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Comparative Structural Analysis and Design of Regular and Irregular G+20 Reinforced Concrete Buildings Using STAAD Pro

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Abstract - This study investigates the seismic performance of reinforced cement concrete (RCC) G+20 multi-storey framed structures with both regular and irregular plan configurations constructed on sloping terrain. The buildings are modeled and analyzed using STAAD.Pro, employing equivalent static analysis to assess their response under seismic loading. The primary objective is to evaluate the influence of plan geometry on structural response and to determine the effectiveness of shear walls in enhancing lateral load resistance. Comparative assessment between regular and irregular configurations focuses on key seismic parameters, including lateral displacement, base shear, and bending moments in beams and columns. The role of shear walls in improving seismic stability, particularly for structures located on inclined ground, is also examined. The findings provide meaningful insights into the importance of structural configuration and lateral force–resisting systems in mitigating earthquake-induced damage and improving the overall safety of multi-storey buildings.

Keywords: Reinforced Cement Concrete (RCC); G+20; multi-storey structures; seismic performance; STAAD.Pro; inclined terrain; regular configuration; irregular configuration; shear walls; lateral forces; equivalent static analysis.

1. INTRODUCTION

Rapid population growth, urbanisation, and limited land availability have accelerated the development of multi-storey buildings in metropolitan regions. As land prices continue to rise sharply, vertical construction has become a practical solution to accommodate increasing residential and commercial demands within restricted urban footprints. Modern multi-storey buildings, which began emerging prominently in the late nineteenth and early twentieth centuries, rely on advancements in materials, structural systems, and essential utilities such as elevators. Their evolution parallels the rising skyline of cities worldwide, driven by technological progress and the need for efficient land use.

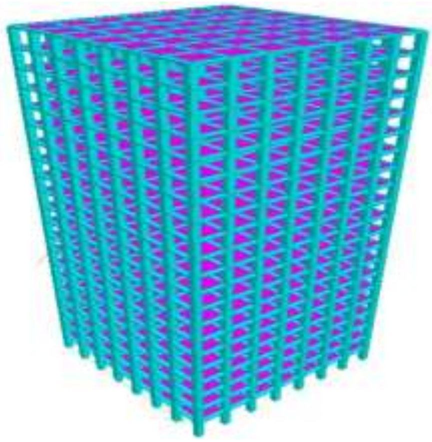
One of the most critical challenges faced by multi-storey structures is their vulnerability to earthquakes. Earthquakes generate ground vibrations due to the sudden release of energy within the earth's crust, producing seismic waves that induce horizontal and vertical motions in structures. Tectonic activity, governed by the theory of plate tectonics, is responsible for the majority of destructive earthquakes. Several catastrophic events—including the 2001 Bhuj earthquake, the 2005 Kashmir earthquake, the 2010 Haiti earthquake, the 2011 Japan earthquake, and the 2015 Nepal earthquake—have resulted in immense loss of life and property, highlighting the need for earthquake-resistant construction.

The dynamic forces generated during seismic events subject buildings to lateral loads, making lateral load-resisting systems such as shear walls essential for structural safety. Shear walls enhance lateral stiffness, minimise deformation, and reduce the risk of collapse. Design provisions for seismic analysis in India are governed by IS 1893, which specifies procedures for determining design base shear, natural period, load combinations, and lateral force distribution along the height of the structure.

Given that 56% of India's land area lies in seismically active zones, seismic analysis becomes crucial for ensuring structural stability and serviceability. This study investigates the behaviour of G+20 RCC multi-storey framed buildings—both plan-regular and plan-irregular—modelled and analysed in STAAD.Pro using equivalent static analysis. The research evaluates lateral displacement, base shear, shear forces, and bending moments to understand the seismic response and performance of both configurations.

1.2 OBJECTIVES OF THE PRESENT STUDY

1. To model RCC G+20 multi-storied framed buildings with both regular and irregular plans on sloping ground using STAAD.Pro software.



2. To analyze the seismic performance of RCC G+20 multi-storied framed buildings with regular and irregular plans on sloping ground using equivalent static analysis.

3. To evaluate and compare the analysis results for both regular and irregular plan building models under seismic loading conditions.
4. To study the seismic performance of RCC G+20 multi-storied framed buildings with and without shear walls subjected to lateral loads on sloping ground.

