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A Comparative Evaluation of Classical Structural Analysis Methods and the Matrix Stiffness Method for Beams and Frames Considering Axial Effects

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Abstract

This study addresses the influence of axial stiffness assumptions on the results obtained by different methods of structural analysis and their implications on the education of structural analysis. Students frequently use structural analysis software such as ETABS without fully understanding the analytical procedures implemented by the software. To address this issue, a continuous beam and a sideways portal frame were analyzed using the Slope-Deflection Method, Moment Distribution Method, Kani's Method, Matrix Stiffness Method, and ETABS. For the purpose of controlled evaluation, the cross-sectional area of the frame members was reduced while the bending stiffness (EI) was maintained constant. Results showed identical outcomes for all methods for the continuous beam in both configurations, demonstrating that its response was mainly controlled by flexural behavior. However, different behavior was observed in the portal frame. The three classical methods (SDM, MDM, and Kani's Method) showed no change in the results because axial deformation effects are not explicitly included in their formulations, whereas the Matrix Stiffness Method and ETABS produced noticeable changes due to the inclusion of axial stiffness effects. The results highlight the significance of stiffness-based formulations in capturing of structural behavior, and show how knowledge of the Matrix Stiffness Method can help students in understanding results obtained from software. The study also emphasizes the importance of giving more attention to the stiffness-based analysis methods in structural analysis education while maintaining the educational value of the traditional hand-calculation methods.

Keywords: Structural Analysis, Classical Methods, Stiffness Method, Portal frame, Engineering education, MDM, SDM

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1. Introduction

Structural analysis is the determination of the response of structures under loads and other external influences such as support settlements and temperature variations [1]. Structural analysis is a core subject in civil and structural engineering. It offers methods for evaluating structures under various types of loading, including wind, seismic and gravity loads. These analytical methods allow engineers to calculate displacements and internal forces that are essential to the safe and economic design of buildings, bridges and other infrastructure systems. In the past, when the use of computers was very limited, manual analytical procedures and simplified analytical models were widely employed and formed the basis of structural analysis education for many decades [2]. However, with the increasing use of computers, numerical methods have become important tools for structural analysis and design [3]. Computer-based analysis allows engineers to analyze structural systems that would be difficult and time-consuming to analyze manually. Modern software is able to handle efficiently a high number of degrees of freedom efficiently, various loading conditions and complex structural configurations. However, the accuracy of the results still depends on the assumptions and mathematical formulations of the underlying analytical method.

The application of computer technology greatly improved the ability of engineers to model and analyze complex structural systems. Modern software can effectively manage a large number of degrees of freedom, different loading conditions, and structural configurations that would be difficult to evaluate with manual procedures only. However, the accuracy of the results still depends on the assumptions and mathematical formulations of the underlying analytical method. Hence, knowledge of the theoretical principles of structural analysis is still important for the interpretation and validation of computational results.

Since industry has rapidly moved toward automation, the use of commercial software has become very common, especially in the engineering field. When using software such as ETABS, students often face challenges in understanding the calculations performed by the software in the background; therefore, they tend to trust the software outcomes uncritically. While classical methods remain important for understanding the fundamentals of structural analysis, they demonstrate limitations in the current era of software applications. These methods are generally suitable for the manual analysis of simple structures but become less efficient for complex structural systems. Moreover, several classical methods mainly focus on the flexural stiffness (EI) and neglect the axial effects (EA), which can lead to an incomplete representation of the structural behavior. On the other hand, the Matrix Stiffness Method takes into account not only flexural but also axial effects. It provides a more complete representation of structural response. It is the basis of modern structural analysis and other engineering software. In this method, the main unknowns are the joint displacements, which are determined from the equilibrium equations [4]. Structural analysis methods have been the subject of several studies concerning their effectiveness, applicability, and engineering education curricula. This study investigates the effect of axial stiffness on the results obtained from classical flexure-based methods, the Matrix Stiffness Method, and ETABS through the analysis of a continuous beam and a sideways portal frame using several analytical approaches,

including the Moment Distribution Method (MDM), Slope-Deflection Method (SDM), Kani's Method, Matrix Stiffness Method, and ETABS. The study aims to demonstrate how various analytical approaches affect structural response and to evaluate the educational implications of these variations. In addition, the research highlights the importance of strengthening stiffness-based analysis methods within structural analysis education while preserving the educational value of classical hand-calculation approaches. The following section reviews the relevant analytical methods and previous studies in structural analysis.

2. Literature Review

Structural analysis of statically indeterminate systems has been extensively developed through a variety of classical analytical methods. The force method is one of the classical approaches used for analyzing statically indeterminate structures. In this Method, selected redundant constraints are removed to transform the structure into a statically determinate system. The unknown redundant forces are then determined by satisfying equilibrium equations together with compatibility conditions of deformation [5]. Another important displacement-based technique is the Slope-Deflection Method, which relates member end moments to joint rotations and translations [6]. Hardy Cross developed the Moment Distribution Method. It is an iterative technique used to obtain equilibrium of joint moments without directly solving equations. The method offers a practical and intuitive way for manual structure analysis. It distributes the imbalanced moments according to the relative stiffness of the joined members [7]. Likewise, the Rotation Contribution Method proposed by Gasper Kani in 1947 is based on redistributing the fixed-end moments to the adjacent joints so that the continuity conditions for rotations and displacements are satisfied [8].

The application, effectiveness, and educational value of these analytical methods in the practice and teaching of structural engineering have been the subject of some studies. For example, P. Patil et al. [8] have done a comparative study on end moments of the portal frame. Their findings showed that iterative methods such as the Moment Distribution Method and Kani's Method are practical and efficient substitutes for conventional analysis techniques, which are often complicated and time-consuming. Gouveia and Coimbra [9] have made a study of the Force Method and the Displacement Method for statically indeterminate structures. They found the Displacement Method to be more effective than the Force Method for complex structures and software implementation. They stressed, too, the need to be familiar with both approaches in the practice of engineering. Bhat and Hassan [10] investigated the application of approximate and exact methods in structural analysis and concluded that, while exact methods provide more rigorous and accurate results, approximate methods can yield reasonably accurate results in preliminary structural design.

John and Rajendran [11] conducted a study focusing on the use of several exact and approximate methods and their practical applications in structural analysis. In their study, they highlighted that approximate approaches offer reasonably acceptable results for rapid assessment and preliminary analysis. Also, the study showed that exact methods and computer-based methods present more accuracy for detailed structural evaluation.

Turkan et al. [12] reported that a great number of students face challenges in understanding the basic concepts in structural analysis. In particular, they have difficulties in visualizing structural behavior and relating theoretical models to real structures. These difficulties are attributed to the limitations of traditional teaching methods. Huang et al. in their work [13] suggested that to improve students' understanding and problem-solving skills, engineering education should bridge theory with practice. Johnson & May [14] pointed out a mismatch between the content of structural analysis courses and the skills required by industry and highlighted the need for updating curricula and teaching methods. Teng et al. [15] pointed out that traditional teaching methods usually focus on numerical procedures and neglect the development of structural intuition and creativity among students.

In the past, studies have examined the effectiveness of various structural analysis techniques and challenges in engineering education. However, little attention has been paid to illustrating the effect of axial stiffness assumptions on results obtained from different analytical methods. In particular, the distinction between classical flexure-based methods and stiffness-based formulations is not always clearly demonstrated in an educational setting. Consequently, students may learn the computational procedures associated with individual methods without fully appreciating the assumptions that are built into those methods or their relationship to modern structural analysis software.

3. Methodology

3.1 Structural Model

This study uses a comparative analytical approach to evaluate selected structural analysis methods and investigate the influence of axial stiffness (EA) on structural response. Two structural systems, namely a continuous beam and a portal frame with sidesway as shown in Fig. 1 and Fig. 2, respectively, were analyzed using five different analytical and computational methods. The influence of the variation of the cross-sectional area (A), and consequently the axial stiffness (EA), on the results obtained from different analysis approaches is also discussed.

The first structural system is a continuous beam subjected to both distributed and concentrated loading. The beam is prismatic with constant material and sectional properties, defined by a modulus of elasticity of E = 200 GPa and a moment of inertia $I = 6 \times 10^7$ mm⁴. The continuous beam is chosen because its response is mainly governed by flexural behavior. Thus, the influence of the variation of the cross-sectional area on the structural response is expected to be minimal. This makes the beam well suited for checking the consistency of different analytical methods and software-based results.

