JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

A Comparative Study of Flat slab, Waffle Slab and Conventional RCC Slab under Dynamic loading

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

Mikiyas Seifu

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By

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A COMPARATIVE STUDY OF FLAT SLAB, WAFFLE SLAB AND CONVENTIONAL RCC SLAB UNDER DYNAMIC LOADING

MIKIYAS SEIFU

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Declaration

I, the undersigned, declare that this thesis is my own work and all sources of material used for the thesis have been duly acknowledged. And it is also approved by my advisors.

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Abstract

In this modern era of infrastructure development the main issue is the shortage of land. To overcome this problem construction of tall building has been taking place everywhere. Most building is using framed structure to design and construct. The most determinant effect on a structure is generally caused by lateral component of earthquake load. As compared to gravity load effect, earthquake load effects on buildings are quite variable and increase rapidly as the height of building increases. The strength requirement is a dominant factor in the design of structure. As height increases the rigidity and stability of structure get affected and it becomes necessary to design the structure preferably for lateral forces, moments, story drift and total horizontal deflection at top most story level. During earthquakes, inspite of the weaknesses in the structural system, either code imperfections or error in analysis and design, the configuration of structural system has played a vital role in catastrophe

The main objective of the study are to compare the seismic behavior of multi storey buildings having flat slab with and without drop panel, waffle slab and conventional R.C.C slab, in seismic zone 4 according to EBCS EN 1998-1:2013 and to study the effect of height of building on the performance under seismic forces. Linear dynamic response spectrum analysis performed on the structure to get the seismic behavior.

In conclusion, the analysis and design result showed, there is a significant difference in the behavior of the parameter. The study reveals that the displacement of waffle slab is lower 19.50% compare to conventional slab, 21.77% compare to Flat slab with drop panel and 41.42% compare to Flat slab without drop panel. The base shear of waffle slab is lower 19.45% compare to conventional slab, 19.19% compare to Flat slab with drop panel and 47.24% compare to Flat slab without drop panel.

The study showed that waffle slab building is much superior than Conventional, Flat slab with drop panel and Flat slab without drop panel not only in weight reduction but also the performance under dynamic loading.

Key word:- *Conventional Slab, flat slab with drop panel, flat slab without drop panel, waffle slab, Response spectrum analysis, Story displacement, story drift.*

Acknowledgement

First and foremost I would like to thanks to GOD who is there for me always through the times of trouble and good times. Then I would like to express my sincere appreciation and gratitude to my supervisors to Asso. Prof. Elmer C. Agon and Co- Advisor Eng. Goshu Kegea (MSC), who helped me without any restriction by guiding and showing me the directions and by sharing idea on problems that facing me, with valuable guidance, encouragement, respected hospitality, brotherly and energetic approach.

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Symbols and Acronyms

ETABS	Extended Three-Dimensional Analysis of Building Systems
EBCS EN	Ethiopian Building code of standard
R.C.C	Reinforced cement concrete
E_{cm}	Secant modulus of elasticity
Es	Modulus of elasticity
γs	Partial safety factor
f_{yk}	Characteristic yield strength of reinforcement
f_{ctm}	Mean value of axial tensile strength of concrete
fck	Characteristic cylindrical compressive strength of concrete at 28 days
β_a	Coefficient for effective depth
ν	Poisson's ratio
γ_I	Important factor
a_g	design ground acceleration
S	Soil factor
ζ	viscous damping ratio
q	Behavior factor
k_w	failure mode
DCL	Ductility class low
DCM	Ductility class low
DCH	Ductility class low
SDOF	Single degree of freedom
λ	Correction factor
k	number of modes taken into account
T_k	period of vibration of mode k

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Earthquake resistant design of reinforced concrete structures is a continuing area of research since the earthquake engineering has started. The structures still damage due to one or other reason during earthquakes. In spite of all the weaknesses in the structural system, either code imperfections or error in analysis and design, the configuration of structural system has played a vital role in catastrophe.

In this modern era of infrastructure development the main issue is the shortage of land. To overcome this problem, construction of tall building has been taking place everywhere. This high rise building constructed with different material like concrete, steel, wood and steel-concrete composite material and also their method of construction, generally they are using framed structure to design and construct. This structure are subjected to vertical and lateral load, the vertical load are mainly dead load and live load. Whereas, the lateral load are wind load and earthquake load this lateral load are variable and increase as building height increases. The lateral loads are considerably higher at the top storey than the bottom storey due to height of the building tends to act as cantilever. These lateral force are tends to sway the frame. In many of the seismic prone areas failure of structure occurs at the point where it is weak during earthquake**.** Earthquake appears due to the geotechnical aspect of the earth bed, it is unpredictable, if it occurs in populated areas, and it causes heavy loss to both life and properties. Many times damage caused by the earthquake is enormous.

Components of flat slab, waffle slab and conventional R.C. slab are dissimilar so, the performance also varies. Slab system cannot resist lateral load like wind and earthquake but, it gives rigidity for the structure.

In this paper three different reinforced concrete slab system were considered under dynamic load.

- Flat slab

  Slab system would consist of slab and column without beams. The slab is directly supported by the column and load from the slab is directly transferred to the columns and then to the foundation.

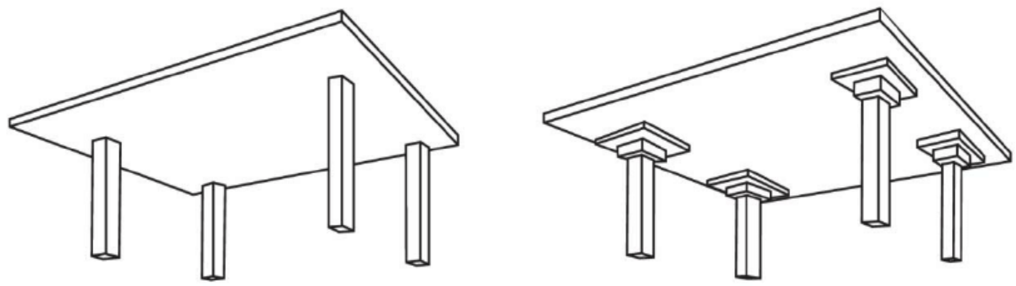


Figure 1-1 Flat slab systems (M. Adan,Scott & Luft, Rene & Naguib, Wassim,2010)

- Waffle slab

  Floors consisting of equally spaced ribs are usually supported directly by columns. They are either one-way spanning systems known as ribbed slab or a two-way ribbed system known as a waffle slab.

Figure 1-2 Waffle slab system (Idrizi, Zekirija & Idrizi, Isak, 2017)

- Conventional R.C.C slab

  This type of slab is supported by beam and column

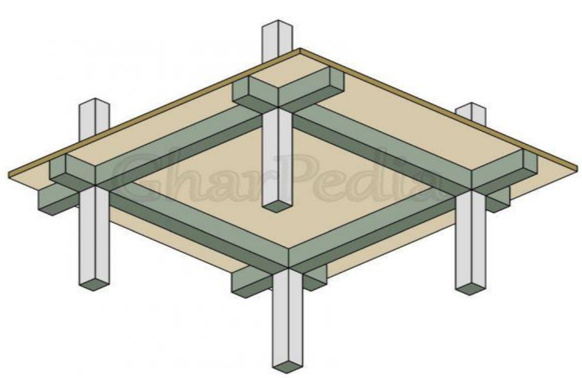


Figure 1-3 Conventional R.C.C slab system (Ritesh patel, what is two-way slab)

Flat slab structure is preferred over other slab system in construction due to their advantages in reducing storey height and construction period as compared with conventional structure leading to reduction of construction costs (S.Pahwa, V. Tiwari. M. Prajapati, 2014).

Because of absence of deep beam flat slab building structures are more significantly flexible than conventional concrete structures, thus becoming more vulnerable to seismic loading. Thus the seismic analysis of these structures is necessary to know the vulnerability of these structures to seismic loading (Navyashree K, Sahana T.S, 2014).

1.2 Statement of the problem

A structure must resist the load that expected to occur in its life time, but still damage due to one or the other reason during earthquakes. In spite of all the weaknesses in the structural system, either code imperfections or error in analysis and design, the configuration of structural system has played a vital role in catastrophe (Muniraju K.S & Subramanya K.G, 2015).

Building structures are subjected to both vertical and lateral loads. The vertical load is carried by the slab system and transfer to the adjacent structure like beam and column, and also the slab system gives rigidity to the structure under lateral load. The Lateral loads due to wind and earthquake governs the design rather than the vertical loads.

Extensive research has been done on slab system in different country to study their performance under dynamic loading. The performance of slab under seismic loading is greatly affected by the soil type, the magnitude of the earthquake and the configuration of the structure. Knowing the performance of slab system greatly help the designer to achieve a safe, economy and comfort in multistoried building.

1.3 Research question

In this study, flat slab, waffle slab and conventional RCC slab were investigated under dynamic loading to answer the following questions: -

- What are the behaviors of different reinforced concrete slab system under dynamic loading?
- What is the behavior of slab system with different storey height under dynamic load?
- Which type of slab system that is flat slab, waffle slab and conventional slab economical and performs better under different parameter like base shear, displacement, storey drift, axial load and time period?

1.4 Objective of the study

1.4.1 General objective

- To compare the performance of flat slab, waffle slab and conventional slab structure subjected dynamic loading

1.4.2 Specific objective

- To study the behavior of flat slab, waffle slab and conventional slab for the parameters like storey shear, drift ratio, base shear, storey displacement, axial force and time period.
- To study and compare flat slab, waffle slab and Conventional R.C.C slab with different building height.
- To study the economical aspect of flat slab, waffle slab and conventional slab.

1.5 Significance of the study

The main goals of the research are to study the behavior of different reinforced concrete slab system and also the effect when building height increase under dynamic loading. This study is certainly useful for architect, designer, engineer, researchers and governmental authority. This also helps students and researcher to refer the behavior of different slab and its dynamic effect on the structure and to be a bench mark for further study. The work helped greatly in achieving the better safety, economy and comfort in the design of the multistoried building.

1.6 Scope and limitation of the study

1.6.1 Scope of the study

The structures are modeled in 3D structures by using ETABS software. In the present work, 6 and 12 storied reinforced concrete frame buildings situated in Zone 4 as per EBCS EN are considered for the study.

Data used for modeling

- Flat slab without drop panel
- Flat slab with drop panel
- Waffle slab
- Conventional R.C.C slab
- Typical storey height 3m
- Building Plan dimension 30m x 30m
- Grade of concrete C-30
- Grade of steel Fe 400

The buildings are studied as space frames. The designed space frames are studied for dead loads, live loads and seismic loads. The analyses are done for the following 8 models. G+6 and G+ 12 storey RCC structure with Conventional slabs, waffle slab, Flat slab with and without drop panel in ETABS software and results are tabulated and compared. From the analysis displacement, time period, story drift, storey shear and base shear are obtained and compared. In the economical aspect of the study amount of concrete and steel used to compute the cost of the building but other parameter like formwork and scaffolding also affect the building cost. In this study only concrete and steel quantity considered to compute economical aspect.

1.6.2 Limitation of the study

The study focuses on the behavior of flat slab, ribbed slab and conventional R.C.C slab under dynamic loading.

Some of the limitations are

- ❖ The study only conducted on square plan view of building
- ❖ No shear wall considered

CHAPTER TWO

RELATED LITERATURE REVIEW

2.1 General

The rapid growth of population in urban areas and the consequent pressure on limited space considerably influenced tall building constructions. These tall buildings can be design and constructed using various systems. These buildings subjected to different loads like live load, dead load, wind load, seismic load and so on. In tall structures Lateral loads due to seismic and wind governs the design rather than the vertical loads. The structure designed for vertical load cannot resist these lateral loads. Lateral loads are quite variable and increases as height of the structure increases. The lateral loads are considerably higher in the top storey than the bottom storey due to which building act as cantilever. These lateral forces induce sway in the frame. In many of the seismic areas there are several instances of failure of structures due to improper design for seismic loads.

The trend of irregular plan and high rise building in urban areas are common due to the concentration and increase of population, rapid increase of land cost, limited availability of land and since they provide such a high ratio rentable floor space per unit area of land. Therefore these high-rise buildings are sensitive to lateral loading

2.2 Earthquake

Earthquake (also known as a quake, tremor or temblor) is the shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's lithosphere that creates seismic waves. Earthquakes can range in size from those that are so weak that they cannot be felt to those violent enough to toss people around and destroy whole cities. The seismicity, or seismic activity, of an area is the frequency, type and size of earthquakes experienced over a period of time. https://en.wikipedia.org/wiki/Earthquake

At the Earth's surface, earthquakes manifest themselves by shaking and displacing or disrupting the ground. When the epicenter of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami. Earthquakes can also trigger landslides, and occasionally volcanic activity. https://en.wikipedia.org/wiki/Earthquake

In its most general sense, the word earthquake is used to describe any seismic event—whether natural or caused by humans—that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults, but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. An earthquake's point of initial rupture is called its focus or hypocenter. The epicenter is the point at ground level directly above the hypocenter.

Shaking and ground rupture are the main effects created by earthquakes, principally resulting in more or less severe damage to buildings and other rigid structures. The severity of the local effects depends on the complex combination of the earthquake magnitude, the distance from the epicenter, and the local geological and geomorphologic conditions, which may amplify or reduce wave propagation. The ground-shaking is measured by ground acceleration. https://en.wikipedia.org/wiki/Earthquake

Earthquakes are a real threat to people's lives and property. One of the most devastating earthquakes in recorded history was the 1556 Shaanxi earthquake, which occurred on 23 January 1556 in Shaanxi province, China. More than 830,000 people died. Most houses in the area were yaodongs—dwellings carved out of loess hillsides—and many victims were killed when these structures collapsed. The 1976 Tangshan earthquake, which killed between 240,000 and 655,000 people, was the deadliest of the 20th century. https://en.wikipedia.org/wiki/Earthquake>

2.2.1 Earthquake in Ethiopia

The Great Rift Valley of east Africa is stretching from Beqaa Valley in Lebanon in Asia to Mozambique in southeastern Africa with a length of 6,000km,(Wilks, M & Ayele, A & Kendall, J & Wookey, J,2016). This area is under stress to tear up the African continent in to two. Seismicity in the main Ethiopian rift valley is generally diffuse along the rift basin (Fig. 2.1), where earthquakes are typically of small to intermediate magnitudes ($M < 6$). However, numerous examples of structurally damaging events have been documented over the past century, such as:

- A M6.3 event close to Hawassa in 1960 that was felt 200 km away and produced 28 aftershocks (Gouin, 1979).
- A MW 5.3 earthquake on the eastern escarpment of the Hawassa basin in 1983 that caused a rock slide and building collapse in Wendo Genet (Hofstetter and Beyth, 2003).
- A mb4.8 earthquake in 1985 that was strongly felt at Lake Langano, cracking hotels and buildings around the resort (Asfaw, 1998).
- A pair of events (mb > 4.1) on consecutive days in 1993 in the northern CMER, the second of which, caused damage in Nazret (Asfaw, 1998)
- A M_w 5.0 event at Chabbi in 1995 (Hofstetter and Beyth, 2003).

On the 24th January 2016 at 18:34:35.590 UTC (21:34 local time), an earthquake occurred in the Hawassa region that was felt up to 100 km away, including the major towns and cities of Hawassa (pop. 165 275, [2012]), Shashemene (pop. 122 046, [2012]) and Dila (pop. 79 892, [2012]) (Fantahun, 2016). A series of further tremors were also reported, causing minor structural damage in Hawassa as well as scattered power outages. (Wilks, Matthew & Ayele, Atalay & Kendall, J-Michael & Wookey, James,2016)

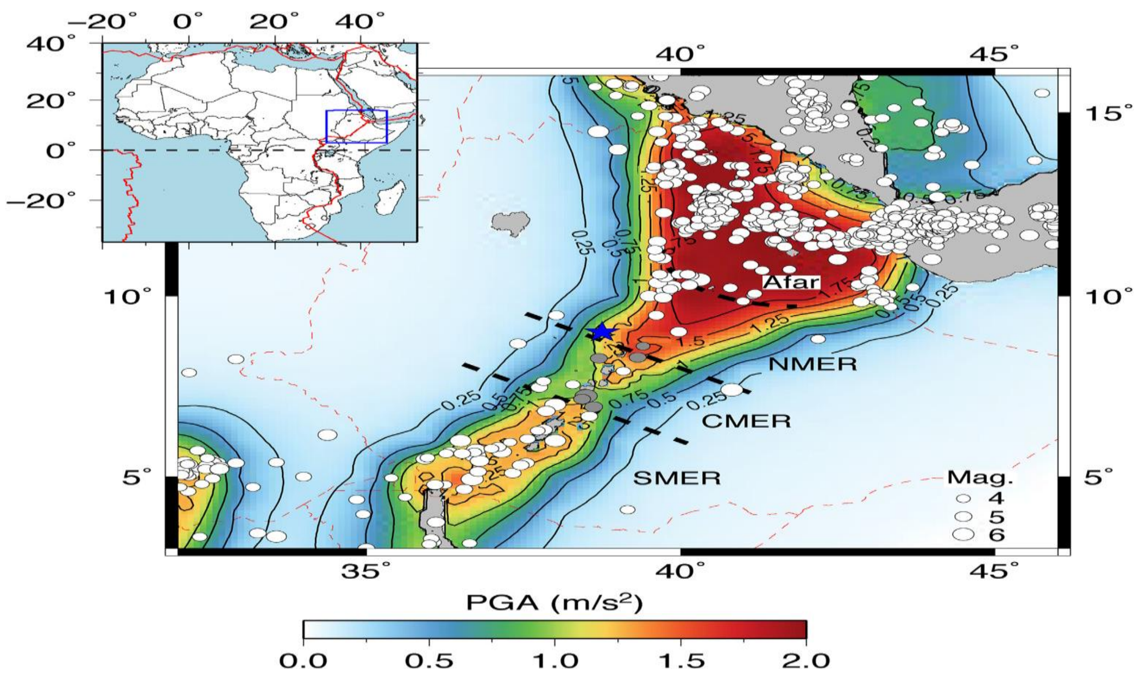


Figure 2-1Seismic hazard map of Ethiopia and the Main Ethiopian Rift (Wilks, Matthew & Ayele, Atalay & Kendall, J-Michael & Wookey, James,2016)

The strongest earthquake in Ethiopia happened on 06/01/1961 in the region Karakore with a magnitude of 6.5 on the Richter scale. The shifting of tectonic plates in a depth of 21 km resulted in 30 deaths. (https://www.worlddata.info/africa/ethiopia/earthquakes.php

According to EBCS 8 Design of structure for earthquake resistance the figure shows a seismic zone of Ethiopia. The seismic zone range from Zone 4 to zone 0

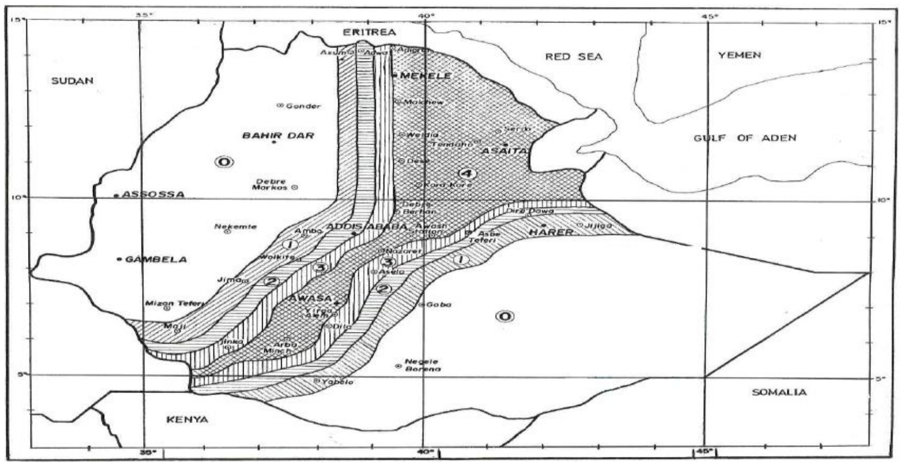


Figure 2-2 Seismic hazard map of Ethiopia for 100-year return period as per EBCS 8: 1995 (Asrat W, 2011)

2.3 Reinforced concrete structure

Reinforced concrete (RC) *(also called reinforced cement concrete or RCC)* is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength or ductility. The reinforcement is usually, though not necessarily, steel reinforcing bars (rebar) and is usually embedded passively in the concrete before the concrete sets. Reinforcing schemes are generally designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking and/or structural failure. Modern reinforced concrete can contain varied reinforcing materials made of steel, polymers or alternate composite material in conjunction with rebar or not. Reinforced concrete may also be permanently stressed (concrete in compression, reinforcement in tension), so as to improve the behavior of the final structure under working loads.

For a strong, ductile and durable construction the reinforcement needs to have the following properties at least:

- High relative strength
- High toleration of tensile strain
- Good bond to the concrete, irrespective of pH, moisture, and similar factors
- Thermal compatibility, not causing unacceptable stresses (such as expansion or contraction) in response to changing temperatures.

2.4 Slab System

A structure uses different type of slab system according to parameter like economy, Aesthetic, space, safety, strength and etc.

- In buildings, floors (including the roof) play a very important role in the overall seismic behaviour of the structure. They act as horizontal diaphragms that collect and transmit the inertia forces to the vertical structural systems and ensure that those systems act together in resisting the horizontal seismic action. The action of floors as diaphragms is especially relevant in cases of complex and non-uniform layouts of the vertical structural systems, or where systems with different horizontal deformability characteristics are used together (e.g. in dual or mixed systems). (**EBCS EN 1998-1-1:2013)**

- Floor systems and the roof should be provided with in-plane stiffness and resistance and with effective connection to the vertical structural systems. Particular care should be taken in cases of non-compact or very elongated in-plan shapes and in cases of large floor openings, especially if the latter are located in the vicinity of the main vertical structural elements, thus hindering such effective connection between the vertical and horizontal structure. (**EBCS EN 1998-1-1:2013)**

- Diaphragms should have sufficient in-plane stiffness for the distribution of horizontal inertia forces to the vertical structural systems in accordance with the assumptions of the analysis (e.g. rigidity of the diaphragm), particularly when there are significant changes in stiffness or offsets of vertical elements above and below the diaphragm.(**EBCS EN 1998-1-1:2013**)

2.4.1 Flat slab

A flat slab is a two-way reinforced concrete slab that usually does not have beams and girders, and the loads are transferred directly to the supporting concrete columns

Advantages of Flat Slab

Flat Slabs are used by engineers in many building due to its advantages over other reinforced concrete floor system in different cases. The most important advantages of flat slabs are given below:

1. Flexibility in room layout.
   - ✓ Partition walls can be placed anywhere.
   - ✓ Offers a variety of room layout to the owner
   - ✓ False ceilings can be omitted.
2. Reinforcement placements are easier.
   - ✓ As reinforcement detailing of flat slab is simple, it is easier to place
3. Ease of Framework installation.
   - ✓ Big table framework can be used in flat slab
4. Building heights can be reduced.
   - ✓ As no beam is used, floor height can be reduced and consequently the building height will be reduced.
   - ✓ Approximately 10% of the vertical member could be saved
   - ✓ Foundation load will also reduce.
5. Less construction time.
   - ✓ Use of big table framework helps to reduce construction time
6. Prefabricated welded mesh.
   - ✓ Standard sizes
   - ✓ Less installation time
   - ✓ Better quality control.
7. Auto sprinkler is easier.

