Comparative Evaluation of Flat and Waffle Slab Systems Using Numerical Analysis

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Abstract—**The selection of an efficient slab system plays a vital role in improving the structural performance, economy, and serviceability of reinforced concrete buildings. This study presents a comparative numerical evaluation of flat slab and waffle slab systems using ETABS software. Both slab systems were modelled with identical plan dimensions, material properties, and loading conditions in accordance with relevant Indian Standard provisions. The structural behaviour was assessed by considering bending moment, maximum deflection, self-weight, concrete volume, and steel consumption. Manual design calculations were carried out to verify the analytical results obtained from ETABS. To provide a comprehensive comparison, an Integrated Structural Efficiency Index (ISEI) was developed by combining multiple structural performance parameters into a single evaluation criterion. The comparative results indicate that the waffle slab system exhibits lower self-weight, reduced material consumption, and improved stiffness compared with the flat slab system. The proposed ISEI provides a practical framework for evaluating slab systems based on overall structural efficiency rather than individual performance parameters. The study concludes that waffle slabs are a more efficient structural solution for large-span reinforced concrete floor systems.**

Index Terms—**Flat Slab, Waffle Slab, ETABS, Structural Efficiency, Integrated Structural Efficiency Index (ISEI), Numerical Analysis, Reinforced Concrete.**

I. INTRODUCTION

Reinforced concrete slabs are among the most important structural components in modern buildings, as they transfer gravity loads to beams, columns, and foundations while ensuring adequate strength, stiffness, and serviceability. The overall behaviour and performance of a building are significantly influenced by the type of slab system adopted during the design stage. Therefore, selecting an appropriate slab system is essential for achieving structural safety, construction economy, and long-term durability.

Among the various floor systems, flat slabs and waffle slabs are widely used because of their distinct structural and architectural advantages. A flat slab is a beamless system in which loads are transferred directly to supporting columns, often with drop panels or column capitals to improve punching shear resistance. This system provides greater architectural flexibility, reduced floor height, and simplified formwork. In contrast, a waffle slab consists of a thin topping slab supported by intersecting reinforced concrete ribs, which enhance flexural stiffness, reduce self-weight, and improve load distribution. These characteristics make waffle slabs particularly suitable for long-span structures where material efficiency and structural performance are important.

Previous research has mainly compared flat and waffle slab systems using individual structural parameters such as bending moment, deflection, stiffness, and material consumption. Although these comparisons provide valuable insights, they do not fully represent the overall structural performance because engineering efficiency depends on the combined influence of multiple parameters. Evaluating slab systems based on a single criterion may therefore lead to incomplete or conflicting conclusions.

To address this limitation, the present study proposes an Integrated Structural Efficiency Index (ISEI) that combines multiple structural performance parameters into a unified evaluation framework..The proposed approach provides a comprehensive basis for selecting the most structurally efficient slab system for reinforced concrete buildings.

