ijergs
Open Access
International Journal of Engineering Research and Generic Science (IJERGS)
Available Online at www.ijergs.in
ISSN: 2455 - 1597
Volume -4, Issue - 4, July - August - 2018, Page No. 01 - 05

Study on Fatigue Behaviour of CFRP Strengthened Hollow Circular Steel Tubes

Nahala Majeed [1], Anagha Manoharan [2]

[1] PG Scholar, Dept of Civil Engineering, Universal Engineering College, Vallivattom, Thrissur, Kerala, India.

[2] Assistant professor, Dept of Civil Engineering, Universal Engineering College, Vallivattom, Thrissur, Kerala, India.

Abstract

In recent years, CFRP externally bonded to steel members has been considered as an effective technique for rectifying failure of steel components. This project investigates the fatigue behaviour of hollow circular steel tubes. From both short column and long column category after being strengthened by CFRP laminates. FEM analysis using the software ANSYS 15.0 is adopted here to evaluate the circular steel tubes. A geometric imperfection is crated in the tubes to simulate the initial damage. Parametric study will be based on L/D ratios, position of imperfection, hole diameter, CFRP width and no:of CFRP layers. S-N curve of grade 250 steel is implemented for calculating fatigue life of structural steel .This study helps to realise the effectiveness of using CFRP for improving the fatigue life of steel structures and provides useful suggestions for the strengthening method.

Keywords: Fatigue, CFRP laminates, Hysteresis loop, Fatigue life, L/D ratios, CHS tubes, S-N curve

Introduction

Steel hollow structural sections are being used in the construction industry progressively. They can supply significant weight and cost reductions as a result of its high strength-to-weight ratios. Circular hollow section steel members are used as structural members in bridges, civil buildings and offshore structures. These members are often subjected to bending under external actions during service, and they may have structural deficiencies due to fabrication or harsh environments. Tubular structures have become increasingly popular for economic and aesthetic reasons, eventhough member deterioration and fatigue cracking is reported. There are various properties for tubular sections like loading in compression, torsion and bending in all directions and these excellent properties are combined with an attractive shape for architectural applications. Furthermore, the closed shape without sharp corners reduces the area to be protected and extends the corrosion protection life. Another aspect which is especially favourable for circular hollow sections is the lower drag coefficients if exposed to wind or water forces. Many pillars of bridges are built of tubular columns, and are exposed to deterioration and corrosion due to rough environmental conditions or the gradual growth of fatigue cracks due to dynamic loading. Therefore measures for structural upgrading and repair have become imperative. The FRP laminate is a very useful method for strengthening tubular columns deteriorated under various conditions. .

Methodology

Circular hollow tubes are modelled in ANSYS 15.1 using SHELL181. SHELL181 is suitable for analysing thin to moderately-thick shell structures. For fatigue analysis, the S - N curve of structural steel needs to be provided. Here we are using steel of tensile yield strength 250 MPa and ultimate tensile strength 456 MPa. The endurance limit of the structural steel is 86.2 MPa which is defined as the maximum stress below which the steel could endure an infinite number of cycles. The Circular imperfection is covered up by a 2 mm thick CFRP laminate inorder to check the amount

by which it will enhance the fatigue behaviour of a steel element with geometric imperfections. The bottom end of the circular hollow section is restrained and cyclic loading is applied as per ATC 24.

The fatigue behaviour of each hollow circular tubes under corresponding cyclic loading which is provided as per ATC 24 is investigated analytically. The circular tubes are subjected to various parametric studies inorder to understand the influence of L/D ratio, position of circular imperfection, diameter of imperfection, CFRP laminate width and No.of layers of CFRP. The optimum value of each parameter is obtained to adopt the most economical method of strengthening steel tubes against fatigue failure, using CFRP.

