ENGTHENING OF EXISTING STEEL BEAMS USING CFRP

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ABSTRACT

The strengthening of the steel beams is the only way to solve the problem of damage due to several factors, The means of support is always associated with the manner and strengthening in terms of the risk and the operational status, The mineral origin of the consolidation is simple and easy in terms of implementation method whenever he has the acceptance and desire to follow this method for that In this study we will strengthen the steel beams in the operating mode and by strengthening them with sheets of CFRP in many shape to reach the best of these methods.

The aim of this research is to study the strengthening of steel beams in sheets of CFRP, by means of three shapes and their comparison using many sections and many lengths for modeling purposes .In order to analyze the result, a finite element analysis software ANSYS version 15.0 and software SAP version 16.0 is used.

Moreover, a comparison is conducted between results of the ANSYS and SAP program by conducting laboratory tests for three samples similar in properties and dimensions and different in the shape of the CFRP. A comparison will be made between the load and the deflection of all tested elements, whether the laboratory test or the representation of the section in the ANSYS or SAP program.

KEYWORDS: CFRP, Strengthening, Deflection, Steel Beams, Capacity.

1. INTRODUCTION

1.1 GENERAL

We often need to raise the efficiency of the steel beams by using the easiest method, which is consistent with the presence of loads, at least dead load, and from these methods is to support the steel beams with CFRP.

1.2 IMPORTANCE AND BACK GROUND

Steel beams are known for their considerable small section in line with high load carrying capacity. Strengthening steel beam will help engineers to get the most efficient use of steel beams. Using CFRP in the strengthening of steel beams will provide engineers with so many benefits due to its small weight, low consumption of time in installation, cost compared to strength and ease of applying on steel beam compared to other strengthening methods.

1.3 OBJECTIVE

In this study, a comparison is carried out between steel beams that are strengthened with different shapes of CFRP to calculate the percentage of increase in the load carrying capacity as a result of the presence of the fiber.

1- Kambiz Narmashiri, Zamin Jumaat and Hafizah Ramli Sulong, Local stiffening of steel I-Beam by using CFRP materials, 12August 2016.

2- Maged A. Youssef, Mostafa Abushagur and Ashraf ElDamatty, Experimental and Analytical investigation of steel beams rehabilitated using GFRP sheets, steel and composite structures, 3(6): 421-438, December 2003.

3- Katsuyoshi Nozaka, Carol K. Shield and Jerome F. Hajjar, Effective bond length of Carbon-fiber-reinforced polymer strips bonded to Fatigued steel bridge I-Girders, journal of bridge engineering 10(2), March 2005.

2. Test Beam

Four steel beams specimens were tested. The tested specimens were examined to understand the effect of using CFRP strips of different shape to strengthen steel I-Beams of the same cross section. All specimens were of constant dimensions; their nominal dimensions resembled IPE 80 mm.

The sections used were compact so as not to be susceptible to local buckling; as failure by elastic and inelastic local buckling of a single member would not be appropriate in investigating the global behavior of the tested beams. The tested beams were classified as large-scale three–dimensional, steel beams, consisting of one span, simply supported that are strengthened with different shapes of CFRP sheets.

2.1. Table (2-1): Beam Details.

No	Beam Code	Beam dimension	Shape of CFRP used
1	B1	IPE80	No CFRP used
2	B2	IPE80	Partially Strengthened with CFRP
3	B3	IPE80	Strengthened with one layer of CFRP
4	B4	IPE80	Strengthened with two layers of CFRP

2.1 The Steel Beams

IPE 80 steel profiles are beams with parallel internal surface of flanges and dimensions according to EN10365. They can be used commercially or in industry, they also can be used in machinery or construction of buildings. The beams used in the research were all hot rolled sections so as to have high flexibility and to reduce the cost of building process. Material used was grade steel (37) with nominal yield stress of (2.4 t/cm^2), commonly used in Egypt.

From the tested control beam (B1) the strain curve of the specimens was determined as follows:

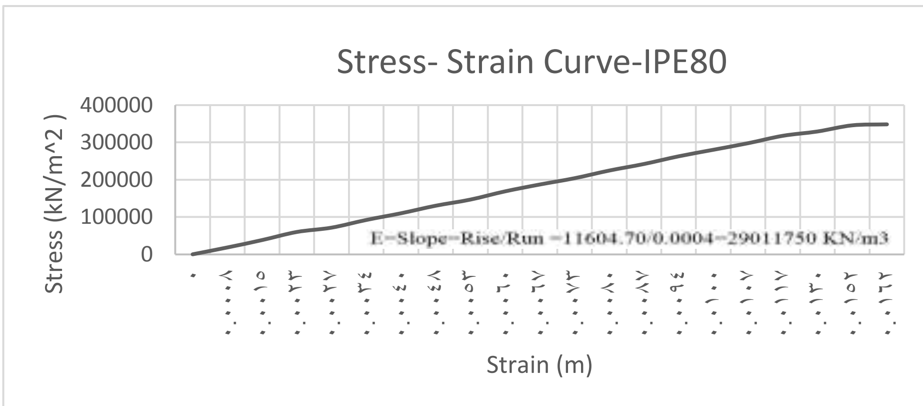

Figure (2-2): Stress-Strain Curve of the control specimen.

