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Structural Analysis of Fractured I Beam Strengthened with Prestressed CFRP Plates

Minu U
PG Student
Civil Engineering Department
AWH Engineering College
Calicut, India

Priyanka Dilip
Assistant Professor
Civil Engineering Department
AWH Engineering College
Calicut, India

***Abstract*—The increasing service loads and harsh environmental conditions make metallic structures even more vulnerable to fatigue failure. As a result, the fatigue strengthening of metallic structures has attracted much interest. Externally bonded carbon fiber reinforced polymer (CFRP) plates can significantly improve the fatigue behavior of cracked steel members. CFRP laminates are extremely strong and light fibre reinforced polymer which contains carbon fibres and have high strength to weight ratio and rigidity. Due to this property carbon fibre reinforced polymer strengthening is a promising way to make structural members stiffer and stronger. In this paper the fatigue behaviour of damaged I beams strengthened by prestressed CFRP plates is investigated by finite element analysis using ANSYS. A double-edged cracked steel beam was considered for modelling. The propagation of cracks after strengthening was analysed in terms of stress intensity at the location of cracks by varying the prestressing force.**

Keywords:- Prestressing; CFRP plates; crack width; crack propagation

I. INTRODUCTION

A large number of steel structures worldwide are currently aging, and most of these structures, such as road and railway bridges, offshore structures, and communication towers, are subjected to fatigue loading. The increasing service loads and harsh environmental conditions make these structures even more vulnerable to fatigue failure. As a result, the fatigue strengthening of metallic structures has attracted much interest. Various techniques such as using bolted or welded cover plates to bridge existing cracks, overloading the structure to retard the fatigue crack propagation, as well as drilling stop holes at crack tips have been conventionally used to prolong the fatigue life of cracked metallic members.

Externally bonded fiber-reinforced-polymer (FRP) laminates have been widely used for strengthening and retrofitting concrete structures in the past two decades. In recent years, the utilization of FRP materials for strengthening damaged steel structures has attracted increasing attention, and the bonded and un-bonded FRP techniques have been used in the strengthening of steel structures. Fatigue failure is common for steel structures subjected to cyclic loading; thus, one important application of FRP materials is to improve the fatigue behavior of steel structures.

For the last two decades, however, the unique advantages of carbon fiber reinforced polymer (CFRP) composites such as high corrosion resistance, light weight, high strength and elastic modulus, as well as excellent fatigue life, have made CFRP composites a well-accepted alternative for the static and fatigue strengthening of such structures. The study results indicated that the externally bonded CFRP laminates could significantly decrease the crack growth rate and prolong the fatigue life of the damaged steel members. Moreover, this method was more effective than the traditional welding method.

II. OBJECTIVES OF THE PRESENT STUDY

- To investigate the structural behaviour of fractured I beam strengthened by prestressed CFRP plates by varying the prestressing force
- To study the crack propagation behaviour of fractured I beam after strengthening with pre-stressed CFRP plates.

III. METHODOLOGY

- Collecting various literature reviews on strengthening of fractured I beams and effect of prestressing on metallic structures.
- Validation of Aluminium I beam strengthened with CFRP tendon-anchor system using ANSYS.
- Modelling & analysis of fractured I beam strengthened by prestressed FRP plates by varying the parameters using ANSYS workbench 16.1.
- Comparing the results of various models to find the best one.
- Concluding from the results.

IV. FINITE ELEMENT MODELLING

Modelling of the double edged fractured I beams was done using ANSYS WORBENCH 16.1. The CFRP plates and the steel were simulated using the 8-noded 3D solid element SOLID45. Standard hot-rolled ISLB 350 steel beams with a length of 3000mm were chosen for finite element modelling. Five typical specimens are chosen, including one un-strengthened beam and four strengthened beams. The specimens were strengthened by one layer of high modulus CFRP (HM-CFRP) plates and high-strength CFRP (HS-CFRP) plates. The material properties of steel and CFRP plates used in ANSYS are shown in Table 1 and 2 respectively. Details of the various models are given in Table 3.

