Effect of Vertical Aspect Ratio on Mass, Stiffness and Vertical Geometric Irregular Structures

Lathasri Bathula[1], Galapati Deepa[2], Bhagyalaxmi Akkinapally[3]

[1]Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, bathula.lathasri@gmail.com

[2]Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, deepakalva08@gmail.com

[3] Assistant Professor, Department of Civil Engineering, Guru Nanak Institute of Technology, Hyderabad, Telangana, India, bhagya.laxmi98@gmail.com

ABSTRACT:

Occurrence of earthquake will highly damage the structures which are not modelled and designed to resist such loads it may cause sometimes the collapse of structures leads to loss of human lives. The size of the building and slenderness ratio are the important factors for the efficient structural design. The aspect ratio of buildings is considerably effects under seismic loads. It is important to know the influence of aspect ratio on the irregular structures in high seismic zone areas. The research has been performed on the 15 storey building frames of five cases with mass, stiffness and vertical geometric irregularities. Each case comprises of four models having various vertical aspect ratios. The purpose of this study is to investigate the influence of vertical aspect ratio on mass, stiffness and vertical geometric irregular structures and how the structure will vary under seismic loads. The irregularities are incorporated in to the buildings by increasing the loads and column height in particular storeys and by eliminating the columns and beam sections compared to adjacent storeys. Linear dynamic analysis is performed. It is observed that with the decrease of vertical aspect ratio the structural response will increases the response of storey displacement, base shear, storey drift and over turning moment in the cases of mass and stiffness irregular structures. In the case of vertical geometric irregular structures with the decrease of vertical aspect ratio the storey displacement and storey drift values decrease for all the models, the base shear, overturning moment and stiffness increases with the decrease of vertical aspect ratio.

Key words: Mass irregularity, Stiffness irregularity, Vertical geometric irregularity, Vertical aspect ratio, Linear dynamic analysis.

1.Introduction:

The behavior of multi-storey building frames subjected to strong earthquake motions are depended up on the distribution of mass, stiffness and strength in both vertical and horizontal planes. Irregular structures are most effected than the regular structures under seismic loads. Earthquakes can cause damage not only an account of the shaking but also due to other effects like landslides, floods, fires and disruption to communication, hence it is important to take necessary precautions in the planning and design of structures so that they are safe against such secondary effects. So far, many researchers investigated the effect of seismic response on the vertical and horizontal irregular structures. Abraham N.M et al. [1] studied behavior of structures having single and combination of irregularities. Out of various types of irregularities analyzed stiffness irregularity had maximum influence on the response and among the cases having combination of irregularities, the configuration with mass, stiffness and vertical geometric irregularities had shown maximum response. Prajwal T P et al. [2] studied the behavior of building during seismic event, they had considered three RC buildings one is regular doubly symmetric building remaining are Re-entrained corner in L shaped plan having different projections in X and Y directions. They had concluded that variation in the seismic demand due to angle of incidence cannot be neglected. H Gokdemir et al. [3] had studied the effect of buildings with various plans such as L, rectangle and square shape. Determined that separating big building sections from each other with proper separation distance decreases the effect of torsion. Renuka Ramtake [4] had recognized the limiting plan aspect ratio and slenderness ratio by doing the analysis of 15 models of multistoried rcc flat slab structures using response spectrum method in ETABS13 software. The models are considered with same plan area but different plan aspect ratio(L/B) and slenderness ratio (H/B) under seismic condition. Explained the behavior of structures such as lateral deformation, fundamental period, storey drift and base shear. M M Ahmed et al. [5] had studied influence of various vertical aspect ratios on the behavior of RCC multi storied buildings. They had analyzed seven building models with different vertical aspect ratios using ETABS software, concluded as the storey drift, displacement and base shear increases with the increase of building height. Sadh S K et al [6] had focused on the influence of aspect ratio and plan configurations on seismic performance of multi-storeyed regular buildings.16 building models with different horizontal and vertical aspect ratios are analyzed by response spectrum analysis. It is observed that all the seismic parameters increase with the number of bays and number of storeys. Pradeep Sarkar et al. [7] had discussed a number of the key issues regarding analysis and style of stepped buildings and a replacement approach for quantifying the irregularity in stepped building is proposed. It accounts for properties related to mass and stiffness distribution in the frame. This approach is found to perform better than the prevailing measures to quantify the irregularity. Most of the investigations done on the comparison of behavior of regular structures with irregular structures and response of buildings with single and combination of irregularities under seismic loads are observed. The vertical aspect ratio or slenderness ratio affect the efficiency of the structure. Hence there is a necessity to design these structures for earthquake loading so that they sustain moderate to strong earthquake. In most of the previous papers the aspect ratio is considered in regular structures know it is used in case of irregular structures. In this paper the structures are modeled and analyzed by considering the different irregularities at certain levels of the structures with various vertical aspect ratios. The main objective of this work is to study the effect of vertical aspect ratio on the behavior such as displacement, storey drift, base shear and etc. of buildings having mass, stiffness and vertical geometric irregularities and to identify the irregular structure which shows the less response under seismic loads.

2.Methodology:

In this work 15 storey building frames of five different cases in which two are of mass and stiffness irregularities in single story (MI-1, SI-1) and two with irregularities introduced in two storeys (MI-2, SI-2) other one is vertical geometric irregular structures are analyzed. In each case four models with various vertical aspect ratios are considered. The vertical aspect ratio is the H/B ratio i.e., Slenderness ratio (where H is the total height of the building frame and B is the base width) of buildings. The building frames are modelled by using ETABS and analyzed by Response spectrum method.

3.Modelling of the structures:

3.1. Geometric details:

The models are designed with different plan configurations and with equal number of storeys. The number of bays considered in x and y direction are identical are mentioned in Table-1. Grade of concrete taken as M25; Poisson’s ratio of concrete is 0.2 grade of steel Fe415. Type of structure considered is special moment resisting frame. The size of beams 0.35mx0.30m and columns 0.4mx0.4m are considered. Thickness of slab considered is 150mm and bay width is 5m in all models, section element type is shell-thin.

Table-1: Geometric details of the structures

	Model-1	Model-2	Model-3	Model-4
Number of bays in X direction	3	4	5	6
Number of bays in Y direction	3	4	5	6
Number of storeys	15	15	15	15
Plan dimensions	15mX15m	20mX20m	25mX25m	30mX30m

Totally 20 models are designed by considering the vertical aspect ratio and with mass, stiffness and vertical geometric irregularities. Each case comprises of four models are shown in below figures.

