# A Comparison Of ACI-318(2005) And Euro Code 4 (2004) For Uniaxially Loaded Composite Column

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*Abstract :* Steel concrete composite systems have been widespread use in recent decades because of the benefits of combining the two construction materials. Reinforced concrete is inexpensive, massive and stiff, while steel members are strong, light weight and easy to assemble. In composite columns there are two principle types, Steel Reinforced Concrete (SRC) where a steel section is encased in concrete fully or partially and Concrete Filled Steel Tubes (CFST). Indian standard codes IS: 11384 (1985) and IS: 3935 (1966) for Composite Constriction have not covered the design of for uniaxially loaded steel concrete composite columns. Recent code IS: 800 (2007) has also not furnished the limit state design of composite columns. Therefore to design composite columns we need to go for different codes in use worldwide. EC 4 (2004) gives plastic stress distributions at different point in interaction curve for Uniaxially loaded composite column. ACI-318 (2005) gives strain compatibility method to draw interaction curve for Uniaxially loaded composite column. American Concrete Institute (ACI)-318 (2005) and Eurocode (EC) 4 (2004) design approaches for Uniaxially loaded Steel concrete composite columns are compared for Previous experimental studies. The ratio of Test/ Code is compared with concrete strength, steel strength, percentage of steel and width to thickness for both codes.

*IndexTerms–* **Fully Encased Steel Reinforced Concrete (SRC), Square Concrete Filled Steel Tubes (CFST), and Circular Concrete Filled Steel Tubes (CFST).**

## I. Introduction

There are three different types of composite columns; commonly in use are Fully Encased SRC Section, Square CFST Section and Circular CFST Section as shown in Fig 1. The experimental test data of these three types of Composite columns subjected to axially compression with uniaxial bending are collected from the previous Researchers. $P_{test}$ is a axial load in kN and $M_{test}$ respective moment in kN-m applied on experimental test sample. An interaction curve is drawn for each experimental test sections as per ACI-318 (2005) and EC4 (2004) using excel worksheet. For fixed value of axial load $P_{test}$ and $M_{ACI}$ or $M_{EC4}$ moments are identified in interaction curve. The ratios of Test/ACI and Test/ EC4 are calculated and compared with concrete strength, steel strength, percentage of steel and width to thickness. The calculated strength values are also statistically analyzed using indicators Mean, Standard deviation and Coefficient of variation.

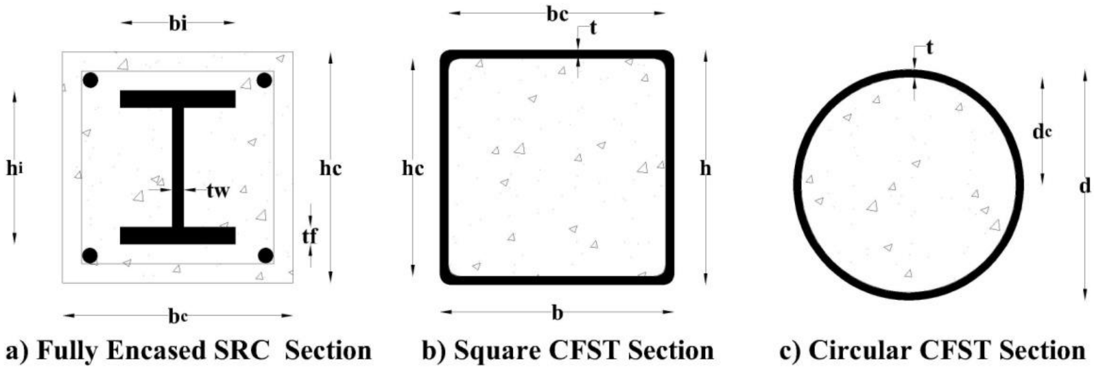


**Fig 1: Different types of Composite column sections**

## 2. CODE PROVISION FOR UNIAXIALLY LOADED COMPOSITE COLUMN

### ACI-318 (2005)

The Axially Compression with Uniaxial Bending Column is calculated using strain-compatibility method.

- Subdivide the cross section into a large number of areas.
- Assume a strain distribution across the cross-section and a location of the neutral axis.
- Compute stresses based on the assumed stress-strain relationships for the different components (concrete, reinforcing bars, and the steel shape).
- Integrate the stresses over the cross section to obtain the total axial load and the moment about the plastic neutral axis (or other commonly assumed axis).
- Iterate steps 2 through 4 to obtain an axial load-moment interaction surface for the column.

Fig. 2.a shows the subdivision of the cross-section into a series of "fibers" representing three different materials: confined concrete inside the ties (shaded), reinforcing bar steel, and rolled shape steel. Fig. 2.b shows a linear strain distribution with an arbitrary location of the neutral axis. Fig. 2.c shows the material properties. For each material, it shows both the nonlinear stress-strain curves as may be assumed for the strain-compatibility analysis and the bilinear rigid-plastic curves (dashed lines) that would be assumed for a simplified analysis.

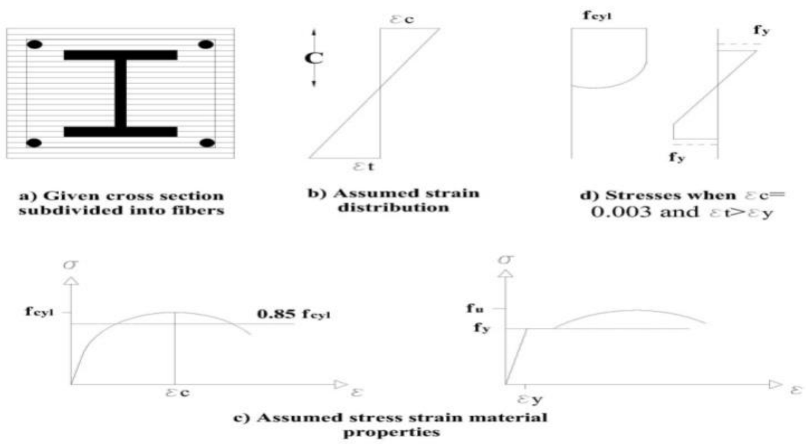


**Fig. 2: Development of composite beam-column cross-section strength EC4 (2004)**

The cross-sectional resistance of a composite column under axial compression and uniaxial bending is given by an M-P interaction curve as shown in Fig. 4.

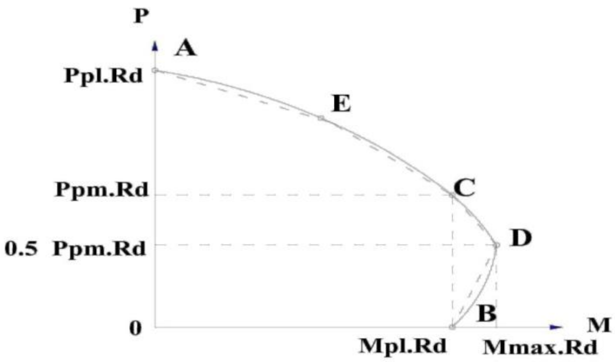


**Fig. 3: M-P interaction curve for Uniaxial bending**

- **Point A :** Axial compression resistance alone:

$$P_A = P_{pl.Rd}$$
$$M_A = 0$$

- **Point B :** Uniaxial bending resistance alone:

$$P_B = 0$$
$$M_B = M_{pl.Rd}$$

- **Point C :** Uniaxial bending resistance identical to that at point B, but with non-zero resultant axial compression force:

$$P_C = P_{pm.Rd} = A_c \, 0.85 \, \frac{f_{cyl}}{\gamma_c} \text{ (concrete encased section)}$$

- $= P_{pm.Rd} = A_c \frac{f_{cyl}}{\gamma_c}$ (concrete filled hollow section)

$$M_B = M_{pl.Rd}$$

Note: $\mathbf{f_{cyl}}$ may be factored by $\left[\mathbf{1+\ \eta_1 \frac{t}{d}\frac{f_{ys}}{f_{cyl}}}\right]$for circular concrete filled hollow section

❖ **Point D :** Maximum moment resistance

$$\mathbf{P_D} = \frac{1}{2}\,\mathbf{P_{pm.Rd}} = \frac{1}{2}\,\mathbf{A_c}\frac{\mathbf{f_{cyl}}}{\boldsymbol{\gamma_c}} \text{ (Concrete- encased section)}$$

$$\mathbf{P_D} = \frac{1}{2}\,\mathbf{P_{pm.Rd}} = \frac{1}{2}\,\mathbf{A_c}\frac{\mathbf{f_{cyl}}}{\boldsymbol{\gamma_c}} \text{ (Concrete- filled hollow section)}$$

Again $\mathbf{f_{cyl}}$ may be factored by $\left[\mathbf{1+\ \eta_1 \frac{t}{d}\frac{f_{ys}}{f_{cyl}}}\right]$for circular concrete filled hollow section in which $\mathbf{Z_s}$, $\mathbf{Z_c}$, and $\mathbf{Z_r}$ are the plastic moduli of steel, concrete and reinforcement respectively.

