كلية الدراسات العليا

Sudan University of Science and Technology

College of Graduate Studies

Comparative Study of Seismic Behavior of Multi-Storey Framed Composite Steel and Reinforced Concrete Buildings

دراسة مقارنة السلوك الزلزالي للمباني الإطارية العالية من الفولاذ المركب والخرسانة المسلحة

Thesis submitted to the department of StructuralEngineering in the partial fulfillment of the requirements for the degree of Master of Sciencein Civil Engineering (Structural Engineering).

Prepared By:

IbtihalEldaw Osman Hassan
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Supervisors:

Dr Alia Osman Mohamed
Professor Abdel RahmanElzubeir Mohamed

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Abstract

In this study a comparative analysis of seismic behavior of Multi-storey Composite and Conventional RCC Frame Structures at various heights has been carried out. Two models of ten storey high rise framed building structures were analyzed using ETABS Finite Element Program. The results obtained were, then, analyzed using Excel Spread sheet. The main variables considered for comparison were natural time period, coefficient of response acceleration, base shear, and the maximum displacement. According to these variables the comparison showed that the Composite steel structures are more resisted in seismic behavior compared to the Reinforced concrete structures. Hence, it is recommended to use the composite steel structures in high seismic load zones.

المستخلص:

تم في هذه الدراسة تحليل لمقارنة السلوك الزلزالي للمباني الاطارية العالية من الفولاذ المركب والخرسانة المسلحة لإرتفاعات مختلفة. تم تحليل نموذجين من المباني العالية (العشر طوابق) باستخدام برنامج العناصر المحددة ETABS. تم استخراج النتائج وعرضها ببرنامج EXCEL. المتغيرات الأساسية في المقارنة كانت زمن الدورة الطبيعي، معامل تسارع الاستجابة، قاعدة القص والازاحة القصوي.بناءاً علي هذه المتغيرات أظهرت المقارنة أن المنشآت الفولاذية المركبة تعطي مقاومه للسلوك الزلزالي من المنشات الخرسانية المسلحة. عليه يوصي إستخدام منشآت الفولاذ المركب في المناطق الزلزالية.

الآيـــــة

قال تعالي:

(وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ)

صدق الله العظيم

سُورةالتوبة (105)

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This thesis would not have been possible to produce without the support of my parents and my husband. I owe very much to them, in fact everything. This thesis is fully dedicated to them.

Finally I would like to express my sincerest thanks to all my friends for their encouragement, belief in me and for their good spirit.

You all deserve the best!

Contents

Page

List of figures:

List of table:

Symbols:

ML local magnitude
A maximum trace amplitude in micrometers recorded on a standard Wood
MS Surface wave magnitude
PGA ground acceleration
MMI Modified Mercalli Intensity
ZPA zero period acceleration
PGV peak ground velocity
PGD peak ground displacement
Sd displacement response spectrum
Sv velocity response spectrum
Sa acceleration response spectrum
Z Zone Factor
I Importance Factor
R F Response Reduction Factor
DBE design basis earthquake
Ta fundamental natural period
h height of building
d base dimension of the building at the plinth level
V_B Design base shear
Q_i Design lateral force at floor i
W_i Seismic weight of floor i
hi height of floor i
n number of factor (stories in the building)
Sa/g Coefficient of Response Acceleration

Chapter One

Introduction

Chapter One

Introduction

1.6 General Introduction

In the present world, high rise buildings are becoming a usual practice in the infra structural development due to the progressive population increment in the cities and limitation of land. This brings up the idea of vertical development (i.e. the constructions of high rise buildings) so as to accommodate the entire population. The conventional reinforced concrete is the most common practice in the constructions of low rise and medium rise buildings but in high rise buildings it is consider being uneconomical and bound to risk of failure due to high weight. But with the development of design methods and experimental researches for CFST columns and composite beams, the steel-concrete composite frame has been widely used in multi-story and high-rise buildings. The composite structure has the advantages of fabrication in factories; assemble construction, short construction period, high bearing force and good ductility. When earthquakes occur, a building undergoes dynamic motion. This is because the building is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces, called seismic loads, are usually dealt with by assuming forces external to the building. Since earthquake motions vary with time and inertia forces vary with time and direction, seismic loads are not constant in terms of time and space. In designing buildings, the maximum story shear force is considered to be the most influential; therefore seismic loads are the static loads to give the maximum story shear force for each story, i.e. equivalent static seismic loads. Time histories of earthquake motions are also used to analyze high-rise buildings, and their elements and contents for seismic design. The earthquake motions for dynamic design are called design earthquake motions. In the previous recommendations, mainly the equivalent static seismic loads were considered in the seismic. In this study, not only equivalent static seismic loads but also design earthquake motions as time histories are included in seismic loads considered in the wider sense. In ISO/TC98 which deals with “bases for design of structures”, the term “action” is used instead of “load” and action includes not only load as external force but various influences that may cause deformations to the structures.

1.2 Research problem statement

The building type and materials used has an effect on the seismic behavior. This effect is usually evaluated by carrying out a comparative study. It has been stated by researchers that conventional RCC is only suitable for low and medium rise buildings in seismic zones. Composite steel frame and RCC are claimed to be more effective. Static analysis Equivalent Lateral Force method using finite element program such as ETABS will clearly show the difference in behavior of RCC and composite steel structures.

1.3 Objective of Research

The General objective of the research is to carry out a comparison through study the behavior of the composite steel framed structure and reinforcement concrete framed structure in seismic analysis for multi-stories building.

The specific objectives are:

1- To learn how to use static analysis of multi-storey buildings under seismic loads.
2- To identify the factors necessary for carrying out the comparative study.
3- To determine the behavior of the different material types under seismic load based on the identified factors.
4- To draw the conclusions and present recommendation based on the analysis of the results obtained.

1.4 Research Methodology

- Carrying out a comprehensive literature review comparison between composite steel framed structure and reinforcement concrete framed structure in seismic analysis for multi-stories building. The review is based on published researches, books, papers and Internet.
- The methodology used in this research is scientific analytic ETABS software used to analyze case study under seismic loads of both composite steel frame structure and reinforced concrete frame structure (RCC). EXCEL spread sheet software is then used to present and analyze the results.

The factor to be used for comparative study

1. Natural time period.
2. Coefficient of Response Acceleration.
3. Base Shear.
4. The Maximum Displacement.

- Based on the results analysis conclusions are drawn and recommendations are presented.

1.5 Thesis Outlines

The research includes the following:

Chapter one presents general introduction, research problem statement, objective of research, research methodology and thesis outlines.

Chapter two presents Historical backgrounds on earthquake, its causes and effects and literature review on the research problem.

Chapter three presents the theoretical framework which includes measurement of earthquakes, time history, elastic response spectra analysis, framing systems and seismic analysis methods.

Chapter four presents the modeling using ETABS of multi-storey framed building .The results obtained analysis and discussion of results using EXCEL.

Chapter five presents conclusions and recommendations.

Chapter Two

Historical Background and Literature Review

Chapter Two

Historical Background and Literature Review

2.1 Introduction:

This chapter provides the studies that were made by engineer researchers in the seismic analysis to understanding earthquakes, causes of earthquakes, explaining how earthquakes measured and explaining how seismicity can be characterized.

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 (structural engineering) in regions where earthquakes are prevalent.

2.2 Historical Background:

From time immemorial, nature's forces have influenced human existence. Even in the face of catastrophic natural phenomena, human beings have tried to control nature and coexist with it. Of all the natural disasters, for example, earthquakes, floods, tornadoes, hurricanes, droughts, and volcanic eruptions, the least understood and the most destructive are earthquakes. Although the average annual losses due to floods, tornadoes, hurricanes, etc., exceed those due to earthquakes, the total, unexpected, and nearly instantaneous devastation caused by a major earthquake has a unique psychological impact on the affected. Thus, this significant life hazard demands serious attention.

An earthquake may be defined as a wave-like motion generated by forces in constant turmoil under the surface layer of the earth (the lithosphere), travelling through the earth's crust. It may also be defined as the vibration, sometimes violent, of the earth's surface as a result of a release of energy in the earth's crust. This release of energy can be caused by sudden dislocations of segments of the crust, volcanic eruptions, or even explosions created by humans. Dislocations of crust segments, however, lead to the most destructive earthquakes. In the process of dislocation, vibrations called seismic waves are generated. These waves travel outwards from the source of the earthquake at varying speeds, causing the earth to quiver or ring like a bell or tuning fork.

During an earthquake, enormous amounts of energy are released. The size and severity of an earthquake is estimated by two important parameters—intensity and magnitude. The magnitude is a measure of the amount of energy released, while the intensity is the apparent effect experienced at a specific location.

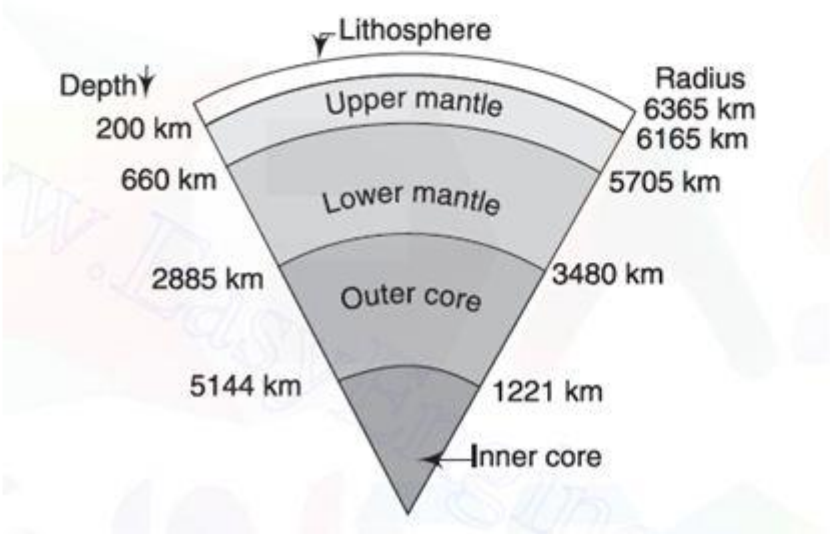

Fig. 2.1 Interior of the earth (Chen and Lui, 2006)

2.2.1 The Interior of the Earth

The earth is conceived to be composed of a sequence of shells or layers called geospheres, the heaviest of which forms the core as shown in Fig. (2.1).Various geospheres that constitute the earth are discussed further.

Barysphere Also known as the core, it is the densest central part of the earth. It is composed of the inner and outer cores. The inner core, 1221 km in radius, is composed mainly of nickel and iron. Its density is 16,000 kg/m3 and it behaves like a solid mass. The outer core surrounding the inner core is 2259 km thick and is composed of an alloy of nickel, iron, and silica. The outer core exists as a liquid of density 12,000 kg/m3. The temperature at the core is about 2500°C and the pressure is about 4×10^6 atm.

Asthenosphere Also known as the mantle, it is 2685 km thick, surrounding the core. It is composed of hot, dense ultrabasic igneous rock in a plastic state with a density of 5000–6000 kg/m3.

Lithosphere Also known as the crust, it is the thinnest outer solid shell. It is 200 km thick with a density of 1500 kg/m3. The temperature of the crust is about 25°C and the pressure within it is 1 atm.

2.2.2 Causes of Earthquakes

Earthquakes are vibrations or oscillations of the ground surface caused by a transient disturbance of the elastic or gravitational equilibrium of the rocks at or beneath the surface of the earth. The disturbance and the consequent movements give rise to elastic impulses or waves. Natural earthquakes are classified as tectonic (relative movement of plates), plutonic (deep-seated changes), or volcanic, on the basis of the source of the stresses that cause the movement.

Volcanic earthquakes are a special feature of explosive eruption, small in energy and seldom damaging. There is an emerging realization that volcanoes and earthquakes may have a common origin in the deep movement of mantle materials. The coincidence of belts of major earthquake activity with belts that include active volcanoes supports this idea. The most obvious common cause of seismic and volcanic activity relates to plate interactions, in the process of which fracture zones allow volcanic material to well up from the lower crust of the mantle. These boundaries are also areas in which earthquakes would naturally occur due to plate interactions in zones of convergence or divergence, or areas where two plates slide past one another along the parallel boundaries.

In a global sense, tectonic earthquakes result from motion between a number of large plates comprising the earth's crust or lithosphere (about 15 large plates, in total), Figure (2.1). These plates are driven by the convective motion of the material in the earth's mantle, which in turn is driven by the heat generated at the earth's core. Relative plate motion at the fault interface is constrained by friction and/or asperities (areas of interlocking due to protrusions in the fault surfaces). However, strain energy accumulates in the plates, eventually overcomes any resistance, and causes slip between the two sides of the fault. This sudden slip, termed elastic rebound by Reid (1910) based on his studies of regional deformation following the 1906 San Francisco Earthquake, releases large amounts of energy, which constitutes or is the earthquake. The location of initial radiation of seismic waves (i.e., the first location of dynamic rupture) is termed the hypocenter, while the projection on the surface of the earth directly above the hypocenter is termed the epicenter. Other terminology includes near-field1 (within one source dimension of the epicenter, where source dimension refers to the width or length of faulting whichever is shorter), far-field (beyond near-field), and meizoseismal (the area of strong shaking and damage). Energy is radiated over a broad spectrum of frequencies through the earth, in body waves and surface waves (Bolt 1993). Body waves are of two types: P waves (transmitting energy via push–pull motion) and slower S waves (transmitting energy via shear action at right angles to the direction of motion). Surface waves are also of two types: horizontally oscillating Love waves (analogous to S body waves) and vertically oscillating Rayleigh waves.

While the accumulation of strain energy within the plate can cause motion (and consequent release of energy) at faults at any location, earthquakes occur with greatest frequency at the boundaries of the tectonic plates. The boundary of the Pacific plate is the source of nearly half of the world's great earthquakes. Stretching 40,000 km (24,000 miles) around the circumference of the Pacific Ocean, it includes Japan, the west coast of North America, and other highly populated areas, and is aptly termed the Ring of Fire. The interiors of plates, such as ocean basins and continental shields, are areas of low seismicity but are not inactive — the largest earthquakes known to have occurred in North America, for example, occurred in 1811–1812 in the New Madrid area, far from a plate boundary. Tectonic plates move relatively slowly (5 cm per year is relatively fast) and irregularly, with relatively frequent small and only occasional large earthquakes. Forces may build up for decades or centuries at plate interfaces until a large movement occurs all at once. These sudden, violent motions produce the shaking that is felt as an earthquake. The shaking can cause direct damage to buildings, roads, bridges, and other man-made structures as well as triggering landslides, fires, tidal waves (tsunamis), and other damaging phenomena.

Faults are the physical expression of the boundaries between adjacent tectonic plates and thus may be hundreds of miles long. In addition, there may be thousands of shorter faults parallel to or branching out from a main fault zone. Generally, the longer a fault the larger the earthquake it can generate. Beyond the main tectonic plates, there are many smaller subplates, ‘‘platelets,’’ and simple blocks of crust that occasionally move and shift due to the ‘‘jostling’’ of their neighbors and the major plates. The existence of these many subplates means that smaller but still damaging earthquakes are possible almost anywhere, although often with less likelihood.

Faults are typically classified according to their sense of motion, Figure 2.2. Basic terms include transform or strike slip (relative fault motion occurs in the horizontal plane, parallel to the strike of the fault), dip-slip (motion at right angles to the strike, up- or down-slip), normal (dip-slip motion, two sides in tension, move away from each other), reverse (dip-slip, two sides in compression, move toward each other), and thrust (low-angle reverse faulting).

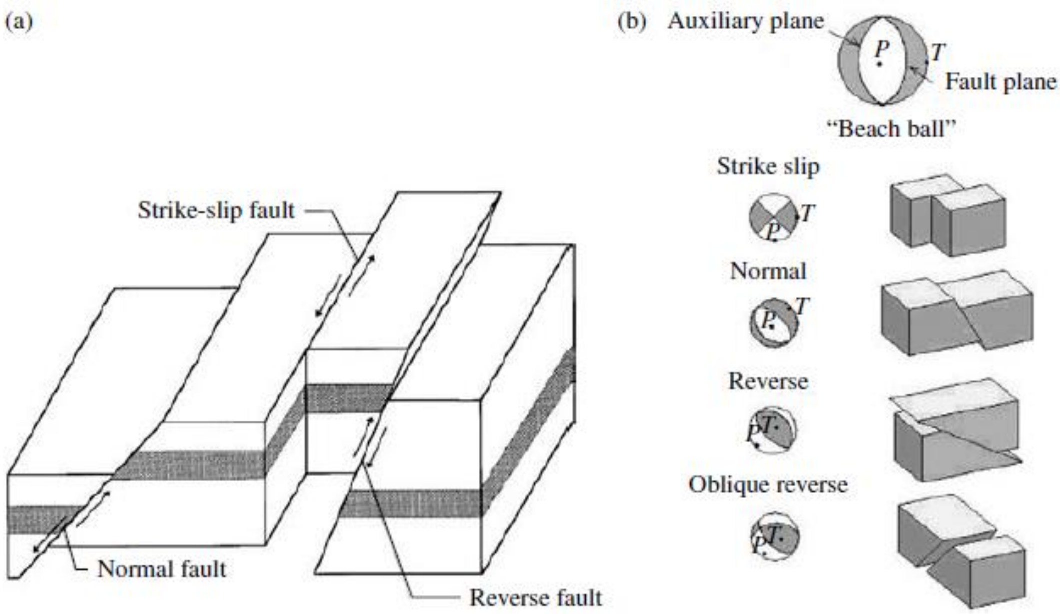

Fig. 2.2 (a) Type of faulting and, (b) focal mechanisms (Chen and Lui, 2006)

2.2.3 Nature and Occurrence of Earthquakes

When there is a sudden localized disturbance in rocks, waves similar to those caused by a stone thrown into a pool spread out through the earth. An earthquake generates a similar disturbance. The maximum effect of an earthquake is felt near its source, diminishing with distance from the source (earthquakes shake the ground even hundreds of kilometers away). The vibrations felt in the bedrock are called shocks. Some earthquakes are preceded by smaller foreshocks and larger earthquakes are always followed by aftershocks. Foreshocks are usually interpreted as being caused by plastic deformation or small ruptures. Aftershocks are usually due to fresh ruptures or readjustment of fractured rocks.

The point of generation of an earthquake is known as the focus, centre, or hypocenter. The point on the earth’s surface directly above the focus is known as epicenter. The depth of the focus from the epicentre is known as the focal depth. The distance from the epicenter to any point of interest is known as the focal distance or epicenter distance (Fig. 2.3). Seismic destruction propagates from the focus through a limited region of the surrounding earth's body, which is called the focal region. The line joining locations experiencing equal earthquake intensity is known as the isoseismal line and the line joining locations at which the shock arrives simultaneously is known as the homoseismal line.

