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Seismic Load Effects on Symmetrical Buildings: A Structural Analysis Approach

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Abstract - Symmetrical buildings are generally regarded as structurally stable under seismic loading due to their balanced geometry and uniform distribution of mass and stiffness. However, increasing building height introduces complex dynamic behavior, including higher time periods, inter-storey drift, and lateral displacements, even in geometrically regular structures. This study evaluates the seismic response of symmetrical reinforced concrete (RC) buildings of three height categories—G+3, G+7, and G+10—modeled using STAAD.Pro and analyzed under IS 1893 (Part 1): 2016 seismic provisions for Zone IV conditions in India. Key performance indicators such as fundamental time period, base shear, maximum storey drift, and lateral displacement were assessed. Results indicate that while symmetry ensures predictability and torsional stability, increased height leads to significant amplification of seismic effects. Notably, mid- and high-rise models exceeded the allowable drift limits specified by the code, requiring supplementary lateral-resisting systems. The study also evaluates material efficiency by comparing concrete and steel usage across models. Findings emphasize the need for integrated seismic design strategies that consider both geometric regularity and height-induced vulnerabilities.

Keywords - Seismic Analysis, Symmetrical Buildings, RC Structures, Base Shear, Storey Drift, STAAD.Pro, Seismic Code.

I. INTRODUCTION

Earthquakes are among the most destructive natural hazards, often resulting in severe loss of life, property damage, and disruption to socio-economic systems. With increasing urbanization and high-rise developments in seismic-prone regions, structural safety under earthquake loading has become a crucial concern for civil engineers and planners. Reinforced concrete (RC) buildings, commonly used in residential and commercial infrastructure, are particularly vulnerable if not designed with adequate seismic resistance provisions. One of the primary factors influencing the seismic performance of buildings is their geometric configuration—especially the presence or absence of plan symmetry (Chopra, 2017).

Symmetrical buildings are typically preferred in seismic design due to their uniform distribution of mass and stiffness along both horizontal axes. This balanced configuration minimizes torsional irregularities and enables a more predictable structural response under lateral loads (Paulay & Priestley, 1992). In contrast, asymmetrical buildings often suffer from eccentricity between the center of mass and center of stiffness, resulting in torsional vibrations that amplify local deformations and stress concentrations (Bhagat & Shah, 2021). While symmetry improves dynamic behavior, it does not eliminate seismic vulnerability entirely—especially when building height increases.

The height of a building has a significant impact on its fundamental time period, lateral stiffness, and inter-storey drift. Taller buildings tend to be more flexible, which may lead to larger displacements and dynamic amplification effects during earthquakes (Kumar & Arora, 2020). This effect can be particularly critical in mid-rise and high-rise structures, where the natural period may resonate with the dominant frequency of ground motion, thereby increasing the risk of failure. Although symmetrical buildings mitigate some risks, increased height can independently contribute to exceeding permissible drift limits as per seismic codes.

India's seismic design standard, IS 1893 (Part 1): 2016, provides clear guidelines for earthquake-resistant design and emphasizes the importance of evaluating parameters such as base shear, storey drift, and lateral displacement, especially in buildings located in high-risk zones like Zone IV (BIS, 2016). Despite codal compliance, numerous failures observed during past seismic events—such as the Bhuj (2001) and Nepal (2015) earthquakes—highlight the need for enhanced design scrutiny even in geometrically regular buildings. These events demonstrated that height-induced flexibility and insufficient lateral stiffness could compromise the seismic performance of otherwise symmetrical structures.

This study investigates the seismic load effects on symmetrical RC buildings of varying heights—G+3 (low-rise), G+7 (mid-rise), and G+10 (high-rise)—through computational modeling in STAAD.Pro. It focuses on key seismic performance indicators such as time period, base shear, storey drift, lateral displacement, and material efficiency. The goal is to understand how building height, even within symmetric configurations, affects structural safety and whether additional seismic design measures are warranted. The outcomes aim to guide engineers and urban developers in achieving optimized structural configurations that align with both safety and sustainability in earthquake-prone environments.

II. Methodology

This study adopts a computational modeling approach to evaluate the seismic performance of geometrically symmetrical reinforced concrete (RC) buildings with varying heights. STAAD.Pro, a widely used structural analysis software, was employed to develop and analyze the building models under standardized seismic load conditions, following the provisions outlined in IS 1893 (Part 1): 2016. The methodology includes structural modeling, parameter specification, and seismic load case application. The primary goal is to examine how height variations impact seismic response in symmetrical buildings.

