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FINITE ELEMENT MODELING TO PREDICT FLEXURAL PERFORMANCE OF STEEL I-SECTION BEAM EXTERNALLY BONDED BY VARIOUS FRP FABRICS: A REVIEW

Nagesh Angad Yadav[*1] & Vidya Malgonda Patil[2]

[*1]P.G. Student, Department of Civil Engineering, Annasaheb Dange College of Engineering and Technology Ashta, Dist. Sangli, Maharashtra, India -416301

[2]Assistant Professor, Department of Civil Engineering, Annasaheb Dange College of Engineering and Technology Ashta, Dist. Sangli, Maharashtra, India -416301

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ABSTRACT

Use the fiber reinforced polymers fabric (FRP) in repair and strengthening of bridges, steel structure, etc. This article is review of literature available on flexural behavior of I-section steel beams with externally attached with FRP fabrics. It can be useful to decide which FRP sheet is best to use with steel beam to enhance flexural strength. Also this study comprises of cost comparison of Steel I beam strengthened by various FRP i.e. Basalt-FRP, Glass-FRP and Carbon-FRP. This can be achieved by bonding various FRP sheet at bottom flange, top flange & two faces of web to steel I section beam. It was studied through experimental, analytical, numerical investigation. Most of work is done on carbon-FRP fabric attached to steel beam as compared with Basalt-FRP. Some literature studied properties of FRP, adhesive bond, and fatigue behavior. In experimental method, four point bending test was performed and model were analyzed using FE analysis. From this review, Carbon-FRP gives better performance of Steel I beam as compared with other FRPs.

KEYWORDS: Flexural performance, steel I-section beam, BFRP, CFRP, GFRP.

1. INTRODUCTION

In construction industry, most commonly steel are used. Increasing Use of steel structure gives more attention towards Enhance quality, life span, and rehabilitation. Under ordinary method, Repairing of steel Structure involves upgrading structure to improve performance under present loads or to expand quality of part of structural member. Upgrade by removing damaged parts and welding steel plates. It is help to extend life period of steel structure, lead to save the money and reduced material wastage. Construction practice's ordinary method was successful but limitations exist to rise weight of original structure, lifting is heavy, machinery required and corroding additional steel plates in vulnerable environment, which will increase maintenance costs. In ordinary method of strengthening easily take yielding take Place. Drawback is additional size and weight increases and bonding are required properly.

So therefore, need of new method that removes limitation of ordinary method. Fiber reinforce polymer strengthening method are can use. That have alternative to ordinary method. FRP is known as fiber reinforced polymers. Recently fiber reinforced polymers are commonly used for strengthening of structure. FRP has more Advantages such as light weight, great strength, rust resistant, non-magnetic, and environ-mentally safe. Fiber reinforce polymer used in different kind of advance engineering structures. The use of FRP improves the material property of existing structure. It also used in various kinds of fields. It takes more attention due their increasing use in construction industry. FRP composite has no corrosion resistance, construction are easy and specific stiffness. Due these benefits it used in construction practices and rehabilitation of structure. It has high loading carrying capacity than convention steel reinforce bars and pre stressing tendons. The transverse shear strength is

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small and there is no plastic behavior. These are most severe problem in structural point of view. In repair cost of labor is high than cost of material. The cost of material is not matter.

2. MATERIALS AND METHODS

2.1 Commonly used composite material

Carbon fiber reinforced polymers (CFRP): Carbon-FRP is a very strong and light fiber lined with carbon. Carbon-FRP possesses high tensile strength to weight ratio. CFRP are more popular than other material. It is popular because enhance resistance of crack and increase strength, rigidity of structure. It has brilliant mechanical and physical properties. Four to eight time's High tensile strength compare to conventional steel.

Glass fiber reinforced polymers (GFRP): Glass fiber reinforce polymer has become staple in the building industry. It used for construction part. GFRP can use for both interior and exterior fixtures in variety of shape & style and textures. GFRP has very high strength to weight ratio. Other advantages are lightweight, low maintenance, durability, resistance to salt water.

Basalt fiber reinforce polymer (BFRP): Basalt fiber is material made from extremely fine fiber with nearly 10 to 20 micrometer in diameter. This material is made of minerals such as plagioclase, pyroxene and olivine.

This study focused on gap between previous research paper on steel I beam bonded with various FRP sheet.