2. METHODOLOGY

A G+20 framed building, both regular and irregular in plan, situated in seismic zone II, has been simulated using STAAD Pro. The buildings were evaluated in accordance with the Indian Code of Practice IS 1893: Part 1 2016, for seismic loading. The structures are presumed to be anchored at the foundation. The cross-sections of structural elements are rectangular. The heights of building storeys, including the lowest story, are presumed to be uniform. Figures 1.

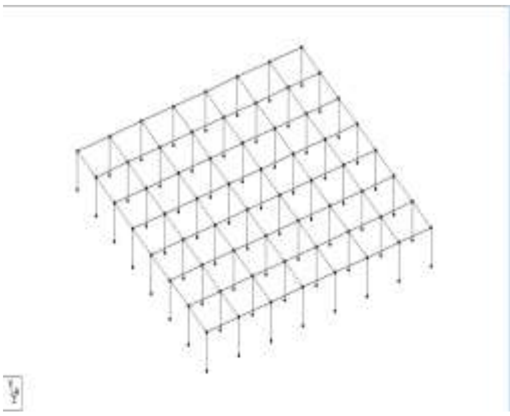


Fig.1 Plan view of Model-1(Building with plan regular)

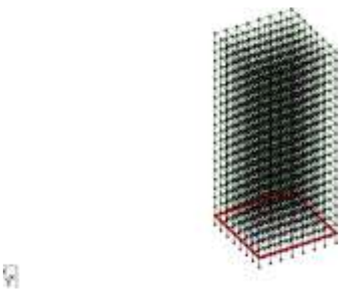


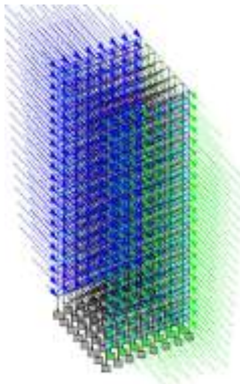
Fig 2 Framed structure G+20 model-1

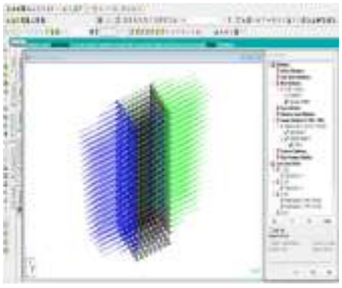
Fig 3D View of Model -1 (Building with plan regular)

A G+20 RCC multi-storied structure is selected for linear static earthquake analysis. The primary aim of the research is to analyse the behaviour of framed structures and assess lateral displacement in accordance with seismic zone II.

The primary function of a framed structure composed of columns and beams is to withstand lateral forces resulting from seismic activity. The columns and beams are firmly coupled to resist bending moments and shear forces.

Figure 3 Wind load Y-Direction for model1





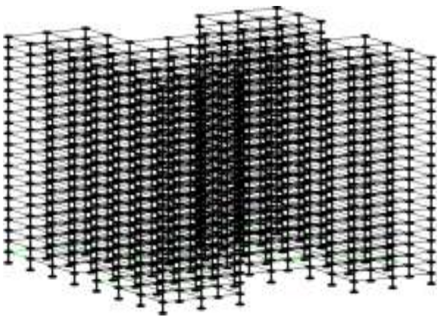


Figure 4 Irregular g+20 framed structures

3.Member properties

Table 3.1 Geometrical Parameters of both building models

S. No	PARTICULARS	DIMENSIONS/SIZE/VALUE
1	MODEL	G+20
2	FLOOR HEIGHT	3m
3	PLAN SIZE	28.0m X28.0m
4	SIZE OF COLUMNS	0.8mX 0.8m
5	SIZE OF BEAMS	0.3Mx 0.6m
6	WALLS	EXTERNAL WALLS – 0.23m INTERNAL WALLS – 0.115m
7	THICKNESS OF SLAB	150mm
8	TYPE OF SOIL	TYPE – II ROCKY HARD SOIL AS PER 1893
9	MATERIAL USED	CONCRETE
10	STATIC ANALYSIS	LINEAR STATIC ANALYSIS
	SOFTWARE USED	STAAD PRO

