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Damage Mitigation Study in Tapered Concrete Filled Double Skin Tubular Columns with Artificial Damages

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Abstract - *Tapered Concrete Filled Double Skin Tubular (CFDST) Columns are widely used in construction of modern buildings and structures due to their enhancement in stability, high strength, light weight, and better cyclic performance. This paper presents a numerical investigation on the performance of tapered CFDST stub columns with locally corroded and surface corroded steel tubes by Finite Element method using ANSYS 16.1 WORKBENCH. Based on prior research the local corrosions in the steel tubes were represented by artificial notches and surface corrosion is represented by reducing the thickness of the steel tube. To develop the critical data needed for understanding the behavior of such stub columns, a group of 20 specimens were designed and analyzed. From the parametric analyses using the validated computer models the percentage decrease in strength for each specimen is calculated and strengthen the corroded section using CFRP.*

***Key Words*: CFDST, Local corrosion, Surface corrosion, Artificial notch and CFRP**

1. INTRODUCTION

Composite steel-concrete construction is widely used in construction of modern buildings and structures, even in highly seismic regions. Structural members that are made up of two or more different materials are known as composite elements. The main benefit of composite elements is that the properties of each material can be combined to form a single unit that performs better overall than its separate constituent parts. As a material, concrete works well in compression, but it hasless resistance in tension. Steel, however, is very strong in tension, even when used only in relatively small amounts. Steel-concrete composite elements use concrete's compressive strength alongside steel's resistance to tension, and when tied together this results in a highly efficient and lightweight unit that is commonly used for structures such as multistorey buildings and bridges. There are several different types of composite column; the most common being a hollow section steel tube which is filled with concrete; or an open steel section encased in concrete. CFDSTs are structural members that have a double steel skin with concrete sandwiched between the two steel tubes. The concrete infill adds to the compression resistance of the steel section, preventing the steel from buckling. Although the combination of steel and concrete across the CFST column cross-section is optimal from the structural performance perspective, it exposes the steel tube directly to the working environment which can be corrosive [1]. In comparison with the abundant investigations on the other aspects of the CFDST columns, the research on the behaviors of the CFDST columns with the corroded steel tubes is fairly scarce, very limited work has been done for the CFST columns with the steel tubes locally corroded[1-2]. Deterioration due to corrosion is a serious problem for all structures that causes enormous economic, social and environmental losses. Aggressive environment conditions and inadequate maintenance are the main reason for corrosion related damages. The costs attributed to corrosion damages of all kinds are estimated to be 3% to 5% of industrialized countries gross national products.

The behavior of tapered concrete filled double skin tubular columns subjected to local groove corrosion in the form of artificial notches are studied. And also, the comparative study on local groove corrosion and surface corrosion in tapered CFDST columns are studied. Further, the results from past surveys show that local corrosion triggered more than 80% of the reported corrosion accidents [1]. Therefore, there is an urgent need to extend the research from the CFDST columns with the uniformly corroded steel tubes to those with locally corroded steel tubes. Due to those damages found out how much amount of strength is lost from the member, change in the behavior of column and CFRP method is proposed to strengthen the damaged tapered CFDST column. Modelling and analysis are done in Finite Element (FE) Software ANSYS 16.1

2. OBJECTIVES OF PAPER

1) Performing the axial load and eccentric load study of corrosion damaged tapered CFDST under local grove corrosion.

2) Study of surface area corrosion in form of artificial way of reducing the thickness in steel are made.

3) Strengthening methods proposed to overcome these damages according to the severity.

3. METHODOLOGY

In this study, the literature review is done, the modelling of specimen is done using ANSYS 16.1 WORKBENCH, conducting parameter study using ANSYS 16.1 WORKBENCH and the interpretation of results.

4. FINITE ELEMENT MODELLING

Tapered Concrete Filled Double Skin Tubular columns with local groove corrosion in the form of artificial notches are modelled. 18 models are created using ANSYS software with artificial notches in different direction (vertical, horizontal, inclined) and at different depth (top, middle, bottom). The concrete type used is M30 Grade Concrete.

