

# Numerical Modelling of the Stress–Strain Curve of Confined Concrete in Rectangular and Square CFST Elements Under Axial Compression

S. K. Katariya<sup>1</sup>, Alok Bhatt<sup>2</sup>, Pankaj Prasad<sup>3</sup>

<sup>1</sup>Associate Professor, Civil Department, G.B. Pant University of Agriculture and Technology Pantnagar  
Dist. U.S Nagar (Uttarakhand), India 263145)

<sup>2</sup>M. Tech. Student, Civil Department, G.B. Pant University of Agriculture and Technology Pantnagar  
Dist. U.S Nagar (Uttarakhand), India 263145

<sup>3</sup>Assistant Professor, College of Technology, SVPUAT Meerut (UP), India 263145)

**Abstract**—Concrete-filled steel tube (CFST) column specimens are widely recognized for their superior ductility, enhanced axial load-carrying capacity, and excellent energy absorption characteristics. However, their application in practice remains limited, primarily because the existing IS Codes do not adequately address the behaviour or axial capacity of CFST columns. In this study, a numerical model is developed to represent the stress–strain behaviour of confined concrete under axial compression in rectangular and square CFST column specimens. The proposed model is applicable for concrete with a cylindrical compressive strength ranging from 30 MPa to 100 MPa.

**Index Terms**—CFST, Axial capacity, Load, Axial, Axial shortening

## I. INTRODUCTION

Concrete-filled steel tube (CFST) columns are composite structural members consisting of an outer steel tube filled with concrete. Under axial compression, the steel tube not only carries part of the total axial load but also provides passive confinement to the concrete core, enhancing its strength and ductility. The infilled concrete, in turn, restrains inward local buckling of the steel tube, thereby increasing its critical buckling strength and improving the overall performance of the composite column [1–3]. At the member level, CFST columns offer several advantages over conventional reinforced concrete columns, including enhanced fire resistance, higher load-carrying capacity, improved global buckling resistance, and reduced time-dependent

effects such as creep and shrinkage [4]. The axial compressive behaviour of CFST columns has been extensively studied experimentally [5–7] and analytically [8–10], and several design codes and specifications have been established [11]. In this study, CFST columns with different cross-sections—specifically rectangular and square were considered. A constitutive equation for confined concrete was developed to determine the stress corresponding to any given strain.

To formulate this equation, experimental data from various research studies were compiled, and the reported load–strain and load–deformation curves were digitized. From these experimental results, the confined concrete stresses and the corresponding deformation/strain responses were extracted. Based on this dataset, a nonlinear stress–strain model was proposed to represent the behaviour of confined concrete under axial compression. A total of eleven specimens were used to validate the proposed equation. For the study the cylinder strength of concrete ranging between 30 MPa to 110 MPa were taken. The equations are based on axial shortening and average load values. The obtained equations from each group is compared to the experimental curves obtained from various research papers. It was found that the results obtained through developed equation well matched with the results obtained with the experimental work of same specimens. The different type of sections of CFST columns are shown in Fig. 1.

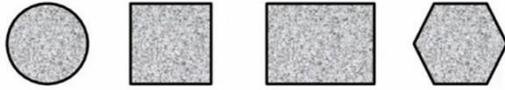


Fig. 1 Sections of Concrete Filled Steel Tubular (CFST) column cross-sections

II. NUMERICAL MODEL FOR CONFINED CONCRETE

Where the cylinder strength of concrete was not provided, the given cube strength was converted into an equivalent cylinder strength using the relation: Cylinder strength = Modification factor × Cube strength (MPa). Table 1 presents the calculated cylinder strengths of the in-filled concrete used in the CFST specimens.

