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Study on the Ductility Behavior of Reinforced Concrete Columns with 10 mm Shear Reinforcement Diameter under Variable Axial Loads

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A B S T R A C T

Understanding the ductility behavior of reinforced concrete columns is critical for ensuring structural safety in seismic regions, yet there remains limited research on the specific effects of shear reinforcement diameter under varying axial loads. This research investigates the ductility behavior of reinforced concrete columns with a 10 mm shear reinforcement diameter under varying axial loads of 1000 kN, 2500 kN, and 5000 kN. The study aims to understand the effect of shear reinforcement on the ductility of columns and how varying axial loads influence their performance. Numerical modeling was performed using Xtract software, with columns designed to have dimensions of 600 mm x 600 mm (unconfined) and 450 mm x 450 mm (confined). The study focuses on key parameters such as curvature at initial load, curvature at first yield, ultimate curvature, and moment-curvature relationships. The results show that as the axial load increases, the curvature ductility decreases, with the column under 1000 kN demonstrating the highest ductility and the column under 5000 kN showing the lowest. The findings highlight the significant role of shear reinforcement in enhancing the ductility of columns, suggesting that optimal reinforcement design is crucial for ensuring structural resilience under variable loading conditions.

1. Introduction

Reinforced concrete columns are essential structural elements supporting both axial and lateral loads. Their ability to absorb energy and undergo significant deformation without failure, known as ductility, is a critical factor in ensuring the safety and stability of structures, particularly in seismic regions [1], [2]. The behavior of concrete columns under varying loading conditions is affected by multiple factors, such as the properties of the concrete, the reinforcement, and the configuration of the shear reinforcement. Studies have shown that these factors significantly affect the strength and performance of the columns under both static and dynamic loading conditions [3], [4].

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The ductility of reinforced concrete columns is highly dependent on the shear reinforcement provided. Shear reinforcement, typically in the form of stirrups, plays a significant role in enhancing the strength and ductility of columns. However, the effect of varying the diameter of shear reinforcement on the ductility of reinforced concrete columns remains insufficiently explored, especially under different axial loads. Previous studies have indicated that larger diameters of shear reinforcement may improve ductility, but further investigation is needed to understand their full impact [5-7]. In contrast, some studies have pointed out that the optimal configuration of shear reinforcement is still debated, especially under varying axial loads [8], [9].

This research is crucial due to the growing demand for safer and more efficient designs of reinforced concrete columns, especially in earthquake-prone regions. As structures are subject to extreme loading conditions, including high axial and lateral forces, understanding how shear reinforcement influences column performance is crucial for maintaining stability and safety under such conditions [10], [11]. Given the varying performance of columns under different load scenarios, investigating the influence of shear reinforcement diameter on the ductility behavior is critical for improving structural design guidelines and optimizing the use of materials in construction [12-14].

In this study, the key variables analyzed include the diameter of the shear reinforcement (specifically 10 mm), axial load levels (1000 kN, 2500 kN, and 5000 kN), and the effects on the ductility and moment-curvature relationship of reinforced concrete columns. These parameters are crucial for understanding how variations in shear reinforcement impact the overall structural behavior and safety of the column under different load conditions [15-17]. This approach is consistent with previous research that highlighted the importance of shear reinforcement size in enhancing the seismic performance of reinforced concrete columns [18], [19].

Although previous studies have examined the relationship between shear reinforcement and column performance, few have focused specifically on the effect of varying shear reinforcement diameters on ductility under different axial loads [20-22]. This study introduces a novel approach by analyzing columns with 10 mm shear reinforcement under varying axial loads and using advanced structural analysis software [23], [24]. The findings will aid in developing more accurate and efficient design methods for reinforced concrete columns, considering the effect of shear reinforcement size.

The main objective of this research is to investigate the effect of shear reinforcement diameter (specifically 10 mm) on the ductility of reinforced concrete columns subjected to variable axial loads. This study aims to understand the relationship between shear reinforcement size and ductility performance, providing insights that can inform the design of more resilient structural systems [25], [26]. The research also aims to enhance current design practices by offering detailed analysis and recommendations based on the findings [27], [28].

