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Seismic Design of High-Rise Buildings with Structural Irregularities

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ABSTRACT: An earthquake is the shaking of the earth's surface caused by waves that emerge from a source of disturbance in the ground as a result of energy released from the earth's crust. During an earthquake, failure begins at the weakest place. The discontinuity of the structure's mass, stiffness, and geometry may cause this weakness. Vertical irregularities are one of the many significant reasons of earthquake structural failure, and discontinuous structures are known as irregular structures. Vertical irregular constructions have an uneven distribution of weight, strength, and stiffness over the building height. When these structures are to be built in seismically active locations, the research and layout become more difficult. Using ETABs G+10 storey reinforced concrete building located in zones III and IV with mass and stiffness irregularities are studied by response spectrum method and various seismic parameter such as storey displacement, storey drift, Base shear and time period is studied. Based on the analysis and results obtained, it is observed that Seismic design of high-rise buildings with structural irregularities is effective and efficient.

KEYWORDS: Mass irregularities, stiffness irregularities, response spectrum method, ETABs.

I. INTRODUCTION

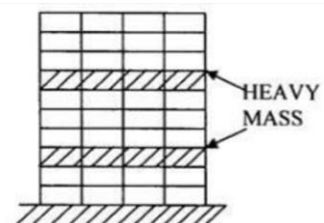
Earthquake forces are sporadic forces that may or may not affect the structure, but when they do, they have a significant structural influence and can result in structural collapse. As a result, in the event of a multi-story structure, the seismic structure's reaction becomes required. According to the Indian seismic code IS 1893-2002, there are five seismic zones, each with a varied potential for shaking strength. During an earthquake, failure begins at the weakest place. The discontinuity of the structure's mass, stiffness, and geometry may cause this weakness. Vertical irregularities are one of the many significant reasons of earthquake structural failure, and discontinuous structures are known as irregular structures. Vertical irregular constructions have an uneven distribution of weight, strength, and stiffness over the building height. The irregular structure is explicitly defined in the Indian seismic code version of 2002. When these structures are to be built in seismically active locations, the research and layout become more difficult.

Plan irregularities

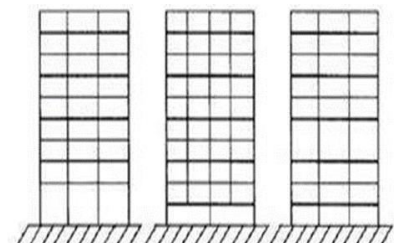
a) Vertical irregularities

Vertical irregularities are mainly of three types, i.e. stiffness irregularity, mass irregularity, and vertical geometric irregularity.

1. Mass irregularity - Mass irregularity is known to occur where any storey's seismic weight is more than 200% of that of its neighbouring stories.



2. Stiffness irregularity (soft storey) – A soft storey is one in which the lateral stiffness of the three stories above is less than 70% or less than 80% of the average lateral stiffness.



II. OBJECTIVE OF THE STUDY

- 1] To develop the model of RC frame in seismic zone III and zone IV with mass and stiffness irregularities
- 2] To study the G+10 storied RC frame, with mass and stiffness by dynamic analysis (response spectrum) and static analysis.
- 3] To study parameters like time period, base shear, storey displacement, storey drift ratio, in seismic zone III and IV.

III. METHODOLOGY



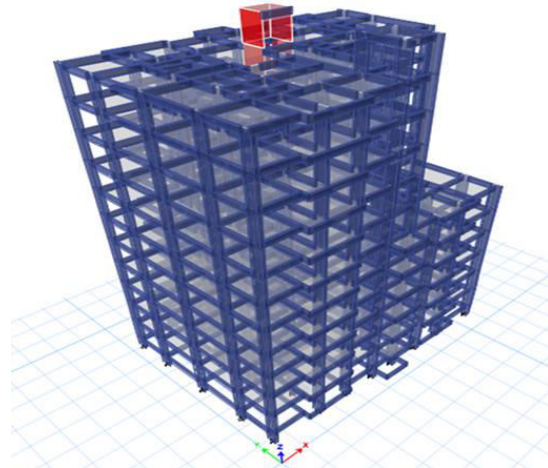
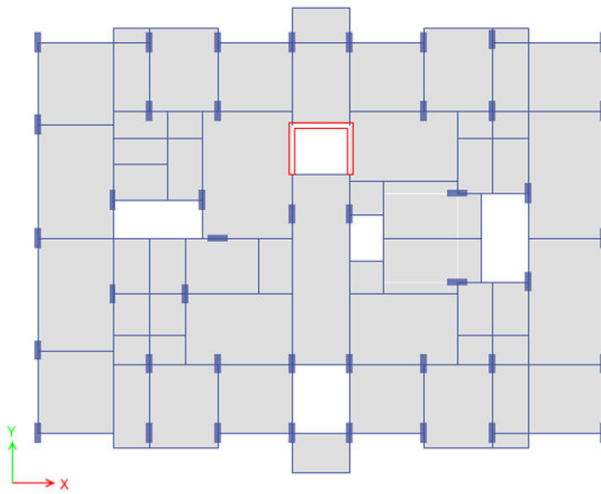
IV. MODELLING

