The Seismic Behavior Of Reinforced Concrete Buildings Exhibiting Irregularities In Mass And Stiffness

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Abstract: Vibration of ground surface due to rapid release of energy from earth's lithosphere gives rise to seismic waves and the phenomenon is called earthquake. Earthquake has very harsh effectson life and property. Response of multi storey structures during seismic activity depends on structural alignment. Irregularity either in plan or in elevation is one of major reasons for failure of the structure. Irregular structures located in seismic zones are a matter of great concern. Buildings generally possess combination of irregularities. Due to irregularities,structures may partially or fully collapse as they cannot resist seismic force due to demand earthquake. The current design procedure stops at demand earthquake, analysis and design and consequently cannot assure that the building meets objectives at the beginning, therefore the designer's approach should be performance-based design. The current study stresses on carrying out performance based seismic design for RCC structures for combination of irregularities for horizontal and vertical irregularities and evaluate the performance of 10 storey residential apartment building located in zone 3. The structure is designed as per IS 456-2000 and seismic analysis is carried out by using dynamic analysis such as response spectrum, time history analysis and non-linear pushover analysis using ETABS 2017 software. Pushover analysis is carried out using default hinges for beams and columns. The response of the building is studied in terms of pushover curve, safety ratio, ductility ratio, storey displacement & storey drift.

Keywords: Irregularity, Demand Earthquake, Safety Ratio, Ductility ratio

1. INTRODUCTIONS

Vibration of ground surface is the cause for abrupt liberation of energy from outer most part of earth's surface gives rise to seismic waves and the phenomenon is called earthquake. Earthquake is a natural hazard and has harsh effects on life and property. Earthquakes are mainly due to two reasons, instigation by tectonic activity and volcanic eruptions. When the ground surface shakes below building foundation, the structurequaver along with neighbouring earth's surface which may result in part or absolute debacle of the structure. Generally high-rise buildings are more susceptible to seismic activity than shorter buildings. Study of earthquake and seismic waves are called seismology. There are three kinds of seismic waves which are caused during seismic activity, primary waves & secondary waves and third is caused due to association of primary & secondary waves. Seismograph or Seismometer is instrument used to measure seismic waves. Seismograph & Seismometer creates the seismogram. P waves are thefirst waves to reach the seismogram followed by S waves. Charles Richter in 1932 wasthe first person to device the magnitude scale for measuring earthquake size and is namedafter him as Richter scale. Earthquake has a point from where seismic waves are generated and it is called epicentre. To locate epicentre, we need at least three seismic stations, P & S wave's helps to determine the location of epicentre. Buildings may be symmetric or asymmetric according to their plan, architecture and functionality, Buildings symmetric in plan and elevation is more capable in resisting earthquake loads, but buildings with irregular allocation of mass, stiffness and geometry of structure are more susceptible to seismic activity, therefore such buildings are called irregular structure. Irregularity either in plan or in along the height of the building is one of m reasons for failure of the structure. Structures generally have combination of irregularities.

A building may have single irregularity or it may have combination of irregularities. The current study induces combination of selected irregularities to structures to make them horizontally and vertically irregular and compare their performance during seismic activity for selected combination of irregularities, Comparative study due to combinations of vertical irregularities & plan/horizontalirregularities in terms of pushover curve, safety ratio & ductility ratio, Comparative study due to combinations of vertical irregularities & plan/horizontal irregularities in the form of storey displacement and storey drift.

