SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V6I7P105

Volume 6 Issue 7, 23-29, July 2019

Validation of Load Carrying Capacity of Composite Steel Column Using MATLAB-Vibration Tool Box

Yaseen Ahmed Khan[1], Dr. N S Kumar[2]

[1]*Student, Department of Civil Engineering, Ghousia College of Engineering, India*

[2]*Prof & Director (R&D), Department of Civil Engineering, Ghousia College of Engineering, India*

Abstract

In this study, composite steel columns' load-carrying capacity will be validated for hollow, equivalent solid, and self-compacting concrete infill of different grades obtained using MATLAB-Vibration toolbox. The complex behavior of composite steel columns plays an important role in seismic design. Natural frequencies and periods are obtained for different grades of infill, including different L/D and D/t ratios. Different slenderness ratios(l/d) of steel columns varying from 2.5-15.0, i.e., both short and long columns filled with M-20, M-30 & M-40 SCC, are considered for the validation. The diameter of the columns is from 26.9mm-160mm, and thickness from 2.5mm-4.0mm is considered.

Keywords *- MATLAB, Composite Steel Columns, Self-Compacting Concrete, Natural Frequencies, Mode Shapes*

I. INTRODUCTION

A. About MATLAB:

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

- Math and computation
- Algorithm development
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran. The MATLAB system consists of five main parts:

- The MATLAB language.

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs and "programming in the large" to create complete large and complex application programs.

- The MATLAB working environment.

This is the set of tools and facilities that you work with as a MATLAB user or programmer. It includes facilities for managing the variables in your workspace and importing and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

- Handle Graphics.

This is the MATLAB graphics system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete Graphical User Interfaces on your MATLAB applications.

- The MATLAB mathematical function library.

This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

- The MATLAB Application Program Interface (API).

This is a library that allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from

MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

B. About Composite columns:

Composite Columns are a combination of two traditional structural forms: structural steel and structural concrete. As composite columns were generally developed after steel columns and reinforced concrete columns, their design approach could have been based on either steel or concrete design methods. However, steel column design methods have differed from concrete design methods in a number of fundamental ways. Despite this, either design approach can be used as the basis for developing a design method for composite columns, and this can be seen in the different methods currently used in Europe and the USA for composite columns. While the design approaches appear fundamentally different, the end results can be surprisingly similar. By understanding the design philosophies, designers can take full advantage of each approach for the effective use and economy of composite columns.

C. Self-compacting concrete (SCC):

Self-Compacting Concrete is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement. The use of SCC can also help minimize hearing-related damages on the worksite that are induced by the vibration of concrete. Another advantage of SCC is that the time required to place large sections is considerably reduced. Current studies in SCC, which are being conducted in many countries, can be divided into the following categories:

- Use of rheometers to obtain data about flow behavior of cement paste and concrete
- Mixture proportioning methods for SCC
- Characterization of SCC using laboratory test methods
- Durability and hardened properties of SCC and their comparison with normal concrete
- Construction issues related to SCC

Self-consolidating concrete is a highly flowable type of concrete that spreads into the form without the need for mechanical vibration. Self-compacting concrete is a non-segregating concrete that is placed by means of its own weight. The importance of self-compacting concrete is that it maintains all concrete's durability and characteristics, meeting expected performance requirements. In certain instances, the addition of superplasticizers and viscosity modifiers are added to the mix, reducing bleeding and segregation.

Concrete that segregates loses strength and results in honeycombed areas next to the formwork. A well designed SCC mix does not segregate, has high deformability and excellent stability characteristics. Self-compacting concrete produces resistance to segregation by using mineral fillers or fines and using special admixtures. Self-consolidating concrete is required to flow and fill special forms under its own weight; it shall be flowable enough to pass through highly reinforced areas and must be able to avoid aggregate segregation. This type of concrete must meet special project requirements in terms of placement and flow. Self-compacting concrete with a similar water-cement or cement binder ratio will usually have slightly higher strength compared with traditional vibrated concrete due to the lack of vibration, giving an improved interface between the aggregate and hardened paste. The concrete mix of SCC must be placed at a relatively higher velocity than that of regular concrete. Self-compacting concrete has been placed from heights taller than 5 meters without aggregate segregation. It can also be used in areas with normal and congested reinforcement, with aggregates as large as 2 inches.

