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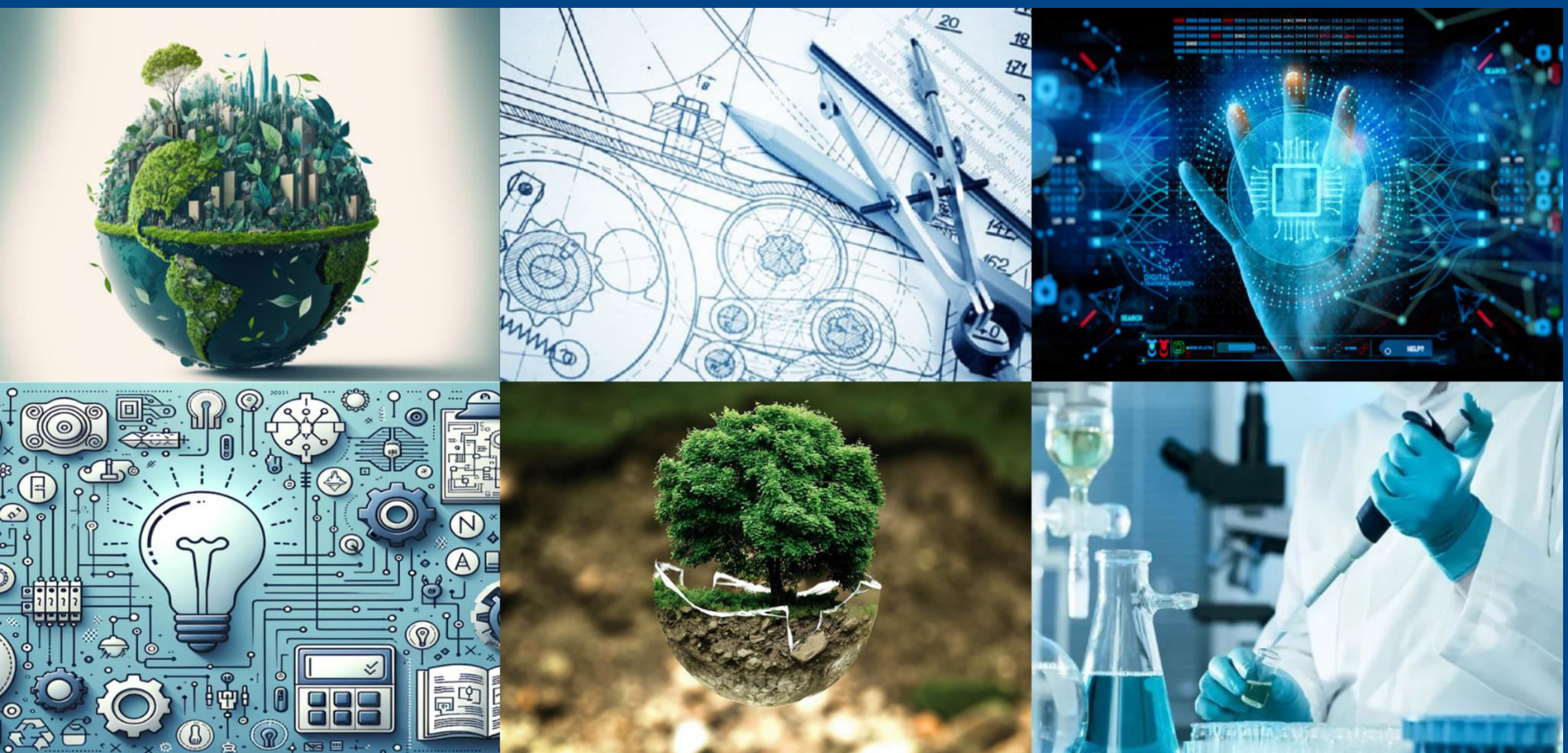

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Comparative Study of Behaviour of Vertically Irregular Building under the Influence of Seismic Load

