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RESEARCH ARTICLE

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STUDY OF BEHAVIOR OF HOLLOW SQUARE STEEL COLUMN STRENGTHENED WITH CFRP

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ABSTRACT

Retrofitting of the structure is better alternative instead of whole replacement of structure. Retrofitting by using Carbon Fiber Reinforced Polymer (CFRP) has been gaining increasing interest. Recently, CFRP is being used for metallic structures also. The purposes of using CFRP materials are i) High Strength to Weight ratio ii) Better durability in worst environment. CFRP bonded structures have less cost as compared to cost of replacement of structure. It increases load carrying capacity and improves stiffness and buckling behavior of structure. In this paper, study of behavior of Hollow Square Section strengthened with Carbon Fiber Reinforced Polymer is carried out. Square hollow sections were used as columns and CFRP as a strengthening material. CFRP bonded columns with change in width of CFRP strip and various numbers in layers were tested. Strip wrapping sections increased load about 4% to 6% and full wrapping of CFRP sections increased load about 13% to 16%. These column sections were analysed using finite element software ABAQUS. In comparison of intact section and CFRP bonded sections, load carrying capacity of CFRP bonded sections were increased at about 4% to 16%.

Keywords— Hollow column section, CFRP, retrofitting, strengthening, stiffness, strength, durability.

INTRODUCTION

Steel structures often have required to modify and improve their performance during their whole service life. Some reasons contributing are lack of maintenance practices, change in use of these structures, new design standards, deterioration due to corrosion caused by exposure to an environment and accidental events such as earthquakes. There are two possible solutions for such circumstances, one is replacement and another is retrofitting. Whole structure replacement might have determinate disadvantages such as high cost for material and labour, a stronger environmental impact and inconvenience due to difficulty in providing the function of the structure. As per possibility, it is often better to repair or upgrade the structure by retrofitting.

In conventional method of repairing or strengthening steel structures, there is mostly the use of large amount of steel plates. These plates are heavy, bulky, difficult to fix and also susceptible to environmental degradation and corrosion. Along with these,there are fatigue problems because of defects in weld, while a bolted or riveted connection has high cost and it is time consuming. Thus, there is a need to look for alternatives in order to upgrade the structures to carry larger loads there by increasing the capacity. The use of CFRP is better alternative for this.

CFRP has very high strength to weight ratio. It resists corrosion and environmental degradation. Thus, like retrofitting of concrete structures, CFRP can also be used in steel structures to strengthen them. All kinds of shapes can be made because of its flexibility. Along with this, it is easy to handle at the time of construction.

Epoxy Resin is an adhesive material used for steel and CFRP bonding. This resin is made by mixing two components; Component 1 (Resin) and Component 2 (Hardener) having ratio of mix given by manufacturer as per weight. The elastic modulus of Epoxy Resin is about 1 to 13 GPa depending upon adhesive manufacturers.

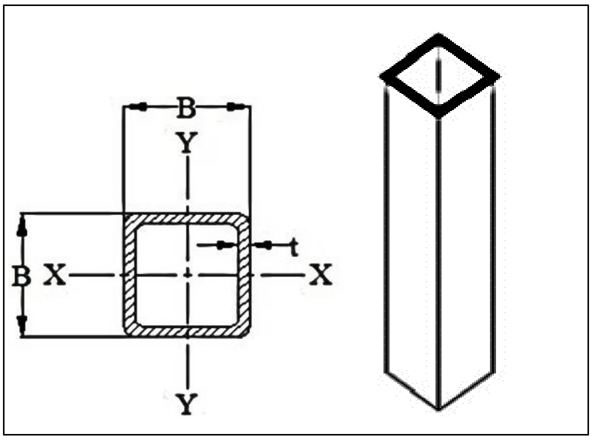

Fig-1: Square Hollow Section

Slender hollow steel columns are commonly used in practice. In these columns, generally overall buckling takes place before it develops plastic capacity. The use steel column with CFRP sheets contributes to the flexural stiffness of it and resists tension at the outer face of column during large deflection.

