RELIABILITY ANALYSIS OF CFST COLUMNS BY USING FORM AND LATIN HYPERCUBE METHOD

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Abstract- *This thesis focus to study the behavior of axially loaded concrete filled steel tube (CFST) segments under monotonic loading by utilizing the finite element software ANSYS. Modeling exactness is built up by using outcomes obtained from BS 5400, Eurocode 4 and AS 3600 codes. It is inferred that various parameters have considerable impact on the behavior of concrete filled steel columns, the prime variables are cross sectional area, thickness, and diameter of steel tube etc.., Most of the Researches on concrete filled steel tube is limited to deterministic approach yet in this thesis it also includes the reliability analysis of concrete filled steel tubes using First Order Reliability method and Latin Hypercube method utilizing 2R rel software.*

KeyWords: CFST, ANSYS, Reliability, FORM, Latin Hypercube, 2R rel

1. INTRODUCTION

Nowadays, the composite components are very much effectively used in tall Buildings, Bridges and other various types of structures because CFST columns have several advantages over the conventional reinforced concrete and structural steel columns. The first one is the concrete infill is confined by the steel tube.

The second one is concrete infill delays local buckling of the steel tube. And finally the combined capacity of the steel and concrete significantly increases the stiffness and ultimate strength of CFST columns which makes them very suitable for columns and other compressive members. Finally, the steel tube serves as longitudinal reinforcement and permanent formwork for the concrete core.

1.1 CONCEPT OF RELIABILITY

Reliability is the ability to meet specific requirements under a specified period. Structural reliability of the system cannot be find through failure rates because

- the structure are unique in nature
- structure fails due to loads exceeding the residual strength.

Therefore structural reliability models are built for Resistance R and loads S independently and then structural reliability is evaluated through probability of failure.

That is, Probability of failure, Pf = P(R-S< 0)

Reliability = 1-pf

➢ First order reliability method(FORM)

FORM was first developed by Hosfer st al (1974). It is fit for handling non linear performance function using Taylor series. FORM utilizes only mean and standard deviation of variables.

Therefore, limit state function is given by Z= R-S

If both R & S are assumed as normal random variables, then Z can also be referred as a random variables.

that is $(\mu R - \mu s, \sqrt{\sigma R2 + \sigma s2})$. Then probability of failure can be defined as

pf = P(Z<0)

$pf = \Phi[0-(\mu R-\mu S)/\sqrt{\sigma R2 + \sigma S2}\,]$

$pf = 1 - \Phi\,[\mu R - \mu S/\sqrt{\sigma R2 + \sigma S2}\,]$

Φ is the CFD of the standard normal variant

Thus, the probability of failure is a function of the mean value of Z to its standard deviation.

$\beta = \mu R - \mu S/(\mu R-\mu S)/\sqrt{\sigma R2 + \sigma S2}\,]$

The probability of failure can be expressed in terms of the safety index as follows.

$pf = \Phi\,(-\beta) = 1 - \varphi(\beta)$

➢ Latin hypercube method (LHM)

To increase the efficiency of monte carlo simulation technique, a new sampling method is introduce called Latin hypercube sampling. Latin hypercube sampling utilizes the stratified sampling scheme to improve the coverage of input space.

2. EXPERIMENTAL RESULTS

The ultimate loads are calculated by using ANSYS software which are shown below table i.e. Table:2.1

