SEISMIC ANALYSIS AND DESIGN OF VERTICALLY IRREGULAR RC BUILDING FRAMES

A thesis submitted by

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CERTIFICATE

This is to certify that this thesis entitled "SEISMIC ANALYSIS AND DESIGN OF VERTICALLY IRREGULAR RC BUILDING FRAMES" submitted by **Ankesh Sharma(109CE0062)** and **Biswobhanu Bhadra(109CE0033)** in partial fulfillment for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Date-10th May,2013

Prof. K.C. Biswal

Department of Civil Engineering

(Project Guide)

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ABSTRACT

This paper is concerned with the effects of various vertical irregularities on the seismic response of a structure. The objective of the project is to carry out Response spectrum analysis (RSA) and Time history Analysis (THA) of vertically irregular RC building frames and to carry out the ductility based design using IS 13920 corresponding to Equivalent static analysis and Time history analysis. Comparison of the results of analysis and design of irregular structures with regular structure was done. The scope of the project also includes the evaluation of response of structures subjected to high, low and intermediate frequency content earthquakes using Time history analysis. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. According to our observation, the storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The mass irregular structures were observed to experience larger base shear than similar regular structures. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts. The absolute displacements obtained from time history analysis of geometry irregular structure at respective nodes were found to be greater than that in case of regular structure for upper stories but gradually as we moved to lower stories displacements in both structures tended to converge. Lower stiffness results in higher displacements of upper stories. In case of a mass irregular structure, time history analysis gives slightly higher displacement for upper stories than that in regular structures whereas as we move down lower stories show higher displacements as compared to that in regular structures. When time history analysis was done for regular as well as stiffness irregular structure, it was found that displacements of upper stories did not vary much from each other but as we moved down to lower stories the absolute displacement in case of soft storey were higher compared to respective stories in regular structure. Tall structures were found to have low natural frequency hence their response was found to be maximum in a low frequency earthquake. It is because low natural frequency of tall structures subjected to low frequency earthquake leads to resonance resulting in larger displacements. If a high rise structure (low natural frequency) is subjected

to high frequency ground motion then it results in small displacements. Similarly, if a low rise structure (high natural frequency) is subjected to high frequency ground motion it results in larger displacements whereas small displacements occur when the high rise structure is subjected to low frequency ground motion.

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INTRODUCTION

1.1 INTRODUCTION:

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the 'regular' building.

IS 1893 definition of Vertically Irregular structures:

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated. There are two types of irregularities-

1. **Plan Irregularities**
2. **Vertical Irregularities**.

Vertical Irregularities are mainly of five types-

i a) Stiffness Irregularity — Soft Storey-A soft storey is one in which the lateral stiffness is less than 70 percent of the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

b) Stiffness Irregularity — Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storeys above.

ii) Mass Irregularity-Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. In case of roofs irregularity need not be considered.

iii) Vertical Geometric Irregularity- A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

iv) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force-An in-plane offset of the lateral force resisting elements greater than the length of those elements.

v) Discontinuity in Capacity — Weak Storey-A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.

As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of limited height as in this process lateral forces are calculated as per code based fundamental time period of the structure. Linear dynamic analysis are an improvement over linear static analysis, as this analysis produces the effect of the higher modes of vibration and the actual distribution of forces in the elastic range in a better way.

Buildings are designed as per Design based earthquake, but the actual forces acting on the structure is far more than that of DBE. So, in higher seismic zones Ductility based design approach is preferred as ductility of the structure narrows the gap. The primary objective in designing an earthquake resistant structures is to ensure that the building has enough ductility to withstand the earthquake forces, which it will be subjected to during an earthquake.

1.2 OBJECTIVES:

1. To calculate the design lateral forces on regular and irregular buildings using response spectrum analysis and to compare the results of different structures.
2. To study three irregularities in structures namely mass, stiffness and vertical geometry irregularities.
3. To calculate the response of buildings subjected to various types of ground motions namely low, intermediate and high frequency ground motion using Time history analysis and to compare the results.
4. To carry out ductility-based earthquake-resistant design as per IS 13920 corresponding to equivalent static analysis and time history analysis and to compare the difference in design.

1.3 SCOPE OF THE STUDY:

1. Only RC buildings are considered.
2. Only vertical irregularity was studied.
3. Linear elastic analysis was done on the structures.
4. Column was modeled as fixed to the base.
5. The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account.
6. The effect of soil structure interaction is ignored.

1.4 METHODOLOGY:

1. Review of existing literatures by different researchers.
2. Selection of types of structures.
3. Modelling of the selected structures.
4. Performing dynamic analysis on selected building models and comparison of the analysis results.
5. Ductility based design of the buildings as per the analysis results

1.4.1 ANALYSIS METHODS:

SEISMIC ANALYSIS:

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. In the past the buildings were designed just for gravity loads and seismic analysis is a recent development. It is a part of structural analysis and a part of structural design where earthquake is prevalent.

There are different types of earthquake analysis methods. Some of them used in the project are-

I. **Equivalent Static Analysis**
II. **Response Spectrum Analysis**
III. **Time History Analysis**

EQUIVALENT STATIC ANALYSIS:

The equivalent static analysis procedure is essentially an elastic design technique. It is, however, simple to apply than the multi-model response method, with the absolute simplifying assumptions being arguably more consistent with other assumptions absolute elsewhere in the design procedure.

The equivalent static analysis procedure consists of the following steps:

1. Estimate the first mode response period of the building from the design response spectra.
2. Use the specific design response spectra to determine that the lateral base shear of the complete building is consistent with the level of post-elastic (ductility) response assumed.
3. Distribute the base shear between the various lumped mass levels usually based on an inverted triangular shear distribution of 90% of the base shear commonly, with 10% of the base shear being imposed at the top level to allow for higher mode effects.

RESPONSE SPECTRUM ANALYSIS:

This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except for very simple or very complex structures. The structural response can be defined as a combination of many modes. Computer analysis can be used to determine these modes for a structure. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and the modal mass, and then they are combined to estimate the total response of the structure. In this the magnitude of forces in all directions is calculated and then effects on the building is observed. Following are the types of combination methods:

- absolute - peak values are added together
- square root of the sum of the squares (SRSS)
- complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes

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

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

TIME HISTORY ANALYSIS:

Time history analysis techniques involve the stepwise solution in the time domain of the multidegree-of-freedom equations of motion which represent the actual response of a building. It is the most sophisticated analysis method available to a structural engineer. Its solution is a direct function of the earthquake ground motion selected as an input parameter for a specific building. This analysis technique is usually limited to checking the suitability of assumptions made during the design of important structures rather than a method of assigning lateral forces themselves.
The steps involved in time history analysis are as follows:

1. Calculation of Modal matrix
2. Calculation of effective force vector
3. Obtaining of Displacement response in normal coordinate
4. Obtaining of Displacement response in physical coordinate
5. Calculation of effective earthquake response forces at each storey.
6. Calculation of maximum response

1.4.2 DESIGN METHOD

DUCTILITY BASED DESIGN:

Ductility in the structures results from inelastic material behavior and reinforcement detailing such that brittle fracture is prevented and ductility is introduced by allowing steel to yield in a controlled manner. Thus the chief task is to ensure that building has adequate ductility to withstand the effects of earth quakes, which is likely to be experienced by the structure during its lifetime. Ductility of the structure acts as a shock absorber and reduces the transmitted forces to the structure. the ductility of a structure can assessed by-

- Displacement ductility
- Rotational and Curvature ductility
- Structural ductility

Ductility is the capability of a material to undergo deformation after its initial yield without any significant reduction in yield strength.

The factors which affect the ductility of a structure are as follows-

- Ductility increases with increase in shear strength of concrete for small axial compressive stress between 0-1MPa.The variation is linear in nature.
- Ductility varies linearly up to the point when axial compressive stress becomes equal to the compressive stress at balanced failure.
- The ductility factor increases with increase in ultimate strain of concrete. Thus confinement of concrete increases ductility.
- The ductility increases with increase in concrete strength and decreases with the increase in yield strength of steel.

- The effect of lateral reinforcement is to enhance the ductility by preventing the shear failure .It also restrains the compression reinforcement from buckling.

Requirements of ductility:

- It allows the structure to develop its maximum potential strength through distribution of internal forces.
- Structural ductility allows the structure as a mechanism under its maximum potential strength resulting in the dissipation of large amount of energy.

  IS 13920 was followed for ductility based design.

1.5 ORGANISATION OF THESIS:

The first chapter of thesis covers the introduction, objectives of the project, scope of study, methodology, analysis methods employed and finally design technique involved. The first chapter shows the importance of seismic analysis of structures and the requirement of an efficient design technique. It provides an overview of the analysis methods followed along with the importance of ductility based design.

The second chapter encompasses the literature survey carried to gain an idea about research work done by various researchers and scientists on topics related to the project. This included works by various researchers from 1997 to 2012.

The third chapter involves the results and discussions of analysis methods and design method followed. Firstly, response spectrum analysis was carried for three types of irregular structures namely mass irregular, stiffness regular and vertically geometry irregular and the storey shear forces were compared to that of a regular structure. Secondly, time history analysis was carried out for irregular structures considering three different kinds of ground motion namely low(Imperial),intermediate(IS code) and high frequency(San Francisco) and the results were compared. Lastly, design of irregular structures as per IS 13920 corresponding to Equivalent static analysis and Time history analysis was performed and the design results were compared.

The fourth and final chapter covers the conclusion and references of project. Under conclusion, the results have been presented in brief manner and references cover the papers, journals etc related to the project.

CHAPTER 2

LITERATURE REVIEW

Rajeeva and Tesfamariam (2012) Fragility based seismic vulnerability of structures with consideration of soft -storey (SS) and quality of construction (CQ) was demonstrated on three, five, and nine storey RC building frames designed prior to 1970s. Probabilistic seismic demand model (PSDM) for those gravity load designed structures was developed, using non-linear finite element analysis, considering the interactions between SS and CQ. The response surface method is used to develop a predictive equation for PSDM parameters as a function of SS and CQ. Result of the analysis shows the sensitivity of the model parameter to the interaction of SS and CQ.

Sarkar et al. (2010) proposed a new method of quantifying irregularity in vertically irregular building frames, accounting for dynamic characteristics (mass and stiffness). The salient conclusions were as follows:

(1)A measure of vertical irregularity, suitable for stepped buildings, called 'regularity index', is proposed, accounting for the changes in mass and stiffness along the height of the building.

(2) An empirical formula is proposed to calculate the fundamental time period of stepped building, as a function of regularity index.

Karavasilis et al. (2008)studied the inelastic seismic response of plane steel moment-resisting frames with vertical mass irregularity. The analysis of the created response databank showed that the number of storeys, ratio of strength of beam and column and the location of the heavier mass influence the height-wise distribution and amplitude of inelastic deformation demands, while the response does not seem to be affected by the mass ratio.

Athanassiadou (2008) concluded that the effect of the ductility class on the cost of buildings is negligible, while performance of all irregular frames subjected to earthquake appears to be equally satisfactory, not inferior to that of the regular ones, even for twice the design earthquake forces. DCM frames were found to be stronger and less ductile than the corresponding DCH ones. The over strength of the irregular frames was found to be similar to that of the regular ones, while DCH frames were found to dispose higher over strength than DCM ones. Pushover analysis seemed to underestimate the response quantities in the upper floors of the irregular frames.

Lee and Ko (2007) subjected three 1:12 scale 17-story RC wall building models having different types of irregularity at the bottom two stories to the same series of simulated earthquake excitations to observe their seismic response characteristics. The first model had a symmetrical moment-resisting frame (Model 1), the second had an infilled shear wall in the central frame (Model 2), and the third had an infilled shear wall in only one of the exterior frames (Model 3) at the bottom two stories. The total amounts of energy absorption by damage are similar regardless of the existence and location of the infilled shear wall. The largest energy absorption was due to overturning, followed by the shear deformation.

Devesh et al. (2006) agreed on the increase in drift demand in the tower portion of set-back structures and on the increase in seismic demand for buildings with discontinuous distributions in mass, strength and stiffness. The largest seismic demand was found for the combined stiffness and strength irregularity.
It was found out that seismic behavior is influenced by the type of model.

Shahrooz and Moehle (1990) undertook an experimental and analytical study to understand the earthquake response of setback structures. The experimental study involved design, construction, and earthquake simulation testing of a quarter- scale model of a multistory, reinforced concrete, setback frame. The analytical studies involved design and inelastic analysis of several multistory frames having varying degrees of setbacks. Among the issues addressed were:
(1) The influence of setbacks on dynamic response;
(2) The adequacy of current static and dynamic design requirements for setback buildings; and
(3)Design methods to improve the response of setback buildings.

Valmundsson and Nau(1997) evaluated the earthquake response of 5-, 10-, and 20story framed structures with non-uniform mass, stiffness, and strength distributions. The response calculated from TH analysis was compared with that predicted by the ELF procedure embodied in UBC. Based on this comparison, the aim was to evaluate the current requirements under which a structure can be considered regular and the ELF provisions applicable.

Das (2000) found that most of the structures designed by ELF method performed reasonably well. Capacity based criteria must be appropriately applied in the vicinity of the irregularity.

Sadjadi et al. (2007) presented an analytical approach for seismic assessment of RC frames using nonlinear time history analysis and push-over analysis. The

analytical models were validated against available experimental results and used in a study to evaluate the seismic behavior of these 5-story frames.

It was concluded that both the ductile and the less ductile frames behaved very well under the earthquake considered, while the seismic performance of the GLD structure was not satisfactory. The retrofitted GLD frame had improved seismic performance.

Kim and Elnashai (2009) observed that buildings that are seismically designed to contemporary codes would have survived the earthquake. But, the vertical motion would have significantly reduced the shear capacity in vertical members.

Duan et al. (2012)- According to the numerical results, the structures designed by GB50011-2010 provides the inelastic behavior and response intended by the code and satisfies the inter-storey drift and maximum plastic rotation limits recommended by ASCE/SEI 41-06. The push-over analysis indicated the potential for a soft first story mechanism under significant lateral demands.

Poonam et al. (2012)- Results of the numerical analysis showed that any storey, especially the first storey, must not be softer/weaker than the storeys above or below. Irregularity in mass distribution also contributes to the increased response of the buildings. The irregularities, if required to be provided, need to be provided by appropriate and extensive analysis and design processes.

Moehle found that standard limit analysis and static inelastic analysis provide good measures of strength and deformation characteristics under strong earthquake motions.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 RESPONSE SPECTRUM ANALYSIS:

Response Structure analysis was performed on regular and various irregular buildings using Staad-Pro. The storey shear forces were calculated for each floor and graph was plotted for each structure.

