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STRENGTHENING OF DEFICIENT STEEL SECTIONS USING HYBRID FRP COMPOSITES UNDER VARIOUS LOADING SCENARIO

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Abstract – *Recently, strengthening of steel sections using various fibre reinforced polymer (FRP) has come to the attention of many researchers. The deficiency in steel members may be due to the errors caused by construction, corrosion, fatigue cracking, and other reasons. This study investigates the behaviour of circular hollow section (CHS) and square hollow section (SHS) steel members, comparing them with and without deficiency and strengthening the most load carrying capacity steel section by using HYBRID FRP composites under compressive, tensile, torsion and seismic loadings. To analyse the steel members, three dimensional (3D) modeling and nonlinear static analysis methods were applied, using ANSYS software. The results expected is that the HYBRID FRP composites strengthening on the most load carrying capacity steel section had an impact on raising the ultimate capacity of deficient steel members and could recover the strength lost due to deficiency*

***Key Words*: Fiber Reinforced Polymer, Deficiency, CHS, SHS, Strengthening, Hybrid FRP composites**

1. INTRODUCTION

Strengthening of existing steel structures built within the last decades is one of the most important issues considered by structural engineers. Steel structures built in the past often need to be strengthened due to increased life loads, repair due to corrosion, fatigue cracking, and other reasons. In recent years, FRP composites, as a strengthening material of steel structures, has attracted greater attention. Fiber-reinforced polymer (FRP) has been a practical alternative construction material for replacing steel in the construction industry for several decades. The advantages of hybrid structural systems include the cost effectiveness and the ability to optimize the cross section based on material properties. This study investigates the behaviour of circular hollow section (CHS) and square hollow section (SHS) steel members, comparing them with and without deficiency and strengthening the most load carrying capacity section by HYBRID FRP composites under compressive, tensile, torsion and seismic loadings. To analyse the steel members, three dimensional (3D) modeling and nonlinear static analysis methods were applied, using ANSYS software.

2. LITERATURE REVIEW

A H Kheykha (2020)[1] studied the “Strengthening of Deficient Steel Sections using CFRP Composite under Combined Loading” in which he investigated the behavior of deficient square hollow section (SHS) steel members strengthened by CFRP sheets under two types of the combined loads. To study the effect of CFRP strengthening on the structural behavior of the deficient steel members, 17 specimens, 12 of which were strengthened using CFRP sheets, were analyzed. To analyze the steel members, three dimensional (3D) modeling and nonlinear static analysis methods were applied, using ANSYS software. The results showed that CFRP strengthening had an impact on raising the ultimate capacity of deficient steel members and could recover the strength lost due to deficiency, and the impact of CFRP strengthening on rising and recovering the ultimate capacity of the steel members under loading scenario 2(combined torsion and tension) was more than the steel members under scenario 1(combined compression and torsion).

A.H Kheykha (2020)[2] studied “The effect of CFRP strengthening on the behavior of deficient steel beams under concentrated and distributed loading” in which he investigated the behavior and performance of CFRP-strengthened deficient SHS steel beams under concentrated and distributed loads. Finite element method (FEM), using ANSYS, has been employed for modeling of steel beams. Ten steel beams, two non-strengthened steel beams and eight CFRP-strengthened steel beams have been analyzed. The results indicate the dimensions and number of composite layers is being effective on the ultimate capacity of the SHS steel beams. Also, the results have shown that in deficient steel beams CFRP can significantly be recovered the strength lost due to deficiency.

A.H Kheykha (2020)[3] studied the“Carbon-fibre strengthening of deficient hollow steel sections under combined loading”. Most previous research studies have studied the behaviour of structural steel members without deficiencies such as cracks and holes. The work described in this paper is about the effect of CFRP strengthening on the structural behaviour of SHS steel members having an initial deficiency under combined axial and lateral load. To study the effects of the strengthening, 17 specimens were tested, with 12 specimens strengthened using CFRP sheets. The deficiency was created by cutting vertical or horizontal slots in one flange. Three- dimensional modelling and non-linear static analyses were used to analyse the steel members. The results showed that the strengthening significantly improved the ultimate capacity of the deficient steel members and the effect of a transverse deficiency on the ultimate capacity of the steel members was greater than the effect of a longitudinal deficiency.

A.H Kheykha (2018)[4] studied the "Behaviour of Deficient Steel Members Strengthened Using CFRP Under Combined Compressive Load and Torsional Moment" in which he explored the effect of CFRP strengthening on the structural behaviors of square hollow sections (SHS) steel members having initial deficiencies under combined compressive load and torsional moment. In this study, 17 specimens were analyzed. To analyze the specimens, three dimensional (3D) modelling and nonlinear static analysis using ANSYS software were applied. The results indicated that application of CFRP sheets for the strengthening of the deficient hollow steel members under combined compressive load and torsional moment could recover the strength lost due to deficiency, significantly.

Nadim I Shbeeb, Rajai Al Rousan (2018)[5] studied the "Impact of bonded carbon fibre composite on the shear strength of reinforced concrete beams" in which they studied to determine the effectiveness of using externally bonded CFRP composite sheets as a method of increasing the shear strength of reinforced concrete beams. The investigated parameters were the amount and distribution of the composite, the bonded surface and fibre orientation. The overall behaviour of the test beams up to failure, the onset of cracking and crack development with increased load and ductility were recorded. Depending on the variables investigated, the externally bonded composite increased the shear capacity by 34–75% compared with other beams. Some previously published models found to give consistently good correlations with the test data, with acceptable coefficients of variation.

A.H Kheykha (2017)[6] studied the "Numerical investigation on the behavior of SHS steel frames strengthened using CFRP". This study explored the use of CFRP composite on retrofitting square hollow section (SHS) steel frames, using numerical investigations. Ten Finite Element (FE) models, were strengthened with CFRP sheets, were analyzed under different coverage length, number of layers, and location of CFRP composite. One FE model without strengthening was analyzed as a control FE model to determine the increase of the ultimate load in the strengthened steel frames. ANSYS software was used to analyze the SHS steel frames. The results showed that the coverage length and the number of layers of CFRP composite have a significant effect on increasing the ultimate load of the SHS steel frames. The results also showed that the location of CFRP composite had no similar effect on increasing the ultimate load and the amount of mid span deflection of the SHS steel frames.

A H Kheykha, Masoud Nekooi, Reza Rahgozar (2016)[7] studied the"Analysis and strengthening of SHS steel columns using CFRP composite materials" in which they explored the use of flexible adhesively bonded CFRP sheets in retrofitting slender SHS steel columns by numerical and analytical investigations. The finite element method (FEM) was used for modeling. ANSYS was employed for the analysis of samples. To determine the critical load of SHS steel columns, 15 samples, strengthened with CFRP, were analyzed under different support conditions. The results showed that the support condition and the CFRP coverage are effective in the critical load of columns.

3. OBJECTIVES OF THE STUDY

1.To study the performance of CHS (Circular Hollow Sections) without damage under axial, tensile and torsional loadings.

2.To study the performance of CHS with damage (25% surface corrosion) along 25% of total height under axial, tensile and torsional loadings.

3.To study the performance of SHS (Square Hollow Sections) without damage under axial, tensile and torsional loadings.

4.To study the performance of SHS with damage (25% surface corrosion) along 25% of total height under axial, tensile and torsional loadings.

5.To find the most load carrying capacity section.

6.Proposing the effective method (2 layer or 4 layers of Hybrid FRP) of strengthening the deficient beam.

7.To perform the seismic analysis of multistorey frame under deficiency conditions at the corner of the column and strengthening and improving the performance.

4. SCOPE OF THE STUDY

1. The work is limited to modelling and analysis of CHS and SHS with hybrid composites FRP using ANSYS software.

5. MODELING OF CHS AND SHS WITHOUT CORROSION AND WITH SURFACE CORROSION

Table -1: Dimensions of Circular Hollow Section(CHS)

Diameter	101.6 mm
Thickness	4.8 mm
Area	1460 mm^2
Height	1800 mm

Table-2: Dimensions of Square Hollow Section(SHS)

Cross sectional dimension	100x100x4mm
Area	1495 mm^2
Height	1800 mm

Square Hollow Section and Circular Hollow Section are analysed without corrosion and with surface corrosion under loading types Compression, Tension and Torsion. The maximum load carrying capacity member is selected for the next part of the analysis. It is then analysed under Seismic loading in a multi-storeyed frame. For the compensation of strength lost, the steel members are strengthened using 2 layers and 4 layers of hybrid FRP composites which consists of Aramid and Glass fibre. The dimensions for CHS is taken from IS 1161(1998) and the dimensions for SHS is taken from IS 4923(1997). 25% of the Surface corrosion is given in 25% of the total height of the section (25% of 1800mm = 450 mm). Here, corrosion is given in the middle section. After corrosion, thickness in the middle portion of SHS= 4-(25% of 4) = 3mm. After corrosion, thickness in the middle portion of CHS= 4.8- (25% of 4.8) = 3.6mm.

