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Punching Behavior of Unbonded Post Tensioned flat slab

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Abstract: **Further improvements are needed in building technology to save time and resources. Nowadays, principal and public buildings are designed as long-span structures. The prestressed concrete system has proven to be more effective for spans exceeding 6 meters instead of the traditional reinforced concrete system, helping to reduce deformations and save materials. There are two types of prestressed concrete systems: pre-tension, where tendons are tensioned before concrete pouring, and post-tension, where tendons are tensioned after pouring. The unbonded system is one type of post tension system. At this research, the ultimate punching shear load was tested on the unbonded post tensioned slab and compared to the theoretical calculated value of the punching shear capacity of reinforced concrete flat slab. Strain behavior of reinforced steel bars and unbonded tendons of the specimen were studied. Also, deformation behavior of specimen during test up to failure was studied.**

Keywords: **Prestressing strands, Unbonded tendons, Post-tensioned flat slab.**

1. INTRODUCTION

Reinforced concrete building are more used compared to steel building globally, mainly due to economic reasons. previously, structures of long-spans were usually made of the steel material because of the difficulty of implementation with reinforced concrete and the subsequent problems of large deformation and cost. Prestressed concrete system can achieve lower deformation and save resources when compared to traditional reinforced concrete flat slabs for long spans[1]. Prestressed concrete consisted of combination of concrete with prestressed and non-prestressed steel bars, allowing for optimization usage of the concrete section [2]. Prestressed concrete depends on tensioning of strands to apply compressive stress on a concrete element [3]. During external loading, increasing the usage of compression concrete section and decreasing the tensile concrete section due to prestressing results in subsequently decreasing amount of steel usage at concrete sector and cost that is one important advantage of prestressed concrete [4].

On the other hand, the prestressed concrete system can control deflection and reduce cracks[5]. the prestressed concrete system has two types depending on the timing of stressing the tendons [3], [6], [7]. Pretensioned concrete is one type of prestressing concrete in which tensioning the strands before the concrete is pour, and then the concrete is poured around the tendons. Subsequently, after the concrete has hardened and reached the required compressive strength, the strands are severed from between the concrete surface and the abutments, as shown in Figure 1. Pre-tensioning concrete is typically used in pre-casting and is common in various construction projects, including the construction of bridges. [8], [9], [10].

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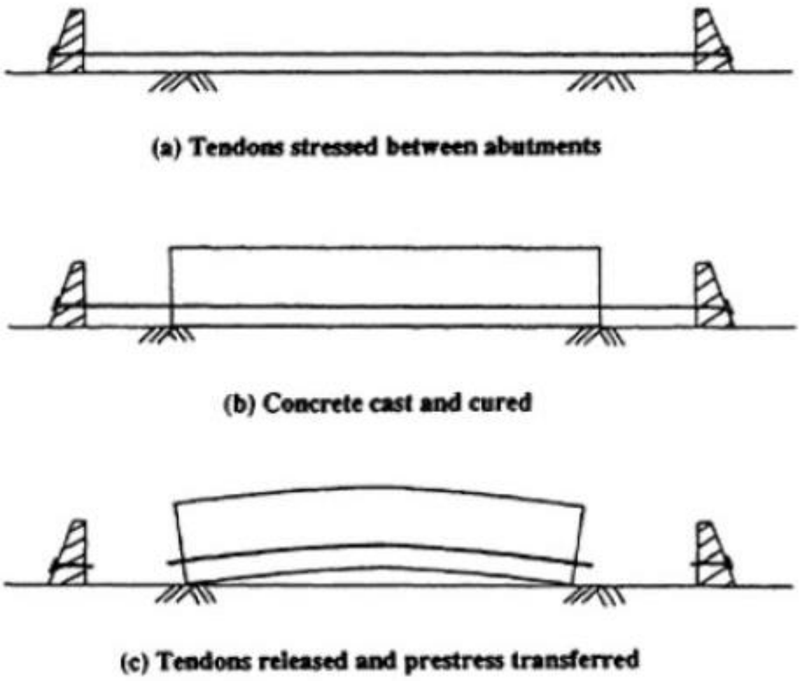

Figure 1. Pre-tensioning process[9]

Post-tensioned concrete is the second type of prestressed concrete. The post tensioning system is widely used around the world for several reasons such as a higher span-to-depth ratio leading to decreased usage of construction materials and thus lowering overall costs, fewer expansion joints, effective control over deformation, the ability to extend span lengths, and improved durability [3]. The post tension system depends on stressing the concrete after casting and the concrete reaches around 75 % of its compressive strength by stressing tendons as shown in figure 2 [11], [12].

