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Seismic Evaluation of RC Building with Vertical Setbacks as per IS1893 (Part 1):2016

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Abstract

Earthquake forces are the least predictable and most devastating form of forces. These forces are not only responsible for loss of economy, property and material but possess a huge threat to lives of people as well. In past several years, severe damages to buildings and causalities have been witnessed due to these disastrous forces there by challenging the designing and construction authorities. Many buildings are designed with vertical setbacks due to architectural, functional or economic reasons wherein fewer stories in a building are wider than rest of the building. Such setbacks in buildings cause sudden jump in seismic forces at the level of discontinuity due to change in stiffness, mass and strength distribution along height. This might lead to torsion in the building under seismic forces. Structures incorporating vertical irregularities need to be studied for their behavioural aspects, identifying the weak links which might trigger the collapse. In the present study, effect of vertical geometric irregularities in a building is studied with respect to a regular building using equivalent static method and response spectrum method as per IS1893 (Part 1): 2016. The results obtained are compared in terms of displacements, storey drift, base shear, forces, modal time period, modal mass participation factor and % increase in structural members along with concrete quantity.

Keywords: Equivalent Static Method, Response Spectrum Method, Mode Shapes, Modal Mass Participation Factor, Inter Story Drift

1. Introduction

Structurally buildings can be classified as regular and irregular. The response of a regular building during a seismic event is comparatively better as mass and stiffness are uniformly distributed throughout its height. Past experiences reveal that buildings with vertical setbacks attribute more complex behaviour than regular building during a seismic event. The term "setbacks" refers to the presence of abrupt change in the plan dimension of the building at particular levels in elevation. These are the points of sudden change in stiffness, mass and strength of the building and are also known as weak points. As per IS1893 part 1[1], Vertical Geometric Irregularity exists where the horizontal dimension of the lateral force resisting system in any story is more than 125 percent of the storey below. The constructions of irregular structures are inevitable with increasing architectural and functional demands and hence the structural designers need to understand the complexity of the behaviour of these structures under strong ground excitation [4]. Incorporating high engineering efforts can reduce the threat upon irregular structures.

2. Problem formulation

The aim of the present research is to study and compare the performance and behaviour of G+11 RC regular hypothetical building (RB) to that of buildings with vertical setbacks in zone III. The buildings are modelled in ETABS 17 and analysed using equivalent static method and response spectrum method as per IS1893 part-1. Various cases of vertical irregularities considered are:

- Building with setback (SB1) at 4th floor level.
- Building with setback (SB2) at 4th floor level.
- Building with multiple setbacks (SB3) at 4th and 8th floor level.
- Building with symmetrical setback (SB4) at 4th floor level.

The plan dimension of regular building is 20m x 12m with aspect ratio 1.67 and floor height 3m. The plan and elevation of regular building is shown in Fig. 1(a) and (b). The structural detail of regular building is shown in Table 1. The elevations of setback buildings are shown in Fig. 2 (a), (b), (c) and (d). Sizes of beams and columns are assumed so as to allow maximum of 1.75 % area of steel in beams and 2.5% area of steel in columns in all buildings. Gravity loads are assumed as per IS875 part 1 [2] and part II [3]. Seismic forces are assumed as per IS1893 part 1. Load combinations for the analysis and design of buildings are as per IS1893 part 1.

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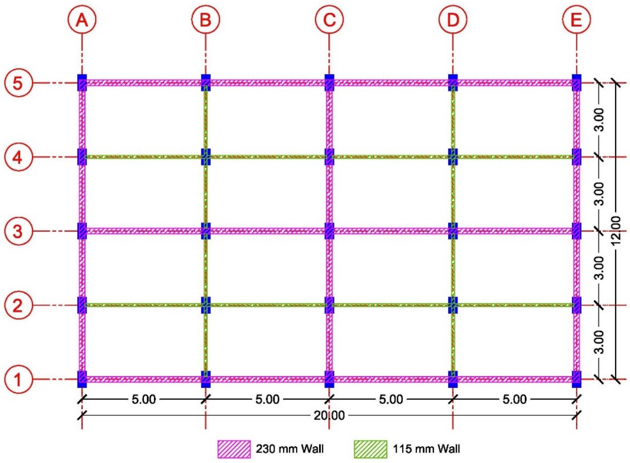