The second system is a single-bay, single-story portal frame with sidesway. Like the beam model, the frame members are assumed prismatic with constant properties, including E = 200 GPa, $I = 6 \times 10^7$ mm⁴, and an initial cross-sectional area of A = 600 mm². For the entire process of the analysis, the material behavior is assumed to be linear elastic.

The portal frame is chosen because its behavior is affected by flexural and axial effects. The frame will move sideways such that one column tends to shorten and the other tends to elongate. This makes the structural response sensitive to axial stiffness. This property

makes the frame a suitable one to study the axial deformation effect of various analytical methods. The two structural systems were chosen because they represent different structural behaviors. The continuous beam is subjected predominantly to flexural action, whereas the sidesway portal frame is subjected to both flexural and axial forces. Thus, these two systems represent an appropriate basis to study the effect of axial stiffness and the assumptions associated with several analysis methods. The loading conditions imposed on each structural system are chosen to best represent the expected structural response, and the structural systems are analyzed accordingly.

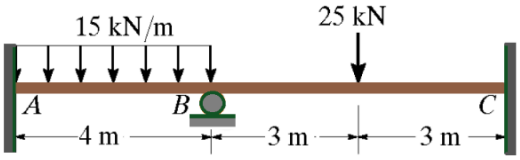


Fig.1. Continuous Beam.

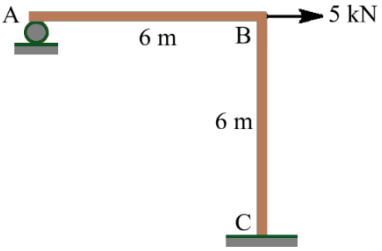


Fig. 2. Portal Frame.

3.2 Structural Analysis Methods

The two structural systems are analyzed with a number of classical analytical methods such as the Moment Distribution Method, Rotation Contribution (Kani) Method, Slope-Deflection Method, and the Matrix Stiffness Method. The classical methods reviewed in this paper are mainly based on flexural behavior. For example, in the Moment Distribution Method, the stiffness of a member is given by $K = 4EI/L$ and the distribution factor is given by $DF_i = K_i / \Sigma K$. Since these formulations are based on the flexural stiffness EI, the effect of the axial stiffness is not explicitly taken into account. Similarly, the Slope-Deflection Method relates the member end moments to the joint rotations and displacements by equations extracted from beam theory, which are mainly based on the flexural behavior. Kani's Method also uses members' flexural stiffness and distributes the moments by iterating through the rotation contribution factors. Therefore, these classical methods do not explicitly take into account the effect of axial deformation. On the contrary, the member stiffness matrices in the Matrix Stiffness Method contain the flexural and axial stiffness. The structural response is found from the relation between the matrices $\{F\} = [K]\{U\}$, where $\{F\}$ is the force vector, $[K]$ is the global stiffness matrix, and $\{U\}$ is the displacement vector. The member stiffness matrix, unlike the classical methods, contains axial stiffness terms in the form of EA/L, which enables the analysis to include the effect of axial deformation. In addition, the two structural models are developed and analyzed using ETABS 2021[16]. In the ETABS models, general material and section properties are assigned to maintain direct control over the input parameters. This approach enables the specification of the modulus of elasticity, cross-sectional area, and moment of inertia in accordance with the relevant analytical models to permit a reliable comparison between analytical and computational results. The modeling

procedure involves defining and assigning the structural geometry, material and section properties, boundary conditions, and the application of the required loading conditions. ETABS is included in the study because it is one of the most popular programs in structural analysis in engineering practice. Since the software is based on stiffness-based numerical procedures, the comparison of the results of the software with those of the Matrix Stiffness Method can show the relationship between manual analysis and modern computational tools**.**