1. Model with mass irregularity at ground floor

Model regular framed structure with mass irregularity at ground floor consists of length 34 metres and breadth 28 metres having 10 floors is analysed for seismic zones III and the results are noted down

2. Model with mass and stiffness irregularity at mid floor

Model 2A regular framed structure with mass irregularity at mid floor consists of length 34 metres and breadth 28 metres having 10 floors is analysed for seismic zones IV and the results are noted down.



Plan of Building

3D regular model of Building

Building size- 34mx 28m

Beams of size 200X900 is used

Columns of size 300x900 is used

Slab of thickness 125mm

Live load on floor – 2.00, 3.00 KN/m²

Live load on roof - 1.50 KN/m²

Zone factor – II,III,IV,V

Soil type – Medium

Importance factor – 1

V. EXPERIMENTAL RESULTS

Storey displacement

The maximum values of displacements are tabulated by comparing X and Y directions. The values of displacement of different models are obtained by subjecting the models to static analysis and response spectrum analysis shows max displacement.

S. NO.	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	38.238	61.181	91.771	137.656
2	MODEL WITH MASS IR @ MID STOREY	37.534	60.054	90.081	135.121
3	MODEL WITH MASS IR @ TOP STOREY	40.476	64.761	97.142	145.713

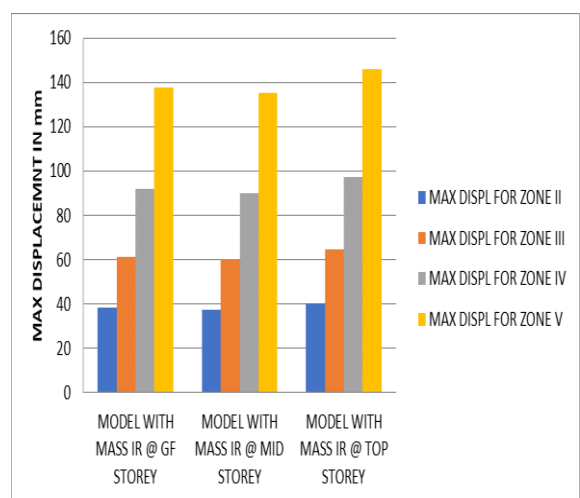


Table: Max Displacement values for different storey mass irregularity models (Static analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	21.625	34.6	51.899	77.849
2	MODEL WITH MASS IR @ MID STOREY	21.143	33.829	50.743	76.115
3	MODEL WITH MASS IR @ TOP STOREY	21.58	36.587	54.881	82.322

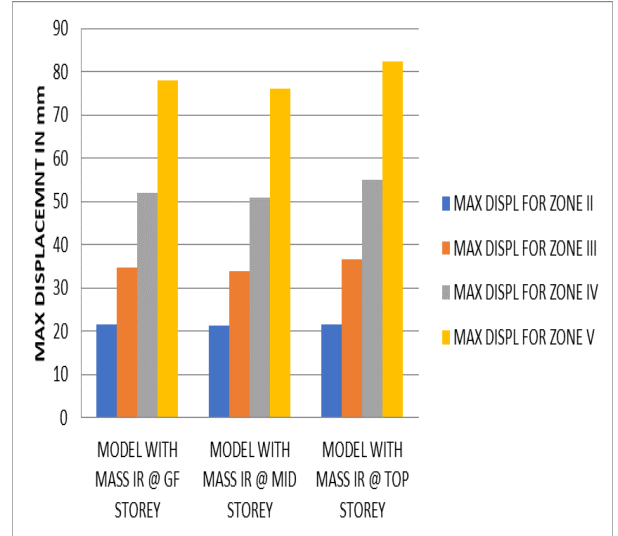


Table:Max Displacement values for different storey mass Graph of maximum displacement irregularity models (Static analysis in Y direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	31.802	50.884	76.326	114.489
2	MODEL WITH MASS IR @ MID STOREY	32.797	52.475	78.713	118.07
3	MODEL WITH MASS IR @ TOP STOREY	34.21	54.736	82.104	123.155

