Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Slenderness effect on the behavior of composite RC columns under eccentric loads

Zaynab S. Mohammed[*], **Bassman R. Muhammad**, **Ali S. Resheq**

Civil Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
[*] Corresponding author Email: zaynabsabah20@gmail.com,

HIGHLIGHTS

- 12 RC slender columns casted, six of them have a structural steel channel imbedded inside the cross section.
- The columns tested up to failure. The variables were the eccentricities and the slenderness ratios.
- Good strengthening ratios have been obtained for ultimate load capacity, lateral defamation and energy absorption.

ARTICLE INFO

Handling editor: Imzahim A. Alwan

Keywords:
Reinforced concrete columns
Eccentric loading
Slenderness effect
Composite cross sections
Stability analysis

ABSTRACT

The structural performance of reinforced concrete (RC) columns plays a pivotal role in ensuring the safety and stability of buildings and infrastructure. In structural engineering, the quest for optimizing the design and behavior of RC columns has been a persistent pursuit. This research is focused on the columns having a "large" height that the secondary bending moments induced will affect the behavior of the RC column element. Therefore, one critical aspect that has garnered considerable attention is the influence of slenderness on the behavior of these columns, particularly when subjected to eccentric loading. As structures become taller and larger, slenderness is valuable to meet the demands of modern architectural design and urbanization, and understanding how slenderness affects the response of composite RC columns becomes increasingly vital. This study is focused on the strength of composite RC slender columns under eccentric loading. As such, it aims to contribute valuable insights to structural engineering, ultimately enhancing our ability to design resilient and efficient structural systems in a world where tall and slender buildings continue to shape our urban landscapes. Due to its numerous benefits, the concrete-steel composite column with a partially enclosed or full steel section encasement is currently more attractive to people than the reinforced concrete column. Strengthening RC columns by steel channel cross-section embedded in the column will contribute to the column stiffness for ultimate strength capacity and decrease the lateral deformation. Twelve RC columns were tested under eccentric loading, a rectangular cross-section of (150×200) mm. Six have a steel structural channel embedded in the cross-section, while the rest of the RC columns have the same cross-section properties but without a steel channel inside. The improvement in column capacity was (65 to 74)% for columns under moderate eccentricity axial loading and (35 to 50)% for columns under large eccentricity axial loading. Also, the improvement in column stiffness for the lateral deflection was (142 to 69)% for columns under moderate eccentricity axial loading and 84% to 87% for columns under large eccentricity axial loading.

1. Introduction

When the column cross-section dimension is small compared to column height, the induced bending moment is significantly increased, and the column is susceptible to "large" lateral deflection. This introduces an extra secondary moment ($M_{sec} = P_u\ \delta$), which should be accounted for during column design. The load-bearing capacity of the column is typically diminished by the slenderness of the column. Failure to account for this would result in the column experiencing an abrupt collapse and ultimately failing catastrophically, as shown in Figure 1 [1]. In civil engineering, the evolution of structural systems has been pivotal in shaping the built environment to accommodate the burgeoning demands of modern society [2]. Among the myriad structural elements, reinforced concrete slender columns with embedded steel sections stand as quintessential components in the construction of tall buildings, bridges, and infrastructure projects [3]. The amalgamation of

http://doi.org/10.30684/etj.2024.147078.1702
Received 20 February 2024; Received in revised form 31 March 2024; Accepted 03 April 2024; Available online 02 June 2024
2412-0758/University of Technology-Iraq, Baghdad, Iraq

concrete's compressive strength with steel's tensile prowess has revolutionized the design and construction of high-rise structures, enabling engineers to achieve unparalleled heights while ensuring structural stability and safety [4].

Figure 1: Collapse and failing of slender columns; Slenderness Effects for Concrete Columns in Sway Frame- Moment Magnification Method (CSA A23.3-19) [1]

Reinforced concrete slender columns fortified with embedded steel sections epitomize the synergy between two formidable construction materials: concrete and steel [5]. This amalgamation capitalizes on the inherent strengths of each material, offering a holistic approach to structural design that optimizes compressive and tensile capacities. Concrete, renowned for its exceptional compressive strength and durability, is the primary load-bearing component in slender columns, efficiently withstanding vertical loads and resisting deformation under compressive forces [6]. However, concrete's inherent brittleness and limited tensile strength necessitate reinforcement to enhance structural performance, particularly in slender column configurations subjected to significant bending moments and lateral loads. Steel is an indispensable ally in this regard, providing robust tensile strength and ductility to counteract the tensile stresses induced by lateral deflection and eccentric loading. By embedding steel sections within reinforced concrete columns, engineers bolster structural integrity, mitigate the risk of premature failure, and ensure the longevity of critical infrastructure assets [7].