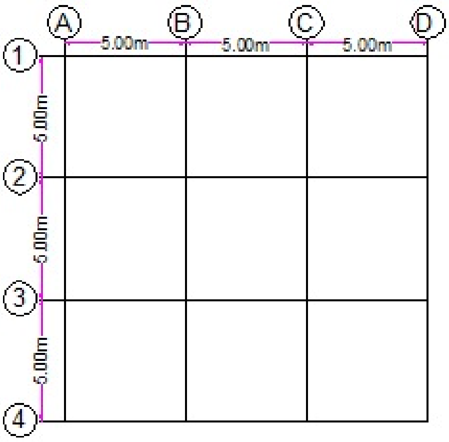

Fig 1.1 Plan view of Model-1

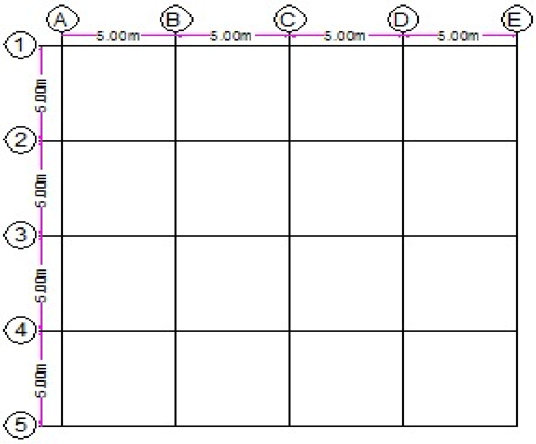

Fig 1.2 Plan view of Model-2

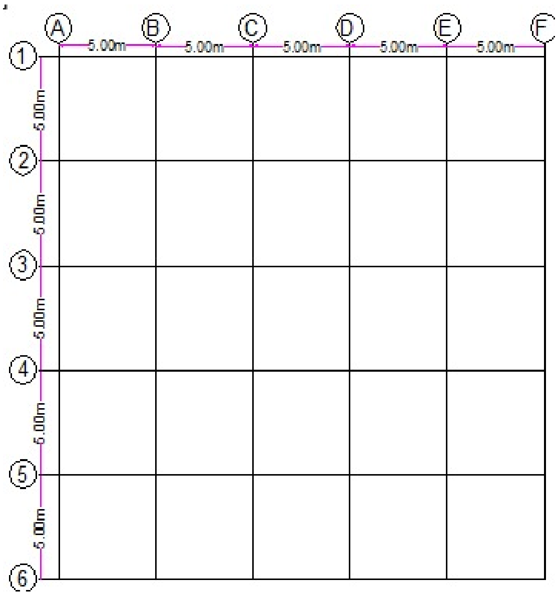

Fig 1.3 Plan view of Model-3

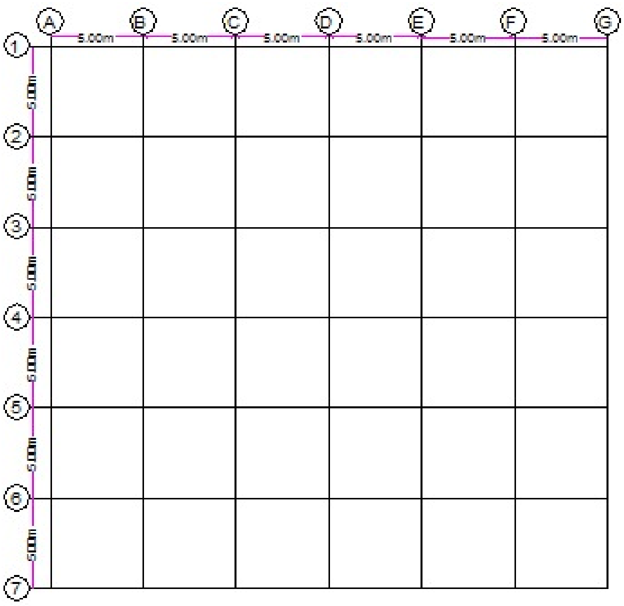

Fig 1.4 Plan view of Model-4

3.2. Applied loads on structures:

The details of loads applied to the structural members of the models are shown in the Table-2. Shell loads are considered in the present work. The dead load and live loads are considered as per IS 875(Part-1) and IS 875 (Part-2) respectively.

Table-2: Assignment of loads on Structures

Live load on floors	3.0kn/m^2
Live load on Mass irregular floors	5.0kn/m^2
Live load on roof	1.5kn/m^2
Dead load on floors	1.5kn/m^2
Dead load on roof	1.0kn/m^2

3.3. Seismic details of the structures:

The seismic details of the structures are considered in this study as per IS1893:2016 Part-1 are listed in the Table-3.

Table-3: Seismic details of the structures

Seismic zone factor Z	0.36	IS Table-3
Response reduction factor R	5	IS Table-9
Importance factor I	1.5	IS Table-8
Damping Ratio	0.05	IS 7.2.4
Site Type	II	IS Table-4

3.4. Irregular configurations:

Each case varies with different irregularities are explained here and the considered irregularities are satisfying the code IS1893:2016(Part-1).

3.4.1. Case-I (Mass Irregular structures MI-1):

Mass irregularity introduced in one floor of the structure of four models having vertical aspect ratios continuously 3,2.25,1.8 and 1.5. Irregularity was incorporated by increasing the loads on a particular storey compared to adjacent storeys is 3kn/m^2 to 5kn/m^2. In this case irregularity applied at 8th storey is shown in figure 2.1.

3.4.2. Case-II (Mass Irregular structures MI-2):

Mass irregularity introduced in two floors of the total structure by increasing the loads. In this case the models have the vertical aspect ratios are 3,2.25,1.8 and 1.5. In this case irregularity applied in 6th and 9th storeys is shown in figure 2.2 and the load increased from 3kn/m^2 to 5kn/m^2. Height of all the building frames in these two cases are 45m.

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3.4.3. Case-III (Stiffness Irregular structures SI-1):

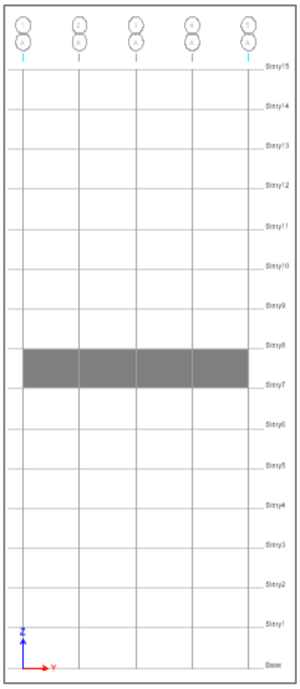
Stiffness irregularity incorporated by increasing the length of columns in a single floor compered to remaining floors of a structure. Column height is increased at 8th floor from 3m to 4.5m for all the models of this case is shown in figure 2.3. Height of the building frames are 46.5m and the vertical aspect ratios are 3.1,2.32,1.86 and 1.55.

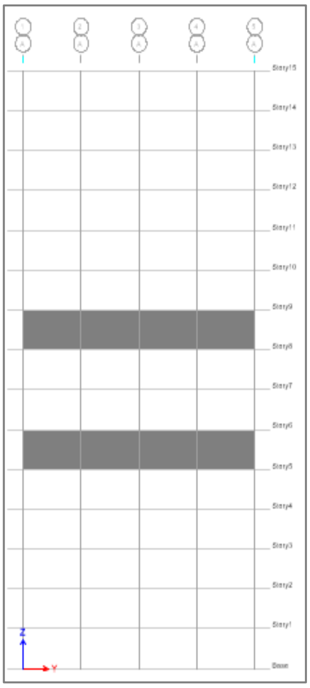
3.4.4. Case-IV (Stiffness Irregular structures SI-2):

In this case stiffness irregularity introduced in two floors at 6th and 9th storey by increasing the column height from 3m to 4.5m as shown in figure 2.4. Height of all models are 48m and the vertical aspect ratios are continuously 3.2,2.4,1.92 and 1.6.