2. Research Method

This research uses a systematic approach method to analyze the ductility behavior of reinforced concrete columns with a focus on the effect of varying shear reinforcement diameters under different axial loads. This section outlines the procedures and techniques employed in this study.

1. Modeling and Simulation
   The study begins with the creation of numerical models for reinforced concrete columns. The columns are modeled using structural analysis software, specifically Xtract, which allows for detailed evaluation of column behavior under different loading conditions. The columns are designed with dimensions of 600 mm x 600 mm for the unconfined region and 450 mm x 450 mm for the confined region. The material properties are assigned based on

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standard values: concrete strength f'c = 30 MPa and steel yield strength fy = 420 MPa [29], [30].

2. Shear Reinforcement Configuration
   The primary focus of the research is on the impact of shear reinforcement on the ductility of the column. For this study, a diameter of 10 mm is selected for the shear reinforcement, with a spacing of 150 mm between the stirrups. The longitudinal reinforcement consists of bars with a diameter of 25 mm. The total reinforcing area for the column is set to 490.9 mm² [31], [32].
3. Axial Load Variations
   Three different axial load levels are applied to the models to simulate various real-world loading conditions: 1000 kN, 2500 kN, and 5000 kN. These loads represent typical scenarios for structural elements in multi-story buildings and are intended to capture the column's performance across a range of load intensities [33], [34].
4. Loading and Displacement Control
   The analysis is performed using displacement control to simulate the column's response under increasing axial loads. The software incrementally applies the axial loads while monitoring the column's behavior, including deformations, moments, and strain distribution [35].
5. Analysis Parameters
   The following key parameters are analyzed during the simulation:
   - Curvature at Initial Load: Measures the initial bending response of the column.
   - Curvature at First Yield: Indicates the curvature at the onset of yielding.
   - Ultimate Curvature: Represents the curvature at ultimate failure.
   - Moment at First Yield and Ultimate Moment: These values correspond to the moments at which the column first yields and the maximum moment before failure.
   - Centroid Strain at Yield and Ultimate: These strains are calculated to evaluate the deformation at the centroid of the column.
   - Energy per Length: This parameter assesses the energy absorption capacity of the column.
   - Effective Yield Curvature and Moment: Measures the effective curvature and moment that the column can sustain under yielding conditions [36], [37].
6. Deformation and Moment-Curvature Relationship
   The deformation of the column under the applied axial loads is observed and analyzed through graphical representations of the curvature-moment relation and curvature-moment bilinearization. These graphs help to understand the ductility capacity of the column and provide insights into the relationship between load and deformation at various stages of loading [38] .
7. Data Interpretation and Comparison
   The results obtained from the analysis are compared across the different axial load levels (1000 kN, 2500 kN, and 5000 kN) to observe how shear reinforcement diameter affects ductility. Key parameters, such as curvature ductility and plastic rotation capacity, are used to evaluate the column's overall performance under each loading condition.

3. Results and Discussions

This section presents the analysis results and discusses the behavior of the reinforced concrete columns with a 10 mm shear reinforcement diameter under varying axial loads (1000 kN, 2500 kN, and 5000 kN). The results are presented in Tables and Figures for each axial load, and a detailed discussion follows each set of results.

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3.1 Section Report

Table 1 provides the key geometric and material properties of the reinforced concrete column, including centroid coordinates, section area, moment of inertia, and reinforcing steel details. These properties are used in the analysis to evaluate the structural behavior of the column under different loading conditions. Table 2 shows the materials used in the column analysis, including confined and unconfined concrete and strain-hardening steel.

