Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)
July 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 332
DOI: 10.11159/iccste25.332

.

Load Uncertainty and Modeling Methods in Reinforced Concrete Floor Systems

Khalid Najib , Osama Mohamed
Abu Dhabi University, College of Engineering
Address , Abu Dhabi, United Arab Emirates
1059233@students.adu.ac.ae , osama.mohamed@adu.ac.ae

Abstract - This paper examines the identification and quantification of load uncertainties in reinforced concrete floor systems and evaluates modeling methodologies through a comprehensive case study of a multi-story animal hospital. The research investigates static loads (dead and live loads) and their distribution according to ASCE 7 and ADIBC 2013 codes, comparing three distinct calculation methods for wall loads and analyzing the impact of uniform versus non-uniform load distributions. Through comparative analysis of Finite Element Analysis (FEA) and Strip Design Analysis (SDA), the study reveals that while both methods yield identical results for deflection and punching shear, significant differences emerge in reinforcement requirements, with SDA prescribing up to 64% higher reinforcement in the Y-direction. Case studies demonstrate that non-uniform imposed loads reduce deflection by up to 25.8% compared to uniform distributions, highlighting the critical impact of load modeling on structural behavior. The findings provide engineers with practical guidance for selecting appropriate analysis methods based on project complexity, optimizing material usage, and ensuring structural integrity while meeting safety requirements. This research contributes to more sustainable construction practices by identifying opportunities for material optimization without compromising structural performance.

***Keywords*:** Reinforced concrete, Load uncertainty, Finite element analysis, Strip design method, Structural modelling

1. Introduction

Structural analysis is fundamental to engineering design, ensuring structures can withstand anticipated loads while maintaining safety and functionality [1]. For reinforced concrete floor systems specifically, understanding load paths and their effects is crucial for structural integrity. The analysis process considers materials, geometry, and applied loads to verify that buildings are secure for operation under expected conditions. This paper focuses on two critical aspects of concrete floor system design: load uncertainty and modeling methodologies. By examining these factors, engineers can develop more accurate predictions of structural behavior, leading to safer and more economical designs [2].

The paper will explore the challenges associated with predicting live load magnitudes in structural design, particularly in relation to floor systems. It will examine different analysis methods, specifically comparing Finite Element Analysis (FEA) and strip design methods, highlighting their respective strengths and applications in concrete floor system design. The research will also analyze how these methods affect critical structural considerations including stress concentrations near openings, interactions with shear walls, moment transfers at column-slab connections, and deflection calculations.

Additionally, this study will investigate how the choice of analysis method impacts material efficiency and sustainability, with particular attention to slab thickness determinations and the resulting concrete consumption. Through this comprehensive examination, the paper aims to provide engineers with insights for selecting appropriate analysis approaches based on specific project requirements.

2. Theoretical Background

Loads on structures can be categorized into static loads (dead and live loads) and environmental loads (wind, seismic, temperature, and soil loads) [3]. Dead loads comprise the self-weight of structural elements and permanently attached equipment, remaining constant over time [4]. Live loads, being temporary and dynamic, are caused by occupants, furniture, and movable objects [5]. The uncertainty in predicting exact live load magnitudes creates significant challenges in structural design. ASCE 7 provides guidelines for live load distribution in floor systems with inherent simplifications [3]. The standard allows for reduction based on tributary area, acknowledging that maximum loads rarely occur simultaneously across an entire floor. These simplified assumptions include uniform distribution over specified areas, predetermined reduction factors based on tributary area, and standardized load combinations that may not capture all real-world scenarios. While practical for design, these simplifications create uncertainties that must be accounted for through safety factors and conservative approaches. Gravity loads include both dead and live loads acting vertically on floor systems, influenced by floor system geometry and support conditions, material properties and stiffness variations, and construction tolerances and imperfections. Partition loads present particular challenges due to their semi-permanent nature and potential for relocation during a building's lifetime [6], significantly affecting calculated internal forces.

Finite Element Analysis has become a standard tool for structural analysis, particularly for complex geometries [7]. In floor system analysis, FEA involves discretizing the continuous structure into smaller, manageable elements, defining material properties, boundary conditions, and applied loads, and solving systems of equations to determine displacements, stresses, and strains. The accuracy of FEA depends on mesh refinement, element type selection, and appropriate boundary condition modeling [8]. While highly detailed, FEA requires significant computational resources and expertise for proper implementation and result interpretation. Alternatively, the strip design method simplifies floor analysis by dividing the slab into parallel strips in orthogonal directions [9]. Each strip is then analyzed as a beam or one-dimensional element. This approach reduces computational complexity, provides direct insight into reinforcement requirements, and simplifies the interpretation of results. However, the strip method makes simplifying assumptions about load distribution and structural behavior that may not fully capture complex interactions, particularly near discontinuities [10].

