

# Shear Retrofitting of Steel Beam with CFRP Straps

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**ABSTRACT:** Fibre Reinforced Polymer (FRP) laminates/strips which are characterized by their high strength to weight ratio offer an attractive strengthening alternative. Lately, FRP laminates/strips were widely used to retrofit reinforced and prestressed concrete structures. Regarding strengthening of steel structures using FRP laminates/strips, investigations to-date have been limited to applying the laminates/strips to the tension flanges of the steel beams in order to increase the beam's flexural strength. The current work focuses on a FRP retrofitting technique that uses unbounded carbon FRP CFRP straps.

## I. INTRODUCTION

Regarding strengthening of steel structures using FRP laminates/strips, investigations to-date have been limited to applying the laminates/strips to the tension flanges of the steel beams in order to increase the beam's flexural strength. However, for thin walled I-section steel beams the risk of buckling failure is also a major concern. For flexural strengthening I-beams, the CFRP strip is installed on the tensile flange due to its significant tensile strength. One of the most important criterions for the CFRP strengthened steel structure is the bond between CFRP, adhesive, and steel surfaces. As an alternative to strengthening or repairing steel structures with welded or bolted plates, bonded CFRP laminates can be second-hand. The improvements that can be expected are increased stiffness and strength and an extension to the fatigue life of the strengthened member. One advantage of using CFRP is its high tensile strength and stiffness compared with its low self-weight. The strengthening scheme is less labour intensive compared with other existing techniques, which makes it even more interesting as a system for repairing and/or strengthening existing structures. Laminate bond relies on the strength of the adhesive layer. Both theoretical work and laboratory tests have shown that this strength is governed by stress along the connection line, which occur due to difference in strain, cause by external many or the difference in coefficients of thermal growth stuck clutch in between the strengthen beam in adding up to the laminate. Concentrations of interfacial stress obtain place in the district of the geometric discontinuities; in exacting, at the end of a connection line other than also at the position of a crack in the substrate or a bond defect in the strengthenlayer.

## II. LITERATURE REVIEW

- **Retrofitting Beam-Column Joint Using GFRP with NSM Technique under Seismic Loading (2019)**  
Recent development of seismic action has highlighted the consequences of poor performance of beam-column joints, which has been identified as the main principle cause of failure when the frame is subjected to earthquake loading. This paper summarized numerous past studies according to the type of beam-column joint, retrofitting techniques and fiber reinforced polymer (FRP). For this purposes, 100 research works from previous researchers were collected. The structural behavior of beam-column joint has been extensively studied in the past decades. Experimental and analytical solutions have been conducted and proposed by many researchers to understand the behavior of the beam- column joint. However, Near Surface Mounted (NSM) technique using Glass Fiber Reinforced Polymer (GFRP) in retrofitting beam-column joint has yet to be investigated. Therefore, this study is proposed for future research. In-depth investigations must be carried out as to gain more thorough understanding on the behavior of retrofitted beam- column joint using GFRP with NSMtechnique.
- **Flexural Strengthening of Steel Beams using CFRP Sheets(2019)**  
While traditional retrofitting methods for steel structures could be time consuming and uneconomical, an alternative repair method is suggested using Carbon Fiber Reinforced Polymers (CFRP) sheets, providing engineers with a competitive solution that will increase the life-cycle of steel structures. This study investigated feasibility of CFRP as an option to strengthen and rehabilitate steel structures. The main advantages of using CFRP sheets are their light weight and durability, which results in ease of handling and maintenance. The research conducted experimental to

evaluate the effectiveness of strengthening steel beams by the use of novel CFRP laminate sheets configurations. The research involved the testing of five experimental composite beams to analyze the variation in yield load, ultimate load and deformation characteristics. When the steel beam wrapped with CFRP sheets in the lower and upper portion of bottom flange as well as in the bottom portion of web i.e, SB 4, there was an increase of 10% and 8.54% in the yield load and ultimate load respectively.

