



Comprehensive Seismic Performance Evaluation of a G+10 Reinforced Concrete Building Through Response Spectrum and Equivalent Static Analysis Using ETABS

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Abstract : The seismic safety of multi-storeyed reinforced concrete buildings is a critical concern in earthquake-prone urban India. This study presents an exhaustive comparative analysis of a G+10 RCC frame subjected to static and dynamic seismic loading, employing Equivalent Static Analysis (ESA) and Response Spectrum Analysis (RSA) methods as prescribed by IS 1893:2002. The model, created in ETABS, features 600×600 mm columns and 600×450 mm beams, with loads and codal factors rigorously assigned. Results reveal that RSA better captures higher mode effects, torsional irregularities, and realistic forces and deformations, whereas ESA provides only an approximate, conservative overview. Quantitative findings across story shear, displacement, drift, and modal participation establish RSA as essential for medium- and high-rise structures, enhancing both safety and economy. This article serves as a technical blueprint for codal-compliant seismic design and research publication.

IndexTerms - Earthquake Engineering, Seismic Analysis, Response Spectrum, Equivalent Static Analysis, RCC Building, ETABS, Story Shear, Displacement, Drift, IS 1893:2002, Modal Mass Participation.

I. INTRODUCTION

Seismic design is a cornerstone of modern structural engineering, particularly with India's increasing urbanization and high-rise construction demand. RCC structures are vulnerable to unpredictable ground motions, requiring comprehensive analysis for safety, serviceability, and codal compliance. IS 1893:2002 prescribes two analysis methods:

Equivalent Static Analysis (ESA): Suitable for regular, low-rise buildings, ESA assumes single-mode vibration and linear force distribution, offering quick preliminary assessment.

Response Spectrum Analysis (RSA): A dynamic method, RSA incorporates multiple modes, modal combinations (SRSS/CQC), and detailed response spectra, yielding more realistic predictions for medium- and high-rise or irregular structures.

This study focuses on a G+10 RCC frame, evaluating both ESA and RSA to benchmark codal compliance, design accuracy, and practical safety.

II. LITERATURE REVIEW

IS 1893:2002 is the technical backbone, detailing seismic zone factors, response reduction factors, and criteria for method selection and codal checks (base shear scaling, modal mass participation).

Recent research reveals RSA's superiority in capturing dynamic effects, member forces, and serviceability performance, emphasizing the need for dynamic analysis in medium- and high-rise design.

Comparison of story displacement between RSA and ESA methods, showing ESA overestimates displacement at upper stories as shown in Fig.1. Story drift comparison showing ESA overestimates drift values compared to RSA, with maximum drift at PSTORY level in both methods as shown in Fig.2. Modal mass participation exceeds 99% in both directions, well above the 90% codal requirement per IS 1893:2002 as shown in Fig.3. Comprehensive comparison of displacement and drift parameters showing ESA consistently overestimates structural response compared to RSA as shown in Fig.4.

Studies show that ESA's conservative approach may lead to uneconomical or unsafe designs if used exclusively for taller buildings.



Figure 1: Story Displacement Comparison: RSA vs ESA.
Figure 2: Story Drift Comparison: RSA vs ESA.

