DECEMBER 2017 M.Sc. in Civil Engineering KAMARAN SHEKHA ABDULLAH

# UNIVERSITY OF GAZİANTEP
# GRADUATE SCHOOL OF
# NATURAL & APPLIED SCIENCES

## NONLINEAR FINITE ELEMENT MODELING OF POST-TENSIONED TWO-WAY CONCRETE SLABS

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**BY**

**KAMARAN SHEKHA ABDULLAH**

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# Nonlinear Finite Element Modeling of Post-Tensioned Two-Way Concrete Slabs

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**Kamaran Shekha ABULLAH**

## ABSTRACT

**NONLINEAR FINITE ELEMENT MODELING OF POST-TENSIONED TWO-WAY CONCRETE SLABS**

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**M.Sc. in Civil Engineering**
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Post-tensioning is a technique that was used for constructions of (buildings, bridges, towers and offshore structures… etc..), Due to its efficiency and economy for achieving the requirements of long span with small depth. Post-tensioned concrete two-way slabs are one of the widely used slabs because of their good performance and cost effective compared with another slab type. This thesis investigates the structural behavior of post-tensioned two-way spanning concrete slabs. A nonlinear finite element model for the analysis of post- tensioned bonded concrete slabs was developed. The interface between the tendon and surrounding concrete was also modelled, allowing the tendon to retain its profile shape during the deformation of the slab. The load–deflection behavior, crack pattern in concrete and the failure modes are presented. The numerical analysis was conducted by the finite element ANSYS software and was validated by post-tensioned two-way concrete slab chosen from literature. A parametric study was conducted to investigate the effect of several selected parameters on the overall behavior of post-tensioned two-way concrete slab. The parameters are the effect of tendon layout, type of support, type of loading, position of the tendons, number and area of the tendons. Comparison between one-direction and two-direction tendon layout with the same number of tendons showed that two-direction tendon slab has higher failure load capacity.

**Keywords:** Bonded tendon, post tensioned concrete, two way slab.

# ÖZET

## ARD GERMELI ÇIFT YÖNLÜ BETONARME PLAKLARIN DOĞRUSAL OLMAYAN MODELLEMESI

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**63 sayfa**

Ard germe teknikleri, küçük kalınlıkla geniş açıklıkları geçebilmek için, köprüler, kuleler ve deniz yapıları gibi inşaatlarda kullanılan etkin ve ekonomik bir yöntemdir. Ard germeli iki yönlü beton döşemelerde, diğer döşeme tiplerine kıyasla iyi performans ve maliyet etkinliği nedeniyle yaygın olarak kullanılan döşeme tiplerinden biridir. Bu çalışmada ard germeli iki yönlü beton döşemelerin yapısal davranışları incelenmiştir. Bu beton döşemelerin analizi için doğrusal olmayan sonlu elemanlar modeli geliştirilmiştir. Tendon ve çevresindeki beton bir arayüz ile modellenlenerek tendonun döşeme şekli boyunca profil şeklini muhafaza etmesi sağlanmıştır. Yük deplasman davranışı, betonun çatlak modeli ve kırılma modları sunulmuştur. Sayısal analizler sonlu elemanlar ANSYS yazılımı ile yapılmış ve doğruluğu literatürden seçilen ard germeli iki yönlü beton döşeme üzerinden gerçekleştirilmiştir. Ayrıca farklı değişkenlerin ard germeli iki yönlü beton döşemenin genel davranışı üzerindeki etkisini araştırmak için de bir parametrik çalışma yürütülmüştür. Bu parametreler, tendon yerleşimi, mesnet tipleri, yük tipleri, tendon sayısı ve alanı gibi değişkenlerdir. Tek yönlü tendon yerleşimi ile aynı toplam tendon sayısına sahip iki yönlü tendon yerleşimi arasındaki karşılaştırma, iki yönlü tendon yerleşiminin daha yüksek kırılma yük kapasitesine neden olduğunu göstermektedir.



**Anahtar Kelimeler**: bitişik tendon, ard germeli beton, iki yönlü döşeme.

To

My Parents

My Beloved Wife RAZAN

My Son KARDIN

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## LIST OF SYMBOLS/ABBREVIATIONS

| | |
|---|---|
| FE | Finite Element |
| FEA | Finite Element Analysis |
| FEM | Finite Element Method |
| 3-D | Three Dimensional |
| PT | Post-Tensioned |
| BPT | Bonded Post-Tensioned |
| UPT | Unbonded Post-Tensioned |
| ACI | American Concrete Institute |

# CHAPTER 1

# INTRODUCTION

## 1.1 General

Concrete is a common material that used in structural engineering construction by various methods. It has a high compressive strength, but tension zones are very weak. Concrete tensile strength is changed and varies between ranges from 8 to 14 percent of its strength in compression. After applying loads to the concrete member cracks seem in tension zones because of concrete weakness in tension comparing to compression. Some technics were discovered to avoid such cracks that happen in tension zone, one of them was carried out high compressive force longitudinal or parallel along to the axis of the structural elements, this force can be reducing crack from growing by removing and significantly reduce tensile stress. Thus, this applied force can affect to raising of shear, torsion and bending moment capacity of the sections of the element, the section can behave elastically. After load applications, concrete will have a full capacity, it can be used strongly throughout the depth of the concrete section. This important technique was named prestressing force (Nawy, 2011).

Concrete post tensioning is a well-developed common technology, it has been found to be a good solution for the brittleness and low concrete tensile strength. Advantage of post-tensioning is increased crack control and smaller crack width, reduce the deflections and more slender than other methods in concrete structures. Post-tensioning in flat slab allows longer span and smaller slab thickness, it is a necessary in several typical flat slab structures such as parking garages and industrial buildings. Figure 1.1 shows the principle of post-tensioned reinforcement.

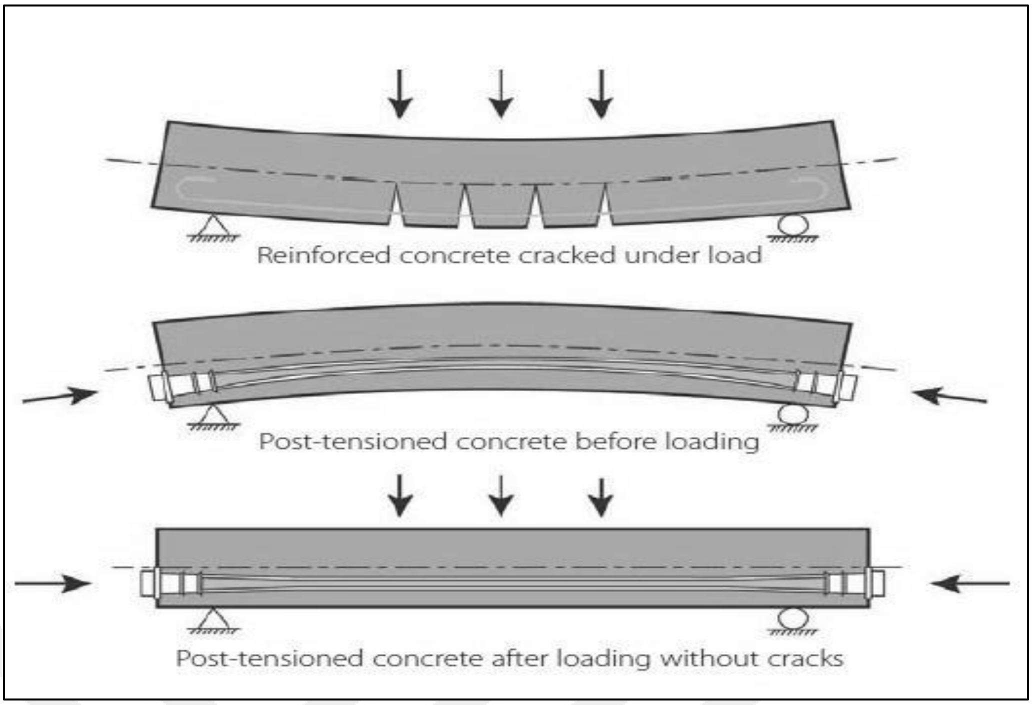



**Figure 1.1** Principle of post-tensioned reinforcement (Gribniak et al 2012)

The main purpose of this research is a detailed analytical investigation of the flexural behavior of post-tensioned prestressed concrete two-way slabs with different bonded tendon layout. This will be achieved by non-linear Finite Element Analysis (FEA) program's method, to choose the required number of tendons under different tendon layout and load cases on the concrete two-way slab. ANSYS computer program will be used for non-linear FEA based on incremental-iterative load methods, this program is a highly stable and reliable commercial software for FEA.

## 1.2 Finite Element Method

Now Finite Element Method (FEM) has applied for the analyzing of the reinforced concrete structures, to understanding the responsibility of the prestressed concrete slabs due to transverse loading, with behavior in both linear and nonlinear ranges, since the start of computers in the 1940s, the (FEM) technique has been speedily developed. In past years, Advances in computer software knowledge and ability have increased the use of FEA in structural engineering. FEM subdivides large structures into smaller, simpler parts that are called FE, then reconnected element parts by nodes. Ngo and Scordelis, (1967) firstly applied FEM to the reinforced concrete structures, they used predetermined cracks to simulate the cracks in the concrete as revealed in Figure 1.2.

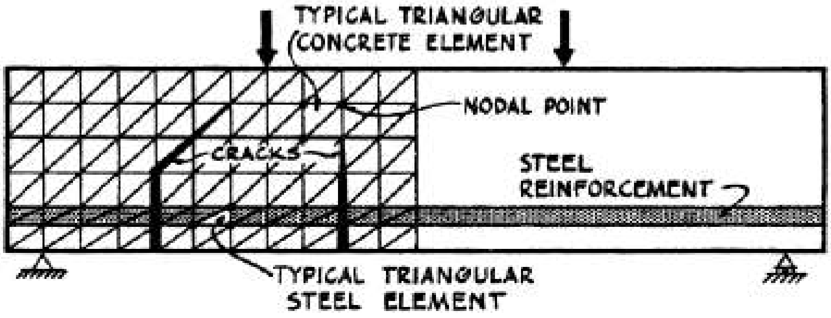



**Figure 1.2** FEM of reinforced concrete member (Ngo and Scordelis, 1967)

The concrete cracking, crushing, the interaction between concrete and reinforcement and the capability of the concrete to transfer shear after cracking by aggregate interlock can be idealized and represented by FEM.

FEA provides a tool that can predict and simulate the responses of reinforced prestressed concrete structures. Generally, the models of nonlinear material were integrated for many purposes. FE programs are ABAQUS, STRAND7, ANSYS, or MSC NASTRAN. Those FEA programs have an important function in nonlinear response analyses, each material components tends to hold the complicated stress-strain behavior. ANSYS package is chosen among those computer programs, for the FEA with Three-Dimensional (3-D) of reinforced concrete structures (Dahmani ,2010).

### 1.3 Post-Tensioned Method

Method Post-Tensioned (PT) is a technic that applied to concrete structures all over the world, to preventing deflections and cracks which are happened due to externally applied loads. In PT concrete, after concrete placing and reach adequate hardening then stress is applied. All tendons are covered by using ducts before casting of the concrete, after hardening of concrete, stressing jacks are using to apply the stress to all tendons to the required load. All tendons must be anchorage at the ends of the member to maintain the PT force. The applied tension stress counteracts with the external dead and live loads to reduce cracks and deflections.

By this method, greater applied loads, longer spans with the same depth of member, smaller member sizes and crack controls can be achieved. Also, in steel structures it can be used to improve higher resistance for seismic, and can be applied both externally and internally. It can also be used for repairing and reinforcing existing concrete structures. segmental bridges, parking, Slabs, continuous beam with long spans, etc. can be constructed by the PT method. The PT method can be used in cast in place and precast concrete. By this method both bonded tendons and unbonded tendons can be used in the same member and design long span with smaller depth (Mohammed et al. 2017).

## 1.4 Problem Statement

When applying external load on the Bonded Post-Tensioned (BPT) slab, the change in strain in tendons at all sections is the same to the change in strain in adjacent section of concrete. The strain of tendons depending on the deformation of strain in concrete section. The layout and number of tendons affect the strain and failure loads of the slab. In PT concrete slabs, the tendons have been classically placing continuously through the supports. Most of the previous analytical tests and investigations focused on the simply supported flexural concrete members. The use of nonlinear finite element modeling is limited, while little researches have been performed particularly for concrete slab (Kim, M. S., & Lee, Y. H., 2016).

This study provides a large overview of some of the key factors and the lack for simple and reliable design procedures in the PT concrete two-way slab structures. The ultimate capacity of the two-way concrete slab and failure loads cannot be evaluated by a local analysis of the critical section. A nonlinear analysis of the whole slab structural system is required. The FEM was selected for its capability to modeling irregular structures and different loading and boundary conditions.

## 1.5 Research Objectives

The main objective of this research to find out the effect of various tendon layout and numbers on the flexural behavior of BPT reinforced concrete two-way slab. Also, this study aims to grow comprehensive analytical models to predict the history of entire load deformations of PT concrete slabs with different tendon layout. Nonlinear FEA will be achieved to find out the optimum tendon layout with different numbers under different load cases. The ANSYS computer package program will be used for these purposes. The optimum tendon layout will decrease costs and increase load carrying capacity, so the optimum tendon layout may be recommended after this analysis.

### 1.6 Layout of Thesis

In order to achieve the objectives mentioned above, this thesis is organized into five chapters.

Chapter one covers a brief description, the aim, and objective of the thesis.

In chapter two briefly, the background and reviews of the previous studies on prestressing techniques which covers the existing experimental and analytical investigations will be specified.

Chapter three explains FE modeling and ANSYS computer program to analyze concrete two-way slab, which includes all material properties and modeling parameters.

Chapter four presents and compares the results obtained from nonlinear analyses of each model. Includes a load-deflection relationship at mid span of the slabs.

In chapter five, the conclusions from the overall results of the analysis will be given.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 General

Prestressing method is defined as concrete with embedded reinforcements in it to produce internal stress, this internal stress counteracts with external service loads to a preferred degree. This method is done by applying high stress to reinforce tendons in tension and compression zone, which cracks takes place in it due to external loadings, and then it gives a section that has the ability to resist higher loads before cracking occurs. This system increases the external load capacity to crack (Abeles, 1965). The prestressed method has much application, especially in concrete constructions. A large part of bridges in the US are constructed by the prestressed system. For the prestressed concrete system two different methods are using which are pretension and post-tension (Allouche, 1999).

In the pre-tensioned method at first stress is applied to the tendons and after that concrete is placing to form. In this method, all tendons were tensioned in a stressing bed. The formworks gathering anchorages at the ends and placed with stressing beds, then the concrete will be place. After the concrete get adequate strength, the tendons must be unrestricted at the ends. This process producing a big interior force, this force that produced by tendons are conveyed to the concrete member by bonds between concrete and tendon. usually used this technique in precast constructions that many identical elements are required (Allouche, 1999).

In post-tensioned method at first concrete placing and after that stress is applied to the tendons. Duct is used to obtain the desired profile and to allow free movement of tendons in the member. When the concrete has gained sufficient strength, each tendon is stressed to the desired load by using a stressing jack and anchored at each end of the member to maintain the prestressing force in the concrete. PT technique is a generally used technique around the world for reinforced concrete structures, to minimize deflections and prevent cracks that produce by externall applied loads.

In this chapter, a review of published experimental and analytical studies carried out on internally PT concrete slabs will be provided. The main parameters affecting the behavior of PT concrete slabs such as area and depth of non-prestressing steel, span-to-depth ratio, loss of prestressing force due to shrinkage and creep of the concrete, as well as relaxation of the prestressing tendons, location of tendons, force in tendons, and types of loading had been investigated, especially for simply supported and continuous reinforced concrete slabs. This chapter points out the various researches related to the slabs PT and reviews the developed predictions of the stress at failure in the bonded and unbonded tendons through experimental works were undertaken by different researchers. As well as this chapter deals with previous studies related to the FEM and the analytical models by ANSYS package program to investigate the flexural response of bonded and unbonded prestressed concrete structures.

## 2.2 Post-Tensioned Method

The PT method is a technology widely used around the world for concrete structures, to minimize the deflection and prevent the concrete members from cracks and, which formed by applying external loads. By PT method, the same member depth can be used for longer span, greater applied loads and controlling cracks. According to bond types, there are two different PT concrete members: (bonded and unbonded post-tensioned).

### 2.2.1 Bonded post-tensioned

In BPT, the stress force is held by the bonds between surrounding concrete and tendons. The adhesion between concrete and steel tendons importantly affects the resistance of the PT concrete members. The bond between tendon and concrete is prepared by transforming force of tendons to the concrete (Hoyer, 1939). In system of BPT, usually there is a space between the ducts and tendons, cement mortar is grouted to this space under specific pressure, that effectively increases the strain and bond compatibility between concrete and tendons, this process also keeps surface of tendons against corrosion (Allouche, 1999). BPT can be used in all environmental conditions. BPT has not needed a large area of tendons to obtain the required strength as compared to Unbonded Post-Tensioned (UPT). Due to the adequate bonds between tendon and concrete the tensile stress transform from the nearby concrete to the reinforcements, BPT can be precast or cast in place.

The change in the strain adjacent section of concrete is the same to the change of tendon strains for any sections. The strain of tendons depends on the changes of strain in the concrete sections.

Bailey (2009) studied a numerical investigation on the whole building behavior of PT concrete floor slab systems under fire situations. A nonlinear FE model was used, according to the results of eight BPT slabs fire tests, the results shown that the failure mode of the slabs under fire situations is predominately due to splitting of tensile along the tendons in two directions that extend to the top surface and the failure mode at ambient temperature has been punching shear.

Ellobody and Bailey (2008) investigate a FE model highlighting the behavior of BPT one-way slabs in fire situations. The model was verified against ten fire tests on bond posttensioned concrete slabs at ambient and high temperatures. It was shown that predictions were more ranged with the finite element analysis predictions.

Seible et al. (1990) tested four pre-tensioned concrete beams under applying point loads. Tendons were harped under two-point loads. Their results showed that by strengthening member, the average strength increased by 115 % when single strand was used. The deflections at mid span at the ultimate load were about 60 % of the corresponding beam deflections. Beams fails when concrete crushed.

Manalip et al. (1994) tested five beams of high strength concrete. Beams were subjected to pure bending and analyzed to measure their ductility and to realize the real strain-softening performance of their compressed zones. For the experimentally tested beams, it was found that the use of high strength concrete instead of normal strength concrete effects the results by the doubling of the plastic rotation capacity.

Hussien et al. (2012) studied an experimental program to investigate the behavior of unbonded and bonded prestressed beams with normal strength and high strength concrete. Their results showed that by using partially prestressed concrete beams with bonded tendons provide better behavior than those of unbonded tendons.

### 2.2.2 Unbonded post-tensioned

When mortar or grouting not used to fill the spaces between tendons and ducts, then it is called Unbonded Post-Tensioned (UPT) system, instead, naturally filled with grease as a defense against corrosion. In UPT may be avoiding the expensive of time-consuming of grouting process, it is an economical alternative to conservative to bonded pre-stressed. This system has some problems, which stoped it from being more widely used, the unbonded system cannot be used in corrosive environments due to disposed of corrosion like bridges (Nowak, 1994), but may be used in parking structures with offering suitable protections against corrosion (Litvan, 1996). This system requires a larger area of tendons to obtain the required strength because of the ultimate strength of unbonded tendons about ten to thirty percent lower than bonded members (Park and Paulay, 1975). The behavior of UPT tendons does not wholly understand yet. Furthermore, it has not a modest and accurate method for predicting the stress in unbonded tendons at failure. The tensile stress cannot be moved from the adjacent concrete to the reinforcement due to the lack of bond, thus the cracking pattern of failure characterized by single or little cracks in the maximum moment region.

