COMPARISON OF RELIABILITY OF CIRCULAR AND SQUARE CFST COLUMNS USING IMPORTANCE SAMPLING METHOD

Jyothi M[1], Khalid Nayaz Khan[2], Dr. N S Kumar[3]

[1]Final Year Student, Department of Civil Engineering, Ghousia College of Engineering, Affiliated to VTU, Belagavi, Ramanagaram-562159, Karnataka, India
[2] Ass.Professor, Dpt.of Civil Engineering, Affiliated to VTU, Belagavi, Ramanagaram-562159, Karnataka, India
[3]Prof. & Director (R&D), Dpt.of Civil Engineering, Affiliated to VTU, Belagavi, Ramanagaram-562159, Karnataka, India

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Abstract - In this study, analysis of CFST columns is done with the help of ANSYS software. The models are prepared and analyzed in ANSYS software to ascertain the failure loads for different lengths, thickness and slenderness ratios of CFST columns. Here we compare the reliability of both circular and square CFST columns. The analytical Pu values are compared with Codal provisions such as Euro code, AS3600-1999 and BS5400 Code. Graphs are plotted to know the difference between analytical Pu and Codal Pu values. The reliability analysis is carried out to know the design goal so as to achieve the nominal load carrying capacity with less deflection. The reliability analysis is carried out with the help of 2rRel software and the results such as reliability index and probability of failure are tabulated for each CFST model. The reliability analysis is performed by FORM. Simulation technique namely Importance sampling method is used in this work. The Taguchi's approach is adopted to identify and pick the combination of parameters which yield the best reliability index.

Key Words*: *CFST, ANSYS, Reliability, Importance Sampling, FORM, 2R rel.

1.INTRODUCTION

In these days, the composite structural elements are extensively used in tall buildings, bridges and different types of structures. Because of its composite effects, the disadvantage of two materials may be compensated and the benefits may be combined to impart an efficient structural system.

Concrete filled steel structural section columns are an efficient, cost-effective, and aesthetically desirable members through which large compressive loads are supported in buildings. These structural members include a hallow steel tube which is in-packed with concrete and through composite action, advanced load carrying capacity and better fire resistance can be obtained compared to unfilled steel tubes.

The concrete infill and the metal tube work together to provide several key advantages. The steel tube acts as stay-in-place formwork all through casting of the concrete, lowering forming and stripping expenses. It gives lateral confinement to the infill concrete that could enhance the concrete's compressive strength and axial deformability, and it offers an easy, rugged, and strong architectural floor finish.

1.1 Concept of Reliability

Reliability of the structure can be described as its potential to satisfy its design reason over a special time period. In its narrowest sense, reliability considers the chance that the systems will not reach any of the desired limits during the time span under reference.

If it does, the probability of failure should be anticipated and that degree of reliability decided.

1.2 First Order Reliability Method

FORM was initially proposed by Hasofer et al. (1974). It is capable of handling non-linear performance functions, and correlated non –normal variables. FORM is also referred to as Mean Value First order second moment method (MVFOSM). FORM linearizes the performance function using Taylor series approximation. FORM uses only mean and standard deviation of the variables. The performance / limit state function is given by **Z = R-S**

1.3 Importance Sampling Method

Importance sampling specializes in the area of space that contributes the maximum to the failure probability of a system. This characteristic selection enables a better sampling density within the location of interest. Nevertheless, variable independence is assumed, which results in biased effects if the correlation between any pair of variables is different to zero. The information phase summarizes the number of iterations that were run N as well as the probability of failure that was obtained Pf.

2. Material and Methodology

2.1 Material Properties

STEEL:

a) Material: Structural Steel Fe 310Mpa

b) Young's Modulus E=200Gpa

c) Poison's ratio μ =0.3

d) Density ρ =7850kg/m3

CONCRETE:

a) Grade of Concrete: M20, M30, M40

b) Young's Modulus E=22360.7Mpa, 27386.1Mpa, 31622.7Mpa

c) Poison's ratio μ=0.15,0.27,0.33.

d) Density ρ =2400kg/m3

2.2 Section Properties

Table -1a): Details of section properties for Circular CFST

Sl. No.	Diameter (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)
1	165.1	4.5	330.2	20	310
2	165.1	4.8	330.2	20	310
3	165.1	5.4	330.2	20	310
4	165.1	4.5	660.4	20	310
5	165.1	4.8	660.4	20	310
6	165.1	5.4	660.4	20	310
7	165.1	4.5	990.6	20	310
8	165.1	4.8	990.6	20	310
9	165.1	5.4	990.6	20	310

