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Behaviour of Irregular Reinforced Concrete Frames under Seismic Loading

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Abstract

The present world demands the multi storey buildings due to lack of space availability in the urban areas to accommodate the increased population with their proposed requirements. Multi-storey building's behaviour during high seismic action depends mainly on Structural configuration. Structural configuration having any discontinuities in plan or in elevation are termed as building with irregularities. When these irregularities are present in the structure, buildings suffer much more damage during strong earthquake excitations which was recorded in the past. The Irregularities are defined as per IS:1893 (Part 1)-2016 code.
This paper is concerned about the various types of plan, vertical and combined irregularities and their effect under seismic loading. The objective of the present study is doing linear static and dynamic analysis i.e., ESA and RSA on various irregular building frames and calculating their response using some seismic parameters like displacement response, storey drift, inter storey drift ratio and base shear for which the frames are designed using IS 456-2000 and special detailing for fulfilling the ductility requirement is done as per IS: 13920-2016. Comparison of the results of analysis in X and Y directions of irregular structures is done with regular structure. The scope of the present study also includes the maximum and minimum effect on the various types of irregular structures under seismic loading and to know if the presence of irregularities always amplifies the response or not.

Keywords: Seismic performance, Response Spectrum, Irregular Building, Combined Irregularity, Equivalent Static Analysis, Re-entrant Corners, Vertical Geometric Irregularity

1. Introduction

Structures generate inertial forces and their resultant forces act through the center of mass (CM) of structure when seismic action has occurred. Vertical members in the structures (i.e., columns, walls) resist these forces and their resultant forces act through a point called center of stiffness (CS). When the center of mass (CM) and center of stiffness (CS) doesn't coincide eccentricity may develop which may lead to development of torsion in the structure. The torsional force may generate in the building structure due to the reaction of lateral forces and resisting forces. This torsion may cause severe damage in the structures. Eccentricities may generate in the building due to the irregularities in structure.
As per study on existing literatures, researches mainly focused on single irregularities. In reality, structures contain multiple irregularities or various combination of irregularities. Irregularities are introduced in the structures because of aesthetics and their requirement for ventilation in urban areas. However, study of combination of irregularities are scarce and also analysing by single irregularity doesn't predict actual effect under seismic action. In the present study the plan, vertical and combination of irregularities are introduced and their effects are noticed compared with the regular building when seismic excitations occurred.

Three types of irregular building frames i.e., plan irregular frames with re-entrant corners, elevation irregular frames with vertical geometrical irregularity and combined irregular frames with both re-entrant corner and vertical geometrical irregularity are considered in this present work. Also, which type of irregular frame experiences most severe response under earthquake loading is investigated. For this work the building frame models are considered with reinforced concrete special moment resisting frames of G+5 buildings analysed using SAP2000.

2. Details of Models

All the nine models are taken as special moment resisting frames with G+5 stories each. Height of each floor is 3m. Plan Dimensions of the regular frame is 20m x 16m. Number of bays in X-Direction is 5 and in Y-Direction is 4. All the columns are of size 0.45m x 0.4m and beams are of size 0.35m x 0.3m. Slab thickness is 150 mm. Thickness of outer walls are 0.23m and inner partition walls are 0.15 m. Floor live load is 3 kN/m^2, roof live load is 1.5 kN/m^2, floor finish is 1 kN/m^2, roof treatment is 1 kN/m^2. Grade of concrete and steel are M25 & Fe415. Parameters are taken from IS 1893-2016 (Part 1). Soil type is considered as medium soil, seismic zone V, importance factor 1, response reduction factor 5 and damping is 5%.

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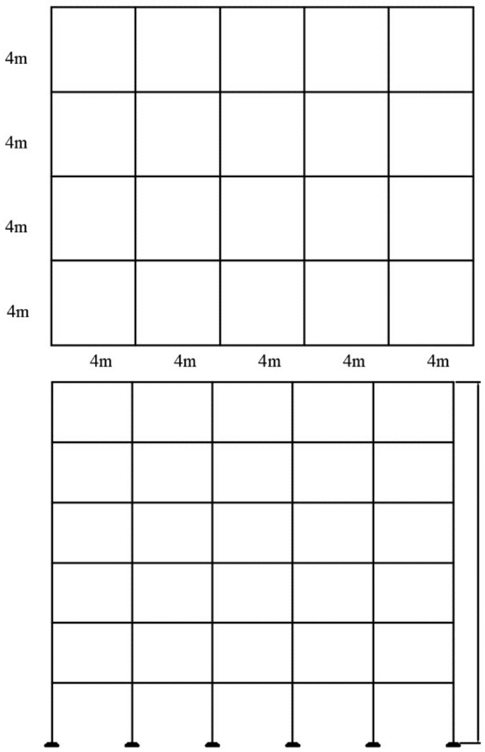


Model 1

Fig.1. Plan & Elevation of Regular Building

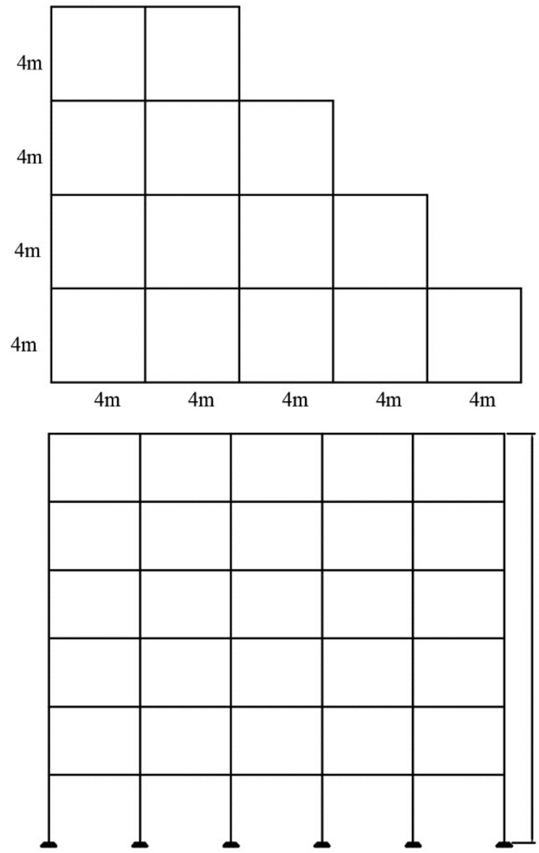
3. Plan Irregularities

Plan irregularities with only re-entrant corners are studied with different structural configurations. Here three plan irregular buildings are considered along with one regular building to know the performance of the building in both X and Y directions under seismic action and their seismic response is calculated by roof displacement, storey drift, inter-storey drift and base shear.