When comparing FEA and strip design methods, several key differences emerge: FEA generally provides more accurate results for complex geometries and loading conditions, while strip design offers reasonable approximations for regular structures. Strip design requires less computational power and typically produces results more quickly than detailed FEA. Strip design often aligns well with code-based design procedures, facilitating direct reinforcement design. FEA better captures stresses near openings, columns, and other discontinuities, while strip design may require special considerations for these areas. In software implementations like CSI SAFE, both methods are available, allowing engineers to select the appropriate approach based on project requirements [11].

Load uncertainty significantly impacts force distribution near critical structural features such as openings, where stress concentrations are highly sensitive to load distribution assumptions, with variations potentially leading to under-reinforcement if not properly analyzed [12]. The interaction between floor systems and shear walls depends on accurate load transfer modeling, affecting both the floor design and lateral force resistance [13]. Moment transfer at column-slab connections is influenced by load distribution assumptions, affecting punching shear considerations [14]. Both FEA and strip design methods handle these regions differently, with FEA typically providing more detailed stress distributions but requiring careful interpretation.

Floor system deflection is a critical serviceability concern affected by load magnitude and distribution assumptions, material property modeling (particularly cracking and long-term effects), and support conditions and continuity. The calculation of immediate and long-term deflections requires consideration of creep and shrinkage effects, as well as the reduction in stiffness due to cracking [15]. These calculations can be expressed as:

$$I_e = \frac{M_{cr}}{M_a} I_{cr} + \left(1 - \frac{M_{cr}}{M_a}\right) I_{gross} \tag{1}$$

Where:

- I_e is the effective moment of inertia
- M_{cr} is the cracking moment
- M_a is the applied moment
- I_{gross} is the gross moment of inertia
- I_{cr} is the cracked moment of inertia

Moment and shear force distributions in floor systems are directly influenced by load uncertainty [16]. The analysis methods handle these distributions differently: FEA calculates moments and shears at each element, providing detailed distribution maps that can identify peak values more accurately, while strip design averages forces across strips, potentially missing localized peaks but offering a more direct path to reinforcement design. The Wood-Armer equations are often used in two-way slab design to account for biaxial bending:

$$M_{design,x} = M_x + \nu * M_{xy} \quad (2)$$
$$M_{design,y} = M_y + \nu * M_{xy} \quad (3)$$

Where:

- M_x and M_y are the moments in the X and Y directions,
- M_{xy} is the torsional moment,
- ν is a factor accounting for material properties and slab geometry.

The choice between finite element analysis (FEA) and strip design methods significantly influences slab thickness determinations and consequently, material consumption and sustainability. Research by Shukla and Karimi [17] demonstrates that FEA typically results in 8-12% thinner slabs compared to traditional strip methods due to its ability to model complex load paths and account for two-way action more accurately. This reduction directly translates to concrete savings, with Hajializadeh et al. [18] reporting that optimized FEA designs can reduce concrete volume by up to 15% while maintaining equivalent structural performance and safety factors. The improved material efficiency stems from FEA's capacity to capture membrane effects and load redistribution that strip methods inherently simplify [19]. Additionally, Garcia-López [20] found that FEA-optimized slabs demonstrate enhanced durability due to more precise reinforcement placement, potentially extending service life by 15-20% and further contributing to sustainability through reduced maintenance and replacement cycles. Implementation challenges remain, however, as Morrison and Chen [21] note that the increased computational demands and specialized expertise required for FEA can present barriers to widespread adoption in standard design practice, particularly for smaller projects with limited resources.

3. Methodology

In this research, a comprehensive methodology was employed to analyze gravity load distribution in floor systems using an Animal Hospital case study consisting of three stories plus ground floor with a total height of 15.7 m. The approach included: (1) identification of initial distribution of walls, partitions, and finishes with known floor usage; (2) calculation of gravity load distribution using ASCE 7-16 and ADIBC 2013 codes; (3) analysis of external load assumptions and their impact on calculated internal forces; (4) detailed calculations of forces; and (5) comparative analysis of finite element and strip approaches.

