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COMPARATIVE ANALYSIS OF VERTICALLY IRREGULAR STRUCTURES IN DIFFERENT SEISMIC ZONES

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ABSTRACT

Generally, buildings are designed taking into account only the gravity loads. Also, the current design seismic codes are not fully practiced while designing a building. Hence, a higher degree of damage may be expected during an earthquake if the seismic resistance of the building is inadequate. This work 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 the seismic analysis of vertically irregular RC building frames in different seismic zones as per IS 1893:2016. Comparison of the results of analysis 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 equivalent static analysis. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. 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 static 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, 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 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. The analysis proves that irregularities are harmful for the structures and it is important to have simpler and regular shapes of frames as well as uniform load distribution around the building. Therefore, as far as possible irregularities in a building must be avoided. But, if irregularities have to be introduced for any reason, they must be designed properly following the conditions of IS 13920:1993. The complex shaped buildings are now days getting popular, but they carry a risk of sustaining damages during earthquakes. Therefore, such buildings should be designed properly taking care of their dynamic behaviour.

Keywords: *Mass Irregularity, Stiffness Irregularity, Geometric Irregularity, Sesimic analysis, Base Shear, Drift, Displacement, ETABS 2018.*

INTRODUCTION

In India, about 50-60% of the total area is vulnerable to the seismic activity. Past earthquakes occurrences demonstrate that, buildings with irregularity are prone to earthquake damages. In order it is essential to identify the seismic response of the structure even in low seismic zones to reduce the seismic damages in buildings. Irregularities in plan and lack of symmetry may imply significant eccentricity between the building mass and stiffness centres, giving rise to damaging coupled lateral/torsion-al response. Irregular structures need a more careful structural analysis to reach a suitable behaviour during a devastating earthquake. The irregularity of the structure may can classify in two types i.e. plan and vertical, these can be characterized to five different types such as torsion-al, re-entrant corners, diaphragms discontinuity, out of plane offset and non-parallel system for plan irregularity as well as vertical irregularity such as stiffness (soft storey), mass, vertical geometric, in plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity (weak storey) (IS 1893(Part I): 2016). The probable reasons for the need of proper analysis of a building may be as follows:

1. Buildings have not been designed and detailed to resist seismic forces.
2. Buildings may have designed for seismic forces, before the publication of current design seismic codes.
3. The lateral strength of the building does not satisfy the seismic forces as per the revised seismic zones or designed base shear.
4. Construction is apparently of poor quality.
5. There have been additions of change of use of building with increased vulnerability.

If all the building elements are arranged with uniformity and the earthquake striking in the familiar direction is optimal. Due to lack of availability of land in big cities, architects usually go for the irregular building structures to make the effective use of available area and to impart provision of proper light and ventilation in the structures. However, the structural irregularity is a combined state of two types that is horizontal and vertical. The horizontal irregularity may be classified on the bases of Asymmetrical plan shapes, Re-Entrant corners, Diaphragm discontinuity and irregular distribution of mass, strength, stiffness along plan etc., and the vertical irregularity may be classified on the bases of Mass, Strength, Stiffness and Setback. Adequate to most of such asymmetries, the structure's lateral resistance of earthquake is generally torsionally uneven & thus creating great amount displacement, drift and high force concentrations within the resisting elements which can cause severe damages and may lead to collapse of the structure

- **Vertical Irregularity:** Vertical irregularity results from the uneven distribution of mass, strength or stiffness along the elevation of a building structure. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a structure. Stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setbacks in the elevation of a building.
- **Plan Irregularity:** Plan irregular structures are those in which seismic response is not only translational but also torsional, and is a result of stiffness and/or mass eccentricity in the structure. A regular structure may actually be asymmetric if the structure has masonry infill walls or stiffer lateral resisting systems on one side of the structure that has not been taken into consideration in the analysis. Asymmetry may in fact exist in a nominally symmetric structure because of uncertainty in the evaluation of centre of mass and stiffness, inaccuracy in the measurement of the dimensions of structural elements.

In the past several major earthquakes have expose the shortcomings in buildings which had caused them to damage or collapse. It has been found that regular shape buildings perform better during earthquakes. The structural irregularities cause non- uniform load distribution in various members of a building. There must a continuous path for these inertial forces to be carried from ground to the building. A gap in this transmission path results in failure of the structure at that location. The vertical irregularities are considered and described as follows.

STIFFNESS IRREGULARITY

1.1.1 SOFT STOREY; A soft story is one in which the lateral stiffness is less than 70 % of that in the storey above or less than 80% of the average lateral stiffness of three storeys above.

1.1.2 EXTREME SOFT STORY: An extreme soft storey is one in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average stiffness of the thee storeys above.

MASS IRREGULARITY

Mass irregularity is considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. The effective mass is the real mass consisting of the dead weight of the floor plus the actual weight of partition and equipment. Excess mass can lead to increase in lateral inertial forces, reduced ductility of vertical load resisting elements, and increased tendency towards collapse. Irregularities of mass distribution in vertical and horizontal planes can result in irregular response and complex dynamics. The central force of gravity is shifted above the basic in the case of heavy masses in upper floors resulting in the large bending moments.

VERTICAL GEOMETRIC IRREGULARITY

Geometric irregularity exists when the horizontal dimension of the lateral force existing system in any storey is more than 150% of that in an adjacent storey. The setback can also be visualized as a vertical re-entrant corner. The general solution of a setback problem is the total seismic separation in plan through separation section, so that the portion of building is free to vibrate independently.

The purpose of this hypothetical study is to evaluate the seismic properties and characteristics for regular & vertical geometry structures. The main aspect of this analysis is to obtain the sustainability of the building regarding the performance of the buildings by using the aid of capacity and the demand of the structure for a designed strong motion earthquake characteristics using the different method of analysis.

OBJECTIVES OF THE STUDY

This paper includes the major objectives of the research work are as follows:

- To study the effect of mass irregularity and performance level of the structure.
- To study the effect of stiffness irregularity and performance level of the structure.
- To study the effect of vertical geometric irregularity and performance level of the structure.
- Comparison between regular and vertical irregular frame on the basis of storey drift & displacement, base shear etc.
- To obtain the Seismic performances of different irregular buildings located in different earthquake zones of India as per IS 1893:2016, and also identify the most vulnerable building among them.
- Evaluation of design lateral forces on buildings with irregularities namely vertical geometric irregularity (irregular shear wall), mass irregularity and stiffness irregularity subjected to biaxial excitation and to compare the results of different structures. A comparative study was performed on 3-D analysis model created in ETABS, a commercial computer program for the analysis of structures.
- Implement the proposed multi-scale modelling technique to assess the seismic performance of the vertical irregularity of RC building frames to evaluate the seismic safety and collapse vulnerability of existing buildings.

MODELLING & ANALYSIS

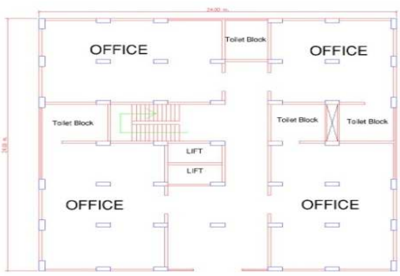
In this paper, for analysis purpose, regular and irregular building models with different vertical irregularities, in different seismic zones as per IS 1893:2016 have been used and response spectrum analysis has been carried out using Etabs 2018 for G+9 storey building.

Details of Buildings considered in this work are as follows:

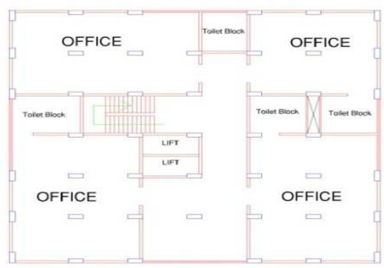
Type of structure	:	Residential Building
Number of stories	:	9
Height of typical floor	:	3.6m
Column size	:	400 mm X 800 mm
Beam size	:	400 mm X 500 mm
Slab thickness	:	150 mm
Masonry wall thickness	:	230 mm
Live load	:	2 KN/m2
Floor finish	:	1 KN/m2
Soil types considered as type II	:	Medium soil.
F_{ck}	:	20 N/mm2
F_y	:	500N/mm2
Zone Factor	:	Zone II – 0.1
		Zone III – 0.16
		Zone IV – 0.24
		Zone V – 0.36
Response Reduction Factor	:	3
Importance Factor	:	1

The dimensions of beams, columns and slab are kept constant for the purpose of analysis. Other data used for the purpose of analysis have been taken from IS 1893:2016.

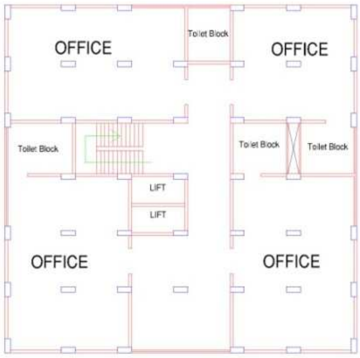
Plan & Elevation for Model 1 – Regular Frame Building



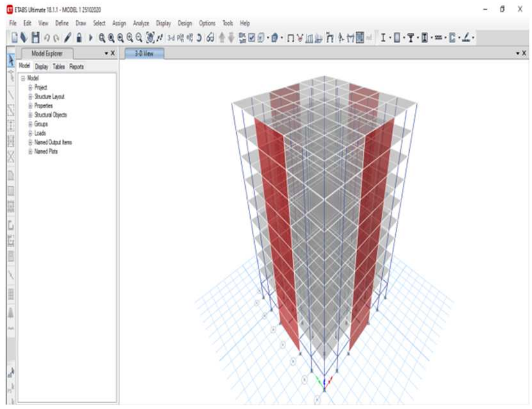
GROUND FLOOR PLAN (+1'-6")



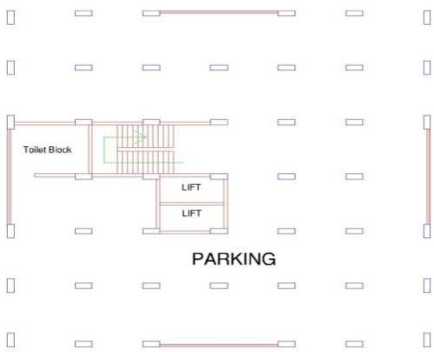
FIRST FLOOR PLAN (+13'-6")



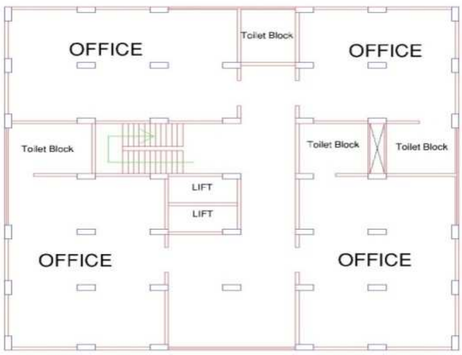
TYPICAL FLOOR PLAN



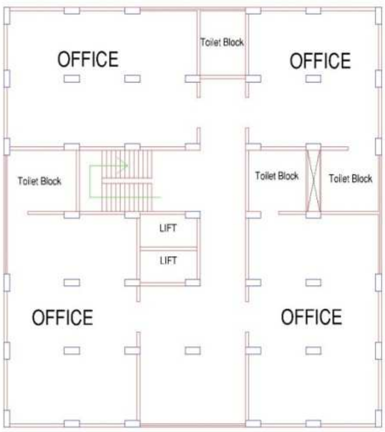
Plan & Elevation for Model 2
Stiffness Irregular Building: Height of Ground Floor – 5 m. for parking while the height of other floor considered – 3.5 m.



