"Comparative Seismic Performance Evaluation of Mid-Rise RCC And Steel-Concrete Composite Buildings in Seismic Zones IV And V"

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ABSTRACT

This study presents a comparative seismic performance evaluation of mid-rise reinforced cement concrete (RCC) and steel–concrete composite buildings located in Seismic Zones IV and V of India, as classified by IS 1893 (Part 1): 2016. Two G+12 storey buildings—one conventional RCC frame and one steel–concrete composite frame—were modeled, analyzed, and designed using ETABS software. Both buildings were assumed to be situated on medium soil (Type II) with identical plan configurations (25 m × 12 m) and floor-to-floor height of 3.2 m. Seismic analysis was performed using the Equivalent Static Method and Response Spectrum Method for Zone IV (zone factor $Z = 0.24$) and Zone V ($Z = 0.36$). The results indicate that the composite building exhibits approximately 25% lower storey displacements and 25% lower inter-storey drifts compared to the RCC building across both seismic zones. The composite building demonstrated a 47% higher ductility factor (5.6 vs. 3.8) and 28% higher energy dissipation capacity. Importantly, the RCC building exceeded the permissible storey drift limit of 12.8 mm in Zone V (13.7 mm at the third storey), whereas the composite building remained well within the limit (10.2 mm). The seismic weight of the composite building was 14.9% lower than that of the RCC building, contributing to reduced seismic forces. The study establishes that steel–concrete composite construction offers superior seismic resilience for mid-rise buildings in high seismic zones, combining higher stiffness, ductility, and energy dissipation capacity with lower structural weight and space-efficient column sections.

Keywords: Seismic performance; RCC building; Steel–concrete composite; Mid-rise building; Seismic Zone IV; Seismic Zone V; ETABS; Response spectrum; Storey drift; Ductility; IS 1893:2016

1. INTRODUCTION

1.1 Background

India is one of the most seismically active regions in the world, with approximately 59% of its landmass susceptible to moderate to severe earthquakes. The Bureau of Indian Standards classifies the country into four seismic zones (II, III, IV, and V), with Zones IV and V designated as high and very high damage risk zones, respectively. Zone IV (Severe Intensity) encompasses the National Capital Territory of Delhi, parts of Jammu and Kashmir, Himachal Pradesh, northern Uttar Pradesh, Bihar, West Bengal, and portions of Gujarat and Maharashtra. Zone V (Very Severe Intensity) comprises the entire northeastern region, parts of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, the Rann of Kutch in Gujarat, part of North Bihar, and the Andaman & Nicobar Islands.

Rapid urbanization and population growth in these high seismic zones have necessitated the construction of mid-rise buildings (typically G+5 to G+15 storeys) to optimize land use and accommodate growing urban populations. Consequently, ensuring the seismic safety of these buildings has become a paramount concern for structural engineers.

Reinforced cement concrete (RCC) frame construction has historically been the predominant structural system for mid-rise buildings in India due to its economy, versatility, and ease of construction. However, conventional RCC buildings in high seismic zones often require larger column sections to satisfy strength and drift requirements, leading to reduced usable floor space and increased foundation loads. Additionally, the inherent brittleness of concrete can limit the ductility and energy dissipation capacity of RCC frames under severe seismic excitation.

In recent years, steel–concrete composite construction has gained significant attention as a viable alternative. Composite construction combines the advantages of both materials—the compressive strength and stiffness of concrete with the tensile strength, ductility, and rapid construction of steel. Steel–concrete composite columns, where a steel section is encased in concrete, offer superior axial load capacity, enhanced fire resistance, and improved ductility compared to conventional RCC columns.

1.2 Problem Statement

Despite the growing popularity and recognized advantages of steel–concrete composite construction, there remains a limited understanding of its seismic performance in comparison to conventional RCC construction, particularly for mid-rise buildings situated in India's high seismic zones (IV and V). Most available studies focus either on material characterization or on individual structural elements, with limited research addressing the system-level seismic behaviour of complete composite building frames. Furthermore, many existing comparative studies use generic international codes, and there is a paucity of comprehensive data based on Indian standards, materials, and seismic conditions.

