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Prediction of Axial Load Carrying Capacity of LWC in Filled CFST Columns- Anova Approach

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***Abstract:** Concrete-filled steel tubular columns have gained immense importance in recent decades due to numerous structural benefits especially in developed countries like china, Japan, U.S.A, Britain. Composite circular steel tubes Columns - with lightweight concrete as infill for two different grades say M20 and M30 are tested for ultimate load capacity by previous researchers (both at international and national) in addition to results obtained by previous post-graduate students of Ghousia College of Engineering, R & D center, Civil department have been verified by ANOVA approach is presented in this paper. Steel tubes are tested for a different combination of Length, Thickness & Diameter with the help of Taguchi's L9 (Latin squares) - Orthogonal array in order to save time and cost of experimentation and also to determines the effect of each parameter. This study further presents a numerical investigation into the behavior of concrete filled tubular columns using three-dimensional nonlinear finite element software ABAQUS 6.10.1 is carried out in this paper. The analytical results obtained are compared with the numerical results obtained from Abaqus 6.10.1. For this purpose, a comparison between designs codes Eurocode -4 and AISC-LRFD have been made in evaluating the axial compressive strength of concrete filled tubular columns. The obtained results were analyzed with the help of Signal/Noise (S/N) Ratio, Main Effects Plot & Analysis of variance (ANOVA) using Mini Tab V16. Regression equations are developed for all two grades of infills separately. This paper focuses on modeling of Infilled concrete filled steel tube (CFST) column under axial loading and economical aspects.*

***Keywords:** CFST Column, Lightweight Concrete, Abaqus.6.10.1, Taguchi Approach, Signal/Noise (S/N) Ratio, Main Effects Plot & Analysis Of Variance (Anova), Linear Regression.*

I. INTRODUCTION

Concrete-filled steel tubular (CFST) element utilize the advantages of both steel and concrete. When the concrete-filled steel tubular columns are employed under favorable conditions, the steel casing confines the core and the filled concrete inhibits local buckling of the shell. However, the thermal conductivity of lightweight concrete, as well as the low specific gravity that produces lighter structures, seem to be logic reasons for using lightweight concrete in composite construction. Among the advantages of solely steel tubular columns, one can list good spatial performance, ductility, excellent performance against the effects of torsion, and speed of the constructive process.

According to the past study on the concentric compression behavior of the CFT columns, the ultimate axial strength of CFT column is considerably affected by the wall thickness of the steel tube, the strength of in-filled concrete and the length of the CFT. The present work is intended to study the parameters affecting the ultimate axial load carrying capacity of the CFT using ANOVA approach.

II. FINITE ELEMENT MODELING

Light weight concrete filled in the CFST column are accurately model in finite element software ABAQUS 6.10.1 and verified with experimental results and codes of practice. The below figure shows on cross section of CFST columns

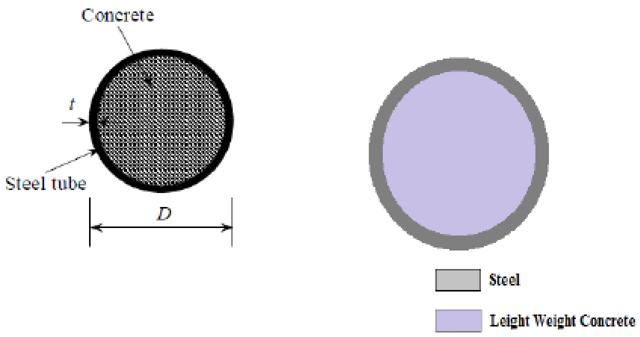


Fig. 1: Cross Section of CFST column

A. MATERIAL PROPERTIES

STEEL:

Young's modulus =310000 M pa

Poison ratio = 0.3

Density = 7860 kg/m^3

CONCRETE (LWC)

Grade of concrete:

M20. Young's modulus E= 22360.7 M pa

M30, Young's modulus E= 27386.12 M pa

Poison ratio =0.2

Density = 1850 kg/m^3

B. MODELING AND MESHING

The 3D hollow and light weight concrete-filled steel tube columns are modeling are created in CATIA.V5 and meshing is done in Hypermesh-11.0 software and then exported to ABAQUS 6.10.1. Because creating a model is difficult in ABAQUS when compare to the Hyper mesh. The element library of finite element software ABAQUS-6.10.1 is used to select different types of elements.