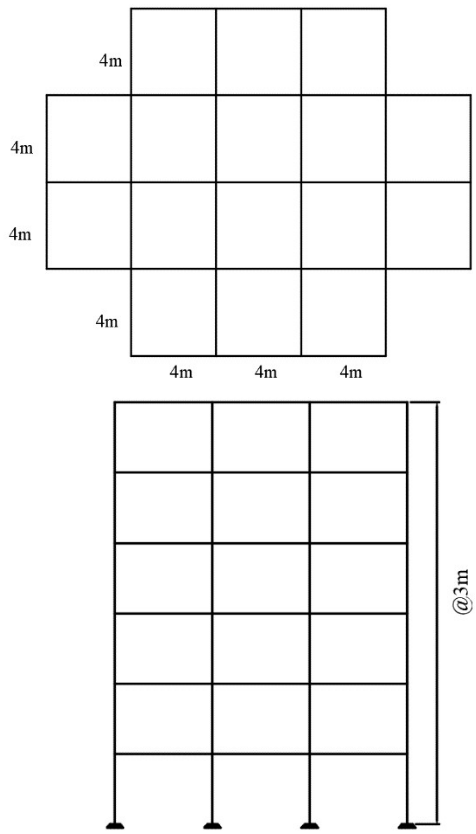
Table 1. Condition for Plan Irregularity

Type of Irregularity		
Model 1	No Irregularity (Ref. Fig.1)	
Model 2	A/L=0.75>0.15	Re-Entrant Corner
Model 3	A/L=0.25>0.15	Re-Entrant Corner
Model 4	A/L=0.8>0.15	Re-Entrant Corner

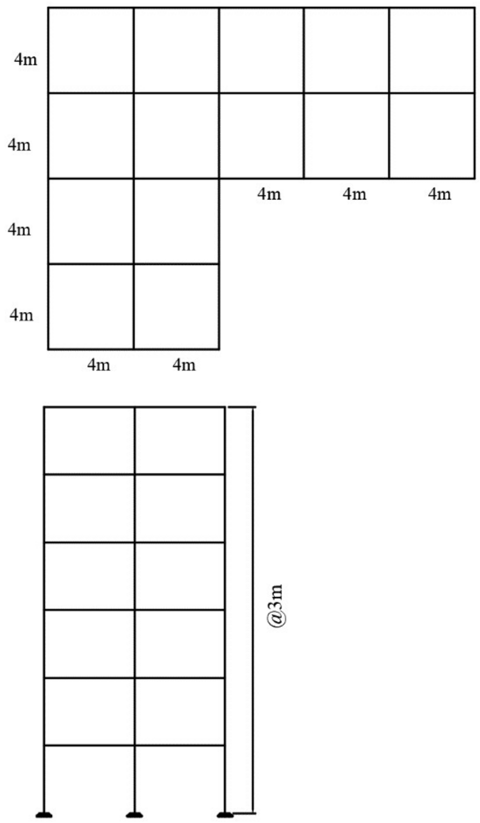
A and L as explained in Fig 3 in IS 1893(Part-1)-2016



Model 2



Model 3



Model 4

Fig.2. Plan & Elevation of Plan Irregular Models

3.1. Results

According to IS: 1893 Part 1- 2016 the storey drift should not be greater than 0.004 X h, where h is the building height. Therefore, maximum allowable roof displacement will be 72 mm for all these models.

Seismic response of three different structural configuration of plan irregular buildings with only re-entrant corners are obtained and compared with one regular building to know the performance of the plan irregular buildings. Responses in both X and Y directions under seismic action are calculated by roof displacement, storey drift, inter-storey drift and base shears.