Incorporating steel sections within reinforced concrete columns augments load-bearing capacity enhances structural resilience, and facilitates the realization of ambitious architectural visions [8]. The synergistic interaction between concrete and steel fosters a composite structural system that surpasses the capabilities of individual materials, enabling engineers to push the boundaries of design innovation and construct monumental edifices that define skylines worldwide [9]. Composite columns are an exceptionally efficient load-bearing system; compared to reinforced concrete or steel columns, composite columns of significantly reduced dimensions can still provide the same load-bearing capacity [10]. Utilizing composite columns in multi-story or high-rise structures can significantly save the usable floor area [10].

The evolution of civil engineering structures in the contemporary era reflects the dynamic interplay between technological advancements, societal needs, and environmental imperatives. From towering skyscrapers that punctuate urban landscapes to expansive bridges that span vast waterways, modern civil engineering endeavors epitomize the relentless pursuit of innovation, sustainability, and resilience [11]. One of the defining characteristics of contemporary civil engineering structures is their ability to transcend conventional limitations and embrace cutting-edge methodologies and materials [12]. The advent of computational design tools, such as Building Information Modeling (BIM) and finite element analysis, has revolutionized the design process, enabling engineers to optimize structural performance, streamline construction workflows, and minimize material waste [13].

Furthermore, the proliferation of innovative construction techniques, such as prefabrication, modular construction, and 3D printing, has catalyzed efficiency gains, accelerated project delivery timelines, and unlocked new realms of design freedom. These advancements have reshaped the architectural landscape and democratized access to construction methodologies, empowering communities to address pressing societal challenges, including housing affordability, infrastructure resilience, and disaster recovery [14]. In essence, the development of civil engineering structures in the contemporary era is emblematic of humanity's boundless ingenuity, unwavering resilience, and collective aspiration to build a better world. As we navigate the complexities of the 21st century, civil engineers stand at the forefront of innovation, harnessing technology, sustainability, and collaboration to forge a sustainable future where infrastructure catalyzes progress and prosperity [15].

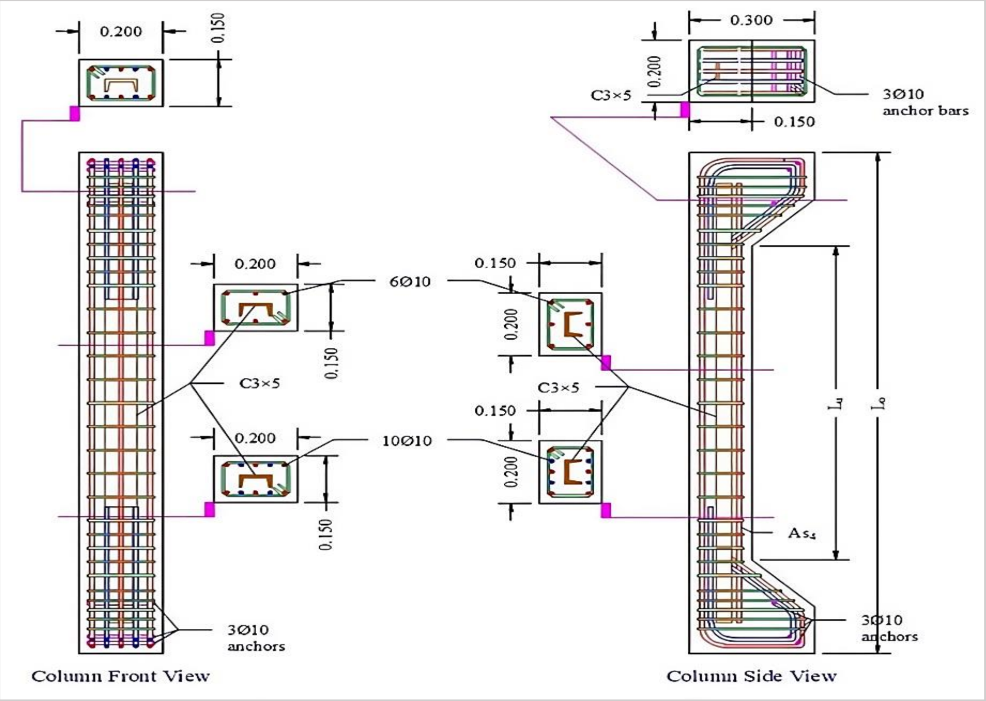
In recent years, research efforts have increasingly focused on understanding the behavior of composite reinforced concrete (RC) columns subjected to eccentric loads, with particular attention to the influence of slenderness. However, despite significant strides in this field, there remain gaps in comprehensively addressing the nuanced effects of varying slenderness ratios on the structural response of these columns. This study seeks to fill some of these voids by examining the slenderness effect on the behavior of composite RC columns, aiming to provide valuable insights into their performance under eccentric loading conditions. Through meticulous analysis and experimentation, this research contributes to advancing design guidelines and strategies for more resilient and efficient structural systems.

