NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

COMPARATIVE STUDY BETWEEN SOLID, HOLLOW BLOCK, FLAT AND POST-TENSIONED SLABS WITH DIFFERENT PARAMETERS

M.Sc. THESIS

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MASTER THESIS

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Approval

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Omar Ahmad

3/1/2022

Acknowledgments

First of all I would like to thank God for letting me pass through all the obstacles and difficulties.

I would like to express my deepest thanks and appreciation for my supervisor Prof. Dr. Kabir Sadeghi. I thank you professor for sharing your experience and helpful information on each step during the research. Thank you for teaching us the structural courses during undergraduate and master courses. It was my pleasure to be supervised by you.

Special thanks to Assoc. Prof. Dr. Rifat Reşatoğlu and Assist. Prof. Dr Fatemeh Nouban for their advices during this research and expanding our horizons in civil engineering.

Finally I want to thank my family and friends for their supports during the research.

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Omar Ahmad

Abstract

Comparative Study between Solid, Hollow Block, Flat and Post-Tensioned Slabs with Different Parameters

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MA, Department of Civil Engineering

January, 2022, 85 Pages

Reinforced concrete slab is a structural member filled with concrete and steel bars which included in any reinforced concrete project. There are several types of slabs that used in reinforced concrete structures like solid, hollow block, flat, waffle, post-tensioned and precast slabs. There are plenty of factors that have an effective role in choosing the slab, for instance loads, span length, economy, strength requirements and serviceability requirements. Furthermore, among the reinforced structural members, slab costs the most due to its large volume and steel bars needed. Relying on this, a comparative study has been done between solid, hollow block, flat and post-tensioned slabs. The analysis and design for the slabs were done by using SAFE software 2016 according to the ACI-318-14 code on three different span length to detect the most economical slab at each span length. At each span length the volume of concrete needed in slabs, beams and drop panels were calculated for the 4 types of slabs. In addition to that, the cut length, number, total length and weight of steel bars required for each slab were found. Finally by taking in consideration the cost of concrete, steel, hollow blocks in hollow block slab, tendons in post-tensioned slab and formwork, the total cost for each slab on different span length were found. The results obtained from the study showed that the volume of concrete needed for hollow block slab in first two cases is the least compared to the other slabs while in third case post-tensioned slab needed the least quantity. Regarding the weight of steel bars, post-tensioned slabs required the least quantity among all slabs in all cases. From the economic aspect, flat slab is the most economical in case of span 4 meters, while in case of span 6 and 8 meters post-tensioned slab is the cheapest slab. Besides, post-tensioned slab gives the architects a free space and numerous possibilities for design due to the absence of beams and greater floor to floor height.

Keywords: solid slab, hollow block slab, flat slab, post-tensioned slab, concrete

Özet

Kirişli, Asmolen, Kirişsiz Ve Ardgermeli Döşemeler Arasında Karşılaştırmalı Çalışma

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Betonarme döşeme, herhangi bir betonarme projesinde yer alan, beton ve çelik çubuklarla doldurulmuş yapı elemanıdır. Betonarme yapılarda kullanılan kirişli, asmolen, kirişsiz, kaset, ardgerme ve prekast döşeme gibi birçok döşeme çeşidi vardır. Döşeme seçiminde rol oynayan birçok faktör vardır, örneğin tasarım yükleri, açıklık uzunluğu, ekonomi, kuvvet gereksinimleri ve sehim gereksinimleri. Ayrıca, betonarme yapı elemanları arasında, büyük hacmi ve ihtiyaç duyulan çelik çubuklar nedeniyle döşeme maliyeti en yüksek olanıdır. Buna dayanarak, kirişli, asmolen, kirişsiz ve ardgermeli döşemeler arasında karşılaştırmalı bir çalışma yapılmıştır. ACI-318-14 koduna göre CSI SAFE 2016 kullanılarak, her bir açıklık uzunluğunda en ekonomik döşemeyi tespit etmek için üç farklı açıklık uzunluğu üzerinde döşemelerin analiz ve tasarımı yapılmıştır. Her açıklık uzunluğunda, 4 tip döşeme için döşeme, kiriş ve tablalar ihtiyaç duyulan beton hacmi hesaplanmıştır. Ayrıca her bir döşeme için gerekli olan çelik çubukların kesme boyu, sayısı, toplam uzunluğu ve ağırlığı da bulundu. Beton, çelik, asmolen bloklar, tendonlar ve İnşaat kalıp maliyeti dikkate alınarak farklı açıklık uzunluklarında her bir döşemenin toplam maliyeti bulunmuştur. Çalışmadan elde edilen sonuçlar, ilk iki durumda asmolen döşeme için ihtiyaç duyulan beton hacminin diğer döşemelere göre en az olduğunu, üçüncü durumda ise ardgermeli döşemeye en az ihtiyaç duyduğunu göstermiştir. Çelik çubukların ağırlığı ile ilgili olarak, ardgermeli döşeme her durumda tüm döşemeler arasında en az miktarı gerektiriyordu. Ekonomik açıdan, 4 metre açıklıkta kirişsiz döşeme en ekonomik, ama 6 ve 8 metre açıklıkta ise ardgermeli döşeme en ucuz döşemedır. Ayrıca, ardgermeli levha, kirişlerin olmaması ve zeminden zemine daha fazla yükseklik nedeniyle mimarlara serbest bir alan ve çok sayıda tasarım olanağı sağlar.

Anahtar kelimeler: kirişli döşeme, asmolen döşeme, kirişsiz döşeme, ardgerme döşeme, beton

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CHAPTER I
Introduction

1.1 Overview

Reinforced concrete slab is a structural member filled with concrete and steel bars which included in any reinforced concrete project. It can be laid on beams in which the load first transfers to beams and then to columns or directly laid on columns in which the load transfers directly to columns. There are several types of slabs that used in reinforced concrete structures like solid, hollow block, flat, waffle, post-tensioned and precast slabs. These slabs can be one way or two slabs according to the beams and the direction of load or they can be beamless slabs. When the slab is supported by beams in 2 opposite directions it is one way slab and when the slab is supported by beams in all directions it is two way slab. These types of slabs differ in construction, design, use and cost. There are many factors that play a role in choosing the slab, for instance design loads, span length, economy, strength requirements and serviceability requirements (Park & Gamble, 1999). According to each project and its requirements there is uncertainty about the best choice of slab that should be used. Therefore, this study will focus on designing different types of slabs on different span lengths and concluding which is the most preferable type of slab in short and long spans. Solid, hollow block and flat slabs are the most used slabs in all reinforced concrete structures while nowadays post-tensioned slabs started to be much popular and used in many construction projects. Economy is one of the important factors that plays a role in choosing the best type of slab. Besides by considering the formwork, volume of concrete and weight of steel needed, slab in reinforced concrete structures is considered as the most costing member compared to the structural members so it is essential to study the most economical choice of slab for the project. In this study the main purpose is to choose the most economical slab in short, medium and long spans because the span length has an efficient effects on the slab especially on deflection and moments which by the result will lead to thicker slab to control the deflection and more reinforced steel bars to resist the negative and positive moments.

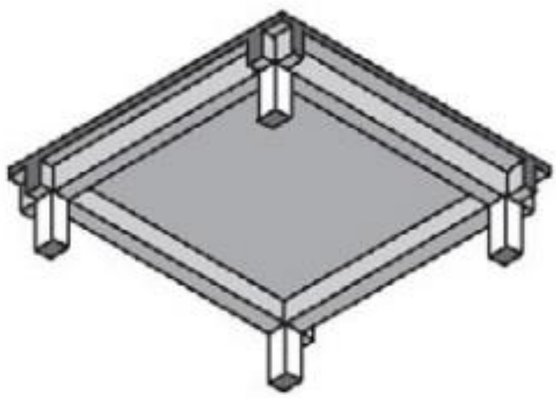
1.2 Solid Slabs

Solid slab is a traditional slab which consists of concrete and reinforced by steel bars. This type of slabs can be one way or two way solid slabs. In one way case the slab is laid on beams on one direction, the main reinforcement is on the shorter direction and the bending in one direction. In two way case the slab is laid on beams in all directions, the main reinforcement in both directions, and the bending is also in both directions as shown in Figure 1. It is recommended to use one way solid slab if the longer span over the shorter span is more than 2 while it is more recommended to use the two system if the ratio of longer span over the shorter span is less than 2.

The solid or concrete slab system consists of framing beam system into columns which are supporting the slab. As these beams go deeper the ability to resist the lateral loads is higher and it helps in providing longer spans. However, the popularity of this type of slab decreased due to many reasons. The main reasons are the complicated formwork for the deep beams, coordination of services and the floor to floor height. Solid slabs same as any other types of slabs, they have advantages and disadvantages. The advantages of solid slab are economical choice for structures with short or medium length of spans, familiar for all the contractors and local market and it is considered as an effective solution for the traditional slabs. The disadvantages of this slab are the height of floor to floor is greater, has a negative effect on any fixation related to electrical or mechanical services, not recommended for long spans due to the total cost, the thickness of slab is high in long spans and very hard to handle any penetrations for the ducts through the beams (Kiran & Issac, 2018).

Figure 1

Two Way Solid Slab (Mehta et al., 2012)



1.3 Hollow Block Slabs

Hollow block slabs consist of ribs, blocks and solid part as shown in Figure 2. This type of slab can be called hardy slab, ribbed slab, joist slab and waffle slab. Waffle slab is another name of hollow block slab when the ribs are placed in two directions, on other words when the slab is two way slab it is called waffle slab. The ribs in slab are placed between the hollow blocks and reinforced like the beams.

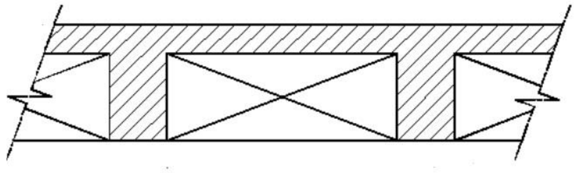
Hollow block slabs have shallow and wide beams in order to provide a ceiling like the flat slab. The depth of slab is determined in design by taking in consideration the dimensions of block between the ribs and then adding above the height of block a thin solid part. Hollow block slabs are so popular in turkey and they are widely used all over turkey. The usual depth of these slabs in turkey is approximately 30 to 32 cm. Although hollow block slabs have many benefits, they have been restricted by Turkish Earthquake Code due to the poor performance against the lateral loads. First the code allowed using this type of slabs in seismic zones with the special requirement which is having shear walls if the building height exceeds a certain height. Then the code allowed the usage of this slab without shear falls only if the structural members designed ductile (Ince et al., 2018).

Hollow block slabs are used widely all over the world in the last decades. One way hollow block slabs are preferable when the spans length between 5 to 7 meters in which the ribs are placed only in x or y direction. The load is transferred from ribs to beams in one direction and the ribs should be placed in the shorter direction. When the span is more than 7 meters, it is recommended to use two hollow block slabs where the ribs are placed in both x and y direction (Musa, 2018).

The advantages of hollow block slab are reduction in materials and weight of slab because the slab is not fully filled with concrete there are blocks on slab, economical if the formwork pans are usable again, provide long spans, easy penetration between the ribs. The disadvantages are requires special formwork, floor to floor height is greater, and controlling the fire rating may occurs due to the depth of slab (Paul, 2014).

Figure 2

Cross Section in Hollow Block Slab (Mohamed, 2014)



1.4 Flat Slabs

Reinforced concrete flat slabs have been entered the structural field since the reinforced concrete design began. Robert Millar is one of the first group father of flat bit of material in Europe. These materials nowadays are known as Millar. On 1909 Robert Millar made a series of tests on flat slab. The flat slab had been analyzed by many different values of loads and the design of the slab is also empirical (Borkar et al, 2021)

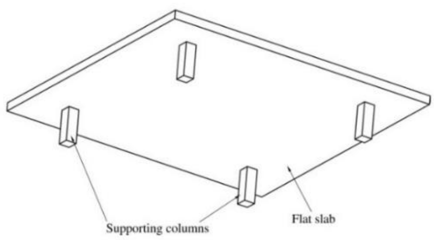
Reinforced concrete flat slab is a slab which is supported by columns directly with absence of beams as shown in Figure 3. Beamless slab is another name for flat slab. Panel is name of one part of flat slab which is bounded on the four sides by a columns while flat plate is a name for slab which does not have a column capital or drop panel. The strength is limited for the flat plates due to the punching action. For designing the flat slab, there are two different method which are direct design method and equivalent frame method (Sathawane & Deotale, 2012).

Flat slabs can be in four types which are flat slab with drop panel and column head, flat slab with column head only, flat slab with drop panel only and flat slab without drop panel and column head. Column heads are provided to the flat slab to resist the negative moments that had transferred from the slab to the columns. Drop panels are provided to the flat slab to resist the punching shear actions between the slab and the columns. Drop panels and column heads are provided to the flat slab in rare cases in order to resist the shear failure (Khan & Jeelani, 2018).

Flat slab has many advantages for instance floor height can be reduced, the time of construction can be reduced because there are no beams which will need extra time for reinforcing and formwork, provides a better ability for interior designing, dead load can be reduced and easier insertion for pipes. On the other hand flat slab has many disadvantages for example the risk of punching shear failure is high, poor performance under load of temperature, less efficiency under the lateral loads and the rigidity is less due to the slab column connection without beams (Thomas, 2020).

Figure 3

Flat Slab (Sahab et al., 2005)



1.5 Post-tensioned Slabs

Post-tensioning system is a system that can be induced in different structural members in which different types of slabs, beams, bridges and foundations were done by this system. This system is working with the help of steel tendons of high tensile strength which is about 1860 MPa. Ducts, strands, anchorage block, grout vent and wedges are components of post-tensioned slabs. After placing the steel bars on slab, the tendons are placed concavely same as the bending moment diagram same as Figure 4. Then after the concrete has been casted and the concrete achieved its strength, the tendons are stressed by hydraulic jack. Then the end of tendons are fixed by using anchorage blocks and wedges. The last step is grouting the tendons through the grout vent. The tendons have 2 ends, one called dead end as shown in Figure 5 and live end where the tendons are stretched as shown in Figure 6.

There are two types of post-tensioned slabs which are slabs with bonded or unbounded tendons. In case of unbounded slabs the forces of tendons transfer to the concrete by the end anchors. And the friction forces between the concrete and tendons are neglected because the tendons are placed in a thin ducts. In case of bonded slabs the forces of tendons transfer to the concrete by curvature of tendons, end anchors and the bond that occurred between concrete and tendons (Bailey & Ellobody, 2009).

Post-tensioned slabs system have been became so popular in the construction field in America and these slabs were mostly with unbounded tendons. The estimation of post-tensioned systems in service in America is about 2.5 billion ft^2. The bonded post-tensioned slabs are mostly used in Australia, Europe and Asia (Bondy, 2012).

Post-tensioned slab is considered as a variant of pre stressed slab where the tensioning of tendons is occurring after the concrete has been casted. The tendons are placed inside a protective duct which prevents the contact of tendons with the concrete. After casting and setting the concrete the tendons are stressed by specific needed forces and fixed up by anchors (Patil & Ismail, 2019).

In some situations like the complicated architectural plans precast can be not possible to meet the requirements of the irregular shapes. In order to meet the requirements of these complicated plans, the designers go for cast in place with the idea of post-tensioning which means tensioning the tendons after the concrete has been casted. Post-tensioning gives the engineer the flexibility in dealing with the irregular geometric shapes. Overall post-tensioning is considered as a solution for any architectural challenging applications (Kumar et al., 2014).

There are many advantages for post-tensioned slabs which are saving in concrete and steel materials due to the high tensile strength of tendons, the deflection is low, perfect protection of steel bars from the corrosion due to the good crack behavior, high fatigue strength, constant serviceability, providing longer spans, providing greater slenderness and reduction in time of construction due to the early removal of slab formwork (Singh et al., 2018).

Figure 4

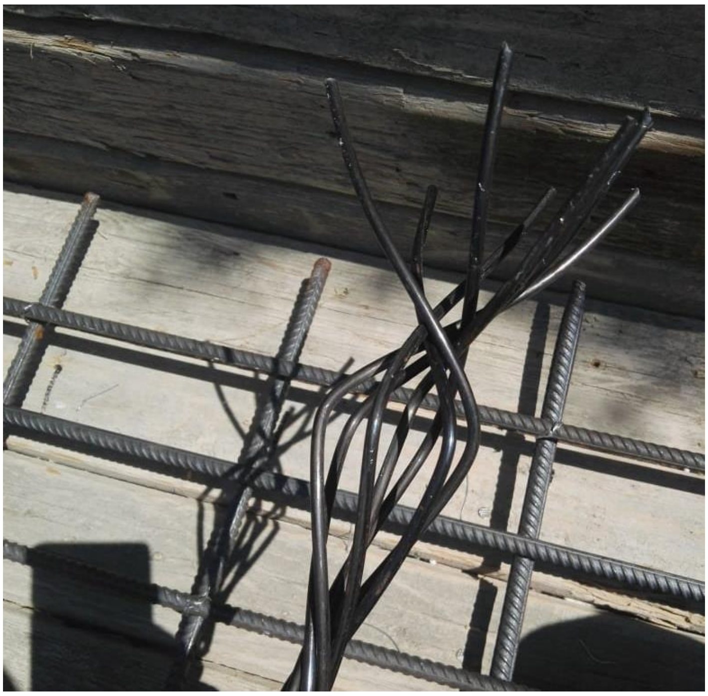
Post-tensioned Slab

Figure 5

Live End of Tendons in Post-tensioned Slab

Figure 6

Dead End of Tendons in Post-tensioned Slab



1.6 Punching Shear Failure

Punching shear failure is a phenomenon which is occurring mostly in slabs and foundations. This mechanism occurs in the beamless slabs when the slab is supported directly by columns. Because of the high concentrated load, it leads to punching through the slab. In the study cases, the flat and post-tensioned slabs are beamless slabs and there was a risk of punching shear failure.

