

Comparative study and analysis of Vertical Mass irregularities of RCC building with zone 3 and zone 5

Vinod Kumar Prajapati¹, R. K. Grover²

¹Department of Civil Engineering, Jabalpur Engineering College, Jabalpur (M.P.)

¹M.E. (Student), Department of Civil Engineering, Jabalpur Engineering College, Jabalpur (M.P.)

²Associate Professor, Department of Civil Engineering, Jabalpur Engineering College, Jabalpur (M.P.)

ABSTRACT

As the population continues to grow, the demand for high-rise buildings is escalating. To ensure their safety, it is crucial that these structures are designed to withstand earthquake forces. The combination of architectural innovation and economic limitations has led to an increase in vertical irregularities in buildings, especially in urban areas. Proposing effective solutions to minimize the potential damage during earthquakes is, therefore, essential. In this study (G+9) RCC buildings considered for this study are designed with vertical mass irregularities in 4th & 7th floors, and their seismic response is evaluated in both Zone 3 (moderate seismic activity) and Zone 5 (high seismic activity) according to IS 1893:2016 part-1. In this study design of structure for this RCC building is carried out by using ETABS. The results highlight the influence of vertical mass irregularities on the max storey displacement, max base shear and max storey drift under both static and dynamic loading conditions.

KEYWORDS: Multi storey building, Seismic Analysis, Vertical Mass Irregularity, Equivalent Static Method and Response Spectrum Analysis.

1. INTRODUCTION

Uneven distributions of mass, strength, and stiffness along the height of the building may be the cause of the irregularity in the building structures. One of the main causes of building breakdowns during earthquakes is irregularities such as mass, stiffness, plans, and torsion.

Structural analysis is essential for designing and evaluating the performance of Reinforced Concrete (RCC) buildings, particularly in earthquake-prone areas. Among the various factors affecting a structure's seismic response, mass irregularity plays a crucial role in stability and dynamic behaviour. It arises due to uneven mass distribution along the building's height, leading to changes in lateral displacement, inter-storey drift, and overall stability.

2. KINDS OF IRREGULARITIES

Plan Irregularities (Horizontal Irregularities)

These occur when the layout of the building is not uniform in shape, causing uneven force distribution.

- **Torsional Irregularity.**
- **Re-entrant Corner Irregularity.**
- **Diaphragm Discontinuity.**
- **Out-of-Plane Offset.**
- **Non-Parallel Lateral Force Systems.**

Vertical Irregularities

These occur when there are inconsistencies in strength, stiffness, or mass along the height of the structure.

- **Stiffness Irregularity (Soft Storey).**
- **Weak Storey Irregularity.**
- **Vertical Geometric Irregularity.**
- **In-Plane Discontinuity in Vertical Elements.**

- **Mass Irregularity:** When a building has a sudden increase in mass at a particular level—exceeding 150%–200% of the adjacent floors—it results in mass irregularity, making the structure more vulnerable to seismic forces.

3. LITERATURE REVIEW

[1] B Swapnil & Basavalingapp (2015)

They had carried out research on comparative analysis of the combined RC-masonry's seismic behaviour. In their study, irregularity is examined between G+9 multi-storey R.C.C. and Composite buildings and taken into account as mass. Using SAP 2000 software, equivalent static and response spectrum methods are employed to analyse the building in accordance with IS 1893 (Part 1):2002. According to the study, composite structures with uneven mass will perform better than R.C.C. structures.

[2] Vijayan Asha & Prakash Aswathy (2016)

With the aid of the ETABS programme, they had used a time history analysis method to examine the multi-storey RCC building while taking into account mass irregularity at various floor levels. The first step is to simulate a typical G+11-storey building across the building. The model consists of a G+11-storey building with irregular mass distribution on the first, fifth, and tenth floors by altering the dead load on the structure. By using time history analysis, compare these three models. Compare the structure's natural frequency, base shear, and tale drift as well. Which led them to the conclusion that constructions with no mass anomalies are better able to withstand seismic loads. If there are any large imperfections, they should be concentrated on the bottom, top, or any core portions of construction components.

[3] Mya Mya Aye & Narasimhara P. (2017)

In this study, twelve-storeyed vertical irregular RCC building is selected to analyze the behavior of the structural members due to change of mass and inter-storeyed height. This building is situated in seismic zone IV. It is composed of special moment-resisting frame system. The superstructure is designed with ETABS software. The structure is initially analyzed and designed with static analysis. It is found that the safety factor values are satisfied within allowable limits. And then, this structure is analyzed with dynamic (time history analysis) based on change of mass and inter-storeyed height. The results of column size in dynamic analysis are greater than that in static analysis.

[4] Hossain Md. Sabbir & Singh S.K. (2022)

In this study, two different irregulars Reinforced Cement Concrete (RCC) building plans of 25th storey buildings with the ground floor (G+25) and 9th storey buildings with the ground floor (G+9) were subjected to four different zones making a total of eight model structures to test their ability to withstand gravity and seismic loads. The design was response spectrum method (RSM) then subjected to an earthquake load in accordance with Indian Standard (IS) 1893.

[5] Hussain Syed Aatif & H. Gajendra (2023)

In this study Nonlinear Time History Analysis Of Mass And Geometric Regular And Irregular Multi Storey Moment Resisting RCC Frames. A G+10 stories building with mass and geometric irregularity has been modeled for seismic analysis. In this thesis design of structure for this building is carried out by using ETABS software. After being analyzed, structural response such as Storey displacement, Storey drift, and Base shear are compared.

All previous papers have deal with plan irregularity and seismic zones. But here I have worked here model vertical mass irregularity with the two seismic zones and shown difference between them which have not seen shown in any previous paper. This study aim to analysis the Equivalent Static and Response Spectrum Analysis RCC building according to IS-1893.

4. OBJECTIVES

- 1 To study the behaviour of RCC building (G+9) storey with vertical mass irregularities by using Equivalent Static Method and Response Spectrum Analysis.
- 2 To analyse the performance of RCC building under seismic forces such as base shear, storey drift, and storey displacement.
- 3 Max storey drift in a storey to compare axial force max bending moment and max shear force.
- 4 To compare the structure behaviour of building with the seismic zone 3 and zone 5 vertical mass irregularities of building.

5. METHODOLOGY

- Analyse of G+9 Storey in medium soil ground, A multi storey RCC Building with help of Equivalent Static method and Response spectrum method in ETABS Software. For seismic zone 3 and zone 5.
- Comparison of mass irregular Four model i.e. (zone 3 and zone 5) Taking parameters like displacement, shear force, Bending moment, Storey Drift.

