

Effectiveness of Carbon Fibre Reinforced Polymer (CFRP) & Textile Reinforced Mortar (TRM) Strengthening on Circularised Non-Slender Reinforced Concrete Columns

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Abstract— This research paper presents an experimental investigation into the effectiveness of Carbon fibre Reinforced Polymer (CFRP) and Textile Reinforced Mortar (TRM) for strengthening Circularised non-slender reinforced concrete columns. The experiment examined the following parameters cross-section shape namely; - square, circular, and Circularised, the strengthening material i.e. CFRP or TRM, and the number of wrapping layers of the strengthening material (one and two layers). 45 specimens were prepared, given various treatments, strengthened, and loaded uniaxially until failure. The specimens were categorised into three series based on their cross-section geometry; - circular, square, and circularised. The results showed that the circular specimens recorded the highest axial capacity followed by the Circularised specimens while the square specimens recorded the least axial capacity, CFRP confinement was more effective compared to TRM confinement in enhancing the axial capacity and ductility, and doubling the number of both CFRP and TRM layers from 1 to 2 resulted in a significant increase in both the axial capacity and ductility of the specimens. Consequently, the gain in axial capacity and the ductility of the strengthened specimens was sensitive to the number of wraps and the strengthening material. It was also noted that the failure modes of the specimens differed depending on the cross-section geometry. From the findings of this study, it is believed that Circularisation and confinement using TRM & CFRP is a promising solution for retrofitting inadequate square columns.

Confinement, Circularised, Ductility, Hoop strain, Axial Capacity.

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1. Introduction

Upgrading existing Reinforced Concrete (RC) structures through retrofitting is becoming increasingly necessary. External strengthening techniques such as CFRP, steel jacketing, steel angles, and TRM have been used to improve both the axial and flexural capacities of reinforced concrete members. Specifically, the use of Fibre Reinforced Polymer and TRM has gained pace over the past decade or so. This is due to their superior tensile strength and high durability. Strengthening reinforced concrete columns using CFRP and TRM has been found to significantly increase the axial capacity and ductility of columns [1] and [2]. However, the effectiveness of the confining material depends on both the cross-section shape of the column and the number of layers used [3]. This investigation will show that the effectiveness of strengthening is low in square columns due to stress concentration at the corners of the specimen which causes premature rupture of the wrap. Also, from the results, it will be seen that additional layers are more effective in confining.

To improve confinement effectiveness, the square columns are circularised through a process that involves roughening their surfaces and putting mortar infill around them. This process yields circularised columns, eliminating the sharp corners that cause stress concentration. Another approach that can be used to reduce stress concentration is rounding the corners of both square and rectangular columns[4], like other researchers investigated column shape modification confined with FRP [5] and [6] circularised the shapes of columns and tested them under axial load. Their findings indicated significant enhancement of both axial capacity and deformation capacity of the columns.

Previously, reported similar findings when investigating the effect of shape modification on the effectiveness of FRP confinement on square concrete compression members [7]. The enhancement of axial capacity and deformation is ascribed to the improved distribution of hoop stresses along the concrete surface, which consequently delays the premature rupture of the FRP. However, it is important to note that circularisation by use of mortar infills increases the cross-section area as well as the stiffness of the column. This experimental research presents a comprehensive study of the effectiveness of confinement of non-slender columns, focusing on column cross-section shape, confining material, and the number of confining layers.

2. Method

2.1 Test Specimens

A total of 45 columns were cast for this investigation. 15 columns were cast square with dimensions of 100×100mm in cross-section. These specimens were strengthened using either CFRP or TRM and allowed to cure ahead of testing. Another 15 columns were cast with the geometric properties of the first batch but circularised using cement mortar. They were then strengthened using either CFRP or TRM and allowed to cure before testing.

The last batch of 15 columns was cast with a circular cross-section, strengthened using either CFRP or TRM, and allowed to cure ahead of testing. Both the circularised circular columns had a diameter of 141mm, and all the forty-five columns had a height of 350mm. Figure 1 shows specimens details.