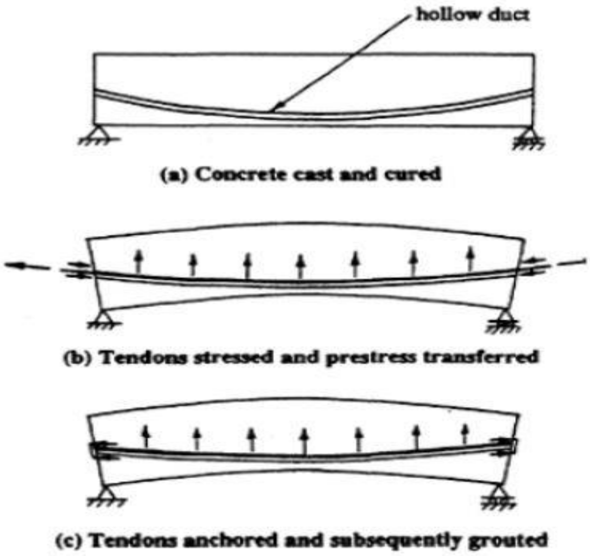

Figure 2. Post-tension process of concrete element [9]

Post-tension systems can use unbonded or bonded strands. Bonded post-tension structures consist of steel or plastic ducts that the injected with cementitious material, such as grout, after stressing. Alternatively, unbonded post-tension strands consist of seven-wire steel strands coated with anti-corrosion grease and encased in a continuous plastic sheath. Stress is transmitted from the tendons to the concrete via anchors, given the absence of bonding between the tendon and the concrete. The sheath acts as a moisture barrier and shields the tendon from corrosion. [13]. Additionally, it is easy to implement on site and saves time, as shown in Figure 3.

Figure 3. Unbonded post tension slab

The primary challenge encountered with flat slabs is punching shear failure. The area around the slab-column connection becomes highly crucial due to the concentration of shear stress developed in this zone. [14]. The traditional solution is to increase the concrete thickness either with a drop panel or column head to increase the compressive concrete section that resists this failure. Prestressed concrete saves the majority of the concrete section and can be effective in resisting punching shear failure. It is found that post-tensioning using enhances punching shear capacity by about 30% for a banded distributed layout compared to RC flat slabs [15].

2. EXPERAMINTAL PROGRAM

At this research, punching shear behavior will be studied on reinforced concrete flat slab with banded unbonded post tensionedtendons at one diretion.

2.1. Materials

2.1.1. Concrete

An economical concrete mix was made without any additives using Portland cement with grade 42.5 N [16], aggregate with maximum sizes of 1 and 2 [17], natural sand [17] and clean water. Concrete cubes with standard dimensions of 15 cm for each adage were tested at various ages as shown in Figure 4. The resulted compressive strength of the concrete at 7, and 28 days was 28.3 and 35.7 MPa respectively.

Figure 4. Molding and testing of standard compressive strength cubes

2.1.2 Non-prestressing steel bars

The main mesh reinforcement of the slab, with top and bottom layers, is applied using high tensile steel grade (400/600) with a diameter of 10 mm. Additionally, additional mesh consisting of 6 bars with a diameter of 16 mm is placed at the top and bottom of the slab around the slab column connection. Mild steel stirrups with a diameter of 8 mm are used at the anchorage zone of the prestressed system.

Prestressing System:

A mono anchorage system is used for the unbonded strands with an ultimate strength of 1860 MPa. The unbonded strands have a diameter of 0.5 inches and consist of low relaxation 7 wires, as indicated in Figure 4. Five unbonded strands are located at mid-span of one direction of the RC flat slab with a distance of 15 cm between them.