D. COMSOL Multiphysics Software:

COMSOL Multiphysics is the physics that describes specific phenomena to solving and postprocessing models for is a simulation platform that encompasses all of the steps in the modeling workflow — from defining geometries, material properties and producing accurate and trustworthy results. Engineers and scientists use the COMSOL Multiphysics® software to simulate designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. COMSOL Multiphysics is a tool for modeling and simulating engineering tasks. The problems we want to solve in real life are always based on Multiphysics phenomena. Thus, it's required to take into account the interaction between two or more physics domains at one time. COMSOL Multiphysics is defined for solving these complex problems. The program offers a unique user-friendly working environment and also provides a wide range of tools for fast and effective analysis. COMSOL Multiphysics allows you to minimize the needs for physical prototypes, shorten product development times, and achieve substantial savings in the development process. This modeling approach helps you to develop better products and bring them faster to the market.

II. MATERIAL PROPERTIES

Table 1: Properties of Materials

Properties of Materials	**Structural Steel**	**Concrete**
Density(ƒ)	7850kg/m^3	2300kg/m^3
Poisson's ratio(μ)	0.33	0.33
Young's Modulus(E)	200000MPa	22360.7MPa(M20),27386.12MPa(M30), 31622.77MPa(M40)
Co-efficient of thermal expansion(α)	12.3*10e-6/°C	10*10e-6/°C
Thermal Conductivity(k)	44.5 W/ (m K)	1.8 W/ (m K)

III. ANALYTICAL STUDY

A. By using Eurocode 4: EC4 is the most recently completed international standard code for composite construction. It covers CFST columns with or without reinforcement. EC4 considers the confinement effect for a composite column when the relative slenderness ratio(λ) has a value less than 0.5. The ultimate axial force for the square column is given by,

$$Pu=Acfc + Asfs$$

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

B. American Concrete Institute: Building Code Requirements for Structural Concrete
The American Concrete Institute ACI uses the formula to calculate squash load. This code doesn't consider the effect of confinement. The squash load for the circular column is given by,

$$Pu=0.95Acfc + Asfs$$

A modification given by the ACI code is too conservative, whereas those calculated by using the revised equation are more realistic, especially for circular columns.

IV. SPECIMEN DETAILS

Table 2: Details of the specimen

Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D
160	750.4	2.5	64	4.69
139.6	800	4	34.9	5.73
	2000	4	34.9	14.32
111.25	750.4	2.5	44.5	6.75
160	400	2.8	57.14	2.5
	1000	2.8	57.132	6.25
60.3	301.5	2.9	20.79	5
	422.1	3.6	16.75	7
26.9	215.8	3.2	8.4	8
	404.8	3.2	8.4	15
33.7	215.8	3.2	10.53	6.4
	404.8	3.2	10.53	12

V. RESULTS

A. Analytical results, Eurocode 4, ACI Code

Table 3: Hollow Tube

Type of Steel	Year	Authors	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)	ω(frequency) (rps)
Hollow	2007	Dong Keon Kim	160	750.4	2.5	64	4.69	461.4	0.0514
	2010		139.6	800	4	34.9	5.73	453.3	1.5510
				2000	4	34.9	14.32	510.7	0.0417
	2011	Shehdeh Ghannam	111.25	750.4	2.5	44.5	6.75	411.3	0.0503
	2013	Darshika K.Shahl	160	400	2.8	57.14	2.5	291.3	0.0382
				1000	2.8	57.132	6.25	523.3	0.0334
	2014	Pradeep, Khalid Nayaz Khan, Dr. N S Kumar	60.3	301.5	2.9	20.79	5	153.12	0.0562
				422.1	3.6	16.75	7	174.01	0.0465
	2016	Deepak, E Ramesh Babu, Dr N S Kumar	26.9	215.8	3.2	8.4	8	70	0.0403
				404.8	3.2	8.4	15	75	0.0399
			33.7	215.8	3.2	10.53	6.4	84	0.0668
				404.8	3.2	10.53	12	90	0.0489