❖ **Point E :** Situated midway between **A** and **C**.

## 3. METHDOLOGY

i. Collection of experimental data from previous researchers for composite columns
ii. For collected test samples size, strength of concrete, strength of steel and other parameters interaction curve is drawn as per ACI-318(2004) as shown in figure 4 and as per EC4 as shown in figure 5
iii. For fixed value of axial load $P_{test}$ and $M_{ACI}$ or $M_{EC4}$ moments are identified in interaction curve.
iv. The ratio of Test/ ACI and Test/ EC4 are calculated.
v. Test/ ACI and Test/ EC4 compared with graphs for concrete strength, steel strength, percentage of steel and width to thickness for both codes.

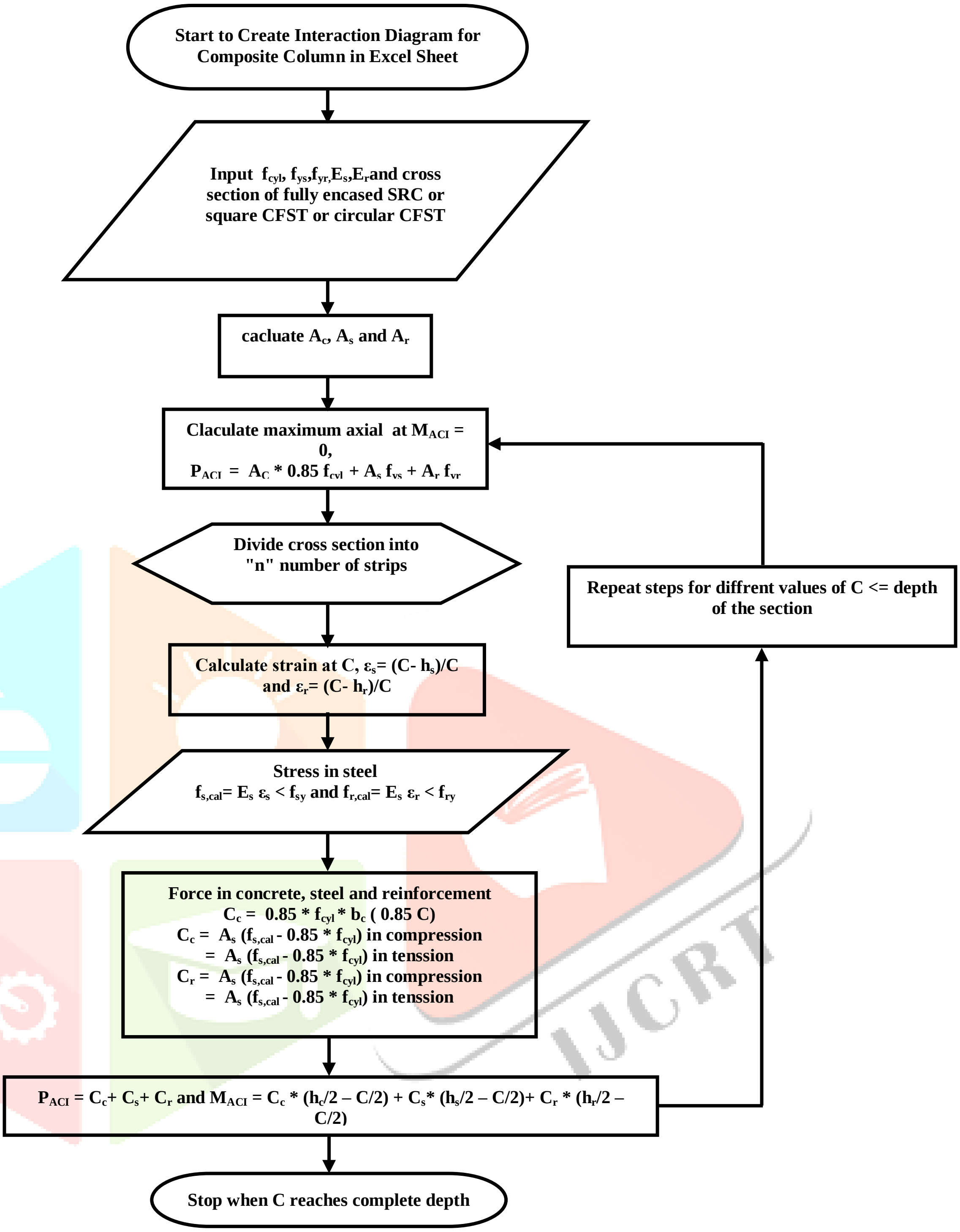


**Fig 4:Flow chart to draw interaction curves for composite columns section as per as per ACI**

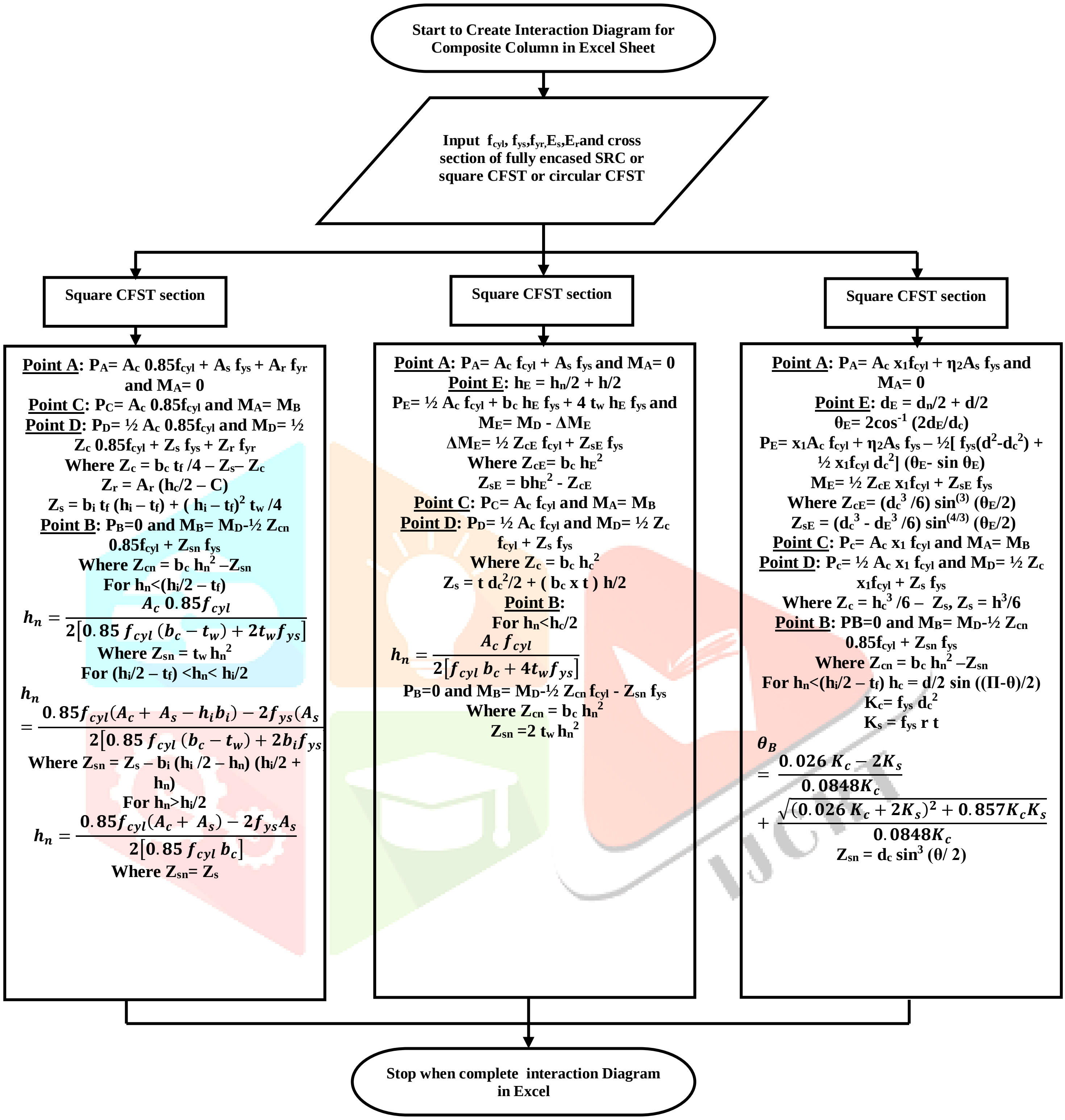


**Fig. 5: Flow chart to draw interaction curves for composite columns section as per EC4**

## 4. COMPARATIVE RESULTS OF UNIAXIALLY LOADED FULLY ENCASED SRC

Test results of 28 fully encased SRC sections are compared with ACI and EC4. Individual specimens used by previous researchers are identified by notations