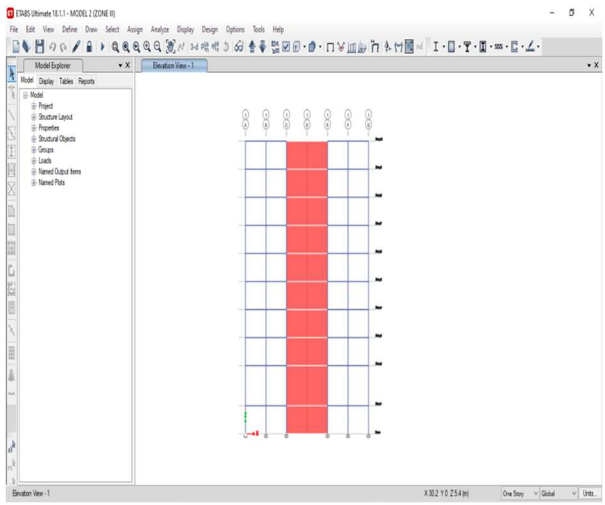
GROUND FLOOR PLAN (+0'-0")



FIRST FLOOR PLAN (+15'-0")



TYPICAL FLOOR PLAN



Plan & Elevation for Model 3 – Mass Irregular Building
Swimming Pool has been considered on the fifth floor of the building which increases the weight of the floor as compared to other floors.

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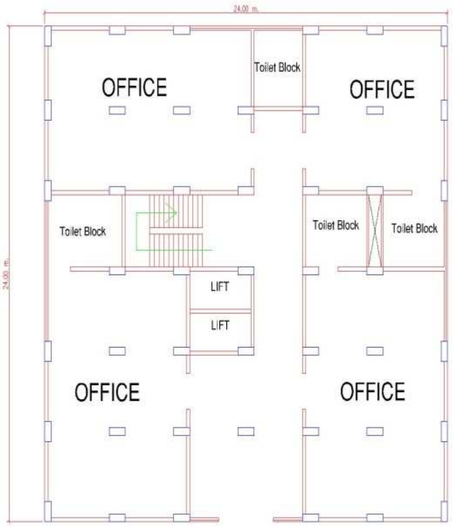
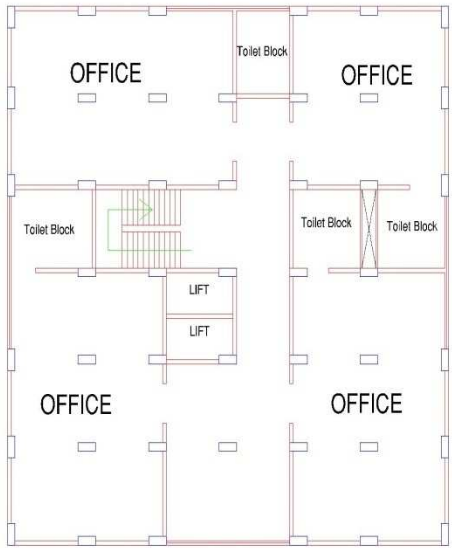
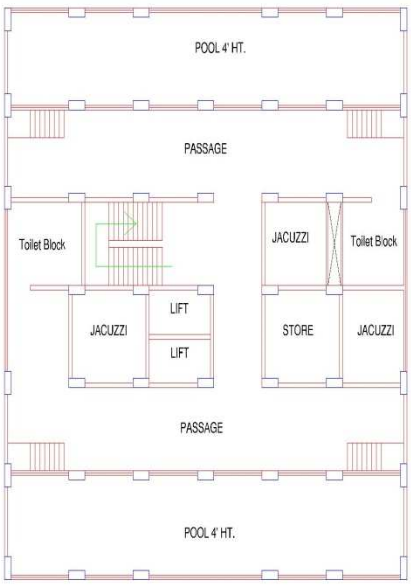


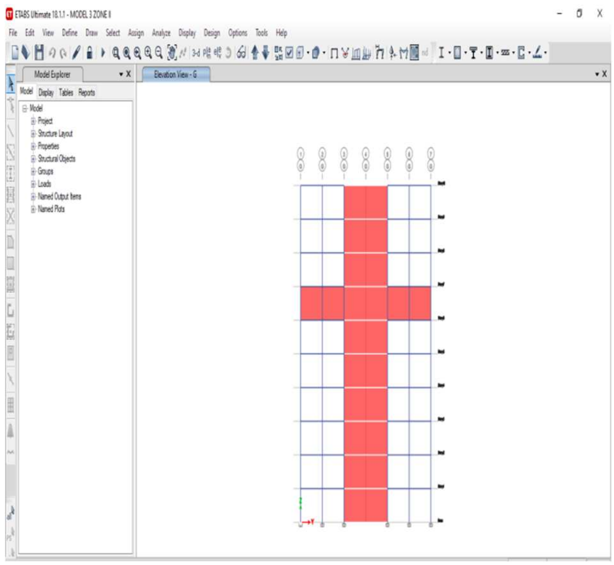
GROUND FLOOR PLAN (+1'-6")



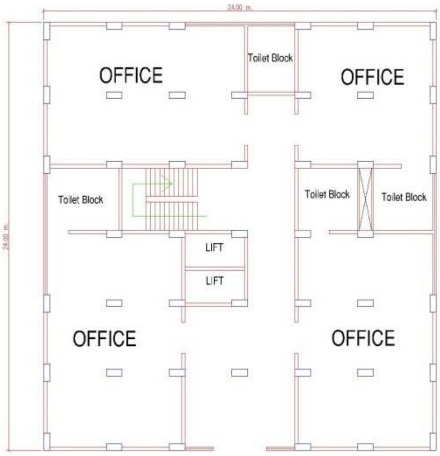
FIRST FLOOR PLAN (+13'-6")



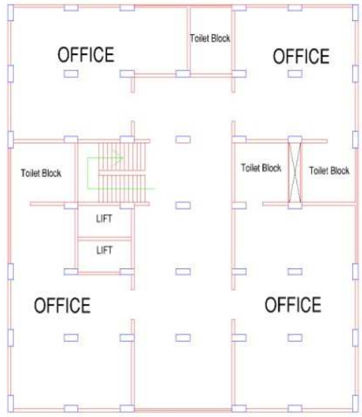
FIFTH FLOOR PLAN



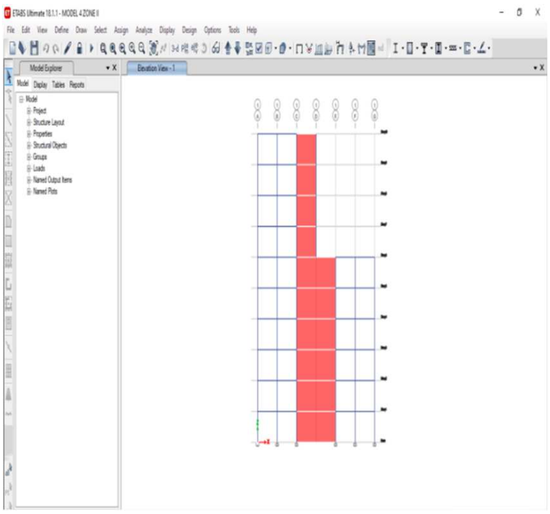
Plan & Elevation for Model 4 – Geometric Irregular Building
Bottom Dimension of Building – 24 m x 24 m
Top Dimension of Building – 12 m x 24 m

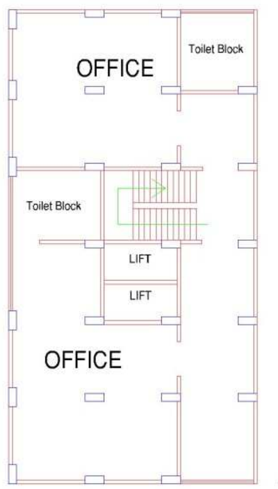


GROUND FLOOR PLAN (+1'-6")



FIRST, SECOND, THIRD, FOURTH FLOOR PLAN





FIFTH, SIXTH, SEVENTH, EIGTH FLOOR PLAN

Seismic analysis is a subset of structural analysis and is the calculation of the response of the building structure to earthquake and is a relevant part of structural design where earthquakes are prevalent. The seismic analysis of a structure involves evaluation of the earthquake forces acting at various level of the structure during an earthquake and the effect of such forces on the behaviour of the overall structure. The analysis may be static or dynamic in approach as per the code provisions. Thus broadly we can say that linear analysis of structures to compute the earthquake forces is commonly based on one of the following three approaches.

1. An equivalent lateral procedure in which dynamic effects are approximated by horizontal static forces applied to the structure. This method is quasi-dynamic in nature and is termed as the Seismic Coefficient Method in the IS code.

2. The Response Spectrum Approach in which the effects on the structure are related to the response of simple, single degree of freedom oscillators of varying natural periods to earthquake shaking.