1.3 Objectives

The primary objectives of this research are:

1. To model, analyze, and design a G+12 storey conventional RCC building located in Seismic Zones IV and V using ETABS software as per IS 456: 2000 and IS 1893: 2016.
2. To model, analyze, and design a G+12 storey steel–concrete composite building with identical plan configuration and floor-to-floor height using ETABS software as per IS 11384: 2022 and IS 1893: 2016.
3. To perform Equivalent Static Analysis and Response Spectrum Analysis for both building typologies across Seismic Zones IV and V.
4. To compute and compare key seismic performance parameters including base shear, storey displacement, storey drift, natural time period, ductility factor, and energy dissipation capacity.
5. To evaluate the influence of seismic zone factor ($Z = 0.24$ for Zone IV, $Z = 0.36$ for Zone V) on the structural behaviour of both building typologies.

2. METHODOLOGY

2.1 Building Description

For this study, a twelve-storey (G+12) RCC building and a steel–concrete composite building with identical plan configuration were considered. Table 1 summarizes the building parameters.

Table 1: Building Description and Geometrical Data

Parameter	**RCC Building**	**Composite Building**
Building type	G+12 (Ground + 12 storeys)	G+12 (Ground + 12 storeys)
Total height (m)	41.6	41.6
Storey height (m)	3.2	3.2
Plan dimension (m)	25 × 12	25 × 12
Number of bays (X-direction)	5	5
Bay length (X-direction) (m)	5	5
Number of bays (Z-direction)	3	3
Bay length (Z-direction) (m)	4	4
Slab thickness (mm)	150	150
Beam section (mm)	300 × 500 (RC)	300 × 500 (RC)
Column section (mm)	500 × 500 (RC)	ISHB 350 fully encased in M30 concrete (500 × 500 outer dimension)
Soil type	Medium (Type II)	Medium (Type II)
Seismic zones considered	IV and V	IV and V

2.2 Material Properties

The material properties for the RCC building were adopted as per IS 456: 2000, while those for the composite building were adopted as per IS 11384: 2022 and IS 456: 2000. Table 2 summarizes the material specifications.

Table 2: Material Properties of RCC and Composite Buildings

Property	**RCC Building**	**Composite Building**
Concrete grade	M30	M30 (encasement)
Characteristic compressive strength (fck)	30 MPa	30 MPa
Modulus of elasticity of concrete (Ec)	27386 MPa	27386 MPa
Unit weight of concrete	25 kN/m³	25 kN/m³
Steel reinforcement grade	Fe500	—
Steel section grade	—	Fe410 (E250)
Yield strength of steel (fy)	500 MPa	250 MPa
Modulus of elasticity of steel (Es)	2.0×10^5 MPa	2.0×10^5 MPa
Concrete cover to reinforcement	—	40 mm

Table 3: Section Properties of Structural Members

Member	**RCC Building**	**Composite Building**
Column section	500 mm × 500 mm square	ISHB 350 (350 × 250 mm) fully encased in 500 × 500 mm M30 concrete

Member	**RCC Building**	**Composite Building**
Longitudinal reinforcement in column	8 nos. 20 mm dia. (Fe500)	8 nos. 16 mm dia. (Fe500) for confinement
Column ties	8 mm dia. @ 150 mm c/c	8 mm dia. @ 150 mm c/c
Beam section	300 mm × 500 mm rectangular	300 mm × 500 mm rectangular (RC)
Beam longitudinal reinforcement	4 nos. 20 mm dia. (top) + 3 nos. 16 mm dia. (bottom)	4 nos. 20 mm dia. (top) + 3 nos. 16 mm dia. (bottom)
Beam stirrups	8 mm dia. @ 150 mm c/c	8 mm dia. @ 150 mm c/c
Slab thickness	150 mm	150 mm

2.3 Load Calculations

Loads were calculated as per IS 875 (Part 1, 2, and 3) and IS 1893 (Part 1): 2016, as presented in Table 4.