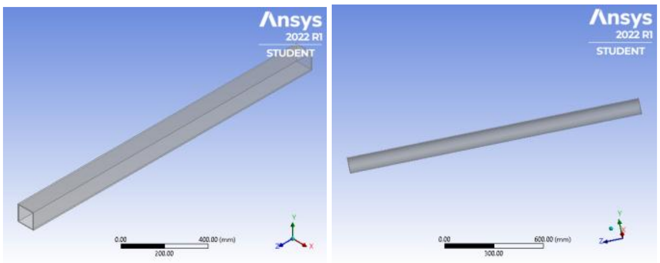

Fig-1: SHS and CHS models without corrosion

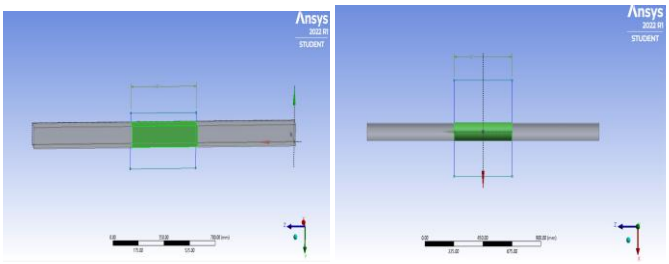

Fig-2: SHS and CHS models with surface corrosion

5.1 Compression loading

Square Hollow Section (SHS) and Circular Hollow Section (CHS) under compression loading is analysed using ANSYS Software. Surface corrosion is given in the middle portion of the total height. Models with and without corrosion is analysed in the ANSYS software. Model names are given in the table as follows:

Table-3: Model names in detail for Compression loading

Model name	Names in detail
CL SQ	Compression loading in Square Hollow Section
CL SQ WITH SC	Compression loading in Square Hollow Section with Surface Corrosion
CL CS	Compression loading in Circular Hollow Section
CL CS WITH SC	Compression loading in Circular Hollow Section with Surface Corrosion

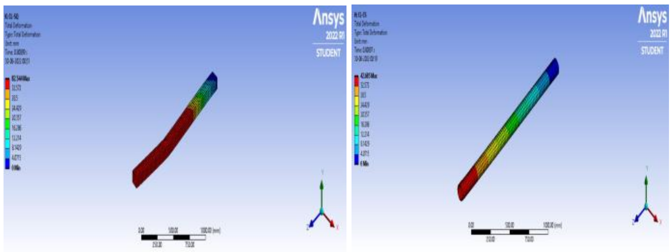

Fig-3: Total deformation figures of SHS and CHS without corrosion under compression loading

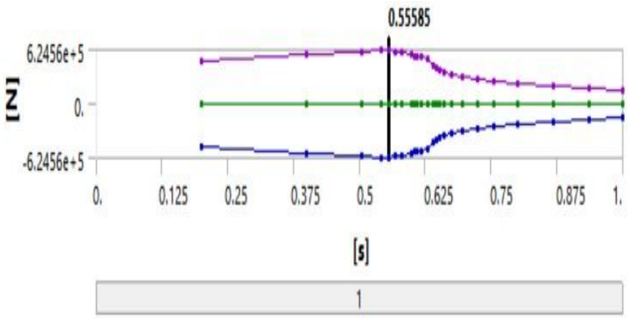

Fig-4: Axial loading diagram of SHS without corrosion

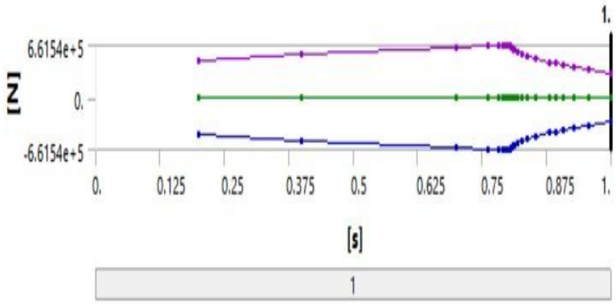

Fig-5: Axial loading diagram of CHS without corrosion

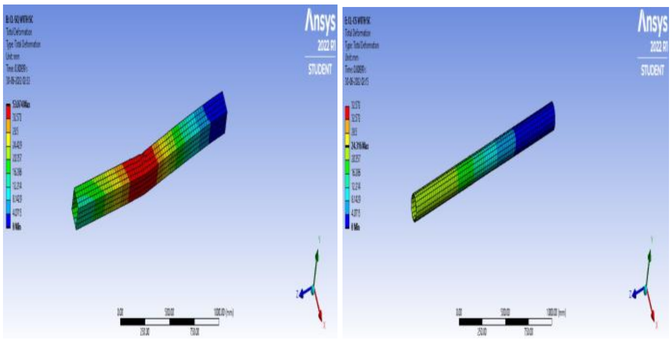

Fig-6: Total deformation figures of SHS and CHS with surface corrosion under compression loading

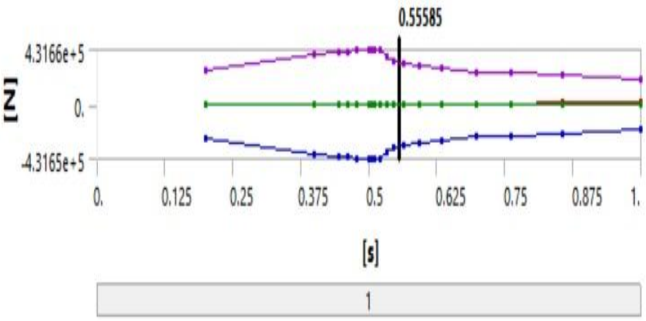

Fig-7: Axial loading diagram of SHS with surface corrosion

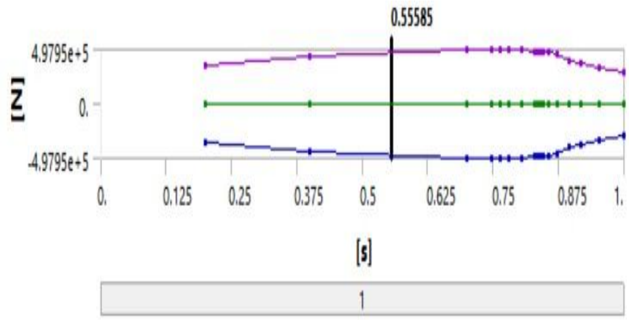

Fig-8: Axial loading diagram of CHS with surface corrosion

Table-4: Comparison table of SHS and CHS under compression loading

Load type	Models	Deformation (mm)	Load (KN)
Compression	CL SQ	27.731	624.56
Compression	CL SQ WITH SC	10.354	431.66
Compression	CL CS	39.119	661.54
Compression	CL CS WITH SC	21	497.95

5.2 Tensile loading

Square Hollow Section (SHS) and Circular Hollow Section (CHS) under tensile loading is analysed using ANSYS Software. Surface corrosion is given in the middle portion of the total height. Models with and without corrosion is analysed in the ANSYS software. Model names are given in the table as follows:

Table-5: Model names in detail for tensile loading

Model name	Names in detail
TL SQ	Tensile loading in Square Hollow Section
TL SQ WITH SC	Tensile loading in Square Hollow Section with Surface Corrosion
TL CS	Tensile loading in Circular Hollow Section
TL CS WITH SC	Tensile loading in Circular Hollow Section with Surface Corrosion

