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ECONOMICAL RETROFITTING OF STEEL BEAMS USING SAFSTRIP PLATES

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Abstract: This paper present an analytical program to study the behavior of damaged steel I beam strengthened using two different retrofitting plates and to find which one give economical retrofitting. The materials adopted are Carbon Fibre Reinforced Polymer (CFRP) and SAFSTRIP Plates. Multiple stages of crack propagation in a steel beam are simulated by various notch lengths, including 5 mm, 15 mm, 25 mm, 35 mm and 50 mm. Each cracked beams were retrofitted using plates of varying length 1500 mm, 1000 mm, 500 mm and 250 mm. All beams were simply supported and loaded in four point bending. The decrease of CFRP plate length, only increased the strength of the beam until reach 25.25% length of beam span. But SAFTRIP of 12.5 % length of span carry load similar to that of the other lengths. Test results showed that, three layer SAFSTRIP plates as retrofitting material gives the maximum strength to the damaged beam economically.

***Index Terms*- Steel; CFRP; SAFSTRIP plate; Four point bending;**

1. INTRODUCTION

Retrofitting is the modification of existing structures to make them more resistant to external force quantities. Steel structures are susceptible to fatigue induced cracks and corrosion damage. Many older steel bridges in-service are structurally deficient. To retrofit or rehabilitate structurally deficient steel structures, several traditional methods are used, including replacing damaged section of the member by steel plates or adding stiffening plates to existing member by bolting or welding.

In recent years, carbon fiber reinforced polymer (CFRP) composites have been commonly regarded as one of the efficient methods to retrofit steel structures because of its high strength to weight ratio and resistance to corrosion. But this method is economically inconvenient. The high initial material cost of fiber reinforced polymer (CFRP) can be same with reduced long term maintenance cost. To reduce cost of repairing, the best way is to find the minimum length of CFRP to strengthen the steel beam. Most investigations are done on carbon fiber reinforced polymer (CFRP) and the use of SAFSTRIP as retrofitting material in steel beams are limited.

SAFSTRIP Carbon is a unidirectional, carbon fiber reinforced polymer (CFRP) comprised of high tensile strength and high modulus of carbon fibers encapsulated in a thermoset resin through the pultrusion process, SAFSRIP is designed to be used as an externally applied reinforcement for strengthening concrete, steel, timber and masonry structures. A peelply fabric is adhered to the plate that, when removed, leaves a prepared bonding surface for adhesion to a prepared substrate. These have high tensile strength, light weight, corrosion resistant, easy to fabricate, continuous length etc. SAFSTRIP has high bearing and longitudinal properties and is designed to strengthen the flexural capacity on the tension face of concrete girders, slabs, and decks. Installation on bridges can occur without any interruption of service. But investigation on the use of SAFSTRIP as retrofitting material in steel beams are limited.

The CFRP and SAFSTRIP plates were glued to the steel beams by using epoxies. Firstly, influence of different adhesive types of the strips on the strengthening effect is examined. Two types of the two-component epoxy adhesives, named as Araldite-2015 and Sikadur-30, were used to bond the CFRP and SAFSTRIP plates. The mechanical properties for the two adhesives are quite different. The ultimate strength and Young's modulus of the adhesive Sikadur-30 are higher than those of the adhesive Araldite-2015, but the adhesive Sikadur-30 is brittler than the adhesive Araldite-2015.

ARALDITE-2015 adhesive offers high resistance to dynamic loads and weathering, making it ideal for tough jobs on land and at sea. A long open time makes ARALDITE 2015-1 adhesive a cost-effective solution for bonding mid to large-sized metal and composite parts. Sikadur-30 is a thixotropic, structural two part adhesive, based on a combination of epoxy resins and especially designed for use at higher temperatures between +25°C and +55°C. Sikadur-30 LP IN may only be used by experienced professionals. It is used as Adhesive for bonding structural reinforcement, particularly in structural strengthening works.

