"ANALYTICAL STUDIES ON DYNAMIC BEHAVIOUR OF COMPOSITE COLUMNS INFILLED WITH SELF COMPACTING CONCRETE (SCC) USING MATLAB AND MIDAS CIVIL"

DISSERTATION

Submitted to

VISVESVARAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI

In partial fulfillment of the Requirement for the Award of Degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

BY

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DEPARTMENT OF CIVIL ENGINEERING

(Accredited by National Board of Accreditation)

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2017-2018

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CERIFICATE

Certified that the project work entitled **"ANALYTICAL STUDIES ON DYNAMIC BEHAVIOUR OF COMPOSITE COLUMNS INFILLED WITH SELF COMPACTING CONCRETE (SCC) USING MATLAB AND MIDAS CIVIL"** is carried out by Mr. MOHAMED GHAYAAS ANJUM bearing USN: 1GC16CSE08, a bonafide student of Ghousia College of Engineering, Ramanagaram in partial fulfillment for the award of Master of Technology in Structural Engineering of Visvesvaraya Technological University (VTU), Belagavi, during the year 2017-2018. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The project report has been approved, as it satisfies the Academic requirements in respect of Project work prescribed for the 4th semester Master of Technology Degree.

17/5/18 17/5/18

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DECLARATION

I, **MOHAMED GHAYAAS ANJUM**, student of 4th semester, M.Tech, Structural Engineering, Ghousia College of Engineering, Ramanagaram, the undersigned declare that this Dissertation work entitled **"ANALYTICAL STUDIES ON DYNAMIC BEHAVIOUR OF COMPOSITE COLUMNS INFILLED WITH SELF COMPACTING CONCRETE (SCC) USING MATLAB AND MIDAS CIVIL"** is a bonafide work carried out by me (during 2017-2018) in partial fulfillment of the requirements for the award of the post graduate degree of Master of Technology in Structural Engineering of Visvesvaraya Technological University, Belagavi, Karnataka and is the work carried out and results obtained under the guidance of **Dr. N.S.KUMAR**, Professor & Director (R&D), Department of Civil Engineering, Ghousia College of Engineering, Ramanagaram-562169.

I also declare that this Dissertation has not been submitted to any other University or Institution for the award of any degree.

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CONTENTS

ABSTRACT

The CFST column is a composite materials system which employs the various advantages of different materials and combines them together in a steel tube column with filled concrete. Composite sections are becoming increasingly popular in construction. Combining the strength of two different materials to form a composite section might be beneficial. Example for widely used composite section in construction is composite slabs, which is very popular in recent years, here concrete slabs and steel beams combine to resist load. There is a surge in popularity of composite columns. Concrete filled steel tubes (CFSTs) are used in many structural applications including columns, supporting platforms of roofs of storage tanks, offshore structures, columns in seismic zones and bridge piers.

In this study, the load carrying capacity of the composite steel columns will be validated for **Self Compacting Concrete (SCC)** of different grades such as **M20 M30 M40** by developing programs using **MATLAB** software. The complex behavior of composite steel columns plays an important role in the seismic design. Natural frequencies, time periods and modal frequencies are obtained for different slenderness ratios (L/D) of steel columns varying from **15** to **156** i.e, only short columns filled with SCC are considered for carrying this study. Diameter of column varying from **337mm** to **483mm** and length from **202.2mm** to **678.4mm** 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.

The above considered columns are also modelled in a FEM software MIDAS CIVIL 2018 for different end support conditions such as fixed and hinged. Comparative studies have been carried out in variation of loads for the different end conditions.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In buildings where cost of land is at a peak, any savings in floor. area will be of considerable advantage both. in terms of cost of the construction. of floor and better utilization of materials. With this in view, some of the innovations. which are prevalent. in the basement floors for parking purpose. in order to overcome land / space scarcity, are use. of steel in columns for reduction in area. compared to concrete. and use of steel-concrete composites offsetting some of the costs in using steel completely. Generally columns in high rise buildings. are larger in size when concrete. is used and occupy more space cutting. into the floor / carpet area. of the apartment resulting. in more cost. Concrete Filled Steel Tubular (CFST) composite columns. represent. a class of structural systems in which the two major components are so combined, that their utmost advantage is derived. When suitably utilized under favorable and suitable conditions the steel outher casing encases the core multiaxially creating a confinement or boundary for. better seismic resistance. and the concrete filled inside the tube inhibits or prevents. the local buckling and crippling of the. tubular shell.

Tubular circular columns have considerable advantage over spirally reinforced concrete composite tubes in which the core and. the cover shell behave as two separate or. different layers. In reinforced concrete columns, the cover is inferior to the. core and the spiral. Reinforcement and it only comes. into action or existence until. the cover spalls or gets ripped off. Whereas. in the concrete infilled steel. tubular composite columns, the core forms one. continuous homogeneous. medium. Also in the case of slender or long tubular. columns, where buckling occurs .before the concrete is confined, the shell. adds to the strength. Tubular columns, when considered. as reinforced. concrete columns, represent. columns with a well dispersed. reinforcement. Ties and. spirals could. be avoided and. tubes themselves form. the shuttering.

In the early and years of1980s to 1990s, several. Buildings. designed and constructed at a well known place called “Seattle” in .USA became well and extensively. known for their. extensive use of concrete infilled. steel tubes. Many developed. countries like USA, Japan, Germany, Singapore, Australia, Canada, Belgium etc., adopt. this kind of composite. Sections. to facilitate speedy construction. Because. of the increased. use of composite .columns, many experimental, analytical and theoretical research works were carried out to study and understand the .strength, stability and .behaviour of the CFST columns. Rational methods. of designing .CFST columns. have also been developed.

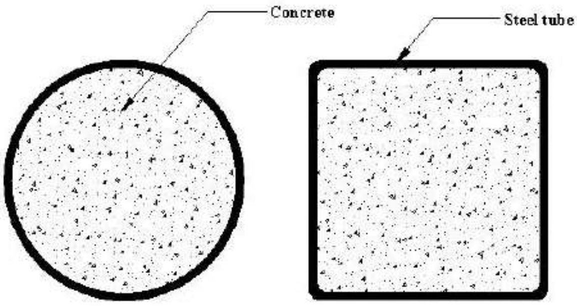
1.2 COMPOSITE CONSTRUCTION

In composite multi material construction, the use of bare steel. sections is that it supports the initial stages in the .construction loads, including the dead load or the self weight. of structure during constructions. Concrete is the later on cast around the periphery of. the steel sections, or can also be filled inside. the tubular sections. The concrete and steel proportions. are mixed or combined in such a manner that the. advantages of both the materials are utilized in carrying the load effectively in the composite columns.

The higher strength properties and light weight characteristics of steel permits the .use of small and lighter foundations thereby improving the economy considerably. The subsequent addition of concrete around or inside the steel casings enables the skeleton of the building. to easily and effectively prevent the sway and also controls lateral deflections.

No additional .reinforcing steel is required for CFST. columns except for requirements of fire protection to stanchions in steel framed buildings. Since the columns are subjected mainly to axial loads, the transverse shear (change in bending moment along the length) is much lower. Therefore the mechanical shear connectors are normally not required to develop complete interaction in composite columns. The use of round, square and rectangular steel tubular columns is becoming popular for high-rise structures and they are also of special interest to the architects from an aesthetic view point and to the engineers from a structural effectiveness view point.

The generalised term ‘Composite Column’ is used to refer to any compression member in which the steel part acts compositely with the brittle concrete element, so that the combined effect of both elements resist compressive forces. In other words. by definition, a steel-concrete column is a member hving a cross section consisting of a steel section (or sections) and concrete which act together to resist axial compression. There is an innumerably wide variety of column types having various cross- sections, but only two common types of composite column are in use. That is, A “steel - concrete composite column” is a compression .member comprising either of a concrete encased steel section in the outer periphery or it can be a concrete infilled steel tubular section which is often abbreviated as CFST and is generally used as a load-bearing/resisting member in a composite framed structure. Below showed are the 2 typical concrete filled steel tube cross sections in which it can be Noted that there is necessarily, no requirement of providing any additional reinforcing steel except for where there is a requirement of fire resistance where ever appropriate.



In composite column construction, both steel and the concrete would resist and counteract the external loading applied too it by interacting together by friction and bonding. Also, the steel tube provides tri-axial resistance or confinement which is same as that provided by stirrups in reinforced concrete columns. Hence, CFST columns reduce the requirement of expensive steels required for supporting the given load substantially. While, the dimensions of the column are lesser or smaller than those of a reinforced cement concrete column having same strength therefore increasing the available floor space.

1.3. ADVANTAGES OF CFST SECTIONS

1. The steel tube acts as a formwork beneath production of the CFST hence reducing the material costs and the labour costs.

2. The steel in the CFST at the outer edge serves most efficaciously under tension and it also resists bending moment.

3. The stiffness of the CFST increases greatly and the metallic is placed farthest from the centroid contributing large moment of inertia as modulus of elasticity of the steel has better elasticity when compared with concrete.

4. The use of the CFST has expanded solidness and clasping resistance prompting decreased slimness.

5. The concrete present at core avoids local buckling of metallic by undergoing compressive load packages.
6. Individuals having transverse reinforcement in bolstered concrete for seismic design, minimizes the congestion of reinforcement and the spalling of concrete.
7. There is an increase in the slenderness due to decrease in the size of the sections. Hence more columns can become prone to second-order effects.
8. CFST has precise fire resistance due to the presence of concrete which also serves as ecology motive where metal pipes and aggregates can be reused with the concrete of excessive quality.
9. By utilization of smaller CFST columns length in excessive strength programs, the floor area in office homes is grown. Because of lighter framework, CFST exerts a lesser load on the muse which inturn reduces the costs.
10. CFST column is very useful in rehabilitation of structures such as high-rise buildings, bridge piers etc.

1.4 STRUCTURAL BEHAVIOUR:

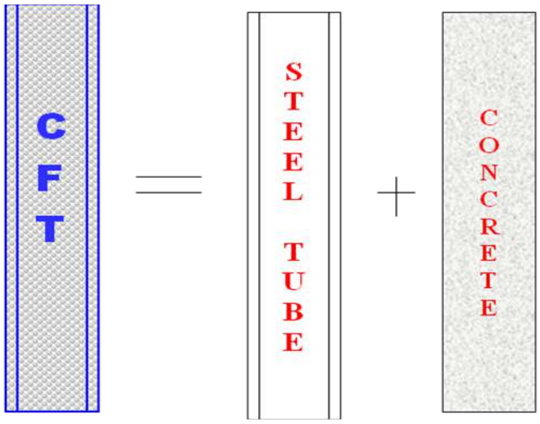
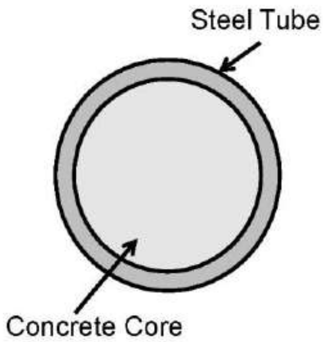


Fig. 1: Behavior of composite filled metallic or steel tube

Steel and concrete form composite materials with dissimilar stress-strain curvatures. The parameters distressing the ultimate strength, performance and let-down mechanism under given loading situations are:- The geometric restrictions such as (cross-section, member-size, and thickness of steel hose), Grades concrete and steel, L/d proportion of the cylinder, amount of loading, Sort of loading and boundary conditions.

1.5 CFST COLUMN TYPES:

There are many types of CFST column sections, in which rectangular and circular section shapes are most common shapes used in building as shown in fig. 2 & 3. Steel tubes infilled with concrete and steel tube encased with concrete are as shown in fig. 4.



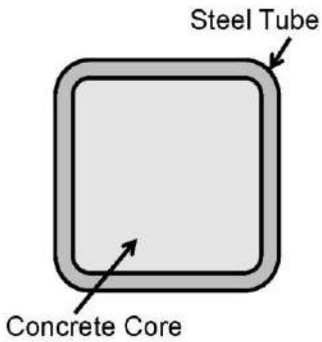


Fig. 2: Circular CFST section Fig. 3: Rectangular CFST section

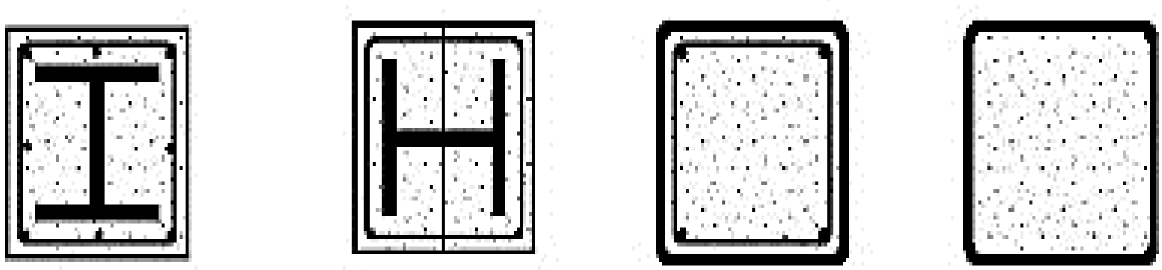


Fig. 4: Infilled and encased CFST sections

Composite infilled or encased column are used to reduce the size of column when compared to regular reinforced column needed to carry same load. Hence, by considering the economic saving, CFST columns are more advantageous.

1.6 SELF COMPACTING CONCRETE (SCC)

Self compacting concrete, also known by the name self consolidating concrete, is a one which has high flow ability and therefore, it spreads into the formwork without need of mechanical vibration or any further compaction. The self compacting concrete is non-segregating concrete which gets placed due to its own self weight. One majorly important characteristic of self-compacting concrete is that it maintains all the properties of concrete's durability and therefore meets all the required performance characteristics.

However, In certain instances it has been observed that the addition of certain admixtures such as plasticizers, superplasticizers and viscosity modifiers results in reduced segregation and bleeding.

It is a well-known fact that a concrete which segregates, loses strength and is highly undesirable and results in formation of honeycombs next and inside of the formwork. When SCC is properly designed to its required specifications, it does not segregate and shows high deformability and utmost characteristics of stability.

1.7 USES OF SELF COMPACTING CONCRETE:

Self-compacting concrete is extensively being used in construction of bridges and also has applications in pre cast members and sections. Therefore, this SCC can be used in the following applications:

- Drilled shafts
- Construction of Columns
- Earth retaining walls, structures and systems
- Places having higher concentration of rebar steel, pipes or conduits.

1.8 BENEFITS OF SCC:

The use of self-compacting concrete provides several advantages and benefits over regular/ conventional concrete. Some of those benefits are:

1. Improvement in constructability.
2. Reduction in labor and related costs.
3. Higher degree of bonding to reinforcing steel.
4. Higher structural Integrity.
5. Accelerates schedules of the project.
6. Requirement of skilled labor is minimized.
7. Also flows into complex forms.
8. Reduces wearing and damages to the equipment.
9. Voids are greatly minimized.
10. Easy and accessible pumping procedures can be employed.

1.9 FACTORS THAT AFFECT SELF COMPACTING CONCRETE:

Self compacting concrete must not be inappropriately and vividly used. Some of the factors that can affect the performance and behavior of self-compacting concrete are:

1. High temperature conditions or hot weather.
2. Flowability of self-compacting concrete can get reduced by long haul distances.
3. Delays in time on job sites can affect the mix design performance of the concrete.
4. Water addition on job sites to Self-Compacting Concrete may not yield the increased flowability as expected and may also cause problems in stability.

1.10 OBJECTIVES OF PRESENT STUDY:

1. To identify the effects of Composite Steel Columns with different L/D ratios and also for hollow and different grades of Self Compacting Concrete as infill material.

2. To determine and study the Natural frequencies, Time Period and Modal frequencies for different lengths and grades of concrete including hollow tubes.

3. To study the ultimate load bearing capacity of composite columns for increase in length of columns and also for different grades of infills and hollow tubes.

4. To study the variation of Natural frequency, Time Period and Modal frequencies of composite columns with different end conditions.

5. To study Buckling analysis by modelling in a FEM software MIDAS CIVIL.

6. To determine ultimate load bearing capacity of the composite columns for different mode shapes and also the variation in load for different end conditions of the columns.

CHAPTER 2

LITERATURE REVIEW

The literature review consists of the details of the recent researches and journals carried out on behavior and properties of self-compaction/consolidation concrete filled in steel - tubes. This includes the Hypothetical and trial inquires about performed all through the globe in the course of recent years on concrete filled steel tube.

2.1 "NASA TECHNICAL PAPER": (3090 – MARCH_1991): "VIBRATION AND BUCKLING ANALYSIS OF A SIMPLY SUPPORTED COLUMN WITH CONSTANT PIECEWISE C/S".

Authors: "Martin M. Mikulas Jr." and "Mark .S. Lake".

This paper presents and delivers information on sample results of lateral buckling and vibration of columns which are compressively loaded and whose cross section is constant throughout its length. The columns considered in this study have symmetry about its midspan and consists of three number of sections, with its center section having a cross section stiffer than the other two identical, outboard sections. The vibration and buckling characteristics of the columns are calculated from a numerical solution of the exact eigen value problems. Then, Parametric structural efficiency are analyzed and are performed by using a non dimensionalized governing equation sets for determining the optimum ratio between the center section lengths and lengths of outboard sections which are based on both buckling load and vibration-frequency requirements. In the performance of these analyses two relationships which are considered are between cross-sectional mass and bending stiffness. In which one is a method of low-efficiency for increasing the bending stiffness of cross section. And other one is a method of high efficiency. Collectively, the effect of axial load on the frequency of vibration is also analyzed and later on compared with that of column of uniform cross section.

2.2 "NASA TECHNICAL NOTE", NASA TN D-8109. "AXIAL LOAD EFFECT ON FREQUENCIES AND MODE SHAPES OF BEAMS".

AUTHOR: "FRANCIS J. SHAKER", "LEWIS RESEARCH CENTRE".

This paper consists of investigations carried out on the effect of axial load on the natural frequency and mode shapes of beams with uniform cross section and with vivid types of boundary conditions, one having a cantilevered beam with mass concentrated at its tip is presented. This investigation also yielded certain expressions for characteristic equations and mode shapes for various cases considered. For beams with uniform cross section, the characteristic equations are solved either by numerically or in a closed form. And the results are later on presented by a series of graphs which are showing the effect of pre load on beams of various types. The axial load effects on mode shapes are also shown in this paper in a graphical form for several types loading conditions.

2.3 "ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF CONCRETE FILLED STEEL TUBULAR (CFST) COLUMNS".

AUTHORS: "Zhijing Ou", "Baochun Chen", "P.E", "Kai H. Hsieh", "Marvin.W. Halling", "S.E", ASCE; and "Paul J. Barr", M.ASCE.

In the above mentioned paper, an analytical and experimental investigation of concrete-filled steel tubular (CFST) columns with laces is presented. These types of columns essentially consists of four different concrete-filled steel tubes which are bound together with lacing. Totally, 27 experiments and tests were carried out to analyze and quantify the column failure mechanism at their ultimate load values. These experiments were designed for obtaining load-deflection curves. Later on, these curves were subsequently utilized to analyze and to quantify the structural behavior of each element in the hybrid column. The experimental results concludes that the compression force in the longitudinal direction of the members dominated the failure mechanism over other directions in CFST columns. It also indicated that In-plane bending occurred only when a member segment reached to the compression failure load. The forces in the lacing members (diagonal and horizontal bracing) were found to be small and remained in the elastic range through failure. The experimental study and the subsequent results were then used to validate parametric study analysis.

This analytical study concluded that the increase in the slenderness ratios and eccentricities reduced considerably the ultimate load capacity of the columns. Additionally, the FEM analysis of the CFST columns based on 4 different in situ structures were also performed to determine the ultimate load-carrying capacity and eventually were compared to a few building codes. Finally, on the basis of the analyzes, calculations and results, a new methodology was proposed to calculate the ultimate load carrying capacity of the columns.

CHAPTER 3

MATERIAL PROPERTIES AND SPECIFICATION

3.1 SPECIMEN DETAILS AND EXPERIMENTAL LOADS:

EXPERIMENTAL LOADS & OTHER DATA					
sl no.	**Length (mm)**	**Diameter (mm)**	**Load P (KN)**	**Weight (kg)**	**Grades**
1	678.4	48.3	142.8	3.054	M20
			146.8	3.126	M30
			150.2	3.25	M40
			131.3	2.402	H
2	594.6	42.4	118.9	2.934	M20
			121.8	2.886	M30
			124.2	2.986	M40
			109.3	1.732	H
3	508.8	42.4	162.2	2.38	M20
			166.1	2.416	M30
			169.2	2.52	M40
			121.8	1.512	H
4	424	42.4	233.5	2.112	M20
			239.1	2.215	M30
			243.9	2.022	M40
			180.6	1.22	H
5	339.2	42.4	323.24	1.154	M20
			331.31	1.182	M30
			379.9	1.088	M40
			334.2	0.714	H
6	254.4	42.4	220	1.208	M20
			227	1.118	M30
			238	1.156	M40
			200	0.627	H
7	202.2	33.7	170	0.658	M20
			178	0.698	M30
			184	0.69	M40
			145	0.462	H

3.2 STRUCTURAL STEEL

Three different **diameters 33.7mm, 42.4mm and 48.3 with same thickness 3.2mm** are used in current work. Tata steel is the material used in the current work where hot rolled steel tube sections of various cross sections are used and these are supplied in stock lengths of 6m and they were cut into required lengths. **These steel tubes are having a tensile strength of 500 MPa, yield strength of 310 MPa, modulus of elasticity (young's modulus) of 210 Gpa. and Poisson's ratio = 0.3.**

3.3 CONCRETE

Concrete grades : M20, M30, M40

Elasticity modulus (or) young's modulus E=22360.7Mpa (M20)

Elasticity modulus (or) young's modulus E=27386.12Mpa (M30)

Elasticity modulus (or) young's modulus E=31622.78Mpa (M40)

Poissson‟s ratio v=0.16

Density of SCC ῤ= 2400 kg/m^3

CHAPTER 4

BRIEF DESCRIPTION OF SOFTWARES USED

Finite element method considers to be the best tool for analyzing the structure. Many software used for analyzing and designing structure .the most popular software for analyzing and learning is ansis work bench. It combines the strength of our core product solvers with the project tools necessary to manage the project workflow. similarly another software used for meshing a given geometry is hyper mesh is a numerical method for analysis of complex engineering problems. It is useful in areas where analytical solutions are not available/possible due to complex geometry, BC's and loading. FEA gives answer to "real world or practical engineering problems.

4.1 MATLAB (r2015a):

The term MATLAB is an abbreviation for the full name of the software "matrix laboratory" which is a multi paradigm calculation environment and is also the fourth generation in the course of programming languages.

This proprietary programming language have been developed by "MathWorks". The software MATLAB allows computations in highly complicated matrix manipulations and simultaneous plotting of various functions and data. Various algorithm implementations can also be performed by this. It also provides creation of various user interfaces and also interfacing with programs which are written in other computer languages including FORTRAN, C, C++, PYTHON and many more.

MATLAB platform is extensively used by scientists, engineers and any person involved in researches and its use in not permitted to any single field. In various fields such as image and signals processing, control systems in industries, communications, smart grid design systems, robotics and also computational finance.

4.1.1 ADVANTAGES OF MATLAB OVER OTHER PROGRAMS:

MATLAB helps in performing calculations in a very rapid and quick way also ensuring reliability in design of mainly engineering systems. The language of MATLAB is written in the form of a mathematical scripting code and is also similar to C++. It has the following advantages over other programs:

1. It uses effective and efficient matrix and vector computations.

2. Allows provisions for string processing.

3. It is highly object oriented.

4. It allows easy and fast creation of engineering graphics.

5. It has various toolboxes and add-ons which can be used for extensibility.

4.1.2 BENEFITS OF MATLAB:

1. A flexible data structure to store matrices without having to worry about memory allocation and deallocation.
2. Algorithms for numerical methods.
3. Provide an interactive environment (REPL - Read, Evaluate, and Print Loop) to do mathematical computations and visualize data through graphs.
4. SimuLink graphical simulation tool.
5. A programming language to extend its features.
6. Toolboxes for specialized applications such as image processing, computer vision, generic algorithms and many more.
7. A scientific computation workflow including a notebook feature to document your code.

4.2 MIDAS CIVIL – 2018:

Midas civil is highly sophisticated and a state of the art civil engineering software which set a new heights and standards for the design of various types of bridges and civil structures. The software features a very easy and user friendly interface options and optimal design functions for solutions that could account for construction stages, time dependent properties. The highly developed and sophisticated modelling and analysis functions and procedures enables the engineers to overcome majority of common challenges, uncertainties and inefficiencies of other finite element analysis. With Midas civil, one could be able to model and produce high quality designs with unprecedented and unmatched levels of accuracy and high efficiency.

4.2.1 FEATURES OF MIDAS CIVIL:

1. Highly user friendly - GUI (graphical user interface).
2. Intuitive modelling.
3. Provides complete analyzing options
4. Very powerful post processor
5. Auto load rating and auto design capability
6. Easy and quick Modeling Processes in the software
7. Advanced analysis capabilities including linear analysis, nonlinear analysis with static and dynamic analysis options.
8. Designs and reports can be generated for steel and concrete bridges.
9. Various designing codes are available to carry out designs fast and easily.