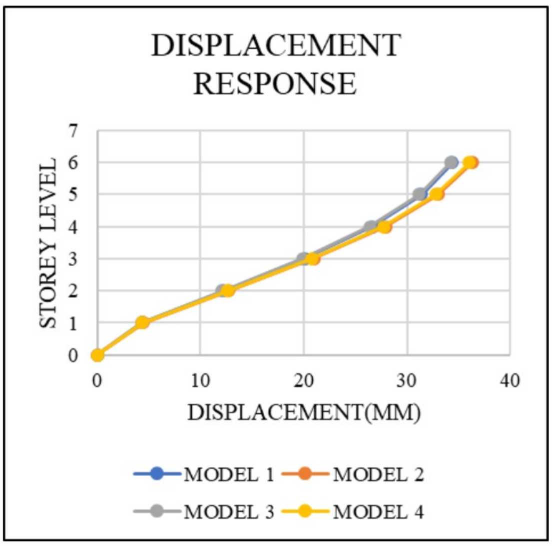


Fig. 3. Displacement Response in X-Direction

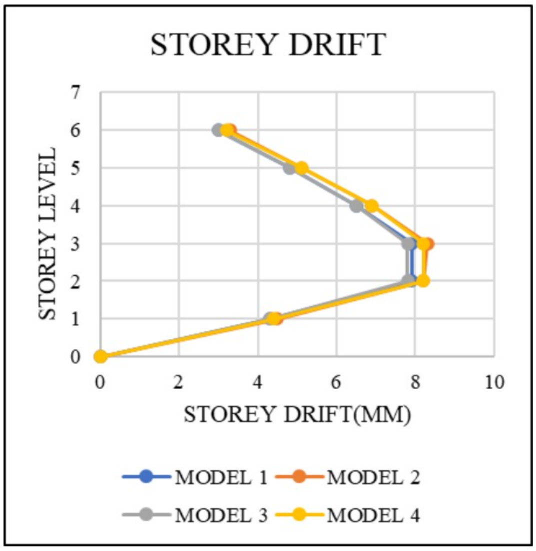


Fig. 4. Storey Drift in X-Direction

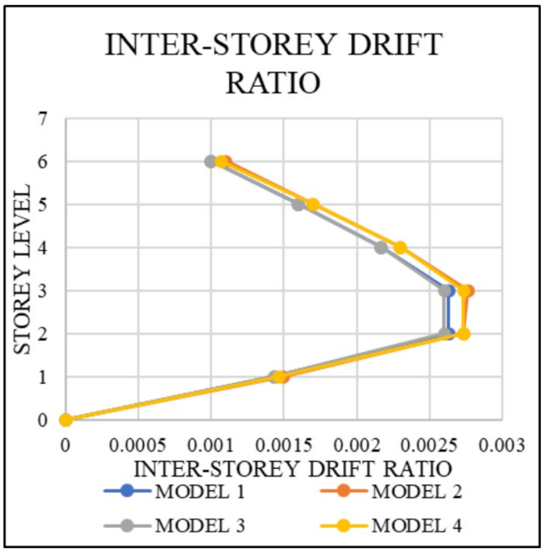


Fig. 5. Inter-Storey Drift Ratio in X-Direction

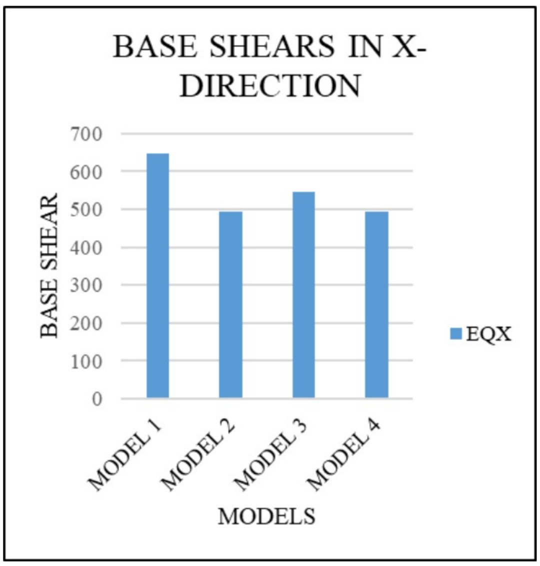


Fig. 6. Base Shear in X-Direction

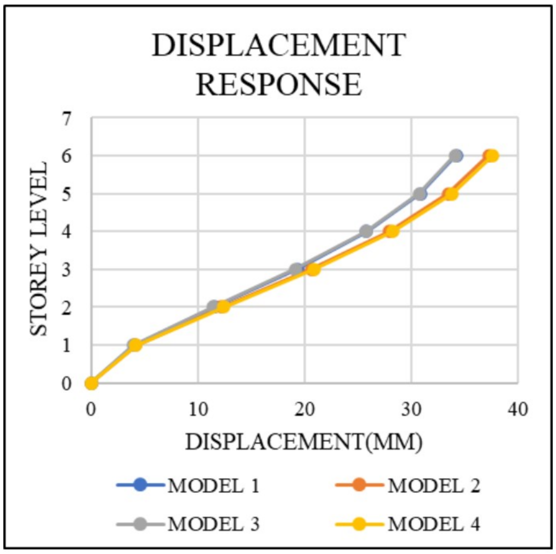


Fig. 7. Displacement Response in Y-Direction

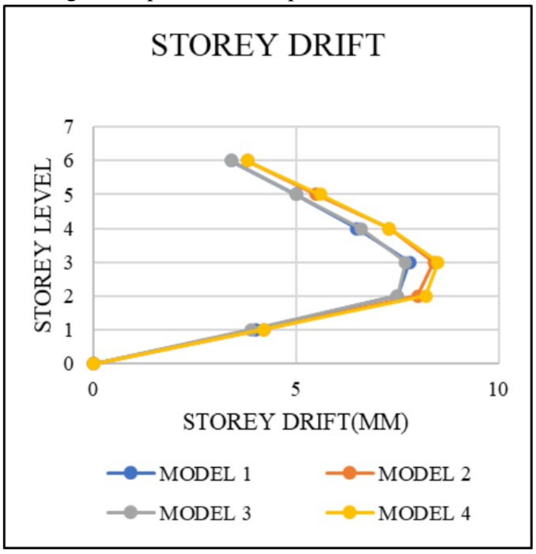


Fig. 8. Storey Drift in Y-Direction

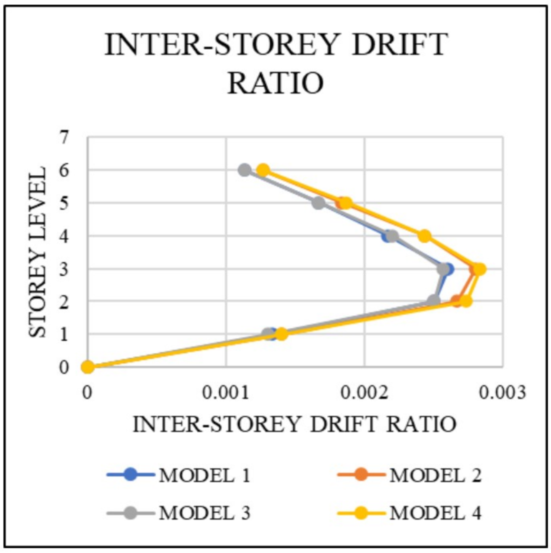


Fig. 9. Inter-Storey Drift Ratio in Y-Direction

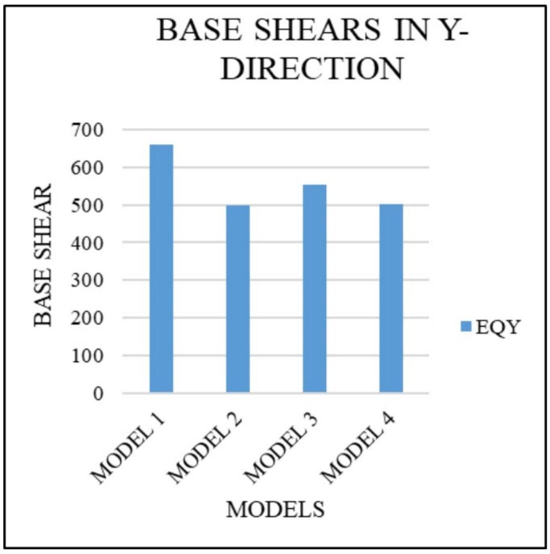


Fig. 10. Base Shear in Y-Direction

Response Spectrum Analysis (RSA) in X-direction gives maximum roof displacement and storey drift compared to that in Y-direction in the case of Model 1 and Model 3 because of symmetry of the frames in X and Y directions. In Model 2 and Model 4 maximum roof displacement and storey drift are more in Y-direction compared to that of the X-direction because of asymmetry of frames both in X and Y directions. In RSA of X-direction Model 2 displays more displacement where as Y-direction Model 4 displays more displacemnt. Therefore Model 2 experiences more irregularity in X-direction compared to remaining frames. In the same way Model 4 experiences more irregularity in Y-direction compared to the remaining building frames.

