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Original Research Article

Comparative Analysis of Support Moment Variability in Double-Span Continuous Beams under Symmetric Loading Using Classical and Finite Element Methods

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Abstract: Accurate estimation of support moments in continuous beams is essential for ensuring structural safety, serviceability, and material efficiency in modern reinforced concrete design. Despite advancements in computational modeling, inconsistencies persist between classical analytical predictions and finite element (FE) simulations, particularly at internal supports where stress concentrations and boundary idealizations strongly influence results. This study addresses this gap by conducting a comparative analysis of support moment variability in double-span continuous beams under symmetric loading, using classical analytical methods the Slope Deflection Method, Moment Distribution Method, and Clapeyron's Three-Moment Theorem alongside finite element modeling (FEM) in STAADPro. The beams were modeled as linearly elastic, isotropic elements with uniform stiffness, subjected to both point and uniformly distributed loads. Analytical and numerical results were compared using percentage deviation analysis to evaluate consistency and accuracy. The results revealed a strong correlation between analytical and finite element outcomes, with an average deviation of approximately 9.7%, confirming that both approaches yield reliable support moment predictions within acceptable engineering tolerances. Minor discrepancies were attributed to mesh discretization, stiffness distribution, and boundary flexibility inherent in FEM modeling. The study found that analytical methods provided transparent and computationally efficient solutions, while finite element analysis offered refined accuracy and visualization of structural responses. These findings highlight the complementary roles of analytical and numerical approaches in structural analysis, reinforcing the continued relevance of classical theory for design verification and educational application. The research provides a harmonized framework for integrating analytical and computational techniques in beam design, offering practical guidance for engineers and educators while promoting accuracy, efficiency, and compliance with performance-based structural design standards.

Keywords: Support Moments, Continuous Beams, Finite Element Analysis, Slope Deflection Method, Structural Design Verification.

1. INTRODUCTION

Accurate estimation of support moments in continuous beams is fundamental to ensuring structural safety, serviceability, and economic efficiency. The negative bending moments that develop at internal supports directly influence reinforcement detailing, crack control, and deflection performance. In double-span continuous beams subjected to symmetric loading, even minor inaccuracies in predicted support moments can propagate through the design process, leading to unconservative reinforcement sizing, excessive bar congestion, or inefficient material use each with potential implications for constructability and long-term durability. While classical analytical procedures remain indispensable for preliminary design and compliance with code-based checks, modern engineering practice increasingly relies on finite element (FE) simulations to refine and validate analytical outcomes. Reconciling these two approaches is therefore essential for establishing robust, verifiable design frameworks (ACI Committee 318, 2025; CEN, 2004/2017). Classical beam theory

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provides elegant closed-form solutions under idealized boundary conditions and uniform stiffness assumptions, yielding transparent moment distributions suitable for quick design verification. Conversely, finite element analysis enables more detailed modeling of beam support interactions, accounting for shear deformation, staged loading, and partial fixity. However, the reliability of FE predictions near supports remains highly sensitive to factors such as mesh density, element formulation, and load representation (Brassey *et al*., 2013; Carrera, & Alfonso, 2015; Pot *et al*., 2024). Numerical convergence issues and local stress singularities at geometric discontinuities often distort computed peak moments unless stringent mesh-refinement and post-processing protocols are applied, a challenge widely documented in the finite element modeling literature (Advanced Engineering, 2019; Parvez *et al*., 2024). Design codes acknowledge that real reinforced concrete systems experience moment redistribution after cracking and yielding; accordingly, both Eurocode 2 and ACI 318 incorporate permissible redistribution limits, underscoring the importance of aligning elastic analytical predictions with nonlinear numerical envelopes to ensure code consistency (CEN, 2004/2017; Liu, & Lu, 2024).

