BEHAVIOUR OF COMPOSITE STEEL TUBES INFILLED WITH FRC UNDER MONOTONIC LOADING

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Abstract

In this paper, experimental investigation on the behavior of concrete filled steel tube infilled with Polypropylenefibre (PPF) under monotonic loading is carried out. Here the strength of 54 Specimens was tested. The parameters varied in this study are 1) percentage of PPF (0%, 0.2%, 0.3%, 0.4%) 2) Diameter of the hollow circular steel tubes (33.7mm and 42.4mm) 3)L/D ratios(10,12 and 14) and 4) Grades of concrete(M20 and M30). The thickness of steel tubes is 3.2mm which remains same for all the specimens. Polypropylene fiber concrete filled steel columns exhibit higher strength than steel tubes filled with conventional concrete. The results show that load carrying capacity increased with increase in percentage of polypropylene. it was observed that the load carrying capacity of the steel tube decreased as the D/t ratio increased. The experimental results were compared with theoretical results and analysis results using ABAQUS software

Keywords: *Concrete Filled Steel Tube (CFST), Polypropylene Fibre (PPF)*

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1. INTRODUCTION

CFST is a composite structural member, which resists the applied loads through the composite action of concrete and steel. CFST increases the ultimate load bearing of the member and it is also gives aesthetically pleasing. Since the steel confines concrete bucking resistance of the CFST member increases. The restrained effect of concrete present in the CFST tube helps in delaying the local buckling of the steel tube and also prevents the failure of the member. The confinement effect of the steel tube increases the strength of and also strength deterioration is not that serious because concrete does not spall due to the confinement. Having listed all the advantages, however the major disadvantage of a composite column is the exposure of tube to the environmental effects (such as heat, cold, UV etc). For steel tubes, this raises concerns related to susceptibility to corrosion and fire safety. CFST column posses high strength, high ductility more energy absorption capacity. The ultimate load bearing capacity and resistance to bending, compression and shear are all better than that of the reinforced concrete. On other hand Use of thin walled steel tubes in construction reduces the cost of construction significantly The reduction of the steel tube thickness in thin-walled CFST columns has the potential to significantly reduce construction costs. Concrete filled steel tubular (CFST) column, comprising a hollow steel tube infilled with concrete with or without additional reinforcements or steel section, has been widely used in high rise building construction.

1.1 Types of CFST Columns

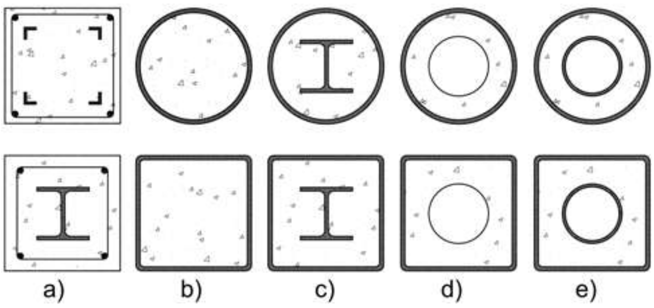

Fig 1: Types of concrete filled steel tubular cross sections

1.2 Materials and Methodology

1.2.1 Cement

In this experiment 53 grades ordinary Portland cement (OPC) was used for all concrete mixes. The properties of cement used are as shown in table.1.

Table 1 properties of Cement

Sl. no	properties	value
1	Brand of Cement	Zuari
2	Type of Cement	53 grade
3	Specific gravity	3.14

1.2.2 Fine Aggregates

For this investigation manufactured sand is used as fine aggregates free from deleterious materials. The properties of Fine aggregates used are tabulated in table.2.

Table 2: Properties of fine aggregates

Sl. No	properties	value
1	Specific gravity	2.50
2	Fineness modulus	3.015
3	Grading of sand	Zone II

1.2.3 Coarse Aggregates

The coarse aggregates used for this experiment is 12mm size which is free from deleterious materials. The physical properties are as given in table.3.

Table 3: Properties of coarse aggregates

Sl. No	properties	value
1	Specific gravity	2.67
2	Fineness modulus	2.24

1.2.4 Water

Clean portable tab water available from library is used for the experiments.

1.2.5 Polypropylene

Polypropylene is one of the cheapest and more available fibers. It has high resistant to chemical attacks and high melting point about 165 degree centigrade. It can withstand a working temp 100 degree centigrade.

Fig 2: Polypropylene Fiber

1.3 Concrete Mix Design

The Mix Proportions for M20 Cement: A: CA 1:1.5:3
The Mix Proportions for M20 Cement: A: CA 1:1.5:2.5

1.4 Compressive Strength After 28 Days

Table 4: Compressive Strength after 28 days

Sl no	Mix designation	% of PPF	C/S Area of cube in mm^2	Load in Tons	28 days Compressive strength in N/mm^2
1	M20	0%	225	51.5	22.5
2		0.2%	225	62	27.05
3		0.3%	225	65.5	28.6
4		0.4%	225	69	30.05
5	M30	0%	225	73.2	31.95
6		0.2%	225	78	34.06
7		0.3%	225	81.5	35.5
8		0.4%	225	85.5	37.28