2. OBJECTIVE OF THE PROJECT

- To find minimum length of CFRP for maximum strength
- Compare the same characteristics of CFRP with SAFSTRIP material
- To find number of SAFSTRIP layers

3. BEAM DETAILS

The total span of all steel beams were 1982 mm. Indian Standard Medium Weight Beam 125 (ISMB 125) were designed. This is the minimum specified I section according to the Indian standard. ISMB 125 has a total mass of 8.9 kg/m. The depth of beam (D) is 125 mm and the flange width (B) is 75 mm. The column has thickness of flange (T) equal to 7.6 mm and thickness of web (t) equal to 4.7 mm.

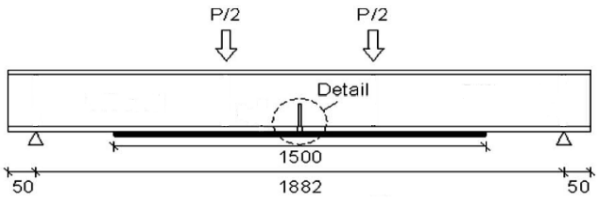

Fig. 1 Beam Details

Damage of steel beams was simulated by notching the web of thickness 0.63mm in addition to cut of 30 mm on both side of tensile flange as shown in fig 5.2. Then provide five different notch lengths to represent various stages of crack propagation. Cracks of 0 mm, 5 mm, 15 mm, 25 mm, 35 mm and 50 mm length were selected.

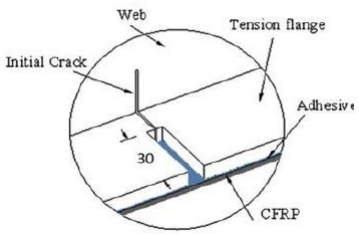

Fig. 2 Damage of Steel Beam

4. DETAILS OF RETROFITTED PLATES

Carbon fiber reinforced polymer (CFRP) or SAFSTRIP were glued to the tension flange of steel beam with various length along the span. The CFRP and SAFSTRIP had a thickness of 0.176 mm with a tensile modulus (E) of 227 GPa and 167 GPa respectively. Length of retrofitted plates used are 1500 mm, 1000 mm, 500 mm and 200 mm. The epoxy adhesive (t = 0.224 mm) used had a tensile strength (Fy) of 54 MPa and corresponding modulus of 3 GPa.

5. MATERIAL PROPERTIES

Table 1: Material Properties

	Steel beam	CFRP	SAFSTRIP	Adhesive
TensileStrength (MPa)	400.00	3800.00	2800.00	54.00
Tensile Modulus (GPa)	200.00	227.00	167.00	3.00
Poisson's Ratio	0.30	0.27	0.29	0.40

6. MODELING AND ANALYSIS

Three-dimensional FE models was constructed to predict the behaviour of experimental beams using the general purpose FEA program ANSYS 16.0. All steel I beams were supported and loaded in four point bending as shown in fig. 1. Total span of beam is 1980mm. supports were provided 50mm from both ends of the beam. Two point load were applied to 250 mm from centre to both sides of I beam.

Damage of steel beams was simulated by notching the web of thickness 0.63mm in addition to cut of 30mm on both side of tensile flange as shown in fig 2. Cracks of 0 mm, 5 mm, 15 mm, 25 mm, 35 mm and 50 mm length were selected. Then provide different notch length to represent various stages of crack propagation. 1500 mm, 1000mm, 500 mm and 250 mm were the length of retrofitting plates. Retrofitting plates were glued to the tension flange with various length along the span.

The identification code of the specimens represents the length of crack, retrofitting plates (CFRP-C or SAFSTRIP- S) and its length. For example, B25-C-500 denotes beam with crack 25mm and retrofitted by using CFRP of 500 mm length whereas B35-S-1500 designates beam with crack 35 mm and retrofitted by using SAFSTRIP of 1500 mm length.