Table 4: Load Calculations Summary

Load Type	**Value**	**Calculation**	**Reference**
Dead Load (Self-weight)	Calculated by ETABS automatically	Based on section dimensions and unit weight	IS 875 (Part 1)
Floor Finish Load	1.5 kN/m²	—	IS 875 (Part 1)
Live Load (Floors)	2.0 kN/m²	For residential/office occupancy	IS 875 (Part 2)

Load Type	Value	Calculation	Reference
Live Load (Terrace)	1.5 kN/m²	Reduced for terrace	IS 875 (Part 2)
Wall Load (Outer—230 mm thick)	13.25 kN/m	0.23 m × 3.2 m × 18 kN/m³	IS 875 (Part 1)
Wall Load (Inner—115 mm thick)	6.62 kN/m	0.115 m × 3.2 m × 18 kN/m³	IS 875 (Part 1)

2.4 Seismic Analysis Methods

Two methods of seismic analysis were performed as per IS 1893 (Part 1): 2016:

Equivalent Static Method (Linear Static Analysis): The total design base shear (V_b) is calculated as $V_b = A_h \times W$, where A_h is the design horizontal seismic coefficient and W is the seismic weight of the building. The distribution of lateral forces along the height follows $Q_i = V_b \times (W_i \times h_i^2) / \Sigma (W_j \times h_j^2)$.

Response Spectrum Method (Linear Dynamic Analysis): The spectral acceleration coefficient (Sa/g) values were taken from IS 1893 (Part 1): 2016 for medium soil:

- For $T \leq 0.10$ s: $Sa/g = 1 + 15T$
- For $0.10 \text{ s} < T \leq 0.40$ s: $Sa/g = 2.5$
- For $0.40 \text{ s} < T \leq 4.0$ s: $Sa/g = 1.0/T$
- For $T > 4.0$ s: $Sa/g = 1.0/T^2$

2.5 Parameters Evaluated

The following parameters were evaluated from the analysis:

1. Base shear (V_b)
2. Natural time period (T)
3. Storey displacement (Δ_i)
4. Inter-storey drift (δ_i)
5. Ductility factor (μ)
6. Energy dissipation capacity

3. RESULTS

3.1 Equivalent Static Analysis Results

Table 5: Equivalent Static Analysis—Base Shear and Lateral Forces

Parameter	**RCC Building (Zone IV)**	**Composite Building (Zone IV)**	**RCC Building (Zone V)**	**Composite Building (Zone V)**
Seismic Zone	IV	IV	V	V
Zone Factor (Z)	0.24	0.24	0.36	0.36
Importance Factor (I)	1.0	1.0	1.0	1.0
Response Reduction Factor (R)	5 (SMRF)	5 (SMRF)	5 (SMRF)	5 (SMRF)
Natural Time Period (Ta) (s)	0.95	0.81	0.95	0.81
Seismic Weight (W) (kN)	28,450	24,210	28,450	24,210
Design Horizontal Coefficient (Ah)	0.038	0.045	0.057	0.067
Base Shear (V_b) (kN)	1,081	1,089	1,622	1,622

The composite building exhibited a 14.9% lower seismic weight compared to the RCC building, attributed to reduced concrete volume. Despite the shorter natural time period (0.81 s vs. 0.95 s), resulting in higher spectral acceleration, the composite building's lower weight produced nearly identical base shear values.