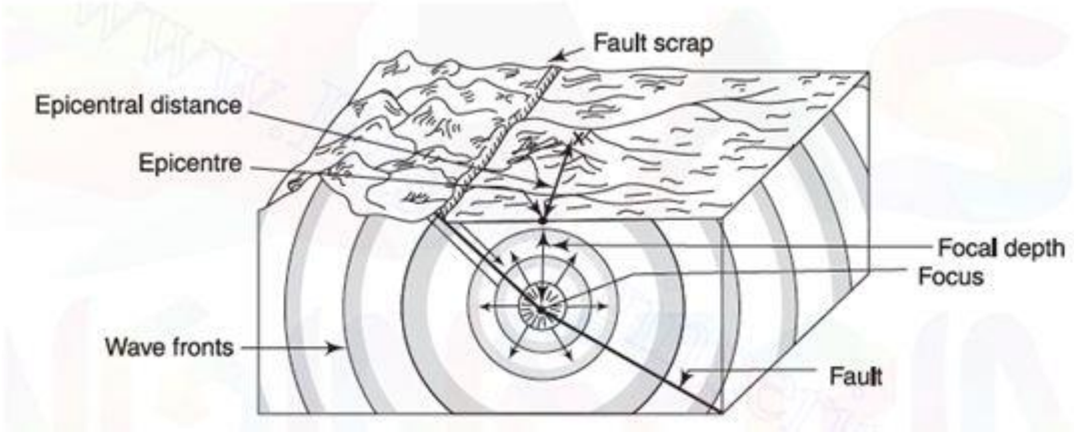

Fig. 2.3 Occurrence of earthquake (Chen and Lui, 2006)

The location of an earthquake's focus is important because it indicates the depth at which rupture and movement occur. Although movement of material within the earth occurs throughout the mantle and core, earthquakes are concentrated in the upper 700 km only. Shallow-focus earthquakes are most frequent and originate from up to a depth of 70 km from the surface of the earth. Intermediate-focus earthquakes occur between 70 and 300 km. Earthquakes having a focal depth of more than 300 km are classified as deep-focus earthquakes. The maximum energy released by an earthquake progressively tends to become smaller as the focal depth increases. Also, seismic energy from a source deeper than 70 km gets largely dissipated by the time it reaches the surface. Therefore, the main consideration in the design of earthquake-resistant structures is shallow-focus earthquakes. The focus of an earthquake is calculated from the time that elapses between the arrivals of three major types of seismic waves.

The movement caused by an earthquake at a given point of the ground surface may be resolved into three translations, parallel to the three mutually perpendicular axes. There are also three rotations about these axes, which, being small, may be neglected. The translations (or displacements) are measured by seismographs.

2.2.4 Seismic Waves

The large strain energy released during an earthquake travels in the form of seismic waves in all directions (Fig. 2.4), with accompanying reflections from earth's surface as well as reflections and refractions as they traverse the earth's interior (Fig.2.5). These waves can be classified as body waves travelling through the interior of the earth consisting of P-waves (primary, longitudinal, or compression waves) and S-waves (secondary, transverse, or shear waves), and surface waves resulting from interaction between body waves and surface layers of earth—consisting of L-waves (Love waves) and Rayleigh waves (Fig.2.6). Body waves travel through the interior of elastic media and surface waves are bound to free surfaces as shown in Fig. (2.4).

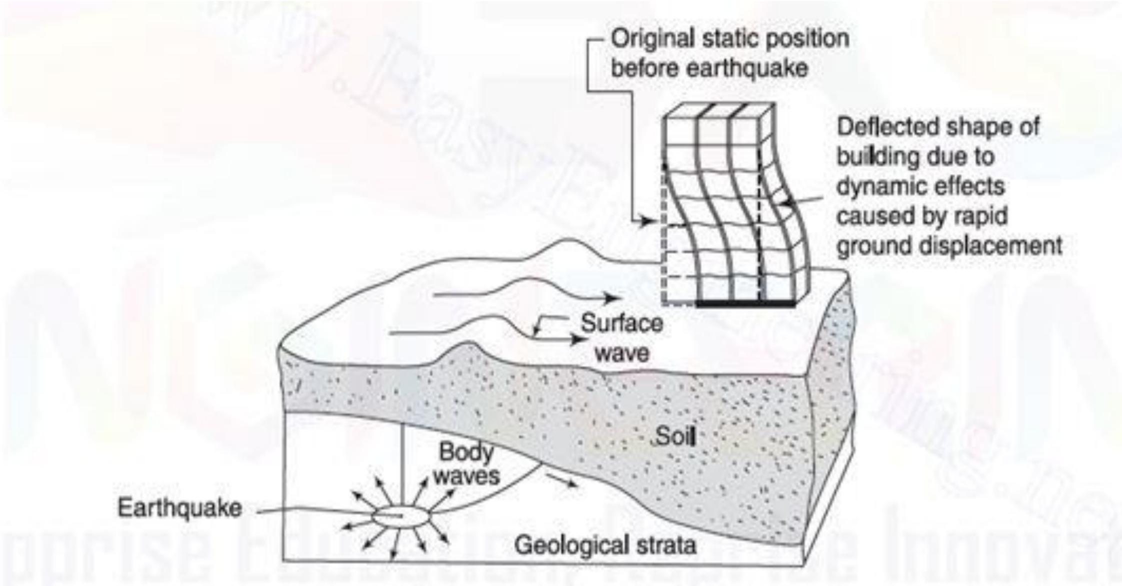

Fig. 2.4 Arrival of seismic wave (Chen and Lui, 2006)

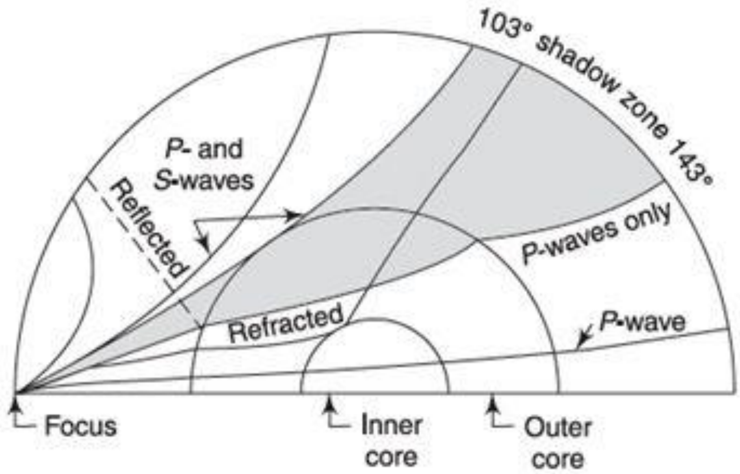

Fig. 2.5 Seismic wave paths (Chen and Lui, 2006)

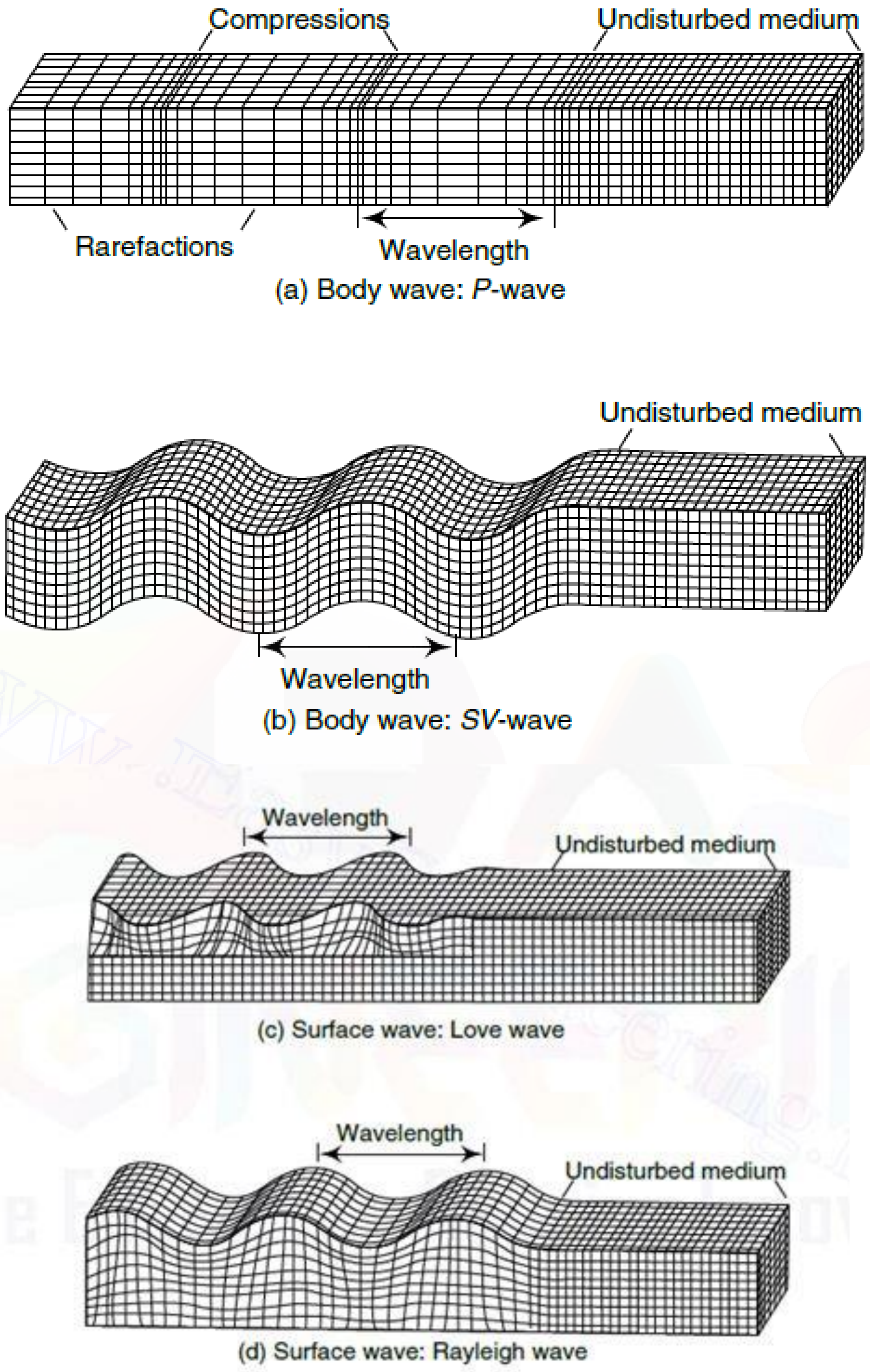

Fig. 2.6 Deformation produced by seismic waves (Chen and Lui, 2006)

2.2.5 Effects of Earthquakes

Earthquakes are major hazards and can cause catastrophic damage. They have two types of effects direct and indirect. Direct effects cause damages directly and include ground motion and faulting. Indirect effects cause damages indirectly, as a result of the processes set in motion by an earthquake. The direct effects of earthquakes are as follows:

(a) Seismic waves, especially surface waves, through surface rock layers and regolith result in ground motion.
(b) In regions consisting of hills and steep slopes, earthquake vibration may cause landslides and mudslides and cliffs to collapse, which can damage buildings and lead to loss of life.
(c) Soil vibration can shake a building off its foundation, modify its supports, or cause its foundation to disintegrate.
(d) Ground shaking may compound the problem in areas with very wet ground—unfilled land, near the coast, or in locations that have a high water table. This problem is known as liquefaction. When an earthquake shakes wet sandy soil, the soil particles may be jarred apart, allowing water to seep in between them.
(e) Strong surface seismic waves make the ground heave and lurch and damage the structure.
Indirect or consequential effects
The following are indirect effects of an earthquake:
(a) If the epicenter of an earthquake is under the sea, one side of the ocean floor drops suddenly, sliding under the other plate and, in doing so, creates a vertical fault.
(b) Since a tsunami occurs because of sudden displacement of a large body of water, this displacement may be caused by
• Undersea landslides whereby large amount of sediment is dislodged from the sea floor, displacing a water column and potentially generating a localized tsunami;
• Surface land sliding into the ocean due to earthquake, resulting in local tsunami; and
• Volcanic eruptions in or near the ocean which may cause tsunami, but are not usual.
(c) Sieches, similar to small tsunamis, occur as a result of the sloshing of enclosed water in reservoirs, lakes, and harbors shaken by earthquakes.
(d) Earthquakes can cause fire by damaging gas lines and snapping electric wires.
(e) Earthquakes can rupture dams and levees (raised river embankments), causing floods, resulting in damage to structures and considerable loss of life.

2.2.6 Framing Systems

The load-bearing wall system is the most common building system for low-rise structures where gravity loads are the dominant loads. However, this system is inherently weak in resisting lateral loads, and is seldom recommended for multi-storey buildings. The framework of a multi-storey building consists of a number of beams and columns built monolithically, forming a network. The ability of a multi-storey building to resist the lateral forces depends on the rigidity of the connections between the beams and the columns. When the connections are fully rigid, the structure as a whole is capable of resisting the lateral forces. The moment-resisting frame is thus the fundamental structural system. However, if the strength and stiffness of a frame are not adequate, the frame may be strengthened by incorporating load-bearing walls, shear walls, and/or bracings.

Shear walls and bracings are also useful in preventing the failure of non-structural components by reducing drift. Shear walls are walls situated in advantageous positions in a building that can effectively resist lateral loads originating from earthquakes or winds. These may be made of RCC, steel, composite, and masonry. RCC shear walls are most commonly used in multi-storey structures

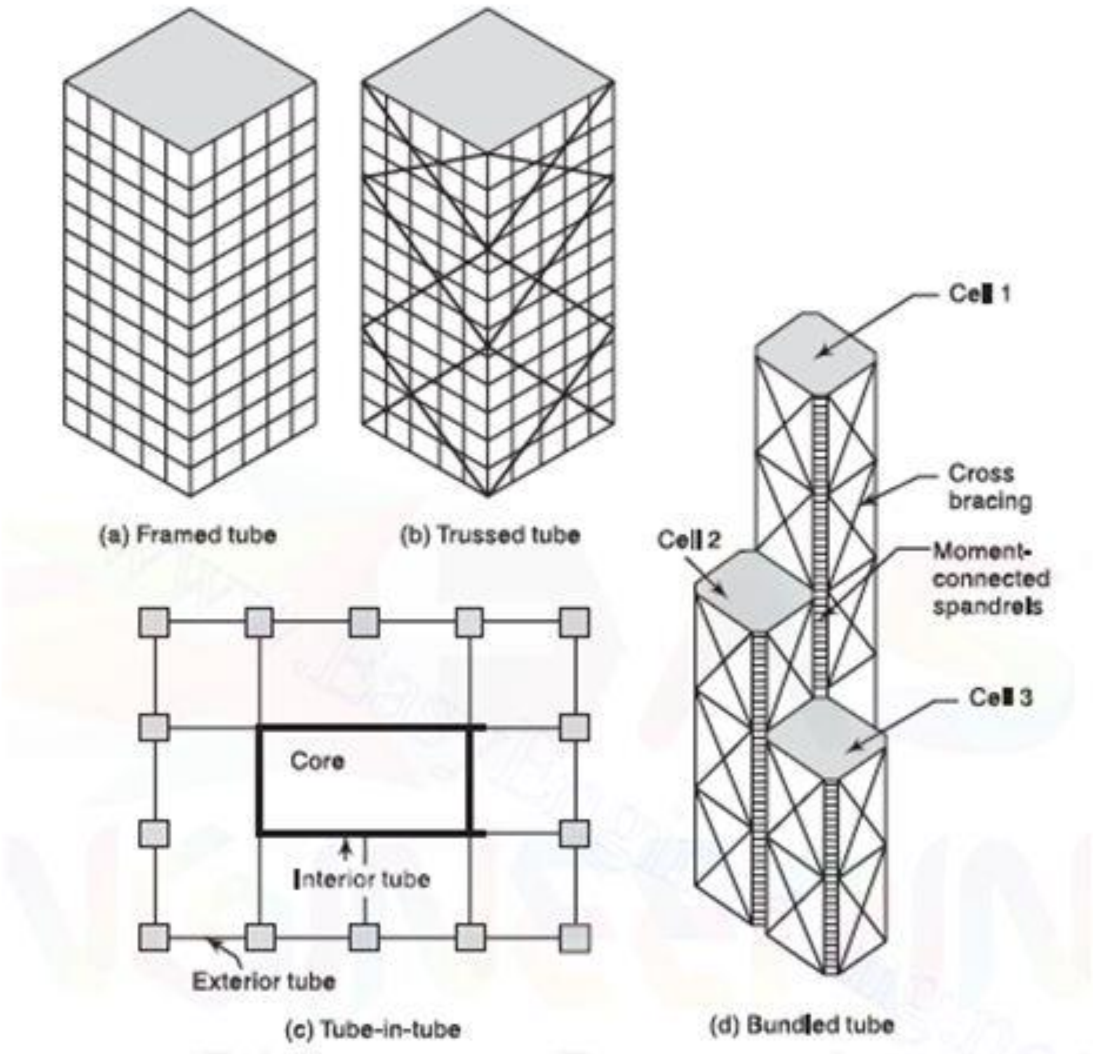

Fig. 2.7 Types of tubes structures (Earthquake Behavior of Buildings, 2012)

The flat slab system is one of the most favorite reinforced concrete structural forms with the architects. It provides architectural flexibility, maximum usage of space, easier formwork, and shorter construction period. However, the flat slab systems need special attention as these perform poorly under earthquake loading and are less efficient. This is primarily due to the absence of deep beams or shear walls in this form of construction. When subjected to even moderate earthquakes, the excessive deformations cause damage to the non-structural members creating panic.

For buildings taller than about forty stories, the effect of lateral forces becomes increasingly intense, and tube systems become economical. Tube systems may be classified as framed-tube, trussed-tube, tube-in-tube, and bundled-tube systems.

In the framed-tube system [Fig. 3.6(a)], closely spaced columns are tied at each floor level by deep spandrel beams, thereby creating the effect of a hollow tube, perforated by openings for windows. This system represents a logical evolution of the conventional framed structure, possessing the necessary lateral stiffness with excellent torsional qualities, while retaining the flexibility of planning. The trussed-tube system shown in [Fig. 3.6(b)] is advancement over the framed tube system. The diagonal members, along with girders and columns, form a truss system that imparts a great deal of stiffness to the building. The tube-in-tube system [Fig. 3.6(c)] consists of an exterior tube that resists the bending moment due to lateral forces and an interior slender tube, which resists the shear produced by the lateral forces. The bundled-tube system [Fig. 3.5(d)] is made up of a number of tubes separated by shear walls; the tubes rise to various heights and each tube is designed independently.

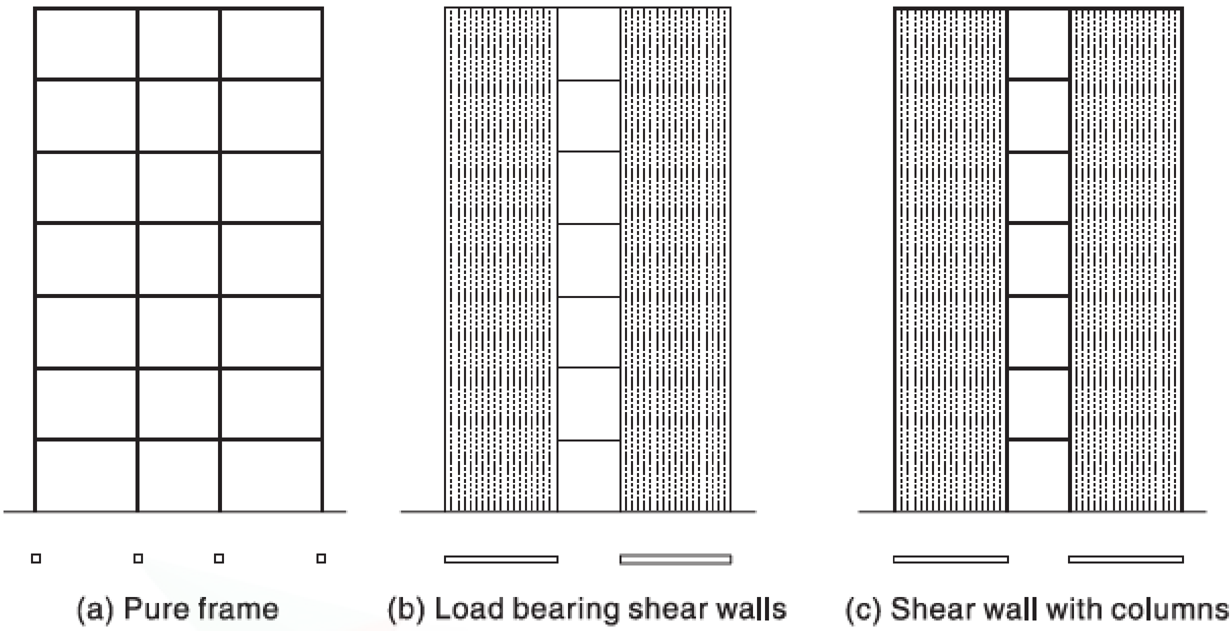

Fig. 2.8 Types of system framing (Earthquake Behavior of Buildings, 2012)

In a multi-storey building, the moment-resisting frames, along with shear walls [Fig. 3.8(a)] or the bracing, work to resist lateral forces. Frames deform in a predominantly shear mode [Fig. 3.8 (b)], where the relative storey deflection depends on the shear applied at the storey level. The walls deform in an essentially bending mode [Fig. 3.8 (c)]. A structural framework with load-bearing walls hence exhibits an intermediate form of behavior as shown in Fig. 3.8 (d). In the lower part of the building, the walls resist the greater part of the shear force, but the shear gradually decreases in higher stories. If flexural deformation occurs in a load-bearing wall, the adjacent boundary beam undergoes a large deformation and should have adequate ductility. Also, adjacent columns are subjected to large axial force, so the difficulties arise, both in designing the column cross-section and in dealing with the pull-out force on the foundation. To overcome this situation, the building may be braced or shear walls may be provided.

