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Influence of Variation in Tie Reinforcement Diameter on the Ductility of Reinforced Concrete Columns

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Reinforced concrete columns are crucial structural elements in ensuring the strength and stability of buildings. Column ductility, which is the ability to absorb energy and undergo deformation before failure, is a primary concern in structural engineering, especially in extreme external loading situations such as earthquakes. This study aims to evaluate the influence of variation in Tie reinforcement diameter on the ductility of reinforced concrete columns using Xtract software. The research method involves creating column structure models with specified dimensions and specifications, followed by the gradual application of axial loads to each model. Three models were created with varying Tie reinforcement diameters, namely 10 mm, 12 mm, and 14 mm. Structural analysis was conducted to examine the structure's response to the applied axial and moment loads, including evaluation of stresses, deformations, and column capacities. The analysis results show differences in ductility levels among the models. The model with a 10 mm Tie reinforcement diameter achieves higher ductility levels at low axial loads but fails to meet the requirements at

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higher axial loads according to the SNI 1726:2019 standard. However, models with Tie reinforcement diameters of 12 mm and 14 mm also exhibit a similar pattern, with good ductility at low axial loads but failing to meet the requirements at higher axial loads. In conclusion, variations in Tie reinforcement diameter affect the ductility of reinforced concrete columns. To ensure full ductility under various axial load conditions, adjustments to the design or specifications of the reinforced concrete column structure are necessary. This research contributes to understanding the factors influencing the ductility of reinforced concrete columns and can serve as a basis for the development of more effective design methods in the future.

Keywords: Concrete; columns; xtract; software.

1. INTRODUCTION

In the world of structural engineering, reinforced concrete columns play a crucial role in ensuring the strength and stability of buildings. Columns are responsible for supporting vertical and lateral loads in buildings, making them crucial structural elements [1,2]. With the advancement of technology and knowledge in the field of structural engineering, significant progress has been made in the methods and techniques of designing and analyzing structures, aiming to improve the ductility performance of reinforced concrete columns [3]. Ductility is one of the important aspects in structural engineering, referring to the ability of a structure to absorb energy and undergo significant deformation before reaching ultimate failure, especially in extreme external loading situations such as earthquakes.

The background of this research refers to the importance of a deep understanding of the factors influencing the ductility of reinforced concrete columns. Although structural engineering practices have reached a high level of complexity, there is still a lack of understanding regarding the influence of Tie reinforcement diameter on column ductility [4]. Tie reinforcement, which is a key element in increasing the capacity and ductility of reinforced concrete columns, still requires further research to understand how variations in Tie reinforcement diameter can affect ductility behavior.

The issue addressed in this research is the influence of Tie reinforcement diameter variation on the ductility of reinforced concrete columns. To address this issue, the research will delve into the failure mechanisms of reinforced concrete column structures, the principles of concrete and reinforcement steel material behavior, and the theories related to column ductility. Basic concepts such as failure mechanisms in reinforced concrete columns, the role of Tie reinforcement in increasing column capacity and ductility, and the principles of structural design under extreme external loading conditions will be the focus of this research.

The main objective of this research is to systematically evaluate the influence of Tie reinforcement diameter variation on the ductility of reinforced concrete columns using Xtract software. It is hoped that this research will make a significant contribution to understanding the structural behavior of reinforced concrete columns in facing various external loading conditions and provide a strong basis for the development of more effective and efficient design methods to improve the ductility of reinforced concrete columns in the future.

Several previous studies have attempted to understand the influence of Tie reinforcement diameter on the ductility of reinforced concrete columns. One significant study is the work of [4–7], where researchers conducted a series of experiments to analyze how variations in Tie reinforcement diameter affect column capacity and ductility behavior. The results showed that increasing the Tie reinforcement diameter can increase column capacity and ductility, but there is an optimal limit that needs to be considered.

