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Comparison of Analysis and Design of Regular and Irregular Configuration of Multi Story Building in Seismic Zones

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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.

I. 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-

1) **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.
2) *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.
3) *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.
4) *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.
5) *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.

II. OBJECTIVE

A. To calculate the design lateral forces on regular and irregular buildings using response spectrum analysis and to compare the results of different structures.
B. To study three irregularities in structures namely mass, stiffness and vertical geometry irregularities
C. 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.
D. 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.

III. SCOPE OF THE STUDY

A. Only RC buildings are considered.
B. Only vertical irregularity was studied.
C. Linear elastic analysis was done on the structures.
D. Column was modeled as fixed to the base.
E. The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account.
F. The effect of soil structure interaction is ignored.

IV. 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

A. Analysis Methods

1) *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-

a) *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.
b) *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 are observed.
c) *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.

B. Design Method

1) *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-
a) Displacement ductility
b) Rotational and Curvature ductility
c) 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.

2) *Requirements of Ductility*
a) It allows the structure to develop its maximum potential strength through distribution of internal forces.
b) Structural ductility allows the structure as a mechanism under its maximum potential strength resulting in the dissipation of large amount of energy.
c) IS 13920 was followed for ductility based design.

V. 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.

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Ravi Kiran, Sridhar R (2016), the most objective of this project is that the comparative study of standard and vertically irregular building having twenty storey's with RC framed structure having three differing types of sculpturesque structures area unit below earthquake forces. The structure is analyzed and designed by exploitation SAP 2000 code. The Comparison is completed on the idea of shear force, bending moment, level drifts and node displacement.

The reduction in drift, deflection and elementary period of time of the regular and irregular building area unit to be supported with equivalent static and dynamic (Response Spectrum) loading cases for the zones II to V. he conclude that, among the 3 structures thought-about (Regular, set up irregularity and vertical irregularity), Regular structure shown most displacement and drift for all the zones in each static and dynamic analysis.

Inchara K P, Ashwini G (2016), the most objectives of this study were to review the performance and variation in steel proportion and quantities concrete in RC framed irregular building in gravity load and completely different unstable zones. And to grasp the comparison of steel reinforcement proportion and quantities of concrete once the building is meant as per IS 456: 2000 for gravity masses and once the building is meant as per IS 1893 (Part 1):2002 for earthquake forces in numerous unstable zones. During this study 5 (G+4) models were thought-about for the analysis.

All the four models were sculpturesque and analyzed for gravity masses and earthquake forces in numerous unstable zones. ETABS code was used with ESLM and RSM were adopted for the analysis of the models. In line with their analysis, it will be inferred that support reactions attended increase because the zone varied from II to V, that successively raised volume of concrete and weight of steel reinforcement in footings and just in case of beams, proportion of steel reinforcement raised through zones II to V.

Abdul Khadeer Quraishi, Arsad Syed Masood Ahmed, and Md Zubair Ahmed (2015), the study was conducted on RC framed structure having G+10 storeys with unsymmetrical form.

The whole model was analyzed and designed by exploitation STAAD-Pro code. To check proportion of steel quantities for buildings subjected to gravity masses, seismic forces in conjunction with wind load. Once analysis and style they have to be compelled to the conclusion that proportion of reinforcement in column with most load is one.985% to 45.438%, just in case of beams it had been thirty five.112% to 95.867% for basement floors. because the concrete grade raised reinforcement space cut. Steel proportion is a lot of in exterior and edge columns whereas it's less in interior columns and just in case of beam external beam needs less proportion of reinforcement compared to internal beams.

Ravindra N. Shelke et.al [1] studied the effects of various vertical irregularities on the seismic response of a structure. He concluded that, base shear and lateral displacement with height of the structure as the seismic intensity increases from zone-2 to zone-5 which indicates more seismic demand the structure should meet.

Pardeshi Sameer and Prof. N. G. Gore (2016): 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) of regular and irregular RC building frames and Time History Analysis (THA) of regular RC building frames and carry out the ductility based design using IS 13920 corresponding to response spectrum analysis. Comparison of the results of analysis of irregular structures with regular structure is done.

Vijaya Bhaskar reddy. S et. al. (2015): This paper presents illustration of a comparative study of static loads for 5 and 10 storey multi storeyed structures. The significance of this work is to estimate the design loads of a structure. They conclude that deflection of the members is high with an increase in no. of floors. It can be observed that axial force is high in 10-storey compared to 5-storey building.

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.

VI. RESULTS AND DISCUSSION

A. 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.

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1) Structural Modelling

Specifications

Live Load	3kN/m2
Density of RCC considered	25kN/m3
Thickness of slab	150mm
Depth of beam	400mm
Width of beam	350mm
Dimension of column	400x400mm
Density of infill	20kN/m3
Thickness of outer 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	SMR 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.

a) Regular Structure (10 Storeys)

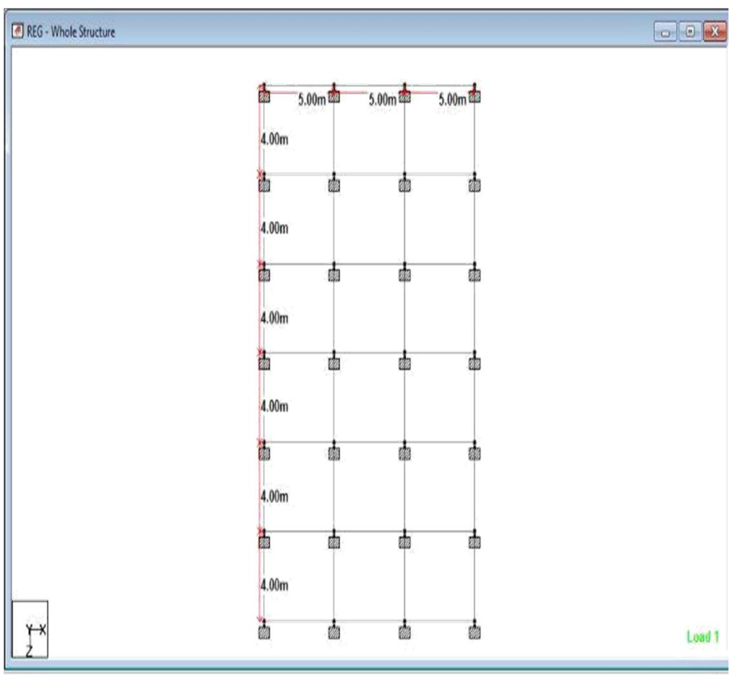

Fig 1: plan of regular structure (10 storeys)