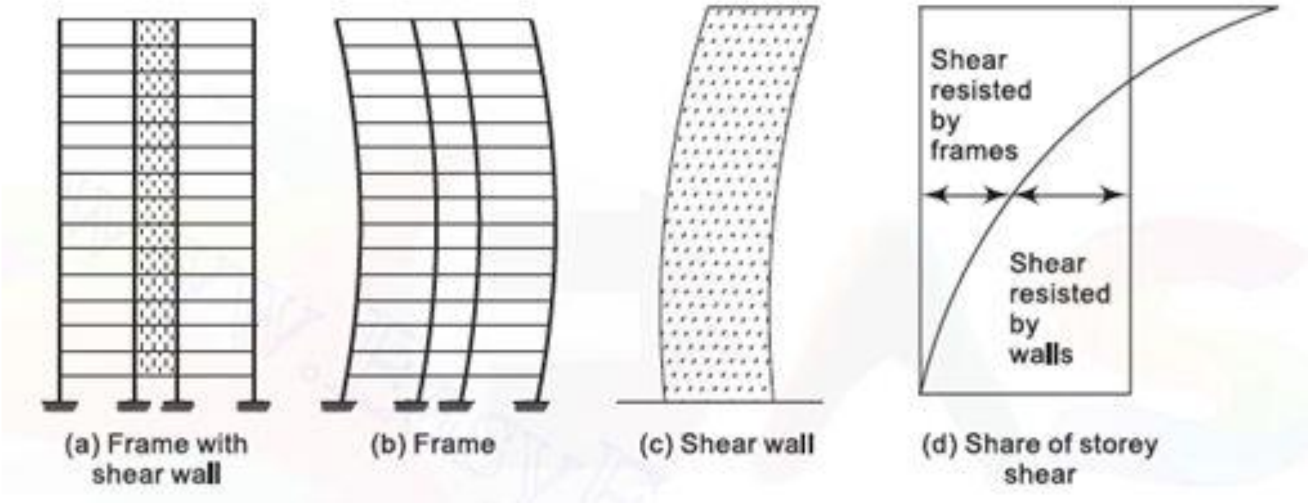

Fig. 2.9 Contribution of frames and shear walls to storey shear (Earthquake Behavior of Buildings, 2012)

The framed-tube system combines the behavior of a true cantilever, such as a shear wall, with that of a beam–column frame. Overturning under the lateral load is resisted by the tube form, causing compression and tension in the columns. The shear from the lateral load is resisted by bending in columns and beams, primarily in the two sides of the building parallel to the direction of the lateral load.

2.3 Literature Review:

The subject of earthquake engineering has been attracting the attention of researchers for several decades with civil engineering researchers. There exist several review papers that address various topics within this discipline of research and here we make brief mention about these works.

The results thus obtained were analyzed and compared with each other. Liu et al (2010) proposed a performance based fragility analysis based method in which the uncertainty due to variability in ground motion and structures are considered. By the proposed method of fragility analysis they performed analysis of a 15 storied building having composite beam and concrete filled square steel tube column Panchal and Marathe (2011) used a comparative method of study for RCC, Composite and steel options in a G+30 storey commercial building situated in earthquake Zone IV. For this they used Equivalent static method and used the software ETABS. The comparative study included size, deflections, material consumption of members in RCC and steel sections as compared to Composite sections was also studied closely and based on this study a cost comparison analysis was also performed.

Panchal & Patodi (2011) evaluated the seismic performance of multistoried building for which they have considered Steel-Concrete Composite and R.C.C. For their analysis the methods that they used were Equivalent static method and Linear Dynamic Response Spectrum Analysis.

Srikanth and Ramesh (2013) comparative study of seismic response for seismic coefficient and response spectrum methods. In this thesis, the earthquake response of symmetric multi-storied building by two methods is studied. The methods include seismic coefficient method as recommended by IS Code and modal analysis using response spectrum method of IS Code in which the stiffness matrix of the building corresponding to the dynamic degrees of freedom is generated by idealizing the building as shear building. The responses obtained by above methods in two extreme zones as mentioned in IS code i.e. zone II and V are then compared. Test results Base Shears, Lateral Forces and Storey Moments are compared.

Sharma and Maru (2014) studied about dynamic analysis of multistory G+30 regular building.These buildings have the plan area of 25m x 45m with a storey height 3.6m each and depth of foundation is 2.4 m. & total height of chosen building including depth of foundation is 114 m. The static and dynamic analysis has done on computer with the help of STAAD-Pro software using the parameters for the design as per the IS-1893- 2002-Part-1 for the zones- II and III and the post processing result obtained has summarized.

Mahmoud and Abdallah (2014) have done a research on response analysis of multistory RC buildings under equivalent static and dynamic loads according to Egyptian code. The objective of this research is to assess the seismic performance of an existing shear wall residential building located in Cairo. Both dynamic response spectrum (RS) and equivalent static force (ESF) methods are used in the seismic analysis. The design RS curve suggested by the Egyptian Code (EC) for seismic design is utilized to perform the dynamic analysis. The response analysis of the building under the acting seismic loads has been performed using ETABS, universal finite element analysis software for dynamic analysis. The results of the study show significant differences in building's responses obtained using ESF and RS analysis methods. It has been found that the application of static method in a specified direction results in responses in the same direction. However, the applications of dynamic RS method induces response in both directions regardless the direction of loading.

Mahesh and Rao (2014). The behavior of G+11 multi story building of regular and irregular configuration under earth quake is complex and it varies of wind loads are assumed to act simultaneously with earth quake loads. In this paper a residential of G+11 multi story building is studied for earth quake and wind load using ETABS and STAAD PRO V8i. Assuming that material property is linear static and dynamic analysis is performed. These analyses are carried out by considering different seismic zones and for each zone the behavior is assessed by taking three different types of soils namely Hard, Medium and Soft. Different response like story drift, displacements base shear are plotted for different zones and different types of soils.

Gottala and Nanda (2015) carried out comparative study of static and dynamic seismic analysis of a multistory building. A multi-storied framed structure of (G+9) pattern is selected. Linear seismic analysis is done for the building by static method (Seismic Coefficient Method) and dynamic method (Response Spectrum Method) using STAAD-Pro as per the IS-1893-2002-Part-1. A comparison is done between the static and dynamic analysis, the results such as Bending moment, Nodal Displacements, Mode shapes are observed, compared and summarized for Beams, Columns and Structure as a whole during both the analysis.

Thermou, Elnashai, Plumierand Doneux et al (2002) have discussed clauses and deficiencies of the Eurocode which earlier used to cause problem for the designers. For obtaining the response of the frames, methods of pushover analysis were also employed. Their main purpose was to study and investigate if the designed structure could behave in an elastically dissipative way.

Koppad and Itti (2013) considered steel-concrete composite with RCC options for analyzing a B+G+15 building which is situated in earthquake zone III and earthquake loading is as per the guidelines of IS1893(part-I): 2002. The parameters like bending moment and maximum shear force were coming more for RCC structure than the composite structure. Their work suggested that composite framed structures have many benefits over the traditional RC structures for high rise buildings.

Elnashai and Elghazouli (1993) developed a model for analysis of structures subjected to cyclic and dynamic loads. These structures were primarily Steel-Concrete Composites and the model they developed was a non-linear model. The efficiency and accuracy of the developed model is shown through correlation between the experimental results and analytical simulations. The model was used for parametric studies resulting in providing important conclusion for ductility based earthquake-resistant design.

From these Papers reviews I found that there were many studies in seismic analysis, so it helps me to figure out firstly the Methods of Seismic Analysis, the way to make comparison between these methods (Linear Static, Linear Dynamic, Non-linear Static, and Non- linear Dynamic analysis). Secondly learn How to make simulation by using software program (ETABS, STAAD-Pro, etc). Finally make comparison between the results come from analysis to know which materials of building suitable in seismic areas.

Chapter Three
Theoretical Study

Chapter Three
Theoretical Study

3.1 Introduction:

Structural analysis is mainly concerned with finding out the behavior of a structure when subjected to some action. This action can be in the form of load due to weight of things such as people , furniture , wind snow etc .or some other kind of excitation such as 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.

3.2 Measurement of Earthquakes

Earthquakes are complex multidimensional phenomena, the scientific analysis of which requires measurement. Prior to the invention of modern scientific instruments, earthquakes were qualitatively measured by their effect or intensity, which differed from point to point. With the deployment of seismometers, an instrumental quantification of the entire earthquake event the unique magnitude of the event — became possible. These are still the two most widely used measures of an earthquake, and a number of different scales for each have been developed, which are sometimes confused.

Engineering design, however, requires measurement of earthquake phenomena in units such as force or displacement.

3.2.1Magnitude

An individual earthquake is a unique release of strain energy - quantification of this energy has formed the basis for measuring the earthquake event. Richter (1935) was the first to define earthquake magnitude, as

$$M_L = log_A - log_{A_0} \qquad \textbf{(3.1)}$$

where ML is the local magnitude (which Richter only defined for Southern California), A is the maximum trace amplitude in micrometers recorded on a standard Wood–Anderson short-period torsion seismometer, at a site 100 km from the epicenter, and log A_0 is a standard value as a function of distance for instruments located at distances other than 100 km and less than 600 km. Subsequently, a number of other magnitudes have been defined, the most important of which are surface wave magnitude MS, body wave magnitude m_b, and moment magnitude MW. Due to the fact that ML was only locally defined for California (i.e., for events within about 600 km of the observing stations), surface wave magnitude MS was defined analogously to ML, using teleseismic observations of surface waves of 20 s period.

3.2.2 Intensity

In general, seismic intensity is a metric of the effect, or the strength, of an earthquake hazard at a specific location. While the term can be generically applied to engineering measures such as peak ground acceleration (PGA), it is usually reserved for qualitative measures of location-specific earthquake effects, based on observed human behavior and structural damage. Numerous intensity scales developed in preinstrumental times — the most common in use today are the modified Mercalli (MMI).

Modified Mercalli Intensity (MMI) is a subjective scale defining the level of shaking at specific sites on a scale of I to XII. (MMI is expressed in Roman numerals, to connote its approximate nature.) For example, moderate shaking that causes few instances of fallen plaster or cracks in chimneys constitutes MMI VI. It is difficult to find a reliable relationship between magnitude, which is a description of the earthquake's total energy level, and intensity, which is a subjective description of the level of shaking of the earthquake at specific sites, because shaking severity can vary with building type, design and construction practices, soil type, and distance from the event.

3.2.3 Time History

Sensitive strong motion seismometers have been available since the 1930s, and record actual ground motions specific to their location, Figure 3.1. Typically, the ground motion records, termed seismographs or time histories, have recorded acceleration (these records are termed accelerograms) for many years in analog form on photographic film and, more recently, digitally. Analog records required considerable effort for correction due to instrumental drift, before they could be used.

Time histories theoretically contain complete information about the motion at the instrumental location, recording three traces or orthogonal records (two horizontal and one vertical). Time histories (i.e., the earthquake motion at the site) can differ dramatically in duration, frequency content, and amplitude. The maximum amplitude of recorded acceleration is termed the peak ground acceleration, PGA (also termed the ZPA, or zero period acceleration) — peak ground velocity (PGV) and peak ground displacement (PGD) are the maximum respective amplitudes of velocity and displacement. Acceleration is normally recorded, with velocity and displacement being determined by integration; however, actual velocity and displacement meters are also deployed, to a lesser extent.

3.2.4 Elastic Response Spectra

If a single degree-of-freedom (SDOF) mass is subjected to a time history of ground (i.e., base) motion similar to, the mass or elastic structural response can be readily calculated as a function of time, generating a structural response time history, as shown in Figure (3.1)for several oscillators with differing natural periods. However, this is time consuming, and the elastic response is more typically calculated is the Fourier transform of the input motion (i.e., the Fourier transform of the ground motion time history), which takes advantage of computational efficiency using the fast Fourier transform .

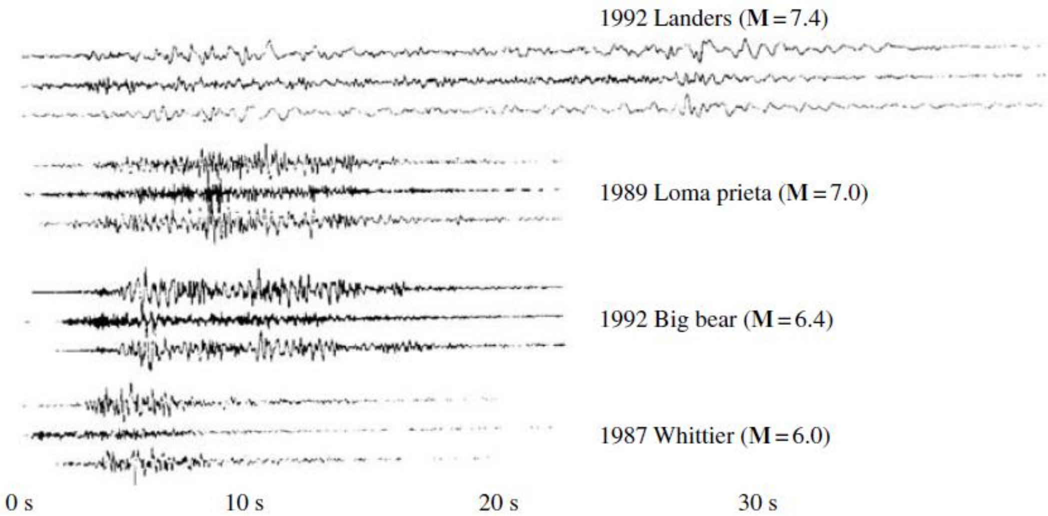

Figure (3.1) Typical earthquake accelerograms

For design purposes, it is often sufficient to know only the maximum amplitude of the response time history. If the natural period of the SDOF is varied across a spectrum of engineering interest, then the plot of these maximum amplitudes is termed a response spectrum. Figure 3.2 illustrates this process, resulting in S_d, the displacement response spectrum, while Figure 3.3 shows (a) the S_d, displacement response spectrum, (b) S_v, the velocity response spectrum (also denoted PSV, the pseudo spectral velocity, pseudo to emphasize that this spectrum is not exactly the same as the relative velocity response spectrum; Hudson,
1979), and (c) S_a, the acceleration response spectrum.

Response spectra form the basis for much modern earthquake engineering structural analysis and design. They are readily calculated if the ground motion is known. For design purposes, however, response spectra must be estimated—this process is discussed in another chapter. Response spectra may be plotted in any of several ways, as shown in Figure (3.2) with arithmetic axes, and in Figure 3.4, where the velocity response spectrum is plotted on tripartite logarithmic axes, which equally enables reading of displacement and acceleration response. Response spectra are most normally presented for 5% of critical damping.

While actual response spectra are irregular in shape, they generally have a concave-down arch or trapezoidal shape, when plotted on tripartite log paper. Newmark observed that response spectra tend to be characterized by three regions: (1) a region of constant acceleration, in the high frequency portion of the spectra; (2) constant displacement, at low frequencies; and (3) constant velocity, at intermediate frequencies, as shown in

Figure (3.5). If a spectrum amplification factor is defined as the ratio of the spectral parameter to the ground motion parameter (where parameter indicates acceleration, velocity, or displacement), then response spectra can be estimated from the data, provided estimates of the ground motion parameters are available. An example spectrum using these data is given in Figure (3.5).

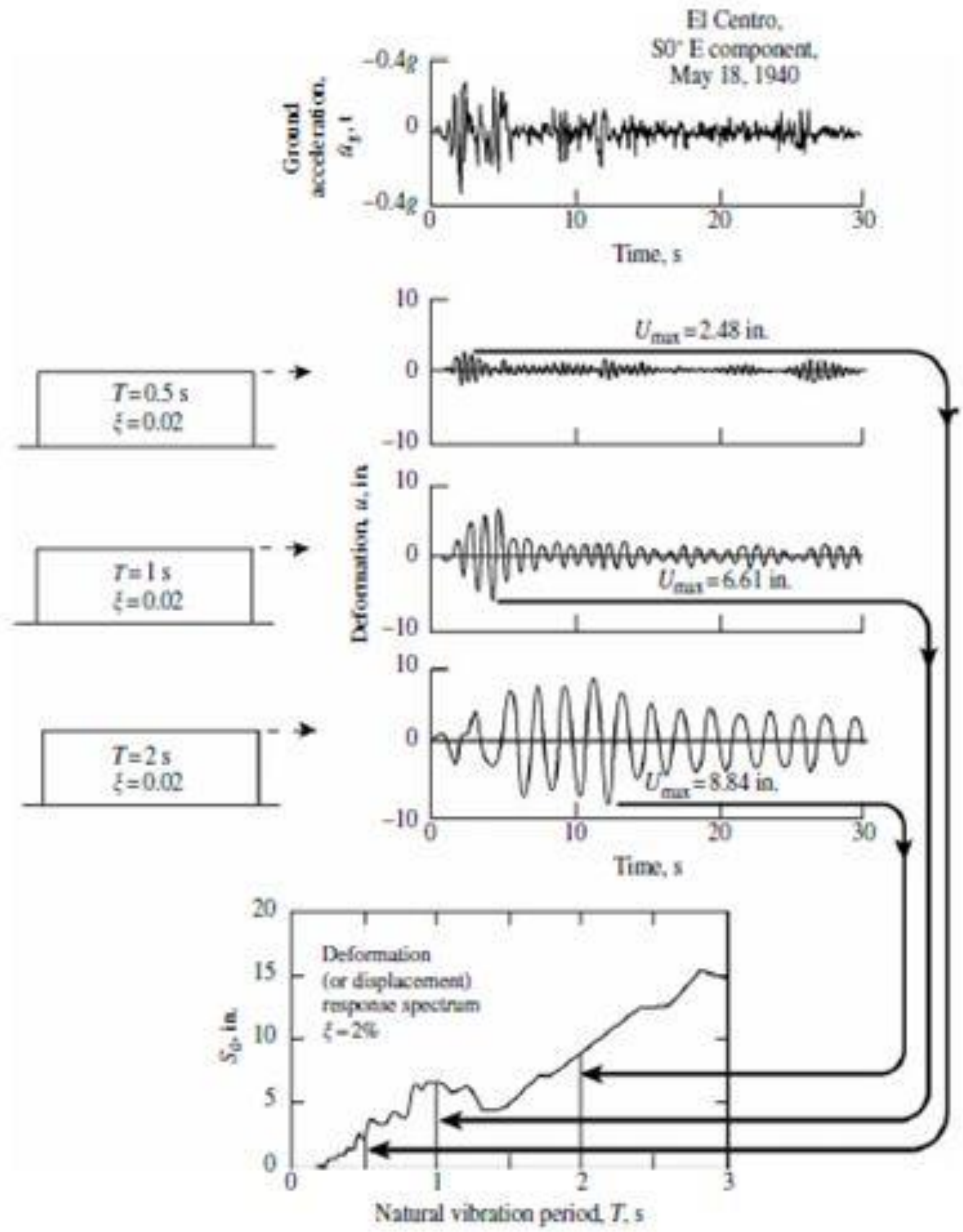

Fig.3.2Computation of deformation (or displacement) response spectrum
(Chopra, 1981)

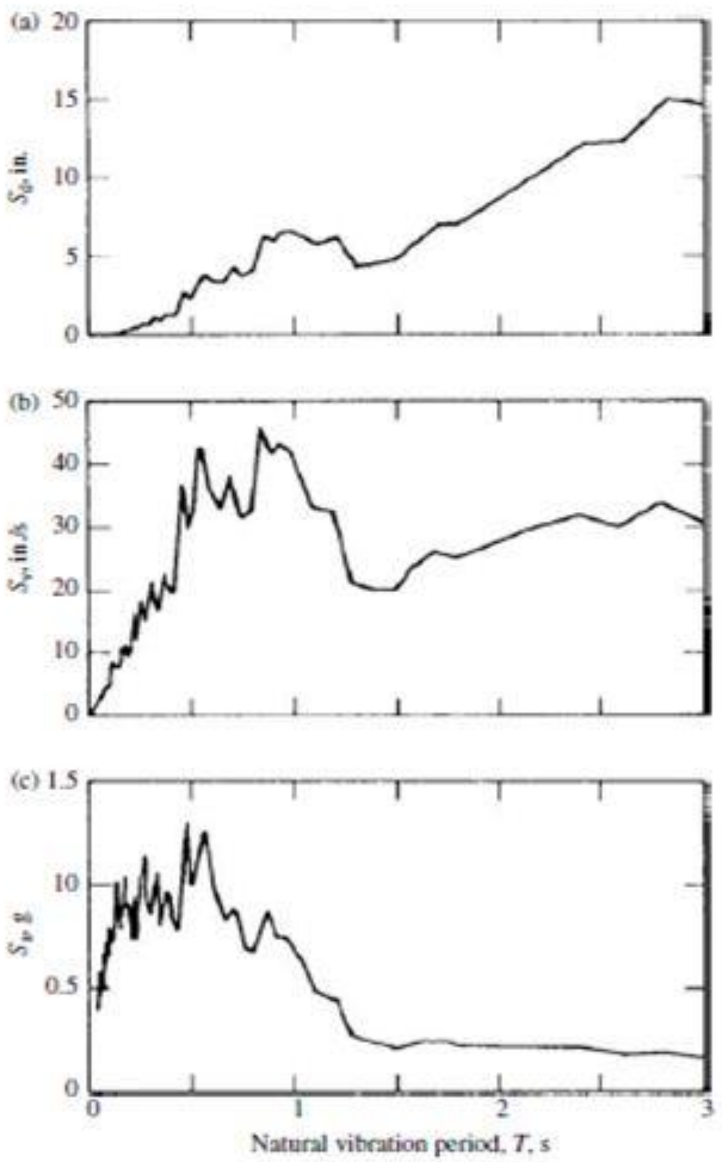

Fig. 3.3 Response spectra (Chopra, 1981).

