

Development of Analytical Model for Buckling Capacity of Composite Steel Tubes using MSC-NASTRAN & validating with Matlab-ANN

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ABSTRACT: In this research, a suitable model for computing Buckling load of axially compressed composite steel tubes is developed using MSC-NASTRAN & validated using ANN-Matlab R2016a. Behaviour of Self Compacting Concrete (SCC) infilled with different grades columns are modelled for the parameters like Diameter, Thickness, Length, L/D ratio, & D/T ratio. The software used for this work being NASTRAN-2013 having high computational capabilities & the modern technique of ANN-Matlab technique is also adopted. Analysis is done by making a suitable finite element model using solid element from NASTRAN elemental library. Suitable analytical model is arrived based on FEM results & results are validated using ANN-Matlab. Analysis was run for both Hollow & CFST. Result of analytical solution was compared with experimental results and theoretical formulas. Comparison of Hollow & CFST tubes showed that the concrete core delayed the onset of local buckling of the steel tube.

KEYWORDS: Finite Element analysis, Hypermesh, NASTRAN, Artificial Neural Network, Matlab, Composite Steel Tubes.

I. INTRODUCTION

Concrete filled tubular steel columns possess excellent strength to earth quake resistant properties such as high strength and ductility and large energy absorption capacity. CFST which combines the advantages of steel and concrete has been developed as an excellent structural element for building columns, bridge piers, and arch ribs throughout worldwide engineering practises. Since the steel tube can serve as a form work for casting of core concrete, CFST structures possess economical merits in construction. Concrete filled steel tubes are used in many structural elements including columns, supporting platforms of off-shore structures, roof of storage tanks, bridge piers, piles and columns in seismic zones. CFST columns offer excellent structural performance such as high strength, high ductility and large energy absorption capacity and have been used widely as a primary axial load carrying members in high rise buildings, bridges. Applications of the CFST concept can lead to structural steel systems. Moreover, compared with hollow steel tube, core concrete can prevent buckling of steel tube, which may improve the compressive stability enormously. Use of composite columns can result in significant savings in column size, which ultimately can lead to considerable economic savings. This reduction in column size provides is practically beneficial where floor space is at premium, such as in car parks and office blocks. However if the concrete core and the steel tube are loaded simultaneously the steel tube expands more than the concrete core under moderate loads since Poisson's ratio is higher for the steel section.

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II. RELATED WORK

In this research work, steel tubes of different Length, Diameter, Thickness, L/D ratio & D/t ratio infilled with different grades of Self Compacting Concrete such as M20, M30 & M40 are modelled using Catia software. Then the models are imported to Hypermesh, software widely used for meshing. The models are divided into finite solid elements & a gradual axial load is applied for compression. The Analysis is performed for both Hollow Steel Tubes & Steel Tubes infilled with Self compacting Concrete of different grades. The analysis is done using MSC-NASTRAN software having high computational capabilities. The results obtained from the analysis are then compared with the experimental results performed by Noorain Khanum at R&D laboratory, Department of Civil Engineering, Ghousia College of Engineering, Ramanagaram, Karnataka, India under the guidance of Dr N.S Kumar. The results are validated using Artificial Neural Network Technique in Matlab R2016a. The results predicted from ANN & NASTRAN were found to be consistent. It can be concluded that 5-13-10-1 neural network architecture provides perfect model to verify the results. Almost error is subsidized to 0.58% and is approximately providing results coinciding with the experimental results.

III. FINITE ELEMENT ANALYSIS & MSC-NASTRAN

The basic concept of finite element method is discretization of a structure into number of finite elements, connected at finite number of points called nodes. The material properties and the governing relationships are considered over these elements and expressed in terms of nodal displacement at nodes. An assembly process duly considering the loading and constraints results in a set of equations governing the structural response, which are established through the application of appropriate variation principle. Solutions of these equations give the response of the structure. Selecting proper elements and subdividing the structure with large number of finite elements or by taking higher order elements can increase the accuracy of solution obtained by finite element method.

