

RESEARCH ARTICLE

Seismic Drift Evaluation of a High-Rise Reinforced Concrete Building using Advanced SAP2000

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Abstract. Inter-storey drift is one of the most critical seismic response parameters governing the performance of high-rise buildings, as it directly affects global structural stability, damage to non-structural components, and occupant safety during earthquake events. With the increasing height and complexity of modern skyscrapers, conventional simplified analysis approaches are often inadequate to capture realistic lateral deformation behavior. The advancement of structural analysis software has enabled more accurate modeling of dynamic response under seismic loading. In this study, a comprehensive and code-compliant seismic drift evaluation of a reinforced concrete high-rise building is carried out using the advanced features of SAP2000. A detailed three-dimensional finite element model is developed, incorporating realistic material properties, cracked-section stiffness modifiers, rigid diaphragm action, and appropriate mass source definitions. Seismic forces are applied through response spectrum analysis in accordance with the provisions of IS 1893 (Part 1):2016 and ASCE 7-22, ensuring consistency with both national and international design practices. Modal analysis is performed to capture dominant vibration modes and achieve sufficient mass participation. Inter-storey drift ratios are directly extracted from SAP2000 outputs and evaluated against the permissible drift limits prescribed by the respective codes. The variation of drift along the building height is analyzed to identify critical storey levels and assess the influence of higher-mode effects. The results indicate that maximum drift typically occurs at mid-height storeys and remains within allowable limits for both code provisions, demonstrating satisfactory seismic performance of the structural system. The study highlights the effectiveness of advanced SAP2000 modeling and analysis capabilities in accurately predicting drift behavior and supporting safe, serviceable, and code-compliant design of high-rise reinforced concrete buildings in seismic regions.

Keywords: Skyscraper, storey drift, SAP2000, seismic analysis, high-rise buildings

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1. Introduction

Rapid urbanization and increasing population density have significantly accelerated the construction of high-rise buildings across metropolitan regions worldwide. In seismic-prone areas, the structural performance of such tall buildings is primarily governed by their response to lateral loads induced by earthquakes and wind actions. Unlike low-rise structures, high-rise buildings exhibit complex dynamic behavior due to higher-mode participation, flexibility, and mass distribution along the height [1]. Among the various seismic response parameters, inter-storey drift is widely recognized as one of the most critical indicators of seismic performance, as it directly influences structural safety, serviceability, and damage to non-structural components [2]. Inter-storey drift represents the relative lateral displacement between consecutive floors and serves as a key criterion in seismic design codes to limit excessive deformation. Excessive drift can lead to severe cracking of structural members, failure of infill walls, damage to façade systems, malfunctioning of building services, and discomfort or panic among occupants, even when the structure does not collapse [3]. Consequently, modern seismic design philosophies emphasize drift control as an essential requirement for achieving acceptable performance levels during moderate to strong ground motions [4].

Several international and national seismic design standards, including IS 1893 (Part 1):2016 and ASCE 7-22, explicitly prescribe allowable limits on inter-storey drift to ensure both life safety and serviceability [5,6]. These codes recommend the use of dynamic analysis methods, particularly for tall and irregular buildings, as simplified static approaches may underestimate deformation demands [7]. Response spectrum analysis has emerged as a widely accepted linear dynamic method due to its balance between computational efficiency and accuracy in capturing modal contributions [8]. The accuracy of drift prediction largely depends on realistic

structural modeling and appropriate representation of stiffness degradation due to cracking in reinforced concrete members. Advanced structural analysis software such as SAP2000 incorporates refined finite element formulations, cracked-section stiffness modifiers, automated mass participation checks, and direct drift extraction capabilities, enabling engineers to perform reliable seismic performance evaluations [9,10]. Despite widespread use of such software in professional practice, detailed studies demonstrating code-compliant drift assessment of high-rise buildings using advanced SAP2000 features remain limited in open literature.