II. LITERATURE REVIEW

1) Sarita R. Khot et al. (2016): "Comparative study of Waffle slabs with flat slabs and conventional RCC slabs". The study compared conventional RCC slabs, flat slabs, and waffle slabs to evaluate their structural performance. The study focused on slab thickness, deflection, and load distribution. Results showed that waffle slabs reduced self-weight and concrete consumption due to their ribbed configuration. They also exhibited higher stiffness and better load transfer, leading to lower bending effects and improved stability. Although flat slabs offered architectural flexibility, waffle slabs were found to be more economical and suitable for long-span structures because of their superior structural efficiency and serviceability.
2) Anithu Dev et al. (2017): "Analysis and Parametric study of Waffle slabs". This study presented a parametric analysis of waffle slabs using ETABS based on the Rankine–Grashoff method and plate theory. The study examined the influence of rib spacing and rib depth on deflection, bending moment, shear force, and torsion. The results showed that larger rib spacing increased deflection, while greater rib depth enhanced stiffness and load-carrying capacity. The authors concluded that proper rib geometry is essential for achieving safe, economical, and efficient waffle slab design.
3) Nithyambigai G et al. (2021): "Behaviour of Waffle slab". The study investigated the behaviour of waffle slabs with different rib spacing arrangements. The study evaluated load-carrying capacity, stiffness, and displacement under external loading. Results indicated that closely spaced ribs improved structural stiffness and reduced deflection, whereas wider rib spacing decreased rigidity. Waffle slabs consumed less concrete while carrying higher loads than conventional slabs. The study concluded that optimum rib spacing improves structural efficiency, durability, and serviceability, making waffle slabs suitable for long-span reinforced concrete structures.
4) Efendi et al. (2025): "A Comparative Study of Flat Slab and Waffle Slab Structure for Slab System Efficiency". The study evaluated the structural efficiency of flat slab and waffle slab systems under identical loading conditions by comparing deflection, concrete volume, and overall performance. The analysis focused on deflection, concrete volume, and structural efficiency. The waffle slab demonstrated better stiffness, reduced self-weight, and lower concrete consumption because of its ribbed configuration. Although flat slabs provided easier construction, waffle slabs were found to be more economical for larger spans. The authors concluded that slab selection should consider span length, loading conditions, and overall structural performance.
5) Payal Hanwat and Afzal Khan (2024): "A Review Performance Evaluation of Ribbed and Waffle Slab Systems Under Lateral Loading". The study reviewed the performance of ribbed and waffle slab systems under lateral loading by analysing stiffness, bending moment, strength, and deformation characteristics. Ribbed slabs showed better lateral load resistance, whereas waffle slabs offered lower dead load and improved material efficiency. The authors emphasized that slab stiffness plays an important role in controlling deformation. They recommended integrating strength, stiffness, and efficiency parameters into a single evaluation method for better slab selection.
6) M. Shariq Salim & Dr. Syed Aqeel Ahmad (2023): "Comparative Analysis of Flat Slab and Waffle Slab Using ETABS Software". The study compared the structural behaviour of flat slab and waffle slab systems using ETABS by analysing displacement, bending moment, shear force, and deflection. Parameters such as displacement, bending moment, shear force, and deflection were analysed. The waffle slab exhibited lower deflection and improved stiffness because of its ribbed structure. It also reduced concrete consumption and self-weight while maintaining adequate strength. The study concluded that waffle slabs are more suitable for long-span commercial buildings requiring improved structural efficiency and economical material usage.
7) R. Pradeep Kumar & K. Naveen Kumar (2022): "Performance Evaluation of Ribbed, Flat and Waffle Slab Systems in Multi-storey Buildings". The study assessed the performance of flat slab,

ribbed slab, and waffle slab systems under gravity and lateral loads by comparing stiffness, displacement, and concrete consumption. The results showed that waffle slabs provided higher stiffness, better load distribution, and reduced dead load due to lower concrete consumption. Flat slabs simplified construction but experienced greater deflection. The authors recommended waffle slabs for long-span buildings because of their improved structural performance and optimized material utilization.

The literature review indicates that waffle slab systems generally provide better structural efficiency than flat slabs due to their reduced self-weight, improved stiffness, and lower material consumption. Most of the previous studies focused on comparing individual parameters such as bending moment, deflection, concrete volume, and reinforcement requirement. However, a comprehensive evaluation combining multiple structural performance parameters has received limited attention. Based on these observations, the present study aims to develop an Integrated Structural Efficiency Index (ISEI) for a more effective comparison of flat slab and waffle slab systems.

III. OBJECTIVES

- To analyse the structural behaviour of flat slab and waffle slab systems under identical dead load and live load conditions using ETABS.
- To compare the performance of both slab systems in terms of bending moment, deflection, self-weight, concrete volume, and reinforcement requirement.
- To evaluate the structural efficiency of flat slab and waffle slab systems using the Integrated Structural Efficiency Index (ISEI).
- To identify the most efficient slab system for long-span reinforced concrete buildings based on structural performance and material optimization.

IV. GEOMETRY OF SLAB SYSTEMS

Geometry of Flat Slab

The flat slab model consists of slab panels directly connected to columns. The flat slab system considered in this study consists of a slab panel measuring 20.6 m × 20.6 m with a uniform slab thickness of 275 mm. A drop panel of 5 m × 5 m × 500 mm was provided around the column locations to enhance punching shear resistance and improve load transfer. The slab was modeled using M30 grade concrete and Fe500 grade reinforcement steel, with a clear concrete cover of 25 mm provided for durability and reinforcement protection. The selected geometric configuration and material properties were adopted for ETABS modelling to evaluate the structural behaviour of the flat slab under the specified loading conditions.

