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Vibrational Analysis of Composite Steel Tubes Infilled with Conventional Concrete Using MATLab and MIDAS CIVIL Software

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Abstract: ***The Composite Steel Column consists of both Steel and Concrete as main components. In this study, the load carrying capacity of the composite steel columns will be validated for Conventional Concrete (CC) of different grades such as M20 M30 M40 by developing programs using MATLAB (R2015a) software. The complex behavior of composite steel columns plays an important role in the seismic design. Natural frequencies and periods are obtained for different slenderness ratios (L/D) of steel columns varying from 6 to 14 i.e, both short and long columns filled with CC are considered for carrying this study. Constant diameter of column of 42.4mm and length varies from 254.4mm to 594.6mm is considered as experimental results are available from different national and international research works including R&D works carried out at Civil Engineering research laboratory at Ghousia College of Engineering by previous UG, PG and research scholars since 2010 till date. Percentage error between obtained experimental values and MATLAB vibration tool box output will be studied in depth along with effect of slenderness ratio. Further analysis for buckling of columns and modelling is carried out with a 3-dimensional non-linear analysis software named MIDAS CIVIL. Obtained results are also compared with available codes of BS and ASCI.***

Keywords: Concrete filled steel tubes, Hollow CFST, MATLab, Mode Shapes

1. Introduction

Concrete filled steel tubular (CFST) members utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high-rise and multi storey buildings as columns and beam-columns, and as beams in low-rise industrial buildings where a robust and efficient structural system is required. There are a number of different advantages related to such structural systems in both terms of structural performance and construction sequence. The inherent buckling problem related to thin-walled steel tubes is either prevented or delayed due to the presence of the concrete core. Furthermore, the performance of the concrete in-fill is improved due to confinement effect exerted by the steel shell. The distribution of materials in the cross section also makes the system very efficient in term of its structural performance. The steel lies at the outer perimeter where it performs most effectively in tension and bending. It also provides the greatest stiffness as the material lies farthest from the centroid.

1.1. Benefits of using CFST columns

The composite column has higher ductility than the concrete column and connections may be constructed following the experience of steel constructions. The concrete filling not only leads to a bearing capacity which is much higher than that of steel columns but it also promotes resistance against fire. As far as ductility and rotation capacity are concerned, concrete filled steel tubular columns show the best seismic behavior compared to other types of composite columns. The concrete is held by the steel profile and cannot split away even if the ultimate concrete strength is reached.

1.2. Description of software used

Finite element method is considered for being the best tool for analyzing the structures. Numerous software's use this technique for analyzing, designing and creating. The software used here is MATLab which stands for matrix laboratory. It is a multi-paradigm numerical computing environment. Here, validation of the load carrying capacity of the composite steel columns is done. Various results such as Natural frequencies and periods are obtained for different slenderness ratios which are later compared with experimental and available codal results. For Modelling, the software used is MIDAS CIVIL. It was developed in KOREA as a structural design software for bridges and other civil structures. The 3D hollow and concrete filled steel conduit columns are created in the software and then analyzed for buckling and mode shapes under failure are generated.

1.3. Finite element modeling

Conventional concrete filled in the CFST column are modelled accurately in finite element software MIDAS CIVIL and compared with experimental results and available codes of BS and ASCI.

2. Material Properties and Constitutive Models

2.1. Steel

Modelling of the Steel tube is done as elastic-perfectly plastic with von mises yield criterion. As the steel tube is subjected to multiple stresses and hence the stress-strain curve crosses elastic limit and reaches in plastic region. The steel tube's nonlinear behavior is obtained from uniaxial tension test and used in steel modeling. The data taken for this analysis are: Young's Modulus E=210Gpa, Poisson's Ratio μ=0.3, Density P=7860kg/m3.