Table 1. Section details

Property	Value
X Centroid	-1.031E-16 m
Y Centroid	3.211E-17 m
Section Area	3.600 m²
EI gross about X	3.16E+8 N·m²
EI gross about Y	3.16E+8 N·m²
I trans (Confined1) about X	12.17E-3 m⁴
I trans (Confined1) about Y	12.17E-3 m⁴
Reinforcing Bar Area	7.854E-3 m²
Percent Longitudinal Steel	0.02182
Overall Width	0.6000 m
Overall Height	0.6000 m
Number of Fibers	128
Number of Bars	16
Number of Materials	3

Source : Research Result (2025).

Table 2. Material types and names

Material Type	Name
Confined Concrete	Confined
Unconfined Concrete	Unconfined
Strain Hardening Steel	Steel

Source : Research Result (2025).

3.2 Modeling of Column Structure

Figure 1 illustrates the modeling of the column structure with a shear reinforcement diameter of 10 mm. The materials used in the analysis are shown in Figures 2 to 4. Figure 2 presents the stress-strain curve for confined concrete, which exhibits a maximum stress of approximately 35 MPa at a strain of around 0.003. The curve demonstrates good ductility characteristics, with a gradual reduction in stress after reaching the peak, maintaining around 15 MPa at a strain of 0.020. This indicates that confined concrete has a greater energy absorption capacity before failure. Meanwhile, Figure 3 shows the stress-strain curve for unconfined concrete, which reaches a maximum stress of about 30 MPa at a strain of approximately 0.002. The stress then decreases more rapidly compared to confined concrete, reaching zero at a strain of around 0.006. This behavior highlights the brittle nature of unconfined concrete, which has a more limited deformation capacity. Furthermore, Figure 4 displays the stress-strain curve for reinforcing steel, which exhibits elastic-plastic behavior with a yield point of approximately 400 MPa. The curve then shows a gradual strain hardening phase, reaching a maximum stress of around 600 MPa at a strain of 0.09. This behavior reflects the high ductility of steel, which significantly enhances the column structure's ability to withstand

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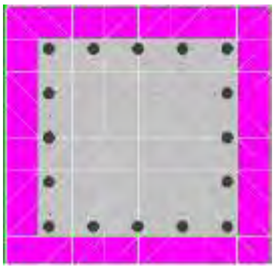
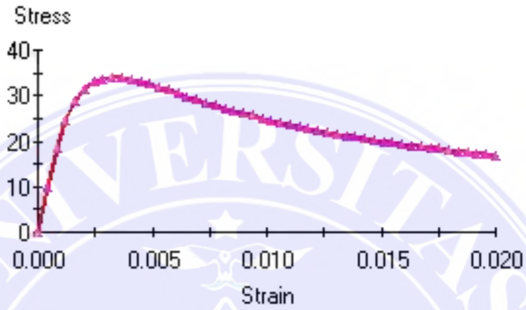
deformation without sudden failure. The modeling of these materials is crucial for analyzing the behavior of reinforced concrete columns under varying axial loads, as the stress-strain characteristics of each material determine the overall deformation capacity and ductility of the structure.



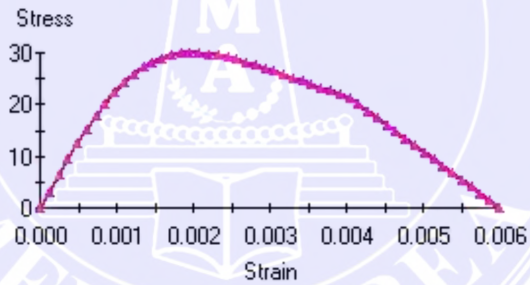
Source : Research Result (2025).

Figure 1. Modeling of the column structure with 10 mm shear reinforcement diameter.



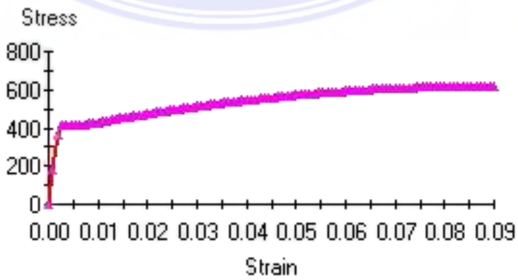
Source : Research Result (2025).