Ellobody and Bailey (2009) studied the structural behavior of unbonded post-tensioned one-way concrete slabs in fire situations. They established a nonlinear FE model for the analyzing of UPT concrete slabs at higher temperatures, during the deformation of the slab the tendon allows to retain its profile shape. The distribution of temperature throughout the slab, time–longitudinal expansion, time–deflection behavior, time–stress behavior in the tendon, and the failure modes are verified against test data and predicted by the model.

Zhang et al. (2011) developed a method of nonlinear analysis for calculating ultimate stress in unbonded tendons. A numerical design that calculates stress increments at unbonded tendons is a spatial displacement relationship. They established a computer software exactly for predicting the nonlinear response of a prestressed curved concrete slab structure with unbonded tendons and finding the ultimate stress in unbonded tendons. Six models of pre-stressed concrete curved slabs were tested with unbonded tendons and reported.

Marinković and Alendar (2008) used a program which was designed to estimating the punching shear strength of UPT flat slabs at edge columns. Three lonely samples, which exemplified a part of the edge panel were loaded to failure in the locality of the column at full scale. Their results showed that critical zone of slab round the steel collar was exposed to unevenly distributed stresses with great concentrations at collar's corners, these localized zones were exposed to a greater triaxial compressive stress state.

Gardner and Kallage (1998) tested a two bay by two bays unbounded PT flat plate, all tendons had a draped profile. The punching shear failure happened in a circular edge slab-column connection through a uniformly distributed load increase. The researcher proposed a method to calculate the punching shear strength and determined that the presence of pre-compression in a slab might affect the shear strength of edge and corner slab-column connections.

Tam and Pannell (1976) experimentally used eight prestressed beams with using unbonded tendons. The ratio of span to the depth, prestressing stress, and non-prestressing reinforcing steel amounts was fixed. Their results showed that diagonal cracks occurred, which cutting across the flexural cracks in the case of using a high reinforcement index.

Mojtahedi and Gamble (1978) their study was focused on the effecting of the spans to the depth ratio of the ultimate stress of unbonded tendons. Their results showed that at ultimate nominal resistance, the stress in prestressing steels has been significantly influenced by span to the depth ratio. Increasing the span to the depth ratio, effects on the stress of unbonded tendons, the results showed that the strain in a tie at mid-span decreased suddenly as a span-to-depth ratio increased

Harajli (1990) presented a theoretical model for unbounded pre-stressed concrete members to evaluate the influence of the effects of the span-depth ratio parameters of the stress in pre-stressed steels. Harajli showed that the increase in stress in unbonded prestressing steels mainly depends on the geometry of the applied loads and depends on the plastic region length relative to the span length. By increasing span to the depth ratio decreases the predicted stress.

Bums et al. (1991) experimentally tested two continuous PT concrete beams with internally unbonded tendons to predict change in the prestressing force in tendons. The results showed that the tendon forces under cycle service loads did not change up to the compressive stress level of ($12\sqrt{fc'}$). When the beams overloaded in just single span, tendons are tended to slide into a loaded span, this causes stress in tendons decreases at the end of the loaded beam span and increases stress in the unloaded span at the end

Campbell and Chouinard (1991) experimentally used six partially unbounded pre-stressed concrete beams with rectangular cross-sections, their results showed that by increasing the amount of non-pre-stressed bonded steels decreases the stress in the prestressing tendons at ultimate loads. Their test results were compared with predictions from two related design codes and identified some limitations of these code applications to unbonded pre-stressed concrete construction.

Vu et al. (2010) calculated the structural response of UPT prestressed beams, including both the ultimate bearing capacity and the deflections under service load, before and after cracking. They predicted the total lengthening of the unbonded tendons at all loading periods: serviceability, cracking, and ultimate. The calculations of the deflection and bearing capacity at failure were very precise.

## 2.3 Finite Element Analysis

FEA is one of the more suitable numerical method, used to solve and analyze complex problems, it is very important to engineering researchers. Recent developments in computer technology make it possible to use FEA computer programs in all engineering branches in dealing with different properties of the material, boundary conditions, relations between structural components, and dynamically or statically applied loads.

FEA can determine the response of linear and nonlinear structures with good accuracy. Problems require resolution of the 3-D distribution of one or more dependent variables or elements, mathematically, then this element is expressed by differential equations or by integrations, these elements are connected at point nodes.

A 3-D FEA is still the most comprehensive and general technique, which is used for dynamic and static analyses, taking all aspects affecting the response of structures. It becomes the numerical method of choice in several applied science areas and engineering (Kim, 2014).

A collection of papers was appeared by several researchers which explains the FEA for the behavior of reinforced concrete structures such as shear failure of slabs, cyclic loading of columns, the behavior of structure to seismic, and bond models between concrete and steel.

### 2.3.1 Finite element analysis of reinforced concrete structures

To predict the response of reinforced concrete elements, Vecchio, (1989) developed a nonlinear FE procedure. Based on the secant stiffness formulation. He showed that by nonlinear FE techniques, the response of reinforced concrete members can be predicted accurately, and this technique is enough simple for nonlinear finite element formulation.

Vacev et al., (2015) used nonlinear FEA by ANSYS package program to predict the behavior of reinforced concrete footings and columns under applied concentrated load until failure. Their results showed that the ANSYS FEM is a powerful method for solving even multiple complex structural problems, such is the behavior of reinforced column footings laid on deformable subgrade.

Luu et al., (2017) developed an FEA to predict the inelastic reinforced concrete behavior shell structures in the program a cyclic softened membrane model. To confirm the developed FEA program several large-scale structural tests were employed. The results showed that, for studying the cyclic response of both curved and flat reinforced concrete shell structures, the newly developed program based on the shell elements could be a powerful and versatile analytical tool.

Li et al., (2017) established the corresponding nonlinear FEA to analyze the behavior of mechanical of high-strength concrete filled with high-strength square steel tube. The obtained load-displacement curves from the numerical analyses are consistent with the experimental results. Experimental tests and FEA results were the most compatible with the calculated result.

### 2.3.2 Finite element analysis of prestressed concrete structures

Kang and Scordelis (1980) presented a numerical procedure based on the nonlinear analysis by FEM for the geometric and material of plane prestressed concrete frames, in this method creep, shrinkage, aging of concrete, temperature history, time dependent effects due to load history and prestress relaxation were developed. Different material properties inside frame elements were calculated by a reinforcing steel layers and composite concrete. The contribution of prestressing steel was combined directly.

Roca and Mari (1993) described unbonded prestressed tendons. They used the virtual work and FE formulations for the nonlinear analysis of shell elements to solve the problem, by using a formulation of the nonlinear material and geometric proposed numerical treatments, and analyzing long term of prestressing concrete members. The unusual focus was given to such aspects as the geometric description of the layout of the tendons. They focused on the aspect of increment of geometry under external load.

Figueiras and Povoas (1994) explained a technic for structural modeling of prestressed tendons by FEM. To create strand model curved elements that were embedded in FEM has been used for both unbonded and bonded tendons, to finding ultimate strength capacity of prestressed members and the serviceability behavior. The formulation was advanced to be combined with curved thick shell elements and the applicability of the computer code is confirmed by the results of two numerical samples.

Moon and Bums (1997) developed a computer program which was used for analyzing concrete structures by prestressing method for unbonded stress variation and members in the tendons. The program was called (time dependent analysis) program. The total compatibility requirements used for developing analytical models. Total elongation for unbonded tendons equal to the integrated deformation value of concrete. This method can carry into account shrinkage, creep, and mechanical deformation of inelastic range in a continuous fashion.

Kachlakev et al. (2001) in their study the computer programs were used to compare test results for both nonlinear and linear FEs of concrete models. Two programs such as ANSYS, (SAS 2003) were used to find behaviors of concrete beams with externall bonded with carbon fiber reinforced polymer fabric. The plotted results of load deflection curves of concrete beams with non-carbon fiber reinforced polymers show the reasonable correlation with experimental.

Shing and Tanabe (2001) published a collection of papers together for analyzing the inelastic behaviors of reinforced concrete structure under seismic loadings. They explained the applications of the FEA to demonstrate the ductility of reinforced concrete columns under post-peak cycling behavior, analyzing of reinforced concrete components in bridge seismic design, connections between beam-column, and shear behavior in the reinforced concrete bridge analysis.

Ariyawardena and Ghali (2002) analytically predicted the behaviors of prestressed concrete structures with external or internal tendons up to failure. The analysis contains the effects of tension stiffening, material nonlinearities and geometric, and. The computer software established to perform the analysis method, analysis method was verified by using an experimental study of continuous and simple beams with external or internal tendons.

Ibrahim (2010) presented the parametric study of the flexural behavior of prestressed continuous concrete members with external tendons. A 3-D nonlinear FEM by ANSYS computer program was used. At a result showed that increasing the effective depth will increase the ultimate load capacity and the increase in the beam capacity in the beams exposed to loads at the third span were bigger than in the beams with the single load at mid-span.

### 2.3.3 Finite element analysis of post tensioned concrete slabs

El Semelawy (2012) used a numerical device that is capable of discovering the optimum design of a pre-stressed concrete slab system using new heuristic search algorithms. Optimization techniques have been considered. In the result showed that use of Multi objective algorithm can open a door for counting other objective roles that may be of importance to the designer such as maximum consistency index, minimum deflection and minimum environment effect.

Panfilov (2015) used a numerical investigation of monolith beam and slab floor with using pre-stressed wire rope reinforcement, a FE used in calculations the situation of the wire rope reinforcement and slab reinforcement concrete connections, in a result showed that monolith intermediate pre-stressed wire rope reinforcement and slabs of reinforced concrete significantly changes the stress and strain condition allowing to the reinforcement intensity of stress. Also, it can influence intermediate slab deflection (up to 40%).

Martinez (1993) tested on a post tensioned slab which investigated UPT edge slab-column connections and two corner connections, preparation of tendon layouts was used for the slab with the edge connection. One of the conclusions gotten in the study was that the presence of high compressive stress in the slab-column connection region increasing the shear strength of the connection. The increase of tensile stress was very small in the strand under constant gravity and increased lateral load.

Yang, (2013) used twelve partially post tensioned light weight concrete one-way slabs which were tested under a symmetrical top one-point loading and a symmetrical top two-point loading, in a result presented that the tendon profiles had no major effect on the cracking moment capability of the post-tensioned lightweight concrete one way slabs, whereas the slabs with a harped tendon plan showed a 4–10% higher ultimate moment than the companion slabs with a straight tendon preparation.

Kim and Lee (2012) used nonlinear analysis technique to find the flexural behavior of continuous UPT member. The results of their study showed that the loading type effect on the flexural behavior of continuous UPT, which was reflected by curvature distribution in the region of maximum moment and the accuracy of the flexural behavior of the proposed analysis model were constant, irrespective of the type of applied loads and section shapes.

Ellobody and Bailey (2009) used the nonlinear finite element model for the analysis of UPT concrete slab in the elevated temperatures have been established and offered. The boundary between the surrounding concrete and tendon was modeled, allowing the tendons to retaining its profile shapes during the distortion of the slab. In a result shown that the model was proficiently capable to predict the tensile stresses explanation the longitudinal cracking noticed above the tendons in all the tests.

# CHAPTER 3

# FINITE ELEMENT MODELING

## 3.1 General

In this chapter, FE modeling of PT concrete two-way slab will be explained. One of the most important numerical methods for solving engineering problems is FEM to solve mathematical physics characterized by variable formulas and differential equations. FEM was firstly invented from structural mechanics and can be used to other fields of solid mechanics such as heat transfer, electromagnetism and fluid dynamics. FEM is one of the most powerful software to solve partial differential method and integral equation. This is an important and the periodic engineering analysis method because the support of the multipurpose computer program requires minimal training to solve many complicated practical problems (Kim, 2014).

3D FE modeling is may be the most involved and time consuming but the most common and comprehensive method for static and dynamic analysis capturing all aspects affecting structural response.

Some methods for modeling concrete structural elements analytically and numerically have emerged. FEA is one of the numerical analysis generally used to concrete structural elements built on the use of nonlinear materials behavior and FEA provide a program to predict and simulate the response of reinforced and pre-stressed concrete members. However, in recent years, due to advances in technology and ability of computer hardware and software, the use of FEA is increasing. This is currently the method of choice for analyzing structural of concrete parts. By using computer software to modeling these elements is very cost effective and much faster. Complex shapes like PT reinforced concrete slab with tendon can be easily modeled and analyzed using FEA. ANSYS package is one of the FEA computer programs that used for solid modeling, it is a very reliable and accepted commercial FEA program. It has the ability to structure nonlinear modeling and analyses

## 3.2 Basic Steps in the Finite Element Method

The basic steps involved in any FEA contain following steps below (Bathe, 1996):

1. The structure is created, then divided into FE connected these elements together at their nodes.

2. The shape function is assumed to represent the physical behavior of the element. That is assumed that an approximate continuous function represents the solution of the element.

3. The stress distribution and stiffness equation for the element is created.

4. A set of FE equations to present the whole problem, then an overall (or structural) stiffness matrix is constructed.

5. Boundary conditions, initial conditions, and loads are applied.

6. A band of linear or nonlinear algebraic equations are simultaneously decided to obtain nodal results such as displacement values at different guests or other significant data such as stresses and strains obtained for nodes or components.

## 3.3 ANSYS Finite Element Modeling

ANSYS is a general purpose FEA package for numerically solving a wide variety of complex engineering problems both linearly and nonlinearly. This is a numerical way to break down complex models into real small elements called elements. ANSYS software implements equations that control the behavior of these elements and solve all of them. After resolution, the results can be presented in tabular or graphical format. Setting up FEA with this software requires three phases. The first stage is preprocessing, in which a solid model consisting of definitions of key points, lines, regions, and volumes is defined, properties of elements and materials are defined, and finally lines, regions, the second phase is the solution phase. At this level, boundary conditions, load assignment, and resolution control are properly set. The third stage is postprocessing, in which the overall results of analysis, such as nodal displacement, deflection plot, stress contour map, element force and moment are displayed.

While the model is meshed, the volume, area, or line cannot be deleted as it is connected to an existing mesh element. Based on the shape and size of the whole solid model, ANSYS have different solid FEs with their own expertise. Structural analysis should be chosen as the type of analysis (Madenci and Guven, 2015).

### 3.3.1 Finite element representation

ANSYS package program is used to analyze all slab models. Table 3.1 shows the structural elements encountered throughout the current study, the corresponding FE representations and element designations in ANSYS.

**Table 3.1** FE representation of structural components

| Structural component | Element designation in ANSYS |
|---|---|
| Concrete | SOLID65 |
| Reinforcement | LINK8 |
| Steel plate | SOLID45 |
| Interface surface | CONTA175 and TARGE170 |
| Anchorage steel | SHELL181 |

### 3.3.2 Finite element model for concrete

The model used for concrete idealization must have the ability to existing concrete crushing in compression, concrete cracking in tension, the capability to transfer shear after cracking by aggregate interlock and interaction between concrete and reinforcements (Izzet, 2016).

In ANSYS package SOLID65 used for modeling the concrete element, this element has three degrees of freedom and eight nodes, nodes in the x, y and z directions are translated, it means that concrete has the ability for cracking in three orthogonal directions, creep and plastic deformation. This elements behavior is operated as a nonlinear isotropic material property. Figure 3.1 illustrates the coordinate system and node locations for this element (ANSYS, 2011).

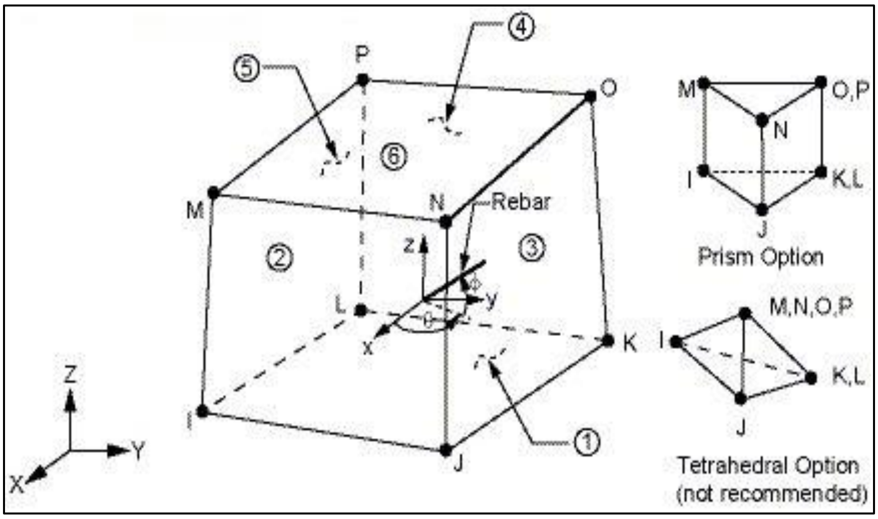



**Figure 3.1** SOLID65 geometry (ANSYS, 2011)

### 3.3.3 Finite element model of steel reinforcement and tendon

The model that used for reinforcement elements must have the ability to exist creep, plasticity, stress stiffness, swelling and large deflection, to display the behavior of steel reinforcements, ties reinforcements and prestressing tendons. Three technics are used to model reinforcements, which are discrete, embedded and smeared technics (Tavarez, 2001).

LINK8 is a separate model and spare element, which is used in various engineering work, by this element the sagging cables, trusses, springs and links can be modeled. This element is uniaxial tension-compression element and 3D spare. LINK8 has three degrees of freedoms at each node, nodes in the x, y and z directions are translated, no bending of the element is considered (ANSYS, 2011).

Prestress stress is the initial value of the strain of this link element. The PT force is transmitted via the slab and is connected at the end of the anchor. The coordinate system, node position and geometry of this component are illustrating in Figure 3.2.

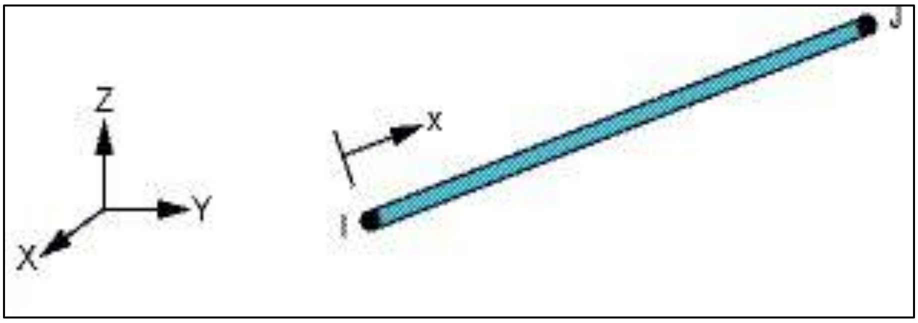



**Figure 3.2** LINK8 geometry (ANSYS, 2011)

### 3.3.4 Finite element model of anchorage Steel

All tendons at both ends of the slab members must be anchored for both directions to keep internal forces, forces make a high stress on both ends, the shell plates must be used at the ends in order to keep slab ends from crushing.

SHELL181 is capable for analyzing thin element to moderately thick shell structures. It has four node elements with six degrees of freedom at each node, translations in the x, y, and z directions, and rotations about the x, y and z axes. The coordinate system geometry and node locations for this element are illustrate in Figure 3.3 (ANSYS, 2011).