Model Properties Configuration

The building is taken G+9 RCC building with vertical mass irregularity due to heavier machine equipment or due to heavier impose load acting on floor is provided. There is two different zone that is zone 3 and zone 5.

Model 1: A RCC mass regular building zone 3.

Model 1: A RCC mass irregular building at 4th & 7th storey zone 3.

Model 1: A RCC mass regular building zone 5.

Model 1: A RCC mass irregular building at 4th & 7th storey zone 3.

- Impose load Loading due to heavy loading - 7kn/m²
- Weight of 4th & 7th - 7 kn/m²
- Weight of remaining storey- 1.8 kn/m²
- Weight of 7th storey = 2.5* Weight of adjacent stories (Mass Irregularity - $W_i > 1.5W_{i+1}$) Hence, as per IS 1893 this modelled is mass irregular structure.

Table 1: Model Specifications

S No	Description	Design Data
1	Plan	16mx20m
2	Number of Storey	G+9
3	Floor to Floor Height	3.5m
4	Column Size	450x450mm and 450x600mm
5	Beam Size	300x450mm
6	Thickness of Slabs	150mm
7	Thickness of External wall	200mm
8	Thickness of Internal wall	100mm
9	Grade of Concrete	M30
10	Grade of Steel	Fe500, Fe415
11	Density of concrete	25Kn/m ³
12	Density of Brick Work	20Kn/m ³
14	Floor finish load	1.8Kn/m ²
15	Floor finish load and imposed load at mass irregular storey	7Kn/m ²
16	Live load on all floor	2Kn/m ²
17	Roof live load	1.5Kn/m ²
18	Seismic zones	III and V
19	Soil type	Medium soil
20	Earthquake loads	As per IS 1893:2016 (Part1)
21	Damping ratio	5%
22	Response reduction factor	5
23	Importance Factor	1.2