Figure 2. Confined concrete.



Source : Research Result (2025).

Figure 3. Unconfined concrete.



Source : Research Result (2025).

Figure 4. Steel.

3.3 Analysis Results

1. Axial Load 1000 kN

Table 3 presents the analysis results for the column under an axial load of 1000 kN. The column demonstrates good ductility, as indicated by the curvature ductility value of 22.29.

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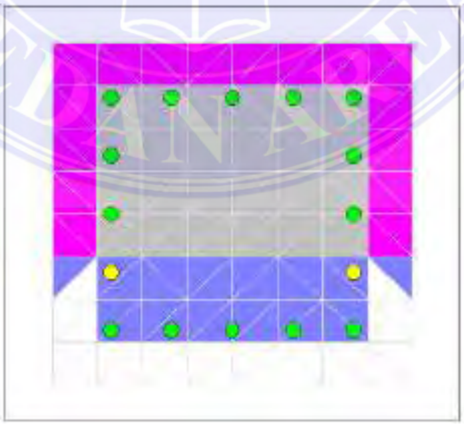
This value indicates a significant ability of the column to deform without failure, which is crucial for structural resilience. Figure 5 illustrates the deformation of the column under 1000 kN axial load, and Figure 6 presents the curvature-moment relation and the bilinearization of the moment-curvature curve for this load.

Table 3. Analysis results for the column under an axial load of 1000 kN

Property	Value
Failing Material	Confined
Failure Strain	20.00E-3 Compression
Curvature at Initial Load	2.3808E-20 1/m
Curvature at First Yield	7.1575E-3 1/m
Ultimate Curvature	0.1678 1/m
Moment at First Yield	772.1 kN·m
Ultimate Moment	845.5 kN·m
Centroid Strain at Yield	6.517E-3 Ten
Centroid Strain at Ultimate	13.56E-3 Ten
N.A. at First Yield	91.06E-3 m
N.A. at Ultimate	80.82E-3 m
Energy per Length	135.9 kN
Effective Yield Curvature	7.5929E-3 1/m
Effective Yield Moment	812.2 kN·m
Over Strength Factor	1.041
Plastic Rotation Capacity	48.093E-3 rad
EI Effective	1.08E+8 N·m²
Yield EI Effective	207.6E+3 N·m²
Bilinear Hardening Slope	0.01925
Curvature Ductility	22.29

Source : *Research Result (2025).*



Source : *Research Result (2025).*

Figure 5. Deformation of the column under 1000 kN axial load.

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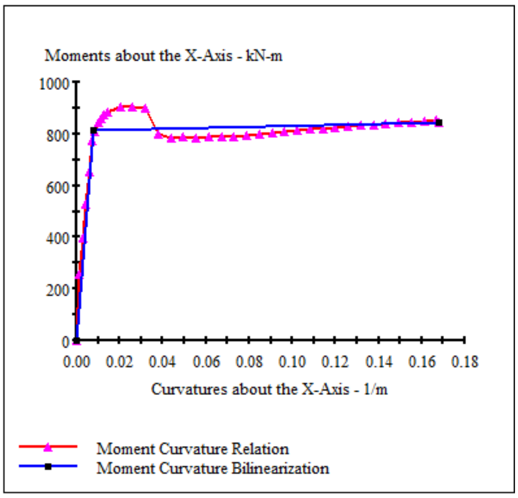

Source : Research Result (2025).

Figure 6. Curvature-moment relation and the bilinearization of the moment-curvature curve.

2. Axial Load 2500 kN

Table 4 shows the results for the column under an axial load of 2500 kN. The curvature ductility decreases to 15.47, indicating that while the column still demonstrates significant ductility, the performance is not as high as under the 1000 kN load. Figure 7 shows the deformation of the column under 2500 kN axial load, and Figure 8 presents the curvature-moment relation and bilinearization for this load.

