A COMPARATIVE STUDY OF BEHAVIOR OF HIGH RISE REINFORCED CONCRETE BUILDING WITH DIFFERENT STRUCTURAL SYSTEMS

A Project Report

Submitted by

NIKHIL SAINI

In partial fulfillment of the requirements for

the award of Degree of

MASTER OF TECHNOLOGY

In

STRUCTURAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY, DELHI
(FORMERLY DELHI COLLEGE OF ENGINEERING)
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2015

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Roll No. 2K13/STE/10

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Under the guidance of

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2015

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Candidate's Declaration

I do hereby certify that the work presented in this report entitled "**A comparative study of behavior of high rise reinforced concrete building with different structural systems"** in partial fulfillment of curriculum of final semester of Master of Technology in Structural Engineering, submitted in the department of civil engineering, DTU is an authentic record of my work under the supervision of Dr. Nirendra Dev, Professor in department of civil engineering.

I have not submitted this matter for the award of any other degree or diploma.

Date: 16 June, 2015

(Nikhil Saini)
2K13/STE/10

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. Nirendra Dev)
Professor (HOD)
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ACKNOWLEDGEMENT

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Nikhil Saini

ABSTRACT

Keywords: *Tall Building, structural systems, dynamic analysis, gust factor, modal parameters, Lateral drift, story shear.*

The race to the new heights and architecture has not been without challenges. High rise structures have continued to face extreme loading effects such as dynamic wind and seismic effects. The lateral loading becomes more dominating as the structure height increases. The tall buildings shall be designed by taking various important parameters in mind such as strength, serviceability etc. As the building becomes slender, the most important consideration is human comfort against the various lateral loads. In the design of high rise building the most important feature is stiffness, which can be incorporated in the building by adopting different lateral load resisting systems. For example, in field of bridge engineering the upper and lower span limits of the bridge is decided considering the maximum efficiency. Similarly, in the field of tall buildings different structural systems are required for different heights. Therefore, each system is economical up to a certain height above which system has to be changed. There are a lot of structural systems present which resists the lateral loading as well as gravity loading. The first and important task of any designer is to ensure that the selected system resists the lateral displacements of the building under the permissible limits.

In this research, a study has been carried out on the efficiency and viability of different structural systems up to certain heights. In the first part of this report, background of the study and literature review of the previous study is presented. Initially a RCC building in zone 4 is adopted with square plan 45x45 m and story height 3.5 m. The building height is increased simultaneously and different structural systems are incorporated as per their efficiency. The modal parameters like drift, lateral sway are the deciding parameters for each structural system. The building is subjected to both wind and seismic effects. A total of 9 structural systems are adopted in this study and thier models are analyzed. The wind forces both static and dynamic in nature acting on the building with the height is manually prepared by using IS guidelines (IS 875-3). Different results are studied for each structural system such as story shear, lateral displacements, story drifts, modal time period and modal participation factors. The final result showed that up to what height a structural system is efficient in the selected domain and which leads to the practical significance of this research work. This study is intended to be useful to clear the ambiguity choosing the type of system according to requirements of our building height, location and loading intensities.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

High rise buildings have always fascinated human beings from the ancient times, initially the taller buildings represents the monuments rather than urban habitat. Nowadays it is a common trend to build larger and larger buildings for commercial purposes or residential. High rise building represents a status symbol in big cities. However it is the technology, due to which today the engineers are able to go at such heights. The construction of tall buildings are dependent on available materials and well equipped transportation system through which people can go up and down while construction process. From last 100 years, engineers and architects are involved in developing new technologies to build higher structures. In late 1850s, most of the buildings were erected using cast iron, later on during 1900s steel mega columns and beams with bracing leads to the era of taller buildings. However, the structural form of any building or skyscraper is the only key which decides the human comfort and other modal parameters. As the height of any building increases the lateral forces such as wind and earthquake behaves dynamically. The building must be designed to resist such larger lateral forces; structural system of the building should resist such forces. With the growth of technology many structural systems get developed, however it is quite a task to choose an appropriate structural form. In tall buildings, both gravity as well as lateral loading must be resisted therefore structural system adopted should be capable of doing the same. In today's scenario designer has freedom to select suitable and efficient structural system which fulfils the criteria of human comfort and as well as under the limits of codal provisions.

1.2 OBJECTIVES OF THE STUDY

Following are the main objectives of the present study:

a) To understand the behavior of different structural systems which have been adopted in the analysis of high rise reinforced concrete building available in literature.

b) To perform the dynamic analysis of the building subjected to wind and seismic effects.

c) To find out the efficient and viable structural system best suited up to a particular height.

1.3 SCOPE OF THE STUDY

The present work is about the study of different structural systems being adopted in high rise reinforced concrete buildings and viability of each system up to certain height. A total of 9 structural systems are adopted in this study. Reinforced concrete design is not considered in this study. The present work is carried out considering zone 4 region. Dynamic analysis of the building is performed under both wind and seismic effects. The different responses like story shear, story drift, lateral displacement, modal time period, modal participation factor are studied. ETABS 9.7.4 software is used throughout this study for the structural modeling and analysis of building.

1.4 METHODOLOGY

a) A thorough literature review to understand the behavior of high rise building under seismic and wind effects.

b) A thorough literature review to understand the behavior of various structural systems adopted for high rise building.

c) Selection of a RCC building with geometrical and structural details and modeling it in ETABS incorporating all the structural systems.

d) The number of stories in building is increased and analysis is carried out simultaneously, finally reaching at a conclusion that which structural system is efficient up to certain height in terms of modal parameters.

1.5 RESEARCH SIGNIFICANCE

This research yields valuable results regarding the structural behavior of high rise building. The investigation on the structural behavior of high rise building is unique as the effect of dynamic earthquake loading is combined with dynamic wind loading. This study proposes analytical method to compute the lateral deflection of building under the dynamic loading. In addition, the study verifies the IS approach (IS 1893 part 1, IS 875 part 3) for the calculation of different modal parameters of the building. The results obtained show the efficiency of different structural systems under dynamic loading. This research contributes a lot in understanding the viability of a structural system corresponding to the height of the building.

1.6 ORGANISATION OF THESIS

This thesis is divided into five chapters. This first introductory chapter presents the background; objectives; scope; methodology and research significance of the project. In the second chapter, a literature review on the behavior of high rise building is reported. Focus is placed on the lateral loading i.e. earthquake and wind loading acting on the high rise building. The structural behavior of different structural systems is also reported. This chapter also includes the previous researches on the high rise building. Chapter 3 presents the design parameters including wind and earthquake, structural modeling of the different models of building incorporating different structural systems. Chapter 4 presents the analysis results and different interpretations of the results. Finally in the last chapter, the work carried out is reviewed. The findings from the study are reported.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The literature available on the efficiency of various RCC structural systems in the high rise building is very limited; however we can get a number of published literatures on the analysis of different structural systems. It becomes a bit tedious to analyze the RCC building incorporating different structural forms. In addition, literature on the dynamic analysis of wind and earthquake acting on a high-rise building are very limited. Thus the literature survey is presented here in two main areas: (i) the high rise behavior of buildings under dynamic effect of wind and earthquake and (ii) the behavior of different structural systems being adopted in high rise buildings.

2.2 TALL BUILDING AND CLASSIFICATION

The exact definition of tall building is a difficult task as it clearly depends upon different parameters and conditions. However, defining a tall building is a relative task.

Bungale S Taranath [1] describes that tall building cannot be defined in terms of height or number of stories, however it depends on the perception of an individual or consideration of the community, so there is no universal definition of tall building.

The CTBUH [3] gives a classification of tall building on different categories:

a) **Height relativity:** This category defines tallness of any building on the height of other surrounding buildings. A 20 story building cannot be considered in high rise criteria if it is present in high rise cities like Tokyo, Hong Kong however the same will be considered if it exists in suburban areas.

b) **Proportion:** Again a tall building cannot be defined in terms of height. There are a lot of buildings which are not high but there appearance looks like. So this category includes proportion of the building which means slenderness appearance, height to base ratio.

c) **High rise technologies:** If any building contains technologies like large vertical elevators, structural bracing systems etc, then these can be considered as a product of tall buildings.

The CTBUH [3] gives definition of super tall building comprising of height more than 300 m and mega tall building above 600 m.

2.3 DEMAND FOR HIGH RISE BUILDING

It is of quite interest that in today's scenario high rise buildings are making their way at a very faster rate. *Alex Coull* [2] defined tall buildings have been serving mankind from ancient times for the purposes of defense and big monuments but in later 1800s it started residential and commercial purposes. Higher buildings often described as landmark and statue symbols in the cities. However, fast growth of population results into small space available on land. Therefore, on a small space of land, taller building results into accommodation of huge population.

Various points can be considered as demand of high rise buildings:

a) Scarcity of land in urban areas

b) Increased demand for housing and office space

c) Innovation in structural system/engineering

d) Concept of city skyline

e) Economic growth

2.4 LOADING ON A TALL BUILDING

Loading on a high rise building is quite different from low rise building, as the height of the building increases the wind and earthquake effects starts dominating. There are various loads that can be considered on a tall building:

a) Gravity loading – Dead load, Live load, Superimposed load, Impact gravity loading, construction load

b) Lateral loads – Wind load, Seismic load, earth pressure(basement)

c) Deformation load – Creep, Shrinkage, Temperature effects

Although there are various loads present in design of building, for the present study scope is limited to Dead load, Live load, Wind and Earthquake loads only.

a) GRAVITY LOADING

The gravity load accumulation in the high rise building is generally higher at lower levels because of more number of stories. The dead loading however can be computed by the member sizes and their densities. Dead load can be computed easily using IS guidelines (IS 875 part 1) [18]. Gravity loading also includes live load which is defined as the uniformly load distributed on floor area, magnitude of which is directly adopted from IS guidelines (IS 875 part 2) [19].

b) LATERAL LOADING

Lateral loads are the horizontal forces acting on the building; mainly lateral loads are wind and earthquake. Mostly the lateral load magnitude depends upon the geographical features, terrain, zone, height, shape and size of structure. Under the action of such lateral forces, the building behaves like a vertical cantilever connected to ground rigidly.

WIND LOADING:

It is the most common lateral load which acts parabolically on a building. Wind builds up positive and negative pressure on both sides of building. The pressure magnitude varies proportionally to square of the wind speed. Wind forces depend upon various factors like geography, terrain, and wind speed. However wind forces vary according to the height of building, at lower heights it is static but as the building becomes slender dynamic effect of wind dominates. The figure 2.1 shows the variation of wind.

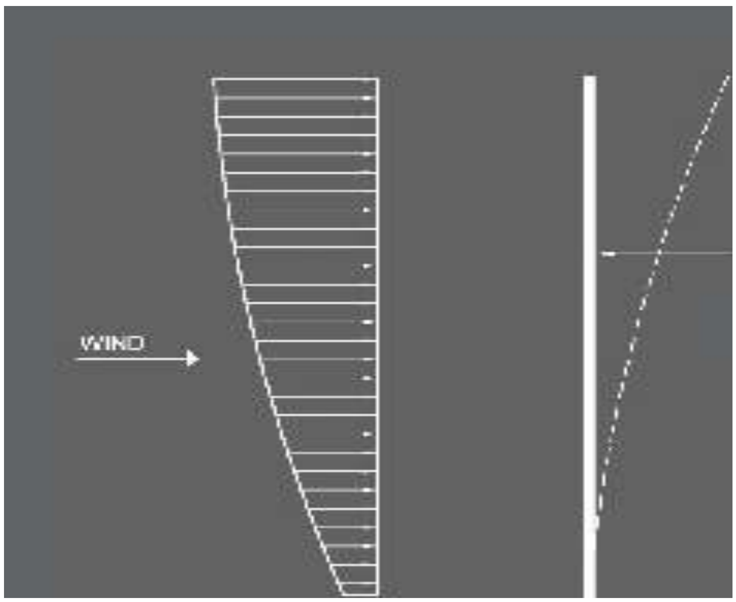

Fig.2.1: figure showing wind pattern acting on the building. [1]

Holmes, Tamura and Krishna [5] studied the wind effects on a 183 m high building. They investigated that wind has a dynamic response in the terms of shear, bending and acceleration at the top of building. The wind variation coefficients for along and cross wind components are 14-18 %, while for medium rise building there was no significant correlation observed. However, the gust factor becomes more dominant at higher levels.

Ranjitha, Khan and Raja [4] studied the effect of wind pressure on reinforced concrete building including gust effect. A 15 story RCC building was investigated with both static as well as dynamic gust loading factor. The lateral displacement at the top increases by 4.12 % by including gust effect and story drift increases by 7.0 %.

EARTHQAUKE LOADING:

Earthquake is more complex and potentially causes more damage to the structures than wind. Earthquake causes the ground to shake, which further leads to the movement of building resting on the ground. The earthquake forces depend upon the mass of the structure. It consists of the inertial forces of the building mass.

Bungale S Taranath [1] describes the behavior of building during an earthquake as follows:

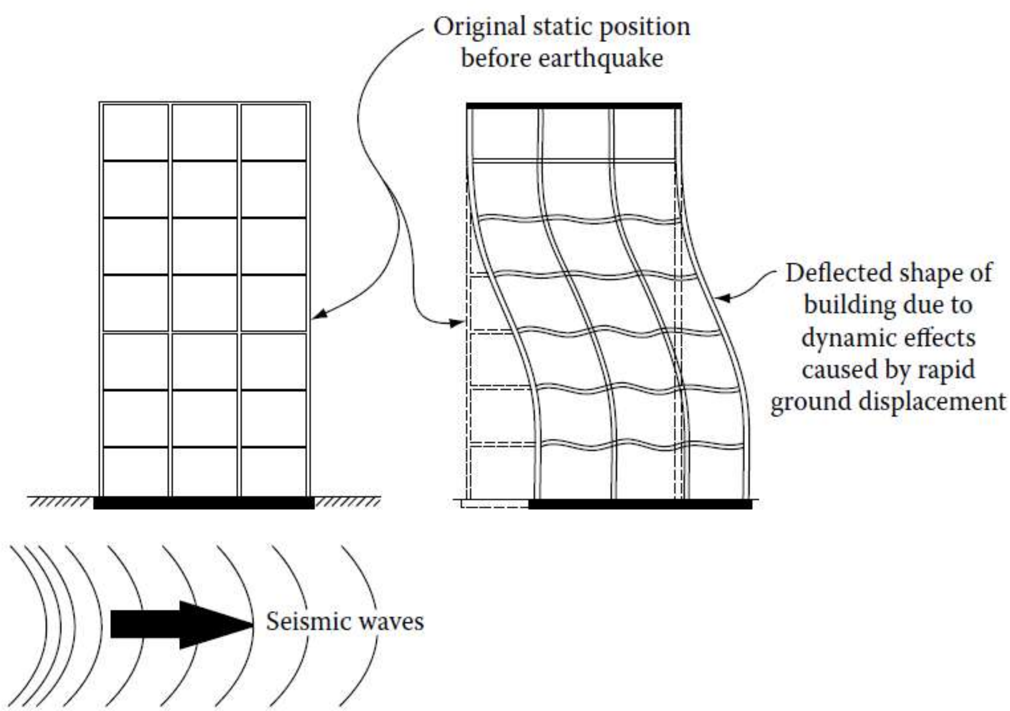

Fig.2.2: figure showing effect of earthquake on the building. [1]

The figure above shows how the original shape of building gets deflected due to earthquake. Seismic analysis is generally carried out using response spectrum analysis.

Patil, Ghadge and Konapure [6] studied the effect of seismic analysis using response spectrum analysis. The parameters considered in the study were base shear, time period and lateral sways.

2.5 STRUCTURAL SYSTEMS WITH PREVIOUS RESEARCH FINDINGS

The structural system in any building is the most important task for an engineer, as it is the one which resists both gravity and lateral loads. As the building becomes taller, more important the choice of structural system becomes as the lateral forces becomes dynamic. Every structural system has its limitations; *Alex Coull* [2] stated that above a certain height high lateral flexibility is required which results into large uneconomical members to overcome the drift produced in the building. Therefore at a certain height it becomes necessary to adopt different structural system.

2.5.1 RIGID FRAME SYSTEM

This type of structural system consists of columns and beams connected together by rigid connections. However the lateral stiffness of this system is totally dependent on stiffness of beams, columns and connections. However rigid frame system may be either of OMRF (ordinary moment resisting frame) or SMRF (special moment resisting frame), the latter follows the ductile detailing guidelines as per IS 13920 [21].

Alex Coull [2] stated that this system is more suitable for reinforced concrete constructions because of the rigidity of the joints and the behavior of this system under the lateral loads as shown in figure 2.3 below:

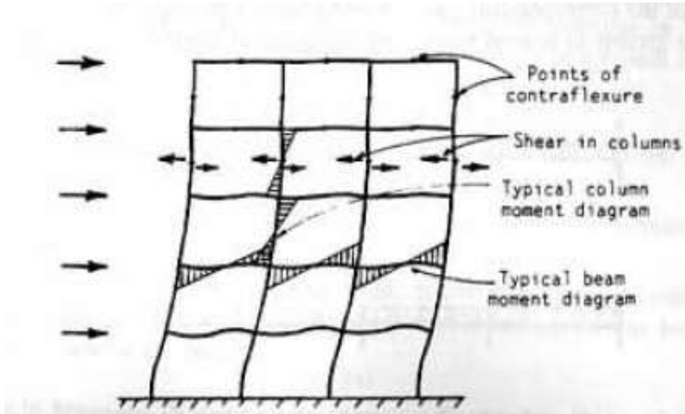

Fig.2.3: figure showing behavior of rigid frame system under lateral load. [2]

Prasad and Adiseshu [7] conducted a comparative study on OMRF and SMRF structural system for high rise building. This study gave a comparison between OMRF and SMRF systems under seismic loads; SMRF gives a more safe design as compared to ordinary moment resisting frame. The top lateral sway observed was 40 mm for SMRF system as compared to OMRF system which had 60 mm sway at the top. The SMRF system gives better serviceability and more life span to structure.

2.5.2 FRAMED TUBE SYSTEM

In framed tube system, the outer perimeter of the building consists of closely spaced columns connected by deep beams such that high resistance is provided to the lateral forces. The outer perimeter tube resists all the lateral load and the gravity load is resisted by the inner columns. However the economy of this system depends upon the spacing of perimeter columns and depth of beams. *Bungale S Taranath* [1] described the behavior of framed tube system, when subjected to lateral forces the frame parallel to the lateral load acts as web while the normal frames behaves as flange and the frame aligned in the direction of lateral load are subjected to in plane bending. The figure 2.4 shows the frame tube system.

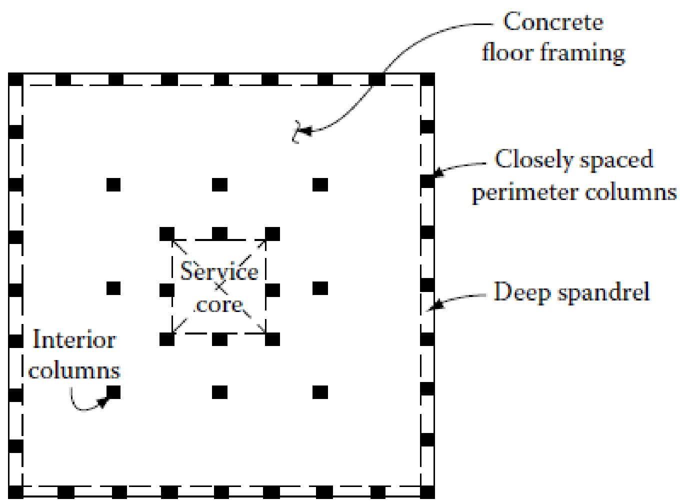

Fig.2.4: figure showing framed tube system. [1]

2.5.3 TUBE IN TUBE SYSTEM OR HULL CORE SYSTEM

This system consists of an outer framed tube with an interior tube, thus comprising of tube in tube structure. However, the inner core sometimes referred to as core and the outer tube as hull. The hull and core both acts jointly to resists the lateral and gravity load. The inner core may be comprised of shear wall in reinforced concrete system. The figure 2.5 shows the tube in tube system.

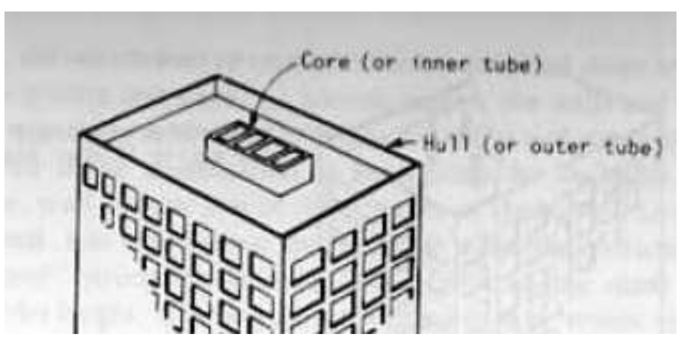

Fig.2.5: figure showing tube in tube system. [2]

Kang-Kun Lee, Yew-Chaye Loo, and Hong Guan [8] studied the analysis of framed tube structures with multiple internal tubes. They analysed three buildings with 30, 50 and 70 storey without internal tubes and then with multiple internal tubes. They concluded that with the addition of internal tubes the lateral stiffness of the building increases and also there is reduction in bending stress between the centre and corner columns which leads to the reduction of shear lag effects as compared to the framed tube system.

2.5.4 BUNDLED TUBE SYSTEM

The main principle under this structural system is to connect two or more number of tubes to connect to each other, thus forming a bundled system of tubes. However the main motive is to considerably reduce the shear lag effects. The frames in the direction of lateral force resist the shear while the frames normal resists the overturning moments. The greatest advantage of this system is that floors can be stopped at any height required. The closer spacing of the columns and deep beams provides the much higher stiffer building. Dr Fazlur khan first introduced this structural system being adopted in the design of 108 story wills tower Chicago. The figure 2.6 shows the bundled tube system.

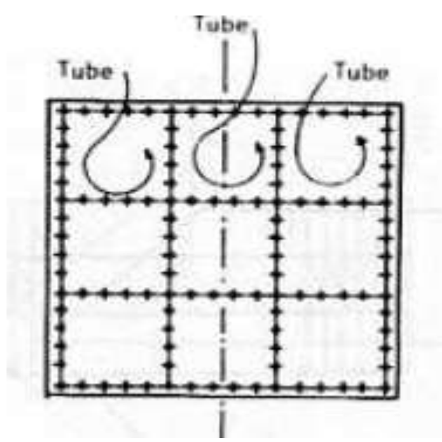

Fig.2.6: figure showing bundled tube system. [2]

Deepak, Chore and Dode [9] analysed G+40 RCC residential building with partial tubular and tubular systems under the dynamic seismic effects. The top lateral sway gets reduced to 60 mm from 100 mm by introducing the inner tubes in the building also the time period reduces to 3.4 sec from 5.2 sec. They found that the model with inner tubes or bundled tubes is effective in resisting the lateral forces as compared to framed tube system because of the box effect of the modular tubes; it is increasing complete stiffness of the building and thus helping in reducing the drift.

2.5.5 WALL FRAME SYSTEM

Shear wall is a structural element designed to carry most of the lateral loads, wind or seismic. Shear wall has very high in plane bending stiffness and makes the whole building strong. There stiffness is very much higher than rigid frames. "We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls." Mark Fintel, a noted consulting engineer in USA. These walls basically originate from the foundation level and continue up to level required. However, foundation design of walls must be of prime importance. Their thickness may vary from 150 to 400 mm depending upon the height of the building. However, the important point to be kept in mind that shear wall resists the lateral forces in their direction of its orientation; therefore walls must be present in both directions of the building. *Alex Coull* [2] explained that when walls are combined with frames, walls deflects in flexural configuration and the frame deflects in shear mode and both interacts at the top providing stiffness in the building. The walls resist most of the lateral load and frame carries the gravity loading. The mode of interaction between the wall and frame is shown in figure 2.7.

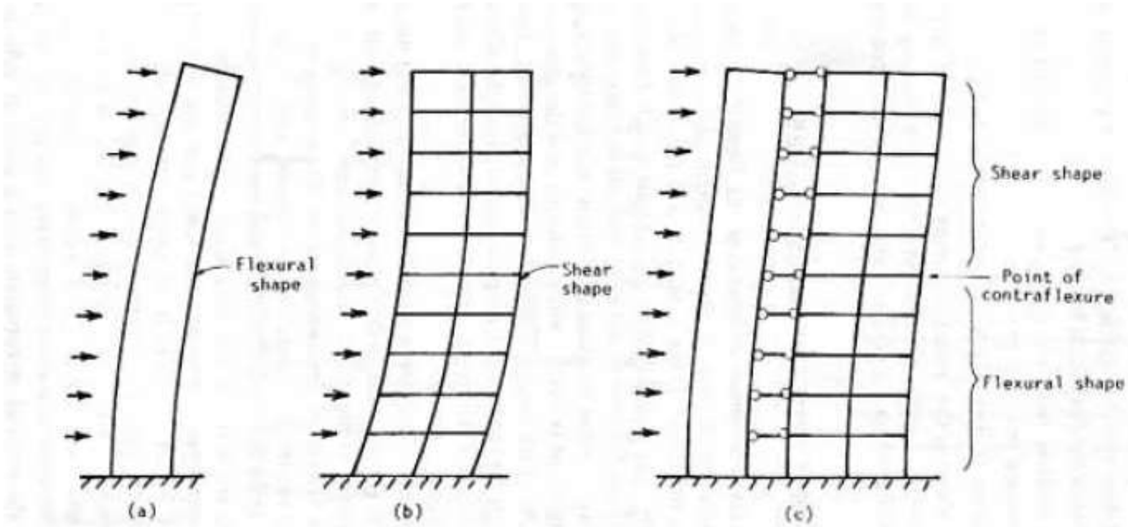

Fig.2.7: figure showing interaction wall and frame. [2]

Varsha R. Harne [10] performed the analysis of RC shear wall at different location in multi storied building. He investigated three different positions of shear wall in the building, L shape, cross shape and wall at the periphery of the building. The lateral deflection of the building for periphery wall is lesser as compared to other positions of shear wall. The lateral sway at the top reduces up to 33.33 % and 32.06 % as compared to L type and cross type shear wall.

Anshul, Raghav and Poonam Dhiman [11] showed the best placement of shear wall in RCC building under seismic effects, he observed a multistory building located in zone 5 with five different positions of shear walls: located at central core, at periphery and at exterior bays. He shown that the introduction of shear walls considerably reduces the bending moment, shear force, story drift and lateral sways as compared to bare frame. The results showed that the frame with shear walls at the centre periphery of the building showed minimum deflection as compared to other configurations. The reduction in the response is 83 % i.e. from 60.9 to 10.14 mm.

2.5.6 COUPLED WALL SYSTEM

Coupled wall structural system comprises of interconnected shear walls with openings wherever required. The stiffness of coupled wall is much far than single shear wall because the coupled wall is connected together with a coupling beam which restrains the wall against lateral forces. These walls can be placed around elevators or outer periphery of the building. However the design of coupling beam is of prime importance as it links the two walls together. The coupling beams are generally provided with diagonal reinforcement. The figure 2.8 shows the coupled wall.

