Strengthening of the Deficient Steel Sections Using Hybrid Composites under Various Loading Scenarios

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***Abstract*— Recently ,the strengthening of steel sections using various fiber reinforced polymer (FRP) has come to the attention of several researchers. For different reasons, this type of structures may be placed under combination of loads. The deficiency in steel members may be due to errors caused by construction, corrosion, fatigue cracking, and other reasons. This study investigated the behavior of deficient tubular hollow section (THS) steel members strengthened by HYBRID composite FRP under two types of combined loads. To study the effect of HYBRID composite FRP strengthening on the structural behaviour of the deficient steel members, various parametric studied were conducted by varying damage level, various strengthening methods were analysed. To analyse the steel members, three dimensional (3D) modelling and nonlinear static analysis methods were applied, using ANSYS software. The results expected that HYBRID composite FRP strengthening had an impact on raising the ultimate capacity of deficient steel members and could recover the strength lost due to deficiency.**

Keywords*— *Fiber Reinforced Polymer, Tubular Hollow Sections, Non Linear Static Analysis.

I. INTRODUCTION

Strengthening of the steel structures can be done using Fiber-reinforced polymer (FRP) FRP, also Fibre-reinforced plastic, is a composite material made of a polymer matrix reinforced with fibres. The fibres used are usually glass, carbon, or aramid. It is actually a stronger material than steel, making it a much stronger system whilst maintaining being a very lightweight material. Hence FRP is able to maintain its high strength even being a very lightweight material. Fiber reinforced polymer (FRP) composites or advanced composite materials are very attractive for use in civil engineering applications due to their high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, light weight and potentially high durability. FRP outperforms wood and concrete structures, while holding up to decades of wear and tear. Fiber-Reinforced Polymer (FRP) composites offers five major benefits for any infrastructure , faster installation time, Lightweight material, Resistance to corrosion & very little maintenance, Cost savings, Design flexibility. Fiber Reinforced Polymer (FRP) includes a system of both carbon fibres and the bonding epoxy. The carbon fibres themselves are great in fire as they will not lose strength, even while glowing red hot. One drawback of FRP materials is their relatively high cost compared to other materials. Other drawbacks include: The need for various saw blades and drill bits than those used with wood or steel. Attention if irritation persists, or if severe coughing or breathing difficulty occurs. This provides the raw materials used for economical alternatives to conventional construction materials such as steel and wood. Most important in the context of sustainability, FRP manufacturing represents a radically low environmental impact over the traditional material preparation methods. Fiberglass reinforced plastics (FRP), are indeed initially more overpriced than traditional materials. However, it offers huge merits over these materials and has a lower overall cost of ownership and many other benefits. FRP panels are normally 0.09 inch in thickness and weigh about 12 ounces per square foot. Variations in material removal rates and hardness between the matrix and filler materials create difficulties in preparation such as polishing relief or rounding. These problems can cause wrong measurements, disguise problems or create artificial damage. Fiber Reinforced Plastics or Fiber Reinforced Panels (FRP) are plastics that contains fiber such as glass, carbon, aramid, or basalt. The deficiency in steel members may be due to errors caused by construction, corrosion, fatigue cracking, and other reasons. The use of externally bonded FRP has become increasingly popular for civil infrastructure applications. CFRP, GFRP, AFRP, BFRP etc. are some of the types of FRP. CFRP contains carbon as the fibre component, whereas GFRP contains glass as the fiber component. Moreover, CFRP is highly expensive, which limits the use of this material in many applications. BFRP – It is a composite material containing rigid polymer resin bounding unidirectional basalt fibers. Basalt Fibre Reinforced polymer bars have the advantage of corrosion resistance, high strength, light weight, good dielectric properties. AFRP- Aramid Fibre Reinforced Polymer is made up of aramid fibers, and have excellent corrosion resistance. The most common FRP systems for concrete strengthening applications are carbon based (CFRP). Carbon has high mechanical properties and higher tensile strength, stiffness, and durability compared with glass fiber based systems. Prefabricated FRP elements are typically stiff and cannot be bent on site to wrap around columns or beams. FRP fabric, on the other hand, is available in continuous unidirectional sheets supplied on rolls that can be easily tailored to fit any geometry and can be wrapped round almost any profile. FRP fabrics may be adhered to the tension side of structural members (e.g. slabs or beams) to provide additional tension reinforcement to increase flexural strength, wrapped around the webs of joists and beams to increase their shear strength, and wrapped around columns to increase their shear and axial strength and improve ductility and energy dissipation behavior.

II. OBJECTIVES

- Study the properties of the tubular sections without damage and with damage by varying the damage levels and to analyse the 3D model developed using ANSYS software.
- Various types of damage includes, surface level corrosion, local level corrosion etc. and to determine the type of damage and strength loss.
- To propose effective method of strengthening the deficient case.
- Hybrid composite FRP means the composition of combination of various FRP elements like GFRP, BFRP and ASRP (cost effective than CFRP).
- By varying the thickness and combinations, best strengthening and deficiency improvement technique are introduced
- Output parameters are Ultimate load, Ultimate deflection, Ultimate strength and strength index.