MSC-NASTRAN is finite element software that was originally developed for NASA in the late 1960's under UNITED STATES government funding for the Aerospace industry. NASTRAN software was developed by Joe Mule, Gerald Sandler & Stephen J at University of Rochester (current). The NASTRAN system was released to NASA in 1968. It is also used in designing railroad tracks and cars, bridges, power plants, skyscrapers and aircraft. The NASTRAN programme has evolved over many versions. Each new version contains enhancements in analysis capability and numerical performance. Today, NASTRAN is widely used throughout the world in the aerospace, automotive and maritime industries. It has been claimed that NASTRAN is the industry standard for the basic types of analysis for aerospace structures like linear elastic static & dynamic analysis.

IV. ARTIFICIAL NEURAL NETWORK

An artificial neural network (ANN) is a computational model which is designed to perform the complex pattern recognition tasks such as pattern classification, pattern mapping and pattern association. Thus a neural network can be characterized as a computing architecture, which consists of a large number of simply highly interconnected data processing elements called neurons, designed to resemble the learning and storing capability of human brain for performing the task of pattern to learn & acquire knowledge and to make that knowledge available for use.

When the signals received are strong enough, the neuron is activated and emits a signal through the axon. The signal might be sent to another synapse and might activate other neurons. The complexity of real neurons is highly abstracted, hence modelling artificial neurons. These basically consist of inputs which are multiplied by weights and then computed by a mathematical function which determines the activation of the neuron. Another function computes the output of the artificial neuron. ANN's combines artificial neurons in order to process information.

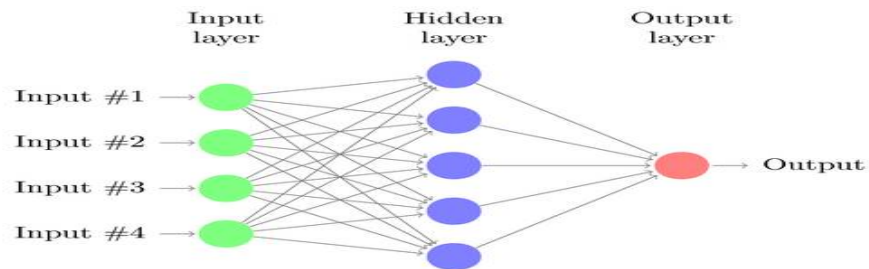


Figure 1: Artificial Neural Network

V. MATERIAL PROPERTIES

Self Compacting Concrete: Self compacting Concrete is a flowing concrete mixture that is able to consolidate under its own weight, suitable for structures with congested reinforcement ensuring a good balance between deformability and stability. The concrete remains homogeneous in a form during and after the placing process.

Steel Tubes: The steel tubes are modelled for different cross-sections. Steel tubes of circular cross-sections are modelled having different Diameter, Length & Thickness.

Table 1: Material properties

Density Kg/m ³				Elastic Modulus N/mm ²				Poisson's ratio			
Steel	M20	M30	M40	Steel	M20	M30	M40	Steel	M20	M30	M40
7860	2400	2400	2400	210	24.6	30.4	34.80	0.30	0.16	0.18	0.20

VI. EXPERIMENTAL PROGRAM

Self compacting concrete of different grades such as M20, M30 & M40 of design strength of 24.21MPa, 36.97MPa & 48.45MPa respectively was produced. The SCC of three different grades is filled in the steel tubes. A typical model created in Hypermesh is as shown below in Figure 2.