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ABSTRACT: Architecturally Irregular buildings like setback buildings are characterized by staggered abrupt reductions in floor area along the height of the building, with consequent drops in mass, strength and stiffness. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the 'regular' building. The increasing number of damage after seismic ground motion has provided strong evidence that setback buildings exhibit inadequate behavior though they were designed according to the current seismic codes. Many investigations have been performed to understand the behavior of irregular structures as well as setback structures and to ascertain method of improving their performance. So, there is a need to study the seismic performance of setback structures designed by recent codes the adequacy of current seismic design requirements for setback buildings, and new design methods to improve the seismic response of setback buildings. It is possible to evaluate the seismic performance of setback building accurately using STAAD. Pro. Software. It is instructive to study the performance of static equivalent analysis methodology as well as other alternative methodologies for setback buildings and to suggest improvements suitable for setback buildings. After study all models in details it is concluded that consideration of the revised seismic codes provisions for geometric vertical irregularities seems to be essential to stipulate more restrictive limits or apply more accurate analytical procedures to predict the seismic performance of setback structures under the seismic excitations, especially for structures with critical setback ratios.

KEYWORDS: Architecturally Irregular structure, vertical irregularity, setback.

I. INTRODUCTION

During an earthquake, the ground shakes unpredictably in all directions, forcing buildings to sway and endure powerful inertial forces. To resist these forces, structures must be designed with strength to prevent collapse, ductility to absorb energy without breaking, and proper detailing to distribute seismic loads safely. Engineers follow seismic codes based on local earthquake risks and soil conditions to ensure buildings remain stable and functional, prioritizing life safety while minimizing damage.

In densely built urban areas, structures are often constructed very close to each other due to high land costs. During earthquakes, these adjacent buildings can collide a phenomenon called pounding leading to structural or architectural damage, or even collapse. This risk also applies to bridges and towers built in proximity. While modern seismic codes now mandate separation gaps between buildings, many older cities in earthquake-prone zones lack this precaution. Past earthquakes have demonstrated the severe consequences of pounding, prompting extensive research into its effects and mitigation strategies.

II. LITERATURE REVIEW

Earthquakes rank among the most destructive natural disasters, posing severe risks to populations in vulnerable regions—especially in critical facilities like nuclear plants, where failure is unacceptable. Yet, the primary cause of earthquake-related deaths isn't the ground shaking itself, but the failure of buildings and infrastructure. This underscores the critical role of civil engineers in designing earthquake-resistant structures to prevent collapses, save lives, and mitigate damage. Their work is essential to bridging the gap between natural forces and human safety.

Many of the researchers have adopted different method for design and analysis earthquake resisting structure of setback buildings. Some of which is presented under,

Sharon L, Wood, et al. They modelled the various symmetrical & unsymmetrical arrangement of setback in building. Over that they observed that Setback frame is not observed to be more susceptible to damage or more susceptible to higher mode effect than the frames with uniform profiles

I. J. Sharma et, al**.** Analyze seismic pounding effects between buildings and to observe the structural behavior in the post elastic range. For this, SAP 2000, a linear and non-linear static and dynamic analysis and design program for three dimensional structures has been used.

H. Shakib et al, have modelled one side setback building, which is investigated by probabilistic approach and also observed effect of two orthogonal ground motion with different setback ratio are assessed by studying. They applying Limit state capacities, mean annual frequencies of exceeding performances levels and confidence levels in meeting performance objectives. They conclude that Elasticity to global instability and assessment of code design setback structure by incremental dynamic analysis demonstrates the poorer performance of these tortionally coupled structure relative to regular structure depending upon the setback ratio values. Therefore, revision of seismic code.

Jack P. Moehle, et al. in this article, they perform combined experiment of two frame wall structure Using various method or analysis. They collect result on that; elastic static and dynamic method were superior to the elastic method in interpreting effects of the structural discontinuities. Vertical irregular building, Seismic response & Design of setback building. Experimental – Ductile moment resting reinforced concrete test structure. – A static lateral – load design method to improve performance is proposed.

I. J. Sharma et, al**.** Analyze seismic pounding effects between buildings and to observe the structural behavior in the post elastic range. For this, SAP 2000, a linear and non-linear static and dynamic analysis and design program for three dimensional structures has been used.