Table -1b): Details of section properties for Square s/c

Sl. No.	Side (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)
1	146.32	4	330.2	20	310
2	146.32	4.3	330.2	20	310
3	146.32	4.8	330.2	20	310
4	146.32	4	660.4	20	310
5	146.32	4.3	660.4	20	310
6	146.32	4.8	660.4	20	310
7	146.32	4	990.6	20	310
8	146.32	4.3	990.6	20	310
9	146.32	4.8	990.6	20	310

3.1 Design Codes

EUROCODE:

According to the Euro Code, the ultimate load carrying capacity of columns is calculated by using below equation

Pu=Asfy+Acfc

BS 5400:

According to the BS 5400, the ultimate load carrying capacity of columns is calculated by using below equation

Pu=Asfy+0.675Acfc

AS 3600-1999:

According to the AS 3600-1999, the ultimate load carrying capacity of columns is calculated by using below equation

Pu= Asfy+0.85Acfc

6. Results and Comparison

Table 6.1: Analytical Results obtained from FEM software ANSYS

SI.No	Diameter (mm)	Thickness (mm)	Side (mm)	Thickness (mm)	l/d	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)	Ac(mm^2)	As(mm^2)	Analytical Pu (kN) (circular)	Analytical Pu (kN) (square)
1	165.1	4.5	146.3	4	2	330.2	20	310	19137.96	2270.43	891.00	858.40
2	165.1	4.8	146.3	4.3	2	330.2	20	310	18991.12	2417.27	925.92	892.04
3	165.1	5.4	146.3	4.8	2	330.2	20	310	18699.14	2709.25	995.35	958.94
4	165.1	4.5	146.3	4	4	660.4	20	310	19137.96	2270.43	901.86	869.27
5	165.1	4.8	146.3	4.3	4	660.4	20	310	18991.12	2417.27	937.21	903.33
6	165.1	5.4	146.3	4.8	4	660.4	20	310	18699.14	2709.25	1007.49	971.08
7	165.1	4.5	146.3	4	6	990.6	20	310	19137.96	2270.43	912.73	880.13
8	165.1	4.8	146.3	4.3	6	990.6	20	310	18991.12	2417.27	948.50	914.62
9	165.1	5.4	146.3	4.8	6	990.6	20	310	18699.14	2709.25	1007.49	983.21
10	165.1	4.5	146.3	4	2	330.2	30	310	19137.96	2270.43	1022.37	1009.59
11	165.1	4.8	146.3	4.3	2	330.2	30	310	18991.12	2417.27	1055.26	1042.07
12	165.1	5.4	146.3	4.8	2	330.2	30	310	18699.14	2709.25	1120.67	1106.66
13	165.1	4.5	146.3	4	4	660.4	30	310	19137.96	2270.43	1047.93	1022.37
14	165.1	4.8	146.3	4.3	4	660.4	30	310	18991.12	2417.27	1081.64	1055.26
15	165.1	5.4	146.3	4.8	4	660.4	30	310	18699.14	2709.25	1148.68	1120.67
16	165.1	4.5	146.3	4	6	990.6	30	310	19137.96	2270.43	1060.71	1035.15
17	165.1	4.8	146.3	4.3	6	990.6	30	310	18991.12	2417.27	1094.83	1068.45
18	165.1	5.4	146.3	4.8	6	990.6	30	310	18699.14	2709.25	1162.69	1134.68
19	165.1	4.5	146.3	4	2	330.2	40	310	19137.96	2270.43	1175.48	1160.78
20	165.1	4.8	146.3	4.3	2	330.2	40	310	18991.12	2417.27	1207.20	1192.10
21	165.1	5.4	146.3	4.8	2	330.2	40	310	18699.14	2709.25	1270.22	1254.34
22	165.1	4.5	146.3	4	4	660.4	40	310	19137.96	2270.43	1204.86	1175.48
23	165.1	4.8	146.3	4.3	4	660.4	40	310	18991.12	2417.27	1237.37	1207.19
24	165.1	5.4	146.3	4.8	4	660.4	40	310	18699.14	2709.25	1301.97	1270.22
25	165.1	4.5	146.3	4	6	990.6	40	310	19137.96	2270.43	1219.56	1190.17
26	165.1	4.8	146.3	4.3	6	990.6	40	310	18991.12	2417.27	1252.46	1222.28
27	165.1	5.4	146.3	4.8	6	990.6	40	310	18699.14	2709.25	1317.85	1286.10

