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Effect of Vertical and Mass Irregularity on RCC Structure Subjected to Seismic Loading

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Abstract

The greatest challenge for any structural engineer in today's scenario is to design seismic-resistant structures. The presence of vertical geometrical irregularity in building is a matter of concern when it is subjected to devastating earthquakes. Irregular configuration either in plan or in elevation is recognize as one of major causes of failure during earthquakes. The performance of a high rise building during strong earthquake motions depends on the distribution of stiffness, strength and mass along both the vertical and horizontal directions. If there is discontinuity in stiffness, strength and mass between adjoining storeys of a building then such a building is known as irregular building which triggers structural collapse of building when subjected to seismic loading. In present study G+14 story building with mass and vertical geometrical irregularity is analysed using static method and dynamic method in ETABS v 18.0.2 as per IS-1893-2016 (part 1). Analysis is performed for zone III. Also, response spectra analysis is done for torsion check in building. For dynamic analysis linear time history data of Bhuj, Mexico, and Kobe (Medium, Low & High Intensity) is used. Comparison of behaviour of irregular building is done with G+14 regular building in form of max storey shear, story displacement, story drift. From the analysis results, it is found that the mass irregularity has maximum storey shear, story displacement, story drift compares to regular and vertical geometrical irregular building. Also, sudden change in story shear is observed at set back level.

Keywords: RCC building, Equivalent Static Analysis, Response Spectrum Analysis, Linear Time History Analysis, Irregularity, Story Displacement, Inter Story Drift, Storey Shear.

1. Introduction

The earthquakes are one of the most devastating natural hazards that cause great loss of life and livelihood. The earthquake is a violent shaking of the Earth during which large elastic strain energy released spreads out in the form of seismic waves that travel through the body and along the surface of the Earth. Most earthquakes in the world occur along the boundaries of the tectonic plates and are called Inter-plate Earthquakes. A number of earthquakes also occur within the plate itself but away from the plate boundaries these are called Intra-plate Earthquakes. The losses in earthquake are due to building collapses or damages. Therefore, it is very important for structures to resist moderate and severe ground motions depending on its site location or importance of structure. During an earthquake, failure of structure starts at points of weakness. The weakness arises because of any discontinuity in mass, stiffness or geometry of structure. The structures having any such kind of discontinuity are termed as Irregular structures. One of the major reasons of failures of structures during earthquakes are vertical geometrical irregularities. Hence, changes in mass and stiffness render the dynamic characteristics of these buildings different from the regular building. In present study only vertical geometrical and mass irregularity are considered. As per IS-1893-2016 these two irregularities are classified as follow:

1) Setback or vertical geometrical irregularity: When the horizontal dimension of the lateral force resisting system in any storey is more or less than 125% of the storey below, the vertical geometrical irregularity is considered to exist. Shown in fig. 1.
2) Mass irregularity: When the seismic weight of any floor is more than or less than 150% of that of the floors below, mass irregularity shall be considered to exist. Shown in fig 2.

Literature Survey

Siva Naveen E. el al [1] studied response of nine story reinforced concrete building with plan, elevation and combination of both irregularities numerically. Total 54 configuration are made and response is compared. Out of various single irregularity analysed, stiffness irregularity has shown maximum seismic response. Among the cases having combinations of irregularities, the configuration with mass, stiffness and vertical geometric irregularity have shown maximum response.

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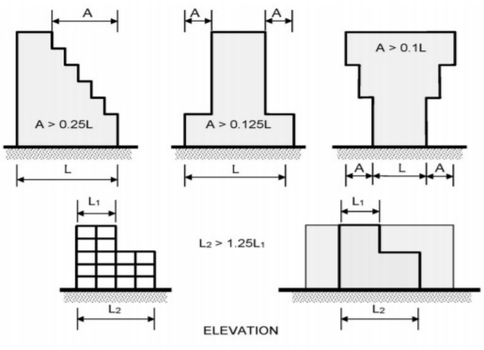


Figure 1 Vertical Geometrical Irregularity

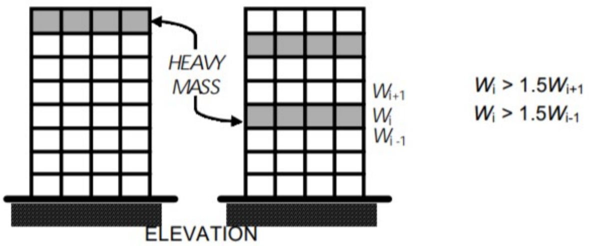


Figure 2 Mass Irregularity

Mahdi and Soltangharaie [2] studied seismic behavior of building with plan configurations of the structure contain reentrant corners of five, seven and ten story moment-resistant space frame using the static and dynamic analysis. Found result of these two analyses are quite wide but the linear dynamic analysis has shown slightly better results than nonlinear static analysis.

