SEISMIC BEHAVIOR OF DIFFERENT YPES OF SLAB AND LOCATION OF SHEAR WALL IN ERBIL-IRAQ

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
SARHAD ABDULLAH S.MUHAMMAD

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my wife Zhiry, my son Baha and my daughter Zhya…

ABSTRACT

Due to rapid increase in population leading to a rising number of multi-storey reinforced concrete (RC) buildings in the commercial districts of the country. These buildings are becoming more slender than the previous ones. However, less attempt has been made about the geometric arrangement of the buildings to resist seismic forces especially those that constructed in high seismic zones. The decision on an appropriate floor system for the buildings needs to be considered because it affects in resisting seismic loads. Flat slab systems are commonly adopted for many buildings in Erbil city due to economic advantages over conventional slab but flat slab poorly provides seismic resistance.Adding shear walls in flat slab buildings leads to improve their seismic performance. The main aim of this study is to investigate the seismic performance of flat slab, flat slab with drop panel, flat slab with edge beam, conventional slab, flat slab with both drop and edge beam, and flat slab with shear walls at five different locations. A five-storey residential building is analysed by using equivalent lateral force method (ELFM) and pushover analysis by ETABS software as per ISC-2017 in Erbil city. The results obtained are lateral displacement, time period, storey drift, base shear, and elastic stiffness. The results show that type of slab and shear wall location have main role in seismic performance evaluation.

Keywords: Flat slab; drop panel; edge beam; shear wall; seismic force; ISC-2017

ÖZET

Nüfusun hızla artması, ülkenin ticari bölgelerinde, çok katlı betonarme binaların artışına neden olmaktadır. Bu binalar öncekilerine göre daha narin bir hal almaktadırlar.Bununla birlikte, özellikle yüksek deprem bölgelerinde inşa edilen binaların, sismik kuvvetlere karşı koymak için geometrik düzenlemeleri konusunda daha az girişimde bulunulmuştur.Binalar için uygun bir döşeme sistemi kararının,deprem yüklerine karşı direnç açısından dikkate alınması gerekmektedir. Kirişsiz döşeme sistemleri, geleneksel döşeme yapımına göre ekonomik avantajlar sağladığından, Erbil şehrinde birçok bina için yaygın olarak kullanılmaktadır. Ancak bu sistemler deprem yüklerine karşı zayıf bir mukavemet göstermektedirler.Kirişsiz döşeme sistemli binalara yerleştirilen perde duvarları, bu yapıların sismik performanslarının artmasına yol açmaktadır. Bu çalışmanın temel amacı, tamamı kirişsiz döşeme, başlıklı kirişsiz döşeme, kenar kirişli kirişsiz döşeme, geleneksel kirişli döşeme, başlıklı ve kenar kirişli kirişsiz döşeme ve beş farklı noktada perde duvarlı kirişsiz döşemenin sismik performansını incelemektir. ISC-2017 yönetmeliği uyarınca, Erbil şehrindeki beş katlı konut yapının yapısal analizi, eşdeğer deprem kuvvet yöntemi, statik itme analizi ve ETABS yazılım programı kullanılarak elde edilmiştir. Elde edilen sonuçlar yanal yer değiştirme, zaman periyodu, katlar arası yerdeğiştirme, taban kesme kuvveti ve elastik rijitliktir. Sonuçlar döşeme tipinin, perde duvarı yerinin, sismik performans değerlendirmesinde önemli bir yer tuttuğunu göstermektedir.

Anahtar kelimeler: Kirişsiz döşeme; başlıklı; kenar kiriş; perde duvar; sismik kuvvet; ISC-2017

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LIST OF ABBREVIATIONS

ACI 318-14:	American Concrete Institute Code no. 318 in the year 2014
ASCE7-16:	American Society of Civil Engineers Code no. 7 in the year 2016
BC:	Before Christ
ELFM:	Equivalent lateral force method
ETABS:	Extended three dimensional analysis of building system
IMF:	Intermediate moment frame
IS:	Indian Standard
ISC-2017:	Iraqi Seismic Code in the year 2017
MCE:	Maximum considered earthquake
MRF:	Moment resisting frame
NL:	Not limited
NP:	Not permitted
OMF:	Ordinary moment frame
RC:	Reinforced concrete
SAP:	Structural analysis program
SDC:	Seismic design category
SMF:	Special moment frame
STAAD pro:	Structural analysis and design program
SW:	Shear wall
UNESCO:	United Nations Educational, Scientific and Cultural Organization

CHAPTER 1
INTRODUCTION

1.1 Background

Reinforced concrete (RC) is considered as the most sufficient and ancient material for construction in civil engineering since 19th century. RC buildings have high stiffness, long service life, low-maintenance, low cost and high resistance to fire (MaCormac and Brown, 2015). In Erbil, there is rapid increase in population leading to rising number of multi-storey RC buildings and becoming more slender than the previous ones. However, less attempt has been made about the geometric arrangement of building elements to resist seismic forces. Therefore, there is need for seismic performance study related to the building configurations. Depending on their configuration, the floor systems are divided into several types. In general, five types of floor systems are widely used as shown in Figure 1.1. In recent years, flat slab systems are commonly adopted due to their advantages over conventional slab in terms of free design of space, simple formwork, a shorter construction period and low cost. Due to the absence of beams and/or shear walls in the flat slab systems excessive lateral deformation can be seen. The other main disadvantage in this system is punching shear failure. This type of failure of RC slabs subjected to high localized forces due to transfer of shear forces and unbalanced moments between slabs and columns. In flat slab it occurs at the column support point, it is not suitable to use flat slab in the active seismic zones. Therefore, placement of shear walls in flat slab buildings can overcome this poor performance in seismic zones (Lande and Raut, 2015a).

Shear walls are widely used as a lateral forced resisting system which provides lateral stiffness to the structures. Shear walls provide various performance due to their location. When shear walls are located in an appropriate position, they can provide a sufficient force resisting during an earthquake. Therefore, it is needed to find an ideal location for shear walls (Oliveira et al., 2014; Behera and Parhi, 2017; Mishra et al., 2018; Gu et al., 2019; Lapi et al., 2019).

(a) Conventional slab (beam slab)

(b) Flat slab

(c) Flat slab with drop panel

(d) Flat slab with edge beam

(e) Flat slab with both drop panel and edge beam

Figure 1.1: Different types of slab

1.2 Problem Statement

After an extensive literature review, it is observed that:

- The behaviour of different types of slab of RC building with respect to the seismic effect in Erbil has not been studied yet.
- There are limited studies about the behaviour of flat slab with both drop panel and edge beams together in the RC building with respect to seismic force.
- Many contradictions are noted in existing studies about the ideal location of shear walls, whether it is at exterior or interior.

1.3 Research Questions

- How to apply flat slab systems for multistorey RC buildings in Erbil city to reduce the impact of earthquakes?
- How to find best location for RC shear walls for multistorey RC buildings in Erbil city to reduce the impact of earthquakes?

1.4 Scope and Limitations of the Study

The present study examines the residential five storeys RC building of 15m height and 3m typical floor height which focused on seismic behaviour of different types of slab and locations of shear walls. The study is limited to plot area of 20.4m x 20.4m, beam size 50cm x 25cm and column size 40cm x 40cm. The seismic design parameters to be used is solely for Erbil. The study considers only the analysis and design of the frames in the buildings. Seismic forces are assumed only in the lateral directions.

1.5 Objectives of the Study

The main aim of this study, is to make a comparative investigation among different types of slab and different locations of shear walls in a multi-storey RC building under the effect of seismic forces in Erbil – Iraq. The following objectives will be performed in order to achieve the aim of this study.

- To examine moment-resisting frame (MRF) and moment-resisting frame with shear wall (MRF+SW) in a regular building.

- To perform equivalent lateral force method (ELFM) and pushover analysis using ETABS 2016 software.
- To verify the seismic parameters such as base shear, lateral displacement, story drift and time period on a RC building.
- To use new Iraqi Seismic Code (ISC-2017).
- To explore the resulting data of different types of slab system and different locations of shear wall in multi-storey RC buildings.

CHAPTER 2
LITERATURE REVIEW

2.1 Preface

The literature review concentrates the effect of different types of slab and different locations of shear wall on seismic performance. Also, provides of previous studies on different types of slab and different locations of shear wall.

2.2 Types of Slab

Generally, lateral load critically changes with overall size, shape (configuration) of the buildings. Thereby, slab configuration has a main role in the seismic performance of a building. Slab contributes a large area of RC buildings, also they transmit gravity and lateral loads to the beams or columns. Slabs are mainly divided into two types namely; slab with beam and flat slab. Slab with beam is also called conventional slab which transmits the loads to the beams. Flat slab transmits the loads directly to the columns. Structural engineers do not prefer to use of flat slab in seismic zones, because they do not offer lateral resistance under seismic force which makes a huge lateral displacement and punching shear failure around the columns. Punching shear need to be considered in flat slab design (Whittle, 2013; Sagaseta et al., 2014; Eid et al., 2014; Purushothama and Mithanthaya, 2016; Chaudhari and Katti, 2016; Coulbourne Consulting, 2017; Soundarya et al., 2018; Saleh et al., 2018; Lapi et al., 2019; Liberati et al., 2019; Akhundzada et al., 2019). Punching shear check for flat slab is mentioned in detail in Appendix 1.

To increase the performance of flat slab, there are two methods. The first one is to increase the thickness of flat slab and the second one is to alter the slab configuration. The first method is limited, while the second one is widely used where drop panel or edge beams are provided to increase punching shear resistance and prevent punching shear failure of flat slabs (Kodali et al., 2014; Navyashree and Sahana, 2014; Thakkar et al., 2017).

2.3 Location of Shear Walls

Shear walls provide stiffness to buildings in the direction of their orientation, which reduces lateral sway, and thereby reduces damage to structure and its contents. In other words, shear walls are vertical elements of the horizontal force resisting system. When shear walls are placed in advantageous positions in the building, they can form an efficient lateral force resisting system by reducing lateral displacement under earthquake loads. (McCormac and Nelson, 2005; Sable et al., 2012; Agrawal and Charkha, 2012 ; Danish et al., 2013; Sardar and Karadi, 2013; LovaRaju and Balaji, 2015; Pawar and Jain, 2015; Resmi and Roja, 2016; Behera and Parhi, 2017; Hosseini et al., 2017; Tarigan et al., 2018; Bongilwar et al., 2018; Mishra et al., 2018; Khy et al., 2019; Sudhan, 2018).

2.4 Structural Systems

Generally, based on how seismic forces are resisted, structural systems have been classified into six categories namely; non seismic resistance system, cantilevered column system, bearing wall system, building frame system, moment frame system, and dual system. Also, depending on detail of reinforcement, moment frames are classified into three classes such as ordinary moment frame, intermediate moment frame and special moment frame as shown in Figure 2.1 (FEMA, 2010; ASCE 7-16; ISC-2017).

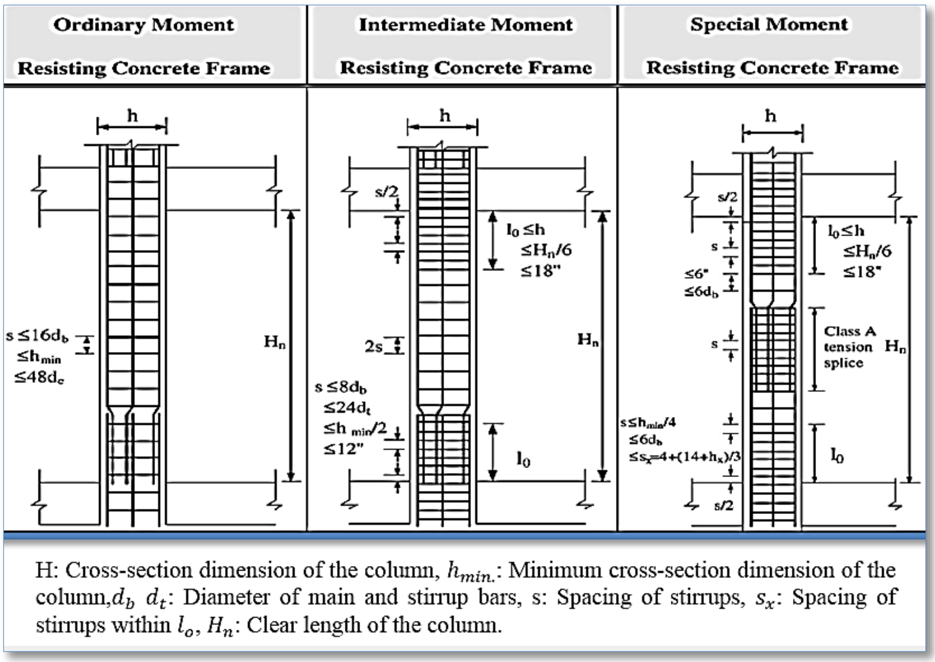

Figure 2.1: Minimum detailed reinforcement of columns for different cases (Han and Jee, 2005)

2.5 Seismic Forces

Ground shaking is the primary way an earthquake affects buildings. The acceleration of ground beneath the building creates interior forces in the structure. During an earthquake, ground shaking can impact strong lateral loads. The horizontal forces are considered in seismic design of building but the vertical forces are normally ignored (Alashker et al., 2015; Thakkar et al., 2017; Reşatoğlu et al., 2018). Earthquake as a natural disaster occurs around the world and results many death and collapse of several structures. Earthquakes happen without warning at anytime and anywhere. There are about more than a million deadly earthquakes in each year in the world. (Mubarak et al., 2009; Hamed, 2018). Iraq is located between four seismic plates namely; Arabian plate, Indian plate, African plate and Eurasian plate as shown in Figure 2.2. These plates are the sources of earthquakes in Iraq (Ameer et al., 2005; Aleqabi and Ghalib, 2016; Onur et al., 2017). There are three seismic zones in Iraq; zone 1, zone 2, and zone 3 as shown in Figure 2.3. Among these three zones, zone 1 is referred to as the seismically active zone which is located close to the border of Iraq-Tureky and Iraq-Iran. (Yaseen et al., 2014; Onur et al., 2017)

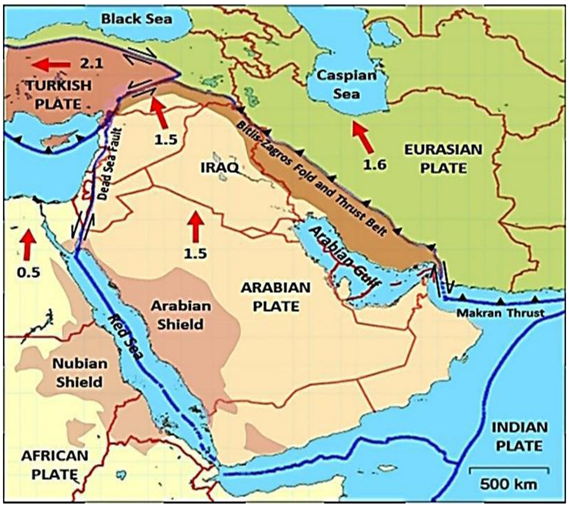

Figure 2.2: Iraqi map among four plates (Onur et al., 2017)

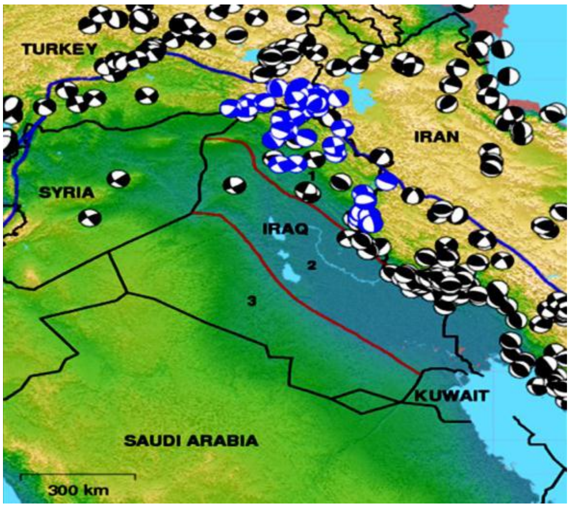

Figure 2.3: Seismic zones in Iraq (Onur et al., 2017)

Iraq experiences many destructive earthquakes (Yaseen et al., 2014). On November 12, 2017 an earthquake with a magnitude of 7.5 hit Iraq and caused a lot of deaths and left a lot of buildings damaged as shown in Figure 2.4 and 2.5. Normally, most of the buildings were not designed to resist earthquake forces (Aziz et al., 2001; Yaseen et al., 2014; Yaseen and Ahmed, 2018).

Figure 2.4: Earthquake in Iraq-Iran border (Mills, 2017)

Figure 2.5: A damaged house in Iraq-Iran border (Goran, 2017)

Erbil which is the case study is located in the zone 1 that has been known to be in the seismically active zone in Iraq (Galib et al., 2006; Gritto et al., 2008; Aleqabi and Ghalib, 2016; Onur et al., 2017; Yaseen and Ahmed, 2018). In recent years, Erbil was struck by a number of deadly earthquakes that caused a lot of casualties and collapsed of buildings. Moreover, with the awareness that 75% of the losses caused by the earthquake events are due to the collapse of the buildings which are seismically poorly designed (Yaseen et al., 2014; Yaseen et al., 2015; Onur et al., 2017; Yaseen and Ahmed, 2018).

2.6 Analytical Studies on Different Types of Slab

Apostolska, Necevska-Cvetanovska, Cvetanovska and Mircic (2008) investigated the design role of five types of slab on seismic performance, such as conventional slab, purely flat slab, flat slab with edge beam, flat slab with shear walls and flat slab with edge beam and shear walls together. SAP 2000 program was used for the analysis and design of seven storeys RC residential building. This study was done in a high-risk seismic zone in Skopje- Macedonia as per Eurocode 8. Higher displacement and time period was observed in the flat slab.

Sanjay, Mahesh Prabhu and Umash (2014) studied the design role of drop panels in a flat slab system in multi-storey buildings to resist earthquake forces. In this study, flat slab and flat slab with drop panels were used. A six-storey building was analyzed using ETABS program in seismic zones II, III and IV in India as per Indian code. A dynamic analysis was performed by using the response spectrum method. It was concluded that the flat slab with drop panels provided higher time period than to the flat slab.

Tafheem, Nahid, Rahman and Shamim (2014) investigated and presented a comparative study between flat slab with edge beams and flat slab with shear walls. In this study, seismic behavior of these floor systems was determined according to Bangladesh code. Also, an eight-storey RC building was modeled and analyzed using ETABS program. It was observed that the horizontal displacement and horizontal drift are smaller in the flat slab with edge beam and the smallest in the flat slab with the shear wall while compared to the purely flat slab.

Lande and Raut (2015a) studied and compared the seismic performance of different types of slab. They include flat slab, flat slab with edge beam, flat slab with drop panel, flat slab with shear wall and conventional slab. In this study, 7 and 13-storey RC buildings were modelled and analyzed using ETABS software, linear dynamic response spectrum method was carried out as per Indian code IS 456:2000 in seismic zone V. The outputs of this study showed that the flat slab has a maximum lateral displacement and storey drift if compared to the other types of the slabs because it does not have a lateral resisting system.

Lande and Raut, (2015b) have presented a comparative study on the seismic performance of different types of slab as per the Indian code IS 1893-2001 in seismic zone V. These types of slab include conventional slab, flat slab, flat slab with and without shear walls. In this study, a seven-storey RC building was analyzed using the equivalent static method and ETABS. It is clear that lateral displacement is smaller in the conventional slab and the smallest in the flat slab with shear wall if compared to the purely flat slab. Also, maximum story drift was seen at the mid-storey of the building.

Mohana and Kavan (2015) presented a comparative study on the seismic behavior of conventional slab and flat slab. This study was done in all the seismic zones in India as per the Indian code. Commercial six-storey building was modelled and analysed using ETABS program. The results showed that the flat slab gives higher storey shear and lateral displacement if compared to the conventional slab. The maximum displacement occurs at the top of the buildings and minimum at the bottom. Also, it was noted that maximum storey shear is recorded at the base of the buildings which is also known as base shear.

Srinivasulu and Kumar (2015) examined the seismic realization and dynamic analysis of a given six-storey RC building located in seismic zone III in India as per the Indian code IS 1893:2002. In this study, flat slab, flat slab with drop panels and flat slab with shear wall were used. Moreover, the response spectrum method was done to determine the seismic response of the buildings using ETABS software. It was observed that either shear wall or drop panel are preferred in the flat slabs constructed in seismic zone areas.

Devtale, Sayyed, Kulkarni and Chandak (2016) examined a comparative study on seismic performance of conventional slab and flat slab with and without shear walls. In this study, a four-storey RC building was performed. The equivalent lateral force method was done as per Indian code IS 1893 in seismic zone III using SAP2000 software. It was concluded that using shear walls leads to an increase in base shear, but time period and displacement are decreased. Also, time period and displacement of the conventional slab are less when compared to the flat slab but base shear of the conventional slab is more than of the flat slab.

Gowda and Tata (2016) carried out a study in India in seismic zone II and III in order to determine the role of drop panels in the floor systems under seismic forces. In this study, flat slab and flat slab with drop panels were considered in a commercial ten-storey RC building. ETABS Software was used to make the models that were analyzed by the response spectrum method as per the Indian code IS 456:2000. It was noted that lateral displacement, storey drift and storey shear of the flat slab with drop panels were small when compared to the flat slab. Also, observed that maximum storey shear occurs at the base and minimum at the top of the buildings.

Thakkar, Chandiwala and Bhagat (2017) studied the seismic performance between purely flat slab and flat slab with drop panel in relative to the conventional slab in India, in seismic zone III as per the Indian code. They used three multi-storey RC buildings with different height i.e. 6, 9 and 12 storey, they were modelled and analysed using ETABS software and using the linear dynamic response spectrum method. It was concluded that lateral displacement of the flat slab was 44.11% greater than the conventional slab and 26.19% greater than to the flat slab with drop panel. Moreover, increasing height of the buildings results to increase in displacement and base shear. Also, Time period of the purely flat slab is 25.17% greater than the conventional slab and 14.04% greater than the flat slab with drop panel and the time period is directly increased with increasing the height of the building.

2.7 Analytical Studies on Different Locations of Shear Wall

Chandurkar and Pajgade (2013) studied the effect of various locations of shear walls on lateral displacement and storey drift. In this study, a ten-storey RC building was used using ETABS program as per the Indian code. The shear walls were used at the exterior edges and exterior corners. It was shown that adding shear walls at the appropriate location reduces the lateral displacement.

Bhat, Shenoy and Rao (2014) conducted a study on the seismic performance of 50-storey RC Building by adding shear walls at the exterior edges, exterior corners and interior. The main objective of this study was to determine the role of the location of the shear walls on the seismic behavior of RC building. In this study, estimation of lateral displacement and base shear were carried out using STAAD.Pro and the response spectrum method as per the

Indian code. It was seen that the interior shear walls of the building are the best alternative location for increasing the seismic performance.

Basavaraj and Rashmi (2015) studied and tried to find the best location of shear walls that has more effect against seismic forces in Indian. The analysis was done according to the Indian code using SAP software and the equivalent lateral force method. In this study, a multi-storey RC building in different height was performed i.e. 5 and 9 storie. The models were created and the shear walls were added at the exterior edges, exterior corners and interior of the building. The results showed that shear wall at the exterior corner is the preferred effective position to minimize deflection and torsion in the buildings.

LovaRaju and Balaji (2015) analysed a residential eight-storey RC building using ETABS software as per Indian code. In this study different locations of shear walls were checked to determine the role of the locations of the shear walls on lateral displacement and base shear. Nonlinear static pushover method was used. It was revealed that seismic performance in terms of lateral displacement and base shear was much better when shear walls were located in the advantageous positions of the buildings.

Suresh and S. (2015) determined the optimum location of shear walls of the building. In this study, twelve-storey RC building was analyzed as per Indian code by using ETABS program and the equivalent Lateral Forces Method. Seismic parameters such as storey displacement, base shear, storey drift and stiffness were determined. Hence it was concluded that the best location of the shear walls was at the exterior corners.

Magendra, Titiksh and Qureshi (2016) considered an eleven-storey RC building under seismic forces in India to determine the most efficient position of shear walls using STAAD.Pro. The response spectrum method was used to calculate the earthquake load as per the Indian code. Three models were made with different locations of the shear walls i.e. at the exterior edges, exterior corners and interior. It was observed that shear walls at the interior of the building was the best choice for earthquake resistance.