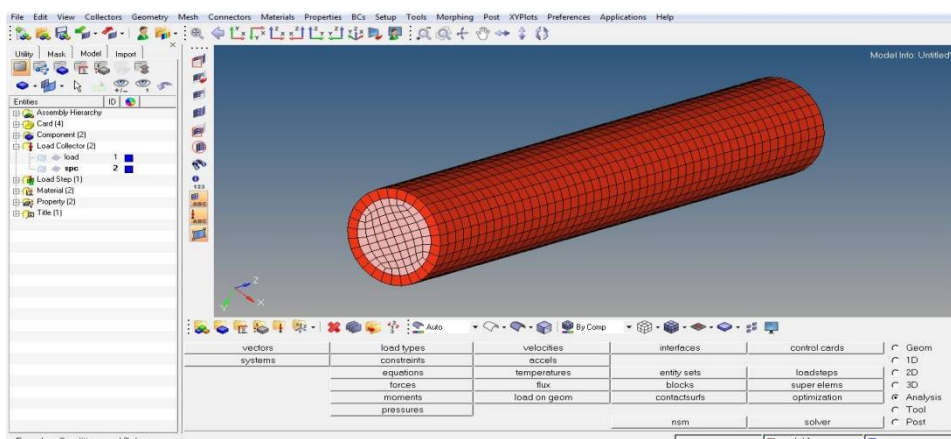


Figure 2: FEM model

The model is analysed for Cyclic loading conditions. The bottom face of the CFST is fixed and axial compressive load is applied on the top face. The model is then analysed using MSC-NASTRAN software and the required results are obtained. A model of applying load and boundary conditions is given in the Figure 3 below.

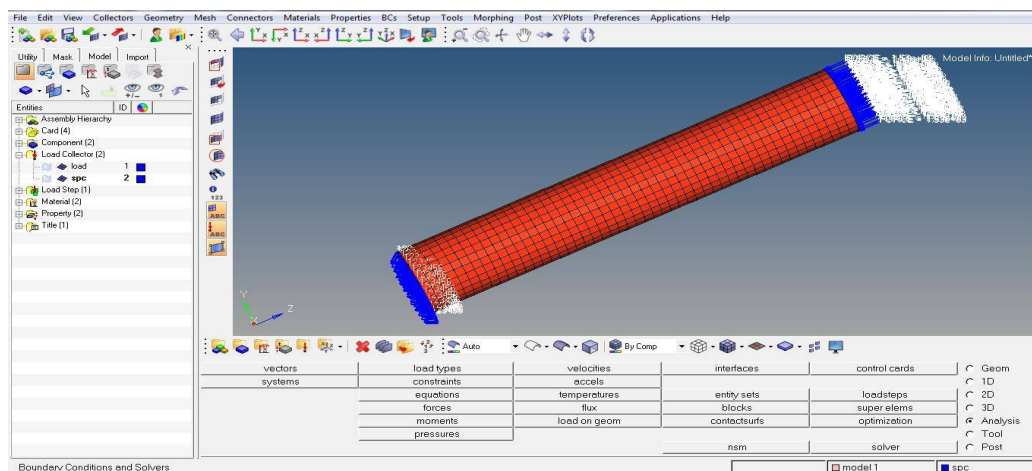


Figure 3: Loads & Boundary conditions

VII. RESULTS & DISCUSSIONS

The Analytical results obtained are viewed in Altair Hyperview. Various contour plots are plotted and the Ultimate Load is calculated. From the experiment, it can be said that with increase in Diameter the Ultimate Load carrying capacity increases (Figure 6) and with increase in Length the Ultimate Load carrying capacity decreases. Further, the sections of Steel tubes which were filled with concrete produced more carrying capacity when compared with Hollow Steel Tubes. Furthermore, the concrete core inside the steel tubes prevented the Steel tube from Buckling. A typical view of Hyperview is shown in the Figure 4. The results from NASTRAN & ANN are shown in the Table 2 & Figure 5.