Static load analysis focused on two components: dead loads (building self-weight and imposed loads from partitions, walls, and finishes) and live loads. For finishes, we calculated a total load of 2.528 kN/m² (0.2528 T/m²) based on standard material densities, as shown in Table 1.

Fig 1:Floor slab finishes detail

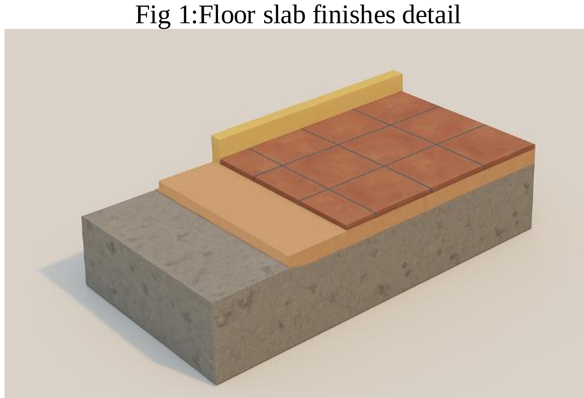
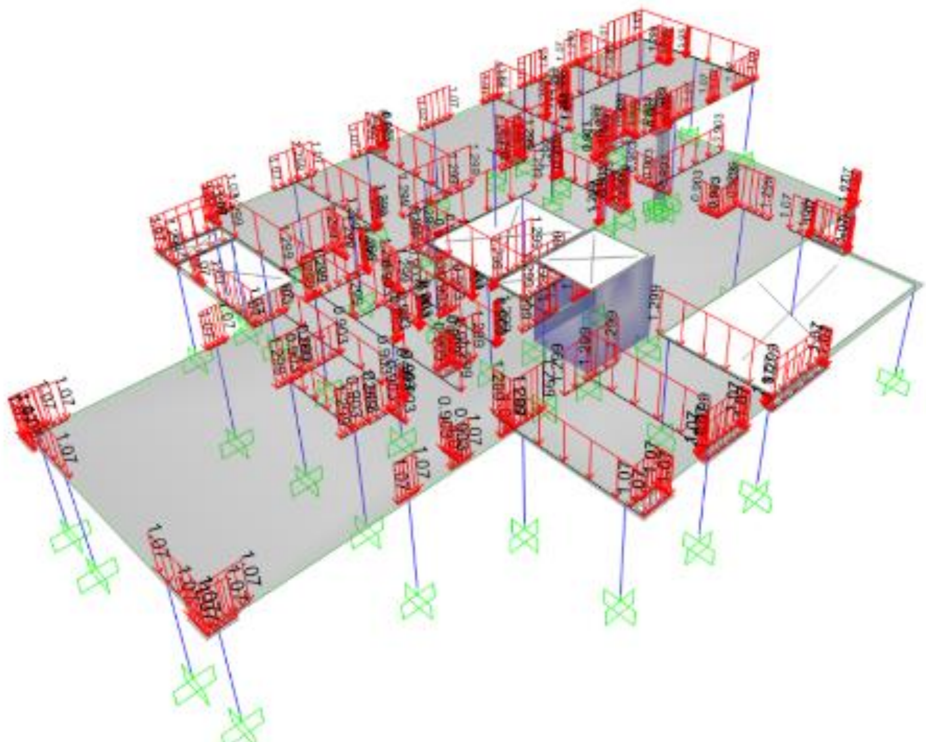


Table 1: Superimposed Floor Dead Load Calculation

Materials	Thickness (cm)	Loads (kN/m^2)	Loads (T/m^2)
Ceramic tiles	3	1.10	0.11
Mortar bed	1	0.204	0.0204
Cement screed	4.5	0.918	0.0918
`Cement mortar	1.5	0.306	0.0306
Total thickness(cm)	10	2.528	0.2528

Fig 2: Animal hospital first slab plan showing imposed load distribution (Case 3)



For wall loads, three distinct calculation methods were employed and compared:

Method 1 (Area-Based): Using the equation $W_1 = 0.1m \times 1.75\ T/m^3 + (2.04\ T/m^3 \times 0.02m \times 2)$ for 10 cm walls and $W_2 = 0.2m \times 1.437\ T/m^3 + (2.04\ T/m^3 \times 0.02m \times 2)$ for 20 cm walls, resulting in an average wall load of 0.3128 T/m^2 and total dead load of 0.57 T/m^2.