The use of structural analysis software has become an important part of research related to the ductility of reinforced concrete columns [8,9]. Several studies have used software such as SAP2000, ETABS, and ANSYS to simulate and numerically analyze reinforced concrete columns with various Tie reinforcement configurations [10–12]. The use of this software allows researchers to model and analyze column behavior under various loading and reinforcement configurations.

Theories related to the design of reinforced columns are also continuously evolving.

Concepts such as performance-based design and failure mechanism-based design are major concerns in efforts to improve the ductility of reinforced concrete columns [13]. This approach allows for designing structures by considering the ductility behavior of columns holistically, rather than focusing solely on structural strength.

Understanding the behavior of concrete and reinforcement steel materials is also continuously evolving. Experimental research and numerical analysis have been conducted to understand the response of these materials to lateral loads and extreme environmental conditions [14,15]. This is important in developing accurate mathematical models to predict the ductility behavior of reinforced concrete columns with various reinforcement configurations.

In addition to Tie reinforcement diameter, there are also studies exploring other factors that affect the ductility of reinforced concrete columns. For example, the influence of structural stiffness, longitudinal reinforcement configuration, and planning and construction methods can play an important role in determining column ductility [15–18].

2. METHODS

The first step is to create a reinforced concrete column structure model using Xtract software. The first model has dimensions of 600 mm x 600 mm with a 75 mm thick concrete cover. This rectangular column shape has dimensions of 600x600 mm for the unconfined region and 450x450 mm for the confined region. The materials used include concrete with a compressive strength of 30 MPa and reinforcement steel with a tensile strength of 420 MPa. The main reinforcement consists of 16 bars with a diameter of 25 mm, while the Tie reinforcement has a diameter of 10 mm.

Next, Model 2 and Model 3 are created, maintaining the specifications of Model 1 except for the Tie reinforcement diameter. In Model 2, the Tie reinforcement diameter is set to 12 mm, while in Model 3, it is set to 14 mm. This variation is done to evaluate the impact of Tie reinforcement diameter on the ductility of reinforced concrete columns.

After the models are created, axial loads are gradually applied to each model. Axial loads of 1000 kN, 2500 kN, and 5000 kN are applied to the columns to create different moments about the X-axis (Mxx). Structural analysis is then performed using Xtract software to examine the structure's response to the applied axial and Mxx loads. The analysis includes evaluation of stresses, deformations, and column capacities at each load stage.

The analysis results will be observed and interpreted to understand the ductility behavior of reinforced concrete columns in each model. The variation in Tie reinforcement diameter is evaluated to see its effect on column ductility capacity. A comparison between Model 1, Model 2, and Model 3 is made to draw conclusions about the effects of Tie reinforcement diameter variation on the ductility of reinforced concrete columns.

Thus, it is expected that this research will provide a better understanding of the factors influencing the ductility of reinforced concrete columns and can serve as a basis for the development of more effective design methods in the future.

3. RESULTS AND DISCUSSION

3.1 Model 1: Tie Reinforcement Diameter 10 mm

The analysis results show that in Model 1, the reinforced concrete column achieves varying levels of ductility depending on the applied axial load. At an axial load of 1000 kN, the Curvature Ductility value obtained is 22.29, indicating that the column has very good ductile capacity. However, at an axial load of 2500 kN, the Curvature Ductility value decreases to 15.47, and at an axial load of 5000 kN, it decreases further to 13.71.

In the context of the SNI 1726:2019 standard, to ensure full ductility of a reinforced concrete column structure, the recommended Curvature Ductility value should be greater than 16. Based on the results obtained, in Model 1, the Curvature Ductility value at an axial load of 1000 kN meets this requirement, so the column can be considered to have full ductility according to the standard. However, at axial loads of 2500 kN and 5000 kN, the Curvature Ductility value is below the recommended standard value. This indicates that in both load conditions, the column does not achieve full ductility according to the requirements of SNI 1726:2019. The decrease in Curvature Ductility value with increasing axial load indicates that the column experiences a degradation in ductile performance.

