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# ENHANCEMENT OF PUNCHING SHEAR STRENGTH OF FLAT SLAB WITH INTERNAL POST-TENSION CABLES

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## ملخص البحث:

شاع استخدام نظام البلاطات المسطحه فى المبانى الانشائيه فى العقود الاخيره لسبب بساطه انشاؤها وامكانيه العماره بها. حيث يوجد شكل من الانهيار شائع بها وهو انهيار القص الثاقب عند منطقه اتصال العمود بالبلاطه وهذا النوع من الانهيار قصف ومفاجئ. يوجد العديد من الدراسات والتى تمت فى السنوات الاربعين السابقه وتهدف الى منع هذا الانهيار عن طريق عمل خطط مختلفه كتدعيم للبلاطه ضد هذا الانهيار. حيث مقاومه قوى القص الثاقب تعتمد على قوه البلاطه باستخدام خرسانه سابقه الاجهاد كما فى هذا البحث تم عمل تحليل عددى باستخدام برنامج الانسيزس. وتم عمل دراسه عن العوامل التى تؤثر على كفاءه البلاطه عند تدعيمها باستخدام خرسانه سابقه الاجهاد داخليا والتى تؤثر على اجهاد القص الثاقب بها.

## ABSTRACT

In the last few decades, the flat slab systems was commonly used in building structures because its construction simplicity and architectural flexibility. One of the common failure modes of this structural system is punching shear-failure of slab-column connection. This type of failure is brittle and sudden. Large number of studies was carried out in the last forty years aiming to prevent such failure exploring different strategies for strengthening the slab against this failure. This research work aims to study the possibility of increasing capacity of the slab is resist punching shear using internal prestressing. A numerical analysis using the well-known FE software, ANSYS, is used to carry out a parametric study to assess the effectiveness and the key parameters which affects the punching shear enhancement due to applying internal prestressing technique.

**Keywords:** Punching, Flat Slab Connection, Internal Prestressing, Post-Tension, Shear Failure, Enhancement.

## 1. INTRODUCTION

Reinforced Concrete flat-slab is a common type of floor systems that is widely used in modern buildings. In this structural system the punching shear failure can commonly occur due to bad construction, lack of shear reinforcement and, errors in design. Punching shear failure is brittle and catastrophic due to high localized forces. Several punching shear reinforcing systems were developed in the past, such as studs, stirrups. The efficiency of such systems is strongly influenced by their development conditions (anchorage and bond) and detailing rules. In the last few years, new techniques were proposed to resist the punching shear in flat slab floors are such as prestressing and, strengthening by FRP composites.

Using of internal prestressing to increase the punching shear capacity of the slab section was firstly introduced by since 1888, After that, many researches were conducted to study the factors that affect the punching shear capacity when using the internal prestressing. Several researchers studied the punching of post-tensioned slabs such as [Alami 1994, Harajli and Soudki 2003, Subramanian, N., 2005, Kang and Soudki 2006, Ramos and Lucio 2008, Kheyroddin, et al 2008, Redl 2009, Clement et al 2013, Faria, D.M., V.J. Lúcio 2012, Ruiz, et al 2013].

This new technique was proven to be efficient with respect to the ultimate and the serviceability state. Results indicate that, significant improvements in strength, ductility, energy absorption and non-brittleness of failure can be achieved with adding prestressing cables in flat slab and increases in punching shear load capacity.

In the current research, the technique of using internal post-tension cables in the flat slab is investigated to determine the key factors that significantly affect the punching shear capacity of the flat slab. A numerical study is conducted using the well-known Finite Element (FE) software, ANSYS. A finite element numerical model for a flat slab strengthened with the internal post-tension cables was constructed and a parametric study was conducted to reveal these key parameters. Step-by-step nonlinear static analysis is performed during this study taking into account the material, as well as, the geometric non-linarites.