Table 1 Cylinder strength of concrete of CFST specimens

Specimen	$f'_c$ (MPa)	Reference
R1-1	54.00	Liu (2005)
R2-2	54.00	
R3-2	54.00	
C1-2	65.63	Liu (2003)
C2-2	78.42	
C-3	65.63	
C-4	78.42	
C5-1	65.63	
C6-2	78.42	
A4-1	83.00	
R7-1	83.00	

The behaviour of confined concrete under axial compression was represented using the following nonlinear equation:

where the constants are:

$$a = 1, b = 0.01, d = 6.2 \times 10^{-8}$$

The parameter  $c$  is defined as:

$$c = \frac{k + gf'_c}{1 + hf'_c + if'_c{}^2}$$

with:  $k = -0.0072, g = 0.00036, h = 0.71$  and  $i = 0.0001$

In this formulation:

- $y$ = confined concrete stress (MPa)
- $x$ = axial strain (multiplied by  $10^6$ )
- $f'_c$ = cylinder compressive strength of concrete (MPa)

Table. 2 Stress-Strain values of steel according to Han (2000) model [18]

Strain	Stress (MPa)
$\epsilon_e = \frac{0.8 \times f_y}{E_s}$	$f_p = E_s \times \epsilon_e$
$\epsilon_{e1} = 1.5 \times \epsilon_e$	$f_y$
$\epsilon_{e2} = 10 \times \epsilon_{e1}$	$f_y$
$\epsilon_{e3} = 10 \times \epsilon_{e2}$	$f_u$

$f_y$  is yields strength of steel,  $f_u$  is ultimate strength of steel,  $\epsilon_e$  is strain in steel,  $E_s$  is modulus of elasticity of steel. Table 3 shows the calculation procedure for the load capacity at any value of strain in the specimen.

Table. 3 Calculation for specimen C1-2 in tabular form

Strain	Stress $S_{st}$ (MPa)	Load <sub>st</sub> (kN)	Stress $S_{con}$ (MPa)	Load <sub>c</sub> (kN)	Load <sub>co</sub> (kN)
0	0	0	0	0	0
0.0001	20.00	32.38	2.06	17.77	50.15
0.0005	100.00	161.90	7.10	61.03	222.93
0.0010	200.00	323.80	15.27	131.25	455.05
0.0015	300.00	485.70	25.54	219.41	705.11
0.0020	400.00	647.60	37.23	319.90	967.50
0.0025	470.00	760.93	48.83	419.51	1180.44
0.0030	520.00	841.88	58.27	500.67	1342.55
0.0033	550.00	890.45	62.21	534.48	1424.93
0.0035	550.00	890.45	64.01	549.91	1440.36
0.0036	550.00	890.45	64.65	555.48	1445.93
0.0038	550.00	890.45	65.48	562.55	1453.00
0.0040	550.00	890.45	65.71	564.56	1455.01
0.0042	550.00	890.45	65.43	562.12	1452.57
0.0045	550.00	890.45	64.21	551.63	1442.08

0.00 46	550.0 0	890.4 5	63.63	546.6 7	1437.1 2
0.00 48	550.0 0	890.4 5	62.28	535.0 5	1425.5 0
0.00 50	550.0 0	890.4 5	60.72	521.6 7	1412.1 2
0.00 52	550.0 0	890.4 5	59.02	507.0 7	1397.5 2
0.00 55	550.0 0	890.4 5	56.31	483.8 2	1374.2 7
0.00 60	550.0 0	890.4 5	51.70	444.1 6	1334.6 1
0.00 65	550.0 0	890.4 5	47.26	406.0 6	1296.5 1
0.00 70	550.0 0	890.4 5	43.19	371.0 6	1261.5 1
0.00 75	550.0 0	890.4 5	39.53	339.6 5	1230.1 0
0.00 80	550.0 0	890.4 5	36.29	311.7 9	1202.2 4
0.00 85	550.0 0	890.4 5	33.43	287.2 2	1177.6 7
0.00 90	550.0 0	890.4 5	30.91	265.5 7	1156.0 2
0.00 95	550.0 0	890.4 5	28.68	246.4 6	1136.9 1
0.01 00	550.0 0	890.4 5	26.72	229.5 6	1120.0 1
0.01 05	550.0 0	890.4 5	24.97	214.5 6	1105.0 1
0.01 10	550.0 0	890.4 5	23.41	201.1 9	1091.6 4
0.01 15	550.0 0	890.4 5	22.02	189.2 3	1079.6 8
0.01 20	550.0 0	890.4 5	20.77	178.4 9	1068.9 4
0.01 25	550.0 0	890.4 5	19.65	168.8 1	1059.2 6
0.01 30	550.0 0	890.4 5	18.62	160.0 5	1050.5 0
0.01 35	550.0 0	890.4 5	17.70	152.0 8	1042.5 3
0.01 40	550.0 0	890.4 5	16.85	144.8 3	1035.2 8
0.01 45	550.0 0	890.4 5	16.08	138.1 9	1028.6 4

