COMPARATIVE WIND LOAD ANALYSIS OF WAFFLE AND CONVENTIONAL SLAB SYSTEMS IN G+7 COMMERCIAL BUILDING USING ETABS

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ABSTRACT. This project focuses on the wind load analysis of two different slab systems, a conventional solid slab and a waffle slab in a G+7 commercial building, using ETABS software for structural analysis. The study follows IS 875 (Part 3):1987 guidelines for wind loads, considering terrain category 3 and a basic wind speed of 39 m/s, with overall design carried out as per IS 456:2000. In the modeling, the solid slab structure is analysed without shear walls, while the waffle slab system is supported by shear walls. Known for their ribbed grid pattern and thinner top slab, waffle slabs are designed to reduce self-weight, it also optimizes material usage and provide better load distribution across larger spans. The analysis examines how both systems respond to combined loads that is dead load, live load, and wind load. The result is compared by focusing on structural behaviours like storey drift, storey displacement, storey stiffness. Results show that the waffle slab system, when combined with shear walls, offers improved resistance to lateral loads and greater overall stiffness compared to the conventional solid slab. These findings suggest that waffle slabs are structurally efficient and support sustainability and economical building practices.

KEYWORDS: Waffle slab design, Solid Slab, commercial buildings, structural performance, load distribution, dead load reduction, wind loading, construction efficiency, material optimization, Storey drift, Storey Displacement.

1. INTRODUCTION

For any building design it's important to select an appropriate slab system because it affects the strength of the structure, stability and overall performance. In modern construction, two of the most used slab systems are the conventional solid slabs and waffle slabs. Each has its own advantages and design considerations. Solid slabs are mostly used as it is simple to design, are reliable, and ease for construction, which makes them a convenient option for many projects. However, waffle slabs, with their ribbed or grid-like designs, offer an innovative approach that reduces material usage while providing greater strength and better load distribution across large spans. Growing construction industry requires slowly shifting towards more sustainable and performance driven solutions, the demand for efficient structural systems, especially in multi story buildings, continues to grow. Since wind load is a critical factor in the design of tall structures. This analysis of how waffle slabs and conventional solid slabs were performed in a G+7 commercial building located in Ambikapur, Chhattisgarh. In a region surrounded by mountainous terrain, Ambikapur experiences moderate wind conditions with a basic wind speed of 39 m/s. As per IS 875 (Part 3):1987, the location falls under Wind Zone II and terrain category 3, which significantly influences the calculation of wind pressure and overall structural behaviour. The analysis uses the ETABS software to model two structural configurations: a conventional solid slab system without shear walls and waffle slab system combined having shear walls. The structural design was conducted in line with IS 456:2000, considering all relevant load combinations—dead, live, and wind loads. The focus is on how each system responds to lateral forces, with key performance metrics including the story drift and story displacement under wind loading. The analysis examines how both systems respond to the combined loads of dead, live load, and wind load

according to IS 456:2000 The results are compared by focusing on key structural behaviours, for story drift and story displacement. The results show that the waffle slab system, when combined with shear walls, offers improved resistance to lateral loads and greater overall 1 stiffness than the conventional solid slab. These findings suggest that waffle slabs are not only structurally efficient but are also support sustainable, economical building practices.
The wind speed in this region average ranges from about 5 to 15 km/h, depending on the season. However, during the monsoon and certain stormy periods, wind speeds can increase significantly. The maximum wind speed recorded or considered for structural design in this area is around 39 m/s (approximately 140 km/h), as per IS 875 (Part 3):1987, which considers the area's topography and wind zone classification. This wind speed is especially important for engineers when designing buildings to ensure they remain safe and stable during extreme weather conditions.

2. PRELIMINARIES

OBJECTIVE

1. Wind load analysis: Assess how wind loads affect the structural performance of both slab types, considering the local wind conditions of Ambikapur (Wind Zone II, terrain category 3), using guidelines from IS 875 (Part 3):1987. This helps simulate realistic environmental forces the building might face.
2. Load combinations analysis: Evaluate how each slab system responds to combined structural loads dead load, live load, and wind load as per IS 456:2000. This step is crucial in determining the overall stability and safety of the building design under everyday and extreme conditions.
3. Using ETABS software: Modelling both slab configurations in ETABS to visualize and compare how they behave under the same loading conditions. Key focus areas include measuring storey drift and storey stiffness to understand their resistance to lateral movement and overall rigidity.