## 2. MODEL CONFIGURATIONS

In this paper, a model of a flat slab is employed. The specimen (S1) was selected to be a control slab in this study which was tested by Kheyroddin, et al. (2008). The model was $3000x3000x150mm^3$. the steel reinforcement is 7T10/m´ with internal column dimensions of $300*300mm^2$. The vertical load was applied centrally through the column stub and the slab is supported along four edges to simulate an inverted slab-column connection.

It has been studied in this research another model of flat slab enhanced by post –tension tendons. The specimen (AR1) was studied by Ramos et al. (2008). The model was $2300x2300x100mm^3$. The bottom and top reinforcement consisted of twelve 6 mm, rebar's at 200 mm centers and thirty nine 10 mm rebar's at 60 mm centers respectively, in both orthogonal directions with internal steel plate dimensions of $200*200mm^2$. The vertical load was applied to eight points on the top of the specimen by steel tendons. Centrally through the column stub and the slab is supported along four edges to simulate an inverted slab-column connection.

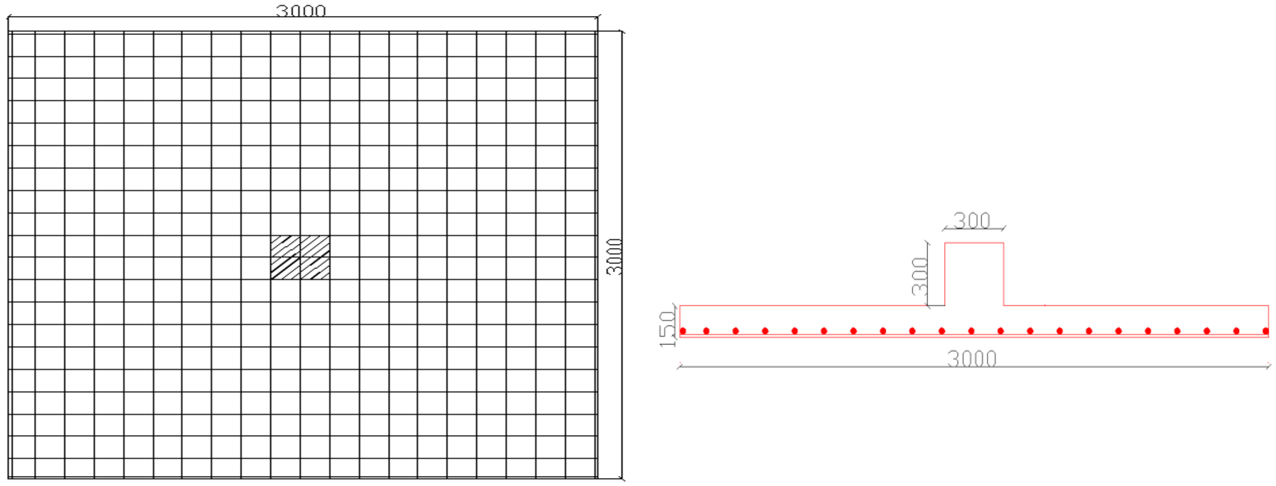
The material properties for the concrete, as well as, the reinforcing steel are presented in Table 1 for S1 specimen and Table 2 for AR1 specimen. Figure (1) shows the plan and sectional elevation of the studied slab (S). Figure (2) shows the plan of the studied slab (AR1).

Table 1: Material properties of concrete and reinforcing steel for SP1 model.

| Steel properties | | | Concrete properties | |
|---|---|---|---|---|
| Es (MPa) | Fy (MPa) | υ | Fcu(MPa) | υ |
| 2E5 | 360 | 0.3 | 28 | 0.2 |

Table 2: Material properties of concrete and reinforcing steel for AR1 model.

| Steel properties | | | | Concrete properties | |
|---|---|---|---|---|---|
| Es (MPa) | Fy (MPa) | | υ | Fcu(MPa) | υ |
| | T 6 | T 10 | | | |
| 2E5 | 555 | 481 | 0.3 | 44.6 | 0.2 |



(a) (b)

Fig. 1. Geometric Configuration of Specimen SP1 Kheyroddin et al. (2008).