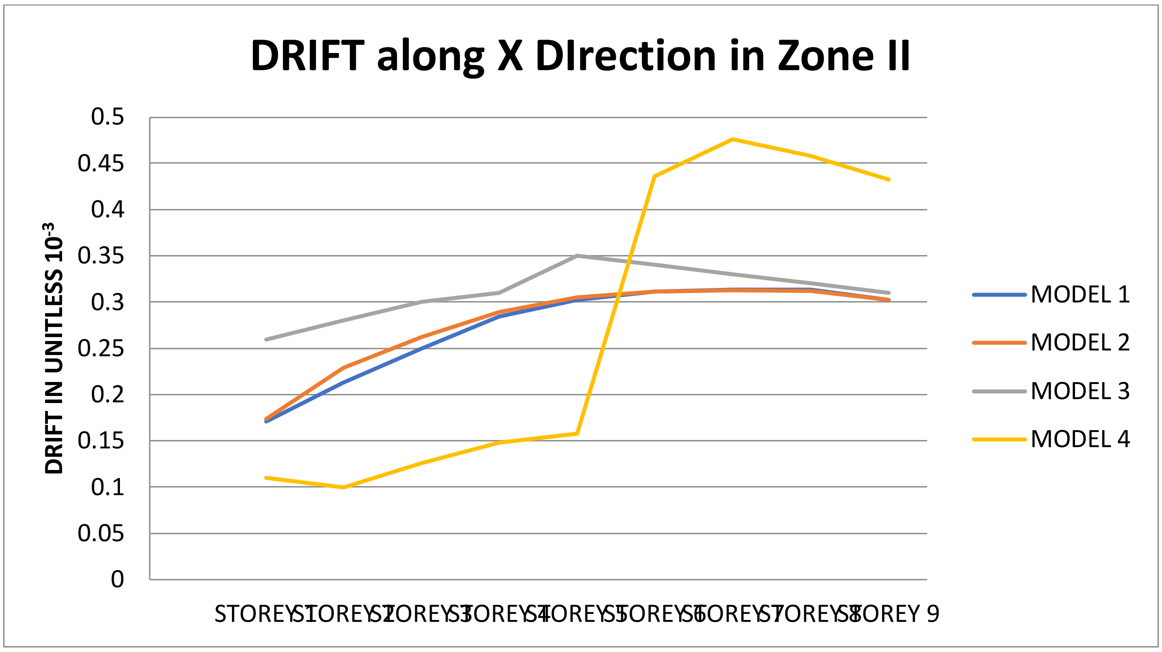
3. Response History Method or Time History Method in which direct input of the time history of a designed earthquake into a mathematical model of the structure using computer analyses. Two of the above three methods of analysis, i.e. Seismic Coefficient Method and Response Spectrum Method, are considered for the analysis of buildings studied here. Details of these methods are described in the following section. The seismic method of analysis based on Indian standard 1893:2016 (Part – 1) is described as follows

- Equivalent Static Analysis - This is a linear static analysis. This approach defines a way to represent the effect of earthquake ground motion when series of forces are act on a building, through a seismic design response spectrum. This method assumes that the building responds in its fundamental mode. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces. In the equivalent static method, the lateral force equivalent to the design basis earthquake is applied statically. The equivalent lateral forces at each storey level are applied at the design 'centre of mass' locations. It is located at the design eccentricity from the calculated 'centre of rigidity (or stiffness)'.
- Response Spectrum Analysis - The response spectrum method plays an important role in analysis and design of multi storied buildings for seismic loads. The maximum response of the building is estimated directly from the elastic and inelastic design spectrums. The building codes are characterized for earthquake motions are based on simplification of the response spectrum method, so this method is extremely significant in the analysis and design procedures. The load combinations will be used for analysis of these models will be according to IS code 1893:2016. Response Structure analysis was performed on regular and various irregular buildings using ETAB. The storey shear forces were calculated for each floor and graph was plotted for each structure. 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.

Results and Discussion - The results of building model are presented in this chapter. The analysis carried out using response spectrum analysis. The results of Base shear, Lateral displacement, story drift were presented for different irregularities for different seismic zones of India.

Values of Drift for Zone II

Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2000 Cl 7.11.1[3]. Along X direction model IV i.e. geometric vertically irregular model has got higher drift value in all stories when compared with other structures. It has got the value of 0. 0.00047 in the seventh storey. The code recommends a maximum permitted drift value of 0.004H where H is the storey height (H=3.5m) and the permissible drift value is 0.014. Along Y direction model IV holds the higher drift value of 0.000497.



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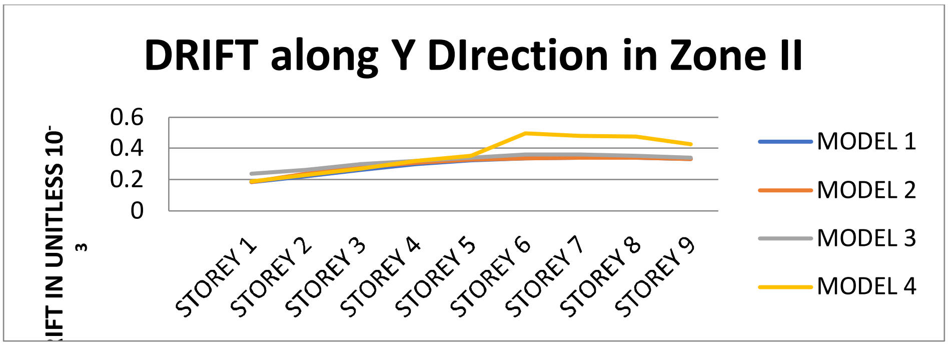
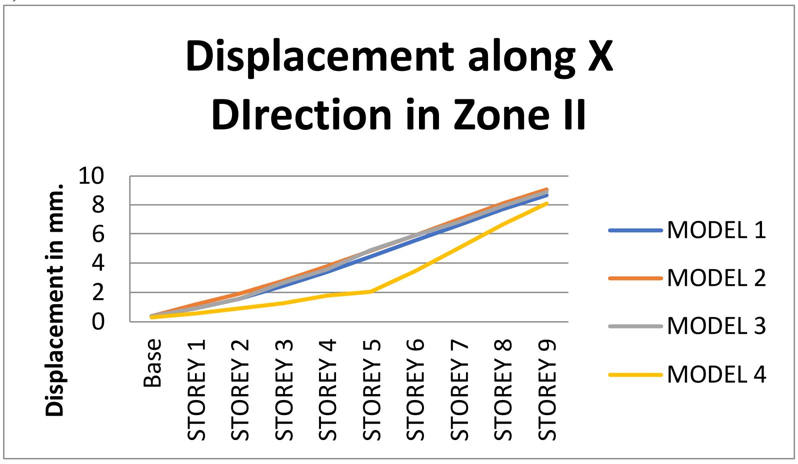
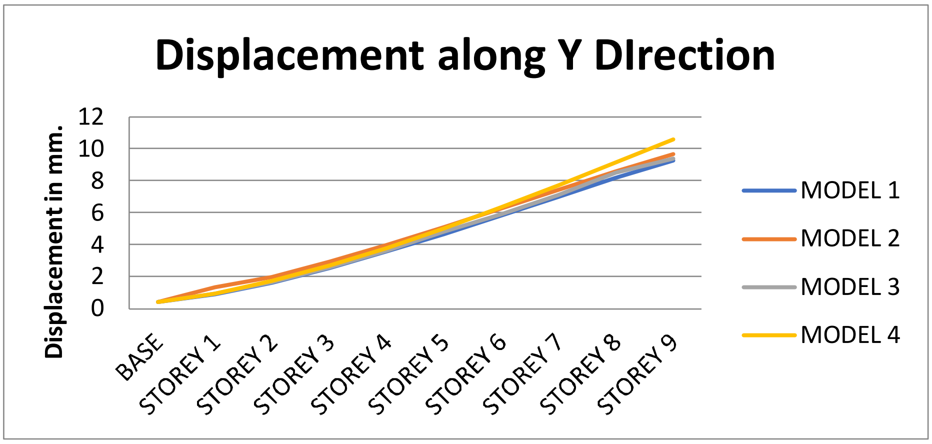


Values of Displacement for Zone II

The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure. Model II shows the maximum displacement along X direction followed by model III, I and model IV.

