EFFECT OF UNSYMMETRICAL SETBACKS IN ELEVATION OF RC BUILDINGS

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Abstract: This paper study focuses on the effect of vertical geometric irregularity i.e., unsymmetrical setbacks in reinforced concrete buildings. Different national codes given standards to quantify the geometric vertical irregularity which only depends on the horizontal dimension of lateral resisting system of structure. Realistic response of this irregular buildings can be appropriately studied from the nonlinear dynamics analysis that is Non-linear Time history Analysis (NLTHA) than Linear static procedures. In this study, two regular buildings of 6 and 9 storeys are considered for the reference and three different setbacks of 20, 60 and 80 percent of horizontal dimension are introduced one side in these designed regular buildings. Each regular building is analyzed and designed as per IS 1893: 2016 and IS 13920: 2016 clauses and in these designed regular buildings, the setbacks are introduced and with seven ensemble of ground motions, Nonlinear time History Analysis (NLTHA) is carried out with adoption of auto non-linear hinges as per ASCE 41-13 in SAP2000. The inelastic drifts are used to assess the performance of these considered regular and irregular buildings. From this Nonlinear analysis, it is observed that, as the percentage of setback increases the drift increased at corresponding storey level. Hinge formation at setback level reached more deformation capacity than the other storey levels, it indicates there is more seismic demand at that level.

***Index Terms* – Reinforced concrete building, Vertical irregularity, Non-Linear Analysis, Inelastic response.**

I. INTRODUCTION

Irregularities in the building leads to the uncertainty in behaviour of the structure. Because of increase in irregularities seismic demand of increases in specific element which is insufficient in strength and ductility leads to the early collapse under strong seismic motion. During earthquakes irregular buildings shows most unfavorable behaviour. Past earthquakes, have shown how the irregular or asymmetrical configuration buildings got greater damage compare to regular one. These irregularities may cause interruption of force flow and stress concentrations. Asymmetrical arrangements of mass and stiffness of elements may cause a large torsional force where the center of mass does not coincide with the centre of rigidity. Briefly these irregularities broadly divided into two types viz., Plan and vertical irregularity. This paper focus on the unsymmetrical setbacks in regular building that is vertical geometric irregularity. Different national codes such as IS 1893: 2016, ASCE 7-16, Eurocode 8 part 1: 2004 and NZS 1170.5: 2004 define and quantify this vertical geometric irregularity based on the horizontal dimension of the lateral force resisting system in any storey is more than the storey below. According to IS 1893: 2016 the vertical geometric irregularity exists if setback percent is more than 25 percent than the total lateral dimension of building.

Humar and Wright (1977) studied seismic response of steel frames with symmetric set-backs by using one ground motion with some modelling assumptions. They found story drifts are maximum in the tower parts of set-back structures than the regular buildings. Decreased story drifts were observed in the base parts of set-back building as compared to the regular building. The difference in elastic and inelastic story drifts between set-back and regular buildings depends on the level of story considered. At the location of irregularities, high displacements and ductility demands are observed. Sharon Wood (1992) studied the seismic behaviour of reinforced concrete frames with setbacks is investigated using the measured response of two small-scale models one with symmetrical setback and other with unsymmetrical setback. Linear dynamic analysis had done on these models to get the responses of the setback frames during earthquake simulations are compared with the uniform profile building. Following observations are made from his study: Frames with strong beams and weak columns (SBWC) experienced larger interstory drifts than those of frames with strong columns and weak beams (SCWB). Maximum accelerations at the top of the setback frames were approximately twice those measured at the top of the uniform SCWB frames were observed. Setback frames are not observed to be more susceptible to damage or more susceptible to higher mode effects than the frames with uniform profiles. Karavasilis (2008) proposed an alternative approach to quantify the irregularity in a building frame due to the presence of steps. The indices proposed in his study represent the irregularity in stepped frame in an improved manner compared to the code procedures. However, it is not convenient to use two indices to represent the irregularity of the same stepped building. Moreover, these indices are based on geometrical considerations alone. It is assumed that the column and beam sizes are uniform throughout their length and masses are uniformly distributed along the height and width of the frame. But this may not be the case in practical buildings.