2. Experimental work

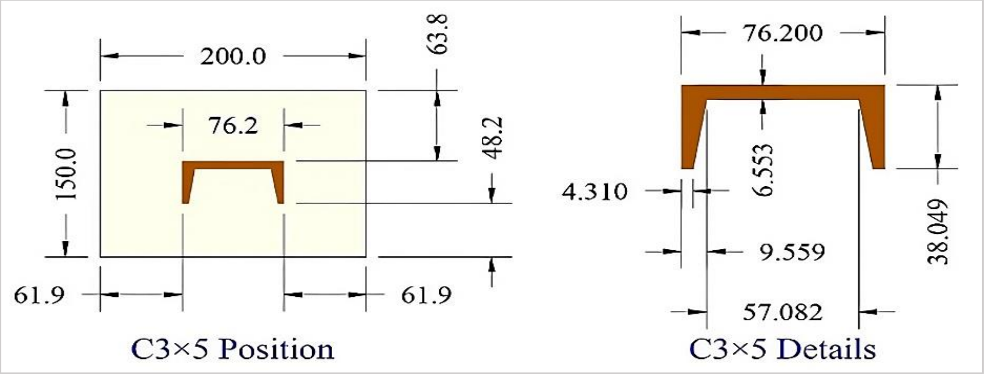
The experimental testing program tests 12 rectangular, slender RC columns divided into two main groups. The first group comprises 6 RC columns cast without structural steel sections (as control specimens). In comparison, the second group consists of the remaining six columns, including a structural steel section (composite specimens). All tested specimens have a rectangular cross-section of (200×150) mm with a specified cylinder concrete compressive strength ($f'c$) of 35 MPa. Columns were tested under eccentric load about the (hx) equals 150 mm of (ex = 45 mm; e/h = 0.3 and ex = 90 mm; e/h = 0.6) with various slenderness ratios ranging from 22 to 31 up to failure. These variables were designated based on preliminary analyses or literature reviews. Also, this division in testing programs was to get the improvements in RC columns when strengthening by a structural steel section. All rectangular cross sections were reinforced with (6#3: db = 9.5 mm, ab = 71 mm^2) reinforcement bars, specified yield strength (fy) = 420 MPa. The structural steel channels Figure 2b have a yield strength of 380 MPa. All mechanical properties tests have been at the University of Technology Las. These variables were designated to make a valuable comparison for the ultimate strength and the enhancement in the behavior of RC slender normal and composite RC columns.

3. Specimens description

According to the eccentricities of the applied loading, the tested columns were divided into two groups. $\ell u = 1.0$ m, $\ell u = 1.2$ m, and $\ell u = 1.4$ m. A relative slenderness ratio $\ell u / r = 22.2$, 26.7, and 31.1. All columns are reinforced by 6 longitudinal reinforcing bars of (#3 - nominal diameter = 9.5 mm and nominal area of 71 mm^2) and a 6 mm in diameter spaced 75 mm as transverse reinforcement (ties) so that the steel ratio (ρg) equals 1.42 percent, [(within the ACI 318M-19 Code requirements limits (1 to 8)%] [16]. The clear concrete cover was 20 mm from all sides of the cross-section. The tested columns' full details are shown in Figures 2 (a and b) and Figure 3.



a- Tested RC columns front and side cross section (dimensions are in m)



b- Structural steel cross section in columns (dimensions are in m)

Figure 2: Reinforced concrete schematic tested columns, a- Steel reinfrocemnt details, b- Structural steel channel used for composite tested columns

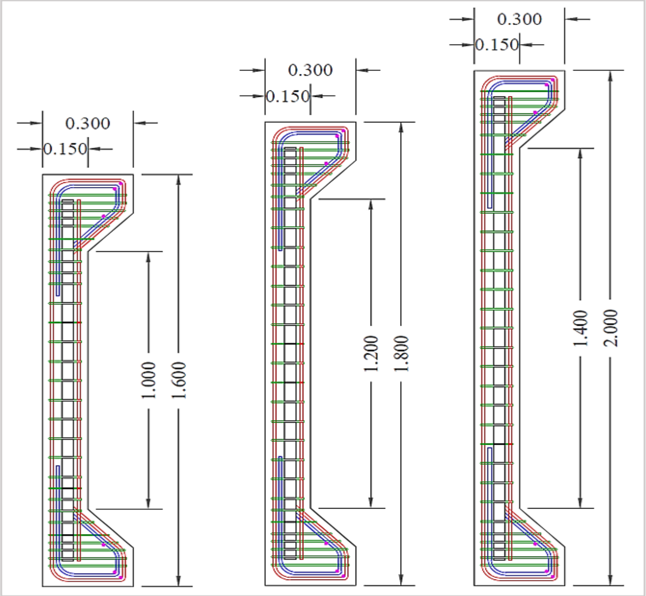


Figure 3: Tested RC columns cross section (dimensions are in m)

The ends of RC Corbels were designed to ensure that the applied test load transfers to the almost midspan cross-section of the column (according to the ACI 318M-19 approach), [16].

4. Specimens identification

To identify the column specimens with the various variables used, including the specimens' length, cross-section dimensions, slenderness ratio, and eccentric loading, The major details of the following experimental program throughout this study are illustrated in Table 1, which describes the tested columns.