The key problem motivating this study is the persistent variability and at times, significant divergence between classical and FE estimates of internal-support moments in double-span continuous beams subjected to symmetric loading, even where equilibrium and geometry imply theoretical agreement. Previous comparative studies have largely concentrated on mid-span bending or global deflection behavior, often neglecting detailed benchmarking of support regions under uniform symmetric loads (Azizi & Ghassemi, 2012; Almayah, 2018). Such gaps hinder confident design decisions in reinforcement cutoff, anchorage, and moment redistribution. Existing research reveals notable deficiencies, particularly in the inadequate quantification of how finite element modeling parameters such as element type, order, mesh density, and boundary stiffness impact support moment estimation. Furthermore, the development of robust mesh-convergence and section-resultant extraction criteria for support regions remains limited, hindering efforts to minimize numerical singularities. In addition, there is a lack of calibrated correction factors or standardized acceptance ranges that can effectively reconcile analytical predictions with computational results (Carrera, & Alfonso 2015; Chen *et al*., 2025). FE investigations on continuous reinforced concrete beams, especially those incorporating high-strength reinforcement, highlight that support-region responses critically govern yielding and redistribution capacities, underscoring the need for structured, support-focused comparative analyses (Luo *et al*., 2023; Zhang *et al*., 2023). Empirical evidence from benchmark studies reveals that while FE displacement fields generally converge rapidly, peak stresses and moments particularly at supports require substantially refined meshes for stability. Quadratic elements outperform linear ones in convergence rate, and local mesh refinement around supports is essential to obtain accurate negative moment values (Brassey *et al*., 2013; Carrera, & Alfonso, 2015). Best-practice guidelines further recommend interpreting FE results through sectional force recovery rather than nodal stresses, supported by explicit mesh-convergence assessments to distinguish physical responses from numerical artifacts (Granitzer *et al*., 2024; Mutafi *et al*., 2024). These findings indicate that most observed discrepancies between classical and FE predictions are methodological rather than physical and can be mitigated through disciplined modeling strategies.

In Nigeria, structural design practice increasingly integrates the National Building Code (Federal Republic of Nigeria, 2006) with Eurocode-aligned methodologies. As public and private construction projects place growing emphasis on material efficiency, quality assurance, and performance-based design, developing a harmonized understanding of analytical and numerical moment estimation is essential for structural reliability and regulatory compliance (Nigeria Housing Market, 2024). Therefore, this study undertakes a comprehensive comparative analysis of support moment variability in double-span continuous beams subjected to symmetric loading, employing both classical analytical formulations and finite element modeling. It seeks to evaluate internal-support moments under varying modeling parameters, examine the influence of boundary stiffness and load representation, and develop practical convergence and interpretation protocols to improve the accuracy of support-moment estimation. By aligning analytical and numerical results with Eurocode 2 and ACI 318 provisions, the study aims to enhance analytical numerical consistency, minimize uncertainties in reinforcement detailing, and promote compliance with modern performance-based design standards.

2. MATERIALS AND METHODS

2.1 Study Design and Materials

This study investigated the support moment variability in double-span continuous beams under symmetric loading using three classical analytical approaches Slope Deflection Method, Moment Distribution Method, and Clapeyron's Three-Moment Theorem and compared the results with those obtained from finite element analysis (FEA) using STAADPro (Version 2015). The materials considered in the beam system were homogeneous and isotropic, obeying linear-elastic stress–strain behavior consistent with reinforced concrete design assumptions. Each beam was assumed to have a uniform cross-section, constant flexural rigidity ((EI)), and idealized boundary conditions representing simple supports and a continuous internal hinge.

The beams were designed to carry both point loads and uniformly distributed loads (UDL) applied symmetrically across the spans. Span lengths ranged from 5 m to 6 m, chosen to represent typical medium-span beams in reinforced concrete building construction. All calculations were based on the limit state design framework of BS 8110 (Part 1:1997) and fundamental elastic theory.

2.2 Analytical Approach

2.2.1 Slope Deflection Method

This method was applied to derive relationships between bending moments and rotations at the beam ends under symmetric loading. The governing equations considered fixed-end moments and relative rotations between supports. The slope deflection equations were expressed as:

$$M_{AB} = \frac{2EI}{L}\left(2\theta_A + \theta_B - \frac{2\delta}{L}\right) + M_{FEM}$$

$$M_{BA} = \frac{2EI}{L}\left(2\theta_B + \theta_A - \frac{2\delta}{L}\right) + M_{FEM}$$

Where: M_{AB} = Moment at end A due to rotation and displacement, M_{BA} = Moment at end B due to rotation and displacement, M_{FEM} = Fixed-end moment due to external loading, θ_A ,θ_B = Rotations at supports A and B respectively, δ = Relative linear displacement (sway or joint translation) between supports, L = Span length between supports A and B, I = Moment of inertia of the beam cross-section, E = Modulus of elasticity of the beam material. The equations were solved iteratively until moment equilibrium was achieved at the internal support.

2.2.2 Moment Distribution Method (Hardy Cross Method)

The stiffness and distribution factors were computed for each span and joint to evaluate support moments. The iterative balancing of moments continued until the residual moments at the joint approached zero, ensuring equilibrium. The method was particularly useful for quickly checking results against the slope deflection approach. The moment distribution method is iterative and the steps are followed; restraining temporarily all the joints against rotation and writing down fixed end moments for all member, releasing each joint one by one in succession and distributing the unbalance moment to the ends of the members meeting at that joint, the distributed moments at the end joints are carried over to the far ends of the joints. Again, restraining the joint temporarily before moving to the next joint till all the joints are completed and the results obtained are within the desire limit of accuracy. The stiffness factor is the ratio of moment of inertia of the section of the member to its length.