3.3 Comparative Evaluation

To enable comparative evaluation, two separate analytical cases are considered. In the first case, the structures are analyzed using the original member properties. In the second case, the cross-sectional area is reduced from $A = 600\ mm^2$ to $A = 6\ mm^2$ while all other parameters remain unchanged. The cross-sectional area is reduced to produce a substantial decrease in axial stiffness while maintaining the same material properties and flexural stiffness. This condition is not a practical design situation, but it does provide a controlled analytical case where the influence of axial stiffness is more easily observed. In order to highlight the variation between the analytical methods and to intensify the effect of axial stiffness on the structural response, a considerable decrease was intentionally chosen. The results obtained from different methods are compared in terms of displacements and internal moments. The comparison focuses on consistency between analytical approaches and software-based results for each structural system. Special attention is paid to the effect of the cross-section change on the analytical results. If the method gives the same results after reducing the area, it is insensitive to changes in the axial stiffness. However, the variation of displacements or internal forces shows that the effects of the axial deformation are included in the formulation of the analysis. The approach allows the numerical results obtained from each method to be studied, as well as the assumptions that govern their behavior.

4. Results and Discussion

Both the continuous beam and the portal frame were analyzed through analytical approaches such as the Moment Distribution Method, Slope-Deflection Method, Rotation Contribution (Kani) Method, Matrix Stiffness Method, and the ETABS software. The obtained results were compared for each structural system to examine the consistency, limitations, and practical relevance of the different analytical approaches.

For the continuous beam, all analytical methods presented the same results in terms of internal moment and displacements. These results remained unchanged for both the initial configuration and after varying the cross-sectional area. This is because the beam behaves in flexure. Since both the classical methods and the stiffness method effectively capture flexural behavior, consistent results were derived from all approaches. In addition, the ETABS results closely matched those obtained from the analytical methods. The internal moment distributions derived from the different analytical approaches, together with the ETABS results, are presented in Figures 3 and 4.

The consistency among methods guarantees that the continuous beam response is governed by flexural action. The beam does not develop significant axial forces under the

loading conditions applied, and thus its response is governed mainly by the flexural rigidity (EI). Although the Matrix Stiffness Method and ETABS take into account the axial stiffness term (EA/L) in their formulation, this term has a negligible contribution in this structural system. Hence, the reduction of the cross-sectional area does not affect the internal moments or displacements from the analysis.

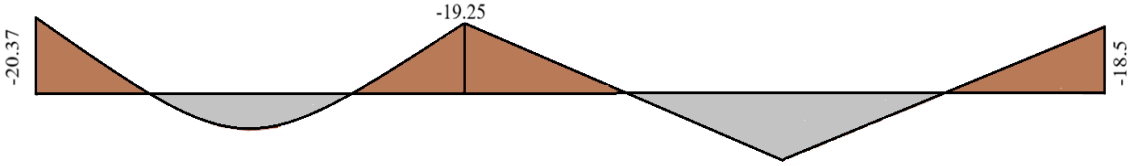


Fig.3. Bending Moment (Different Analytical Methods).

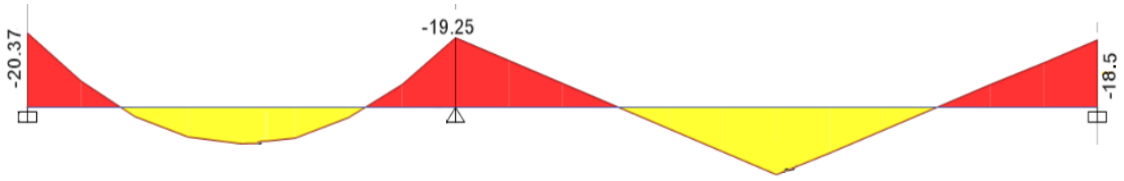


Fig.4. Bending Moment (ETABS).

In contrast, the portal frame with sidesway exhibits a different structural response. For the initial configuration, all analytical approaches produce closely matching results. As illustrated in Figures 5 and 6, the displacements and joint moments determined from the analytical methods, including the stiffness method, correspond closely with the ETABS results presented in Figures 7 and 8. For example, the lateral displacement at joint B is approximately 13.16 mm, while the base moment and the moment at joint B are about 18.77 kN·m and 11.22 kN·m, respectively.

