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Finite Element Analysis Hollow Circular Steel Section Strengthened by FRP Tow Sheets

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Abstract: This paper presents the comparison of conventional steel section and FRP (Fibre Reinforced Polymer) tow sheet wrapped steel section, which gives high strength and resists the buckling behaviour. The circular hollow steel section is widely used in structural and non-structural elements, on off shower and on shower buildings. More excellent properties of the tubular shape with regard to loading in tension, compression, bending in all directions. To increase the strength and durability of steel structure, FRP tow sheet are used in the section. The section according to the class 4 according to the euro code 3,EN 10219-2:2006(E) Cold form steel section, 200mm diameter, 800mm length hollow circular steel section .FRP has been established as an effective method of strengthening of steel and concrete. The different fibres combination is called as tow sheets (one layer of glass sheet placed between two carbon sheets.). New technique of using FRP tow sheet has gained importance as the bond that has been created by wrapping. The finite element software (Using ABAQUSE software) under axial loading is determined. Use carbon and glass laminates in the section to increase the load bearing capacity and delay the buckling failures.

Keywords: Circular hollow section column, Carbon laminates, Glass laminates, Nitowrap Adhesive, Euro code 3, Buckling behaviour, finite element analysis.

I. INTRODUCTION

Circular hollow sections, also known as round steel tubes, are a common type of steel section. These steel sections are rolled from steel sheet or slit coil. The slit strip of steel coil goes through a forming and sizing section in a normal cold forming steel mill. The mill consists of a number of passes through which the sheet is gradually formed, each pass bending the steel sheet more and changing the radii on each pass. Round steel sections can be rolled from a variety of materials. Most common is hot and cold rolled steel tubes. Hot rolled sections are predominantly used for structural purposes while tubes rolled from cold rolled steel has better bending ability and gives a better aesthetic appearance after being powder coated. The cold formed circular hollow section steel column is analysed by both numerical simulation in finite element Abaqus software and experimental testing.

A. Applications of circular hollow section

- Circular hollow sections are symmetric about any censorial axis.Circular hollow sections are considered aesthetically pleasing.
- The circular hollow sections mainly are introduced for isolated columns. it is even recommended for pile piers. where, there is no particular face to the column but all lateral and imposed impact traverseMore uniformly within the column. The circular column is the function of the diameter, and varies. but widely used inbuilding

B. Objective

- To determine the behaviour of circular hollow section column under the compression loading.
- To determine the strength and stability of the circular hollow section column.

C. Cold formed steel

Cold rolled steel is essentially hot rolled steel that has had further processing. The steel is processed further in cold reduction mills, where the material is cooled (at room temperature) followed by annealing and/or tempers rolling. This process will produce steel with closer dimensional tolerances and a wider range of surface finishes.

D. Advantage of Cold Formed Steel

- High strength and stiffness
- Lightness in weight
- Ease of prefabrication and mass production
- Fast and easy erection and installation

- Substantial elimination of delays due to weather
- More accurate detailing
- Non shrinking and non-creeping at ambient temperatures
- No formwork needed
- Termite-proof and rot proof
- Uniform quality

E. FRP Material

Fibre-reinforced plastic (FRP) (also called fibre-reinforced polymer, or fiber-reinforced plastic) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass (in fibreglass), carbon, aramid, or basalt. Rarely, other fibres such as paper, wood, or asbestos have been used. The polymer is usually an epoxy, vinyl ester, or polyesterthermosetting plastic, though phenol formaldehyde resins are still in use.

F. Characteristics of FRP

- FRP is known for its mechanical strength and a popular choice when it comes to corrosion resistance.
- Furthermore is FRP lightweight, has excellent temperature-resistant properties, offers thermal insulation and can be formed in complex shapes.
- FRP products are easy to repair and hardly require any maintenance.

G. Structural Applications of FRP

FRP can be applied to strengthen the beams, columns, and slabs of buildings and bridges. It is possible to increase the strength of structural members even after they have been severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and filling in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through wet, hand lay-up of impregnating the fibre sheets with epoxy resin then applying them to the cleaned and prepared surfaces of the member.

