PERFORMANCE OF ECCENTRICALLY SHORT SQUARE REINFORCED CONCRETE COLUMNS CONFINED WITH TRADITIONAL OR SPIRAL STIRRUPS

Hesham Ali Ezz-Eldeen[*1], Emad Mohamed Helal Elsaied[*2]

[1]Associate Prof., Civil Eng. Dept., Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
[2] Lecturer - October University for Modern Sciences and Arts – MSA., Cairo, Egypt.

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Abstract *- The performance of short square reinforced concrete columns constrained with traditional (separate) or spiral stirrups under eccentric loads was explored in this research. Under eccentric loading, steel spiral stirrups are suggested to improve the load capacity of square reinforced concrete columns. Experimental tests have been performed for ten square reinforced concrete columns that were loaded to failure at various eccentricities. Each column has 150x150 mm cross section and 900 mm length reinforced by vertical bars 4ϕ8, and horizontal stirrups ϕ6@120 mm. Five samples with traditional stirrups were tested under various eccentricities (e/t = 0, 5 %, 10 %, 15 % and 25 %). Whereas, the other five samples were confined using spiral stirrups and tested under the same eccentricities (e/t = 0, 5 %, 10 %, 15 % and 25 %). To model the behaviour of typical and spiral stirrups, a numerical analysis utilising the finite element approach has been performed. In this study, the finite element software program "ANSYS version 15" has been applied. The finite element model's results provided a good agreement with the experimental results. It was concluded that changing typical steel stirrups to spiral stirrups increased the load capability of the columns at various eccentricities. The results indicated that using square spiral stirrups for columns increased its load capacity by 15% to 29.5% when compared to using traditional stirrups at the same eccentricity (e/t = 0% to 25%).*

Keywords: reinforced concrete column, eccentricity, stirrups , spiral, experimental, finite element.

I. INTRODUCTION

Spiral stirrups have lately been utilized to constrain reinforced concrete columns. Junfeng Guan and Juan Wang (2012) proposed using regression analysis on existing test data to compute the shear capacity of a continuous compound spiral hoop reinforced concrete column. In addition, the suggested method's engineering applicability was verified in a practical example, that gives support for continuous compound spiral hoop reinforced concrete column engineering applications. Sun, L. et al. (2017) performed experimental tests to study the behaviour of glass fibre reinforced polymer reinforced concrete columns (GFRP-RCCs) considering the eccentricity of the applied axial loading. The tested samples were 9 short columns (L/h=4), three each with 175 mm, 125 mm, and 75 mm initial eccentricities. The effects of basalt fibre on the axial compressive mechanical behaviour of short RC columns with spiral stirrups were investigated by Xinzhong, W. et al. (2017). A cube test of basalt fibre concrete was used to establish the ideal fibre length and content. Six samples of short basalt fibre reinforced concrete (BFRC) columns with spiral stirrups and six samples of short RC columns with spiral stirrups were used in an axial compression experiment. Hassan, A. et al. (2018) investigated the overall behaviour of self-compacting short concrete columns with various types of reinforcements. The slenderness ratio of columns, as well as reinforcement type, and confinement techniques, were the main investigated parameters. Strengthening techniques include FRP tubes and spiral stirrups with two different volumetric ratios. The influence of form modification of stirrup on the axial capacity of concrete columns was investigated by Widiarsa, B. R., and Giri, B. D. (2018). Twelfe experimental samples of concrete columns have been casted and tested. The samples were divided into four groups based on their shape and stirrup spacing. By performing experiments and finite element modelling, Raza, A. et al. (2021) investigated and compared the structural performance of GFRP-reinforced concrete columns with hybrid fibres (GHC columns) and steel-reinforced concrete columns with hybrid fibres (SHC columns) confined with spirals and subjected to concentric and eccentric loading. The hybrid fibre reinforced concrete (HFRC) was generated by combining steel fibres (SF) with polypropylene fibres (PF). Six GHC and six SHC circular columns of 250 mm diameter, and 1150 mm height were constructed. The columns were analyzed through FEA approach using ABAQUS 6.14 and a modified concrete damage plastic (CDP) model for HFRC. An experimental investigation on the compressive behaviour of spiral stirrup reinforced concrete-filled square steel tubular (SSRCFSST) columns was studied by Chen, Z. et al. (2021). They studied experimentally the impacts of sample size, concrete strength, steel tube thickness, diameter to width ratio, spiral stirrup spacing, and steel ratio through performing tests on twenty-nine axial compression specimens and eighteen eccentric compression specimens. Furthermore, the influence of eccentricity ratio on eccentric compression specimens was studied. M. Naghipour et al. (2022) investigated several types of concrete confinement and their effects on the bearing capacity of SRC columns, where, six reinforced concrete column specimens with two types of H-shaped and cruciform steel core sections were loaded under three different eccentricities in an experimental programme. In addition, using the ABAQUS programme, a finite element model was performed to examine the principles and undertake numerical analysis, which was then checked against the experimental conclusions. Furthermore, these columns were subjected to a parametric investigation with a greater number of eccentricities than the test specimens, and locations with high, moderate, and low confinement levels were identified. The load-bearing contribution of each of these concrete zones to the concrete portion of the overall column's load-bearing capacity was then computed. Zhang, P. et al. (2022) suggested employing glass fibre reinforced polymer (GFRP) composite spiral stirrups made of several outer rectangular GFRP stirrups and an inner spiral GFRP stirrup to transversely confine square concrete columns. The composite spiral stirrups' twin restraints overcome the disadvantage of GFRP's lower elastic modulus compared to steel and provided effective lateral restraint for the core concrete. Experiments were conducted on the axial compressive performance of GFRP-reinforced square concrete columns with composite spiral stirrups.