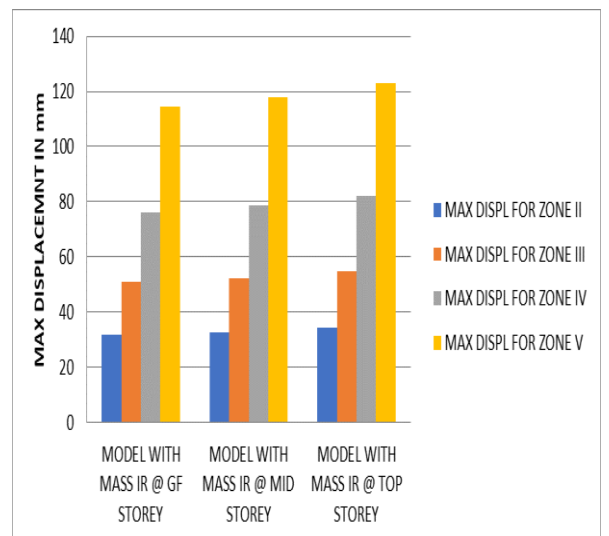


Table:Max Displacement values for different storey mass Graph of maximum displacement irregularity models (Response spectrum analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	19.33	33.092	46.391	69.586
2	MODEL WITH MASS IR @ MID STOREY	19.84	31.744	47.617	71.425
3	MODEL WITH MASS IR @ TOP STOREY	22.633	36.212	54.319	81.478

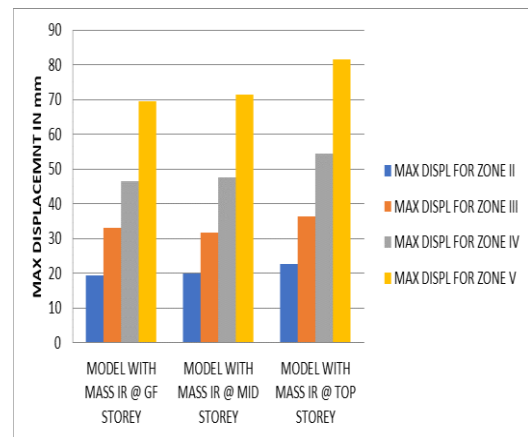


Table 5.4: Max Displacement values for different storey mass irregularity models (Response spectrum analysis in Y direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	38.415	61.465	92.197	138.295
2	MODEL WITH STIFFNESS IR @ MID STOREY	39.965	63.945	95.917	143.876
3	MODEL WITH STIFFNESS IR @ TOP STOREY	38.498	61.597	92.396	138.593

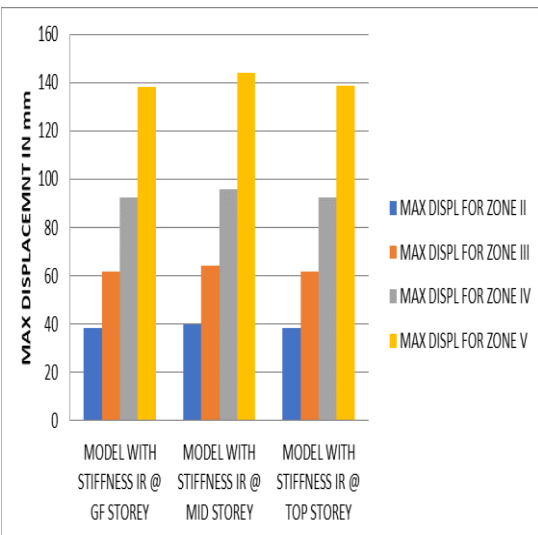


Table: Max Displacement values for different storey stiffness irregularity models (Static analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	21.77	34.832	52.247	78.371
2	MODEL WITH STIFFNESS IR @ MID STOREY	22.583	36.133	54.199	81.299
3	MODEL WITH STIFFNESS IR @ TOP STOREY	21.279	34.046	51.069	76.603