Table 1: Details of column specimens properties

Group No.	Specimen No.	Column Designation	ℓ_u (m)	Slenderness Ratio ℓ_u/r	e/h	Steel Section
A	1	C0E45L1.0	1.0	22.22	0.3	0
	2	C0E45L1.2	1.2	26.67		
	3	C0E45L1.4	1.4	31.11		
	4	C0E90L1.0	1.0	22.22	0.6	
	5	C0E90L1.2	1.2	26.67		
	6	C0E90L1.4	1.4	31.11		
B	7	C1E45L1.0	1.0	22.22	0.3	1
	8	C1E45L1.2	1.2	26.67		
	9	C1E45L1.4	1.4	31.11		
	10	C1E90L1.0	1.0	22.22	0.6	
	11	C1E90L1.2	1.2	26.67		
	12	C1E90L1.4	1.4	31.11		

5. Procedure for mixing and casting for tested specimens

In this investigation, each wooden mold was cast individually. After cleaning and oiling the interior faces, the steel reinforcement cages were positioned in the mold where they were needed. A 0.19 m^3 capacity tilting rotary mixer was used to mix the concrete. Before combining the components in the following order, the amount of weight required was gathered and stored in accordance with the predetermined percentages as previously stated. For around five to six minutes, the mixture was mixed with the addition of the cement and the fine and coarse aggregates. After gradually combining the water and superplasticizer, the mixture was split in half and mixed for ten minutes. One batch requires about 30 minutes to mix to get the desired consistency. Superplasticizer (SP) was blended for 10 minutes, and the remaining SP was added afterward. The concrete mix proportion was 1:1.5:2.2 for cement, sand, and aggregate. Slump tests show that the concrete mix was acceptable (35 – 45) mm. Following the mixing process, the mixture was poured into the wooden molds in three levels, with each layer being compacted by an internal vibrator to produce the concrete mixture's consolidation, as shown in Figure 4. The concrete preparation and casting process are shown in Figure 4a to Figure 4d. Figure 4a shows the initial step of preparing the mix, while Figure 4b captures the mixing of concrete materials. The casting process is depicted in Figure 4c, and finally, Figure 4d displays the molds filled with concrete, completing the procedure. It is essential to mention that the columns were cast horizontally.

a- Preparing the mix **b-** Mixing the concrete materials

c- Casting process **d-** Molds filled with concrete

Figure 4: Concrete mixing and casting process, a- Preparing the materials quantity to mixing the concrete to cast test columns, b- Concrete mixing process ,c- Tested columns casting in wood forms, d- Tested columns after casting

6. Testing process

After 28 days of curing, the column specimens were removed and let dry for 24 hours. To make it easier to identify and indicate the cracks during testing, the surfaces of column specimens were painted white and placed within the testing frame. The column specimens were then modified to set the centerline, supports, point load, and LVDTs in the proper positions. A hydraulic universal testing machine (2500 kN maximum capacity) was used to apply the load on the specimens monotonically. At either end of the test column, prefabricated steel loading caps are provided as support. A wedge plate located in grooves at the appropriate two eccentricities (45 and 90 mm) from the column cross-section center applied the load to the loading cap. The top and bottom ends of the column have identical eccentricity to ensure the same moment value along the column's length. This kind of support is supposed to stand in for a hinged connection at each end of the columns. A load cell at the base of the testing machine was placed and connected with a data logger to record the load applied.

The load was increased up to failure with a recorded load-deflection response. Additionally, the axial and lateral displacements of the eccentric columns were recorded using two LVDTs mounted along the column's height. One was placed at the center of the column to measure the lateral deflection, and the other was placed at the base of the machine along the axial height of the columns to gauge the shortening for each degree of loading. Each stage of loading was completed by repeating this procedure. Cracking observations with special safety precautions were taken. The failure mode, crack pattern, and load capacity were carefully examined. The schematic diagrams for the column are shown in Figure 5.