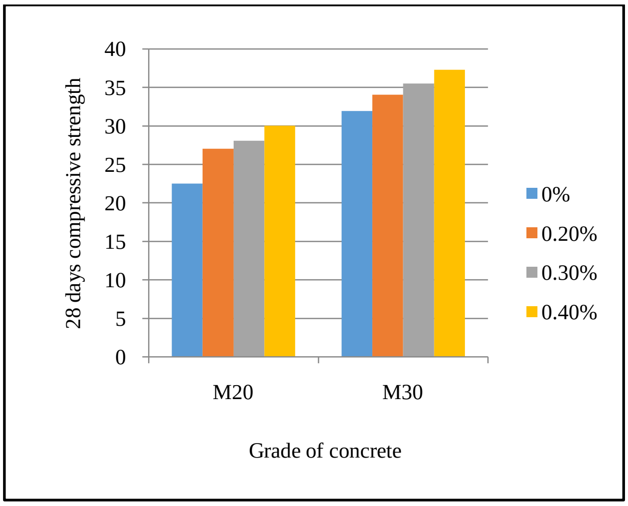

Chart 1: Variation of Compressive Strength for M20 and M30 Grade of Concrete

1.5 Preparing Concrete Mix

Fig 3: preparing concrete mix and adding fiber to concrete

1.6 Steel Tube

Circular steel tubes of yield strength310Mpa from Tata steel company were used

Table 5: Circular tubes size and corresponding L/D ,D/T ratios for yield strength 310grade

SL NO	Dia (mm)	t (mm)	L/D ratio	Length (mm)	D/T ratio
1	33.7	3.2	10	337	10.53
2	33.7	3.2	12	405	10.53
3	33.7	3.2	14	472	10.53
4	42.4	3.2	10	424	13.25
5	42.4	3.2	12	510	13.25
6	42.4	3.2	14	594	13.25

Fig 5: filling of steel tube with concrete and placing for curing

2. EXPERIMENTAL SETUP:

The tests were conducted using a 2000 ton capacity monotonic loading machine placing the specimen in the testing machine and geometry of the specimens are as shown in Fig. 1 to 3. The specimen was placed between the bearing plates in such a manner that the upper bearing plates was directly in line with the lower plate and the bearing plates extend at least 25 mm from each end of the specimen. The columns were placed on smooth plates at both ends. Care was taken to ensure that truly axial load was applied to each of the columns. Plumb bob and Theodolite has been employed to place the specimen truly vertical and hence load the specimen concentrically as shown in Fig. 4.

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Fig 6: 200 Ton Capacity Hydraulic Monotonic Loading Machine

Fig 7: CFST column before and after applying load

3. THEORETICAL FORMULAE & CALCULATION

3.1 EC 4 - Euro Code

EC-4 considers confinement effects of CFST member. This code is used to check ultimate load capacity. For circular column, where λ is defined as

$$\lambda = \frac{\sqrt{\text{Asfs} + 0.85\text{Acfc}}}{\text{Ncr}}$$

$$N_{cr} = \frac{(\text{EsIs} + \text{EcIc})\pi^2}{L^2}$$

$$\eta 1 = 4.9 - 18.5\lambda + 17\lambda^2 + 1$$

$$\eta 2 = 0.25(3.2\lambda)$$

$$P_u = Asfs\eta 2 + \text{Acfc}(1 + \eta 1 \frac{tfs}{dfc})$$

3.2 ACI 318-1999: American Concrete Institute- Building Code Requirements for Structural Concrete

The ultimate load, Pu is given by equation

Pu=AsFs+0.85AcFc

3.3 BS 5400 (British Standards)

BS 5400 is based on limit state design and ultimate load carrying capacity (Pu) is given by the equation

NBS = 0.91 As fy + 0.45 Ac Fc

3.4 CCECS Methods (China Engineering and Construction Specification)

$$N_{CESS} = \phi 1.\phi 2.N_0$$

$\phi 1 = 1$ for $(L/D) \leq 4$

$\phi 1 = 1 - 0.115 L/D\ (\sqrt{\ } \left(\frac{L}{D}\right) - 4)$ for $(L/D) > 4$

ϕ1 and ϕ2 are reduction factors

N_0 = fc Ac + fs As + SQRT ((fcAc). (FsAs))