CHAPTER 5

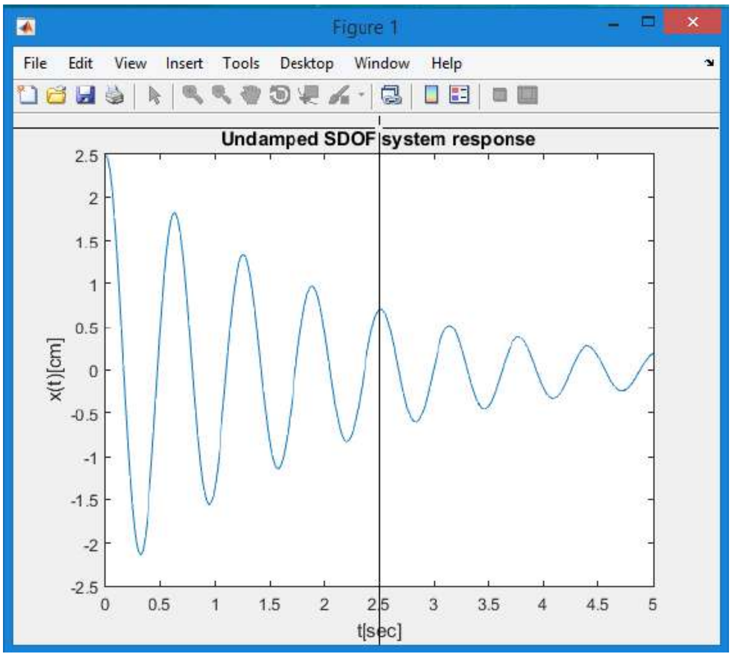
5.1 ANALYSIS USING MATLAB:

5.1.1 SOLVED TEXT BOOK PROBLEMS USING MATLAB

EXAMPLE 1: RESPONSE OF AN UNDAMPED SDOF SYSTEM.

```
wn=10; %Natural frequency
:zeta= [0.05;0.1;0.15;0.2] %damping_factors
:x0=2.5; %initial_displacement
;v0=0; %initial_velocity:
;t0=0; %time.
delt=0.02% step
'tf=5 %final.time
t=[t0:delt:tf];
%COMPUTATION OF DAMPED NATURAL FREQUENCIES
for "i=1";length(zeta),
    wd=_sqrt((1-zeta(i)^2))*wn;_%damped;frequency
   ; A=sqrt(x0^2+((zeta(i);*wn*x0+v0)/wd);^2);%Response amplitude
    phi=atan2((zeta(i);;*wn*x0+v0),(wd*x0));%phase angle
    x=A*exp;(-zeta(i)*wn*t).*cos(wd*t-phi);%response
    %PLOT A GRAPH BETWEEN x AND t
    plot(t,x)
    hold on
,end
.title('Undamped SDOF system;response')
/xlabel('t[sec]')
-ylabel('x(t)[cm]')
gtext('damping=0.05')
gtext('damping=0.1')
gtext('damping=0.15')
gtext('damping=0.2')
grid
```

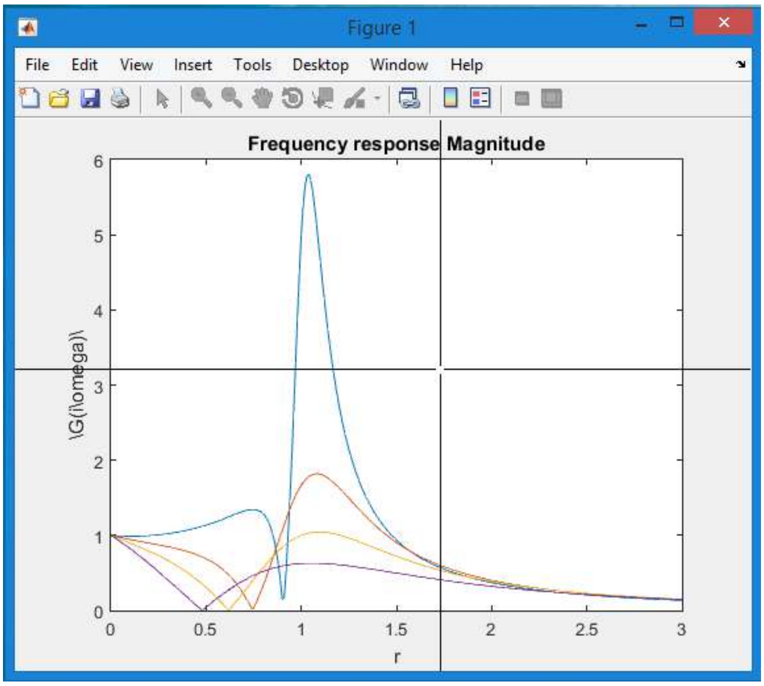
RESULT:



EXAMPLE 2: FREQUENCY RESPONSE MAGNITUDE

```
zeta=[0.1;0.3;0.5;0.8];%.damping;factors
;r=.[0:0.01:3];%rati_frequency
For; k=1:length(zeta),;
    G=(1-r.'^2-i*2*zeta'(k)*r)./((1-;r.^2).^2+(2*zeta(k)*r).^2);
    %frequency response
    magG=abs(G)
    phi=atan2(-imag(G),real(G));
    figure(1)
    plot(r,magG)
    hold on
end
figure(1)
title('Frequency response Magnitude')
xlabel('r')
ylabel('\G(i\omega)\')
g.text('zeta=0.1')
g;text('zeta=0.3')
g'text('zeta=0.5')
g/;text('zeta=0.8')
grid
```

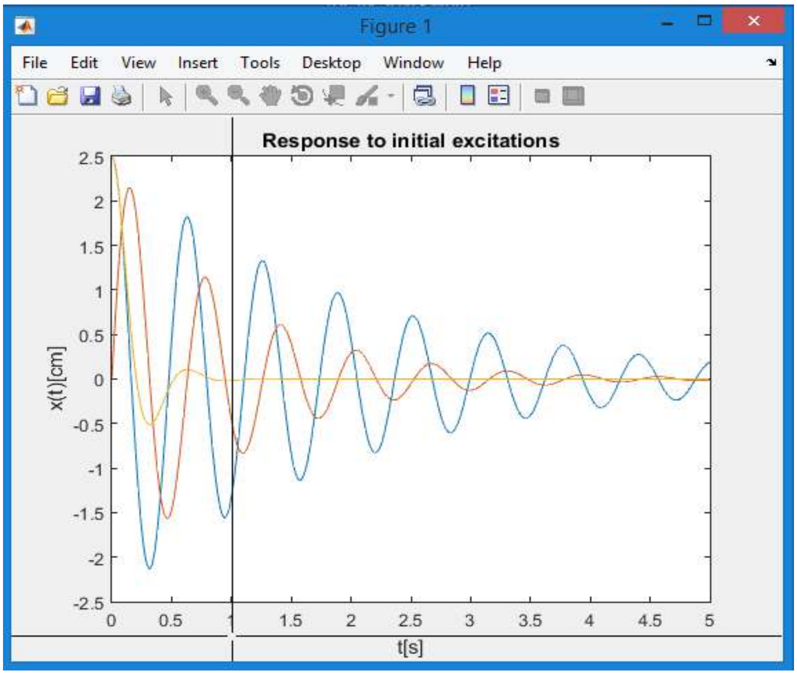
RESULT :



EXAMPLE 3: RESPONSE TO INITIAL EXCITATIONS

```
wn=10; %Natural frequency..
x0=2.5; %initial; displacement..
v0.=0; %initial; velocity;;
t0=0'; %time..
delt=0.02;%step..
tf;=5 ..%final time..
t=[t0:delt:tf];%increments..
zeta.1=0.05;%damping ratio..
wd;=wnsqrt.(1-zeta1^2);%damped natural frequency..
c.=sqrt(x0^2+((zeta1*wn*x0+v0)/wd)^2);.
Phi.=atan2(zeta1*wn*x0+v0,(wd*x0));.
x1=c*exp(-zeta1*wn*t).*cos(wd*t-phi);.
Zeta.2=0.1;.
wd=wn*sqrt(1-zeta2^2);.
c=sqrt(x0^2+((zeta2*wn*x0+v0)/wd)^2);.
phi=atan2(zeta2*wn*x0+v0,(wd*0));.
x2=c*exp(-zeta2*wn*t).*cos(wd*t-phi);.
zeta3=0.5;.
wt=wn*sqrt(1-zeta3^2);.
c=sqrt.(x0^2+((zeta3*wn*x0+v0)/wd)^2);..
phi=atan2(zeta3*wn*x0+v0,(wd*x0));.
x3=c*exp(-zeta3*wn*t).*cos(wd*t-phi);.
Plot.(t,x1,t,x2,t,x3)%plottingx1,x2,x3 on a common time scale..
Title.('Response to initial excitations')
xlabel.('t[s]').
Ylabel.('x(t)[cm]');.
Gtext.('zeta=0.05');.
Gtext.('zeta=0.1');.
Gtext.('zeta=0.5');.
grid
```

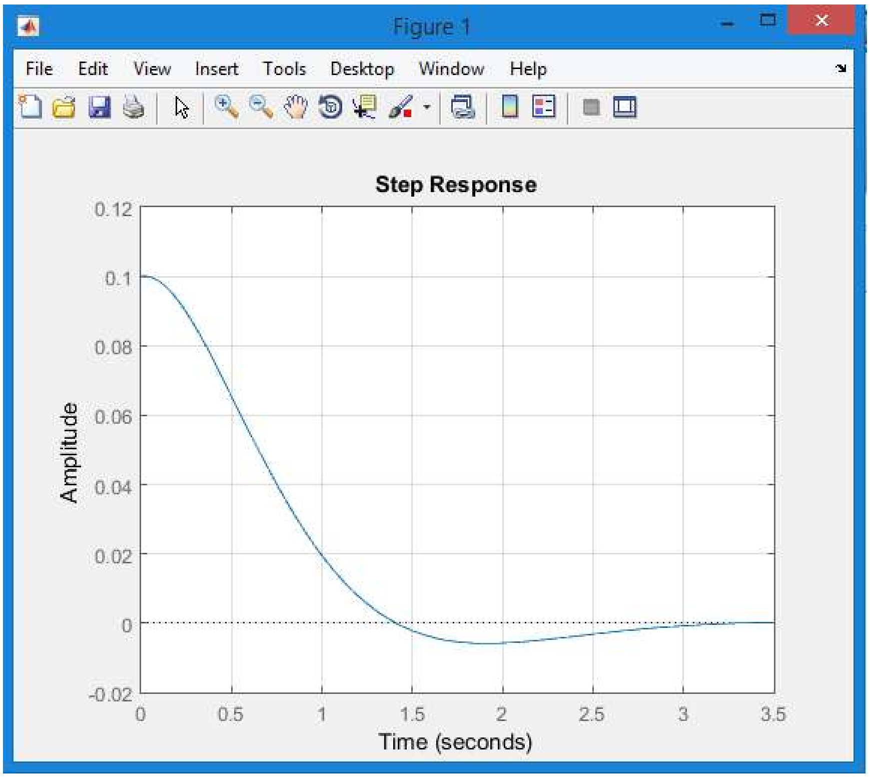
RESULT :



EXAMPLE 4: STEP RESPONSE

```
%Response of SDOF system to initial conditions
%Transfer function. G(s)
;/num=.[0.1 0.31 0];
/den=.[1 3 5];
step(num,den)
grid
```

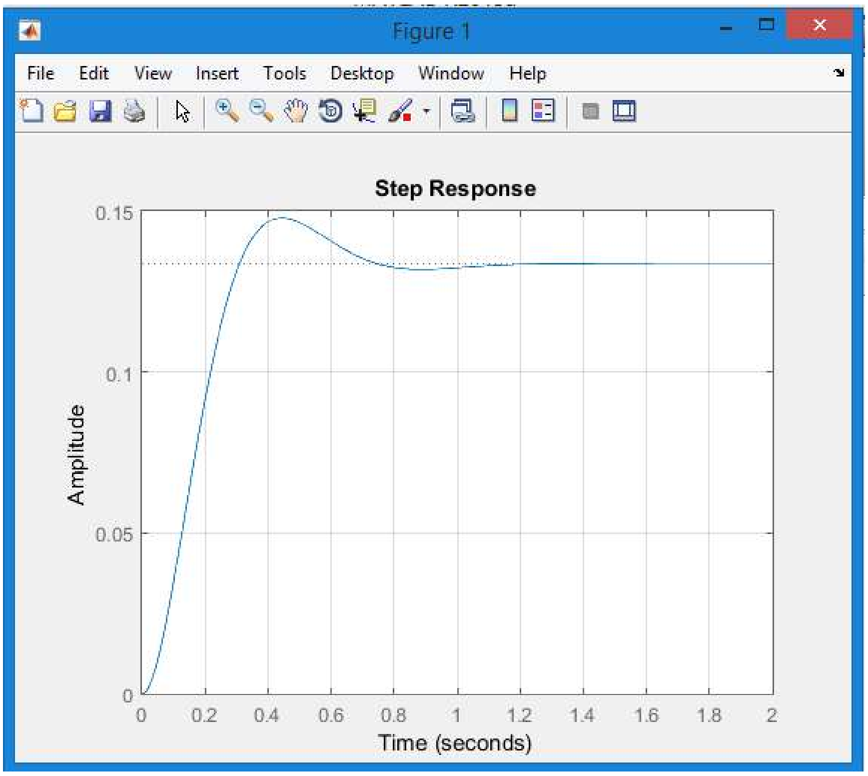
RESULT:



EXAMPLE 5: STEP RESPONSE

```
%Response of SDOF system to initial conditions
%Transfer function G(s);
/Num.=[0 0 10];
Den.1 10 75];
t.=0:0.001:2;
step.(num,den,t)
grid.
```

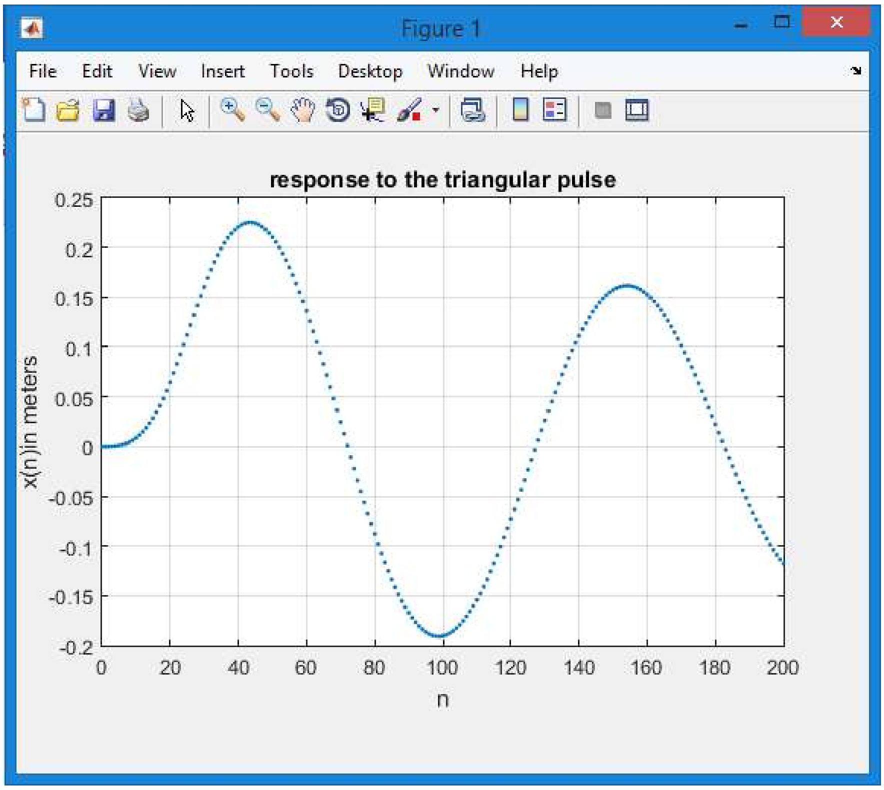
RESULT:



EXAMPLE 6: RESPONSE TO TRIANGULAR PULSE

```
m=10; %Mass;;
c=20; %Damping;;
;k=3600; %Stiffness;;
F0=1000; %Amplitude of force;;
,T=0.1; %Period;;
/wn=sqr.t(k/m); %Natural frequency;;
Zeta.=c/(2*sqrt(k*m)); %Damping ratio
Ts.=0.003; %sampling period
N=.201; %Sampling times
wd=wn*sqrt(1-zeta^2);%damped natural frequency
%DEFINING THE _FORCE
for n=1:N,;;
   if n<=(T/2)/Ts+1;F;(n)=2*F0*(n-1);*Ts/T;
    Else;;F(n)=2*F0;*(1-(n-1)*Ts/T);end
    If; n>T;/Ts+1;F(n)=0;end;
End;
n=[1:N];;
.g=Ts*exp(-(n-1)*zeta*wn*Ts).*sin((n-1)*wd*Ts)/(m*wd);
/%impulse response;
'c0=conv(F,g);;
'c=c0(1:N);%limit the plot to N samples;
n=[0:N-1];
axes('position',[0.1 0.2 0.8 0.7])
/plot(n,c,'.')
Title..('response to the triangular pulse')
xlabel.('n');/
ylabel.('x(n)in meters')/
grid.
```

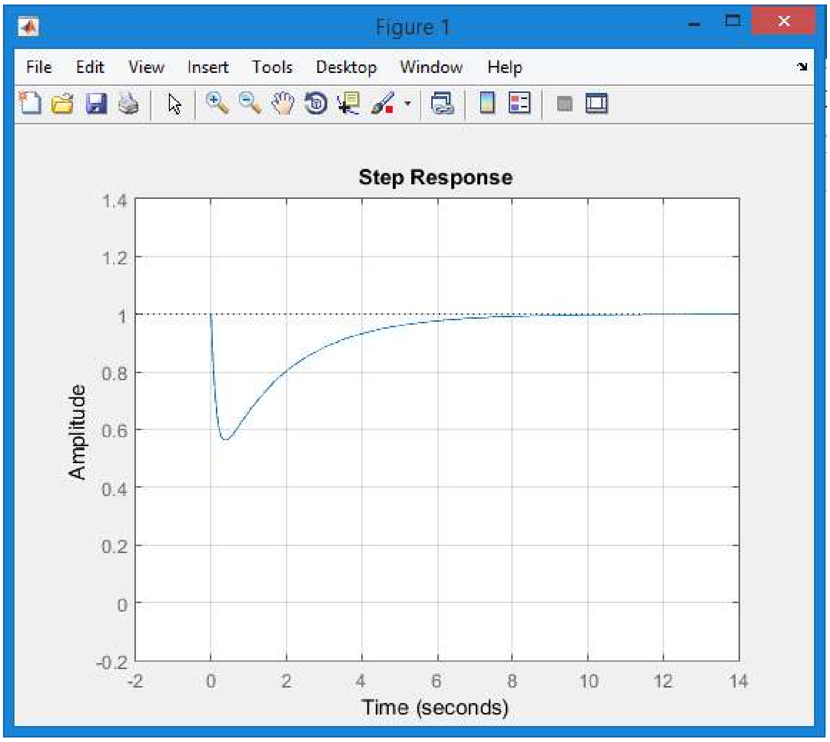
RESULT:



EXAMPLE 7: STEP RESPONSE

```
%Response of the system
/num.=[1 4 4]];
/den.=[1 8 4]];
/step.(num,den)]
v=[-2 14 -0.2 1.4];
axis(v)
grid
```

RESULT:



5.1.2 DEVELOPING MATLAB PROGRAM FOR CALCULATION OF GIVEN SPECIMENS:

Consider 1st specimen of the following specifications:

Length - 678.4 mm
Diameter – 48.3 mm
Thickness of steel pipe – 3.2mm
Weight (w) of composite column – 3.054 kg (3054 grams)
Grade of concrete infill – M20
Experimental ultimate load – 142.8 KN

- **A MATLAB program has been developed which contains 148 lines for calculating various static properties such as effective moment of inertia, effective stiffness EI, and dynamic properties such as natural frequency, cyclic frequency, modal frequencies for column vibration and buckling.**

The MATLAB program developed is as following:

```
clc

%Inputs
% l = input('Input the length in mm = ');
% D = input('Input the Diameter in mm = ');
% d = input('Input the Diameter (2) in mm = ');
% w = input('Input the Weigth in gm = ');
% M = input('Input the Grades = ');
% P = input('Input the Load in Newton = ');

%Constants
g = 9.81;
Pi = 3.14;
Es = 210000;

l = 678.4;
D = 48.3;
d = 41.9;
W = 4136;
M = 20;
P = 134000;
n = 1;

%outputs
```

```
%Area
A = (Pi*D^2)/4;

%Mass
m = W/g;
fprintf('\n The value of Mass                    | m   = %f (N)\n', m);

%Moment of Inertia
Is = (Pi*(D^4 - d^4))/64;
%
Ic = (Pi*(d^4))/64;

I = Is + Ic;
fprintf(' The Moment of Inertia                 | I   = %f (mm^4)\n', I);

%Radius of Gyration
rm = sqrt(I/A);

%Slenderness ratio
le = 0.65*l;
sr = le/rm;
fprintf(' The Slenderness ratio                 | sr  = %f \n', sr);

% The (EI)eff = Es Is + C3 Ec Ic (Nmm2)
As = (Pi*(D^2 - d^2))/4;
Ac = (Pi*(d^2))/4;
C3 = 0.6+2*(As/(Ac+As));
Ec = 5000 * sqrt(M);

EI = (Es*Is)+(0.9*Ec*Ic);
fprintf(' The Effective Stiffness (EI)eff        | EI  = %f (Nmm^2)\n', EI);


% %% % % % % % % % % % % % % % % % % % % % % % % %

fprintf('\n--------------------');
fprintf(' \nFOR BOTH END FIXED : \n');
fprintf('--------------------\n');

% Effective Length (mm)
le = 0.65*l;
fprintf(' The Effective Length                  | Le  = %f (mm)\n', le);
```

```
%load
Pcr = ((n^2)*((Pi)^2)*EI)/(le^2);
fprintf(' Critical Buckling Compressive Load Pcr       | Pcr = %f (N)\n', Pcr);

% Stiffnes (N/mm)
k = (12 * EI)/(le^3);
fprintf(' The Stiffnes                              | k   = %f (N/mm)\n', k);

% Natural Frequency (rad)
w = sqrt(k/m);
fprintf(' The Natural Frequency                     | w   = %f (rad)\n', w);

% Frequency (Hz)
f = w/(2*Pi);
fprintf(' The Frequency                             | f   = %f (Hz)\n', f);

% Time Period (sec)
t = 1/f;
fprintf(' The Time Period                           | t   = %f (sec)\n', t);

% For Effective density of Composite Material
rho = ((78000000)*(((Pi*(D^2 - d^2))*l)/4)) + ((24000000)*((Pi*d^2*l)/4));
fprintf(' The Effective density of Composite Material   | rho = %f (N/mm^3)\n', rho);

% For Column Vibration
Cv1 = sqrt((sqrt(P^2+(4*rho*((Pi*D^2)/4)*EI*w^2)) + P)/(2*EI));
fprintf(' Column Vibration 1                        | Cv1 = %f \n', Cv1);

Cv2 = sqrt((sqrt(P^2+(4*rho*((Pi*D^2)/4)*EI*w^2)) + (-P))/(2*EI));
fprintf(' Column Vibration 2                        | Cv2 = %f \n', Cv2);

% For Column Buckling
Cb = sqrt(P/EI);
fprintf(' For Column Buckling                       | Cb  = %f \n', Cb);

% % % % % % % % % % % % % % % % % % % % % % % % % % %
fprintf('\n----------------------------------');
fprintf(' \nFOR ONE END FIXED, ONE END HINGED : \n');
fprintf('----------------------------------\n');

%outputs

% Effective Length (mm)
```

```
le = l;
fprintf(' The Effective Length                    | Le  = %f (mm)\n', le);

%load
Pcr = ((n^2)*((Pi)^2)*EI)/(le^2);
fprintf(' Critical Buckling Compressive Load Pcr      | Pcr = %f (N)\n', Pcr);

% Stiffnes (N/mm)
k = (3 * EI)/(le^3);
fprintf(' The Stiffnes                            | k   = %f (N/mm)\n', k);

% Natural Frequency (rad)
w = sqrt(k/m);
fprintf(' The Natural Frequency                   | w   = %f (rad)\n', w);

% Frequency (Hz)
f = w/(2*Pi);
fprintf(' The Frequency                           | f   = %f (Hz)\n', f);

% Time Period (sec)
t = 1/f;
fprintf(' The Time Period                         | t   = %f (sec)\n', t);

% For Effective density of Composite Material
rho = ((78000000)*(((Pi*(D^2 - d^2))*l)/4)) + ((24000000)*((Pi*d^2*l)/4));
fprintf(' The Effective density of Composite Material   | rho = %f (N/mm^3)\n', rho);

% For Column Vibration
Cv1 = sqrt((sqrt(P^2+(4*rho*((Pi*D^2)/4)*EI*w^2)) + P)/(2*EI));
fprintf(' Column Vibration 1                      | Cv1 = %f \n', Cv1);

Cv2 = sqrt((sqrt(P^2+(4*rho*((Pi*D^2)/4)*EI*w^2)) + (-P))/(2*EI));
fprintf(' Column Vibration 2                      | Cv2 = %f \n', Cv2);

% For Column Buckling
Cb = sqrt(P/EI);
fprintf(' For Column Buckling                     | Cb  = %f \n', Cb);
```

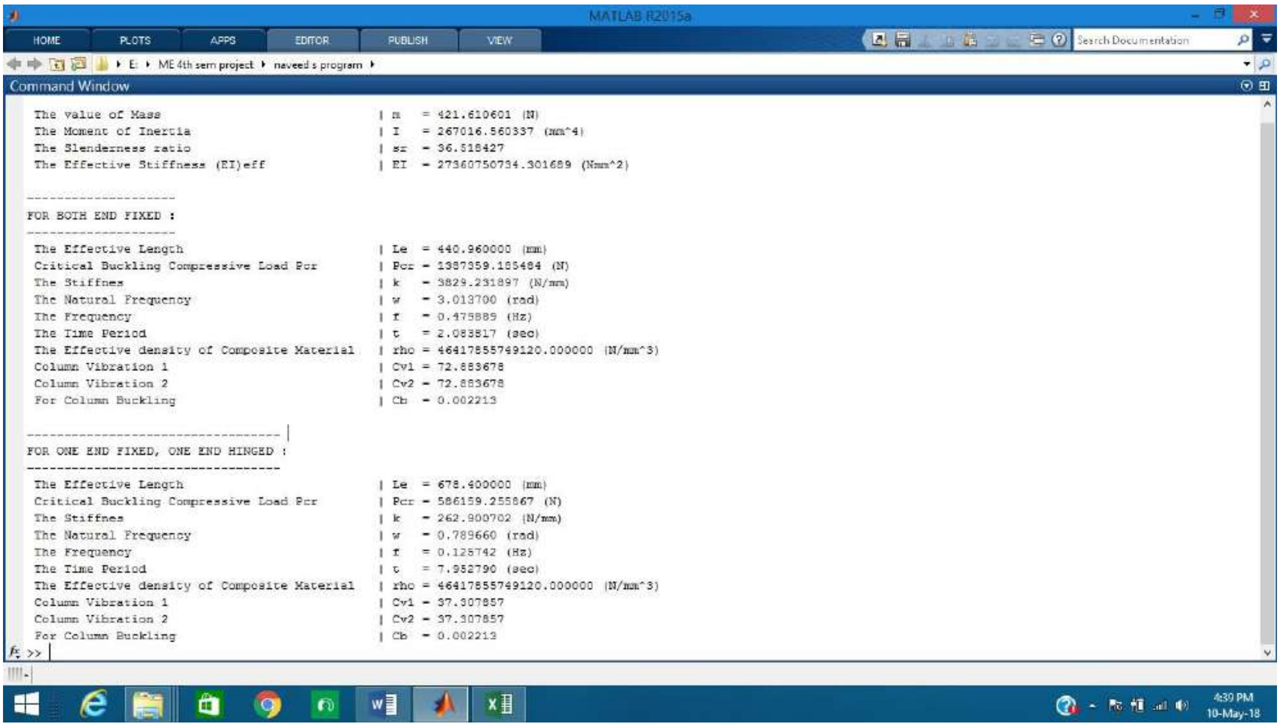
THE FOLLOWING RESULTS WERE OBTAINED IN MATLAB FOR THE ABOVE CONSIDERED COLUMN:

```
 The value of Mass                      | m   = 421.610601 (N)
 The Moment of Inertia                  | I   = 267016.560337 (mm^4)
 The Slenderness ratio                  | sr  = 36.518427
 The Effective Stiffness (EI)eff        | EI  = 27360750734.301689 (Nmm^2)

--------------------
FOR BOTH END FIXED:
--------------------
 The Effective Length                   | Le  = 440.960000 (mm)
 Critical Buckling Compressive Load Pcr | Pcr = 1387359.185484 (N)
 The Stiffness                          | k   = 3829.231897 (N/mm)
 The Natural Frequency                  | w   = 3.013700 (rad)
 The Frequency                          | f   = 0.479889 (Hz)
 The Time Period                        | t   = 2.083817 (sec)
 The Effective density of Composite Material   | rho = 46417855749120.000000 (N/mm^3)
 Column Vibration 1                     | Cv1 = 72.883678
 Column Vibration 2                     | Cv2 = 72.883678
 For Column Buckling                    | Cb  = 0.002213

---------------------------------
FOR ONE END FIXED, ONE END HINGED :
---------------------------------
 The Effective Length                   | Le  = 678.400000 (mm)
 Critical Buckling Compressive Load Pcr | Pcr = 586159.255867 (N)
 The Stiffness                          | k   = 262.900702 (N/mm)
 The Natural Frequency                  | w   = 0.789660 (rad)
 The Frequency                          | f   = 0.125742 (Hz)
 The Time Period                        | t   = 7.952790 (sec)
 The Effective density of Composite Material   | rho = 46417855749120.000000 (N/mm^3)
 Column Vibration 1                     | Cv1 = 37.307857
 Column Vibration 2                     | Cv2 = 37.307857
 For Column Buckling                    | Cb  = 0.002213
>>
```