Fig. 1 (a) RB plan

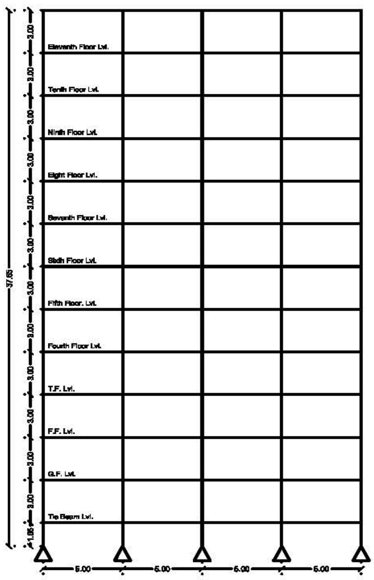

Fig. 1 (b) RB elevation

Table – 1. RB specifications

Specifications	
Type of Building	RC Residential - SMRF
Location	Ahmedabad
Plan area	20 m x12 m
Grade of concrete	M30 for Beams, M40 for Columns & Shear Wall
Grade of steel	HYSD 500D
Slab thickness	135 mm
Wall thickness	230 mm and 115 mm
Density of concrete	25 kN/m^3
Density of masonry	20 kN/m^3
Yield strength of steel	500 N/m^2
Zone factor	0.16
Type of soil	Medium
Tie beam / Beam size	230x525 / 230x500 mm
Column size	450 x 600 mm

3. Results and discussions

Post analysis, results are interpreted and discussed in terms of maximum displacement values and inter storey drifts, base shear, forces in beams and columns, modal time period, modal mass participation factors, % increase in sections and concrete quantity.

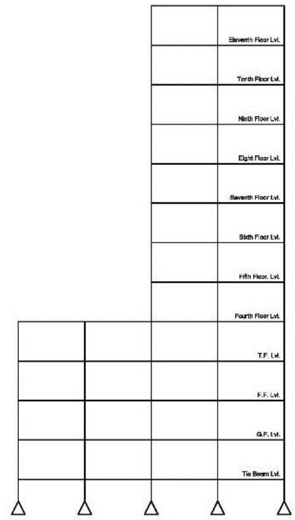

Fig. 2 (a) SB1 elevation

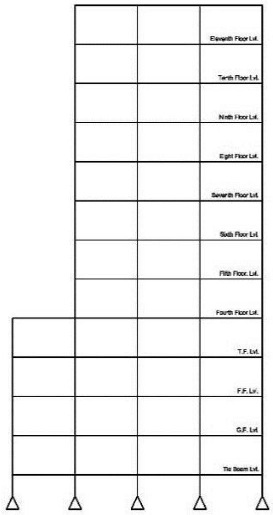

Fig. 2 (b) SB2 elevation

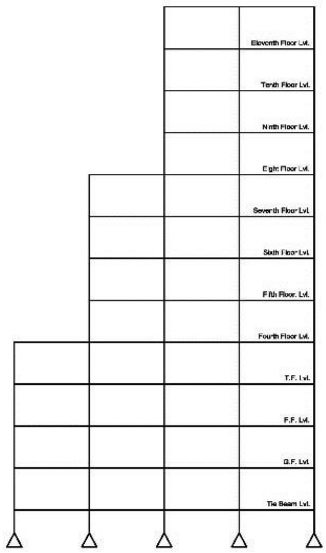

Fig. 2 (c) SB3 elevation

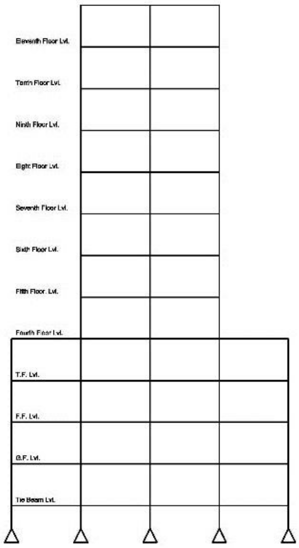

Fig. 2 (d) SB4 elevation

3.1. Maximum displacements and inter storey drifts

Maximum permissible drift as per IS1893 part-1 is 150.6mm. Fig. 3 (a), (b), (c) and (d) shows maximum displacements in buildings as per equivalent static method and response spectrum method in X and Y directions.

Maximum permissible inter storey drift as per IS1893 part-1 is 12mm. Fig. 4 (a) (b), (c) and (d) shows maximum inter storey drift in buildings as per equivalent static method and response spectrum method in X and Y directions.

3.2. Base shear

Comparisons of base shear for all buildings have been shown in Fig. 5.

3.3. Forces in beams and columns

Comparisons of shear force and bending moment in beams and columns at 4th floor for all buildings have been shown in Fig. 6 (a), (b), (c), (d) and (e).