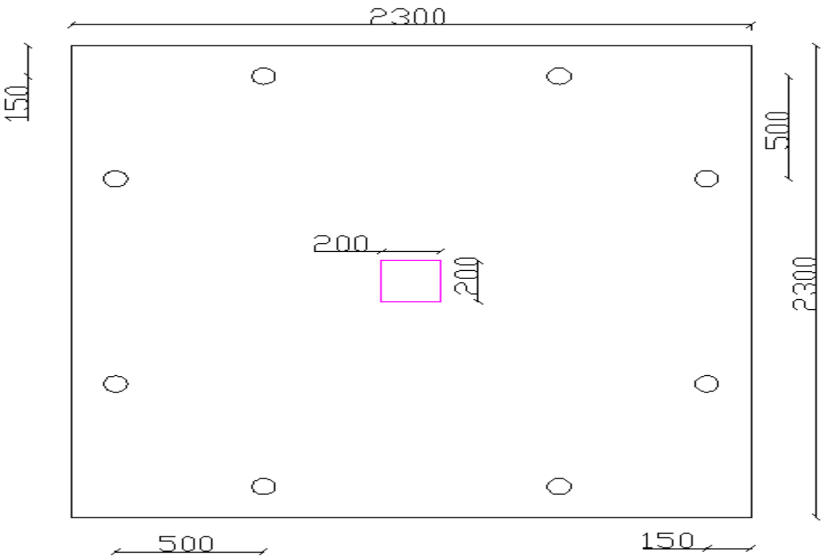
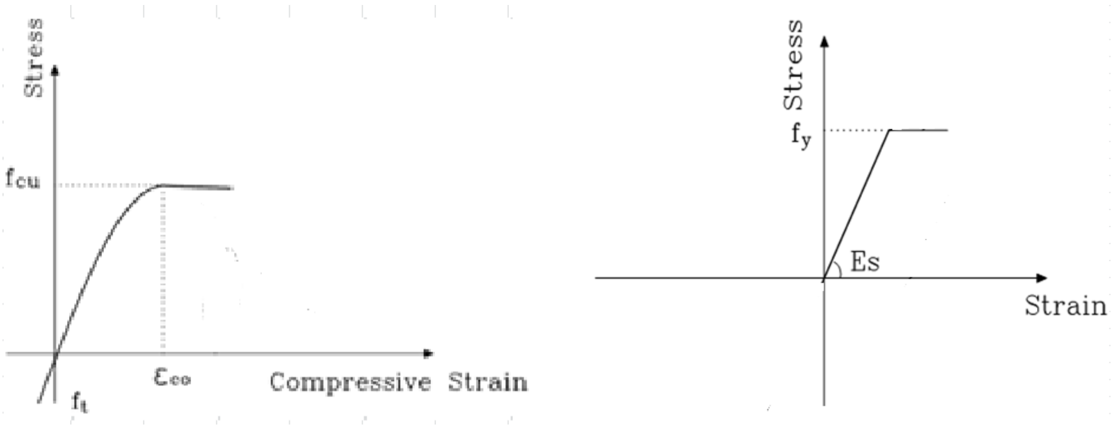


Fig. 2. Geometric Configuration of Specimen AR1 Ramos et al. (2008).

A schematic representation of the material models that have been used in the analysis is shown in (Fig. 3) for concrete and steel, respectively.



a. Material model of concrete  b. Material model of the steel

Fig. 3. Material models for (a) Concrete, (b) Reinforcing steel

## 3. Type of ANALYSIS

The slab has been modeled using solid65 element which is a 3-D structural has the ability of cracking in tension and crushing in compression. The reinforcing steel has been modeled using link8 element which is 2-nodes structural element capable of modeling element subjected to tension and compression. The slab has been simply supported along four sides. The load was applied at column area as a displacement till-failure. The non-linear static analysis has been triggered and the loads have been applied in 20 load step. The full Newton-Raphson method has been used to help in the conversion.

## 4. Verification

To verify the modeling process and to assess the reliability and the accuracy of the model, its results have been compared to experimental. Figure 4 shows a comparison between the obtained results of the verified model and those experimental ones of specimen P1 by [El-Kheyroddin 2008].