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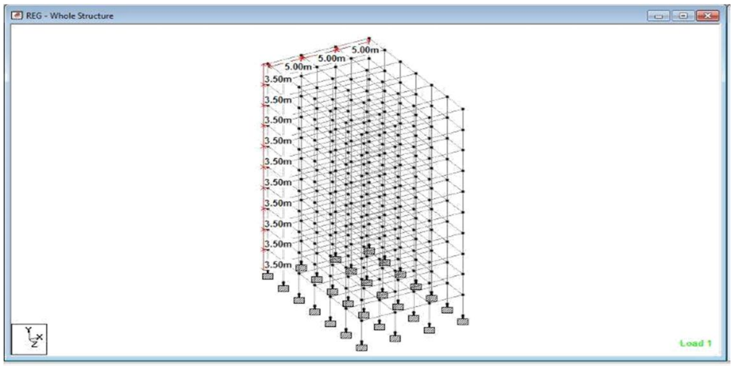

Fig 1.2: 3D view of regular structure (10 storeys)

b) Mass irregular Structure (10 Storeys)

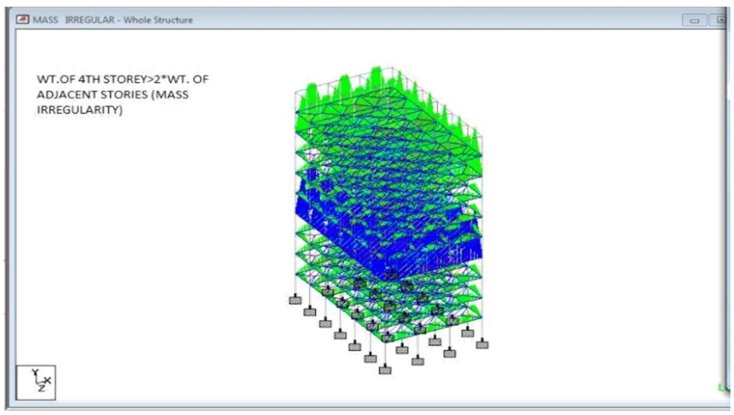

Fig 2: 3D view of mass irregular structure (10 storeys)

c) 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.

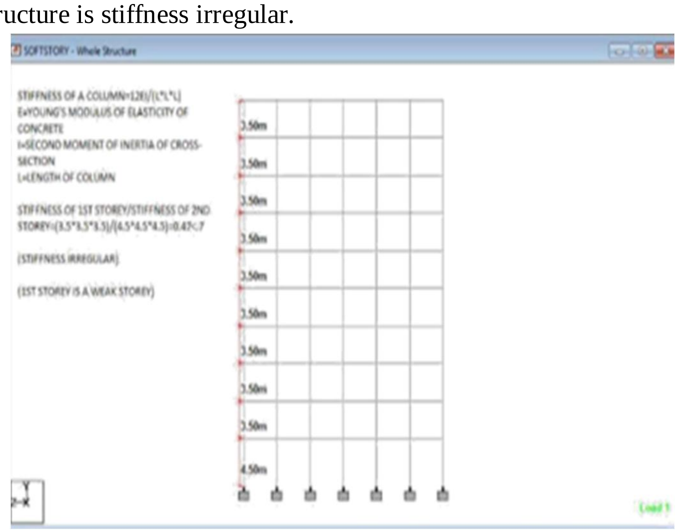

Fig 3: stiffness irregular structure (10 storeys)

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d) 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.

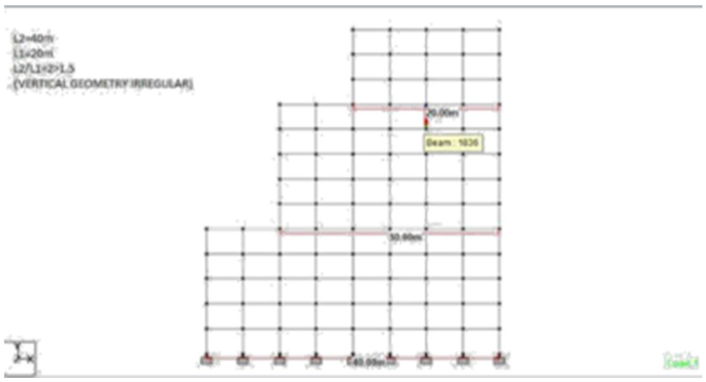


Fig 4: Vertical Geometric irregular structure (14 storeys)