Table 4. Analysis results for the column under an axial load of 2500 kN

Property	Value
Failing Material	Confined
Failure Strain	20.00E-3 Compression
Curvature at Initial Load	1.274E-20 1/m
Curvature at First Yield	5.595E-3 1/m
Ultimate Curvature	0.1037 1/m
Moment at First Yield	792.1 kN·m
Ultimate Moment	802.0 kN·m
Centroid Strain at Yield	1.288E-3 Ten
Centroid Strain at Ultimate	7.39E-3 Ten
N.A. at First Yield	23.16E-3 m
N.A. at Ultimate	7.12E-3 m
Energy per Length	88.41 kN
Effective Yield Curvature	6.702E-3 1/m
Effective Yield Moment	955.0 kN·m
Over Strength Factor	0.8397
Plastic Rotation Capacity	29.10E-3 rad
EI Effective	1.43E+8 N·m²
Yield EI Effective	1.57E+6 N·m²
Bilinear Hardening Slope	-0.01107
Curvature Ductility	15.47

Source : Research Result (2025).

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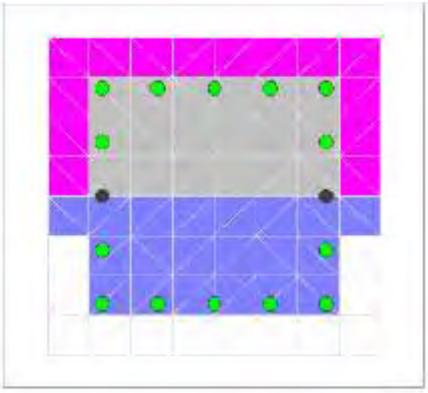
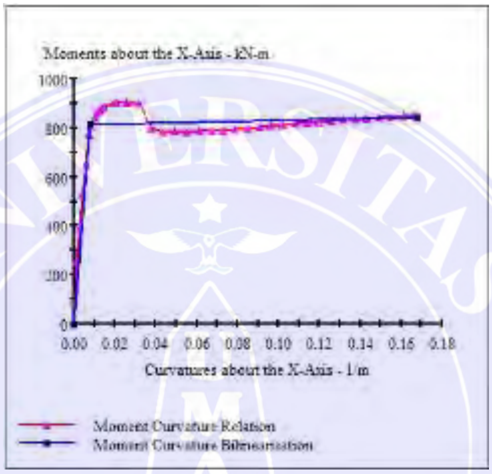


Source : Research Result (2025).

Figure 7. Deformation of the column under 2500 kN axial load.



Source : Research Result (2025).

Figure 8. Curvature-moment relation and the bilinearization of the moment-curvature curve.

3. Axial Load 5000 kN

Table 5 presents the analysis results for the column under an axial load of 5000 kN. At this load, the curvature ductility further decreases to 13.71, indicating a reduction in ductility as the axial load increases. Figure 9 shows the deformation of the column under 5000 kN axial load, and Figure 10 presents the curvature-moment relation and bilinearization for this load.

Table 5. Analysis results for the column under an axial load of 5000 kN

Property	Value
Failing Material	Confined
Failure Strain	20.00E-3 Compression
Curvature at Initial Load	6.875E-19 1/m
Curvature at First Yield	3.334E-3 1/m
Ultimate Curvature	0.6222 1/m
Moment at First Yield	749.1 kN·m
Ultimate Moment	570.3 kN·m
Centroid Strain at Yield	4.83E-3 Comp
Centroid Strain at Ultimate	7.55E-3 Comp
N.A. at First Yield	-1.449 m
N.A. at Ultimate	-1.214 m
Energy per Length	48.17 kN