Punching shear failure is typical collapse that mostly happen in concrete slabs. It may result from many reasons which are when the reaction is acting on small area or from a high concentrated load (Sucharda et al., 2018).

Since in beamless slabs the weight of slab and the other loads are directly move to columns from the slab, a high stress concentration around the columns develops which cause the punching shear failure. The unbalanced moments and high shear forces that moved from the slab to columns result in brittle punching failure. In order to resist and control the brittle punching shear failure, the shear reinforcement is essential (Kim & Lee, 2021).

There are major problems of beamless slab system which is punching shear failure or by other words sudden brittle failure. Controlling and overcoming this failure can be done by increasing the punching shear strength of slabs. The punching shear strength can be increased by increasing column dimensions, increasing the thickness of slab in the side of columns and by adding a shear reinforcement. Increasing the dimensions of columns may cause collapse with the architectural desire. Shear reinforcement is considered as best solution from the economic and structural aspects (Hassan et al., 2017).

1.7 Purpose of the Study

Economy is one of the most important factors that plays an essential role in choosing the appropriate slab for the structure. This research aims to make a comparison between solid, hollow block, flat and post-tensioned slab by evaluating the quantity of concrete and steel needed. After evaluating the bill of quantities, total cost at different span length were found. This leads to conclude the most economical slab at each span length while meeting the code requirements. Therefore the structural engineer will have a background about choosing the suitable slab for structure at any span length.

1.8 Significance of the Study

This study provides a quick method to analyze and design the mentioned slabs. Also it shows the way of evaluation the volume of concrete and weight of steel needed in beams, drop panels and slabs. In addition to that, it gives a wide view in evaluating the total cost of slabs by taking in consideration the materials and formwork costs. Finally the research provides an ability to the structural engineer to select the most appropriate slab for the structure.

1.9 Thesis Structure

Chapter 1 gives an introduction about the study by mentioning an overview about the slabs that will be used in the research and the objective of study. Chapter 2 includes the literature review about the comparisons that had been done between the slabs in previous researches. Chapter 3 shows the procedure of analysis and design of the slabs followed by evaluation the volume of concrete in beams, slabs and drop panels. Chapter 4 covers the results of design, total costs of slabs and comparisons between the materials and the costs. Chapter 5 shows the discussion of the study with the studies in literature. Chapter 6 indicates the conclusions that have been issued from the finals results.

CHAPTER II

Literature Review

2.1 Overview

This chapter explains briefly the comparisons that had been done between slabs in previous studies. In the previous studies, the comparisons were not between the four slabs directly, so this chapter will show these comparisons.

2.2 Comparisons between Slabs

Among post-tensioned flat slab with and without beams, flat and reinforced concrete slab with beams, post-tensioned slab is the most economical type of these slabs while the reinforced concrete slab with reinforced concrete beams is the most expensive one. By comparing post-tensioned slab and flat slab it can be concluded that the flat slab is greater than the post-tensioned slab by 27 % and 12.5% regarding the cost and thickness of slab respectively. Among the four cases the quantity of concrete and reinforcing steel is less in post-tensioned flat slab without beams and by the result the total cost of post-tensioned slab without beams is the least one. Moreover the total floor to floor height in post-tensioned slabs without beams is also the smallest one. Due to the fast removal of form work of post-tensioned slabs without beams, it is also need less time of construction than the other types of slabs. And since the time of construction is less, it results in reducing the cost because of reducing of labor charges (Bahoria et al., 2010).

By comparing the flat slab and conventional slab, the story shear is more in flat slab than the conventional slab and this is due to higher stiffness in conventional slabs. The lateral displacement is more in flat slab than the conventional slab and this is due to the higher stiffness of conventional slab which has beams (Balhar & Vyas, 2019).

Both post-tensioned and flat slabs are slabs without beams. The quantity of concrete in post-tensioned slab is less than in reinforced concrete flat slabs and this due to thinner thickness in post-tensioned slab. Also the quantity of concrete needed in columns is less in post-tensioned slab and this because the post-tensioned slabs with tendons provide longer spans than the flat slabs. Because there are tendons with high tensile strength in post-tensioned slabs, they play the role of steel bars in resisting the moments so this makes the quantity of steel bars in post-tensioned slab is less than the flat slab. Even though the cost of tendons is high but comparing to the quantity of concrete and steel saved the total cost in post-tensioned slab is less than the flat slab (Ahmad, 2021).

Due to more quantity of displacement in seismic analysis post-tensioned flat slab has more flexibility that the conventional slab. Upon comparing the normal flat slab with the conventional slab it was found that the magnitude of displacement is more in flat slab while upon comparing the conventional slab with the post-tensioned slab it was found the magnitude of displacement in post-tensioned slab less than the conventional slab by 7-10%. Post-tensioned and flat slabs have the same reactions on columns and less than the conventional slab by 28%. By comparing the forces on slabs, normal flat slab has more forces than the conventional slab while post-tensioned slab has slab forces less than the conventional slab by 60%. Among the 3 types of slabs, post-tensioned slab has the least bending moment while flat slab has the highest bending moment and by the result the area of steel needed in post-tensioned slab will be less than the other 2 types. The area of steel in post-tensioned slab is less than in conventional slab by 25% which proves that post-tensioned slab is more economical from the economic aspect (Rath et al., 2019).

After analyzing and designing the post-tensioned and reinforced concrete slab on ETABS, it was found that the quantity of steel needed for post-tensioned slab is less than reinforced concrete slab by 16.01 %, while the quantity of concrete in post-tensioned slab is greater than in reinforced concrete slab by 32.41%. Overall the total cost of post-tensioned slab more than the reinforced concrete slab by 7.39%. Although the post-tensioned slab costs more, it reduces the time of construction and provides better space and design for the architects (Tin, 2019).

Upon comparing post-tensioned slab and reinforced concrete slab on four different panels of different dimensions, the moment carrying capacity of post-tensioned slab is more than of reinforced concrete slab in the four panels in both cases of columns and middle strip. Regarding the long term deflection, in four panel's post-tensioned slab has less long term deflection than the reinforced concrete slab which shows that the serviceability of post-tensioned slab is better. In the biggest panel of dimensions 12×12 m, the quantity of steel per meter in reinforced concrete slab is more than in the post-tensioned slab by 45%, the thickness of reinforced concrete is greater by 18% and the total cost of reinforced concrete slab is greater by 13% (Ajay, 2020).

In comparison between post-tensioned, post-tensioned with beams, reinforced concrete flat and typical reinforced concrete slabs, the bending moment in post-tensioned slab is the least among the other types of slab in cases of middle and column strip. The thickness of post-tensioned slab was less than the thickness of reinforced concrete slab by 30 to 35%. The amount of steel need for resisting the bending positive and negative moments in post-tensioned slab is less than in the traditional slab by 25%. Post-tensioned slabs have many benefits that make it more preferable than the traditional reinforced slab, for example post-tensioned slab more affordable, better resisting against the seismic loads, better choice for extended panels, provides more chances for architectural look, reduces the slab thickness and it is more durable (Ahmed, 2021).

After analyzing and designing the slab by equivalent frame method, it was found that reinforced concrete slab with reinforced concrete beams is the costlier one compared to post-tensioned slab. The thickness of reinforced concrete flat is slab is greater than the thickness of post-tensioned slab by 12.5%. Same for the total cost the reinforced concrete flat slab is greater by 27%. For post-tensioned with and without beams, the quantity of steel required for post-tensioned slab without beams is 15 kg/m^2 less than in post-tensioned slabs with beams which is 20.15 kg/m^2. Among all the cases post-tensioned slabs without beams requires the least amount of concrete and steel. Also, the construction time is also the least for post-tensioned slab without beams due to the early removal of formwork which also leads to reduce in labor costs. From architectural view, post-tensioned slab provides les floor to floor height which gives free design for them (Sharma, 2021).

For both cases of simply supported and continuous end in one way slabs, post-tensioned slabs provide more moment capacity resistance than composite slab with deck sheet and reinforced concrete slab. In case of one way slab with three continuous spans reinforced concrete slab has more shear resistance than the post-tensioned slab and composite slab with deck sheet. In case of simply supported two way slab, the composite slab with deck sheet has more shear resistance than the post-tensioned and reinforced concrete slabs. Again for simply supported and continuous end of one way slab, post-tensioned slab has less deflection than composite slab with deck sheet and reinforced concrete slab. This is due to upward deflection provided by the tendons in post-tensioned slab. From the economic aspect, composite slab with deck sheet is more economical then the reinforced concrete and post-tensioned slabs by 20- 30% in case of simply supported and continuous end of one way slab. While in case of simply supported two slabs, post-tensioned slab is more economical than composite slab with deck sheet and reinforced concrete slab by 20-40% (Panchal, 2016).

Among flat, grid and two way slabs with same span length and grid size, the quantity of concrete used in flat slab is the minimum in case of slab system only, while upon making the comparison for multi-story building with all structural members it was found that the flat slab needs maximum amount of concrete and grid slab needs the minimum. For the all slabs the amount of steel needed in short spans is less than in long spans in which as the span length increases the quantity of steel increases. Since there are no beams in flat slab so the amount of shear and main reinforcement will be reduced which will make the flat slab needs the minimum quantity of steel compared to the other slabs. Flat slab has more shear forces and bending moments than the two way and grid slabs. On the other hand, flat slab is more preferable than the grid and two way slabs because of ease concrete casting, ease installation of flexural reinforcement, provides open space for water and air pipes and provides flexibility for architects. Furthermore, all of these make the flat slab more economical than grid and two way slabs and also it is also more recommended to be used in high rise buildings. Two way slabs are recommended in case of short spans while grid slabs are recommended in longer spans (Sawwalakhe & Pachpor, 2021).

By comparing post-tensioned and flat slabs in multi-story commercial building, the quantity of concrete needed in post-tensioned slab is 247 m^3 less than in reinforced concrete flat slab which is 330 m^3. Also the total cost of the commercial building with post-tensioned slabs is much less than with the reinforced concrete slabs. Hence it more economical to use post-tensioned slab in commercial building construction. Moreover, there are another benefits of post-tensioned system compared to reinforced concrete flat slab which are, the thickness of slab is much smaller and lighter weight of slab which reduces the dead load of structure (Reddy & Pradeep, 2017).

Between reinforced concrete flat and conventional slab, reinforced concrete flat slab shows maximum reaction reduction up to 80% compared to conventional slab. Also reinforced concrete flat slab shows maximum displacement addition up to 46% on X direction and 60% on Y direction compared to conventional slab. For overturning moment, reinforced concrete flat slab shows maximum reduction in overturning moment up to 92% compared to conventional slab. Finally reinforced concrete flat slab shows addition in story drift up to 50 % compared to conventional slab (Suri & Jain, 2018).

Among two way ribbed slab (waffle slab), flat slab and conventional slab of same size 7.5×7.5 m, the slab thickness of waffle slab 100 mm less than the thickness of flat and conventional slabs which are 315 and 260 mm respectively. The deflection also in waffle slab is 7.65mm less than in flat and conventional slab which are 22.9 and 31.25 mm respectively. The maximum shear force in waffle slab is 25 kN less than in flat and conventional slab which are 54 and 61.26 kN respectively. Regarding the maximum moment, conventional slab has 43.62 kN.m maximum moment less than in flat and waffle slab which are 284.11 and 56 kN.m respectively. Finally the area of steel needed to control the design and resist the moments in waffle slab is 1118.58 mm^2 less than the area of steel needed in flat and conventional slab which are 9010.5 and 1894 mm^2 respectively. Overall, conventional slab is more recommended for spans with short length and it is very easy in construction where he qualified and expert workers are not required. Flat slab is recommended in medium span length and it is faster in construction due to the absence of beams. Waffle slab is more advantageous than the conventional and flat slabs even though it requires more time in construction but on the other hand, it is appropriate for larger loads, longer spans and more economical in repetitive work (Khot et al., 2016).

Upon analyzing and designing a structure by using either solid slab or hollow block slab, it was found that in case of hollow block slab where hollow blocks used to fill the slab with reinforced concrete ribs and concrete in the solid part, the total weight of slab per square meter was 790 kg less than the total weight of solid slab which was 1228.13 kg per square meter. From the economic view the cost of beams on hollow block slab was more than the cost of beams on solid slab while the cost of hollow block slab only is less than the cost of solid slab. By adding the cost of slabs with beams, the total cost of solid slab is more than the cost of hollow block slab. Hence hollow block slab is more economical than solid slab. Because of the ribs in hollow block slab, it can be used as advantage in placing the walls on them without taking their loads much in consideration, while in solid slab the wall loads are taken in consideration by multiplying the load with a factor and then dividing over the area of slab to transform these loads to uniform distributed load. This will increase the weight of solid slab and make it heavier than the hollow block slab. Due to the hidden beams in hollow block slab, there is better ability for architects to create and implement anything according to their design while in solid slab such things cannot be implemented. The percentage saving in materials cost for hollow block slab compared to solid slab is 6.23%. The percentage saving for the labor for slabs for hollow block slab compared to solid slab is 15.59%. The percentage saving for the labor for beams for hollow block slab compared to solid slab is 58.5%. Therefore hollow block slab is recommended over the solid slab according to the advantages of hollow block and especially from the economic aspect (Mashri, 2020).

In comparison between reinforced concrete flat and conventional slab, the cost and quantity of concrete of beams in reinforced concrete flat slab is 68% less than in conventional slab. Also the cost and quantity of concrete of columns in reinforced concrete flat slab is 29.1% less than in conventional slab. Regarding the steel bars, the cost and quantity of steel bars of beams in reinforced concrete flat slab is 84.48% less than in conventional slab. Also the cost and quantity of steel bars of columns in reinforced concrete flat slab is 15.48% less than in conventional slab. Since the thickness of reinforced flat slab is thinner than thickness of conventional slab, the total weight of structure is less than in case of reinforced concrete flat slab. From economic aspect, reinforced concrete flat slab is more economical than conventional slab where the total cost of structure with reinforced concrete flat slab reduced by 15.8%. From the structural aspect, reinforced concrete flat slab is recommended in high rise building. From the architectural aspect, reinforced concrete flat slab provides free space and design for the architects for work formation and insertion (Manvi et al., 2015).

Upon comparing frames with solid and ribbed slabs, the quantity of concrete in columns and beams were approximately the same while the quantity of concrete in slab in solid was more than the quantity of concrete in ribbed slab. The total quantity of concrete in frame with solid slab was 12% more than the frame with ribbed slab. The quantity of steel in slab, columns and beams in frame with solid slab less than the quantity of steel in frame with ribbed slab. The total steel quantity for beams, columns and slab in frame with solid slab less than in frame with ribbed slab by 33%. By considering the cost of steel bars, concrete and hollow concrete blocks the total cost of frame with solid slab less than the frame with ribbed slab by 15%. Therefore frame with solid slab considered as more economical than frame with ribbed slab. Also the frame with solid slab has better displacement resistance, bending and shear behavior compared to frame with ribbed slab (Ajema & Abeyo, 2018).

Grid and conventional slabs have been compared in two different type of structures which are regular and irregular shape for structure. In case of regular shape of structure the conventional slab recorded more deflection than the grid slab while in case of irregular shape of structure grid slab recorded more deflection than the conventional slab. In the regular shape symmetric structure the deflection in conventional slab was 6.01 % more than the deflection in grid slab. In the irregular shape of asymmetric structure the deflection in conventional slab was 4.7% more than the deflection in grid slab. In the vertical irregular shape asymmetric the deflection in conventional slab was 5.57% more than the deflection in grid slab. In the irregular shape asymmetric structure the deflection in conventional slab was 3.05% more than the deflection in grid slab. In both cases regular and irregular shape of structure the story stiffness in conventional is a maximum and minimum in grid slab. Also the story shear in conventional slab is maximum while in grid slab it is minimum. Finally in the case of study, it was shown that grid slab is more economical than conventional slab (Latha & Pratibha, 2021).

CHAPTER III
Methodology

3.1 Overview

The analysis and design for the Solid, Hollow block, flat and Post-tensioned slabs had been done by using safe software 2016 according to the ACI-318-14 code. For each case the first step is setting the grids according to the span length and dimensions of slab. Then the concrete, steel and tendons materials were defined. After defining the materials, the columns, beams and slabs were defined. Defining the load patterns and load combination are the next step. After that, the slabs were modelled with assigning the loads on them. The last step is running the model and running the detailing to get the analysis and design of the slabs. The study is to find the volume of concrete and weight of steel required for each case and compare them, then to find the cost of each slab in the 3 different cases by adding the cost of concrete, steel, tendons, blocks, and formwork. After finding the cost for each slab, the next step is to find which type of slabs is the most economical in each span length.

3.2 Cases of Study

In order to deduce the most economical and effective slab at short and long spans the study of solid, hollow block, flat and post-tensioned slabs had been done in different span lengths which are 4, 6 and 8 m as explained in Figure 7. Figures 8, 9, 10 and 11 are showing the 2D view of slabs in case of span 4 m.