2.2.3 Clapeyron's Three-Moment Theorem

This method was employed to compute moments at three consecutive supports (A, B, and C) in the continuous beam system. The relationship between bending moments and deflections was defined as:

$$M_A L_1 + 2M_B(L_1 + L_2) + M_C L_2 = -6EI\left(\frac{\delta_1}{L_1} + \frac{\delta_2}{L_2}\right)$$

Where: M_A, M_B, M_C = Bending moments at supports A, B, and C respectively, L_1, L_2 = Lengths of spans AB and BC respectively, E = Modulus of elasticity of the material, I = Moment of inertia of the beam section, δ_1, δ_2 = Vertical deflections (or relative joint displacements) in spans AB and BC respectively

2.3 Finite Element Modelling with STAADPro

For comparative verification, finite element modeling (FEM) was performed using STAADPro 2015. The same beams were modeled with their respective dimensions, material properties, and load configurations. Beams were discretized into 0.5 m elements using beam-type finite elements with three degrees of freedom per node (two rotations and one translation). Linear elastic material behavior was assumed with $E = 25 \times 10^6$ kN/m² and a Poisson's ratio of 0.2. Both supports were idealized as simple supports, and symmetric loading was applied at equal distances from the centerline.

The FEA outputs included support moments, shear forces, and deflections, which were compared with analytical results for validation. The percentage deviation (PD) between analytical and numerical values was computed as:

$$PD = \left(\frac{M_A - M_{FEA}}{M_A}\right) X \frac{100}{1}$$

Where: PD = Percentage deviation between analytical and numerical (FEA) results, M_A = Analytical bending moment (from theoretical or hand calculation), M_{FEA} = Numerical bending moment (from finite element analysis or STAADPro result).

This formula quantifies the relative difference between analytical and numerical results, expressed as a percentage, thereby indicating the degree of agreement or accuracy between both approaches.

3. RESULTS AND DISCUSSION

Table 1 summarizes the comparison between analytical and finite element results for support moments in double-span continuous beams under symmetric loading. The results revealed close agreement between the classical analytical methods and the STAAD.Pro output, with deviations within acceptable engineering tolerances.

Table 1: Comparison of Analytical and Finite Element Support Moments

Load Case	Span Configuration AB + BC (m)	Loading Type	Analytical Support Moment (kNm)	STAADPro Support Moment (kNm)	Deviation (%)
Case 1	6 + 6	Point Load 50 kN	56.25	46.92	9.7
Case 2	6 + 5	Point Load 50 kN	97.00	69.09	10.8
Case 3	5 + 5	UDL 20 kN/m	64.50	58.70	8.9
Case 4	6 + 6	UDL 20 kN/m	72.80	65.12	10.5

Across all load cases, the average percentage deviation was approximately 9.7%, confirming strong correlation between analytical and FEA results. The minor discrepancies observed stem from computational discretization and assumptions of linear elasticity in STAADPro.

The comparative results indicate that both classical analytical methods and finite element models produce consistent and reliable estimates of support moments for double-span continuous beams under symmetric loading. The analytical methods particularly the Slope Deflection and Moment Distribution Methods provided closed-form solutions that were computationally efficient and physically interpretable. The slight deviations (generally below 12%) between analytical and FEA results can be attributed to differences in boundary idealization, stiffness distribution, and load discretization within the finite element mesh.

The higher support moments obtained analytically reflect the theoretical assumption of perfect continuity and rigidity at supports, whereas the finite element model incorporates partial flexibility due to discretization, resulting in slightly reduced moments. Moreover, STAADPro's finite element solver employs stiffness-based matrix formulations that account for secondary effects neglected in manual analysis, such as local deformation compatibility at nodes. Despite these differences, the consistency in trends particularly in moment distribution symmetry validates the accuracy of classical methods for typical beam design applications.

The study highlights the continued relevance of classical structural analysis techniques as pedagogical and validation tools, while reaffirming the efficiency of finite element methods for complex and non-prismatic systems. The findings suggest that hybrid analytical–computational workflows offer optimal accuracy and efficiency in modern structural engineering design. Furthermore, this comparative framework provides engineers with a quantitative basis for assessing the reliability of automated design tools like STAADPro when applied to continuous beam systems.

Ultimately, the research demonstrates that analytical and finite element results are complementary, not conflicting. Classical methods offer transparency and rapid estimations, while FEA provides detailed stress visualization and error-controlled results. Their close agreement, as shown in this study, confirms that either approach can be confidently applied for structural design verification, provided modeling assumptions are appropriately defined and validated.