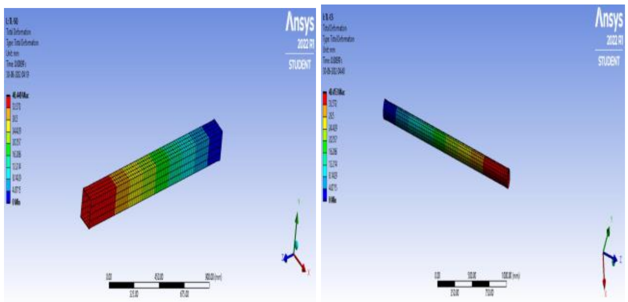

Fig-9: Total deformation figures of SHS and CHS without corrosion under tensile loading

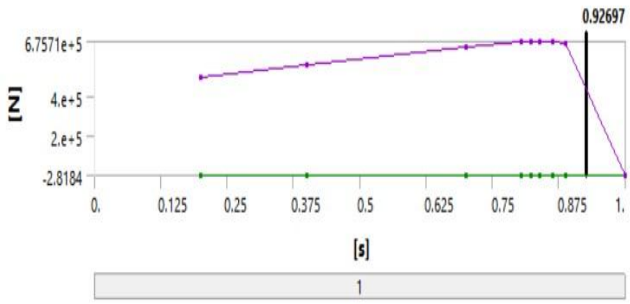

Fig-10: Tensile loading diagram of SHS without corrosion

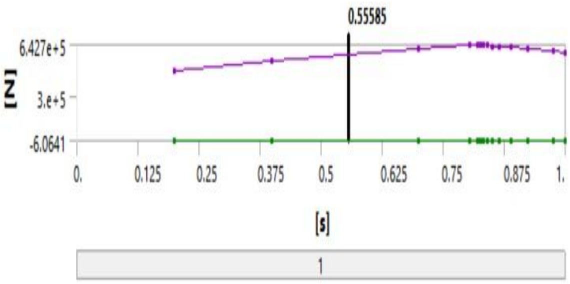

Fig-11: Tensile loading diagram of CHS without corrosion

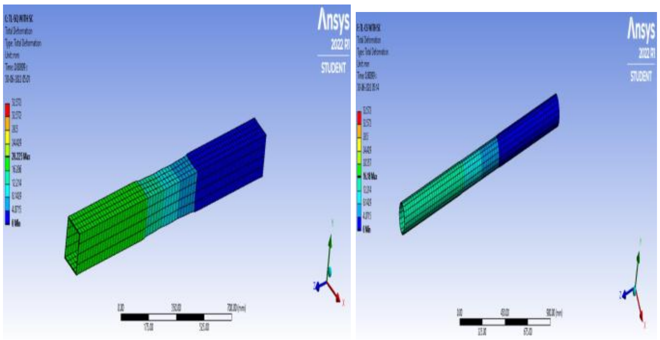

Fig-12: Total deformation figures of SHS and CHS with surface corrosion under tensile loading

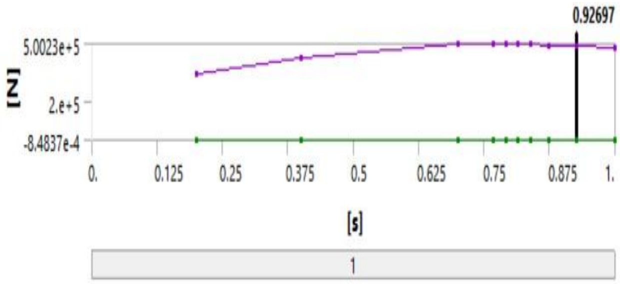

Fig-13: Tensile loading diagram of SHS with surface corrosion

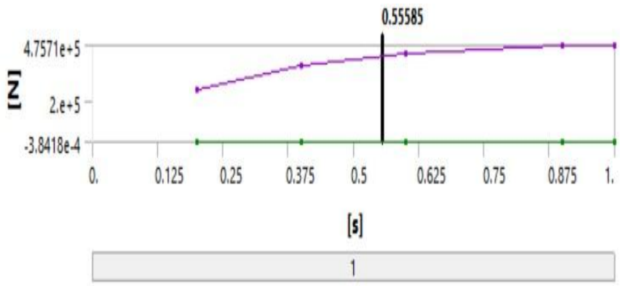

Fig-14: Tensile loading diagram of CHS with surface corrosion

Table-6: Comparison table of SHS and CHS under tensile loading

Load type	Models	Deformation (mm)	Load (KN)
Tension	TL SQ	41.077	675.71
Tension	TL SQ WITH SC	19.188	500.23
Tension	TL CS	40.254	642.7
Tension	TL CS WITH SC	18	475.71

5.3 Torsional loading

Square Hollow Section (SHS) and Circular Hollow Section (CHS) under torsional loading is analysed using ANSYS Software. Surface corrosion is given in the middle portion of the total height. Models with and without corrosion is analysed in the ANSYS software. Model names are given in the table as follows:

Table-7: Model names in detail for torsional loading

Model name	Names in detail
TR SQ	Torsional loading in Square Hollow Section
TR SQ WITH SC	Torsional loading in Square Hollow Section with Surface Corrosion
TR CS	Torsional loading in Circular Hollow Section
TR CS WITH SC	Torsional loading in Circular Hollow Section with Surface Corrosion

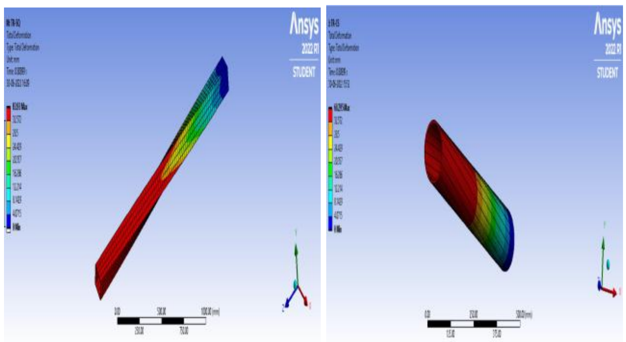

Fig-15: Total deformation figures of SHS and CHS without corrosion under torsional loading

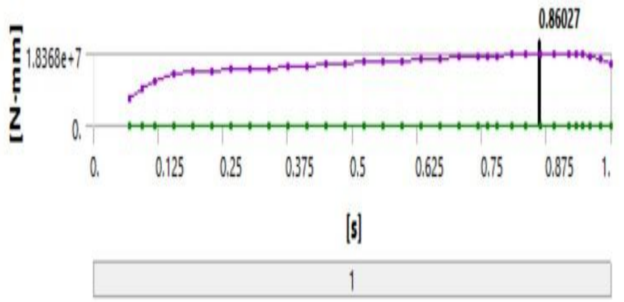

Fig-16: Torsional loading diagram of SHS without corrosion

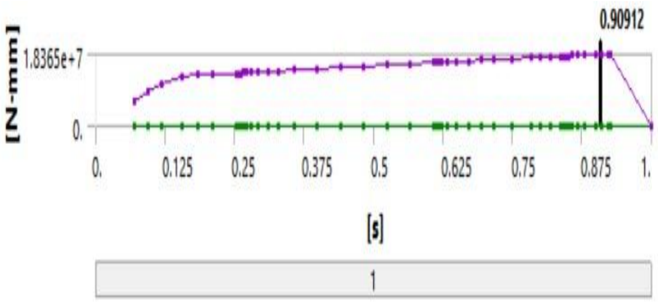

Fig-17: Torsional loading diagram of CHS without corrosion

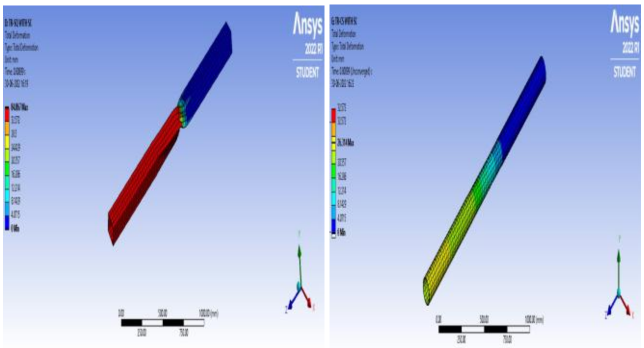

Fig-18: Total deformation figures of SHS and CHS with surface corrosion under torsional loading