2.2. Conventional concrete

A rational mix design method of conventional concrete using a variety of materials is necessary such as Coarse aggregate and fine aggregate content in concrete is fixed at 50% & 40% of the total mortar volume. The data taken for this analysis are: Poisson's Ratio μ=0.16, Density P=2400kg/m3, Young's Modulus E=22.36Gpa for M20, 27.38Gpa for M30 and 31.62Gpa for M40.

2.3. Material Model of Concrete

To understand the concrete behavior in the finite element model, a nonlinear stress-strain diagram for confined concrete should be established. The equivalent stress-strain curve for confined and unconfined concrete under compressive loading is depicted in Figure 1. This is used in proposed finite element model. The stress-strain curve is divided into 3 parts namely elastic part (Linear), Elasto-Plastic part and Perfectly Plastic part (nonlinear).

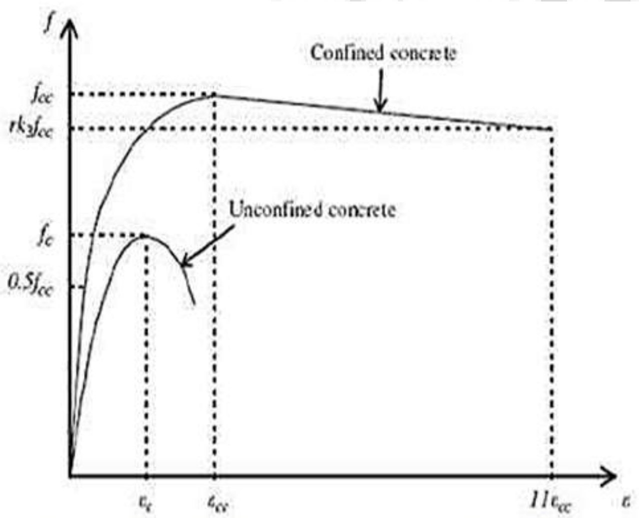


Figure 1: Equivalent stress-strain curve for confined and unconfined concrete

3. Details of the Specimens and Solution Procedure

The experimental loads and other specimen details considered for carrying out the investigations is given in table 1.

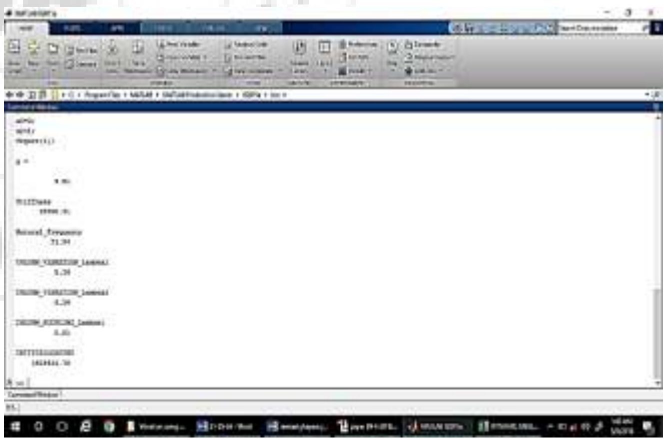
After developing the program in MATLaB, various results are generated in the output command window such as Stiffness, Natural frequency, Column vibrations λ1 & λ2, Column buckling, critical loading, etc. The output result is as shown in the Figure 2.

3.1 Solution procedure

The calculation of Natural frequencies, Modal frequencies and critical loadings of CFST columns (for both hollow CFST

Table 1: Specimen details

Sl. No.	*Length (mm)*	*Diameter (mm)*	*Weight (kg)*	*Load P (kN)*	*Grades*
1	254.4	42.4	1.186	612.2	M20
			1.23	628.7	M30
			1.234	636	M40
			0.627	591	H
2	339.2	42.4	1.166	344.5	M20
			1.212	351	M30
			1.308	359.6	M40
			0.714	334.2	H
3	424	42.4	2.455	222.1	M20
			2.516	228.6	M30
			2.58	245	M40
			1.22	214.6	H
4	508.8	42.4	2.624	209	M20
			2.654	215	M30
			2.71	229	M40
			1.512	121.8	H
5	594.6	42.4	3.088	111.2	M20
			3.092	116.4	M30
			3.15	123.6	M40
			1.732	109.3	H



and infilled conventional concrete) for different slenderness ratios (L/D) of steel columns and also for different grades of concrete like M20, M30 & M40 is done by using the below procedure.