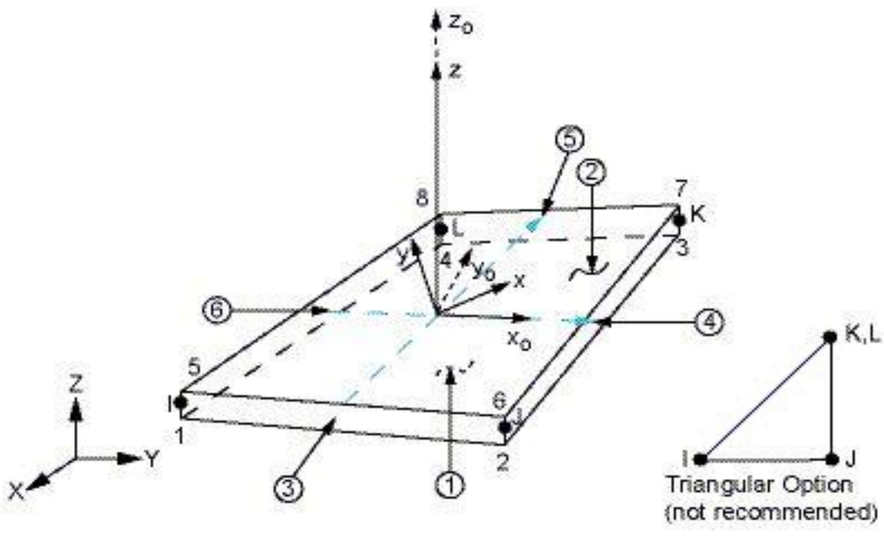



**Figure 3.3** SHELL181 geometry (ANSYS, 2011)

### 3.3.5 Finite element model of bearing steel plate

Bearing plates are used to avoid crushing at a location that applied point loads. SOLID 45 is used for 3D modeling of three-dimensional structure. This element is having eight nodes with three degrees of freedom at each node, and nodes in the x, y, and z direction are transformed. This element has swelling, plasticity, stress hardening and creep, large strain and large deflection capacity. The geometry, node position, and coordinate system of this element are illustrate in Figure 3.4 (ANSYS, 2011).

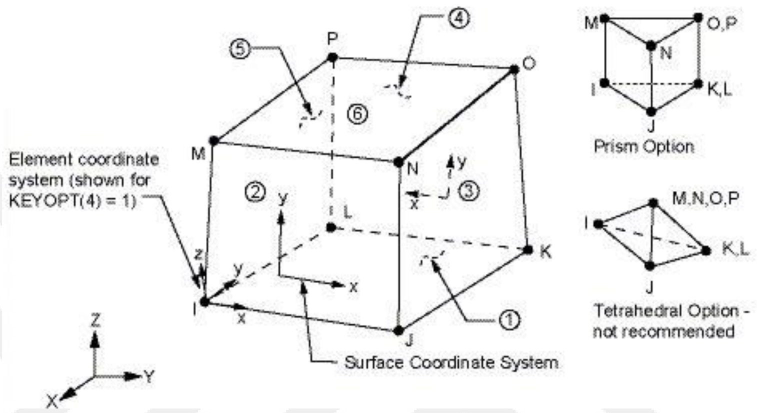



**Figure 3.4** SOLID45 geometry (ANSYS, 2011)

### 3.3.6 Finite element model of contact

TARGE 170 is used to represent the various 3 D "target" surfaces of the associated contact element CONTA 175, the contact elements themselves overlaying solids, shells, or line elements that describe the boundaries of the deformable body, Defined by TARGE 170. This target surface is discretized by the set of target segment elements TARGE 170 and paired with the associated contact surface via a shared real constant set. It can impose any translational or rotational displacement, temperature and magnetic potential on the target segment element. For rigid target surfaces, these elements can easily model complex target shapes. For flexible targets, these elements overlay elements of solid, shell, or line that describe the boundaries of the deformable target body.

CONTA 175 is used to express sliding and contact between two surfaces in two or three dimensions (between nodes and surfaces, or between surfaces and surfaces). This element can be applied to 2D or 3D structures and coupled field contact analysis. This element is positioned on the surface of the solid element, the beam element, and the shell element. 3D solid and plate element, intermediate nodes are matched and supported with no isolated contact. Contact will occur when the element surface penetrates through one of the target segment elements TARGE 170 on the specified target surface. This element also allows separation of the bonded contacts to simulate interfacial delamination. The node position and coordinate system of these elements are shown in Figure 3.5 (ANSYS, 2011).

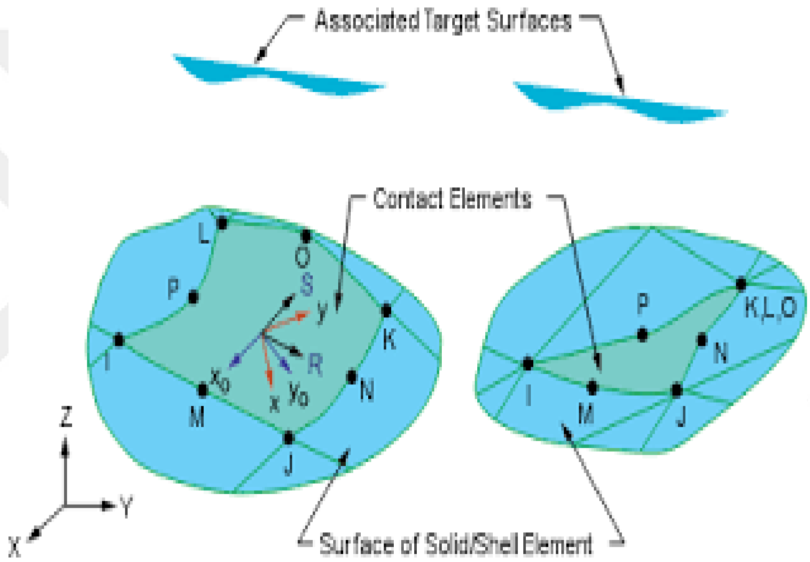



**Figure 3.5** CONTA175 and TARGE170 geometry (ANSYS, 2011)

### 3.3.7 Real constants

The element types that defined in ANSYS needs nodal coordinates, material properties, and geometrical parameters. All element types may not need real constants. Usually, real constants are areas, thicknesses, inner diameters, outer diameters, moments of inertia, etc. If the real constants are not defined and not assigned. ANSYS automatically uses a default value and assigns a number for that particular parameter (Madenci and Guven, 2015).

## 3.4 Material Properties

### 3.4.1 Material modeling of concrete

PT material constituents such as concrete, reinforcement, tendon, contact surface etc. are modeled by ANSYS element. The element type requires an input property depending on the analysis type. Properties of material can be orthogonal, linear or nonlinear, isotropic or anisotropic. The Solid 65 elements need multilinear and linear isotropic material properties to properly model concrete. Concrete density is added to the material model.

### 3.4.2 Material modeling of steel

Steel bars and prestress tendons are slim. It can be assumed that only axial force is transmitted. Modeling common steel and pre-stressed steel in reinforced concrete is much easier (Ibrahim et al., 2012). In Figure 3.6 can be seen the stress-strain relationship of a normal reinforced steel bar. This is a bilinear relationship hypothesized to be elastic-perfectly plastics (Ng and Tan, 2006).

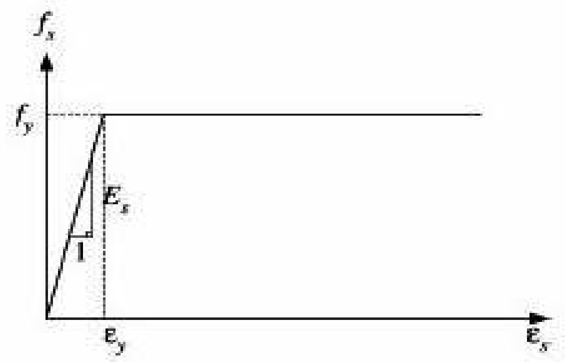



**Figure 3.6** Constitutive law for steel reinforcement (Ng and Tan, 2006)

### 3.4.3 Material modeling of pre-stressed tendon

The multilinear isotropic stress-strain relationship for prestressing tendons are illustrated in Figure 3.7.

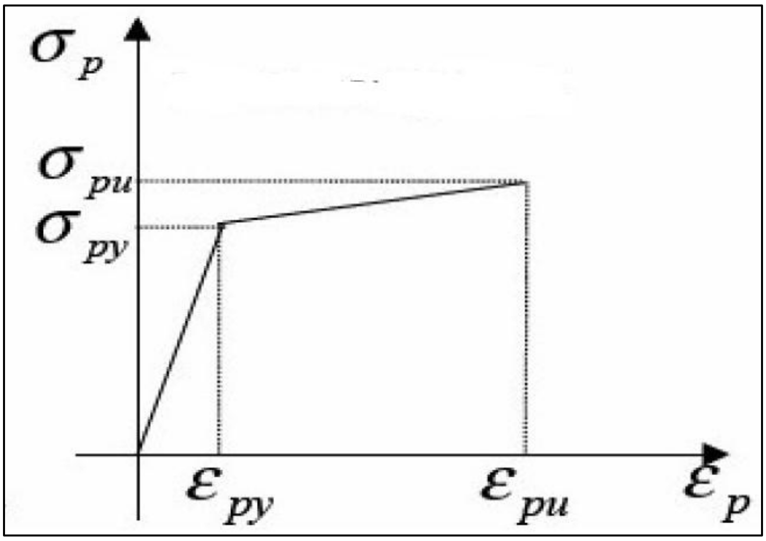



**Figure 3.7** Constitutive law for prestressing steel (Ng and Tan, 2006)

## 3.5 Nonlinear Solutions Methods

The Newton-Raphson analysis method is used to calculate the nonlinear response of the PT 2-way concrete slab model, and for all models and load cases, as required by the Newton-Raphson procedure, Application will be done gradually. Later on each load increment is used, use the restart option to go to the next step after convergence. Load steps, sub steps, and loads applied per start option can be listed in ANSYS. Displacement is the convergence criterion used for analysis. The load increment increased slightly until subsequent cracking and breakage of the slab occurred. Failure of slab occurs when convergence fails when slab starts to crack, and convergence of nonlinear analysis is impossible with default value. The convergence of the solution of the model has been difficult to reach due to the nonlinear behavior of the reinforced concrete member. Then, the convergence tolerance increased to a maximum of 5 times than the default tolerance limit of 5% due to the displacement check to obtain convergence of the solution (Dahmani et al., 2010). The reinforced steel reaches the yield, the size of the load increment begins to decrease and the displacement increases more rapidly (Wolanski, 2004).

### 3.6 Verification of Post-Tensioned Concrete Two-Way Slabs

The ANSYS program results are verified by comparison the physical results. To validate the proposed nonlinear models, one of the experimentally simply supported post tensioned concrete two-way slab experimentally tested by (Kim and Lee, 2016) is chosen. One of their slabs was named as the slab FP-PT-$xy$ and tested under static loading up to failure. FP-PT-$xy$ had five tendons in both directions with seven wire, steel strand 12.7 mm, with a 13 mm diameter non-pre-stressed bars which is used in both directions at bottom of slab for each 280-mm spacing, with overall slab geometry dimensions equal to 3000 mm, 3000 mm and 250 mm length, width and thickness respectively. The non-pre-stressed steel reinforcement bars were made of deformed high tensile steel with a yield stress of 400 MPa and modulus of elasticity of 200 GPA. The nominal ultimate tensile strength of the tendon was 1860 MPa. The tendon layout applied similarly to the bending moment induced from the concentrated loads. The tendons are bonded and grouted with 1488 MPa prestressing force. Figure 3.8 shows the dimensions and section details of the pre-stressed slab specimen. Figure 3.9 shows the concrete mesh. Figure 3.10 shows the reinforcements and mesh of the tendon.

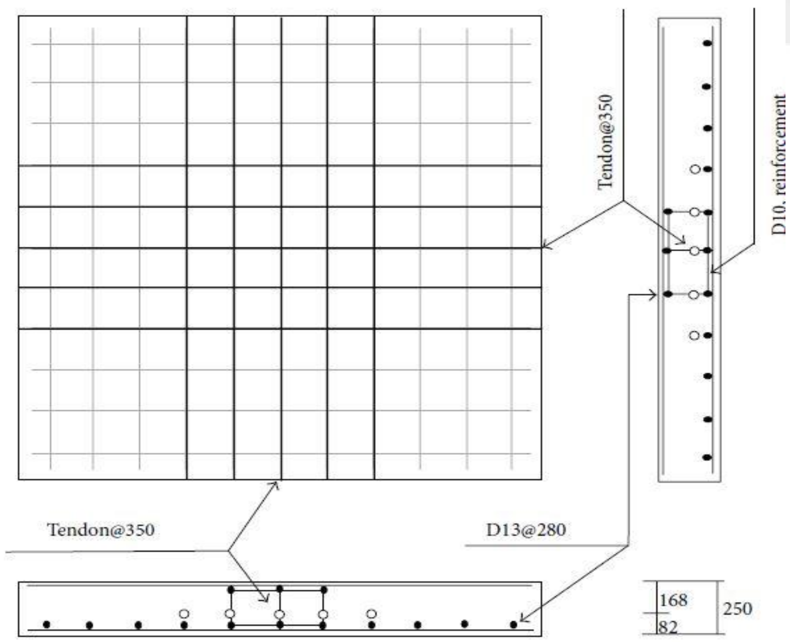



**Figure 3.8** Reinforcement and dimension details of Post tensioned slab FP-PT-$xy$ by (Kim and Lee ,2016)

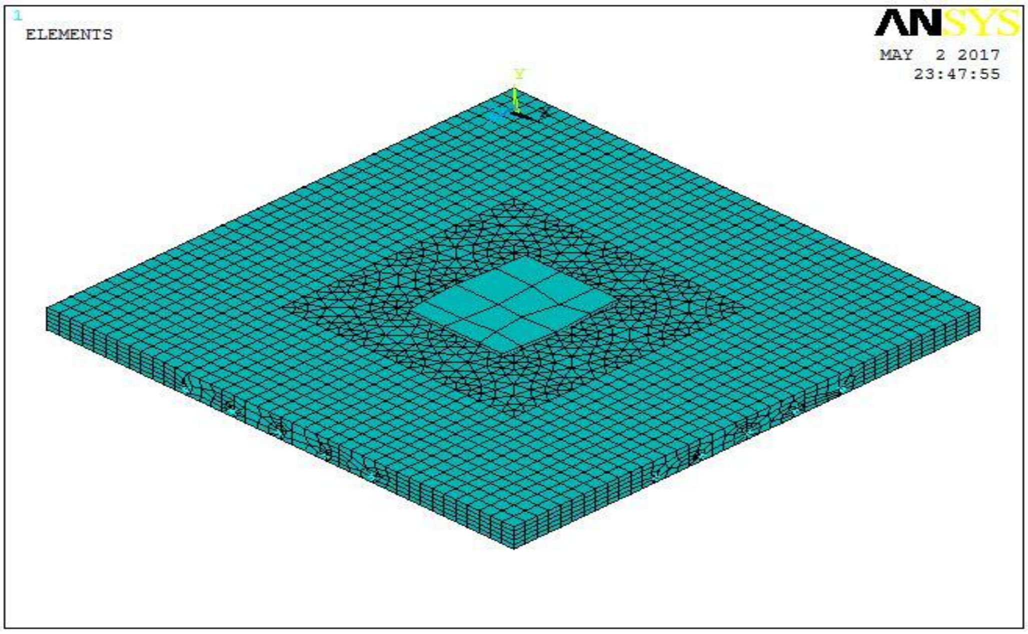



**Figure 3.9** Concrete mesh of the two-way slab FP-PT-$xy$ by (Kim and Lee ,2016)

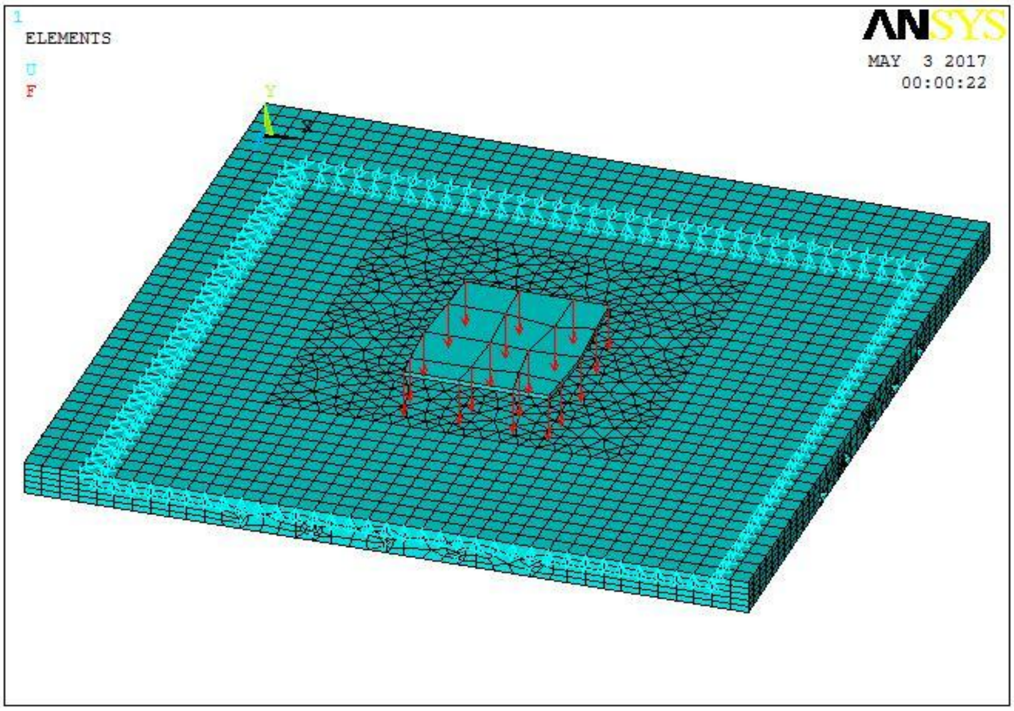



**Figure 3.10** Boundary condition and defined load for the slab FP-PT-$xy$ by (Kim and Lee ,2016)

After modeling and analyzing the experimental model slab FP-PT-$xy$ by ANSYS program, the numerical results of ANSYS program is similar to the results of experimental work that tested by (Kim and Lee, 2016), It shows the accuracy of a program that chosen for this work as shown in Figure 3.11

The type of failure mode in experimental slab model was concrete crushing, so while the slab modelled in ANSYS program the same failure mode chosen for analyzing, in that time analysis is continue however cracks was appeared and it was continuing in applying load until the slab will be crush and analyzing stop, it is show the higher displacement at a result.

