Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings

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In

Structural Engineering

By

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CERTIFICATE

Certified that Abhishek Mishra have carried out the project work presented in this report entitled ***"Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings"*** for the award of **Master of Technology** in Structural Engineering from **Babu Banarasi Das University, Lucknow (UP)** under my supervision and guidance. The report embodies result of original work and study carried out by students themselves and the contents of the report do not form the basis for the award of any other degree to the candidate or to anybody.

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CANDIDATE'S DECLARATION

I declare that this written submission represents my work and ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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It is matter of great pleasure and satisfaction for me to present this dissertation work entitled "***Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings***", as a part of curriculum for award of "Master of Technology" from Babu Banarasi Das University, Lucknow (U.P.) India.
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ABSTRACT

As we all know population is growing extensively these days and hence the requirement of multistory residential buildings is also increasing which are exposed to the possibility of being damaged and collapse of buildings in earthquake prone zones. In past few year earthquake has caused so many losses of human life and substantial economic loss due collapse of tall structures. The technique base isolation is one of the most prominent vibration control techniques that has been used around the world to defend the buildings from the harmful results of earthquake. The base isolators minimize the effect of seismic waves by dissipating the energy into the isolation materials and transforming the energy into another form depending upon their property. This paper describes relative study of different floor plan shaped multistory buildings with and without use of base isolation. For this study Lead Rubber Bearing and Friction Pendulum System type base isolations has been considered. Also this analysis includes the modelling of 15 storied RC framed square shaped plan, rectangular shaped plan and H-shaped plan buildings in seismic zone V resting on soft soil and Linear Modal Time History Analysis is carried out using software ETABS version 17.0.1 considering ground motion data of El Centro earthquake as time and function value. The analysis carried out with the help of IS 1893:2016 (Part 1). The responses acquired from the analysis due to maximum time history load case in X & Y-direction will compared in terms of maximum story displacement, maximum story drift, maximum story acceleration, maximum base shear, maximum absolute joint acceleration at the top story and the modal time period of 15 storied square, rectangular and H-shaped plan building having fixed base and isolators at base such as LRB and FP

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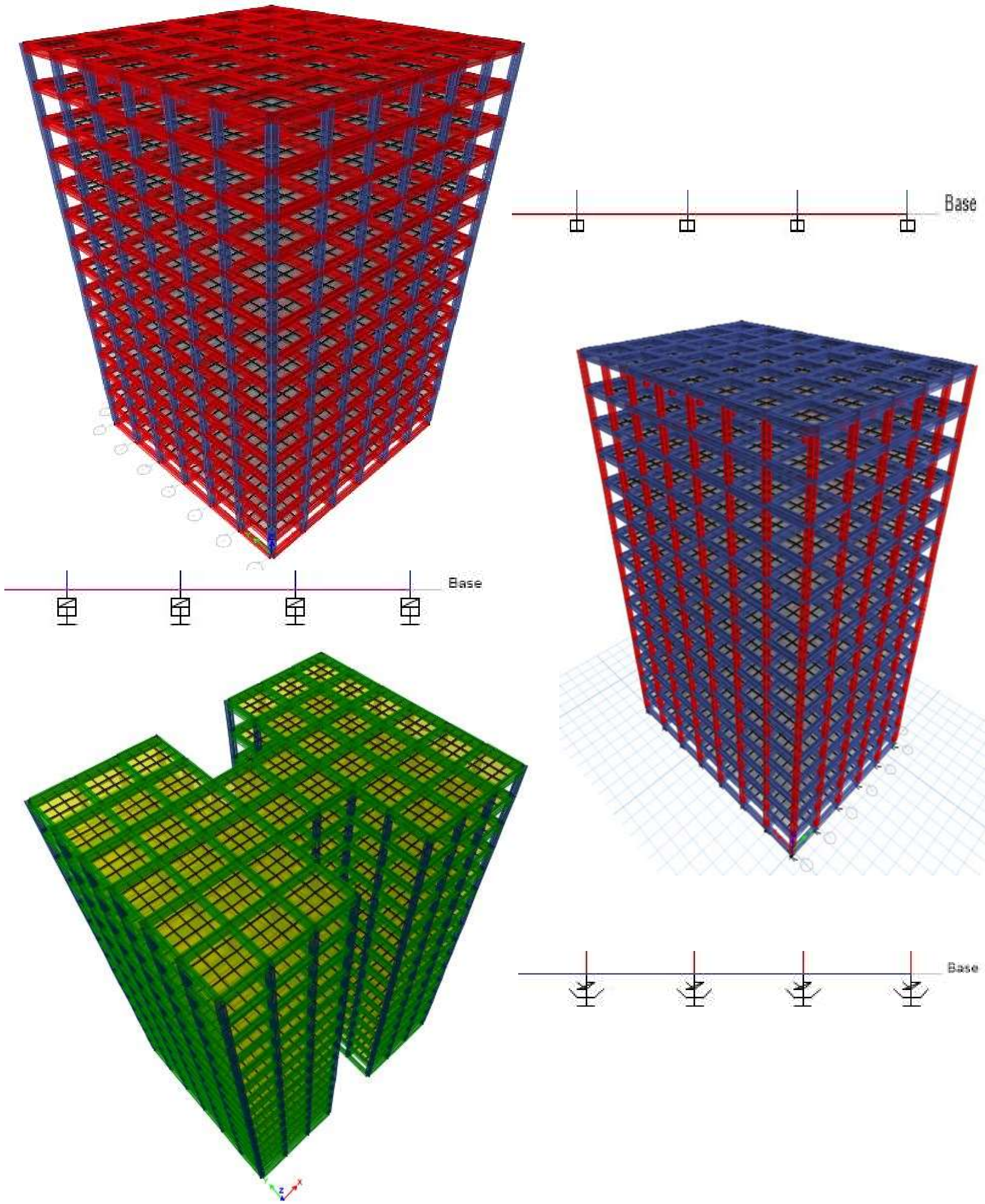
LIST OF ABBREVIATIONS

LRB	Lead Rubber Bearing
FPS	Friction Pendulum System
B-I	Base Isolation
DL	Dead Load
LL	Live Load
EqX	Earthquake Load in X direction
EqY	Earthquake Load in Y direction
FB	Fixed Base
TH-X	Time History Load Case in X direction
TH-Y	Time History Load Case in Y direction
Z	Zone Factor
I_{xx} & I_{yy}	Moment of Inertia in X & Y direction
HYSD	High Yielding Strength Deformed Bars
M20 & M25	Design Mix of Concrete
kN	Load/Weight unit in Kilo Newton
m	Length unit in Meters
mm	Length unit in Millimeters
s or sec	Time unit in Seconds



EFFECT OF FLOOR PLAN SHAPE ON SEISMIC RESPONSES OF BASE-ISOLATED BUILDING

CHAPTER 1

(INTRODUCTION)

Now a day, earthquake is major problem for high rises structures because need of high rises residential building is increasing day by day due to enormous growth in population. In past few years, lots of losses in human life and economic losses are caused due to earthquake. The reason of earthquake is the seismic wave which generates into the earth because of tectonic plates movement, mining, nuclear explosions or volcanic explosions etc. Seismic waves travel through the earth crust and strikes the ground and building foundations with some intensity which results into swaying, cracks development or collapsing of buildings.

1.1. Base Isolation

Base isolation now days is a best technique considered for protecting the tall structures from effects of earthquake. The isolation technique disconnects the structures from horizontal component of seismic waves by interposing the seismic isolators between structure and foundation. The base isolators installed in the base or foundations of buildings and it dissipates the energy and transforms it into another form so that the effect of seismic waves are minimized and we can save the human lives and other losses related to economy. Fig. 1.1 shows the behavior of fixed base and base-isolated structures during the earthquake [1].

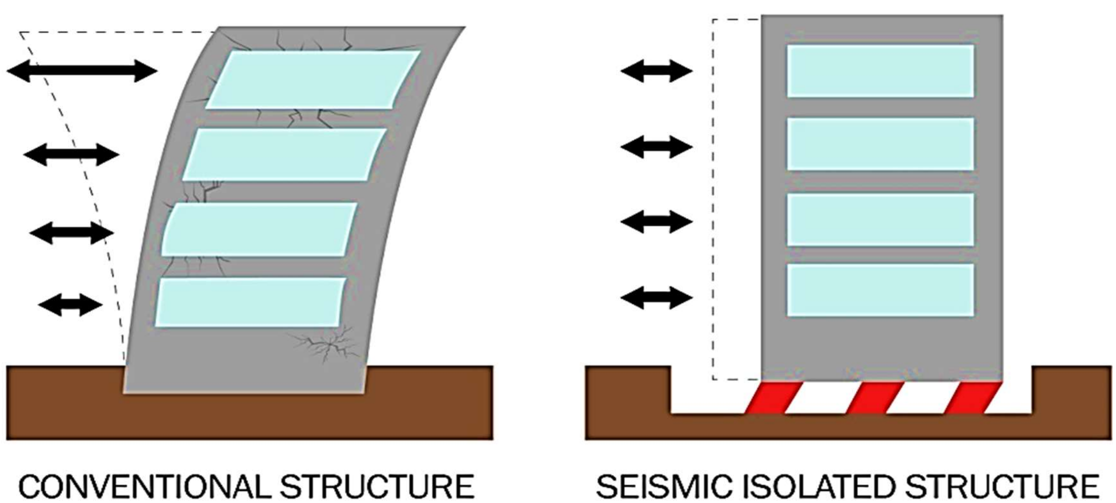


Figure 1.1. Fixed and Base-Isolated Structure during Earthquake

The types of base isolators are such as Laminated Rubber Bearing (LRB), Lead Rubber Bearing or New Zealand Bearing (N-Z Bearing), Pure Friction System, Friction Pendulum System (FPS), Resilient Friction Base Isolator and Electric de France System (EDF). The most common types of base isolators installed in multistory buildings for seismic isolation are, (A) Lead Rubber Bearing (N-Z Bearing) and (B) Friction Pendulum System (FPS). The brief introduction about these two bearing systems are given below:

(A) Lead Rubber Bearing (N-Z Bearing):

The basic component of Lead Rubber Bearings are steel and rubber plates placed in alternate layers and in the center a lead core is stabilized. It is characterized with high damping capacity, horizontal flexibility, high vertical stiffness and the lead core provides additional means of energy dissipation and initial rigidity against minor ground waves and wind. The energy absorbing potential with the aid of the lead center reduces the bearing displacement. These bearings are also called as New Zealand Bearings because they are developed and tested in New Zealand and are also referred as N-Z system [2]. Fig. 1.2 shows the typical lead rubber bearing [3].

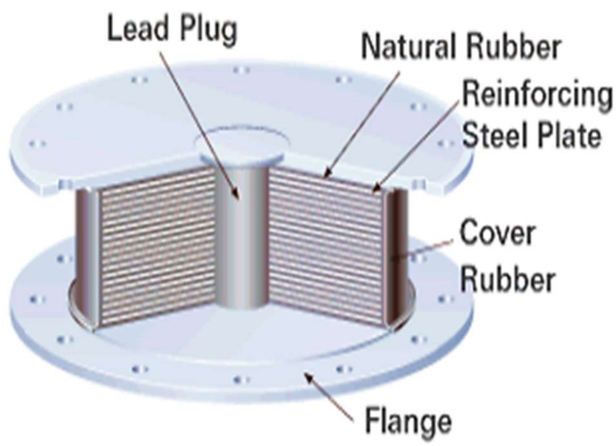


Figure 1.2. Lead Rubber Bearing

(B) Friction Pendulum System (FPS):

In Friction Pendulum System, the isolated building is placed on bearings and each bearing consist of an articulated slider (faced with bearing material) placed on a polished spherical concave chrome surface. The FPS is activated only when the earthquake forces overcome the static value of friction, so we can say that it acts like a fuse. Friction Pendulum System develops a lateral force identical to the aggregate of the mobilized frictional force and the restoring force that develops due to rising of the shape along the spherical surface, when the whole system is in motion [2]. Fig. 1.3 shows the typical friction pendulum system [4].

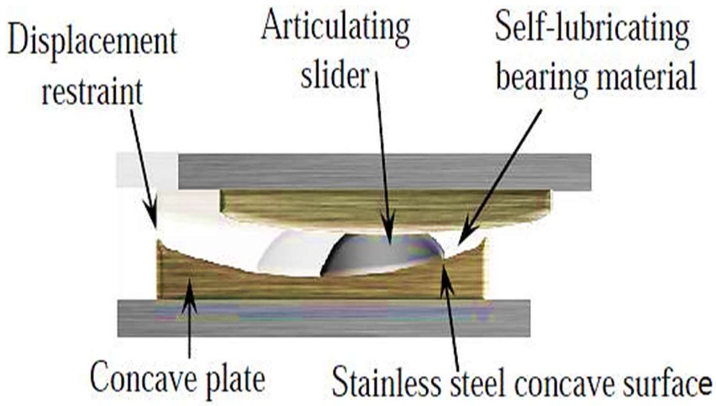


Figure 1.3. Friction Pendulum System

1.2. Regular and Irregular Configuration

In previous years, numerous earthquakes have exposed the imperfection in buildings, which result in damage or downfall of buildings. It has been observed that regular shaped structures have uniform load distribution so regular buildings perform better during earthquake. In irregular shaped structures the members have non-uniform load distribution so they slightly more affected due to ground motion. Buildings with simple regular shape and uniform load distribution and stiffness in plan and elevation, suffer much less damage, than structures with irregular configurations. According to IS 1893 (Part 1): 2016 Criteria for Earthquake Resistant Design of Structures code, there are several types of irregularity in the multistory buildings and mainly divided into two groups i.e. (i) Plan Irregularities and (ii) Vertical Irregularities [5].

(A) Plan Irregularity:

It contains types of irregularities such as Fig. 1.4 Torsional Irregularity, Fig. 1.5 Re-Entrant Corners, Floor Slabs having Excessive Cut-Outs or Openings, Out-of-Plane Offsets in Vertical Elements and Non-Parallel Lateral Force System [5].

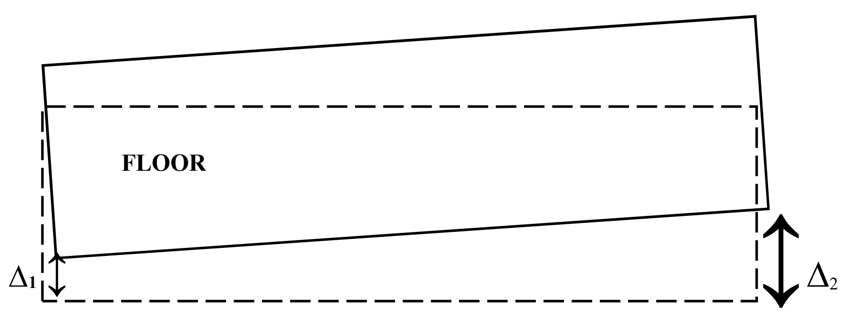


Figure 1.4. Torsional Irregularity (Plan)

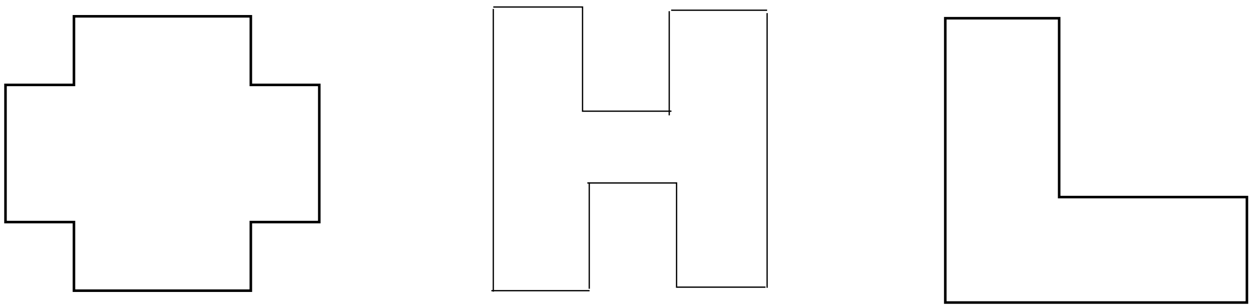


Figure 1.5. Re-Entrant Corners (Plan)

(B) Vertical Irregularity:

It contains types of irregularities such as Fig. 1.6 Stiffness Irregularity (Soft Storey), Fig. 1.7 Mass Irregularity, Fig. 1.8 Vertical Geometry Irregularity, In-Plane Discontinuity in Vertical Elements Resisting Lateral Force, Strength Irregularity (Weak Storey), Floating or Stub Columns and Irregular Modes of Oscillation in Two Principal Plan Directions [5].

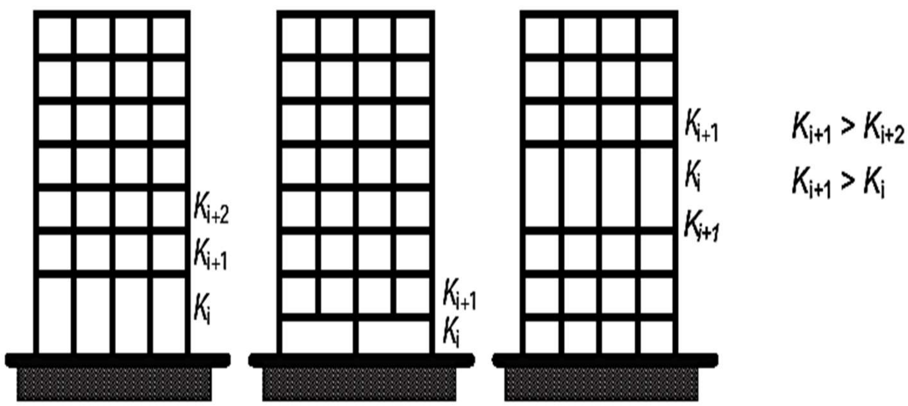


Figure 1.6. Stiffness Irregularity (Elevation)

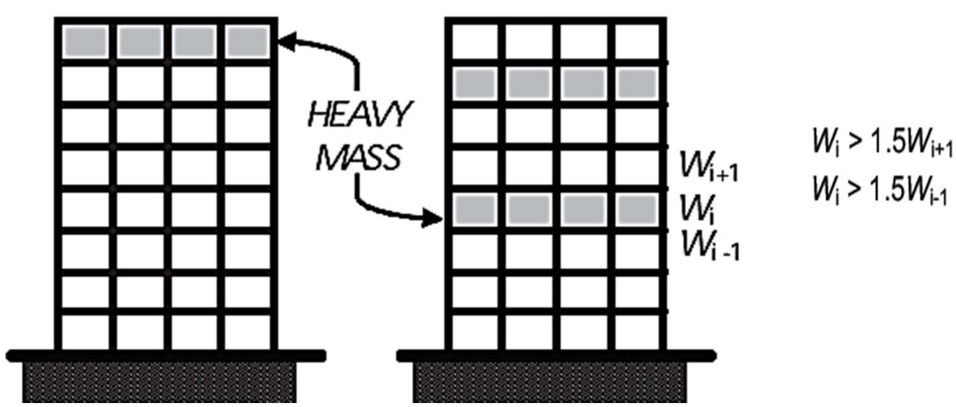


Figure 1.7. Mass Irregularity (Elevation)

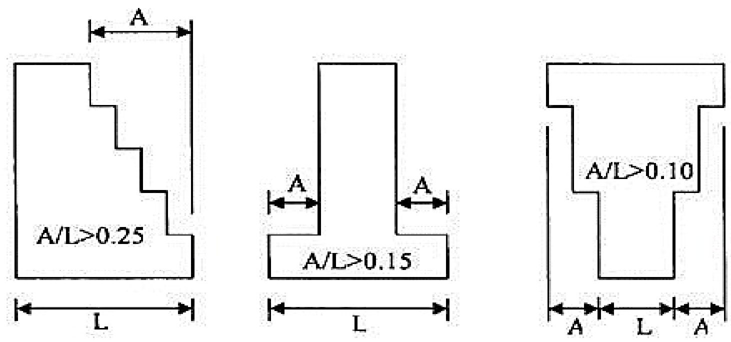


Figure 1.8. Vertical Geometry Irregularity (Elevation)

1.3. Seismic Analysis:

It is a part or subset of structural analysis and it is the evaluation of seismic responses of a building structure towards the earthquake. It is the part of the process of earthquake engineering, structural design and retrofitting in the areas where seismic ground motions are common [6].

1.4. Seismic Response:

The seismic responses are evaluated in following terms:

(A) Storey Displacement:

It can be defined as the displacement of a storey with respect to the base of the building structure.

(B) Storey Drift:

It is the relative displacement between the floors above and/or below the storey under consideration [5].

(C) Stiffness:

It is the ability to resist the displacement of a building under the action of seismic force. For example, there is two buildings X and Y and the building X requires more force to displace than building Y then we can say that building X is stiffer.

(D) Time Period:

It can be defined as the time taken by the building to complete one cycle of oscillation under the influence of seismic waves [7]. Time period (T) is a property of a building dependent on its mass (m) and stiffness (k). Its unit is second and is given by:

$$\mathbf{T = 2\pi \sqrt{(m/k)}}$$

(E) Base Shear:

It is an evaluation of maximum expected horizontal lateral force that will arise because of ground motion during the earthquake at the base of the structure.

(F) Acceleration:

The buildings resting on ground experience some vibration at its base during earthquake ground motion. Since the base is connected through the wall and column to the roof so they move along with each other due to ground motion. This movement will cause an acceleration in the building and is in opposite direction of ground acceleration.

1.5. Seismic Zone and Zone Factor (Z):

According to the behavior of a region towards the earthquake, the areas of a country are divided in four zones known as seismic zones. According to IS 1893 (Part 1): 2016, zone factor is the peak value of seismic ground acceleration in each seismic zone and is denoted by Z [5]. The different seismic zones and their zone factor are given in following table 1.1 [5]:

TABLE 1.1 SEISMIC ZONE & ZONE FACTOR

Sr. No.	Seismic Zone	Zone Factor (Z)
1	II	0.10
2	III	0.16
3	IV	0.24
4	V	0.36

1.6. Importance Factor (I):

It is a factor used to calculate design seismic force based on functional use of building structure, characterized by post-earthquake functional need, hazardous consequences of its failure, historical value or economic importance. It is denoted by 'I' [5].

1.7. Soil Classification:

The type of soil on which the building structure is placed shall be recognized by following classification [5]:

a) Soil Type I – Rock or Hard Soils;

b) Soil Type II – Medium or Stiff Soils; and

c) Soil Type III – Soft Soils.

1.8. Time History Analysis:

When the base of the structure is subjected to specific ground motion, the analysis of the dynamic response of the structure at every moment of time is known as time history analysis [5].

CHAPTER 2

(LITERATURE REVIEW)

2.1. Introduction

In this chapter of thesis, base-isolated regular and irregular RC multistory buildings are investigated from different research papers and discussed about their behavior considering fixed base, base-isolation, building configurations, analysis, results, advantages and disadvantages, applications.

2.2 Literature Review

M.Z. Habib et. al. (2016), has been studied the "Effect of Plan Irregularity on RC Buildings due to BNBC-2006 Earthquake Load". Bangladesh National Building Code (BNBC) 2006 necessitates that essentially all multi-storied structures be analysed as three-dimensional frameworks. In this study he has chosen six buildings of different shapes and analysed by applying earthquake loads using software ETABS (version 9.7.4). The considered shapes of buildings are square, rectangular, L-shaped, T-shaped, U-shaped and inverted L-shaped and also each has G+6 number of stories. All the considered buildings are located in seismic Zone-I of BNBC 2006. In this study the responses evaluated are such as: Lateral displacement, Storey Drift, Time period, Base Shear, Torsional Irregularity Ratio and Overturning Moment. The result revealed that the rectangular shaped building experience maximum drift as well as displacement in both directions. Base shear and overturning moment is analysed maximum for T-shaped building structures and also in Time period, no change is found because of change in building plan. It also concludes that the rectangular shaped buildings are torsionally irregular [8].

Shiva Naveen E et. al. (2019), has described the "Analysis of irregular structures under earthquake loads". This study addresses the seismic response of RC structures having different types of irregularities. A nine-storied regular frame is developed by introducing in different forms in both plan and vertical to produce 34 configurations with single irregularity and 20 forms with addition of irregularities. Hence, 54 irregular cases are analyzed and compared along with regular configuration. From the results, it is observed among various types of single irregularities analyzed, stiffness irregularity has shown maximum impact on seismic response. Out of different cases having combination of irregularities, the cases with stiffness, mass and vertical irregularities is found have maximum seismic response [9].

H. Gokdemir et. al. (2013), studied the "Effects of torsional irregularity to structures during earthquake". In this paper the author described that the torsion is caused due to the eccentricity between centre of mass and centre of stiffness. The result concluded that the intensity of moment due to torsion was found to be a function of eccentricity ratio. Torsional irregularity may cause pounding of adjacent buildings so the buildings are separated from each other properly [10].

A. Abrishambaf and G. Ozay (2010), analysed the "Effects of isolation damping and stiffness on the seismic behaviour of structures". In this research the author has studied the seismic performance and optimization of bearing. For his study, he considered 3, 6 and 9 storied base isolated buildings and the isolation used for this study are lead rubber bearing, high damping rubber bearing and friction pendulum system. The seismic responses such as maximum displacement, acceleration and earthquake coefficient were compared with seismic isolated and non-isolated building structures. This study concluded that lead rubber bearing has minimum earthquake coefficient, minimum acceleration and maximum displacement as compared to high damping rubber bearing and friction pendulum system [11].

Omkar Sonawane and Swapnil B. Walzade (2018), has analysed the "Effect of base isolation in multistoried RC regular and irregular building using time history analysis". In this analysis, 15 storied RC frame regular and irregular building has been taken and Time History Analysis has been done using software ETABS version 2013. The Lead Rubber Bearing has been used as base isolation for this study. The result of this analysis concluded that the base isolated structures have higher Time Period than that of non-isolated structures. The Story Acceleration and Base Shear in X and Y direction, are reduced exceptionally because of isolators in contrast of non-isolated buildings. In plan irregularity, re-entrant corner and in vertical irregularity, vertical geometric irregularity buildings having base isolation have given better performance relative to base isolated regular building structures [12].

Konuralp Girgin et. al. (2014), has determined the "Torsional irregularity in multi-story structures". In this study the author has done the investigation on six group of particular structures with changing story, axis number and shear wall position. The result concluded that the coefficient of torsional irregularity is indirectly proportional to number of stories. The author found the maximum value of placing shear walls as near as possible to centre of mass. A fresh transitional clarification for coefficient of irregularity based on rotation of floors is proposed [13].

Rachit Seth and Himanshu Pandey (2018), have been studied the "Seismic analysis of regular and irregular buildings having fixed base and base isolator using time history analysis". In this paper comparative study of fixed base and base isolated RC regular and irregular building structures has been done with the help of linear dynamic time history analysis. In this analysis G+9 RC multi-storied regular and irregular (L-shape and T-shape) buildings and the ground motion data of Kozani, 1995 and Jiashi, 1997 earthquakes have been considered. From the results it is concluded that the base isolated buildings have more story displacement, less axial force and less moment than the non-isolated buildings. T-shape base isolated building has shown similar story displacement along Y direction for all stories. L-shape base isolated building has less axial force as compared to L-shape fixed base building for both Kozani and Jiashi earthquakes [14].