3.4.5. Case-V (Vertical Geometric Irregular structures VGI):

The vertical geometric irregularity considered as from the 8th storey level in all 4 models according to the code IS1893:2016 (Part-1) Clause7.1 the value of A>0.125L. The vertical aspect ratios of structures are 3,2.25,1.8 and 1.5. These models are shown in figures 3.1,3.2,3.3 and figure 3.4.





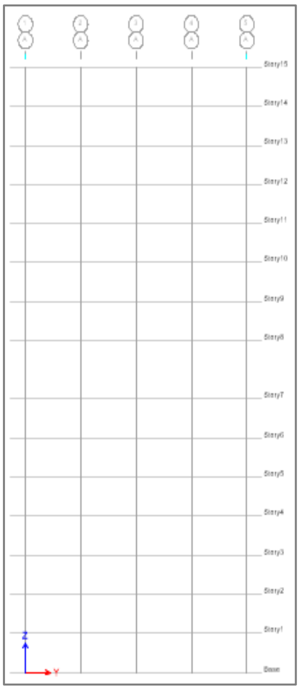


Fig 2.1 MI-1 ***Fig 2.2 MI-2*** ***Fig 2.3 SI-1***

Fig 2.4 SI-2

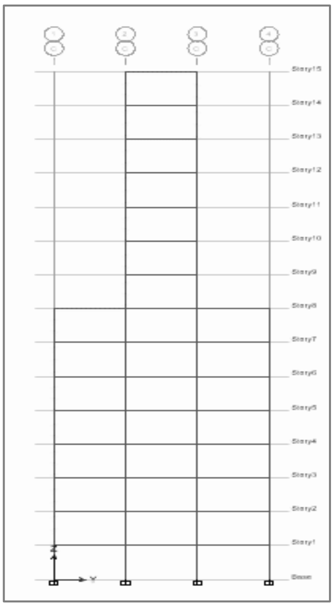


Fig 3.1 VGI of Model-1

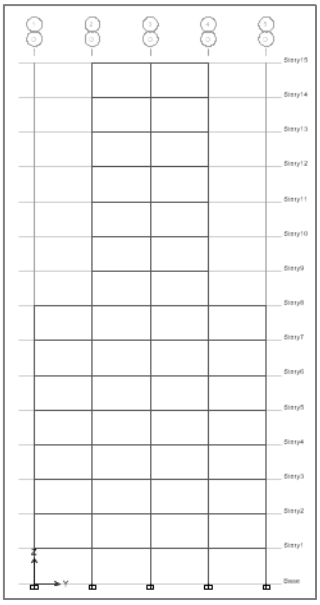


Fig 3.2 VGI of Model-2

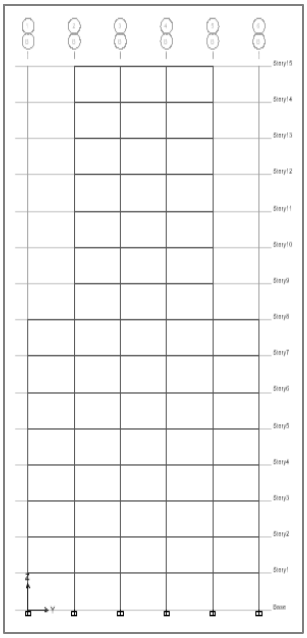


Fig 3.3 VGI of Model-3

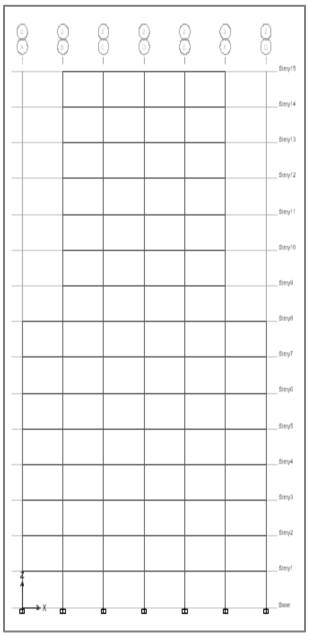


Fig 3.4 VGI of Model-4

4.Results and Discussions:

In this study five cases (MI-1, MI-2, SI-1, SI-2 and VGI) with mass, stiffness and vertical geometric irregular structures are modelled in ETABS Software, each case comprises of four models with different vertical aspect ratios are considered and analyzed by using response spectrum method. The results obtained from the mass, stiffness and vertical geometric irregular structures are plotted. Due to the symmetry of the building plan the responses attained in RSA-X and RSA-Y are almost same. Graphs are drawn by taking the storey response of the structure on x-direction and the number of storeys on y-direction. The parameters of structural models such as displacement, storey drift, storey shear, stiffness and OTM values were observed.

4.1. Mass Irregular structures:

Mass irregular structures are taken as two cases based on application of high mass at the different level of storeys. The outcomes from every model are drawn and compared.

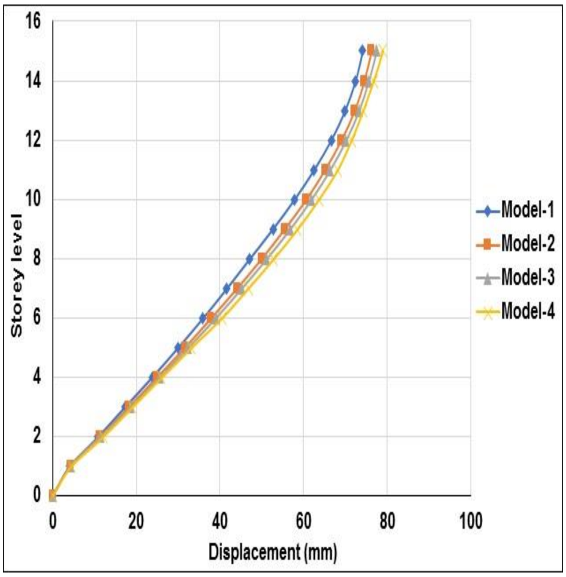


Fig 4.1 Displacement response for MI-1

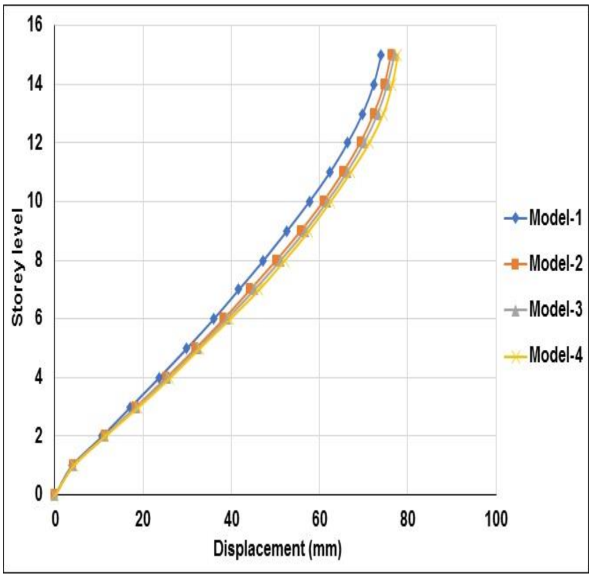


Fig 4.2 Displacement response for MI-2

Figure-4.1 and 4.2 represents the storey displacement of four models of mass irregular structures of first and second case. From above figures it is observed that the storey displacement is less for the model-1 which has the high vertical aspect ratio compared to the remaining three models. Model-4 shows maximum displacement response than the other models, it has six bays in x and y direction which is higher than the remaining models. From this it can be say that the storey displacement is maximum for the structure having less vertical aspect ratio that is 1.5 and minimum for the structure with vertical aspect ratio of 3. Displacement response is high for MI-1 where the seismic weight of 8th floor is high compared to the models of case MI-2 where the seismic weight of 6th and 9th floor is higher than the adjacent floors.