III. METHODOLOGY

Earthquakes generate complex, multidirectional shaking that spreads outward from the epicentre, creating unpredictable horizontal and vertical ground movements. These sudden motions force buildings to shake violently, creating powerful stress forces within their structural systems. To withstand these forces, buildings in earthquake-prone areas require specialized engineering that accounts for three key principles: structural integrity (strength), resistance to collapse (stability), and maintained functionality (serviceability). Modern seismic design approaches carefully evaluate both the expected intensity of potential earthquakes and their likelihood of occurrence to determine appropriate safety measures.

a) The methodology adopted to perform the seismic evaluation of the building requires an understanding of equivalent lateral force procedure also recognized as equivalent static procedure in literature.
b) In deep, knowledge of STAAD Pro software is required as the building was modelled in STAAD Pro and post analysis data obtained from it will be used in the design of the structure.
c) The seismic stability of the structure under the various load combinations in accordance with IS 1893-2016 (part 1)

This research focuses on simple rectangular frame structures with consistent floor heights and column spacing. The buildings were taken with different shapes and layouts to understand how design variations affect performance. Specifically, 6 types of stepped or setback buildings - some with uniform designs, others with more dramatic changes in their floor plans as they go taller are taken. The models ranged from 4 to 4 spans in the front/back (X) and side-to-side (Z) directions (each span being 4m wide and 3m deep), while maintaining 11 spans along the length (Y direction).

In standard construction practices across India and Europe, the spacing between columns typically ranges from 4 to 6 meters. For this study, we examined 10-story buildings (G+10) with uniform 3-meter floor heights. The research compared different architectural designs, including a conventional building without setbacks (R) alongside two modified versions featuring progressively smaller upper floors - S1 (25% reduction), S2 (50% reduction). These variations allowed us to analyze how different degrees of setback affect structural performance. Using STAAD.Pro

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software, we created detailed models of each design to systematically evaluate their behavior under various conditions. This approach helped us understand the practical implications of setback irregularities in multi-story buildings.

The earthquake ground motion is defined by the equivalent static analysis available in the software. The column sections defined for the frames satisfy both the requirements for strength and stiffness. All the selected models were designed with M-20 grade of concrete and Fe-415 grade of reinforcing steel as per Indian Standards.

Table 1: Building description

Sr. No.	DISCRIPTION	SPECIFICATION
1	Building Type	Reinforced concrete frame
2	Usage	Institutional Building
3	Number of stories	G+10
4	Plan dimension	16m X 12m
5	Building height	33m
6	Number of bay in X- Direction	4 Bay
7	Number of bay in Z- Direction	4 Bay
8	Number of bay in Y- Direction	11 Bay
9	Size of Beam	0.45m X 0.3m
10	Size of Column	0.45m X 0.45m

Table 2: Grade of Material

Sr. No.	DISCRIPTION	SPECIFICATION
1	Concrete	M20
2	Reinforcing Steel	Fe415

Modeling in STAAD Pro:

Table No. 3 Details of reference structure

Sr. No.	Description	Dimension
1	Plan area	16m X 12m
2	Height of building	33m
3	No. of bay in X	4 Bay
4	No. of bay in Z	4 Bay
5	Length	16m
6	Width	12m
7	Height	33m

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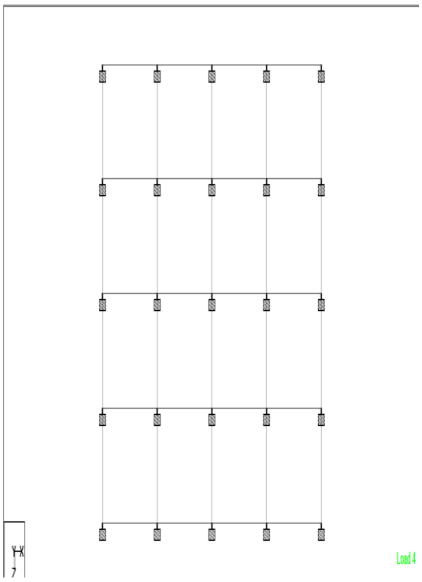

Figure 1: Plan of Reference Building Setback Critical Ratios

1) Reference Building (R1).