Table 3 Theoretical calculations

Sl No	Grade of concrete	% of fiber	D/T ratio	L/D ratio	Exp load, kN	Axial Load Carrying Capacity (kN)			
						ACI	BS	EC-4	CCECS
1	HOLLOW	-	10.53	10	112	76.04	86.50	95.05	95.36
2		-	10.53	12	109	76.04	86.50	95.05	95.36
3		-	10.53	14	103	76.04	86.50	95.05	95.36
4		-	13.25	10	135	97.73	111.17	122.16	122.51
5		-	13.25	12	128	97.73	111.17	122.16	122.51
6		-	13.25	14	124	97.73	111.17	122.16	122.51
7	M20	0	10.53	10	130	85.00	92.42	107.26	103.15
8	M20	0.2	10.53	10	136	86.81	93.62	109.92	107.52
9	M20	0.3	10.53	10	139	87.43	93.89	110.83	108.46
10	M20	0.4	10.53	10	133	88.00	94.41	111.68	110.28
11	M20	0	10.53	12	127	85.00	92.42	108.22	96.89
12	M20	0.2	10.53	12	133	86.81	93.62	110.89	100.99
13	M20	0.3	10.53	12	137	87.43	93.89	111.79	101.88
14	M20	0.4	10.53	12	130	88.00	94.41	112.64	103.59
15	M20	0	10.53	14	125	85.00	92.42	108.22	91.38
16	M20	0.2	10.53	14	130	86.81	93.62	110.89	95.25
17	M20	0.3	10.53	14	136	87.43	93.89	111.79	96.08
18	M20	0.4	10.53	14	129	88.00	94.41	112.64	97.70
19	M20	0%	13.25	10	165	113.31	121.48	145.07	142.20
20	M20	0.2	13.25	10	171	116.46	123.56	149.70	149.19
21	M20	0.3	13.25	10	176	117.53	124.02	151.28	150.70
22	M20	0.4	13.25	10	168	118.53	124.93	152.75	153.63
23	M20	0	13.25	12	161	113.31	121.48	145.07	133.57
24	M20	0.2	13.25	12	167	116.46	123.56	149.70	140.14
25	M20	0.3	13.25	12	169	117.53	124.02	151.28	141.56
26	M20	0.4	13.25	12	163	118.53	124.93	152.75	144.31
27	M20	0	13.25	14	158	113.31	121.48	145.07	125.97
28	M20	0.2	13.25	14	162	116.46	123.56	149.70	132.16
29	M20	0.3	13.25	14	166	117.53	124.02	151.28	133.50
30	M20	0.4	13.25	14	160	118.53	124.93	152.75	136.10
31	M30	0	10.53	10	140	88.76	94.91	112.79	112.00
32	M30	0.2	10.53	10	146	89.60	95.47	114.03	113.87
33	M30	0.3	10.53	10	149	90.17	95.85	114.87	115.13
34	M30	0.4	10.53	10	142	90.88	96.32	115.91	116.67
35	M30	0	10.53	12	137	88.76	94.91	113.75	105.20
36	M30	0.2	10.53	12	141	89.60	95.47	114.99	106.96
37	M30	0.3	10.53	12	146	90.17	95.85	115.83	108.14
38	M30	0.4	10.53	12	139	90.88	96.32	116.87	109.59
39	M30	0	10.53	14	133	88.76	94.91	113.75	99.22
40	M30	0.2	10.53	14	138	89.60	95.47	114.99	100.87
41	M30	0.3	10.53	14	142	90.17	95.85	115.83	101.99
42	M30	0.4	10.53	14	135	90.88	96.32	116.87	103.35
43	M30	0	13.25	10	175	119.85	125.80	154.69	156.39
44	M30	0.2	13.25	10	180	121.31	126.77	156.83	159.40
45	M30	0.3	13.25	10	184	122.30	127.43	158.30	161.43
46	M30	0.4	13.25	10	178	123.54	128.25	160.11	163.92
47	M30	0	13.25	12	171	119.85	125.80	154.69	146.90
48	M30	0.2	13.25	12	178	121.31	126.77	156.83	149.73
49	M30	0.3	13.25	12	175	122.30	127.43	158.30	151.64
50	M30	0.4	13.25	12	173	123.54	128.25	160.11	153.97
51	M30	0	13.25	14	163	119.85	125.80	154.69	138.54
52	M30	0.2	13.25	14	169	121.31	126.77	156.83	141.21
53	M30	0.3	13.25	14	172	122.30	127.43	158.30	143.01
54	M30	0.4	13.25	14	165	123.54	128.25	160.11	145.21

From above results we can concluded that

- ➢ load carrying capacity of the CFST column increases with decreasing l/d ratio.
- ➢ As D/T ratio enhances the load bearing capacity of the member increases.
- ➢ The columns of smaller slenderness ratio Columns with greater slenderness ratio fail by overall buckling.
- ➢ From the analytical results that the decrease in L/D ratio increases the capacity of the CFST section.
- ➢ As grade of concrete increases the strength of the CFST member.

3.4 Graphical Representation of Theoretical Calculations

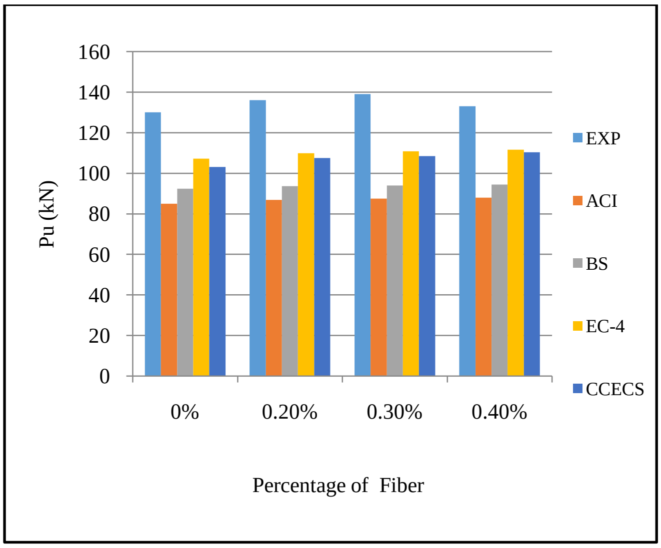


Chart 2: Variation of Pu for different Percentage of fiber d1=33.7mm L/D ratio =10 for M20 grade of concrete.

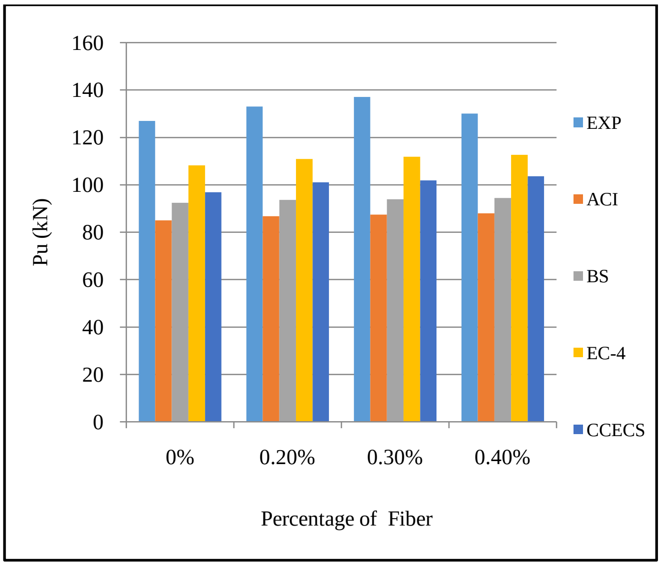


Chart 3: Variation of Pu for different Percentage of fiber d1=33.7mm L/D ratio =12 for M20 grade of concrete.