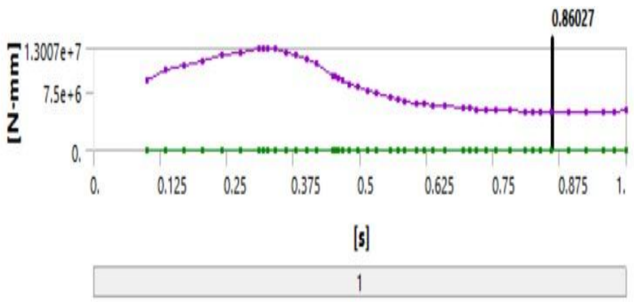

Fig-19: Torsional loading diagram of SHS with surface corrosion

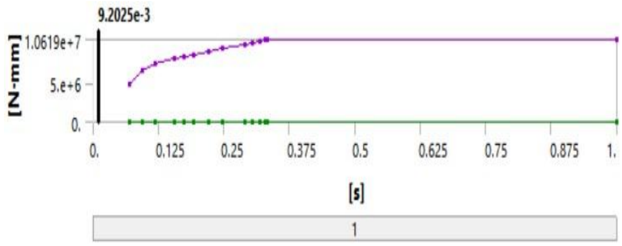

Fig-20: Torsional loading diagram of CHS with surface corrosion

Table-8: Comparison table of SHS and CHS under torsional loading

Load type	Models	Deformation (mm)	Load (KNm)
Torsion	TR SQ	94.528	18.368
Torsion	TR SQ WITH SC	35.976	13.007
Torsion	TR CS	67.598	18.365
Torsion	TR CS WITH SC	26.314	10.619

Consider the load deformation relationship graphs of loading types compression, tension and torsion given as follows:

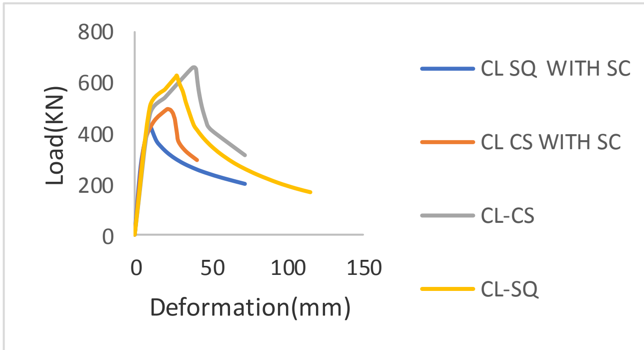

Fig-21: Load-deformation relationship graph of CHS and SHS under compression loading

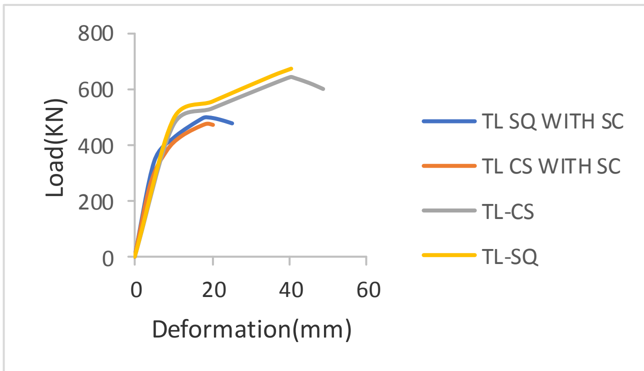

Fig-22: Load-deformation relationship graph of CHS and SHS under tensile loading

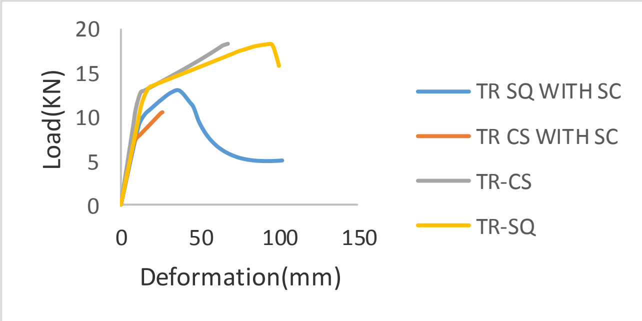

Fig-23: Load-deformation relationship graph of CHS and SHS under torsional loading

Consider the comparsion charts of load and deformation cases of SHS and CHS under loading types compression, tension and torsion given as follows:

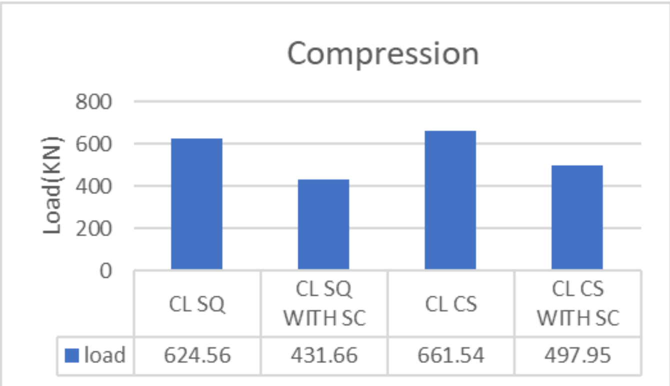

Fig-24: Load comparison chart of CHS and SHS under compression loading

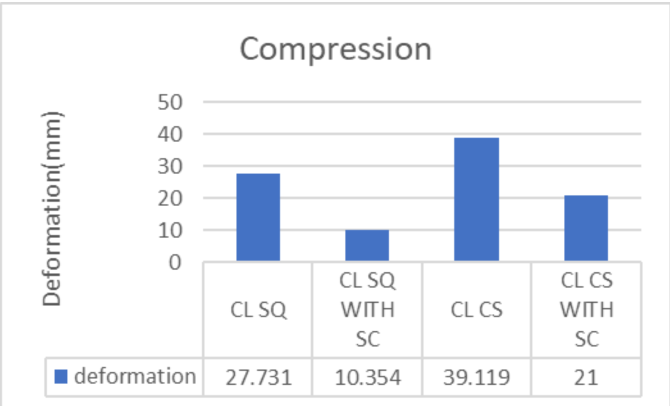

Fig-25: Deformation comparison chart of CHS and SHS under compression loading

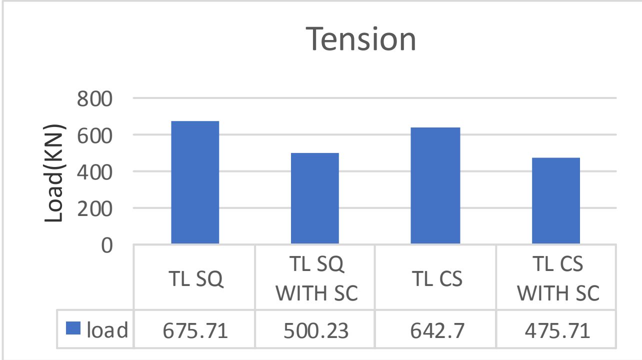

Fig-26: Load comparison chart of CHS and SHS under tensile loading

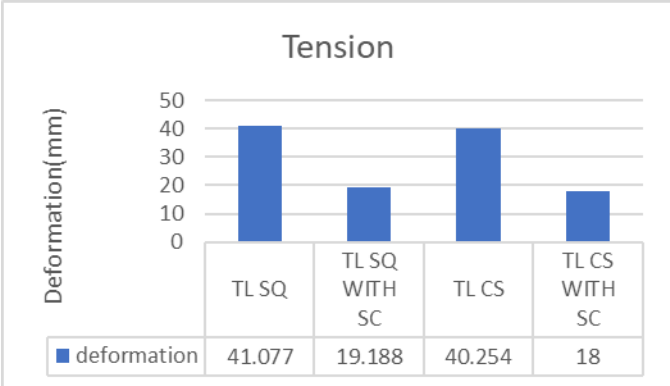

Fig-27: Deformation comparison chart of CHS and SHS under tensile loading

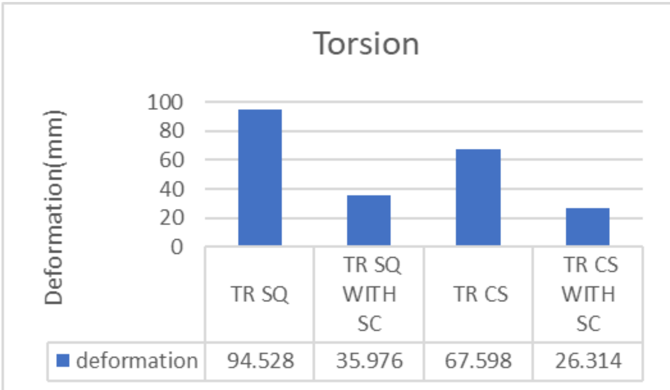

Fig-28: Load comparison chart of CHS and SHS under torsional loading

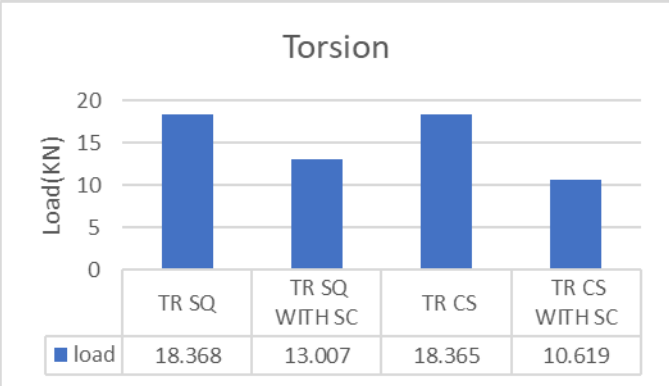

Fig-29: Deformation comparison chart of CHS and SHS under torsional loading

6. STRENGTHENING THE MOST LOAD CARRYING CAPACITY STEEL SECTION USING HYBRID FRP COMPOSITES

From the comparison charts of loading and deformation and also considering the load deformation relationship graphs of all 3 loading types, it is concluded that the most load carrying capacity steel section is Square Hollow Section (SHS). Hence, for the further analysis of the work, SHS is chosen. Wrapping of SHS in 2 and 4 layers of Hybrid FRP Composites is carried out. Seismic analysis study of a multi-storeyed frame is also carried out. It is also strengthened using Hybrid FRP Composites in 2 and 4 layers.

6.1 Hybrid FRP Composites

Fiber-reinforced polymer (FRP) has been a practical alternative construction material for replacing steel in the construction industry for several decades. The advantages of hybrid structural systems includes the cost effectiveness the ability to optimize the cross section based on material properties. The hybrid FRP composites have been prepared to enhance the mechanical, thermal, damping properties compared to single FRP composites. Among the types of FRP composites available in the market, Glass and Aramid are the two types of fibers which are used for strengthening in this study.

Glass Fibre Reinforced Polymer (GFRP): Glass fibres are basically made by mixing silica sand, limestone, folic acid and other minor ingredients. Glass is generally a good impact resistant fibre but weighs more than aramid. Glass fibres have excellent characteristics equal to or better than steel in certain forms. The material properties of GFRP used in this study are given in the table as follows:

Table-9: Material properties of GFRP used in the study

Property	Dimension
Modulus of elasticity	71,000 N/mm^2
Tensile Strength	2000 N/mm^2
Thickness	0.17 mm

Aramid Fibre Reinforced Polymer (AFRP): Aramid is the short form for aromatic polyamide. Their main advantages over common reinforcing steel rebars rely on their lightness, durability performances and mechanical properties. Here, 1414 Kevlar fabric is used for the study. The material properties of GFRP used in this study are given in the table as follows:

Table-10: Material properties of AFRP used in the study

Property	Dimension
Modulus of elasticity	60,000 N/mm^2
Tensile Strength	2400 N/mm^2
Thickness	0.26 mm

6.2 Wrapping Hybrid FRP (2 and 4 layers) in SHS

Hybrid FRP Composites consisting of Aramid and Glass each one by one is assigned in the worksheet of ANSYS Software. Screenshot of the Hybrid FRP composites given in 2 layers and 4 layers is given below:

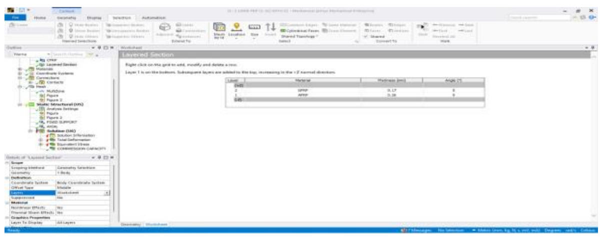

Fig-30: Hybrid FRP given in 2 layers in worksheet in ANSYS workbench

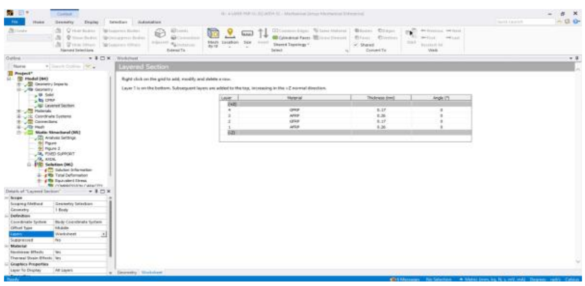

Fig-31: Hybrid FRP given in 4 layers in worksheet in ANSYS workbench

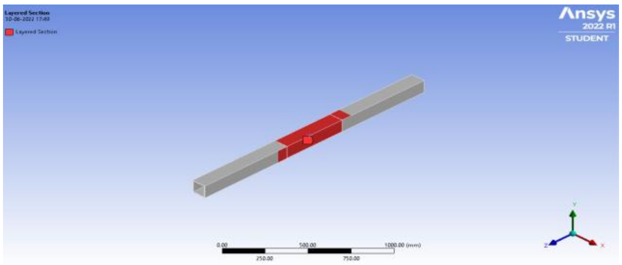

Fig-32: Hybrid FRP wrapped in 2 and 4 layers in SHS

6.2.1Compression loading

Model names designated for compression loading are given as follows:

Table-11: Model names in detail for compression loading

Model name	Names in detail
CL SQ	Compression loading in Square Hollow Section
CL SQ WITH SC	Compression loading in Square Hollow Section with Surface Corrosion
4 LAYER FRP CL SQ WITH SC	Hybrid FRP wrapped in 4 layers in Square hollow section in compression loading
2 LAYER FRP CL SQ WITH SC	Hybrid FRP wrapped in 2 layers in Square hollow section in compression loading

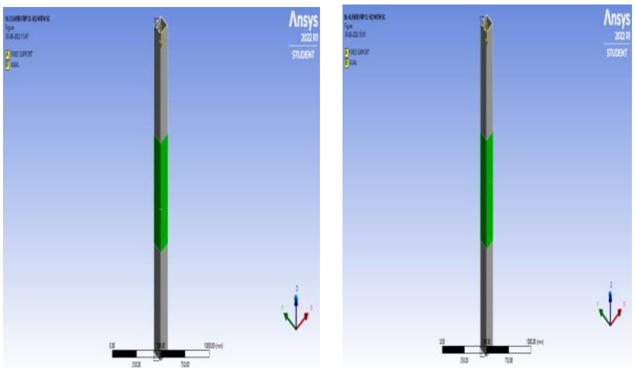

Fig-33: Boundary condition of SHS wrapped in 2 and 4 layers of hybrid FRP under compression loading

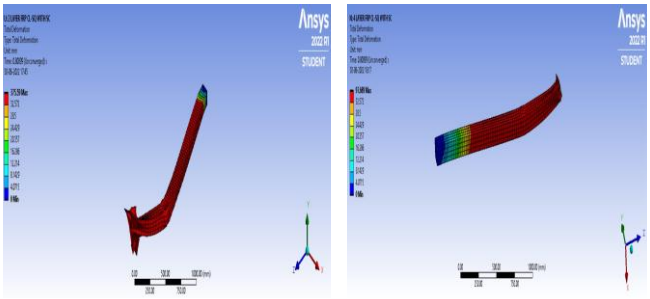

Fig-34: Total deformation figures of SHS wrapped in 2 and 4 layers of hybrid FRP under compression loading

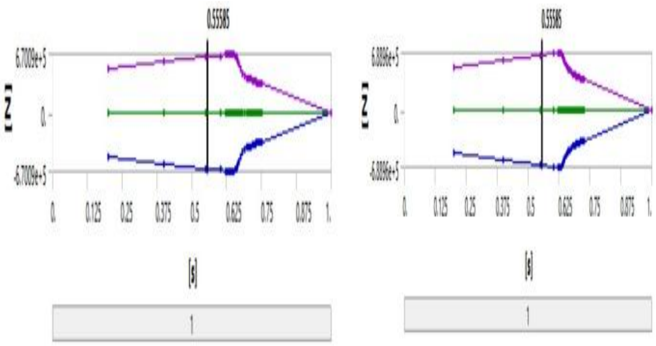

Fig-35: Loading diagrams of SHS wrapped in 2 and 4 layers of hybrid FRP under compression loading