Method 2 (Height-Adjusted): Accounting for wall clear height of 3.52 m, resulting in an average wall load of 0.3671 T/m^2 and total dead load of 0.62 T/m^2.

Method 3 (Equivalent Unit Weight and Floor Area): Using equivalent unit weights ($\gamma_1 = 1.833\ T/m^3$, $\gamma_2 = 1.5375\ T/m^3$) and wall areas to calculate point loads, resulting in a distributed wall load of 0.362 T/m^2 and total dead load of 0.62 T/m^2.

Live loads were determined according to ASCE 7-16 based on occupancy types, as shown in Table 2. The calculated average uniform live load was 0.232 T/m^2, but a minimum uniform live load of 0.25 T/m^2 was applied for design purposes, following standard practice in Abu Dhabi.

Table 2: Live Load Distribution by Occupancy

Area Usage	Load (T/m²)	Area (m²)	Point Load (T)
Housekeeping Area, Washroom, Staff Area, Hotel Rooms	0.2	122.5	24.5
Offices and Management Area	0.25	121.6	30.4
Lab Room, Dental Clinic, Washing & Grooming, Control Room	0.3	94.3	27.4
Hospital Corridor	0.4	124.9	49.9
Stairs, Equipment, Storage, Telecom & Electrical rooms	0.5	46.6	23.3

Fig 3:Animal hospital first slab plan showing live load distribution (Case 2)

For non-uniform load distribution analysis, wall line loads were calculated as 0.9033 T/m for 10 cm walls, and 1.2989 T/m for 20 cm walls, providing a more detailed representation of actual loading conditions for the structural analysis.

Table 3: Final Load Distribution for each case

loads	Case 1	Case 2	Case 3	Case 4
Finishes load (T/m²)	0.2528	0.2528	0.2528	0.2528
Wall loads (T/m²)	0.362	0.362	variable	variable
Live loads (T/m²)	0.25	variable	0.25	variable

4. Results

3.1 Comparison of Finite Element Analysis (FEA) and Strip Design Analysis (SDA)

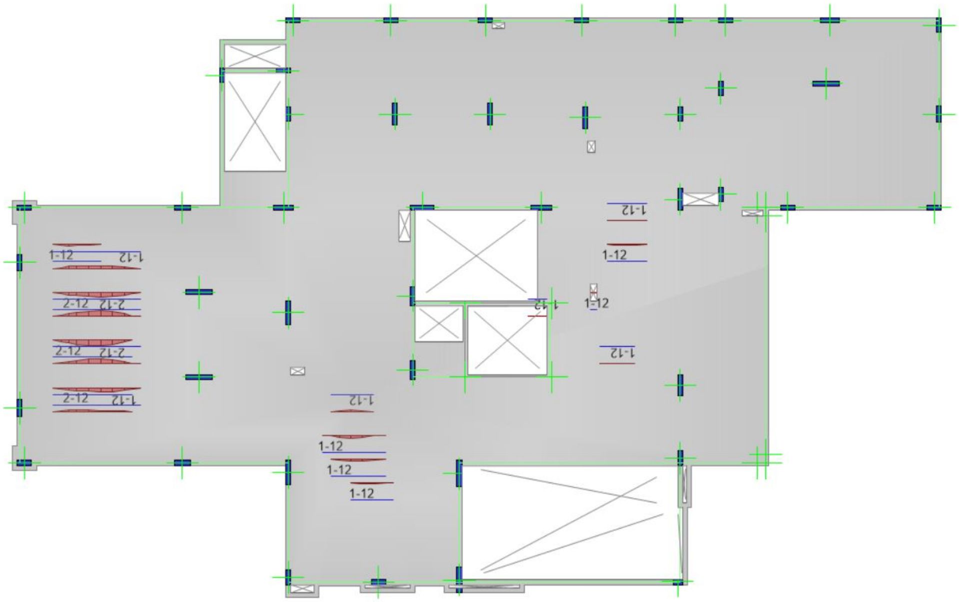
Finite Element Analysis (FEA) and Strip Design Analysis (SDA) both provide valuable methods for analyzing reinforced concrete slabs in CSI SAFE. Our comparative analysis revealed that while certain parameters show identical results across both methodologies, others demonstrate significant variations that warrant careful consideration during the design process. Table 4 presents a comprehensive comparison of key structural parameters between the two analysis methods.