Mirza (MXXX), Ricles (RXXX), Naka (NXXX) and Wakabayashi (WXXX). Loading is indicated by XUXX (Uniaxial bending with axial compression). Section is indicated by XXFX (Fully encased) and XXXS (Steel reinforced concrete). The sample of interaction curve specimen MUFS1, 2 and 3 is as shown in figure 6. Similarly interaction curves are drawn to reaming specimens for different data. The comparison of uniaxially loaded fully encased SRC column for ACI and EC4 are tabulated in Table1. Graphs are drawn for $M_{Test}/M_{ACI}$ ( or) $M_{test}/M_{ACI}$ ratio verses concrete cylinder strength, yield strength of steel and percentage of steel as shown in figure 7, 8 and 9.

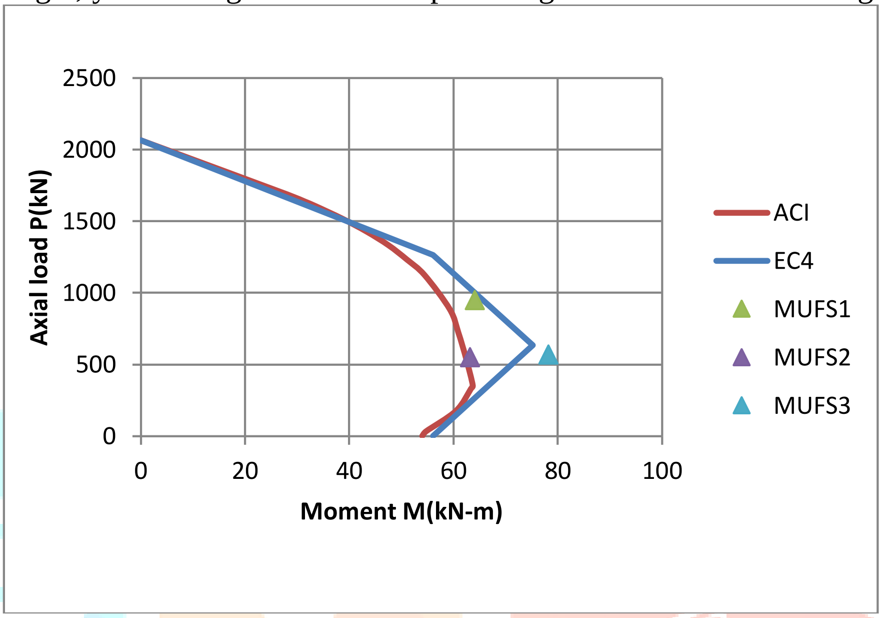


**Fig. 6: Interaction curve sample of fully encased SRC column for specimens MUFS1, 2 and 3**

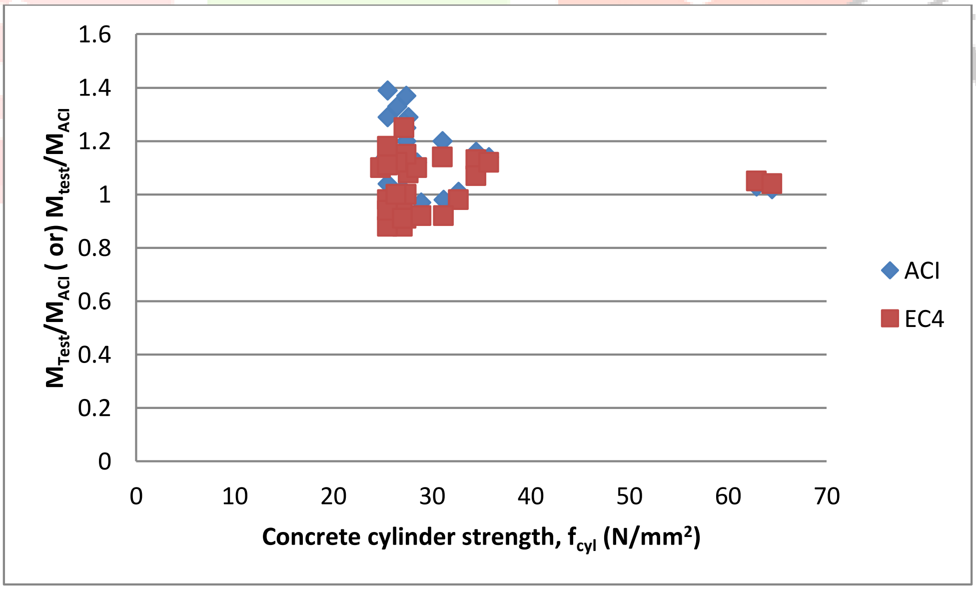


**Fig. 7: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs concrete cylinder strength of uniaxially loaded fully encased SRC columns**

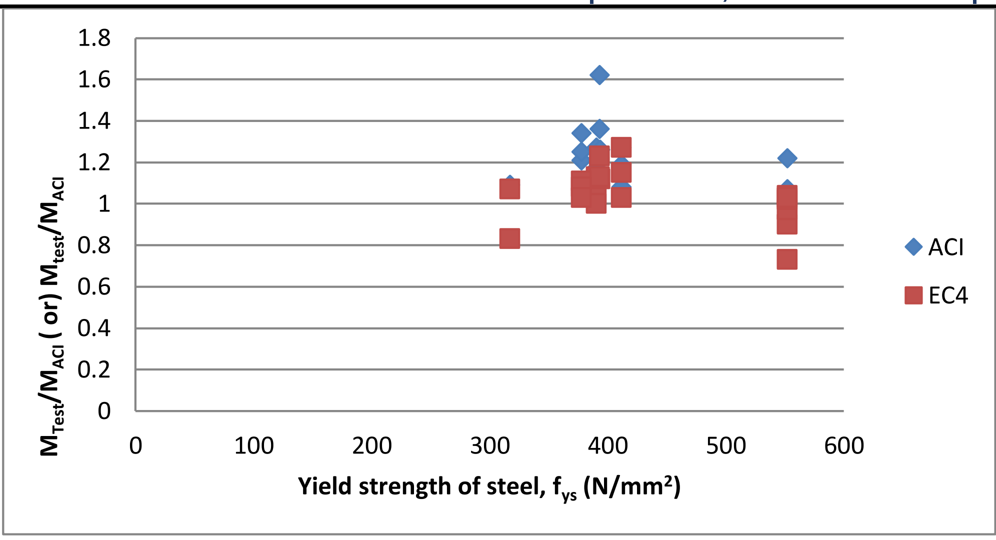


**Fig. 8: : Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs yield strength of steel of uniaxially loaded fully encased SRC columns**