Additionally, the results of modeling the column structure with a 10 mm Tie reinforcement diameter are shown in Fig. 1. Column structure deformations can also be seen in Fig. 2 for all tested axial loads. Furthermore, the curvature-moment relation and curvature-moment bilinearization of the column are displayed in Fig. 3 for all axial loads.

From these results and discussions, it can be concluded that Model 1 meets the requirement of full ductility according to the SNI 1726:2019 standard at an axial load of 1000 kN but not at axial loads of 2500 kN and 5000 kN. Therefore, to ensure full ductility under various axial load conditions, adjustments to the design or specifications of the reinforced concrete column structure are necessary.

3.2 Model 2: Tie Reinforcement Diameter 12 mm

The analysis results for Model 2 show variations in the ductility level of the reinforced concrete column depending on the applied axial load. At an axial load of 1000 kN, the Curvature Ductility value obtained is 22.21, indicating that the column has good ductile capacity. Although the Curvature Ductility value in Model 2 is slightly lower than in Model 1 at the same axial load, it still meets the requirement for full ductility according to the SNI 1726:2019 standard.

At an axial load of 2500 kN, the Curvature Ductility value in Model 2 is 15.46, while at an axial load of 5000 kN, it decreases to 13.75. Although the Curvature Ductility value in Model 2 tends to be lower than in Model 1 at the same axial load, both are still below the minimum value recommended by the standard, indicating that the column does not achieve full ductility under both load conditions.

The results of modeling the column structure with a 12 mm Tie reinforcement diameter are shown in Fig. 4. Column structure deformations for Model 2 can be seen in Fig. 5 for all tested axial loads. Furthermore, the curvature-moment relation and curvature-moment bilinearization of the column are displayed in Fig. 6 for all axial loads.

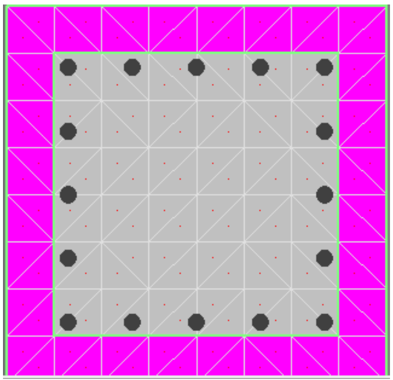
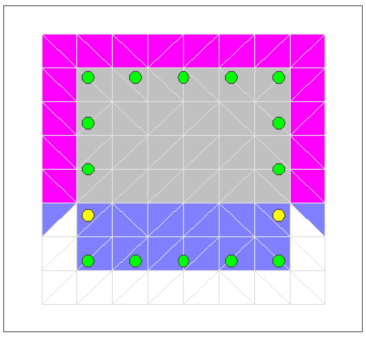
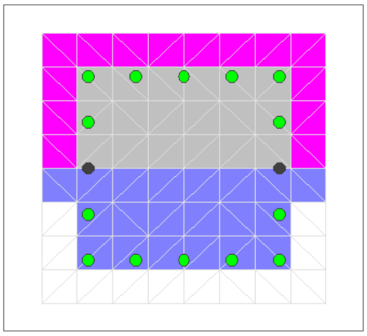


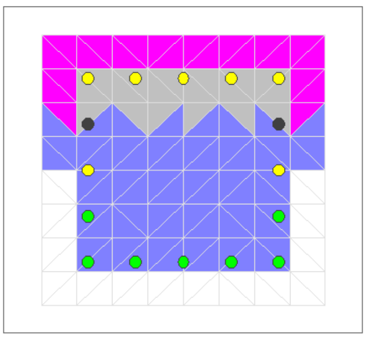
Fig. 1. Modeling of column structure with Tie reinforcement diameter of 10 mm



