tensioned deep beams. Yielding of post tensioned cables was initiated at the mid span for all tested post tensioned deep beams as shown by the schematic view in Figure 14.

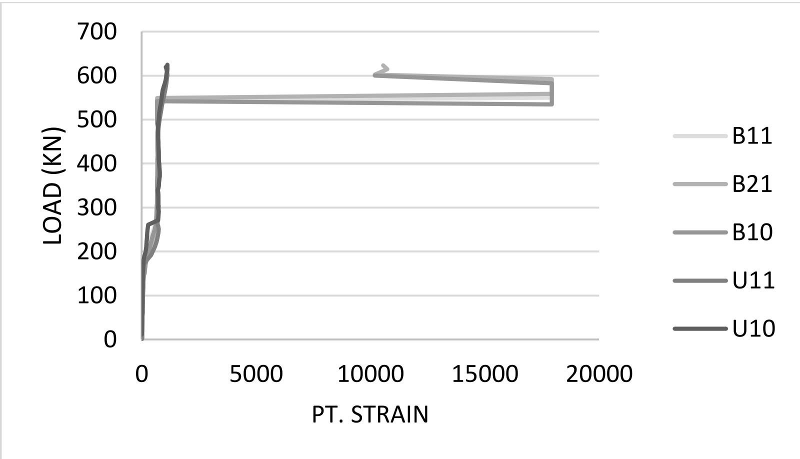

Figure 14 - Load versus post tensioned cables strain for all tested specimens

4.8 Strain on concrete of Tested Specimens:

The concrete strain was placed on two side of deep beam for all the tested specimens were recorded with load increment and up-till specimens' failure. Figure 15 shows the load versus concrete strains at mid-span (ε_1) for all tested post tensioned deep beams. This figure is used to determine the cracking loads of beams when yielding strain of concrete is reached. The yield strains of the concrete, based on laboratory tests, are measured for all tested post tensioned deep beams. Cracking of concrete was initiated at the mid span for all tested post tensioned deep beams as shown by the schematic view in Figure 15.

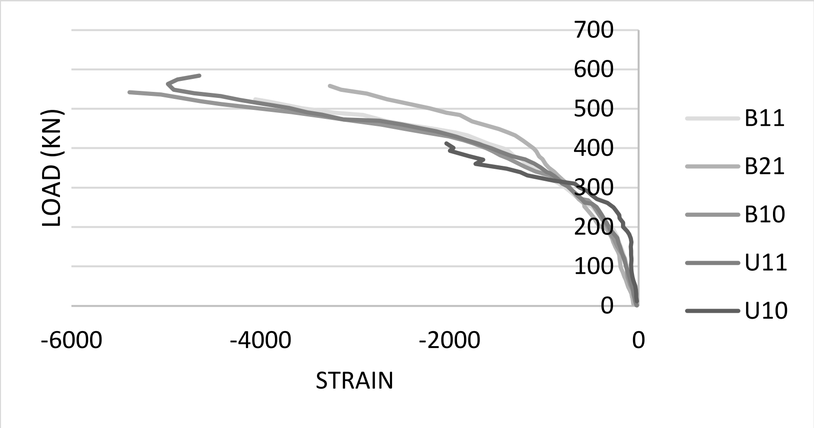

Figure 15 - Load versus concrete strain for all tested specimens

5. Conclusion:

From the experimental studies in the present paper, the following conclusion are drawn:
1- code provisions for post-tensioned beam capacity equations are conservative.
And the experimental result shows a good agreement with the Empirical design method in the ECP203-2007 design equation for deep beams shear design.
2-Post tensioned deep beams had shown that vertical shear reinforcement, perpendicular to the longitudinal axis of the beam, is more effective in shear strength than horizontal shear reinforcement, parallel to the longitudinal axis of the member, in a deep beam.

3-Post tensioned cables increase the stiffness and durability of the concrete.

5- Crack distributions on the middle of the loaded deep beams indicate that the post tensioned cables are helpful against the propagation of inclined cracks

References

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3. ASTM A416, Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete.