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Structural Response of Transfer Beams: Evaluating the Effect of Staged Construction

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***Abstract* –** The accurate analysis and design of transfer beams are crucial for the stability and safety of high-rise buildings. Traditional classical analysis methods often fall short in capturing the complexities of the staged construction process, leading to potential underestimation of internal forces and deflections. This study investigates the structural response of transfer beams by comparing classical analysis and staged construction analysis using ETABS 21 software. The research aims to highlight the influence of various design parameters, such as beam geometry and material properties, on the structural performance of transfer beams. The results reveal that staged construction analysis provides a more realistic depiction of the structural response, particularly in terms of span moments, support moments, and axial forces. The findings emphasize the importance of incorporating construction stage effects for a comprehensive assessment, ensuring enhanced structural integrity and safety. The study concludes that staged construction analysis is essential for accurate prediction and design of transfer beams in high-rise buildings.

Keywords – Transfer beams, Staged construction analysis, Structural response, Beam geometry, design parameters.

I. INTRODUCTION

Transfer beams are essential in modern structural engineering, serving as horizontal elements that redistribute concentrated loads from upper floors to a broader base of support, thereby enabling flexible architectural designs and larger open spaces. They are commonly employed in multi-story buildings, commercial complexes, and parking structures due to their ability to support unconventional column placements and enhance overall structural stability. The unique load-carrying demands of transfer beams necessitate careful design and analysis, especially in seismic-prone regions.

Previous research has extensively examined the seismic performance of transfer beams. Liu Yan and Zhang (2011) investigated their behavior under seismic action using finite element models, highlighting the distinct stress patterns induced by earthquakes [1]. Qi et al. (2011) demonstrated that haunched transfer beams improve seismic resistance in frame-supported short-leg shear wall systems, underscoring the importance of such design considerations [2]. However, transfer beams also exhibit vulnerability to seismic forces. Li et al. (2003) identified the susceptibility of these beams to brittle failure during seismic events, emphasizing the need for accurate assessment and design to mitigate these risks [3].

Further, the construction sequence plays a critical role in the structural response of transfer beams. Uneven loading during the building phases can lead to inaccurate load distribution, affecting the overall stability and safety of the structure. To address these challenges, innovative reinforcement techniques have been explored. Chen et al. (2015) assessed the effectiveness of using Carbon Fiber Reinforced Polymer (CFRP) hybrid reinforcement to enhance seismic resilience, demonstrating improvements in ductility and energy absorption [4]. Ribeiro et al. (2017) explored post-tensioning as a means to minimize deflections and optimize load-carrying capacity, showing its benefits in improving the performance of transfer beams during seismic events [5]. Building on this body of work, the present study aims to evaluate the structural response of transfer beams with a focus on the effect of staged construction. By employing both classical and construction stage analysis using ETABS 21 software, this research investigates how design parameters, including beam geometry and material properties, influence the performance of transfer beams. The findings are expected to provide valuable insights into optimizing transfer beam designs for enhanced seismic resilience, contributing to the development of safer structures in earthquake-prone areas.

II. COMPARISON BETWEEN CONSTRUCTION STAGES AND CLASSICAL ANALYSIS

This study delves into the comparison between classical analysis (all loads applied at once on the complete final structure) and construction stages analysis for a transfer beam model (Fig. 1). The study aims to highlight the significance of incorporating construction sequencing into the analysis to accurately predict the beam's behavior under load.

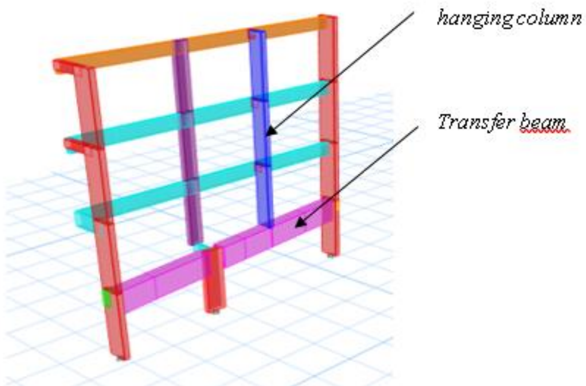

Fig. 1 3D Physical View of the Transfer Beam Model.

The comparison of displacements between the classical analysis and the construction stages (Fig. 2) analysis shows that the latter results in more significant deflections. This indicates that considering construction stages in the analysis provides a more realistic representation of the beam's behavior under load

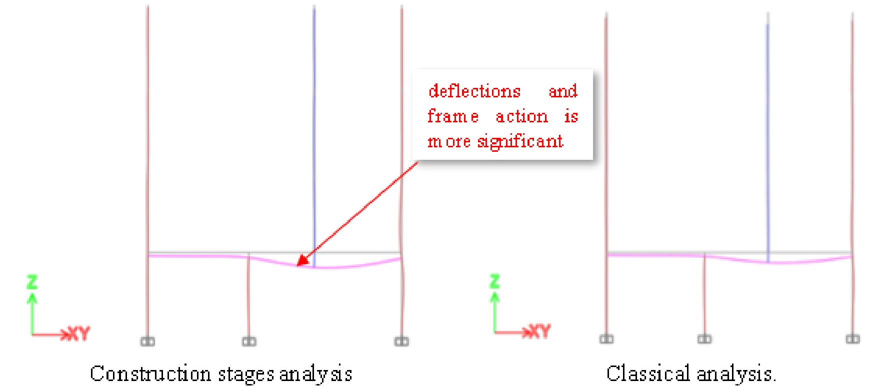

Fig. 2 Displacement comparison between classical and construction stage analysis.

When examining axial forces (Fig.3), the construction stages analysis demonstrates higher values compared to the classical analysis. This highlights the importance of considering the sequence of construction to accurately predict internal forces within the structure.

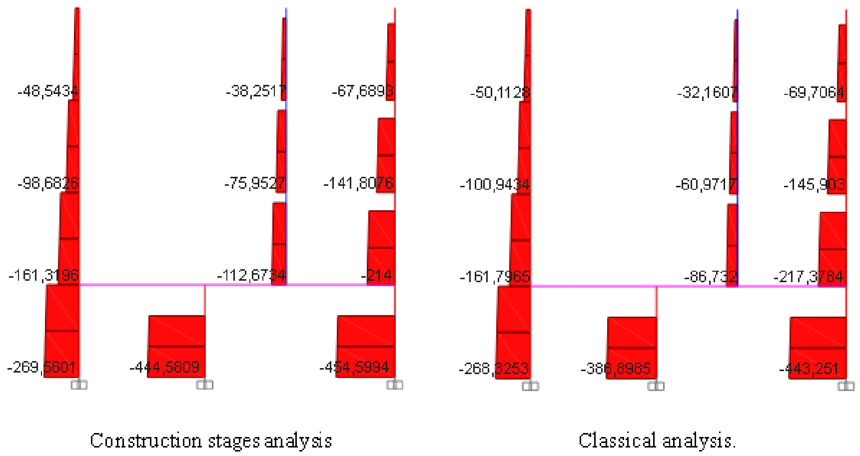

Fig.3 Axial force comparison between classical and construction stage analysis.

The comparison of bending moment diagrams (Fig. 4) reveals discrepancies between classical analysis and construction stages analysis. The latter method captures the evolving structural response more effectively.

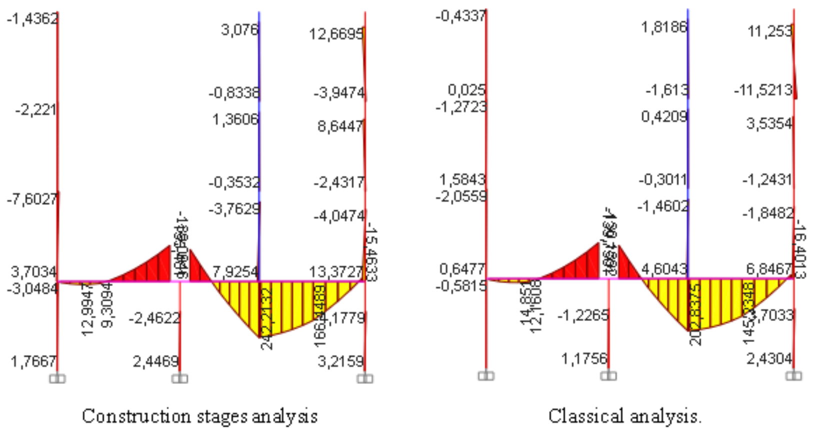

Fig. 4 Bending moment diagram comparison.

III. IMPACT OF DESIGN PARAMETERS OF TRANSFER BEAM

A. Influence of Beam Geometry

Influence of beam depth

To understand the influence of beam depth, several beam sections were analyzed while keeping the width constant at 50 cm. Various depths were selected to study their effect on deflection behavior. The results indicate that greater beam depths lead to reduced deflections, demonstrating the critical role of beam depth in enhancing structural stiffness. The figures 5 illustrates this influence:

Figure 5 demonstrates the influence of beam depth on span moment, support moment, axial force, and deflection. As the beam depth increases, several key structural parameters are affected. For span moments (Figure 5a), there is a noticeable decrease with greater beam depth, indicating enhanced load distribution capabilities and reduced internal bending stresses. In terms of support moments (Figure 5b), deeper beams similarly exhibit lower moments, suggesting improved stability and resistance to bending at the supports. Regarding axial force (Figure 5c), a deeper beam tends to show a reduction in these forces, highlighting the beam's improved capacity to handle compressive loads. Finally, for deflection (Figure 5d), there is a significant reduction as the depth increases, which corresponds to greater stiffness and better structural integrity. This decrease in deflection is crucial for maintaining the overall serviceability and safety of the structure. The analysis demonstrated also that the classical method consistently produces lower estimates for deflections and internal forces than those calculated during the construction stage analysis.

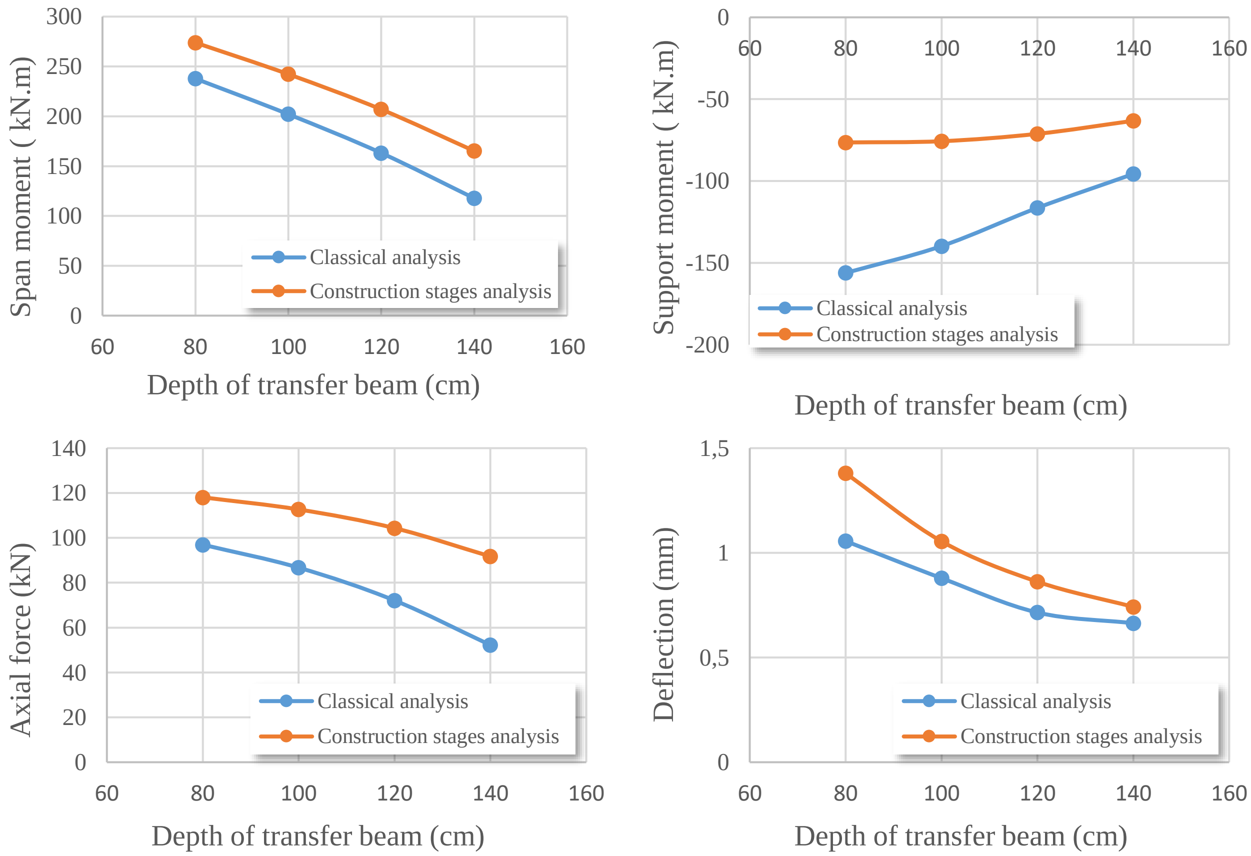

Fig. 5 Influence of beam depth on : a) Span moment, b) Support moment, c) Axial Force, and d) Deflection

Influence of beam width

The analysis also included varying the width of the beams while keeping the depth constant at 120 cm. This parameter affects the overall stability and deflection of the beams. Wider beams exhibited lower deflections, which signifies the importance of beam width in structural design. Additionally, the effect of different beam widths on span moment, support moment, axial force, and deflection were evaluated.

Figure 6 illustrates the impact of varying beam widths on key structural parameters: span moment, support moment, axial force, and deflection. As the width of the beam increases, the span moments decrease because wider beams distribute the applied loads more effectively, reducing the internal moments and lowering bending stresses, thus enhancing structural performance. Similarly, support moments also decrease with an increase in beam width, suggesting improved stability at the supports due to greater resistance to bending and twisting. The axial forces tend to decrease as the beam width increases, indicating that wider beams can better resist compressive forces, thereby enhancing the structure's ability to carry axial loads and reducing stress levels within the beam. Additionally, there is a significant reduction in deflection with increasing beam width, as wider beams exhibit higher stiffness, directly correlating to reduced deflections, which is crucial for maintaining the structural integrity and serviceability of the building. Compared to the construction stage analysis, the classical method underestimates deflections and internal forces. The analysis presented in Figure 6 clearly shows that increasing the width of the beams positively influences the structural performance. By decreasing span moments, support moments, axial forces, and deflections, wider beams enhance the stability, strength, and overall reliability of the structure. This interpretation underscores the importance of considering beam width as a critical design parameter in the engineering of transfer beams for multi-story buildings.

