

Numerical Analysis of CFRP Partially Confined Square Reinforced Concrete Column under Eccentric Loading

Maroua Hafi, Nasr-Eddine Chikh*, Salah Eddine Bensebti

Laboratory of Materials and Construction Durability, University Frères Mentouri Constantine 1, Algeria

Received May 7, 2025; Revised October 23, 2025; Accepted November 20, 2025

Cite This Paper in the Following Citation Styles

(a): [1] Maroua Hafi, Nasr-Eddine Chikh, Salah Eddine Bensebti, "Numerical Analysis of CFRP Partially Confined Square Reinforced Concrete Column under Eccentric Loading," *Civil Engineering and Architecture*, Vol. 14, No. 1, pp. 106 - 117, 2026. DOI: 10.13189/cea.2026.140108.

(b): Maroua Hafi, Nasr-Eddine Chikh, Salah Eddine Bensebti (2026). *Numerical Analysis of CFRP Partially Confined Square Reinforced Concrete Column under Eccentric Loading*. *Civil Engineering and Architecture*, 14(1), 106 - 117. DOI: 10.13189/cea.2026.140108.

Copyright©2026 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract The use of fiber reinforced polymers (FRP) jackets as an external technique to strengthen existing reinforced concrete (RC) columns has become increasingly popular in recent years, resulting in very promising results. Existing research, primarily focused on columns fully wrapped with FRP jackets, has demonstrated that FRP strengthening considerably affects both their strength and ductility. However, the current focus has transitioned towards partial confinement, which is more cost-effective as it requires less FRP and adhesive, and is also simple and quick to implement on-site. Using the finite element program ATENA GID 3D, a 3D finite element model of a CFRP partially confined square reinforced concrete column subjected to eccentric loading has been created for this investigation. The numerical models were validated through comparison with the results from a subsequent experimental study. To investigate the effects of confinement configurations, slenderness ratio, strengthening ratio, concrete strength, and load eccentricity on column behavior, parametric research was conducted. The results indicated that an increase in load eccentricity leads to a considerable decrease in the load-bearing capacity of columns, while the mid-height horizontal displacements remain unaffected by eccentricity. The effectiveness of partial confinement decreases as the concrete grade rises. An increase in the slenderness ratio results in a significant reduction in their ultimate load-bearing capacity, accompanied by an enhancement in the lateral ductility of the columns. Concerning the strengthening ratio, an optimal value is found between 3

and 5 confining layers, which helps to minimize material waste and reduce costs. The best performance regarding ultimate load and lateral ductility ratio is attained by both configurations featuring small distributed wraps and a single large central wrap, which also necessitate the least amount of labor cost.

Keywords RC Columns, Partial Confinement, CFRP, Numerical Analysis, Load Eccentricity, Load-Carrying Capacity, Lateral Displacement

1. Introduction

For reinforcing existing reinforced concrete (RC) columns, Fiber Reinforced Polymer (FRP) has become the material of choice over the last two decades, primarily due to its various advantages over traditional methods. FRP strengthening has a significant effect on both strength and ductility, according to existing research, which mostly focuses on columns completely wrapped with FRP jackets. The numerous experimental investigations carried out on FRP confined RC columns subjected to eccentric loadings have indicated that their load-carrying capacity and ductility are influenced by several factors, including load eccentricity, column slenderness, strengthening ratio, type of FRP, and concrete grade, among others [1-12]. Numerical modeling is a valuable approach for predicting test results and saving material and human resources for laboratory experiments. In this context, many researchers

have used software based on the Finite Element Method (FEM) to model FRP-confined RC columns, thereby achieving a comprehensive understanding of the factors that affect their investigations [13–21]. Balla et al. [13] tested axially loaded RC columns with hybrid NSM-EBR reinforcement and validated their 3D modeling results using ABAQUS software. The impact of column size and the ratio of EB to NSM reinforcement on the effectiveness of hybrid FRP strengthening was also investigated through parametric research. A series of RC columns were used by Alrayes et al. [14] to investigate the impact of internal steel stirrup spacing and CFRP confinement. Excellent agreement was found when comparing the experimental results with numerical models using ATENA 3D software. CFRP confinement significantly increased the strength and ductility of the columns. These results demonstrate that the strength of the concrete, the confinement system itself, the cross-sectional shape of the column, the presence of transverse stirrups, and the orientation of the composite fibers all affect the effectiveness of FRP confinement. In their research, Chellapandian et al. [15] studied hybrid reinforcement and confinement techniques (NSM and EBR) for RC columns, employing 3D modeling with ABAQUS software. The findings showed that hybrid reinforcement technique significantly improved the stiffness, strength, and ductility of columns when subjected to both eccentric and axial compression. Zeng et al. [16] established a reliable 3D F.E. model of a partially FRP-confined circular column. An accurate plastic-damage model for concrete subjected to multiaxial compression is used in the suggested FE method. The proposed FE approach's accuracy was confirmed by comparing the test results with the numerical results. A better understanding of the confinement mechanics of partially FRP-confined concrete columns was then obtained by presenting numerical data. In their research, Fossetti et al. [17] developed a simplified analytical model to calculate the performance of RC columns confined with FRP in terms of strength, ductility, and energy dissipation, with validation provided by a subsequent experimental study. This allowed a simulation of a wide range of numerical outcomes derived from F.E. modeling using ATENA-3D software. The performance of the improved model was verified by comparison with other

confinement models available in the literature. The proposed model overcame the shortcomings of previous models and provided a simplified approach for estimating strength, ductility, and energy absorption capacity. Angga et al. [18] used SALOME platform [19] to develop 3D models for circular RC columns fully confined with CFRP wraps and eccentrically loaded. The analysis outcomes from the 3D-NLFEA, in terms of axial load as a function of the mid-height lateral displacement, show good agreement with existing experimental data. The 3D-NLFEA results revealed an intriguing detail about the negative consequences of confinement in the outer concrete area. This adverse effect is attributed to a notable difference in concrete dilatation rates between the inner and outer core regions. In the compressed concrete sections at the elastic stages, there is a noticeable concentration of lateral modulus at the hoops. Following the yielding of the steel, this concentration of lateral modulus dissipates, which can be linked to the negative confinement effect. Using ABAQUS software, Khan et al. [20] carried out a numerical modeling of RC columns strengthened with CFRP under axial loading. Various techniques for partial and full confinement were considered to evaluate the effectiveness of CFRP strengthening on the load-bearing capacity of the columns, as well as the impact of longitudinal reinforcement bars on their behavior. The numerical simulation using ATENA 3D software showed a strong correlation with experimental results. The findings indicated that CFRP reinforcement significantly enhances the load-bearing capacity of the columns. A cylindrical specimen representing a short column was modeled using Ansys environment by Sureshkumar et al. [21]. Under axial compression, they numerically analyzed concrete columns that were completely wrapped in different composite materials. The findings included assessments of stress variations, ultimate load capacity, percentage reductions in deformation, percentage increases in load, and the behaviour of the different wrapping materials. Furthermore, a cost analysis of the wrapping materials, based on the maximum allowable working load and material expenses, indicated that CFRP is the most cost-effective and efficient option compared to the other materials evaluated.

