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Original Research Article

A comparative study of waffle and flat slabs and conventional slabs in symmetrical high-rise building across various zones in India

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ABSTRACT
This research presents a comparative analysis of three different slab systems—waffle slabs, flat slabs, and conventional RCC slabs—in symmetrical high-rise buildings across various seismic zones in India. Using ETABS software, a G+10 storey building model was developed with each slab configuration and analyzed under seismic loading conditions as per IS 1893:2016. Key structural parameters such as storey drift, base shear, lateral displacement, and time period were evaluated to understand the seismic performance of each slab type. The results indicate that waffle slabs exhibit superior stiffness and reduced lateral displacement, making them more effective in resisting seismic forces, especially in higher seismic zones. Flat slabs, while offering architectural and construction advantages, showed increased drift and displacement. Conventional slabs performed moderately but with better ductility. The study concludes with recommendations on optimal slab selection based on structural performance and seismic zone considerations, aiming to guide safer and more efficient high-rise construction in earthquake-prone regions of India.

1. Introduction

The rapid pace of urbanization and economic growth in India has led to an unprecedented demand for high-rise buildings, transforming city skylines and addressing the critical need for vertical expansion in densely populated areas. These towering structures, typically exceeding seven stories, present complex engineering challenges, particularly concerning their structural integrity and resilience against dynamic forces such as seismic activity and high winds. Within the myriad of structural components that constitute a high-rise building, the floor system plays a pivotal role. It not only supports gravity loads—the self-weight of the structure and its occupants—but is also instrumental in transferring lateral forces throughout the building's frame, influencing the overall stability and dynamic response. The judicious choice of slab system significantly impacts a high-rise building's constructability, economic viability, and architectural flexibility, making it a critical decision in the design process.

This research paper undertakes a comprehensive comparative study of three prominent reinforced concrete slab systems: conventional beam-slab, flat slab, and waffle slab. Each of these systems possesses distinct structural characteristics, advantages, and disadvantages that dictate its suitability for specific applications. While conventional beam-slab systems have historically been the norm, flat slabs and waffle slabs have gained considerable traction in modern high-rise construction. This shift is driven by their potential for achieving greater spans, reducing material consumption, and offering enhanced architectural freedom, which are highly desirable attributes in contemporary urban developments. However, their performance under the unique demands of high-rise structures, especially when subjected to significant seismic forces, warrants rigorous investigation to ensure safety and efficiency.

India, characterized by its diverse and significant seismic zones, necessitates a meticulous approach to earthquake-resistant design for all critical infrastructure, particularly high-rise buildings. The Indian Standard (IS) 1893:2016 provides comprehensive guidelines for seismic analysis and design, incorporating essential parameters such as seismic zone factors, importance factors, response reduction factors, and considerations for various soil types. Understanding how each slab system interacts with these seismic design principles and performs across India's varied seismic hazards (Zones II, III, IV, and V) is crucial for ensuring life safety, maintaining structural integrity, and guaranteeing long-term serviceability of high-rise developments. The symmetrical nature of the building plan, a common design choice for optimizing space

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and achieving structural regularity, further influences how these slab systems interact with the overall structural frame under seismic excitation, simplifying the analysis of torsional effects and allowing for a more direct comparison of inherent slab performance.

This study aims to evaluate the structural behavior, seismic performance, constructability, economic implications, and architectural flexibility of waffle, flat, and conventional slabs when implemented in symmetrical high-rise buildings across various seismic zones in India. By synthesizing existing research and comparative analyses, this paper seeks to provide a holistic understanding of the optimal application of these slab systems. This will contribute valuable insights for structural engineers, architects, and policymakers involved in the design and construction of resilient high-rise infrastructure in India. The findings will highlight the trade-offs and synergies inherent in each slab type, guiding informed decision-making for sustainable and safe urban development in a seismically active region.

2. Objective of the study

1. To model waffle, flat, and conventional slabs in ETABS.
2. To compare seismic performance of the slabs in different zones.
3. To identify the most efficient slab system under seismic loads.
4. To recommend the best slab type for high-rise buildings in India.

3. Literature review

Khot et al. [1] conducted a comparative study to evaluate the performance of waffle slabs in comparison with flat slabs and conventional RCC slabs. Their research highlighted that waffle slabs significantly reduce the dead load of structures, making them more structurally efficient and cost-effective. They concluded that waffle slabs allow for better load distribution and support longer spans with reduced slab thickness. These slabs not only optimize material usage but also contribute to architectural aesthetics. Overall, waffle slabs emerged as a superior alternative due to their structural and economic advantages.

Kodali [2] analyzed the seismic behavior of a 30-storey high-rise building designed with three different slab systems: flat slab, beam slab, and an alternate flat-beam slab. His findings revealed that flat slab structures tend to experience higher storey drifts compared to beam slab structures, indicating greater vulnerability during seismic events. Beam slab systems, on the other hand, demonstrated greater base shear resistance and achieved 90% mass participation earlier in the vibration mode spectrum, suggesting better seismic performance. The study emphasizes the need for careful consideration of structural systems in high seismic zones.