2.2 Carbon Fiber Reinforced Polymer laminates

The used fiber consisted of woven carbon fiber fabric. The laminates used have a thickness of about 1 mm; their ultimate load carrying capacity is 480kN/m widths per layer and tensile young's modulus is 35kN/mm^2. The used fiber was a product of Sika Construction Company named SikaWrap -300 C (data sheet in the last letter) which is a woven carbon fiber fabric for structural strengthening.

2.3Epoxy Impregnation Resin.

Thixotropic impregnating resin / adhesive was used to adhere the carbon fiber reinforcing fabric to the beams B2, B3 and B4. The used Epoxy was Sikadur -330 which is also a product of Sika Construction Company as well.

2.4 Measuring Device

2.4.1 Hydraulic jack

An (0.5kN) hydraulic jack with (100 mm) stroke was mounted on the bottom flange of the loading steel beam so as to be in alignment with the center of the loading system that distributes load equally to the test specimen. Therefore, the vertical load was applied to the beams without eccentricity.

2.4.2 Load Cell

Digital Load cell of capacity 550kN with accuracy of 0.1kN was adopted to measure the applied load. The value of loads was recorded from a monitor connected to the load cell.

2.4.3 Deflection Measurements

Deflection was measured using a dial gauge which was placed right in the center of the beam; this position was chosen because this is the place where the maximum deflection may occur in case of beams.

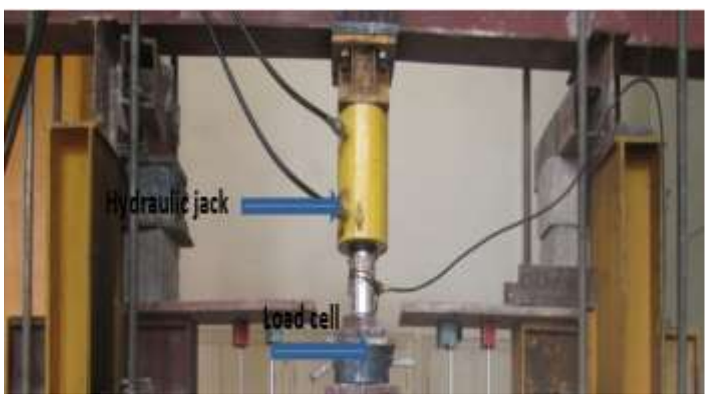

Figure (2-3): The Hydraulic Jack and the load cell used in the experimental program.

2.5 Specimens Preparation

In our research four specimens were prepared; one of which was prepared as a control specimen, it was tested to determine the properties of the other steel beams.

The other three beams have the same dimensions; but they were strengthened with different shapes of Carbon Fiber Reinforcing polymer. The strengthening process was done before testing all the other three beams (B2, B3 and B4).

Beam (B2) was strengthened with one layer of CFRP that extended for about 1/2 of the length of the web of the IPE80.

Figure (2-4): showing the dimensions and strengthening of beam (B2) before testing.

Beam (B3) was fully strengthened with one layer of CFRP. Beam (B4) was fully wrapped with CFRP as beam (B3) but two layers of CFRP were used rather than one layer used in beam (B3).

2.6 Test Setup

2.6.1 Loading Method

The loading method was carried out using a point load. A hydraulic jack acted with a load that increased with a specified increment; the load was chosen to act right in the middle of the beam so that it causes a high bending moment and consequently the beam deflects. The beam was simply supported using a roller support on one side and hinged support on other side so as the load transfers smoothly along the whole beam and deformation occurs. This was all done to investigate the effect of using CFRP on the behavior of the steel beams.

Figure (2-5): The test setup used in the Experimental program.

3. Test Results and Analysis.

Load (KN)	0.49	1.02	1.6	1.91	2.46	2.94	3.48	3.92	4.51	5
δ (mm)	2.33	4.523	6.862	8.135	10.294	12.108	14.284	16.039	18.039	20.201
Load (KN)	5.45	6	6.47	7.02	7.49	7.96	8.49	8.8	9.24	9.31
δ (mm)	22.007	24.148	26.135	28.242	30.04	32.129	35.156	39.104	45.6	48.7

Table (3-1): Showing the loads and corresponding deflection values for beam (B1).