Most of the previous numerical investigations into the structural performance of loaded RC columns strengthened with FRP have primarily considered full confinement. However, the current focus has moved towards partial confinement, which offers practical benefits over full wrapping. Because it requires less FRP and adhesive and can be quickly and easily implemented on-site, partial wrapping is more economical. Partial confinement of FRP strips could be an efficient and economical solution for RC columns that are in need of a moderate enhancement in strength and ductility. To understand the effects of critical factors on the performance of partial confinement, simulations are essential. The present work examines the case of square RC columns strengthened partially with CFRP wraps under eccentric loading. The numerical models, developed with ATENA GID 3D software, are based on the experimental data from Mai et al. [9].

2. Configuration of the Tested Columns

The above-mentioned experimental study examined the structural behavior of CFRP-strengthened RC columns under load increases that were monotonic until failure. Four columns with a 20 mm concrete cover, each measuring 800 mm in height (h) and $150 \times 150 \text{ mm}^2$ in square cross-section (axa), were examined. Four longitudinal HA 12mm bars were used to reinforce the columns, which were fixed at their base, and transverse $\text{Ø}6$ mm ties spaced 80 mm apart, each with a 20 mm concrete cover, as illustrated in Figure 1. The concrete used has a characteristic strength (f_c) of 36 MPa at 28 days. The Young's modulus of the longitudinal and transverse reinforcement bars is 173 GPa and 182 GPa, respectively, as shown in Table 1. The loading eccentricity (e) varies from 0 to 25 mm. Table 2 displays the characteristics of CFRP, whereas Figure 1 depicts the specifics of the CFRP confinement. Several results presented in terms of the load-displacement diagram and observed failure mode demonstrate clearly that the use of external CFRP

confinement on the columns increases their strength and ductility.

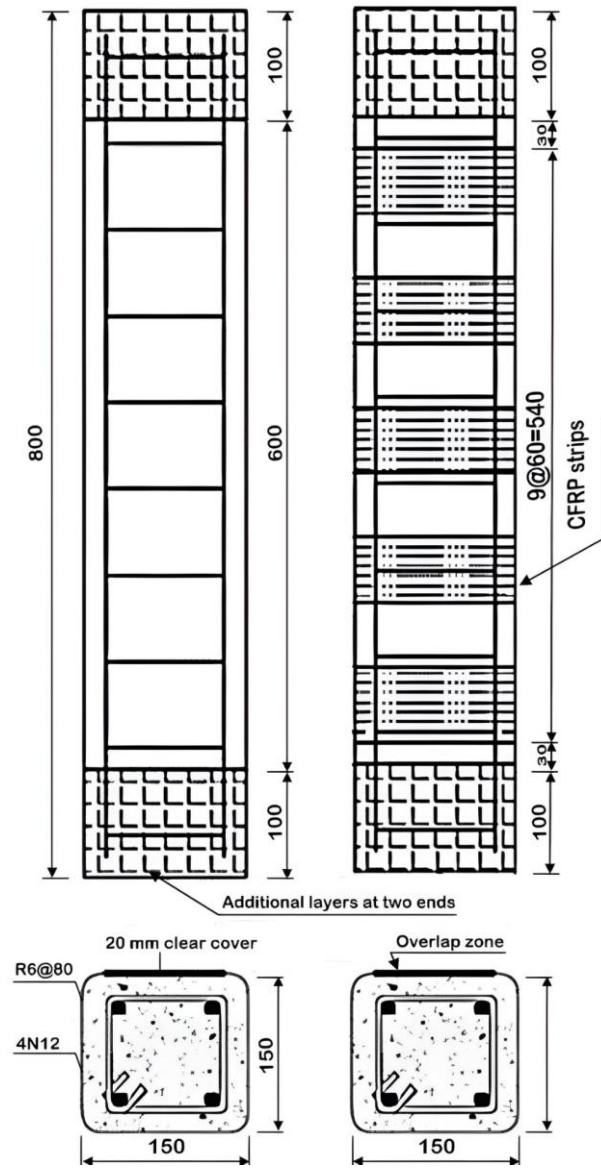


Figure 1. Details of RC specimens

Table 1. Mechanical properties of steel bars

Reinforcement	Diameter (mm)	Average tensile strength f_y (MPa)	The average tensile strain ϵ_y (%)	The tensile modulus of elasticity E (GPa)
Longitudinal	12	568	0.327	173
Transverse	6	517	0.284	182

Table 2. Mechanical properties of a CFRP layer

Material	Number of layers	Nominal thickness (mm)	Width (mm)	Ultimate tensile strength (MPa)	Strain at ultimate tensile strength (%)	Young's modulus (GPa)
Carbon fiber	1	0,167	22,75	3726	1.55	240.43

3. Modeling Parameters

ATENA GID 3D is specialized software in civil engineering for the numerical modeling of various construction problems providing highly satisfactory results in the nonlinear analysis of structural elements. It utilizes the finite element method during solution procedures and the updated Lagrangian formulation to determine the deformed shape of the elements. The numerical modelling was conducted for four RC columns considering the following parameters: types of confinement (none, partial), load eccentricity 'e' with respectively 0 and 25 mm values.

The partial confinement was achieved through 3 CFRP layers with the characteristics shown in Table 2. The model for these columns features a fixed base, with two steel loading plates simulated at the top and the bottom. A monotonic increasing load was applied to the upper plate, considering the eccentricities defined above. ATENA provides default material behavior laws that simulate the real behavior of materials [22]. The concrete behavior law in tension and compression is shown in Figure 2. A bilinear law with hardening (Figure 3) represents the behavior of steel and a linear law (Figure 4) represents the behavior of the CFRP composite in tension.