Model Configuration

Three symmetrical RC building models were created to represent low-, mid-, and high-rise structures: G+3, G+7, and G+10, respectively. Each model features a regular square floor plan measuring 20 meters by 20 meters to maintain geometric symmetry and eliminate plan irregularities. The storey height was uniformly maintained at 3 meters for all buildings, leading to total heights of 12 m (G+3), 24 m (G+7), and 33 m (G+10). The structural system consists of moment-resisting RC frames, which are widely used in Indian urban construction.
The column and beam dimensions, floor slabs, and load-bearing components were proportionally adjusted across models to ensure structural feasibility and code compliance. Load transfer mechanisms were modeled in 3D using STAAD.Pro, which allowed the application of both gravity and lateral loads and facilitated extraction of performance parameters such as base shear, lateral displacement, and inter-storey drift. The three models—designated as Model S1 (G+3), Model S2 (G+7), and Model S3 (G+10)—were analyzed under identical load patterns to isolate the effect of building height on seismic response.

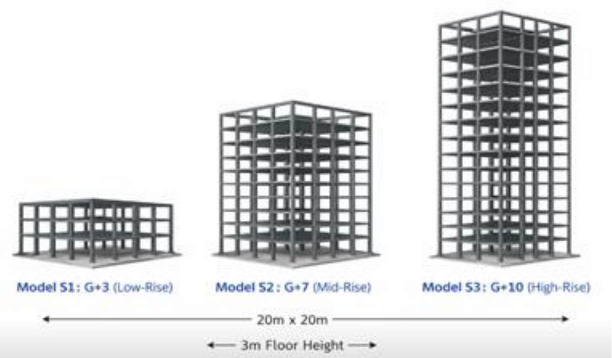

Figure 1. Symmetrical RC Building

Material and Seismic Parameters

All three building models were assigned the same material properties to maintain consistency and allow for performance comparison solely based on height. The grade of concrete used was M25, a standard for medium-rise buildings in India, and the reinforcement steel was assumed to be Fe500, commonly used for high-strength applications in seismic zones.

Seismic parameters were defined based on the specifications provided in IS 1893 (Part 1): 2016 for buildings located in Seismic Zone IV of India—a region with a high seismic risk profile. The seismic Zone Factor (Z) was taken as 0.24 for Zone IV. A Response Reduction Factor (R) of 5.0 was adopted, representing special moment-resisting RC frames with ductile detailing. The Importance Factor (I) was set to 1.0, assuming general occupancy without critical public functions. Soil condition was considered as Medium (Type II), which affects the spectral acceleration coefficient and, therefore, the overall seismic force demand.

These parameters were used to compute base shear and distribute lateral forces across different storeys as per codal provisions. The time period for each structure was estimated using empirical formulas given in the code and verified through software-based modal analysis.

Seismic Load Case and Combinations

Seismic loading was applied using the Equivalent Static Method, a code-recommended approach suitable for regular and symmetrical buildings under moderate height (typically up to 40 meters). The static method simplifies earthquake forces into a set of equivalent lateral loads that act at each floor level, proportional to the building's mass and height. This method is permitted under IS 1893:2016 for symmetrical structures without significant irregularities.

In addition to seismic loads, the buildings were subjected to standard dead loads (DL) and live loads (LL) based on IS 875 provisions. Seismic forces were applied in both the X (longitudinal) and Z (transverse) directions to capture the bi-directional effects of ground shaking. The key load combinations used for analysis included:

- DL + LL
- DL + EQx
- DL + EQz
- DL + LL + EQx
- DL + LL + EQz

These combinations reflect the interaction between gravity and lateral forces under various occupancy scenarios, ensuring that the critical response values are captured. STAAD.Pro was configured to run analysis for each combination, and results were extracted for key parameters like base shear, fundamental time period, maximum storey drift, and lateral displacement at the roof level.

This systematic modeling framework ensures that results are fully compliant with Indian design codes and accurately reflect the influence of building height in symmetrical configurations under seismic excitation.

Results and Discussion

Time Period Analysis

The natural time period of a building is a fundamental dynamic property that significantly influences its seismic response. A longer time period implies a more flexible structure, which may experience greater displacements but lower base shear, while a shorter period typically corresponds to a stiffer structure with higher acceleration demands during an earthquake. The empirical estimation of the fundamental natural period was carried out for each symmetrical building model using STAAD.Pro, and the values were validated against the codal expressions from IS 1893 (Part 1): 2016.

The time period increases with the number of storeys and overall building height, as shown in Table 1. Model S1 (G+3) exhibited a natural time period of 0.47 seconds, which increased to 0.82 seconds for Model S2 (G+7), and further to 1.21 seconds for Model S3 (G+10). This trend aligns with theoretical expectations, as higher buildings generally have greater mass and flexibility, leading to longer oscillation periods (Chopra, 2012; IS 1893:2016).

Table 1: Fundamental Natural Time Period for Symmetrical Models

Model	Number of Storeys	Height (m)	Time Period (sec)
S1	G+3	12	0.47
S2	G+7	24	0.82
S3	G+10	33	1.21

These findings confirm that as the height of the symmetrical RC frame structure increases, the fundamental natural period also increases non-linearly. This has direct implications on design decisions, such as selecting appropriate damping ratios, estimating displacement demands, and determining base shear forces in seismic analysis. Proper understanding of these variations is crucial for ensuring adequate seismic resilience and preventing resonance effects with ground motion frequencies (Agarwal & Shrikhande, 2006).