Figure 5. Used unbonded tendon

2.2 Test specimen

The reinforced concrete specimen had dimensions of 2 meters in width and length, and a thickness of 0.2 meters, with unbonded tendons running in one direction of the slab as shown in Figure 5. The specimen was tested under punching shear failure using a steel block simulating a column with dimensions of 0.2m x 0.2m to transfer the load from the load cell to the slab. Four LVDTs were fixed at the bottom surface of the slab, with one LVDT at the mid-point of the slab and three LVDTs around 0.5 meters from mid-point of the slab span. Steel strain gauges were fixed at the mid-span of the middle steel bar in the tendon and reinforced concrete direction on the tension side. The other two tendons were fixed at the mid-span of the tendons in the middle of the slab, and one tendon was placed 15 cm off the mid-point of the slab as shown in Figure 5.

Figure 6. installation of tendons' strain gauge

The mesh reinforcement used in the specimen consisted of five steel bars per meter with a diameter of 10 mm in the reinforced concrete direction and 3 steel bars per meter in the tendons' direction. This meets the minimum requirements for mesh in the R.C system and post-tension system according to ECP-203 [21]. In addition, an additional mesh of six bars with 16 mm diameter was distributed under the column area, with one meter used at the top and bottom to prevent flexural failure as shown at figure 7. Five tendons were stressed, not exceeding 75% of the ultimate strength of the tendon, once the concrete reached 75% of its strength.

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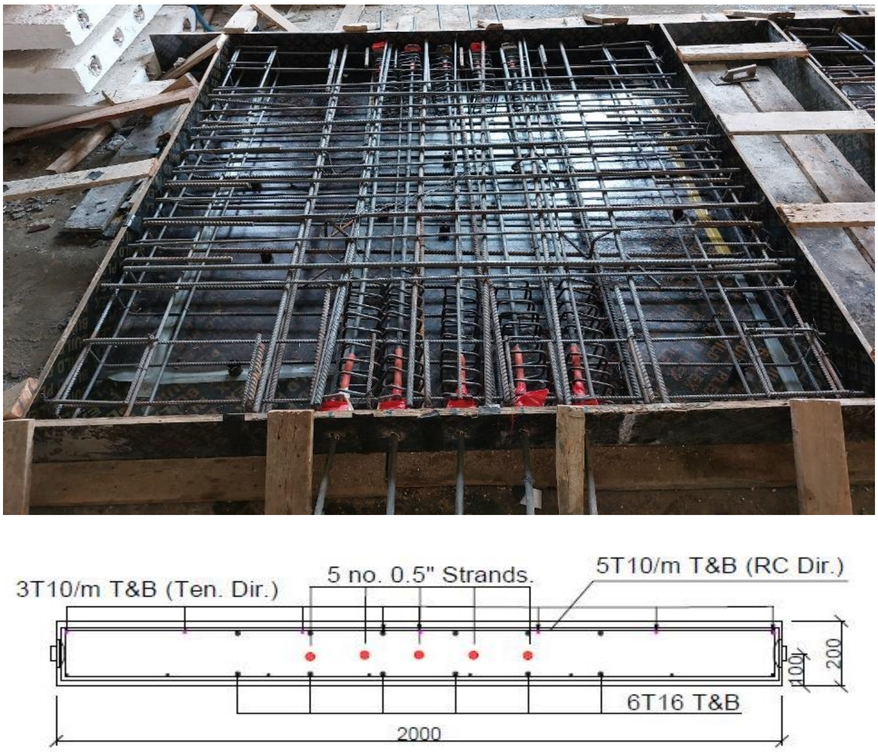

Figure 7. full reinforcement details of specimen

3. RESULTS AND DISCUSSION

The specimen was tested for punching shear failure and the ultimate load was 59.7 tons. The deformation behavior with load is shown in Figure 7 and the maximum deflection of each LVDT at the failure load is shown in Table 1.