Disadvantages of Flat Slab

Flat slabs have some disadvantages also. The major disadvantages are given below.

1. Span length is medium.
    - ✓ In flat plate system, it is not possible to have large span.
2. Not suitable for supporting brittle (masonry) partitions
3. Use of drop panels may interfere with larger mechanical ducting
4. Critical middle strip deflection
    - ✓ In flat slabs, the middle strip deflection may be critical.
5. Higher slab thickness
    - ✓ Compared to typical reinforced concrete two way slab system, the thickness of flat plate slabs are higher.

2.4.2 Drop Panels

Drop panels are the rectangular portion provided above the column and below the slab in order to restrict slab from getting sheared and undergo rupture.

Drop panel increases the contact surface area between the column and slab, which will enable a better distribution of load from slab to column. Thus, it will reduce the chance of slab failure due to unbalanced moments.

Reasons behind the drop panel's construction are as given below.

- ❖ Increase in flexibility of planning the layout for room,
- ❖ Easier installation of framework and reinforcement,
- ❖ The building height is reduced through provision of extra support,
- ❖ Construction time needed for large table frameworks is reduced,
- ❖ The auto sprinkling process is easier and Welded mesh is of standard size, in case of a prefabricated one. It requires lesser installation time and also provides with more control over construction quality.

The main uses of the drop panel are as below.

- ❖ Drop panel tends to improve the competence to resist shear failure, which can happen in the flat slab,
- ❖ Drop panel tends to enhance negative moment capacity of the flat slab and
- ❖ Drop panel tends to minimize the deflection through fabrication of the flat slab

2.4.3 WAFFLE SLAB

A waffle slab is a type of slab with holes underneath, giving an appearance of waffles. It is usually used where large spans are required (e.g. auditorium) to avoid many columns interfering with space. Hence thick slabs spanning between wide beams (to avoid the beams protruding below for aesthetic reasons) are required. Since the tensile strength of concrete is mainly satisfied by the steel bar reinforcement, only the "ribs" containing the reinforcement are kept where the remaining 'unused' concrete portion below the neutral axis is removed, to reduce the self-weight of the slab. This is achieved by placing clay pots or other shapes on the formwork before casting of the concrete.

Purpose of waffle slab:

Waffle slabs provide stiffer and lighter slabs than an equivalent flat slab. The speed of construction for such slab is faster compared to conventional slab. Relatively lightweight henceit is economical. It uses 30% less concrete and 20% less steel than a raft slab. They provide low floor deflections. It has good finishes and robustness. Fairly slim floor depth and fire resistant excellent vibration control.

Uses and applications of waffle slab:

It is used where vibration is an issue and where large span slabs are to be constructed i.e. areas having less number of columns. For example airport, hospitals, commercial and industrial buildings etc & where low slab deflections and high stability are required.

Advantages of waffle slab:

- ❖ Larger span of slab and floor with less number of columns.
- ❖ Load carrying capacity is greater than the other types of slab.

- Savings on weight and materials.
- Good vibration control capacity.
- Attractive soffit appearance when exposed.
- Lightweight.
- Vertical penetrations between ribs are easy.
- Economical when reusable formwork is used.
- Fast and speedy construction.

Disadvantages of waffle slab:

- Require greater floor-to-floor height.
- Requires special or proprietary formwork which is costly.
- Requires strict supervision and skilled labor.
- Difficulty in maintenance.
- Not suitable in highly windy area

2.5 Structural Analysis

Structural analysis is mainly concerned with finding out the behavior of a physical structure when subjected to force. This action can be in the form of load due to the weight of things such as people, furniture, wind, snow, etc. or some other kind of excitation such as an earthquake, shaking of the ground due to a blast nearby, etc. In essence all these loads are dynamic, including the self-weight of the structure because at some point in time these loads were not there. The distinction is made between the dynamic and the static analysis on the basis of whether the applied action has enough acceleration in comparison to the structure's natural frequency. If a load is applied sufficiently slowly, the inertia forces (Newton's first law of motion) can be ignored and the analysis can be simplified as static analysis. Structural dynamics, therefore, is a type of structural analysis which covers the behavior of structures subjected to dynamic (actions having high acceleration) loading. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Any structure can be subjected to dynamic loading. Dynamic analysis can be used to find dynamic displacements, time history, and modal analysis. (K. Venkatarao, 2016)

A dynamic analysis is also related to the inertia forces developed by a structure when it is excited by means of dynamic loads applied suddenly (e.g., wind blasts, explosion, and earthquake).

A static load is one which varies very slowly. A dynamic load is one which changes with time fairly quickly in comparison to the structure's natural frequency. If it changes slowly, the structure's response may be determined with static analysis, but if it varies quickly (relative to the structure's ability to respond), the response must be determined with a dynamic analysis.

Dynamic analysis for simple structures can be carried out manually, but for complex structures finite element analysis can be used to calculate the mode shapes and frequencies.

Seismic load is one of the basic concepts of earthquake engineering which means application of an earthquake-generated agitation to a building structure or its model. It happens at contact surfaces of a structure either with the ground, or with adjacent structures, or with gravity waves from tsunami.

Seismic loading depends, primarily, on

- Anticipated earthquake’s parameters at the site
- Geotechnical parameters of the site
- Building structure’s parameters

Sometimes, seismic load exceeds ability of a structure to resist it without being broken, partially or completely. Due to their mutual interaction, seismic loading and seismic performance of a structure are intimately related

K. Venkatarao [2016] Seismic motion consists of horizontal and vertical ground motions, with the vertical motion usually having a much smaller magnitude. Further, factor of safety provided against gravity loads usually can accommodate additional forces due to vertical acceleration due to earthquakes. So the horizontal motion of the ground causes the most significant effect on the structure by shaking the foundation back and forth. The mass of building resists this motion by setting up inertia forces throughout the structure. The magnitude of the horizontal shear force “F” depends on the mass of the building “M”, the acceleration of the ground “a” and the nature of the structure. If a building and the foundation were rigid, it would have the same acceleration as the ground as given by Newton’s second law of motion, i.e. F = M x a.

However, in practice all buildings are flexible to some degree. For a structure that deforms slightly, thereby absorbing some energy, the force will be less than the product of mass and acceleration. But a very flexible structure will be subject to a much larger force under repetitive ground motion. This shows the magnitude of the lateral force on a building is not only dependent on acceleration of the ground but it will also depend on the type of the structure. As an inertia problem, the dynamic response of the building plays a large part in influencing and in estimating the effective loading on the structure.

2.6 Seismic analysis

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent.

A building has the potential to 'wave' back and forth during an earthquake (or even a severe wind storm). This is called the 'fundamental mode', and is the lowest frequency of building response. Most buildings, however, have higher modes of response, which are uniquely activated during earthquakes. The figure just shows the second mode, but there are higher 'shimmy' (abnormal vibration) modes. Nevertheless, the first and second modes tend to cause the most damage in most cases.

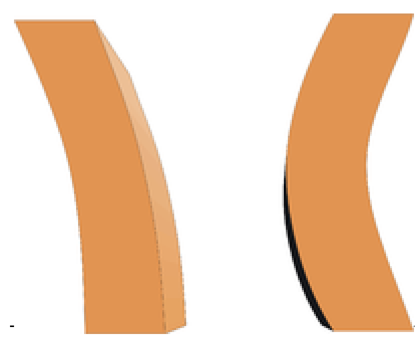


Figure 2-3 First and second modes of building seismic response

The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight (applied at each floor level). This approach was adopted in the appendix of the 1927 Uniform Building Code (UBC), which was used on the west coast of the United States. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. In the Los Angeles County Building Code of 1943 a provision to vary the load based on the number of floor levels was adopted (based on research carried out at Caltech in collaboration with Stanford University and the U.S. Coast and Geodetic Survey, which started in 1937). The concept of "response spectra" was developed in the 1930s, but it wasn't until 1952 that a joint committee of the San Francisco Section of the ASCE and the Structural Engineers Association of Northern California (SEAONC) proposed using the building period (the inverse of the frequency) to determine lateral forces.

Structural analysis methods can be divided into the following five categories.

1. Equivalent static analysis

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

General according to EBCS EN 1998-1-1:2013

1. This type of analysis may be applied to buildings whose response is not significantly affected by contributions from modes of vibration higher than the fundamental mode in each principal direction.

2. The requirement in **(1)** of this sub clause is deemed to be satisfied in buildings which fulfil both of the two following conditions.

   a) They have fundamental periods of vibration T_1 in the two main directions which are smaller than the following values

$$T_1 \leq \begin{cases} 4 \cdot T_C \\ 2.0\,\text{s} \end{cases}$$

Where T_C is given in Table 3.4 or Table 3.5;

b) They meet the criteria for regularity in elevation also.

Base shear force

1. The seismic base shear force F_b, for each horizontal direction in which the building is analysed, shall be determined using the following expression:

$$F_b = S_d (T_1) \cdot m \cdot \lambda$$

Where

$S_d (T_1)$ is the ordinate of the design spectrum at period T_1;

T_1 is the fundamental period of vibration of the building for lateral motion in the direction considered;

m is the total mass of the building, above the foundation or above the top of a rigid basement,

λ is the correction factor, the value of which is equal to: $\lambda = 0.85$ if $T_1 \leq 2\ T_c$ and the building has more than two storeys, or $\lambda = 1.0$ otherwise.

2. For the determination of the fundamental period of vibration T_1 of the building, expressions based on methods of structural dynamics (for example the Rayleigh method) may be used.

3. For buildings with heights of up to 40 m the value of T_1 (in s) may be approximated by the following expression:

$$T_1 = C_t \cdot H^{3/4}$$

Where

C_t is 0.085 for moment resistant space steel frames, 0.075 for moment resistant space concrete frames and for eccentrically braced steel frames and 0.050 for all other structures;

H is the height of the building, in m, from the foundation or from the top of a rigid basement.

4. Alternatively, for structures with concrete or masonry shear walls the value C_t in expression

$$C_t = 0.075 / \sqrt{A_c}$$

Where

$$A_c = \sum \left[A_i \cdot \left(0.2 + \left(l_{wi}/H \right)^2 \right) \right]$$

And

A_c is the total effective area of the shear walls in the first storey of the building, in m^2;

A_i is the effective cross-sectional area of the shear wall i in the first storey of the building, in m^2;

l_{wi} is the length of the shear wall i in the first storey in the direction parallel to the applied forces, in m, with the restriction that l_{wi}/H should not exceed 0.9.

5. Alternative, the estimation T_1 (in s) may be made by using the following expression:

$$T_1 = 2 \cdot \sqrt{d}$$

Where

d is the lateral elastic displacement of the top of the building, in m, due to the gravity loads applied in the horizontal direction.

Distribution of the horizontal seismic forces

1. The fundamental mode shapes in the horizontal directions of analysis of the building may be calculated using methods of structural dynamics or may be approximated by horizontal displacements increasing linearly along the height of the building.

2. The seismic action effects shall be determined by applying, to the two planar models, horizontal forces F_i to all storeys.

$$F_i = F_b \cdot \frac{s_i \cdot m_i}{\sum s_j \cdot m_j}$$

Where

F_i is the horizontal force acting on storey i;

F_b is the seismic base shear

s_i, s_j are the displacements of masses m_i, m_j in the fundamental mode shape;

m_i, m_j are the storey masses

3. When the fundamental mode shape is approximated by horizontal displacements increasing linearly along the height, the horizontal forces F_i should be taken as being given by:

$$F_i = F_b \cdot \frac{z_i \cdot m_i}{\sum z_j \cdot m_j}$$

Where

z_i, z_j are the heights of the masses m_i,m_j above the level of application of the seismic action (foundation or top of a rigid basement).

4. The horizontal forces F_i determined in accordance with this clause shall be distributed to the lateral load resisting system assuming the floors are rigid in their plane.

2. Response spectrum analysis

This approach permits the multiple modes of response of a building to be taken into account (in the frequency domain). This is required in many building codes for all except very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the "harmonics". Computer analysis can be used to determine these modes for a structure. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure. In this we have to calculate the magnitude of forces in all directions i.e. X, Y & Z and then see the effects on the building.

Although the SRSS method is commonly used for the dynamic analysis of structures, a number of other methods have been proposed to estimate the maximum response.

Square root of the sum of the squares (SRSS)

In case the natural frequencies are not close to each other, the SRSS gives good estimate of the maximum response.

$$x_{i\mathrm{maxSRSS}} = \sqrt{\sum_{j=1}^{n} \{\beta_j \, \phi_{ij} \, S_{\mathrm{d}}(\omega_j)\}^2}$$

ABSSUM : Absolute sum

Since the SRSS sometimes underestimates the maximum response, ABSSUM has been proposed to give the extreme of the maximum response.

$$x_{i\mathrm{maxABS}} = \sum_{j=1}^{n} \left| \beta_j \, \phi_{ij} \, S_{\mathrm{d}}(\omega_j) \right|$$

Average SRSS and ABSSUM

The ABSSUM gives the extreme of the maximum response and usually overestimates it. This is because the maximum response of each mode does not occur simultaneously. Therefore the average of SRSS and ABSSUM has been proposed.

$$x_{i\max} \approx \frac{1}{2}\left(x_{i\max\mathrm{SRSS}} + x_{i\max\mathrm{ABS}}\right)$$

CQC: Complete Quadratic Combination

Since the SRSS does not give good estimate of the maximum response, especially when the natural frequencies are close to each other, CQC has been proposed. The CQC is derived from the random vibration theory, which takes into account the correlation between natural frequencies.

$$x_{\mathrm{imaxCQC}} = \sqrt{\sum_{j=1}^{n} \sum_{k=1}^{n} \{\beta_j \, \phi_{ij} \, S_{\mathrm{d}}(\omega_j)\} \, \rho_{jk} \, \{\beta_k \, \phi_{ik} \, S_{\mathrm{d}}(\omega_k)\}}$$

$$\rho_{jk} = \frac{8\sqrt{\zeta_j \, \zeta_k}\,(\zeta_j \; + \; r_{jk}\,\zeta_k)\,r_{jk}^{2/3}}{(1 \; - \; r_{jk}^2)^2 \; + \; 4\zeta_j\,\zeta_k\,r_{jk}\,(1 \; + \; r_{jk}^2) \; + \; 4(\zeta_j^2 + \zeta_k^2)\,r_{jk}^2}$$

Where, ζ_j and ζ_k are the damping ratios for the j-th and k-th mode, respectively, and r_{jk} is the ratio of the j-th mode natural frequency to the k-th mode natural frequency.

All modes having significant contribution to total structural response should be considered in the above Equation.

The result of a response spectrum analysis using the response spectrum from a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, since phase information is lost in the process of generating the response spectrum.

In cases where structures are either too irregular, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static analysis or dynamic analysis.

General according to EBCS EN 1998-1-1:2013

1. This type of analysis shall be applied to buildings which do not satisfy the conditions given for applying the lateral force method of analysis.

2. The response of all modes of vibration contributing significantly to the global response shall be taken into account.

3. The requirements specified in paragraph (2) may be deemed to be satisfied if either of the following can be demonstrated:

   - ✓ the sum of the effective modal masses for the modes taken into account amounts to at least 90% of the total mass of the structure;
   - ✓ All modes with effective modal masses greater than 5% of the total mass are taken into account.

The effective modal mass m_k, corresponding to a mode k, is determined so that the base shear force F_{bk}, acting in the direction of application of the seismic action, may be expressed as $F_{bk} = S_d(T_k)\, m_k$. It can be shown that the sum of the effective modal masses (for all modes and a given direction) is equal to the mass of the structure.

4. When using a spatial model, the above conditions should be verified for each relevant direction.

5. If the requirements specified in **(3)** cannot be satisfied (e.g. in buildings with a significant contribution from torsional modes), the minimum number k of modes to be taken into account in a spatial analysis should satisfy both the two following conditions:

$$k \geq 3 \cdot \sqrt{n}$$

And

$T_k \leq 0.20$ s

Where

k is the number of modes taken into account;

n is the number of storeys above the foundation or the top of a rigid basement;

T_k is the period of vibration of mode k.

Combination of modal responses

a. The response in two vibration modes *i* and *j* (including both translational and torsional modes) may be taken as independent of each other, if their periods T_i and T_j satisfy (with $T_j \leq T_i$) the following condition:

$T_j \leq 0.9 \cdot T_i$

b. Whenever all relevant modal responses may be regarded as independent of each other, the maximum value E_E of a seismic action effect may be taken as:

$$E_E = \sqrt{\sum E_{Ei}^2}$$

Where

E_E is the seismic action effect under consideration (force, displacement, etc.);

E_{Ei} is the value of this seismic action effect due to the vibration mode *i*.

c. If **(1)** is not satisfied, more accurate procedures for the combination of the modal maxima, such as the "Complete Quadratic Combination" shall be adopted.

3. Linear dynamic analysis

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsional irregularities, or non-orthogonal systems, a dynamic procedure is required. In the linear dynamic procedure, the building is modeled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

The seismic input is modeled using either modal spectral analysis or time history analysis but in both cases, the corresponding internal forces and displacements are determined using linear elastic analysis. The advantage of these linear dynamic procedures with respect to linear static procedures is that higher modes can be considered. However, they are based on linear elastic response and hence the applicability decreases with increasing nonlinear behavior, which is approximated by global force reduction factors.

In linear dynamic analysis, the response of the structure to ground motion is calculated in the time domain, and all phase information is therefore maintained. Only linear properties are assumed. The analytical method can use modal decomposition as a means of reducing the degrees of freedom in the analysis.

4. Nonlinear static analysis

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism.

This approach is also known as "pushover" analysis. A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to define a capacity curve. This can then be combined with a demand curve (typically in the form of an acceleration-displacement response spectrum (ADRS)). This essentially reduces the problem to a single degree of freedom (SDOF) system.

Nonlinear static procedures use equivalent SDOF structural models and represent seismic ground motion with response spectra. Story drifts and component actions are related subsequently to the global demand parameter by the pushover or capacity curves that are the basis of the non-linear static procedures.

5. Nonlinear dynamic analysis

Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares.

In non-linear dynamic analysis, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios. This has led to the emergence of methods like the incremental dynamic analysis.

Several researchers studied the behavior of flat slab, waffle slab and conventional slab on reinforced cement concrete structures under dynamic loading. A brief review of previous studies on the behavior of flat slab, waffle slab and conventional slab on reinforced cement concrete structures under dynamic loading are presented in this section and past efforts most closely related to the needs of the present work.

Vishesh, Anuj, Unnati (April 2017) studied the seismic behavior of flat slab with drop panel, flat slab without drop panel and conventional R.C framed slab also with different height of the building that is G+5, G+8 and G+11, seismic zone III and type II medium soil in India, it will be modeled and analyzed in ETABS software. Linear dynamic response spectrum analysis performed on the structure for the parameters like storey displacement, storey drift, storey shear, base shear and time period.

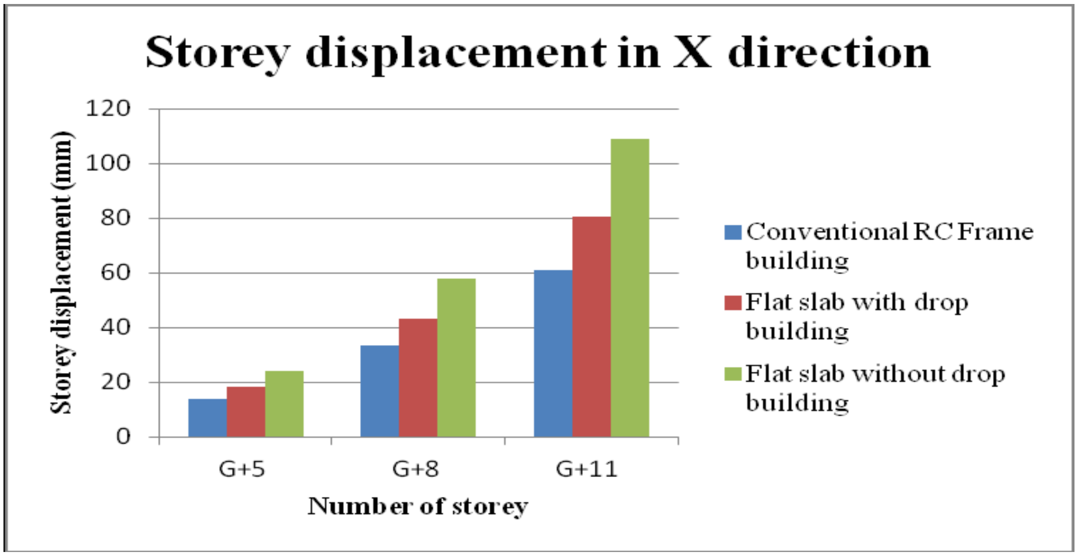


Figure 2-4 Storey displacement of 5, 8 and 11 storey building (Vishesh, Anuj, Unnati**, 2017)**

By comparing all above parameters it was found that conventional building has superior performance in earthquake against flat slab with drop and flat slab without drop.

Navjot Kaur Bhatia (June 2016) studied that dynamic performance of flat slab and grid slab compare to conventional slab. In the study of the project the writer perform the dynamic analysis for seismic and wind forces of multistory reinforced concrete building with different plan like square, hexagonal, orthogonal for flat slab , grid slab and conventional slab. The above analysis done for different story like 10, 20 and 30 and also for the different earthquake zone as per the Indian standard code of practice is 1893 – 2002. They made the relation between earthquake responses and intensities. It is revealed from the study that the performance and structural behavior of flat slab & grid slab is superior in compare to conventional slab. It is show in term of deflection and cost of material.