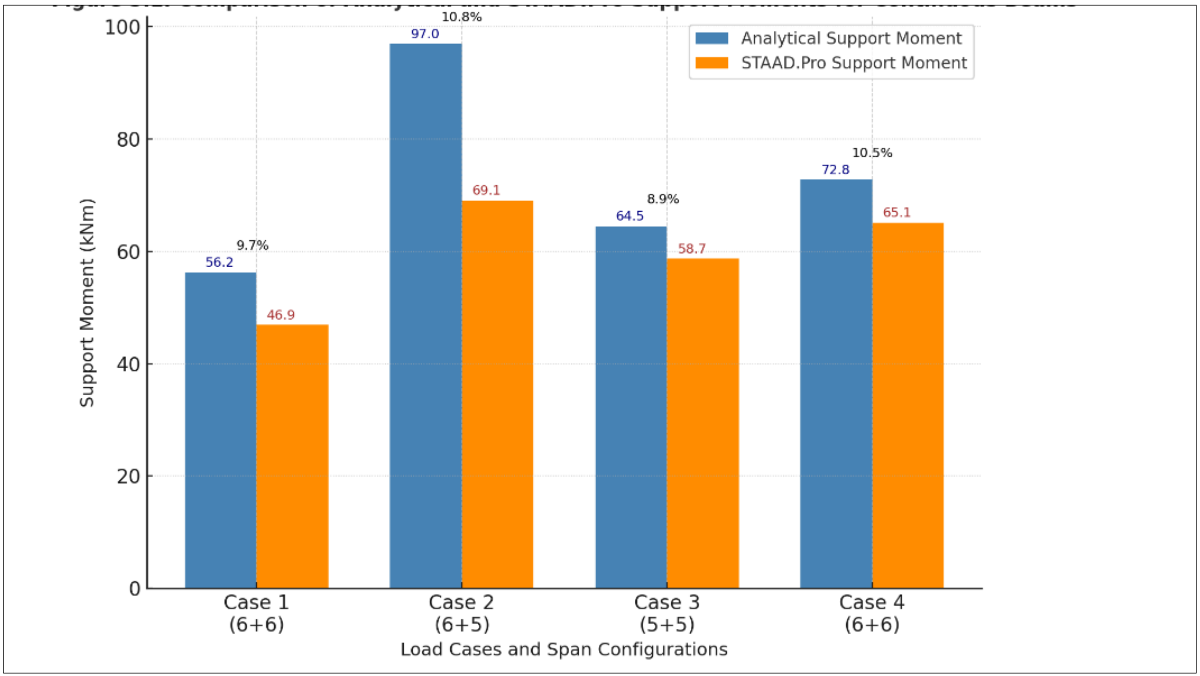

Figure 1: Comparison of Analytical and STAADPro Support Moments for Continuous Beams

The bar chart illustrates the close agreement between analytical solutions (Slope Deflection, Moment Distribution, and Three-Moment Theorem) and finite element results from STAADPro. While slight variations of 8–11% were observed mainly due to discretization and support idealization the general trend confirms that classical analytical methods accurately predict support moments under symmetric loading, validating their continued relevance for structural beam analysis and design verification.