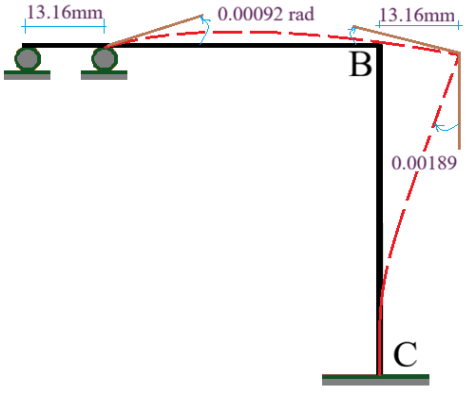


Fig.5. Frame Deflected Shape (Other Analytical and Stiffness Method).

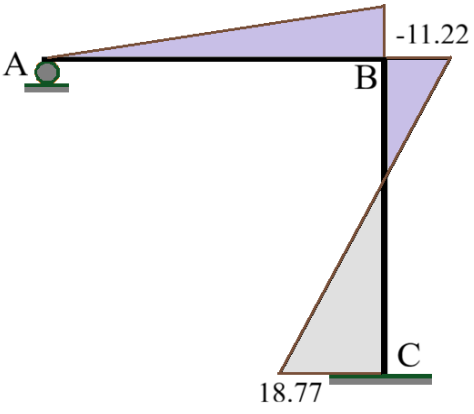


Fig.6. Bending Moment Diagram (Other Analytical and Stiffness Method).

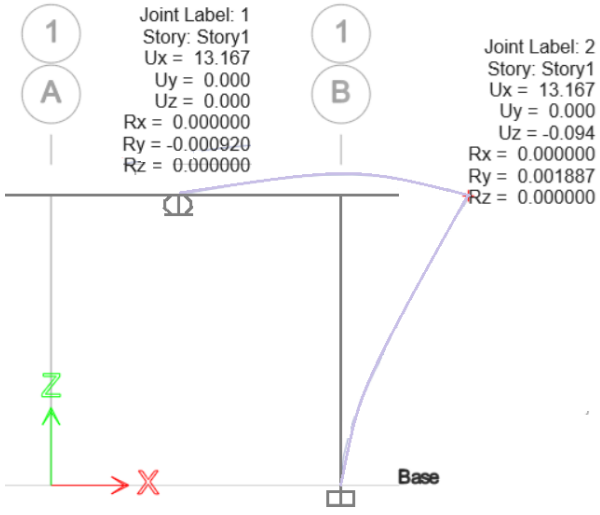


Fig.7. Frame Deflected Shape (ETABS).



Fig.8. Bending Moment Diagram (ETABS).

However, when the cross-sectional area is reduced to 6 mm² just for the purpose of controlled evaluation, while all other parameters remain unchanged, a clear divergence in the results becomes evident. The classical methods continue to produce the same results as those shown in Figures 5 and 6, whereas the stiffness method (Figures 9 and 10) and ETABS (Figures 11 and 12) exhibit changes in both displacements and internal forces. In particular, the stiffness-method results remain in close agreement with the ETABS outputs, while both differ from those obtained using the classical approaches. For example, the lateral displacement at joint B increases from approximately 13.16 mm to 16.04 mm, the base moment rises to about 20.69 kN·m, and the moment at joint B changes to approximately 9.31 kN·m. This behavior is associated with the influence of axial stiffness on the structural response. Since classical methods are primarily formulated based on flexural behavior, axial deformation effects are generally neglected. Consequently, variations in cross-sectional area do not affect the results obtained from these methods.

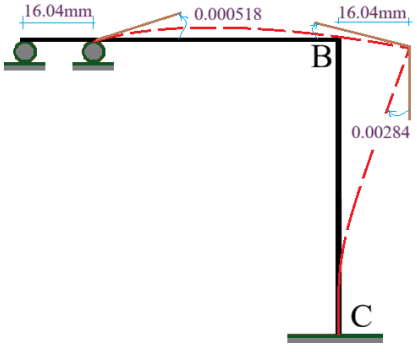


Fig.9. Frame Deflected Shape (Stiffness Method).

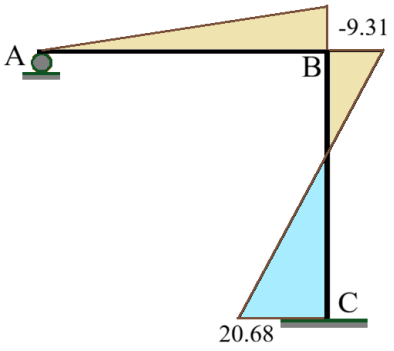


Fig.10. Bending Moment Diagram (Stiffness Method).