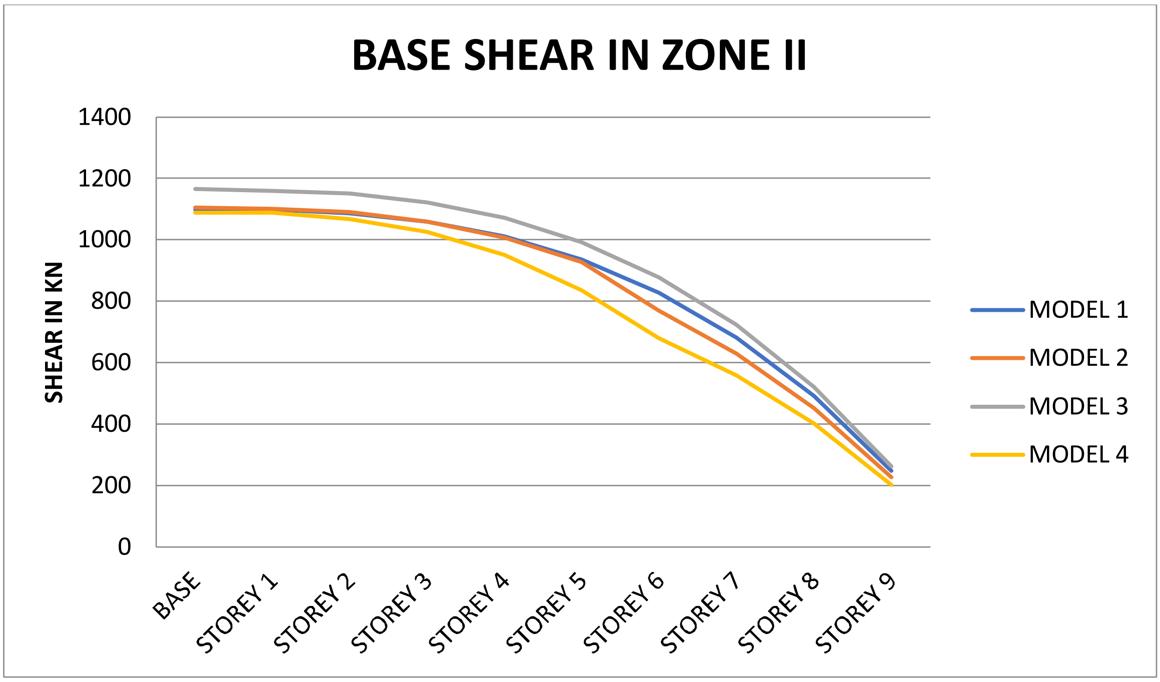




Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

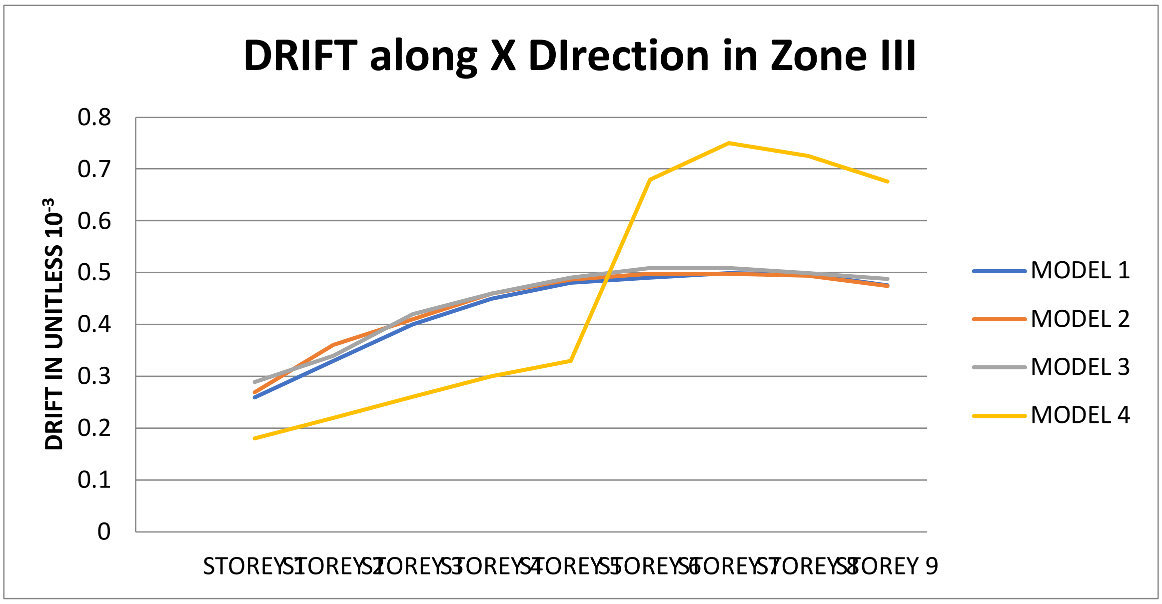
Values of Base Shear for Zone II

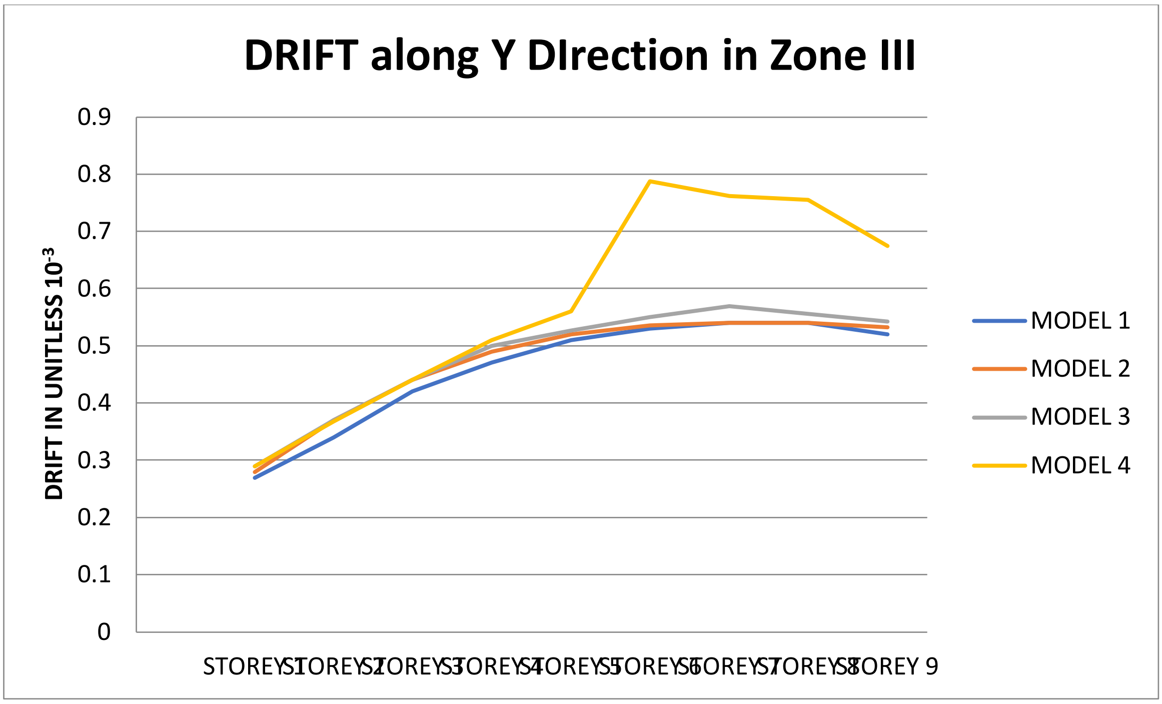
The value of base shear mainly depends on the stiffness factor of the structure and it is found more in model 3 than other models indicating that structure is much stiffer for seismic response due to its overall mass distribution.



Values of Drift for Zone III

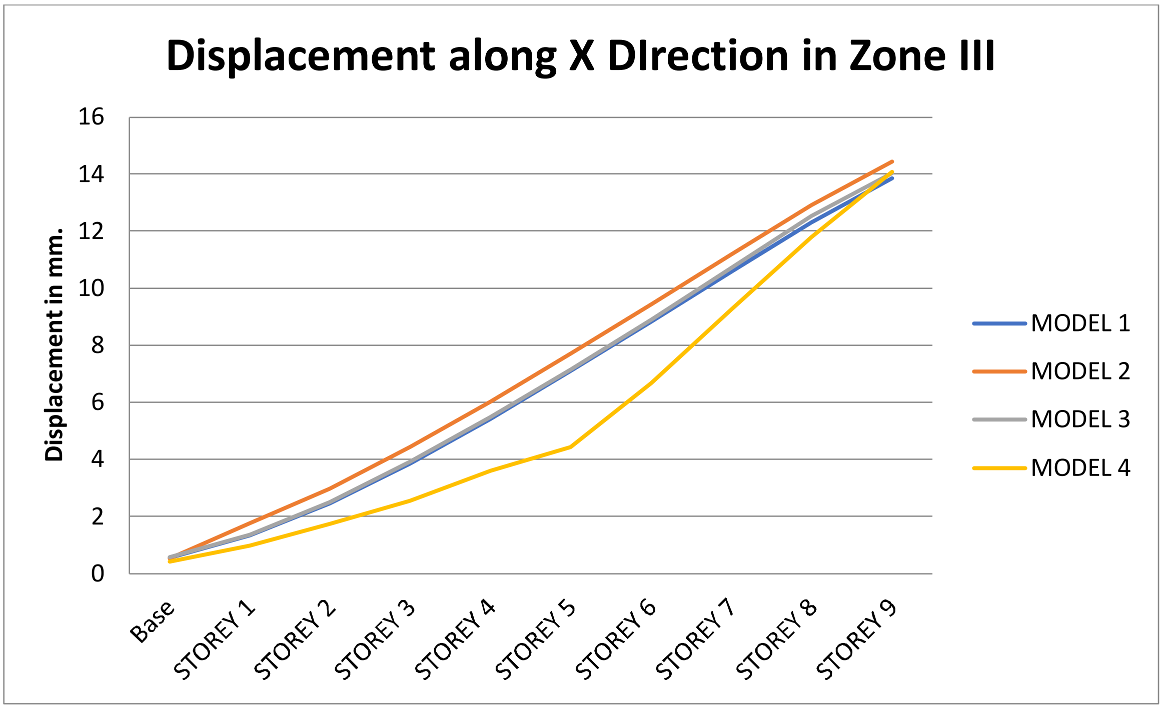
Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2000 Cl 7.11.1[3]. Along X direction model IV i.e. geometric vertically irregular model has got higher drift value in all stories when compared with other structures. It has got the value of 0. 0.00047 in the seventh storey. The code recommends a maximum permitted drift value of 0.004H where H is the storey height (H=3.5m) and the permissible drift value is 0.014. Along Y direction model IV holds the higher drift value of 0.000497.

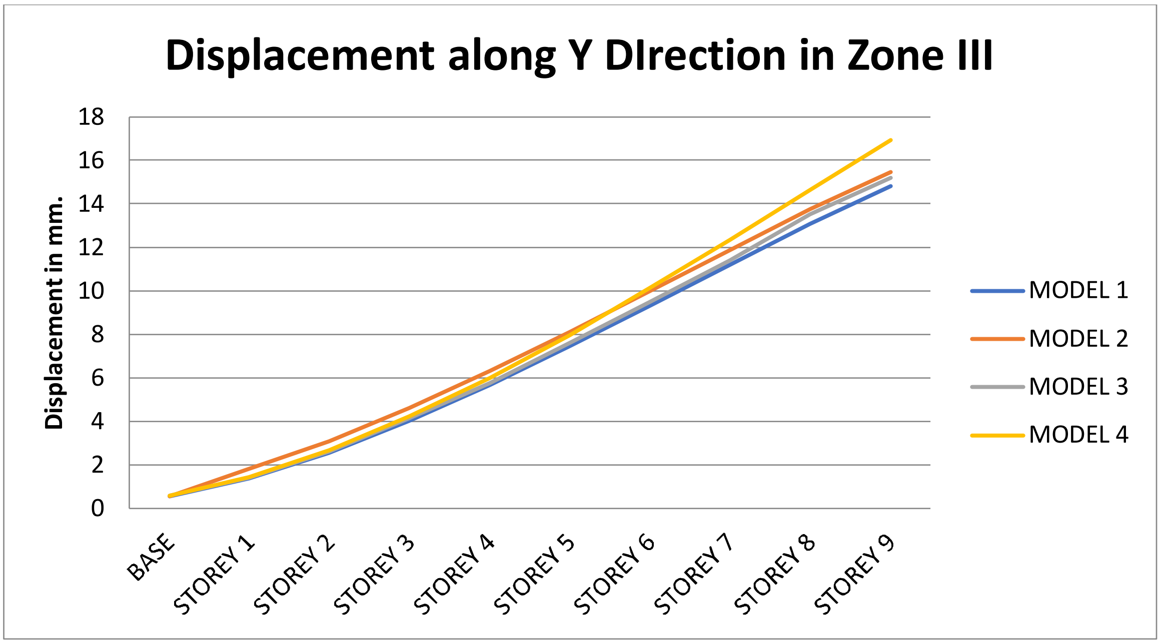




Values of Displacement for Zone III

The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure. Model II shows the maximum displacement along X direction followed by model III, I and model IV.