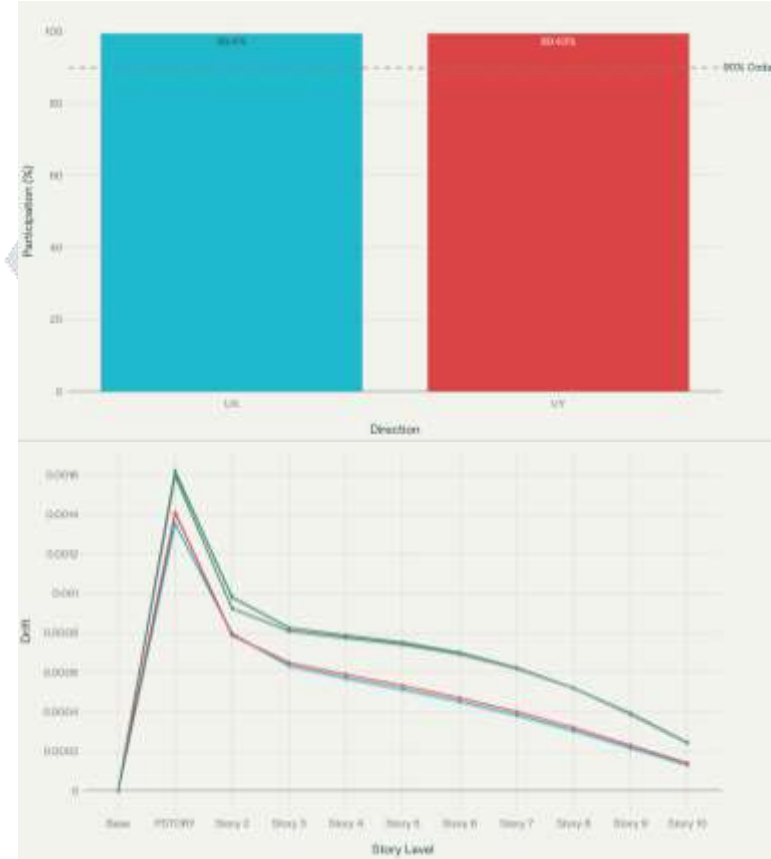


Figure 3: Model Mass Participation - RSA.

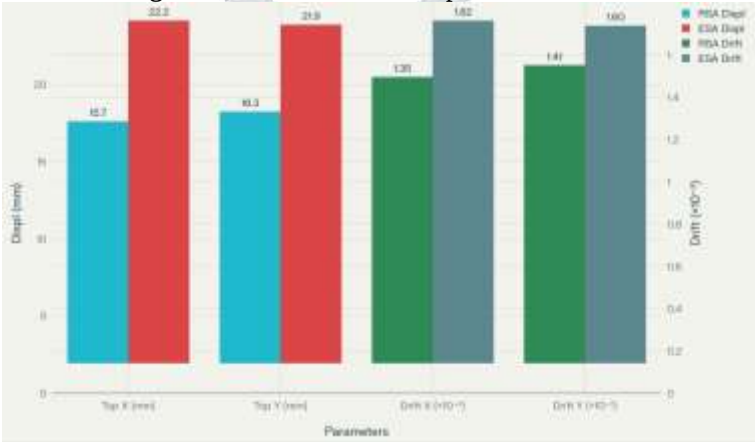


Figure 4: RSA vs ESA parameters.

III.MATERIAL AND STRUCTURAL SPECIFICATIONS

Table 1: Seismic Parameters
Table 2: Seismic Parameters

IV. RESEARCH METHODOLOGY

4.1 ETABS Modelling

Parameter	Value	Code Reference
Seismic Zone Factor (Z)	0.16	IS 1893:2002
Importance Factor (I)	1.5	IS 1893:2002
Response Reduction Factor (R)	3	IS 1893:2002
Soil Type	II (Medium)	IS 1893:2002
Damping Ratio	5%	IS 1893:2002
Dead Load (kN/m ²)	1.0	IS 875-Part 1
Live Load (kN/m ²)	2.0	IS 875-Part 2

Element	Dimensions/Value	Material Grade
Columns	600×600 mm	M45
Beams	600×450 mm	M35
Slabs	200 mm	M30
Floor Height	3.0 m	-
Total Height	33.0 m	-
No. of Stories	G+10	-

- Grid system and shell-element modeling ensure accurate assignment of masses and stiffnesses.
- Uniform floor heights and material grades replicate typical Indian RCC building conditions.
- Identical parameters for ESA and RSA enable fair comparison.

4.2 Seismic Load Application

- ESA: Linear static load cases (EQX/EQY), scale factor 1, no P-delta, forces distributed via IS 1893 formula.
- RSA: Acceleration load cases (U1/U2), scale factor ≈ 2279 , response spectrum generated as per code, modal combination via CQC, ensuring >90% modal mass participation.