Figure 7

Cases of Study

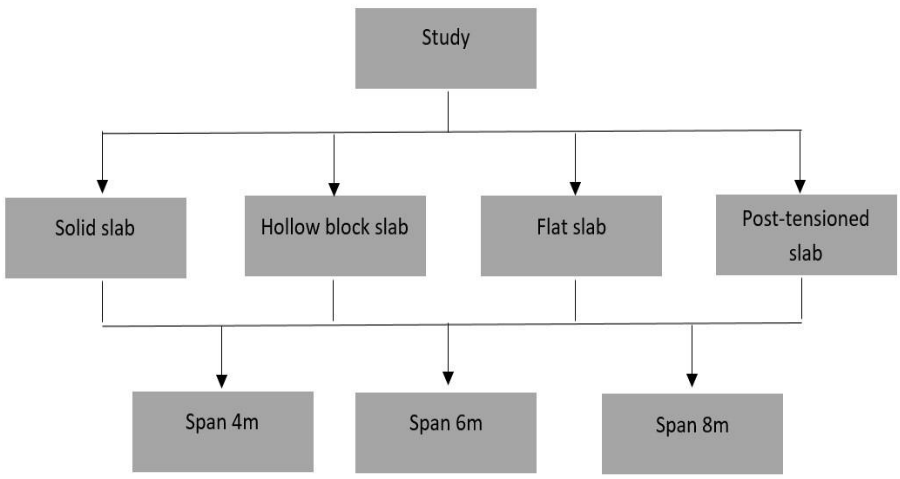


Figure 8

2D View of Solid Slab of Span 4 m

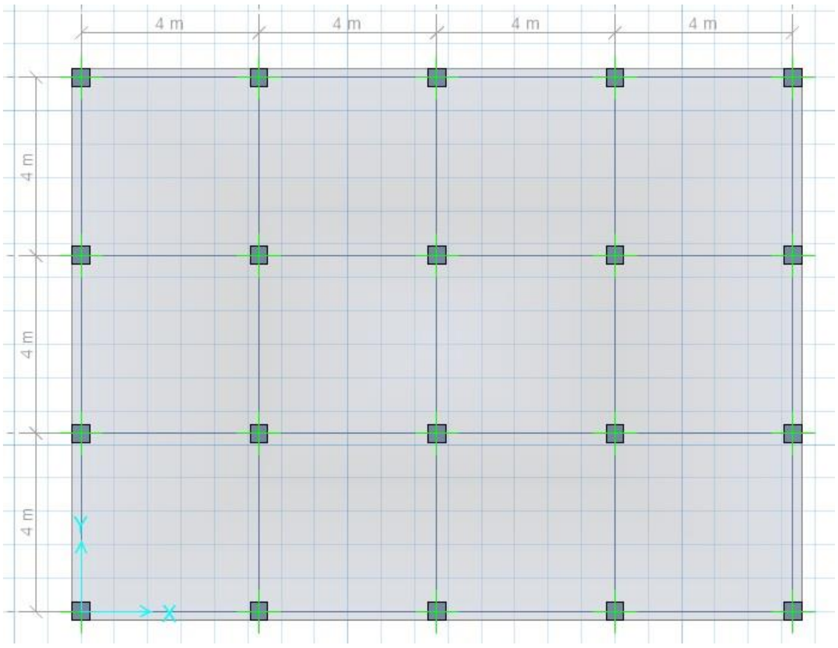


Figure 9

2D View of Hollow Block Slab of Span 4 m

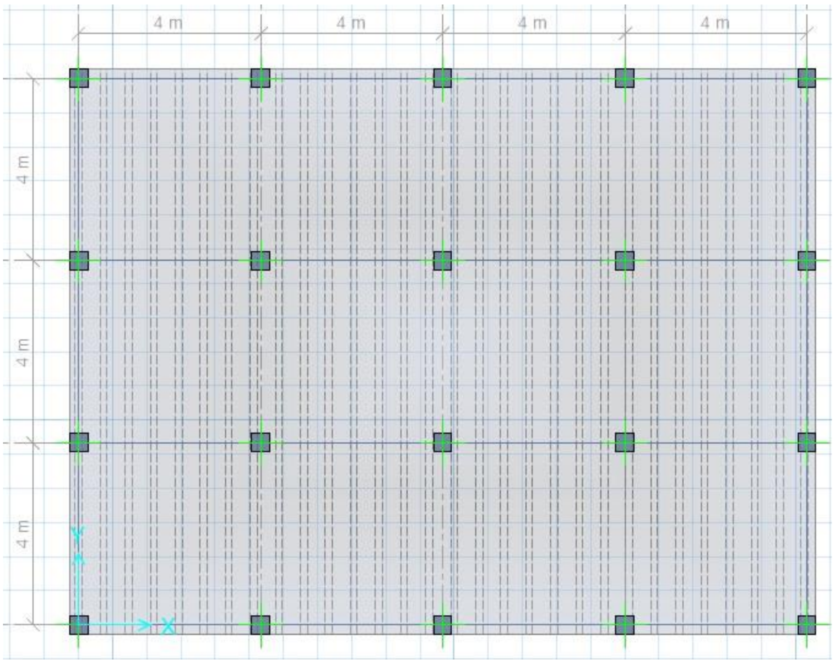


Figure 10

2D View of Flat Slab of Span 4 m

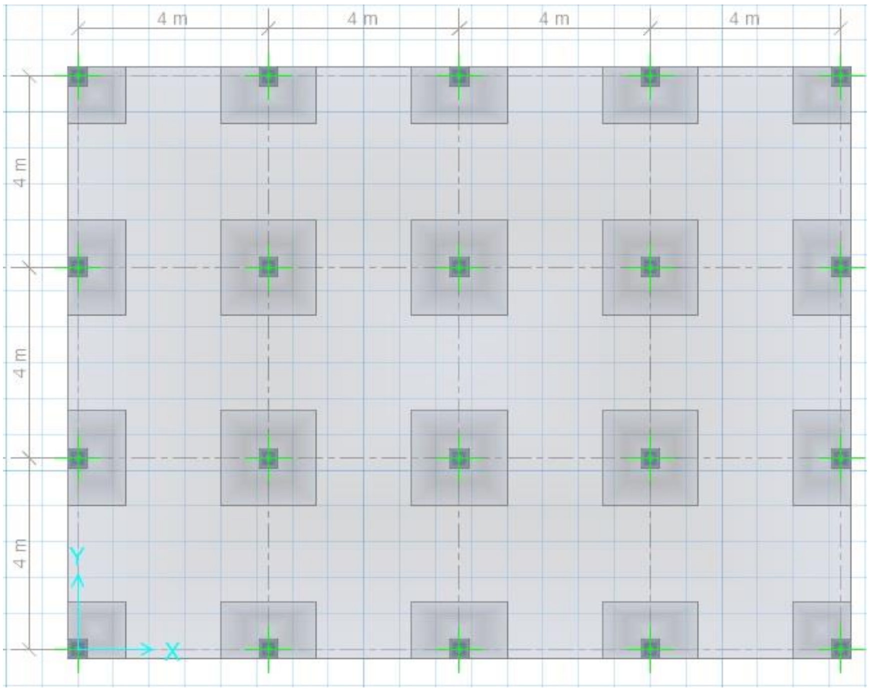
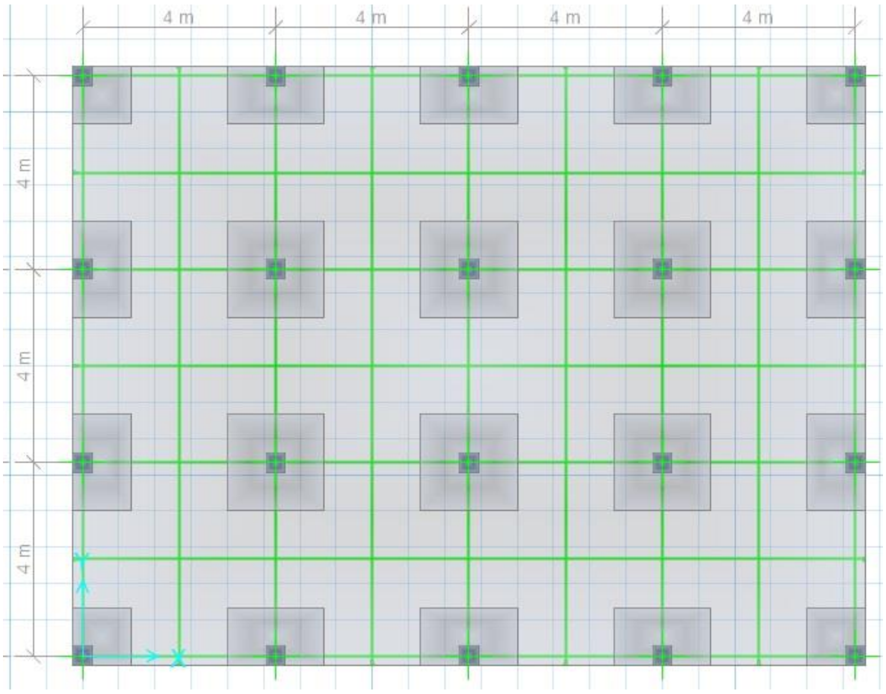


Figure 11

2D View of Post-tensioned Slab of Span 4 m



3.3 Material Properties

The materials used in the study are concrete, steel rebar and post-tensioned tendons. The compressive strength of concrete, modulus of elasticity and weight per unit volume are 30 MPa, 25742.9602 MPa and 24 kN/m^3 respectively. The yield strength, ultimate tensile strength, modulus of elasticity and weight per unit volume are 400 MPa, 500 MPa 200000 MPa and 76.98 kN/m^3 for steel and 1690 MPa, 1860 MPA, 200000 MPa and 76.98 kN/m^3 for tendons respectively as presented in Table 1.

Table 1

Material Properties

Material	Concrete Strength (MPa)	Yield Strength of Steel (MPa)	Ultimate Tensile Strength of Steel (MPa)	Modulus of Elasticity (MPa)	Weight per Unit Volume (kN/m^3)
Concrete	30	-	-	25742.9602	24
Steel	-	400	500	200000	76.98
Tendon	-	1690	1860	200000	76.98

3.4 Load Patters and Combinations

By assuming that the floor for each type of slab is residential building, the live load for rooms and corridors with the load of internal walls can be 3.5 kN/m^2. For the dead load the software calculates automatically the self-weight of slab, while the others dead loads are calculated as shown in Table 2. Also the load of external walls is considered to be dead load so the total dead load can be also 3.5 kN/m^2.

Table 2

Dead Load Calculation

Material	Unit Weight (kN/m^3)	Thickness (m)	Weight (kN/m^2)
Tiles	25	0.025	0.625
Mortar	22	0.025	0.55
Gypsum	22	0.015	0.33
Aggregates	18	0.08	1.44
Plaster	22	0.015	0.33

There are two load combinations used in the study. The first load combination is for checking the deflection and the second load combination is for ultimate design.

Service: Dead load+ Live load

Ultimate design: 1.2 Dead load+ 1.6 Live load

3.5 Beam Dimensions

Post-tensioned and flat slabs are slabs without beams in which the load moves directly to columns. Table 3 shows the beam's dimensions for solid and hollow block slab.

Table 3

Beam Dimensions

Slab	Beam Dimensions (mm)
Solid	300 × 600
Hollow Block	300 × 600
Post-tensioned	-
Flat	-

3.6 Evaluation the Volume of Beams

There is no beams in post-tensioned and flat slabs while in solid and hollow block there are beams in 1 or 2 directions according to the span length. Solid slabs are two way slab in which there are beams in all directions in the 3 cases while in hollow block slabs, there are beams in 1 direction in cases 1 and 2 and beams in 2 directions in case3. Tables 4, 5 and 6 show the evaluation of the volume of beams in all cases.

Table 4

Volume of Beams in Span 4 m

Slab	Beam Length (m)	Beam Width (m)	Beam Depth (m)	Number	Volume (m^3)
Solid	4	0.3	0.6	31	22.32
Hollow Block	4	0.3	0.6	22	15.84
Post-tensioned	-	-	-	-	-
Flat	-	-	-	-	-

Table 5

Volume of Beams in Span 6 m

Slab	Beam Length (m)	Beam Width (m)	Beam Depth (m)	Number	Volume (m^3)
Solid	6	0.3	0.6	31	33.48
Hollow Block	6	0.3	0.6	22	23.76
Post-tensioned	-	-	-	-	-
Flat	-	-	-	-	-

Table 6

Volume of Beams in Span 8 m

Slab	Beam Length (m)	Beam Width(m)	Beam Depth (m)	Number	Volume (m^3)
Solid	8	0.3	0.6	31	44.64
Hollow Block	8	0.3	0.6	31	44.64
Post-tensioned	-	-	-	-	-
Flat	-	-	-	-	-

Volume of beams can be evaluated by multiplying the length, width, depth and number of beams. As shown in Table 4 the volume of beams in case of span 4 m are around 22 and 16 m^3 in solid and hollow block slabs respectively. Table 5 shows that the volume of beams in solid and hollow block slabs in case of span 6 m are around 33 and 24 m^3 respectively. Table 6 shows that the volume of beams in solid and hollow block slabs in case of span 8 m are the same which is around 45 m^3.

3.7 Evaluation the Volume of Drop Panels

In post-tensioned and flat slabs, the drop panels were essential in order to control the punching. Tables 7 and 8 show that the volume of drop panels were the same in first 2 cases while Table 9 shows the volume of drop panels in third case.

Table 7

Volume of Drop panels in Span 4 m

Drop panel	Length (m)	Width (m)	Depth (m)	Number	Volume (m^3)
1	1.2	1.2	0.35	4	2.016
2	1.2	2	0.35	10	8.4
3	2	2	0.35	6	8.4

Table 8

Volume of Drop panels in Span 6 m

Drop panel	Length (m)	Width (m)	Depth (m)	Number	Volume (m^3)
1	1.2	1.2	0.35	4	2.016
2	1.2	2	0.35	10	8.4
3	2	2	0.35	6	8.4

Table 9

Volume of Drop panels in Span 8 m

Drop panel	Length (m)	Width (m)	Depth (m)	Number	Volume (m^3)
1	1.7	1.7	0.45	4	5.202
2	1.7	3	0.45	10	22.95
3	3	3	0.45	6	24.3

According to the different location of column in slab the dimensions of drop panels were different. There were 3 different dimensions in each case. The volume of drop panels can be found by multiplying the length, width, depth and number of drop panels. Tables 7 and 8 show the volume of drop panels in flat and post-tensioned slabs in cases of spans 4 and 6 m which are the same in both cases in which the volumes were around 2 , 8 and 8 m^3 in drop panels 1, 2 and 3 respectively. Table 9 shows the volume of drop panels in flat and post-tensioned slabs in case of span 8 m which were around 5, 23 and 24 m^3 in drop panels 1, 2 and 3 respectively.

3.8 Evaluation the Volume of Slabs

The slab's dimensions for the first, second and third case were 12×16 m, 18×24 m and 24×32 m respectively. In order to control the deflection the thickness of slabs were different in the 3 cases. In first case the slab thickness for solid, flat and post-tensioned slabs were 10 cm and 15 cm in hollow block slab as shown in Table 10. In second and third case the thickness of slab increased to increase the stiffness and control the deflection, so the thickness of solid, hollow block, flat and post-tensioned slabs are 14, 22, 17 and 13 cm and 20, 22, 24 and 15 cm respectively as shown in Tables 11 and 12.

Table 10

Volume of Slabs in Span 4 m

Slab	Thickness (m)	Length (m)	Width (m)	Volume (m^3)
Solid	0.1	16	12	19.2
Hollow Block	0.15	16	12	14.82
Post-tensioned	0.1	16	12	19.2
Flat	0.1	16	12	19.2

Table 11

Volume of Slabs in Span 6 m

Slab	Thickness (m)	Length (m)	Width (m)	Volume (m^3)
Solid	0.14	24	18	60.48
Hollow Block	0.22	24	18	47.65
Post-tensioned	0.13	24	18	56.16
Flat	0.17	24	18	73.44

Table 12

Volume of Slabs in Span 8 m

Slab	Thickness (m)	Length (m)	Width (m)	Volume (m^3)
Solid	0.2	32	24	153.6
Hollow Block	0.22	32	24	116.04
Post-tensioned	0.15	32	24	115.2
Flat	0.24	32	24	184.32

The volume of slabs were calculated by multiplying the length, width and thickness of slabs. Table 10 shows that the volume of solid, flat and post-tensioned slabs in case of span 4 were the same which is about 19 m^3 while the volume of hollow block slab was about 15 m^3. Table 11 represents the volume of solid, hollow block, flat and post-tensioned slabs in case of span 6 m which are about 60, 48, 73 and 56 m^3 respectively. Table 12 represents the volume of solid, hollow block, flat and post-tensioned slabs in case of span 8 m which are about 154, 116, 184 and 115 m^3 respectively.

CHAPTER IV
Findings and Discussions

4.1 Overview

In this chapter the deflection of each slab in each case will be checked first. Then the punching in flat and post-tensioned slabs will also be checked. After that the reinforcement needed for each slab will be found. Then the total cost for each slab in all cases will be evaluated. Finally a comparison between the slabs in different cases will be done regarding the materials and total costs.

4.2 Check for Deflection

Deflection check is essential to make sure that the thickness of slab is enough to control it. Deflection can be controlled by increasing the thickness of slab which will increase the moment of inertial which will increase the stiffness that controls the deflection. Figures 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 23 show the deflection diagrams of slabs on each span length. By taking in consideration that the maximum allowed deflection is L/240, in all cases the deflection was less than maximum allowed deflection.