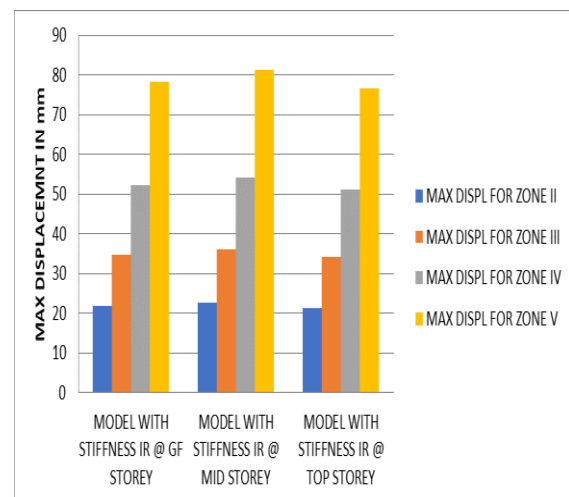


Table 5.6: Max Displacement values for different storey stiffness irregularity models (Static analysis in Y direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	34.829	55.726	83.589	125.383
2	MODEL WITH STIFFNESS IR @ MID STOREY	34.29	54.864	82.296	123.443
3	MODEL WITH STIFFNESS IR @ TOP STOREY	32.702	52.324	78.486	117.729

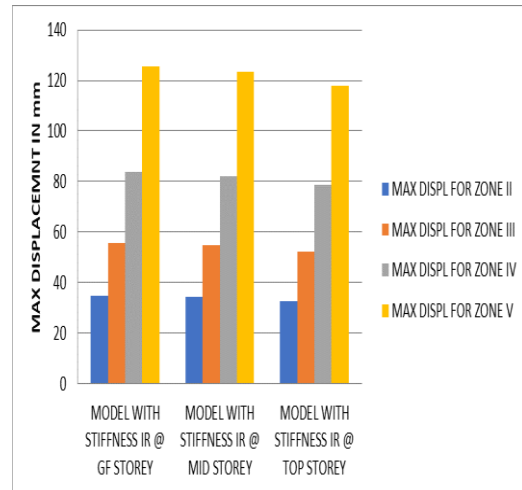


Table: Max Displacement values for different storey stiffness Graph of maximum displacement irregularity models (Response spectrum analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	21.776	34.842	52.263	78.395
2	MODEL WITH STIFFNESS IR @ MID STOREY	22.211	35.537	53.306	79.959
3	MODEL WITH STIFFNESS IR @ TOP STOREY	19.883	31.813	47.72	71.58

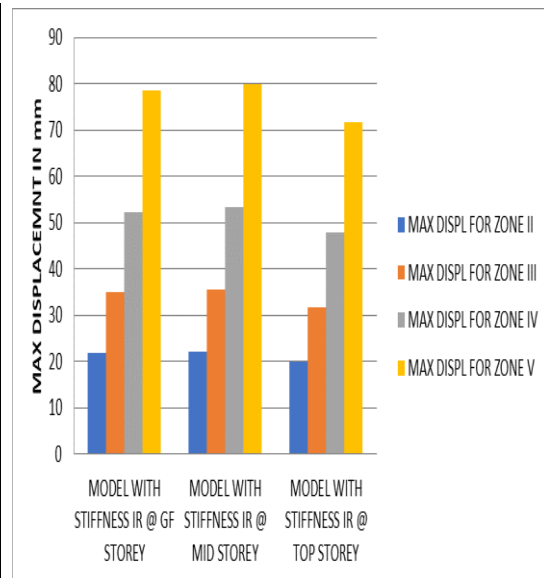


Table: Max Displacement values for different storey stiffness Graph of maximum displacement irregularity models (Response spectrum analysis in Y direction)

Storey Drift

The lateral movement of a floor with respect to the floor below is known as storey drift. The values of drift of different models are obtained by subjecting the models to static analysis and response spectrum analysis shows max drift.

SL NO	MODEL	For Zone II	For Zone III	For Zone IV	For Zone V
1	MODEL WITH MASS IR @ GF STOREY	0.001261	0.002017	0.003026	0.004539
2	MODEL WITH MASS IR @ MID STOREY	0.001219	0.00195	0.002924	0.004387
3	MODEL WITH MASS IR @ TOP STOREY	0.001322	0.002115	0.003172	0.004758

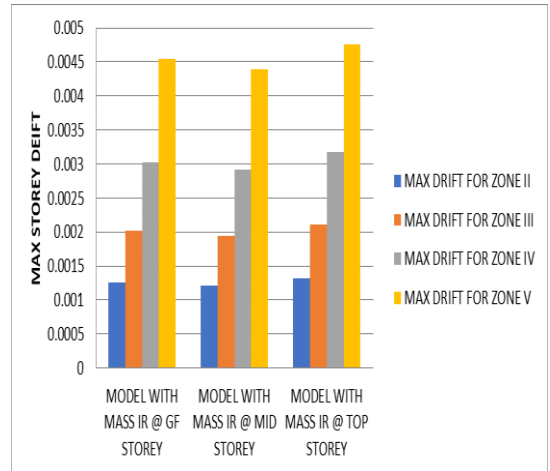


Table 5.17: Max Drift values for different storey mass irregularity models (Static analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	0.000772	0.001235	0.001853	0.002779
2	MODEL WITH MASS IR @ MID STOREY	0.00076	0.001215	0.001823	0.002734
3	MODEL WITH MASS IR @ TOP STOREY	0.000795	0.001271	0.001907	0.00286