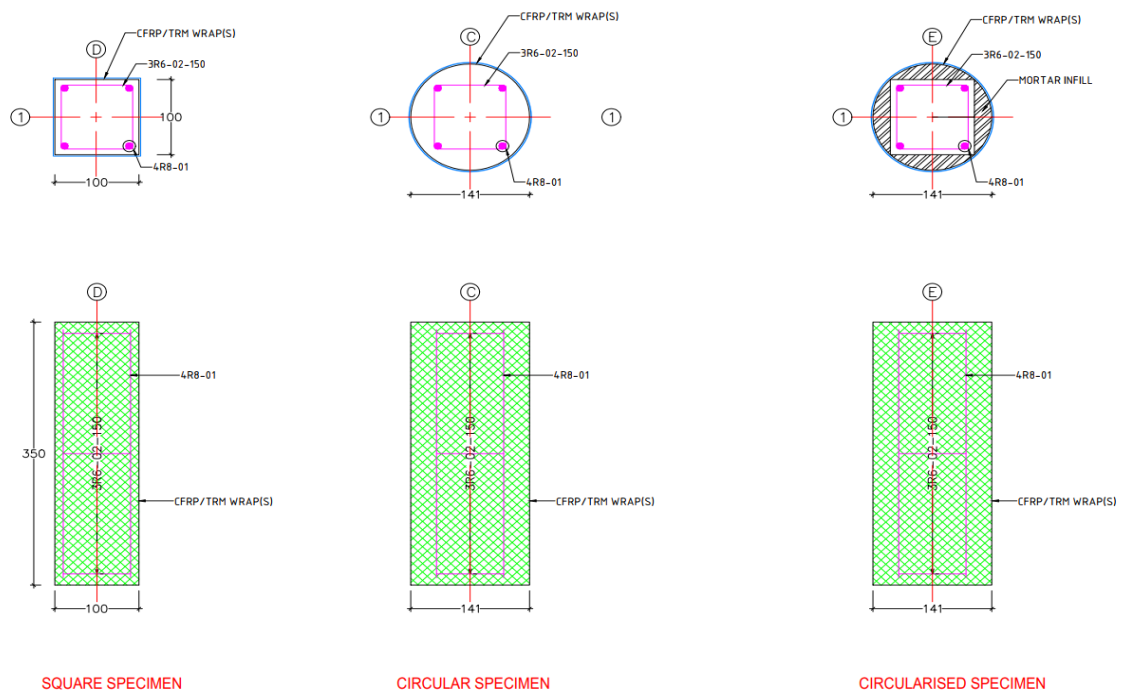


Figure 1. Specimen details

2.2 Materials

All 45 columns were cast using class C16/20 concrete. The water-cement ratio was 0.58. The concrete mix followed the ratios prescribed by [8]. This mix design targeted a compressive strength of 20 MPa. The class C16/20 concrete strength was a deliberate attempt to simulate a deficient concrete column. A total of nine 150mm concrete cubes were taken during casting and tested as per Eurocode standard EN 1992-1-1:2004 to ascertain the concrete strength.

The mortar used for circularisation was of a cement-to-sand ratio of ratio 1:3. This ratio followed the standard specifications outlined in [9]. A total of nine 50mm mortar cubes were taken for testing compressive strength. The mortar cube results conformed to the expected 28-day strength of 7.5 MPa as per the requirements of masonry mortar. The average failure stress of the concrete & mortar cubes is presented in Table 1.

The rebar used was mild round steel bars, 8mm diameters for main bars and 6mm for stirrups. The yield strength of both main and stirrup bars was 250MPa. The choice of diameter and yield strength of the bars was arrived at to make it easy to cut and bend the bars as well as to create design deficiency.

Strengthening was done using both TRM and CFRP. The Textile used had a nominal thickness of 0.062mm and a tensile strength of 3800MPa. The mortar used to reinforce the textile was of a cement-to-sand ratio of 1:2.25. This ratio adopted followed the suggestions by [10]. The CFRP used had a nominal thickness of 0.152mm and a tensile strength of 3950MPa. The epoxy adhesive was a set of two viscous fluids; - an epoxy and a hardener mixed in a ratio of 2:1 by weight as per the manufacture's mixing guidelines.

2.3 Column Shape Modification

Circularisation was done on 7-day cured square cross-section specimens, and entailed roughening the concrete surface to aid bonding between the specimen and the mortar. The roughened specimens were then put in cylindrical moulds of the desired diameter and cement mortar was placed around them. The specimens were then vibrated, allowed to set then cured. Figure 2 shows roughened specimens' surface and cement mortar being placed round the specimens for circularisation.



Figure 2. Specimen circularisation process: (a) roughened specimen and (b) mortar placement around the specimen

2.4 Strengthening procedure

TRM strengthening involved making a 3mm deep groove on the specimen surface using a grinding machine to enhance bonding between the concrete substrate and the textile. This was followed by thoroughly cleaning the surface of the specimen to rid of any loose particles before reinforcing the textile using cement mortar. The TRM was then allowed to cure ahead of testing. Figure 3 shows the TRM strengthening procedure.

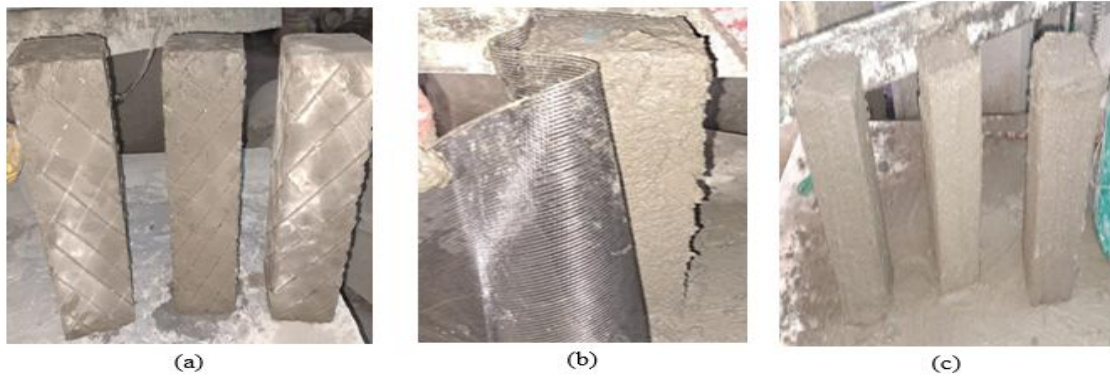


Figure 3. Details of the TRM strengthening: (a) grooves made on specimens' surface, (b) textile impregnation in cement mortar (c) TRM strengthened square specimens.