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TABLE 1 MATERIAL PROPERTIES OF STEEL

Property	Value
Young's modulus	200000 MPa
Yield strength	415 MPa
Poisson's ratio	0.3

TABLE 2 MATERIAL PROPERTIES OF CFRP PLATES

Material	HM-CFRP	HS-CFRP
Young's modulus (GPa)	436.4	145
Ultimate strength (MPa)	1540	2123
Width (mm)	150	150
Thickness (mm)	2	1.4

TABLE 3 DESCRIPTION OF THE MODELS

Model	Material	Prestressing force (kN)
UN-BEAM	ISLB 350	0
HM-BEAM	ISLB 350&HM CFRP	10
HM-BEAM-1	ISLB 350&HM CFRP	20
HS-BEAM	ISLB 350&HS CFRP	10
HS-BEAM-2	ISLB 350&HS CFRP	20

To simulate the initial damage, two U-shaped notches with a width of 8 mm and a length of 21.8 mm were cut in both edges of the tension flange at the mid-span. In order to avoid the compression flange buckling, a steel cover plate with a cross-section of 240×12 mm was welded on the compression flange of the steel beam. Mechanical anchorage devices were applied to avoid the premature debonding of the FRP plates. The loading is done with the help of 25 mm thick bearing plates. Two point load is applied. The loading of 100 kN was applied to the FE models at the loaded point. The prestressing force is applied to the CFRP plates by using bolt pretension tool.

Fig.1 shows the model used in the analysis. Fig.2, Fig.3 and Fig.4 shows the enlarged view of the midspan crack for unstrengthened and strengthened specimens respectively. Prestressing force and type of CFRP plate are taken as variables for the analysis.

Total 5 number of models are considered for the analysis by varying the level of prestressing foce and type of CFRP plate.