And also overview on de-bonding failure steel beam and FRP, adhesive failure as follows:
(Bastani *et al.*, 2019),studied carbon-FRP fabric and basalt-FRP fabric retrofit with steel beam. Comparing performance of both FRP is attached at tension zone of steel beam. Author is taken eight beams. The test specimens were made from regular hot rolled W150x24, I-section beam. In experiments, test specimens were tested in four point bending test. Modeling beam done in finite element simulation software. ABAQUS used for finite element analysis. Carbon-FRP is lesser ductility of retrofitted beam than BFRP of same depth. The research also discovered that all FRPs are good at enhancing yield load, elastic stiffness, ultimate load of beam, moreover layers of Basalt-FRP needed is greater compare to layers of Carbon-FRP required. The validation of model is done by using experimental result. The result suggested that basalt fiber is competitive and environmentally friendly choice to carbon- FRP. The depth of Basalt-FRP fabric is used to reach target strength for steel beam is approximately 1.5 to 2 times higher than Carbon- FRP fabric. **(Colombi and Fava, 2016),** investigated steel beam bonded with carbon-fiber reinforced polymers (CFRP) strip in fatigue crack development. Steel beam developed artificial crack with CFRP strip at tension flange in bottom side beam. The notches are provided at bottom of steel beam. Epoxy adhesive are used as bonding material for steel beam and CFRP strip. Single layer and double layer CFRP are arranged in experiment. Four point bending test carryout on test specimen. This gives deflection of test beam. Strain redeployment growth of crack in strip. It suggested that for beam stiffness decrease with increasing crack length. Higher compressive force if thickness of strip used large. For double layer of CFRP strip which has less fifty percentage stress intensity factor than single CFRP strip. **(Dong, *et al.*, 2012),** studied on fatigue and post fatigue on experimental research carryout to calculate static behavior of reinforce beam strengthening with fiber reinforce polymer sheet at vertically placed or inclined placed. The fiber reinforce polymer sheets are glass or carbon material. For fatigue, test every beam under four point bending. It has 1,000,000 cycles with 5 Hz frequency. Use of fiber reinforce polymer sheets test result show that increasing fatigue resistance of beam and post tension monotonous result show that enhance ductility and ultimate strength of beam due to attached FRP. Vertical glass fiber reinforce polymer are less effective than diagonal reinforcement diagonal reinforcement, which increase stiffness and shear strength. Ultimate load on beam is calculated by adding moment deflection models which experimental result has best relationship between ultimate strength and lowest deflection. It concludes that when fatigue loading connected to 10^6 cycle in that case FRP strengthening beam gives eighteen to seventy percentage smaller deflection compare to without strengthen beam. **(Elkhabeery *et al.*, 2018),** investigated on repair and strengthening of I-section beam bonded with Carbon-FRP in bending. This