3.2.5 Inelastic Response Spectra

While the foregoing discussion has been for elastic response spectra, most structures are not expected, or even designed, to remain elastic under strong ground motions. Rather, structures are expected to enter the inelastic region.

3.3 Code-based Analysis Method

When a structure is subjected to ground motions in an earthquake, it responds by vibrating. The random motion of the ground caused by an earthquake can be resolved in any three mutually perpendicular directions: the two horizontal directions (x and y) and the vertical direction (z). This motion causes the structure to vibrate or shake in all three directions; the predominant direction of shaking is horizontal.

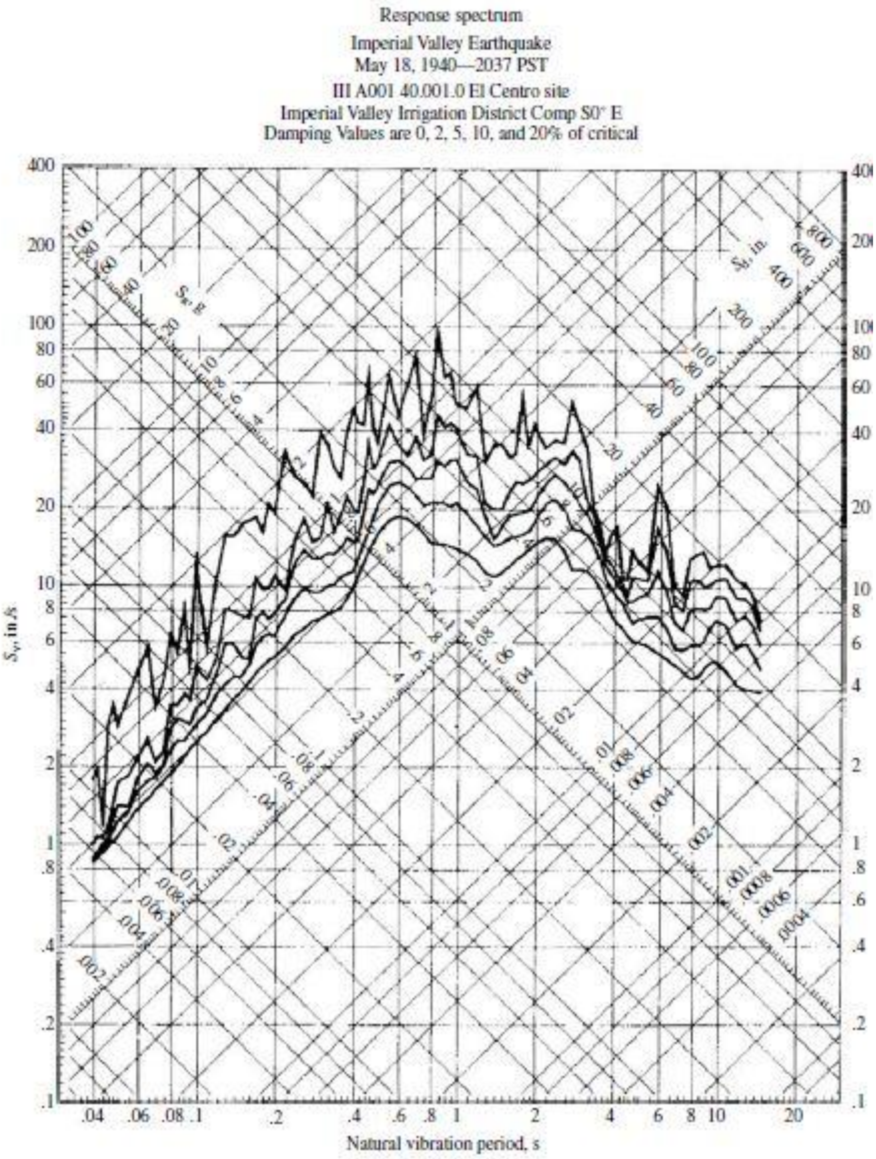

Fig. 3.4 Response spectra, tripartite plot (El Centro) (Chopra, 1981).

All the structures are primarily designed for gravity loads force equal to mass time's gravity in the vertical direction. Because of the inherent factor of safety used in the design specifications, most structures tend to be adequately protected against vertical shaking. However, earthquake-generated vertical inertia forces must be considered in the design unless checked and proved to be insignificant. In general, buildings are not particularly susceptible to vertical ground motion, but its effect should be borne in mind in the design of RCC columns, steel column connections, and prestressed beams. Vertical acceleration should also be considered in structures with large spans, those in which stability is a criterion for design, or for overall stability analysis of structures. Structures designed only for vertical shaking, in general, may not be able to safely sustain the effect of horizontal shaking. Generally, however, the inertia forces generated by the horizontal components of ground motion require greater consideration in seismic design. Hence, it is necessary to ensure that the structure is adequately resistant to horizontal earthquake shaking too.

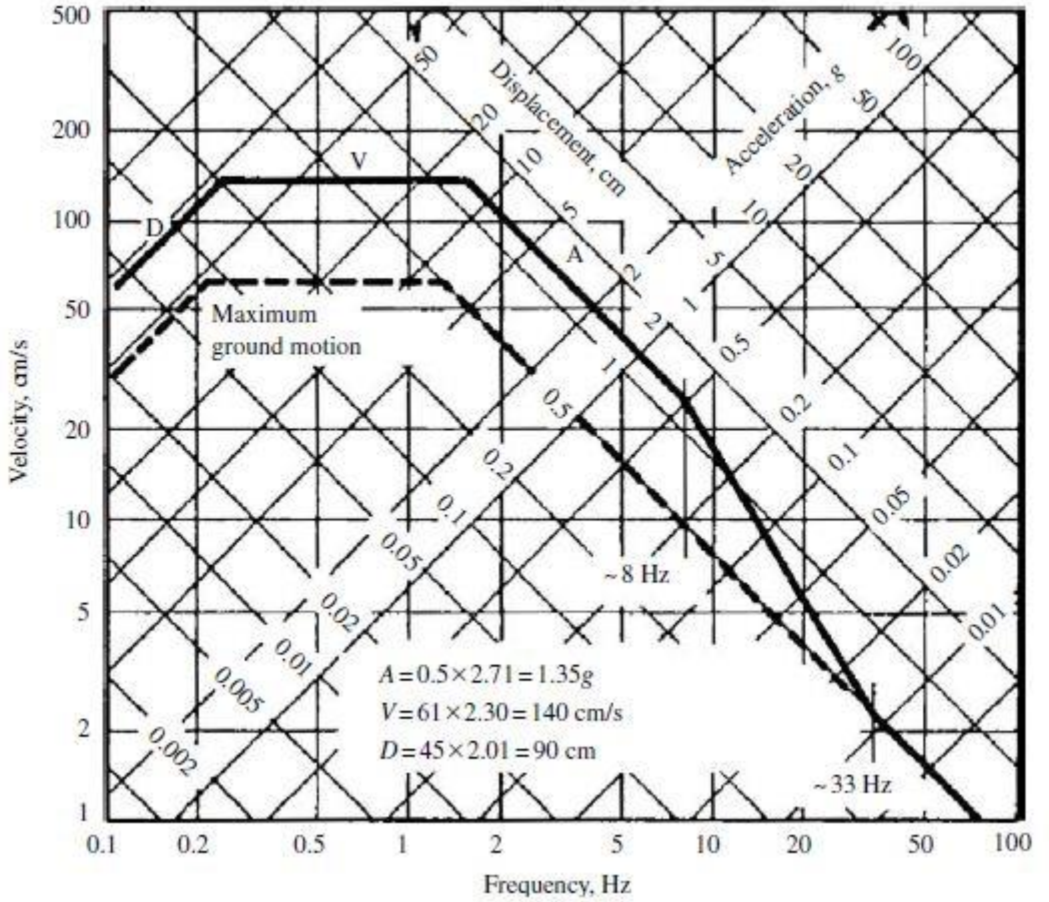

Fig. 3.5 Idealized elastic design spectrum, horizontal motion (ZPA¼0.5g, 5% damping, one sigma cumulative probability (Chen and Lui, 2006)

As the ground on which a building rests is displaced, the base of the building moves suddenly with it, but the roof has a tendency to stay in its original position. The tendency to continue to remain in its original position is known as inertia. So the upper part of the structure will not respond instantaneously but will lag because of inertial resistance and flexibility of the structure. Since the roofs and foundations are connected with the walls and columns, the roofs are dragged along with the walls/columns. The building is thrown backwards and the roof experiences a force called the inertia force (Fig. 3.6). The maximum inertia force acting on a simple structure during an earthquake may be obtained by multiplying the roof mass m by the acceleration a. When designing a building according to the codes, the lateral force is considered in each of the two orthogonal horizontal directions of the structure. For structures having lateral force-resisting elements (e.g., braced frames, shear walls) in both directions, the design lateral force is considered along one direction at a time, and not in both the directions simultaneously. Structures with lateral force-resisting elements in directions other than the two orthogonal directions are analyzed for the load combinations.

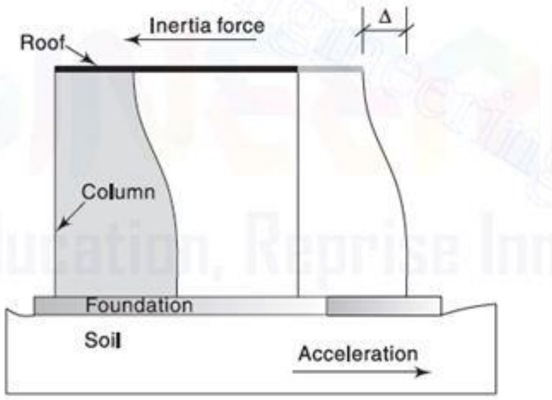

Fig.3.6 Inertia force due to ground motion (Chen and Lui, 2006)

The steps involved in an adequate earthquake-resistant design for a structure include the following:
1. Selecting a workable overall structural concept.
2. Establishing preliminary trial member sizes
3. Performing a structural analysis of the members to verify that stress and displacement requirements are satisfied.
4. Providing structural and non-structural details so that the building will accommodate the distortions and stresses. Elements which cannot accommodate these stresses and distortions, such as rigid stairs, partitions, and irregular wings, should be isolated to reduce detrimental effects to the lateral force-resisting system.

3.4 Seismic Design Requirements

The two most important elements of concern to a structural engineer are calculation of seismic design forces and the means for providing sufficient ductility. In most structural engineering problems, dead loads (DLs), live loads, and wind loads can be evaluated with a fair degree of accuracy. However, the situation with regard to earthquake forces is entirely different. The loads or forces that a structure sustains during an earthquake result directly from the distortion induced in the structure by the motion of the ground on which it rests. Base motion is characterized by displacements, velocities, and accelerations, which are erratic in direction, magnitude, duration, and sequence.

Earthquake loads (ELs) are inertia forces related to the mass, stiffness and energy-absorbing (e.g., damping and ductility) characteristics of the structure. The design seismic loading recommended by building codes is in the form of static lateral loading, which depends upon the weight, the gross dimensions, and the type of structure, as well as the seismicity of the area in which it is to be built. These static design loads are used to determine the strength of the structure necessary to withstand the dynamic loads induced by earthquakes. When the proper earthquake design loads are determined by the traditional static approach, uncertainties arise from a number of factors; the most important of these are as follows:

(a) Not enough empirical data are available at present to make a reliable prediction of the character of the critical earthquake motions (i.e., amplitude, frequency characteristics, and duration) to which a proposed structure may be subjected during its lifetime.
(b) Analysis by elastic assumptions does not take into account the change in the properties of the building materials during the progress of an earthquake. This presents difficulties in ascertaining the values of the structural parameters affecting the dynamic response (e.g., stiffness and damping), as well as the dynamic properties of the soil or supporting medium.
(c) Soil–structure interaction and geological conditions have a profound effect on structural performance. At present there is no clear-cut method to correctly incorporate these effects.

Despite these uncertainties, the structure should perform satisfactorily beyond the elastic-code-stipulated stress. Ductility, the foremost important property in the inelastic range thus becomes a necessity for an earthquake-resistant design of a structure. It is generally accepted that sufficient ductility will be achieved by following the codes. However, design codes are prepared for regular structures. For structures requiring high ductility, e.g., a light flexible structure attached to a large structure, careful analysis may be required.

3.4.1 Importance of Ductility

The seismic forces specified in the code are quite small in comparison to the actual forces (4 – 6 times) expected at least once in the lifetime of the building. In spite of the large difference, the structures designed for the lateral loads specified by the code have survived severe earthquakes because of the following reasons.

1. Due to the ductility of the structure, energy is dissipated by post-elastic deformations.
2. It is the reduced response due to increased damping and soil–structure interaction.

Figure (3.7) shows the relationship between lateral design forces for an elastic structure and for a yielding ductile structure. Much larger design forces are required for an elastic structure without ductility.

During the life of a structure located in a seismically active zone, it is generally expected that the structure will be subjected to many small earthquakes, a few moderate earthquakes, one or more large earthquakes, and, possibly, a very severe earthquake. If the earthquake motion is severe, most structures will yield in some of their elements. The energy absorption capacity of the yielding structure will limit the damage. Thus, buildings that are properly designed and detailed can survive earthquake forces, which are substantially greater than the design forces that are associated with allowable stresses in the elastic range. It is evident that it would be uneconomical to design a structure to withstand the greatest likely earthquake, without damage within the elastic range. Hence, the structure is allowed to be damaged in case of severe shaking. The cost of securing the structure against strong shaking must be weighed against the importance of the structure and the probability of earthquakes. Seismic design concepts must consider the building’s proportions, and details of its ductility (capacity to yield) and reserve energy absorption capacity, to ensure that it survives the inelastic deformations that would result from a maximum expected earthquake. Special attention must be given to connections that hold the lateral force-resisting elements together.

3.4.2 Regular and Irregular Configurations

It is ensured that lateral loads are transferred to the ground without excessive rotations in ductile manner. Reasonable strength and ductility can be achieved by the mandatory requirements of the code. A building with irregular configuration may be designed to meet all code requirements, but it will not perform well as a building with a regular configuration. If the building has an odd shape that is not properly considered in the design, then good design and construction are of secondary value.

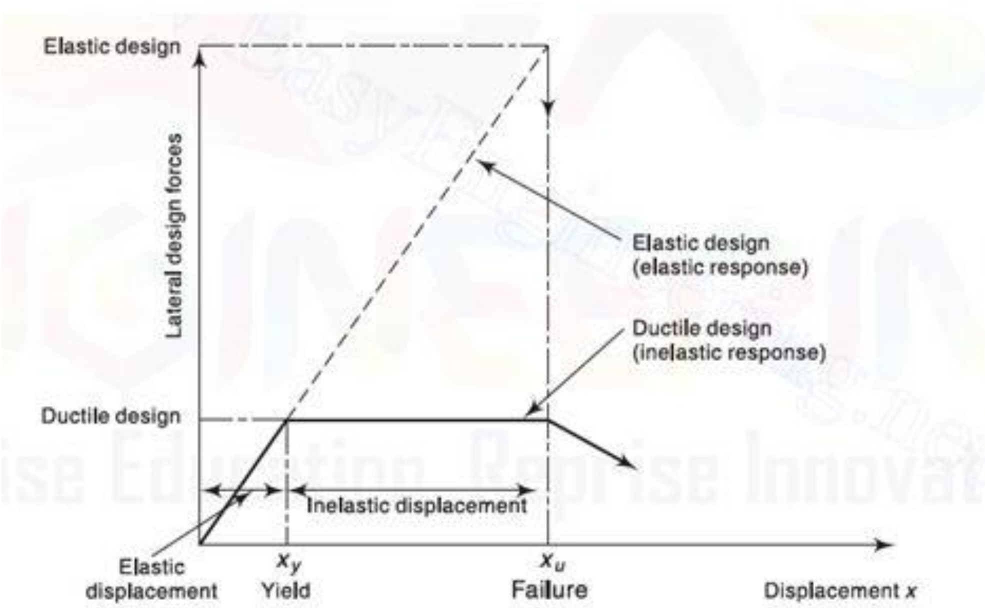

Fig.3.7 Lateral forces and ductility (ductility factor x/x y, ductile capacity x u/x y) (Chen and Lui, 2006)

However, to perform well in an earthquake, a building should possess four main attributes simple and regular configuration, adequate lateral strength, stiffness, and ductility. Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage than buildings with irregular configurations. When a building has an irregular feature, such as asymmetry in plan or vertical discontinuity, the assumptions used in analysis of buildings with regular features may not apply. These irregularities result in building responses significantly different from those assumed in the equivalent static force procedure. Therefore, it is best to avoid creating buildings with irregular features. A building is considered as irregular if at least one of the conditions given in Appendices IV and V is applicable.

A building is analyzed for its response to ground motion by representing the structural properties in an idealized mathematical model as an assembly of masses interconnected by springs and dampers. The tributary weight to each floor level is lumped into a single mass, and the force-deformation characteristics of the lateral force-resisting walls or frames between floor levels are transformed into equivalent storey stiffness. Because of the complexity of the calculations, the use of a computer program is necessary, even when the equivalent static force procedure is used in design.