Behera and Parhi (2017) stated that shear walls provide different performance due to their positions. In this study, lateral displacement and storey drift were considered as per Indian code and a residential RC building G+10 storey was modelled by using computer software STAAD pro. Shear walls were added in various positions such as at the exterior edges, exterior corners and interior edges of the building. Based on this study, minimum displacement and storey drift was obtained when the shear walls were situated at the exterior corners of the building.

Patil and Vijayapur (2017) studied the location of shear walls and seismic performance of ten-storey RC building, using the non-linear pushover method and SAP computer program. In this study, shear walls were used at the exterior edges and exterior corners. It was observed that adding shear walls to the exterior corners was more efficient.

Rokanuzzaman, Khanam, Das and Chowdhury (2017) conducted a study on the appropriate location of shear walls based on decreasing top displacement and base shear in a residential 16- storey RC building in Bangladesh. In this study, two different locations of the shear walls were adopted i.e at the exterior edges and exterior corners. The equivalent static method was used using ETABS program. It was shown that when shear walls are situated at exterior edges, minimum displacement and base shear were experienced.

Kumar (2018) studied and determined the ideal location of shear wall in a multistorey building located in the seismic zone V in India. The aim of this study was to understand the seismic behavior of different locations of shear walls in a five-storey rectangular building as per Indian code and using ETABS software. It was observed that interior corners are the ideal location for the shear walls of the building to reduce displacement in X and Y directions.

Mishra, Rai and Mishra (2018) studied the seismic behavior of an eleven-storey building in India, and also the effect of location of shear walls on the behaviour. The shear walls were added at the edges and corners. Response spectrum method was done. The ETABS program was used to make 3-D models. The results showed that minimum lateral displacement was observed when the shear walls were added at the edges of the building.

Tarigan, Manggala and Sitorus (2018) conducted a study on the optimum location of shear walls in the buildings based on seismic performance. In this study, the shear wall at the exterior edges and interior edges were investigated in five-storey RC building. It was concluded that shear walls at the interior edges placed symmetrically were more effective than shear walls at the exterior edges also placed symmetrically in terms of displacement and storey drift.

CHAPTER 3
METHODOLOGY

3.1 Preface

This chapter describes the models, the method, and the seismic code that have been adopted in order to define the boundaries and variables affecting the outcomes of seismic analysis.

3.2 Case Study

The case study is Erbil city in Iraq. Erbil has been regarded by UNESCO as one of the oldest continuously inhabited cities in the world and its history dated back to around 6000 year before Christ (B.C) (Ibrahim et al., 2015). The total area cover is around 130 Km^2 and 420 m above sea level. The Latitude of Erbil is 36.19 N, and the Longitude is 41.1 E. The population of Erbil is about 1,532,081. In recent times, there is decrease in the amount of residential areas as Erbil is developing and becoming a centre of trade, therefore, there is a significant increase in the number of multi-storey RC buildings as shown in Figures 3.1 and 3.2 (Khalid, 2014; Baiz, 2016; Onur et al., 2016).

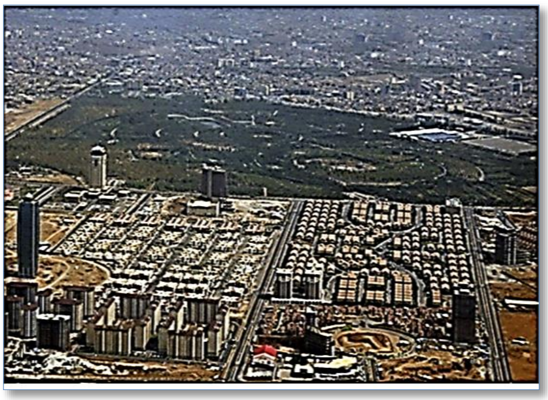

Figure 3.1: Erbil city (Ibrahim et al., 2015)

Figure 3.2: Residential buildings in Erbil (Ibrahim et al., 2015)

3.3 Modelling of the RC Buildings

In this study, the seismic behaviour of RC multi-storey building with different types of slab and different location of shear wall is studied. A regular building having 5 storey is chosen for seismic design category, C in Erbil city. The analysis is performed by using equivalent lateral force method (ELFM) and pushover by using ETABS commercial computer program as per ISC-2017. General building information and dimension of the members are given in Tables 3.1 and 3.2 respectively.

Table 3.1: General building information in Erbil

Specifications	**Values**
Dimension of building, length and width	20.4m x 20.4m
Building height	15 m
Typical floor height	3 m and 3.7 m
Total floor area	416 m^2.
Cross-section of columns	0.4m x 0.4m
Dimension of shear walls, length and width	2 m x 0.25m
Dimension of beams, depth and width	0.5 m x 0.25 m
Size of drop panel	2 m x 2 m
Thickness of drop panel	0.1 m
Intended purpose	Residential
Concrete class	25 MPa and 30 MPa
Steel class	300 MPa and 420 MPa

Table 3.2. Thickness of the slabs for the buildings

Different Types of Slab	**Thickness of Slab, mm**
Flat slab	290
Flat slab with drop	200
Flat slab with edge beam	210
Conventional slab	150
Flat slab with drop and edge beam	150
Flat slab with shear wall	240

In this study, two structural systems are used:

1. Moment resisting frame (MRF) as shown in Figures 3.3 – 3.7
2. Moment resisting frame (MRF) + shear walls (SW) as shown in Figures 3.8 – 3.12.

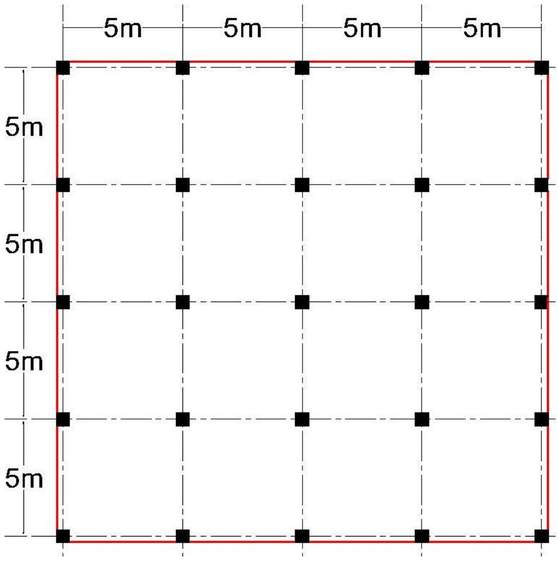

Figure 3.3: Floor plan of flat slab (MRF)

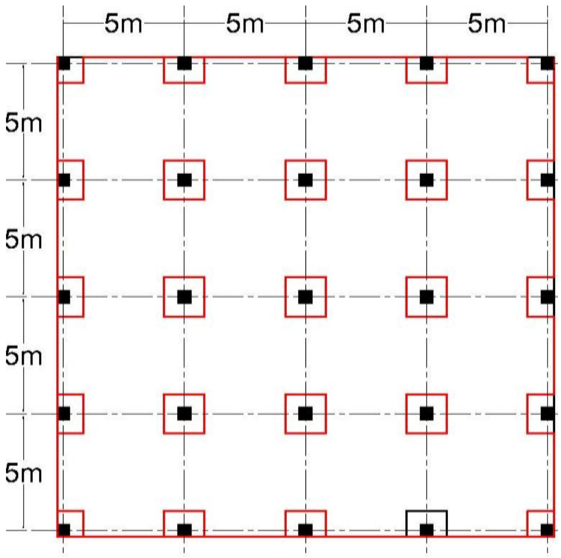

Figure 3.4: Floor plan of flat slab with drop panel (MRF)

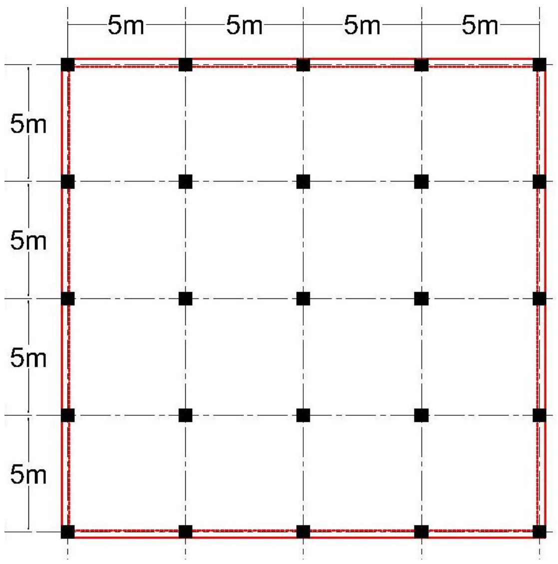

Figure 3.5: Floor plan of flat slab with edge beam (MRF)

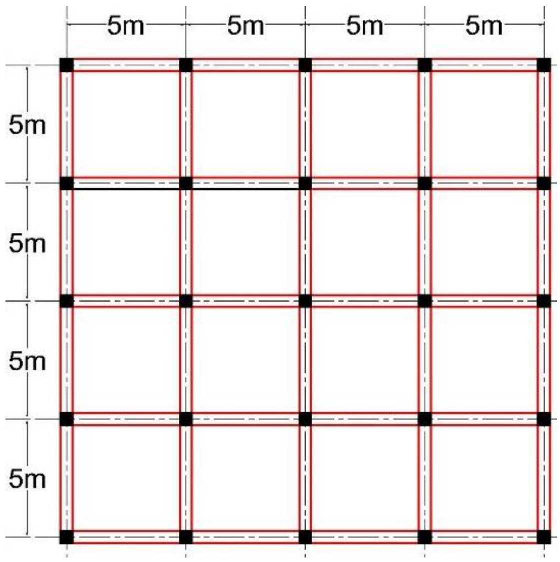

Figure 3.6: Floor plan of conventional slab (MRF)

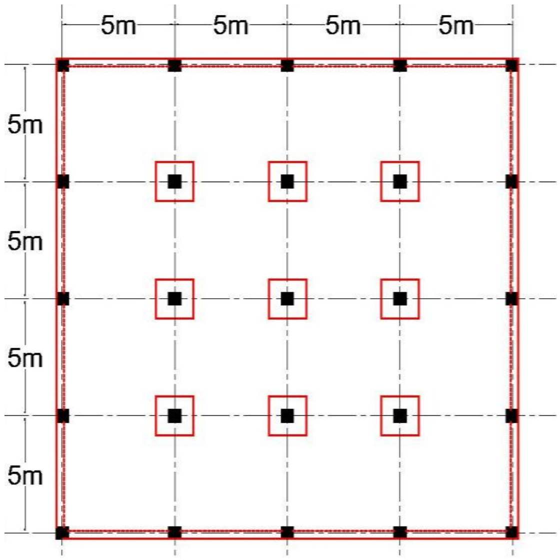

Figure 3.7: Floor plan of flat slab with drop panel and edge beam (MRF)

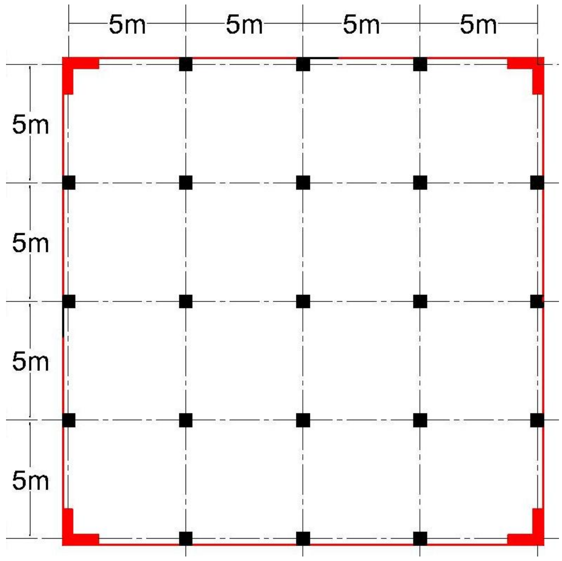

Figure 3.8: Floor plan of flat slab with shear wall at exterior corners (MRF)

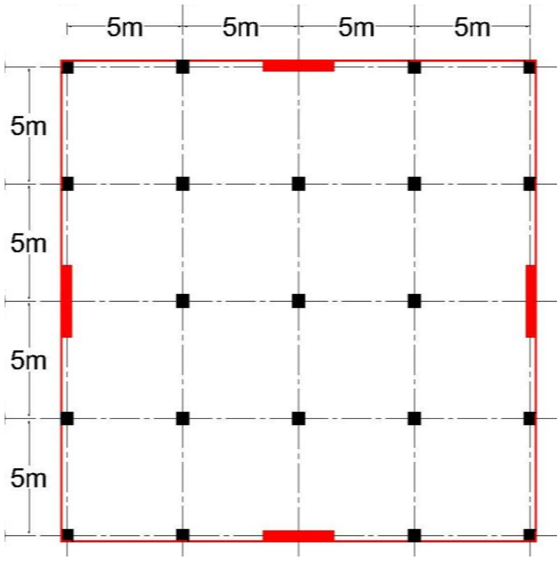

Figure 3.9: Floor plan of flat slab with shear wall at exterior edges (MRF+SW)

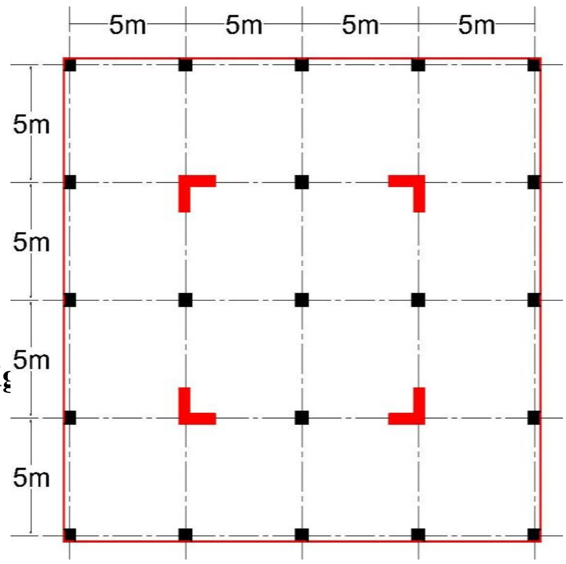

Figure 3.10: Floor plan of flat slab with shear wall at interior corners (MRF+SW)

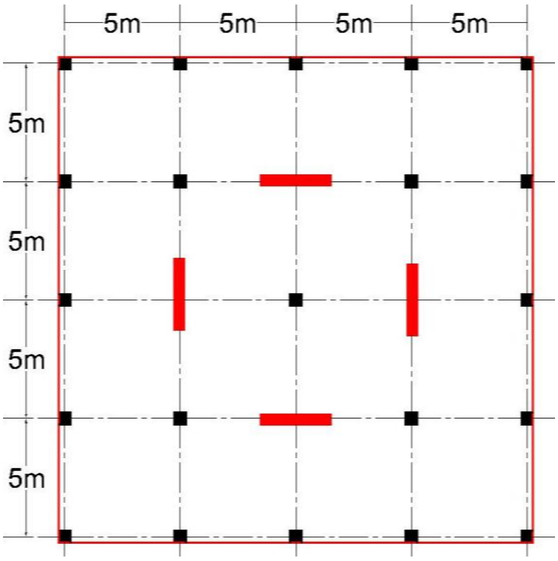

Figure 3.11: Floor plan of flat slab with shear wall at interior edges (MRF+SW)

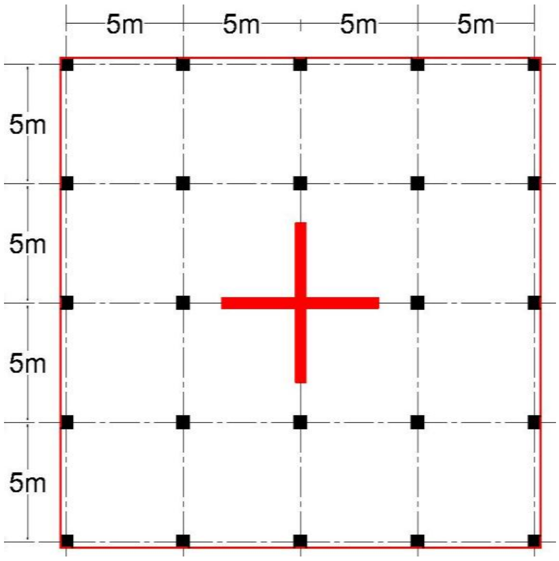

Figure 3.12: Floor plan of flat slab with shear wall at the center (MRF+SW)

3.4 Dimension of the Members

Dimension of the members of the buildings are determined according to ACI 318-14.

3.4.1 Flat slab

Minimum thickness of flat slab is determined from Table 3.3.

Table 3.3: Minimum thickness of flat slab systems according to ACI 318-14

Grade of steel Mpa	Without Drop Panel			With Drop Panel		
	Exterior		Interior	Exterior		Interior
	Without Edge Beam	With Edge Beam		Without Edge Beam	With Edge Beam	
280	$L_n/33$	$L_n/36$	$L_n/36$	$L_n/36$	$L_n/40$	$L_n/40$
420	$L_n/30$	$L_n/33$	$L_n/33$	$L_n/33$	$L_n/36$	$L_n/36$
520	$L_n/28$	$L_n/31$	$L_n/31$	$L_n/31$	$L_n/34$	$L_n/34$

L_n: Is the clear span from face to face of the vertical supports in the long direction.
The minimum thickness of the flat slabs with drop panel should be ≥ 100 mm.
The minimum thickness of the flat slabs without drop panel should be ≥ 125 mm

3.4.2 Conventional slab

In order to determine the minimum thickness of the conventional slab, there are two equations that mainly depend on the stiffness of the beams.

If $\alpha_m \leq 0.2$

This case is considered as the flat slab, and the thickness is decided from Table 3.3.

If $0.2 < \alpha_m \leq 2$

$$t_{min.} = \frac{L_n\,(0.8+\frac{fy}{1400})}{36+5\,\beta(\alpha_m - 0.2)} \geq 120\text{mm} \qquad (3.1)$$

If $\alpha_m > 2$

$$t_{min.} = \frac{L_n\,(0.8+\frac{fy}{1400})}{36+9\beta} \geq 90\text{ mm} \qquad (3.2)$$

Where

α_m: The average of α in one panel, $\alpha = \frac{Ib}{Is}$

Ib: The moment of inertia of the beam, mm^4.

Is: The moment of inertia of the slab, mm^4.

$t_{min.}$: Minimum thickness of the conventional slab, mm.

$\beta = \frac{L_{n1}}{L_{n2}}$

L_{n1} : Clear span in long direction, mm.

L_{n2} : Clear span in short direction, mm.

L_n : Clear span in long direction, mm.

Note: increasing 10% thickness for discontinues panels if $\alpha_m \geq 0.8$ (ACI)

3.4.3 Beams

The depth of the beams should be higher than the values obtained from Equations 3.3 and 3.4.

For the beams that one end is continuous;

$$h_{min.} = L/18.5 \quad (3.3)$$

For the beams that both ends are continuous;

$$h_{min.} = L/21 \quad (3.4)$$

Also, the width of the beams should be higher than the value obtained from Equation 3.5.

$$b_{min.} = 0.5 \text{ h} \quad (3.5)$$

Where

$h_{min.}$: The minimum depth of the beams.

$b_{min.}$: The minimum width of the beams.

L : Clear span between the vertical supports.

3.4.4 Drop panel

The size of the drop panels and its thickness are determined based on the following equations which are shown in detail in Figure 3.13.

$$\text{Length of drop panel in each direction} \geq L/3 \quad (3.6)$$

$$t_{drop} \geq 0.25 \text{ h} \quad (3.7)$$

Where

L: The greatest of L1 and L2, mm, which is taken in Figure 3.13.

h: Thickness of the flat slab, mm.

t_{drop}: Thickness of the drop panel, mm.

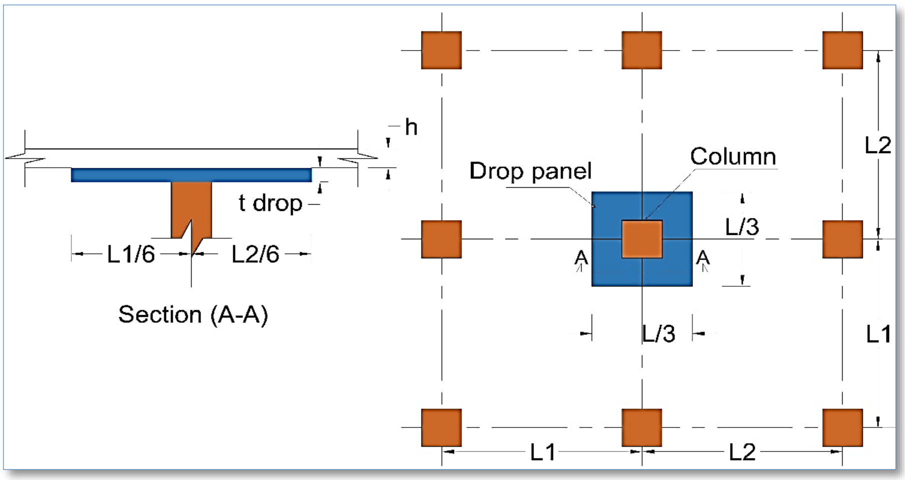

Figure 3.13: Dimensions of drop panel defined by ACI 318-14

3.4.5 Shear wall

The thickness of RC shear wall is the highest value of the following equations.

$$t_{min.} = 1/25 * \text{length of the shear wall} \geq 10\text{cm} \quad (3.8)$$

$$t_{min.} = 1/25 * \text{height of the shear wall} \geq 10\text{cm} \quad (3.9)$$

Where

$t_{min.}$: Minimum thickness of the shear wall, mm.

3.5 Load Patterns

In the present study, the loads used are dead load, live load and seismic load. In ETABS, all the loads must be defined in the "define load pattern" box as shown in Figure 3.14.

a. Dead load: Dead load is the structure self-weight which is automatically calculated by ETABS software.

b. Super dead load: Super dead load is the additional load on the structures, it represents the weight of the finishing materials and partition walls of a building. In this study, 3KN/m^2 is taken.

c. Live load: Live load is the movable loads on the structures, it depends on types of building. However, in this study live load for residential building is taken as 3KN/m^2 and assumed for all the floors.

d. Earthquake load: The earthquake load is calculated based on the provisions of ISC-2017 and ELFM. In which available local data for Erbil is used. These provisions are explained in Section 3.9, in detail.

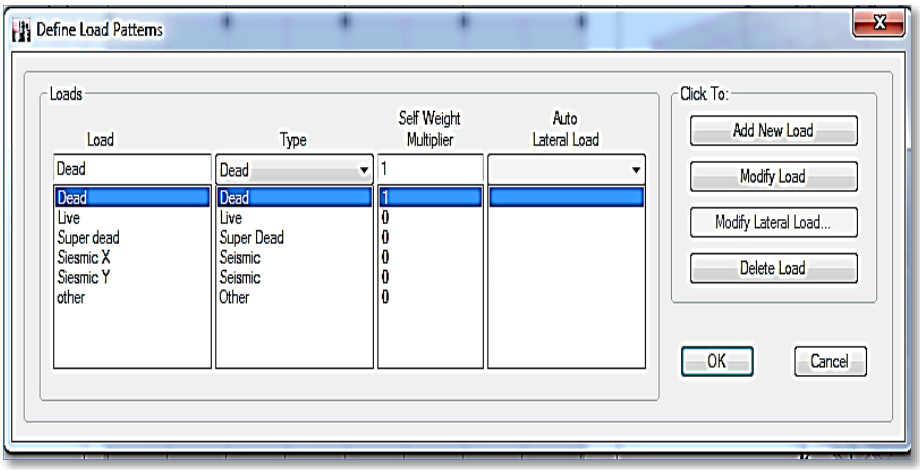

Figure 3.14: Definition of Load patterns by ETABS software.

3.6 Load Combinations

Generally, the pure loads are increased by multiplying with a factor which is always greater than 1.0. The factored loads are used for all members of the buildings. Load factors are used because the real load does not accurately estimate the values. The load factors for live loads are greater than that of dead loads, because dead loads are estimated more accurately than live loads. In seismic design, the buildings are designed for critical loads that are gained from various load combinations. ETABS makes load combination by using the load patterns that are defined as per the used code as shown in Table 3.4 (McCormac and Brown, 2015; Kodali et al., 2014)

Table 3.4: Load combinations (ISC-2017)

Cases	ISC-2017
Dead load (DL)	1.4DL
Dead load and live load (LL)	1.2DL+1.6LL
Dead load, live load and seismic load (E)	1.2DL+1.0LL+1.0E
Dead load and seismic load	0.9DL+1.0E

3.7 Mass Source

The mass source of a building is considered as entirely dead load with 25% live load when the live load is equal or smaller than 3 KN/m^2. Also, the mass source will be entirely dead load with 50% live load when the live load exceeds 3 KN/m^2 as shown in Figure 3.15.