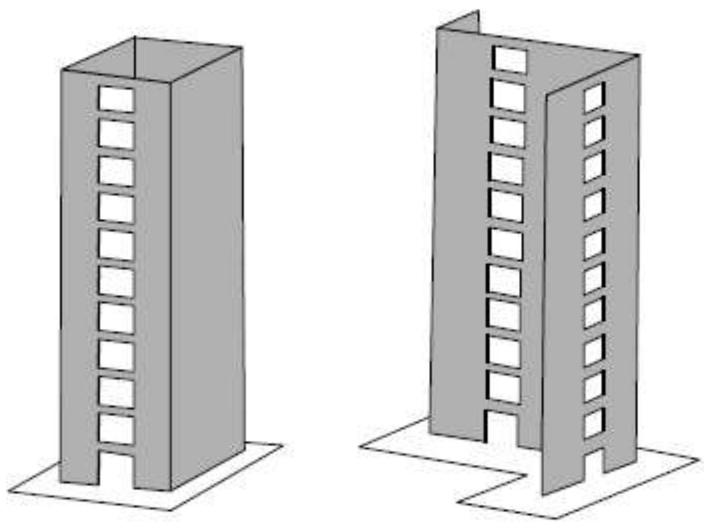

Fig.2.8: figure showing coupled wall system. [1]

E. Emsen, C. D. Turkozer, O. Aksogan, R. Resatoglu and M. Bikçe [12] investigated multistory building with coupled shear walls having stiffening beams. The analysis was made with SAP 2000, the results showed that stiffened coupled walls leads to reduction in the top displacement. Thus by introducing such coupling beams the height of the building can be increased further.

2.5.7 OUTRIGGER / SPINAL WALL SYSTEM

This type of system is generally adopted for ultra tall buildings. In this system shear walls are placed along the full length of corridors of the building, therefore referred as spinal walls or outriggers. The system basically consists of a central core to which outriggers are connected at certain levels of the building where ever required. These outriggers are connected to outer columns at other end. These walls may be of one or two story deep.

Bungale S Taranath [1] describes the behavior of this system, when this system is subjected to lateral loads the outriggers extended to outer columns resist the core rotation and also reduces the excessive deflections. The external moment is resisted by core and also by tension and compression of outer columns connected to outriggers. The figure 2.9 shows the outrigger system.

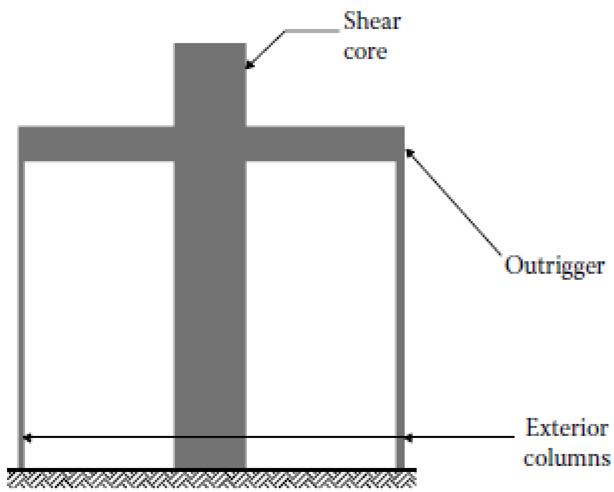

Fig.2.9: figure showing outrigger system. [1]

This system is adopted in burj khalifa, Dubai in which after every 30 stories, two story deep outriggers are connected to exterior. *Bungale S Taranath* [1] also showed optimum location for outriggers in building. A single outrigger must be at mid height, while optimum locations for two outriggers must be at one third and two third of the height of building.

Kiran Nanduri, B.Suresh, and Hussain [13] investigated on the optimum position of outriggers in 30 story RCC building under wind and seismic effects. They examined the study by placing outriggers at different positions at the top, at top and mid height, at top and one fourth height, at top and three fourth heights. They concluded that with the use of outriggers the efficiency of building increases in resisting the lateral loads. The maximum drift at the top with only core present is 50.63 mm while it gets reduced to 48.20 mm with outrigger. The optimum location found is at the mid height of the building.

Badami and Suresh [14] studied four types of structural systems i.e. rigid frame, wall frame, coupled wall and outrigger system for tall building subjected to lateral loading. The aim was to select an appropriate system. The efficiency is measured in terms of story drift, sways, shear and time period. They concluded that story drift is maximum in case of rigid frame minimum in outrigger system. With the increase in height of building time period from 45 to 50% with every addition of 15 stories.

Beneditt T. Laogan and Elnashai [15] studied the structural performance of tall buildings under seismic regions. They investigated 10 buildings of 24 stories under different earthquake loading. The dynamic analysis is performed using 3 earthquake records and twice the design values. They concluded that increase in the cost of structure is due to steel while the member reductions can be made by increasing the concrete grade. Thus high strength concrete is of prime importance in design of tall buildings.

Ali Sherif, Dar al-Handashah [16] published a research paper in CTBUH on structural design of reinforced concrete tall building. They have undergone various case studies of buildings height varying from 400 m to 800 m.

The structural systems of all the buildings were studied and a conclusion was made that for achieving ultra tall buildings, the material selection is most important thing. For the buildings up to 600 m concrete can be lifted but above 400 m use of composite steel and concrete constructions seems to be efficient and effective. It also reduces the gravity loads at such greater heights.

Bungale S Taranath [1] described a system which has an outrigger at the top of the building, referred to as cap or hat wall system. Under the action of lateral forces, the exterior columns bend in tension and compression along with the central core. But due to presence of hat wall at the top, the bending moments are reduced in the core and drift also. Therefore the cap wall may be considered as restraining spring at top which opposes the rotation of the core. The system is shown in figure 2.10.

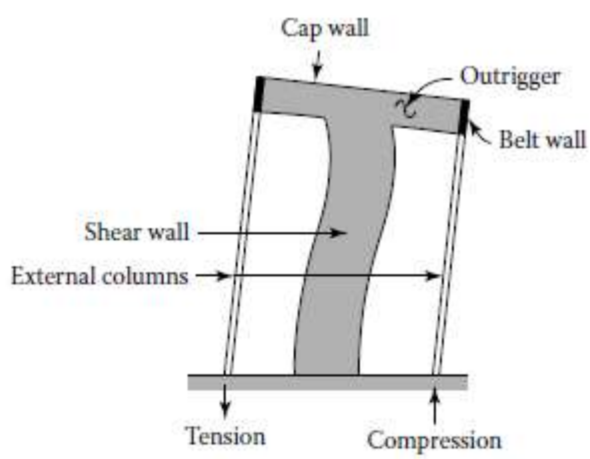

Fig.2.10: figure showing outrigger system with cap/hat. [1]

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The study in this report is concerned with the behavior of different structural systems in high rise buildings under the dynamic effects of wind and earthquake and efficiency of the structural systems as the height of building increases. This chapter includes the modeling of the building in ETABS software and different design parameters considered in the study each structural has its efficiency above a certain height it is necessary to adopt different structural system. The efficiency of any structural system is decided on the basis of different modal parameters.

3.2 MODELING OF BUILIDING

A RCC building is adopted for the present study having square plan and it is regular in nature. The building is assumed to be located in zone 4. The centre line dimension of the building is 45x45 m which forms 6 bays and each bay is 7.5 m. Each floor has a height of 3.5 m. The building is provided with a central core service i.e. 15x15 m. The plan of the building modeled in ETABS is shown in the figure 3.1.

3.3 PROBLEM FORMULATION

This present study has main focus on the efficiency and viability of different structural systems according to the height of the building. The basic problem is to incorporate different structural systems in the building plan as shown in figure 3.1. However the stiffness is maintained in every structural form. As all the structural systems are incorporated in the plan of the building, the floor numbers are also increased simultaneously with carrying out the analysis under seismic and wind effects. The viability of systems is decided on the modal parameters such as drift index, lateral sway etc. The main focus is to develop a relation between structural systems and number of floors in the building.

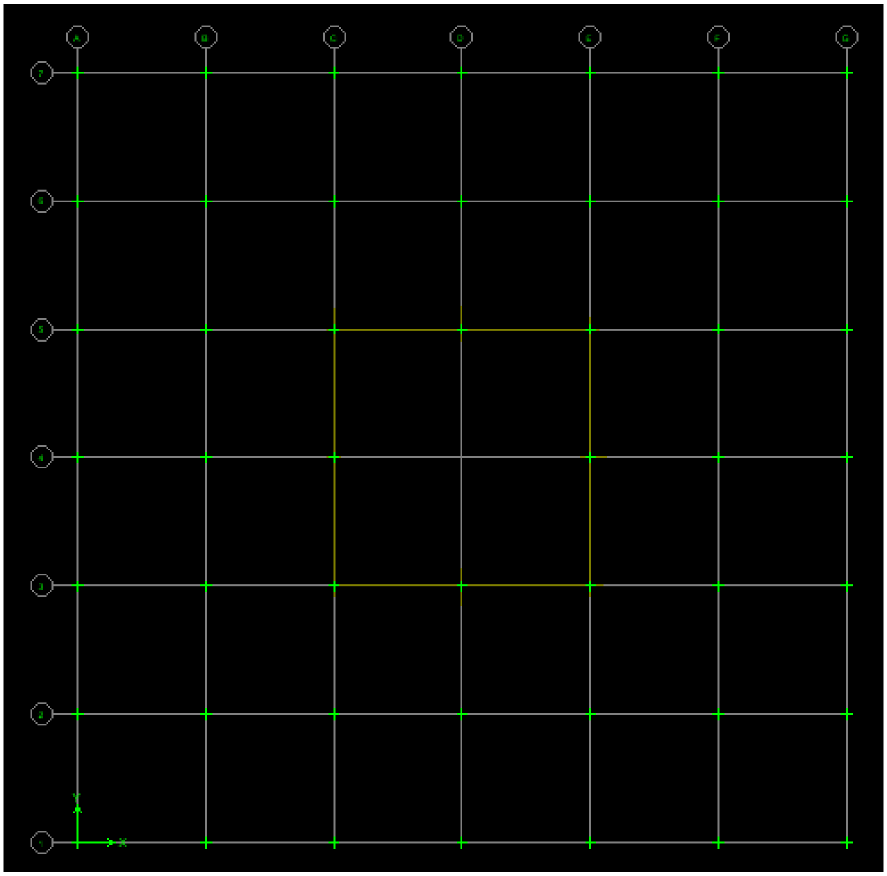

Fig.3.1: figure showing building plan.

3.4 DIFFERENT DESIGN PARAMETERS FOR THE BUILDING

The different loads that are to be considered on the building in the present study are:

a) Gravity loads: Dead load, Live load, Floor finish load

b) Lateral loads: Wind load and Seismic load

1) **Dead load:** The dead load is the self weight of the different members in the building. However in this study only bare frame is considered so wall load are not counted far.

2) **Live load:** Live loads are the load generating due to the human beings, as the nature of the building is business cum office therefore the live load is taken as 4.0 KN/ sq m. The live load is taken from IS guidelines (IS 875 part 2) [19].

3) **Floor Finish:** The floor finish load comes from the finishing of the floor, the floor finish load calculation is taken from IS guideline (IS 875 part 1) [18].

4) **Wind parameters:** The wind design in this study is carried out as per IS guidelines (IS 875 part 3) [20]. Various wind design parameters are tabulated in table 3.1.

Table 3.1: wind design parameters

City	Delhi
Basic wind speed	47 m/s
Risk Coefficient factor K1	1
Terrain, height factor K2	refer APPENDIX A
Topography factor K3	1
Terrain category	3

The wind load acting on the building is calculated manually by the force coefficient method as per IS guidelines (IS 875 part 3) [20]. In this study, both static and dynamic wind effects are computed as per IS code, if building height to minimum lateral dimension exceeds 5 then dynamic analysis has to be performed including the gust effect. The static and dynamic wind calculations are presented in APPENDIX A and APPENDIX B respectively.

5) **Seismic parameters:** The building is assumed to occur in Zone 4, with hard soil and regular in nature. The seismic design is carried out by IS guidelines (IS 1893 part 1 2002) [17]. The building is designed using ductile detailing guidelines by IS 13920 [21]. The various seismic design parameters are tabulated in table 3.2.

Table 3.2: seismic design parameters

Zone factor	0.24
Importance factor	1
Soil type	2
Response reduction factor	5
Design eccentricity	5%

3.5 ANALYSIS OF THE BUILDING

The building is analysed for both wind as well as seismic effects. However as per IS guidelines (IS 1893 part 1 2002) [17] dynamic seismic analysis is carried out in zone 4 if the building height is greater than 40.0 m. In present study, the dynamic seismic analysis is carried out by the software itself using Response spectrum analysis.

Response spectrum method:

Response spectrum method is a dynamic analysis of earthquake; various responses like displacement, velocity, acceleration of various frequencies are forced into motion. This method basically works on stiffness and mass matrix developing the different modal parameters like mode shapes, modal time periods and participation factors.

Response spectra can also be used in assessing the response of linear systems with multiple modes of oscillation (multi degree of freedom systems), while they are only accurate for low levels of damping. Modal analysis is done to identify the modes, and the response in that mode can be picked from the response spectrum.

3.6 COMPUTATIONAL MODELS

In this study a total of 9 models are developed, each model has different structural systems. The structural configuration, material selection, dimensions of the structural members is described for each model and the plan view of each model is presented.

MODEL 1: RIGID FRAME

The plan of the system is shown in figure 3.2 and various details of the system are shown in table 3.3.

Table 3.3: Salient features of the building model 1

1	**Type of structural form**	**Rigid Frame(SMRF)**
2	**Layout**	**As shown in Fig**
3	**Floor height**	**3.5 m**
4	**Slab thickness**	**175 mm**
5	**Beam size**	**300X600 mm**
6	**Column size**	**400X1200 mm**
7	**Live load**	**4.0 KN/m2**
8	**Materials**	**M35, M40, M50, Fe415**

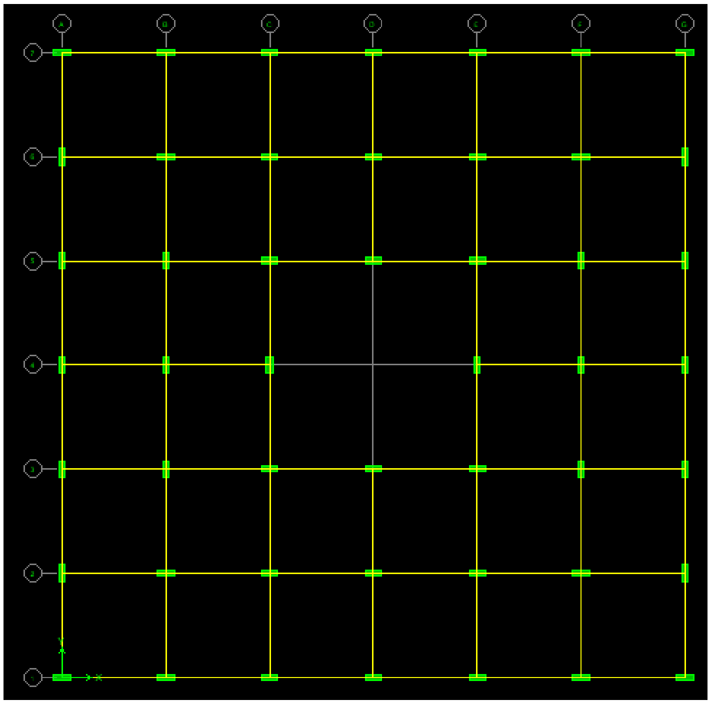

Fig.3.2: Typical floor plan of building model 1

MODEL 2: FRAMED TUBE SYSTEM

In this system, columns of dimension 300X450 mm are placed at outer perimeter of the building as show in figure 3.3 at a spacing of 2.50 m centre to centre. The various structural details are tabulated in table 3.4.

Table 3.4: Salient features of the building model 2

1	**Type of structural form**	**Framed tube**
2	**Layout**	**As shown in Fig**
3	**Floor height**	**3.5 m**
4	**Slab thickness**	**175 mm**
5	**Beam size**	**300X500 mm interior 300X700 mm outer tube**
6	**Column size**	**400X900 mm inner 300X450 mm outer tube**
7	**Live load**	**4.0 KN/m2**
8	**Materials**	**M35, M40, M50, Fe415**

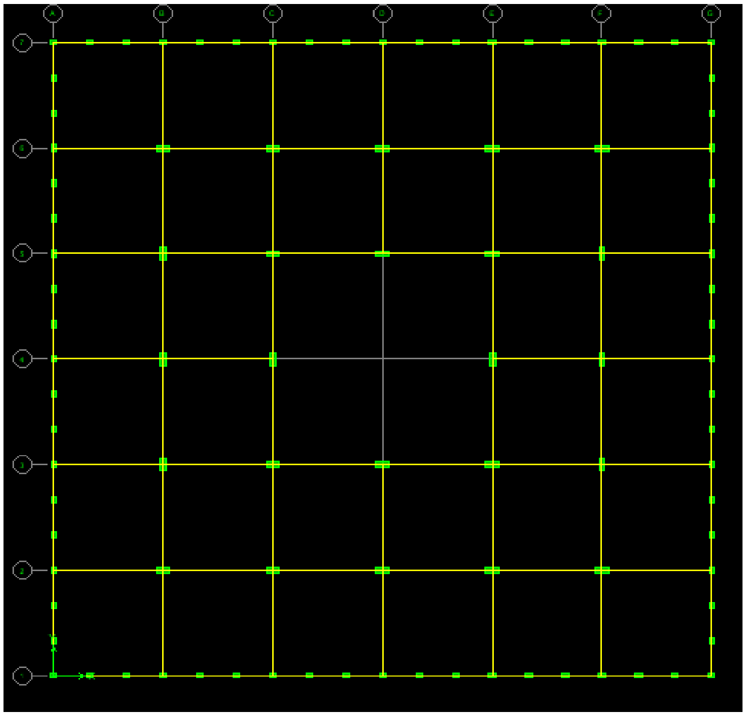

Fig.3.3: Typical floor plan of building model 2

MODEL 3: TUBE IN TUBE SYSTEM

This system comprises of inner as well as outer tube, the inner tube is surrounding the central core of the building with 400X400 columns at a spacing of 1.88 m c/c. The plan of the building and details of system is shown as below:

Table 3.5: Salient features of the building model 3

1	Type of structural form	Tube in tube
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X500 mm inner 300X700 mm outer tube
6	Column size	400X900 mm interior 300X450 mm outer tube 400X400 mm inner tube
7	Live load	4.0 KN/m2
8	Materials	M35, M40, M50, Fe415

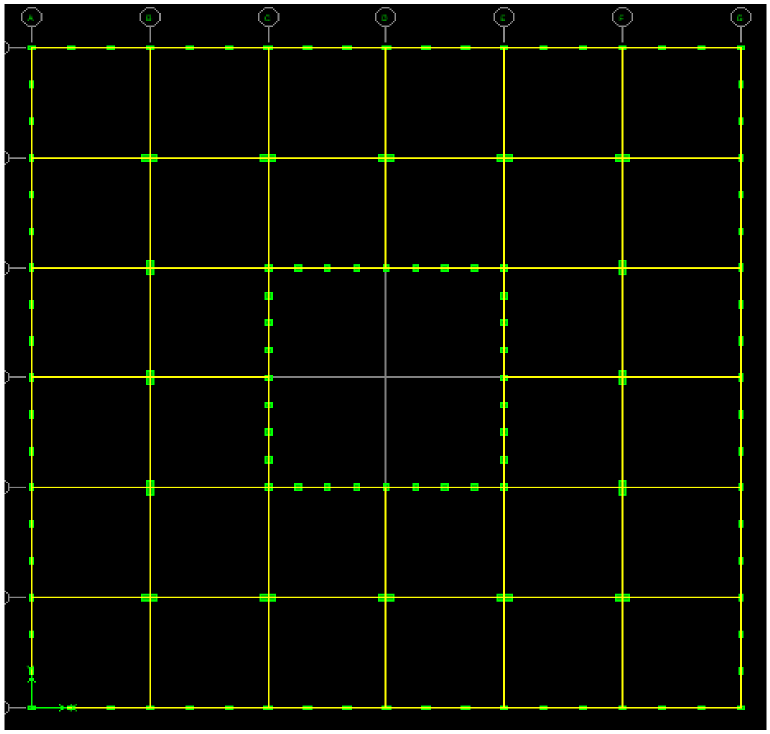

Fig.3.4: Typical floor plan of building model 3

MODEL 4: BUNDLED TUBE SYSTEM

In this system, a total of 9 tubes are formed having 15x15 m area and connected to form the plan of building as shown in figure 3.5. The tube columns having size 450X450 mm are placed at a distance 2.50 m c/c. the structural details are tabulated in table 3.6.

Table 3.6: Salient features of the building model 4

1	Type of structural form	Bundled tube
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X450 mm inner 300X700 mm outer tube
6	Column size	400X900 mm interior 450X450 mm tube columns
7	Live load	4.0 KN/m2
8	Materials	M35, M40, M50, Fe415

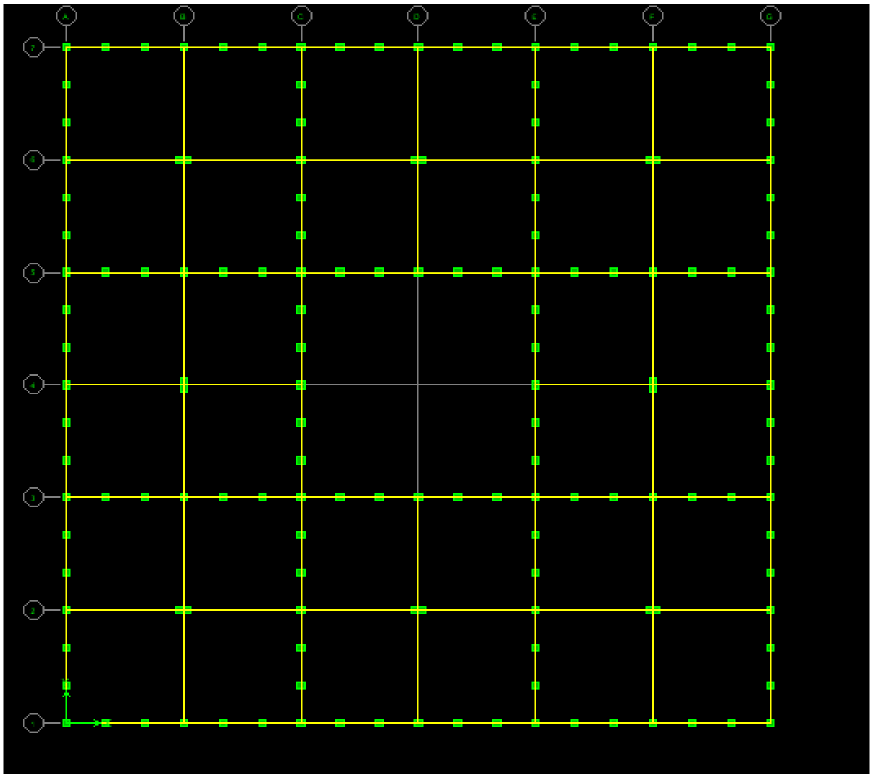

Fig.3.5: Typical floor plan of building model 4

MODEL 5: WALL FRAME SYSTEM

In this system, shear wall is placed at the outer periphery of the building as well as at the periphery of central core as shown in the figure 3.6. The various structural details are tabulated in table 3.7.

Table 3.7: Salient features of the building model 5

1	Type of structural form	Wall frame
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X500 mm
6	Column size	400X750 mm interior 600X600 mm core columns
7	Live load	4.0 KN/m2
8	Shear wall	230 mm
9	Materials	M35, M40, M50, Fe415

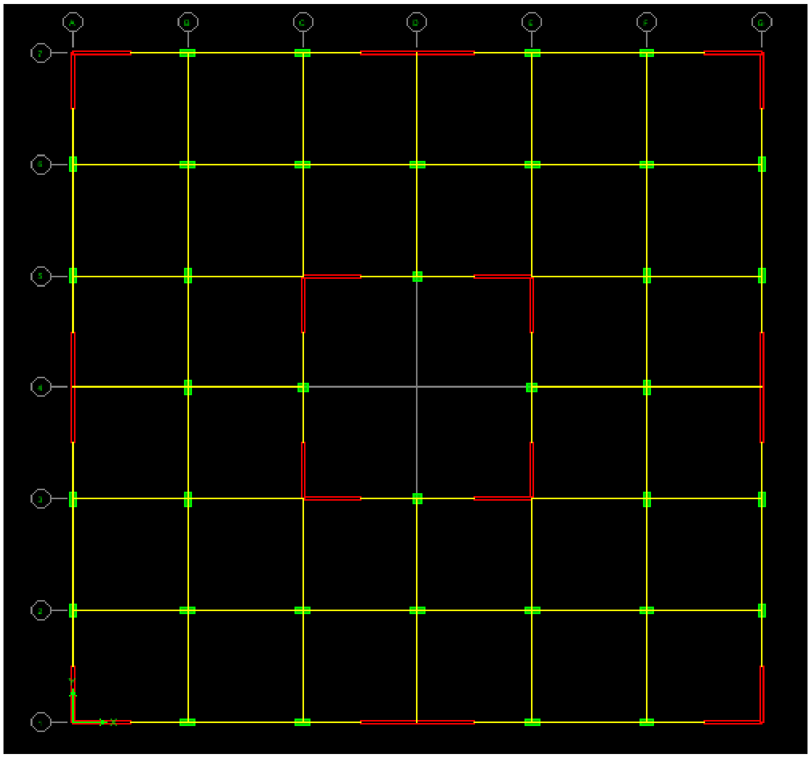

Fig.3.6: Typical floor plan of building model 5

MODEL 6: COUPLED WALL SYSTEM

In this system, a core supported coupled wall is modeled at the central core of the building, various openings are provided for the doors/service requirements as shown in figure 3.7,3.8 and 3.9. The various structural details are tabulated in table 3.8.

Table 3.8: Salient features of the building model 6

1	**Type of structural form**	**Coupled wall**
2	**Layout**	**As shown in Fig**
3	**Floor height**	**3.5 m**
4	**Slab thickness**	**175 mm**
5	**Beam size**	**300X500 mm**
6	**Column size**	**400X900 mm**
7	**Live load**	**4.0 KN/m2**
8	**Shear wall**	**230 mm**
9	**Materials**	**M35, M40, M50, Fe415**

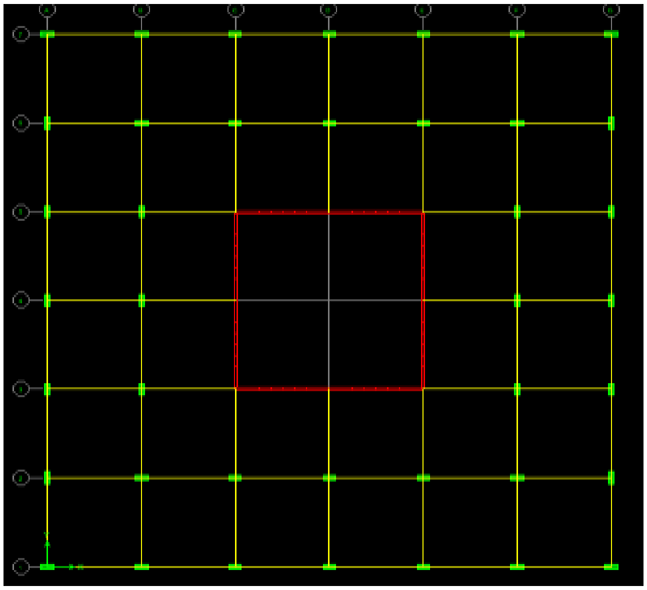

Fig.3.7: Typical floor plan of building model 6

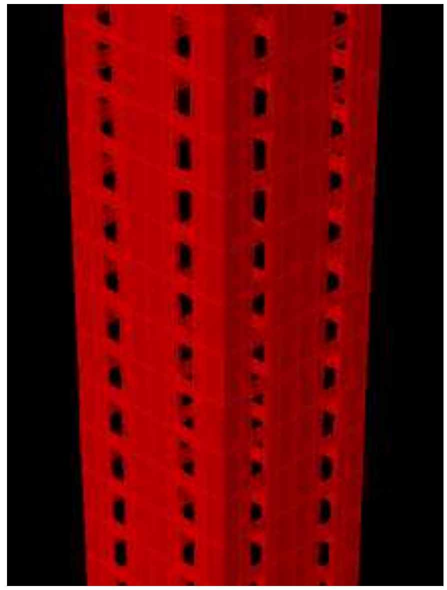

Fig.3.8: figure showing 3D view of the central core coupled wall

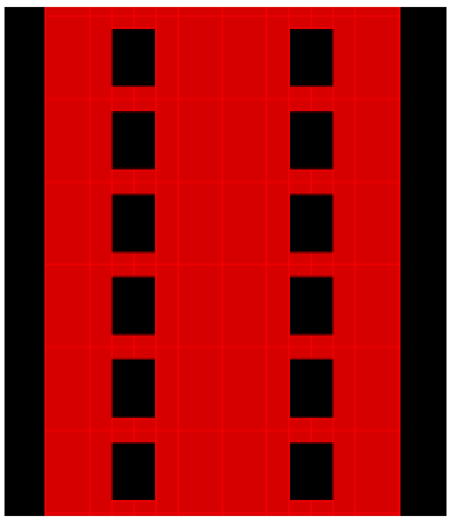

Fig.3.9: figure showing openings in core wall

MODEL 7: HULL CORE SYSTEM

It is combination of the framed tube and core supported system, an outer tube is formed with columns having 450450 mm size at a spacing of 2.5 m c/c and a central core is modeled with shear wall as shown in the figure 3.10. The various structural details are tabulated in table 3.9.