a) Axial load 1000 kN

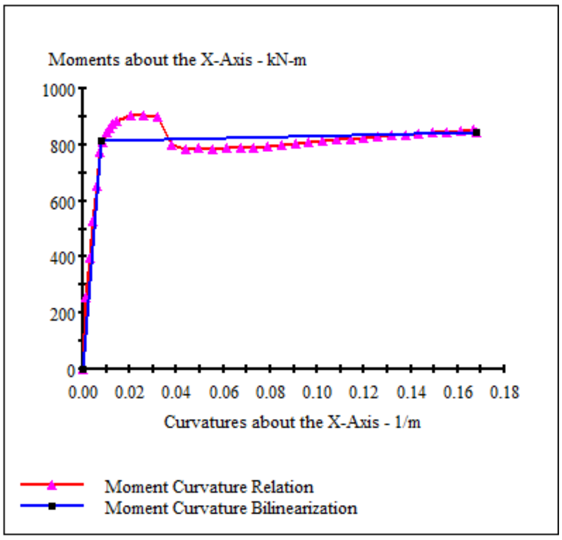


b) Axial load 2500 kN

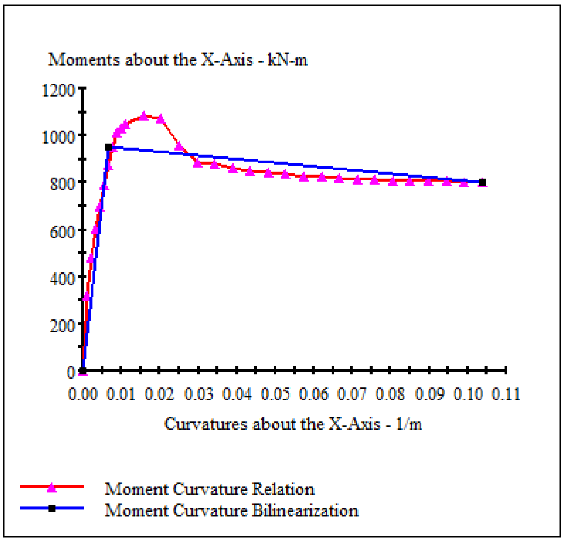


c) Axial load 5000 kN

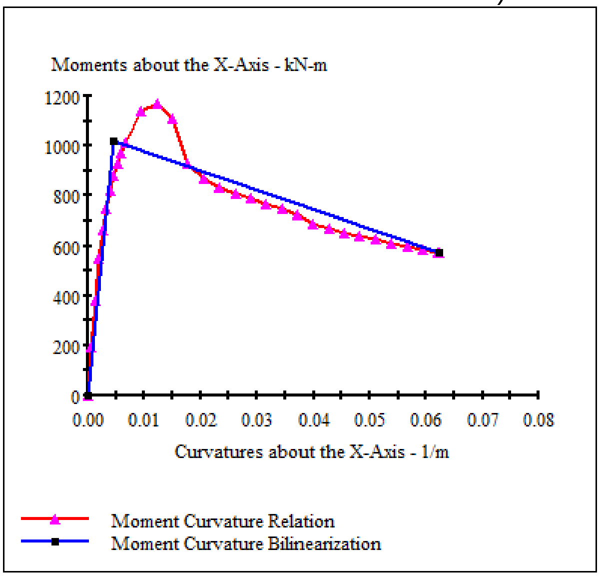
Fig. 2. Column structure deformation



a) Axial load 1000 kN