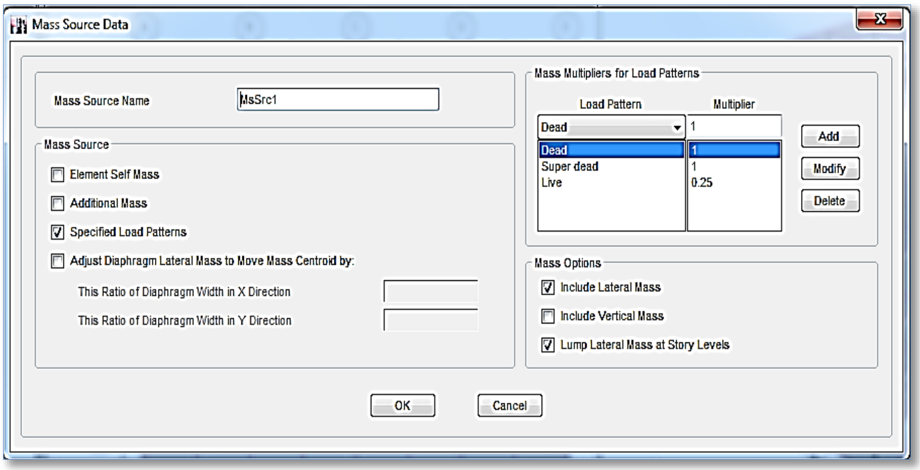

Figure 3.15: Definition of mass source by ETABS software.

3.8 Seismic Analysis Methods

Commonly, there are four methods that are used to calculate seismic forces of structures as shown in Figure 3.16. There are some factors should be considered during the decision of choosing an appropriate method of analysing a building. These factors are; height of the building, regularity of the building, and seismic design category. In this study, equivalent lateral force method and pushover analysis are used (ISC-2017; Touqan and Salawdeh, 2013).

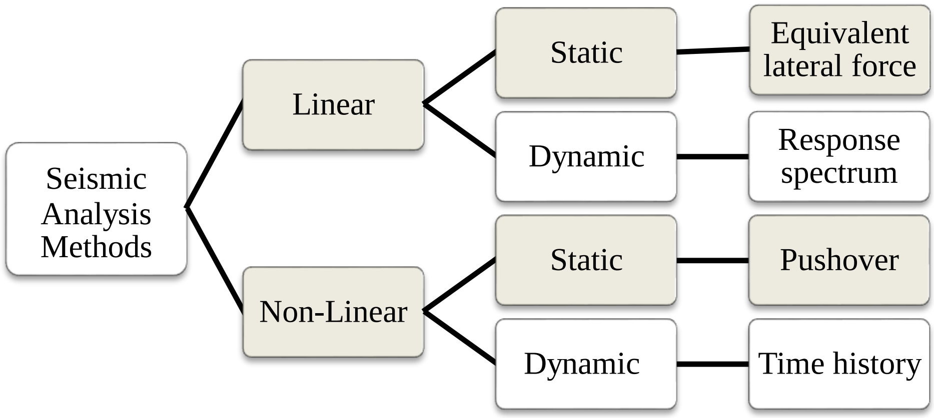

Figure 3.16: Seismic analysis methods (Čada and Máca, 2017; Hamed, 2018)

3.8.1 Equivalent lateral force method

This method is known as the linear static method. In this approach, the effect of earthquake is represented by lateral forces applied along height of building. These forces contribute to the connections of the structures and are transferred through diaphragms to the frame members and finally to the foundation. ELFM is commonly used for concrete and steel structures (Gottala et al., 2015; Hamed, 2018; Čada and Máca, 2017; Bagheri et al., 2012; Tarafder et al., 2015; Taylor et al., 2016)

3.8.2 Pushover analysis

Pushover is an inelastic nonlinear analysis method which is used in order to evaluate the behaviour of structures under lateral forces. In this analysis, the gravity loads are carried out and the lateral loads are then implemented. The lateral loads are increased on the buildings up to where the lateral displacement gets to the maximum level of deflection then the analysis will be finished (Oguz, 2005). This process means that analysis continues until the structure looks unstable. In pushover analysis, displacement-controlled or force-controlled can be used. The displacement-controlled means that the applied loads is not known, the loads are increases till the displacement gets a specified value. Otherwise, the force-controlled can be used in the case of know the loads for example the gravity loads.

According to Ismail, A. (2014) and Mouzzoun et al. (2013), the pushover analysis goals are as follows:

- To determine the structures' behavior throughout inelastic analysis for a new or existing buildings.
- To identify the position of failure at the ends of the beams, columns and shear walls, this is called plastic hinges.

There are some procedures of pushover analysis that need to be made:

- Define a load case for gravity loads.
- Define a load case for seismic loads which means that the seismic loads push the structures up to the target displacement.
- Select the beams of the buildings, then assign the plastic hinges at the ends of the beams from 0.05 and 0.95 of length.
- Select the columns and shear wall of the buildings, then assign the plastic hinges at the ends of the columns and shear walls from 0.05 and 0.95 of length.
- Select "Do Not Run" in analysis menu for all the load cases.
- Select "Run" in analysis menu only for gravity and push load cases
- Run and display the pushover curve.

3.9 Determination of Seismic Loads for Erbil City According to ISC-2017

All the parameters that relate with seismic load are determined as per ISC-2017.

3.9.1 Maximum considered earthquake (MCE)

MCE is the most severe earthquake which is predicted to occur. The degree of ground motion due to MCE is represented by spectral response acceleration S_s and S_1 (ISC-2017).

3.9.2 Spectral response acceleration, S_s

This shows the effect of maximum considered earthquake on the structures at a period of 0.2 second. Figure 3.17 shows S_s of Iraqi regions, in which Erbil has S_s= 0.6g where g is earth's gravity (ISC-2017).

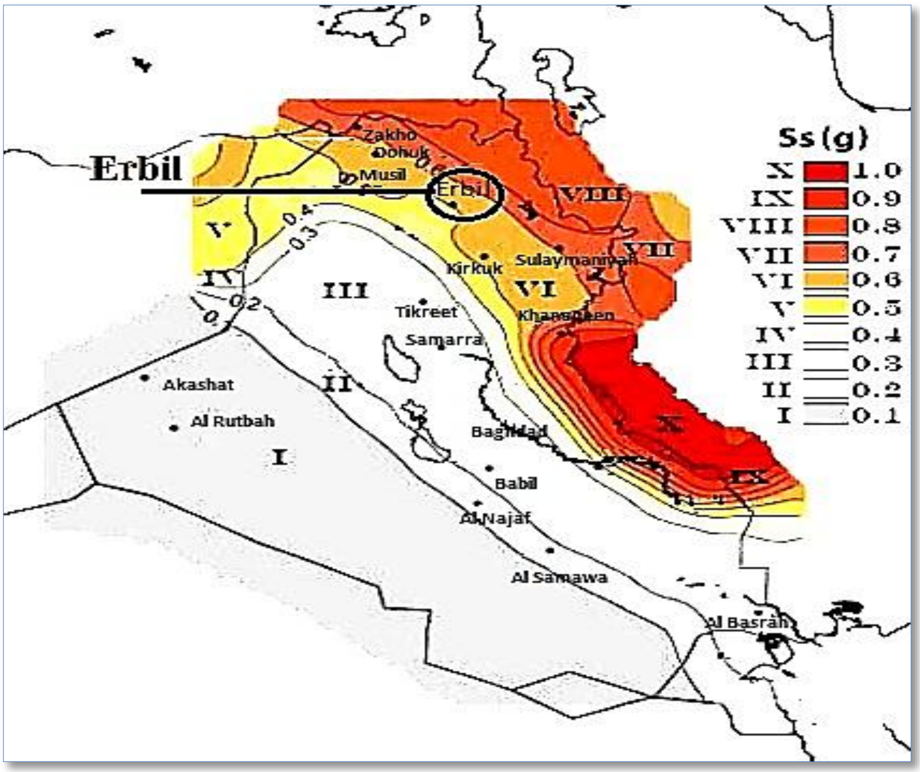

Figure 3.17: Distribution of spectral response acceleration S_s in Iraq (ISC-2017).

3.9.3 Spectral response acceleration, S_1

This shows the effect of maximum considered earthquake on the structures at a period of 1 second. Figure 3.18 shows S_1 of Iraqi regions, in which Erbil has S_1= 0.2g, where g is earth's gravity (ISC-2017).

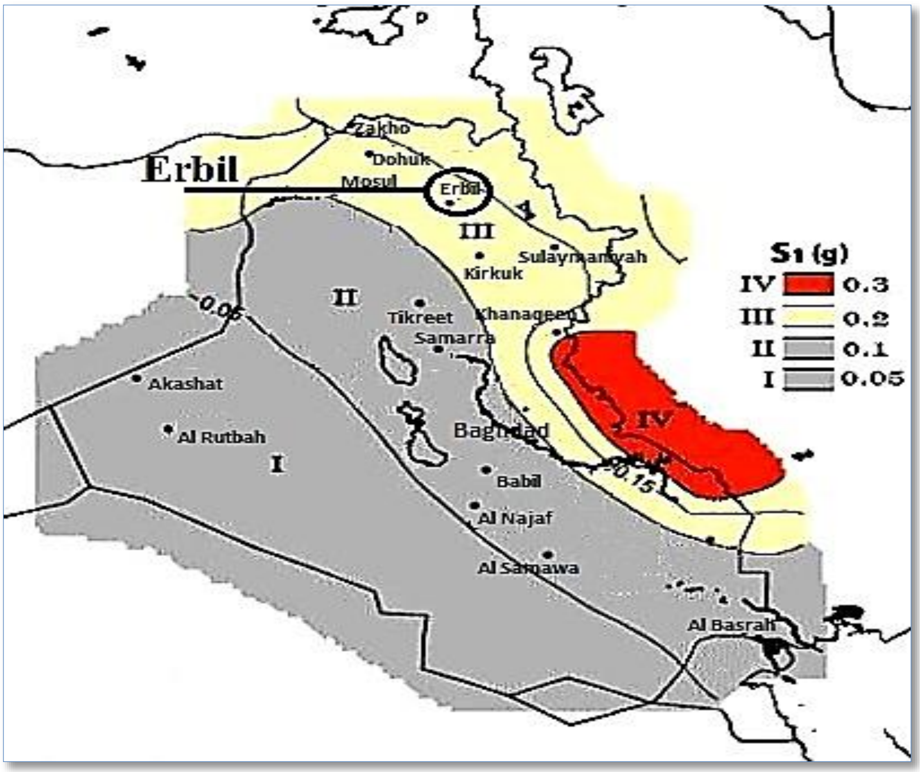

Figure 3.18: Distribution of spectral response acceleration S_1 in Iraq (ISC-2017).

3.9.4 Site classes

According to ISC-2017, there are six site classes of soil. They start from low seismic force A to high seismic force F as shown in Table 3.5. Determination of soil site class depends on shear wave velocity, which is measured in 30m depth through the underground. In the case of unknown shear wave velocity, soil site class D can be used (ISC-2017; McCormac and Brown, 2015; Anbazhagan et al., 2019; Al-Taie, et al., 2013).

Table 3.5: Soil site classes (ISC-2017)

Soil Site Class	Soil Properties	Velocity of Shear Waves (m/s)
A	Hard rock	V_S >1500
B	Rock	760 to 1500
C	Very intensive soil, and soft rock	370 to 60
D	Stiff soil, (default site class)	180 to 370
E	Soft and clay soil	V_S < 180
F	Weak soil, that need to analyze	

3.9.5 Site coefficient factors F_a and F_v

Usually, these factors are obtaining based on the site class and spectral response acceleration for short period (S_S) and long period (S_1) according to ISC-2017 as shown in Tables 3.6 – 3.7 respectively.

Table 3.6: Site coefficient for short period, F_a (ISC-2017)

Soil Site Class	$S_s \leq$ 0.25	S_s= 0.5	S_s= 0.75	S_s= 1.0	$S_s \geq$ 1.25
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

Note: 1- a:it is needed for special soil investigate. 2- Using linear interpolation for mid values.

Table 3.7: Site coefficient for long period, F_v (ISC-2017).

Soil Site Class	S_s≤ 0.25	S_s= 0.5	S_s= 0.75	S_s= 1.0	S_s≥ 1.25
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a

Note: 1- a:it is needed for special soil investigate. 2- Using linear interpolation for mid values.

Modified spectral response acceleration in short and long period S_{MS} and S_{M1} respectively.

$$S_{MS} = F_a * S_s \quad (3.10)$$

$$S_{M1} = F_v * S_1 \quad (3.11)$$

Designed spectral response acceleration in short and long period S_{DS} and S_{D1} respectively.

$$S_{DS} = \left(\frac{2}{3}\right) * S_{MS} \quad (3.12)$$

$$S_{D1} = \left(\frac{2}{3}\right) * S_{M1} \quad (3.13)$$

3.9.6 Risk category

The risk category of a building is determined according to the importance of the building for human life. ISC-2017 has classified the buildings in Iraq into four different categories I, II, III and IV as shown in Table A.2.1 in Appendix 2. Also, for each of these categories a corresponding importance factor is given as shown in Table 3.8.

Table 3.8: The importance factor for various risk categories (ISC-2017).

Risk Category	Importance Factor
I, II	1.0
III	1.25
IV	1.5

3.9.7 Seismic design category (SDC)

SDC is a classification of the structures. It is determined based on the spectral response parameters, site class, and risk category. According to ISC-2017, there are four types of SDC that start from A to D as shown in Tables 3.9 – 3.10 (ISC-2017).

Table 3.9: SDC according to S_{DS} and risk category (ISC-2017)

Values	Risk Category		
	I or II	III	IV
$\boldsymbol{S_{DS}}$ <0.167	A	A	A
0.167 ≤ $\boldsymbol{S_{DS}}$ < 0.33	B	B	C
0.33 ≤ $\boldsymbol{S_{DS}}$ < 0.5	C	C	D
0.5 ≤ $\boldsymbol{S_{DS}}$	D	D	D

Table 3.10: SDC according to S_{D1} and risk category (ISC-2017).

Values	**Risk Category**		
	I or II	**III**	**IV**
S_{D1} <0.067	A	A	A
$0.067 \le S_{D1} < 0.133$	B	B	C
$0.133 \le S_{D1} < 0.20$	C	C	D
$0.20 \le S_{D1}$	D	D	D

3.9.8 Determination of structure system

From Tables 3.9 - 3.10, the seismic design category C has been chosen and also, according to Table A.3.1 in Appendix 3, the intermediate reinforced concrete moment frame and intermediate reinforced concrete shear wall in dual system are chosen for Erbil city.

3.9.9 Fundamental period T, Sec.

Fundamental period is the period of shaking of a structure during an earthquake. It is determined based on seismic mass and rigidity of the structure. According to ISC-2017, the fundamental period shall be equal to or smaller than the values of C_u, shown in Table 3.11. However, fundamental period could not be exactly determined. In fact, it is very difficult to estimate the real amount of seismic weight and rigidity of a structure. Therefore, it is a common implementation to use approximate fundamental period (ISC-2017; Aninthaneni and Dhakal, 2016).

Table 3.11: Coefficient C_u and S_{D1} (ISC-2017).

S_{D1}	C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
0.1	1.7
≤ 0.05	1.7

According to the ISC-2017, the approximate fundamental period can be calculated from Equation 3.14.

$$T_a = C_t\ h_n^x \tag{3.14}$$

Where

C_t, x: The period coefficients, that are taken in Table 3.12.

h_n: The height of the building, m.

And, for the buildings that are made from concrete and steel materials while the number of storeys do not exceed 12 storeys and the average storey height is not smaller than 3m, T_a can be determined from Equation 3.15.

$$T_a = 0.1N \tag{3.15}$$

Where N indicates the number of storeys.

Also, for concrete and masonry shear wall buildings. T_a can be derived from Equation 3.16

$$T_a = \frac{0.0019}{\sqrt{C_w}}\ h_n \tag{3.16}$$

Where, C_w is a factor determined from the following Equation 3.17.

$$C_w = \frac{100}{A_B} \sum_{i=1}^{x} \left(\frac{h_n}{h_i}\right)^2 \frac{Ai}{\left[1+0.83\ \left(\frac{h_i}{D_i}\right)^2\right]} \tag{3.17}$$

Where

h_n: The height of the building, m.

A_B: The building area, m^2.

Ai : The shear wall base area, m^2.

D_i: Shear wall length, m.

h_i: Shear wall height, m.

x: Number of the effective shear wall that resists the horizontal loads in the considered direction.

Table 3.12: The approximate parameters C_t , and x (ISC-2017)

Structure Type	C_t	**x**
Steel moment frames that resist 100% of the earthquake loads	0.068	0.8
Concrete moment frames that resist 100% of the earthquake forces	0.044	0.9
Steel eccentrically braced frames	0.07	0.75
Whole other systems	0.055	0.75

3.9.10 Base shear design according to ISC-2017

Base shear is the maximum shear force on the base of a building as shown in Figure 3.19. It can be calculated from Equation 3.18 (ISC-2017; Coulbourne Consulting, 2017).

$$\mathbf{V} = C_S \, \mathrm{W} \qquad (3.18)$$

Where

C_S: The seismic response factor.

W: The effective seismic weight, KN/m^2 (dead load + 0.25 live load).

Seismic response factor, C_S

The value of C_S is the smallest of the following three equations

$$\mathrm{C_S} = \frac{\mathrm{S_{Ds}}}{(\frac{\mathrm{R}}{\mathrm{I}})} \qquad (3.19)$$

$$C_S = \frac{S_{D1}}{T\,(\frac{R}{I})} \quad \text{if } T \le T_L \qquad (3.20)$$

$$C_S = \frac{S_{D1}\,T_L}{T^2\,(\frac{R}{I})} \quad \text{if } T > T_L \qquad (3.21)$$

Or C_S should be equal to or greater than the following Equations

$$C_S = 0.044\, S_{DS}\, I \geq 0.01 \quad (3.22)$$

$$C_S = 0.55 \frac{S_1}{\left(\frac{R}{I}\right)} \text{ if } S_1 \geq 0.6g \quad (3.23)$$

Where

S_{DS}, S_{D1}: The design spectral response for short and long period respectively that are determined by Equations 3.12 and 3.13.

R: Response modification coefficient, which is taken from Table A.3.1 in Appendix 3.

I: The importance of buildings, which is taken from Table 3.8.

T: Time period of the building, Sec, which is taken from Section 3.9.9.

T_L: A long period transition, which is 6 seconds according to ISC-2017.

S_1: Spectral response acceleration in the long period, g which is taken from Figure 3.18.

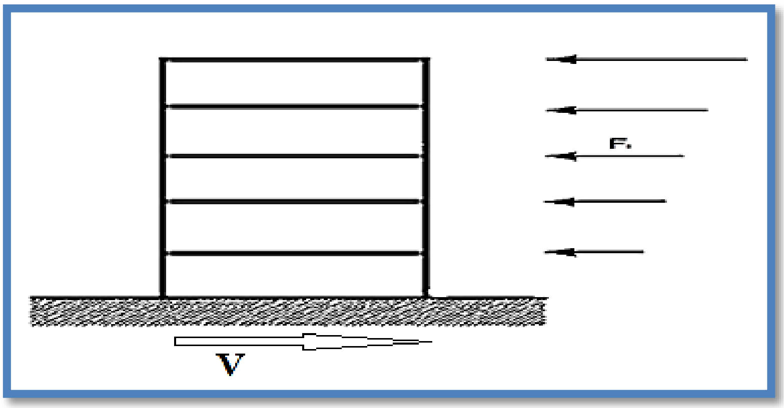

Figure 3.19: Lateral forces on a building (Hamed, 2018)

3.10 Numerical Applications

The seismic force parameters of Erbil city are summarized and shown in Table 3.13.

Table 3.13: Earthquake data for the buildings (ISC-2017)

Parameters	**According to ISC-2017 Code**
Spectral response acceleration in the short period (0.2 Sec.), S_s (Figure 3.17)	0.6 g
Spectral response acceleration in the long period (1 Sec.), S_1 (Figure 3.18)	0.2 g
Site class of Erbil (Table 3.5)	B
Site coefficient, Fa (Table 3.6)	1
Site coefficient, Fv (Table 3.7)	1
S_{DS}= = 2/3*Fa*Ss (Equation 3.12)	0.4
S_{D1}= = 2/3*Fv*S1 (Equation 3.13)	0.14
Risk category for "residential building" (Table A.2.1 in Appendix 2)	II
The seismic design category (Tables 3.9 – 3.10)	C
Long-Period Transition Period	6 Sec.
Approximate fundamental period T_a (Equation 3.15)	0.5 Sec.
The occupancy Importance factor, I (Table 3.8)	1
Type of structural system, (Table A.3.1 in Appendix 3)	IMF
Response modification, R (Table A.3.1 in Appendix 3)	4
Overstrength factor, Ω (Table A.3.1 in Appendix 3)	3
Deflection Amplification, C_d (Table A.3.1 in Appendix 3)	4.5

3.11 Three Dimensional View of Building Models

The models are made by ETABS program including moment frame and moment frame with shear wall.