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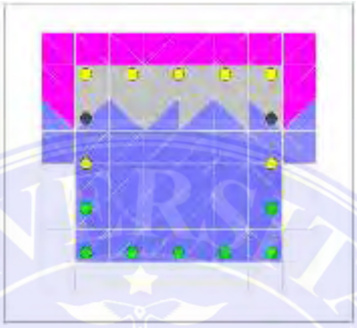
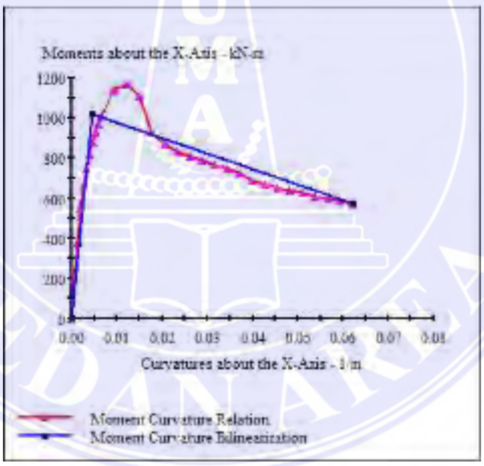
Property	Value
Effective Yield Curvature	4.578E-3 1/m
Effective Yield Moment	1019 kN·m
Over Strength Factor	0.5594
Plastic Rotation Capacity	17.31E-3 rad
EI Effective	2.25E+8 N·m²
Yield EI Effective	-7.786E+6 N·m²
Bilinear Hardening Slope	-0.03466
Curvature Ductility	13.71

Source : Research Result (2025).



Source : Research Result (2025).

Figure 9. Deformation of the column under 5000 kN axial load.



Source : Research Result (2025).

Figure 10. Curvature-moment relation and the bilinearization of the moment-curvature curve.

The results indicate that as the axial load increases, the curvature ductility of the column decreases. This is consistent with expectations, as higher axial loads reduce the capacity of the column to undergo plastic deformations before failure. The analysis confirms that the shear reinforcement diameter significantly influences the column's ductility, with higher values of curvature ductility observed under lower axial loads.

In the context of the SNI 1726:2019 standard, the column under 1000 kN axial load demonstrates adequate ductility, while the column under 2500 kN and 5000 kN axial loads shows a reduction in ductility, falling below the required threshold. This suggests that adjustments to the design or specifications of the column may be necessary to ensure full ductility under various loading conditions.

4. Conclusion and Suggestion

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4.1 Conclusion

The research successfully demonstrated the influence of shear reinforcement diameter on the ductility of reinforced concrete columns under different axial loads. The study revealed that as axial loads increase, the ductility of the columns decreases, with the columns under 1000 kN axial load showing the highest ductility. The analysis confirmed that the 10 mm shear reinforcement diameter significantly enhances the column's ductility, especially under lower axial loads. However, at higher axial loads, the ductility diminishes, indicating that further optimization of shear reinforcement and column design may be required to maintain the desired structural performance.

4.2 Suggestion

Future research could explore the impact of different shear reinforcement diameters and configurations, such as varying the spacing and reinforcement material, on column behavior under seismic loading conditions. It is also recommended to conduct experimental studies to validate the numerical modeling results. Furthermore, further investigations could focus on optimizing column design for higher axial loads while maintaining adequate ductility, ensuring that structural performance meets the requirements of safety standards like SNI 1726:2019.

References

[1] P. P. A. Huy, T. Y. Yuen, C. C. Hung, and K. M. Mosalam, "Seismic behaviour of full-scale lightly reinforced concrete columns under high axial loads," Journal of Building Engineering, vol. 56, p. 104817, 2022.

[2] A. C. Barrera, J. L. Bonet, M. L. Romero, and M. A. Fernández, "Ductility of slender reinforced concrete columns under monotonic flexure and constant axial load," Engineering Structures, vol. 40, pp. 398-412, 2012.

[3] Y. C. Ou and D. P. Kurniawan, "Shear behavior of reinforced concrete columns with high-strength steel and concrete," ACI Structural Journal, vol. 112, no. 1, pp. 35-45, 2015.

[4] R. Eid, K. Kovler, I. David, W. Khoury, and S. Miller, "Behavior and design of high-strength circular reinforced concrete columns subjected to axial compression," Engineering Structures, vol. 173, pp. 472-480, 2018.