CFRP was cut to match the specimen dimensions. The cut lengths for the square specimen were 500mm for one-layer confinement and 900mm for two-layer strengthening. For the cylindrical specimens, the cut lengths were 550mm and 1000mm for one-layer wrap and two-layer wrap respectively. All the cut lengths allowed a 100mm overlap to prevent joint failure. The strengthening procedure followed externally bonding the CFRP to the specimen surface by use of prepared epoxy mix. Ahead of applying the CFRP, the specimen surface was thoroughly cleaned to remove any dust particles. A thin layer of the adhesive was then applied over the fibre and then the fibre was placed over the cleaned concrete surface using a plastic roll. This was done carefully to ensure that the resin well impregnates the fibre. The procedure was similar for both one and two-layer wraps. Figure 4 shows circular and circularised specimens wrapped with CFRP.



Figure 4. CFRP wrapped specimens

2.5 Testing of Specimen

All the specimens were loaded uniaxially using a 2000kN hydraulic actuator capacity. Before testing, the strain gauges were externally mounted at mid-height of the specimen to measure hoop strains as loading continued. The strain gauges were firmly bonded to the surface of the specimen using a proper adhesive to ensure the accurate and proper transfer of deformations caused by the load on the specimen. Figure 5 shows the details of the experimental setup.



Figure 5. Test setup

3. Result and Discussion

Table 1 summarises the test results of the specimens. This summary includes the specimen's ID, the cross-section geometry, the strengthening material, the peak load; - which is the highest load attained by the specimens, the compressive strength; - which is the axial stress at the peak load, the hoop strains at failure, ductility of the specimens, and the percentage gain in axial capacity due to strengthening.

3.1 Ultimate axial load capacity

Circular specimens recorded the highest axial load followed by circularised specimens for similar treatments while the square columns recorded the least axial capacity across the three categories. As shown in Table 1, the non-strengthened specimens; - specimens G & M recorded the ultimate axial load capacity of 292.75kN & 280.12kN respectively. The specimens strengthened using one-layer TRM; - specimens H & N recorded ultimate axial load capacity of 377.60kN & 352.41kN respectively and the one-layer CFRP strengthened specimens I & P recorded the ultimate axial load capacity 421.11kN & 624.27kN respectively. These findings were similar to the findings of [11], who investigated the axial behaviour of strengthened circular reinforced-concrete columns. Generally, circular and circularised cross-section specimens exhibit excellent resistance to both axial loading and lateral deformation due to their higher safety factor.

Strengthening resulted in an increase in both the axial capacity and ductility of the specimens, with CFRP-strengthened specimens having substantial gains. For the square-section columns, the gain in axial capacity was 68.54% and 95.06% for one and two-layer strengthening respectively. For the circular-section columns, the gain in axial capacity was 129.79% and 236.78% for one and two-layer strengthening respectively. For the circularised columns, the gain in axial capacity 122.86% and 223.55% for the similar treatments. These results are consistent with findings reported by [12] and is attributed to the increased confinement pressure created by the TRM & CFRP wraps.

3.2 Load-deflection behaviour

The peak load at failure was taken as the axial capacity of the specimens while the hoop strains were recorded using strain gauges externally mounted at mid-heights of the specimens. The data was used to plot the load-deformation curves of the specimens which are presented in Figure 6.

Table 1. Specimen details, concrete & mortar test results

Series	Cross-section	Strengthening Material	Number of layers	Concrete cube Compressive strength (MPa)	Mortar cube compressive strength (MPa)	Peak load (kN)	Compressive strength (MPa)	Percentage gain in Axial capacity (%)	Ultimate hoop strain corresponding to the peak load	Ductility(%)
A	Square	-	-	17.33	6.40	210.00	21.00	–	0.00325	–
B	Square	TRM	1	17.33	6.40	259.46	25.94	23.55	0.00289	-11.08
C	Square	TRM	2	16.89	7.40	306.67	30.67	46.03	0.00275	-15.38
D	Square	CFRP	1	16.89	7.40	353.94	35.39	68.54	0.00222	-31.69
E	Square	CFRP	2	19.33	7.60	409.62	40.96	95.06	0.00176	-45.85
G	Circular	-	-	19.33	7.60	292.75	18.74	–	0.00327	–
H	Circular	TRM	1	20.44	7.60	377.60	24.17	28.98	0.00259	-20.80
I	Circular	TRM	2	20.44	7.60	421.11	26.95	43.85	0.00220	-32.72
J	Circular	CFRP	1	20.44	7.00	672.73	43.07	129.80	0.00197	-39.76
K	Circular	CFRP	2	19.56	7.40	985.92	63.12	106.98	0.00119	-63.61
M	Circularised	-	-	19.56	7.40	280.12	17.93	–	0.00310	–
N	Circularised	TRM	1	21.33	6.00	352.41	22.56	25.81	0.00257	-17.10
O	Circularised	TRM	2	21.33	6.00	395.77	25.34	41.29	0.00229	-26.13
P	Circularised	CFRP	1	19.11	7.20	624.27	39.96	122.86	0.00208	-32.90
Q	Circularised	CFRP	2	19.11	7.20	906.32	58.02	223.55	0.00159	-48.71