2. METHODOLOGY

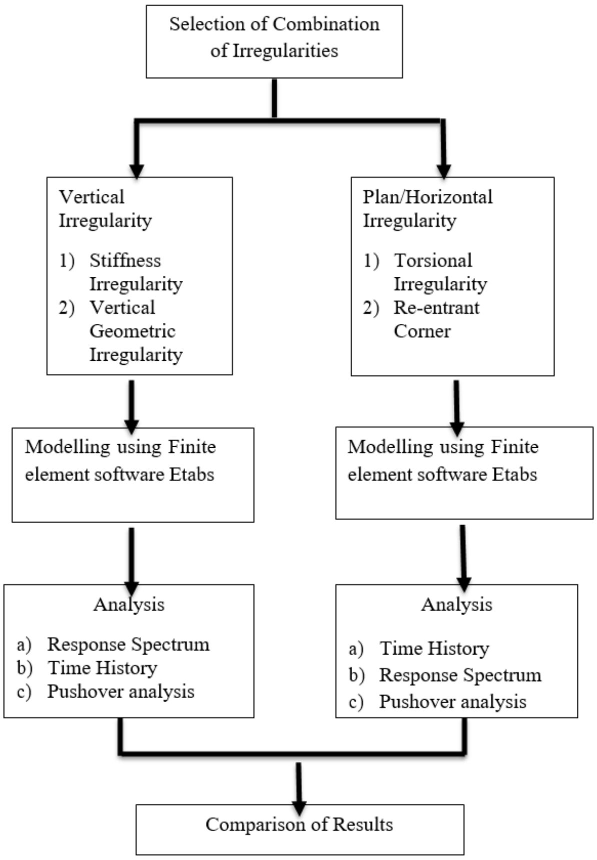


Figure 1: Methodology

2.1 VERTICAL IRREGULARITY

Structure is three-dimensional MRF with soft storey, unreinforced brick infill walls in rest of storey. Plan and 3D view is Building is having G+9 storeys. Columnsare fixed at base. There are no walls in bottom storey and 230 mm external & internal wallsin rest of storeys. Modelling of structure is carried out in finite element software Etabs. Stiffness irregularity & vertical geometric irregularity are taken as combination of irregularity for modelling the structure. Stiffness irregularity is induced by varying storey height at 3rd storey from 3.5 m to 4.5 m. Vertical geometric irregularity is induced varying vertical configuration along the height at top storey. Equivalent static analysis, response spectrum analysis, pushover analysis and time history analysis is carried out for Northridge earthquake data. Auto hinges M_3 were allocated to beams and P-M_2-M_3 hinges were to columns.