Table 3.9: Salient features of the building model 7

1	Type of structural form	Hull core
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X500 mm
6	Column size	400X900 mm interior 450X450 outer tube
7	Live load	4.0 KN/m2
8	Shear wall	230 mm
9	Materials	M35, M40, M50, Fe415

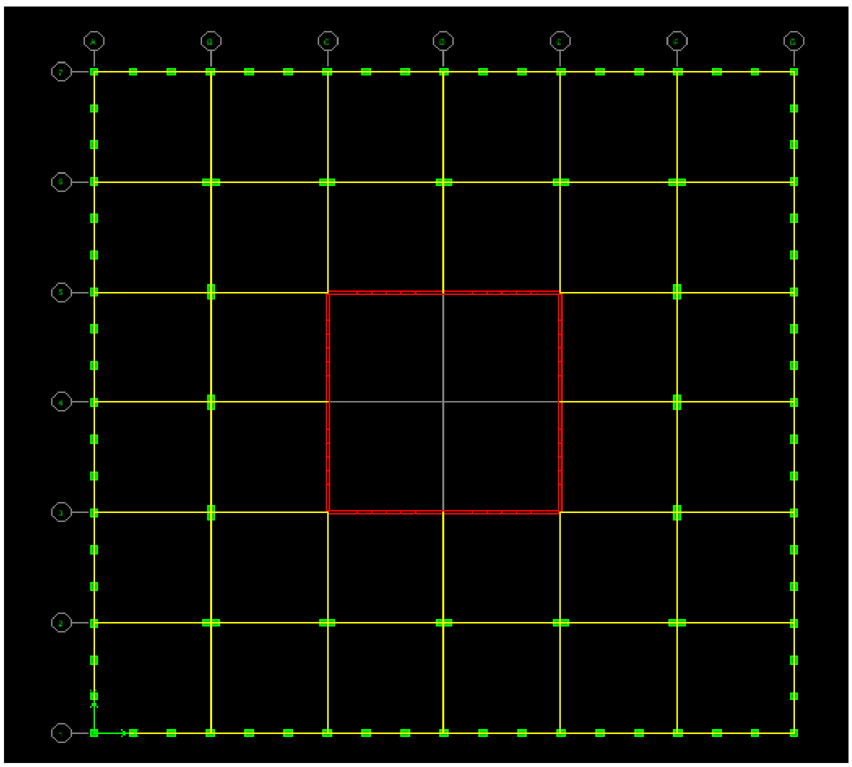

Fig.3.10: Typical floor plan of building model7

MODEL 8: OUTRIGGER/ SPINAL WALL SYSTEM

In this system, an outrigger or spinal wall is modeled as RC shear wall around the four

Corridors of the building as shown in the figure 3.11. The outrigger is placed at the mid height of the building. The outrigger is one story deep and connected to the central core. The various structural details are tabulated in table 3.10.

Table 3.10: Salient features of the building model 8

1	Type of structural form	Outrigger system
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X500 mm
6	Column size	400X900 mm
7	Live load	4.0 KN/m2
8	Shear wall	230 mm
9	Materials	M35, M40, M50, Fe415

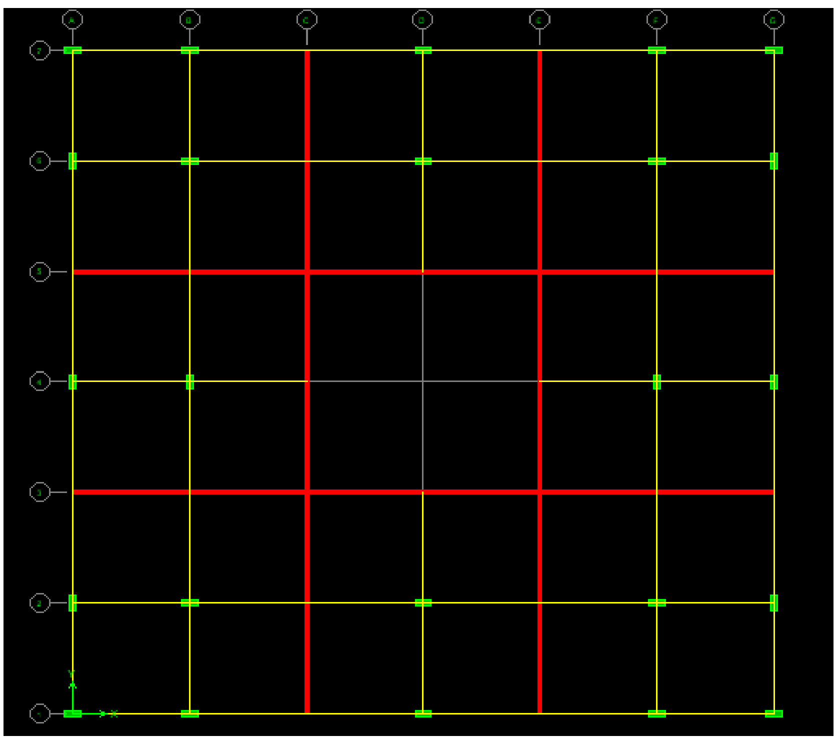

Fig.3.11: floor plan of building of model 8 with outrigger at mid height

MODEL 9: OUTRIGGER WITH CAP/HAT SYSTEM

This is a modified system of outrigger system mentioned above, in this system an outrigger is placed at the top referred to as cap or hat. While the 3 more outriggers are placed in the building at one fourth, half and three fourth distances. The outrigger depth here again kept as one story deep. The figure 3.12 shows the top view of the system and the structural details are tabulated in table 3.11.

Table 3.11: Salient features of the building model 9

1	Type of structural form	Outrigger with hat
2	Layout	As shown in Fig
3	Floor height	3.5 m
4	Slab thickness	175 mm
5	Beam size	300X500 mm
6	Column size	400X900 mm
7	Live load	4.0 KN/m2
8	Shear wall	230 mm
9	Materials	M35, M40, M50, Fe415

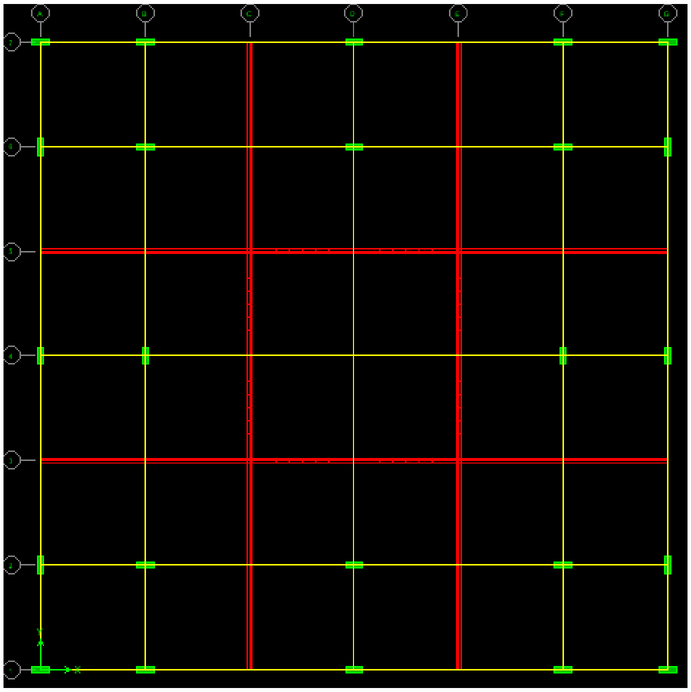

Fig.3.12: Top plan of building model 9 showing the outrigger at top

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTON

The building models are analysed using computer based software ETABS. This chapter includes various parameters which are being studied such as modal time periods, modal participation factors, story shear, story drift and lateral displacements. The results obtained are verified with the permissible limits of IS codes. On the basis of these modal parameters viability of different structural systems are decided. This chapter includes all the results of 9 models with their graph plots and tables. The various modal parameters are defined as below:

4.2 NATURAL AND MODAL TIME PERIOD

Natural time period of a building is time period of its undamped free vibrations. While the Modal time period may be defined as the time period of vibration in any particular mode k. Time period is very important modal parameter in the building analysis.

4.3 MODE SHAPE

Mode shape may be defined as the orientation of the building in any mode. It may be either translational or rotational with respect to any mode k. However, in any analysis the number of modes to be considered must be such that the total sum of the modal masses would be minimum 90 % of the total seismic mass.

4.4 STORY DRFIT AND LATERAL DISPLACEMENT

Lateral displacement or lateral sway is the horizontal displacement of the building under lateral forces. While the story drift is the relative displacement of one story to the other above or below. As per IS 1893 part 1 2002 [17], story drift must not exceed 0.004 times the story height and the lateral sway must not exceed total height of building by 500.

4.5 MODAL PARTICIPATION FACTOR

When building is subjected to lateral forces, the whole building undergoes vibrations. So the modal participation factor of any mode k is the amount by which it contributes to the whole vibration of the building.

4.6 STORY SHEAR

Story shear may be defined as the sum of the lateral forces acting on the stories above the considered one. At the base, it is defined as base shear.

4.7 MODEL RESULTS

Model 1 – Rigid Frame system

Modal Participating Mass Ratios

Edit View

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	4.246204	0.0000	79.6813	0.0000	0.0000	79.6813
2	4.115558	79.0341	0.0000	0.0000	79.0341	79.6813
3	3.689374	0.0000	0.0000	0.0000	79.0341	79.6813
4	1.373953	0.0000	9.6692	0.0000	79.0341	89.3504
5	1.318647	9.8027	0.0000	0.0000	88.8369	89.3504
6	1.182392	0.0000	0.0000	0.0000	88.8369	89.3504
7	0.778976	0.0000	3.6496	0.0000	88.8369	93.0000
8	0.735826	3.7926	0.0000	0.0000	92.6295	93.0000
9	0.661224	0.0000	0.0000	0.0000	92.6295	93.0000
10	0.520700	0.0000	2.0028	0.0000	92.6295	95.0028
11	0.482904	2.1190	0.0000	0.0000	94.7485	95.0028
12	0.432539	0.0000	0.0000	0.0000	94.7485	95.0028

Fig.4.1: Modal participation ratio and time period of model 1

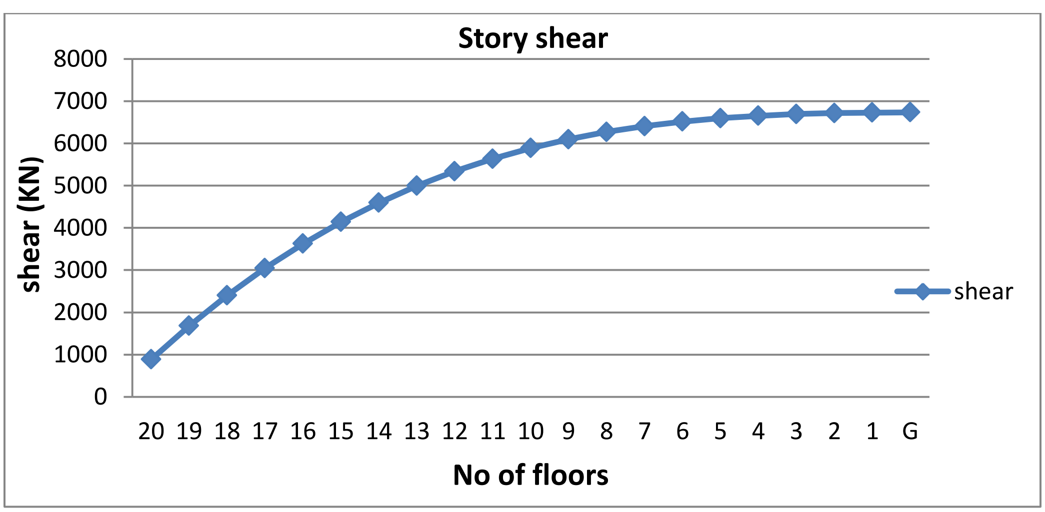

Fig.4.2: graph showing story shear of model 1

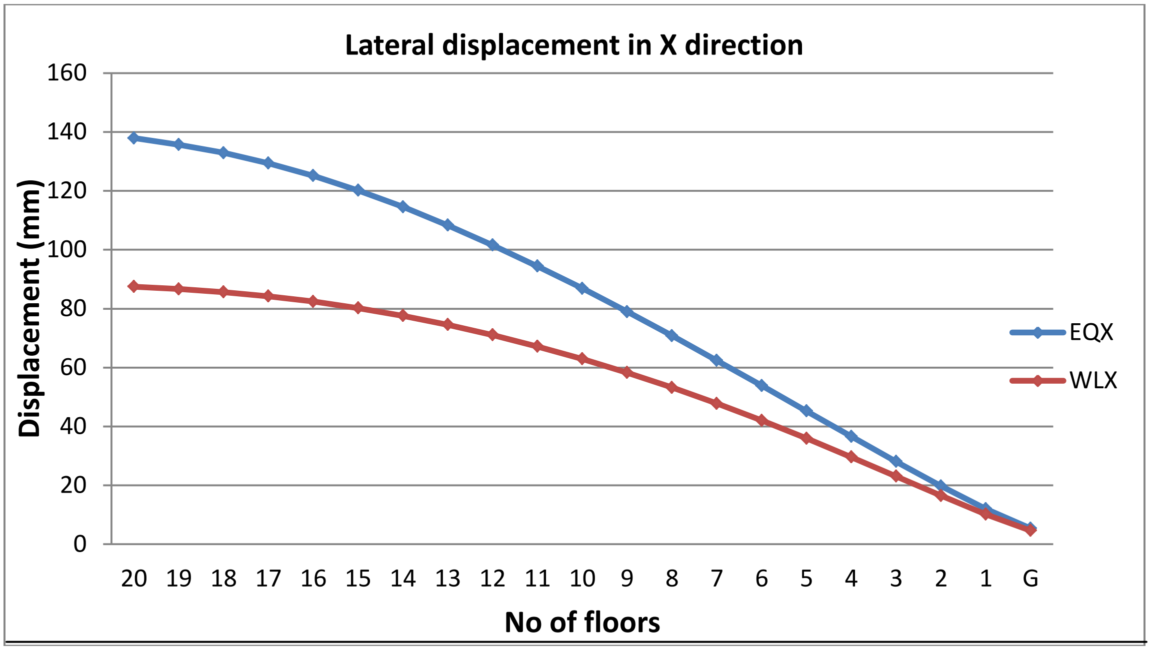

Fig.4.3: graph showing lateral displacement in X direction of model 1

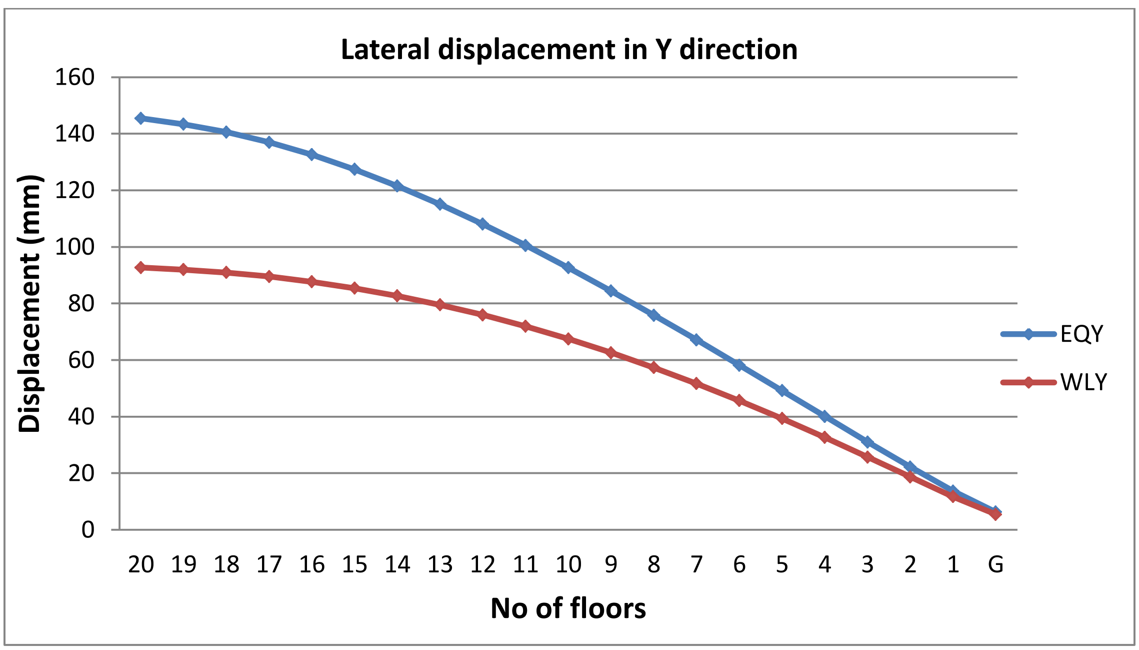

Fig.4.4: graph showing lateral displacement in Y direction of model 1

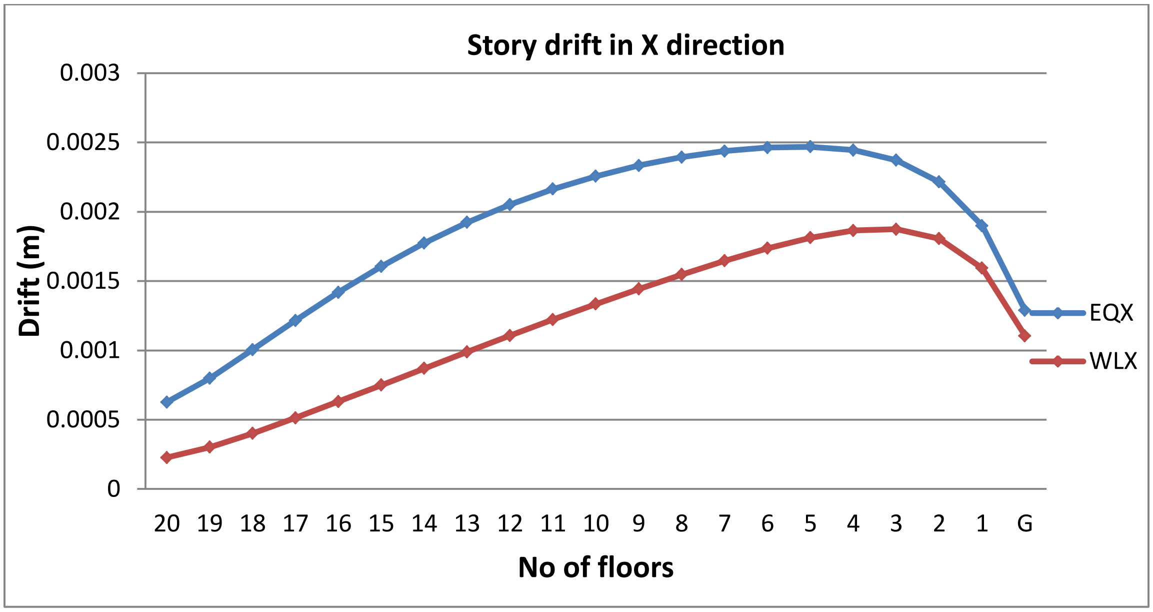

Fig.4.5: graph showing story drift in X direction of model 1

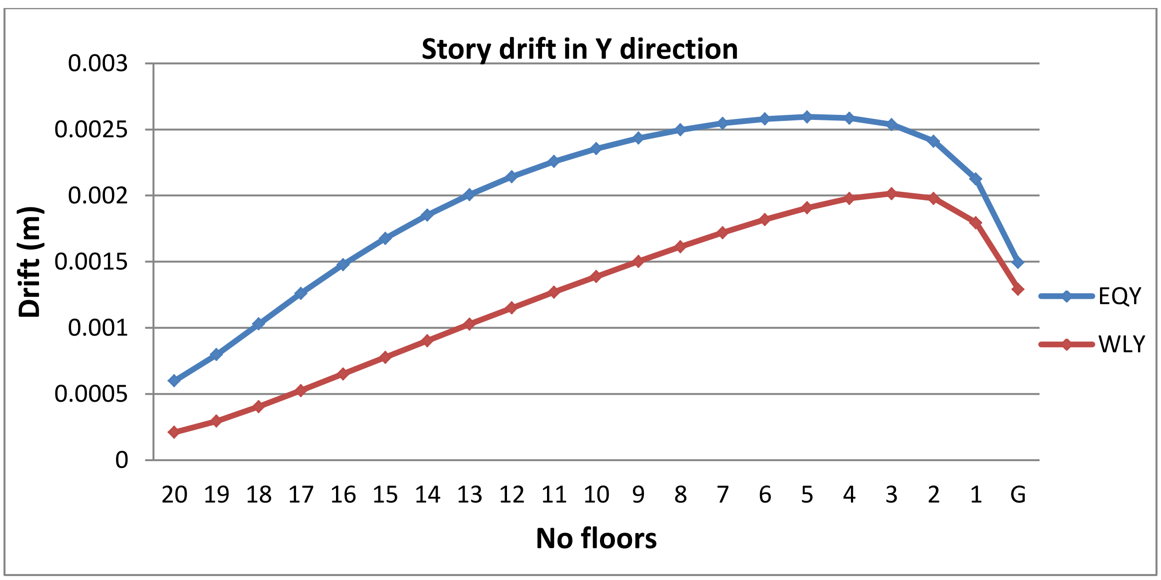

Fig.4.6: graph showing story drift in Y direction of model 1

The lateral sway is slightly greater in Y direction as compared to X direction because building participation ratio is dominating in Y direction. Also, at this height the sway due to earthquake is more than wind. The top lateral sway i.e. 145.46 mm is under the permissible limit i.e. 147 mm and drift is also under the limits i.e. 0.014 m. Further if another story is

Added above 21st story, the top sway becomes 154.8 mm which exceeds the permissible limit (154 mm). Therefore, this system can be said efficient up to 21 stories. Above this, system calls for large uneconomical sections. The shear at base is 6735.56 KN.