3.1.1 STRUCTURAL MODELLING:

SPECIFICATIONS:

Live Load	$3kN/m^2$
Density of RCC considered:	$25kN/m^3$
Thickness of slab	150mm
Depth of beam	400mm
Width of beam	350mm
Dimension of column	400x400mm
Density of infill	$20kN/m^3$
Thickness of outside wall	20mm
Thickness of inner partition wall	15mm
Height of each floor	3.5m
Earthquake Zone	IV
Damping Ratio	5%
Importance factor	1
Type of Soil	Rocky
Type of structure	Special Moment Resisting Frame
Response reduction Factor	5

Four types of Irregular buildings were considered, Regular structure, Mass irregular structure, structure with ground storey as the soft storey and vertically geometric irregular building. The first three structures were 10 storeyed.

1 Regular structure (10 storeys):

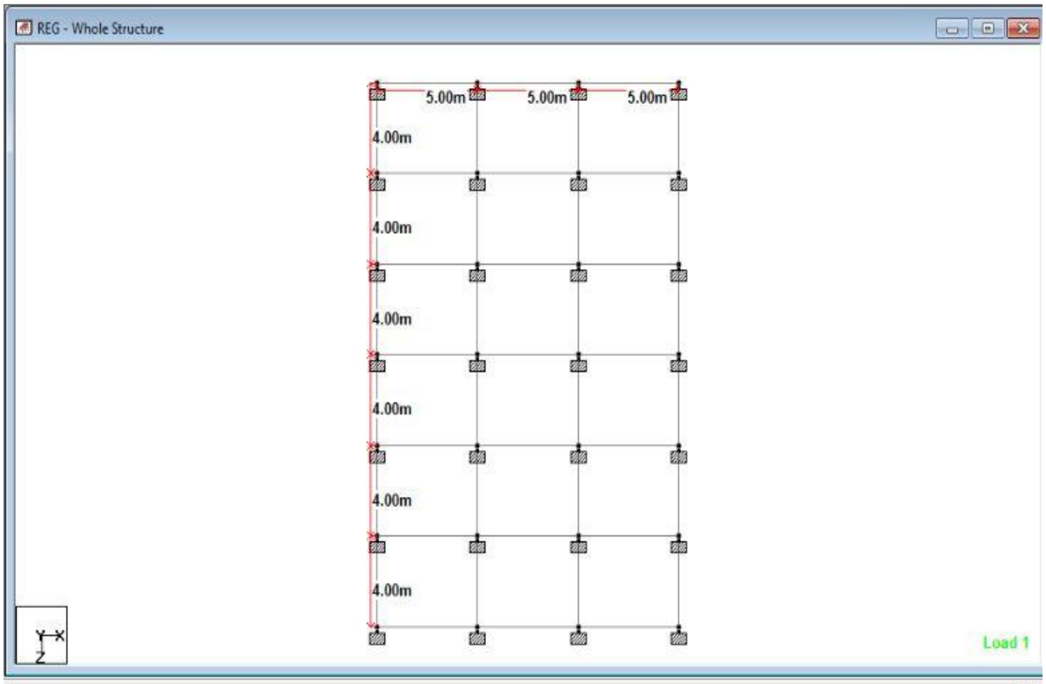


Fig 3.1: plan of regular structure (10 storeys)

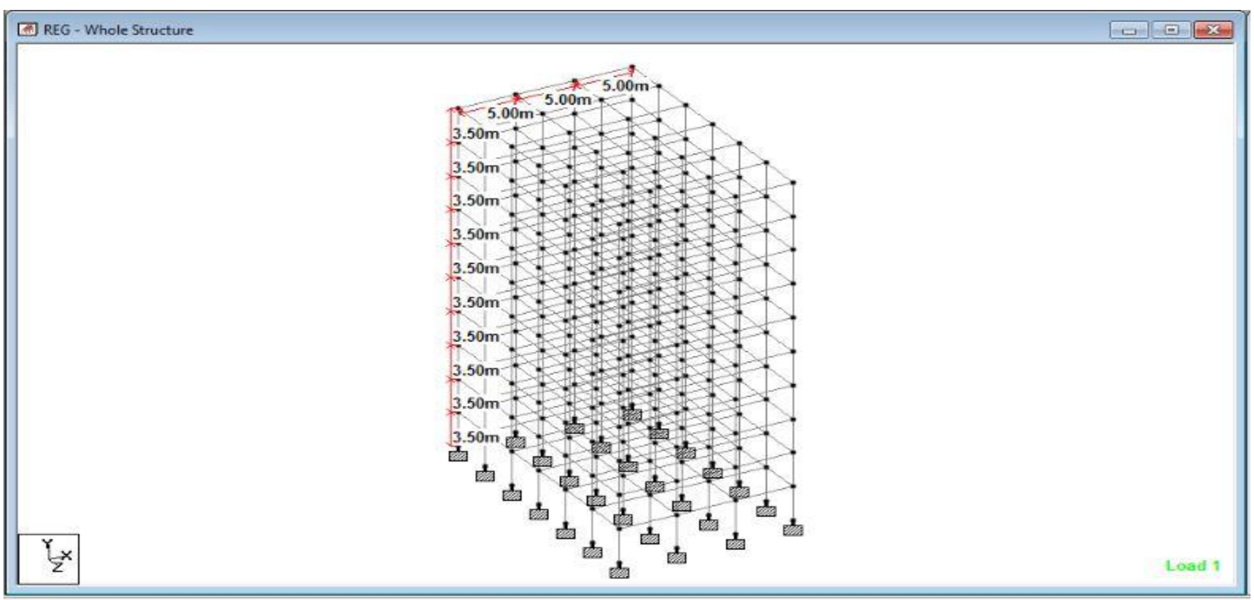


Fig 3.2: 3D view of regular structure (10 storeys)

2 **Mass Irregular Structure(10 storeys):** The structure is modeled as same as that of regular structure except the loading due to swimming pool is provide in the fourth and eighth floor.

Height of swimming pool considered- 1.8m

Loading due to swimming pool -18kN/m^2

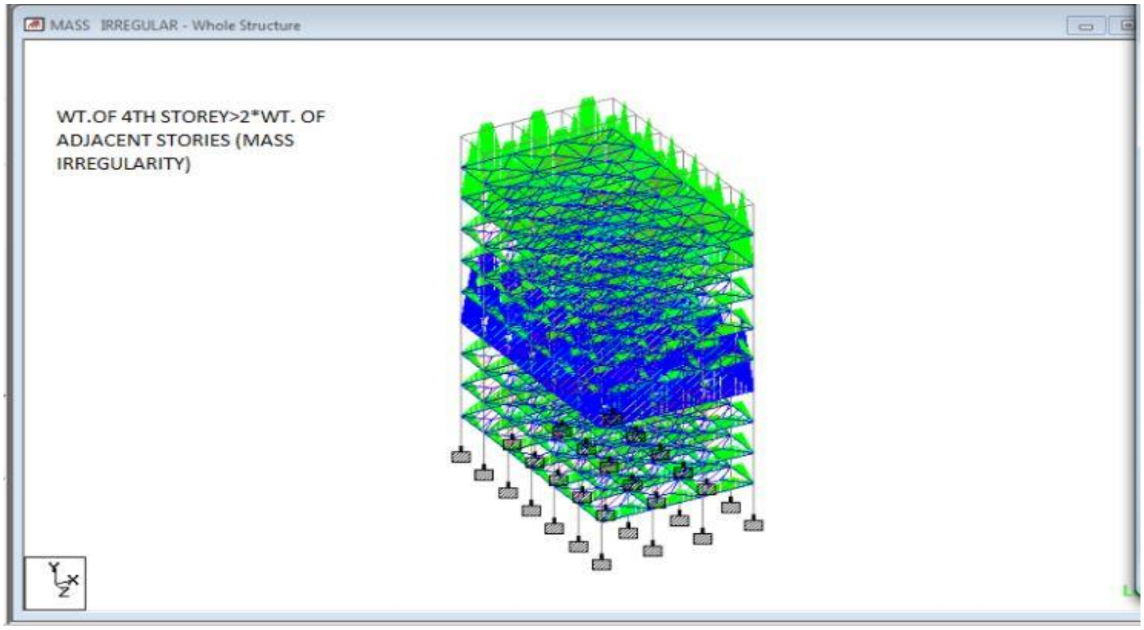


Fig 3.3: 3D view of mass regular structure (10 storeys) with swimming pools on 4^{th} and 8^{th} storeys

3 **Stiffness Irregular Structure (Soft Storey):** The structure is same as that of regular structure but the ground storey has a height of 4.5 m and doesn't have brick infill.

Stiffness of each column= $12EI/L^3$

Therefore,

Stiffness of ground floor/stiffness of other floors=

$(3.5/4.5)^3 = 0.47 < 0.7$

Hence as per IS 1893 part 1 the structure is stiffness irregular.

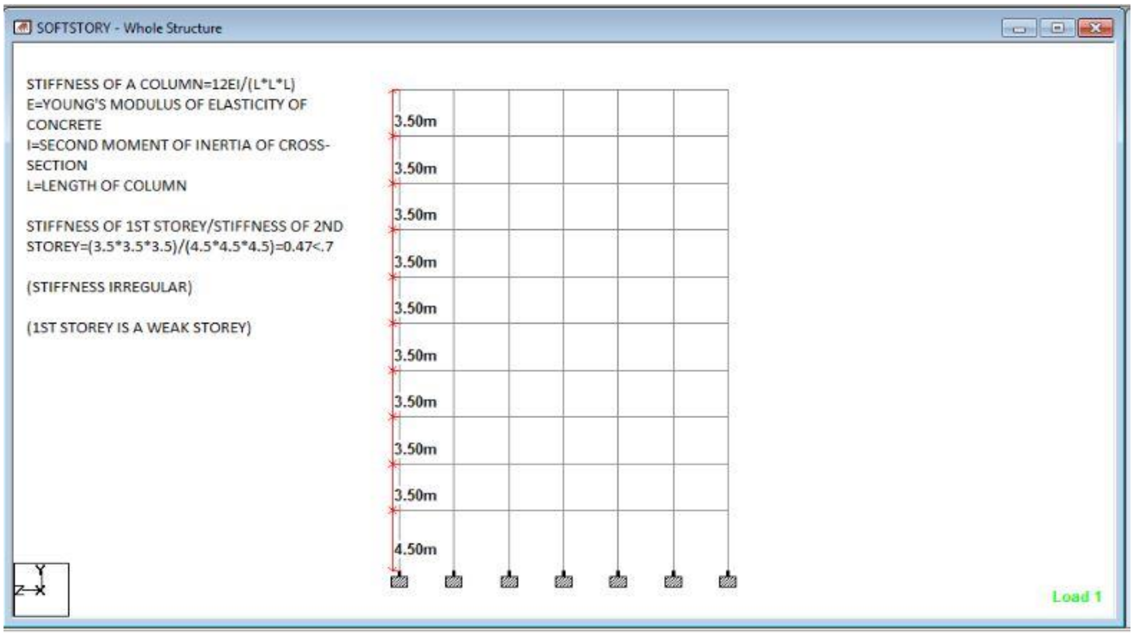


Fig 3.4: stiffness irregular structure (10 storeys)

4 **Vertically Geometric Irregular**- The structure is 14 storeyed with steps in 5th and 10th floor. The setback is along X direction.

Width of top storey= 20m

Width of ground storey=40

40/20=2>1.5

Hence, as per IS 1893, Part 1 the structure is vertically geometric irregular structure.

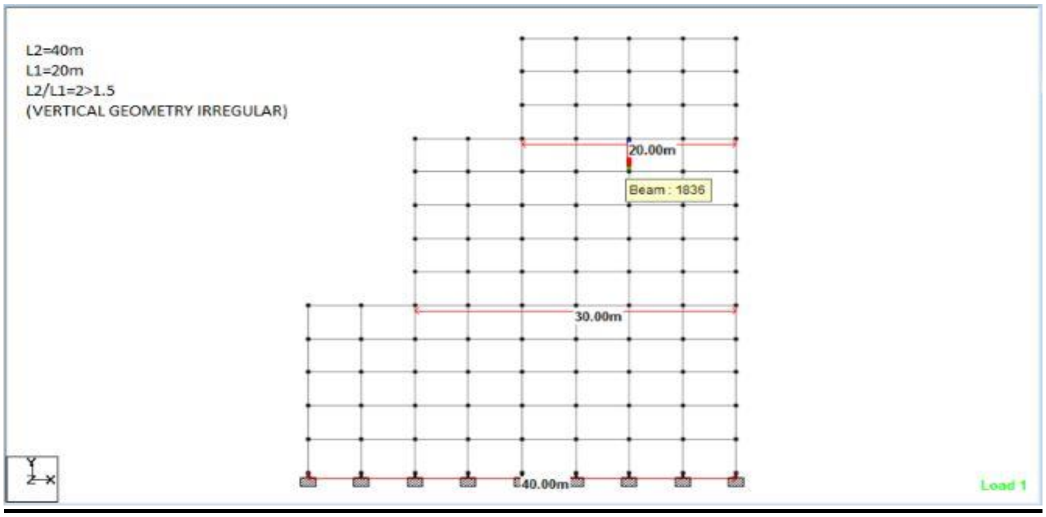


Fig 3.5: Vertical Geometric irregular structure (14 storeys)

3.1.2 Comparison of Peak storey shear forces of Regular structure and Mass Irregular structure

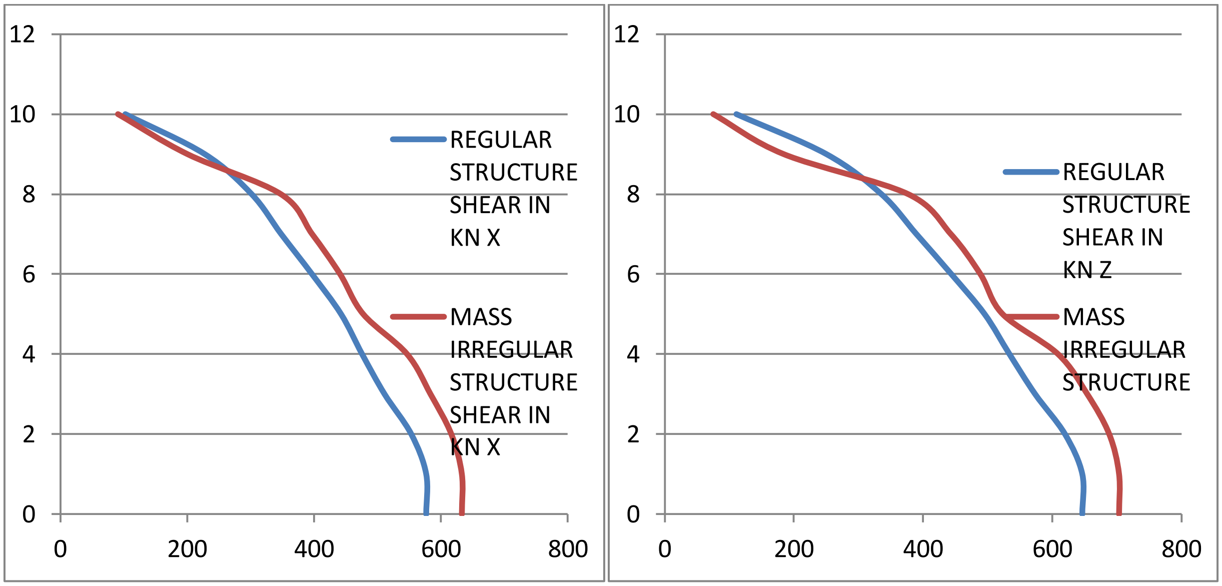


Fig 3.6: Comparison of Peak storey shear forces of regular and mass irregular structure.