Tejananda and Chetan [3] conducted a study to assess the earthquake resistance of conventional RC slabs and flat slabs, both with and without inverted V-bracing, across different seismic zones. Their analysis showed that incorporating inverted V-bracing with flat slabs significantly improved seismic performance. The structure with this combination exhibited the lowest displacement and storey drift values, making it the most stable configuration under earthquake loads. The study concluded that flat slabs with bracing systems are best suited for seismic-prone areas due to their enhanced stiffness and reduced lateral deformation.

Manu et al. [4] focused on the seismic response of flat slabs compared to conventional RC slab systems in high-risk earthquake zones. Their findings indicated that although flat slabs offer advantages such as reduced height and better aesthetics, they are not as seismically resilient as conventional RC slabs. In earthquake-prone areas, flat slabs showed poor performance unless additional design measures like drop panels or bracing were incorporated. The study recommended extra reinforcement and seismic detailing for flat slabs to make them viable for such regions.

Singh and Mishra [5] examined the seismic performance of commercial buildings with waffle slabs supported by bracing systems and compared them to conventional slabs without bracing. Their research demonstrated that waffle slabs with bracing systems showed superior structural behavior under seismic conditions, including lower joint displacement and storey drift. In contrast, conventional slabs without bracing were less stiff and exhibited higher displacement during seismic loading. The study emphasized that combining waffle slabs with bracing provides a highly efficient solution for earthquake-resistant structures.

Kalyani and Srividya [6] analyzed how different seismic zones influence the structural design of a G+15 RC building, focusing on both rectangular and C-shaped sections. Their study underlined the significant impact seismic zone classifications have on the design parameters, such as bending moment, shear force, and lateral displacement. They concluded that buildings in higher seismic zones require more robust structural elements and reinforcements to ensure safety. This research contributes valuable insights into the necessity of zone-specific design adaptations for high-rise buildings.

Chamelka [7] conducted an in-depth assessment of the seismic performance of wide-span multistory buildings using various slab types. His study aimed to understand how different slab configurations affect stiffness and load-carrying capacity under earthquake loads. The findings revealed that the choice of slab type significantly influences the building's resistance to seismic forces. Certain slab systems improved the structural stiffness and distributed the seismic forces more evenly. The research provides important guidance for architects and engineers in selecting slab systems for earthquake-prone, large-span structures.

Pethe et al. [8] and his colleague compared conventional slabs, flat slabs, and waffle slabs using the Finite Element Method in a seismic context. The analysis, performed on a G+10 storey building using ETABS, concluded that waffle slabs outperformed the other two in terms of story drift and lateral displacement under seismic loads. Flat slabs, however, experienced the highest lateral movement. The research emphasized that waffle slabs not only provide structural efficiency but also cost savings, especially when designed as per standard codes.

Ramhari [9] explored the structural performance of flat slabs versus conventional slabs using ETABS software for a G+9 building. His findings suggested that flat slabs, though more flexible and susceptible to seismic forces, could be a cost-effective alternative if executed with proper structural supervision. Flat slabs proved advantageous in terms of construction speed and architectural flexibility but needed additional reinforcements to withstand seismic loads effectively. The study advocates for careful supervision and detailing when opting for flat slabs in earthquake-sensitive

regions.

Kilinc [10] carried out a comparative study on the seismic response of various RC slab systems, including flat slabs, grid slabs, and conventional slabs. Using ETABS for simulation, the research analyzed parameters such as displacement, shear force, and base shear under earthquake excitation. Grid slabs were found to offer better seismic performance due to their interconnected framework, while flat slabs showed higher susceptibility to lateral movements. The study concluded that selecting the right slab system is critical in ensuring the safety and integrity of buildings in seismic areas.

4. Methodology

This study evaluates the seismic performance of three major slab types—Conventional Slab, Flat Slab, and Waffle Slab—in a symmetrical G+12 high-rise structure located in varying seismic zones across India. The building is modeled using ETABS 2018 software, ensuring adherence to relevant Indian Standards (IS 1893:2016 and IS 456:2000).

The key aim is to analyze and compare lateral load behavior such as storey drift, storey displacement, stiffness, shear force, base shear, and bending moments under seismic loading conditions using the Response Spectrum Method.

4.1 Structural modeling in ETABS

Table 1: Building parameters.

Parameter	Value
No. of Storeys	G+12 (Total 13 storeys)
Floor Height	3 m
Plan Dimensions	5 columns @ 5 m in X-direction6 columns @ 6 m in Y-direction (30 columns total)
Concrete Grade	M30
Steel Grade	Fe500
Seismic Zones Considered	Zone II and Zone V
Soil Type	Medium (Type II as per IS 1893)
Importance Factor	1.0
Response Reduction Factor	5 (Special RC Moment Resisting Frame)
Damping Ratio	5%

Table 2: Slab properties.

Slab Type	Thickness	Rib Width / Spacing (for waffle)
Conventional Slab	150 mm	N/A
Flat Slab	100 mm	N/A
Waffle Slab	300 mm	Rib width: 110 mm, Spacing: 600 mm

4.2 Model setup in ETABS

Three models were created for each seismic zone:

Seismic Zone II, III, IV and V:

- Model 1: Conventional Slab
- Model 2: Waffle Slab
- Model 3: Flat Slab

All other parameters (columns, beams, loadings) remained consistent across models to ensure fair comparison.