To study the effect of unsymmetrical setback in buildings, in this study three regular buildings of 6 and 9 storeys are considered for the reference and three different setbacks of 20, 60 and 80 percent of horizontal dimension are introduced in these designed regular buildings. The inelastic behaviour of these buildings is obtained from Nonlinear Time History Analysis (NLTHA).

II. ANALYTICAL METHOD

The objective of this paper is approached by following sections, that is selection of building models, linear analysis and design of models considered and next to Nonlinear analysis part of this study.

2.1 Selection and description of models

In this analytical study, the effect of unsymmetrical setback in reinforced concrete (RC) building is studied by considering the three different heights viz., G+5 and G+8 RC regular building models. Three different setbacks of 20, 60 and 80 percent of horizontal dimension are introduced at one side in these regular buildings. As per IS 1893: 2016 if the setback percent is more than 25% then it is defined as vertical geometric irregularity exists. Table 1. Shows the description of the considered regular buildings model, seismic and load data considered in this study. Table 2. shows dimension of beams and columns considered for corresponding regular buildings such that satisfying the minimum requirements of IS 13920: 2016 of structural elements. Fig.1 Shows the building plan for all considered buildings with five bays of 4 m spacing in both X and Y directions. Fig. 2. Shows the building elevation of G+5 building and similarly, G+8 building is modelled.

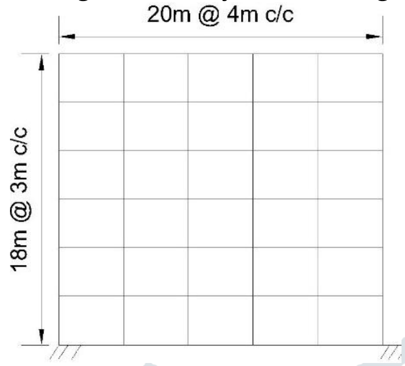

Figure 1. Elevation of G+5 building

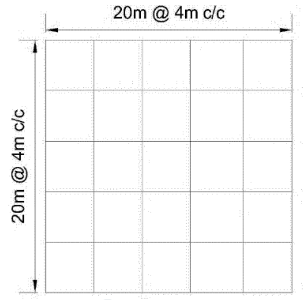

Figure 2. Plan of buildings

Table 1. Description of considered models.

1.	Type of Structure	Bare Moment Resisting Frame (MRF) of RC building.
2.	Seismic Zone	Zone IV
3.	No. of bays in X and Y	5 x 5
4.	Bay width dimensions	4 m in both X and Y directions
5.	Height of storey	3 m
6.	Slab thickness	150 mm
7.	Grade of concrete	M25
8.	Grade of steel Rebar	Fe415
9.	Unit weight of concrete	25 kN/m^3
10.	Type of Soil	Medium Soil as per IS 1893(Part 1)-2016
11.	Importance factor	1
12.	Response reduction factor	5
13.	Floor finish load	1 kN/m2
14.	Live load	3 kN/m2
15.	Roof live load	1 kN/m2

Table 2. Beam and column dimensions of considered regular buildings.

Dimensions in mm	G+5	G+8	G+11
Column (B x D)	450 X 450	500 X 500	550 X 550
Beam (B x D)	350 X 400	400 X 450	450 X 500

2.2 Analysis and design of models

Further, these three buildings are analyzed as per IS 1893: 2016 code clauses which includes the Equivalent static method (ESA) and Response spectrum method (RSA). As per IS 1893: 2016 for structural analysis, the moment of inertia in columns 70 percent and in beams 35 percent of gross moment of inertia is considered in this study.