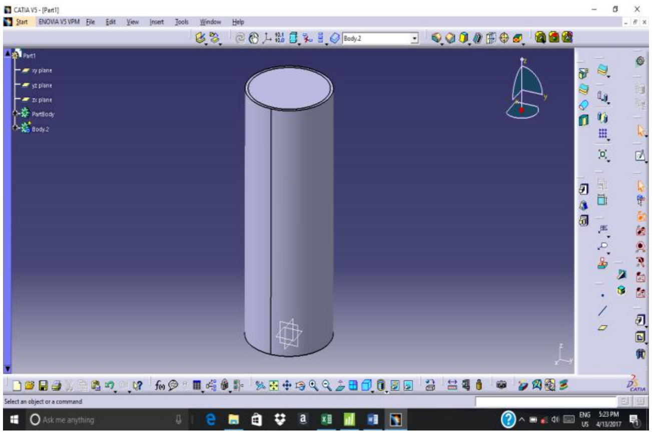
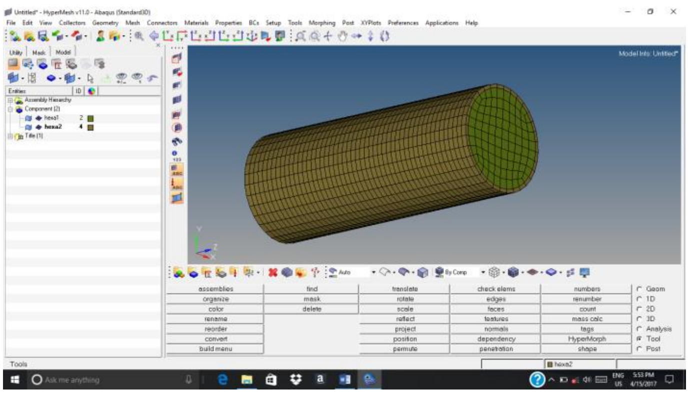


Fig 3: Modeling of the component



sFig 4: Meshing of the component

1. **Load Application:** A compressive load is uniformly distributed over the top surface of column nodes as shown in figure 4. The load is applied in Z-direction and is allow to move freely in Z-direction but restrained in X and Y-direction.

2. **Boundary Conditions:** Bottom end of the column is fixed in all directions that are $\Delta x=0$, $\Delta y=0$, $\Delta z=0$. The top surface of the column is restrained in X and Y-direction ($\Delta x=0$, $\Delta y=0$) and allowing displacement in Z-direction as shown in the figure.

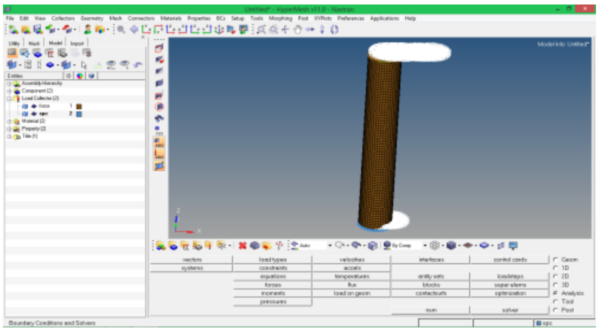


Fig 5: Application of load & Boundary Condition

III. VERIFICATION OF FINITE ELEMENT MODEL

A. Experimental Results

In order to check the accuracy of the finite element model, the modeling results were compared with experimental tests results which are carried out by previous researchers (both at international and national) in addition to results obtained by previous post-graduate students of Ghousia Collage of Engineering, R & D center, Civil department. The Ultimate loads obtained from finite element analysis (**Abaqus 6.10.1**) [(2)] is P_{FE} and that for experimental tests is Pexpt. CFST columns obtained experimentally and numerically using the finite element model. It was found that the nonlinear finite element simulations are in a good agreement with the experimental results.