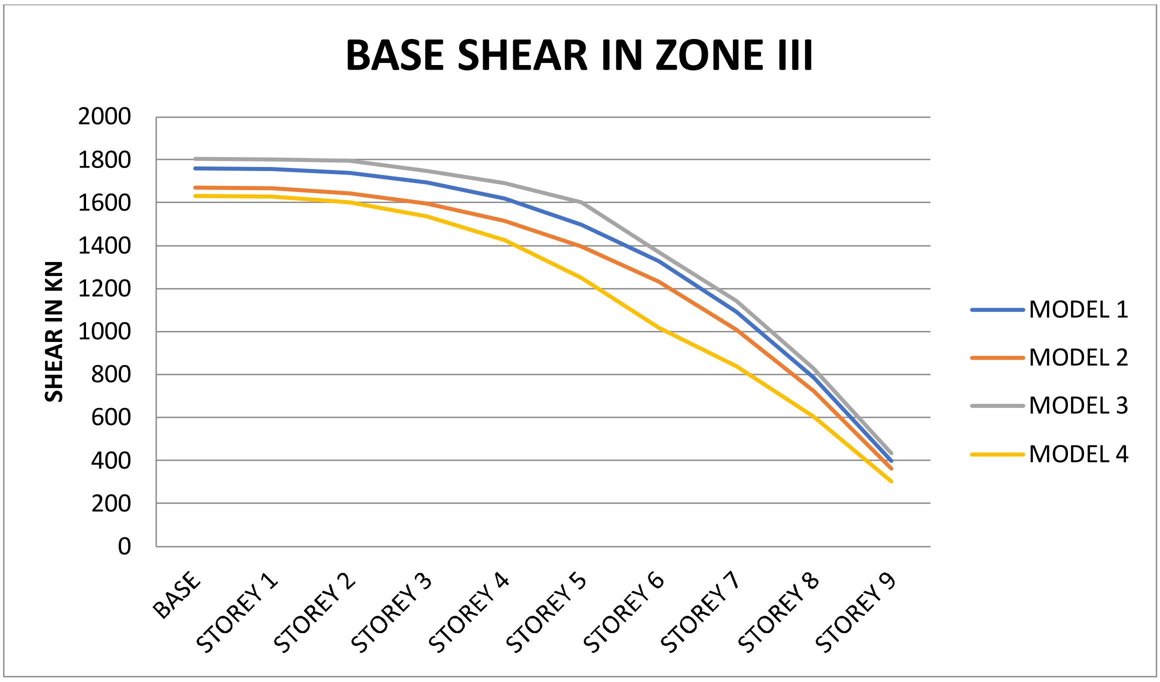




Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

Values of Base Shear for Zone III

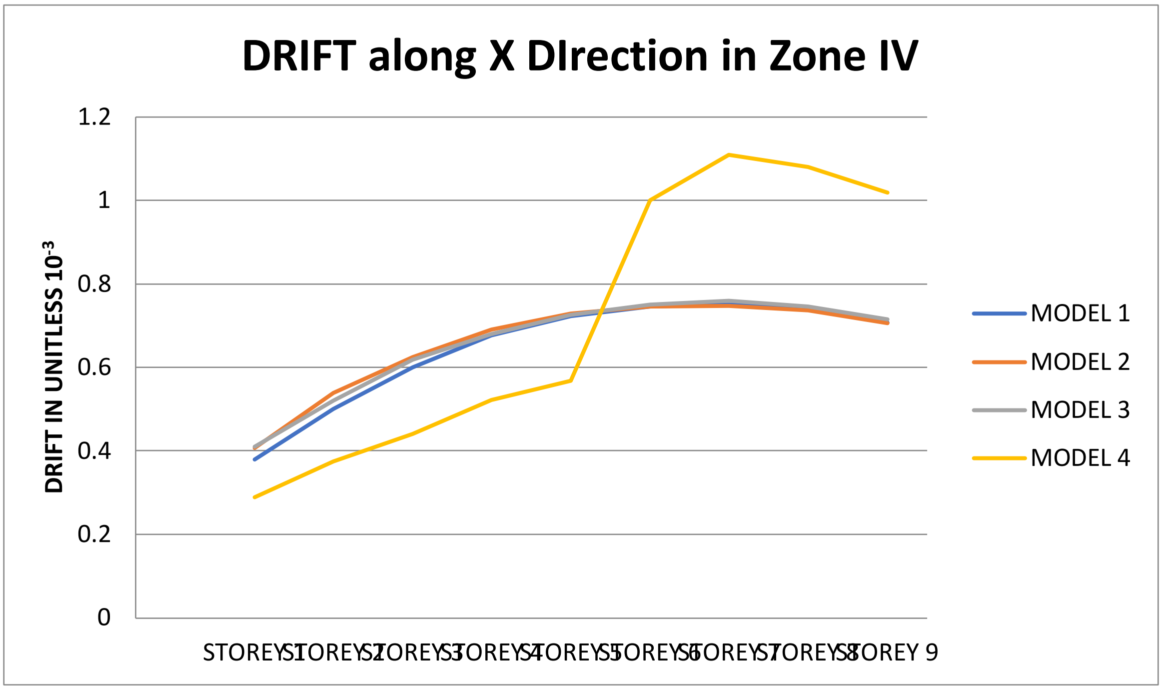
The value of base shear mainly depends on the stiffness factor of the structure and it is found more in model 3 than other models indicating that structure is much stiffer for seismic response due to its overall mass distribution.

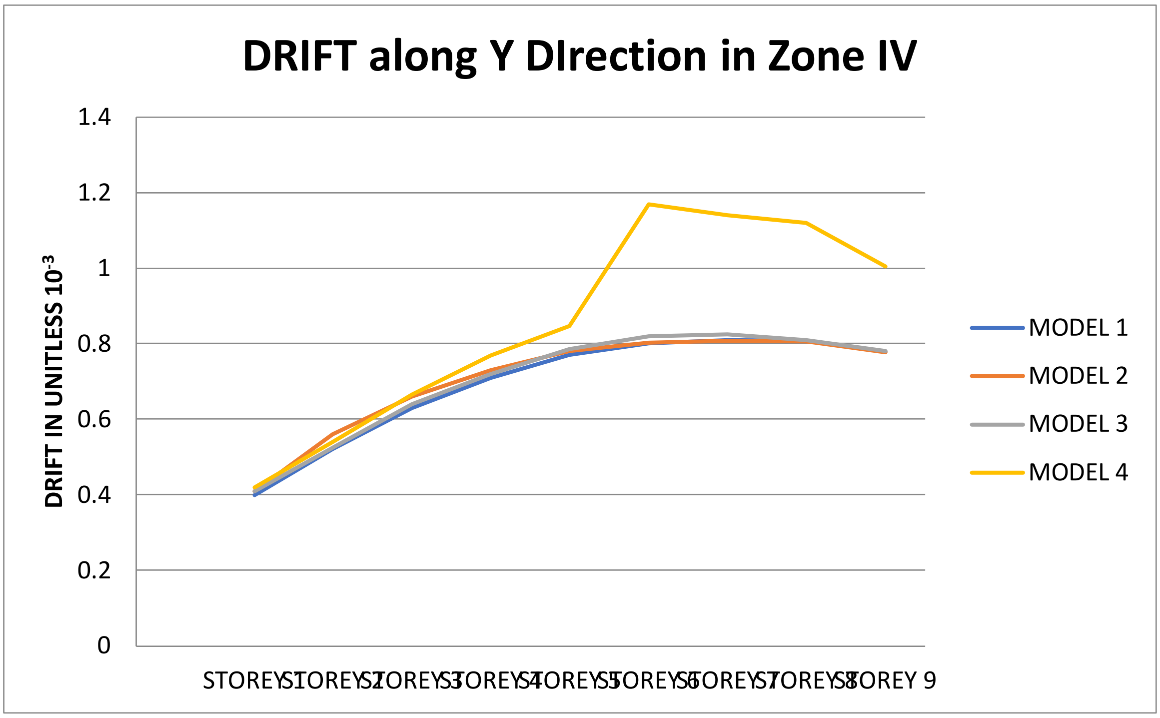


Values of Drift for Zone IV

Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2000 Cl 7.11.1[3]. Along X direction model IV i.e. geometric vertically irregular model has got higher drift value in all stories when compared with other structures. It has got the value of 0. 0.00047 in the seventh storey. The code recommends a maximum permitted drift value of 0.004H where

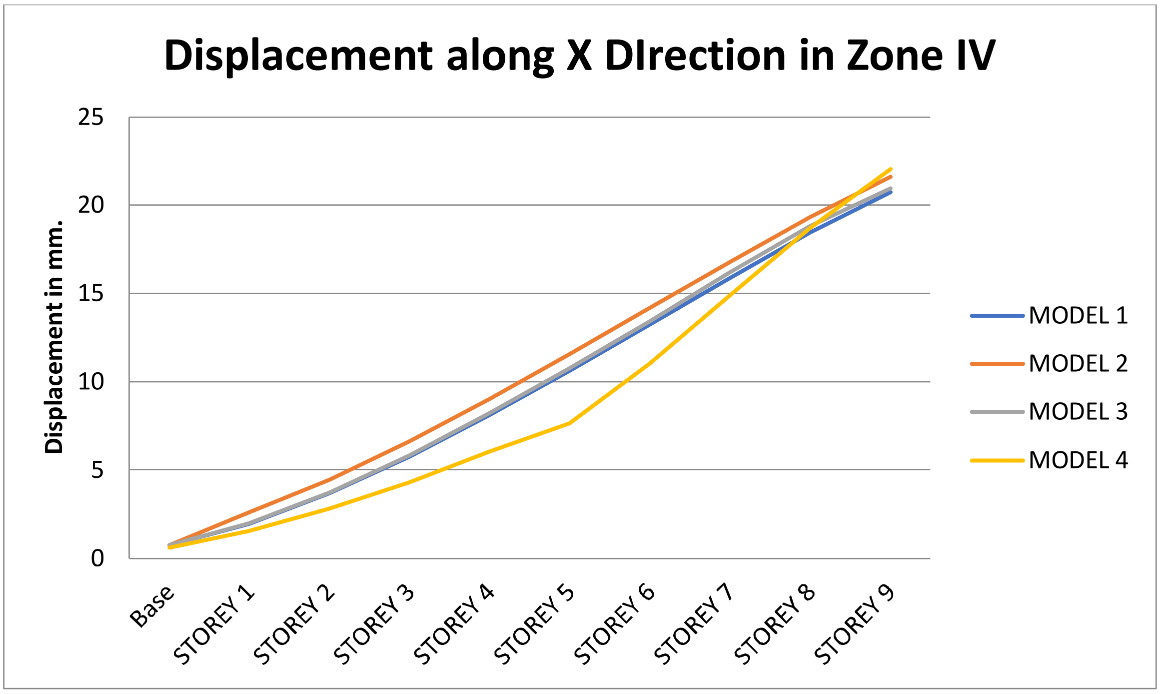
H is the storey height (H=3.5m) and the permissible drift value is 0.014. Along Y direction model IV holds the higher drift value of 0.000497.