2.2.1 Equivalent static method (ESA)

Equivalent static method is carried out with prescribed time period by IS 1893 2016 for RC bare MRF given as equation (1)

$$T = 0.075h^{0.75} \quad (1)$$

Here h = Direct height of building for regular building and it is weighted average of height; calculated based on plan area of storey levels in case of irregular building. Base shear (V_b) values are calculated as per IS 1893: 2016 for zone IV and medium type of soil as mentioned in the description of the building.

2.2.2 Free vibration analysis

After modelling the buildings, free vibration analysis characteristics are obtained. The mass source is defined with dead load plus appropriate live load factor (i.e. 0.25 in this study) as per IS 1893: 2016. Table 3. Shows the obtained fundamental time periods of considered regular buildings, as it can be observed as the height of building increases the time period decreases.

Table 3. Fundamental time period of regular buildings.

Regular buildings	G+5	G+8
Time peroid (secs)	1.13	1.468

2.2.3 Response spectrum analysis (RSA)

RSA is carried out for considered regular buildings, obtained the base shear ($\underline{V}_b$). These obtained RSA base shear values are scaled up with ESA base shear values (V_b) as shown in Table 4. The design eccentricity is accounted while performing the RSA as per IS 1893: 2016.

Table 4. Base shear values and scale factor of considered regular buildings for both x and y directions.

Regular building	ESA (kN)	RSA (kN)	Scale Factor in X and Y ($\underline{V}_b$/ V_b)
G+5	1037	504	2.06
G+8	1283	329	3.9

Once they are analyzed by applying base shear correction factor, with all required load combinations these buildings are designed and provided reinforcement as per IS 13920: 2016 code clauses.

III. NONLINEAR ANALYSIS

The elastic analysis gives a good indication of the elastic capacity of structures and indicates where first yielding will occur, it cannot predict failure mechanisms and account for redistribution of forces during progressive yielding. Inelastic analysis procedures help demonstrate how buildings really work by identifying modes of failure and the potential for progressive collapse. The use of inelastic procedures for design and evaluation is an attempt to help engineers better understand how structures will behave when subjected to major earthquakes, where it is assumed that the elastic capacity of the structure will be exceeded. This resolves some of the uncertainties associated with the code and elastic procedures. The term "stiffness" defines the fundamental difference between linear and nonlinear analysis. Stiffness is a property of a part or assembly that characterizes its response to the applied load. When a structure deforms under a load its stiffness changes, due to one or more of the factors like shape, material, support conditions.

Nonlinearity broadly divided as

1. Materially-Nonlinearity
   - Strains are indefinitely small.
   - The stress-strain relationship is nonlinear.
   - It is linear analysis until the yield point has not been reached.
2. Geometric-Nonlinearity
   - That is "p-delta" effect.
   - Additional forces and moments in the members induced due to large displacements change i.e., in geometry.

Broadly classification of nonlinear analysis

1. Non-linear static analysis
2. Non-linear Dynamic analysis

In this study, the Nonlinear Time History Analysis (NLTHA) is adopted to evaluate the inelastic behaviour of buildings. From the literature survey, it is observed that Nonlinear static analysis doesn't give the reliable results of vertical irregular buildings. Default nonlinear hinges of ASCE 41-13 of beam and columns are used in this study. These regular buildings are analyzed and designed, to study the effect of setback in RC buildings three percentages viz., 20, 60 and 80 of the lateral dimension are introduced in these regular designed buildings. In G+5 R, R indicates regular building and S1 indicates 20 percent setback building similarly, 60 percent as S2 and 80 percent as S3 are designated as shown in Fig. 3. Similarly, same nomenclature given to G+8 regular and irregular buildings.