Table 2.1: ANSYS results

Sl No	D mm	T mm	L mm	f_{ck}	f_y	P_u
1	21.3	2	290	23.93	310	30.39
2	21.3	2	290	28.06	310	31.23
3	21.3	2	290	29.01	310	31.92
4	21.3	2.3	290	23.93	310	39.95
5	21.3	2.3	290	28.06	310	40.12
6	21.3	2.3	290	29.01	310	40.86
7	21.3	2.6	290	23.93	310	45.62
8	21.3	2.6	290	28.06	310	46.21
9	21.3	2.6	290	29.01	310	47.36
10	21.3	2.9	290	23.93	310	50.12
11	21.3	2.9	290	28.06	310	50.94
12	21.3	2.9	290	29.01	310	51.62
13	21.3	3.2	290	23.93	310	55.32
14	21.3	3.2	290	28.06	310	56.78
15	21.3	3.2	290	29.01	310	56.93
16	21.3	3.6	290	23.93	310	59.86
17	21.3	3.6	290	28.06	310	60.52
18	21.3	3.6	290	29.01	310	60.76
19	21.3	4	290	23.93	310	63.59
20	21.3	4	290	28.06	310	64.08
21	21.3	4	290	29.01	310	64.83
22	21.3	4.5	290	23.93	310	67.21
23	21.3	4.5	290	28.06	310	67.94
24	21.3	4.5	290	29.01	310	68.02
25	21.3	4.8	290	23.93	310	70.12
26	21.3	4.8	290	28.06	310	71.35
27	21.3	4.8	290	29.01	310	71.79

Table -2.2: Reliability Results

Sl no	P_u	LHM (β)	P_f	R	R in%
1	30.39	2.4	0.0076	0.9923	99.231
2	31.23	2.4	0.0075	0.9924	99.246
3	31.92	2.3	0.01	0.99	99
4	39.95	1.1	0.125	0.875	87.5
5	40.12	1.2	0.09	0.91	91
6	40.86	1.2	0.11	0.89	89
7	45.62	0.8	0.2	0.8	80
8	46.21	0.8	0.1925	0.8075	80.75
9	47.36	0.7	0.2225	0.7775	77.75
10	50.12	0.9	0.162	0.838	83.8
11	50.94	1.1	0.1317	0.8683	86.83
12	51.62	1	0.147	0.853	85.3
13	55.32	0.9	0.169	0.831	83.1
14	56.78	1	0.1415	0.8585	85.85
15	56.93	1	0.1562	0.8438	84.38
16	59.86	1	0.1575	0.8425	84.25
17	60.52	1.1	0.1301	0.8699	86.99
18	60.76	1.1	0.1293	0.8707	87.07
19	63.59	1.8	0.0313	0.9687	96.87
20	64.08	2	0.0216	0.9784	97.84
21	64.83	1.9	0.025	0.975	97.5
22	67.21	1.5	0.06	0.94	94
23	67.94	1.7	0.0422	0.9578	95.78
24	68.02	1.7	0.0445	0.9555	95.55
25	70.12	1.4	0.065	0.935	93.5
26	71.35	1.6	0.05	0.95	95
27	71.79	1.6	0.0511	0.9489	94.89

Ultimate Loads For Different D/T Ratio

The ultimate loads are calculated for different L/D ratios and the results are compared with different available codes which is listed in below tables.

Table 2.3: For Thickness 2mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13.6	10.65	23.93	30.3	43.21	42.37	41.3
26.9	10.7	13.5		50.1	58.34	56.87	55.1
33.7	8.61	16.9		60.1	78.31	75.82	72.9
21.3	13.6	10.65	28.06	31.2	44.18	43.19	42.0
26.9	10.7	13.5		50.6	60.05	58.31	56.2
33.7	8.61	16.9		60.8	81.17	78.25	74.8
21.3	13.6	10.65	29.01	31.9	44.4	43.38	42.1
26.9	10.7	13.5		51.3	60.44	58.64	56.5
33.7	8.61	16.9		61.3	81.83	78.81	75.3