Jack P. Moehle et al [3] studied combined experimental and analytical study is made of the response to strong base motions of reinforced concrete structures having irregular vertical configurations. Measured responses of the structures are compared with responses computed by several conventional analysis methods and found that the inelastic static and dynamic methods were superior to the elastic methods in interpreting effects of the structural discontinuities.

The main objective of present work is (i) to study behaviour of irregular RC building having vertical geometrical and mass irregularity. (ii) to analyse G+14 storey building as per IS-1893-2016 (part-1) in CSI ETABS v 18.0.2 software. Static and dynamic analysis is carried out for zone III. (iii) to compare response like storey shear, storey displacement, storey drift between regular and vertical geometrical irregular building.

2. Seismic analysis method

Seismic analysis is an important tool in earthquake engineering which is used to understand the responses of building due to seismic excitations in a simpler manner. In the past, the buildings were designed just for gravity loads and seismic analysis is a recent development. It is a part of structural analysis and structural design where earthquake is prevalent. Different types of earthquake analysis methods are discussed below.

3.1 Equivalent static method (ESA)

All design against seismic loads must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular building (height less than 15m & zone II). It begins with an estimation of base shear, load and its distribution on each story calculated by using formulas given in the code.

3.2 Response spectrum method

The representation of maximum response of idealized single degree freedom system having certain period and damping, during earthquake ground motions. The maximum response is plotted against undamped natural period and for various damping value and can be expressed in term of maximum absolute acceleration, maximum relative velocity and maximum relative displacement.

3.3 Time history method (TH)

In this analysis dynamic response of the building will be calculated at each time intervals. This analysis can be carried out by taking recorded ground motion data from past earthquake database. Its solution is a direct function of the earthquake ground motion selected as an input parameter for a specific building. This analysis technique is usually limited to checking the suitability of assumptions made during the design of important structures rather than a method of assigning lateral forces themselves.

3. Problem formulation

Table 1. Building Model Nomenclature

Type of Irregularity	Model Name
Regular	REG
Vertical Irregularity - I	VI1
Vertical Irregularity - II	VI2
Mass	MI

Table 2. Geometrical and Material Data

Number of Storeys	15 (G+14)
Ground story height	3 m
Typical story height	3 m
Bay width	4 m
No of bay	7
Column size	700 mm X 900 mm up to 5^{th} storey 700 mm X 800 mm up to 10^{th} storey 700 mm X 700 mm up to 15^{th} storey
Beam size	550 mm X 450mm
Slab thickness	150 mm
Outer wall thickness	230 mm
Inner wall thickness	150 mm
Parapet wall height	1 m
Concrete grade	M 30
Steel grade	HYSD 500
Brick masonry density	20 kN/m^3