4.3 Load combinations

Based on IS 1893 (Part 1)-2016 and IS 456:2000, the following load combinations were used:

- 1.5(DL + LL)
- 1.2(DL + LL + EQX)
- 1.2(DL + LL - EQX)
- 1.2(DL + LL + EQY)
- 1.2(DL + LL - EQY)
- 1.5(DL + EQX)
- 1.5(DL - EQX)
- 1.5(DL + EQY)
- 1.5(DL - EQY)

Where:

- DL = Dead Load (includes self-weight + slab weight)
- LL = Live Load = 3 kN/m²
- EQX/EQY = Seismic loads in X and Y directions.

4.4 Calculation of seismic loads

Seismic weight and base shear were calculated as per IS 1893 (Part 1)-2016 using the Response Spectrum Method.

Seismic Weight (*W*)

Total Seismic Weight (*W*) is calculated as:

$$W = W_{dead} + \psi \times W_{live}$$

where,

$\psi = 0.5$ (As per IS code for live loads > 3 kN/m²),

Dead weight includes self-weight of all structural members + wall loads + floor finish.

Assuming approximate weights:

Member	Unit Weight (kN/m² or kN/m)
Slab (150mm)	~ 3.75 kN/m²
Slab (100mm)	~ 2.5 kN/m²
Slab (Waffle)	~ 4.5 kN/m²
Floor Finish	1.0 kN/m²
Wall Load (230 mm thick)	~ 11.5 kN/m

The design base shear is calculated using the following expression:

$$V_s = \frac{ZI(S_a/g)}{2R} \times W$$

where:

- V_s = Design base shear
- Z = Seismic zone factor
  - Z = 0.10 for Zone II
  - Z = 0.36 for Zone V
- I = Importance factor = 1.0
- R = Response reduction factor = 5
- S_a/g = Average response acceleration coefficient, obtained from the IS 1893 response spectrum curves
- W = Seismic weight of the structure

The calculated lateral seismic forces were applied at the respective floor levels and then summed to obtain the total seismic weight and corresponding base shear.

Response Spectrum Function

Based on:

- Soil Type II (Medium soil)

- Natural time period calculated using empirical formula: $T = 0.075 \times h^{0.75}$

  where,

  h = building height = 39 m

  $\rightarrow T \approx 0.075 \times (39)^{0.75} \approx 1.2$ s

  From IS 1893:2016 charts for medium soil and T = 1.2s, approximate $S_a/g \approx 1.2$.

4.5 Result extraction parameters

For each model, the following results were extracted and compared:

- Storey Displacement (mm): Measures lateral sway.
- Storey Drift Ratio: Δ displacement between adjacent storeys / storey height.
- Bending Moment (kNm): Flexural demand in slabs.
- Shear Force (kN): Lateral shear at base.
- Stiffness (kN/m): Overall lateral stiffness.
- Base Shear (kN): Total horizontal force at base.

4.6 Analysis approach step-by-step analysis

1. Create 3D Model of G+12 RC frame in ETABS for each slab type.
2. Assign section properties to slab, beam, and column.
3. Apply loads (DL, LL, Seismic) as per IS 875 and IS 1893.
4. Define response spectrum as per zone.
5. Assign boundary conditions (Fixed base).
6. Run modal analysis and extract natural periods and mode shapes.
7. Perform response spectrum analysis.
8. Extract and compare results.

4.7 Software analysis

- ETABS 2018 for structural modeling and seismic analysis.
- AutoCAD for slab layout plan modeling.
- Excel for manual calculations and result tabulation.

5. Results

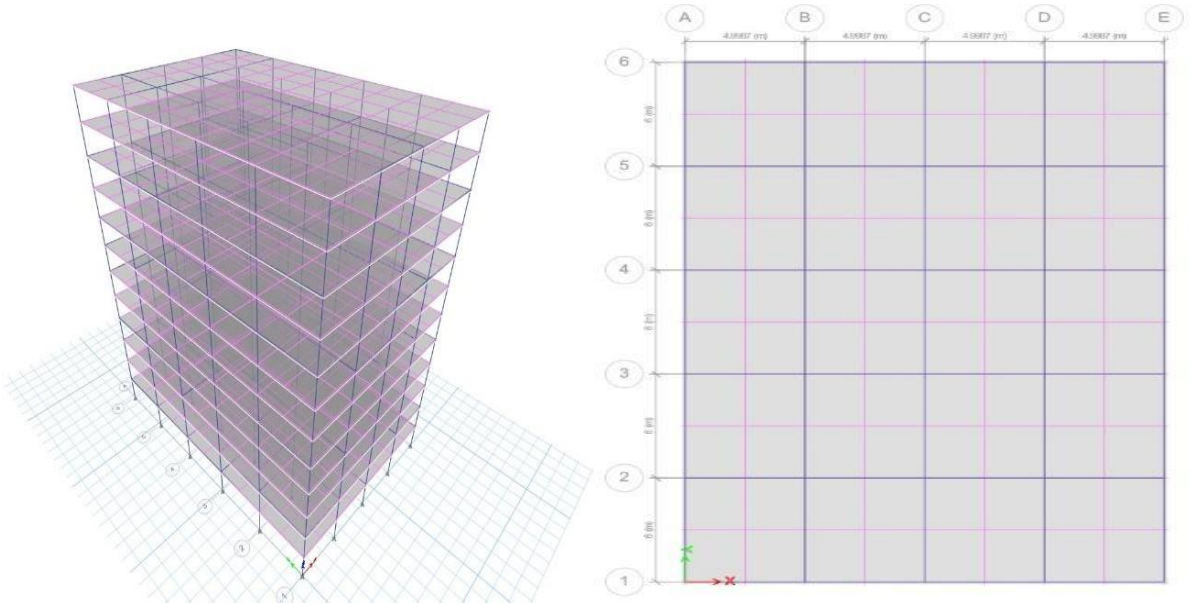


Figure 1: Conventional Slab.