EXPERIMENTAL WORK

To get the compressive strength of Hollow Square Section strengthened with CFRP, all specimens were tested in Universal Testing Machine having both ends fixed. The Hollow Square Section having dimensions 49.5mm X 49.5mm X 2.9mm was used. The length of this section was 750mm. The buckling behavior of the parent and CFRP wrapped columns for displacement under compressive loading was studied. The geometrical details of the Square Hollow Columns are given in Fig. 2.

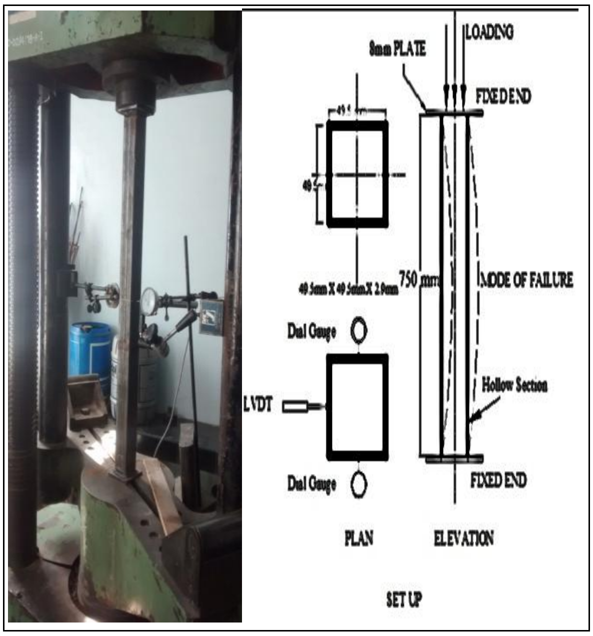

Fig-2: Experimental set up

Section properties

The properties of square hollow section is as follows,

Table -I: Properties of Square Hollow Section

Section	Weight (per meter)	c/s Area (cm2)	$I_{xx}= I_{yy}$ (cm4)	$r_{xx} = r_{yy(cm)}$
49.5 X 49.5X 2.9 mm	4.07	5.19	18.37	1.88

CFRP Material

Carbon Fiber Reinforced Polymer sheets having thickness 1mm were used for experiment. These CFRP sheets were cut into strips as per parameters. Strips were cut into two widths, 80mm and 60mm strips. These strips wrapping is shown in fig.3 Tensile strength and elastic modulus of CFRP is 5500 MPa and 200GPa respectively.

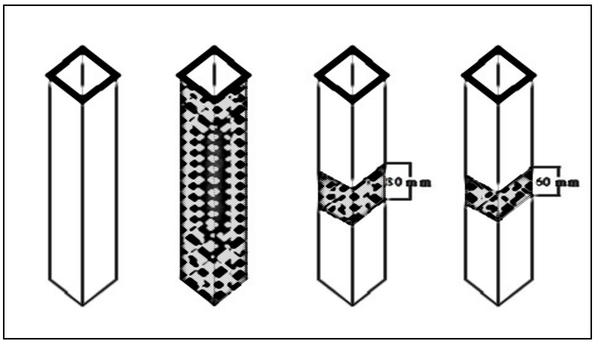

Fig -3: Test Specimens

Adhesive Material

Epoxy Resin (Araldite AW106, HV953) was used as adhesive material. Epoxy Resin having mix ratio of Component 1 (Resin) and Component 2 (Hardener) as (1:1) by weight. The elastic modulus of epoxy resin is 2.1 GPa.

Preparation of test specimen

Hollow Sections (49.5mm X 49.5mm X 2.9mm) having 750mm length were attached with 8mm thick plate welding on both ends of specimen. For attaching a CFRP sheet on Hollow Section, it was required to prepare smooth surface. Sand paper was used for rust free surface preparation and to achieve proper bonding between Steel Column and CFRP sheets. CFRP sheets were cut as per required dimensions and attached to the section by using standard epoxy resin as an adhesive material. Standard Epoxy Resin having mix ratio of component 1 (resin) and component 2 (hardener) as (1:1) by weight was mixed and apply it on section.