3.1 Analysis of building by STAAD pro softwar

STAAD.Pro is a widely used structural analysis and design software originally developed by Research Engineers International and later acquired by Bentley Systems in 2005. It enables 3D modelling, analysis, and design of RCC and steel structures under various loads and combinations. In this study, STAAD.Pro is used to model and analyse G+20 RCC framed buildings with different plan configurations on sloping ground. The software offers advanced visualisation, linear and nonlinear analysis, extensive material libraries, and design capabilities for beams, columns, slabs, shear walls, and foundations. Its powerful 64-bit solver efficiently handles complex models and generates detailed graphical outputs and construction-ready drawings.

4.Result and discussion

This section presents the analysis of seismic performance for the G+14 RCC framed buildings, both plan-regular and plan-irregular, located in Seismic Zone II. The models were developed and analysed using STAAD.Pro, and the results are interpreted to understand the structural behaviour under earthquake loading. Key response parameters—including lateral displacement, base shear, bending moments, and shear forces in beams and columns—are examined to evaluate the influence of plan configuration on seismic performance. Comparative assessment of these parameters provides insights into how irregularity affects the dynamic response and stability of the structure. The following subsections detail the behaviour of the building models under lateral loading, highlighting critical observations essential for performance-based seismic design.

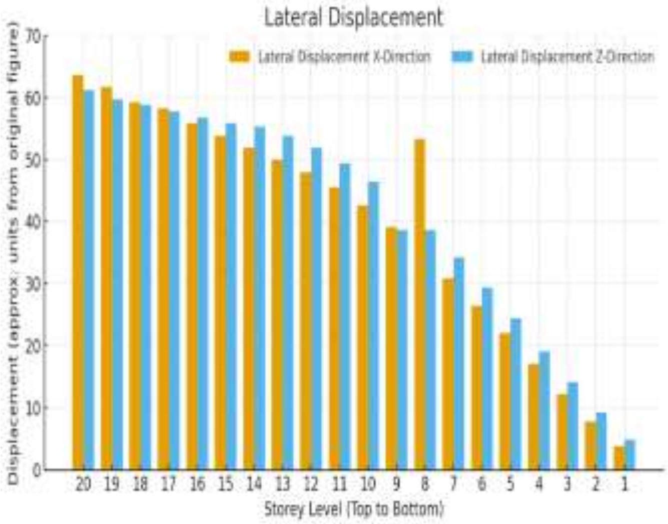


Figure5 Comparison of lateral displacement of Building Model 1 (plan-regular) in the X and Z directions under seismic loading.

From the analysis of Fig 5 and the data presented in it is evident that model 1 experiences significantly higher lateral displacement compared to model 2 when subjected to earthquake loads. This variation highlights the influence of plan regularity in the X and Z directions on the seismic response of buildings. For model 1, the maximum displacements at the top story level are 52.14 mm in the X-direction and 55.67 mm in the Z-direction, indicating a 6.77% increase in Z-direction displacement. Conversely, model 2, with plan irregularity in the Z-direction, shows lower displacement values of 19.83 mm and 13.59 mm in the X and Z directions, respectively, but a higher percentage increase of 18.96% in Z-direction displacement. Despite these differences, the maximum observed displacements for both models remain well within the permissible limit of H/500 (85 mm). These results underline the critical role of plan configuration and stiffness in determining the seismic performance of structures. Understanding these variations helps in optimizing design strategies to ensure safety and compliance with displacement criteria.

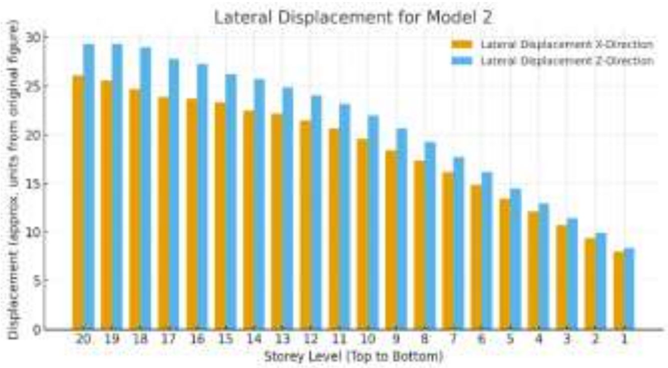


Figure 6. Comparison of lateral displacement for the plan-irregular Building Model 2 in the X and Z directions under seismic loading.