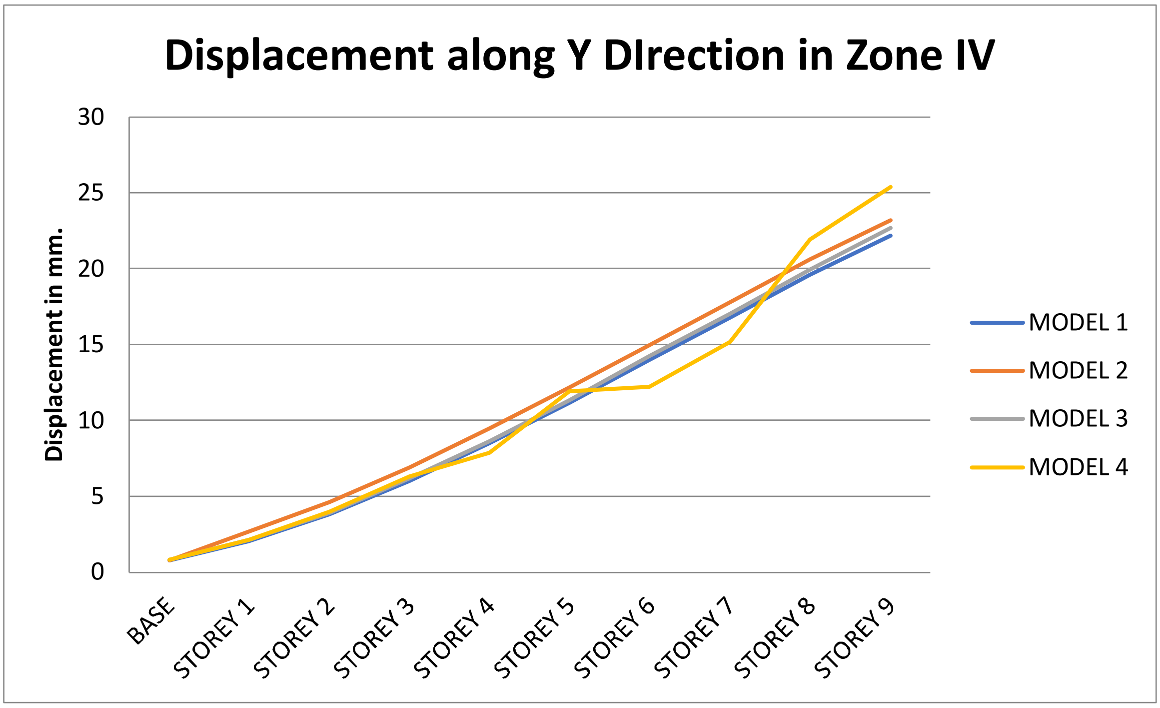




Values of Displacement for Zone IV

The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure. Model II shows the maximum displacement along X direction followed by model III, I and model IV.

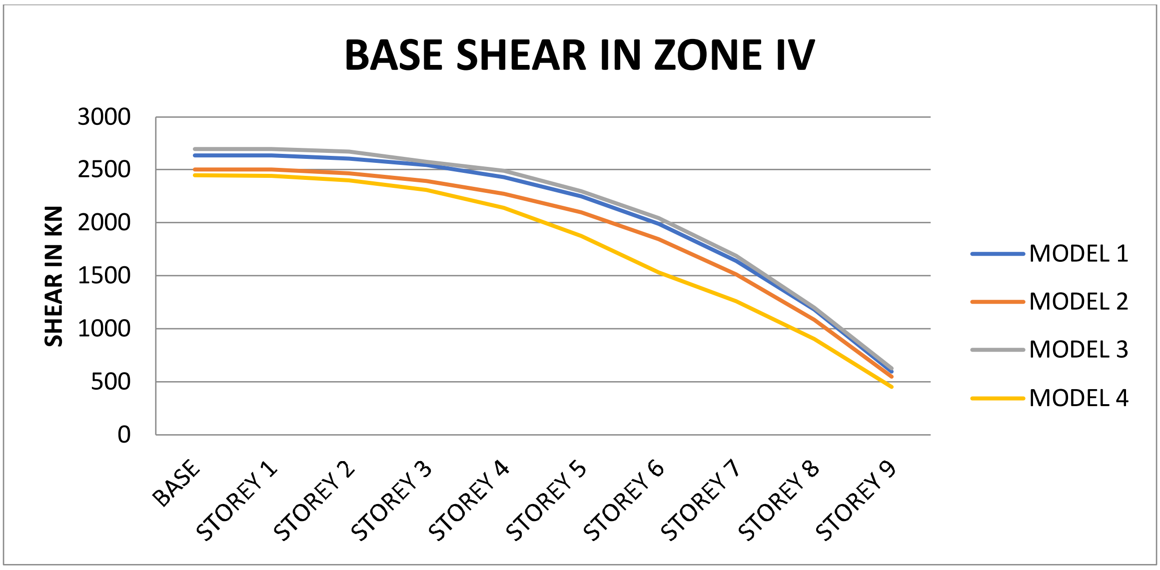




Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

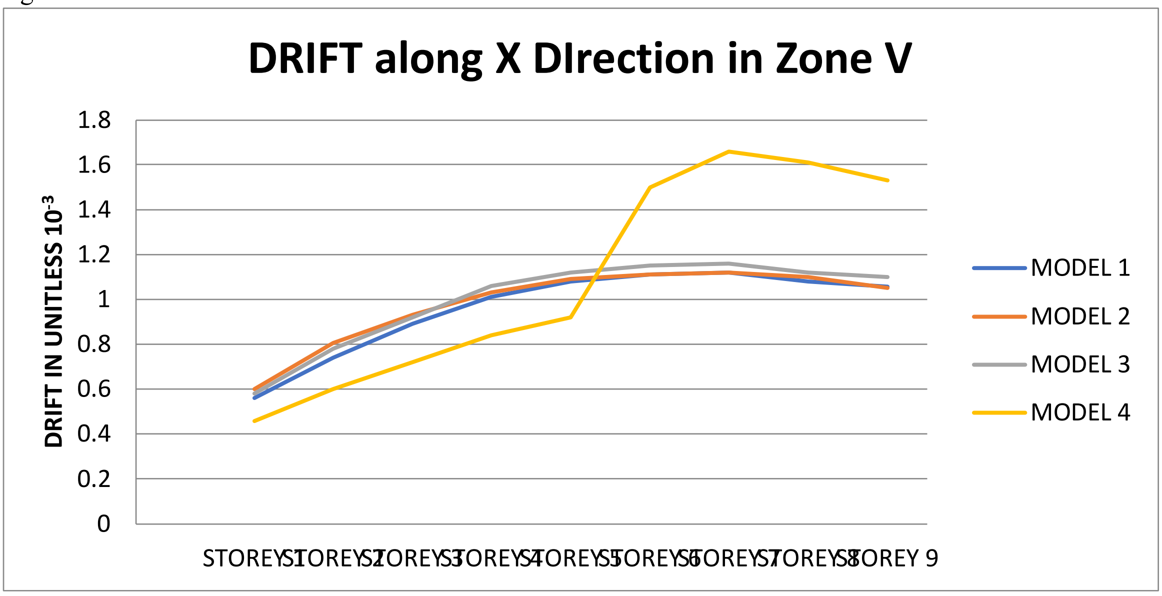
Values of Base Shear for Zone IV

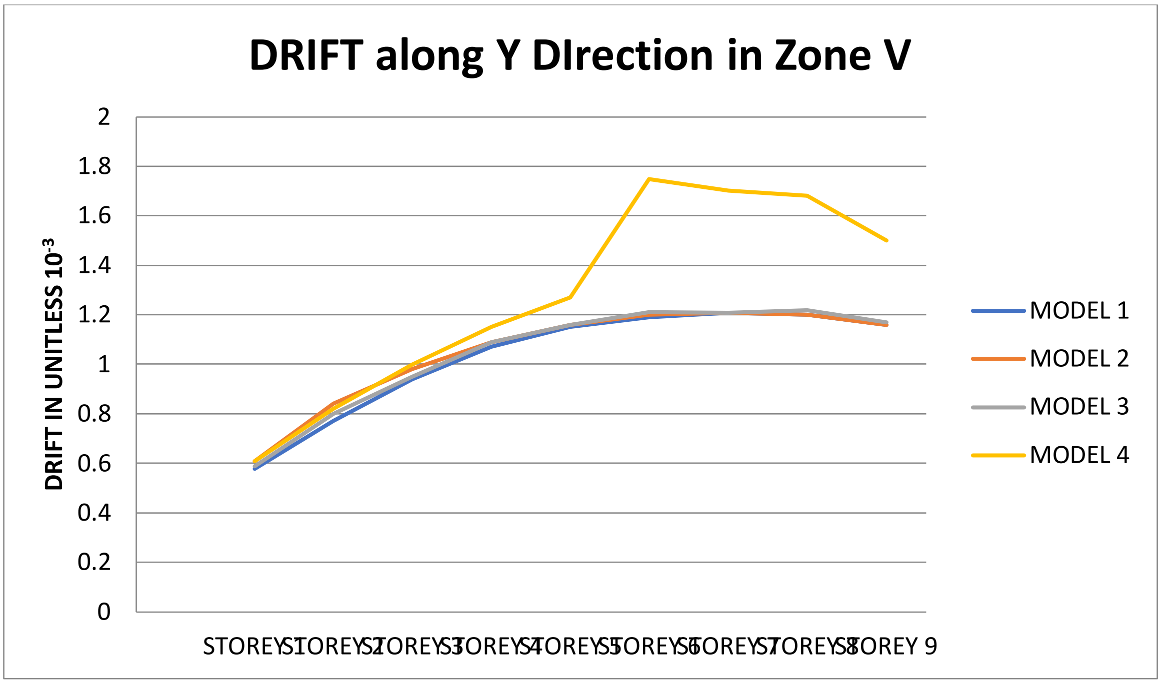
The value of base shear mainly depends on the stiffness factor of the structure and it is found more in model 3 than other models indicating that structure is much stiffer for seismic response due to its overall mass distribution.