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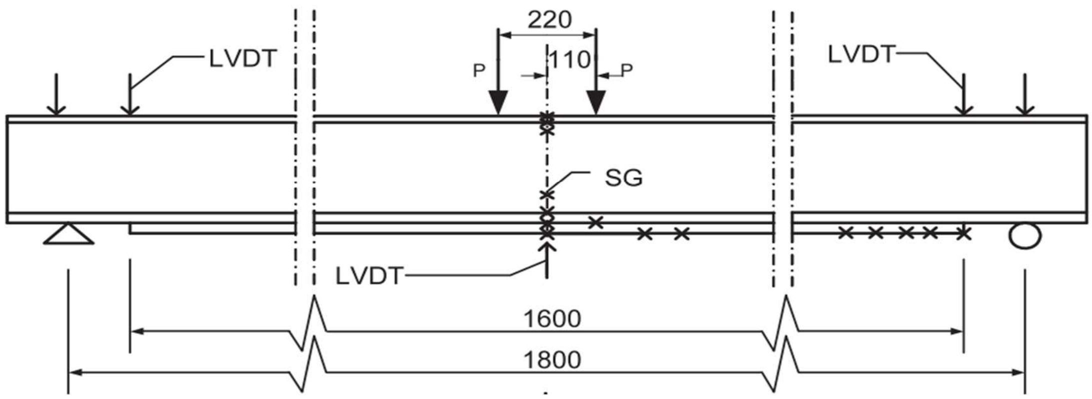
carbon-FRP is more commonly used due to their load bearing capacity and weight is light. Researcher was taken 178 models with six variables for analysis. 6 variables such as web slenderness ratio, I beam mono-symmetrical ratio, Carbon-FRP plate area, Carbon-FRP modulus of elasticity, tensile strength, Carbon-FRP sheet length. Parametric study analysis was done. For parametric study binder properties used. Those binder properties were taken from experiment test. The Carbon-FRP double strap steel with different bond length used. ANSYS-17.0 for finite element simulation software was used. In ansys-17.0, model of main component such as web, flange, sheet of Carbon-FRP is represented 3d solid element, solid 186 for FE analysis. From parametric study, bending ability of compact section enhance up to thirty seven percentages. It suggests that Carbon-FRP when bonded with compact mono symmetrical section of steel beam is additional capable than non compacted section. In non compact section of steel, improvement is extremely little. **(Lenwari *et al.*, 2006),** studied on strength deboning of steel beam bonded with carbon fiber reinforce polymer plate. Static and fatigue test on beam .that test gives govern aspect of stress intensity de-bonding strength. Static and fatigue loading on steel beam attached with carbon fiber reinforce polymer plate which causes de-bonding due to maximum stress on end steel plate. The location of de-bonding was steel and or adhesive corner. Stress intensity factor is worked out by using betti's law basis of Reciprocating work contour integral method. Finite element method analysis completed on half-length of strengthening beam because to symmetry of steel beam. It conducted four point bending test on seven sample of W100X17.2 steel beam with three various CFRP plate. It concluded that de-bonding strength most affected by adhesive modulus then follows by modulus of plate and plate thickness. CFRP bonded with steel de-bonding occur because failure taking place at the steel–adhesive interface. **(Linghoff *et al.*, 2010),** Presented beam behavior strengthened with various configuration of carbon fiber reinforces polymer (CFRP) laminate. It is under ultimate & service-ability limit state done in University of Chalmers technology and also discuss about bond line, failure modes and shear stresses interfacial. In this research laboratory test method are used and use the easy analytical solution. In experimental setup, 5 beams are used test. Out of 5, one beam considered controlled beam and remaining four beams attached with CFRP at various locations. CFRP laminate and epoxies are fix to tension flange which with different material to tension flange which with different material properties of steel beam with I cross section. Four point bending test has conducted on strengthen of beam (shown in fig1). The test gives deformation beam and laminate. The test output gives that to enhance the moment capacity of steel beam of tension flange bonded to CFRP and use simplified analytical result technique to calculate degree of rise. Researcher has conduct laboratory test method. Test outcome is load carrying capacity of beam strengthened with CFRP is enhanced compare differentiate with parent beam. It concludes that in laboratory test and analytical solution result enhancing the flexural strength 20% when the tension flange of steel beam bonded with Carbon fiber laminate. It produces desirable behavior of steel beam with increasing in moment capacity. Limitation of this paper is low strength when CFRP laminate with high modulus, which gives failure and brittle behavior of beam. Steel beam initiate yield after strengthening. **(Linghoff *et al.*, 2009),** Presented strengthening and repair of steel structure can using composite material in last few years. Researcher conducts work at Chalmers university technology. In this conduct, the various type of test gives the outcomes. In this paper discussions on stress study of revise joint, joint of binder, as well as failure mode. To assess stress strain behavior of adhesive for this 3 various types adhesive tested under various condition curing times and temperature vary. Author was taken 5-beams of HEA 180 reinforced with various carbon-FRP. It was testing under 4-point bending. Advantage of strengthening work there are outline properties of material composites. Properties are lightweight, high elastic modulus, better durability, and high elastic modulus and improve the fatigue behavior. In this standard tension test conducted on adhesive and carbon fiber composites. For stress analysis technique can be use numerical analysis based on finite element (F.E) method. It can conclude that repair method is bonding of CFRP laminates. To gain load-bearing capacity of steel element this disintegrated due to corrosion. It suggests that highly enhancing moment capability in compression part of I-beam is require strengthening. Strength as well as consistency in binder joint in experiment work which mostly depend on workmanship and preparation of surface. At laminate end is tapering to reduce the interfacial stress. **(Narmashiri *et al.*, 2011),** investigated on carbon-FRP attached to steel I cross section beam. There are 8 test sample steel beam bonded by carbon fiber reinforced polymer use. Carbon-FRP was use with constant span but various kind and depth. Author was taken I steel beam of A 36 ASTM strengthen by Carbon-FRP. Sikadur-30 used as binder material. Author conducted numerical as well as experimental study. In experiment setup 4- point bending test performed under static loading condition. For FE analysis, ANSYS software was use. From result conclude that mode of failure, capabilities of load, and distribution of strain on Carbon- FRP plate effect due to varying depth and kind of carbon-FRP. Depth of CFRP is large it also increases load bearing capability but Carbon-FRP show brittle performance and de-bonding occur. **(Periyardhasan *et al.*, 2018),** Presented Hand lay-up or carpet sweeper insertion procedure is for glass fiber reinforced polymer (GFRP). On bidirectional glass fiber reinforced polymer, this analysis assesses tensile strength, flexural strength, and izod effect strength. Glass-FRP has 0.3 diameter of steel wire enclosed laminated. Laminate fabricated with lay up of steel wire at 1\4th and 3\4th thick placed with pitch interval 3, 5, 7-mm. Flexure strength, tensile strength and total energy absorb by specimen evaluating for GFRP and steel wire GFRP. At range of thickness, tensile strength, flexural strength, izod resistances were increase due to effect of steel wire. In this research epoxy, resin LY 556 and Hardener HYS9 used 1:10 proportion. Dimension of sample is 300 x 300 mm and thickness 4 mm. This researcher conducts bending test and tensile strength test on universal testing machine (UTM). It concludes that in GFRP insertion of steel wire enhances ultimate yield strength, energy absorption, and laminates rigidity. It also enhances ultimate tensile strength of specimen. Bending behavior of steel wire GFRP lowers than plain GFRP. **(Photiou *et al.*, 2006),** investigated on Steel girders increase the flexural load carrying capacity by bonding carbon reinforce polymer composite attached to tension flange. In this paper experimental results gives to examine value of high modulus. Author conducted four point loading test are used in condition of strengthening of carbon reinforce polymer prepare an artificial degraded steel beam of rectangle cross sectional. Improvement four-beam U shaped prepared unit two are utilizing. Flat plate prepared two beams. Every shapes of geometrical high carbon fiber reinforce polymer was use. In situ test are perform on fabrication material. All this attached to steel substrate. If carbon fiber strain reached up to pure moment region carbon fiber reinforce polymer in composite will fail. Damage of beam happen due to failure load increased at point plastic collapse load applied. The beam attached with high modulus carbon fiber reinforce polymer, which reach maximum ultimate load. Not any fiber breakage and not any adhesive failure were observe in U shaped and flat plate strengthening. **(Siddique and El Damatty, 2013),** investigated on steel beam local behavior at wide flange. Steel beam externally bonded with GFRP. Author used numerical method. In numerical method, non linear FE analysis is use. In model, simulation of steel beam, GFRP plate, and adhesive consist of element of shell. Validation is using experiment data and calculation of numerical available in literature. In model different collapse mode are observed such as local buckling of flange beam, shear failure at adhesive, rupture of GFRP. Author conducted parametric study to assess effect of bonding GFRP plate on wide flange of beam enhancing behavior of local buckling. From result declare that steel beams of the compression flange attachment of GFRP plate's increases load bearing capability. After all, the enhancement variable for slender beams is greater than plastic beams.

