ISSN2394-3777 (Print)
ISSN2394-3785 (Online)
Available online atwww.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 12, April 2018

Seismic Analysis of Multistoried Building Frames with Vertical Irregularities

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***Abstract*-This paper is concerned with the effects of various vertical irregularities on the seismic response of a structure. The objective of the project is to carry out Response spectrum analysis (RSA) of vertically irregular RC building frames using IS 1893:2002. Comparison of the results of analysis and design of irregular structures with regular structure was done. According to our observation, the storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts.**

Index Terms*: *Response spectrum analysis, Storey displacement, Storey drifts, Setback, Vertical irregularity.

I. Introduction

There is a weakness in the building. This weakness causes deterioration of the building which results in structural collapse. This weakness mostly occurs due to the presence of irregularities in stiffness, strength and mass in a building. These irregularities are classified into two forms namely plan irregularity and vertical irregularity. As per IS The failure in the multistorey building due to seismic loading generally initiates at the location where 1893:2002 (part I) vertical irregularities are classified as follows:

1. **Stiffness irregularity:**
a). Soft storey: A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above. b). Extreme soft storey: A extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storeys above.
2. **Mass irregularity**: Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys.
3. **Vertical geometric irregularity**: Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.
4. **In plane discontinuity in vertical elements resisting lateral force:** An in-plane offset of the lateral force resisting elements greater than the length of those elements.
5. **Discontinuity in capacity:** A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.

II. Literature Review

Shaikh and Deshmukh[1] performed linear static & dynamic analysis of G+10 vertically irregular building as per IS 1893:2002 (part I) provisions. The building was modeled as a simplified lump mass model having stiffness irregularity at fourth floor. The response parameters like storey drift, storey deflection and storey shear of the building were evaluated. The results show that, stiffness irregularity causes instability in the building and attracts huge storey shear.

Mahesh and Rao[2] studied the behavior of regular and irregular G+11 residential building under seismic motion. They considered different seismic zones and three different types of soils namely hard, medium and soft. The analysis was done by two softwares ETABS and STAAD PRO.

Bansal and Gagandeep[3] carried out response spectrum analysis (RSA) and time history analysis (THA) of vertically irregular RC building frames. They considered mass, stiffness and vertical geometric irregularity. They found that mass irregular building experience larger base shear than similar regular building. The stiffness irregular building experienced lesser base shear and has larger inter storey drifts.

Rana and Raheem[4] studied the performance of vertical geometric irregular RC frame structures under seismic motion. A comparative study between one regular frame & four irregular building frames were carried out. Various seismic responses like shear force, bending moment, storey drift, storey displacement etc. were obtained. It was concluded that regular building frames possess very low shear force compared to setback irregular frames.

The objectives of the present study are (i) to study the performance and behavior of total eight regular and irregular RC buildings having stiffness and setback irregularity, (ii) to analyse all the G+9 RC buildings as per IS1893:2002 (part I) criteria using SAP2000 software. (iii) to compare the responses like storey displacement, storey drift, time period and natural frequency between the regular and vertical irregular buildings.

III. METHODOLOGY

In this study seismic analysis of all the eight regular and irregular RC buildings has been carried out. Two types of vertical irregularities namely stiffness and setback are considered. The structural details of the regular building is shown in Table I.

Table I: Structural Detail of Regular Building Model

Specification	For stiffness irregularity	For setback irregularity
No. of Stories	G+9	G+9
Storey height	3 m	3.5 m
No. of bays in X and Y direction	3	6 and 3
Spacing of frame in X and Y direction	4 m	5 m
Grade of concrete	M 25	M 25
Modulus of elasticity of concrete	25×103 MPa	25×103 MPa
Thickness of slab	0.125 m	0.150 m
Beam size	0.45 m × 0.30 m	0.40 m × 0.35m
Column size	0.45 m × 0.45 m	0.40 m × 0.40 m
Damping ratio	5%	5%
Seismic zone	V	iv
Response reduction factor (R)	5	5
Soil type	Medium	Rocky soil
Zone factor (Z)	0.36	0.24
Importance factor (I)	1	1

3.1 Stiffness Irregularity:

Four types of building models are analysed in this case: one regular building (B1) as shown in Fig. 1 and three irregular buildings namely ground storey, fourth storey and seventh storey as soft storey. These buildings are modeled as G+10 storey having three bays in both the direction. The irregularity in the building is generated by increasing the height of the storey. Thus, the irregular storey has a height of 4.5 m as shown in Fig. 2.Stiffness of each column= 12EI/L3 Therefore, stiffness of ground storey/stiffness of other storey = (3/4.5)3 = 0.3< 0.7 Hence as per IS 1893:2002 (part I) the building has stiffness irregularity.