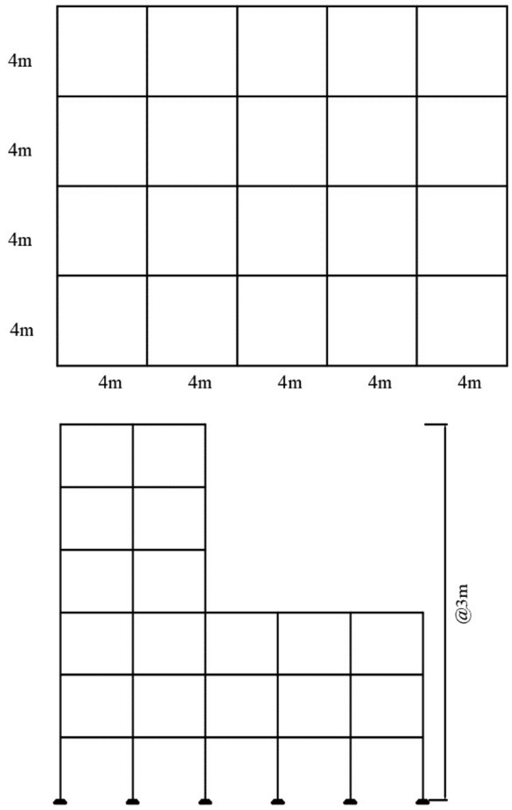
4. Vertical Irregularities

Vertical irregularities with only vertical geometrical irregularities are studied with different structural configuration of 3 vertical irregular buildings are considered along with 1 regular building to know the performance of the building in both X and Y directions under seismic action and their seismic response is calculated by roof displacement, storey drift, inter-storey drift and base shears.

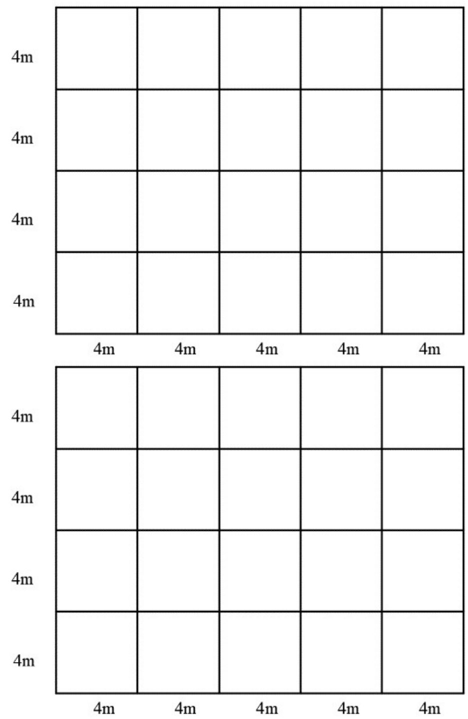
Table 2. Condition for Vertical Irregularity

Type of Irregularity		
Model 1	No Irregularity	
Model 5	A/L=0.48>0.25	Vertical Irregularity
Model 6	A/L=0.64>0.25	Vertical Irregularity
Model 7	A/L=0.32>0.25	Vertical Irregularity

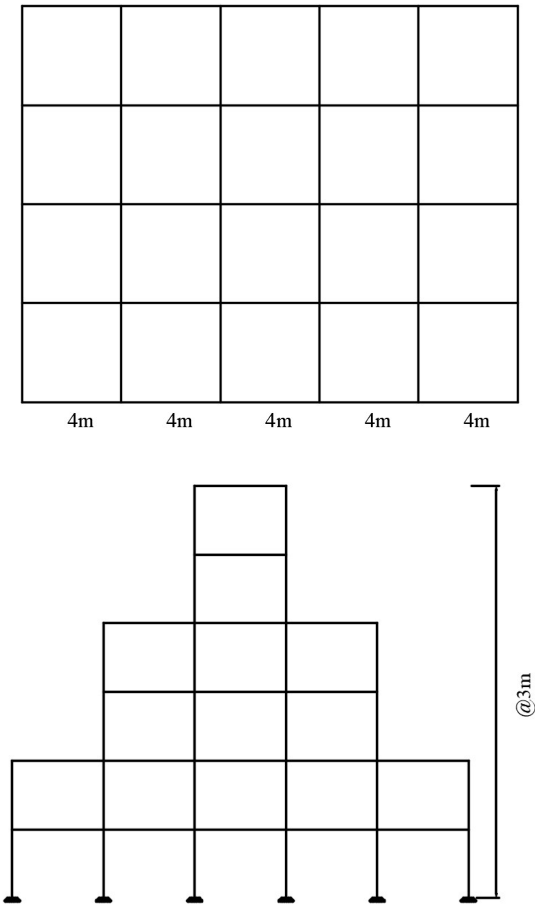
A and L as explained in Fig 3 in IS 1893(Part-1)-2016