2. EXPERIMENTAL PROGRAM

The impact of steel conventional (separate) and spiral square stirrups used to confine square short reinforced concrete columns under eccentric loads on the column's load capability was investigated in this study. The experimental study has been performed through casting 11 column specimens, each with a cross section of 150x150 mm and a height of 900 mm. As indicated in figures (1) and (2), all columns are reinforced by vertical mild steel bars 4ϕ8 and and horizontal mild steel stirrups ϕ6@120 mm. Table [1] shows the detailed data for the tested columns. Internal vertical and horizontal reinforcement were attached with epoxy-bonded electrical resistance strain gauges at the maximum expected strain locations.

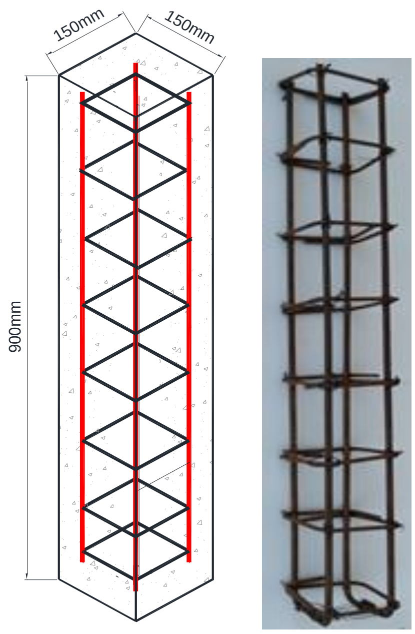


Fig 1: Detailing of column CT_{e0}

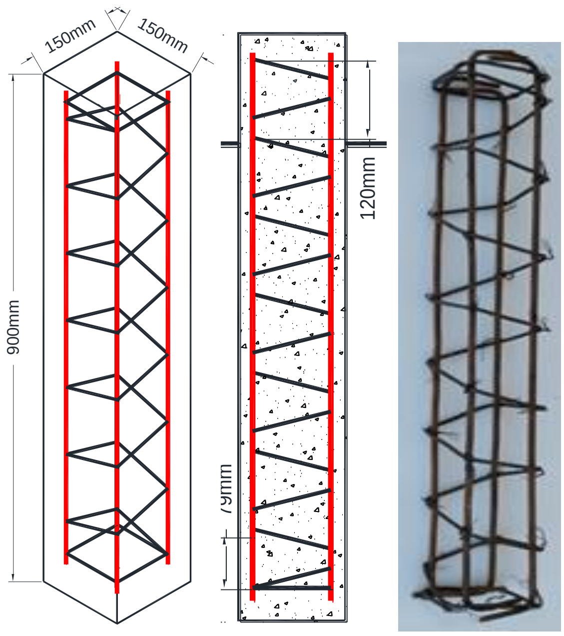


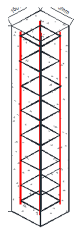
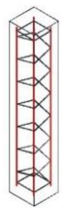
Fig 2 : Detailing of column CS_{e0}

The column specimens were divided into two groups as follows:

Group 1: Five reinforced concrete column specimens (CT_{e0}), (CT_{e1}), (CT_{e2}), (CT_{e3}) and (CT_{e4}) confined with traditional (separate) stirrups were tested under different eccentricities (e = 0%, 5 %, 10 %, 15 % and 25 %) as shown in [Figure 3 and 4].

Group 2: Five reinforced concrete column specimens (CS_{e0}), (CS_{e1}), (CS_{e2}), (CS_{e3}) and (CS_{e4}) confined with square spiral stirrups were tested under different eccentricities (e = 0%, 5 %, 10 %, 15 % and 25 %) as shown in [Figure 3 and 4].

Table 1: List of tested column specimens' details.

Group	Col. Code	Col. Dim.	Reinforcement		Key	eccentricity	
			Vertical	Stirrups Φ 6 mm / 12cm		e (mm)	e/t %
Group No. 1	CT_{e0}	150 X 150 X 900 mm	4 Ø8 mm	Traditional		0.0	0
	CT_{e1}					7.5	5
	CT_{e2}					15.0	10
	CT_{e3}					22.5	15
	CT_{e4}					37.5	25
Group No. 2	CS_{e0}			Spiral		0.0	0
	CS_{e1}					7.5	5
	CS_{e2}					15.0	10
	CS_{e3}					22.5	15
	CS_{e4}					37.5	25

2.1. TEST SETUP AND PROCEDURE

At the college of engineering, Al-Azhar University in Cairo, Egypt, all column specimens were tested under static load with a capacity of 2000 kN. To achieve the applicable eccentricity, the column head steel plates indicated in figure (3) were attached. Figure (4) depicts the test setup.

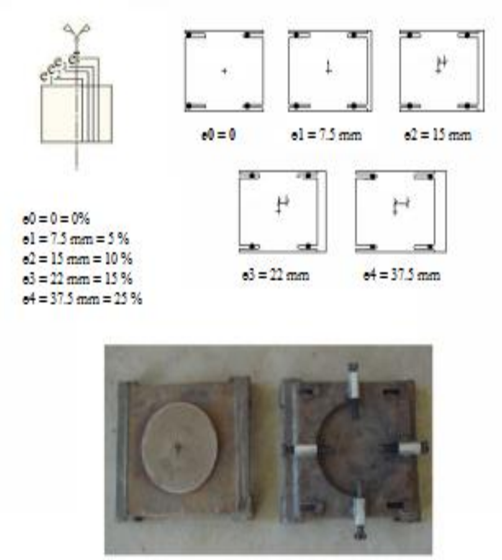


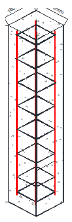
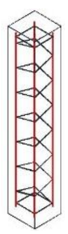
Fig. 3: Column head steel plates and eccentricity values

Fig. 4: Test loading.