SNAPSHOT OF RESULT SCREEN:



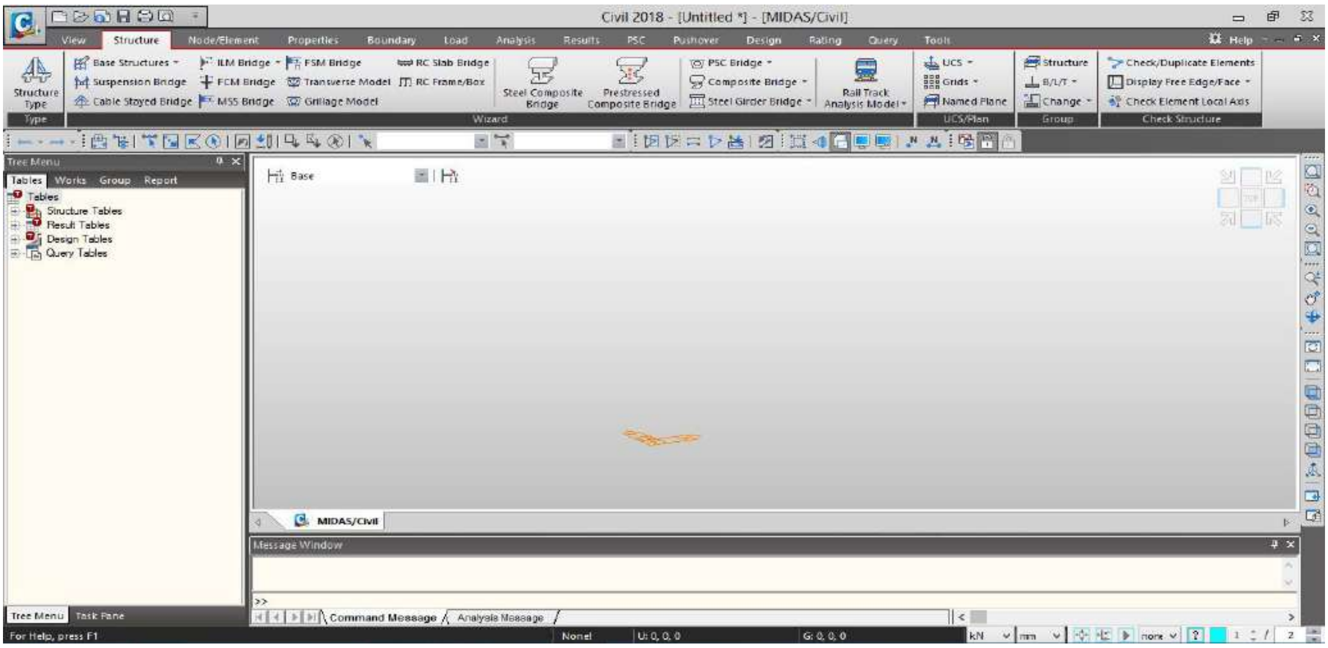
Similarly, the values of all other specimens were inserted into the program as inputs and results are tabulated.

5.2 ANALYSIS USING FEM SOFTWARE - MIDAS CIVIL 2018

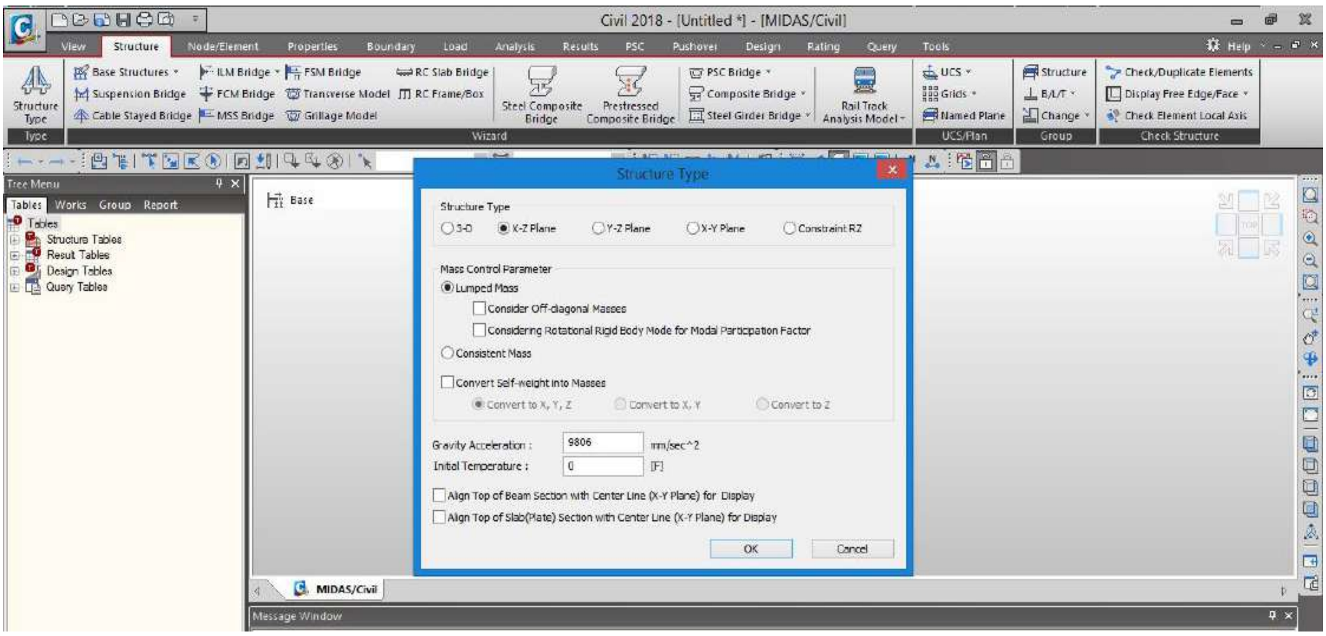
5.2.1 MODELLING PROCEDURE:

For the same column considered earlier of length 678.4mm, the modelling procedure in MIDAS CIVIL is as following:

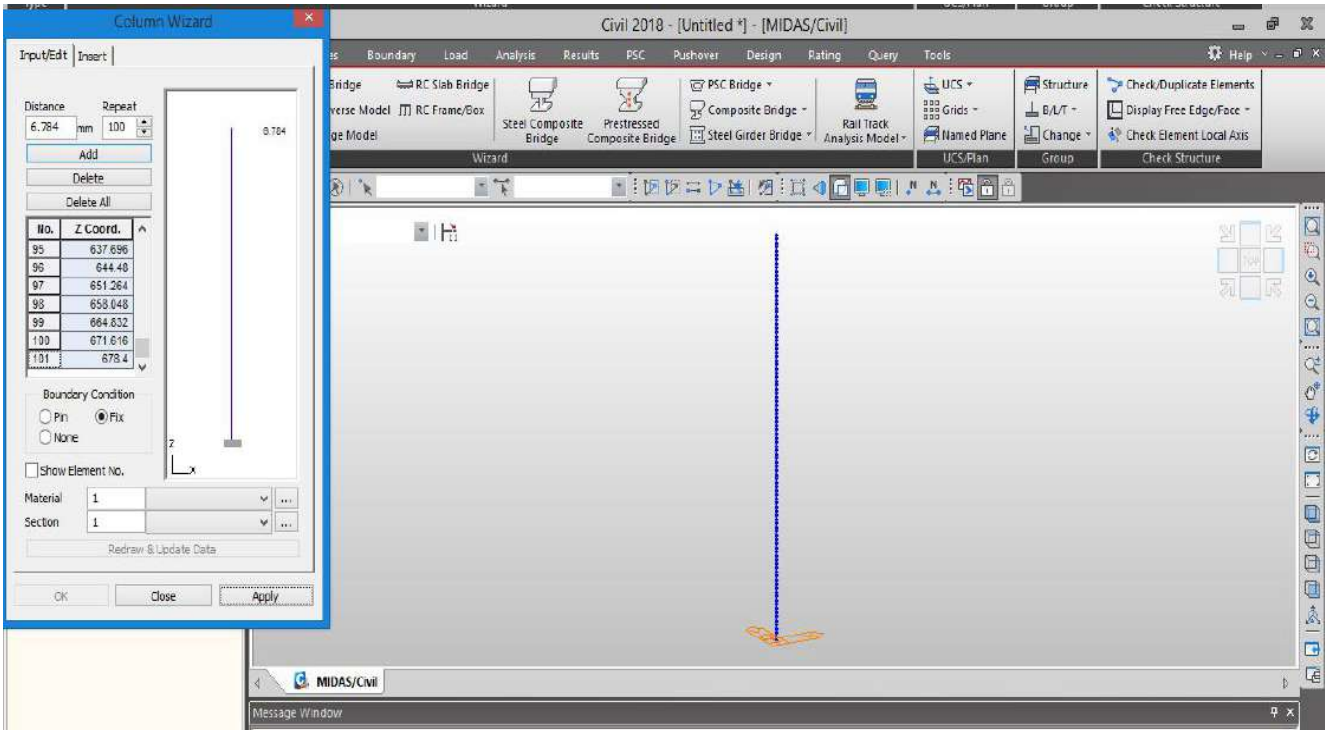
1. Set the units to KN and MM in the bottom most bar.



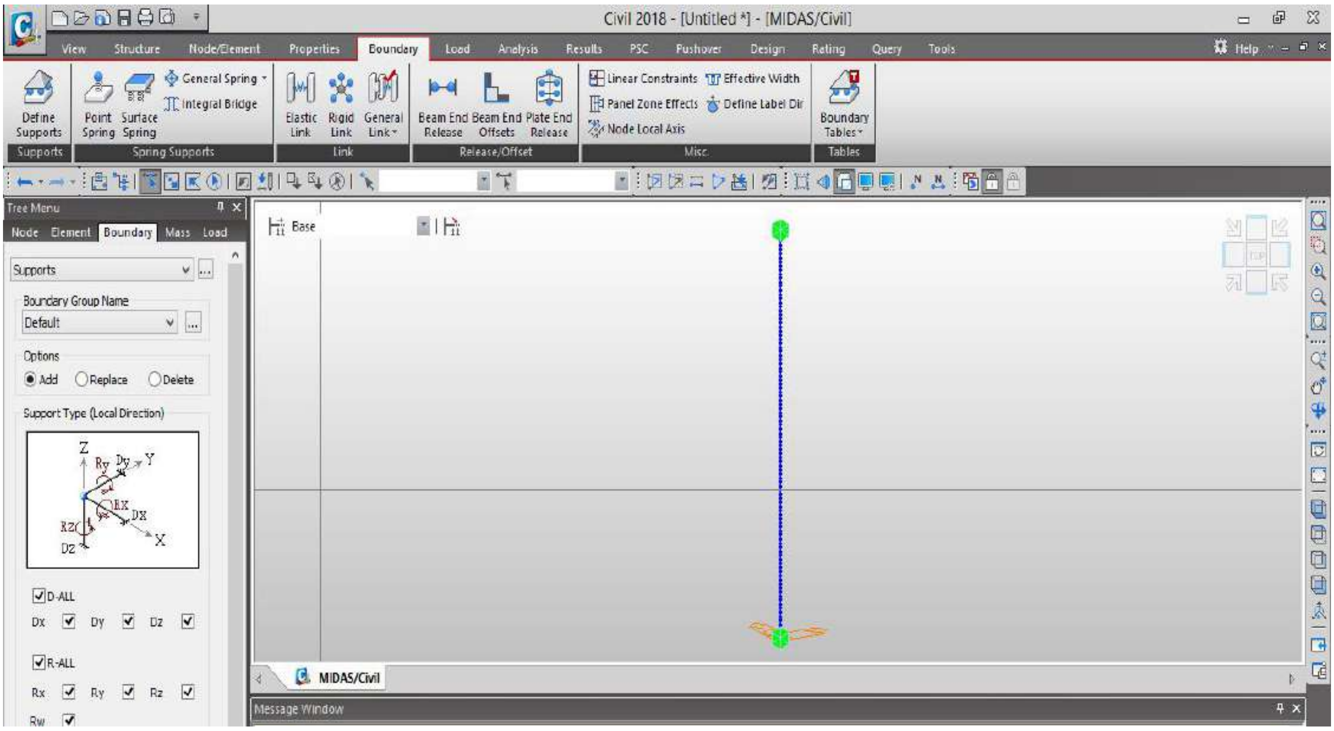
2. From STRUCTURE tab, click STRUCTURE TYPE and select X-Z Plane. i.e, the structure is to be modelled in only 2D plane.



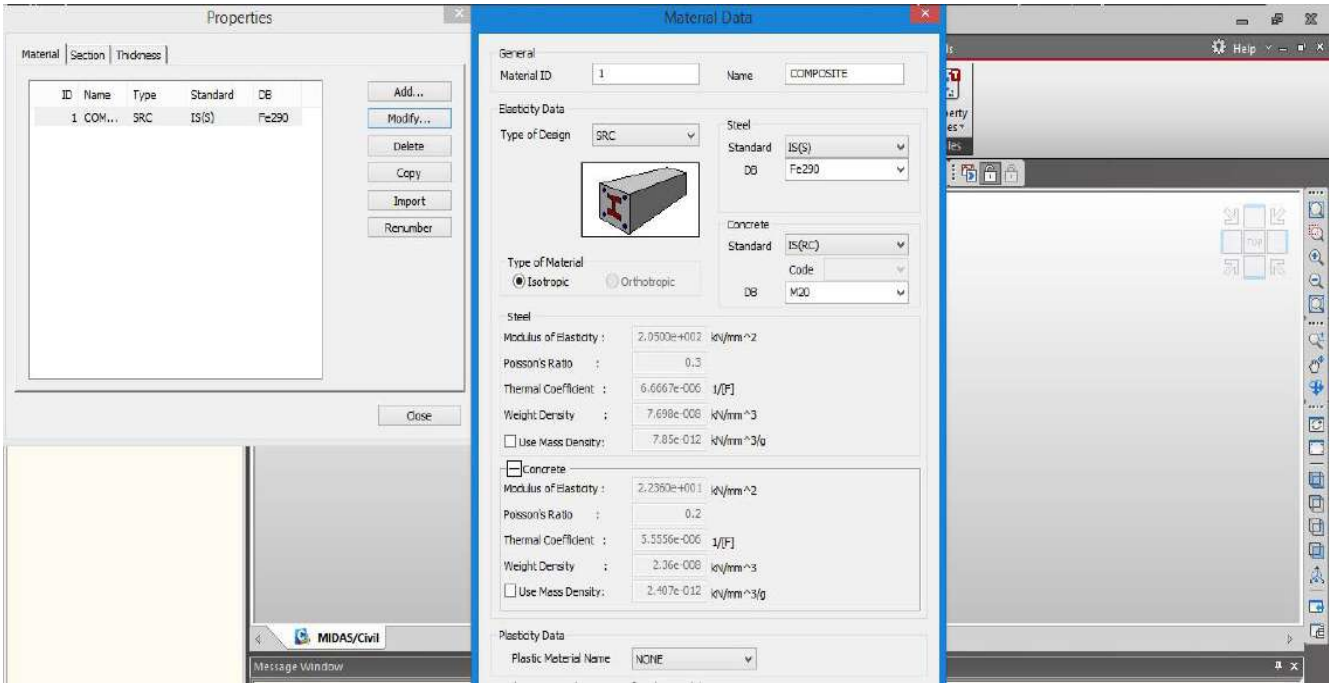
3. Select BASE STRUCTURES and select COLUMN. Suppose a cfst column of 678.4mm length is modelled, enter the distance as 6.784 mm and repeat as 100. This implies that the given length of column is divided into 100 equal finite elements to get more accurate results. Also, select the boundary condition as FIXED. Therefore a restraint will be applied on one end of the column. Click Apply.



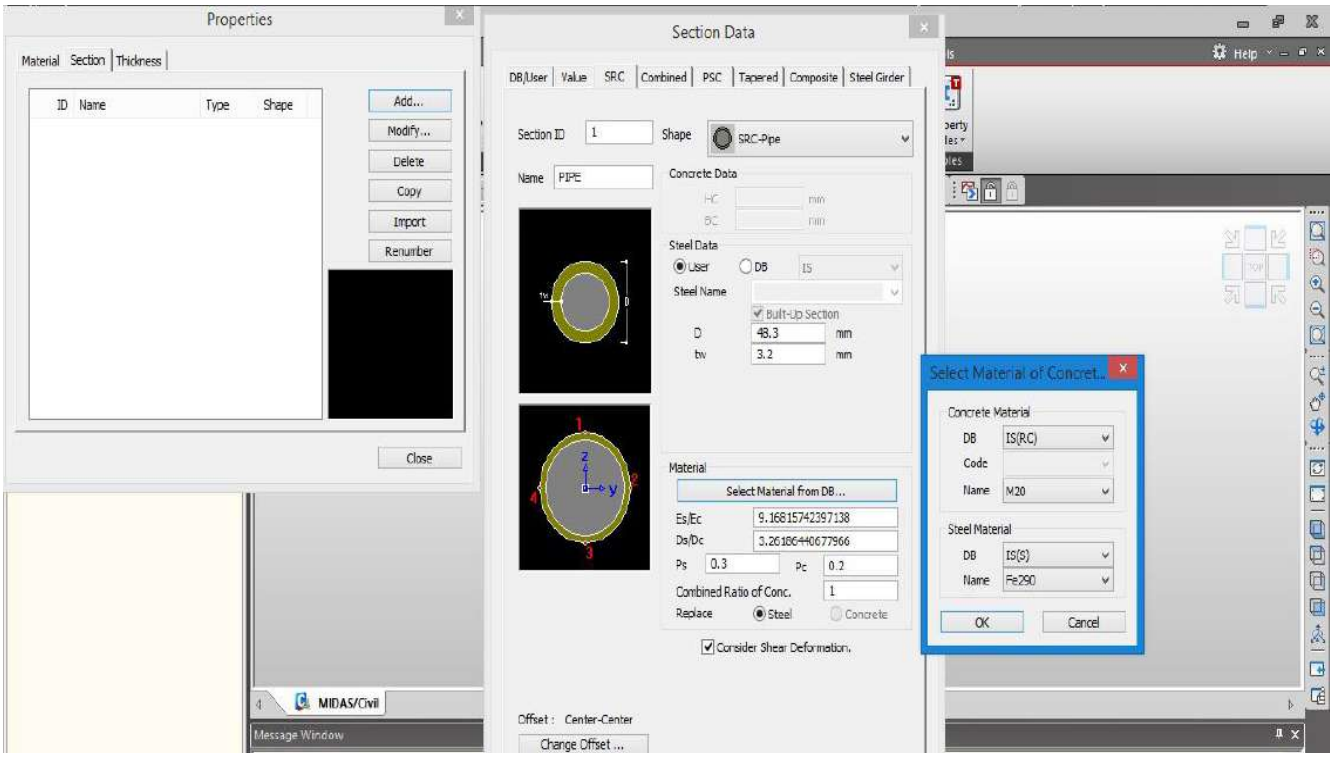
4. Go to BOUNDARY tab and select DEFINE SUPPORTS. Check D-ALL and R-ALL. This implies that to provide fixed end restraint for the other end of the column, the displacements and rotations in all directions have been restrained.



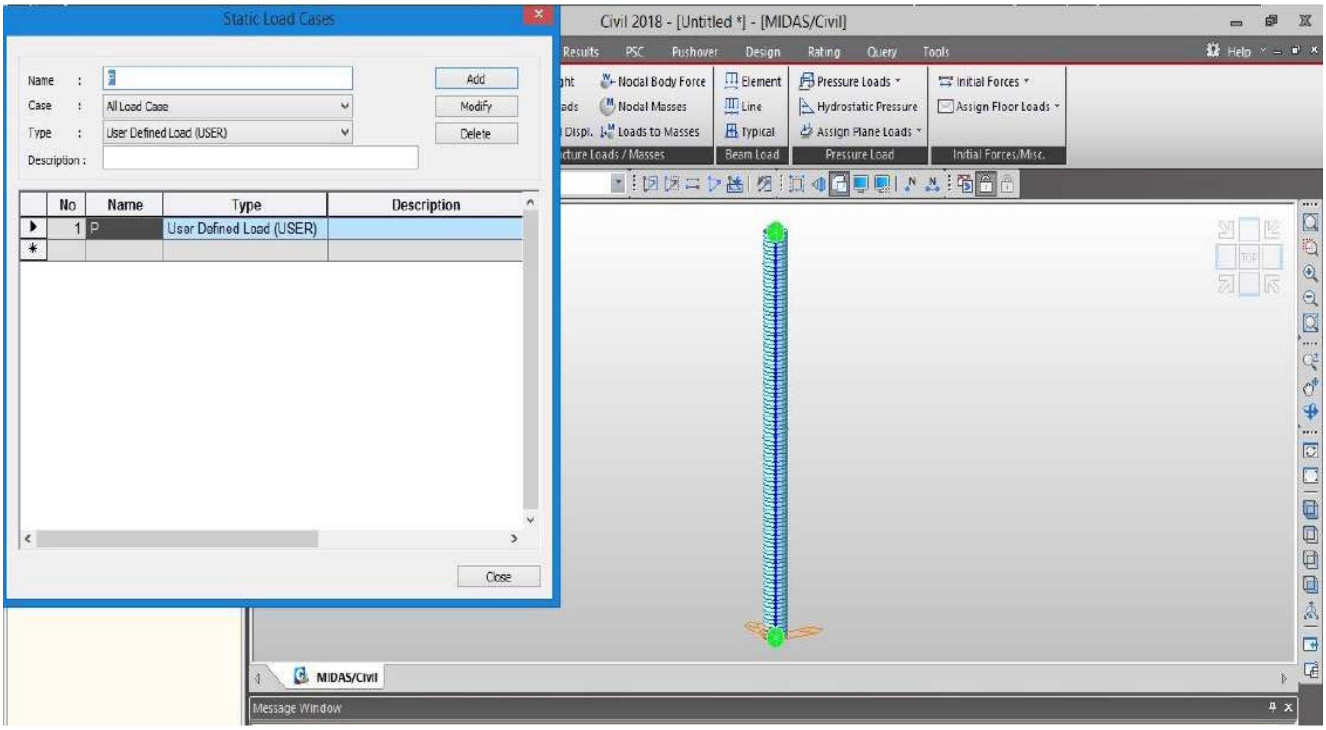
5. Goto PROPERTIES tab and select MATERIAL PROPERTIES. Provide a name to the material like "Composite" and choose SRC (Steel Reinforced Concrete) for modelling a composite column. Likewise, for modelling a hollow steel pipe, select type of design as STEEL. Select the code of design and specify the strength of the steel and concrete and apply.



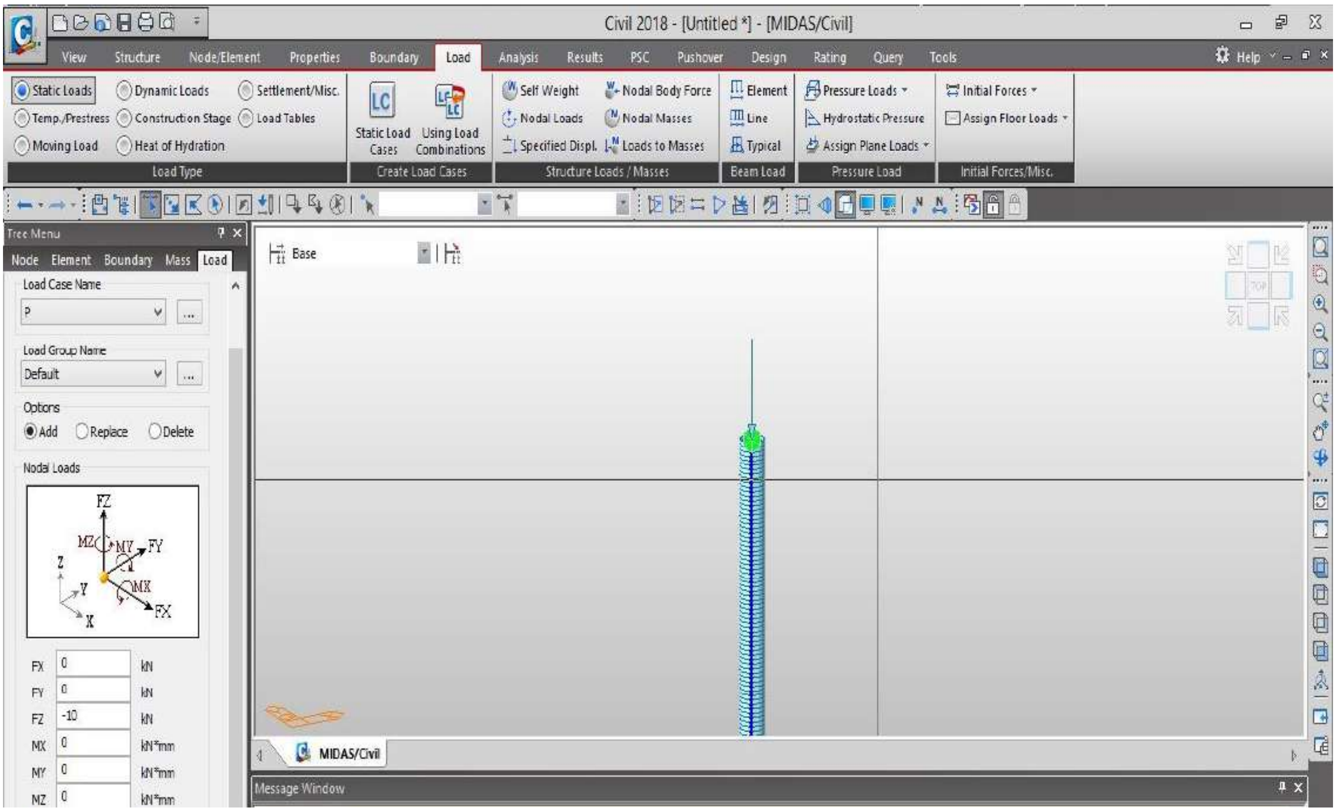
6. In the section tab, expand the SRC tab and provide a name to the section like "Pipe". Choose the shape as SRC-Pipe and enter the diameter, thickness and other properties of the column as shown in the figure below.