[5] L. Jin, S. Zhang, D. Li, H. Xu, X. Du, and Z. Li, "A combined experimental and numerical analysis on the seismic behavior of short reinforced concrete columns with different structural sizes and axial compression ratios," International Journal of Damage Mechanics, vol. 27, no. 9, pp. 1416-1447, 2018.

[6] T. Dirikgil, "Experimental investigation of the effects of concrete strength and axial load ratio on the performances of CFRP-wrapped and externally collared RC short columns," Engineering Structures, vol. 230, p. 111647, 2021.

[7] M. M. El-Attar, H. Z. El-Karmoty, and A. A. EL-Moneim, "The behavior of ultra-high-strength reinforced concrete columns under axial and cyclic lateral loads," HBRC Journal, vol. 12, no. 3, pp. 284-295, 2016.

[8] H. Qi, L. Guo, J. Liu, D. Gan, and S. Zhang, "Axial load behavior and strength of tubed steel reinforced-concrete (SRC) stub columns," Thin-Walled Structures, vol. 49, no. 9, pp. 1141-1150, 2011.

[9] S. D. Adhikary, B. Li, and K. Fujikake, "Strength and behavior in shear of reinforced concrete deep beams under dynamic loading conditions," Nuclear Engineering and

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

Design, vol. 259, pp. 14-28, 2013.

[10] D. Sokoli and W. M. Ghannoum, "High-strength reinforcement in columns under high shear stresses," ACI Structural Journal, vol. 113, no. 3, p. 605, 2016.

[11] X. Cheng, C. Lu, X. Ji, Y. Li, and Y. Song, "Seismic behavior of reinforced concrete slender walls subjected to variable axial loads," Soil Dynamics and Earthquake Engineering, vol. 175, p. 108253, 2023.

[12] K. M. Quang, V. P. Dang, S. W. Han, M. Shin, and K. Lee, "Behavior of high-performance fiber-reinforced cement composite columns subjected to horizontal biaxial and axial loads," Construction and Building Materials, vol. 106, pp. 89-101, 2016.

[13] J. Liu, "Seismic behaviour of reinforced concrete columns," Ph.D. dissertation, 2013.

[14] X. Ji, X. Cheng, and M. Xu, "Coupled axial tension-shear behavior of reinforced concrete walls," Engineering Structures, vol. 167, pp. 132-142, 2018.

[15] H. Tobbi, A. S. Farghaly, and B. Benmokrane, "Behavior of Concentrically Loaded Fiber-Reinforced Polymer Reinforced Concrete Columns with Varying Reinforcement Types and Ratios," ACI Structural Journal, vol. 111, no. 2, 2014.

[16] Y. Z. Murad, "Predictive model for bidirectional shear strength of reinforced concrete columns subjected to biaxial cyclic loading," Engineering Structures, vol. 244, p. 112781, 2021.

[17] X. Su, H. Yang, Q. Liu, X. Wang, and J. Fu, "Experimental study on seismic behavior of reinforced concrete exterior beam-column joints under varying axial load," Engineering Structures, vol. 318, p. 118682, 2024.

[18] X. Li, J. Dai, and M. Deng, "Shear behavior of high ductile fiber reinforced concrete beams," Alexandria Engineering Journal, vol. 60, no. 1, pp. 1665-1675, 2021.

[19] J. C. M. Ho, "Limited ductility design of reinforced concrete columns for tall buildings in low to moderate seismicity regions," The Structural Design of Tall and Special Buildings, vol. 20, no. 1, pp. 102-120, 2011.

[20] L. Sun, Z. Yang, Q. Jin, and W. Yan, "Effect of axial compression ratio on seismic behavior of GFRP reinforced concrete columns," International Journal of Structural Stability and Dynamics, vol. 20, no. 06, p. 2040004, 2020.

[21] M. Shariq, F. Saifi, M. Alam, and S. M. Anas, "Effect of concrete strength on the dynamic behavior of axially loaded reinforced concrete column subjected to close-range explosive loading," Materials Today: Proceedings, vol. 87, pp. 1-8, 2023.