3.1.1 Natural frequency (ω)

The natural frequency of the CFST columns are calculated by using the formula

$$\omega = \sqrt{\frac{K}{M}} \quad \text{in rad/sec} \qquad (1)$$

Where, K = Stiffness of CFST in N/mm
M = Mass of CFST in N-sec^2/m

3.1.2 Modal Frequencies (λ_1 & λ_2)

The modal frequency of the CFST columns are calculated by using the formulae

(a) For column vibration

$$\lambda_1 = \sqrt{\frac{P+(P^2+4\rho A(EI)_{eff}\,\omega^2)^{1/2}}{2(EI)_{eff}}} \quad (2)$$

$$\lambda_2 = \sqrt{\frac{-P+(P^2+4\rho A(EI)_{eff}\,\omega^2)^{1/2}}{2(EI)_{eff}}} \quad (3)$$

(b) For buckling

$$\lambda_3 = \sqrt{\frac{P}{(EI)_{eff}}} \quad (4)$$

Where, P = Crippling load in N, D = Outer diameter in mm
ω = Natural frequency in rad/sec

3.1.3. Critical Load (N_{cr})

Critical loading obtained from MATLab are compared with available codes to check the accuracy. The Critical loading of CFST columns are calculated by using the formulae:

$$N_{cr} = \frac{\pi^2 (EI)_{eff}}{l^2} \quad (5)$$

Where, L= buckling length of column, $(EI)_{eff}$ = Effective elastic flexural stiffness of concrete sections

$(EI)_{eff} = E_a I_a + 0.8 E_{cd} I_c$ (for short columns)

$(EI)_{eff} = E_a I_a + 0.6 E_{cd} I_c$ (for long columns)

Where, I_a and I_c are the moment of inertia of steel and concrete, E_a = elastic modulus of steel structures,

$$E_{cd} = \frac{E_{cm}}{\gamma_c},$$

Where, E_{cm} = mean value of concrete elasticity modulus
γ_c = partial safety factor of concrete reduced to 1.35

The results are compared with following codes:

3.1.4. BS5400 Code

The Critical load of CFST columns are calculated by using below formula according British Standards 5400

$$N_{cr} = A_s f_s + 0.675\, A_c f_c \quad (6)$$

3.1.5. ACI Code

The Critical load of CFST columns are calculated by using below formula according American Concrete Institute

$$N_{cr} = A_s f_s + 0.85\, A_c f_c \quad (7)$$

Where, A_s = Area of steel in mm^2, f_s = Yield strength of steel in N/mm^2, A_c = Area of concrete in mm^2, f_c = Characteristic strength of concrete in N/mm^2

4. Verification of Results

The experimental, Analytical and MATLab results of Natural Frequencies, Modal Frequencies and Critical loading of CFST columns are compared with code. Table 2 represents a comparison of natural frequency of CFST obtained analytically and with MATLab software. The graphical representation of the same is plotted in Figure 3.

Table 2: Comparing of analytical Natural Frequency with MATLab

Sl. No.	*Length l (mm)*	*Diameter D (mm)*	*Natural Frequency (Analytical) ω (rad/sec)*	*Natural Frequency (MATLab) ω (rad/sec)*	*Grades*
1	254.4	42.4	19.685	18.7376	M20
			19.5327	18.3994	M30
			19.6703	18.3695	M40
			25.7704	25.7704	H
2	339.2	42.4	12.895	12.2743	M20
			12.7807	12.0392	M30
			12.4095	11.5889	M40
			15.6854	15.6855	H
3	424	42.4	6.3588	6.0528	M20
			6.3472	5.979	M30
			6.3224	5.9044	M40
			8.5862	8.5862	H
4	508.8	42.4	4.6789	4.4538	M20
			4.7013	4.4285	M30
			4.6928	4.3825	M40
			5.8672	5.8672	H
5	594.6	42.4	3.4141	3.2498	M20
			3.4477	3.2477	M30
			3.4454	3.2177	M40
			4.3392	4.3393	H