VII. STRUCTURAL MODELS AND THEIR TOP FLOOR TIME HISTORY DISPLACEMENT

A. Regular Structure

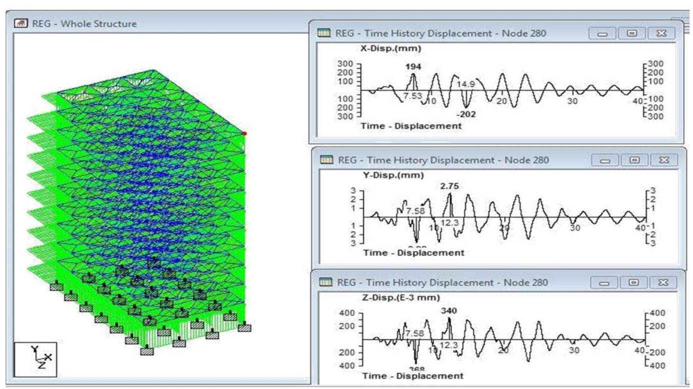


Fig : Time history displacement of the highlighted node of regular structure

B. Stiffness Irregular Structure

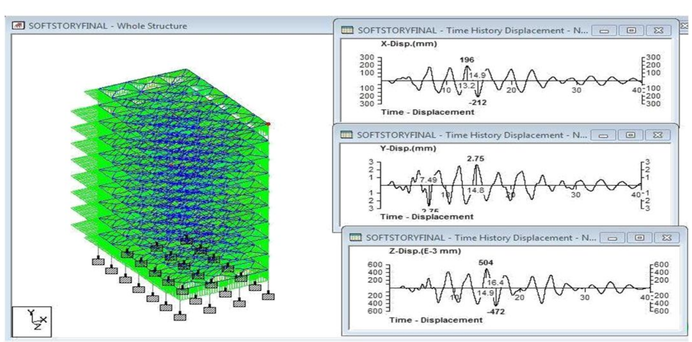
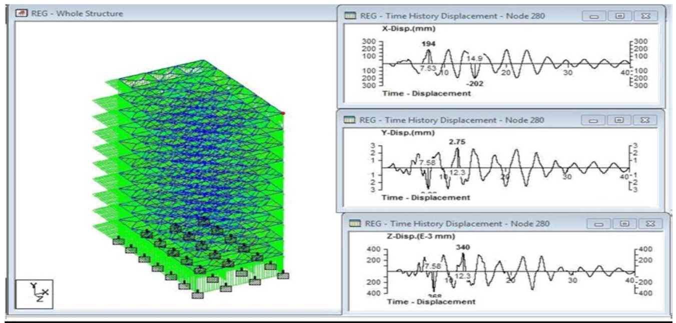


Fig : Time history displacement of the highlighted node of stiffness irregular structure

C. *Mass Irregular Structure*



D. *Vertically Geometric Irregular Structure*

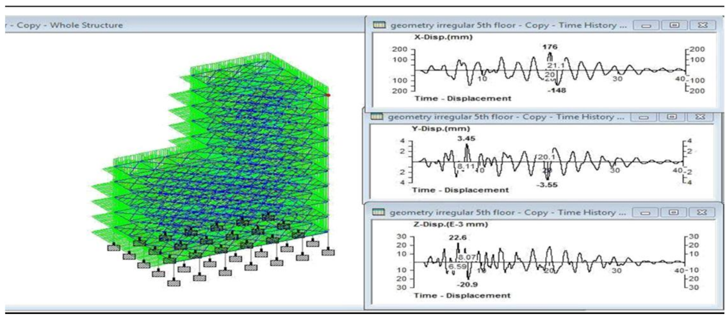


Fig : Time history displacement of the highlighted node of geometry irregular structure

1) *Comparison of Time History Displacements of different floors of Regular structure and Stiffness Irregular Structure*

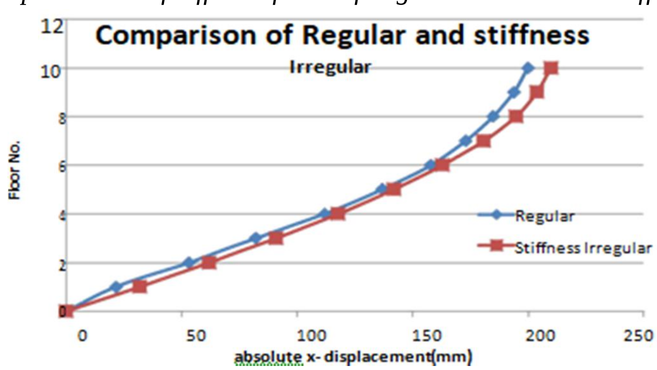


Fig : comparison of displacements along x-direction of regular and stiffness irregular structure

2) *Comparison of Time history displacements of different floors of Regular structure and Mass Irregular structure*

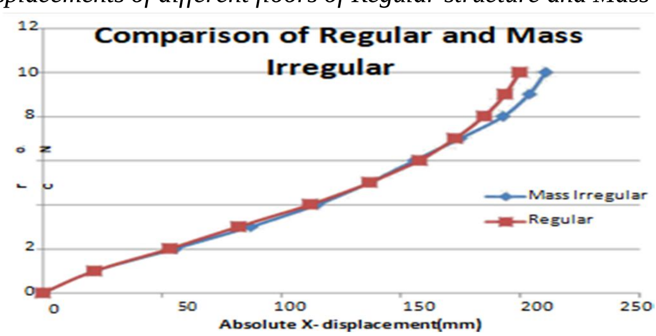


Fig : comparison of displacements along x-direction of regular and mass irregular structure

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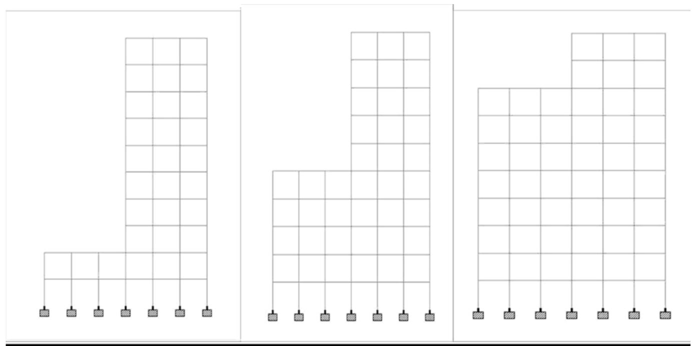
3) Comparison Of Absolute Displacement Of Setback Structures With Setback At Different Floors



Setback in 2nd fl Setback in 5th fl Setback in 8th fl

Fig : Setback in different geometry irregular structures

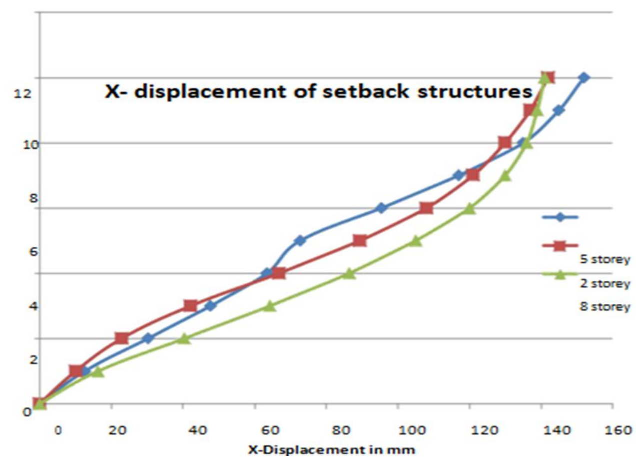


Fig : comparison of displacements along x-direction of 5,2 and 8 storey setback structures

VIII. INTRODUCTION TO ELEVEN GROUND MOTIONS USED

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.