4.1 Material Properties

For the specimen the properties of concrete were Young's modulus (E) = 2.33×10^5 MPa, Poisson's ratio (μ) = 0.2, Density (ρ) = 2400 kg/m^3 and Grade of concrete is M30. And the steel tube specimen with following material properties is used Young's modulus (E) = 1.96×10^5 MPa, Poisson's ratio (μ) = 0.3, Density (ρ)= 7860 kg/m^3.

4.2 Geometry

Geometrical details of the column specimen used in the study are given in Table 1.

TABLE-1: Dimensions of Tapered CFDST column

Model	Top diameter (mm)		Bottom diameter (mm)		Steel Tube Thickness (mm)	
	outer	Inner	outer	Inner	outer	Inner
NP3	140	100	180	140	5	3

TABLE-2: Dimensions of Notch Orientation

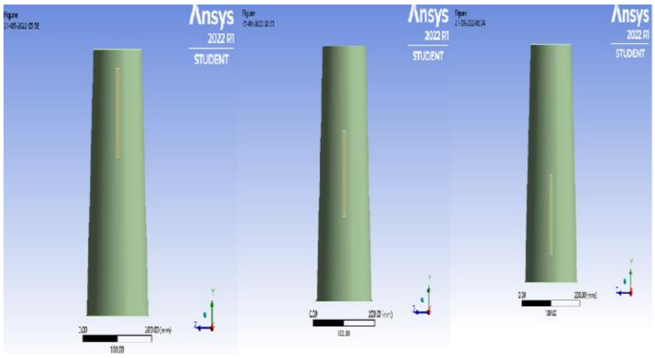
Model	Length (mm)	Width (mm)	Depth (mm)
V-140-5-6	140	6	5

TABLE-3: Dimensions of Surface Corrosion in CFDST column

Model	Length (mm)	Width (mm)	Thickness (mm)
SC-150-110-0.28	150	110	0.28

4.3 Modelling, Meshing and Loading

Tapered CFDST columns are modelled in ANSYS software. The local groove corrosion is provided in vertical, horizontal and inclined direction at different depths of the tapered CFDST columns. Length of column is taken as 420mm, thickness of the steel inner and outer is 3mm and 5mm respectively. The surface corrosion is provided in the form of reducing the thickness of the steel tube Modelling of concrete and steel is done by using element types of SOLID186 and hexahedron meshing is provided. Program controlled coarse mesh is adopted formeshing the columns. Load is applied as displacement of 10mm according to displacement convergence method.



(a) (b) (c)

Fig -1: Model of Tapered CFDST columns with vertical notch at (a) Top (b) Middle (c) Bottom

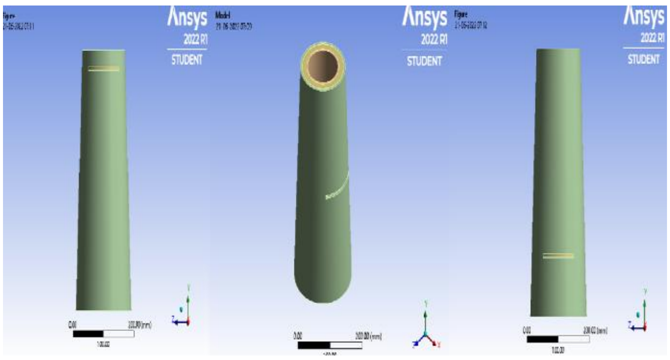


Fig -2: Model of Tapered CFDST columns with horizonal notch at (a) Top (b) Middle (c) Bottom