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4.2 Base shear

Base shear represents the total lateral force induced at the base of a structure due to seismic excitation. It is primarily influenced by the seismic weight of the building and increases proportionally with it. The computed base-shear values for both building models are presented in Figure 7.

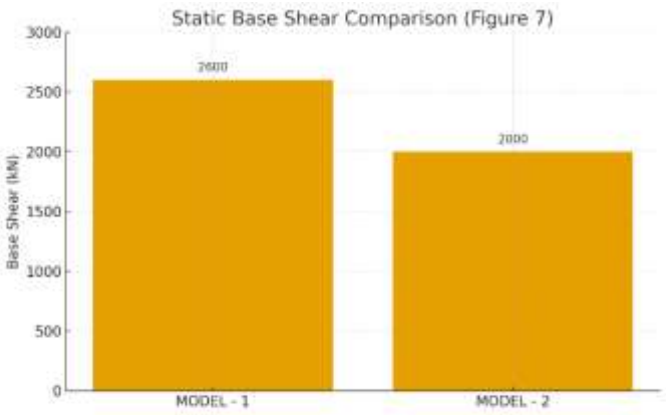

Figure 7. Comparison of base shear for both building models under static seismic analysis.

The value of design base shear obtained for building model 1 by performing Static Earthquake Analysis is 2657.27kN. Whereas for model 2, the value of base shear was 2033.48kN. Base shear increases if the mass of the structure increases.

4.3 Bending moment in beams and columns

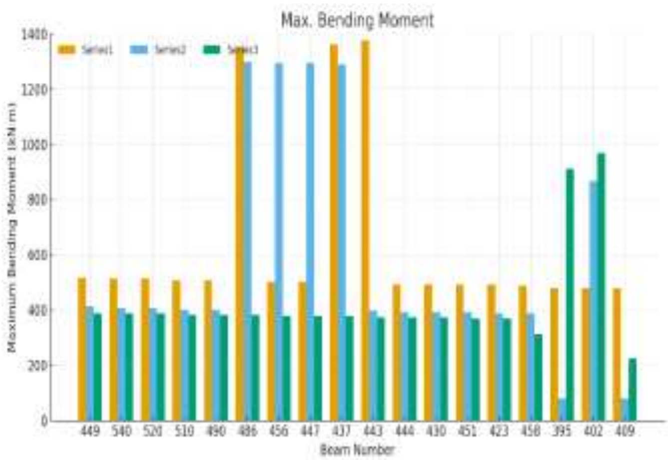

Figure 8. Maximum bending moment values in the beams of Building Model 1 under various load combinations.

The results indicate that model 1 exhibits the highest bending moment in beams for the load combination 1.5(DL+LL), demonstrating a significant increase compared to other combinations. Specifically, there is a 25% increase in the bending moment for 1.5(DL+LL) compared to 1.2(DL+LL+EQZ+) and a 32.16% increase for 1.5(DL+EQZ+). These variations highlight the influence of different load combinations on the structural response, emphasizing the importance of considering dynamic effects in design. A thorough understanding of these bending moment patterns helps engineers design beams with adequate strength and stiffness to safely resist applied loads while maintaining structural integrity.

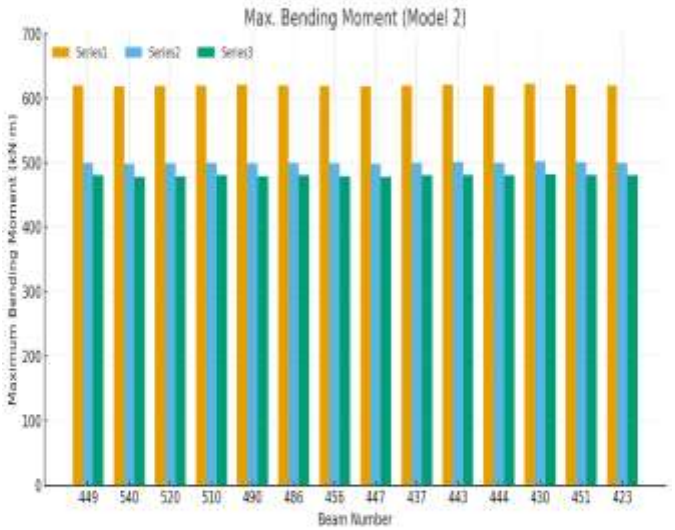

Figure 9. Maximum bending moment values in the beams of Building Model 2 at all storey levels for various load combinations.