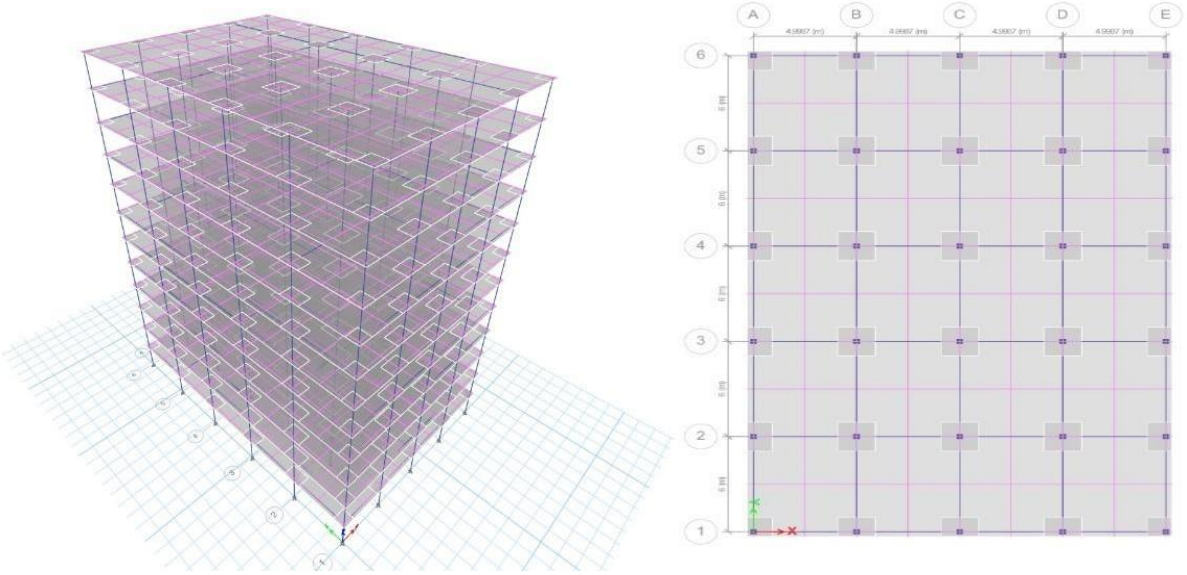


Figure 2: Waffle Slab.

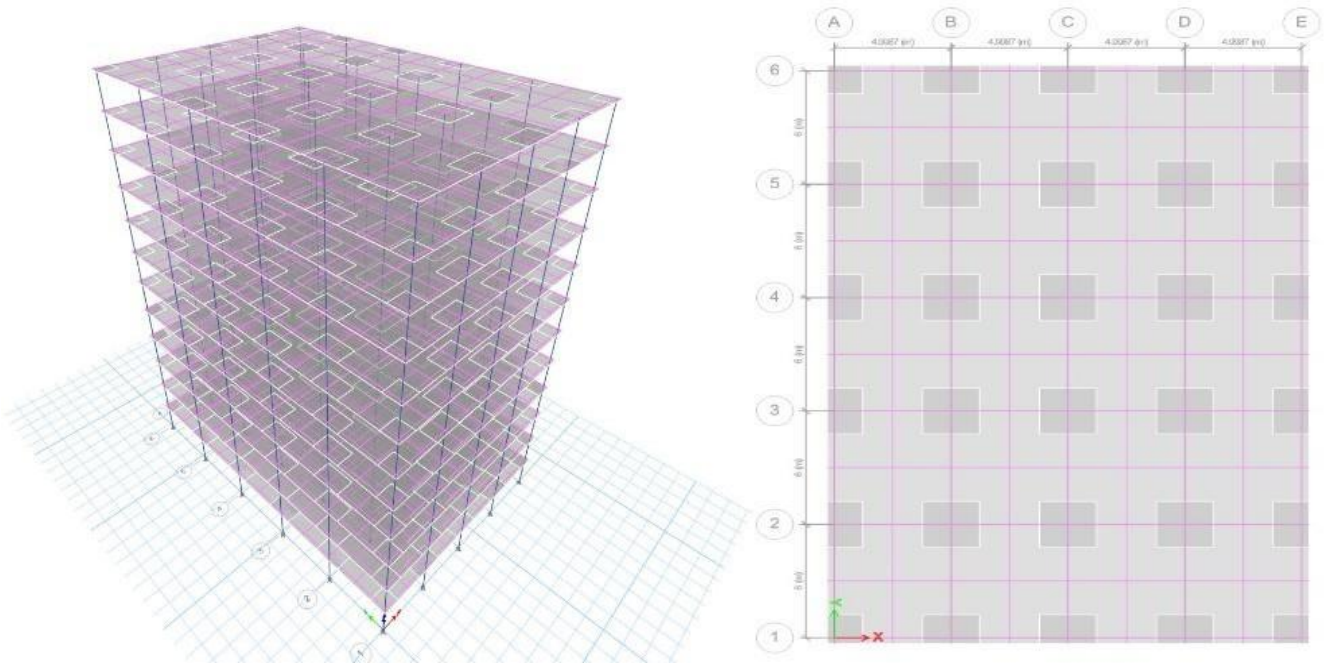


Figure 3: Flat Slab.