B. Analytical Study by using Eurocode 4

EC4 [(3)] is the most recently completed international standard code for composite construction. It covers CFST columns with or without reinforcement. EC4 consider the confinement effect for a composite column when relative slenderness ratio (λ) has a value less than 0.5. The ultimate axial force for square column is given by

$$Pu=Acfc + Asfs$$

Where; Ac=Area of concrete As= Area of steel, and fc and fs are the yield strength of concrete and steel respectively.

C. American Concrete Institute: Building Code Requirements For Structural Concrete

The American concrete institute ACI [(1)] use the formula to calculate squash load. This code doesn't consider the effect of confinement. The squash load for circular column is given by

$$Pu=0.95Acfc + Asfs$$

A modification for above equation is proposed by Giakoumelis and Lam [11]. A coefficient is proposed for above ACI equation to take into account the effect of confinement on the axial load capacity of CFST column and for the hollow first term is zero. A revised equation is given by

$$Pu=1.3Acfc + Asfs$$

The capacities given by ACI code are too conservative whereas those calculated by using revised equation are more realistic, especially for circular columns.

IV. ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statically tool which helps to reduce the error variance and quantifies the dominance of control factor. This analysis aids in justifying the effects of input changes on the responses in the experiment.

1. Taguchi's Approach

In order to save time and material cost involved in experimentation, a lesser number of the experiment are desired. Therefore Taguchi's method is adopted. Experiments are carried out according to combination levels indicated by L9 orthogonal array (Table) for two grades of in filled concrete for steel tubes.

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Response Table for Means

Level	Diameter (mm)	Length(mm)	Thickness(mm)
1	78.08	85.20	70.87
2	89.31	115.02	126.87
3	84.43	180.22	485.00
4	133.44	137.01	92.19
5	162.54	91.42	188.08
6	348.50	188.08	348.50
7	485.00	485.00	641.80
8	641.80	641.80	
Delta	563.72	556.60	570.93
Rank	2	3	1

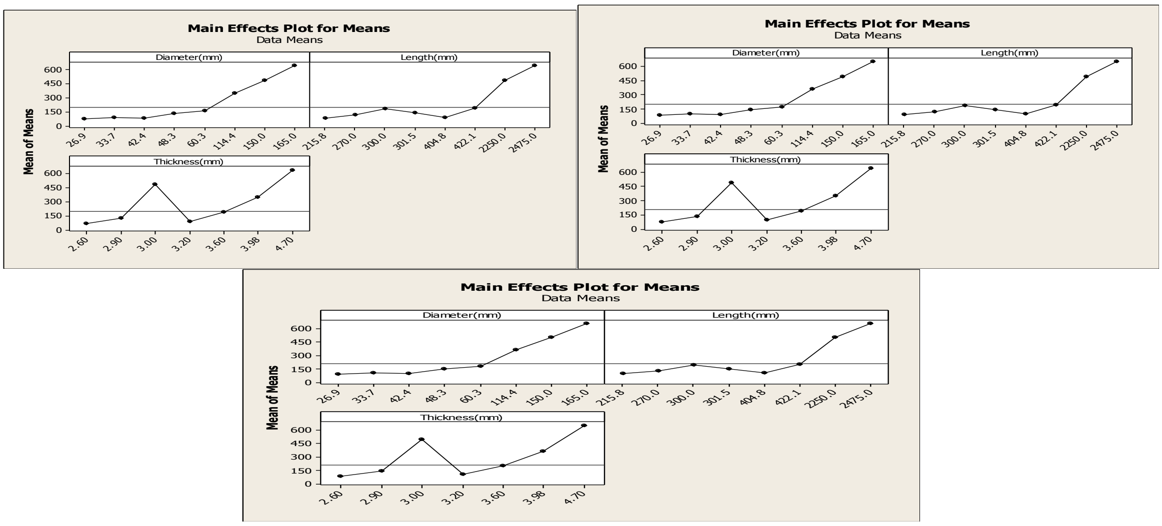
Response Table for Signal to Noise Ratios
Larger is better