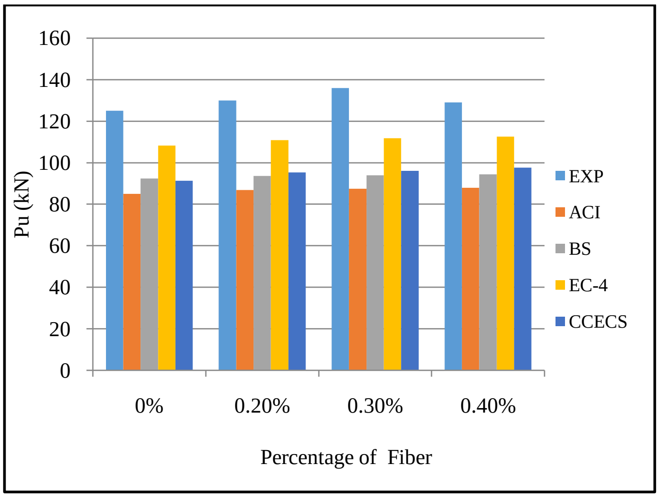


Chart 4: Variation of Pu for different Percentage of fiber d1=33.7mm L/D ratio =14 for M20 grade of concrete.

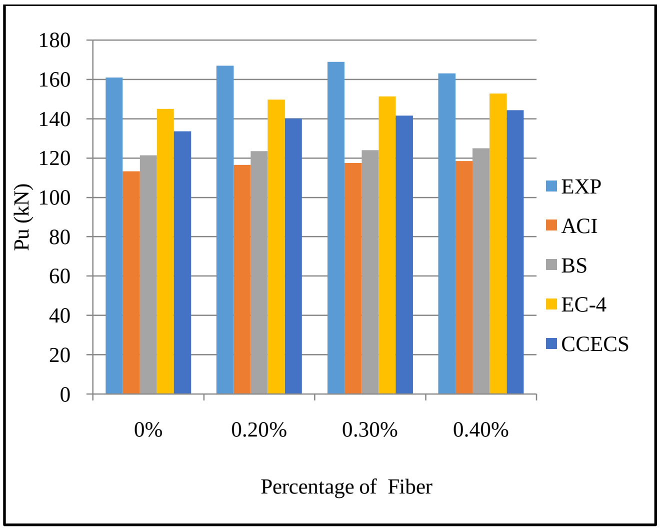


Chart 5: Variation of Pu for different Percentage of fiber d2=42.4mm L/D ratio =10 for M20 grade of concrete.

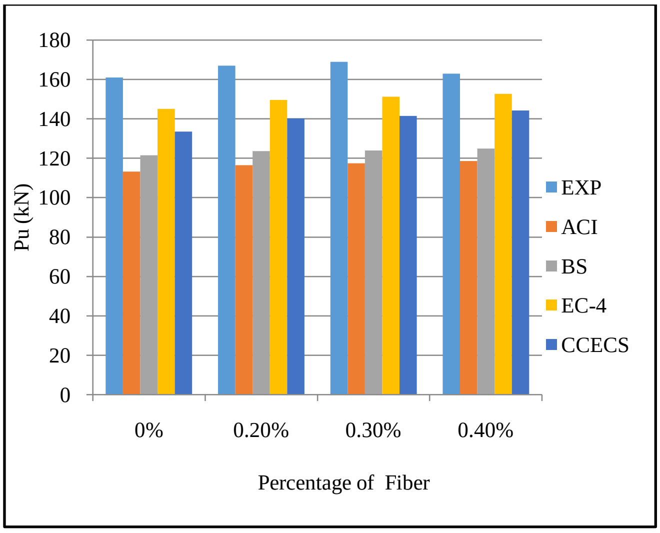


Chart 6: Variation of Pu for different Percentage of fiber d2=42.4mm L/D ratio =10 for M20 grade of concrete.

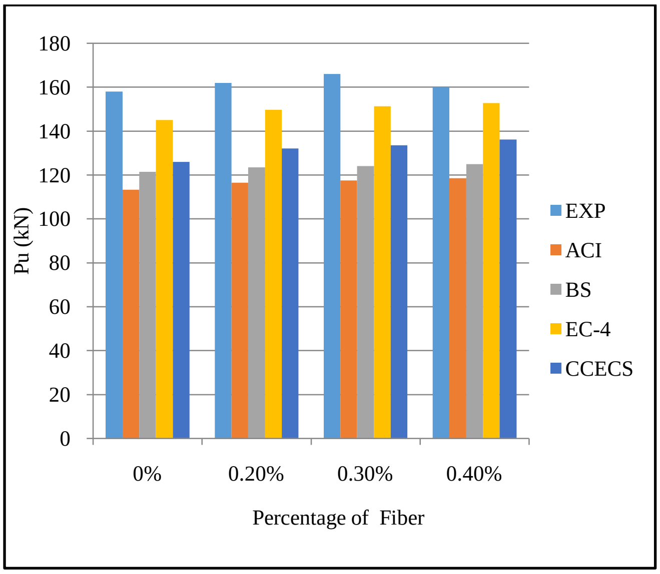


Chart 7: Variation of Pu for different Percentage of fiber d2=42.4mm L/D ratio =10 for M20 grade of concrete.

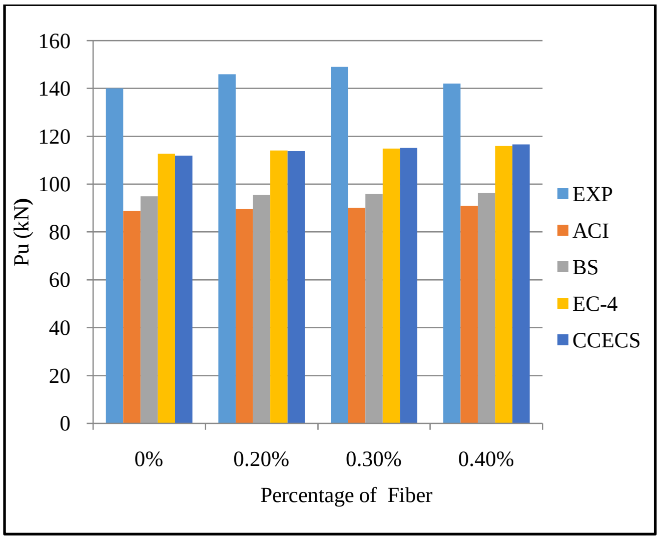


Chart 8: Variation of Pu for different Percentage of fiber d1=33.7mm L/D ratio =10 for M30 grade of concrete.