Idrizi, Zekirija & Idrizi, Isak. (2017). comparatively study between waffle and solid slab systems in Terms of Economy and Seismic Performance on a 14 storey building, in their study they divided into two part first study is focused in deriving an optimal solution for a solid and waffle slab system which are later on considered as constituents of all stories of the 14-story building. In the second part, it is elaborated the effect of both slab systems over the 14-story building model. This study aims to emphasize the advantages of mid-rise buildings constituted of waffle slab system over the buildings characterized with solid types of slabs, in terms of economy, structural safety and performance. In the study response spectrum analysis was performed. The analysis results derived from response spectra, figure 2.1 and 2.2 shows

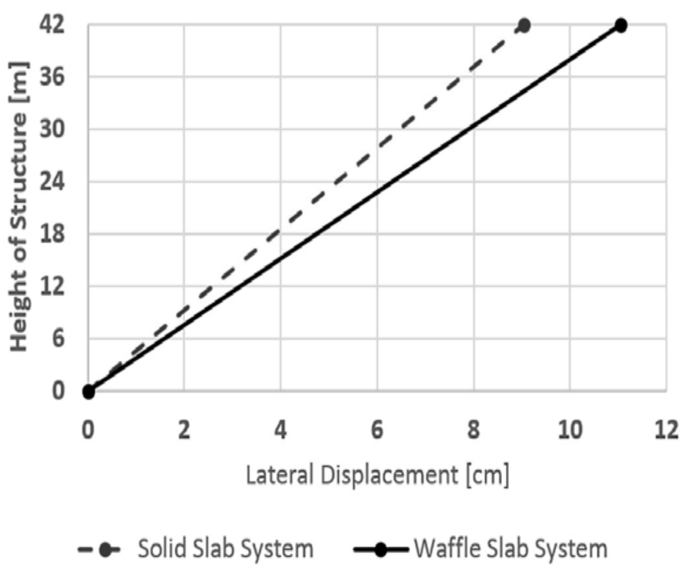


Figure 2-5 Lateral building displacements due to seismic design actions (Idrizi, Zekirija & Idrizi, Isak**, 2017)**

For both types of buildings, the input parameters of the response spectra analysis were kept identical. According to Fig. 2.2, the building with waffle slab system has larger lateral displacement in respect to the same building consisted of solid slab system due to the higher flexibility of the waffle slab system

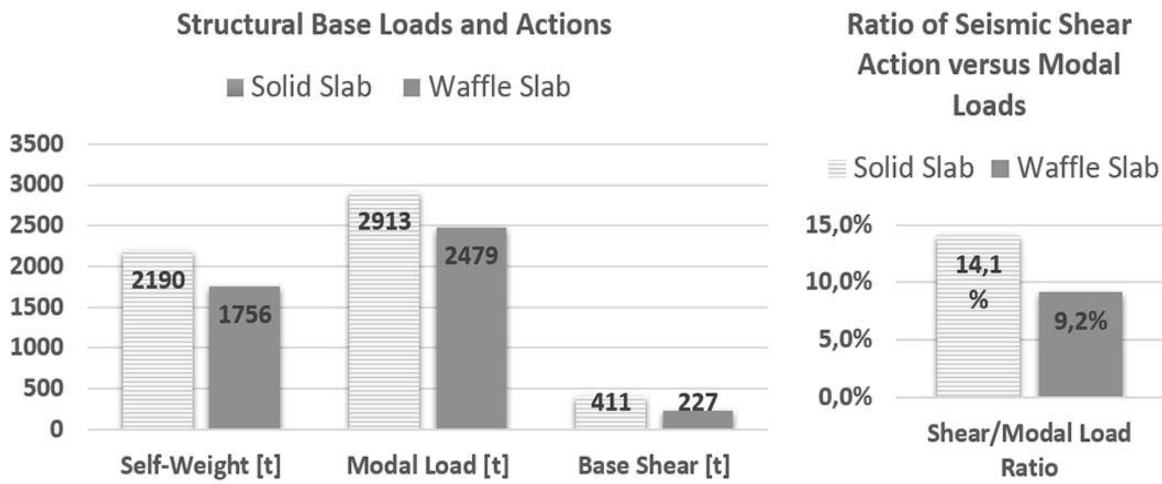


Figure 2-6 Structural base loads and ratio of seismic base shear VS. Modal loads (Idrizi, Zekirija & Idrizi, Isak, 2017)

In Fig. 2.6 can be seen that the ratio of the seismic shear forces over the modal loads of the 14-story building with solid slab system is about 14%, while for the same building with adopted waffle slab system is minimized down to about 9%. This means that the building with adopted waffle slab system, being lighter and more flexible absorbs smaller seismic shear forces in comparison to the same building with adopted solid slab system. More specifically, according to Fig. 2.6, in the building with solid slab is generated about 411 t of shear force at the base of the structure, while for the building with waffle slabs is generated somewhat less than half its value, respectively 211 t. In other words, the absorption of seismic actions in this building is almost doubly reduced by slightly simultaneously reducing the building mass and increasing its flexibility, respectively by changing the slab system from solid to waffle type.

Finally the study conclude that the benefits of using a waffle slab system over the solid slab system are significant not only in the sense of achieving a lighter and economical structure but also in the sense of providing a safer structure with improved level of seismic performance in seismic design situations.

Indrani V, Shubha D. K, Lavina E. J (2018) conducted a Dynamic Analysis of multistory RCC building frame with flat slab and grid slab, The main objective of analysis is to study the difference between flat slab and grid slab and also comparison of shapes of rectangle square and hexagon which shapes is best in seismic behavior of analysis using ETABS software. To study the behavior the response parameters selected are lateral displacement and storey drift. The study showed that Building drift in grid slab building is less as compared to flat slab building in each story

K. Venkatarao [2016] studied the seismic behavior of conventional RC framed building, flat slab with drop and without drop building in all seismic zones of India. Different parameters like displacement, lateral drift, base shear, time period and axial force are compared.

Table 2-1 Lateral displacement (in mm) in X and Y-direction for seismic zone-V (K. Venkatarao**, 2016]**

Model X	Story 1	Story 2	Story 3	Story 4	Story 5	Story 6	Story 7	Story 8
Conventional Building	3.40	11.00	21.30	29.20	37.40	42.40	46.00	48.50
Flat Slab Building Without Drops	3.60	11.80	23.30	32.30	41.70	47.60	52.00	55.20
Flat Slab Building With Drops	3.20	9.70	18.30	24.70	31.30	35.30	38.00	39.60

Model Y	Story 1	Story 2	Story 3	Story 4	Story 5	Story 6	Story 7	Story 8
Conventional Building	3.40	10.90	21.10	28.90	37.10	42.10	45.70	48.10
Flat Slab Building Without Drops	3.50	11.70	23.00	31.90	41.10	46.90	51.30	54.40
Flat Slab Building With Drops	3.10	9.50	18.00	24.20	30.80	34.60	37.30	38.90

It was concluded that lateral displacement of conventional RC frame is less as compared to flat slab without drop building.

Renuka Gurusiddappa Madiwalar and Vinayak Vijapur (2016) Study Different Type of Flat Slab and Conventional Slab for an RC Structure under Earthquake Loading. Equivalent static method comparative analysis of conventional slab, flat slab without drop, flat with drop, flat slab with column head and flat with both drop and column head. And we are considering 5 (G+4) storey, 10(G+9) storey, 15 (G+14) storey. The same buildings were studied for different seismic zone and taking soil type II. Also parameters like Lateral Displacement, Storey Drifts, Storey Shear, Design Base Shear, and Axial Forces are studied. The study conclude that Conventional slab experiences less displacement as compare to flat slab without drop, with drop, with column head, and both with drop and column head.

Saksheshwari, Guruprasad T. D and Raghu K. S (2016). Perform a Comparative Study on conventional beam slab and flat slab under various seismic zones and soil conditions" The objective of the present work is to compare the behavior of multi-storey commercial buildings having flat slabs with drop and peripheral beams and beam slab. Present work provides good source information on the parameters base shear, lateral displacement and storey drift. The analysis is carried out by ETABS V9.7.4 software in a G+10 building

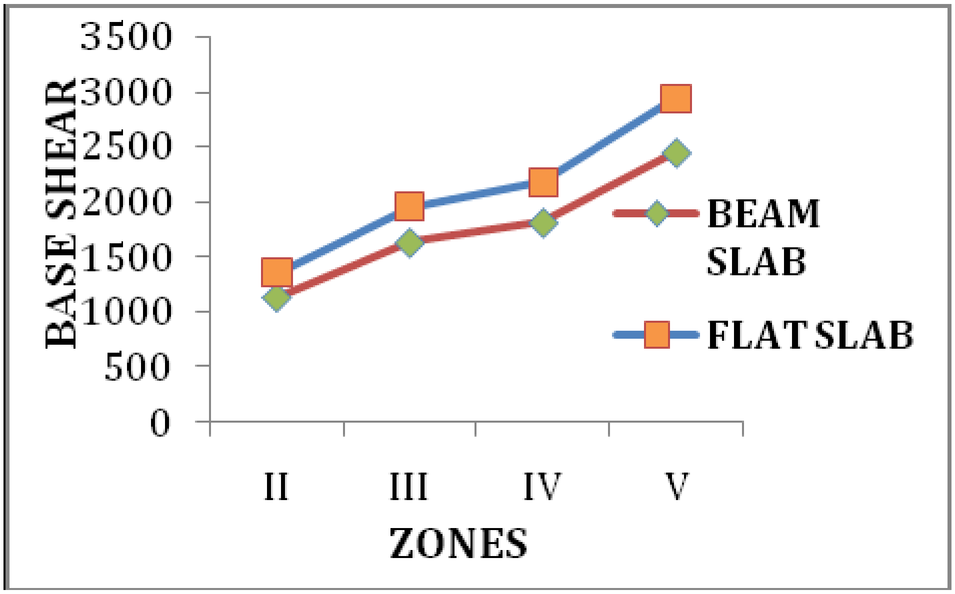


Figure 2-7 Comparison of base shear along X direction for rock soil (Saksheshwari, Guruprasad T. D and Raghu K. S, 2016).

Mohamed A. A. El-Shaer (2013), Analysis Seismic Load of different R.C. Slab Systems for Tall Building, This Paper introduced the lateral analysis for tall buildings due to the seismic performance for different reinforced concrete slab systems. It study three systems, flat slab, ribbed slab, and paneled beam slab. The study conducted in a 30 stories building using Response Spectrum analysis for earthquakes under ETABS software. The study shows

Table 2-2 Inter Story Drift in X&Y-direction for three systems (Mohamed A. A. El-Shaer**, 2013)**

Direction	Flat slab	Pannelled beams	Ribbed slab
(m)X	0.00545	0.00488	0.00238
(m)Y	0.0202	0.0156	0.0153

Table 2-3 Base Shear in X & Y-direction for three systems (Mohamed A. A. El-Shaer, **2013)**

Direction	Flat slab	Pannelled beams	Ribbed slab
(KN)X	36800	36600	36600
(KN)Y	36700	36700	36700

Table 2-4 Displacement in X &Y-direction for three systems (Mohamed A. A. El-Shaer**, 2013)**

Direction	Flat slab	Pannelled beams	Ribbed slab
(m)X	0.466	0.415	0.202
(m)Y	1.68	1.3	1.29

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 General

The object of the present work is to compare the behavior of multi-storey buildings having different types of slab system under seismic forces. For this purpose two cases of multi-storey buildings are considered. Each case is analyzed for the models of conventional slab, flat slab without drop, flat slab with drop and waffle slab by using ETABS 2016 software.

- ✓ In case-I, building area provided is 30 m x 30 m with G + 6 building.
- ✓ In case-II, building area provided is 30 m x 30 m with G +12 building.

The material property used for the study is shown below with a concrete grade of C-30 and a steel of S-400 is used.

3.2 Study Area

The study focuses on highly affected area with earthquake that is zone 4 according to Ethiopian Building Code Standard 8 (EBCS EN 1998-1: 2013). This area is along the rift valley of Ethiopia. The study will be conducted in SNNPR, Awasa. The location is 7.0504° N; 38.4955° E. This is the line with a tectonic force trying to break the African continent into two.

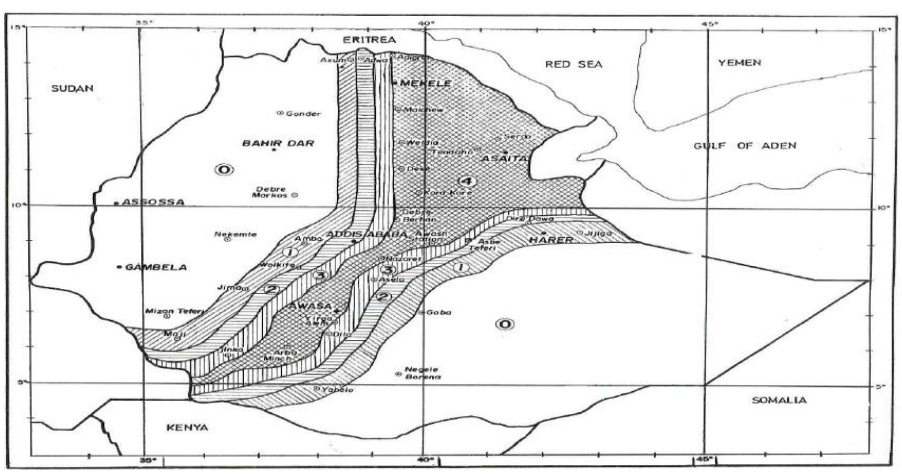


Figure 3-1 Seismic hazard map of Ethiopia for 100-year return period as per EBCS 8: 1995 (Asrat W, 2011)

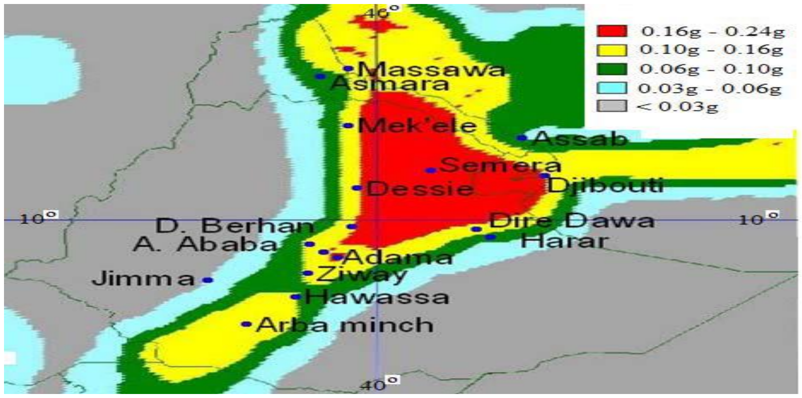


Figure 3-2 Seismic hazard map of Ethiopia based on the GSHAP data for a return period of 475 years (Asrat W, 2011)

3.3 Research design

The study is about analytical investigation. It concerned on a comparative study of flat slab with and without drop panel, waffle slab and conventional R.C.C slab under dynamic loading and also to investigate the effects of change in building height on the performance of the structure under seismic load. The study perform using different parameter like base shear, storey shear, drift ratio, displacement and time period. The study consists of 8 model flat slabs with drop panel, flat slab without drop panel, waffle slab and conventional R.C.C slab using ETABS software. The dynamic analysis is carried out by Response Spectrum analysis. The building Plan dimension is taken to be 30m x 30m. The load and the vertical member (column) in all structure are kept identical.

3.4 Study variables

Dependent and independent variables that are closely related with the effects of dynamic load on reinforced concrete slab. The variables that mainly affect the behavior of R.C.C slab system and focused on to see the effects are listed as follows.

Independent variables

- ❖ Base shear
- ❖ Displacement
- ❖ Drift ratio
- ❖ Axial load
- ❖ Time period
- ❖ Concrete grade
- ❖ Steel grade

Dependent variables

- ❖ Performance of slab system
- ❖ Economy of the building

3.5 Source of data

For the purpose of this research and to achieve the objectives both primary and secondary data collect. The Primary data collected from software output. But most of the data input is assumed, like building plan, storey height, and material for the design.

Secondary data will contribute toward the formation of background information. This data collect through reviewing building codes, journals and literature review.

3.6 Data collection process

This section describes the details of data collection during study and analysis investigation then the data collected through:

- ❖ ETABS structural software Output
- ❖ Building code EBCS EN 1998-1: 2013
- ❖ Literature review

3.7 Data presentation and Analysis

3.7.1. Data analysis

Data analyze through a step by step procedure for the 8 building model that is flat slab with and without drop panel, waffle slab and conventional slab with a G+ 6 and G+ 12 storeys. The building analyzes using frame structure.

1. The building modeled using ETABS software.
2. All the load that is dead load, live load and seismic load assign on the structure.
3. The models analyze using response spectrum analysis.
4. Data will collect from the response spectrum analysis like storey shear, base shear, displacement and time history.
5. The modal analyze and design to compute axial load.

6. Finally the Economy of building will be computed.

3.7.2 Data presentation

Data presented in a comparative manner for flat slab, waffle slab and conventional slab. The method use for data presentation is graph and table.

The data that will be present

- Base shear
- Displacement
- Storey drift,
- Storey shear
- Axial load
- Time period
- Economy

3.8 Material Data

During the analysis and/or design of the building, the following material properties are used for concrete and reinforcement bar

3.8.1 Concrete

Concrete grade of C-30 (fcu = 30MPa) with Class-I workmanship. (EBCS EN 1992-1-1:2013)

Partial safety factor, = 1.5

Secant modulus of elasticity, Ecm

$E_{cm} = 22[(fcm)/10]^{0.3}$

- Poisson's ratio, ν

Any value between 0 and 0.2

Coefficient of thermal expansion, α

$\alpha = 10x10^{-6}$ per ^{o}c

- Unit weight, $\gamma = 25KN/m3$

Table 3-1Concrete property (EBCS EN 1992-1-1:2013)

Grade of concrete	C-30/37	--
Density	25	(KN/m3)
f_{cm} (MPa)	38	MPa
f_{ctm} (MPa)	2.9	MPa
$f_{ctk,\ 0.05}$ (MPa)	2	MPa
$f_{ctk,\ 0.95}$ (MPa)	3.8	MPa
E_{cm} (GPa)	33	GPa
Poisson's ratio, ν	0.2	--

3.8.2 Reinforcing Steel

• Steel grade of S-400 (fyk = 400MPa) with Class-I workmanship. (EBCS EN 1992-1-1:2013)

• Partial safety factor, γs

γ s =1.15

• Design strength [tension & compression], fyd

$f_{yd} = \frac{f_{yk}}{\gamma s}$ [EBCS - 2, 1995 Eqn. 3.6]

• Modulus of elasticity, Es

Es = 200GPa

• Coefficient of thermal expansion, α = 10 x 10-6 per 0C

• Unit weight, γ = 77KN/m3

3.9 ETABS Software

ETABS (Extended Three-Dimensional Analysis of Building Systems) is special purpose analysis and design program developed specially for buildings. Original development of TABS 30 years back led to the development of the today's ETABS. Early releases of ETABS provided input, output and numerical solution that took into consideration the characteristics unique to building type structures, providing a tool that offered significant savings in time and increased accuracy over general purpose programs. As computers and computer interfaces evolved, ETABS added computationally complex analytical options such as dynamic nonlinear behavior, and powerful CAD-like drawing tools in a graphical and object-based interface. ETABS offers the widest assortment of analysis and design tools available for the structural engineer working on building structures. The following list represents just a portion of the types of systems and analysis that ETABS can handle easily

- ✓ Multi-story commercial, government and health care facilities
- ✓ Parking garages with circular and linear ramps
- ✓ Staggered truss buildings
- ✓ Buildings with steel, concrete, composite or joist floor framing
- ✓ Flat and waffle slab concrete buildings
- ✓ Buildings subjected to any number of vertical and lateral load cases and combinations, including automated wind and seismic loads
- ✓ Multiple spectrum load cases, with built-in input curves
- ✓ Automated transfer of vertical loads on floors to beams and walls
- ✓ P-Delta analysis with static or dynamic analysis
- ✓ Explicit panel-zone deformations
- ✓ Construction sequence loading analysis
- ✓ Multiple linear and nonlinear time history load cases in any direction Foundation/support settlement
- ✓ Large displacement analysis
- ✓ Non linear static pushover
- ✓ Buildings with base isolators and damper
- ✓ Floor modeling with rigid or semi-rigid diaphragms

The figure shown below is the floor plan of the building.