3.5 Seismic Methods of Analysis

After selecting the structural model, it is possible to perform analysis to determine the seismically induced forces in the structures. The analysis can be performed on the basis of the external action, the behavior of the structure or structural materials, and the type of structural model selected. Based on the type of external action and behavior of structure, the analysis can be further classified as linear static analysis, linear dynamic analysis, non-linear static analysis, or non-linear dynamic analysis.

Linear static analysis or equivalent static analysis can be used for regular structures with limited height. Linear dynamic analysis can be performed in two ways, either by the response spectrum method or by the elastic time-history method. The significant difference between linear static and linear dynamic analyses is the level of the forces and their distribution along the height of the structure.

Non-linear static analysis is an improvement over linear static or dynamic analysis in the sense that it allows inelastic behavior of the structure. The method is simple to implement and provides information on the strength, deformation, and ductility of the structure, as well as the distribution of demands. This permits the identification of the critical members that are likely to reach limit states during the earthquake, to which attention should be paid during the design and detailing process. But the non-linear static method is based on many assumptions, which neglect the variation of loading patterns, the influence of higher modes of vibration, and the effect of resonance. In spite of the deficiencies, this method, known as push-over analysis, provides a reasonable estimation of the global deformation capacity, especially for structures that primarily respond according to the first mode.

A non-linear dynamic analysis or inelastic time-history analysis is the only method to describe the actual behavior of a structure during an earthquake. The method is based on the direct numerical integration of the differential equations of motion by considering the elasto-plastic deformation of the structural element.

3.6 Equivalent Lateral Force Method (Seismic Coefficient Method)

Seismic analysis of most structures is still carried out on the assumption that the lateral force is equivalent to the actual (dynamic) loading. This method requires less effort because, except for the fundamental period, the periods and shapes of higher natural modes of vibration are not required. The base shear, which is the total horizontal force on the structure, is calculated on the basis of the structure’s mass, its fundamental period of vibration, and corresponding shape. The base shear is distributed along the height of the structure, in terms of lateral forces, according to the code formula. Planar models appropriate for each of the two orthogonal lateral directions are analyzed separately; the results of the two analyses and the various effects, including those due to tensional motions of the structure, are combined. This method is usually conservative for low- to medium-height buildings with a regular configuration.

The assumptions common to the equivalent lateral force procedure is as follows (a) forces and deformations can be determined by combining the results of independent analyses of a planar idealization of the building for each horizontal component of ground motion, and by including torsion moments determined on an indirect, empirical basis and (b) non-linear structural response can be determined to an acceptable degree of accuracy, by linear analysis of the building using the design spectrum for inelastic systems. Both analysis procedures are likely to be inadequate if the dynamic response behavior of the building is quite different from what is implied by these assumptions, and also if the lateral motions in two orthogonal directions and the torsion motions are strongly coupled.

Buildings with large eccentricities at the centers of storey resistance relative to the centers of floor mass, or buildings with close values of natural frequencies of the lower modes and essentially coincident centers of mass and resistance, exhibit coupled lateral-torsional motions. For such buildings independent analyses for the two lateral directions may not suffice, and at least three degrees of freedom per floor—two translational motions and one torsional—should be included in the idealized model. The modal method, with appropriate generalizations of the concept involved, can be applied to analyses of the model. Because natural modes of vibration will show a combination of translational and torsional motions, it is necessary while determining the modal maxima to account for two facts: that a given mode might be excited by both horizontal components of ground motion; and modes that are primarily torsional can be excited by translational components of ground motion. Because natural frequencies of a building with coupled lateral torsional motions can be rather close to each other, the modal maxima should not be combined in accordance with the SRSS formula; instead a more general formula should be employed.

The factors taken into account in assessing lateral design forces and the design response spectrum are described as follows.

(a) Zone Factor [IS 1893 (Part 1): 2002, Clause 6.4]

Seismic zoning assesses the maximum severity of shaking that is anticipated in a particular region. The zone factor (Z), thus, is defined as a factor to obtain the design spectrum depending on the perceived seismic hazard in the zone in which the structure is located. The basic zone factors included in the code are reasonable estimate of effective peak ground acceleration.

(b) Importance Factor [IS 1893 (Part 1): 2002, Clause 7.2]

The importance factor is a factor used to obtain the design seismic force depending upon the functional use of the structure. It is customary to recognize that certain categories of buildings should be designed for greater levels of safety than the others, and this is achieved by specifying higher lateral design forces. Such categories are

(a) Buildings which are essential after an earthquake—hospitals, fire stations, etc.

(b) Places of assembly—schools, theatres, etc.

(C) Structures the collapse of which may endanger lives—nuclear plants, dams, etc.

(c) Response Reduction Factor [IS 1893 (Part 1): 2002, Clause 6.4]

The basic principle of designing a structure for strong ground motion is that the structure should not collapse but damage to the structural elements is permitted. Since a structure is allowed to be damaged in case of severe shaking, the structure should be designed for seismic forces much less than what is expected under strong shaking, if the structures were to remain linearly elastic. Response reduction factor (R) is the factor by which the actual base shear force should be reduced, to obtain the design lateral force. Base shear force is the force that would be generated if the structure were to remain elastic during its response to the design basis earthquake (DBE) shaking. The values of response reduction factors arrived at empirically based on engineering judgment are given in the Table. IS 1893 (Part I): 2002 uses R in the design to account for ductility. For example, a high value such as five, for special RCC moment-resisting frames, reflects their high ductility. Overstrength, redundancy, and ductility together contribute to the fact that an earthquake-resistant structure can be designed for a much lower force than that imparted by strong shaking of the structure (Fig. 3.8).

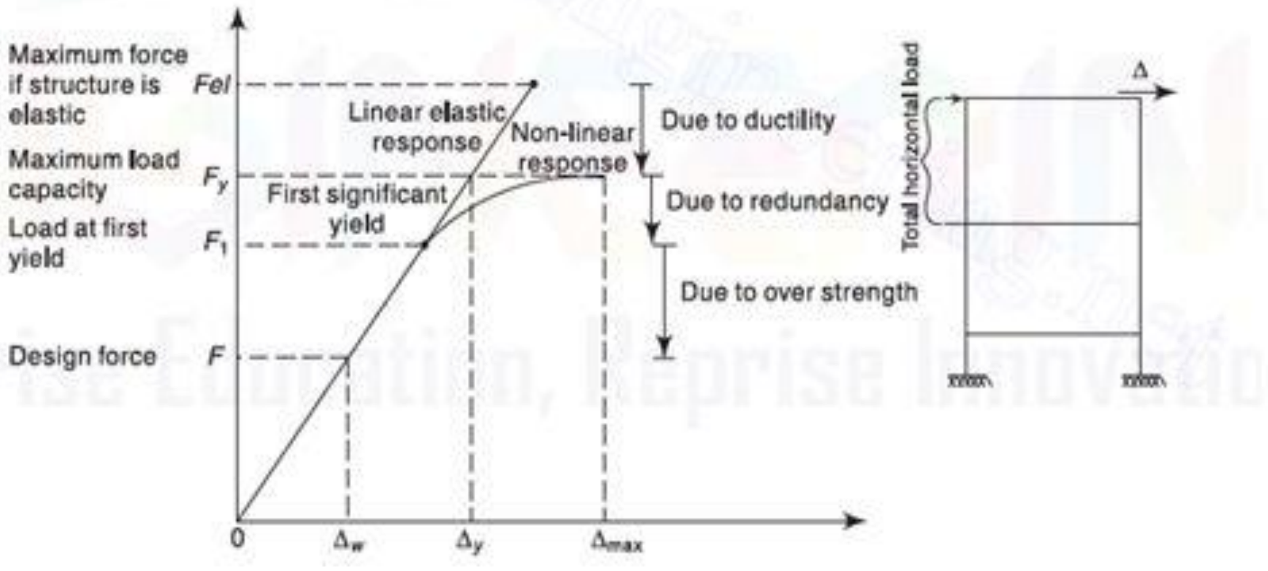

Fig.3.8 Concept of response reduction factor (Chen and Lui, 2006)

Overstrength: The factors that account for the yielding of a structure at loads higher than the design loads are

(a) Partial safety factors on seismic loads, gravity loads, and materials

(b) Material properties such as over-sized member, strain hardening, confinement of concrete, and higher material strength under cyclic loads

(c) Strength contributions of non-structural elements

(d) Special ductile detailing

Ductility Higher ductility indicates that a structure can withstand stronger shaking without collapse. When a structure yields there is more energy dissipation in the structure due to hysteresis. Also, the structure becomes softer and its natural period increases, which implies that the structure has to now resist a lower seismic force.

The fundamental natural period Ta is the first (longest) modal time period of vibration of the structure. Because the design loading depends on the building period, and the period cannot be calculated until a design has been prepared, IS 1893 (Part 1): 2002, clause 7.6, provides formulae from which Ta may be calculated.

For a moment-resisting frame building without brick infill panels, Ta may be estimated by the empirical expressions [IS 1893 (Part 1): 2002, clause 7.6.1]

For RC frame building $Ta = 0.075*h^{0.75}$ **(3.2)**

For steel frame building $Ta = 0.085*h^{0.75}$ **(3.3)**

For all other buildings, including moment-resisting frame buildings with brick infill panels, Ta may be estimated by the empirical expression [IS 1893 (Part 1): 2002, clause 7.6.2]

$$T_a = \frac{0.09\, h}{\sqrt{d}} \qquad (3.4)$$

Where h is height of building in meters (this excludes the basement stories, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement stories, when they are not so connected), and d is the base dimension of the building at the plinth level, in meters, along the considered direction of the lateral force.

This method of finding design lateral forces is also known as the static method or the equivalent static method or the seismic coefficient method. This procedure does not require dynamic analysis, however, it accounts for the dynamics of building in an approximate manner. The static method is the simplest one it requires less computational effort and is based on formulae given in the code of practice. First, the design base shear is computed for the whole building, and it is then distributed along the height of the building. The lateral forces at each floor level thus obtained are distributed to individual lateral load-resisting elements.

Vertical distribution of base shear to different floor levels [IS 1893 (Part 1): 2002, Clause 7.7.1].The design base shear (V_B) is distributed along the height of the building as per the following expression.

$$Q_i = V_B \frac{W_i\, h_i}{\sum_{i=1}^{n} W_i\, h_i^{\;2}} \qquad (3.5)$$

Where $Q_i$is the design lateral force at floor i, W_i is the seismic weight of floor i, hi is the height of floor i measured from the base, and n is the number of stories in the building, i.e., the number of levels at which masses are located

3.7Seismic Analysis Using ETABS:

3.7.1Introduction

ETABS is a highly efficient analysis and design program developed especially for building systems. It is loaded with an integrated system with an ability to handle the largest and most complex building models and configurations.

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS2016 features an intuitive and powerful graphical interface coupled with unmatched modeling, analytical, design, and detailing procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviors necessary for performance based design, making it the tool of choice for structural engineers in the building industry.

3.7.2History and Advantages of ETABS

Dating back more than 40 years to the original development of TABS, the predecessor of ETABS, it was clearly recognized that buildings constituted very special class of structures. Early releases of ETABS provided input, output and numerical solution techniques 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.

Although ETABS 2016 looks radically different from its predecessors of 40 years ago, its mission remains the same: to provide the profession with the most efficient and comprehensive software for the analysis and design of buildings. To that end, the current release follows the same philosophical approach put forward by the original programs, namely:

- Most buildings are of straightforward geometry with horizontal beams and vertical columns. Although any building configuration is possible with ETABS, in most cases, a simple grid system defined by horizontal floors and vertical column lines can establish building geometry with minimal effort.
- Many of the floor levels in buildings are similar. This commonality can be used to dramatically reduce modeling and design time.
- The input and output conventions used correspond to common building terminology. With ETABS, the models are defined logically floor-by-floor, column-by-column, bay-by-bay and wall by wall and not as a stream of non-descript nodes and elements as in general purpose programs. Thus the structural definition is simple, concise and meaningful.
- In most buildings, the dimensions of the members are large in relation to the bay widths and story heights. Those dimensions have a significant effect on the

stiffness of the frame. ETABS corrects for such effects in the formulation of the member stiffness, unlike most general-purpose programs that work on centerline-to-centerline dimensions.

- The results produced by the programs should be in a form directly usable by the engineer. General-purpose computer programs produce results in a general form that may need additional processing before they are usable in structural design.

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 analyses that ETABS can handle easily:

- Multi-story commercial, government and health care facilities
- Parking garages with circular and linear ramps
- Buildings with curved beams, walls and floor edges
- Buildings with steel, concrete, composite or joist floor framing
- Projects with multiple towers
- Complex shear walls and cores with arbitrary openings
- Performance based design utilizing nonlinear dynamic analyses
- Buildings based on multiple rectangular and/or cylindrical grid systems
- 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 response spectrum load cases, with built-in input curves
- Automated transfer of vertical loads on floors to beams and walls
- Capacity check of beam-to-column and beam-to-beam steel connections
- P-Delta analysis with static or dynamic analysis
- Explicit panel-zone deformations
- Punching shear checks for concrete slabs
- Construction sequence loading analysis
- Multiple linear and nonlinear time history load cases in any direction
- Foundation/support settlement
- Large displacement analyses
- Nonlinear static pushover
- Buildings with base isolators and dampers
- Design optimization for steel and concrete frames
- Design of concrete slabs using mild reinforcement and post tensioning
- Design capacity check of steel column base plates
- Floor modeling with rigid or semi-rigid diaphragms
- Automated vertical live load reductions

3.7.3An Integrated Approach

ETABS is a completely integrated system. Embedded beneath the simple, intuitive user interface are very powerful numerical methods, design procedures and international design codes, all working from a single comprehensive database. This integration means that you create only one model of the floor systems and the vertical and lateral framing systems to analyze, design, and detail the entire building.

Everything you need is integrated into one versatile analysis and design package with one Windows-based graphical user interface. No external modules are required. The effects on one part of the structure from changes in another part are instantaneous and automatic. The integrated components include:

- Drafting for model generation
- Seismic and wind load generation
- Gravity load distribution for the distribution of vertical loads to columns and beams when plate bending floor elements are not provided as a part of the floor system
- Finite element-based linear static and dynamic analysis
- Finite element-based nonlinear static and dynamic analysis(available in ETABS Nonlinear & Ultimate versions only)
- Output display and report generation
- Steel frame design (column, beam and brace)
- Concrete frame design (column and beam)
- Concrete slab design
- Composite beam design
- Composite column design
- Steel joist design
- Shear wall design
- Steel connection design including column base plates
- Detail schematic drawing generation

ETABS 2016 is available in three different levels that all share the same graphical user interface:

- ETABS 2016 Plus. Includes all available capabilities except for some design and certain nonlinear and dynamic analyses (p-delta and tension/compression only frame members are provided in all versions). Features include unmatched solution capacity with 64- bit optimized solvers, shear wall modeling, multiple response spectrum analyses, linear modal time histories, numerous import and export options, and comprehensive report generation. The steel frame design, concrete frame design, composite beam design, composite column design, steel joist design, shear wall design, steel connection design and steel base plate design components are all present.
- ETABS 2016 Nonlinear. Includes all of the features of ETABS2016 Plus, with additional nonlinear static and dynamic capabilities such as pushover, base isolation and dampers using Fast Nonlinear Analysis (FNA), Staged Construction, and multi-linear P-y springs.
- ETABS 2016 Ultimate. Includes all of the features of ETABS2016 Nonlinear with additional features such as concrete slab design with post-tensioning, nonlinear layered shell elements, dynamic analysis utilizing nonlinear frame and wall

hinges, linear and nonlinear direct integration time history analysis, buckling, and the modeling of creep and shrinkage behavior.

3.7.4 Modeling Features

The ETABS building is idealized as an assemblage of shell, frame, link, tendon, and joint objects. Those objects are used to represent wall, floor, column, beam, brace, tendon, and link/spring physical members. The basic frame geometry is defined with reference to a simple three dimensional grid system. With relatively simple modeling techniques, very complex framing situations may be considered.

The buildings may be unsymmetrical and non-rectangular in plan. Torsion behavior of the floors and inter story compatibility of the floors are accurately reflected in the results. The solution enforces complete three dimensional displacement compatibility, making it possible to capture tubular effects associated with the behavior of tall structures having relatively closely spaced columns.

Semi-rigid floor diaphragms may be modeled to capture the effects of in plane floor deformations. Floor objects may span between adjacent levels to create sloped floors (ramps), which can be useful for modeling parking garage structures.

Modeling of partial diaphragms, such as in mezzanines, setbacks, atriums and floor openings are possible without the use of artificial (“dummy”) floors and column lines. It is also possible to model situations with multiple independent diaphragms at each level, allowing the modeling of buildings consisting of several towers rising from a common base.

The column, beam and brace elements may be non-prismatic, and they may have partial fixity at their end connections. They also may have uniform, partial uniform and trapezoidal load patterns, and they may have temperature loads. The effects of the finite dimensions of the beams and columns on the stiffness of a frame system are included using end offsets that can be automatically calculated.

The floors and walls can be modeled as membrane elements with plane stiffness only or full shell-type elements, which combine both in plane and out-of-plane stiffness. Floor and wall members may have uniform and non-uniform load patterns in-plane or out-of-plane, and they may have temperature loads. The column, beam, brace, floor and wall members are all compatible with one another.

3.7.5 Analysis Features

Static analyses for user specified vertical and lateral floor or story loads are possible. If floors with out-of-plane bending capability are modeled, vertical loads on the floor are transferred to the beams and columns through bending of the floor elements. Otherwise, vertical loads on the floor are automatically converted to span loads on adjoining beams, or point loads on adjacent columns, thereby automating the tedious task of transferring floor tributary loads to the floor beams without the need to explicitly model the secondary framing. The program can automatically generate lateral wind and seismic load patterns to meet the requirements of various building codes. Three dimensional mode shapes and frequencies, modal participation factors, direction factors and participating mass percentages are evaluated using eigenvector or Ritz-vector analysis. P-Delta effects may be included with static or dynamic analysis.

Response spectrum analysis, linear time history analysis, nonlinear time history analysis, and static nonlinear (pushover) analysis are all possible.
The static nonlinear capabilities also allow you to perform incremental construction analysis so that forces that arise as a result of the construction sequence are included.
Results from the various static load cases may be combined with each other or with the results from the dynamic response spectrum or time history analyses.
Output may be viewed graphically, displayed in tabular output, compiled in a report, exported to a database file, or saved in an ASCII file. Types of output include reactions and member forces, mode shapes and participation factors, static and dynamic story displacements and story shears, inter-story drifts and joint displacements, time history traces, and more.
Import and export of data may occur between third-party applications such as Revit and AutoCAD from Autodesk, or with other programs thatsupport the CIS/2 or IFC data models.

ETABS uses the SAP Fire™ analysis engine, the state-of-the-art equation solver that powers all of CSI's software. This proprietary solver exploits the latest in numerical technology to provide incredibly rapid solution times and virtually limitless model capacity.

3.7.6 Design Features

Design of steel frames, concrete frames, concrete slabs, concrete shear walls, composite beams, composite columns, and steel joists can be performed based on a variety of US and International design codes. Flexural, shear and deflection checks may all be performed depending upon the material and member type. Steel and concrete frame members may be optimized from auto select lists, and concrete sections are designed using reinforcing bar sizes chosen from US or International standards. Concrete slab design may be done using either design strips, or be based on the finite element method, and may include the effects of post- tensioning. Steel connection design automates the review of beam-beam and beam-column connections based on user specified bolt and shear plate preferences. Steel base plate design verifies the size, thickness, and anchorage of the connection.

3.7.7 Detailing Features

Schematic construction drawings showing floor framing, column schedules, beam elevations and sections, steel connection schedules, and concrete shear wall reinforcing may be produced. Concrete reinforcement of beams, columns, and walls may be selected based on user-defined rules.
Any number of drawings may be created, containing general notes, plan views, sections, elevations, tables, and schedules. Drawings may be printed directly from ETABS or exported to DXF or DWG files for further refinement.