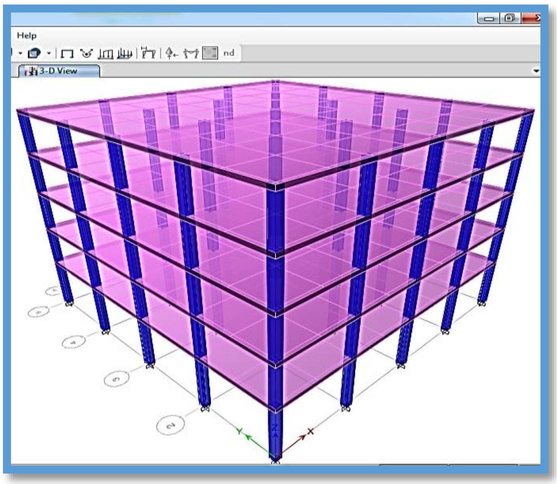

Figure 3.20: 3D model of flat slab

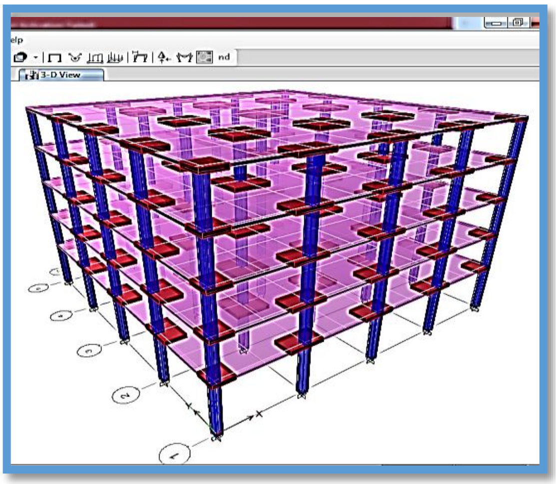

Figure 3.21: 3D model of flat slab with drop panel

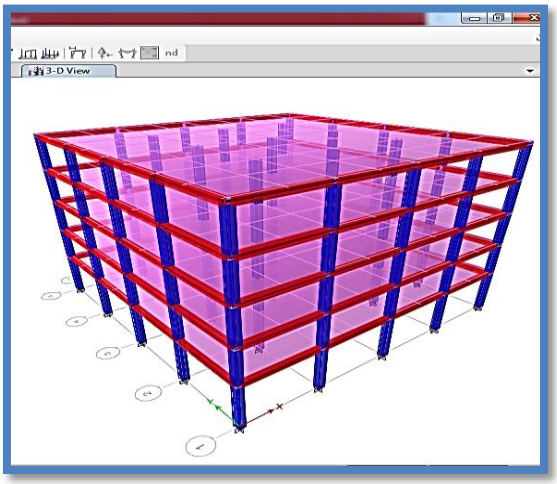

Figure 3.22: 3D model of flat slab with edge beam

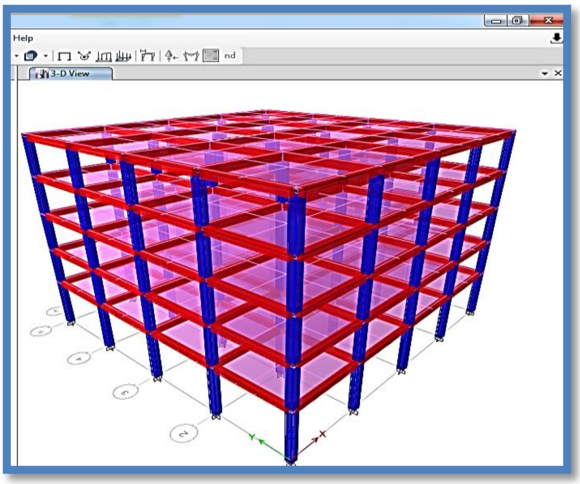

Figure 3.23: 3D model of conventional slab

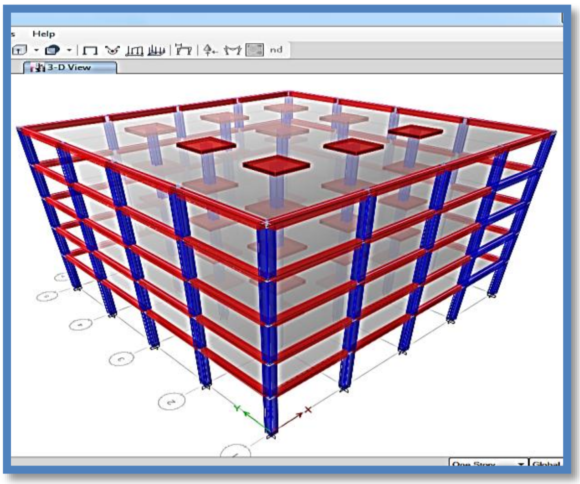

Figure 3.24: 3D model of flat slab with drop and edge beam

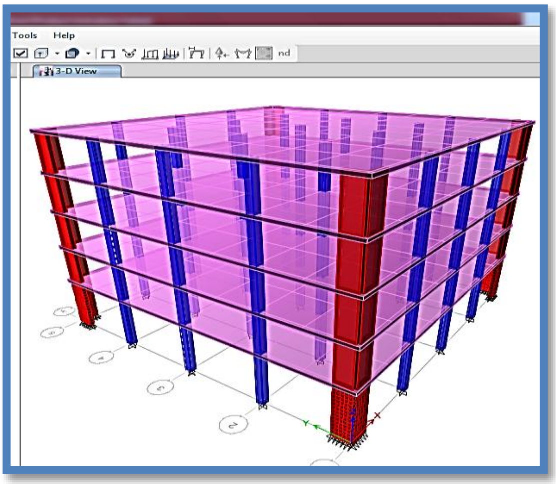

Figure 3.25: 3D model of flat slab with shear wall at exterior corners

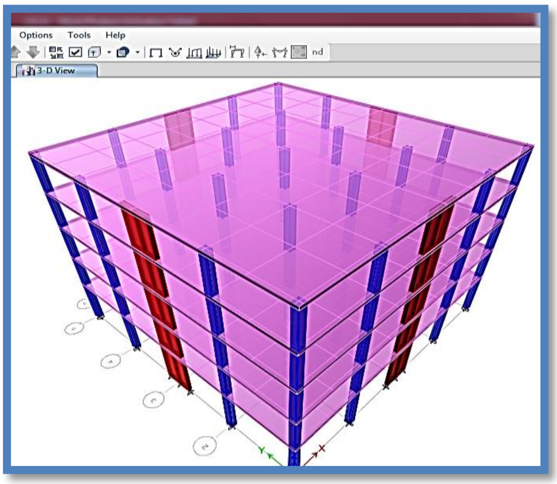

Figure 3.26: 3D model of flat slab with shear wall at exterior edges

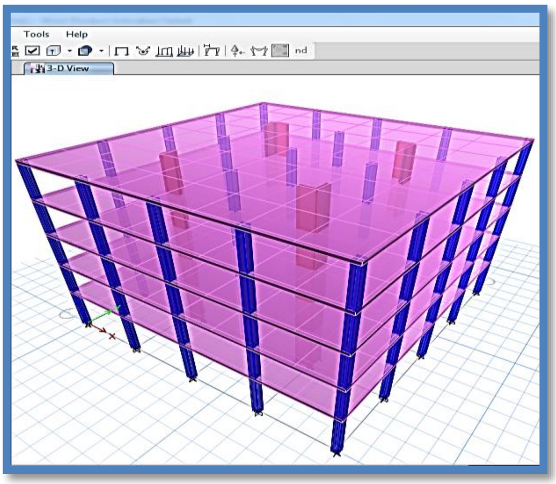

Figure 3.27: 3D model of flat slab with shear wall at interior corners

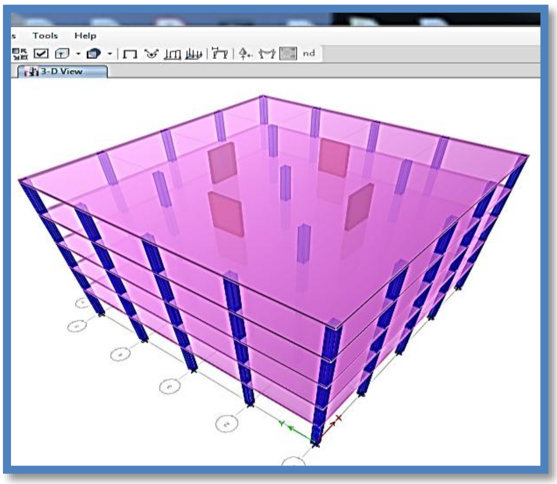

Figure 3.28: 3D model of flat slab with shear wall at interior edges

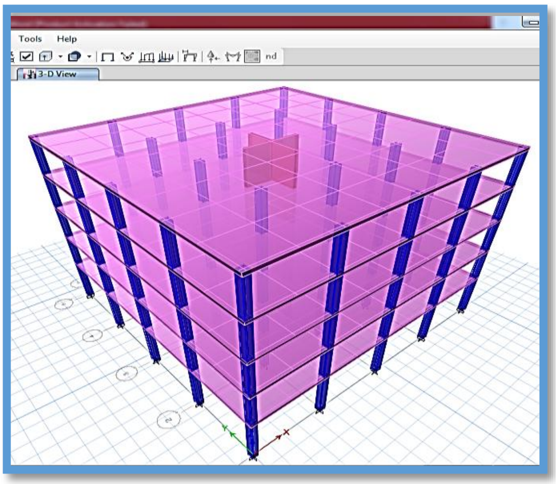

Figure 3.29: 3D model of flat slab with shear wall at the center

3.12 Analysis and Design Process by ETABS Program

The analysis and design steps of the buildings performed by ETABS are shown in Figure 3.30

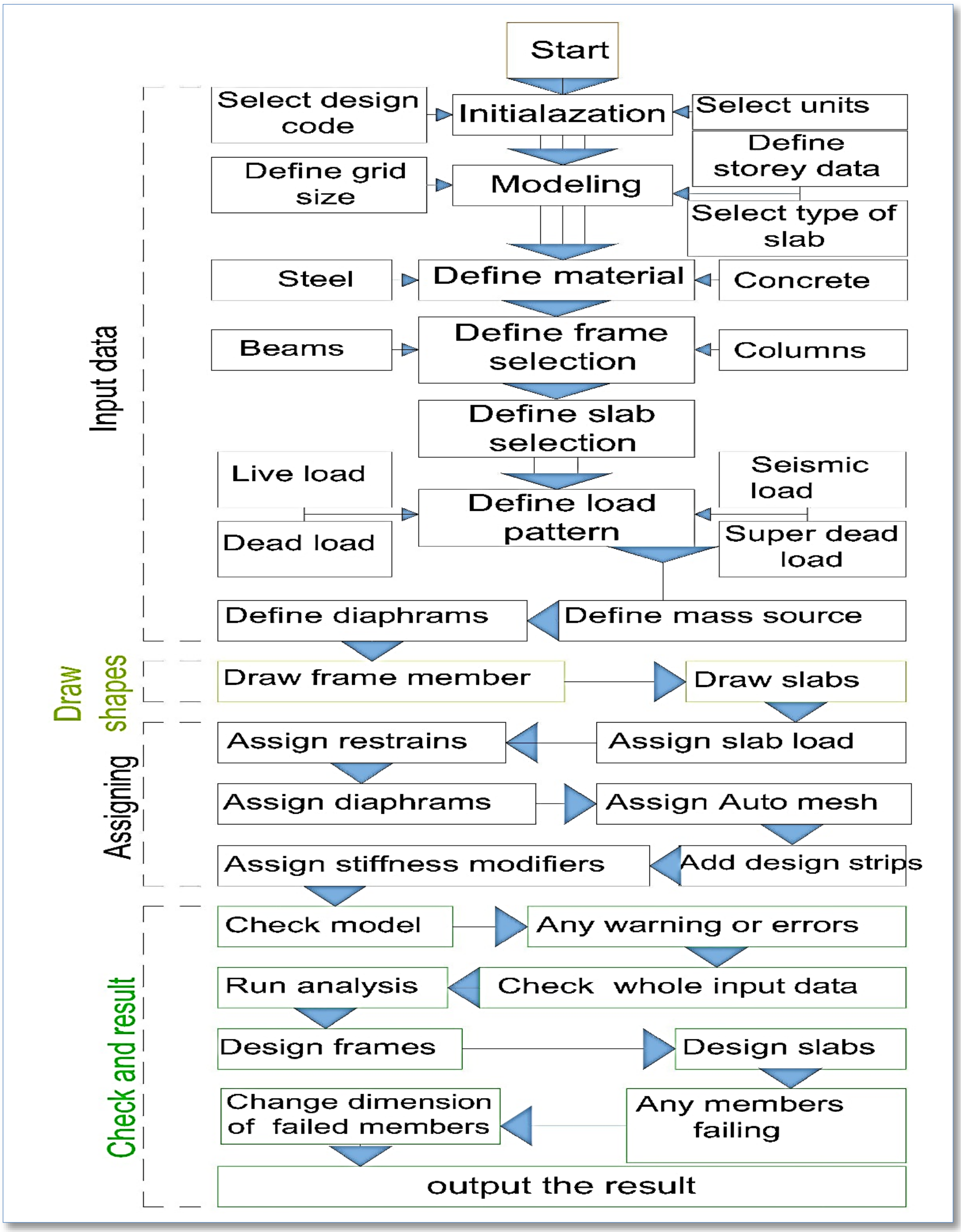

Figure 3.30: Analysis and Design Procedure of the buildings by ETABS Program

3.13 Seismic Parameters

In the present study, five seismic parameters are verified as the measurement tools (dependent variables) to evaluate the seismic behaviour of the RC buildings.

3.13.1 Lateral displacement, mm

Lateral displacement is the horizontal movement of a building due to lateral forces with respect to the base in x and y directions. The maximum displacement of a building occurs at the top and minimum at the bottom as shown in Figure 3.31 (Basavaraj and Rashmi, 2015) (ISC-2017). Lateral displacement relies on the height and slenderness of the buildings because the buildings are more flexible as height and slenderness increases (Thakkar et al., 2017). In the case of adding shear wall, decrease in lateral displacement is experienced (Lande and Raut, 2015b; Sudhan, 2015)

3.13.2 Storey drift, mm

Storey drift is the horizontal movement of a storey due to lateral forces with respect to the bottom of the same storey in both directions as shown in Figure 3.32. Distribution of storey drift of a building depends on the stiffness of its members, especially the beam-column connections. Storey drift appears as a parabolic path over the height of buildings with the highest value close to the middle storey. Storey drift decreases by embedding shear walls (ISC-2017; Moehle, et al, 2008; Tarigan et al., 2018).

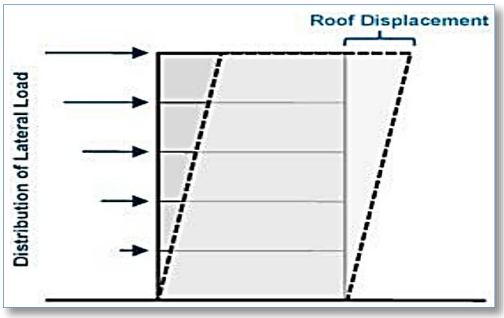

Figure 3.31: Lateral displacement of a building (Kazi and Shaikh, 2016)

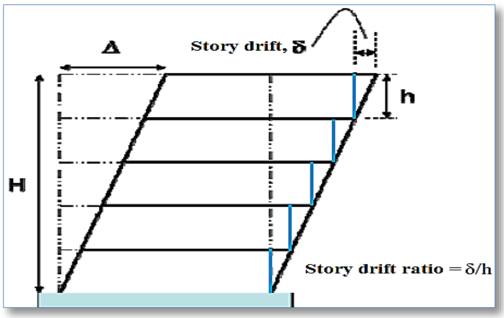

figure 3.32: Storey drift of a building (Jaya and Alandkar, 2016)

3.13.3 Base shear, KN

Base shear is the maximum shear force on the base of a building as shown in Figure 3.33. Base shear depends on seismic mass, height and stiffness. It increases with increase in the mass, height, and stiffness of the building. Moreover, base shear of buildings increase by adding shear walls due to an increase in stiffness. (Basavaraj and Rashmi, 2015; Kumar, 2018; ISC-2017; Thakkar et al., 2017; Krishna and Arunakanthi, 2014; Williams and Tripathi, 2016; Harinkhede et al., 2016).

3.13.4 Time period, Sec

Time period is a period needed to complete one cycle of vibration of a building during an earthquake until the building attempts to resume to its original position as shown in Figure 3.34. Time period depends on the mass, number of storeys, height, and width as well as stiffness of the building. It reduces with decrease in mass and increase in stiffness, and also by adding shear walls. Time period increases with increasing number of storeys even the height of the building does not change (ISC-2017; Williams, P. M., & Tripathi, 2016; Thakkar et al., 2017; Velani and Ramancharla, 2017; Patel et al., 2011; Hadzima-Nyarko et al., 2015; Bhuskade and Sagane, 2017).

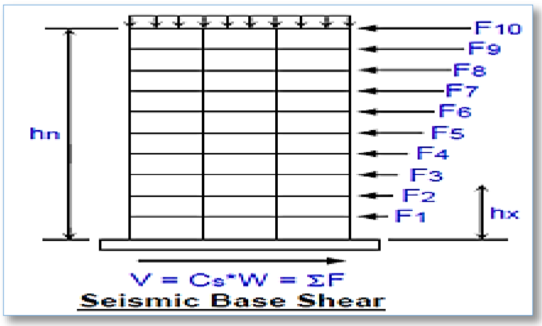

Figure 3.33: Base shear of a building (ISC-2017)

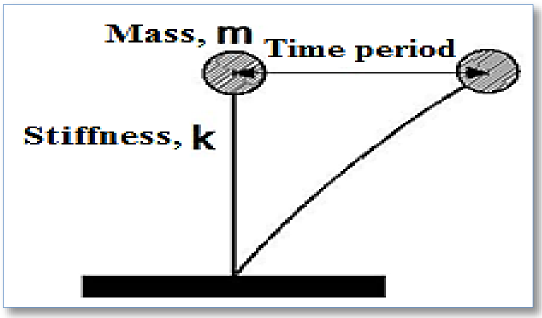

Figure 3.34: Time period due to seismic forces defined by (ISC-2017)

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Preface

This study gives the results and discussion of the seismic analysis of a regular RC building having 5 storeys with different types of slab and different locations of shear wall. The results include lateral displacement, storey drift, base shear, time period and stiffness. These results are used to examine the effect of five factors on seismic behaviour of the RC buildings. The factors considered in this study are namely; type of slab, shear wall, location of shear wall, compressive strength of concrete, yield strength of steel and floor height. The results are obtained by using equivalent lateral force method (ELFM) and pushover analysis by using ETABS program as per ISC-2017 in Erbil.

4.2 Lateral Displacement

In this section, factors are presented that have effects on lateral displacement. These factors are; types of slab, shear wall, locations of shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.2.1 The effect of different types of slab on the lateral displacement

The slab of type is one of the factors which effects the lateral displacement and seismic performance of RC buildings. Therefore, changing slab type of the buildings causes increase or decrease in the lateral displacement, because weight of the buildings are changed. Figure 4.1and 4.2 show the lateral displacement of the buildings having different type of slab.

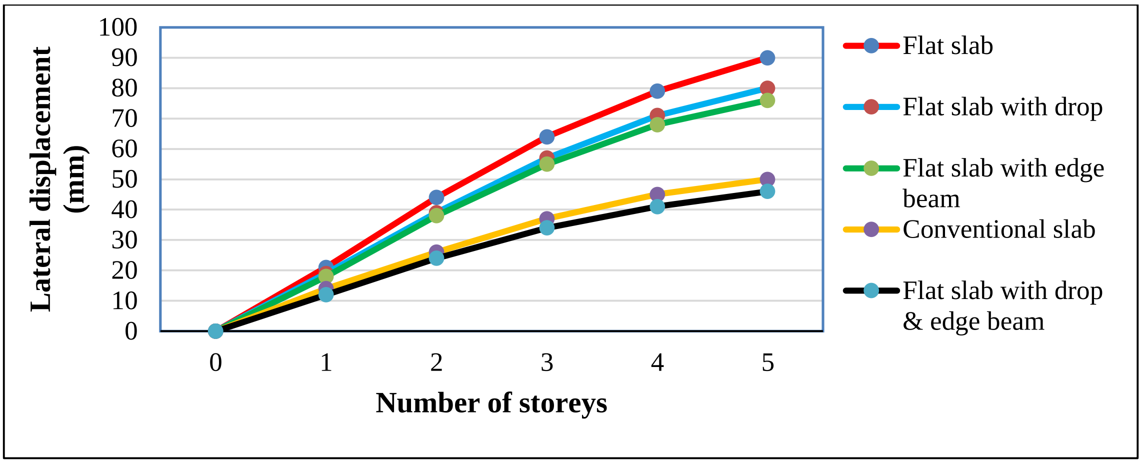

Figure 4.1: Lateral displacement of the buildings relative to number of storeys

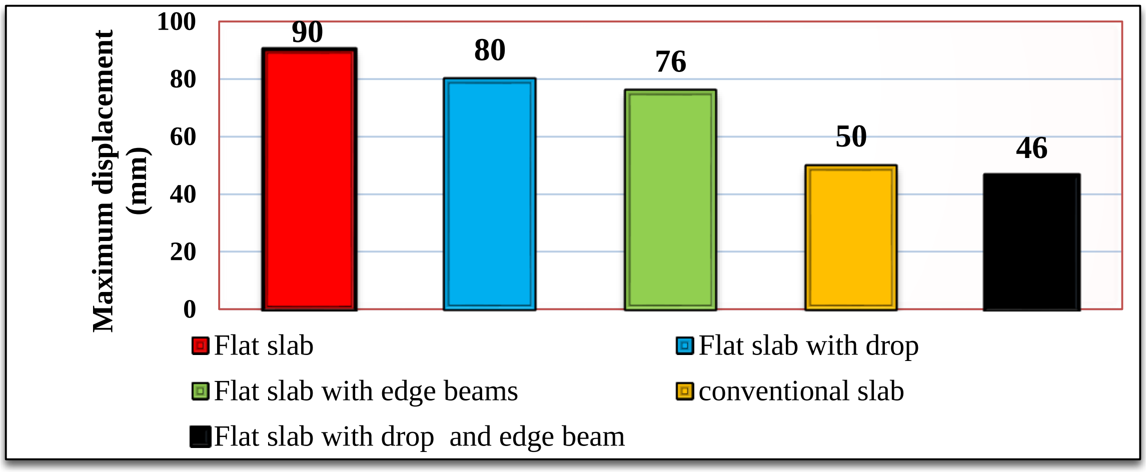

Figure 4.2: Maximum lateral displacement at the top of the buildings

Figure 4.2 shows that the lateral displacement of the purely flat slab is 11.11% more when compared to the flat slab with drop panel and 15.55% more when compared to the flat slab with edge beam. Also, lateral displacement of the purely flat slab is 44.44% more when compared to the conventional slab and 48.88% higher when compared to the flat slab with both drop panel and edge beam.

4.2.2 The effect of shear wall and shear wall location on the lateral displacement

Shear walls decrease lateral displacement but it also depends on the location it is fixed. It is also observed that as the location of shear walls approaches the centre of the buildings, the lateral displacement decreases as shown in Figure 4.3 and 4.4.

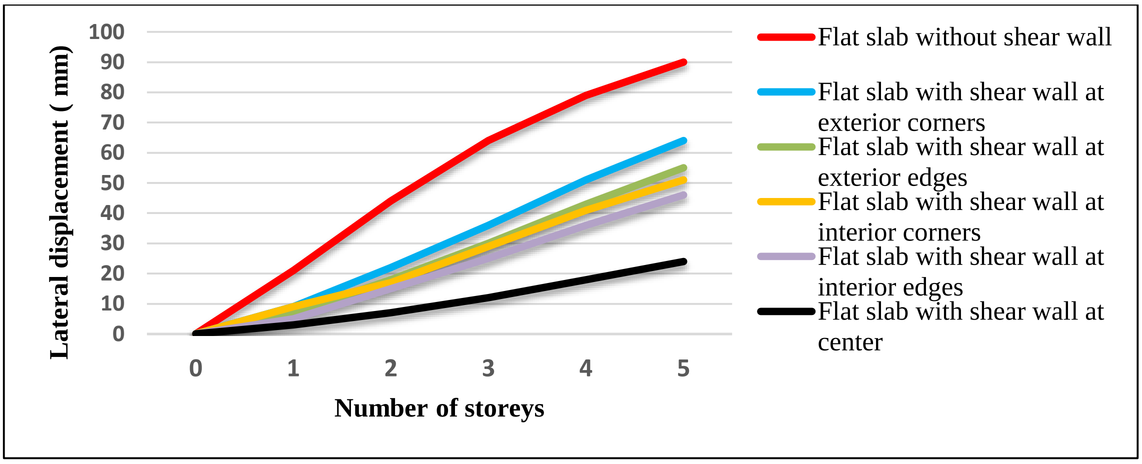

Figure 4.3: Lateral displacement of flat slab and flat slab with shear wall at different locations relative to the number of storey

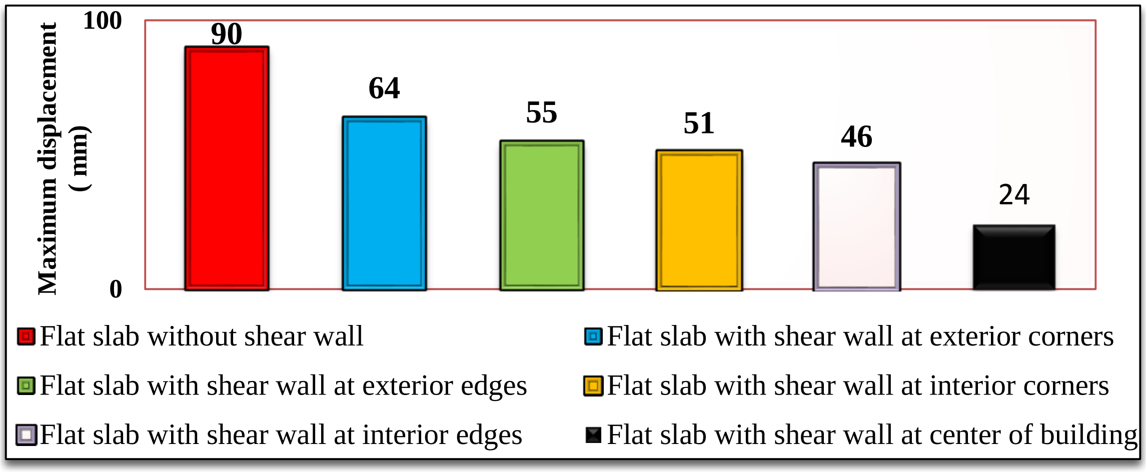

Figure 4.4: Maximum lateral displacement of flat slab and flat slab with shear wall at top of the buildings.

Figure 4.4 shows that lateral displacement of flat slab without shear wall is 28.88% more as compared to flat slab with shear wall at exterior corners, 38.88% more as compared to the flat slab with shear wall at exterior edges, 43.33% more as compared to the flat slab with shear wall at interior corners. Also, lateral displacement of flat slab without shear wall is 48.88% more as compared to the flat slab with shear wall at interior edges and 73.33 higher when compared to the flat slab with shear wall at the center of the building.

4.2.3 The effect of compressive strength of concrete on the lateral displacement

Changing the compressive strength of concrete from 25 MPa to 30MPa leads to decrease in lateral displacement of the buildings as shown in Figure 4.5 and Table 4.1.