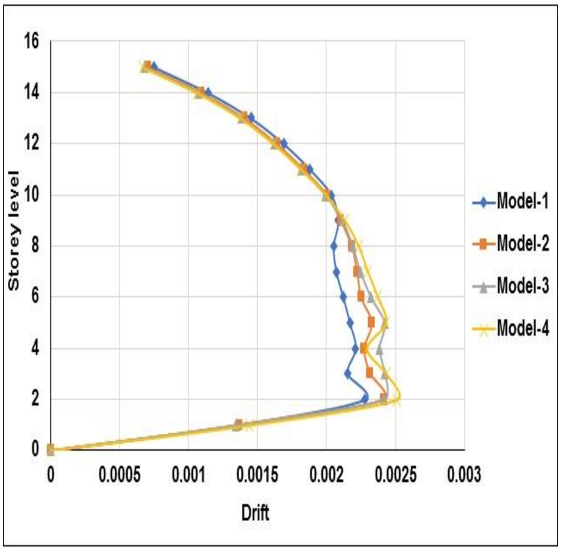


Fig 4.3 Storey drift for MI-1

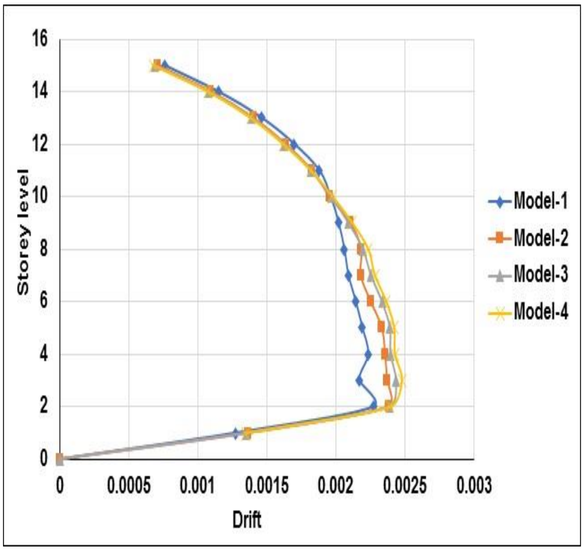


Fig 4.4 Storey drift for MI-2

Figure-4.3 and 4.4 shows the storey drift of four models in the first and second case of mass irregular structures. Model-4 has the higher drift in all the models which has the high number of bays with vertical aspect ratio of 3 and model-1 shows the less storey drift compared to others. It is observed that the storey drift increases from model-1 to model-4 i.e., with increase of number of bays from 3 to 6 and with the decrease of vertical aspect ratio. It is noted that the storey drift is high at second storey level in all the models. Maximum drift is observed for the 1st case, it is maximum at second storey for all models in the first case and in the second case it is maximum at second storey for model-1 and 2, at third storey for models-3 and 4. The minimum storey drift is noted at 15th storey in all the models.

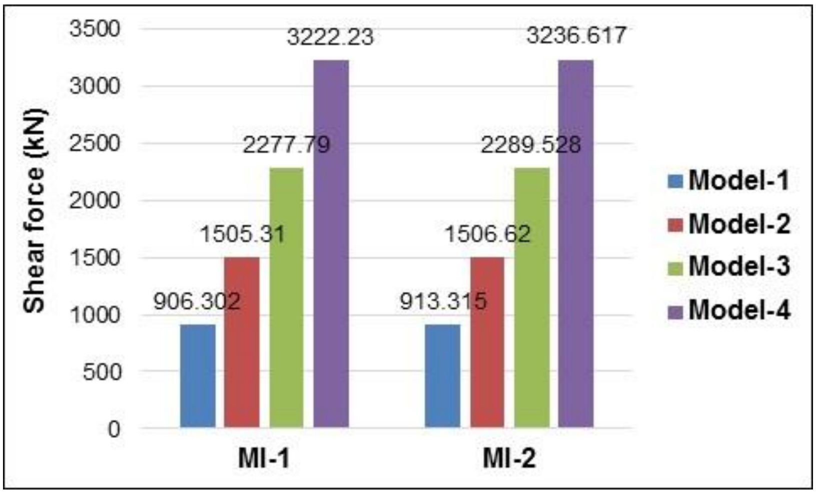


Fig 4.5 Storey Shear for MI-1 and MI-2

Figure-4.5 shows the storey shear of above said two cases. In all the models maximum base shear is observed for model-4 which has the six number of bays with vertical aspect ratio of 1.5 and the minimum base shear is for model-1 which has the smaller number of bays compared to other models and it has the vertical aspect ratio of 3. The maximum shear detected in the case MI-2 than MI-1. In both the cases rate of response increases from model-1 to model-4 continuously i.e., with the decrease of vertical aspect ratio (increase of number of bays simultaneously in x and y direction).