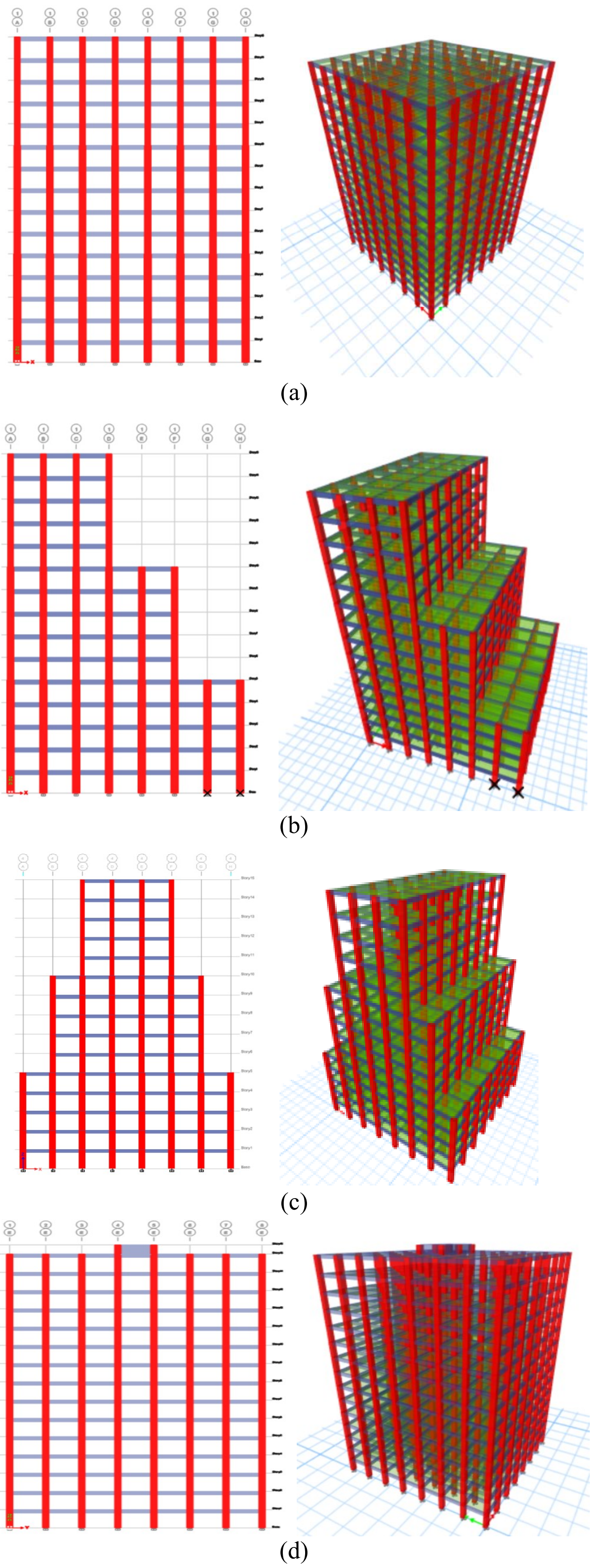


Figure 3 (a) REG (b) VI1 (c) VI2 (d) MI

Table 3. Loading Data

Deal load (DL)	2 kN/m^2 & 3 kN/m^2 on roof
DL of external wall	11.27 kN/m
DL of inner wall	7.35 kN/m
DL of parapet	4.6 kN/m
Live load	4 kN/m^2
Earthquake Zone	III
Damping Ratio	5%
Importance Factor	1.2
Type of Soil	Medium
Type of Structure	OMRF
Response Reduction Factor	3
Natural Time Period	$0.075h^{0.75} = 1.303$ sec

Table 4. Specific Data for Mass Irregularity Building Model

Modification for Mass Irregularity on 7th Storey	
Live Load	6 kN/m^2
Slab Thickness	200 mm
Dimension of Water Tank provided at the top of building	
Column Size	700 mm x 900 mm
Beam Size	450 mm x 1600 mm

Table 5. Time History Linear Model Analysis Data

Earthquake	PGA	Time (Sec)	Frequency (Hz)
Mexico	0.1g	180	0.0055
Bhuj	0.25g	133	0.0075
Kobe	0.8g	36	0.0277