A. San Francisco
B. IS code earth quake
C. Kern County
D. Park field

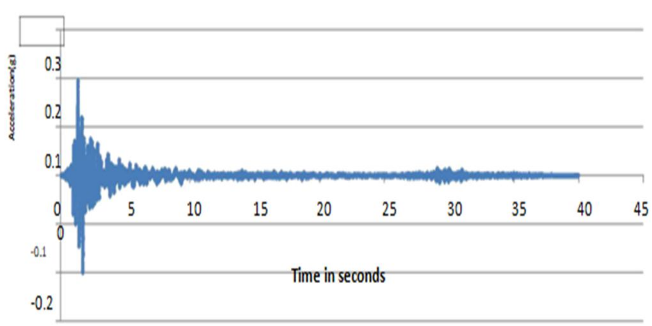


Fig : San Francisco ground motion

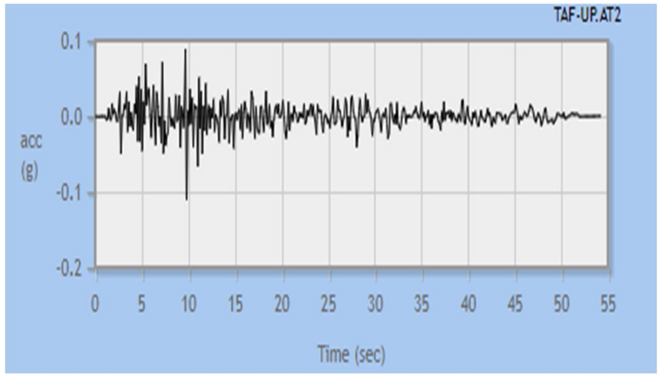


Fig : Kern County ground motion

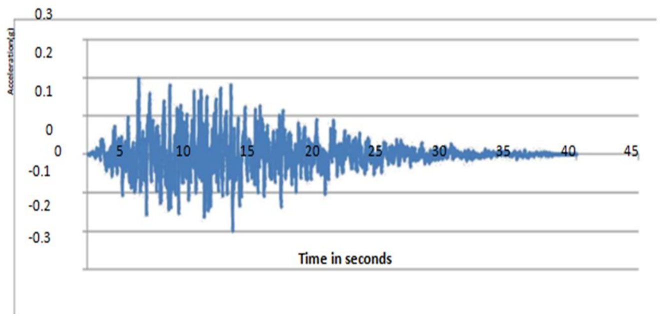


Fig: IS Code ground motion

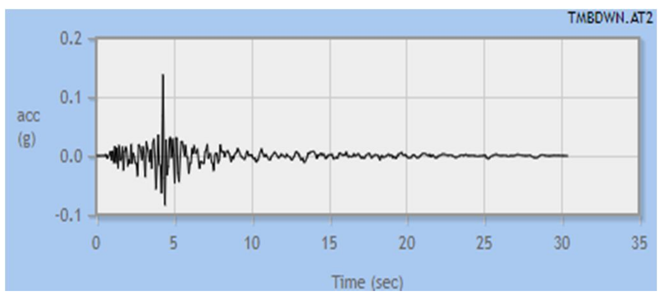


Fig: Pak Field ground motion

IX. TIME HISTORY DISPLACEMENT OF STRUCTURES DUE TO GROUND MOTIONS OF DIFFERENT FREQUENCY CONTENT

A. *Regular 2-storey*

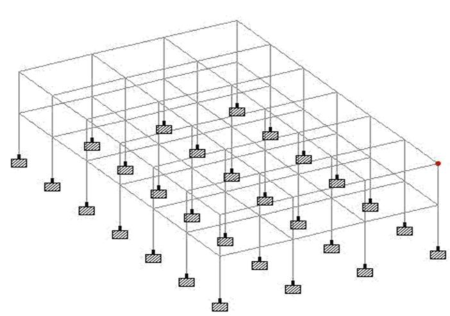


Fig: 3-D view of regular 2-storey structure

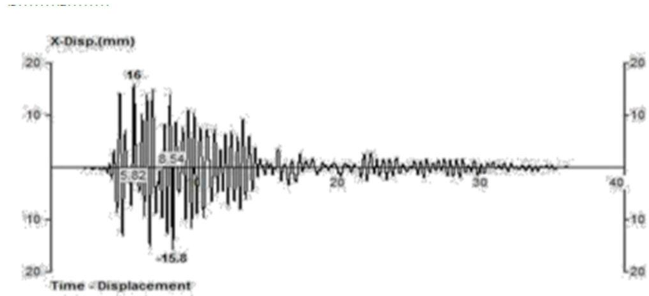


Fig: x- displacement of highlighted node of regular 2 storey building subjected to IS Code ground motion

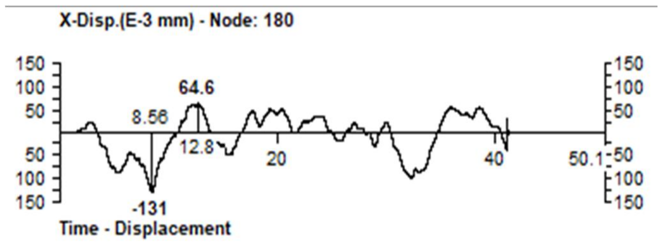


Fig: x- displacement of highlighted node of regular 2 storey building subjected to Kern County ground motion