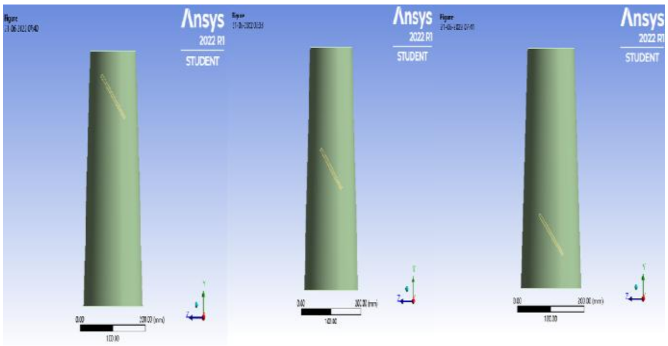
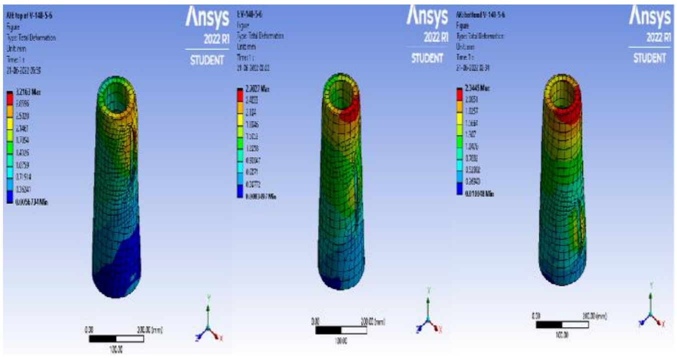


Fig -3: Model of Tapered CFDST columns with vertical notch at (a) Top (b) Middle (c) Bottom

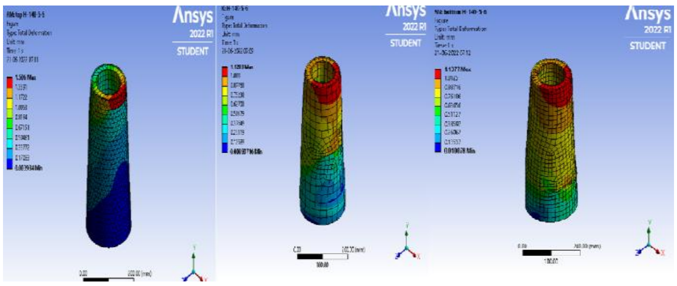
4.4 Analysis

Analysis is carried out to study the performance of Tapered Concrete Filled Double Skin Tubular Columns with local groove corrosion at top middle and bottom of the column and surface corrosion of the column. Nonlinear staticsstructural analysis is carried out in ANSYS software. Deformation and load carrying capacity is studied.



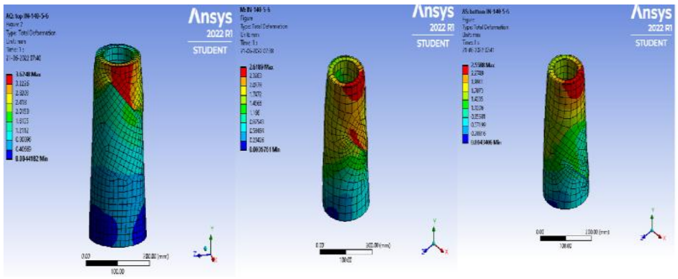
(a) (b) (c)

Fig -4: Deformation of Tapered CFDST columns with vertical notch at (a) Top (b) Middle (c) Bottom



(a) (b) (c)

Fig -5: Deformation of Tapered CFDST columns with horizontal notch at (a) Top (b) Middle (c) Bottom



(a) (b) (c)

Fig -6: Deformation of Tapered CFDST columns with inclined notch at (a) Top (b) Middle (c) Bottom

5. RESULTS AND DISCUSSION

5.1 Axial Loading

The axial loading capacity of Tapered CFDST column subjected to local groove corrosion and surface corrosion was determined from FE analysis. Table 4 and 5 shows the maximum load and deflection of axially loaded Tapered CFDST column under local groove corrosion and surface corrosion.