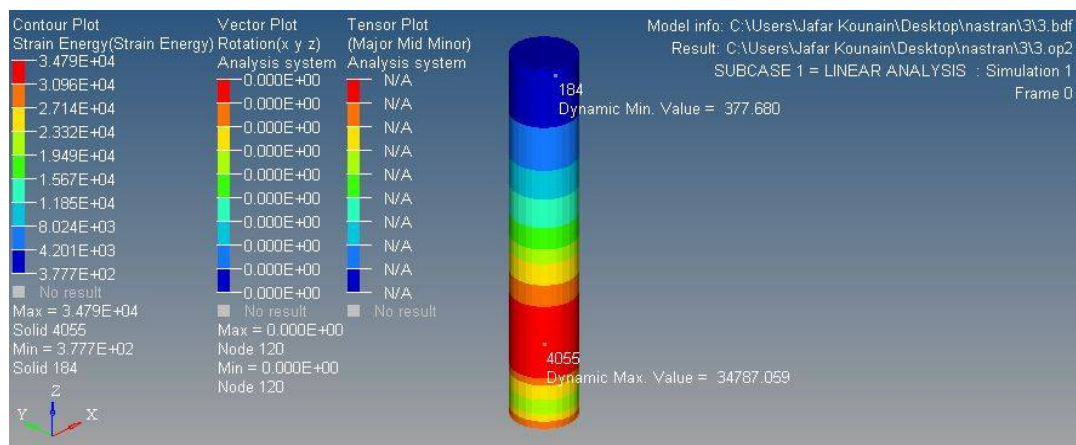


Figure 4: Results from Analysis

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Table 2: Analytical results and validation

Diameter (mm)	L/D	D/T	Length (mm)	Grade	Pu Exp (KN)	Pu Abacus (KN)	Pu AIJ (KN)	Pu Nastran (KN)	Pu ANN (KN)
33.7	6	10.5	202.2	Hollow	145	120.72	140.44	143.5	145
33.7	6	10.5	202.2	M20	170	132.76	166.54	167.45	170.01
33.7	6	10.5	202.2	M30	178	139.11	177.15	177.50	184.56
33.7	6	10.5	202.2	M40	184	144.82	179	181.52	184
33.7	12	10.5	404.4	Hollow	134	112.28	133.50	133	133.98
33.7	12	10.5	404.4	M20	155	124.02	151.89	153.80	155.13
33.7	12	10.5	404.4	M30	163	130.12	158.12	160.63	163.01
33.7	12	10.5	404.4	M40	174	135.58	169.11	171.30	159.12
33.7	16	10.5	539.2	Hollow	132	103.84	130.56	130.98	132.49
33.7	16	10.5	539.2	M20	150	115.27	146.98	147.76	150.01
33.7	16	10.5	539.2	M30	159	121.13	154.71	156.27	158.94
33.7	16	10.5	539.2	M40	167	126.34	161.78	164.71	167.01
42.4	6	13.3	254.4	Hollow	200	155.15	197.47	196.59	199.98
42.4	6	13.3	254.4	M20	220	176.10	217.56	217.89	220.01
42.4	6	13.3	254.4	M30	227	187.14	223.54	225.36	227.01
42.4	6	13.3	254.4	M40	238	197.07	233.45	237.45	238.03
42.4	12	13.3	508.8	Hollow	175	144.44	172.89	173.10	210.5
42.4	12	13.3	508.8	M20	209	164.94	206.75	206.50	209.05
42.4	12	13.3	508.8	M30	215	175.61	211.88	214.15	214.96
42.4	12	13.3	508.8	M40	229	185.17	224.64	225	229.03
42.4	16	13.3	678.4	Hollow	156	133.74	153.44	154.42	155.98
42.4	16	13.3	678.4	M20	179	153.79	176.78	177.26	176.89
42.4	16	13.3	678.4	M30	189	164.09	186.56	186.66	189
42.4	16	13.3	678.4	M40	207	173.26	202.77	205.54	207
48.3	6	13.3	289.8	Hollow	235	178.50	232.97	233.14	235.23
48.3	6	13.3	289.8	M20	265	206.87	262.35	263.10	264.2
48.3	6	13.3	289.8	M30	285	221.83	281.45	284.13	286.6
48.3	6	13.3	289.8	M40	301	235.28	296.28	296.83	298.29
48.3	12	13.3	579.6	Hollow	210	166.26	208.12	208.39	210
48.3	12	13.3	579.6	M20	235	194.07	231.75	232.18	235.02
48.3	12	13.3	579.6	M30	265	208.56	261.42	263.45	261.28
48.3	12	13.3	579.6	M40	289	221.53	284.15	288.19	284.38
48.3	16	13.3	772.8	Hollow	189	154.02	188.32	187.56	189.02
48.3	16	13.3	772.8	M20	225	181.26	222.15	222.89	224.98
48.3	16	13.3	772.8	M30	238	195.28	234.55	237.33	238.02
48.3	16	13.3	772.8	M40	250	207.77	245.15	246.73	255.5