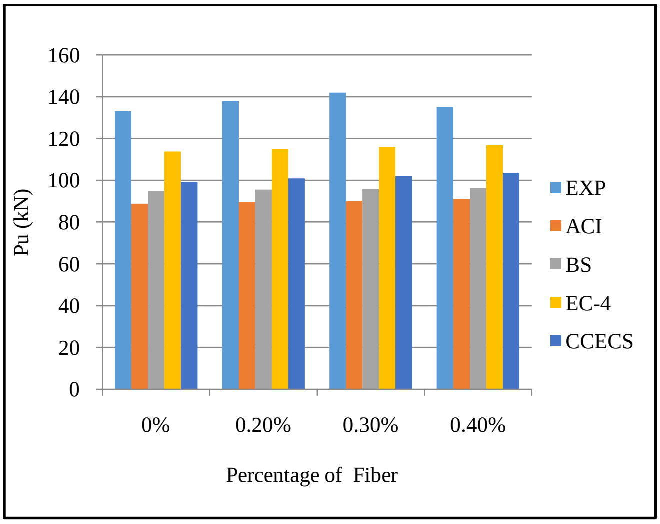


Chart 9: Variation of Pu for different Percentage of fiber d12=42.4mm L/D ratio =10 for M30 grade of concrete.

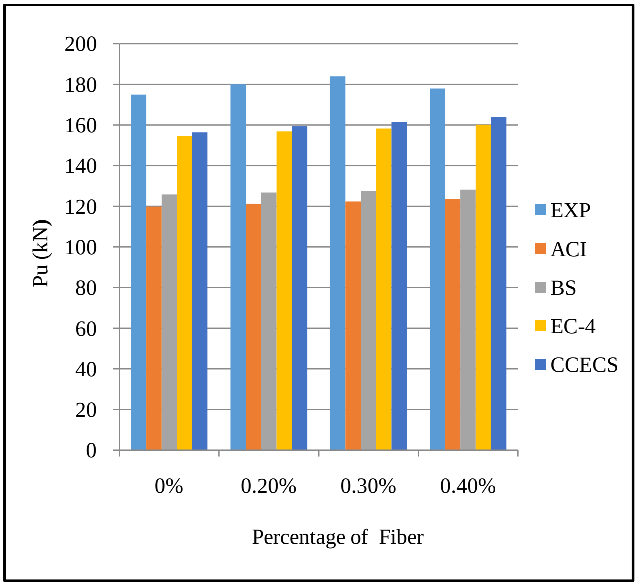


Chart 10: Variation of Pu for different Percentage of fiber d12=42.4mm L/D ratio =10 for M30 grade of concrete.

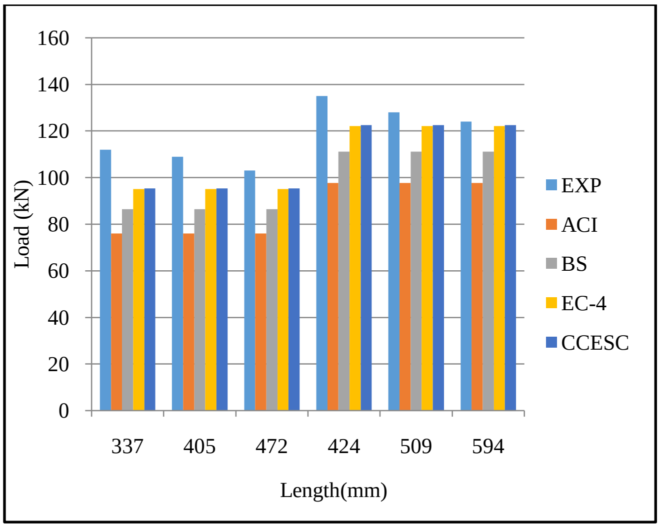


Chart 11: Variation of Pu for different length of hollow tubes

4. FINITE ELEMENT ANALYSIS

4.1. Introduction

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is also referred to as finite element analysis (FEA). FEM helps in subdividing the large problem into smaller parts called finite elements.

The various considerations taken in the dicritization process is:

1. Type of elements
2. Size of elements
3. Location of nodes
4. Number of elements
7. Node numbering scheme
8. Automatic node generation

4.2 Load Carrying Capacity Using ABAQUS Software

MODELLING

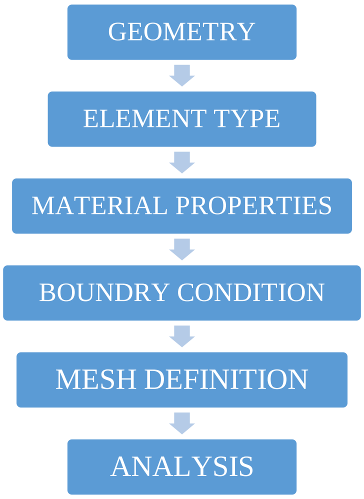


Fig 8: Modeling Procedure

4.3 Material Specification

CONCRETE

Grade of concrete

M20. Young's modulus E=22360 M pa
M30, Young's modulus E=27386.5 M pa
Poison ratio =0.2
Density = 2400 kg/m3

STEEL

Grade of steel: Fe = 250 M pa
Young's modulus =210000 M pa
Poison ratio = 0.3
Density = 7850 kg/m3

4.4 Boundary Condition

The bottom ends are fixed, for fixed condition the degree of freedom is 6 i.e. 3 degree of rotation, 3 degree of displacement.