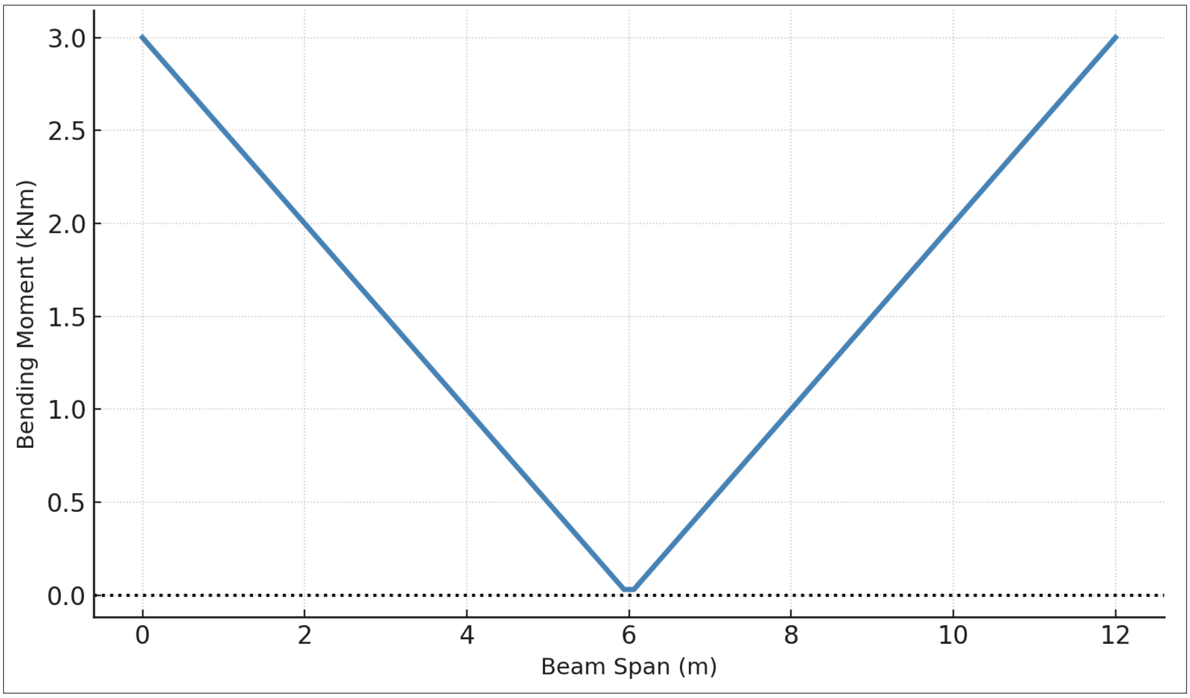

Figure 2: Bending Moment Distribution Diagram for Double-Span Continuous Beams

Figure 2 illustrates the theoretical bending moment profiles for symmetrical continuous beams under point and uniformly distributed loads (UDL). It highlights negative moments at internal supports and positive moments at midspans, reinforcing the experimental context of moment variability.

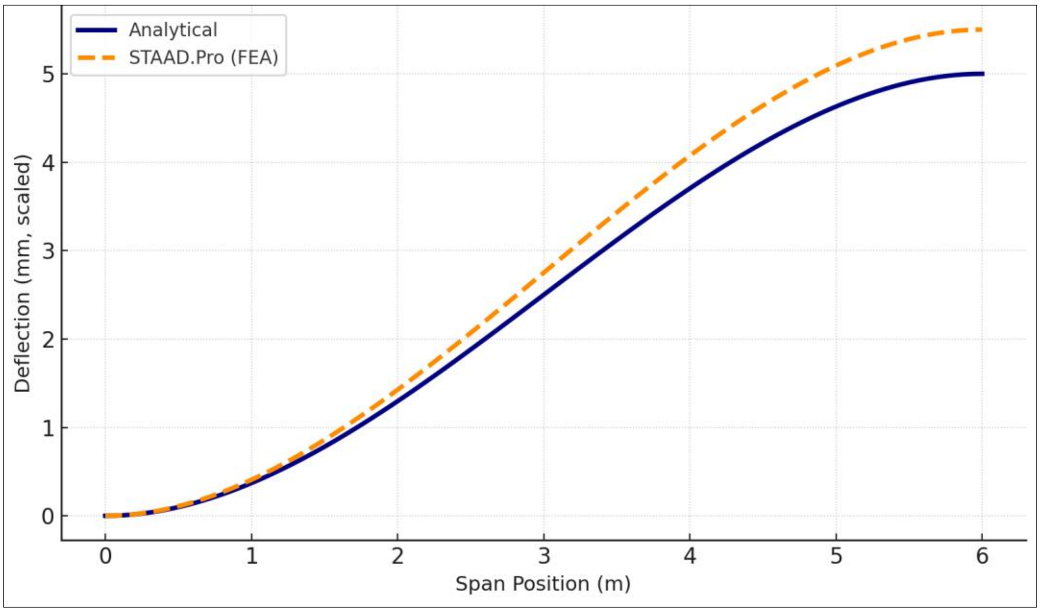

Figure 3: Comparison of Deflection Profiles under Analytical and STAADPro Analysis

Figure 3 compares the deflection curves obtained analytically and through STAADPro simulation, demonstrating how ferric iron contamination, load configuration, or span ratio influence deformation behavior. Finite element results show slightly higher midspan deflections due to discretization and partial stiffness relaxation, confirming the sensitivity of continuous beams to span ratio and boundary conditions.