Momen M.M. Ahmed et. al. (2016), studied the "Irregularity effects on the seismic performance of L-shaped multi-story buildings". The aim of this study was to catch the seismic performance of irregular L-shaped plan by the calculation of earthquake response due to presence of re-entrant corners. For the reference model nine storied three dimensional finite element moment resisting building frame is developed and analysed with the help of software ETABS version 2013 and the methods used are equivalent static load and response spectrum methods. The result of this study concluded that the buildings having irregularity are more exposed to possibility of being damaged or collapse as compared to regular buildings during earthquake because of torsional behaviour and shear force which is produced normally to the seismic insertion. For the calculation of fundamental vibration period the practical equation would not get remarkable higher modes of vibration [15].

Rincy M. A and Shwetha Saju (2016), described the "Comparative study of RC framed building with isolator and dampers". In this study relative analysis of isolated buildings with dampers and base isolators has been done with fixed base buildings. In this analysis the seismic responses analysed were story displacement, story drift, story acceleration and modal time period with the help of software. From the study it is concluded that the story displacement and story drift of base isolated structures has been reduced considerably. It is found that story displacement, story drift and story acceleration is reduced in the structures with viscous dampers. The study also shows that in the isolated structures the fundamental period is almost double as compared to non-isolated structures [16].

Julie S and Sajeeb R (2012), has been analysed the "Performance of base isolators and tuned mass dampers in vibration control of multistoried building". In this paper a ten storied RC building has been considered and lead rubber bearing and friction pendulum system type base isolators and tuned mass dampers (TMD) are designed for this. The numerical evaluation and comparison of execution of lead rubber bearing, friction pendulum and TMD has been done. The result concluded that the base isolated structures perform poorly in low frequency regions as compared to TMD. It is found that the base isolators and TMD were working effectively in reduction of displacement and acceleration when the frequency is close to fundamental frequency. It may clearly observe that application of base isolators and dampers reduced the possibility of collapse of structures by avoiding the resonance condition. Base isolators are better than TMD in reducing acceleration response [17].

Swathirani K. S. et. al. (2015), has been described the "Earthquake response reinforced concrete multi storey building with base isolation". In this paper isolators such as lead rubber bearing, friction pendulum system and high damper rubber bearing has been analysed and compared with fixed base building under the action of strong seismic force. In this study author considered eight storied C-shaped building and time history analysis and response spectrum analysis is carried out using software SAP 2000. The analysis concluded that high damping rubber isolators executes better than other isolators [18].

Anoop Mokha et. al. (1991), has been done a "Experimental study of friction-pendulum isolation system". In this study a six storied, quarter-scale, 52-kip model structure has been considered and friction pendulum isolation system's shake table study fixed in it. Two types of bearing materials have been considered and analysed one with peak coefficient of friction 0.075 and another with peak coefficient of friction 0.095 having rigid-body mode period of 1 sec for both. Base isolated structure withstand without any deformation and a peak ground surface acceleration in base isolated structure is six time greater than in non-isolated structure in experiment with ground motion data of El Centro city. It is concluded that the bearing displacements evaluated are small and the permanent bearing displacements are very small at the free vibration end, essentially not greater than 6% of bearing design displacement [19].

L. T. Guevara et. al. (1992), has been described about "Floor-plan shape influence on the response to earthquakes". In this paper H-shaped and L-shaped floor plan buildings have been considered and results of dynamic analysis applied to analyse the torsional effects in building. The software program that has been used for the study was Structural Engineering Tool (SET). The variations on dimensions of re-entrant corners has impact on building performance that is figure out by SET program. Both H-shaped and L-shaped building plan analysed independently by breaking each of them in rectangles (regular rectangular blocks) detached seismic joints. Finally, their modes of vibration correlated and the result of the analysis determines the movement of each of them when they are next to each other and influence of each of them on the adjacent one [20].

Thomas H. Heaton et. al. (1995), has been studied the "Response of high-rise and base-isolated buildings to a hypothetical M_w 7.0 blind thrust earthquake". This paper describes the execution of building structures when dangerous earthquake produced below an urban area. 20-story steel frame building structure and 3-story base-isolated structure model are shaped and earthquake ground motion thrust of M_w 7.0 imitated near the mathematical model. The incorporated earthquake ground motion were representing huge displacement vibration up to 2 meters and huge ground velocity. Hence huge deformation and collapse of building frames occurred due to these higher motions of ground [21].

Ashvin G. Soni et. al. (2015) [16], has been described the "Effect of irregularities in buildings and their consequences". In this paper the author has evaluated the execution of RC buildings with irregularities. Ten story RC irregular building assuming in seismic zone IV and having importance factor 1.5 has been considered for the study. The influencing responses and dynamic characteristic describes the effects of vertical irregularities on RC buildings in this paper. The analysis has been done with the help of CSI-ETABS program. This study concluded that the presence of irregularities in building is injurious to structures and it is important construct regular shapes of frame as well as uniform distribution of loads everywhere in the building [22].

Ravikumar C M et. al. (2012) [17], has been presented the "Effect of irregular configurations on seismic vulnerability of RC buildings". In this paper the plan irregularity, with geometric and diaphragm discontinuity and vertical irregularity, with setback and sloping ground have been discussed. The performance of various irregular buildings in pushover analysis also examined in this study. RC three storied moment resisting frame in seismic zone V of India has been considered with various irregularities. The analysis, modelling and design has been done with the help of ETABS version 6.0 software. The result concluded that the irregular effects in building are not considered by the equivalent static method and in comparison to response spectrum method the result found are unusual because it is dependent on fundamental formula. From the results it is also found that seismic demand of building changes with changing in building configuration [23].

T. Ariga et. al. (2005), has been analysed the "Resonant behaviour of base-isolated high-rise buildings under long-period ground motions". In this paper ten-storied base isolated shear building based original data used in japan, with isolations such as linear rubber bearing, friction type rubber bearings and additional viscous dampers has been considered for the study. The ground motion data of El Centro NS (Imperial Valley 1940), OSA NS (simulated Nankai earthquake), Tomakomai EW (Tokachi-Oki, 2003) and a simulated motion of damping ratio 0.05 compatible with response spectrum of level 2 has been taken. The new Japanese earthquake-resistant design code (2000) has been used for safety check. The objective of this study is to reveal that in Japan, the recorded ground motion components of long period have the intensity to make base isolated structure in resonance. From the results it is concluded that in general, the friction type rubber bearings are successful in keeping away the resonance having narrow range frequencies but are hazardous for ground motions having wider range of frequencies in the longer period range. It can also be observed that maximum drift under El Centro NS is nearly one-third as compared to that of under OSA NS, Tomakomai EW and simulated ground motion of Nankai earthquakes [24].

James M. Kelly (1986), has been reviewed the "Aseismic base isolation: review and bibliography". This review outline so many literature article on conceptual characteristic of seismic isolation, elaborates testing programmes and summarize those seismic isolations which have been implemented in under-construction or completed structures. It elaborates the range of relevant use and appraisal of development, of different used seismic isolation and their features. A bibliography of published papers on similar topic from 1900 to 1984 has been covered in this study. The result of review concluded that the researches on seismic isolation and construction of seismic base-isolated building structures give confidence to engineers that structures with seismic isolation will be economical and free from unexpected problems which is beneficial for contractors too. Also the inventions in seismic isolation gives a motivation for resuming the researches in this area [25].

Zeynep Yeşim ilerisoy (2019), has represented the "Discussion of the structural irregularities in the plan for architectural design within the scope of earthquake codes". In this paper earthquake codes of eight distinct countries which are on active fault line with discrete histories of earthquake has been studied and it has disclosed that criteria for irregularity explanation vary among them.

Irregularities in plan due to design judgement are considered and the result concluded that this analysis can be taken as a genesis for understanding the directive for earthquake design, disclosing details about architecture against the dynamic phenomenon of seismicity and control of the tool that architects can practice productively regarding this [26].

Md. Arman Chowdhury and Wahid Hassan (2013), has presented the "Comparative study of the dynamic analysis of multi-storey irregular building with or without base isolator". For this analysis 20-storied irregular multi-storied building structure with fixed base and with base isolator has been considered and analysed with the help of the software SAP 2000 version 15 for earthquake regions of Bangladesh. With the help of ground motion data of real earthquake, Chi-Chi, Taiwan 1999 and Northridge dynamic response of building has been examined. Using time history analysis and response spectrum analysis isolated and fixed base buildings have been compared. The result concluded that displacement of fixed base buildings was exceedingly higher than base isolated buildings. Non-linear behaviour of structure can be seen executing time history analysis for irregular structure and also the time history analysis is more accurate as compared to response spectrum analysis [27].

L. Di Sarno et. al. (2011), has analysed the "Seismic response analysis of an irregular base isolated building". In this paper linear and non-linear dynamic analysis for irregular building structure with base isolation system (BIS) has been described. A case study consists of a big RC multi-storied frame hospital which was then newly constructed in Naples (Sothern Italy) having 327 high damping rubber bearings considered for the analysis. The three-dimensional finite element modelled structure has been analysed by spectral and linear and non-linear time history analysis. Also the single degree of freedom (SDOF) system has been analysed by simplified analysis. The result of the analysis concluded that the base isolation system may give a number of superiority for non-structural and structural sections. Also for the structures with base isolations far away and high magnitude earthquakes are productive however such earthquakes are lacking in seismic database [28].

Vlad Lupășteanu et. al. (2019), has been briefly described the "Installation of a base isolation system made of friction pendulum sliding isolators in a historic masonry orthodox church". In this paper the discussion focuses on necessity of rehabilitating the heritage church buildings, techniques and processes of rehabilitation and on a case study of first historic heritage church that was seismically base isolated St. Nicolae Aroneanu Orthodox Church in Iasi County, Romania.

After so many evaluations and investigations the seismic isolation method is elected as the suitable rehabilitation solution. 48 friction pendulum sliding isolators were installed in the system in between two horizontal RC carrying members that has been moulded at the base level and disconnect the superstructure of the church from the actual base and transfers to the base isolators. The results concluded that by applying base isolations rehabilitation strategy, response of the structure enhanced remarkably to the high intensity earthquake actions that are specific in the north eastern region of Romania. Also notable reduction has been seen in drift displacement and in shear forces of structural masonry walls. Without harming the heritage architectures and aesthetic component of the church all compulsory rehabilitation works were executed at foundation level [29].

C. F. Ma et. al. (2014), has been reviewed the "Seismic response of base-isolated high-rise buildings under fully nonstationary excitation". In this paper twenty storied base isolated building has been considered by a finite element model and a shear type multi degree of freedom model, individually. The result of 3D framed building having height to width ratio of 4 concluded that the story drift and absolute acceleration of the high-rise building will be considerably underrated if the shear type multi degree of freedom model was used or the higher modes of the building structure were neglected; nevertheless, this has almost zero impact on the drift of the base slab [30].

F. Vilca-Cordova et. al. (2017), has studied the "Performance of lead rubber bearing system and triple friction pendulum system at Piura's hospital, in Peru". In this research Time history analysis were carried out with nonlinear analytical models taking into account the horizontal component of scaled seismic records obtained from overseas events. The study concluded in terms of average floor acceleration LRB provide better average floor acceleration than TFP system for undertaking lower bound analysis while TFP provide better floor acceleration than LRB for undertaking the upper bound analysis [31].

Radmila B. SALIC et. al. (2008), has analysed the "Response of Lead-Rubber Bearing Isolated Structure". The author studied the effect of lead rubber bearing in a GF+7 story building at different height levels as compared to fixed base buildings and concluded that increase of natural time period, reduction of base-shear, increase of displacement, reduction of inter-story drifts and reduction of story acceleration [32].

Amer Hassan and Shilpa Pal (2018), studied the "Effect of soil condition on seismic response of isolated base building". In this study author compared the base-isolated building with fixed base bulding in different soil condition such as hard, medium and soft soil. The study concluded that soft soil produces largest displacement and drifts in soft soil condition as compared to hard and medium soil [33].

M.K.Sharbatdar et. al. (2011), has performed the analysis on the "Seismic response of base-isolated structures with LRB and FPS under near fault ground motions." This study concluded that large displacement and velocity pulses of near fault ground motion can significantly change the results of seismic response of base-isolated structures. The responses with fps and lrb has been compared in tabulated form and describes that value of maximum base displacement can be different up to 66% for 4 records of imperial valley earthquake in zone restricted within a distance of 4kms from the ruptured fault. Also in this zone maximum top floor acceleration can be differed up to 35% for the records of imperial valley [34].

CHAPTER 3

(MODELLING APPROACH)

3.1 Introduction

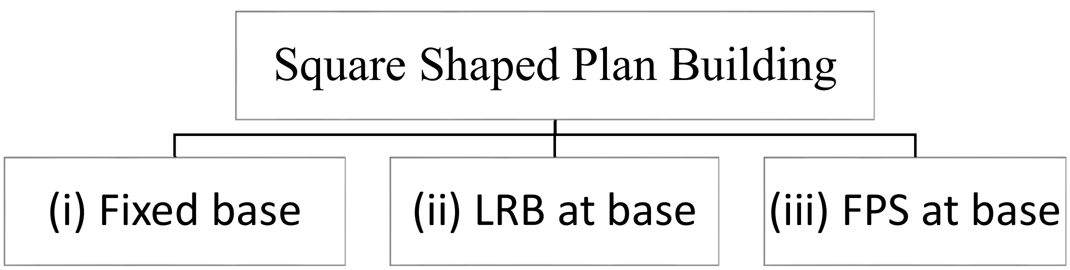
In this chapter of thesis, we discussed about the software used for modelling, design data considered such as building element size, grade of steel and concrete used, different IS codes used, amount of different loads acting etc.

3.2 Modelling Approach

Modelling work has been done with the help of the software named ETABS version 17.0.1. In following models three different type of building plans with fixed base and two different types of base isolations i.e. lead rubber bearing (LRB) and friction pendulum system (FPS) have been used. Modelling of following building has been done

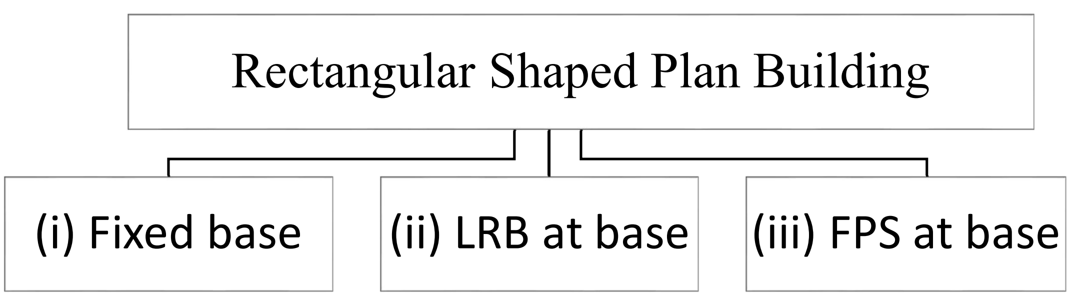
3.2.1 Square Shaped Floor Plan Buildings:

Square shaped plan buildings have been considered with different base configuration as shown below and their responses will be recorded.



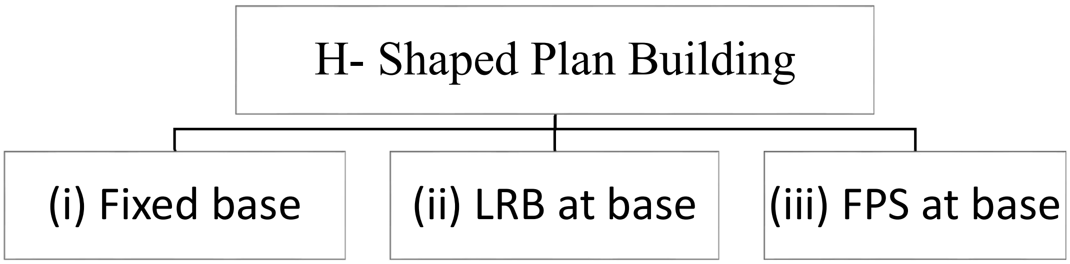
3.2.2 Rectangular Shaped Floor Plan Buildings:

Rectangular shaped plan buildings have been considered with different base configuration as shown below and their responses will be recorded.



3.2.3 H- Shaped Floor Plan Buildings:

Square shaped plan buildings have been considered with different base configuration as shown below and their responses will be recorded.



Note:

- Assuming that the seismic wave strikes the building normally, i.e. either in X-direction or in Y-direction at a time.
- Area of plan considered for all buildings are almost same.
- Size and configurations of all materials and element are same for all the buildings.
- The properties of LRB and FPS used is same for all types of buildings.

So, total 9 models have been prepared and description about their building elements, loadings and different parameters is given in following table 3.1:

TABLE 3.1 DESCRIPTION ABOUT BUILDING ELEMENTS, LOADINGS AND DIFFERENT PARAMETERS

Sr. No.	Parameters	Description
1	Modelling Software	ETABS version 17.0.1
2	Display Units	Metric SI
3	Steel Section Database	Indian
4	Steel Design Code	IS 800:2007
5	Concrete Design Code	IS 456:2000
6	Number of Stories	15
7	Typical & Bottom Story Height	3m
8	Importance Factor	1.2

9	Height of Building	45m
10	Beam Size	450mmX600mm
11	Column Size	450mmX450mm
12	Slab Thickness	125mm
13	Live Load on Floors	2.5 kN/m^2
14	Dead Loads on Floors and Roof	1 kN/m^2
15	Dead Load of Outer Walls	0.23x20x3= 13.8 kN/m
16	Dead Load of Inner Walls	0.115x20x3= 6.9 kN/m
17	Dead Load of Parapet Walls on Roof	0.115x20x1= 2.3 kN/m
18	Location for Seismic Wave Data	El Centro City
19	Seismic Zone for Analysis	Seismic Zone V (Z= 0.36)
20	Soil Type Considered	Soil Type III (Soft Soil)
21	Earthquake Design Code	IS 1893:2016
22	Concrete Mix Grade for Column/Beam	M25
23	Concrete Mix Grade for Slab	M20
24	Steel Rebar Grade	HYSD 415

3.3 Properties of Base Isolations:

The properties of base isolations used here have been taken from a reference research paper "Performance assessment of lead rubber bearing system and friction pendulum system" in which author estimated the linear and non-linear properties of LRB and FPS [31], which are given below.

3.3.1 Lead Rubber Bearing (LRB) System:

"Rubber Isolator" has been used for LRB system in the ETABS. The effective stiffness in axial direction U1 was considered $1.3x10^6$ kN-m while effective damping is considered 0 kN-s/m. The U2 and U3 directional properties of LRB are shown below in table 3.2:

TABLE 3.2 THE PROPERTIES OF LRB IN THE DIRECTION U2 AND U3

U2 and U3 Properties				
Type of LRB	Linear Properties	Non-Linear Properties		
	Effective Stiffness (kN/m)	Stiffness (kN/m)	Yield Strength (kN)	Post Yield Stiffness Ratio
LRB	180	8000	120	0.1

3.3.2 Friction Pendulum System (FPS):

"Friction Isolator" has been used for FPS system in ETABS. The effective damping is considered 0 kN-s/m and the effective stiffness and the non-linear stiffness in the axial direction U1 is 215×10^4 kN/m. The properties of FPS in the direction U2 and U3 are shown in table 3.3 below:

TABLE 3.3 THE PROPERTIES OF FPS IN THE DIRECTION U2 AND U3

U2 and U3 Properties						
Type of FPS	Linear Properties	Non-Linear Properties				
	Effective Stiffness (kN/m)	Initial Stiffness (kN/m)	Friction (Slow)	Friction (Fast)	Rate Parameter (sec/mm)	Radius of Sliding Surface (m)
FPS	180	7800	0.060	0.120	0.050	4.25

CHAPTER 4

(METHODOLOGY)

4.1 Methodology:

In this section the analysis, ground motion data and some common steps which are adopted in the modelling with the help of ETABS version 17.0.1 software are briefly explained.

4.1.1 Ground Motion Data:

The El-Centro ground motion data has been considered in the ETABS which has already given in the program file of the software. This ground motion data has been considered because it is recorded very close to fault rupture in a major earthquake and it is the most dangerous earthquake till now hence it is topic of interest for the earthquake researchers.

4.1.2 Time History Analysis:

In this study, the dynamic time history analysis has been carried out in which linear modal analysis has been selected for all the models in the ETABS. We have assumed that the waves are striking normally, i.e. either in X-direction for which load case TH-X has been defined or in Y-direction for which load case TH-Y has been defined. The ground motion data record has been given up to 12 seconds so for 0.1 sec time steps 120 steps will be defined. The analysis has been done as per IS 1893: 2016.

4.1.3 General Steps (All Models):

- Open ETABS version 17 and select new model.
- Model initialization window will open in which select “Use Built-in Settings With:” and define as follow:
    - Display Units: Metric SI
    - Steel Section Database: Indian
    - Steel Design Code: IS 800:2007
    - Concrete Design Code: IS 456:2000

- In square plan building 7x7 grid lines spaced at 4m are defined in X and Y-direction respectively. The area of square plan building is 24m x 24m i.e. 576 m^2. In rectangular plan building 8 grid lines in X and 6 grid lines in Y-direction spaced at 4m are defined. The area of rectangular plan building is 28m x 20m i.e. 560 m^2. In H- shaped plan building 9 grid lines in X and 7 grid lines in Y-direction spaced at 4m has been defined. The area of H-shaped plan building is 12m x 24m x 2 + 8m x 8m i.e. 640 m^2. So, we can say that area of all the buildings are almost same.

- In case of all models under the define menu, material properties are defined as per Indian region are such as M20 & M25 concrete design mix and HYSD 415 rebar.
- Further, in section properties under frame section two rectangular section are defined such as Beam450x600 and Column450x450 for all the models. In Beam450x600, the width of the beam is 450 mm and depth of the beam is 600 mm has been defined. For the beam, M3 design only (Beam) selected and HYSD 415 rebar material has been selected under reinforcement. In Column450x450, the width and thickness is defined as 450 mm. For the column, P-M2-M3 design (column) design type selected and rebar material defined as HYSD 415 in which 12 longitudinal bars of dia. 16mm and confinement bar dia. 8mm has been defined under reinforcement. The material defined for both beam and column is M25 design concrete mix. In property modifier, the moment of inertia about 2-axis and 3-axis is taken 0.35 for beams and 0.70 for columns as per the IS 1893:2016.
- Again in section properties, slab section is defined as Slab125 in which M20 design mix selected and the thickness of the slab is defined as 125 mm for all the models.
- Diaphragms is defined as rigid and named as D for all the models.
- Now, with the draw tools the building elements has drawn up to 15 story and dead loads and live loads is assigned as described in modelling approach. The wall loads are also assigned in form of dead load as described in modelling approach.
- If the building is not fixed at the base, then we have to define link/support property in which LRB is defined with rubber isolator and FPS is defined with friction isolators and their linear and non-linear properties in U1, U2 and U3 direction are defined as described in modelling approach. Then again go to define, select the spring properties, define point spring as LRB or FPS.
- When the building elements are drawn up to top story and loading has assigned the go to the base of building, if it is fixed base, select the base and assign the joint restraint as fixed. If it is base isolated then, select the base, assign the joint as point spring in which select either LRB or FPS and assign as per requirement.

- Now define the load patterns as follows:

Load	Type	Self-Weight Multiplier	Auto Lateral Load
✓ Dead	Dead	1	-
✓ Live	Live	0	-
✓ EqX	Seismic	0	IS 1893:2016
✓ EqY	Seismic	0	IS 1893:2016

EqX is earthquake load in X-direction and EqY is earthquake load in Y-derection, under which importance factor 1.2 and soil type III is defined for all the models.

- Now under define tool time history function is defined as ELCENTRO selected from software program file and again for which time history load case are defined as TH-X in X-direction and TH-Y in Y-direction for which linear modal time-history is defined.
- After, defining the load cases, load combination has been generated for concrete frame design as follows:

Load Combination	Combination with Scale Factor
✓ UDCon1	1.5DL
✓ UDCon2	1.5DL+1.5LL
✓ UDCon3	1.2DL+1.2LL+1.2EqX
✓ UDCon4	1.2DL+1.2LL-1.2EqX
✓ UDCon5	1.2DL+1.2LL+1.2EqY
✓ UDCon6	1.2DL+1.2LL-1.2EqY
✓ UDCon7	1.5DL+1.5EqX
✓ UDCon8	1.5DL-1.5EqX
✓ UDCon9	1.5DL+1.5EqY
✓ UDCon10	1.5DL-1.5EqY
✓ UDCon11	0.9DL+1.5EqX
✓ UDCon12	0.9DL-1.5EqX
✓ UDCon13	0.9DL+1.5EqY
✓ UDCon14	0.9DL-1.5EqY

- Now, finally in the plan view select the top story as similar story and assign the rigid diaphragms as D.
- Go to analyse section and check the model first then if you have got no warning message generated then finally go for run analysis.
- Hence in the display menu we can find the required results.

CHAPTER 5

(MODELS)

5.1 Introduction

In this chapter of thesis, snap-shots of all the models which is created by the author with the help of software ETABS version 17.0.1 have been shown which are discussed in the previous chapter.

5.2 Modelling Work

There are total nine models have been prepared such as three of square plan shaped, three of rectangular plan shaped and three of H-shaped plan building.

5.2.1 Square Plan Shaped Building

In square shaped plan building there are total three models will be prepared such as fixed base, LRB base and FPS base.

5.2.1.1 Model of fixed base square plan building

In this model plan, 3-dimensional and elevation view of fixed base square plan building has been shown in fig. 5.1 having plan area 576 m^2.

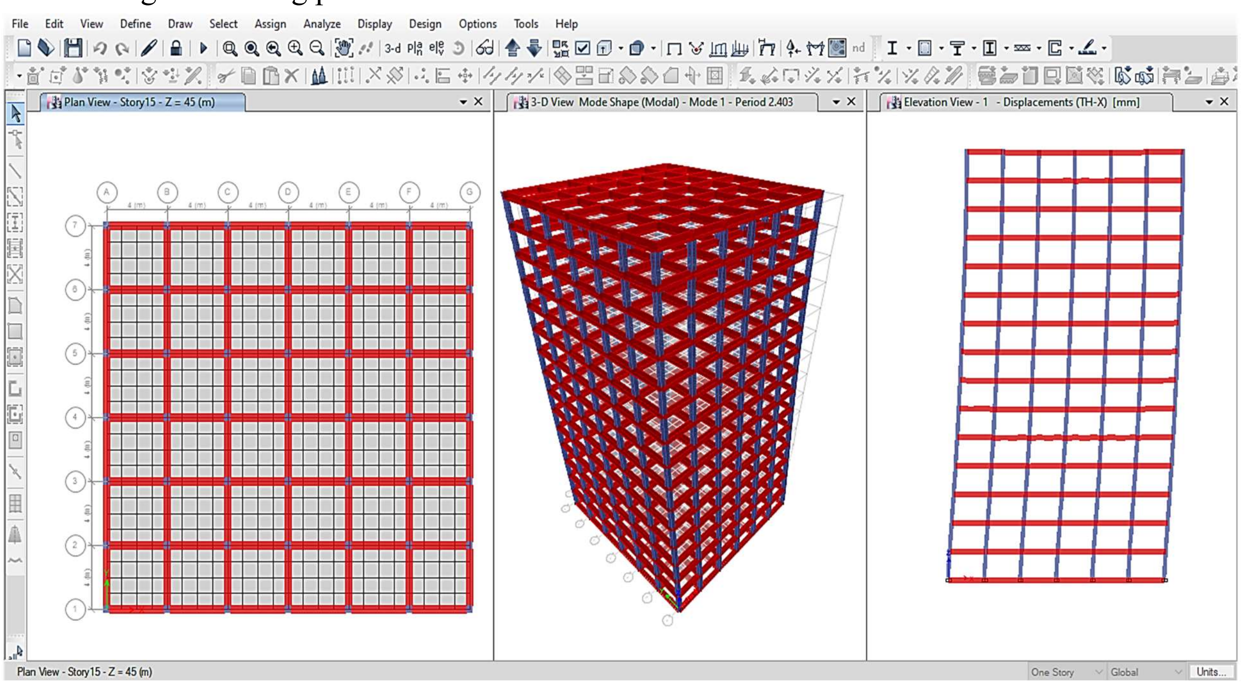


Figure 5.1. Plan, 3D & Elevation view of fixed base square plan building

5.2.1.2 Model of LRB base square plan building

In this model plan, 3-dimensional and elevation view of LRB base square plan building has been shown in fig. 5.2 having plan area 576 m^2.