H. Carbon Fiber(Carbon laminates)

Carbon-fiber-reinforced polymers are composite materials. In this case the composite consists of two parts: a matrix and reinforcement. In CFRP the reinforcement is carbon fiber, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. CFRP can also be applied to enhance shear strength of steel section by wrapping fabrics or fibers around the section to be strengthened. Wrapping around sections can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economic than alternative methods.Figer.1 shown in carbon laminates.

There are two types of carbon fibre

The thickness are varied

1. 450 GSM (Grams per Square Meter)
2. 250 GSM

I. Glass Fiber (Glass Laminates)

Glass fiber is a material consisting of numerous extremely fine fibers of glass. Glass fiber is commonly used as an insulating material. It is also used as a reinforcing agent for many polymer products; to form a very strong and light fiber-reinforced polymer(FRP) composite material called glass-reinforced plastic (GRP), popularly known as "fiberglass". Glass fiber has roughly comparable properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle.Figer.2 shown in glass laminates.

Fig.1 Carbon laminates

Fig.2 Glass laminates

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J. Nitowrap Adhesive

Nitowrap is used for strengthening columns and beams of load bearing structures specifically where improvement to shear strength and deformation properties is required. Typical applications include piers, columns, connecting beams and slabs of railway and road bridges, buildings and towers. Nitowrap is a high strength, high elastic modulus carbon fibre sheet which when used in conjunction with a specially developed primer, improves structural performance by strengthening and improving shear strength and deformation properties.

K. FRP Tow Sheets

Carbon and glass fibers are the most commonly used fiber types. The term tow sheet is used to describe a wide, dry carbon fiber product in which individual carbon tows are aligned parallel to each other and held in place by glass fiber with epoxy-soluble adhesive. Figer.3 shown in tow sheet.

Fig.3 Tow Sheet

L. Composite System

- First layer is the primer. It can be applied by a brush.
- The next layer is the carbon laminates with epoxy resins.(450 gsm and 250 gsm)
- The next layer is the glass laminates with epoxy resins.
- The next layer is the carbon laminates with epoxy resins.(450 gsm and 250 gsm)

- ➢ Specimen – 1(CHS)
- ➢ Specimen – 2(CHS-CFRP 450gsm-GFRP-CFRP 450gsm)
- ➢ Specimen – 3(CHS-CFRP 250gsm-GFRP-CFRP 250gsm)
- ➢ Specimen – 4(CHS-CFRP 450gsm-GFRP-CFRP 250gsm)