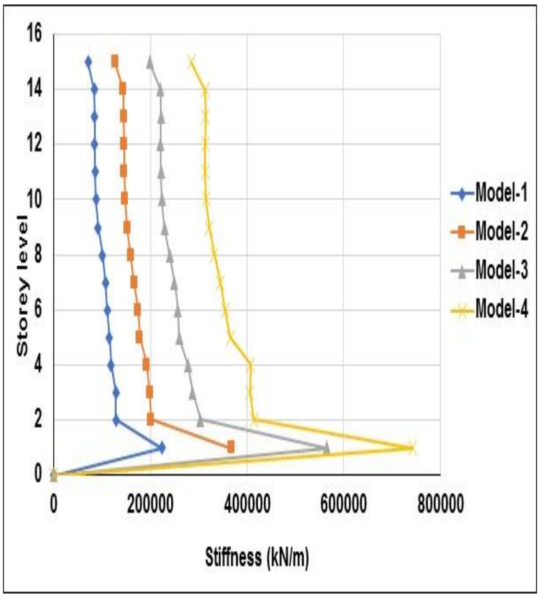


Fig 4.7 Storey Stiffness of MI-1

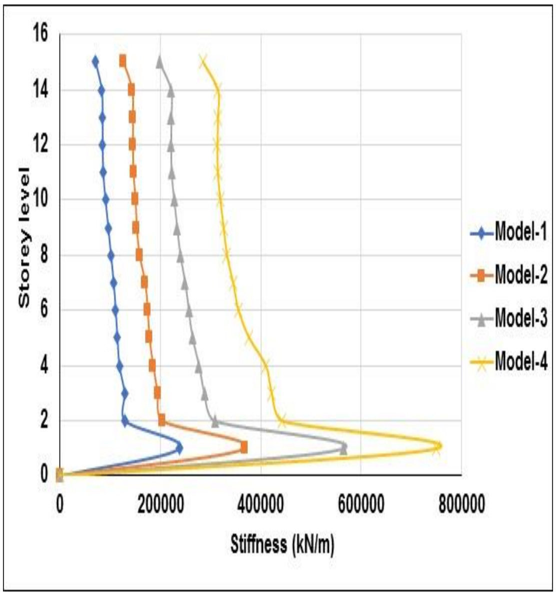


Fig 4.8 Storey Stiffness of MI-2

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Stiffness is a quantity of how much force is needed to displace a certain amount of a building. A storey stiffness is measured as the lateral force in that storey is that results in unit lateral translational deformation. Figure-4.7 and 4.8 shows the variation of stiffness at each storey of structural models considered in mass irregular structures of both cases. In the case of MI-1 the maximum storey stiffness from model-1 to model-2 has an increment of 64.4%, model-2 to model-3 has 54% and from model-3 to model-4 has the increment of 31.4%. In the case of MI-2 the maximum storey stiffness in an increment of 53.7% from model-1 to model-2, from model-2 to model-3 is 53.6% and from model-3 to model-4 has an increment of 32.73%. While observing both the cases the stiffness maximum in the second case for fourth model.

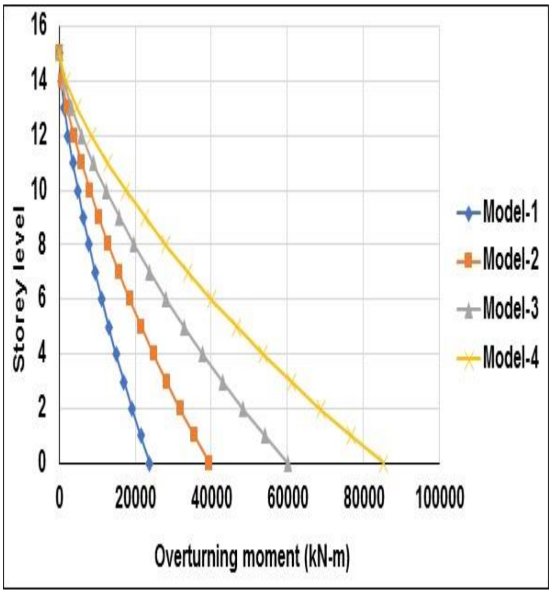


Fig 4.9 OTM for MI-1

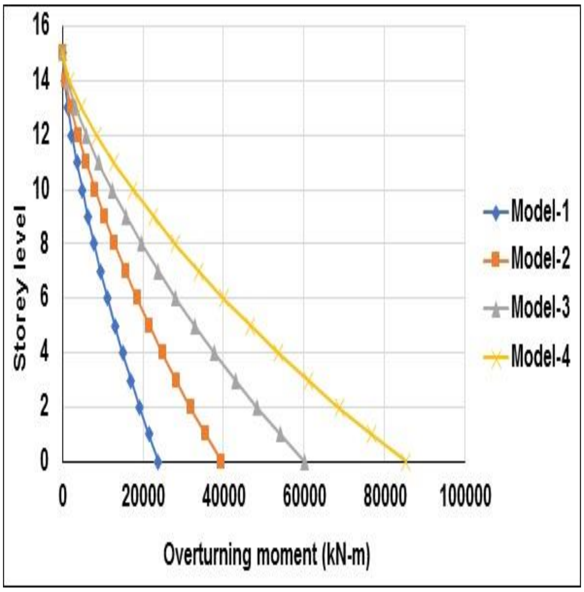


Fig 4.10 OTM for MI-2

Over turning moments are those moments that threaten to make system or structure to unstable and turn over. Because of the lateral forces such as wind loads, seismic loads etc. the overturning of the structures happens. Sometimes it may result in serious consequences and causes huge loss of life and property. Figure-4.9 and 4.10 shows the overturning moment of models in case of mass irregular structures. The OTM values of every model taken in the first case of mass irregular structures show that the higher value has an increment of 40% from model-1 to model-2, model-2 to model-3 shows 34% and from model-3 to model-4 has 29.35% of increment. In mass irregular structures of second case increment of maximum OTM value from model-1 to model-2 is 39.6%, from model-1 to model-2, model-2 to model-3 is 34.3% and from model-3 to model-4 is an increment of 29.5%. The rate of increment in both the cases are almost equal. While observing both the cases the overturning moment maximum in the second case for fourth model.

4.2. Stiffness Irregular structures:

In this study stiffness irregular structures are categorized in to two cases based on the irregularity introduced in storeys. These are checked as per code IS 1893:2016 Part-1, the stiffness of the floor at where the irregularity introduced is less compared to the adjacent floors. In each case four models are considered and the results are computed.

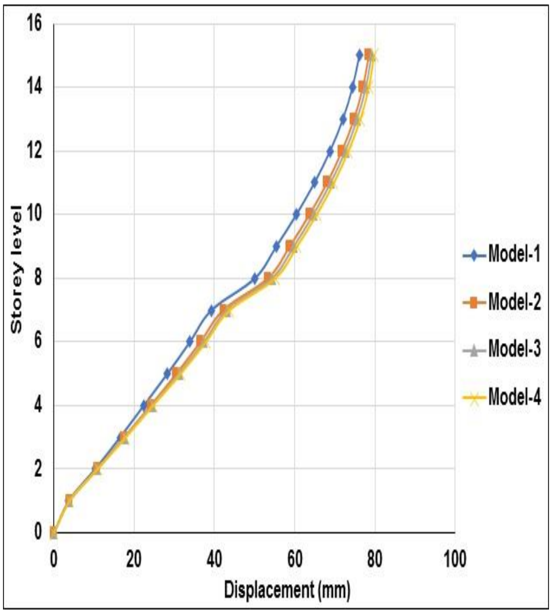


Fig 5.1 Storey Displacement for SI-1

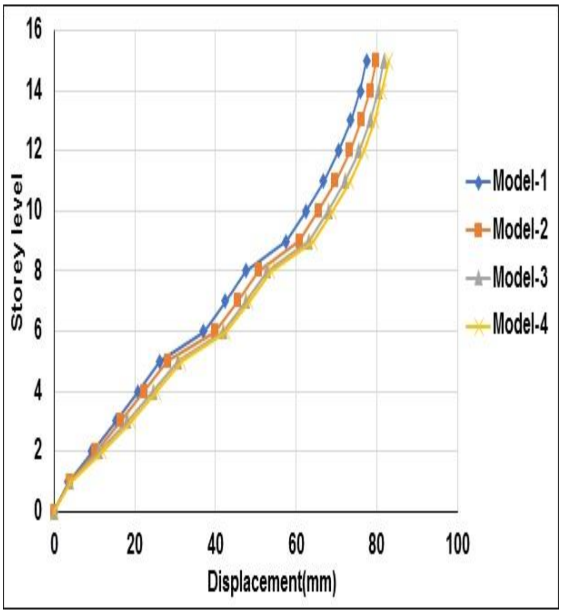


Fig 5.2 Storey Displacement for SI-2

The storey displacement of stiffness irregular structure of cases 1 and 2 (SI-1 and SI-2) are shown in the figures-5.1 and 5.2. It is observed that the model-1 has the less storey displacement than other models and it has the smaller number of bays with vertical aspect ratio of 1.55. Maximum storey displacement is for fourth model which has the high number of bays with vertical aspect ratio of 3.1. Displacement response is high for the models of case SI-2 in which the column height is increased at 6th and 9th floors whereas less in the case of SI-1 in which the column height is increased only at 8th floor.