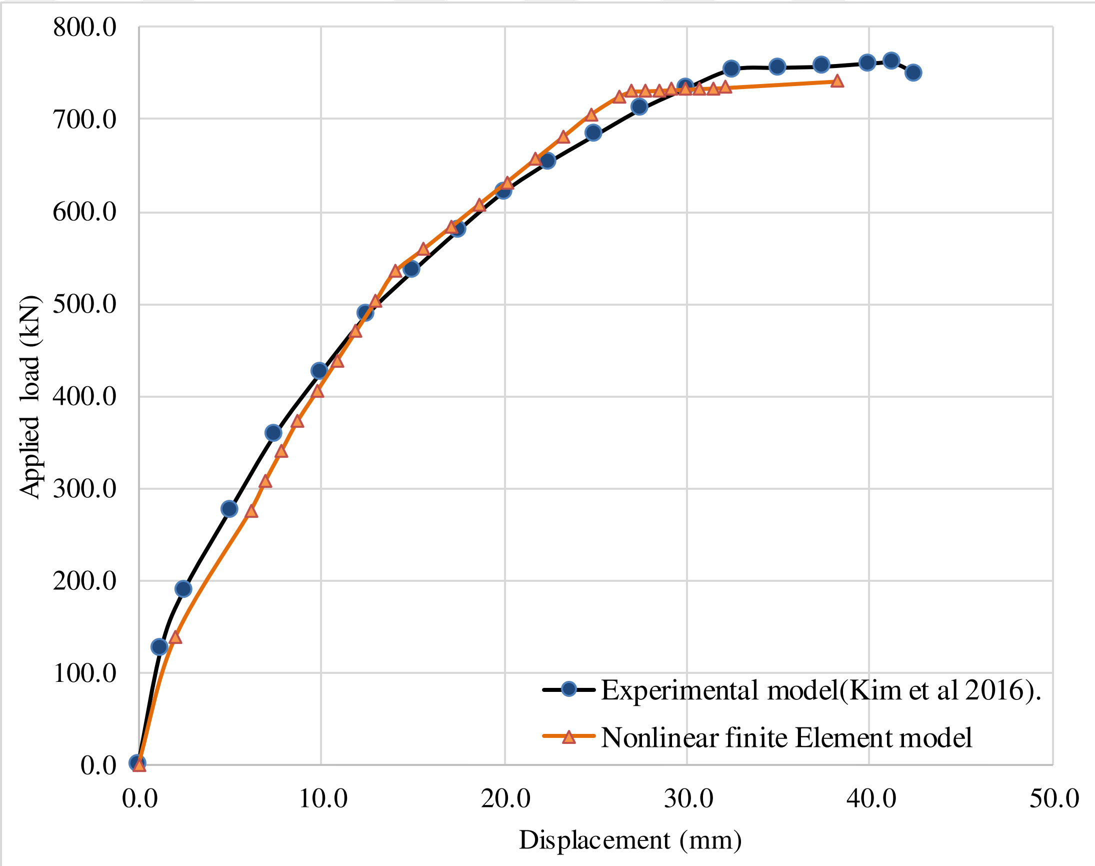



**Figure 3.11** Load- deflection curves for the slab FP-PT-$xy$ by (Kim and Lee ,2016) and FE results

# CHAPTER 4

# PARAMETRIC STUDY

## 4.1 Problem Statement

In this chapter, the parametric study of concrete two-way slab models have been presented. When applying external load on the BPT slabs, the change in strain in adjacent concrete section is equal to the change in strain in tendons at any section. The layout of tendons affects the strain and failure loads of the slab members. In PT concrete slabs, tendons are classically placed continuously through the supports. Tendon layouts with different numbers have a good effect on the ultimate load capacity. Different tendon layout, number of tendons and area of tendons is used with a different spacing and different position between tendons to select the optimum case. The results include mid-span deflection, stress and strain in concrete, failure loads, concrete crushing and cracking, and deformed shapes.

Fifty BPT two-way slab models are chosen. The slab dimensions, prestressed tendons, anchorages, supports and load plates are modeled in ANSYS by, lines, keypoints , volumes and areas. The slab model is 4000 mm by 4000 mm, with a thickness of 200 mm, as showed in Figure 4.1. The diameter of the longitudinal reinforcements is 12 mm that used at the bottom of the slab each 250 mm.

The type of failure mode for all fifty BPT two-way slab models are concrete cracking, the ANSYS program apply load incrementally to slab and running analysis, if there is not any crack appeared in top and bottom of slab automatically increase the applied load and analyzing again, when cracks appeared the program stop the analyzing and find out the failure load capacity with displacements.

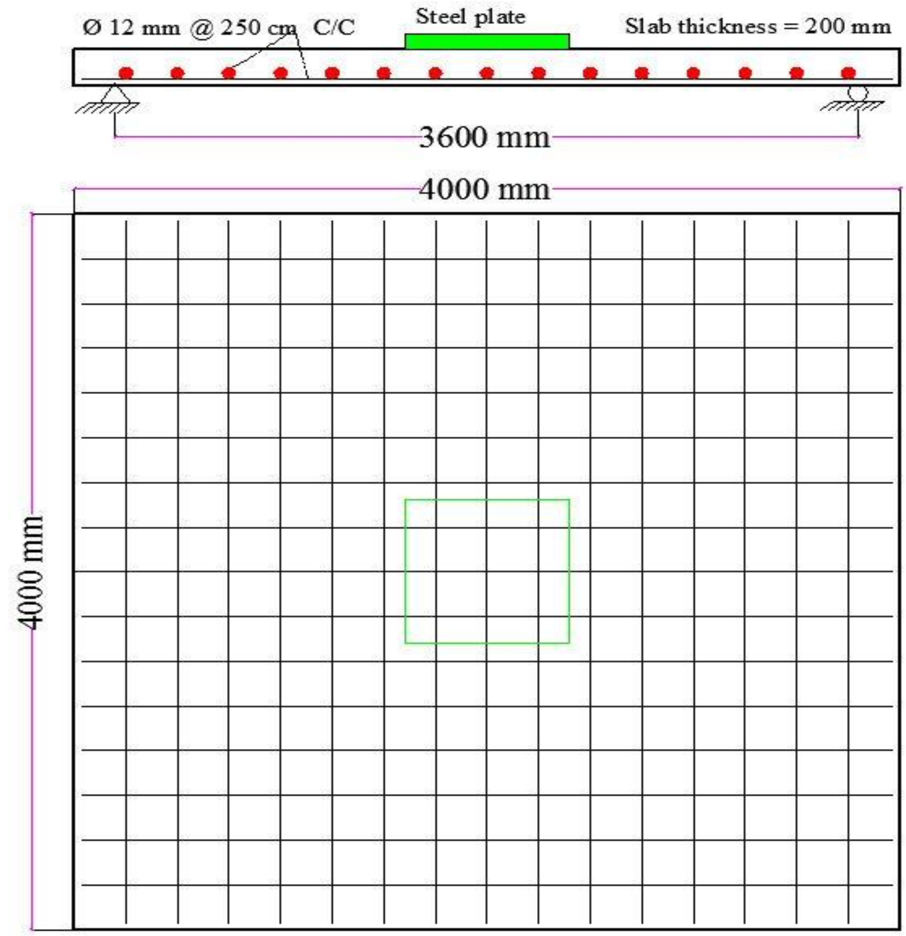



**Figure 4.1** Concrete two-way slab dimension and cross section

The concrete material properties, reinforcements, and tendons for BPT two-way slabs are shown in Table 4.1.

**Table 4.1** Concrete material properties, reinforcements, and tendons.

| Descriptions | Concrete | Steel plate & reinforcement | Tendon |
|---|---|---|---|
| Ultimate compressive strength (MPa) (*f 'c*) | 30 | —— | —— |
| Ultimate tensile strength (MPa) (*ft*) | 3.8 | —— | —— |
| Modulus of elasticity (GPa) | 30 | 200 | 206.290 |
| Poisson's ratio (υ) | 0.2 | 0.3 | 0.3 |
| Yield strength (MPa) | —— | 400 | 1741 |

## 4.2 Tendon Layouts

Prestressing is a method of offsetting the effects of structural external loading by imposing a state of stress that is inconsistent with the loading effect. The most used method to reach this is by means of tendons, which stressed prior to the final loading of the structure. Tendons are typically located near the bottom; which positive moments occur in this zone. Different tendon layout used such as: (without tendon) as shown in Figure 4.2, PT tendons in one direction with a various number of tendons as shown in Figure 4.3 and PT tendons in two directions with different number as shown in Figure 4.4.

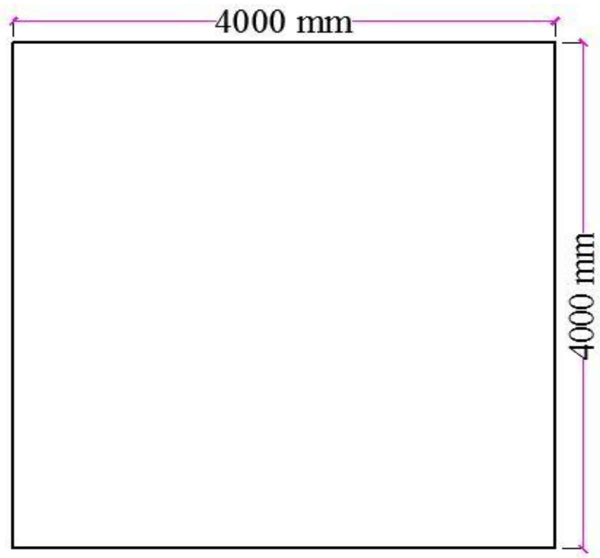



**Figure 4.2** Two-way slab without PT tendon

In first case tendon not used, it is a control specimen and the slab only reinforced by a deformed steel reinforcement and used minimum steel reinforcement for shrinkage and temperature, all other cases had a PT tendon and will be compared with this two-way slab.

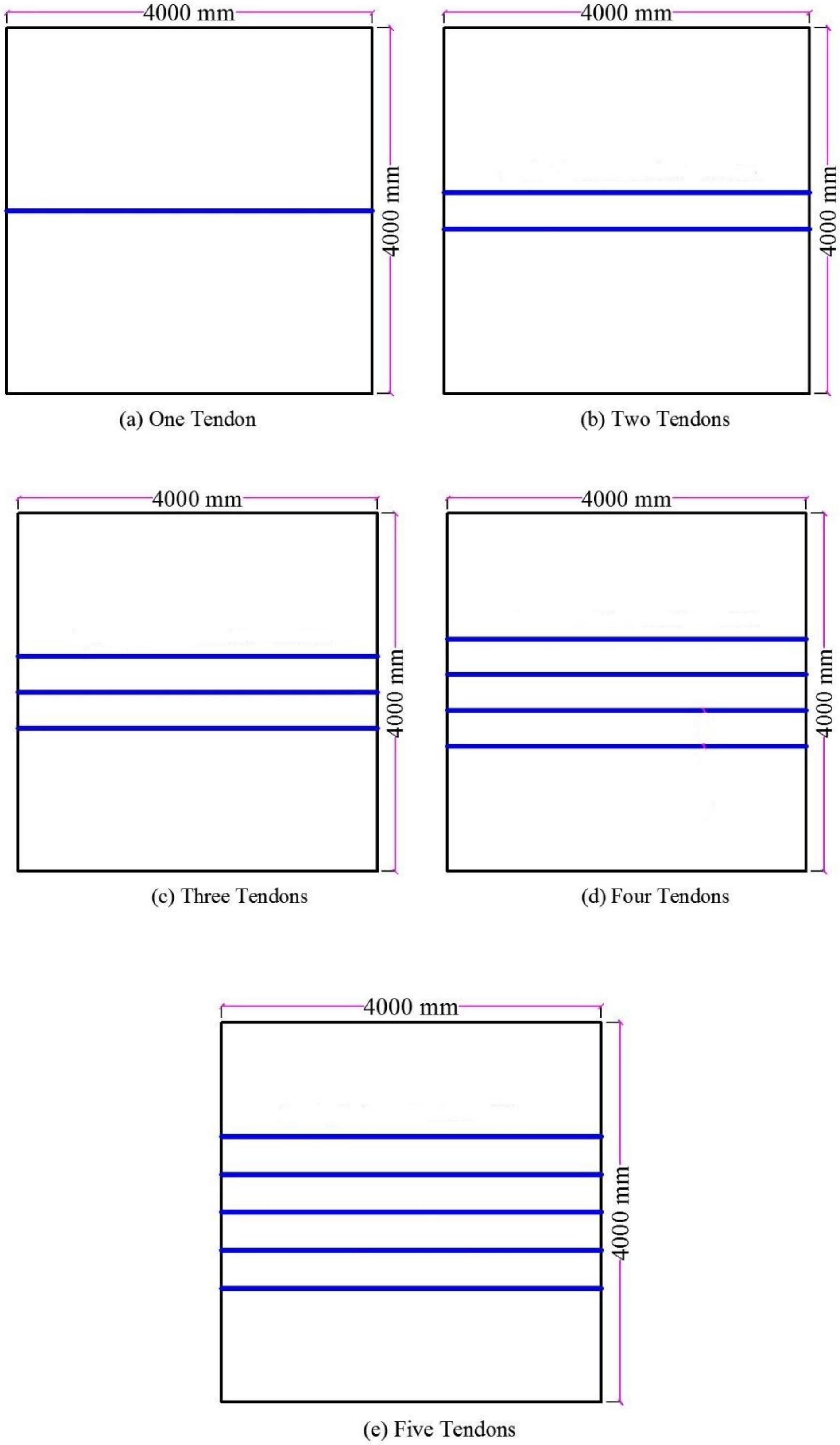



**Figure 4.3** Tendon layout in one direction with different numbers and spacing between tendons are 400 mm

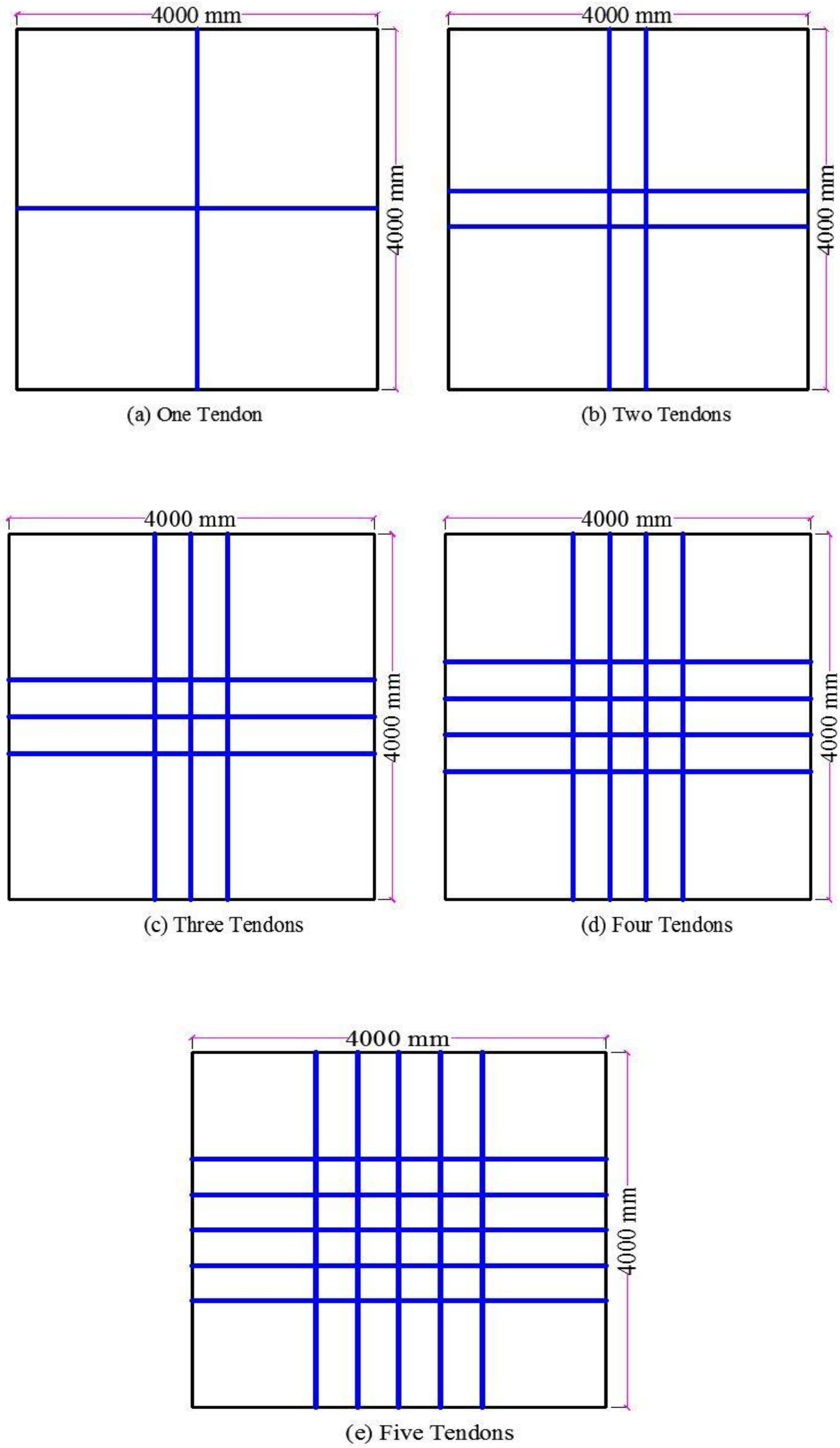
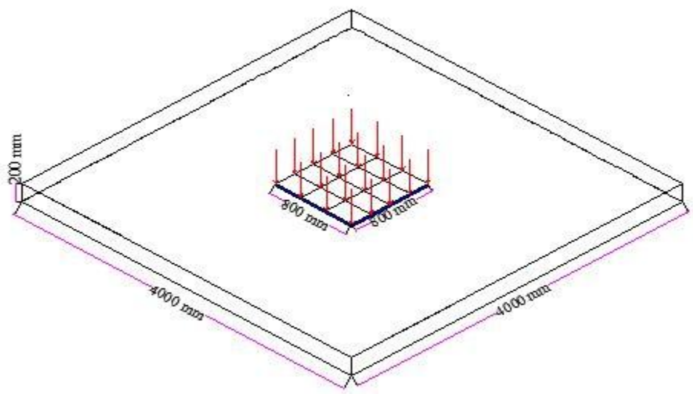



**Figure 4.4** Tendon layout in two directions with different numbers and spacing between tendons are 400

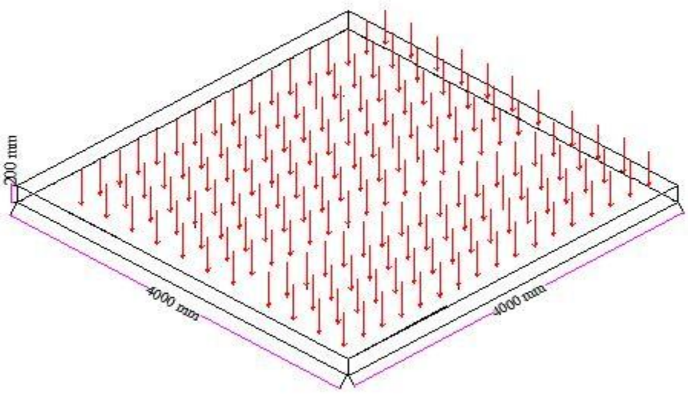
## 4.3 Loading and Boundary Conditions

The boundary conditions of the slab include supports and loads are applied to constrain the model to obtain a unique solution. Boundary conditions must be applied at both supports, nodes on both supports must be constrained in the transverse direction. For roller support all nodes at the support centerline are given a constant value of zero in the X and Z directions, in hinge support all the nodes that lie on the middle line of the supports are given a constant value of zero in the Z directions. The external load applied on the steel plates on the top face of the slab incrementally up to failure by nodal forces.

Two different type of loading cases are applied on the top of slab models up to failure, these load cases conditions are shown in Figure 4.5.