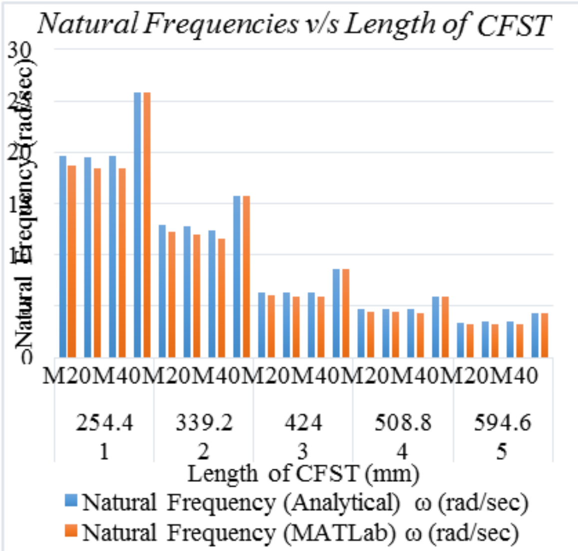


Figure 3: Natural frequencies v/s length of CFST

Table 3 and 4 represents Modal frequency of CFST obtained analytically and with MATLab software. The graphical representation of the same is plotted in Figure 4.

Table 3: Modal frequency (Analytical)

Sl. No.	*Length l (mm)*	*Grades*	*Modal Frequency (Analytical)*		
			λ1	*λ2*	*λ3*
1	254.4	M20	7.081312	7.081312	0.0058
		M30	7.017076	7.017076	0.0059
		M40	7.01142	7.01142	0.0058
		H	8.304624	8.304624	0.006
2	339.2	M20	5.788092	5.788092	0.0044
		M30	5.7324	5.7324	0.0044
		M40	5.624178	5.624178	0.0044

		H	6.543096	6.543096	0.0045
3	424	M20	4.0446735	4.0446735	0.0035
		M30	4.0199075	4.0199075	0.0035
		M40	3.9947355	3.9947355	0.0036
		H	4.8172915	4.8172915	0.0036
4	508.8	M20	3.486564	3.486564	0.0034
		M30	3.47667	3.47667	0.0034
		M40	3.458616	3.458616	0.0035
		H	4.001766	4.001766	0.0027
5	594.6	M20	2.949099	2.949099	0.0025
		M30	2.948089	2.948089	0.0025
		M40	2.934454	2.934454	0.0025
		H	3.40774	3.40774	0.0026

Table 4: Modal frequency (MATLab)

Sl. No.	*Length l (mm)*	*Grades*	*Modal Frequency (MATLab)*		
			λ1	*λ2*	*λ3*
1	254.4	M20	7.0112	7.0112	0.0062
		M30	6.9476	6.9476	0.0063
		M40	6.942	6.942	0.0063
		H	8.2224	8.2224	0.0061
2	339.2	M20	5.6746	5.6746	0.0046
		M30	5.62	5.62	0.0047
		M40	5.5139	5.5139	0.0047
		H	6.4148	6.4148	0.0046
3	424	M20	3.9849	3.9849	0.0037
		M30	3.9605	3.9605	0.0038
		M40	3.9357	3.9357	0.0039
		H	4.7461	4.7461	0.0037
4	508.8	M20	3.4182	3.4182	0.0036
		M30	3.4085	3.4085	0.0037
		M40	3.3908	3.3908	0.0038
		H	3.9233	3.9233	0.0028
5	594.6	M20	2.9199	2.9199	0.0026
		M30	2.9189	2.9189	0.0027
		M40	2.9054	2.9054	0.0028
		H	3.374	3.374	0.0026