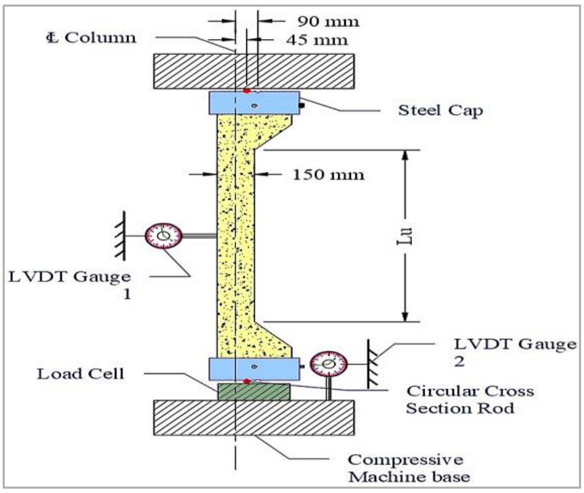


Figure 5: Column testing setting

7. Test results and influence of the slenderness versus eccentricity

Test results of the column capacity for each column as ultimate load capacity and the maximum lateral deflection at midspan are shown in Table 2 and Figure 6. Based on the reference chased column (the lowest RC column axial load capacity – C0E90L1.4), Figure 6 shows that the improvement of the ultimate column capacity obtained for each tested reinforced concrete column in comparison to the weakest column capacity obtained (C0E90L1.4). The bar chart shows that, as expected, for all columns containing steel channels embedded inside of the column, the improvement was larger than the companion conventional columns, for example, for tested columns under eccentrically loaded of e = 45 mm of unsupported length (Lu) = 1.0 m, the improvement in ultimate column axial load capacity was 65% and 74.2%. Meanwhile, for the columns under eccentricity of e = 90 mm of unsupported length (Lu) = 1.0 m, the improvement in ultimate column axial load capacity was 30% and 50%. These results were in the same manner, and there were improvement ratios in the ultimate column capacities for the rest of the columns. The eccentricity and slenderness ratios are major factors affecting the axial load capacity for all the tested columns.

Table 2: Column specimens test results

No	**Column Designation**	**Ultimate Stage**		**Max. Lateral Deflection (mm)**
		P_u (kN)	**Deflection at P_u (mm)**	
1	C0E45L1	289.81	6.20	7.51
2	C0E45L1.2	285.61	8.89	9.90
3	C0E45L1.4	245.96	7.01	8.06
4	C0E90L1	144.36	14.97	15.25
5	C0E90L1.2	123.27	9.90	11.48
6	C0E90L1.4	101.45	12.31	13.95
7	C1E45L1	392.59	8.97	9.64
8	C1E45L1.2	288.35	6.84	7.65
9	C1E45L1.4	281.96	13.77	16.44
10	C1E90L1	203.04	8.16	10.05
11	C1E90L1.2	169.20	8.16	10.17
12	C1E90L1.4	155.17	10.18	12.14

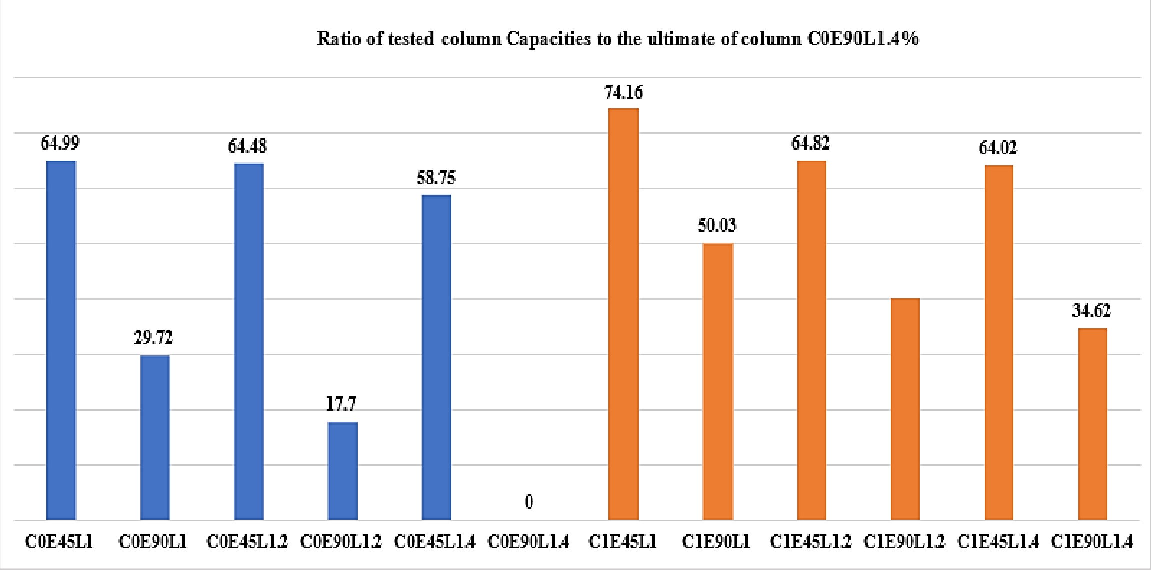


Figure 6: Ratio of tested column (e/h = 0.3 and 0.6) capacities to the ultimate of column C0E90L1.4 (%)

Based on the reference chased column (the largest RC column lateral deflection – C0E90L1.4). Figure 7 shows that the improvement of the lateral midspan deflection of columns obtained for each tested reinforced concrete columns in comparison to the weakest column capacity obtained (C0E90L1.4). The bar chart shows that, as expected, for all columns containing steel channels embedded inside of the column, the midspan lateral deflection was less than the reference companion conventional columns, for example, for tested columns under eccentrically loaded of e = 45 mm of unsupported length (Lu) = 1.0 m, the improvement in the midspan lateral deflection was 119% and 142%. Meanwhile, for the columns under eccentricity of e = 90 mm of unsupported length (Lu) = 1.0 m, the improvement in the midspan lateral deflection was 51% and 84%. These results were similar, and the ratios in the midspan lateral deflection were improved for the rest of the columns. The eccentricity and slenderness ratios are major factors affecting the axial load capacity for all the tested columns. Figure 8 shows the load -Lateral deflection at the midspan of the tested columns under the full load history.