LITERATURE REVIEW

1. [1] The study analyses composite and waffle slabs using ETABS software, focusing on parameters such as shear forces, bending moment, deflection, and axial load, while emphasizing role of slabs on tall buildings. For a G+20 commercial building, composite slabs outperformed flat and grid slab systems, particularly in column design due to their composite section. Additionally, waffle slabs demonstrated significant benefits by reducing dead loads and enhancing load distribution through their efficient structural configuration.
2. [2] While ribbed and waffle slabs offer real benefits like lighter weight of structure, better spans, and more flexible space use, they're still not widely used in residential construction. Many developers still prefer solid slabs, often because they believe the alternatives are too expensive or require complicated Molds. However, this shows a gap between what research says is possible and what actually gets built. Some studies aim to challenge the belief that waffle or grid slabs aren't cost-effective, especially for spans over 12 meters. They suggest these designs can create adaptable, efficient spaces that work well over time, especially when long spans or open layouts are needed. Unfortunately, despite highlighting the potential of these slab systems, some papers don't back up cost concerns with real data or examples. This makes it harder to fully understand the true economic trade-offs. In short, there's clear potential in ribbed and waffle slabs—but changing industry habits and perceptions may be the biggest challenge.

3. [3] The study highlights key differences between flat slabs and grid block systems under seismic conditions. Flat slabs offer advantages like simpler formwork and reduced construction time, while grid block systems demonstrate superior seismic performance. Economic analysis shows flat slabs are cost-effective for general use, whereas grid systems are more efficient for long-span structures. These findings stress the importance of choosing slab systems based on seismic demands and project-specific requirements

4. [4] The waffle slab system demonstrates superior load-bearing performance compared to conventional slabs. However, as the spacing between grid beams increases, the load-bearing capacity decreases, indicating an inverse relationship. Waffle slabs with intermediate grid beam spacing exhibit the highest load-bearing capacity. Additionally, systems with wide grid beam spacing perform better when shear reinforcements are provided at the supports. Closely spaced grid beams outperform conventional slabs but are less effective than intermediately spaced systems or those with shear reinforcements.

5. [5] Studies on C-shaped buildings with different slab systems - conventional, flat, grid, and loadbearing—reveal significant variations in performance. Storey displacement is highest in conventional slabs and lowest in loadbearing walls, increasing with height. Loadbearing walls offer superior resistance to wind and earthquakes, ensuring safety. However, grid slab systems balance safety and cost-effectiveness, making them an economical choice.

METHODOLOGY

1. GENERAL

The study involves a systematic approach in analysing the performance of conventional solid slabs and waffle slab for **G+7** commercial building in Ambikapur using ETABS software. The steps are outlined below:

2. DATA COLLECTION

a) Geographical and Climatic Data: Gather information about the location (Ambikapur), wind speed 39m/s and Wind Zone II classification and terrain category 3 as per **IS 875 (Part 3): 1987**.
b) Building Parameters: Defining the dimensions, floor height, and overall design parameters of the G+7 building.
c) Material Properties: Specify the grades of materials for concrete and steel reinforcement as per **IS 456: 2000**.

3. MODEL CREATION IN ETABS

a) Structural Elements: Columns, beams, slabs, and walls.
b) Slab Systems: Model waffle slabs and conventional solid slabs separately.
c) Material Specifications: Assign appropriate material properties for concrete and steel.

4. LOAD APPLICATION

a) Dead Load: Apply self-weight of structural elements using ETABS, as per **IS 875 (Part 1)**.
b) Live Load: Incorporate live loads based on building usage (commercial) following **IS 875 (Part 2)**.
c) Wind Load: Calculate and apply wind loads for the region's, basic wind speed, building height, and exposure as per **IS 875 (Part 3): 2015**.
d) Load Combinations: Create load combinations including dead, live, and wind loads as specified in **IS 456: 2000**.

5. MODELLING PARAMETERS

The table below outlines key parameters such as building area, height, column specifications, beam details, and slab configuration. These elements form the basis of the structural model used to analyse the building's performance under various loading conditions as per design standards.