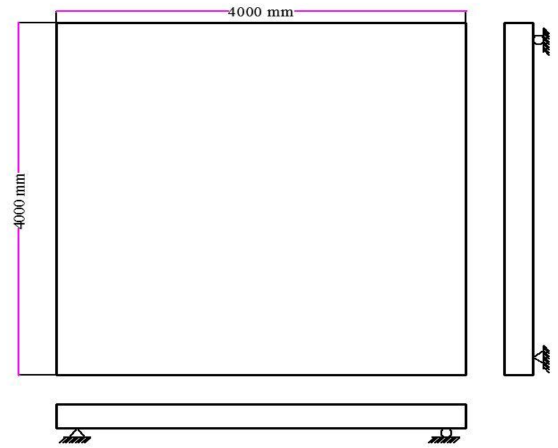

(a) Concentrated load at center of slab



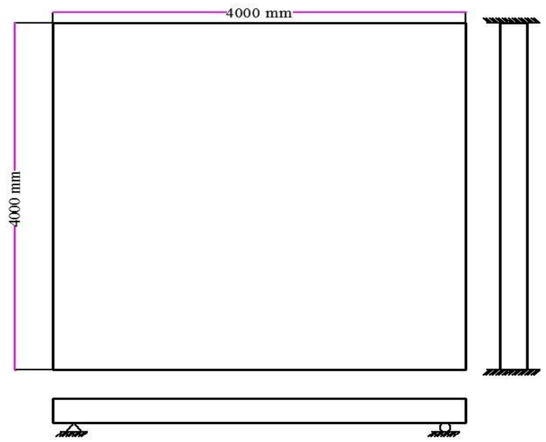

(a) Distributed load on the slab

**Figure 4.5** Load cases of the slab

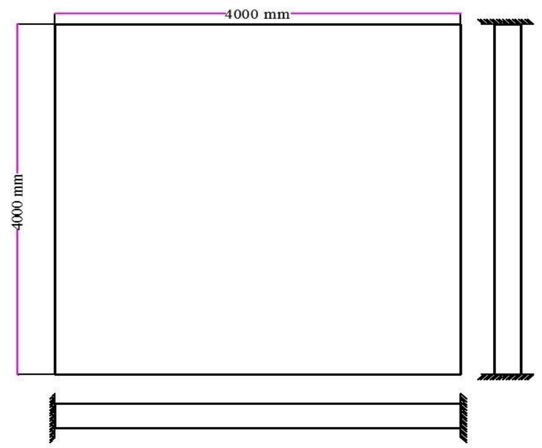
Three different boundary conditions of supports are defined for the slab models and illustrated in Figure 4.6.




(a) Simply supported in both directions




(b) Simply supported and fixed




(c) Fixed in both directions

**Figure 4.6** Type of boundary conditions

## 4.4 Discussion of Results

The most important thing in the PT concrete two-way slab is to find out the effectiveness of the tendon layout on the load-deflections and failure behavior. The nonlinear FEA was achieved to find the optimum tendon layout, number of tendons, area of tendons, spacing between tendon and variable boundary conditions under different load cases.

In ANSYS, when the solid models are finished, the models are ready to perform mesh creation. Meshing can only be done after element type specification. In FEA as the first step, PT reinforced concrete slab needs to be divided into many small elements. This is performed by the concrete slab meshing with mesh size of (X, Y, Z) appropriate mesh density in all directions of (100, 40, 100) mm respectively. The mesh density of BPT slab is revealed in Figure 4.7.

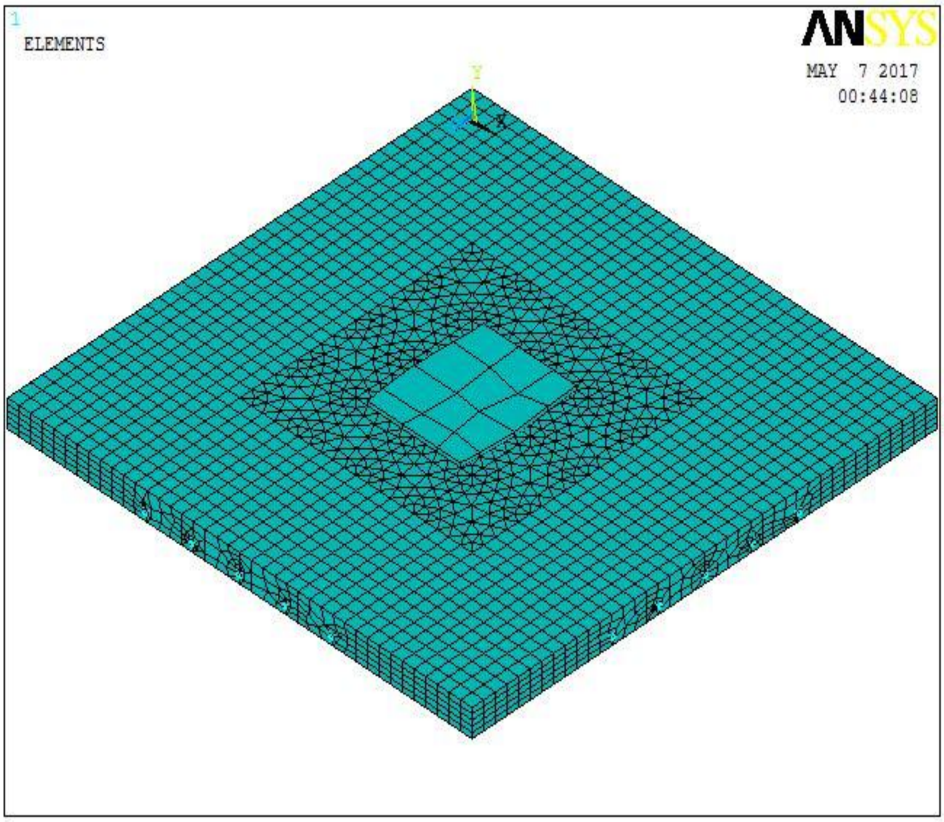



**Figure 4.7** Meshing of the slab

### 4.4.1 Load-displacements curves of two-way slabs for varies tendon layout

The ultimate load capacity increased by using tendons in both directions. The slabs with five tendons in both directions showed stiffer response and highest ultimate load capacity compared to the slabs with less than five tendons and also that tendons in one direction, for all load cases and boundary conditions when tendons used in both directions the tendons can carry out applied positive moments in mid span and negative moments at supports for both sides, also it is can reduce cracks in a bottom face in the center of slab and reducing cracks at the top of slab surface near the supports. But while using tendons in one direction the resistance of the concrete slab to applied load will be decreased due to a big applied moment on the side without tendon and make it to be failing and cracks will be appearing in this direction.

Figures 4.8, 4.9, and 4.10 show the load-displacement curves at midpoint of slab for concentrated load cases and different boundary conditions that were founded from FEA, the results showed that the slabs with two-directional tendons has stiffer response and give maximum load capacity compared to the slabs with one-directional tendons, it also showed that flexibility of support help the tendons to be more rigid in anchorage zone and resist to higher applied load.

Figures 4.11, 4.12 and 4.13 show the load-displacement curves at the midpoint of the slab for the distributed and different boundary conditions which is obtained from FEA, and the results show that the slab with two-directional tendons Showed a stronger response as compared to the slabs that tendons in one direction with the same number of tendons, indicating that the flexibility of the support makes the tendons more rigid and helps to withstand higher applied loads in the end anchorage zones.

Boundary conditions have a good response to resisting failure load of two-way slabs as shown in Table 4.2, in cases that the boundary conditions of slabs are simply supported one side and fixed in other side, with five tendons in one direction is nearly strong like a slab with five tendons in both direction and boundary conditions are simply supported which is equal to 532.2 in and 551.6 KN respectively. In cases that the boundary conditions of slabs are fixed all edges, with five tendons in one direction has a higher failure load than a slab with five tendons in both direction and boundary conditions are simply supported, which is equal to 635.2 kN and 551.6 kN respectively.

**Table 4.2** Failure load of slabs different tendon layout and boundary conditions

| Group | Slab | Tendons Layout | support | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load |
|---|---|---|---|---|---|---|---|---|
| G1 | S1 | Without tendon | S.S. | Concentrated (kN) | 0 | 150 | -1.0 | 257.7 |
| | S2 | One-direction | | | 5 | | -0.92 | 291.2 |
| | S3 | Two-directions | | | 5 | | -2.35 | 551.6 |
| G2 | S4 | Without tendon | S.S. & Fixed | Concentrated (kN) | 0 | 150 | -1.5 | 281.8 |
| | S5 | One-direction | | | 5 | | -2.4 | 532.2 |
| | S6 | Two-directions | | | 5 | | -3.8 | 930.0 |
| G3 | S7 | Without tendon | Fixed | Concentrated (kN) | 0 | 150 | -2.2 | 448.1 |
| | S8 | One-direction | | | 5 | | -2.5 | 635.2 |
| | S9 | Two-directions | | | 5 | | -4.46 | 1170.1 |
| G4 | S10 | Without tendon | S.S. | Distributed ($kN/m^2$) | 0 | 150 | -1.4 | 68.7 |
| | S11 | One-direction | | | 5 | | -1.3 | 76.3 |
| | S12 | Two-directions | | | 5 | | -1.54 | 110.2 |
| G5 | S13 | Without tendon | S.S. & Fixed | Distributed ($kN/m^2$) | 0 | 150 | -1.7 | 79.1 |
| | S14 | One-direction | | | 5 | | -1.5 | 86.7 |
| | S15 | Two-directions | | | 5 | | -2.1 | 124.4 |
| G6 | S16 | Without tendon | Fixed | Distributed ($kN/m^2$) | 0 | 150 | -2.0 | 100.1 |
| | S17 | One-direction | | | 5 | | -3.5 | 199.1 |
| | S18 | Two-directions | | | 5 | | -3.95 | 264.5 |