7. RESULTS AND DISCUSSIONS

7.1. CFRP of Minimum Length

To find the carbon fiber reinforced polymer (CFRP) of minimum length, 24 models were analyzed. Five different notch depths were used to represent various crack propagations. 0mm, 5mm, 15mm, 25mm, 35mm and 50mm cracks are selected. Each beams were retrofitted with carbon fiber reinforced polymer (CFRP) of lengths 1500mm, 1000mm, 500mm and 250mm.

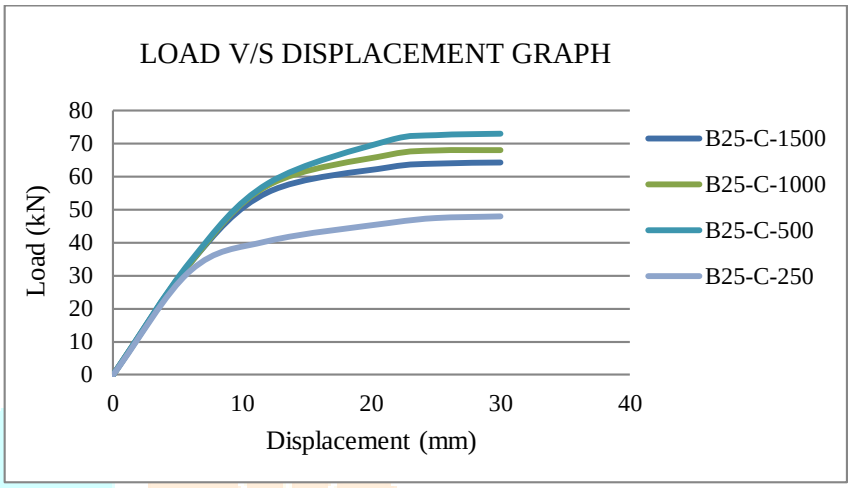

Fig. 3 Load Displacement Graph of 25 mm Cracked Beam Retrofitted with CFRP

From ANSYS result, it is found that the CFRP of length 500mm can carry more load than others. The decrease of CFRP plate length, only increased the strength of the beam until reach 25.25% length of beam span.

7.2 SAFSTRIP of Minimum Length

Similarly that of CFRP, to find the carbon fiber reinforced polymer (CFRP) of minimum length to attain its maximum strength, 20 models were analyzed. Five different notch depths were used to represent various crack propagations. 0mm, 5mm, 15mm, 25mm, 35mm and 50mm cracks are selected.. Each beams were retrofitted with carbon fiber reinforced polymer (CFRP) of lengths 1500mm, 1000mm, 500mm and 250mm.

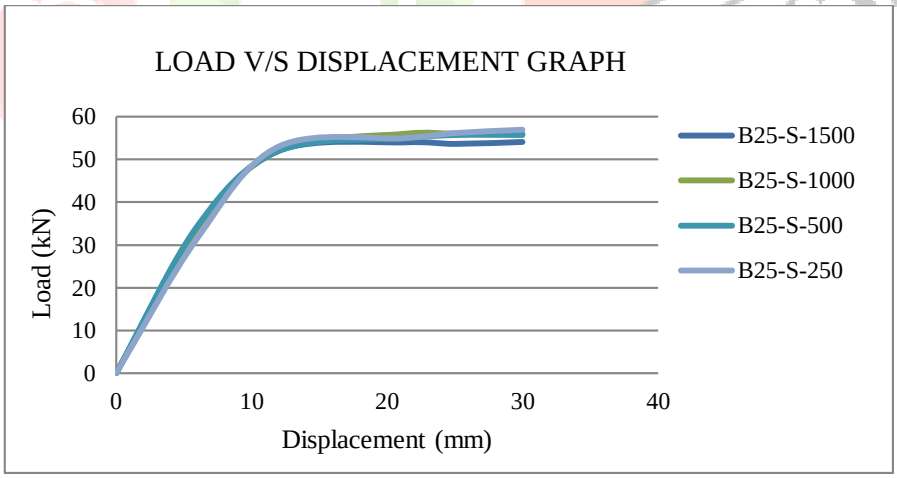

Fig. 4 Load Displacement Graph of 25 mm Cracked Beam Retrofitted with SAFSTRIP

From ANSYS result, it is found that the SAFSTRIP of length 250 mm can carry more load than others. The decrease of SAFSTRIP plate length, only increased the strength of the beam until reach 12.5% length of beam span.