TABLE-4: Maximum load and deflection of axially loaded local corroded Tapered CFDST column

Model	Deformation (mm)	Load (kN)	% Decrease in load
NP3	1.40	1197.8	1
TOP- V-140-5-6	1.83	1152.8	3.75
V-140-5-6	1.64	1143.6	4.52
BOTTOM-V-140-5-6	2.03	1148.6	4.10
TOP- H-140-5-6	1.08	1047.3	12.56
H-140-5-6	1.12	1031.6	13.87
BOTTOM-H-140-5-6	0.87	1112	7.16
TOP- IN-140-5-6	1.10	1011.3	15.57
IN-140-5-6	1.44	1072.8	10.43
BOTTOM-IN-140-5-6	0.87327	1112	7.16

TABLE-5: Maximum load and deflection of axially loaded surface corroded Tapered CFDST column

Model	Deformation (mm)	Load (kN)	% Decrease in load
NP3	1.40	1197.8	1
V-140-5-6	1.64	1143.6	4.52
SC-150-110-0.28	1.216	1165.8	2.67

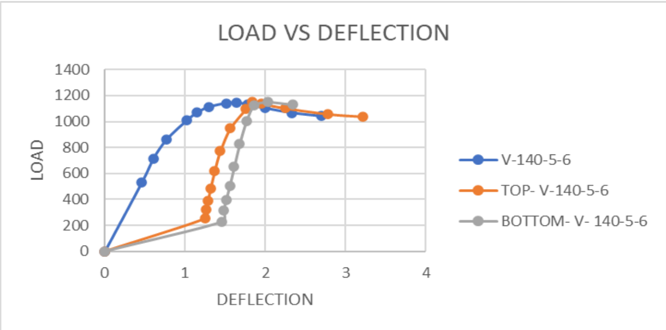


Fig -7: Load-Deformation curve of vertical notch in Tapered CFDST column.

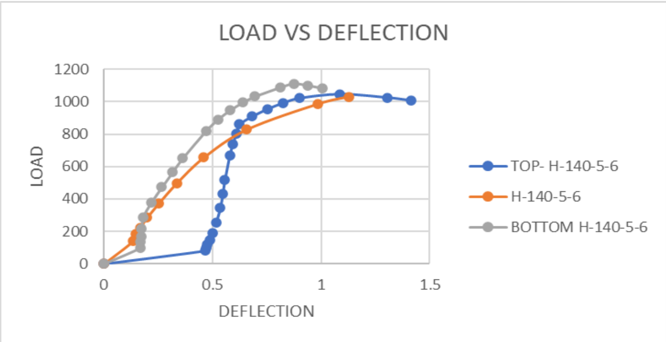


Fig -8: Load-Deformation curve of horizontal notch in Tapered CFDST column.

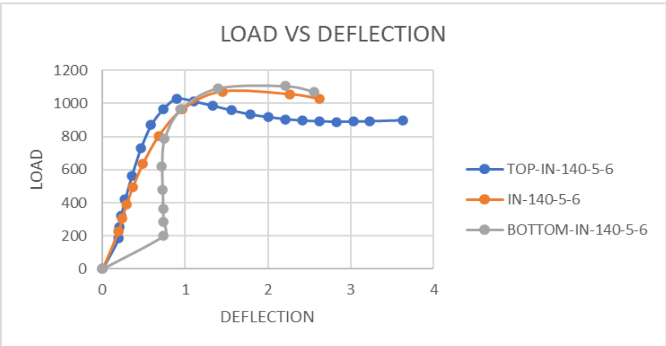


Fig -9: Load-Deformation curve of inclined notch in Tapered CFDST column.