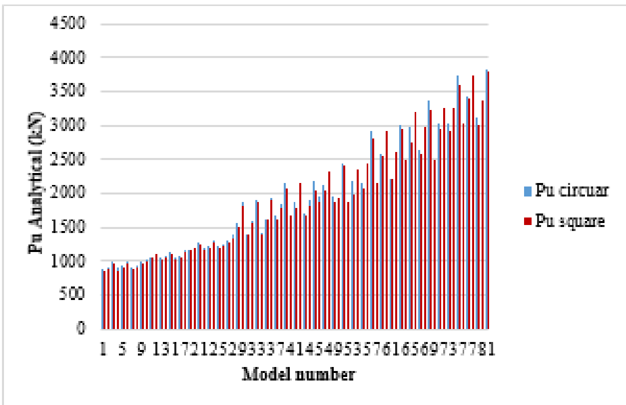

Fig 6.1: Pu value obtained from ANSYS software

6.2 Analytical Pu value for different grade of concrete

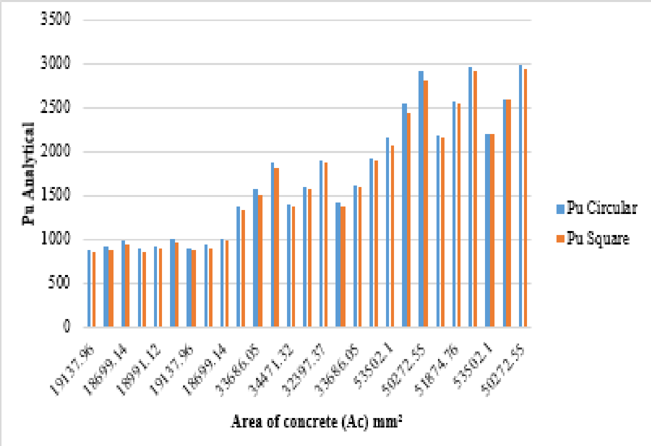

Fig 6.8: Comparison of Pu values with Area of concrete (Ac) for M20

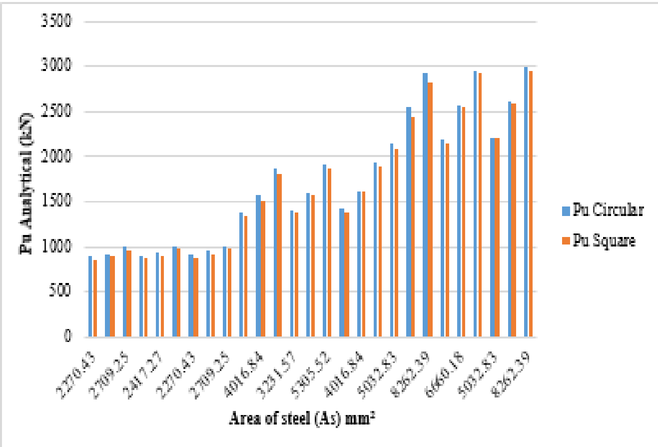

Fig 6.9: Comparison of Pu values with Area of steel (As) for M20

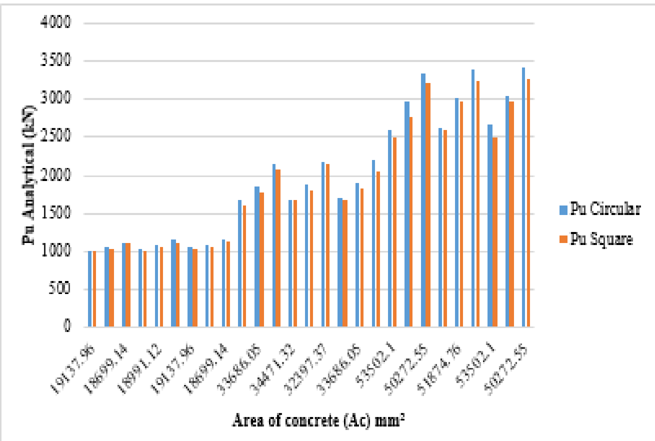

Fig 6.10: Comparison of Pu values with Area of concrete (Ac) for M30

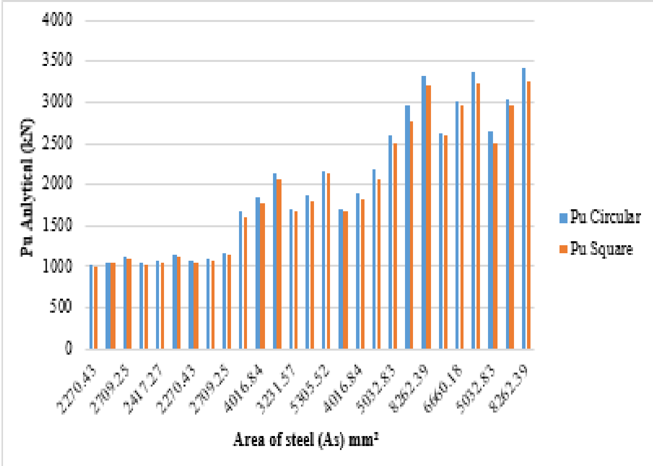

Fig 6.11: Comparison of Pu values with Area of steel (As) for M30

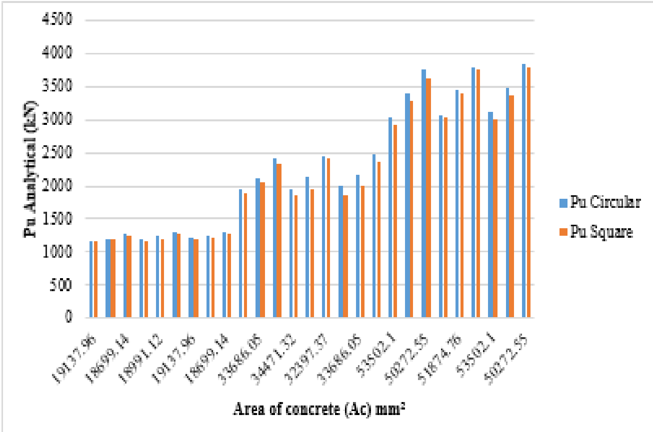

Fig 6.12: Comparison of Pu values with Area of concrete (Ac) for M40

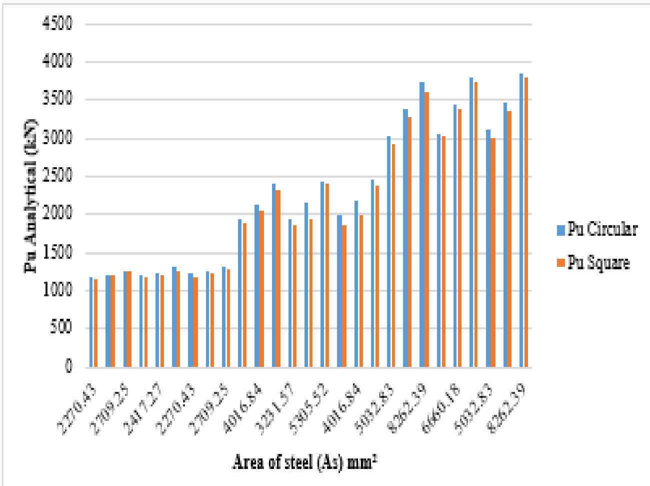

Fig 6.13: Comparison of Pu values with Area of steel (As) for M40

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Table 6.8: Reliability Analysis Results obtained from FORM method for circular section

Sl No.	Diameter (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)	Reliability index β (FORM)	Probability of failure Pf	Reliability	Reliability in %
1	165.1	4.5	330.2	20	310	-0.874	0.1726	0.8274	82.74
2	165.1	4.8	330.2	20	310	-0.760	0.2235	0.7765	77.65
3	165.1	5.4	330.2	20	310	-0.921	0.1786	0.8214	82.14
4	165.1	4.5	660.4	20	310	-0.845	0.1808	0.8192	81.92
5	165.1	4.8	660.4	20	310	-0.807	0.2118	0.7882	78.82
6	165.1	5.4	660.4	20	310	-0.636	0.2643	0.7357	73.57
7	165.1	4.5	990.6	20	310	-0.817	0.2089	0.7911	79.11
8	165.1	4.8	990.6	20	310	-0.750	0.2266	0.7734	77.34
9	165.1	5.4	990.6	20	310	-0.684	0.2482	0.7518	75.18