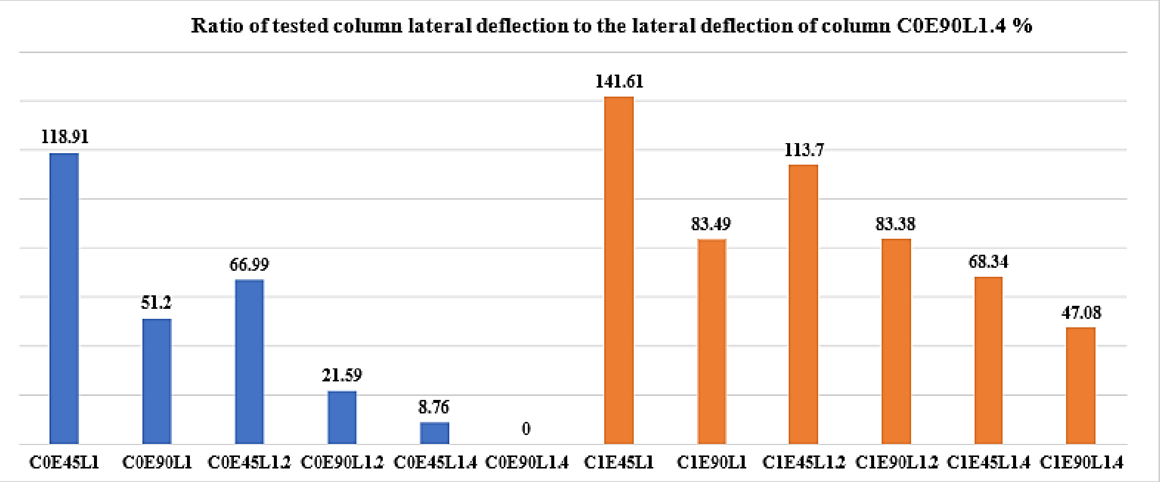


Figure 7: Ratio of tested column (e/h = 0.3 and 0.6) lateral deflection to the ultimate deflection of column C0E90L1.4 (%)

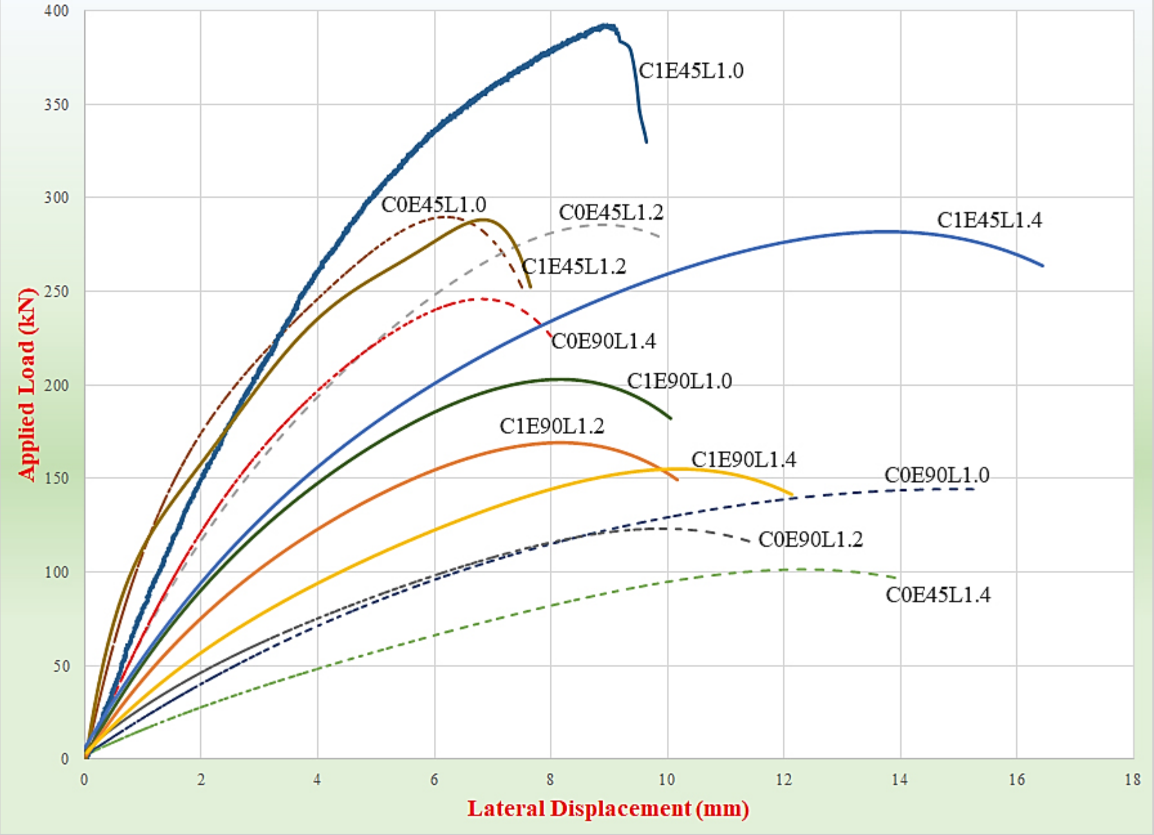


Figure 8: Applied load-lateral deflection at midspan of the tested columns

From the figures above, it is clear that the reduction in load capacity and or increase in the lateral deflection for the columns is proportional to the increase in the column slenderness ratios. In other words, the RC composite columns have more stiffness for columns with less slenderness ratio under a small eccentricity axial load.