Table 4: Equivalent Solid Column

Type of Steel	Year	Authors	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)	ω(frequency) (rps)
Equivalent Solid	2007	Dong Keon Kim	160	750.4	2.5	64	4.69	461.4	1.1667
	2010		139.6	800	4	34.9	5.73	453.3	1.9551
				2000	4	34.9	14.32	510.7	1.2347
	2011	Shehdeh Ghannam	111.25	750.4	2.5	44.5	6.75	411.3	2.9265
	2013	Darshika K.Shahl	160	400	2.8	57.14	2.5	291.3	0.0341
				1000	2.8	57.132	6.25	523.3	2.5695
	2014	Pradeep, Khalid Nayaz Khan, Dr N S Kumar	60.3	301.5	2.9	20.79	5	153.12	0.0423
				422.1	3.6	16.75	7	174.01	1.5922
	2016	Deepak, E Ramesh Babu, Dr N S Kumar	26.9	215.8	3.2	8.4	8	70	0.0662
				404.8	3.2	8.4	15	75	0.0399
			33.7	215.8	3.2	10.53	6.4	84	0.0401
				404.8	3.2	10.53	12	90	1.9359

Grade	Year	Authors	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)	ω(frequency) (rps)
M20 (E=22360.7MPa)	2007	Dong Keon Kim	160	750.4	2.5	64	4.69	461.4	1.8517
	2010		139.6	800	4	34.9	5.73	453.3	2.3477
				2000	4	34.9	14.32	510.7	3.0197
	2011	Shehdeh Ghannam	111.25	750.4	2.5	44.5	6.75	411.3	1.3519
	2013	Darshika K.Shahl	160	400	2.8	57.14	2.5	291.3	1.1044
				1000	2.8	57.132	6.25	523.3	1.8689
	2014	Pradeep, Khalid Nayaz Khan, Dr. N S Kumar	60.3	301.5	2.9	20.79	5	153.12	0.1137
				422.1	3.6	16.75	7	174.01	0.1232
	2016	Deepak, E Ramesh Babu, Dr N S Kumar	26.9	215.8	3.2	8.4	8	70	0.0542
				404.8	3.2	8.4	15	75	1.8879
			33.7	215.8	3.2	10.53	6.4	84	0.0627
				404.8	3.2	10.53	12	90	2.0850

Table 5: M20 Self-Compacting Concrete Infill

Grade	Year	Authors	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)	ω(frequency) (rps)
M30 (E=27386.7MPa)	2007	Dong Keon Kim	160	750.4	2.5	64	4.69	461.4	2.6468
	2010		139.6	800	4	34.9	5.73	453.3	4.1078
				2000	4	34.9	14.32	510.7	1.5227
	2011	Shehdeh Ghannam	111.25	750.4	2.5	44.5	6.75	411.3	3.3433
	2013	Darshika K.Shahl	160	400	2.8	57.14	2.5	291.3	3.9852
				1000	2.8	57.132	6.25	523.3	1.6140
	2014	Pradeep, Khalid Nayaz Khan, Dr. N S Kumar	60.3	301.5	2.9	20.79	5	153.12	6.3591
				422.1	3.6	16.75	7	174.01	1.0070
	2016	Deepak, E Ramesh Babu, Dr N S Kumar	26.9	215.8	3.2	8.4	8	70	7.0843
				404.8	3.2	8.4	15	75	2.6554
			33.7	215.8	3.2	10.53	6.4	84	4.2551
				404.8	3.2	10.53	12	90	4.9756