Load (KN)	0.52	1	1.51	2.06	2.61	3.1	3.55	4.02	4.6	5.16
δ (mm)	2.244	4.033	6.037	8.075	10.019	11.79	13.527	15.411	17.595	19.565
Load (KN)	5.54	6.13	6.61	6.97	7.51	8.04	8.54	9.05	9.55	9.81
δ (mm)	21.353	23.082	24.785	26.23	28.147	30.237	32.34	35.77	40.9	50.654

Table (3-2): Showing the loads and corresponding deflection values for beam (B2).

Load (KN)	0.4	1.06	1.52	1.94	2.63	3.12	3.56	3.99	4.54	5.09	5.57
δ (mm)	1.8	3.99	5.43	7.12	9.33	10.91	12.6	14.03	15.8	17.719	19.387
Load (KN)	5.97	6.53	7.05	7.71	8.28	8.75	9.19	9.59	9.92	10.28	--
δ (mm)	20.746	22.767	24.745	26.809	28.813	30.774	32.61	34.394	36.94	41.85	--

Table (3-3): Showing the loads and corresponding deflection values for beam (B3)

Load (KN)	0.58	1.06	1.65	2.15	2.65	3.43	4.08	4.73	5.33	6.11
δ (mm)	2.197	3.797	5.71	7.46	9.10	11.7	13.72	15.812	17.798	20.241
Load (KN)	6.71	7.2	7.77	8.25	8.74	9.25	10.08	10.83	11.41	11.86
δ (mm)	22.09	23.982	25.607	26.983	28.565	30.363	33.003	35.566	37.748	40.141
Load (KN)	12.12	--	--	--	--	--	--	--	--	--
δ (mm)	42.231	--	--	--	--	--	--	--	--	--

Table (3-4): Showing the loads and corresponding deflection values for beam (B4).

3.1 Ultimate Loads of the tested specimens

Tables (4-1, 4-2, 4-3, & 4-4) illustrate the outcomes of the experiments for all tested specimens as the maximum loads, and the maximum deflection. For all tested specimens, the ultimate load increased compared to control specimens as shown in Figure (3-5)

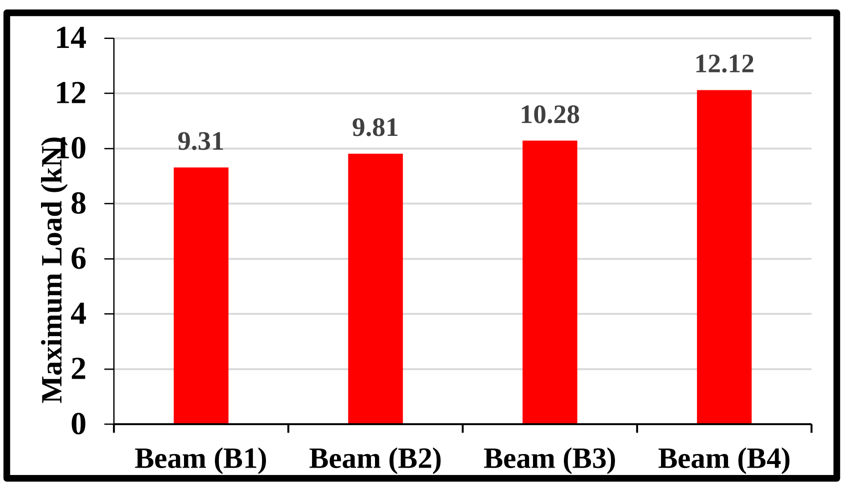

Figure (3-5): The Ultimate Load for Each Specimen.

4. Numerical Investigation

4.1 Linear Finite Element Analysis

Finite element analysis is a numerical method to solve partial differential equations by first discretizing these equations in their spatial dimensions. This discretization is done locally in small regions of simple shape (the finite elements) connected at discrete nodes. The solution of the variation equations is approximated with local shape functions defined for the finite elements.

Selecting the proper boundary condition has an important role in structural analysis. Effective modelling of support conditions at bearing joints were considered. For a static analysis, it is common to use a simpler assumption of supports (i.e. fixed, pinned, roller). For the model, the units used were (KNand mm); the beams were modelled as beam elements using SAP2000 package. The defined boundary conditions are roller and hinged support. The dimensions for the beams' models where calculated from the centre planes at the mid width of the beams.