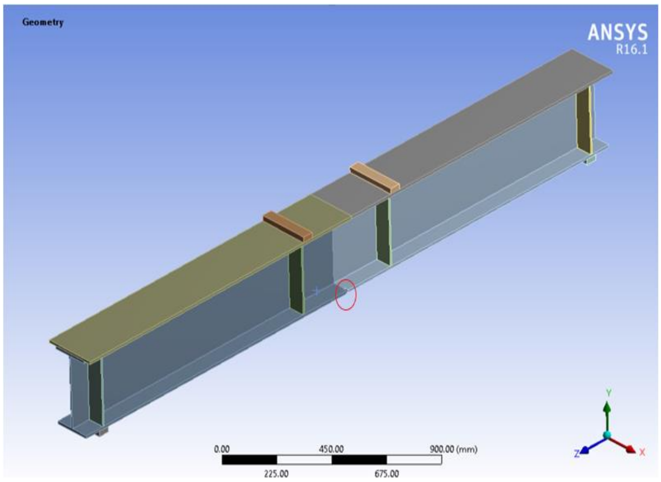

Fig. 1 Model

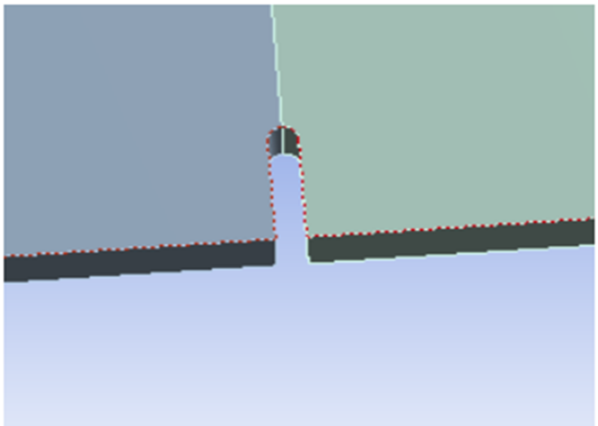

Fig.2 Enlarged view of UN-BEAM

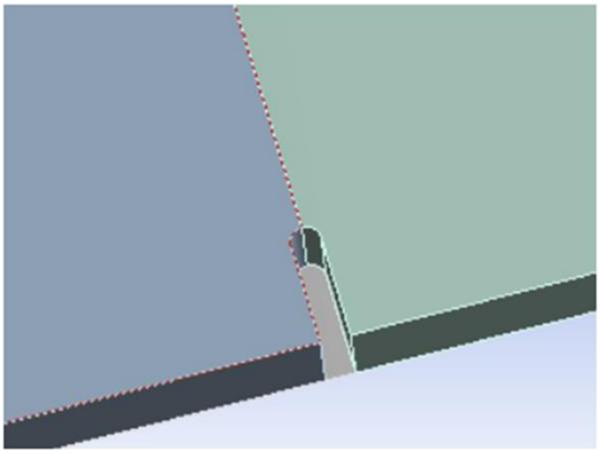

Fig.3 Enlarged view of HM-BEAM

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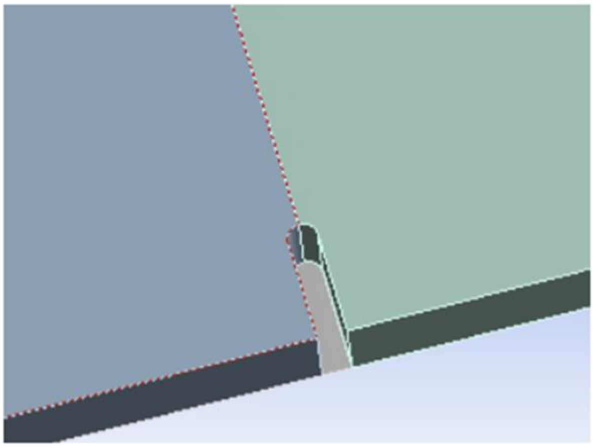

Fig.4 Enlarged view of HS-BEAM

V. ANALYTICAL RESULTS

The stress intensity is a key parameter for determining the crack growth behaviour of un-strengthened and CFRP strengthened cracked steel beams. Fig. 5 -9 plots the variation of stress intensity with main crack length of un-strengthened beam and strengthened beams.