Geometry of Waffle Slab

The waffle slab system was modeled with a panel size of 20.6 m × 20.6 m, consisting of a 120 mm thick topping slab supported by reinforced concrete ribs. The ribs were designed with a width of 120 mm, a depth of 400 mm, and a uniform spacing of 1.0 m in both directions to improve structural stiffness and load distribution. The slab was constructed using M30 grade concrete and Fe500 grade reinforcement steel with a 25 mm clear cover. A live load of 3 kN/m² and a floor finish load of 1.5 kN/m² were considered in the ETABS analysis. These geometric and loading parameters were adopted to evaluate the structural performance and efficiency of the waffle slab system.

V. MODELLING OF SLAB SYSTEMS IN ETABS

Load Application:

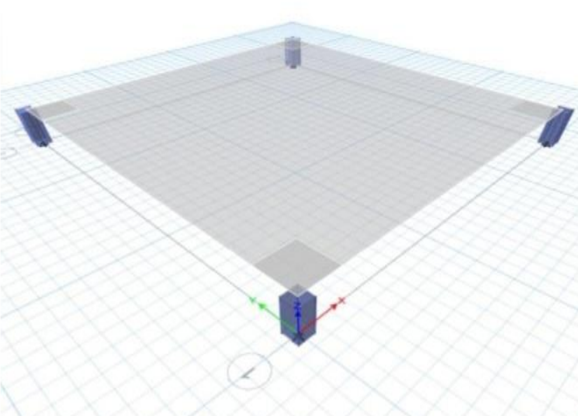
Dead load, live load, and self-weight of the structure were considered during the analysis process. The loads were assigned according to IS 875 code provisions to ensure safe and reliable structural performance. Identical loading conditions were applied for both slab systems to compare their efficiency and behavior accurately.

Analysis Procedure:

The structural analysis of flat slab and waffle slab systems was carried out using ETABS software. Both slab models were analysed under the same loading and support conditions to ensure accurate comparison. The analysis results such as deflection, bending moment, self-weight, and material quantities were obtained and evaluated for structural efficiency.

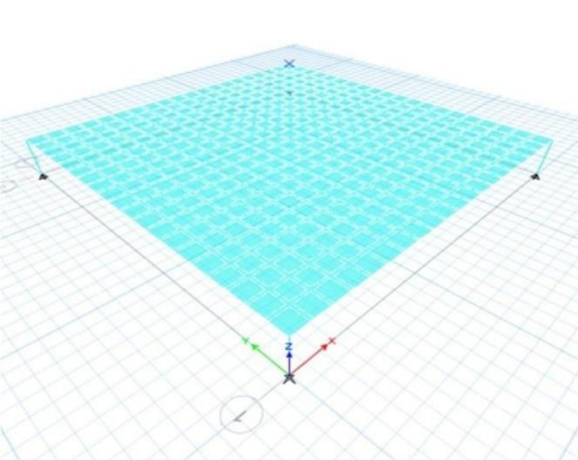
The ETABS model shows the complete 3D representation of the flat slab system.

FIG 1: 3D View of Flat Slab Model



The waffle slab model includes ribs and slab panels in ETABS.

FIG 2: 3D View of Waffle Slab Model



VI. RESULTS AND DISCUSSION

Bending Moment Distribution in Flat Slab:

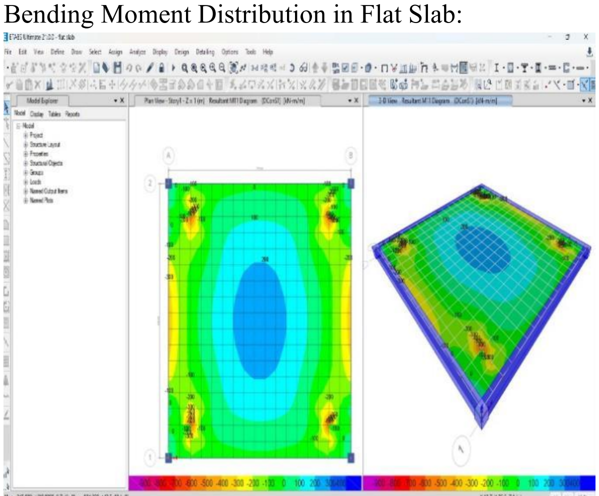


FIG 3: Bending Moment Distribution in Flat Slab

The Bending Moment contour indicates the distribution of flexural stresses across the flat slab under the applied gravity loads, with maximum moments observed near the column regions.