Model 5



Model 6



Model 7

Fig. 11. Plan & Elevation of Vertical Irregular Models

4.1. Results

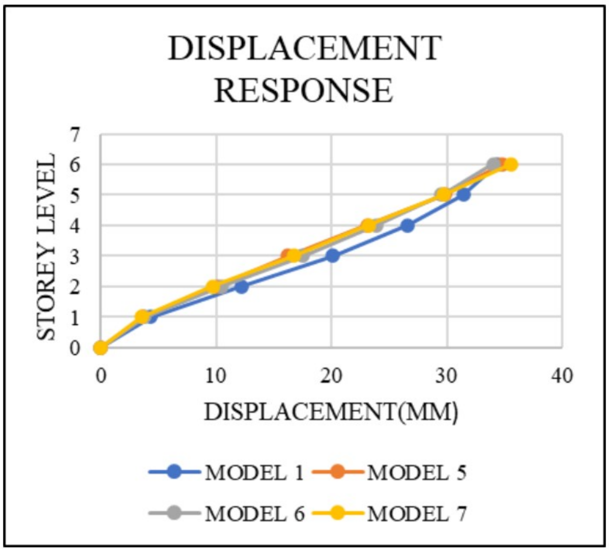


Fig. 12. Displacement Response in X-Direction

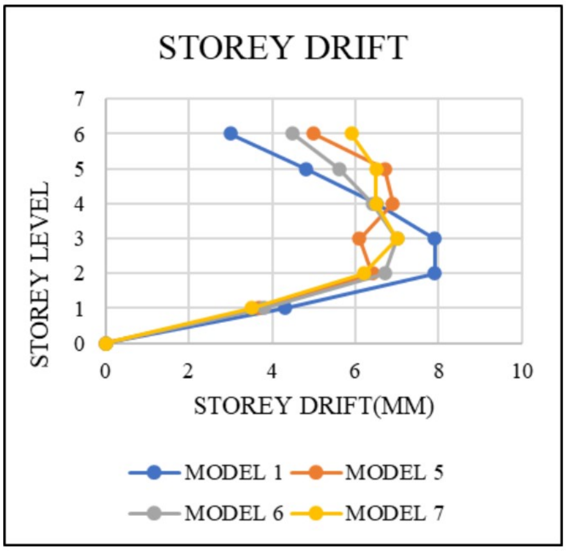


Fig. 13. Storey Drift in X-Direction

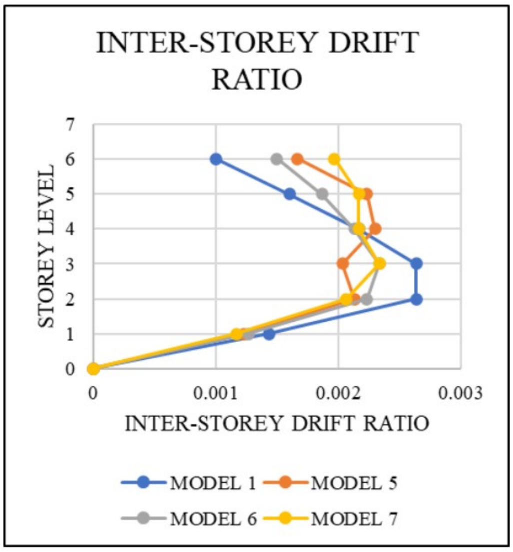


Fig. 14. Inter-Storey Drift Ratio in X-Direction

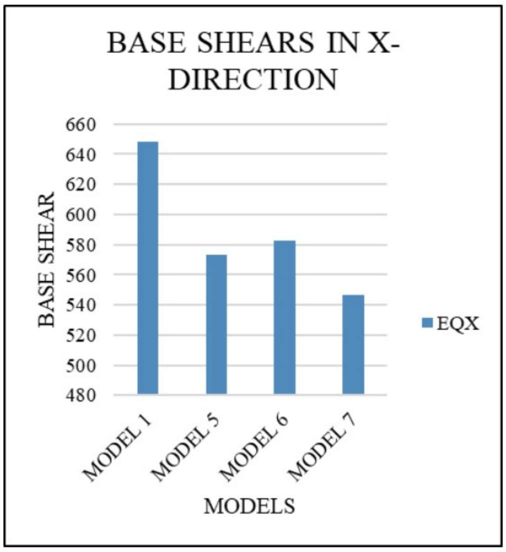


Fig. 15. Base Shear in X-Direction

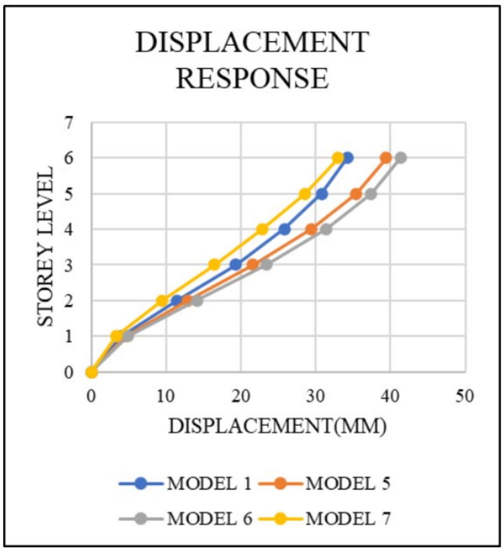


Fig. 16. Displacement Response in Y-Direction

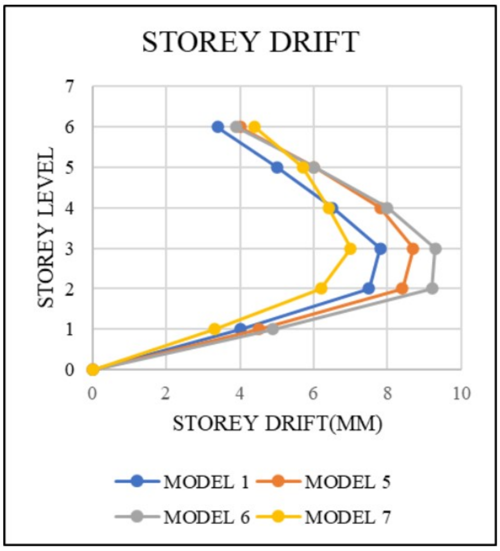


Fig. 17. Storey Drift in Y-Direction

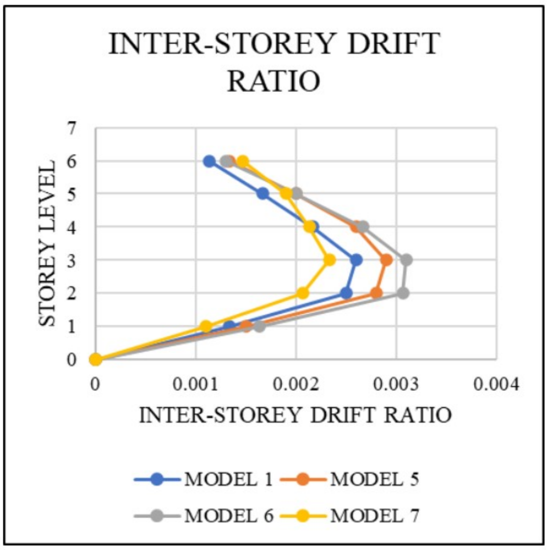


Fig. 18. Inter-Storey Drift Ratio in Y-Direction

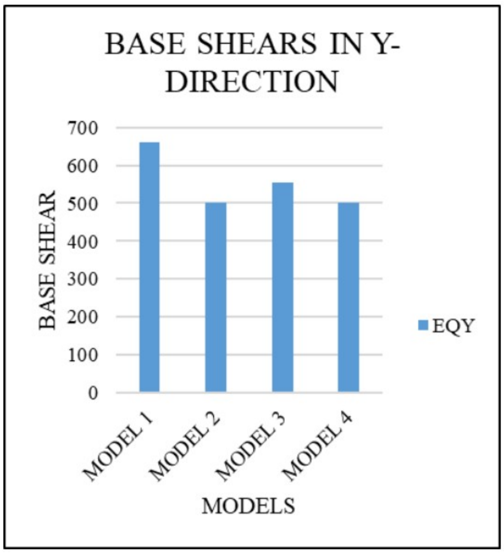


Fig. 19. Base Shear in Y-Direction

Table 3. Condition for Plan & Vertical Irregularity

TYPE OF IRREGULARITY				
DETAILS	**PLAN IRREGULARITY**		**VERTICAL IRREGULARITY**	
MODEL 1	No Irregularity		No Irregularity	
MODEL 8	A/L= 0.75> 0.15	Re-Entrant Corner	A/L= 0.48> 0.25	Vertical Irregularity
MODEL 9	A/L= 0.8> 0.15	Re-Entrant Corner	A/L= 0.48> 0.25	Vertical Irregularity
MODEL 10	A/L= 0.48> 0.15	Re-Entrant Corner	A/L= 0.48> 0.25	Vertical Irregularity