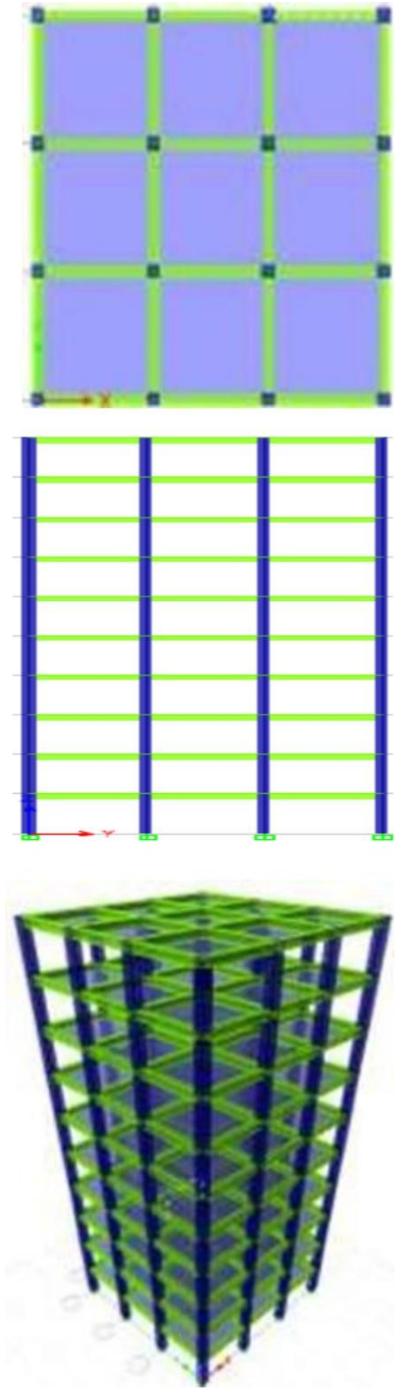

Figure 1: Plan, : Elevation, & 3D View of regular building model(B1)

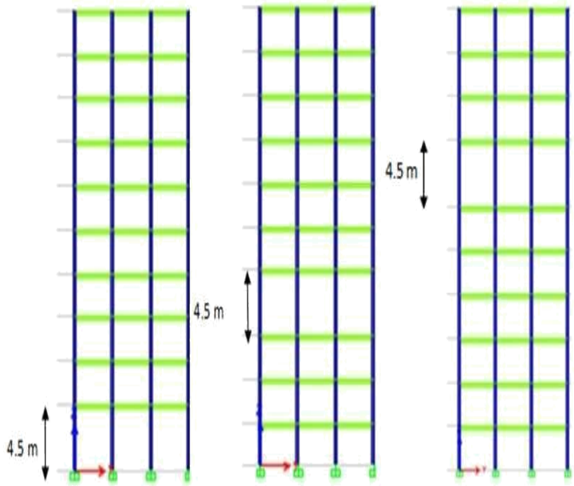

Figure 2: Elevation of stiffness in Ground storey as soft storey (S1), Fourth storey as soft storey (S2), Seventh storey as soft storey (S3) Irregular building models.

3.2 Setback Irregularity:

Four types of building models are selected in this case: one regular building as shown in Fig. 3 and three irregular buildings having setback irregularity in eighth, fifth and second storey along X-direction as shown in Fig. 4. These buildings are modeled as G+9 storey having four bays in both the direction.