**Table 1: Comparison of Uniaxially fully encased SRC Composite Column for test samples**

| Specimen | $h_c$ x $b_c$ (mm) | Steel section $h_i \times b_i \times t_w \times t_f$ (mm) | $A_r$ (mm²) | % of steel | $f_{cyl}$ (N/mm²) | $f_{ys}$ (N/mm²) | $f_{yr}$ (N/mm²) | Test: $P_{Test}$ (kN) | Test: $M_{test}$ (kN-m) | ACI: $M_{ACI}$ (kN-m) | ACI: $M_{test}/M_{ACI}$ | Eurocode4: $M_{EC4}$ (kN-m) | Eurocode4: $M_{test}/M_{EC4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mirza (1996) | | | | | | | | | | | | | |
| MUFS 1 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27 | 293 | 565 | 950 | 64.1 | 58 | 1.11 | 66 | 0.98 |
| MUFS 2 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27 | 293 | 565 | 550 | 63.2 | 62 | 1.02 | 72 | 0.88 |
| MUFS 3 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.6 | 293 | 565 | 570 | 78.2 | 61 | 1.29 | 72.5 | 1.08 |
| MUFS 4 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 24.8 | 293 | 565 | 154.3 | 66 | 59 | 1.12 | 60 | 1.1 |
| MUFS 5 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 28.5 | 293 | 565 | 95 | 65.6 | 59 | 1.12 | 60 | 1.1 |
| MUFS 6 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.4 | 311 | 634 | 925 | 82.2 | 60 | 1.37 | 72 | 1.15 |
| MUFS 7 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.4 | 311 | 634 | 775 | 76 | 61 | 1.25 | 76 | 1 |
| MUFS 8 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.4 | 311 | 634 | 927 | 72 | 60 | 1.2 | 72 | 1 |
| MUFS 9 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.4 | 311 | 634 | 720 | 69.9 | 62 | 1.13 | 77 | 0.91 |
| MUFS 10 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 26.5 | 293 | 565 | 540 | 82.3 | 62 | 1.33 | 74 | 1.12 |
| MUFS 11 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 27.2 | 293 | 565 | 107.5 | 73.5 | 58 | 1.27 | 59 | 1.25 |
| MUFS 12 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 25.5 | 311 | 634 | 540 | 83 | 60 | 1.39 | 75 | 1.11 |
| MUFS 13 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 25.5 | 311 | 634 | 296 | 79.9 | 62 | 1.29 | 68 | 1.18 |
| MUFS 14 | 240 x 240 | 96 x 100 x 5.1 x 8.6 | 284 | 3.68 | 25.5 | 311 | 634 | 100 | 68.7 | 59 | 1.17 | 62 | 1.11 |
| Ricles(1994) | | | | | | | | | | | | | |
| RUFS | 406 x | 210 x 206 x 9.5 | 314 | 4.6 | 32. | 37 | 45 | 149 | 62 | 62 | 1.0 | 64 | 0.9 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 406 | x 14.3 | 8 | 2 | 7 | 4 | 6 | 0 | 6 | 0 | 1 | 0 | 8 |
| RUFS 2 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 1548 | 4.62 | 34.5 | 374 | 434 | 1490 | 593 | 515 | 1.16 | 525 | 1.13 |
| RUFS 3 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 4645 | 4.62 | 31.2 | 374 | 448 | 1490 | 670 | 690 | 0.98 | 730 | 0.92 |
| RUFS 4 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 2581 | 4.62 | 31.1 | 374 | 448 | 1490 | 670 | 560 | 1.2 | 590 | 1.14 |
| RUFS 5 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 4645 | 4.62 | 34.5 | 374 | 434 | 1490 | 776 | 710 | 1.1 | 730 | 1.07 |
| RUFS 6 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 2581 | 4.62 | 35.8 | 374 | 448 | 1490 | 667 | 590 | 1.14 | 600 | 1.12 |
| RUFS 7 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 4645 | 4.62 | 62.9 | 374 | 434 | 1490 | 840 | 820 | 1.03 | 800 | 1.05 |
| RUFS 8 | 406 x 406 | 210 x 206 x 9.5 x 14.3 | 4645 | 4.62 | 64.5 | 374 | 434 | 1490 | 832 | 820 | 1.02 | 800 | 1.04 |
| Naka(1977) | | | | | | | | | | | | | |
| NUFS 1 | 240 x 300 | 180 x 120 x 4.5 x 12 | 2323 | 4.97 | 25.5 | 345 | 461 | 1470 | 197 | 180 | 1.1 | 225 | 0.88 |
| NUFS 2 | 240 x 300 | 180 x 120 x 4.5 x 12 | 2323 | 4.97 | 25.5 | 345 | 461 | 980 | 235 | 200 | 1.18 | 240 | 0.98 |
| NUFS 3 | 240 x 300 | 180 x 120 x 4.5 x 12 | 2323 | 4.97 | 25.5 | 345 | 461 | 490 | 228 | 220 | 1.04 | 245 | 0.94 |
| Wakabayashi(1971) | | | | | | | | | | | | | |
| WUFS 1 | 210 x 210 | 150 x 100 x 6 x 9 | 284 | 5.88 | 26.4 | 306 | 361 | 239.6 | 72.4 | 72.5 | 1 | 72.5 | 1 |
| WUFS 2 | 210 x 210 | 150 x 100 x 6 x 9 | 284 | 5.88 | 28.9 | 306 | 361 | 587.1 | 67.7 | 70 | 0.97 | 74 | 0.92 |
| WUFS 3 | 210 x 210 | 150 x 100 x 6 x 9 | 284 | 5.88 | 27 | 306 | 361 | 880.7 | 59 | 59 | 1 | 65 | 0.91 |
| Mean | | | | | | | | | | | 1.15 | | 1.04 |
| Standard deviation | | | | | | | | | | | 0.12 | | 0.10 |
| Coefficient of variation | | | | | | | | | | | 0.11 | | 0.10 |

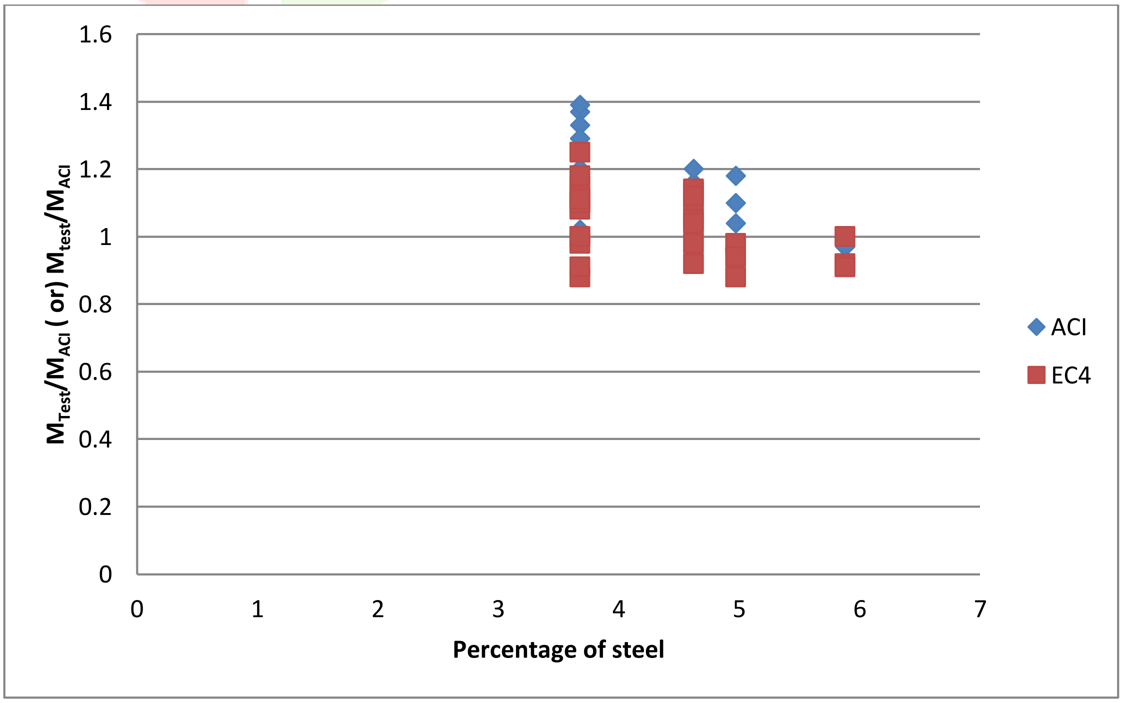


**Fig. 9: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs percentage of steel of uniaxially loaded fully encased**

## 5. COMPARATIVE RESULTS OF UNIAXIALLY LOADED SQUARE CFST

Individual specimens for axial compression and uniaxial bending Square CFST used by previous researchers are identified by notations Amit H Varma (AXXX) and Made S Haradika (MXXX). Loading is indicated by XUXX (Uniaxial bending with axial load). Section is indicated by XXSX (Square) and XXXC (Concrete filled steel tube). The sample of interaction curve of square CFST column for specimens AUSC1 and 2 is as shown in figure 10. Similarly interaction curves are drawn to reaming specimens for different data. The comparison of uniaxially loaded Square CFST Composite Column specimens for ACI and EC4 are tabulated in Table 2. Graphs are drawn for $M_{Test}/M_{ACI}$ ( or) $M_{test}/M_{ACI}$ ratio verses concrete cylinder strength, yield strength of steel and b/t ratio as shown in figure 11, 12 and 13.