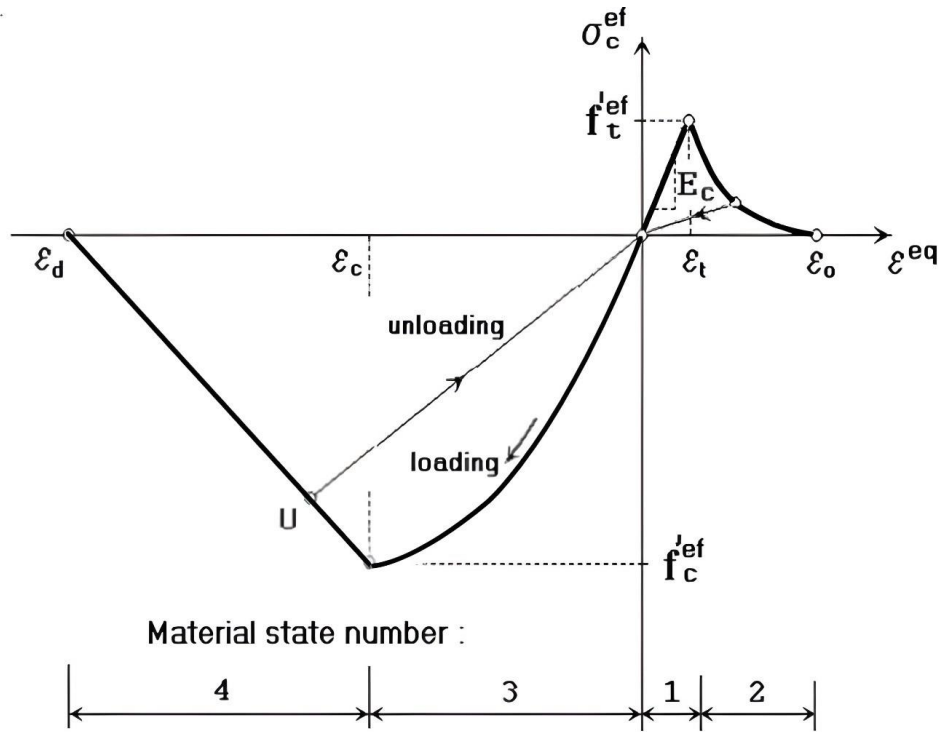


Figure 2. Concrete behavior law

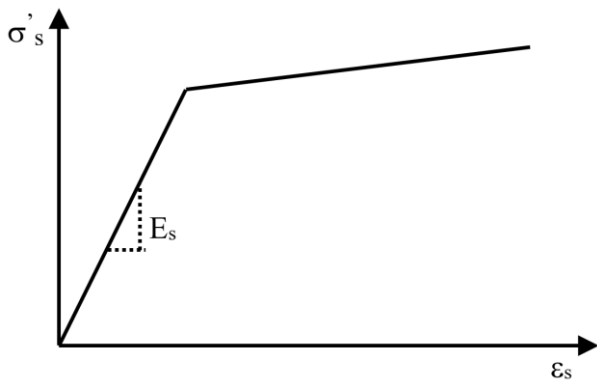


Figure 3. The bilinear behavior law of steel with strain hardening

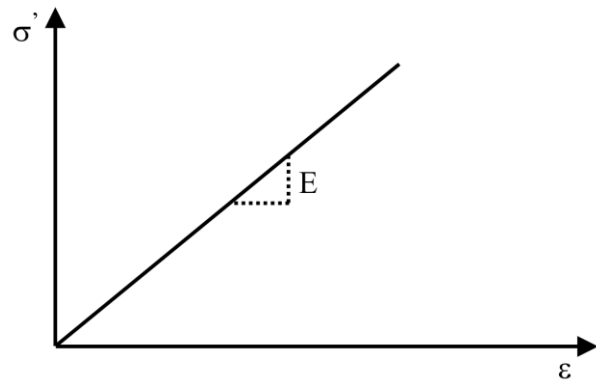


Figure 4. The linear behavior law of carbon fiber-reinforced polymer

Each material is represented by an appropriate definition, with all 3D elements modeled as closed volumes with six surfaces and eight nodes, except for the CFRP, which is represented as surfaces. The content of Figure 5 depicts the concrete column, the partial CFRP wrapping, the reinforcement bars and the partially confined RC column. The modeling of each element is specified in the framework of ATENA. The concrete is modeled with the 3D combined fracture–plastic material model referred to as 'CC3DNonlinCementitious2'. The loading steel plates are represented as 3D volumes named 'CC3DElastIsotropic'. The reinforcement is represented by a 1D element called 'CCReinforcement', while the FRP is modeled as 2D surfaces using an element identified as 'CCCombinedMaterial'. The resin was neglected due to the absence of its properties in the validation reference [9], but it was assumed that the column and the FRP were in perfect contact. The contact surface between two separate elements, such as between the column and the plates, is called 'fixed contact for surfaces'. The column is assumed to be the 'master' element, and the plates are considered 'slave' elements. The static monotonic loading is applied until failure with an imposed displacement of 0.0001 m at the loading point. Meshing is a crucial stage in numerical modeling because only by choosing the right mesh type can prediction accuracy be increased. The mesh convergence investigation was completed, and an optimum mesh size of 0.05 m was selected.

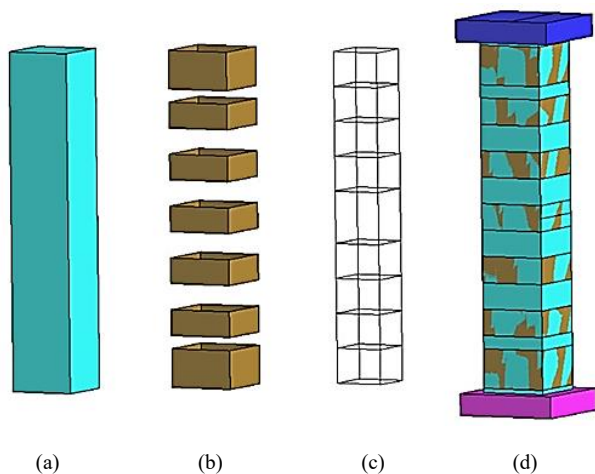


Figure 5. Modelling of: (a) concrete column, (b) partial CFRP wrapping, (c) reinforcing bars, and (d) partially confined RC column

4. Numerical Validation

4.1. Ultimate Load and Lateral Displacements

The experimental and numerical results are presented in Table 3, which illustrates the ultimate load (P_u) and

corresponding lateral displacement (Δ_{Pu}) for non-confined and partially confined columns, considering different eccentricities of the loading (e). The numerical results show consistency with experimental results in terms of the maximum load under eccentric loading and, to some degree, the related lateral displacements.