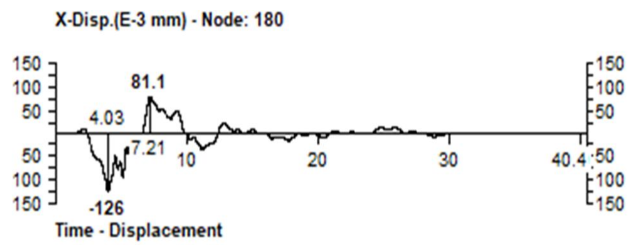


Fig: x- displacement of highlighted node of regular 2 storey building subjected to Park field ground motion

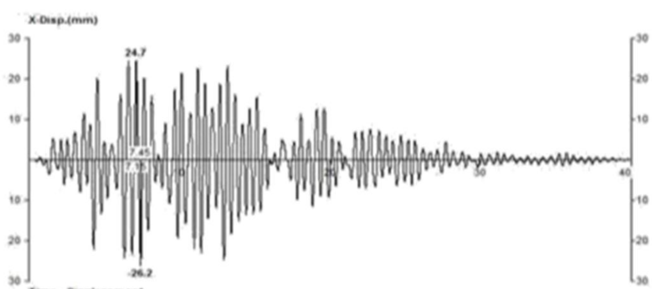


Fig : x- displacement of highlighted node of regular 2 storey building subjected to San Francisco ground motion

B. Regular 20 Storey

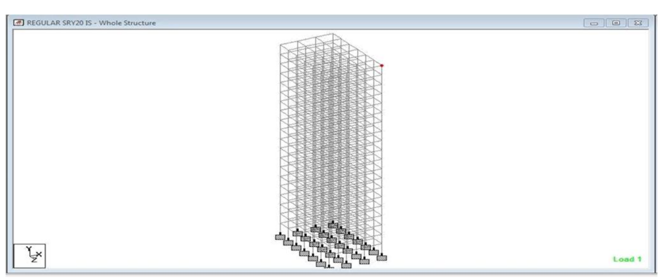


Fig : 3-D of a regular 20-storey building

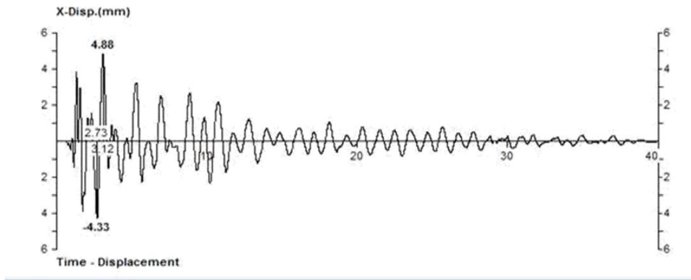


Fig: x- displacement of highlighted node of regular 20 storey building subjected to San Francisco ground motion

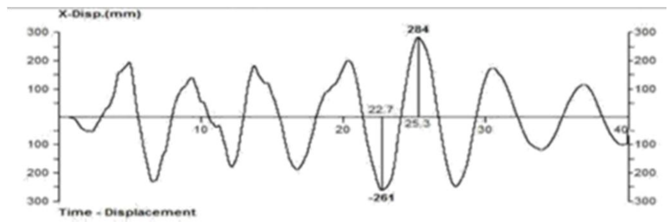


Fig: x- displacement of highlighted node of regular 20 storey building subjected to IS code ground motion

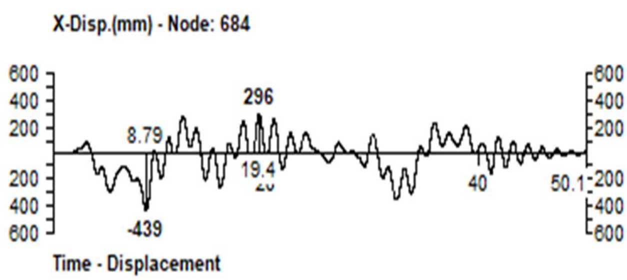


Fig : x- displacement of highlighted node of regular 20 storey building subjected to Kern County ground motion

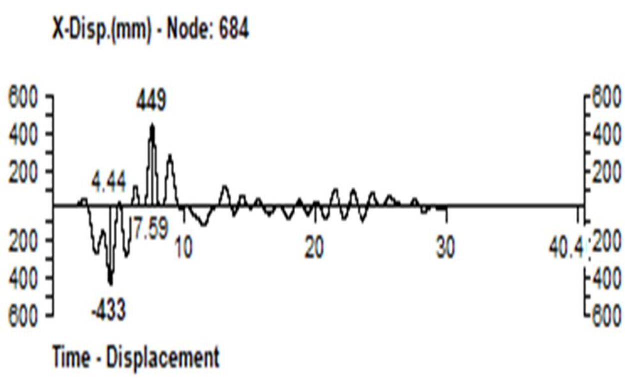


Fig: x- displacement of highlighted node of regular 20 storey building subjected to Parkfield ground motion

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.