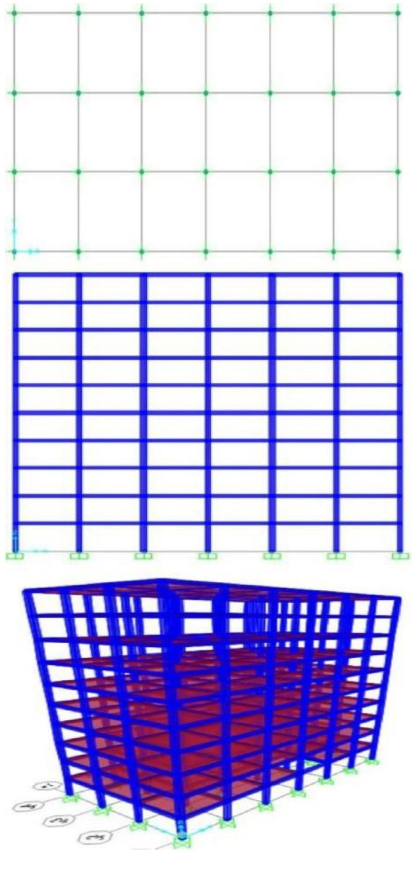

Figure 3: Plan, elevation and 3D of regular building model

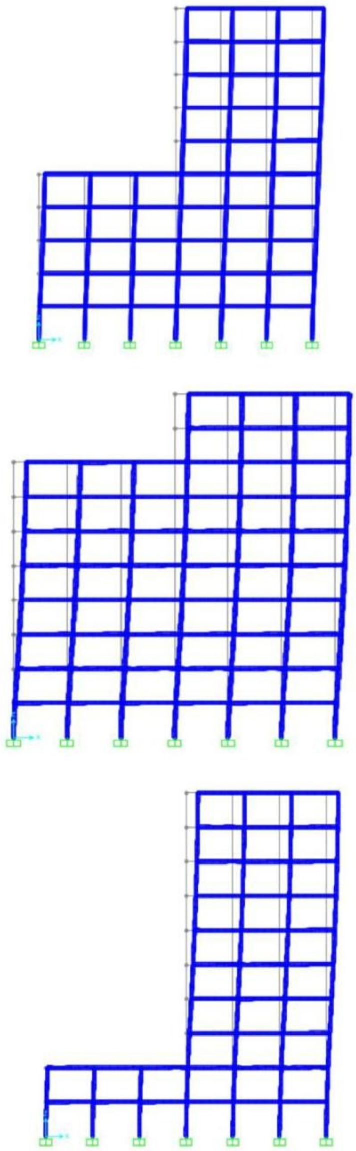

Figure 4: Elevation of setback in Setback in 5th storey(G1), Setback in 8th storey (G2) Setback in 2nd storey (G3)in Irregular building models.

IV .Results and Discussion

4.1 Stiffness irregularity:

The storey displacement curve shown in Fig. 5 concludes that, stiffness irregular buildings undergo much more displacement as compare to regular building. In case of model S1 the displacement in the ground storey is 1.5 times more than that of regular building model B1, and it taper off towards the top of the building. A sudden change in the slope of storey displacement curve has been observed with change in stiffness of a storey. The storey drift curve as shown in Fig. 6

indicates that, due to stiffness irregularity there is sudden extreme change in storey drift as compared to the regular building.