It can be seen that the analysis results show good agreement with experimental results. And the ultimate load is equal to that obtained from the experimental results. Figure 4 shows the load-deflection curve of P1 and Figure 5 shows the load-deflection curve of AR1. Figure 6 Shows the crack pattern obtained by the numerical analysis for a strip of 1.0 width at the column area too clarity. It can be seen that the cracks forms the trapezium shape which identify the punching shear failure surfaces.

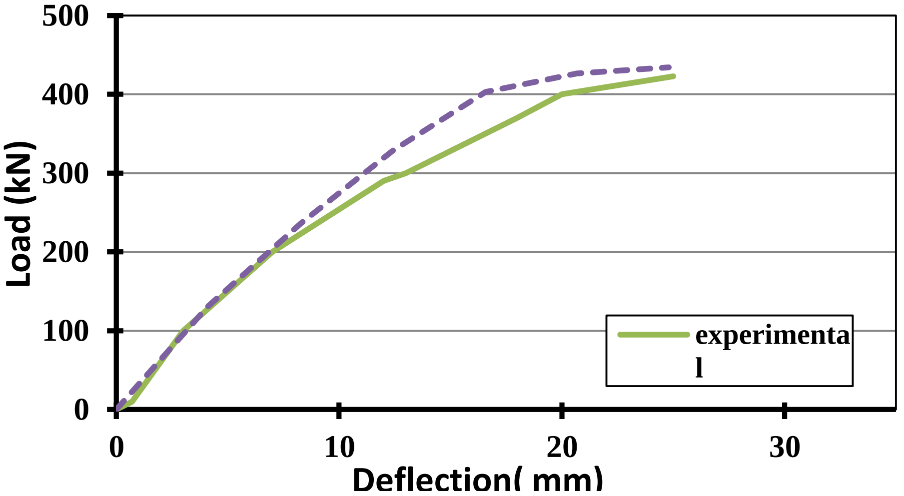


Fig. 4. Load-Deflection Curve of Numerical and Experimental Model P1

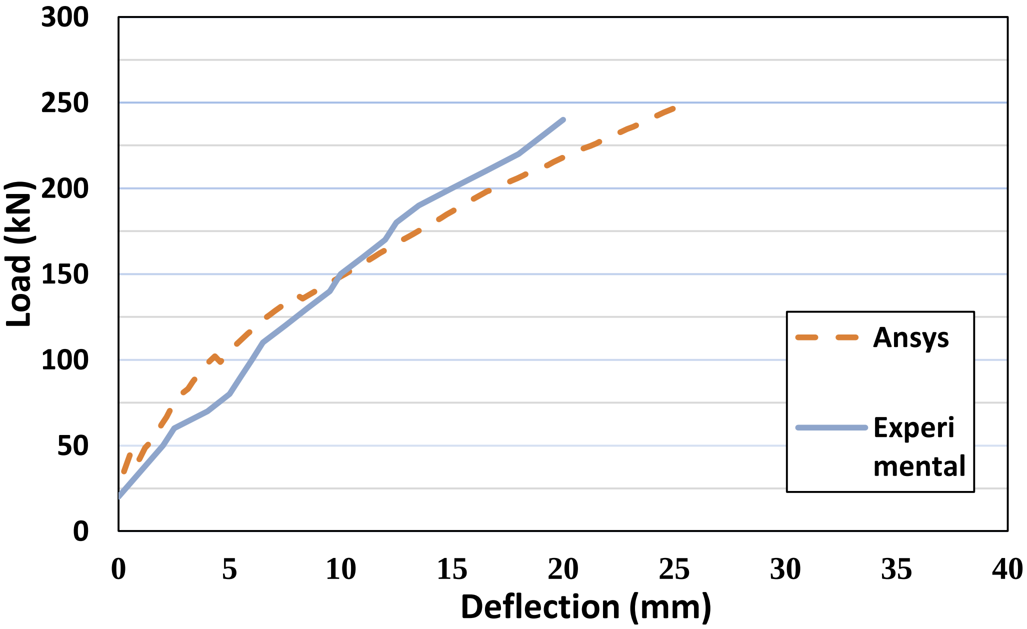


Fig. 5. Load-Deflection Curve of Numerical and Experimental Model AR1

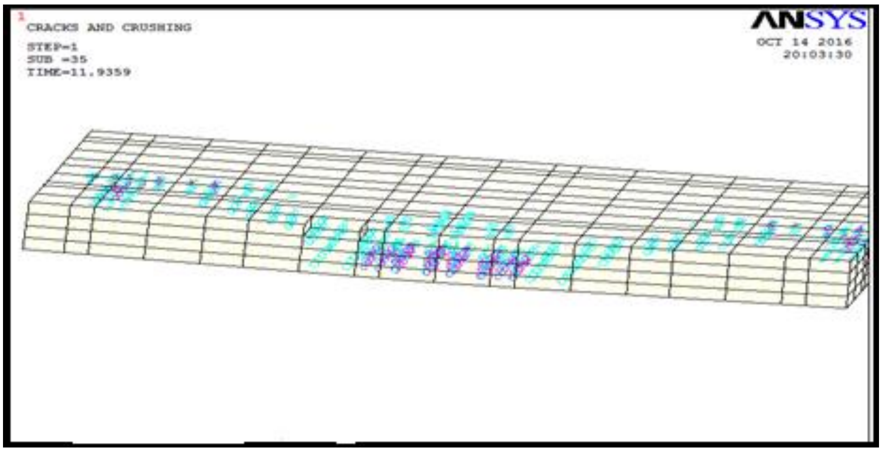
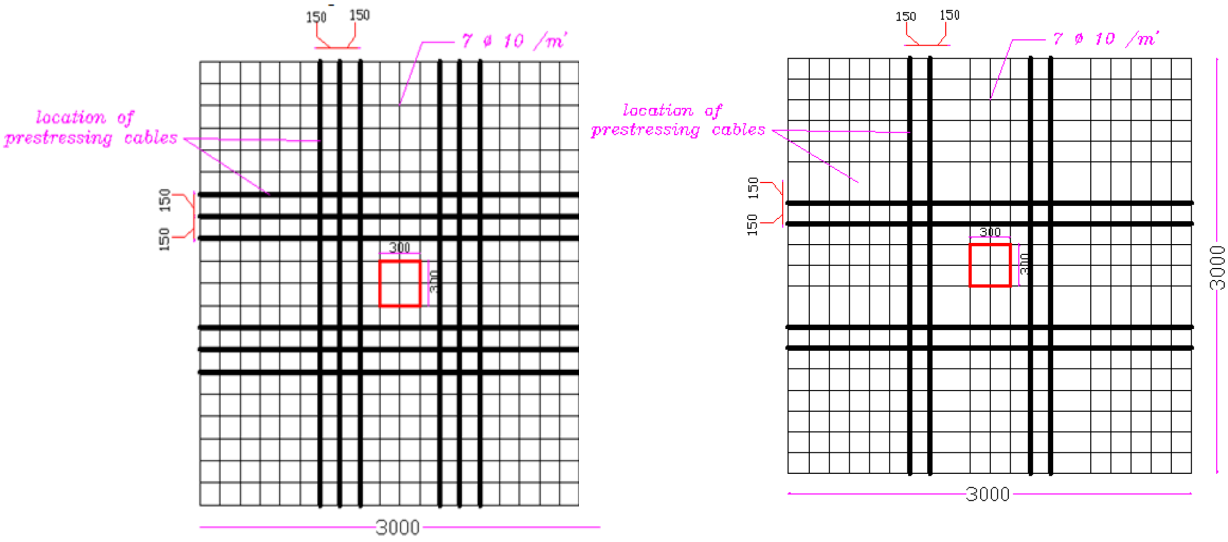


Fig. 6. Crack Configuration in the strip at columns area of P1.