5.1 Storey displacement

Floor	Floor 1	Floor 2	Floor 3	Floor 11	Floor 12	Floor 13
Zone 2 - Conventional	0	1	3	40.6	43.1	43.4
Zone 3 - Conventional	0	1.5	4.5	61	64.8	65.25
Zone 4 - Conventional	0	2.3	6.8	92.1	97.9	98.57
Zone 5 - Conventional	0	3.5	10.3	138.3	147.2	148.21
Zone 2 - Waffle	0	0.9	2.8	37.6	39.9	40.1
Zone 3 - Waffle	0	1.4	4.3	56.7	60.2	60.5
Zone 4 - Waffle	0	2.1	6.4	85.2	90.6	91.05
Zone 5 - Waffle	0	3.2	9.7	127.8	136	136.68
Zone 2 - Flat	0	1.1	3.3	44.8	47.5	47.9
Zone 3 - Flat	0	1.6	4.9	67.2	71.3	71.9
Zone 4 - Flat	0	2.4	7.5	101.7	107.9	108.8
Zone 5 - Flat	0	3.7	11.4	152.8	162.2	163.55

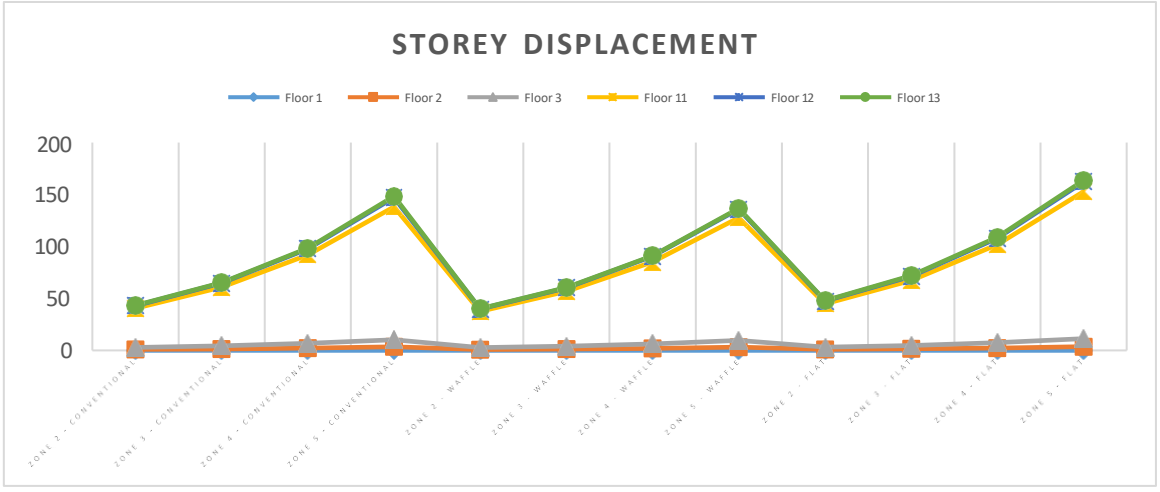


Figure 4: Storey Displacement.

5.2 Storey drift

Floor	Floor 1	Floor 2	Floor 3	Floor 11	Floor 12	Floor 13
Zone 2 - Conventional	0.5	1	2	4.2	2.5	0.3
Zone 3 - Conventional	0.75	1.5	3	6.3	3.8	0.45
Zone 4 - Conventional	1.12	2.3	4.5	9.6	5.8	0.67
Zone 5 - Conventional	1.69	3.5	6.8	14.4	8.9	1.01
Zone 2 - Waffle	0.4	0.9	1.9	3.9	2.3	0.2
Zone 3 - Waffle	0.6	1.4	2.9	5.9	3.5	0.3
Zone 4 - Waffle	0.9	2.1	4.3	9	5.4	0.45
Zone 5 - Waffle	1.35	3.2	6.5	13.5	8.2	0.68
Zone 2 - Flat	0.5	1.1	2.2	4.6	2.7	0.4
Zone 3 - Flat	0.75	1.6	3.3	6.9	4.1	0.6
Zone 4 - Flat	1.12	2.4	5.1	10.5	6.2	0.9
Zone 5 - Flat	1.69	3.7	7.7	15.8	9.4	1.35

