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# Dynamic Response of Symmetric and Asymmetric Setback Buildings

**Thejaswini R. M., L. Govindaraju, V. Devaraj**

***Abstract: Numerical studies have been carried out to study the dynamic behaviour of a five-storey regular building, symmetric setback and asymmetric setback buildings having three bays along longitudinal direction and one bay along transverse direction. The objective of the study is to compare the irregularity indices with respect to different codal provisions such as IS:1893-2016, Euro Code 8-2004 and ASCE 7.05-2005 as well as with the expressions proposed by Karavasilis et al. (2008), and Pradip sarkar et al.(2010). These buildings are subjected to seismic excitations with time history analysis and the response parameters such as fundamental period of vibration of the structures, displacements and storey drifts were evaluated.***

***Keywords: Regular building, Symmetric setback building, Asymmetric Setback building.***

## I. INTRODUCTION

It is widely accepted that the structural behaviour of buildings during high intensity earthquakes depends on mass, stiffness and strength distributions both in plan and in elevation. The failure in the multi-storey building due to seismic loading generally initiates at the location where there is a weakness in the building. This weakness mostly occurs due to the presence of irregularities in stiffness, strength and mass in a building.

Stepped building frames with vertical geometric irregularity are becoming increasingly popular in modern multi-storey building construction. This is because of their functional and aesthetic architecture. In particular, such a stepped form provides for adequate daylight and ventilation for the lower storeys in an urban locality with closely spaced tall buildings. Fig. 1 shows a typical example of a setback buildings and these buildings needs to be checked for safety during earthquakes.

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As per IS 1893:2016 (Part I), vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 125% of that in its adjacent storey.

Presently, the behaviour of a five storey M25 grade R.C buildings with vertical irregularities have been studied when subjected to earthquake loads numerically. Fig. 2 shows the elevation of building geometries considered for study along with their plan at the base level (Fig. 3). Here ‘RB’ indicates regular building, ‘SSB’ for symmetric setback building and ‘ASB’ for asymmetric setback building. All these buildings have a uniform storey height of 3m.

**Fig. 1.Setback buildings(http://www.google.com).**

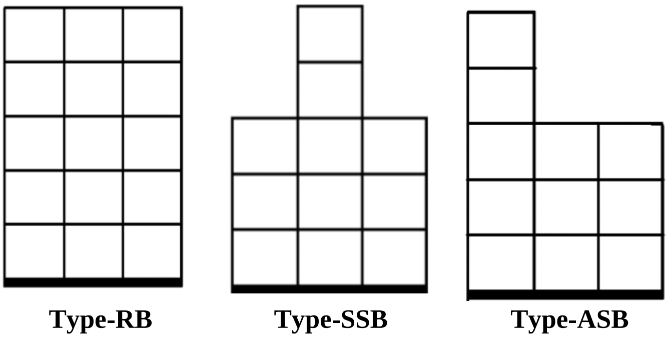



**Fig 2: Typical building elevations for five-storey variants (RB, SSB andASB).**

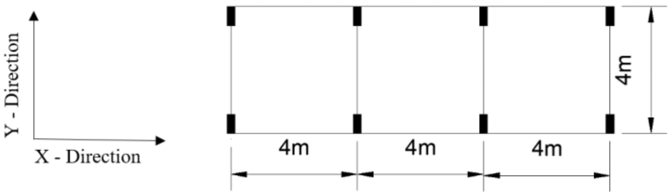



**Fig. 3. Plan of the building along with column orientation**

Vertical irregularities are characterized by vertical discontinuities in the geometry, distribution of mass, stiffness and strength. Setback buildings are a subset of vertically irregular buildings where there are discontinuities with respect to geometry. However, geometric irregularity also introduces discontinuity in the distribution of mass, stiffness and strength along the vertical direction. The irregularities of the buildings shown in Fig. 2 are computed and analysed.