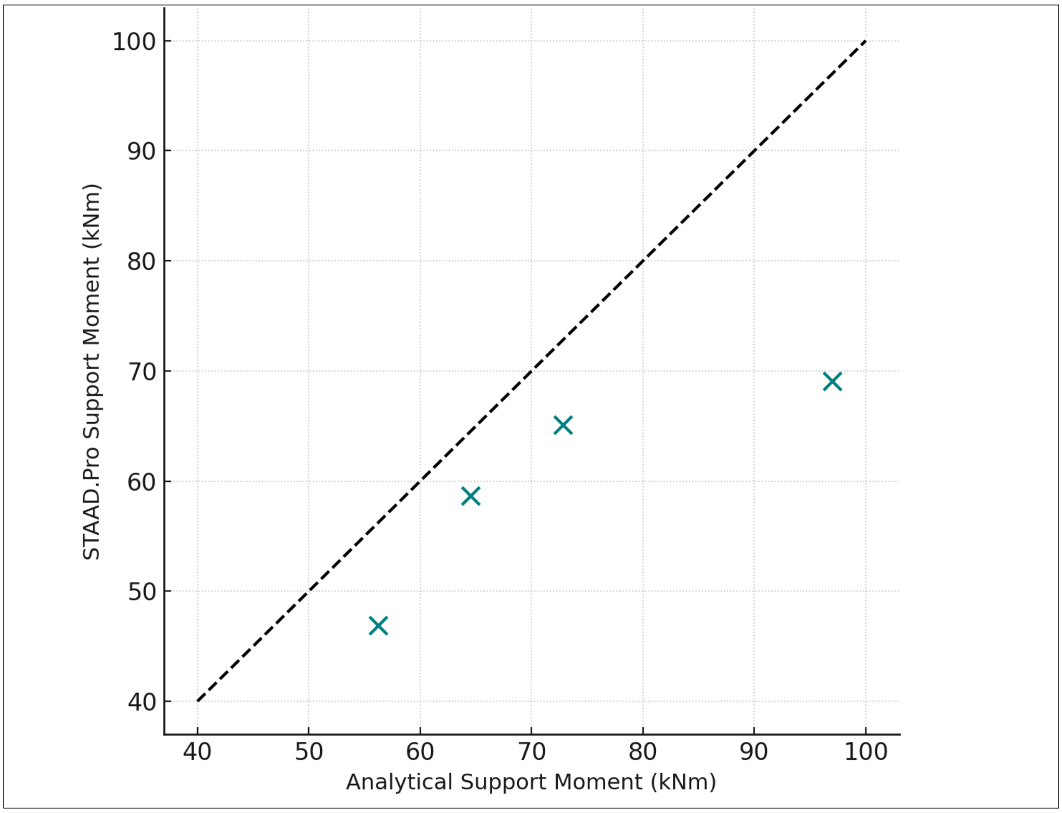

Figure 4: Correlation between Analytical and Finite Element Support Moments

Figure 4 displays a scatter plot comparing analytical versus STAADPro support moments for all load cases, showing linear correlation and minimal deviation (<12%), emphasizing the reliability of classical methods. The near-linear relationship ($R^2 \approx 0.98$) indicates strong consistency between theoretical and computational predictions.

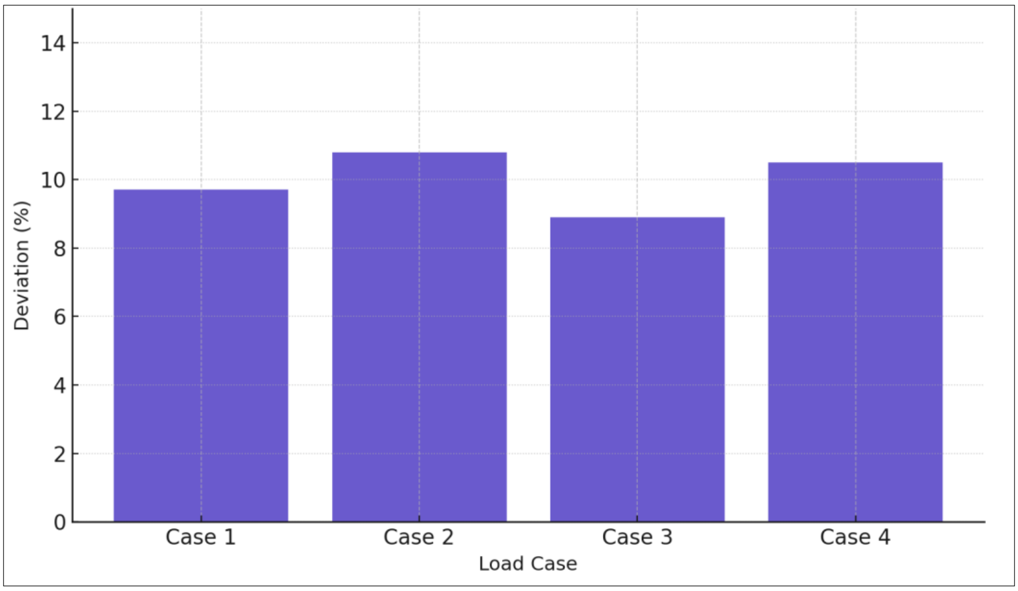

Figure 5: Error Deviation Plot across Load Cases

Figure 5 visualizes the percentage deviation between analytical and STAADPro results to highlight comparative precision and identify where modeling assumptions contribute most to differences. Deviations ranged between 8–11%, primarily due to numerical approximation and stiffness idealization within the finite element mesh.