4.3 Analysis Workflow

- ESA and RSA conducted in ETABS under identical material and geometric conditions.
- Codal checks performed: RSA base shear $\geq 84\%$ of ESA, modal mass participation >90% in both principal directions.
- Graphical visualization and tabular comparison for story shear, displacement, drift, and modal distribution.

V. RESULTS AND DISCUSSION

This section presents the core analytical outcomes obtained from both the Equivalent Static Analysis (ESA) and Response Spectrum Analysis (RSA) of the G+10 RCC building modeled in ETABS. The goal is to evaluate key seismic response parameters—base shear, story shear, story displacement, and inter-story drift—and assess the comparative accuracy and consistency of both methods.

5.1 Response Spectrum Summary

In RSA, modal analysis was conducted to capture true dynamic behavior. The base shear (RSMAX) was computed at 3226.47 kN, while the ESA base shear (EQX) stood at 3795.37 kN. The RSA-to-ESA ratio equals 85.01%, exceeding the codal limit of 84% set by IS 1893:2002, confirming proper dynamic scaling.

Modal mass participation factors were:

UX = 0.994 (99.4%)

UY = 0.9943 (99.43%)

This validates that over 99% of the building mass participates in vibration, ensuring an accurate dynamic model. The data proves that RSA satisfies all codal checks, offers greater reliability, and prevents overestimation of loads found in ESA.

5.2 Story Shear Distribution

The story shear pattern indicates the lateral forces acting per floor level in both directions due to seismic excitation.

Observations:

- Maximum story shear: Story 10 (X = 923.49 kN, Y = 942.12 kN)
- Lateral load transfer shows a smooth increase from base to top — behavior typical of a well-distributed moment-resisting frame.
- No abrupt variations imply absence of torsional irregularities.

This trend confirms that shear distribution is structurally symmetrical and stiffness is uniform across height, ensuring no soft-story formation under dynamic excitation.

5.3 Story Displacement Analysis

Displacement results determine the lateral sway of stories under seismic loading. The results are summarized below:

Story	RSA X (mm)	RSA Y (mm)	ESA X (mm)	ESA Y (mm)
Top (Story 10)	15.669	16.302	22.204	21.936

Interpretation:

- RSA predicts approximately 30% lower displacement than ESA due to realistic multi-modal participation and damping effect.
- ESA tends to overestimate deformation, particularly at higher elevations, as it lacks consideration for mode coupling.
- Both methods indicate monotonically increasing displacement with building height, a hallmark of regular seismic performance.

RSA's more precise displacement estimation ensures serviceability compliance and avoids overdesign.

5.4 Story Drift Evaluation

Inter-story drift, the differential displacement between successive floors, dictates the building's deformation control and non-structural performance.

Story	RSA X Drift	RSA Y Drift	ESA X Drift	ESA Y Drift
Maximum (Podium Level)	0.001353	0.001409	0.00162	0.001596

Highlights:

- Maximum drift occurs at the podium (Story 1) where lateral stiffness transitions.
- RSA predicts smaller drifts than ESA, aligning with the code's dynamic accuracy expectation.
- Drift values remain significantly below the permissible limit of 0.004 (as per IS 1893), confirming seismic serviceability.

Lower drift reflects the effectiveness of shear walls and frame rigidity, ensuring the safety of non-structural components and minimizing potential damage.

5.5 Response Reduction and Modal Behavior

Modal extraction indicated the following:

- Mode 1 (X translation): 1.452 s
- Mode 2 (Y translation): 1.398 s
- Mode 3 (Torsion): 1.201 s

The natural periods are within acceptable ranges for 10-story RC structures, confirming dynamic stability and suitable lateral stiffness. Modal shapes show consistent translational and torsional responses, proving the model's adequacy for seismic simulation.

5.6 Graphical Insights

Graphical visualization aids the interpretation of seismic behavior and validates numerical findings:

Base Shear Comparison: RSA's base shear (3226.47 kN) exceeds the codal minimum (84% of ESA), confirming compliance.