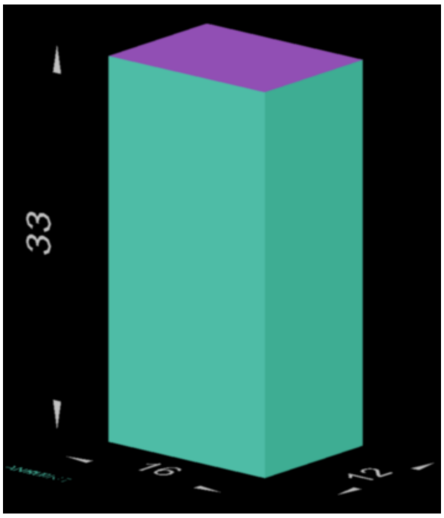

Figure 2: Dimension of building is 16mX12m in plan and 33m Height.

Table 4: Setback Critical Ratios S1

Sr. No.	Along plan area-RA	Along height-RH
1	RA=0.25	RH=3/8
		RH=6/5

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2) Setback building of type (S1).

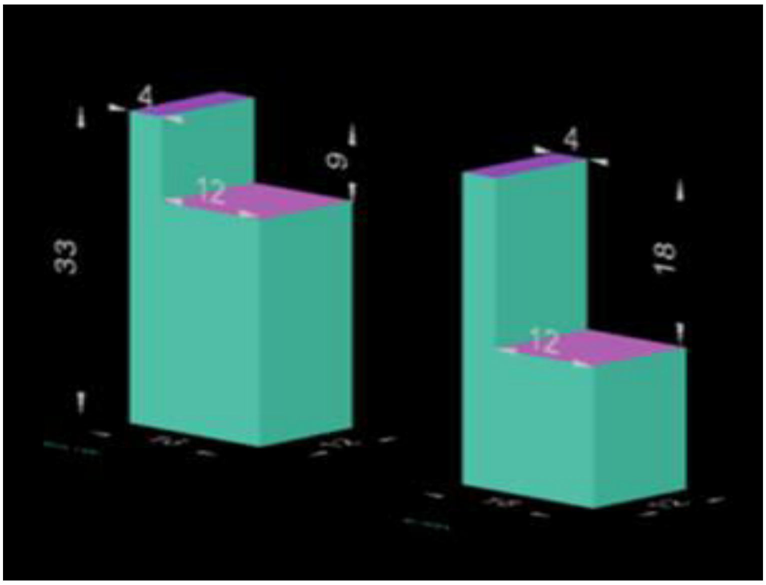

Figure 3: Irregularities in height i.e. RA=0.25 and RH=3/8, RH=6/5

Table No. 5-Setback Critical Ratios S2

Sr. No.	Along plan area-RA	Along height-RH
1	RA=0.50	RH=3/8
		RH=6/5

3) Setback building type (S2).