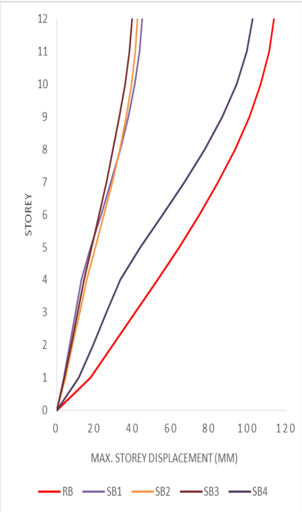

Fig. 3 (a) EQX displacement

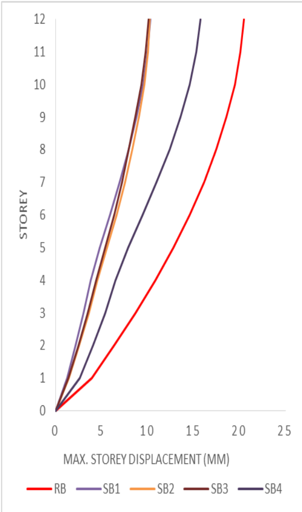

Fig. 3 (b) RSX displacement

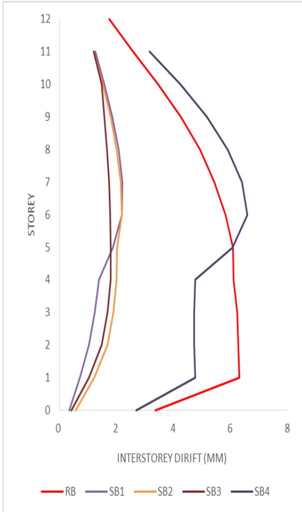

Fig. 4 (c) EQY Interstorey drift

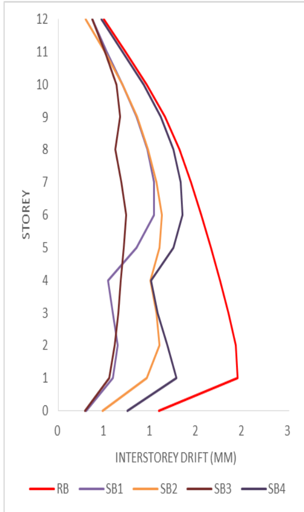

Fig. 4 (d) RSY Interstorey drift

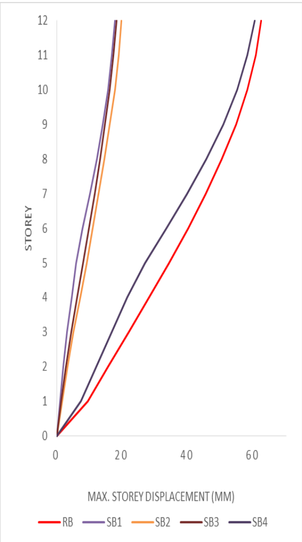

Fig. 3 (c) EQY displacement

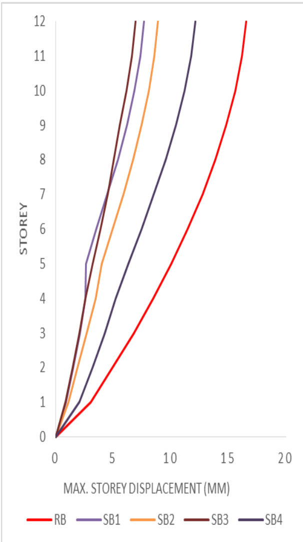

Fig. 3 (d) RSY displacement

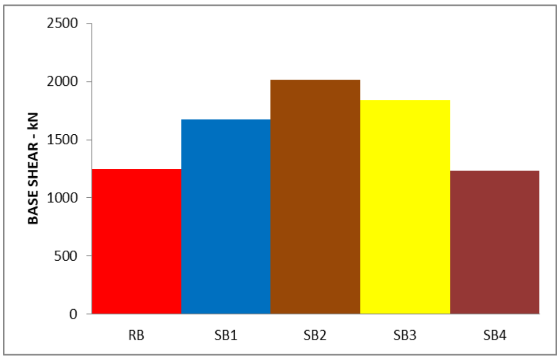

Fig. 5 Base shear comparison

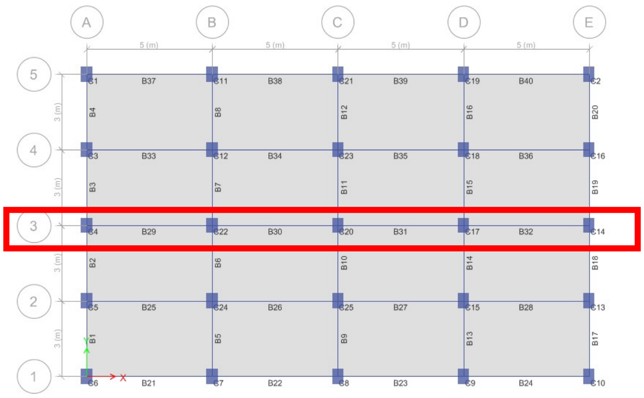

Fig. 6 (a) Beams and columns in plan for comparison