III. SUMMARY OF LITERATURE REVIEW

The main advantages of using CFRP laminates are their light weight and their durability, which result in ease of handling and maintenance. CFRP sheet wrapping decreases the corrosion rate, the corrosion of steel reinforcement could continue to occur, eventually showing a decrease in ultimate axial compression capacity. The findings showed that a deficiency leads to reduced load-carrying capacity of steel SHS columns and the retrofitting method is responsible for the increase in the load-bearing capacity of the steel columns.

CFRP performed better than steel plates in compensating the axial force caused by the cross-section reduction due to the problems associated with the use of steel plates, such as in welding, increased weight, thermal stress around the welding location, and the possibility of creating another deficiency by welding.

IV. FINITE ELEMENT MODELLING AND MODELLING SPECIMENS

It can be observed that many investigations were conducted on the behavior of the steel members strengthened with CFRP composite, but it seems that there is a lack of understanding about the behavior of deficient hollow steel members under combined loads. Therefore, this study explored the effect of CFRP strengthening on the structural behaviours of deficient hollow steel members under combined loads, using numerical investigations. Loading scenarios applied to the SHS steel members were five types. Loading scenario 1 (Pure Tension), loading scenario 2 (Pure Compression), loading scenario 3 (Pure Torsion), loading scenario 4(Combination of tension and torsion), loading scenario 5(Combination of compression and torsion). To obtain accurate results, 5 hollow steel members were analysed (one non-strengthened member without deficiency) 10 members with local corrosion and Surface corrosion were analysed. CFRP strengthened sections with deficiencies were also analysed. The coverage length and the number of CFRP layers, loading scenarios, lengths, widths and orientations of deficiency were implemented to examine the ultimate capacity of the hollow steel members. Nonlinear finite element models were prepared using ANSYS software to investigate the structural behavior of the SHS steel members strengthened with CFRP sheets in length.

A. *SECTIONAL PROPERTIES*

All models were prepared as steel members of fixed-pinned ends. The dimensions of local corrosion were 500 mm × 25 mm × 8 mm (8 mm thickness of the THS steel). Also, the dimensions of surface level corrosion were 175mm × 5 mm × 8 mm. In this study, three types of materials were used. Type 1 of the material used was SHS steel. The THS steel had a dimension of 80 mm × 80 mm. The length and thickness of the used SHS steel were 3000 mm and 3 mm, respectively. Also, the modulus of elasticity, the yield strength, and the ultimate tensile strength of the used SHS steel were 200000 N/mm2, 240 N/mm2, and 375 N/mm2, respectively. These values were extracted from studies conducted by Keykha A H. Type 2 of the materials used was CFRP sheet. The CFRP sheet used in the present research was SikaWrap-200C. The SikaWrap-200C is a unidirectional carbon fiber. This CFRP had a modulus of elasticity of 230000 N/mm2 and a tensile strength 3900 N/mm2. The thickness of this CFRP sheet was 0.111 mm. These values were extracted from studies conducted by Abdollahi Chahkand and Zamin umaat. The last material used in this study was adhesive used to paste CFRP sheets to SHS steel. The adhesive used in this study was suggested by the supplier of the CFRP product. The adhesive commonly used for the SikaWrap-200C, was called Sikadur-330. The Sikadur-330 is a two part adhesive, a hardener and a resin. The Sikadur 330 had a modulus of elasticity about 4500 N/mm2 and a tensile strength about 30 N/mm2. These values were retrieved from studies conducted by Keykha A H.

The sectional properties of the finite element model are tabulated in table 1.

TABLE 1. Sectional Properties of the Model

PARAMETERS	
Thickness	8 mm
Length	3000 mm
Depth	80 mm
Mesh size	100 mm
Material	Steel

B. *MATERIAL PROPERTIES*

The material mechanical properties of the finite element model are tabulated in table 2.

TABLE 2. Material properties of the section

Element	**Young's modulus (GPa)**	**Yield stress (MPa)**	**Ultimate stress (MPa)**
Section	200	240	375

C. 3D MODEL OF STEEL TUBULAR HOLLOW SECTION

To simulate the THS steel members, the full three-dimensional modelling and nonlinear static analysis methods were applied. The THS steel member, CFRP sheet, and adhesive were simulated using the 3D solid triangle elements (ten-nodes 187). Nonlinear static analysis was carried out to achieve the characteristics of failures in the steel members. In this case, the load was incrementally applied until the plastic strain in an element reached its ultimate limit. Subsequently, linear and nonlinear properties of materials were defined. The CFRP sheet material properties were defined as linear and orthotropic because CFRP materials had linear properties which were unidirectional. Also, the adhesive was defined as linear because the adhesive used had linear properties. In addition, the SHS steel members were defined as the materials having nonlinear properties. For meshing, map meshing was used.