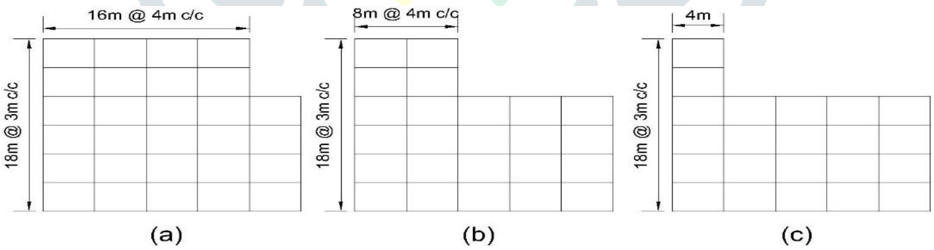

Figure 3. Irregular buildings with setbacks in elevation at different levels (a) G+5 S1 (b) G+5 S2 and (c) G+5 S3.

As mentioned in the section of the design of buildings, these regular buildings are designed for all load combinations as per IS 1893: 2016. The grouping of beams was done based on the reinforcement provided than the required reinforcement obtained from the analysis and satisfying clauses of reinforcement in beams and column as per IS 13920: 2016.

3.1 Selection of time histories

According to IS 1893: 2016 the selected time histories must be compatible with the response spectrum which are considered for the given soil type and zone. In this study, seven-time histories as shown in Table 5 are considered and scaled to the response spectra of zone IV and medium type soil of IS 1893: 2016. Figure 4. Shows the Pseudo acceleration response spectrum of considered above time histories.

Table 5 Time history data.

Time history	**Scaled PGA**
El-Centro site earthquake	0.28g
Loma Prieta earthquake	0.26g
Parkfield earthquake	0.26g
Kern County Earthquake	0.28g
Imperial Valley Earthquake	0.27g
Oakland Earthquake	0.27g
San Fernando Earthquake	0.27g

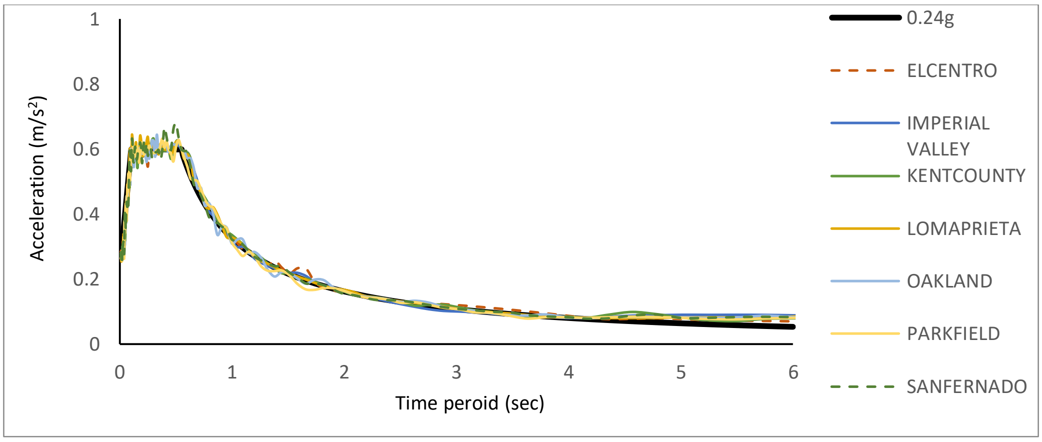

Figure 4. Pseudo-Acceleration Response spectrum.

3.2 Non-Linear Time History Analysis

Non-Linear time history analysis can be performed with Fast Nonlinear Analysis (FNA) in this method only nonlinear material behaviour in link objects is considered; frame hinge and geometric nonlinearity are excluded and another method is Direct-integration time-history analysis in which it solves equations for the entire structure at each time step, as compared with a modal time-history analysis that uses the method of mode superposition. In this study, Direct-integration time history analysis is adopted and performed in SAP2000. By applying above considered seven histories in two principal directions, G+5 and G+8 of regular and irregular buildings are analysed with assigning the Nonlinear hinges to beam and column elements as per ASCE 41-13.