Model 2 – Framed tube system

Modal Participating Mass Ratios

Edit View

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	5.920050	0.0000	80.6818	0.0000	0.0000	80.6818
2	5.829212	80.3651	0.0000	0.0000	80.3651	80.6818
3	4.066521	0.0000	0.0000	0.0000	80.3651	80.6818
4	1.953748	0.0000	10.1488	0.0000	80.3651	90.8306
5	1.918834	10.2017	0.0000	0.0000	90.5668	90.8306
6	1.353752	0.0000	0.0000	0.0000	90.5668	90.8306
7	1.138287	0.0000	3.3748	0.0000	90.5668	94.2054
8	1.113579	3.4129	0.0000	0.0000	93.9796	94.2054
9	0.809952	0.0000	0.0000	0.0000	93.9796	94.2054
10	0.803755	0.0000	1.6984	0.0000	93.9796	95.9038
11	0.782837	1.7319	0.0000	0.0000	95.7115	95.9038
12	0.617278	0.0000	1.0059	0.0000	95.7115	96.9097

Fig.4.7: Modal participation ratio and time period of model 2

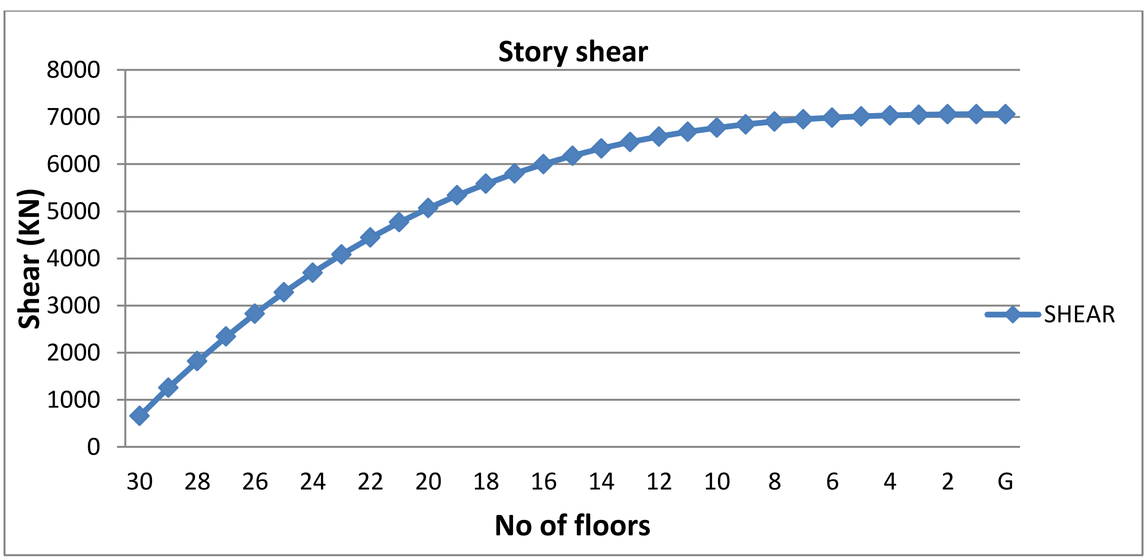

Fig.4.8: graph showing story shear model 2

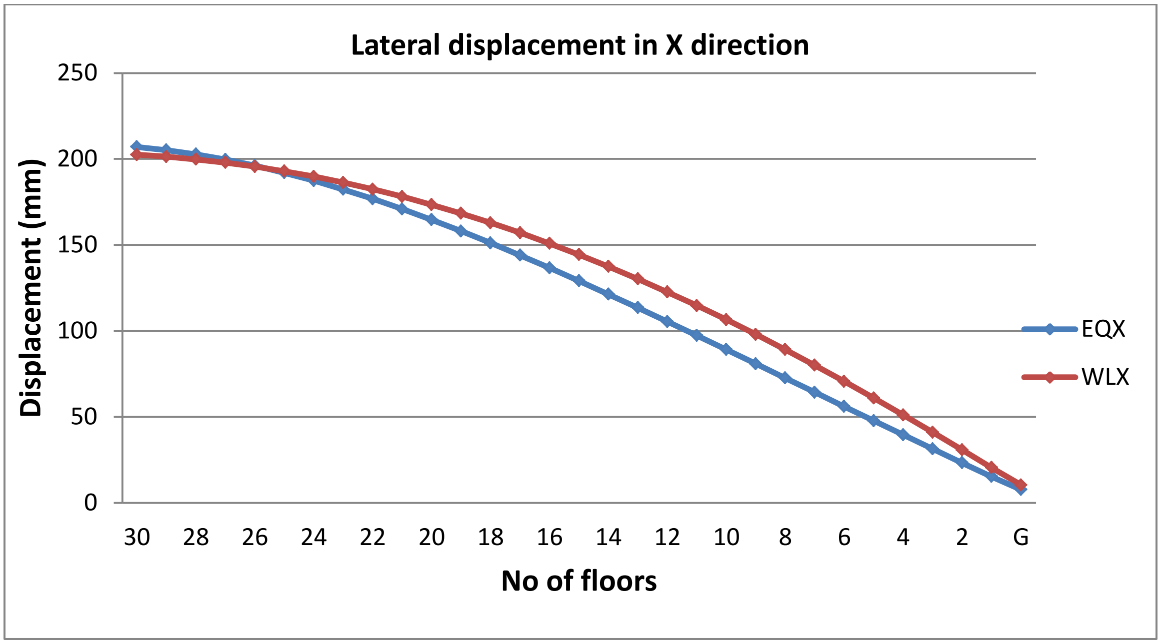

Fig.4.9: graph showing lateral displacement in X direction of model 2

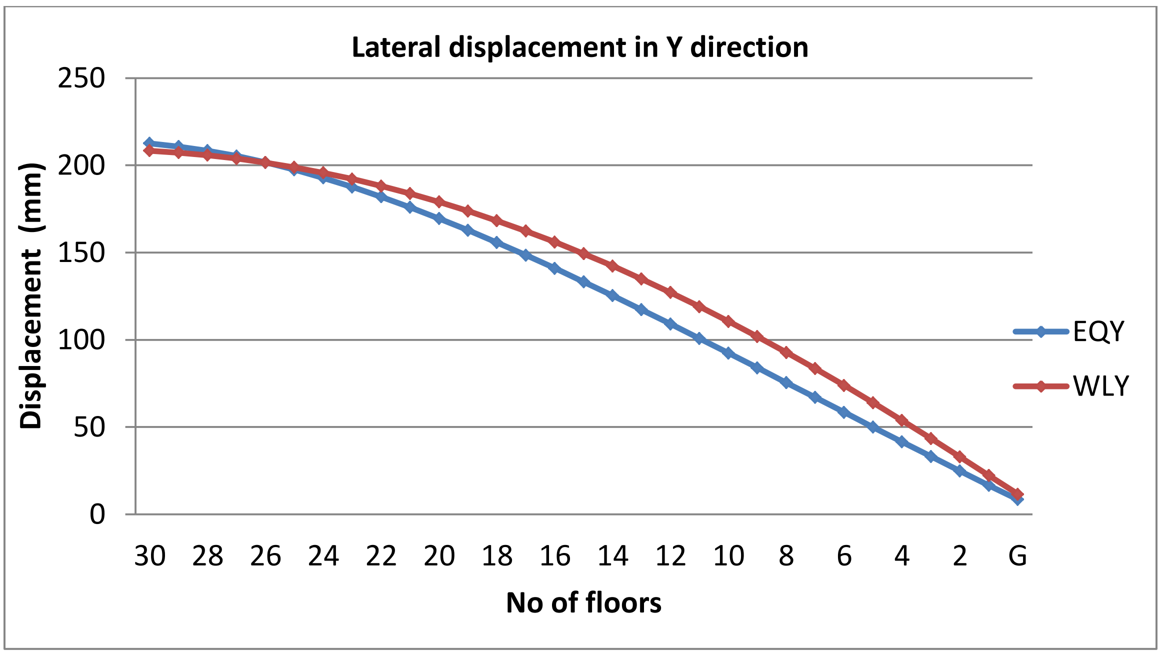

Fig.4.10: graph showing lateral displacement in Y direction of model 2

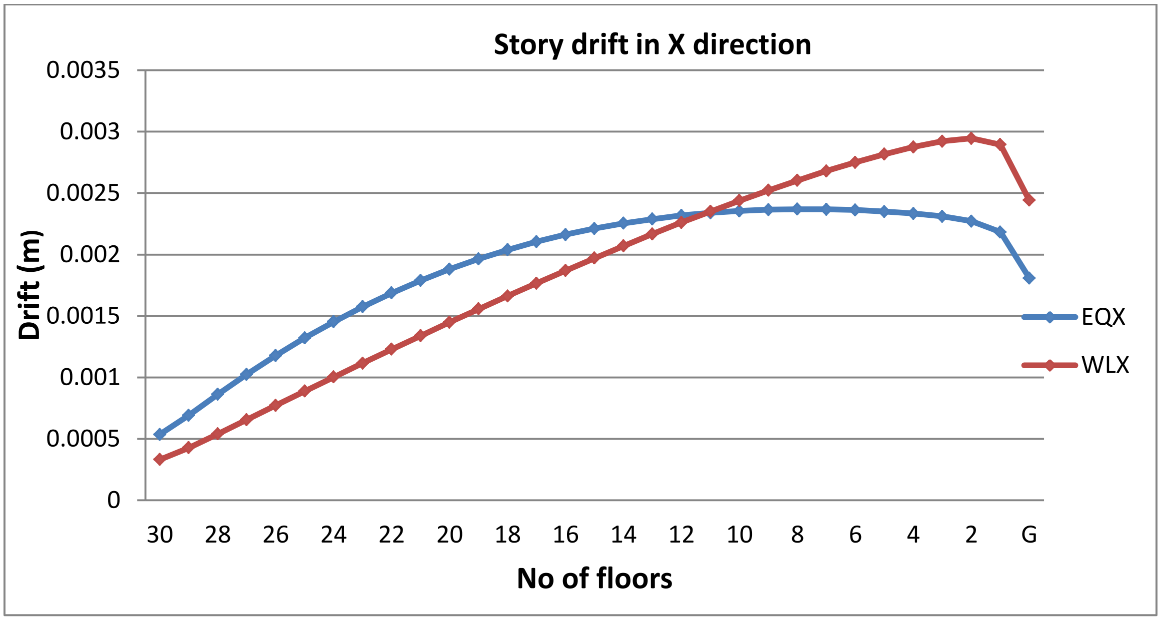

Fig.4.11: graph showing story drift in X direction of model 2

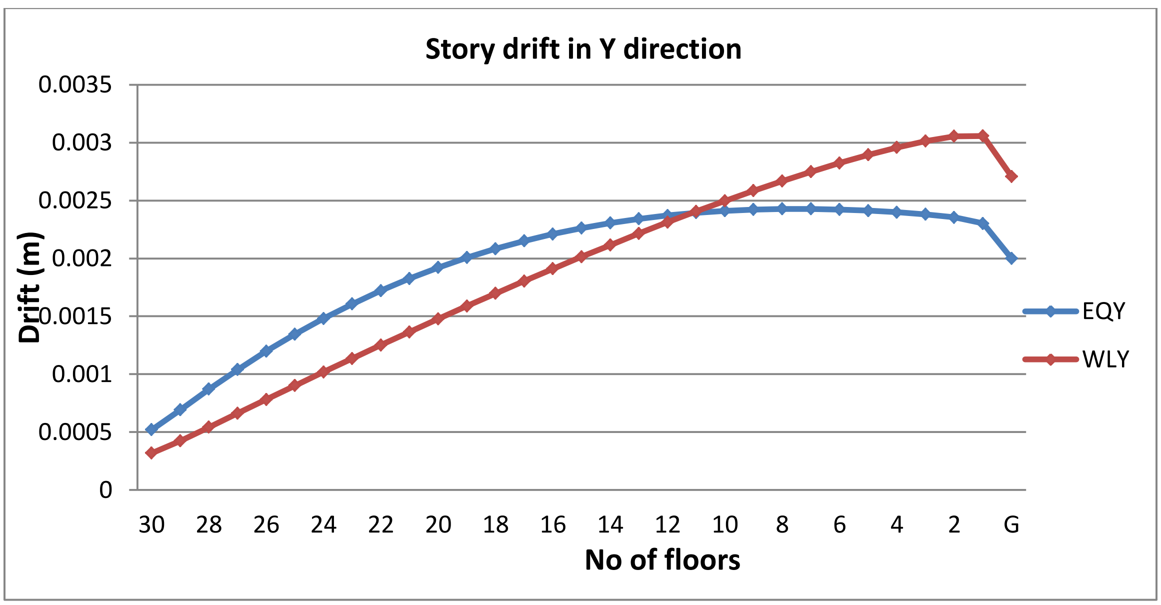

Fig.4.12: graph showing story drift in Y direction of model 2

At this height, both wind and earthquake are producing almost same lateral displacements. The top sway is 212.6 mm which is under permissible limits i.e. 217 mm. the story drifts are in permissible limits. The shear at base is 7063 KN.

While if another story is further added above 31st story, lateral sway becomes 225 mm which exceeds the permissible limit of 224 mm. Therefore this structural system is efficient up to 31 stories.

Model 3 – Tube in tube system

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	6.248272	0.0000	80.2481	0.0000	0.0000	80.2481
2	6.198930	80.0738	0.0000	0.0000	80.0738	80.2481
3	4.523904	0.0000	0.0000	0.0000	80.0738	80.2481
4	2.057771	0.0000	10.4559	0.0000	80.0738	90.7039
5	2.038452	10.4993	0.0000	0.0000	90.5731	90.7039
6	1.506491	0.0000	0.0000	0.0000	90.5731	90.7039
7	1.192427	0.0000	3.4208	0.0000	90.5731	94.1247
8	1.178652	3.4431	0.0000	0.0000	94.0162	94.1247
9	0.901912	0.0000	0.0000	0.0000	94.0162	94.1247
10	0.842502	0.0000	1.7146	0.0000	94.0162	95.8394
11	0.831010	1.7315	0.0000	0.0000	95.7477	95.8394
12	0.648388	0.0000	1.0110	0.0000	95.7477	96.8504

Fig.4.13: Modal participation ratio and time period of model 3

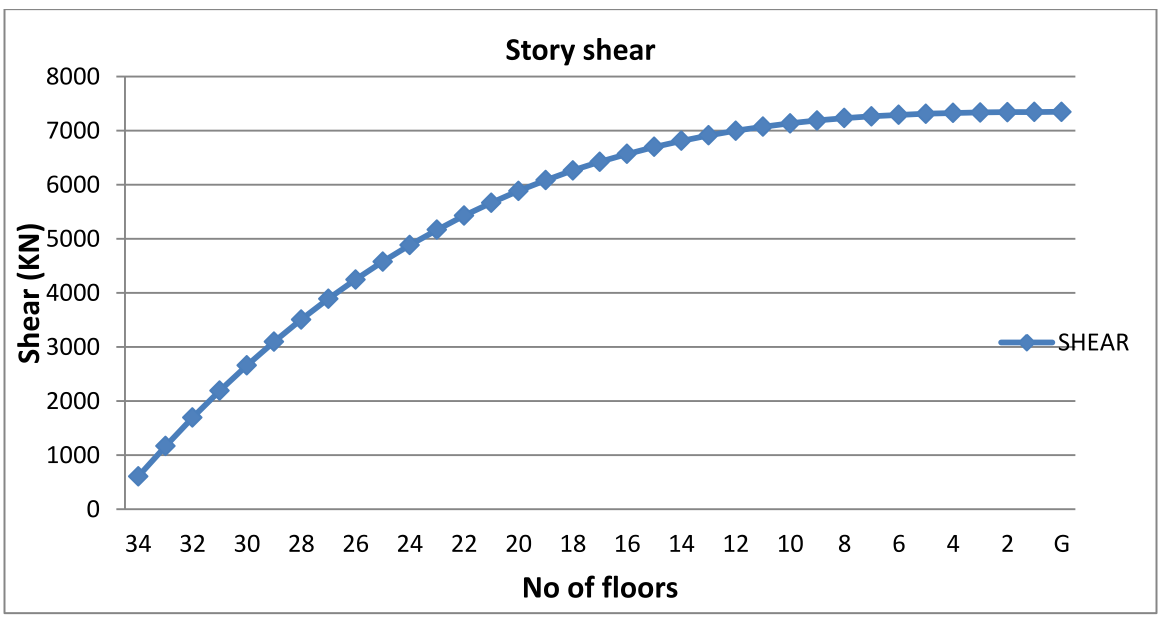

Fig.4.14: graph showing story shear model 3

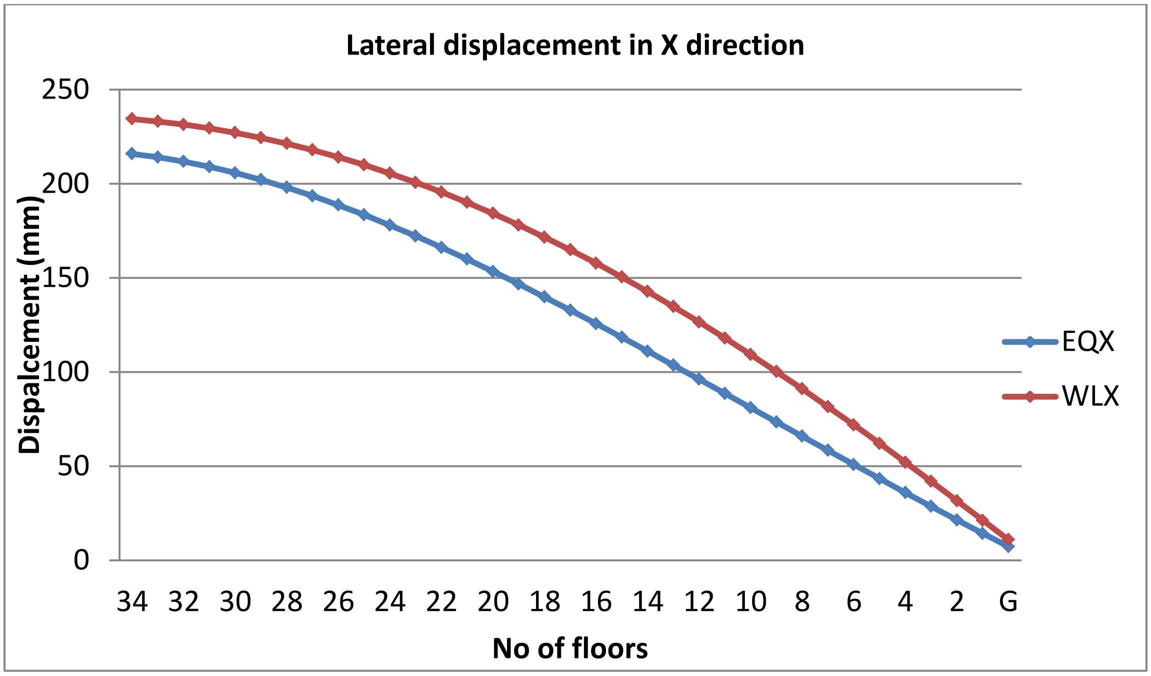

Fig.4.15: graph showing lateral displacement in X direction of model 3

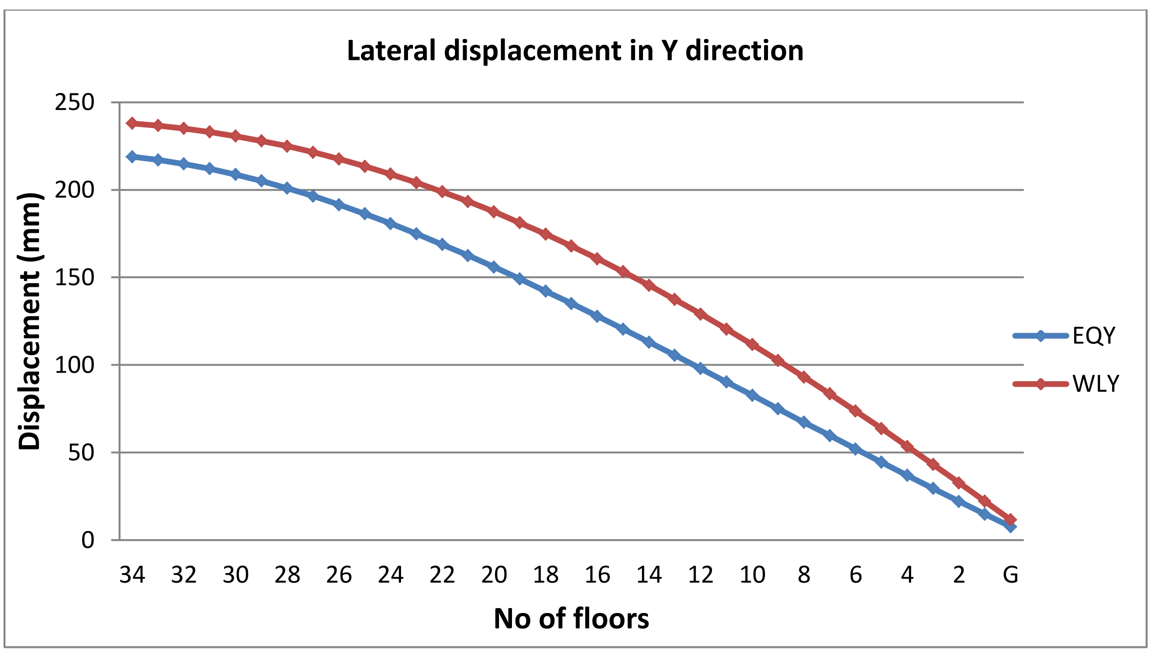

Fig.4.16: graph showing lateral displacement in Y direction of model 3

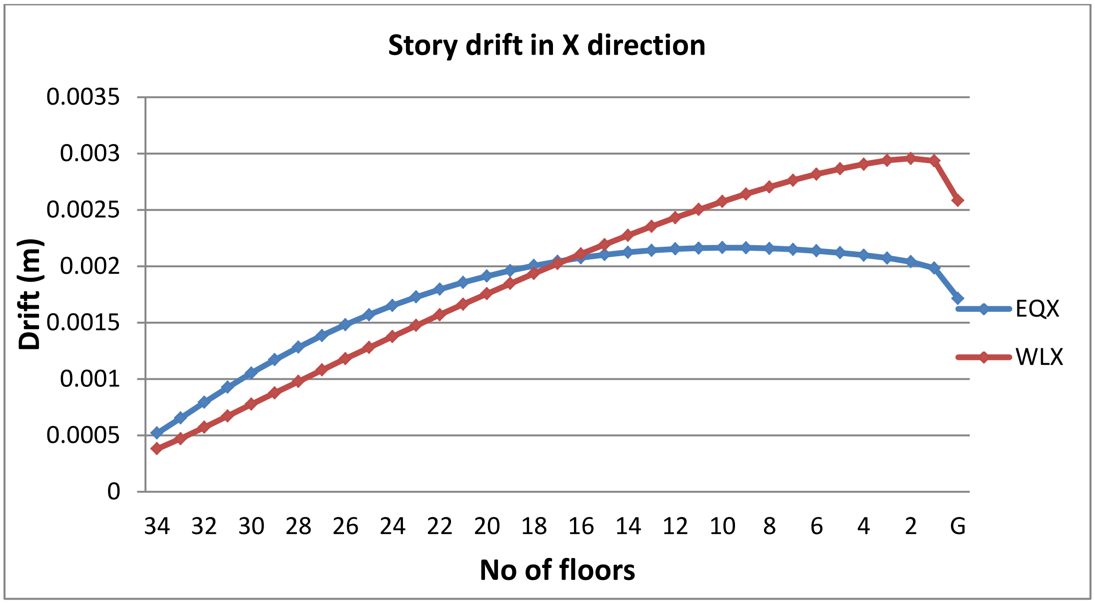

Fig.4.17: graph showing story drift in X direction of model 3

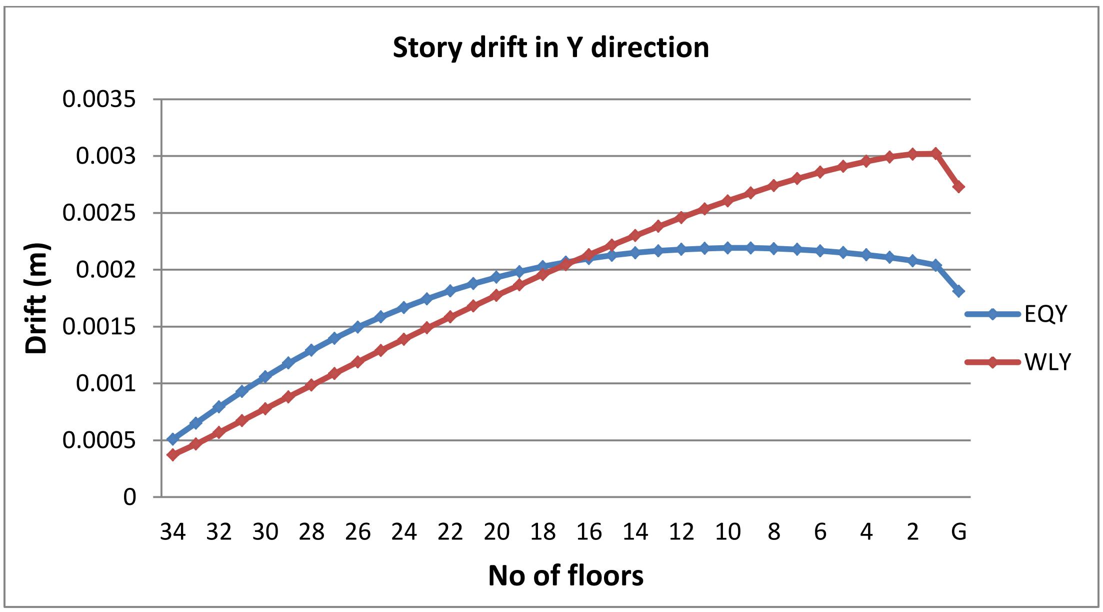

Fig.4.18: graph showing story drift in Y direction of model 3

However, at this height the wind starts dominating the earthquake effects. It can be clearly seen that the sway due to wind is more than earthquake. The maximum top sway is 237.91 mm which is under the limit of 245 mm. With addition of another story above 35th story sway becomes 254.48 mm which exceeds the limit of 252 mm. Therefore; this system can be said efficient up to 35 stories. The shear at the base is 7348 KN.

Model 4 – Wall Frame system

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	6.939365	0.0000	73.6081	0.0000	0.0000	73.6081
2	6.909263	73.6315	0.0000	0.0000	73.6315	73.6081
3	5.225152	0.0000	0.0000	0.0000	73.6315	73.6081
4	2.072219	0.0000	12.1407	0.0000	73.6315	85.7488
5	2.064256	12.1289	0.0000	0.0000	85.7604	85.7488
6	1.528864	0.0000	0.0000	0.0000	85.7604	85.7488
7	1.055612	0.0000	4.5488	0.0000	85.7604	90.2976
8	1.052185	4.5436	0.0000	0.0000	90.3040	90.2976
9	0.759175	0.0000	0.0000	0.0000	90.3040	90.2976
10	0.656391	0.0000	2.5608	0.0000	90.3040	92.8584
11	0.654556	2.5578	0.0000	0.0000	92.8618	92.8584
12	0.460546	0.0000	0.0000	0.0000	92.8618	92.8584