Table 6.9: Reliability Analysis Results obtained from Importance Sampling method for circular section

Sl No.	Diameter (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)	Reliability index β (Importance Sampling)	Probability of Failure Pf	Reliability	Reliability in %
1	165.1	4.5	330.2	20	310	-0.87	0.1726	0.8274	82.74
2	165.1	4.8	330.2	20	310	-0.76	0.2235	0.7765	77.65
3	165.1	5.4	330.2	20	310	-0.92	0.1786	0.8214	82.14
4	165.1	4.5	660.4	20	310	-0.84	0.1808	0.8192	81.92
5	165.1	4.8	660.4	20	310	-0.80	0.2118	0.7882	78.82
6	165.1	5.4	660.4	20	310	-0.63	0.2643	0.7357	73.57
7	165.1	4.5	990.6	20	310	-0.81	0.2089	0.7911	79.11
8	165.1	4.8	990.6	20	310	-0.75	0.2266	0.7734	77.34
9	165.1	5.4	990.6	20	310	-0.68	0.2482	0.7518	75.18

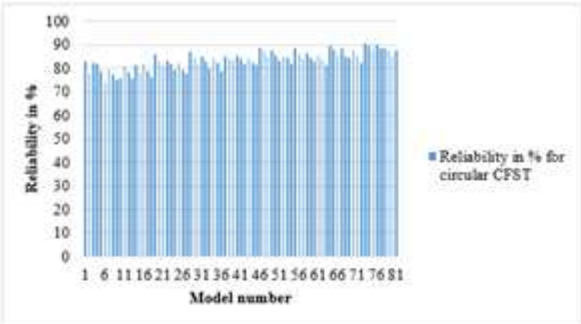

Fig 6.14: Reliability in % v/s Model number

Table 6.10: Reliability Analysis Results obtained from FORM method for square section

Sl No.	Side (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)	Reliability index β (FORM)	Probability of failure Pf	Reliability	Reliability in %
1	146.3	4	330.2	20	310	-0.742	0.2172	0.7828	78.28
2	146.3	4.3	330.2	20	310	-0.646	0.2464	0.7536	75.36
3	146.3	4.8	330.2	20	310	-0.782	0.2055	0.7945	79.45
4	146.3	4	660.4	20	310	-0.718	0.2386	0.7614	76.14
5	146.3	4.3	660.4	20	310	-0.686	0.2349	0.7651	76.51
6	146.3	4.8	660.4	20	310	-0.541	0.2945	0.7055	70.55
7	146.3	4	990.6	20	310	-0.694	0.2361	0.7639	76.39
8	146.3	4.3	990.6	20	310	-0.637	0.2541	0.7459	74.59
9	146.3	4.8	990.6	20	310	-0.581	0.2808	0.7192	71.92
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 6.11: Reliability Analysis Results obtained from Importance Sampling method for square section

Sl No.	Side (mm)	Thickness (mm)	Length (mm)	f_{ck} (N/mm^2)	f_y (N/mm^2)	Reliability index β (Importance sampling)	Probability of failure Pf	Reliability	Reliability in %
1	146.3	4	330.2	20	310	-0.74	0.2172	0.7828	78.28
2	146.3	4.3	330.2	20	310	-0.64	0.2464	0.7536	75.36
3	146.3	4.8	330.2	20	310	-0.78	0.2055	0.7945	79.45
4	146.3	4	660.4	20	310	-0.71	0.2386	0.7614	76.14
5	146.3	4.3	660.4	20	310	-0.68	0.2349	0.7651	76.51
6	146.3	4.8	660.4	20	310	-0.54	0.2945	0.7055	70.55
7	146.3	4	990.6	20	310	-0.69	0.2361	0.7639	76.39
8	146.3	4.3	990.6	20	310	-0.63	0.2541	0.7459	74.59
9	146.3	4.8	990.6	20	310	-0.58	0.2808	0.7192	71.92