The results indicate that model 1 exhibits the highest bending moment in beams for the load combination 1.5(DL+LL), demonstrating a significant increase compared to other combinations. Specifically, there is a 25% increase in the bending moment for 1.5(DL+LL) compared to 1.2(DL+LL+EQZ+) and a 32.16% increase for 1.5(DL+EQZ+). These variations highlight the influence of different load combinations on the structural response, emphasizing the importance of considering dynamic effects in design. A thorough understanding of these bending moment patterns helps engineers design beams with adequate strength and stiffness to safely resist applied loads while maintaining structural integrity.

maximum Bending Moment were observed in columns of both building models by performing static earthquake analysis. The values of maximum Bending Moment obtained in columns of model I are observed to be maximum for load combination 1.5(D. L+EQX+) when compared to load combination 1.5(D. L+L.L). Increase in maximum bending moment is observed to be 1972.2

% in column of model 1. Whereas for load combination 1.2(D. L+L.L+EQX+), the increase in values of bending moment in columns is 1562.13% when compared to load combination 1.5(D. L+L.L).

5. shear force

The shear force values obtained through static earthquake load analysis for both building models. The results reveal that model 1 experiences the maximum shear force in beams for the load combination 1.2(DL+LL+EQZ+). This indicates the significant impact of incorporating seismic forces into load combinations on the structural response of beams. A comparison of load combinations shows that for 1.2(DL+LL+EQZ+), the shear force in beams increases by 20% compared to 1.5(DL+LL). This increase highlights the added influence of seismic forces (EQZ+) in amplifying internal forces in structural elements. Additionally, when analyzing the shear force for load combination 1.5(DL+EQZ+), an even higher increase of 22.09% is observed in comparison to 1.5(DL+LL). This demonstrates that seismic forces contribute more significantly to the shear force in beams when acting independently in combination with dead loads, as opposed to when they are combined with live loads.

These findings underscore the importance of accounting for seismic loads during structural analysis and design. Understanding these variations enables engineers to enhance the structural resilience of buildings, ensuring that the beams can adequately resist the increased shear forces induced by seismic events.

6.CONCLUSION

This study evaluated the seismic performance of two reinforced concrete building models, one with a regular plan (Model 1) and the other with an irregular plan (Model 2), and the results highlight significant differences in their structural response. Model 1 exhibited maximum top-storey displacements of 52.14 mm in the X-direction and 55.67 mm in the Z-direction, whereas Model 2 showed higher variations due to its plan irregularity, demonstrating that lateral deformation is highly influenced by structural configuration. The base shear was also higher in Model 1 (2657.27 kN) compared to Model 2 (2033.48 kN) because of its greater seismic mass. Beam bending moments in Model 1 decreased under seismic load combinations, with a 25% reduction for 1.2(DL+LL+EQZ+) and a 32.16% reduction for 1.5(DL+EQZ+) when compared to 1.5(DL+LL), while Model 2 showed consistently lower bending moments across all combinations, indicating reduced flexural demand in irregular structures. In contrast, column bending moments in Model 1 increased significantly, showing a 1562.13% rise for 1.2(DL+LL+EQZ+) and a 1972.2% increase for 1.5(DL+EQZ+) relative to 1.5(DL+LL), highlighting higher seismic demands on vertical elements in regular-plan buildings. Shear forces in the beams of Model 1 decreased by 24% and 3.15% for the same seismic combinations, while Model 2 showed even lower shear forces in both beams and columns due to its irregular mass and stiffness distribution. Overall, the seismic behavior analysis reveals that Model 1 attracts higher base shear and column moments but lower beam stresses, whereas Model 2, despite lower overall force demands, is more susceptible to torsional effects and uneven load distribution. These observations reinforce the critical importance of considering plan regularity and structural configuration in the seismic design of buildings.

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