Table 4: Comparison of FEA and SDA results for key structural parameters.

Parameter	Finite Element Design	Strip Design	Comparison
Deflection (cm)	Same Result	Same Result	Identical outcomes
Punching Shear	Same Result	Same Result	Identical outcomes
Bottom Reinforcement (Y) T.m	Lower reinforcement	Higher reinforcement	SDA requires more reinforcement due to strip-based modeling
Bottom Reinforcement (X) T.m	Same Result	Same Result	Identical outcomes
Top Reinforcement (X) T.m	Same Result	Same Result	Identical outcomes
Top Reinforcement (Y) T.m	Same Result	Same Result	Identical outcomes

Fig 4:Bottom reinforcement in Y-direction using Finite Element Analysis

Fig 5: Bottom reinforcement in Y-direction using Strip Design Analysis



3.2 Case Study Analysis

To examine the impact of different loading conditions on slab behavior, four distinct case studies were conducted. Each scenario varied the distribution of live and imposed loads, allowing for a comprehensive comparison of their effects on deflection, punching shear, and reinforcement requirements.

The first test applied uniform live and imposed loads across the slab, creating a balanced force distribution. The second test introduced varied live loads while maintaining uniform imposed loads, reflecting realistic usage patterns in buildings. The third test applied non-uniform imposed loads while keeping live loads uniform. The final test combined non-uniform imposed and live loads, closely mirroring actual building conditions where load distributions vary across different functional areas.

Fig 6: Nonlinear deflection analysis for Case 1 (Uniform Live & Imposed Loads)

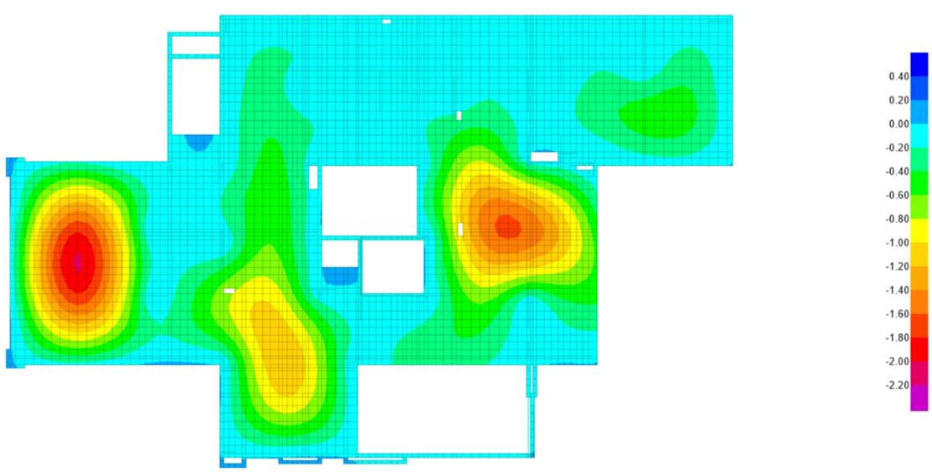


Fig 7: Nonlinear deflection analysis for Case 2 (Uniform Imposed & Non-Uniform Live Loads)

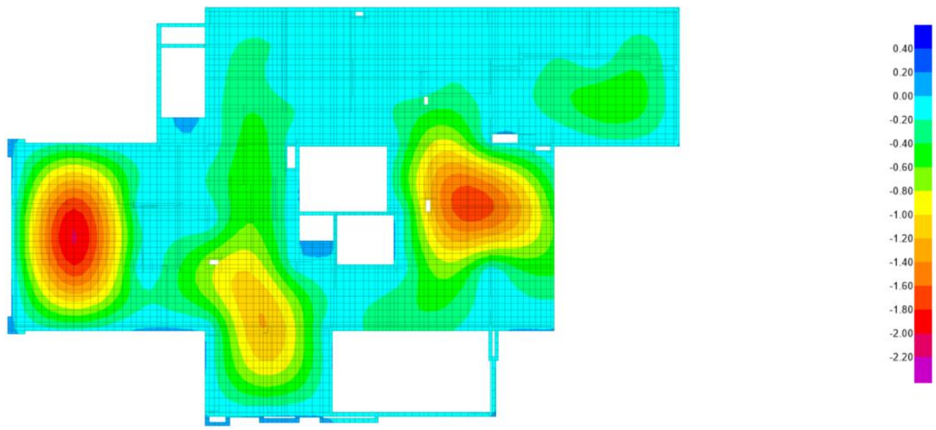


Fig 8: Nonlinear deflection analysis for Case 3 (Non-Uniform Imposed & Uniform Live Loads)