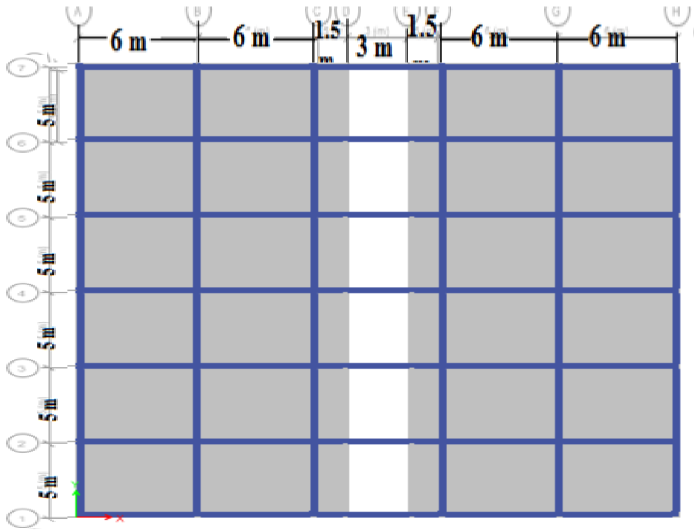


Figure 3-3 Floor views of G+6 and G+12 building

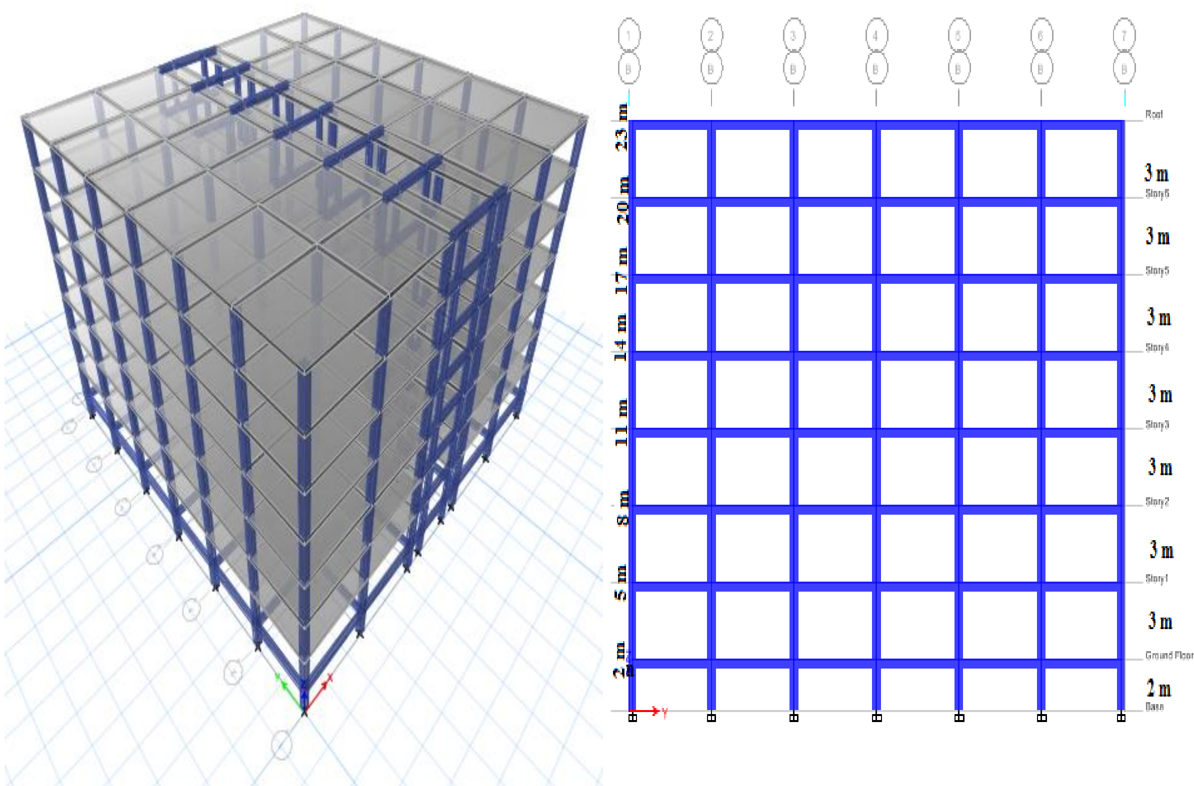


Figure 3-4 Building elevation views G+6

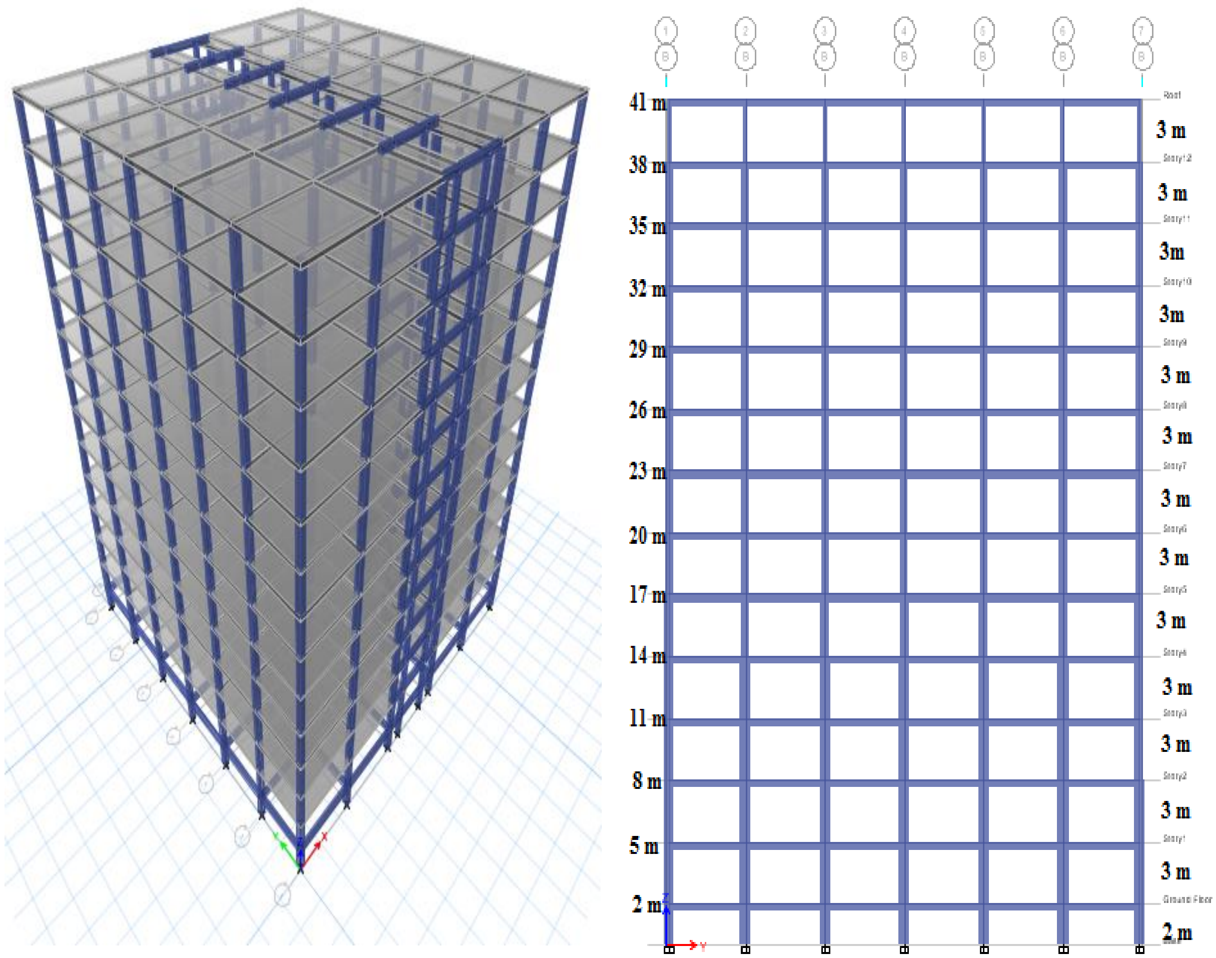


Figure 3-5 Buildings elevation view G+12

3.10 Loading on the Structure

Dead load

Table 3-2 Dead load

Dead load	Value	Unit	Thickness (m)	Load
Floor finish (terrazzo)	23	KN/m3	0.025	0.58
Cement screed	23	KN/m3	0.03	0.69
Ceiling	23	KN/m3	0.03	0.69
Total dead load				1.96 KN/m2

Live load

The live load depends on the purpose of the building. In this case it's a mixed use building so the live load is under category D according to EBCS 1-1995.

Live load for shopping area is Q_k= 5 KN/m^2

Live load for roof area is $Q_{k\,=}$ 2 KN/m^2

Seismic load

Seismic load apply in two planar models one for each main horizontal direction along the X and Y direction. For the purpose of EBCS EN 1998, national territories shall be subdivided into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant.

For most of the applications of EBCS EN 1998, the hazard is described in terms of a single parameter, i.e. the value of the reference peak ground acceleration on type A ground, a_{gR}, Additional parameters required for specific types of structures are given in the relevant parts of EBCS EN 1998.

The study area is in Hawassa which is zone 4 according to EBCS 8 Design of structure for earthquake resistance. Other data shown in the table

Table 3-3 Earthquake data

Earthquake data	Zone 4
	Soil Class C
	Important factor= 1.2
	Damping ratio = 0.05

Combination of the effects of the components of the seismic action

Horizontal components of the seismic action

1. In general the horizontal components of the seismic action shall be taken as acting simultaneously.

2. The combination of the horizontal components of the seismic action may be accounted for as follows.

   A. The structural response to each component shall be evaluated separately, using the combination rules for modal responses

   B. The maximum value of each action effect on the structure due to the two horizontal components of the seismic action may then be estimated by the square root of the sum of the squared values of the action effect due to each horizontal component.

   C. The rule B) generally gives a safe side estimate of the probable values of other action effects simultaneous with the maximum value obtained as in B). More accurate models may be used for the estimation of the probable simultaneous values of more than one action effect due to the two horizontal components of the seismic action.

3. As an alternative to b) and c) of **(2)** of this sub clause, the action effects due to the combination of the horizontal components of the seismic action may be computed using both of the two following combinations:

a. E_{Edx} *"+"* 0.30 E_{Edy}

b. 0.30 E_{Edx} *"+"* E_{Edy}

Where

"+" implies "to be combined with";

E_{Edx} represents the action effects due to the application of the seismic action along the chosen horizontal axis x of the structure;

E_{Edy} represents the action effects due to the application of the same seismic action along the orthogonal horizontal axis y of the structure.

4. If the structural system or the regularity classification of the building in elevation is different in different horizontal directions, the value of the behaviour factor q may also be different.

5. The sign of each component in the above combinations shall be taken as being the most unfavourable for the particular action effect under consideration.

Load combination

Load combinations used in the study were listed below:

For Frame

Combo1 = 1.35DL

Combo 2 = 1.35 DL + 1.5 LL

Combo 3 = DL + 0.3LL + RSx

Combo 4 = DL + 0.3LL + RSy

Combo 5 = DL + RSx

Combo 6 = DL + RSy

For Slab

Combo1 = 1.35DL

Combo 2 = 1.35 DL + 1.5 LL

Combo 3 = DL + 0.3LL+ RSx

Combo 4 = DL + 0.3LL - RSx

Combo 5 = DL + 0.3LL+ RSy

Combo 6 = DL + 0.3LL - RSy

Combo 7 = DL + RSx

Combo 8 = DL - RSx

Combo 9 = DL + RSy

Combo 10 = DL + RSy

3.11 Method of analysis

Basic representation of the seismic action according to EBCS EN 1998

3.11.1 General

1. Within the scope of EBCS EN1998 the earthquake motion at a given point on the surface is represented by an elastic ground acceleration response spectrum, henceforth called an "elastic response spectrum".

2. The shape of the elastic response spectrum is taken as being the same for the two levels of seismic action for the no-collapse requirement (ultimate limit state – design seismic action) and for the damage limitation requirement.

3. The horizontal seismic action is described by two orthogonal components assumed as being independent and represented by the same response spectrum

4. For the three components of the seismic action, one or more alternative shapes of response spectra may be adopted, depending on the seismic sources and the earthquake magnitudes generated from them.
5. When the earthquakes affecting a site are generated by widely differing sources, the possibility of using more than one shape of spectra should be considered to enable the design seismic action to be adequately represented. In such circumstances, different values of ag will normally be required for each type of spectrum and earthquake.
6. For important structures ($\gamma_I > 1$) topographic amplification effects should be taken into account

3.11.2 Horizontal elastic response spectrum

1. For the horizontal components of the seismic action, the elastic response spectrum $S_e(T)$ is defined by the following expressions.

$$0 \le T \le T_B: \quad S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)\right]$$

$$T_B \le T \le T_C: \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5$$

$$T_C \le T \le T_D: \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5\left[\frac{T_C}{T}\right]$$

$$T_D \leq T \leq 4s: \quad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5\left[\frac{T_C T_D}{T^2}\right]$$

Where

S_e(T) is the elastic response spectrum;

T is the vibration period of a linear single-degree-of-freedom system;

a_g is the design ground acceleration on type A ground ($a_g = \gamma_I . a_{gR}$);

T_B is the lower limit of the period of the constant spectral acceleration branch;

T_C is the upper limit of the period of the constant spectral acceleration branch;

T_D is the value defining the beginning of the constant displacement response range of the spectrum;

S is the soil factor;

η is the damping correction factor with a reference value of $\eta = 1$ for 5% viscous damping,

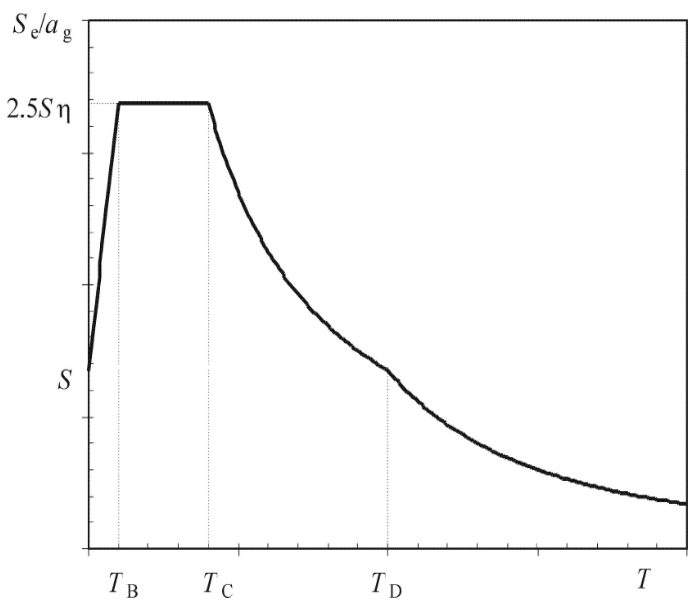


Figure 3-6 Shape of the elastic response spectrum (EBCS EN 1998-1:2013)

2. The values of the period T_B, T_C and T_D and of the soil factor S describing the shape of the elastic response spectrum depend upon the ground type.

If deep geology is not accounted, the recommended choice is the use of two types of spectra: Type 1 and Type 2. If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, M_s, not greater than 5.5, it is recommended that the Type 2 spectrum is adopted. For the five ground types A, B, C, D and E the recommended values of the parameters S, T_B, T_C and T_D are given in

Table 3.2 for the Type 1 Spectrum and in Table 3.3 for the Type 2 Spectrum. Figure 3.2 and Figure 3.3 show the shapes of the recommended Type 1 and Type 2 spectra, respectively

Table 3-4 Values of the parameters describing the recommended Type 1 elastic response spectra (EBCS EN 1998-1:2013)

Ground type	S	T_B(s)	T_C(s)	T_D(s)
A	1.0	0.05	0.25	1.2
B	1.35	0.05	0.25	1.2
C	1.5	0.10	0.25	1.2
D	1.8	0.10	0.30	1.2
E	1.6	0.05	0.25	1.2

Table 3-5 Values of the parameters describing the recommended Type 2 elastic response spectra (EBCS EN 1998-1:2013)

Ground type	S	T_B(s)	T_C(s)	T_D(s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.4	0.15	0.5	2.0

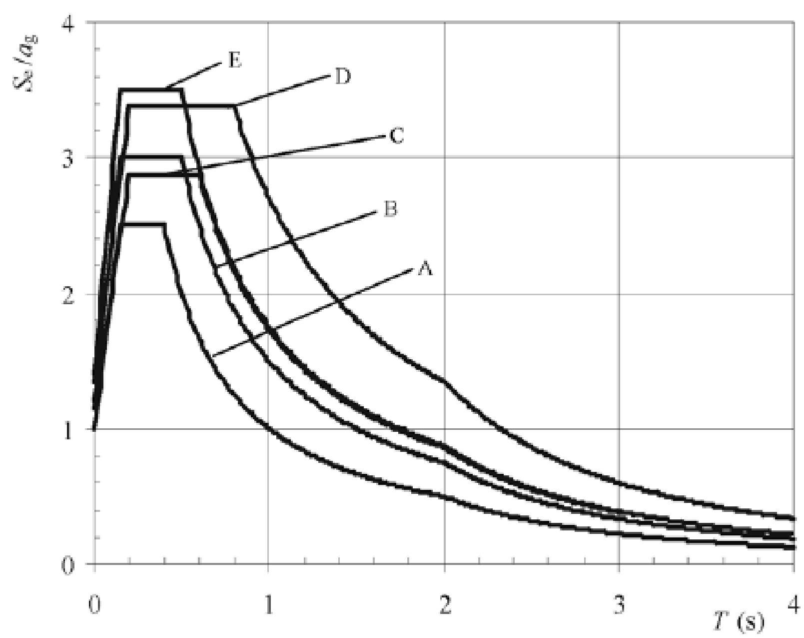


Figure 3-7 Recommended Type 1 elastic response spectra for ground types A to E (5% damping) (EBCS EN 1998-1:2013)

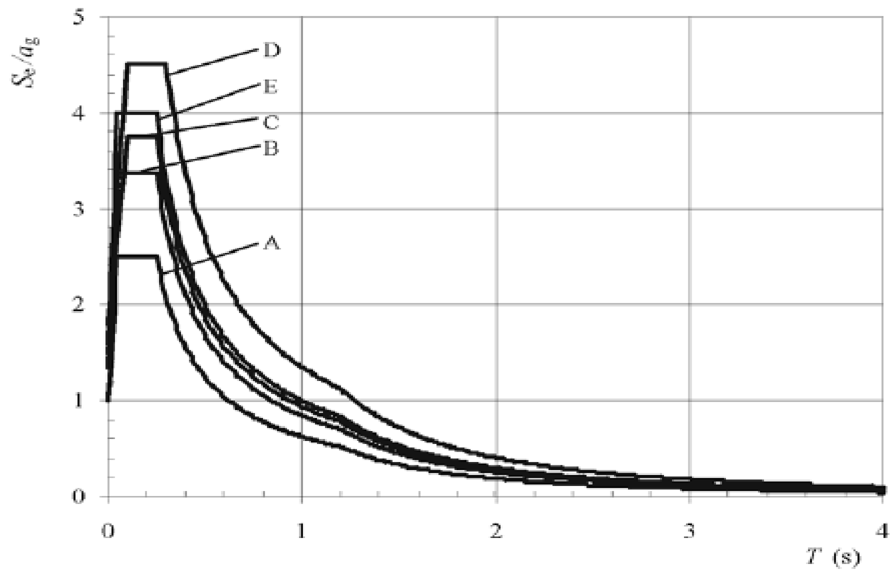


Figure 3-8 Recommended Type 2 elastic response spectra for ground types A to E (5% damping) (EBCS EN 1998-1:2013)

3. The value of the damping correction factor η may be determined by the expression:

$$\eta = \sqrt{10/(5+\xi)} \geq 0.55$$

Where

ξ is the viscous damping ratio of the structure, expressed as a percentage.

4. If for special cases a viscous damping ratio different from 5% is to be used, this value is given in the relevant Part of EBCS EN 1998.

5. The elastic displacement response spectrum, S_{De}(T), shall be obtained by direct transformation of the elastic acceleration response spectrum, S_e(T), using the following expression:

$$S_{De}(T) = S_e(T)\left[\frac{T}{2\pi}\right]^2$$

6. Expression (3.7) should normally be applied for vibration periods not exceeding 4.0 s. For structures with vibration periods longer than 4.0 s, a more complete definition of the elastic displacement spectrum is possible.

Ductility class

Ductility is defined as the ability of the structure or parts of it to sustain large deformations beyond the yield point without breaking. In the field of applied seismic engineering, the ductility is expressed in terms of demand and availability. The ductility demand is the maximum ductility level that the structure can reach during a seismic action, which is a function of both the structure and the earthquake. The available ductility is the maximum ductility that the structure can sustain without damage and it is an ability of the structure. So, a great part of the standard aims to ensure the existence of a stable and trustworthy model of absorbing energy in predefined critical areas that restrict no inertial loading that appears in other parts of the structure. The designing rules achieve to develop the wanted ductility in these critical areas, with the benefits of the reduced no inertial loading, that are received by more strict construction arrangements and designing rules (Elghazouli, 2009). In the case of reinforced concrete structures, this behavior can be achieved only through the reduction of capacity through delay circles from suitable construction arrangements of such critical zones to ensure stable plastic behavior that it is not undermined by brittle modes of failure such as concrete shearing, concrete crushing, or reinforcement bending.

This leads to the adaptation of three levels of absorbing energy:

- Low (Ductility class low (DCL)) that does not require delayed ductility and the resistance to seismic loading is achieved through the capacity of the structure (q=1.5).
- Medium (DCM) that allows high levels of ductility and there are responsive design demands (1.5
- High (DCH) that allows even higher levels of ductility and there are responsive strict and complicated design demands (q>4).

The Ductility Class Low (DCL) predicts the design of the members with the seismic loading that occurs from the design seismic action (of the 475 years) with a behavior factor of q=1.5 and reinforcement calculations like in the case of usual, non-seismic actions, with some material restrictions (the minimum concrete quality that can be used is C16/20 etc). EC8 suggests that the design with DCL should be limited only in areas with low earthquake activity (i.e. in areas with maximum ground design acceleration less than 0.10g). In areas of medium or high earthquake activity, the buildings designed with DCL are not supposed to be financially efficient. In addition, because of the low ductility, it is likely that they would not have a sufficient security level against an earthquake bigger than the design seismic action.

In the two higher ductility classes (DCM and DCH) the design ensures the existence of a stable and trustworthy model of absorbing energy in predefined critical areas and uses a behavior factor $q>1.5$. These two ductility classes differ in

- Geometrical restrictions and materials (steel strain)
- The design loadings
- The rules of capacity design and local ductility

If the design forces are calculated according to ductile response demand, then it is necessary to ensure that the structure will fail in a ductile way. This demand is the main idea of the capacity design.

The capacity design contents:

- Insurance of formation of plastic hinges on the beams and not on the columns.
- Providing of sufficient shear reinforcement (dense steel stirrups).
- Insurance that the steel objects fail far away from the connection points.
- Avoidance of big structural irregularities.
- Insurance that the tensile capacity will exceed the shear capacity.

Behavior factors for horizontal seismic actions

The behaviour factor q

$q = q_o k_w \geq 1.5$

Where

q_o is the basic value of the behavior factor, dependent on the type of the structural system and on its regularity in elevation

k_w is the factor reflecting the prevailing failure mode in structural systems with walls

For buildings that are regular in elevation, the basic values of *qo* for the various structural types are given in Table 5.1. EBCS EN 1998-1-1:2013

Table 3-6 Basic value of the behavior factor, q_o, for systems regular in elevation (EBCS EN 1998-1:2013**)**

STRUCTURAL TYPE	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_u/\alpha_1$	$4.5\alpha_u/\alpha_1$
Uncoupled wall system	3.0	$4.0\alpha u/\alpha_1$
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

α_l and α_u are defined as follows:

α_1 is the value by which the horizontal seismic design action is multiplied in order to first reach the flexural resistance in any member in the structure, while all other design actions remain constant;

α_u is the value by which the horizontal seismic design action is multiplied, in order to form plastic hinges in a number of sections sufficient for the development of overall structural instability, while all other design actions remain constant. The factor α_u may be obtained from a nonlinear static (pushover) global analysis.

When the multiplication factor α_u/α_1 has not been evaluated through an explicit calculation, for buildings which are regular in plan the following approximate values of α_u/α_1 may be used.

a) Frames or frame-equivalent dual systems.

- One-storey buildings: $\alpha u/\alpha 1=1.1$;
- multistorey, one-bay frames: $\alpha u/\alpha 1=1.2$;
- multistorey, multi-bay frames or frame-equivalent dual structures: $\alpha u/\alpha 1=1.3$.

The factor k_w reflecting the prevailing failure mode in structural systems with walls shall be taken as follows:

$$k_w = \begin{cases} 1.00, \text{ for frame and frame-equivalentdual systems} \\ (1+\alpha_0)/3 \leq 1, \text{ but not less than 0.5, for wall-equivalent and torsionally} \\ \quad \text{flexible systems} \end{cases}$$

Where

α_o is the prevailing aspect ratio of the walls of the structural system.