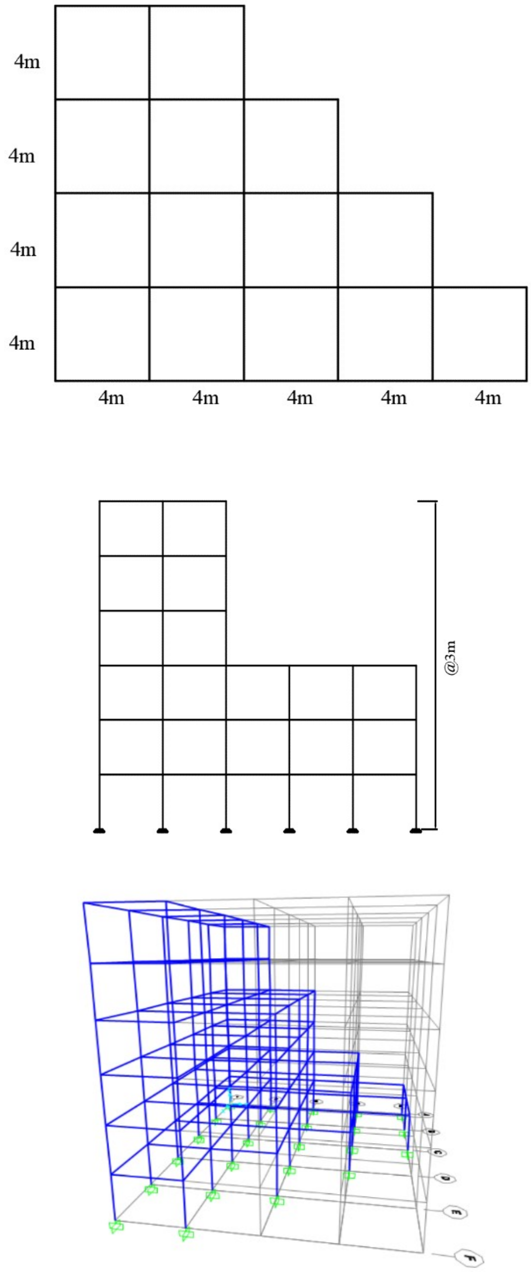
For all the cases of vertical geometrical irregularities, where there is a sudden change in the vertical configuration at any storey,storey drift at that particular storey abruptly increases and then decreased. This increased drift in that particular storey is due to reduced mass and stiffness(change in vertical congfiguration) and it leads the frame to act flexibly giving increased drift value.

A and L as explained in Fig 3 in IS 1893(Part-1)-2016

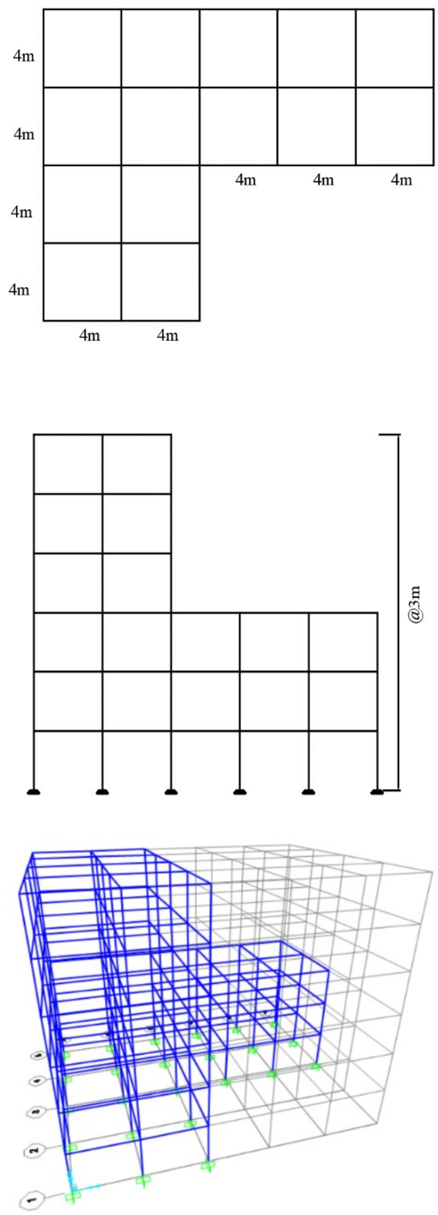
RSA in X-direction gives maximum roof displacement for model 1 and model 7 compared to Y-axis and in Y-direction maximum roof displacement is obtained for model 5 and model 6 compared to that in X-direction. It is noticed that both in X and Y direction, Displacement Response is increased irrespective of the areas of discontinuity in geometry throughout the height of building in all the cases of the vertical geometric irregularities. The most critical frame is Model 6 which gives the maximum roof displacement in Y-direction among all vertical geometrical irregular frames. Model 7 gives maximum roof displacement in X-direction but least displcement in Y-direction this shows that reponse varies with geometry, plan and type of irregularity.

5. Combined Irregularities

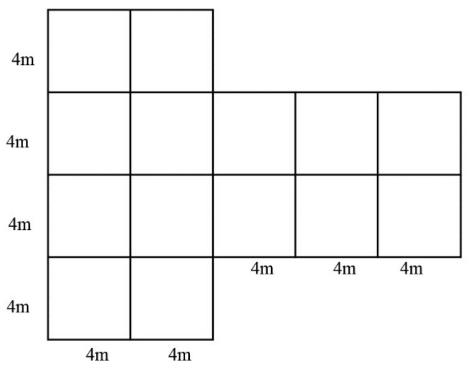
Combined irregularities of re-entrant corners with vertical geometrical irregularities are studied with different structural configuration of three combined irregular buildings. The response of combined irregular buildings are compared with regular building (Fig-1) to know the performance of the buildings in both X and Y directions under seismic action and their seismic response is calculated by roof displacement, storey drift, inter-storey drift and base shears.