b) Axial load 2500 kN



c) Axial load 5000 kN

Fig. 3. Curvature-moment relation and curvature-moment bilinearization

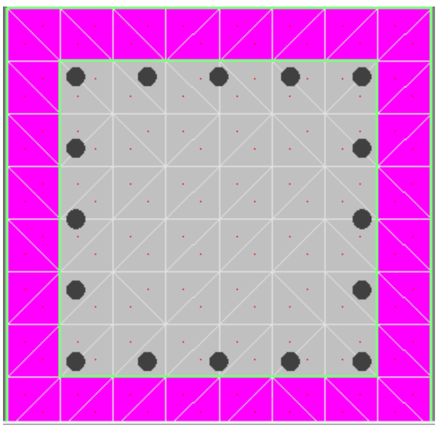
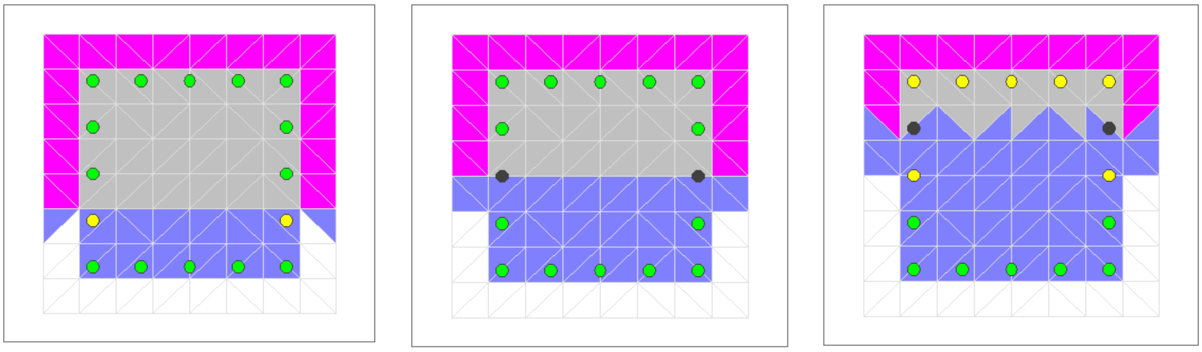
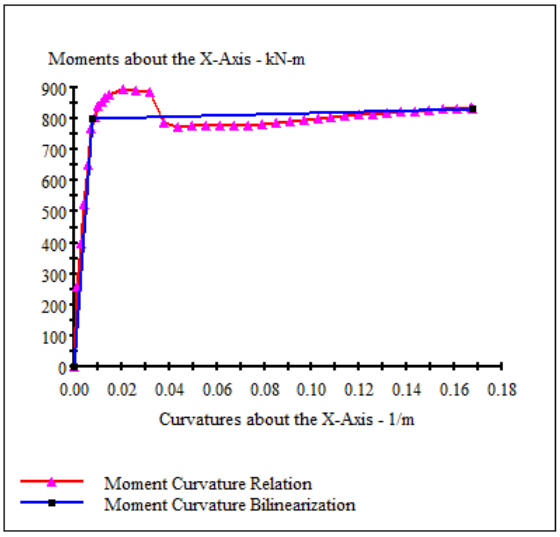