Table (1) : Maximum deflection of each LVDT at the failure load:

LVDT No.	LVDT 1	LVDT 2	LVDT 3	Mid LVDT
Deformation (mm)	7.28	7.9	9.22	11.24

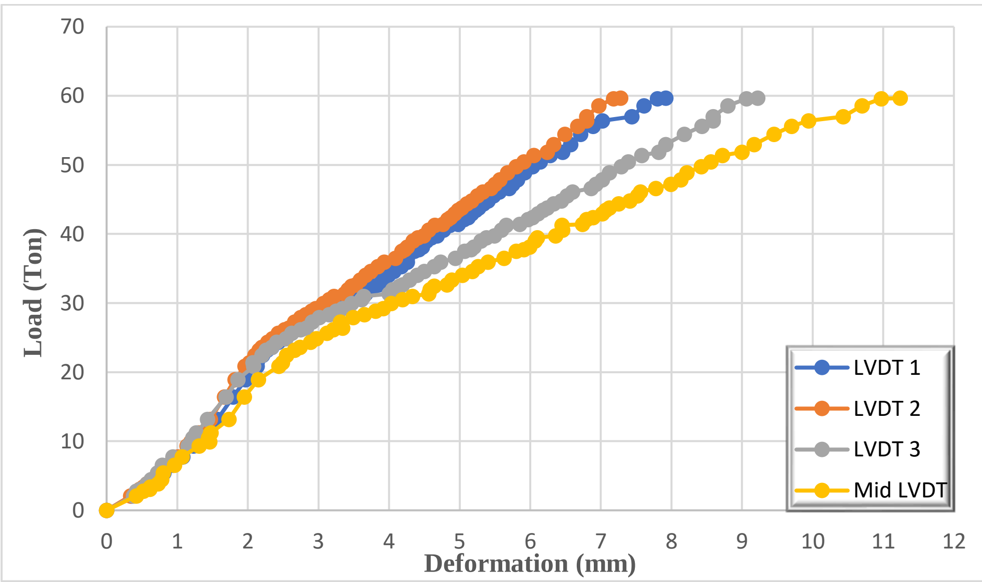

Figure 8. The deformation behavior with load of specimen

Using the puncging shear capacity of reinforced concrete flat slab of ECP-203 as shown at equation (1) [18]

$$\text{Qcup-uncracked} = \text{min. of} \begin{Bmatrix} 0.8\left(\frac{\propto . d}{bo} + 0.20\right).\sqrt{fcu} \\ 0.316\left(0.5 + \frac{a}{b}\right).\sqrt{fcu} \\ 0.316\sqrt{fcu} \\ 1.70 \end{Bmatrix} \quad \text{(MPa)} \qquad \text{equ (1)}$$

where ∝=4 for interior column. d is slab thickness; fcu is compressive strength of concrete; and b and a are the long and short dimensions of column, respectively.

The calculated ultimate capacity of a reinforced concrete flat slab according to the Egyptian code [18] is 45.5 tons, while the experimental punching shear capacity using unbonded tendons was 59.7 tons. This means that strengthening an RC flat slab with post-tension tendons in one direction of the slab improves the punching capacity by 23.7%. According to Figure 8, the strain behavior of steel bars in the tendon direction is stronger compared to steel bars in the RC direction. The yield strain of the bars is 2x10^-3 mm/mm, while the strain behavior of the steel bars at yield points is still increasing. It is confirmed that the failure was a punching shear failure, indicating a low effect of flexure failure in this case. Two strain gauges were fixed to the two tendons, as shown in Figure 5, but the second strain gauge on the tendon at 15 cm off the mid-tendon of the slab did not yield any results. It may have been cut during post-tensioning before testing.