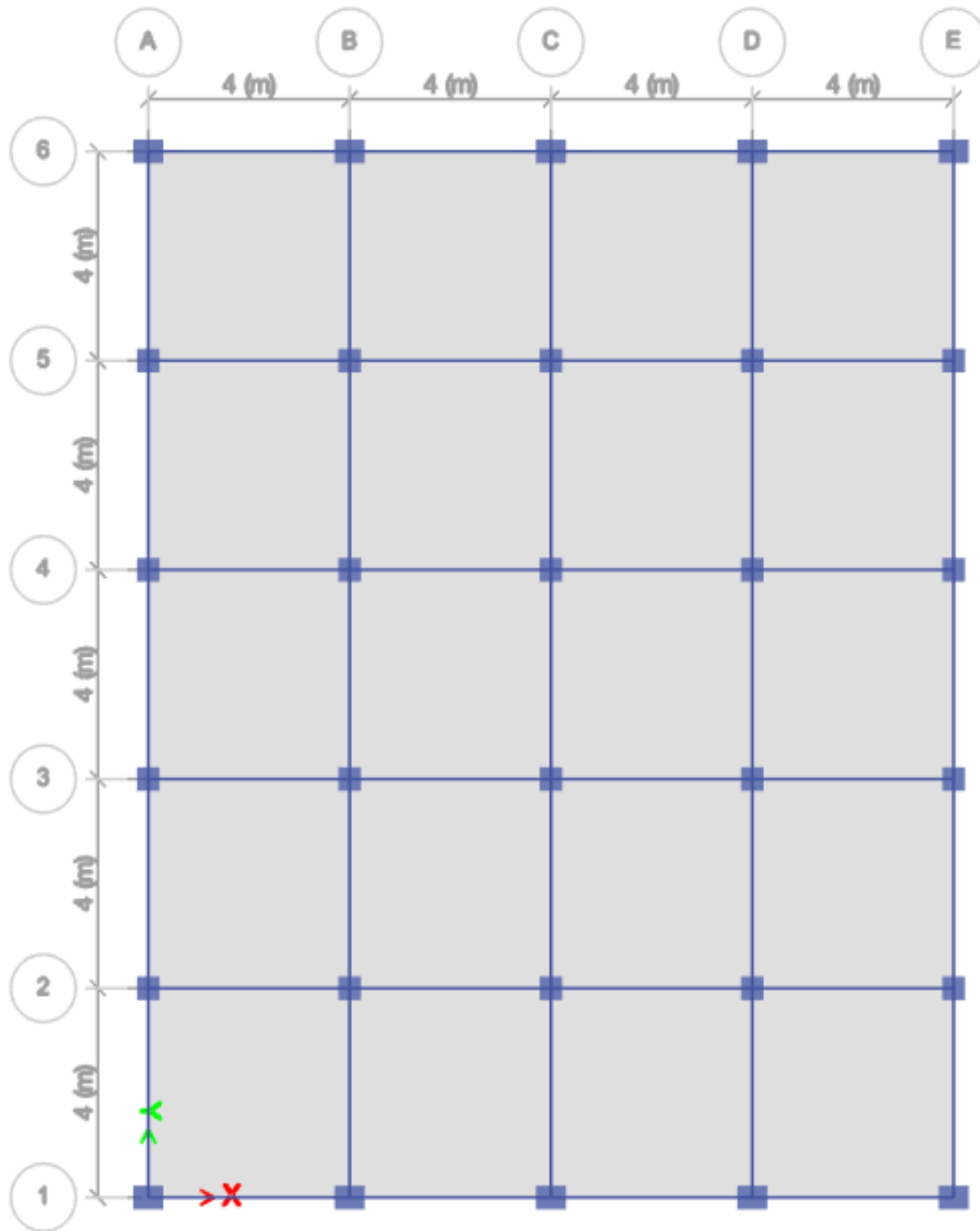


Fig.1. Plan of model

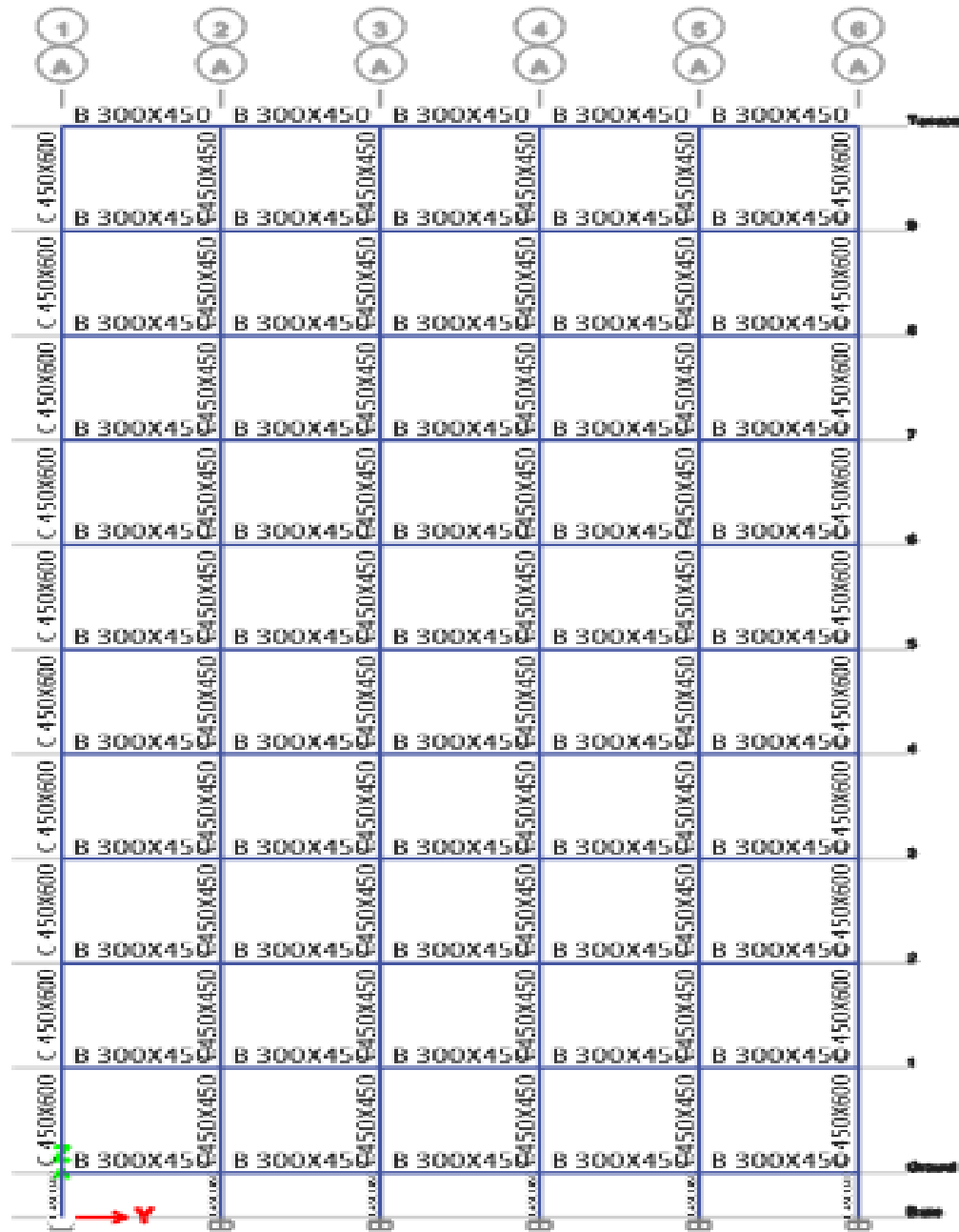


Fig.2. Vertical section of model

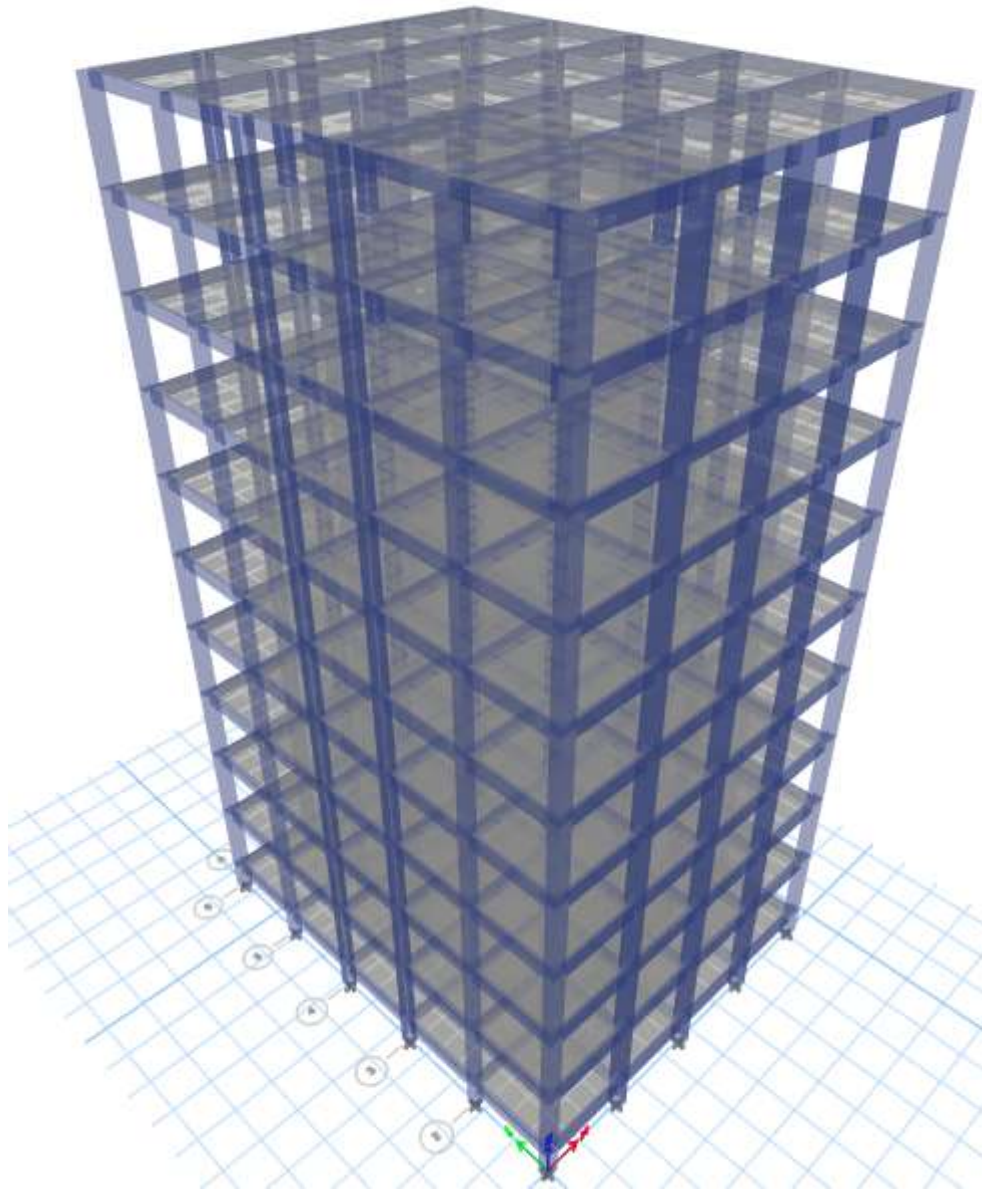


Fig. 3. 3D view of models

6. RESULTS & DISCUSSION

In this research all the various parameters like Base shear, Storey displacement, Storey drift and member forces are obtained by ETABS using referred IS 1893(part-1):2016, IS 456:2000 for using criteria and limitations.