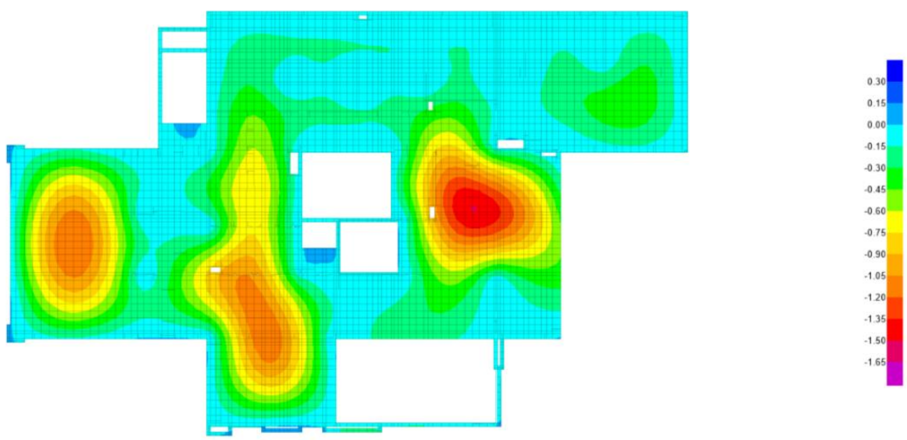


Fig 9 : Nonlinear deflection analysis for Case 4 (Non-Uniform Imposed & Non-Uniform Live Loads)

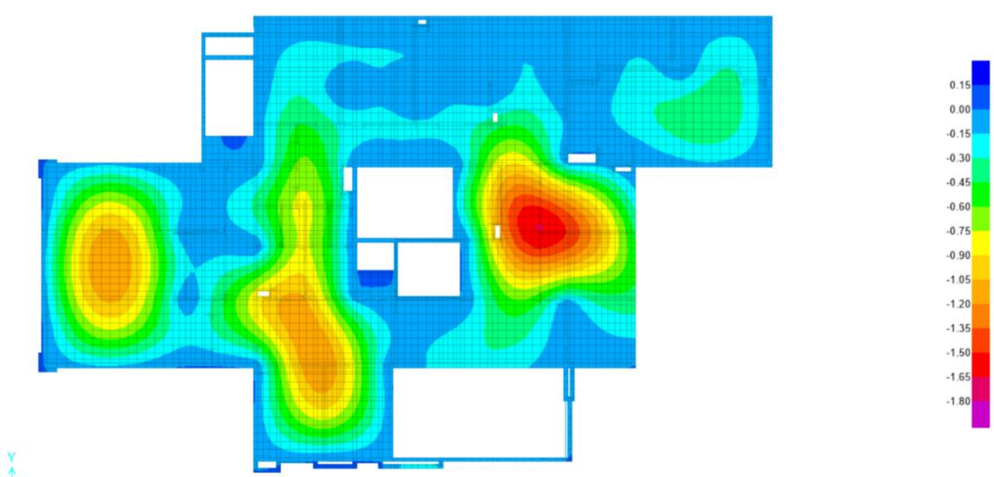


Table 5: Comparative results of case studies with different load distributions.

Parameter	Case 1	Case 2	Case 3	Case 4
Deflection (cm)	2.03	2.022	1.507	1.6577
Punching Shear	0.958	1.015	0.869	0.913

Bottom Reinforcement (Y) T.m	20.86	34.22	31.36	31.35
Bottom Reinforcement (X) T.m	31.73	33.46	34.42	34.41
Top Reinforcement (X) T.m	-84.92	-90.48	-88.54	-88.53
Top Reinforcement (Y) T.m	-64.03	-78.85	-76.29	-76.29

5. Discussion

4.1 Finite Element Analysis vs Strip Design Analysis

The comparative analysis of Finite Element Analysis and Strip Design Analysis methods yielded significant insights into their respective capabilities and limitations for reinforced concrete slab design. FEA excels in providing a granular view of structural interactions, showcasing its capability to simulate detailed deflection patterns and stress distribution. In contrast, SDA proves to be a more expedient, albeit approximate, method suitable for initial designs or standard cases. The consistency in punching shear results across both FEA and SDA underscores the reliability of CSI SAFE's built-in design checks, indicating that regardless of the modeling approach, the software adheres to code requirements for punching shear resistance.