M. Methodology

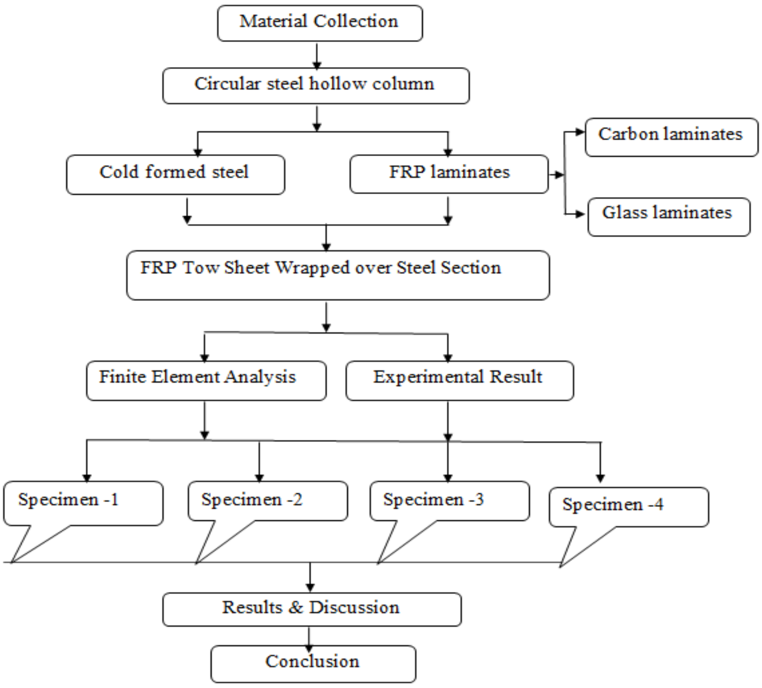

Fig.1 Methodology flowchart

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II. SECTIONS DETAIL

A. Column Section Property

The cross section of circular hollow section columns of 200 mm diameter were used for both numerical modelling and experimental testing. The cross sections used as per the code EN 10219-2-2006. The thicknesses of the columns are 2 mm. The aspect ratio of the column is 4 for cross sections. The cold formed steel of 235 grade is used. The Poisson's ratio for the used steel is 0.3 and young's modulus is 200Gpa and 210Gpa for cold formed steel section and hot rolled steel section respectively. Circular hollow section columns were used for numerical modelling and experimental testing.Fig.5 shown in Circular hollow section. Circular hollow section shown in fig.4.

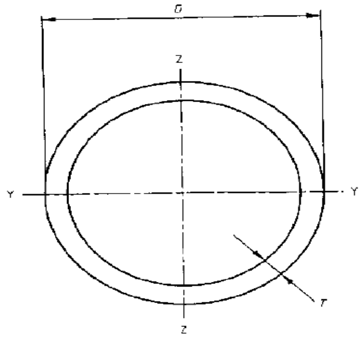

Fig.4Circular hollow section

B. Computation of Column Parameters

In this study circular hollow section stub columns 200mm x 2mm, are used. The circular hollow section columns areas of cross section, moment of inertia are calculated by referring the code EN 10219-2-2006. The length of stub column cold formed steel should not be less than three times the largest dimension of the cross section and not greater than $20r_y$ wherer_y is the radius of gyration about minor axis

Specified outer diameter	(D) = 204mm
Specified thickness	(t) = 2mm
Inside diameter	(d) = 200mm
Specified length	(L) = 800mm

Where,
D = Outer diameter,
d = inside diameter

Superficial area per meter length	(A_s)	$= \frac{\pi D}{10^3}$	= 0.640 (m^2/m)
Cross sectional area	(A)	$= \frac{\pi(D^2-d^2)}{4\times10^2}$	= 12.64 (cm^2)
Mass per unit length	(M)	= 0.785×A	= 9.965
Second moment of area	(I)	$= \frac{\pi(D^4-d^4)}{64\times100^2}$	= 647.41 (cm^4)
Radius of gyration	(r)	$= \sqrt[2]{I/A}$	= 7.142 (cm)

C. Cross Section Classification

The role of cross section classification is to identify the extent to which the resistance of cross sections is limited by its local buckling resistance. Four classes of cross-sections, namely Class 1 to 4 have been defined with limiting slenderness values. For the special case of circular hollow sections with the slenderness limits for circular hollow sections in Euro code 3 has been achieved. Four classes of cross-sections are defined, as follows:

- Class 1 cross-sections are those which can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance.
- Class 2 cross-sections arc those which can develop their plastic moment resistance, but have limited rotation capacity because of local buckling.
- Class 3 cross-sections are those in which the stress in the extreme compression fibre of the steel member assuming an elastic distribution of stresses can reach the yield strength, but local buckling is liable to prevent development of the plastic moment resistance.
- Class 4 cross-sections are those in which local buckling will occur before the attainment of yield stress in one or more parts of the cross-section.

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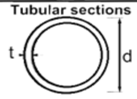
Local buckling is based on the concept of cross section classification. Classification is made by comparing the slenderness of the cross section with the prescribed limits specified in code. Elliptical hollow section steel column is new to the construction industry, so there is no any specified slenderness parameters in any code of practice. According to the L.Gardner and T.M Chan [2] that circular hollow section class slenderness limit from EN 1993-1-1-2005 will be suitable for the elliptical hollow section steel column. Cross section classification limits for the circular hollow section are adopted for the circular hollow section.Maximum width-to-thickness ratios for compression parts- CHS shown in fig.5.