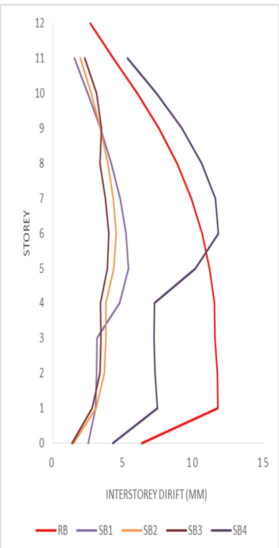

Fig. 4 (a) EQX Interstorey drift

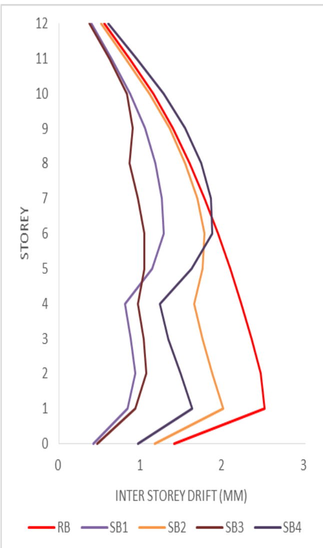

Fig. 4 (b) RSX Interstorey drift

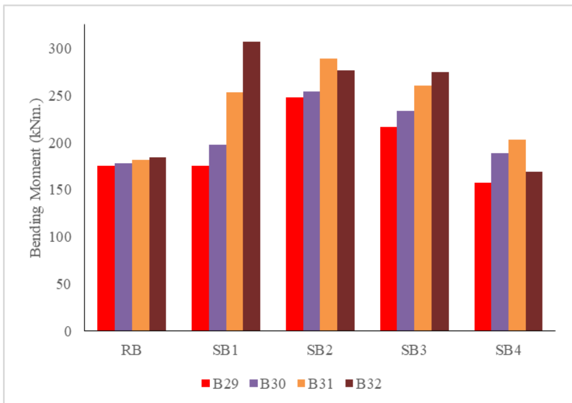

Fig. 6 (b) Bending moments in beams

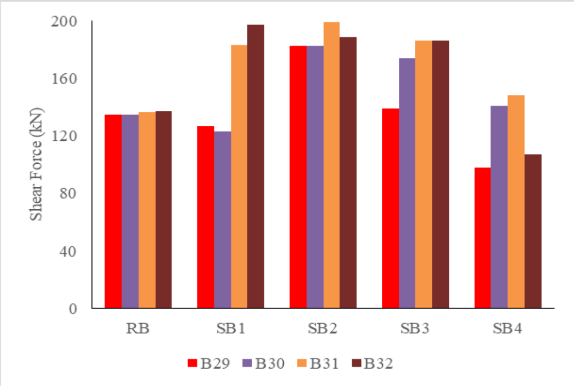

Fig. 6 (c) Shear forces in beams

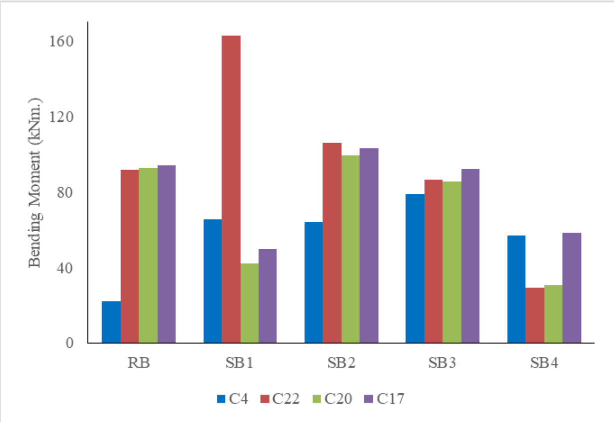

Fig. 6 (d) Bending moments in columns

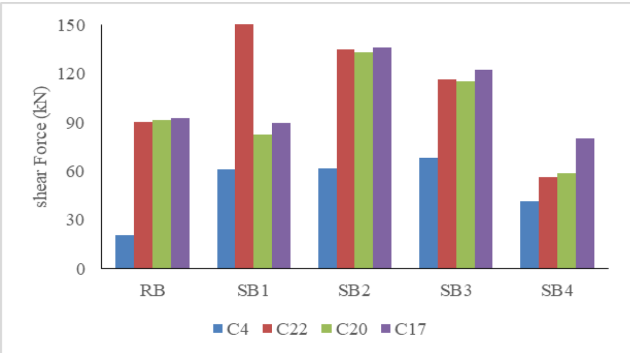

Fig. 6 (e) Shear forces in columns

3.4. Modal time period

Comparisons of modal time period for all buildings have been shown in Table 2.