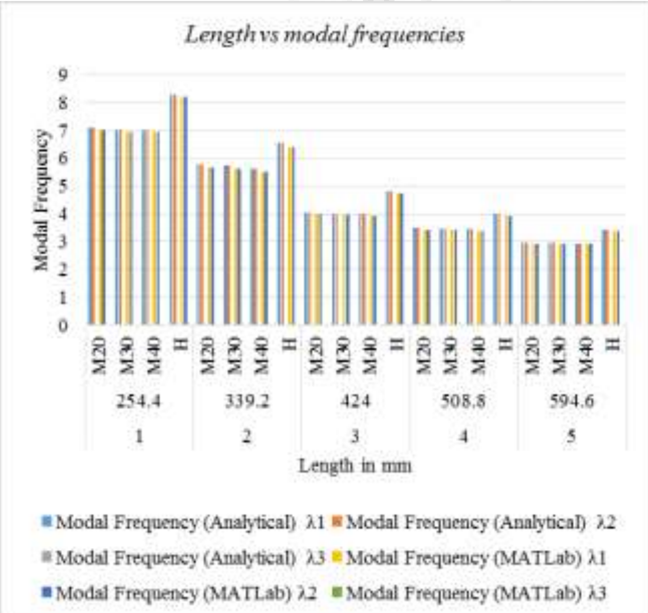


Figure 4: Model frequencies v/s length of CFST

Table 5 represents a comparison of Critical loading of CFST obtained experimentally and with MATLab software. The graphical representation of the same is plotted in Figure 5.

Table 5: Comparing of experimental critical loading with MATLab

S. no	Length l (mm)	Grades	Experimental Pcr in kN	MATLab Pcr in kN
1	254.4	M20	2689.2	2439
		M30	2745.98	2439
		M40	2793.85	2439
		H	2436.56	2439
2	339.2	M20	1512.68	1372
		M30	1544.62	1372
		M40	1571.54	1372
		H	1370.56	1372
3	424	M20	968.11	878.05
		M30	988.55	878.05
		M40	1005.79	878.05
		H	877.16	878.05
4	508.8	M20	672.3	609.76
		M30	686.5	609.76
		M40	698.46	609.76
		H	609.14	609.76
5	594.6	M20	492.27	446.48
		M30	502.67	446.48
		M40	511.43	446.48
		H	446.03	446.48

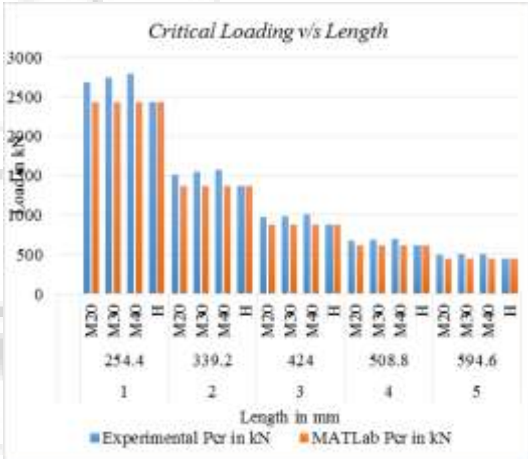


Figure 5: Critical Loading v/s Length of CFST

5. Modelling of CFST Columns in Midas Civil Software

The modelling of CFST columns is carried out by using the above properties for various lengths and different mode shapes are obtained. These mode shapes also gives the critical loads which are further compared with experimental loads. Figures 6 – 9 represents the 1st – 4th mode shape respectively.