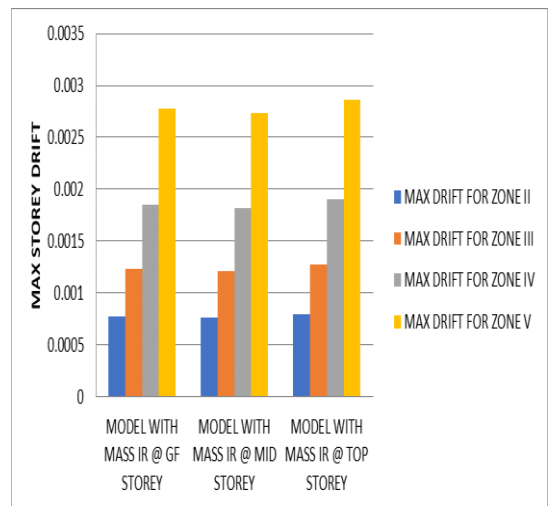


Table: Max Drift values for different storey mass irregularity models (Static analysis in Y direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH MASS IR @ GF STOREY	0.001098	0.001757	0.002636	0.003954
2	MODEL WITH MASS IR @ MID STOREY	0.001114	0.00096	0.002675	0.004012
3	MODEL WITH MASS IR @ TOP STOREY	0.001165	0.001864	0.002796	0.004194

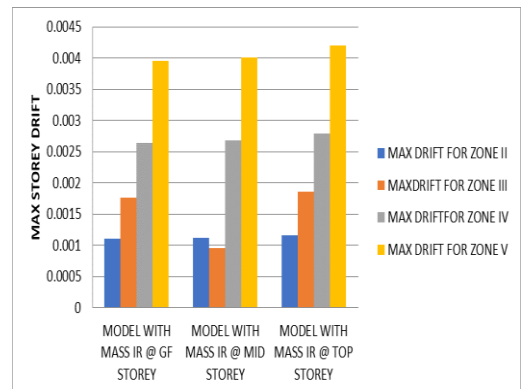


Table: Max Drift values for different storey mass irregularity models (Response spectrum analysis in X direction)

SL NO	MODEL	For Zone II	For Zone III	For Zone IV	For Zone V
1	MODEL WITH MASS IR @ GF STOREY	0.000654	0.001122	0.00157	0.002354
2	MODEL WITH MASS IR @ MID STOREY	0.000656	0.00104	0.001574	0.002361
3	MODEL WITH MASS IR @ TOP STOREY	0.000784	0.001255	0.001882	0.002823

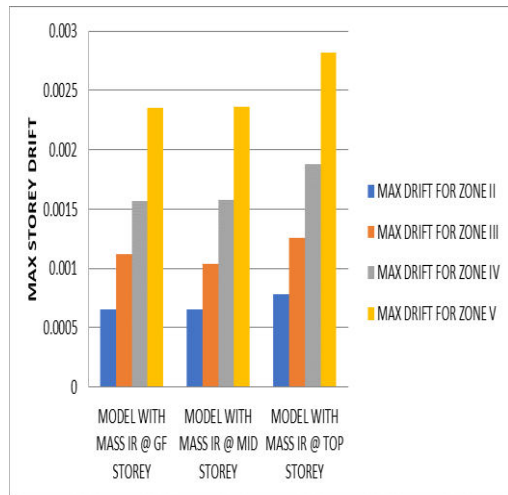


Table: Max Drift values for different storey mass irregularity modelsGraph of maximum drift (Response spectrum analysis in Y direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	0.001182	0.001891	0.002837	0.004255
2	MODEL WITH STIFFNESS IR @ MID STOREY	0.001386	0.002217	0.002982	0.004988
3	MODEL WITH STIFFNESS IR @ TOP STOREY	0.00121	0.001937	0.002905	0.004357