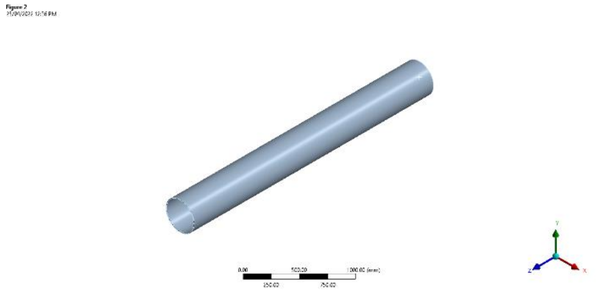


Fig.1 3D Model of the Tubular Steel Section

VALIDATION

It was necessary to validate the software calculations. In this study, the software results were validated and calibrated by the experimental results of A.H. Keykha, "Strengthening of Deficient Steel Sections using CFRP Composite under Combined Loading ", MACS,2020 Department of Civil Engineering, Islamic Azad University, Zahedan Branch, and Zahedan, Iran. Model is validated using ANSYS software .For the analysis of the specimens, as mentioned in the previous section, the solid element of 187 with the mesh size of 25 was used. From the studies conducted by A.H. Keykha, Department of Civil Engineering, Islamic Azad University, Zahedan Branch, Zahedan, Iran The ultimate capacity of the specimens, were obtained from experimental, theoretical, and numerical analysis . As mentioned in the Introduction section, A.H. Keykha carried out an experimental and a theoretical study on the behavior of CFRP strengthened SHS steel beams in pure torsion.

- Depth = 60 mm
- Length= 1600 mm
- Thickness= 6 mm
- Modulus of elasticity= 200000 N/mm2
- Yield strength = 240 N/mm2
- Ultimate tensile strength= 375 N/mm2
- End restraints= One end fixed and the other end pinned.
- Loading scenario included tension pull and rotation
- Tension pull = 10 mm
- Rotation = 5 to 90 degrees