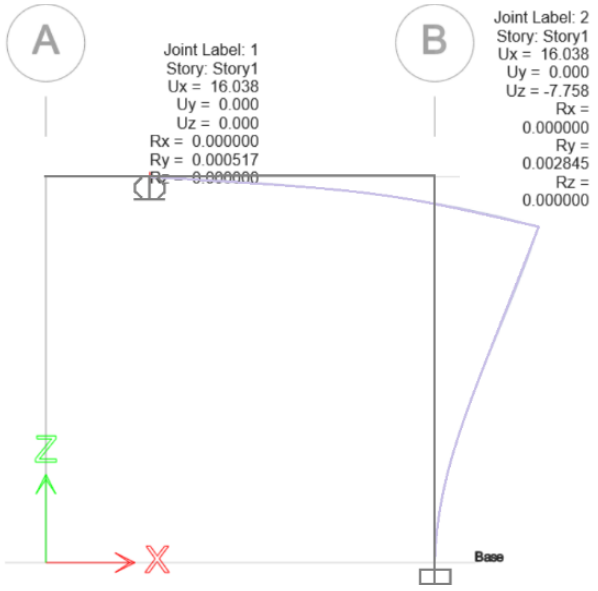


Fig.11. Frame Deflected Shape (ETABS).

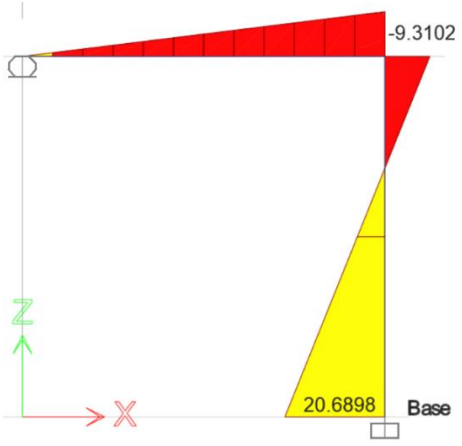


Fig.12. Bending Moment Diagram (ETABS).

This should not be considered a weakness of the classical methods. These methods were developed for practical hand calculation and are still quite effective in many engineering applications. But they are based on simplifying assumptions which are mainly focused on flexural behavior. Hence, when axial deformation plays an important role in the structural response, the differences between the classical methods and stiffness-based formulations can be more apparent. The divergence of the portal frame is due to the interaction of axial deformation and flexural deformation. Sideways of the frame subjects one column to axial tension and the other to axial compression. In the original configuration, the axial stiffness of the members is large enough that these effects only influence the overall response to a limited extent. However, after the reduction of the cross-sectional area, the axial stiffness is significantly reduced, which results in larger axial deformations and redistribution of internal forces in the entire frame.

On the other hand, the stiffness method includes both the axial and the flexural stiffness in one formulation, so that it is able to consider the interaction between different deformation mechanisms. The close agreement between the stiffness method and ETABS should not be interpreted merely as confirmation of their common theoretical basis. Rather, it demonstrates how fundamental analytical concepts are implemented in practical computational tools. Although it is widely recognized that modern structural analysis software relies on stiffness formulations, the present study clearly shows that differences in analytical modeling, particularly the consideration or neglect of certain stiffness components, can directly influence the obtained results. This comparison points out the limitations of classical analytical methods and stresses the need to understand stiffness-based formulations in order to correctly interpret and efficiently use the results generated by software. The comparative results of the two structural systems are presented in Table 1.