Table–2. Modal time period

Mode	Time period (sec.)				
	RB	SB1	SB2	SB3	SB4
1	2.92	1.30	1.39	1.28	1.99
2	2.31	0.81	0.95	0.82	1.53
3	2.15	0.65	0.79	0.68	1.25

3.5. Modal mass participation factors

Comparisons of modal mass participation factors for all buildings have been shown in Table 3.

Table–3. Modal mass participation factors

Model	Direction	Modal Mass Participation Value (%)	Mode
RB	X	0.9201	4
	Y	0.9196	5
SB1	X	0.9071	6
	Y	0.8899	12
SB2	X	0.9231	6
	Y	0.9137	11
SB3	X	0.9155	6
	Y	0.9285	12
SB4	X	0.9320	7
	Y	0.9013	5

3.6. Percentage increase in cross sections

Comparisons of % increase in cross sections for all buildings keeping RB as reference, to be within permissible limits have been shown in Table 4 and Table 5.

Table–4. Cross sections size

Section	Section size (mm)				
	RB	SB1	SB2	SB3	SB4
Column	450 x 600	500 x 1000	500 x 1000	500 x 1000	450 x 650
Tie Beam	230 x 525	500 x 700	500 x 700	500 x 700	230 x 600
Typical Beam	230 x 500	500 x 900	500 x 900	500 x 900	230 x 600
Shear Wall	0	230 x4000	230 x 2500	230 x 3000	0

Table–5. % increase in cross sections size

Section	% increase in cross sections			
	SB1	SB2	SB3	SB4
Column	85.19	85.19	85.19	8.33
Tie Beam	189.86	189.86	189.86	16.67
Typical Beam	291.3	291.3	291.3	16.67

3.7. Concrete quantity

Concrete quantities for all buildings have been calculated excluding foundation and are shown in Table 6 and Fig. 7.

Table–6. Concrete quantity

Section	Concrete quantity in m^3			
	SB1	SB2	SB3	SB4
Column	254.06	331.70	391.68	361.69
Beam	208.54	439.38	524.76	482.07
Wall	0.00	34.63	21.64	25.97
Slab	388.69	259.12	323.90	291.51

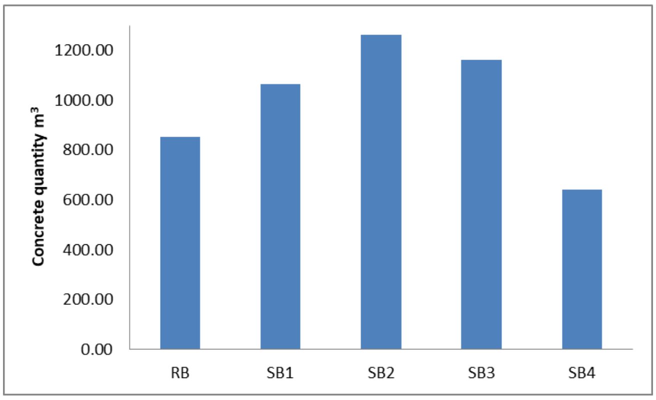

Fig. 7 Total concrete quantity

4. Conclusions

- Maximum storey displacements in X and Y direction for all buildings obtained by static equivalent method are approximately 76% and 61% higher than response spectrum method.
- Inter storey drifts in X and Y directions for all buildings obtained by static equivalent method are approximately 71% and 60% higher than response spectrum method.
- Bending moments in beams and columns in buildings with setbacks are approximately 30% and 13% higher at the setback level than in regular building.
- Shear forces in beams and columns in buildings with setbacks are approximately 18% and 30% higher at the setback level than in regular building.
- Number of modes required to attain 90% mass participation in regular building are lesser as compared to buildings with vertical setbacks.
- Total concrete quantity obtained in buildings with vertical setbacks is approximately 21% higher than regular building due to increase in cross section sizes and incorporation of shear walls.
- Hence, performance of buildings with vertical setbacks reduces as compared to regular building during seismic events.

Disclosures

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