Fig 2.1: Pu vs D/t ratio for 2mm thickness

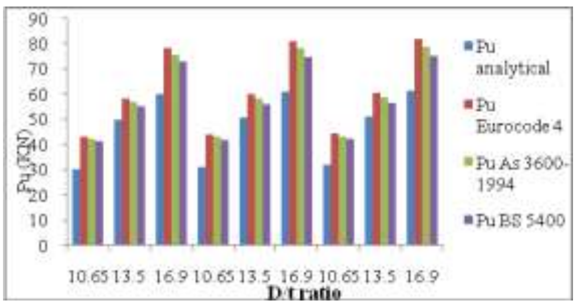


Table 2.4 For Thickness 2.3mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13.6	9.3	23.93	39.9	47.79	47.01	46.0
26.9	10.7	11.7		55.7	64.44	63.04	61.4
33.7	8.61	14.7		68.5	86.23	83.85	82.9
21.3	13.6	9.3	28.06	40.1	48.7	47.77	46.7
26.9	10.7	11.7		56.1	66.05	64.41	62.4
33.7	8.61	14.7		69.2	88.98	86.18	83.3
21.3	13.6	9.3	29.01	40.8	48.9	47.95	46.8
26.9	10.7	11.7		56.8	66.42	64.72	62.74
33.7	8.61	14.7		70.1	89.61	86.72	89.04

Fig 2.2 Pu vs D/t ratio for 2.3mm thickness

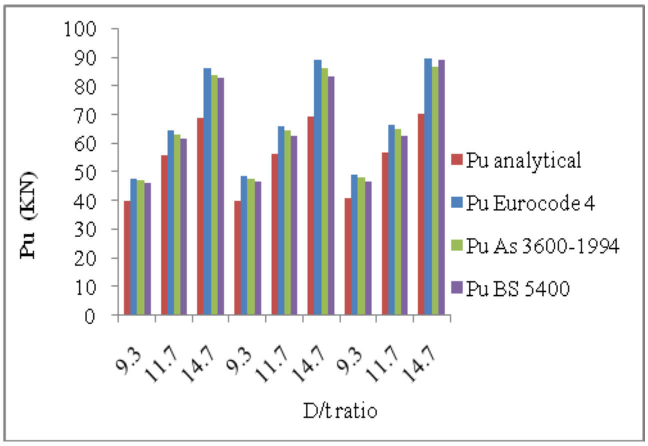


Table 2.5 For Thickness 2.6mm and length 290mm

Diameter mm	*L/D ratio*	*D/T ratio*	*f_{ck} N/mm²*	*P_u Analytical*	*Pu Eurocode 4*	*Pu As 3600-1994*	*Pu BS 5400*
21.3	13.6	8.2	23.93	45.6	52.2	51.4	50.6
26.9	10.7	10.3		59.9	70.3	69.0	67.4
33.7	8.61	13		75.3	94	91.7	89.0
21.3	13.6	8.2	28.06	46.2	53.0	52.2	51.2
26.9	10.7	10.3		60.4	71.8	70.3	68.5
33.7	8.61	13		76.1	96.6	93.9	90.8
21.3	13.6	8.2	29.01	47.3	53.2	52.3	51.3
26.9	10.7	10.3		60.9	72.2	70.6	68.7
33.7	8.61	13		76.7	97.2	94.4	91.2