3. EXPERIMENTAL TEST RESULTS

Figures 5–9 illustrate the failure load for all specimens, as well as the relationship between failure load and stirrup type at various eccentricities, in addition to the influence of stirrups on column carrying capacity at various eccentricities. The findings for all tested cases, however, are given in a table (2).

Table 2: All details of the tested column specimens as well as ultimate failure load.

Group	Col. Code	Key	Eccentricity		Failure load (kN) (EXP.)	Control Failure load (kN)	% Of Control Failure load	% Of CTe0 Failure load
			e (mm)	e/t%				
Group No. 1	CT_{e0}		0.0	0	531.79	531.79	0.000	0.000
	CT_{e1}		7.5	5	492.65		-7.360	-7.360
	CT_{e2}		15.0	10	430.43		-19.060	-19.06
	CT_{e3}		22.5	15	391.29		-26.420	-26.42
	CT_{e4}		37.5	25	305.35		-42.581	-42.58
Group No. 2	CS_{e0}		0.0	0	612.04	612.04	0.000	15.09
	CS_{e1}		7.5	5	582.72		-4.791	9.577
	CS_{e2}		15.0	10	530.17		-13.377	-0.305
	CS_{e3}		22.5	15	478.87		-21.758	-9.951
	CS_{e4}		37.5	25	395.44		-35.390	-25.64

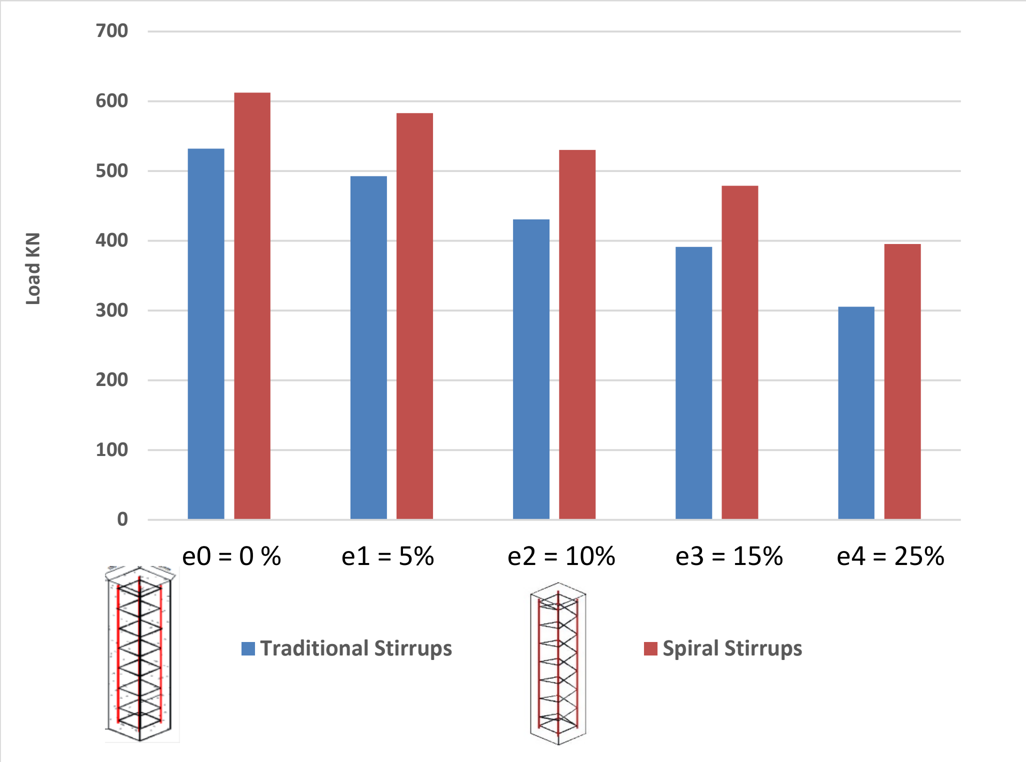


Fig. 5: Comparison of the maximum failure load for columns (Traditional and spiral stirrups) under different eccentricity.