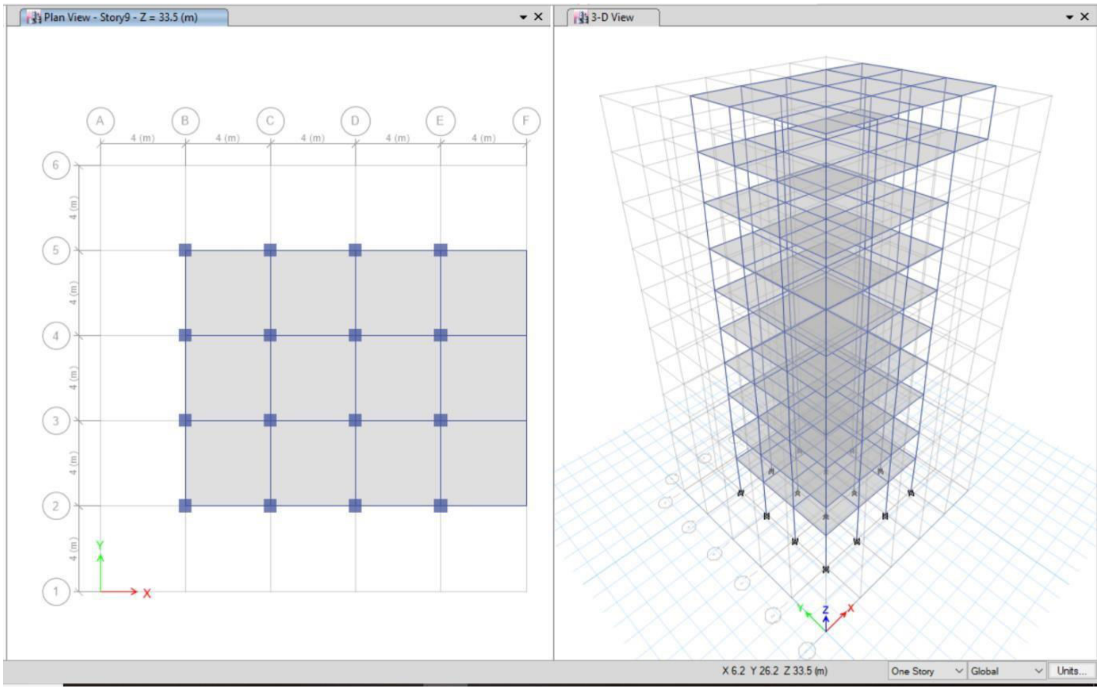


Figure 2: Plan & 3D view of vertically irregular model

Table 1: Specifications of vertically irregular RC Building

Geometric Details	
Plan Dimension	12m*12m base to 9th storey 16m*16m at top storey
Structure	SMRF
Type of Building	Irregular along height at top storey
Bottom Storey Building Typical Storey Height 3rd Storey Height No. of Storeys	4.5m 3.5m 4.5m G+9 Storeys
Purpose of Building	Residential
Material Characteristics	
Grade of Concrete	M20
Grade of Steel	Fe500
Section Properties	
Beam	0.3m*0.5m
Column	Base storey to storey 4 circular columnwith 0.6m diameter Storey 5 to top storey square column of 0.6m*0.6m
Slab	150mm
Primary Load Cases	
Wall Load (Dead)	13.8kN/m
Live Load on Floor	3kN/m2
Live Load On Roof	2kN/m^2
Floor Finish	1.5kN/m^2
Earthquake Load In ‘X’ Direction	IS 1893 2016 Part 1

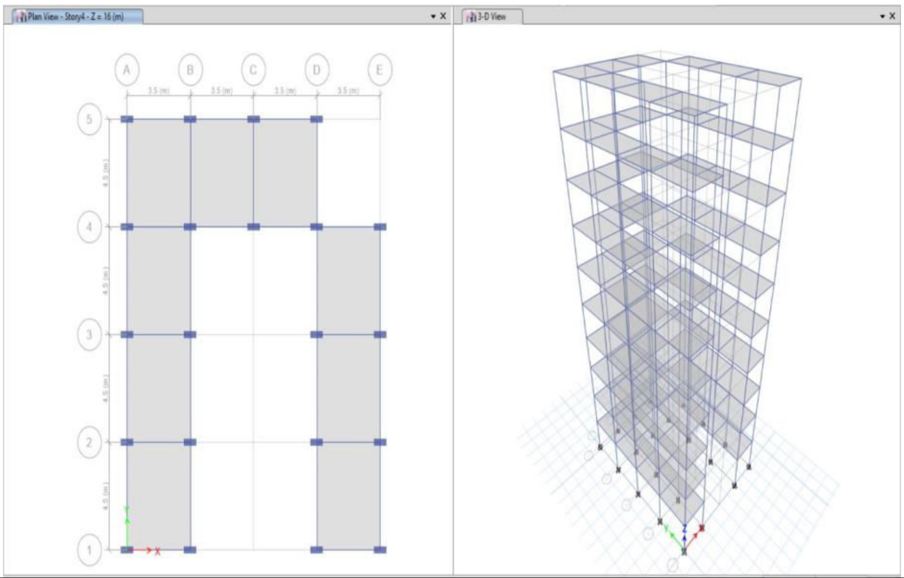
Earthquake Load in 'Y' Direction	IS 1893 2016 Part 1
Seismic Properties	
Zone Factor (Z)	0.16
Response Reduction Factor (R)	5
Importance Factor (I)	1
Soil Type	Type Ⅱ
Damping Ratio	0.05
Fundamental Time period	Along 'X' – 0.832 s & 'Y'-0.961 s

2.2 PLAN / HORIZONTAL IRREGULARITY

Structure is three-dimensional MRF with soft storey, unreinforced brick infill walls in rest of storey. Plan and 3D view is shown in figure 2. Building is having G+9 storeys. Columnsare fixed at base. There are no walls in bottom storey and 230 mm external & internal wallsin rest of storeys. Modelling of structure has been done in etabs. Re-entrant corner &torsional irregularity is taken as combination of irregularity of modelling the structure. Irregularity is induced by altering plan of the building. Equivalent static analysis, response spectrum analysis, nonlinear static pushover analysis and time history analysis is carried out for Northridge earthquake data. Auto hinges M_3 were alloted to beams and P-M_2-M_3 hinges tocolumns.