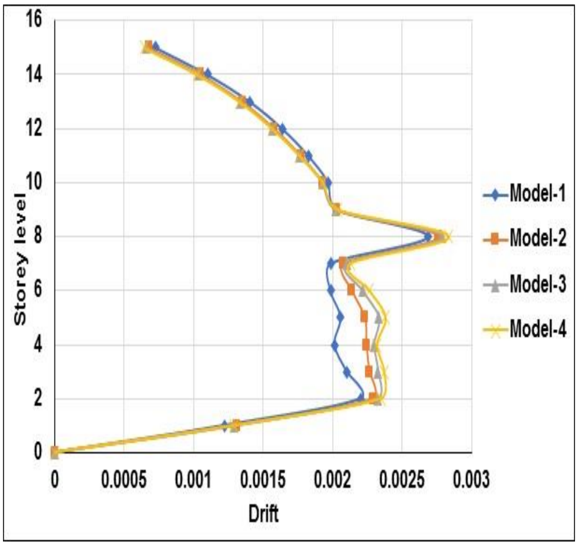


Fig 5.3 Storey drift for SI-1

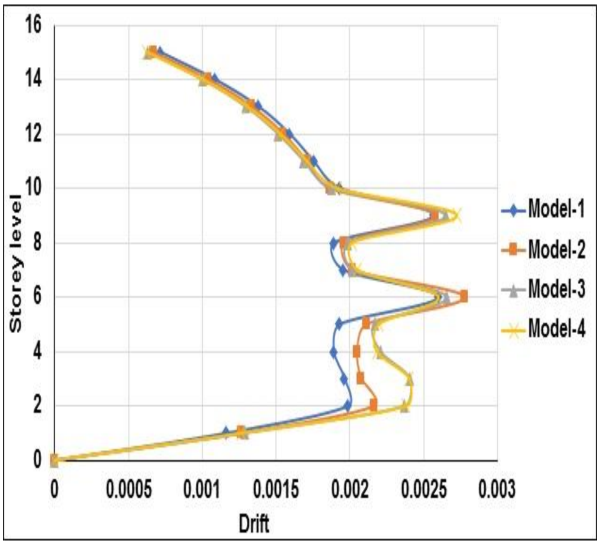


Fig 5.4 Storey drift for SI-2

The figures-5.3 and 5.4 represents the storey drift of two cases SI-1 and SI-2. Maximum drift is observed at 8th storey for all the models of SI-1due to the storey is less stiff compered to remaining storeys. In the case SI-2 drift is maximum at 6th storey for the models 1,2 and at 9th storey for the models 3,4 because of the stiffness of these two storeys less than remaining storeys. The minimum drift happened at 15th storey in all the models. In both of these cases high storey drift is observed for model-4 of case SI-1. Storey drift is maximum at the floors where the stiffness irregularity is incorporated.

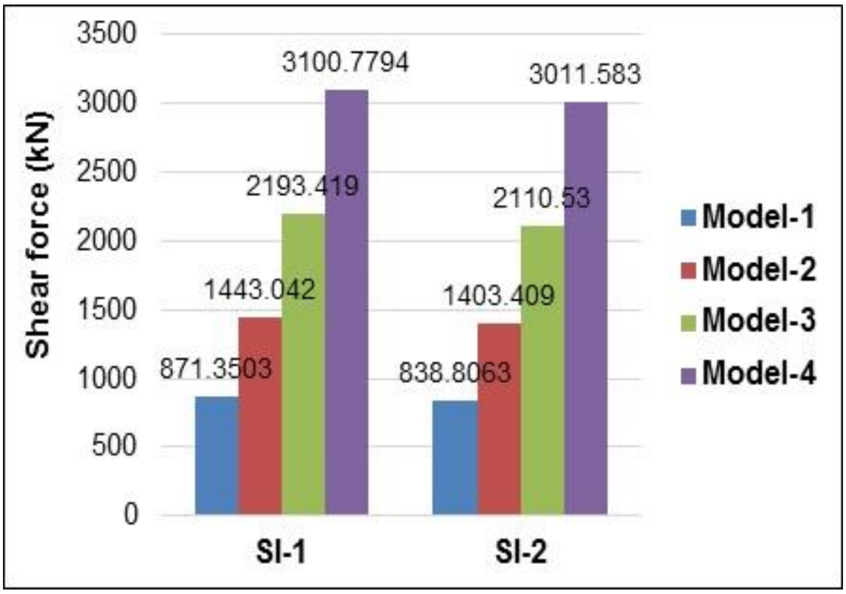
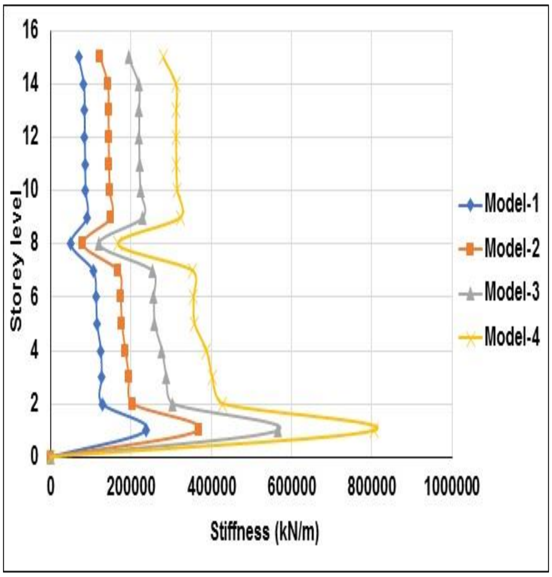


Fig 5.5 Storey Shear for SI-1 and SI-2

Figure-5.5 expresses the storey shear of SI-1and SI-2. In all the models maximum base shear is observed for model-4 which has the six number of bays with vertical aspect ratio of 1.6 and the minimum base shear is for model-1 which has the smaller number of bays compared to other models and it has the vertical aspect ratio of 3.2. The shear value is high for SI-1 than SI-2 and the maximum shear value is increased by 2.96%. In these two cases the response increases with decrease of vertical aspect ratio.