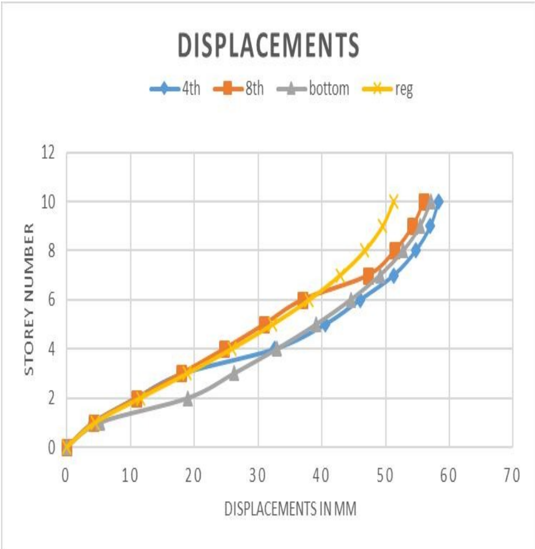

Figure 5 : Storey Number Vs Displacement Plot

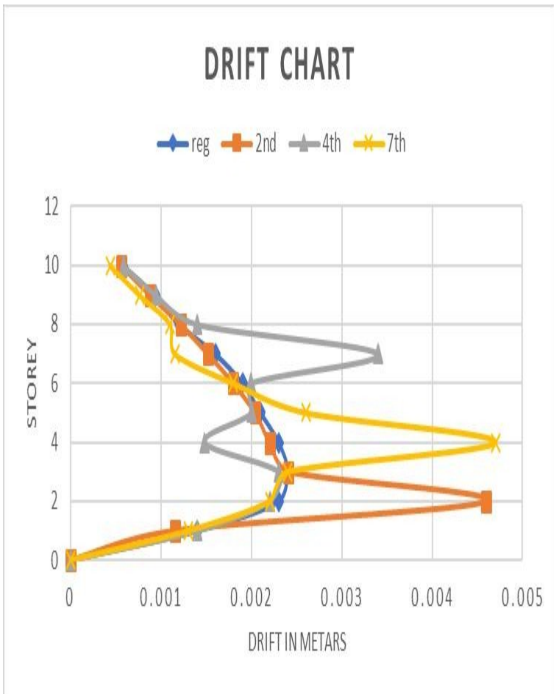

Figure 6: Storey number Vs Drift(mm) Plot

Table. II .**Displacements table:**

Storey	**Regular Building**	**Ground Storey Soft Storey**	**Fourth Storey Soft Storey**	**Seventh Storey Soft Storey**
0	0	0	0	0
1	0.0044	0.0052	0.0042	0.0041
2	0.0115	0.019	0.011	0.0109
3	0.0189	0.0262	0.0179	0.0183
4	0.0259	0.033	0.0247	0.0327
5	0.0323	0.0391	0.0309	0.0405
6	0.038	0.0445	0.0369	0.046
7	0.0429	0.0491	0.0472	0.0513
8	0.0467	0.0528	0.0514	0.0547
9	0.0495	0.0554	0.0542	0.057
10	0.0513	0.0571	0.056	0.0583

Table .III - **Drift Table:**

storey	**Regular building**	**Ground storey soft storey**	**Fourth storey soft storey**	**Seventh storey soft storey**
0	0	0	0	0
1	0.0014	0.00115	0.0014	0.0013
2	0.0023	0.0046	0.0022	0.0022
3	0.0024	0.00241	0.0023	0.0024
4	0.0023	0.0022	0.00148	0.0047
5	0.0021	0.00204	0.002	0.0026
6	0.0019	0.0018	0.00199	0.0018
7	0.0016	0.00152	0.0034	0.00115
8	0.0012	0.00122	0.0014	0.0011
9	0.00093	0.00088	0.00094	0.00076
10	0.000579	0.000562	0.00058	0.000433

Table.IV : **Time period and natural frequency:**

S	T.P	N.F	T.P	N.F	T.P	N.F	T.P	N.F
1	0.54	1.851	0.59	1.6949	0.606	1.6501	0.57	1.754
2	0.54	1.851	0.59	1.6949	0.606	1.6501	0.57	1.754
3	0.48	2.0833	0.53	1.8867	0.53	1.8867	0.51	1.960
4	0.17	5.8823	0.19	5.2631	0.18	5.5555	0.198	5.050
5	0.17	5.8823	0.19	5.2631	0.18	5.5555	0.198	5.050
6	0.15	6.6666	0.17	5.8823	0.16	6.25	0.177	5.649
7	0.1	10	0.11	9.0909	0.11	9.0909	0.102	9.803
8	0.1	10	0.11	9.0909	0.11	9.0909	0.102	9.803
9	0.09	11.111	0.1	10	0.1	10	0.093	10.75
10	0.06	16.666	0.07	13.513	0.075	13.333	0.077	12.98
11	0.06	16.666	0.07	13.513	0.075	13.333	0.077	12.98

S-Storey, T.P-Time Period(sec), N.F- Natural Frequency(Cps)

4.2. Setback irregular building:

In setback structures due to setback the stiffness and mass of the structure both decreases.

In setback structure with offset at 8th storey at lower storeys the displacement is more than the other two. This behaviour may be attributed to the increase mass of the structure. In setback structure with offset at 5th floor there is a sudden change in slope of the curve due to offset. But what is most conspicuous behavior is that its top node displacement is more than the former structure. This can be attributed to less stiffness in the upper stories of the structure. The behavior of setback structure with offset at 2nd floor is similar to second setback structure. The difference is the fact that the curve is smoother in this case. Notably the displacement at first three floors is less when compared to other two setback structures.