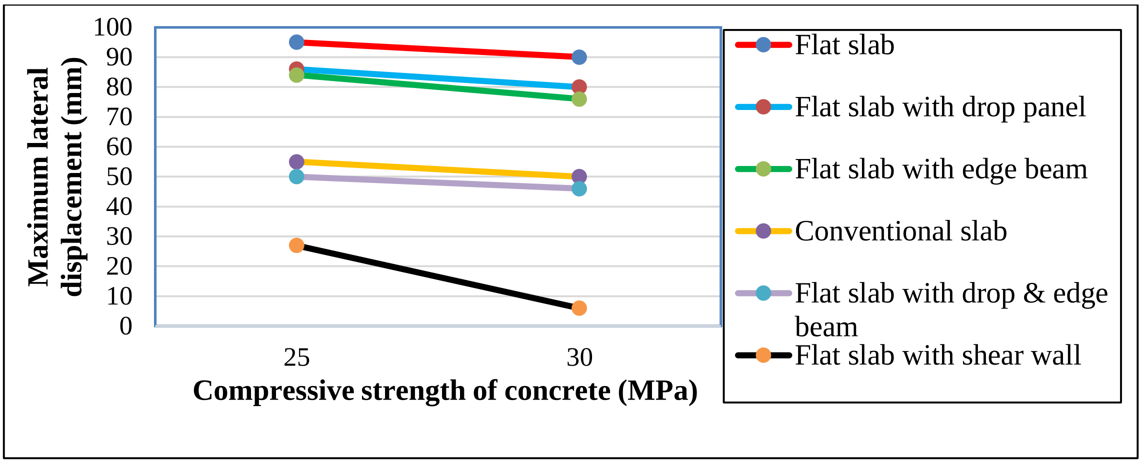

Figure 4.5: Maximum lateral displacement of different types of slab with different compressive strength of concrete

Table 4.1: Maximum lateral displacement of the buildings with different concrete compressive strength

Types of Slab	Concrete Compressive Strength	
	25 Mpa	**30 Mpa**
Flat slab	95	90
Flat slab with drop panel	86	80
Flat slab with edge beam	84	76
Conventional slab	55	50
Flat slab with both drop and edge beam	50	46
Flat slab with shear wall	27	24

4.2.4 The effect of yield strength of steel on the lateral displacement

Changing the yield strength of steel from 300 MPa to 420 MPa has no significant change in lateral displacement of the buildings as shown in Figure 4.6 and Table 4.2.

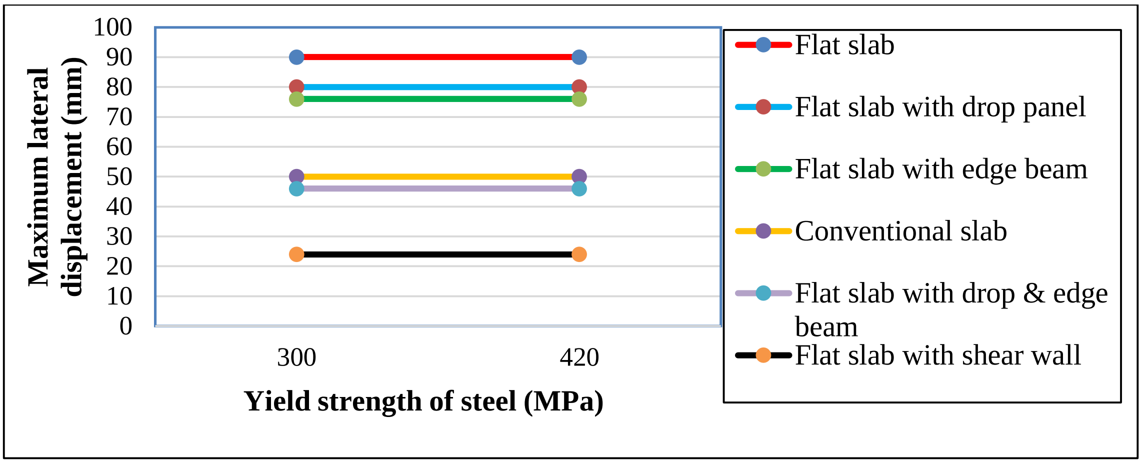

Figure 4.6: Maximum lateral displacement of different types of slab with different yield strength of steel

Table 4.2: Maximum lateral displacement of the buildings with different yield strength of steel

Type of Slab	Yield Strength of Steel	
	300 Mpa	**420 Mpa**
Flat slab	90	90
Flat slab with drop panel	80	80
Flat slab with edge beam	76	76
Conventional slab	50	50
Flat slab with both drop and edge beam	46	46
Flat slab with shear wall	24	24

4.2.5 The effect of floor height on the lateral displacement

Increasing the floor height of the buildings leads to increase in lateral displacement as shown in Figure 4.7 and Table 4.3.

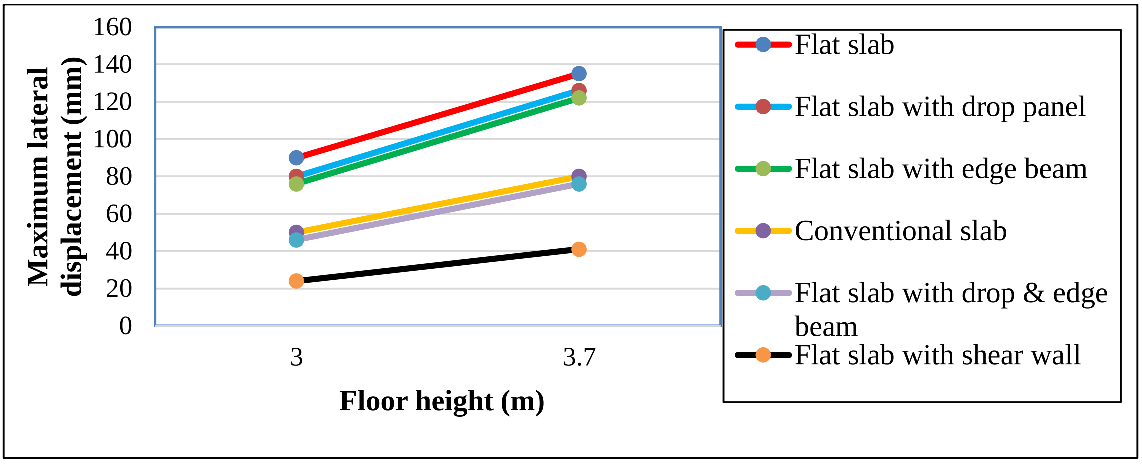

Figure 4.7: Maximum lateral displacement of different types of slab with different floor height

Table 4.3: Maximum lateral displacement of the buildings with different floor height

Types of Slab	**Floor Height**	
	3 m	**3.7 m**
Flat slab	90	135
Flat slab with drop panel	80	126
Flat slab with edge beam	76	122
Conventional slab	50	80
Flat slab with both drop and edge beam	46	76
Flat slab with shear wall	24	41

4.3 Storey Drift

In this section, factors are focused that have effects on storey drift. These factors are; types of slab, shear wall, locations of shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.3.1 The effect of different types of slab on the storey drift

The slab type is one of the factors which influences the storey drift and seismic performance of the buildings. Storey drift will be decreased or increased with changing in floor type of the buildings. This is due to decrease or increase in mass and slab-column rigidity. Figure 4.8 and 4.9 show the storey drift of five different types of slab.

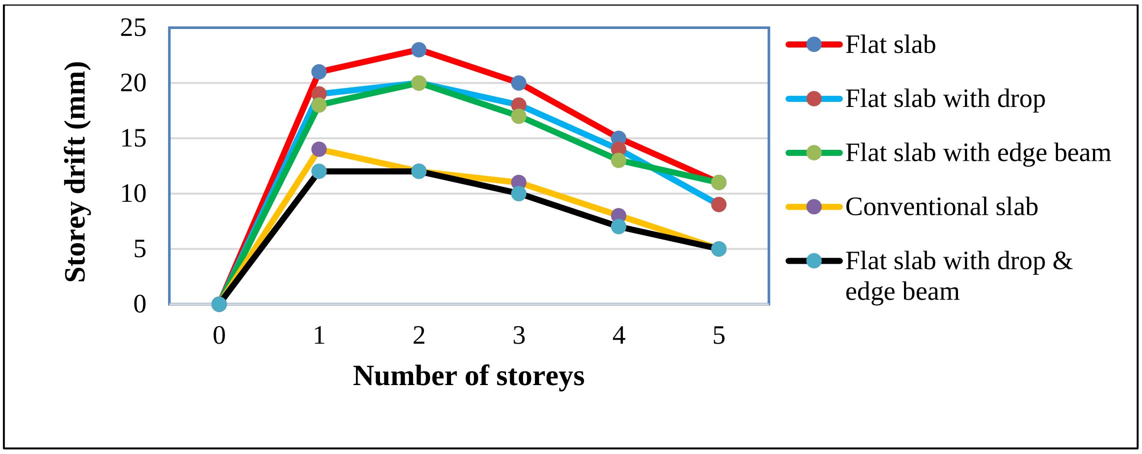

Figure 4.8: Storey drift of the buildings relative to the number of storeys

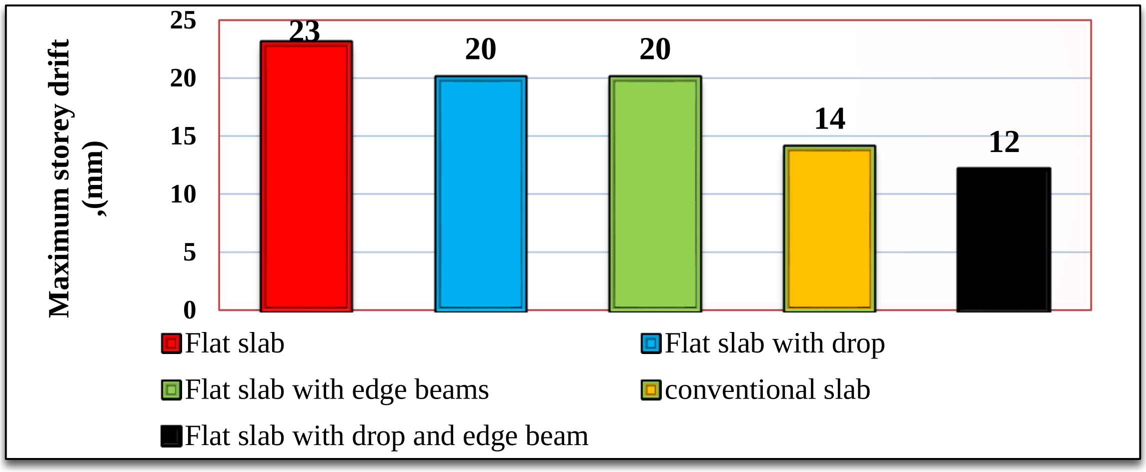

Figure 4.9: Maximum storey drift of the buildings

Moreover, Figure 4.9 shows that the storey drift of the flat slab is 13% more as compared to the flat slab with drop panel and 13% more as compared to the flat slab with edge beam. Also, storey drift of the flat slab is 39.13% more as compared to the conventional slab and 47.82% more as compared to the flat slab with both edge beam and drop panel.

4.3.2 The effect of shear wall and location of shear wall on the storey drift

Shear walls decrease storey drift of the buildings but it also depends on the location it is fixed. It is also observed that as the location of shear walls approaches the centre of the buildings, the storey drift decreases as shown in Figure 4.10 and 4.11.

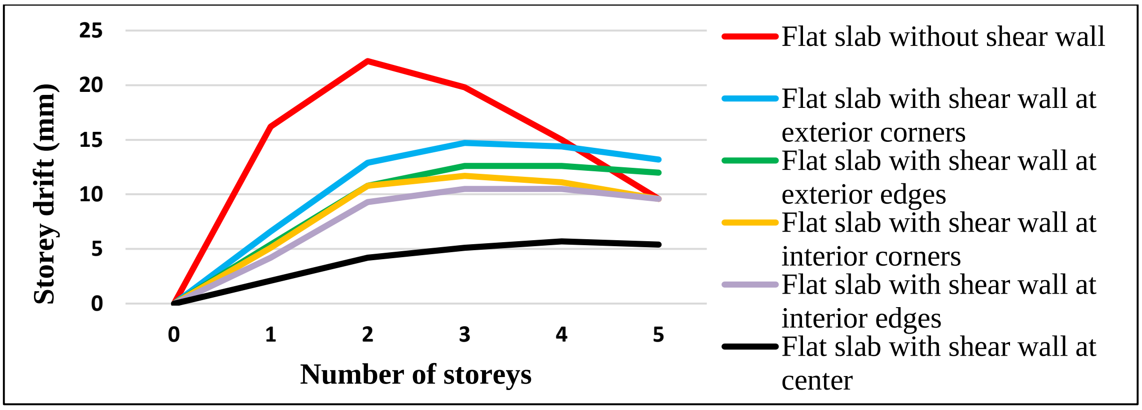

Figure 4.10: Storey drift of flat slab and flat slab with shear wall at different locations relative to the number of storeys

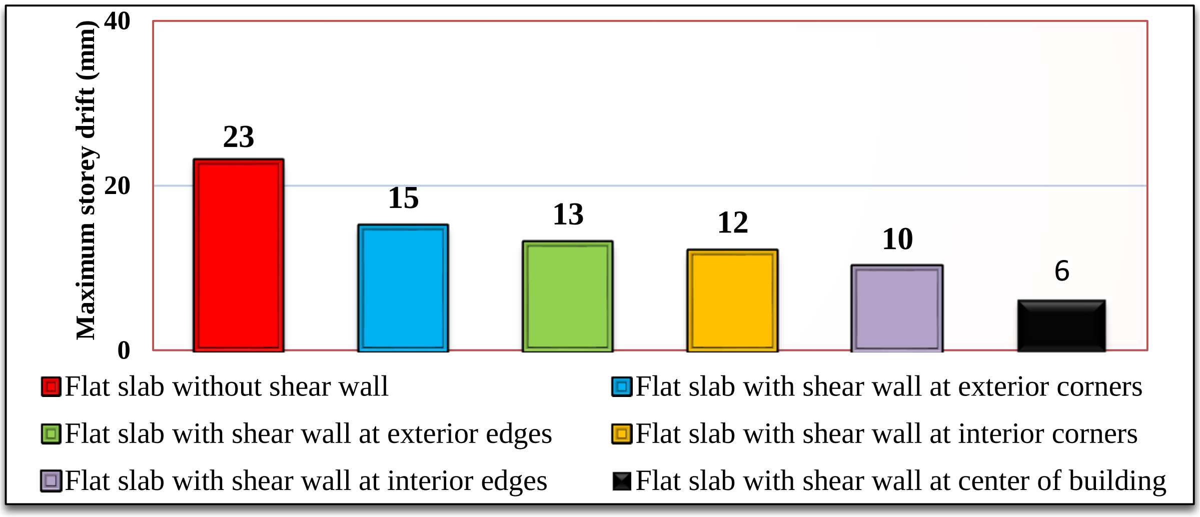

Figure 4.11: Maximum storey drift of flat slab and flat slab with shear wall at different locations of the buildings

Figure 4.11 shows that storey drift of flat slab without shear wall is 34.78% more as compared to flat slab with shear wall at exterior corners, 43.47% more as compared to flat slab with shear wall at exterior edges, 47.28% more as compared to the flat slab with shear wall at interior corners. Also, storey drift of flat slab without shear wall is 56.52% more as compared to flat slab with shear wall at interior edges and 73.91% more as compared to flat slab with shear wall at the center of building.

4.3.3 The effect of compressive strength of concrete on the storey drift

Changing the compressive strength of concrete from 25 MPa to 30MPa leads to decrease in the storey drift of the buildings as shown in Figure 4.12 and Table 4.4.

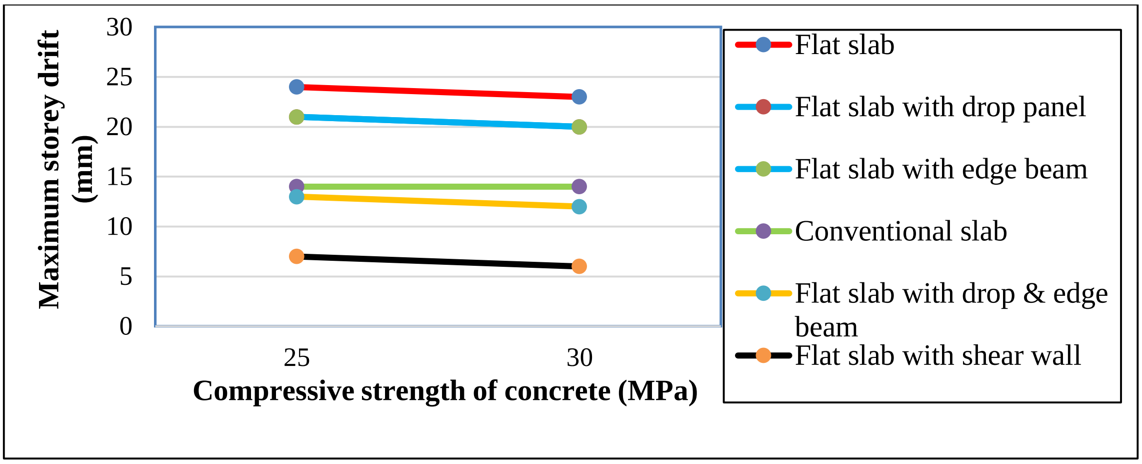

Figure 4.12: Maximum storey drift of different types of slab with different compressive strength of concrete

Table 4.4: Maximum storey drift of the buildings with different concrete compressive strength

Types of Slab	Concrete Compressive Strength	
	25 Mpa	**30 Mpa**
Flat slab	24	23
Flat slab with drop panel	21	20
Flat slab with edge beam	21	20
Conventional slab	14	14
Flat slab with both drop and edge beam	13	12
Flat slab with shear wall	7	6

4.3.4 The effect of yield strength of steel on the storey drift

Changing the yield strength of steel from 300 MPa to 420 MPa has no significant change in storey drift of the RC buildings as shown in Figure 4.13 and Table 4.5.

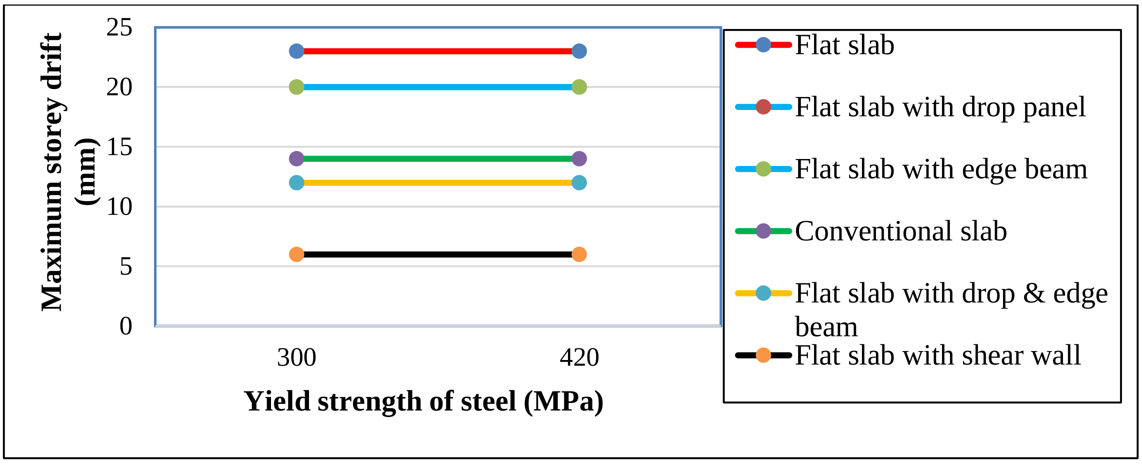

Figure 4.13: Maximum storey drift of different types of slab with different yield strength of steel

Table 4.5: Maximum storey drift of the buildings with different yield strength of steel

Types of Slab	Yield Strength of Steel	
	300 Mpa	420 Mpa
Flat slab	23	23
Flat slab with drop panel	20	20
Flat slab with edge beam	20	20
Conventional slab	14	14
Flat slab with both drop and edge beam	12	12
Flat slab with shear wall	6	6

4.3.5 The effect of floor height on the storey drift

Increasing the floor height of the buildings leads to increase in storey drift as shown in Figure 4.14 and Table 4.6.

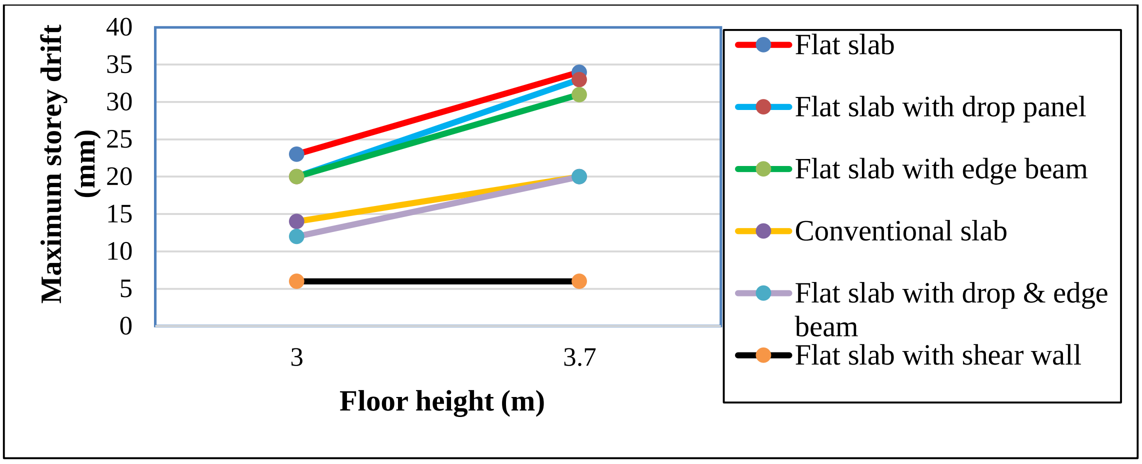

Figure 4.14: Maximum storey drift of different types of slab with different floor height

Table 4.6: Maximum storey drift of the buildings with different floor height

Types of Slab	Floor Height	
	3 m	**3.7 m**
Flat slab	23	34
Flat slab with drop panel	20	33
Flat slab with edge beam	20	31
Conventional slab	14	20
Flat slab with both drop and edge beam	12	20
Flat slab with shear wall	6	10

4.4 Base Shear

In this section, many factors are stated that have effects on the base shear. These factors are; types of slab, shear wall, location of shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.4.1 The effect of different types of slab on the base shear

Changing in slab type is one of the factors which influence the base shear and seismic performance of the buildings. Base shear will be decreased or increased with changing floor type of the buildings as shown in Figure 4.15. This is due to decrease or increase in mass of the buildings.

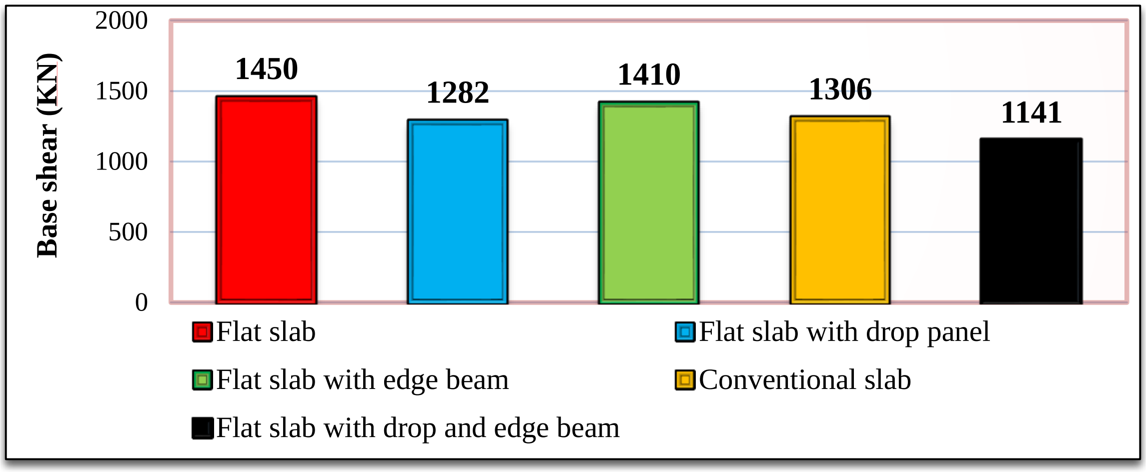

Figure 4.15: Base shear of the buildings

From Figure 4.15, it is found that base shear of the flat slab is 2.75% more as compared to the flat slab with drop panel and 5.86% more as compared to the flat slab with edge beam. Also, base shear of the flat slab is 9.93% more as compared to the conventional slab and 21.31% more as compared to the flat slab with drop panel and edge beam.