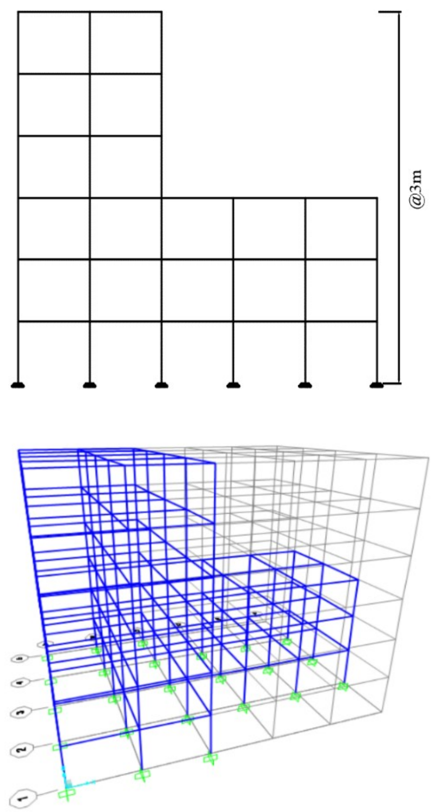


Model 8



Model 9





Model 10

Fig. 20. Plan, Elevation & 3D view of Combined Irregular Models

5.1. Results

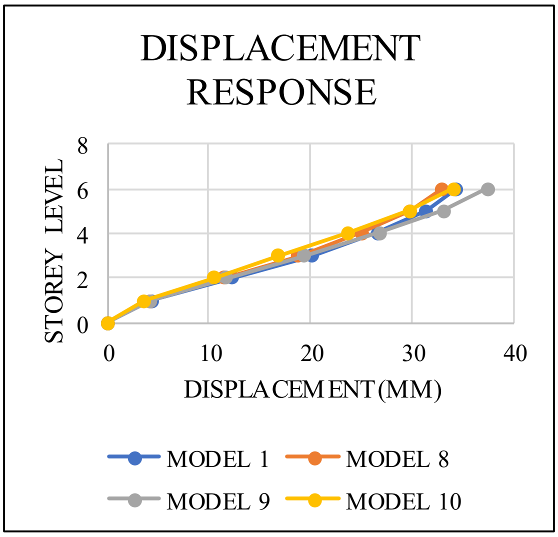


Fig. 21. Displacement Response in X-Direction

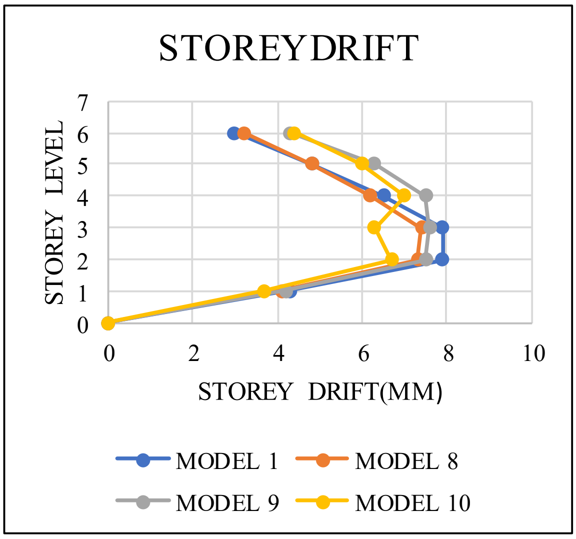


Fig. 22. Storey Drift in X-Direction

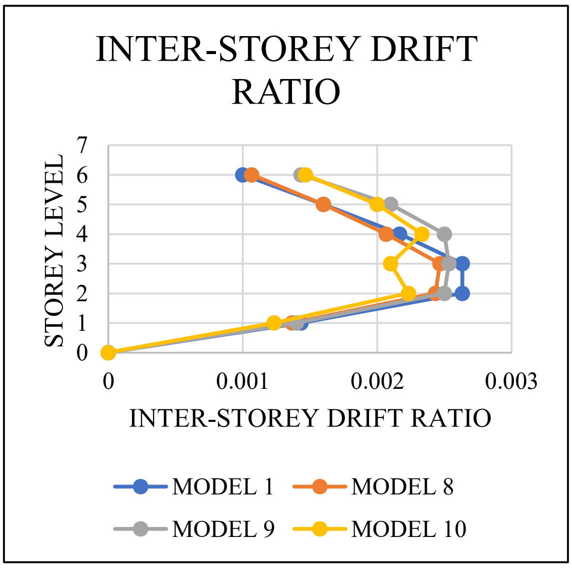


Fig. 23. Inter-Storey Drift Ratio in X-Direction

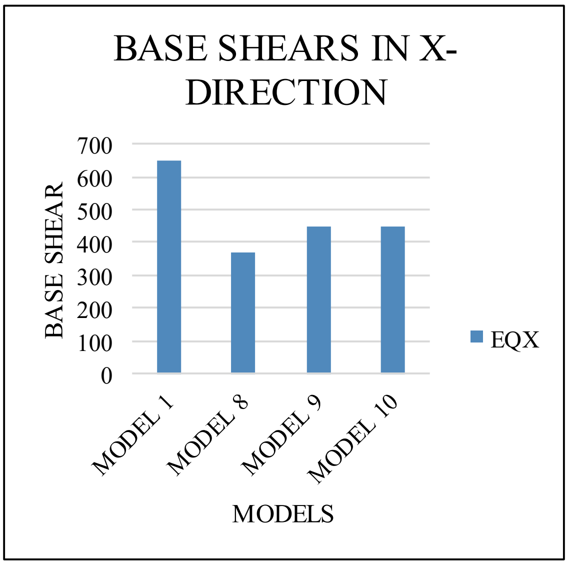


Fig. 24. Base Shear in X-Direction

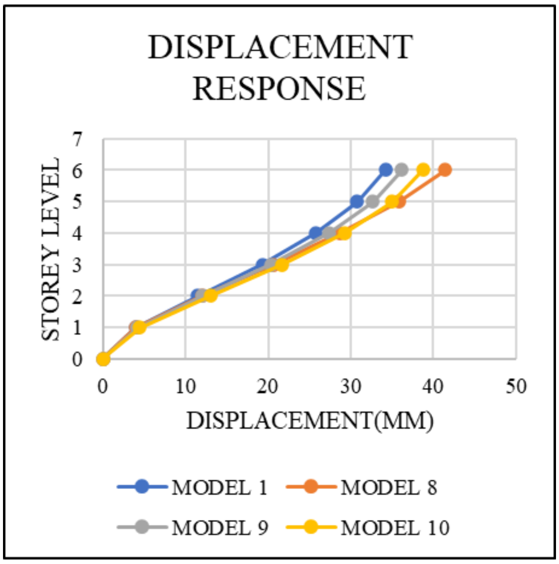


Fig. 25. Displacement Response in Y-Direction

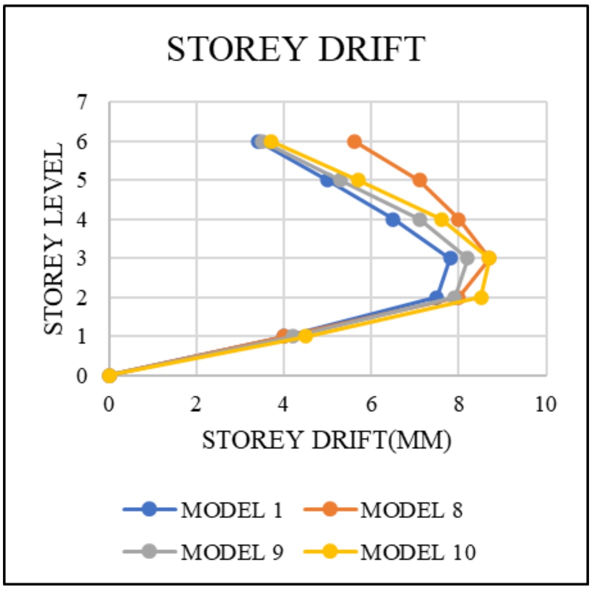


Fig. 26. Storey Drift in Y-Direction

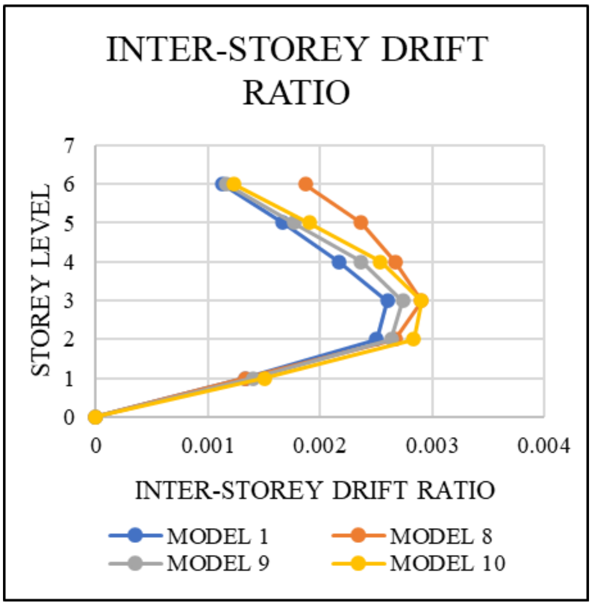


Fig. 27. Inter-Storey Drift Ratio in Y-Direction

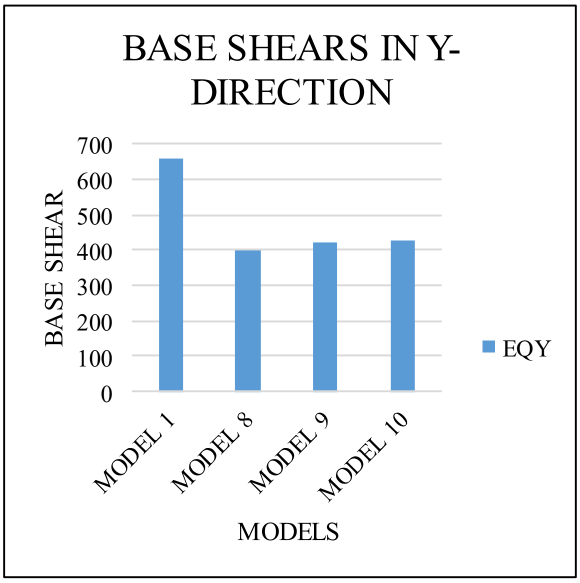


Fig. 28. Base Shear in Y-Direction

RSA in X-direction gives maximum roof displacement for model 9 compared to Y-axis and in Y-direction RSA gives maximum roof displacement for model 8 compared to that of X-direction. And also, if any building is symmetrical about any axis even with irregularities the displacement response is less compared to the other axis. The most critical frame in combination of irregular frames is model 8 in Y-Direction. The Displacement response of model 8 and 10 are less than model 1 in X-direction which means irregularity doesn't always amplifies the response in both directions. However in Y direction response of all the models is more than the regular frames.

6. Conclusions

To study the seismic behaviour of irregular buildings a set of plan, vertical and combined irregularities are selected. While studying the seismic behaviour various response parameters such as storey drift, roof displacement, inter storey drift ratio and base shear are considered. The aim of the work is to notice the most critical response of the considered buildings for avoiding and also to know if the combination of irregularities always amplify the response or not.

The irregularities in plan, vertical and in combination considered in the present study and their performance on seismic loading is obtained using linear dynamic analysis. From the study it is evident that the buildings with irregularities always do not suffer damage under seismic loading. For model 3 the displacement response in both X and Y directions are less compared to the regular frame because even with irregularity, the frame is symmetrical about both the axis. It is also noted that even with symmetry along one axis, in that axis displacement response is less than regular frame which was concluded in model 7 and model 10. All the models taken in the present study show that the displacement response for regular and symmetrical buildings is more in X-direction and for all remaining irregular buildings the displacement response is more in Y-direction.