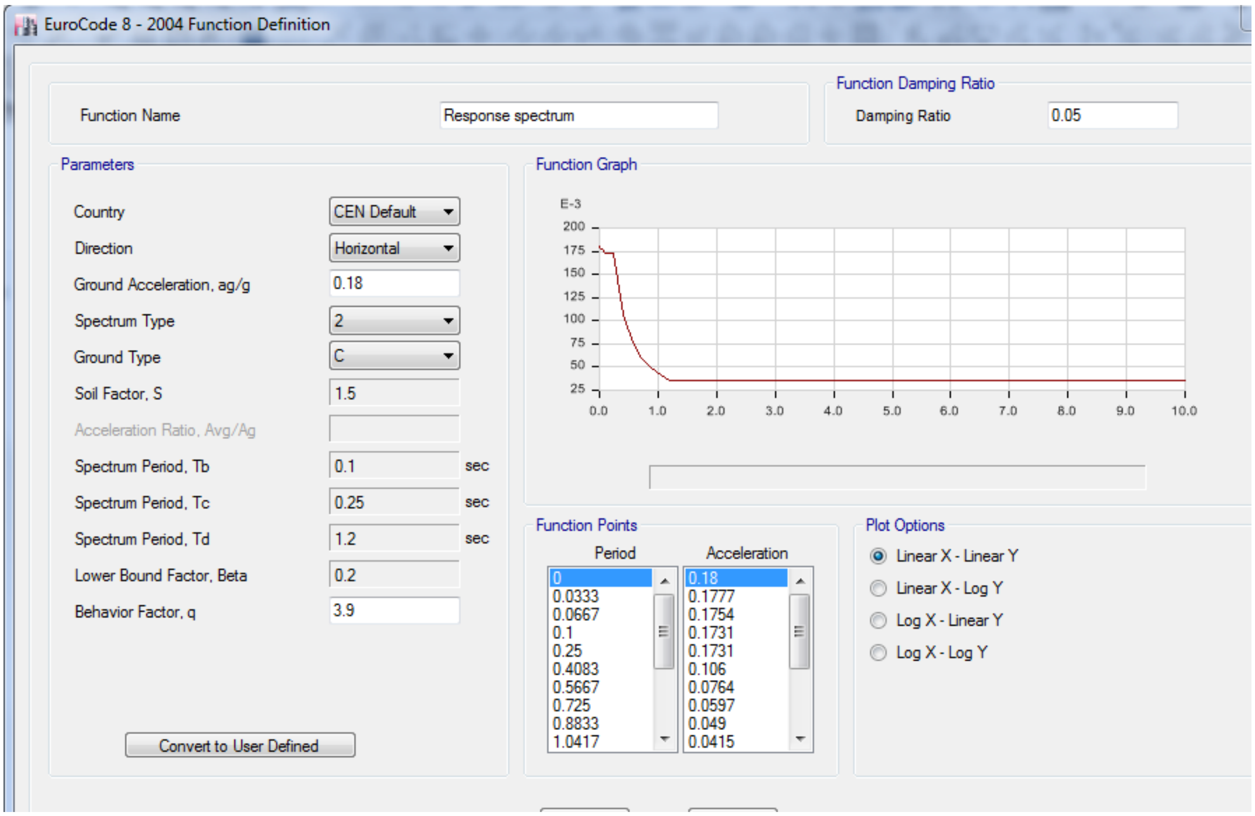
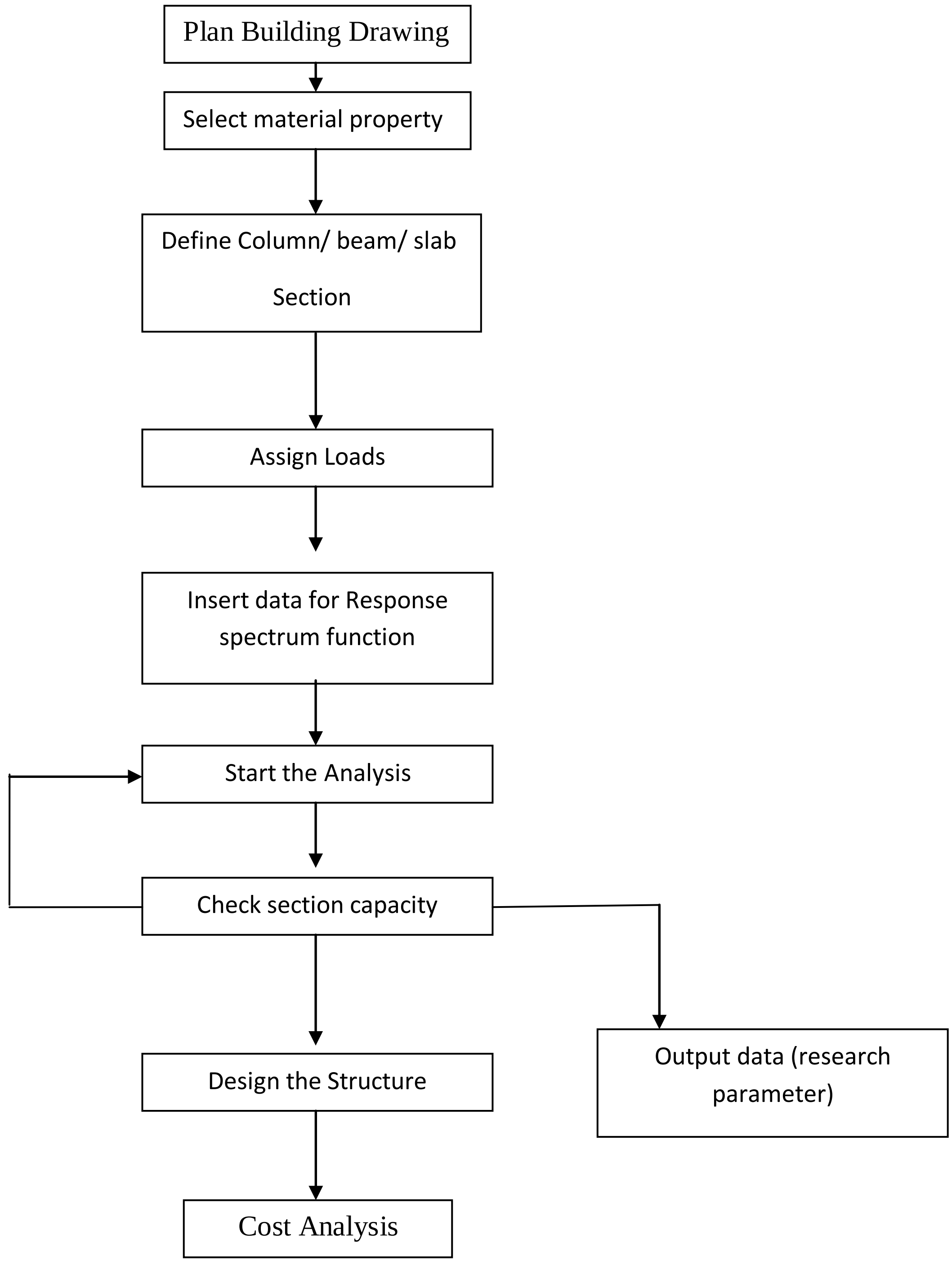


Figure 3-9 Response spectrum function

3.12 Flow Chart of ETABS analysis



3.13 Validation

The validity of the proposed analysis and modeling is checked through different software. That is ETABS 2016 and SAP2000 V14. ETABS 2016 is much simpler for user and can also design and analyze different slab system. The figure below shows analysis conducted on four model structure that is Flat slab without drop panel and conventional slab for both G+6 and G+12 building. The comparison showed a good agreement between ETABS 2016 and SAP2000 V14 analysis result.

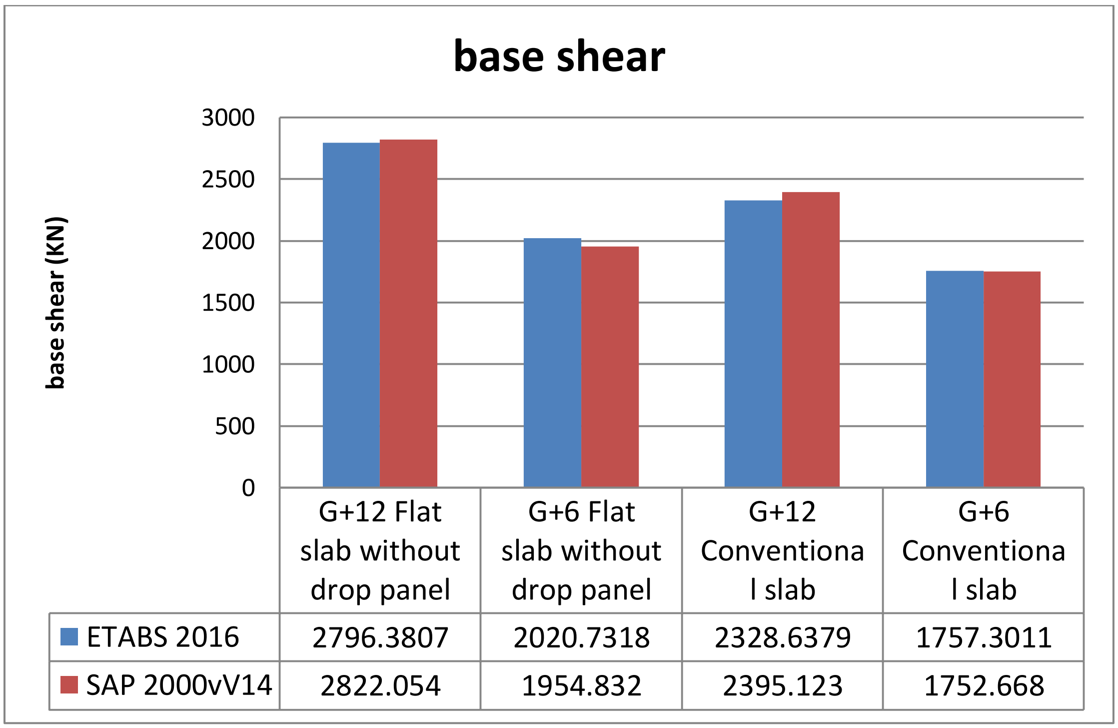


Figure 3-10 Comparison showed between ETABS 2016 and SAP2000 v14

The validation is compared for four modeling out of eight models, this is due to the drawback of SAP2000 v14 software to model and analyze waffle slab and flat slab with drop panel.

CHAPTER FOUR

MODELING, RESULT AND DISCUSSIONS

4.1 General

Dynamic analysis for conventional slab, waffle, flat slab with drop panel and flat slab without drop panel was done by using response spectrum analysis for earthquake zone 4 as per EBCS. The effect of height on these building is evaluated. The structure model using ETABS 2016 software with eight numbers of model for G+6 and G+12.

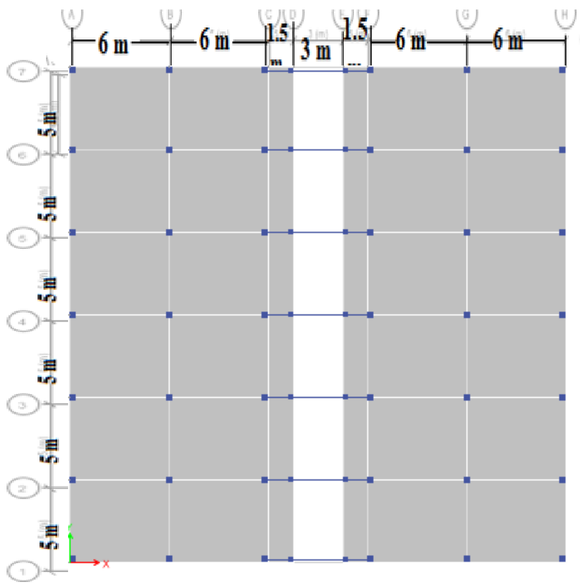
In the modeling the vertical structure that is the column is kept the same in section size for all the modeling this helps clearly too see the difference in the behavior of each slab and to compare the parameter like of lateral displacement, storey drift, base shear, storey shear and time period.

In this study a G+6 and G+12 building with a flat slab, flat slab with drop panel, waffle slab and Conventional RCC slab analyzed to determine its dynamic capacity. The geometry of the building is a square with a dimension of 30m X 30m and an opening at the middle for stair case, lift and light. The typical storey height is 3m.

Table 4-1 Structural layout of a building

Number of storey	G+6	G+12
Storey height	3 m	3 m
Bottom story (foundation)	2m	2m
Column	0.5 m x 0.5 m,0.4m x 0.4m	0.5 m x 0.5 m 0.6m x 0.6m
Beam	0.4 m x 0.3 m	0.4 m x 0.3 m
Thickness of flat slab without drop	270 mm	270 mm
Thickness of flat slab with drop	210 mm	210 mm
Size of drop	2 m x 2 m	2 m x 2 m
Thickness of Waffle slab	280 mm	280 mm
Thickness of Conventional slab	190 mm	190 mm
Grade of concrete	C-30	C-30
Grade of steel	Fe 400	Fe 400
Restraints	Fixed support	Fixed support

4.2 Modeling



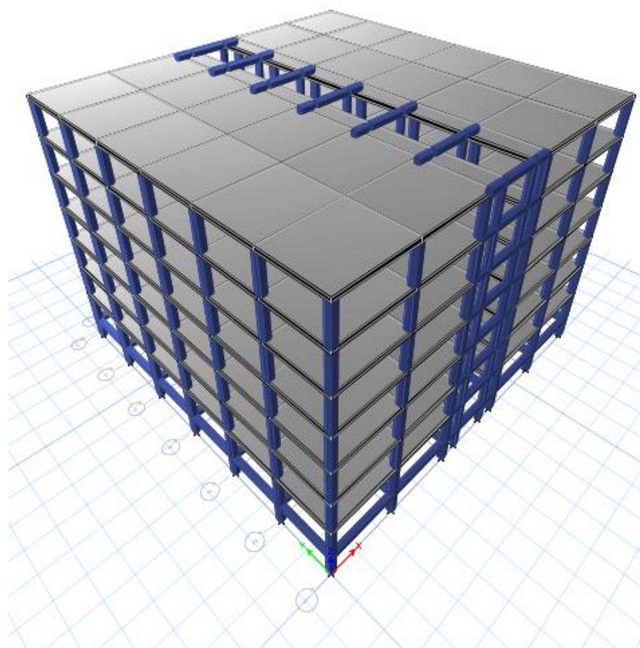
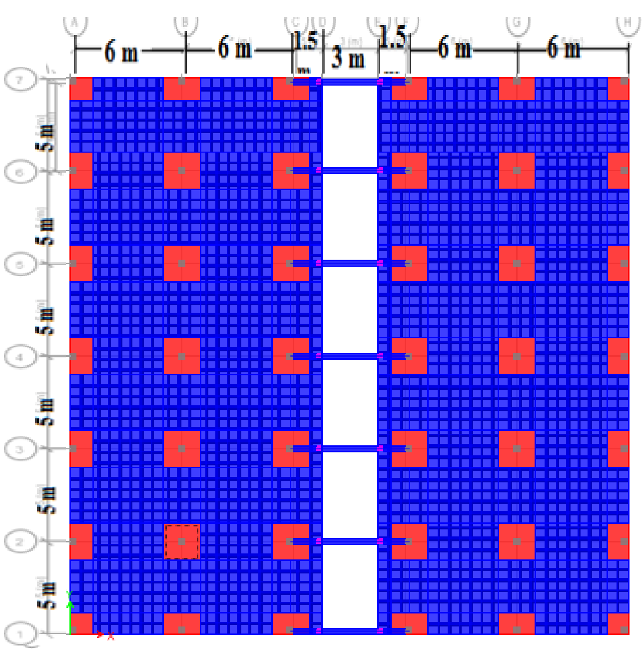


Figure 4-1 Flat slabs without drop panel G+ 6 models



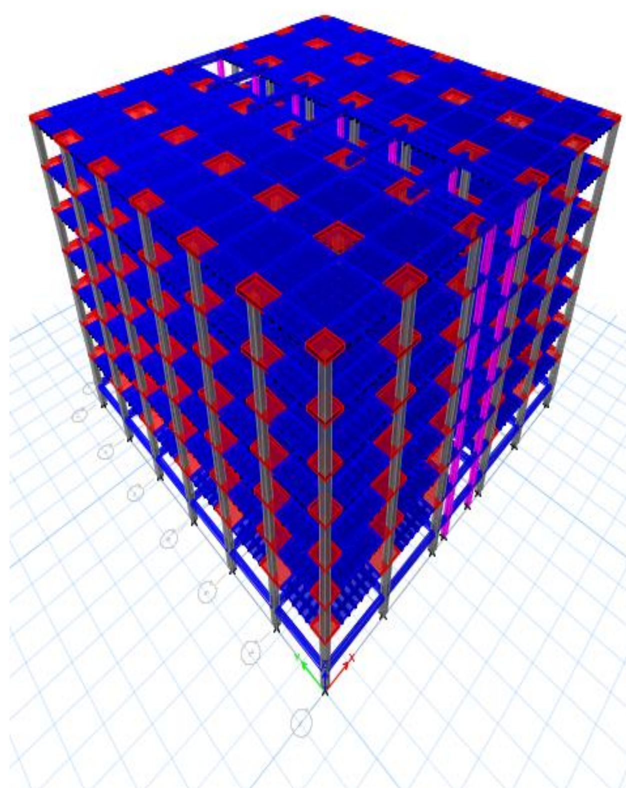
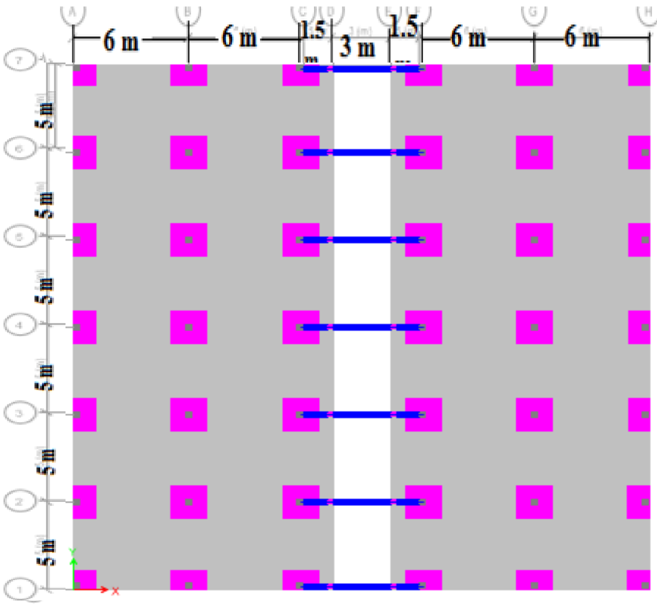


Figure 4-2 Waffle slab G+6 model



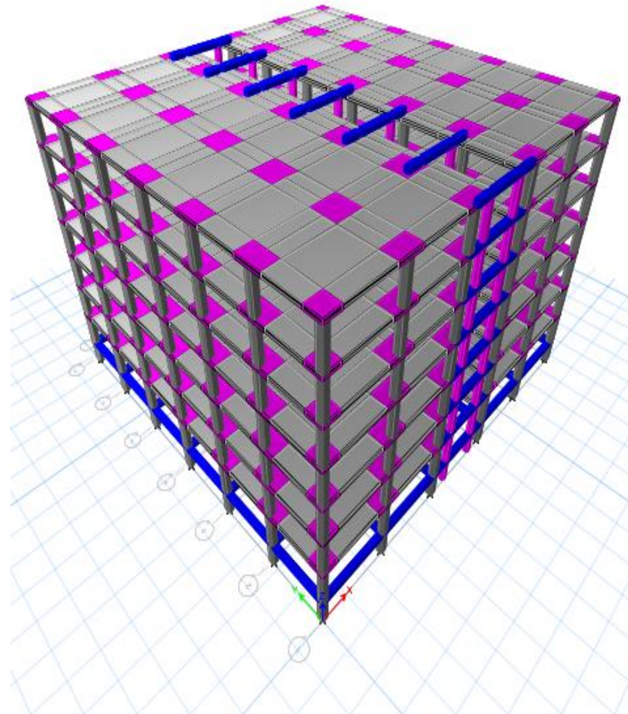
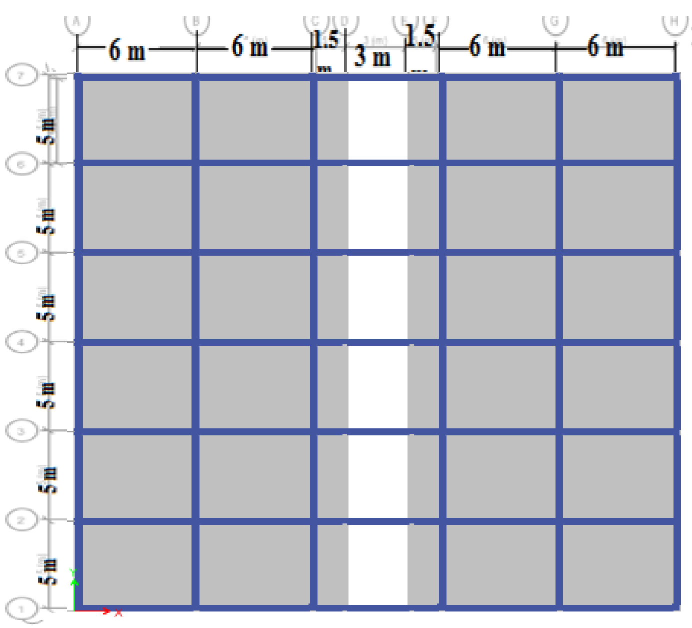