Figure1:



Four point bending setup

3. DISCUSSION AND CONCLUSION

Analyzing the obtain results and distinguish the results of other related research paper done by researchers. Basalt fibers are achieved similar strength as like Carbon-FRP if using more number of layers of BFRP than CFRP. As Glass-FRP was applied to the compression flange of a steel beam, the load bearing capability was improved. Steel structure strengthening with FRP reinforcement in external bonding is better technique than other ordinary strengthening method. Preparation of steel surface and adhesion are follows extensive process to avoid adhesion failure. Issue of this paper is some topics like life span of bonding adhesive, fire resistance steel structure strengthening with fiber reinforce polymer and steel structure strengthening against explosion and impact loading cannot explored ,but have more importance in construction practices. Use of Carbon-FRP when connection is with compact mono symmetrical section of steel beam is extra capable than non compacted section. In non compact part of steel, upgrading is extremely little. Use of carbon fiber reinforce polymer that high strength and resistance fatigue. Bending strength enhance 20% of tension flange attached with carbon fiber reinforce polymer (CFRP) laminate. The effect of varying depth and type of carbon-FRP on the mode of failure, load capabilities, and strain distribution on carbon-FRP plates. Since the depth of CFRP is so great, it also improves load bearing capacity. It observe that length of crack increases ten beam stiffness decreases .the two layer of reinforcement arrangement are used stress intensity factor 50 percent less than arrangement of single layer. Adhesive modulus is mainly affected on de-bonding strength then other also affected i.e. modulus and thickness of plate. De-bonding of CFRP plate commencement at face of steel/adhesive bonded with it. De-bonding also happen due to Ultimate load on CFRP plate attached with steel beam de-bonding start at plate end. Conduct the study on fiber reinforce polymer and steel bond, steel hollow section member are strengthened, steel and FRP which has crack propagation of fatigue. Ordinary strengthening of steel structure has best alternative is FRP strengthening. CFRP laminate are more effective method than conventional method that has high strength, lightweight, improve fatigue behavior. Use of steel wire embedded GFRP composite which help to increase flexural and tensile strength. It also enhances impact resistance. It suggests that in FRP composite material, E-glass fibers reinforce polymers are low cost material due to it is commonly used. Aramid fiber has high cost. So it cannot utilize broadly in civil engineering. Diagonal GFRP reinforcement is best than vertical reinforcement for increases stiffness and shear strength. It subjected 1 million cycles of fatigue loading, conventional beam shows higher deflection than FRP beam. Peak initial crack load of beam reinforce diagonal GFRP sheet is 24.7% higher than reference beam. Some researcher has studied the behavior CFRP, BFRP, GFRP attached to compression flange and tension flange of steel I-cross section beam but limited research on BFRP fabric. So, in future scope, these CFRP, GFRP and more focus on BFRP fabric can be reinforced at top flange, bottom flange and also sides of web of steel I section beam. From this, location of FRP sheet is to be decided which will improve efficiency of flexural capacity of parent steel I beam.

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