Tubular sections



Class	Section in bending and/or compression
1	$d/t \le 50\varepsilon^2$
2	$d/t \le 70\varepsilon^2$
3	$d/t \le 90\varepsilon^2$ NOTE For $d/t > 90\varepsilon^2$ see EN 1993-1-6.

$\varepsilon = \sqrt{235/f_y}$						
	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71
	ε^2	1,00	0,85	0,66	0,56	0,51

Fig 5 Maximum width-to-thickness ratios for compression parts- CHS

Where,

Yield strengths (ε) = $\frac{235}{fy}$ = 1

Table.1 cross section classification

Column section	$\frac{D}{t}$	Limiting value	Cross section classification
200 x 2mm	102	<90	Class-4

Support condition

(Hinged –Hinged condition)

Slenderness ratio = $\frac{l\,(eff)}{r}$ = 11.2

III. FINITE ELEMENT ANALYSIS OF COLUMNS

The finite element program ABAQUSis a computational tool for modelling structures with material and nonlinear behaviour. ABAQUSversion 6.14 was used to simulate the model and find maximum deflection and load carrying capacity of FRP wrapped specimens. Four circular hollow section column models of 200mm×2mm(specimen 1, 2, 3, 4) are designed in the finite element software ABAQUS/CAE, provides a complete modelling and visualization environment for ABAQUS analysis products. With direct access to CAD models, advanced meshing and visualization, and with an exclusive view towards ABAQUS analysis products, ABAQUS/CAE is the modelling environment of choice for many ABAQUS users. In finite element software ABAQUS the columns are analysed by defining the following part, property, assembly, step, load, mesh.

- **Pre-processing or modelling**: This stage involves creating an input file which contains an engineer's design for a finite-element analyzer (also called "solver").
- **Processing or finite element analysis:** This stage produces an output visual file.
- **Post-processing** or generating report, image, animation, etc. from the output file: This stage is a visual rendering stage.

1. Modelling

All circular hollow steel sections were modelled by using shell elements. Circular hollow section diameter 200mm. Wrapped with FRP sheets.The modal plan view of the specimens shown in figer.6.

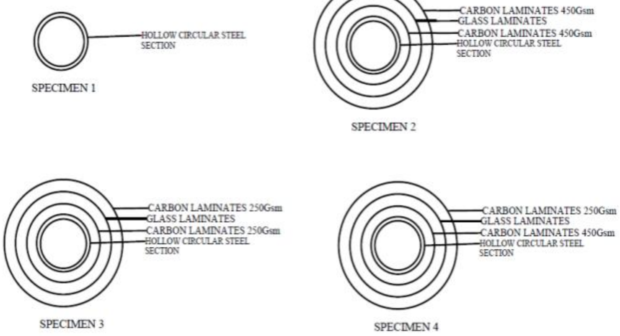


Fig.6The modal plan view

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2. Materials Geometry**:**

All CHS models were created as surface body elements and they are extruded to the length of 800mm.The CHS were made as thin shell element. The strip wrapping was also drawn thin shell element and then extrude to the required thickness. This procedure is continued for entire length of the section.Material properties are shown in table.2.

TABLE .2 MATERIAL PROPERTIES

MATERIAL	THICKNESS(mm)	YOUNG'S MODULUS (N/mm^2)	YIELD STRENGTH (N/mm^2)	POISSON RATIO
STEEL	2	2×10^5	235	0.3
GFRP	0.2	76×10^3	2200	0.2
CFRP (450GSM)	0.3	285×10^3	3500	0.3
CFRP (250GSM)	0.2	235×10^3	2100	0.2

3. Material Modeling

The first step in the finite element modelling is defining the part. The Parts Module is where you make all the basic definitions of Parts (shapes, sections, etc. not boundary conditions or any analysis) the defining part means the creation of model shapes, section in this study it is circular hollow section column of cross section diameter 200 mm. The height of the column is 800mm. the shell shape, extrusion type section is created for this circular hollow section column.