Level	Diameter (mm)	Length(mm)	Thickness(mm)
1	37.80	38.48	35.63
2	38.39	38.29	40.37
3	37.97	42.23	52.18
4	40.42	42.18	39.01
5	43.80	39.09	45.42
6	48.82	45.42	48.82
7	52.18	52.18	51.52
8	51.52	51.52	
Delta	14.38	13.89	16.55
Rank	2	3	1

Table. A typical Response from Minitab V16

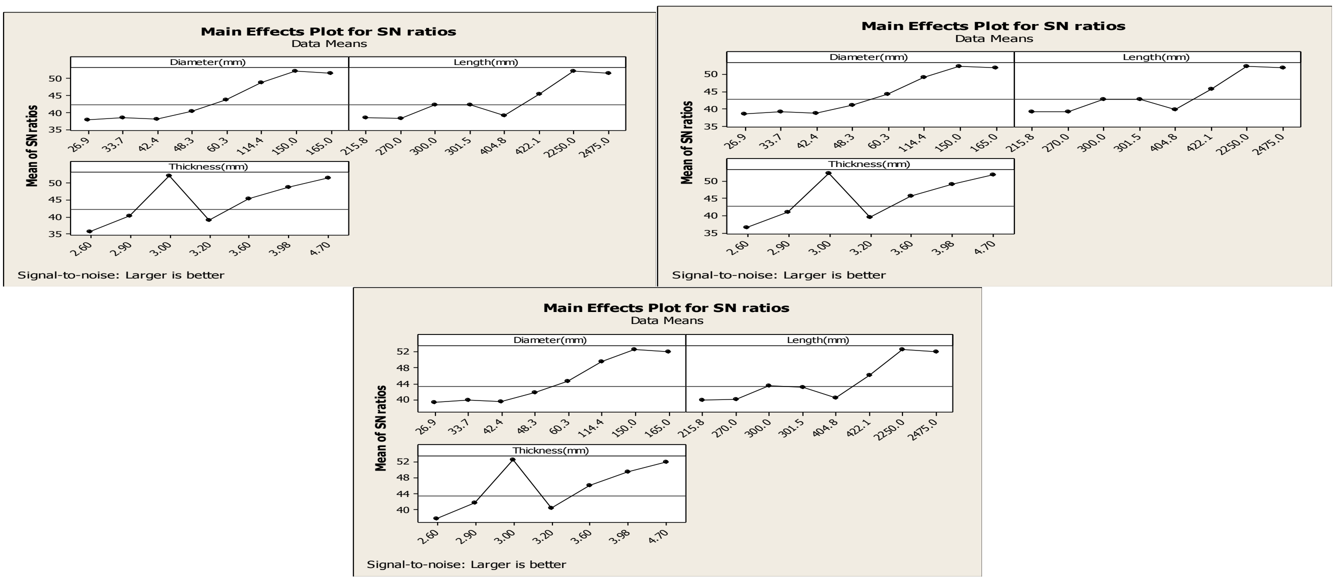
1.1. Main effect plots

After performing the experiments as per Taguchi's experimental design, main effects plots for an ultimate axial load for steel tubes are plotted for tubes infilled with concrete of proportion M20 and M30. The main effect is a direct effect on parameters on response and dependent variables.