- Shear retrofitting of RC Beams(2017)

Studies on rehabilitation and retrofitting are gaining importance due to the need for restoration of partially damaged structures due to wind load and earthquake. This project presents an experimental investigation on retrofitting the capacity of damaged RC beams. In this work retrofitting of shear deficient RCC beam using diagonal stitching method will be studied. Nine beams of size 120mm x 210mm x 1500mm were cast. Out of this one control beam was used and remaining 8 beams are categorized in to two sets of beams with each set containing 4 beams as shear deficient beams. Out of these 8 beams, two beams were tested without retrofitting and remaining six beams were shear deficient used for retrofitting. Control Beam designed for ultimate shear & flexure was loaded up to ultimate load in the Loading frame using a Hydraulic jack of 500 kN capacity. Shear deficient beams were retrofitted using diagonal stitching and cover concrete was bonded Nitto bond. Load deflection behavior of beams, retrofitted with different layers of stitched mat was compared. All the beams were casted using M25 grade concrete and Fe500 steel. After the 28 days of curing they were tested and kept safe for retrofitting. It was observed that stitching method is effective in restoring the capacity of damaged beams. Among all the shear retrofitting techniques, diagonal stitching is effective and easy to implement.

### III. STRENGTHENING OF STEEL

**Appropriate Use of FRP in the Strengthening of Steel Structures** The method of FRP confinement is attractive not only in the strengthening of steel tubular structures, but also in the construction of new tubular columns. The combination of adhesive bonding with shape flexibility makes bonded wet lay-up FRP laminates an attractive strengthening method in a number of applications. Needless to say, steel plates can also be adhesively-bonded but bonding is less attractive for steel plates due to their heavy weight and inflexibility in shape. Furthermore, for the same tensile capacity, a steel plate has a much larger bending stiffness than an FRP laminate so a steel plate leads to higher peeling stresses at the interface between the steel plate and the steel substrate. It is also easier to anchor FRP laminates to a steel member by wrapping FRP jackets around the steel member. Steel plates can also be attached by welding to strengthen existing steel structures, but the bonding of FRP laminates is superior to the welding of steel plates in the following situations:

- Bonding of FRP laminates for enhanced fatigue resistance has the advantage that the strengthening process does not introduce new residual stresses;
- In certain applications where fire risks must be minimized, welding needs to be avoided when strengthening a structure; bonding of FRP laminates is then a very attractive alternative;
- High-strength steels suffer significant local strength reductions in heat-affected zones of welds, so bonded FRP laminates offer an ideal strength compensation method.

#### Flexural Strengthening of Steel Beams

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A number of failure modes as shown in figure are possible for such FRP-plated steel beams, including:

- 5 In-plane bending failure
- 6 Lateral buckling
- 7 Plate-end debonding and
- 8 Intermediate debonding due to local cracking or yielding away from the plate ends. Additional failure modes.
- 9 Local buckling of the compression flange; and
- 10 Local buckling of the web.

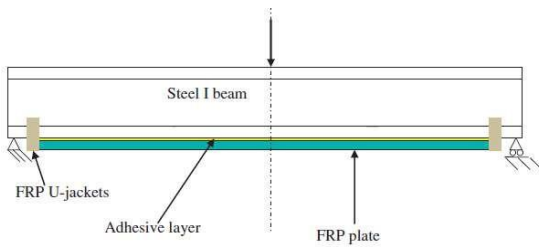


Figure.1. Strengthening of Steel Beams with a Bonded FRP Plate

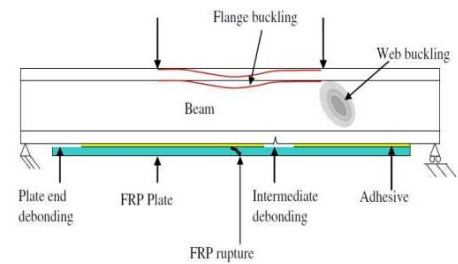


Figure.2. Failure Modes of Steel Beams Bonded with an FRP Plate.