4. Materials Definition

The materials that are to be assigned to different parts are defined .The elastic and mechanical properties of the materials are created. Materials are defined to each part based on its type. Material properties are applied by figer.7, 8,9,10.

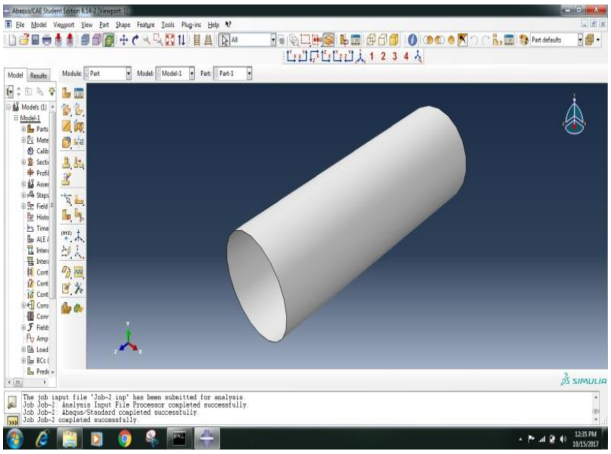

Fig.7Circular hollow section column

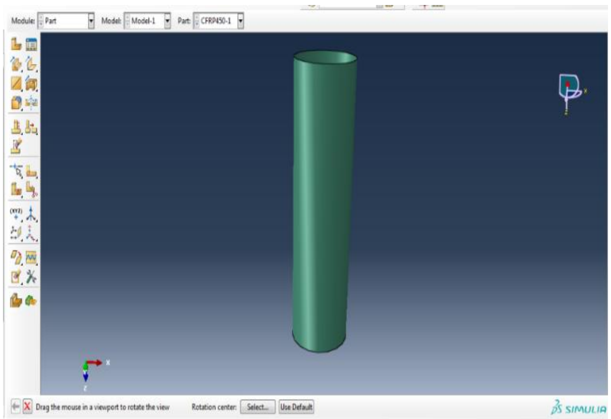

Fig.8Carbon laminates 450gsm

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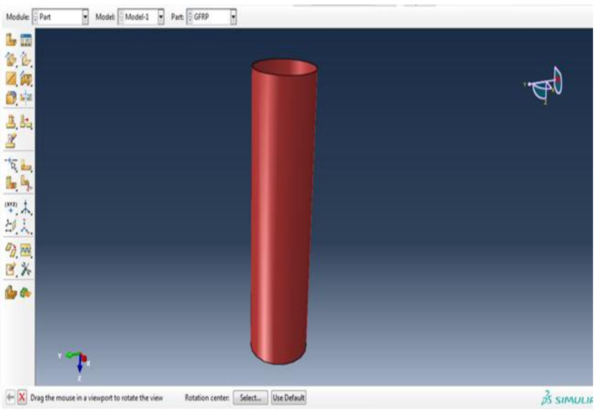

Fig.9 Carbon laminates 250gsm

5. Assembly

After creating section and materials, instance are created by assembling the parts to create the exact model of the proposed problem .Instances are created for all the four connection types considered in the study.Assembly of modal Shown in figer.11.