Figure 4-3 Flat slab with drop panel G+ 6 models



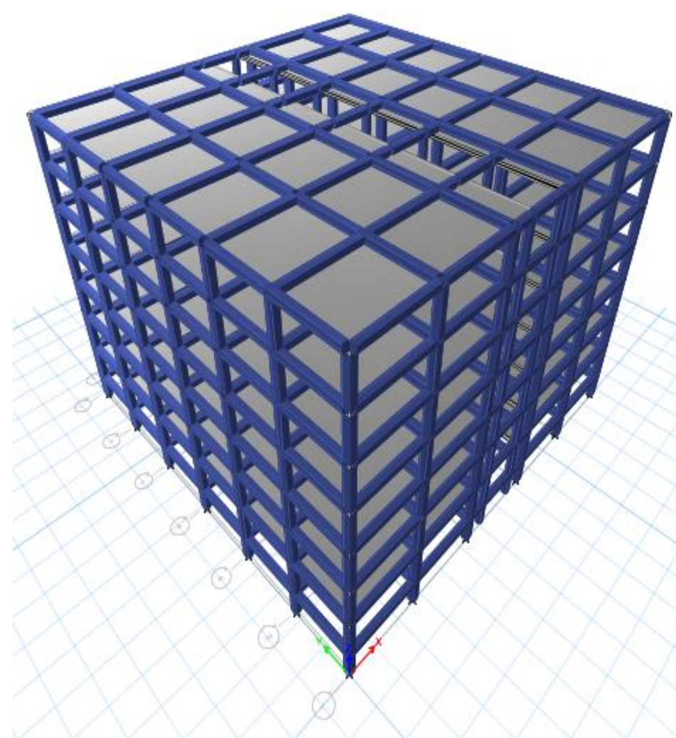


Figure 4-4 Conventional beam slab G+6 mode

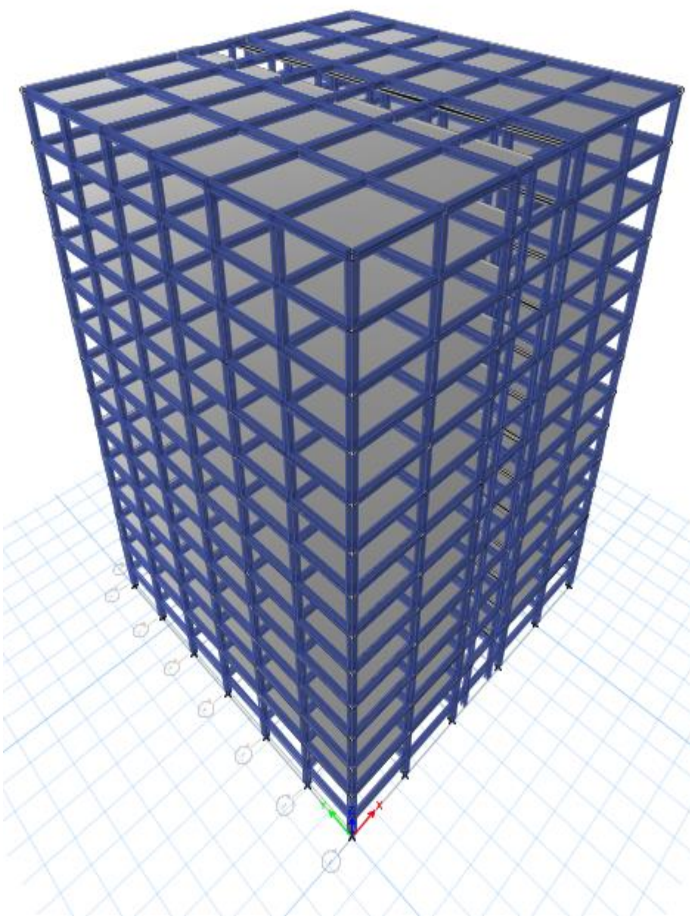


Figure 4-5 Conventional beam slab G+12 model

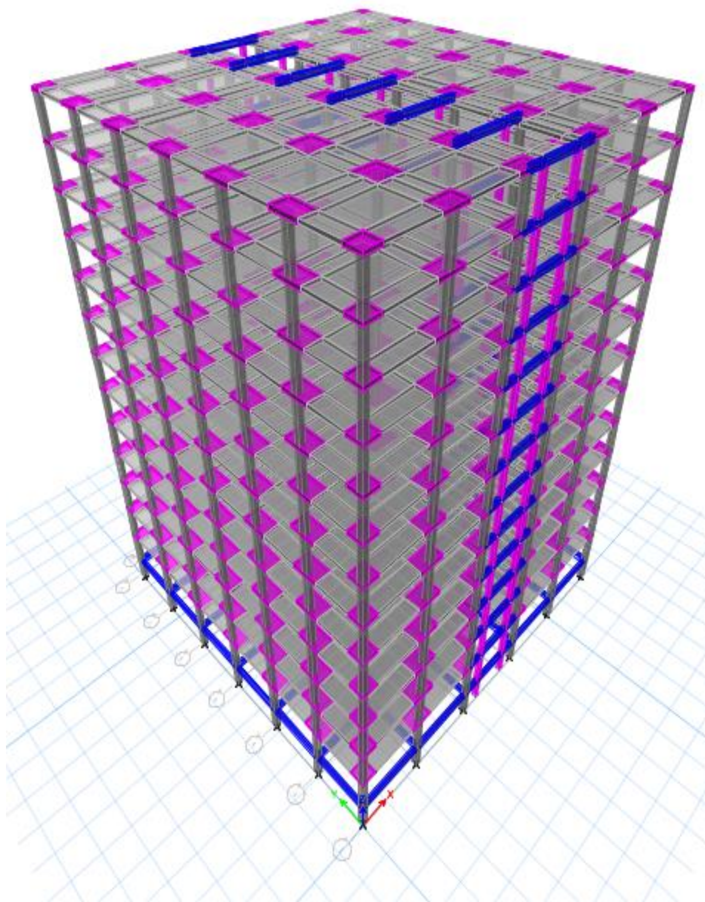


Figure 4-6 Flat slabs with drop panel G+ 12 models

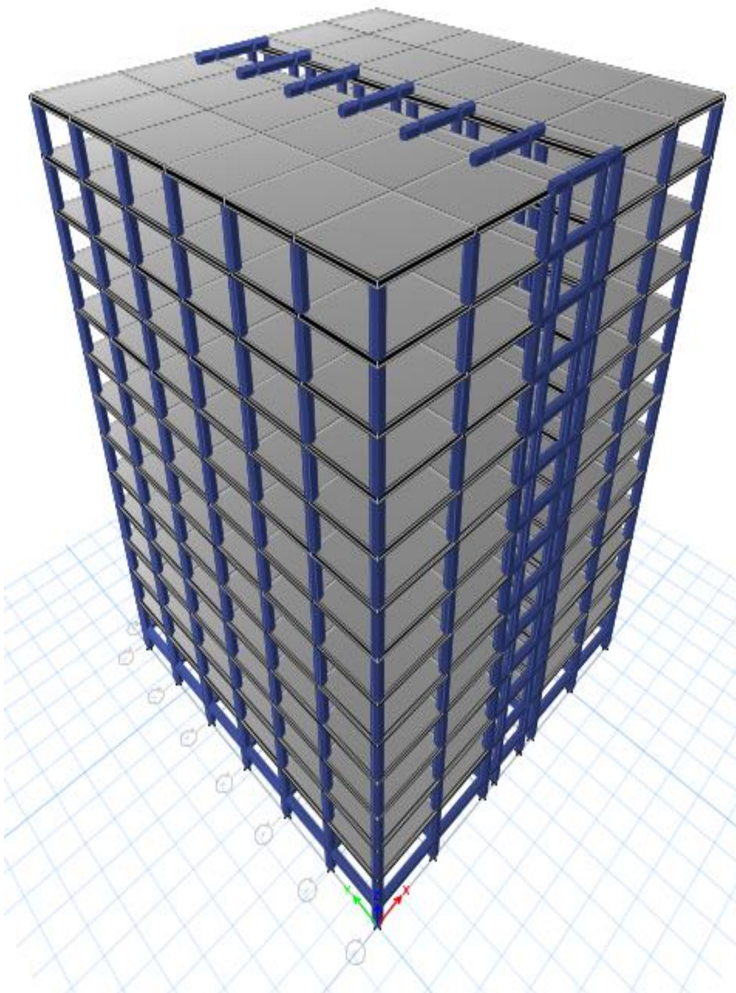


Figure 4-7 Flat slabs without drop panel model G+12

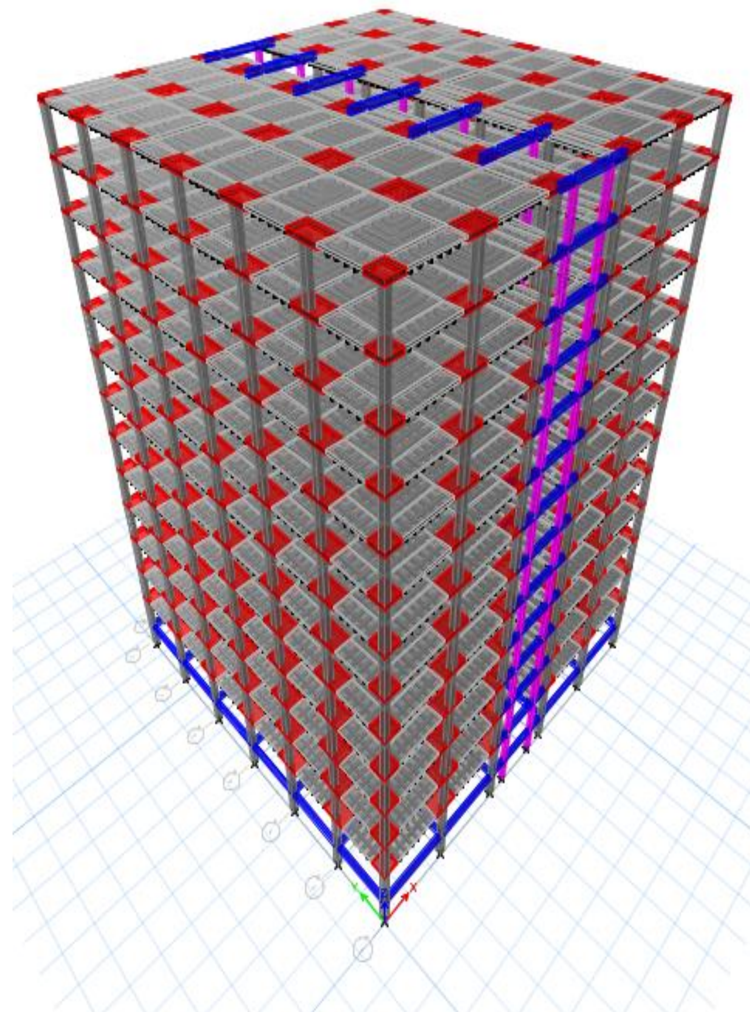


Figure 4-8 Waffle slab model G+12 model

4.3 Result from the analysis ETABS

There is significant change in seismic parameters like storey displacement, storey drift, storey shear, time period and base shear is noticed and discussed below.

4.3.1 Storey displacement

Storey displacement is important when structures are subjected to lateral loads like earthquake and wind loads. Displacement depends on height of structure and slenderness of the structure because structures are more vulnerable as height of building increases by becoming more flexible to lateral loads.

Lateral displacement of a building increases as building height increase as shown in figure 4.9. Flat slab without drop panel shows higher story displacement compares to other slab system. As shown from table 4.2 the value of displacement of flat slab without drop panel is about 6.13% higher compare to flat Slab with drop panel, 26.48% higher compare to Conventional Slab and 38.64% compare to Waffle Slab.

Table 4-2 Story displacement along X- direction G + 6

Slab Type			Flat without drop panel	Flat with drop panel	Conventional	Waffle
Story	**Elevation**	**Location**	**X-Dir**	**X-Dir**	**X-Dir**	**X-Dir**
	m		mm	mm	mm	mm
Roof	23	Top	25.86	24.369	20.445	18.652
Story6	20	Top	24.026	22.523	19.065	17.234
Story5	17	Top	21.465	20.023	17.097	15.322
Story4	14	Top	18.211	16.898	14.578	12.955
Story3	11	Top	14.363	13.238	11.579	10.196
Story2	8	Top	10.046	9.16	8.167	7.109
Story1	5	Top	5.464	4.881	4.482	3.847
Ground Floor	2	Top	1.259	1.094	1.034	0.966
Base	0	Top	0	0	0	0

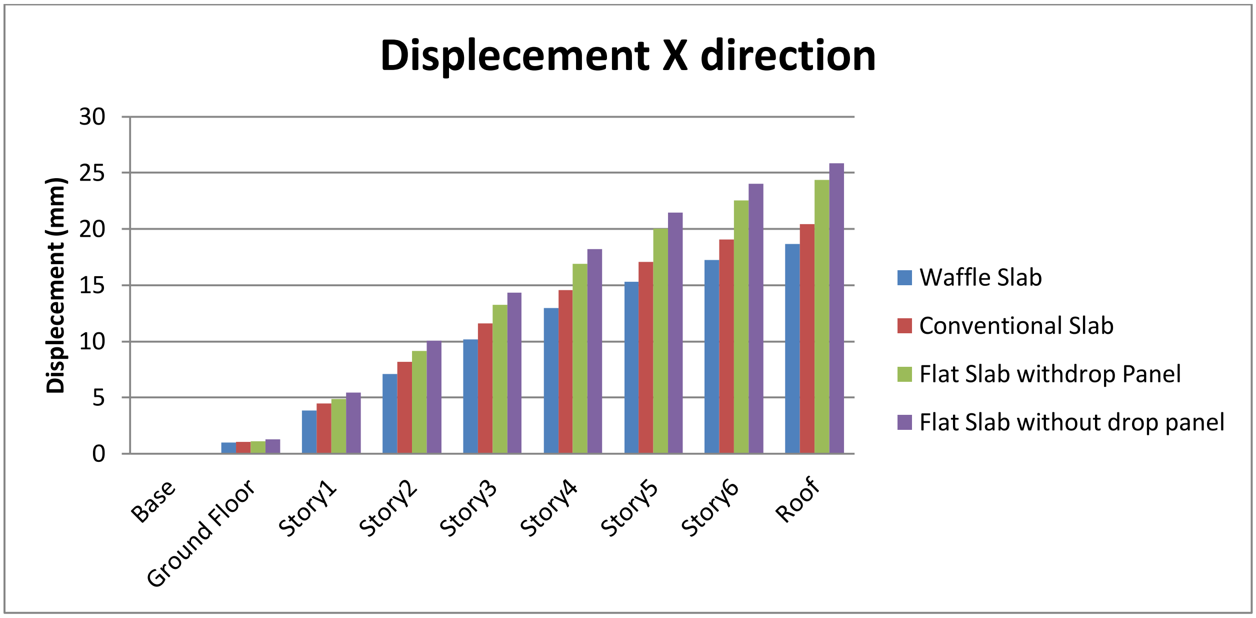


Figure 4-9 Displacement of G+ 6 along X direction

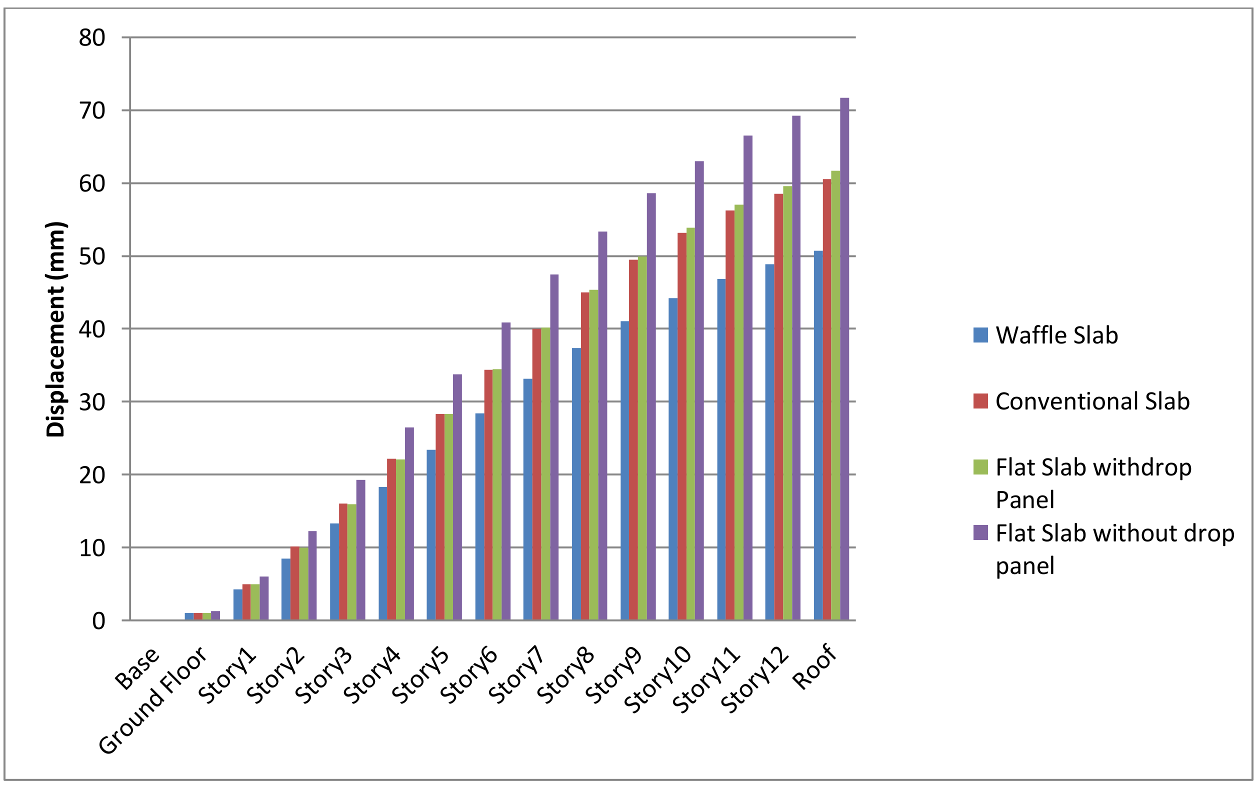


Figure 4-10 Displacement of G+ 12 along X direction

4.3.2 Storey drift

Story drift is the difference of displacements between two consecutive stories divided by the height of that story. Story displacement is the absolute value of displacement of the storey under action of the lateral forces.

The importance of story drift is in design of partitions/ curtain walls. They must be so designed as to accommodate the storey drift, else they will crack. For structural glazing/ brick walls on external surfaces, this could prove catastrophic

Storey drift follows a parabolic path along storey height. As shown in Figure 4.11 the maximum drift shows at story two. After storey two, storey drift decreases as the height of building increases. The storey drift of flat slab without drop panel is about 7.019% higher compare to flat Slab with drop panel, 24.19% higher compare to Conventional Slab and 39.61% compare to Waffle Slab.

Table 4-3 Story drift along X- direction G + 6

Slab Type			Flat without drop panel	Flat with drop panel	Convention al	Waffle
Story	**Elevation**	**Location**	**X-Dir**	**X-Dir**	**X-Dir**	**X-Dir**
	m					
Roof	23	Top	0.000719	0.000726	0.000567	0.000568
Story6	20	Top	0.00098	0.000963	0.000786	0.000757
Story5	17	Top	0.001193	0.001155	0.000955	0.000898
Story4	14	Top	0.00136	0.001299	0.001081	0.000995
Story3	11	Top	0.001482	0.001402	0.001179	0.001067
Story2	8	Top	0.00154	0.001439	0.00124	0.001103
Story1	5	Top	0.001419	0.001277	0.001158	0.000999
Ground Floor	2	Top	0.000629	0.000547	0.000517	0.000483
Base	0	Top	0	0	0	0

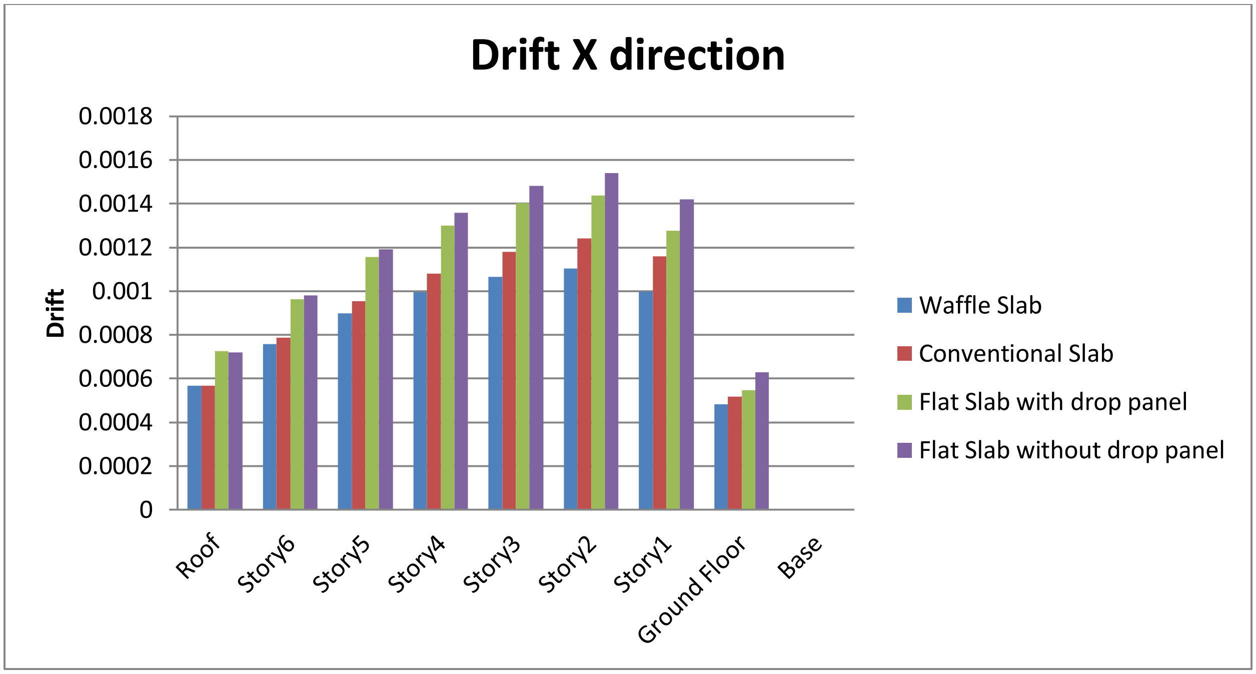


Figure 4-11 Storey drift of G+ 6 along X direction

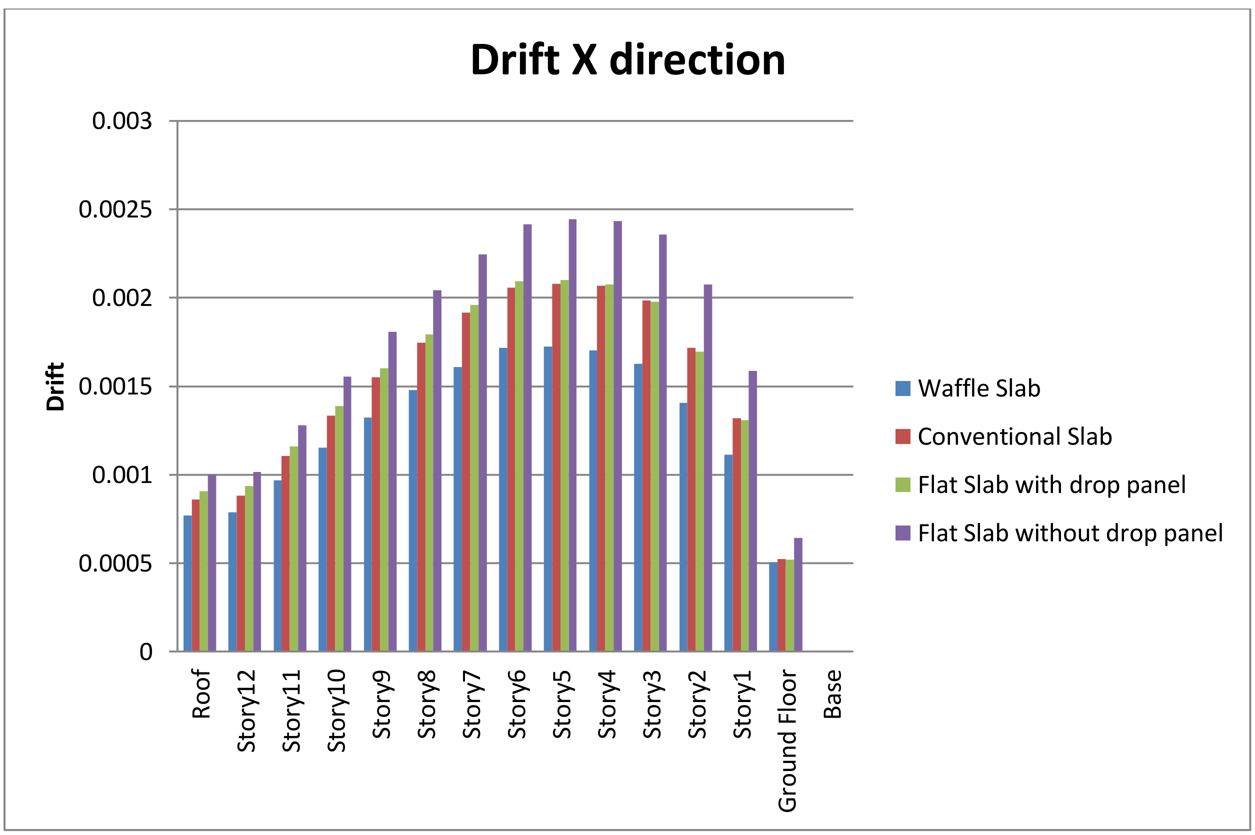


Figure 4-12 Storey drift of G+ 12 along X direction

4.3.3 Storey shear and base shear

Storey shear is the lateral force acting on a storey due to the forces such as seismic and wind force. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.