Base shear

The base shear resisting lateral forces caused by earthquake. The base shear value represents the cumulative lateral forces acting from the top storey to bottom of the building. The structure is analyzed using equipment static method and response spectrum method. In this analysis the base shear is highest at lower floor and lowest at the upper floor.

- The Comparison of Base shear of RCC building with mass regular and mass irregularity with different zone 3 and zone 5. It seems that the base shear of the RCC building with mass irregularity is increase in zone with the highest value observed in zone 5.
- Base shear is minimum for model 1 zone 3 along X direction is 1601.1433kn and along Y direction is 1790.1414kn.
- Base shear is maximum for model 4 zone 5 along X direction is 3850.6569kn and along Y direction is 4297.8866kn.
- When compared base shear in zone 3 and zone 5 is increasing 125% along X direction and along Y direction. Hence more resistance and stiff of high rise structure in Y direction.
- Base shear increase by seismic zone increase and also increase by mass growth.

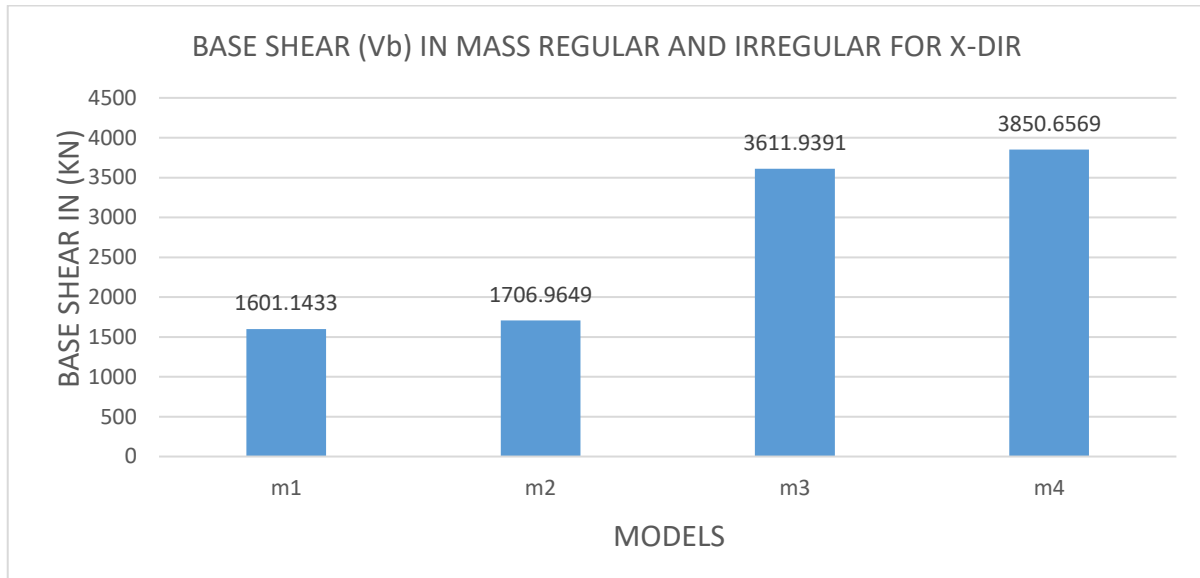


Fig.4. Base shear in X direction

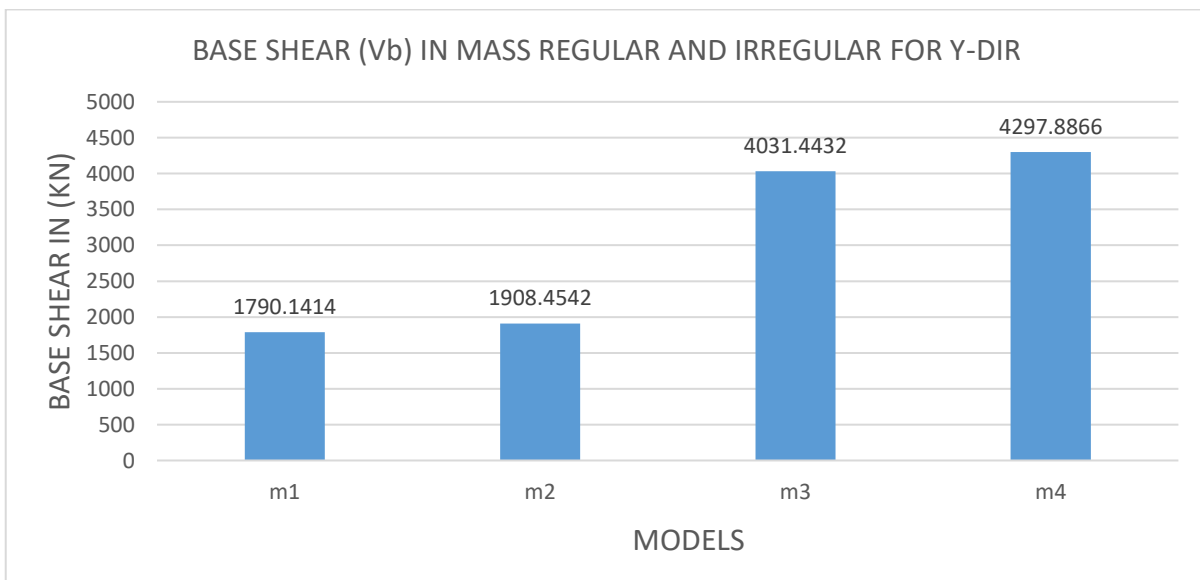


Fig.5. Base shear in Y direction

Maximum storey displacement

The storey displacement is average of all node displacement at the floor level due to lateral force acting on the structure in the direction. Average storey displacement is increasing order from bottom floor level to top floor level for seismic zone 3 and zone 5 for maximum load combination.