Fig.4.19: Modal participation ratio and time period of model 4

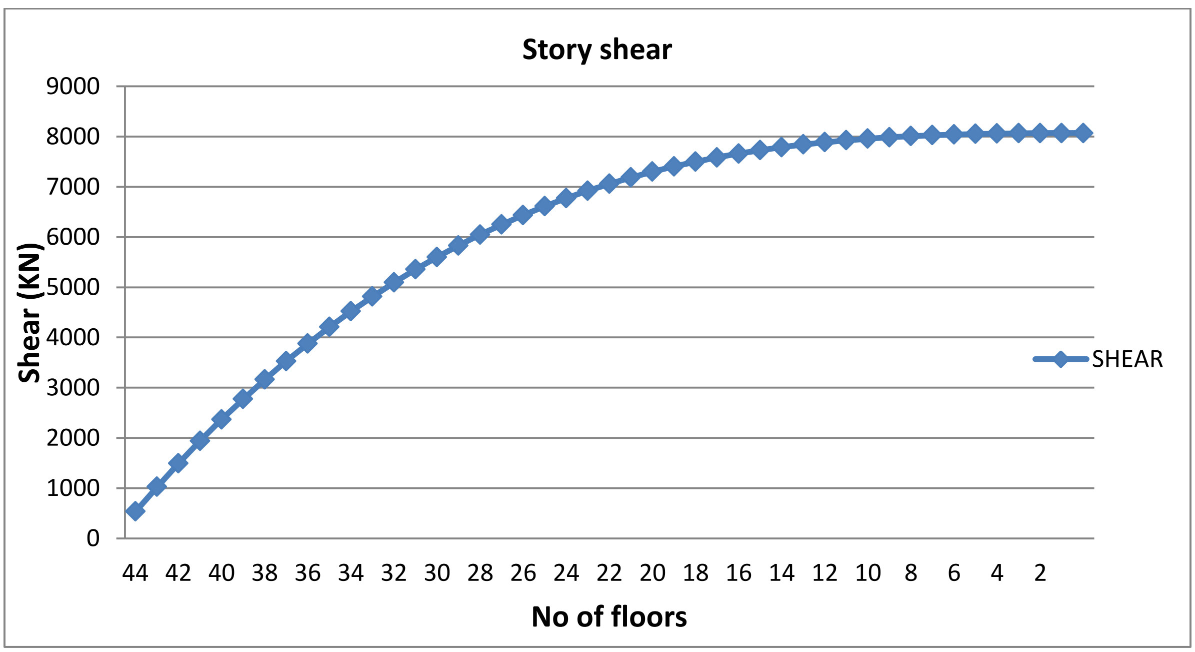

Fig.4.20: graph showing story shear model 4

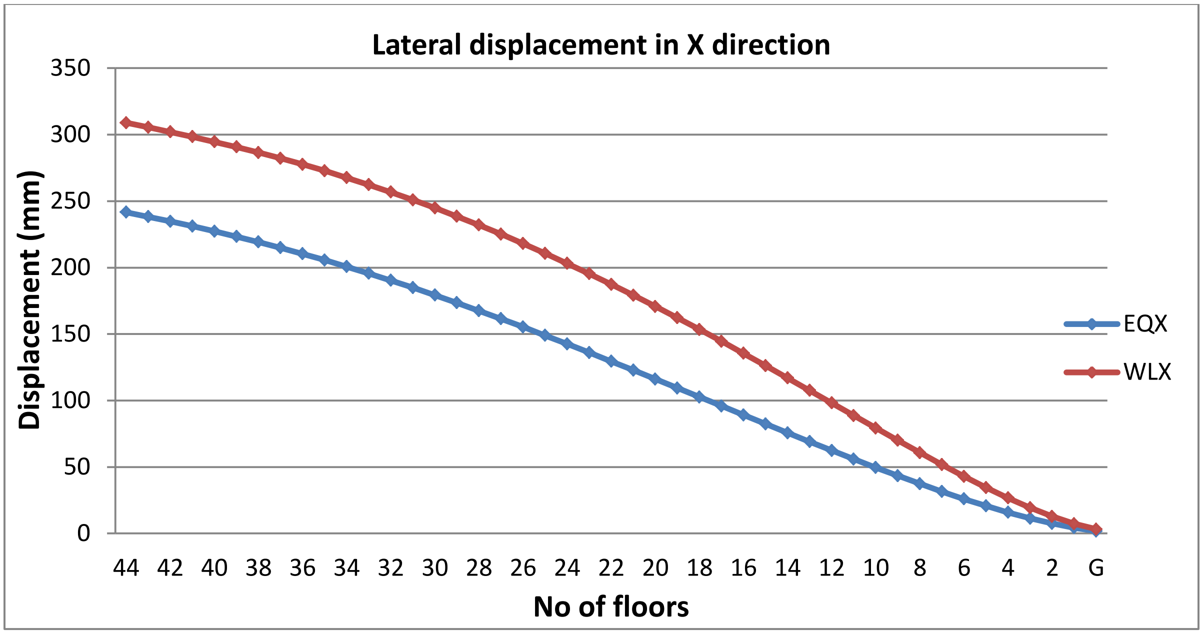

Fig.4.21: graph showing lateral displacement in X direction of model4

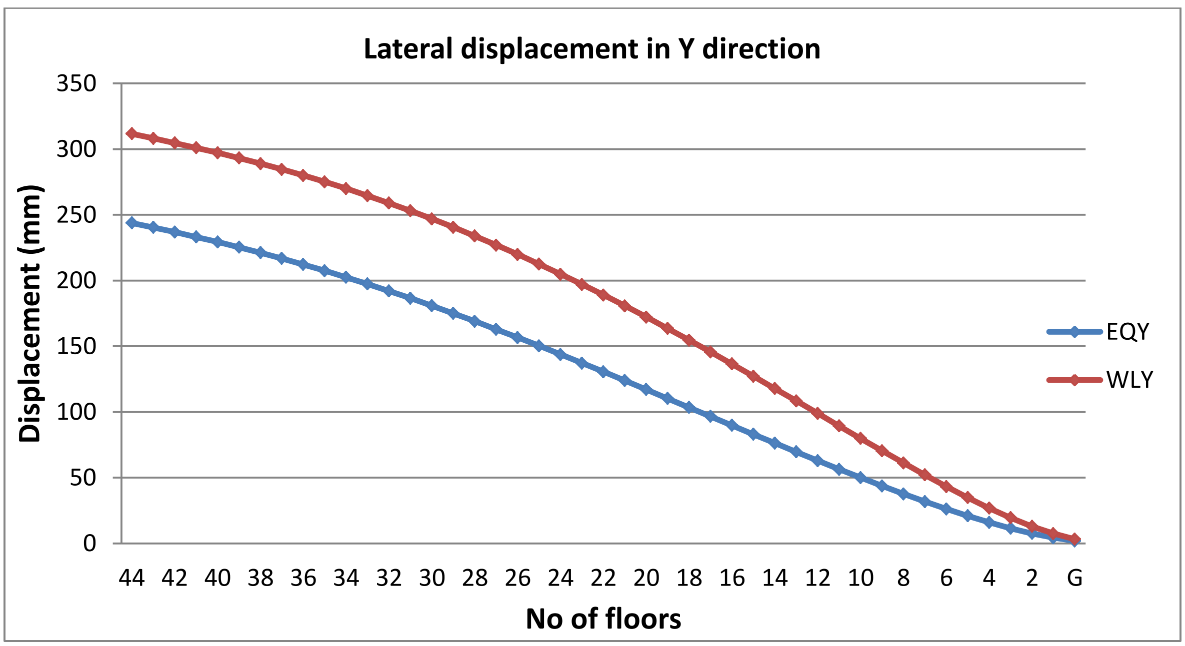

Fig.4.22: graph showing lateral displacement in Y direction of model 4

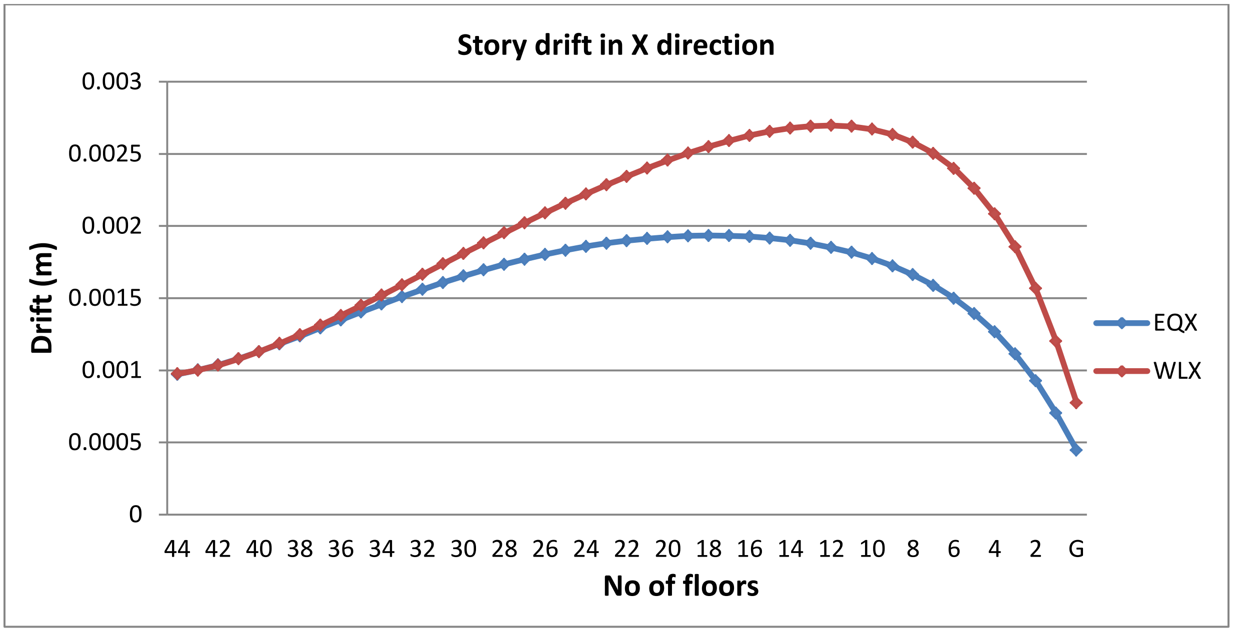

Fig.4.23: graph showing story drift in X direction of model 4

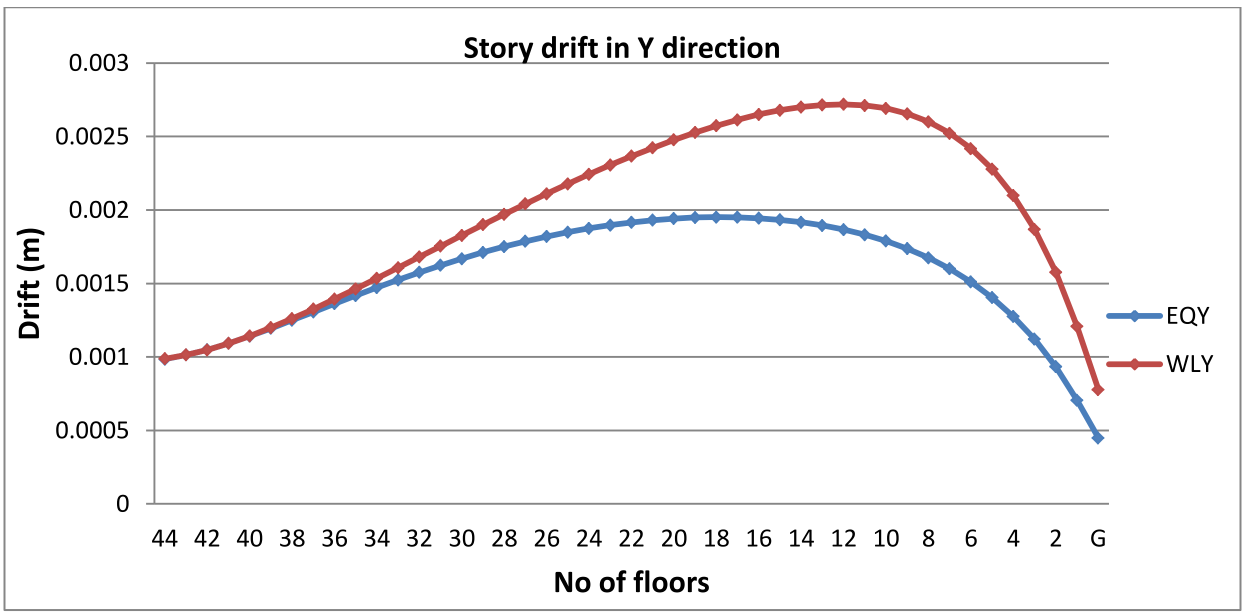

Fig.4.24: graph showing story drift in Y direction of model 4

Here, the lateral sway at top due to wind is 311.7 mm and due to earthquake it is 243.83 mm, which directly means wind effect increases with height as compared to earthquake. The top sway is 311.7 mm which is under permissible limit of 315 mm.

The shear at the base is 8070 KN. However if another story is added above 45th story, the top sway becomes 330 mm which exceeds the permissible value of 330 mm. Therefore, this system can be said efficient up to 45 stories.

Model 5 – Bundled tube system

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	7.364321	0.0000	78.7962	0.0000	0.0000	78.7962
2	7.353512	78.7510	0.0000	0.0000	78.7510	78.7962
3	5.720893	0.0000	0.0000	0.0000	78.7510	78.7962
4	2.409976	0.0000	11.4608	0.0000	78.7510	90.2570
5	2.405626	11.4650	0.0000	0.0000	90.2160	90.2570
6	1.907190	0.0000	0.0000	0.0000	90.2160	90.2570
7	1.371965	0.0000	3.4980	0.0000	90.2160	93.7549
8	1.369007	3.4991	0.0000	0.0000	93.7151	93.7549
9	1.142683	0.0000	0.0000	0.0000	93.7151	93.7549
10	0.970030	0.0000	1.7597	0.0000	93.7151	95.5147
11	0.967600	1.7616	0.0000	0.0000	95.4767	95.5147
12	0.815301	0.0000	0.0000	0.0000	95.4767	95.5147

Fig.4.25: Modal participation ratio and time period of model 5

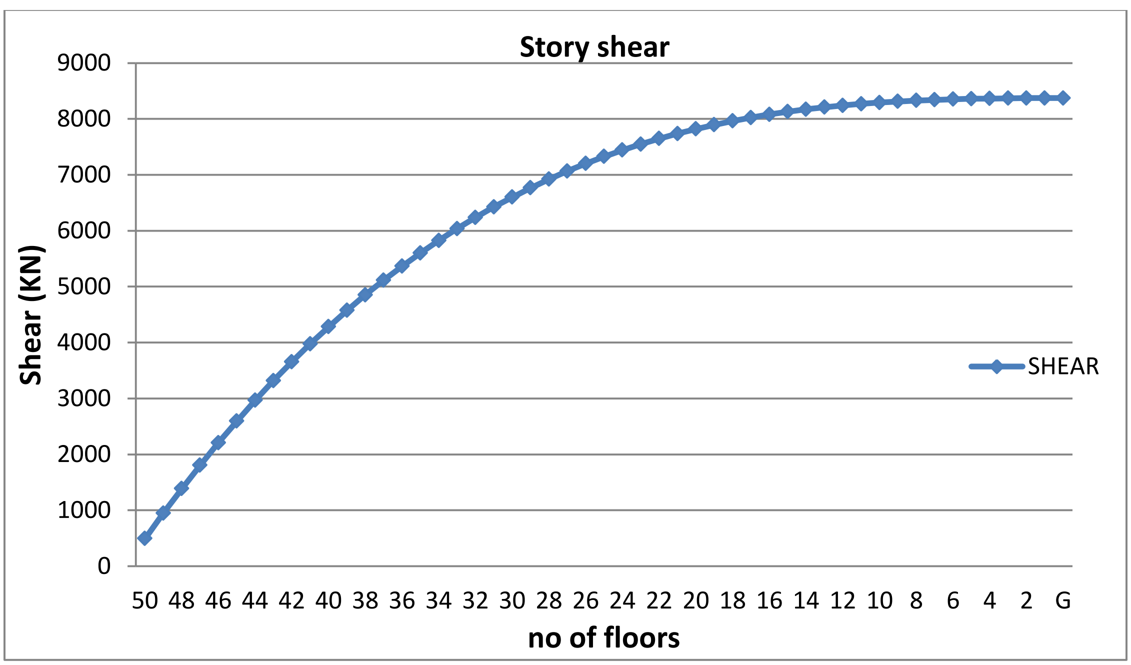

Fig.4.26: graph showing story shear model 5

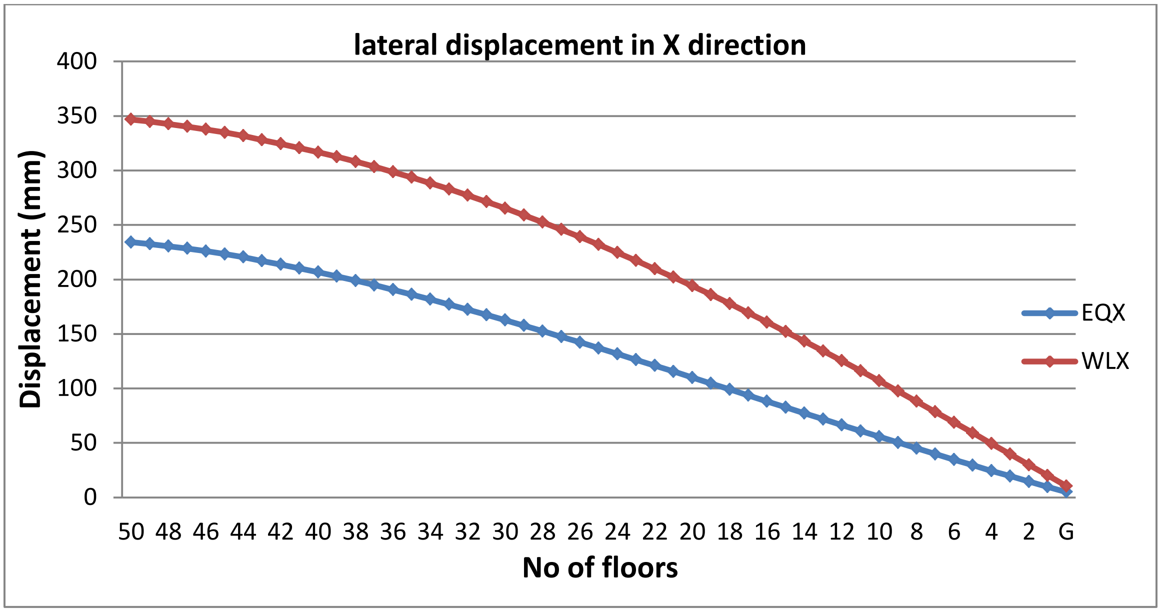

Fig.4.27: graph showing lateral displacement in X direction of model 5

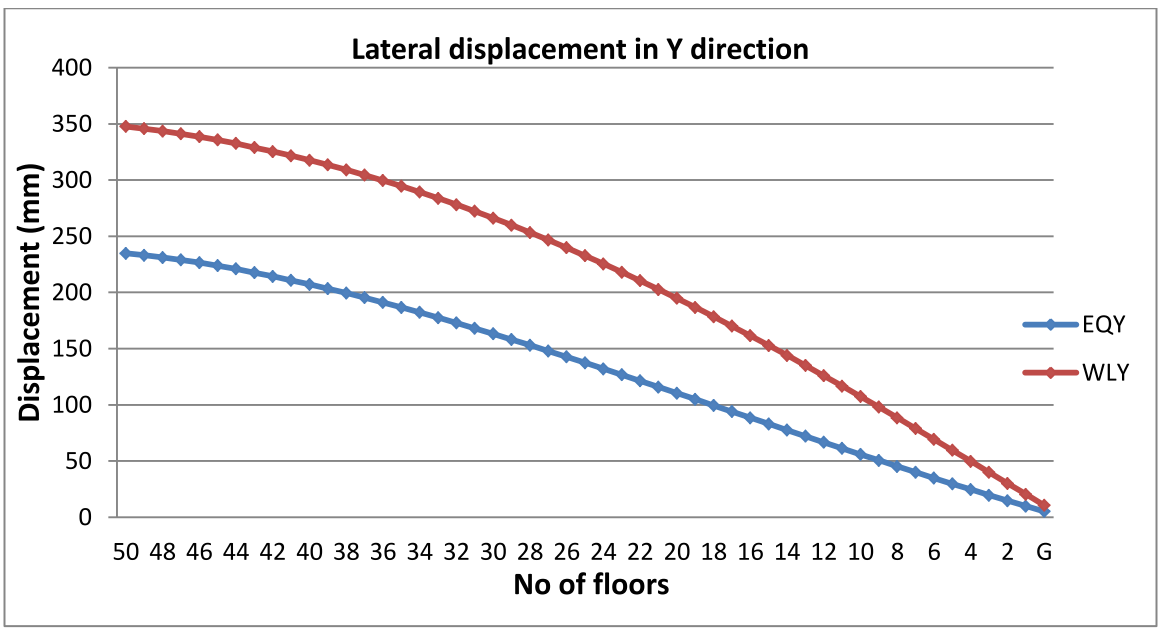

Fig.4.28: graph showing lateral displacement in Y direction of model 5

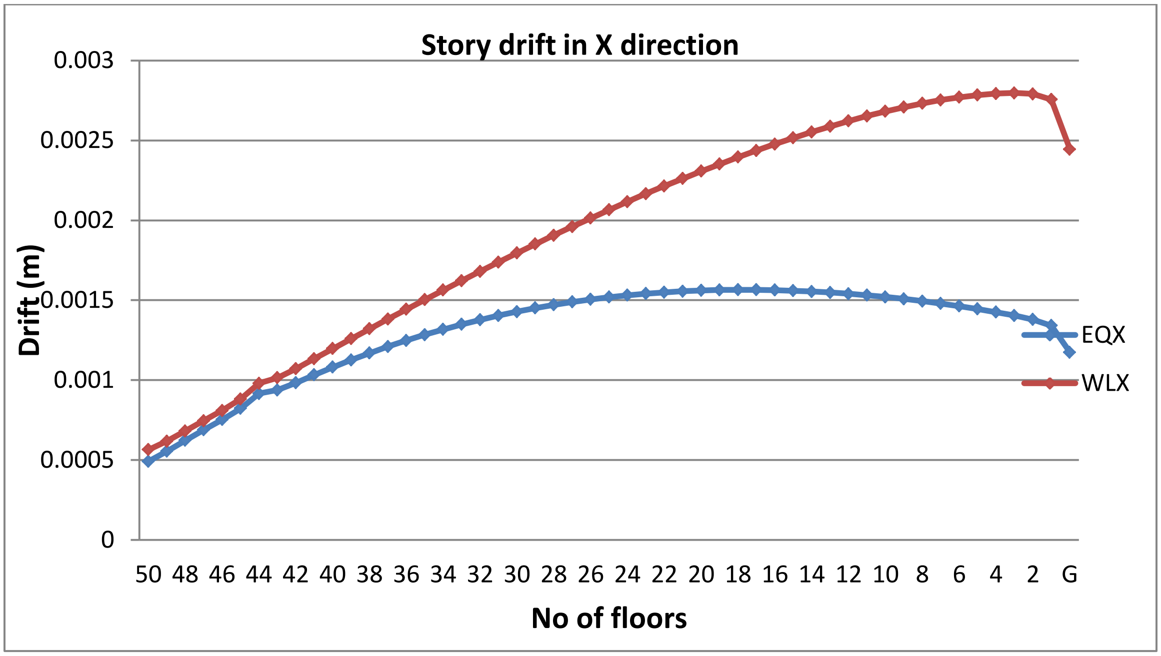

Fig.4.29: graph showing story drift in X direction of model 5

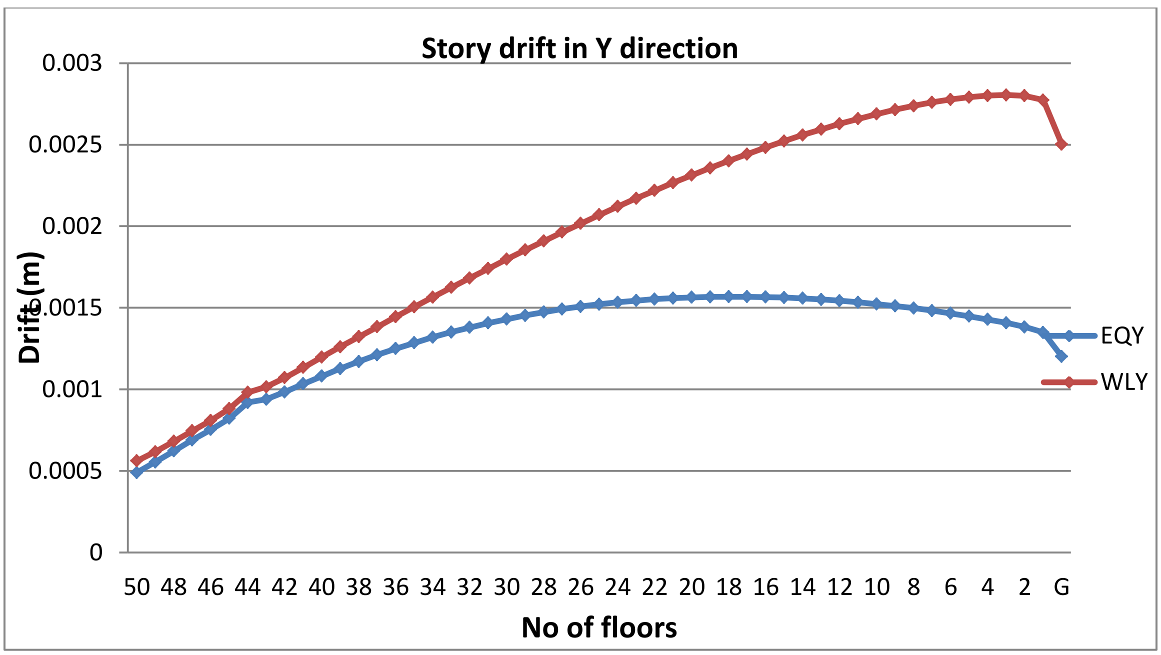

Fig.4.30: graph showing story drift in Y direction of model 5

The modal participation mass ratio in this system is exactly same for 1st and 2nd mode i.e. 78.7, therefore displacements produced by lateral forces are equal in X and Y direction. The top sway in X direction is 346.7 mm and in Y direction is 347 mm.

The top lateral sway is 347 mm which is under permissible limit of 357 mm. The shear at the base is 8372 KN. With an addition of one story above 51st story, the sway at the top becomes 365.4 mm while limit is 364 mm. therefore this system is efficient up to 51 stories.

Model 6 – Coupled wall system

Modal Participating Mass Ratios

Edit View

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	7.101806	0.0025	69.4027	0.0000	0.0025	69.4027
2	7.067245	69.4106	0.0025	0.0000	69.4132	69.4051
3	4.898760	0.0000	0.0000	0.0000	69.4132	69.4051
4	1.882605	0.0295	16.0322	0.0000	69.4427	85.4373
5	1.874584	15.9787	0.0290	0.0000	85.4214	85.4663
6	1.628231	0.0003	0.0000	0.0000	85.4216	85.4663
7	0.970979	0.0006	0.0000	0.0000	85.4222	85.4664
8	0.893115	0.0303	5.6869	0.0000	85.4525	91.1532
9	0.889524	5.6630	0.0301	0.0000	91.1155	91.1834
10	0.688339	0.0000	0.0000	0.0000	91.1155	91.1834
11	0.560569	0.0158	2.7242	0.0000	91.1313	93.9076
12	0.558357	2.7238	0.0161	0.0000	93.8551	93.9237