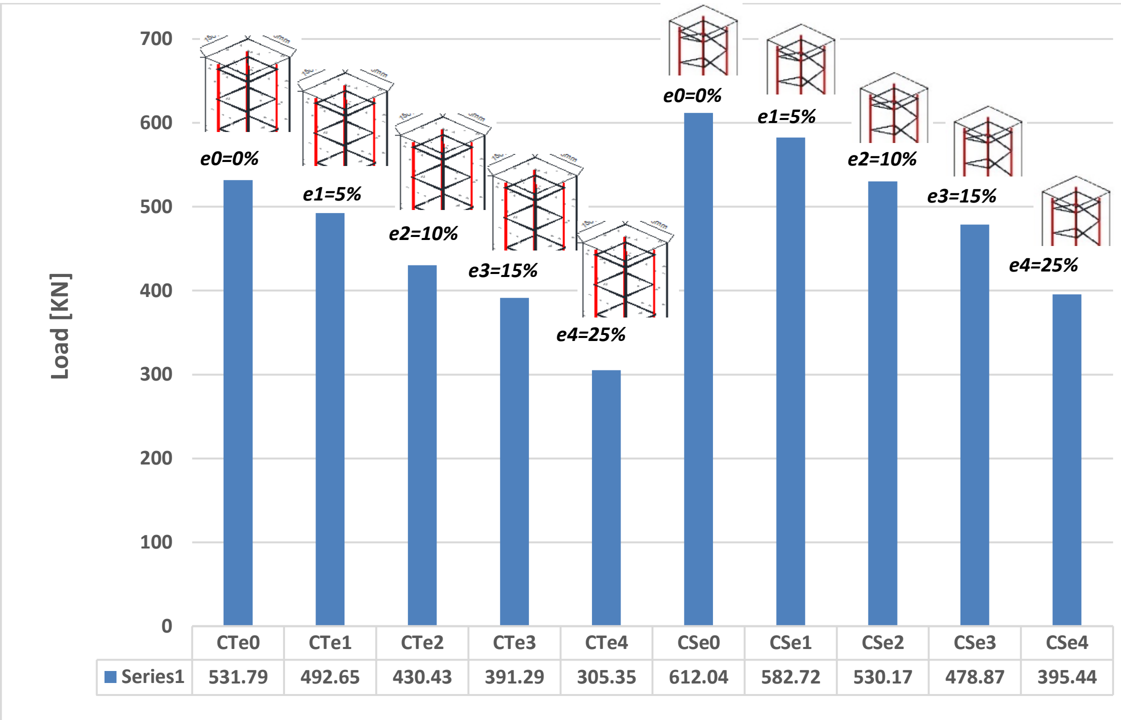


Fig. 6: Comparison of the failure load for columns (Traditional and spiral stirrups) under different eccentricity.

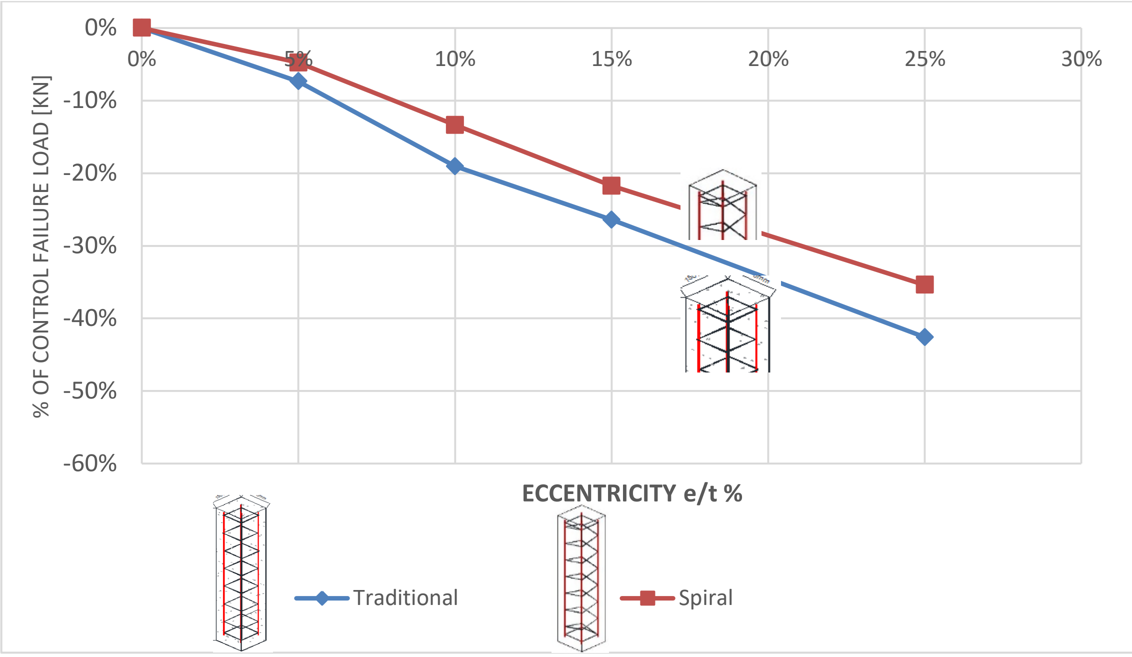


Fig. 7: Relation between eccentricity e/t and % of control failure load for columns confined with Traditional or spiral stirrups.

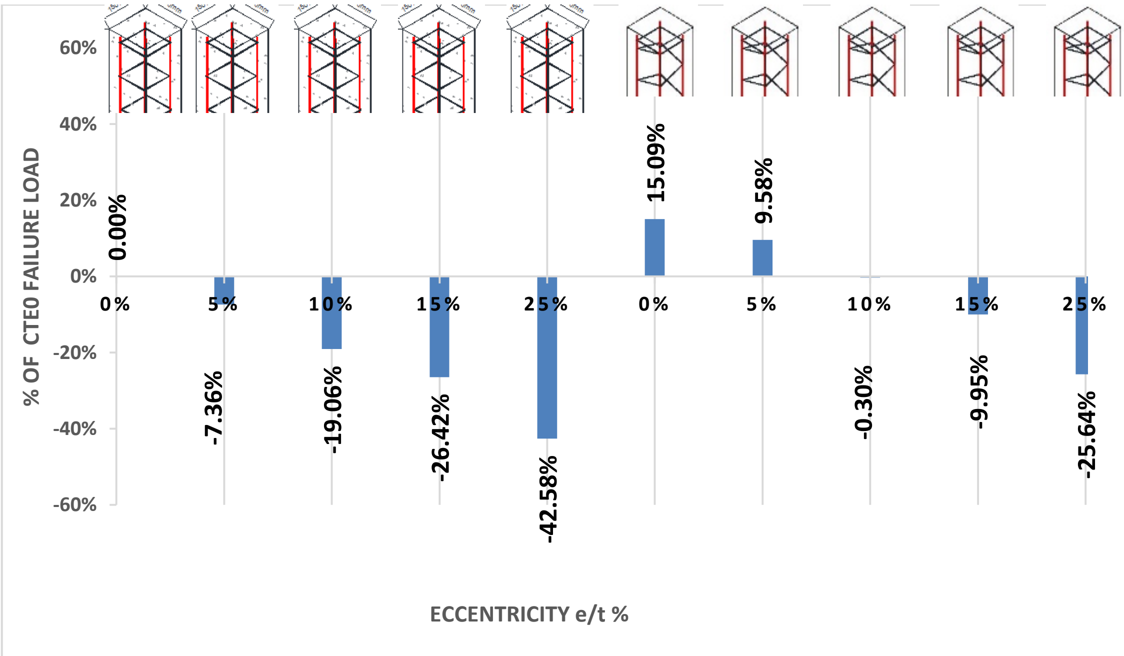


Fig. 8: Comparison % of failure load of column CT_{e0} failure load for columns confined with Traditional or spiral stirrups under different eccentricities.