The storey shear force is maximum in ground storey and it decreases as we move up in the structure. Mass irregular storey shear force is more in lower storeys as compared to regular structure. The graph closes in as we move up the structure and the mass irregular storey shear force becomes less than that in regular structure above 8^{th} storey.

3.1.3 Comparison of Peak storey shear forces of Regular structure and Stiffness Irregular structure

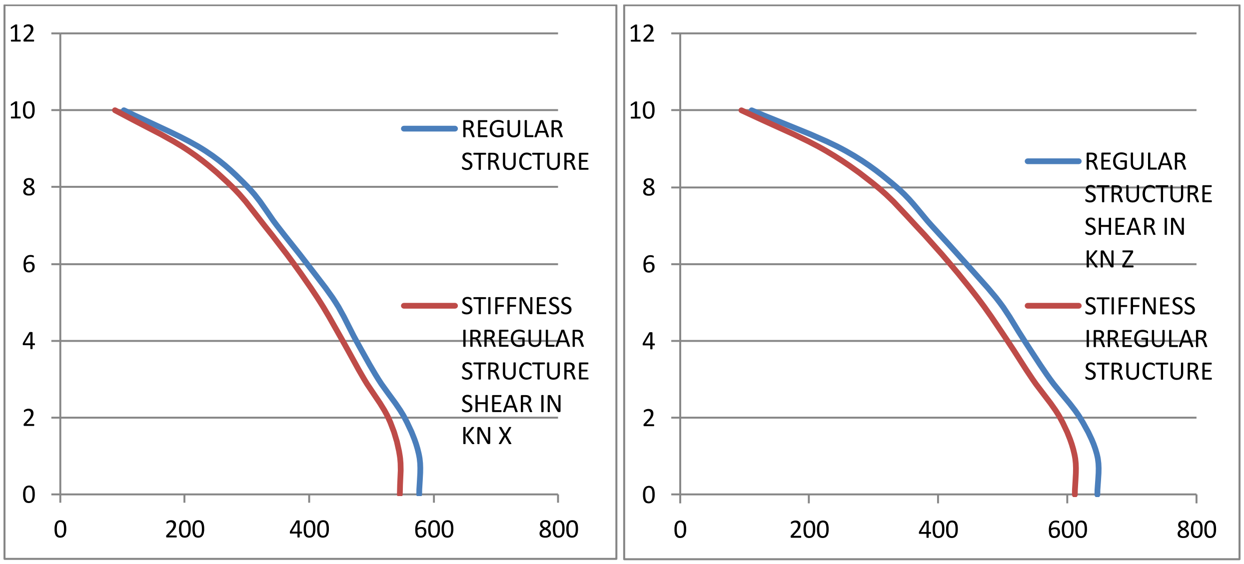


Fig 3.7: Comparison of Peak storey shear forces of regular and stiffness irregular structure.

The Stiffness Irregular structure has a ground storey height of 4.5m(more than height of the above storeys). This makes the building less stiff than regular structure. Hence the interstorey drift is observe to be more in stiffness irregular structure. And hence, the storey shear force is more in regular structure as compared to stiffness irregular structure.

3.2TIME HISTORY ANALYSIS:

3.2.1 INTRODUCTION TO IS CODE GROUND MOTION USED:

Regular and various types of irregular buildings were analyzed using THA and the response of each irregular structure was compared with that of regular structure for IS code Ground motion. The IS code ground motion used for the analysis had PGA of 0.2g and duration of 40 seconds.

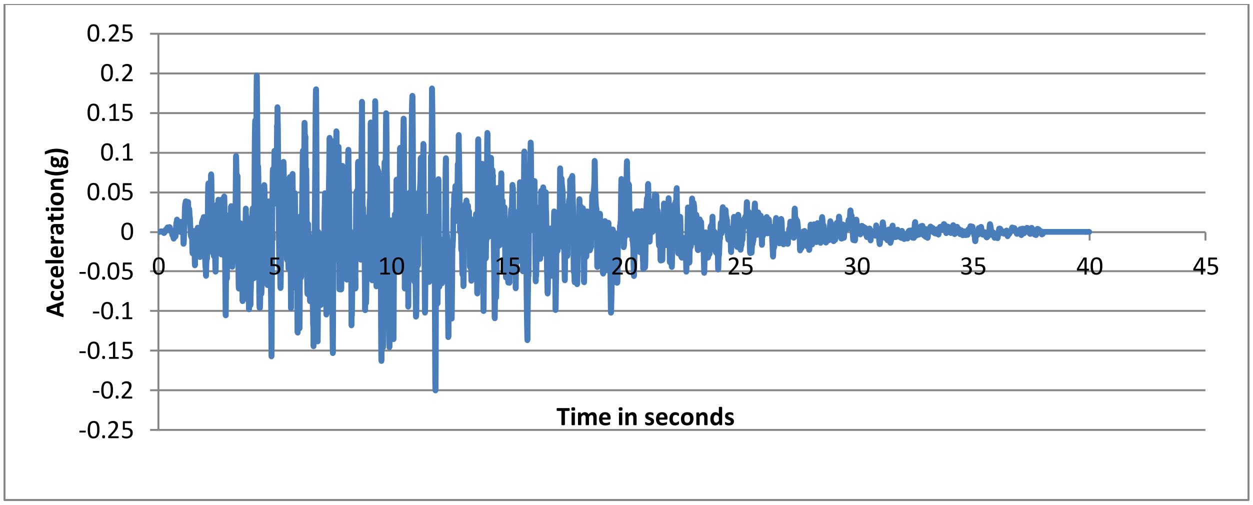


Fig 3.8: IS code ground motion with PGA scaled to 0.2g and duration equal to 40 seconds

3.2.2 STRUCTURAL MODELS AND THEIR TOP FLOOR TIME HISTORY DISPLACEMENT

SPECIFICATION:

Live Load	3kN/m^2
Density of RCC considered:	25kN/m^3
Thickness of slab	150mm
Depth of beam	400mm
Width of beam	350mm
Dimension of column	400x400mm
Density of infill	20kN/m^3
Thickness of outside wall	20mm
Thickness of inner partition wall	15mm
Height of each floor	3.5m
Force Amplitude factor	9.81

REGULAR STRUCTURE:

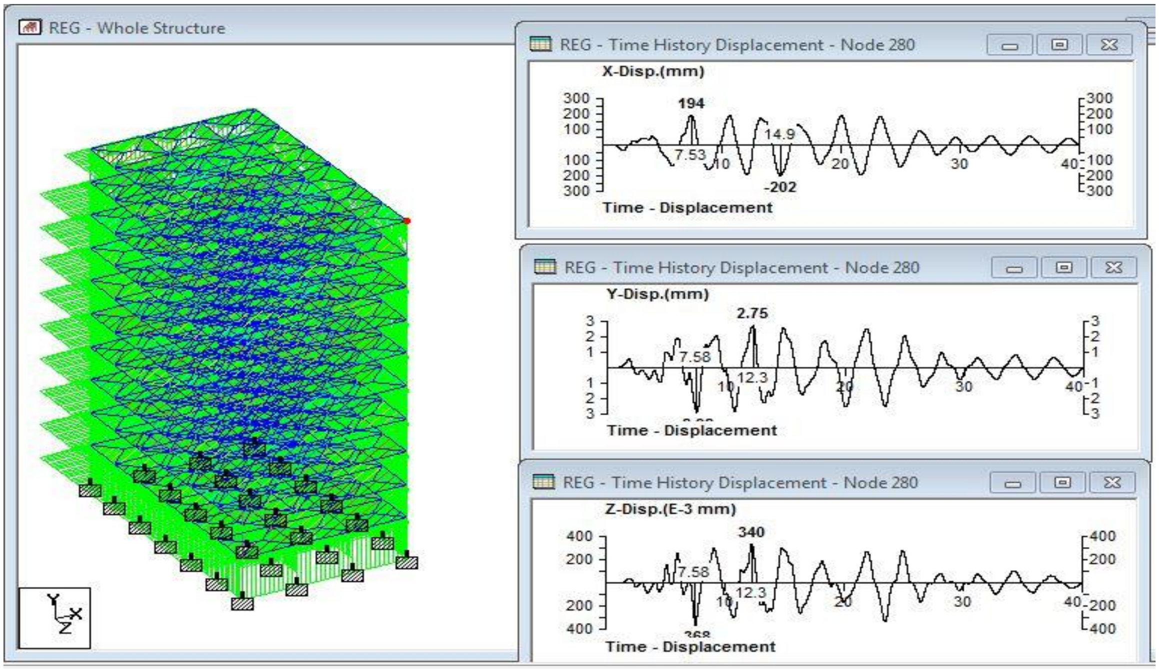


Fig 3.9: Time history displacement of the highlighted node of regular structure

STIFFNESS IRREGULAR STRUCTURE:

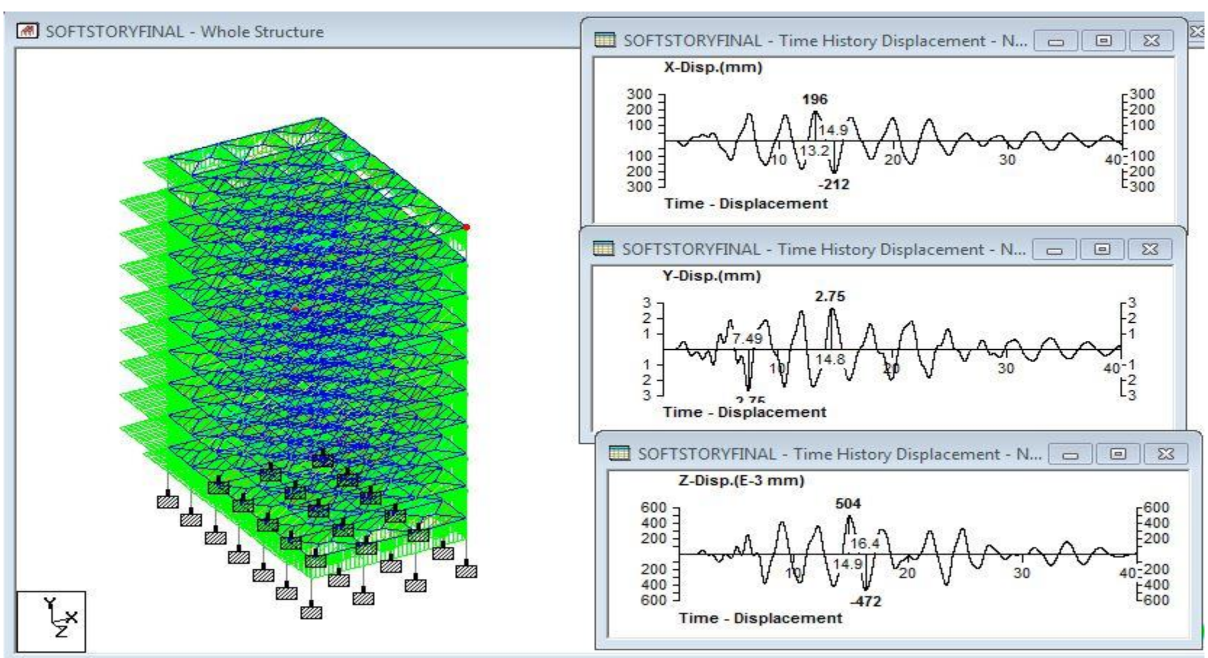


Fig 3.10: Time history displacement of the highlighted node of stiffness irregular structure

.**MASS IRREGULAR STRUCTURE:**

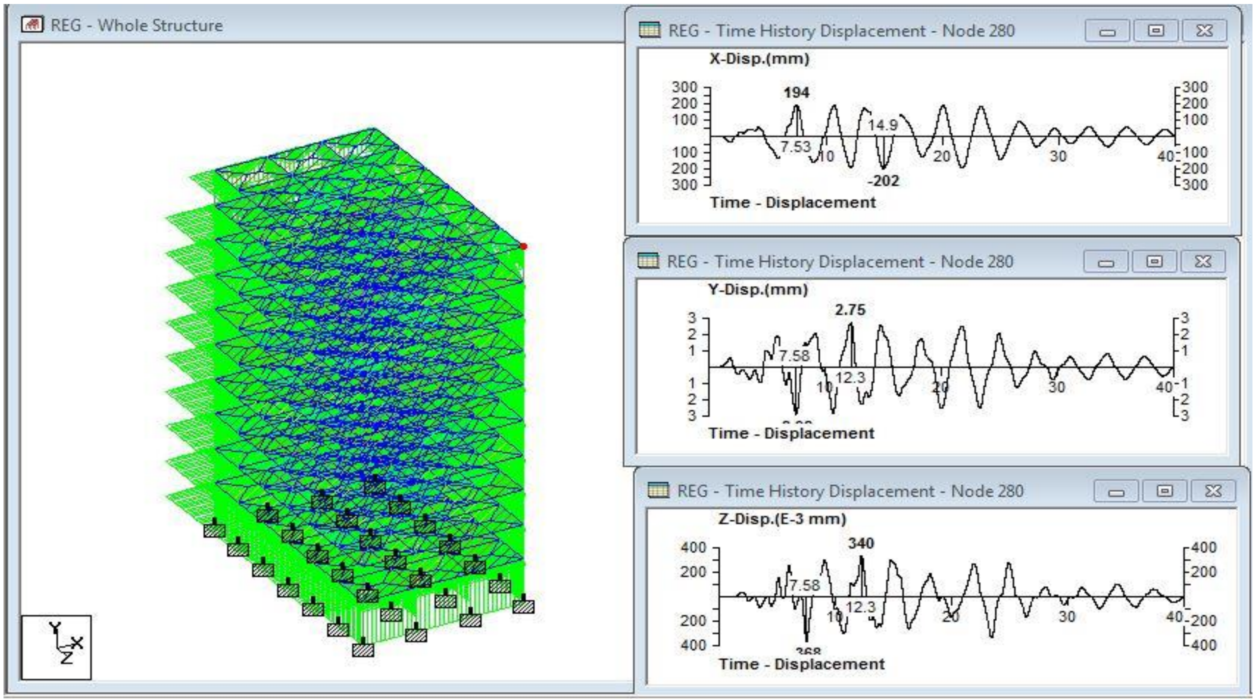


Fig 3.11: Time history displacement of the highlighted node of mass irregular structure

VERTICALLY GEOMETRIC IRREGULAR STRUCTURE:

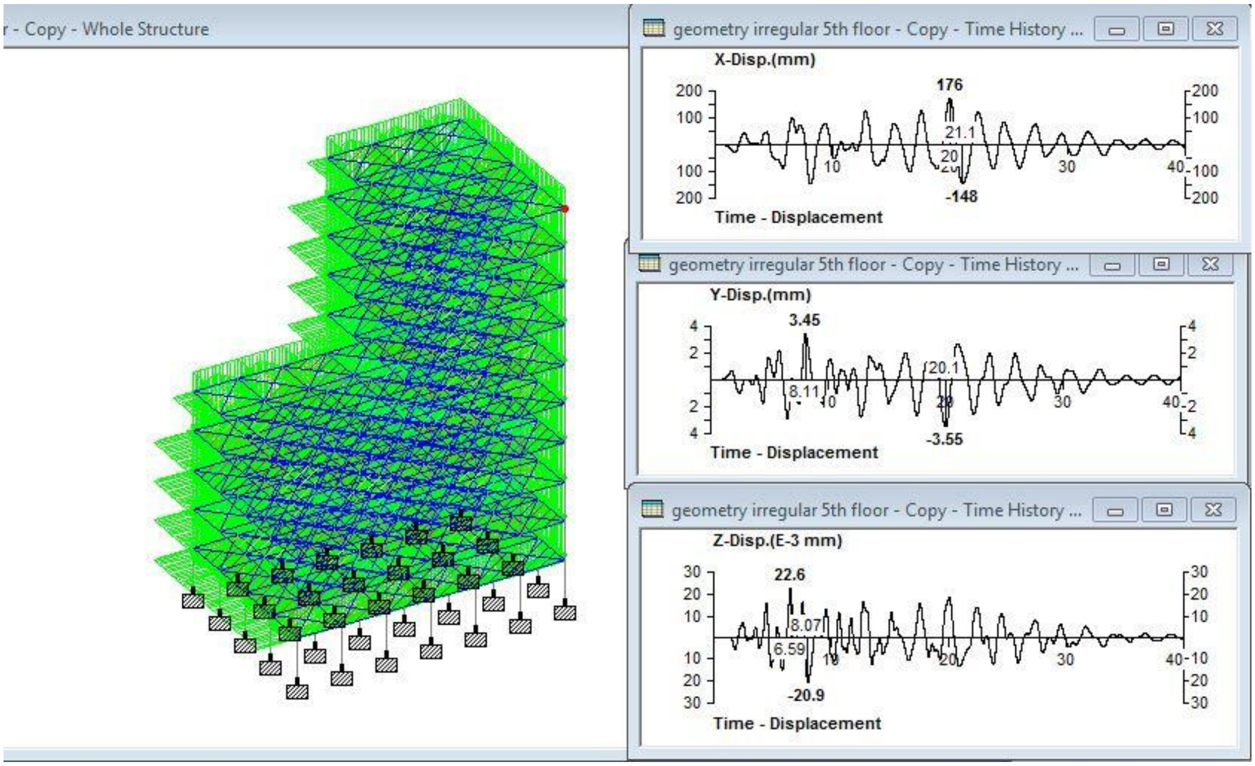


Fig 3.12: Time history displacement of the highlighted node of geometry irregular structure

The above figures show the Time history displacements of the topmost node of regular, stiffness irregular and geometry irregular structure respectively. Similarly time history displacements were obtained for other floors in the structure and the maximum displacement was plotted in the graph. The graphs of Irregular structure were compared with that of Regular structure.

3.2.3 Comparison of Time history displacements of different floors of Regular structure and Stiffness Irregular structure

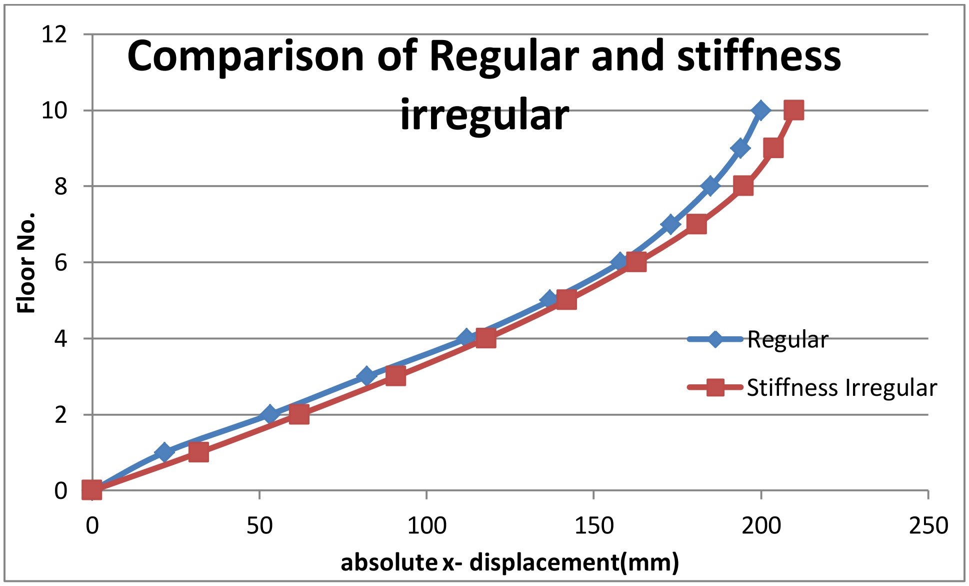


Fig 3.13: comparison of displacements along x-direction of regular and stiffness irregular structure

Due to less stiff ground storey the interstorey drift is found to be more in stiffness irregular structure. Hence, the floor displacement is more in stiffness irregular structure than regular structure.

3.2.4 Comparison of Time history displacements of different floors of Regular structure and Mass Irregular structure

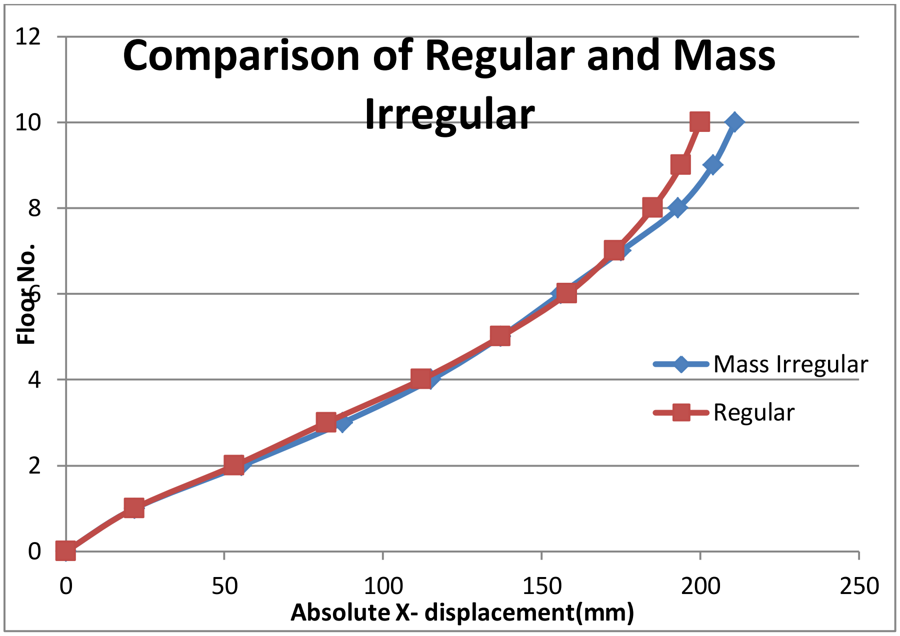


Fig 3.14: comparison of displacements along x-direction of regular and mass irregular structure

Mass irregular structure has swimming pool in 4th and 8th floor hence the 4th storey displacement is more in mass irregular structure. The effect of extra mass is found to be more in 8th storey where higher inter storey drift is observed. Higher the position of extra mass the moment of the inertial force is more leading to larger displacement.

3.2.5 Comparison of Time history displacements of different floors of Regular structure and Geometry Irregular structure

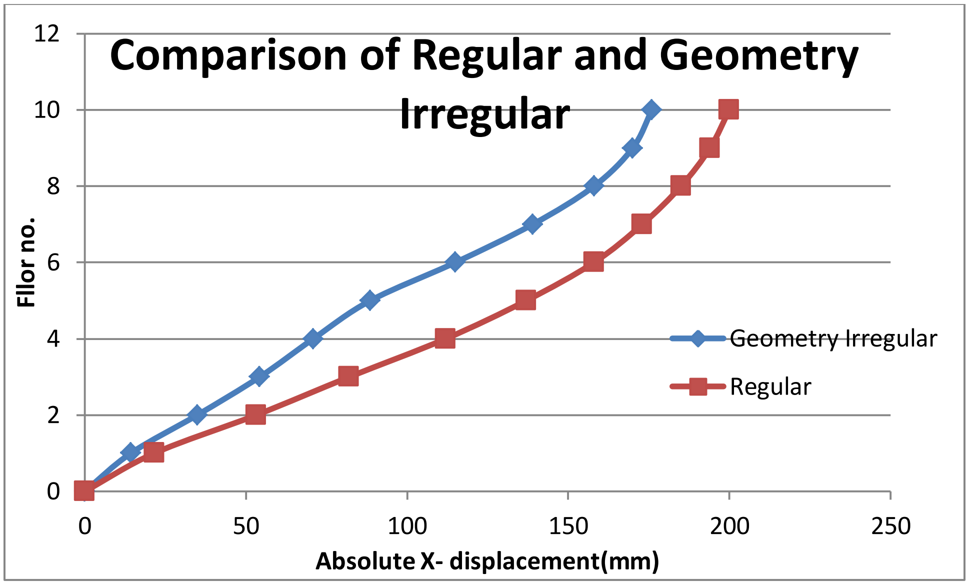
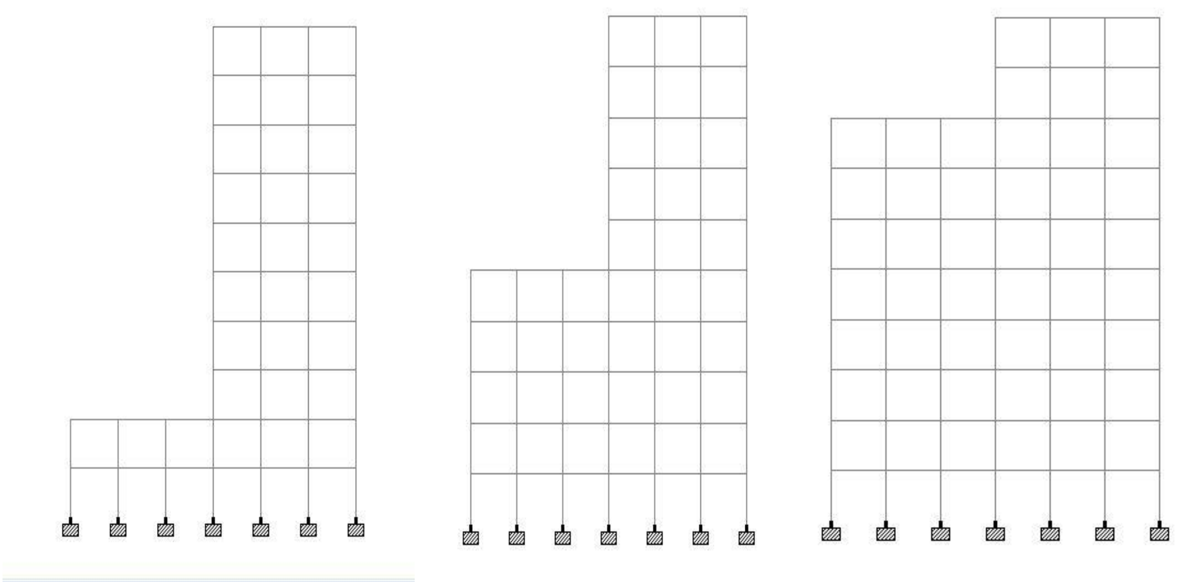


Fig 3.15: comparison of displacements along x-direction of regular and geometry irregular structure

In geometry irregular structure the stiffness upto 5th storey is far more than that of regular structure. So the displacement in lower storeys of geometry irregular structure is very less as compared to regular structure. But at 5th storey due to setback there is a sudden increase in the displacement and hence there is decrease in slope of the graph.

3.2.6 COMPARISON OF ABSOLUTE DISPLACEMENT OF SETBACK STRUCTURES WITH SETBACK AT DIFFERENT FLOORS:



Setback in 2nd floor   Setback in 5th floor   Setback in 8th floor

Fig 3.16: Setback in different geometry irregular structures

Live Load	3kN/m^2
Density of RCC considered:	25kN/m^3
Thickness of slab	150mm
Depth of beam	450mm
Width of beam	350mm
Dimension of column	450x450mm
Density of infill	20kN/m^3
Thickness of infill	20mm

Height of each floor	3.5m
Total height of the structure	35m
Force Amplitude factor	9.81

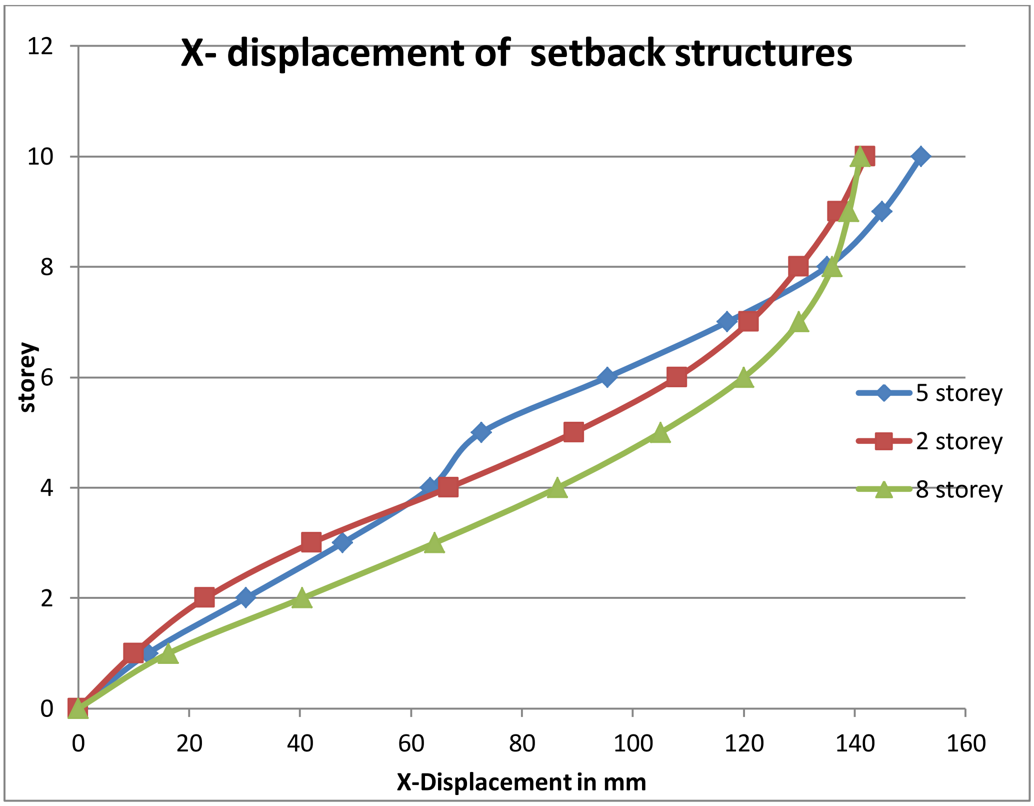


Fig 3.17: comparison of displacements along x-direction of 5,2 and 8 storey setback structures

The above figure shows the absolute displacements of Setback structures with setback at different floors.