IV. Results And Discussions

From Nonlinear analysis the inelastic response i.e., maximum interstory drifts are obtained which are subjected to the seven-time histories ensembles as mentioned in earlier section. Following Figures 5 to 11 shows the inelastic response i.e., maximum interstorey drifts of G+5 regular and irregular buildings. In each figure median of all seven-time histories response median is also represented. Here only G+5 regular and irregular buildings inelastic response figures are shown as the similar response is observed in G+8 buildings. So, median inelastic maximum interstorey drift of both G+5 and G+8 buildings are in figures 12 to 15. Mostly in X direction all irregular buildings performed as regular buildings, but in Y direction the effect of setback clearly depicted. As the percentage of setback increases in regular building, the interstorey drift is increases in both X and Y directions when compared to regular building. There is more interstorey drift in Y direction than in X direction which can be observed from Figures 6 to 11. At level of setback in building there is more drift is observed from following figures. G+5 S3 that is 80% setback building has more interstorey drift when compared to regular G+5 R, S1 and S2 buildings. The hinges reach upto the Life safety (LS) state in all regular buildings of beam and column elements, it represents that sufficient reinforcement is provided and favourable collapse mechanism is observed. At level of setbacks the hinges deformation capacity reached upto Immediate occupancy (IO) state. So, median of maximum interstorey drifts of G+5 and G+8 buildings are shown in Figures 12 to 15. In Figures 12 to 15, it can observe that S3 buildings shows the maximum interstorey drift than the lesser setback buildings. Interestingly the G+5 S1 shows the interstorey greater than the G+5 S2, so the vertical geometric irregularity exists with the modal mass participation, it cannot define with only one parameter with lateral dimension that is setback percent.