In this context, the present study aims to conduct a comprehensive seismic drift evaluation of a reinforced concrete skyscraper using advanced SAP2000, explicitly incorporating the provisions of IS 1893 (Part 1):2016 and ASCE 7-22. The study focuses on understanding drift distribution along the building height, identifying critical storey levels, and verifying compliance with prescribed code limits, thereby contributing to safer and more efficient seismic design of high-rise structures.

2. Code Provisions for Drift Control

Inter-storey drift control forms a fundamental component of seismic design philosophy, as excessive lateral deformation is directly linked to both structural damage and failure of non-structural components. To ensure acceptable performance levels under seismic loading, design codes explicitly specify drift limits based on experimental observations, analytical studies, and post-earthquake damage assessments. In the present study, drift evaluation is carried out in accordance with IS 1893 (Part 1):2016 and ASCE 7-22, which represent widely adopted national and international seismic standards.

2.1. IS 1893 (Part 1):2016

The Indian Standard IS 1893 (Part 1):2016 provides explicit guidelines for controlling storey drift in buildings subjected to earthquake loading.

As per Clause 7.11.1, the maximum permissible inter-storey drift for reinforced concrete buildings is limited to:

$$\Delta_{max} \leq 0.004 \times h \quad \dots\dots\dots (1)$$

where Δ_{max} is the inter-storey drift, defined as the relative lateral displacement between two consecutive floors, and h is the corresponding storey height.

This drift limit is prescribed to minimize damage to both structural and non-structural elements such as infill walls, partitions, glazing systems, and cladding components [11]. The code emphasizes that drift calculations must be performed using design seismic forces with load factors equal to unity, ensuring that deformation demands are assessed under realistic seismic action rather than factored strength-based load combinations [12].

IS 1893 further recommends the use of dynamic analysis methods, such as response spectrum analysis, for buildings with greater height and complexity, as these structures exhibit significant higher-mode effects that strongly influence drift response [13]. The drift limit of $0.004h$ reflects a serviceability-based criterion intended to restrict damage and maintain post-earthquake functionality of buildings.

2.2. ASCE 7-22

The American standard ASCE/SEI 7-22 adopts a performance-oriented approach to drift control, wherein allowable inter-storey drift limits vary depending on the structural system, occupancy category, and targeted performance level. According to Section 12.12.1, the allowable drift for reinforced concrete moment-resisting frames at the Life Safety performance level is given by:

$$\Delta_{allow} = 0.02h \quad \dots\dots\dots(2)$$

where Δ_{allow} is the allowable storey drift, and h is the storey height.

Unlike IS 1893, ASCE 7 requires that elastic analysis drifts be amplified using the deflection amplification factor (C_d) to account for inelastic behavior expected during strong ground motion

[14]. This amplification ensures that the calculated drift more accurately represents actual structural deformation under seismic excitation. The ASCE drift provisions are derived from extensive experimental research and post-earthquake performance data, and they are particularly suitable for performance-based seismic design frameworks [15]. The relatively higher allowable drift limit reflects the emphasis on preventing collapse while accepting controlled levels of structural and non-structural damage.

3. Building Description and Modeling

Accurate representation of building geometry, structural configuration, and material properties is a prerequisite for reliable seismic response prediction, particularly for high-rise reinforced concrete structures. In tall buildings, even minor assumptions related to stiffness distribution, mass modeling, or boundary conditions can significantly influence dynamic characteristics and inter-storey drift response [16]. Therefore, careful definition of building parameters and modeling strategy is essential to ensure realistic analytical results.

In the present study, a reinforced concrete (RC) high-rise building is considered as a representative prototype commonly adopted in urban developments. The building consists of ground plus twenty storeys (G+20), with a uniform storey height of 3.2 m, resulting in a total structural height that qualifies the building for dynamic seismic analysis as per both IS 1893 and ASCE 7 provisions. The structural system is modeled as a reinforced concrete moment-resisting frame, which relies on beam–column action to resist lateral seismic forces and dissipate energy through controlled inelastic behavior [17].

The building is assumed to be regular in plan and elevation to isolate the effects of seismic loading on drift behavior without the influence of geometric or mass irregularities. Such regularity allows clearer interpretation of drift distribution along the height and facilitates direct comparison with code-prescribed drift limits [18].