**Surface Preparation and Treatment for Steel Beam Strengthening**

The different types of notch can be categorized as follows:

- 1 Rectangular notch on both edges
- 2 U-shaped notch on both edges
- 3 U-shaped notch through the whole tension flange

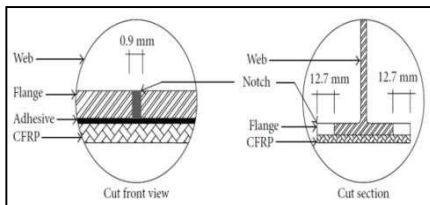


Figure.3. Rectangular Edge Notch

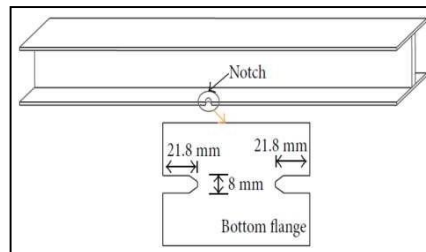


Figure.4. U Shaped Edge Notch

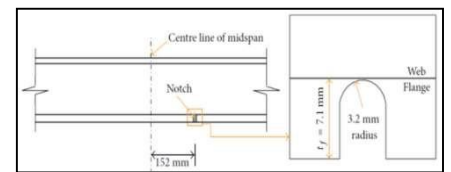


Figure.5. U Shaped Notch



Figure.6. CFRP Sheet

**Table.1: Nominal Dimensions of ISMB 150**

Mass, M	15 Kg/m
Sectional area, a	19.1 cm <sup>2</sup>
Depth, D	150 mm
Width of Flange, B	75 mm
Thickness of web, t	5 mm
Thickness of flange, l	8 mm
Radius at foot R1	9.0 mm
Radius at foot R2	4.5 mm
Moment of inertia about X-X axis, I <sub>x</sub>	718 cm <sup>4</sup>
Moment of inertia about Y-Y axis, I <sub>y</sub>	46.8 cm <sup>4</sup>
Radius of gyration about X-X axis, r <sub>x</sub>	6.1 mm
Radius of gyration about Y-Y axis, r <sub>y</sub>	1.6 mm
Modulus of section about X-X axis, Z <sub>x</sub>	95.7 mm
Modulus of section about Y-Y axis, Z <sub>y</sub>	12.5 mm

• Adhesive

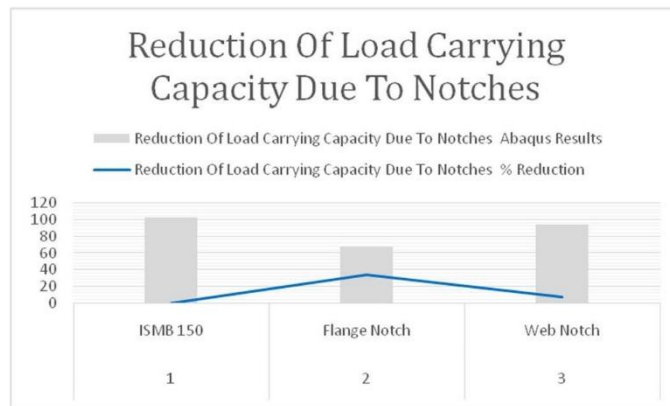
The adhesive used is Araldite AW 106 epoxy resin with hardener HV 953 IN in order to bond CFRP sheet to steel beam and also to bond layers of CFRP sheets together. Equal quantity by volume of epoxy resin and hardener is mixed thoroughly to get adequate bonding property. The properties of epoxy adhesive a provided by the manufacturer is shown in Table

**IV. RESULT ANDDISCUSSION**

1. Reduction Of Load Carrying Capacity Due To Notches

**Table.4:** Result for Reduction Of Load Carrying Capacity Due To Notches

Sr. No	Section	ABAQCUS Results	% Reduction
	-	KN	-
1	ISMB 150	102.5	0
2	Flange Notch	67.497	34.15
3	Web Notch	94.826	7.49



**Figure.8.** Reduction Of Load Carrying Capacity Due To Notches

Figure 8 shows that load carrying capacity due to notches. Load carrying capacity calculated by ABAQUS software. Notches provided for web and flanges show that load carrying capacity of section with web notch is more as compare to section with flange notch.