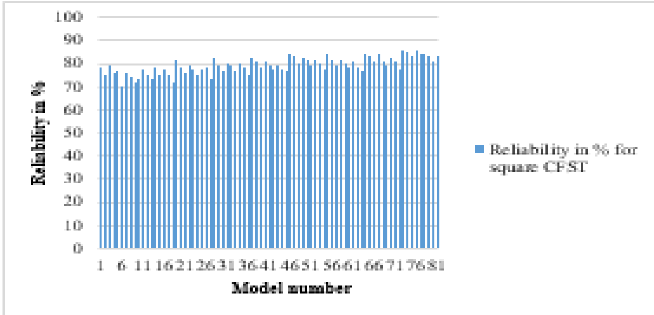

Fig 6.15: Reliability in % v/s Model number

6.4 Comparison of Reliability with different grade of concrete

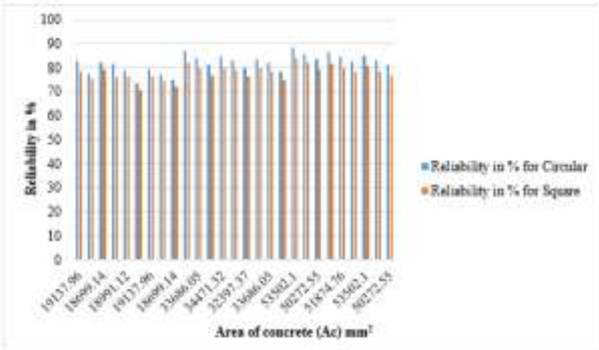

Fig 6.16: Comparison of Reliability in % with Area of concrete (Ac) for M20

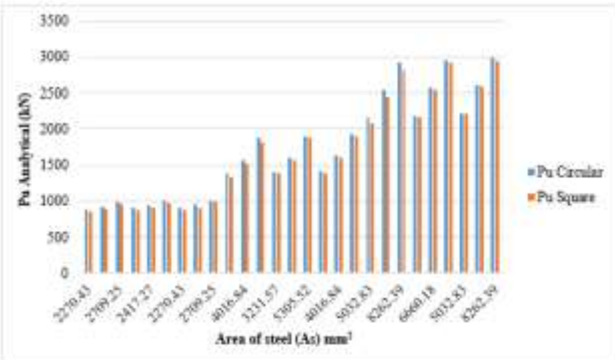

Fig 6.9: Comparison of Pu values with Area of steel (As) for M20

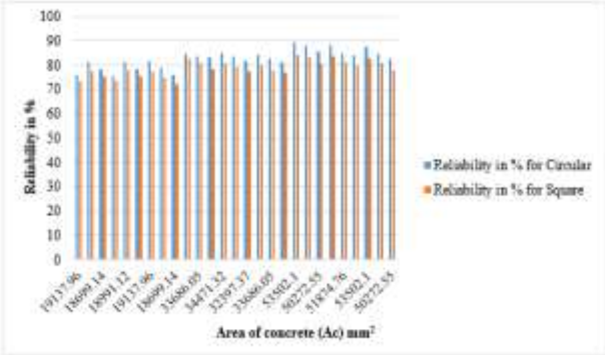

Fig 6.18: Comparison of Reliability in % with Area of concrete (Ac) for M30

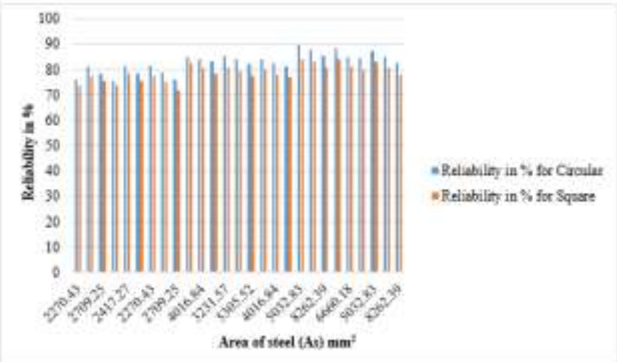

Fig 6.19: Comparison of Reliability in % with Area of steel (As) for M30

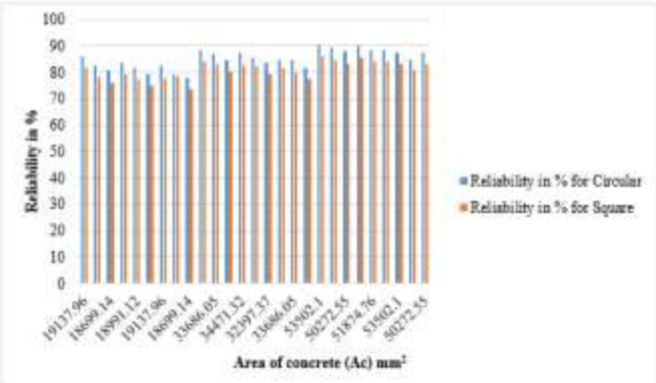

Fig 6.20: Comparison of Reliability in % with Area of concrete (Ac) for M40

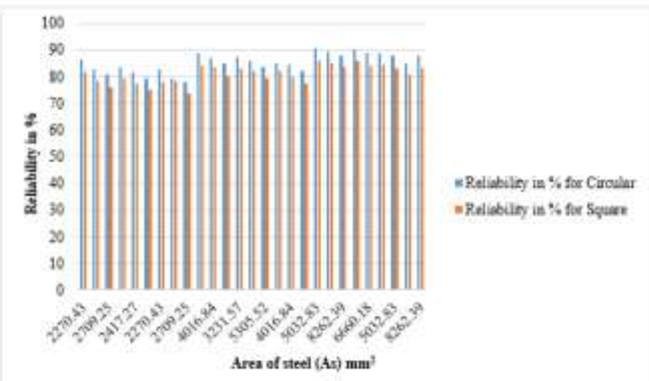

Fig 6.21: Comparison of Reliability in % with Area of steel (As) for M40

Table 6.16: The ratio between Strength and Weight obtained from Taguchi's Method for circular and square sections

For circular section

Model number	Diameter (mm)	Thickness (mm)	fck (N/mm²)	Pu (kN)	Area (mm²)	Weight (N)	Strength / weight