Figure 12

Deflection in Solid Slab of Span 4 m

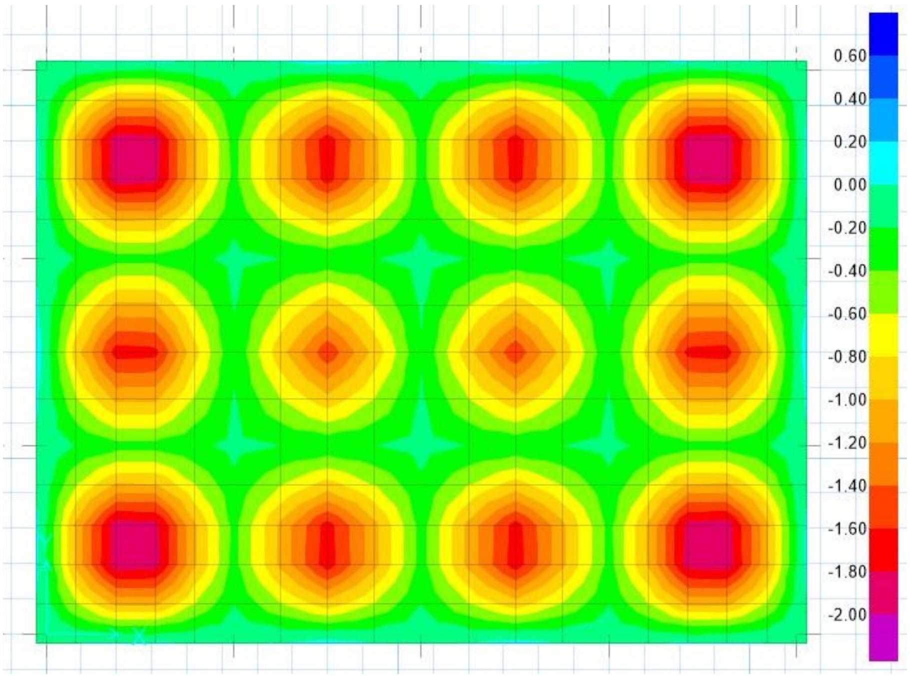


Figure 13

Deflection in Solid Slab of Span 6 m

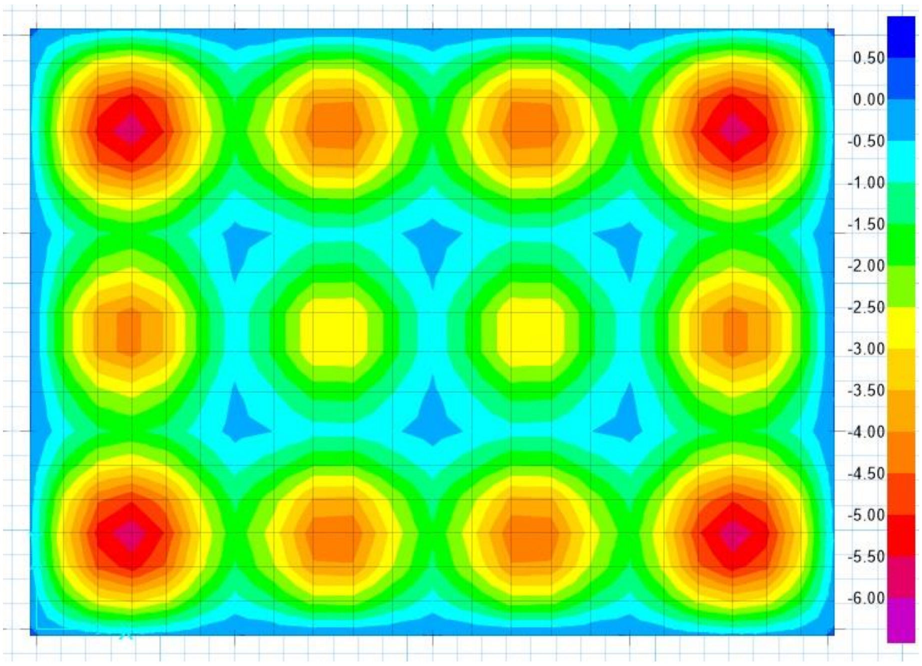


Figure 14

Deflection in Solid Slab of Span 8 m

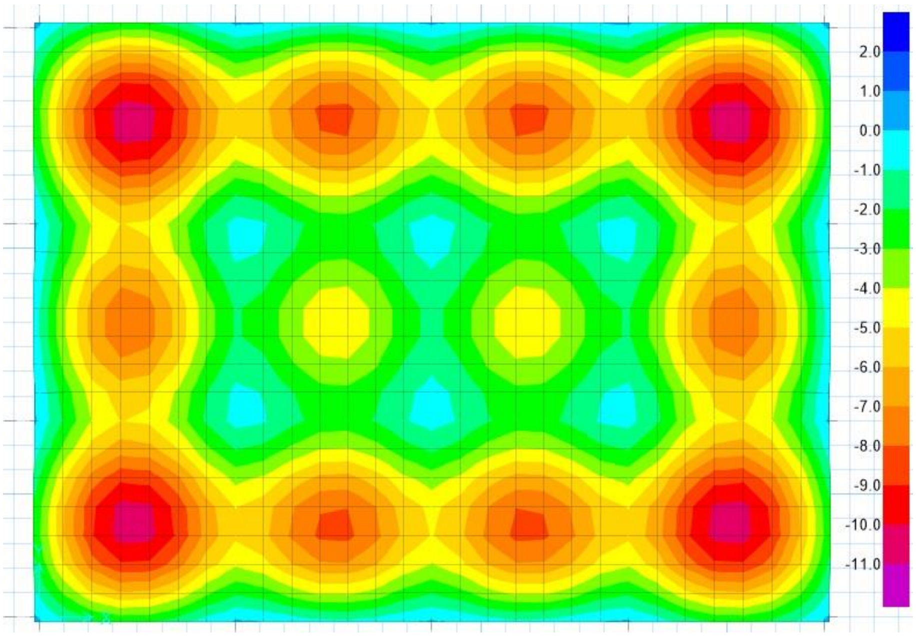


Figure 15

Deflection in Hollow Block Slab of Span 4 m

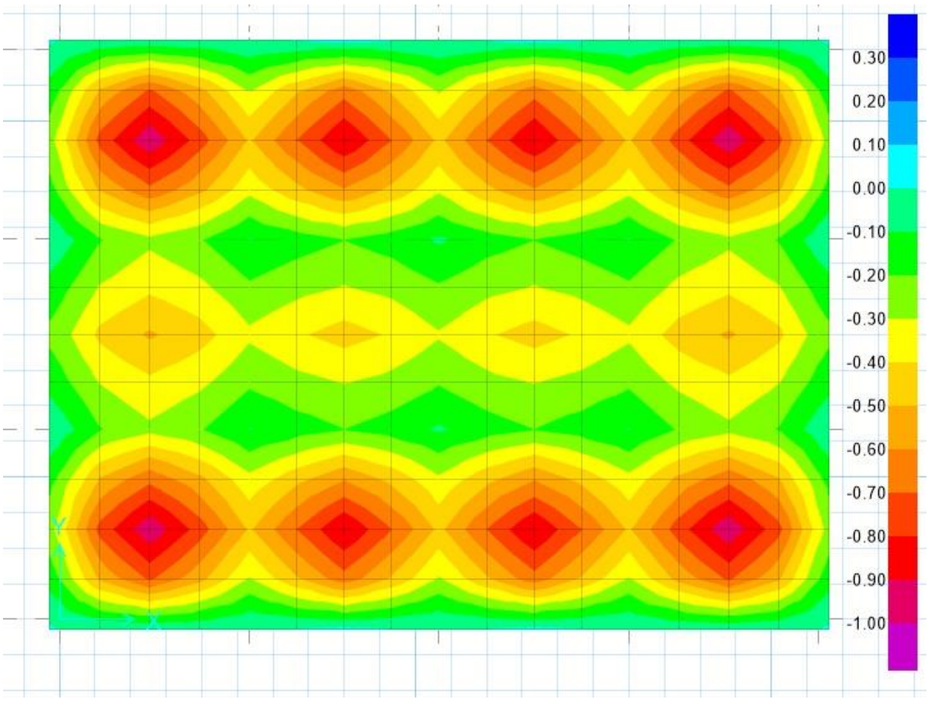


Figure 16

Deflection in Hollow Block Slab of Span 6 m

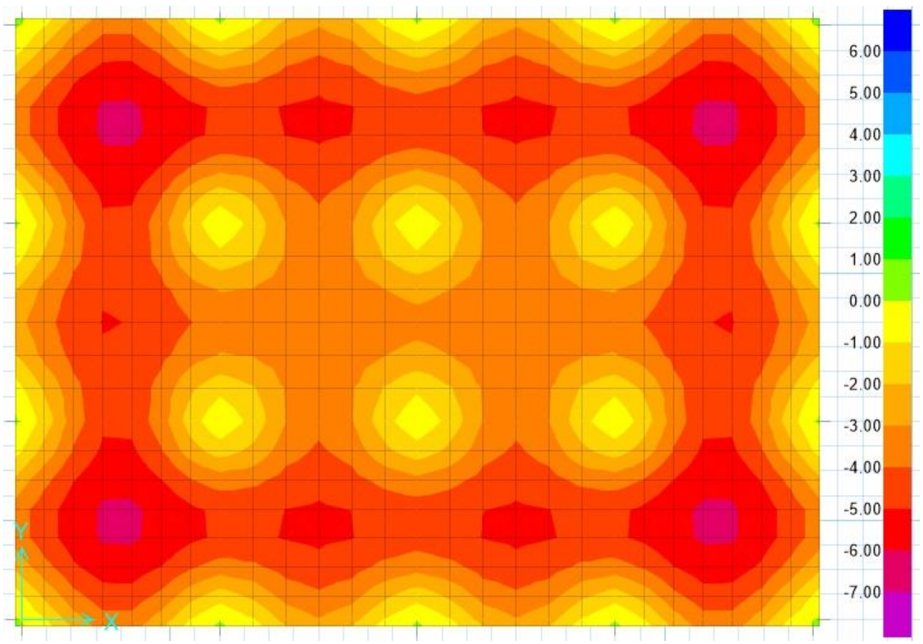


Figure 17

Deflection in Hollow Block Slab of Span 8 m

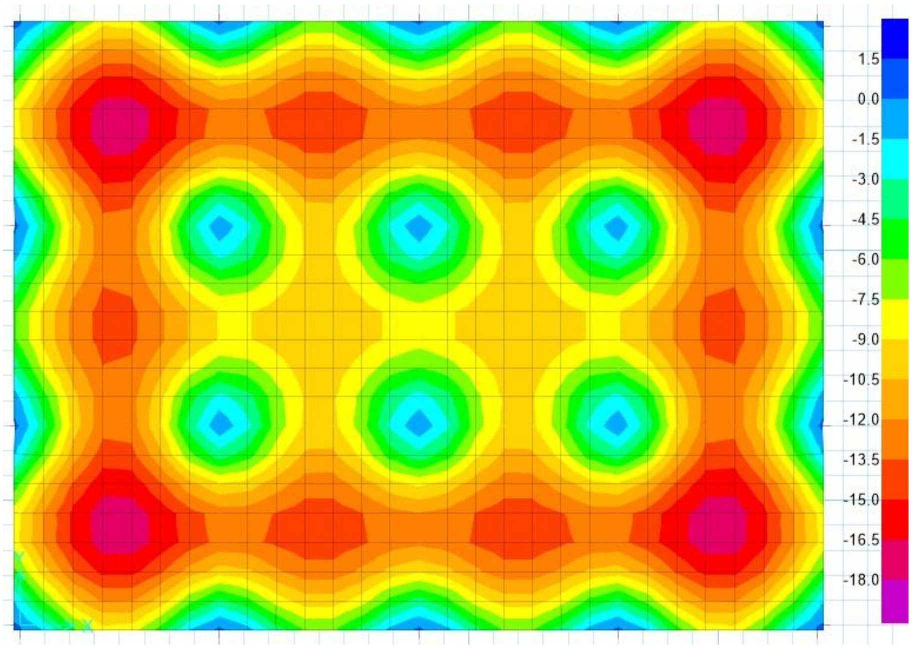


Figure 18

Deflection in Flat Slab of Span 4 m

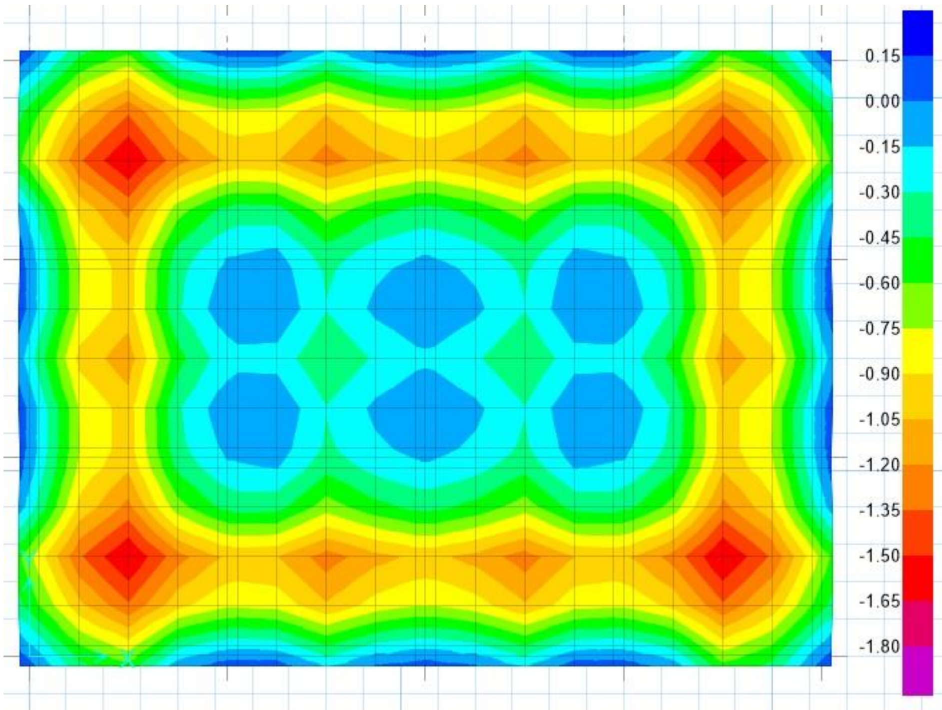


Figure 19

Deflection in Flat Slab of Span 6 m

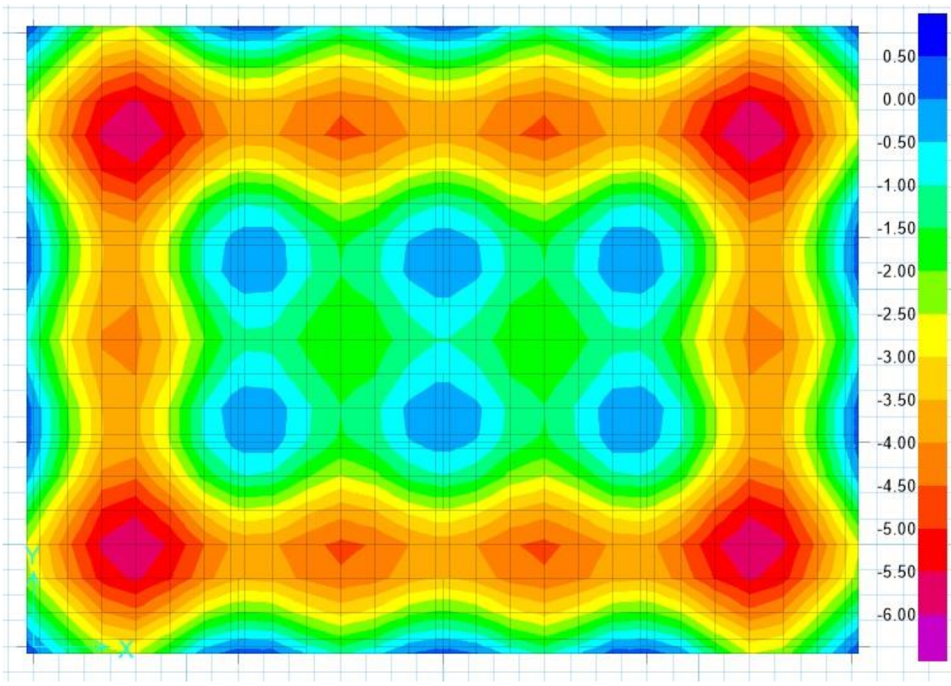


Figure 20

Deflection in Flat Slab of Span 8 m

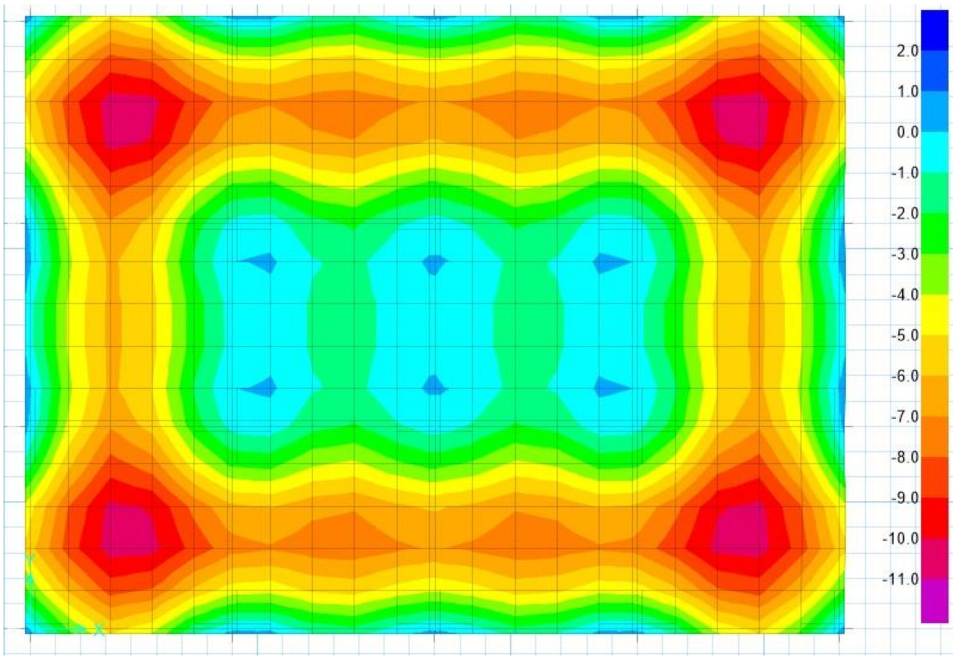


Figure 21

Deflection in Post-tensioned Slab of Span 4 m

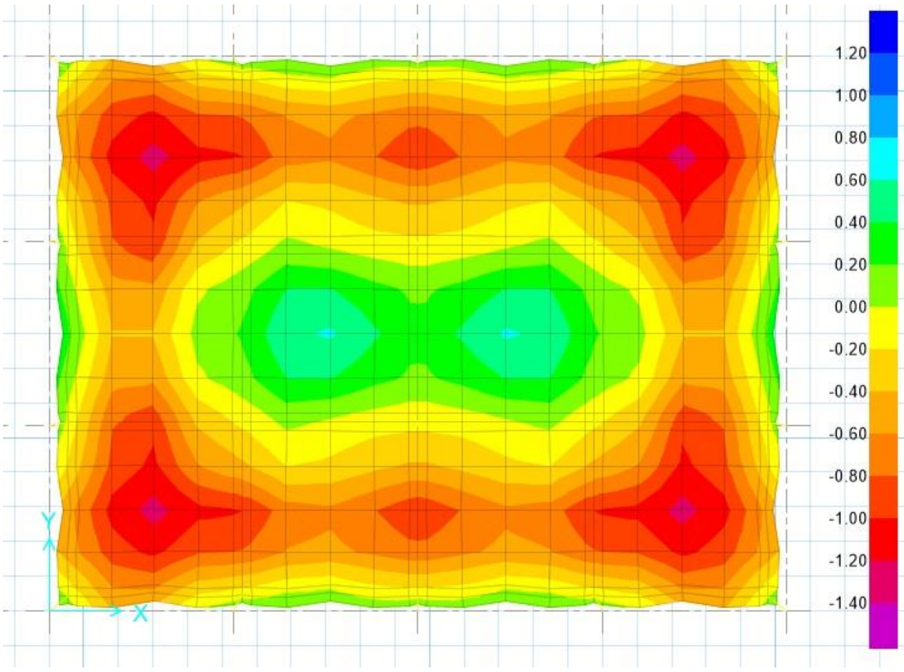


Figure 22

Deflection in Post-tensioned Slab of Span 6 m

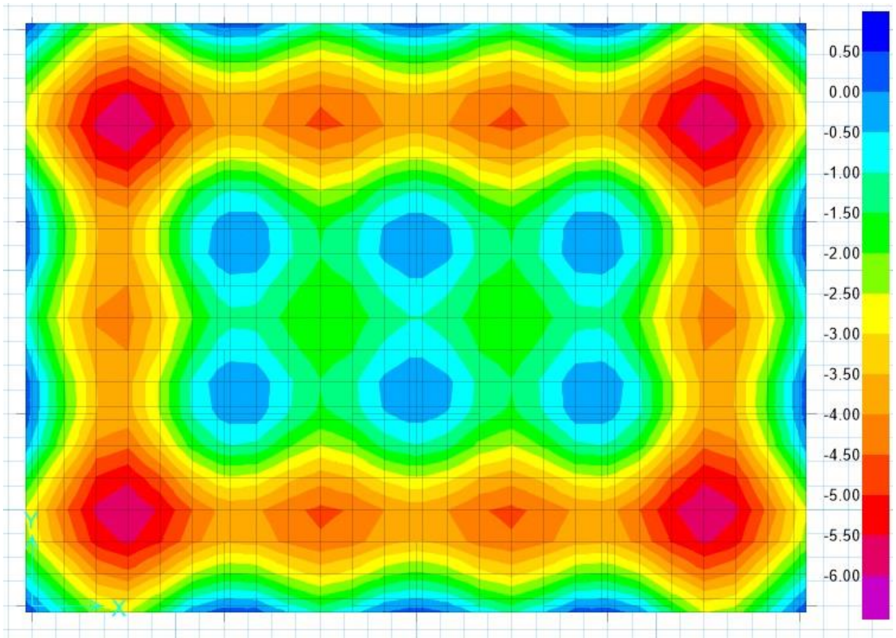


Figure 23

Deflection in Post-tensioned Slab of Span 8 m

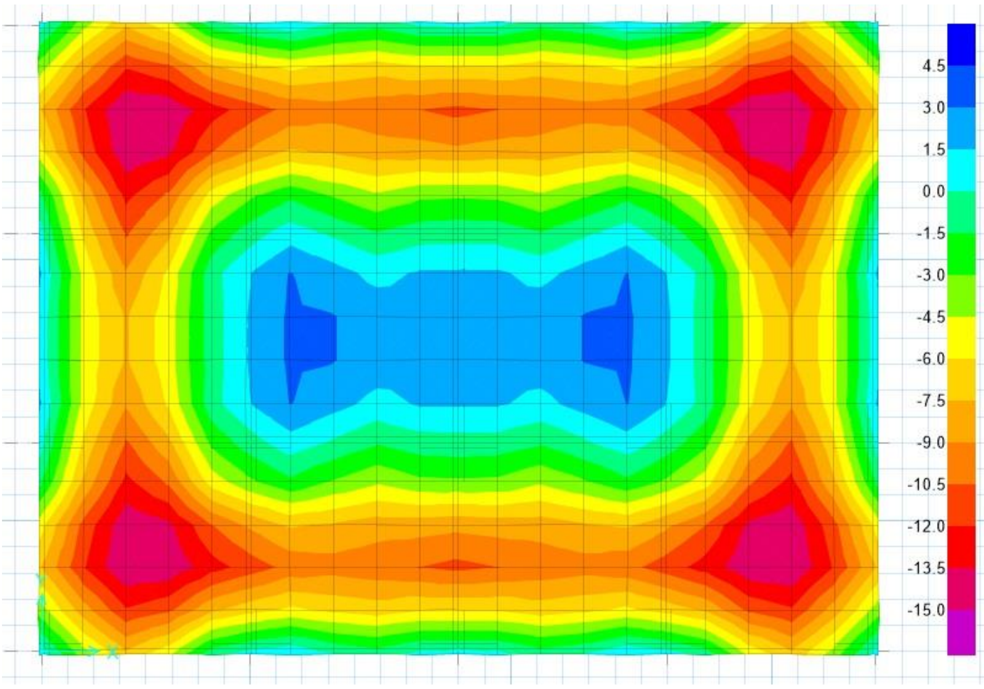


Figure 12 shows the maximum deflection in solid slab of span 4 m which is about 2 mm, Figure 13 shows the maximum deflection in solid slab of span 6 m which is about 6 mm, Figure 14 shows the maximum deflection in solid slab of span 8 m which is about 11 mm, Figure 15 shows the maximum deflection in hollow block slab of span 4 m which is about 1 mm, Figure 16 shows the maximum deflection in hollow block slab of span 6 m which is about 7 mm, Figure 17 shows the maximum deflection in hollow block slab of span 8 m which is about 18 mm, Figure 18 shows the maximum deflection in flat slab of span 4 m which is about 1.8 mm, Figure 19 shows the maximum deflection in flat slab of span 6 m which is about 6 mm, Figure 20 shows the maximum deflection in flat slab of span 8 m which is about 11 mm, Figure 21 shows the maximum deflection in post-tensioned slab of span 4 m which is about 1.4 mm, Figure 22 shows the maximum deflection in post-tensioned slab of span 6 m which is about 6 mm and Figure 23 shows the maximum deflection in post-tensioned slab of span 8 m which is about 15 mm. The maximum deflection allowed is about 16.6, 25 and 33.3 in case of spans 4, 6 and 8 m respectively. This means that the deflection in all cases is controlled.

4.3 Check for Punching Shear

For flat and post-tensioned slab there was a possibility of shear failure and that's why the drop panels were added. After analyzing the models, the punching shear ratio for flat and post-tensioned slabs were checked as mentioned in Tables 13, 14 and 15.

Table 13

Punching Shear Ratio in Span 4 m

	Coordinates (m)		Punching Shear Ratio	
Column	x	y	Flat Slab	Post-tensioned Slab
1	0	0	0.29	0.33
2	4	0	0.27	0.28
3	8	0	0.22	0.22
4	12	0	0.27	0.28
5	16	0	0.29	0.33
6	0	4	0.27	0.27
7	4	4	0.37	0.37
8	8	4	0.29	0.23
9	12	4	0.37	0.37
10	16	4	0.27	0.27
11	0	8	0.27	0.27
12	4	8	0.37	0.37
13	8	8	0.29	0.23
14	12	8	0.37	0.37
15	16	8	0.27	0.27
16	0	12	0.29	0.33
17	4	12	0.27	0.28
18	8	12	0.22	0.22
19	12	12	0.27	0.23
20	16	12	0.29	0.33

Table 14

Punching Shear Ratio in Span 6 m

Column	Coordinates (m)		Punching Shear Ratio	
	x	y	Flat Slab	Post-tensioned Slab
1	0	0	0.77	0.91
2	6	0	0.62	0.73
3	12	0	0.55	0.67
4	18	0	0.62	0.73
5	24	0	0.77	0.91
6	0	6	0.62	0.71
7	6	6	0.6	0.65
8	12	6	0.5	0.52
9	18	6	0.6	0.65
10	24	6	0.62	0.71
11	0	12	0.62	0.71
12	6	12	0.6	0.65
13	12	12	0.5	0.52
14	18	12	0.6	0.65
15	24	12	0.62	0.71
16	0	18	0.77	0.91
17	6	18	0.62	0.73
18	12	18	0.55	0.67
19	18	18	0.62	0.73
20	24	18	0.77	0.91

Table 15

Punching Shear Ratio in Span 8 m

Column	Coordinates (m)		Punching Shear Ratio	
	x	y	Flat Slab	Post-tensioned Slab
1	0	0	0.8	0.91
2	8	0	0.67	0.75
3	16	0	0.56	0.61
4	24	0	0.27	0.75
5	32	0	0.68	0.91
6	0	8	0.8	0.73

Table 15 (Continued).

7	8	8	0.66	0.79
8	16	8	0.84	0.62
9	24	8	0.67	0.79
10	32	8	0.84	0.73
11	0	16	0.66	0.73
12	8	16	0.84	0.79
13	16	16	0.67	0.62
14	24	16	0.84	0.79
15	32	16	0.66	0.73
16	0	24	0.8	0.91
17	8	24	0.67	0.75
18	16	24	0.56	0.61
19	24	24	0.68	0.75
20	32	24	0.8	0.91

Tables 13, 14 and 15 illustrate the punching shear ratio of flat and post-tensioned slabs in cases 4, 6 and 8 m respectively. The punching shear ratio must be less than 1 in order to control the punching. Without drop panels the punching shear ratios were more than 1, that's why the drop panels were added. Since the span length increased in second and third cases, the dimensions of drop panels had to be increased also in order to control the punching. After adding the drop panels the punching shear ratios were checked and the Tables 13, 14 and 15 show that the punching shear ratios are less than 1 which means that the punching is controlled.