1.2. Signal/ Noise Ratio plots

S/N ratio is used as measurable value instead of standard deviation due to the fact that, as the mean decreases, the standard deviation also deceases and vice versa.



2 Regression

Linear regression models are developed for all grade of infill but regression models of M20 and M40 are shown below (Eq.) to predict ultimate axial load for steel tubes at all two levels of circular tube samples. The equations are as in nomenclature table. These equations are used to predict the ultimate axial load capacity of samples used in the experimental program. To verify the accuracy of such prediction of load carrying capacity of samples the remaining experiments are conducted and a comparison of experimental values is made with predicted values it is observed that regression model based on experiments Pu reasonable well. A plot of experimental values vs. predicted values is plotted for all two levels steel tube.

2.1 Simple linear regression

Pu (expt)

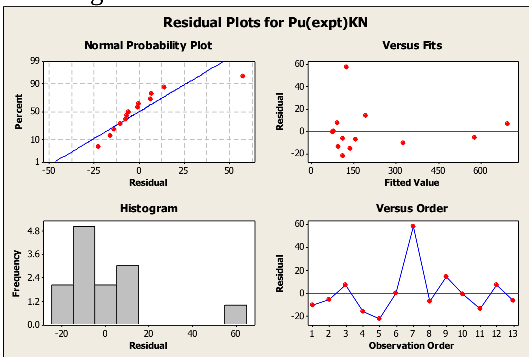
- Pu (20) = - 119 + 2.45 Diameter + 0.101 Length + 33.6 Thickness
- Pu (40) = - 451 + 3.83 Diameter + 0.0590 Length + 130 Thickness

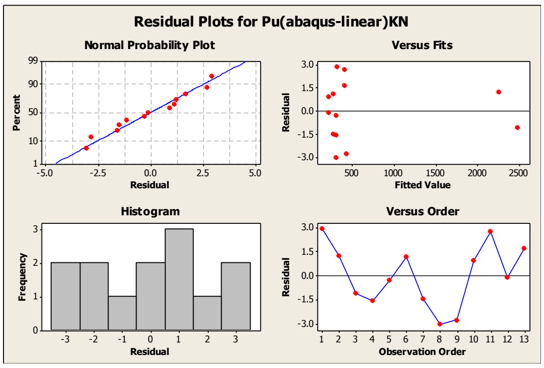
Pu (abaqus-linear)

- Pu (20) = - 0.77 + 0.155 Diameter + 0.991 Length + 1.25 Thickness
- Pu (40) = - 445 + 3.83 Diameter + 0.0590 Length + 130 Thickness

Pu (abaqus-nonlinear)

- Pu (20) = 7.68 + 0.155 Diameter + 0.991 Length + 1.25 Thickness
- Pu (40) = - 437 + 3.83 Diameter + 0.0590 Length + 130 Thickness





2.2 Multi linear regression

Pu (expt)

- Pu (20) = -119.333 + 2.45378 Diameter + 0.101442 Length + 33.6042 Thickness
- Pu (40) = -451.375 + 3.82669 Diameter + 0.0589958 Length + 130.271 Thickness

Pu (abaqus-linear)

- Pu (20) = -0.765367 + 0.154814 Diameter + 0.990611 Length +1.25026 Thickness
- Pu (40) = -445.084 + 3.82659 Diameter + 0.0590023 Length +130.274 Thickness

Pu (abaqus-nonlinear)

- Pu (20) = 7.68463 + 0.154814 Diameter + 0.990611 Length +1.25026 Thickness
- Pu (40) = -436.625 + 3.82669 Diameter + 0.0589958 Length +130.271 Thickness