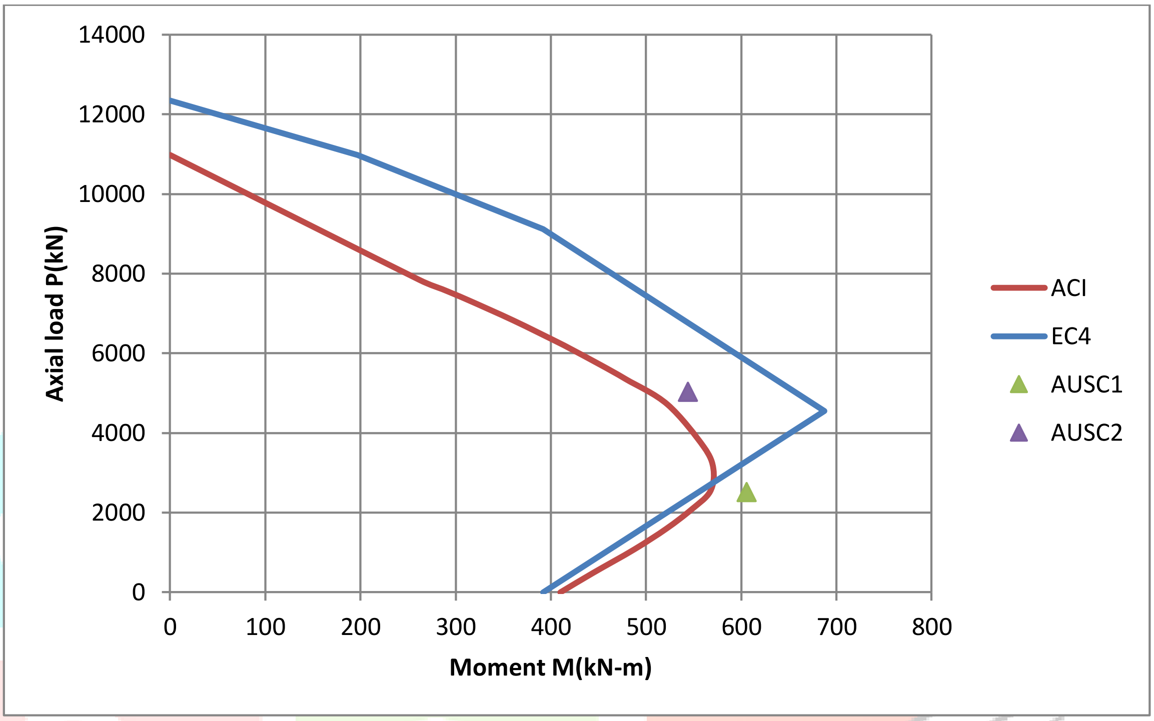


**Fig. 10: Interaction curve sample of square CFST column for specimens AUSC1 and 2**

**Table 2: Comparison of Uniaxially Square CFST Composite Column for test samples**

| Specimen | $h_c$ x $b_c$ (mm) | Steel section h x b x t (mm) | L (mm) | b/t | $f_{cyl}$ (N/mm²) | $f_{ys}$ (N/mm²) | Test | | ACI | | Eurocode 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $P_{Test}$ (kN) | $M_{Test}$ (kN-m) | $M_{ACI}$ (kN-m) | $M_{Test}/M_{ACI}$ | $M_{EC4}$ (kN-m) | $M_{Test}/M_{EC4}$ |
| Amit H Varma, James M Ricles, Richard sause, Le wu lu (2002) | | | | | | | | | | | | |
| AUSC 1 | 287.8 x 287.8 | 305 x 305 x 8.6 | 1520 | 35.4 | 110 | 317 | 2520 | 606 | 560 | 1.1 | 570 | 1.07 |
| AUSC 2 | 287.8 x 287.8 | 305 x 305 x 8.6 | 1520 | 35.4 | 110 | 317 | 5035 | 544 | 500 | 1.1 | 660 | 0.83 |
| AUSC 3 | 287.2 x 287.2 | 305 x 305 x 8.9 | 1520 | 34.3 | 110 | 552 | 3050 | 933 | 770 | 1.2 | 900 | 1.04 |
| AUSC 4 | 287.2 x 287.2 | 305 x 305 x 8.9 | 1520 | 34.3 | 110 | 552 | 6100 | 806 | 800 | 1 | 900 | 0.9 |
| AUSC 5 | 293.4 x 293.4 | 305 x 305 x 5.8 | 1520 | 52.6 | 110 | 552 | 2360 | 597 | 620 | 1 | 620 | 0.97 |
| AUSC 6 | 293.4 x 293.4 | 305 x 305 x 5.8 | 1520 | 52.6 | 110 | 552 | 2520 | 629 | 620 | 1 | 620 | 1.02 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUSC 7 | 292.8 x 292.8 | 305 x 305 x 6.1 | 1520 | 50 | 110 | 552 | 2740 | 700 | 660 | 1.1 | 680 | 1.03 |
| AUSC 8 | 292.8 x 292.8 | 305 x 305 x 6.1 | 1520 | 50 | 110 | 552 | 5480 | 574 | 575 | 1 | 790 | 0.73 |
| Made S Haradika and N J Gardens (2004) | | | | | | | | | | | | |
| MUS C1 | 194.18 x 194.18 | 203 x 203 x 4.41 | 1800 | 46 | 44.4 | 390 | 300 | 140.1 | 124 | 1.1 | 125 | 1.13 |
| MUS C2 | 194.18 x 194.18 | 203 x 203 x 4.41 | 1800 | 46 | 44.4 | 390 | 700 | 142.6 | 122 | 1.2 | 138 | 1.04 |
| MUS C3 | 194.18 x 194.18 | 203 x 203 x 4.41 | 1800 | 46 | 44.4 | 390 | 1200 | 131.2 | 104 | 1.3 | 132 | 1 |
| MUS C4 | 185.04 x 185.04 | 203 x 203 x 8.98 | 1800 | 22.6 | 44.4 | 393 | 430 | 257.4 | 205 | 1.3 | 230 | 1.12 |
| MUS C5 | 185.04 x 185.04 | 203 x 203 x 8.98 | 1800 | 22.6 | 44.4 | 393 | 860 | 263.9 | 195 | 1.4 | 234 | 1.13 |
| MUS C6 | 185.04 x 185.04 | 203 x 203 x 8.98 | 1800 | 22.6 | 44.4 | 393 | 1740 | 250.8 | 155 | 1.6 | 205 | 1.23 |
| MUS C7 | 194.26 x 194.26 | 203 x 203 x 4.37 | 1800 | 46.4 | 98.6 | 411 | 520 | 160.8 | 150 | 1.1 | 140 | 1.15 |
| MUS C8 | 194.26 x 194.26 | 203 x 203 x 4.37 | 1800 | 46.4 | 99.1 | 411 | 1150 | 190 | 150 | 1.3 | 150 | 1.27 |
| MUS C9 | 194.26 x 194.26 | 203 x 203 x 4.37 | 1800 | 46.4 | 98.9 | 411 | 1700 | 190.3 | 160 | 1.2 | 185 | 1.03 |
| MUS C10 | 184.64 x 184.64 | 203 x203 x 9.18 | 1800 | 22.1 | 82.9 | 378 | 570 | 265 | 220 | 1.2 | 240 | 1.11 |
| MUS C11 | 184.64 x 184.64 | 203 x203 x 9.18 | 1800 | 22.1 | 86.9 | 378 | 1200 | 272.9 | 220 | 1.3 | 255 | 1.08 |
| MUS C12 | 184.64 x 184.64 | 203 x203 x 9.18 | 1800 | 22.1 | 89.5 | 378 | 1750 | 272.9 | 205 | 1.3 | 265 | 1.03 |
| Mean | | | | | | | | | | 1.2 | | 1.05 |
| Standard deviation | | | | | | | | | | 0.15 | | 0.13 |
| coefficient of variance | | | | | | | | | | 0.13 | | 0.12 |