- The comparison of storey displacement of RCC building with mass regular and mass irregularity with different zone 3 and zone 5. It seems that the storey displacement of the RCC building with mass irregularity is increase in zone with the highest value observed in zone 5.
- The minimum storey displacement obtained from model 1 zone 3 is 43.327 mm along X direction and zone 3 is 49.516 mm along Y direction.
- The maximum storey displacement obtained from model 4 zone 5 is 103.023 mm along X direction and zone 5 is 117.561 mm along Y direction.
- Overall storey displacement of G+9 RCC building is 117.561 mm.
- Storey displacement increase by seismic zone increase and also increase by mass growth.

Note – The permissible value of storey displacement has been taken as per IS 456:2000

$$h/500 = (36.5 \times 1000) / 500 = 73 \text{ mm}$$

(All values zone 3 are within the permissible limits)

Table 2: Storey displacement in X direction

Storey	Height	Zone 3		Zone 5		% Increment	
		M1	M2	M3	M4		
Base	0	0	0	0	0	0	0
GROUND	1.5	0.589	0.627	1.328	1.415	125.47%	125.68%
1	5	4.98	5.309	11.235	11.976	125.60%	125.58%
2	8.5	10.35	11.033	23.347	24.89	125.57%	125.60%
3	12	15.852	16.902	35.76	38.128	125.59%	125.58%
4	15.5	21.274	22.678	47.991	51.158	125.59%	125.58%
5	19	26.475	28.179	59.724	63.569	125.59%	125.59%
6	22.5	31.304	33.287	70.617	75.09	125.58%	125.58%
7	26	35.588	37.801	80.281	85.272	125.58%	125.58%
8	29.5	39.132	41.421	88.276	93.44	125.59%	125.59%
9	33	41.737	44.056	94.153	99.385	125.59%	125.59%
TERRACE	36.5	43.327	45.669	97.74	103.023	125.59%	125.59%

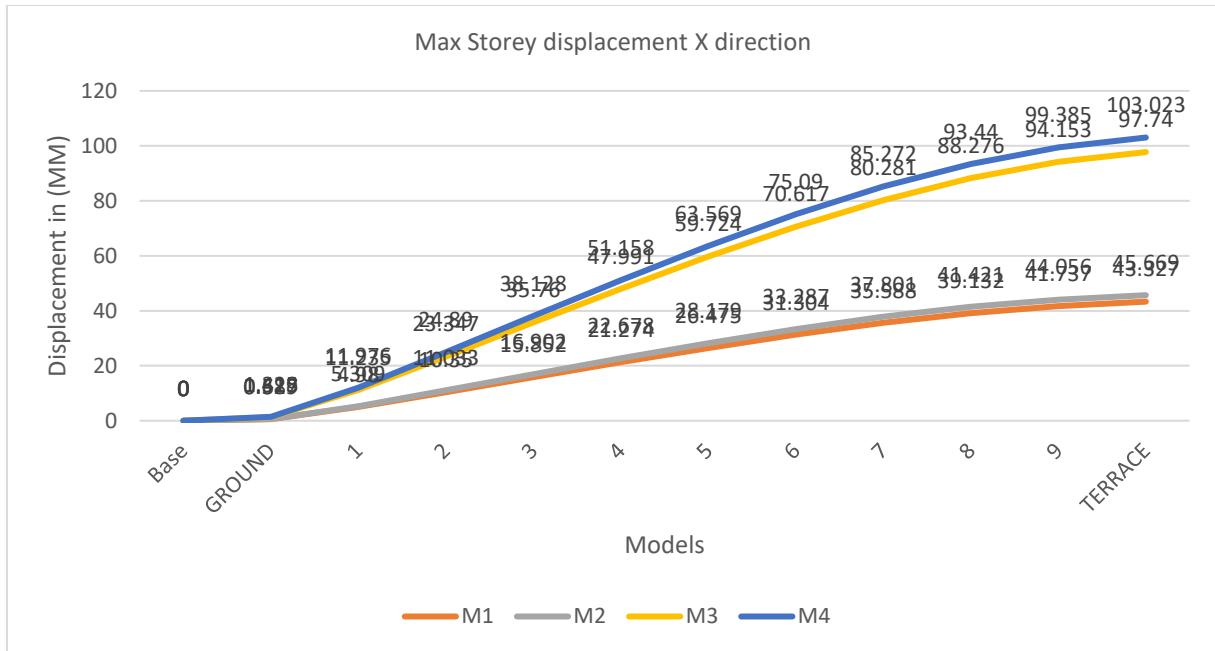


Fig.6. Storey displacement in X direction

Table 3: Storey displacement in Y direction

Storey	Height	Zone 3		Zone 5		% Increment	
		M1	M2	M3	M4		
Base	0	0	0	0	0	0	0
GROUND	1.5	0.701	0.748	1.579	1.684	125.25%	125.13%
1	5	6.022	6.42	13.562	14.458	125.21%	125.20%
2	8.5	12.288	13.101	27.672	29.503	125.20%	125.20%
3	12	18.621	19.858	41.936	44.721	125.21%	125.20%
4	15.5	24.826	26.472	55.909	59.615	125.20%	125.20%
5	19	30.752	32.739	69.254	73.729	125.20%	125.20%
6	22.5	36.231	38.536	81.593	86.785	125.20%	125.21%
7	26	41.066	43.638	92.481	98.274	125.20%	125.20%
8	29.5	45.031	47.676	101.41	107.368	125.20%	125.20%
9	33	47.886	50.555	107.84	113.85	125.20%	125.20%
TERRACE	36.5	49.516	52.203	111.511	117.561	125.20%	125.20%