Results and Discussions

5.1 Storey Shear

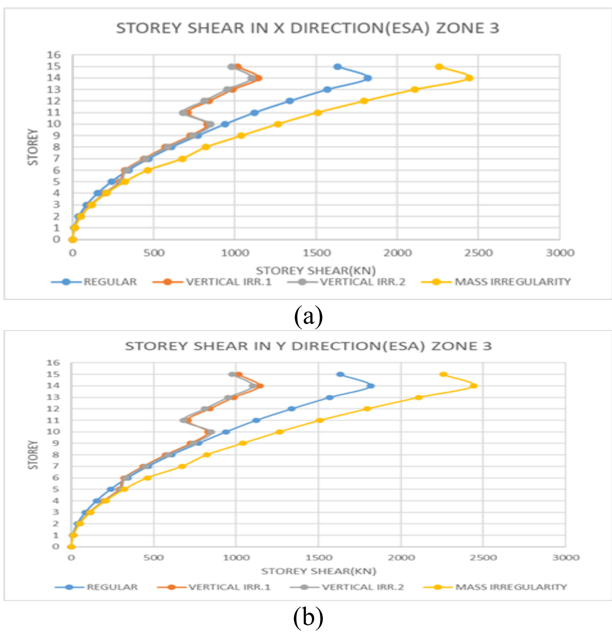
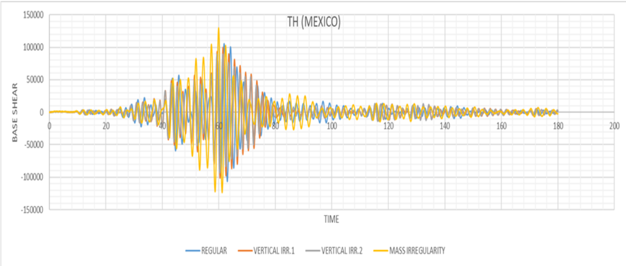


Figure 4 ESA Results for (a) EQX and (b) EQY Load Case



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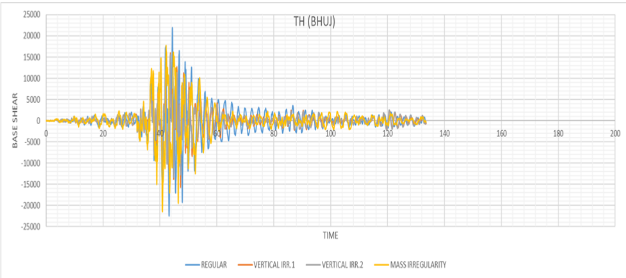

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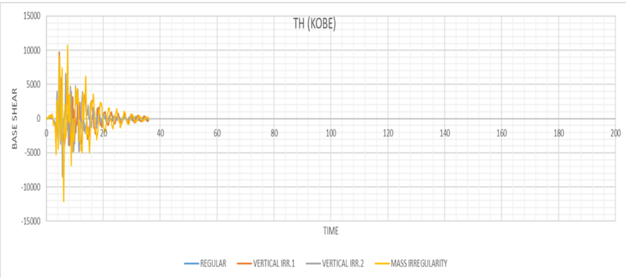

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Figure 5 Time History Results (a)Mexico, (b)Bhuj and (c)Kobe

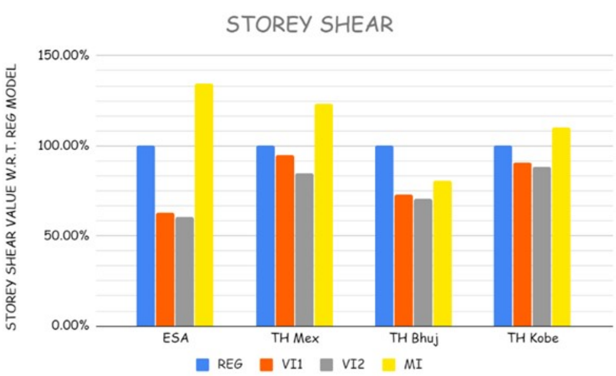
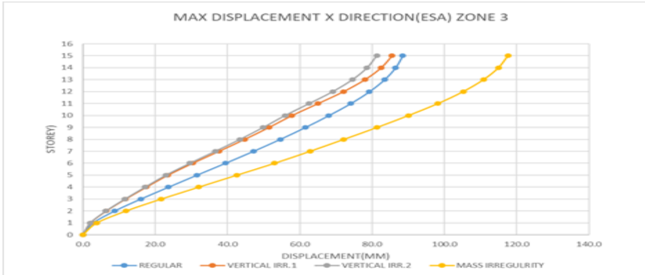


Figure 6 Storey Shear Comparisons with Analysis Methods

Maximum Storey Shear Force of Models VI1, VI2 and MI are 62.9%, 60.66% and 134.4% of Maximum value of Storey Shear Force of REG for Equivalent Static Analysis (ESA). In both types of analysis (ESA and THA), asymmetric building will have more Storey Shear than that of symmetric building.