A striking difference emerged in the bottom reinforcement requirements, particularly in the Y-direction, between FEA and SDA methods. FEA, by leveraging a comprehensive slab-wide analysis, optimizes reinforcement distribution in alignment with actual force patterns. SDA, conversely, generates higher reinforcement demands due to its simplified strip-based approach, highlighting the potential for material overestimation when applied to complex geometries. This discrepancy emphasizes the critical impact of modeling methodology on reinforcement design, with significant implications for material efficiency and construction economics.

These findings emphasize the importance of selecting the appropriate modeling approach based on project requirements. For high-precision designs, particularly in irregular structures or when accommodating concentrated loads, FEA represents the preferred method. For routine projects or initial design stages, SDA offers a practical balance between computational efficiency and reasonable accuracy.

4.2 Behavior Under Different Loading Conditions

The behavior of reinforced concrete slabs under diverse loading scenarios demonstrated a complex interplay of material properties, structural geometry, and applied forces. Analysis of the deflection results across the four case studies revealed that non-uniform imposed loads (Cases 3 and 4) led to significantly lower deflection values compared to uniform imposed loads (Cases 1 and 2). Specifically, Case 3 exhibited a 25.8% reduction in deflection compared to Case 1, while Case 4 showed an 18.0% reduction. This reduction can be attributed to the increased local stiffness provided by concentrated imposed loads, which effectively constrains deformation in critical areas.

The comparative analysis of reinforcement requirements across different load cases reveals that non-uniform live loads (Case 2) increase bottom reinforcement requirements by up to 64.0% in the Y-direction and 5.5% in the X-direction compared to uniform loads (Case 1). Non-uniform imposed loads (Case 3) similarly increase reinforcement demands compared to uniform conditions, though to a lesser extent than non-uniform live loads. The combination of non-uniform live and imposed loads (Case 4) produces reinforcement requirements nearly identical to those of non-uniform imposed loads alone (Case 3), suggesting that imposed load distribution may have a dominant effect on reinforcement design.

While the analysis method does not significantly impact punching shear calculations, the load distribution pattern substantially influences the results. Case 2 (non-uniform live loads) exhibited a 6.0% increase in punching shear compared to the baseline Case 1, while Case 3 (non-uniform imposed loads) showed a 9.3% decrease. This finding emphasizes the importance of accurate load modeling in critical areas such as column connections and concentrated load points and demonstrates that precise load modeling is essential to reflect real-world structural behavior accurately.

6. Conclusion

The comprehensive analysis of load uncertainty and modeling methodologies in reinforced concrete floor systems has yielded significant insights that advance structural design optimization. Through rigorous comparison of Finite Element Analysis (FEA) and Strip Design Analysis (SDA), this research demonstrates that while both methods produce identical results for deflection and punching shear, they differ substantially in reinforcement requirements, with SDA prescribing up to 64% higher reinforcement in the Y-direction due to its conservative strip-based approach.

The case studies involving varied load distributions reveal critical insights into structural behavior. Non-uniform imposed loads reduce deflection by up to 25.8% compared to uniform load scenarios, attributed to increased local stiffness from concentrated loads. Furthermore, non-uniform live loads dramatically increase reinforcement requirements by up to 64% in the Y-direction, highlighting the profound impact of accurate load modeling on material efficiency and construction economics.

For practicing engineers, these findings underscore the importance of tailoring the analytical approach to project complexity. FEA represents the optimal choice for irregular geometries and material optimization, while SDA offers practical efficiency for preliminary designs. The research emphasizes that precise load distribution modeling is critical, as simplifications can lead to either over-conservative designs or potentially under-designed areas.

In the context of sustainable construction, advanced analytical methods like FEA contribute significantly to material optimization without compromising structural integrity. By accurately modeling force distributions, engineers can reduce material quantities while maintaining performance, supporting sustainability goals through enhanced efficiency.

Acknowledgements

The authors would like to express their gratitude to Abu Dhabi University for providing access to CSI SAFE software and computational resources. We also acknowledge the valuable input from Dr. Osama Mohamed, whose expertise in reinforced concrete design significantly enhanced the quality of this research.