## II. COMPUTATION OF IRREGULARITY INDEX

The irregularity of setback buildings shown in Fig. 2 are categoraised according to IS: 1893-2016, ASCE 7.05-2005, Euro code 8-2004, Karavasilis et al. (2008*)* approach, and Pradip sarkar et al.(2010) approach. Fig. 4 illustrates the computation of irregularities according to IS: 1893-2016,ASCE 7.05-2005 and Euro code 8-2004.

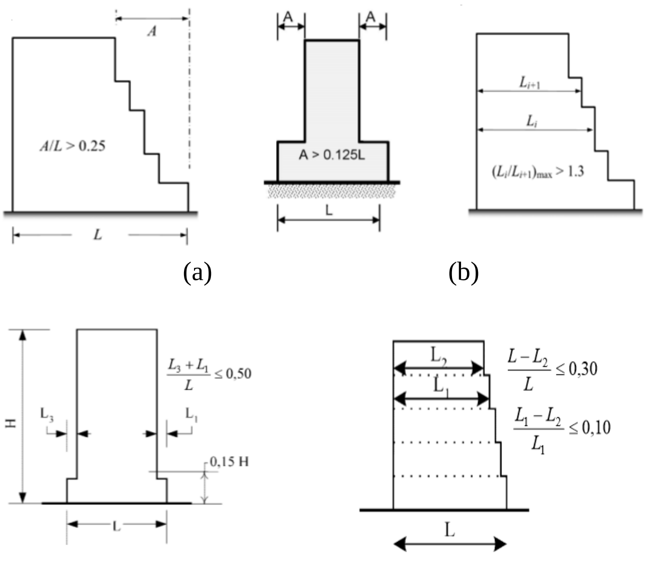



**Fig. 4. Vertical geometric irregularity according to (a) IS: 1893-2016, (b) ASCE 7.05-2005 and (c) Euro code 8-2004.**

Karavasilis et al., (2008) proposed an alternative approach to quantify the irregularity in a building frame due to the presence of steps (Fig. 5). They proposed two irregularity indices for stepped buildings, '$ø$'$_s$, and '$ø_b$' (for storey-wise and bay-wise stepping respectively) as given in (1) and (2) and 1(b).

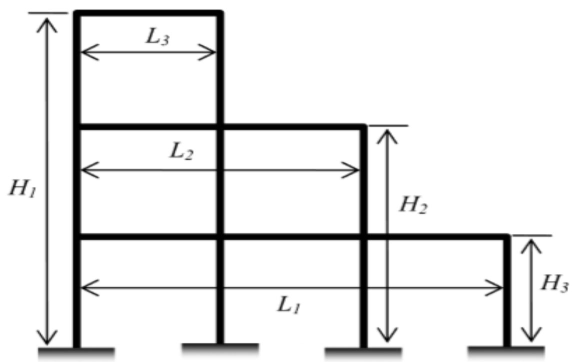



**Fig. 5. Vertical geometric irregularity according to Karavasilis et al(2008) approach.**

$$\emptyset_s = \frac{1}{n_s-1}\sum_{1}^{n_s-1}\frac{L_i}{L_i+1} \qquad (1)$$

$$\emptyset_b = \frac{1}{n_b-1}\sum_{1}^{n_s-1}\frac{H_i}{H_i+1} \qquad (2)$$

Pradip sarkar et al.,(2010)proposed a new approach for quantifying the irregularity in stepped building. It accounts for properties associated with mass and stiffness distribution in the frame. They proposed a measure of vertical irregularity, called 'regularity index', wich is given in (3).

$$\eta = \frac{\Gamma_1}{\Gamma_{ref}} \qquad (3)$$

Where, $\Gamma_1$ is the 1st mode participation factor for the setback building frame under consideration and $\Gamma_{ref}$ the 1st mode participation factor for the similar regular building frame without steps.