Fig.4.31: Modal participation ratio and time period of model 6

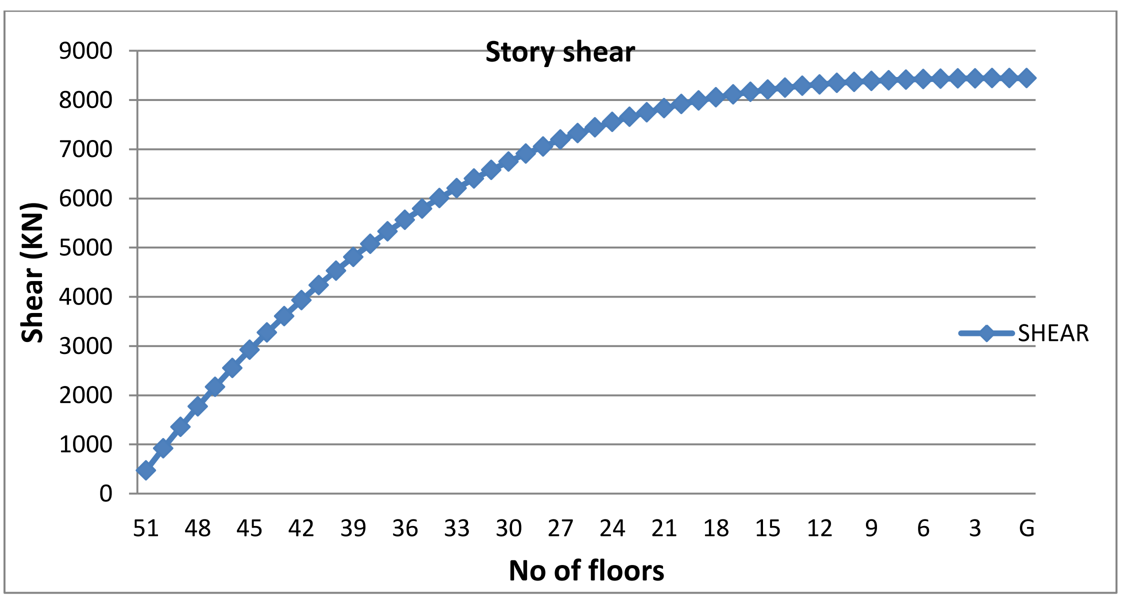

Fig.4.32: graph showing story shear model 6

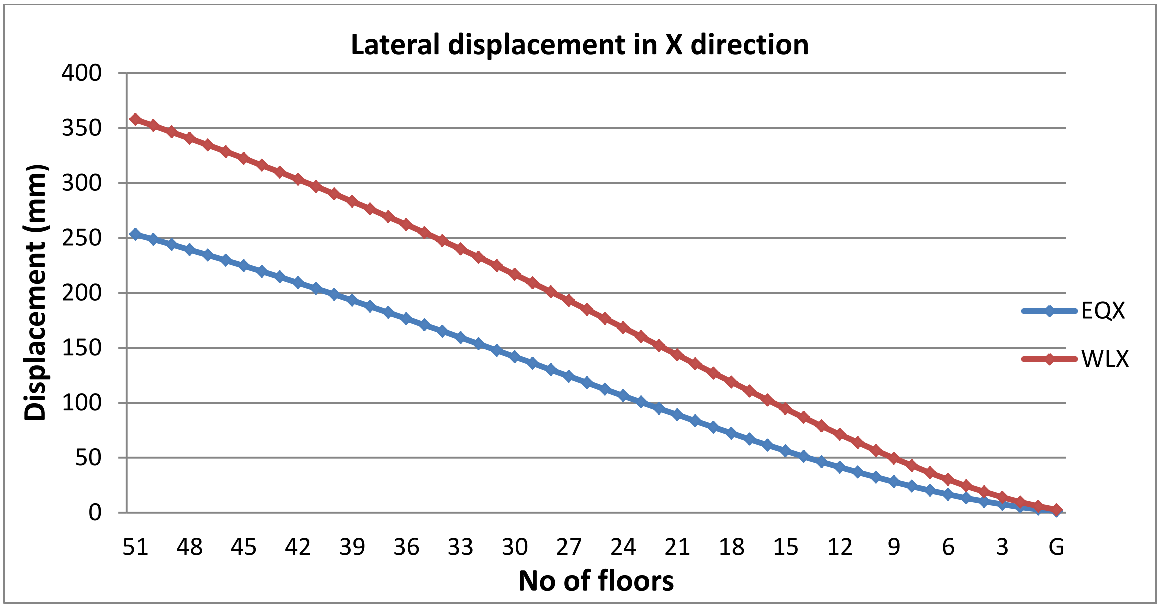

Fig.4.33: graph showing lateral displacement in X direction of model 6

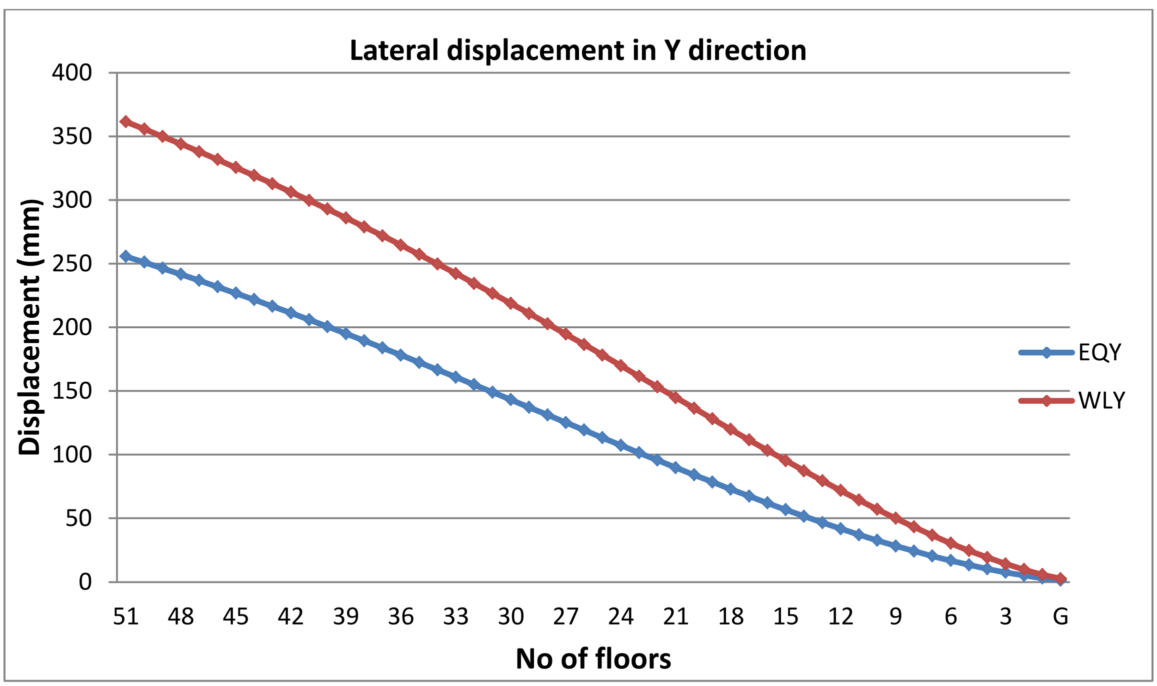

Fig.4.34: graph showing lateral displacement in Y direction of model 6

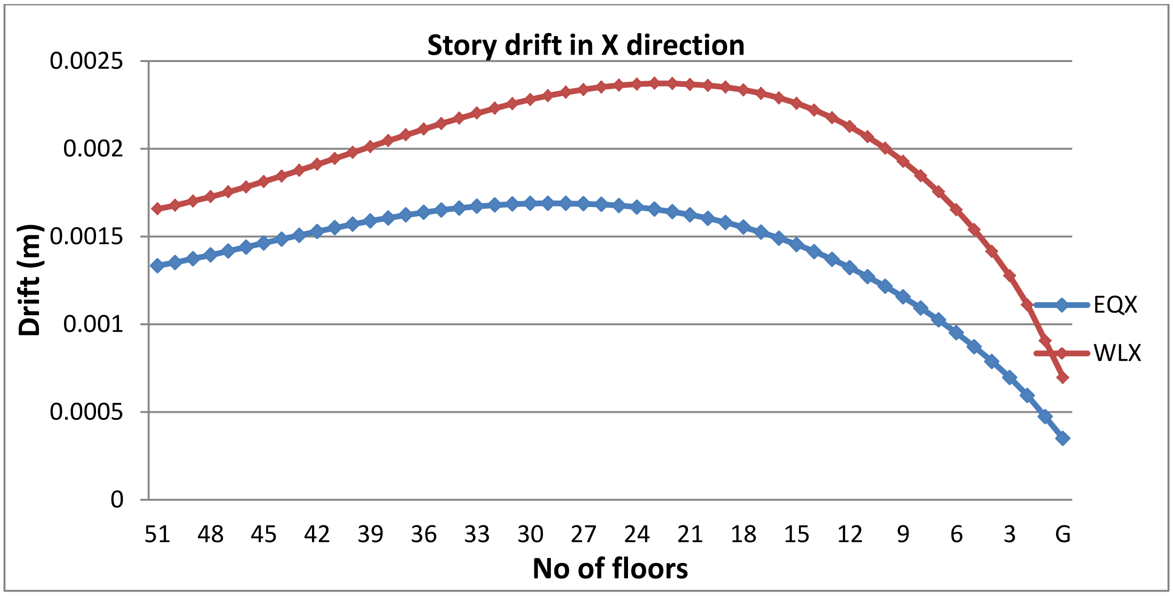

Fig.4.35: graph showing story drift in X direction of model 6

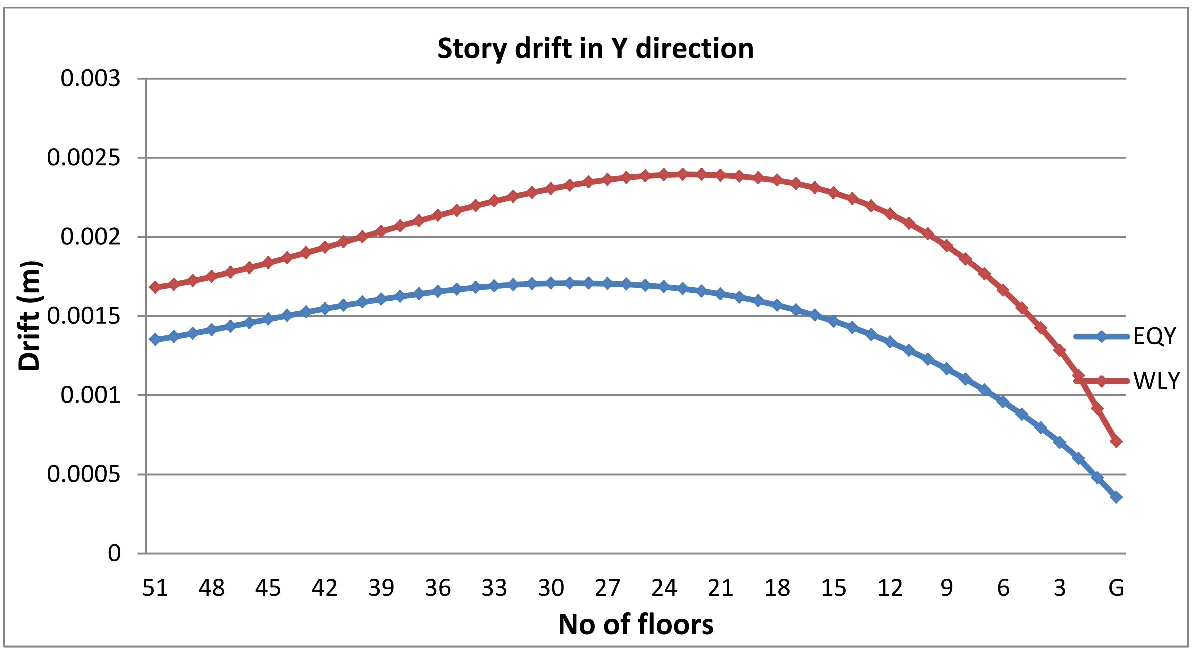

Fig.4.36: graph showing story drift in Y direction of model 6

The top lateral sway in this system is 361.4 mm which is under the permissible limit i.e. 364 mm. The story drift is also within the limits 0.014 mm. The shear at the base is 8444 KN.

With further addition of a single story above 52nd story, the top sway is 38.5 mm while the permissible limit is 371 mm. therefore this system is efficient up to 52 stories.

Model 7 – Hull core system

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	7.590162	0.0308	70.5389	0.0000	0.0308	70.5389
2	7.580509	70.5223	0.0306	0.0000	70.5531	70.5695
3	4.539744	0.0000	0.0000	0.0000	70.5531	70.5695
4	2.103714	0.1041	14.9043	0.0000	70.6572	85.4739
5	2.100489	14.8807	0.1035	0.0000	85.5379	85.5773
6	1.511780	0.0000	0.0000	0.0000	85.5379	85.5773
7	1.023059	0.0781	5.4046	0.0000	85.6160	90.9819
8	1.021223	5.3905	0.0778	0.0000	91.0065	91.0598
9	0.905292	0.0001	0.0000	0.0000	91.0066	91.0598
10	0.645898	0.0342	2.6962	0.0000	91.0408	93.7560
11	0.645227	0.8433	0.0017	0.0000	91.8841	93.7577
12	0.644359	1.8569	0.0382	0.0000	93.7411	93.7959

Fig.4.37: Modal participation ratio and time period of model 7

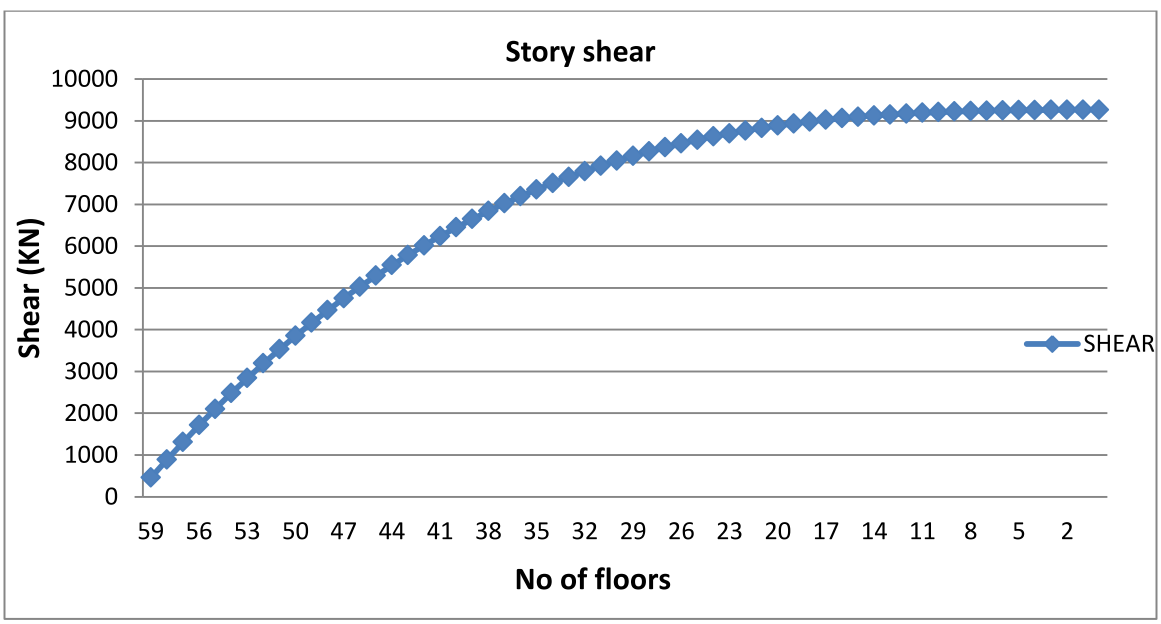

Fig.4.38: graph showing story shear model 7

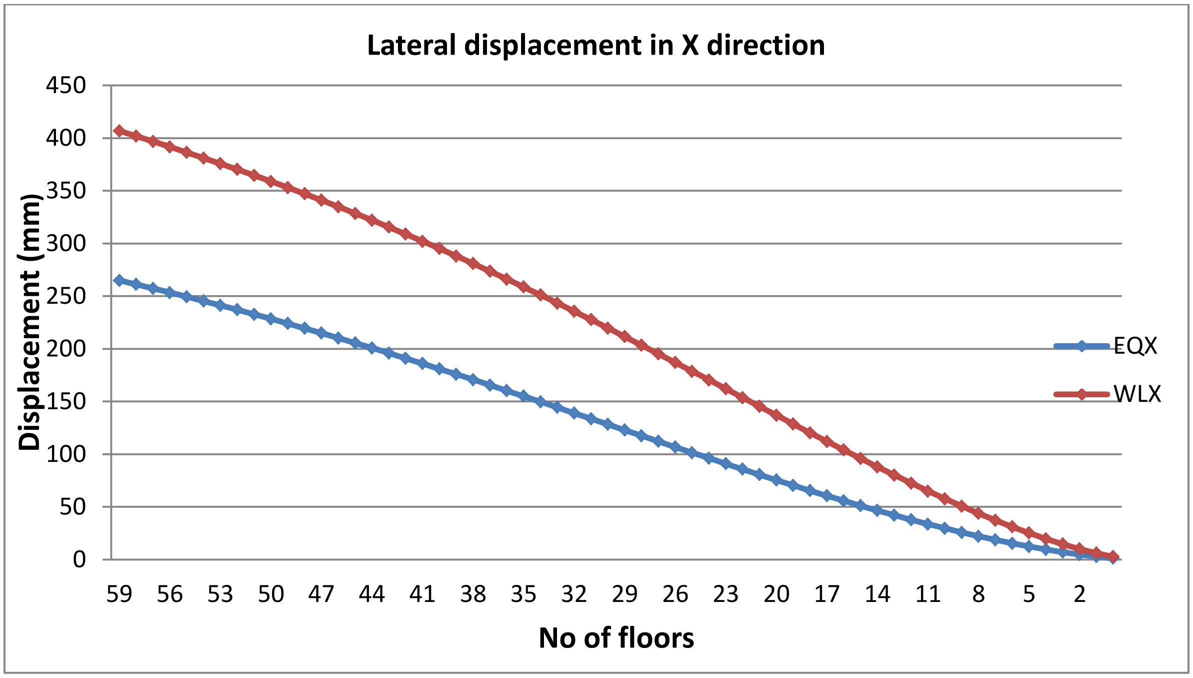

Fig.4.39: graph showing lateral displacement in X direction of model 7

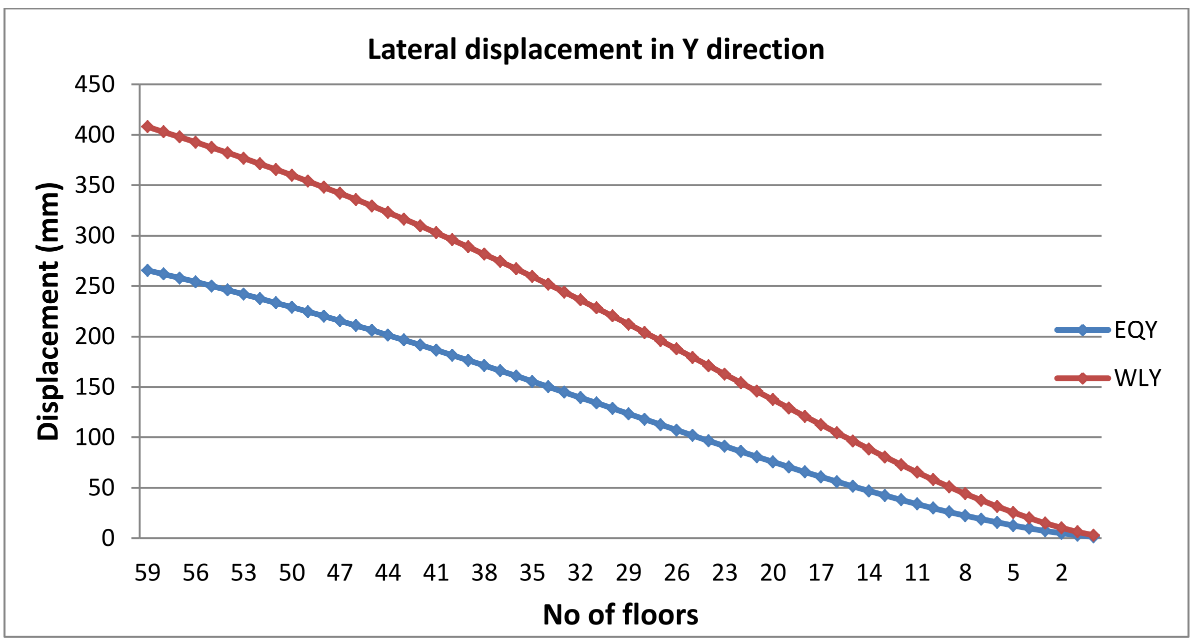

Fig.4.40: graph showing lateral displacement in Y direction of model 7

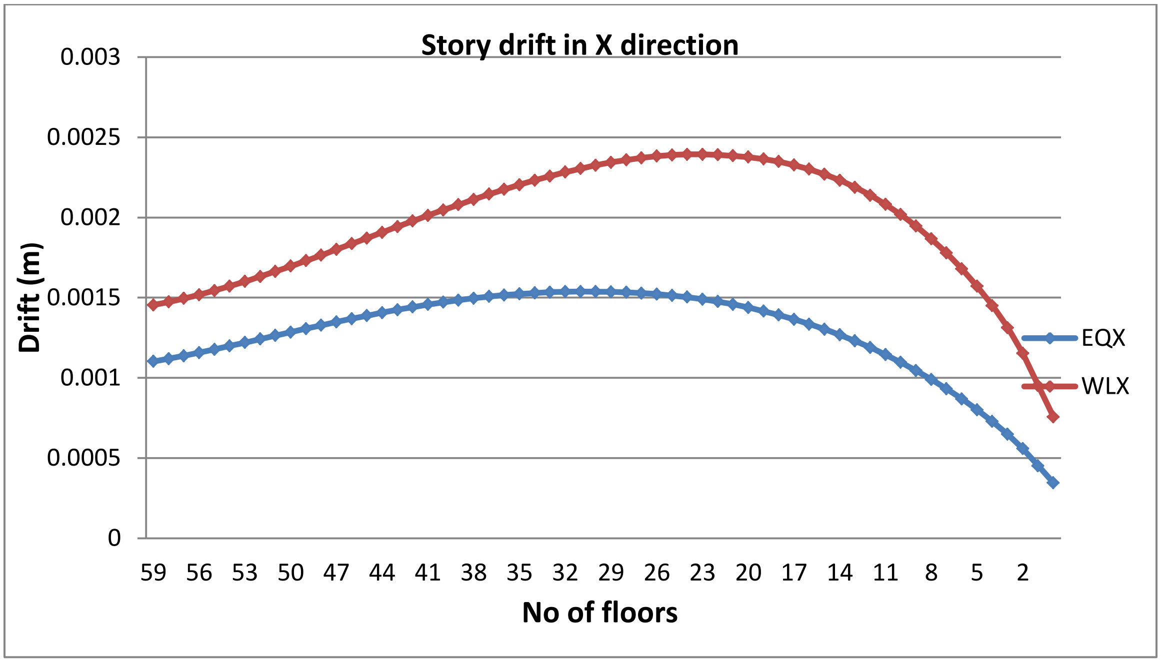

Fig.4.41: graph showing story drift in X direction of model 7

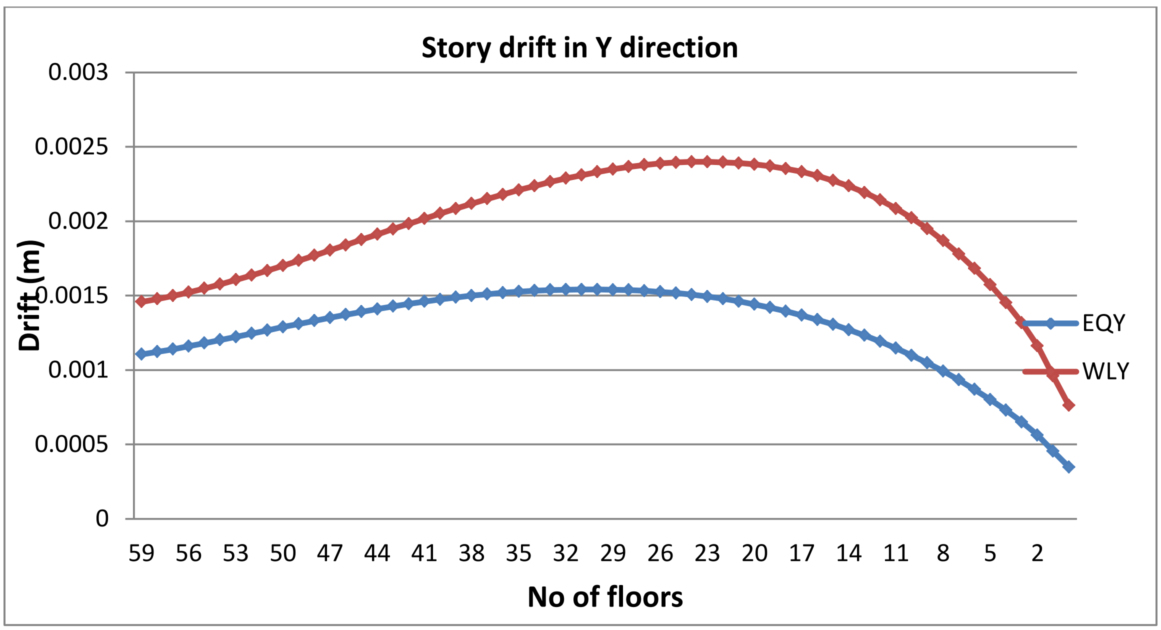

Fig.4.42: graph showing story drift in Y direction of model 7

The lateral sway at the top is 407.86 mm of 60 story building which is under permissible limit i.e. 420 mm. The shear at the base is 9262 KN. When an additional story is added above 60th story the sway at the top reaches to 428 mm, while the permissible limit is

427 mm. Therefore, this system is efficient up to 60 stories.

Model 8 – Outrigger/Spinal wall system

Modal Participating Mass Ratios

Edit View

Modal Participating Mass Ratios

Mode	Period	UX	UY	UZ	SumUX	SumUY
1	7.356904	0.0047	71.0999	0.0000	0.0047	71.0999
2	7.322218	71.1073	0.0046	0.0000	71.1120	71.1045
3	5.427924	0.0000	0.0000	0.0000	71.1120	71.1045
4	2.185389	0.0146	14.4813	0.0000	71.1266	85.5858
5	2.176232	14.4416	0.0144	0.0000	85.5682	85.6002
6	1.807406	0.0000	0.0000	0.0000	85.5682	85.6002
7	1.073034	0.0003	0.0000	0.0000	85.5686	85.6002
8	0.975069	0.0222	5.6745	0.0000	85.5907	91.2747
9	0.970797	5.6473	0.0219	0.0000	91.2381	91.2966
10	0.765703	0.0000	0.0000	0.0000	91.2381	91.2966
11	0.644689	0.0110	2.4819	0.0000	91.2491	93.7784
12	0.642313	2.4789	0.0113	0.0000	93.7280	93.7897