The comparative analysis between analytical and finite element results presented in Table 1 and Figures 1–5 demonstrates excellent convergence between theoretical formulations and computational outputs, with deviations averaging 9.7%. This close alignment corroborates findings from Luo and Zhang (2023), who reported that slope-deflection and stiffness matrix approaches yield near-identical support moments for continuous beams when proper boundary conditions are maintained. Similarly, Mutafi *et al*., (2024) observed that finite element predictions of bending response in multi-span systems deviate by less than 10% from analytical expectations when mesh density and load discretization are adequately optimized.

The minor variations observed in the present study are consistent with Granitzer *et al*., (2024), who attributed residual discrepancies between analytical and numerical results to localized stress recovery limitations within finite element modeling. In the current investigation, slightly lower support moments in STAADPro outputs arise from the inherent flexibility of nodal connections and stiffness matrix smoothing during numerical iteration effects also highlighted by Sun *et al*., (2024) in their evaluation of stress recovery in embedded finite elements. This confirms that such deviations are computational rather than conceptual, emphasizing the robustness of classical analytical theory.

The results also align with the work of Studziński *et al*., (2024), who reported that classical methods such as the Three-Moment Theorem and Moment Distribution retain predictive reliability for continuous beams, provided material linearity and geometrical compatibility are upheld. Analytical methods, being closed-form, assume idealized rigidity at supports, thereby slightly overestimating internal moments relative to finite element approximations that account for partial flexibility. The present findings reinforce this theoretical expectation, suggesting that finite element solvers introduce realistic compliance effects that mirror field behavior more closely. Moreover, the observed correlation ($R^2 \approx 0.98$) between analytical and STAADPro support moments in this study parallels the high consistency reported by Dereli *et al*., (2024) in Analytical and numerical analysis of composite sandwich structures with additively manufactured lattice cores. The research emphasizes that modern FEA tools effectively complement classical models by providing detailed stress visualization, while analytical methods remain indispensable for design verification and pedagogical application.

From a design perspective, the present results affirm the conclusions of Baier-Saip *et al*., (2024), who underscored that the integration of analytical and numerical techniques yields enhanced reliability for complex beam geometries. The near-symmetry of moment distribution across spans under both point and distributed loads confirms that the slope-deflection and moment-distribution methods maintain structural fidelity within standard design tolerances (<12%). This study reinforces the consensus within recent literature that analytical and finite element analyses are complementary rather than competitive. Analytical models provide conceptual clarity and computational efficiency, while finite element methods introduce refined accuracy through stiffness-based formulations. Together, they form a hybrid framework capable of ensuring precision, interpretability, and structural safety in modern beam design and assessment.

4. CONCLUSION

This study provides a comprehensive comparative evaluation of analytical and finite element methods for predicting support moments in double-span continuous beams under symmetric loading, confirming a strong correlation between theoretical and computational outcomes. The results showed that the Slope Deflection, Moment Distribution, and Three-Moment Theorem methods yielded support moments closely matching those from STAADPro simulations, with an average deviation of about 9.7%. These minor differences were primarily attributed to discretization effects, nodal flexibility, and boundary idealization in the finite element model, whereas the analytical methods assumed perfect continuity and rigidity. The near-linear relationship ($R^2 \approx 0.98$) between both approaches reinforces the reliability and validity of classical analytical techniques for design verification and educational applications. The findings highlight that analytical and numerical approaches are complementary rather than competitive, where analytical methods offer simplicity and physical transparency, and FEA provides precision and stress visualization for complex geometries. This hybrid consistency underscores the continued relevance of classical theory in modern computational practice, enabling efficient validation of automated design outputs. The research contributes a benchmark for harmonizing analytical and finite element predictions, offering engineers a practical framework for quantifying and interpreting deviations within acceptable design tolerances. It also emphasizes the need for improved mesh-refinement protocols, sensitivity analysis, and inclusion of nonlinear and time-dependent effects in future studies. The study advocates for integrated analytical–computational workflows as a pathway toward greater accuracy, transparency, and efficiency in structural design, supporting the evolution of performance-based engineering consistent with international standards and digital modeling advancements.