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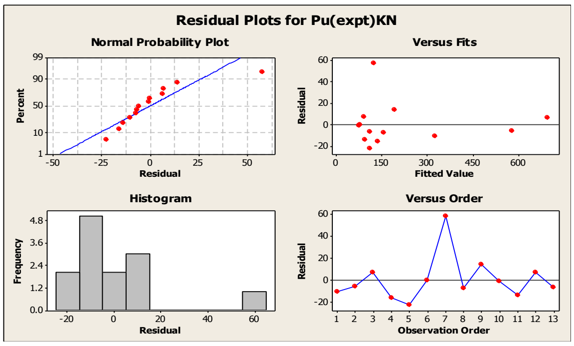

Year	Grade	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)KN	Pu(Ec4) KN	Pu(ACI) KN	Pu(abaqus-linear) KN	Pu(abaqus-nonlinear) KN
2007	Hollow	114.4	300	3.98	28.74	2.622	197	201.6	201.6	205	213.45
	M20	114.4	300	3.98	28.74	2.622	315	453.86	438.512	322.0	330.45
	M30	114.4	300	3.98	28.74	2.622	533.5	542.8	524.444	539.8	548.25
2010	Hollow	150	2250	3	50	15	285	288.9	288.9	291.3	299.75
	M20	150	2250	3	50	15	572	602.5	582.126	578.3	586.75
	M30	150	2250	3	50	15	598	605.2	584.734	604.3	612.75
2011	Hollow	165	2475	4.7	35.1	15	235.3	238.76	238.76	241.6	250.05
	M20	165	2475	4.7	35.1	15	701	753.2	727.729	707.3	715.75
	M30	165	2475	4.7	35.1	15	989.1	1043.3	1008.02	995.4	1003.85
2012	Hollow	48.3	300	3.2	15.09	6.2	75.14	94.41	94.41	81.4	89.89
	M20	48.3	300	3.2	15.09	6.2	121	118.2	114.203	127.3	135.75
	M30	48.3	300	3.2	15.09	6.2	127	131.98	127.517	133.3	141.75
	Hollow	42.4	300	2.9	14.62	7	62.3	71.8	71.8	68.6	77.05
	M20	42.4	300	2.9	14.62	7	90	92.9	89.7585	96.3	104.75
	M30	42.4	300	2.9	14.62	7	101	103.48	99.9807	107.3	115.75
2013	Hollow	33.7	270	2.6	12.9	8	43.2	50.78	50.78	49.5	57.95
	M20	33.7	270	2.6	12.9	8	78	73.53	71.0435	84.3	92.75
	M30	33.7	270	2.6	12.9	8	91.4	89.9	86.8599	97.7	106.15
	Hollow	48.3	270	2.9	16.65	5.59	72.4	82.68	82.68	78.7	87.15
	M20	48.3	270	2.9	16.65	5.59	181.7	191.04	184.58	188.0	196.45
	M30	48.3	270	2.9	16.65	5.59	223.4	225.22	217.604	229.7	238.15
2014	Hollow	60.3	301.5	2.9	20.79	5	101	104.53	104.53	107.3	115.75
	M20	60.3	301.5	2.9	20.79	5	149	151.17	146.058	155.3	163.75
	M30	60.3	301.5	2.9	20.79	5	161.03	173.5	167.633	167.3	175.78
	Hollow	60.3	422.1	3.6	16.75	7	174.01	178.2	178.2	180.3	188.76
	M20	60.3	422.1	3.6	16.75	7	206.3	172.4	166.57	212.6	221.05
	M30	60.3	422.1	3.6	16.75	7	183.92	194.6	188.019	190.2	198.67
2016	Hollow	26.9	215.8	3.2	8.4	8	70	77.68	77.68	76.3	84.75
	M20	26.9	215.8	3.2	8.4	8	75	74.225	71.715	81.3	89.75
	M30	26.9	215.8	3.2	8.4	8	80	87.52	84.5604	86.3	94.75
	Hollow	26.9	404.8	3.2	8.4	15	75	77.68	77.68	81.3	89.75
	M20	26.9	404.8	3.2	8.4	15	81.2	84.225	81.3768	87.5	95.95
	M30	26.9	404.8	3.2	8.4	15	87.3	87.52	84.5604	93.6	102.05
	Hollow	33.7	215.8	3.2	10.53	6.4	84	81.29	81.29	90.3	98.75
	M20	33.7	215.8	3.2	10.53	6.4	99.78	103.99	100.473	106.1	114.53
	M30	33.7	215.8	3.2	10.53	6.4	102.4	106.7	103.092	108.7	117.15
	Hollow	33.7	404.8	3.2	10.53	12	90	81.29	81.29	96.3	104.75
	M20	33.7	404.8	3.2	10.53	12	105	103.99	100.473	111.3	119.75
	M30	33.7	404.8	3.2	10.53	12	110	106.7	103.092	116.3	124.75

