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COMPARATIVE STUDY OF DIFFERENT VERTICALLY IRREGULAR HIGH RISE BUILDINGS IN HIGH SEISMIC ZONE

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Abstract - *Vertically irregular buildings are very common across the globe for its functional and aesthetic considerations. Irregularity results from a number of causes such as extra heavy mass in one or more storey, large openings at ground storey for parking, abrupt change in stiffness, different storey heights etc. Regular buildings with uniformly distributed mass and stiffness perform relatively well during earthquake than the irregular buildings. Earthquake code IS 1893 (part 1): 2016 suggest special attention to the design of irregular structures and forbid the construction of some of these buildings in active seismic zones. In this paper the effects of geometric, mass irregularity on the seismic performance is studied under the ductility parameter and compared with regular building. Structures are chosen for performing response spectrum and static pushover analysis to study its performance during earthquake. Results showed the drift is highest in stepped building with value within the permissible limit. While comparing the periods and ductility at the performance point, the regular shaped buildings are more ductile than the geometrical irregular buildings. But the global ductility is highest in setback buildings.*

Key Words: Vertical irregularity, Performance point, Ductility ratio, Global ductility, Storey drifts

1. INTRODUCTION

Construction of modern high rise building started to meet various needs such as population requirement, high cost of land and even to showcase the economic status in the case of corporate buildings. Earlier these structures used to be regular in shape but nowadays with advancement in technology and materials, it is possible to construct buildings with varieties of plan, shape and size. These irregular buildings are very common across the globe for its functional and aesthetic considerations. Irregularity results from a number of causes such as extra mass in one or more storeys may be due to the presence of public gathering places such as gym, hall etc, and different storey heights, abrupt change in stiffness opted with respect to architectural needs. Soft storey building with large openings for parking is mostly preferred in apartments. Such buildings with discontinuity in mass and stiffness in plan or elevation are known as Irregular buildings. Performance level indicates the damage state of the building which gives idea whether the building is safe for occupation or level of repair needed and also about its serviceability condition after earthquake. Different performance levels require different design criteria. Hence one single design parameter cannot satisfy all performance objectives. Though these performance objectives may impose conflicting demands on strength and stiffness, one should not compromise life safety and collapse prevention. (Praveen and Madhavan 2018) checked the necessity of strengthening the building located in the revised seismic zone and other modification in the revised seismic code IS 1893:2016. It was found that the irregular building located in seismic zone above III need to be strengthened. (Titiksh 2018) discussed the effect of variety of irregularity on its seismic performance and found base shear of mass irregularity is more than the other hence to have less seismic force, mass should be reduced. (Ghosh and Debbarma 2017) examined the seismic performance of setback structures resting on plain ground and slope of a hill with soft storey configuration. To avoid the stiffness deficiency problem in case of open ground storey (OGS) author suggested replacing OGS columns by shear walls, RCFSTC and also by designing the OGS columns for 2.5 times the shear force and bending moment, these performed even better than fully infilled frames. (Avadhoot S Bhosale, Davis, and Sarkar 2018) checked the effectiveness of using the present irregularity indicators to evaluate the seismic risk and found setback model performed better than the other irregular model as well as the regular model. (Dutta et al. 2018)presented the effect of irregularity in terms of time period, base shear and concluded that the vulnerability in these buildings arise due to force or moment rather than the periods.

Fig -1: Soft storey collapse (Ground and intermittent storey)

In this work, the effects of different types of irregularity along the elevation on the seismic responses of moment resisting frames are investigated using nonlinear dynamic analysis. The buildings considered are high rise building with 30 stories taken to be located at high seismic zone (IV). All the parameters taken as per latest seismic code IS 1893 (part 1): 2016. Response spectrum as well as static push over analysis is performed to study its performance during earthquake.

1.1 Objectives

- To study the effect of irregular distribution of mass, stiffness on the seismic response of the high-rise building.
- To check the performance of the high rise vertical irregular buildings with regular buildings in terms of ductility as per IS 1893:2016 code.
- To assess the global ductility of the building for different vertical irregularity.

2. PROBLEM FORMULATIONS

The problem considered for the work is with reference to the IS 1893:2016(part 1). All the buildings considered have 30 storey and located in high seismic zone i.e., zone IV with medium soil type (Type B), designed as special moment resisting frame with response reduction factor 5, damping 5% and residential apartments with importance factor 1.2. Four models are modelled and analysed using ETABSv17.0.1 Software having the latest seismic code. Out of the four models three models has irregularity in mass and geometry and one model with regular features. All the models have plan dimension 18*18 m2. Typical storey height is 3.15m and bay width is 3m. Grade of steel is HYSD 500. Slab thickness is 0.15m. SDL for walls and floors are 10.8 kN/m2 and 2kN/m2 respectively. Live load unless mentioned is 2 kN/m2.