Fig. 4. Modeling of column structure with Tie reinforcement diameter of 14 mm

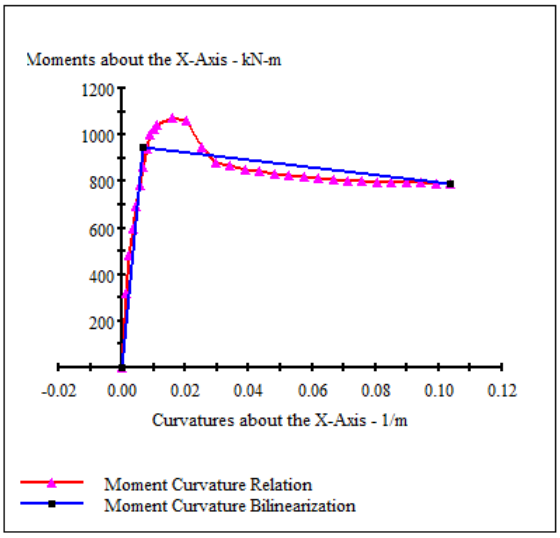


a) Axial load 1000 kN b) Axial load 2500 kN c) Axial load 5000 kN

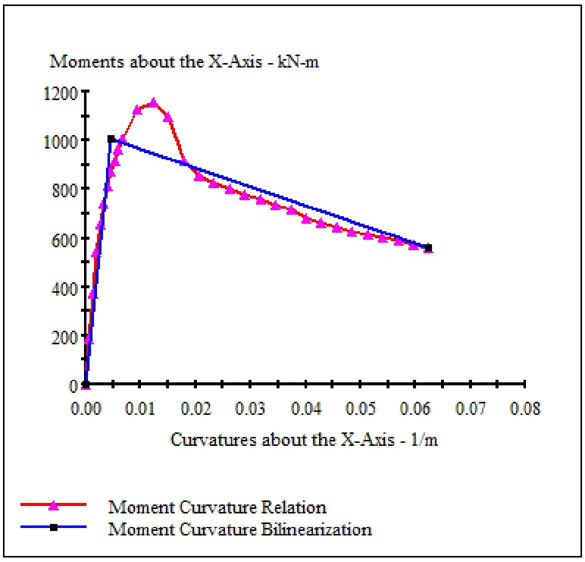
Fig. 5. Column structure deformation



a) Axial load 1000 kN



b) Axial load 2500 kN



c) Axial load 5000 kN

Fig. 6. Curvature-moment relation and curvature-moment bilinearization

3.3 Model 3: Tie Reinforcement Diameter 14 mm

The analysis results for Model 3 show variations in the ductility level of the reinforced concrete column depending on the applied axial load. At an axial load of 1000 kN, the Curvature Ductility value obtained is 22.13, indicating that the column has good ductile capacity. Although the Curvature Ductility value in Model 3 is slightly lower than in Model 1 at the same axial load, it still meets the requirement for full ductility according to the SNI 1726:2019 standard.

At an axial load of 2500 kN, the Curvature Ductility value in Model 3 is 15.45, while at an axial load of 5000 kN, it increases to 13.79. Although there is an increase in the Curvature Ductility value in Model 3 at an axial load of 5000 kN compared to 2500 kN, both are still below the minimum value recommended by the standard, indicating that the column does not achieve full ductility under both load conditions.

The results of modeling the column structure with a 12 mm Tie reinforcement diameter are shown in Figure 7. Column structure deformations for Model 3 can be seen in Figure 8 for all tested axial loads. Furthermore, the curvature-moment relation and curvature-moment bilinearization of the column are displayed in Figure 9 for all axial loads.

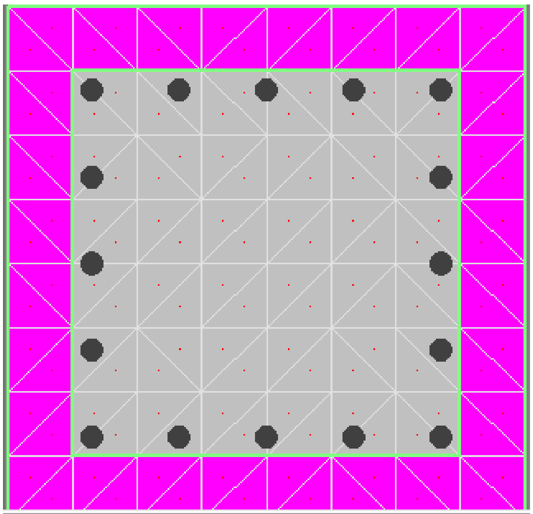
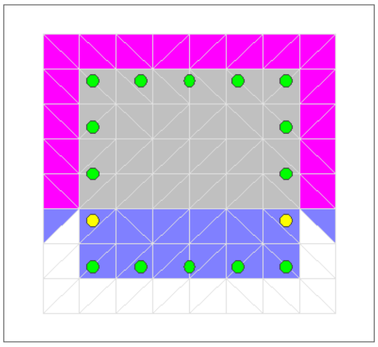
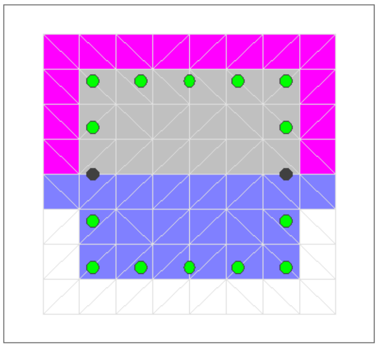