The axial load capacity and ductility of columns are improved when partial CFRP strips are bonded to the column surface. As seen in Figure 6, the CFRP strips prevent lateral deformations brought on by the axial loading, which confines the concrete core and delays concrete rupture. This increases the column's ultimate load and ultimate lateral displacement. A typical bilinear trend with a transition zone is displayed by partially constrained columns. All specimens exhibited a comparable linear ascending portion of the load–lateral displacement response, which is controlled by the stiffness of the unconfined concrete. Given the extremely low lateral strains in the compressed concrete, this suggests that no confinement is activated in the CFRP wraps. Once the ultimate load is reached, the unconfined RC columns exhibit a sharp decline in strength and stiffness. As the compressed concrete expands, a nonlinear transition takes place in partially reinforced RC columns, resulting in greater lateral strains. In response, the CFRP wrap creates a confining effect on the compressed concrete core, increasing its load-bearing capacity. In the post-peak behavior, the load progressively drops until failure, exhibiting a declining response.

The experimental and numerical curves show a reasonable degree of agreement, according to the validation results shown in Figure 6. In particular, the initial stiffness, peak loads and to a lesser extent associated lateral displacements are all accurately predicted by the FE model, along with the transition zone and the descending response observed in the post-peak behavior.

4.2. Failure Modes

Figure 7 illustrates how a partially confined RC column fails under eccentric loading. It exhibits both compressive and tensile cracks, with the high compression side of the column experiencing spalling of the non-wrapped concrete cover. There was no evidence of delamination in the CFRP reinforcement layers, which exhibit signs of tension represented by red areas in the compressed zone. The numerical failure shows good agreement compared to that from the experimental work.

In light of the previous findings, it may be concluded that the numerical results provided using ATENA GID 3D software demonstrate a good correlation regarding ultimate loads, corresponding lateral displacements and failure modes when compared to experimental data.

Table 3. Validation of ultimate load/lateral displacement results

Confinement	Experimental / numerical results						
	e=0			e=25 mm			
	Pu (kN)	Variation	ΔPu (mm)	Pu (kN)	Variation	ΔPu (mm)	Variation
None	993.5/993.5	0%	- / 0.11	630.2/631.0	-0.12%	2.52/2.30	+8.73%
Partial	1114.2/1114,3	0%	- / 0.12	684.9/697.9	-1.90%	3.42/2.56	25.14%

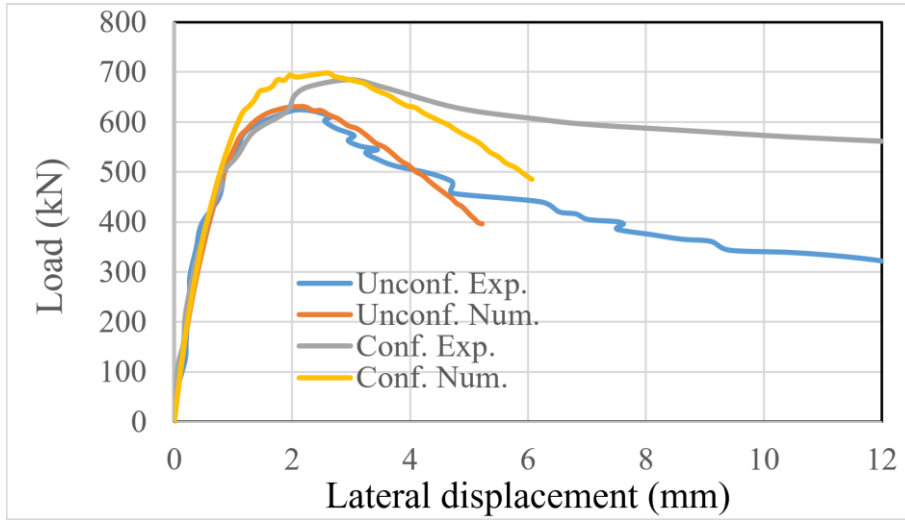


Figure 6. Experimental versus numerical load-lateral displacement curves

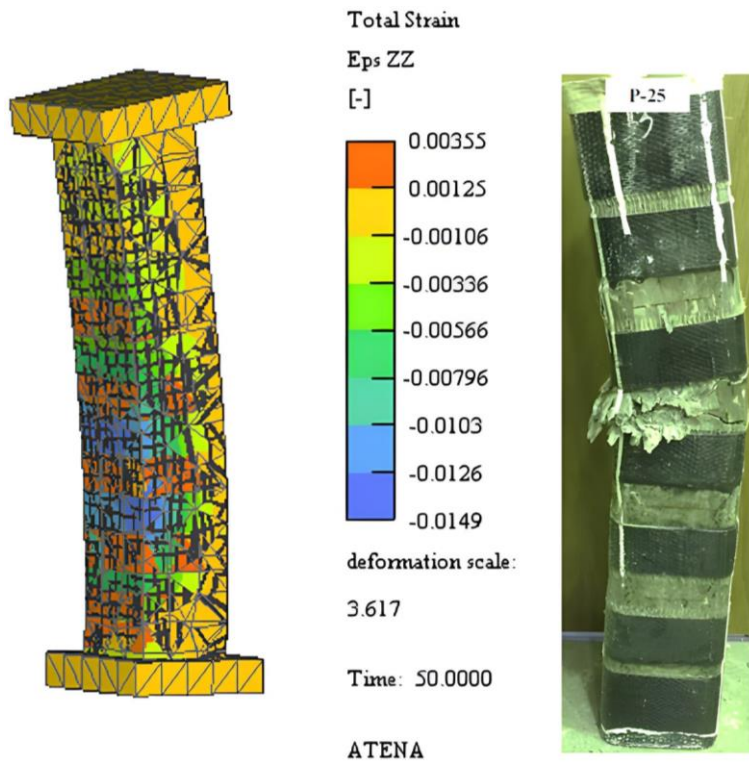


Figure 7. Failure Mode of CFRP partially confined column

5. Parametric Study

A parametric analysis of RC columns partially confined by CFRP strips was carried out following the calibration of the F.E. models using test data, as seen in Figure 2. They have the following basic characteristics: a concrete strength (f_c) of 33.7 MPa, a load eccentricity (e) of 25 mm, a partial CFRP confinement of 7 strips each with 3 layers (L), and a square cross-section ($a \times a$) of $150 \times 150 \text{ mm}^2$ with a height (h) of 800 mm. Investigations on the effects of changing load eccentricity, concrete strength, column slenderness, strengthening ratio, and partial confinement configurations were conducted in order to comprehend the significance of each of these characteristics. The focus was on the ultimate carrying capacity and the columns' lateral deformations at mid-height, which were brought on by both the initial and second-order moments. The lateral ductility (μ), which is the ratio of ultimate lateral deformation (δ_u) to yield lateral deformation (δ_y), was evaluated in the same way as Balla et al. [13]. The idealized bilinear load-deformation behavior shown in Figure 8 is thought to determine the yield deformation corresponding to the limit of elastic behavior. The yield deformation is associated with the extended linear component of the load-displacement curve and is represented by the horizontal line from the peak load. The ultimate deformation is the distortion caused by a 30% reduction in the ultimate load.