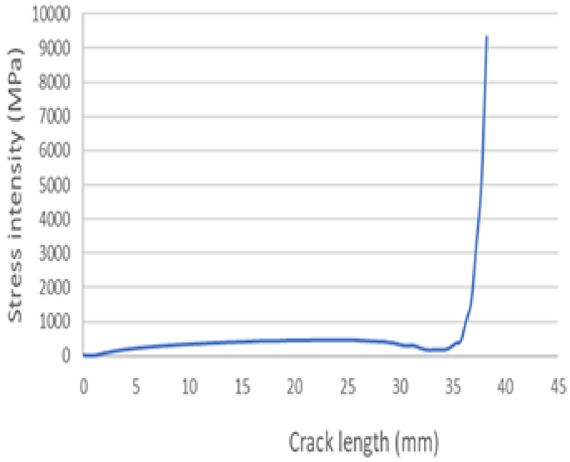

Fig.5 UN-BEAM

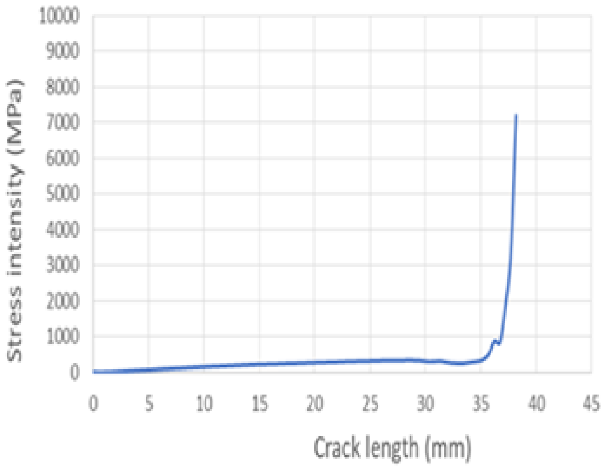

Fig.6 HM-BEAM

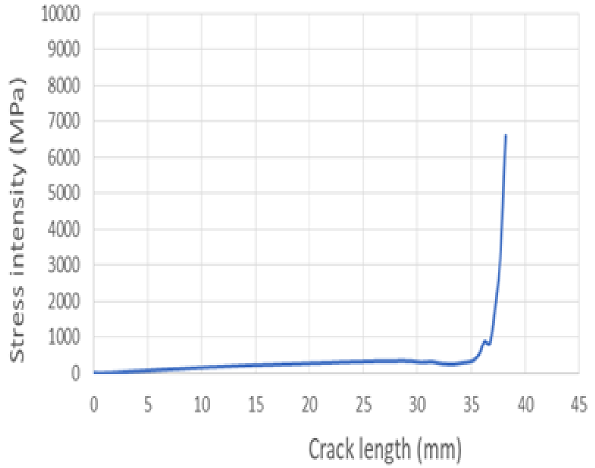

Fig.7 HM-BEAM-1

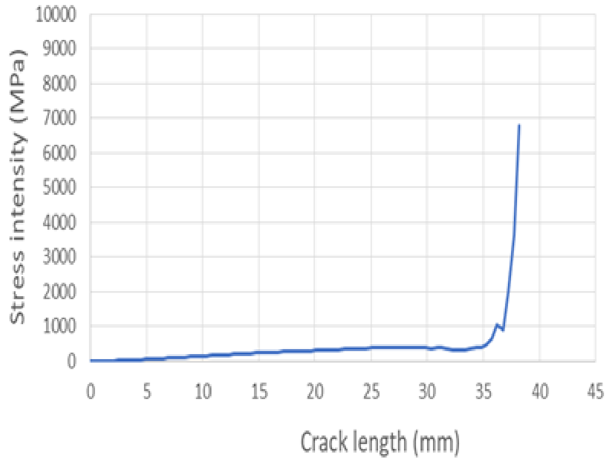

Fig.8 HS-BEAM

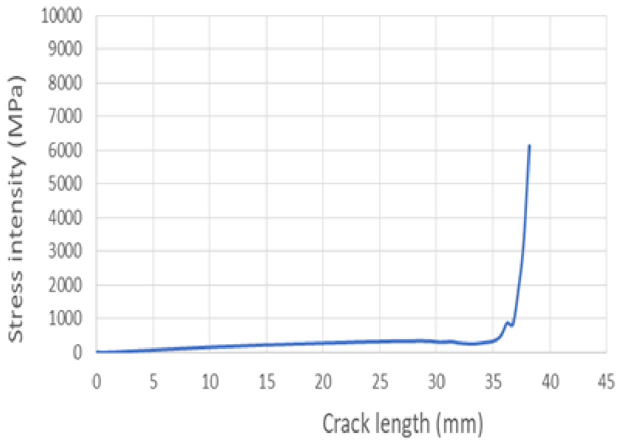

Fig.9 HS-BEAM-1

In the above figures, the crack length in the horizontal axis incudes the length of the initial notch. The stress intensity of the main crack gradually increases with the increase in the crack length up to 30 mm. Then there is a small reduction in stress intensity up to 34 mm crack length after that there is a sudden increase of stress intensity before it reaches the boundary between the flange and the web. The serious stress concentration exists around the crack tip with a stress intensity of 9316.2 MPa.

The crack propagation behaviour of double edged cracked steel beams strengthened with prestressed HS-CFRP plate and HM-CFRP plate are analysed. The crack propagation behaviour of strengthened beams are almost similar for all four models. But the stress concentration at the tip of the crack differs. As the stress intensity at the crack tip decreases the crack propagation tendency also decreases. The prestressing forces used were 10 kN and 20 kN. Models were analysed using with different prestressing forces and CFRP plates.