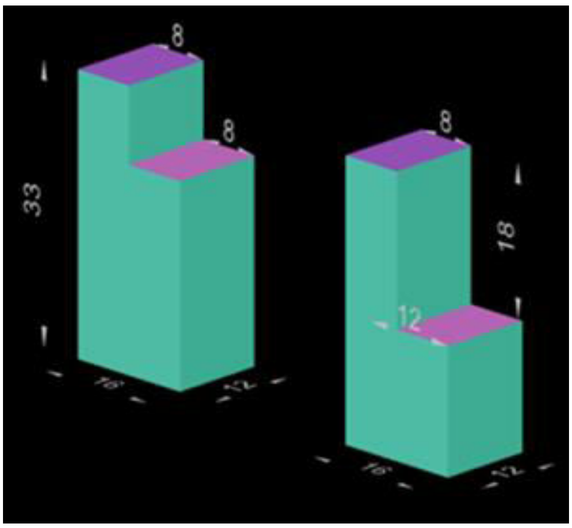

Figure 4: Irregularities in height i.e. RA=0.50 and RH=3/8, RH=6/5

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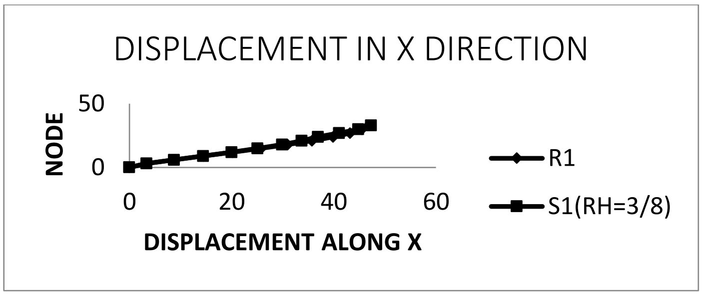
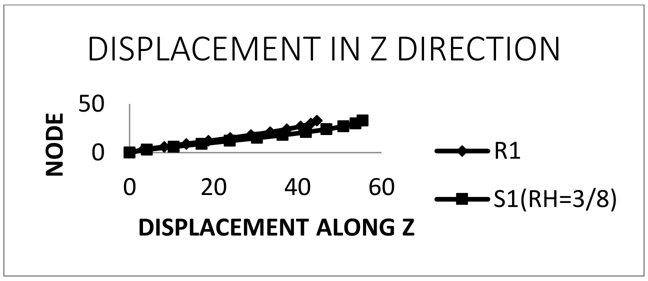
IV. RESULTS AND DISCUSSION

To study the behaviour of architecturally irregular structure nine different model considered with one reference regular model and results and discussions carried out accordingly.

Analysis Result of Critical Setback Ratio- RH=3/8 & RA=0.25 (S1)

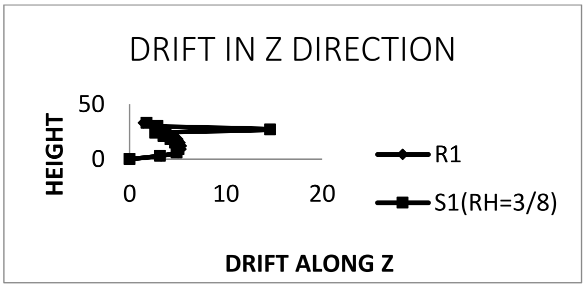


Graph Showing Displacement in X direction for RA=0.25 and RH=3/8



Graph Showing Displacement in Z direction for RA=0.25 and RH=3/8

Graph Showing Storey Drift in X & Z direction for RA=0.25 and RH=3/8



Graph Showing Storey Drift in Z direction for RA=0.25 and RH=3/8

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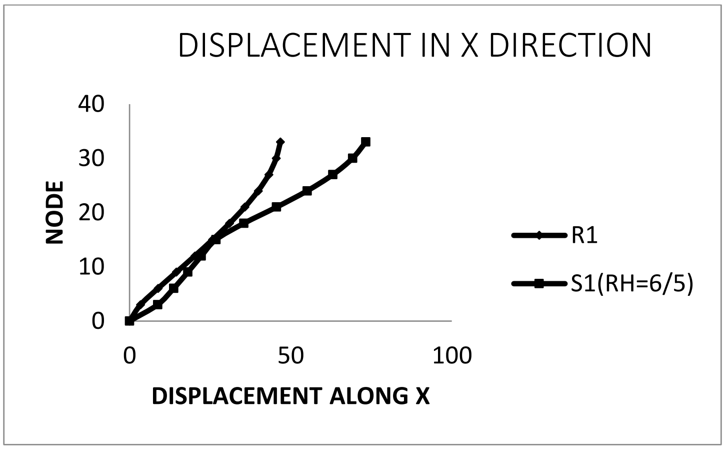
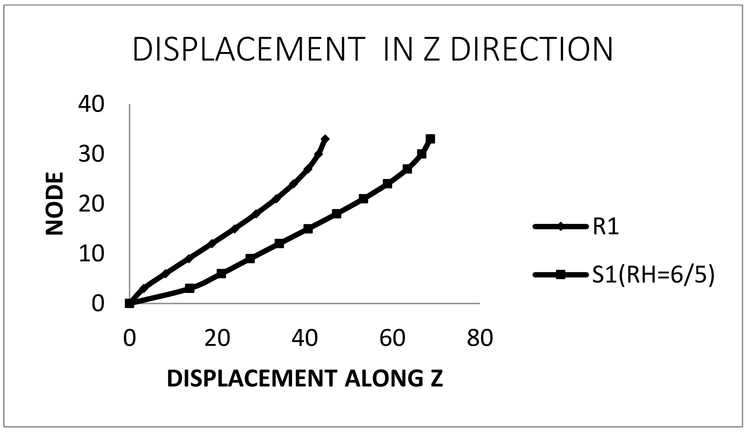
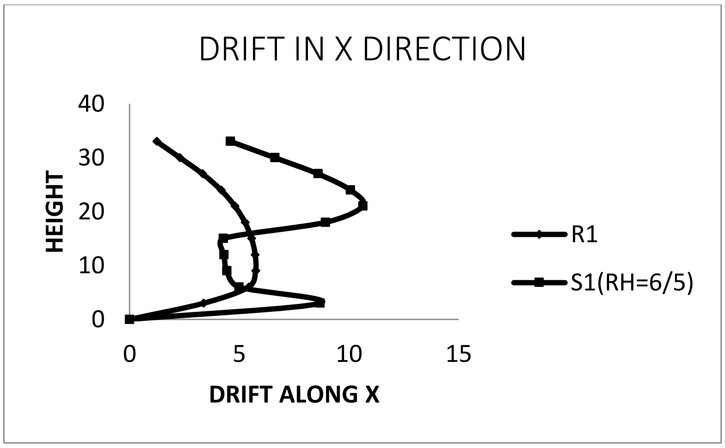
Analysis Result of Critical Setback Ratio- RH=6/5 & RA=0.25 (S1)