Fig 2.3: Pu vs D/t ratio for 2.6mm thickness

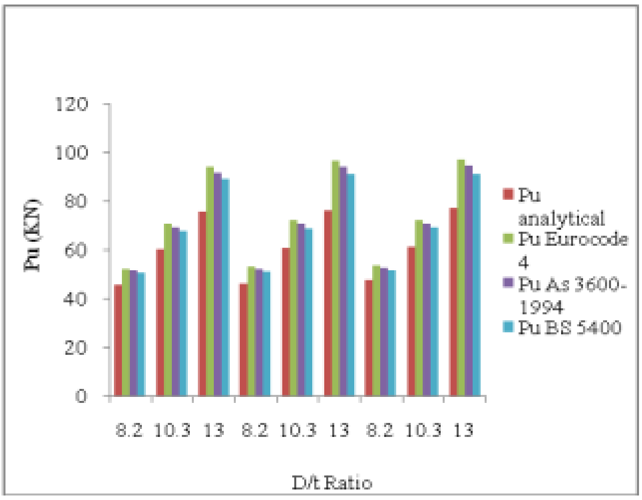


Table 2.6 For Thickness 2.9mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13.6	7.3	23.93	50.1	56.4	55.79	55
26.9	10.7	9.3		63.5	76.1	74.88	73.4
33.7	8.61	11.6		81.5	101.	99.4	96.8
21.3	13.6	7.3	28.06	50.9	57.2	56.46	55.5
26.9	10.7	9.3		63.9	77.5	76.11	74.3
33.7	8.61	11.6		82.0	104.	101.5	98.3
21.3	13.6	7.3	29.01	51.6	57.4	56.61	55.6
26.9	10.7	9.3		64.1	77.9	76.39	74.6
33.7	8.61	11.6		82.6	104.	102.0	98.9

Fig 2.4 Pu vs D/t ratio for 2.9mm thickness

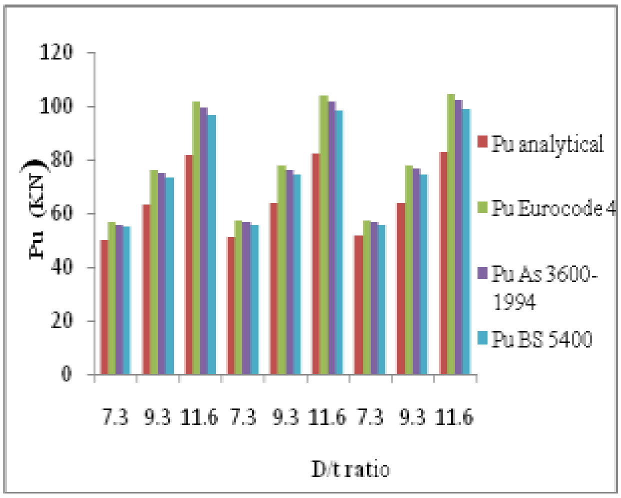


Table 2.7 For Thickness 3.2mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13	6.7	23.93	55.32	60.57	59.94	59.21
26.9	10	8.4		68.49	81.74	80.56	79.18
33.7	8.	10.5		87.32	109.0	106.9	104.4
21.3	13	6.7	28.06	56.78	61.29	60.56	59.7
26.9	10	8.4		69.38	83.11	81.72	80.1
33.7	8.	10.5		87.61	111.4	108.9	106.1
21.3	13	6.7	29.01	56.93	61.45	60.7	59.81
26.9	10	8.4		69.81	83.42	81.98	80.31
33.7	8.	10.5		88.09	112.0	109.7	106.4