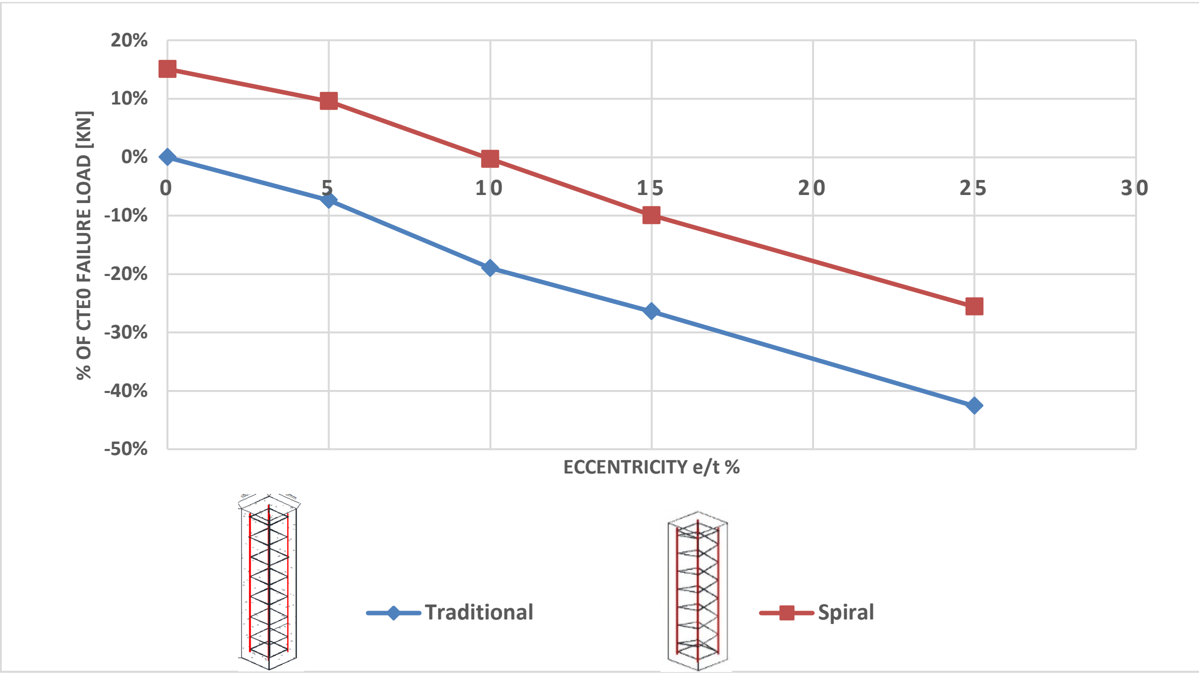


Fig. 9: Relation between eccentricity e/t and % of failure load of column CT_{e0} failure load for columns confined with Traditional or spiral stirrups.

4. FINITE ELEMENT MODELING

The current research focuses on modelling three-dimensional nonlinear finite element analysis (FEA) for short reinforced concrete columns. The ANSYS programme was used to execute the nonlinear FEA.

4.1. REINFORCEMENT CONCRETE

3-D (8-node) solid elements were used to simulate concrete and resin. Cracking in three perpendicular dimensions, plastic deformation and crushing, and creep are all could be considered using this element. The element is made up of eight nodes, each of which has three translation degrees of freedom in the x, y, and z directions.

4.2. STEEL REINFORCEMENT

The steel reinforcement was modelled using a Link180 element. This element necessitates the use of two nodes. In the nodal x, y, and z directions, each node has three degrees of freedom translations. Plastic deformation is also capable with this element.

4.3. CONCRETE

Concrete is considered as a quasi-brittle material. To reliably represent structural behaviour to failure and post-failure, complete stress-strain curves of concrete are required. The simplified uniaxial compressive stress-strain curve for concrete employed in this finite element model is constructed using ECP 203-2007, as illustrated in Fig. 10. According to ECP 203 2007, the Poisson's ratio for concrete was assumed to be 0.2 for all samples. Shear transfer coefficients typically vary from (0.0 to 1.0), with 0.0 denoting a smooth crack (complete loss of shear transfer) and 1.0 denoting a rough crack (no loss of shear transfer). A little amount of stiffness is imparted to the element when it is cracked or crushed for numerical stability.

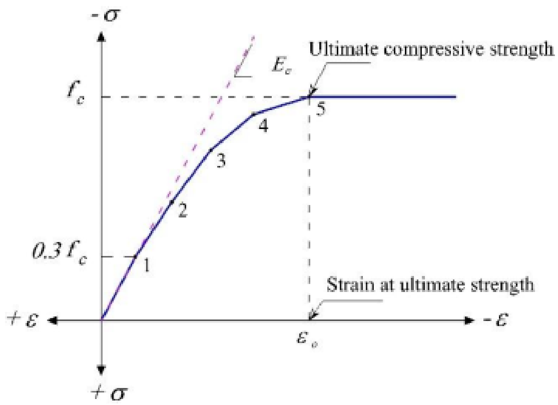


Fig. 10: Simplified compressive uniaxial stress-strain curve for concrete

4.4. STEEL REINFORCEMENT

As illustrated in Fig. 11, the reinforcement element was considered to be a bilinear isotropic elastic-perfectly plastic material that was identical in tension and compression. The modulus of elasticity and Poisson's ratio for all cases of steel reinforcement were set to 2 x 10^5 MPa and 0.3, respectively.