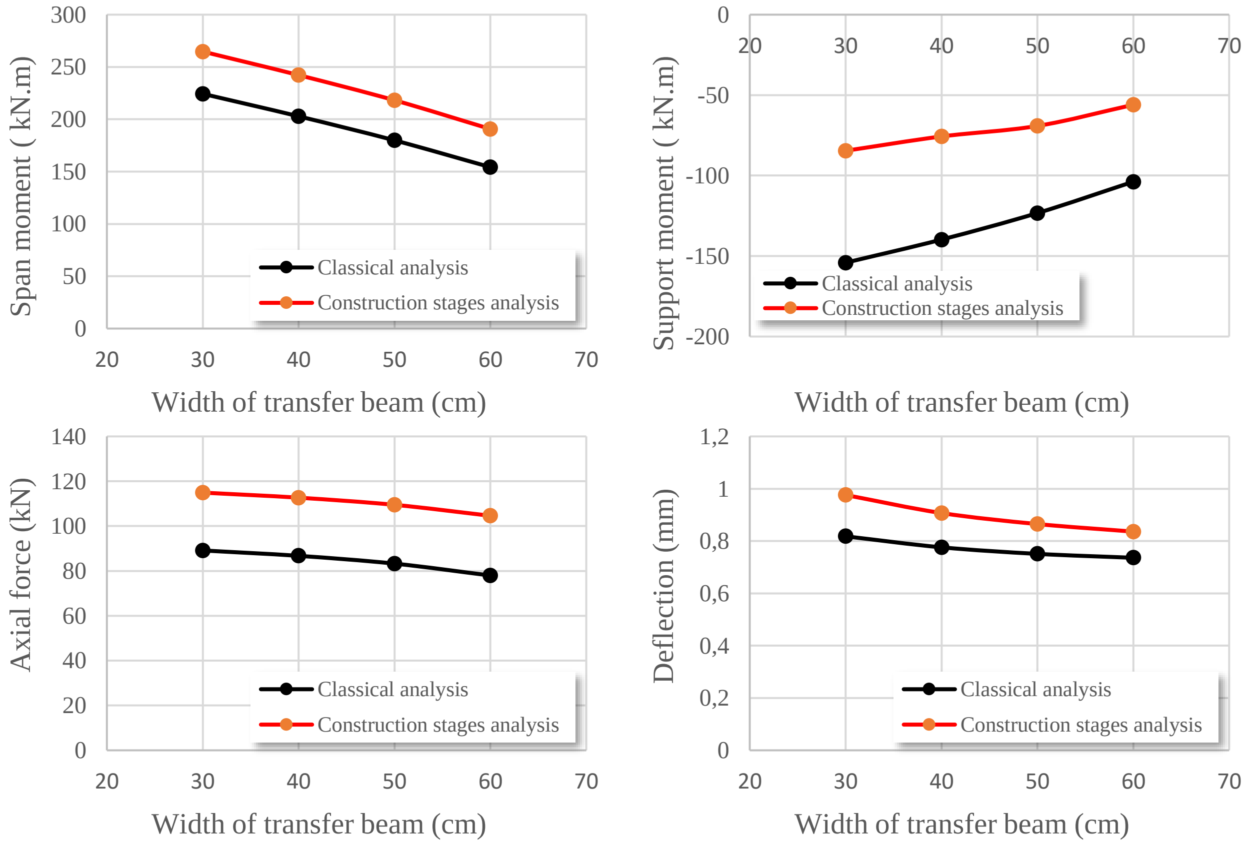

Fig. 6 Influence of beam width on: a) Span moment, b) Support moment, c) Axial Force, and d) Deflection

Influence of hanging column section

The section of the hanging column plays a crucial role in determining the structural response of the transfer beam. To evaluate this influence, different column sections were tested, including variations in dimensions and reinforcement configurations. The analysis was conducted using ETABS 21 to simulate real-world conditions accurately (Fig. 7).

When varying the cross-sectional dimensions of the hanging column, it was observed that larger sections contributed to a more stable transfer beam performance. Specifically, wider columns reduced the overall deflections of the transfer beam, thereby enhancing its stiffness and load-carrying capacity. Conversely, smaller column sections resulted in higher deflections, indicating a less efficient load transfer and increased stress on the transfer beam.

Additionally, the reinforcement within the hanging column significantly impacted the beam's response. Columns with higher reinforcement ratios provided better support and reduced moments and axial forces in the transfer beam. This finding underscores the importance of optimizing both the geometric and reinforcement properties of hanging columns to ensure the structural integrity of the entire system.