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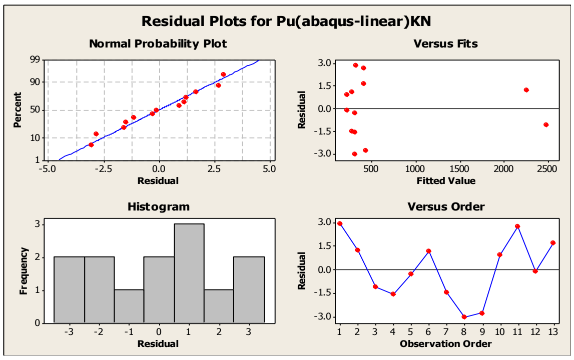

VII. RESULTS

A. Numerical Values (2007-2016 IN REFERENCES)

B. Regression

1. M20 GRADE

Simple reg(expt)	Simple reg(linear)	simple reg(nonlinear)	multi reg(expt)	multi reg(linear)	multi reg(nonlinear)
325.308	319.237	327.687	325.556748	319.1046894	327.5546864
576.55	2255.98	2264.43	577.7911	2255.082263	2263.53226
693.145	2483.405	2491.855	694.54939	2482.41739	2490.867387
137.155	308.0165	316.4665	137.150614	307.8962812	316.3462782
112.62	306.727	315.177	112.592052	306.6078006	315.0577976
78.195	275.2735	283.7235	78.119646	275.1675108	283.6175078
124.045	277.9115	286.3615	124.026094	277.8028732	286.2528702
156.6265	310.988	319.438	156.666877	310.8648877	319.3148847
192.3271	431.3776	439.8276	192.4237222	431.2077563	439.6577533
76.2208	221.2573	229.7073	76.0983056	221.1738154	229.6238124
95.3098	408.5563	417.0063	95.2708436	408.3992944	416.8492914
92.8808	222.3113	230.7613	92.7840096	222.2265506	230.6765476
111.9698	409.6103	418.0603	111.9565476	409.4520296	417.9020266

2. M30 GRADE

simple reg(expt)	simple reg(linear)	simple reg(nonlinear)	multi reg(expt)	multi reg(linear)	multi reg(nonlinear)
522.252	528.252	536.252	522.575656	528.869106	537.325656
646.25	652.25	660.25	646.18205	652.481675	660.93205
937.975	943.975	951.975	938.317155	944.6218425	953.067155
167.689	173.689	181.689	168.020067	174.317787	182.770067
106.092	112.092	120.092	106.361296	112.658706	121.111296
32.001	38.001	46.001	32.217919	38.515104	46.967919
126.919	132.919	140.919	127.168893	133.465518	141.918893
174.7375	180.7375	188.7375	174.9475407	181.2431705	189.6975407
272.8529	278.8529	286.8529	273.2521342	279.5506478	288.0021342
80.7592	86.7592	94.7592	81.16145464	87.46076734	95.91145464
91.9102	97.9102	105.9102	92.31166084	98.61220204	107.0616608
106.8032	112.8032	120.8032	107.1829466	113.4815793	121.9329466
117.9542	123.9542	131.9542	118.3331528	124.633014	133.0831528