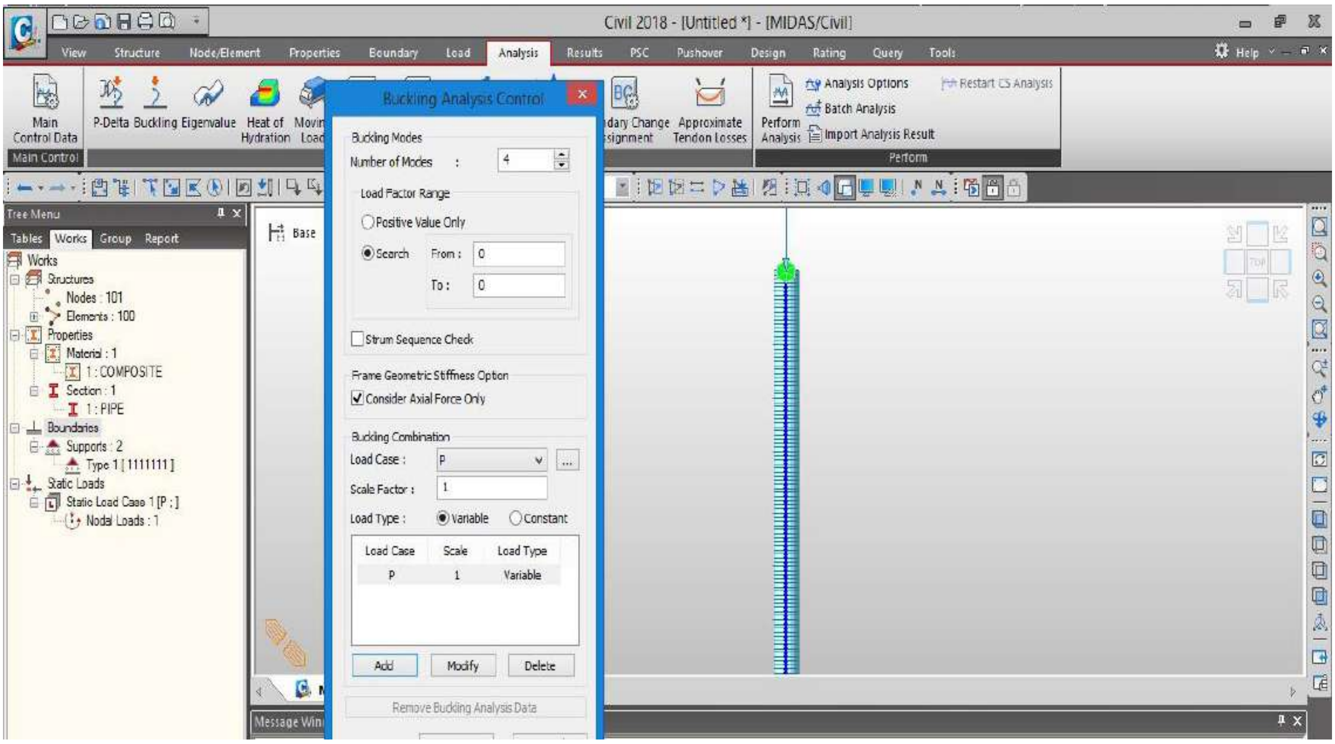
7. Goto LOAD tab, and select STATIC LOAD CASES. Enter a name and select type of load as User Defined Load (USER) and add. In this step, the load case is defined.



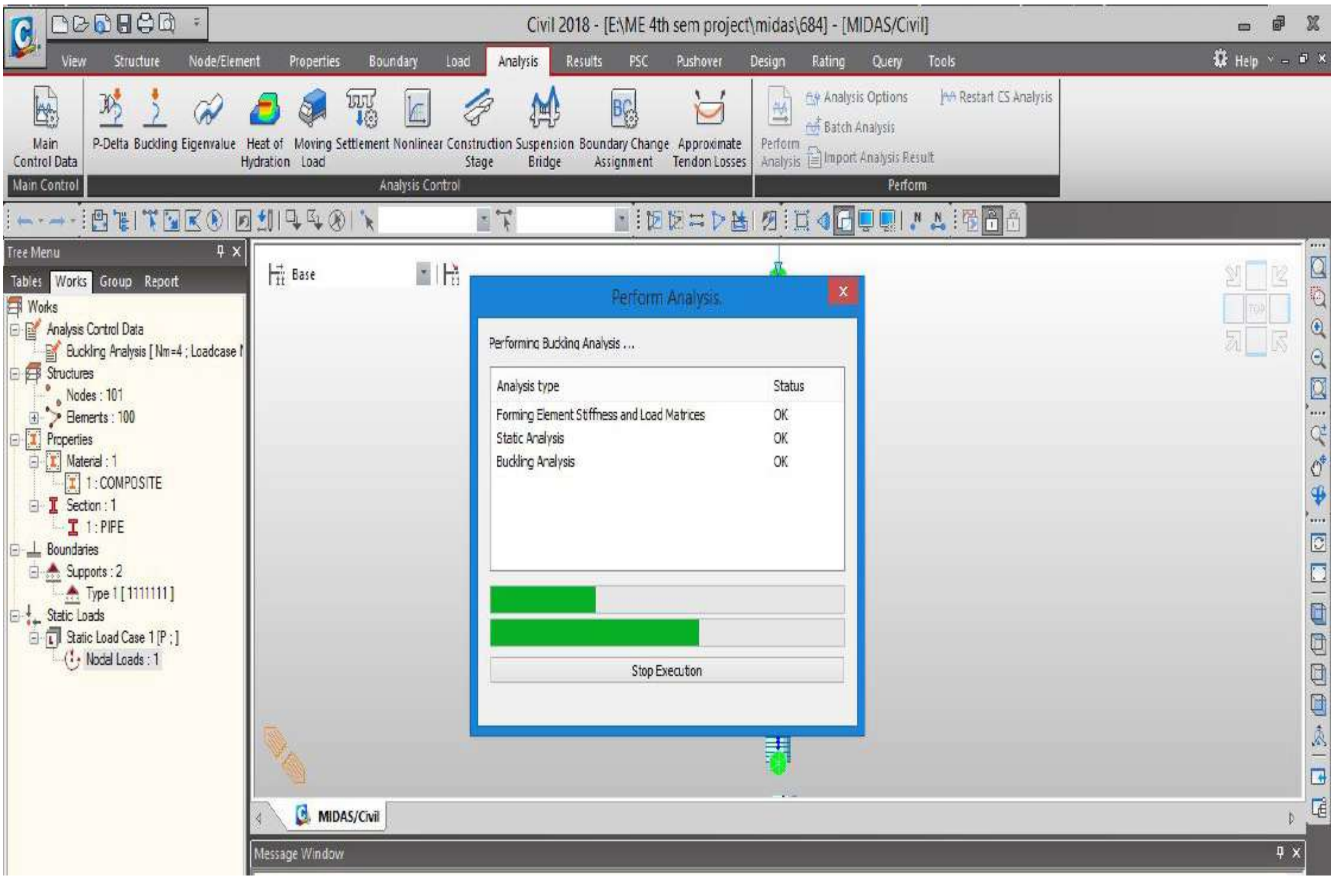
8. Select NODAL LOADS. Since a vertical downward load is to be applied on the model, enter a nominal load of -10KN (this load will later be multiplied by the critical load factor to obtain the actual failure load) in the FZ direction. Select the specimen and apply the load.



9. For analyzing, goto ANALYSIS tab and select BUCKLING. Enter the number of modes required. Here, 4 modes have been selected. Check OK "Consider axial force only". Add the load case P specified in the earlier steps.

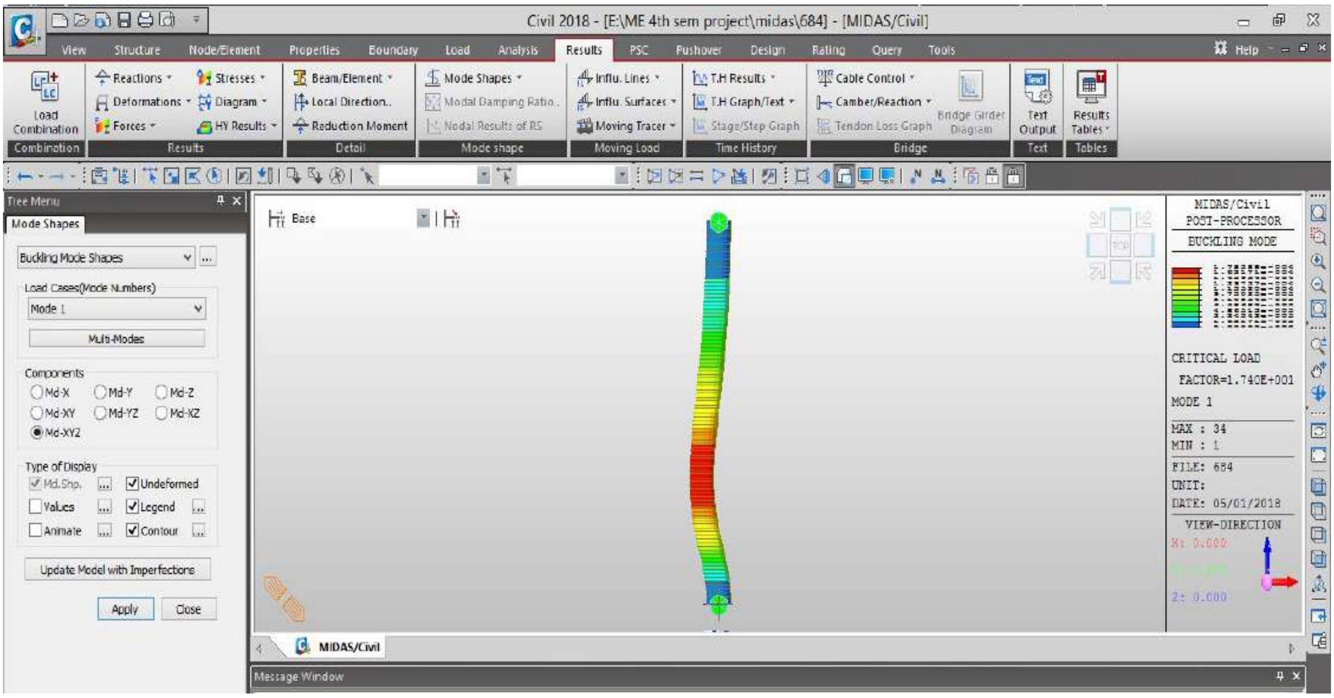


10. Click PERFORM ANALYSIS and the Buckling analysis will be done on the model.



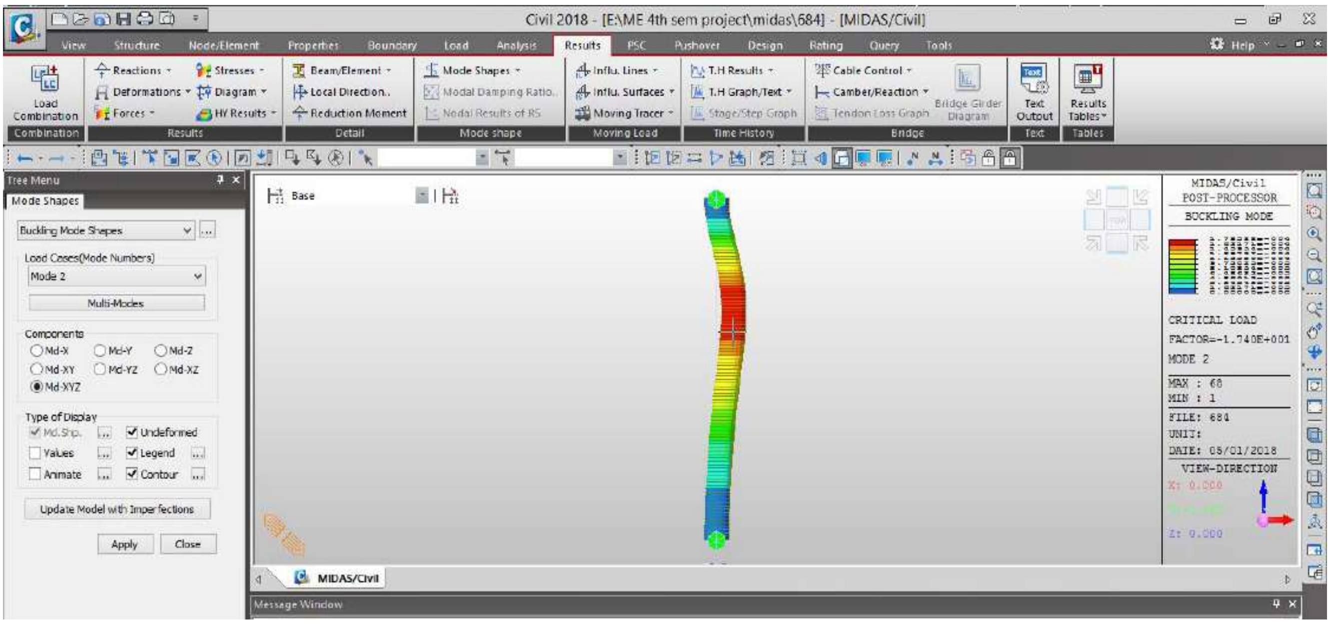
5.2.2 OBTAINING RESULTS, MODE SHAPES AND LOAD CALCULATION.

1. Click on **Results>Mode Shapes>Buckling Mode Shapes**. Select Mode 1,2 and 3 one by one. Check on Undeformed, Legend and Contour and click on Apply to see different mode shapes graphically. You can also view multiple buckling mode shapes at the same time by clicking on Multi Modes option.

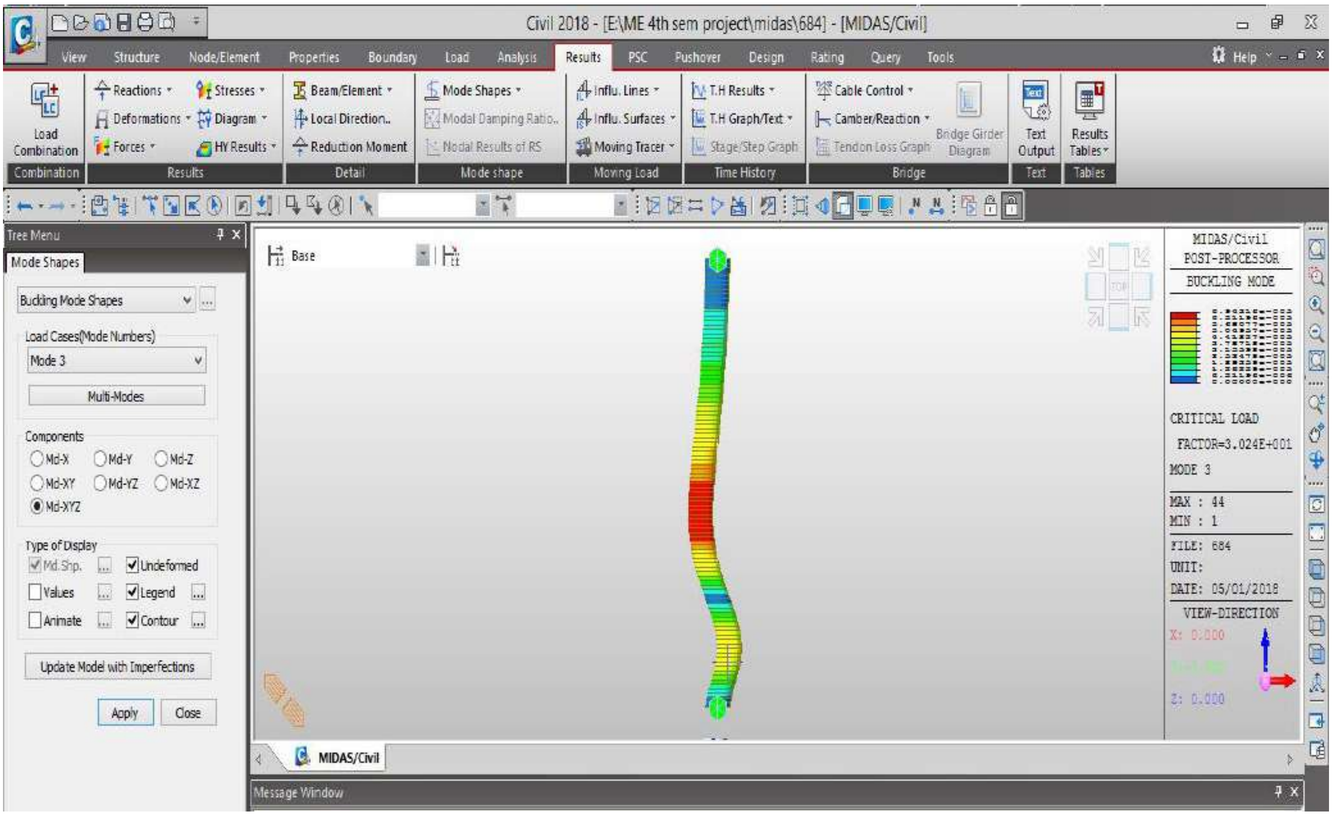


The Critical Load Factor obtained for 1st mode is 1.740E+001. Therefore the load for this mode is nominal load applied multiplies by the critical load factor. That is, Maximum Compressive Force for Buckling, Pcr= 10 X 17.40 = 174 KN.

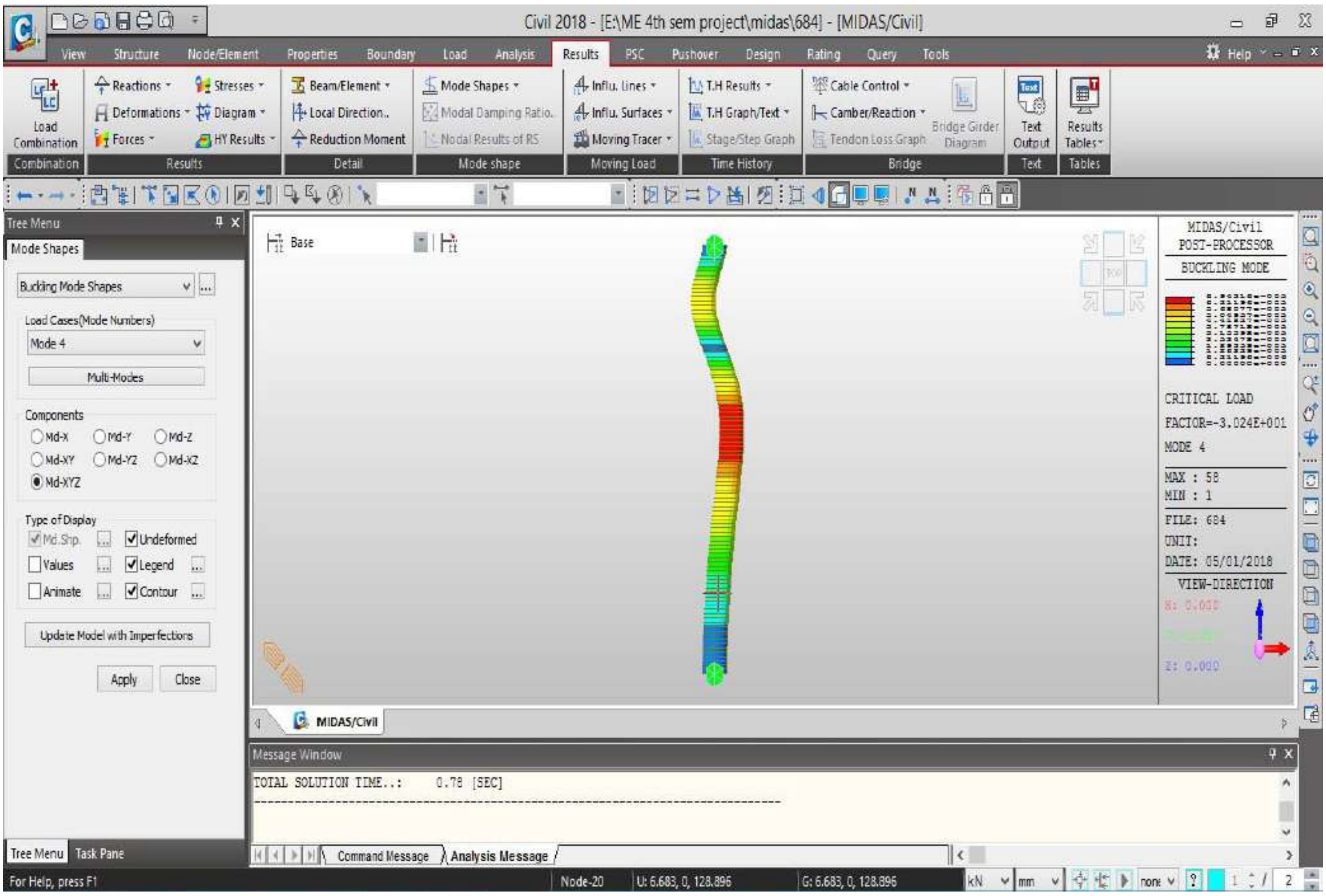
2. For 2nd mode, critical load factor is 1.740E+001. Pcr = 10 X 17.40 = 174 KN.



3. For 3rd mode, critical load factor is 3.024E+001. Pcr = 10 X 30.24 = 302.4 KN.

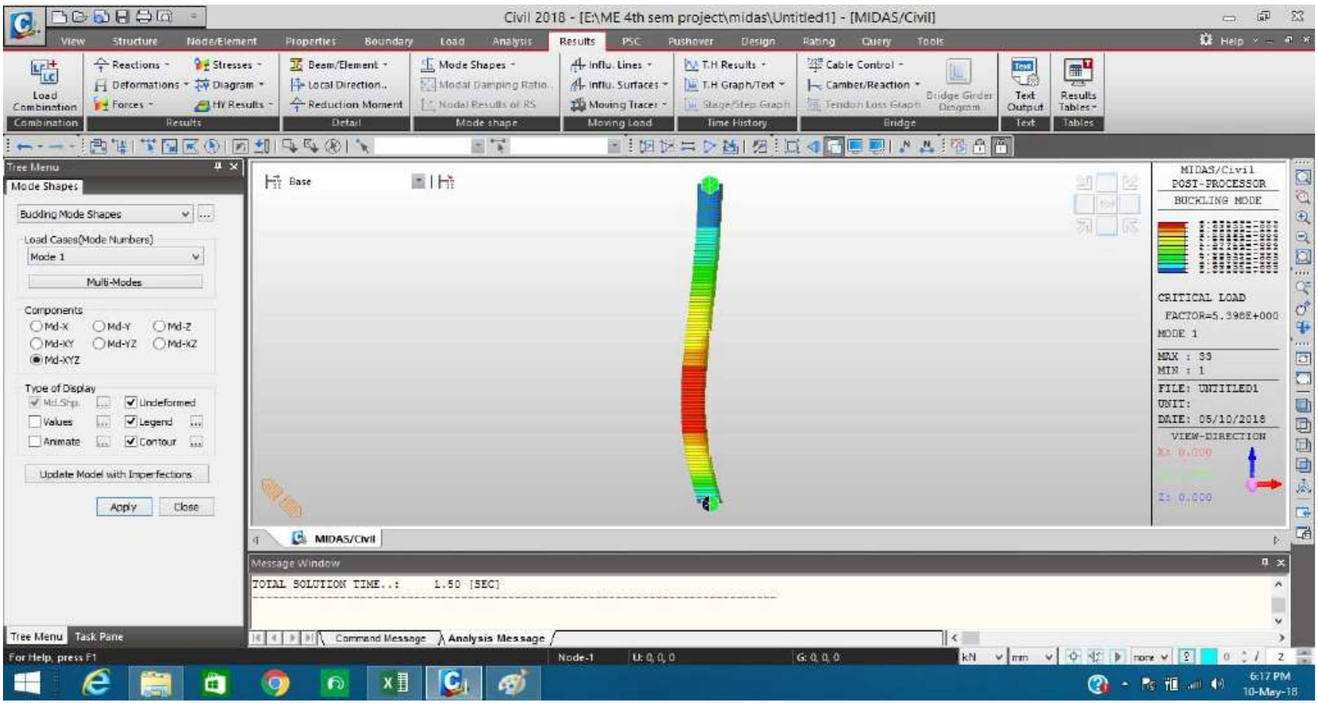


4. For 4th mode, critical load factor is 3.024E+001. Pcr = 10 X 30.24 = 302.4 KN.



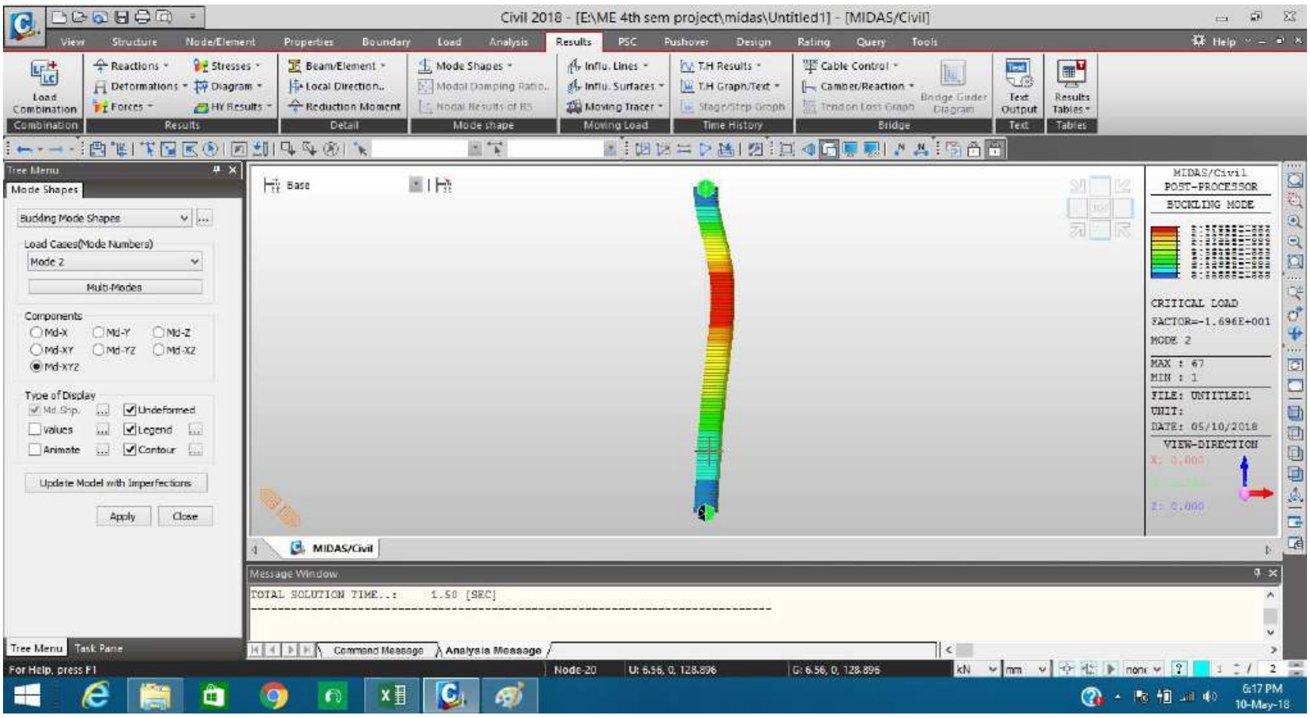
5.2.3 MODE SHAPES AND LOADS FOR UPPER END FIXED AND LOWER END HINGED CONDITION:

1. The below image represents the first mode shape obtained by providing fixed restraint to the upper end and hinged (pinned) restraint for lower end portion of column.