Advanced modeling and analysis are performed using SAP2000 (Advanced version), which offers robust finite element capabilities suitable for high-rise seismic analysis. Beams and columns are modeled as three-dimensional frame elements, while floor slabs are idealized using shell elements with appropriate diaphragm constraints to simulate in-plane rigidity. Rigid diaphragm assumptions are adopted at each floor level to ensure realistic lateral load distribution among vertical resisting elements [19]. Material properties, section definitions, and mass sources are assigned in accordance with seismic code recommendations. Cracked-section stiffness modifiers are incorporated to account for stiffness degradation in reinforced concrete members under seismic loading, which has been shown to significantly affect drift estimation in tall buildings [20]. Fixed supports are assumed at the base, representing rigid foundation conditions for the purpose of superstructure drift evaluation.

A summary of the key building parameters adopted in this study is presented in Table 1.

Table 1. General Building Details

Parameter	Description
Structure type	RC high-rise building
Number of storeys	G + 20
Typical storey height	3.2 m
Structural system	RC moment-resisting frame
Analysis software	SAP2000 (Advanced version)

The adopted building configuration and modeling approach provide a realistic and code-consistent framework for evaluating seismic drift performance using advanced analytical tools.

4. SAP2000 Advanced Modeling Strategy

The seismic response of high-rise reinforced concrete buildings is highly sensitive to modeling assumptions adopted during numerical analysis. To ensure realistic prediction of inter-storey drift and overall dynamic behavior, advanced modeling features available in SAP2000 (Advanced version) are utilized in the present study. These features allow accurate representation of stiffness, mass

distribution, and load transfer mechanisms under seismic excitation.

A three-dimensional space-frame model is developed to capture the interaction between beams, columns, and slabs in resisting lateral loads. This modeling approach enables the simulation of torsional effects and higher-mode participation, which are particularly significant in tall buildings subjected to earthquake loading [21]. Beams and columns are idealized as frame elements with appropriate sectional properties, ensuring realistic force–deformation behavior.

Floor slabs are modeled using shell elements, allowing both membrane and bending actions to be represented. This approach provides a more accurate simulation of floor stiffness and its contribution to lateral load distribution compared to simplified rigid slab assumptions [22]. To ensure effective in-plane force transfer, rigid diaphragm constraints are assigned at each floor level, enforcing uniform lateral displacement across the slab and enabling realistic load sharing among vertical resisting elements.

Table 2. IS 1893 Seismic Parameters

Parameter	Value
Seismic zone	Zone III
Zone factor (Z)	0.16
Importance factor (I)	1.2
Response reduction factor (R)	5
Soil type	Medium

To account for stiffness degradation in reinforced concrete members due to cracking, cracked-section stiffness modifiers are applied to beams and columns in accordance with the recommendations of IS 1893 (Part 1):2016. The seismic parameters are represented in Table 2. These modifiers reduce the effective flexural stiffness of members, resulting in more realistic estimation of lateral displacements and inter-storey drift demands [23]. Accurate dynamic analysis also requires proper representation of seismic mass. In this study, automated mass source definition in SAP2000 is employed, where mass is derived from dead load and appropriate

percentages of live load as specified by seismic design codes. This ensures correct modal characteristics and reliable mass participation during response spectrum analysis [24].

5. Analysis Methodology

The seismic analysis of the high-rise reinforced concrete building is carried out using a systematic and code-consistent procedure to accurately evaluate inter-storey drift response. The methodology adopted in this study ensures reliable prediction of dynamic behavior and direct verification of drift limits prescribed by seismic design standards. Initially, modal analysis is performed to determine the natural periods and corresponding mode shapes of the building. The number of modes considered is selected such that the cumulative mass participation in each principal horizontal direction exceeds 90% of the total seismic mass, ensuring adequate representation of the dynamic characteristics of the structure.