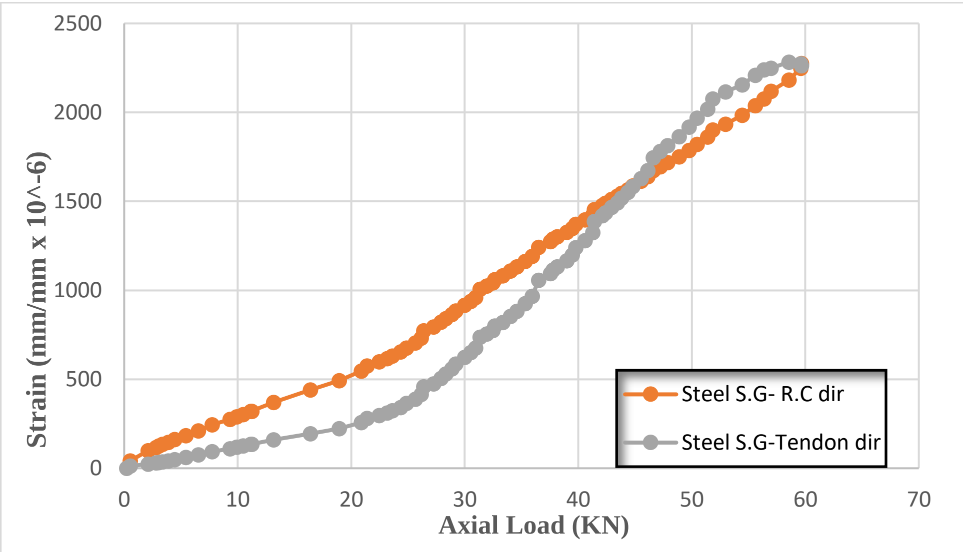

Figure 9. Behavior of steel bar's strain gauge of spacimen

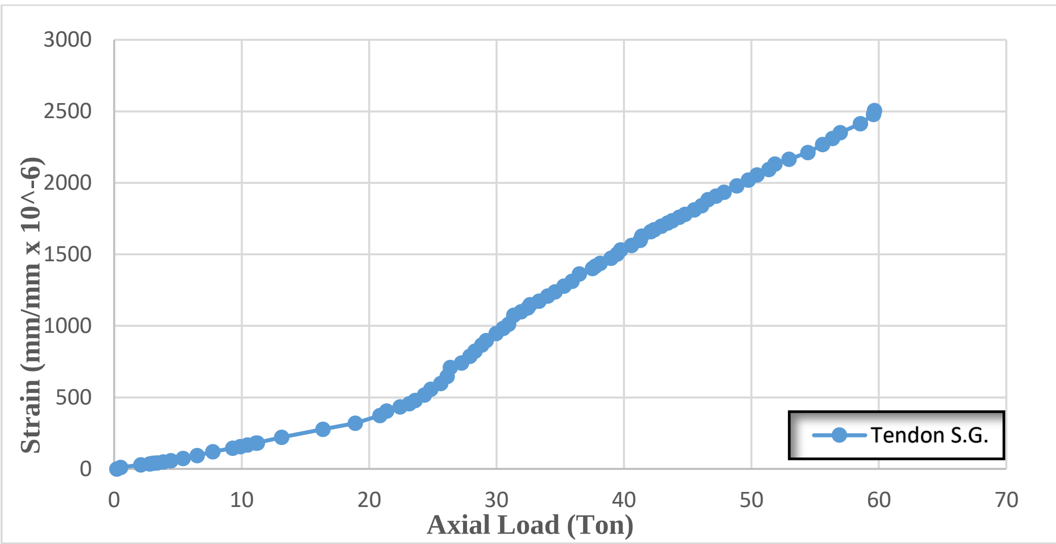

Figure 10. Behavior of Tendon's strain gauge of spacimen

4. CONCLUSION

1) Using the reinforced concrete flat slab with unbonded tendons in one direction improves punching shear capacity by 23.7% compared to a regular R.C flat slab.

2) the unbonded post tensiond slab helps control deformation.

3) Steel strain gauges do not reach yield strain that It indicates that the slab collapsed due to punching shear failure insead of flexural failure

4) Strain gauges on tendons can be cut off during the tensioning process.

Future studies

1) Studying punching shear failure in an post tensioned slab using distributed unbonded tendons with larger spacing

2) Testing the impact of flexural failure on the unbonded post tensiond slab.

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