X. MASS IRREGULAR STRUCTURE

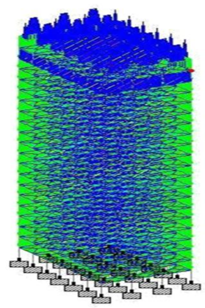


Fig: 3-D view of 20 storey mass irregular structure

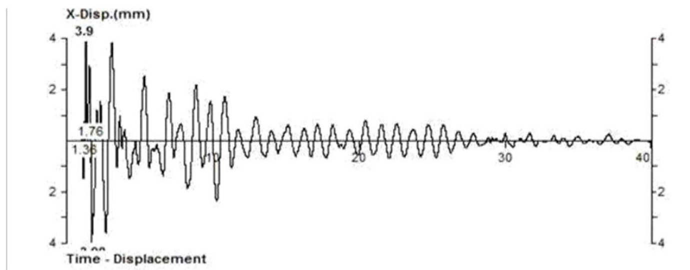


Fig: x- displacement of highlighted node of mass irregular 20 storey building with San Francisco ground motion

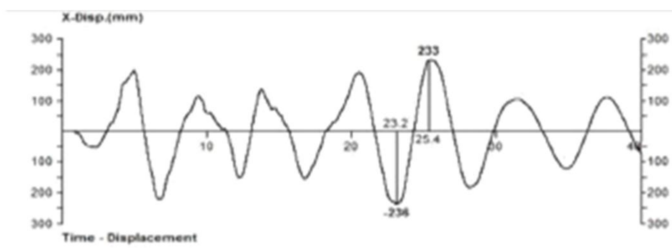


Fig: x- displacement of highlighted node of mass irregular 20 storey building with IS Code ground motion

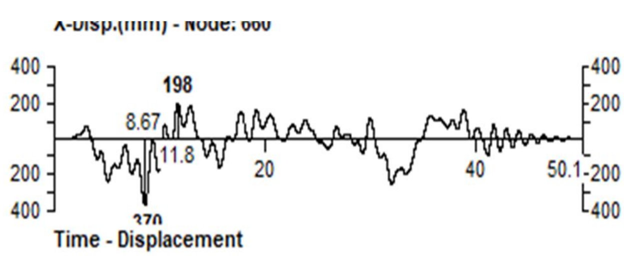


Fig: x- displacement of highlighted node of mass irregular 20 storey building with Kern County ground motion

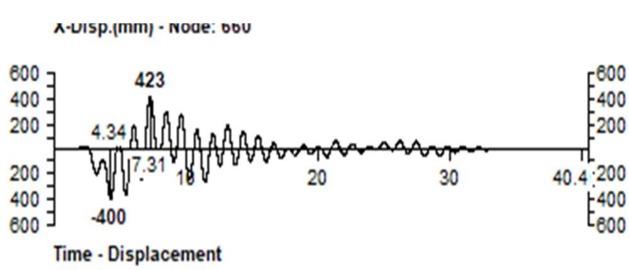


Fig: x- displacement of highlighted node of mass irregular 20 storey building with Park field ground motion

XI. DUCTILITY BASED DESIGN

Specification

Live Load	3kN/m2
Density of RCC considered	25kN/m3
Thickness of slab	150mm
Depth of beam	450mm
Width of beam	350mm
Dimension of column	450mmx450mm

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

A. Comparison of design based on ESA and THA

1) Regular Structure

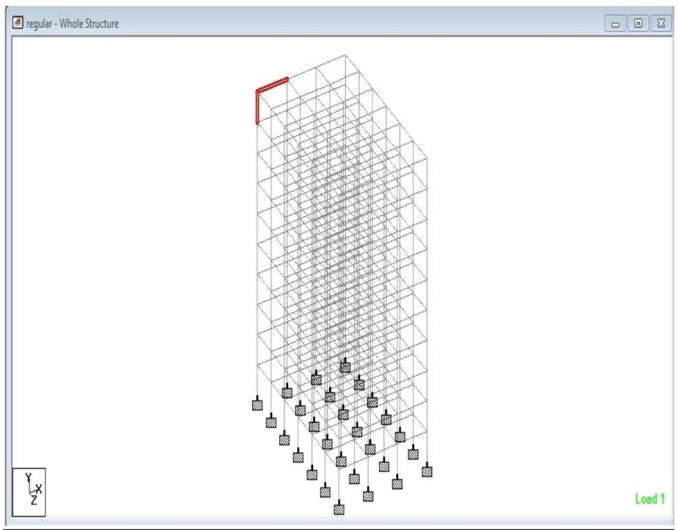


Fig: 3-D view of a 10-storey regular structure with highlighted beam and column

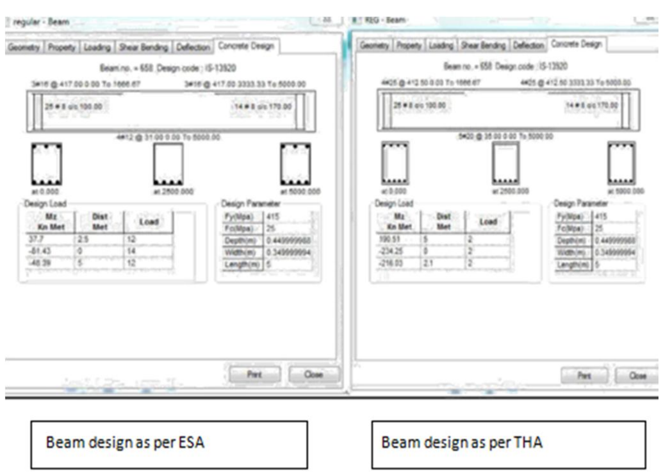


Fig: Results of Design of beam as per ESA and THA

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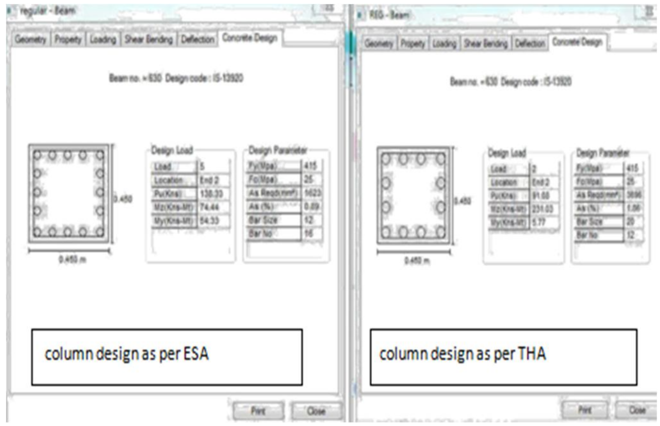