The irregularity index computed for setback buildings shown in Fig. 2 as per IS: 1893-2016 and Euro code 8-2004 are presented in Table I and Table II respectively. As per ASCE 7.05-2005 vertical geometric irregularity is defined to exist where the horizontal dimension of the seismic force-resisting system in any story is more than 130% of that in an adjacent story. The irregularity index calculated for setback buildings shown in Fig. 2 as per ASCE 7.05-2005 are given in Table III. Table IV and Table V gives the computed irregularity indices as per Karavasilis et al.(2008)approach, and Pradip sarkar et al.(2010) approach respectively.

**Table-I: Calculation of Irregularity Index as per IS 1893-2016.**

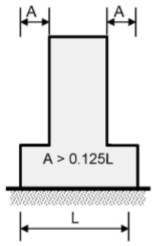
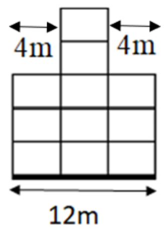
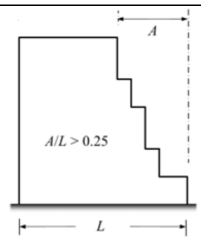
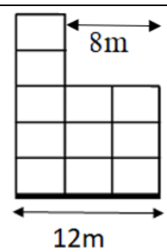
| Sl. No. | Vertical Irregularity calculation as per IS:1893-2016 | Vertical Irregular buildings | Calculation of Irregularity Indicies |
|---|---|---|---|
| 1 |  |  | L=12m<br>A=4m<br>Irregularity Index=A/L= 0.33 |
| 2 |  |  | L=12m<br>A=8m<br>Irregularity Index=A/L= 0.66 |

**Table-II: Calculation of Irregularity Index as per Euro Code 8-2004**

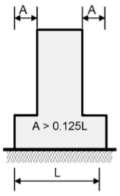
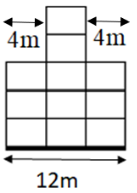
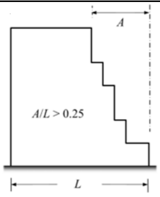
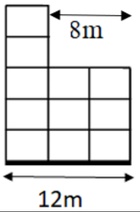
| Sl.No. | VerticalIrregularity calculation as per Euro Code 8-2004 | Vertical Irregular buildings | Calculation of Irregularity Indicies |
|---|---|---|---|
| 1 |  |  | L=12m<br>$L_1$=4m<br>$L_3$=4m<br>Irregularity Index = $\frac{L_3+L_1}{L}$ = 0.66 |
| 2 |  |  | L=12m<br>$L_1$=4m<br>$L_2$=4m<br>Irregularity Index $=\frac{L-L_2}{L}$ = 0.66 |

**Table-III: Calculation of Irregularity Index as per ASCE 7.05-2005**

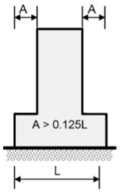
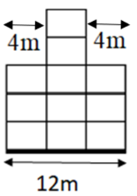
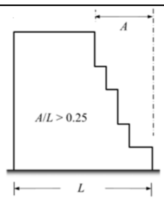
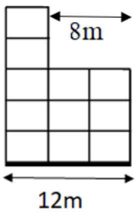
| Sl.No. | VerticalIrregularity calculation as per ASCE 7.05-2005 | Vertical Irregular buildings | Calculation of Irregularity Indicies |
|---|---|---|---|
| 1 |  |  | $L_i$=12m<br>$L_{i+1}$=4m<br>Irregularity Index =<br>$L_i$ / $L_{i+1}$=3 |
| 2 |  |  | $L_i$=12m<br>$L_{i+1}$=4m<br>Irregularity Index =<br>$L_i$ / $L_{i+1}$=3 |