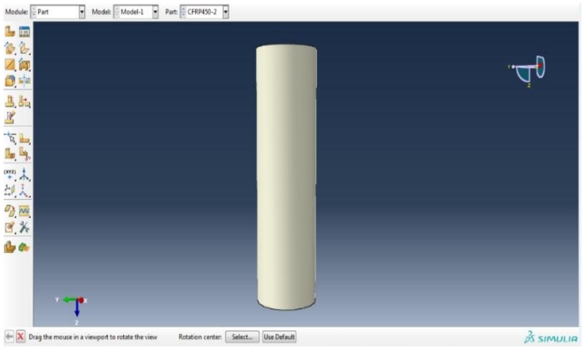

Fig.10 Glass laminates

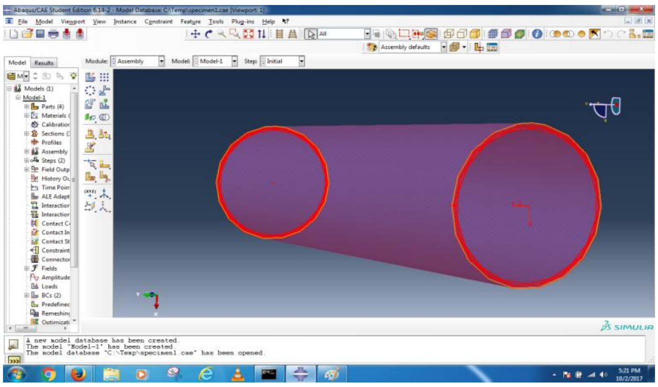

Fig.11Assembly of modal

1. Step Module

In finite element modeling, step module is for setting the type of analysis we needed and the analysis procedure. In this study, elliptical hollow section buckling analysis has been done. The step module is used for setting the buckling analysis. Buckling analysis calculates buckling load magnitudes that cause buckling and associated buckling modes. FEA programs provide calculations of many buckling modes and the associated buckling-load factors (BLF). The BLF is expressed by a number which the applied load must be multiplied by (or divided — depending on the FEA package) to obtain the buckling-load magnitude.Step Module is view on figer.12.

2. Load and Boundary conditions**:**

The step sequence provides a convenient way to capture changes in the loading and boundary conditions of the model, changes in the way parts of the model interact with each other, the removal or addition of parts, and any other changes that may occur in the model during the course of the analysis.

The initial step allows defining boundary conditions, predefined fields, and interactions that are applicable at the very beginning of the analysis. Analysis step is associated with a specific procedure that defines the type of analysis to be

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performed during the step, such as a static stress analysis or a transient heat transfer analysis. After interaction module is done for the instance Boundary conditions are defined at the end of the model and point load is given at the centre node to as per the simplified analysis.Boundary Conditionare applied by figer.13.

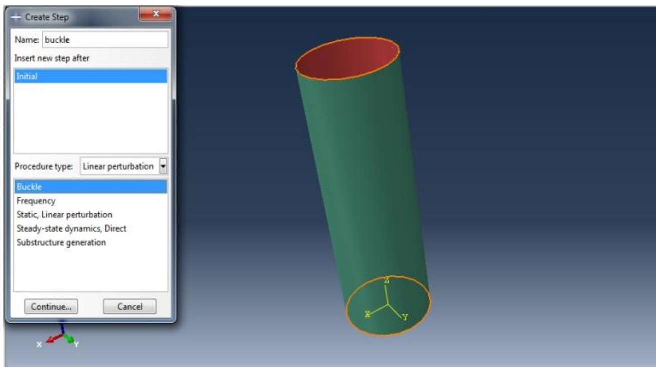

Fig.12Step Module

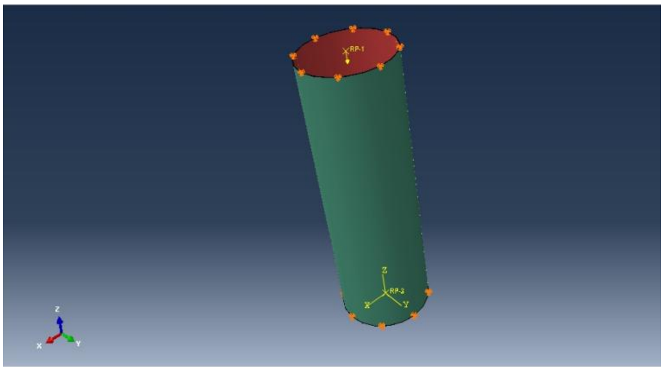

Fig.13Boundary Condition

3. Finite element mesh**:**

The influence of the finite element size on the behavior of circular hollow steel section was first studied. Meshing is used for accurate presentation of complex geometry, easy representation of the total solution, and capture of local effects. According to results requirement meshing can be increase (or) decrease and apply the mesh size as were generated automatically by the abaqusprogram and used in all simulations.Meshed Circular hollow section columnsshown in figer.14.