2.1 Model details

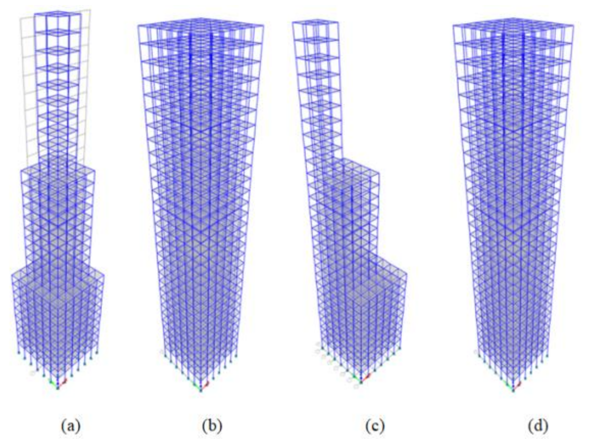

Fig -2: Building models (a) Set-back (b) Mass irregular (c) Step-back (d) Regular

1. Setback Model (SB): Two frames removed from all the sides for every ten storey making the building having setbacks at two stages as shown in Figure 2.(a).
2. Mass Irregular Model (M): Heavy mass of 5kN/m^2 at 10th and 25th storey (Figure.2.(b).
3. Step-back or stepped model (ST): Same as setback but frames are removed only from two sides as shown in Figure 2.(c).
4. Regular model (R): Model with uniform cross section and mass throughout the building refer Figure 2.(d).

Table -1: Section details of all models

Storey No	Grade of concrete (MPa)	SB Column size(m^2)	SB Max Pt (%)	M Column size(mm^2)	M Max Pt (%)
1-10	40	0.3X0.45 0.3X0.50 0.3X0.60	3.7 2.99 2.87	0.4X0.50 0.4X0.50	3.86 3.03
11-20	35	0.3X0.45 0.3X0.45	1.61 3.53	0.3X0.45 0.3X0.45	3.08 3.37
21-30	30	0.3X0.45	2.6	0.3X0.45 0.3X0.45	0.88 2.65

Storey No	Grade of concrete (MPa)	ST Column size(mm^2)	ST Max Pt (%)	R Column size(mm^2)	R Max Pt (%)
1-10	40	0.3X0.60 0.3X0.65 0.3X0.70	2.11 2.72 3.85	0.4X0.50 0.4X0.50	3.7 2.54
11-20	35	0.3X0.60 0.3X0.60	3.89 1.7	0.3X0.45 0.3X0.45	3.72 3.66
21-30	30	0.3X0.45	2.64	0.3X0.45 0.3X0.45	1.5 2.6

3. RESULTS AND DISCUSSIONS

3.1 Storey Drift

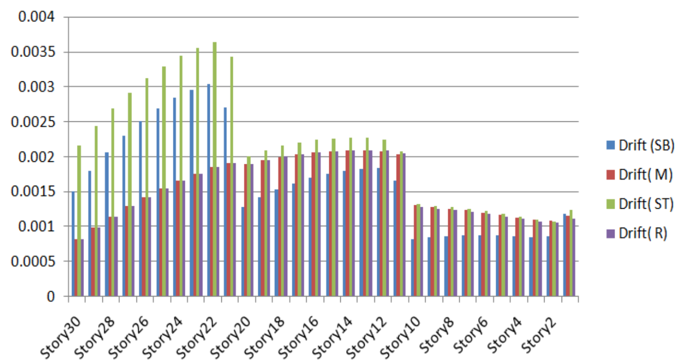

Chart -1: Storey drifts variations

- Chart -1 shows the storey drift variation in all the models. Highest drift value found in ST at 21st storey with value 0.003648m.
- None of the building crossed the storey drift value specified by the IS code i.e., 0.004*storey height.
- Drift values increased towards the top of the buildings having geometrically irregularity (SB and ST). While the effect is not significant in the regular geometry models (R and M).
- The mass irregular model did not show any significant variations in drift; it behaved more or less like the regular building. This indicates

geometric irregularity has much influence on drift than the mass irregularity.

3.2 Ductility ratio

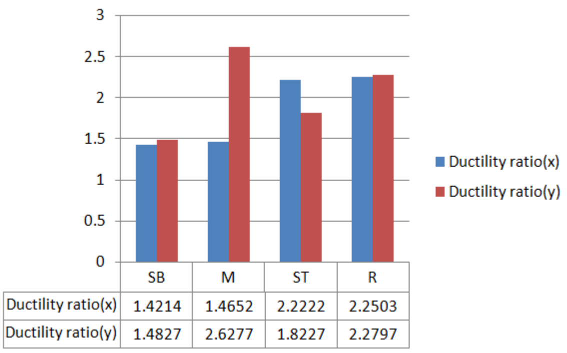

Chart -2: Ductility Ratio

- Chart-2 shows the ductility ratio variation in all the models. Ductility ratio is the ratio of maximum displacement by the yield displacement.
- Ductility ratio(X) of SB is 37% less, 35% less in M, 1.3% less in ST than R. This indicates the global yielding capacity of the all the irregular buildings are lesser than the regular building.
- Ductility ratio along Y direction is highest in M with value 2.6277 and least in SB with value 1.4827. In ST and R are 1.8227 and 2.2797 respectively.
- Ductility ratio(Y) of SB is 35% less, 15% more in M, 25% less in ST than R.
- Ductility ratio along Y is 4.31% more, 79% more, and 22% less, 1.3% more than in X direction for SB, M, ST and R respectively.