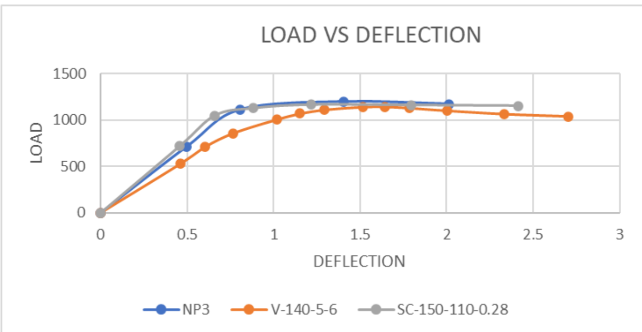


Fig -10: Load-Deformation curve of surface corroded Tapered CFDST column.

From Table 4, Tapered CFDST columns with vertical groove corrosion has more load carrying capacity than the Tapered CFDST column with horizontal and inclined local groove corrosion. The load carrying capacity of Tapered CFDST column with horizontal notch at the middle and inclined notch at top has percentage decrease of load is 23.43 and 35.81 respectively when compared with the non-corroded NP3 Tapered CFDST column.

From Table 5, Tapered CFDST column with surface corrosion shows more load carrying capacity than the Tapered CFDST column with local groove corrosion. Only a 2.6% of decrease in load carrying capacity in surface corroded Tapered CFDST column but there is a 4.5% of decrease in load carrying capacity when subjected to local groove corrosion.

5.2 Eccentric Loading

The eccentric loading capacity of Tapered CFDST column subjected to local groove corrosion and surface corrosion was determined from FE analysis. Table 6 shows the maximum load and deflection of axially loaded Tapered CFDST column under local groove corrosion.

TABLE-6: Maximum load and deflection of eccentric loaded local corroded Tapered CFDST column

Model	Deformation (mm)	Load (kN)	% Decrease in load
NP3	2.1	424.02	1
V- 140-5-6	2.51	487.42	14.95
H-140-5-6	1.51	523.39	23.43
IN-140-5-6	2.68	575.88	35.81

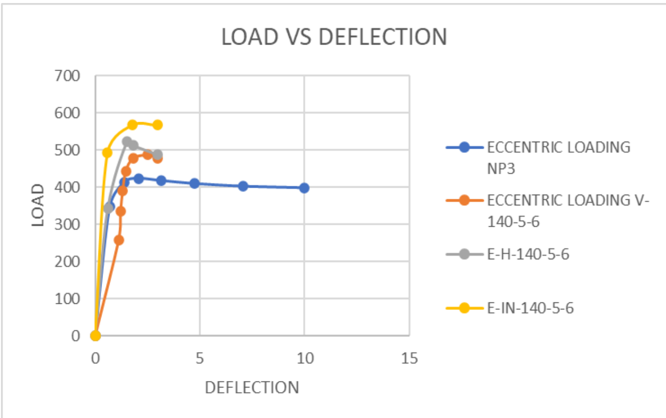


Fig -11: Eccentric Load-Deformation curve of Tapered CFDST column.

From Table 6 Tapered CFDST columns with vertical groove corrosion has more eccentric load carrying capacity than the Tapered CFDST column with horizontal and inclined local groove corrosion. The load carrying capacity of Tapered CFDST column with horizontal notch at the middle and inclined notch at top has percentage decrease of load is 23.43 and 35.81 respectively when compared with the non-corroded NP3 Tapered CFDST column.

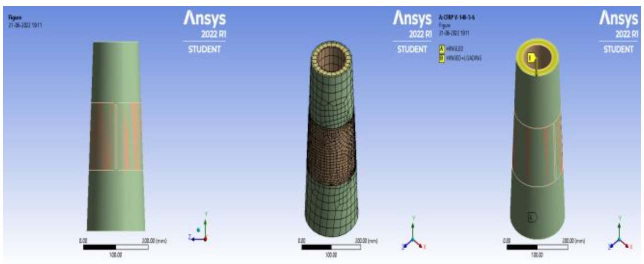
6. REHABILITATION OF DAMAGED TAPERED CFDST COLUMN USING CFRP

The material properties of the CFRP laminates are improved due to its wide range of usage in construction industries. Carbon fibre reinforced polymer has a higher compression strength than materials like aluminium and steel. This means that carbon fibre handles more pressure than its traditional alternatives. It is light weight and it has high fatigue resistance and the flexible carbon fibres crack far less frequently than traditional alternatives like concrete and steel (especially when they're subject to repeat load-bearing weight).