0.01 50	550.0 0	890.4 5	15.37	132.1 0	1022.5 5
0.01 55	550.0 0	890.4 5	14.72	126.5 0	1016.9 5
0.01 60	550.0 0	890.4 5	14.12	121.3 3	1011.7 8
0.01 65	550.0 0	890.4 5	13.56	116.5 4	1006.9 9
0.01 70	550.0 0	890.4 5	13.04	112.1 1	1002.5 6
0.01 75	550.0 0	890.4 5	12.56	107.9 8	998.43
0.01 80	550.0 0	890.4 5	12.12	104.1 4	994.58
0.01 85	550.0 0	890.4 5	11.70	100.5 4	990.99
0.01 90	550.0 0	890.4 5	11.31	97.18	987.63
0.01 95	550.0 0	890.4 5	10.94	94.03	984.48
0.02 00	550.0 0	890.4 5	10.60	91.07	981.52
0.02 05	550.0 0	890.4 5	10.27	88.29	978.74
0.02 10	550.0 0	890.4 5	9.97	85.66	976.11
0.02 15	550.0 0	890.4 5	9.68	83.19	973.64
0.02 20	550.0 0	890.4 5	9.41	80.84	971.29
0.02 25	550.0 0	890.4 5	9.15	78.63	969.08
0.02 30	550.0 0	890.4 5	8.90	76.52	966.97
0.02 35	550.0 0	890.4 5	8.67	74.53	964.98
0.02 40	550.0 0	890.4 5	8.45	72.63	963.08
0.02 45	550.0 0	890.4 5	8.24	70.83	961.28
0.02 50	550.0 0	890.4 5	8.04	69.11	959.56
0.03 00	550.0 0	890.4 5	6.46	55.56	946.01
0.03 50	550.3 9	891.0 8	5.40	46.40	937.48
0.04 00	551.3 6	892.6 5	4.63	39.81	932.46

0.0450	552.34	894.23	4.05	34.85	929.09
0.0500	553.31	895.82	3.60	30.98	926.81
0.0550	554.29	897.39	3.24	27.88	925.28
0.0600	555.27	898.98	2.95	25.34	924.33
0.0650	556.24	900.55	2.70	23.23	923.78
0.0700	557.22	902.13	2.49	21.44	923.58
0.0750	558.20	903.72	2.31	19.90	923.63
0.0800	559.17	905.30	2.16	18.57	923.88
0.0850	560.15	906.89	2.02	17.41	924.30
0.0900	561.13	908.47	1.90	16.38	924.85

Based on the steel model suggested by Han and the proposed confined concrete model, the experimental results of various CFST columns under axial compression were validated. The comparisons, presented in Fig. 2 to Fig. 12, show that the predicted curves closely match the experimental data, indicating good agreement between the proposed models and the test results.