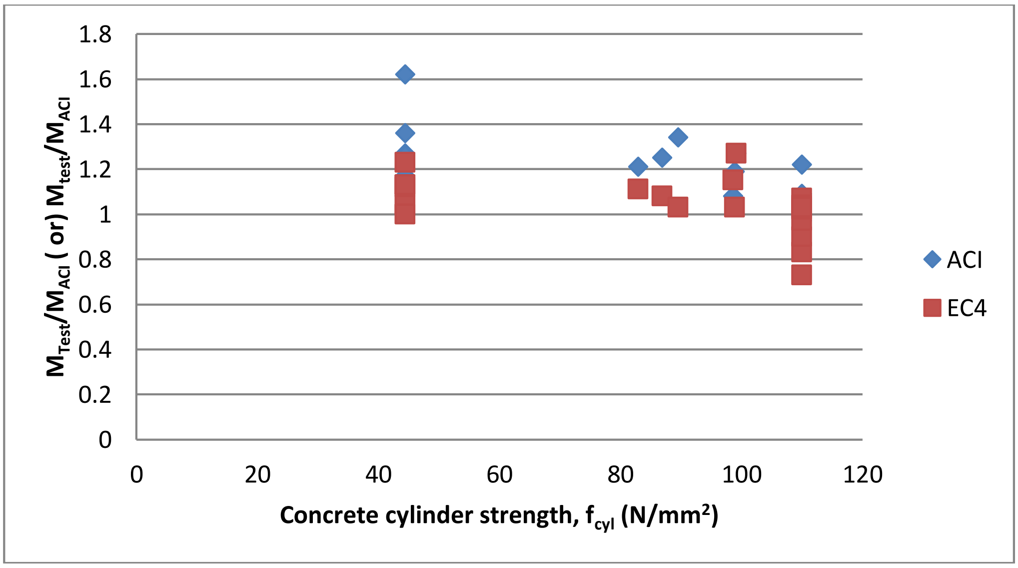


**Fig.11: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs concrete cylinder strength for circular CFST columns**

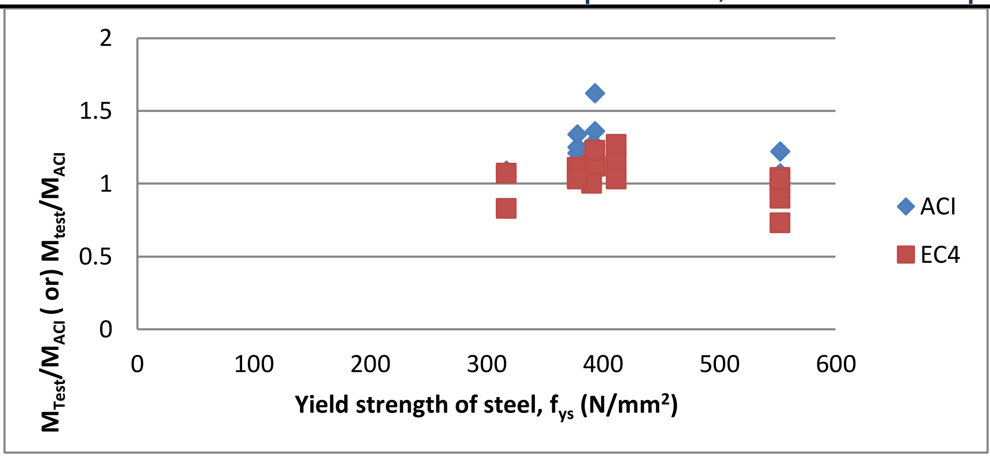


**Fig. 12: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs Yield strength of steel of square CFTS columns**

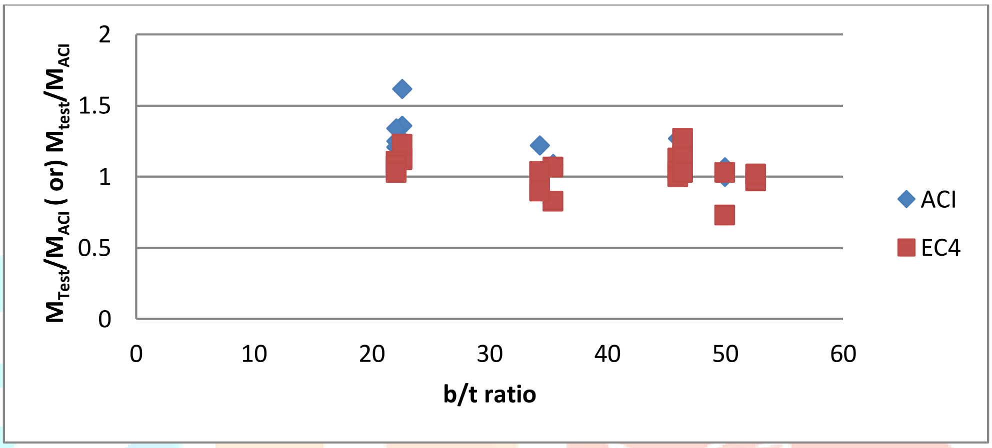


**Fig. 13: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs b/t ratio of square CFTS columns**

## 6. COMPARATIVE RESULTS OF UNIAXIALLY LOADED CIRCULAR CFST

Individual specimens for axial compression and uniaxial bending circular CFST used by previous researchers are identified by notations Martin D O'shea (MXXX) and Amir Fam (AXXX). Loading is indicated by XUXX (Uniaxial bending with axial load). Section is indicated by XXCX (Circular) and XXXC (Concrete filled steel tube). The sample of interaction curve of circular CFST column for specimens MCCC1 and 2 is as shown in figure 14. Similarly interaction curves are drawn to reaming specimens for different data. The comparison of uniaxially loaded Circular CFST Composite Column specimens for ACI and EC4 are tabulated in Table 3. Graphs are drawn for $M_{Test}/M_{ACI}$ ( or) $M_{test}/M_{ACI}$ ratio verses concrete cylinder strength, yield strength of steel and d/t ratio as shown in figure 15, 16 and 17.

