BEHAVIOR OF CFRP STRENGTHENED CHS MEMBERS UNDER CYCLIC LOADING USING FE MODELLING

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Abstract - *Tubular hollow steel members have been widely used as structural elements in civil infrastructure throughout the last few years. Despite the likelihood of steel structures being damaged during an earthquake due to their cyclic features, few investigations have been made on the cyclic strengthening of CHSs. The cyclic performance of carbon fiber reinforced polymer (CFRP) enhanced CHS specimens is investigated using a finite element (FE) modelling methodology in this study. A previous investigation was used to determine the material properties of CFRP and adhesive. The CHS specimen dimensions and material properties are taken from IS codes. A study was done to list out the parameters which result on CHS member. The impacts of T-CFRP/T-CHS and D-CHS/T-CHS on the cyclic performance of strengthened CHS members are then evaluated in a detailed parametric investigation. The comparison of FE results of Bare CHS element and CFRP strengthened elements is done by using the Backbone curve of the moment (kN.m) vs rotation (radians), a Bar graph of the maximum moment (kN.m) of a member, and stiffness (kN/m) of a member at a particular rotation. The results show that these parameters have a considerable impact on the cyclic performance of CFRP-strengthened CHS components. Increases in the T-CFRP/T-CHS, as well as the D-CHS/T-CHS specimens, enhance the efficiency of enhancing strength of CHS members.*

***Key Words*: CFRP; Finite Element Modelling; Circular Hollow Section (CHS); Cyclic Loading; Strengthening; IS-1161-2014.**

1.INTRODUCTION

When the cyclic load is applied to tubular hollow members, they become incredibly unstable. They've been widely utilized in onshore and offshore civil infrastructure where earthquakes, waves, currents, and wind may cause cyclic loading. As a result, to handle both static and cyclic loads, tubular hollow steel members may have to be strengthened. In the present study externally-bonded carbon fiber-reinforced polymer (CFRP) has been used to strengthen the circular hollow section (CHS) steel specimens. As a result, a detailed analysis of the strengthening of tubular hollow steel members is essential. Although the carbon fiber-reinforced polymer (CFRP) strengthening approach has demonstrated its efficacy in improving the structural response of various steel members, few studies of the structural response of circular hollow section (CHS) steel elements reinforced with CFRP have been conducted. By comparing the FE model simulated outcomes, an effective finite element (FE) model is first established throughout this study. The impact of the T-CFRP/T-CHS, as well as the D-CHS/T-CHS on the structural response of the strengthened component subjected to cyclic loading, is studied in parametric research. The analysis shows that these parameters have a considerable impact on the cyclic performance of CFRP-strengthened CHS elements. The effectiveness of enhancement is improved by increasing the T-CFRP/T-CHS and D-CHS/T-CHS specimen.

2.SCOPE

In this investigation, an effort is made to study and analyze parameters that affect the strength of CHS retrofit with CFRP under cyclic loading. The sections will be designed as per Indian standard codes. The study helps out to reduce the cost of material required for the parametric investigation of CHS members under cyclic loading. The study also helps to analyze and optimize the requirement of the CFRP material required for strengthening.

3.OBJECTIVES

1. To develop finite element models of the circular hollow steel sections.
2. Under cyclic loads, to analyse the effect of T-CFRP/T-CHS.
3. To study the behavior of the D-CHS/T-CHS under cyclic loading.
4. Compare and conclude the results of Bare and CFRP strengthened CHS steel members subjected to cyclic loading.

4. MODELLING AND ANALYSIS OF CHS MEMBER

Steel section specifications are derived from IS code and modelled using FE software with member's specimen is 12 mm, an external diameter of 324 mm, and 5000 mm long.

The bond length of CFRP has been modelled for a length of 3000 mm from fixed support. The T-CFRP is 0.6 mm, and T-Adhesive is 0.1 mm. The adhesive layer is plotted between steel and strength enhancing CFRP material to find the failure pattern.