Base shear is reduced in case of all irregular models which are taken in the present study compared to regular frame because of the reduction of the mass of the building. For all the cases of vertical geometrical irregularities, where there is a sudden change in the vertical configuration at any storey,storey drift at that respective storey abruptly increases and then decreased which was clearly noticed in X-direction where irregularities are present. Displacement Response is increased irrespective of the areas of discontinuity in geometry throughout the height of building in all the cases of the vertical geometric irregularities.

The most critical frame of plan irregular frame is model 4 which is L shape frame. Because of the shape torsion is induced in the building but that is well within the prescribed limit as per IS codes even though these types of irregular frames should be avoided for better performance under seismic actions. The most critical frame of vertical irregular frame is model 6 which is step back frame. Because of this irregularity in each floor the response is very high which is much more than plan irregular building response. In case of the combined irregular frames the most critical frame is model 8 because it shows severe response and also more than plan and vertical irregular frames. From all these outcomes it can be concluded that for all the building models studied here, the combined irregularities amplify the response most.

In all the models of the plan, vertical and combined irregular frame cases inter-storey drift ratios are within the prescribed limits given in IS1893 (Part 1): 2016 (i.e., <0.004). RSA gives different and less value of base shear than ESA. It is observed that in the irregular frames more coupling of modes will occur and we have to consider more mode shapes because in each mode, modal mass participation is less. That's why it is needed to consider the modes where more than 90% mass is participated. This is completely different for regular frame i.e., more mass is participated in the initial modes only and consideration of mode shapes is less when analysed using RSA. For irregular frames whether it is a plan/vertical/combined irregular frame, consideration of vertical excitations is very important for proper earthquake resistant design.

From all the above discussion it can be concluded that the irregular building located in high seismic zone must be analyzed and design carefully and special attention is required for the vertical and combined irregular frames to reduce the effect of excessive displacement response at the time of seismic event.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

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