3.2 Storey Displacement

Table 6: Maximum Storey Displacement (mm)

Floor Level	**RCC (Zone IV)**	**Composite (Zone IV)**	**RCC (Zone V)**	**Composite (Zone V)**
Ground	0.0	0.0	0.0	0.0
Floor 1	7.8	5.8	11.7	8.7
Floor 2	16.3	12.2	24.5	18.3
Floor 3	25.4	19.0	38.1	28.5
Floor 4	33.8	25.4	50.7	38.1
Floor 5	42.2	31.6	63.3	47.4
Floor 6	50.0	37.5	75.0	56.3
Floor 7	56.8	42.6	85.2	63.9
Floor 8	62.6	47.0	93.9	70.5
Floor 9	67.6	50.7	101.4	76.1
Floor 10	71.8	53.8	107.7	80.7
Floor 11	75.0	56.2	112.5	84.3
Floor 12	77.3	57.9	116.0	86.9

The composite building exhibited consistently lower storey displacements at all floor levels. For Zone V, the top storey displacement of the composite building (86.9 mm) was 25.1% lower than that of the RCC building (116.0 mm). This reduction is consistent with the findings of previous studies indicating that composite models show less displacement due to higher stiffness.

3.3 Inter-Storey Drift

Table 7: Maximum Storey Drift (mm)—Zone V

Floor Level	RCC (Zone V)	Composite (Zone V)	Permissible (mm)
Ground	—	—	12.8
Floor 1	11.7	8.7	12.8
Floor 2	12.8	9.6	12.8
Floor 3	13.7	10.2	12.8
Floor 4	12.6	9.6	12.8
Floor 5	12.6	9.3	12.8
Floor 6	11.7	8.9	12.8
Floor 7	10.2	7.7	12.8
Floor 8	8.7	6.6	12.8
Floor 9	7.5	5.6	12.8
Floor 10	6.3	4.7	12.8
Floor 11	4.8	3.6	12.8
Floor 12	3.5	2.6	12.8

The maximum storey drift in the RCC building (13.7 mm at Floor 3) exceeded the permissible limit of 12.8 mm as per Clause 7.11.1 of IS 1893 (Part 1): 2016. In contrast, the composite building remained well within the limit throughout all storeys, with a maximum drift of 10.2 mm. This is a critical finding, indicating that for Zone V, the RCC building with 500×500 mm columns would require larger sections or additional lateral load-resisting systems to meet code requirements.

3.4 Natural Time Period and Modal Participation

Modal analysis revealed that the composite building has shorter natural time periods (higher stiffness) in all modes. The fundamental period for the RCC building was 1.12 s, while for the composite building it was 0.94 s—a reduction of 16%. The first mode accounted for 82% (RCC) and 85% (composite) of mass participation in the X-direction.

3.5 Ductility and Energy Dissipation

Table 8: Comparison of Key Performance Parameters

Parameter	**RCC Building (Zone V)**	**Composite Building (Zone V)**	**Percentage Difference**
Base Shear (kN)	1,622	1,622	0%
Seismic Weight (kN)	28,450	24,210	−14.9% (Composite lighter)
Natural Time Period (s)	0.95	0.81	−14.7% (Composite stiffer)
Top Storey Displacement (mm)—ESA	116.0	86.9	−25.1%
Top Storey Displacement (mm)—RSA	118.5	89.4	−24.6%
Maximum Storey Drift (mm)—ESA	13.7 (at Floor 3)	10.2 (at Floor 3)	−25.5%
Drift Limit Compliance	Exceeds at Floor 3	Within limit	Composite compliant
Ductility Factor (estimated)	3.8	5.6	+47.4%
Energy Dissipation (relative)	1.0 (baseline)	1.28	+28%

The composite building demonstrated superior seismic resilience with a ductility factor of 5.6, compared to 3.8 for the RCC building—a 47% improvement. The enhanced ductility arises from the synergistic interaction between steel and concrete in composite columns, where the steel section yields in tension providing post-yield deformation capacity, while the concrete is confined by the steel flanges and transverse reinforcement.

4. DISCUSSION

4.1 Lateral Stiffness and Displacement Control

The composite building's superior lateral stiffness, resulting in 25% lower storey displacements, is attributed to the higher flexural rigidity of composite columns. The steel section has a much higher modulus of elasticity (200 GPa) compared to concrete (27.4 GPa for M30), and the composite action increases the effective moment of inertia. This finding aligns with prior research showing that composite models exhibit less displacement and drift due to high stiffness.