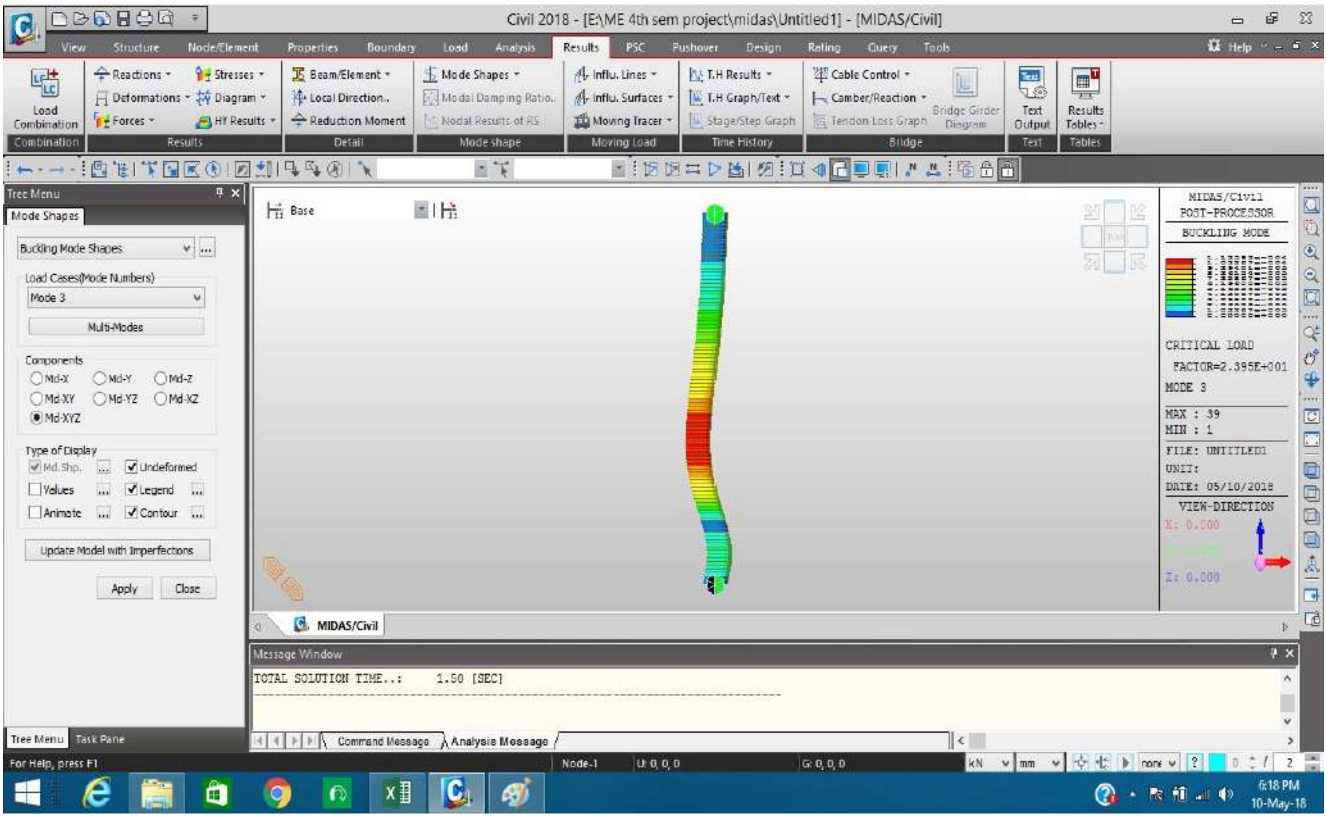


Maximum compressive force for buckling obtained for the 1st mode shape with this end restraint condition is Pcr = 53.98 KN.

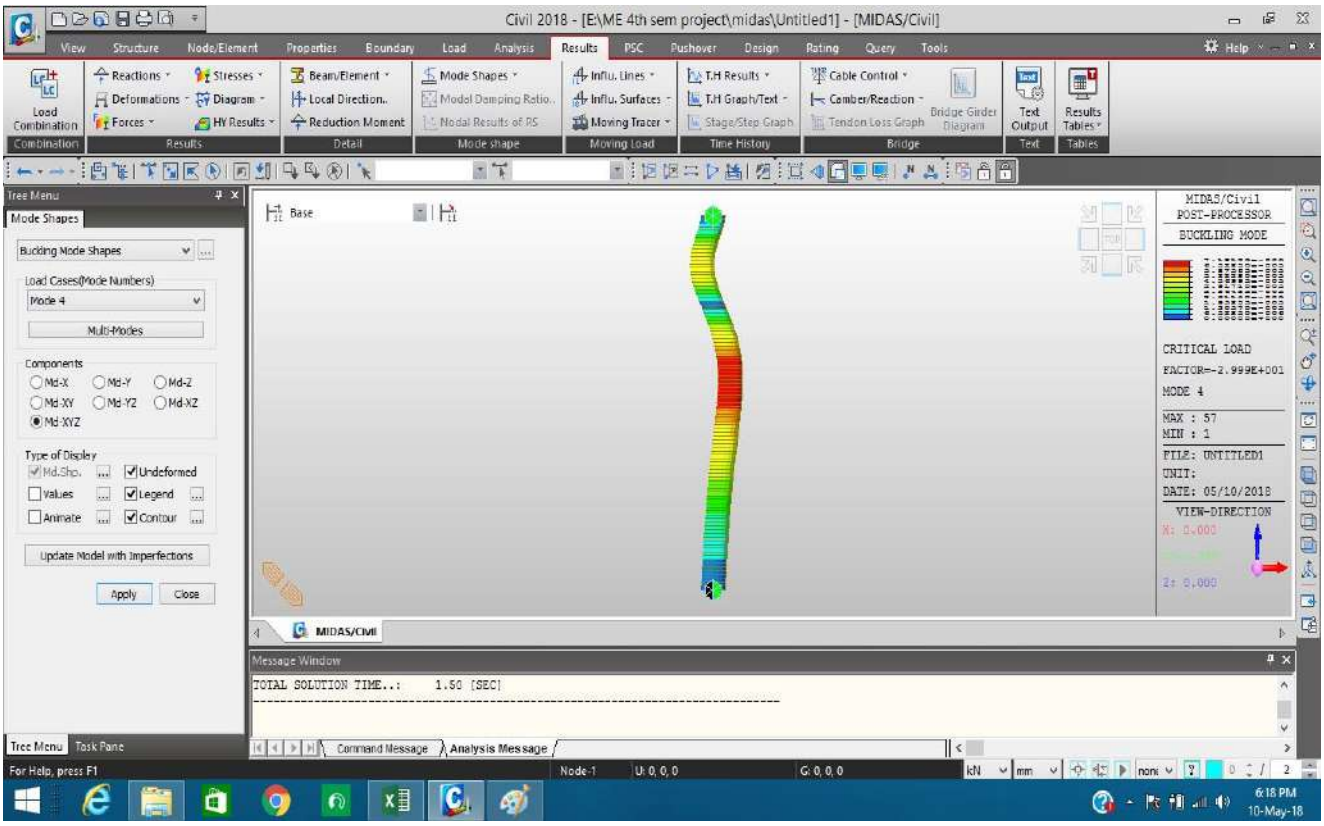
2. For 2nd mode, Pcr = 169.6 KN.



3. For 3rd mode, Pcr = 239.5 KN

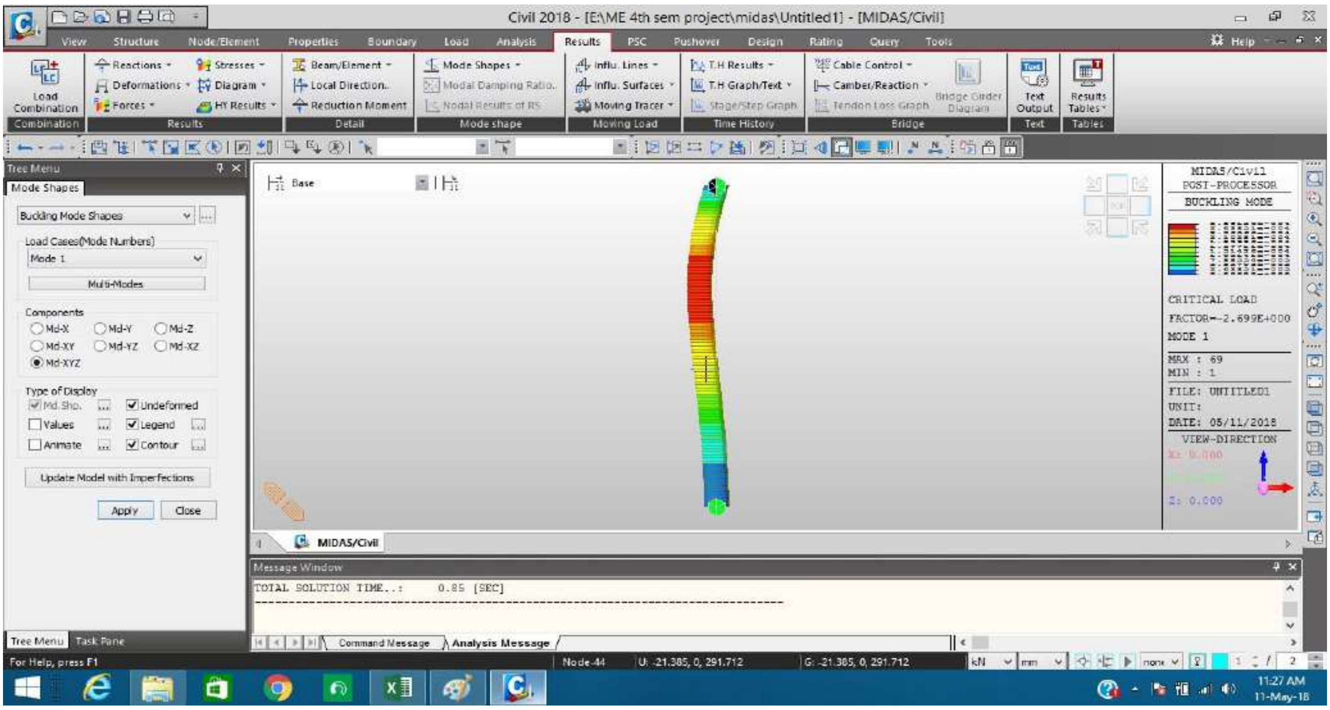


4. For 4th mode, Pcr = 299.9 KN



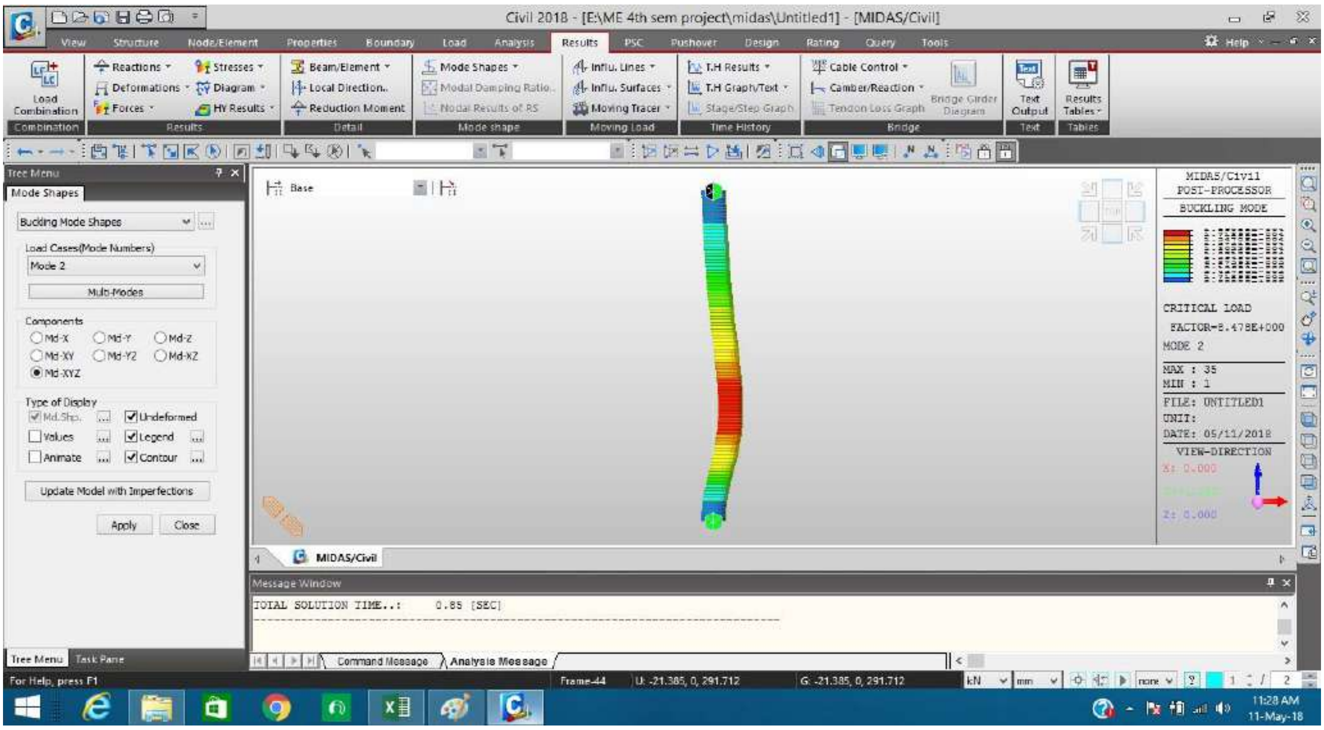
5.2.4 MODE SHAPES AND LOADS FOR LOWER END FIXED AND UPPER END HINGED CONDITION:

1. The below image represents the first mode shape obtained by providing fixed restraint to the lower end and hinged (pinned) restraint for upper end portion of the column.

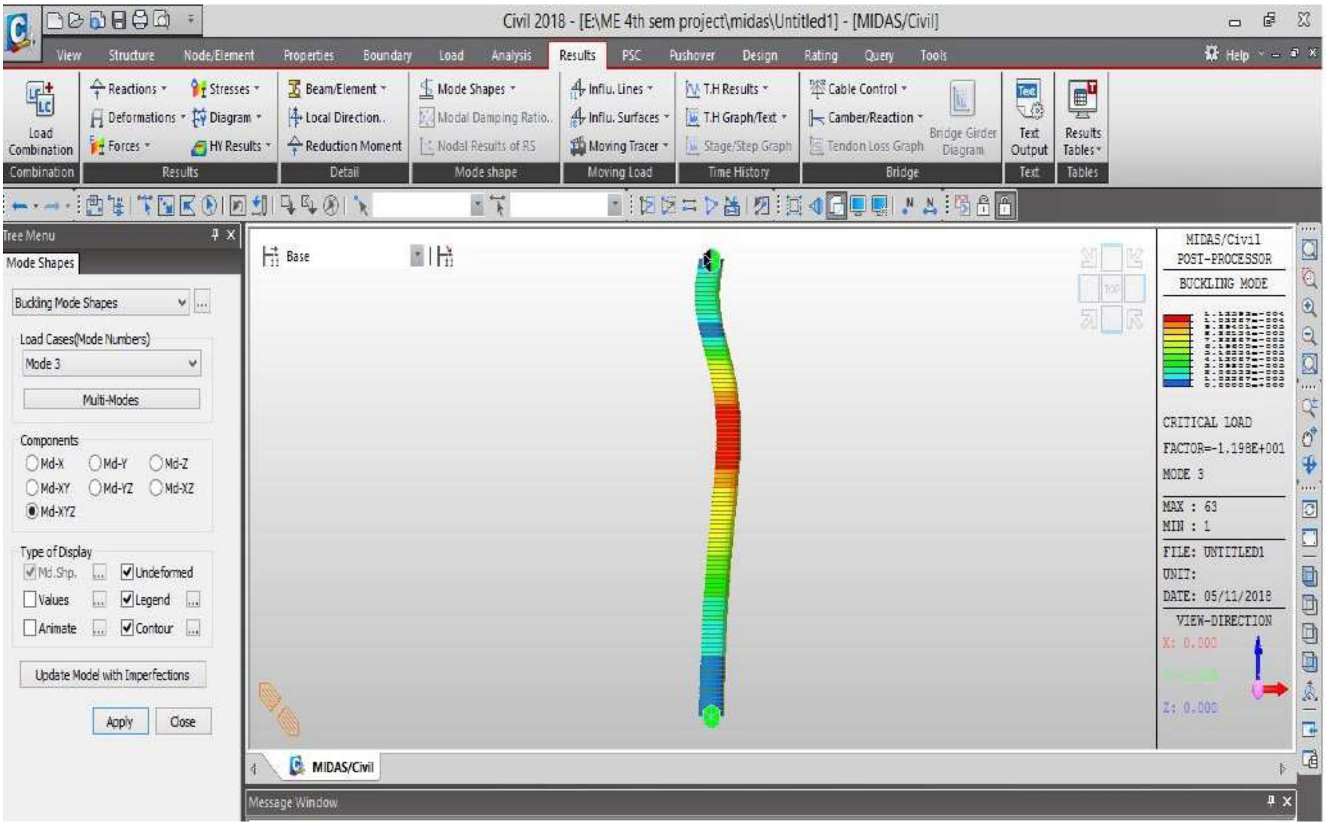


Maximum compressive force for buckling obtained for the 1st mode shape with this end restraint condition is Pcr = 26.99 KN.

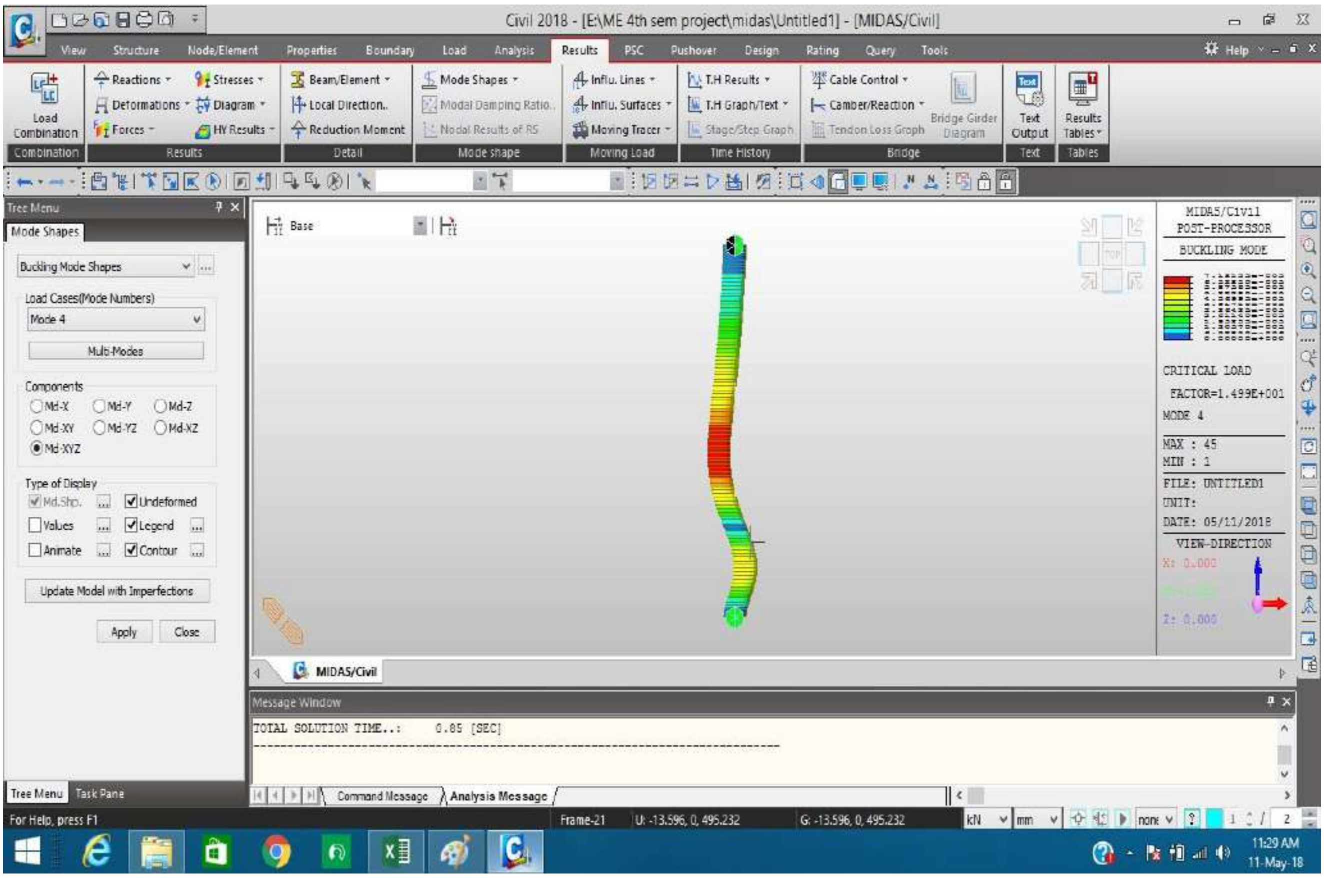
2. For 2nd mode, Pcr = 84.78 KN.



3. For 3rd mode, Pcr = 119.8 KN.



4. For 4nth mode, Pcr = 149.9 KN.



5.3 MANUAL ANALYSIS:

Following are the list of formulae that have been used to calculate the below mentioned properties for composite columns of SCC infill:

1. Mass, *M*:

$$M = \frac{W}{g} \quad \text{in } N\text{-}sec^2/m$$

2. Moment of Inertia, *I:*

$$I = I_S + I_C \quad \text{in } mm^4$$

Where,

a. $I_S = \frac{\pi (D^4 - d^4)}{64}$ in mm^4 *(Is – Steel moment of interia)*

b. $I_C = \frac{\pi d^4}{64}$ in mm^4 *(Ic – Concrete moment of inertia)*

3. Effective Stiffness, $(EI)_{eff}$:

$$(EI)_{eff} = Es\ Is + C3\ Ec\ Ic \quad \text{in } Nmm^2$$

Where,

a. $C_3 = 0.6 + 2\left[\frac{A_S}{A_C + A_S}\right] \le 0.9$

b. $A_S = \frac{\pi (D^2 - d^2)}{4}$ *in* mm^2

c. $A_C = \frac{\pi d^2}{4}$ *in* mm^2

d. $Ec = 5000\sqrt{f_{ck}}$ *in* N/mm^2

e. $Es = 210000$ N/mm^2

4. Effective Length, *le:*

$le = 0.65\ l$ *in mm* (for both ends fixed)

$le = 1.0\ l$ *in mm* (for one end fixed, other end hinged)

(Referring to Lecture 19, “COMPOSITE MATERIALS”, by Prof. R. Velmurugan, Dept. of Aerospace Engineering, IIT Madras) The following expression for Effective density has been obtained.

5. Effective Density, $\acute{\rho}_c = \acute{\rho}_s V_s + \acute{\rho}_c V_c$ in N/mm^3 Or KN/m^3

   Where,

   $\acute{\rho}_c$ = Density of composite material

   $\acute{\rho}_s$ = Density of steel

   V_s = Volume of steel

   $\acute{\rho}_c$ = Density of concrete

   V_c = Volume of concrete

6. Stiffness, k:

$$k = \frac{12(EI)_{eff}}{l^2} \quad \text{in N/mm} \qquad \text{(for both ends fixed)}$$

7. Natural Frequency, ω:

$$\omega = \sqrt{\frac{k}{M}} \quad \text{in rad}$$

8. Frequency, f:

$$f = \frac{\omega}{2\pi} \quad \text{in Hz}$$

9. Time Period, t:

$$t = \frac{1}{f} \quad \text{in sec}$$

(Referring to “NASA TECHNICAL PAPER”3090 – MARCH 1991 : Vibration and buckling analysis of a simply supported column with constant piecewise cross section) The following expressions modal frequencies have been obtained.

10. Modal frequency for Column Vibration,

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

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

11. Modal frequency for Column Buckling,

$$\lambda_1 \,\&\, \lambda_2 = \sqrt{\frac{P}{(EI)_{eff}}} \quad \text{in Hz}$$

The results obtained for the composite columns by manual analysis have been mentioned in the Results section – “CHAPTER 6” of this thesis.