Base shear is an estimate of the maximum lateral force on the base of the structure due to seismic activity. Base shear depend on:-

- Soil condition of the site
- Magnitude of the Earthquake
- Behavior factor
- Weight of the structure

The storey shear is maximum at ground level and keeps on decreasing towards the top storey of the structure. As height of the building increases the value of storey shear and base shear also increases. The storey shear of flat slab without drop panel is about 23.93% higher compare to flat Slab with drop panel, 22.38% higher compare to Conventional Slab and 46.71% compare to Waffle Slab.

Table 4-4 Story Shear along X- direction G + 6

Slab Type			Flat without drop panel	Flat with drop panel	Conventional	Waffle
Story	**Elevation**	**Location**	**X-Dir**	**X-Dir**	**X-Dir**	**X-Dir**
	m		kN	kN	kN	kN
Roof	23	Top	638.2857	555.8983	546.287	450.0826
Story6	20	Top	1009.661	869.8726	869.4611	718.227
Story5	17	Top	1260.755	1071.045	1066.99	872.9604
Story4	14	Top	1476.691	1239.047	1220.945	986.2872
Story3	11	Top	1665.176	1390.961	1364.488	1099.198
Story2	8	Top	1842.834	1545.199	1520.185	1232.894
Story1	5	Top	2024.058	1706.174	1684.185	1371.971
Ground Floor	2	Top	2041.918	1724.919	1703.252	1391.809
Base	0	Top	0	0	0	0

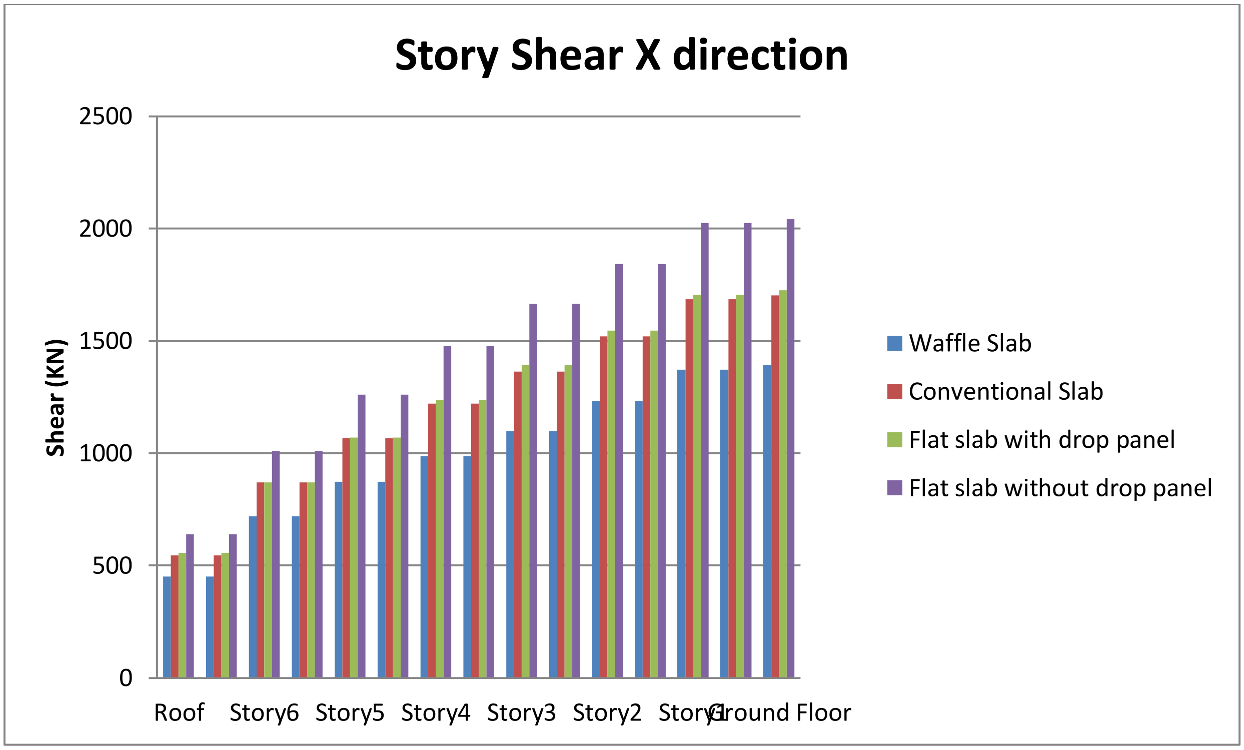


Figure 4-13 Storey shear of G+ 6 along X direction

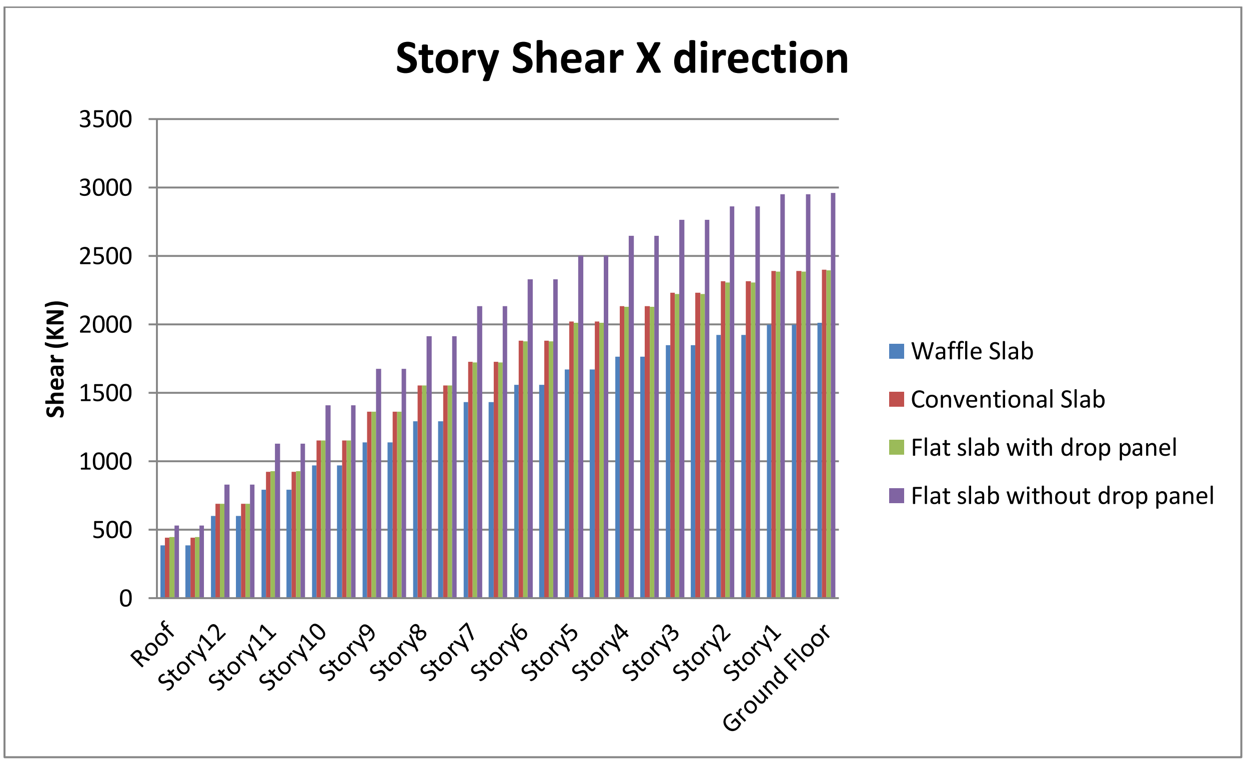


Figure 4-14 Storey shear of G+12 along X direction

❖ Base Shear

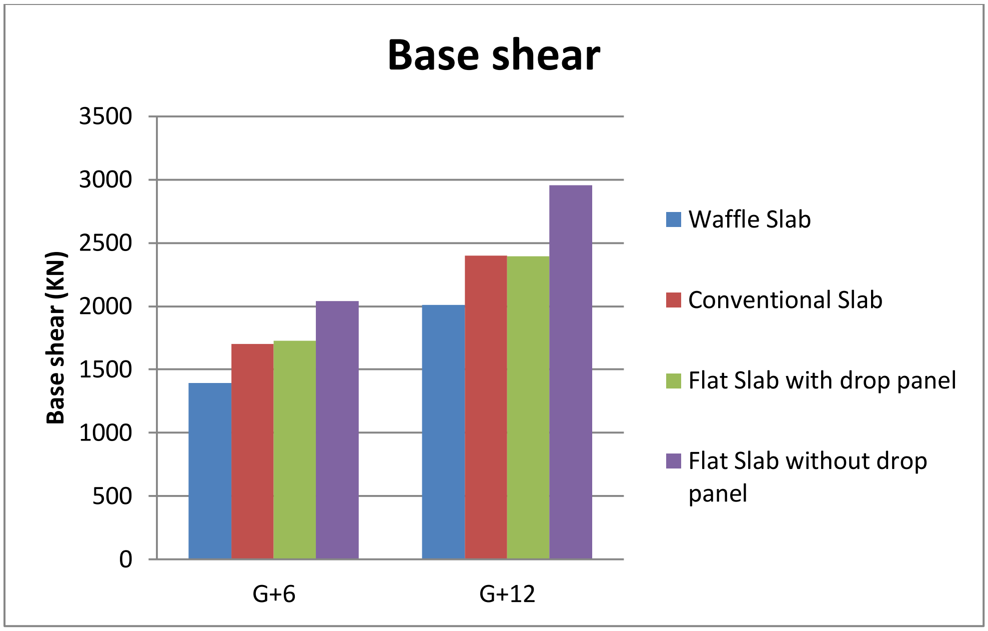


Figure 4-15 Base shear

4.3.4 Axial force

Axial force is vertical force acting on a member as a compression or tension. The total axial force on the base of the building helps to design the foundation and to determine the capacity of the soil needed to support the building.

As shown from table 4-5 of G+12 the axial load shows flat slab without drop panel is about 18.98% higher compare to flat Slab with drop panel, 14.41% higher compare to Conventional Slab and 34.65% compare to Waffle Slab.

Table 4-5 Total Axial Load At The Base

Total Axial load At the base				
	Axial load			
	G+6		G+12	
Flat Slab without drop panel	4001.6149	KN	8194.27	KN
Flat Slab with drop panel	3721.2977	KN	6886.964	KN
Conventional Slab	3472.8573	KN	7161.892	KN
Waffle Slab	3170.0064	KN	6085.46	KN

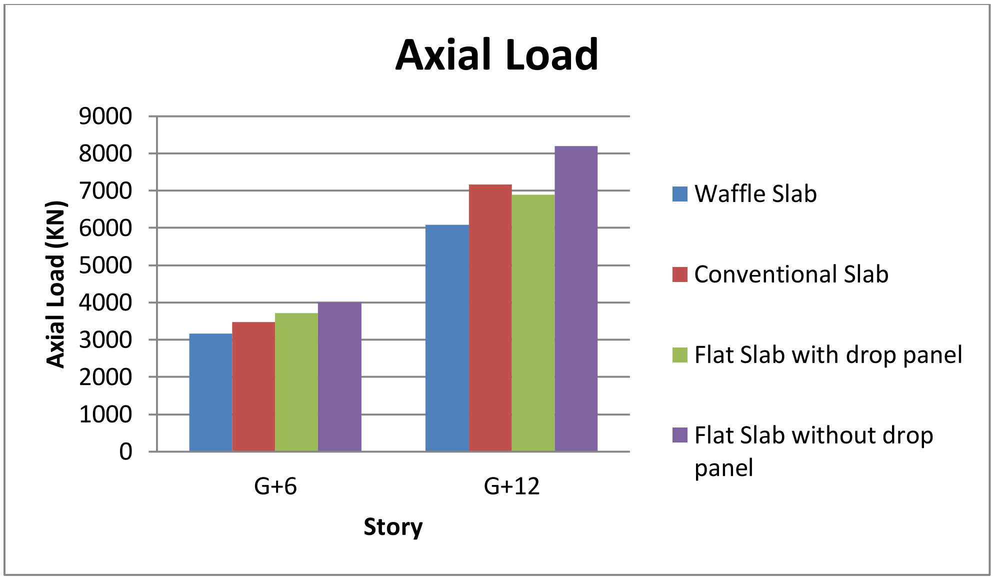


Figure 4-16 Axial load at the base

4.2.5. Time period

Time required for the undamped system to complete one cycle of free vibration is the natural time period of vibration of system in unit of second. According to EBCS EN the minimum number k of modes to be taken into account in a spatial analysis should satisfy both the two following conditions:

$k \geq 3 \cdot \sqrt{n}$ => $24 \geq 10.4$ And $T_k \leq 0.20$ s

The time period of flat slab without drop panel is about 0.8% higher compare to flat Slab with drop panel, 16.38% higher compare to Conventional Slab and 15.29% compare to Waffle Slab.

Table 4-6 Modal Periods of G+6 building

		Flat Slab without drop panel	Flat Slab with drop panel	Conventional Slab	Waffle Slab
Case	**Mode**	**Period**	**Period**	**Period**	**Period**
		sec	sec	sec	sec
Modal	1	1.598	1.585	1.373	1.386
Modal	2	1.375	1.342	1.206	1.189
Modal	3	1.341	1.3	1.178	1.139
Modal	4	0.48	0.471	0.418	0.414
Modal	5	0.416	0.402	0.371	0.358

Modal	6	0.41	0.394	0.362	0.347
Modal	7	0.249	0.24	0.219	0.212
Modal	8	0.217	0.207	0.197	0.184
Modal	9	0.216	0.205	0.192	0.181
Modal	10	0.151	0.143	0.135	0.127
Modal	11	0.136	0.129	0.125	0.114
Modal	12	0.134	0.126	0.12	0.113
Modal	13	0.1	0.094	0.091	0.084
Modal	14	0.094	0.088	0.086	0.079
Modal	15	0.091	0.085	0.082	0.076
Modal	16	0.073	0.068	0.066	0.061
Modal	17	0.07	0.065	0.065	0.059
Modal	18	0.067	0.062	0.061	0.056
Modal	19	0.058	0.054	0.053	0.048
Modal	20	0.058	0.053	0.053	0.048
Modal	21	0.054	0.049	0.05	0.045
Modal	22	0.032	0.032	0.032	0.032
Modal	23	0.032	0.032	0.031	0.032
Modal	24	0.03	0.03	0.03	0.03

❖ Time period

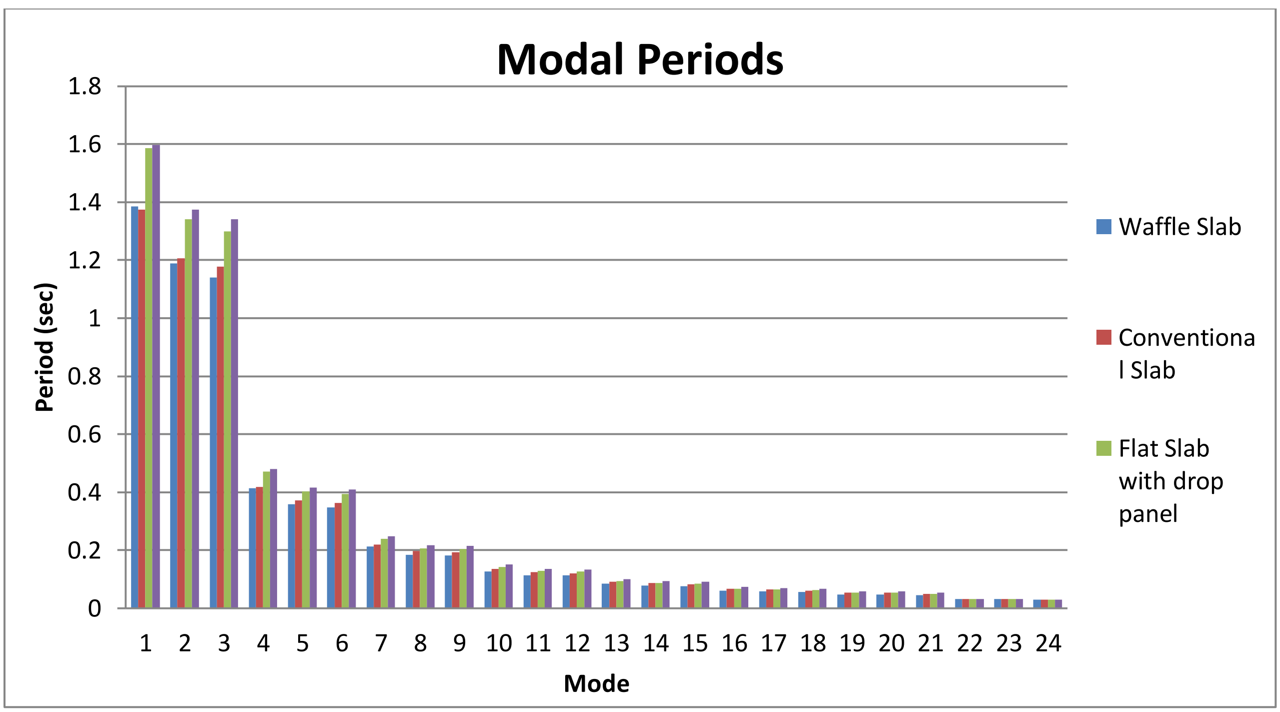


Figure 4-17 Mode number and time period G+6

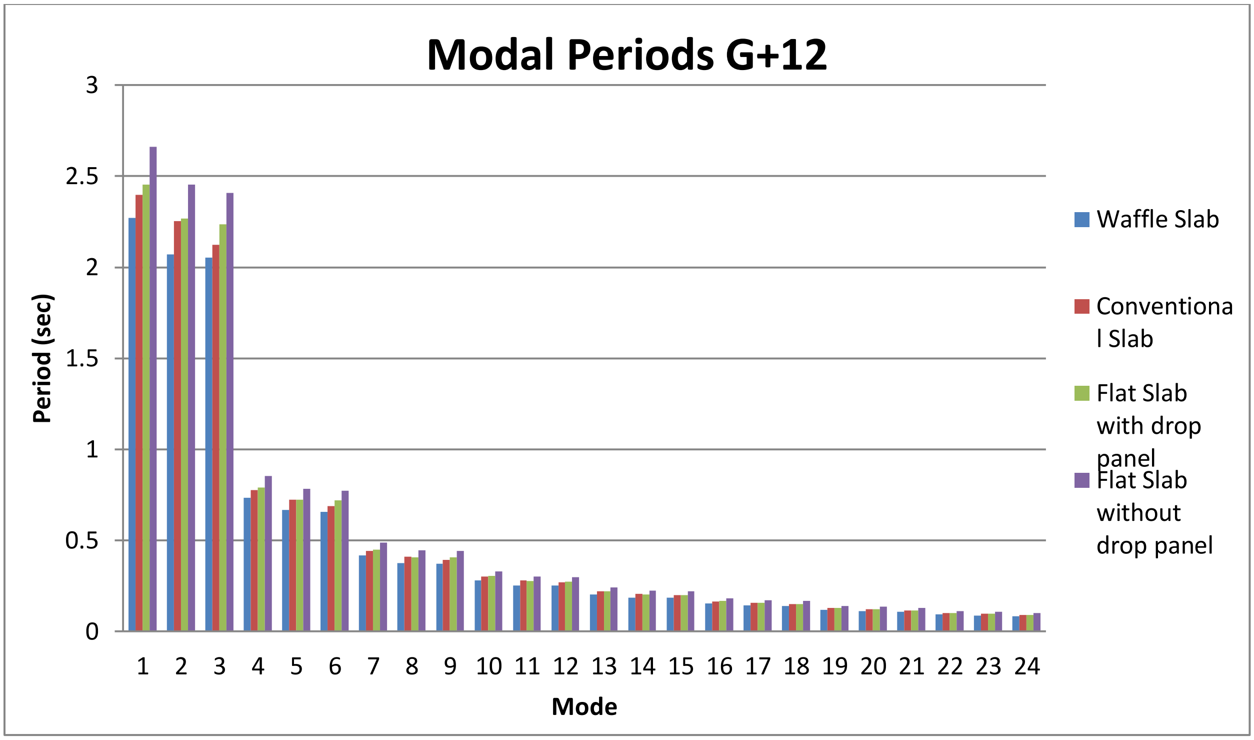


Figure 4-18 Mode number and time period G+6

4.2.6 Economy aspect

Economy is one of the main factors in the design and construction of building structure. The economy of the building greatly affect by the type of material used in the structure.

In this study only concrete and steel material used to compare the economical aspect of different slabs, but other material like scaffolding, form work and method used can also greatly affect the economy of the structure.

As shown in the figure the quantity of concrete is computed as the mass of the entire structure for each building. The quantity of concrete shows a great difference in value compare to each slab type. The quantity of concrete of G+ 6 flat slabs without drop panel is about 5.27% higher compare to flat Slab with drop pane18.3% higher compare to Conventional Slab and 30.3% compare to Waffle Slab.

Whereas quantity of steel (reinforcement bars) is computed for one floor only for each slab type.