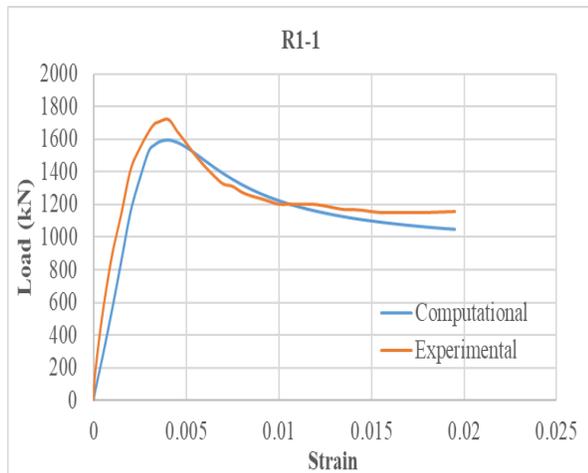


Fig. 2 Comparison of computational and experimental load-strain behaviour for specimen R1-1

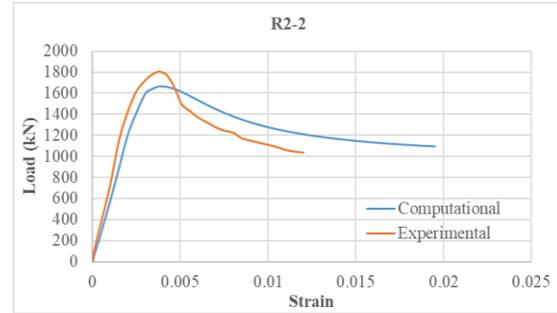


Fig. 3 Comparison of computational and experimental load-strain behaviour for specimen R2-2

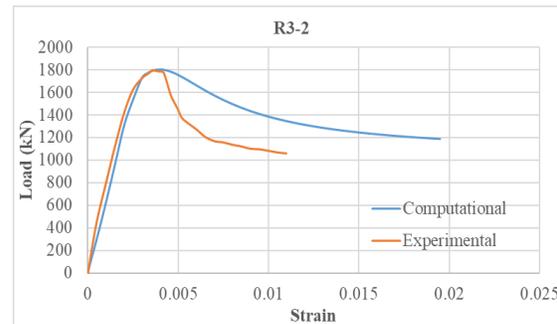


Fig. 4 Comparison of computational and experimental load-strain behaviour for specimen R3-2

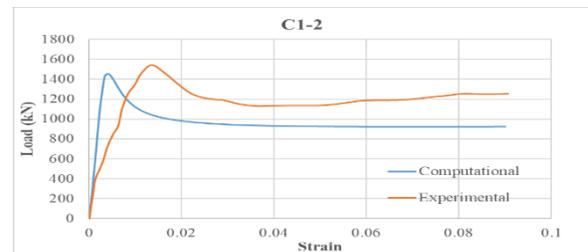


Fig. 5 Comparison of computational and experimental load-strain behaviour for specimen C1-2

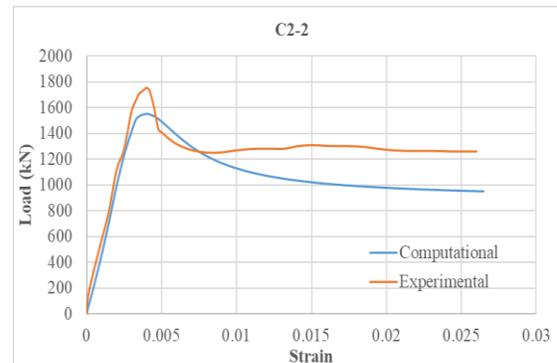


Fig. 6 Comparison of computational and experimental load-strain behaviour for specimen C2-2

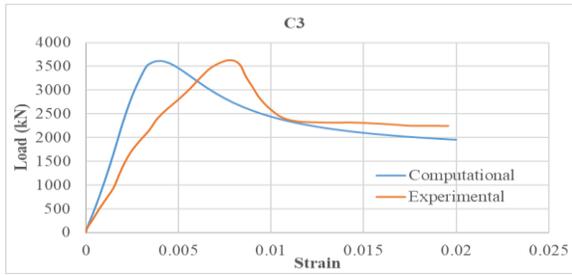


Fig. 7 Comparison of computational and experimental load-strain behaviour for specimen C3