Table 3. ASCE 7 Seismic Parameters

Parameter	Value
Seismic Design Category	D
Site class	D
Importance factor	1.0
Response modification factor (R)	8
Deflection amplification factor (Cd)	5.5

Subsequently, response spectrum analysis is conducted using design response spectra defined as per IS 1893 (Part 1):2016 and ASCE 7-22. The spectra are applied independently in both orthogonal horizontal directions to capture the combined effects of seismic excitation. Modal responses are combined using appropriate modal combination rules to obtain overall structural response.

After completion of the dynamic analysis, storey displacements are extracted at each floor level from SAP2000 output results. These displacement values form the basis for evaluating inter-storey deformation demand along the height of the building. SAP2000's built-in functionality is then utilized for automatic inter-storey drift

calculation, wherein the relative lateral displacement between consecutive floors is computed directly for each storey. This automated process minimizes manual error and ensures consistency in drift evaluation. Finally, the calculated inter-storey drift ratios are subjected to code-based drift verification by comparing them with the permissible limits specified in IS 1893 and ASCE 7. Compliance with these limits confirms the adequacy of the structural system under seismic loading.

6. Results and Drift Evaluation

The seismic analysis results obtained from response spectrum analysis are evaluated to assess the inter-storey drift performance of the high-rise reinforced concrete building. Storey drift ratios are examined along the height of the structure in accordance with the drift limits prescribed by IS 1893 (Part 1):2016 and ASCE 7-22. The variation of drift response provides valuable insight into the deformation characteristics and stiffness distribution of the building under seismic loading. The maximum inter-storey drift values observed at different height levels of the building are summarized in Table 4.

Table 4. Maximum Inter-Storey Drift Results

Storey Level	Drift Ratio (IS 1893)	Drift Ratio (ASCE 7)
Bottom storeys	0.0012	0.006
Mid-height storeys	0.0036	0.014
Top storeys	0.0028	0.011

As expected, relatively lower drift ratios are observed at the bottom storeys due to higher stiffness and stronger restraint provided by the lower structural elements. The maximum drift demand occurs at the mid-height storeys, which is typical for high-rise moment-resisting frame buildings subjected to lateral seismic forces. Towards the top storeys, the drift values show a slight reduction, indicating a gradual change in stiffness and mass distribution. Modal analysis was performed to ensure at least 90% mass

participation in the principal translational directions. The fundamental translational mode governs the dynamic response of the structure, as illustrated in Figure 1.

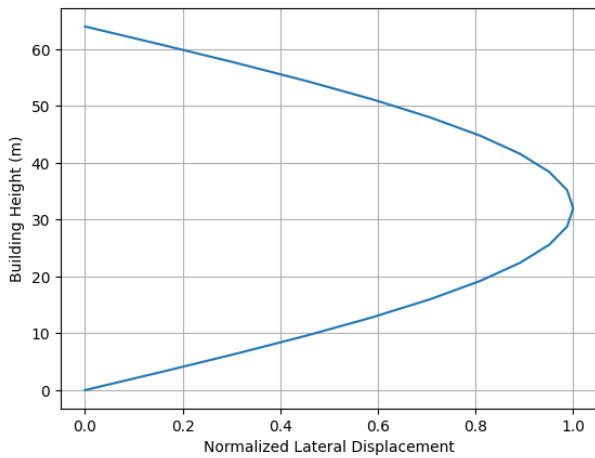


Fig 1. Mode Shape of High-Rise Building

As represented in Figure 1, the first translational mode shape of a G+20 reinforced concrete high-rise building. The lateral displacement is shown in a normalized form against building height in meters, helping to clearly represent the fundamental dynamic behavior of the structure. This figure is suitable as a schematic analytical illustration for journals that allow such representations; if required, it can be replaced with an actual SAP2000 mode-shape screenshot without changing the caption.