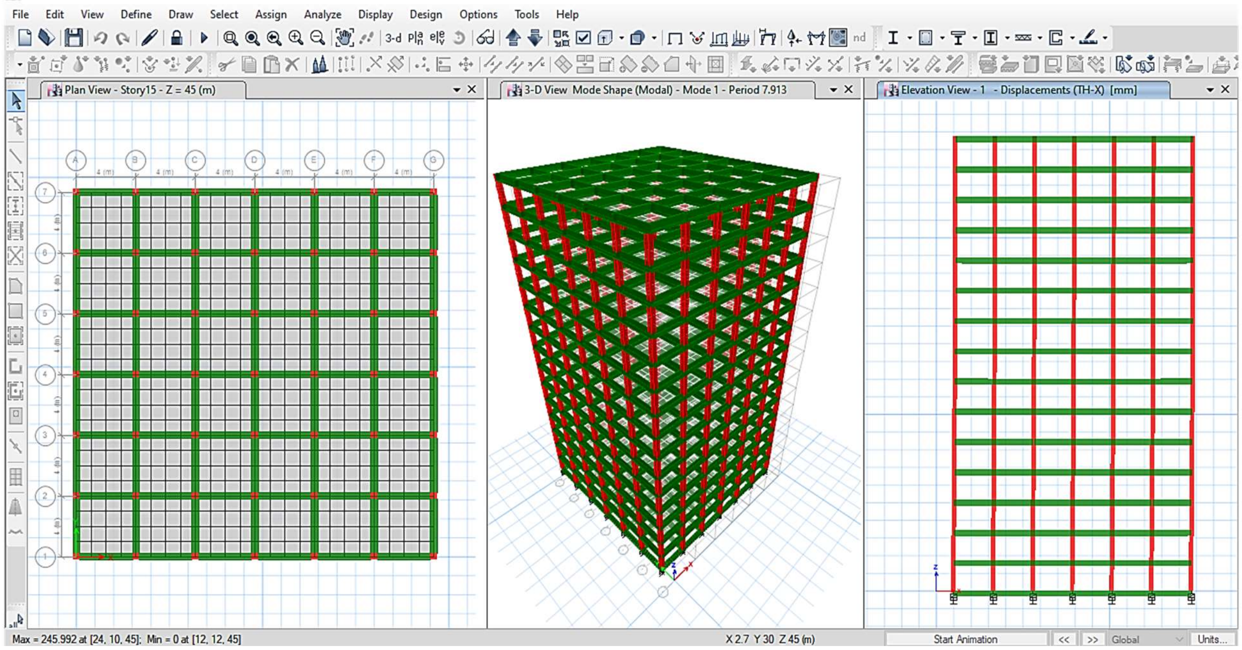


Figure 5.2. Plan, 3D & Elevation view of LRB base square plan building

5.2.1.3 Model of FPS base square plan building

In this model plan, 3-dimensional and elevation view of FPS base square plan building has been shown in fig. 5.3 having plan area 576 m^2.

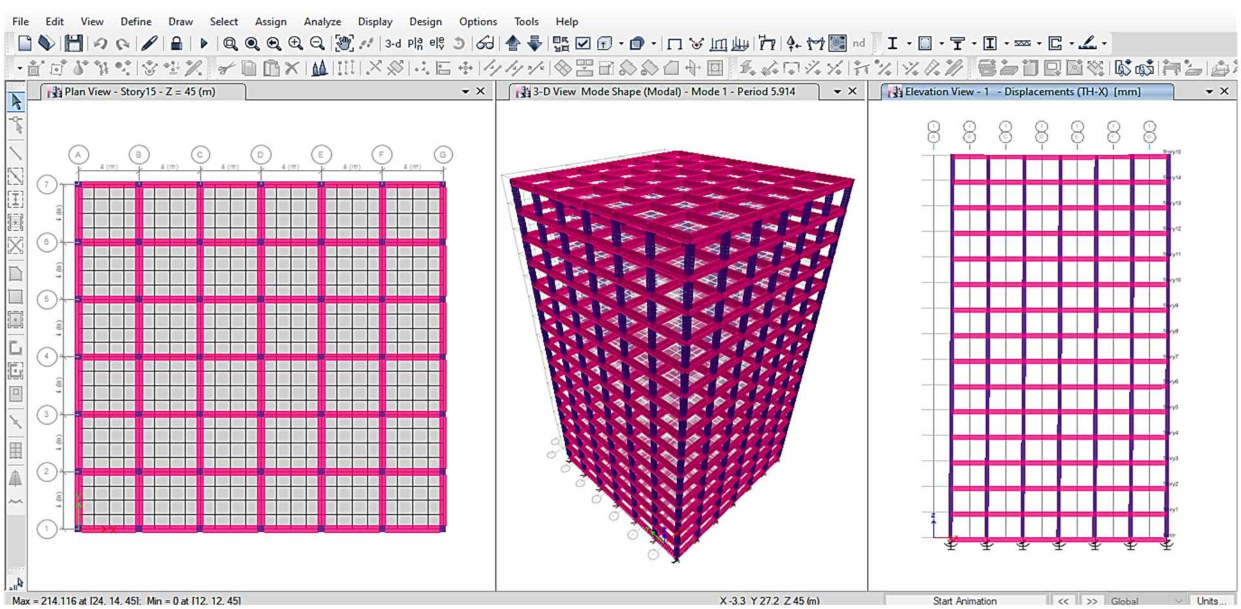


Figure 5.3. Plan, 3D & Elevation view of FPS base square plan building

5.2.2 Rectangular Plan Shaped Building

In rectangular shaped plan building there are total three models will be prepared such as fixed base, LRB base and FPS base.

5.2.2.1 Model of fixed base rectangular plan building

In this model plan, 3-dimensional and elevation view of fixed base rectangular plan building has been shown in fig. 5.4 having plan area 560 m^2.

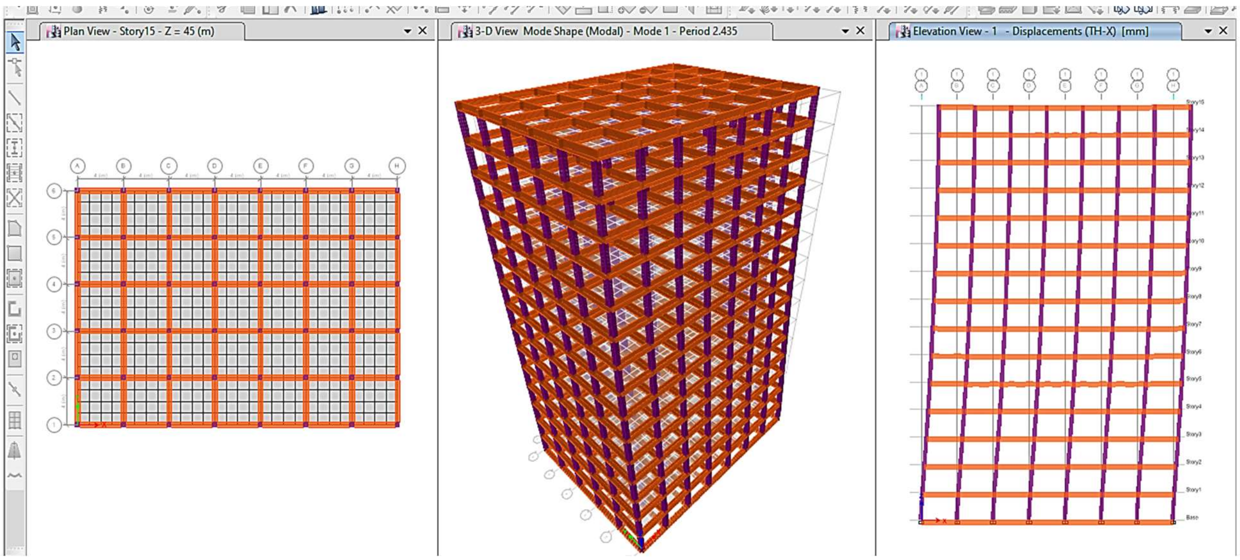


Figure 5.4. Plan, 3D & Elevation view of fixed base rectangular plan building

5.2.2.2 Model of LRB base rectangular plan building

In this model plan, 3-dimensional and elevation view of LRB base rectangular plan building has been shown in fig. 13 having plan area 560 m^2.

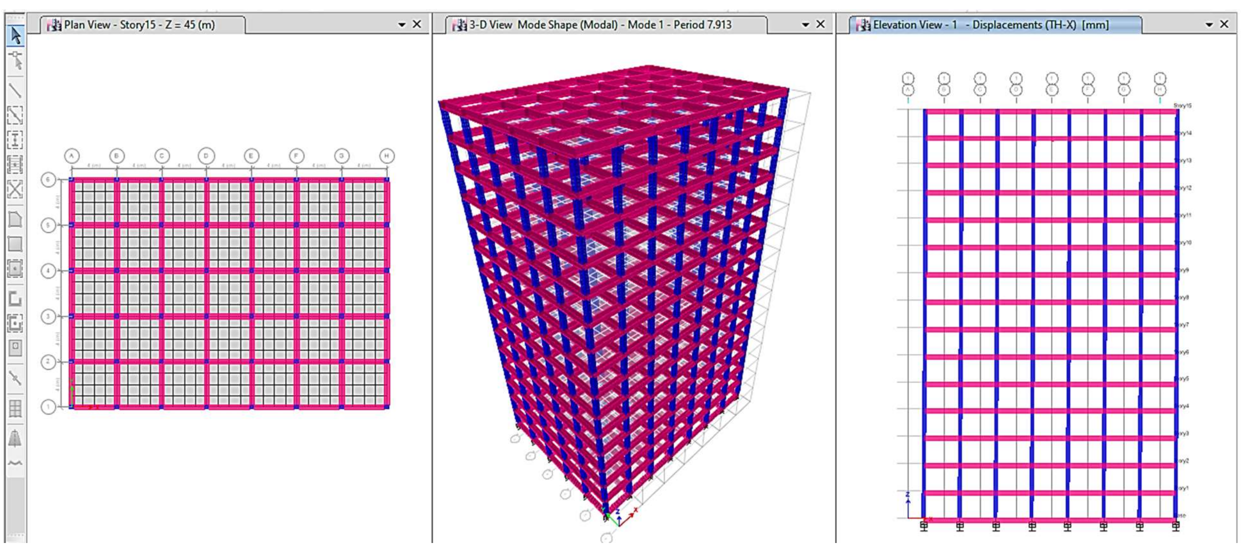


Figure 5.5. Plan, 3D & Elevation view of LRB base rectangular plan building

5.2.2.3 Model of FPS base rectangular plan building

In this model plan, 3-dimensional and elevation view of FPS base rectangular plan building has been shown in fig. 5.6 having plan area 560 m^2.

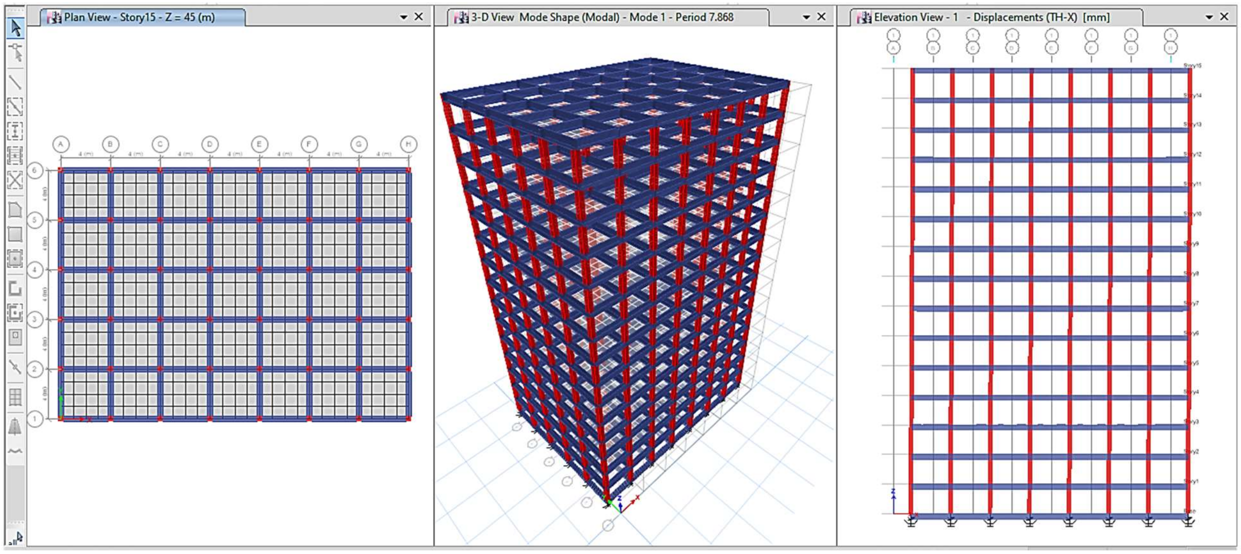


Figure 5.6. Plan, 3D & Elevation view of FPS base rectangular plan building

5.2.3 H-Shaped Plan Building

In H-shaped plan building there are total three models will be prepared such as fixed base, LRB base and FPS base.

5.2.3.1 Model of fixed base H-shaped plan building

In this model plan, 3-dimensional and elevation view of fixed base H-shaped plan building has been shown in fig. 5.7 having plan area 640 m^2.

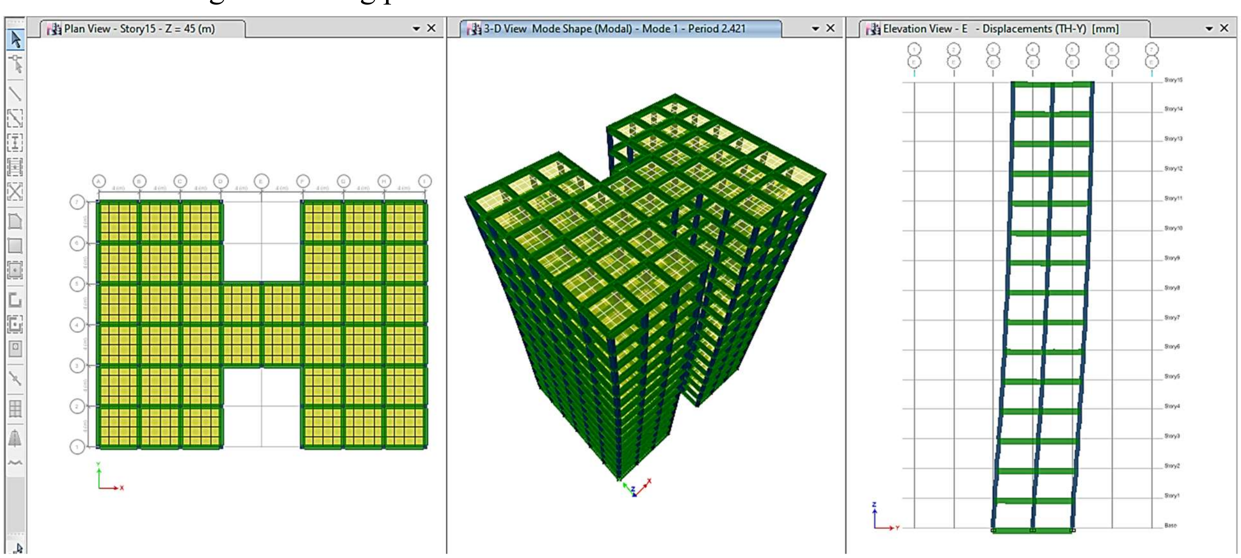


Figure 5.7. Plan, 3D & Elevation view of fixed base H-shaped plan building

5.2.3.2 Model of LRB base H-shaped plan building

In this model plan, 3-dimensional and elevation view of LRB base H-shaped plan building has been shown in fig. 5.8 having plan area 640 m^2.

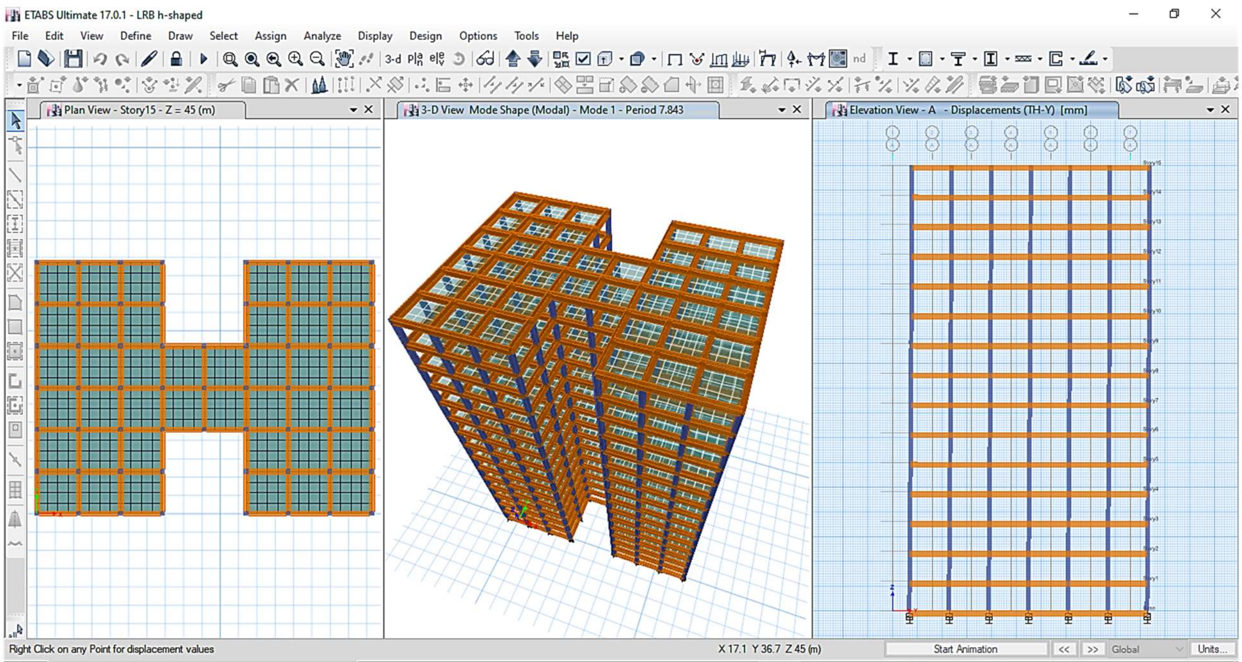


Figure 5.8. Plan, 3D & Elevation view of LRB base H-shaped plan building

5.2.3.3 Model of FPS base H-shaped plan building

In this model plan, 3-dimensional and elevation view of FPS base H-shaped plan building has been shown in fig. 5.9 having plan area 640 m^2.

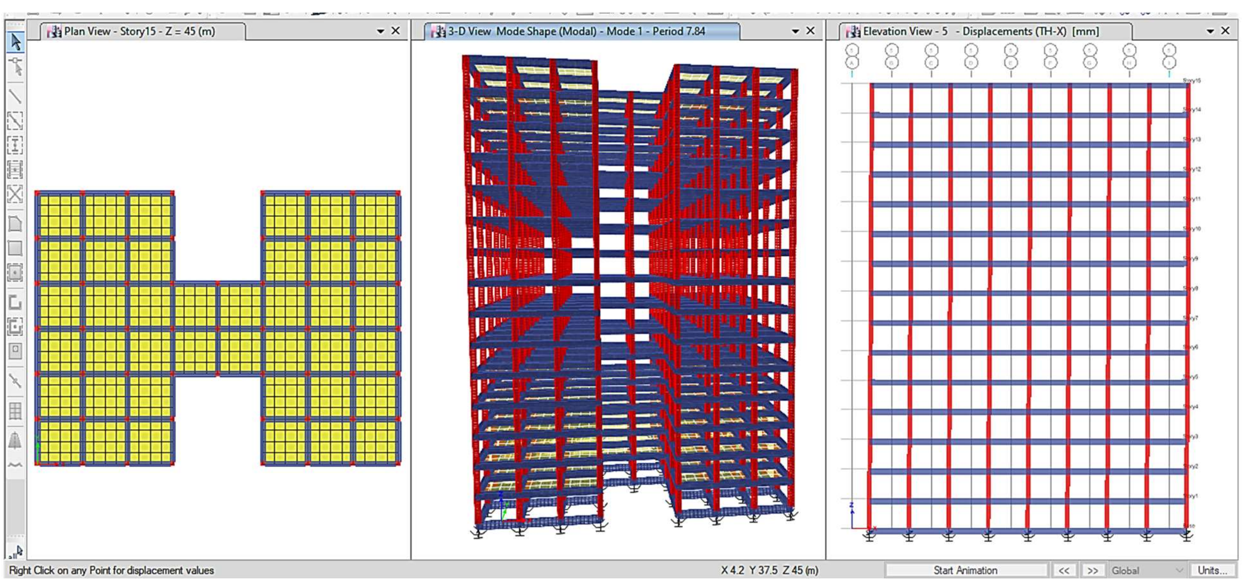


Figure 5.9. Plan, 3D & Elevation view of FPS base H-shaped plan building

CHAPTER 6

(ANALYSIS & COMPARISON)

6.1 Introduction

In this chapter of thesis, the linear modal time history analysis with the El Centro ground motion has been applied on every model to get the required results such as maximum story displacement, maximum story drift, maximum story acceleration, base shear, absolute joint acceleration and modal time period. After getting the required results they compared individually with the same plan buildings with base isolated buildings.

6.2 Time History Analysis & Seismic Responses of Square Plan Building

In this section linear modal time history analysis with El Centro ground motion data provided in program file of the ETABS software has been done on three different type of base such as fixed, LRB base and FPS base of square plan building respectively. The responses recorded are such as maximum story displacement, maximum story drift, maximum story acceleration, maximum base shear, maximum absolute joint acceleration and modal time period which are shown below:

(i) Maximum Story Displacement

When earthquake ground motion strikes the building either in X or in Y-direction the building experience some deviation in that direction and the top story of the buildings experience maximum displacement as compared to other stories. So we will compare only the top story displacement in similar plan buildings due to time history load cases. The maximum story displacements are same due to uniformity in case of square plan model, in X & Y-direction due to load case TH-X & TH-Y respectively and shown below:

- **Table 6.1 shows Maximum Story displacement of square plan building due to load case TH-X & TH-Y in X & Y-direction respectively (mm) are shown below and compared in fig. 6.1:**

TABLE 6.1 MAXIMUM STORY DISPLACEMENT OF SQUARE PLAN BUILDING IN X & Y

Story No.	Fixed Base	LRB Base	Diff % (Fixed & LRB)	FPS Base	Diff % (Fixed & FPS)
Story15	413.797	245.992	40.55	214.115	48.26
Story14	407.553	245.535	39.75	213.648	47.58
Story13	397.115	244.815	38.35	212.931	46.38

Story12	382.431	243.814	36.25	212.415	44.46
Story11	363.934	243.146	33.19	211.791	41.81
Story10	342.068	242.375	29.14	210.981	38.32
Story9	317.188	241.288	23.93	209.965	33.80
Story8	289.978	239.853	17.29	208.735	28.02
Story7	263.962	238.071	9.81	207.29	21.47
Story6	234.302	235.961	0.70	205.633	12.24
Story5	200.682	233.56	14.08	203.769	1.51
Story4	163.049	230.903	29.39	201.7	19.16
Story3	121.737	228.02	46.61	199.424	38.96
Story2	77.578	224.932	65.51	196.934	60.61
Story1	32.665	221.684	85.27	194.254	83.18
Base	0	218.678	-	191.728	-

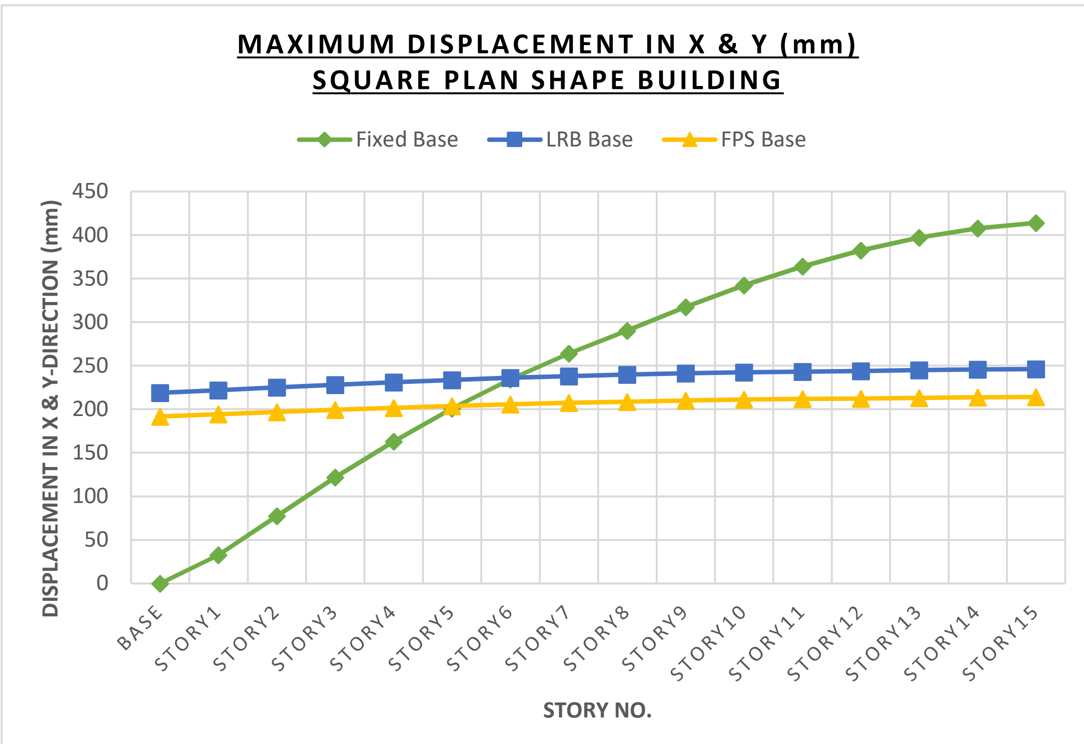


Figure 6.1. Story displacement graph between Fixed, LRB & FPS base of Square Plan Building

(ii) Maximum Story Drift

The story drift is a unit less quantity. The maximum story drifts are same due to uniformity in case of square plan model, in X & Y-direction due to load case TH-X & TH-Y respectively and shown below:

- **Table 6.2 shows Maximum Story drifts of square plan building due to load case TH-X & TH-Y in X & Y-direction respectively are shown below and compared in fig. 6.2:**