Table 6: M30 Self-Compacting Concrete Infill

Grade	Year	Authors	Diameter (mm)	Length (mm)	Thickness (mm)	D/t	L/D	Pu(expt)	ω(frequency) (rps)
M40 (E=31622.77MPa)	2007	Dong Keon Kim	160	750.4	2.5	64	4.69	461.4	2.0492
	2010		139.6	800	4	34.9	5.73	453.3	1.2529
				2000	4	34.9	14.32	510.7	1.3067
	2011	Shehdeh Ghannam	111.25	750.4	2.5	44.5	6.75	411.3	1.3035
	2013	Darshika K.Shahl	160	400	2.8	57.14	2.5	291.3	1.6609
				1000	2.8	57.132	6.25	523.3	1.0293
	2014	Pradeep, Khalid Nayaz Khan, Dr. N S Kumar	60.3	301.5	2.9	20.79	5	153.12	1.3746
				422.1	3.6	16.75	7	174.01	1.4853
	2016	Deepak, E Ramesh Babu, Dr N S Kumar	26.9	215.8	3.2	8.4	8	70	1.9878
				404.8	3.2	8.4	15	75	1.8175
			33.7	215.8	3.2	10.53	6.4	84	2.1435
				404.8	3.2	10.53	12	90	3.0215

Table 7: M40 Self-Compacting Concrete Infill

B. Simulation results of Mode shapes:

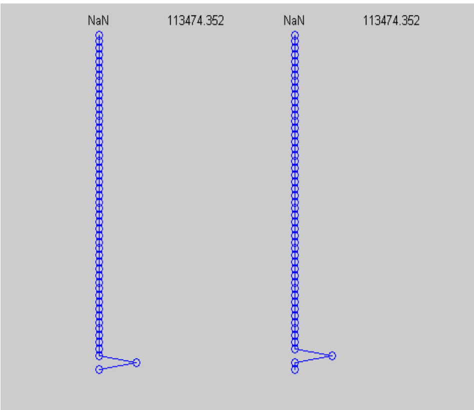

Figure 1: Mode Shapes of Beam in rad/sec

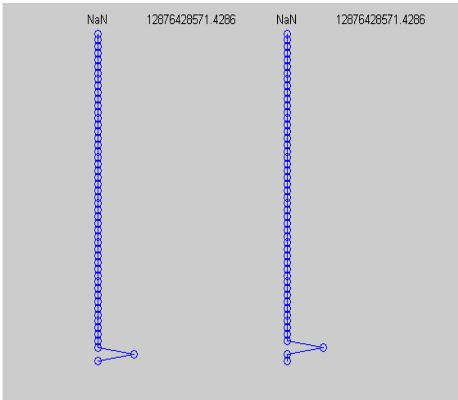

Figure 2: Buckling Load in N

When a building is subjected to an earthquake, the building undergoes different mode shapes at different instances of earthquake waves, as shown in Figure 1 & Figure 2.

