

Studying Damaged Moment Beams Reinforced With Carbon Polymer

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Abstract

Generally, passing of time and environmental factors such as oxidation and corrosion in some parts of the structure, has a significant effect on decreasing load capacity and creating a defect in structure members. Because of resistance and hardness of carbon fiber reinforced polymer (CFRP), they are suggested as the best materials for repairing the structure. In this paper, for investigating the effect of CFRP sheets for reinforcing steel beam which has initial defect, seven beams were studied for modeling by ABAQUS software. It should be noted that in all these beams, initial defect was created in middle tension flange area of beam bilaterally. This study determines the appropriate performance of CFRP sheets in increasing load capacity and preventing the spread of defect in steel beam.

Keywords: Reinforcement, Steel Beam, Member Defect, Load Capacity, CFRP

Introduction

In 1967, once imperative auditing and control was done on bridges in the US, American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Station (FHWA) determined to develop programs for six month inspection. As a result, it was determined that more than one-third of a highway bridge in US were under standard significantly (1). Klaiber et al (1987) suggested that more than 43% of bridges in the US were built by steel. Based on NBI report, metal bridges are part of the category which are suggested for improvement more than others that their main problem related to the fatigue and exhaustion are needed for increasing service load, corrosion and inappropriate maintenance. Also, repairing and reinforcing before making decision for bridge displacement is recommended. Repairing and rebuilding in most of the cases has lower cost than displacement and it takes less time. Considering limitation of available resource for decreasing problems related to the steel bridges, there's a need for adopting new material and thrifty method (2).

Lorenzo (1986) suggested that CFRP sheets with fatigue sensitive features in the metal member causes increasing resistance and life cycle of fatigue. Mechanical features and the superior fatigue of fiber polymer reinforced by carbon fiber can introduce them as the best option for repairing and reinforcing steel girders of bridges. CFRP sheets guarantee one

million cycle from the fatigue load and tension suffering 1.5 times more than final resistance(3). Tavakolizade and Saadat manesh (2003) proposed results of research which was done about repairing Slotted steel beams with CFRP pieces for the fatigue load with average cycle of (R=0.1) (4). A set of 21 steel beam samples built from A36, S127×4.5 were tested. Unreinforced beams were tested as control samples. Steel beams were tested under four moment points with load ratio between 5 and 10 Hertz. Consistent tension with various domains were considered between 69 and 379 MPa. Length and thickness of pieces were considered equal for all repaired samples. Additionally, number of rupture cycle, hardness changings and fracture reopening and its spreading along each sample also were considered. Results show that CFRP piece not only tends to extend fatigue life of one piece more than 3 hours but also decreases the speed of fracture extension significantly. The importance of life restoration and delaying deterioration of steel structures, motivates researchers for easy and useful progress of rehabilitation techniques of structures. One of the development techniques is adhering CFRP to the wing of steel beams.

Colombi et al (2003) done analysis of fracture in the metal members reinforced with thepre-stressed composite and the fatigue failure. They used 3-layer technique for studying rupture extension in the metal system. They found that in sheet samples, detachment is not the dominant mode and using very hard metal sheets has not considerable increasing in the effectiveness of retrofitting(5). Kim and Harris (2011) investigated moment behavior of damaged metal beams reinforced by CFRP sheets. This damage was created in high tensile area. For evaluating fatigue, repaired beam was tested with emphasis on plastic area of six-beam. The amount of damage extension, fatigue life and plastic strain in repaired beams had improved. The amount of observed fatigue response in contact surface of CFRP and beam is related to the number of fatigue cycles and applied tension. Except in the damage area, in which strain focus is significant, strain along the CFRP sheet increases gradually. Damage degree was not influenced by range and tension amount till 60% of fatigue life and with increasing fatiguecycles, damage degree influenced by tension amount. In the beam web, fatigue life was not considerable by 40-50% of vertical fracture extension. But with increasing life, fatigue had

increased highly and suddenly a fragile rupture was happened in web (6).

Ghafouri et al (2012) investigated beam behavior containing reinforced damage with two types of CFRP (pre-stressed and without pre-stressed). Effects of fatigue loads, humidity and water going of FRP and metal were considered. In a PBR system in which adhesive was used for adhering CFRP, local strain was centralized while in PUR system, the regular local strain was observed along the FRP sheet and also it can show better fatigue performance with a high degree of pre-stressed that strain extension along the CFRP was regular. Beam with reinforced damage has equal load capacity both in PUR and PBR systems while failure modes in two systems were different. Beam reinforced with CFRP has pre-stressed 5 times more than fatigue life. Different modes of fracture including passive, semiactive and activewere introduced. Whenever

fracture is passive, it has no considerable effect on structural behavior. In semi-active mode, with increasing external bending moment, bending hardness begin to decrease until fracture becomes active suddenly (7).

In this paper, effect of adhering CFRP sheets on structural behavior of steel beam and recovering hardness of damaged beam load capacity were investigated. Different sizes of CFRP sheets were used for reaching an appropriate length of modeling.