## 5. Parametric study

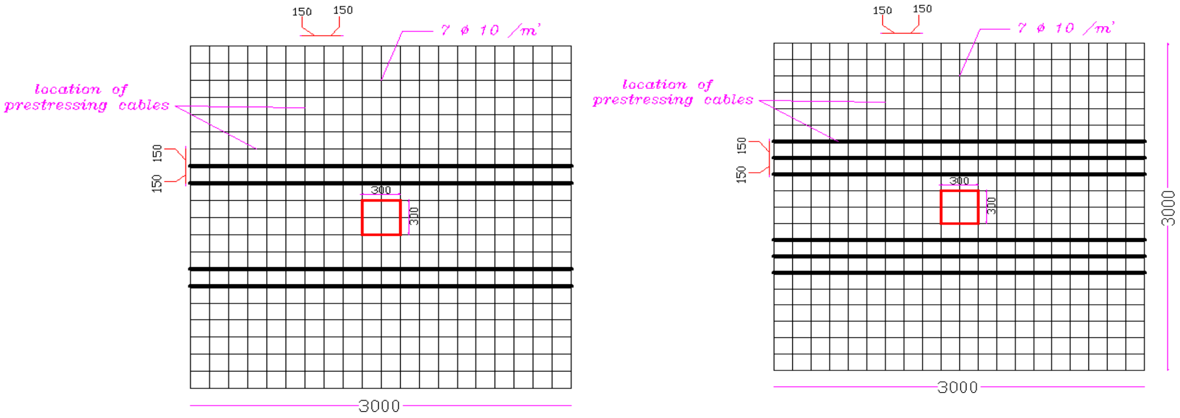
In order to investigate the effectiveness of using internal prestressing in increasing the punching shear resistance of the flat slab system. A slab with dimensions similar to that used in the verification and with a lower reinforcement ratio has been used in the parametric study. The reinforcement ratio has been reduced to about 70% of that used in the verified model to decrease the slab resistance for punching shear. Furthermore, internal prestressing cables were provided to apply the prestressing force within the slab.

Three different parameters have been studied in order to investigate their effects on the punching shear capacity of the slab which are the number of the prestressing cables, the direction of the cables and the applied prestressing force per cable. In all the studied cases the first cable has been located at a distance of 150mm from the column face. The distance between the Cables equal 150mm as shown in figures 7 and 8.



(a) (b)

Fig. 7. Details of Arrangement of Cables in Two Directions(a), Details of arrangement of cables in two directions (b).



(c) (b)

Fig. 8 .A3 Details of Arrangement of Cables in Two Directions (c), A4 Details of arrangement of cables in two directions (d).

Table 3 summarizes the studied cases for all parameters. In this table, the cables directions have been studied in two configuration; in one direction (E-W) and, in two orthogonal directions.

On the other hand the number of cables in each direction has been set to 4 and 6 cables per direction. Furthermore, the prestressing force ranges between 10kN to 80Kn.

According to the proposed parameters, a number of 8 cases have been studied four of them corresponds to changes in the cables´ arrangement (direction and number of cables) which are referred to by A1 to A4. The remaining four models correspond to changes in the prestressing force (models F1to F4).The control model which represents slab with no cables is referred by "S".

Table 4. Summarizes the parameters studied in this research. Figure 8 shows the load-deflection curve of changing arrangements of cables and figure 9 shows the load-deflection curve of changing force in cables.

Table 3: Studied parameters of S model.

| Model | Cable direction | Number of Cables | Force/Cable(kN) | Main reinforcement ratio |
|---|---|---|---|---|
| S | ______________ | _____________ | _______ | **7T10/m´ both ways** |
| A1 | Both direction | (6 in each direction) | 80 | |
| A2 | Both direction | (4 in each direction) | 80 | |
| A3 | One direction | 6 | 80 | |
| A4 | One direction | 4 | 80 | |
| F1 | Both direction | (6 in each direction) | 10 | |
| F2 | Both direction | (6 in each direction) | 30 | |
| F3 | Both direction | (6 in each direction) | 50 | |
| F4 | Both direction | (6 in each direction) | 70 | |

## 5.1 Modeling of prestressing cables

Table 4 shows the material properties of prestressing cables .The internal prestressing cables have been modeled using link8 element which is 2-nodes structural element capable of modeling element subjected to tension and compression.