5.2 Storey Displacement



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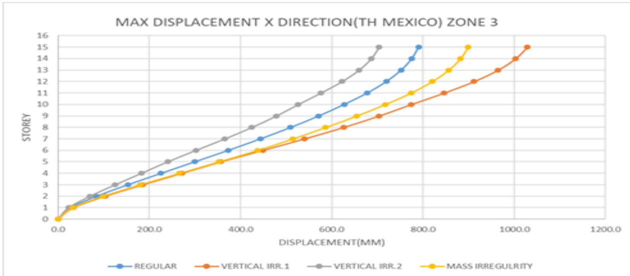

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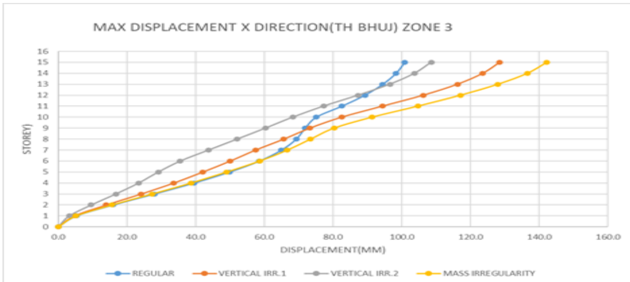

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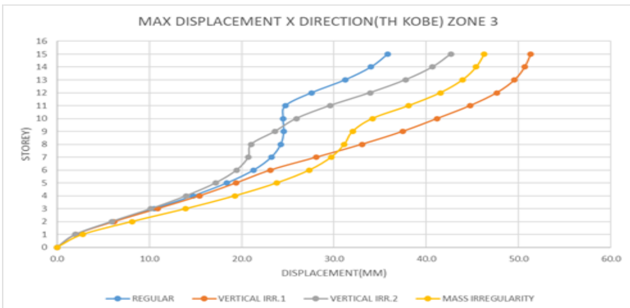

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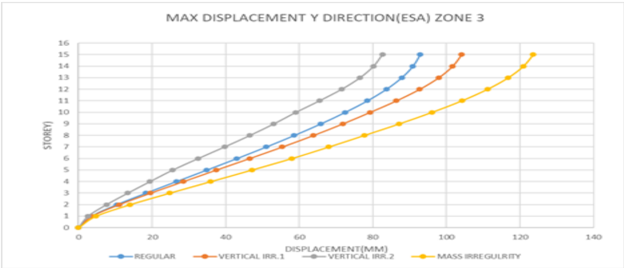
Figure 7 Storey Disp. Results for (a)ESA, (b)TH Mexico, (c)TH Bhuj and (d)TH Kobe – EQX Load Case



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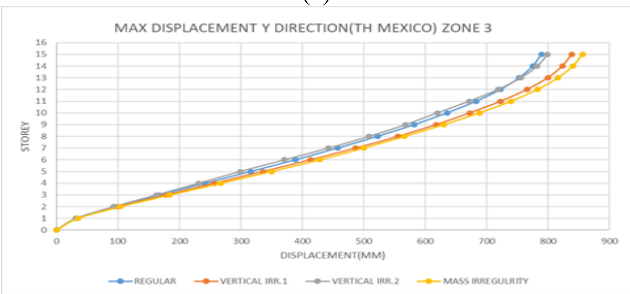

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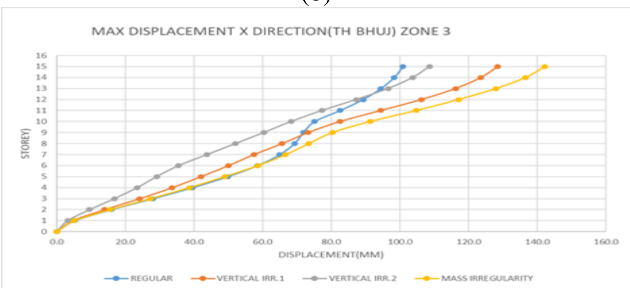

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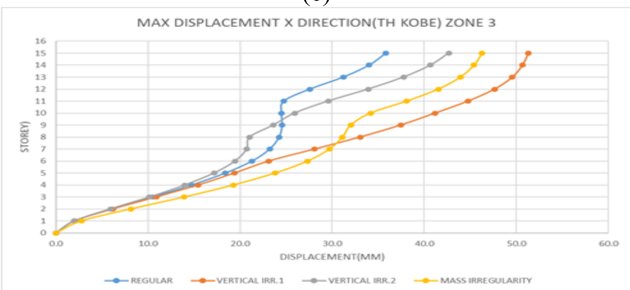