Materials and samples specifications

In this paper, different sizes of defect points were used. At first, for reaching an appropriate length of CFRP, defect with $20 \times 30 \text{ Mm}^2$ was used in which, the first number is the length of defect and the second one is the width of defect according to the below figure (1).





Specifications of selected steel beam

Steel beam of IPE160 with 2350 mm length, final resistance of 370 MPa and final strain of 13.5% was modeled as nonlinear. Geometrical figure of the beam is shown in figure (2). Table (1) proposes specifications of the steel beam.

Composite specifications (CFRP)

For reinforcing steel beam under pure bending, CFRP carbon composites with elastic modulus of 210000MPa, strip thickness of 1.4 mm and Poisson's ratio of 0.12 were used as isotropic.

Beam dimensionIPE160			Elasticity	Tensions		Strain		
)mm(modulus(MPa)	(MPa)		percentage		
width	Height	Flange thickness	Web thickness	200000	Flow tension (Fy)	Final tension (Fu)	Flow strain (ε _y)	Final strain (ε _u)
82	160	7.4	5		250	370	0.12	13.5

Table1: Dimensions and Specifications of Steel Beam



The tension – strain curve of this material shows linear elastic behavior till rupture stage without any specific point of flow and in modeling, they don't show non-linear behavior; because of this, it is only needed to enter elastic mechanical specification into the software. Carbon composites specifications are shown in table (2).

Adhesive specifications

Adhesivesuppliesthe shear transmission path between steel surface and composite material and causes similar performance of composite and beam. Reinforced CFRP strips are adhered to the steel beam by using special epoxy with 1 mm thickness and elastic modulus of 11520 MPa. Table (3) shows specifications of adhesive used in this paper.

Table (2):	Dimensions and	l specifications of	CFRP	reinforced sheet	

	dimensions (mm)	Elasticity	Final strain(percentage)	
width	thickness	length	modulus (MPa)		
82	1.4	300 to 1700	210000	1.35	

Table (3): Specifications of Epoxy Resin

Final strain)percentage(Elasticity	Tensile strength	Shear	Poisson's
	modulus[MPa]	[MPa]	strength[MPa]	ratio
0.9	11520	22.7	31.7	0.2

Beam samples

The defect with bilaterally dimensions of $(20\times30\text{mm})$ with CFRP with a medium modulus of (2400 GPa), thickness of (1/4mm) and different lengths of (1000,700,500,400 and 300mm) are investigated for obtaining appropriate length that finally, length of 400mm is chosen as an appropriate length. It should be noted that in samples, the first number is the length and the second one is the width of defect (figure 1).

Modeling and software analysis

For modeling, ABAQUS V6.11 was used in which, steel beam, hardening sheets, CFRP sheets and 3D solid adhesive with TET element of modeling (10 nodes) and for reaching fracture mode from the non-linear static analysis were used. Also, linear and non-linear specifications of material were used and results of samples analysis are shown in table (4).

For reaching an appropriate length of CFRP sheet, defect dimensions of $(20\times30\text{mm})$ with CFRP strip and medium modulus of (2400GPa), thickness of (1/4mm) and different lengths of (1000,700,500,400 and 300mm) were modeled. Figure (3) shows that created defect in defectless beam causes decreasing in loadcapacity by 30%. For restoration and reaching load capacity of defectless beam which is the control beam, lengths of 1000,700,500,400 and 300 mm from CFRP strips with 1/4 thickness were used that increasing of 37%, 34%,32%,30 and 28% were obtained respectively. It can be inferred that 400mm length is the best selection for repairing defect as it can have performance such as defectless beam and it is also recommended for sample beams with greater defect. Also in figure (4), fracture mode of reinforced beam sample is shown in defect area that strain focus on adhesive, end-debonding phenomenon at the end of CFRP sheet and tension focus in defect area are observed.

G 1	Sample	CFRP length)mm(Defect	Load capacity		
No.			dimensions)mm ² (Load amount)KN(increase/decrease (%)	
1	S_1	0	0	127	0	
2	S_2	0		89	-30	
3	S ₃	1000		137	+7	
4	S_4	700		133	+4	
5	S 5	500	30×20	129	+2	
6	S_6	400		127	0	
7	S 7	300		125	-2	

Table (4): Specifications of steel beam samples which have reinforced defect with CFRP

Figure (3): Vertical displacement in the mid span for the defect beam $(20 \times 30 Mm^2)$



Figure (10): strain focus on adhesive, end-deboning phenomenon at the end of CFRP sheet and tension focus in defect area



Conclusion

- This research shows the possibility of using CFRP sheets in repairing the defect beam and restoring lost strength because of the defect. Tension level and plastic strain had been improved in repaired beam.

- Defect expansion in non-reinforced beam happens quickly, the level and amount of defect are influenced by applied load amount.

- Local debonding in CFRP sheets resulted from defect, causes a sudden increase in adhesive tension, and respectively, CFRP slips. With increasing load amount, the strain of CFRP sheet in defect area and debonding strain is considerable.

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