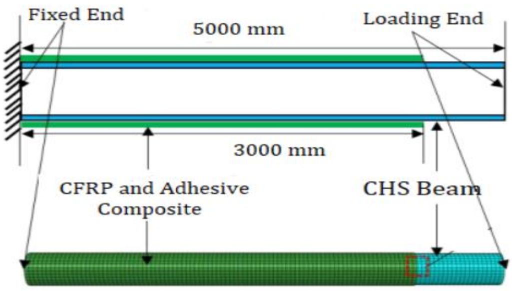


Fig-1: Model

4.1 Finite Element Model

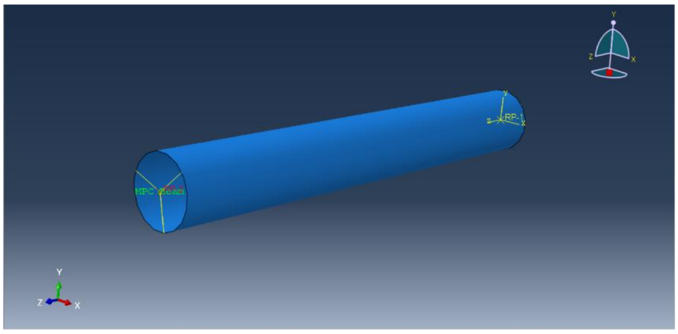
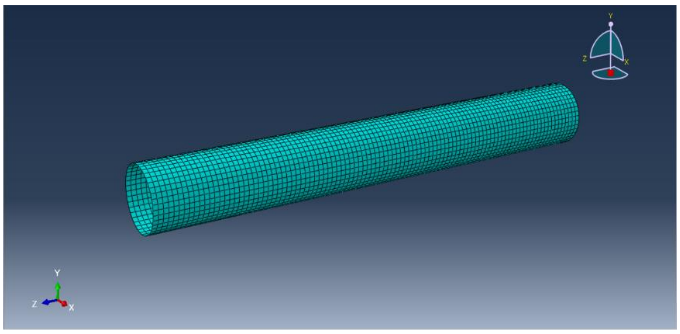


Fig-2: Geometry



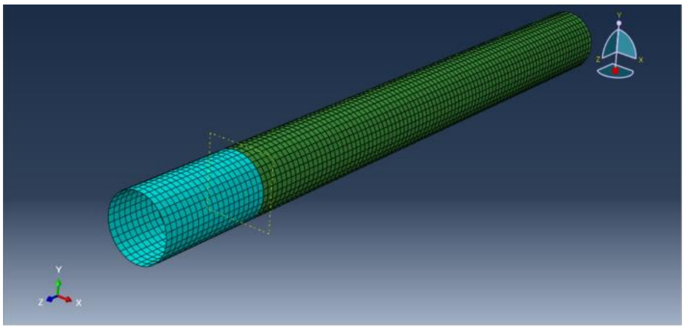


Fig-3: Meshing Bare and Strengthened Element

- **Steel –** 4-node shell element (**S4R**).
- **Adhesive –** 8-node 3D cohesive element **(COH3D8)** by solid offsetting in the outward direction of orphan mesh.
- **CFRP –** 8-node shell element (**SC8R**).
- **Meshing** – Meshing of adhesive and CFRP is done by solid offsetting in the outward direction of orphan mesh. The size of the mesh is 50mm.

4.2 Input Engineering Data

I. Loading Protocol

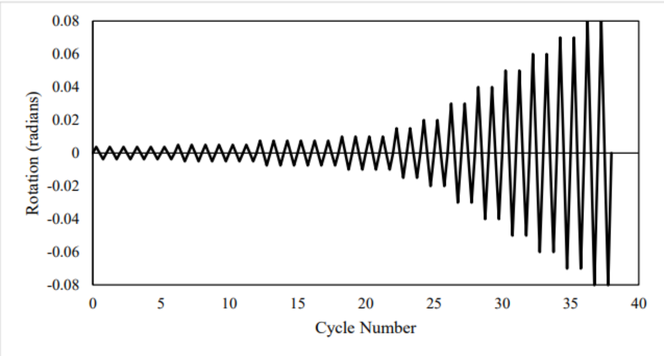


Fig-4 : **ASCI** Cyclic Loading Protocol

II. Material Properties

Steel:

Elastic Modulus – 210 GPa
Tensile Strength – 480 MPa
Yield Strength – 200 MPa
Poisson's Ratio – 0.3

Adhesive: M-brace saturant

Modulus of Elasticity (E_a) – 2.86 GPa
Tensile Strength (σ_{max}) – 46.0 MPa
Normalized elastic modulus of adhesive in mode-I (k_{nn}) - 2.8 × 10^{13} N/m^3
Normalized elastic modulus of adhesive (k_{ss} = k_{tt}) - 1.4 × 10^{13} N/m^3

CFRP:

Modulus of Elasticity (E_{1c}) - 75 GPa
Modulus of Elasticity (E_{2c}) - 25 MPa
Tensile Strength (T^L) - 987 MPa
Fracture Energy Fiber Tension (G_{ft}) - 91,600 N/m
Fracture Energy Fiber Compression (G_{fc}) - 79,900 N/m
Fiber Energy Matrix Compression (G_{mc}) - 1100 N/m
Fiber Energy Matrix Tension (G_{mt}) - 220 N/m
Longitudinal Tensile Strength - 987 MPa
Longitudinal Compressive Strength – 197.4 MPa
Longitudinal Shear Strength - 98.7 MPa

Transverse Tensile Strength - 98.7 MPa
Transvers Compressive Strength - 98.7 MPa
Transvers Shear Strength - 98.7 MPa
Poisson's ratio – 0.33

5. PARAMETRIC INVESTIGATION AND RESULTS

➢ Effect of the ratio of T-CFRP to T-CHS

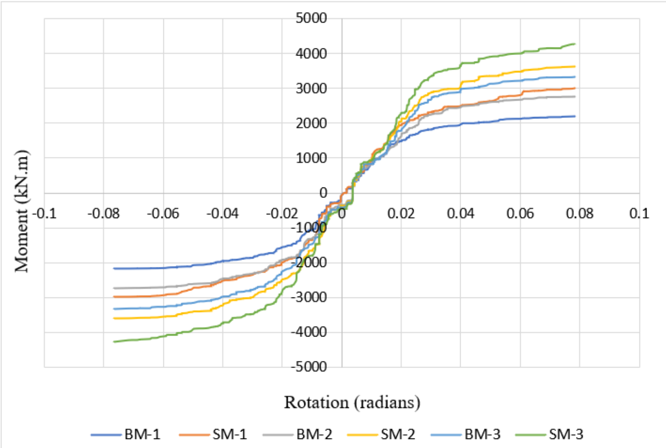


Fig-5: Moment Vs Rotation Backbone Curve

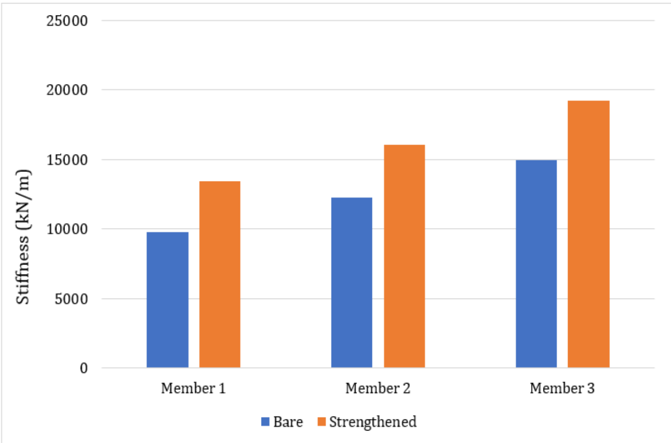


Fig-6: Stiffness @ 0.04 radians

Table-1: Percentage increase in Stiffness

Thickness of CHS Specimen (mm)	Percentage Increase in Stiffness
8	35.88%
10	31.39%
12	28.89%

The thickness of CHS members are 8 mm, 10 mm, and 12 mm with common outer diameter of 324 mm are considered. The members are enhanced with three layers of CFRP of bond length of 3000 mm to analyse the effect of T-CFRP/T-CHS under cyclic loading. As the T-CFRP is constant so the T-CFRP/T-CHS decreases with increase in T-CHS. The decrease in this ratio affects the efficiency of strengthening.