Table-12: Comparison table of SHS wrapped in 2 and 4 layers of hybrid FRP under compression loading

Load type	Models	Deformation (mm)	Load (KN)
Compression	CL SQ	27.731	624.56
Compression	CL SQ WITH SC	10.354	431.66
Compression	4 LAYER FRP CL SQ WITH SC	31.487	688.96
Compression	2 LAYER FRP CL SQ WITH SC	32.318	670.09

6.2.2 Tensile loading

Model names designated for tensile loading are given as follows:

Table-13: Model names in detail for tensile loading

Model name	Names in detail
TL SQ	Tensile loading in Square Hollow Section
TL SQ WITH SC	Tensile loading in Square Hollow Section with Surface Corrosion

4 LAYER FRP TL SQ WITH SC	Hybrid FRP wrapped in 4 layers in Square hollow section in tensile loading
2 LAYER FRP TL SQ WITH SC	Hybrid FRP wrapped in 2 layers in Square hollow section in tensile loading

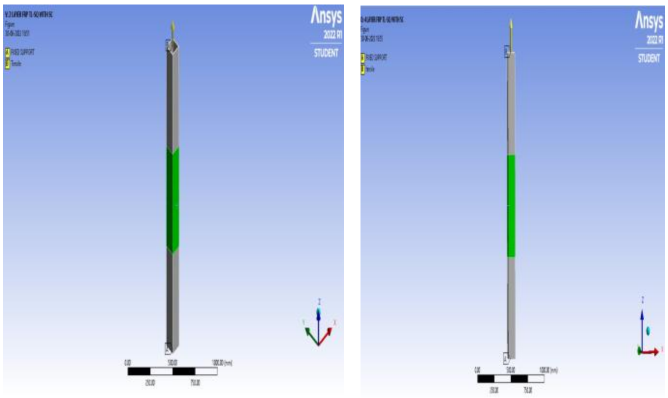

Fig-36: Boundary condition of SHS wrapped in 2 and 4 layers of hybrid FRP under tensile loading

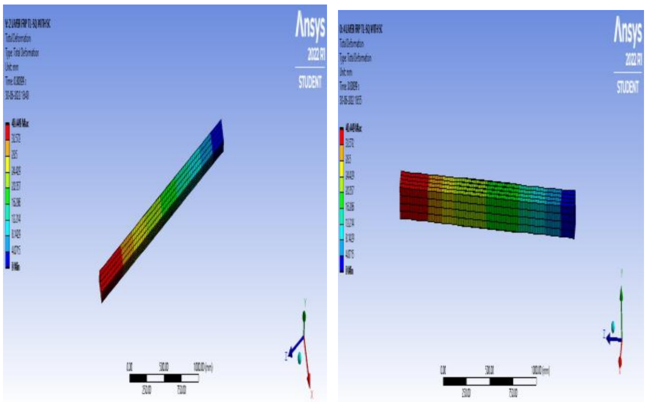

Fig-37: Total deformation figures of SHS wrapped in 2 and 4 layers of hybrid FRP under tensile loading

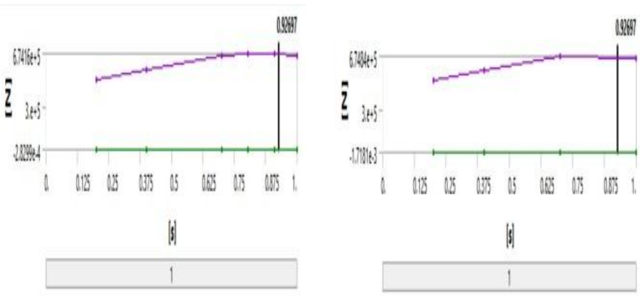

Fig-38: Loading diagrams of SHS wrapped in 2 and 4 layers of hybrid FRP under tensile loading

Table-14: Comparison table of SHS wrapped in 2 and 4 layers of hybrid FRP under tensile loading

Load type	Models	Deformation (mm)	Load(KN)
Tension	TL SQ	41.077	675.71
Tension	TL SQ WITH SC	19.188	500.23
Tension	4 LAYER FRP TL SQ WITH SC	35	674.84
Tension	2 LAYER FRP TL SQ WITH SC	50	674.16

6.2.3 Torsional loading

Model names designated for torsional loading are given as follows:

Table-15: Model names in detail for torsional loading

Model name	Names in detail
TR SQ	Torsional loading in Square Hollow Section
TR SQ WITH SC	Torsional loading in Square Hollow Section with Surface Corrosion
4 LAYER FRP TR SQ WITH SC	Hybrid FRP wrapped in 4 layers in Square hollow section in torsional loading
2 LAYER FRP TR SQ WITH SC	Hybrid FRP wrapped in 2 layers in Square hollow section in torsional loading

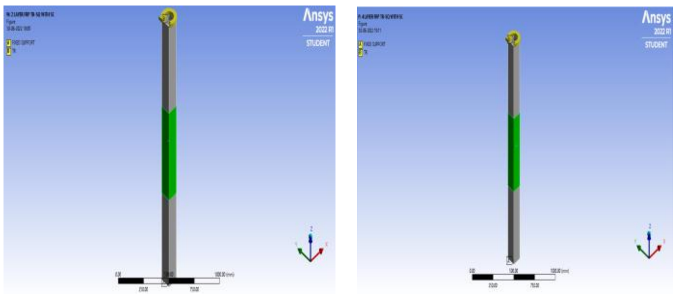

Fig-39: Boundary condition of SHS wrapped in 2 and 4 layers of hybrid FRP under torsional loading

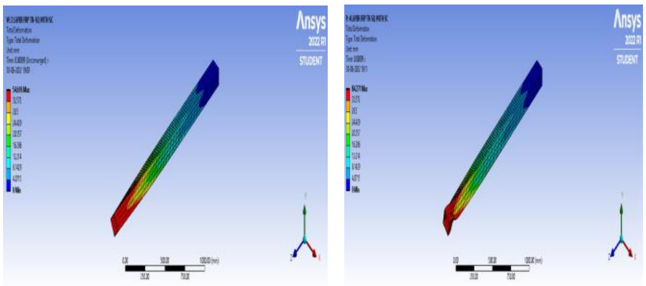

Fig-40: Total deformation figures of SHS wrapped in 2 and 4 layers of hybrid FRP under torsional loading

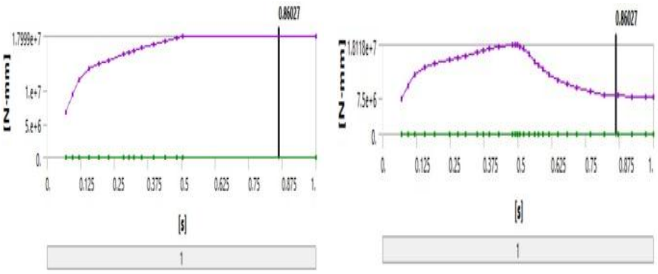

Fig-41: Loading diagrams of SHS wrapped in 2 and 4 layers of hybrid FRP under torsional loading

Table-16: Comparison table of SHS wrapped in 2 and 4 layers of hybrid FRP under tensile loading

Load type	Models	Deformation (mm)	Load(KNm)
Torsion	TR SQ	94.528	18.368
Torsion	TR SQ WITH SC	35.976	13.007
Torsion	4 LAYER FRP TR SQ WITH SC	52.983	18.12
Torsion	2 LAYER FRP TR SQ WITH SC	54.616	17.99