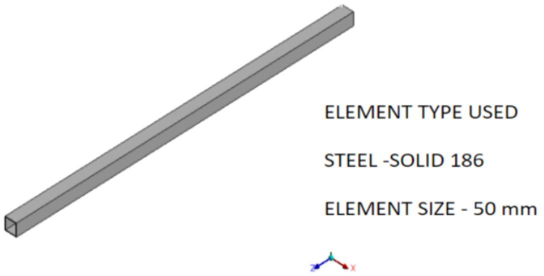


Fig.2 3D Model of the Square Steel Section

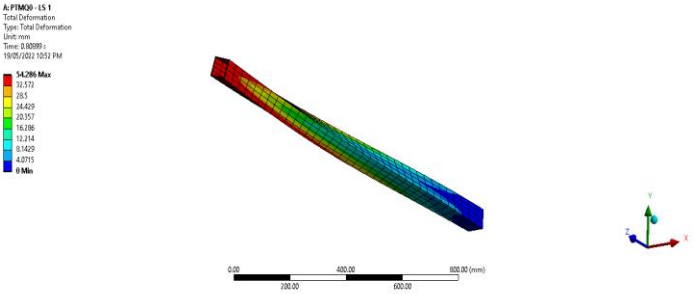


Fig.3. Total Deformation

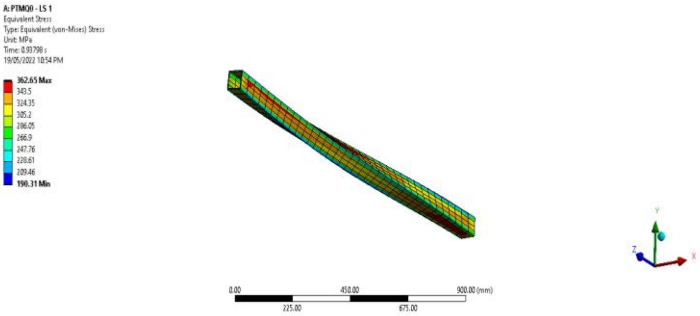


Fig.4 Equivalent stress

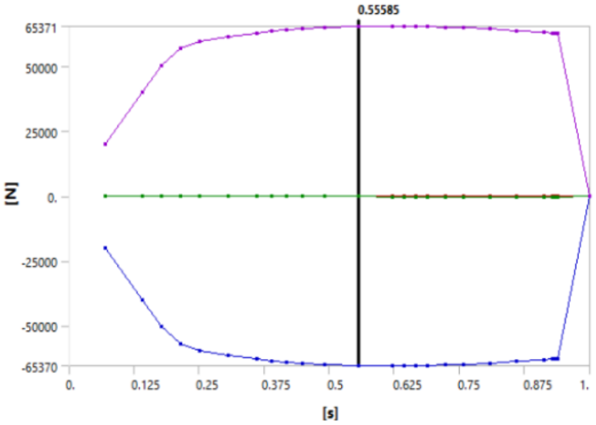


Fig 5. Compression capacity

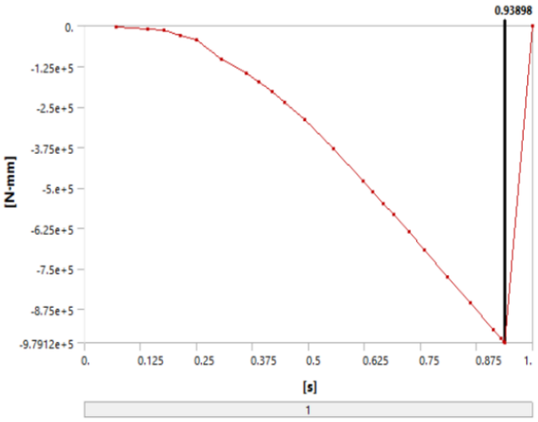


Fig 6. Torsional capacity

TABLE 3. Comparison of the Results obtained from software and Journal

RESULT		
	Compression capacity(kN)	Torsional Capacity(kNm)
Journal	68.28	0.96
FEA	65.20	0.97
%	4.36	4.36

V. PARAMETRIC STUDY

The steel members included one control specimen, five non-strengthened specimens with different loading scenarios and 10 specimens with deficiency and steel sections strengthened with two and four CFRP layers applied on all four sides of the steel members. The control specimen was analysed without strengthening to determine the rate of the ultimate capacity increase in the strengthened steel members. To easily identify each specimen, steel members were designated W TL- Without deficiency Torsion loading, W TE L Without deficiency Tension Loading -, W C L- Without deficiency Compression Loading, W TE TL- without Deficiency Tension Torsion Loading, W CTL- Without deficiency Compression Torsion Loading.

Without deficiency, 5 models were designed and analysed using ANSYS software.

CASE 1

Pure Compression: By varying the values of the Compressive forces, So many models were drawn and solved and got -50 kN/m^2 as the limit force.

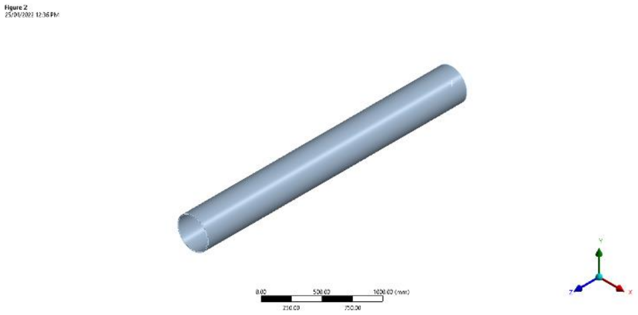


Fig.6. 3D Model of the section subjected to pure Compression

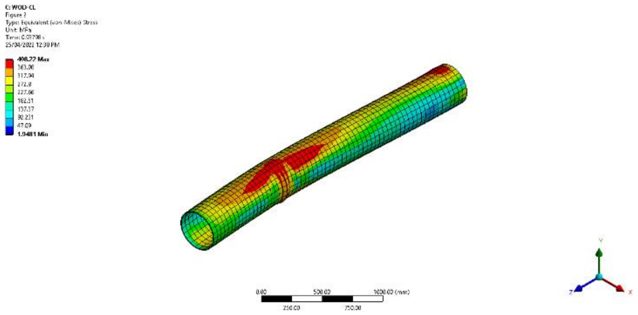


Fig.7.Deformation of the section subjected to pure Compression

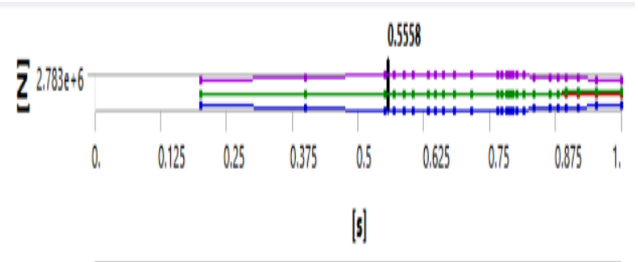
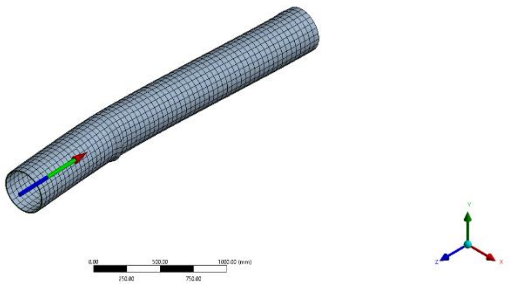


Fig.8.Compression capacity of the section subjected to pure Compression



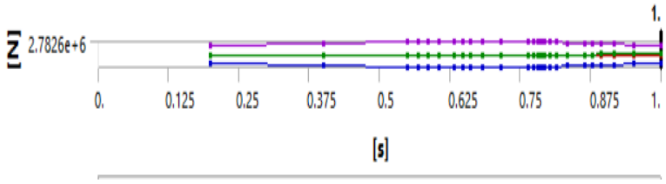


Fig 9 .Force reaction of the section subjected to pure Compression

CASE 2

Pure Tension: By varying the values of the Compressive forces, So many models were drawn and solved and got 150 kN/m^2 as the limit force.