Bending Moment Distribution in Waffle Slab:

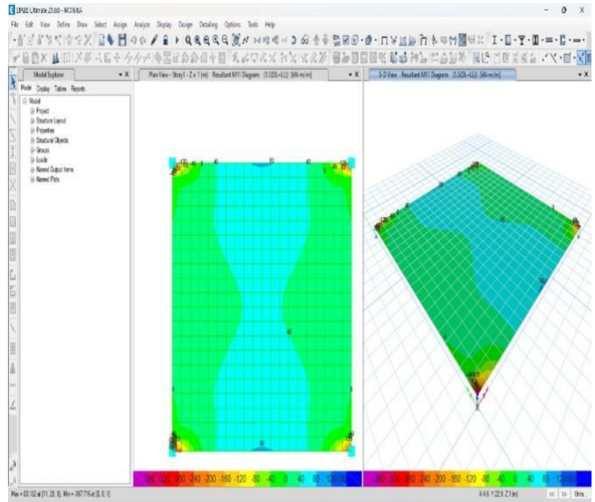


FIG 4: Bending Moment Distribution in Waffle Slab

The bending moment distribution demonstrates efficient load transfer through the ribbed configuration, resulting in lower flexural moments compared to the flat slab.

Deflection Analysis of Flat Slab:

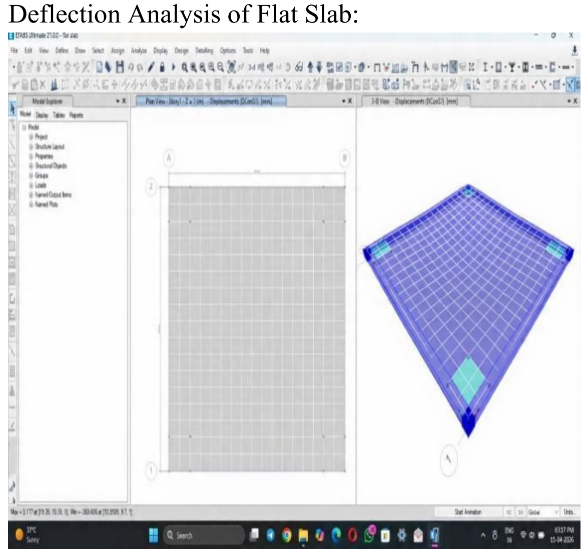


FIG 5: Deflection Analysis of Flat Slab

The deflected shape illustrates the deformation of the flat slab under loading, with the maximum deflection occurring at the mid-span.

Deflection Analysis of Waffle Slab:

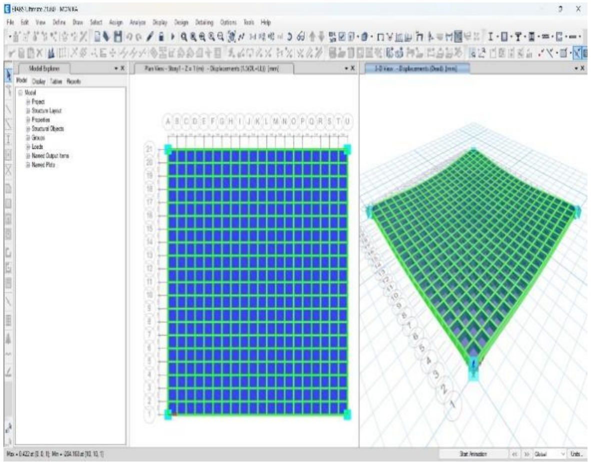


FIG 6: Deflection Analysis of Waffle Slab

The deflection contour shows improved stiffness and reduced deformation of the waffle slab due to its ribbed structural system.

TAB 1: COMPARISON OF FLAT SLAB AND WAFFLE SLAB

(ETABS RESULTS)

PARAMETERS	FLAT SLAB	WAFFLE SLAB	UNITS
Concrete Volume	127	70.2	m^3
Concrete per Area	0.30	0.165	m^3/m^2
Steel Weight	17.5	6.12	tons
Steel per Area	41.2	14.4	kg/m^2
Self Weight	6.9	5.63	kN/m^2
Deflection	52.5	26.2	mm
Moment (Mu)	454	315	kN-m

VII. INTEGRATED STRUCTURAL EFFICIENCY INDEX (ISEI)

The Integrated Structural Efficiency Index (ISEI) is a performance-based parameter used to evaluate and compare structural systems by combining multiple factors such as strength, weight, deflection, and material usage into a single efficiency value. This study adopts the conceptual framework of Ashby's Material Selection Method to develop an Integrated Structural Efficiency Index (ISEI) for comparative evaluation of different slab systems based on structural performance and material efficiency. This formula is used to compare the overall efficiency of different structural systems and identify the most optimized solution. The performance parameter (like strength or stiffness) is high and the penalty parameters (such as weight, cost, or deflection) are low. Thus, a higher ISEI value represents a better and more efficient structural system.