Figure 6 shows the reduction between the strongest column (C0E45L1.0) and the lower column capacity among tested columns (C0E90L1.4). The area under the load-deflection curves for each column refers to the kinematic energy provided by each column.

8. Failure mode observation

The columns were free of cracks in the early loading phases; tension and compression cracks were examined and noted at load increment commencing from the first application of load till failure. Tension cracks first appeared near and at the middle height of columns due to the applied eccentricity. As the load increases, further tensional cracks appear at both column ends (where the column connects with the corbels). It is important to note that the main cracks appear near the mid-height of all columns because the applied bending moment was larger at the mid-height section due to the maximum lateral deflection induced according to the geometrical properties of the tested RC columns.

These cracks begin to increase in number along the height of the column simultaneously with the increase in the applied load until final failure occurs. The width of the estimated tensional crack was roughly proportionate to the size of the cross-section. Despite this, several cracks were nearly constant. The differences in total column heights, Figures 9 (a to i) show that the width of the tension cracks along the longitudinal axis of the column examined was nearly similar in all the tested columns, with noticeable variations and differences in increasing lateral deflection for each column. Based on the preceding discussion, it is evident that utilizing structural steel sections within the cross-section of reinforced concrete (RC) columns leads to enhancements in column behavior.

a- Failure of column C0E45L1.0

b- Failure of column C0E45L1.2

c- Failure of column C0E45L1.4

d- Failure of column C0E90L1.0

e- Failure of column C0E90L1.2

f- Failure of column C1E45L1.4

g- Failure of column C1E45L1.0

h- Failure of column C1E45L1.2

i- Failure of column C1E45L1.4

j- Failure of column C1E90L1.0

k- Failure of column C1E90L1.2

l- Failure of column C1E90L1.4

Figure 9: Failure mode of tested columns

9. Nominal load capacity analysis

The shortest column (C1E45L1.0) with a slenderness ratio (k ℓu/r) of 22.2 and a small applied eccentricity ratio (e/h) of 0.3 failed under a load of 392 kN. This represents a reduction in load capacity of 26.18% compared to a column with a slenderness ratio of 26.7 under the same applied eccentricity. The decrease in load capacity can be attributed to increased lateral deflection, which induces additional stresses on the column, thereby reducing its capacity. For columns with greater heights (k ℓu/r = 31.1) and the same applied eccentricity ratio (0.3), the reduction in load capacity was similar to that of columns with a slenderness ratio of 26.7, albeit with increased lateral deflection. This suggests that columns with higher slenderness ratios benefit from the added contribution of embedded steel sections, which undergo strain hardening without experiencing de-bonding issues between the concrete and steel sections.

Columns subjected to larger eccentricities exhibited even greater reductions in load capacity due to the increased bending moments applied to the columns compared to those with lower eccentricity ratios. Overall, columns with higher slenderness ratios demonstrated a greater contribution from the steel cross-section, as evidenced by reduced load capacity percentages under the same eccentricity ratio. For instance, a column with e/h = 0.6 and k ℓu/r = 26.7 experienced a 39.3% reduction in load capacity. In comparison, a column with e/h = 0.6 and k ℓu/r = 31.1 experienced a slightly lower reduction of 28.9% due to the strain-hardening effect of the steel cross-section. In summary, the study highlights the critical influence of the slenderness ratio and eccentricity on the load capacity of columns. Columns with higher slenderness ratios exhibit increased reliance on the contribution of embedded steel sections, particularly evident in the strain-hardening effect observed. Moreover, the analysis underscores the detrimental impact of larger eccentricities on column capacities, emphasizing the importance of careful consideration in structural design to mitigate such effects. Overall, the findings provide valuable insights for optimizing column design and performance in real-world applications, guiding engineers toward more robust and efficient structural solutions.

10. Conclusion

One significant benefit of the research is its contribution to advancing structural engineering knowledge and practices. By investigating the effects of slenderness ratio and eccentricity on column load capacity, the research provides valuable insights into optimizing column design for enhanced structural performance. This knowledge can lead to the development of more efficient and resilient structural systems, ultimately improving built environments' safety, reliability, and sustainability. Additionally, the findings can inform the refinement of structural design codes and standards, ensuring that future construction projects are better equipped to withstand varying loading conditions and environmental challenges. Overall, the research benefits the engineering community by facilitating the creation of safer and more robust structures that meet the evolving needs of society.