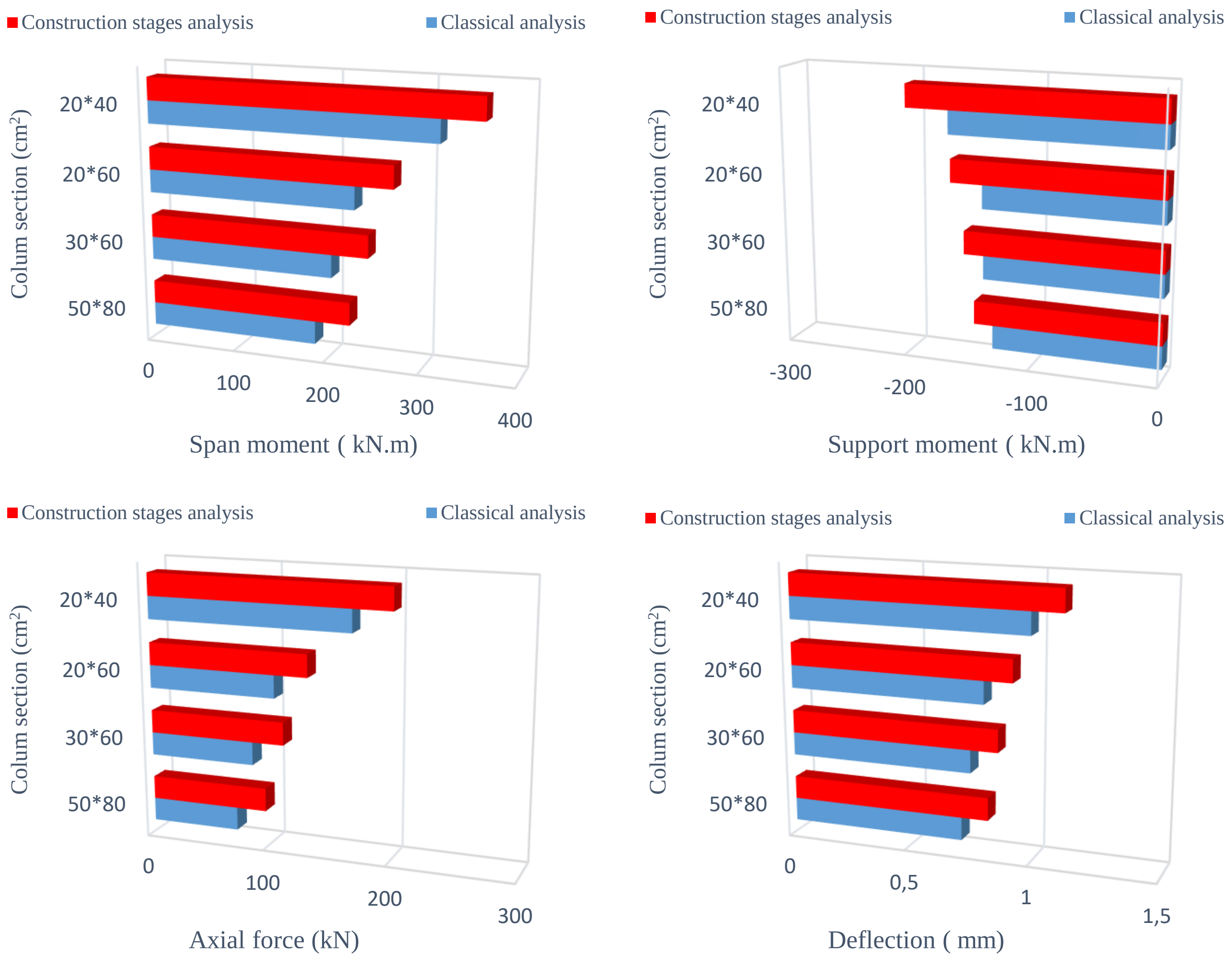

Fig. 7 Influence of Column section on: a) Span Moment, b) Support Moment, c) Axial Force, and d) Deflection

The analysis revealed that the classical method underestimates the deflections and internal forces when compared to the construction stage analysis. The latter method captures the progressive nature of load application and the sequential activation of structural elements, providing a more realistic representation of the structural behavior under different column sections.The results highlight the need for a detailed assessment of hanging column sections during the design phase. By carefully selecting the appropriate column dimensions and reinforcement, engineers can significantly enhance the performance and safety of transfer beams in multi-story buildings.