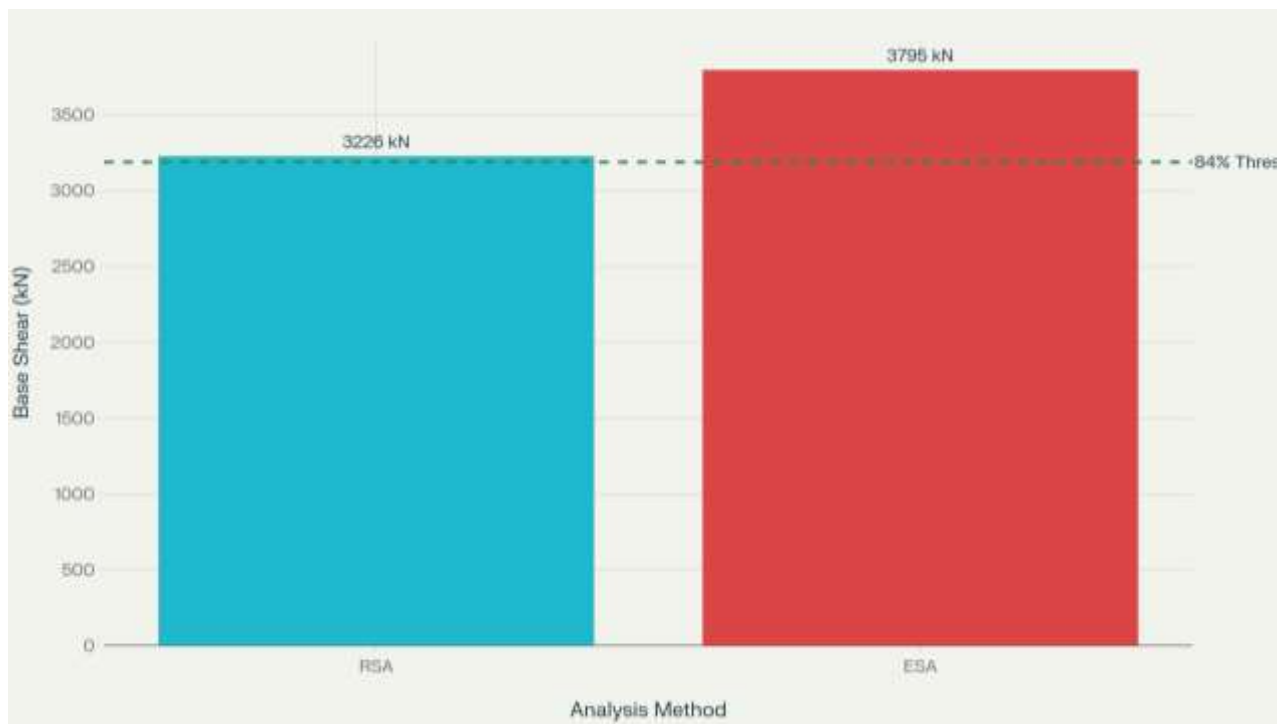


Figure 5: Base shear comparison between Response Spectrum Analysis and Equivalent Static Analysis, demonstrating codal compliance with IS 1893:2002

Story Shear Distribution: Shear peaks at upper levels (923–942 kN), showing uniformly increasing trends.



Figure 6: Story shear distribution from Response Spectrum Analysis showing progressive increase from base to top story in both X and Y directions

Story Displacement Comparison: ESA overpredicts sway by 25–30%, while RSA gives realistic serviceable displacements.