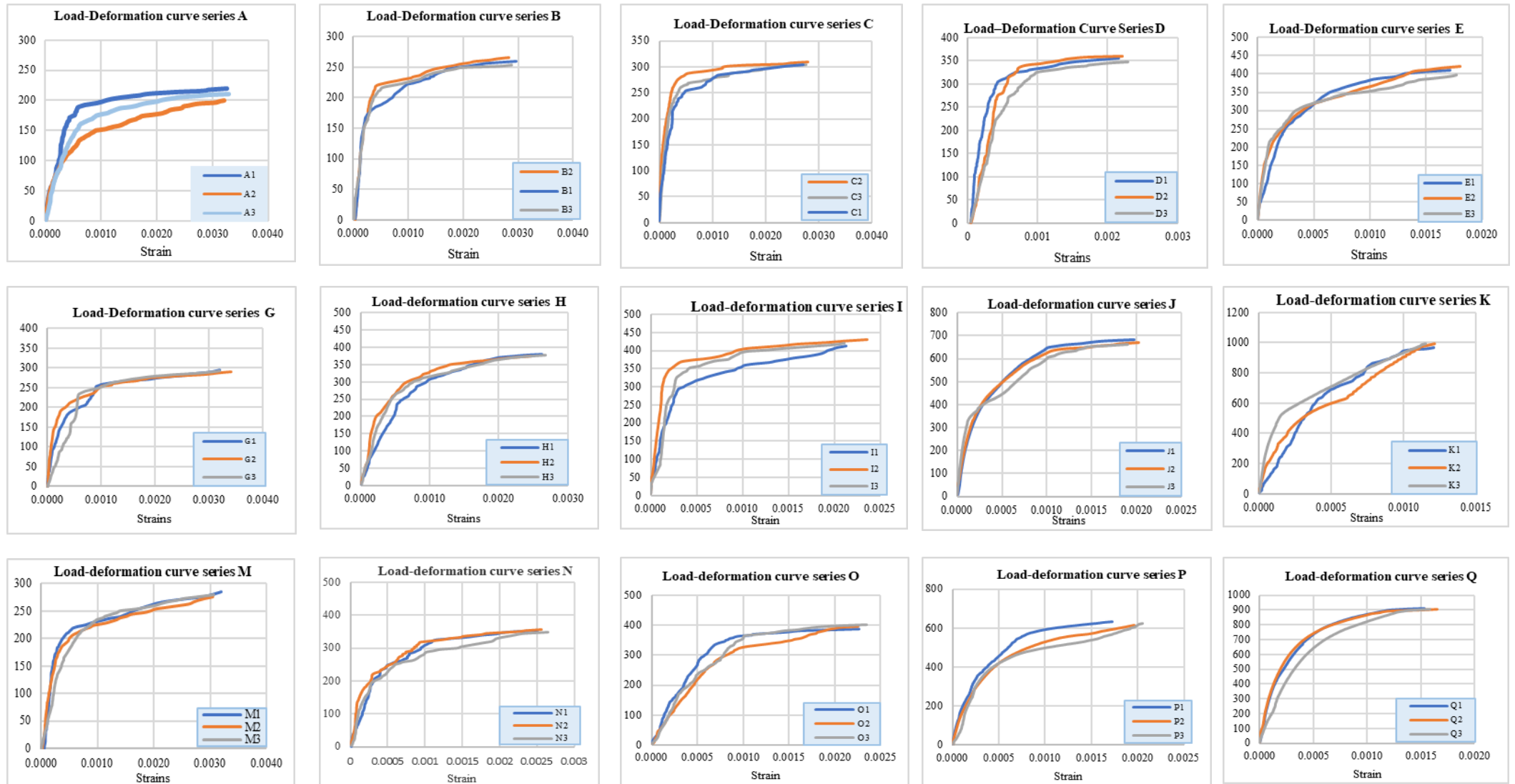


Figure 6. Load-deflection curves of specimens

3.3 Deformation capacity and ductility

Table 1 records both the ultimate hoop strains corresponding to the peak loads as well as the ductility of the test specimens. To calculate the ductility of the specimens, the strains of the non-strengthened specimens were compared to the strains of the strengthened specimens. The strains of specimens A, G & M were used as the initial hoop strains for the three categories; - category 1 (series A-E) with square cross sections, category 2 (series G-K) with circular cross sections, and category 3 (series M-Q) which were cast with square cross-section then circularised using mortar infills. For purposes of reporting in this study, the ductility in the hoop direction was taken as negative. From the results, it was noted that strengthening using CFRP/TRM considerably enhances the deformation capacity in the hoop direction. Additionally, doubling the number of strengthening layers from 1 to 2 led significantly increases the ductility of the specimens. Lastly, it was also observed that CFRP strengthening yields better results compared to TRM strengthening. These results conform with the findings reported by both [13] and [14]. The ductility of the specimens was calculated using Equation 1.