Among the above 5 models the best model is HM BEAM 1. Here the stress intensity at the tip of the crack is 6130.2 MPa and the crack is propagated up to 38.2 mm length

The deformed shapes of UN-BEAM and HM-BEAM-1 are shown in Fig. 10 and Fig.11 respectively

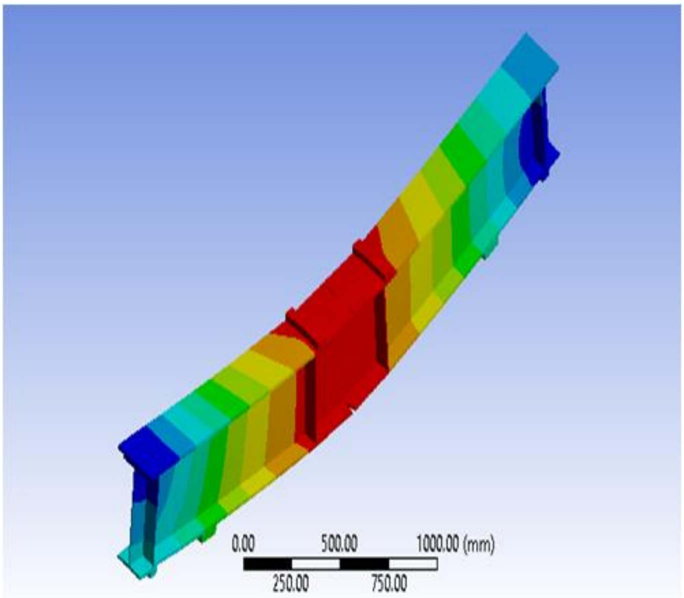

Fig.10 Deformed shape of UN-BEAM

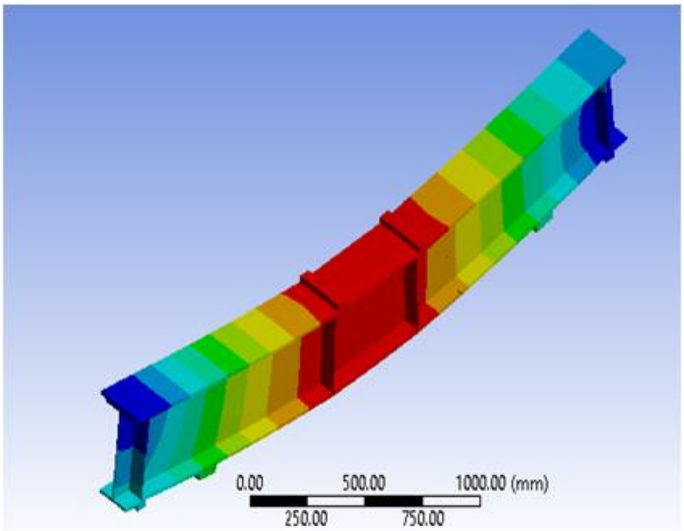

Fig.10 Deformed shape of HM-BEAM-1

VI. CONCLUSIONS

- Compared with the un-strengthened beam, the stress intensity factors of the main crack of the HM-CFRP strengthened beam are decreased significantly, demonstrating that the externally bonded HM-CFRP plates are very effective for improving the fatigue behavior of the cracked steel beams.
- Corresponding to a crack length of 38.2 mm the stress intensity is 9316.2 MPa and 6130.2 MPa in UN BEAM and HM BEAM 1 respectively.
- Among the 5 models the best model is HM BEAM 1.
- For the models strengthened with HS CFRP plates the maximum stress intensity is less than that of un-strengthened beam but more than that of HM BEAM.
- There is a 34.1 % reduction in the value of maximum stress intensity at the tip of crack for HM BEAM-1 when compared with UN BEAM.
- As the stress concentration at the tip of the crack decreases the crack propagation tendency decreases
- As the applied prestress level increases the stress intensity at the crack location decrease
- Strengthening of fractured I beam using prestressed CFRP plates is an effective method for reducing crack propagation

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