B Influence of Material Properties

The strength of the concrete used in the beams plays a crucial role in their performance. Beams constructed with higher concrete strengths displayed significantly lower deflections. This emphasizes the need for selecting appropriate concrete strength to ensure optimal structural performance. The impact of different concrete strengths on deflection is depicted in the figure 8.

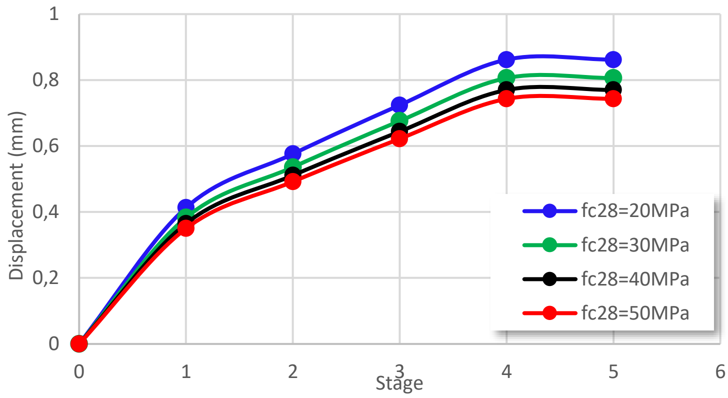

Fig.8 Influence of concrete strength on deflection with different stage.

Figure 8 reveals a strong inverse relationship between concrete strength and deflection in transfer beams, with higher strength leading to significantly reduced deflections across all construction stages. This is due to the increased stiffness of stronger concrete, enabling better resistance to deformation under load. Notably, staged construction analysis, which accounts for the sequential load application during construction, provides a more accurate representation of deflection behavior compared to classical analysis, highlighting the importance of this approach for realistic predictions. While deflection reduction with increasing strength is consistent across stages, the rate of reduction varies, with initial stages showing a more pronounced decrease due to the structure's evolving stiffness. This analysis emphasizes the need to optimize concrete strength for enhancing transfer beam performance and serviceability, particularly in high-rise structures.