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Figure 8 Storey Disp. Results for (a)ESA, (b)TH Mexico, (c)TH Bhuj and (d)TH Kobe – EQY Load Case

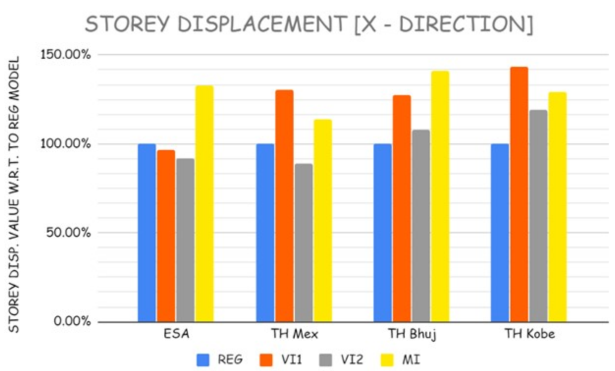


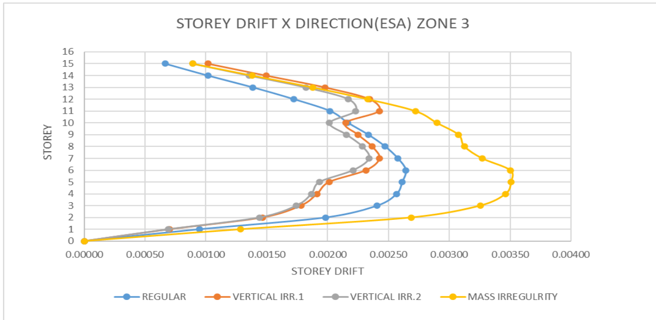
Figure 9 Storey Displacement Comparisons with Analysis Methods

Table 6. Storey Displacement Results for different Time History Analysis

Earthquake	Load Case	Maximum Storey Displacement with respect to REG Model (%)		
		VI1	VI2	MI
Mexico	EQX	130.15	88.96	113.69
	EQY	106.22	101.28	108.48
Bhuj	EQX	127.39	107.66	141
	EQY	119.5	107.73	139.62
Kobe	EQX	143.21	119.06	129.2
	EQY	87.75	101.98	120.1

In case of ESA, Maximum Storey Displacement for Load Case EQX of Models VI1, VI2 and MI are 96.6%, 91.9% and 132.9% of Maximum value of Story Displacement of REG. This signifies that for same seismic weight buildings, building which is having vertical geometrical Irregularity will have more displacement than regular building. Asymmetric building will have rotational characteristics along with translational displacement in direction of asymmetricity when seismic force is acting in the direction of asymmetricity. In Time History analysis, Maximum Storey Displacement depends upon PGA (peak ground acceleration) and time duration of earthquake along with distribution of load and storey stiffness.

5.3 Storey Drift



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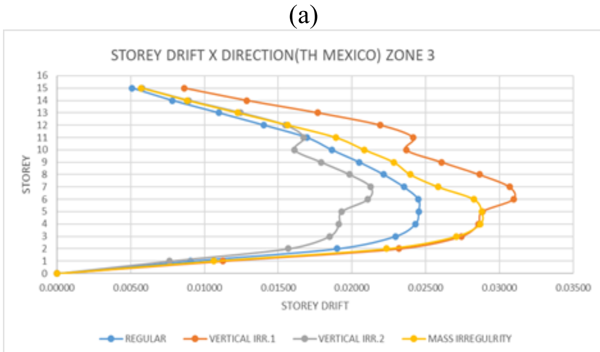