Figure 3: Plan & 3D view of the plan irregular model

Table 2: Specifications of plan irregular RC Building



Geometric Details	
Bay width along X direction Bay width along Y direction	3.5m 4.5m
Structure	SMRF
Type of Building	Irregular along height at top storey
Bottom Storey Building Typical Storey Height 3rd Storey Height No. of Storeys	4.5m 3.5m 4.5m G+9 storeys
Purpose of Building	Residential
Material Characteristics	
Grade of Concrete	M20

Grade of Steel	Fe500
Section Characteristics	
Beam	Base to storey 9 - 0.3m*0.5m Top storey - 0.3m*0.4m
Column	0.3m*0.7m
Slab	150mm
Primary Load Cases	
Wall Load (Dead)	13.8kN/m
Live Load on Floor	3kN/m^2
Live Load On Roof	2kN/m^2
Floor Finish	1.5kN/m^2
Seismic Load In ‘X’ Direction	IS 1893 2016 Part 1
seismic Load in ‘Y’ Direction	IS 1893 2016 Part 1
Seismic Properties	
Zone Factor (Z)	0.16
Response Reduction Factor (R)	5
Importance Factor (I)	1
Soil Type	Type II
Damping Ratio	0.05
Fundamental Time Period	Along ‘X’- 0.962 s & ‘Y’- 0.848 s

3. RESULTS AND DISCUSSIONS

The overall intent of the study is comparing seismic performance of RCC structures due to combination of irregularities as building does not have single irregularity because of its function and architecture. The study compares the seismic performance in terms of safety ratio, ductility ratio, storey displacement and storey shear. From the study models with combination of irregularities are more susceptible to earthquake than model usedin validation as it's a structure without any irregularities both along plan and height. Responsespectrum and time history analysis has been done and pushover analysis has also been carriedout. Comparison between structures with vertical irregularities and plan irregularities show that, structures with plan irregularities show better performance in terms of safety ratio, but storey displacements and storey drift are more than structure with vertical irregularities.

Table 3: Ratio of design base shear and base shear at performance point

	Design Base Shear (kN)	Base Shear at Performance Point(kN)	Safety Ratio
Vertical Irregularity	561.81	972.93	1.73
Plan Irregularity	697.7	1779.76	2.55

Buildings are assessed as safe if the safety ratio is greater than or equivalent to one and seismically vulnerable if the safety ratio is below one. From the table 3 we can see that boththe models are safe, however building with plan irregularity is safer than structure with vertical irregularity.

Table 4: Ductility Ratio

Shape of structure	Ductility Ratio
Vertical Irregularity	6.5
Plan Irregularity	2.63

Table 4 shows ductility ratio values for both plan and vertical irregular models. Structurewith vertical irregularities has greater ductility than structure with plan irregularities

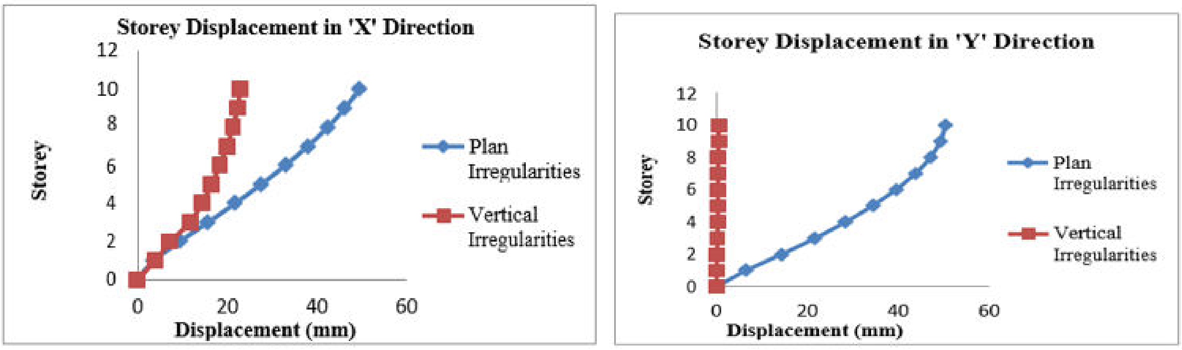


Figure 4: Displacement profile due to response spectrum (RsX) in X and Y Direction

displacement profiles of structures at different storeys and they show that structure possessing plan irregularities has greater displacement than structure with vertical irregularities.