4.4 Reinforcing Requirements for Slabs

After modelling and analyzing the slabs on safe software, the steel bars required for slabs to resist the positive and negative moments were found. For the flat and post-tensioned slab the steel bars found are the reinforcement for both slabs and drop panels while for solid and hollow block slabs the steel found are for slabs only. Tables 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 show the diameter, cut length, numbers and total length of bars.

Table 16

Total Length of Steel Bars for Solid Slab in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	1.66	110	182.02
10	8.6	2	17.2
10	5.6	2	11.2
10	4.6	2	9.2
10	1.6	2	3.2
10	1.16	2	2.3
10	4.8	9	43.14
10	3.8	26	98.88
10	4.28	36	154.1
10	4.38	22	96.16
10	3.3	33	109.06
10	4.58	17	77.8
10	2.9	144	416.72
10	4.5	69	310.02
10	3.92	15	58.86
10	6.22	4	24.88
10	2.38	6	14.32
10	8.04	4	32.16
10	6.28	6	37.64
10	2.16	4	8.66
10	1.22	4	4.84
10	3.06	7	21.46
10	6.64	34	225.64
10	5.64	4	22.54
10	0.68	16	58.96
10	3.54	8	28.32
10	5.34	18	96.14

Table 17

Total Length of Steel Bars for Solid Slab in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.46	24	59.02
10	1.56	86	134.42
10	5.22	24	125.42
10	2.7	16	43.2
10	5.4	118	637.2
10	3.86	6	23.12
10	6.5	296	1921.94
10	5.56	74	410.96
10	5.98	18	107.64
10	1.86	84	155.8
10	3.46	148	512.5
10	3.72	38	141.66
10	4.5	98	441.48
10	2.34	46	107.58
10	6.24	32	199.82
10	2.52	55	138.18
10	2.4	21	50.4
10	4.8	21	100.9
10	3.4	116	394.62
10	3	10	30
10	5	8	40
10	2.8	28	78.4
10	3.6	56	201.2
10	1.66	24	39.76
10	5.64	18	101.4
10	2.24	18	40.16
10	1.94	26	50.34
10	3.26	54	176.4
10	1.74	26	45.42

Table 18

Total Length of Steel Bars for Solid Slab in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.7	174	471.16
10	5.2	196	1019.9
10	3.2	338	1081.6
10	4.8	14	67.2
10	1.9	116	221.3
10	8.44	566	4780.56
10	0.3	158	1153.94
10	6.3	69	435.04
10	2.06	146	301.9
10	3.7	420	1552.5
10	3.56	102	362.4
10	7.1	232	1647.98
10	5.9	18	637.72
10	5.38	32	172.3
10	5.26	92	483.7
10	3.64	184	669.96

Table 19

Total Length of Steel Bars for Hollow Block Slab in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	1.62	184	297.66
10	2.6	486	1263.6
10	4.46	168	748.64
16	4.52	124	561.26

Table 20

Total Length of Steel Bars for Hollow Block Slab in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	6.32	1333	8428.28
10	2.12	554	1173.24
10	6.46	84	542.32
10	1.98	18	35.6

Table 21

Total Length of Steel Bars for Hollow Block Slab in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.72	836	2272.06
10	4.8	791	3796.8
10	4.92	411	2022.12
10	2.58	176	453.68
10	8.32	840	6991.14
10	5.02	1182	5940.5
16	8.32	208	1731.14
16	8.52	200	1705.26

Table 22

Total Length of Steel Bars for Flat Slab in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	10.08	6	60.42
10	6.38	6	38.24
10	6.34	13	82.42
10	5.6	12	67.3
10	4.5	152	682.94
10	3.8	56	213
10	3.3	17	56.18
10	8.6	60	516
10	4.6	14	64.4
10	3.7	54	199.98
10	3.1	28	86.94
10	1.6	58	93.26
10	3.88	24	93.16
10	2.36	14	33.12
10	3.22	10	32.2
10	1.9	24	45.66
10	1.1	18	19.94
10	6.26	16	100.1
10	2.78	6	16.66
10	6.28	14	87.88

Table 23

Total Length of Steel Bars for Flat Slab in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.1	228	480.58
10	4.6	350	1610
10	2.74	36	98.42
10	2.5	84	210
10	1.5	80	120.62
10	6.5	412	2675.14
10	5.56	162	899.66
10	4.8	75	360.36
10	1.68	16	26.8
10	5.4	250	1350
10	4.5	50	225.24
10	2.8	109	305.44
10	2.64	109	287.16
10	5	42	210

Table 24

Total Length of Steel Bars for Flat Slab in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.7	287	777.14
10	5.46	194	1059.48
10	3.2	286	915.2
10	4.8	92	441.6
10	1.9	95	181.24
10	2.6	18	46.94
10	8.58	117	1003.44
10	6.7	8	53.66
10	7.86	16	125.9
10	6.88	8	55.08
10	2.32	2	4.66
10	8.42	16	134.72
10	7.8	82	639.6

Table 24 (Continued).

10	2.18	9	19.7
10	8.34	82	683.14
10	5.9	10	59.04
10	6.3	7	44.14
12	8.28	33	273.06
12	5.9	20	118.1
12	6.3	10	63.04
14	8.26	44	363.82
14	5.9	20	118.1
14	6.3	20	126.1
16	3.68	38	139.76
16	3.38	38	128.5
16	3.28	93	305.94
16	5.78	168	971.58
16	7.1	113	801.32
16	6.3	18	113.48
16	7.3	142	1035.38
16	8.6	282	2422.72

Table 25

Total Length of Steel Bars for Post-tensioned Slab in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	4.5	136	611.06
10	3.8	63	239.62
10	3.3	17	56.18
10	4.78	18	86.16
10	4.56	20	91.38

Table 26

Total Length of Steel Bars for Post-tensioned Slab in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	2.6	17	44.34
10	4.1	36	147.6
10	2.6	14	36.4
10	2.1	2	4.22

Table 26 (Continued).