1	165.1	4.5	20	891.00	21408.39	57.73	0.7209
2	165.1	4.8	30	1055.26	21408.39	61.46	0.8020
3	165.1	5.4	40	1270.22	21408.39	68.89	0.8612
4	165.1	4.5	20	901.86	21408.39	115.46	0.3648
5	165.1	4.8	30	1081.64	21408.39	122.93	0.4109
6	165.1	5.4	40	1301.97	21408.39	137.78	0.4413
7	165.1	4.5	20	912.73	21408.39	173.19	0.2461
8	165.1	4.8	30	1094.83	21408.39	184.40	0.2773
9	165.1	5.4	40	1317.85	21408.39	206.67	0.2978

Table 6.17: For square section

Model number	Side (mm)	Thickness (mm)	fck (N/mm²)	Pu (kN)	Area (mm²)	Weight (N)	Strength / weight
1	146.3	4	20	858.40	21403.69	57.73	0.6947
2	146.3	4.3	30	1042.07	21403.69	61.46	0.7921
3	146.3	4.8	40	1254.34	21403.69	68.89	0.8506
4	146.3	4	20	869.27	21403.69	115.46	0.3517
5	146.3	4.3	30	1055.26	21403.69	122.93	0.4010
6	146.3	4.8	40	1270.22	21403.69	137.78	0.4307
7	146.3	4	20	880.13	21403.69	173.19	0.2374
8	146.3	4.3	30	1068.45	21403.69	184.40	0.2707
9	146.3	4.8	40	1286.10	21403.69	206.67	0.2907

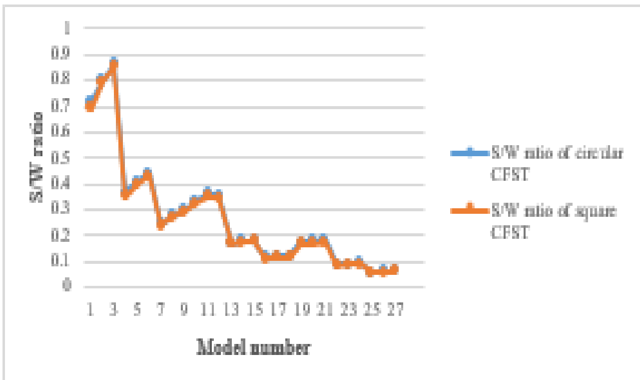

Fig 6.22: L9 Array Combination for strength/weight

Table 6.18: Taguchi's L9 Orthogonal Array Combination for Importance sampling method