$$\text{Ductility} = \frac{\text{Specimen Hoop Strain} - \text{Reference Hoop Strain}}{\text{Reference Hoop Strain}} \times 100\% \quad (1)$$

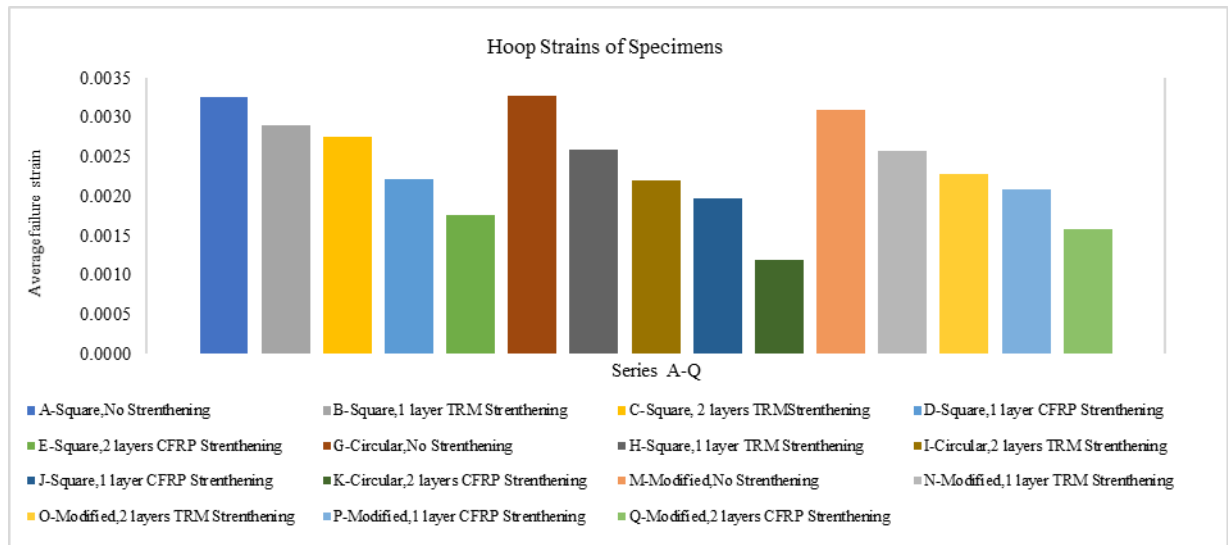


Figure 7. Hoop strains at failure

The ductility of the specimens improved based on the confining material and the number of wrapping layers. As seen in Table 1, for every specific cross-section, the ductility increased with increasing confinement. Again, CFRP confinement resulted in better ductility regardless of the specimen cross-section shape. Figure 7 shows the hoop strains at failure while Figure 8 compares the ductility results of 1-layer and 2-layer TRM & CFRP confinement. Just like determined by previous researchers, these results were sensitive to the parameters being investigated i.e. specimen geometry, the confining material (TRM & CFRP), and the number of confining layers. The investigated parameters are discussed in section 3 of this paper.

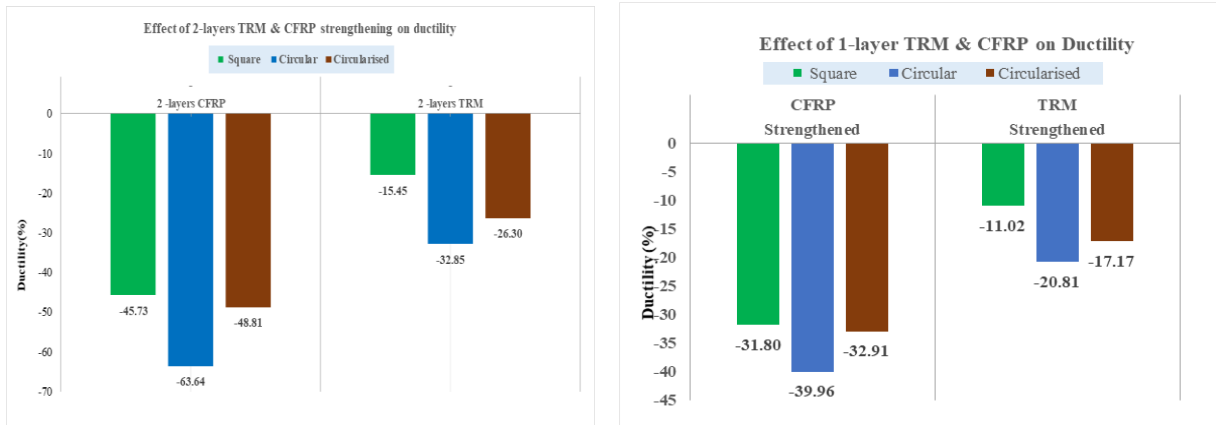


Figure 8. Effect of TRM & CFRP on ductility

3.4 Failure modes

The failure of the specimens was monitored by visual inspection along with the testing. unwrapped specimens A, G & M exhibited somewhat similar failure modes. The circular specimens bulged at or near mid-heights while square specimens exhibited concrete crumbling at mid-heights exposing the rebar. The concrete cover peeled off, and the longitudinal reinforcement was observed to have buckled, consistent with the findings of [15] . Figure 9 shows the observed failure modes of the specimens.