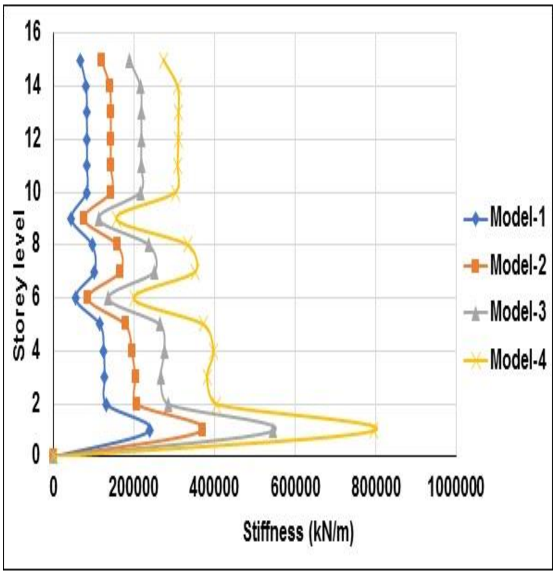


Fig 5.6 Storey Stiffness of SI-1 *Fig 5.7 Storey Stiffness of SI-2*

Above figures shows the stiffness values of all models considered in the first and second case of stiffness irregular structures. Storey stiffness is less for 8th storey in the first case and for 6th and 9th storeys in the second case by comparing with the adjacent storeys. It is examined that the Stiffness is maximum at the 1st storey for all the models in both cases of stiffness irregular structures and is increases with the decrease of vertical aspect ratio. In the first case maximum storey stiffness is an increment of 54.6% from model-1 to model-2, from model-2 to model-3 is 53.79% and from model-3 to model-4 has an increment of 42.44%. Structural models considered in stiffness irregular structures of second case shows the maximum storey stiffness from model-1 to model-2 has an increment of 55.17%, model-2 to model-3 has 47.49% and from model-3 to model-4 has the increment of 45.74%.

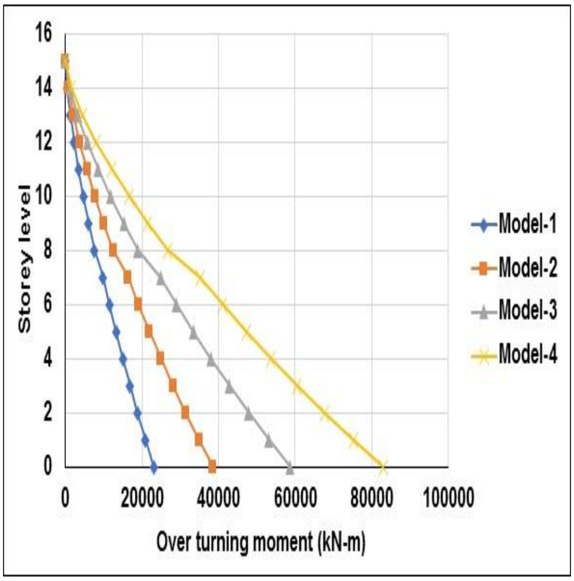


Fig 5.8 OTM for SI-1

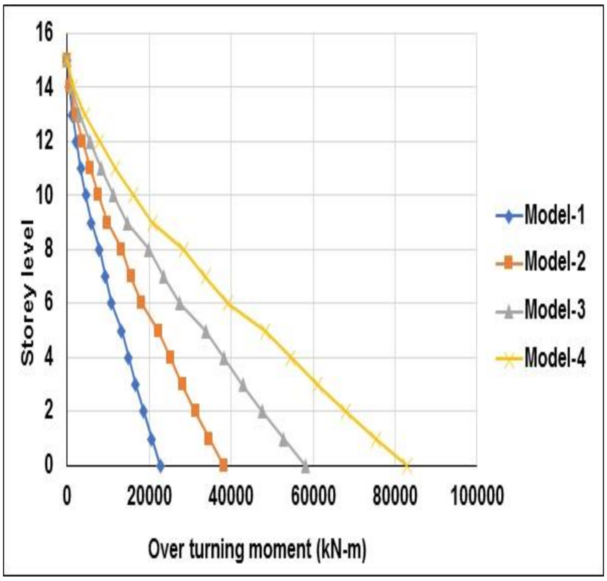


Fig 5.9 OTM for SI-2

The figures 5.8 and 5.9 shows variation of OTM for the models in stiffness irregular structures of two cases. Increment of maximum OTM value from model-1 to model-2 is 66.8%, from model-1 to model-2 to model-3 is 52.35% and from model-3 to model-4 is an increment of 41.39%. The rate of increment in both the cases are almost equal. The variation of OTM for every model in the second case of mass irregular structures show that the higher value has an increment of 68.36% from model-1 to model-2, model-2 to model-3 shows 52.23% and from model-3 to model-4 has 42.65% of increment.

4.3. Vertical Geometric Irregular structures:

Vertical geometric irregular structures of four models with different vertical aspect ratios are considered and analyzed the results are drawn below. The vertical geometric irregular structures are considered by reducing the horizontal dimension of the lateral resisting force system.