FINITE ELEMENT MODELLING

Modelling of Intact and CFRP wrapped column is done in ABAQUS. The modelled Hollow Columns are shown in fig 4. (A), (B), (C), (D) and (E) with loading details and support conditions.

Section Modelling

Section modelling was done by assuming homogeneous and isotropic material in which part module was solid and deformable type shown in fig.4 (A).

Boundary conditions

Fixed-fixed Boundary conditions were assigned at both ends of section shown in fig.4 (B).

Loading

An initial compressive load was applied on the top surface of the section shown in fig.4 (B).

Meshing

In mesh control, 'tetrahedral' type element shape and 'default' mesh size was used to cover enough elements ofthe section shown in fig.4(C).

CFRP Layer module

The CFRP material was assumed as isotropic having thickness of 1mm. Elasticity of the CFRP was calculated using following equation;

$$E_{CFRP} = \frac{E_a t_a + E_{cf} t_{cf}}{t_a + t_{cf}} \qquad (8)$$

Where, E_{cf} = elasticity of Carbon Fiber Sheet

E_a = elasticity of adhesive

t_{cf} = Thickness of Carbon Fiber Sheet

t_a = Thickness of adhesive layer

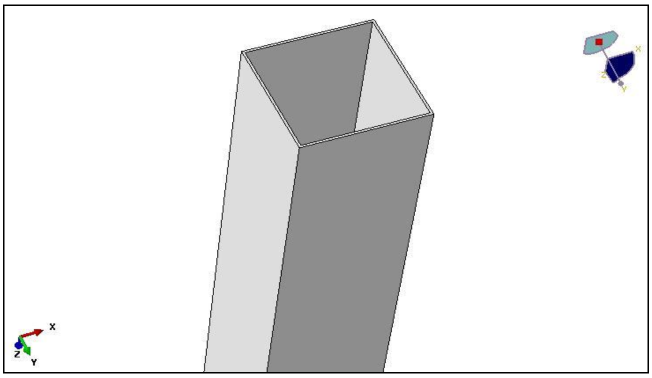

Fig-4 (A):Modelling of Hollow column

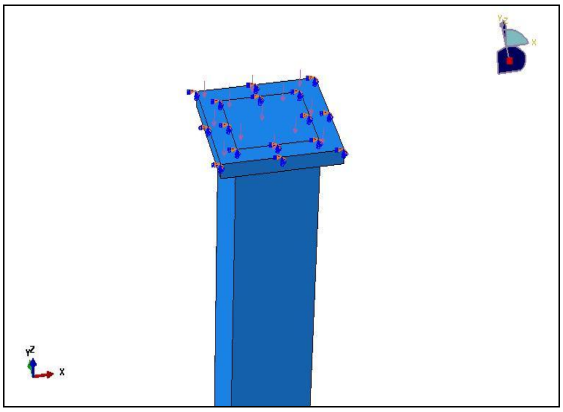

Fig-4(B): Loading and Boundary Condition

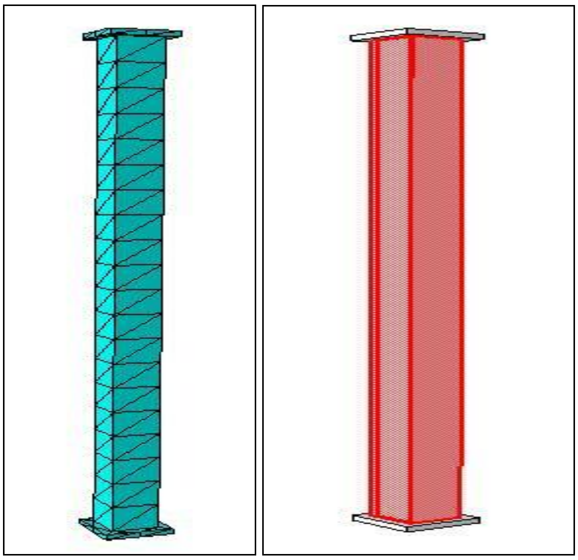

Fig-4(C): Meshing of Modell (Left)
Fig-4(D): Full Wrapping CFRP Layer(right)