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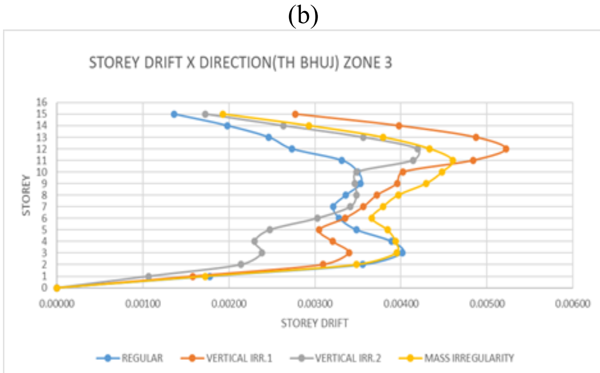

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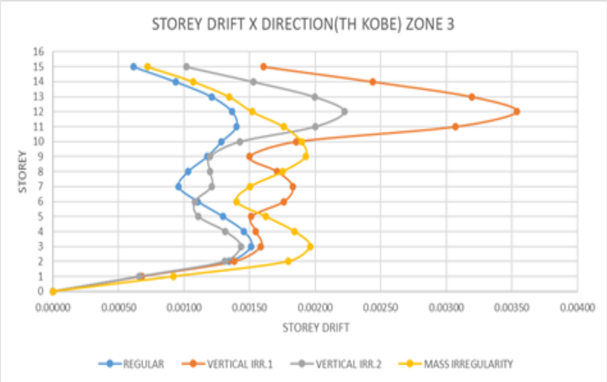

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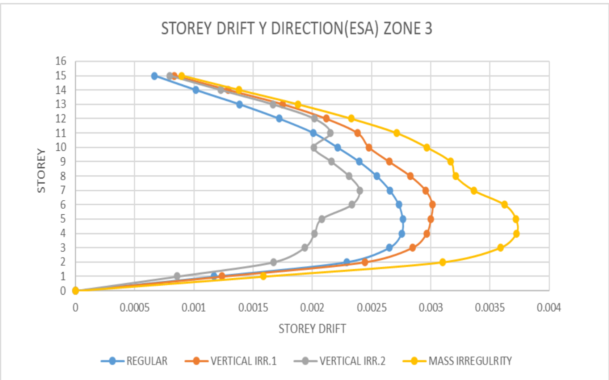
Figure 10 Storey Drift vs Storey Graphs for EQX Load Case



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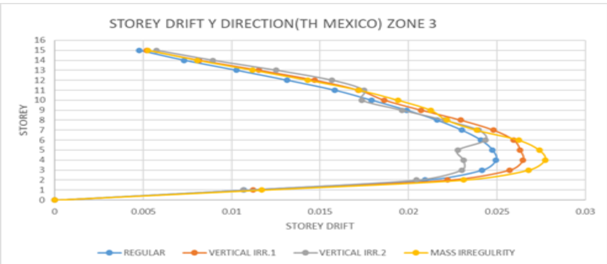

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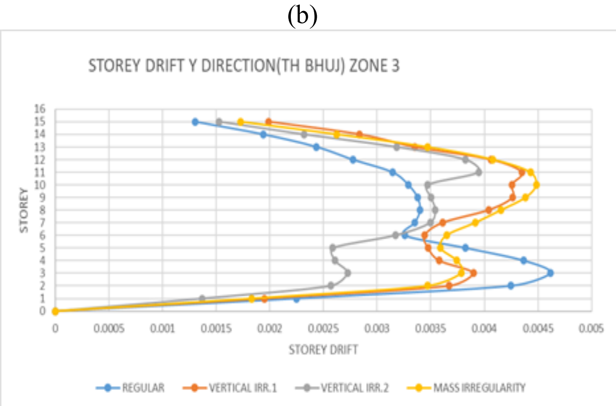

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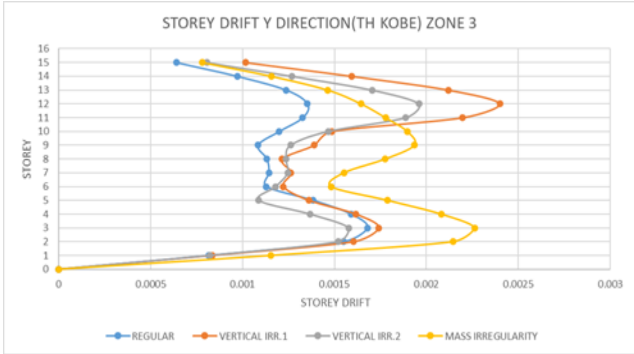