Table 6.2 Maximum Story drifts of Square plan building in X & Y

Story No.	Fixed Base	LRB Base	Reduction% (Fixed & LRB)	FPS Base	Reduction% (Fixed & FPS)
Story15	0.002152	0.000168	92.19	0.000168	92.19
Story14	0.003752	0.000281	92.51	0.000257	93.15
Story13	0.005307	0.000389	92.67	0.000344	93.52
Story12	0.006575	0.00049	92.55	0.000422	93.58
Story11	0.008062	0.000574	92.88	0.000491	93.91
Story10	0.009408	0.000664	92.94	0.000554	94.11
Story9	0.010532	0.000755	92.83	0.00064	93.92
Story8	0.011373	0.000834	92.67	0.000717	93.70
Story7	0.011906	0.000901	92.43	0.000779	93.46
Story6	0.012146	0.000965	92.05	0.000824	93.22
Story5	0.01267	0.001024	91.92	0.00085	93.29
Story4	0.013771	0.00107	92.23	0.000857	93.78
Story3	0.01472	0.001102	92.51	0.000868	94.10
Story2	0.014971	0.001112	92.57	0.000919	93.86
Story1	0.010888	0.001016	90.67	0.000862	92.08
Base	0	0	-	0	-

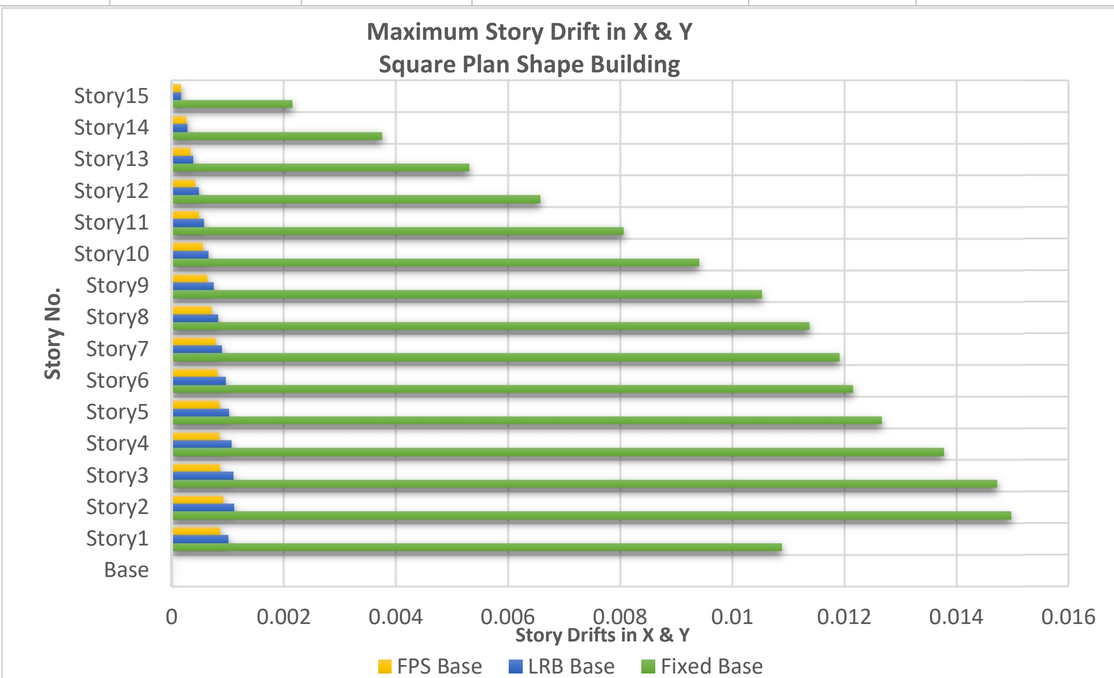


Figure 6.2. Story drift plot in X & Y for Fixed, LRB & FPS base of Square Plan Building

(iii) Maximum Story Acceleration

The maximum story acceleration is the study of behaviour of maximum acceleration at particular story of square plan building and will be compared with different type of base such as fixed, LRB and FPS at each story due to considered ground motion data. The story acceleration is same due to uniformity in square plan building in X & Y direction due to load case TH-X & TH-Y respectively and are shown below in table 6.3 and compared in fig. 6.3:

TABLE 6.3 MAXIMUM STORY ACCELERATION IN SQUARE PLAN BUILDING IN X & Y

Story No.	Fixed Base Story Acceleration in X & Y (mm/s^2)	LRB Base Story Acceleration in X & Y (mm/s^2)	Reduction% (Fixed & LRB)	FPS Base Story Acceleration in X & Y (mm/s^2)	Reduction% (Fixed & FPS)
Story15	4681.36	268.3	94.27	578.14	87.65
Story14	4235.01	253.15	94.02	560.35	86.77
Story13	3583.2	233.84	93.47	531.19	85.18
Story12	3549.26	206.22	94.19	496.63	86.01
Story11	3667.78	180.84	95.07	462.99	87.38
Story10	3454.55	173.22	94.99	423.18	87.75
Story9	3404.93	178.6	94.75	378.69	88.88
Story8	3286.74	187.15	94.31	373.12	88.65
Story7	3032.62	185.83	93.87	404.66	86.66
Story6	3231.22	198.37	93.86	426.98	86.79
Story5	3538.88	198.05	94.40	437.31	87.64
Story4	3336.56	185.69	94.43	437.19	86.90
Story3	2823.01	192.77	93.17	449.39	84.08
Story2	2401.51	216.73	90.98	475.14	80.21
Story1	2206.8	242.76	89.00	489.22	77.83
Base	2461.11	261.99	89.35	491.77	80.02

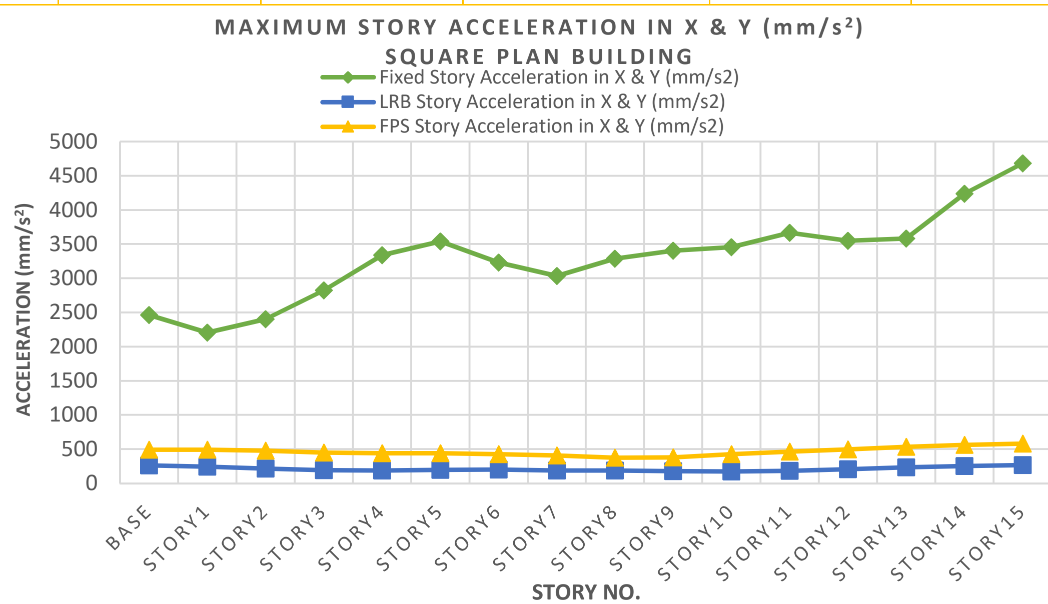


Figure 6.3. Story Acceleration in X & Y of Square Plan Building with Fixed, LRB & FPS Base

(iv) Maximum Base Shear

The maximum horizontal lateral force arises at the base of the building due to the considered ground motion data of El Centro at a particular time interval for all type of base such as fixed, LRB and FPS of square plan building is shown below in fig. 6.4, fig. 6.5 and fig. 6.6 respectively, through the seismograph of base shear and the crest of the graph define the maximum base shear of the building at particular time interval which is shown in table 6.4 for all type of base:

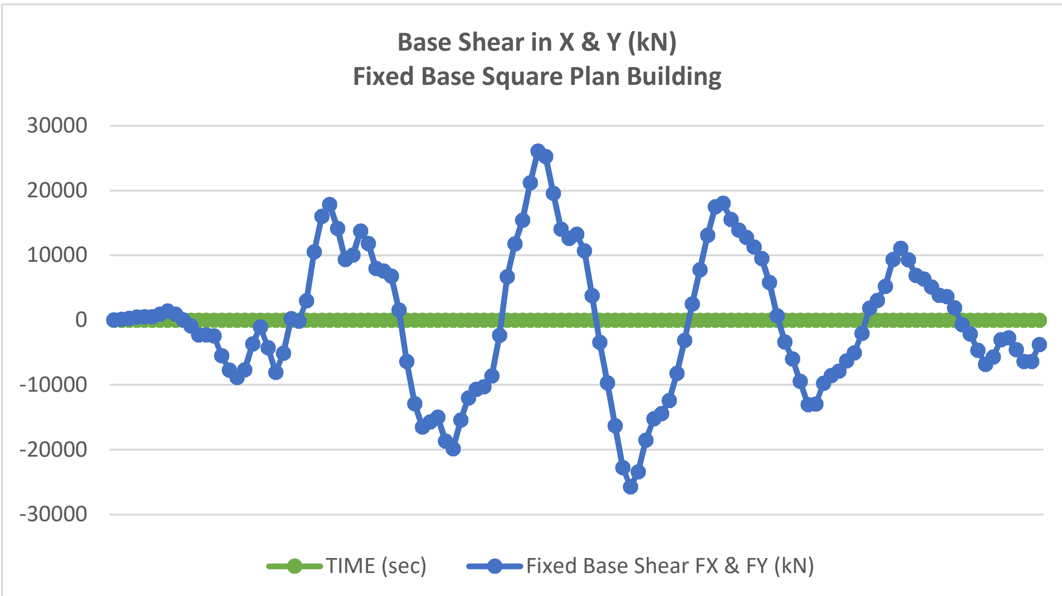


Figure 6.4. Base Shear of fixed base square plan building

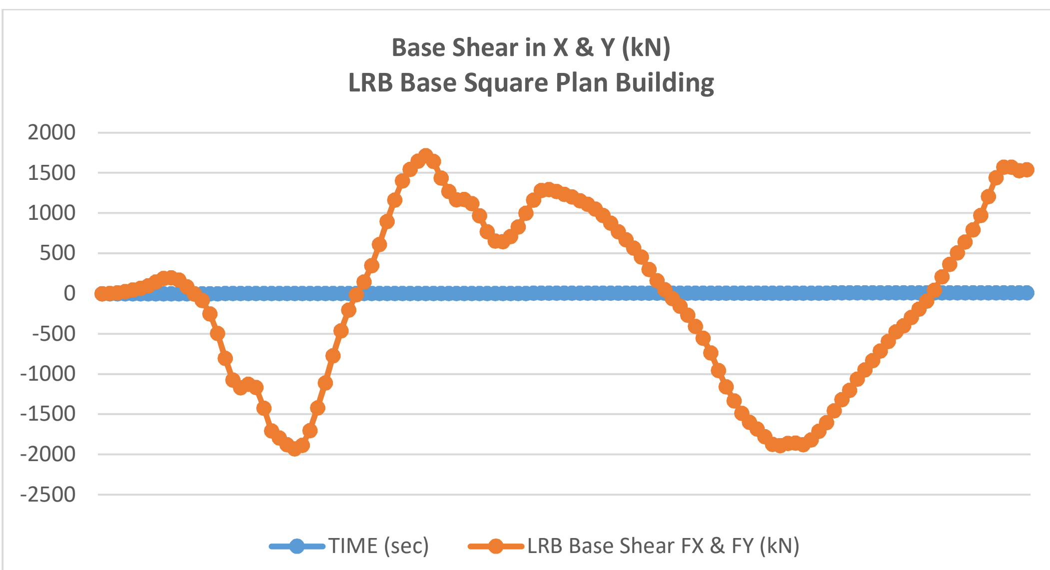


Figure 6.5. Base Shear of LRB base square plan building

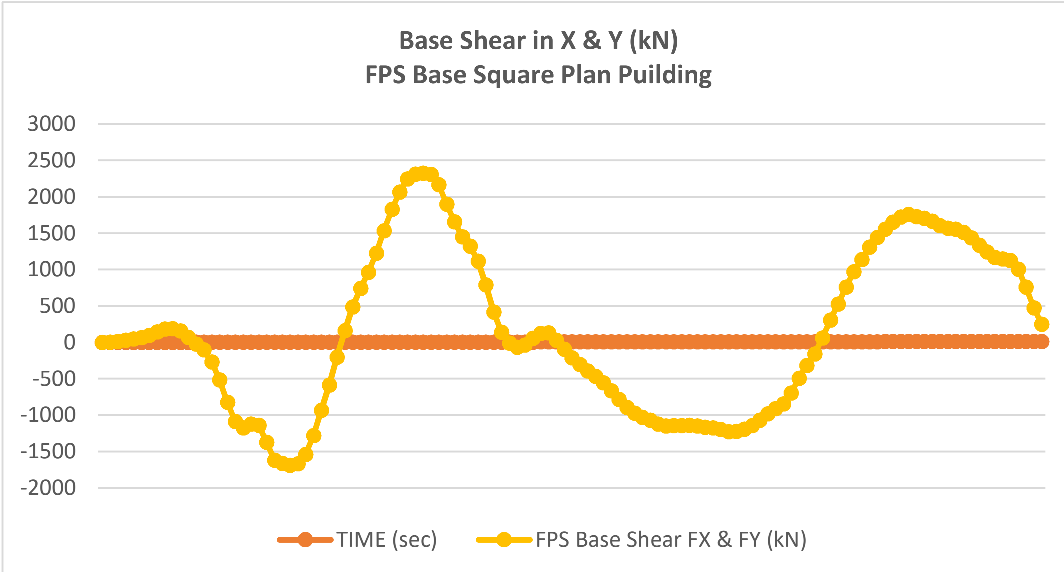


Figure 6.6. Base Shear of FPS base square plan building

TABLE 6.4 MAXIMUM BASE SHEAR OF SQUARE PLAN BUILDING IN X & Y

Maximum Base Shear of Square Plan Building (kN)			Reduction% b/w Fixed & LRB (FX & FY)	Reduction% b/w Fixed & FPS (FX & FY)
FIXED BASE (FX & FY)	LRB BASE (FX & FY)	FPS BASE (FX & FY)		
26124.124	1716.867	2326.095	93.43	91.10

(v) Maximum Absolute Joint acceleration

The maximum absolute joint acceleration generated at the top story of the square plan building with fixed base, LRB base and FPS base due to selected ground motion are shown in fig. 6.7, fig. 6.8 and fig. 6.9 respectively as seismograph at different time interval and crest of the graph defines the maximum joint acceleration of the story at a particular time. The maximum joint acceleration values are different for different base of square plan building are shown in table 6.5 and compared with the fixed base building in X & Y-direction respectively. Since, there is uniformity in the plan shape and waves are striking normally, so the joint acceleration will be same in both direction and shown below:

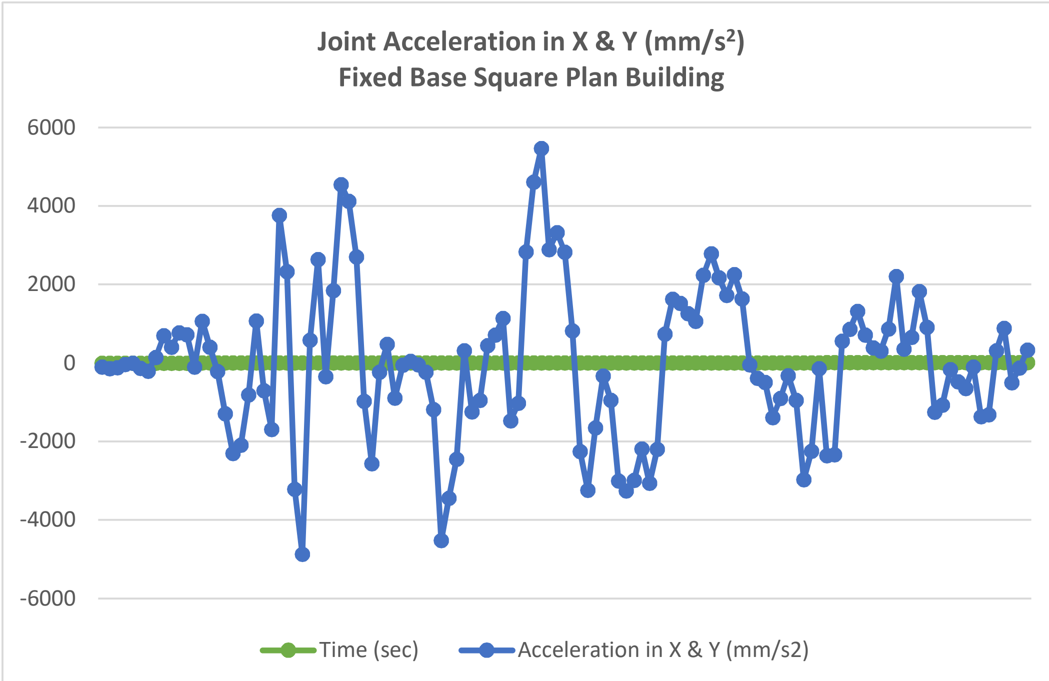


Figure 6.7. Top story Joint acceleration of fixed base square plan building

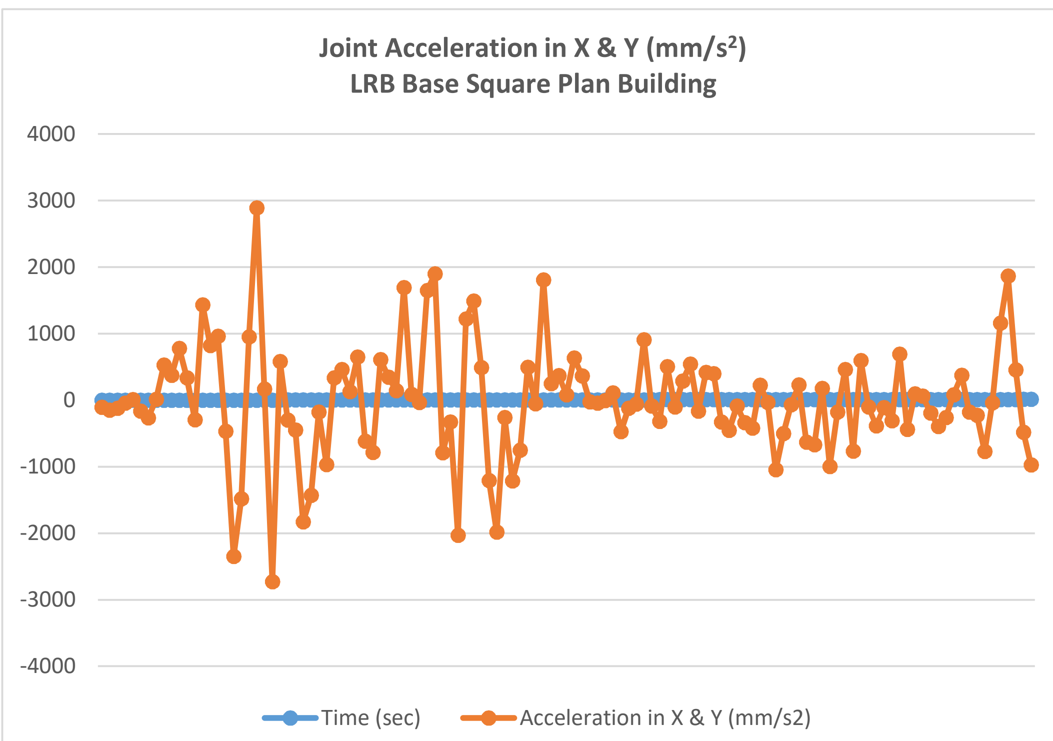


Figure 6.8. Top story Joint acceleration of LRB base square plan building

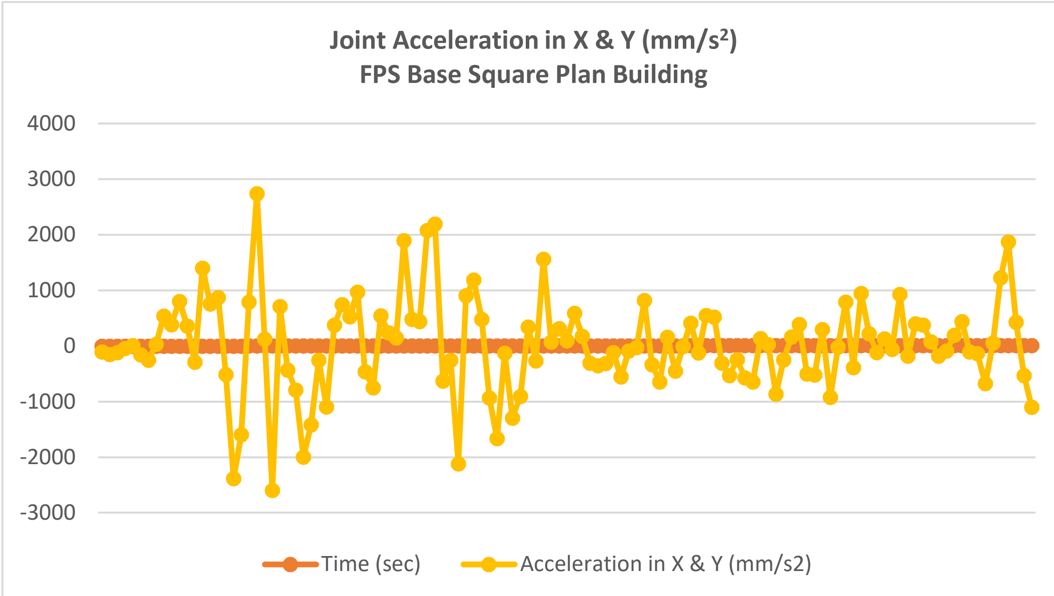


Figure 6.9. Top story Joint acceleration of FPS base square plan building

TABLE 6.5 MAXIMUM JOINT ACCELERATION OF SQUARE PLAN BUILDING IN X & Y

Maximum Joint acceleration of Square Plan Building (mm/s²)			Reduction% b/w Fixed & LRB (X & Y)	Reduction% b/w Fixed & FPS (X & Y)
FIXED BASE (X & Y)	LRB BASE (X & Y)	FPS BASE (X & Y)		
5468.81	2889.49	2744.73	47.16	49.81

(vi) Modal Time Period

The time taken by the building to complete one oscillation in the first mode shape of the building. It is different for different base of square plan building and are shown in table 6.6 below:

TABLE 6.6 MODAL PERIOD T OF SQUARE PLAN BUILDING

Modal Period T of Square Plan Building (sec)			Amplification%	Amplification%
Fixed Base	**LRB Base**	**FPS Base**	**(Fixed & LRB)**	**(Fixed & FPS)**
2.403	7.913	5.914	69.63	59.37

6.3 Time History Analysis & Seismic Responses of Rectangular Plan Building

In this section linear modal time history analysis with El Centro ground motion data provided in program file of the ETABS software has been done on three different type of base such as fixed, LRB base and FPS base of rectangular plan building respectively. The responses recorded are such as maximum story displacement, maximum story drift, maximum story acceleration, maximum base shear, maximum absolute joint acceleration and modal time period which are shown below:

(i) Maximum Story Displacement

When earthquake ground motion strikes the building either in X or in Y-direction the building experience some deviation in that direction and the top story of the buildings experience maximum displacement as compared to other stories. So we will compare only the top story displacement in similar plan buildings due to time history load cases. The maximum story displacements in case of rectangular plan model in X & Y-direction due to load case TH-X & TH-Y respectively are shown below:

- **Table 6.7 represents Maximum Story displacement of rectangular plan building due to load case TH-X in X-direction (mm) and compared in fig. 6.10:**

TABLE 6.7 MAXIMUM STORY DISPLACEMENT OF RECTANGULAR PLAN BUILDING IN X

Story No.	Fixed Base Dis. in X (mm)	LRB Base Dis. in X (mm)	Diff % (Fixed & LRB)	FPS Base Dis. in X (mm)	Diff % (Fixed & FPS)
Story15	402.339	246.798	38.66	246.215	38.80
Story14	396.72	246.361	37.90	245.848	38.03
Story13	387.023	245.643	36.53	245.26	36.63
Story12	373.124	244.628	34.44	244.434	34.49
Story11	355.349	243.328	31.52	243.38	31.51
Story10	334.055	242.017	27.55	242.108	27.52
Story9	311.548	240.977	22.65	240.624	22.77
Story8	288.597	239.601	16.98	238.934	17.21
Story7	262.521	237.889	9.38	237.039	9.71
Story6	232.895	235.857	1.26	235.306	1.02
Story5	199.398	233.538	14.62	233.42	14.58
Story4	161.979	230.962	29.87	231.315	29.97
Story3	120.96	228.155	46.98	228.992	47.18
Story2	77.149	225.136	65.73	226.457	65.93
Story1	32.571	221.948	85.32	223.752	85.44
Base	0	218.987	-	221.252	-

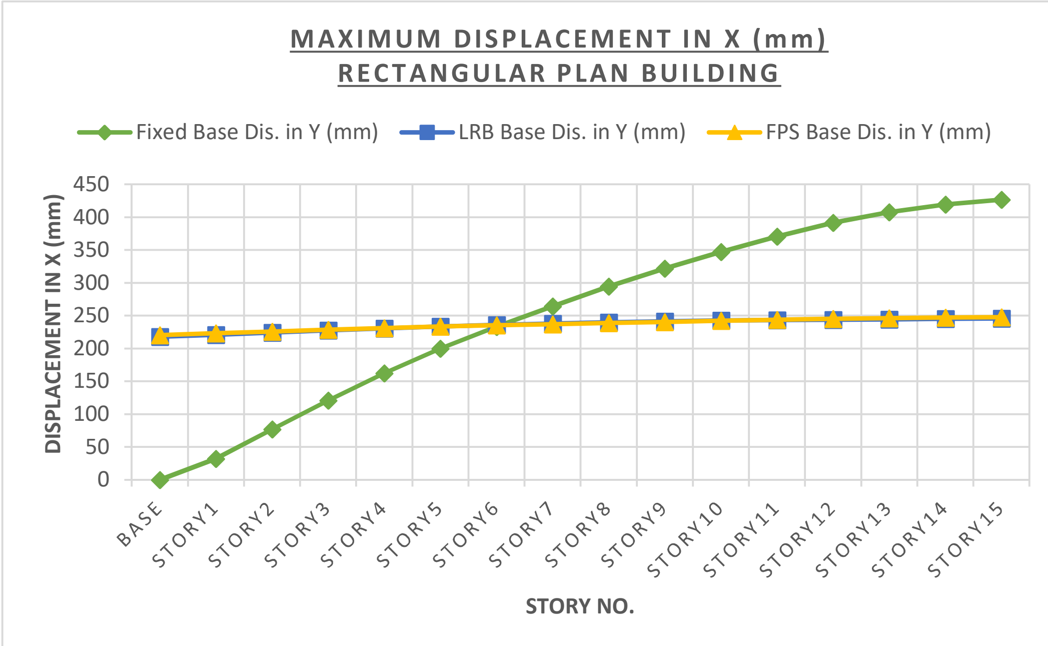


Figure 6.10. Max story displacement in X of rectangular plan building

- **Table 6.8 represents Maximum Story displacement of rectangular plan building due to load case TH-Y in Y-direction (mm) and compared in fig. 6.11:**