4.5 Modeling and Analysis Using Hypermesh and Abacus

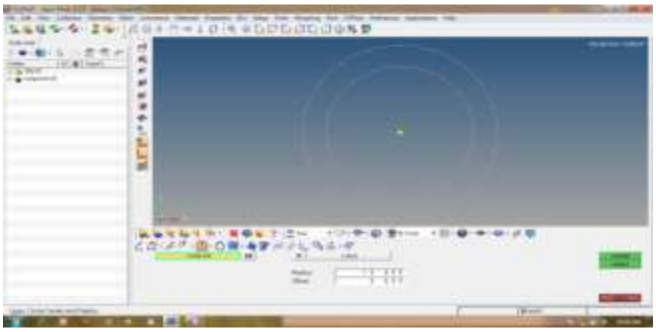


Fig 9: Creating CFST model

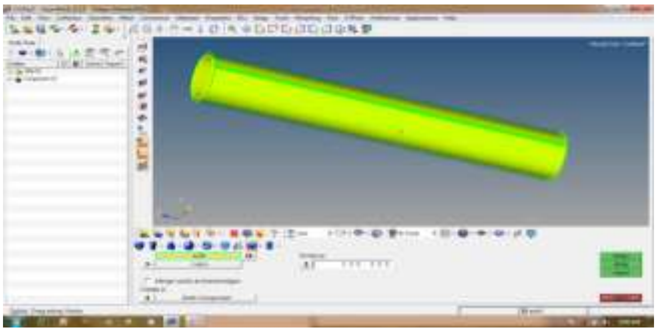


Fig 10: Segregation Of Elements

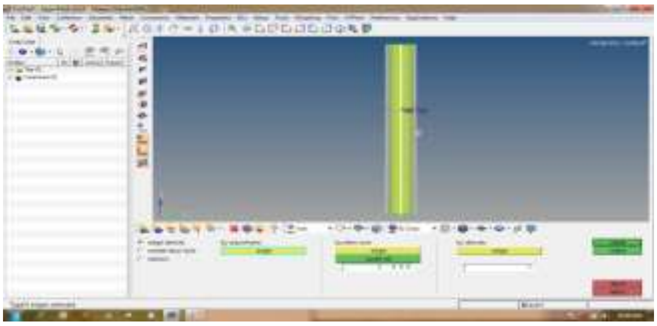


Fig 11: Meshing of CFST column

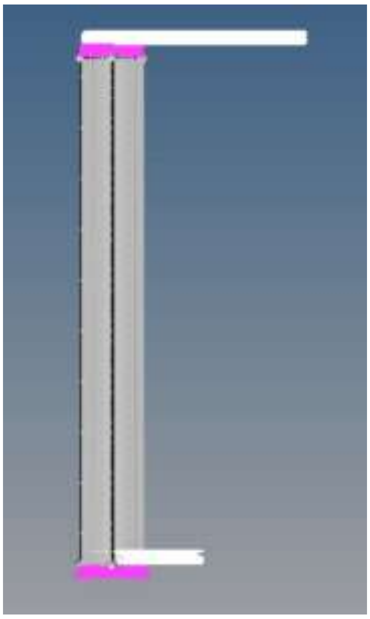


Fig12: applying the load

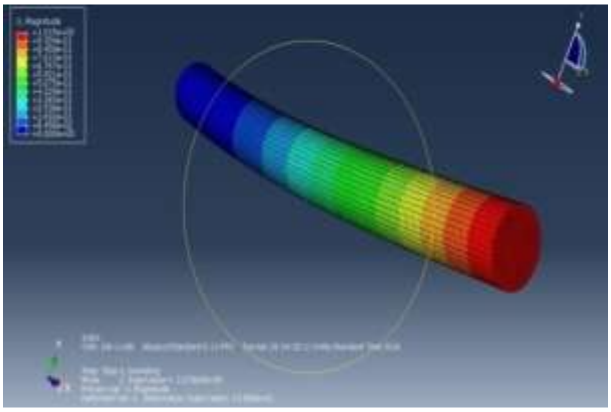


Fig 13: Mode 1 deformation

4.6 Analysis Result

Exp no	*Percentage of Fiber*	*Grade*	*Length, mm*	*Area, mm 2*	(ANALYSIS) PU (kN)	Exp Load, PU(kN)	Percentage ERROR	Grade of concrete
1		-	337	306.62	146	112	12.5	HOLLOW
2		-	405	306.62	142	109	11.9	
3		-	472	306.62	135	103	16.5	
4		-	424	394.08	163	135	3.7	
5		-	509	394.08	157	128	7.0	
6		-	594	394.08	142	121	12.4	
7	0	M20	337	891.96	183	130	13.8	M20
8	0.2	M20	337	891.96	198	136	13.2	M20
9	0.3	M20	337	891.96	212	139	13.7	M20
10	0.4	M20	337	1411.95	188	133	13.5	M20
11	0	M20	405	1411.95	176	127	15.0	M20
12	0.2	M20	405	1411.95	189	133	13.5	M20
13	0.3	M20	405	891.96	209	137	13.1	M20
14	0.4	M20	405	891.96	181	130	13.8	M20
15	0	M20	472	891.96	171	125	12.8	M20
16	0.2	M20	472	1411.95	181	130	13.8	M20
17	0.3	M20	472	1411.95	198	136	10.3	M20
18	0.4	M20	472	1411.95	176	129	10.9	M20
19	0	M20	424	891.96	232	165	6.1	M20
20	0.2	M20	424	891.96	258	171	10.5	M20
21	0.3	M20	424	891.96	273	176	9.7	M20
22	0.4	M20	424	1411.95	265	168	10.1	M20
23	0	M20	509	1411.95	239	161	6.8	M20
24	0.2	M20	509	1411.95	258	167	8.4	M20
25	0.3	M20	509	891.96	262	169	11.2	M20
26	0.4	M20	509	891.96	241	163	9.2	M20
27	0	M20	594	891.96	230	158	5.7	M20