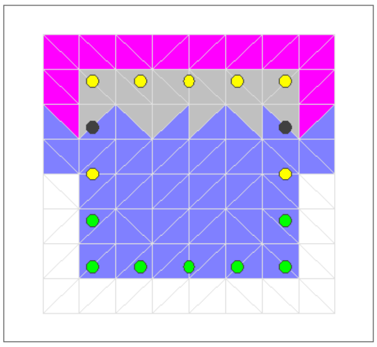
Fig. 7. Modeling of column structure with tie reinforcement diameter of 14 mm



a) Axial load 1000 kN

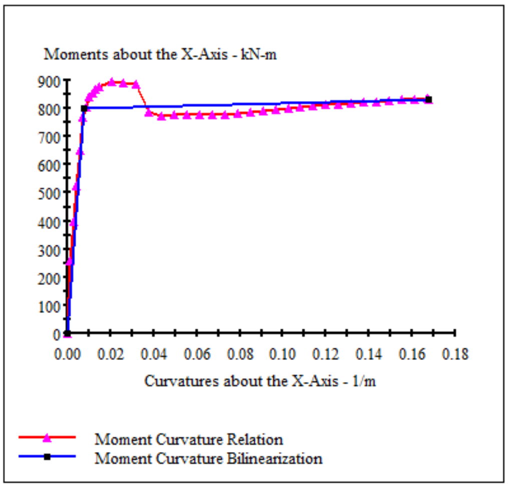


b) Axial load 2500 kN

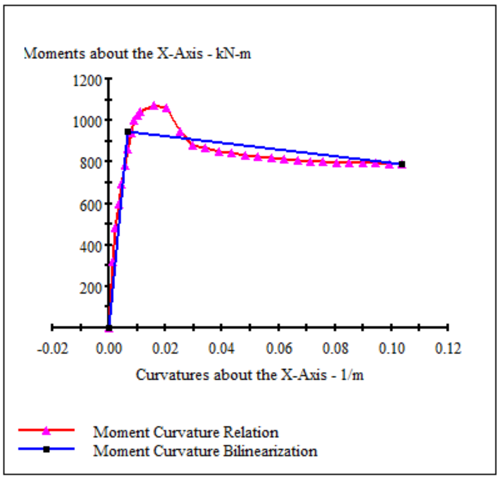


c) Axial load 5000 kN

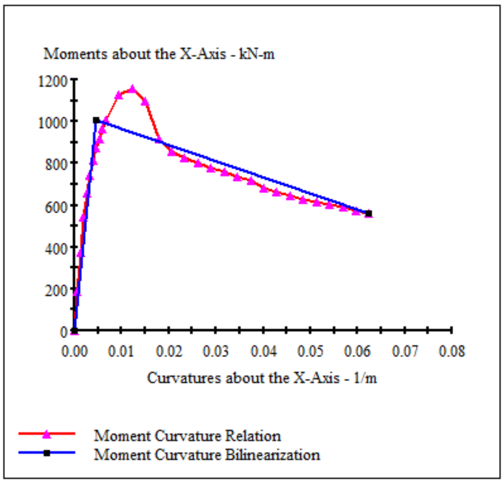
Fig. 8. Column structure deformation



a) Axial load 1000 kN



b) Axial load 2500 kN



c) Axial load 5000 kN

Fig. 9. Curvature-moment relation and curvature-moment bilinearization

4. CONCLUSION

Based on the analysis results of the three models discussed, there are differences in the ductility levels among the models. In terms of percentage differences, it can be seen that Model 1 has a higher ductility level than Model 2 and Model 3 at all tested axial load conditions. The percentage difference in ductility between Model 1 and Model 2 tends to be small, as seen at an axial load of 1000 kN, where the difference is only about 0.08%. However, this difference becomes more significant at higher axial loads, with a percentage difference in ductility between Model 1 and Model 3 reaching around 0.16%. Although there are differences in ductility percentages among the three models, overall, they exhibit a similar pattern of achieving good ductility at lower axial loads but failing to meet the requirements at higher axial loads.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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