TABLE 6.8 MAXIMUM STORY DISPLACEMENT OF RECTANGULAR PLAN BUILDING IN Y

Story No.	Fixed Base Dis. in Y (mm)	LRB Base Dis. in Y (mm)	Diff % (Fixed & LRB)	FPS Base Dis. in Y (mm)	Diff % (Fixed & FPS)
Story15	426.649	245.658	42.42	247.629	41.96
Story14	419.43	245.18	41.54	247.095	41.09
Story13	407.816	244.463	40.06	246.293	39.61
Story12	391.429	244.007	37.66	245.207	37.36
Story11	370.379	243.446	34.27	243.855	34.16
Story10	346.951	242.615	30.07	242.259	30.17
Story9	322.043	241.453	25.02	240.438	25.34
Story8	294.47	239.93	18.52	238.737	18.93
Story7	264.229	238.046	9.91	237.184	10.24
Story6	233.15	235.828	1.14	235.383	0.95
Story5	199.712	233.316	14.40	233.346	14.41
Story4	162.204	230.549	29.64	231.084	29.81
Story3	121	227.562	46.83	228.608	47.07
Story2	76.974	224.38	65.69	225.93	65.93
Story1	32.279	221.053	85.40	223.101	85.53
Base	0	217.986	-	220.501	-

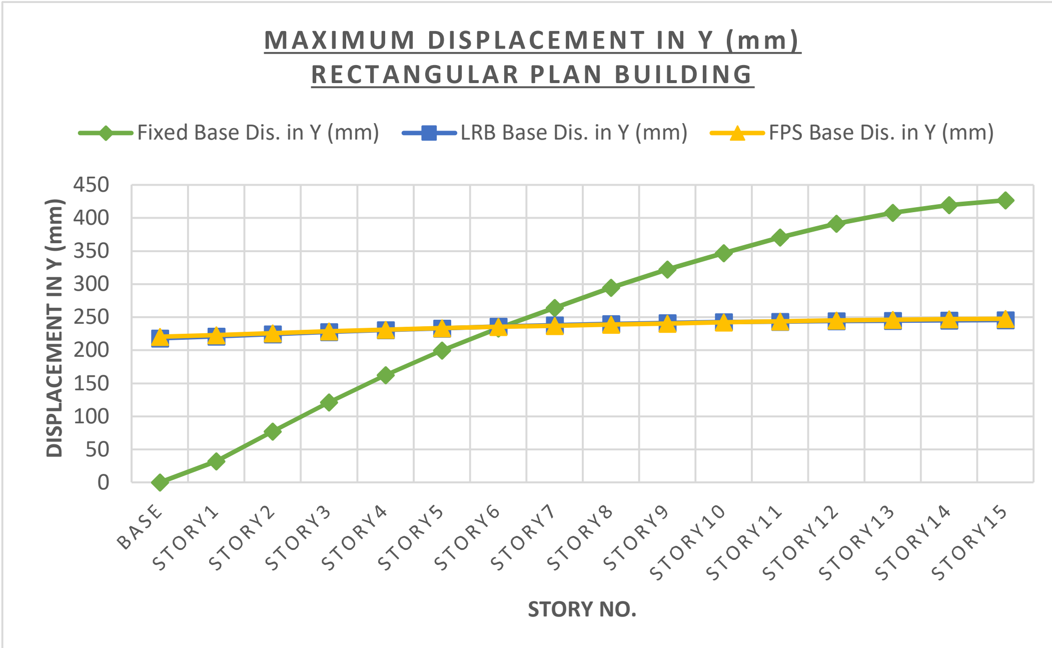


Figure 6.11. Max story displacement in Y of rectangular plan building

(ii) Maximum Story Drift

The story drift is a unit less quantity. The maximum story drifts in case of rectangular plan model individually in X & Y-direction due to load case TH-X & TH-Y respectively are shown below:

- **Table 6.9 shows Maximum Story drifts of rectangular plan building due to load case TH-X in X-direction below and compared in fig. 6.12:**

TABLE 6.9 MAXIMUM STORY DRIFTS OF RECTANGULAR PLAN BUILDING IN X

Story No.	Fixed Base Drift in X	LRB Base Drift in X	Reduction % (Fixed & LRB)	FPS Base Drift in X	Reduction % (Fixed & FPS)
Story15	0.001906	0.00015	92.13	0.000132	93.07
Story14	0.003418	0.000259	92.42	0.000219	93.59
Story13	0.004883	0.000369	92.44	0.00031	93.65
Story12	0.006162	0.000468	92.41	0.00039	93.67
Story11	0.007639	0.00055	92.80	0.000466	93.90
Story10	0.008987	0.000636	92.92	0.000537	94.02
Story9	0.010112	0.000725	92.83	0.000601	94.06
Story8	0.010939	0.000809	92.60	0.00066	93.97
Story7	0.011438	0.000887	92.25	0.000713	93.77
Story6	0.0117	0.000955	91.84	0.000763	93.48
Story5	0.012473	0.001013	91.88	0.000824	93.39

Story4	0.013673	0.001057	92.27	0.000877	93.59
Story3	0.014604	0.001088	92.55	0.000922	93.69
Story2	0.014859	0.0011	92.60	0.000947	93.63
Story1	0.010857	0.001003	90.76	0.00086	92.08
Base	0	0	-	0	-

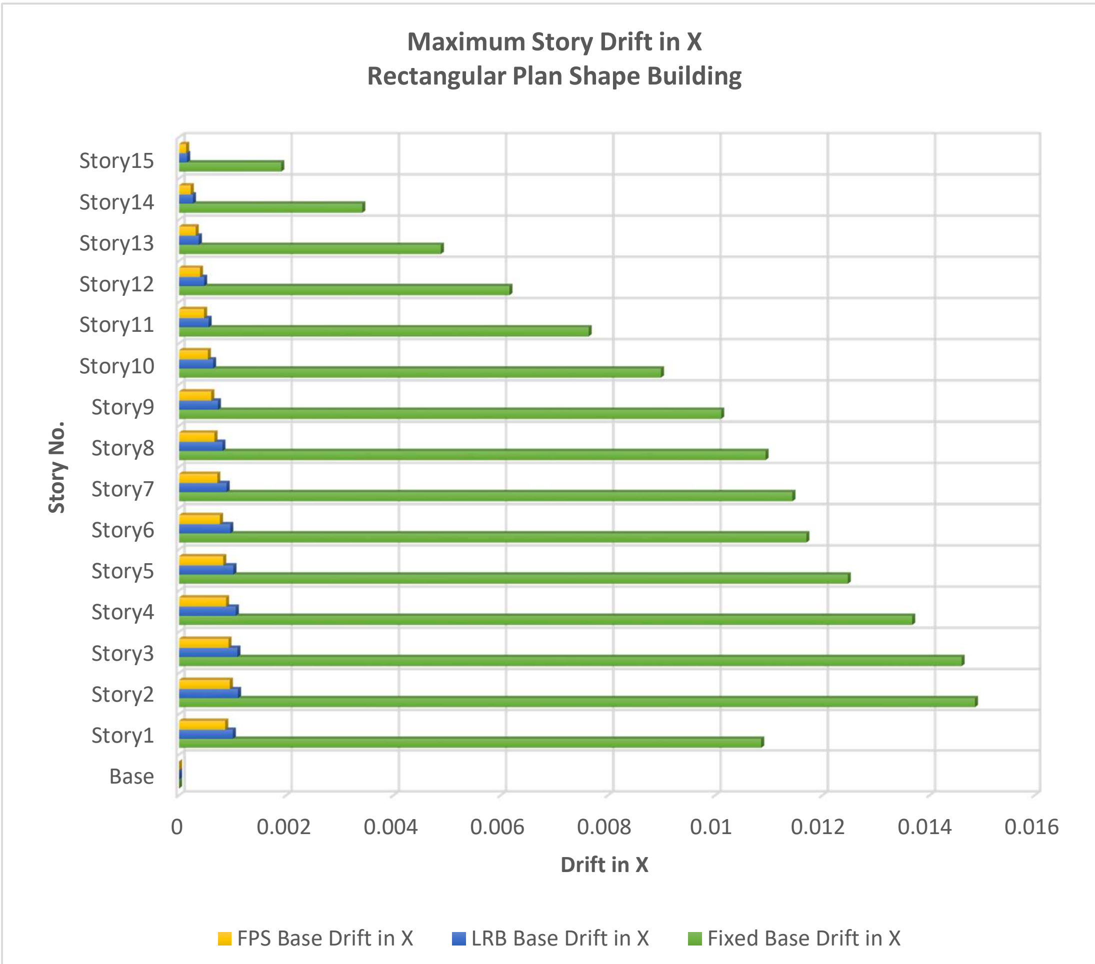


Figure 6.12. Story drift plot in X for Fixed, LRB & FPS base of Rectangular Plan Building

- **Table 6.10 shows Maximum Story drifts of rectangular plan building due to load case TH-Y in Y-direction below and compared in fig. 6.13:**

<u>**TABLE 6.10 MAXIMUM STORY DRIFTS OF RECTANGULAR PLAN BUILDING IN Y**</u>

Story No.	Fixed Base Drift in Y	LRB Base Drift in Y	Reduction % (Fixed & LRB)	FPS Base Drift in Y	Reduction % (Fixed & FPS)
Story15	0.002447	0.000194	92.07	0.000178	92.73
Story14	0.004115	0.000312	92.42	0.000267	93.51

Story13	0.005741	0.000423	92.63	0.000362	93.69
Story12	0.007147	0.000521	92.71	0.000451	93.69
Story11	0.008658	0.000607	92.99	0.000532	93.86
Story10	0.009974	0.000687	93.11	0.000607	93.91
Story9	0.011002	0.00077	93.00	0.000677	93.85
Story8	0.011708	0.000852	92.72	0.000742	93.66
Story7	0.012266	0.000921	92.49	0.000803	93.45
Story6	0.012566	0.000978	92.22	0.00086	93.16
Story5	0.012852	0.001024	92.03	0.00091	92.92
Story4	0.013735	0.001074	92.18	0.000952	93.07
Story3	0.014675	0.001112	92.42	0.000984	93.29
Story2	0.014898	0.001127	92.44	0.000993	93.33
Story1	0.01076	0.001036	90.37	0.000891	91.72
Base	0	0	-	0	-

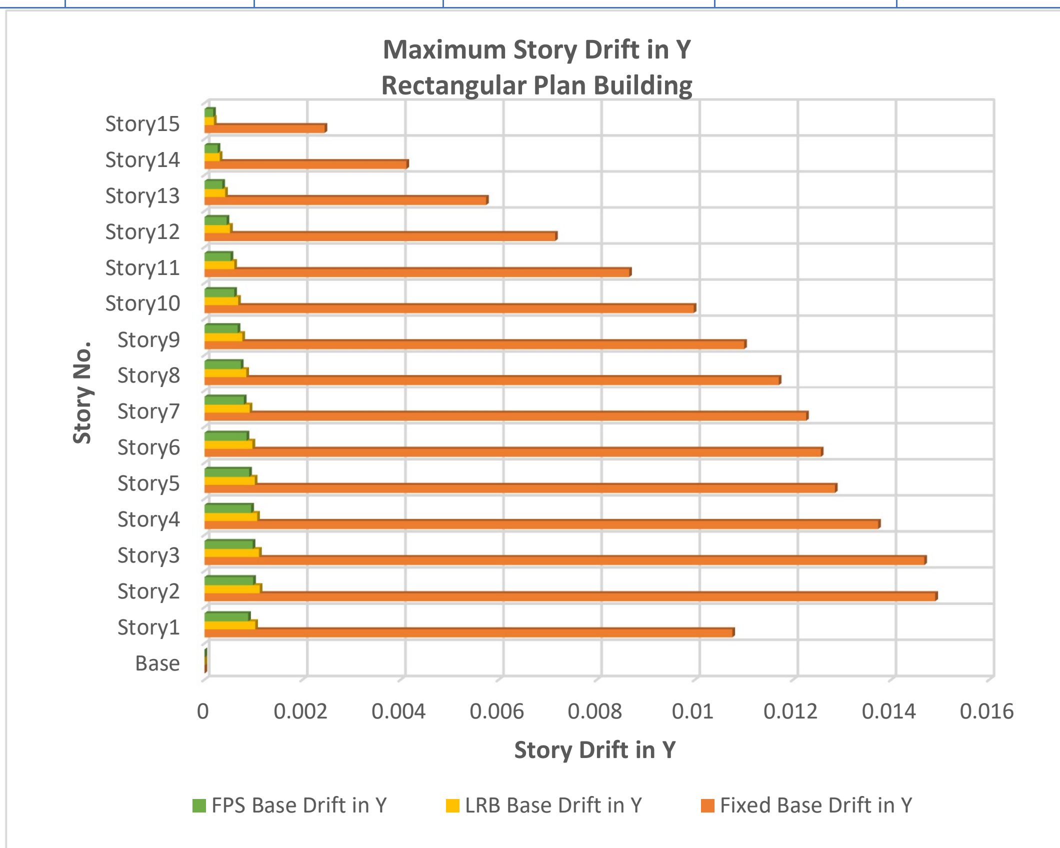


Figure 6.13. Story drift plot in Y for Fixed, LRB & FPS base of Rectangular Plan Building

(iii) Maximum Story Acceleration

The maximum story acceleration is the study of behaviour of maximum acceleration at particular story of rectangular plan building and will be compared with different type of base such as fixed, LRB and FPS at each story due to considered ground motion data. The story acceleration in rectangular plan building in X & Y direction due to load case TH-X & TH-Y are shown in table 6.11 & table 6.12 and compared in fig. 6.14 and fig. 6.15 respectively:

TABLE 6.11 MAXIMUM STORY ACCELERATION IN RECTANGULAR PLAN BUILDING IN X

Story No.	Fixed Base Story Acceleration in X (mm/s^2)	LRB Base Story Acceleration in X (mm/s^2)	Reduction% (Fixed & LRB)	FPS Base Story Acceleration in X (mm/s^2)	Reduction% (Fixed & FPS)
Story15	4519.46	267.84	94.07	253.42	94.39
Story14	4099.43	253.25	93.82	241.13	94.12
Story13	3409.63	233.47	93.15	231.73	93.20
Story12	3396.63	205.21	93.96	218.89	93.56
Story11	3505.98	181.97	94.81	197.95	94.35
Story10	3300.15	180.45	94.53	172.44	94.77
Story9	3229.12	172.18	94.67	156.26	95.16
Story8	3298.65	184.96	94.39	163.33	95.05
Story7	3042.23	188.24	93.81	166.29	94.53
Story6	3271.64	197.03	93.98	173.31	94.70
Story5	3601.83	201.58	94.40	194.43	94.60
Story4	3399.7	194.24	94.29	210.92	93.80
Story3	2861.89	199.77	93.02	220.47	92.30
Story2	2412.51	214.29	91.12	231.9	90.39
Story1	2215.85	244.98	88.94	238.12	89.25
Base	2461.11	264.63	89.25	238.74	90.30

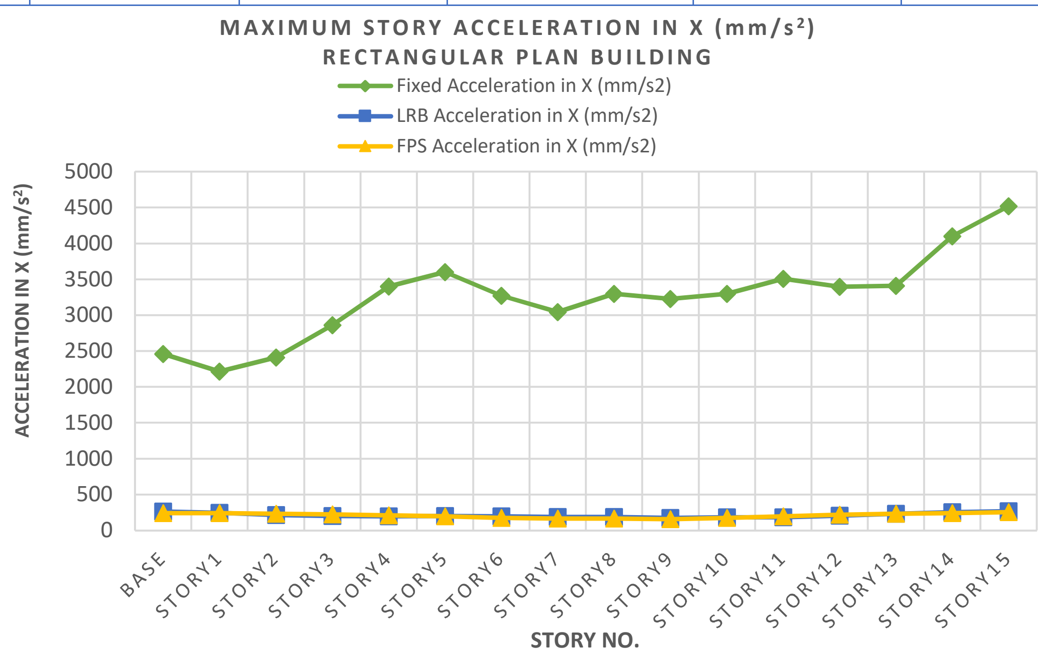


Figure 6.14. Story Acceleration in X of Rectangular Plan Building with Fixed, LRB & FPS Base

TABLE 6.12 MAXIMUM STORY ACCELERATION IN RECTANGULAR PLAN BUILDING IN Y

Story No.	Fixed Acceleration in Y (mm/s2)	LRB Acceleration in Y (mm/s2)	Reduction% (Fixed & LRB)	FPS Acceleration in Y (mm/s2)	Reduction% (Fixed & FPS)
Story15	4754.71	278.68	94.14	263.7	94.45
Story14	4291.74	265.55	93.81	249.57	94.18
Story13	3761.76	242.43	93.56	224.98	94.02
Story12	3701.18	211	94.30	203.85	94.49
Story11	3785.71	176.66	95.33	191.91	94.93
Story10	3538.62	168.37	95.24	169.61	95.21
Story9	3567.37	185.07	94.81	159.76	95.52
Story8	3480.05	188.93	94.57	162.96	95.32
Story7	3070.68	191.46	93.76	166.39	94.58
Story6	3178.7	199.17	93.73	178.62	94.38
Story5	3463.09	193.54	94.41	189.19	94.54
Story4	3350.38	181.59	94.58	196.56	94.13
Story3	2885.17	192.1	93.34	209.24	92.75
Story2	2328.13	216.51	90.70	219.53	90.57
Story1	2169.23	235.75	89.13	232.73	89.27
Base	2461.11	254.38	89.66	244.01	90.09

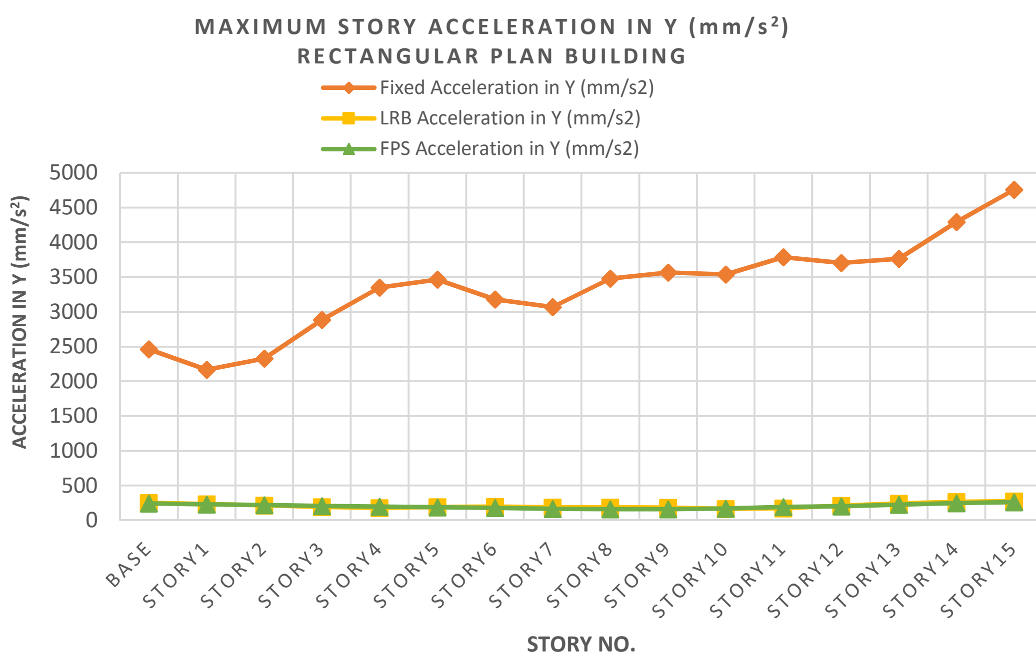


Figure 6.15. Story Acceleration in X of Rectangular Plan Building with Fixed, LRB & FPS Base

(iv) Maximum Base Shear

The maximum horizontal lateral force arises at the base of the building due to the considered ground motion data of El Centro at a particular time interval for all type of base such as fixed, LRB and FPS of rectangular plan building in X-direction (due to TH-X load case) is shown below in fig. 6.16, fig. 6.17 and fig. 6.18 and in Y-direction (due to TH-Y load case) is shown in fig. 6.19, fig. 6.20 and fig. 6.21 respectively through the seismograph of base shear and the crest of the graphs define the maximum base shear of the building at particular time interval in X & Y which is shown in table 6.13 & table 6.14 respectively for all type of base:

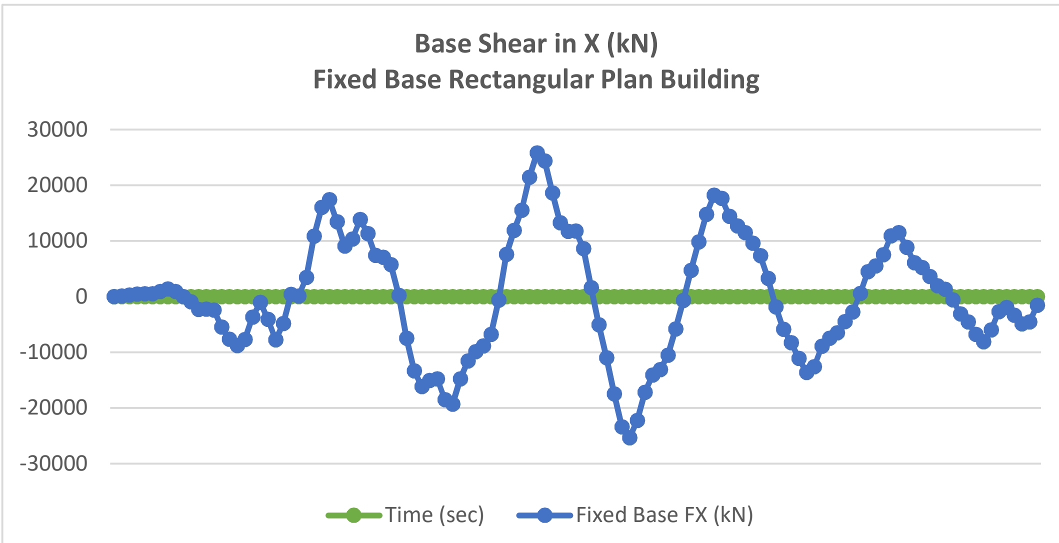


Figure 6.16. Base Shear in X of fixed base rectangular plan building

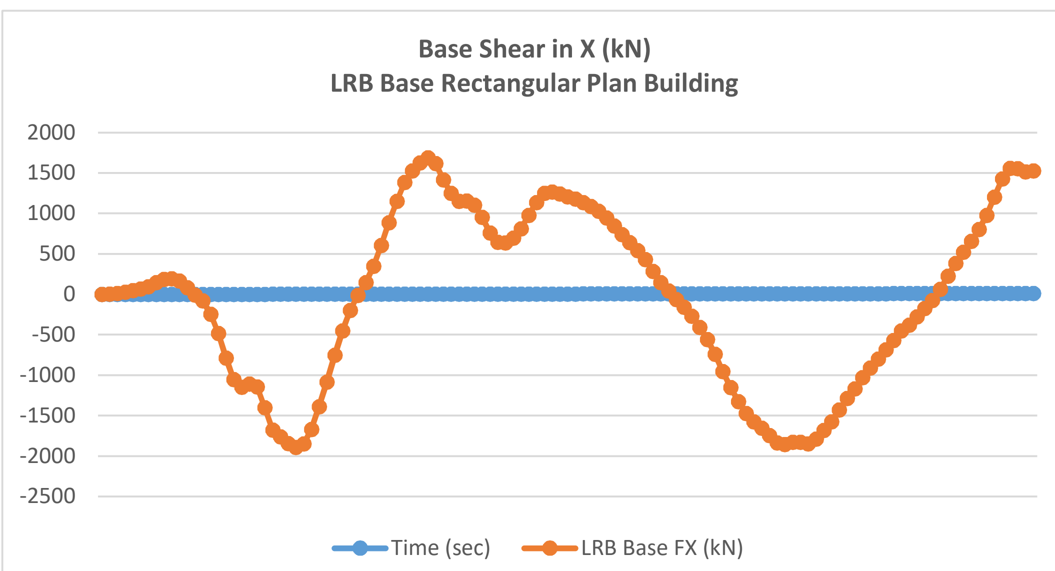


Figure 6.17. Base Shear in X of LRB base rectangular plan building

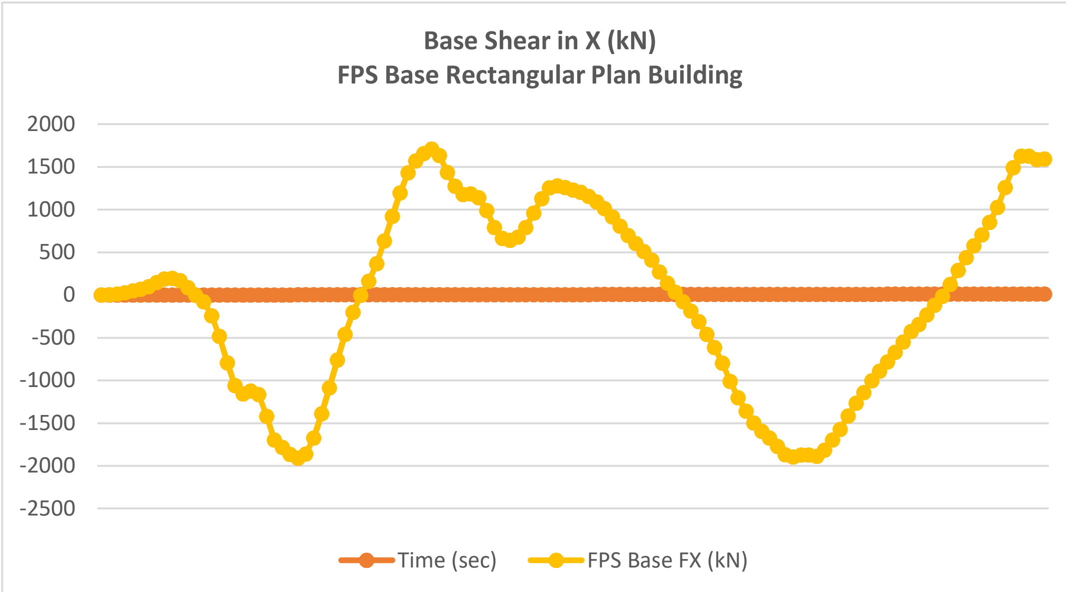


Figure 6.18. Base Shear in X of FPS base rectangular plan building

TABLE 6.13 MAXIMUM BASE SHEAR OF RECTANGULAR PLAN BUILDING IN X

Maximum Base Shear of Rectangular Plan Building in X (kN)			Reduction% b/w Fixed & LRB FX	Reduction% b/w Fixed & FPS FX
FIXED BASE FX	LRB BASE FX	FPS BASE FX		
25834.151	1689.982	1708.317	93.46	93.38