Graph Showing Displacement in X direction for RA=0.25 and RH=6/5



Graph Showing Displacement in Z direction for RA=0.25 and RH=6/5



Graph Showing Storey Drift in X direction for RA=0.25and RH=6/5

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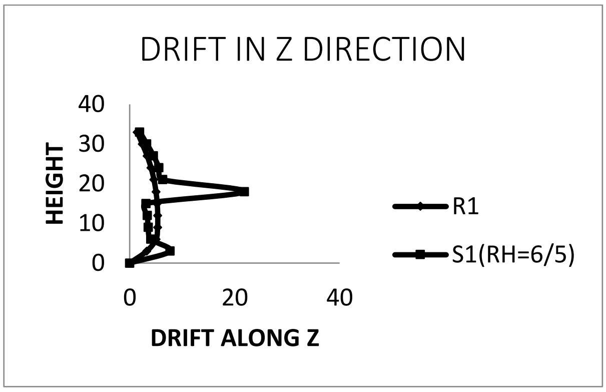
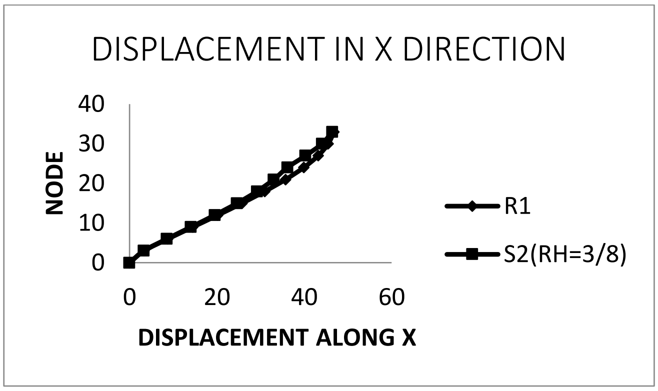
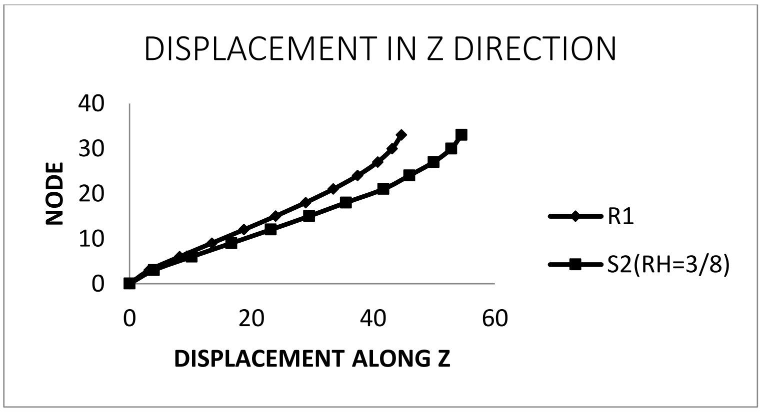