Table 1: Comparison of Structural Analysis Methods

Structural System	Parameter	Classical Methods	Stiffness Method	ETABS
Beam (Initial & Modified Area)	Displacement	Same	Same	Same
	Internal Forces	Same	Same	Same
	Effect of Area Change	No effect	No effect	No effect
Frame (Initial Case)	Displacement at B	≈ 13.16 mm	13.16 mm	≈ 13.16 mm
	Rotation at B	≈ 0.00189 rad	0.00189 rad	≈ 0.00188 rad
	Moment at Joint B	≈ −11.22 kN·m	−11.22 kN·m	≈ −11.23 kN·m
	Base Moment	≈ 18.77 kN·m	18.77 kN·m	≈ 18.77 kN·m
Frame (Reduced Area)	Displacement at B	No change	16.04 mm	≈ 16.04 mm
	Moment at B	No change	9.31 kN·m	≈ 9.31 kN·m
	Base Moment	No change	20.69 kN·m	≈ 20.69 kN·m
	Effect of Area Change	Not captured	Captured	Captured

A closer look at the numerical results further illustrates the effect of axial stiffness on the frame behavior. The lateral displacement at joint B increased from about 13.16 mm to 16.04 mm, i.e., an increase of about 21.9%. Similarly, the base moment increased from about 18.77 kN.m to 20.69 kN.m, which corresponded to an increase of about 10.2%. On the contrary, the moment at joint B reduced from about 11.22 kN·m to 9.31 kN·m, a reduction of about 17.0%. These changes indicate that axial stiffness is not only affecting the displacement response of the structure but also the distribution of internal forces.

In general, the Matrix Stiffness Method and ETABS can clearly capture the response of a structure when the cross-sectional area is changed. This is because the Matrix Stiffness Method uses the member stiffness matrix with the axial stiffness term (EA/L), and ETABS executes the respective calculations based on the same formulation. In this way, the obvious changes in the results help students to understand that software is governed by mathematical principles and not by some hidden procedures.

The findings of this study are also in agreement with observations reported in the literature regarding structural analysis education. Previous studies have shown that students often face difficulties in visualizing structural behavior and in understanding the relation between theoretical concepts and real engineering applications. Students can compare the results obtained by classical methods and the Matrix Stiffness Method (MSM) and ETABS, so they can see how the different analytical assumptions influence the structural response and have a clearer idea of the mechanics that govern the structural behavior. By comparing their hand-calculation results obtained from the Matrix Stiffness Method, Moment Distribution Method, Slope-Deflection Method, and Kani's Method with those obtained from ETABS, students can observe that the classical methods are primarily based on flexural behavior and generally neglect axial deformation effects. They also learn that ETABS is not a black box but a predictable computational tool that implements the Matrix Stiffness Method, represented by the relationship F=KU. This

numerical experiment can help students move from viewing software as something difficult to understand to developing a more critical understanding of structural analysis. As a result, they are better able to interpret software results, to understand the theory behind computational tools, and to use both analytical knowledge and practical engineering tools in professional practice.

4.1 Limitations and Future Work

The current study is restricted to linear elastic analysis of a continuous beam and a one-bay sidesway portal frame. The comparison was made for specific load and boundary conditions and thus does not represent all possible structural systems. Furthermore, the effect of axial stiffness was studied by changing only the cross-sectional area, with all other parameters kept constant. Further studies can be done for the comparison of multi-story frames, three-dimensional structural systems, and nonlinear analysis approaches. These investigations will help to better understand the influence of the axial stiffness on the structural behavior and the applicability of different analysis methods.

5. Conclusion

This study is a comparative analysis of a continuous beam and a sidesway portal frame by hand calculation methods such as the Moment Distribution Method, Slope Deflection Method, Kani's Method, Matrix Stiffness Method, and ETABS. The results showed that the assumptions in each method have a direct effect on the structural response obtained from the analysis. The five methods gave the same results for the beam, both in the original configuration and after changing the cross-sectional area. This indicates that, for structural problems governed primarily by flexural behavior, both classical methods and stiffness-based approaches provide consistent results. However, different behavior was observed in the portal frame. When the cross-sectional area of the members was reduced, the three traditional methods (MDM, SDM, and Kani's Method) continued to produce the same results because they primarily consider flexural behavior and do not explicitly account for axial stiffness effects. In contrast, the Matrix Stiffness Method and ETABS showed noticeable changes in the results. The inclusion of both axial and flexural stiffness could allow these approaches to capture structural effects that are not captured by the classical approaches considered in this study. The results also show that the effect of axial stiffness depends on the considered structural system. In the case of the continuous beam, full agreement was found among all the analytical approaches due to the negligible influence of axial deformation. In contrast, the portal frame showed significant changes when the axial stiffness was reduced, which shows the interaction of axial and flexural behavior in frame structures. The close agreement between the Matrix Stiffness Method and ETABS indicates that both approaches produce consistent results for stiffness-based formulations in the structural cases considered. This also highlights the relationship between theoretical stiffness-based analysis and its implementation in modern structural analysis software. Such differences can be shown to students in order to teach structural analysis in a more practical way and to help them better understand the behavior of structures. Finally, although traditional methods are still useful for conceptual understanding, this study advocates for increased emphasis on the Matrix Stiffness