10	6.5	90	584.38
10	5.56	50	277.68
10	4.86	2	9.7
10	6.52	4	26.08
10	5.8	2	11.58
10	4.6	44	202.4
10	3	24	72.08
10	2.06	10	20.64
10	2.88	22	63.38
10	4.2	2	8.4
10	5.18	4	20.72
10	5.4	2	10.8
10	3.6	15	54
10	2.4	10	24
10	5.1	9	45.9

Table 27

Total Length of Steel Bars for Post-tensioned Slab in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
10	3.92	28	109.66
10	2.62	26	68.26
10	7	104	727.28
10	6	34	203.7
10	1.88	44	82.76
10	1.78	78	138.9
10	8.5	247	2097.78
10	7.1	10	71.04
10	2.7	93	251.82
10	7.3	154	1124.72
10	6.94	21	145.82
10	838	17	142.48
10	6.28	5	31.42
10	1.88	22	41.58
10	6.72	10	67.24
10	7.02	5	35.14

Table 16 shows the total length of steel bars needed in solid slab of span 4 m which is around 2165 m of diameter 10 mm. Table 17 shows the total length of steel bars needed in solid slab of span 6 m which is around 6509 m of diameter 10 mm. Table 18 shows the total length of steel bars needed in solid slab of span 8 m which is around 15059 m of diameter 10 mm. Table 19 shows the total length of steel bars needed in hollow block slab of span 4 m which is around 2310 m of diameter 10 mm and 561 m of diameter 16 mm. Table 20 shows the total length of steel bars needed in hollow block slab of span 6 m which is around 10179 m of diameter 10 mm. Table 21 shows the total length of steel bars needed in hollow block slab of span 8 m which is around 21476 m of diameter 10 mm and 3436 m of diameter 16 mm. Table 22 shows the total length of steel bars needed in flat slab of span 4 m which is around 2590 m of diameter 10 mm. Table 23 shows the total length of steel bars needed in flat slab of span 6 m which is around 8860 m of diameter 10 mm. Table 24 shows the total length of steel bars needed in flat slab of span 8 m which is around 6245 m of diameter 10 mm, 454 m of diameter 12 mm, 608 m of diameter 14 mm and 5919 m of diameter 16 mm. Table 25 shows the total length of steel bars needed in post-tensioned slab of span 4 m which is around 1084 m of diameter 10 mm. Table 26 shows the total length of steel bars needed in post-tensioned slab of span 6 m which is around 1664 m of diameter 10 mm. Table 27 shows the total length of steel bars needed in post-tensioned slab of span 4 m which is around 5365 m of diameter 10 mm.

4.5 Reinforcing Requirements for Beams

In the same way for the slabs, Tables 28, 29, 30, 31, 32 and 33 represent the reinforcement for the beams in solid and hollow block slabs.

Table 28

Total Length of Steel Bars for Solid Slab's Beams in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.58	417	655.7
10	1.38	9	12.34
10	3.76	18	67.56
10	2.02	12	24.14
10	4.32	8	34.56
10	4.02	18	72.2

Table 28 (Continued).

10	3.14	27	84.88
10	4.6	108	496.44
10	4.72	78	368.2
10	3.46	18	62.34
10	3.12	10	31.26
10	1.86	10	18.6
10	2.58	2	5.14
10	2.72	10	27.24

Table 29

Total Length of Steel Bars for Solid Slab's Beams in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.58	651	1023.64
10	1.98	36	71.16
10	1.88	18	33.7
10	4.44	16	71.14
10	3.82	68	259.44
10	2.98	16	47.7
10	2.66	80	212.84
10	4.16	12	49.96
10	6.6	158	1042.28
10	6.72	78	524.2
10	2.92	20	58.42
10	4.36	20	87.08
10	2.84	4	11.38
10	3.98	16	63.66
10	5.32	6	31.86
12	2.78	36	99.92
12	2.22	8	17.78
12	1.98	4	7.92
12	2.3	8	18.36
12	2.12	6	12.7

Table 30

Total Length of Steel Bars for Solid Slab's Beams in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.58	885	1391.6
10	2.38	110	260.94
10	5.06	148	749.5
10	4.98	160	796.9
10	3.5	292	1023.9
10	8.26	20	165.02
10	7.1	6	42.66
10	7.7	6	46.18
12	4.02	36	144.72
12	3.56	22	78.24
12	3.5	4	13.98
12	8.62	48	413.88
12	8.22	36	296.1
12	7.08	24	170.04
12	8.72	21	183.06
12	5.72	3	17.16
14	8.64	72	622.7
14	8.72	46	400.9
14	8.26	12	99.02
14	5.72	4	22.86

Table 31

Total Length of Steel Bars for Hollow Block Slab's Beams in Span 4 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.58	216	339.64
8	1	255	253.18
8	0.9	381	340.18
10	2.14	22	47.16
10	1.38	9	12.34
10	4.48	18	80.48
10	2.4	5	12.02
10	4.32	26	112.34
10	2.08	2	4.18

Table 31 (Continued).

10	3.1	11	34.02
10	2.5	20	50.02
10	2	9	17.94
10	4.6	88	404.52
10	4.72	68	321
10	1.92	2	3.86
10	3.32	4	13.32
10	3.44	4	13.76
10	2.16	4	8.66
10	3.58	10	35.82
10	3.04	10	30.4
10	4.9	4	19.6
10	3.86	6	23.1

Table 32

Total Length of Steel Bars for Hollow Block Slab's Beams in Span 6 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.6	600	955.72
8	1.34	402	539.82
8	1.58	335	526.76
10	1.98	16	31.62
10	1.88	36	67.4
10	4.34	24	103.96
10	3.82	48	183.08
10	2.66	56	149.08
10	4.16	8	33.3
10	3.98	36	142.98
10	3.5	4	13.98
10	6.6	132	870.76
10	6.72	86	577.98
10	2.84	16	45.54
10	3.56	10	35.6
10	3.42	10	34.12
10	5.32	8	42.5
10	2.4	8	19.14

Table 32 (Continued).

10	2.52	12	30.16
10	3.06	6	18.34
12	2.8	16	44.7
12	2.32	16	37.1
12	2.6	8	20.76
12	2.46	22	54.06

Table 33

Total Length of Steel Bars for Hollow Block Slab's Beams in Span 8 m

Diameter (mm)	Cut Length (m)	Number	Total Length (m)
8	1.14	2821	3224
10	2.4	102	244
10	6.4	36	230.1
10	5.32	18	95.74
10	4.16	20	83.28
10	4.12	6	24.66
10	6.34	8	50.68
10	5.2	25	130.08
10	4.04	12	48.58
10	5.26	4	21.04
10	3.3	18	59.52
10	2.96	8	23.72
10	2.62	18	47.24
10	8.62	48	413.6
10	8.22	32	263.02
10	7.08	24	169.96
10	8.72	36	313.94
10	7.92	12	95.1
10	5.72	12	68.64
10	5.52	10	55.2
10	4.36	10	43.68
10	4.24	12	50.92
10	3.88	4	15.52
10	5.42	14	75.78
10	3.98	16	63.64

Table 33 (Continued).

10	5.12	2	10.24
10	3.08	10	30.84
10	2.86	10	28.64
10	3.78	3	11.36
10	5.02	6	30.12
12	3.28	18	59.14
12	2.28	26	59.44
12	2.38	18	42.7
12	7.92	28	221.82
12	5.72	14	80.04
12	8.72	28	244.08
14	8.66	40	346.74
14	8.28	40	330.84
14	7.12	20	142.58

Table 28 shows the total length of steel bars needed in beams of solid slab of span 4 m which is around 656 m of diameter 8 mm and 1305 m of diameter 10 mm. Table 29 shows the total length of steel bars needed in beams of solid slab of span 6 m which is around 1024 m of diameter 8 mm, 2565 m of diameter 10 mm and 157 m of diameter 12 mm. Table 30 shows the total length of steel bars needed in beams of solid slab of span 8 m which is around 1392 m of diameter 8 mm, 3085 m of diameter 10 mm, 1172 m of diameter 12 mm and 1145 m od diameter 14 mm. Table 31 shows the total length of steel bars needed in beams of hollow block slab of span 4 m which is around 933 m of diameter 8 mm and 1245 m of diameter 10 mm. Table 32 shows the total length of steel bars needed in beams of hollow block slab of span 6 m which is around 2023 m of diameter 8 mm, 2400 m of diameter 10 mm and 157 m of diameter 12 mm.

4.6 Bills of Quantity of Steel bars

After getting the total length needed for reinforcing the slabs, the weight of steel bars were calculated by multiplying the weight of bar per meter according to its diameter with the total length of bar. The weight of steel bars needed in each slab are shown in Tables 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44 and 45.

Table 34

Solid Slab's Bill of Quantity for Steel in Span 4 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	655.7	655.7	0.26
10	2165.48	1304.92	3470.4	2.143
Total Weight (ton)		2.403		

Table 35

Solid Slab's Bill of Quantity for Steel in Span 6 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	1023.64	1023.64	0.41
10	6508.9	2564.84	9073.74	5.6
12	-	156.7	156.7	0.14
Total Weight (ton)		6.15		

Table 36

Solid Slab's Bill of Quantity for Steel in Span 8 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	1391.6	1391.6	0.55
10	15059.14	3085.08	18144.22	11.3
12	-	1172.46	1172.46	1.1
14	-	1145.48	1145.48	1.4
Total Weight (ton)		14.35		

Table 37

Hollow Block Slab's Bill of Quantity for Steel in Span 4 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	933	933	1.17
10	2309.9	1244.52	3554.42	2.2
16	561.26	-	561.26	0.14
Total Weight (ton)		3.51		

Table 38

Hollow Block Slab's Bill of Quantity for Steel in Span 6 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	2023.3	2023.3	0.8
10	10179.44	2399.54	12578.98	7.77
12	-	156.66	156.66	0.14
Total Weight (ton)		8.71		

Table 39

Hollow Block Slab's Bill of Quantity for Steel in Span 8 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
8	-	3224	3224	1.28
10	21476.32	2798.86	24275.18	14.99
12	-	707.22	707.22	0.63
14	-	820.18	820.18	1
16	3436.4	-	3436.4	5.44
Total Weight (ton)		23.34		

Table 40

Flat Slab's Bill of Quantity for Steel in Span 4 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	2589.8	-	2589.8	1.6
Total Weight (ton)		1.6		

Table 41

Flat Slab's Bill of Quantity for Steel in Span 6 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	8859.4	-	8859.4	5.5
Total Weight (ton)		5.5		

Table 42

Flat Slab's Bill of Quantity for Steel in Span 8 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	6244.72	-	6244.72	3.86
12	454.22	-	454.22	0.41
14	608.02	-	608.02	0.74
16	5918.7	-	5918.7	9.4
Total Weight (ton)		14.41		

Table 43

Post-tensioned Slab's Bill of Quantity for Steel in Span 4 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	1084.4	-	1084.4	0.67
Total Weight (ton)		0.67		

Table 44

Post-tensioned Slab's Bill of Quantity for Steel in Span 6 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	1664.32	-	1664.32	1.03
Total Weight (ton)		1.03		

Table 45

Post-tensioned Slab's Bill of Quantity for Steel in Span 8 m

Diameter (mm)	Length for Slab (m)	Length for Beams (m)	Total Length (m)	Weight (ton)
10	5364.8	-	5364.8	3.32
Total Weight (ton)		3.32		

Table 34 demonstrates the total weight of steel needed in solid slab and its beams of span 4 m which is about 2.5 ton. Table 35 demonstrates the total weight of steel needed in solid slab and its beams of span 6 m which is about 6 ton. Table 36 demonstrates the total weight of steel needed in solid slab and its beams of span 8 m which is about 14 ton. Table 37 demonstrates the total weight of steel needed in hollow block slab and its beams of span 4 m which is about 3.5 ton. Table 38 demonstrates the total weight of steel needed in hollow block slab and its beams of span 6 m which is about 9 ton. Table 39 demonstrates the total weight of steel needed in hollow block slab and its beams of span 8 m which is about 23 ton. Table 40 demonstrates the total weight of steel needed in flat slab of span 4 m which is about 1.5 ton. Table 41 demonstrates the total weight of steel needed in flat slab of span 6 m which is about 5.5 ton. Table 42 demonstrates the total weight of steel needed in flat slab of span 8 m which is about 14.5 ton. Table 43 demonstrates the total weight of steel needed in post-tensioned slab of span 4 m which is about 0.7 ton. Table 44 demonstrates the total weight of steel needed in post-tensioned slab of span 6 m which is about 1 ton. Table 45 demonstrates the total weight of steel needed in post-tensioned slab of span 8 m which is about 3.5 ton.

4.6 Total Cost of Slabs

After finding the reinforcement and volume of concrete needed for each slabs, the total cost of each slab were evaluated. Table 46 illustrates the materials units in dollars. Tables 47, 48 and 49 illustrate the total cost of slabs in the 3 cases.

Table 46

Material's Units

Material	Unit ($)
Concrete per m^3	120
Steel per ton	800
Blocks per Number	0.2
Tendons per m^2	12
Formwork per m^3	40

Table 47

Total Cost of Slabs in Span 4 m

Cost	Solid	Hollow Block	Post-tensioned	Flat
Concrete ($)	4982.4	3679.2	4561.92	4561.92
Steel ($)	1922.4	2808	536	1280
Blocks ($)	-	350	-	-
Tendons ($)	-	-	2304	-
Formwork ($)	1660.8	1226.4	1520.64	1520.64
Total Cost	8565.6	8063.6	8922.56	7362.56

Table 48

Total Cost of Slabs in Span 6 m

Cost	Solid	Hollow Block	Post-tensioned	Flat
Concrete ($)	11275.2	8569.2	8997.12	11070.72
Steel ($)	4920	6968	824	4400
Blocks ($)	-	1185	-	-
Tendons ($)	-	-	5184	-
Formwork ($)	3758.4	2856.4	2999.04	3690.24
Total Cost ($)	19953.6	19578.6	18004.16	19160.96

Table 49

Total Cost of Slabs in Span 8 m

Cost	Solid	Hollow Block	Post-tensioned	Flat
Concrete ($)	23788.8	21772.8	20118.24	28412.64
Steel ($)	11480	18672	2656	11528
Blocks ($)	-	880	-	-
Tendons ($)	-	-	9216	-
Formwork ($)	7929.6	7257.6	6706.08	9470.88
Total Cost ($)	43198.4	48582.4	38696.32	49411.52

Table 47 represents the total cost of slabs in span 4 meters which are around 8565, 8063, 8922 and 7362 $ for solid, hollow block, post-tensioned and flat slabs respectively. Table 48 represents the total cost of slabs in span 4 meters which are around 19954, 19578, 18004 and 19161 $ for solid, hollow block, post-tensioned and flat slabs respectively. Table 49 represents the total cost of slabs in span 4 meters which are around 43198, 48582, 38696 and 49411 $ for solid, hollow block, post-tensioned and flat slabs respectively

4.7 Materials Comparisons

The common materials in all slabs are the steel and concrete so the comparison between slabs in each case were done as shown in figures 24, 25, 26, 27, 28 and 29.

Figure 24

Volume of Concrete Comparison between Slabs of Span 4 m

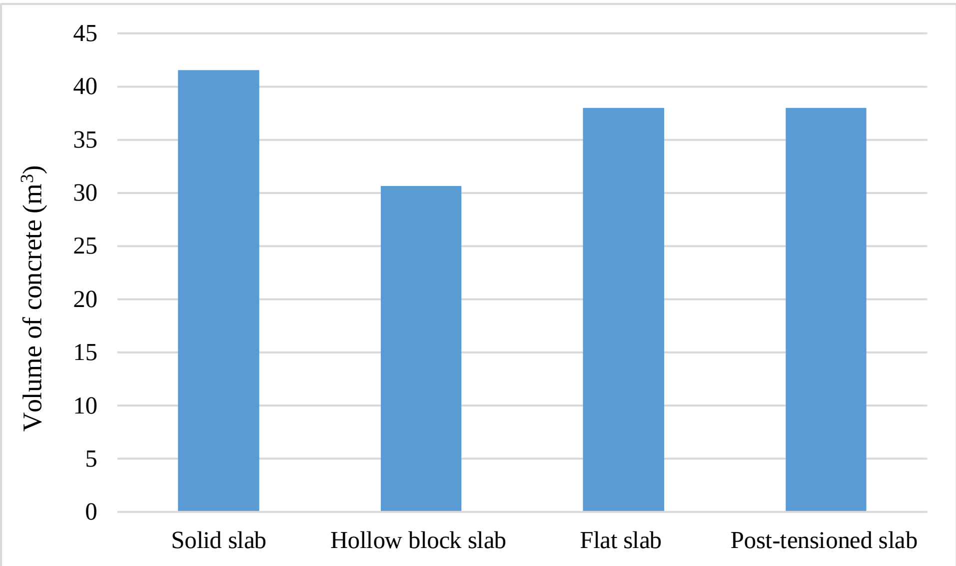
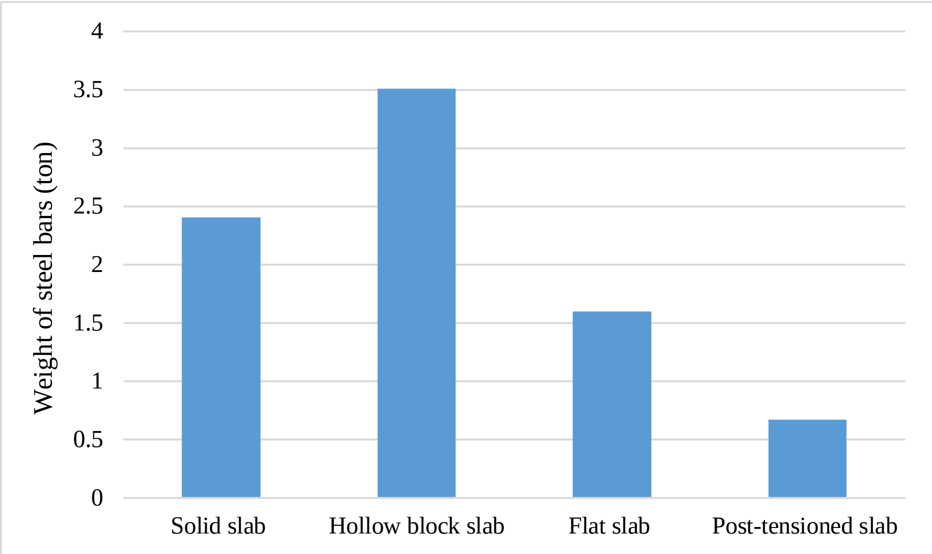


Figure 25

Weight of Steel Comparison between Slabs of Span 4 m



In first case of span 4 m the quantity of concrete and weight of steel bars in solid, hollow block, flat and post-tensioned slabs are 41.52, 30.66, 38.016 and 38.016 m^3 and 2.403, 3.51, 1.6 and 0.67 ton respectively. The hollow block slab in span 4 m needs less volume of concrete than the other slabs in which the percentage saving of concrete for hollow block slab is 26.1, 19.35 and 19.35 % compared to solid, flat and post-tensioned slabs respectively. The post-tensioned slab needs less weight of steel bars in which the percentage saving of steel is 72.12, 80.91 and 58.12 % compared to solid, hollow block and flat slabs as shown above in Figures 24 and 25.