7.3 Comparison of Damaged Steel Beam with CFRP and SAFSTRIP

From fig. 3, it is clear that steel beam retrofitted with CFRP of 500 mm length can carry maximum load, and it is the minimum length CFRP that can carry more load. So that, comparison of CFRP plates and SAFSTRIP plates were done on 500 mm length.

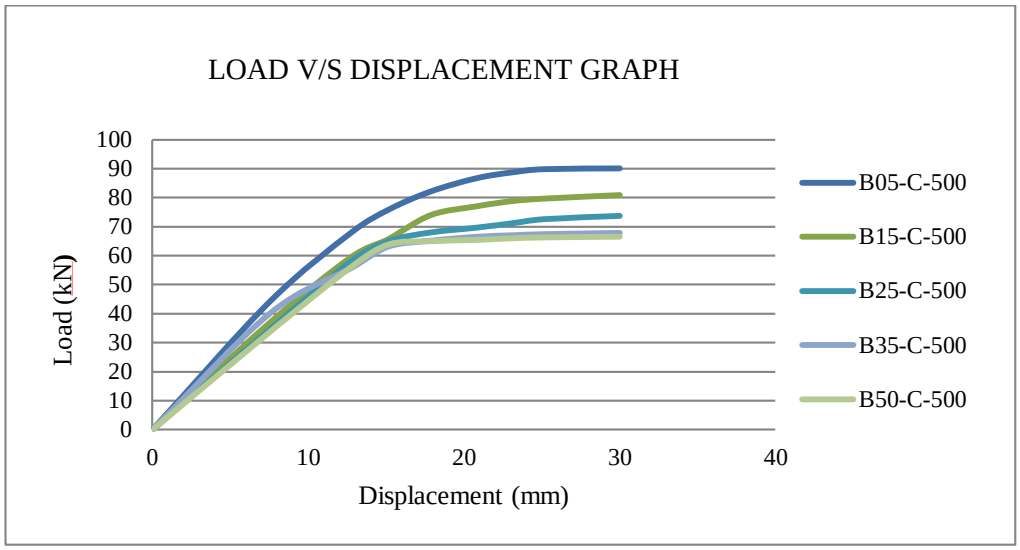

Fig 5 Load Displacement Graph of Steel Beam with CFRP of 500 mm Length

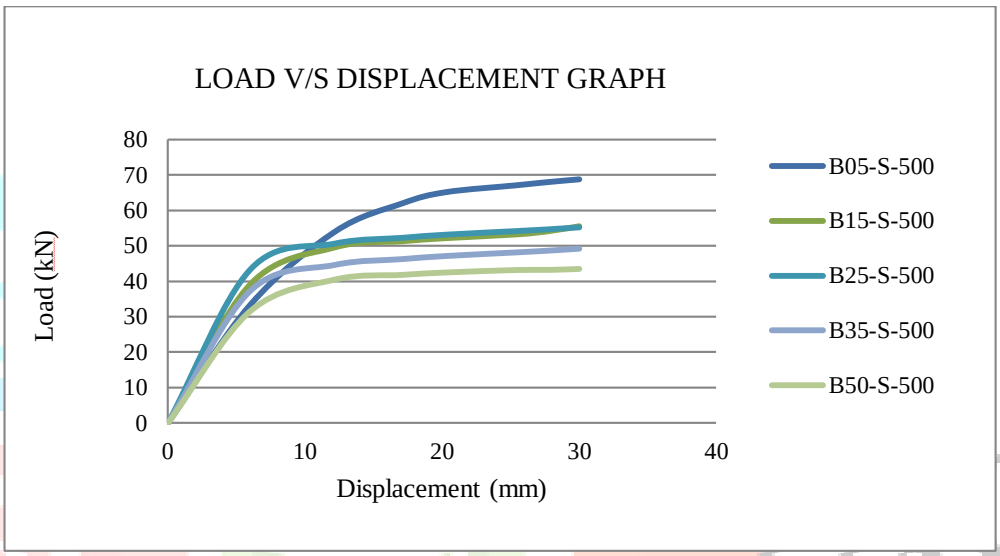

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Fig 6 Load Displacement Graph of Steel Beam with SAFSTRIP of 500 mm Length

Steel beam retrofitted with SAFSTRIP plate of 500 mm length are analyzed and the results were compared with the CFRP of 500mm length. The results showed that SAFSTRIP plates had less load carrying capacity than CFRP. But in the case of SAFSTRIP, 250 mm length give maximum load carrying