Table 1 Modelling Parameters

Area of the building	16m×25m
Building Height	28m
Columns for solid slab	Col1 450mm×450 mm Col2 300mm×230mm
Columns for waffle slab	Col1 650mm×650 mm
Beams for solid slab	550mm×300mm
Beam for waffle slab	750×450 mm
Slab Thickness	150mm for solid slab and 100mm for waffle slab
Overall Depth for waffle slab	200mm
Spacing of Ribs	900 mm

6. MATERIAL PROPERTIES

a) Grade of Concrete: M25
b) Grade of Steel: Fe550

7. LOADING ON STRUCTURE

a) Dead load – Self Weight of Structure
b) Live Load -5 KN/m2
c) Wind load for zone II
d) Seismic load not considered

8. WIND SPEED CALCULATIONS

The wind analysis for this project has been carried out in accordance with IS 875 Part 3, considering the site conditions and structural characteristics. The parameters used in the calculation, such as wind zone classification, terrain category, and various modifying factors (K1 to K4), are outlined below. These values have been carefully selected to ensure accurate estimation of the design wind speed and its impact on the structure.

Wind speed as per IS 875 Part 3

Wind Zone- II

Terrain Category- 3

K1(risk coefficient) = 1.06

K2 (terrain roughness) = 1.01

K3(topography factor) = 1.36

K4(importance factor) = 1.0

Design Wind Speed = 39 m/s

9. LOADING COMBINATIONS

1.5 (DL + LL)

1.5 (DL + WL)

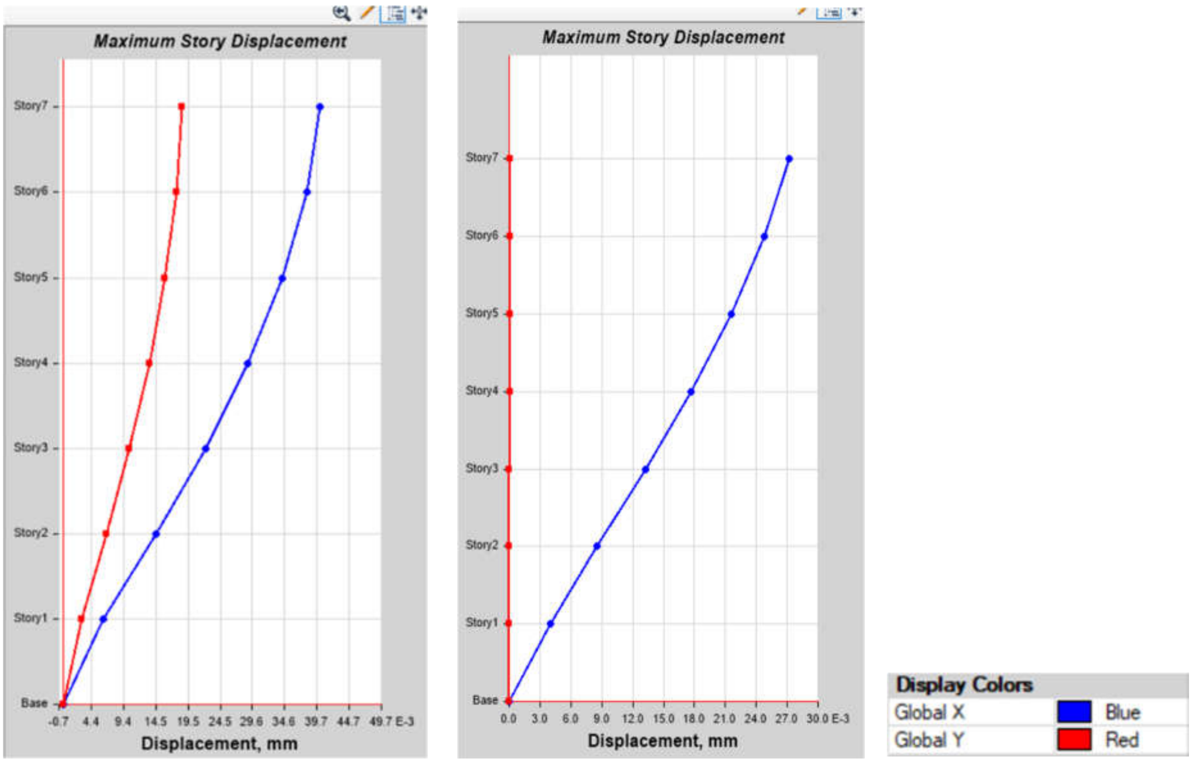
1.2 (DL + LL + WL)