[22] B. Li, E. Siu-Shu Lam, B. Wu, and Y. Y. Wang, "Effect of High Axial Load on Seismic Behavior of Reinforced Concrete Beam-Column Joints with and without Strengthening," ACI Structural Journal, vol. 112, no. 6, 2015.

[23] H. O. Shin, Y. S. Yoon, W. D. Cook, and D. Mitchell, "Axial load response of ultra-high-strength concrete columns and high-strength reinforcement," ACI Structural Journal, vol. 113, no. 2, pp. 325, 2016.

[24] N. Shatarat, H. Katkhuda, and M. Alqam, "Experimental investigation of reinforced concrete beams with spiral reinforcement in shear," Construction and Building Materials, vol. 125, pp. 585-594, 2016.

[25] U. Akguzel and S. Pampanin, "Effects of variation of axial load and bidirectional loading on seismic performance of GFRP retrofitted reinforced concrete exterior beam-column

ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

joints," Journal of Composites for Construction, vol. 14, no. 1, pp. 94-104, 2010.

[26] E. Osorio, J. M. Bairán, and A. R. Marí, "Analytical modeling of reinforced concrete columns subjected to bidirectional shear," Engineering Structures, vol. 138, pp. 458-472, 2017.

[27] C. C. Hung and F. Y. Hu, "Behavior of high-strength concrete slender columns strengthened with steel fibers under concentric axial loading," Construction and Building Materials, vol. 175, pp. 422-433, 2018.

[28] T. R. Mullapudi and A. Ayoub, "Modeling of the seismic behavior of shear-critical reinforced concrete columns," Engineering Structures, vol. 32, no. 11, pp. 3601-3615, 2010.

[29] M. N. Hadi, W. Wang, and M. N. Sheikh, "Axial compressive behaviour of GFRP tube reinforced concrete columns," Construction and Building Materials, vol. 81, pp. 198-207, 2015.

[30] C. Jin, Z. Pan, S. Meng, and Z. Qiao, "Seismic behavior of shear-critical reinforced high-strength concrete columns," Journal of Structural Engineering, vol. 141, no. 8, p. 04014198, 2015.

[31] T. Dirikgil and O. Atas, "Experimental investigation of the performance of diagonal reinforcement and CFRP strengthened RC short columns," Composite Structures, vol. 223, p. 110984, 2019.

[32] M. S. Abdulraheem, "Experimental investigation of fire effects on ductility and stiffness of reinforced reactive powder concrete columns under axial compression," Journal of Building Engineering, vol. 20, pp. 750-761, 2018.

[33] W. C. Choi and H. D. Yun, "Compressive behavior of reinforced concrete columns with recycled aggregate under uniaxial loading," Engineering Structures, vol. 41, pp. 285-293, 2012.

[34] W. Zhu, J. Jia, J. Gao, and F. Zhang, "Experimental study on steel reinforced high-strength concrete columns under cyclic lateral force and constant axial load," Engineering Structures, vol. 125, pp. 191-204, 2016.

[35] K. Murugan and A. K. Sengupta, "Seismic performance of strengthened reinforced concrete columns," Structures, vol. 27, pp. 487-505, Oct. 2020.

[36] S. S. Roudsari, S. A. Hamoush, S. M. Soleimani, and R. Madandoust, "Evaluation of large-size reinforced concrete columns strengthened for axial load using fiber reinforced polymers," Engineering Structures, vol. 178, pp. 680-693, 2019.

[37] J. Shayanfar and H. Akbarzadeh Bengar, "Nonlinear analysis of RC frames considering shear behaviour of members under varying axial load," Bulletin of Earthquake Engineering, vol. 15, pp. 2055-2078, 2017.

[38] Q. Shi, L. Ma, Q. Wang, B. Wang, and K. Yang, "Seismic performance of square concrete columns reinforced with grade 600 MPa longitudinal and transverse reinforcement steel under high axial load," Structures, vol. 32, pp. 1955-1970, Aug. 2021.