- Quantity of concrete

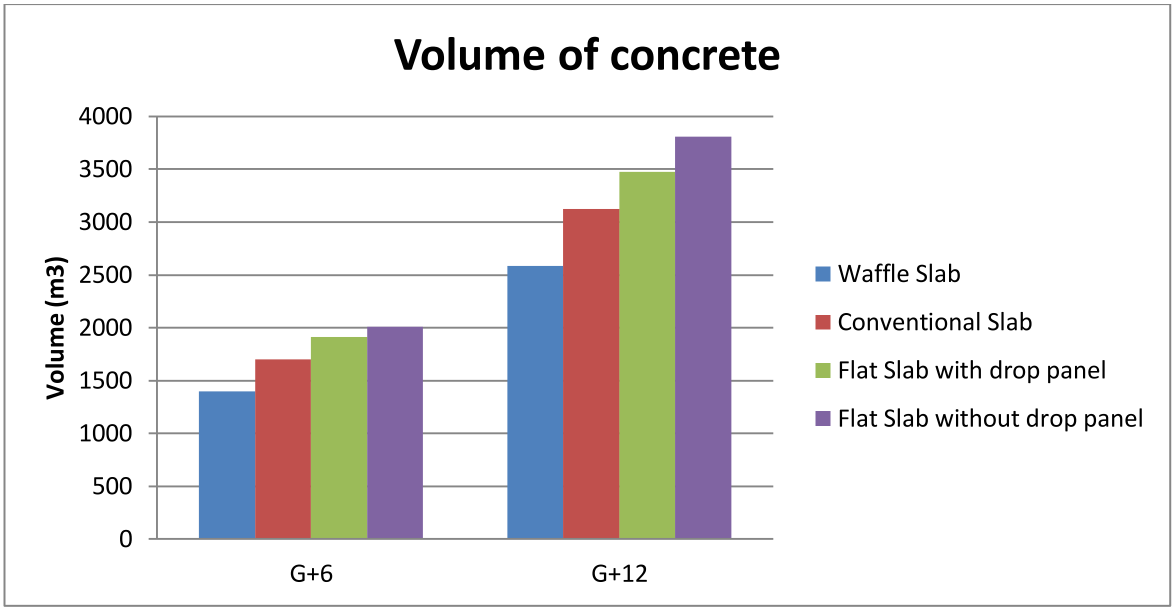


Figure 4-19 Volume of concrete

- Quantity of steel

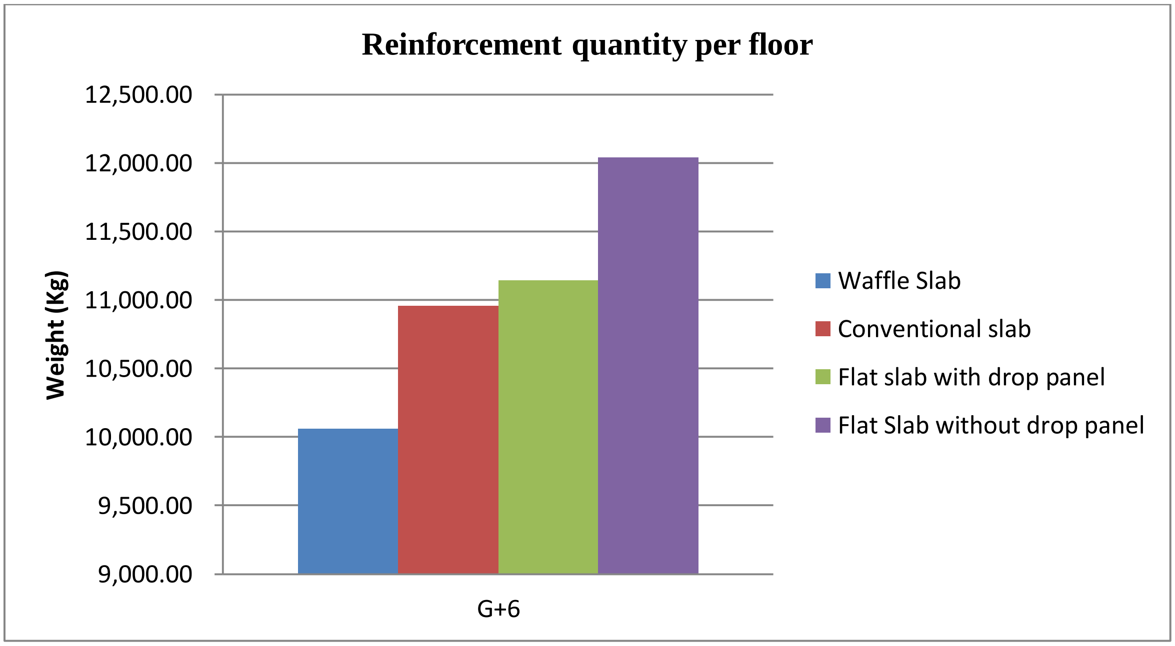


Figure 4-20 Reinforcement quantity

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

The main objective of this research is to study the behavior of flat slab with drop panel, flat slab without drop panel, waffle slab and conventional RCC slab under dynamic loading and also the effect of building height. This research done on two G+6 and G+12 building on a seismic Zone 4 and a soil class C for the parameter like lateral displacement, Story drift, Storey shear, base shear, axial load, time period and Cost effectiveness. . In this chapter, conclusion based on analytical evidences as well as some recommendations for future extension of the work has been presented

5.1 Conclusion

From the study on the behavior of flat slab with drop, flat slab without drop panel, waffle slab and conventional slab building under dynamic loading the following conclusion observed.

- Storey displacement increases as the height of the building increases, the maximum story displacement is higher at the top of the story. As shown from the G+12 building the value of displacement of flat slab without drop panel is about 16.13% higher compare to flat Slab with drop panel, 18.37% higher compare to Conventional Slab and 42.42% compare to Waffle Slab.
- Storey drift follows a parabolic path along storey height. As shown in G+12 the maximum drift shows at story five. After storey five, storey drift decreases as the height of building increases. The storey drift of flat slab without drop panel is about 16.22% higher compare to flat Slab with drop panel, 17.45% higher compare to Conventional Slab and 42.78% compare to Waffle Slab.
- The base shear of flat slab without drop panel is about 19.2% higher compare to flat Slab with drop panel, 19.46% higher compare to Conventional Slab and 47.24% compare to Waffle Slab.
- The time period is maximum at mode 1, 2 and 3. After mode 3 time period reduces drastically. As height of the building increases the value of time period also increases. The time period of flat slab without drop panel is about 8.43% higher compare to flat

Slab with drop panel, 10.88% higher compare to Conventional Slab and 17.12% compare to Waffle Slab.

- Axial load shows flat slab without drop panel is about 18.98% higher compare to flat Slab with drop panel, 14.41% higher compare to Conventional Slab and 34.65% compare to Waffle Slab.
- The economical of a building depend on the quantity material used. From (Fig 4. 19 and 4 .20) waffle slab is more economical compare to others shown in the figure
- By comparing all the above parameter waffle slab building is much superior than Conventional, Flat slab with drop panel and Flat slab without drop panel.
- Flat slab without drop building should be provide column head, drop panel and lateral force resisting structure like shear wall, bracing or damper to reduce the seismic effect.

5.2 Recommendation for future work

- The Structure can be analyzed for different geometry like L-shape, T- shape, rectangular plan shape in different seismic zones with different soil types.
- The structure can be analyzed with shear wall or bracing or damper.
- Comparative study of seismic performance of multistoried RCC building with larger building height.
- Structural optimization of flat slab by providing column capital, drop panel and hidden beam for the seismic performance and economical aspect.
- Fragility analysis flat slab structure can be done.

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Appendix A

Slab thickness determination

I. Conventional Slab

Depth for deflection

$$d \geq (0.4 + 0.6(\frac{fyk}{400})) * \frac{l_e}{\beta a}$$

Table A-1 The value βa

Member	Simply Supported	End Spans	Interior Spans	Cantilevers
Beams	20	24	28	10
Slabs (a) Span ratio = 2:1 (b) Span ratio = 1:1	 25 35	 30 40	 35 45	 12 10
Flat slabs (based on longer span)	24			-

Note: For slabs with intermediate span ratios interpolate linearly.

Table A-2 Conventional slab determination

	le	βa	fyk	D	D = d + Cover + ϕ /2
P1	5800	38	400	152.6316	173.6316
P2	5000	38.4	400	130.2083	151.2083
P2	5000	43.4	400	115.2074	136.2074
P3	4800	30	400	160	181
P3	4800	35	400	137.1429	158.1429
P4	5000	30	400	166.6667	**187.6667**
P5	5000	35	400	142.8571	163.8571

Therefore D = 190 mm

II. Flat slab without drop panel

Depth for deflection

$$d \geq (0.4 + 0.6(\frac{fyk}{400})) * \frac{l_e}{\beta a}$$

Table A-3 Flat slab without drop panel determination

	le	βa	fyk	D	D = d + Cover + ϕ /2
P1	5800	24	400	241.6667	**262.6667**
P2	5000	24	400	208.3333	229.3333
P3	4800	24	400	200	221
	1550	24	400	64.58333	85.58333

D= 262.667mm say 270mm

III. Waffle slab

Key term

Dome: - the voided space between ribs is called dome

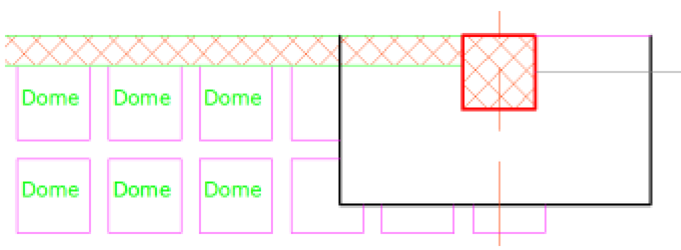

Figure A-1waffle Slab

Proposed Section of waffle slab

According to CRSI design handbook (ref. 1), 2008th version, domes could be found in standard sizes of 19 in by 19 in, 24 in by 24 in and 30 in by 30 in. since formwork for waffle slab domes is fabricated based on this sizes, it is mandatory to follow it.

19 in by 19 in dome size is selected for the slab system to be designed. And if 19 in by 19 in dome is used it is traditional followed by 2 and ½ in topping or flange slab. Other than the

topping, the depth of dome available together with 19 in by 19 in plan dimension are 8,10,12,14 and 16 in. it is proposed to try 8 in depth of dome.

Therefore, dome dimensions

- ✓ Plan dimension 19 in x 19 in (48.26 cm, say 50 cm)
- ✓ Depth 8 in (20.32 cm, say 20 cm)
- ✓ Topping slab: 2.5 in (6.35 cm, say 6 cm)
- ✓ And Rib width: 3.15 in (8 cm)
- ✓ C/c rib spacing in both directions would be: 50 cm+ 8cm/2+8cm/2=58 cm.

Since the dome has 1(H) in 12(V) side slope, the ribs would have different bottom and top widths.

Using the side slopes and the dome dimension:

S_{top} = (dome depth)/12 = 20/12 =1.67cm

W_{top} = 8 cm + 2 x 1.67 cm = 11.33 cm say 12cm

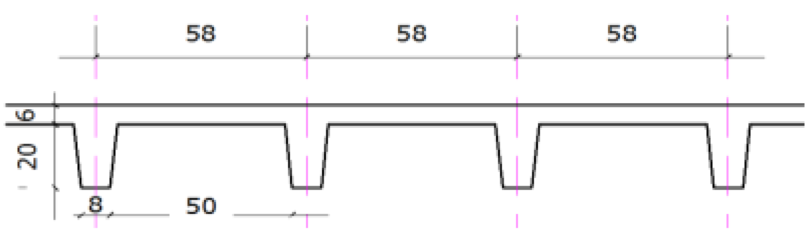

Figure A-2Side view of waffle Slab

Ribbed or waffle slabs need not be treated as discrete elements for the purposes of analysis, provided that the flange or structural topping and transverse ribs have sufficient torsional stiffness. This may be assumed provided that: [EBCS EN 1992-1-1:2013, Art. 3.3.1(5)]

- ✓ The rib spacing does not exceed 1500 mm
- ✓ The depth of the rib below the flange does not exceed 4 times its width.
- ✓ The depth of the flange is at least 1/10 of the clear distance between ribs or 50 mm, whichever is the greater.

- ✓ Transverse ribs are provided at a clear spacing not exceeding 10 times the overall depth of the slab.

The minimum flange thickness of 50 mm may be reduced to 40 mm where permanent blocks are incorporated between the ribs

Verification of proposed slab section against EBCS EN 1992-1-1:2013 recommendations

- Rib spacing 0.58 m < 1.5 m ok.
- Rib depth below flange 0.2 m <4* rib width =0.28 m ok
- Flange depth, 0.06 m > (1/10) *0.5= 0.05 m and 50 mm ok.
- Transverse rib spacing 0.58 m < 10*0.26 =2.6 m ok.

Depth from deflection

Since flat slab has a closer behavior to waffle slabs, following the flat slab procedure:

βa = 24 (Based on longer dimension ly)

$$d \geq (0.4 + 0.6(\frac{fyk}{400})) * \frac{l_e}{\beta a}$$

The longest span on the floor is 5.8 m and f_{yk} = 400

d = 241.67mm   Concrete cover = 15mm

D = 241.67 + 15 + 12/2 = 262.67mm say **<u>270mm</u>**

Drop panel determination

The dimension of drop is taken to be $L_x/6$. When it is summed from both directions it would be $L_x/3$.

=5800/6 = 966.67 mm say 1m

Therefore a drop dimension of 2m by 2m

Depth of drop

In order to have an attractive appearance the depth of drop is taken to be equal to the depth of rib plus the depth of flange i.e.

Depth of drop = 70mm +200mm =270mm

Appendix B

Result from the analysis ETABS G+12

Storey displacement

A. **Flat slab without drop panel**

Table B-1 Displacement of Flat Slab without drop panel along X- direction

Story	Elevation	Location	X-Dir
	m		mm
Roof	41	Top	71.668
Story12	38	Top	69.251
Story11	35	Top	66.518
Story10	32	Top	62.969
Story9	29	Top	58.575
Story8	26	Top	53.377
Story7	23	Top	47.445
Story6	20	Top	40.867
Story5	17	Top	33.739
Story4	14	Top	26.498
Story3	11	Top	19.258
Story2	8	Top	12.211
Story1	5	Top	5.994
Ground Floor	2	Top	1.286
Base	0	Top	0

B. Flat slab with drop panel

Table B-2 Displacement of Flat Slab with drop panel along X- direction

Story	Elevation	Location	X-Dir
	m		mm
Roof	41	Top	61.714
Story12	38	Top	59.54
Story11	35	Top	57.037
Story10	32	Top	53.848
Story9	29	Top	49.946
Story8	26	Top	45.369
Story7	23	Top	40.179
Story6	20	Top	34.459

Story5	17	Top	28.303
Story4	14	Top	22.083
Story3	11	Top	15.913
Story2	8	Top	10.009
Story1	5	Top	4.929
Ground Floor	2	Top	1.045
Base	0	Top	0

C. Conventional Slab

Table B-3 Displacement of Conventional Slab along X – direction

Story	Elevation	Location	X-Dir
	m		mm
Roof	41	Top	60.56
Story12	38	Top	58.535
Story11	35	Top	56.203
Story10	32	Top	53.182
Story9	29	Top	49.444
Story8	26	Top	45.026
Story7	23	Top	39.988
Story6	20	Top	34.404
Story5	17	Top	28.355
Story4	14	Top	22.201
Story3	11	Top	16.056
Story2	8	Top	10.127
Story1	5	Top	4.984
Ground Floor	2	Top	1.046
Base	0	Top	0

D. Waffle Slab

Table B-4 Displacement of waffle slab along X- direction

Story	Elevation	Location	X-Dir
	m		mm
Roof	41	Top	50.677
Story12	38	Top	48.894
Story11	35	Top	46.849
Story10	32	Top	44.245
Story9	29	Top	41.063

Story8	26	Top	37.333
Story7	23	Top	33.106
Story6	20	Top	28.446
Story5	17	Top	23.429
Story4	14	Top	18.354
Story3	11	Top	13.306
Story2	8	Top	8.453
Story1	5	Top	4.241
Ground floor	2	Top	1.013
Base	0	Top	0

Storey drift

A. Flat slab without drop panel

Table B-5 Story drift of flat slab without drop panel along X- direction

Story	Elevation	Location	X-Dir
	m		
Roof	41	Top	0.001
Story12	38	Top	0.001015
Story11	35	Top	0.001281
Story10	32	Top	0.001553
Story9	29	Top	0.001809
Story8	26	Top	0.002042
Story7	23	Top	0.002246
Story6	20	Top	0.002417
Story5	17	Top	0.002443
Story4	14	Top	0.002433
Story3	11	Top	0.002359
Story2	8	Top	0.002075
Story1	5	Top	0.001587
Ground Floor	2	Top	0.000643
Base	0	Top	0

B. Flat Slab with drop panel

Table B-6 Story drifts Flat Slab with drop panel along X- direction

Story	Elevation	Location	X-Dir
	m		
Roof	41	Top	0.000906
Story12	38	Top	0.000937
Story11	35	Top	0.001161
Story10	32	Top	0.001388
Story9	29	Top	0.001603
Story8	26	Top	0.001795
Story7	23	Top	0.00196
Story6	20	Top	0.002093
Story5	17	Top	0.002102
Story4	14	Top	0.002076
Story3	11	Top	0.001978
Story2	8	Top	0.001696
Story1	5	Top	0.001307
Ground Floor	2	Top	0.000522
Base	0	Top	0

C. Conventional Slab

Table B-7 Story drifts conventional slab along X- direction

Story	Elevation	Location	X-Dir
	m		
Roof	41	Top	0.000859
Story12	38	Top	0.000882
Story11	35	Top	0.001106
Story10	32	Top	0.001335
Story9	29	Top	0.00155
Story8	26	Top	0.001745
Story7	23	Top	0.001915
Story6	20	Top	0.002058
Story5	17	Top	0.00208
Story4	14	Top	0.002067
Story3	11	Top	0.001986
Story2	8	Top	0.001717
Story1	5	Top	0.00132

Ground Floor	2	Top	0.000523
Base	0	Top	0

D. Waffle Slab

Table B-8 Story drift waffle slab along X- direction

Story	Elevation	Location	X-Dir
	m		
Roof	41	Top	0.000771
Story12	38	Top	0.000787
Story11	35	Top	0.000969
Story10	32	Top	0.001152
Story9	29	Top	0.001323
Story8	26	Top	0.001477
Story7	23	Top	0.001609
Story6	20	Top	0.001716
Story5	17	Top	0.001723
Story4	14	Top	0.001703
Story3	11	Top	0.001628
Story2	8	Top	0.001407
Story1	5	Top	0.001114
Ground floor	2	Top	0.000507
Base	0	Top	0

Storey shear

A. **Flat slab without drop panel**

Table B-9 Story Shear Flat Slab without drop panel along X- direction

Story	Elevation	Location	X-Dir
Roof	41	Top	528.4186
Story12	38	Top	827.9093
Story11	35	Top	1126.184
Story10	32	Top	1409.557
Story9	29	Top	1672.795
Story8	26	Top	1915.018
Story7	23	Top	2134.278
Story6	20	Top	2329.355
Story5	17	Top	2501.199

Story4	14	Top	2645.144
Story3	11	Top	2762.243
Story2	8	Top	2860.508
Story1	5	Top	2949.452
Ground Floor	2	Top	2957.952
Base	0	Top	0

B. Flat Slab with drop panel

Table B-10 Story Shear Flat Slab with drop panel along X- direction

Story	Elevation	Location	X-Dir
Roof	41	Top	445.7289
Story12	38	Top	690.6945
Story11	35	Top	927.4746
Story10	32	Top	1152.503
Story9	29	Top	1361.37
Story8	26	Top	1551.478
Story7	23	Top	1723.03
Story6	20	Top	1876.956
Story5	17	Top	2013.143
Story4	14	Top	2127.003
Story3	11	Top	2221.665
Story2	8	Top	2306.072
Story1	5	Top	2385.556
Ground Floor	2	Top	2394.587
Base	0	Top	0

C. Conventional Slab

Table B-11 Story Shear Conventional Slab along X- direction

Story	Elevation	Location	X-Dir
Roof	41	Top	443.3189
Story12	38	Top	687.5053
Story11	35	Top	924.7924
Story10	32	Top	1150.887
Story9	29	Top	1360.946
Story8	26	Top	1552.479

Story7	23	Top	1725.593
Story6	20	Top	1881.122
Story5	17	Top	2018.775
Story4	14	Top	2133.747
Story3	11	Top	2228.965
Story2	8	Top	2312.764
Story1	5	Top	2390.902
Ground Floor	2	Top	2399.775
Base	0	Top	0

D. Waffle Slab

Table B-12 Story Shear waffle slab along X- direction

TABLE: Waffle Slab			
Story	**Elevation**	**Location**	**X-Dir**
Roof	41	Top	386.5946
Story12	38	Top	598.0555
Story11	35	Top	791.4754
Story10	32	Top	971.4228
Story9	29	Top	1139.213
Story8	26	Top	1292.833
Story7	23	Top	1432.003
Story6	20	Top	1557.39
Story5	17	Top	1668.467
Story4	14	Top	1762.751
Story3	11	Top	1845.344
Story2	8	Top	1923.518
Story1	5	Top	1998.316
Ground floor	2	Top	2008.898
Base	0	Top	0

Time period

Table B-13 Modal Periods

		Flat Slab without drop panel	Flat Slab with drop panel	Conventional Slab	Waffle Slab
Case	**Mode**	**Period**	**Period**	**Period**	**Period**
		sec	sec	sec	sec
Modal	1	2.66	2.453	2.399	2.271
Modal	2	2.454	2.268	2.253	2.072
Modal	3	2.407	2.237	2.122	2.052
Modal	4	0.854	0.79	0.775	0.734
Modal	5	0.784	0.724	0.723	0.667
Modal	6	0.774	0.719	0.689	0.658
Modal	7	0.488	0.45	0.444	0.418
Modal	8	0.445	0.408	0.41	0.376
Modal	9	0.441	0.406	0.395	0.371
Modal	10	0.331	0.304	0.301	0.281
Modal	11	0.303	0.277	0.279	0.253
Modal	12	0.299	0.274	0.269	0.252
Modal	13	0.242	0.222	0.22	0.205
Modal	14	0.225	0.205	0.207	0.187
Modal	15	0.22	0.201	0.199	0.185
Modal	16	0.183	0.167	0.166	0.154
Modal	17	0.173	0.157	0.159	0.144
Modal	18	0.167	0.152	0.151	0.14
Modal	19	0.141	0.129	0.128	0.119
Modal	20	0.135	0.123	0.123	0.112
Modal	21	0.129	0.117	0.117	0.108
Modal	22	0.111	0.101	0.1	0.093
Modal	23	0.107	0.097	0.098	0.089
Modal	24	0.102	0.092	0.092	0.085