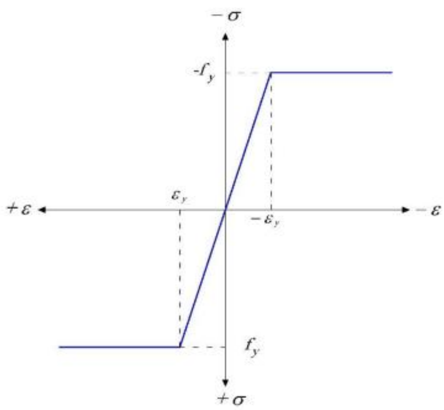


Fig. 11: Stress-strain relationship of steel rebar

4.5. FINITE ELEMENT MODEL

Ten column specimens with a cross section of 150X150 mm and a height of 900 mm are represented using a finite element model as follows:

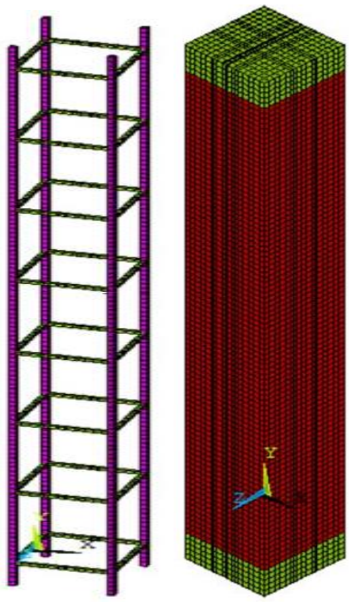


Fig. 12: shows the modeling and detailing of reinforced concrete column [CT_{e0}]

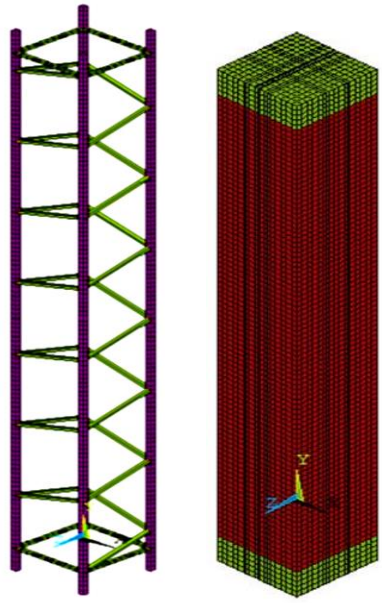


Fig. 13: shows the modeling and detailing of reinforced concrete column [CS_{e0}]

5. RESULTS AND ANALYSIS OF EXPERIMENTAL AND FINITE ELEMENT MODEL RESULT

Table (3) shows the maximum failure load calculated using experimental (EXP) tests compared to results of finite element (FEA) analysis. Figures 14, 15, and 16 provide a comparison of the results.

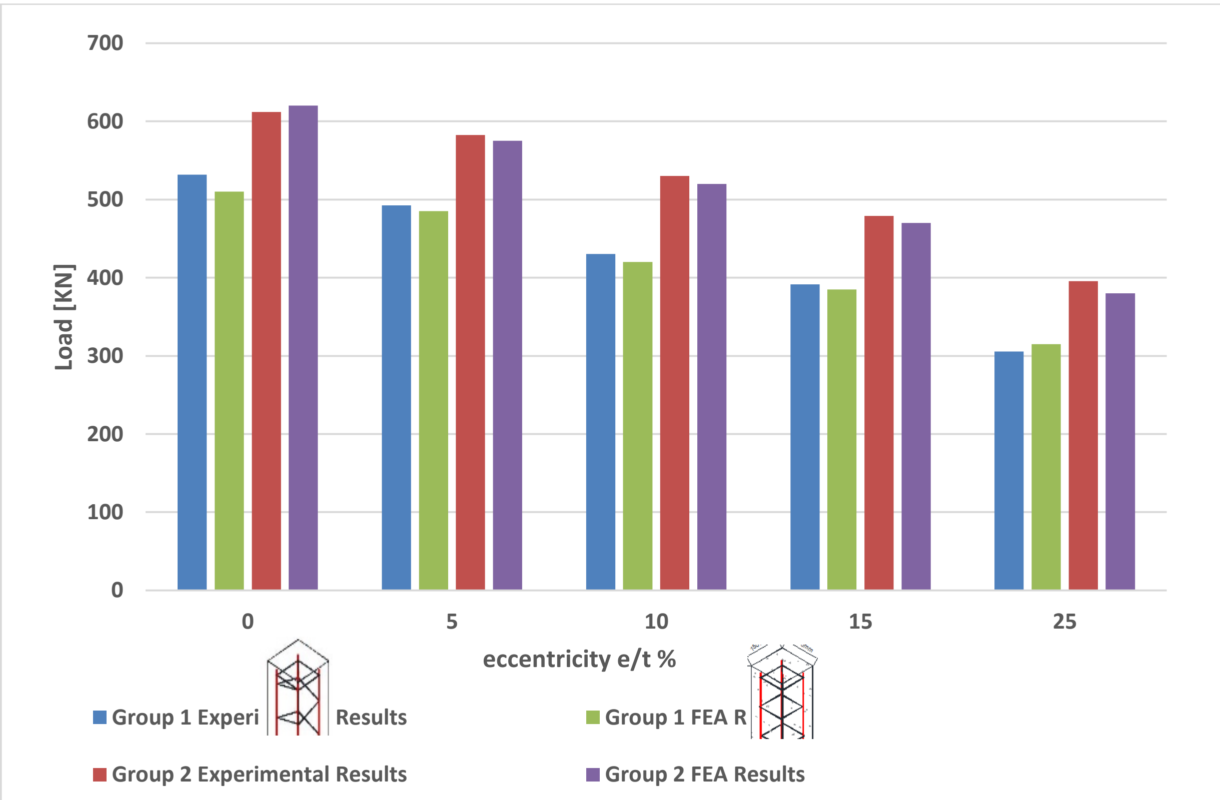


Fig. 14: shows the comparison of the maximum failure load obtained from experimental (EXP) and finite element (FEA) analysis.