Figure 26

Volume of Concrete Comparison between Slabs of Span 6 m

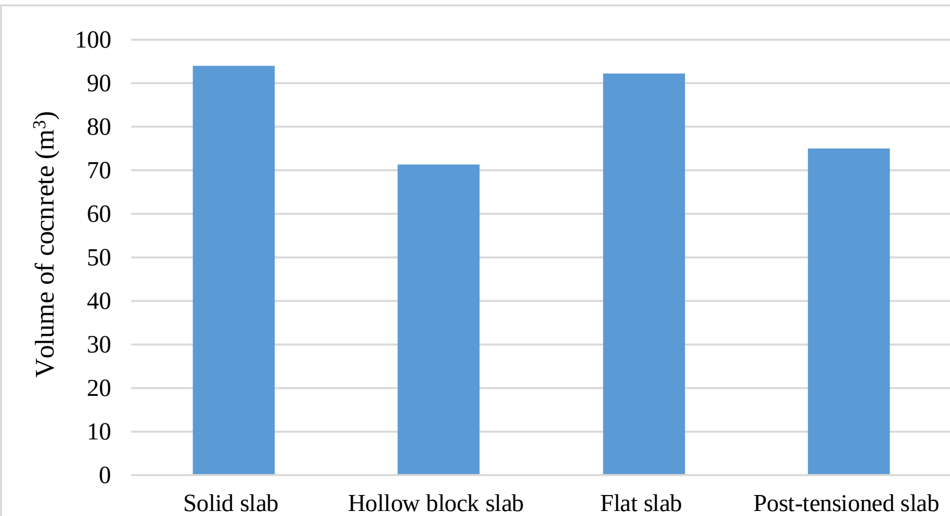
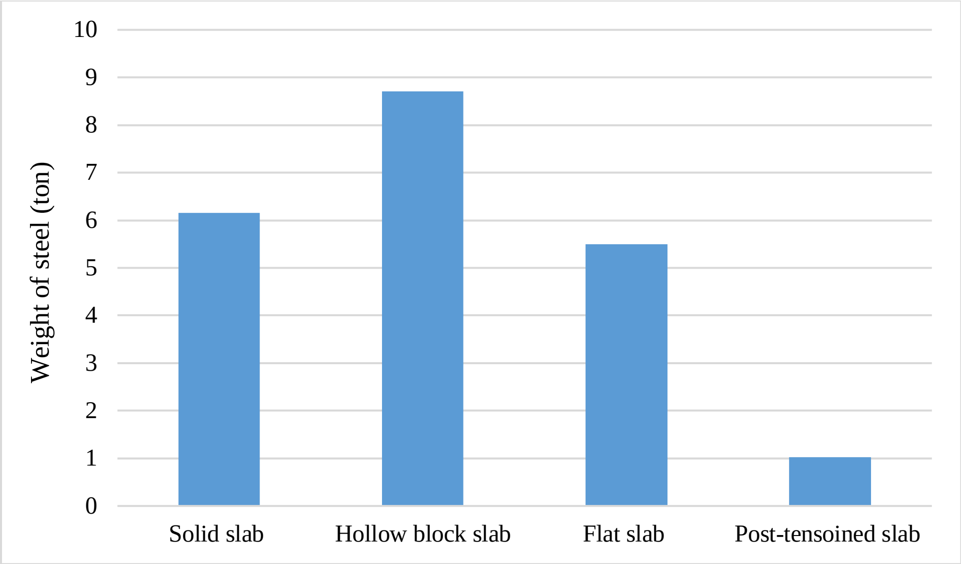


Figure 27

Weight of Steel Comparison between Slabs of Span 6 m



In second case of span 6 m the quantity of concrete and weight of steel bars in solid, hollow block, flat and post-tensioned slabs are 93.96, 71.41, 92.256 and 74.97 m^3 and 6.15, 8.71, 5.5 and 1.03 ton respectively. The hollow block slab in span 6 m needs less volume of concrete than the other slabs in which the percentage saving of concrete for hollow block slab is 23.99, 22.59 and 4.75 % compared to solid, flat and post-tensioned slabs respectively. The post-tensioned slab needs less weight of steel bars in which the percentage saving of steel is 83.25, 88.17 and 81.27 % compared to solid, hollow block and flat slabs as shown above in Figures 26 and 27.

Figure 28

Volume of Concrete Comparison between Slabs of Span 8 m

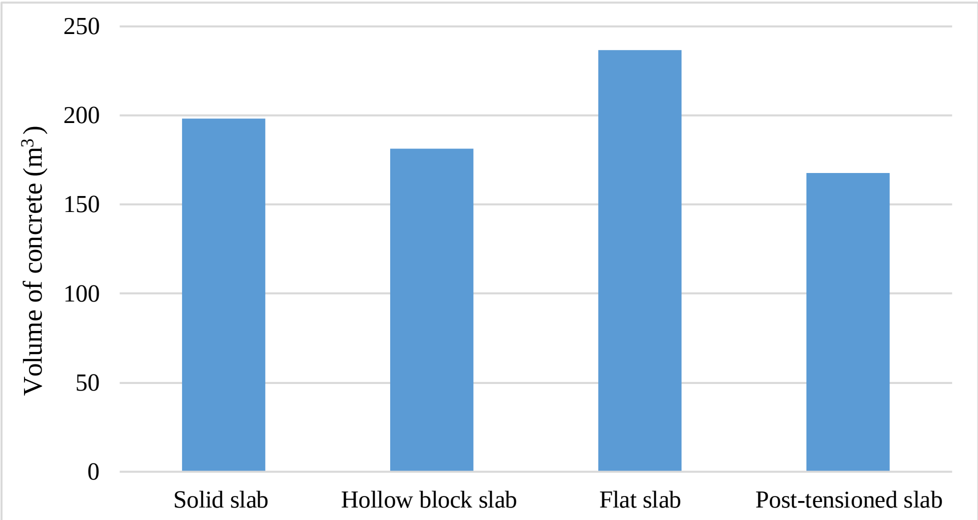
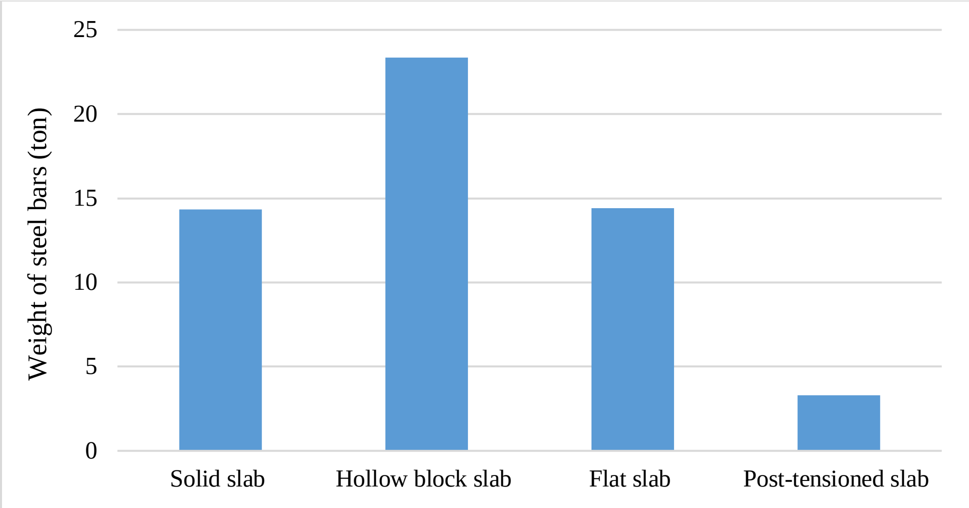


Figure 29

Weight of Steel Comparison between Slabs of Span 8 m

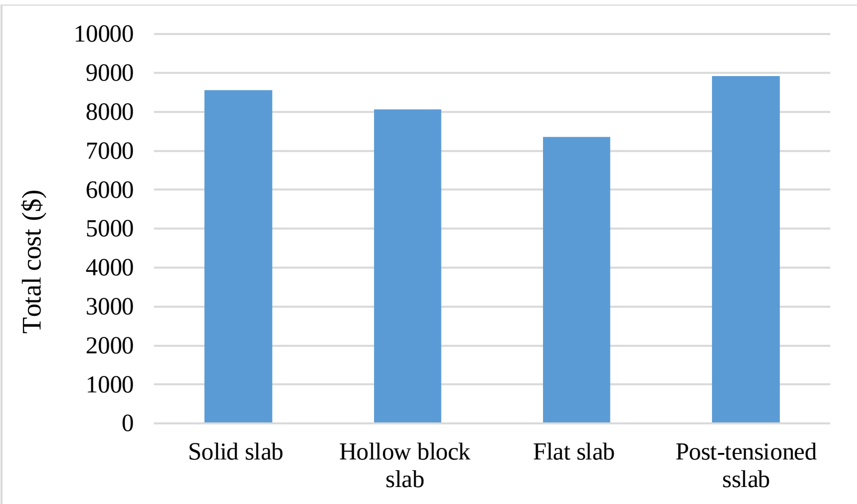


In third case of span 8 m the quantity of concrete and weight of steel bars in solid, hollow block, flat and post-tensioned slabs are 198.24, 181.44, 236.77 and 167.652 m^3 and 14.35, 23.34, 14.41 and 3.32 ton respectively. In this case the post-tensioned needs less volume of concrete than the other slabs in which the percentage saving of concrete is 7.59, 15.42 and 29.19 % compared to hollow block, solid and flat slabs respectively. The post-tensioned slab needs less weight of steel bars in which the percentage saving of steel is 85.77, 76.86 and 76.96 % compared to hollow block, solid and flat slabs as shown above in Figures 28 and 29.

4.8 Total Cost Comparison

Figure 30

Total Cost Comparison between Slabs of Span 4 m



In the first case of span 4 m the total cost of solid, hollow block, flat and post-tensioned slabs are 8565.6, 8063.6, 7362.56 and 8922.56 $ respectively. As shown in figure 30, flat slab is the cheapest choice among the other slabs while post-tensioned slab is the most expensive. Although the quantity of steel bars needed in post-tensioned slab is less than the other slabs, it is still more expensive because of the cost of tendons. Hollow block slab is can be also preferable in this case because of the low weight of slab which decreases also the dead load on slab. The percentage saving of cost for flat slab in first case is 14.04, 8.69 and 17.48 % compared to solid, hollow block and post-tensioned slabs respectively.

Figure 31

Total Cost Comparison between Slabs of Span 6 m

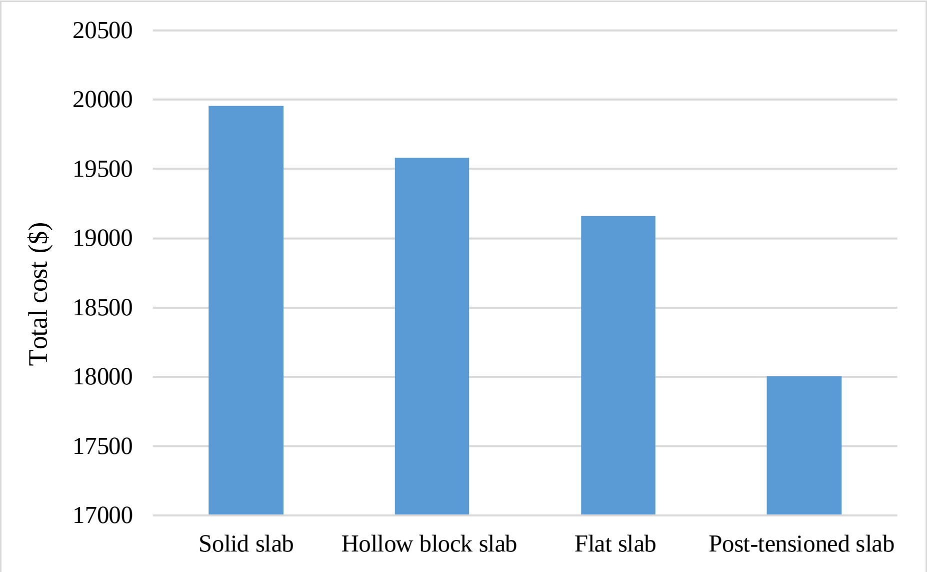


Figure 31 represents the total cost of slabs of span 6 m in which the total cost of solid, hollow block, flat and post-tensioned slabs are 19953.6, 19578.6, 19160.96 and 18004.16 $ respectively. Although the quantity of concrete in post-tensioned slab is not the least one and there are extra price of tendons, it is still the cheapest one because the low quantity of steel used compared to the other slabs. The percentage saving of cost for post-tensioned slab in second case is 9.76, 8.04 and 6.03 % compared to solid, hollow block and flat slabs respectively.

Figure 32

Total Cost Comparison between Slabs of Span 8 m

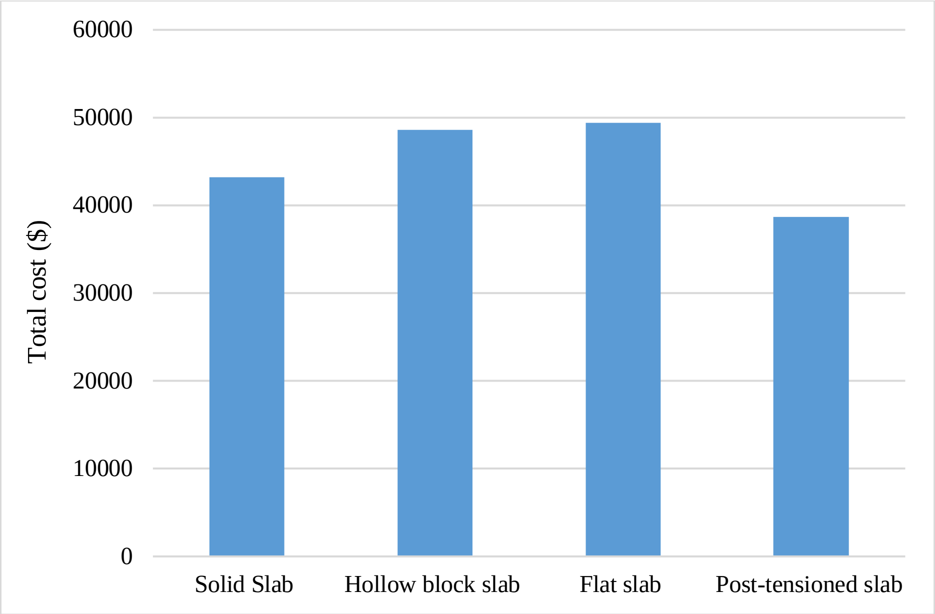


Figure 32 represents the total cost of slabs of span 8m in which the total cost of solid, hollow block, flat and post-tensioned slabs are 43198.4, 48582.4, 49411.52 and 38696.32 $ respectively. In the third case the quantities of concrete and steel bars in post-tensioned slabs are less than in the other types of slabs and it is again the best choice for span 8 m. The percentage saving of cost for post-tensioned slab in third case is 10.42, 20.34 and 21.68 % compared to solid, hollow block and flat slabs respectively.

Figure 33

Difference in Slab's Total Cost in All Cases

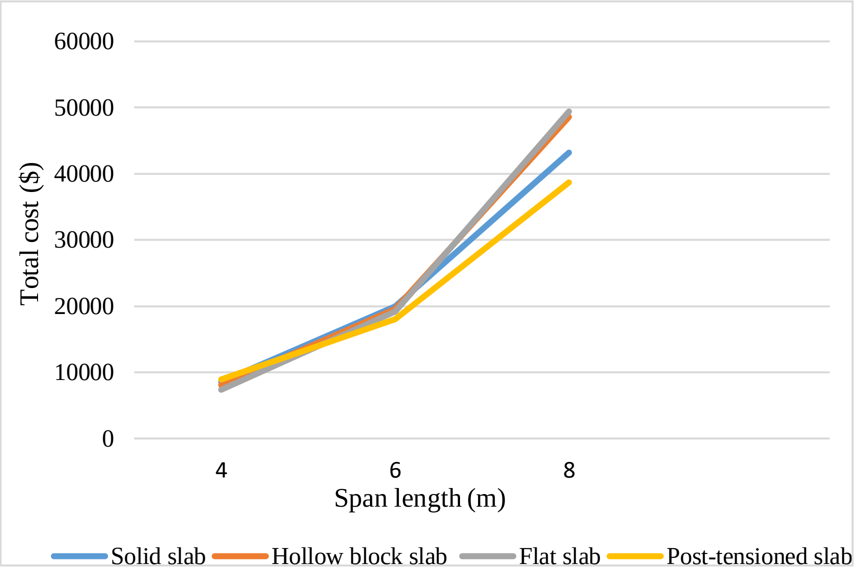


Figure 33 shown above shows the total cost of each slab on 3 different spans length. The total cost of solid, hollow block and post-tensioned slab on span 4 m are approximately the same while flat slab is more economical with a little difference in cost. As the span length increases from 4 to 6 m post-tensioned slab started to be more economical than the other slabs. Furthermore as the span length increases from 6 to 8m post-tensioned slab is still more economical with bigger differences in percentage saving. Since many countries do not have post-tensioned systems solid slab can be better choice than hollow block and flat slabs on long spans.