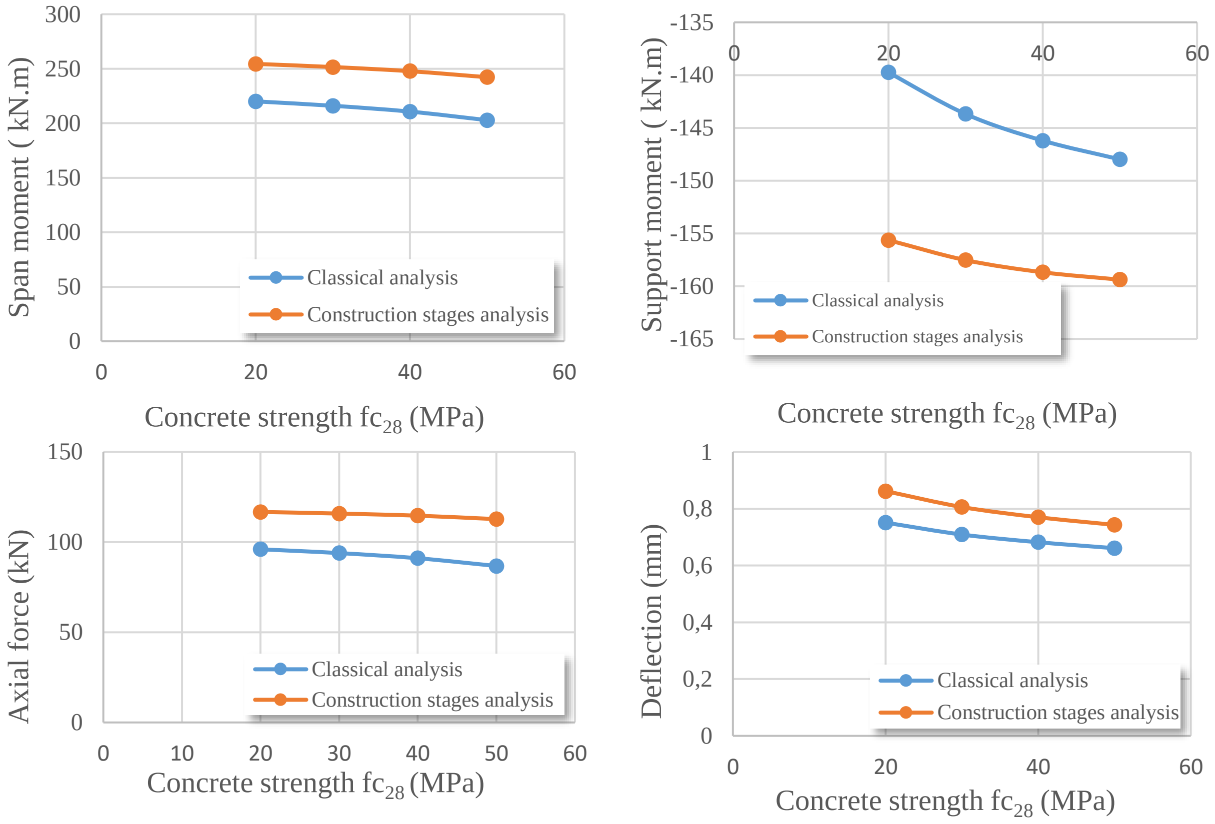

Fig .9 Influence of concrete strength on : a) Span Moment, b) Support Moment, c) Axial Force, and d) Deflection

Figure 9 illustrates the influence of varying concrete strength on key structural parameters: span moment, support moment, axial force, and deflection. As concrete strength increases, span moments and support moments tend to decrease due to the material's improved ability to resist bending and increased stiffness at supports. Axial forces also decrease with stronger concrete, as it can handle higher compressive loads, thereby reducing overall axial stress. Additionally, deflections significantly decrease with higher concrete strength due to increased beam stiffness, which is crucial for maintaining structural serviceability and safety. Overall, the figure highlights that enhancing concrete strength positively impacts the structural performance of transfer beams, contributing to greater stability, strength, and serviceability, emphasizing the need for optimizing concrete strength in high-rise building design and construction.

II. CONCLUSION

This study has comprehensively examined the influence of key design parameters—namely, beam width, depth, and concrete strength—on the structural performance of transfer beams utilizing detailed simulations in ETABS 21. The findings from this analysis are pivotal for enhancing our understanding of transfer beam behavior in structural engineering:

1. *Beam Width and Depth:* The investigation confirms that increasing both the width and depth of transfer beams significantly bolsters structural integrity. These modifications lead to a reduction in span moments, support moments, axial forces, and deflections, culminating in a structure that is stiffer and more stable. Such enhancements facilitate improved load distribution and greater resistance to bending stresses, underscoring the critical role of dimensional parameters in the design of transfer beams.

2. *Concrete Strength:* The study further illustrates that higher concrete strength substantially decreases deflections, span moments, support moments, and axial forces. This finding suggests that stronger concrete not only elevates the load-carrying capacity of the beams but also boosts their overall stability and serviceability. Consequently, the selection of concrete strength emerges as a decisive factor in the design and performance optimization of transfer beams.
3. *Staged Construction Analysis:* A comparative assessment between classical and staged construction analyses underscores the significance of addressing the sequential nature of construction. Staged construction analysis offers a more accurate representation of the structural behavior by incorporating the progressive application of loads. This approach is vital for precise prediction and effective design, particularly in the context of dynamic construction environments.

In conclusion, a thorough analysis of design parameters and construction sequences is essential for achieving optimal structural performance in transfer beams. By integrating these insights into the design process, engineers are equipped to develop safer, more efficient structures, particularly in high-rise building projects. The findings advocate for a meticulous approach to the selection of beam dimensions and material properties, aiming to enhance both the practicality and longevity of structural design

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