Table 4: Properties of prestressing cables

| Es MPa | Fy n/mm2 | υ | Initial strain | γ n/mm |
|---|---|---|---|---|
| 2*10^5 | 400 | 0.3 | 0.000039 | 7.8E-5 |

Table 5: Parameters models of S.

| Models | Force/Cable (kN) | Initial strain | Failure load(kN) | Deflection (mm) | ncrease% |
|---|---|---|---|---|---|
| S | ____ | ____ | 308.76 | 17.12 | ____ |
| F1 | 10 | 0.000196 | 395.96 | 20.96 | 28.6% |
| F2 | 30 | 0.00059 | 408.5 | 20.97 | 32.6% |
| F3 | 50 | 0.00098 | 421.8 | 20.98 | 36.9% |
| F4 | 70 | 0.0014 | 428.85 | 25.2 | 39.2% |
| A1 | 80 | 0.0017 | 437.8 | 25.1 | 42% |
| A2 |  |  | 423.4 | 25.2 | 37.5% |
| A3 |  |  | 373.1 | 20.98 | 21.1% |
| A4 |  |  | 371.8 | 20.98 | 20.5% |

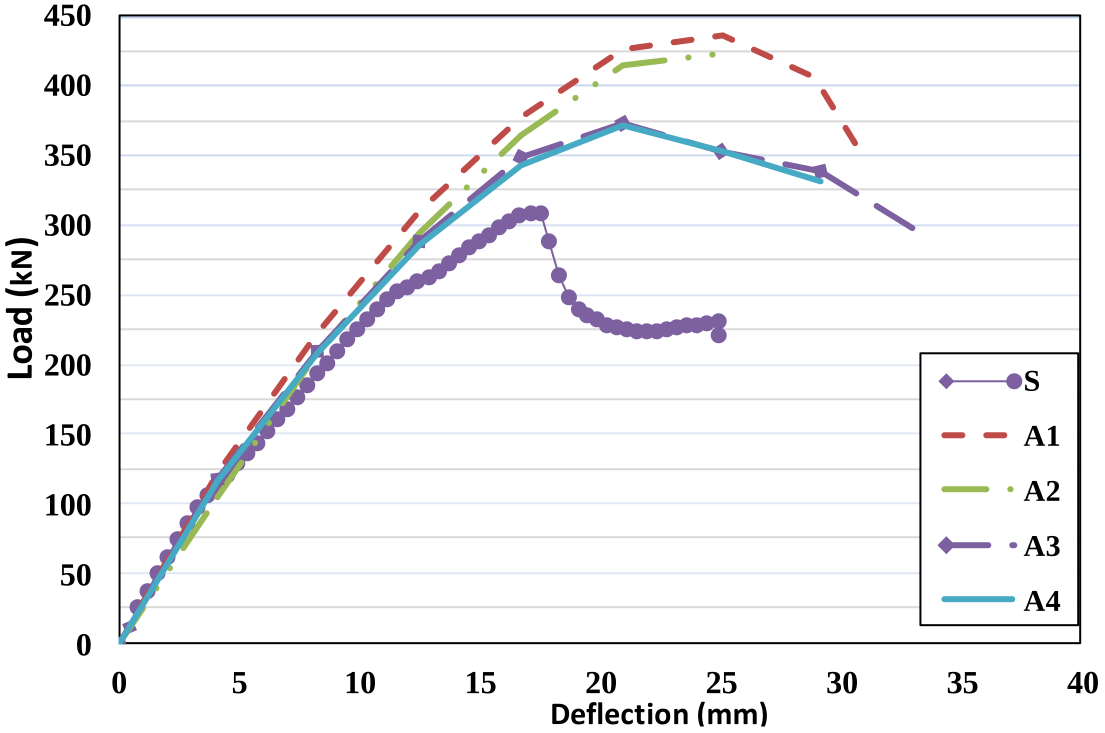


Fig. 9. Load-Deflection of models in changing of arrangements of cables.