In setback structures due to setback the stiffness and mass of the structure both decreases.

In setback structure with offset at 8th storey at lower storeys the displacement is more than the other two. This behaviour may be attributed to the increase mass of the structure. In setback structure with offset at 5th floor there is a sudden change in slope of the curve due to offset. But what is most conspicuous behavior is that its top node displacement is more than the former structure. This can be attributed to less stiffness in the upper stories of the structure. The behavior of setback structure with offset at 2nd floor is similar to second setback structure. The difference is the fact that the curve is smoother in this case. Notably the displacement at first three floors is less when compared to other two setback structures.

3.2.7: <u>Introduction to three ground motions used :</u>

As discussed above in the introduction THA can be used to get a time response of a structure due to particular earthquake excitation. Three earthquake data were considered for analysis.

1. San Francisco(high frequency earthquake)
2. IS code earth quake(Intermediate frequency)
3. Imperial (low frequency)

The time duration of each data was 40 seconds with the peak ground acceleration of 0.2g.

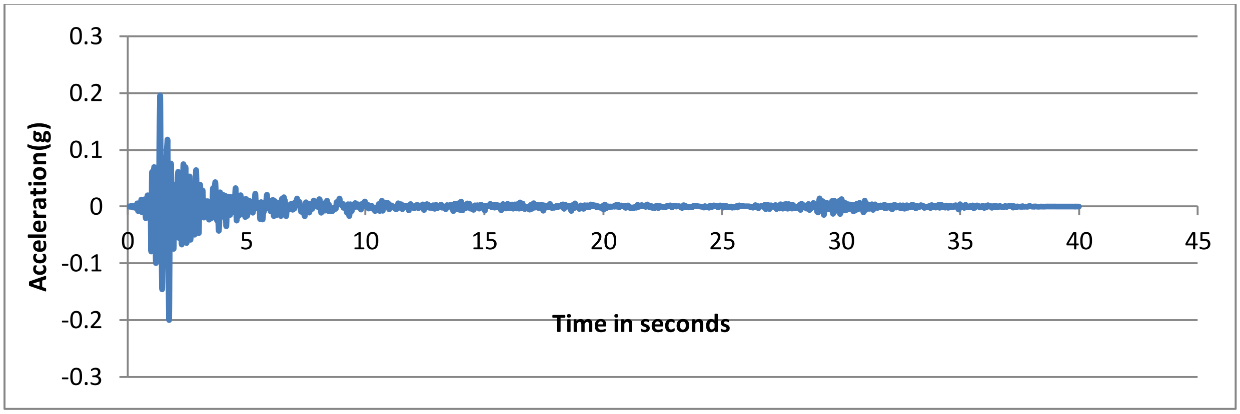


Fig 3.18: San Francisco ground motion (high frequency)

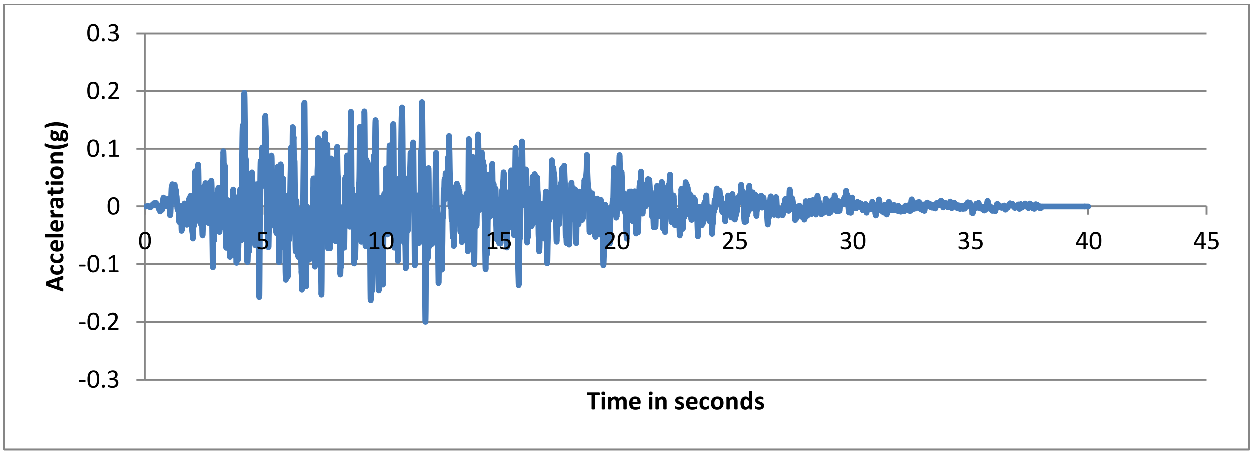


Fig 3.19: IS code ground motion (Intermediate frequency)

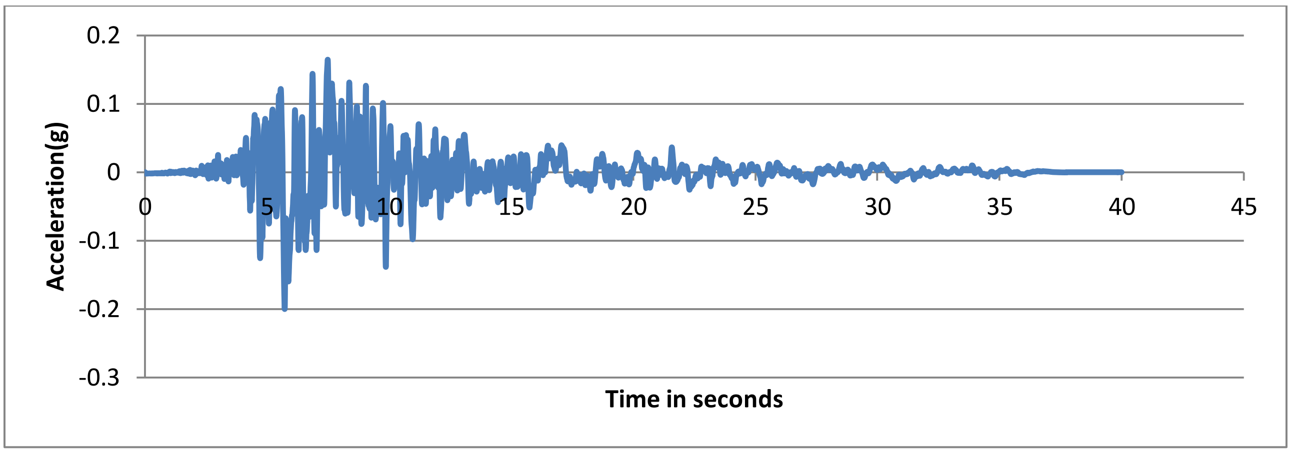


Fig 3.20: Imperial ground motion (low frequency)

These three earthquake excitations were provided to following structures and following structures.1.Regular structure of 2 storeys, 6 storeys and 20 storeys.

1. Stiffness Irregular structure of 20 storeys.
2. Three mass Irregular structures of 20 storeys with swimming pools in 4th, 10th and 19th storey respectively.
3. Three Geometry Irregular structure with steps in 2nd, 5th and 8th storey respectively.

Live Load	$3kN/m^2$
Density of RCC considered:	$25kN/m^3$
Thickness of slab	150mm

Depth of beam	450mm
Width of beam	350mm
Dimension of column	450x450mm
Density of infill	20kN/m^3
Thickness of outside wall	20mm
Thickness of inside wall	15mm
Height of each floor	3.5m
Total height of the structure	10m
Force Amplitude factor	9.81

3.2.8 <u>Time history displacement of structures due to ground motions of different frequency content:</u>

3.2.8.1 <u>Regular 2-storey</u>

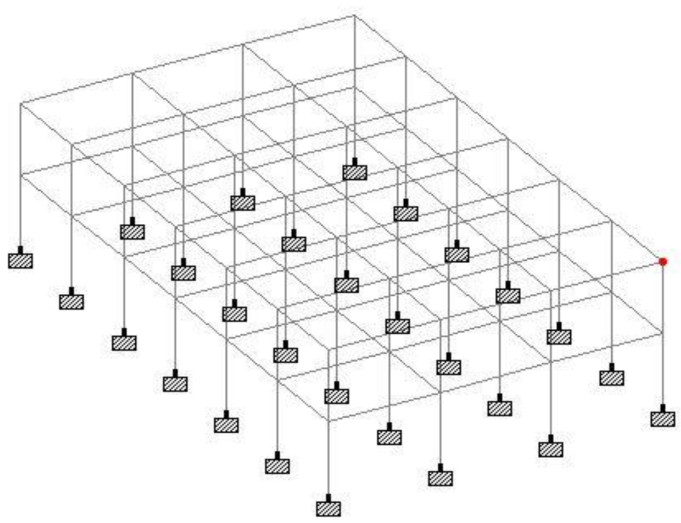


Fig 3.21: 3-D view of regular 2-storey structure

Fig 3.22: x- displacement of highlighted node of regular 2 storey building subjected to Imperial (low frequency) ground motion

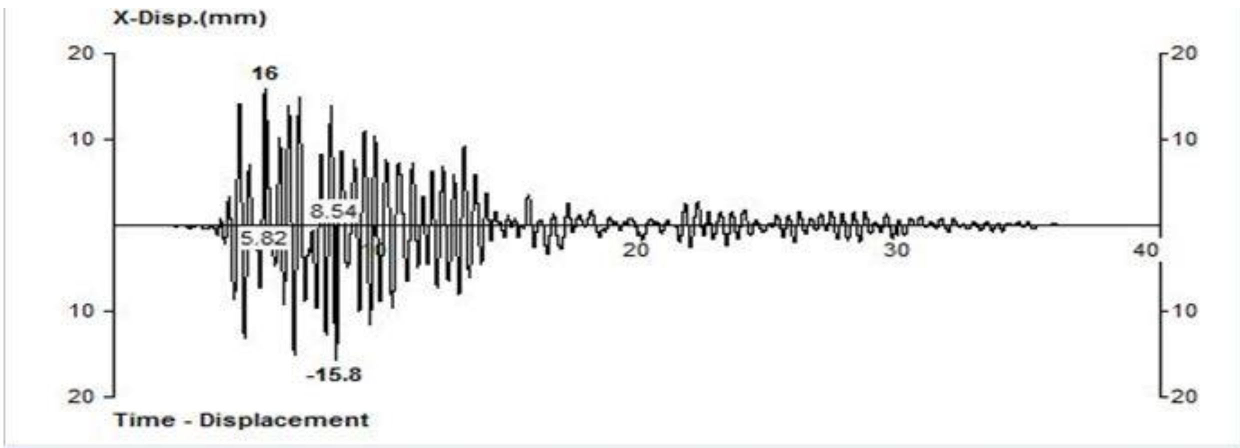


Fig 3.23: x- displacement of highlighted node of regular 2 storey building subjected to IS code (intermediate frequency) ground motion

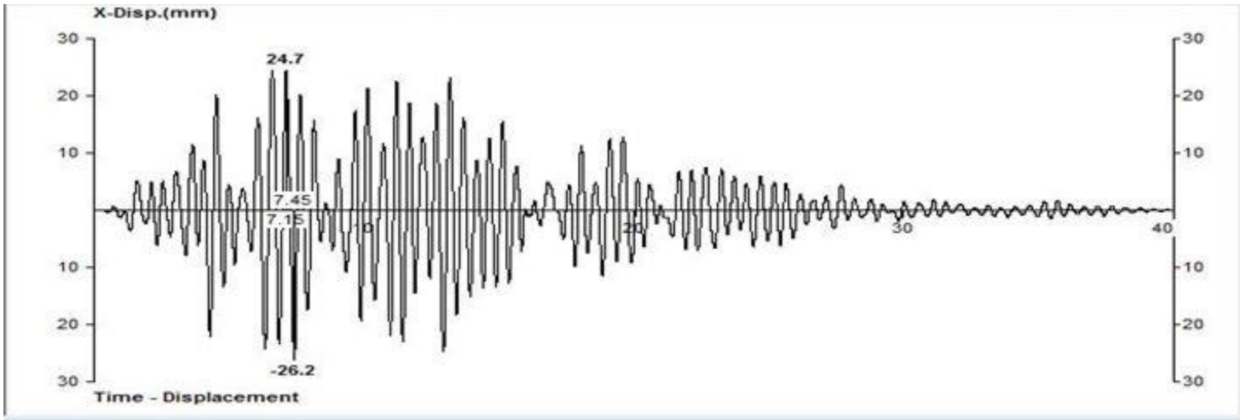


Fig 3.24: x- displacement of highlighted node of regular 2 storey building subjected to San Francisco (high frequency) ground motion

3.2.8.2 Regular 6 storey:

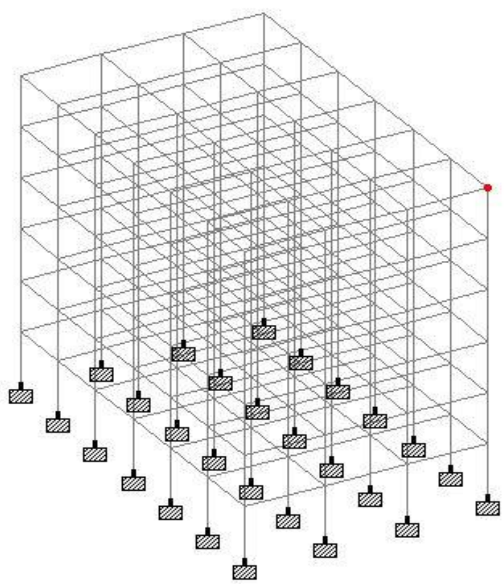


Fig 3.25: 3-D view of regular 6 storey building frame

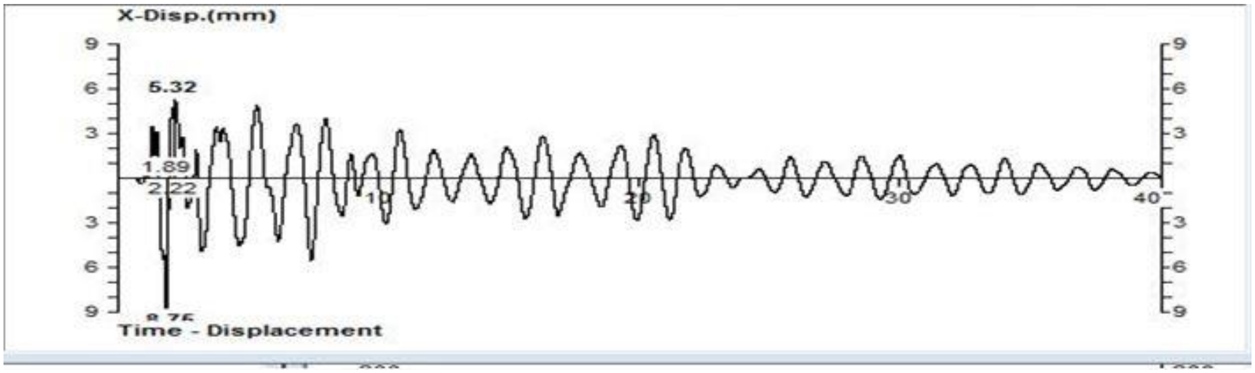


Fig 3.26: x- displacement of highlighted node of regular 6 storey building subjected to San Francisco (high frequency) ground motion