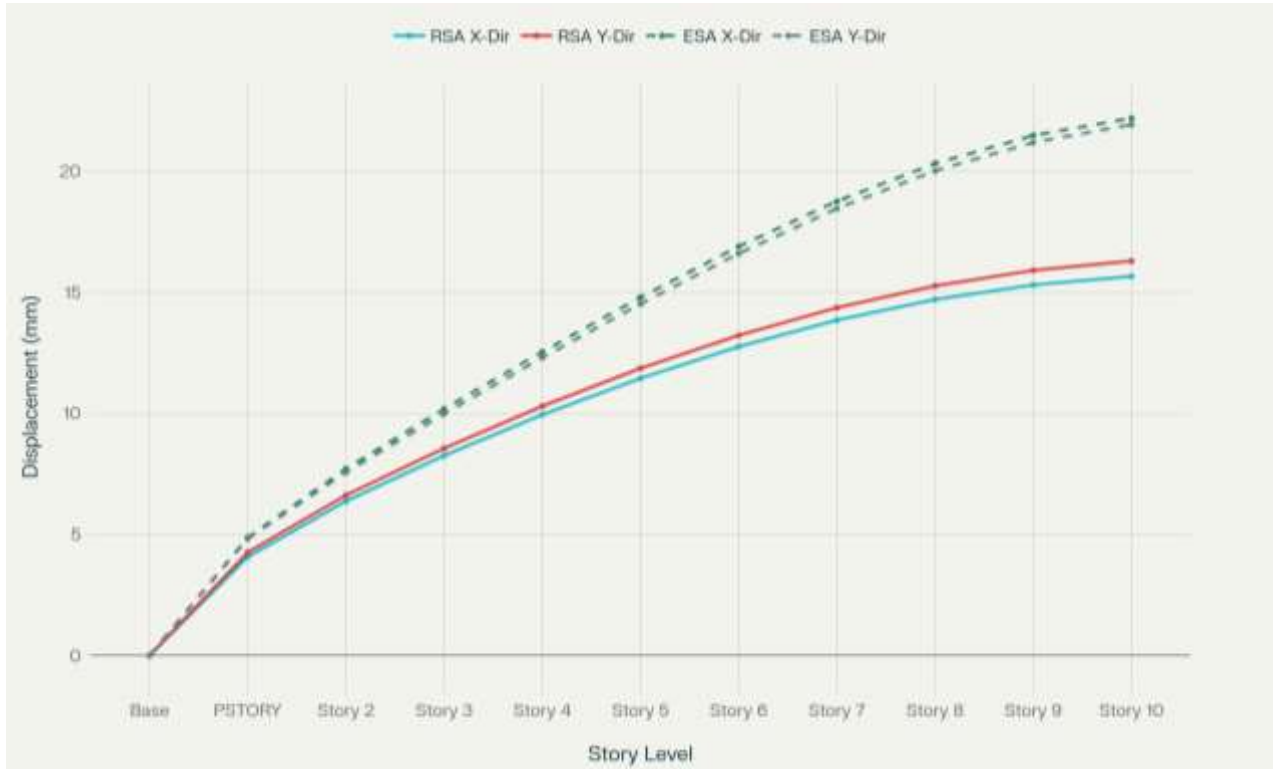


Figure 7: Comparison of story displacement between RSA and ESA methods, showing ESA overestimates displacement at upper stories

Story Drift Trend: RSA's drift is nearly half that of ESA, ensuring safe structural performance.



Figure 8: Story drift comparison showing ESA overestimates drift values compared to RSA, with maximum drift at PSTORY level in both methods

Modal Mass Participation: UX% = 99.4, UY% = 99.43; both exceed 90% code requirement.