Fig 2.5 Pu vs D/t ratio for 3.2mm thickness

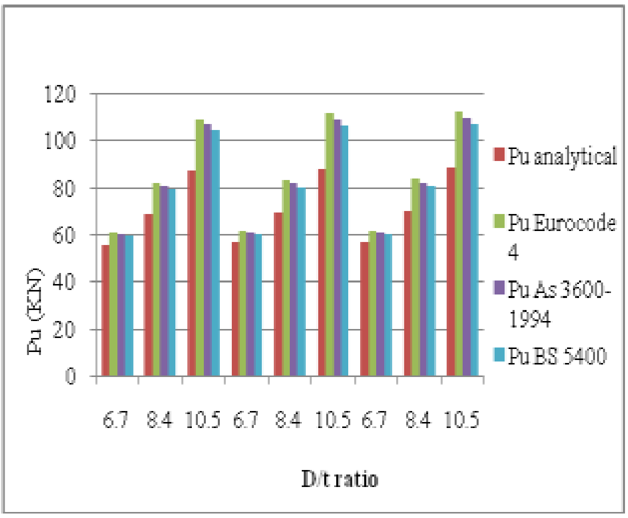


Table 2.8 For Thickness 3.6mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13.6	5.9	23.93	59.86	65.78	65.22	64.57
26.9	10.7	7.5		72.34	88.97	87.87	86.6
33.7	8.61	9.4		88.98	118.7	116.7	114.4
21.3	13.6	5.9	28.06	60.52	66.43	65.77	65
26.9	10.7	7.5		73.19	90.23	88.94	87.45
33.7	8.61	9.4		89.56	120.9	118.6	115.9
21.3	13.6	5.9	29.01	60.76	66.57	65.89	65.1
26.9	10.7	7.5		73.84	90.52	89.19	87.64
33.7	8.61	9.4		90.13	121.5	119.1	116.3

Fig 2.6 Pu vs D/t ratio for 3.6 mm thickness

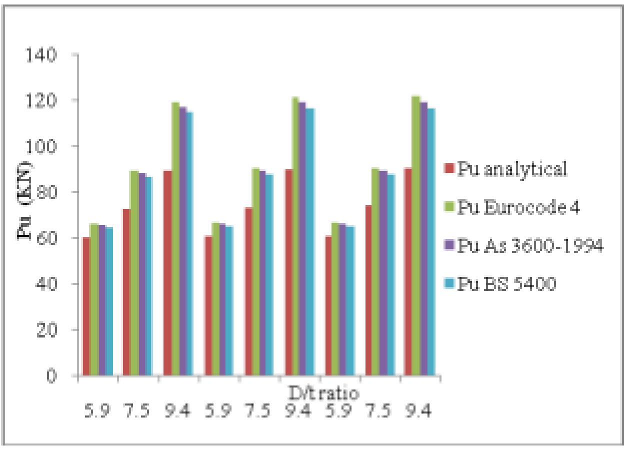


Table 2.9 For Thickness 4mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode 4	Pu As 3600-1994	Pu BS 5400
21.3	13.6	5.3	23.93	63.59	70.7	70.21	69.62
26.9	10.7	6.7		76.31	95.9	94.9	93.72
33.7	8.61	8.4		94.96	128.0	126.2	124.0
21.3	13.6	5.3	28.06	64.08	71.28	70.69	70.01
26.9	10.7	6.7		76.86	97.06	95.88	94.5
33.7	8.61	8.4		95.14	130.2	128.0	125.5
21.3	13.6	5.3	29.01	64.83	71.41	70.81	70.1
26.9	10.7	6.7		77.14	97.33	96.11	94.68
33.7	8.61	8.4		95.65	130.7	128.4	125.8

Fig 2.7 Pu vs D/t ratio for 4mm thickness

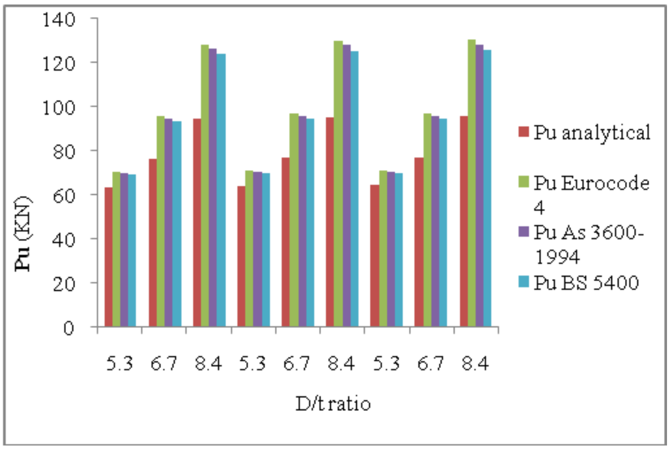


Table 2.10 For Thickness 4.5mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode	Pu As 3600-1994	Pu BS 5400
21.3	13.6	4.7	23.93	67.2	76.4	76.03	75.53
26.9	10.7	6		81.8	104.	103.2	102.2
33.7	8.61	7.5		99.0	139.	137.6	135.6
21.3	13.6	4.7	28.06	67.9	76.9	76.45	75.86
26.9	10.7	6		82.4	105.	104.1	102.2
33.7	8.61	7.5		99.7	141.	139.3	137.0
21.3	13.6	4.7	29.01	68.0	77.0	76.54	75.94
26.9	10.7	6		82.7	105.	104.3	103.0
33.7	8.61	7.5		100.	141.	139.7	137.0