**Table-IV: Calculation of Irregularity Indexas per Karavasilis et al., (2008) approach**

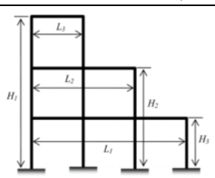
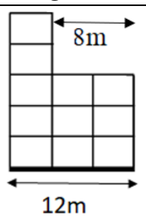
| Sl.No. | VerticalIrregularity calculation as per Karavasilis et al.,(2008) | Vertical Irregular buildings |
|---|---|---|
| 1 |  |  |
| **Calculation of Irregularity Indicies** | | |
| $\phi_s = \frac{1}{n_s-1}\sum_{1}^{n_s-1}\frac{L_i}{L_i+1}$, $\phi_s = \frac{1}{5-1}[\frac{12}{12}+\frac{12}{12}+\frac{12}{12}+\frac{12}{4}]$=1.5, | $\phi_b = \frac{1}{n_b-1}\sum_{1}^{n_b-1}\frac{H_i}{H_i+1}$, $\phi_b = \frac{1}{3-1}[\frac{15}{9}+\frac{9}{9}]$ =1.33 | |

**Table-V: Calculation of Irregularity Index as per Pradip sarkar et al.(2010) approach**

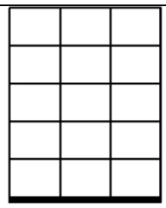
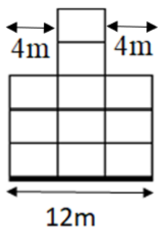
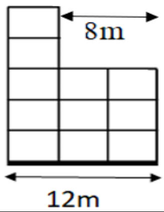
| Sl.No. | VerticalIrregularity calculation as per Pradip sarkar et al (2010) | Vertical Irregular buildings | Calculation of Irregularity Indicies |
|---|---|---|---|
| 1 | First Modal participation factor of reference building $=\Gamma_{ref}$ =14.32KN-m |  | $\eta = \frac{\Gamma_1}{\Gamma_{ref}}$=1 |
| 2 | First Modal participation factor of setback building $=\Gamma_1 = 12.21$KN-m |  | $\eta = \frac{\Gamma_1}{\Gamma_{ref}}$=0.85<br>3 |
| 3 | First Modal participation factor of setback building $=\Gamma_1$ =12.267KN-m |  | $\eta = \frac{\Gamma_1}{\Gamma_{ref}}$=0.856 |

Table VI shows comparision of Irregularity indices which are calculated as per IS: 1893-2016, ASCE 7.05-2005, Euro Code-8(2004), Karavasilis et al (2008) approach and Pradip sarkar et al (2010) approach.

From Table VI it is observed that irregularity indices for buildings SSB and ASB are similar as per Euro Code-8(2004) and Pradip sarkar et al(2010) approach but it is not similar in comparision with IS: 1893-2016 code.

**Table-VI: Comparision of the irregularity indices for setback buildings**

| Building discreption | IS: 1893 - 2016 | ASCE 7.05 (2005) | Euro Code-8 (2004) | Karavasilis et al (2008) approach | | Pradip sarkar et al (2010) approach |
|---|---|---|---|---|---|---|
| | | | | $\phi_s$, | $\phi_b$ | |
| RB | 1 | 1 | 1 | 1 | 1 | 1 |
| SSB | 0.33 | 3 | 0.66 | - | - | 0.853 |
| ASB | 0.66 | 3 | 0.66 | 1.5 | 1.33 | 0.856 |

## III. SEISMIC RESPONSE ANALYSIS

The R.C. buildings shown in Fig.2 are analysed and designed according to IS: 1893(Part 1)-2016 and IS: 456-2000 in such a way that the first mode is obtained along longitudinal direction (X-axis). Live load is 3kN/m$^2$, floor finish of 1 kN/m$^2$, live load of 1.5kN/m$^2$ and floor finish of 2kN/m$^2$ were considered at inner floors and terrace floor respectively. Table VII shows the dynamic details of the buildings. Table VIII shows the details of the designed structural elements of the buildings. Plan of the building along with its column orientation is as shown in Fig 3.