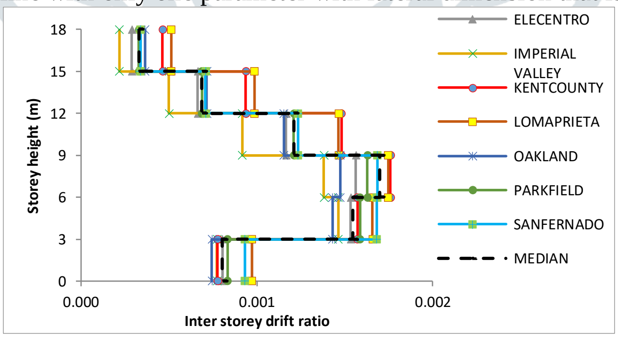

Figure 5. Maximum Interstorey drift of G+5 R buildings in X and Y direction

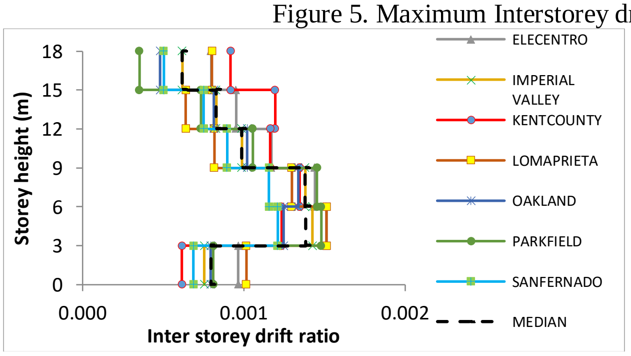

Figure 6. Maximum Interstorey drift of G+5 S1 buildings in X direction

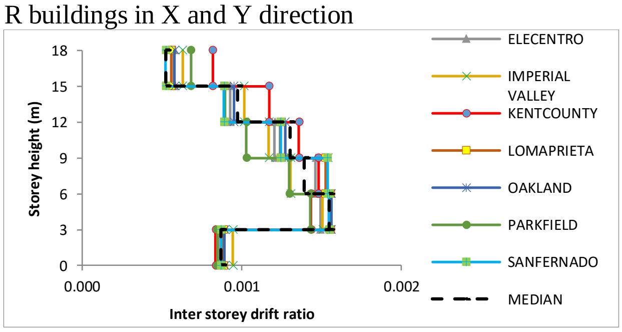

Figure 8. Maximum Interstorey drift of G+5 S2 buildings in X direction

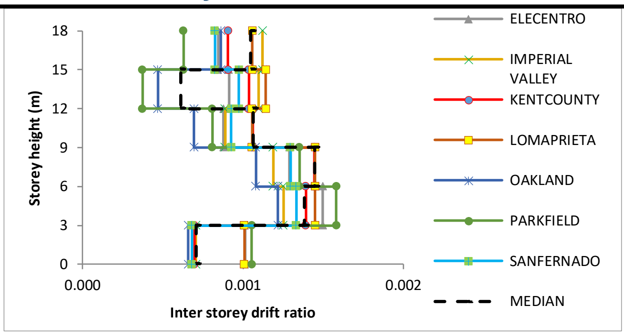

Figure 10. Maximum Interstorey drift of G+5 S3 buildings in X direction

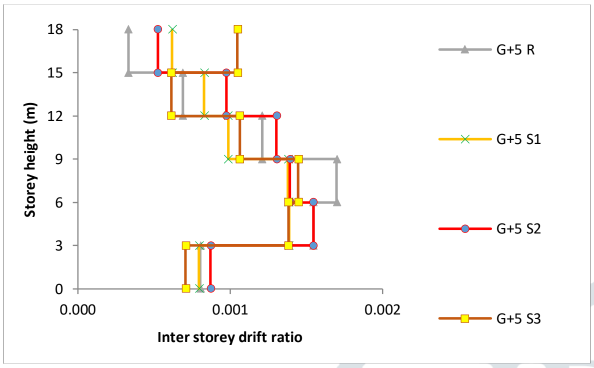

Figure 12. Maximum Median Interstorey drift of G+5 R, S1, S2 and S3 buildings in X direction

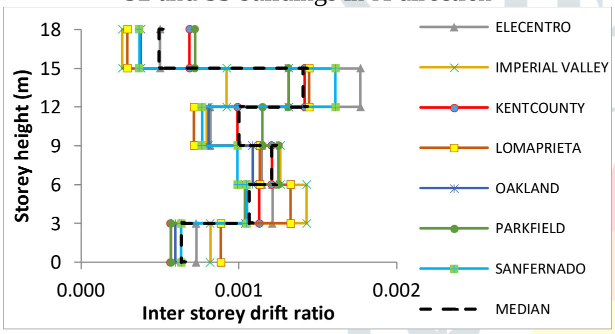

Figure 7. Maximum Interstorey drift of G+5 S1 buildings in Y direction

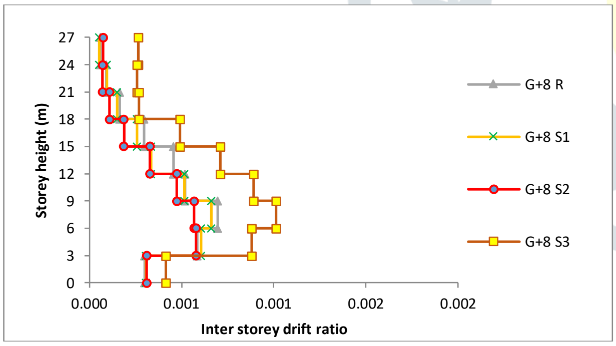

Figure 14. Maximum Median Interstorey drift of G+8 R, S1, S2 and S3 buildings in X direction