Values of Drift for Zone V

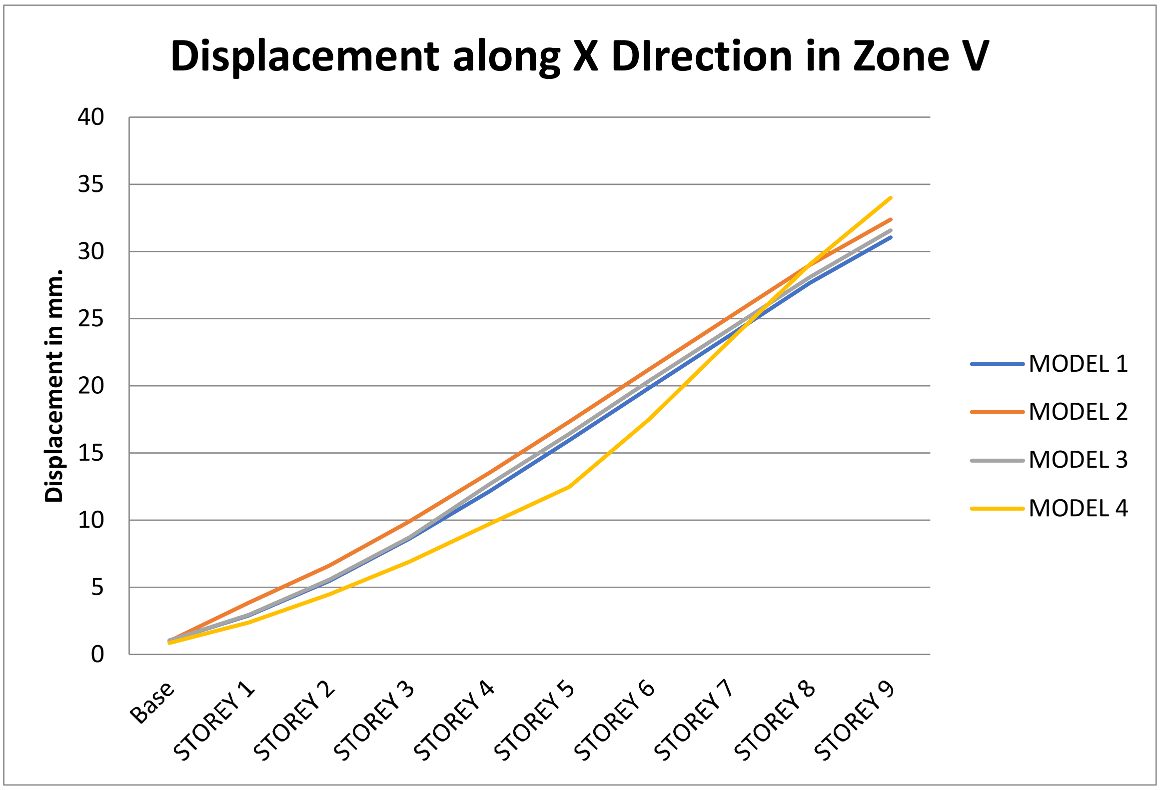
Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2000 Cl 7.11.1[3]. Along X direction model IV i.e. geometric vertically irregular model has got higher drift value in all stories when compared with other structures. It has got the value of 0. 0.00047 in the seventh storey. The code recommends a maximum permitted drift value of 0.004H where H is the storey height (H=3.5m) and the permissible drift value is 0.014. Along Y direction model IV holds the higher drift value of 0.000497.

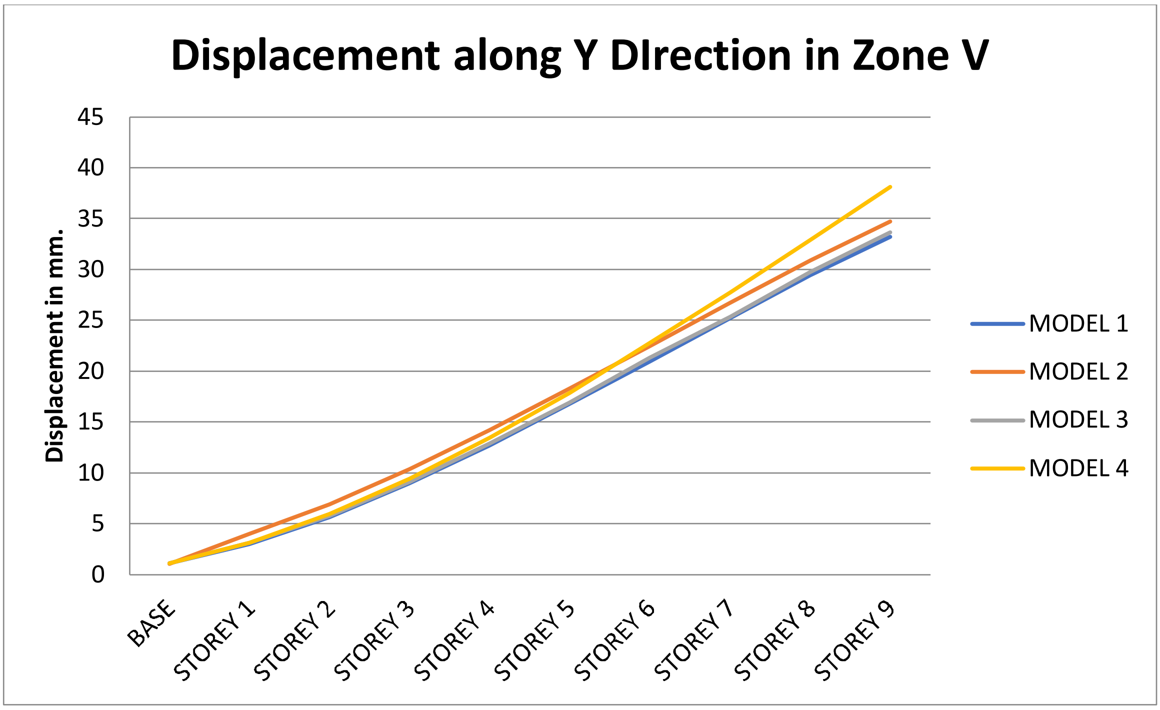




Values of Displacement for Zone V

The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure. Model II shows the maximum displacement along X direction followed by model III, I and model IV.

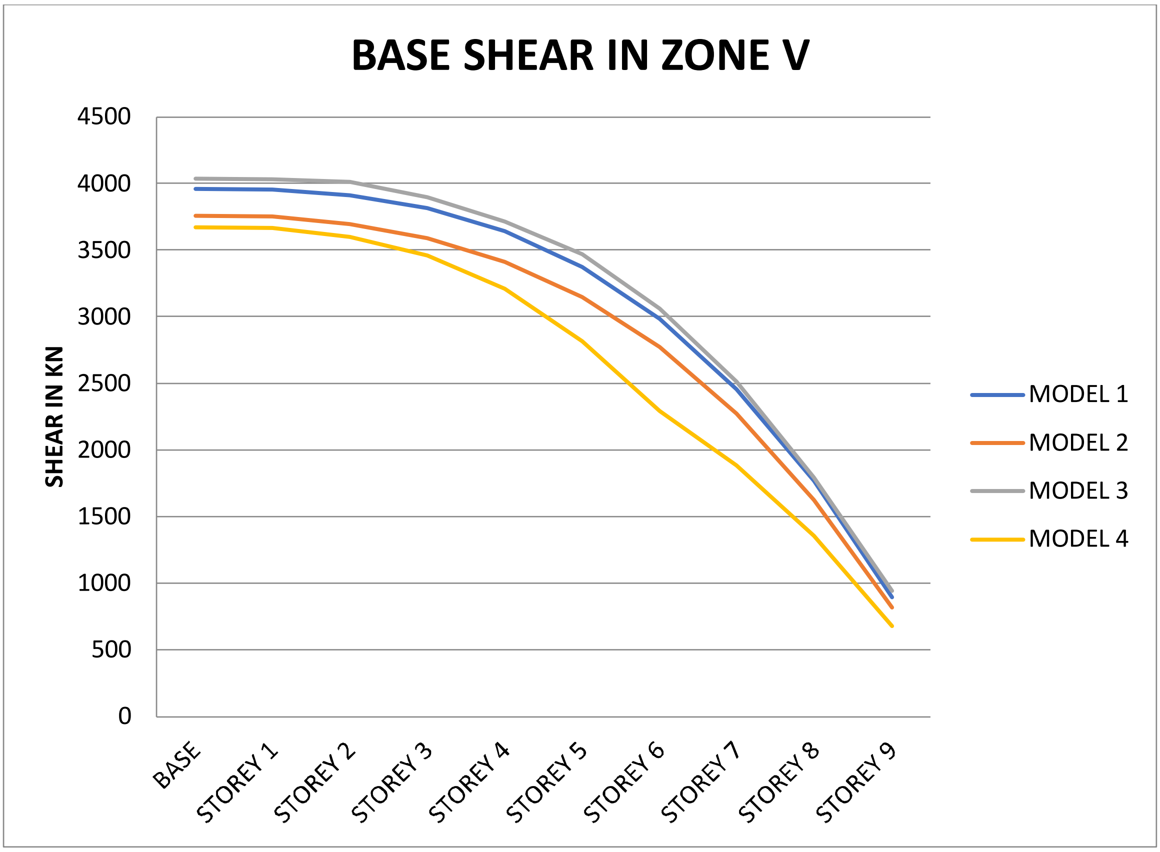




Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

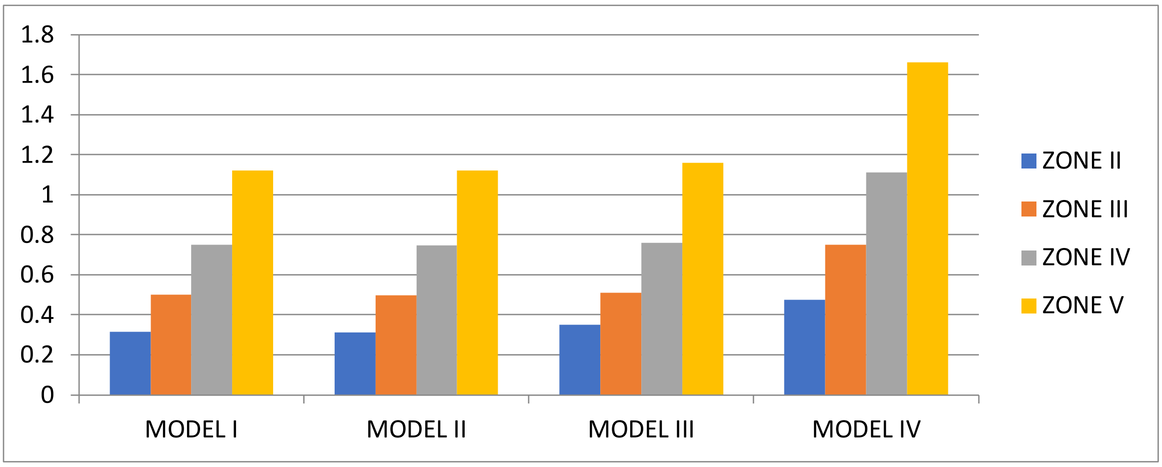
Values of Base Shear for Zone V

The value of base shear mainly depends on the stiffness factor of the structure and it is found more in model 3 than other models indicating that structure is much stiffer for seismic response due to its overall mass distribution.