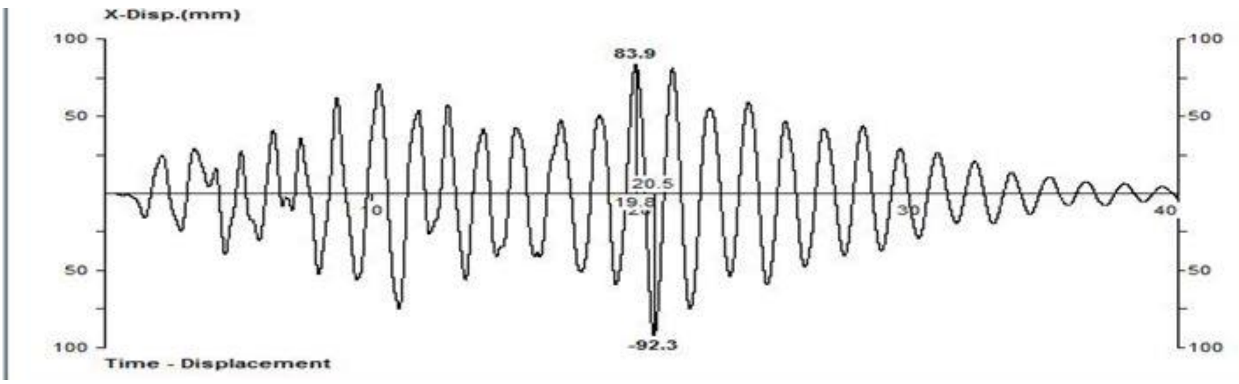


Fig 3.27: x- displacement of highlighted node of regular 6 storey building subjected to IS code (intermediate frequency) ground motion

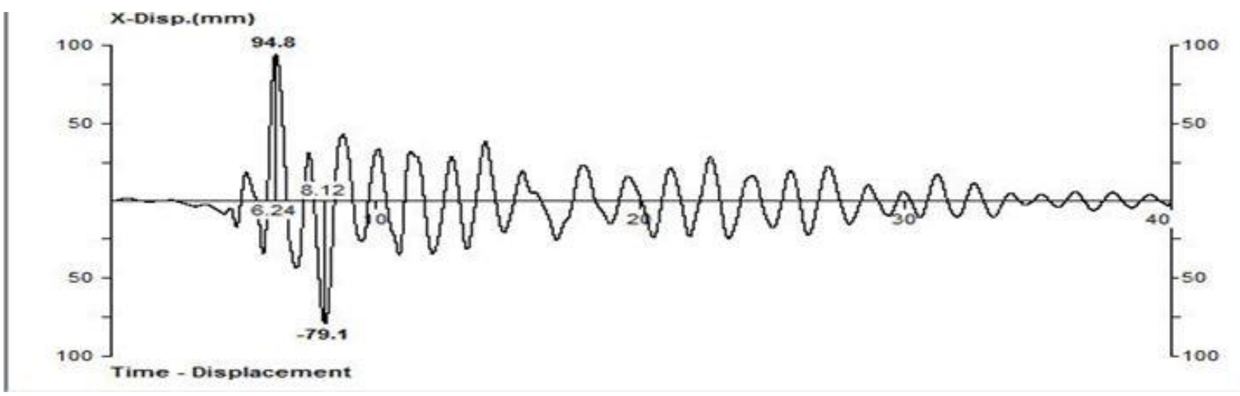


Fig 3.28: x- displacement of highlighted node of regular 6 storey building subjected to Imperial (low frequency) ground motion

3.2.8.3 **<u>Regular 20 storey:</u>**

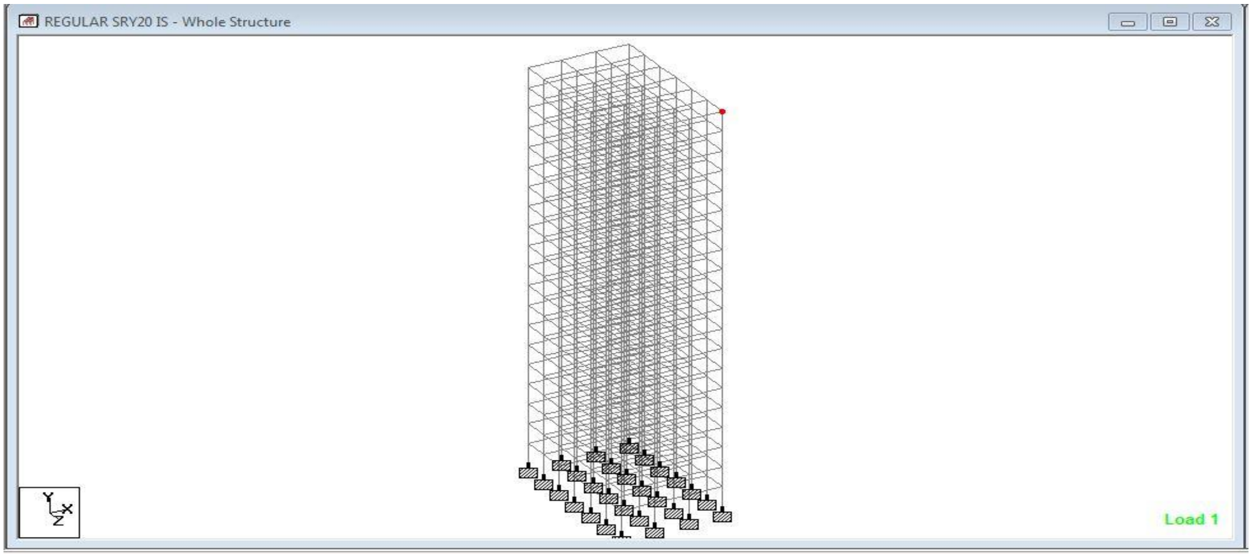


Fig 3.29: 3-D of a regular 20-storey building

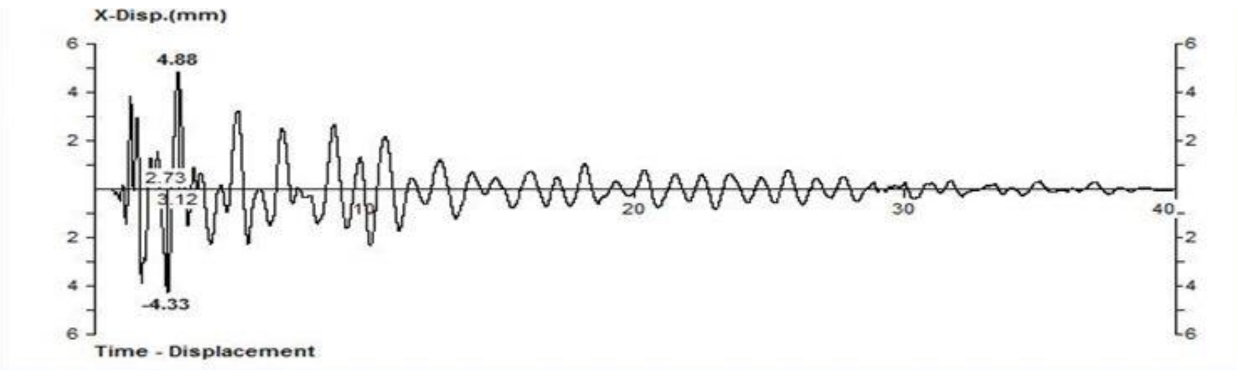


Fig 3.30: x- displacement of highlighted node of regular 20 storey building subjected to San Francisco (high frequency) ground motion

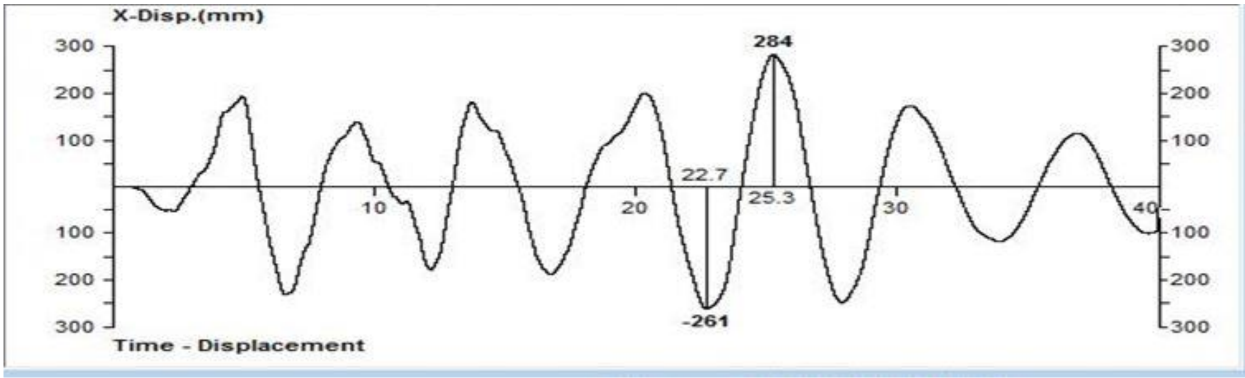


Fig 3.31: x- displacement of highlighted node of regular 20 storey building subjected to IS code (intermediate frequency) ground motion

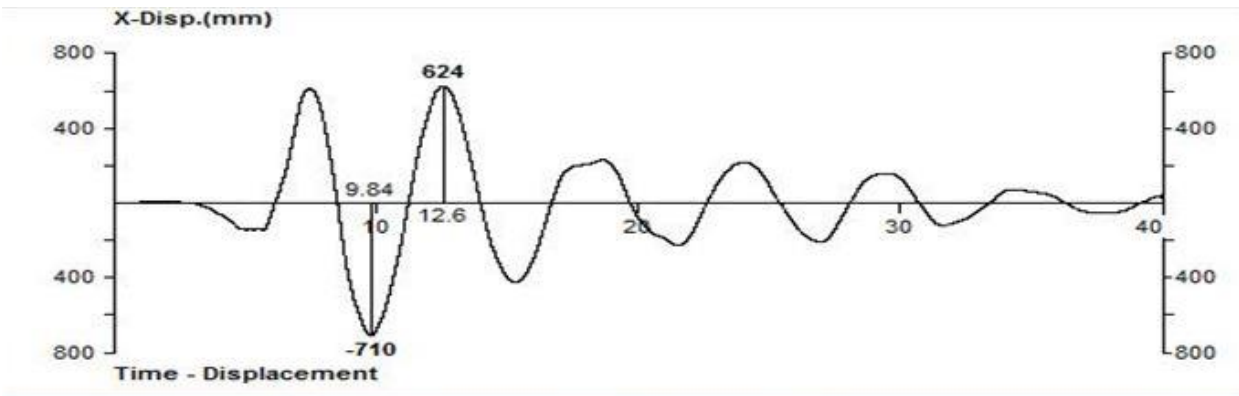


Fig 3.32: x- displacement of highlighted node of regular 20 storey building subjected to Imperial (low frequency) ground motion

The above figures show the Time History displacement of the topmost node of a structure due to a particular ground motion.

From the figures it has been observed that low storeyed structures (< 5 storey) show large displacements in high frequency ground motion and small displacements in low frequency ground motion. This is because low storeyed structures have high natural frequency (frequency is proportional to $(k/m)^{1/2}$) so, in a high frequency earthquake there response is larger due to resonance. Similarly, high rise structures have low natural frequency and hence undergo large displacements in low frequency ground motion and small displacements in high frequency ground motion.

3.2.8.4 <u>Mass Irregular Structure(swimming pool on the 19th floor)</u>

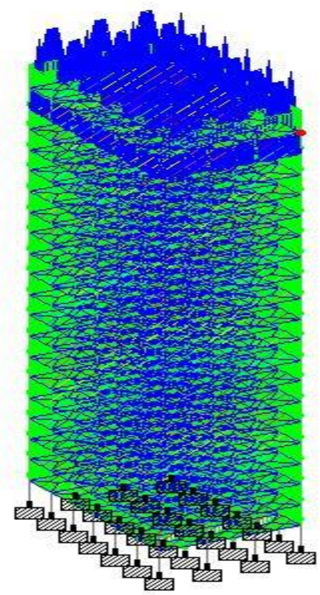


Fig 3.33: 3-D view of 20 storey mass irregular structure showing swimming pool on the 19th floor

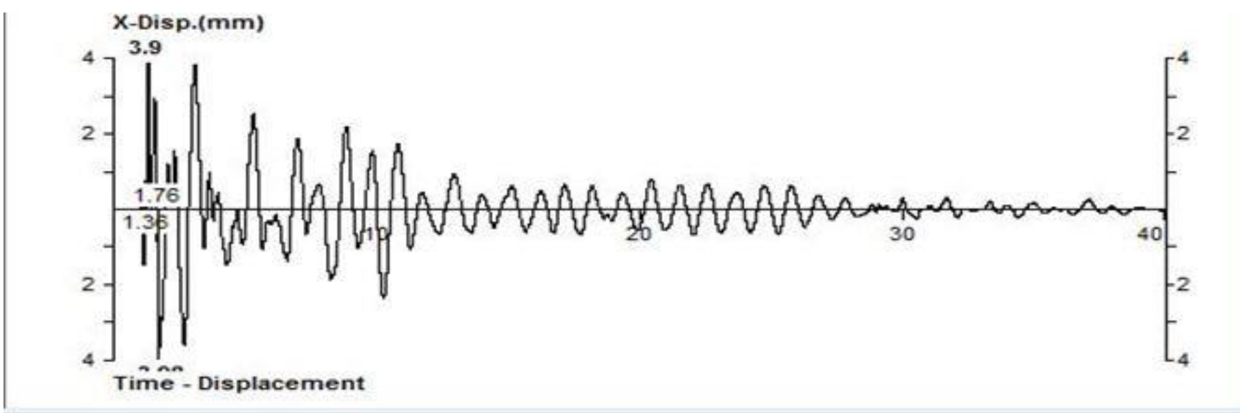


Fig 3.34: x- displacement of highlighted node of mass irregular 20 storey building with swimming pool on 19th floor subjected to San Francisco (high frequency) ground motion