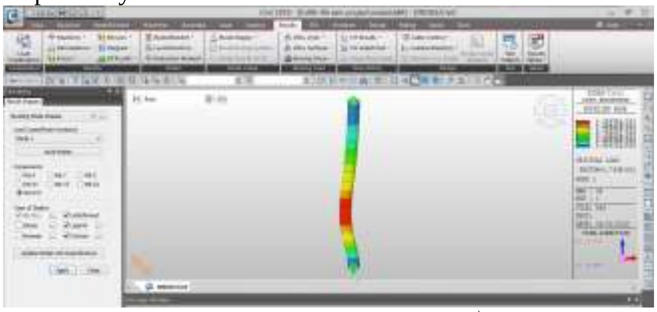


Figure 6: Dialogue box representing the 1st mode shape in MIDAS CIVIL software

1) The Critical Load Factor obtained for 1st mode is 740E+001. Hence, the load for this mode is nominal load applied multiplied by the critical load factor. i.e, Maximum Compressive Force for Buckling, Pcr= 10 X 17.40 = 174 KN
2) Similarly, for 2nd mode, critical load factor is 1.740E+001, hence Pcr = 10 X 17.40 = 174 KN

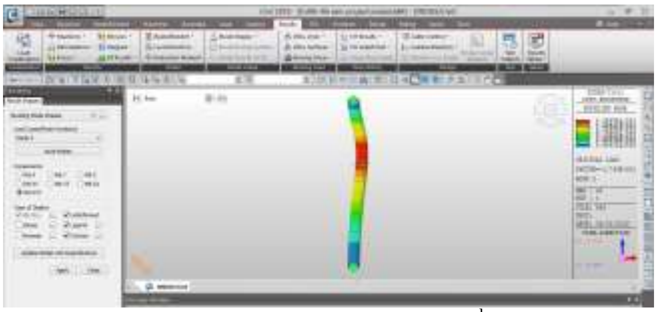


Figure 7: Dialogue box representing the 2nd mode shape in MIDAS CIVIL software

3) Similarly, for 3rd mode, critical load factor is 3.024E+001, hence Pcr = 10 X 30.24 = 302.4 KN

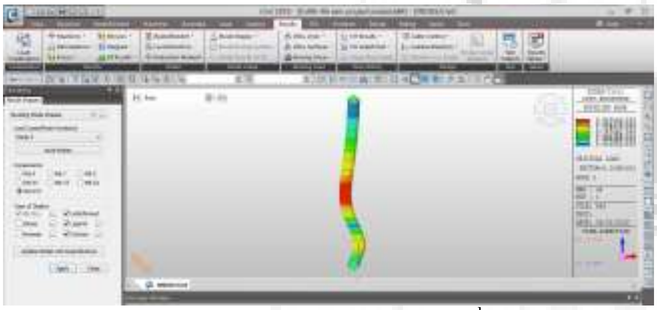


Figure 8: Dialogue box representing the 3rd mode shape in MIDAS CIVIL software

4) Similarly, for 4th mode, critical load factor is 3.024E+001, hence Pcr = 10 X 30.24 = 302.4 KN

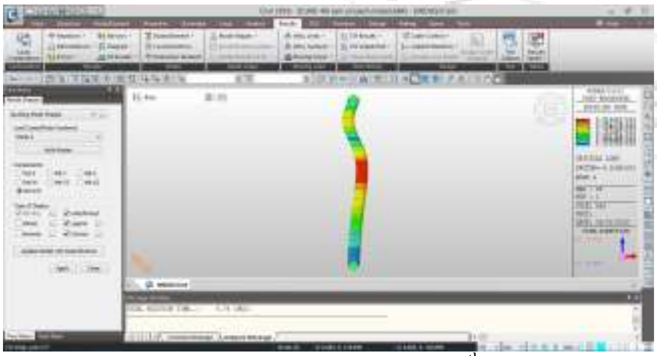


Figure 9: Dialogue box representing the 4th mode shape in MIDAS CIVIL software

Table 6 represents a comparison of experimental loads with loads obtained from MIDAS CIVIL software. The graphical representation of the same is plotted in Fig. 10.