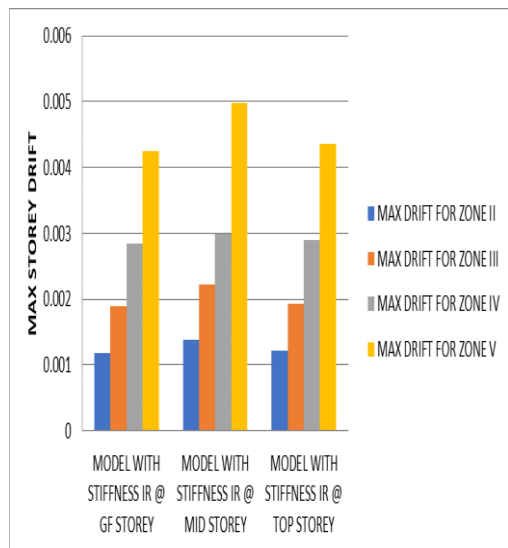


Table: Max Drift values for different storey stiffness irregularityGraph of maximum drift models ((Static analysis in X direction)

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	0.000736	0.001178	0.001767	0.002651
2	MODEL WITH STIFFNESS IR @ MID STOREY	0.00085	0.001361	0.002041	0.003062
3	MODEL WITH STIFFNESS IR @ TOP STOREY	0.000733	0.001172	0.001758	0.002637

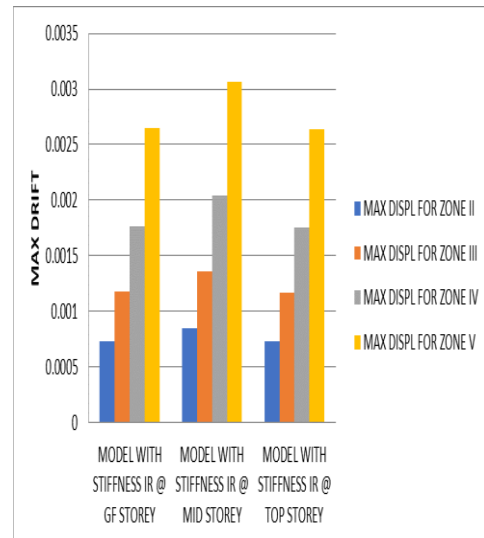


Table : Max Drift values for different storey stiffness irregularityGraph of maximum drift models ((Static analysis in Y direction))

SL NO	MODEL	For Zone II (mm)	For Zone III (mm)	For Zone IV (mm)	For Zone V (mm)
1	MODEL WITH STIFFNESS IR @ GF STOREY	0.001114	0.001782	0.002673	0.00401
2	MODEL WITH STIFFNESS IR @ MID STOREY	0.001235	0.001977	0.002965	0.004447
3	MODEL WITH STIFFNESS IR @ TOP STOREY	0.001073	0.001717	0.002576	0.003864

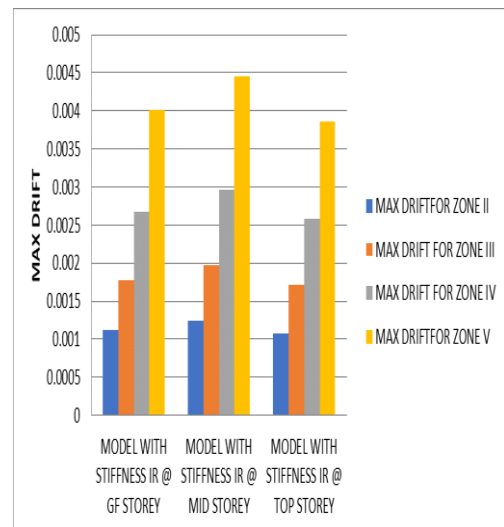
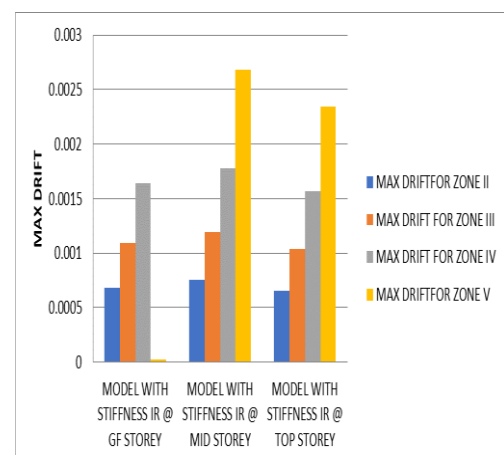


Table: Max drift values for different storey stiffness irregularity models Graph of maximum drift (Response spectrum analysis in X direction)