Fig.4.43: Modal participation ratio and time period of model 8

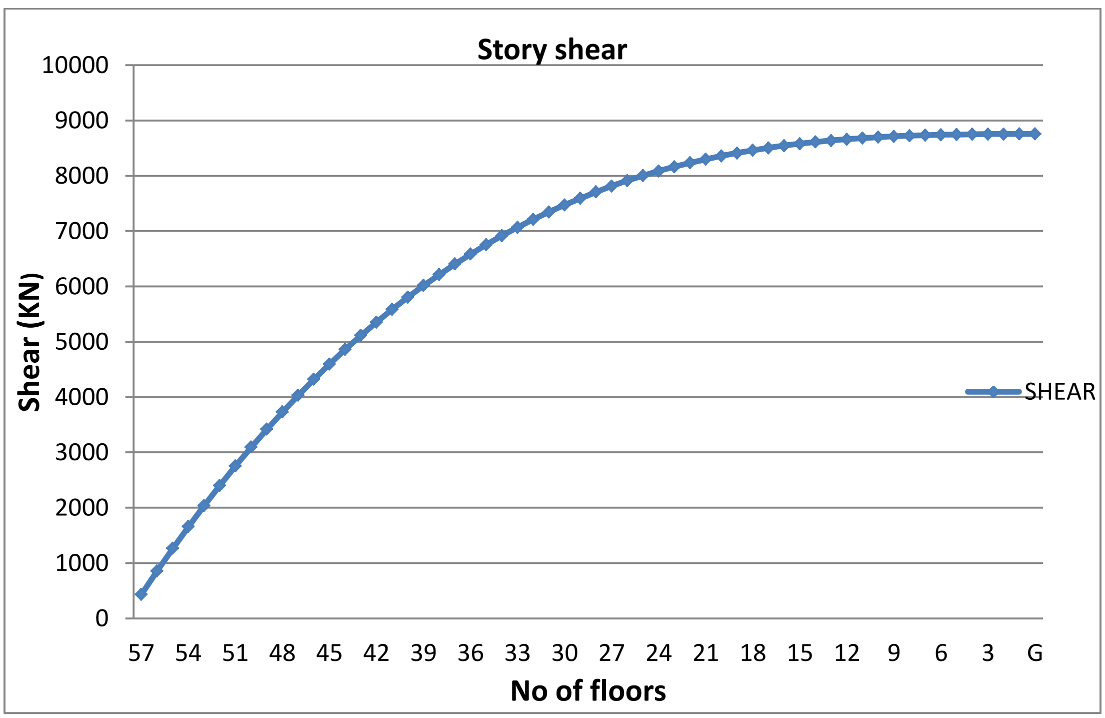

Fig.4.44: graph showing story shear model 8

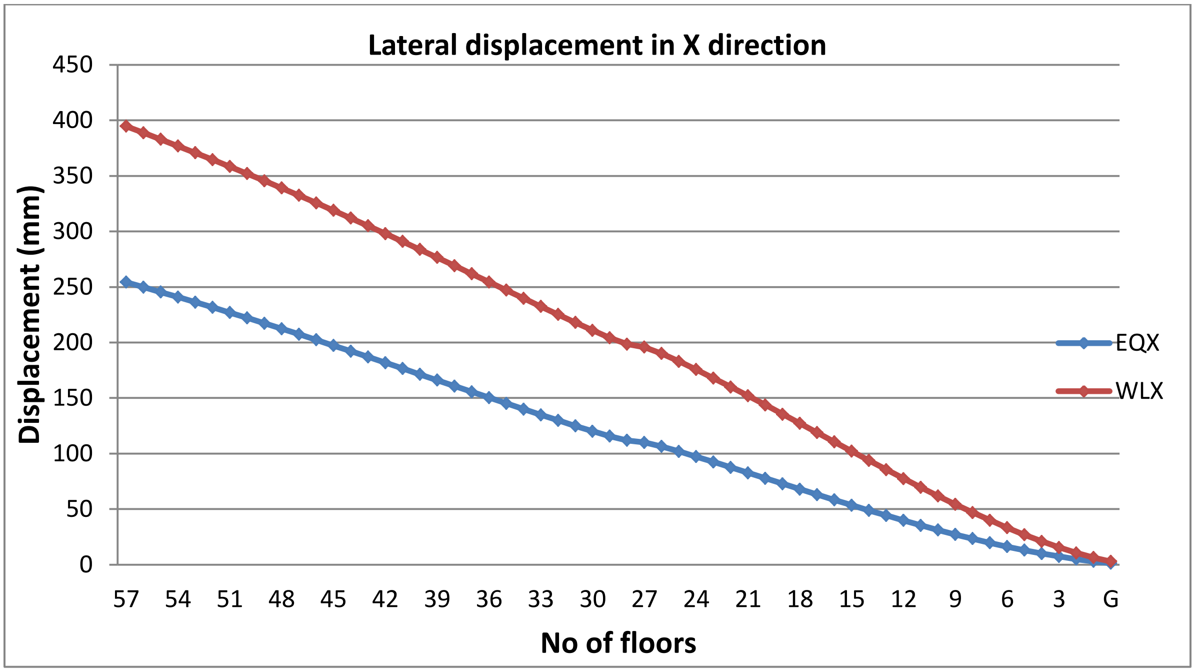

Fig.4.45: graph showing lateral displacement in X direction of model 8

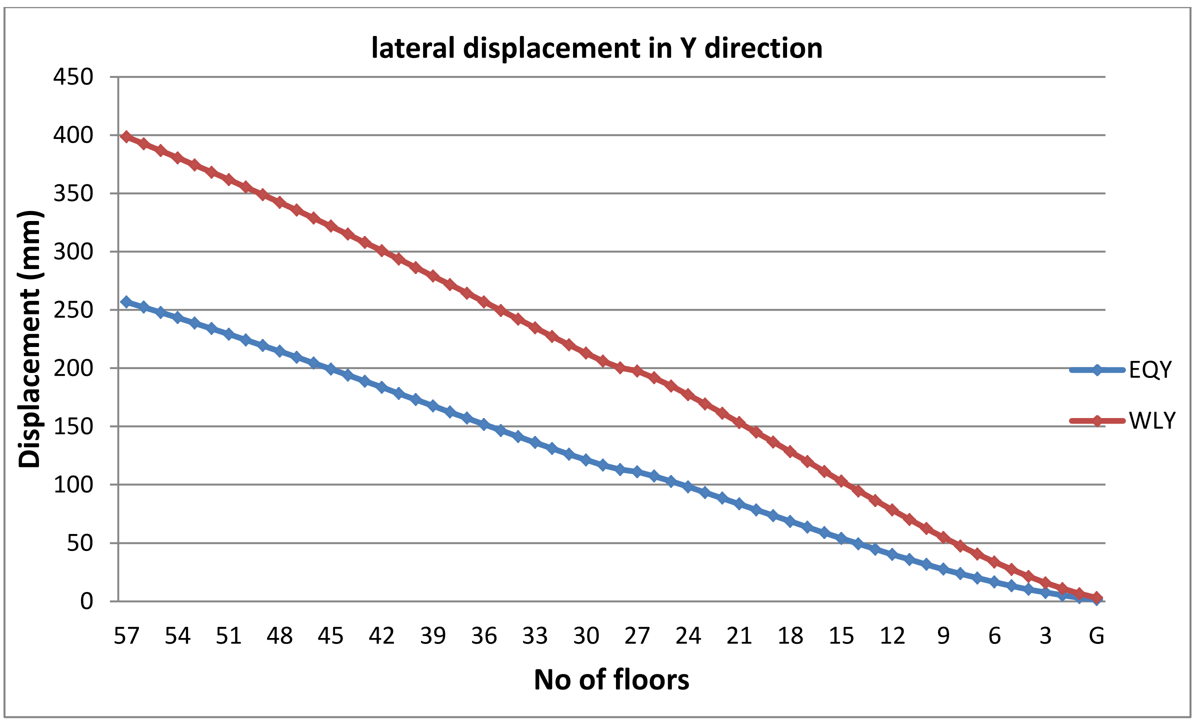

Fig.4.46: graph showing lateral displacement in Y direction of model 8

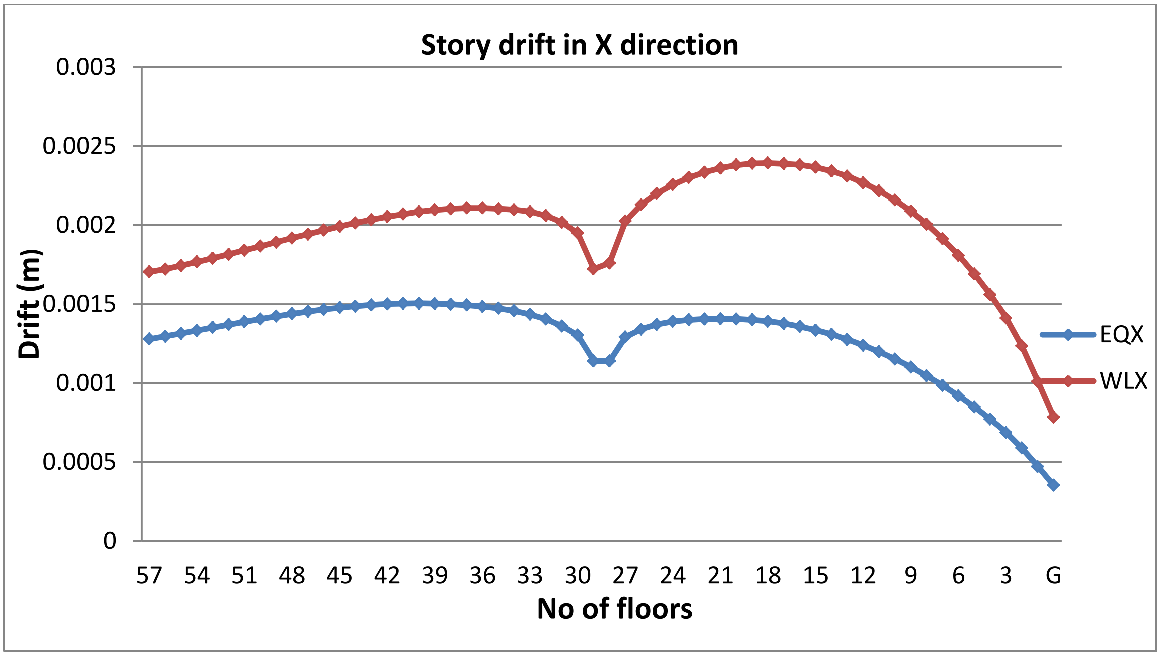

Fig.4.47: graph showing story drift in X direction of model 8

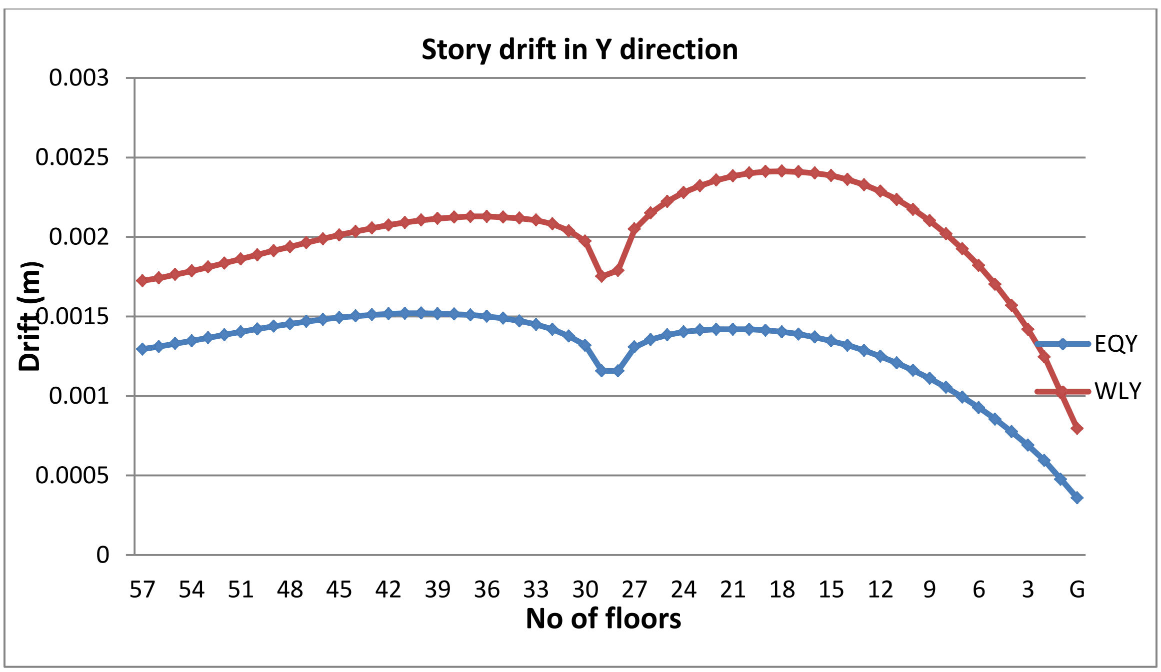

Fig.4.48: graph showing story drift in Y direction of model 8

In this system, the lateral sway at top 398 mm while the permissible limit is of406 mm. The numbers of stories are 58, while the outrigger is placed at mid height i.e. at 28th floor.

The graph of story drift in this case shows a variation at 28th floor, this sudden fall in the story drift occurs because at this level due to very high stiffness of RC wall present around the corridors. The displacement between two levels is very close to each other which can be easily seen in the graph of lateral displacement at 28the story the displacement curve becomes a little constant; therefore the story drift falls suddenly. With addition of further one more story after 58th story, the top sway reaches to 420.87 mm while the permissible limit is 413 mm. the shear at the base is 8756 KN.

Model 9 – Outrigger with Hat/Cap system

Modal Participating Mass Ratios

Edit View

Modal Participating Mass Ratios

	Mode	Period	UX	UY	UZ	SumUX	SumUY
▶	1	7.847769	0.0109	68.3464	0.0000	0.0109	68.3464
	2	7.828548	68.3119	0.0108	0.0000	68.3228	68.3572
	3	5.450599	0.0000	0.0000	0.0000	68.3228	68.3572
	4	2.096049	0.0529	19.1142	0.0000	68.3757	87.4714
	5	2.089321	19.1176	0.0524	0.0000	87.4932	87.5238
	6	1.816690	0.0002	0.0000	0.0000	87.4935	87.5238
	7	1.071558	0.0001	0.0000	0.0000	87.4936	87.5238
	8	0.975877	0.0131	4.4711	0.0000	87.5067	91.9949
	9	0.972549	4.4581	0.0131	0.0000	91.9648	92.0081
	10	0.766951	0.0000	0.0000	0.0000	91.9648	92.0081
	11	0.642353	0.0035	1.5412	0.0000	91.9684	93.5492
	12	0.640532	1.5348	0.0036	0.0000	93.5032	93.5528

Fig.4.49: Modal participation ratio and time period of model 9

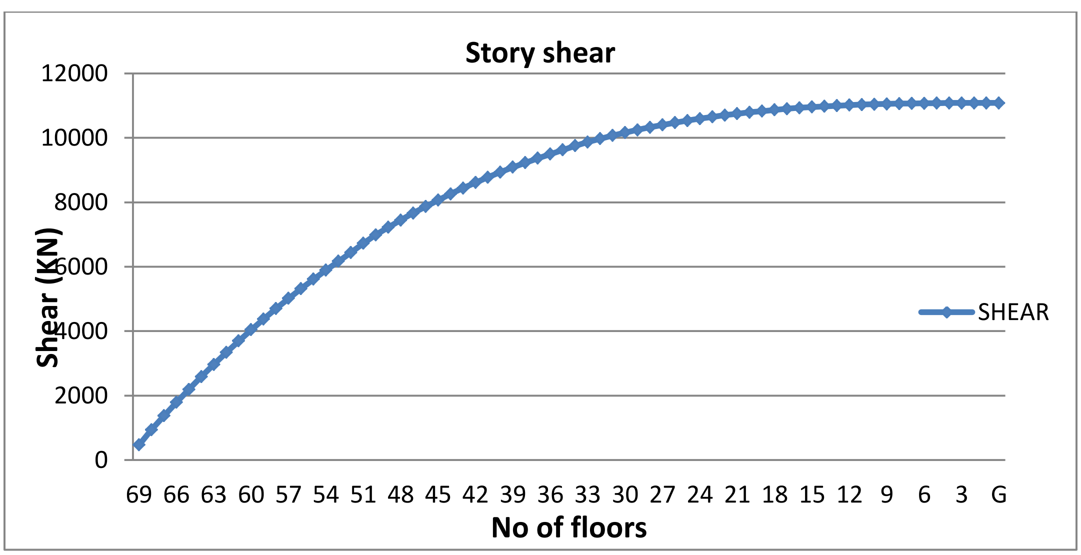

Fig.4.50: graph showing story shear model 9

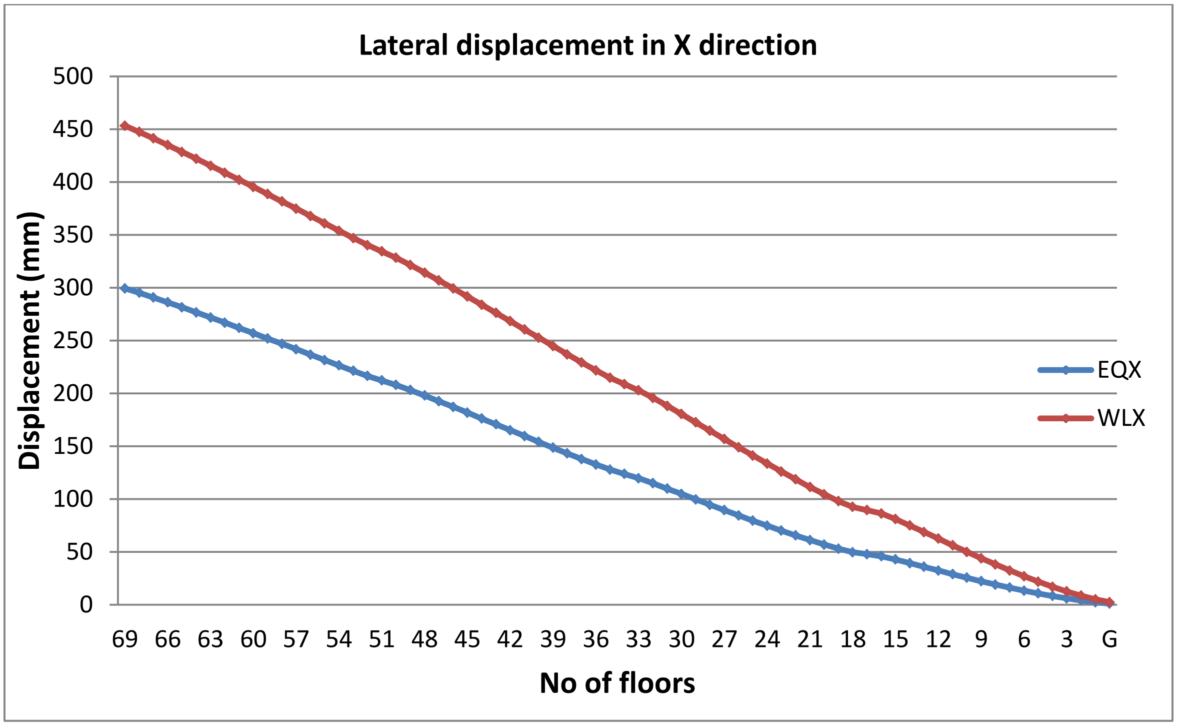

Fig.4.51: graph showing lateral displacement in X direction of model 9

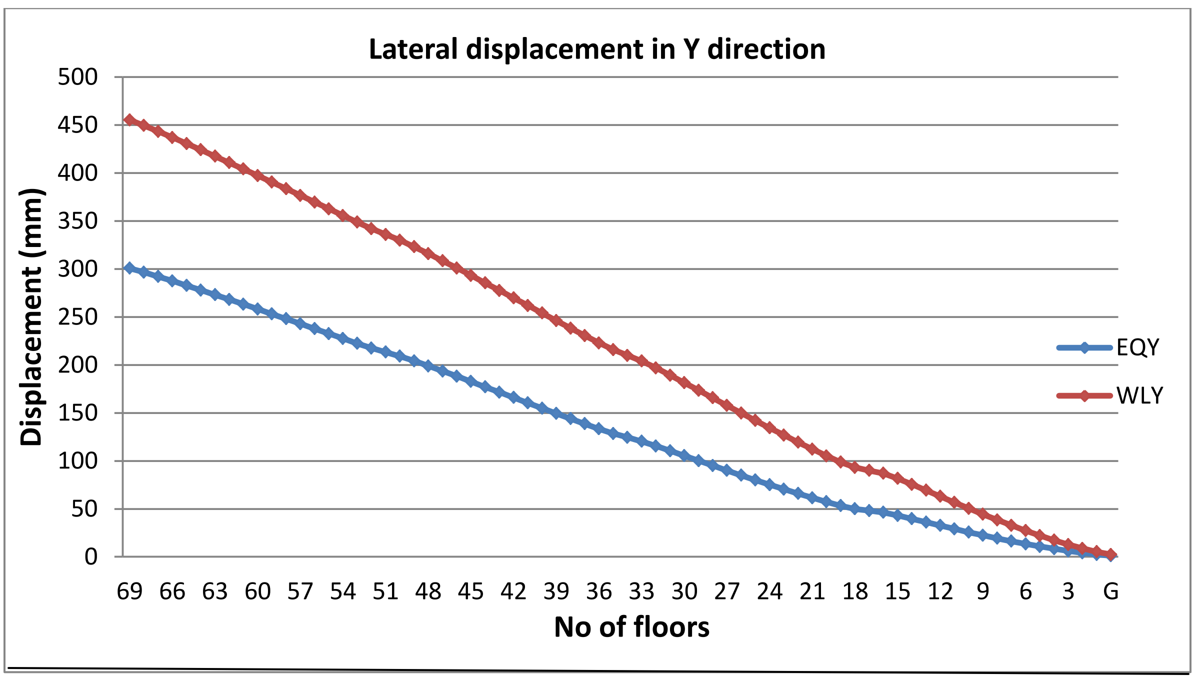

Fig.4.52: graph showing lateral displacement in Y direction of model 9

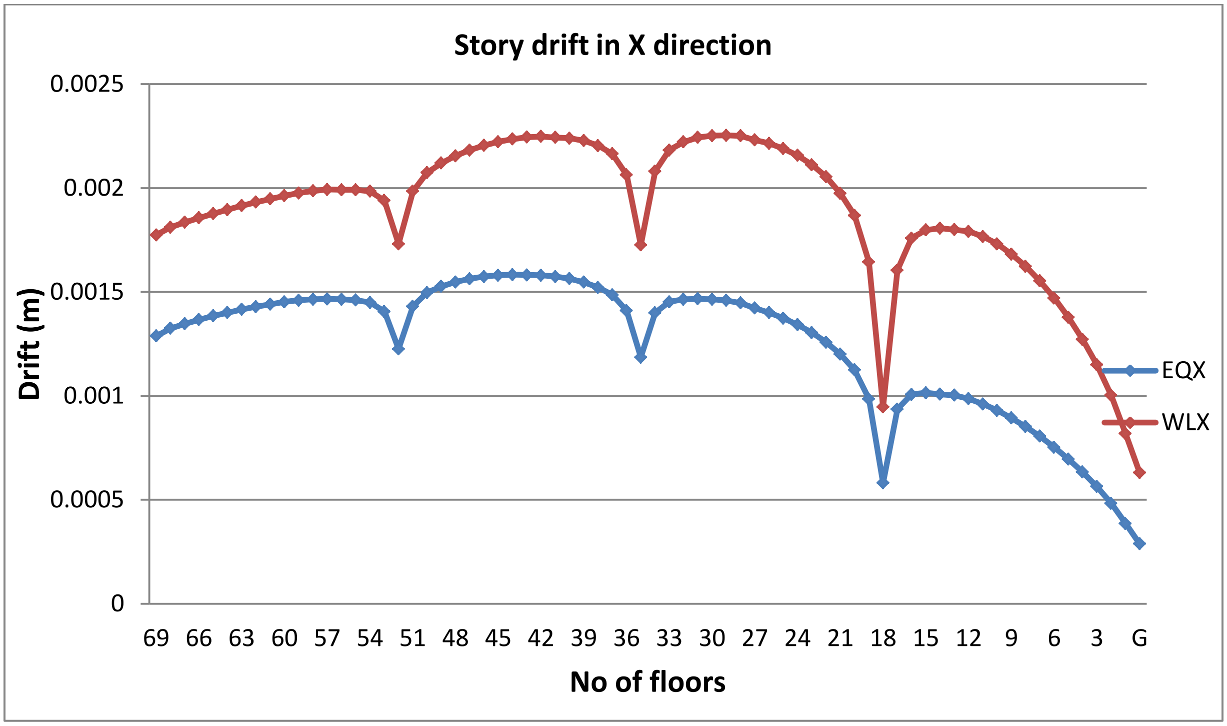

Fig.4.53: graph showing story drift in X direction of model 9

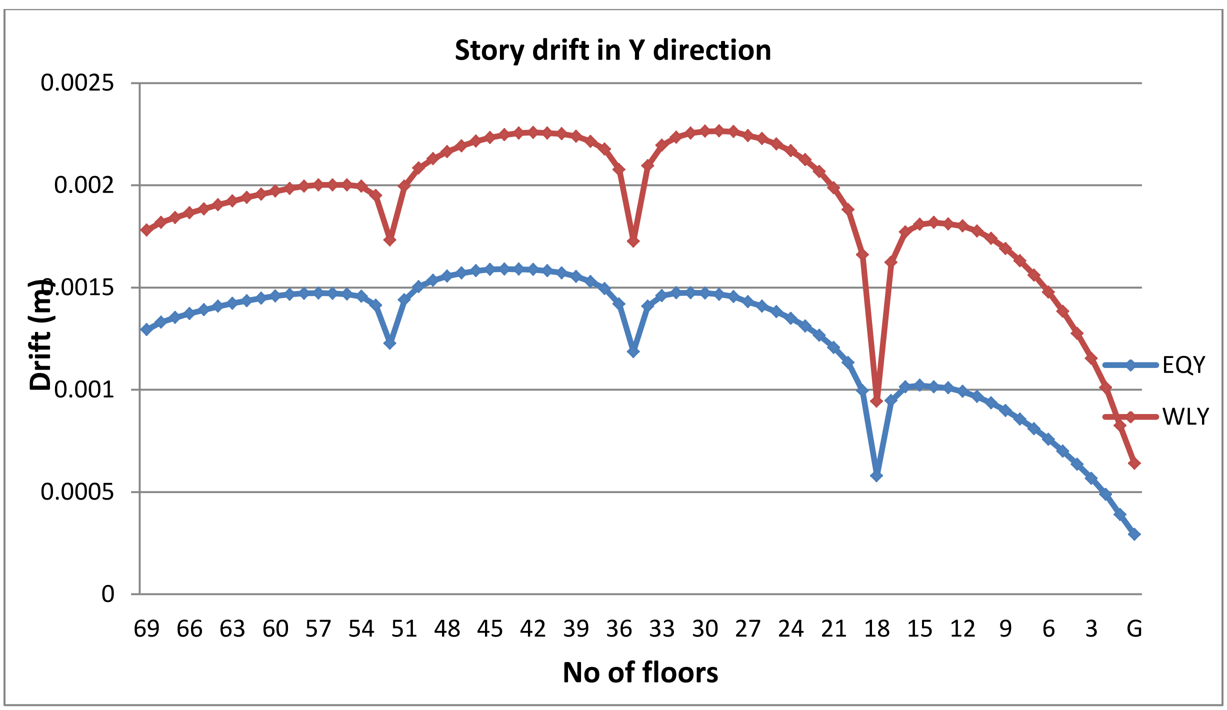

Fig.4.54: graph showing story drift in Y direction of model 9

In this system, an outrigger is placed at the top floor i.e. 70th floor which is referred as cap or hat. Also three more outriggers are placed at 17th, 34th and 51st levels. These outriggers are one story deep and are surrounded around the corridors. The sudden fall in the story drift is again the same reason, due to very high stiffness at such levels. The top sway at the 70th story is 455 mm which is under the permissible limit. With further addition of a story above 70th floor, the sway becomes 504 mm while the limit is 497 mm. Therefore, this system is efficient up to 70 stories.

At last, a chart is prepared on the basis of above study which includes the structural systems versus number of stories. The figure below shows the recommended structural system for different height.

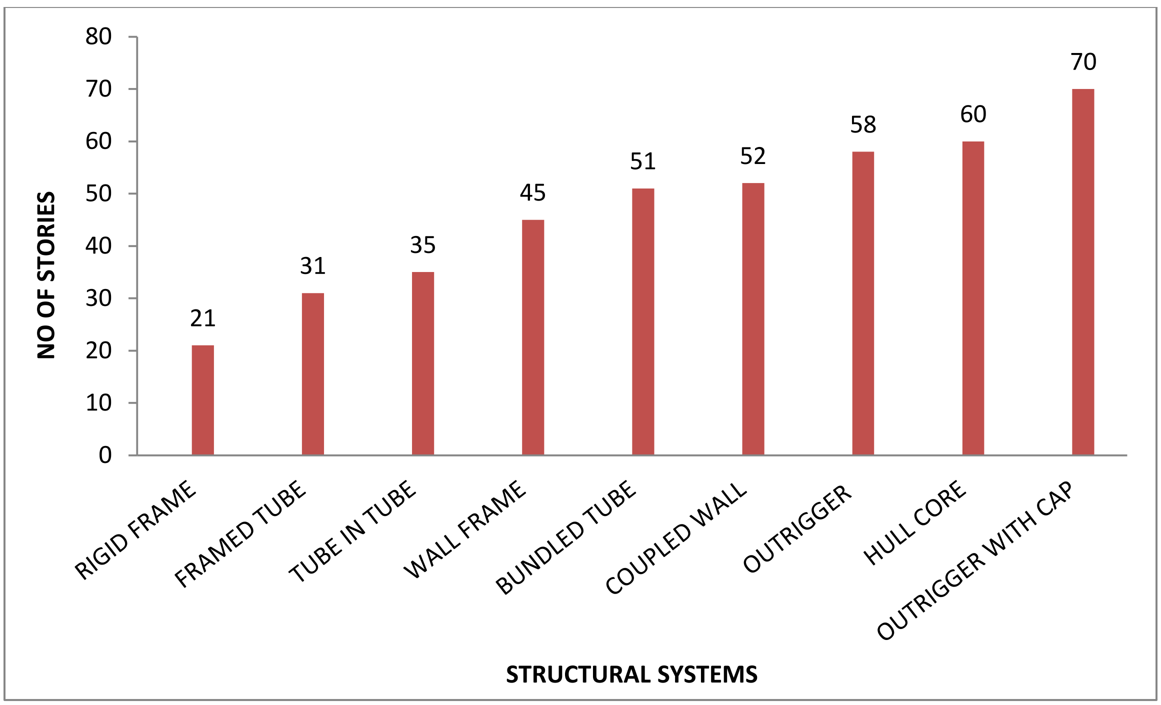

Fig.4.55: graph showing efficiency of structural systems with height

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The design and analysis of a high rise building is never been an easy task, a lot of parameters have to be kept in mind. The most important and very challenging task is to overcome the excessive drifts at the top of the buildings due to intense dynamic effect of wind and earthquake. However, at greater heights the wind effects start dominating the seismic effects. Human comfort is the prime importance while designing any high rise building. The lateral stiffness and flexibility are most important parameters in high rise building. To resist such lateral loads, proper lateral load resisting system should be incorporated in the building which gives proper stiffness and reduces the drift. There are many structural systems which can be adopted in design of tall buildings, but there must be an appropriate selection which gives efficiency as well as economy. In order to address this matter, the aim of the present project is to carry out the analysis of high rise RCC building with an appropriate selection of different structural systems up to certain height.