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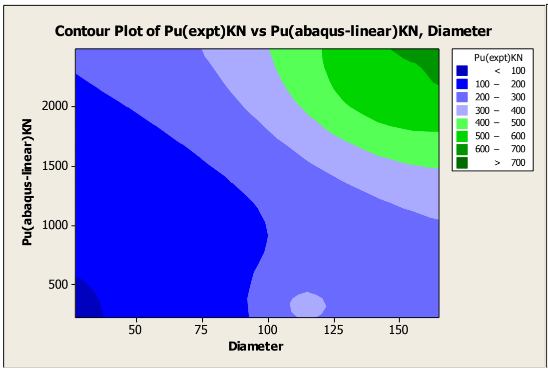
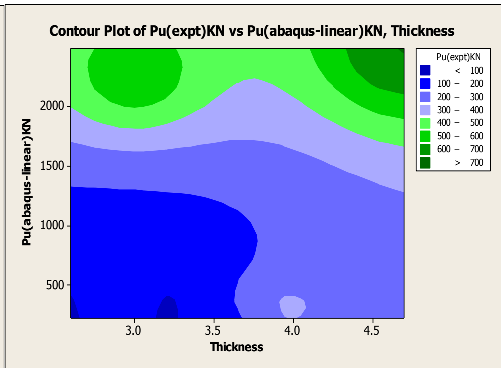
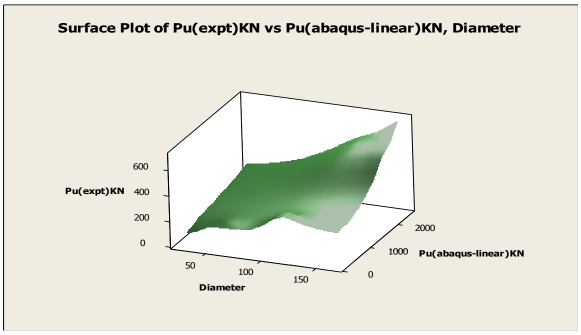
Countour plots





Surface plots



CONCLUSIONS

1) Ultimate load obtained from ABAQUS linear & non-linear Modeling varied by 0.63% to 14.5% & 1.49% to 34.14% when compared with experimental values respectively.
2) Ultimate load values obtain, eurocode-4 varied by 0.83% to 18.46% when compared with ABAQUS values.
3) Ultimate load values obtain, American concrete institute ACI varied by 0.83% to 18.46% when compared with ABAQUS values.
4) As result obtained from the experiment is approximately equal to ANOVA equation obtained by Regression method.
5) Least % error for Ultimate load obtained from experimental, ABAQUS linear, ABAQUS non-linear compared with Regression method (**ANOVA APPROACH)**.

Simple Regression			
	M20	M30	
Pu(EXPT)	0.25	0.949	%
Pu(LINEAR)	0.0142	0.53	%
Pu(NONOLINEAR)	0.014	0.0097	%
Multi Regression			
Pu(EXPT)	0.153	1.45	%
Pu(LINEAR)	0.045	1.345	%
Pu(NONOLINEAR)	0.0448	1.225	%

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BIOGRAPHIES

KARTHIK A. R Obtained B.E degree in Civil Engineering (First Class with distinction) during the year 2015 from Ghousia college of Engineering, Ramanagram. Affiliated to VTU Belgaum. Presently persuing Master of Technology in Structural Engineering at Ghousia College of Engineering, Ramanagaram. Also working on this topic for the dissertation under the guidance of Dr. N.S Kumar

Dr. N.S Kumar, Involved in the Research field related to the behavior of Composite Steel Column since a decade. & He has guided more than 15 M.tech projects including one M.Sc Engineering (by Research under VTU, Belgaum). Presently guiding four Ph.D. Scholars under VTU Belgaum. Has more than 26 years of teaching & 6 years of Research experience at Ghousia College of Engineering, Ramanagaram.s

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