**Table - VII: Dynamic Properties of the Building.**

| Sl.No. | Contents | Description |
|---|---|---|
| 1 | Structure | SMRF |
| 2 | Seismic Zone | V |
| 3 | Importance factor | 1 |
| 4 | Type of soil | I |

**Table -VIII: Details of Structural Elements of the Building.**

| Sl.No. | Contents | Description |
|---|---|---|
| 1 | Slab thickness | 150mm |
| 4 | Beams dimension | 300mm X 400mm |
| 2 | Columns dimension | 250mm X 600mm |

These buildings are modelled and analysed using FEM based software SAP v18. Mass by volume ratio of these buildings is computed as per Vivek Hirave and Mahesh Kalyanshetti (2018) and are presented in Table IX. Time period and frequency are indicated in Table X.

**Table- IX: Mass by volume ratios of all the Buildings**

**(Vivek Hirave and Mahesh Kalyanshetti, 2018)**

| Sl.No | Description | Mass/vol-ratio $(kg/m^3)$ |
|---|---|---|
| 1 | Type-RB | **339.7** |
| 2 | Type-SSB | 350.13 |
| 3 | Type-ASB | 350.13 |

**Table-X: Time period and frequency of all the Buildings.**

| Sl.No | Description | Time Period (Sec) | Frequency (Hz) |
|---|---|---|---|
| 1 | Type-RB | 0.733 | 1.36 |
| 2 | Type-SSB | 0.577 | 1.73 |
| 3 | Type-ASB | 0.582 | 1.72 |

Response spectrum analysis has been carried out and base shear has been computed along X and Y directions. Table XI shows the values of base shear.

**Table-XI: Base Shear of the respective Buildings.**

| Sl.No | Description | Base Shear along X-Axis(kN) | Base Shear along Y-axis(kN) |
|---|---|---|---|
| 1 | Type-RB | 115.46 | 157.21 |
| 2 | Type-SSB | 112.06 | 150.18 |
| 3 | Type-ASB | 112.40 | 150.29 |

Similarly, time history analysis has been carried out with an input motion of El-Centro(N-S) earthquake. Figure 6 indicates time history of El-Centro Earthquake which is having a time step of 0.02 seconds and peak ground acceleration of 0.318g.

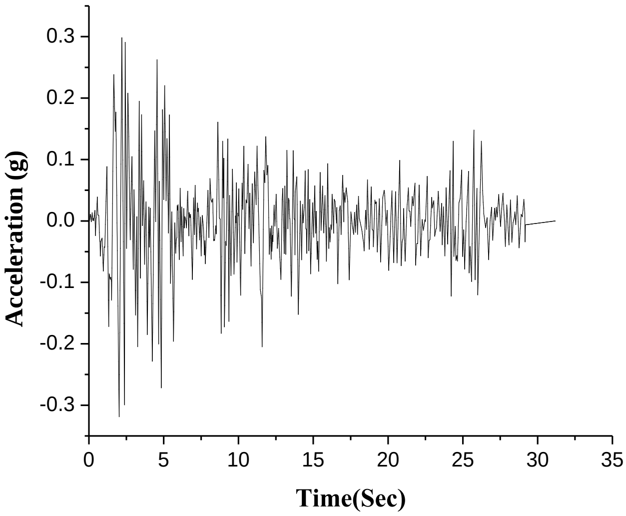



**Fig. 6: Time History of El-Centro Earthquake.**

Displacements of each floor are presented in Table XII for El-Centro (N-S) earthquake loading. Figure 7 and 8 illustrates the storey wise displacements and storey drifts respectively for different buildings.