The used steel was steel 37 with modulus of elasticity equal to 2100 and a yield stress of 2.4 ton/cm^2. The shear modulus was 806.7 ton/cm^2 and Poisson's ratio was 0.3. The used CFRP had a density of 1.76g/cm^3; its modulus of elasticity and tensile strength were 238000 N/mm^2 and 4300 N/mm^2, respectively. Local imperfections were not modeled since the test beams were compromised to be compact sections.

First a model was carried out using the same section (IPE80) and the same dimensions as that used in the experimental program. This was done to verify the tolerance of using the SAP2000 package in having deflection values close to what happened during the testing procedure. CFRP was introduced to the finite element package as a layer installed on the outer surface of the beam section. The properties of this layer were changed to resemble those of the CFRP wraps used in the practical work.

4.2 Non-Linear Finite Element Analysis

To investigate the behaviour of tested specimens non linear, finite element analysis was carried out using Ansys package; This numerical Study is divided into two sections:

First verification of finite element model:

To ensure ANSYS results; verification models are created for the four beams tested in the experimental program (B1, B2, B3 and B4).

Second the Parametric Study:

Studying different parameters and focus on the nonlinear analysis of confined Steel Beams in order to:

1- Predict the behaviour of different sections of steel beams.
2- Explore the effect of changing the beam length on the deflection and stresses values.
3- Study the effect of using CFRP wraps on different section of steel beams with different loads.
4- Obtain the mode of failure, crack patterns and Stresses on beams.

Modelling Assumptions:

1- Steel is modelled as an isotropic homogenous material.
2- Perfect bond exists between the steel beam and CFRP.
3- Bond between CFRP and steel beams is taken into consideration either by using contact element to simulate the epoxy material or by considering perfect bond between Steel and CFRP.

Description of Used Elements:

Elements that were used to simulate the experimental beam are Beam-2node188, and solid 185. The following section will present a brief description for each element to show how it presents the behaviour of the assigned material, and how these elements are linked together to model the behaviour of the tested beam.

4.3 Numerical Results and Analysis for Steel Beams.

Section	NO. FOR CFRP LAYER	My=Fy*Sx t.cm	Mp=Zx*Fy t.cm	Mu=P*L/4 t.m
HSS250X16	0	2636.16	2635.20	16.5
HSS250X16	0.5	2642.76	2637.60	16.5
HSS250X16	1	2648.72	2647.20	16.5
HSS250X16	2	2659.56	2661.60	16.5
UPN240	0	725.184	724.80	4.5
UPN240	0.5	738.720	734.40	4.5
UPN240	1	748.032	741.60	4.65
UPN240	2	764.952	758.40	4.65
IPE240	0	1455.12	734.4	4.8
IPE240	0.5	1473.41	744.0	4.85
IPE240	1	1491.89	756.0	4.8
IPE240	2	1528.94	777.6	4.8
HEA1000	0	196054.3	26068.8	163.50
HEA1000	0.5	197005.9	26203.2	164.25
HEA1000	1	197957.9	26337.6	165.75
HEA1000	2	199863.5	26604.0	167.25
HEA700	0	75930.55	14553.6	90
HEA700	0.5	76337.88	14635.2	91.5
HEA700	1	76745.45	14716.8	92.5
HEA700	2	77561.23	14877.6	93
IPE80	0	34.56	45.6	3.375
IPE80	0.5	35.14	48	3.375
IPE80	1	35.76	48	3.375
IPE80	2	37.44	50.4	3.450

5. Conclusions and Recommendations

The epoxy bonding of CFRP laminates offers an attractive means to strengthen steel beams in flexure. Based on results obtained by laboratory experiments, linear and non-linear finite element analysis, and their discussions, the following conclusions are drawn.

5.1 Conclusions

1. When strengthening steel beams with CFRP it is observed that the place of concentration of stresses or yielding, whether in the tensile area or the pressure zone, is affected, because the CFRP works to increase moment of inertia for the section. As the strength increases in the direction of the influencing force the beam acts in a better way.
2. The effect of strengthening does not appear on steel beams of small-section or short-length as what happened with IPE80. The longer the length of the steel beams and the larger the used sections; the more we reach good results.
3. CFRP works by increasing the stiffness; whereas FY for CFRP equals ten times for steel material.
4. In the case of partial strengthening the length of the ligament should be sufficient because good results were obtained when the ride was 1/6 the length of the web. So that, the breakdown in the bonding material does not occur before main material.
5. The best way to make use of the CFRP is install it such that it is parallel to the length of the strip.

5.2 Recommendations

1. Longer beams should be investigated experimentally to discover the real behavior of steel beams strengthened with different shapes and layers of fiber.
2. Exploring the behavior of steel beam strengthened with different types of fibers that was not used before as Basalt fiber.

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