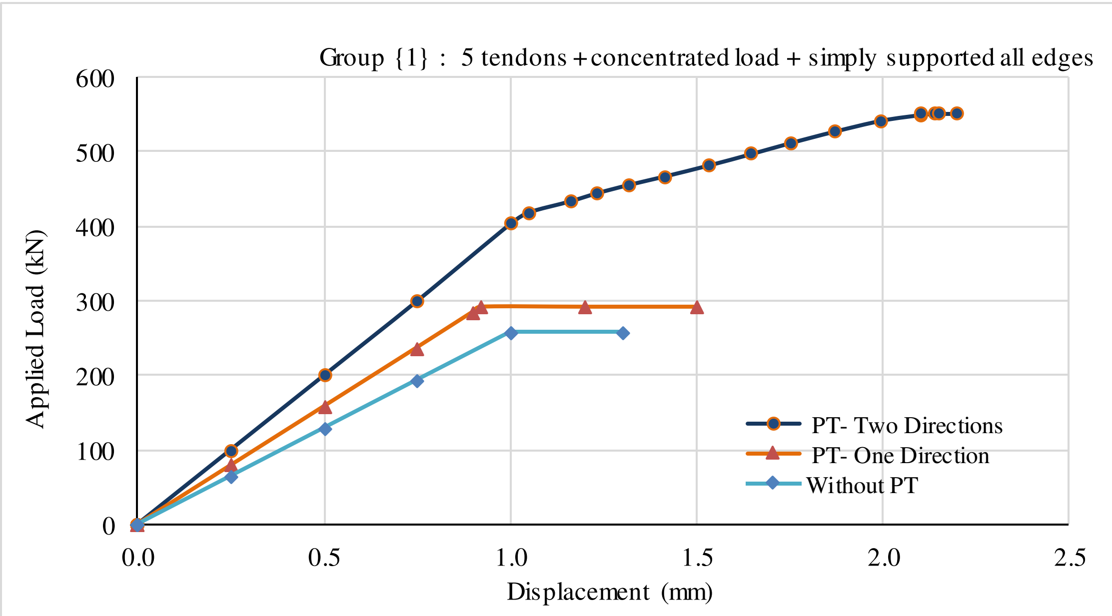



**Figure 4.8** Load- displacement curves at the mid span of slabs for case 1

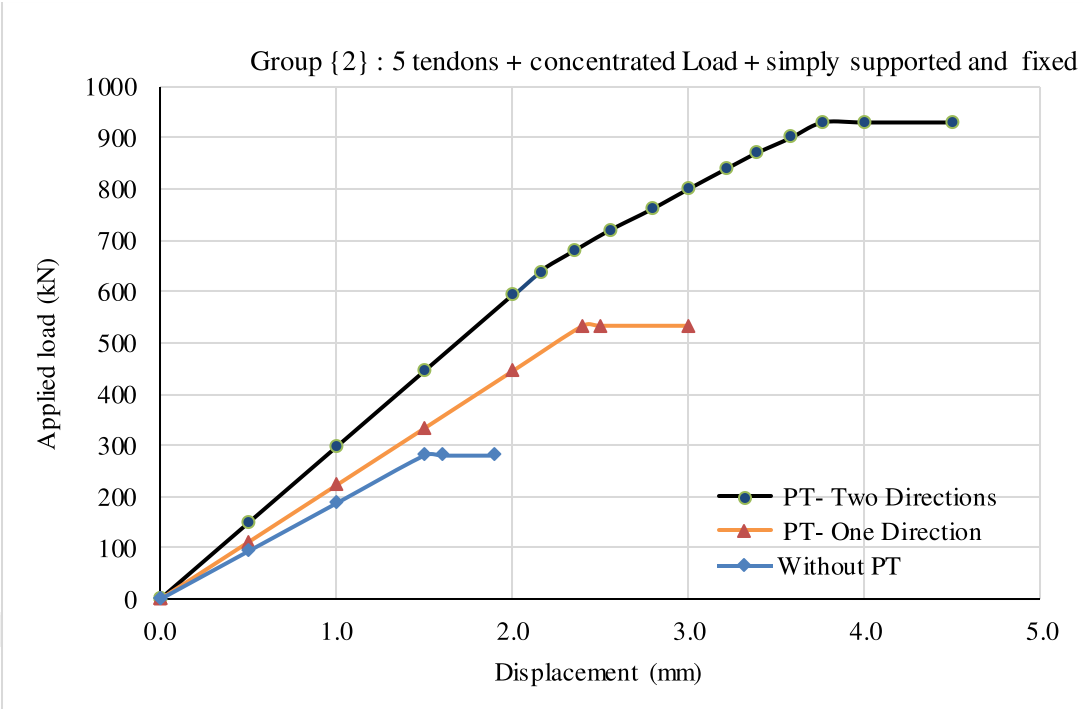



**Figure 4.9** Load- displacement curves at the mid span of slabs for case 2

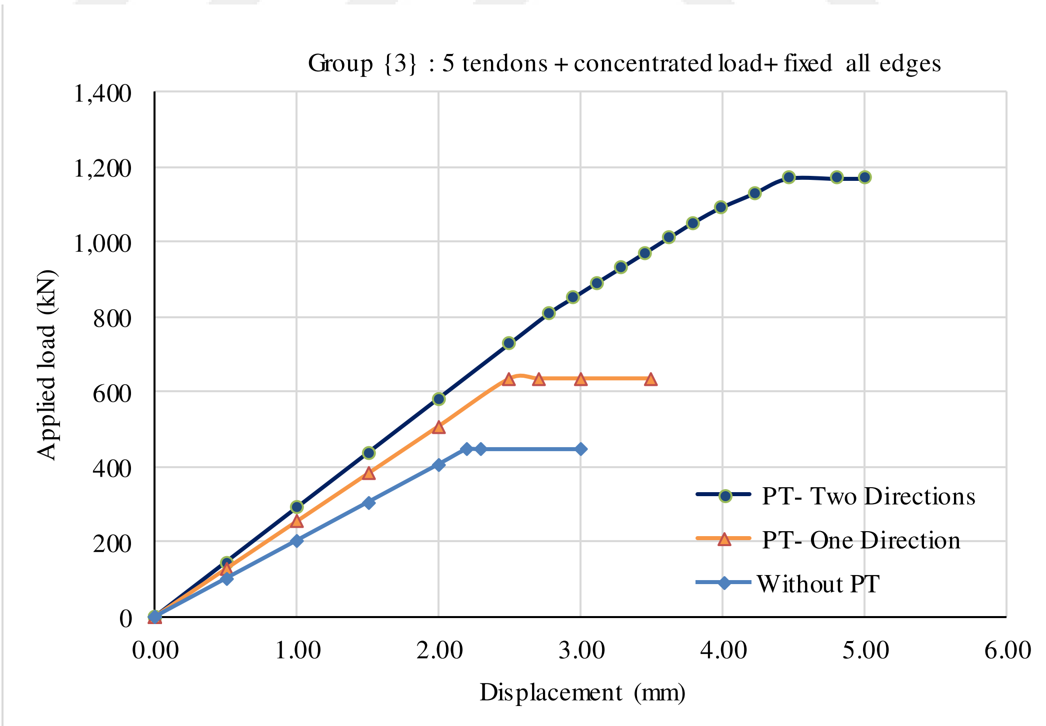



**Figure 4.10** Load- displacement curves at the mid span of slabs for case 3

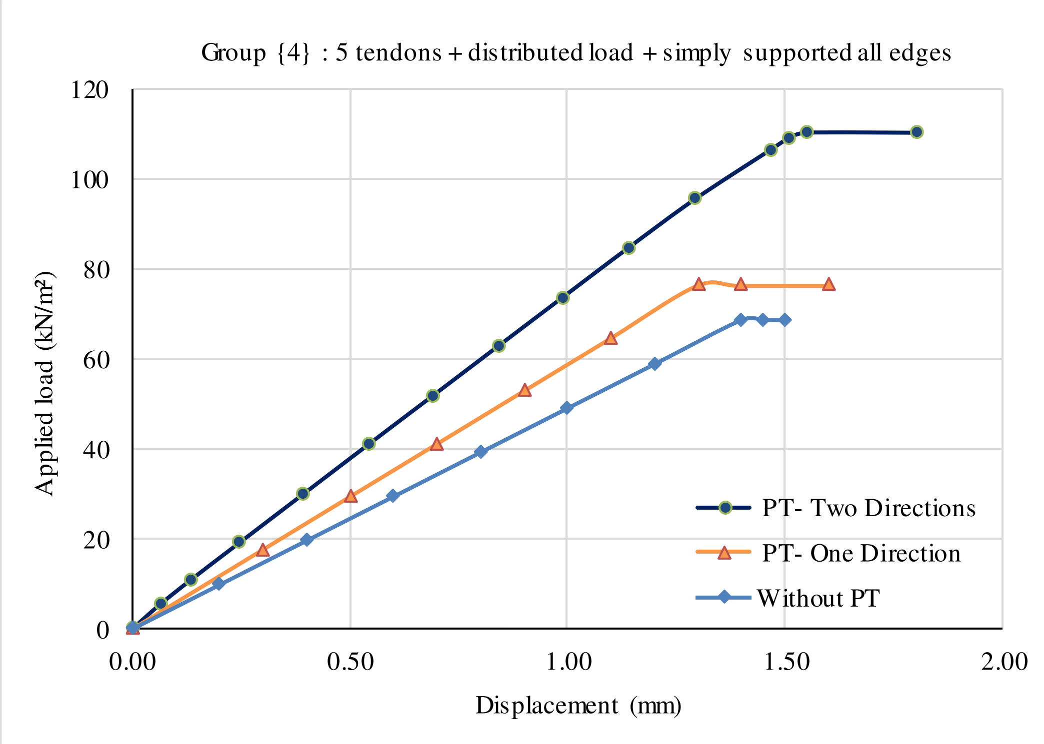



**Figure 4.11** Load- displacement curves at the mid span of slabs for case 4

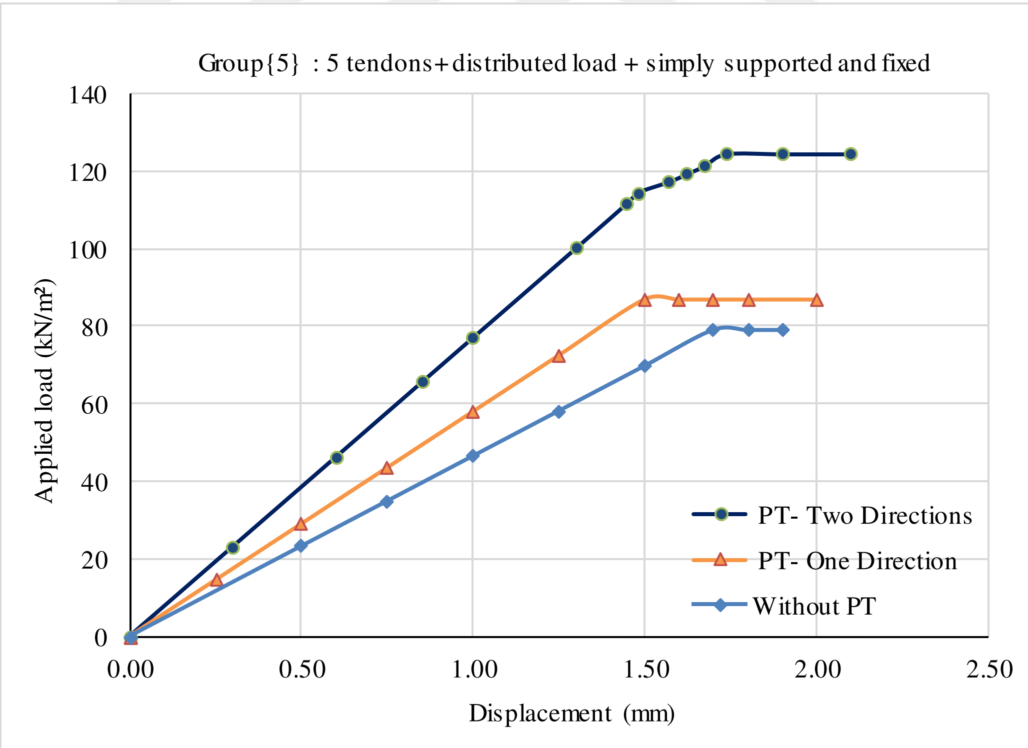



**Figure 4.12** Load- displacement curves at the mid span of slabs for case 5

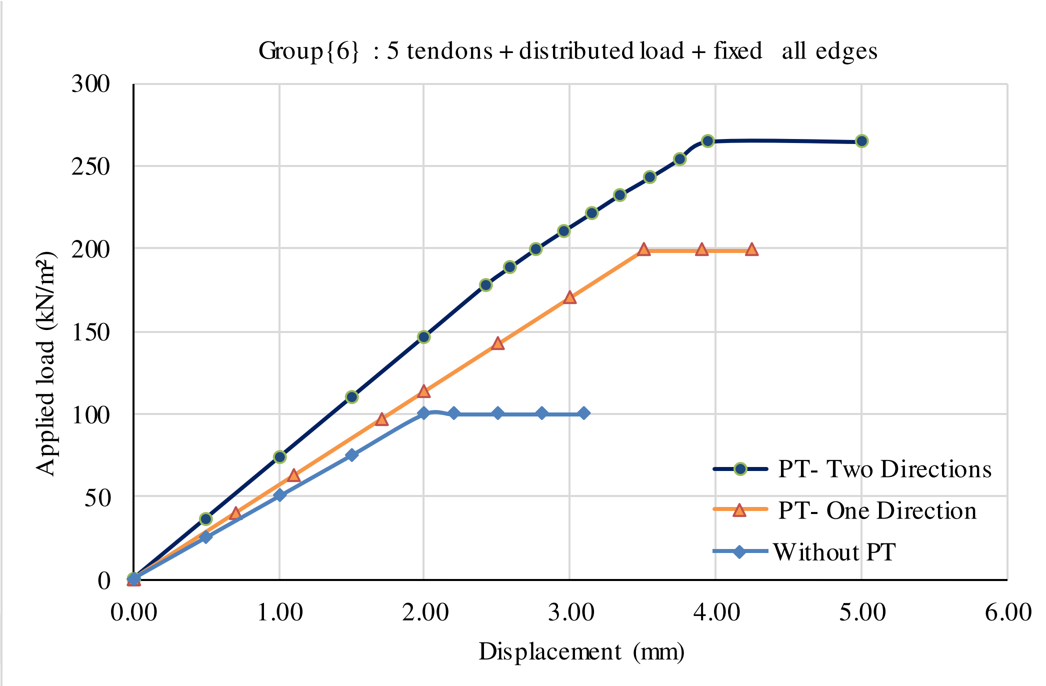



**Figure 4.13** Load- displacement curves at the mid span of slabs for case 6

### 4.4.2 Load-displacements of two-way slabs for various numbers of tendon

PT has a strong effect on failure load of the slab, a various number of tendons used in one direction and also for both direction, at first only one tendon used and after that number of tendon increased in one direction and both direction, FEA results showed that number of tendon has a good effect for strengthening slabs and reducing cracks, increasing number of tendons also means increase applied initial strain to the end of strands with a constant tendon area, for all cases applied load and displacements illustrate in Figure 4.14 and 4.15.

Number of tendons with different tendon layout have a good response to resisting failure load of two-way slabs as shown in Table 4.3, in cases two-way slab that one tendon used in both directions with a constant tendon area has higher resistance to applied load with comparisons to a two-way slab that used five tendons in one direction with the same material properties, tendon area and boundary conditions which is equal to 298.8 kN and 291.2 kN respectively.It is a very important point in optimising to select an optimum number of tendons and distributing in both sides of two-way slabs.

**Table 4.3** Failure load of slabs with different number of tendons

| Group | Slab | Tendons Layout | support | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load (kN) |
|---|---|---|---|---|---|---|---|---|
| G7 | S19 | One-direction | S.S. | Concentrated | 5 | 150 | -0.92 | 291.2 |
| | S20 | | | | 4 | | -1.01 | 283.8 |
| | S21 | | | | 3 | | -1.02 | 276.2 |
| | S22 | | | | 2 | | -1.3 | 272.5 |
| | S23 | | | | 1 | | -1.1 | 268.8 |
| | S24 | | | | 0 | | -1.0 | 257.7 |
| G8 | S25 | Two-directions | S.S. | Concentrated | 5 | 150 | -2.35 | 551.6 |
| | S26 | | | | 4 | | -2.07 | 487.8 |
| | S27 | | | | 3 | | -1.96 | 418.6 |
| | S28 | | | | 2 | | -1.67 | 355.6 |
| | S29 | | | | 1 | | -1.6 | 298.8 |
| | S30 | | | | 0 | | -1.0 | 257.7 |

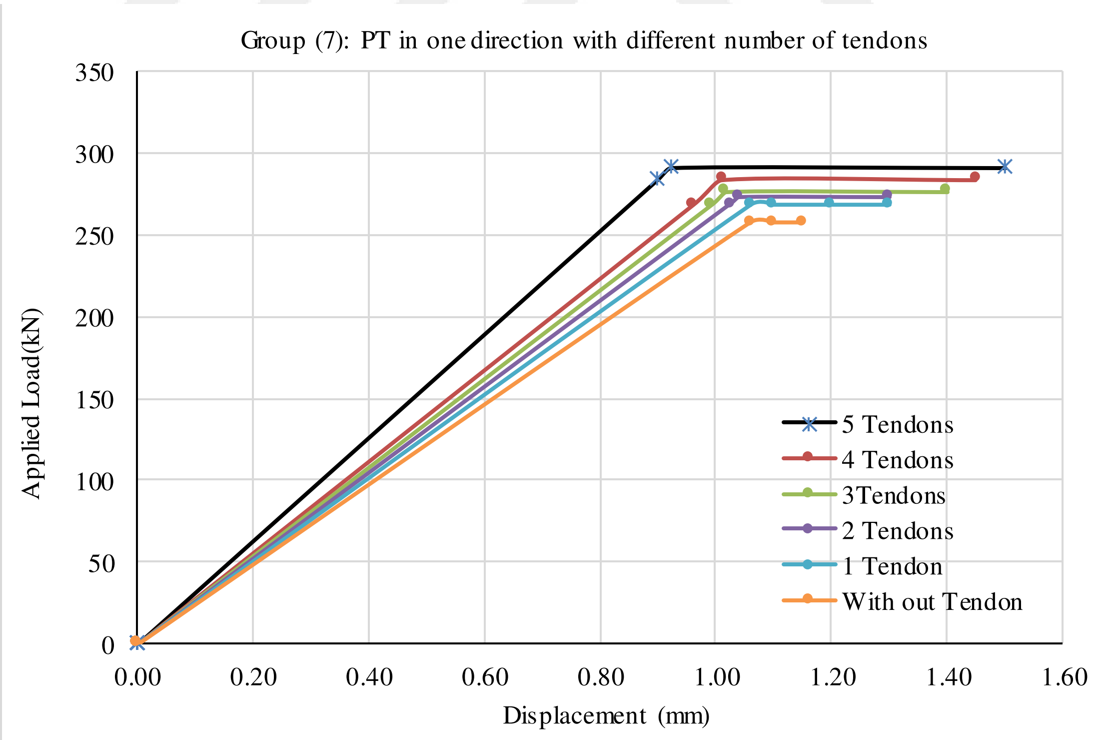



**Figure 4.14** Load- displacement curves at the mid span of slabs for case 7

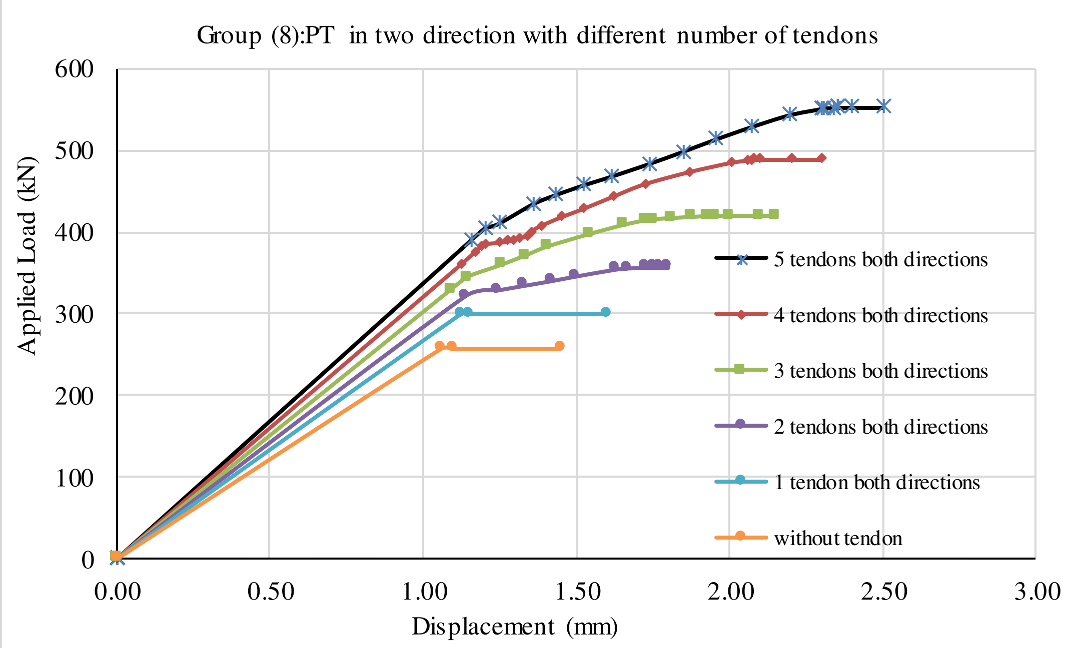



**Figure 4.15** Load- displacement curves at the mid span of slabs for case 8

### 4.4.3 Load-displacements of two-way slabs for various area of tendons

When a concrete member is subjected to a small ultimate moment, it may not behave as probable by the ultimate strength theory. The technique used for computing flexural strength is based on the assumption that concrete in the tension zone is weak, so it is cracked and cannot resisting desired loads. Thus, if the nominal strength of a section having a small amount of steel reinforcement is less than the cracking moment of the section, the slab will fail immediately and without or insufficient warning distress on formation of the first crack, in this slab used a minimum steel reinforcement for temperature and shrinkage, because of using steel tendons and applied tension forces at the end of strands by a special jack, increasing cross-sectional area of tendons means increasing the resisting stress to apply tension force and decreasing strain in the length of the tendons.

Area of tendons has a good effect on the failure load capacity on concrete two-way slabs. Table 4.4 shows the failure load of the slabs with different area of tendons, in case that used three tendons in one direction with cross-sectional area is 175 $mm^2$ is nearly strong like used five tendons in one direction with a cross-sectional area is equal to 150 $mm^2$.

While five tendons used in both directions of slab and increasing area of tendons from 150 mm² to 175 mm² the resistance failure load of the slab increased from 551.6 kN to 595.9 kN, so in same case can be increased area of tendons and small number of strand be used in the slab.

**Table 4.4** Failure load of slabs with different area of tendons

| Group | Slab | Tendons Layout | support | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load (kN) |
|---|---|---|---|---|---|---|---|---|
| G9 | S31 | One-direction | S.S. | Concentrated | 5 | 150 | -0.92 | 291.2 |
| | S32 | | | | 3 | 175 | -1.15 | 280.91 |
| G10 | S33 | Two-directions | S.S. | Concentrated | 5 | 150 | -2.35 | 551.6 |
| | S34 | | | | 5 | 175 | -2.44 | 595.9 |

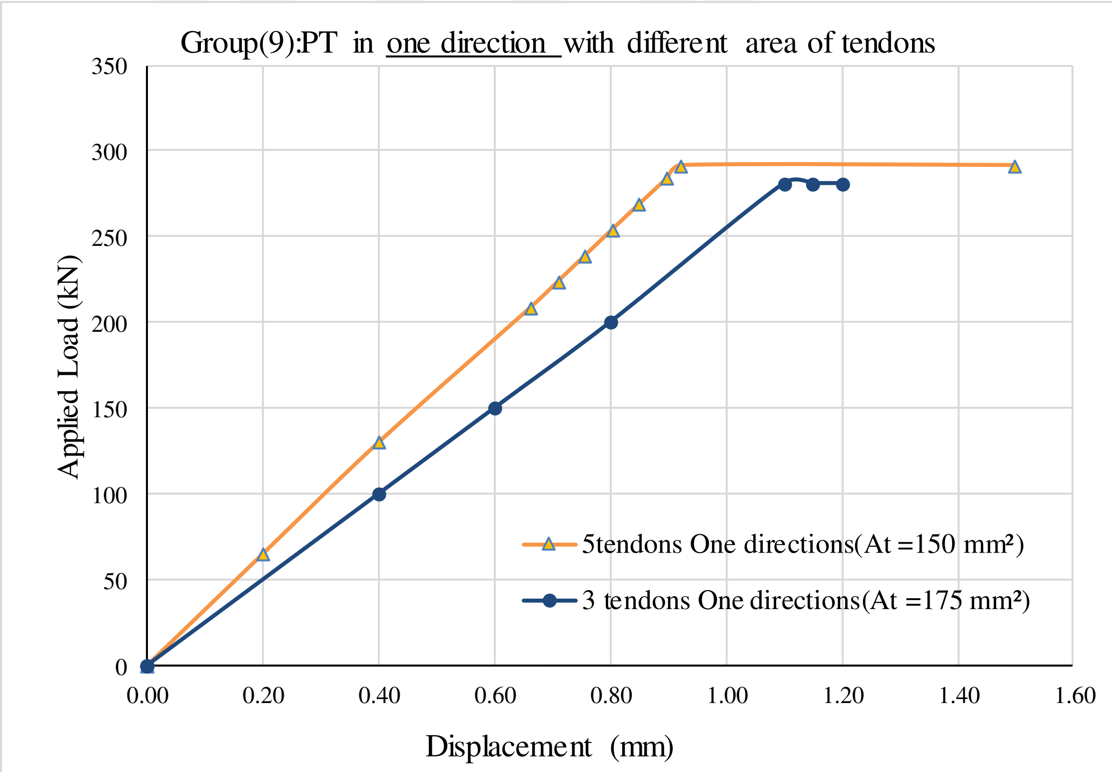



**Figure 4.16** Load- displacement curves at the mid span of slabs for case 9

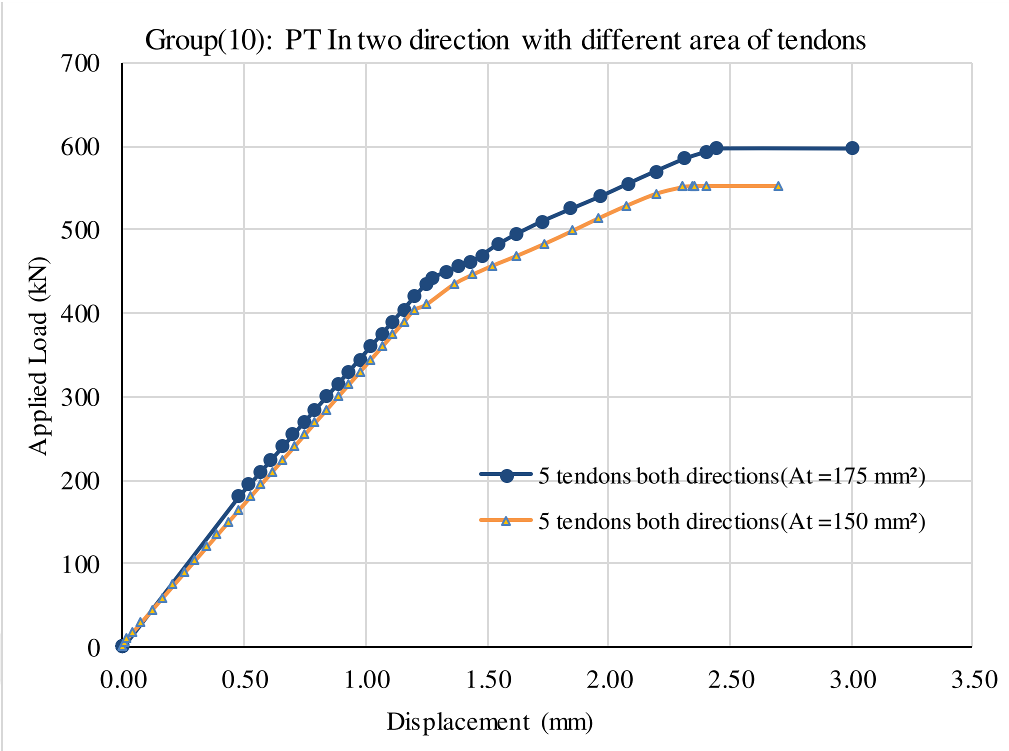


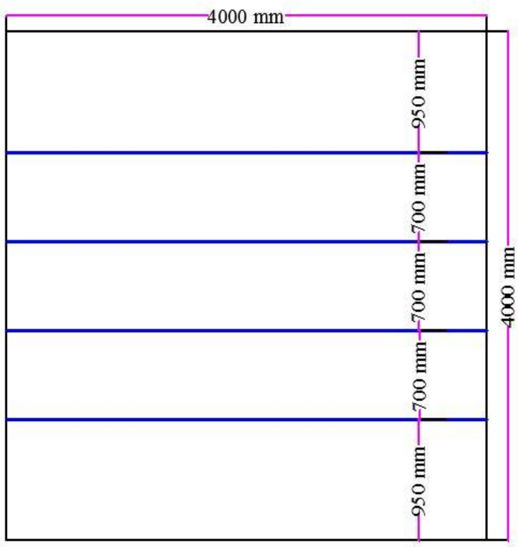

**Figure 4.17** Load- displacement curves at the mid span of slabs for case 10

### 4.4.4 Load-displacements of two-way slabs for various spacing of tendons

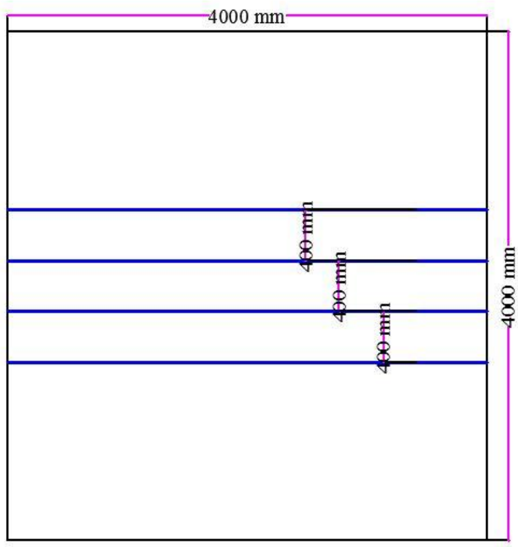
PT tendons commonly distributed on both sides of the concrete two-way slab with a different number and spacings between middle strip and column strip. Figure 4.18 shows the different tendon spacing that placed in one direction of the concrete two-way slabs. Table 4.5 showed the effect of tendon spacing on failure load of concrete two-way slab.