4.4.2 The effect of shear wall and location of shear wall on the base shear

Shear walls increase base shear of the buildings due to increase stiffness but it also depends on the location it is fixed. It is also observed that as the location of shear walls approaches the centre of the buildings, the base shear increases as shown in Figure 4.16.

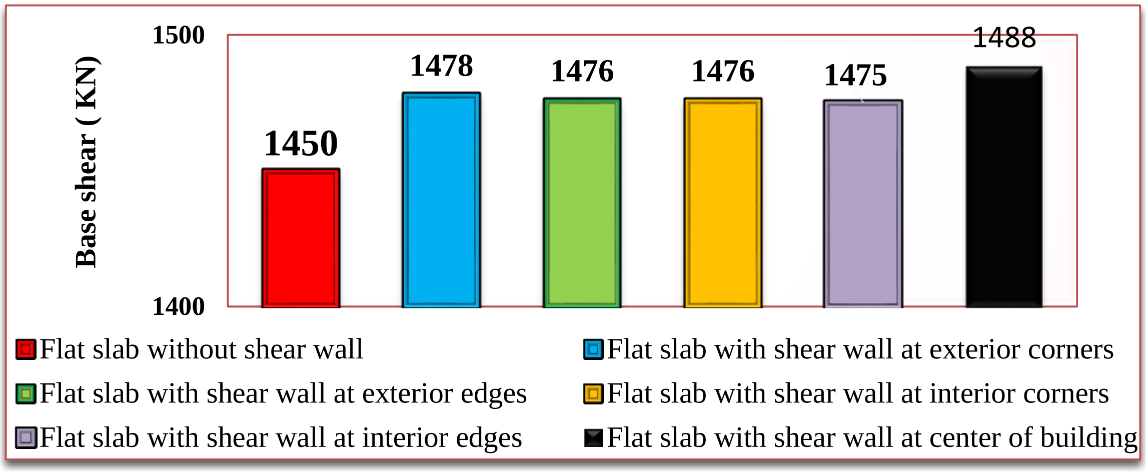

Figure 4.16: Base shear of flat slab and flat slab with shear wall at different locations

4.4.3 The effect of compressive strength of concrete on the base shear

Changing the compressive strength of concrete from 25 MPa to 30MPa leads to a small increase in the base shear of the buildings as shown in Figure 4.17 and Table 4.7.

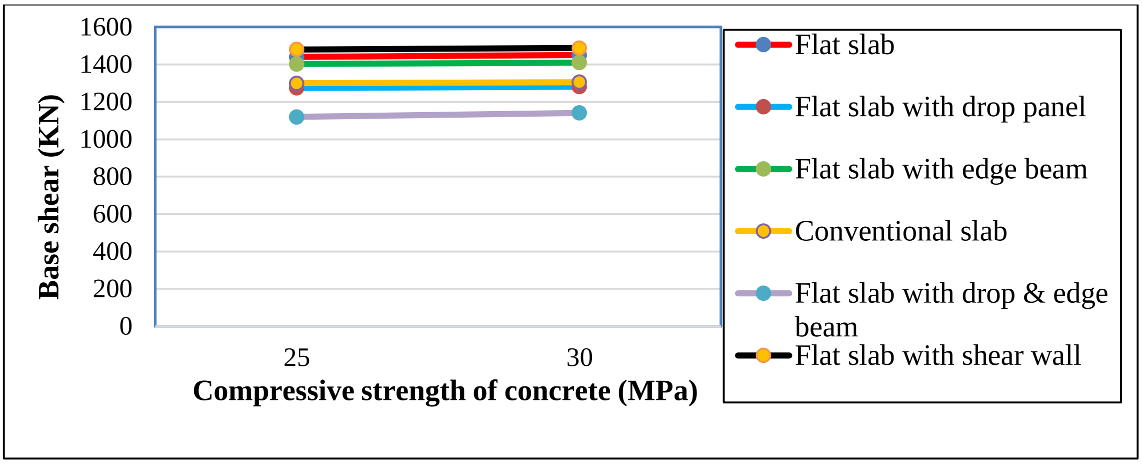

Figure 4.17: Base shear of different types of slab with different compressive strength of concrete

Table 4.7: Base shear of the buildings with different concrete compressive strength

Types of Slab	Concrete Compressive Strength	
	25 Mpa	**30 Mpa**
Flat slab	1440	1450
Flat slab with drop panel	1275	1282
Flat slab with edge beam	1402	1410
Conventional slab	1300	1306
Flat slab with both drop and edge beam	1120	1141
Flat slab with shear wall	1480	1488

4.4.4 The effect of yield strength of steel on the base shear

Changing the yield strength of steel from 300 MPa to 420 MPa leads to a small increase in the value of the base shear of the buildings as shown in Figure 4.18 and Table 4.8.

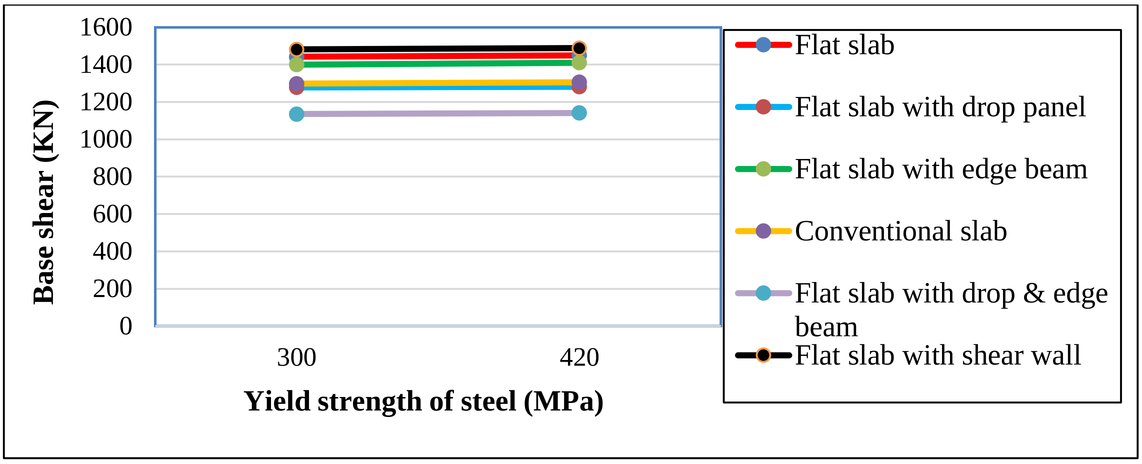

Figure 4.18: Base shear of different types of slab with different yield strength of steel

Table 4.8: Base shear of the buildings with different yield strength of steel

Types of Slab	Yield Strength of Steel	
	300 Mpa	420 Mpa
Flat slab	1442	1450
Flat slab with drop panel	1278	1282
Flat slab with edge beam	1400	1410
Conventional slab	1298	1306
Flat slab with both drop and edge beam	1135	1141
Flat slab with shear wall	1481	1488

4.4.5 The effect of floor height on the base shear

Increasing the floor height of the buildings leads to increase in base shear due to increasing mass of the building as shown in Figure 4.19 and Table 4.9.

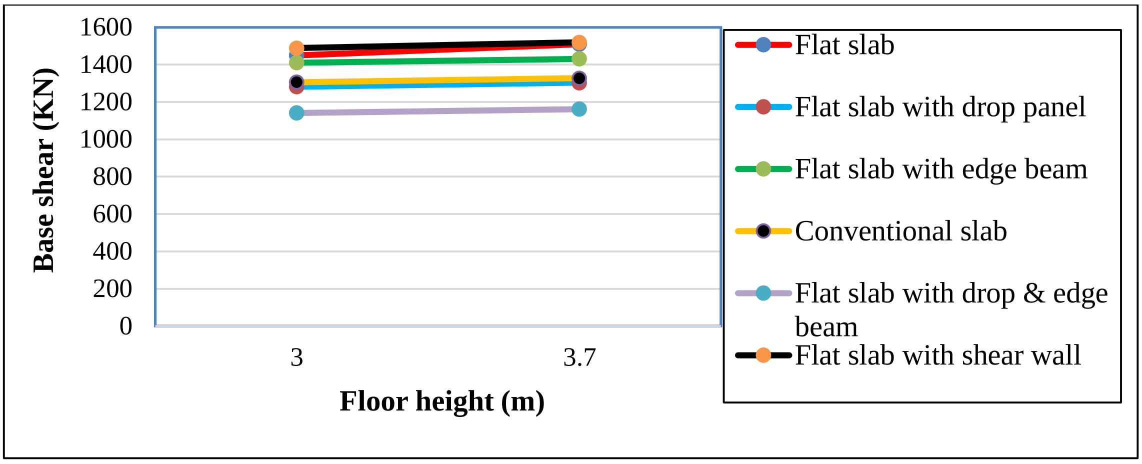

Figure 4.19: Base shear of different types of slab with different floor height

Table 4.9: Base shear of the buildings with different floor height

Types of Slab	Floor Height	
	3 m	3.7 m
Flat slab	1450	1510
Flat slab with drop panel	1282	1303
Flat slab with edge beam	1410	1431
Conventional slab	1306	1327
Flat slab with both drop and edge beam	1141	1162
Flat slab with shear wall	1488	1519

4.5 Time Period

In this section, many factors are presented that effect the time period of the buildings. These factors are; types of slab, shear wall, location of shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.5.1 The effect of different types of slab on the time period

Time period depends on mass and stiffness. Therefore, time period changes with regards to type of slab of the buildings because mass and stiffness are changed as shown in Figure 4.20.

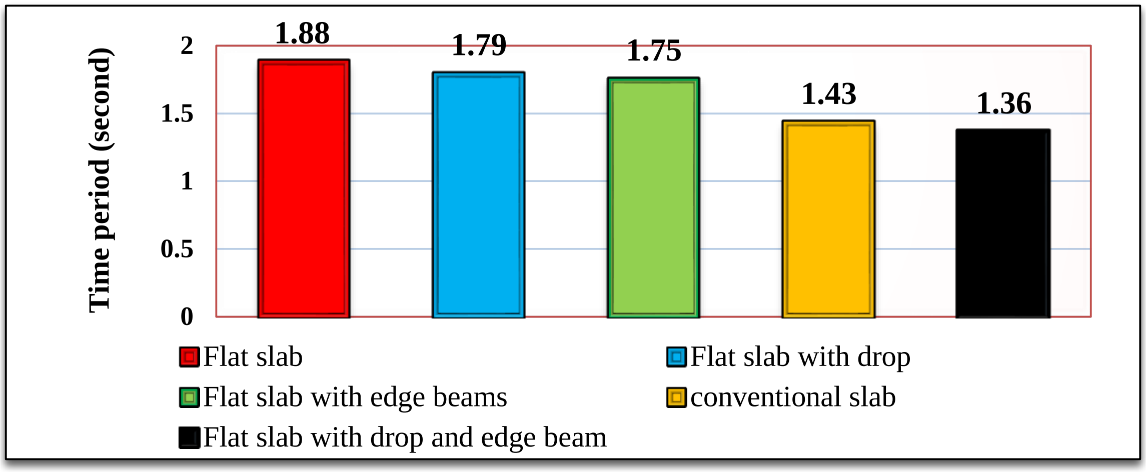

Figure 4.20: Time period of different types of slab in the building

Figure 4.20 shows that time period of flat slab is 4.78% higher as compared to the flat slab with drop panel and 6.91% higher as compared to the flat slab with edge beam. Also, the time period of the flat slab is 23.93% higher as compared to the conventional slab and 27.65% higher as compared to the flat slab with drop panel and edge beam.

4.5.2 The effect of shear wall and location of shear wall on the time period

Shear wall decreases time period of the buildings due to increase in stiffness but it depends on location of the shear wall. Figure 4.21 shows that as the shear walls location approaches the center of the buildings, the time period decreases.

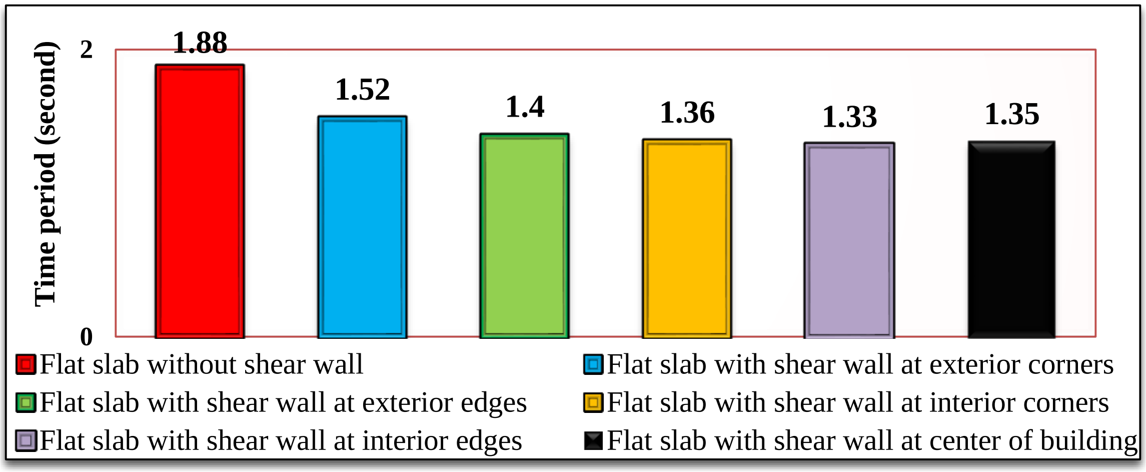

Figure 4.21: Time period of flat slab and flat slab with shear wall at different locations

4.5.3 The effect of compressive strength of concrete on the time period

Changing the compressive strength of concrete from 25 MPa to 30MPa leads to a small decreasing in the time period of the buildings as shown in Figure 4.22 and Table 4.10.

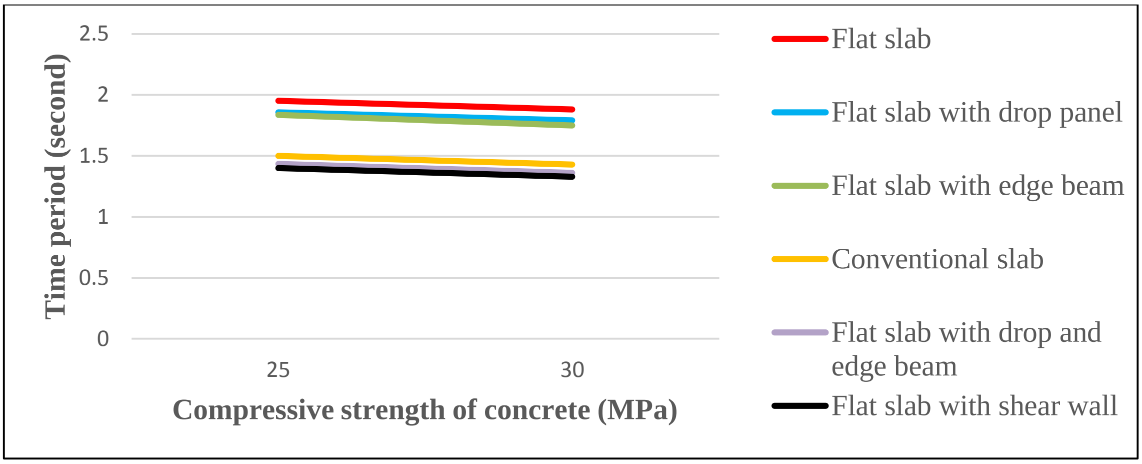

Figure 4.22: Time period of different types of slab with different compressive strength of concrete

Table 4.10: Time period of the buildings with different concrete compressive strength

Types of Slab	Concrete Compressive Strength	
	25 Mpa	**30 Mpa**
Flat slab	1.951	1.88
Flat slab with drop panel	1.857	1.79
Flat slab with edge beam	1.835	1.75
Conventional slab	1.501	1.43
Flat slab with both drop and edge beam	1.433	1.36
Flat slab with shear wall	1.40	1.33

4.5.4 The effect of yield strength of steel on the time period

Changing the yield strength of steel from 300 MPa to 420 MPa leads to a small decrease in the value of the time period of the buildings as shown in Figure 4.23 and Table 4.11.

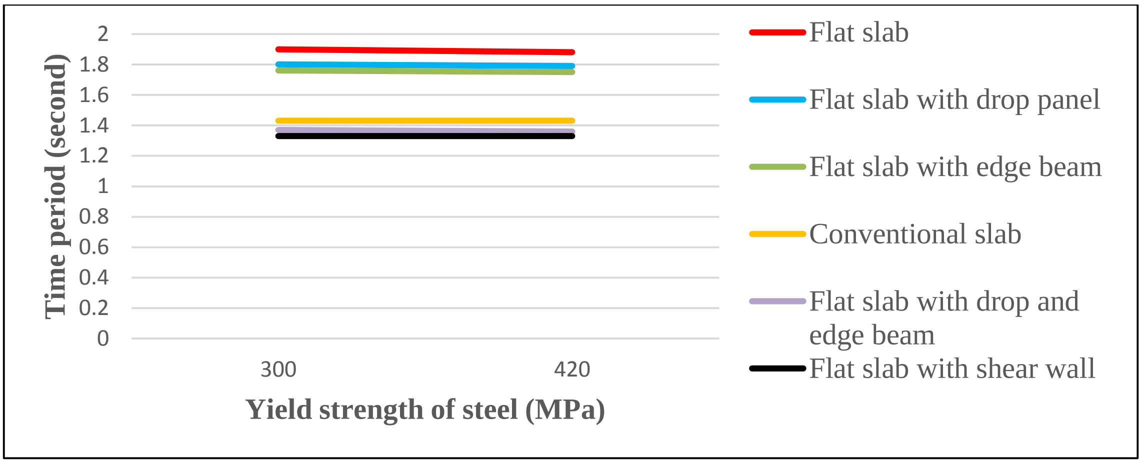

Figure 4.23: Time period of different types of slab with different yield strength of steel

Table 4.11: Time period of the buildings with different yield strength of steel

Types of Slab	Yield Strength of Steel	
	300 Mpa	420 Mpa
Flat slab	1.90	1.88
Flat slab with drop panel	1.80	1.79
Flat slab with edge beam	1.76	1.75
Conventional slab	1.43	1.43
Flat slab with both drop and edge beam	1.37	1.36
Flat slab with shear wall	1.33	1.33

4.5.5 The effect of floor height on the time period

Increasing the floor height of the buildings leads to increase in time period due to increase in mass of the building as shown in Figure 4.24 and Table 4.12.

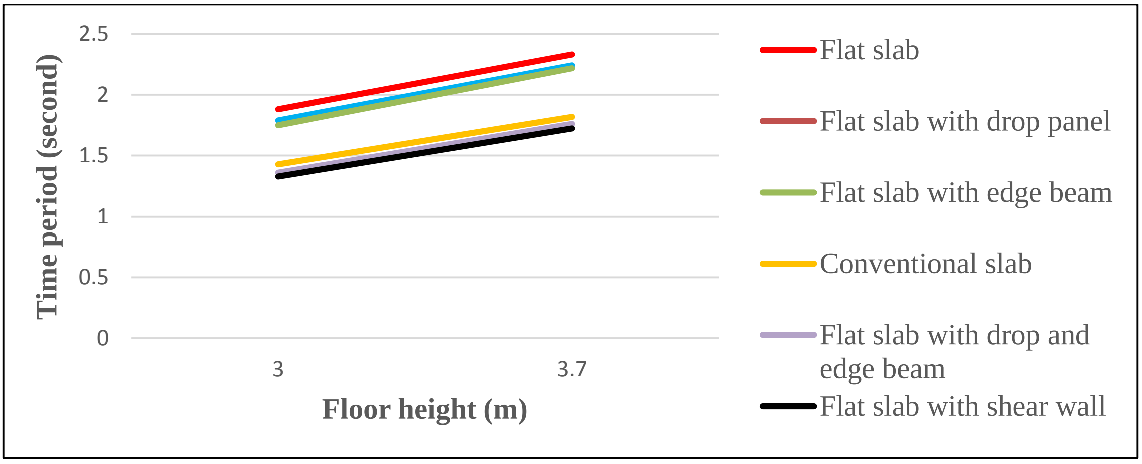

Figure 4.24: Time period of different types of slab with different floor height

Table 4.12: Time period of the buildings with different floor height

Types of Slab	Floor Height	
	3 m	**3.7 m**
Flat slab	1.88	2.33
Flat slab with drop panel	1.79	2.24
Flat slab with edge beam	1.75	2.218
Conventional slab	1.43	1.818
Flat slab with both drop and edge beam	1.36	1.76
Flat slab with shear wall	1.33	1.723

4.6 Elastic Stiffness

In this section, many factors are shown that effect elastic stiffness. These factors are; types of slab, shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.6.1 The effect of types of slab and shear wall on the elastic stiffness

Changing the slab type of the buildings leads to change in the elastic stiffness as shown in Figure 4.25.

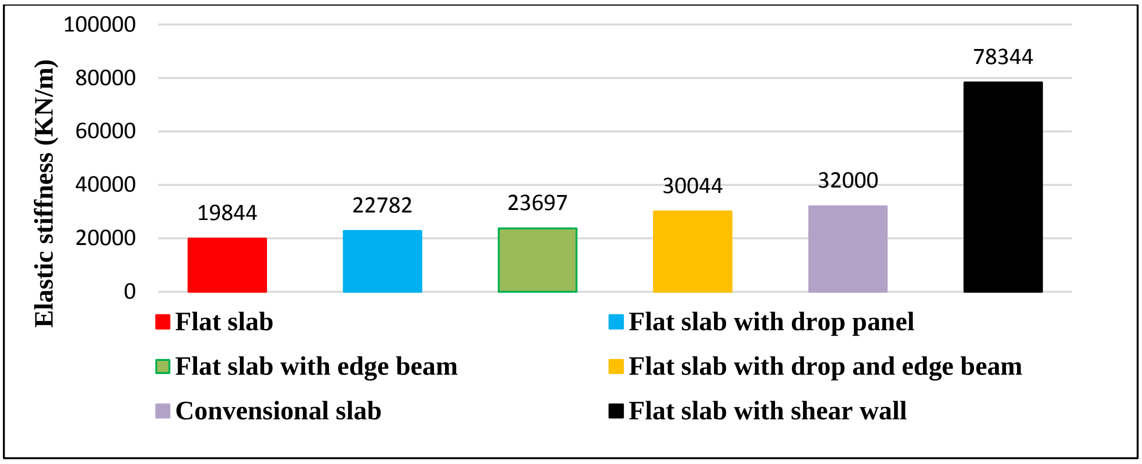

Figure 4.25: Elastic stiffness of different types of slab and flat slab with shear wall

4.6.2 The effect of compressive strength of concrete on the elastic stiffness

Changing the compressive strength of concrete from 25 MPa to 30MPa leads to increase in the elastic stiffness of the buildings as shown in Figure 4.26 and Table 4.13.

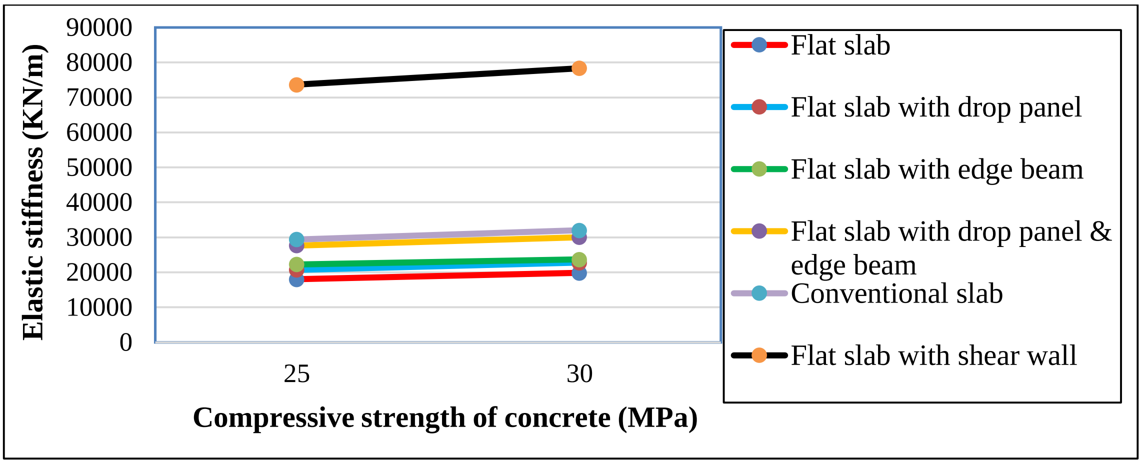

Figure 4.26: Elastic stiffness of different types of slab with different compressive strength of concrete

Table 4.13: Elastic stiffness of the buildings with different concrete compressive strength

Types of Slab	Concrete Compressive Strength	
	25 Mpa	30 Mpa
Flat slab	18000	19844
Flat slab with drop panel	20700	22782
Flat slab with edge beam	22276	23697
Flat slab with both drop and edge beam	27644	30044
Conventional slab	28000	32000
Flat slab with shear wall	73644	78344

4.6.3 The effect of yield strength of steel on the elastic stiffness

Changing the yield strength of steel from 300 MPa to 420 MPa leads to a small or no increase in the value of the elastic stiffness of the buildings as shown in Figure 4.27 and Table 4.14.