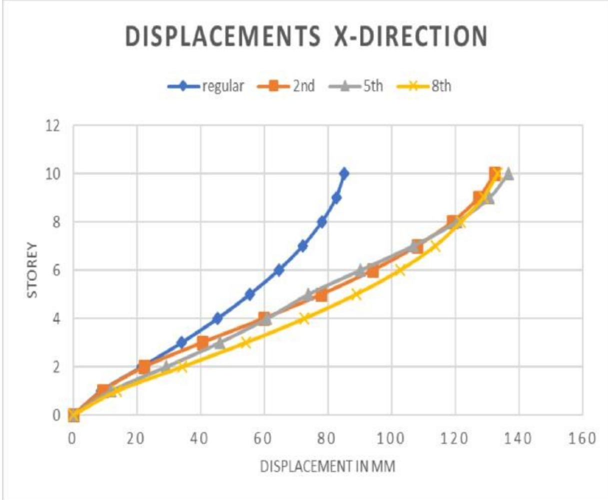

Figure:7 Displacement charts in X direction Vs Displacement(mm)

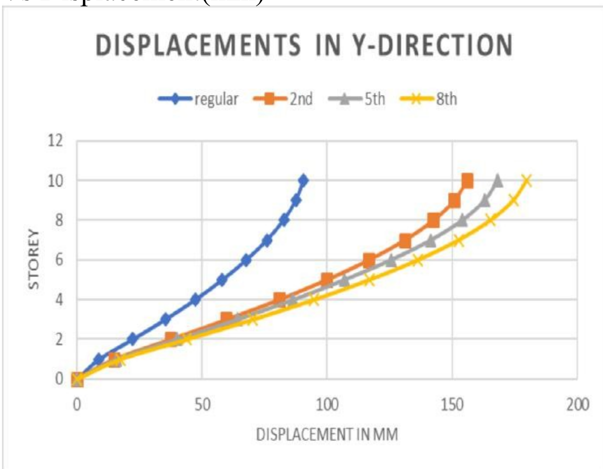

Figure:8 Displacement charts in Y direction Vs Displacement(mm) Table.V Displacement tables

	Regular Building		Setback In 2nd Storey		Setback In 5th Storey		Setback In 8th Storey	
S	**X**	**Y-**	**X**	**Y**	**X**	**Y**	**X**	**Y**
B	0	0	0	0	0	0	0	0
1	0.0088	0.0089	0.00912	0.01489	0.0119	0.016	0.0139	0.0175
2	0.0216	0.0223	0.02234	0.03737	0.0293	0.0401	0.0343	0.044
3	0.0341	0.0354	0.04043	0.05977	0.046	0.0641	0.0543	0.0703
4	0.0454	0.0474	0.05981	0.08077	0.0609	0.0865	0.0727	0.0948
5	0.0555	0.0582	0.07793	0.09986	0.0739	0.107	0.0889	0.117
6	0.0645	0.0678	0.09407	0.1167	0.0902	0.1256	0.1027	0.1363
7	0.0721	0.076	0.10788	0.13103	0.1067	0.1415	0.1137	0.1526
8	0.0781	0.0827	0.11908	0.14253	0.1205	0.1541	0.1218	0.1654
9	0.0826	0.0876	0.12734	0.15087	0.1306	0.1631	0.1288	0.1745
10	0.0851	0.0907	0.13239	0.15586	0.1365	0.1683	0.1333	0.1798

S-STOREY, B-BASE

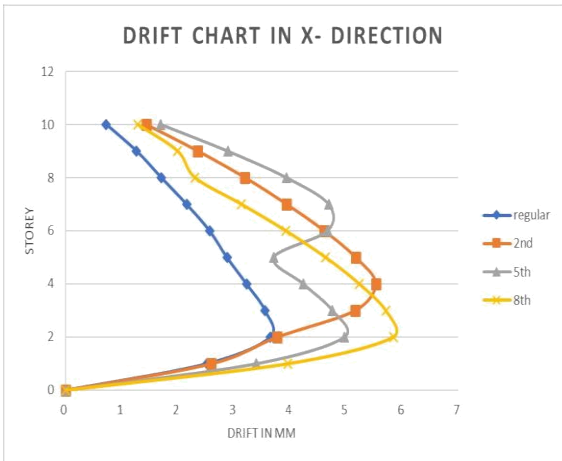

Figure:9 Drift chart in X-Direction Vs Drift(mm)