28	0.2	M20	594	1411.95	251	162	8.6	M20
29	0.3	M20	594	1411.95	258	166	7.8	M20
30	0.4	M20	594	1411.95	226	160	7.5	M20
31	0	M30	337	891.96	218	140	11.4	M20
32	0.2	M30	337	891.96	222	146	11.6	M30
33	0.3	M30	337	891.96	239	149	12.1	M30
34	0.4	M30	337	1411.95	210	142	12.7	M30
35	0	M30	405	1411.95	198	137	8.0	M30
36	0.2	M30	405	1411.95	211	141	12.8	M30
37	0.3	M30	405	891.96	226	146	11.0	M30
38	0.4	M30	405	891.96	189	139	12.2	M30
39	0	M30	472	891.96	192	133	7.5	M30
40	0.2	M30	472	1411.95	216	138	10.1	M30
41	0.3	M30	472	1411.95	229	142	9.9	M30
42	0.4	M30	472	1411.95	190	135	9.6	M30
43	0	M30	424	891.96	259	175	3.4	M30
44	0.2	M30	424	891.96	265	180	8.3	M30
45	0.3	M30	424	891.96	299	184	9.2	M30
46	0.4	M30	424	1411.95	259	178	8.4	M30
47	0	M30	509	1411.95	256	171	4.7	M30
48	0.2	M30	509	1411.95	269	178	6.2	M30
49	0.3	M30	509	891.96	272	175	12.6	M30
50	0.4	M30	509	891.96	223	173	4.6	M30
51	0	M30	594	891.96	234	163	4.9	M30
52	0.2	M30	594	1411.95	246	169	7.7	M30
53	0.3	M30	594	1411.95	258	172	9.9	M30
54	0.4	M30	594	1411.95	214	165	8.5	M30

4.7 Graphical Representation of Experimental and Analytical Results

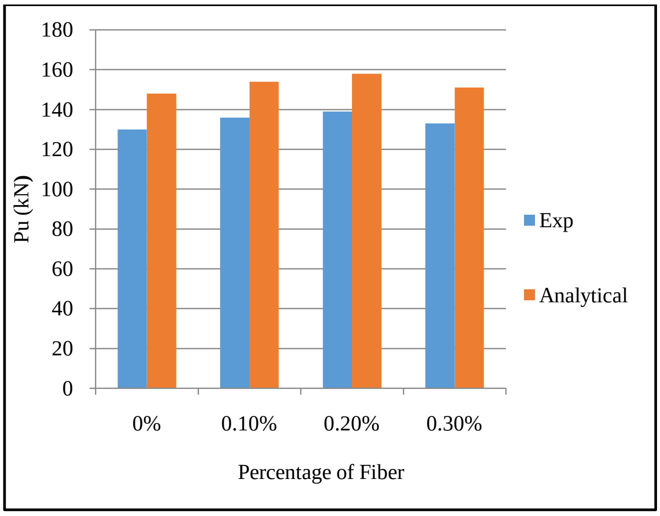


Chart 12: Variation of Pu for different Percentage of fiber d1=33.7 mm L/D ratio =10 for M20 grade of concrete

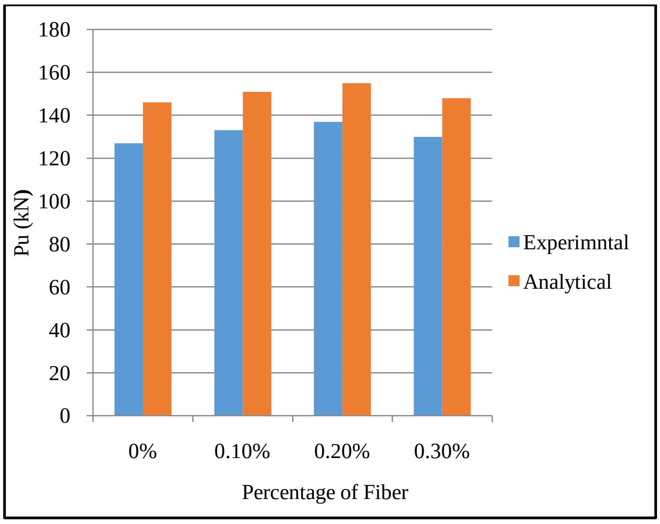


Chart 13: Variation of Pu for different Percentage of fiber d1=33.7 mm L/D ratio =12 for M20 grade of concrete

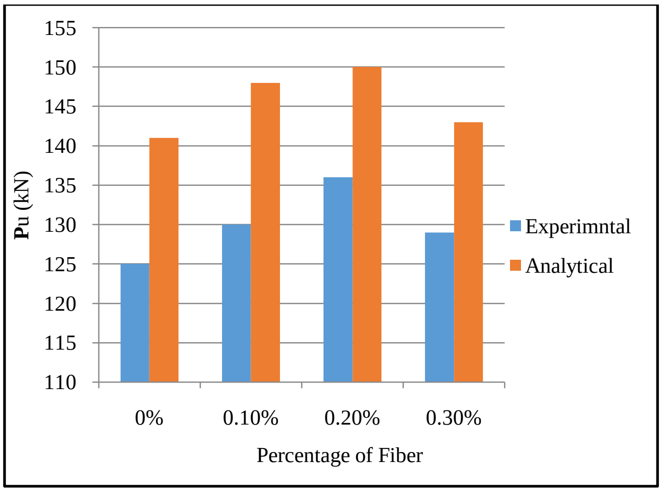


Chart 13: Variation of Pu for different Percentage of fiber d1=33.7 mm L/D ratio =14 for M20 grade of concrete