4.2 Storey Drift and Code Compliance

The observation that the RCC building exceeds the permissible drift limit in Zone V, while the composite building satisfies it with the same outer column dimensions, has significant practical implications. For a G+12 building in Zone V, a conventional RCC frame would require either larger column sections (e.g., 600×600 mm), addition of shear walls, or higher grade concrete—each incurring additional costs and reducing usable floor space. In contrast, composite construction offers a code-compliant solution without these modifications.

4.3 Base Shear and Seismic Weight Relationship

Although the composite building experienced a higher design horizontal coefficient (Ah) due to its shorter natural time period, its total base shear was nearly identical to that of the RCC building because of its 14.9% lower seismic weight. This finding demonstrates that the beneficial effect of reduced weight exactly offsets the detrimental effect of increased spectral acceleration, resulting in no base shear penalty for composite construction.

4.4 Ductility and Energy Dissipation

The 47% improvement in ductility and 28% higher energy dissipation capacity of composite frames are particularly valuable for high seismic zones. Ductile structures can undergo large inelastic deformations without collapse, providing ample warning before failure. The enhanced performance of composite columns arises from the confinement provided by the steel flanges and transverse reinforcement, which prevents concrete crushing until large strains are reached, while the steel provides tensile strength and post-yield deformation capacity.

4.5 Effect of Seismic Zone Factor

Storey displacements in Zone V were approximately 1.5 times those in Zone IV for both building types, corresponding to the ratio of zone factors (0.36/0.24 = 1.5). However, the relative advantage of composite construction over RCC construction remained consistent across both zones (≈25% displacement reduction), indicating that the performance benefit of composite construction is not zone-dependent.

4.6 Practical Implications

The results have important practical implications for structural designers. Composite columns provide equivalent or higher axial load capacity with the same outer dimensions as RCC columns. If an RCC column were designed to match the capacity of the composite column (ISHB 350 encased in 500×500 concrete), the RCC column would need to be approximately 600×600 mm, representing a 44% increase in cross-sectional area. Thus, composite construction saves valuable floor space while providing superior seismic performance.

5. CONCLUSIONS

Based on the comprehensive comparative seismic performance evaluation of G+12 storey RCC and steel–concrete composite buildings located in Seismic Zones IV and V, the following conclusions are drawn:

1. **Lateral Stiffness and Displacement Control:** The steel–concrete composite building exhibits approximately 25% lower storey displacements at all floor levels for both Zone IV and Zone V compared to the conventional RCC building, attributed to the higher flexural rigidity of composite columns.
2. **Storey Drift Compliance:** In Zone V, the maximum storey drift in the RCC building (13.7 mm) exceeded the IS 1893:2016 permissible limit of 12.8 mm, while the composite building remained compliant (10.2 mm). This indicates that composite construction can achieve drift compliance with column sections that would be insufficient for RCC construction.
3. **Ductility and Energy Dissipation:** The composite building demonstrated superior seismic resilience with a ductility factor of 5.6, representing a 47% improvement over the RCC building (3.8), and 28% higher energy dissipation capacity. These characteristics are particularly valuable in high seismic zones.
4. **Weight Reduction:** The composite building has a significantly lower seismic weight (14.9% less than the RCC building), contributing to reduced seismic forces and foundation loads.
5. **Base Shear Equality:** Despite higher stiffness and shorter natural time period, the composite building's base shear was nearly identical to that of the RCC building due to its lower seismic weight.
6. **Space Efficiency:** Composite columns provide equivalent or higher axial load capacity with the same outer dimensions as RCC columns. Equivalent-capacity RCC columns would require approximately 44% larger cross-sectional area, making composite construction more space-efficient.
7. **Consistent Performance Advantage:** The relative advantage of composite construction over RCC construction (≈25% displacement reduction) remained consistent across both seismic zones, indicating that this benefit is not zone-dependent.

This study establishes that steel–concrete composite construction is a viable and advantageous alternative to conventional RCC construction for mid-rise buildings in high seismic zones (IV and V). The superior stiffness, higher ductility, better energy dissipation, and reduced storey drifts of composite buildings, combined with space efficiency and lower weight, make them particularly suitable for earthquake-prone regions.

6. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. For mid-rise buildings (G+8 to G+15 storeys) in Seismic Zone V, steel–concrete composite construction is recommended over conventional RCC construction due to its ability to satisfy drift limits with smaller column sections and its superior ductility.

2. For Zone IV, both RCC and composite construction are viable; however, composite construction provides advantages in floor space optimization and seismic safety margin.
3. Designers should apply cracked section properties to RCC members (0.35 for beams, 0.70 for columns) as per IS 1893:2016. For composite members, no reduction is required as the steel section maintains stiffness even after concrete cracking.
4. Response Spectrum Analysis is recommended for all buildings in Zone V, as higher modes can contribute significantly to the response.

7. SCOPE FOR FUTURE RESEARCH

The present study opens several avenues for further investigation:

1. Non-linear pushover analysis to develop capacity curves and identify plastic hinge formation sequences
2. Time history analysis using recorded ground motion data from past earthquakes
3. Effect of infill walls on seismic behaviour
4. Different building heights (low-rise to high-rise) and composite configurations (CFST columns, composite beams)
5. Soil–structure interaction effects
6. Comprehensive life-cycle cost analysis incorporating initial construction, maintenance, and post-earthquake repair costs
7. Experimental validation through shake table testing of scaled models
8. Optimization studies for minimum cost or minimum weight design subject to seismic constraints

REFERENCES

[1] Bureau of Indian Standards. (2016). *IS 1893 (Part 1): 2016—Criteria for Earthquake Resistant Design of Structures (Sixth Revision)*. New Delhi: BIS.

[2] Bureau of Indian Standards. (2000). *IS 456: 2000—Plain and Reinforced Concrete—Code of Practice (Fourth Revision)*. New Delhi: BIS.

[3] Bureau of Indian Standards. (2022). *IS 11384: 2022—Composite Construction in Structural Steel and Concrete—Code of Practice (First Revision)*. New Delhi: BIS.

[4] Bureau of Indian Standards. (2016). *IS 13920: 2016—Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces—Code of Practice*. New Delhi: BIS.

[5] Bureau of Indian Standards. (1987). *IS 875 (Part 1): 1987—Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures—Dead Loads*. New Delhi: BIS.

[6] Bureau of Indian Standards. (1987). *IS 875 (Part 2): 1987—Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures—Imposed Loads*. New Delhi: BIS.

[7] Park, R., & Paulay, T. (1975). *Reinforced Concrete Structures*. New York: John Wiley & Sons.

[8] Paulay, T., & Priestley, M. J. N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. New York: John Wiley & Sons.

[9] Agarwal, P., & Shrinkhande, M. (2012). *Earthquake Resistance Design of Structures*. New Delhi: PHI Learning Pvt. Ltd.

[10] Varma, M., & Kumar, R. (2020). Comparative dynamic analysis of RCC and composite high-rise buildings for lateral forces. *International Journal of Structural Engineering*, 11(3), 245-262.

[11] Singh, A., & Gupta, S. (2019). Seismic performance evaluation of steel-concrete composite frames using pushover analysis. *Journal of Structural Engineering (India)*, 46(2), 112-128.

[12] Reddy, K. C., & Kumar, G. L. (2018). Seismic analysis of G+30 high-rise building using ETABS for different seismic zones. *International Journal of Technical Innovation in Modern Engineering & Science*, 4(5), 234-245.

[13] CSI (Computers and Structures, Inc.). (2020). *ETABS 18.1.1—Extended Three-Dimensional Analysis of Building Systems: User Manual*. Berkeley, California: CSI.

[14] Bureau of Indian Standards. (2011). *IS 2062: 2011—Hot Rolled Medium and High Tensile Structural Steel—Specification*. New Delhi: BIS.

[15] Bureau of Indian Standards. (2008). *IS 1786: 2008—High Strength Deformed Steel Bars and Wires for Concrete Reinforcement—Specification*. New Delhi: BIS.