3.3 Joint displacements

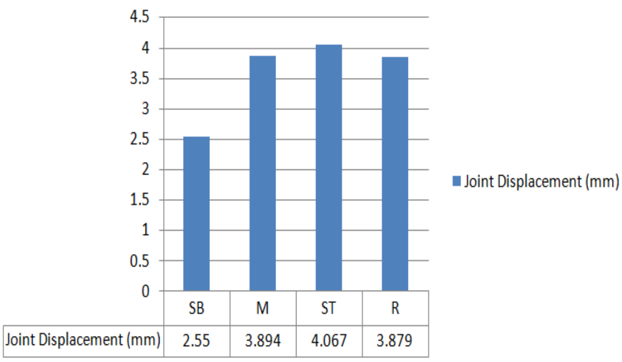

Chart -3: Joint displacement

- Chart -3 shows the joint displacements in all the models. Highest joint displacement found in ST with value 4.067mm and least in SB with value 2.55mm.
- M and R building have very close displacement value of 3.894mm and 3.879mm respectively.
- Joint displacement is 34.2% less, 0.39% more and 4.8% more than the R in SB, M, and ST respectively.

3.4 Pushover curve and performance point

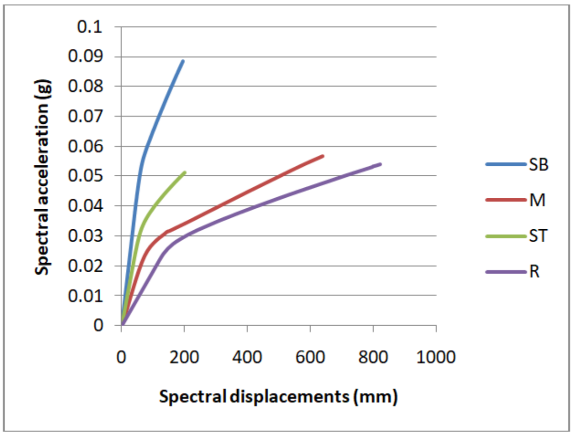

Chart -4: Pushover curve along X direction

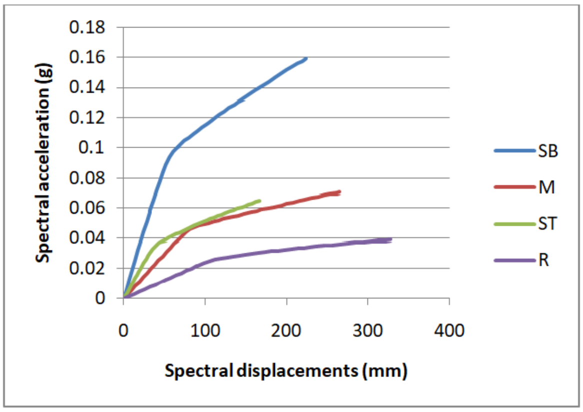

Chart -5: Pushover curve along Y direction

Table -2: Performance point

Building Type	Along X direction		Along Y direction	
	Sa(g)	Sd(m)	Sa(g)	Sd(m)
SB	0.096	0.0588	0.0597	0.1764
M	0.052	0.1152	0.0349	0.0215
ST	0.047	0.0802	0.0394	0.1005
R	0.036	0.2554	0.0364	0.3382

- The point at which the capacity spectrum meets the design spectrum is known as performance point. Demand is the representation of the ground motion.
- Capacity is the ability of the structure to withstand the demand or the ability of the building to deform beyond the elastic limit.
- Hence different earthquake will have different demand while capacity will vary with type or nature of the building.
- At performance point the capacity of the building meets the demand by the seismic force.

3.5 Global ductility

Table -3: Global ductility in all models

Building type	Ultimate displacements (m) U	Yield displacements (m) Y	Ductility=U/Y
SB(X)	0.36	0.0648	5.56
SB(Y)	0.36	0.0936	3.85
M(X)	0.36	0.1007	3.57
M(Y)	0.36	0.0895	4.02
ST(X)	0.36	0.0687	5.24
ST(Y)	0.36	0.0864	4.17
R(X)	0.36	0.1008	3.57
R(Y)	0.36	0.1165	3.09

4. CONCLUSIONS

- In the present project detailed analysis was performed on vertically irregular high-rise RC building by probabilistic approach and the conclusions are drawn as following:
- The comparison of time period suggests that the regular building and Mass irregular building is more ductile in comparison with the other types of building.
- The larger the drift, the less stiff the structure is. The story drift in Stepped building is greater in comparison with the setback, mass irregular and regular building. It is also observed that the story drift is higher in the upper part of the building. But in each case the drift value is within the permissible limit.
- Based on the results obtained from the performance point analysis in comparison with the regular building the displacement the mass irregular building is more ductile compared to setback building and stepped building along X direction and the same trend is observed along the Y direction as well and the other models are more stiffer compared to regular and mass irregular buildings.
- In comparison with the regular building the global ductility of setback building is the highest.

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