CHAPTER 6

RESULTS

6.1 FROM MATLAB: (FOR BOTH ENDS FIXED CONDITION)

6.1.1 Stiffness, Natural Frequency, Frequency and Time Period:

sl no.	Length	Diameter (mm)		Grades	Stiffness	Natural Frequency	Frequency	Time Period
	l (mm)	D	d	M?	k (N/mm)	w (rad)	f (Hz)	T (sec)
1	678.4	48.3	41.9	20	3829.2319	3.507161954	0.5584653	1.7906216
				30	3924.9528	3.50959688	0.558853	1.7893793
				40	4005.6492	3.477196879	0.5536938	1.8060525
				Hollow	3403.3228	3.72820318	0.5936629	1.6844576
2	594.6	42.4	36	20	3669.1467	3.502571299	0.5577343	1.7929685
				30	3746.6184	3.568667392	0.5682591	1.7597605
				40	3811.9301	3.538849298	0.563511	1.7745881
				Hollow	3324.4368	4.339299271	0.6909712	1.4472383
3	508.8	42.4	36	20	5855.9651	4.912983033	0.7823221	1.2782458
				30	5979.6102	4.927452816	0.7846262	1.2744922
				40	6083.8478	4.866574803	0.7749323	1.2904353
				Hollow	5305.8076	5.867246776	0.934275	1.0703487
4	424	42.4	36	20	10119.108	6.855808133	1.0916892	0.9160116
				30	10332.766	6.764815293	1.0771999	0.9283328
				40	10512.889	7.141755321	1.1372222	0.8793356
				Hollow	9168.4355	8.586223802	1.3672331	0.7314042
5	339.2	42.4	36	20	19763.882	12.96187196	2.0639923	0.4844979
				30	20181.184	12.94193128	2.0608171	0.4852444
				40	20532.986	13.60649024	2.1666386	0.4615444
				Hollow	17907.1	15.68548794	2.4976892	0.4003701
6	254.4	42.4	36	20	46847.721	19.50496921	3.1058868	0.3219692
				30	47836.881	20.48778609	3.2623863	0.3065241
				40	48670.782	20.32309045	3.2361609	0.3090081
				Hollow	42446.46	25.77041864	4.1035698	0.2436903
7	202.2	33.7	27.3	20	42889.702	25.2870445	4.0265994	0.2483485
				30	43541.204	24.73756836	3.9391032	0.2538649
				40	44090.445	25.0369947	3.9867826	0.2508288
				Hollow	39990.854	29.14028902	4.6401734	0.2155092

6.1.2. Modal frequencies for column vibration and column buckling:

sl no.	Length	Diameter (mm)		Grades	For Column Vibration		For Column Buckling
	l (mm)	D	d	M?	λ1	λ2	λ1
1	678.4	48.3	41.9	20	78.62454705	78.62454702	0.002284547
				30	78.1678508	78.16785076	0.002287903
				40	77.41133809	77.41133805	0.002290817
				Hollow	83.4895584	83.48955837	0.00232366
2	594.6	42.4	36	20	75.30363266	75.30363261	0.002595324
				30	75.61481132	75.61481128	0.002599484
				40	74.97362397	74.97362392	0.002602385
				Hollow	85.91005213	85.91005209	0.002614173
3	508.8	42.4	36	20	85.77794082	85.77794076	0.00303128
				30	85.45660261	85.45660256	0.003035626
				40	84.56092411	84.56092405	0.003037463
				Hollow	96.07975961	96.07975957	0.002759611
4	424	42.4	36	20	96.81374057	96.81374051	0.003637007
				30	95.66807736	95.66807729	0.003642112
				40	97.87351616	97.87351609	0.00364684
				Hollow	111.0505007	111.0505006	0.003663018
5	339.2	42.4	36	20	125.8966091	125.896609	0.004538503
				30	125.1443123	125.1443122	0.004546581
				40	127.7639297	127.7639297	0.004551404
				Hollow	141.9518092	141.9518092	0.00457117
6	254.4	42.4	36	20	143.7203016	143.7203015	0.006029767
				30	146.5292756	146.5292755	0.006041022
				40	145.3099639	145.3099638	0.006051092
				Hollow	169.3237851	169.323785	0.006078801
7	202.2	33.7	27.3	20	152.3711708	152.3711706	0.007572493
				30	150.139658	150.1396579	0.007583962
				40	150.572966	150.5729658	0.007593625
				Hollow	166.4557432	166.455743	0.007494851

6.2 FROM MATLAB (FOR ONE END HINGED AND OTHER FIXED)

6.2.1 Stiffness, Natural Frequency, Frequency and Time Period:

sl no.	Length	Diameter (mm)		Grades	Stiffness	Natural Frequency	Frequency	Time Period
	l (mm)	D	d	M?	k (N/mm)	w (rad)	f (Hz)	T (sec)
1	678.4	48.3	41.9	20	262.9007025	0.918958418	0.146330958	6.833823897
				30	269.4725398	0.919596426	0.146432552	6.829082653
				40	275.0128549	0.911106868	0.145080711	6.892715026
				Hollow	233.6593797	0.976876387	0.155553565	6.428653702
2	594.6	42.4	36	20	917.2866653	1.75128565	0.278867142	3.585936995
				30	936.6546061	1.784333696	0.284129569	3.519521048
				40	952.9825355	1.769424649	0.281755517	3.549176284
				Hollow	831.1092114	2.169649635	0.345485611	2.894476554
3	508.8	42.4	36	20	1463.99127	2.456491516	0.391161069	2.55649163
				30	1494.90254	2.463726408	0.392313122	2.548984327
				40	1520.961947	2.433287401	0.387466147	2.580870635
				Hollow	1326.451889	2.933623388	0.467137482	2.140697414
4	424	42.4	36	20	2529.776914	3.427904067	0.545844597	1.832023265
				30	2583.191589	3.382407646	0.538599944	1.856665623
				40	2628.222244	3.57087766	0.568611092	1.758671284
				Hollow	2292.108863	4.293111901	0.683616545	1.462808365
5	339.2	42.4	36	20	4940.970535	6.480935978	1.031996175	0.96899584
				30	5045.296073	6.470965642	1.030408542	0.970488849
				40	5133.24657	6.80324512	1.083319287	0.923088892
				Hollow	4476.775124	7.842743972	1.248844581	0.800740152
6	254.4	42.4	36	20	11711.93016	9.752484606	1.552943409	0.643938468
				30	11959.22032	10.24389304	1.63119316	0.613048181
				40	12167.69557	10.16154523	1.61808045	0.618016243
				Hollow	10611.61511	12.88520932	2.051784923	0.487380519
7	202.2	33.7	27.3	20	10722.42557	12.64352225	2.013299721	0.496697034
				30	10885.3009	12.36878418	1.969551621	0.507729774
				40	11022.61115	12.51849735	1.993391298	0.501657653
				Hollow	9997.713488	14.57014451	2.320086706	0.431018374

6.2.2. Modal frequencies for column vibration and column buckling:

sl no.	Length	Diameter (mm)		Grades	For Column Vibration		For Column Buckling
	l (mm)	D	d	M?	λ1	λ2	λ1
1	678.4	48.3	41.9	20	40.24650539	40.24650532	0.002284547
				30	40.01273071	40.01273064	0.002287903
				40	39.62548532	39.62548526	0.002290817
				Hollow	42.73681805	42.73681799	0.00232366
2	594.6	42.4	36	20	53.24770932	53.24770925	0.002595324
				30	53.46774586	53.4677458	0.002599484
				40	53.01435793	53.01435787	0.002602385
				Hollow	60.74758045	60.74758039	0.002614173
3	508.8	42.4	36	20	60.65416365	60.65416357	0.00303128
				30	60.42694322	60.42694315	0.003035626
				40	59.79360288	59.7936028	0.003037463
				Hollow	67.93864957	67.93864951	0.002759611
4	424	42.4	36	20	68.4576525	68.4576524	0.003637007
				30	67.64754627	67.64754617	0.003642112
				40	69.207027	69.2070269	0.00364684
				Hollow	78.52456211	78.52456203	0.003663018
5	339.2	42.4	36	20	89.02234605	89.02234593	0.004538503
				30	88.49039187	88.49039175	0.004546581
				40	90.34274115	90.34274103	0.004551404
				Hollow	100.3750869	100.3750868	0.00457117
6	254.4	42.4	36	20	101.6255999	101.6255997	0.006029767
				30	103.6118445	103.6118443	0.006041022
				40	102.7496609	102.7496607	0.006051092
				Hollow	119.7299967	119.7299966	0.006078801
7	202.2	33.7	27.3	20	107.7426882	107.7426879	0.007572493
				30	106.1647704	106.1647701	0.007583962
				40	106.4711654	106.4711651	0.007593625
				Hollow	117.7019848	117.7019846	0.007494851

6.3 FROM - MIDAS CIVIL:

6.3.1 For Both Ends Fixed Condition:

The maximum compressive force for buckling (in KN) for modes from 1 to 4 are following:

sl no.	Length (mm)	Diameter (mm)	Load P (kN)	Weight (kg)	Grades	MODE 1	MODE 2	MODE 3	MODE 4
1	678.4	48.3	142.8	3.054	M20	174	174	302.4	302.4
			146.8	3.126	M30	180.6	180.6	318.3	318.4
			150.2	3.25	M40	186.1	186.1	331.3	331.3
			131.3	2.402	H	141.1	141.1	221.7	221.7
2	594.6	42.4	118.9	2.934	M20	145.2	145.2	250.7	250.7
			121.8	2.886	M30	149.6	149.6	262	262
			124.2	2.986	M40	154	154	272.2	272.2
			109.3	1.732	H	121.3	121.3	191.4	191.4
3	508.8	42.4	162.2	2.38	M20	185.8	185.8	294.5	294.5
			166.1	2.416	M30	192.6	192.6	310.1	310.1
			169.2	2.52	M40	198.2	198.2	322.9	322.9
			121.8	1.512	H	151.8	151.8	216.7	216.7
4	424	42.4	233.5	2.112	M20	241.3	241.3	340.1	340.1
			239.1	2.215	M30	251.4	251.4	360.7	360.7
			243.9	2.022	M40	259.6	259.6	377.6	377.6
			180.6	1.22	H	190.5	190.5	239.6	239.6
5	339.2	42.4	323.24	1.154	M20	314.9	314.9	379.7	379.7
			331.31	1.182	M30	330.6	330.6	406.1	406.1
			379.9	1.088	M40	343.4	343.4	427.9	427.9
			334.2	0.714	H	235.2	235.2	255	255
6	254.4	42.4	220	1.208	M20	393.3	393.3	400.9	400.9
			227	1.118	M30	419.1	419.1	431.7	431.7
			238	1.156	M40	440.2	440.2	457.6	457.6
			200	0.627	H	259.9	259.9	264.6	264.6
7	202.2	33.7	170	0.658	M20	279.3	279.3	283.5	283.5
			178	0.698	M30	294.4	294.4	301.2	301.2
			184	0.69	M40	306.9	306.9	316.1	316.1
			145	0.462	H	202.1	202.1	205.7	205.7

6.3.2. For Upper End Fixed and Lower End Hinged Condition:

The maximum compressive force for buckling (in KN) for modes from 1 to 4 are following:

sl no.	Length (mm)	Diameter (mm)	Load P (kN)	Weight (kg)	Grades	MODE 1	MODE 2	MODE 3	MODE 4
1	678.4	48.3	142.8	3.054	M20	53.98	169.6	239.5	299.9
			146.8	3.126	M30	55.69	176	250.4	315.6
			150.2	3.25	M40	57.12	181.3	259.2	328.5
			131.3	2.402	H	45.93	137.7	184.5	220.1
2	594.6	42.4	118.9	2.934	M20	45.16	141.5	199.2	248.7
			121.8	2.886	M30	46.39	146.1	207.2	260.3
			124.2	2.986	M40	23.71	75	106.9	134.9
			109.3	1.732	H	39.38	118.3	159	190
3	508.8	42.4	162.2	2.38	M20	60.2	181.3	244.1	292.3
			166.1	2.416	M30	30.96	93.94	127.6	153.9
			169.2	2.52	M40	21.11	64.43	88.03	106.8
			121.8	1.512	H	52	148.4	188.6	215.4
4	424	42.4	233.5	2.112	M20	83.39	235.9	297.1	338.1
			239.1	2.215	M30	42.96	122.8	156.6	179.2
			243.9	2.022	M40	29.34	84.53	108.6	125.1
			180.6	1.22	H	71.11	186.7	220.1	238.6
5	339.2	42.4	323.24	1.154	M20	121.6	309	354.8	378.5
			331.31	1.182	M30	62.85	162.1	188.3	202.3
			379.9	1.088	M40	43.03	112.2	131.6	142.1
			334.2	0.714	H	101.3	231.8	247.7	254.7
6	254.4	42.4	220	1.208	M20	187.8	389.6	396.7	400.9
			227	1.118	M30	97.69	207.3	213	215.8
			238	1.156	M40	67.19	145	150.1	152.5
			200	0.627	H	149.8	259.8	260.6	264.6
7	202.2	33.7	170	0.658	M20	250.7	403.3	405	410.9
			178	0.698	M30	131.3	217.6	218.4	221.7
			184	0.69	M40	90.79	154	154.5	156.8
			145	0.462	H	113.8	202	202.5	205.6

6.3.3. For Lower End Fixed and Upper End Hinged Condition:

The maximum compressive force for buckling (in KN) for modes from 1 to 4 are following:

sl no.	Length (mm)	Diameter (mm)	Load P (kN)	Weight (kg)	Grades	MODE 1	MODE 2	MODE 3	MODE 4
1	678.4	48.3	142.8	3.054	M20	26.99	84.78	119.8	149.9
			146.8	3.126	M30	27.85	87.99	125.2	157.8
			150.2	3.25	M40	57.12	181.3	259.2	328.5
			131.3	2.402	H	45.93	137.7	184.5	220.1
2	594.6	42.4	118.9	2.934	M20	45.16	141.5	199.2	248.7
			121.8	2.886	M30	46.39	146.1	207.2	260.3
			124.2	2.986	M40	47.41	150	213.8	269.9
			109.3	1.732	H	39.38	118.3	159	190
3	508.8	42.4	162.2	2.38	M20	60.2	181.3	244.1	292.3
			166.1	2.416	M30	61.92	187.9	255.1	307.8
			169.2	2.52	M40	63.34	193.3	264.1	320.4
			121.8	1.512	H	52.04	148.4	188.6	215.4
4	424	42.4	233.5	2.112	M20	83.39	235.9	297.7	338.1
			239.1	2.215	M30	85.93	245.7	313.1	358.5
			243.9	2.022	M40	88.03	253.6	325.8	375.2
			180.6	1.22	H	71.11	186.7	220.1	238.6
5	339.2	42.4	323.24	1.154	M20	121.6	309	354.8	378.5
			331.31	1.182	M30	125.7	324.3	376.7	404.6
			379.9	1.088	M40	129.1	336.7	394.7	426.3
			334.2	0.714	H	101.3	231.8	247.7	254.7
6	254.4	42.4	220	1.208	M20	187.8	389.6	396.7	400.9
			227	1.118	M30	195.4	414.6	426	431.7
			238	1.156	M40	201.6	435.1	450.4	457.5
			200	0.627	H	149.8	259.8	260.6	264.6
7	202.2	33.7	170	0.658	M20	135	276.8	280.8	283.5
			178	0.698	M30	139.3	291.5	297.7	301.2
			184	0.69	M40	142.8	303.4	311.9	316
			145	0.462	H	113.8	202	202.5	205.6

6.4. MANUAL CALCULATIONS (For both ends fixed):

Following are the results obtained by hand calculations performed as per analysis procedure and formulae mentioned in section 5.3 of this thesis.

6.4.1 calculation of mass and moment of inertia:

sl no.	Length	Diameter (mm)		Weight	Grades	Load	Mass M	Moment of Inertia, I = Is + Ic (mm4)		
	l (mm)	D	d	w (gm)	M?	P (N)	(NS^2/m)	Is	Ic	I
1	678.4	48.3	41.9	3054	20	142800	311.31498	115797.77	151218.79	267016.5603
				3126	30	146800	318.65443			
				3250	40	150200	331.2946			
				2402	Hollow	131300	244.85219			
2	594.6	42.4	36	2934	20	118900	299.08257	76160.946	82406.16	158567.1062
				2886	30	121800	294.1896			
				2986	40	124200	304.38328			
				1732	Hollow	109300	176.55454			
3	508.8	42.4	36	2380	20	162200	242.60958	76160.946	82406.16	158567.1062
				2416	30	166100	246.27931			
				2520	40	169200	256.88073			
				1512	Hollow	121800	154.12844			
4	424	42.4	36	2112	20	233500	215.29052	76160.946	82406.16	158567.1062
				2215	30	239100	225.79001			
				2022	40	243900	206.11621			
				1220	Hollow	214600	124.3629			
5	339.2	42.4	36	1154	20	363600	117.63507	76160.946	82406.16	158567.1062
				1182	30	372600	120.4893			
				1088	40	379900	110.90724			
				714	Hollow	334200	72.782875			
6	254.4	42.4	36	1208	20	641800	123.13965	76160.946	82406.16	158567.1062
				1118	30	657800	113.96534			
				1156	40	671500	117.83894			
				627	Hollow	591000	63.914373			
7	202.2	33.7	27.3	658	20	465300	67.074414	36028.291	27252.118	63280.40901
				698	30	473800	71.151886			
				690	40	481000	70.336391			
				462	Hollow	425000	47.094801			

6.4.2 calculation of Effective Stiffness (EI_{eff}):

sl no.	Length	Diameter (mm)		Grades	(EI)eff = Es Is + C3 Ec Ic (Nmm2)				
	l (mm)	D	d	M?	As	Ac	:3, C3<=0.:	Ec	(EI)eff
1	678.4	48.3	41.9	20	453.1648	1378.1539	1.0949055	22360.68	2.736E+10
				30				27386.128	2.804E+10
				40				31622.777	2.862E+10
				Hollow				0	2.432E+10
2	594.6	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
3	508.8	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
4	424	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
5	339.2	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
6	254.4	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
7	202.2	33.7	27.3	20	306.464	585.05265	1.2875116	22360.68	8.114E+09
				30				27386.128	8.238E+09
				40				31622.777	8.342E+09
				Hollow				0	7.566E+09

6.4.3 Calculation of Slenderness Ratio:

sl no.	Length	Diameter (mm)		Grades	eff. Length	Radius of Gyration	Slenderness Ratio
	l (mm)	D	d	M?	le (mm)	r(min) in mm	λ
1	678.4	48.3	41.9	20	440.96	12.075	36.5184265
				30			
				40			
				Hollow			
2	594.6	42.4	36	20	386.49	10.6	36.46132075
				30			
				40			
				Hollow			
3	508.8	42.4	36	20	330.72	10.6	31.2
				30			
				40			
				Hollow			
4	424	42.4	36	20	275.6	10.6	26
				30			
				40			
				Hollow			
5	339.2	42.4	36	20	220.48	10.6	20.8
				30			
				40			
				Hollow			
6	254.4	42.4	36	20	165.36	10.6	15.6
				30			
				40			
				Hollow			
7	202.2	33.7	27.3	20	131.43	8.425	15.6
				30			
				40			
				Hollow			

6.4.4 calculation of Stiffness, Frequency, Natural frequency and Time Period:

sl no.	Length	Diameter (mm)		Grades	Stiffness	Natural Frequency	Frequency	Time Period
	l (mm)	D	d	M?	k (N/mm)	ω (rad)	f (Hz)	T (sec)
1	678.4	48.3	41.9	20	3829.2319	3.507161954	0.558465	1.79062161
				30	3924.9528	3.50959688	0.558853	1.7893793
				40	4005.6492	3.477196879	0.553694	1.80605247
				Hollow	3403.3228	3.72820318	0.593663	1.68445755
2	594.6	42.4	36	20	3669.1467	3.502571299	0.557734	1.7929685
				30	3746.6184	3.568667392	0.568259	1.75976052
				40	3811.9301	3.538849298	0.563511	1.77458814
				Hollow	3324.4368	4.339299271	0.690971	1.44723828
3	508.8	42.4	36	20	5855.9651	4.912983033	0.782322	1.27824581
				30	5979.6102	4.927452816	0.784626	1.27449216
				40	6083.8478	4.866574803	0.774932	1.29043532
				Hollow	5305.8076	5.867246776	0.934275	1.07034871
4	424	42.4	36	20	10119.108	6.855808133	1.091689	0.91601163
				30	10332.766	6.764815293	1.0772	0.92833281
				40	10512.889	7.141755321	1.137222	0.87933564
				Hollow	9168.4355	8.586223802	1.367233	0.73140418
5	339.2	42.4	36	20	19763.882	12.96187196	2.063992	0.48449792
				30	20181.184	12.94193128	2.060817	0.48524442
				40	20532.986	13.60649024	2.166639	0.46154445
				Hollow	17907.1	15.68548794	2.497689	0.40037008
6	254.4	42.4	36	20	46847.721	19.50496921	3.105887	0.32196923
				30	47836.881	20.48778609	3.262386	0.30652409
				40	48670.782	20.32309045	3.236161	0.30900812
				Hollow	42446.46	25.77041864	4.10357	0.24369026
7	202.2	33.7	27.3	20	42889.702	25.2870445	4.026599	0.24834852
				30	43541.204	24.73756836	3.939103	0.25386489
				40	44090.445	25.0369947	3.986783	0.25082883
				Hollow	39990.854	29.14028902	4.640173	0.21550919

6.4.5 Calculation of Effective Density and Modal Frequencies for Vibration and Buckling:

sl no.	Length	Diameter (mm)		Grades	Eff. Density	For Column Vibration		For Column Buckling
	l (mm)	D	d	M?	ρ (kN/m3)	λ1	λ2	λ1
1	678.4	48.3	41.9	20	4.6418E+13	78.62455	78.62455	0.002284547
				30		78.16785	78.16785	0.002287903
				40		77.41134	77.41134	0.002290817
				Hollow		83.48956	83.48956	0.00232366
2	594.6	42.4	36	20	3.2786E+13	75.30363	75.30363	0.002595324
				30		75.61481	75.61481	0.002599484
				40		74.97362	74.97362	0.002602385
				Hollow		85.91005	85.91005	0.002614173
3	508.8	42.4	36	20	2.8055E+13	85.77794	85.77794	0.00303128
				30		85.4566	85.4566	0.003035626
				40		84.56092	84.56092	0.003037463
				Hollow		96.07976	96.07976	0.002759611
4	424	42.4	36	20	2.3379E+13	96.81374	96.81374	0.003637007
				30		95.66808	95.66808	0.003642112
				40		97.87352	97.87352	0.00364684
				Hollow		111.0505	111.0505	0.003663018
5	339.2	42.4	36	20	1.8703E+13	125.8966	125.8966	0.004538503
				30		125.1443	125.1443	0.004546581
				40		127.7639	127.7639	0.004551404
				Hollow		141.9518	141.9518	0.00457117
6	254.4	42.4	36	20	1.4027E+13	143.7203	143.7203	0.006029767
				30		146.5293	146.5293	0.006041022
				40		145.31	145.31	0.006051092
				Hollow		169.3238	169.3238	0.006078801
7	202.2	33.7	27.3	20	7.6726E+12	152.3712	152.3712	0.007572493
				30		150.1397	150.1397	0.007583962
				40		150.573	150.573	0.007593625
				Hollow		166.4557	166.4557	0.007494851

6.5. MANUAL CALCULATIONS (For one end fixed, other end hinged):

6.5.1 calculation of mass and moment of inertia:

sl no.	Length	Diameter (mm)		Weight	Grades	Load	Mass M	Moment of Inertia, I = Is + Ic (mm4)		
	l (mm)	D	d	w (gm)	M?	P (N)	(NS^2/m)	Is	Ic	I
1	678.4	48.3	41.9	3054	20	142800	311.31498	115797.77	151218.79	267016.5603
				3126	30	146800	318.65443			
				3250	40	150200	331.2946			
				2402	Hollow	131300	244.85219			
2	594.6	42.4	36	2934	20	118900	299.08257	76160.946	82406.16	158567.1062
				2886	30	121800	294.1896			
				2986	40	124200	304.38328			
				1732	Hollow	109300	176.55454			
3	508.8	42.4	36	2380	20	162200	242.60958	76160.946	82406.16	158567.1062
				2416	30	166100	246.27931			
				2520	40	169200	256.88073			
				1512	Hollow	121800	154.12844			
4	424	42.4	36	2112	20	233500	215.29052	76160.946	82406.16	158567.1062
				2215	30	239100	225.79001			
				2022	40	243900	206.11621			
				1220	Hollow	214600	124.3629			
5	339.2	42.4	36	1154	20	363600	117.63507	76160.946	82406.16	158567.1062
				1182	30	372600	120.4893			
				1088	40	379900	110.90724			
				714	Hollow	334200	72.782875			
6	254.4	42.4	36	1208	20	641800	123.13965	76160.946	82406.16	158567.1062
				1118	30	657800	113.96534			
				1156	40	671500	117.83894			
				627	Hollow	591000	63.914373			
7	202.2	33.7	27.3	658	20	465300	67.074414	36028.291	27252.118	63280.40901
				698	30	473800	71.151886			
				690	40	481000	70.336391			
				462	Hollow	425000	47.094801			

6.5.2 calculation of Effective Stiffness (EI_{eff}):

sl no.	Length	Diameter (mm)		Grades	(EI)eff = Es Is + C3 Ec Ic (Nmm2)				
	l (mm)	D	d	M?	As	Ac	:3, C3<=0.:	Ec	(EI)eff
1	678.4	48.3	41.9	20	453.1648	1378.1539	1.0949055	22360.68	2.736E+10
				30				27386.128	2.804E+10
				40				31622.777	2.862E+10
				Hollow				0	2.432E+10
2	594.6	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
3	508.8	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
4	424	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
5	339.2	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
6	254.4	42.4	36	20	393.8816	1017.36	1.1582058	22360.68	1.765E+10
				30				27386.128	1.802E+10
				40				31622.777	1.834E+10
				Hollow				0	1.599E+10
7	202.2	33.7	27.3	20	306.464	585.05265	1.2875116	22360.68	8.114E+09
				30				27386.128	8.238E+09
				40				31622.777	8.342E+09
				Hollow				0	7.566E+09

6.5.3 Calculation of Slenderness Ratio:

sl no.	Length	Diameter (mm)		Grades	eff. Length	Radius of Gyration	Slenderness Ratio
	l (mm)	D	d	M?	le (mm)	r(min) in mm	λ
1	678.4	48.3	41.9	20	678.4	12.075	56.18219462
				30			
				40			
				Hollow			
2	594.6	42.4	36	20	386.49	10.6	36.46132075
				30			
				40			
				Hollow			
3	508.8	42.4	36	20	330.72	10.6	31.2
				30			
				40			
				Hollow			
4	424	42.4	36	20	275.6	10.6	26
				30			
				40			
				Hollow			
5	339.2	42.4	36	20	220.48	10.6	20.8
				30			
				40			
				Hollow			
6	254.4	42.4	36	20	165.36	10.6	15.6
				30			
				40			
				Hollow			
7	202.2	33.7	27.3	20	131.43	8.425	15.6
				30			
				40			
				Hollow			

6.5.4 calculation of Stiffness, Frequency, Natural frequency and Time Period:

sl no.	Length	Diameter (mm)		Grades	Stiffness	Natural Frequency	Frequency	Time Period
	l (mm)	D	d	M?	k (N/mm)	ω (rad)	f (Hz)	T (sec)
1	678.4	48.3	41.9	20	262.9007	0.918958418	0.146331	6.8338239
				30	269.47254	0.919596426	0.146433	6.82908265
				40	275.01285	0.911106868	0.145081	6.89271503
				Hollow	233.65938	0.976876387	0.155554	6.4286537
2	594.6	42.4	36	20	917.28667	1.75128565	0.278867	3.58593699
				30	936.65461	1.784333696	0.28413	3.51952105
				40	952.98254	1.769424649	0.281756	3.54917628
				Hollow	831.10921	2.169649635	0.345486	2.89447655
3	508.8	42.4	36	20	1463.9913	2.456491516	0.391161	2.55649163
				30	1494.9025	2.463726408	0.392313	2.54898433
				40	1520.9619	2.433287401	0.387466	2.58087063
				Hollow	1326.4519	2.933623388	0.467137	2.14069741
4	424	42.4	36	20	2529.7769	3.427904067	0.545845	1.83202326
				30	2583.1916	3.382407646	0.5386	1.85666562
				40	2628.2222	3.57087766	0.568611	1.75867128
				Hollow	2292.1089	4.293111901	0.683617	1.46280836
5	339.2	42.4	36	20	4940.9705	6.480935978	1.031996	0.96899584
				30	5045.2961	6.470965642	1.030409	0.97048885
				40	5133.2466	6.80324512	1.083319	0.92308889
				Hollow	4476.7751	7.842743972	1.248845	0.80074015
6	254.4	42.4	36	20	11711.93	9.752484606	1.552943	0.64393847
				30	11959.22	10.24389304	1.631193	0.61304818
				40	12167.696	10.16154523	1.61808	0.61801624
				Hollow	10611.615	12.88520932	2.051785	0.48738052
7	202.2	33.7	27.3	20	10722.426	12.64352225	2.0133	0.49669703
				30	10885.301	12.36878418	1.969552	0.50772977
				40	11022.611	12.51849735	1.993391	0.50165765
				Hollow	9997.7135	14.57014451	2.320087	0.43101837

6.5.5 Calculation of Effective Density and Modal Frequencies for Vibration and Buckling:

sl no.	Length	Diameter (mm)		Grades	Eff. Density	For Column Vibratio		For Column Buckling
	l (mm)	D	d	M?	ρ (kN/m3)	λ1	λ2	λ1
1	678.4	48.3	41.9	20	4.6418E+13	40.24651	40.24651	0.002284547
				30		40.01273	40.01273	0.002287903
				40		39.62549	39.62549	0.002290817
				Hollow		42.73682	42.73682	0.00232366
2	594.6	42.4	36	20	3.2786E+13	53.24771	53.24771	0.002595324
				30		53.46775	53.46775	0.002599484
				40		53.01436	53.01436	0.002602385
				Hollow		60.74758	60.74758	0.002614173
3	508.8	42.4	36	20	2.8055E+13	60.65416	60.65416	0.00303128
				30		60.42694	60.42694	0.003035626
				40		59.7936	59.7936	0.003037463
				Hollow		67.93865	67.93865	0.002759611
4	424	42.4	36	20	2.3379E+13	68.45765	68.45765	0.003637007
				30		67.64755	67.64755	0.003642112
				40		69.20703	69.20703	0.00364684
				Hollow		78.52456	78.52456	0.003663018
5	339.2	42.4	36	20	1.8703E+13	89.02235	89.02235	0.004538503
				30		88.49039	88.49039	0.004546581
				40		90.34274	90.34274	0.004551404
				Hollow		100.3751	100.3751	0.00457117
6	254.4	42.4	36	20	1.4027E+13	101.6256	101.6256	0.006029767
				30		103.6118	103.6118	0.006041022
				40		102.7497	102.7497	0.006051092
				Hollow		119.73	119.73	0.006078801
7	202.2	33.7	27.3	20	7.6726E+12	107.7427	107.7427	0.007572493
				30		106.1648	106.1648	0.007583962
				40		106.4712	106.4712	0.007593625
				Hollow		117.702	117.702	0.007494851

CHAPTER 7

CONCLUSIONS:

1. For the composite steel columns infilled with SCC, the experimental load values decreases by 2.4% as the length increases.