**Table-XII: Storey Displacement of buildings due to El-Centro (N-S) Earthquake.**

| Storey No's | Storey Displacement of RB (mm) | Storey Displacement of SSB (mm) | Storey Displacement of ASB(mm) |
|---|---|---|---|
| 1 | 18.67 | 22.6 | 22.47 |
| 2 | 40.37 | 48.65 | 48.27 |
| 3 | 57.95 | 68.17 | 67.88 |
| 4 | 70.25 | 86.29 | 86.94 |
| 5 | 79.76 | 98.72 | 98.97 |

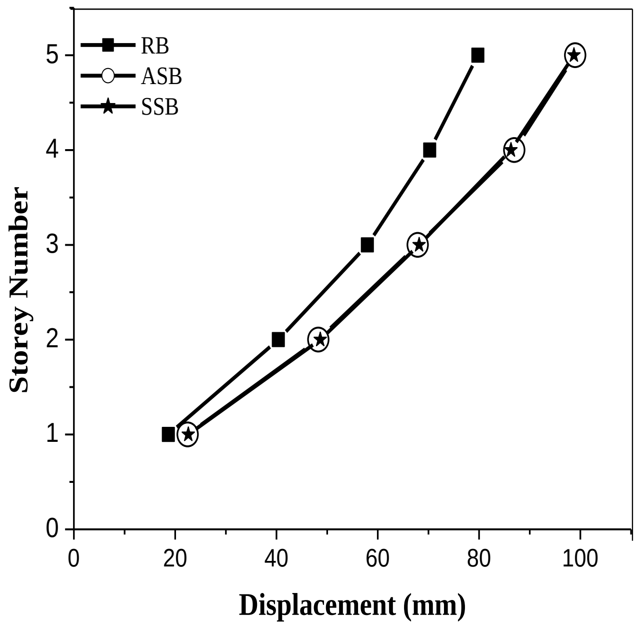



**Fig 7: Displacements Comparison of RB, ASB and SSB.**

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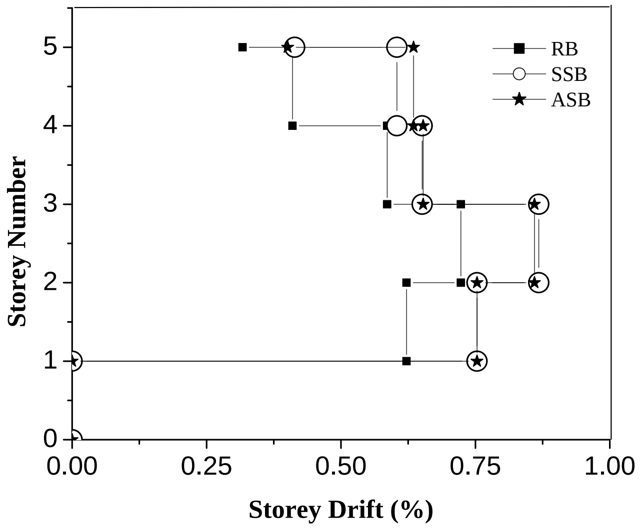


**Fig 8: Variation of different storey height for different buildings.**

From Table 12 it is observed that displacements of each floor of SSB and ASB are approximately equal, Fig. 8 and 9 also illustrates the same.

## IV. CONCLUSION

A comparative study has been carried out for symmetrical setback building (SSB) and asymmetrical setback building (ASB), having different irregularity index as per IS: 1893-2016 and similar irregularity index as per Euro Code-8(2004), ASCE 7.05(2005) and Pradip sarkar approach(2018). From the comparison of the lateral displacement and storey drifts due to seismic excitations, it is observed that behaviour of symmetrical setback building and asymmetrical setback building are similar even though having different irregularity index as per IS:1893-2016.

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**Dr. V. Devaraj**, Former Chairman(UVCE), Research Professor, Department of Civil Engineering, Dr.Ambedkar Institute of Technology, Bangalore-56, B.E.(UVCE, 1978), M.E. (IISc., 1980), PhD (2001,BangaloreUniversity). Member of professional bodies, ISTE, ISET, & GEO_RISK. Experience in teaching UG & PG students for 37 years. Guided 5 PhD, 140 P.G students. Areas of interests are Structural Dynamics, Earthquake Engineering, Structural Reliability, & Fuzzy Reliability.