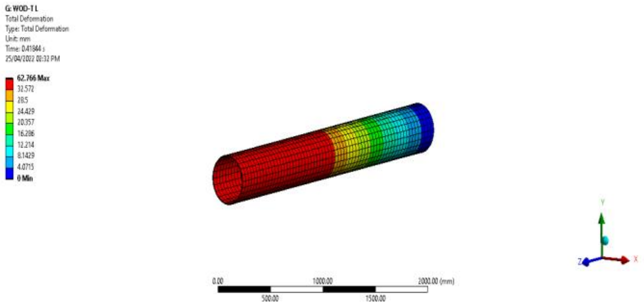


Fig.10. Deformation diagram for pure tension

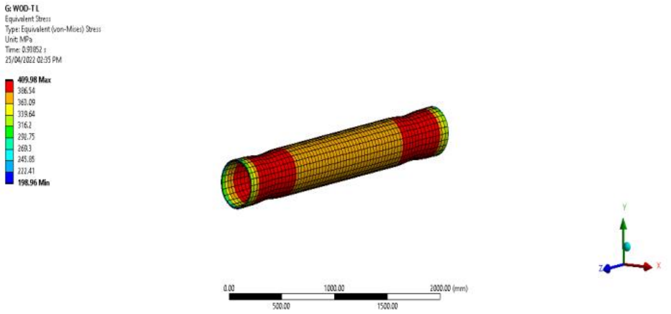


Fig.10. Stress diagram for pure tension

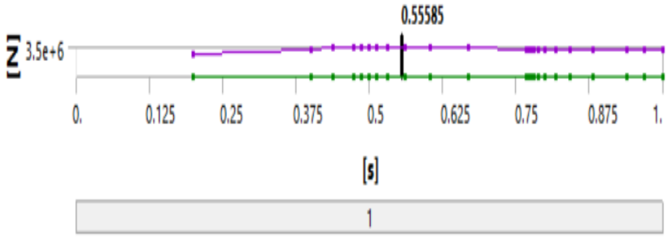


Fig.11. Compression Capacity for Pure Tension

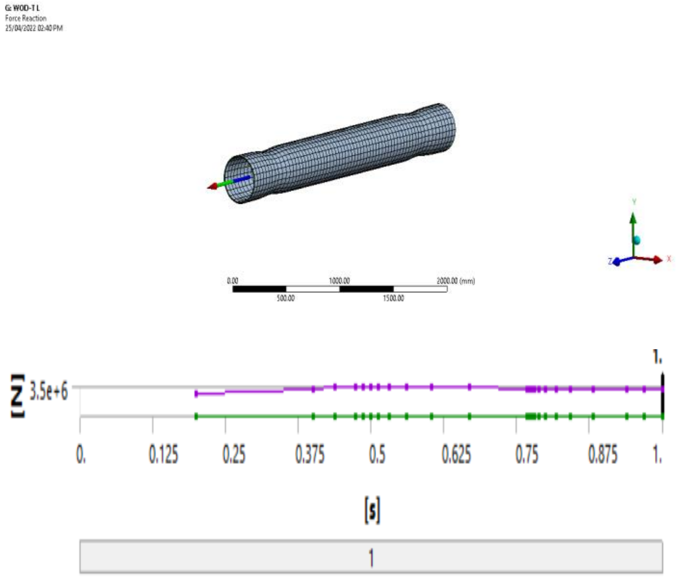


Fig.12. Force Reaction for pure tension

CASE 3

Pure Torsion: By varying the values of the Compressive forces, So many models were drawn and solved and got 40 kNm as the limit force