To achieve this, a building plan is selected in zone 4 and modeled in software ETABS 9.7.4. A total of 9 structural systems are incorporated in the building. All the models are then analysed under wind and seismic effects with their number of stories increasing simultaneously. On the basis of the modal parameters, it is decided that which structural system is efficient up to a certain height.

5.2 CONCLUSIONS

The objective of this study was to understand the behavior of high rise building subjected to lateral loads and behavior of different structural systems, to identify an appropriate and efficient structural system up to a certain height. In this study, 9 models are analyzed and on the basis of their results following conclusions can be drawn from the study:

i) With the increase in height of structure the effect of lateral loads increases simultaneously. At a height of 73.5 m, the sway at the top of building due to earthquake is 56.94 % more than that produced by wind. While at 108.5 m, both earthquake and wind are producing almost same lateral sway at the top i.e. a margin of only 2%. Above this height, the wind load starts dominating and the lateral sway produced by wind is much more than seismic load.

ii) The stiffness plays a very important role in design of high rise building. As the height increases the building demands higher stiffness, so key point is to change the structural system of the building which resists the lateral drifts and make building stable.

iii) The building orientation also depends upon the stiffness. The building will orient first in the direction where the stiffness is less. In all models, 1^{st} and 2^{nd} mode is translational, while 3^{rd} mode is rotational. Due to symmetry of building, building does not participate in rotation.

iv) The building will displace almost equally in both X and Y direction, if the modal participation ratio in the 1^{st} and 2^{nd} mode is equal. In wall frame system, coupled wall, bundled tube and hull core systems the modal participation mass ratio is equal in X and Y direction so are the displacements.

v) The shear at the base of the building increases with increase in the stiffness of the building, as it depends upon the weight of the building.

vi) The lateral displacement of the building lowers down from top to bottom, however displacement curve changes its curvature at lower stories, because at lower levels the displacement values are close to each other.

vii) The story drift increases from top to bottom, but at lower stories drift falls down because at lower levels the displacement values are closer so the marginal decrement between the displacements becomes less than upper stories.

viii) The rigid frame above 21 stories call for uneconomical larger member sections which is not possible, therefore this system is efficient up to 21 stories.

ix) However the tubular systems prove to be quite efficient in resisting lateral forces, because of the closer spacing of the members and provide almost equal stiffness in both directions. Tubular system is more economic than rigid frame system.

x) The wall frame system or coupled wall system increases the flexural stiffness of the building with respect to ordinary frame or tubular systems. In shear wall systems, as the height of the building increase the interaction between wall and frame also increases. The coupled wall system can be efficient up to 52 stories.

xi) Framed tube system when combine with core coupled wall system results into hull core system, which is quite efficient because the lateral forces are resisted by perimeter tube along with shear resistance by the core, thus it is efficient up to 60 stories.

xii) The outrigger system appears to be quite efficient, it not only reduces the lateral sway but also diminishes the inter story drifts. Again the outriggers present in the building increases the flexural stiffness but the shear resistance has to be resisted by core to which outriggers are connected. This system can be adopted up to 70 stories.

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APPENDIX A

CALCULATION OF FORCES FOR STATIC WIND ANALYSIS

Basic wind speed (Vb) = 47m/s

Probability factor (k1) = 1.0

Topography factor (k3) = 1.0

Terrain category = 3

Structure class = C

Terrain, height and structure size factor (k2) is interpolated using Table 2, IS 875 part 3 [20].

Table A1: terrain, height and structure (k2) factor for static analysis

HEIGHT	k2
10.00	0.82
15.00	0.87
20.00	0.91
30.00	0.96
50.00	1.02
100.00	1.1
150.00	1.15
200.00	1.18
250.00	1.2

Design wind speed, (Vz) = Vb*k1*k2*k3.

Design wind pressure, (Pz) = 0.6*Vz^2.

The wind forces are calculated using force coefficient method,

F = Cf*Ae*Pz, where Cf = force coefficient for the building,

Ae = effective frontal area of the building

The values of force coefficient are obtained from Chart 4A (IS 875 part 3). As per, IS guidelines (IS 875 part 3), if the building height to minimum lateral dimension is less than 5 then static analysis has to be performed. Therefore up to 61 stories, static analysis is performed. These forces obtained from calculations are inserted in ETABS.

Table A2: calculation of wind forces for static analysis

STORY	TOTAL HEIGHT	STORY HEIGHT	HEIGHT UPTO THIS FLOOR ABOVE GRND	k2 Table 2, IS 875)	Design Wind Speed (Vz)	Design Pressure (Pz)	Cf	Cf	Ae	Ae	F	F
(UNITS)	(m)	(m)	(m)	--	(m/s)	(kN/m2)	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.
60	213.5	3.5	213.5	1.185	55.72	1.863	1.35	1.35	157.50	157.50	396.08	396.08
59	210	3.5	210	1.184	55.65	1.858	1.35	1.35	157.50	157.50	395.09	395.09
58	206.5	3.5	206.5	1.183	55.59	1.854	1.35	1.35	157.50	157.50	394.24	394.24
57	203	3.5	203	1.181	55.52	1.849	1.35	1.35	157.50	157.50	393.25	393.25
56	199.5	3.5	199.5	1.180	55.45	1.845	1.35	1.35	157.50	157.50	392.26	392.26
55	196	3.5	196	1.178	55.35	1.838	1.35	1.35	157.50	157.50	390.84	390.84
54	192.5	3.5	192.5	1.176	55.25	1.832	1.35	1.35	157.50	157.50	389.43	389.43
53	189	3.5	189	1.173	55.15	1.825	1.35	1.35	157.50	157.50	388.02	388.02
52	185.5	3.5	185.5	1.171	55.06	1.819	1.35	1.35	157.50	157.50	386.76	386.76
51	182	3.5	182	1.169	54.96	1.812	1.35	1.35	157.50	157.50	385.35	385.35
50	178.5	3.5	178.5	1.167	54.86	1.806	1.35	1.35	157.50	157.50	383.95	383.95
49	175	3.5	175	1.165	54.76	1.799	1.35	1.35	157.50	157.50	382.55	382.55
48	171.5	3.5	171.5	1.163	54.66	1.793	1.35	1.35	157.50	157.50	381.16	381.16
47	168	3.5	168	1.161	54.56	1.786	1.35	1.35	157.50	157.50	379.76	379.76
46	164.5	3.5	164.5	1.159	54.46	1.780	1.35	1.35	157.50	157.50	378.37	378.37
45	161	3.5	161	1.157	54.37	1.774	1.35	1.35	157.50	157.50	377.12	377.12
44	157.5	3.5	157.5	1.155	54.27	1.767	1.35	1.35	157.50	157.50	375.74	375.74
43	154	3.5	154	1.152	54.17	1.761	1.35	1.35	157.50	157.50	374.35	374.35
42	150.5	3.5	150.5	1.150	54.07	1.754	1.35	1.35	157.50	157.50	372.97	372.97
41	147	3.5	147	1.147	53.91	1.744	1.35	1.35	157.50	157.50	370.77	370.77
40	143.5	3.5	143.5	1.144	53.75	1.733	1.35	1.35	157.50	157.50	368.57	368.57
39	140	3.5	140	1.140	53.58	1.722	1.35	1.35	157.50	157.50	366.24	366.24
38	136.5	3.5	136.5	1.137	53.42	1.712	1.35	1.35	157.50	157.50	364.06	364.06
37	133	3.5	133	1.133	53.26	1.702	1.35	1.35	157.50	157.50	361.88	361.88
36	129.5	3.5	129.5	1.130	53.09	1.691	1.35	1.35	157.50	157.50	359.58	359.58
35	126	3.5	126	1.126	52.93	1.681	1.35	1.35	157.50	157.50	357.41	357.41
34	122.5	3.5	122.5	1.123	52.76	1.670	1.35	1.35	157.50	157.50	355.12	355.12

STORY	TOTAL HEIGHT	STORY HEIGHT	HEIGHT UPTO THIS FLOOR ABOVE GRND	k2 Table 2, IS 875)	Design Wind Speed (Vz)	Design Pressure (Pz)	Cf	Cf	Ae	Ae	F	F
(UNITS)	(m)	(m)	(m)	--	(m/s)	(kN/m2)	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.
33	119	3.5	119	1.119	52.60	1.660	1.35	1.35	157.50	157.50	352.97	352.97
32	115.5	3.5	115.5	1.116	52.43	1.649	1.35	1.35	157.50	157.50	350.69	350.69
31	112	3.5	112	1.112	52.27	1.639	1.35	1.35	157.50	157.50	348.55	348.55
30	108.5	3.5	108.5	1.109	52.10	1.629	1.35	1.35	157.50	157.50	346.29	346.29
29	105	3.5	105	1.105	51.94	1.619	1.35	1.35	157.50	157.50	344.17	344.17
28	101.5	3.5	101.5	1.102	51.78	1.609	1.35	1.35	157.50	157.50	342.05	342.05
27	98	3.5	98	1.097	51.55	1.594	1.35	1.35	157.50	157.50	339.02	339.02
26	94.5	3.5	94.5	1.091	51.29	1.578	1.35	1.35	157.50	157.50	335.61	335.61
25	91	3.5	91	1.086	51.03	1.562	1.35	1.35	157.50	157.50	332.21	332.21
24	87.5	3.5	87.5	1.080	50.76	1.546	1.35	1.35	157.50	157.50	328.71	328.71
23	84	3.5	84.0	1.074	50.50	1.530	1.35	1.35	157.50	157.50	325.35	325.35
22	80.5	3.5	80.5	1.069	50.24	1.514	1.35	1.35	157.50	157.50	322.01	322.01
21	77	3.5	77.0	1.063	49.98	1.499	1.35	1.35	157.50	157.50	318.68	318.68
20	73.5	3.5	73.5	1.058	49.71	1.483	1.35	1.35	157.50	157.50	315.25	315.25
19	70	3.5	70.0	1.052	49.45	1.467	1.35	1.35	157.50	157.50	311.96	311.96
18	66.5	3.5	66.5	1.046	49.19	1.452	1.35	1.35	157.50	157.50	308.69	308.69
17	63	3.5	63.0	1.041	48.92	1.436	1.35	1.35	157.50	157.50	305.31	305.31
16	59.5	3.5	59.5	1.035	48.66	1.421	1.35	1.35	157.50	157.50	302.07	302.07
15	56	3.5	56.0	1.030	48.40	1.406	1.35	1.35	157.50	157.50	298.85	298.85
14	52.5	3.5	52.5	1.024	48.13	1.390	1.35	1.35	157.50	157.50	295.53	295.53
13	49	3.5	49.0	1.055	49.59	1.476	1.35	1.35	157.50	157.50	313.73	313.73
12	45.5	3.5	45.5	1.038	48.77	1.427	1.35	1.35	157.50	157.50	303.44	303.44
11	42	3.5	42.0	1.020	47.94	1.379	1.35	1.35	157.50	157.50	293.20	293.20
10	38.5	3.5	38.5	1.003	47.12	1.332	1.35	1.35	157.50	157.50	283.25	283.25
9	35	3.5	35.0	0.985	46.30	1.286	1.35	1.35	157.50	157.50	273.48	273.48
8	31.5	3.5	31.5	0.968	45.48	1.241	1.35	1.35	157.50	157.50	263.88	263.88
7	28	3.5	28.0	0.950	44.65	1.196	1.35	1.35	157.50	157.50	254.34	254.34
6	24.5	3.5	24.5	0.933	43.83	1.153	1.35	1.35	157.50	157.50	245.08	245.08
5	21	3.5	21.0	0.915	43.01	1.110	1.35	1.35	157.50	157.50	236.00	236.00
4	17.5	3.5	17.5	0.890	41.83	1.050	1.35	1.35	157.50	157.50	223.22	223.22
3	14	3.5	14.0	0.860	40.42	0.980	1.35	1.35	157.50	157.50	208.43	208.43
2	10.5	3.5	10.5	0.825	38.78	0.902	1.35	1.35	157.50	157.50	191.86	191.86
1	7	3.5	7.0	0.820	38.54	0.891	1.35	1.35	157.50	157.50	189.49	189.49
GROUND	3.5	3.5	3.5	0.820	38.54	0.891	1.35	1.35	157.50	157.50	189.49	189.49

APPENDIX B

CALCULATION OF FORCES FOR DYNAMIC WIND ANALYSIS USING GUST FACTOR

Dynamic effect has to be considered if height to minimum lateral dimension ratio is more than 5, in this case the building becomes slender and gust factor has to be considered.

Gust: it is a positive or negative variation of wind speed from its mean value.

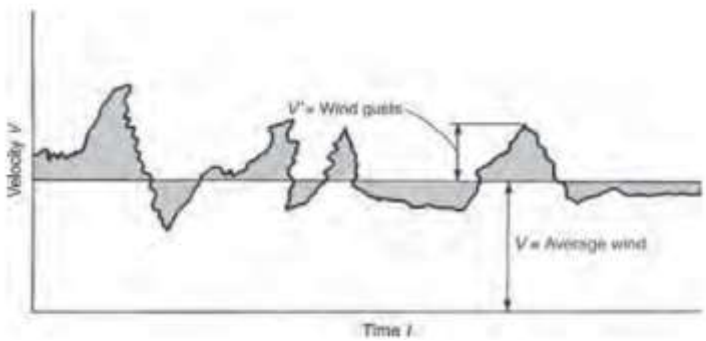

Fig.B1: graph showing nature of gust effect

The K1 and K3 factor remains the same while, K2 factor changes because of the hourly mean wind speed at different heights which is obtained from Table 33 IS 875 part 3.

Table B1: terrain, height and structure (k2) factor for dynamic analysis

HEIGHT	k2
10.00	0.5
15.00	0.55
20.00	0.59
30.00	0.64
50.00	0.70
100.00	0.79
150.00	0.84
200.00	0.88
250.00	0.91

Fz = Cf*Ae*Pz*G, where Cf is force coefficient

Ae is effective frontal area

Pz is 0.6*Vz^2 and G is gust factor.

$$G = 1 + g_f r \sqrt{\left[B(1+\phi)^2 + \frac{SE}{\beta}\right]}$$

The gust factor calculation is done by IS guidelines, IS 875 part 3. In the present study, both lateral dimensions are equal; therefore the gust factor would be same for both directions.

Table B2: calculation of gust factor

Height of the Builing	**gfr**	**Cy** (lateral correlation constant)	**Cz** (longitudinal correlation constant)	**b** (width of the building)	**λ**	**d** (width of building another direction)	**h**	**L(h)**	**B**	**ø**	$T = \frac{0.09 H}{\sqrt{d}}$
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29
245	0.75	10	12	45	0.15	45	245	2250	0.5	0	3.29

fo	K2	Vh	**Fo** (required Frequency) = (Cz*fo*h)/Vh	S	$f_0 L(h)/\bar{V}_h$	E	β	G
0.304	0.5	23.500	38.06	0.041	29.13	0.075	0.016	1.62
0.304	0.55	25.850	34.60	0.047	26.48	0.076	0.016	1.64
0.304	0.59	27.730	32.25	0.05	24.68	0.08	0.016	1.65
0.304	0.64	30.080	29.73	0.052	22.76	0.09	0.016	1.67
0.304	0.70	32.900	27.19	0.064	20.81	0.092	0.016	1.70
0.304	0.79	37.130	24.09	0.081	18.44	0.10	0.016	1.75
0.304	0.84	39.480	22.66	0.095	17.34	0.105	0.016	1.79
0.304	0.88	41.360	21.63	0.1	16.55	0.105	0.016	1.81
0.304	0.91	42.770	20.91	0.123	16.00	0.109	0.016	1.87

Table B3: calculation of wind forces for dynamic analysis

STORY	STORY HEIGHT	HEIGHT UPTO THIS FLOOR ABOVE GRND	k2 Table 33, IS 875)	Design Wind Speed (Vz)	Design Pressure (Pz)	Cf	Cf	Ae	Ae	F	F	GUST FACT OR	GUST FACT OR	F includin gust factor	F includin gust factor
(UNITS)	(m)	(m)	--	(m/s)	(kN/m2)	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.
69	3.5	245.0	0.907	42.63	1.100	1.55	1.55	157.50	157.50	268.54	268.54	1.87	1.87	502.17	502.17
68	3.5	241.5	0.905	42.54	1.090	1.55	1.55	157.50	157.50	266.10	266.10	1.87	1.87	497.60	497.60
67	3.5	238.0	0.903	42.44	1.090	1.55	1.55	157.50	157.50	266.10	266.10	1.87	1.87	497.60	497.60
66	3.5	234.5	0.901	42.34	1.080	1.55	1.55	157.50	157.50	263.66	263.66	1.87	1.87	493.03	493.03
65	3.5	231.0	0.899	42.24	1.080	1.55	1.55	157.50	157.50	263.66	263.66	1.87	1.87	493.03	493.03
64	3.5	227.5	0.897	42.14	1.070	1.55	1.55	157.50	157.50	261.21	261.21	1.87	1.87	488.47	488.47
63	3.5	224.0	0.894	42.04	1.070	1.55	1.55	157.50	157.50	261.21	261.21	1.87	1.87	488.47	488.47
62	3.5	220.5	0.892	41.94	1.060	1.55	1.55	157.50	157.50	258.77	258.77	1.87	1.87	483.90	483.90
61	3.5	217.0	0.890	41.84	1.060	1.55	1.55	157.50	157.50	258.77	258.77	1.87	1.87	483.90	483.90
60	3.5	213.5	0.888	41.75	1.050	1.55	1.55	157.50	157.50	256.33	256.33	1.87	1.87	479.34	479.34
59	3.5	210.0	0.886	41.65	1.050	1.55	1.55	157.50	157.50	256.33	256.33	1.87	1.87	479.34	479.34
58	3.5	206.5	0.884	41.55	1.040	1.55	1.55	157.50	157.50	253.89	253.89	1.87	1.87	474.77	474.77
57	3.5	203.0	0.882	41.45	1.040	1.55	1.55	157.50	157.50	253.89	253.89	1.87	1.87	474.77	474.77

STORY	STORY HEIGHT	HEIGHT UPTO THIS FLOOR ABOVE GRND	k2 Table 33, IS 875)	Design Wind Speed (Vz)	Design Pressure (Pz)	Cf	Cf	Ae	Ae	F	F	GUST FACTOR	GUST FACTOR	F includin gust factor	F includin gust factor
(UNITS)	(m)	(m)	--	(m/s)	(kN/m2)	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.

56	3.5	199.5	0.880	41.35	1.030	1.55	1.55	157.50	157.50	251.45	251.45	1.81	1.81	455.12	455.12
55	3.5	196.0	0.877	41.21	1.020	1.55	1.55	157.50	157.50	249.01	249.01	1.81	1.81	450.70	450.70
54	3.5	192.5	0.874	41.08	1.020	1.55	1.55	157.50	157.50	249.01	249.01	1.81	1.81	450.70	450.70
53	3.5	189.0	0.871	40.95	1.010	1.55	1.55	157.50	157.50	246.57	246.57	1.81	1.81	446.28	446.28
52	3.5	185.5	0.868	40.82	1.000	1.55	1.55	157.50	157.50	244.13	244.13	1.81	1.81	441.87	441.87
51	3.5	182.0	0.866	40.69	1.000	1.55	1.55	157.50	157.50	244.13	244.13	1.81	1.81	441.87	441.87
50	3.5	178.5	0.863	40.56	0.990	1.55	1.55	157.50	157.50	241.68	241.68	1.81	1.81	437.45	437.45
49	3.5	175.0	0.860	40.42	0.990	1.55	1.55	157.50	157.50	241.68	241.68	1.81	1.81	437.45	437.45
48	3.5	171.5	0.857	40.29	0.980	1.55	1.55	157.50	157.50	239.24	239.24	1.81	1.81	433.03	433.03
47	3.5	168.0	0.854	40.16	0.970	1.55	1.55	157.50	157.50	236.80	236.80	1.81	1.81	428.61	428.61
46	3.5	164.5	0.852	40.03	0.970	1.55	1.55	157.50	157.50	236.80	236.80	1.81	1.81	428.61	428.61
45	3.5	161.0	0.849	39.90	0.960	1.55	1.55	157.50	157.50	234.36	234.36	1.81	1.81	424.19	424.19
44	3.5	157.5	0.846	39.77	0.950	1.55	1.55	157.50	157.50	231.92	231.92	1.81	1.81	419.77	419.77
43	3.5	154.0	0.843	39.64	0.950	1.55	1.55	157.50	157.50	231.92	231.92	1.81	1.81	419.77	419.77
42	3.5	150.5	0.840	39.50	0.940	1.55	1.55	157.50	157.50	229.48	229.48	1.81	1.81	415.35	415.35
41	3.5	147.0	0.837	39.34	0.930	1.55	1.55	157.50	157.50	227.04	227.04	1.79	1.79	406.39	406.39
40	3.5	143.5	0.834	39.18	0.930	1.55	1.55	157.50	157.50	227.04	227.04	1.79	1.79	406.39	406.39
39	3.5	140.0	0.830	39.01	0.920	1.55	1.55	157.50	157.50	224.60	224.60	1.79	1.79	402.03	402.03
38	3.5	136.5	0.827	38.85	0.910	1.55	1.55	157.50	157.50	222.15	222.15	1.79	1.79	397.66	397.66
37	3.5	133.0	0.823	38.69	0.900	1.55	1.55	157.50	157.50	219.71	219.71	1.79	1.79	393.29	393.29
36	3.5	129.5	0.820	38.52	0.900	1.55	1.55	157.50	157.50	219.71	219.71	1.79	1.79	393.29	393.29
35	3.5	126.0	0.816	38.36	0.890	1.55	1.55	157.50	157.50	217.27	217.27	1.79	1.79	388.92	388.92
34	3.5	122.5	0.813	38.19	0.880	1.55	1.55	157.50	157.50	214.83	214.83	1.79	1.79	384.55	384.55
33	3.5	119.0	0.809	38.03	0.870	1.55	1.55	157.50	157.50	212.39	212.39	1.79	1.79	380.18	380.18
32	3.5	115.5	0.806	37.86	0.870	1.55	1.55	157.50	157.50	212.39	212.39	1.79	1.79	380.18	380.18
31	3.5	112.0	0.802	37.70	0.860	1.55	1.55	157.50	157.50	209.95	209.95	1.79	1.79	375.81	375.81
30	3.5	108.5	0.799	37.53	0.850	1.55	1.55	157.50	157.50	207.51	207.51	1.79	1.79	371.44	371.44
29	3.5	105.0	0.795	37.37	0.840	1.55	1.55	157.50	157.50	205.07	205.07	1.79	1.79	367.07	367.07
28	3.5	101.5	0.792	37.21	0.840	1.55	1.55	157.50	157.50	205.07	205.07	1.79	1.79	367.07	367.07
27	3.5	98.0	0.786	36.97	0.830	1.55	1.55	157.50	157.50	202.62	202.62	1.75	1.75	354.59	354.59
26	3.5	94.5	0.780	36.67	0.810	1.55	1.55	157.50	157.50	197.74	197.74	1.75	1.75	346.05	346.05
25	3.5	91.0	0.774	36.37	0.800	1.55	1.55	157.50	157.50	195.30	195.30	1.75	1.75	341.78	341.78
24	3.5	87.5	0.768	36.08	0.790	1.55	1.55	157.50	157.50	192.86	192.86	1.75	1.75	337.50	337.50
23	3.5	84.0	0.761	35.78	0.770	1.55	1.55	157.50	157.50	187.98	187.98	1.75	1.75	328.96	328.96
22	3.5	80.5	0.755	35.49	0.760	1.55	1.55	157.50	157.50	185.54	185.54	1.75	1.75	324.69	324.69
21	3.5	77.0	0.749	35.19	0.750	1.55	1.55	157.50	157.50	183.09	183.09	1.75	1.75	320.41	320.41
20	3.5	73.5	0.742	34.89	0.740	1.55	1.55	157.50	157.50	180.65	180.65	1.75	1.75	316.14	316.14

STORY	STORY HEIGHT	HEIGHT UPTO THIS FLOOR ABOVE GRND	k2 Table 33, IS 875)	Design Wind Speed (Vz)	Design Pressure (Pz)	Cf	Cf	Ae	Ae	F	F	GUST FACTOR	GUST FACTOR	F includin gust factor	F includin gust factor
(UNITS)	(m)	(m)	--	(m/s)	(kN/m2)	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.	X-DIR.	Y-DIR.
19	3.5	70.0	0.736	34.60	0.720	1.55	1.55	157.50	157.50	175.77	175.77	1.75	1.75	307.60	307.60
18	3.5	66.5	0.730	34.30	0.710	1.55	1.55	157.50	157.50	173.33	173.33	1.75	1.75	303.33	303.33
17	3.5	63.0	0.723	34.00	0.700	1.55	1.55	157.50	157.50	170.89	170.89	1.75	1.75	299.05	299.05
16	3.5	59.5	0.717	33.71	0.690	1.55	1.55	157.50	157.50	168.45	168.45	1.75	1.75	294.78	294.78
15	3.5	56.0	0.711	33.41	0.670	1.55	1.55	157.50	157.50	163.56	163.56	1.75	1.75	286.24	286.24
14	3.5	52.5	0.705	33.12	0.660	1.55	1.55	157.50	157.50	161.12	161.12	1.75	1.75	281.96	281.96
13	3.5	49.0	0.697	32.76	0.650	1.55	1.55	157.50	157.50	158.68	158.68	1.70	1.70	269.76	269.76
12	3.5	45.5	0.687	32.27	0.630	1.55	1.55	157.50	157.50	153.80	153.80	1.70	1.70	261.46	261.46
11	3.5	42.0	0.676	31.78	0.610	1.55	1.55	157.50	157.50	148.92	148.92	1.70	1.70	253.16	253.16
10	3.5	38.5	0.666	31.28	0.590	1.55	1.55	157.50	157.50	144.03	144.03	1.70	1.70	244.86	244.86
9	3.5	35.0	0.655	30.79	0.570	1.55	1.55	157.50	157.50	139.15	139.15	1.70	1.70	236.56	236.56
8	3.5	31.5	0.645	30.30	0.560	1.55	1.55	157.50	157.50	136.71	136.71	1.70	1.70	232.41	232.41
7	3.5	28.0	0.630	29.61	0.530	1.55	1.55	157.50	157.50	129.39	129.39	1.67	1.67	216.08	216.08
6	3.5	24.5	0.613	28.79	0.500	1.55	1.55	157.50	157.50	122.06	122.06	1.67	1.67	203.84	203.84
5	3.5	21.0	0.595	27.97	0.470	1.55	1.55	157.50	157.50	114.74	114.74	1.67	1.67	191.61	191.61
4	3.5	17.5	0.570	26.79	0.440	1.55	1.55	157.50	157.50	107.42	107.42	1.65	1.65	177.23	177.23
3	3.5	14.0	0.540	25.38	0.390	1.55	1.55	157.50	157.50	95.21	95.21	1.64	1.64	156.14	156.14
2	3.5	10.5	0.505	23.74	0.340	1.55	1.55	157.50	157.50	83.00	83.00	1.64	1.64	136.12	136.12
1	3.5	7.0	0.500	23.50	0.340	1.55	1.55	157.50	157.50	83.00	83.00	1.62	1.62	134.46	134.46
GROUND	3.5	3.5	0.500	23.50	0.340	1.55	1.55	157.50	157.50	83.00	83.00	1.62	1.62	134.46	134.46