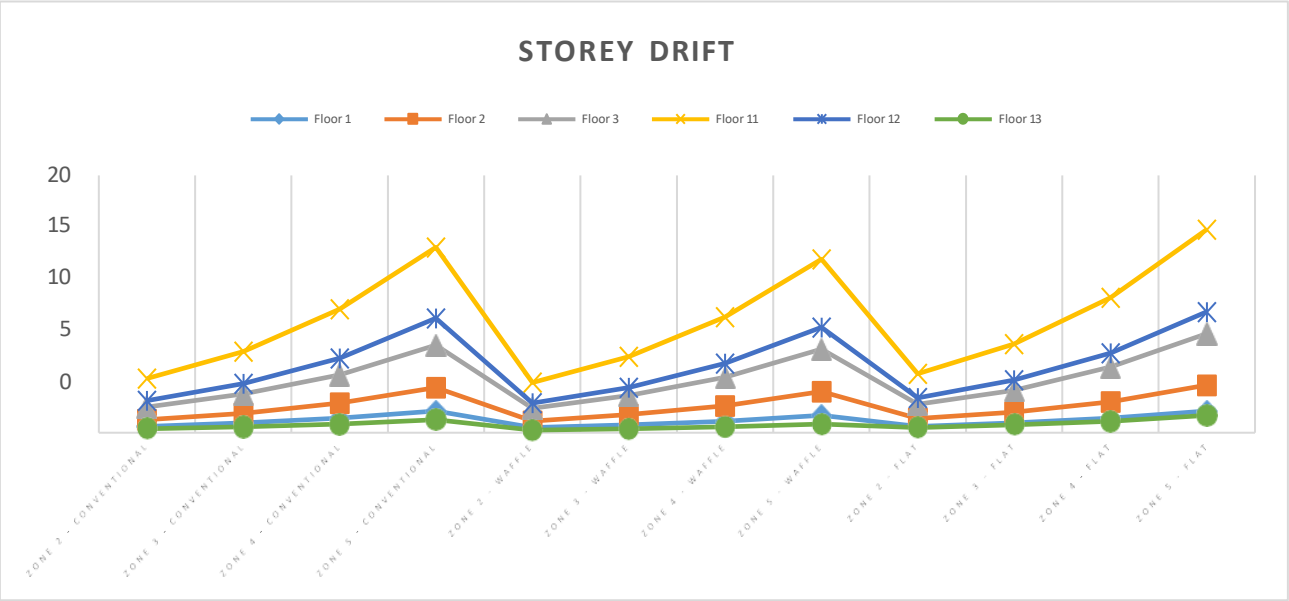


Figure 5: Storey Drift.

5.3 Shear force

Floor	Floor 1	Floor 2	Floor 3	Floor 11	Floor 12	Floor 13
Zone 2 - Conventional	0	1010.945	2021.889	4245.968	2527.362	303.2834
Zone 3 -Conventional	0	1008.621	2017.241	4236.207	2555.172	302.5862
Zone 4 - Conventional	0	1023.765	2003.018	4273.105	2581.668	298.2271
Zone 5 - Conventional	0	1036.114	2013.022	4262.87	2634.691	298.993
Zone 2 - Waffle	0	492.3628	1039.433	2133.572	1258.261	109.414
Zone 3 - Waffle	0	507.6446	1051.55	2139.36	1269.112	108.781
Zone 4 - Waffle	0	505.972	1036.038	2168.451	1301.071	108.4226
Zone 5 - Waffle	0	513.6084	1043.267	2166.786	1316.122	109.1418
Zone 2 - Flat	0	Shear Force 1343.424	2686.848	5617.954	3297.495	488.5177
Zone 3 - Flat	0	1301.808	2684.979	5614.047	3335.883	488.178
Zone 4 - Flat	0	1290.441	2742.188	5645.68	3333.64	483.9154
Zone 5 - Flat	0	1323.448	2754.204	5651.483	3362.275	482.8799

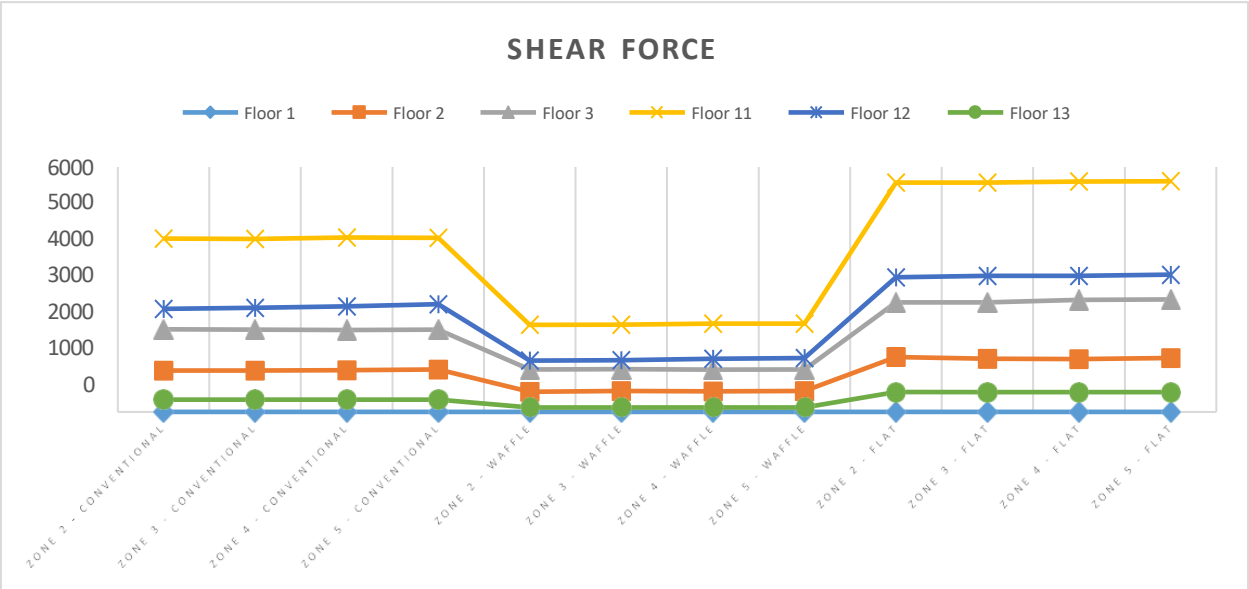


Figure 6: Shear Force.