Fig: Results of Design of column as per ESA and THA

2) Mass Irregular Structure

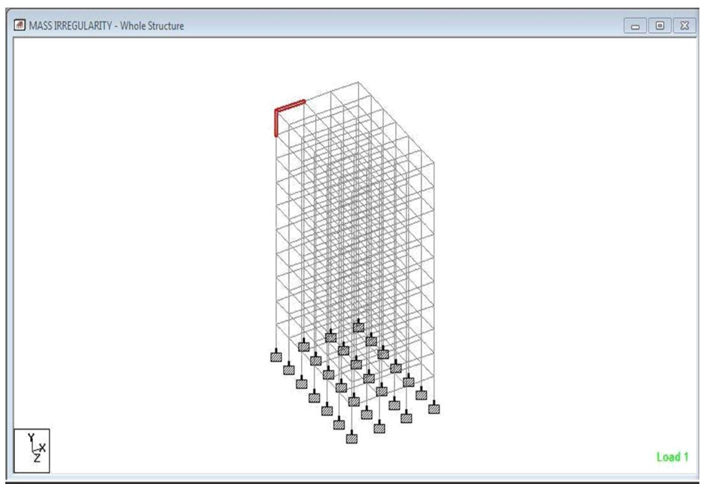


Fig: 3-D view of a10 storey mass irregular structure with highlighted beam and column

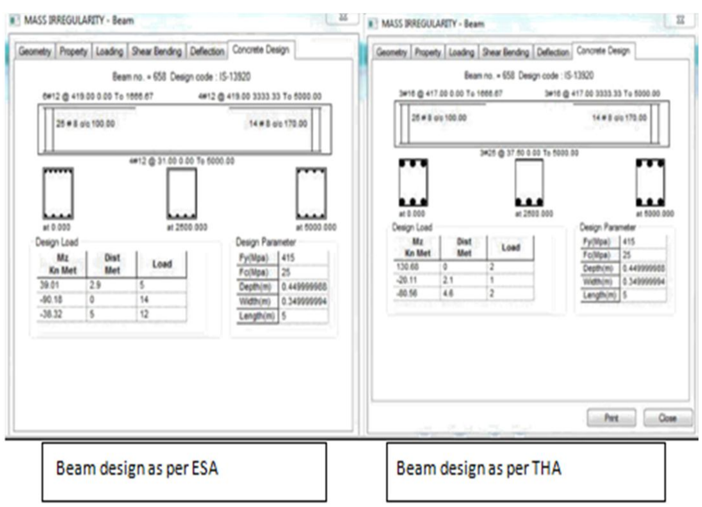


Fig 3.81: Results of Design of beam as per ESA and THA

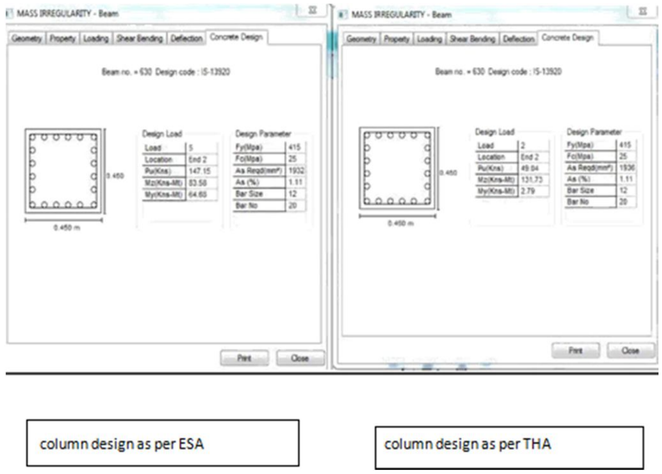


Fig: Results of Design of column as per ESA and THA

3) Geometry Irregular Structure (T- SHAPE)

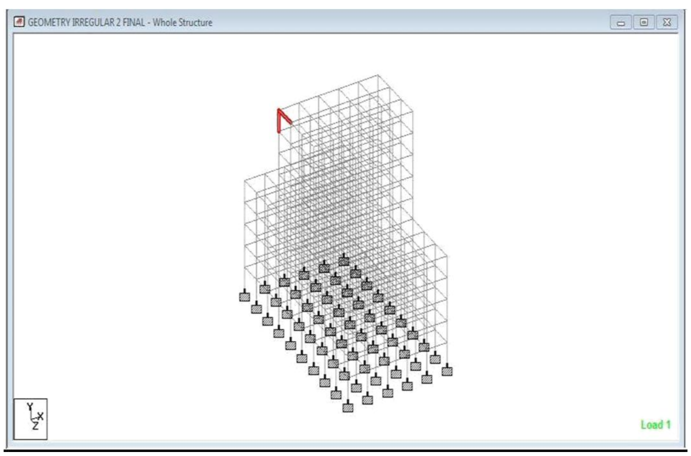
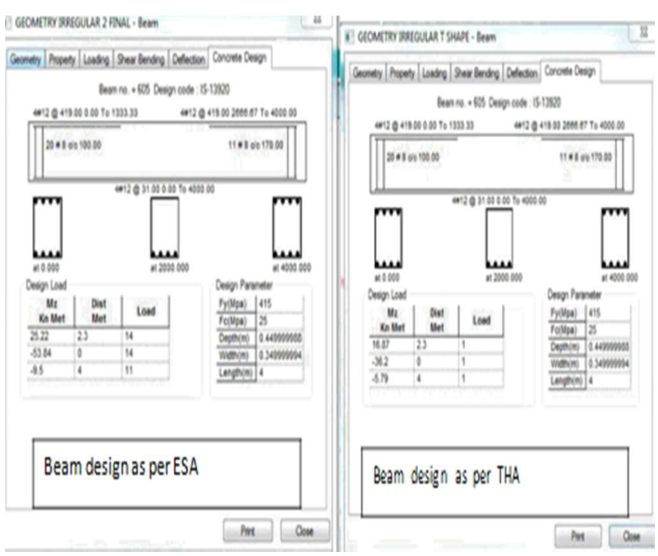


Fig: 3-D view of a10 storey mass irregular structure with highlighted beam and column