Figure:10 Drift chart in X-Direction Vs Drift(mm)

Table.VI- Drift tables:

	Regular Buiding		Setback In 2nd Floor		Setback In 5th Storey		Setback In 8th Storey	
S	**x**	**y**	**x**	**y**	**x**	**y**	**x**	**y**
B	0	0	0	0	0	0	0	0
1	0.0025	0.0026	0.0026	0.0043	0.0034	0.0046	0.004	0.005
2	0.0037	0.0038	0.0038	0.0064	0.005	0.0069	0.0058	0.007
3	0.0036	0.0037	0.0052	0.0064	0.0048	0.0069	0.0057	0.007
4	0.0032	0.0034	0.0055	0.006	0.0042	0.0064	0.0052	0.007
5	0.0029	0.0031	0.0052	0.0055	0.0037	0.0058	0.0046	0.006
6	0.0026	0.0027	0.0046	0.0048	0.0047	0.0053	0.0039	0.005
7	0.0022	0.0023	0.0039	0.0041	0.0047	0.0046	0.0031	0.004
8	0.0017	0.0019	0.0032	0.0033	0.0039	0.0036	0.0023	0.003
9	0.0013	0.0014	0.0024	0.0024	0.0029	0.0026	0.002	0.002
10	0.0007	0.0009	0.0014	0.0014	0.0017	0.0015	0.0013	0.001

Table.VII. Time period and natural frequency:

	Regular Building		Setback In 2nd Floor		Setback In 5th Floor		Setback In 8th Floor	
S	**T.P**	**N.F**	**T.P**	**N.F**	**T.P**	**N.F**	**T.P**	**N.F**
1	1.91	0.523	1.77	0.565	1.74	0.57	1.793	0.5577
2	1.81	0.555	1.66	0.6024	1.51	0.66	1.64	0.6098
3	1.68	0.595	1.34	0.7463	1.11	0.89	1.45	0.6897
4	0.62	1.612	0.58	1.7241	0.69	1.44	0.59	1.6949
5	0.59	1.694	0.56	1.7857	0.64	1.55	0.55	1.8182
6	0.55	1.182	0.45	2.2222	0.58	1.71	0.48	2.0833
7	0.35	2.857	0.35	2.8571	0.34	2.91	0.355	2.8169
8	0.344	2.907	0.34	2.9412	0.33	2.99	0.35	2.8571
9	0.32	3.125	0.31	3.2258	0.29	3.42	0.321	3.1153
10	0.24	4.166	0.246	4.065	0.25	3.96	0.259	3.861
11	0.23	4.347	0.24	4.1667	0.24	4.046	0.248	4.0323

V. CONCLUSION:

After studying the performance and behavior of regular and vertical irregular G+9 reinforced concrete buildings under seismic loading, the following conclusions are drawn.

[1]. The storey displacement in case of stiffness irregular buildings is more than that of the regular building. Considering storey displacement, ground soft storey (S1) is the most critical case because its displacement is 1.5 times more than that of regular building (B1) in the ground storey. The result shows that the top node displacement in case of setback irregular buildings is more than that of the regular building, except in case of model G1.

[2]. In case of stiffness irregular buildings, storey drift is maximum at irregular storeys. Considering storey drift, model S2 is the most critical case. In setback irregular buildings, a sudden extreme change in storey drift due to setback has been observed.

[3]. In case of stiffness irregular buildings, the overturning moment and storey shear force in case of irregular buildings are slightly greater than that in regular building. A moderate increase in the slope of the shear force curve has been observed at the irregular storeys. In

[5]. sudden decrease in stiffness of the building has been observed at the irregular storeys. The results of setback irregular buildings show that, as the amount of setback increases the stiffness of the building decreases.

The analysis shows that the vertical irregularities widely affect the performance of a RC building under seismic loading. As far as possible these irregularities must be avoided, but if it has to be introduced they must be properly designed.

case of setback irregular buildings, the overturning moment and storey shear force are less than that of the regular building. As the amount of setback increases, the overturning moment decreases.

[4]. In case of stiffness irregular buildings, a

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