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Figure 11 Storey Drift vs Storey Graphs for EQY Load Case

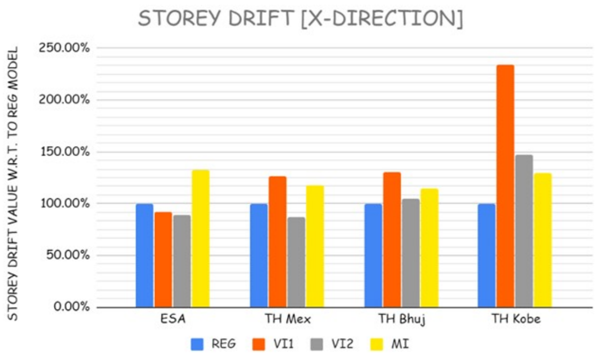

Figure 12 Storey Drift Comparisons with Analysis Methods

In case of ESA, Maximum value of Storey Drift in all Building Model is 0.0084 which is less than 0.012. So, Storey Drift of all Building Models are well within the limit specified by IS: 1893 (Part 1) – 2016. While in case of Time History Analysis for Mexico Earthquake, Storey Drift values are beyond 0.012 due to large time duration of earthquake. For Bhuj and Kobe earthquake all buildings are safe for storey drift criteria. From figure 10 and 11, it is observed that asymmetric building will have more Storey Drift than symmetric building.

Table 7. Storey Drift Results for different Type of Analysis

Analysis Type	Maximum Storey Drift with respect to REG Model (%)		
	VI1	VI2	MI
ESA	109	86.8	135
TH Mexico	126.22	86.65	117
TH Bhuj	130	104.5	114.65
TH Kobe	243.08	147.12	129.85

5.4 Torsional Check

Table 8. Torsional Check Results using Response Spectrum Method

Zone - 3 Modal Participating Mass Ratio [Sum-Rz]					
Mode	*REG*	*VI1*	*VI2*	*MI*	*Check*
1	0	0.208	0	0.0001	Ok
2	0	0.208	0	0.0001	
3	0.7854	0.6303	0.6376	0.7883	

Type	*M.P.M.R.*	*Mode*		
		1	*2*	*3*
REG	Sum - Ux	0	0.7775	0.7775
	Sum - Uy	0.7896	0.7896	0.7896
VI1	Sum - Ux	0	0.6827	0.6827
	Sum - Uy	0.559	0.559	0.7122
VI2	Sum - Ux	0	0.6877	0.6877
	Sum - Uy	0.7099	0.7099	0.7099
MI	Sum - Ux	0	0.7809	0.7809
	Sum - Uy	0.793	0.793	0.7931

It is observed that all models do not exhibit Torsional Irregularity.

4. Conclusion

The seismic response analysis has been evaluated for models of vertical geometrical and mass irregular buildings with the help of ETABS v 18.0.2 software. The seismic performance of regular, vertical geometrical irregular and mass irregular buildings is studied by plotting graph of storey displacement, storey drift, storey shear by equivalent static analysis and 3-time history analysis. The concluding remarks are:

a. As observed from data of Storey Shear, for same seismic weight, VI1, VI2 and MI model will exhibit 85.6%, 82.6% and 99.25% of Storey Shear of REG model. This shows that in ESA, Storey Shear depends upon distribution of load and storey stiffness. While in case of Time History Analysis, Storey Shear depends upon dynamic response of building which includes combination of distribution of load, storey stiffness, PGA and time duration of earthquake.

b. Buildings models with vertical geometrical irregularities (VI1 and VI2) have 25.03% to 31.43% more storey displacement and 21.08% to 52.25% more storey drift than that of regular building model (REG).

c. In THA, as time duration decreases from Mexico earthquake to Kobe earthquake, decrease of 88.57% to 95.47% is observed for storey displacement and storey drift results of models with respect to results of THA of Mexico earthquake. This shows that as time duration decreases, values of storey displacement and storey drift reduces. There are many other factors which are affecting the results of THA like PGA, frequency etc. To find out all these parameters that are affecting results of THA, further study is needed.

d. In both types of analysis (ESA and THA), symmetric and regular building performed better than that of asymmetric building and buildings with irregularities.

Disclosures

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

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