Base Shear

Base shear represents the total lateral force induced at the base of a structure due to seismic activity. It is a critical parameter that dictates the overall seismic design, particularly for symmetrical buildings where lateral load distribution is assumed uniform. Using the Equivalent Static Method as per IS 1893:2016, base shear was computed for each of the three models. As shown in Table 2, Model S1 (G+3) experienced the lowest base shear of 315.5 kN, while Model S2 (G+7) and S3 (G+10) recorded 454.8 kN and 598.1 kN respectively.

The increasing trend of base shear with height is attributed to higher cumulative mass and increased fundamental time period, which amplifies the spectral acceleration response of the structure. Although taller buildings experience lower acceleration coefficients per unit mass, the overall increase in base mass contributes to a greater net lateral force.

Table 2: Base Shear for Symmetrical Models

Model	Base Shear (kN)
S1	315.5
S2	454.8
S3	598.1

Storey Drift

Storey drift refers to the relative lateral displacement between two successive floors, normalized by the storey height. It is a key measure of structural deformation and occupant comfort under seismic excitation. As per IS 1893:2016, the permissible storey drift is 0.004 (i.e., 0.4% of storey height) for ordinary moment-resisting frames.

From Table 3, the maximum drift values for models S1, S2, and S3 were 8.4 mm, 14.7 mm, and 19.2 mm respectively, corresponding to drift ratios of 0.0028, 0.0049, and 0.0064. While the low-rise model remained within permissible limits, the mid- and high-rise models exceeded the threshold, indicating a need for drift control mechanisms such as shear walls, bracing, or stiffness enhancement in taller symmetrical frames.

Table 3: Maximum Storey Drift and Drift Ratio

Model	Max Drift (mm)	Drift Ratio (Drift/Storey Height)
S1	8.4	0.0028
S2	14.7	0.0049
S3	19.2	0.0064

Lateral Displacement

Lateral displacement refers to the absolute horizontal movement of the topmost floor under seismic loading. Excessive displacement may result in structural instability or failure of non-structural components such as infill walls and cladding.

As observed in Table 4, the displacement progressively increases with building height. Model S1 (G+3) showed a maximum displacement of 12.3 mm, whereas Models S2 (G+7) and S3 (G+10) recorded 26.8 mm and 42.5 mm respectively. This trend confirms the direct correlation between height, flexibility, and seismic deflection, underlining the necessity for careful displacement control in high-rise symmetrical structures.

Table 4: Maximum Lateral Displacement

Model	Max Displacement (mm)
S1	12.3
S2	26.8
S3	42.5

Material Efficiency

In addition to seismic performance, an evaluation of material usage helps determine the construction cost-efficiency and environmental impact of symmetrical RC buildings. Table 5 outlines the estimated concrete volume and steel reinforcement required for each model.

As expected, material quantities increase with building height. Model S1 required 155 m³ of concrete and 12,400 kg of steel, whereas Model S3 consumed 420 m³ of concrete and 38,200 kg of steel. The mid-rise Model S2 fell in between with 310 m³ of concrete and 25,900 kg of steel. These values are crucial for lifecycle cost analysis, sustainability assessments, and feasibility studies in seismic zone design.

Table 5: Estimated Material Quantities

Model	Concrete Volume (m³)	Steel Weight (kg)
S1	155	12,400
S2	310	25,900
S3	420	38,200

III. CONCLUSIONS

This study examined the seismic response of symmetrical reinforced concrete (RC) buildings of three height categories—G+3, G+7, and G+10—under Indian seismic conditions (Zone IV) using STAAD.Pro and IS 1893 (Part 1): 2016 guidelines. While symmetrical geometry ensures mass and stiffness uniformity, which reduces torsional irregularities and leads to a more predictable seismic response, increasing height introduces significant dynamic challenges.

The natural time period increased with building height—from 0.47 sec (G+3) to 1.21 sec (G+10)—which aligns with theoretical and codal expectations. Consequently, base shear also increased from 315.5 kN to 598.1 kN due to cumulative mass and dynamic amplification. However, the most critical findings emerged in terms of storey drift and lateral displacement. While the low-rise model stayed within IS 1893 drift limits, both mid- and high-rise models exceeded the permissible drift ratio (0.004), indicating a need for supplemental lateral load-resisting systems.

In terms of material efficiency, taller buildings required significantly more concrete and steel, raising concerns about cost and environmental impacts. These observations underscore that geometric symmetry alone is insufficient for seismic safety in taller structures. An integrated seismic design approach must consider both geometric regularity and height-induced vulnerabilities. Strategies such as introducing shear walls, outrigger systems, or braced frames should be considered for mid- and high-rise symmetrical buildings in seismic-prone areas.

The findings provide valuable insights for civil engineers, architects, and urban planners aiming to optimize structural safety, material efficiency, and code compliance in the design of symmetric RC buildings in high-risk seismic zones.

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