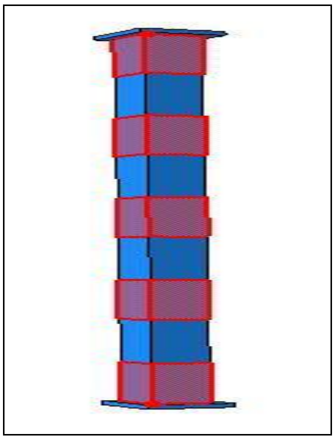

Fig-4(E): CFRP strips on Section

RESULTS AND DISCUSSIONS

Experimental results

CFRP doesn't make any change in mode shape of buckling; it just delays buckling. The failure modes of the specimens are shown in fig.5,

Fig -5:Modes of failure

In Fig.5, mode shapes of intact section and section with single layer CFRP wrapping are shown.

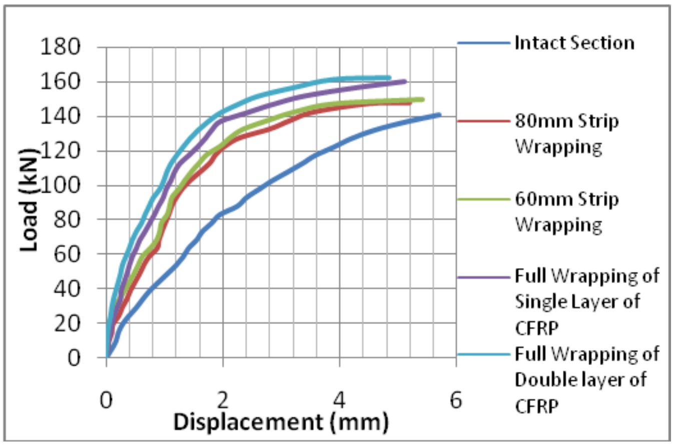

Fig -6: Load Vs. Displacement graph

From testing results, it was observed that load carrying capacity of Hollow Square Section increases because of CFRP sheets. The ultimate load of Intact Section was observed to be 141.21 kN. Due to wrapping of 80 mm and 60 mm CFRP Strips, keeping same covering area of these CFRP strips, there was increase of load about 4.5 % and 5.9 % respectively. In comparison between 80 mm strip and 60 mm Strips, 60 mm Strip wrapping section takes 1.4 % more load, and displacement of this section was less than 80 mm Strip wrapping Section. Due to full wrapping of single and double layer of CFRP sheets, there is increase of load about 13.54 % and 15.28 % respectively. Wrapping of double layer of CFRP section takes 1.75 % more load as compared to wrapping of single layer of CFRP section. Due to CFRP, there was increase in ultimate loading of section for same amount of displacement.

ABAQUS results

The results of loads, displacement of the sections analysed by using ABAQUS software are discussed below :