Method in structural analysis education. A good understanding of this method can help students to interpret software results more critically and understand how computational tools perform structural analysis. It also prepares them for more advanced numerical methods such as the finite element method.

Reference

[1] A. Kassimali, *Structural Analysis*, 6th ed. Boston, MA: Cengage Learning, 2019.

[2] Fiveable, "8.2 Analysis methods for indeterminate structures – Structural Analysis." [Online]. Available: https://fiveable.me/structural-analysis/unit-8/analysis-methods-indeterminate-structures/study-guide/ksDmaOB8KAHhUPfX

[3] V. Plevris, M. Georgioudakis, and M. Kioumarsi, "Computational Methods in Structural Engineering: Current Advances and Future Perspectives," *Computation*, vol. 13, no. 9, pp. 1–7, 2025, doi: 10.3390/computation13090224.

[4] A. KASSIMALI, "Matrix Analysis of Structures".

[5] O. Karnovsky, Igor A. ; Lebed, *Advanced Methods of Structural Analysis: Strength, Stability, Vibration Springer Nature Link*, 2nd Spring. Springer Cham Springer Nature Link, 2021.

[6] R. C. Hibbeler, *STRUCTURAL ANALYSIS*.

[7] N. P. on T. E. L. (NPTEL), "Energy Methods in Structural Analysis (Volume 2)," in *Structural Analysis Web-Course Materials*, Indian Institute of Technology Kharagpur (IIT Kharagpur), 2020. [Online]. Available: https://nptel.ac.in/courses/105105109

[8] P. R. Patil, M. D. Pidurkar, and R. H. Mohankar, "Comparative Study of End Moments Regarding Application of Rotation Contribution Method (Kani ' s Method) & Moment Distribution Method for the Analysis of Portal Frame," vol. 7, no. 1, pp. 20–25, 2013.

[9] M. B. G. Gouveia, J. M.; Coimbra, "Comparative Study of Structural Analysis Methods with Practical Application," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 13, no. 6, pp. 2687–2693, 2025, doi: 10.22214/ijraset.2025.72474.

[10] M. Y. Bhat, "A STUDY ON THE APPROXIMATE METHODS VS EXACT METHODS OF STRUCTURAL," vol. 6, no. 2, pp. 169–174, 2021.

[11] L. John and M. G. Rajendran, "Comparative Studies on Exact and Approximate Methods of Structural Analysis," vol. 3, no. 2, pp. 764–769, 2013.

[12] Y. Turkan, R. Radkowski, A. Karabulut-Ilgu, A. H. Behzadan, and A. Chen, "Mobile augmented reality for teaching structural analysis," *Adv. Eng. Informatics*, vol. 34, pp. 90–100, 2017, doi: https://doi.org/10.1016/j.aei.2017.09.005.

[13] C. Huang, F. Xiong, and S. Pu, "Teaching Reform Research of Structural Mechanics Based on Application-oriented Excellent Engineer Education Training Plan," vol. 49, no. Icemse, pp. 339–342, 2017, doi: 10.2991/icemse-17.2017.83.

[14] D. Johnson and I. M. May, "The teaching of structural analysis," *Struct. Eng.*, vol. 86, no. 22, pp. 32–39, 2008.

[15] J. G. Teng, C. Y. Song, and X. F. Yuan, "Fostering Creativity in Students in the Teaching of Structural Analysis," *Int. J. Eng. Educ.*, vol. 20, no. 1, pp. 96–102, 2004.

[16] I. (CSI) Computers and Structures, "ETABS," 2021, *Computers and Structures, Inc., Walnut Creek, California*: 21.