The unwrapped circularised specimens failed by spalling of the infill and collapse of the core. The square columns wrapped using TRM, like their counterparts wrapped using CFRP failed by the rupture of the wrap at the corner points. This observation was similar to the findings reported by [16].

For the circular columns wrapped using CFRP, specimen failure started with clicks of epoxy cracking followed by an explosion of CFRP. The CFRP ruptured at or near the middle height of the specimen. This observed failure pattern was consistent with that reported by [17]. For the square columns, the rupture of CFRP occurred at the corner points, conforming to the findings of many researchers including [18].

The square specimens exhibit stress concentrations around points of abrupt changes in geometry specifically the sharp corners. Using a fillet or a radius distributes the stress more evenly as it is an effective technical measure of reducing stress concentration [19] and [20] . However, it is important to note that rounding of the column corners or fillets locally affects the axial capacity of the column as it reduces the contact pressure. Also, circularisation significantly increases the column cross-section under loading and consequently the axial capacity[21].

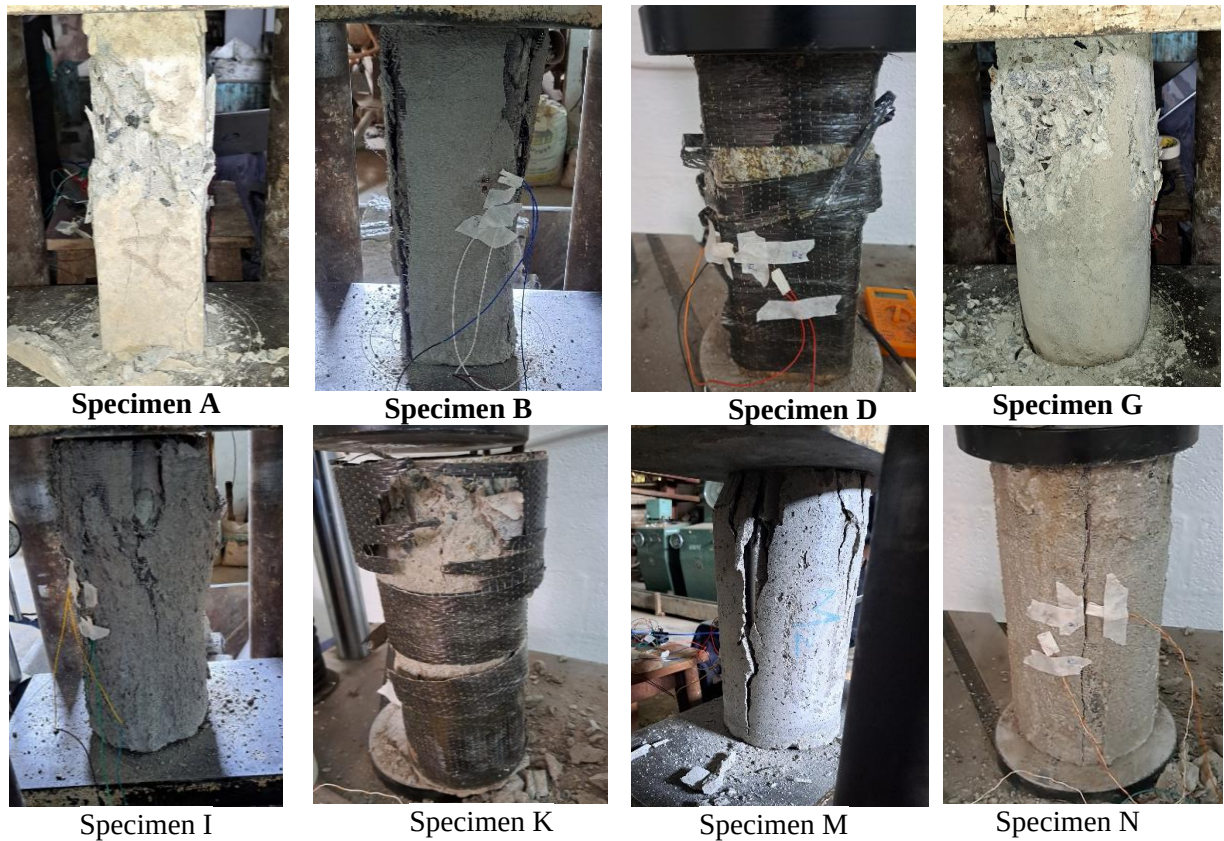


Figure 9. Failure mode of specimens

3.5 Specimen cross-section shape

The specimen cross-section shape had a significant effect on the axial capacity of the specimens. The circular specimens recorded the highest axial capacity followed by the circularised specimens, with the square specimens recording the least axial capacity. Also, the effectiveness of confinement of both TRM & CFRP in enhancing the axial and deformation capacity of the reinforced concrete columns was better in the circular cross-sections followed by the Circularised cross-sections. The square cross-section columns recorded the least gain in axial and deformation capacity. Specifically, as shown in Table 1, the increase of the axial capacity for specimen D (square cross-section) was 68.54% compared to a 122.86% gain for its counterpart P (circularised cross-section). This difference in the performance is ascribed to the sharp corners of the square cross-section specimens that caused stress concentration at the corner points, which resulted in non-uniform stress distribution that led to the premature rupture of the wrap.