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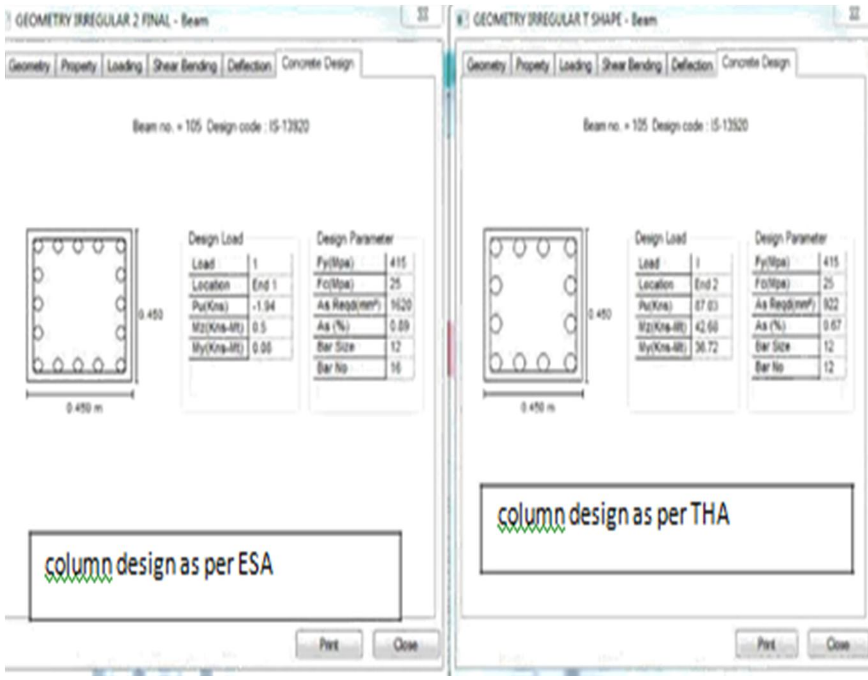

Fig: Results of Design of column as per ESA and THA of a10 storey mass irregular structure

XII. 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-

A. 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.

B. According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.

C. According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.

D. 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

E. 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.

F. Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.

G. 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.

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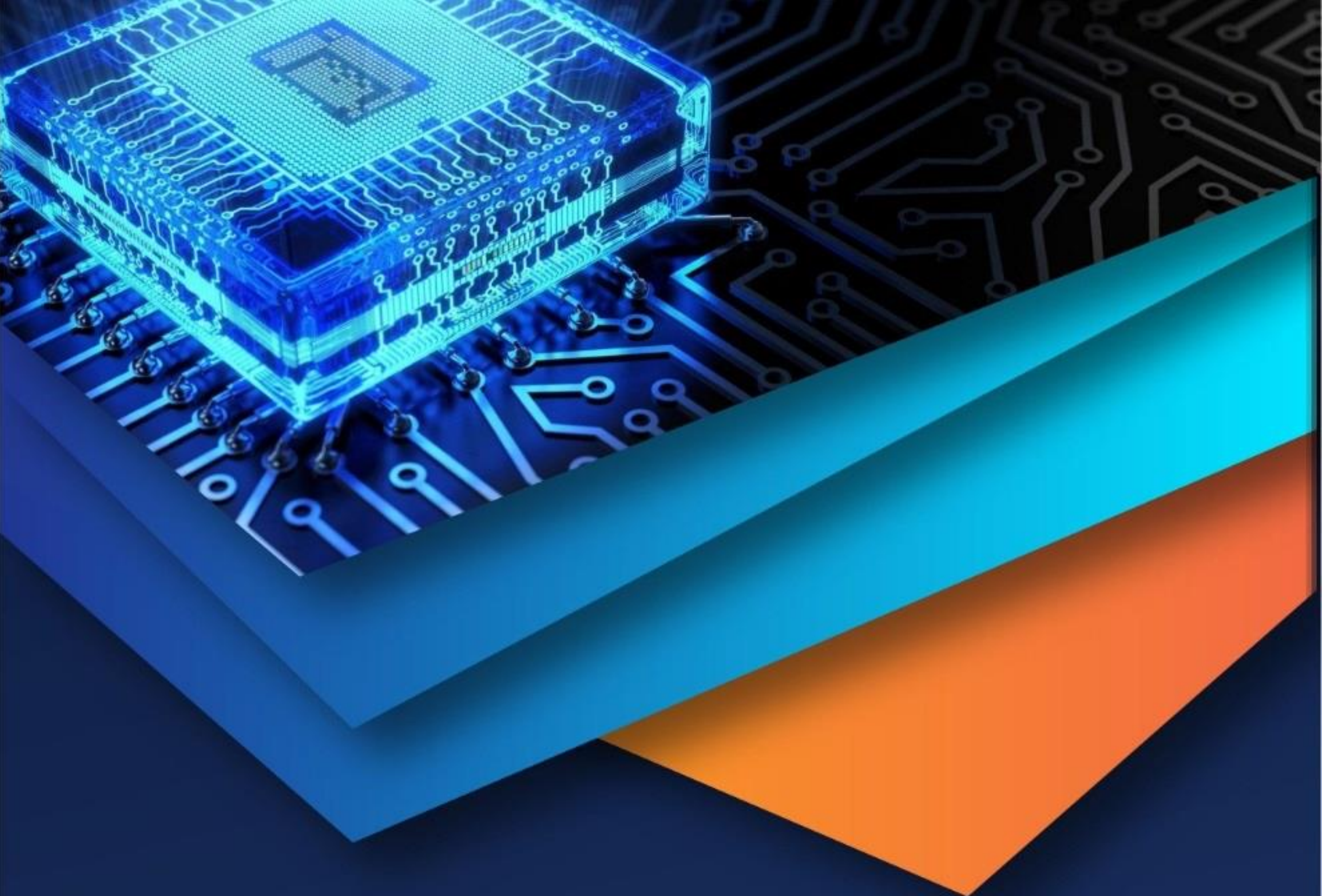

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