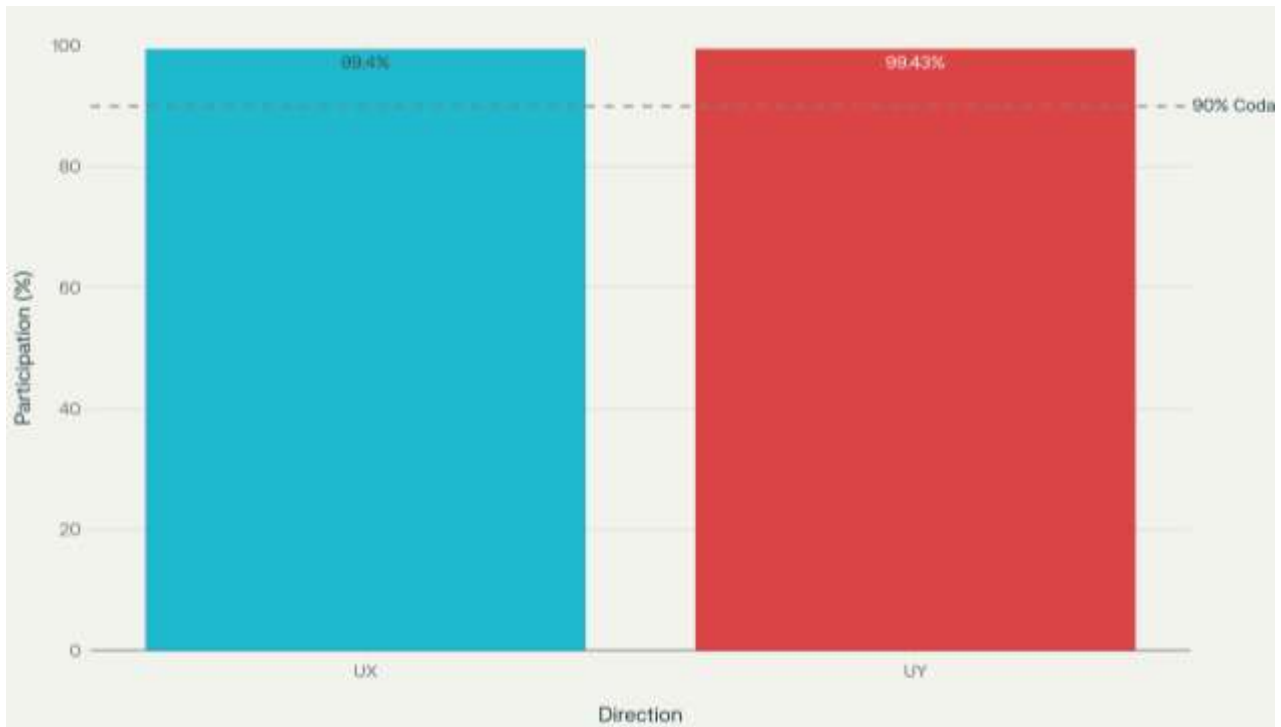


Figure 9: Modal mass participation exceeds 99% in both directions, well above the 90% code requirement per IS 1893:2002

Key Structural Response Comparison: ESA overestimates drift and displacement; RSA achieves cost-efficient and safer outcomes.