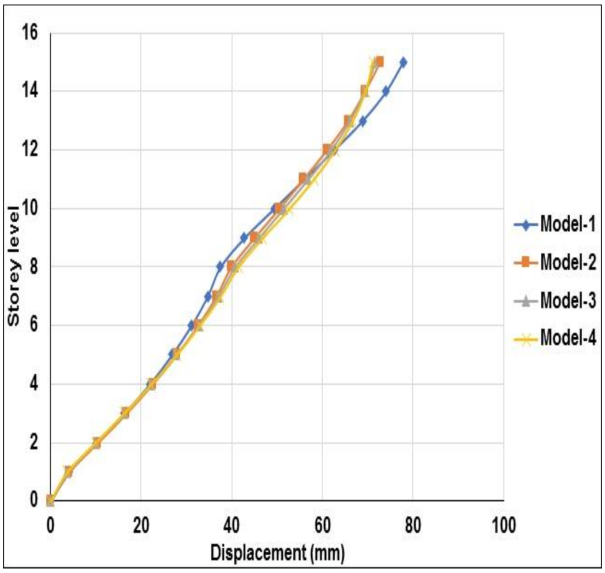


Fig 6.1 Storey Displacement for VGI

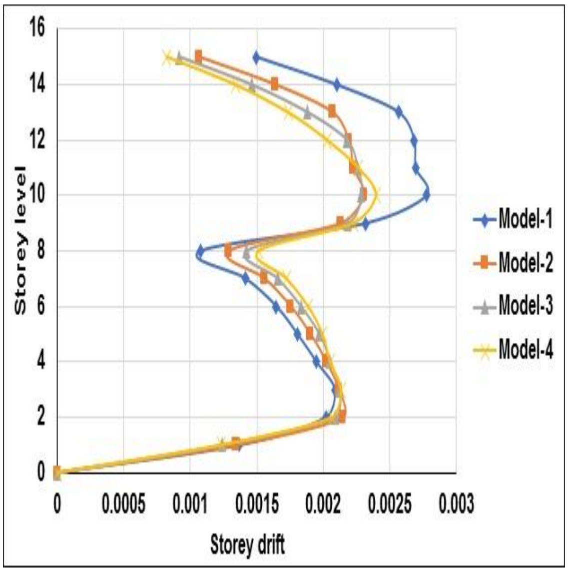


Fig 6.2 Storey Drift for VGI

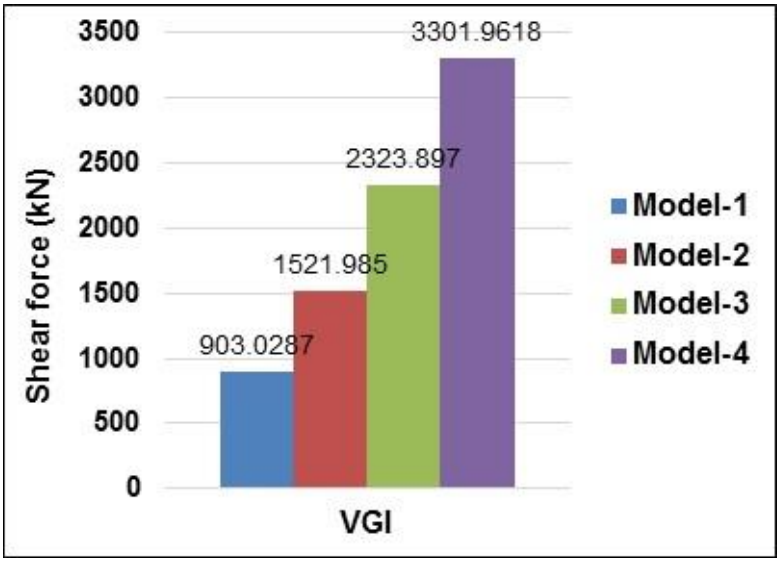


Fig 6.3 Storey Shear for VGI

Figure-6.1 represents the storey displacement along the height of the structures of four models having geometric irregularity. From this the storey displacement is maximum for the 1st model which is having a smaller number of bays i.e., high vertical aspect ratio and is minimum for model-4 which is having high number of bays and smaller vertical aspect ratio compared to other models. Variation of Storey drift of four models having geometric irregularity are shown in the figure-6.2. The drift is observed maximum at 10th storey level in all the models and the value is high for the model-1. Figure-6.3 represents the storey shear of all the models considered as vertical geometric irregular structures. In all the models maximum base shear is observed for model-4 which has the six number of bays with vertical aspect ratio of 1.5 and the minimum base shear is for model-1 which has the smaller number of bays compared to other models and it has the vertical aspect ratio of 3.

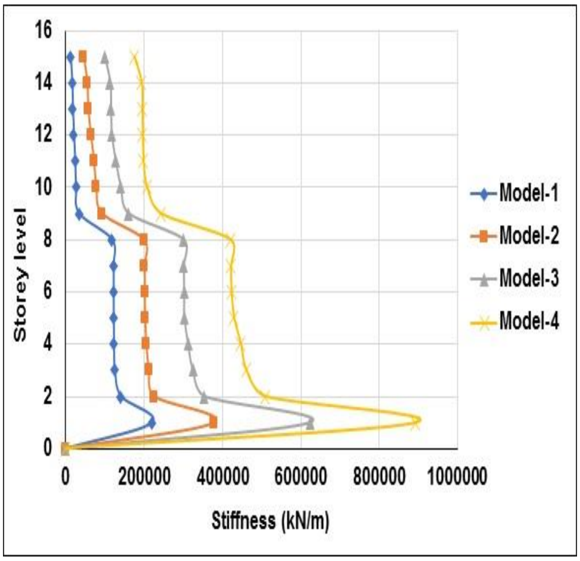


Fig 6.4 Storey Stiffness of VGI

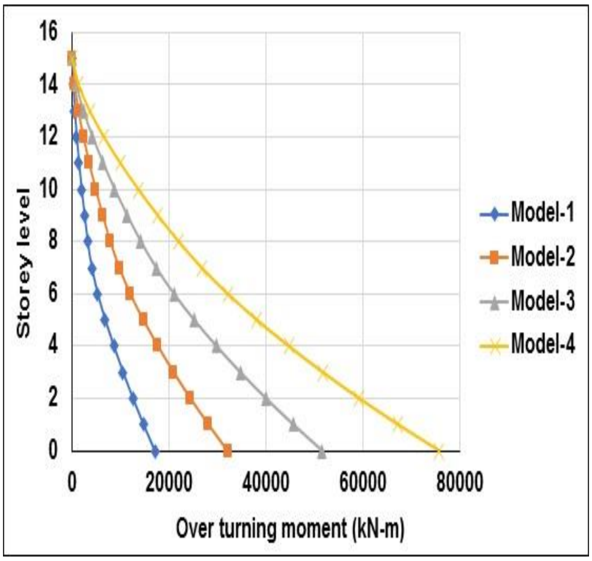


Fig 6.5 OTM for VGI

Figure-6.4 shows the storey stiffness of all models considered in the case of vertical geometric irregular structures. The maximum storey stiffness has an increment of 72.5% from model-1 to model-2, from model-2 to model-3 is 64.72% and from model-3 to model-4 has an increment of 43.04%. The overturning moment of every model taken in the geometric irregular structures shown in figure-6.5. It is observed that the higher value has an increment of 88% from model-1 to model-2, model-2 to model-3 shows 60.64% and from model-3 to model-4 has 46.83% of increment. Stiffness and over tuning moment are maximum for model-4 and stiffness is high at first storey for all the models

4.4. Summary from the results:

The storey displacement increases in a structure moving from bottom to top storeys in case of mass, stiffness and vertical geometric irregular structures. In mass and stiffness irregular structures storey displacement and drift increases from model-1 which has a smaller number of bays to model-4 which has maximum number of bays but in case of vertical geometric irregular structures the storey displacement and drift is maximum in model-1 which has a smaller number of bays compered to remaining models. Shear value is high in the case of VGI structures than mass and stiffness irregular structures. The storey drift is more in the case of stiffness irregular structures than mass and geometric irregular structures and maximum drift value observed for the model-4 of case SI-1. The storey drift values are not exceeded the limit as per code (drift is not exceeded 0.004 times the height of the storey according to IS1893:2016 Part-1) in all the cases.

5.Conclusions:

Three categories of irregular structures namely mass irregularity, stiffness irregularity and vertical geometric irregularity are considered. All are RC building frames with various plan configurations and vertical aspect ratios. Response spectrum analysis was conducted for each model of every case. Storey response is compered among all the cases. Earthquake loads are applied based on IS1893:2016(part-1). From the results conclusions can be derived as follows:

1. The results show that the aspect ratio significantly affects structural response. It is observed with the decrease of vertical aspect ratio i.e., increase of number of bays in x and y direction simultaneously storey drift, displacement, storey shear and overturning moment increases in all the cases but in case of vertical geometric irregular structures the storey displacement and drift get maximum at model-1 which has smaller number of bays compared to other models.
2. In the case vertical geometric irregular structures from the results with the decrease of vertical aspect ratio the storey displacement and storey drift values decrease for all the models. The base shear, overturning moment and stiffness increases with the decrease of vertical aspect ratio (Increase of number of bays).
3. Among five cases displacement response is maximum in the case of SI-2 of model-4 with vertical aspect ratio 1.6 and less for MI-2 of model-1 with vertical aspect ratio 3. In both mass and stiffness irregular structures the models of stiffness irregular structures shown high response.
4. From the results we can say that the structures with high vertical aspect ratio (a small number of bays) will give better performance in case of mass and stiffness irregular structures.

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