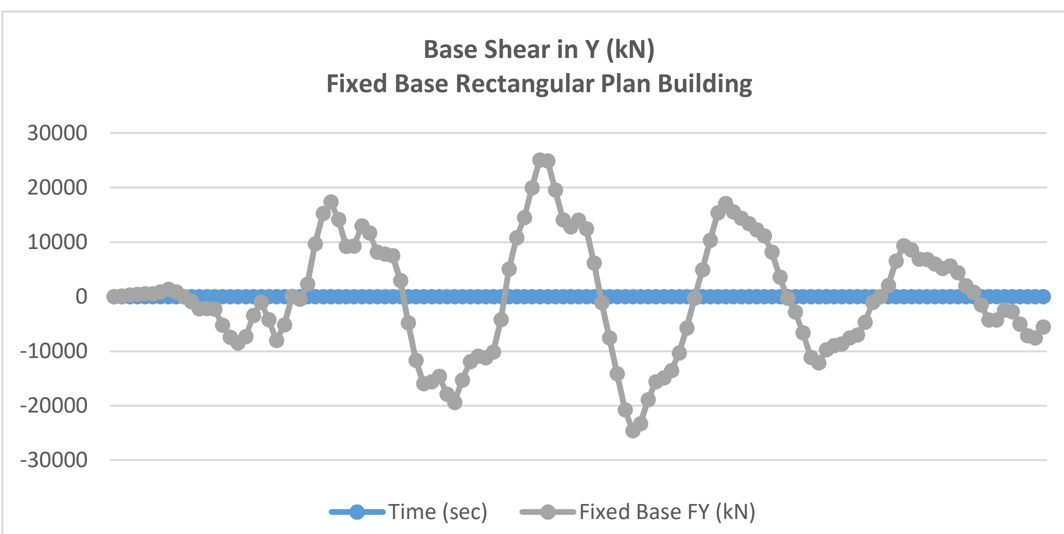


Figure 6.19. Base Shear in Y of Fixed base rectangular plan building

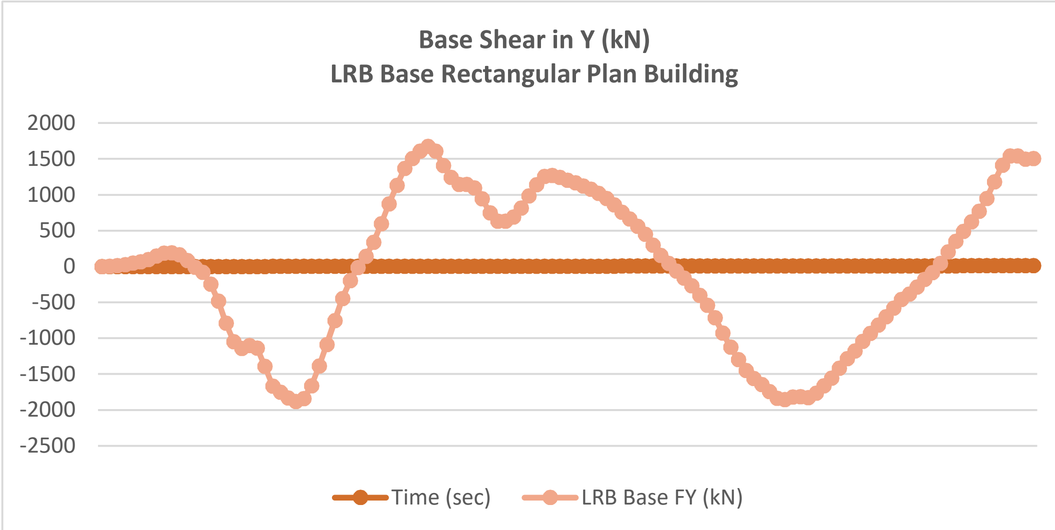


Figure 6.20. Base Shear in Y of LRB base rectangular plan building

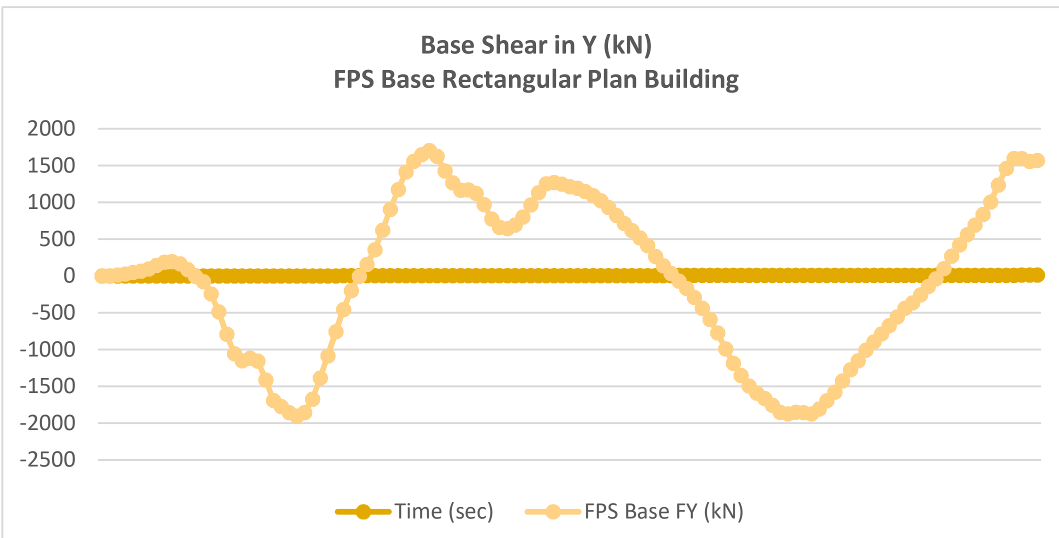


Figure 6.21. Base Shear in Y of FPS base rectangular plan building

TABLE 6.14 MAXIMUM BASE SHEAR OF RECTANGULAR PLAN BUILDING IN Y

Maximum Base Shear of Rectangular Plan Building in Y (kN)			Reduction% b/w Fixed & LRB FY	Reduction% b/w Fixed & FPS FY
FIXED BASE FY	LRB BASE FY	FPS BASE FY		
25064.422	1677.464	1704.092	93.31	93.20

(v) Maximum Absolute Joint acceleration

The maximum absolute joint acceleration generated at the top story of the rectangular plan building with fixed base, LRB base and FPS base due to selected ground motion in X direction (due to TH-X load case) are shown in fig. 6.22, fig. 6.23 and fig. 6.24 and in Y direction (due to TH-Y load case) are shown in fig. 6.25, fig. 6.26 and fig. 6.27 respectively as seismograph at different time interval and the crest of the graph defines the maximum joint acceleration of the story at a particular time. The maximum joint acceleration values are different for different base of rectangular plan building and shown in table 6.15 & table 6.16 and compared with the fixed base building in X & Y-direction respectively:

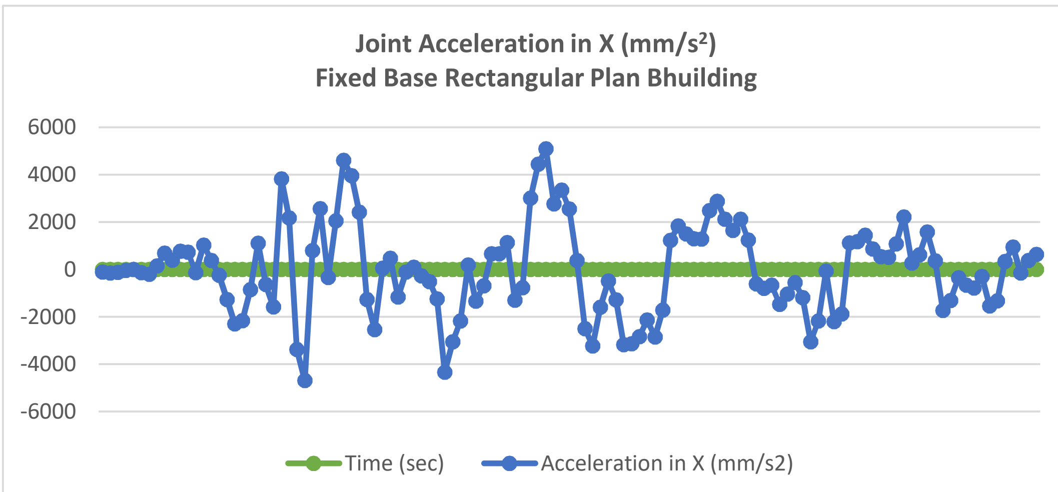


Figure 6.22. Top story Joint acceleration in X of Fixed base rectangular plan building

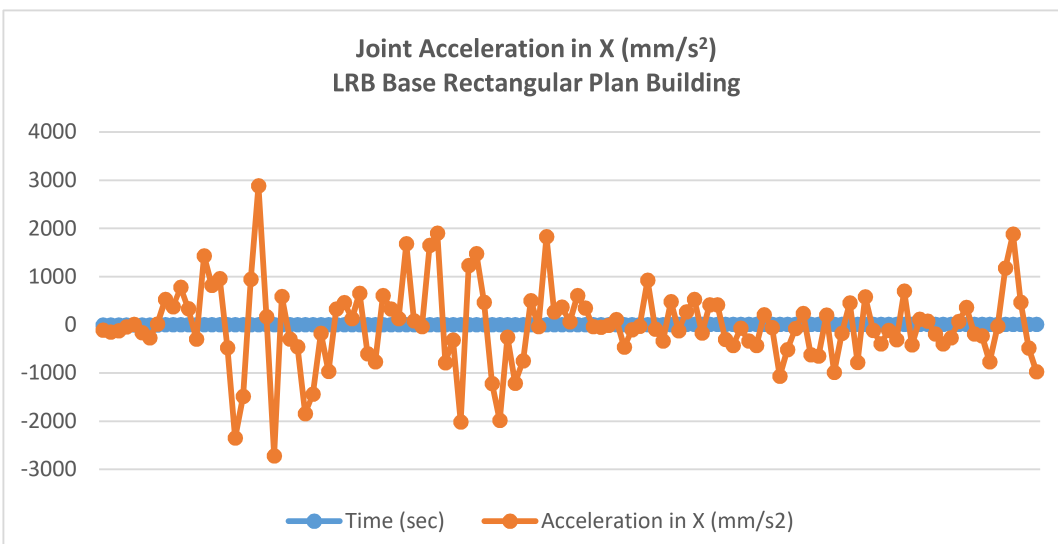


Figure 6.23. Top story Joint acceleration in X of LRB base rectangular plan building

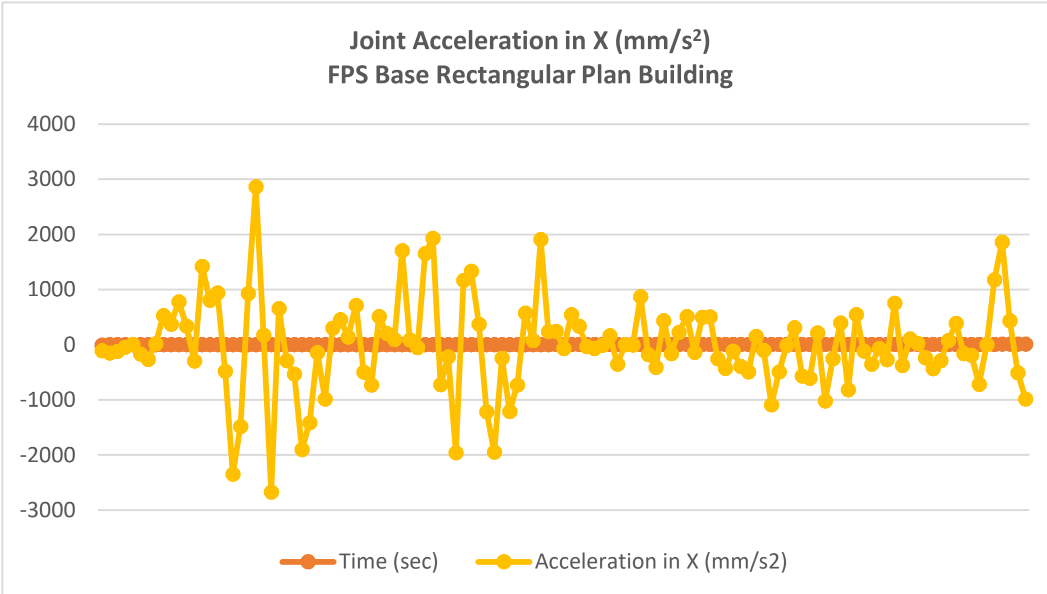


Figure 6.24. Top story Joint acceleration in X of FPS base rectangular plan building

TABLE 6.15 MAXIMUM JOINT ACCELERATION OF RECTANGULAR PLAN BUILDING IN X

Maximum Joint acceleration of Rectangular Plan Building in X (mm/s^2)			Reduction% b/w Fixed & LRB X	Reduction% b/w Fixed & FPS X
FIXED BASE X	LRB BASE X	FPS BASE X		
5103.21	2887.50	2869.67	43.42	43.77

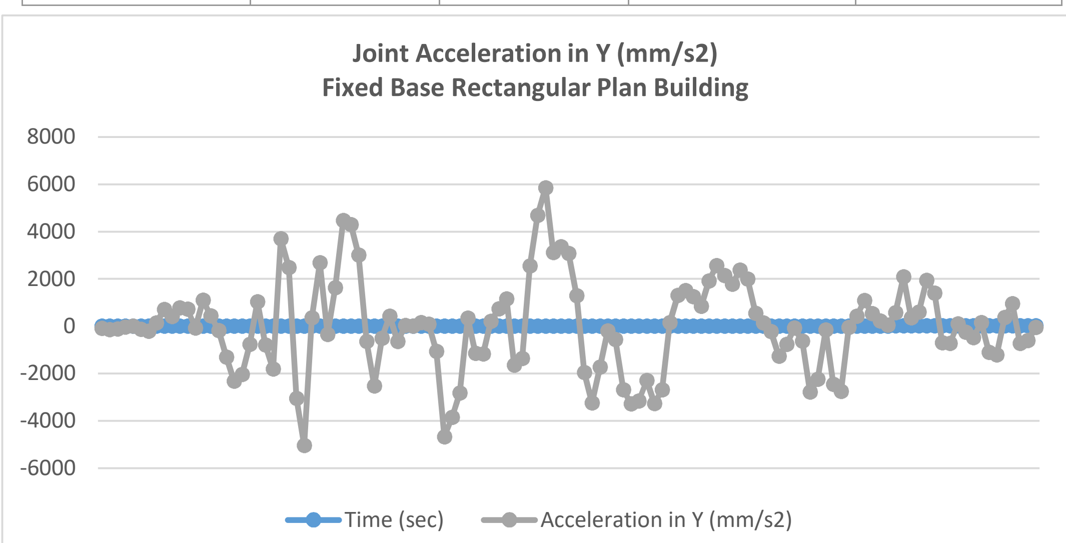


Figure 6.25. Top story Joint acceleration in Y of Fixed base rectangular plan building

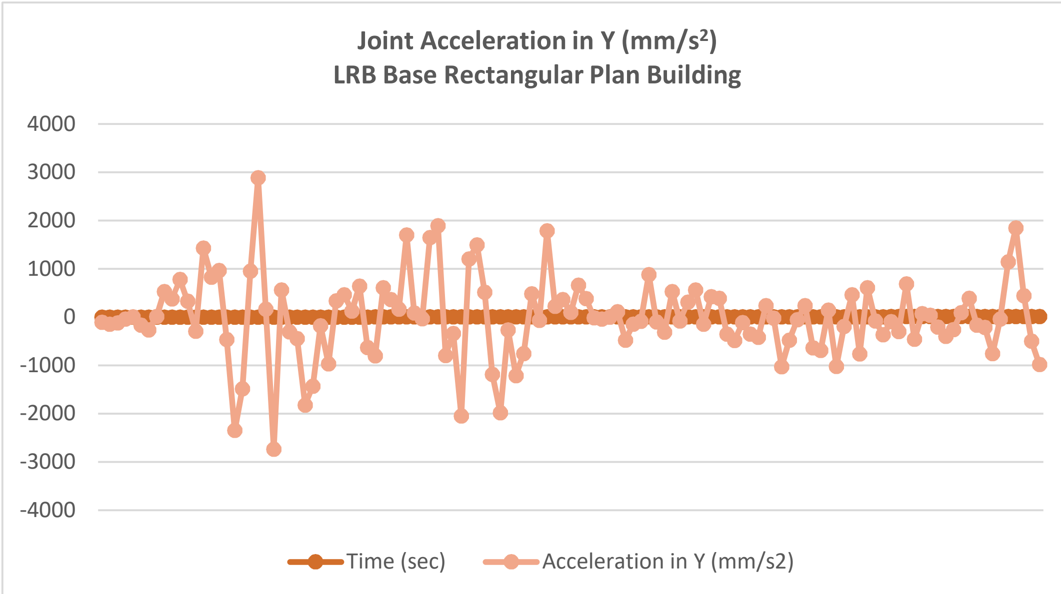


Figure 6.26. Top story Joint acceleration in Y of LRB base rectangular plan building

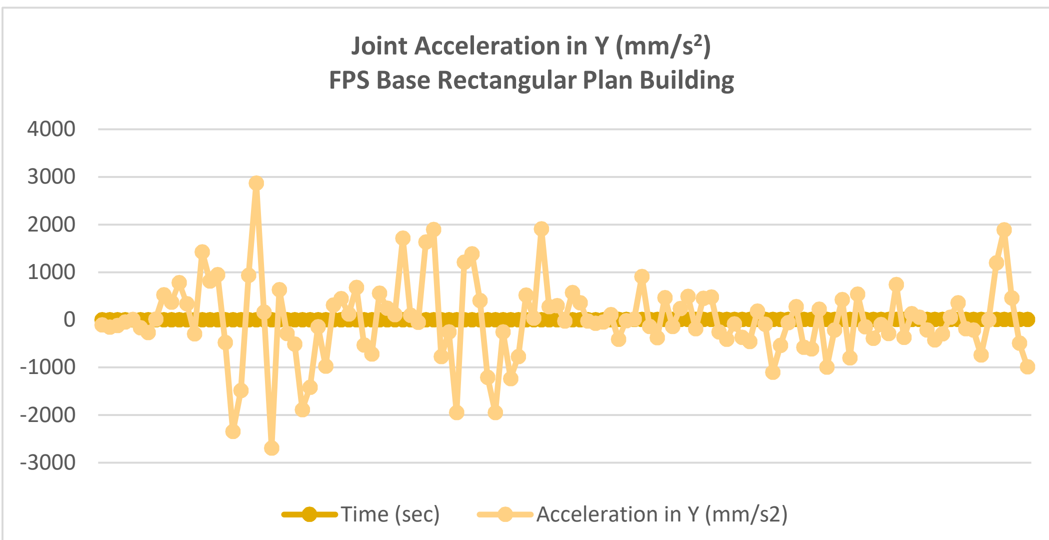


Figure 6.27. Top story Joint acceleration in Y of FPS base rectangular plan building

TABLE 6.16 MAXIMUM JOINT ACCELERATION OF RECTANGULAR PLAN BUILDING IN Y

Maximum Joint acceleration of Rectangular Plan Building in Y (mm/s^2)			Reduction% b/w Fixed & LRB Y	Reduction% b/w Fixed & FPS Y
FIXED BASE Y	LRB BASE Y	FPS BASE Y		
5850.68	2890.49	2869.86	50.59	50.95

(vi) Modal Time Period

The time taken by the building to complete one oscillation in the first mode shape of the building. It is different for different base of rectangular plan building and are shown in table 6.17 below:

TABLE 6.17 MODAL PERIOD T OF RECTANGULAR PLAN BUILDING

Modal Period T of Rectangular Plan Building (sec)			Amplification%	Amplification%
Fixed Base	**LRB Base**	**FPS Base**	**(Fixed & LRB)**	**(Fixed & FPS)**
2.435	7.913	7.868	69.23	69.05

6.4 Time History Analysis & Seismic Responses of H-Shaped Plan Building

In this section linear modal time history analysis with El Centro ground motion data provided in program file of the ETABS software has been done on three different type of base such as fixed, LRB base and FPS base of H-shaped plan building respectively. The responses recorded are such as maximum story displacement, maximum story drift, maximum story acceleration, maximum base shear, maximum absolute joint acceleration and modal time period which are shown below:

(i) Maximum Story Displacement

When earthquake ground motion strikes the building either in X or in Y-direction the building experience some deviation in that direction and the top story of the buildings experience maximum displacement as compared to other stories. So we will compare only the top story displacement in similar plan buildings due to time history load cases. The maximum story displacements in case of H-shaped plan model in X & Y-direction due to load case TH-X & TH-Y respectively are shown below:

- **Table 6.18 represents Maximum Story displacement of H-shaped plan building due to load case TH-X in X-direction (mm) and compared in fig. 6.28:**

TABLE 6.18 MAXIMUM STORY DISPLACEMENT OF H-SHAPED PLAN BUILDING IN X

Story No.	Fixed Base Dis. in X (mm)	LRB Base Dis. in X (mm)	Diff% (Fixed & LRB)	FPS Base Dis. in X (mm)	Diff% (Fixed & FPS)
Story15	420.025	248.269	40.89	248.429	40.85
Story14	412.984	247.764	40.01	247.934	39.97
Story13	401.896	247.021	38.54	247.194	38.49
Story12	386.668	246.021	36.37	246.19	36.33
Story11	367.692	244.773	33.43	244.93	33.39

Story10	345.373	243.28	29.56	243.422	29.52
Story9	320.033	241.548	24.52	241.669	24.49
Story8	291.87	239.573	17.92	239.674	17.88
Story7	262.099	237.356	9.44	237.435	9.41
Story6	232.539	235.028	1.06	235.042	1.06
Story5	199.019	232.457	14.38	232.496	14.40
Story4	161.501	229.63	29.67	229.693	29.69
Story3	120.345	226.582	46.89	226.67	46.91
Story2	76.432	223.341	65.78	223.452	65.79
Story1	31.943	219.957	85.48	220.091	85.49
Base	0	216.997	-	217.146	-

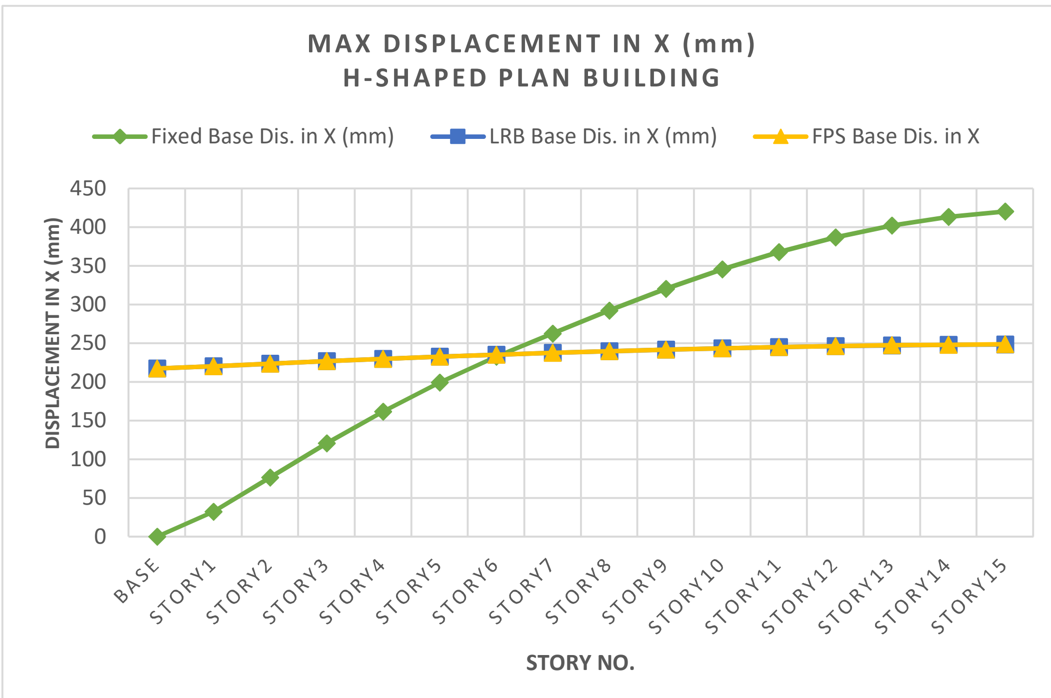


Figure 6.28. Max story displacement in X of H-shaped plan building

- **Table 6.19 represents Maximum Story displacement of H-shaped plan building due to load case TH-Y in Y-direction (mm) and compared in fig. 6.29:**

TABLE 6.19 MAXIMUM STORY DISPLACEMENT OF H-SHAPED PLAN BUILDING IN Y

Story No.	Fixed Base Dis. in Y (mm)	LRB Base Dis. in Y (mm)	Diff% (Fixed & LRB)	FPS Base Dis. in Y (mm)	Diff% (Fixed & FPS)
Story15	401.589	249.278	37.93	249.343	37.91
Story14	395.697	248.797	37.12	248.875	37.10
Story13	385.921	248.041	35.73	248.127	35.71

Story12	372.041	246.991	33.61	247.08	33.59
Story11	354.266	245.658	30.66	245.746	30.63
Story10	332.858	244.053	26.68	244.138	26.65
Story9	310.485	242.187	22.00	242.266	21.97
Story8	287.295	240.067	16.44	240.139	16.41
Story7	261.013	237.699	8.93	237.764	8.91
Story6	231.225	235.093	1.65	235.153	1.67
Story5	197.64	232.65	15.05	232.674	15.06
Story4	160.244	229.987	30.32	230.028	30.34
Story3	119.398	227.093	47.42	227.151	47.44
Story2	75.935	223.991	66.10	224.066	66.11
Story1	31.895	220.726	85.55	220.818	85.56
Base	0	217.722	-	217.83	-

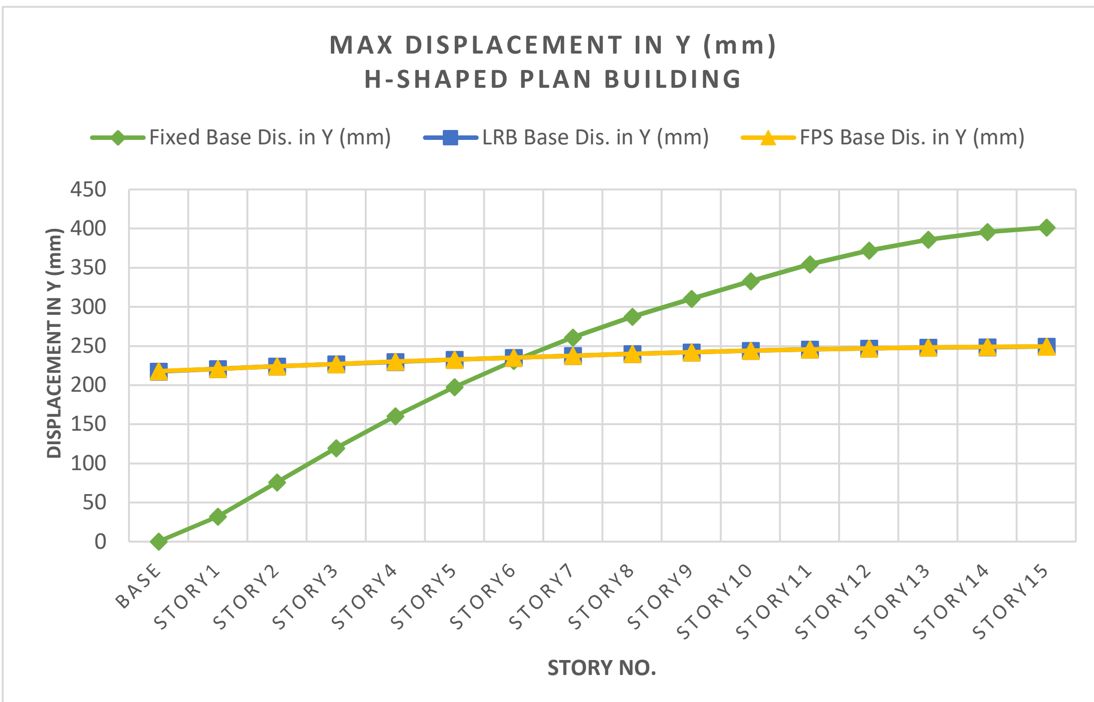


Figure 6.29. Max story displacement in Y of H-shaped plan building

(ii) Maximum Story Drift

The story drift is a unit less quantity. The maximum story drifts in case of H-shaped plan model individually in X & Y-direction due to load case TH-X & TH-Y respectively are shown below:

- **Table 6.20 & table 6.21 shows Maximum Story drifts of H-shaped plan building due to load case TH-X & TH-Y in X & Y-direction respectively and compared in fig. 6.30 & fig. 6.31:**

TABLE 6.20 MAXIMUM STORY DRIFTS OF H-SHAPED PLAN BUILDING IN X

Story No.	Fixed Base Drift in X	LRB Base Drift in X	Reduction% (Fixed & LRB)	FPS Base Drift in X	Reduction% (Fixed & FPS)
Story15	0.002472	0.000206	91.67	0.000198	91.99
Story14	0.00409	0.000326	92.03	0.000318	92.22
Story13	0.005663	0.000439	92.25	0.00043	92.41
Story12	0.007086	0.000539	92.39	0.00053	92.52
Story11	0.008511	0.000627	92.63	0.000618	92.74
Story10	0.009764	0.000709	92.74	0.0007	92.83
Story9	0.010898	0.000789	92.76	0.000787	92.78
Story8	0.011741	0.000872	92.57	0.000871	92.58
Story7	0.012266	0.000942	92.32	0.000941	92.33
Story6	0.012489	0.001001	91.98	0.000998	92.01
Story5	0.012826	0.001048	91.83	0.001047	91.84
Story4	0.013719	0.001099	91.99	0.001098	92.00
Story3	0.014638	0.001139	92.22	0.001136	92.24
Story2	0.014829	0.001156	92.20	0.00115	92.24
Story1	0.010648	0.001101	89.66	0.00109	89.76
Base	0	0	-	0	-

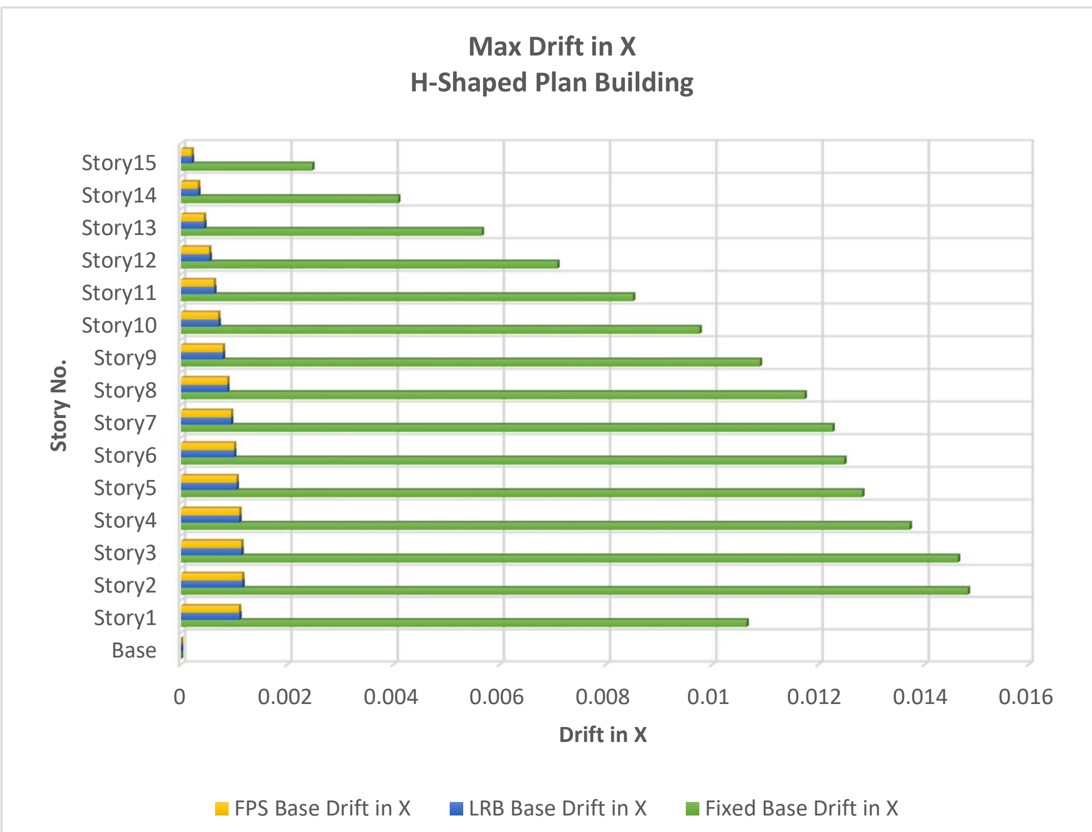


Figure 6.30. Max Story Drift in X of H-shaped Plan Building

TABLE 6.21 MAXIMUM STORY DRIFTS OF H-SHAPED PLAN BUILDING IN Y

Story No.	Fixed Base Drift in Y	LRB Base Drift in Y	Reduction% (Fixed & LRB)	FPS Base Drift in Y	Reduction% (Fixed & FPS)
Story15	0.001999	0.000169	91.55	0.000163	91.85
Story14	0.003464	0.000281	91.89	0.000275	92.06
Story13	0.004884	0.000393	91.95	0.000387	92.08
Story12	0.006224	0.000495	92.05	0.000489	92.14
Story11	0.007693	0.000579	92.47	0.000572	92.56
Story10	0.009034	0.000676	92.52	0.000667	92.62
Story9	0.010149	0.000767	92.44	0.000758	92.53
Story8	0.010959	0.000846	92.28	0.000838	92.35
Story7	0.011429	0.000919	91.96	0.000915	91.99
Story6	0.011769	0.000989	91.60	0.000985	91.63
Story5	0.012465	0.001048	91.59	0.001043	91.63
Story4	0.013615	0.001093	91.97	0.001088	92.01
Story3	0.014488	0.001124	92.24	0.001119	92.28
Story2	0.01468	0.001134	92.28	0.001129	92.31
Story1	0.010632	0.001095	89.70	0.001087	89.78
Base	0	0	-	0	-

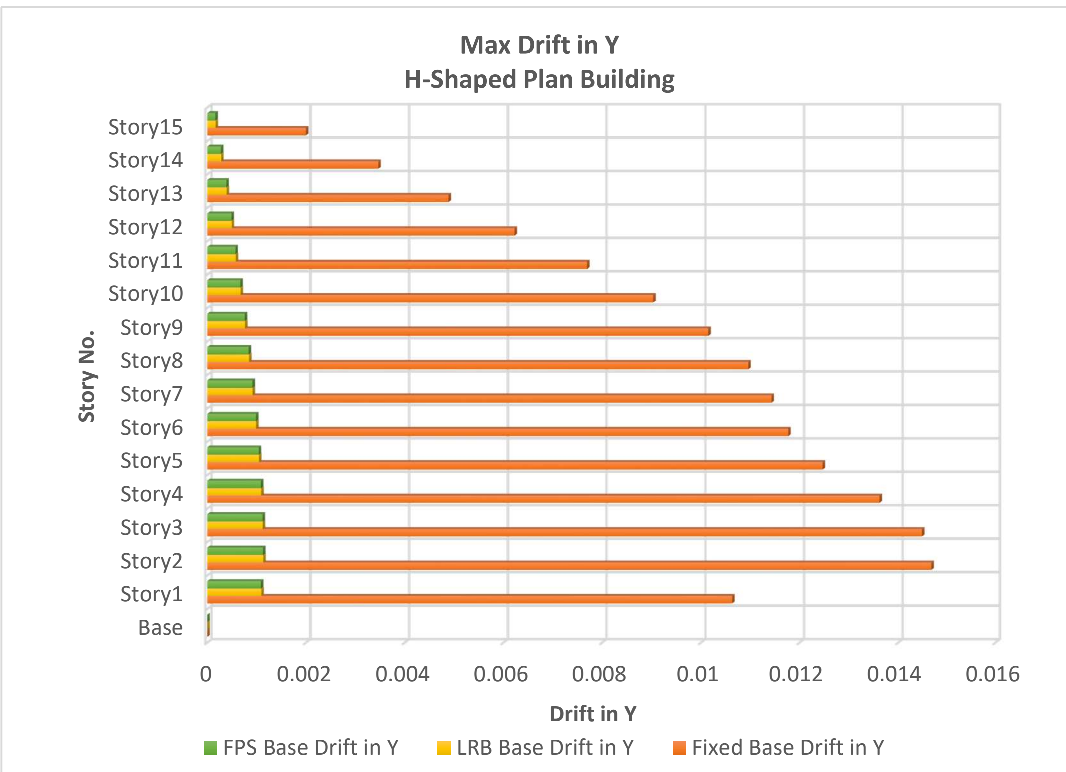


Figure 6.31. Max Story Drift in Y of H-shaped Plan Building

(iii) Maximum Story Acceleration

The maximum story acceleration is the study of behaviour of maximum acceleration at particular story of H-shaped plan building and will be compared with different type of base. The story acceleration in H-shaped plan building in X & Y direction due to load case TH-X & TH-Y are shown in table 6.22 & table 6.23 and compared in fig. 6.32 and fig. 6.33 respectively:

TABLE 6.22 MAXIMUM STORY ACCELERATION IN H-SHAPED PLAN BUILDING IN X

Story No.	Fixed Base Story Acceleration in X (mm/s²)	LRB Base Story Acceleration in X (mm/s²)	Reduction% (Fixed & LRB)	FPS Base Story Acceleration in X (mm/s²)	Reduction% (Fixed & FPS)
Story15	4711.92	282.78	94.00	281.4	94.03
Story14	4249.7	269.14	93.67	267.97	93.69
Story13	3635.57	245.4	93.25	244.45	93.28
Story12	3636.74	213.24	94.14	212.51	94.16
Story11	3726.89	182.58	95.10	184.53	95.05
Story10	3484.52	173.87	95.01	172.64	95.05
Story9	3372.46	190.62	94.35	190	94.37
Story8	3276.97	194.41	94.07	194.49	94.06
Story7	3044.39	196.36	93.55	197.03	93.53
Story6	3277.27	203.93	93.78	205.16	93.74
Story5	3579.94	197.85	94.47	199.56	94.43
Story4	3362.74	185.03	94.50	186.22	94.46
Story3	2878.33	196.93	93.16	197.44	93.14
Story2	2401.3	221.93	90.76	222.49	90.73
Story1	2207.28	240.24	89.12	240.73	89.09
Base	2461.11	259.91	89.44	260.21	89.43

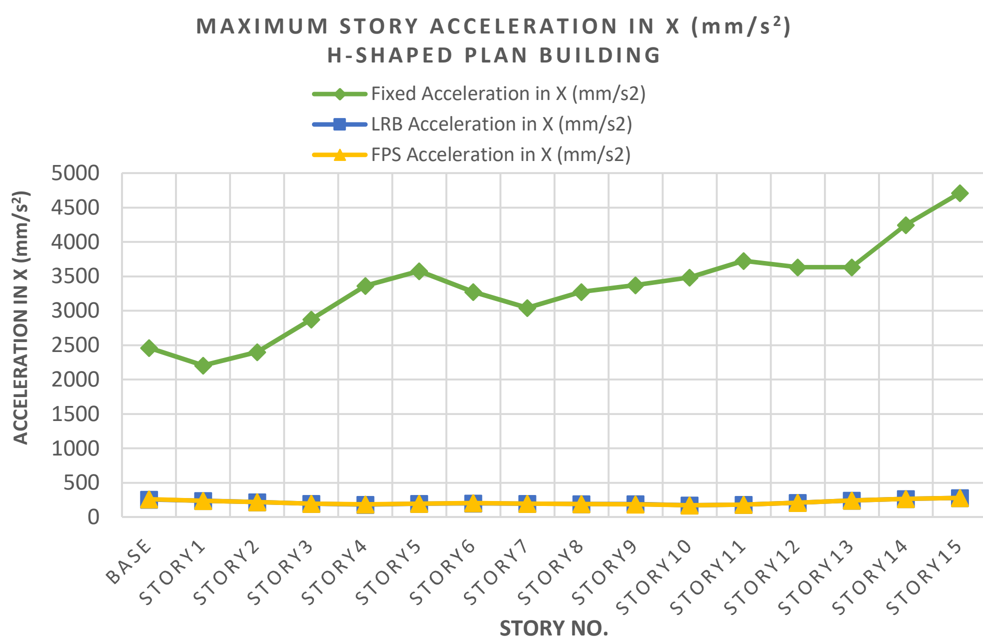


Figure 6.32. Story Acceleration in X of H-Shaped Plan Building with Fixed, LRB & FPS Base

TABLE 6.23 MAXIMUM STORY ACCELERATION IN H-SHAPED PLAN BUILDING IN Y

Story No.	Fixed Base Story Acceleration in Y (mm/s^2)	LRB Base Story Acceleration in Y (mm/s^2)	Reduction% (Fixed & LRB)	FPS Base Story Acceleration in Y (mm/s^2)	Reduction% (Fixed & FPS)
Story15	4413.07	276.9	93.73	276.58	93.73
Story14	4006.98	257.98	93.56	257.64	93.57
Story13	3358.83	237.33	92.93	236.96	92.95
Story12	3412.94	208.06	93.90	207.71	93.91
Story11	3411.3	189.33	94.45	188.97	94.46
Story10	3180.9	182.27	94.27	183.55	94.23
Story9	3088.44	180.43	94.16	179.81	94.18
Story8	3275.7	191.56	94.15	191.58	94.15
Story7	3023.65	192.77	93.62	193.44	93.60
Story6	3328.18	202.22	93.92	203.07	93.90
Story5	3671.76	204.65	94.43	205.86	94.39
Story4	3462.71	194.92	94.37	196.43	94.33
Story3	2906.28	202.01	93.05	202.84	93.02
Story2	2388.24	221.94	90.71	221.62	90.72
Story1	2206.51	250.57	88.64	249.99	88.67
Base	2461.11	271.81	88.96	271.03	88.99

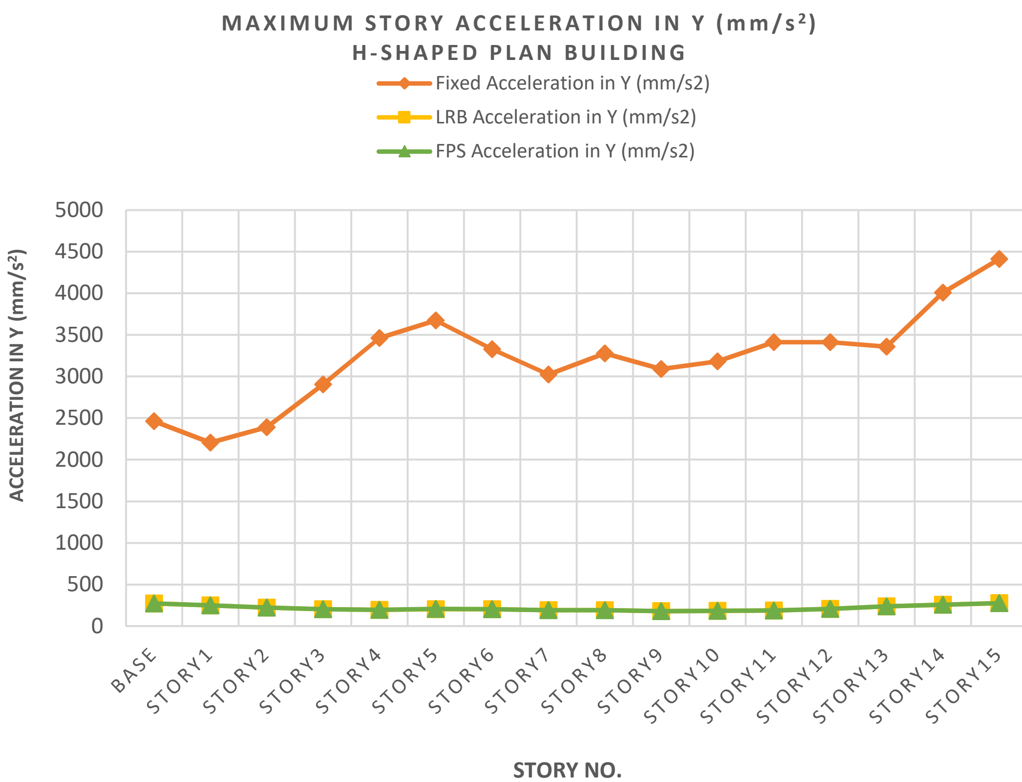


Figure 6.33. Story Acceleration in Y of H-Shaped Plan Building with Fixed, LRB & FPS Base

(iv) Maximum Base Shear

The maximum horizontal lateral force arises at the base of the building due to the considered ground motion data of El Centro at a particular time interval for all type of base such as fixed, LRB and FPS of H-shaped plan building in X-direction (due to TH-X load case) is shown below in fig. 6.34, fig. 6.35 and fig. 6.36 and in Y-direction (due to TH-Y load case) is shown in fig. 6.37, fig. 6.38 and fig. 6.39 respectively through the seismograph of base shear and the crest of the graphs define the maximum base shear of the building at particular time interval in X & Y which is shown in table 6.24 & table 6.25 respectively for all type of base:

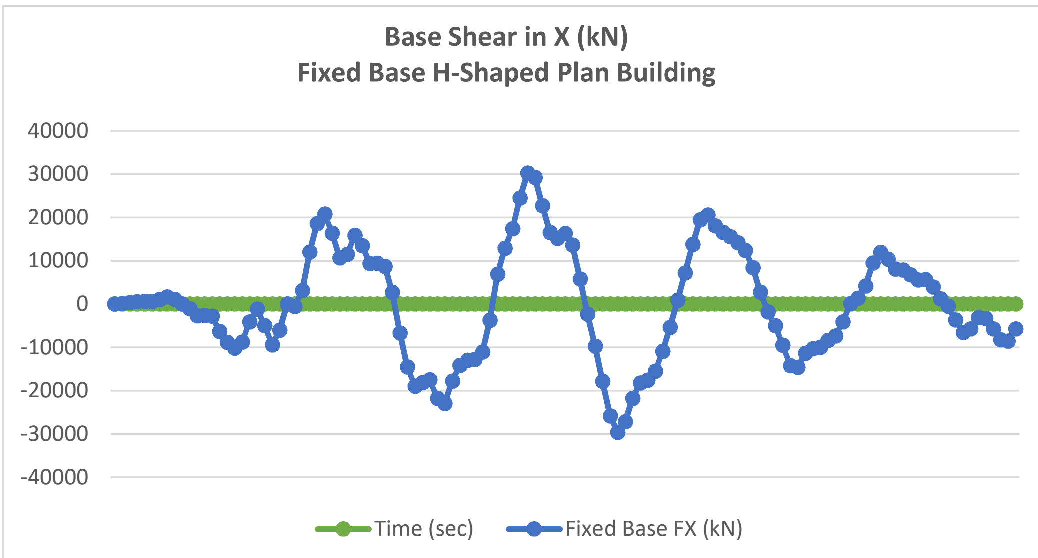


Figure 6.34. Base Shear in X of fixed base H-shaped plan building

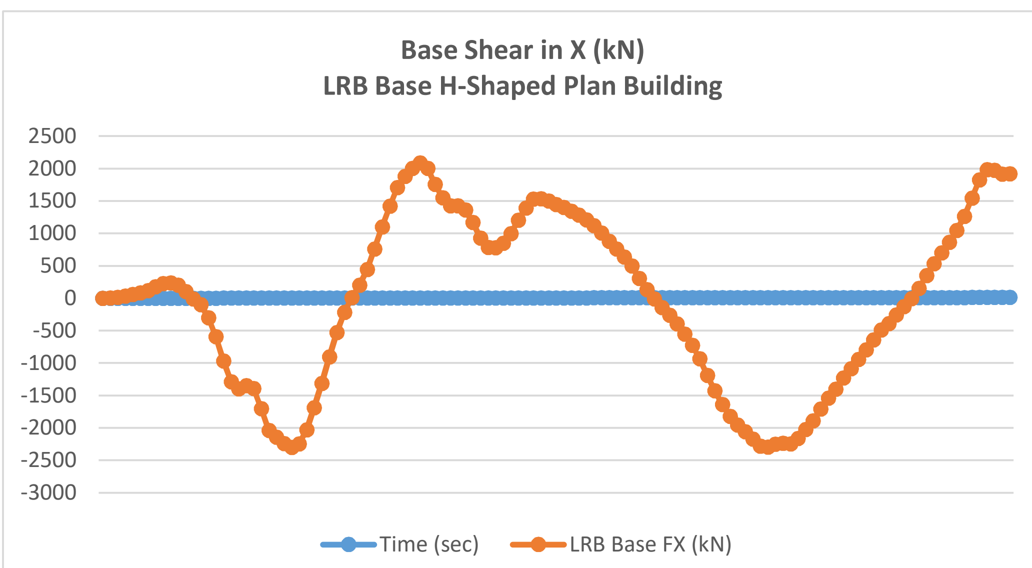


Figure 6.35. Base Shear in X of LRB base H-shaped plan building

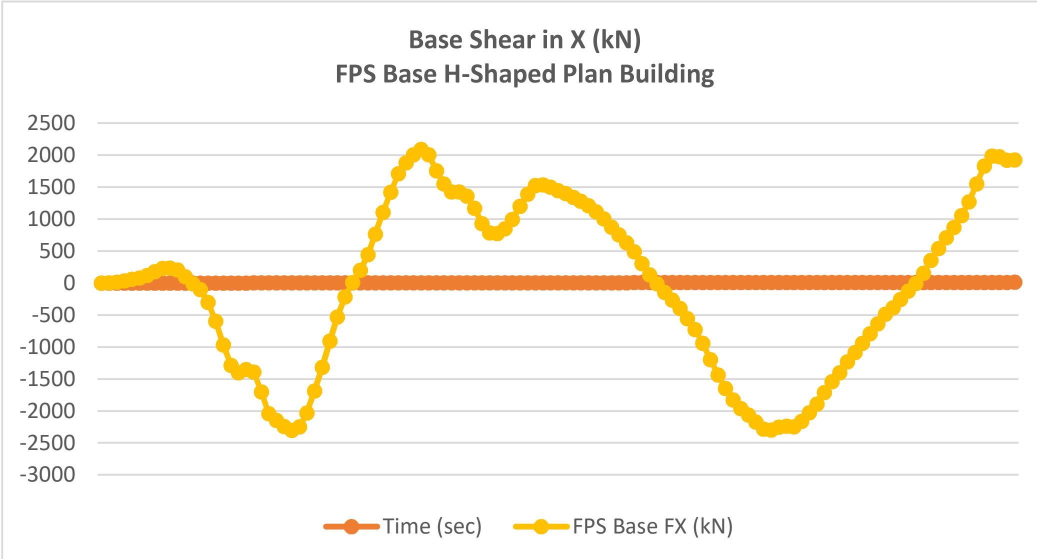


Figure 6.36. Base Shear in X of FPS base H-shaped plan building

TABLE 6.24 MAXIMUM BASE SHEAR OF H-SHAPED PLAN BUILDING IN X

Maximum Base Shear of H-Shaped Plan Building in X (kN)			Reduction% b/w Fixed & LRB FX	Reduction% b/w Fixed & FPS FX
FIXED BASE FX	LRB BASE FX	FPS BASE FX		
30268.435	2086.716	2089.763	93.11	93.10

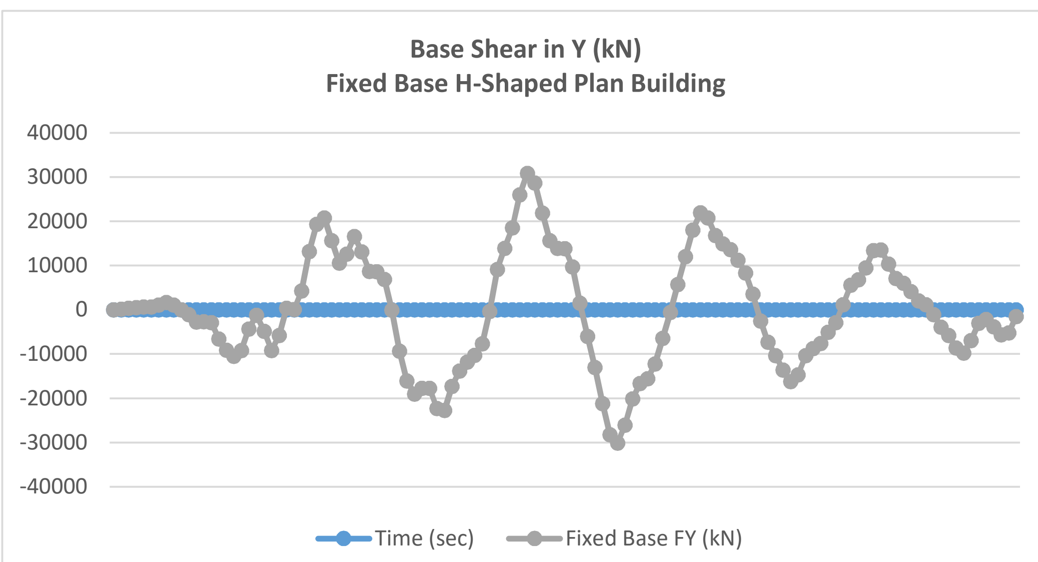


Figure 6.37. Base Shear in Y of Fixed Base H-shaped plan building

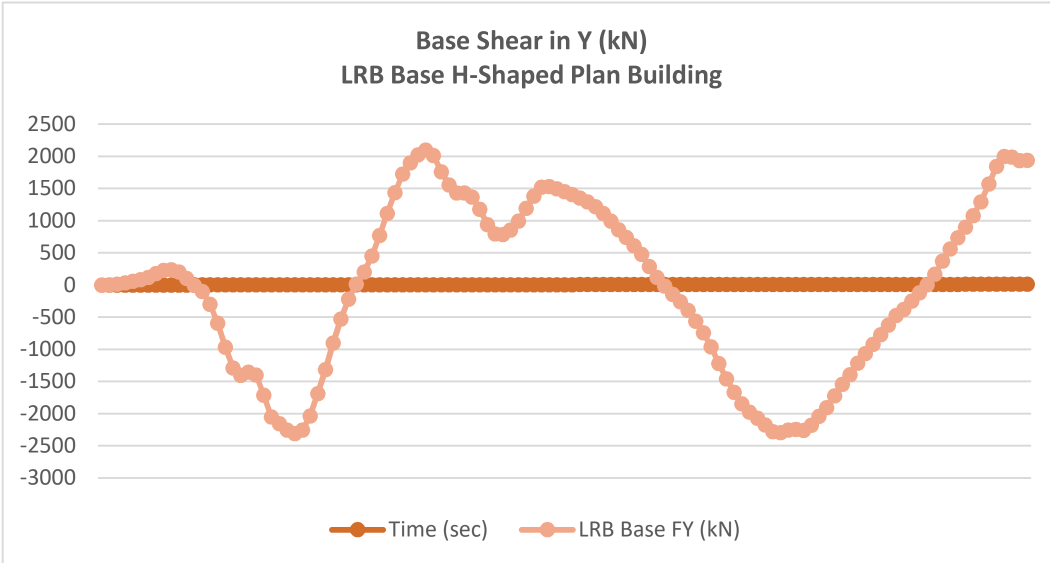


Figure 6.38. Base Shear in Y of LRB Base H-shaped plan building

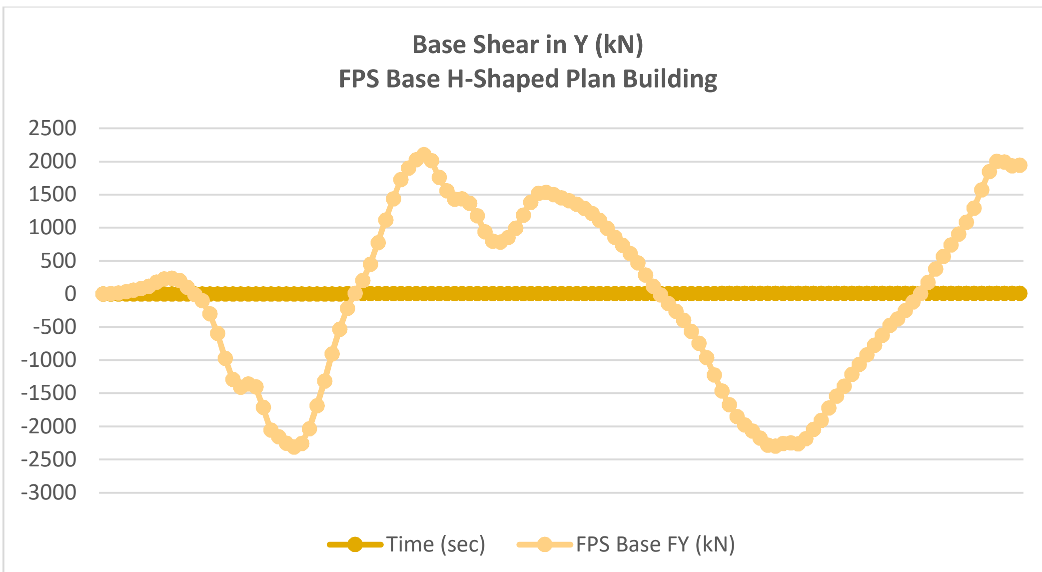


Figure 6.39. Base Shear in Y of FPS Base H-shaped plan building

TABLE 6.25 MAXIMUM BASE SHEAR OF H-SHAPED PLAN BUILDING IN Y

Maximum Base Shear of H-Shaped Plan Building in Y (kN)			Reduction% b/w Fixed & LRB FY	Reduction% b/w Fixed & FPS FY
FIXED BASE FY	LRB BASE FY	FPS BASE FY		
30829.888	2100.558	2102.567	93.19	93.18