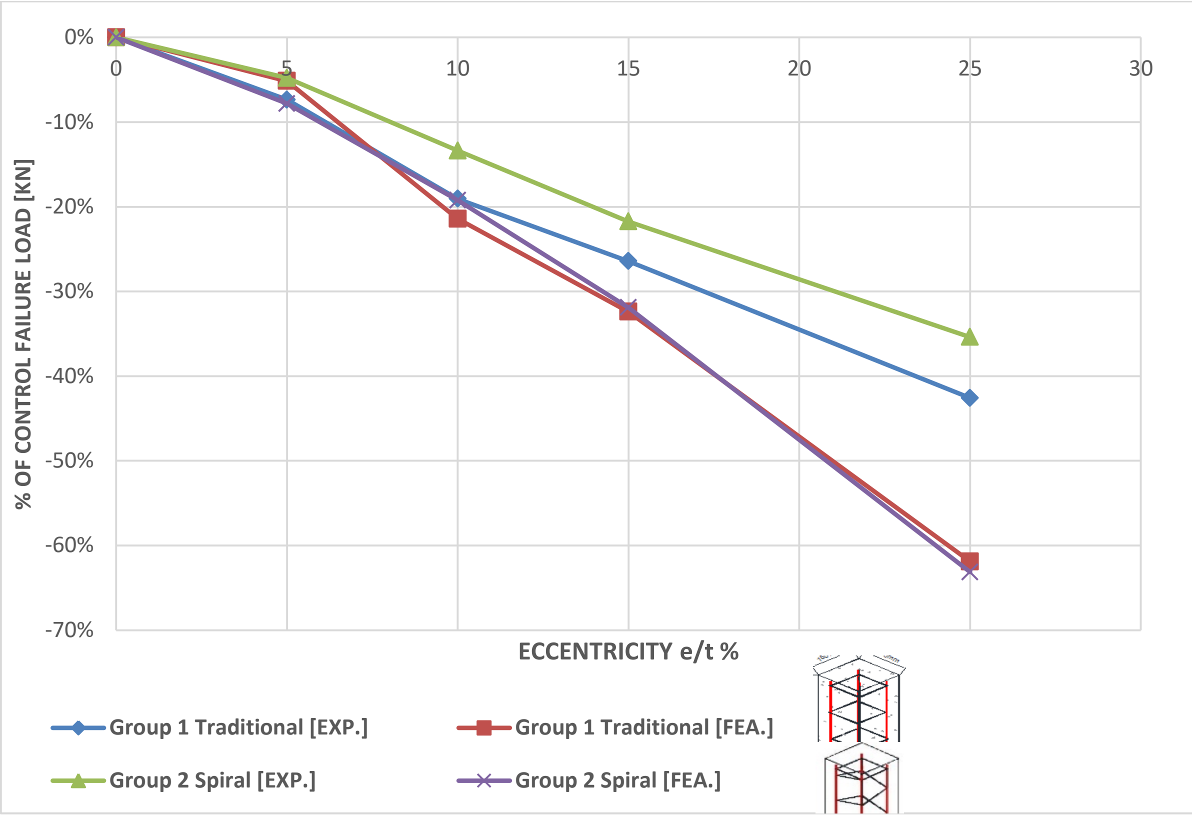


Fig. 15: Comparison between experimental and finite element results of % failure load of control failure load for columns (Traditional and spiral stirrups) under different eccentricity.