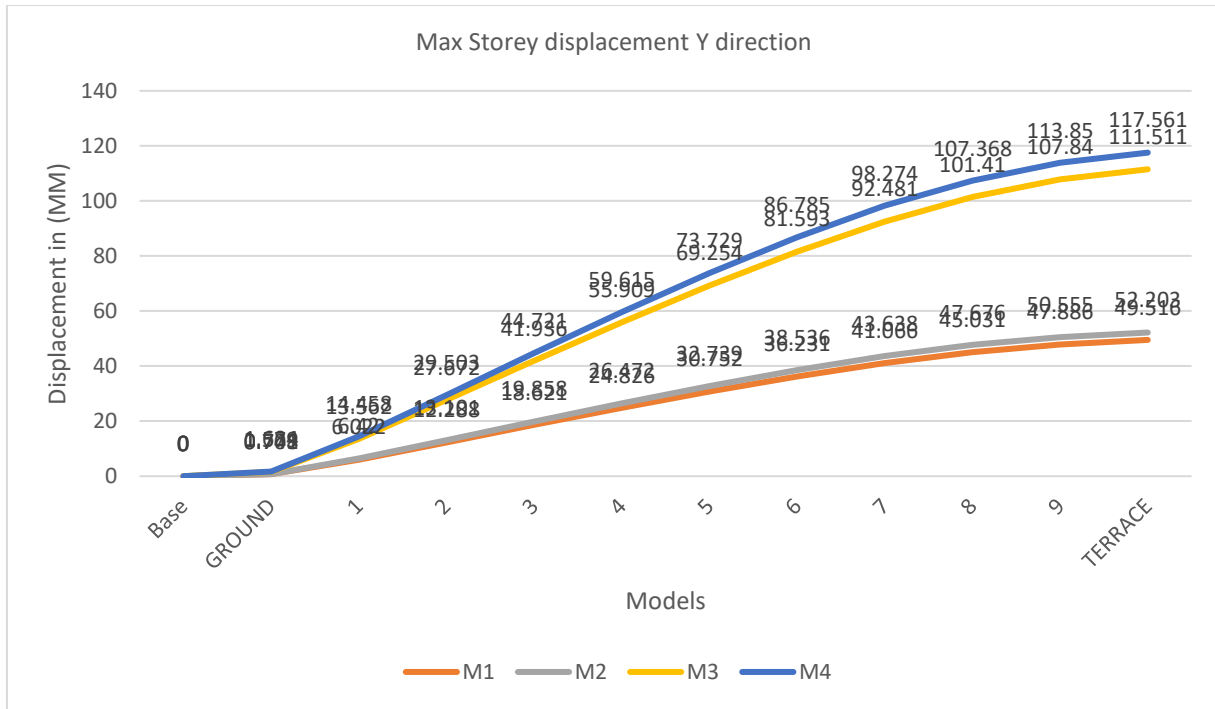


Fig.7. Storey displacement in Y direction

Maximum storey drift

The storey drift is the lateral displacement of a floor relative to the floor below. It storey drift is different from bottom floor level to top floor level for seismic zone 3 and zone 5 from maximum load combination.

- The comparison of storey drifts of RCC building with mass regular and mass irregularity with different zone 3 and zone 5. It seems that the storey drift of the RCC building with mass irregularity is increase in zone with the highest value observed in zone 5.
- The maximum storey drift is seismic model 2 zone 3 and model 4 zone 5 is 0.001677 m and 0.003782 m along X direction
- The maximum storey drift is seismic model 2 zone 3 and model 4 zone 5 is 0.001931 m and 0.004348 m along Y direction
- The maximum storey drift is all storey in X direction is 0.003782 m.
- The maximum storey drift is all storey in Y direction is 0.004348 m.
- Storey drift increase by seismic zone increase and also increase by mass growth.

Note - The permissible value of storey drift has been taken as per IS 1893:2016 (Part1)

$0.004h = 0.004 \times 3.5 = 0.014 \text{ m}$

(All values zone 3 are within the permissible limits)

Table 4: Storey drift in X direction

Storey	Height	Zone 3		Zone 5	
		M1	M2	M3	M4
Base	0	0	0	0	0
GROUND	1.5	0.000392	0.000418	0.000885	0.000943
1	5	0.001255	0.001338	0.002831	0.003017
2	8.5	0.001534	0.001636	0.003461	0.00369

3	12	0.001572	0.001677	0.003546	0.003782
4	15.5	0.001549	0.00165	0.003495	0.003723
5	19	0.001486	0.001572	0.003352	0.003546
6	22.5	0.00138	0.001459	0.003112	0.003292
7	26	0.001224	0.00129	0.002761	0.002909
8	29.5	0.001013	0.001034	0.002284	0.002334
9	33	0.000744	0.000753	0.001679	0.001699
TERRACE	36.5	0.000454	0.000461	0.001025	0.001039