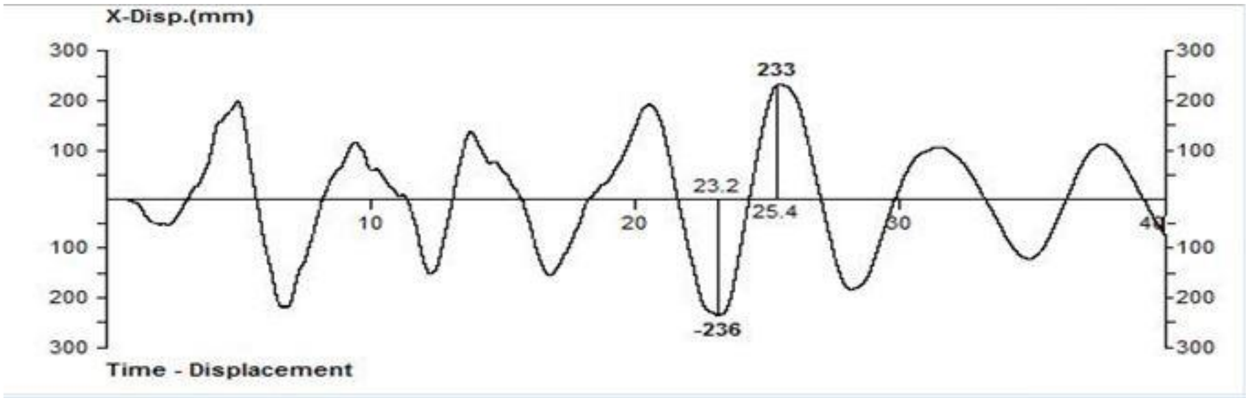


Fig 3.35: x- displacement of highlighted node of mass irregular 20 storey building with swimming pool on 19th floor subjected to IS code(intermediate frequency) ground motion

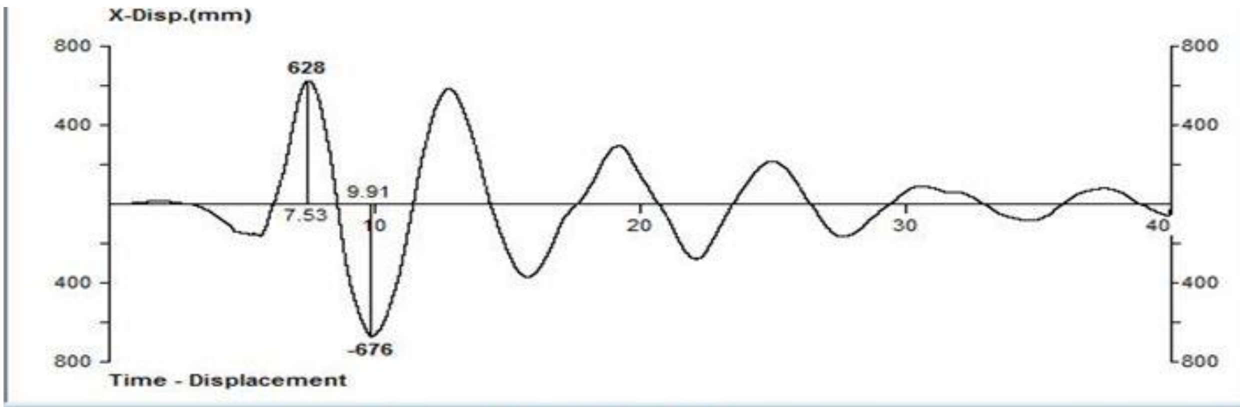


Fig 3.36: x- displacement of highlighted node of mass irregular 20 storey building with swimming pool on 19th floor subjected to Imperial(low frequency) ground motion

3.3 DUCTILITY BASED DESIGN:

3.3.1 SPECIFICATION

Live Load	3kN/m^2
Density of RCC considered:	25kN/m^3
Thickness of slab	150mm
Depth of beam	450mm
Width of beam	350mm
Dimension of column	450x450mm

Density of infill	20kN/m^3
Thickness of outside wall	20mm
Thickness of inside wall	15mm
Height of each floor	3.5m
Total height of the structure	35m
Force Amplitude factor	9.81

The structures were designed as per the analysis results from ESA and THA.

3.3.2 <u>Comparison of design based on ESA and THA</u>

3.3.2.1 <u>REGULAR STRUCTURE</u>

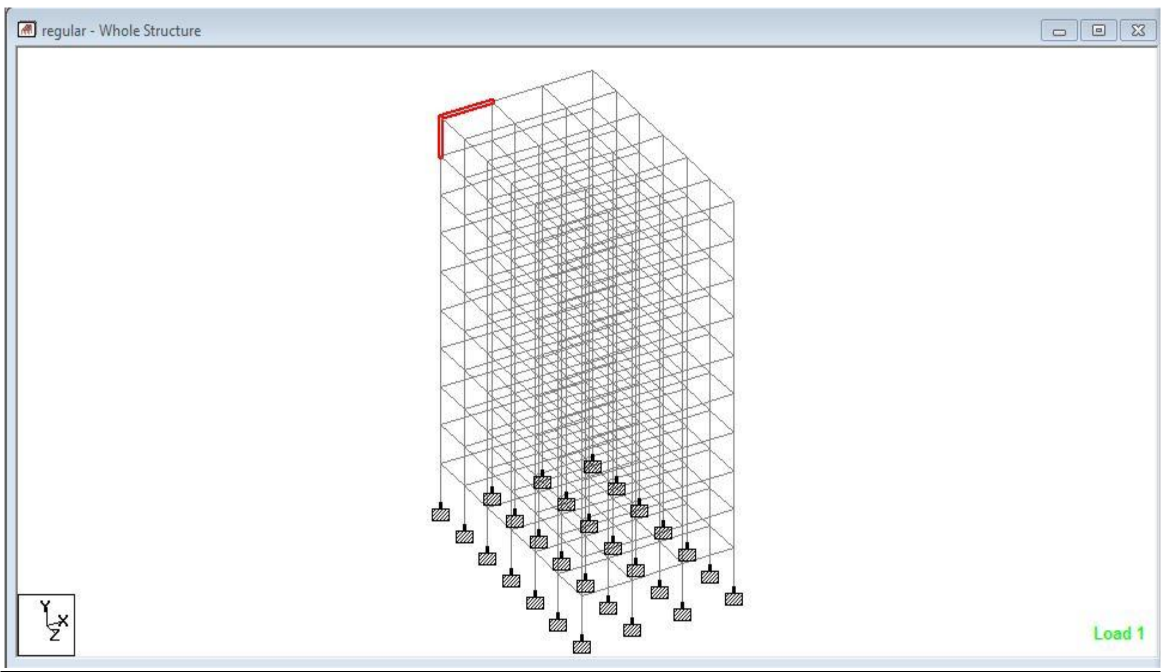
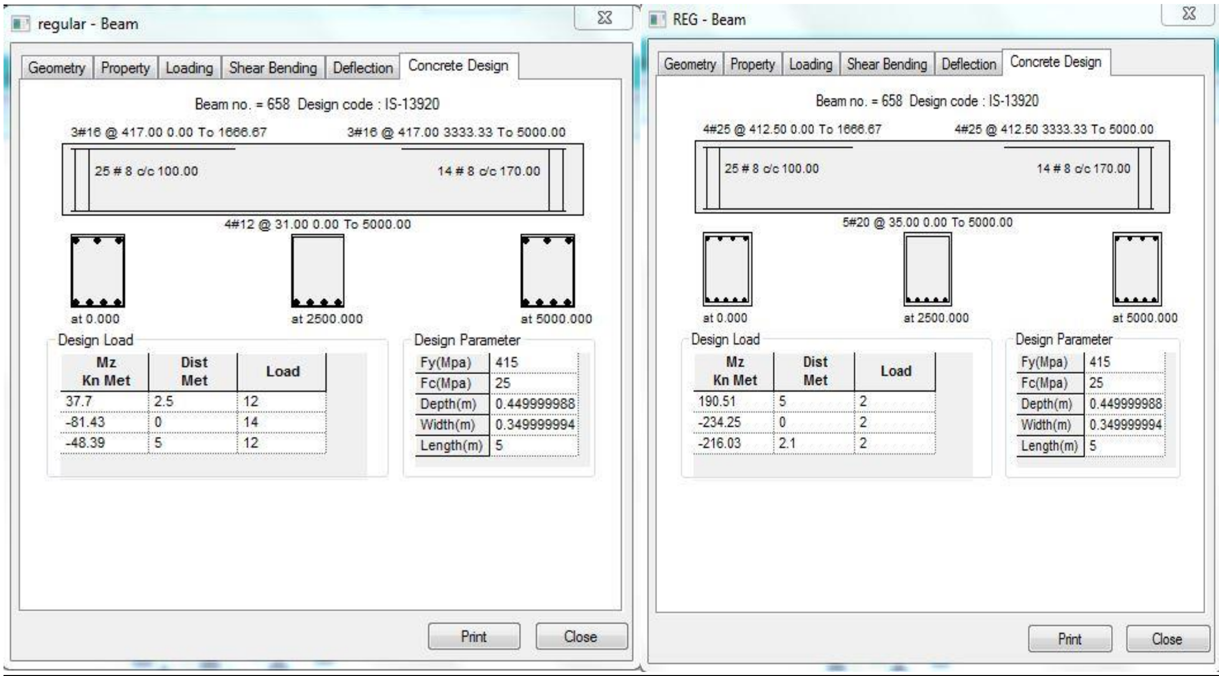


Fig 3.37: 3-D view of a 10-storey regular structure with highlighted beam and column



Beam design as per ESA

Beam design as per THA

Fig 3.38: Results of Design of beam as per ESA and THA

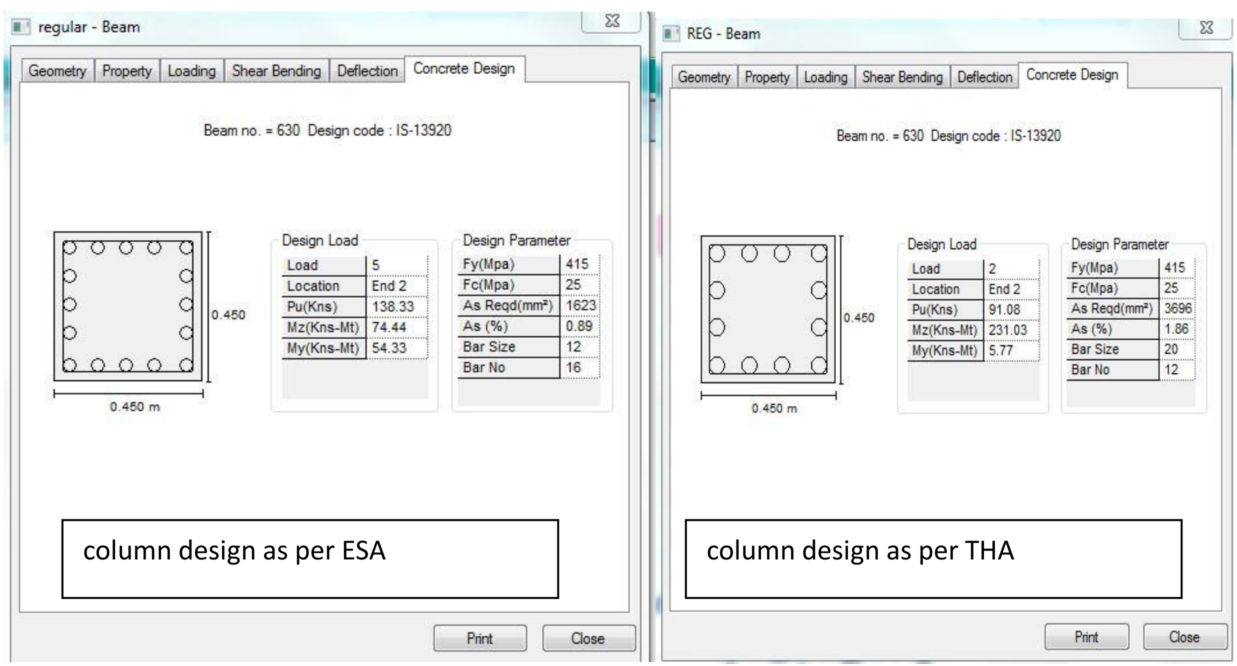


Fig 3.39: Results of Design of column as per ESA and THA

3.3.2.2 MASS IRREGULAR STRUCTURE

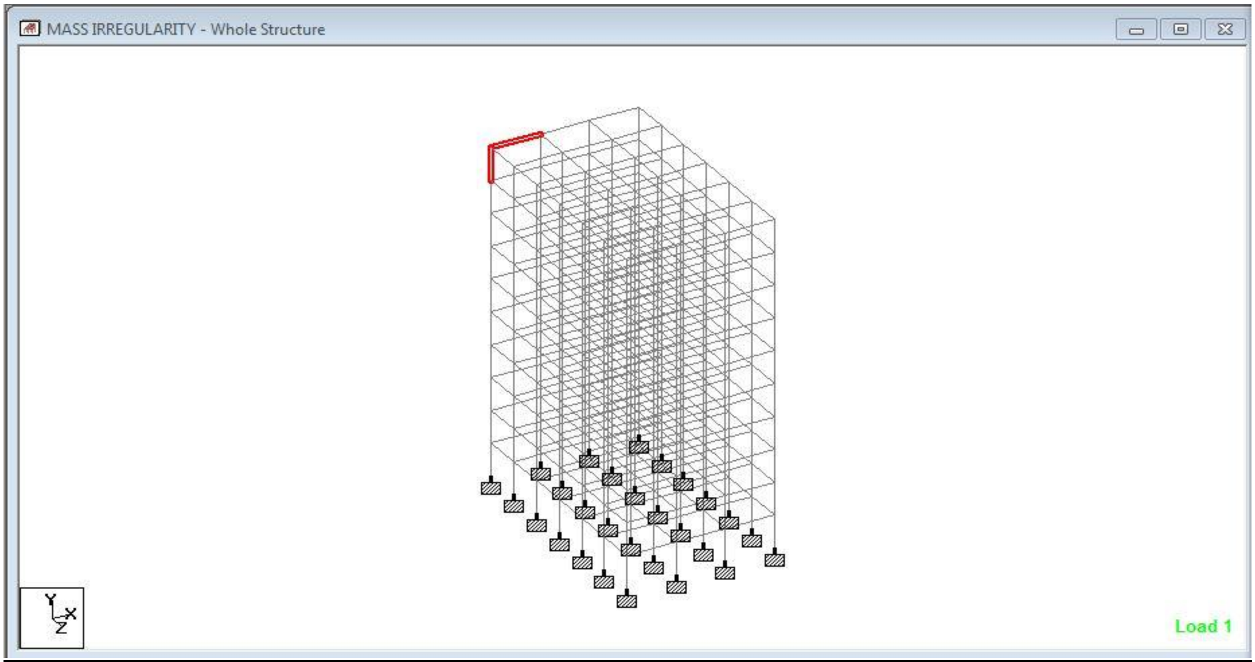
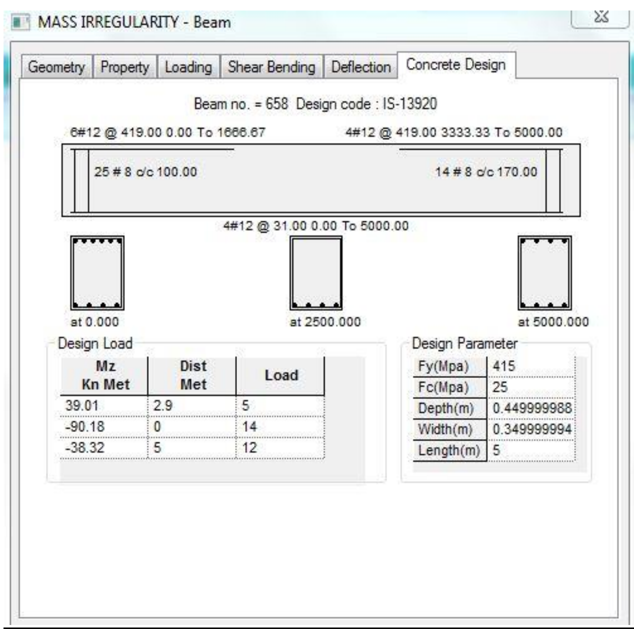
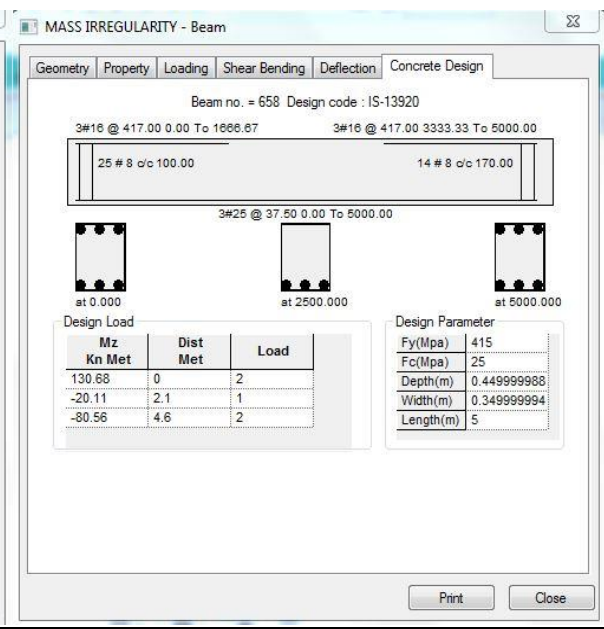