2. For increase in slenderness ratio of composite columns, the load carrying capacity is found to decrease.

3. The slenderness ratio of all the specimens considered was ranging from 15.6 to 36.5. <50. Therefore all columns can be stated as short columns.

CONCLUSIONS FROM MATLAB ANALYSIS:

(For both ends fixed columns and one end fixed and other hinged columns)

1. The values of Euler's critical buckling load found from MATLAB were slightly lower the experimental loads. The variation was found to be 3-5%
2. For a given length and diameter of column, the stiffness K was found to increase by 5% for every 10 N/mm^2 increase in grade of concrete. However for hollow tube of same length, the stiffness decreased by 11% than infilled column.
3. The stiffness K of columns varies inversely with length. i.e., for a given diameter and thickness of column, the stiffness increases as length decreases.
4. As the length of column is decreased, that is for shorter columns, the natural frequency (w) and frequency (f) are found to increase i.e., these frequencies are inversely proportional to length.
5. The natural frequency (w) and frequency (f) for a given length varies by 0.5 to 2% for grades of M20, M30, and M40. Highest frequencies however were observed to be in hollow tube without infill.
6. As the grade of concrete increases, the time period (T) increases by 0.07 – 0.1%
7. For a given length, the time period (T) is found lowest for hollow tube than infilled tubes.
8. Time period (T) is found to be directly proportional to length of columns. Higher length columns showed significantly higher time period when compared to columns of lower length.

9. The modal frequencies for both vibration and buckling for a given length of column if highest for hollow tube than infilled column.
10. The modal frequency is found to vary inversely to length of column. For shorter lengths, higher values of modal frequencies were observed when diameter was kept constant. However, for increase in the grades of concrete, the variation in frequencies was found negligible. That is about 0.01%

COMPARISION BETWEEN BOTH ENDS FIXED AND ONE END FIXED AND ONE END HINGED CONDITION:

1. The stiffness (K) of columns with both ends fixed was found to be 93 – 95% higher than that of one end fixed and other hinged columns.
2. The natural frequency (w) and frequency (f) for both ends fixed columns was 74 – 80% more than for one end fixed and other hinged columns.
3. However, the time period (T) for columns with both ends fixed was found 73 – 78% less than of columns with one end fixed and other hinged.
4. There was no variation in effective density of columns in both the cases.
5. The modal frequencies for vibration and buckling for both ends fixed columns were about 48 – 55% more when compared to one end fixed and other end hinged columns.

CONCLUSIONS FROM FEM ANALYSIS (MIDAS CIVIL):

(for both ends fixed columns).

- The critical load factor and the load value for a given specimen is found to be same for 1st and 2nd mode and 3rd and 4th mode respectively.
- Critical buckling load obtained from MIDAS CIVIL Modeling varied by 17.9% to 20% for modes 1 & 2 with experimental values.
- Critical buckling load obtained from MIDAS CIVIL Modeling varied by 50 % to 55% for modes 3 & 4 with experimental values.
- Critical buckling load for hollow tubes of a given length and diameter is 30 – 35% less than infilled columns in all mode shapes.
- Critical buckling loads in mode 1 and mode 2 are 42.46% lesser than in mode 3 and mode 4.
- For a given length and diameter, the hollow columns showed 15-20% lesser load bearing capacity than infilled columns.
- Shorter columns showed higher critical buckling load carrying capacity than longer columns of same length and diameter.

(for *upper end fixed, lower hinged* and *lower end fixed, upper hinged*):

1. The load values gradually increased from mode 1 to mode 4 for a given length, diameter and grade of concrete of a specimen. The variation between each mode being 68 – 72% approximately.
2. The same variation was observed in hollow tubes of a given length and diameter. However hollow columns showed 15-20% lesser load bearing capacity than infilled columns.

COMPARISION BETWEEN THE THREE END CONDITIONS:

1. For a given length, diameter and grade of concrete, the columns with both ends fixed has higher load bearing capacity than the other two end conditions.
2. Upper end fixed, lower end hinged columns have 50% higher load carrying capacity than lower end fixed, upper end hinged.
3. For both ends fixed columns, the load capacity is 68-70% more than upper end fixed, lower end hinged.
4. For both ends fixed columns, the load capacity is 84-90% more than lower end fixed, upper end hinged.

CONCLUSIONS FROM MANUAL CALCULATIONS:

1. All conclusions obtained from MATLAB analysis are found to be in agreement with manual analysis.
2. The variation in all values obtained through MATLAB analysis and manual analysis are found to be less than 2%.

CHAPTER 8

SCOPE FOR FURTHER WORK

1. Dynamic effects of higher length columns of 1m to 3m shall be tried by manual, MATLAB, and MIDAS CIVIL analysis.
2. Results can be compared with other FEM softwares such as ABAQUS, ANSYS, NASTRAN.
3. Dynamic behavior of composite columns with square and rectangular cross sections shall be modelled and studied.
4. Columns with SCC infill of concrete grades higher than M40 that is M50 to M70 shall be modelled and analyzed.

CHAPTER 9

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Authors (All)	Mohamed Ghayaas Anjum
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Keywords	Nonlinear Analysis, Buckling Analysis, Mode Shapes, Self-compacting Concrete, Filled Steel Tubes, Midas Civil.
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Buckling Analysis and Mode Shapes of Composite Columns with Self Compacting Concrete Infill (SCC) using MIDAS CIVIL

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Abstract: This Research focuses on validation of Ultimate axial load carrying capacity of CFST column filled with self-compacting concrete using MIDAS CIVIL finite element software. Three-dimensional nonlinear finite element model is developed to study the force transfer effect between concrete and hollow steel tube. Model is developed for understanding the complex behavior of conventional composite circular steel tube and self-compacting concrete infilled tube with various grades and different diameters (D), thickness (t) and length (l).Diameter of column varying from 337mm to 483mm and length from 200mm to 680mm 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.

Keywords: Nonlinear Analysis, Buckling Analysis, Mode Shapes, Self-compacting Concrete, Filled Steel Tubes, Midas Civil.

I. INTRODUCTION

Concrete Filled steel tube (CFST) was used in the early 1900s. But till 1960s research on concrete filled steel tube did not begin. Concrete Filled steel tube (CFST) are composite members consists steel tube infilled with concrete materials. Concrete filled column are used in lateral resistance system of both braced and unbraced system of the building, commonly concrete filled steel tubes are used in bridges piers. Moreover Concrete filled steel tube column are used for strengthening the structure in earthquake zones. Concrete Filled Steel Tubular (CFST) composite columns represent a class of structural systems, where the best properties of steel and concrete are used to their maximum advantage. When employed under favourable conditions the steel casing confines the core tri-axially creating a confinement for better seismic resistance and the in-filled concrete inhibits the local buckling of the tubular shell.

Moreover when compare with hollow steel tube, core concrete the concrete filled steel tube (CFST) will give more compressive stability enormously concrete filled steel tube (CFST) will give more excellent compressive resistance capacity, ductility and energy dissipation ability owning to be confining effect provided by steel tube

A. Benefits of Using CFST Column over Reinforced Column

Composite segment joins the benefits of both basic steel and cement, to be specific the pace of development, quality, and light weight steel, and the characteristic mass, firmness, damping, and economy of cement. The steel outline serves as the erection casing to finish the development of whatever remains of the structure. In this way enhancing pliability. Furlong reasons that the solid infill delays the neighborhood clasping of the steel tube. Notwithstanding, no expansion in solid quality because of repression by steel tube was watched.

B. Brief Description of Software Used

Finite element method considers being the best tool for analyzing the structures lately, many software's uses this technique for analyzing and creating. For finite factor evaluation and computer aided design field one of the programs is suitable i. e. 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 analysed for buckling and mode shapes under failure are generated.

C. Finite Element Modeling Self weight concrete filled in the CFST column are accurately model in finite element software MIDAS CIVIL and compred with experimental results and codes of practice.

II. MATERIAL PROPERTIES AND CONSTITUTIVE MODELS

A. Steel*:* Steel tube is modeled as elastic-perfectly plastic with von mises yield criterion. Due to steel tube is subjected to multiple stresses and therefore the stress-strain curve crosses elastic limit and reaches in plastic region. The nonlinear behavior of steel tube is obtained from uniaxial tension test and used in steel modeling. In this analysis Poisson's ratio, density and young's modulus are taken as μ=0.3, ∫=7860kg/m3 and Es=210000MPa, respectively.

B. Self-compacting concrete*:* A rational mix design method of self-compacting concrete using a variety of materials is necessary. Coarse aggregate, fine aggregate content in concrete is fixed at 50% & 40% percent of the mortar volume.

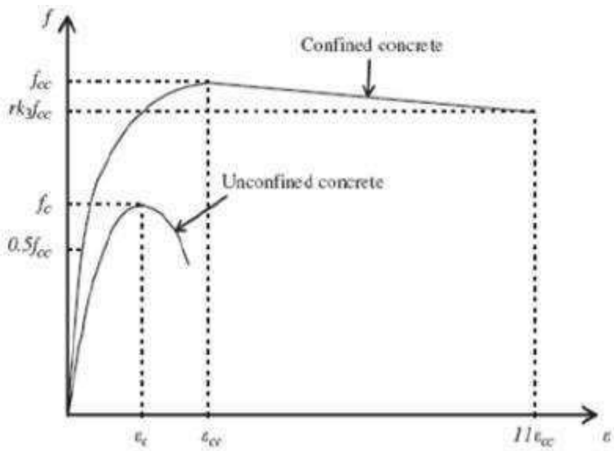


Fig .2 Equivalent stress-strain curves for confined and unconfined concrete

C. Material Model of Concrete: In order to understand concrete behavior in the finite element model, a nonlinear stress-strain diagram for confined concrete should be establish. The equivalent stress-strain curve for confined and unconfined concrete under compressive loading. This is used in proposed FE model. The properties of material shown in figure 2 are used to define the nonlinear behavior of concrete under confinement. This is defined as follows. The stress-strain curve is divided into 3 parts namely elastic part (Linear), Elasto-Plastic part and Perfectly Plastic (nonlinear).

D. Properties of Materials: Table I Properties of Materials

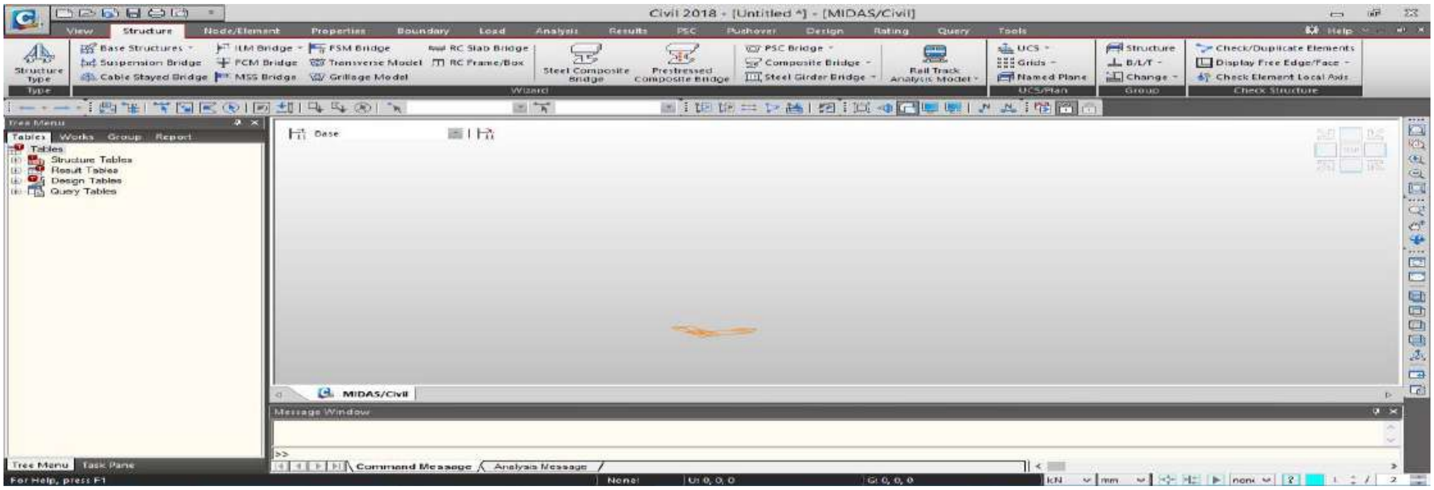
Properties steel	**Steel**	**Self-compacting concrete**
Density(∫)	7860 kg/m3	2400 kg/m3
Poison ratio (v)	0.3	0.16
Young's modules (E)	210000MPa	22360.70000 (M20),27386.12(M30),and 31622.78(M40)MPA

III. SPECIMEN DETAILS AND EXPERIMENTAL LOADS.

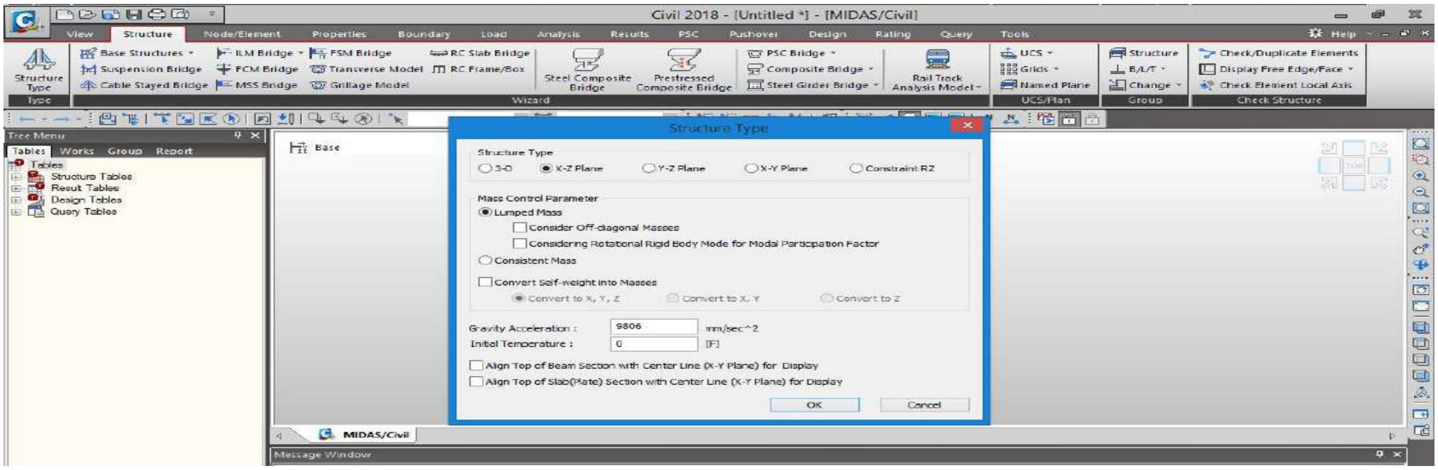
EXPERIMENTAL LOADS & OTHER DATA					
sl no.	Length (mm)	Diameter (mm)	Load P (kN)	Weight (kg)	Grades
1	678.4	48.3	142.8	3.054	M20
			146.8	3.126	M30
			150.2	3.25	M40
			131.3	2.402	H
2	594.6	42.4	118.9	2.934	M20
			121.8	2.886	M30
			124.2	2.986	M40
			109.3	1.732	H
3	508.8	42.4	162.2	2.38	M20
			166.1	2.416	M30
			169.2	2.52	M40
			121.8	1.512	H
4	424	42.4	233.5	2.112	M20
			239.1	2.215	M30
			243.9	2.022	M40
			180.6	1.22	H
5	339.2	42.4	323.24	1.154	M20
			331.31	1.182	M30
			379.9	1.088	M40
			334.2	0.714	H
6	254.4	42.4	220	1.208	M20
			227	1.118	M30
			238	1.156	M40
			200	0.627	H
7	202.2	33.7	170	0.658	M20
			178	0.698	M30
			184	0.69	M40
			145	0.462	H

IV. MODELLING PROCEDURE AND ANALYSIS IN MIDAS CIVIL.

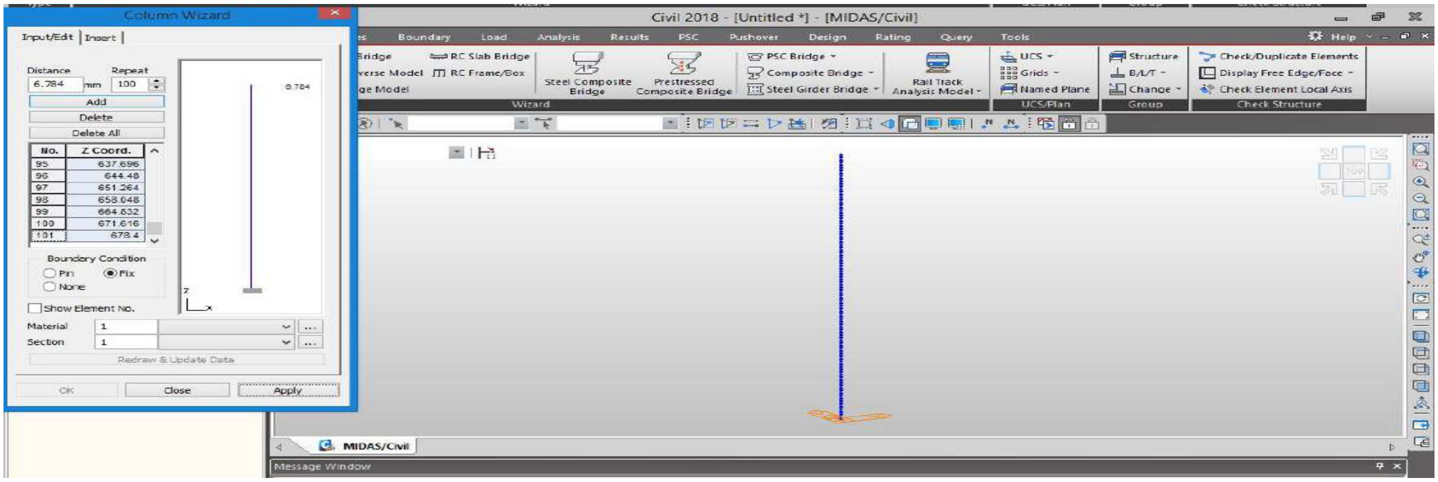
1. Set the units to KN and MM in the bottom most bar.



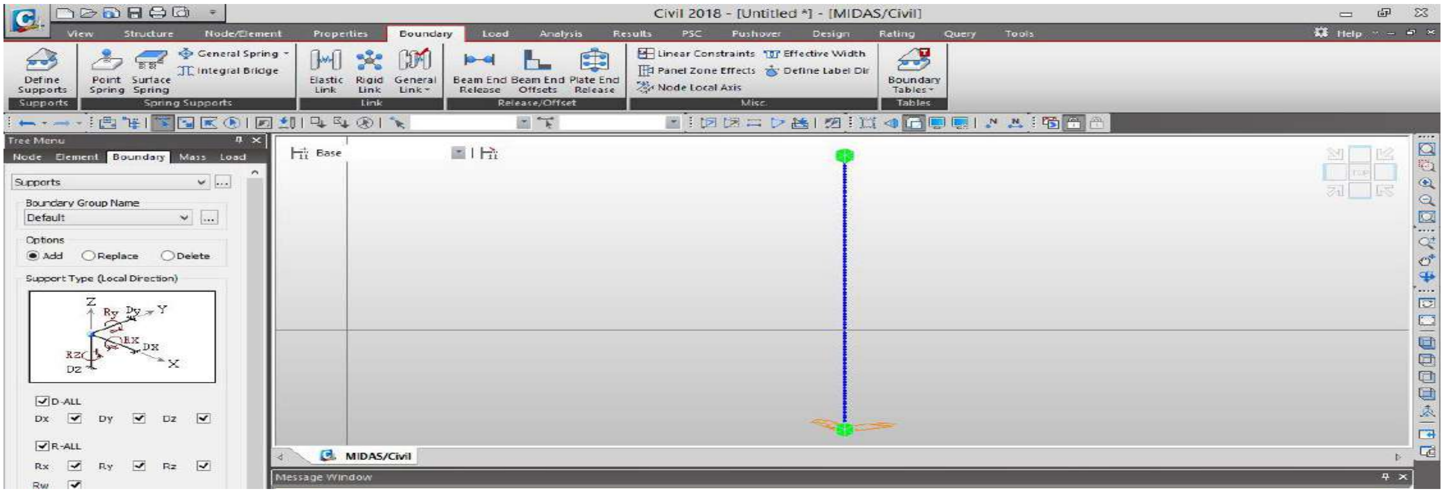
2. From STRUCTURE tab, click STRUCTURE TYPE and select X-Z Plane. i.e, the structure is to be modelled in only 2D plane.



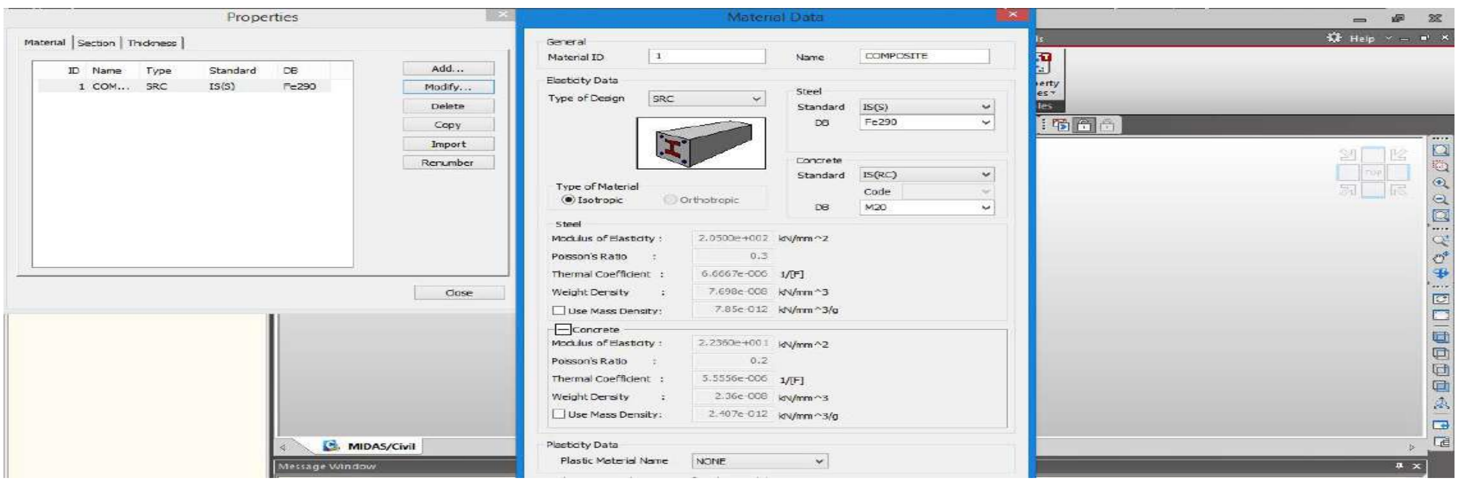
3. Select BASE STRUCTURES and select COLUMN. Suppose a cfst column of 678.4mm length is modelled, enter the distance as 6.784 mm and repeat as 100. This implies that the given length of column is divided into 100 equal finite elements to get more accurate results. Also, select the boundary condition as FIXED. Therefore a restraint will be applied on one end of the column. Click Apply.