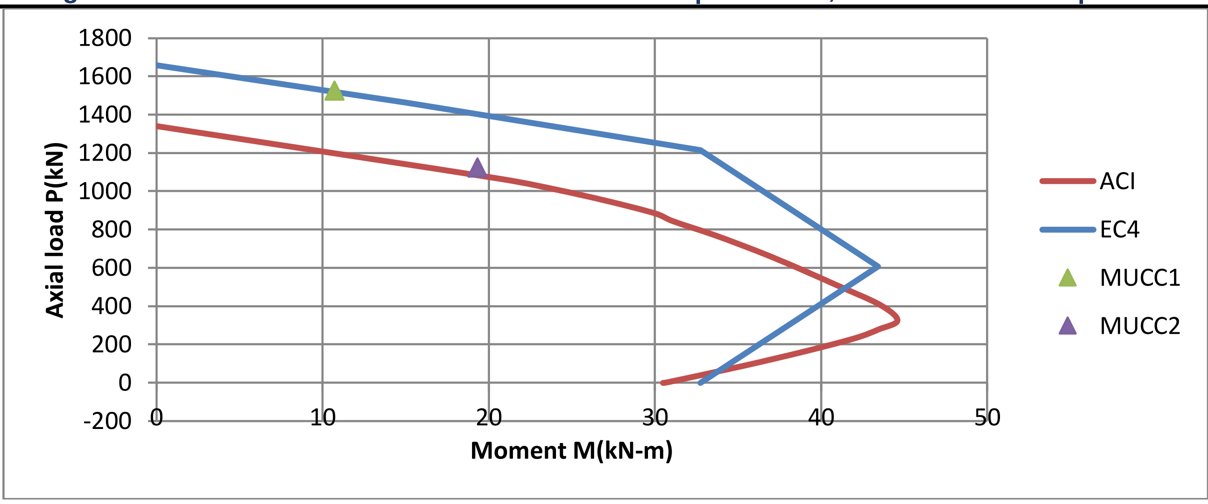


**Fig. 14: Interaction curve sample of circular CFST column for specimens MCCC1 and 2**

**Table 3: Comparison of Uniaxially Circular CFST Composite Column for test samples**

| Specimen | d (mm) | Steel section $d_c$ x t (mm) | L (mm) | d/t | $f_{cyl}$ (N/mm²) | $f_{ys}$ (N/mm²) | Test $P_{test}$ (kN) | Test $M_{test}$ (kN-m) | ACI $M_{ACI}$ (kN-m) | ACI $M_{test}/M_{ACI}$ | Eurocode4 $M_{EC4}$ (kN-m) | Eurocode4 $M_{test}/M_{EC4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Martin D O'shea, Russel Q Bridge(2000) | | | | | | | | | | | | |
| MUCC1 | 159.36 | 165 x 2.82 | 580.2 | 58.5 | 48.3 | 363.3 | 1525 | 10.7 | - | - | 10 | 1.07 |
| MUCC2 | 159.36 | 165 x 2.82 | 580.5 | 58.5 | 48.3 | 363.3 | 1123 | 19.3 | 18 | 1.08 | 35 | 0.56 |
| MUCC3 | 159.36 | 165 x 2.82 | 579.5 | 58.5 | 80.2 | 363.3 | 1940 | 18.2 | - | - | 22 | 0.83 |
| MUCC4 | 159.36 | 165 x 2.82 | 579.5 | 58.5 | 80.2 | 363.3 | 1653 | 29.6 | 20 | 1.48 | 37 | 0.8 |
| MUCC5 | 159.36 | 165 x 2.82 | 578.5 | 58.5 | 112.7 | 363.3 | 2246 | 15.3 | 15 | 1.02 | 40 | 0.39 |
| MUCC6 | 159.36 | 165 x 2.82 | 578.5 | 58.5 | 112.7 | 363.3 | 1880 | 29.3 | 42 | 0.7 | 48 | 0.62 |
| MUCC7 | 186.12 | 190 x 1.94 | 661 | 97.9 | 41 | 256.4 | 1533 | 13.2 | - | - | - | - |
| MUCC8 | 186.12 | 190 x 1.94 | 664 | 97.9 | 41 | 256.4 | 1284 | 20.8 | - | - | 22 | 0.95 |
| MUCC9 | 186.12 | 190 x 1.94 | 662.5 | 97.9 | 74.7 | 256.4 | 2203 | 22 | - | - | 22 | 1 |
| MUCC10 | 186.12 | 190 x 1.94 | 663 | 74.7 | 74.7 | 256.4 | 1730 | 36 | 35 | 1.03 | 37 | 0.98 |
| MUCC11 | 186.12 | 190 x 1.94 | 661.5 | 97.9 | 112.7 | 256.4 | 2683 | 17.4 | 24 | 0.73 | 40 | 0.44 |
| MUCC12 | 186.12 | 190 x 1.94 | 664.5 | 97.9 | 112.7 | 256.4 | 2386 | 40.6 | 52 | 0.79 | 52 | 0.79 |
| MUCC13 | 186.96 | 190 x 1.52 | 662 | 125 | 48.3 | 306.1 | 1260 | 19.5 | 18 | 1.09 | 28 | 0.7 |
| MUCC14 | 186.96 | 190 x 1.52 | 663.5 | 125 | 80.2 | 306.1 | 1925 | 27.5 | 28 | 0.99 | 36 | 0.77 |
| MUCC15 | 186.96 | 190 x 1.52 | 660.5 | 125 | 112.7 | 306.1 | 2420 | 31.2 | 48 | 0.65 | 48 | 0.65 |
| MUCC16 | 187. | 190 x | 663. | 168 | 41 | 185. | 122 | 10. | - | - | 9 | 1.16 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 74 | 1.13 | 5 | | | 7 | 9 | 4 | | | | |
| MUCC17 | 187.74 | 190 x 1.13 | 664 | 168 | 41.3 | 185.7 | 1023 | 19.3 | 9 | 2.15 | 17 | 1.14 |
| MUCC18 | 187.74 | 190 x 1.13 | 662 | 168 | 112.7 | 185.7 | 1928 | 32.9 | 64 | 0.52 | 55 | 0.6 |
| MUCC19 | 188.28 | 190 x 0.86 | 662 | 221 | 41 | 210.7 | 1219 | 9 | - | - | 9 | 1 |
| MUCC20 | 188.28 | 190 x 0.86 | 663 | 221 | 41 | 210.7 | 1017 | 18.2 | 9 | 2.03 | 16 | 1.14 |
| MUCC21 | 188.28 | 190 x 0.86 | 665.5 | 221 | 74.7 | 210.7 | 1910 | 16.4 | - | - | 18 | 0.92 |
| MUCC22 | 188.28 | 190 x 0.86 | 665 | 221 | 74.7 | 210.7 | 1532 | 27.4 | 36 | 0.77 | 32 | 0.86 |
| MUCC23 | 188.28 | 190 x 0.86 | 660.5 | 221 | 112.7 | 210.7 | 2112 | 8.4 | 60 | 0.14 | 50 | 0.17 |
| Amir Fam, Frank S.Qie and Sami Rizkalla (2003) | | | | | | | | | | | | |
| AUCC1 | 145.76 | 152 x 3.12 | 1800 | 48.7 | 55 | 382 | 500 | 44.5 | 40 | 1.12 | 42 | 1.06 |
| AUCC2 | 145.76 | 152 x 3.12 | 1800 | 48.7 | 55 | 382 | 500 | 40 | 40 | 1 | 42 | 0.96 |
| AUCC3 | 145.76 | 152 x 3.12 | 1800 | 48.7 | 55 | 382 | 500 | 44 | 40 | 1.1 | 42 | 1.05 |
| AUCC4 | 145.76 | 152 x 3.12 | 1800 | 48.7 | 60 | 382 | 600 | 35 | 38 | 0.93 | 40 | 0.88 |
| AUCC5 | 145.76 | 152 x 3.12 | 1800 | 48.7 | 60 | 382 | 600 | 45 | 38 | 1.19 | 40 | 1.13 |
| Mean | | | | | | | | | | 1.03 | | 0.84 |
| Standard deviation | | | | | | | | | | 0.46 | | 0.25 |
| Coefficient of variation | | | | | | | | | | 0.45 | | 0.30 |