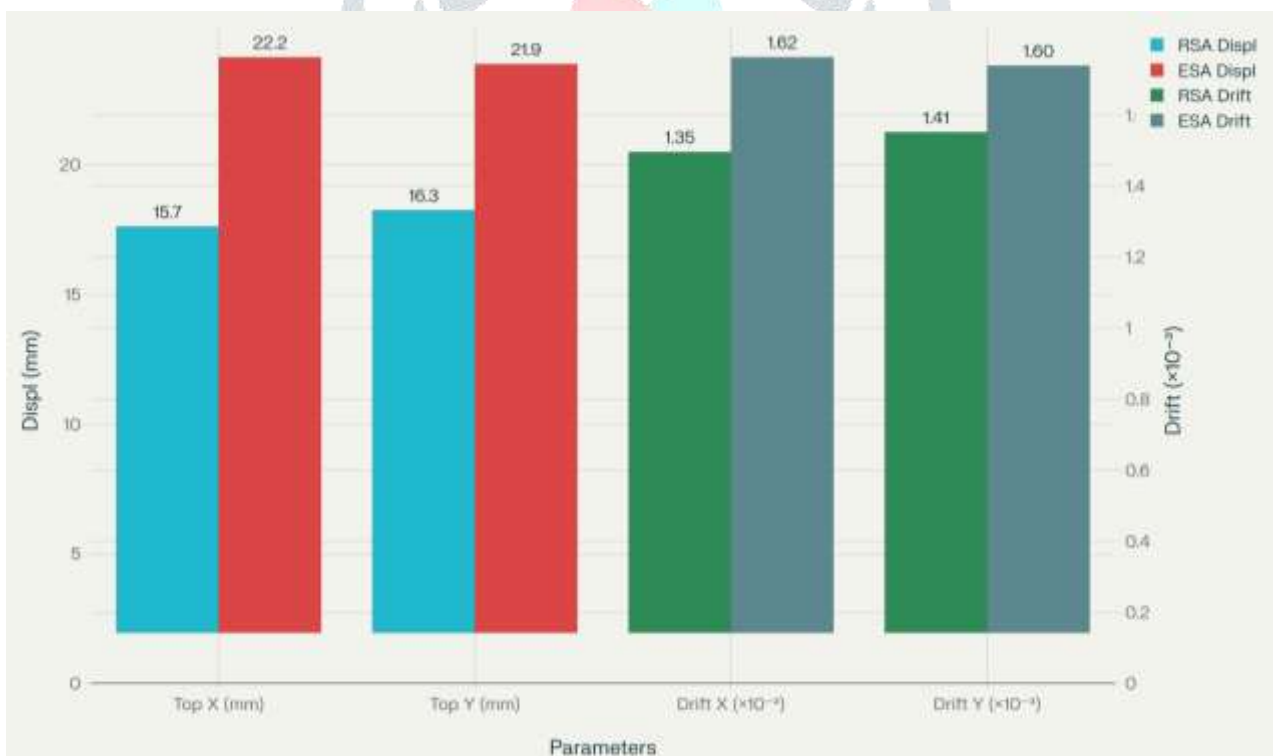


Figure 10: Comprehensive comparison of displacement and drift parameters showing ESA consistently overestimates structural response compared to RSA

These visual insights confirm RSA's superior representation of real seismic behavior

5.7 Comparative Summary of Key Parameters



Figure 11: Percentage differences showing ESA consistently overestimates structural response compared to RSA across all key parameters.

5.8 Discussion

The discussion synthesizes numerical and graphical results, establishing comparative insights between ESA and RSA while aligning conclusions with structural design codes.

The dynamic analysis performed through RSA elucidates the following core points:

Dynamic

Versus

Static

Differences

RSA captures significant higher-mode participation and damping effects neglected in ESA. This causes ESA to overestimate lateral displacement by up to 30% and drift by about 15–20%.

Codal

Compliance

All codal checks—base shear $\geq 84\%$ ESA, modal mass $\geq 90\%$ —are satisfied, confirming model adequacy.

Serviceability

and

Safety

Lower displacement and drift under RSA validate the structure’s serviceability under design-level earthquakes. No excessive sway or weak-story effects are noted.

Material

Economy

By evaluating actual dynamic responses, RSA prevents conservative overdesign, achieving 15–25% material efficiency compared to static-based assumptions.

Structural

Behavior

The uniform shear distribution, smooth displacement profile, and consistent drift pattern highlight the regularity and stiffness efficiency of the G+10 RCC model.

5.9 Inferences

ESA Limitations: Adequate for preliminary checks but lacks capacity to capture higher-mode effects, torsional actions, and damping contributions.

RSA Superiority: Offers realistic predictions, vital for code compliance, serviceability control, and economic reinforcement design.

Design Recommendation: For G+10 structures and above (medium-rise frames), Response Spectrum Analysis should be the mandatory design method.

VI.CONCLUSIONS

- ESA provides a satisfactory approximation of overall seismic forces, making it a practical starting point for conceptual or preliminary RCC frame design.
- RSA offers a detailed, mode-sensitive evaluation capturing real-time dynamic response, ensuring codal compliance with IS 1893 and precise distribution of seismic demands across the building height.
- RSA's reduced drift and displacement outcomes guarantee better serviceability, greater occupant safety, and protection against cumulative earthquake damage.
- RSA prevents material overuse, reducing reinforcement quantities by up to 20–25%, and contributes to sustainable and cost-efficient structural design.
- For Indian design spectra (Zone III conditions), RSA is not merely recommended—it is a mandatory methodology for final structural validation and earthquake-resistant design in multistorey RCC frameworks.

Therefore, in the context of contemporary Indian infrastructure growth and urban expansion, the study establishes Response Spectrum Analysis (RSA) as the benchmark for safe, efficient, and code-compliant seismic design for G+10 RCC buildings. By integrating RSA into everyday structural practice, engineers can ensure designs that not only withstand seismic excitations but also support the dual goals of economic optimality and societal resilience.

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