Chapter Four

Seismic Behavior of Multi-stories Building Results

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Seismic Behavior of Multi-stories Building Results

4.1 Introduction:

The seismic behavior of multi-storey framed building is studied using ETABS for comparison the building is considered to be a reinforced concrete framed or composite steel framed.

4.2 Loadings

Generally, Loading on tall building differs from loading on low rise buildings in its accumulation into much larger structural forces. The collection of gravity loading over a large number of stories in a tall building can produce column loading of an order higher than those in low rise buildings. Wind loading on a tall building not only acts over a larger surface area but also with greater intensity at greater height and with a large moment arm about the base than on a low rise building. Although wind loading on a low rise building has an insignificant influence on the design of structure, wind on a high rise building can have a dominant influence on its structural arrangement and design [7]

In earthquake region, any inertial loads from the shaking of the ground may well exceed the loading due to wind and therefore be dominant in influencing the building's design and cost. The building's dynamic response plays a large part in influencing and in estimating the effective loading on the structure. The following discussion describes some of the most common kinds of loads on multi-storied structures:

4.2.1 Live load:

A load produced by the use and occupancy of the building or other structure that does not include construction or environmental loads, such as wind load, snow load, rain load, earthquake load, flood load. But Wind, flood and earthquake loads are random in nature and it is difficult to predict them. They are estimated based on a probabilistic approach.

4.2.2 Gravity load:

This constitutes the dead loads due to the self-weight of individual elements that make up the structural system as well as the live loads that are acting on the structure when in service. The dead loads are calculated from the member sizes and estimated material densities. Live loads prescribed by codes are empirical and conservative based on experience and accepted practice. A floor should be designed for the most adverse effect of uniformly distributed load and concentrated load as specified in Table-1, but they should not be considered to act simultaneously. All other structural elements such as beams and columns are designed for the corresponding uniformly distributed loads on floors. Reduction in imposed (live) load may be made in designing columns,load bearing walls etc., if there is no specific load like plant or machinery on the floor.

4.2.2.1 Reduction in live loads

Except for roof uniform live loads, all other minimum uniformly distributed live loads, may be reduced according to the following provisions. The supporting members of the roof of the multi-storied building is designed for 100% of uniformly distributed load; further reductions of 10% for each successive floor down to a minimum of 50% of uniformly distributed load is done.

4.2.3 Seismic load:

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.

The earthquake load is estimated by Seismic co-efficient method or Response spectrum method. The later takes account of dynamic characteristics of structure along with ground motion. For detailed information on evaluating earthquake load, reader is referred to IS: 1893 - 2002 [5] and the chapter on Industrial Buildings.

4.2.4 Load Combination:

Load combinations provide the basic set of building load conditions that should be considered by the designer.

i) 1.5(DL+LL)
ii) 1.2(DL+LL+EQX)
iii) 1.2(DL+LL+EQZ)
iv) 1.5(DL+EQX)
v) 1.5(DL+EQZ)
vi) 1.5(DL + WLX)
vii) 1.5(DL + WL Z)
viii) 0.9DL+1.5EQX
ix) 0.9DL+1.5EQZ
x) 0.8DL +0.9 SL
xi) 1.5 DL + 1.2 LL+1.2 SL
xii) 1.2 DL + 1.2 LL +1.2 WL

LL- Live Load
DL- Dead Load
EQX- Earthquake in direction X
EQY- Earthquake in direction Y
EQZ- Earthquake in direction Z
WLX- Wind Load in direction X
WLY- Wind Load in direction Y
WLZ- Wind Load in direction Z
SL- Snow Load

4.3 Modeling Analysis

The main objective of analysis is to study the different forces acting on the building .The analysis carries out in ETABS 2017 software.

4.3.1 Building Description

The building for this study consider an office Building locate in zone (III).The building consist of 3 bays in X-direction and 3 bays in Y-direction as Shown in Fig. (4.1) and the overall height in Z-direction is (31m),with area (18×18) m. The height of ground floor to first floor is (4m) and that of subsequent nine floors are (3m) .

The different components of reinforced concrete (RCC) structure are as follows:

Column section of the building (500×500)mm.

Beam section of the building (300×600)mm.

Slab thickness of the building is (150)mm.

Similarly the different components of composite structures are as follows:

Steel column section of the building ISWB 450

Steel beam section of the building ISHB 350-2

Slab thickness of the building is 150 mm.

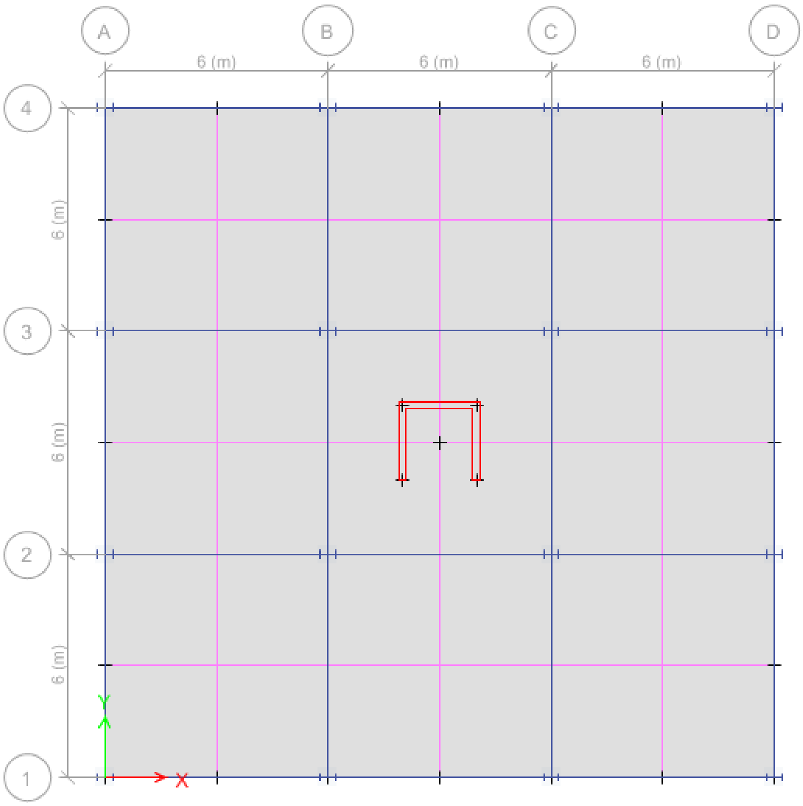

Fig. (4.1) Plan for 10 Stories RCC & Composite Steel Frame Structure

The 3-D view for the RC building is shown in fig. (4.2) and that for composite steel building shown in fig.(4.3).

4.3.2 Description for Loading

The loading on the buildings is considered as per following calculations

1) Dead Loads

i. Wall load with 150mm thickness = 20 x 3 x 0.15 = 9 KN/m

ii. Weight of the slab having thickness 0.150mm = 25 x0.150 = 3.75 KN/m^2

iii. Self-weight of building is automatically considered by

ETABS 2017 software.

2) Live Loads

The live load of 2.0 KN/m2 is considered on the floor of the buildings.

3) Earthquake Forces Data

Earthquake load for the building has been calculated as per IS-1893-2002:

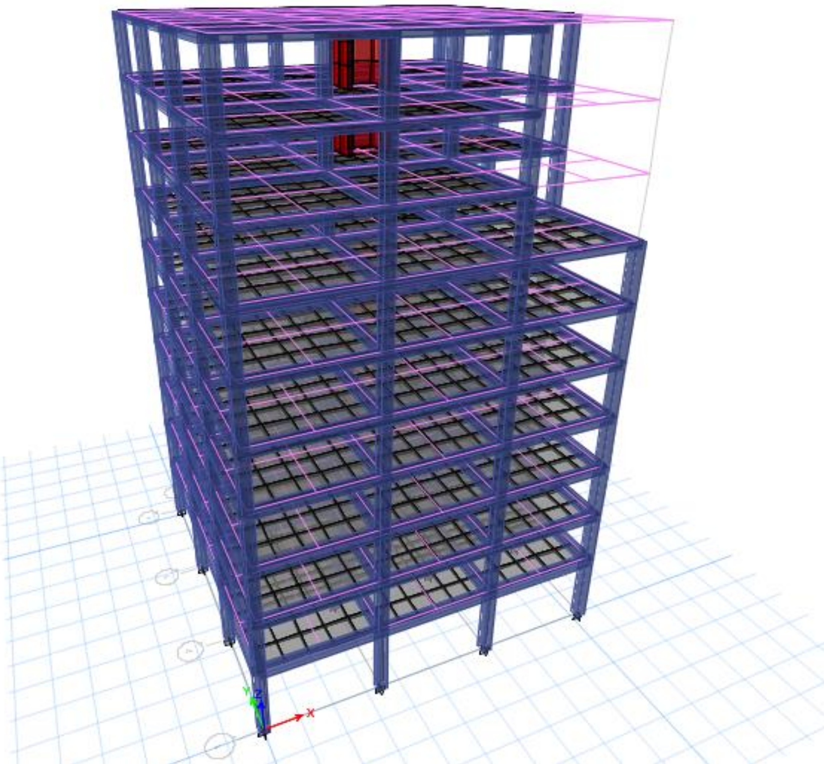

Figure (4.2) 3-D View for 10 Stories RCC Framed Structure

i.From Table (3) clause (6.4.2) in Appendix C Zone factor Z for zone III = 0.16
ii.From Table (9) clause (7.2.6) in Appendix C Response Reduction Factor (RF) = 5
iii.From Table (8) clause (7.2.3) in Appendix C Importance Factor (I) = 1.5

For generating the earthquake forces in the analysis "member weight'' has been provided as per appropriate beam load. Software for the analysis generates effective seismic forces as per the various factors defined above.

4.4. Analysis and Discussion

Samples of the ETABS input and analysis results are presented in Appendix A and B. The results obtain are analyzed using Excel and discussed as follow.

4.4.1 Natural Time Period:

The time required for a system to complete one cycle of free vibration is the natural period of vibrating system in units of seconds. Table (1) shows the result values of natural time period for different model height. Similarly variation of natural time period of different model vs. no. of storey is as shown in Figure (4.4). From Table (4.1) and figure it can be seen that the natural time period increases with height.

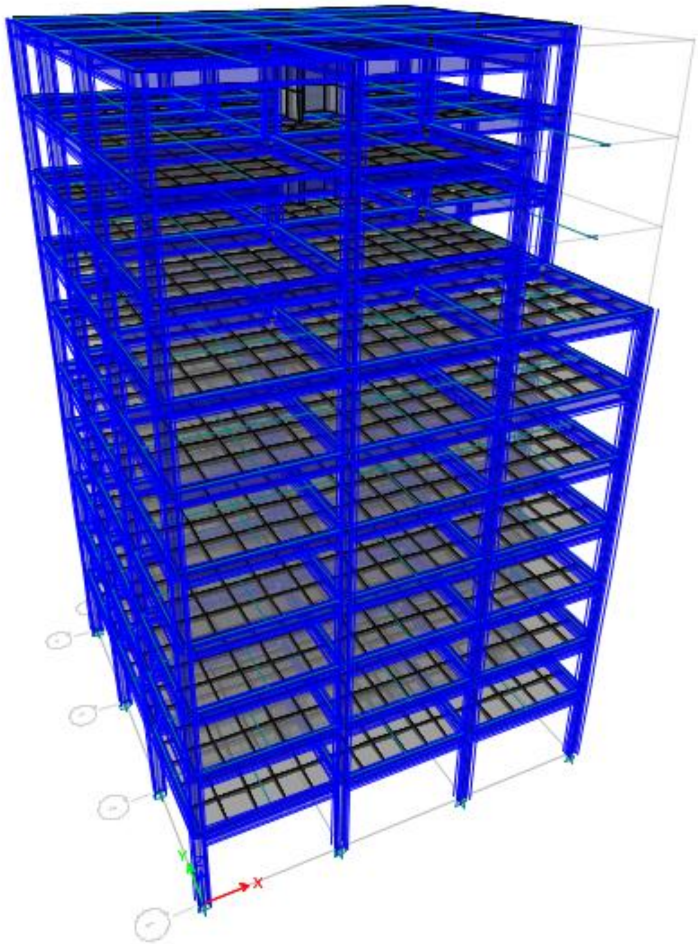

Figure (4.3) 3-D View for 10 Stories Composite Steel Frame Structure

Table(4.1):Natural Time Period (seconds)

Height Of The Building(m)	Number of Stories	Time in seconds (s)		Percentage difference %
		RCC	Composite	
19	G+5	0.6825	0.7735	11.76
25	G+7	0.8385	0.95	11.74
31	G+9	0.985	1.1167	11.79

Those for the composite steel are greater than those for RC with percentage differences 11.76 %.

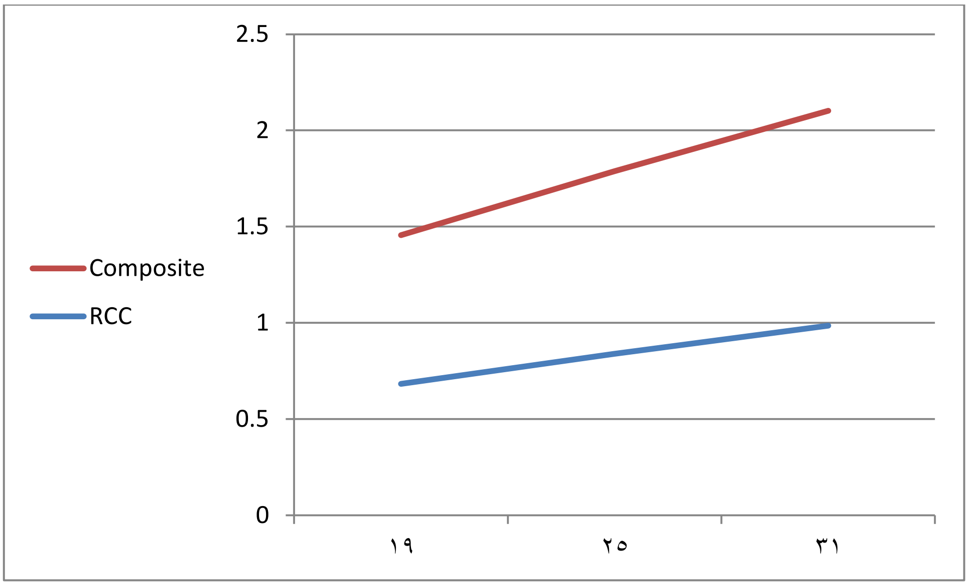

Figure 4.4: Graph of natural time period against number of stories for various models

4.4.2 Coefficient of Response Acceleration (Sa/g) for the various Models

Coefficient of Response Acceleration (Sa/g) is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, it depends on natural period of vibration and damping of the structure. Table (4.2) shows the result values of Sa/g for the tow models. Similarly Figure (4.5) shows Graph of Average Response Acceleration (Sa/g) against Number of stories for various models.

Table(4.2):Average Response Acceleration (Sa/g)

Height Of The Building(m)	Number of Stories	Response Acceleration (Sa/g)		Percentage difference %
		RCC	Composite	
19	G+5	1.99	1.775	12.11
25	G+7	1.621	1.43	13.4
31	G+9	1.38	1.21	14

The table and figure show that the average response acceleration coefficient for both conventional RCC frame and composite frame decreases with increase in the height of building.

Those for the composite steel are lesser than those for RC with percentage differences 13.4%.

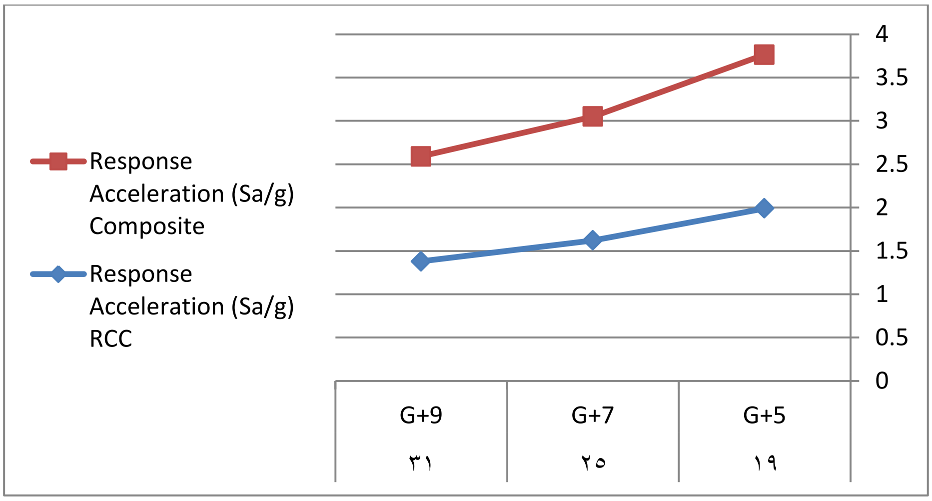

Figure 4.5: Graph of Average Response Acceleration against Number of stories for both models

4.4.3 Base Shear:

The total design lateral forces or design seismic base shear (V_b) along any principal direction shall be determined by the following expression.

$$V_b = A_h W \qquad (4.1)$$

Table (4.3) shows that the bases shear increase with height for both R.C.C and composite steel framed building. Figure (4.6) shows the magnitude of the base shear for composite structure is less than that of the conventional RCC structure this is due less in weight of the composite structure as compare to RCC structure with Percentage difference is 75.44%.

4.4.4 Maximum Displacement:

Maximum Displacement is the maximum displacement at the level. Table (4.4) shows the maximum displacement for the two models RCC & composite steel Framed Structure.

Table (4.4) shows that the maximum displacement increase with height for both RCC and composite steel framed and it is lesser for composite steel than R.C.C as shown in figure (4.7) with percentage difference ranging from (4.8-61.5) %.