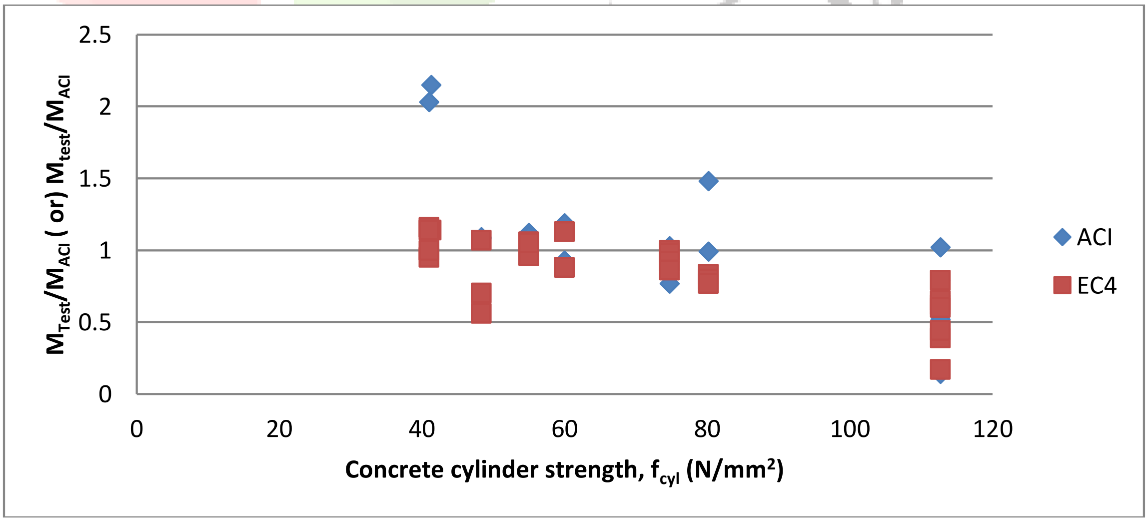


**Fig.15: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs concrete cylinder strength for circular CFST columns**

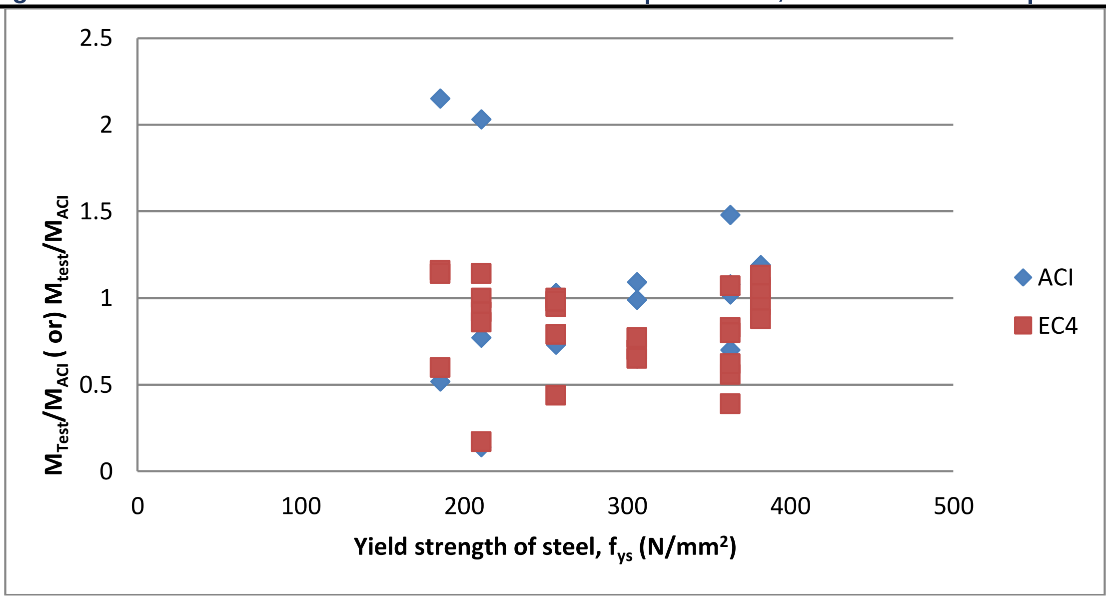


**Fig. 16: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs Yield strength of steel for circular CFST columns**

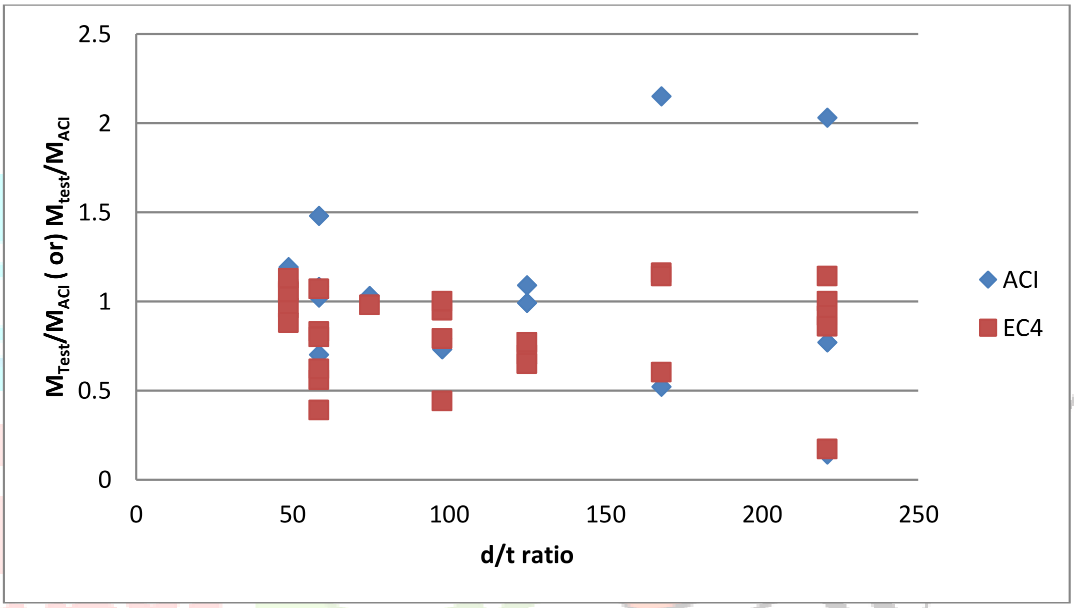


**Fig. 17: Ratio $M_{Test}/M_{ACI}$ ( or) $M_{Test}/M_{ACI}$ vs d/t ratio of Circular CFST columns**

## 7. CONCLUSION

i. Creating interaction curve of composite columns by EC 4- 2004 is straightforward; formulas are used mark interaction curve points. In case of ACI: 318- 2005 creating interaction curve is complex; a perfect smooth curve can be drawn.

ii. ACI: 318- 2005 and EC 4- 2004 furnish better results of Fully Encased SRC. The values of $M_{Test}$ are more nearer to the interaction curve. The ratios of $M_{Test}/M_{ACI}$ or $M_{Test}/M_{EC4}$ verses $f_{cyl}$, $f_{ys}$ and Percentage of steel shows more concentrated and acceptable results. The ratios of Test/Code show high conservative values of mean, standard deviation and coefficient of variation.

iii. ACI: 318- 2005 and EC 4- 2004 provide better results of Circular CFST uniaxially loaded columns. The values of $M_{Test}$ are more closer to the interaction curve. The ratios of $M_{Test}/M_{ACI}$ or $M_{Test}/M_{EC4}$ verses $f_{cyl}$, $f_{ys}$ and b/t shows concentrated and acceptable results. The ratios of Test/Code show conservative values of mean, standard deviation and coefficient of variation.

iv. ACI: 318- 2005 and EC 4- 2004 gives scattered results of Circular CFST uniaxially loaded columns. Due to confinement effect in circular tubes the some experimental specimen shows values of $M_{Test}$ is very much less than $M_{ACI}$ or $M_{EC4}$. The ratios of $M_{Test}/M_{ACI}$ or $M_{Test}/M_{EC4}$ verses $f_{cyl}$, $f_{ys}$ and d/t shows more scattered and different results. The ratios of Test/Code show high radical values of mean, standard deviation and coefficient of variation.

v. To design fully encased SRC, square CFST and circular CFST IS code can adopt EC4-2005 by changing concrete cylinder strength to concrete cube strength.

## SYMBOLS

| | |
|---|---|
| $A_c$ | Cross-sectional area of concrete |
| $A_g$ | Gross cross-sectional area section |
| $A_r$ | Cross-sectional area of longitudinal reinforcing bars |
| $A_s$ | Cross-sectional area of the structural steel section |
| b | Breadth of box steel tube section |
| $b_c$ | Breadth of concrete section |
| $b_i$ | Width of steel I- section |
| c | Depth of NA |
| e | Eccentricity |
| d | Diameter of circular steel tube section |
| $E_s$ | Modulus of elasticity of structural steel |
| $E_c$ | Modulus of elasticity of concrete |
| $(EI)_{eff}$ | Effective flexural stiffness section |
| $I_c$ | second moments of area of the concrete section |
| $I_s$ | second moments of area of the steel section |
| $I_r$ | second moments of area of the reinforcement |
| $f_{cyl}$ | Cylinder compressive strength of concrete |
| $f_{cu}$ | Cube compressive strength of concrete |
| $f_{yr}$ | Yield strength of reinforcement |
| $f_{ys}$ | Yield strength of Structural steel |
| h | Height of box steel tube section |
| $h_c$ | Height of concrete section |
| $h_i$ | Height of steel I- section |
| $h_r$ | Distance of centre of reinforcement bar from top edge of cross section |
| $h_s$ | Distance of centre of steel section from top edge of cross section |
| L | Length of Composite column |
| $M_{test}$ | Experimental moment of composite column |
| $M_{ACI}$ | Nominal moment of composite column as per ACI |
| $M_{EC4}$ | Nominal moment of composite column as per EC4 |
| $P_{test}$ | Experimental axial strength of Composite column |
| $P_{ACI}$ | Nominal axial capacity of composite column as per ACI |
| $P_{EC4}$ | Nominal axial capacity of composite column as per EC4 |
| $P_{cr}$ | Elastic buckling load of the column |
| $P_{pl}$ | Plastic resistance of the cross-section to compression |
| t | Thickness of box or circular steel tube section |
| $t_f$ | Flange thickness of steel I- section |
| $t_w$ | Web thickness of steel I- section |
| $Z_c$ | Plastic section modulus of concrete |
| $Z_s$ | Plastic section modulus of steel |
| $Z_r$ | Plastic section modulus of reinforcement bar |
| $\gamma_c$ | Partial factor of safety for concrete in EC4 |
| $\gamma_s$ | Partial factor of safety for Steel in EC4 |
| $\gamma_r$ | Partial factor of safety for reinforcement in EC4 |
| $\delta$ | Steel contribution ratio |
| $\varepsilon_c$ | Strain in concrete |
| $\varepsilon_s$ | Strain in steel |
| $\varepsilon_r$ | Strain in reinforcement |
| $\eta_1$ | Coefficient of confinement for concrete |
| $\eta_2$ | Coefficient of confinement for steel |
| $\lambda$ | Non dimensional slenderness ratio |

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