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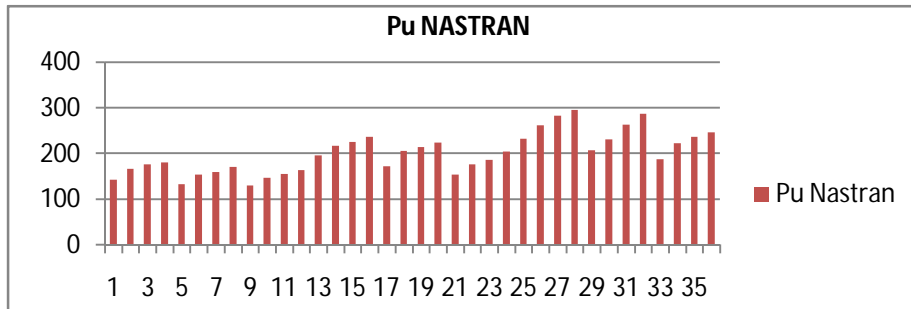


Figure 5: Pu Nastran

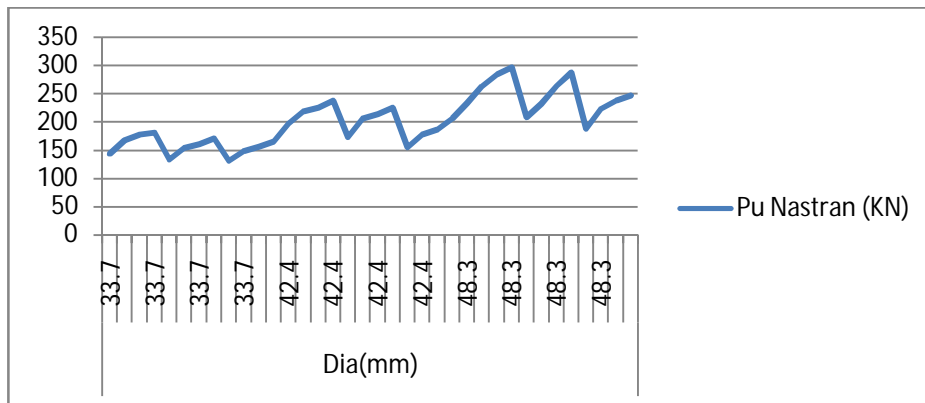


Figure 6: Diameter Vs Pu Nastran

The results obtained from NASTRAN & ANN were found to be consistent with the experimental results. The error was almost subsidized to 0.58% from the experimental results. Hence ANN technique can be well used to predict the Ultimate load carrying capacity of CFST. A graph for Experimental, NASTRAN & ANN is plotted and is as shown in Figure 7.

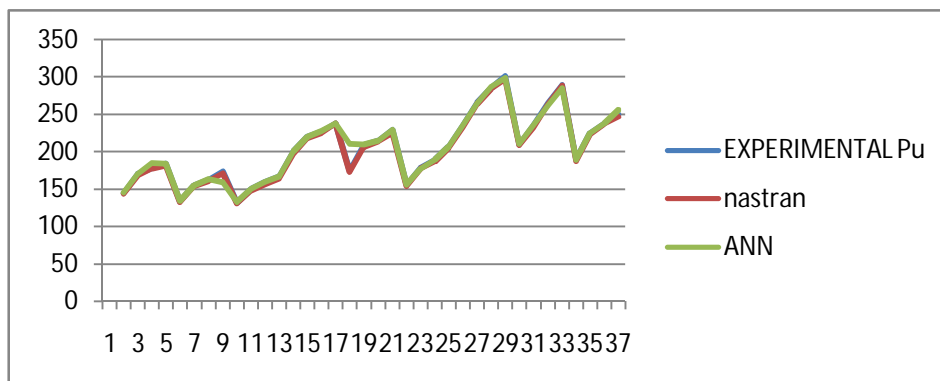


Figure 7: Pu Exp Vs NASTRAN Vs ANN

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VIII. VALIDATION OF RESULTS

Depicts the LOG SIGMOIDAL and TAN SIGMOIDAL used to built the model and train the network. The output parameter is trained separately for both transfer functions (LOGSIG & TANSIG) for predicting the ultimate load of the self compacting concrete filled steel tubes.