capacity same as that of others, which is shown in fig. 4. Therefore next studies were done on the steel beam retrofitted with SAFSTRIP of 250 mm.

7.4 Number of Layers of SAFSTRIP Plates

The load carrying capacity of the undamaged ISMB 125 beam with span of 1980mm is 135.240 kN. Then to find number of layers of SAFSTRIP plates of 250mm length for to attain maximum strength of damaged steel beam. So first analyse the damaged steel beam with two layers of SAFSTRIP plates. Then analyse beam with 3 layers of safstrip plates and to find the load at 30 mm deflection. Fig. 7 and fig. 8 shows the load Vs displacement of the steel beam with SAFSTRIP of two layers and three layers respectively

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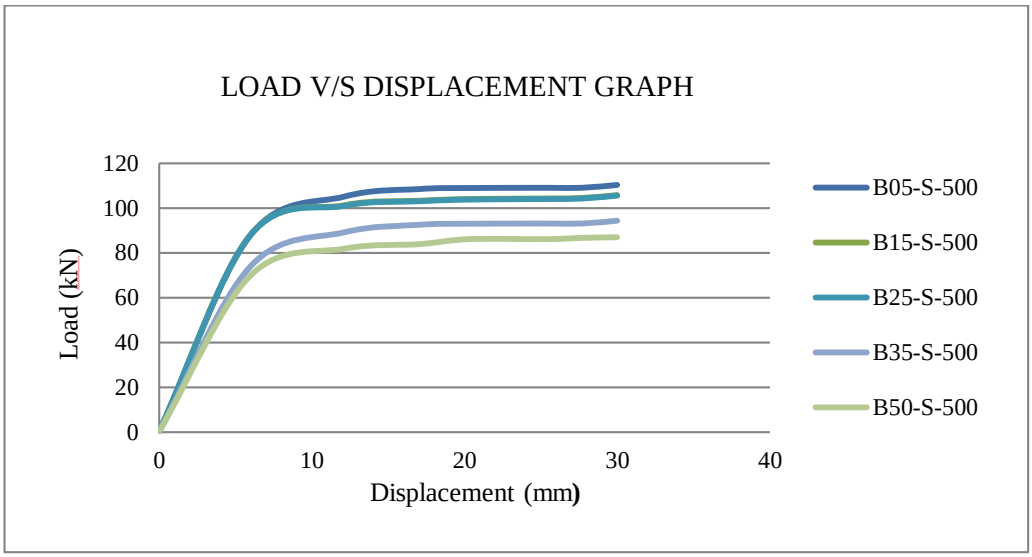

Fig. 7 Load Displacement Graph of Steel Beam with 2 layer SAFSTRIP of 250 mm Length