The following conclusions of the research can be drawn:

1) The slenderness ratio significantly influences the load capacity of columns, with higher slenderness ratios leading to increased reliance on embedded steel sections for structural support.
2) The study demonstrates that columns subjected to larger eccentricities experience greater reductions in load capacity due to the amplified bending moments applied to the structure.
3) Lateral deflection plays a crucial role in reducing column capacity, as observed through increased applied stresses and decreased load-bearing ability.
4) The strain-hardening effect of steel cross-sections contributes to mitigating load capacity reductions, particularly in columns with higher slenderness ratios.
5) Design considerations should consider eccentricity and slenderness ratios carefully to ensure optimal column performance and structural integrity in real-world applications.
6) The findings provide valuable insights for structural engineers, guiding the development of more resilient and efficient column designs that can withstand varying loading conditions while maintaining safety
7) This research indicates testing another RC column's properties, like larger cross section dimensions, anther slenderness ratios, varied concrete compressive strength, etc., to get other results to fill some voids in this field.

Author contributions

Conceptualization, Z. Mohammed, B. Muhammad and A. Resheq; data curation, Z. Mohammed; formal analysis, B. Muhammad; investigation, Z. Mohammed; methodology, B. Muhammad; project administration, B. Muhammad, resources, A. Resheq; software, Z. Mohammed; supervision, B. Muhammad and A. Resheq; validation, Z. Mohammed, B. Muhammad and A. Resheq; visualization, B. Muhammad; writing—original draft preparation, B. Muhammad; writing—review and editing, A. Resheq. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] M.F. Pereira, S. De Nardin, A.L.H.C. El Debs, Structural behavior of partially encased composite columns under axial loads, Steel. Compos. Struct., 20 (2016) 1305–22. https://doi.org/10.12989/scs.2016.20.6.1305

[2] Lu G, Yu TX, Energy absorption of structures and materials, Elsevier, 2003.

[3] C-S Kim et al., Eccentric Axial Load Capacity of High-Strength Steel-Concrete Composite Columns of Various Sectional Shapes. J Struct Eng., 140 (2014). https://doi.org/10.1061/(ASCE)ST.1943-541X.0000879

[4] C. Dundar, S. Tokgoz, A.K. Tanrikulu, T. Baran, Behaviour of reinforced and concrete-encased composite columns subjected to biaxial bending and axial load, Build. Environ., 43 (2008) 1109–20. https://doi.org/10.1016/j.buildenv.2007.02.010

[5] Ketema, E. Design Aid for Composite Columns. MS.c. Thesis, Addis Ababa University, Ethiopia, 2005.

[6] R. Sonnenschein , K. Gajdosova, S. Gramblicka, Comparison of composite, steel and reinforced concrete columns, IOP Conf. Ser. Mater. Sci. Eng., 7 (2020) 960. http://dx.doi.org/10.1088/1757-899X/960/3/032093

[7] W. Anuntasena, A. Lenwari, T. Thepchatri, Finite Element Modelling of Concrete - Encased Steel Columns Subjected to Eccentric Loadings, Eng. J., 23 (2019) 299–310. https://doi.org/10.4186/ej.2019.23.6.299

[8] Q. Wang, Q. Shi, Y. Tao, Experimental and numerical studies on the seismic behavior of steel reinforced concrete compression-bending members with new-type section steel, Adv. Struct. Eng., 19 (2016) 255–69. http://dx.doi.org/10.1177/1369433215624320

[9] M. Elsayed, M. Elassaly, W. Esmail, Behavior of eccentrically loaded R.C. columns confined with CFRP composites, Int. Res. J. Eng Technol., 5 (2018)1336–43.

[10] D. R. Narmatha, Ragupathi M PM, An Analytical and Experimental Study of Concrete Encased Column, Int. Res. J. Eng Technol., 4 (2017) 165-172.

[11] C. Campian, Z. Nagy, M. Pop, Behavior of fully encased steel-concrete composite columns subjected to monotonic and cyclic loading, Procedia Eng., 117 (2015) 439–51. http://dx.doi.org/10.1016/j.proeng.2015.08.193

[12] E. E. Etman, Experimental Study on The Behavior of Slender Rectangular Columns Under Eccentric Loading, Concr. Res. Lett., 1 (2010) 45–59.

[13] C. C. Chen, N. J. Lin, Analytical model for predicting axial capacity and behavior of concrete encased steel composite stub columns, J. Constr. Steel Res., 62 (2006) 424–33. https://doi.org/10.1016/j.jcsr.2005.04.021

[14] S. Tokgoz, C. Dundar, Experimental tests on biaxially loaded concrete-encased composite columns, Steel Compos. Struct., 8 (2008) 423–38. http://dx.doi.org/10.12989/scs.2008.8.5.423

[15] Ellobode E., Finite Element Analysis and Design of Steel-Concrete Composite Bridges, Tanta. Univ. Egypt Elsevier Inc. 2014.

[16] ACI 318M-19, Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, 2019.