Fig 2.8 Pu vs D/t ratio for 4.5mm thickness

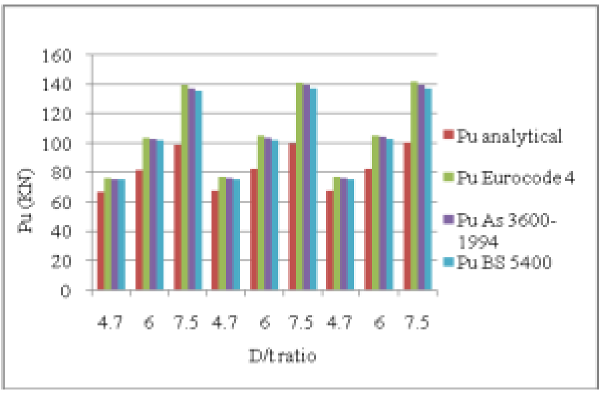
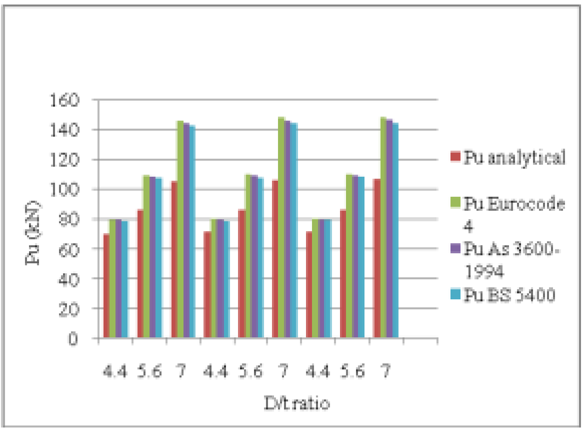


Table 2.11 For Thickness 4.8mm and length 290mm

Diameter mm	L/D ratio	D/T ratio	f_{ck} N/mm²	P_u Analytical	Pu Eurocode	Pu As 3600-1994	Pu BS 5400
21.3	13.6	4.4	23.93	70.1	79.6	79.3	78.8
26.9	10.7	5.6		85.6	108.	108.	107.
33.7	8.61	7		105.	145.	144.	142.
21.3	13.6	4.4	28.06	71.3	80.1	79.6	79.1
26.9	10.7	5.6		85.9	109.	108.	107.
33.7	8.61	7		105.	147.	145.	143.
21.3	13.6	4.4	29.01	71.7	80.2	79.7	79.2
26.9	10.7	5.6		86.3	110.	109.	107.
33.7	8.61	7		106.	148.	146.	144

Fig 2.9: Pu vs D/t ratio for 4.5mm thickness



Following are the results obtained from L9 taguchi's approach

Table:2.12 strength/weight ratio obtained from Taguchi's method

Sl no	D	T	Pu	Weight	Strength/weigh
1	21.3	2	30.39	2.69	31.71
5	21.3	2.3	40.12	3.05	36.92
9	21.3	2.6	47.36	3.39	38.26
11	26.9	2	50.68	3.47	25.70
15	26.9	2.3	56.84	3.94	25.39
16	26.9	2.6	59.95	4.4	23.98
21	33.7	2	61.32	4.42	15.56
22	33.7	2.3	68.51	5.03	15.27
26	33.7	2.6	76.19	5.64	15.15