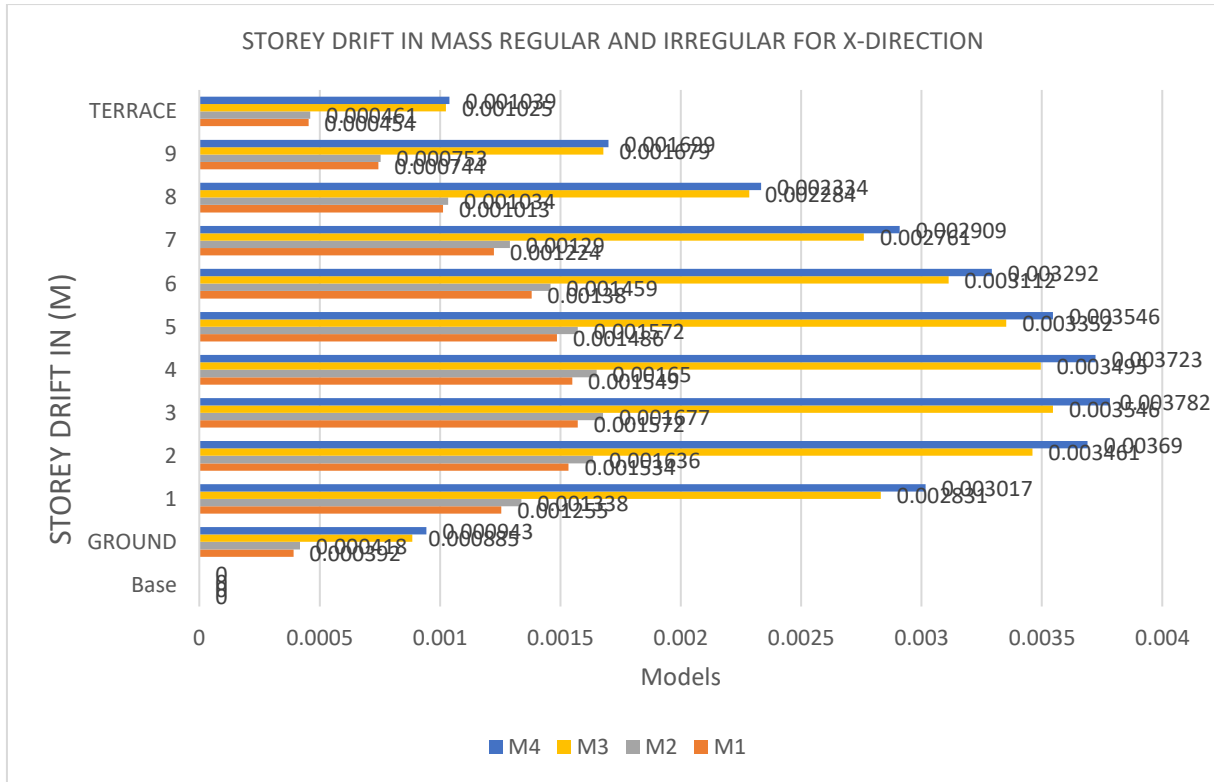


Fig.8. Storey drift in X direction

Table 5: Storey drift in Y direction

Storey	Height	Zone 3		Zone 5	
		M1	M2	M3	M4
Base	0	0	0	0	0
GROUND	1.5	0.000468	0.000498	0.001053	0.001122
1	5	0.00152	0.001621	0.003424	0.00365
2	8.5	0.00179	0.001909	0.004031	0.004299
3	12	0.00181	0.001931	0.004075	0.004348
4	15.5	0.001773	0.00189	0.003992	0.004255
5	19	0.001693	0.001791	0.003813	0.004033

6	22.5	0.001565	0.001656	0.003525	0.00373
7	26	0.001381	0.001458	0.003111	0.003283
8	29.5	0.001133	0.001154	0.002551	0.002598
9	33	0.000816	0.000822	0.001837	0.001852
TERRACE	36.5	0.000466	0.000471	0.001049	0.00106

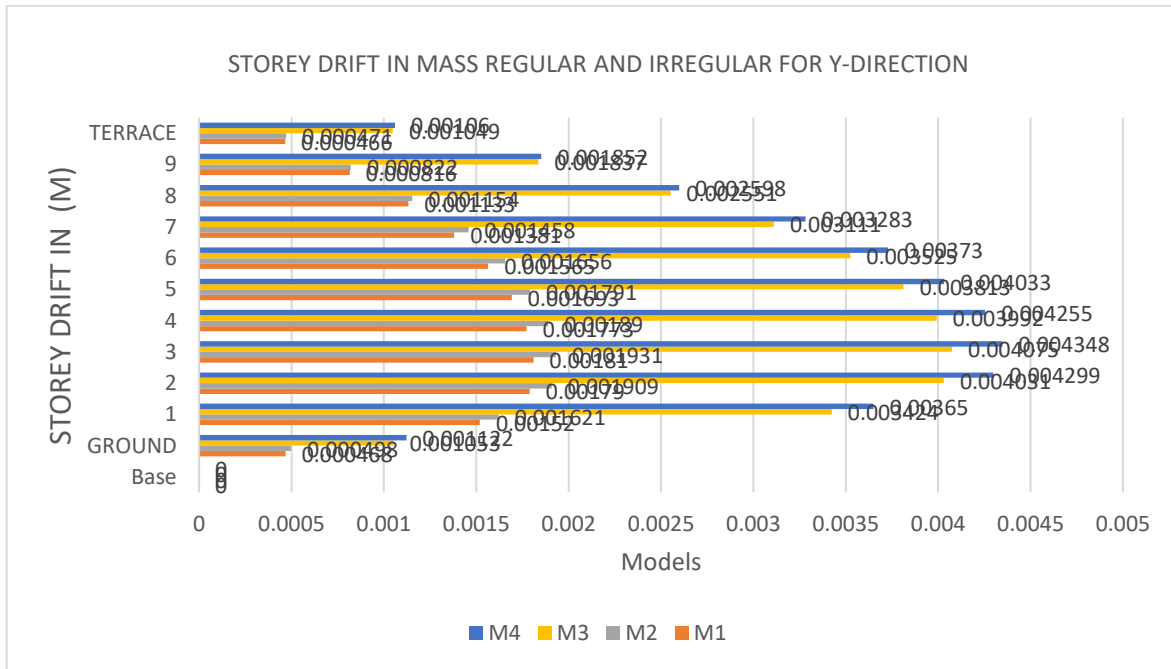


Fig.8. Storey displacement in Y direction

Comparison of Member Forces for normal mass at 8th storey and Change of Mass at 7th storey

Comparison of member forces for beam

- Maximum hogging moment in normal mass of 8th storey model 1 zone 3 is 82.1808 and model 4 zone 5 is 184.9276.
- Maximum hogging moment in mass irregular of 7th storey model 2 zone 3 is 80.8732 and model 4 zone 5 is 214.765.
- Maximum sagging moment in normal mass of 8th storey model 2 zone 3 is 161.5297 and model 4 zone 5 is 281.6764.
- Maximum sagging moment in mass irregular of 7th storey model 2 zone 3 is 161.5297 and model 4 zone 5 is 281.6764.
- Maximum shear force in normal mass of 8th storey model 2 zone 3 is 161.5297 and model 4 zone 5 is 281.6764.
- Maximum shear force in mass irregular of 7th storey model 2 zone 3 is 168.1104 and zone 5 is 283.115.

Table 6: 8th Storey beam forces

		ZONE 3				ZONE 5				% INCREMENT			
		M1		M2		M3		M4		HOGG		SAGG	
Story	Beams	Max HOGG	Max SAGG	Max HOGG	Max SAGG	Max HOGG	Max SAGG	Max HOGG	Max SAGG	%	%	%	%
8	B49	82.2	148.8	80.9	161.5	182.6	264.7	184.9	281.7	122.2%	128.7%	77.9%	74.4%
8	B27	64.1	103.2	65.1	104.5	160.8	200.7	163.1	203.2	151.1%	150.4%	94.4%	94.4%
8	B46	64.1	103.2	65.1	104.5	160.8	200.7	163.1	203.2	151.1%	150.4%	94.4%	94.4%
8	B48	64.1	105.6	65.1	108.7	160.8	200.7	163.1	203.2	151.1%	150.4%	90.0%	86.9%
8	B5	60.8	124.6	65.1	129.8	132.8	208.6	136.1	212.6	118.4%	109.0%	67.5%	63.9%

Table 7: 7th Storey beam forces

		ZONE 3				ZONE 5				% INCREMENT			
		M1		M2		M3		M4		HOGG		SAGG	
Story	Beams	Max HOGG	Max SAGG	Max HOGG	Max SAGG	Max HOGG	Max SAGG	Max HOGG	Max SAGG	%	%	%	%
7	B26	85.9	124.9	85.7	136.2	210.1	249.8	214.8	265.9	144.7%	150.5%	99.9%	95.2%
7	B28	85.9	128.6	85.7	140.2	210.1	249.8	214.8	265.9	144.7%	150.5%	94.2%	89.7%
7	B46	85.9	124.9	85.7	136.2	210.1	249.8	214.8	265.9	144.7%	150.5%	99.9%	95.2%
7	B47	85.9	124.9	85.7	136.2	210.1	249.8	214.8	265.9	144.7%	150.5%	99.9%	95.2%
7	B4	82.2	148.8	80.9	161.5	182.6	264.7	184.9	281.7	122.2%	128.7%	77.9%	74.4%