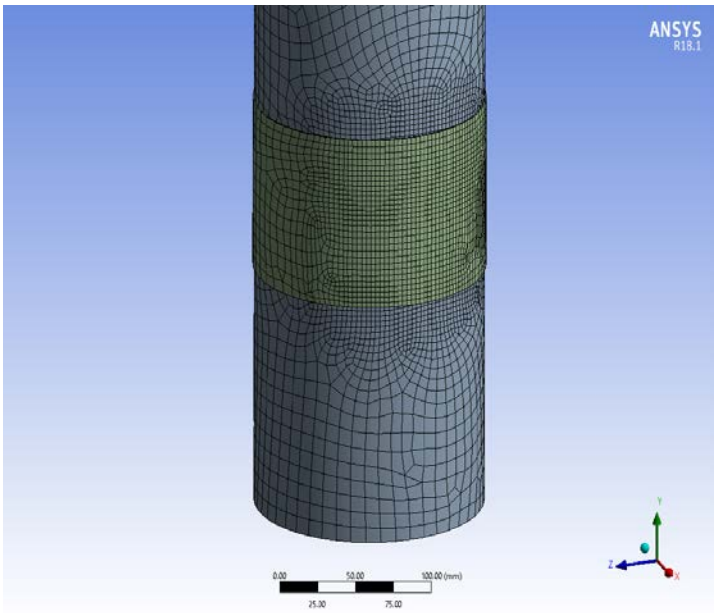

Fig. 1 : Steel tube wrapped with CFRP

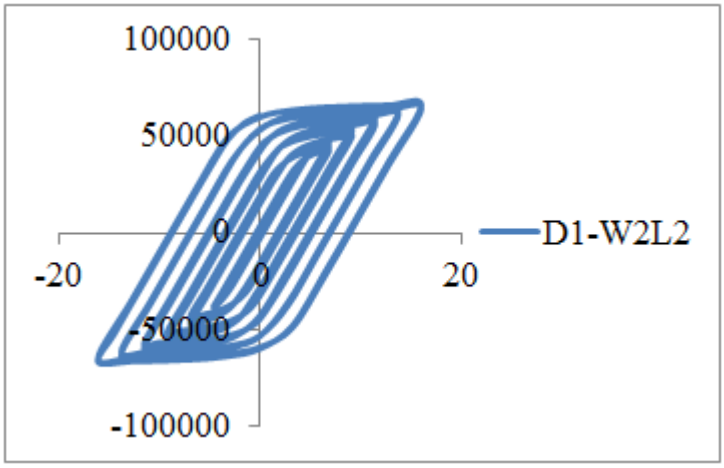

Fig. 2: Hysteresis loop under cyclic loading for short column

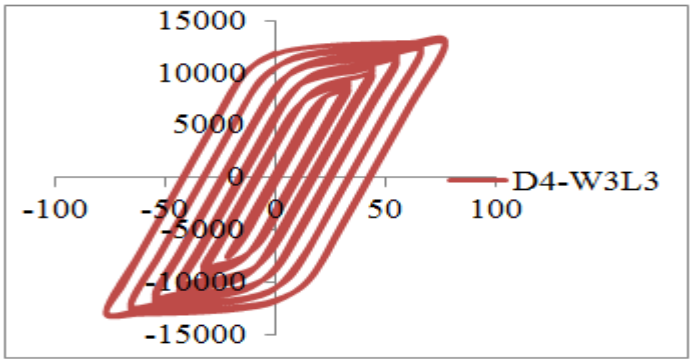

Fig. 3: Hysteresis loop under cyclic loading for short column

Results and Discussions

The optimum value of fatigue life for D1 is obtained at a CFRP width of 2 times the hole diameter and hence the number of layers are added on this width and it was found out that providing 4 layers of CFRP around the circular imperfection gives the maximum improvement in fatigue life of columns ie., almost 98.24% of fatigue life of short column gets improved.

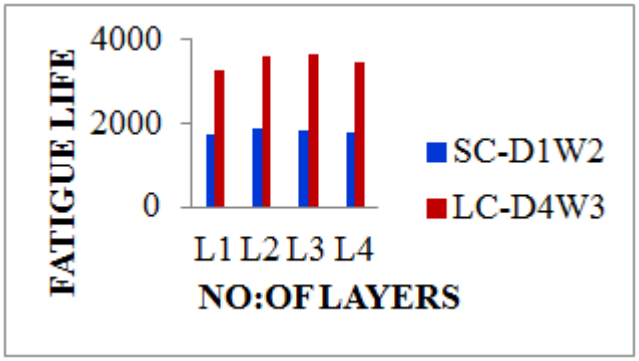

Fig. 4 Effect of number of layers of CFRP on Fatigue Life

Table. 1 Fatigue life of circular steel tubes when wrapped with different layers of CFRP laminates

Specimen Name	No.of Layers	Fatigue Life after CFRP Wrapping (No.of cycles)	% Life Improved
D1H-P1W2	L1	1733.26	75.64
	L2	1882.41	98.24
	L3	1842.15	92.145
	L4	1770.2	81.246
D4H-P1W3	L1	3237.05	45.25
	L2	3603.32	78.45
	L3	3623.66	80.3
	L4	3446.62	64.24

Where L1, L2, L3 and L4 represents 2, 4, 6 and 8 layers of CFRP laminates each having a thickness of 0.5mm respectively.

For long columns, the optimum width of CFRP is 2.5 times the diameter of hole and the number of layers are added on this width and it was found out that the maximum improvement in fatigue life is given by 6 layer wrapping ie., almost 80.3% of fatigue life is enhanced. Increasing number of layers beyond the optimum values resulted in decrease of fatigue life because CFRP itself will initiate a higher stiffness and it cause fatigue failure at the fixed joint provided at the bottom.

Conclusions

The research work included the analysis of circular hollow steel tubes without and with circular imperfections which are subjected to cyclic loading. The tubes are tested for its fatigue life when imperfections occurs at least stable positions and then they are wrapped with CFRP laminates to counteract the weakness caused by imperfections. ANSYS 15.0 is used for modelling and analysing the specimens under cyclic loading. CFRP as a strengthening material for steel components serves an ideal job for enhancing its fatigue life considerably.

i. The optimum value of CFRP width and No.of layers required to improve the fatigue life of short columns are found to be 2d (d = diameter of circular imperfection) and 4 respectively. In this case about 98.24% of fatigue life of columns gets increased.
ii. For long columns, the ideal CFRP width and No.of layers is found to be 2.5d and 6 respectively. Here fatigue life of columns increased by 80.3% which is reasonably a good improvement.

Furthermore, to make the strengthening process more feasible and economical, its important to fix correct width and No.of layers of CFRP since it's a costlier material.

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