6.3 COMPARISON GRAPHS

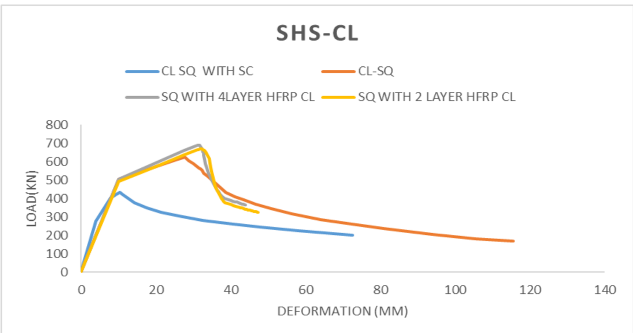

Fig-42: Load deformation relationship of SHS under compression loading

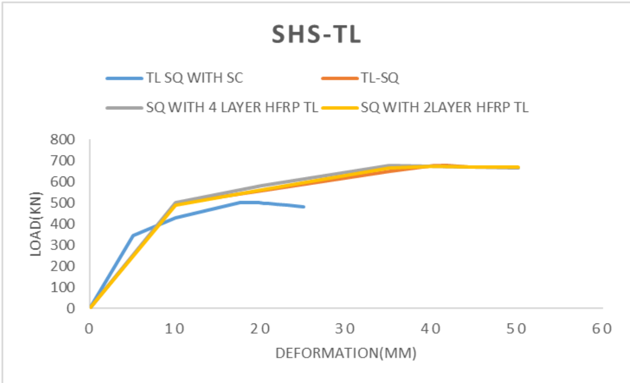

Fig-43: Load deformation relationship of SHS under tensile loading

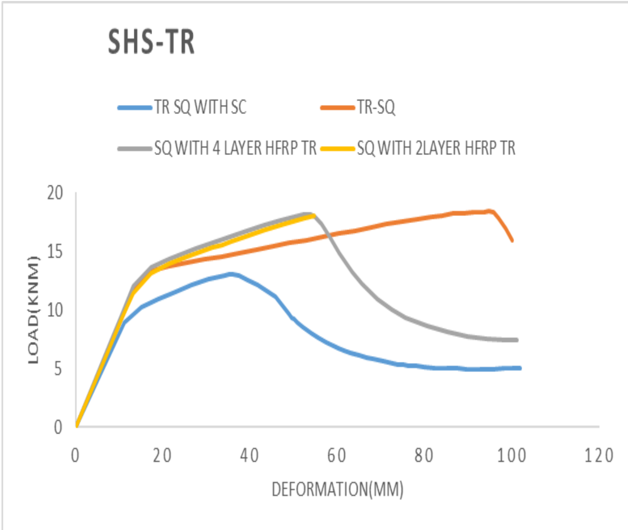

Fig-44: Load deformation relationship of SHS under torsional loading

7. ANALYSIS OF A MULTI-STOREYED FRAME UNDER SEISMIC LOADING AND WRAPPING OF HYBRID FRP (2 AND 4) LAYERS

A multi-storeyed frame having dimensions 3.6m x 3.6m is taken for the analysis under seismic loading. Surface corrosion is given in the bottom most corner of the frame as the base shear first transfers to the corner. It is then wrapped by using 2 and 4 layers of hybrid FRP composites. In this study **EL-Centro earthquake** is taken which has a time duration of 55 seconds.

Model names for seismic analysis given are as follows:

Table-17: Model names in detail for seismic loading

Model name	Names in detail
NORMAL SEISMIC	Seismic loading in multi-storeyed frame without corrosion

WITH SC SEISMIC	Seismic loading in multi-storeyed frame with Surface Corrosion
4 LAYER FRP SEISMIC	Hybrid FRP wrapped in 4 layers in multi-storeyed frame in seismic loading
2 LAYER FRP SEISMIC	Hybrid FRP wrapped in 2 layers in multi-storeyed frame in seismic loading

7.1 MODELS OF MULTI-STOREYED FRAME WITH AND WITHOUT SURFACE CORROSION

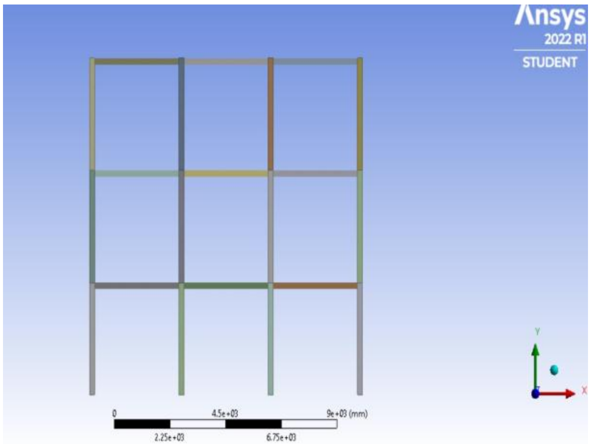

Fig-45: Multi-storeyed frame without corrosion

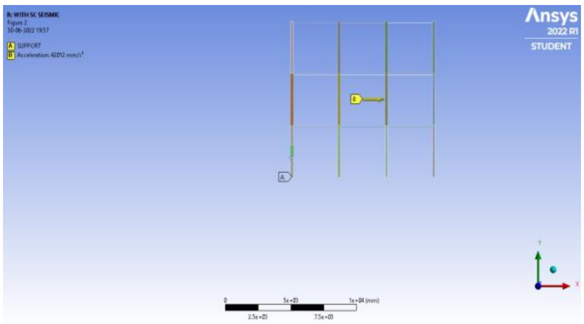

Fig-46: Multi-storeyed frame with surface corrosion in the bottom most corner

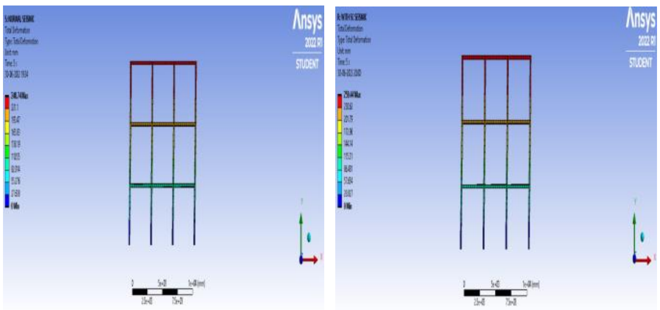

Fig-47: Total deformation figures of multi-storeyed frame without corrosion and with surface corrosion in the bottom most corner

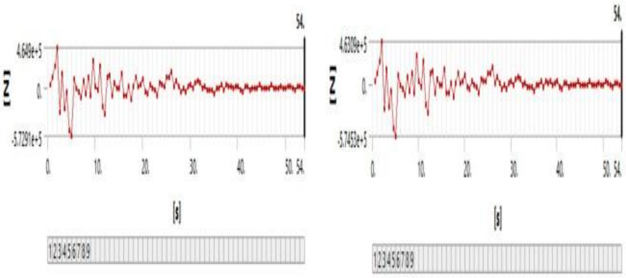

Fig-48: Force reaction diagrams of multi-storeyed frame without corrosion and with surface corrosion in the bottom most corner under seismic loading

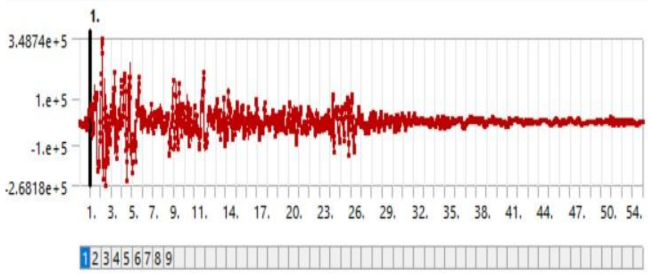

Fig-49: Time-history analysis of a multi-storeyed frame without corrosion under seismic loading

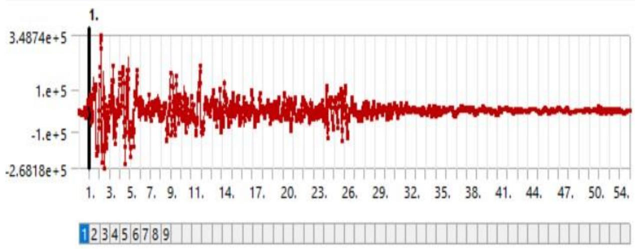

Fig-50: Time-history analysis of a multi-storeyed frame with surface corrosion under seismic loading

Note: Time history analysis is a step-by- step analysis of the dynamic response of a structure to a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake.