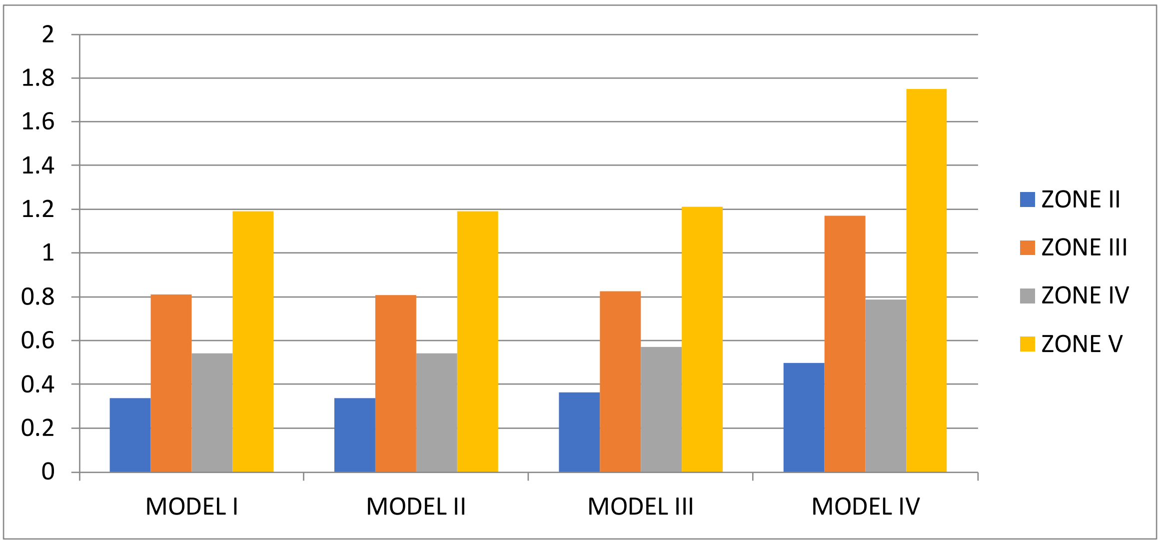


COMPARISON OF RESULTS FOR MAX VALUES IN EACH ZONE FOR EACH MODEL

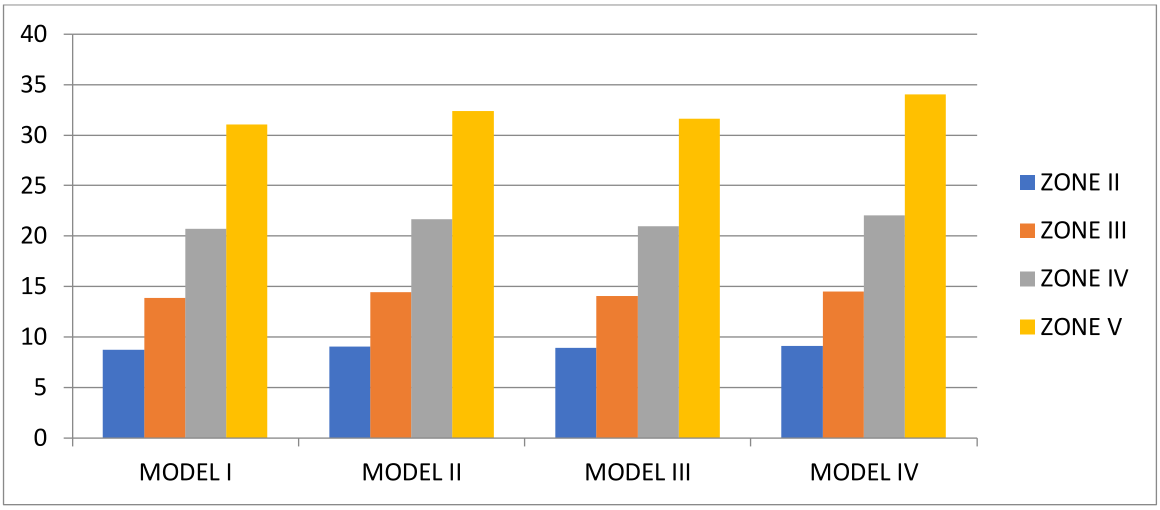
VALUES OF DRIFT IN X DIRECTION					
S.NO.	SEISMIC ZONE / TYPE OF BUILDING	ZONE II	ZONE III	ZONE IV	ZONE V
1	MODEL I	0.314	0.5	0.751	1.12
2	MODEL II	0.313	0.498	0.748	1.12
3	MODEL III	0.35	0.51	0.76	1.16
4	MODEL IV	0.476	0.75	1.11	1.66



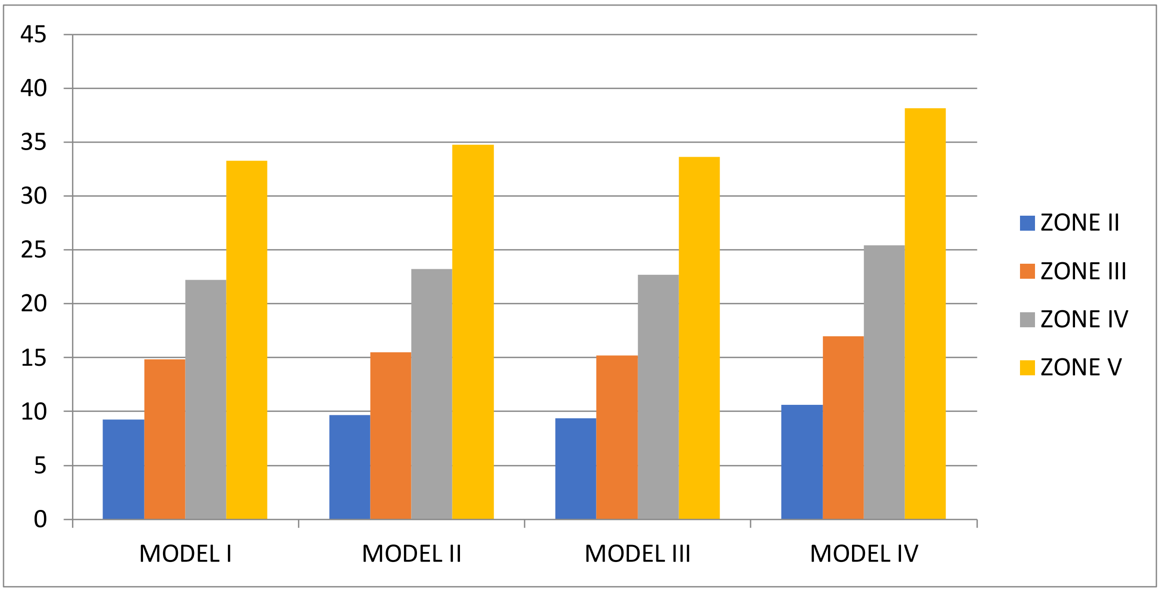
VALUES OF DRIFT IN Y DIRECTION					
S.NO.	SEISMIC ZONE / TYPE OF BUILDING	ZONE II	ZONE III	ZONE IV	ZONE V
1	MODEL I	0.338	0.81	0.54	1.19
2	MODEL II	0.338	0.808	0.54	1.19
3	MODEL III	0.363	0.825	0.57	1.21
4	MODEL IV	0.497	1.17	0.788	1.75



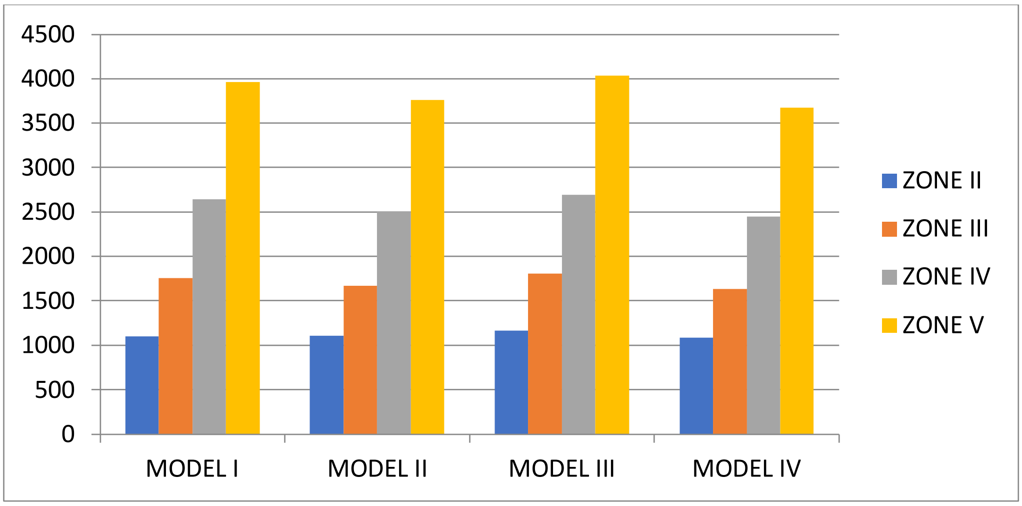
VALUES OF DISPLACEMENT IN X DIRECTION in mm.					
S.NO.	SEISMIC ZONE / TYPE OF BUILDING	ZONE II	ZONE III	ZONE IV	ZONE V
1	MODEL I	8.69	13.85	20.74	31.08
2	MODEL II	9.06	14.45	21.63	32.41
3	MODEL III	8.88	14.05	20.98	31.6
4	MODEL IV	9.09	14.48	22.05	34.02



VALUES OF DISPLACEMENT IN Y DIRECTION IN mm.					
S.NO.	SEISMIC ZONE / TYPE OF BUILDING	ZONE II	ZONE III	ZONE IV	ZONE V
1	MODEL I	9.28	14.81	22.18	33.25
2	MODEL II	9.69	15.48	23.19	34.75
3	MODEL III	9.4	15.2	22.68	33.64
4	MODEL IV	10.6	16.95	25.41	38.11



VALUES OF BASE SHEAR IN KN					
S.NO.	SEISMIC ZONE / TYPE OF BUILDING	ZONE II	ZONE III	ZONE IV	ZONE V
1	MODEL I	1099	1759	2639	3958
2	MODEL II	1106	1670	2506	3759
3	MODEL III	1165	1805	2696	4035
4	MODEL IV	1089	1631	2447	3671



CONCLUSION

In this thesis, various frames and structures having different irregularities but with the same dimension have been analysed to study their behaviour when subjected to lateral loads. All the frames and structures were analysed with the same method as stated in IS 1893- part 1: 2016. The results obtained for the building carried out through equivalent static approach will be near to realistic response of the structure to the actual. Following conclusions are made on the basis of the study -

1. This study quantifies the effect of vertical irregularities in mass and stiffness on seismic demands.
2. From the overall study and observation it can be conclude that, Base shear and lateral displacement will increases as the seismic intensity increases from zone-2 to zone-5 which indicates more seismic demand the structure should meet.
3. The drift is observed in the storey in which the stiffness is reduced. As stiffness increases frequency of the structure increases. Stiffness is dependent on mass of the structure.
4. Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.
5. After carrying out the analysis and the results we came to the conclusion that the seismic performance of regular frame is found to be better than corresponding irregular frames in nearly all the cases. Therefore it is suggested to construct a regular frame to minimize the seismic effects.
6. The absolute displacements obtained 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 geometry irregular structure upper stories have lower stiffness than the lower stories. Lower stiffness results in higher displacements of upper stories.

The analysis also proves that irregularities are harmful for the structures and it is important to have simpler and regular shapes of frames as well as uniform load distribution around the building. Therefore, as far as possible irregularities in a building must be avoided. But if irregularities have to be introduced for any reason, it must be designed properly following the conditions of IS 13920: 1993. Nowadays, complex shaped buildings are getting popular but they carry a risk of sustaining damages during earthquakes. Therefore such buildings should be designed properly by taking care of their dynamic behaviour.

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