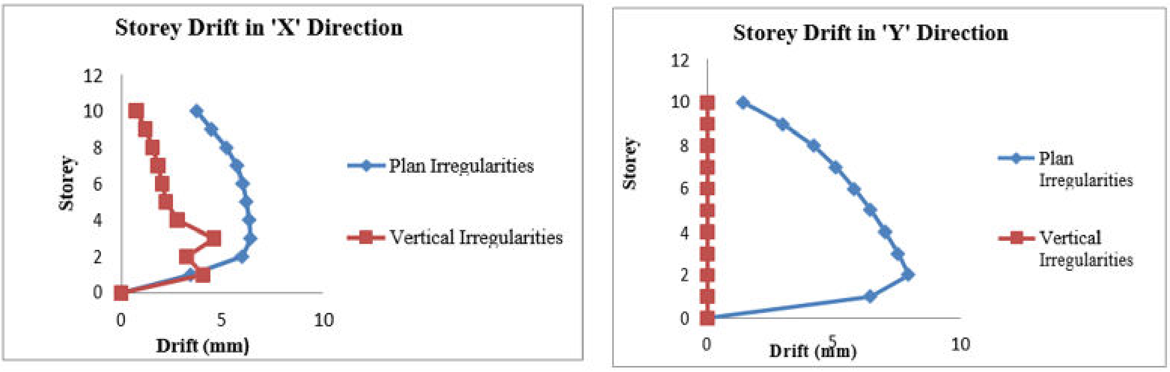


Figure 5: Drift profile due to response spectrum (RsX) in X ‘Y’ direction

drift profile of structures at different storeys and they show that structure possessing plan irregularities has greater drift than structure with vertical irregularities.

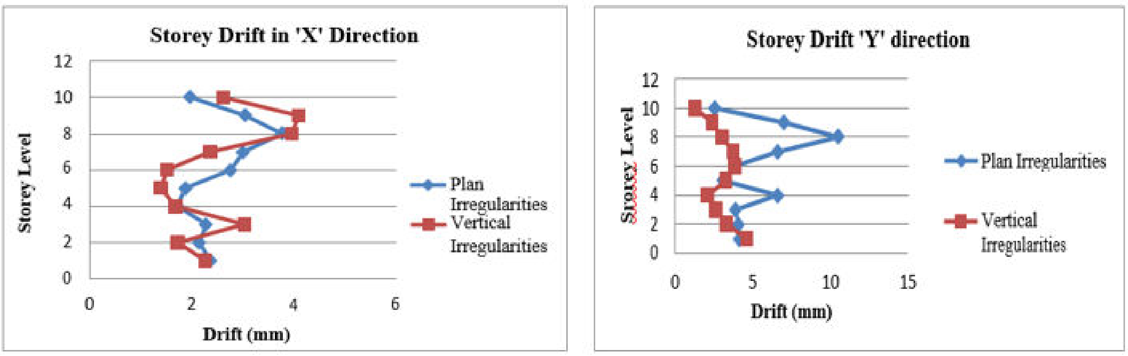


Figure 6: Drift profile due to Time History analysis in X 'Y' direction

drift profile of structures at different storeys and they show thatstructure possessing plan irregularities has greater drift than structure with vertical irregularities.

4. CONCLUSIONS

- It is seen that from table 3 both vertical irregularity model & plan irregularity model aresafe as base force at demand earthquake is more than design base shear. Model with plan irregularity is safer than model with vertical irregularity.
- Model with vertical irregularity is more ductile than model with plan irregularity from table 4.
- From graphs 4 Storey level v/s displacement it is seen that model with plan irregularity has more displacement compared to model with vertical irregularities, which shows if a building with plan irregularities with combination of torsion irregularity & re-entrant corner undergo more displacement compared to building with vertical irregularity with combination of stiffness irregularity & vertical geometric irregularity.
- From graphs 5 storey level v/s drift it is seen that buildings with plan irregularities undergo more drift than building with vertical irregularities. It is seen that from graphs 6 for building with vertical irregularity at 3rdstorey there is increase in drift, as stiffness irregularity is induced at 3rd storey from this we can say storey drift at a particular storey is more compared to other storeys of same building if stiffness irregularity is induced at that particular storey, in this case storey 3.

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