4. Job Module

When the finite element modeling such as geometry, material property, boundary conditions, loading and mesh generation are completed. You can use the job module to analyze your model. The job module is for defining and submitting the job. After the submission of job the section will be analysed. The analysis of the section will be submitting the job. The analysis process will take in the job module and the result will be generated.

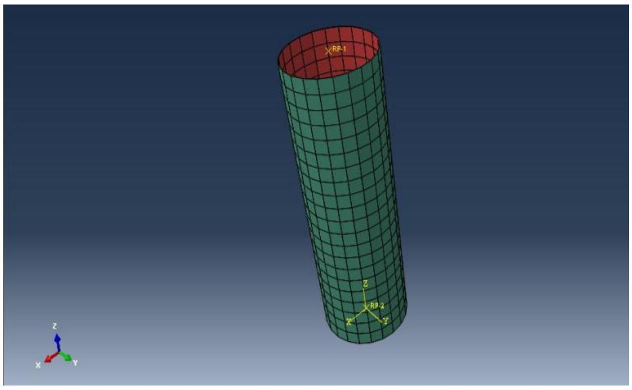

Fig.14Meshed Circular hollow section columns

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5. POST PROCESSING

Finite element analysis successfully according to the prompt in the log tag of job monitor, you can choose the results button in job manager window to enter visualization module to view the result in different methods. The Visualization module provides graphical display of finite element models and results. It obtains model and result information from the output database; you can control what information is placed in the output database by modifying output requests in the step module i.e. the type of analysis. In this study buckling analysis is requested.

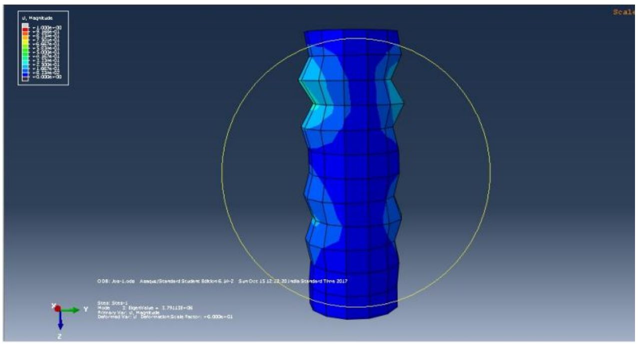

Fig.15 Numerical tested cold formed CHS (Specimen 1)

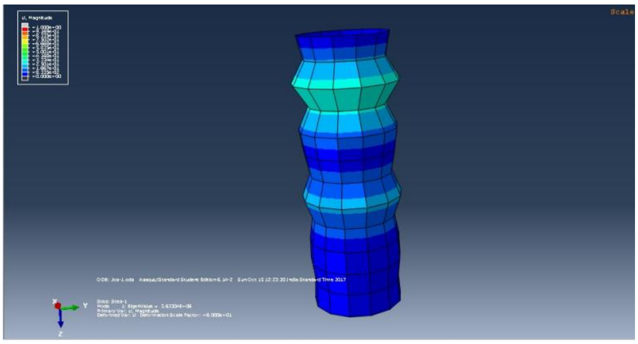

Fig. 16 Numerical tested cold formed CHS with FRP (Specimen 2)

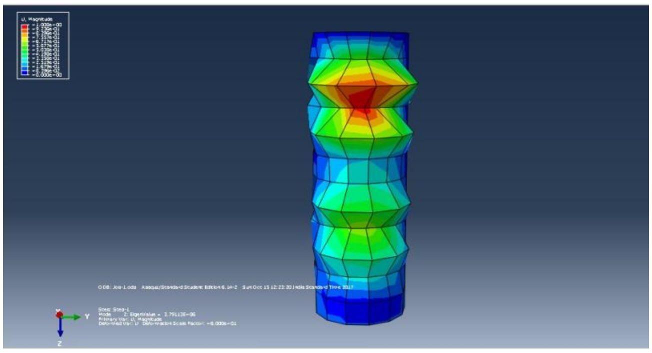

Fig. 5.17 Numerical tested cold formed CHS with FRP (Specimen 3)