Table(4.3):Base Shear (Lateral Load) (kN)

Storey	Height	Base Shear (kN)		Percentage difference %
		RCC	Composite	
1	4	1.481	0.844	75.47
2	7	4.377	2.495	75.43
3	10	8.932	5.091	75.44
4	13	15.096	8.605	75.43
5	16	22.867	13.034	75.44
6	19	32.246	18.380	75.44
7	22	43.049	24.538	75.43
8	25	50.309	28.676	75.43
9	28	63.108	35.971	75.44
10	31	71.305	40.644	75.43

Table (4.4) Maximum Displacement (mm)

Storey	Height	Maximum Displacement		Percentage difference %
		RCC	Composite	
1	4	1.161	0.9	29
2	7	2.445	2.3	6.3
3	10	3.903	4.1	4.8
4	13	5.432	4.7	15.57
5	16	6.954	5.6	24.17
6	19	8.408	6.4	31.37
7	22	9.743	6.053	60.96
8	25	10.87	6.95	56.4
9	28	11.79	7.3	61.5
10	31	12.52	10.069	24.3

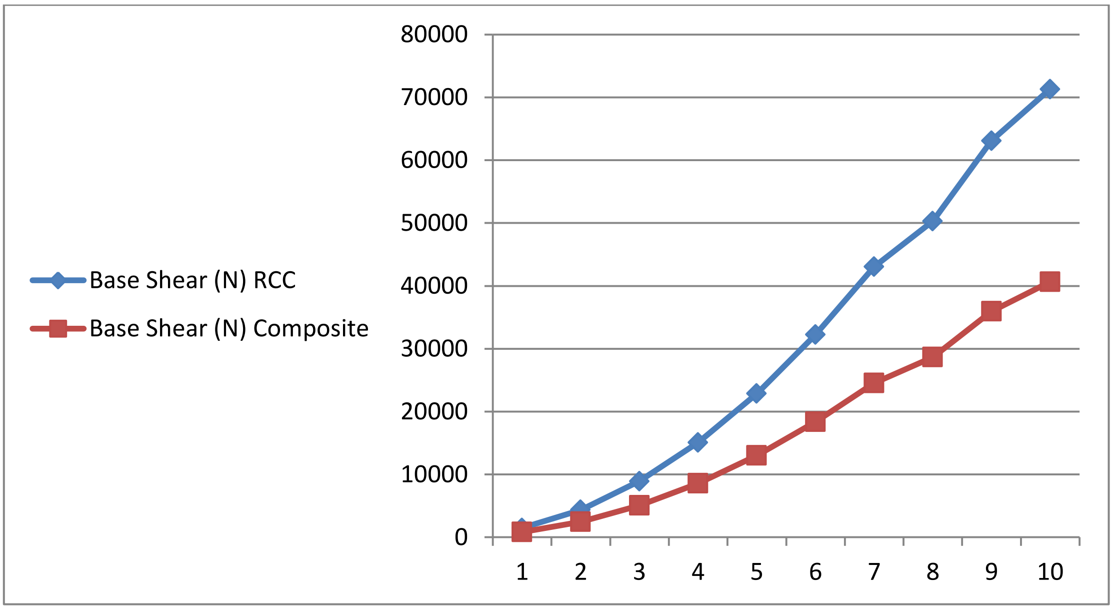

Figure (4.6) Graph of Base Shear against Number of stories

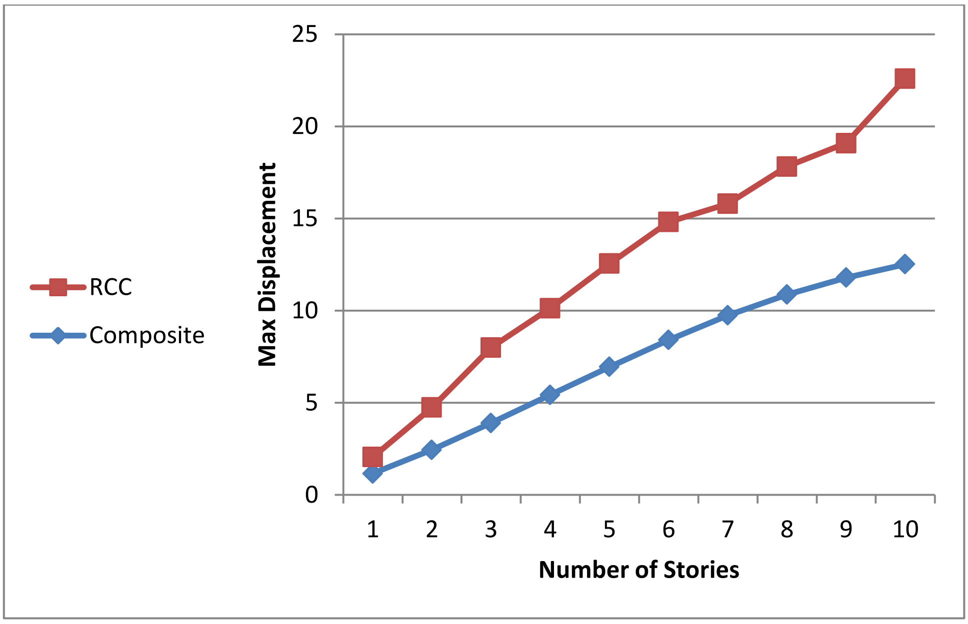

Figure (4.7) Graph of Maximum Displacement against Number of stories.

Maximum displacement in Direction X combination (16) in ETABS (Earthquake in direction x, Live Load, Dead Load)

Chapter Five

Conclusions and Recommendations

Chapter five

Conclusions and Recommendation

5.1 Conclusions

This research presents study of the seismic behavior, for conventional R.C.C frame structure and composite steel frame structure for different floor heights. The study was based on the lateral force method. The effect of seismic load has been studied for the two types of building. Based on the results obtained, the following conclusions have been drawn:

1. The natural time period increases as the height of building (Number of stories) increases, irrespective of type of building viz. conventional structure and composite structure. Percentage difference is ranging from (11.76-11.79) %.

2. In comparison of the conventional RCC frame to composite steel frame structures, the time period is higher for composite steel frame structures than conventional building. This is due the fact that steel is more ductile than concrete. The maximum percentage difference is 11.79 %.

3. The average response acceleration coefficient for both conventional RCC frame and composite frame decreases with increase in the height of building, this is due to the fact the both structures have similar number members that are stiff. The maximum percentage difference is 13.4%.

4. For both structure, base shear increases as the height increases. This increase in base shear shows similar trend in both structures. The maximum percentage difference is 75.47%.

5. The magnitude of the base shear for composite structure is less than that of the conventional RCC structure this is due less in weight of the composite structure as compare to RCC structure.

6. The maximum displacement increases with height for both RCC and composite steel framed and it is lesser for composite steel than R.C.C as shown in figure (4.7) with maximum percentage difference 61.5 %.

With this, it is confirmed that, the use of composite steel frame structure in multi-story and high-rise buildings has the advantages of being safe, with short construction period, high bearing force and good ductility. Thus, the composite steel frame structure in seismic behavior is better than that in reinforced concrete structures.

5.2 Recommendations

From the results of this study it is recommended:

1- To use composite steel frame structure in seismic areas of the country.
2- To use ETABS program for seismic analysis of multi-storey buildings.

For further studies, it is recommended:

1- To carry out comparative cost analysis of composite steel and RCC buildings.
2- To carry out the comparative study for the effect of the height variation of high rise buildings.
3- To carry out the comparative study using nonlinear dynamics methods such as pushover analysis method.

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Appendix A
Maximum Displacement (RCC)

TABLE: Maximum Displacement				
Story	Load Case/Combo	UX mm	UY mm	UZ mm
Story10	Dead	0.33	0.31	1.065
Story9	Dead	0.212	0.192	1.105
Story9	Dead	0.272	0.252	1.08
Story8	Dead	0.204	0.185	1.107
Story8	Dead	0.217	0.198	1.1
Story7	Dead	0.19	0.171	1.108
Story7	Dead	0.169	0.15	1.124
Story6	Dead	0.142	0.13	1.089
Story6	Dead	0.137	0.126	1.093
Story5	Dead	0.101	0.094	1.077
Story5	Dead	0.11	0.103	1.071
Story4	Dead	0.065	0.061	1.067
Story4	Dead	0.084	0.08	1.051
Story3	Dead	0.036	0.034	1.053
Story3	Dead	0.059	0.057	1.032
Story2	Dead	0.014	0.014	1.011
Story2	Dead	0.035	0.035	1.004
Story1	Dead	0.017	0.016	1.052
Story10	Live	0.06	0.055	1.093
Story10	Live	0.138	0.133	1.039
Story9	Live	0.061	0.056	1.094
Story9	Live	0.115	0.11	1.047
Story8	Live	0.059	0.054	1.093
Story8	Live	0.094	0.089	1.057
Story7	Live	0.056	0.051	1.094
Story7	Live	0.074	0.069	1.069
Story6	Live	0.042	0.039	1.074
Story6	Live	0.061	0.058	1.049
Story5	Live	0.03	0.028	1.061
Story5	Live	0.048	0.046	1.037
Story4	Live	0.019	0.018	1.05
Story4	Live	0.036	0.036	1.025
Story3	Live	0.01	0.01	1.032
Story3	Live	0.025	0.025	1.013

Story2	Live	0.004	0.004	1.026
Story2	Live	0.015	0.015	1.007
Story1	Live	0.007	0.007	1.052
Story10	wind x	48.351	45.224	1.069
Story9	wind x	46.583	43.426	1.073
Story8	wind x	44.033	40.963	1.075
Story7	wind x	40.715	37.783	1.078
Story6	wind x	36.789	33.911	1.085
Story5	wind x	32.073	29.294	1.095
Story4	wind x	26.63	24.009	1.109
Story3	wind x	20.591	18.207	1.131
Story2	wind x	14.172	12.153	1.166
Story1	wind x	7.669	6.258	1.225
Story10	wind y	50.164	49.694	1.009
Story9	wind y	48.25	47.872	1.008
Story8	wind y	45.601	45.36	1.005
Story7	wind y	42.126	42.008	1.003
Story6	wind y	37.918	37.804	1.003
Story5	wind y	32.818	32.703	1.004
Story4	wind y	26.882	26.765	1.004
Story3	wind y	20.256	20.136	1.006
Story2	wind y	13.228	13.108	1.009
Story1	wind y	6.402	6.284	1.019
Story10	EQXA	10.209	9.162	1.114
Story9	EQXA	9.61	8.617	1.115
Story8	EQXA	8.844	7.92	1.117
Story7	EQXA	7.92	7.089	1.117
Story6	EQXA	6.852	6.152	1.114
Story5	EQXA	5.682	5.12	1.11
Story4	EQXA	4.452	4.03	1.105
Story3	EQXA	3.21	2.925	1.098
Story2	EQXA	2.019	1.86	1.086
Story1	EQXA	0.966	0.908	1.064
Story10	EQXB	10.283	9.271	1.109
Story9	EQXB	9.719	8.725	1.114
Story8	EQXB	8.959	8.022	1.117
Story7	EQXB	8.051	7.183	1.121
Story6	EQXB	7.057	6.241	1.131
Story5	EQXB	5.948	5.202	1.143
Story4	EQXB	4.764	4.105	1.161
Story3	EQXB	3.549	2.991	1.186
Story2	EQXB	2.353	1.915	1.229
Story1	EQXB	1.231	0.945	1.302

Story10	EQYB	10.194	9.641	1.057
Story9	EQYB	9.609	9.094	1.057
Story8	EQYB	8.855	8.395	1.055
Story7	EQYB	7.951	7.543	1.054
Story6	EQYB	6.942	6.566	1.057
Story5	EQYB	5.812	5.478	1.061
Story4	EQYB	4.599	4.316	1.066
Story3	EQYB	3.348	3.121	1.073
Story2	EQYB	2.118	1.952	1.085
Story1	EQYB	1.002	0.899	1.114
Story10	EQYA	11.017	9.619	1.145
Story9	EQYA	10.446	9.077	1.151
Story8	EQYA	9.688	8.384	1.156
Story7	EQYA	8.74	7.538	1.16
Story6	EQYA	7.623	6.562	1.162
Story5	EQYA	6.381	5.475	1.165
Story4	EQYA	5.054	4.312	1.172
Story3	EQYA	3.691	3.118	1.184
Story2	EQYA	2.349	1.949	1.205
Story1	EQYA	1.119	0.896	1.248
Story10	DCon1	0.322	0.292	1.104
Story10	DCon1	0.496	0.465	1.065
Story9	DCon1	0.318	0.288	1.105
Story9	DCon1	0.408	0.378	1.08
Story8	DCon1	0.307	0.277	1.107
Story8	DCon1	0.326	0.297	1.1
Story7	DCon1	0.285	0.257	1.108
Story7	DCon1	0.253	0.225	1.124
Story6	DCon1	0.213	0.196	1.089
Story6	DCon1	0.206	0.189	1.093
Story5	DCon1	0.152	0.141	1.077
Story5	DCon1	0.165	0.154	1.071
Story4	DCon1	0.098	0.092	1.067
Story4	DCon1	0.126	0.12	1.051
Story3	DCon1	0.054	0.051	1.053
Story3	DCon1	0.089	0.086	1.032
Story2	DCon1	0.021	0.021	1.011
Story2	DCon1	0.053	0.053	1.004
Story1	DCon1	0.026	0.024	1.052
Story10	DCon2	0.413	0.375	1.101
Story10	DCon2	0.703	0.665	1.057
Story9	DCon2	0.409	0.371	1.103
Story9	DCon2	0.581	0.543	1.07

Story8	DCon2	0.395	0.358	1.104
Story8	DCon2	0.467	0.43	1.086
Story7	DCon2	0.368	0.333	1.105
Story7	DCon2	0.364	0.329	1.106
Story6	DCon2	0.276	0.254	1.086
Story6	DCon2	0.297	0.275	1.079
Story5	DCon2	0.196	0.183	1.074
Story5	DCon2	0.237	0.224	1.06
Story4	DCon2	0.126	0.119	1.063
Story4	DCon2	0.181	0.173	1.043
Story3	DCon2	0.07	0.066	1.048
Story3	DCon2	0.127	0.123	1.026
Story2	DCon2	0.027	0.027	1.003
Story2	DCon2	0.076	0.075	1.001
Story1	DCon2	0.036	0.034	1.052
Story10	DCon3	57.691	53.969	1.069
Story9	DCon3	55.572	51.814	1.073
Story8	DCon3	52.524	48.869	1.075
Story7	DCon3	48.564	45.074	1.077
Story6	DCon3	43.927	40.49	1.085
Story5	DCon3	38.33	35.007	1.095
Story4	DCon3	31.855	28.715	1.109
Story3	DCon3	24.654	21.795	1.131
Story2	DCon3	16.984	14.562	1.166
Story1	DCon3	9.203	7.508	1.226
Story10	DCon4	58.351	54.568	1.069
Story9	DCon4	56.227	52.407	1.073
Story8	DCon4	53.156	49.443	1.075
Story7	DCon4	49.153	45.607	1.078
Story6	DCon4	44.368	40.896	1.085
Story5	DCon4	38.644	35.299	1.095
Story4	DCon4	32.057	28.906	1.109
Story3	DCon4	24.765	21.902	1.131
Story2	DCon4	17.028	14.605	1.166
Story1	DCon4	9.203	7.511	1.225
Story10	DCon5	59.634	59.1	1.009
Story9	DCon5	57.435	57.012	1.007
Story8	DCon5	54.347	54.088	1.005
Story7	DCon5	50.26	50.147	1.002
Story6	DCon5	45.264	45.144	1.003
Story5	DCon5	39.192	39.064	1.003
Story4	DCon5	32.114	31.979	1.004
Story3	DCon5	24.205	24.064	1.006

Story2	DCon5	15.813	15.669	1.009
Story1	DCon5	7.657	7.513	1.019
Story10	DCon6	60.759	60.164	1.01
Story9	DCon6	58.364	57.881	1.008
Story8	DCon6	55.094	54.776	1.006
Story7	DCon6	50.843	50.673	1.003
Story6	DCon6	45.739	45.584	1.003
Story5	DCon6	39.571	39.422	1.004
Story4	DCon6	32.404	32.257	1.005
Story3	DCon6	24.408	24.262	1.006
Story2	DCon6	15.934	15.79	1.009
Story1	DCon6	7.709	7.568	1.019
Story10	DCon7	72.204	67.544	1.069
Story9	DCon7	69.556	64.851	1.073
Story8	DCon7	65.743	61.168	1.075
Story7	DCon7	60.788	56.418	1.077
Story6	DCon7	54.971	50.671	1.085
Story5	DCon7	47.957	43.801	1.095
Story4	DCon7	39.847	35.921	1.109
Story3	DCon7	30.833	27.259	1.131
Story2	DCon7	21.236	18.208	1.166
Story1	DCon7	11.503	9.386	1.226
Story10	DCon8	72.848	68.128	1.069
Story9	DCon8	70.192	65.426	1.073
Story8	DCon8	66.356	61.722	1.075
Story7	DCon8	61.358	56.932	1.078
Story6	DCon8	55.397	51.062	1.085
Story5	DCon8	48.261	44.083	1.095
Story4	DCon8	40.043	36.105	1.109
Story3	DCon8	30.941	27.362	1.131
Story2	DCon8	21.279	18.25	1.166
Story1	DCon8	11.504	9.389	1.225
Story10	DCon9	74.75	74.075	1.009
Story9	DCon9	71.966	71.43	1.008
Story8	DCon9	68.075	67.743	1.005
Story7	DCon9	62.936	62.788	1.002
Story6	DCon9	56.671	56.517	1.003
Story5	DCon9	49.062	48.9	1.003
Story4	DCon9	40.197	40.027	1.004
Story3	DCon9	30.295	30.118	1.006
Story2	DCon9	19.789	19.609	1.009
Story1	DCon9	9.58	9.401	1.019
Story10	DCon10	75.742	75.006	1.01

Story9	DCon10	72.782	72.186	1.008
Story8	DCon10	68.727	68.336	1.006
Story7	DCon10	63.442	63.238	1.003
Story6	DCon10	57.083	56.894	1.003
Story5	DCon10	49.392	49.208	1.004
Story4	DCon10	40.45	40.267	1.005
Story3	DCon10	30.472	30.29	1.006
Story2	DCon10	19.896	19.715	1.009
Story1	DCon10	9.627	9.45	1.019
Story10	DCon11	72.333	67.661	1.069
Story9	DCon11	69.683	64.966	1.073
Story8	DCon11	65.866	61.279	1.075
Story7	DCon11	60.902	56.521	1.078
Story6	DCon11	55.056	50.749	1.085
Story5	DCon11	48.018	43.857	1.095
Story4	DCon11	39.886	35.958	1.109
Story3	DCon11	30.854	27.28	1.131
Story2	DCon11	21.245	18.217	1.166
Story1	DCon11	11.503	9.386	1.226
Story10	DCon12	72.719	68.011	1.069
Story9	DCon12	70.065	65.311	1.073
Story8	DCon12	66.234	61.611	1.075
Story7	DCon12	61.244	56.829	1.078
Story6	DCon12	55.312	50.984	1.085
Story5	DCon12	48.2	44.026	1.095
Story4	DCon12	40.004	36.068	1.109
Story3	DCon12	30.919	27.341	1.131
Story2	DCon12	21.27	18.242	1.166
Story1	DCon12	11.504	9.388	1.225
Story10	DCon13	74.949	74.261	1.009
Story9	DCon13	72.13	71.581	1.008
Story8	DCon13	68.205	67.862	1.005
Story7	DCon13	63.037	62.878	1.003
Story6	DCon13	56.753	56.592	1.003
Story5	DCon13	49.128	48.961	1.003
Story4	DCon13	40.248	40.075	1.004
Story3	DCon13	30.33	30.152	1.006
Story2	DCon13	19.811	19.63	1.009
Story1	DCon13	9.59	9.411	1.019
Story10	DCon14	75.543	74.82	1.01
Story9	DCon14	72.619	72.035	1.008
Story8	DCon14	68.597	68.218	1.006
Story7	DCon14	63.341	63.148	1.003

Story6	DCon14	57	56.819	1.003
Story5	DCon14	49.326	49.146	1.004
Story4	DCon14	40.399	40.219	1.004
Story3	DCon14	30.437	30.255	1.006
Story2	DCon14	19.874	19.693	1.009
Story1	DCon14	9.617	9.44	1.019
Story10	DCon15	11.981	10.695	1.12
Story9	DCon15	11.266	10.044	1.122
Story8	DCon15	10.356	9.217	1.124
Story7	DCon15	9.265	8.241	1.124
Story6	DCon15	8.036	7.179	1.119
Story5	DCon15	6.683	5.998	1.114
Story4	DCon15	5.254	4.74	1.108
Story3	DCon15	3.802	3.457	1.1
Story2	DCon15	2.402	2.211	1.086
Story1	DCon15	1.156	1.088	1.062
Story10	DCon16	12.52	11.294	1.109
Story9	DCon16	11.798	10.637	1.109
Story8	DCon16	10.87	9.79	1.11
Story7	DCon16	9.743	8.774	1.11
Story6	DCon16	8.408	7.586	1.108
Story5	DCon16	6.954	6.29	1.106
Story4	DCon16	5.432	4.931	1.102
Story3	DCon16	3.903	3.563	1.095
Story2	DCon16	2.445	2.254	1.085
Story1	DCon16	1.162	1.091	1.065
Story10	DCon17	12.009	10.825	1.109
Story9	DCon17	11.336	10.174	1.114
Story8	DCon17	10.435	9.34	1.117
Story7	DCon17	9.367	8.353	1.121
Story6	DCon17	8.248	7.286	1.132
Story5	DCon17	6.98	6.096	1.145
Story4	DCon17	5.615	4.831	1.162
Story3	DCon17	4.203	3.536	1.188
Story2	DCon17	2.801	2.276	1.231
Story1	DCon17	1.477	1.133	1.304
Story10	DCon18	12.669	11.425	1.109
Story9	DCon18	11.99	10.767	1.114
Story8	DCon18	11.068	9.913	1.117
Story7	DCon18	9.956	8.886	1.12
Story6	DCon18	8.689	7.692	1.13
Story5	DCon18	7.294	6.389	1.142
Story4	DCon18	5.818	5.021	1.159