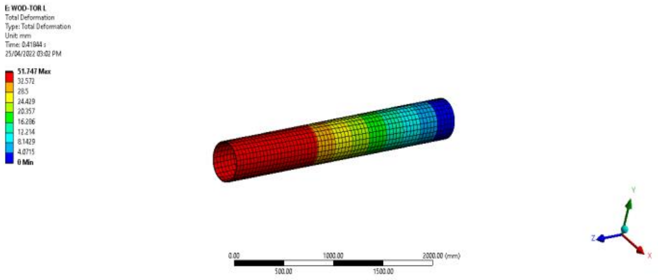


Fig.13. Deformation diagram for pure Torsion

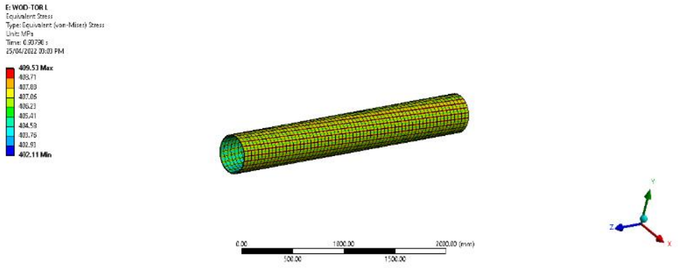


Fig 14. Stress Diagram

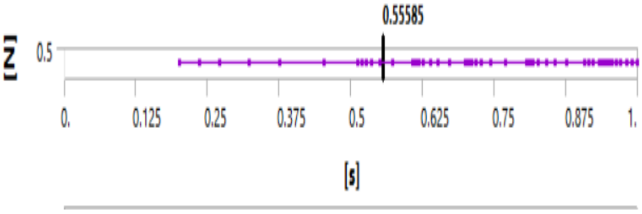


Fig 15. Compression Capacity

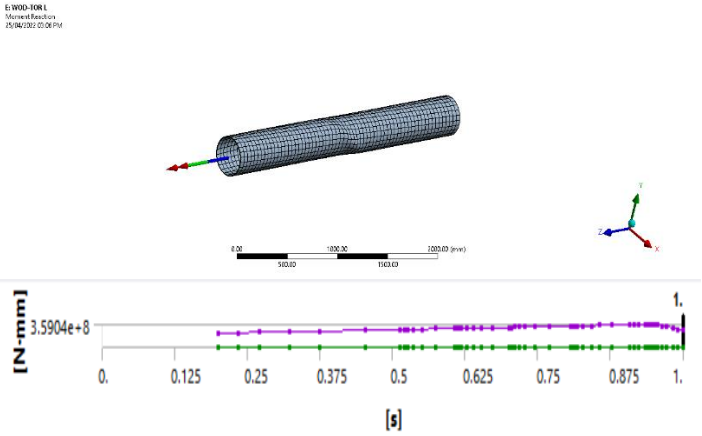


Fig 16. Moment reaction

CASE 4

Compression+ Torsion:

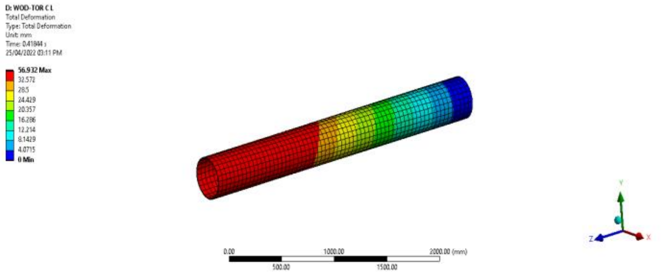


Fig 17: Deformation

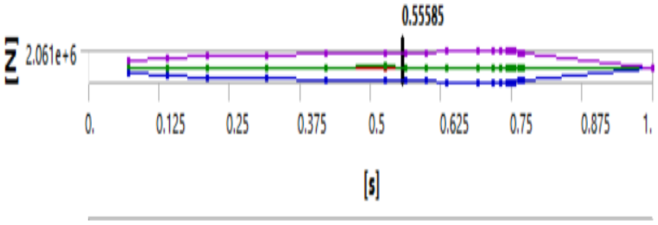


Fig 18: Compression Capacity

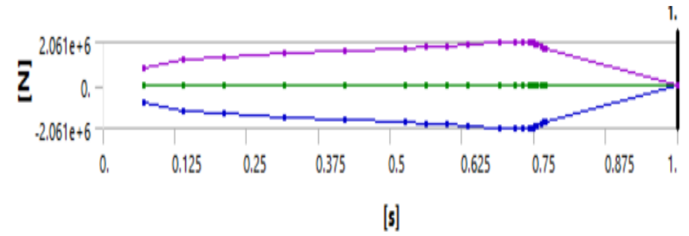


Fig 19. Force reaction

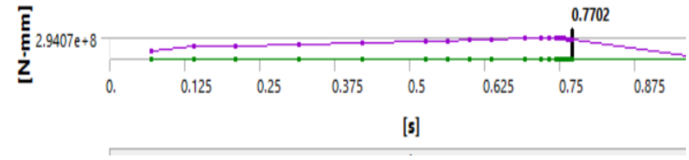


Fig 20. Moment reaction

CASE 5
Tension+ Torsion

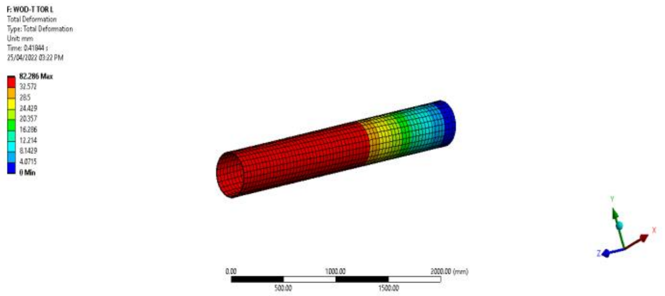


Fig 21: Deformation

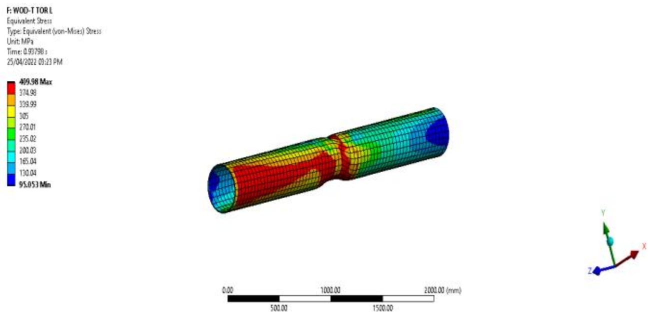


Fig 22: Stress Diagram

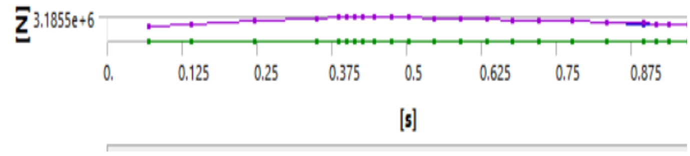
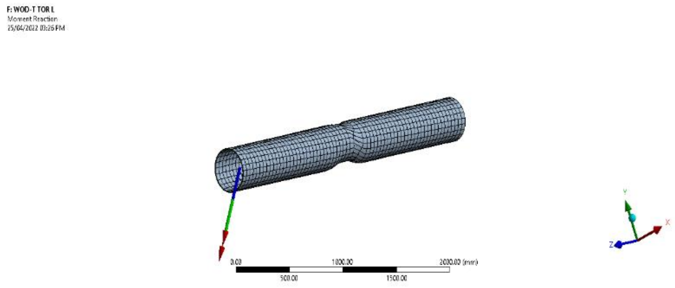


Fig 23 Force reaction



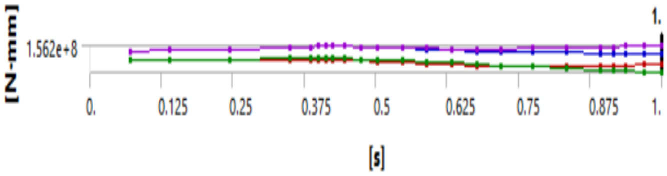


Fig 24. Moment reaction

VI. GRAPHS

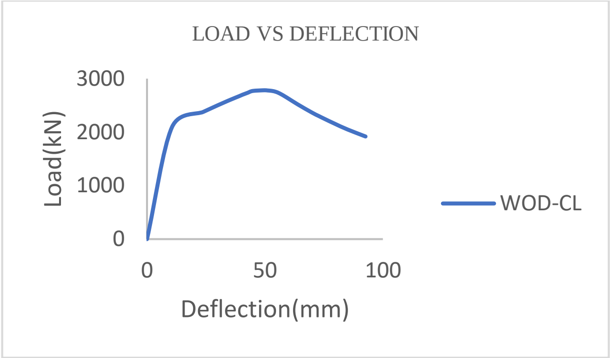


Fig 25. Graph- Pure Compression

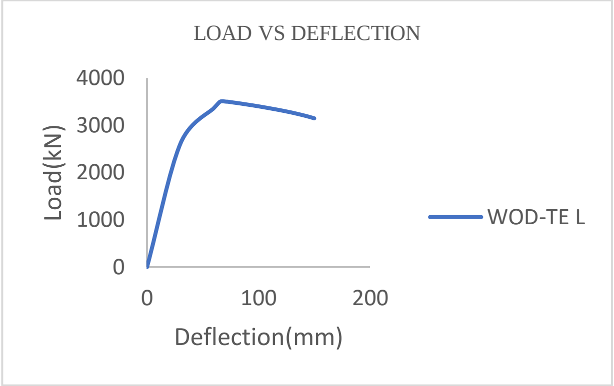


Fig 26. Graph- Pure Tension

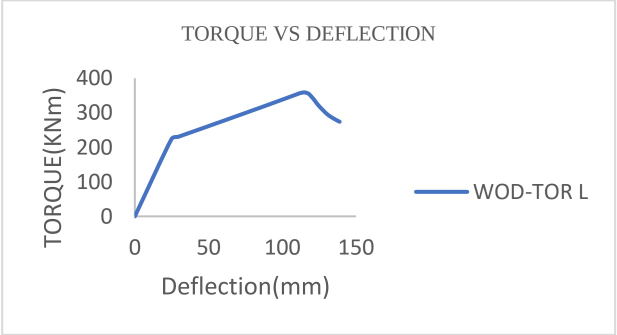
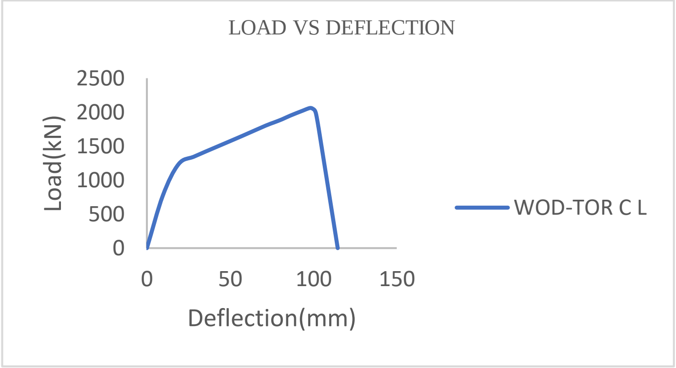