For circular section

Model number	Diameter (mm)	Thickness (mm)	fck (N/mm²)	f_y (N/mm²)	Pu (kN)	ISM β	FORM β	Pf	Sample Id	Reliability in %
1	165.1	4.5	20	310	891.00	-0.87	-0.874	0.1726	1	82.74
2	165.1	4.8	30	310	1055.26	-0.88	-0.883	0.1894	11	81.06
3	165.1	5.4	40	310	1270.22	-0.85	-0.845	0.1942	21	80.58
4	165.1	4.5	20	310	901.86	-0.84	-0.845	0.1808	4	81.92
5	165.1	4.8	30	310	1081.64	-0.86	-0.864	0.1886	14	81.14
6	165.1	5.4	40	310	1301.97	-0.79	-0.798	0.2085	24	79.15
7	165.1	4.5	20	310	912.73	-0.81	-0.817	0.2089	7	79.11
8	165.1	4.8	30	310	1094.83	-0.78	-0.788	0.2115	17	78.85
9	165.1	5.4	40	310	1317.85	-0.75	-0.750	0.2204	27	77.96

Table 19: For square section

Model number	Side (mm)	Thickness (mm)	fck (N/mm²)	f_y (N/mm²)	Pu (kN)	ISM β	FORM β	Pf	Sample Id	Reliability in %
1	146.3	4	20	310	858.40	-0.74	-0.742	0.2172	1	78.28
2	146.3	4.3	30	310	1042.07	-0.75	-0.750	0.2265	11	77.35
3	146.3	4.8	40	310	1254.34	-0.71	-0.718	0.2388	21	76.12
4	146.3	4	20	310	869.27	-0.71	-0.742	0.2386	4	76.14
5	146.3	4.3	30	310	1055.26	-0.73	-0.734	0.2189	14	78.11
6	146.3	4.8	40	310	1270.22	-0.67	-0.678	0.2514	24	74.86
7	146.3	4	20	310	880.13	-0.69	-0.694	0.2361	7	76.39
8	146.3	4.3	30	310	1068.45	-0.67	-0.670	0.2513	17	74.87
9	146.3	4.8	40	310	1286.10	-0.63	-0.637	0.2642	27	73.58

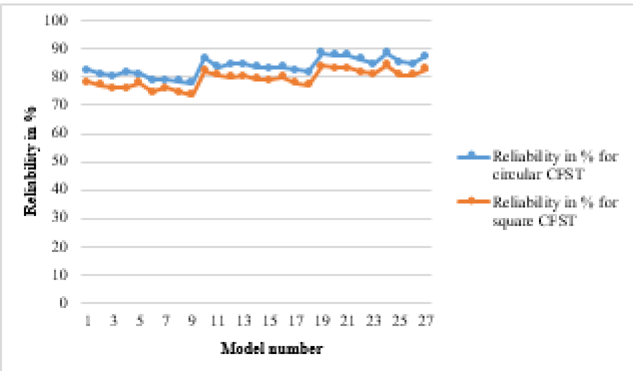

Fig 6.23: Graphical representation of L9 Array Combination for Importance sampling method

5. Conclusions

1. The ultimate load Pu obtained from ANSYS1result shows that the ultimate load carrying capacity of CFST tubes increase with increase in thickness of metal (Table: 6.1).

2. Pu value for circular column is more by 1 to 10% to that of square column for same concrete & steel area (Table: 6.1).1

3. Ultimate load Pu obtained from ANSYS for both circular and square sections with various codes like Euro code, BS 5400 and AC3600-1999 shows that Pu obtained from ANSYS is varying about 15 to 20% (Table: 6.2,6.3,6.4)

4. Reliability Percentage of circular column is more compared to that of square column for similar cross sectional areas (Table:12).

5. Results show that the reliability percentage obtained by FORM method and Importance Sampling method are almost similar.

6. From Taguchi method, model-3 gives the best strength to weight ratio for both circular as well as square sections (Graph: 22).

7. Model-19 from Taguchi array gives maximum reliability for circular section (Graph:6.23)

8. Model-24 from Taguchi array gives maximum reliability for square section (Graph: 6.23)

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BIOGRAPHIES

Graduated in the year 2017 from PES College of Engineering, Mandya, Affiliated by VTU, Belgaum. Presently perusing Master of Technology in Structural Engineering at Ghousia College of Engineering, Ramanagaram. Also working on this topic for the dissertation under the guidance of Mr. Khalid Nayaz khan and Dr. N S Kumar.

Associate Professor Dept. of Civil Engineering GCE, Ramanagaram, 562159. He has a Teaching experience of 33 years. Has published about 15 papers in various journals.

Involved in the Research field related to behavior of Composite Steel Column since a decade. Presently guiding 6 Ph.D. Scholars (Research under VTU, Belgaum). Has more than 30 years of teaching experience &6 years of Research experience at Ghousia College of Engineering, Ramanagaram.