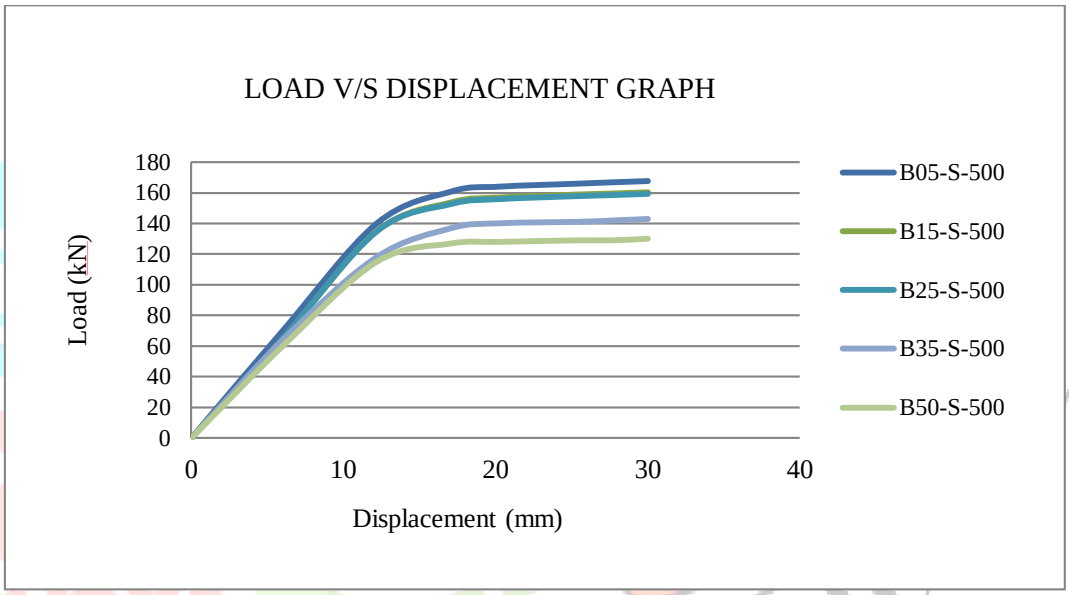

Fig. 8 Load Displacement Graph of Steel Beam with 3 layer SAFSTRIP of 250 mm Length

8. CONCLUSIONS

This paper aims to find maximum strengthened steel I beam retrofitted by retrofitting plates of minimum length. Also to investigate the behaviour of steel I beams retrofitted by using SAFSTRIP plates and also the comparison of SAFSTRIP plates with fiber reinforced polymer (CFRP). A three-dimensional FE models was constructed to predict the behaviour of beams using the general purpose FEA program ANSYS 16.0. The following is concluded**:**

- The load carrying capacity of the repaired beams were significantly affected by the length of notches. And load sharing mechanism between steel I beam and retrofitting plates increased the yield capacity of repaired beam.
- In the case of damaged steel I beam with different crack length repaired with CFRP of length 1500 mm, 1000 mm, 500 mm and 250 mm, it is found that CFRP of length 500 mm can carry more load than others. The decrease of CFRP plate length, only increased the strength of the beam until reach 25.25% length of beam span.
- Similarly, the results of the damaged steel beam repaired with SAFSTRIP plates of length 1500 mm, 1000 mm, 500 mm and 250 mm showed that SAFSTRIP plates of length 250 mm can carry more load. That is, the decrease of SAFSTRIP plates length, increased the strength of beam until reach 12.5 % length of beam span.
- For the comparison of single layer CFRP and SAFSTRIP plates, 500 mm length were used. The results showed that, steel beam retrofitted with SAFSTRIP has less load carrying capacity than that of CFRP. The difference is approximately 20%.
- Among the tested retrofitting material, CFRP had best strengthening effect, whereas SAFSTRIP had the best performance to price ratio, which makes it an economical method for field application.
- SAFRTIP plates of 3 layers with 250 mm length showed best strengthening effect to the damaged steel beam. This give approximately same value of the load carrying capacity of steel beam.

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