Fig 27. Graph- Pure Torsion



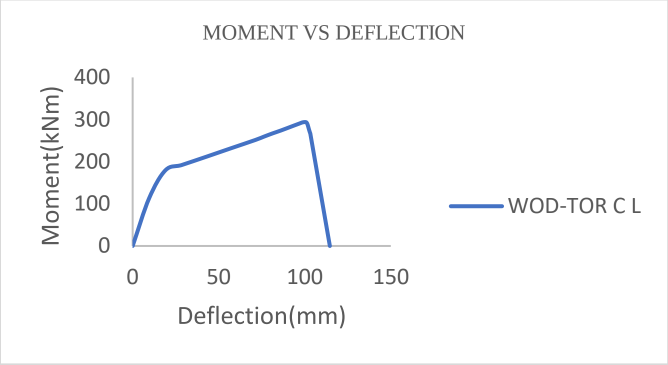


Fig 28. Graph- Combined Torsion and Compression

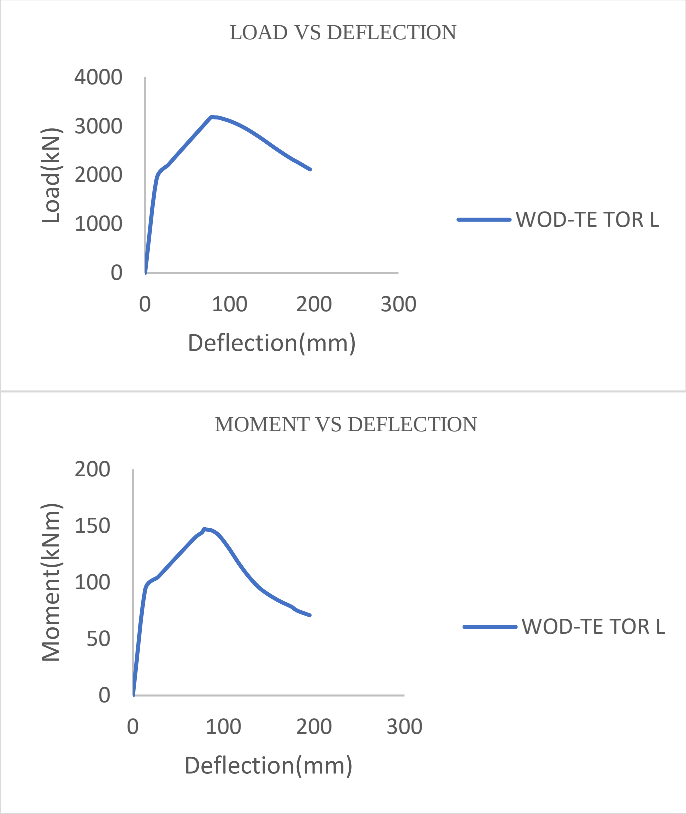


Fig 29. Graph- Combined Torsion and Tension

VII. RESULTS AND DISCUSSION

Under various loading scenarios, substantial changes in the deformation, force reaction and moment reaction are noted. The maximum deflection in the pure axial case was 49.8 mm at the load 2782.6 KN. The maximum deflection obtained in the pure torsion case was 114.7 mm at the moment 359 kNm. The maximum deflection obtained in the pure tension case was 71.03 at the load 3500 kN. In case 4 that is torsion + compression, the deflection obtained is 78.59 mm at the load 3185.5 kN and moment, 147.12 kNm. We can see that the deflection obtained is in between 49.8 mm and 114.7 mm. (deflections obtained in the pure axial and torsion cases respectively.) In the 5 th case, that is torsion + tension, the deflection obtained is 98.7 mm at the load 2061 kN and moment, 293.26 kNm. The deflection in the pure tension case was 71.30 mm at load 3500 kN and that in pure torsion case was 114.78 mm at the moment 359 kNm. The deflection is in between 71.30 mm and 114.78 mm.

VIII. CONCLUSION

Non-linear static analysis of Tubular Hollow steel sections under various loading scenarios are done using ANSYS software. The maximum deflection is obtained for pure torsion loading. Five models were solved effectively using ANSYS. Surface level Corrosion and Local Level Corrosion of the above fixed dimensions are to be drawn and solved, CFRP is to be wrapped and Strength Index is to be found by making appropriate number of models. From the literature review, it can be concluded that the CFRP wrapped sections have more strength and hence the gain in strength is to be measured.

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