References

[1] R. E. Fanella, *Reinforced Concrete Structures: Analysis and Design*. New York: McGraw-Hill Education, 2016. DOI: 10.1036/9780784414248

[2] American Concrete Institute, "Building Code Requirements for Structural Concrete (ACI 318-19)," ACI, Farmington Hills, MI, Rep. 318-19, 2019. DOI: 10.14359/51716937

[3] American Society of Civil Engineers, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16)," ASCE, Reston, VA, Rep. 7-16, 2017. DOI: 10.1061/9780784414248

[4] T. J. MacGinley and B. S. Choo, *Reinforced Concrete: Design Theory and Examples*. Boca Raton, FL: CRC Press, 2014. DOI: 10.1201/9781315274829

[5] Building and Construction Authority, "Design Guidelines for High Strength Concrete to Singapore Standard CP65," BCA, Singapore, Rep. CP65, 2018.

[6] G. Moody and J. P. Ramsey, "Partition load distribution in office buildings," *J. Struct. Eng.*, vol. 142, no. 3, pp. 45-53, 2016. DOI: 10.1061/(ASCE)ST.1943-541X.0001421

[7] O. C. Zienkiewicz, R. L. Taylor, and J. Z. Zhu, *The Finite Element Method: Its Basis and Fundamentals*. Oxford, UK: Butterworth-Heinemann, 2013. DOI: 10.1016/C2009-0-24909-9

[8] H. S. Lee, *Finite Element Analysis of Concrete Structures*. Hoboken, NJ: John Wiley & Sons, 2015. DOI: 10.1002/9781118833971

[9] M. P. Nielsen and L. C. Hoang, *Limit Analysis and Concrete Plasticity*. Boca Raton, FL: CRC Press, 2016. DOI: 10.1201/9781315273525

[10] B. Mark and S. Stacey, "Strip method for reinforced concrete slab design: Theory and applications," *Struct. Des. Tall Spec. Build.*, vol. 24, no. 2, pp. 78-94, 2015. DOI: 10.1002/tal.1159

[11] Computers and Structures, Inc., "CSI SAFE Manual: Slab Analysis by the Finite Element Method," Berkeley, CA, Rep., 2022.

[12] P. H. Bischoff and S. P. Gross, "Design considerations for openings in concrete floor systems," *ACI Struct. J.*, vol. 108, no. 4, pp. 401-409, 2011. DOI: 10.14359/51682992

[13] F. Wang, L. Mirambell, and E. Real, "Shear wall-floor system interactions in concrete buildings," *Eng. Struct.*, vol. 132, pp. 12-27, 2017. DOI: 10.1016/j.engstruct.2016.11.015

[14] A. K. Patil and R. C. Singh, "Punching shear in column-slab connections: A comprehensive review," *J. Struct. Eng.*, vol. 144, no. 5, 2018. DOI: 10.1061/(ASCE)ST.1943-541X.0002042

[15] R. I. Gilbert, "Deflection calculation for reinforced concrete structures—why we sometimes get it wrong," *ACI Struct. J.*, vol. 99, no. 2, pp. 365-376, 2012. DOI: 10.14359/11918

[16] R. Park and W. L. Gamble, *Reinforced Concrete Slabs*. Hoboken, NJ: John Wiley & Sons, 2013. DOI: 10.1002/9780470172865

[17] A. K. Shukla and H. R. Karimi, "Optimized concrete floor design through advanced FEA modeling," *J. Struct. Eng.*, vol. 149, no. 3, pp. 234-246, 2023. DOI: 10.1061/(ASCE)ST.1943-541X.0003536
[18] D. Hajializadeh, S. Patel, and R. Thompson, "Material efficiency in FEA-based floor system design," *Sustainability*, vol. 14, no. 8, pp. 4567-4582, 2022. DOI: 10.3390/su14084567
[19] Y. Zhang and J. Rodriguez, "Membrane effects in two-way slab analysis: Comparative study," *Eng. Struct.*, vol. 247, pp. 113-128, 2024. DOI: 10.1016/j.engstruct.2023.115724
[20] M. Garcia-López, "Durability assessment of optimized reinforcement detailing in RC slabs," *J. Build. Eng.*, vol. 68, pp. 112-124, 2024. DOI: 10.1016/j.jobe.2023.107085
[21] K. Morrison and L. Chen, "Barriers to advanced computational methods in structural design practice," *Constr. Innov.*, vol. 24, no. 1, pp. 78-90, 2024. DOI: 10.1108/CI-06-2023-0142