SL NO	MODEL	For Zone II	For Zone III	For Zone IV	For Zone V
1	MODEL WITH STIFFNES S IR @ GF STOREY	0.000684	0.001095	0.001642	0.000024
2	MODEL WITH STIFFNES S IR @ MID STOREY	0.000754	0.001192	0.00178	0.002682
3	MODEL	0.000651	0.001042	0.001563	0.002345



	WITH STIFFNES S IR @ TOP STOREY				
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Table: Max Drift values for different storey stiffness irregularity models Graph of maximum drift
(Response spectrum analysis in Y direction)

TIME PERIOD

SL NO	MODEL	For Zone II (SEC)	For Zone III (SEC)	For Zone IV (SEC)	For Zone V (SEC)
1	MODEL WITH MASS IR @ GF STOREY	1.605	1.605	1.605	1.605
2	MODEL WITH MASS IR @ MID STOREY	1.66	1.66	1.66	1.66
3	MODEL WITH MASS IR @ TOP STOREY	1.794	1.794	1.794	1.794

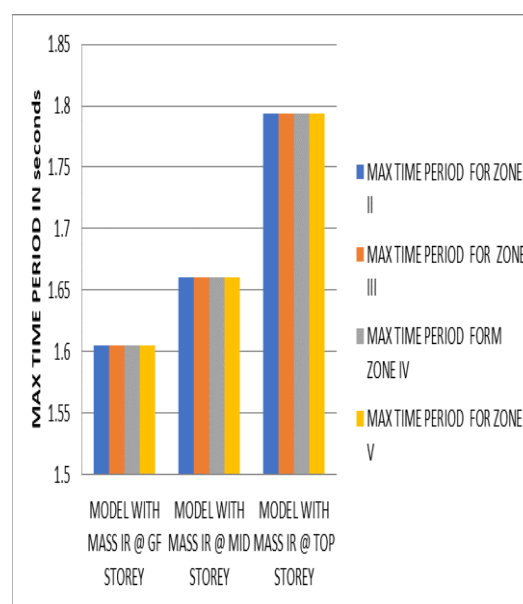
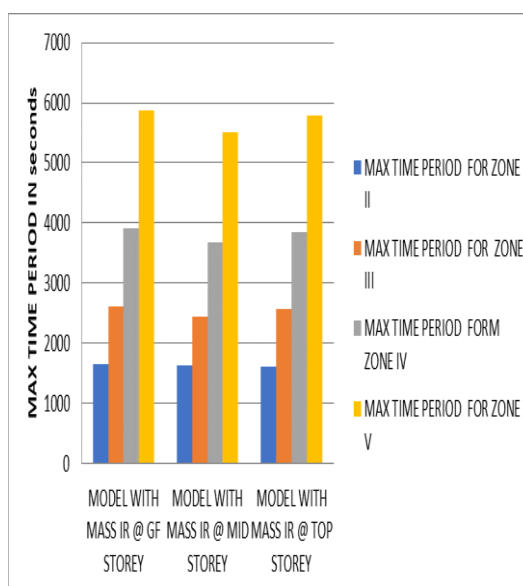


Table: Max time period values for different storey mass irregularity models (Static analysis and response spectrum in X and Y direction)

Base Shear

Base shear is a measure of the maximum expected lateral force that will happen due to the seismic ground motion at the base of the structure. Since base shear value directly proportional to weight of the building, the regular model is having fewer loads compared to other models.

SL NO	MODEL	For Zone II (kN)	For Zone III (kN)	For Zone IV (kN)	For Zone V (kN)
1	MODEL WITH MASS IR @ GF STOREY	1631.07	2609.71	3914.57	5871.86
2	MODEL WITH MASS IR @ MID STOREY	1631.07	2448.59	3672.89	5509.33
3	MODEL WITH MASS IR @ TOP STOREY	1607.11	2571.38	3857.07	5785.61



SL NO	MODEL	For Zone II (SEC)	For Zone III (SEC)	For Zone IV (SEC)	For Zone V (SEC)
1	MODEL WITH STIFFNESS IR @ GF STOREY	1415.02	2264.03	3396.05	5094.07
2	MODEL WITH STIFFNESS IR @ MID STOREY	1415.02	2124.25	3186.38	4779.56
3	MODEL WITH STIFFNESS IR @ TOP STOREY	1394.24	2230.78	3346.16	5019.25