5.4 Stiffness

Floor	Floor 1	Floor 2	Floor 3	Floor 10	Floor 11	Floor 12	Floor 13
Zone 2 - Conventional	inf	1.000	0.333	0.027	0.025	0.023	0.023
Zone 3 - Conventional	inf	0.667	0.222	0.018	0.016	0.015	0.015
Zone 4 - Conventional	inf	0.435	0.147	0.012	0.011	0.010	0.010
Zone 5 - Conventional	inf	0.286	0.097	0.008	0.007	0.007	0.007
Zone 2 - Flat	inf	0.909	0.303	0.025	0.022	0.021	0.021
Zone 3 - Flat	inf	0.625	0.204	0.017	0.015	0.014	0.014
Zone 4 - Flat	inf	0.417	0.133	0.011	0.010	0.009	0.009
Zone 5 - Flat	inf	0.270	0.088	0.007	0.007	0.006	0.006
Zone 2 - Waffle	inf	1.111	0.357	0.030	0.027	0.025	0.025
Zone 3 - Waffle	inf	0.714	0.233	0.020	0.018	0.017	0.017
Zone 4 - Waffle	inf	0.476	0.156	0.013	0.012	0.011	0.011
Zone 5 - Waffle	inf	0.313	0.103	0.009	0.008	0.007	0.007

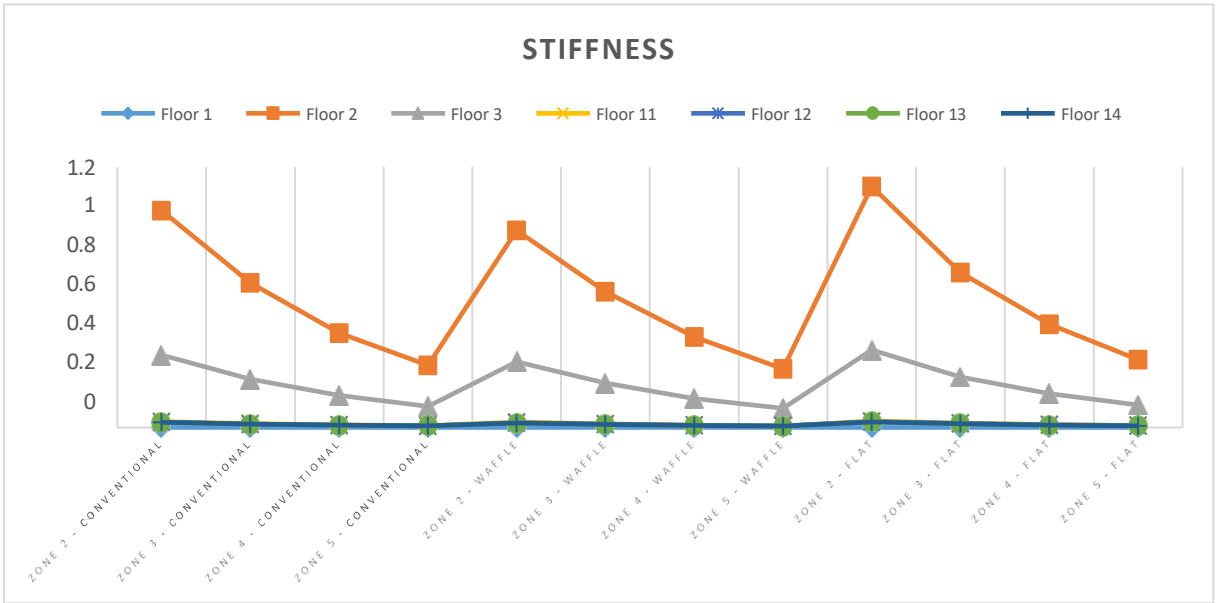


Figure 7: Stiffness.

5.5 Base shear

Slab Type	Zone 2	Zone 3	Zone 4	Zone 5
Conventional	306.88	204.12	135.12	89.86
Waffle	332.14	220.14	146.28	97.44
Flat	278.05	185.24	122.41	81.43