Fig 3.40: 3-D view of a10 storey mass irregular structure with highlighted beam and column

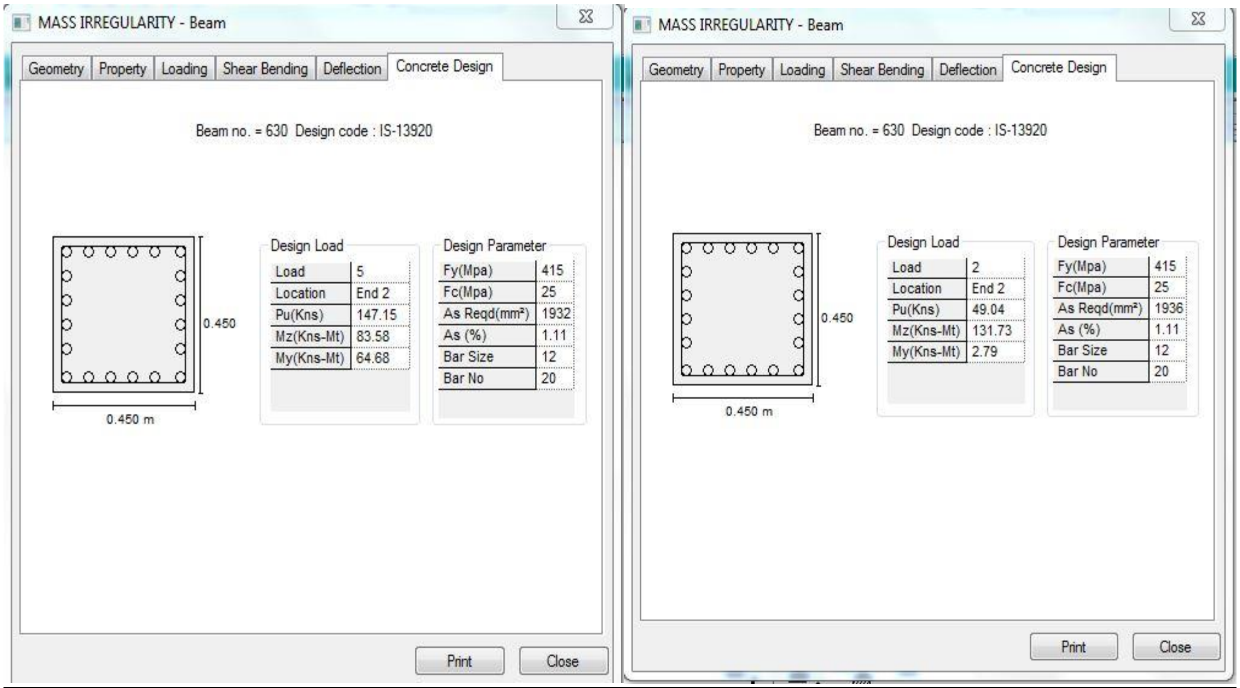




Beam design as per ESA

Beam design as per THA

Fig 3.41: Results of Design of beam as per ESA and THA



column design as per ESA

column design as per THA

Fig 3.42: Results of Design of column as per ESA and THA

3.3.2.3 GEOMETRY IRREGULAR STRUCTURE(T SHAPE):

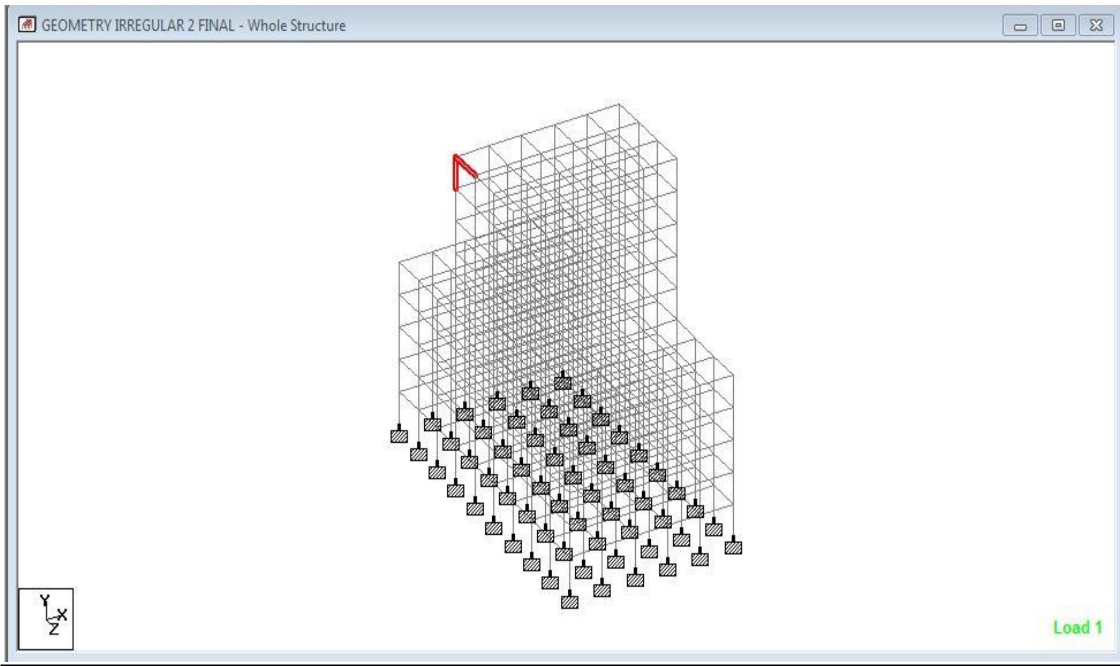


Fig 3.43: 3-D view of a10 storey mass irregular structure with highlighted beam and column

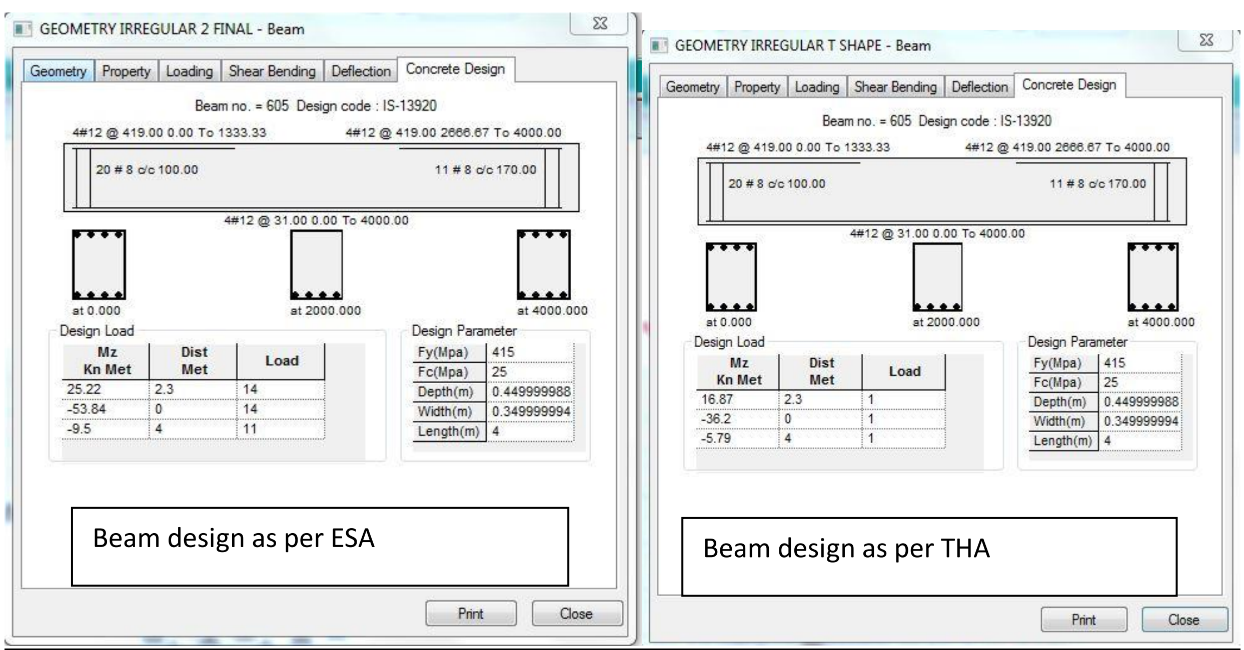


Fig 3.44: Results of Design of beam as per ESA and THA of a10 storey mass irregular structure

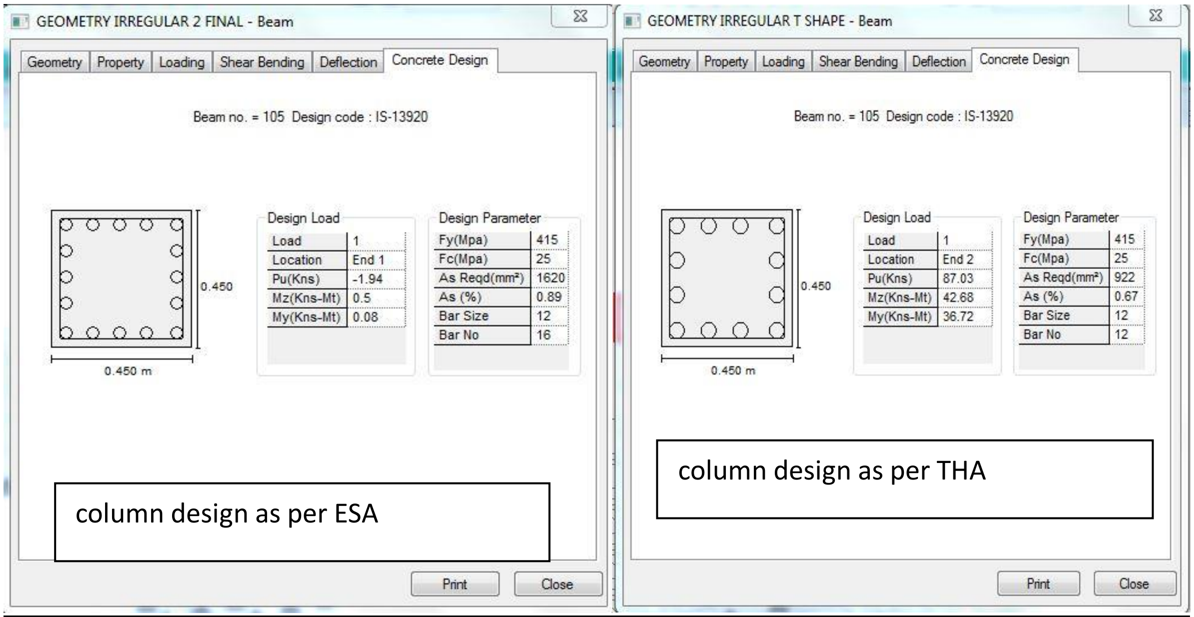


Fig 3.45: Results of Design of column as per ESA and THA of a10 storey mass irregular structure

CHAPTER 4

CONCLUSION

Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered .All three kinds of irregular RC building frames had plan symmetry. Response spectrum analysis (RSA) was conducted for each type of irregularity and the storey shear forces obtained were compared with that of a regular structure. Three types of ground motion with varying frequency content, i.e., low (imperial), intermediate (IS code),high (San Francisco) frequency were considered. Time history analysis (THA) was conducted for each type of irregularity corresponding to the above mentioned ground motions and and nodal displacements were compared. Finally, design of above mentioned irregular building frames was carried out using IS 13920 corresponding to Equivalent static analysis (ESA) and Time history analysis(THA) and the results were compared. Our results can be summarized as follows-

- According to results of RSA, the storey shear force was found to be maximum for the first storey and it decreased to a minimum in the top storey in all cases.
- According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.
- According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.
- The absolute displacements obtained from time history analysis of geometry irregular building at respective nodes were found to be greater than that in case of regular building for upper stories but gradually as we move to lower stories displacements in both structures tended to converge. This is because in a geometry irregular structure upper stories have lower stiffness (due to L-shape) than the lower stories. Lower stiffness results in higher displacements of upper stories.
- In case of a mass irregular structure, Time history analysis yielded slightly higher displacement for upper stories than that in regular building, whereas as we move down, lower stories showed higher displacements as compared to that in regular structures.
- When time history analysis was done for regular as well as stiffness irregular building (soft storey), it was found that displacements of upper stories did not vary much from each other but as we moved down to lower stories the absolute displacement in case of soft storey were higher compared to respective stories in regular building.
- Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.

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