6.1 Material Properties of CFRP

- Tensile Strength (MPa) 1240
- Modulus of Elasticity (MPa) 91700
- Poisson's Ratio 0.3
- Bulk Modulus (MPa) 76417
- Shear Modulus (MPa) 35269
- Thickness (mm) 1.27

6.2 Modelling, Meshing and Loading

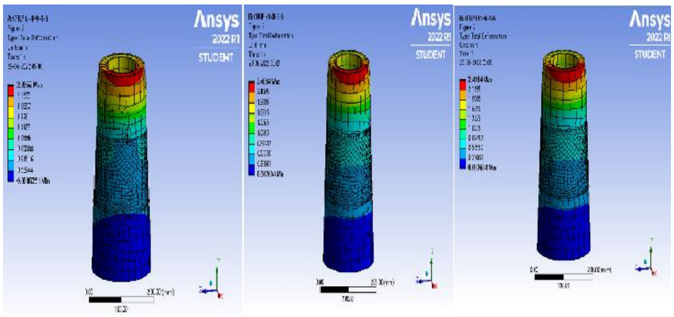


(a) (b) (c)

Fig -12: (a) Modelling (b) Meshing and (c) Loading diagram of V-140-5-6 using CFRP

6.3 Analysis

Analysis is carried out to study the performance of Tapered Concrete Filled Double Skin Tubular columns with CFRP to strengthen. Nonlinear static structural analysis is carried out in ANSYS software. Deformation and load carrying capacity is studied. The deformation diagrams of column specimens are given below.



(a) (b) (c)

Fig -13: Deformation of Tapered CFDST columns with vertical horizontal and inclined notch using CFRP.

6.4 Results and Discussion

The axial loading capacity of repaired Tapered CFDST column with CFRP subjected to local groove corrosion and surface corrosion was determined from FE analysis. Table 7 shows the maximum load, deflection and % increase in axially loaded Tapered CFDST column under local groove corrosion repaired using CFRP.

TABLE-7: Maximum load and deflection of axially loaded vertical local corroded Tapered CFDST column using CFRP

Model	Deformation (mm)	Load (kN)	% Increase in load
V-140-5-6	1.64	1143.6	1
CFRP V-140-5-6	1.62	1227.8	7.3

TABLE-8: Maximum load and deflection of axially loaded horizontal local corroded Tapered CFDST column using CFRP

Model	Deformation (mm)	Load (kN)	% Increase in load
H-140-5-6	1.12	1031.6	1
CFRP H-140-5-6	0.87	1243.1	20.5

TABLE-9: Maximum load and deflection of axially loaded inclined local corroded Tapered CFDST column using CFRP

Model	Deformation (mm)	Load (kN)	% Increase in load
IN-140-5-6	1.48	1072.8	1
CFRP IN-140-5-6	0.87	1247	16.2