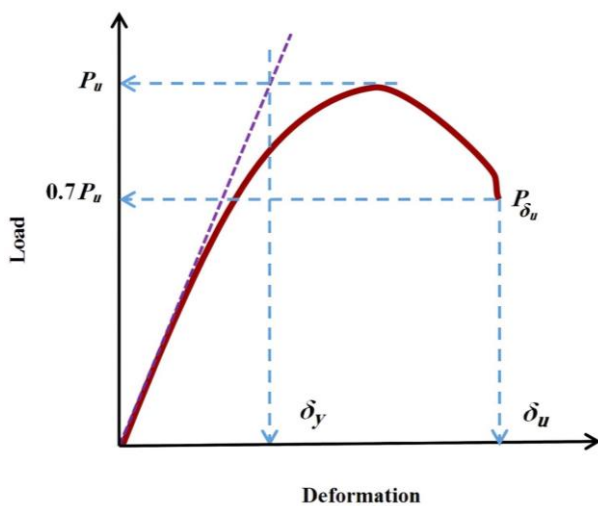


Figure 8. Ultimate and yield displacements in the load deformation curve

5.1. Effect of Load Eccentricity

Variations in the e/a ratio, which is the ratio of the load eccentricity (e) to the column width (a), are taken into consideration in order to examine the impact of load eccentricity on CFRP partially confined RC columns. Figure 9 illustrates how the load capacity of the columns

drops as the e/a ratio rises from 0 to 0.36. Therefore, as concrete works best under compression, increasing eccentricity causes the compressed section of RC columns to decrease. As a result, columns' ability to support loads at high eccentricity is significantly reduced.

It is observed that the curves regarding small eccentricities, such as e/a ratios of 0.1 and 0.16, have two branches: a branch that increases until it reaches the maximum load and then decreases till it fails. In contrast, for larger eccentricities (e/a ratios of 0.3 and 0.36), the load/lateral displacement curves show an increasing branch and a second branch that tends to become almost constant. Xing et al. [10] reported similar findings. In addition, the mid-height lateral displacements remain alike for all eccentricity ratios considered (0.1 to 0.36). Comparable experimental observations were reported in [1]. According to Angga [18], this can be readily comprehended as the failure mode shifts from being primarily governed by axial compression to one that is influenced by bending.

5.2. Effect of Concrete Strength

Concrete strengths ranging from 10 to 100 MPa were taken into consideration in order to examine the impact of the concrete compression strength. Concrete grades $f_c/2$, f_c , $2f_c$, and $3f_c$ were taken into consideration, with a concrete strength f_c value of 33.7 MPa. The ultimate load carrying-capacity of partially restricted RC columns increases approximately linearly with increasing concrete strength, as Figure 10 clearly illustrates.

The strength gain is defined as the ratio of the confined column's ultimate load to that of the unconfined column. Figure 11 displays variations in strength gain for partially confined RC columns with increasing concrete strength. This gain exhibited a nearly exponential decline with rising concrete compressive strength, f_c . The strength gain is more pronounced for low-strength concrete; however, as the concrete reaches higher strength levels, the rate of strength gain diminishes, becoming smaller for concrete with a compressive strength exceeding 70 MPa. This implies that low-strength concrete elements, which are commonly encountered in older concrete buildings, the partial CFRP strengthening approach would be best suited for them.

5.3. Effect of Column Slenderness

Figure 12 shows the load/midheight lateral displacement curves of four partially confined RC columns with the same FRP thickness (3 layers) and load eccentricity ($e/a=0.16$) but different height/side ratios (h/a). Their overall height varied from 80, 160, 240 to 320 cm, giving a height/side ratio (h/a) of 5.33, 10.66, 16 and 21.33, respectively.