Graph Showing Storey Drift in Z direction for RA=0.25and RH=6/5

Analysis Result of Critical Setback Ratio- RH=3/8 & RA=0.5 (S2)



Graph Showing Displacement in X direction for RA=0.5 and RH=3/8



Graph Showing Displacement in Z direction for RA=0.5 and RH=3/8

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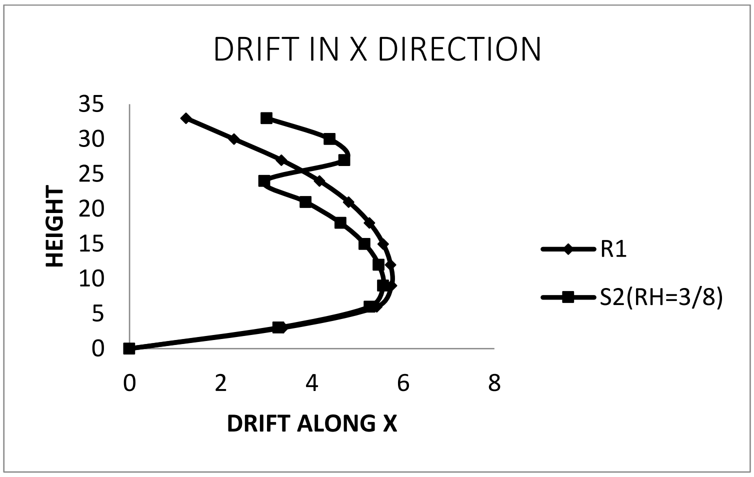
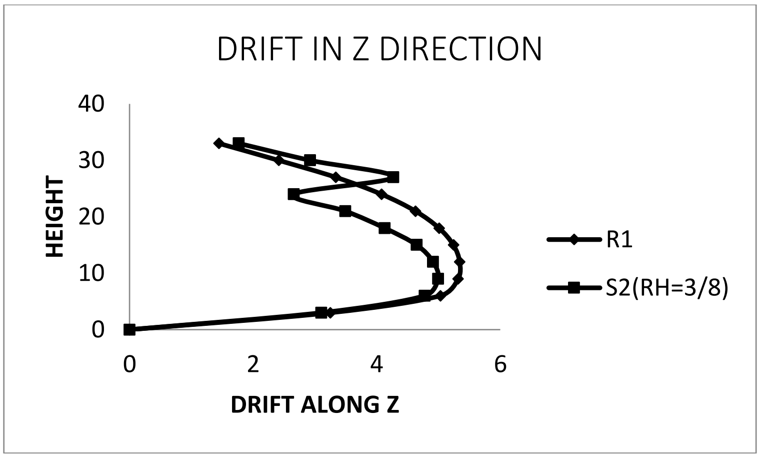


Graph Showing Storey Drift in X direction for RA=0.5 and RH=3/8



Graph Showing Storey Drift in Z direction for RA=0.5 and RH=3/8

V. CONCLUSIONS

Depending on result obtain from analysis of model using different permutation and combinations of architecturally irregular structures and its variations in nodal displacement and story drift are presented in results and discussion chapter. Following conclusion can be draw from the obtaining result,

1) Critical setback ratio RA=0.25 and RH=6/5 shows the variation in story drift which signifies the jumping of the forces due to unequal distribution of mass along the plan as well as along the height.
2) From the obtained results it may be concluded that the irregular structures must be treated with proper understanding and by following the codal provisions given in the code.
3) It may also be concluded that consideration of the revised seismic codes provisions for geometric vertical irregularities seems to be essential to stipulate more restrictive limits or apply more accurate analytical procedures to predict the seismic performance of setback structures under the seismic excitations, especially for structures with critical setback ratios
4) The present research work can be extended for the analysis of steel buildings of same or different configurations.
5) Pounding effect of structure lying in vicinity of structure under consideration can also be useful work in the same area of setback buildings.
6) As a remedial measured in corporation of base isolation system in the structure may give a safe solution for structure having setback. The present work can be extended for the same.

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