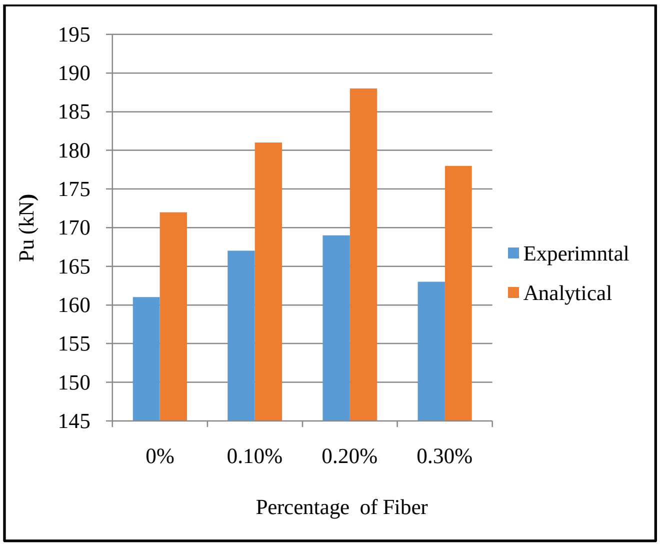


Chart 13: Variation of Pu for different Percentage of fiber d2=42.4 mm L/D ratio =14 for M20 grade of concrete

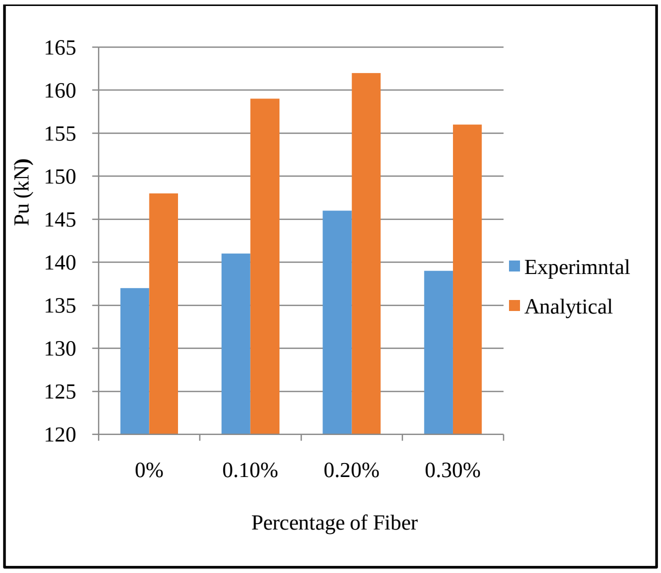
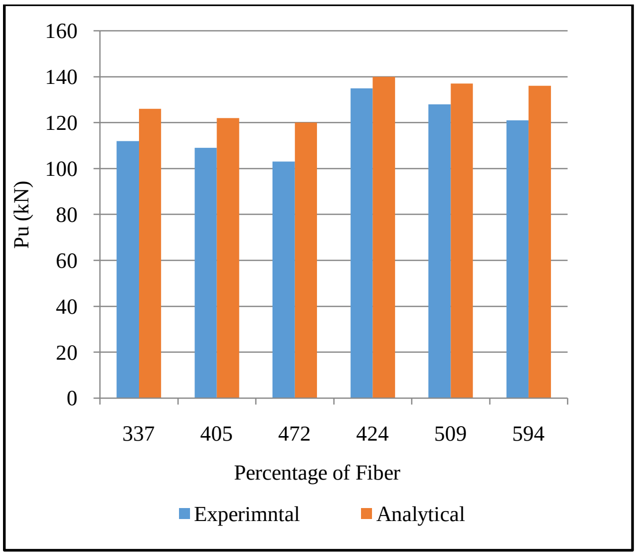


Chart 14: Variation of Pu for different Percentage of fiber d1=33.7 mm L/D ratio =12 for M30 grade of concrete



5. CONCLUSION

1. Load carrying capacity (Pu) decreases with increase in L/D ratio for a given thickness and a given grade of concrete.
2. Load carrying capacity (Pu) increases with increase in diameter of steel tube for a given L/D ratio, grade of concrete and a given thickness.
3. Load carrying capacity (Pu) increases with increase in diameter for addition of fiber up to 0.3%, a slight decrease in Pu is observed for 0.4% of fiber.
4. The deformation decreases with increase in diameter for a given L/D ratio, grade of concrete and thickness of tube.
5. The experimental results closely match with results obtained from various codal formulae.

REFERENCES

[1]. Elremaily, A., and Azizinamini, A. _2002_. “Behaviour and strength of circular concrete-filled tube columns.” *J. Constr. Steel Res.*, 58, 1567–1591.
[2]. Goode, C. D., and Lam, D. _2008_. “Concrete-filled tube columns—Tests compared with Eurocode 4.” *Proc., Engineering Foundation Conf. On Composite Construction*
[3]. Cederwall K., Engstorm B., and Guauers M., (1990), “High strength concrete used in composite columns”, Proceedings of High strength concrete, 2nd International Symposium, Detroit, 195-214 (ACI-SP 121)
[5]. Lu YQ, Kennedy DJL, (1994), “The flexural behaviour of concrete filled hollow structural sections”, Canadian Journal of Civil Engineering, 21(1); 11-130.
[6]. Pan YH., Zhong ST., (1990), “Constitutive relation of concrete filled steel tube under tension”, Ind.