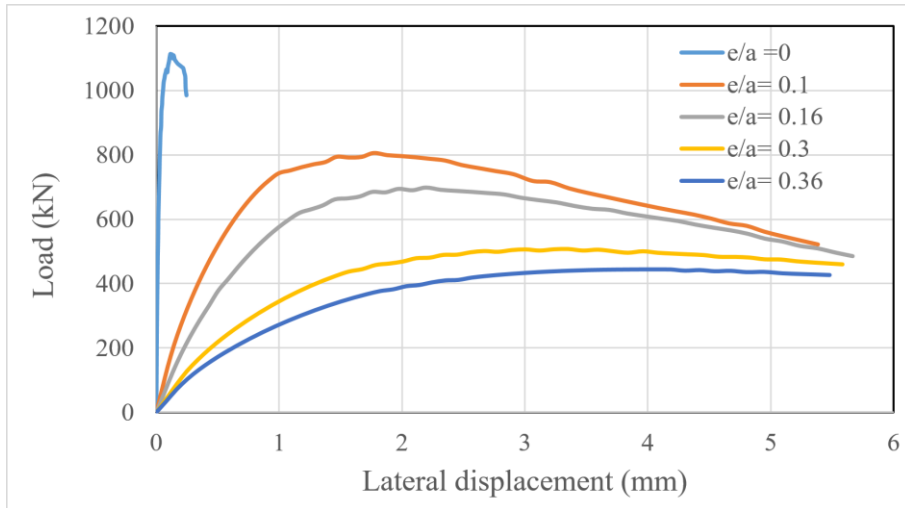


Figure 9. Effect of load eccentricity on load/mid-height lateral displacement

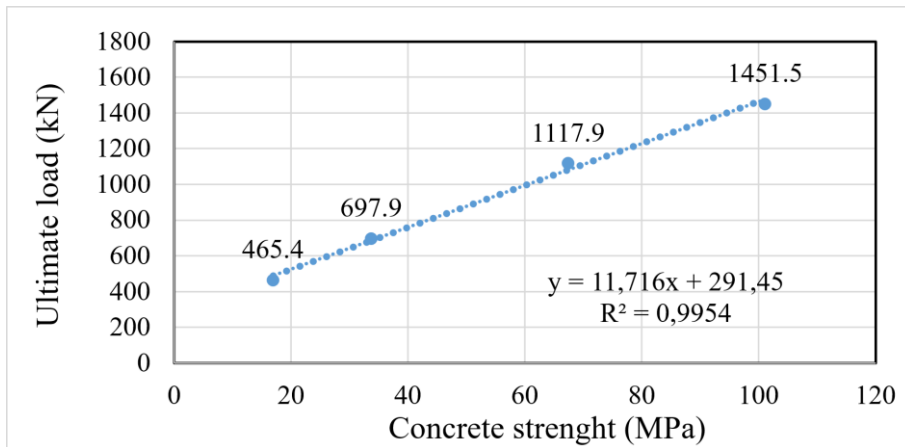


Figure 10. Effect of concrete strength on ultimate load

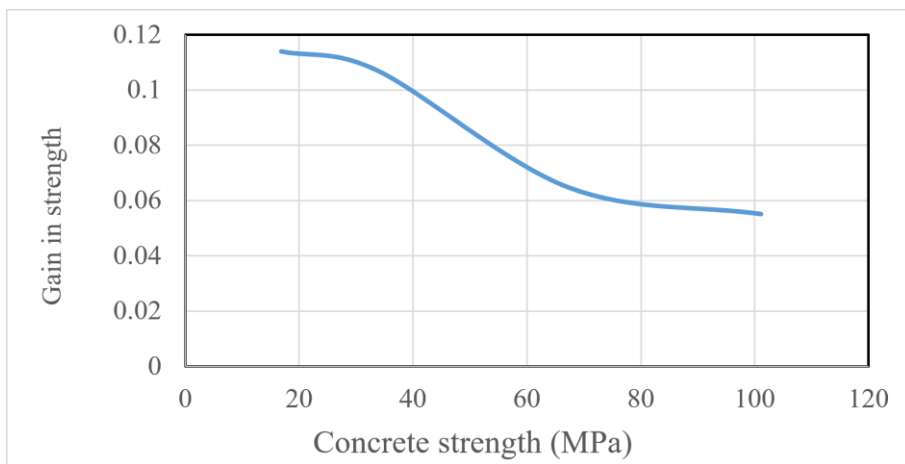


Figure 11. Relationship between the gain strength and the concrete strength

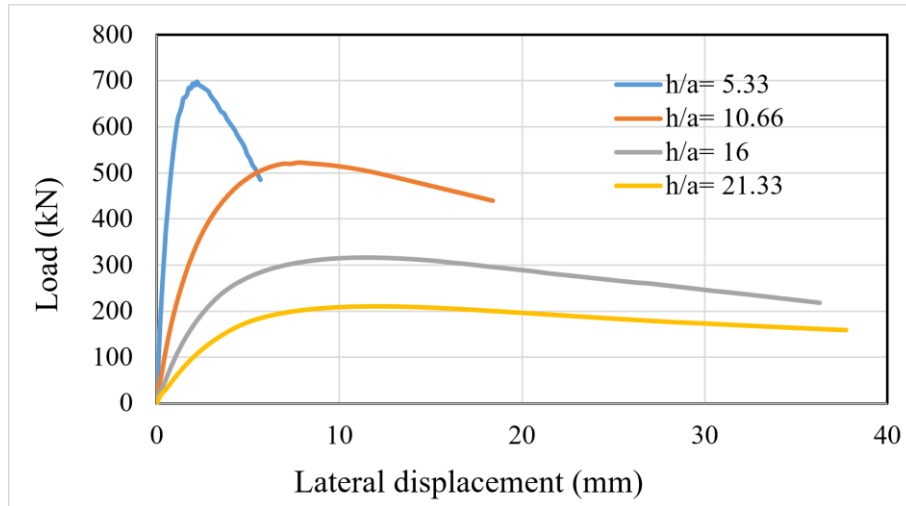


Figure 12. Effect of slenderness on load-midheight lateral displacement

It is evident that increasing slenderness causes the ultimate axial load to decrease while also increasing the lateral displacement at mid-height. Columns with greater slenderness experience a slightly slower rate of load decline in the post-peak range. With the increase in slenderness from 5.33, 10.66, 16 and 21.33, the maximum load drops by 25.12%, 54.6% and 69.8%, respectively. Whereas, the lateral displacement is significantly increased, as displayed by Figure 12. This latter behavior may be attributed to the activation of CFRP confinement that starts at lower loads for higher slenderness ratios, which leads to a notable improvement in the column's lateral ductility and therefore reduces the risk of early buckling failure. Additionally, FRP wrapping can delay the damage in the compression zone and buckling in longitudinal reinforcement [23]. Thus, the increase in slenderness for CFRP partially confined RC columns under eccentric loading results in a notable rise in their lateral displacement at mid-height and a considerable loss in their ultimate load-carrying capacity.

5.4. Effect of CFRP Strengthening Ratio

The volume of the confining CFRP sheets divided by the volume of the column is known as the strengthening ratio, or ρ_f . Its influence was investigated by considering ρ_f with values of 0.00416, 0.0125, 0.0208, 0.0291 and 0.0375 corresponding to 1L, 3L, 5L, 7L and 9L, respectively. The strength increase compared to the unconfined column, as displayed in Figure 13, is about 3.3%, 10.6%, 15.32%, 19.16% and 20.50% for 1L, 3L, 5L, 7L and 9 layers, respectively. It is evident that the difference in the increasing rate declines as ρ_f rises. Nevertheless, the percentage gains in strength from 1L to 3L, from 3L to 5L, from 5L to 7L, and from 7L to 9L are approximately 7%, 4.2%, 3.3%, and 1.2%, respectively. This indicates that raising the strengthening ratio beyond a certain range will not enhance the load-bearing capacity of the columns. Consequently, it is recommended to use

an optimal number of confining layers, specifically between 3L and 5L, to minimize material waste and reduce costs. A similar finding was reported by Chellapandian et al. [15], indicating that increasing the number of confinement layers beyond 4L did not substantially increase strength in axial or eccentric compression as a result of the CFRP wraps' decreased lateral confining pressure.

5.5. Effect of Partial Confinement Configuration

More configurations that are different were considered to assess their impact on the structural response of columns. All the configurations illustrated in Figure 14 have the same strengthening ratio ($\rho_f=0.0125$) and confined area (62.5%). For the first three configurations, confinement was provided through 10, 7 and 3 CFRP strips representing respectively the cases of smaller, average and larger distributed wraps. Regarding configuration 4, two equal wraps located at the top and the bottom of the column produced strengthening. Whereas for configuration 5, only the central area of the column was entirely confined with a single large wrap.