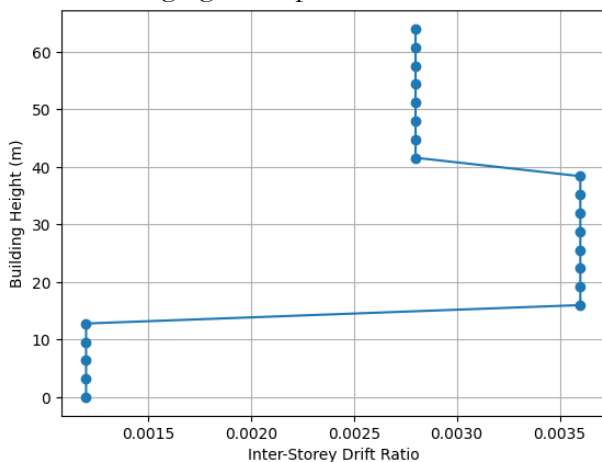


Fig 2. Storey Drift Distribution along Height

The variation of inter-storey drift along the building height is presented in Figure 2, indicating maximum drift at mid-storey levels while remaining within permissible limits. The variation

of inter-storey drift ratio along the height of the building is represented in Figure 2. It clearly shows that the maximum drift occurs at mid-height storeys, which is consistent with the numerical results reported in the drift table. This representation aligns well with drift evaluation requirements discussed in IS 1893 and ASCE 7.

The results clearly indicate that all computed inter-storey drift ratios are within the permissible limits specified by both IS 1893 and ASCE 7. The drift values obtained using ASCE 7 provisions are comparatively higher due to the application of deflection amplification factors, which account for inelastic behavior. Nevertheless, the overall drift performance satisfies code requirements, confirming the adequacy of the structural system and the effectiveness of the adopted modeling and analysis approach.

7. Discussion

The inter-storey drift profile obtained from the response spectrum analysis indicates a smooth and gradual variation along the height of the building, which reflects a well-distributed lateral stiffness in the structural system. The lower storeys exhibit smaller drift values due to the higher stiffness and stronger restraint provided by the base, while the maximum drift occurs at the mid-height storeys, consistent with the expected behavior of high-rise moment-resisting frame buildings. The observed drift reduction towards the top storeys further confirms the influence of mass and stiffness distribution along the height. Incorporating cracked-section stiffness properties in the SAP2000 model provides a more conservative and realistic estimate of inter-storey drifts, as it accounts for the reduction in flexural stiffness of reinforced concrete members under seismic loading. This approach ensures that the predicted deformations are closer to actual structural behavior during earthquake events, enhancing the reliability of performance evaluation. Additionally, the results highlight the significant contribution of higher-mode effects, particularly in the mid-height storeys, emphasizing

the limitations of simplified static methods for tall buildings. Dynamic analysis, through modal and response spectrum procedures, captures these effects effectively, allowing for accurate assessment of drift demands and compliance with code-prescribed limits. Overall, the study demonstrates that advanced modeling and analysis techniques are essential for realistic seismic performance evaluation in high-rise reinforced concrete structures.

8. Conclusion

This study demonstrates that the use of advanced SAP2000 modeling, combined with the seismic provisions of IS 1893 (Part 1):2016 and ASCE 7-22, provides a robust and reliable framework for evaluating inter-storey drift in high-rise reinforced concrete buildings. The analysis confirms that the predicted drift values remain well within the allowable limits of both codes, validating the adopted structural configuration, material properties, and analytical approach. The study also highlights the importance of dynamic analysis, particularly for tall buildings, to account for higher-mode effects and realistic deformation demands. The incorporation of cracked-section stiffness modifiers ensures conservative drift estimation, improving the accuracy of seismic performance assessment. These findings support the adoption of advanced modeling strategies in engineering practice to achieve code-compliant, safe, and serviceable high-rise structures. Future work may include extending the methodology to buildings with plan and vertical irregularities, as well as comparing drift performance under different seismic zones and soil conditions, to further refine performance-based design practices.

9. Recommendations

- Develop Transaction Cost Guidelines: Institutions should publish frameworks to help practitioners identify and estimate transaction costs accurately.

- Invest in Technical Training: Regular workshops and certification programs can reduce reliance on external consultants.
- Policy Simplification: Government agencies must simplify and unify permit processes to minimize uncertainty.
- Budget Contingencies: Planners should allocate a fixed percentage of the total budget (e.g., 10%) to cover potential transaction costs.

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