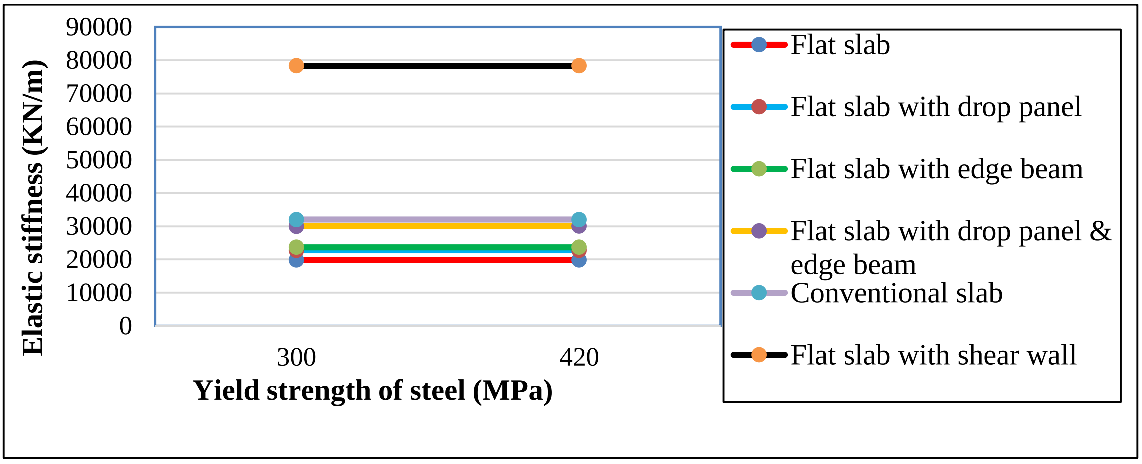

Figure 4.27: Elastic stiffness of different types of slab with different yield strength of steel

Table 4.14: Elastic stiffness of the buildings with different yield strength of steel

Types of Slab	Yield Strength of Steel	
	300 Mpa	420 Mpa
Flat slab	19800	19844
Flat slab with drop panel	22780	22782
Flat slab with edge beam	23697	23697
Flat slab with both drop and edge beam	30000	30044
Conventional slab	32000	32000
Flat slab with shear wall	78340	78344

4.6.4 The effect of floor height on the elastic stiffness

Increasing the floor height of the buildings leads to decrease in elastic stiffness due to increase in mass of the building as shown in Figure 4.28 and Table 4.15.

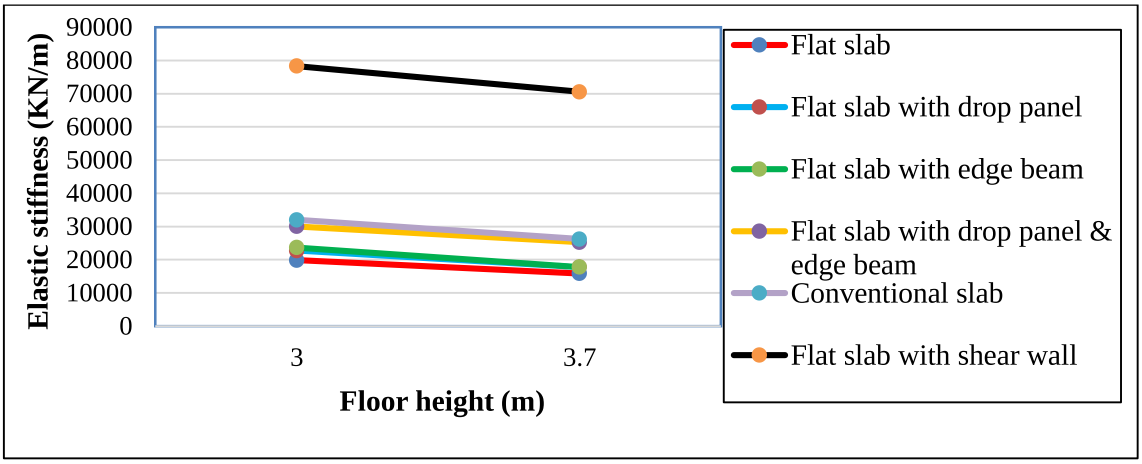

Figure 4.28: Elastic stiffness of different types of slab with different floor height

Table 4.15: Elastic stiffness of the buildings with different floor height

Types of Slab	Floor Height	
	3 m	**3.7 m**
Flat slab	19844	15884
Flat slab with drop panel	22782	17775
Flat slab with edge beam	23697	17797
Flat slab with both drop and edge beam	30044	25244
Conventional slab	32000	26240
Flat slab with shear wall	78344	70544

4.7 Pushover Curve

In this section many factors are shown that effect pushover curve. These factors are; types of slab, shear wall, compressive strength of concrete, yield strength of steel and floor height.

4.7.1 The effect of types of slab and shear wall on pushover curve

The pushover curves of the models are shown in Figures 4.29-4.33. The figures show that pushover curve changes with regards types of slab of the buildings because the capacity and performance of the buildings is changes. Also, the capacity is increased by placing the shear wall. The performance and capacity is increased with increasing concrete compressive strength from 25 to 30. But changing the yield strength leads to a small or remaining in the performance. Increasing the floor height from 3-3.7m leads to decrease in the capacity of the buildings.

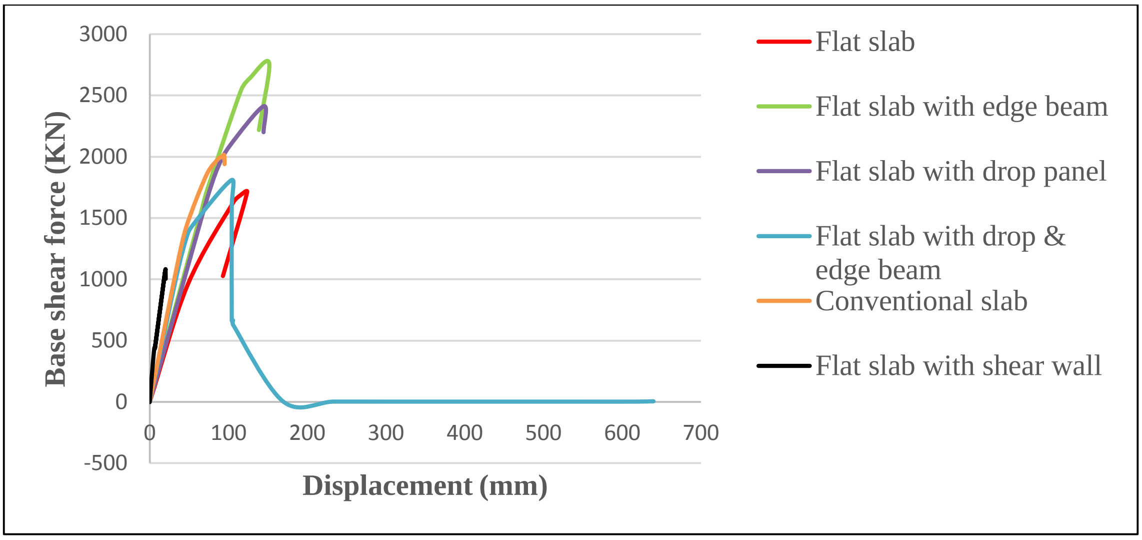

Figure 4.29: Pushover curve for different types of slab buildings and flat slab with shear wall respect to f_c = 30 MPa, f_y= 420 MPa, floor height = 3 m

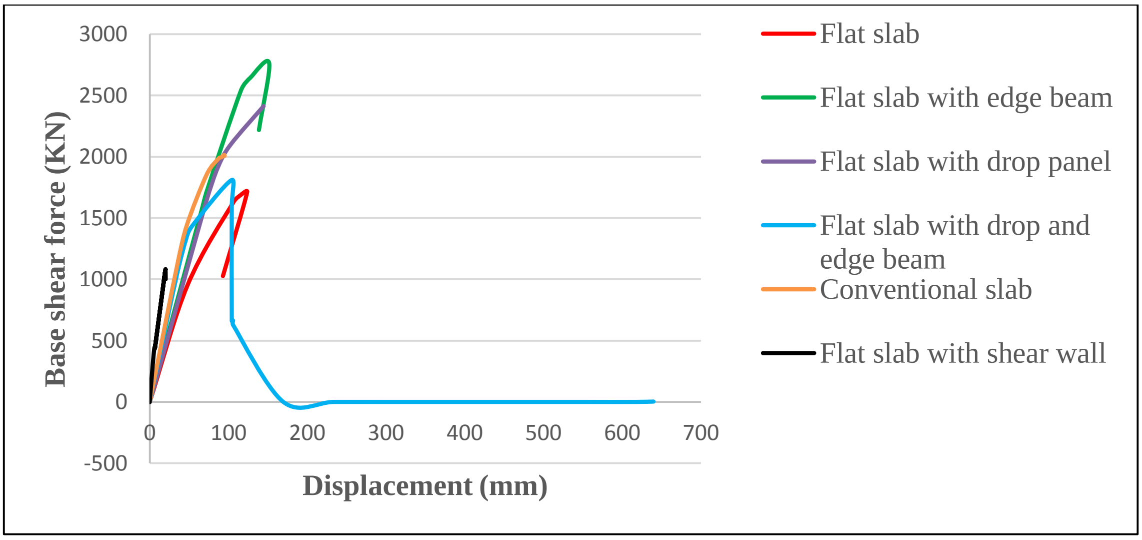

Figure 4.30: Pushover curve for different types of slab buildings and flat slab with shear wall respect to f_c = 30 MPa, f_y= 300 MPa, floor height = 3 m

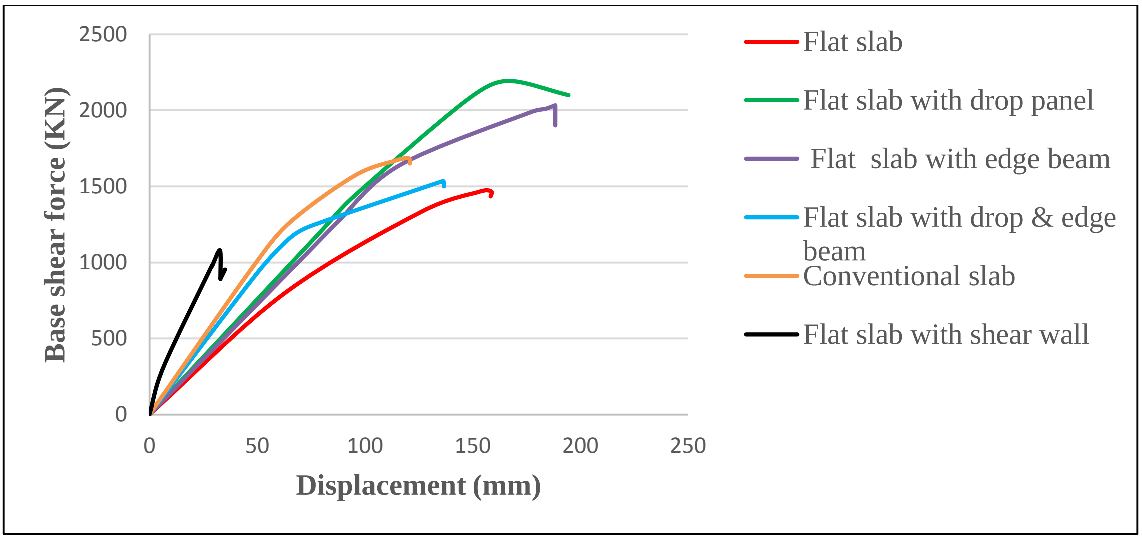

Figure 4.31: Pushover curve for different types of slab buildings and flat slab with shear wall respect to f_c = 30 MPa, f_y= 420 MPa, floor height = 3.7 m

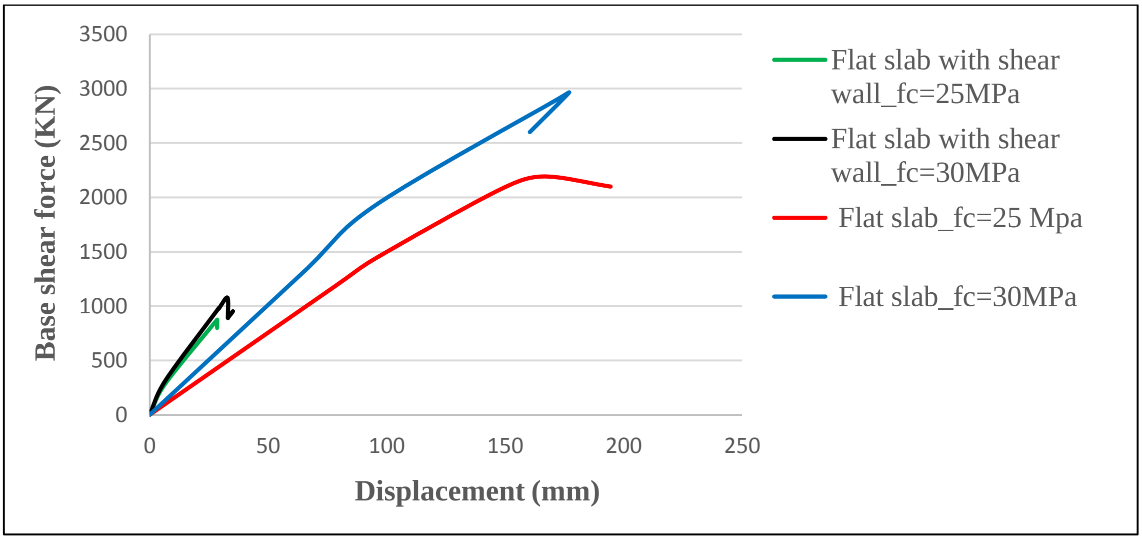

Figure 4.32: Pushover curve for flat slab building and flat slab with shear wall with f_c = 25 MPa and f_c = 30 MPa

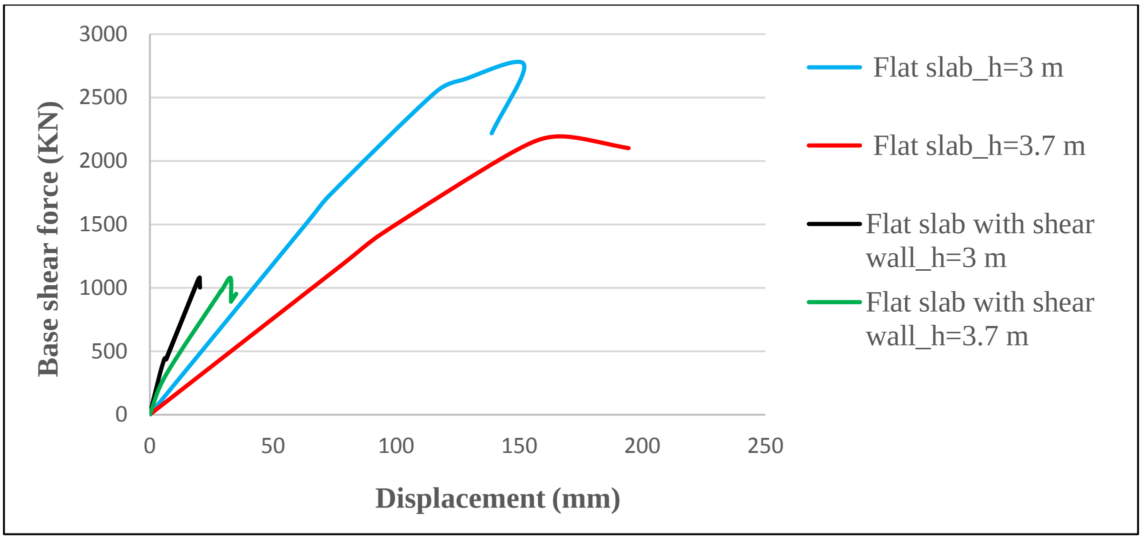

Figure 4.33: Pushover curve for flat slab building and flat slab with shear wall with h = 3 m and h= 3.7 m

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained, from the analysis of RC buildings in Erbil city, it can be concluded that**:**

- Lateral displacement, storey drift, base shear, and time period are maximum and elastic stiffness is minimum in the flat slab building. This is due to the absence of beams and the higher weight of flat slab building when compared to other types of slab systems.
- Lateral displacement, storey drift, base shear, and time period are minimum in the flat slab with both drop panel and edge beam. This is due to the presence of edge beams and the lower weight of flat slab with both drop panel and edge beam when compared to other types.
- Adding drop panel into the flat slab building leads to decrease in lateral displacement, storey drift and time period.
- Adding drop panel into the flat slab building leads to increase in the elastic stiffness.
- Adding edge beam into the flat slab building leads to decrease in lateral displacement, storey drift, and time period.
- Adding edge beam into the flat slab building leads to increase in the elastic stiffness.
- Lateral displacement is maximum at roof level than at base of the building.
- The performance of flat slab increases by placing shear wall which depends on the position of shear wall. This needs to be considered carefully.
- Placement of shear wall into flat slab building effectively decreases in lateral displacement, storey drift, and time period.
- Placing shear wall into flat slab caused an increase in base shear and stiffness
- Increasing compressive strength of concrete for the buildings from 25 MPa to 30 MPa causes to decrease in lateral displacement, storey drift and time period but also causes to increase in elastic stiffness and base shear.

- Increasing yield strength of steel for the buildings from 300 MPa to 420 MPa causes to a small increase in base shear and elastic stiffness. Also causes a small decrease in time period and remaining in lateral displacement and storey drift.
- Increasing floor height for the buildings causes decrease in elastic stiffness and increase in lateral displacement, storey drift, time period and base shear.
- The pushover curve shows that, adding drop panel into the flat slab building leads to increase in stiffness.
- The pushover curve shows that, inserting edge beams into the flat slab building leads to increase in stiffness.
- The pushover curve shows that, placing shear wall into the flat slab building leads to increase in elastic stiffness.

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APPENDICES

Appendix 1

Checking for punching shear of the flat slab systems

Certainly, for checking punching shear, the values of shear stress and shear capacity should be determined and compared. For this purpose, the critical section for punching is taken at a distance d/2 from the face of the columns, column capitals, or drop panels as shown in Figure 1.4 (ACI 318-14).

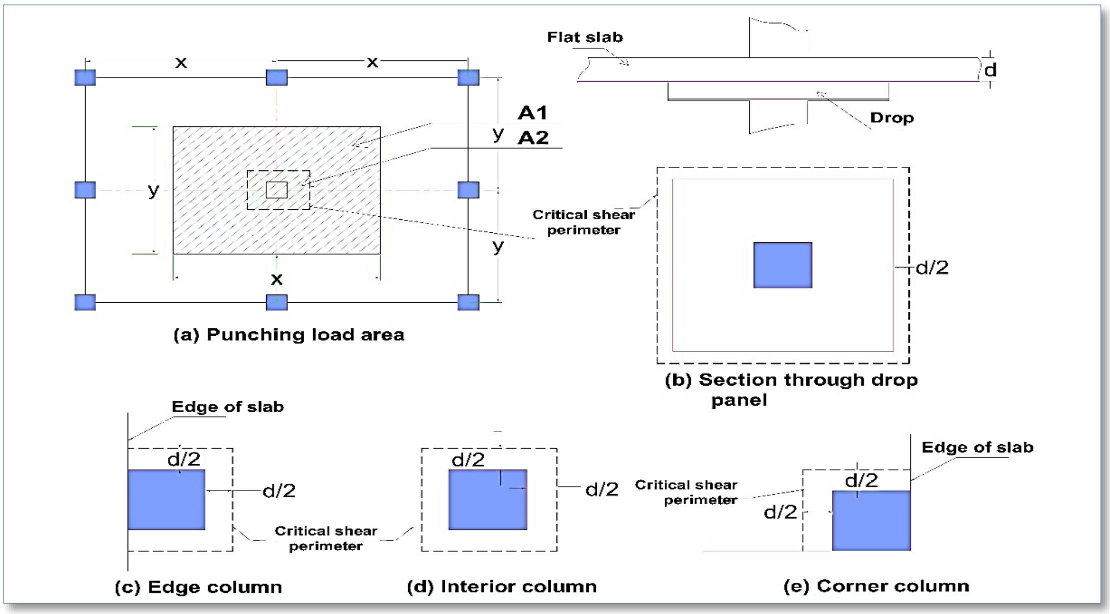

Figure A.1.1: The critical sections for punching, defined by ACI 318-14 for different cases

Shear stress equations are given below, according to ACI code 317-14.

$$V_u = W_u \text{ (A1 – A2)} \qquad \text{(A.1.1)}$$

$$V_n = \frac{V_u}{0.85} \qquad \text{(A.1.2)}$$

Where

V_u = Ultimate shear stress, KN.

W_u= Ultimate design load or factored load, KN/m^2 (W_u = 1.2 DL +1.6 LL).

A1= The area, that entire its' punching loads go to the column, m^2as shown in Figure A.1.1 (a).

A2= The area of the critical section for punching, m^2 as shown in Figure A.1.1 (a).

V_n = Nominal shear stress, KN.

According to ACI code, shear capacity equations are given below. It should be chosen the smallest one.

$$V_c = (1 + \frac{2}{\beta_c}) \frac{\sqrt{f_c}\, b_{o}\, d}{6}$$

(A.1.3)

$$V_c = (2 + \frac{\alpha_s\, d}{b_o}) \frac{\sqrt{f_c}\, b_{o}\, d}{12}$$

(A.1.4)

$$V_c = (\frac{1}{3}) \sqrt{f_c}\, b_o\, d$$

(A.1.5)

Where

V_c = Shear capacity, KN.

β_c= The ratio of long to short sides of the column cross-section.

f_c =Concrete compressive strength, MPa.

b_o = The whole perimeter of the critical section for punching, in meter.

d = Effective depth of slab, mm (slab thickness – cover- $\frac{\text{diameter bar}}{2}$) as shown in Figure A.1.1

α_s = is 20 for corner columns, 30 for edge columns and 40 for interior columns.