Table 8: 8th Storey beam forces

		ZONE 3				ZONE 5				% INCREMENT			
		M1		M2		M3		M4		MAX SHEAR		MIN SHEAR	
Story	Beams	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	%	%	%	%
8	B49	-148.8	-148.8	-161.5	-161.5	-264.7	-264.7	-281.7	-281.7	77.9%	74.4%	77.9%	74.4%
8	B5	-124.6	-124.6	-129.8	-129.8	-208.6	-208.6	-212.6	-212.6	67.5%	63.9%	67.5%	63.9%
8	B20	-124.6	-124.6	-128.7	-128.7	-208.6	-208.6	-212.6	-212.6	67.5%	65.2%	67.5%	65.2%
8	B24	-124.6	-124.6	-128.7	-128.7	-208.6	-208.6	-212.6	-212.6	67.5%	65.2%	67.5%	65.2%
8	B10	-124.1	-124.1	-131.0	-131.0	-204.1	-204.1	-210.9	-210.9	64.4%	60.9%	64.4%	60.9%

Table 9: 7th Storey beam forces

		ZONE 3				ZONE 5				% INCREMENT			
		M1		M2		M3		M4		MAX SHEAR		MIN SHEAR	
Story	Beams	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	MAX SHEAR	MIN SHEAR	%	%	%	%
7	B4	-148.8	-148.8	-161.5	-161.5	-264.7	-264.7	-281.7	-281.7	77.9%	74.4%	77.9%	74.4%
7	B21	-148.8	-148.8	-161.5	-161.5	-264.7	-264.7	-281.7	-281.7	77.9%	74.4%	77.9%	74.4%
7	B24	-148.8	-148.8	-161.5	-161.5	-264.7	-264.7	-281.7	-281.7	77.9%	74.4%	77.9%	74.4%
7	B10	-147.6	-147.6	-168.1	-168.1	-258.6	-258.6	-283.1	-283.1	75.2%	68.4%	75.2%	68.4%
7	B14	-147.6	-147.6	-168.1	-168.1	-258.6	-258.6	-283.1	-283.1	75.2%	68.4%	75.2%	68.4%

Comparison of member forces for column

- Maximum axial load in normal mass of 8th storey zone 3 is 433.7726 and zone 5 is 435.5179.
- Maximum sagging moment in mass irregular of 7th storey zone 3 is 977.7882 and zone 5 is 667.7798.
- Maximum shear force in normal mass of 8th storey zone 3 is 163.9587 and zone 5 is 363.5929.
- Maximum shear force in mass irregular of 7th storey zone 3 is 202.0003 and zone 5 is 409.9621.

Table 10: 8th Storey column axial forces

		ZONE 3		ZONE 5		INCREMENT	
Story	Label	M1	M2	M3	M4		
		MAX AXIAL	MAX AXIAL	MAX AXIAL	MAX AXIAL		
8	C10	433.7726	432.9469	435.5179	434.811	0.40%	0.43%
8	C11	433.7726	432.9469	435.5179	434.811	0.40%	0.43%
8	C6	419.2148	412.8103	416.4171	409.8037	-0.67%	-0.73%
8	C7	419.2148	412.8103	416.4171	409.8037	-0.67%	-0.73%
8	C14	419.2148	412.8103	416.4171	409.8037	-0.67%	-0.73%

Table 11: 7th Storey column axial forces

		ZONE 3		ZONE 5		INCREMENT	
Story	Label	M1	M2	M3	M4		
		MAX AXIAL	MAX AXIAL	MAX AXIAL	MAX AXIAL		
7	C23	903.233	977.7882	541.9398	586.6729	-40.00%	-40.00%
7	C28	903.233	977.7882	541.9398	586.6729	-40.00%	-40.00%
7	C10	593.0864	665.8162	594.9197	667.7798	0.31%	0.29%
7	C11	593.0864	665.8162	594.9197	667.7798	0.31%	0.29%
7	C6	573.7294	642.9359	570.6863	572.1858	-0.53%	11.00%

Table 12: 8th Storey column shear forces

Story	Label	ZONE 3		ZONE 5		INCREMENT	
		M1	M2	M3	M4		
		MAX SHEAR	MAX SHEAR	MAX SHEAR	MAX SHEAR		
8	C24	163.9587	102.769	-330.7523	-349.7522	-494.711	-452.521
8	C29	163.9587	102.769	-330.7523	-349.7522	-494.711	-452.521
8	C23	163.828	103.0272	-346.4671	-363.5929	-510.295	-466.62
8	C28	163.828	-103.0272	346.4671	363.5929	182.6391	466.6201
8	C25	27.7722	70.0695	-73.9523	-67.0091	-101.725	-137.079

Table 13: 7th Storey column shear forces

Story	Label	ZONE 3		ZONE 5		INCREMENT	
		M1	M2	M3	M4		
		MAX SHEAR	MAX SHEAR	MAX SHEAR	MAX SHEAR		
7	C24	188.4267	202.0003	-378.1806	-397.9315	-566.607	-599.932
7	C29	188.4267	202.0003	-378.1806	-397.9315	-566.607	-599.932
7	C23	135.0297	142.9154	391.3408	-409.9621	256.3111	-552.878
7	C21	34.211	35.2059	-38.4555	-42.1364	-72.6665	-77.3423
7	C26	34.211	35.2059	-38.4555	-42.1364	-72.6665	-77.3423

CONCLUSIONS

After analyzing all the results, the following conclusion can be drawn.

- The base shear of mass irregular building is zone 5 is 125% more than zone 3 due to variation in loading condition.
- Base shear increases by seismic zone increase and also increase by mass growth.
- The storey displacement of mass irregular building is zone 5 more displacement than zone 3.
- Storey displacement increases by seismic zone increase and also increase by mass growth.
- The storey drift of Mass irregular building is zone 5 is more drift than zone 3.
- Storey drift increases by seismic zone increase and also increase by mass growth.
- The storey forces of mass irregular storey is more than normal storey.
- When design a building special care should be taken to design the building in higher zone.

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