3.6 The confining material

Generally, external confinement restrains lateral expansion thereby allowing the concrete core to withstand more loads before failure. Both TRM and CFRP strengthening resulted in increased axial capacity of the columns. The results of TRM and CFRP strengthened specimens were compared to determine the individual effects of each of the strengthening material on axial capacity. CFRP strengthening resulted in a higher percentage gain in axial capacity compared to TRM strengthening. TRM strengthening resulted in 23.55%, 28.98% and 25.98% gain in the axial capacity for the square, circular, and circularised specimens respectively. The corresponding gain in the axial capacity for the CFRP-strengthened specimens was 68.54%, 129.80%, and 122.86% respectively. This finding was consistent with the finding of [22], who when investigating the effect of TRM and FRP in strengthening RC beams, deduced that TRM was inferior to FRP.

3.7 The number of confining layers

The axial capacity increased with increasing number of confining layers. For TRM-strengthened specimens, the axial capacity increased by 23.33% and 46.03% for one-layer and two-layer confinement respectively for the square cross-section. For the circular specimens, the axial capacity increased by 28.98% and 50.68% for one-layer and two-layer confinement respectively. For the circularised cross-section specimens, the axial capacity y increased by 25.81% and 45.57%.

For the CFRP-strengthened specimens, the square cross-section specimens recorded gains in the axial capacity of 68.54% and 95.06% for one-layer and two-layer confinement respectively. For the circular specimens, the axial capacity increased by 129.79% and 236.78% for one-layer and two-layer confinement respectively. For the circularised cross-section specimens, the axial capacities increased by 122.86% and 223.55%. Doubling the number of layers of the strengthening material led to a significant gain in axial capacity.

4. Conclusion

The results indicate that increasing the number of confining layers from one to two significantly enhances the axial capacity of columns. CFRP-strengthened specimens exhibited substantial increases of 95.06%, 236.78%, and 223.55% for square, circular, and circularised specimens, respectively. Similarly, TRM-strengthened specimens recorded increases of 42.89%, 50.68%, and 45.57% for the same cross-section types. Additionally, the ductility of strengthened specimens improved notably compared to unstrengthened ones. Among the tested specimens, circularised columns demonstrated superior deformation capacity compared to square columns, highlighting the influence of cross-sectional shape and the number of confining layers on deformation behavior.

Regardless of the strengthening material used, circular specimens achieved the highest increase in axial capacity, followed by circularised and then square specimens. The superior performance of circularised columns can be attributed to the elimination of sharp edges, which, in square specimens, caused premature failure due to stress concentration. Failure in strengthened specimens typically initiated with crushing of the concrete core, followed by rupture of the TRM/CFRP wrap. In square specimens, the TRM/CFRP wrap tore along the corners, whereas CFRP wraps in circular specimens ruptured at mid-height.

References

- [1] D. Kobbekaduwa, O. Nanayakkara, L. Di Sarno, and T. Krevaiakas, ‘Strengthening and repair of deficient reinforced concrete columns using textile-reinforced mortar: State-of-the-art review’, *Structures*, vol. 65, no. 11, 2024, doi: 10.1016/j.istruc.2024.106739.
- [2] Ö. Mercimek, R. Ghoroubi, C. Çakmak, A. Özdemir, and Y. Koprman, ‘Strength, ductility, and energy dissipation capacity of RC column strengthened with CFRP strip under axial load’, *Mech. Based Des. Struct. Mach.*, vol. 51, no. 2, 2023, doi: 10.1080/15397734.2020.1860772.
- [3] Z. E. A. Benzeguir, O. Chaallal, A. Godat, and R. A. Hawileh, ‘Experimental Investigation on the Effectiveness of EB-CFRP Confinement of Elliptical Concrete Columns’, *Symmetry*, vol. 16, no. 12, p. 1595, Nov. 2024, doi: 10.3390/sym16121595.
- [4] Z. Yan and C. Pantelides, ‘Concrete column shape modification with FRP shells and expansive cement concrete’, *Constr. Build. Mater.*, vol. 25, no. 2011, pp. 396–405, 2011.
- [5] M. N. S. Hadi, J. Mohammed T., and S. M. Neaz, ‘Behavior of Circularized Hollow RC Columns under Different Loading Conditions’, *J. Compos. Constr.*, vol. 21, no. 5, 2017, doi: 10.1061/(ASCE)CC.1943-5614.0000808.
- [6] A. Raza, Q. U. Z. Khan, and A. Ahmad, ‘Prediction of Axial Compressive Strength for FRP-Confined Concrete Compression Members’, *KSCE J. Civ. Eng.*, vol. 24, no. 7, pp. 2099–2109, Jul. 2020, doi: 10.1007/s12205-020-1682-x.