Fig 2.10: L9 Array Combination for strength/ weight ratio

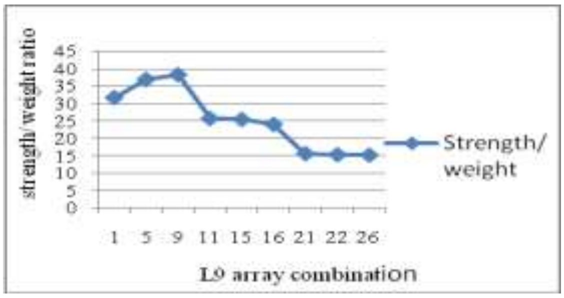
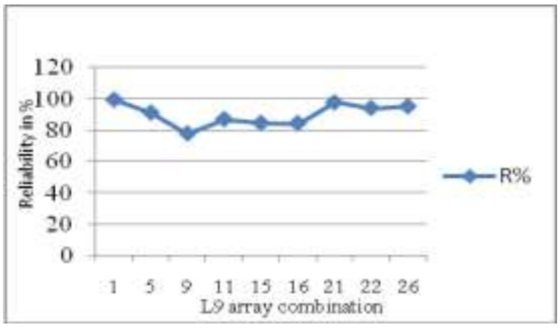


Table: 2.13 Taguchi's L 9 Orthogonal array approach

Sl no	Pu	β(LHM)	P_f	Reliability	R%
1	30.3	2.4	0.077	0.9923	99.2
5	40.1	1.2	0.09	0.91	91.0
9	47.3	0.7	0.222	0.775	77.7
11	50.6	1.1	0.137	0.8683	86.8
15	56.8	1	0.156	0.8438	84.3

16	59.9	1	0.157	0.8425	84.2
21	61.3	1.9	0.025	0.9750	97.5
22	68.5	1.5	0.06	0.94	94
26	76.1	1.6	0.05	0.95	95

Fig: 2.11 Taguchi's method vs Reliability



3. Conclusion

[1] The ultimate load Pu obtained from ANSYS result shows that the ultimate load carrying capacity of CFST tubes increases with increase in thickness.
[2] The ANSYS results shows that the ultimate load carrying capacity of CFST columns increases with decrease in D/t ratio.
[3] Ultimate load Pu obtained from ANSYS and various codes like Eurocode, BS 5400 and AC3600-1999 shows that Pu obtained from ANSYS is higher than the Pu obtained from codes.
[4] It is observed that as the L/D ratio decreases, ultimate load Pu increases.
[5] The Reliability of member decreases with increases in diameter.
[6] Maximum strength/ weight ratio is obtained for model 9 having diameter 21.3mm and thickness 2.6mm.
[7] Maximum reliability of 99.23 % is obtained for model 1 having diameter 21.3mm & thickness 2mm

4. References

[1] Structural Reliability Methods (2005) by O. Dittevsen and H.O Madsen.

[2] Naveen Kumar S, Khalid Nayaz Khan and Dr N.S. Kumar(2017) "Reliability analysis of concrete filled steel Tube columns by FOSM & Subset simulation Technique" Mtech dissertation 2017

[3] Reliability Analysis of composite columns a dissertation by Pankaj Kumar Department of civil engineering IIT Roorke(2002)

[4] Finite Element Analysis Theory and application with ANSYS by Saeed Moaveni, Minnesoter state university Mankato.

[5]Reliability Analysis for Structural design (2009) by Milan Holicky.

[6] Syed Aqeeb Javeed Pasha, Khalid Nayaz Khan and Dr N.S.Kumar "Reliability analysis (FORM level-1 method) of concrete filled steel tube columns using NASTRAN Software Mtech dissertation 2016.

Biographies

Graduated in the year 2016 from 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 Khalid Nayaz khan and Dr. N S Kumar.

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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 29 years of teaching experience &6 years of Research experience at Ghousia College of Engineering, Ramanagaram.