Table 6: Loads obtained experimentally and from MIDAS CIVIL

Experimental loads and other data			*Loads from MIDAS CIVIL (kN)*			
Length (mm)	*Grades*	*Experimental Load (kN)*	*Mode 1*	*Mode 2*	*Mode 3*	*Mode 4*
254.4	M20	612.2	393.3	393.3	400.9	400.9
	M30	628.7	419.1	419.1	431.7	431.7
	M40	636	440.2	440.2	457.6	457.6
	H	591	259.9	259.9	264.6	264.6
339.2	M20	344.5	314.9	314.9	379.7	379.7
	M30	351	330.6	330.6	406.1	406.1
	M40	359.6	343.4	343.4	427.9	427.9
	H	334.2	235.2	235.2	255	255
424	M20	222.1	241.3	241.3	340.1	340.1
	M30	228.6	251.4	251.4	360.7	360.7
	M40	245	259.6	259.6	377.6	377.6
	H	214.6	190.5	190.5	239.6	239.6
508.8	M20	209	185.8	185.8	294.5	294.5
	M30	215	192.6	192.6	310.1	310.1
	M40	229	198.2	198.2	322.9	322.9
	H	121.8	151.8	151.8	216.7	216.7
594.6	M20	111.2	145.2	145.2	250.7	250.7
	M30	116.4	149.6	149.6	262	262
	M40	123.6	154	154	272.2	272.2
	H	109.3	121.3	121.3	191.4	191.4

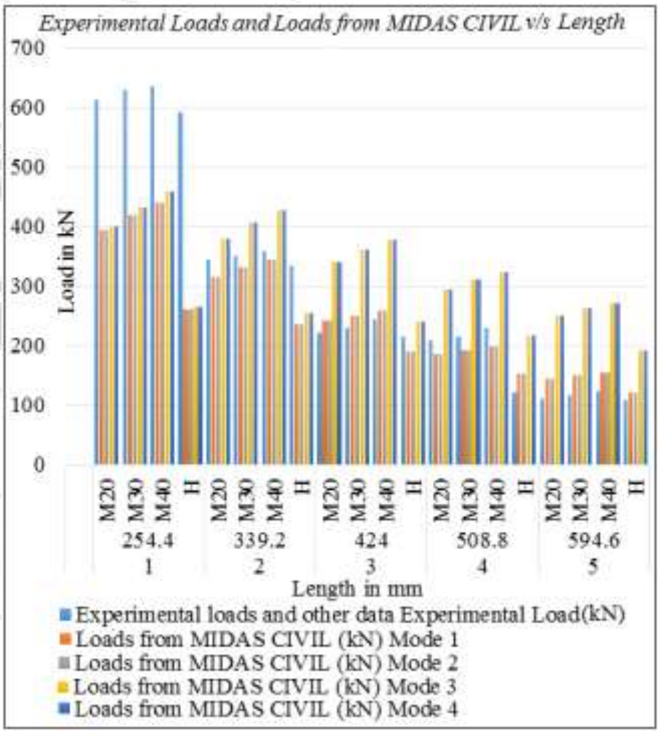


Figure 10: Loads v/s Length of CFST

6. Conclusions

- As the steel tube length increases, natural frequency decreases by 10% - 14% for different conventional grades of concrete infill
- The length of the tube remaining constant, with different grades of concrete infill, modal frequency decreases as the concrete grade strength increases by 0.4% - 0.6%
- Modal frequency value obtained from MATLab programming varies by 1% - 2% of values obtained from analytical procedure for different grades of concrete

- Natural frequency value obtained from MATLab programming varies by 4% - 8% of values obtained from analytical procedure for different grades of concrete
- As the length of the steel tube increases, the load carrying capacity decreases with column length remaining constant
- Critical load obtained from MATLab programming varied by 10% - 12% of experimental values
- The critical load factor and the load value for a given specimen obtained from MIDAS CIVIL is found to be same for 1st and 2nd mode and 3rd and 4th mode respectively

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