1. OVERALL PERFORMANCE OF SLAB SYSTEMS

$$ISEI_1 = (M_u \times k)/((V_c + W_s) \times W)$$

Where,

M_u = Ultimate Moment capacity in kN-m

k = Stiffness = (P/Δ)

V_c = Concrete Volume in m^3

W_s = Weight of the Steel in tons

W = Self Weight in kN/m^2

2.SERVICEABILITY BEHAVIOUR OF SLAB SYSTEMS

$$ISEI_2 = \frac{Mu}{\Delta \times W}$$

Where,

M_u = Ultimate Moment capacity in kN-m

Δ = Deflection in mm

W = Self Weight in kN/m^2

A higher ISEI value indicates better structural efficiency and superior overall structural performance.

TAB 2: COMPARITIVE EVALUATION OF SLAB SYSTEMS USING INTEGRATED STRUCTURAL EFFICIENCY INDEX (ISEI)

INTEGRATED STRUCTURAL EFFICIENCY INDEX (ISEI)	FLAT SLAB	WAFFLE SLAB	PERFORMANCE BASED ON THE ISEI VALUES
$ISEI_1$	0.132	0.344	Waffle slab demonstrates better strength-to-weight efficiency than flat slab.
$ISEI_2$	1.253	6.582	Waffle slab shows higher structural efficiency compared to flat slab.

VIII. CONCLUSION

The present study carried out a comparative evaluation of flat slab and waffle slab systems using ETABS under identical dead load and live load conditions. The structural performance of both slab systems was assessed by considering concrete volume, concrete volume per unit area, steel weight, steel quantity per unit area, self-weight, maximum deflection, bending moment, and the Integrated Structural Efficiency Index (ISEI). The obtained results provided a comprehensive understanding of the structural behaviour and efficiency of the two slab systems. The ETABS analysis indicated that the waffle slab system demonstrated superior structural performance compared to the flat slab system. The concrete volume was reduced from 127 m^3 for the flat slab to 70.2 m^3 for the waffle slab, while the concrete volume per unit area decreased from 0.30 m^3/m^2 to 0.165 m^3/m^2. Similarly, the reinforcement requirement was considerably reduced, with the total steel weight decreasing from 17.5 tonnes to 6.12 tonnes, and the steel quantity per unit area reducing from 41.2 kg/m^2 to 14.4 kg/m^2. These results confirm that the waffle slab provides significant material savings without compromising structural performance. The waffle slab also exhibited a lower self-weight of 5.63 kN/m^2 compared to 6.9 kN/m^2 for the flat slab. Due to its ribbed configuration, the waffle slab distributed the applied loads more efficiently, resulting in a lower maximum bending moment of 315 kN·m, whereas the flat slab recorded 454 kN·m. In addition, the maximum deflection was reduced from 52.5 mm in the flat slab to 26.2 mm in the waffle slab, indicating improved stiffness and enhanced serviceability performance.The Integrated Structural Efficiency Index (ISEI) developed in this study successfully combined multiple structural performance parameters into a single evaluation framework for a comprehensive assessment of slab systems. The calculated $ISEI_1$ values were 0.132 for the flat slab and 0.344 for the waffle slab, while the $ISEI_2$ values were 1.253 and 6.582, respectively. The higher ISEI values obtained for the waffle slab clearly indicate its superior strength-to-weight ratio, improved structural efficiency, and better overall performance.

Based on the ETABS results and the ISEI evaluation, it is concluded that the waffle slab system is structurally more efficient and economical than the flat slab system for long-span reinforced concrete buildings. The reduction in self-weight, concrete consumption, steel requirement, bending moment, and deflection, together with the higher ISEI values, demonstrates that the waffle slab provides an optimal balance between strength, stiffness, and material utilization. Therefore, the waffle slab can be recommended as a suitable floor system for modern reinforced concrete structures where structural efficiency, serviceability, and material optimization are the primary design considerations.

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