0.9 DL ± 1.5 WL

3. MAIN RESULTS

1. STOREY DISPLACEMENT

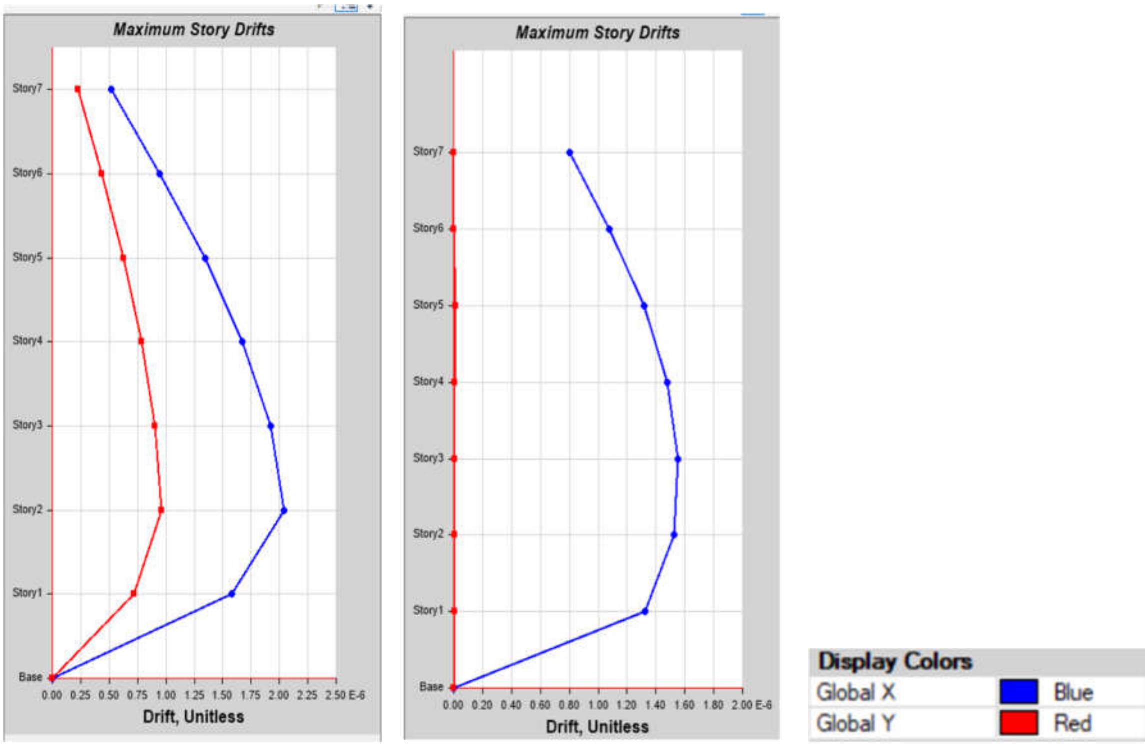
As per the analysis the Story displacement is maximum at the top storey 39.7mm in global x direction and 14.5 mm in global y direction in conventional solid slab without shear wall and is minimum at the structure's base. For waffle slab with shear wall the maximum displacement is 27 mm in global x direction and 0 mm in global y direction. storey displacement for waffle slab is approx. 32% less than solid slab in x direction and no displacement in y direction of waffle slab is seen.



solid slab **waffle slab**

2. STOREY DRIFT

The maximum storey drift as per the graphs obtained is 2.00 in solid slab in global x direction and 1.00 in global y direction and in waffle slab with shear wall, these values are 1.45 in global x direction and 0.00 in global y direction**.**