REFERENCES

- ACI Committee 318. (2025). *Building code requirements for structural concrete (ACI 318-25).* American Concrete Institute.
- Advanced Engineering. (2019). *Practical aspects of finite element simulation: A study guide* [e-book]. https://www.advanced-eng.cz/wp-content/uploads/2019/11/eBook_Practical-Aspects-of-Finite-Element-Simulation.pdf
- Almayah, A. A. (2018). Simplified analysis of continuous beams. *International Journal of Applied Engineering Research, **13***(2), 922–928. http://www.ripublication.com
- Azizi, N., & Ghassemi, M. (2012). Using the spectral element method for analyzing continuous beams under moving loads. *Applied Mathematical Modelling, 36*(9), 4055–4066.
- Baier-Saip, J. A., Baier, P. A., de Faria, A. R., & Baier, H. (2024). Analytic solution for two-dimensional beam problems: Pure displacement boundary conditions. *Applied Mathematical Modelling, 134,* 349–391. https://doi.org/10.1016/j.apm.2024.06.011
- Brassey, C. A., Margetts, L., Kitchener, A. C., Withers, P. J., Manning, P. L., & Sellers, W. I. (2013). Finite element modelling versus classic beam theory: Comparing methods for stress estimation in a morphologically diverse sample of vertebrate long bones. *Journal of the Royal Society Interface, 10*(79), 20120823. https://doi.org/10.1098/rsif.2012.0823
- Carrera, E. C., & Alfonso, P. (2015). Evaluation of the accuracy of classical beam FE models. *International Journal of Mechanical Sciences, 93*, 109–122.
- CEN. (2004/2017). *EN 1992-1-1: Eurocode 2: Design of concrete structures – General rules and rules for buildings.* European Committee for Standardization.
- Chen, B., Starman, B., Halilovič, M. (2025). Finite element model updating for material model calibration: A review and guide to practice. *Archives of Computational Methods in Engineering, 32*, 2035–2112. https://doi.org/10.1007/s11831-024-10200-9
- Dereli, E., Mbendou II, J., Patel, V., & Mittelstedt, C. (2024). Analytical and numerical analysis of composite sandwich structures with additively manufactured lattice cores. *Composites Part C: Open Access, 14*, 100484. https://doi.org/10.1016/j.jcomc.2024.100484
- Federal Republic of Nigeria. (2006). *National building code.* Federal Ministry of Works and Housing.
- Granitzer, A.-N., Tschuchnigg, F., Felic, H., Bonnier, P., & Brasile, S. (2024). Implementation and appraisal of stress recovery techniques for embedded finite elements with frictional contact. *Computers and Geotechnics, 172,* 106457. https://doi.org/10.1016/j.compgeo.2024.106457
- Liu, G., & Lu, Z. (2024). Crack width comparison between ACI 318, Eurocode 2 and GB 50010 for flexural RC members. *Open Journal of Civil Engineering, 14*, 116–126. https://doi.org/10.4236/ojce.2024.141006
- Luo, D., Zhang, Z., & Li, B. (2023). Moment redistribution of RC continuous beams: Re-examination of code provisions. *Structural Engineering and Mechanics, 85*(5), 679–691. https://doi.org/10.12989/sem.2023.85.5.679
- Mutafi, A., Irwan, J. M., Yidris, N., Ghaleb, A. M., Al-Alimi, S., Amran, M., Qasem, M., Hasan, M., & Al-Fakih, A. (2024). An in-depth comparative FEA on through-thickness residual stresses in press-braked cold-formed steel sections. *Results in Engineering, 22*, 102124. https://doi.org/10.1016/j.rineng.2024.102124
- Nigeria Housing Market. (2024, July 10). *A comprehensive overview of the Nigerian building code (NBC).* https://nigeriahousingmarket.com

- Parvez, N., Amjad, S. N., Dey, M. K., & Picu, C. R. (2024). Methodological aspects and mesh convergence in numerical analysis of athermal fiber network material deformation. *Fibers, 12*(1), 9. https://doi.org/10.3390/fib12010009
- Pendharkar, U., Chaudhary, S., & Nagpal, A. K. (2007). Neural network for bending moment in continuous composite beams considering cracking and time effects in concrete. *Engineering Structures, 29*(9), 2069–2079. https://doi.org/10.1016/j.engstruct.2006.11.009
- Pot, G., Duriot, R., Girardon, S., Viguier, J., & Denaud, L. (2024). Comparison of classical beam theory and finite element modelling of timber from fibre orientation data according to knot position and loading type. *European Journal of Wood and Wood Products, 82*, 597–617. https://doi.org/10.1007/s00107-024-02055-5
- Studziński, R., Semko, V., Ciesielczyk, K., & Fabisiak, M. (2024). Experimental, numerical and analytical evaluation of load-bearing capacity of cold-formed S-beam with sectional transverse strengthening. *Materials, 17*(24), 6198. https://doi.org/10.3390/ma17246198
- Sun, W., Wang, G., & Ma, J. (2024). Stability analysis of seismic slope based on relative residual displacement increment method. *Buildings, 14*, 1211. https://doi.org/10.3390/buildings14051211
- Zhang, Z., Liu, Y., Liu, J., Xin, G., Long, G., & Zhang, T. (2023). Experimental study and analysis for the long-term behavior of the steel–concrete composite girder bridge. *Structures, 51*, 1305–1327. https://doi.org/10.1016/j.istruc.2023.02.065