Referring to Figure 15, all configurations exhibit a bilinear behavior, an ascending branch followed by a descending branch. All configurations display a significant plastic phase, with the exception of configuration 4, which demonstrates a nearly brittle failure ($P_u=667.5$ kN, $\mu=4.5$) similar to that of the unconfined column, despite a considerable overall confined area of 62.5%. Thus, configuration 4 highlights the critical role of CFRP wraps in the mid-height region. The best performance regarding ultimate load and ductility ratio is achieved by both configuration 1 ($P_u=709.3$ kN, $\mu=11.33$) and configuration 5 ($P_u=708.8$ kN, $\mu=12.5$), which also requires the lowest labour cost. The performance of partial FRP wrapping shown in configuration 5 is in accordance with the wrapping scheme proposed by Lin et al. [24]. This scheme involves applying a greater number of FRP sheets in the

central zone, with a gradual reduction of FRP materials towards the ends. Tests conducted experimentally to evaluate the effectiveness of several wrapping schemes

showed that the suggested wrapping strategy makes better use of FRP materials along a column's height, increasing the material's strength and ductility.

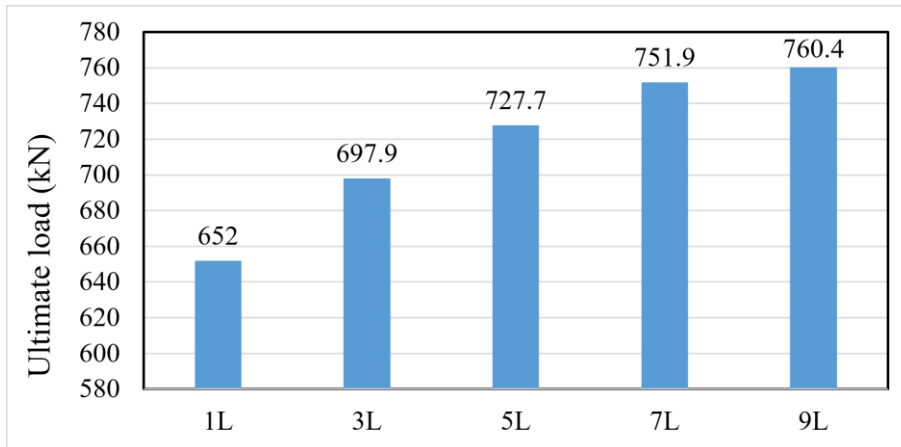


Figure 13. Effect of strengthening ratio on ultimate load

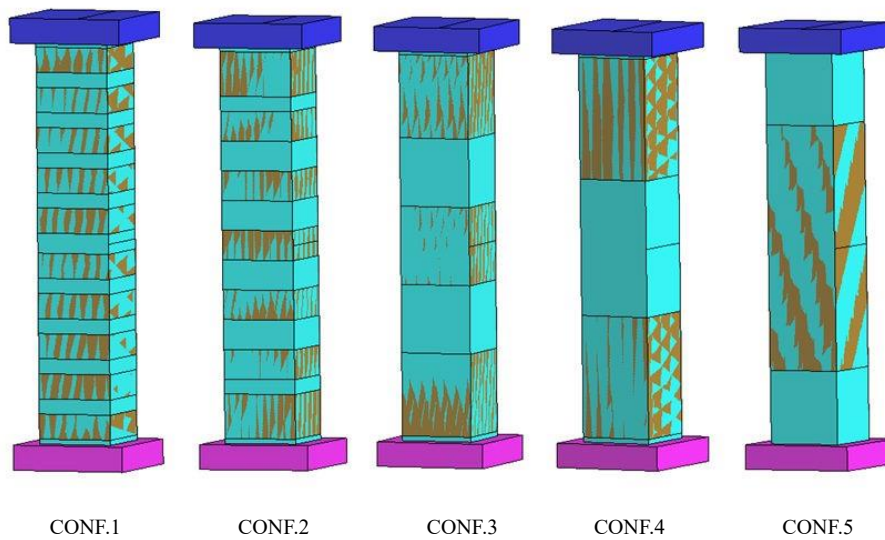


Figure 14. Various confinement configurations

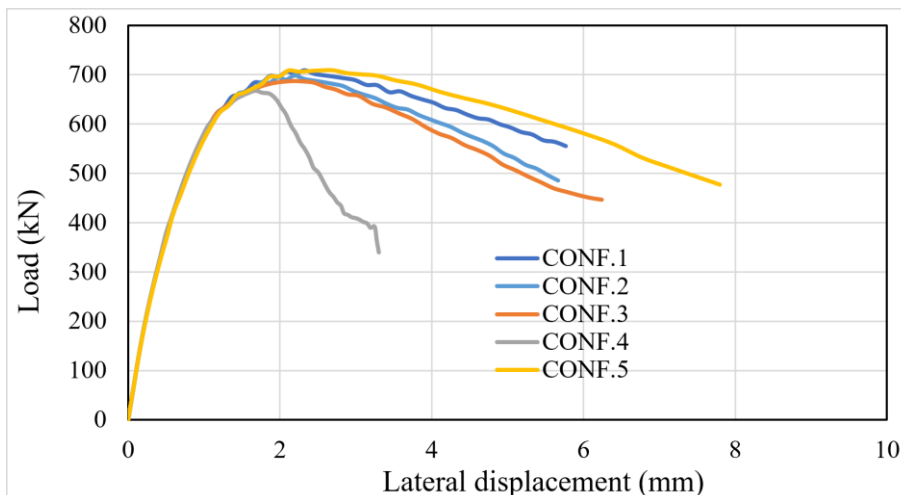


Figure 15. Effect of confinement configurations on load-midheight lateral displacement

6. Conclusions

To understand the behavior of square RC columns partially confined with CFRP and exposed to eccentric loads, a numerical study was conducted. ATENA GID 3D software was used to create a nonlinear finite element model, which was then verified against experimental findings. A parametric investigation was then conducted using this calibrated finite element model to examine the impact of various variables on load-bearing capacity and lateral displacements at mid-height. The following are the main conclusions drawn from this study's findings:

- There is a good correlation between experimental results and those derived from modeling using ATENA GID 3D software.
- The load-bearing capacity of columns is significantly reduced when load eccentricity increases. However, due to partial wrapping, mid-height horizontal displacements stay constant and are not impacted by eccentricity.
- The strength gain is more pronounced in low-strength concrete elements, with a reduction in strength gain observed as the concrete's strength rises.
- The ultimate load-bearing capacity noticeably decreases as the slenderness ratio rises, along with a significant rise in lateral displacements at mid-height. This occurrence improves the lateral ductility of the column.
- It may be advisable to recommend an optimum range of confining layers, specifically between 3 and 5 layers, to minimize material waste and lower expenses.
- The best performance regarding ultimate load and ductility ratio is achieved by both configuration 1 (small distributed wraps) and the surprising configuration 5 (one large central wrap), which additionally require the least labour cost.