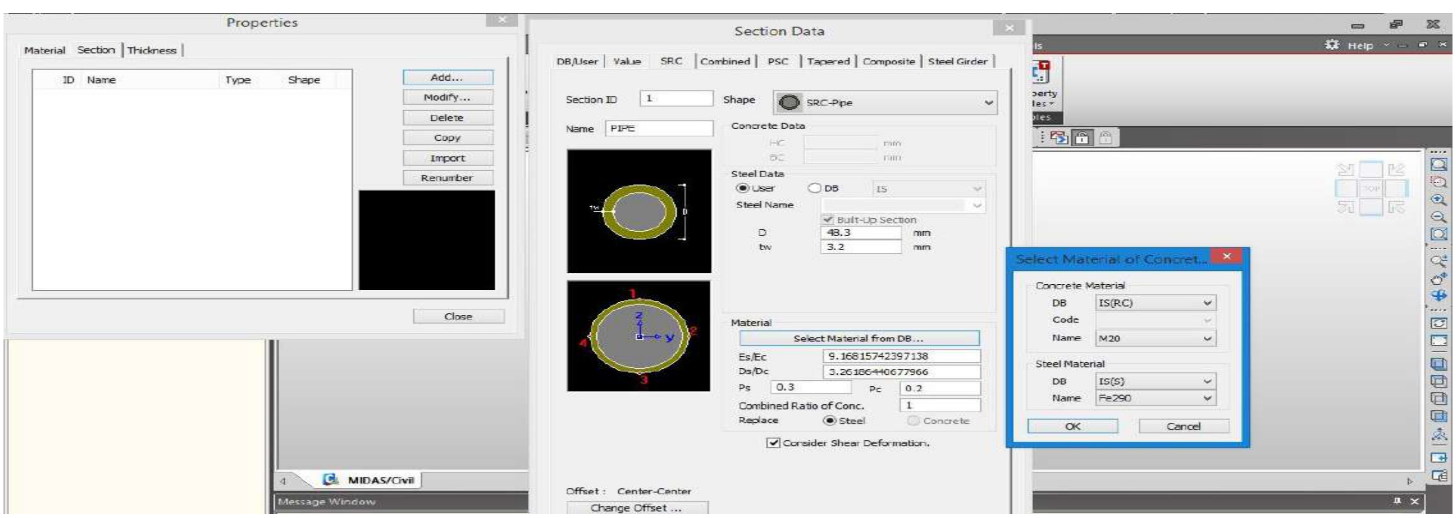
4. Goto BOUNDARY tab and select DEFINE SUPPORTS. Check D-ALL and R-ALL. This implies that to provide fixed end restraint for the other end of the column, the displacements and rotations in all directions have been restrained.



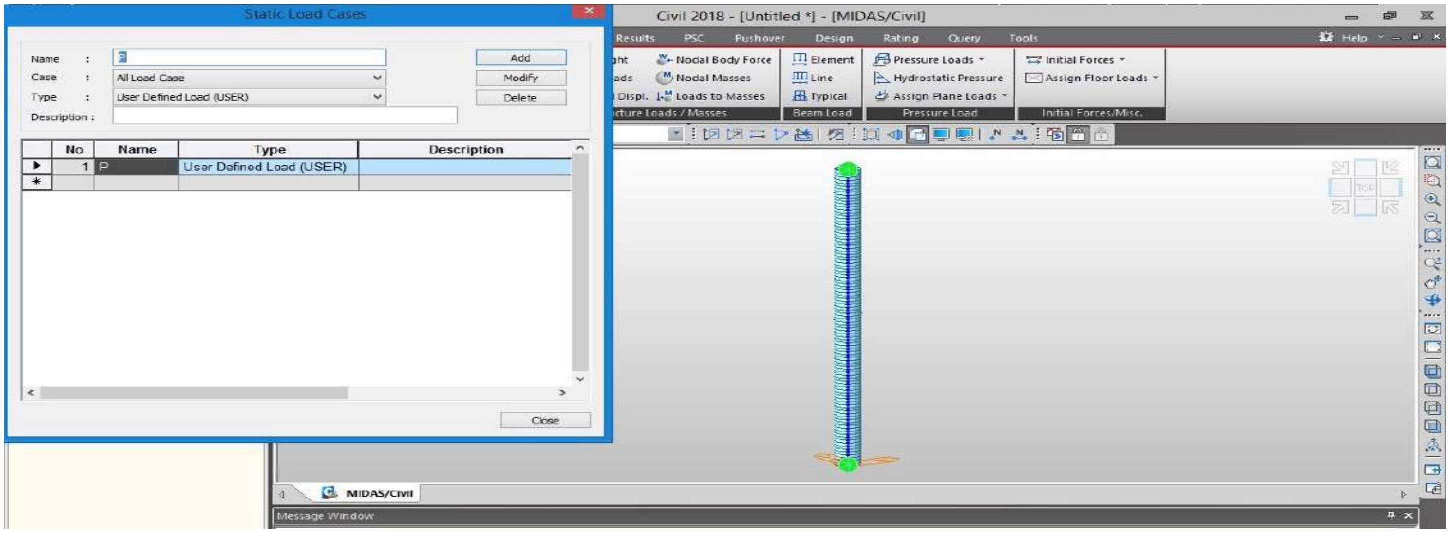
5. Goto PROPERTIES tab and select MATERIAL PROPERTIES. Provide a name to the material like "Composite" and choose SRC (Steel Reinforced Concrete) for modelling a composite column. Likewise, for modelling a hollow steel pipe, select type of design as STEEL. Select the code of design and specify the strength of the steel and concrete and apply.



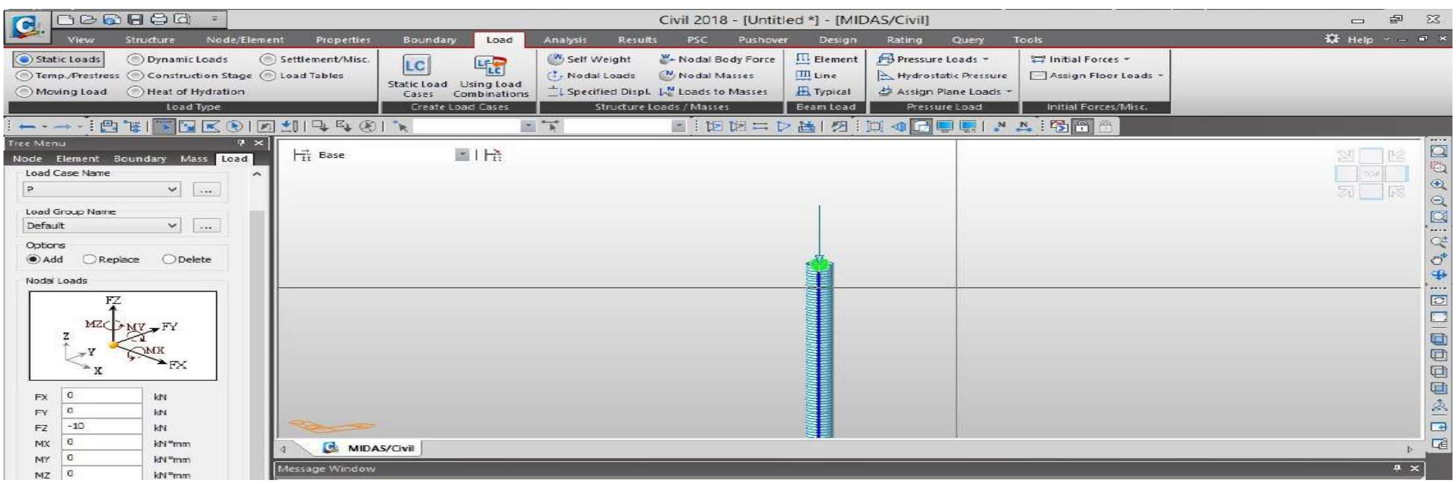
6. In the section tab, expand the SRC tab and provide a name to the section like "Pipe". Choose the shape as SRC-Pipe and enter the diameter, thickness and other properties of the column as shown in the figure below.



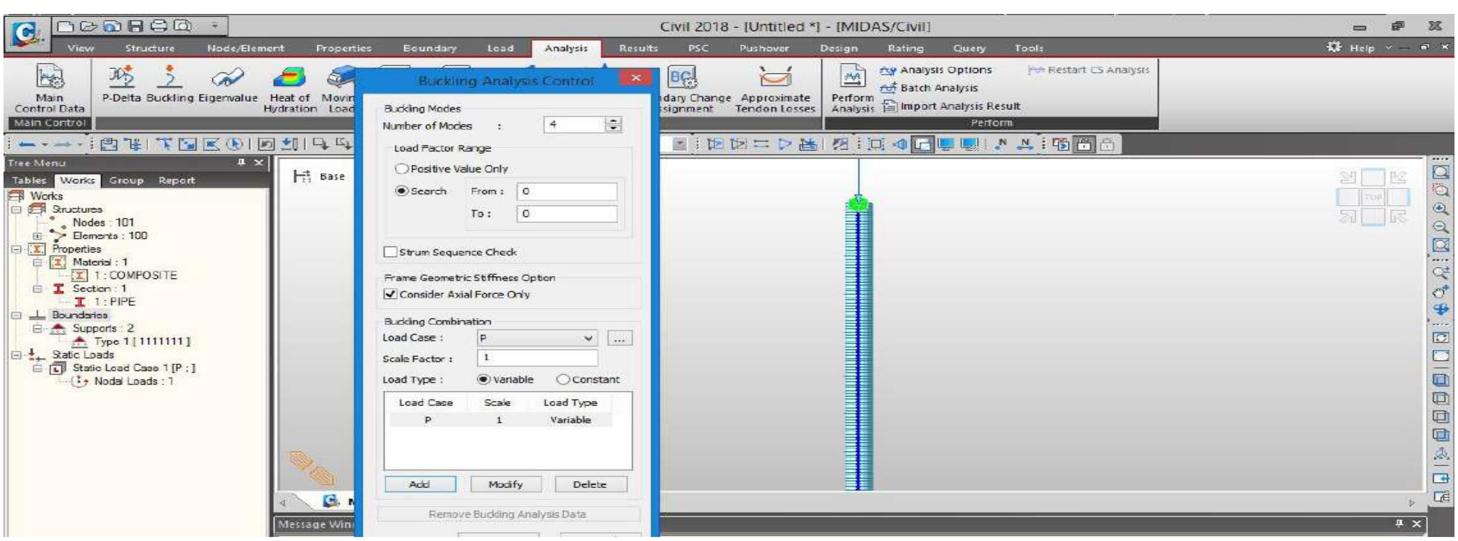
7. Goto LOAD tab, and select STATIC LOAD CASES. Enter a name and select type of load as User Defined Load (USER) and add. In this step, the load case is defined.



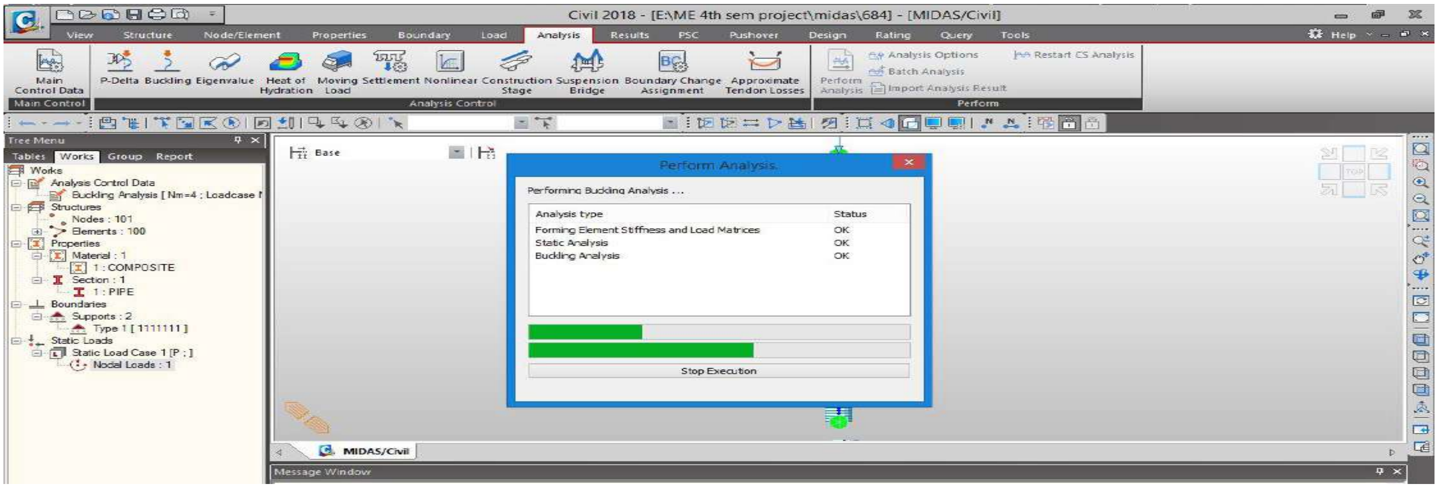
8. Select NODAL LOADS. Since a vertical downward load is to be applied on the model, enter a nominal load of -10KN(this load will later be multiplied by the critical load factor to obtain the actual failure load) in the FZ direction. Select the specimen and apply the load.



9. For analyzing, goto ANALYSIS tab and select BUCKLING. Enter the number of modes required. Here, 4 modes have been selected. Check OK “Consider axial force only”. Add the load case P specified in the earlier steps.

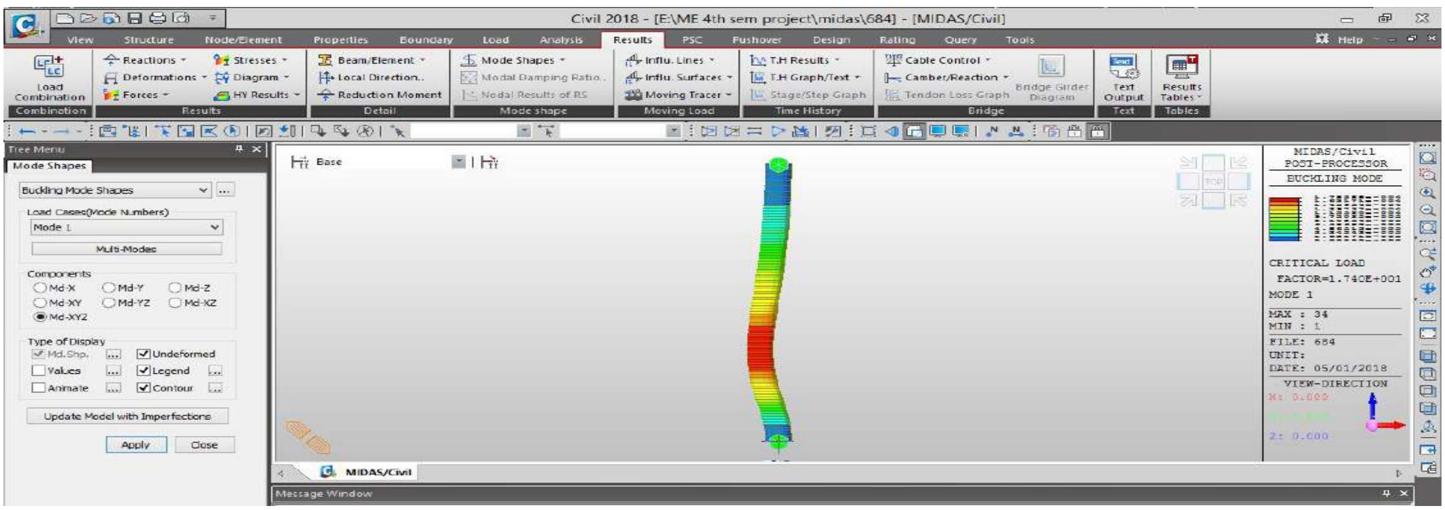


10. Click PERFORM ANALYSIS and the Buckling analysis will be done on the model.



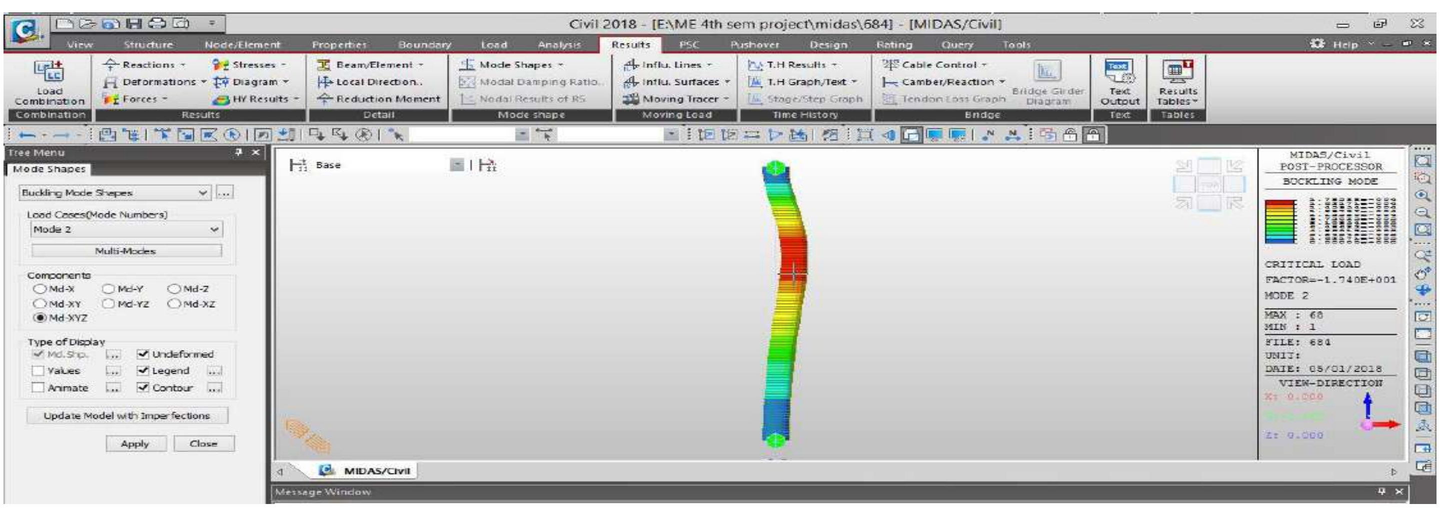
V. OBTAINING RESULTS, MODE SHAPES AND LOAD CALCULATION.

1. Click on **Results>Mode Shapes>Buckling Mode Shapes**. Select Mode 1,2 and 3 one by one. Check on Undeformed, Legend and Contour and click on Apply to see different mode shapes graphically. You can also view multiple buckling mode shapes at the same time by clicking on Multi Modes option.

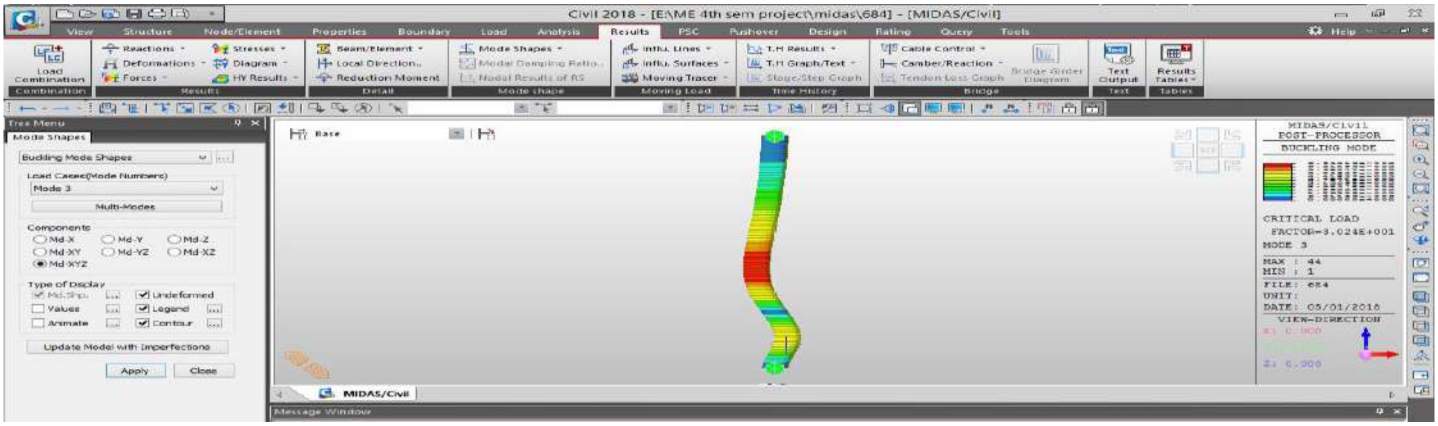


The Critical Load Factor obtained for 1st mode is 1.740E+001. Therefore the load for this mode is nominal load applied multiplies by the critical load factor. That is, Maximum Compressive Force for Buckling, Pcr= 10 X 17.40 = 174 KN.

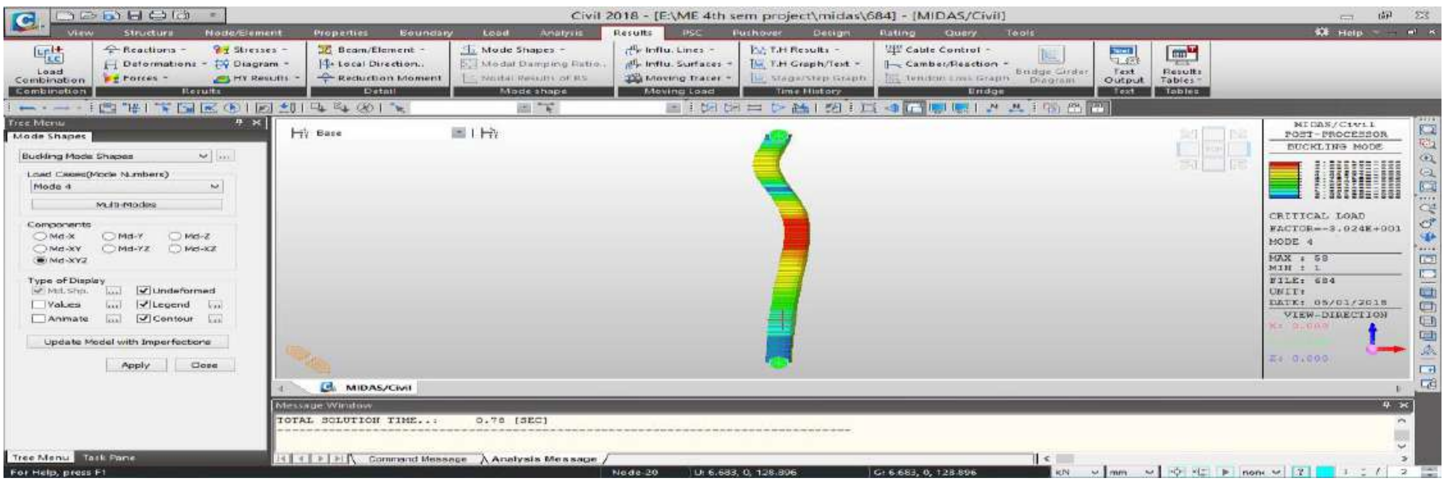
2. For 2nd mode, critical load factor is 1.740E+001. Pcr = 10 X 17.40 = 174 KN.



3. For 3rd mode, critical load factor is 3.024E+001. Pcr = 10 X 30.24 = 302.4 KN.



4. For 4nd mode, critical load factor is 3.024E+001. Pcr = 10 X 30.24 = 302.4 KN.



VI. RESULTS

EXPERIMENTAL LOADS & OTHER DATA						LOADS FROM MIDAS CIVIL (kN)			
sl no.	**Length (mm)**	**Diameter (mm)**	**Load P (kN)**	**Weight (kg)**	**Grades**	**MODE 1**	**MODE 2**	**MODE 3**	**MODE 4**
1	678.4	48.3	142.8	3.054	M20	174	174	302.4	302.4
			146.8	3.126	M30	180.6	180.6	318.3	318.4
			150.2	3.25	M40	186.1	186.1	331.3	331.3
			131.3	2.402	H	141.1	141.1	221.7	221.7
2	594.6	42.4	118.9	2.934	M20	145.2	145.2	250.7	250.7
			121.8	2.886	M30	149.6	149.6	262	262
			124.2	2.986	M40	154	154	272.2	272.2
			109.3	1.732	H	121.3	121.3	191.4	191.4
3	508.8	42.4	162.2	2.38	M20	185.8	185.8	294.5	294.5
			166.1	2.416	M30	192.6	192.6	310.1	310.1
			169.2	2.52	M40	198.2	198.2	322.9	322.9
			121.8	1.512	H	151.8	151.8	216.7	216.7
4	424	42.4	233.5	2.112	M20	241.3	241.3	340.1	340.1
			239.1	2.215	M30	251.4	251.4	360.7	360.7
			243.9	2.022	M40	259.6	259.6	377.6	377.6
			180.6	1.22	H	190.5	190.5	239.6	239.6
5	339.2	42.4	323.24	1.154	M20	314.9	314.9	379.7	379.7
			331.31	1.182	M30	330.6	330.6	406.1	406.1
			379.9	1.088	M40	343.4	343.4	427.9	427.9
			334.2	0.714	H	235.2	235.2	255	255
6	254.4	42.4	220	1.208	M20	393.3	393.3	400.9	400.9
			227	1.118	M30	419.1	419.1	431.7	431.7
			238	1.156	M40	440.2	440.2	457.6	457.6
			200	0.627	H	259.9	259.9	264.6	264.6
7	202.2	33.7	170	0.658	M20	279.3	279.3	283.5	283.5
			178	0.698	M30	294.4	294.4	301.2	301.2
			184	0.69	M40	306.9	306.9	316.1	316.1
			145	0.462	H	202.1	202.1	205.7	205.7

CONCLUSIONS

1) Increase in thickness of steel tube, enhance the capacity (Pu) of both Hollow and composite column as confinement pressure increases with increase in thickness of steel tube
2) Ultimate load obtained from MIDAS CIVIL non-linear Modeling varied by 2% to 11% when compared with experimental values.
3) Ultimate load values obtained were found to be slightly higher in magnitude when compared with experimental values.
4) Finite element model results obtained from MIDAS CIVIL compared with Experimental results of the hollow and composite columns with different grades including different thickness varied very less.
5) The critical load factor and the load value for a given specimen is found to be same for 1st and 2nd mode and 3rd and 4th mode respectively.
6) Thickness of the tube plays a vital role in load carrying capacity, as the thickness increased i.e., for D/t ratio there is a slight decrease in load carry capacity.

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Mohamed Ghayaas Anjum Obtained B.E degree in Civil Engineering (First Class with distinction) during the year 2016 from Ghousia college of engineering, ramanagaram, 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, Prof.&Director(R&D), is involved in this Research field related to behavior of Composite Steel Column since a Decade. He has guided One Ph.D Thesis (under VTU,Belgaum), more than 25 M.tech projects including one M.Sc. Engineering (by Research under VTU, Belgaum). Presently guiding Six Ph.D Scholars under VTU Belgaum. Has more than 29 years of teaching & 6 years of Research experience at Ghousia College of Engineering, Ramanagaram. To his credit, he has 130 Inter National /National research publications as on date.