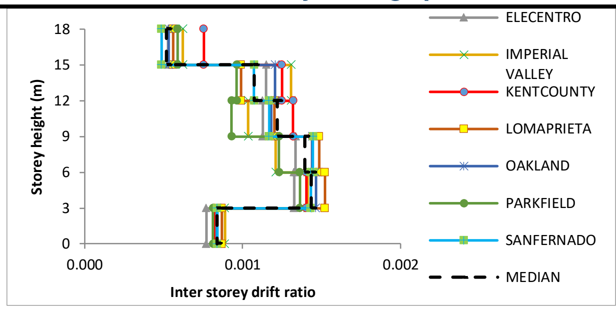

Figure 9. Maximum Interstorey drift of G+5 S2 buildings in Y direction

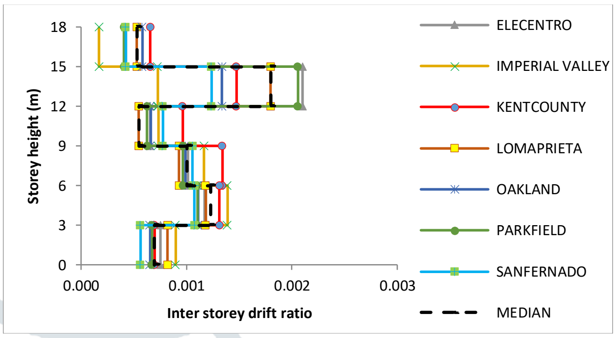

Figure 11. Maximum Interstorey drift of G+5 S3 buildings in Y direction

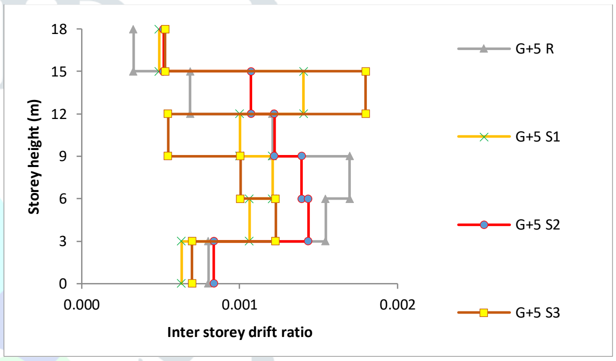

Figure 13. Maximum Median Interstorey drift of G+5 R, S1, S2 and S3 buildings in Y direction

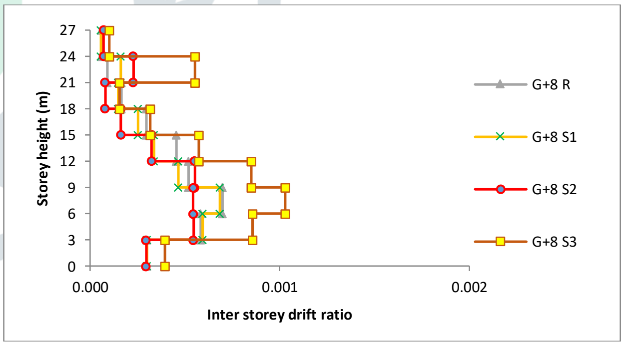

Figure 15. Maximum Median Interstorey drift of G+8 R, S1, S2 and S3 buildings in Y direction

V. CONCLUSIONS

By introducing the setbacks in the regular building following conclusions can be drawn:

- The effect of setbacks is observed in other direction rather than in the direction of setbacks introduced in the building, in this study the setbacks introduced in X direction of building the response in X direction moreover similar to the regular building. In Y direction we can observe the effect of setbacks.
- As the setback percent increases, more inelastic inter storey drift is observed at level of setback introduced in building when compared to regular building, so it indicates the more seismic demand at level of setbacks.
- In storeys below the setback level, there is reduction in inelastic interstorey drift is observed in irregular buildings.
- Deformation capacity of hinges maximum reached upto Immediate Occupancy (IO) state in beam and column elements at the level of setbacks. This suggests that from linear analysis the buildings designed are performed very well by following the codal provisions of structural analysis as per IS 1893: 2016 and design as per 13920: 2016.

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