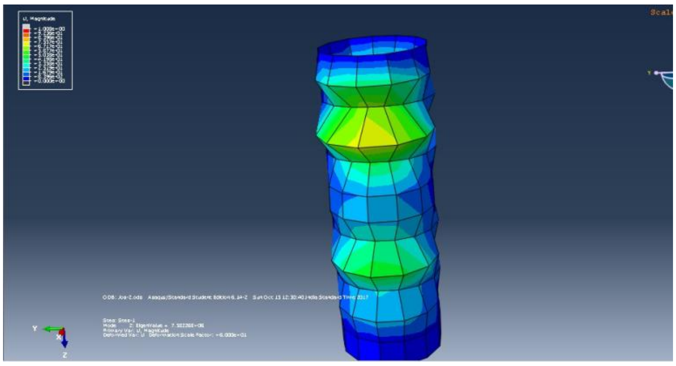

Fig.18 Numerical tested cold formed CHS with FRP (Specimen 4)

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After a finite element model has been prepared and checked, boundary conditions have been applied, and the model has been solved, it is time to investigate the results of the analysis. This activity is known as the post-processing phase of the finite element method. In the visualization module, we can view un-deformed shape, deformed shape, Animation of results, Contour plots, Eigen value (critical load). In the animation of result, the video of section will be shown how the section getting deformed. Analysis results and buckling is shown in figer.15, 16, 17, and 18.

IV. RESULT AND DISCUSSION

Numerical results for the 4 specimens are shown in table 3 and figer.19.

Table .3 Ultimate Load & Deflection From Analysis

Type	Connection	Peak load(KN)	Deflection at mid span (mm)
1	Specimen 1	302.8	7.25
2	Specimen 2	628.3	4.10
3	Specimen 3	463.1	6.83
4	Specimen 4	572.3	6.05

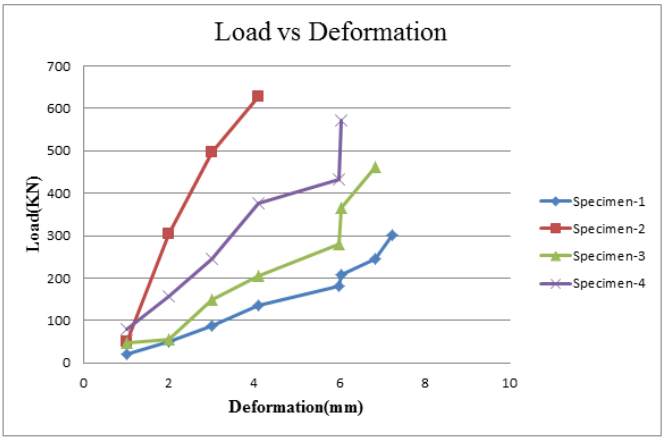

Fig.19 Load vs Deformation

From the analysis, the load bearing capacity of type 3(sigma section sleeved) connection is maximum of all other connections showing flexible behaviour of deflection about 4.10 mm at the ultimate load 628.3kN.

V. CONCLUSION

The preliminary works such as literature study on circular hollow steel, carbon andglass laminates have been explained. Performance study on hollow circular steel columns wrapped with FRP tow sheets are carried out by finite element analysis. Using abaqus/CAE software. FRP tow sheets can be used for rehabilitation works and to avoid heavy damage before complete failure of a structure. In this paper four set of specimens according to the euro code 3 are analysed under axial loading. From the analysis specimen (2) shows higher strength with ultimate load of 628.3kN than that of other three cases. Behaviour of all the four specimens with ultimate load and deflection has been explained. It's mostly used in high-rise buildings, steel frames, and steel bridges.

FUTURE SCOPE OF WORK

Hence, different innovations can be done by changing the thickness and width of the FRP strips. It is recommended that further experimental and numerical research is needed to find the suitable and economical wrapping schemes for strengthening of CHS members under compression.

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