7.2 MODELS OF STRENGTHENING THE MULTI-STOREYED FRAME USING LAYERS (2 AND 4) OF HYBRID FRP COMPOSITES

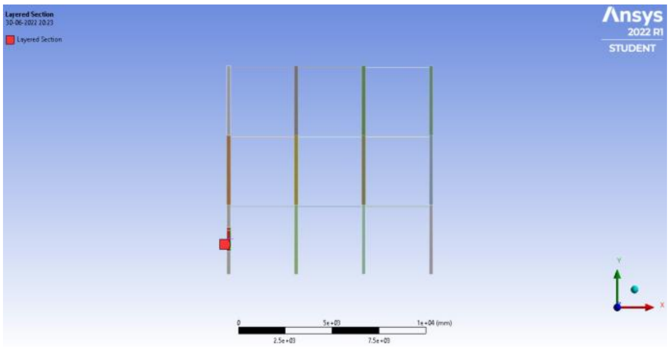

Fig-51: Figure of hybrid FRP wrapped in 2 and 4 layers in the bottom most corner having surface corrosion

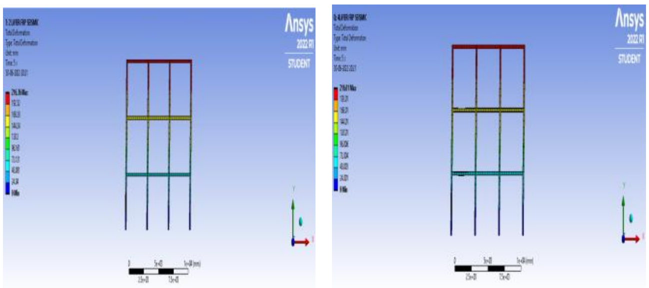

Fig-52: Total deformation figures of multi-storeyed frame strengthened using 2 and 4 layers of hybrid FRP composites

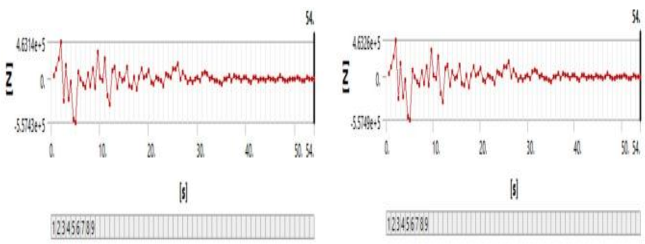

Fig-53: Force reaction diagrams of multi-storeyed frame strengthened using 2 and 4 layers of hybrid FRP composites

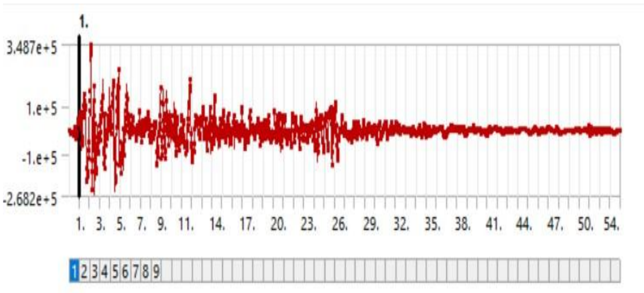

Fig-54: Time history analysis of multi-storeyed frame strengthened using 2 layers of hybrid FRP composites

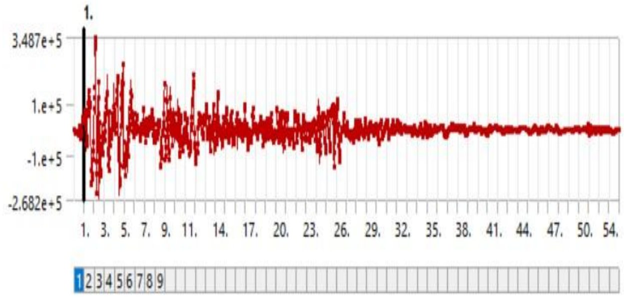

Fig-55: Time history analysis of multi-storeyed frame strengthened using 4 layers of hybrid FRP composites

Table-18: Comparison table of seismic loading

MODELS	Storey deflection (mm)	Base shear(KN))
Normal Seismic	248.74	464.9
With SC Seismic	259.44	463.09
4 layer FRP Seismic	216.01	463.26
2 layer FRP Seismic	216.36	463.14

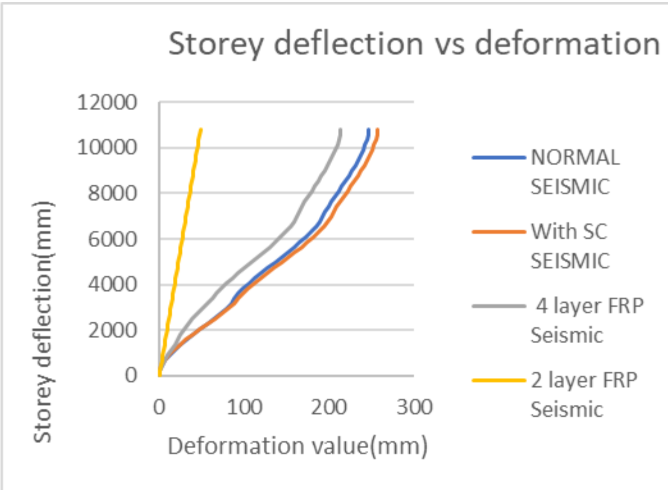

Fig-56: Storey deflection-deformation relationship under seismic loading

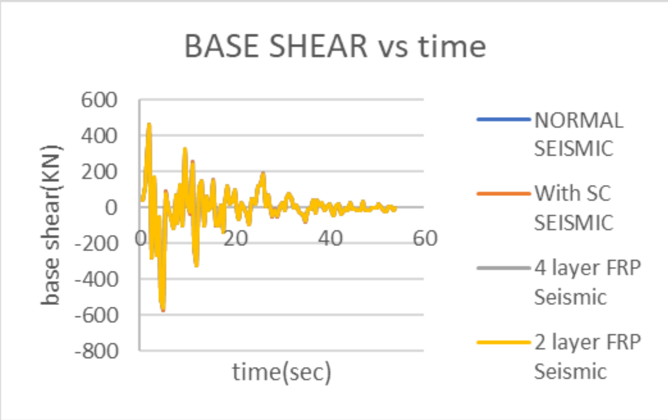

Fig-57: Base Shear-time relationship under seismic loading

8. RESULTS AND DISCUSSIONS

From the comparison charts and graphs of Square Hollow Sections and Circular Hollow Sections,

1. Under compression loading, it is obtained that the circular hollow section without corrosion and with corrosion has more load carrying capacity than square hollow section by a load amount of 36.98 KN and 66.29KN respectively.
2. Under compression loading, it is obtained that the circular hollow section without corrosion and with corrosion has a more amount of deformation than the square hollow section by a deformation amount of 11.388 mm and 10.646 mm respectively.
3. Under Tensile loading, it is obtained that the square hollow section without corrosion and with corrosion has more load carrying capacity than Circular Hollow section by an amount of 33.01 KN and 24.52 KN respectively.
4. Under Tensile loading, it is obtained that the square hollow section without corrosion and with corrosion has some amount of more deformation which is actually neglectible than Circular Hollow section by an amount of 0.823 mm and 1.188 mm respectively.
5. Under Torsional loading, it is obtained that the square hollow section without corrosion and with corrosion has more load carrying capacity than Circular Hollow section by an amount of 26.93 KN and 9.662 KN respectively.
6. Under Torsional loading, it is obtained that the square hollow section without corrosion and with corrosion has some amount of more deformation which is actually neglectible than Circular Hollow section by an amount of 0.003 mm and 2.388 mm respectively.
7. Under Seismic loading, it is obtained that the multi-storeyed frame with corrosion has 10.7 KN more storey deflection than multi-storeyed frame without corrosion.
8. Under Seismic loading, it is obtained that the multi-storeyed frame without corrosion has 1.81 KN more base shear than multi-storeyed frame with corrosion.
9. Under all loading types, it is obtained that 2 layers of Hybrid FRP and 4 layers of Hybrid FRP used for strengthening SHS and multi-storeyed frame has almost similar values.
10. It is clear that 2 layers of Hybrid FRP is enough to mitigate the strength lost due to surface corrosion.

9. CONCLUSIONS

From the analysis of SHS and CHS steel members using ANSYS Software it is concluded that:

1. From the comparison charts and graphs of SHS and CHS, Square Hollow Section steel members have more load carrying capacity than that of Circular Hollow Sectioned members.
2. In the analysis of multistoreyed frame under seismic loading, base shear obtained after strengthening has overcome the value from that of corroded model.
3. 2 layers of Hybrid FRP Composites is enough to mitigate the strength lost due to surface corrosion in Square Hollow Section.

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