CHAPTER V
Discussion

5.1 Overview

Analysis and design processes depend and differ with respect to many factors. There are different types of programs that analyze and design the slabs according to the chosen code. Therefore these factors may change the final results for each study. This chapter contains a comparison between results obtained from the study and another studies.

5.2 Comparing Results with Literature Review

Ajema & Abeyo in 2018 mentioned that upon comparing solid slab with hollow block slab the total quantity of concrete in solid slab was more than in hollow block slab while the weight of steel in solid slab was less than in hollow block slab. These results are matching the results of my study between solid and hollow block slab.

Sawwalakhe & Pachpor in 2021 said that flat slabs are more economical than grid slabs and solid slabs in short spans while in bigger spans it is recommended to use grid slabs. In my study flat slab was more economical than grid slab in short span but in long spans grid slab was more economical. This means that the results are the same compared to my study.

According to Latha & Pratibha in 2021, in long spans up to 8 meters grid slab is more economical than conventional slab. While in my study solid slab on span 8 meters was more economical than hollow bock slab which means that the results did not match.

Khot et al. in 2016 mentioned that the total weight of steel needed in waffle slab is least compared to flat and conventional slab in span of 7.5 meters. While in my results it was found that the weight of steel needed in hollow block slab is the most compared to flat and solid slabs.

According to Reddy & Pradeep in 2017 said that the quantity of concrete and total cost of post-tensioned slab are less than in flat slab on spans of 6.16 and 9.44 meters. Same for Ahmad in 2021 who said that in slabs with up to 8 meters the quantity of concrete and total cost of post-tensioned slab are less than in flat slab. Ajay in 2020 made a comparison between post-tensioned and flat slabs and he found that the in long spans, the quantity of steel, concrete and total cost in post-tension slab are less than in flat slab. Panchal in 2016 also found that in slabs with long spans, post-tension slab is cheaper than the reinforced concrete slab. Sharma in 2021 again said that the post-tension slab costs less than the flat slab in structures with long spans. Ahmed in 2021 stated that while comparing the total cost of flat, traditional and post-tensioned slabs in long spans, it was found that post-tensioned system is the most economical. All these results that obtained from comparing post-tensioned slabs with another types of slabs, are same results of my study which says that post-tension slab more cost efficient compared to the other 3 types of slabs in long spans.

CHAPTER VI
Conclusions and Recommendations

6.1 Conclusions

This thesis has conducted a comparative study between solid, hollow block, flat and post-tensioned slabs with different span length of 4, 6 and 8 meters using CSI SAFE SOFTWARE of same materials properties. The concrete and steel bar strengths were same for all cases while the thickness differs according to the case to control the deflection. After analyzing and designing all types of slabs, the quantity and cost of the materials concrete and steel were calculated in order to make a comparison between the bills of quantities for each case and detect the most economical slab on different span length. This chapter will show the conclusions of the study as follows:

The thickness of post-tensioned slab in case 6 and 8 meters was the least compared to solid, hollow block and flat slab which results in reduction in quantity of concrete and slab's weight which will reduce the dead load.

Post-tensioned slab gives the architects a free space and numerous possibilities for design due to the absence of beams and greater floor to floor height.

In case of span 4 meters hollow block slab requires least quantity of concrete where the percentage saving of concrete about 26, 19 and 19 % compared to solid, flat and post-tensioned slabs respectively.

In case of span 6 meters hollow block slab requires least quantity of concrete where the percentage saving of concrete around 24, 23 and 5 % compared to solid, flat and post-tensioned slabs respectively.

In case of span 8 meters post-tensioned slab requires least quantity of concrete where the percentage saving of concrete about 29, 8 and 15 % compared to flat, hollow block and solid slabs respectively.

In the 4, 6 and 8 meters span lengths post-tensioned slab requires the least weight of steel where the percentage saving of steel in case of 4 meters around 58, 81 and 72 %, in case of 6 meters around 81, 88 and 83 % and in case of 8 meters around 77, 86 and 77 % compared to flat, hollow block and solid slabs respectively.

In the case of 4 meters span, flat slab is the best choice from economic side where the percentage saving in total cost around 14, 9 and 17 % compared to solid, hollow block and post tensioned slabs respectively.

In case of 6 and 8 meters spans, post-tensioned slab is more preferable than the other slabs where the percentage saving in total cost in case of 6 meters span about 10, 8 and 6 % and in case of 8 meters span about 10, 20 and 22 % compared to solid, hollow block and flat slabs respectively. Hence as the span length increases the percentage saving in post-tensioned slab increases.

6.2 Recommendations

This study did not take in consideration the effect of slabs on columns regarding the axial forces and moments. Therefore it should be taken in consideration in future studies. Also this research did not include flat and post-tensioned slabs with edge beams to see the effect of edge beams on slabs. Thus it is recommended in future researches to include the flat and post-tensioned slabs with edge beams in the research. Furthermore the loads that assigned to slabs in this study were only dead and live loads. Thus in coming researches the lateral loads like wind and earthquake should be assigned to see the effect of slabs against the lateral loads.

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APPENDICES

Appendix A

Ethical Approval Letter

YAKIN DOĞU ÜNİVERSİTESİ
MİMARLIK FAKÜLTESİ
NEAR EAST UNIVERSITY
FACULTY OF ARCHITECTURE

September 20th, 2021, Nicosia

ETHICS EVALUATION

Dear Omar Ahmad

Your application titled "Comparative study between solid, hollow block, flat and post-tensioned slabs with different parameters" has been evaluated by me (instead of the Scientific Research Ethics Committee) and granted approval. You can start your research on the conditions that you will abide by the information provided in your application.

This evaluation has been done by me because you have not to use a questionnaire and no need for data collection from the people, and your work will be based on analytical calculations and application of the software.

Sincerely yours

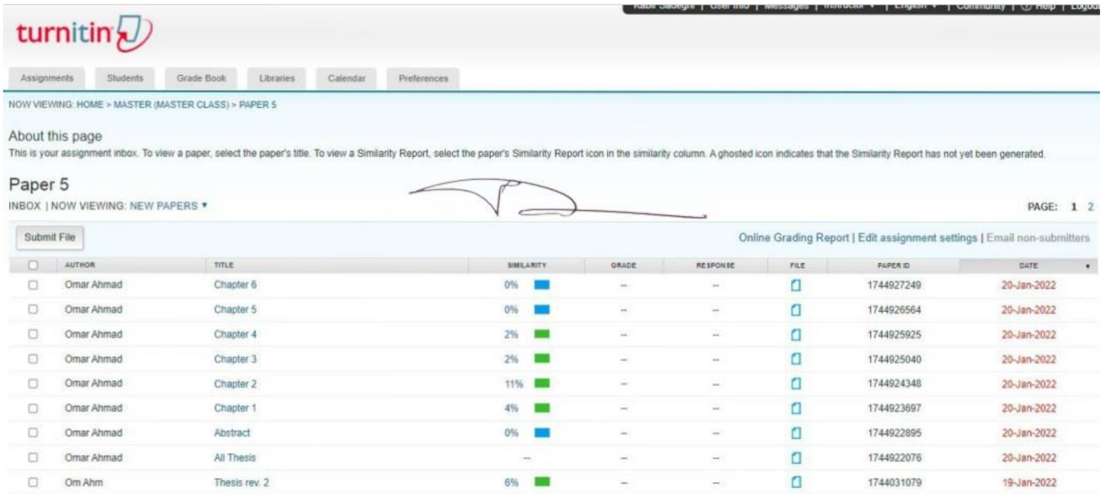
Prof. Kabir Sadeghi, Ph.D., P.E.
Head of Civil Engineering Department-Postgraduate Program

Faculty of Civil and Environmental Engineering
Near East University, Near East Boulevard, ZIP: 99138, Nicosia/TRNC, Mersin 10 - Turkey

YAKIN DOĞU BULVARI, LEFKOŞA - KKTC - TEL-FAKS: (0392) 223 6464 - 281 - www.neu.edu.tr

Appendix B

Similarity Check Report



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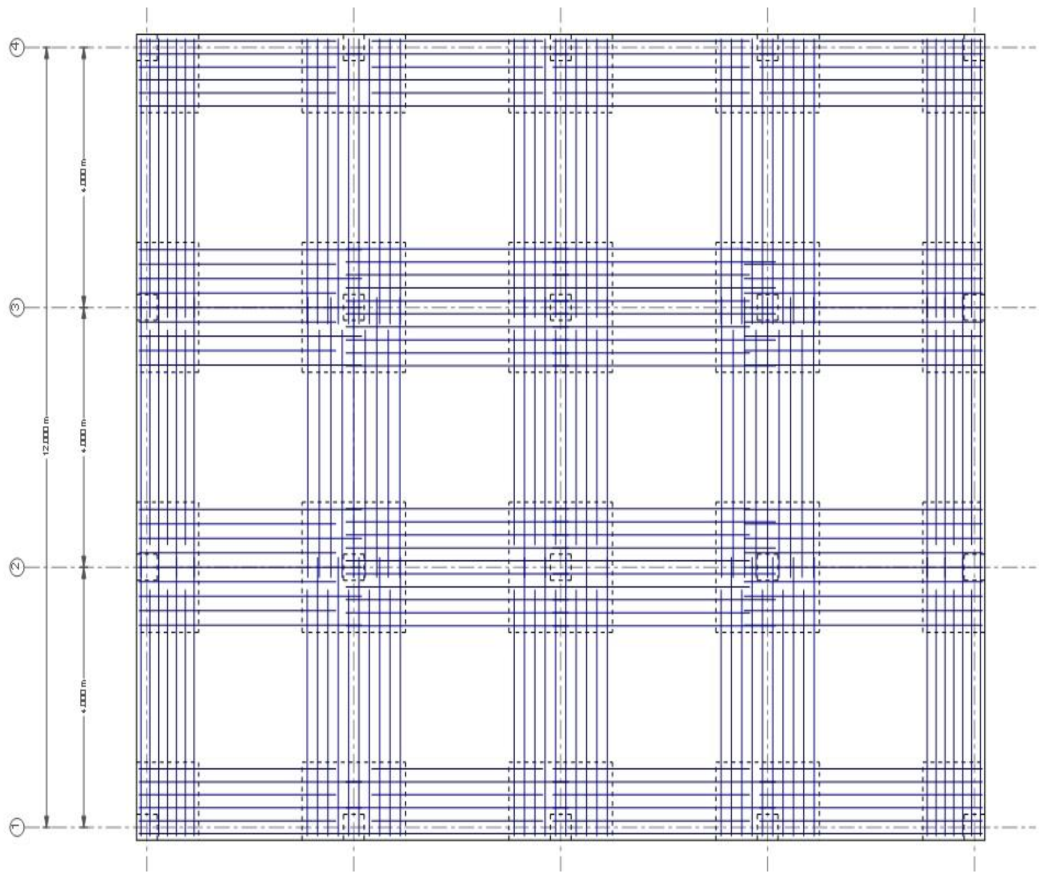
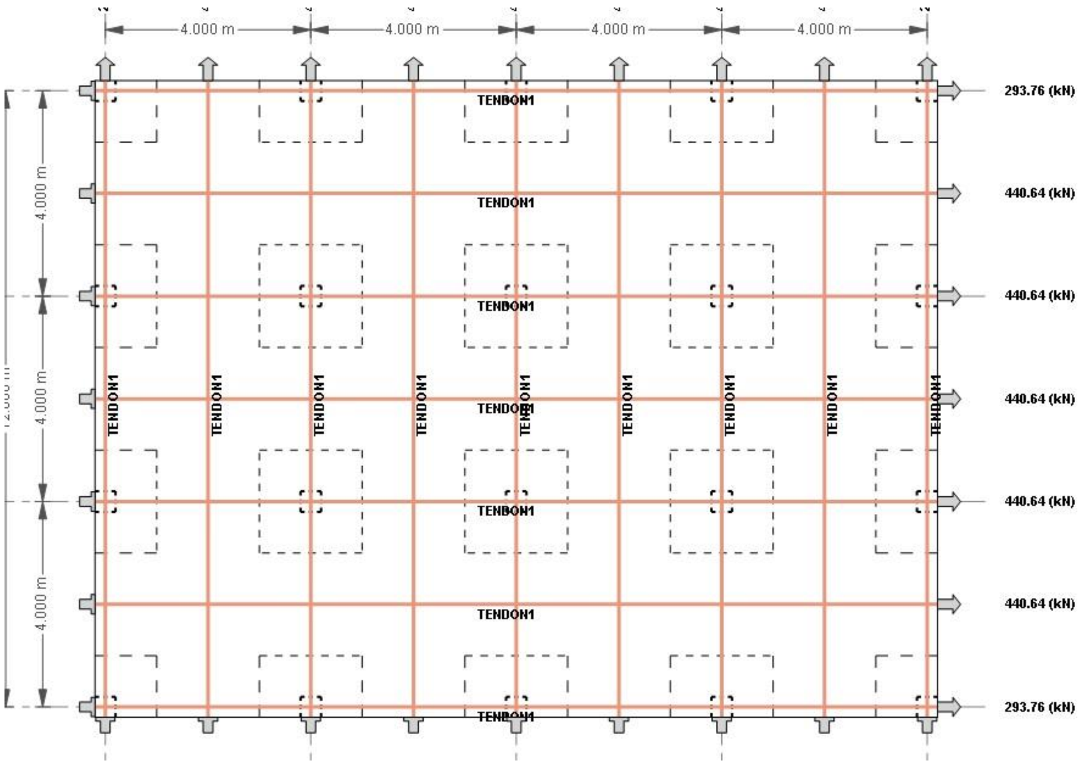
Appendix C

Reinforcement Plan for Post-tensioned Slab in Span 4 m



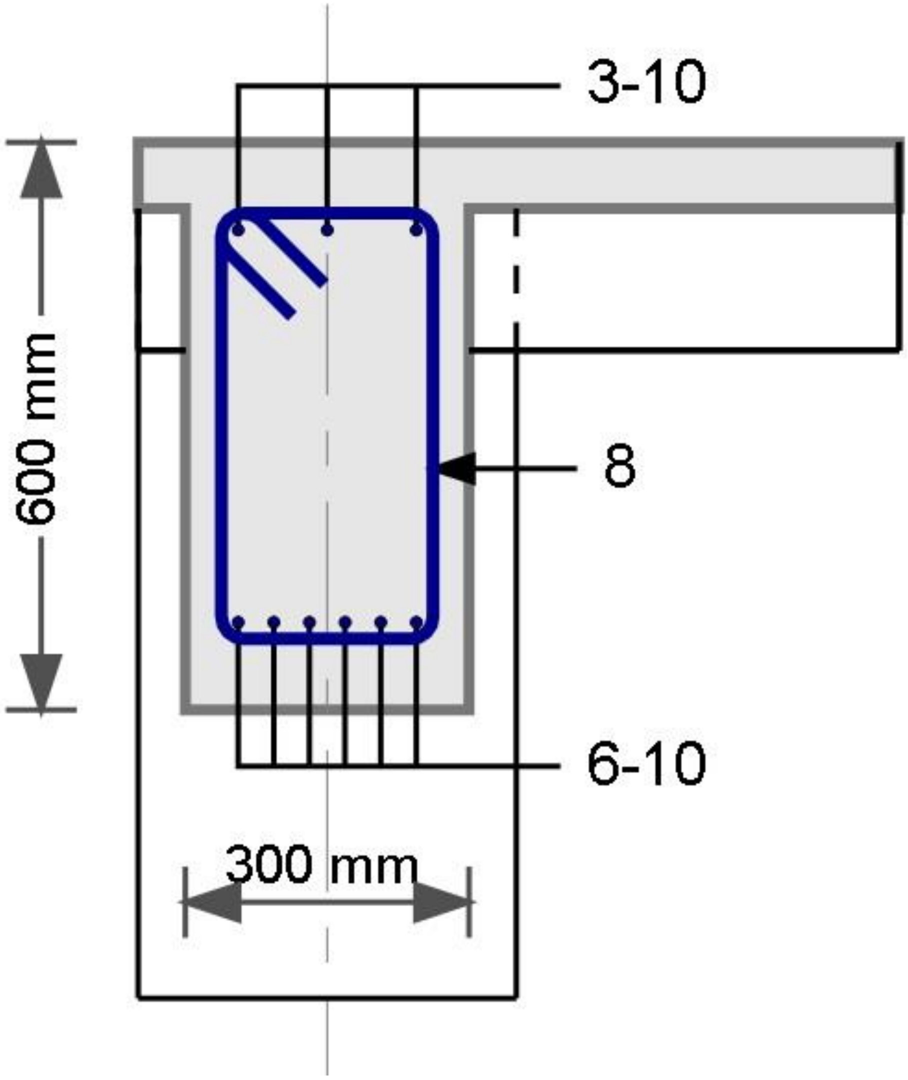
Appendix D

Tensioning Forces for Tendons in Post-tensioned Slab



Appendix E

Example of Beam Design in Solid Slab in Span 4m



Appendix F

Reaction Forces in Post-tensioned Slab in Span 4m