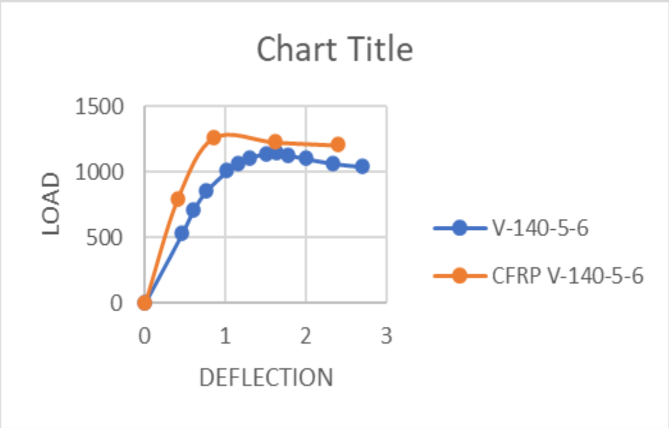


Fig -14: Axial Load-Deformation curve of Tapered CFDST column using CFRP

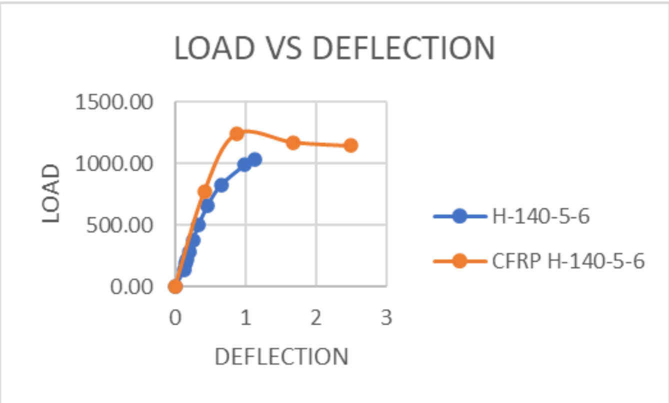


Fig -15: Axial Load-Deformation curve of Tapered CFDST column using CFRP

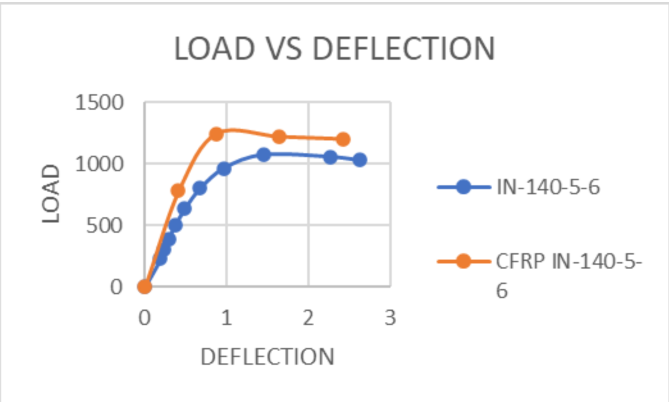


Fig -16: Axial Load-Deformation curve of Tapered CFDST column using CFRP

From figs 14,15,16, damaged Tapered CFDST column with CFRP shows more load carrying capacity in local groove corrosion. 7.3%, 20.5%, and 16.2% increase in load carrying capacity when wrapped with CFRP.

CONCLUSIONS

Tapered Concrete Filled Double Skin Tubular columns with local groove corrosion and surface corrosion are modelled and analysed. The comparison of local groove corrosion and surface corrosion are studied. CFRP is used for strengthening the damaged Tapered CFDST column.

The following conclusions are obtained:

- Based on the research it was found that peak resistance and ductility of tapered CFDST columns can be significantly reduced due to presence of horizontal and slanted artificial notch in steel tube. However, the influences on the peak resistance and ductility become much less remarkable when the notch is along the vertical direction.
- The load carrying capacity of Tapered CFDST column with horizontal notch at the middle and inclined notch at top has percentage decrease of load is 23.43 and 35.81 % respectively
- Local corrosion can be actually more detrimental in CFDST columns since it causes asymmetric cross-section properties and accordingly leads to eccentric loading while compromising the confinement on the concrete fill.
- Tapered CFDST column with surface corrosion shows more load carrying capacity than the Tapered CFDST column with local groove corrosion. Only a 2.6% of decrease in load carrying capacity in surface corroded Tapered CFDST column but there is a 4.5% of decrease in load carrying capacity when subjected to local groove corrosion.
- Moreover, it has been reported that local corrosion is more likely to occur compared with uniform corrosion.
- Using CFRP to rehabilitate the locally grooved tapered CFDST columns enable steel section to restore the lost capacity and resist additional loads.

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