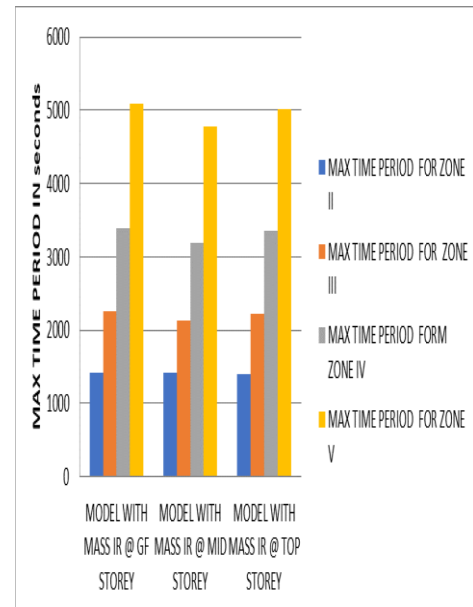


Table: Maximum base shear values for different storey stiffnessGraph of Base Shear irregularity models (Static analysis in Y direction)

VI. CONCLUSION

1. Displacement

a) Static analysis

Mass irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 6.53% and 1.78% compared to model with mass irregularity at top and ground storey for zone IV.

For zone V the maximum reduction in lateral displacement for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 6.77% and 2.68% compared to model with mass irregularity at top and ground storey.

Stiffness irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at top floor, the reduction is about 4.34% and 0.44% compared to model with mass irregularity at middle and ground storey for zone IV.

For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at top floor, the reduction is about 6.49% and 2.68% compared to model with mass irregularity at middle and ground storey.

b) Response spectrum analysis

Mass irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for response spectrum analysis is seen in Model with mass irregularity at ground floor, the reduction is about 14.82% and 11.44% compared to model with mass irregularity at top and middle storey for zone IV.

For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 5.98% and 3.81% compared to model with mass irregularity at top and ground storey.

Stiffness irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at top floor, the reduction is about 4.29% and 6.45% compared to model with mass irregularity at middle and ground storey for zone IV.

For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at top floor, the reduction is about 4.25% and 6.42% compared to model with mass irregularity at middle and ground storey.

2. Storey Drift

a) Static Analysis

Mass irregularity

From the results of top storey drift it is noted that the maximum reduction in lateral drift for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 16.59% and 13.53% compared to model with mass irregularity at top and ground storey for zone IV.

For zone V, the maximum reduction in storey drift for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 16.32% and 3.36% compared to model with mass irregularity at top and ground storey.

Stiffness irregularity

From the results of top storey drift it is noted that the maximum reduction in lateral drift for static analysis is seen in Model with stiffness irregularity at middle floor, the reduction is about 16.32% and 3.36% compared to model with mass irregularity at top and ground storey for zone IV.

For zone V, the maximum reduction in storey drift for static analysis is seen in Model with stiffness irregularity at ground floor, the reduction is about 12.26% and 4.123% compared to model with mass irregularity at top and middle storey.

b) Response Spectrum Analysis

Mass irregularity

From the results of top storey drift it is noted that the maximum reduction in lateral drift for response spectrum analysis is seen in Model with mass irregularity at middle floor, the reduction is about 23.93% and 2.72% compared to model with mass irregularity at top and ground storey for zone IV.

For zone V, the maximum reduction in storey drift for response spectrum analysis is seen in Model with mass irregularity at middle floor, the reduction is about 24.11% and 3.16% compared to model with mass irregularity at top and ground storey.

Stiffness irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at ground floor, the reduction is about 21.69% and 3.18% compared to model with mass irregularity at top and middle storey for zone IV.

For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at ground floor, the reduction is about 21.69% and 3.18% compared to model with mass irregularity at middle and ground storey.

3. Time period

From the results of top time period it is noted that the maximum reduction in time period of building is seen in Model with mass irregularity at top floor, the reduction is about 4.85% and 4.58% compared to model with mass irregularity at top and middle storey for zone IV and V.

4. Base shear

Mass irregularity

From the results of top storey displacement, it is noted that the maximum reduction in base shear for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 6.17% and 4.77% compared to model with mass irregularity at top and ground storey for zone IV. For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with mass irregularity at middle floor, the reduction is about 4.77% and 6.17% compared to model with mass irregularity at top and ground storey.

Stiffness irregularity

From the results of top storey displacement, it is noted that the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at top floor, the reduction is about 4.77% and 6.17% compared to model with mass irregularity at middle and ground storey for zone IV.

For zone V, the maximum reduction in lateral displacement for static analysis is seen in Model with stiffness irregularity at middle floor, the reduction is about 4.77% and 6.17% compared to model with mass irregularity at top and ground storey.

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