In S35 four tendons used with 40 cm spacing between tendons in one direction at the middle strip of the slab, in S36 the same tendons were used, but the spacing between tendons is 70 cm and in S37 the tendons were placed in column strip symmetrically two by two, the results showed that the optimum case was using tendons in the middle strip of the slab with spacing of 40 cm which is a failure load was equal to 283.76 in.

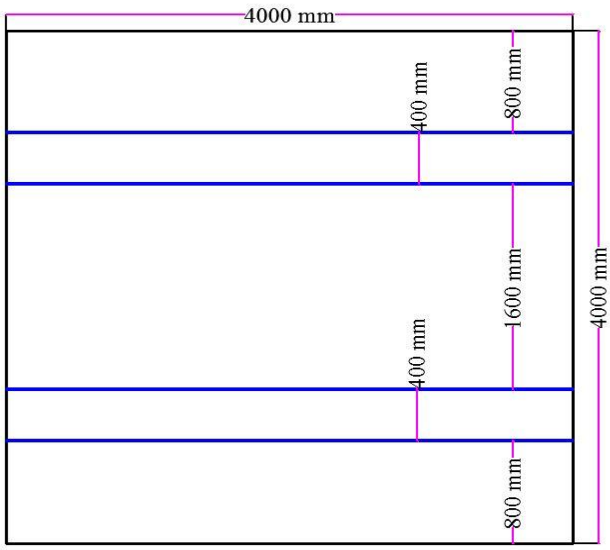
In S38 tendons used in both directions with 40 cm spacing between tendons at the middle strip of the slab, in S39 the same tendons were used, but two tendons in the middle strip with spacing 40cm also two tendons place in column strip symmetrically and in S40 the tendons were placed in column strip symmetrically one tendon around a column strip of the slab, the results showed that the optimum case was using tendons in the middle strip of the slab with spacing of 40 cm which is a failure load was equal to 487.80 kN .




(a)spacing is 700 mm

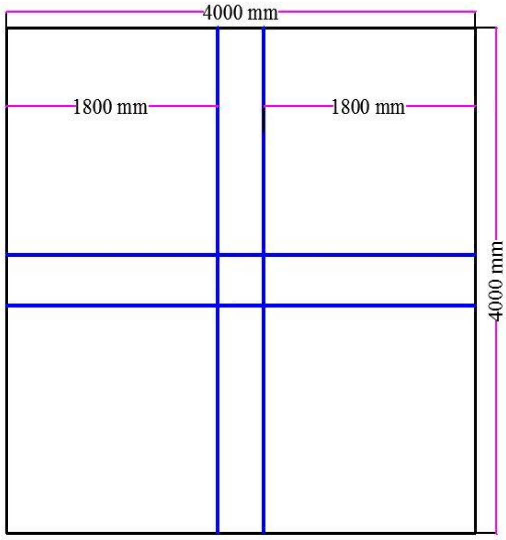



(b) spacing is 400 mm

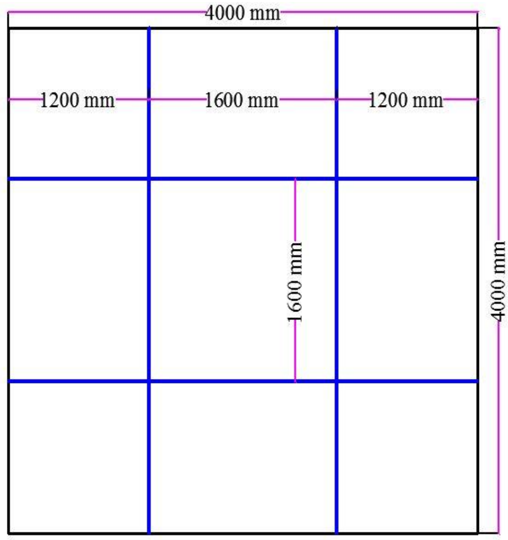



(c) Tendons banded

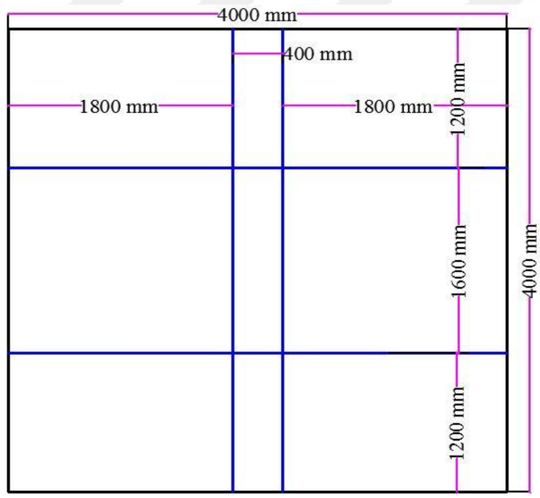
**Figure 4.18** Tendon layout in one direction with different spacing




(a)spacing is 400 mm




(b) Tendons banded




(c) Tendons 400m in one side & banded in other side

**Figure 4.19** Tendon layout in two directions with different spacing

**Table 4.5** Failure load of slabs with different spacing of tendons

| Group | Slab | Tendons Spacing | Support & Layout | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load (kN) |
|---|---|---|---|---|---|---|---|---|
| G11 | S35 | 40 cm c/c | S.S. & One direction | Concentrated | 4 | 150 | -1.01 | 283.76 |
| | S36 | 70 cm c/c | | | 4 | | -1.04 | 279.91 |
| | S37 | banded | | | 4 | | -1.10 | 277.15 |
| G12 | S38 | 40 cm c/c | S.S. & Two directions | Concentrated | 4 | 150 | -2.07 | 487.80 |
| | S39 | 40 cm & banded | | | 4 | | -2.2 | 471.93 |
| | S40 | banded | | | 4 | | -2.3 | 455.23 |

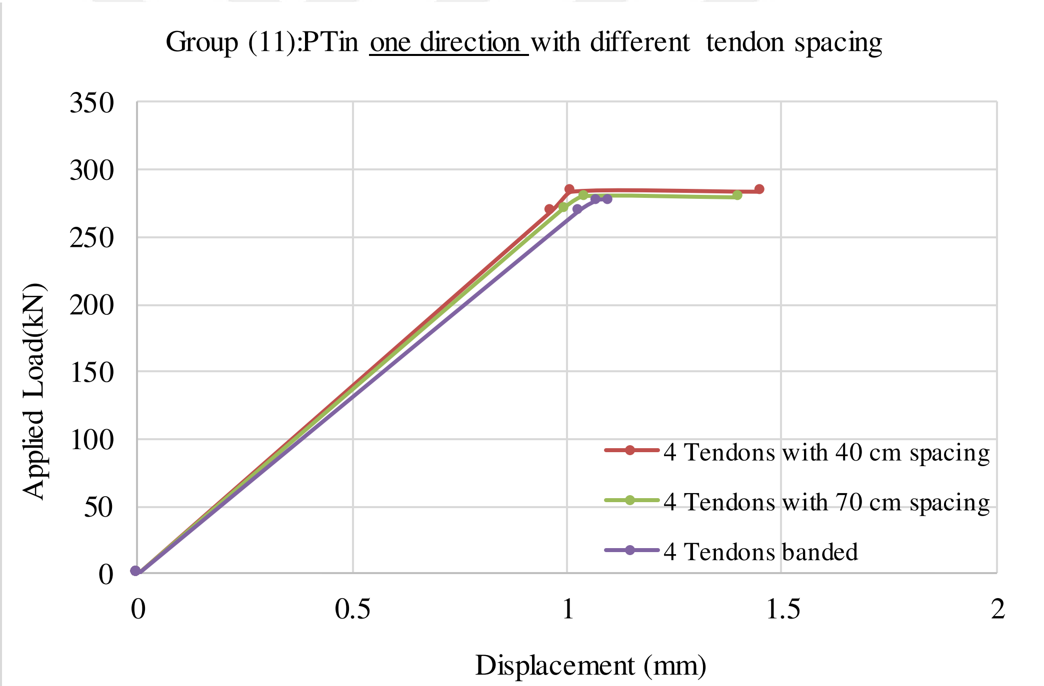



**Figure 4.20** Load- displacement curves at the mid span of slabs for case 11

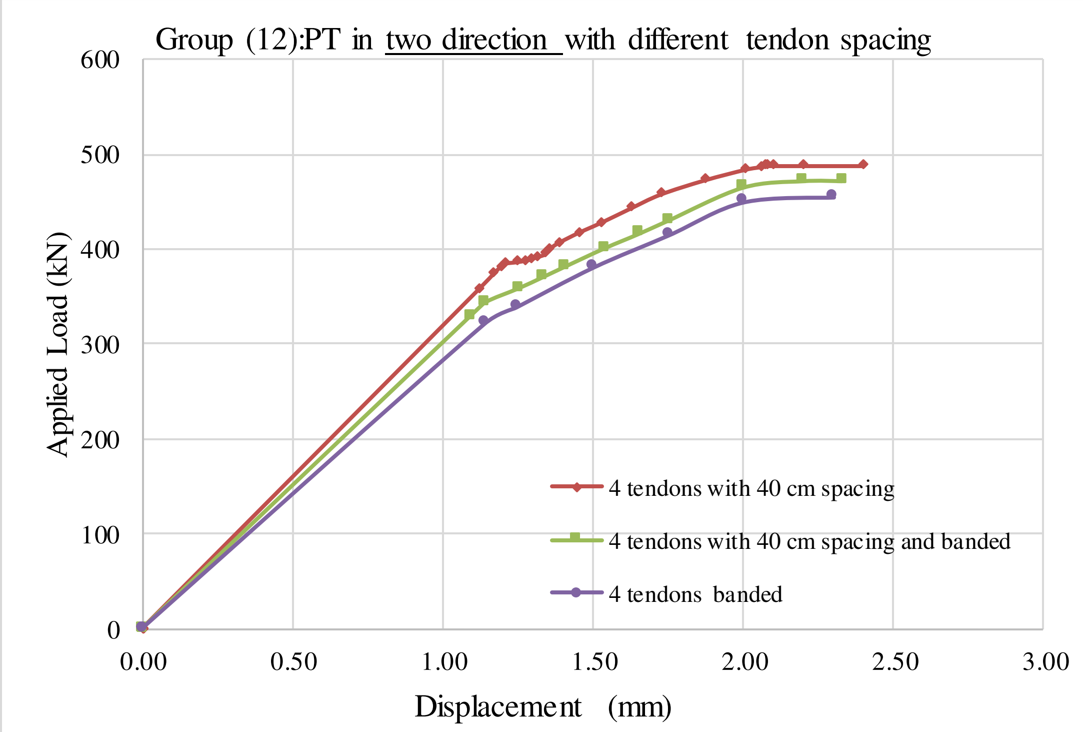



**Figure 4.21** Load- displacement curves at the mid span of slabs for case 12

### 4.4.5 Load-displacements of two-way slabs for various tendons positions

The ultimate load capacity increased by using tendons straight at the bottom of the slab. Because while tendons used straightly as a bottom have the specified values of eccentricity, eccentricity is the distance between the neutral axis of the member and the tendon, and generates an internal moment acting against the moment induced by the external load. Increasing eccentricity will decrease tensile stresses of the concrete and increase the tendon stress. The straight tendons in bottom profile is like to the bending moment of slab, the use of this tendon position presents transverse effects to carry out more counteract the external loads, with both axial shear effects and bending and. In addition, give maximum failure load, it is stronger as compared to other position such as using in mid height and top of slab. Table 4.6 showed the effect of tendon position in concrete two-slab, the optimum position is placing tendons in bottom of slab for both tendon layout in one direction and two direction tendons. While using tendon on top of the slab and applying load the PT working negatively and tried to down wording the and collapsing slab at the end of applying load.

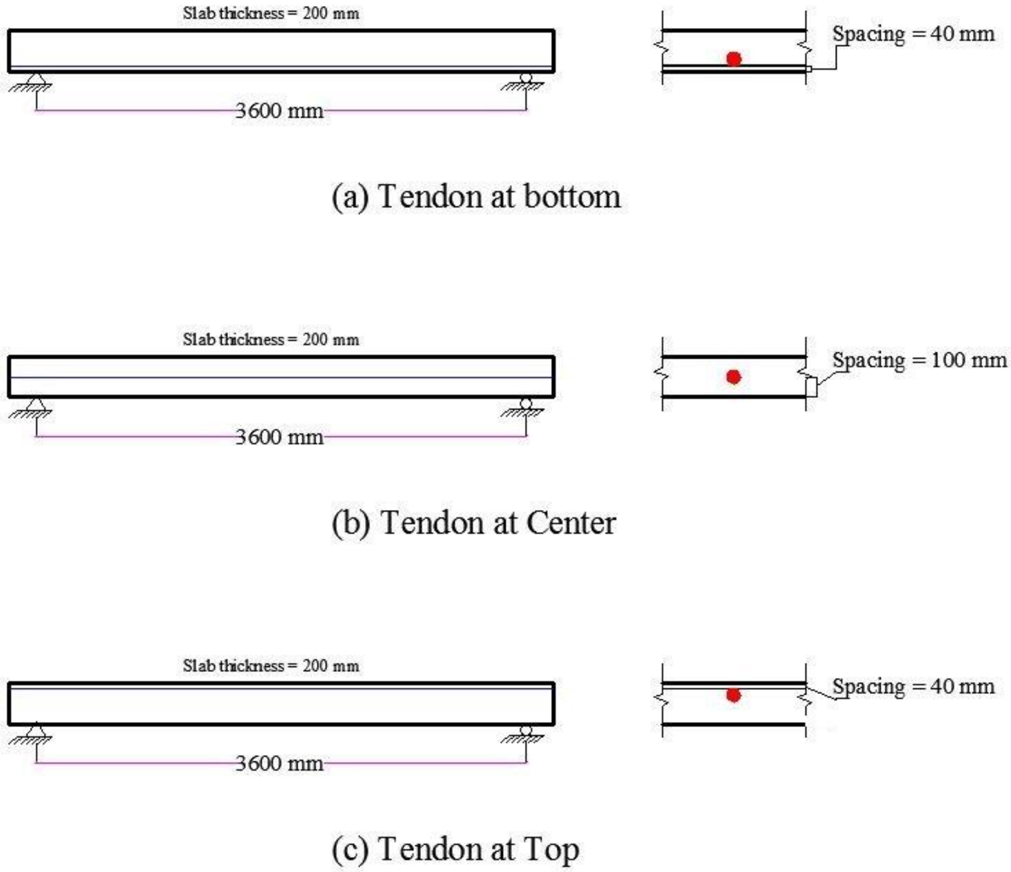



**Figure 4.22** Different tendon positions

**Table 4.6** Failure load of slabs with different tendon position

| Group | Slab | Tendons Position | Support & lay out | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load (kN) |
|---|---|---|---|---|---|---|---|---|
| G13 | S41 | Bottom | S.S. & One direction | Concentrated | 5 | 150 | -0.92 | 291.24 |
| | S42 | Middle height | | | 5 | | -1.01 | 280.27 |
| | S43 | Top | | | 5 | | -1.00 | 261.74 |
| G14 | S44 | Bottom | S.S. & Two directions | Concentrated | 5 | 150 | -2.35 | 551.60 |
| | S45 | Middle height | | | 5 | | -2.00 | 474.47 |
| | S46 | Top | | | 5 | | -1.88 | 417.34 |

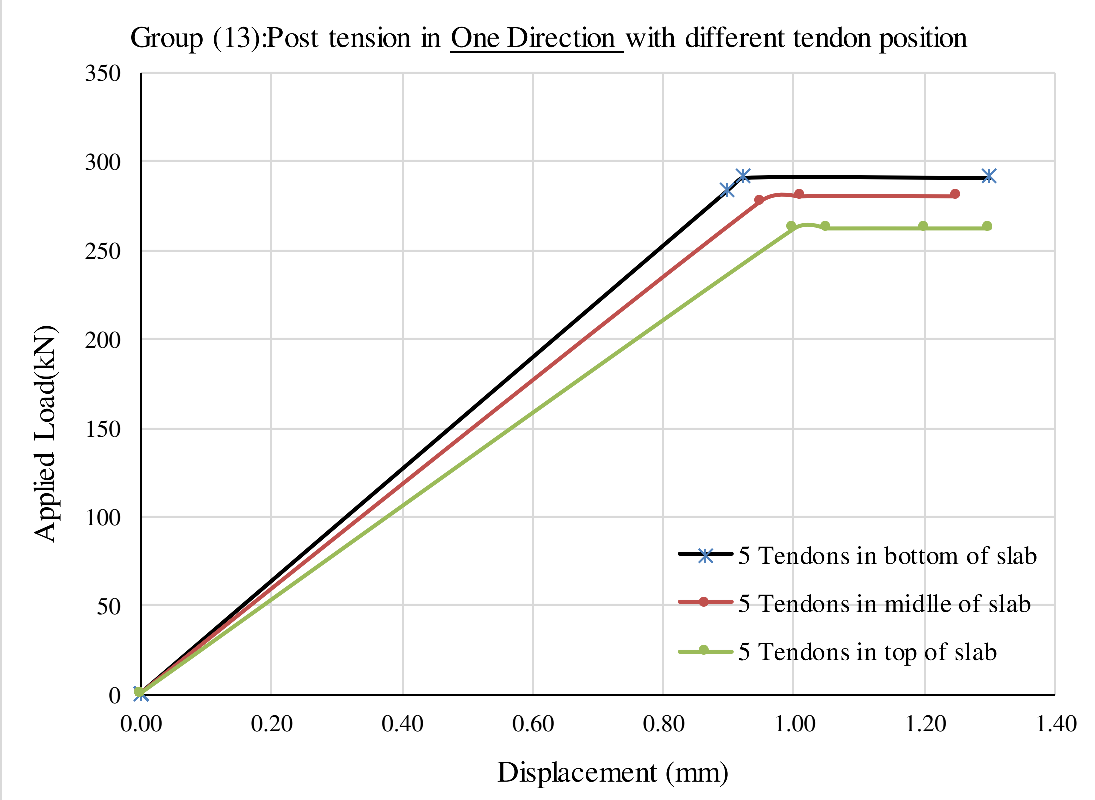



**Figure 4.23** Load- displacement curves at the mid span of slabs for case 13

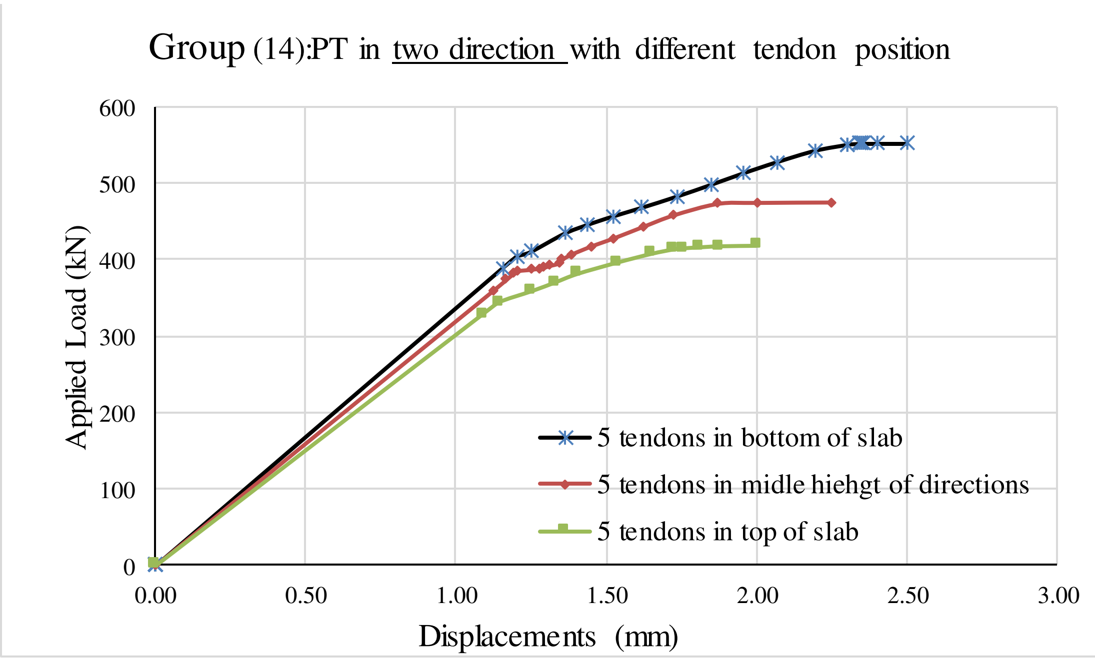



**Figure 4.24** Load- displacement curves at the mid span of slabs for case 14

### 4.4.6 Load-displacements of two-way slabs for constant tendon area and different number of tendons

When applying a concentrated load on the center of the slab, tendons tried to carry out the applied stress and resisting to deflection and cracks, the tensile strength of tendons must be larger than the applied stress at the point of tendons. Table 4.7 showed the effect of using different number of tendon with a constant tendon area

The result showed that increasing numbers of tendons with a smaller area of tendons are better than using a small number of tendons with huge areas of tendons. While five tendons used the applied initial strain was applied to all tendons and made it to be higher internal stress resistance to applied load.