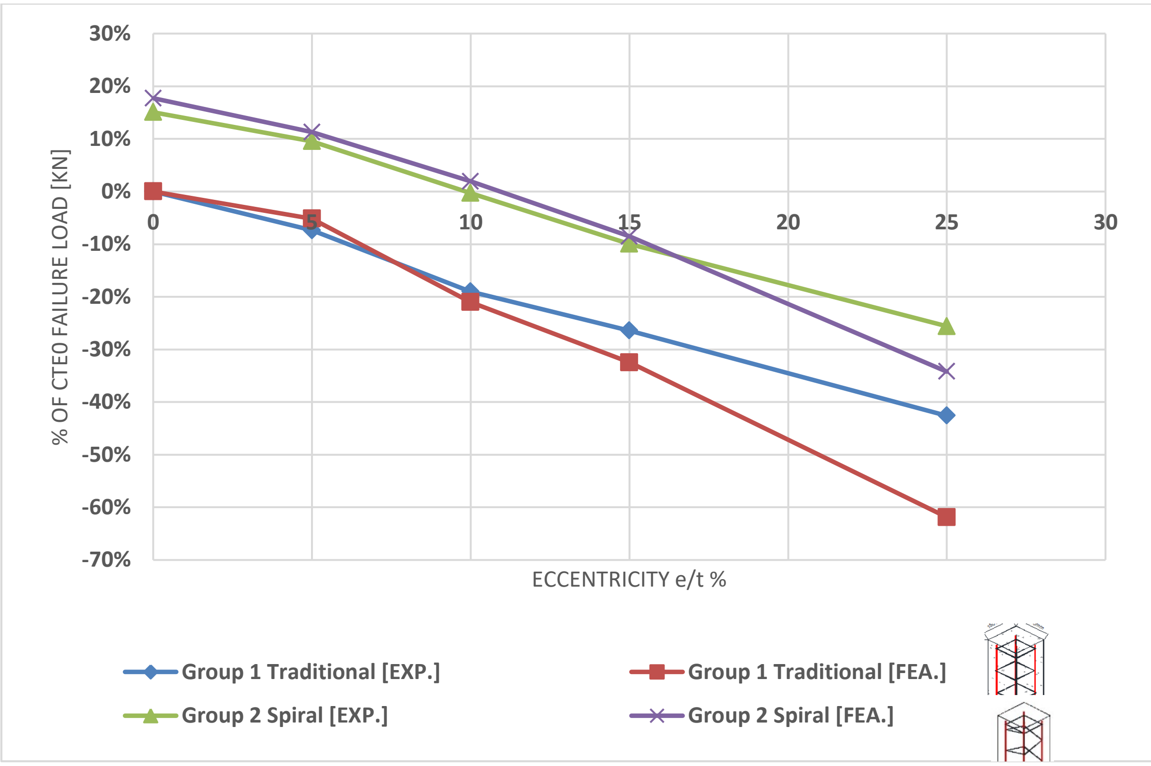


Fig. 16: Comparison between experimental and finite element results of % failure load of CTe0 failure load for columns (Traditional and spiral stirrups) under different eccentricity.

Table 3: The comparison of the maximum failure load obtained from experimental (EXP) and finite element analysis (FEA)

Group	Col. Code	eccentricity		Experimental Results			Finite Element Results		
		e(mm)	e/t%	Failure load (kN) (EXP.)	% Of Control Failure load	% Of CTe0 Failure load	Failure load (kN) (FEA.)	% Of Control Failure load	% Of CTe0 Failure load
Group No. 1	CT_{e0}	0	0	531.79	0	0	510	0	0
	CT_{e1}	7.5	5	492.65	-7.36	-7.36	485	-5.15	-5.15
	CT_{e2}	15	10	430.43	-19.06	-19.0	420	-21.42	-21.
	CT_{e3}	22.5	15	391.29	-26.42	-26.42	385	-32.4	-32.46
	CT_{e4}	37.5	25	305.35	-42.58	-42.58	315	-61.9	-61.90
Group No. 2	CS_{e0}	0	0	612.04	0	15.09	620	0	17.74
	CS_{e1}	7.5	5	582.72	-4.790	9.57	575	-7.82	11.30
	CS_{e2}	15	10	530.17	-13.37	-0.30	520	-19.23	1.923
	CS_{e3}	22.5	15	478.87	-21.75	-9.95	470	-31.9	-8.510
	CS_{e4}	37.5	25	395.4	-35.38	-25.6	380	-63.15	-34.21

6. FAILURE MODES

Figures 17, 18 demonstrate how the column (CTe0) with the measured axial load is utilised as a baseline for comparing the performance advantages of the proposed strengthening techniques (CSe0).

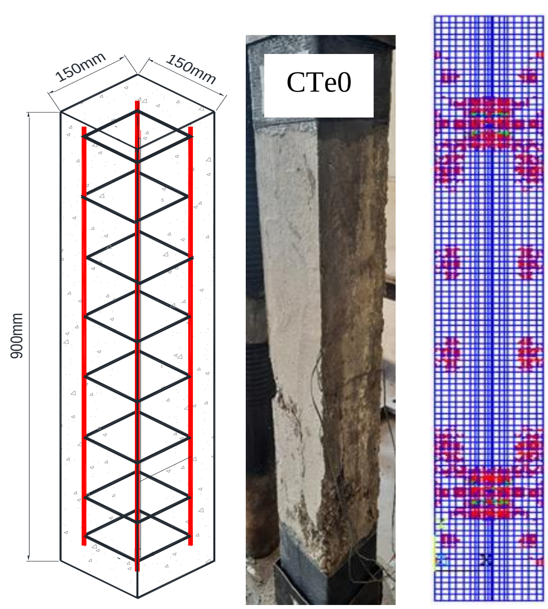


Fig. 17: Crack pattern of control column (CTe0).

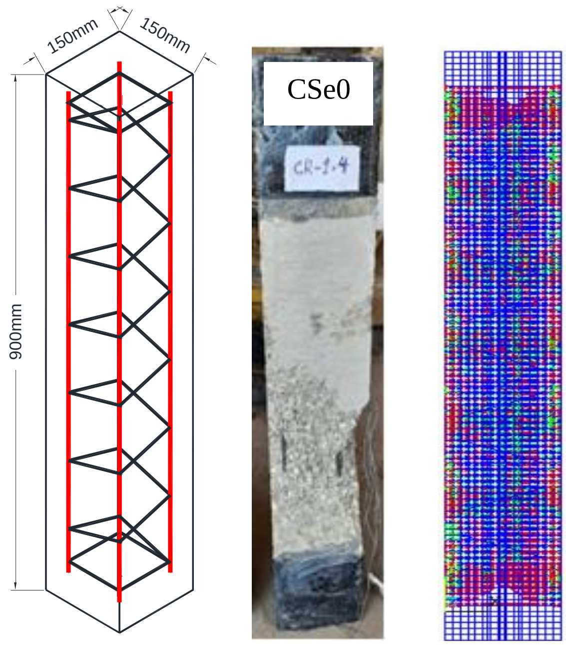


Fig. 18: Crack pattern of control column (CSe0).

7. CONCLUSIONS

The following conclusions were drawn from this study:

- When square spiral stirrups are used to confine a column, the column carrying capacity increases by 15% to 29.5% when compared to a column confined with traditional stirrups at the same eccentricity (e/t = 0 percent to 25%).
- By increasing eccentricity (e/t) from 5% to 25%, the column carrying capacity of column specimens confined with traditional (separate) stirrups decreases from 7.36 percent to 42.58 percent.
- By increasing eccentricity (e/t) from 5% to 25%, the column carrying capacity of column specimens constrained by spiral square stirrups decreases from 4.79 percent to 35.39 percent.
- The use of spiral steel stirrups has been shown to be effective in improving the carrying capacity and ductility of columns subjected to eccentric loads.
- In general, experimental and finite element analysis findings have been shown to be in good agreement.

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