solid slab **waffle slab**

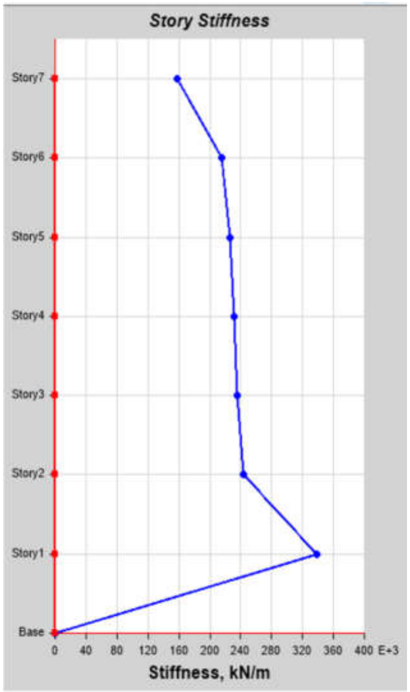
3. STOREY STIFFNESS

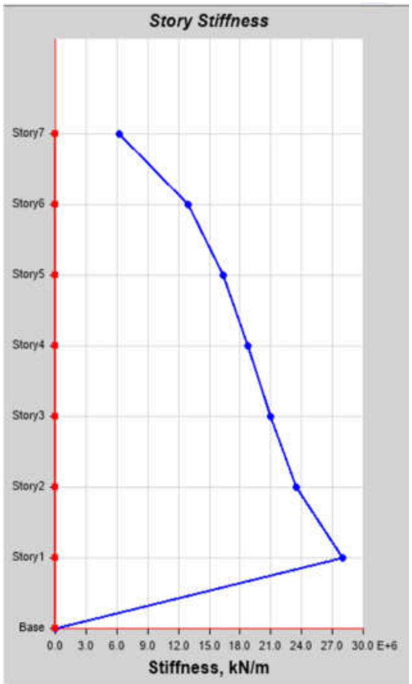
Storey stiffness of two building comparing with two slab system waffle slab and solid slab we found the following:

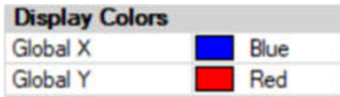
In the global X-direction (one horizontal direction), the waffle slab gave a storey stiffness of 28 kN/m, while the solid slab gave a much higher stiffness of 340 kN/m.

In the global Y-direction (the other horizontal direction), the stiffness was 0 kN/m for both types of slabs. This means neither system provided stiffness in that direction, which could be due to the layout or lack of lateral elements in that direction.

Also, we noticed that in both slab systems, the stiffness gradually reduced towards the top floors, which is normal because the upper storeys usually carry less load and have fewer supporting elements compared to the lower ones.







solid slab **waffle slab**

4. CONCLUSIONS

1. Comparison of Storey Displacement

- For the conventional solid slab system without shear walls, the maximum storey displacement is at top storey, with a value of **39.7 mm in global X direction** and **14.5 mm in global Y direction**. Displacement decreases at lower storeys, with the minimum observed at the base of the structure.
- In contrast, the waffle slab system with shear walls exhibited significantly lower maximum displacement, **27 mm in global X direction** and **0 mm in the global Y direction**. The displacement in the X direction was reduced by approximately **32%** comparative to conventional solid slab system, and no displacement was observed in the Y direction, highlighting the effectiveness of shear walls in providing lateral stability.

2. Comparison of Storey Drift

- The maximum storey drift for conventional solid slab system was found to be **2.00 in global X direction** and **1.00 in the global Y direction**.
- For waffle slab system with shear walls, the drift values were significantly lower, with a maximum of **1.45 in global X direction** and **0.00 in the global Y direction**. This shows a **27.5% reduction in drift in the X direction** and a complete **elimination of drift in the Y direction**, indicating improved lateral load resistance and structural stability.

3. **Comparison of Storey Stiffness**

- When we analyzed storey stiffness under wind loads in ETABS, we saw a clear difference between the two slab systems. In X-direction, the conventional solid slab was much stiffer, with a value of 340 kN/m, while the waffle slab reached only 28 kN/m. In the Y-direction, both systems showed 0 kN/m.

4. **Enhanced Structural Efficiency:**

- The waffle slab system, when integrated with shear walls, demonstrates superior stiffness and better resistance to lateral forces. This results in lower displacements and drift, contributing to the structural performance of the building subjected to wind loads.
- Absence of displacement in the global Y direction in the waffle slab system further indicates its enhanced torsional stability and improved distribution of wind forces, making it a more effective solution in wind-prone regions.

5. **Material and Cost Efficiency:**

- The waffle slab system's grid-like design not only reduces material usage compared to conventional solid slabs but also provides greater strength and load distribution capabilities across large spans. Making it more sustainable and economical, particularly in case of taller buildings in areas subject to significant lateral forces.

6. **Better Performance in Wind-Prone Areas:**

- Given the moderate wind conditions in Ambikapur, Chhattisgarh, having basic wind speed **39 m/s**, waffle slab system with shear walls outperforms the conventional solid slab system in terms of wind resistance. The structural behavior of the waffle slab demonstrates a higher level of stability under wind loads, ensuring the safety and durability of the building in such conditions.

7. **Conclusion for Sustainable Construction:**

- As the construction industry increasingly shifts toward more sustainable and performance-driven solutions, the waffle slab system offers a promising alternative to conventional slab systems. The integration of shear walls significantly enhances its performance under wind loads, making it a more efficient and resilient option for multi-story commercial buildings, especially in regions with moderate to high wind condition.

5. ACKNOWLEDEGEMENTS

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