Story3	DCon18	4.314	3.643	1.184
Story2	DCon18	2.845	2.319	1.227
Story1	DCon18	1.477	1.136	1.3
Story10	DCon19	11.671	11.037	1.057
Story9	DCon19	11.066	10.478	1.056
Story8	DCon19	10.253	9.73	1.054
Story7	DCon19	9.249	8.789	1.052
Story6	DCon19	8.093	7.659	1.057
Story5	DCon19	6.785	6.395	1.061
Story4	DCon19	5.374	5.04	1.066
Story3	DCon19	3.916	3.647	1.074
Story2	DCon19	2.481	2.282	1.087
Story1	DCon19	1.176	1.051	1.119
Story10	DCon20	12.796	12.101	1.057
Story9	DCon20	11.995	11.347	1.057
Story8	DCon20	11	10.417	1.056
Story7	DCon20	9.832	9.315	1.055
Story6	DCon20	8.568	8.099	1.058
Story5	DCon20	7.164	6.753	1.061
Story4	DCon20	5.663	5.318	1.065
Story3	DCon20	4.119	3.844	1.071
Story2	DCon20	2.602	2.403	1.083
Story1	DCon20	1.228	1.106	1.11
Story10	DCon21	12.719	11.011	1.155
Story9	DCon21	12.131	10.458	1.16
Story8	DCon21	11.312	9.717	1.164
Story7	DCon21	10.253	8.782	1.168
Story6	DCon21	8.945	7.654	1.169
Story5	DCon21	7.489	6.391	1.172
Story4	DCon21	5.933	5.036	1.178
Story3	DCon21	4.333	3.643	1.189
Story2	DCon21	2.758	2.279	1.21
Story1	DCon21	1.314	1.048	1.253
Story10	DCon22	13.722	12.075	1.136
Story9	DCon22	12.939	11.327	1.142
Story8	DCon22	11.94	10.404	1.148
Story7	DCon22	10.724	9.308	1.152
Story6	DCon22	9.35	8.094	1.155
Story5	DCon22	7.825	6.748	1.16
Story4	DCon22	6.198	5.314	1.166
Story3	DCon22	4.525	3.841	1.178
Story2	DCon22	2.879	2.399	1.2
Story1	DCon22	1.372	1.103	1.243

Story10	DCon23	15.051	13.451	1.119
Story9	DCon23	14.158	12.638	1.12
Story8	DCon23	13.019	11.603	1.122
Story7	DCon23	11.651	10.377	1.123
Story6	DCon23	10.099	9.032	1.118
Story5	DCon23	8.393	7.539	1.113
Story4	DCon23	6.593	5.953	1.108
Story3	DCon23	4.767	4.336	1.099
Story2	DCon23	3.008	2.769	1.086
Story1	DCon23	1.446	1.36	1.063
Story10	DCon24	15.574	14.035	1.11
Story9	DCon24	14.673	13.213	1.11
Story8	DCon24	13.514	12.157	1.112
Story7	DCon24	12.109	10.891	1.112
Story6	DCon24	10.456	9.424	1.11
Story5	DCon24	8.653	7.821	1.106
Story4	DCon24	6.764	6.136	1.102
Story3	DCon24	4.864	4.439	1.096
Story2	DCon24	3.05	2.811	1.085
Story1	DCon24	1.452	1.364	1.064
Story10	DCon25	15.102	13.614	1.109
Story9	DCon25	14.261	12.8	1.114
Story8	DCon25	13.133	11.756	1.117
Story7	DCon25	11.792	10.518	1.121
Story6	DCon25	10.372	9.165	1.132
Story5	DCon25	8.77	7.662	1.145
Story4	DCon25	7.047	6.065	1.162
Story3	DCon25	5.269	4.435	1.188
Story2	DCon25	3.508	2.851	1.23
Story1	DCon25	1.845	1.416	1.303
Story10	DCon26	15.746	14.198	1.109
Story9	DCon26	14.897	13.376	1.114
Story8	DCon26	13.746	12.31	1.117
Story7	DCon26	12.362	11.032	1.121
Story6	DCon26	10.799	9.557	1.13
Story5	DCon26	9.074	7.944	1.142
Story4	DCon26	7.243	6.249	1.159
Story3	DCon26	5.377	4.538	1.185
Story2	DCon26	3.55	2.893	1.227
Story1	DCon26	1.846	1.419	1.301
Story10	DCon27	14.796	13.996	1.057
Story9	DCon27	14.005	13.263	1.056
Story8	DCon27	12.957	12.295	1.054

Story7	DCon27	11.673	11.09	1.053
Story6	DCon27	10.207	9.66	1.057
Story5	DCon27	8.553	8.063	1.061
Story4	DCon27	6.772	6.353	1.066
Story3	DCon27	4.933	4.596	1.073
Story2	DCon27	3.124	2.875	1.087
Story1	DCon27	1.479	1.324	1.117
Story10	DCon28	15.787	14.927	1.058
Story9	DCon28	14.821	14.019	1.057
Story8	DCon28	13.609	12.889	1.056
Story7	DCon28	12.179	11.54	1.055
Story6	DCon28	10.619	10.038	1.058
Story5	DCon28	8.883	8.371	1.061
Story4	DCon28	7.024	6.594	1.065
Story3	DCon28	5.111	4.768	1.072
Story2	DCon28	3.231	2.981	1.084
Story1	DCon28	1.526	1.373	1.111
Story10	DCon29	16.09	13.964	1.152
Story9	DCon29	15.321	13.238	1.157
Story8	DCon29	14.265	12.279	1.162
Story7	DCon29	12.913	11.081	1.165
Story6	DCon29	11.263	9.654	1.167
Story5	DCon29	9.428	8.058	1.17
Story4	DCon29	7.468	6.349	1.176
Story3	DCon29	5.453	4.592	1.188
Story2	DCon29	3.47	2.871	1.209
Story1	DCon29	1.653	1.32	1.252
Story10	DCon30	16.961	14.895	1.139
Story9	DCon30	16.016	13.994	1.145
Story8	DCon30	14.799	12.872	1.15
Story7	DCon30	13.307	11.531	1.154
Story6	DCon30	11.605	10.031	1.157
Story5	DCon30	9.714	8.366	1.161
Story4	DCon30	7.696	6.589	1.168
Story3	DCon30	5.619	4.764	1.18
Story2	DCon30	3.576	2.977	1.201
Story1	DCon30	1.704	1.369	1.245
Story10	DCon31	15.156	13.568	1.117
Story9	DCon31	14.261	12.753	1.118
Story8	DCon31	13.118	11.714	1.12
Story7	DCon31	11.743	10.48	1.12
Story6	DCon31	10.171	9.111	1.116
Story5	DCon31	8.445	7.595	1.112

Story4	DCon31	6.627	5.989	1.106
Story3	DCon31	4.786	4.357	1.099
Story2	DCon31	3.017	2.778	1.086
Story1	DCon31	1.447	1.361	1.063
Story10	DCon32	15.47	13.918	1.111
Story9	DCon32	14.57	13.098	1.112
Story8	DCon32	13.415	12.046	1.114
Story7	DCon32	12.018	10.788	1.114
Story6	DCon32	10.385	9.346	1.111
Story5	DCon32	8.601	7.764	1.108
Story4	DCon32	6.73	6.1	1.103
Story3	DCon32	4.845	4.418	1.097
Story2	DCon32	3.042	2.803	1.085
Story1	DCon32	1.45	1.363	1.064
Story10	DCon33	15.231	13.731	1.109
Story9	DCon33	14.388	12.916	1.114
Story8	DCon33	13.255	11.867	1.117
Story7	DCon33	11.906	10.62	1.121
Story6	DCon33	10.458	9.243	1.131
Story5	DCon33	8.831	7.719	1.144
Story4	DCon33	7.087	6.102	1.161
Story3	DCon33	5.29	4.456	1.187
Story2	DCon33	3.516	2.86	1.23
Story1	DCon33	1.846	1.417	1.303
Story10	DCon34	15.617	14.081	1.109
Story9	DCon34	14.769	13.261	1.114
Story8	DCon34	13.623	12.199	1.117
Story7	DCon34	12.248	10.929	1.121
Story6	DCon34	10.713	9.478	1.13
Story5	DCon34	9.013	7.888	1.143
Story4	DCon34	7.204	6.212	1.16
Story3	DCon34	5.355	4.518	1.185
Story2	DCon34	3.542	2.885	1.228
Story1	DCon34	1.846	1.419	1.301
Story10	DCon35	14.994	14.182	1.057
Story9	DCon35	14.168	13.414	1.056
Story8	DCon35	13.087	12.414	1.054
Story7	DCon35	11.774	11.18	1.053
Story6	DCon35	10.289	9.736	1.057
Story5	DCon35	8.619	8.125	1.061
Story4	DCon35	6.822	6.402	1.066
Story3	DCon35	4.969	4.631	1.073
Story2	DCon35	3.146	2.896	1.086

Story1	DCon35	1.489	1.334	1.116
Story10	DCon36	15.589	14.741	1.058
Story9	DCon36	14.658	13.868	1.057
Story8	DCon36	13.478	12.77	1.055
Story7	DCon36	12.078	11.45	1.055
Story6	DCon36	10.536	9.962	1.058
Story5	DCon36	8.817	8.31	1.061
Story4	DCon36	6.974	6.546	1.065
Story3	DCon36	5.075	4.734	1.072
Story2	DCon36	3.209	2.96	1.084
Story1	DCon36	1.516	1.363	1.113
Story10	DCon37	16.264	14.15	1.149
Story9	DCon37	15.46	13.389	1.155
Story8	DCon37	14.372	12.398	1.159
Story7	DCon37	12.992	11.171	1.163
Story6	DCon37	11.331	9.729	1.165
Story5	DCon37	9.485	8.12	1.168
Story4	DCon37	7.513	6.397	1.175
Story3	DCon37	5.486	4.626	1.186
Story2	DCon37	3.491	2.892	1.207
Story1	DCon37	1.663	1.33	1.25
Story10	DCon38	16.787	14.708	1.141
Story9	DCon38	15.877	13.843	1.147
Story8	DCon38	14.692	12.754	1.152
Story7	DCon38	13.229	11.441	1.156
Story6	DCon38	11.537	9.956	1.159
Story5	DCon38	9.657	8.304	1.163
Story4	DCon38	7.65	6.541	1.17
Story3	DCon38	5.586	4.729	1.181
Story2	DCon38	3.554	2.955	1.203
Story1	DCon38	1.694	1.359	1.246

Appendix B
Maximum Displacement (Composite Steel)

Story	Load Case/Combo	UX mm	UY mm	UZ mm
Story10	Dead	-0.215	-0.29	-2.355
Story10	Live	-0.06	-0.128	-0.583
Story10	wind x	48.351	-3.106	1.067
Story10	wind y	0.512	49.223	1.082
Story10	EQx	0	0	0
Story10	EQy	0	0	0
Story10	EQx1	0	0	0
Story10	EQXA	8.115	1.03	0.244
Story10	EQXB	10.283	-1.005	0.25
Story10	EQYB	0.583	9.088	0.241
Story10	EQYA	-1.471	11.017	0.235
Story10	DCon1	-0.322	-0.435	-3.533
Story10	DCon2	-0.413	-0.627	-4.408
Story10	DCon3	57.691	-4.229	-2.246
Story10	DCon4	-58.351	3.226	-4.806
Story10	DCon5	0.284	58.566	-2.227
Story10	DCon6	-0.944	-59.569	-4.825
Story10	DCon7	72.204	-5.094	-1.932
Story10	DCon8	-72.848	4.224	-5.133
Story10	DCon9	0.446	73.399	-1.909
Story10	DCon10	-1.09	-74.27	-5.156
Story10	DCon11	72.333	-4.92	-0.519
Story10	DCon12	-72.719	4.398	-3.72
Story10	DCon13	0.574	73.573	-0.496
Story10	DCon14	-0.961	-74.096	-3.743
Story10	DCon15	9.408	0.735	-3.233
Story10	DCon16	-10.069	-1.738	-3.819
Story10	DCon17	12.009	-1.708	-3.226
Story10	DCon18	-12.669	0.705	-3.827
Story10	DCon19	0.37	10.403	-3.237
Story10	DCon20	-1.03	-11.407	-3.815
Story10	DCon21	-2.095	12.719	-3.244
Story10	DCon22	1.435	-13.722	-3.809

Story10	DCon23	11.851	1.11	-3.166
Story10	DCon24	-12.495	-1.981	-3.899
Story10	DCon25	15.102	-1.943	-3.157
Story10	DCon26	-15.746	1.073	-3.908
Story10	DCon27	0.553	13.196	-3.171
Story10	DCon28	-1.197	-14.067	-3.894
Story10	DCon29	-2.529	16.09	-3.18
Story10	DCon30	1.885	-16.961	-3.886
Story10	DCon31	11.98	1.284	-1.753
Story10	DCon32	-12.366	-1.807	-2.486
Story10	DCon33	15.231	-1.769	-1.744
Story10	DCon34	-15.617	1.247	-2.495
Story10	DCon35	0.681	13.37	-1.758
Story10	DCon36	-1.068	-13.893	-2.481
Story10	DCon37	-2.4	16.264	-1.767
Story10	DCon38	2.013	-16.787	-2.473
Story10	Dead	-0.201	-0.29	-3.568
Story10	Live	-0.057	-0.128	-1.015
Story10	wind x	46.266	-3.106	1.166
Story10	wind y	0.198	49.223	0.075
Story10	EQx	0	0	0
Story10	EQy	0	0	0
Story10	EQx1	0	0	0
Story10	EQXA	8.813	1.03	0.259
Story10	EQXB	9.608	-1.005	0.276
Story10	EQYB	0.214	9.088	0.018
Story10	EQYA	-0.539	11.017	0.002
Story10	DCon1	-0.302	-0.435	-5.352
Story10	DCon2	-0.387	-0.627	-6.875
Story10	DCon3	55.21	-4.229	-4.101
Story10	DCon4	-55.829	3.226	-6.899
Story10	DCon5	-0.072	58.566	-5.41
Story10	DCon6	-0.548	-59.569	-5.589
Story10	DCon7	69.097	-5.094	-3.604
Story10	DCon8	-69.701	4.224	-7.101
Story10	DCon9	-0.005	73.399	-5.24
Story10	DCon10	-0.599	-74.27	-5.464
Story10	DCon11	69.218	-4.92	-1.463
Story10	DCon12	-69.58	4.398	-4.96
Story10	DCon13	0.116	73.573	-3.099

Story10	DCon14	-0.478	-74.096	-3.323
Story10	DCon15	10.266	0.735	-5.189
Story10	DCon16	-10.886	-1.738	-5.811
Story10	DCon17	11.22	-1.708	-5.169
Story10	DCon18	-11.84	0.705	-5.831
Story10	DCon19	-0.053	10.403	-5.478
Story10	DCon20	-0.567	-11.407	-5.522
Story10	DCon21	-0.957	12.719	-5.497
Story10	DCon22	0.337	-13.722	-5.503
Story10	DCon23	12.918	1.11	-4.964
Story10	DCon24	-13.522	-1.981	-5.741
Story10	DCon25	14.11	-1.943	-4.939
Story10	DCon26	-14.714	1.073	-5.766
Story10	DCon27	0.02	13.196	-5.325
Story10	DCon28	-0.623	-14.067	-5.38
Story10	DCon29	-1.111	16.09	-5.349
Story10	DCon30	0.507	-16.961	-5.356
Story10	DCon31	13.039	1.284	-2.823
Story10	DCon32	-13.401	-1.807	-3.6
Story10	DCon33	14.231	-1.769	-2.798
Story10	DCon34	-14.593	1.247	-3.625
Story10	DCon35	0.14	13.37	-3.184
Story10	DCon36	-0.502	-13.893	-3.239
Story10	DCon37	-0.99	16.264	-3.208
Story10	DCon38	0.628	-16.787	-3.215

Appendix C

Table 3 Seismic Zone Factor *Z*
(*Clause* 6.4.2)

Seismic Zone Factor (1)	II (2)	III (3)	IV (4)	V (5)
Z	0.10	0.16	0.24	0.36

Table 9 Response Reduction Factor *R* for Building Systems

(*Clause* 7.2.6)

Sl No. (1)	Lateral Load Resisting System (2)	R (3)
i)	**Moment Frame Systems**	
	a) RC buildings with ordinary moment resisting frame (OMRF) (*see* Note 1)	3.0
	b) RC buildings with special moment resisting frame (SMRF)	5.0
	c) Steel buildings with ordinary moment resisting frame (OMRF) (*see* Note 1)	3.0
	d) Steel buildings with special moment resisting frame (SMRF)	5.0
ii)	**Braced Frame Systems** (*see* Note 2)	
	a) Buildings with ordinary braced frame (OBF) having concentric braces	4.0
	b) Buildings with special braced frame (SBF) having concentric braces	4.5
	c) Buildings with special braced frame (SBF) having eccentric braces	5.0
iii)	**Structural Wall Systems** (*see* Note 3)	
	a) Load bearing masonry buildings	
	1) Unreinforced masonry (designed as per IS 1905) without horizontal RC seismic bands (*see* Note 1)	1.5
	2) Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands	2.0
	3) Unreinforced masonry (designed as per IS 1905) with horizontal RC seismic bands and vertical reinforcing bars at corners of rooms and jambs of openings (with reinforcement as per IS 4326)	2.5
	4) Reinforced masonry [*see* SP 7 (Part 6) Section 4]	3.0
	5) Confined masonry	3.0
	b) Buildings with ordinary RC structural walls (*see* Note 1)	3.0
	c) Buildings with ductile RC structural walls	4.0
iv)	**Dual Systems** (*see* Note 3)	
	a) Buildings with ordinary RC structural walls and RC OMRFs (*see* Note 1)	3.0
	b) Buildings with ordinary RC structural walls and RC SMRFs (*see* Note 1)	4.0
	c) Buildings with ductile RC structural walls with RC OMRFs (*see* Note 1)	4.0
	d) Buildings with ductile RC structural walls with RC SMRFs	5.0
v)	**Flat Slab – Structural Wall Systems** (*see* Note 4)	
	RC building with the three features given below:	3.0
	a) Ductile RC structural walls (which are designed to resist 100 percent of the design lateral force),	
	b) Perimeter RC SMRFs (which are designed	

Table 8 Importance Factor (*I*)

(*Clause* 7.2.3)

Sl No. (1)	Structure (2)	*I* (3)
i)	Important service and community buildings or structures (for example, critical governance buildings, schools), signature buildings, monument buildings, lifeline and emergency buildings (for example, hospital buildings, telephone exchange buildings, television station buildings, radio station buildings, bus station buildings, metro rail buildings and metro rail station buildings), railway stations, airports, food storage buildings (such as warehouses), fuel station buildings, power station buildings, and fire station buildings), and large community hall buildings (for example, cinema halls, shopping malls, assembly halls and subway stations)	1.5
ii)	Residential or commercial buildings [other than those listed in Sl No. (i)] with occupancy more than 200 persons	1.2
iii)	All other buildings	1.0

NOTES

1 Owners and design engineers of buildings or structures may choose values of importance factor *I* more than those mentioned above.

2 Buildings or structures covered under Sl No. (iii) may be designed for higher value of importance factor *I*, depending on economy and strategy.

3 In Sl No. (ii), when a building is composed of more than one structurally independent unit, the occupancy size shall be for each of the structurally independent unit of the building.

4 In buildings with mixed occupancies, wherein different *I* factors are applicable for the respective occupancies, larger of the importance factor *I* values shall be used for estimating the design earthquake force of the building.