REFERENCES

- [1] M.N.S. Hadi. "The behaviour of FRP wrapped HSC columns under different eccentric loads", *Composite Structures*, Vol. 78, No. 4, pp. 560–566, 2007.
- [2] P. Sadeghian, A.R. Rahai, M.R. Ehsani. "Experimental Study of Rectangular RC Columns Strengthened with CFRP Composites under Eccentric Loading", *Journal of Composites for Construction*, Vol. 14, No. 4, pp. 443–450, 2010.
- [3] L. Bisby, M. Ranger. "Axial–flexural interaction in circular FRP-confined reinforced concrete columns", *Construction and Building Materials*, Vol. 24, No. 9, pp. 1672–1681, 2010.
- [4] W. T. Trapko, M. Musia. "The effectiveness of CFRP materials strengthening of eccentrically compressed reinforced concrete columns", *Archives of Civil and Mechanical Engineering*, Vol. 11, No. 1, pp. 249–262, 2011.
- [5] B. Csuka and L. P. Kollár. "Analysis of FRP confined columns under eccentric loading", *Composite Structures*, Vol. 94, No. 3, pp. 1106–1116, 2012.
- [6] S. Xiaobin, G. Xianglin, L. Yupeng, C. Tao, Z. Weiping. "Mechanical Behavior of FRP-Strengthened Concrete Columns Subjected to Concentric and Eccentric Compression Loading", *Journal of Composites for Construction*, Vol. 17, No. 3, pp. 336–346, 2013.
- [7] A. Parvin, D. Brighton. "FRP Composites Strengthening of Concrete Columns under Various Loading Conditions", *Polymers*, Vol. 6, No. 4, pp. 1040–1056, 2014.
- [8] V.M. Hassan, O.A. Hodhod, M.S. Hilal, H.M. Bahnasaway. "Behavior of eccentrically loaded high strength concrete columns jacketed with FRP laminates", *Construction and Building Materials*, Vol. 138, pp. 508–527, 2017.
- [9] A.D. Mai, M.N. Sheikh, M.N.S. Hadi. "Investigation on the behaviour of partial wrapping in comparison with full wrapping of square RC columns under different loading conditions", *Construction and Building Materials*, Vol. 168, pp. 153–168, 2018.
- [10] L. Xing, G. Lin, J. F. Chen. "Behavior of FRP-Confined Circular RC Columns under Eccentric Compression", *Journal of Composites for Construction*, Vol. 24, No. 4, 2020.
- [11] W. Janwaen, J.A.O. Barros, I.G. Costa. "New hybrid FRP strengthening technique for rectangular RC columns subjected to eccentric compressive loading", *Journal of Composites for Construction*, Vol. 24, No. 5, 2020.
- [12] M. Abid, H.F. Isleem, M. K. Shah, S. Zeb. "Analytical Review on Eccentric Axial Compression Behavior of Short and Slender Circular RC Columns Strengthened Using CFRP", *Polymers*, Vol. 13, No. 16, p. 2763, 2021.
- [13] T.M.R. Balla, S.S. Prakash, A. Rajagopal. "Role of size on the compression behaviour of hybrid FRP strengthened square RC columns – Experimental and finite element studies", *Composite Structures*, Vol. 303, p. 116314, 2023.
- [14] O. Alrayes, S. Käseberg. "Modelling of circular concrete columns with CFRP sheets under monotonic loads by ATENA-3D", *Forecast Engineering: Global Climate change and the challenge for built environment*, Germany, 2014.
- [15] M. Chellapandian, S.S. Prakash, A. Rajagopal. "Analytical and finite element studies on hybrid FRP strengthened RC column elements under axial and eccentric compression", *Composite Structures*, Vol. 184, pp. 234–248, 2018.
- [16] J. Zeng, G. Yongchang, L. Lijuan, C. Weipeng. "Behavior and Three-Dimensional Finite Element Modeling of Circular Concrete Columns Partially Wrapped with FRP Strips", *Polymers*, Vol. 10, No. 3, p. 253, 2018.
- [17] M. Fossetti, A.F. Siciliano, F. Basone, G. Minafo. "Numerical Calibration of a Simplified Model for FRP Confinement of Columns", *Springer Nature Singapore Pte Ltd.*, Vol. 20, pp. 269–290, 2019.
- [18] B.C. Angga, P. Bambang, F. Faimunb, A. Pujo. "Finite element modeling of circular reinforced concrete column

- confined with CFRP under eccentric loading”, *Journal of Civil Engineering*, Vol. 34, No. 2, pp. 49-54, 2019.
- [19] The Open-Source Integration Platform for Numerical Simulation (2017) from <http://www.salome-platform.org>.
- [20] A.U.R. Khan, R. Nasir, S. Fareed. “Simulation of Reinforced Concrete Columns Strengthened with CFRP Wraps”, *International Journal of Civil Engineering*, Vol. 21, No. 44, pp. 299–313, 2023.
- [21] A. Sureshkumar, A. Antu, F. H. Kabeer, A.L. Gouri, P.E. Kavitha. “Selection of Optimum Fiber Reinforced Plastic Wrapping for Structural Columns”, *Architecture Structures and Construction*, Vol. 2, No. 1, pp. 247-255, 2022.
- [22] V. Červenka, L. Jendele, J. Červenka. *ATENA Program Documentation Part 1: Theory*, Prague, 2021.
- [23] R. Sause, K.A. Harries, S.L. Walkup, S. Pessiki, J.M. Ricles. “Flexural behavior of concrete columns retrofitted with carbon fiber-reinforced polymer jackets”, *ACI Structural Journal*, Vol. 101, pp. 708–716, 2004.
- [24] S. Lin, Y.G. Zhao, J. Li. “An improved wrapping scheme of axially loaded fiber-reinforced polymer confined concrete columns”, *Composite Structures*, Vol. 226, p. 111242, 2019.