C. 3D Modelling using COMSOL Multiphysics Software

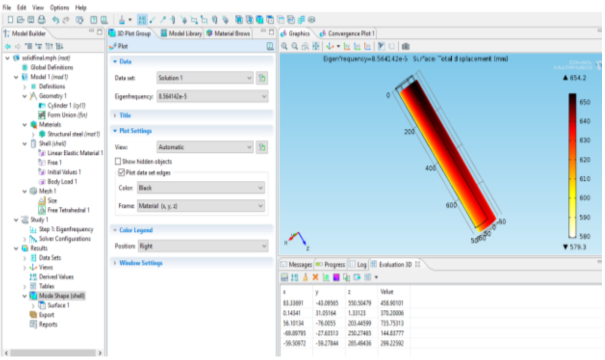

Figure 3: FEA Modelling of Equivalent Solid Steel Column

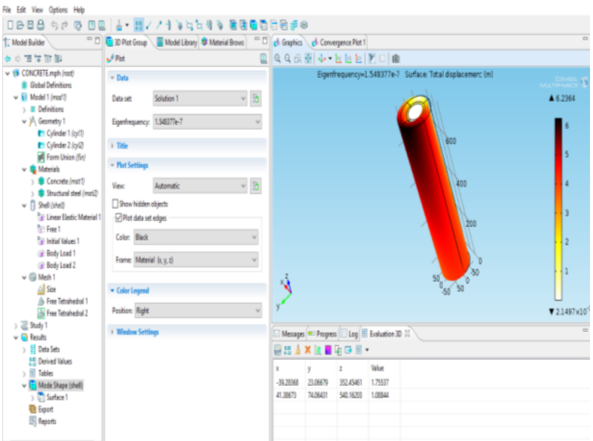

Figure 4: FEA Modelling of SCC Infill

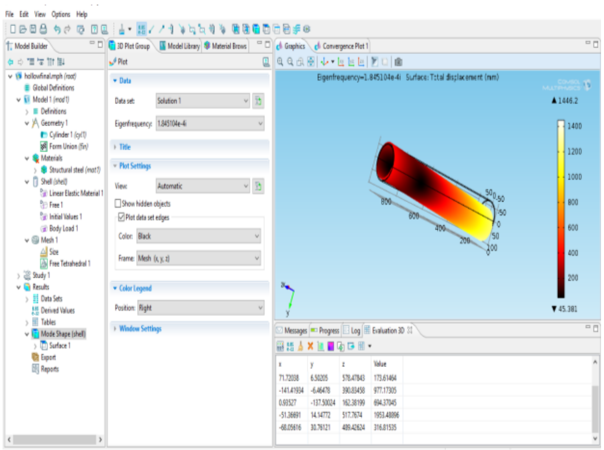

Figure 5: FEA Modelling of Hollow Steel Column

VI. CONCLUSIONS

- The longer the column less is the load-carrying capacity
- As the grade of SCC infill increases from M20-M40, not much increase in load-carrying capacity of the column
- The thickness of the steel tube plays a crucial role
- The higher the thickness, the lower will be the load-carrying capacity
- Natural frequencies decrease as column thickness increases
- As the D/t ratio increases, natural frequency increases by 5-8%, and it increases by 15-20% with an increase in the column area

REFERENCES

[1] American Concrete Institute (ACI), Building code requirements for structural concrete and commentary, ACI 318-95.

[2] Eurocode 4. Design of composite steel and concrete structures. Part 1.1, General rules and rules for buildings (with UK national application document).

[3] Hu, Hsuan-Teh, Chiung-Shiann Huang, Ming-Hsien Wu, and Yih-Min Wu., Nonlinear analysis of axially loaded concrete-filled tube columns with confinement effect., Journal of Structural Engineering. 129,10 (2003),1322-1329.

[4] Gupta, P. K., S. M. Sarda, and M. S. Kumar. , Experimental and computational study of concrete-filled steel tubular columns under axial loads., Journal of Constructional Steel Research 63(2),(2007),182-193.

[5] Zona, Alessandro, Michele Barbato, and Joel P. Conte. , Finite element response sensitivity analysis of steel-concrete composite beams with deformable shear connection., Journal of engineering mechanics 131,11 (2005),1126-1139.

[6] J.Vengadesh Marshall Raman, V.Murali Krishnan, Partial Replacement of Cement with GGBS in Self Compacting Concrete for Sustainable Construction SSRG International Journal of Civil Engineering 4(3) (2017) 22-25.

[7] Siva Srinivas Kolukula, Natural Frequencies and Buckling Load of Columns using Finite Element Method.

[8] Rao V Dukkipati, Vibration Analysis, Alpha Science Int'l Ltd., (2004).

[9] P. Kumar Mehta, Ph.D., Paulo J. M. Monteiro, Ph.D., Concrete: Microstructure, Properties, and Materials, Fourth Edition, McGraw-Hill Education: New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto,(2014), McGraw-Hill Education.

[10] Geert De Schutter, Self-Compacting Concrete, Whittles, (2008).

[11] George Z Voyiadjis, Peter I. Kattan, Mechanics of Composite Materials with MATLAB, Springer Berlin Heidelberg, (2005).