2. Result For Application Of Single CFRP Strip

**Single Strip for BottomFlange**

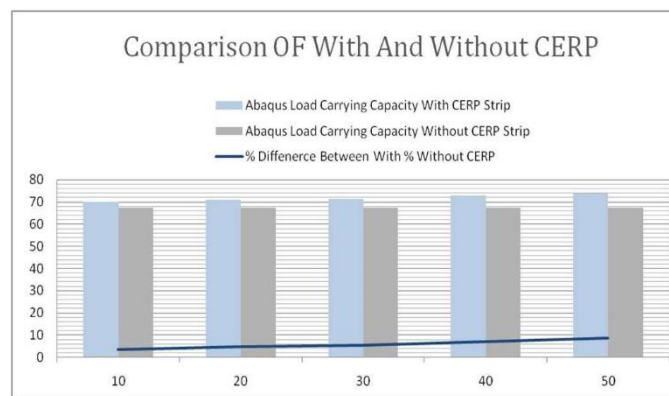
**Table.5:** Result for Single Strip Application Of CFRP At Bottom Flange

Sr.No	Length of Notch	Width of notch	CFRP Strip Width	CFRP Strip Thickness	Abaqus L.C.C	Increase In L.C.C	Actual Increase In Terms Of Ratio
	Mm	mm	mm	mm	KN	KN	
1	5.0	0.9	10	1.65	69.871	-	
2	5.0	0.9	20	1.65	70.875	1.004	0.014
3	5.0	0.9	30	1.65	71.277	1.406	0.020
4	5.0	0.9	40	1.65	72.73	2.859	0.039
5	5.0	0.9	50	1.65	73.926	4.055	0.055

Single Strip For Both Side ofWeb

**Table.6:** Result for Single Strip Application Of CFRP At Web

Sr.No	Length of Notch	Width of notch	CFRP Strip Width	CFRP Strip Thickness	Abaqus L.C.C	Increase In L.C.C	Actual Increase In Terms Of Ratio
	Mm	mm	mm	mm	KN	KN	
1	40.45	0.9	10	1.65	99.099	–	–
2	40.45	0.9	20	1.65	105.51	6.411	0.061
3	40.45	0.9	30	1.65	108.49	9.391	0.087
4	40.45	0.9	40	1.65	109.71	10.611	0.097
5	40.45	0.9	50	1.65	113.96	14.861	0.130
6	40.45	0.9	60	1.65	134.43	35.331	0.263
7	40.45	0.9	70	1.65	137.25	38.151	0.278



**Figure.9.** Comparison of Load Carrying Capacity Of Single Strip Bottom Flange

Figure 9 shows load capacity of single strip application of CERP at bottom flange in steel beam. Result obtained for Load Carrying Capacity of section with CFRP strip is more as compare to without CFRP strip in case of flange connected with CFRP bottom single strip & without CERP with notches. The percentage difference between with & without CFRP is increases with increase width ofplate.