➢ Effect of the Diameter-to-Thickness ratio of CHS

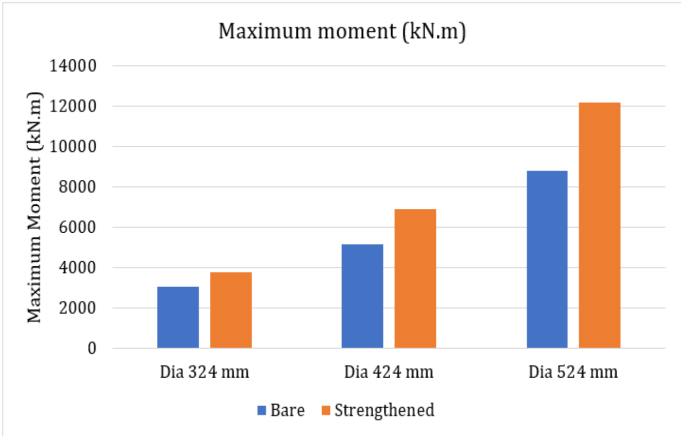


Fig-7: Maximum Moment @ 0.04 radians

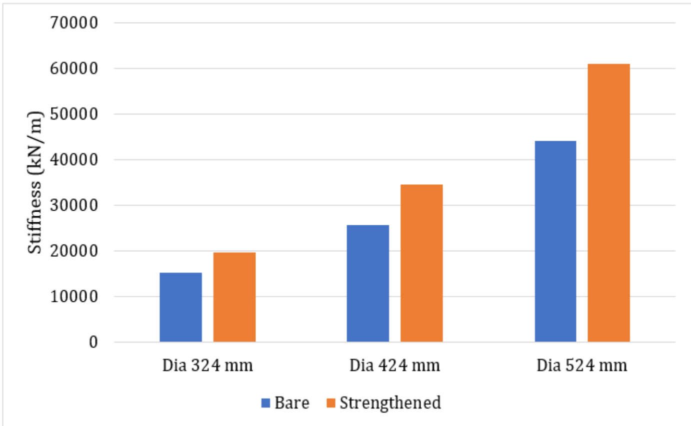


Fig-8: Stiffness @ 0.04 radians

Table-2: Percentage increase in Maximum Moment Capacities

Diameter of CHS (mm)	Percentage increase in Maximum Moment Capacities
324	28.89 %
424	34.15 %
524	38.21%

The diameter of CHS members are 324 mm, 424 mm, and 524 mm with constant thickness of 12 mm are modelled for bare and CFRP enhanced model and analysed under cyclic loading to determine the effect of D-CHS/T-CHS. The D-CHS/T-CHS increases with increase in diameter of CHS member. As we can see in Fig-7 the efficiency of enhancement of strength of strengthened member increases with increase in diameter of CHS member. This technique is applicable to optimise the cost of enhancing bare member.

6. CONCLUSIONS

In this study, the bare and enhanced CHS members are analyzed under cyclic loads. A parametric study is done on bare and enhanced CHS member and results are compared and final conclusion is noted as follow:

1. The above technique of analysis is accurately predicting the behavior of parameters and it will reduce the cost of experiment.
2. The efficiency of CFRP strengthening improves as the ratio of CFRP to CHS thickness rises.
3. The effectiveness of CFRP strengthening enhances as the D-CHS/T-CHS increases, while the CHS specimen's compactness reduces as the D-CHS/T-CHS increases.
4. When compared to bare CHS specimens, CFRP strengthened CHS specimens demonstrated reduced local buckling because the enhanced CHS member help to increase stiffness and distribute the stress efficiently.

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