- [7] W. A. Aules and S. M. Raoof, 'Effect of shape modification on the confinement effectiveness of CFRP strengthened square concrete compression members: Experimental study', *Case Stud. Constr. Mater.*, vol. 15, p. e00679, Dec. 2021, doi: 10.1016/j.cscm.2021.e00679.
- [8] IQSK, *Building Construction Cost Handbook—2023/2024*, vol. Institute of Quantity Surveyors of Kenya. in Handbook No. 2023/2024, vol. Institute of Quantity Surveyors of Kenya. 2023.
- [9] 'IS 2250 (1981): Code of Practice for Preparation and Use of Masonry Mortars'.
- [10] C. C. Ban and M. Ramli, 'Optimization of Mix Proportion of High Performance Mortar for Structural Applications', *Am. J. Eng. Appl. Sci.*, vol. 3, no. 4, pp. 643–649, Apr. 2010, doi: 10.3844/ajeassp.2010.643.649.
- [11] H. Sezen and E. Miller, 'Experimental Evaluation of Axial Behavior of Strengthened Circular Reinforced-Concrete Columns', *J. Bridge Eng.*, vol. 16, pp. 238–247, 2011, doi: 10.1061/(ASCE)BE.1943-5592.0000143.
- [12] M. N. S. Hadi, T. M. Pham, and X. Lei, 'New Method of Strengthening Reinforced Concrete Square Columns by Circularizing and Wrapping with Fiber-Reinforced Polymer or Steel Straps', *J. Compos. Constr.*, vol. 17, no. 2, pp. 229–238, Apr. 2013, doi: 10.1061/(ASCE)CC.1943-5614.0000335.
- [13] L. N. Koutas and D. A. Bournas, 'Confinement of masonry columns with textile-reinforced mortar jackets', *Constr. Build. Mater.*, vol. 258, p. 120343, Oct. 2020, doi: 10.1016/j.conbuildmat.2020.120343.
- [14] A. D. Mai, M. N. Sheikh, and M. N. S. Hadi, 'Performance evaluation of intermittently CFRP wrapped square and circularised square reinforced concrete columns under different loading conditions', *Struct. Infrastruct. Eng.*, vol. 15, no. 5, pp. 696–710, May 2019, doi: 10.1080/15732479.2019.1572201.
- [15] A. Mahdi Jabbar, L. Salim Danha, and Q. Abdulmajeed Hasan, 'Numerical Analysis of Sectional Shape Effect on Behavior of Short Concrete Columns', *Wasit J. Eng. Sci.*, vol. 12, no. 1, pp. 30–37, Jan. 2024, doi: 10.31185/ejuow.Vol12.Iss1.524.
- [16] T. M. Pham, L. V. Doan, and M. N. S. Hadi, 'Strengthening square reinforced concrete columns by circularisation and FRP confinement', *Constr. Build. Mater.*, vol. 49, pp. 490–499, Dec. 2013, doi: 10.1016/j.conbuildmat.2013.08.082.
- [17] V. J. Castro, F. J. León, S. Martínez, A. De Diego, and L. Echevarría, 'Effectiveness of CFRP jackets in RC rectangular columns. Full-scale experimental study', *Constr. Build. Mater.*, vol. 416, p. 134840, Feb. 2024, doi: 10.1016/j.conbuildmat.2023.134840.
- [18] M. R. Esfahani and M. R. Kianoush, 'Axial compressive strength of reinforced concrete columns wrapped with fiber reinforced polymers', *Int. J. Eng.*, vol. 18, no. 1, 2005.
- [19] Y. Wei, Y. Xu, G. Wang, X. Cheng, and G. Li, 'Influence of the Cross-Sectional Shape and Corner Radius on the Compressive Behaviour of Concrete Columns Confined by FRP and Stirrups', *Polymers*, vol. 14, no. 2, p. 341, Jan. 2022, doi: 10.3390/polym14020341.
- [20] B. Shan, F. C. Gui, G. Monti, and Y. Xiao, 'Effectiveness of CFRP Confinement and Compressive Strength of Square Concrete Columns', *J. Compos. Constr.*, vol. 23, no. 6, 2019, doi: 10.1061/(ASCE)CC.1943-5614.0000967.
- [21] M. T. Jameel, M. N. Sheikh, and M. N. S. Hadi, 'Behaviour of circularized and FRP wrapped hollow concrete specimens under axial compressive load', *Compos. Struct.*, vol. 171, pp. 538–548, Jul. 2017, doi: 10.1016/j.compstruct.2017.03.056.
- [22] R. M. Saad, K. N. Lampros, and BournasA. Dionysios, 'Textile-reinforced mortar (TRM) versus fibre-reinforced polymers (FRP) in flexural strengthening of RC beams', *Constr. Build. Mater.*, vol. 151, pp. 279–291, 2017, doi: 10.1016/j.conbuildmat.2017.05.023.