**Table.10:**Comparison of Load Carrying Capacity of Double Strip BottomFlange

Sr No.	CFRP Strip Width	CFRP Strip Thickness	ABAQUS L.C.C With CERP Strip	ABAQUS L.C.C Without CERP Strip	% Difference Between With % Without CERP
	mm	mm	KN	KN	
1	4	1.65	72.473	67.497	6.87
2	6	1.65	74.652	67.497	9.58
3	8	1.65	75.02	67.497	10.03
4	10	1.65	75.778	67.497	10.93
5	12	1.65	76.059	67.497	11.26
6	10	1.65	77.253	67.497	12.63
7	12	1.65	77.79	67.497	13.23

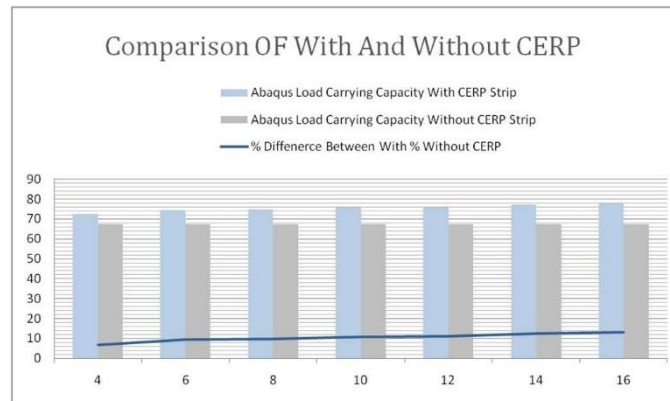


Figure.10. Comparison of Load Carrying Capacity of Double Strip Bottom Flange

Figure 10 shows load capacity of double strip application of CERP at bottom flange in steel beam. Result obtained for Load Carrying Capacity of section with CFRP strip is more as compare to without CFRP strip in case of flange connected with CFRP bottom single strip & without CERP with notches. The percentage difference between with & without CFRP is increases with increase width of plate.

### V. CONCLUSION

The goal of this study were to develop a technique for a CFRP strap retrofitting system without requiring access to the top surface of the beam but which would result in significant strength improvement. It was found that the CFRP straps must encompass a sufficient depth of the compression flange in order to be effective as otherwise shear cracks develop above the CFRP straps and the straps provided negligible shear enhancement. The concrete strength and CFRP strap spacing affect the level of strain in the straps which has a corresponding effect on the load sharing between materials. This has implication for the design of retrofitting system using these CFRP straps since an accurate forecast of the strap strain will be required to predict the specimen capacity. Following conclusion can be listed below:

1. Increase in load Carrying capacity due to increase in single 10mm stripwidth

Flange

In strengthened steel beam maximum increase in load carrying capacity of 50 mm strip width with notches as 4.055 KN as compare to 10 mm width of strip. This section carries 55 % more load than other.

Web

In strengthened steel beam maximum increase in load carrying capacity of 130 mm strip width with notches as 88.951 KN as compare to 10 mm width of strip. This section carries 47.3 % more load than other

Increase in load Carrying capacity due to increase in Double 4 mm strip width

Flange

In strengthened steel beam maximum increase in load carrying capacity of 130 mm strip width with notches as 5.317 KN as compare to 4mm width of strip. This section carries 68 % more load than other

2. Increase in load Carrying capacity due to increase in Double 10 mm stripwidth

Web

In strengthened steel beam maximum increase in load carrying capacity of 55 mm strip width with notches as 37.31 KN as compare to 4mm width of strip. This section carries 26.6 % more load than other

3. Comparison of with and without CFRP

Flange

Single strip CFRP application of bottom flanges steel beam carry more load carrying capacity of 50 mm strip as 73.926 KN as compare to without CFRP strip. Maximum percentage difference between with and without CFRP applied beam is 8.70%

Double strip CFRP application of bottom flanges steel beam carry more load carrying capacity of 16 mm strip as 67.497 KN as compare to without CFRP strip. Maximum percentage difference between with and without CFRP applied beam is 13.23%

□ Web

Single strip CFRP application of at both sides of web steel beam carry more load carrying capacity of 50 mm strip as 188.05 KN as compare to without CFRP strip. Maximum percentage difference between with and without CFRP applied beam is 49.57%

Double strip CFRP application of at both sides of web steel beam carry more load carrying capacity of 50 mm strip as 140.22 KN as compare to without CFRP strip. Maximum percentage difference between with and without CFRP applied beam is 32.37%

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