(v) Maximum Absolute Joint acceleration

The maximum absolute joint acceleration generated at the top story of the H-shaped plan building with fixed base, LRB base and FPS base due to selected ground motion in X direction (due to TH-X load case) are shown in fig. 6.40, fig. 6.41 and fig. 6.42 and in Y direction (due to TH-Y load case) are shown in fig. 6.43, fig. 6.44 and fig. 6.45 respectively as seismograph at different time interval and the crest of the graph defines the maximum joint acceleration of the story at a particular time. The maximum joint acceleration values are different for different base of H-shaped plan building and shown in table 6.26 & table 6.27 and compared with the fixed base building in X & Y-direction individually:

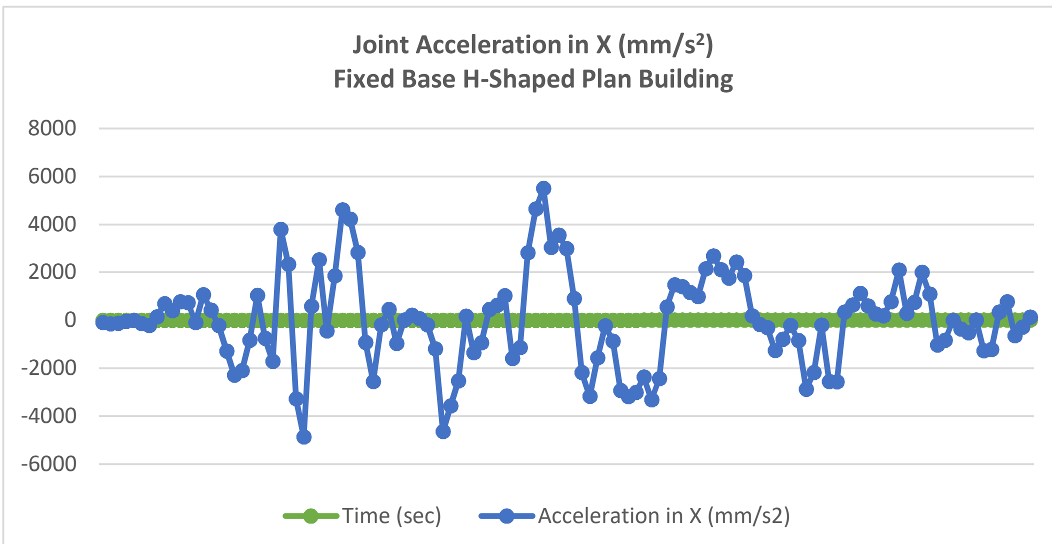


Figure 6.40. Top story Joint acceleration in X of Fixed Base H-shaped plan building

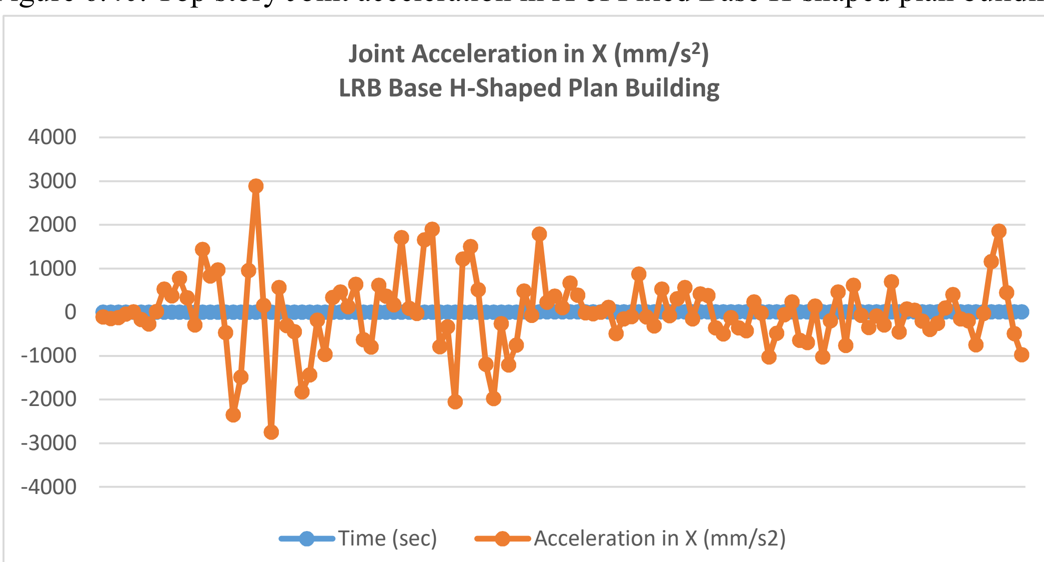


Figure 6.41. Top story Joint acceleration in X of LRB Base H-shaped plan building

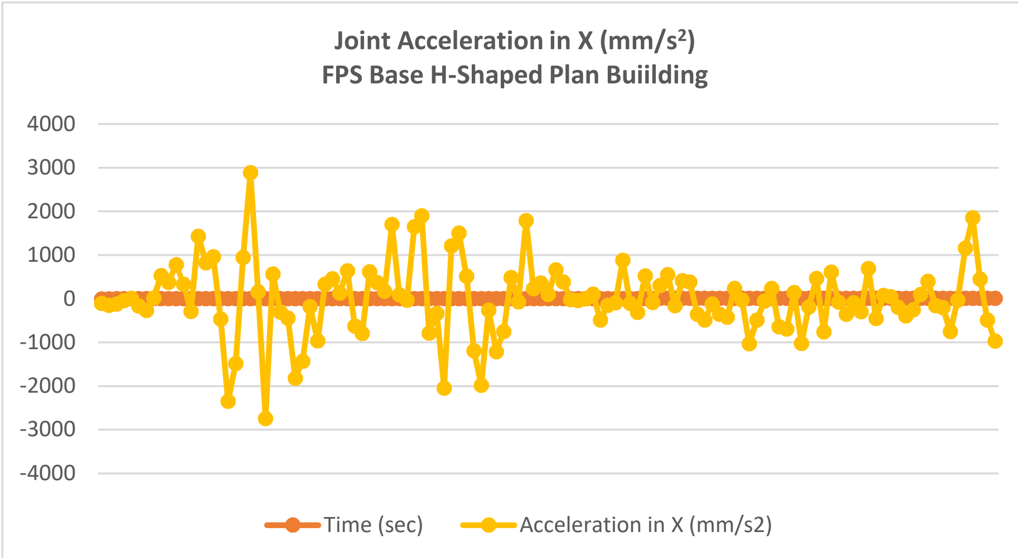


Figure 6.42. Top story Joint acceleration in X of FPS Base H-shaped plan building

TABLE 6.26 MAXIMUM JOINT ACCELERATION OF H-SHAPED PLAN BUILDING IN X

Maximum Joint acceleration of H-Shaped Plan Building in X (mm/s^2)			Reduction% b/w Fixed & LRB X	Reduction% b/w Fixed & FPS X
FIXED BASE X	LRB BASE X	FPS BASE X		
5509.13	2886.21	2886.81	47.61	47.60

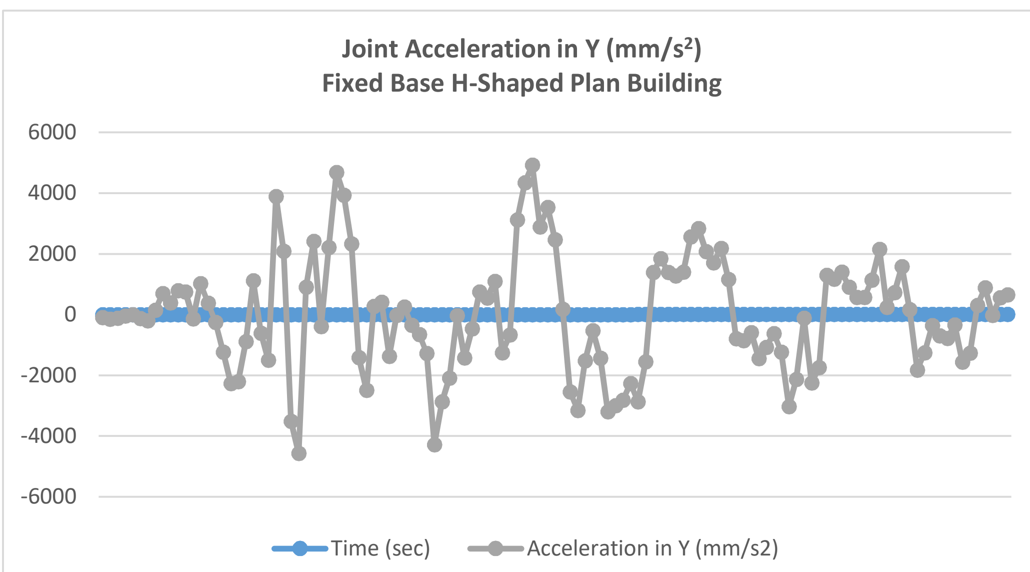


Figure 6.43. Top story Joint acceleration in Y of Fixed Base H-shaped plan building

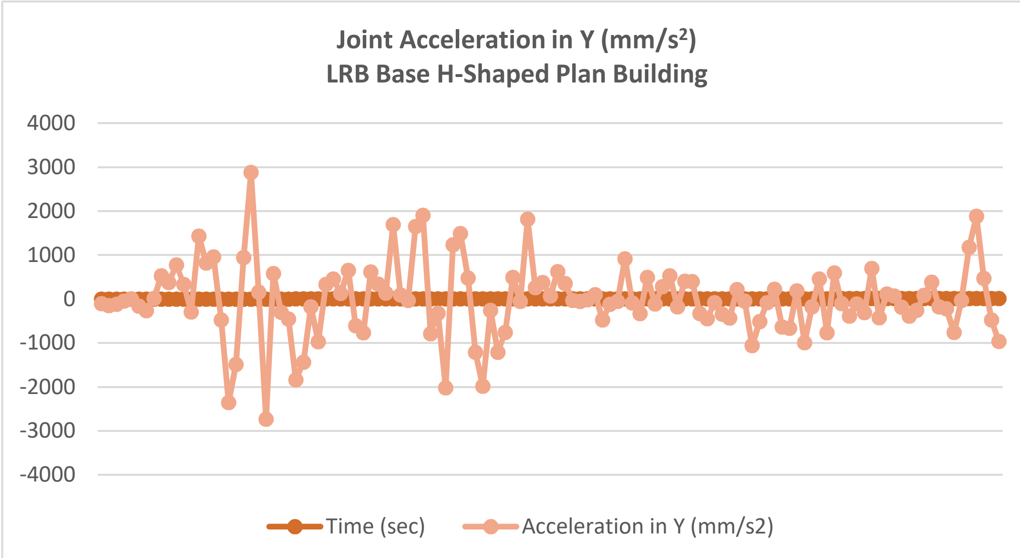


Figure 6.44. Top story Joint acceleration in Y of LRB Base H-shaped plan building

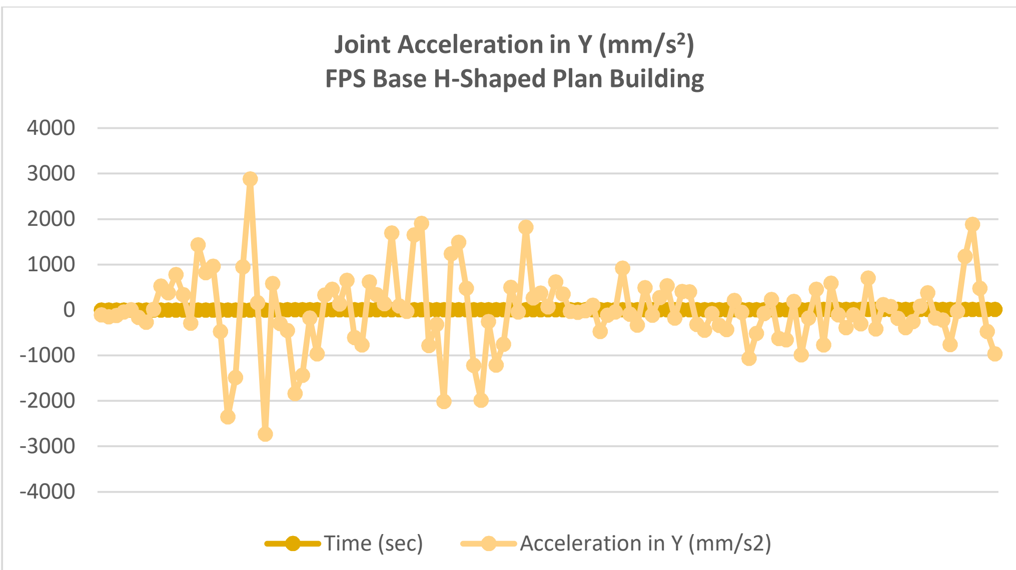


Figure 6.45. Top story Joint acceleration in Y of FPS Base H-shaped plan building

TABLE 6.27 MAXIMUM JOINT ACCELERATION OF H-SHAPED PLAN BUILDING IN Y

Maximum Joint acceleration of H-Shaped Plan Building in Y (mm/s^2)			Reduction% b/w Fixed & LRB Y	Reduction% b/w Fixed & FPS Y
FIXED BASE Y	LRB BASE Y	FPS BASE Y		
4925.63	2883.44	2883.99	41.46	41.45

(vi) Modal Time Period

The time taken by the building to complete one oscillation in the first mode shape of the building. It is different for different base of H-shaped plan building and are shown in table 6.28 below:

TABLE 6.28 MODAL PERIOD OF H-SHAPED PLAN BUILDING

Modal Period T of H-Shaped Plan Building (sec)			Amplification%	Amplification%
Fixed Base	**LRB Base**	**FPS Base**	**(Fixed & LRB)**	**(Fixed & FPS)**
2.421	7.843	7.840	69.13	69.11

CHAPTER 7

(DISCUSSION & CONCLUSION)

7.1 Discussion

Three different plan shape such as square, rectangular and H-shaped 15 story building of approx. similar plan area with fixed base and LRB & FPS type isolated base has been considered. The building element size and material is same in all type of buildings and estimated properties of LRB & FPS type base isolation is taken from the base-paper. The ground motion data of El Centro City is considered for the study and it is assumed that the earthquake waves are striking normally.

Time history analysis has been done on Square Plan Building, Rectangular Plan Building and H-Shaped Plan Building with fixed base and LRB & FPS type base isolations and the responses recorded through this analysis are such as Maximum Story Displacement, Maximum Story Drift, Maximum Story Acceleration, Maximum Base Shear, Maximum Absolute Joint acceleration in Top Story and Modal Time Period. These responses recorded in a particular direction due to particular time history load case and compared on the basis of similar plan of the building. All the responses compared for similar direction in which time history load cases are applied.

7.2 Conclusions

- The maximum story displacement of the top story in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is reduced as compared to fixed type bases of these buildings.
- The maximum story drift in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is also reduced as compared to fixed type bases of these buildings.
- The maximum story acceleration in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is highly reduced as compared to fixed type bases of these buildings.
- The maximum base shear in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is also reduced as compared to fixed type bases of these buildings.

➢ The maximum absolute joint acceleration of top story in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is also reduced as compared to fixed type bases of these buildings.

➢ The modal time period of first mode shape in case of LRB & FPS type isolated base square plan building, rectangular plan building and H-shaped plan building is amplified as compared to fixed bases of these buildings.

➢ Hence we can say that the base isolation such as LRB and FPS perform better and amplifies the structural flexibility and stability during the earthquake ground motion as compared to fixed base building. The base isolation enhances the modal time period of the building during the earthquake and reduces the parameters which can cause harm to the structure during the earthquake. A general comparative overview of fixed base versus isolated base is given through following table 7.1:

TABLE 7.1 COMPARATIVE OVERVIEW OF FIXED BASE VERSUS ISOLATED BASE

S. No.	Comparison of Parameters		
	Parameters	***Fixed Base Buildings***	***Base Isolated Buildings***
1.	Stiffness	Higher	Lesser
2.	Storey Drift	Greater	Lesser
3.	Lateral Displacement at the Base	= 0	> 0
4.	Storey Displacement	Lesser	Higher
5.	Time Period	Shorter	Longer
6.	Joint & Story acceleration	High	Less
7.	Base Shear	Higher	Lesser

➢ In context of base isolations, we can say that FPS perform better than LRB type base isolation because in case of square plan building the maximum story displacement of top story reduced by LRB is good as compared to fixed base building but we can also notice that the maximum story displacement of top story reduced by the FPS is far better than LRB reduction.

- Also, we can notice that the LRB and FPS perform quite similar with respect to each other in case of rectangular plan and H-shaped plan building because there is not enough difference in the responses of these building with LRB and FPS type base isolation.
- Hence on the basis of maximum top story displacement of square plan building we can say that FPS perform better during earthquake as compared to LRB type base isolation.
- Story acceleration and absolute joint acceleration is completely different from each other. The maximum story acceleration shows the behaviour of maximum acceleration for a particular story whereas the maximum absolute joint acceleration shows the behaviour of maximum acceleration for particular joint of a particular story. In this study we can see that the maximum story acceleration is lesser than as that of maximum absolute joint acceleration at the top story in case of all the buildings analysed.

CHAPTER 8

(FUTURE SCOPE)

8.1 Possibilities

As we have discussed about different shapes of plan with and without base isolations and compared their responses with traditional buildings, researchers can also consider more different shapes of plan with other different types of base isolation and can compare the responses. One can also do the same study with changing the position and properties of isolators. In earthquake engineering there is endless possibilities of application and study of seismic isolation with different ground motions and their impact on the structures, economy and mankind and due to endless opportunity of research in this field, it will always be an interesting and attractive area for the structural engineers.

8.2 Scope

The innovation of base isolation technology in the area of structural engineering is something like a boon for the engineers. With the help of base isolation technology engineers can build tallest and undulated designed structures in the active seismic zones and also on undulated ground surfaces which cannot be possible without the introduction of seismic isolation technology in area of civil engineering. Earthquake engineering is a branch of civil engineering and it becomes broader with the introduction of base isolation technology because it is opening the untouched areas of seismic design and evolving more different structural possibilities in the area of structural engineering.

The research towards the new materials for base isolators has a brighter scope in future. The enhancement in the present isolation system will make the structure more stable during seismic ground motion so it is also being the topic of interest for the researchers. As we have discussed earlier, in the area of seismic design, earthquake engineering and seismic isolation there is endless possibilities for innovating something new hence it is giving lots of opportunity to the recent researcher to invent new technologies to make structure more stable during the high magnitude earthquake to save the life and money and to give their valuable part in advancement of civil society and for improving the hazard free future.

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PLAGIARISM REPORT

The work has been done in this thesis by Abhishek Mishra under the supervision of Mr. Faheem Ahamd Khan on the topic *"Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings"* is an original research work with **12%** similarity index in its written content which has been analyzed by an authorised plagiarism checker *URKUND*.

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LIST OF PUBLICATIONS

[1] Abhishek Mishra, Faheem Ahmad Khan, Shubhranshu Jaiswal, *"A Review on Seismic Analysis of Base Isolated Regular and Irregular Multistory Buildings"*. **International Conference on Advances in Computational Technologies in Science and Engineering (ACTSE-2020) Amity University, Lucknow. (Accepted)**

My review research paper has been **accepted** for publication with ISBN in Conference Proceeding by **Cambridge Scholars Publishing** listed in the Clarivate Analytics **Web of Science** Master Book List. The conference was scheduled on 18th & 19th March 2020 but it has been postponed as a preventive measure to combat the Coronavirus (COVID-19), as per guidelines of University Grants Commission (UGC). Fresh date of conference ACTSE-2020 will be intimated very soon.

[2] Abhishek Mishra, Faheem Ahmad Khan, *"Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings"*. **12th Structural Engineering Convention (SEC2020) Organized by National Centre for Disaster Mitigation & Management, Malaviya National Institute of Technology, Jaipur. (Submitted)**

[3] Abhishek Mishra, Faheem Ahmad Khan, Madan Chandra Maurya, *"Soil Condition Influence on Seismic Responses of Base-Isolated Buildings"*. **National Conference on Recent Advances in Structural Engineering (NCRASE-2020) organized by Department of Civil Engineering, National Institute of Technology, Jamshedpur. (Accepted)**

CURRICULUM VITAE

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Career Objective:

To work in tandem with a team in a challenging and competitive environment where I could improve my knowledge and capabilities would be put to use for the development of the organization and for the development of my nation.

Academic Summary:

Course	Branch/Subjects	Year	Board/University	Percentage/CGPA
Post-Graduation	Structural Engineering	2020	BBD University	8.217 CGPA (Pursuing)
Graduation	Civil Engineering	2017	AKTU	64.26%
Intermediate	PCM	2012	CBSE	69.00%
High School	Science	2010	CBSE	8.20 CGPA

Technical Skills:

Drafting Software: Autodesk AutoCAD 2D & 3D (Autodesk Certified)
3D Modelling Software: ETABS v17 and v18 for Structural Analysis
Windows Application: MS Office, Advance Excel
Text Editor: Notepad.

Projects:

PROJECT	METHOD	DESCRIPTION
Soil Condition Influence on Seismic Responses of Base-Isolated Buildings (2020)	Software: ETABS v 17.0.1 Time History Analysis with El Centro ground motion data with soil I, II & III considering IS 1893:2016	*This project uses dynamic time history analysis with different soil and the objective of this project is to prevent the structure from collapse in seismic prone zone subjected to hazardous earthquake and saving life and economy.*

Effect of Floor Plan Shape on Seismic Responses of Base-Isolated Buildings (2020)	Software: ETABS v 17.0.1 Time History Analysis with El Centro ground motion data considering IS 1893:2016	*This project uses linear dynamic time history analysis and the objective of this project is to prevent the structure from collapse in seismic prone zone subjected to hazardous earthquake and saving life and economy.*
A Review on Seismic Analysis of Regular and Irregular Base-Isolated Buildings (2019)	Survey on different researches on irregularity and base-isolation techniques in building construction subjected to earthquake.	*To understand the problems and solution of irregular buildings with and without base-isolators during earthquake and conclude the best technique for resolving such issues.*
Traffic Intensity and Air Pollution in different areas of Lucknow city (2017)	Manually, by tracing the traffic daily up to 30 days into tabular form on the basis of vehicle type in different areas for a selected time interval and comparing the air pollution.	*To measure the impact of traffic and vehicles on the air pollution of a metropolitan city.*

Training & Workshop:

- Summer Training for the duration of 5 weeks from June 11th 2015 to July 15th 2015 at **Public Work Department**, Gorakhpur.
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- Participated in a seminar on **ACC Cement** on November 16th, 2015 at SRMCEM, Lucknow.
- Summer Training in construction work of **Amaravati Housing Scheme**, **Vasundhara Housing Scheme** and **Lohia Enclave Housing Scheme** operated by **Gorakhpur Development Authority (GDA)**, Gorakhpur for the duration of 1 month from June 8th 2016 to July 7th 2016.
- Participated in a workshop on **REVIT & 3DS Max** on September 6th, 2016 at SRMCEM, Lucknow.
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- Co-ordinator of the event PRO-CIVIL in a national level Tech-Fest GANTAVYA 2K16 organised at SRMCEM, Lucknow.
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- Participated in the event BUST-ER in a national level Tech-Fest GANTAVYA 2K15 organised at SRMCEM, Lucknow.
- Participated in the event CHEM-E-CAR in a national level Tech-Fest GANTAVYA 2K15 organised at SRMCEM, Lucknow.
- Participated in the event Beg-Borrow-Buy in a college cultural-fest ABHIVYAKTI 2K14 organised at SRMCEM, Lucknow.

Publication:

1. Abhishek Mishra, Faheem Ahmad Khan, Shubhranshu Jaiswal, **"A Review on Seismic Analysis of Base Isolated Regular and Irregular Multistory Building".** International Conference on Advances in Computational Technologies in Science and Engineering ACTSE 2020 at Amity University, Lucknow Campus (UP). The review research paper has been accepted as regular paper and will be published with ISBN in Conference Proceeding by Cambridge Scholars Publishing listed in the Clarivate Analytics Web of Science Master Book List.
2. Abhishek Mishra, Faheem Ahmad Khan, Madan Chandra Maurya, **"Soil Condition Influence on Seismic Responses of Base-Isolated Buildings".** National Conference on Recent Advances in Structural Engineering NCRASE 2020 at National Institute of Technology (NIT), Jamshedpur, Jharkhand. The research paper has been accepted for oral presentation in the conference and will be published in proceedings of Springer Publications.

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Declaration:

I hereby declare that the information provided above is correct to the best of my knowledge.

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