Also the best value of prediction is obtained for 13 hidden layers and 10 hidden neurons with TANSIG as transfer function. The experimental results which are obtained are given as the desired outputs to the Feed Forward Back Propagation network. These networks were used to predict the output values and are in good agreement with Kolmogorov’s theorem. The output values obtained were tested, trained and validated from 1 to 14 hidden layers. The experimental values are obtained and verified for ultimate axial load. The ultimate axial load’s average deviations are tabulated. The best result is obtained for 13 layers as per Kolmogorov’s principal and this is verified in the ultimate axial load deviation histogram for all the layers. The predicted data is obtained after training the model to 1000 number of epochs and assigning the transfer function to TANSIG with the given inputs and output values. The input is trained using Levenberg-Marquardt algorithm. This performance is measured using MEAN SQUARE ERROR (MSE). The output values are tested, trained and validated, plotted to obtain the best values on the curve fit. The experimental inputs are tested in 1 to 14 layers and it is verified that the deviation for 13 layers gives the best result with TANSIG training function, also the best REGRESSION fit. The Regression plot is plotted as shown in Figure 7.

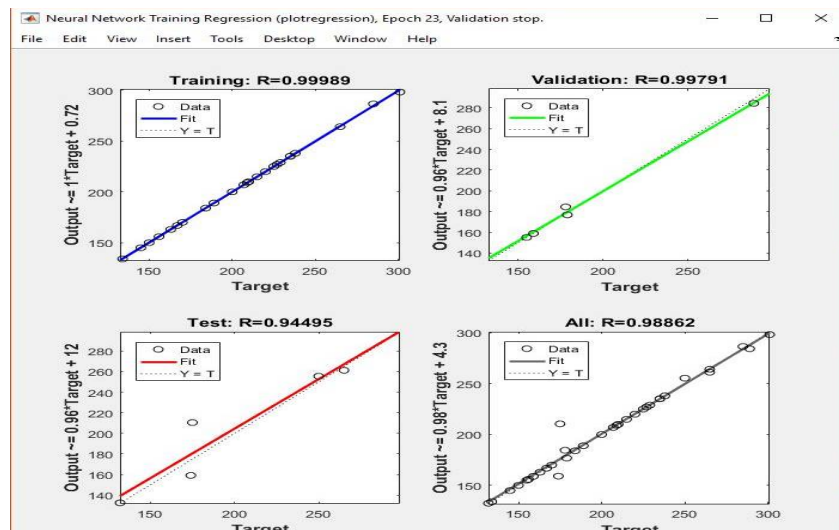


Figure 7: Regression from ANN

IX. DISCUSSION ON THE PREDICTED VALUES FROM ANN

The ANN is one way to include specimen irregularities in the model using the results of the available experiments to predict the behavior of composite tubes subjected to different loading.

The ANN has been shown to successfully predict the crushing behavior of wide range of circular composite steel tubes.

The predicted results obtained, are showed that *Feed Forward Back propagation* network and *Kolmogorov’s* theorem

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with 13 hidden neurons consistently provided the best predictions of the experimental data.

X. CONCLUSIONS

- The Ultimate Load carrying capacity of SCC infilled steel tubes is about (13-20) % higher than the Hollow steel tubes.
- The local Buckling is delayed in CFST compared to the Hollow steel tube and it may be prevented
- With increase in Diameter, load carrying capacity increases and with increase in Length load carrying capacity decreases
- With increase in grade of concrete, the load carrying capacity increases marginally by (4-5)%
- As L/D ratio increases, the load carrying capacity decreases by (7-12) %
- ANN model of 5-13-10-1 neural architecture satisfies the requirement of determining Ultimate load (Pu).
- Percentage variation in MSE 0.58% obtained yields best fit results compared with experimentally obtained values.

XI. ACKNOWLEDGEMENT

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Dr N.S Kumar, Involved in the Research field related to the behaviour of composite steel column since a decade presently guiding 5 PhD scholars (research under VTU Belgaum) has more than 28 years of teaching experience & 6 years of research experience at Ghousia College of Engineering, including one year at TRFI, Bangalore.