Also

$$\text{Punching shear ratio} = \frac{\text{shear stress}}{\text{shear capacity}}$$

(A.1.6)

If the shear capacity greater than the shear stress, it means that the punching shear is checked

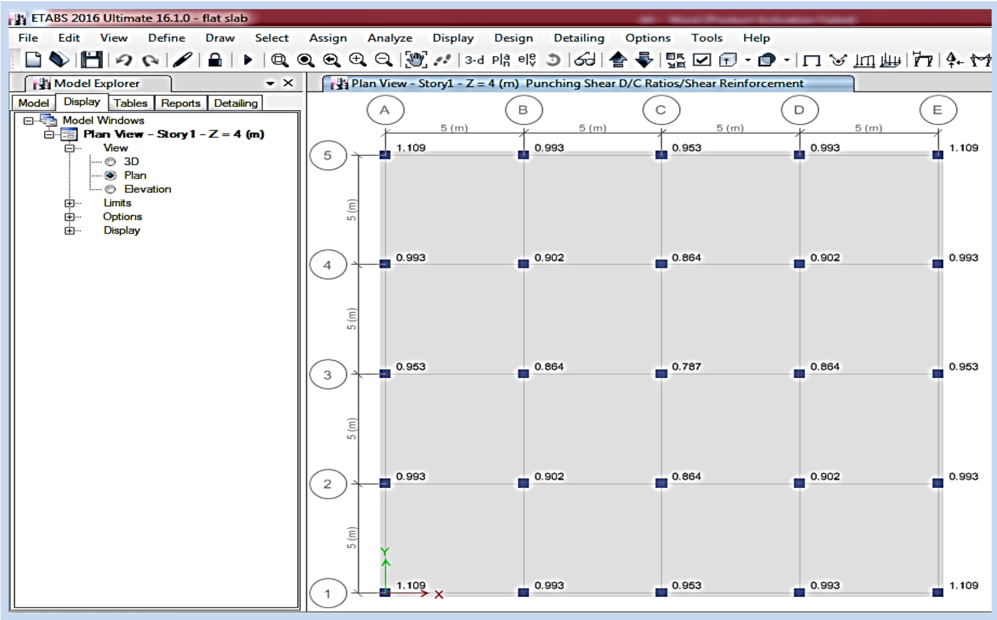

Figure A.1.2: Punching shear ratio of flat slab building by ETABS

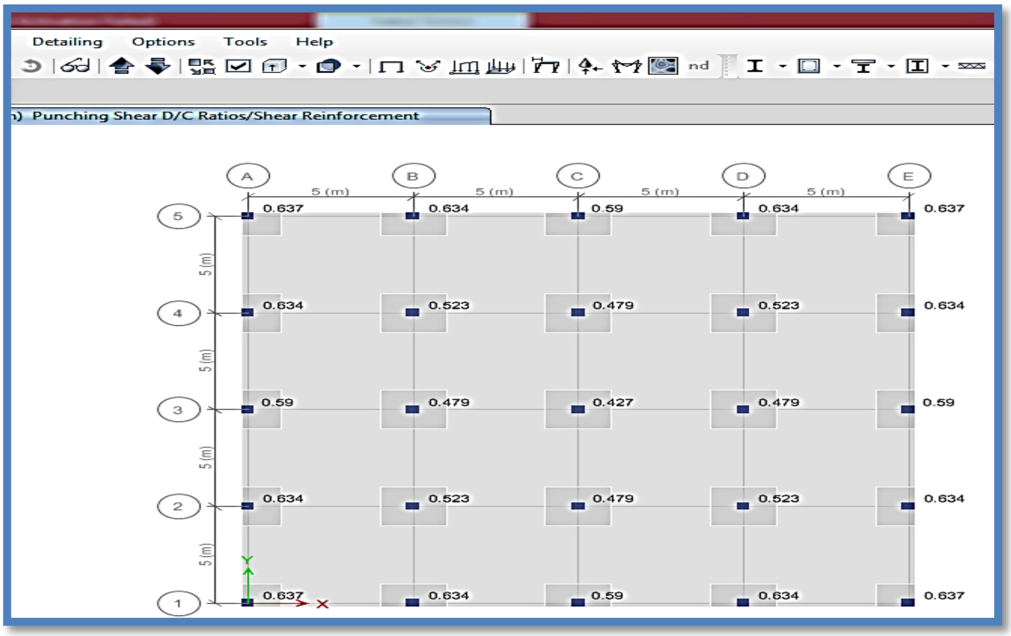

Figure A.1.3: Punching shear ratio of flat slab with drop panel building by ETABS

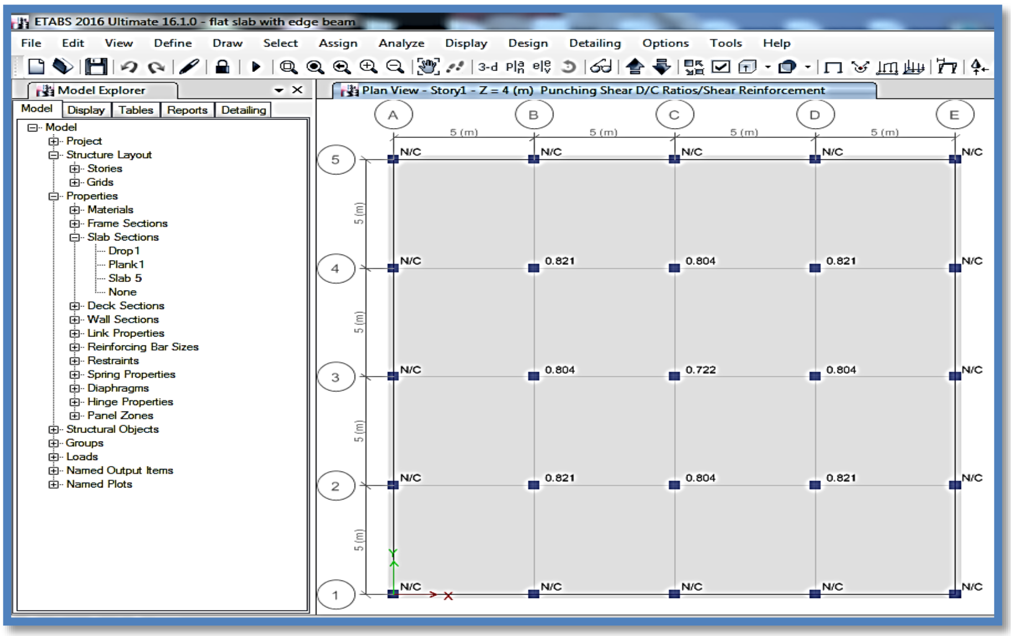

Figure A.1.4: Punching shear ratio of flat slab with edge beam building by ETABS

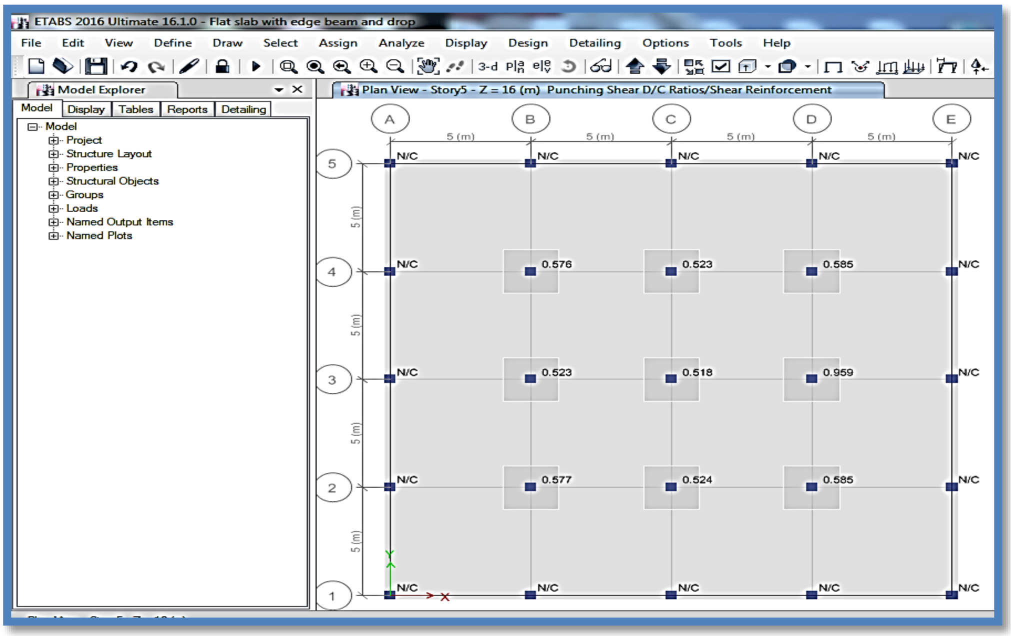

Figure A.1.5: Punching shear ratio of flat slab with both drop panel and edge beam building by ETABS

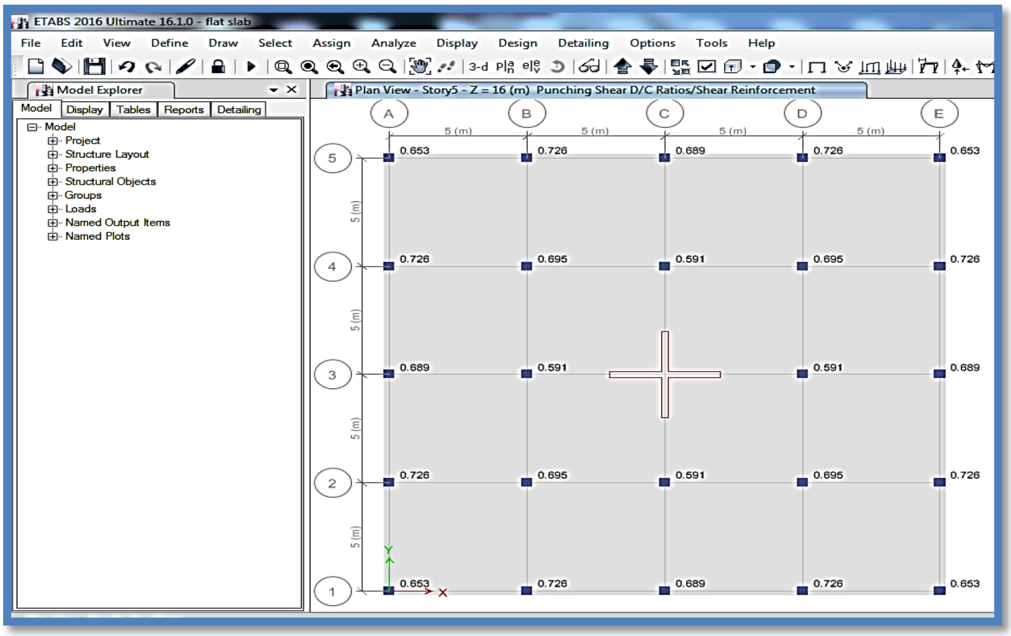

Figure A.1.6: Punching shear ratio of flat slab with shear wall at centre of building by ETABS

Appendix 2

Risk category of the buildings in Iraq

Table A.2.1: Risk Category of Buildings and Other Structures (ISC-2017)

Nature of Occupancy	Risk Category
Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to: • Agricultural facilities • Certain temporary facilities • Minor storage facilities	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with daycare facilities with a capacity greater than 150 • Buildings and other structures with elementary school or secondary school facilities with a capacity greater than 250 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients, but not having surgery or emergency treatment facilities. • Jails and detention facilities	III

Table A.2.1: (Continued)

Nature of Occupancy	Risk Category
Buildings and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure, including, but not limited to: • Power generating stations • Water treatment facilities • Sewage treatment facilities • Telecommunication centers	
Buildings and other structures not included in Occupancy Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.	
Buildings and other structures containing toxic or explosive substances shall be eligible for classification as Occupancy Category I1 structures if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 of ASCE07-05, that a release of the toxic or explosive substances does not pose a threat to the public.	
Buildings and other structures designated as essential facilities, including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities. • Fire, rescue, ambulance, and police stations and emergency vehicle garages. • Designated earthquake, hurricane, or other emergency shelters.	IV

Table A.2.1: (Continued)

Nature of Occupancy	Risk Category
• Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response. • Power generating stations and other public utility facilities required in an emergency. • Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire • Water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for operation of Occupancy Category IV structures during an emergency. • Aviation control towers, air traffic control centers, and emergency aircraft hangars. • Water storage facilities and pump structures required to maintain water pressure for fire suppression. • Buildings and other structures having critical national defense functions. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction. Buildings and other structures containing highly toxic substances shall be eligible for classification as Occupancy Category I1 structures if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 of ASCE 07-05 that a release of the highly toxic substances does not pose a threat to the public. This reduced	

Appendix 3

Seismic forces-resisting system of the building in Iraq

Table A.3.1: Design coefficients and factors for seismic force-resisting systems (ISC-2017)

Seismic Force-Resisting System	Response Modification Coefficient, R	Overst-rength Factor, Ω	Deflection Amplificat-ion Factor, C_d	Structural System Limitations and building height (M) Seismic Design Category		
				A,B	C	D
A.BEARING WALL SYSTEMS						
Special reinforced concrete shear walls	4	2.5	5	NL	NL	50
Ordinary reinforced concrete shear walls	3	2.5	4	NL	NL	NP
Special reinforced masonry shear walls	4	2.5	3.5	NL	NL	50
Intermediate reinforced masonry shear walls	2.5	2.5	2.25	NL	NL	NP
Ordinary reinforced masonry shear walls	1.5	2.5	1.75	NL	50	NP

Table A.3.1: (Continued)

Seismic Force-Resisting System	Response Modification Coefficient, R	Overst-rength Factor, Ω	Deflection Amplificat-ion Factor, C_d	Structural System Limitations and building height (M) Seismic Design Category A,B	C	D
B.BUILDING FRAME SYSTEMS						
Steel eccentrically braced frames, moment resisting connections at columns away from links.	7	2	4	NL	NL	50
Steel eccentrically braced frames, non-moment resisting connections at columns away from links.	6	2	4	NL	NL	50
Special steel concentrically braced frames	5	2	5	NL	NL	50
Ordinary steel concentrically braced frames	4	2	4.5	NL	NL	10
Special reinforced concrete shear walls	5	2.5	5	NL	NL	50
Ordinary reinforced concrete shear walls	4	2.5	4.5	NL	NL	NP
Composite steel and concrete eccentrically braced frames	7	2	4	NL	NL	50

Table A.3.1: (Continued)

Seismic Force-Resisting System	**Response Modification Coefficient, R**	**Overst-renght Factor, Ω**	**Deflection Amplificat-ion Factor, C_d**	**Structural System Limitations and building height (M)**		
				Seismic Design Category		
				A,B	**C**	**D**
Composite steel and concrete concentrically braced frames	4	2	4.5	NL	NL	50
Ordinary steel and concrete braced frames	2.5	2	3	NL	NL	NP
Composite steel plate shear walls	5	2.5	5.5	NL	NL	50
Special composite reinforced concrete shear walls with steel elements	5	2.5	5	NL	NL	50
Ordinary composite reinforced concrete shear walls with steel elements	4	2.5	4.25	NL	NL	NP
Special reinforced masonry shear walls	4	2.5	4	NL	NL	50
Intermediate reinforced masonry shear walls	3	2.5	4	NL	NL	NP
Ordinary reinforced masonry shear walls	2	2.5	2.25	NL	50	NP

Table A.3.1: (Continued)

Seismic Force-Resisting System	**Response Modification Coefficient, R**	**Overstre-ngth Factor, Ω**	**Deflection Amplifica-tion Factor, C_d**	**Structural System Limitations and building height (M)**		
				Seismic Design Category		
				A,B	**C**	**D**
C.MOMENT-RESISTING FRAME SYSTEMS						
Special steel moment frames	7	3	5.5	NL	NL	NL
Intermediate steel moment frames	4	3	4	NL	NL	10
Ordinary steel moment frames	3	3	3	NL	NL	NP
Special reinforced concrete moment frames	6.5	3	5.5	NL	NL	NL
Intermediate reinforced concrete moment frames	4	3	4.5	NL	NL	NP
D.DUAL SYSTEMS WITH SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES						
Steel eccentrically braced frames, moment resisting	7	2.5	4	NL	NL	NL

Table A.3.1: (Continued)

Seismic Force-Resisting System	Response Modification Coefficient, R	Overst-rength Factor, Ω	Deflection Amplifica-tion Factor, C_d	Structural System Limitations and building height (M) Seismic Design Category A,B	C	D
Connections at columns away from links.						
Steel eccentrically braced frames, non-moment resisting connections at columns away from links.	6	2.5	4	NL	NL	NL
Special steel concentrically braced frames	7	2.5	6.5	NL	NL	NL
Special reinforced concrete shear walls	6.5	2.5	6.5	NL	NL	NL
Ordinary reinforced concrete shear walls	5.5	2.5	6	NL	NL	NP
Composite steel and concrete eccentrically braced frames	6.5	2.5	4	NL	NL	NL
Composite steel and concrete concentrically braced frames	5	2.5	5	NL	NL	NL
Composite steel plate shear walls	6.5	2.5	6.5	NL	NL	NL

Table A.3.1: (Continued)

Seismic Force-Resisting System	**Response Modification Coefficient, R**	**Overstr -ength Factor, Ω**	**Deflection Amplifica- tion Factor, C_d**	**Structural System Limitations and building height (M)**		
				Seismic Design Category		
				A,B	**C**	**D**
Special composite reinforced concrete shear walls with steel elements	6.5	2.5	6.5	NL	NL	NL
Ordinary composite reinforced concrete shear walls with steel elements	5.5	2.5	6	NL	NL	NP
Special reinforced masonry shear walls	5.5	3	6.5	NL	NL	NL
Intermediate reinforced masonry shear walls	4.5	2.5	5	NL	NL	NL
Ordinary reinforced masonry shear walls	5	2.5	5	NL	NL	NL
E. DUAL SYSTEMS WITH INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES						
Special steel concentrically braced frames	4	2.5	4.5	NL	NL	10

Table A.3.1: (Continued)

Seismic Force-Resisting System	Response Modification Coefficient, R	Overstr-ength Factor, Ω	Deflection Amplifica-tion Factor, C_d	Structural System Limitations and building height (M) Seismic Design Category		
				A,B	C	D
Special reinforced concrete shear walls	4.5	2.5	5	NL	NL	50
Ordinary reinforced concrete shear walls	4.5	2.5	4.5	NL	50	NP
Intermediate reinforced concrete shear walls	4	3	4.5	NL	NL	NP
Composite steel and concrete concentrically braced frames	4	2.5	4.5	NL	NL	50
Ordinary composite braced frames	3.5	2.5	3	NL	NL	NP
Ordinary composite reinforced concrete shear walls with steel elements	4	3	4.5	NL	NL	NP
Ordinary steel concentrically braced frames	4	2.5	4.5	NL	NL	50
Ordinary reinforced masonry shear walls	2.5	3	2.5	NL	50	NP

Table A.3.1: (Continued)

Seismic Force-Resisting System	**Response Modification Coefficient, R**	**Overstr-ength Factor, Ω**	**Deflection Amplifica-tion Factor, C_d**	**Structural System Limitations and building height (M)**		
				Seismic Design Category		
				A,B	**C**	**D**
F.CANTILEVERED COLUMN SYSTEMS DETAILED TO CONFORM TO THE REQUIREMENTS FOR :						
Special steel moment frames	2	2	2.5	NL	NL	NL
Ordinary steel moment frames	1	2	2.5	NL	NL	NP
Special reinforced concrete moment frames	2	2	1.25	NL	NL	NL
Steel systems not specifically detailed for seismic resistance	2.5	3	3	NL	NL	NP

Appendix 4

The results of horizontal displacement, storey drift, storey shear, base shear and time period for five different types of slab by ETABS For f_c = 30 MPa, f_y= 420 MPa, floor height = 3 m

Table A.4.1: Flat slab, 5-storey RC building

Storey Number	Storey Displacement,mm	Storey Drift,mm	Storey Shear,KN	Time Period,Sec	Self-Weight,KN	Superdead, KN	Live Load,KN
5	90	11	506	1.889	16,685	6,242.4	6,242.4
4	79	15	931				
3	64	20	1258				
2	44	23	1487				
1	21	21	1450				

Table A.4.2: Flat slab with drop panel, 5-storey RC building

Storey Number	Storey Displacement,mm	Storey Drift,mm	Storey Shear,KN	Time Period,Sec.	Self-Weight,KN	Superdead KN,	Live Load,KN
5	80	9	440	1.796	13,559	6,242.4	6,242.4
4	71	14	810				
3	57	18	1095				
2	39	20	1295				
1	19	19	1410				

Table A.4.3: Flat slab with edge beam, 5-storey RC building

Storey Number	Storey Displacement,mm	Storey Drift,mm	Storey Shear,KN	Time Period,Sec.	Self-Weight,KN	Superdead KN	Live Load,KN
5	76	11	425	1.754	12,886	6,242.4	6,242.4
4	68	13	784				
3	55	17	1060				
2	38	20	1254				
1	18	18	1365				

Table A.4.4: Conventional slab, 5-storey RC building

Storey Number	Storey Displacement,mm	Storey Drift,mm	Storey Shear,KN	Time Period,Sec.	Self-Weight KN	Superdead KN	Live Load,KN
5	50	5	406	1.434	11,990	6,242.4	6,242.4
4	45	8	750				
3	37	11	1014				
2	26	12	1199				
1	14	14	1306				

Table A.4.5: Flat slab with drop and edge beam, 5-storey RC building

Storey Number	Storey Displacement,mm	Storey Drift,mm	Storey ShearKN	Time Period,Sec.	Self-Weight KN	Superdead KN	Live Load KN
5	46	5	353	1.369	9,591	6,242.4	6,242.4
4	41	7	654				
3	34	10	885				
2	24	12	1047				
1	12	12	1141				

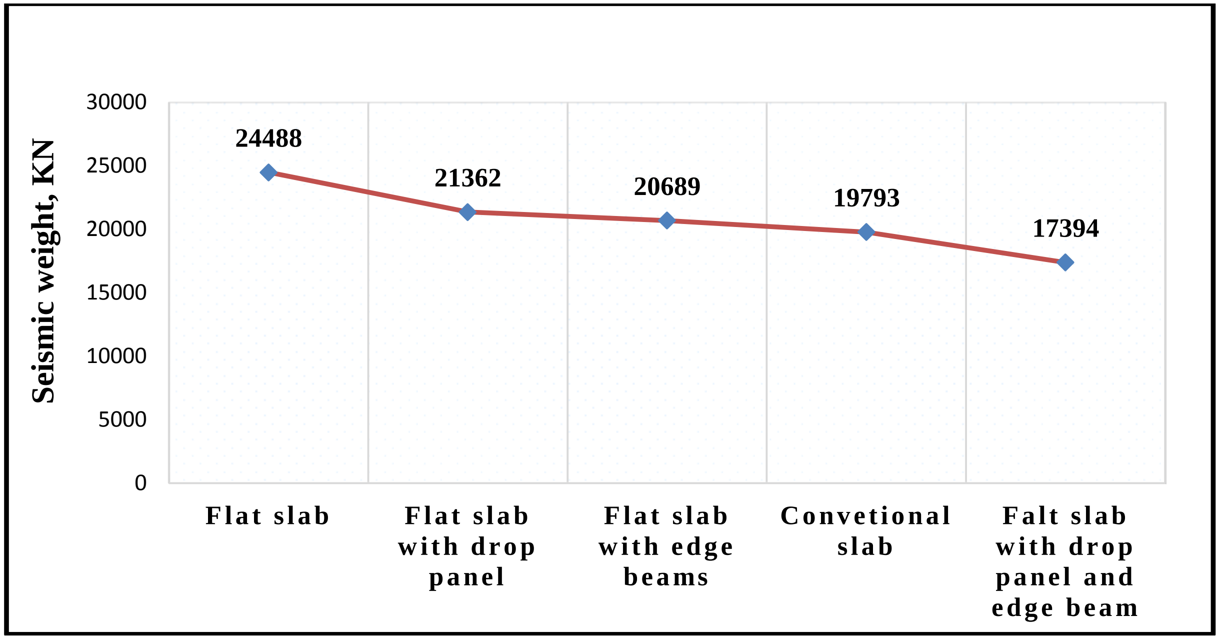

Figure A.4.1: Seismic weight of different types of slab by ETABS

Appendix 5

The results of horizontal displacement, storey drift, storey shear, base shear and time period for flat slab building with shear wall at five different location by ETABS For f_c = 30 MPa, f_y= 420 MPa, floor height = 3 m

T**able A.5.1:** Flat slab with shear walls at exterior corners, 5-storey RC building

Storey Number	Storey Displacement, mm	Story Drift,mm	Storey Shear, KN	Time Period, Second
5	64	13	457	1.526
4	51	15	847	
3	36	14	1147	
2	22	13	1356	
1	9	9	1478	

Table A.5.2: Flat slab with shear walls at exterior edges, 5-storey RC building

Storey Number	Storey Displacement, mm	Storey Drift,mm	Storey Shear, KN	Time Period, Second
5	55	12	459	1.408
4	43	13	851	
3	30	12	1153	
2	18	11	1364	
1	7	7	1476	

Table A.5.3: Flat slab with shear walls at interior corners, 5-storey RC building

Storey Number	Storey Displacement, mm	Storey Drift,mm	Storey Shear, KN	Time Period, Second
5	51	10	457	1.364
4	41	12	846	
3	29	12	1145	
2	17	8	1355	
1	9	9	1476	

Table A.5.4: Flat slab with shear walls at interior edges, 5-storey RC building

Storey Number	Storey Displacement, mm	Storey Drift,mm	Storey Shear, KN	Time Period, Second
5	46	10	457	1.333
4	36	11	845	
3	25	10	1144	
2	15	10	1354	
1	5	5	1475	

Table A.5.5: Flat slab with shear walls at center of building, 5-storey RC building

Storey Number	Storey Displacement, mm	Storey Drift,mm	Storey Shear KN	Time Period Second
5	24	6	459	1.35
4	18	6	852	
3	12	5	1154	
2	7	4	1365	
1	3	3	1488	