**Table 4.7** Failure load of slabs with constant area and different tendon numbers

| Group | Slab | Tendons Layout | support | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load (kN) |
|---|---|---|---|---|---|---|---|---|
| G15 | S47 | Two-directions | S.S. | Concentrated | 5 | 150 | -2.35 | 551.6 |
| | S48 | | | | 4 | 175 | -2.30 | 540.11 |
| | S49 | | | | 3 | 250 | -2.40 | 532.74 |
| | S50 | | | | 2 | 350 | -1.73 | 388.10 |

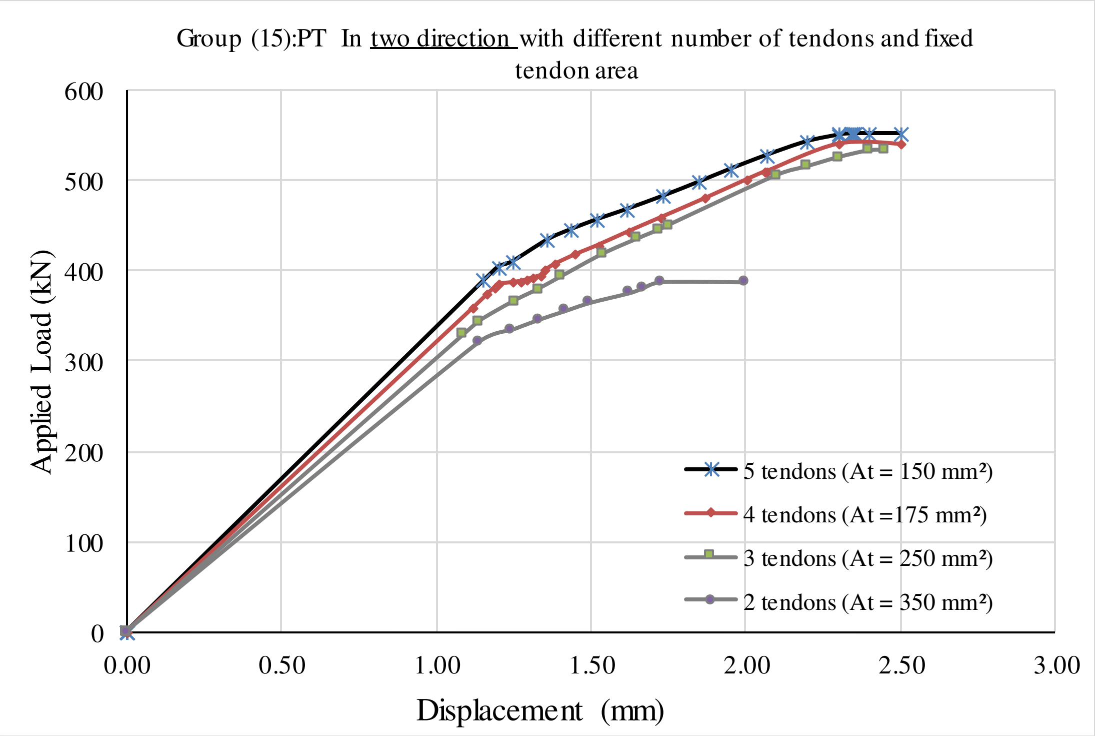



Figure 4.25 Load- displacement curves at the mid span of slabs for case 15

### 4.4.7 Cracking patterns

The uniaxial tensile stress used for concrete element is 3.8 MPa. When the concrete cannot withstand and resist additional tension, crack formation occurs and the tensile stress is transferred to the reinforcing steel during the analysis process. As the steel elongates and the bond between surrounding concrete and reinforcing steel are damaged, cracks begin to extend and propagate, while the uniaxial tensile stress is more than 3.8 MPa. The cracks are initiated in the maximum moment zones, which failure occurs in it and all failure types are concrete cracking suddenly above the mid span part. Figures 4.26, 4.27, and 4.28 shows the typical variation of stress at extreme top fibers of concrete.

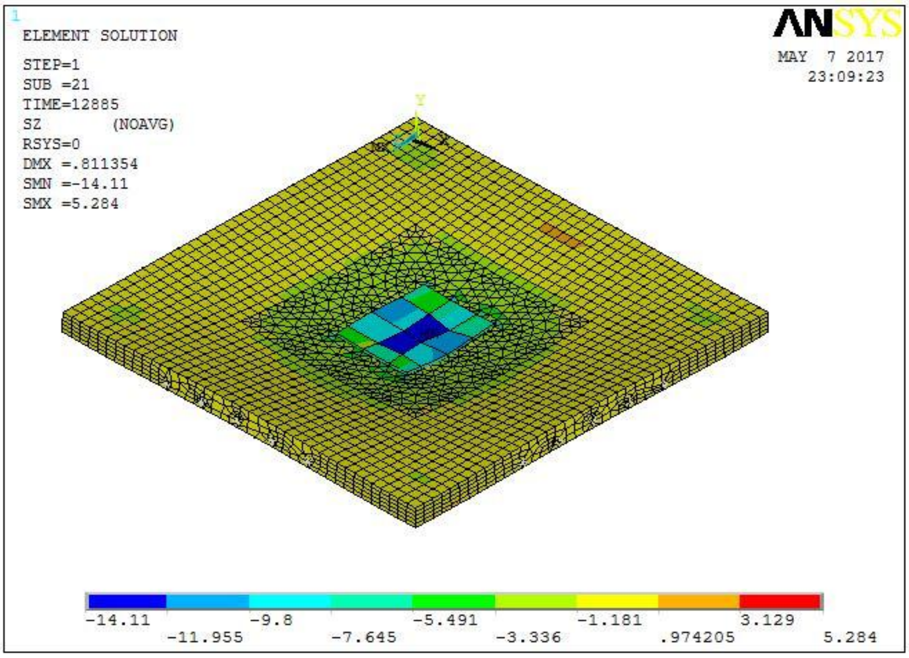



**Figure 4.26** Longitudinal stress in the concrete of slab1

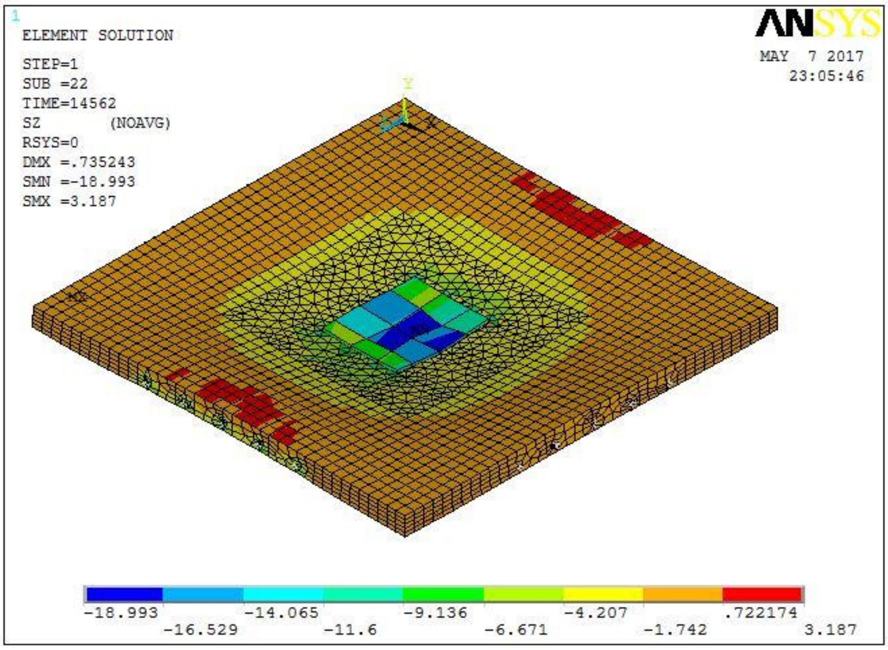



**Figure 4.27** Longitudinal stress in the concrete of slab 2

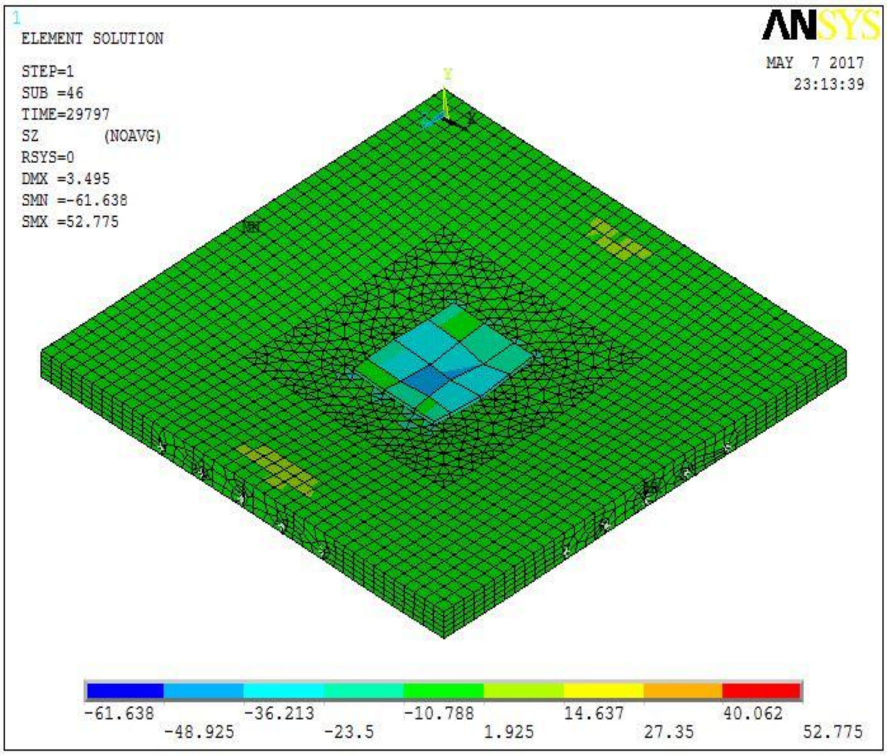



**Figure 4.28** Longitudinal stress in the concrete slab 34

### 4.4.8 Summary of parametric study

The different parameters considered in the parametric study and their results are summarized in Table 4.2.

**Table 4.8** Summary of the parametric study results

| Group | Slab | Tendons Layout | support | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load |
|---|---|---|---|---|---|---|---|---|
| G1 | S1 | Without tendon | S.S. | Concentrated (kN) | 0 | 150 | -1.0 | 257.7 |
| | S2 | One-direction | | | 5 | | -0.92 | 291.2 |
| | S3 | Two-directions | | | 5 | | -2.35 | 551.6 |
| G2 | S4 | Without tendon | S.S. & Fixed | Concentrated (kN) | 0 | 150 | -1.5 | 281.8 |
| | S5 | One-direction | | | 5 | | -2.4 | 532.2 |
| | S6 | Two-directions | | | 5 | | -3.8 | 930.0 |
| G3 | S7 | Without tendon | Fixed | Concentrated (kN) | 0 | 150 | -2.2 | 448.1 |
| | S8 | One-direction | | | 5 | | -2.5 | 635.2 |
| | S9 | Two-directions | | | 5 | | -4.46 | 1170.1 |
| G4 | S10 | Without tendon | S.S. | Distributed ($kN/m^2$) | 0 | 150 | -1.4 | 68.7 |
| | S11 | One-direction | | | 5 | | -1.3 | 76.3 |
| | S12 | Two-directions | | | 5 | | -1.54 | 110.2 |
| G5 | S13 | Without tendon | S.S. & Fixed | Distributed ($kN/m^2$) | 0 | 150 | -1.7 | 79.1 |
| | S14 | One-direction | | | 5 | | -1.5 | 86.7 |
| | S15 | Two-directions | | | 5 | | -2.1 | 124.4 |
| G6 | S16 | Without tendon | Fixed | Distributed ($kN/m^2$) | 0 | 150 | -2.0 | 100.1 |
| | S17 | One-direction | | | 5 | | -3.5 | 199.1 |
| | S18 | Two-directions | | | 5 | | -3.95 | 264.5 |
| G7 | S19 | One-direction | S.S. | Concentrated (kN) | 5 | 150 | -0.92 | 291.2 |
| | S20 | | | | 4 | | -1.01 | 283.8 |
| | S21 | | | | 3 | | -1.02 | 276.2 |
| | S22 | | | | 2 | | -1.3 | 272.5 |
| | S23 | | | | 1 | | -1.1 | 268.8 |
| | S24 | | | | 0 | | -1.0 | 257.7 |
| G8 | S25 | Two-directions | S.S. | Concentrated (kN) | 5 | 150 | -2.35 | 551.6 |
| | S26 | | | | 4 | | -2.07 | 487.8 |
| | S27 | | | | 3 | | -1.96 | 418.6 |
| | S28 | | | | 2 | | -1.67 | 355.6 |
| | S29 | | | | 1 | | -1.6 | 298.8 |
| | S30 | | | | 0 | | -1.0 | 257.7 |
| G9 | S31 | One-direction | S.S. | Concentrated (kN) | 5 | 150 | -0.92 | 291.2 |
| | S32 | | | | 3 | 175 | -1.15 | 280.91 |
| G10 | S33 | Two-directions | S.S. | Concentrated (kN) | 5 | 150 | -2.35 | 551.6 |
| | S34 | | | | | 175 | -2.44 | 595.9 |
| | | | | | | | | |

| Group | Slab | Tendons Spacing | Support & lay out | Load case | No. of tendons | Tendons area ($mm^2$) | Max. deflection (mm) | Failure load |
|---|---|---|---|---|---|---|---|---|
| G11 | S35 | 40 cm c/c | S.S. & One direction | Concentrated (kN) | 4 | 150 | -1.01 | 283.76 |
| | S36 | 70 cm c/c | | | 4 | | -1.04 | 279.91 |
| | S37 | banded | | | 4 | | -1.10 | 277.15 |
| G12 | S38 | 40 cm c/c | S.S. & Two directions | Concentrated (kN) | 4 | 150 | -2.07 | 487.80 |
| | S39 | 40 cm &banded | | | 4 | | -2.2 | 471.93 |
| | S40 | Banded | | | 4 | | -2.3 | 455.23 |
| G13 | S41 | Bottom | S.S. & One direction | Concentrated (kN) | 5 | 150 | -0.92 | 291.24 |
| | S42 | Middle height | | | 5 | | -1.01 | 280.27 |
| | S43 | Top | | | 5 | | -1.00 | 261.74 |
| G14 | S44 | Bottom | S.S. & Two directions | Concentrated (kN) | 5 | 150 | -2.35 | 551.60 |
| | S45 | Middle height | | | 5 | | -2.00 | 474.47 |
| | S46 | Top | | | 5 | | -1.88 | 417.34 |
| G15 | S47 | Two-directions | S.S. | Concentrated (kN) | 5 | 150 | -2.35 | 551.6 |
| | S48 | | | | 4 | 175 | -2.30 | 540.11 |
| | S49 | | | | 3 | 250 | -2.40 | 532.74 |
| | S50 | | | | 2 | 350 | -1.73 | 388.10 |

# CHAPTER 5

# CONCLUSION

## 5.1 Conclusion

Prestressing is a technique used for engineering constructions like towers, buildings, offshore structures and bridges, … etc. Widely all over the world, due to its economy and efficiency for obtaining requirements like a long span with small member depth. Prestressing can be used for flexural strengthening of reinforced concrete structures for improving decrease deflection and cracking at service loads. Two methods can be used for prestressing pre-tensioning and post-tensioning. In this thesis, a 3D nonlinear FEM has been used to demonstrate the behavior of PT concrete two-way slab up to failure with different tendon layout, different position, different numbers and different area of tendons. Numerical analyses package ANSYS program has been used for analysis of nonlinear FE modeling of the PT concrete two-way slab. This thesis is focused on the effect of tendon layouts and numbers of tendon on the flexural behavior of BPT two-way reinforced concrete slabs. Fifty models were studied with different tendons layout and positions. Failure loads, deflections for all models and load versus deflection relationships were studied. The prestressing force was constant for all models, that was greatly affected the failure loads and deflections.

The precision of the analysis was verified by compared with the experimental results. The results obtained by using FEA had shown that similar to the he experimental results.

The results showed that the tendon layouts have good effect on the capacity of ultimate load. The ultimate load capacity increased by using tendons in both directions of the slabs. The slab models with five tendons in both directions in bottom position showed stiffer response and higher ultimate load capacity compared to the slabs with five tendons in one direction and also those slabs without tendon. Slabs used one tendon in one direction gives small failure loads and it was very weak, because the negative moment at the supports and positive moments at mid span needs a strand to resist this applied moment. Consequently, the pre-stressed slabs deflect up wards on the application of prestress. Since the bending moment is the product of the prestressing force and eccentricity, the tendons itself will represent the shape of the bending moment diagram. The application of load types on each model greatly affects the load-deflection response and failure loads.

From Table 4.2, it can be observed that the failure load in PT in both directions about 114 % increases as compared with slab without tendons, and for PT in one direction about 13 % increase as compared with slab without tendons. And for all other cases while using tendons in both directions slabs have greater load capacity.

Also, it can be observed that the failure load in PT in both directions about 89 % increases as compared with slab PT in one direction.

The result shows the ultimate load capacity of the slab with used one tendon in two-direction is larger than the ultimate load capacity of the slab with used five tendons in one-direction.

So, for two-way slabs must be always used tendons in both directions so as to use the minimum number of tendon as an economic reason and resist higher applied load and less number of cracks.

## 5.2 Recommendations for Future Study

To follow up this study, the following topics can be suggested:

1- Study the effect of tendon layout on flexure behavior of PT concrete one way slab.

2- Study the behavior of PT concrete slab subjected to fire.

3- Study the behavior of PT concrete two way slab with opening.

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