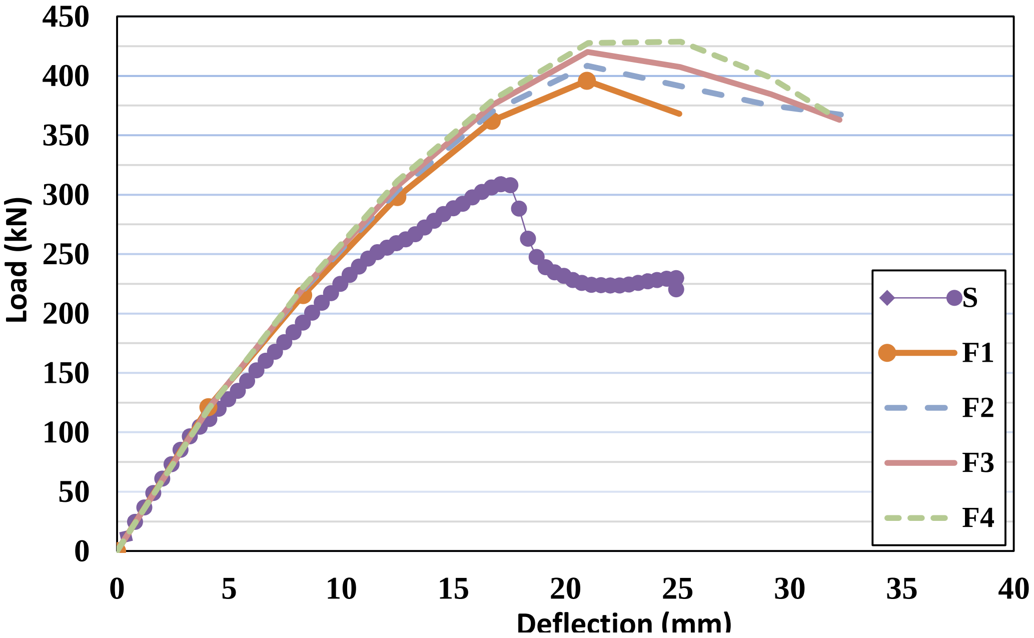


Fig. 10. Load-Deflection of models in changing of Force of cables.

## 5.2 Effect of prestressing force.

Figure 9 has been illustrated that the ultimate load has been increased to 39.2%. Increasing the prestressing force in each cable lead to enhancement in behavior of load-deflection curve, high ultimate load, high deflection which means high ductility.

## 5.3 Effect of prestressing arrangements in cables

Figure 10 has been illustrated that the ultimate load has been increased to 42%. The cable arrangement in both directions is better than in one direction. Increasing number of cable into 6 cables in both direction lead to increasing in ultimate load and in ductility.

## 6. Conclusions

In this research, the effect of using internal prestressing on the punching shear capacity of the flat slab system was studied. The numerical modeling using the well-known FE software (ANSYS) was employed. In this research and a parametric study was conducted.

The parametric study includes studying the effect of the number of prestressing cables, the direction of the cables, the prestressing force on the punching shear resistance of the flat slab.

It was concluded that:

1. Providing 4 cables in one direction increased the punching shear resistance of the slab by 20.5%. If the number of cables is increased to 6 cables, than the increase in the resistance reaches 21.1%.

2. Providing 4 cables in both directions increased the punching shear resistance of the slab by 37.5%. If the number of cables is increased to 6 cables in both directions, than the increase in the resistance reaches 42%.

3. Providing 10kN as a force in each cable increased the punching shear resistance of the slab by 28.6%. If the force in each cable is increased to 70kN per each cable, than the increase in the resistance reaches 39.2%.

4. The best case of all studied parameters is A1 using 6 cable in both directions, force in each cable is 80 kN, It increased the punching shear capacity by 42%.

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