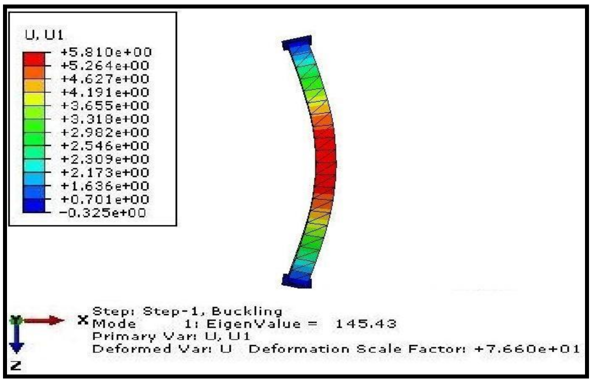

Fig-7(A): Intact section

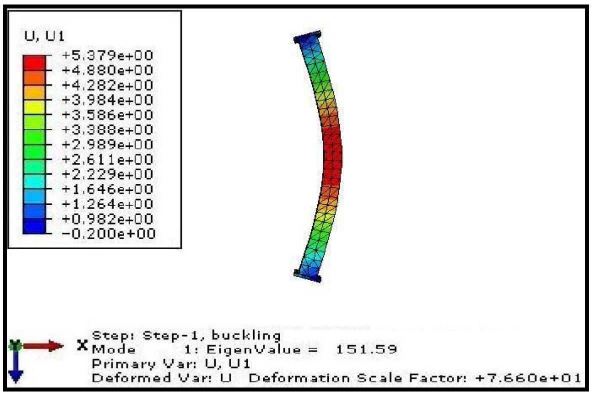

Fig-7 (B): 80mm strip wrapping section

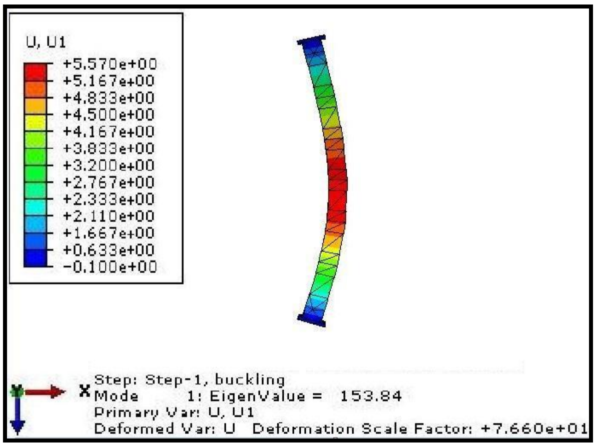

Fig-7(C): 60mm strip wrapping section

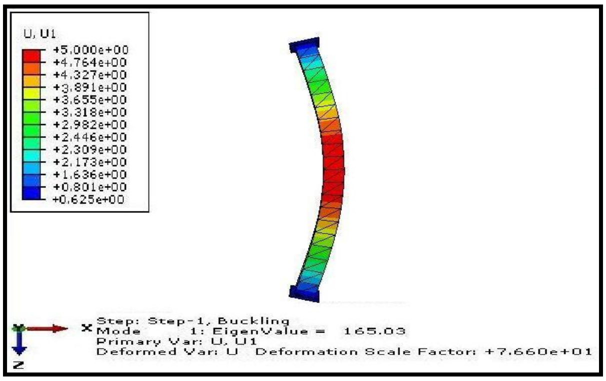

Fig-7(D): Full wrapping CFRP in single layer section

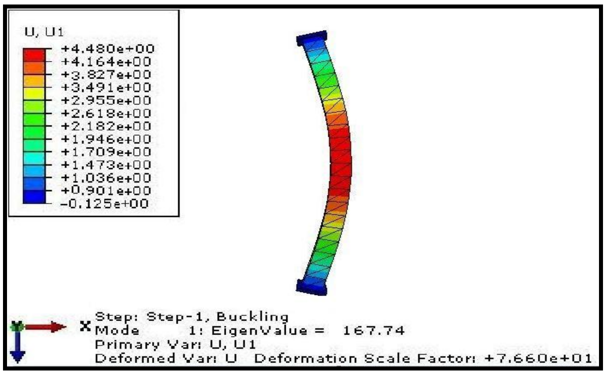

Fig-7(E): Full wrapping CFRP in Double layer section

Comparison of results

Comparison between experimental results and ABAQUS results shown in table II and validation of hollow column optimized.

Table -II: Comparison of results

Section	Buckling Load (kN) by experiment	Buckling Load (kN) by ABAQUS	Error (%)
Intact	141.21	145.43	2.98
80mm Strip of CFRP	147.59	151.59	2.71
60mm Strip of CFRP	149.55	153.84	2.86
Full wrapping of CFRP in Single Layer	160.33	165.03	2.93
Full wrapping of CFRP in Double Layer	162.79	167.74	3.04

CONCLUSIONS

CFRP strengthening just delays buckling; it doesn't make any change in the mode shape of the buckling. CFRP strengthening improves the load carrying capacity of Square Hollow Section up to 4 % to 16%. Thus, it can be used as an alternative strengthening method. For sections with changing CFRP strips, it was effective for 60mm strip wrapping as it covers more buckling region of the section than 80mm.

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