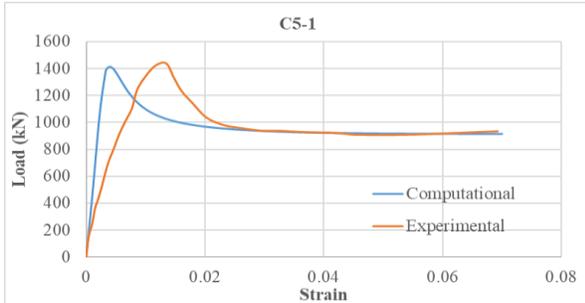


Fig. 9 Comparison of computational and experimental load-strain behaviour for specimen C5-1

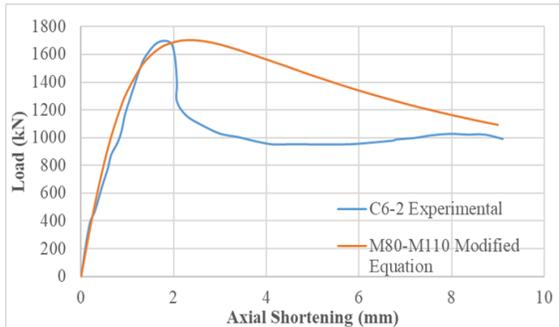


Fig. 10 Comparison of computational and experimental load-strain behaviour for specimen C6-2

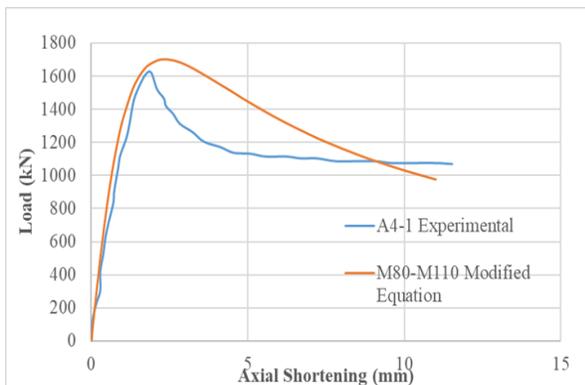


Fig. 11 Comparison of computational and experimental load-strain behaviour for specimen A4-1

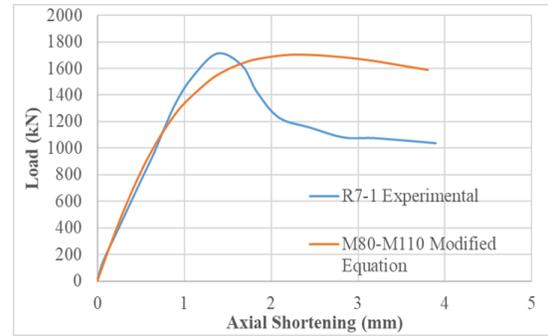


Fig. 12 Comparison of computational and experimental load-strain behaviour for specimen R7-1

### III RESULTS AND DISCUSSION

To develop the nonlinear equation for the infilled concrete in CFST columns, the adopted range of concrete cylinder strengths was 30 MPa to 100 MPa. The load-carrying capacity of square and rectangular CFST columns, when estimated using the proposed model, was found to be approximately 5% lower than the corresponding capacities obtained from experimental results. This deviation ensures a safety margin of about 5%, making the proposed formulation conservative and suitable for design applications.

### IV CONCLUSIONS

1. The proposed numerical model for the stress-strain behaviour of confined concrete in CFST column specimens was validated for concrete with a cylindrical compressive strength ranging from 30 MPa to 100 MPa.
2. The proposed equation accurately reproduced the overall trend of the experimentally observed load-strain curves for the corresponding CFST column specimens.
3. A noticeable increase in the axial load-carrying capacity of CFST column specimens was observed due to the confinement provided by the steel tube in both rectangular and square configurations.
4. The enhancement in axial strength resulting from steel confinement was evident across all considered concrete grades; however, the rate of improvement gradually decreased from M30 to M100.

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