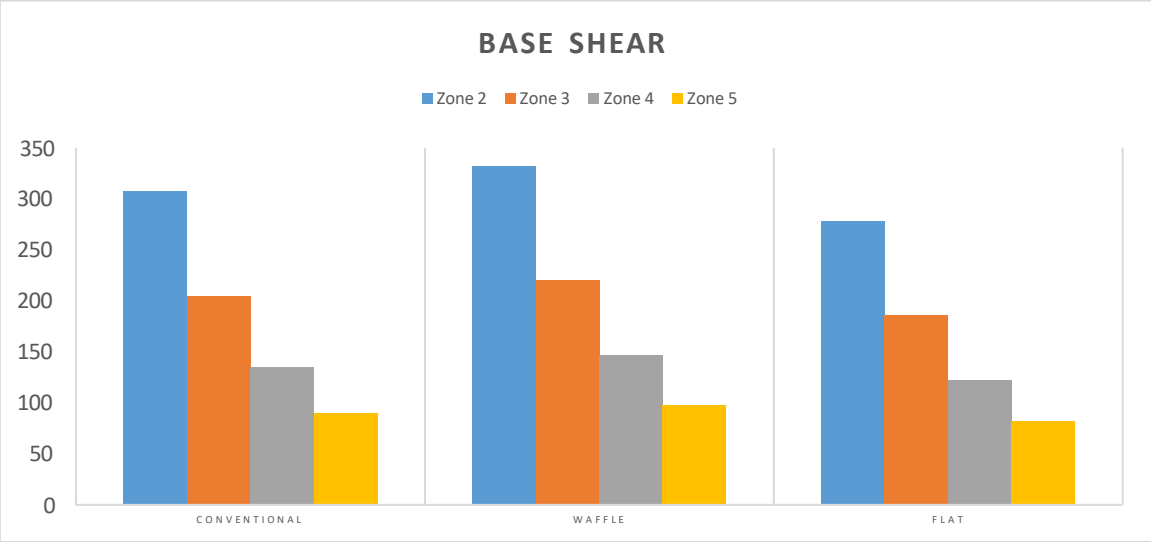


Figure 8: Base Shear.

6. Results and discussion

This study investigates and compares the seismic performance of waffle slabs, flat slabs, and conventional slabs in a symmetrical G+12 high-rise building across Seismic Zones II to V as per IS 1893:2016. Various structural parameters such as storey displacement, storey drift, shear force, stiffness, and base shear were evaluated through ETABS-based response spectrum analysis. The results obtained for key floors (1st, 2nd, 3rd, 11th, 12th, and 13th) are interpreted below.

Storey Displacement: Storey displacement measures the horizontal movement of floors during seismic loading. The results revealed that waffle slabs consistently show the lowest displacements across all seismic zones, indicating better lateral stiffness and structural integrity. Flat slabs exhibited the highest displacement, especially at the top storeys, reflecting poor seismic resistance. The difference between slab types became increasingly significant from Seismic Zone II to Zone V, with waffle slabs reducing top floor displacements by up to 16.4% compared to flat slabs in Zone V.

Storey Drift: Storey drift is a critical criterion for seismic safety, especially for non-structural components. Waffle slabs demonstrated the lowest storey drift values in all seismic zones, confirming superior resistance to inter-storey movement. Flat slabs recorded the highest drift, particularly in upper floors, making them the least favorable option under seismic conditions. Conventional slabs showed moderate performance. The results reaffirm that waffle slabs better control lateral deformation and are safer for both structural and non-structural stability.

Shear Force: Shear force, which represents the lateral load transferred through structural elements, was also significantly influenced by slab type. Waffle slabs outperformed both conventional and flat slabs by significantly reducing shear force, with reductions of approximately 50% compared to conventional slabs and over 60% compared to flat slabs. The reduced shear demand suggests potential material savings in beams and columns and decreased vulnerability to shear failure. On the other hand, flat slabs showed the highest shear values, reinforcing their limitations in seismic applications.

Stiffness: Structural stiffness is crucial in resisting seismic loads. The study showed that waffle slabs consistently delivered the highest stiffness values, followed by conventional slabs, with flat slabs performing the worst. While stiffness naturally reduced with height and increased seismic intensity, the rate of stiffness degradation was slowest in waffle slabs, ensuring better performance under dynamic loading. Flat slabs, with the lowest stiffness, especially at the uppermost floors, were more prone to excessive lateral displacements.

Base Shear: Base shear reflects the total seismic force at the base of the building. Interestingly, waffle slabs attracted the highest base shear values across all zones due to their greater self-weight. Flat slabs, being lightest, induced the least base shear, but at the cost of poor seismic performance in displacement, drift, and stiffness. This highlights a critical trade-off: while waffle slabs increase base shear, they also offer the best seismic behavior. Designers must therefore balance the benefits of seismic safety with the cost implications of higher reinforcement and foundation design.

7. Conclusions

In conclusion, the comparative analysis of waffle slabs, flat slabs, and conventional slabs in a G+12 high-rise building across seismic Zones II to V highlights some important insights for structural designers working in earthquake-prone regions. The results clearly show that waffle slabs consistently outperform the other two slab systems in almost every critical seismic parameter—including storey displacement, storey drift, shear force, and stiffness—making them the most resilient and reliable option under lateral loads. Despite their

slightly higher base shear due to greater self-weight, waffle slabs prove to be far more effective in minimizing structural deformations and enhancing the overall stability of the building, especially in high seismic zones. On the other hand, flat slabs, while lighter and simpler to construct, offer the poorest seismic performance, with the highest values of displacement, drift, and shear, indicating higher susceptibility to damage during earthquakes. Conventional slabs fall somewhere in between, offering moderate resistance and performance. Ultimately, this study emphasizes that structural safety should take precedence over simplicity or marginal weight savings, and that waffle slabs—despite their added mass—provide the best balance of strength, stability, and safety for high-rise buildings in seismic zones. Thus, for structures located in areas with moderate to severe seismic activity, the use of waffle slabs is strongly recommended to ensure long-term durability and occupant safety.

Authors' contributions

All authors contributed equally to the conception, design, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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