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Investigation of load Increment in Hollow Steel short and slender Columns Strengthened using CFRP

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Abstract: Carbon fiber reinforced polymer (CFRP) has been widely used to strengthen steel members in bending. Few research studies have been carried out on strengthening steel members under axial load strengthening by CFRP. The purpose of this study is to evaluate the compressive load capacity of Square Hollow Section (SHS) steel short and slender columns strengthened using CFRP. The numerical analyses using Finite Element Method (FEM) obtained from ANSYS Software were utilized. The results have been verified by experimental analyses. The results showed that CFRP wraps are capable of increasing the compressive load capacity of SHS steel short and slender columns appropriately. In addition when coverage percent CFRP layers was less 100%, CFRP more increased the compressive load capacity of SHS steel slender columns. The numbers of CFRP layers were effective in the compressive load bearing capacity of SHS steel short and slender columns.

Key words: *Steel columns; Strengthening; CFRP; Finite element method; Axial compression*

1. Introduction

Nowadays, most old infrastructures require retrofitting because of initial design and calculation errors, lack of proper implementation, application change after construction, logging damage due to accidental loads, corrosion, and change of some building regulations. Taking into account the high cost of construction and reconstruction and preservation of monuments, some countries spend a large amount of the budget on the construction and repair of the retrofitting of the structures. One of the new materials in helping engineers and designers for retrofitting is carbon fiber reinforced polymers (CFRP), which have been widely used throughout the world in retrofitting of structures. The benefits of this method are as follows: the high-tensile strength to weight ratio, corrosion resistance, and externally strengthening, rapid implementation of polymeric materials. Extensive research studies have been done on retrofitting concrete structures using CFRP, especially for flexural and shear strengthening of concrete beams (Mostofinejad and Shameli, 2013; Toutanji et al., 2006). Several researchers reported on the benefits of strengthening steel structures with CFRP, steel beams and axial loading (Bambach et al, 2009; Narmashiri et al, 2012). Hollow steel structures are widely used in construction and industry.

The use of fiber reinforced polymers (FRP) is an appropriate solution for strengthening infrastructure such as bridges (ACI, 2007). The main reason is that the strength to weight ratio is increased. In fact, weight reduction means cost savings in construction, transportation, and installation. Teng and Hu (2007) investigated the use of hollow steel tubes reinforced with glass fiber reinforced polymer (GFRP). Four steel tubes with and without GFRP were tested. They found that transverse GFRP is mostly caused by flexibility of the hollow steel tubes. Zhao et al. (2005) retrofitted short hollow steel columns once filled with concrete and another time with CFRP sheets. The results revealed that the bearing capacity of the columns increased in the range of 5% to 22% for one layer of CFRP and 20% to 44% for 2 layers of CFRP layer. Jiao and Zhao (2004) used CFRP for strengthening and retrofitting of steel tubes using welded joints. The results of their study indicated that the tensile strength of the pipes was increased from 25% to76%. Shaat and Fam (2006) found that the layers of CFRP can directly affect local exterior buckling of columns. They can also increase the loading of short columns up to 18% and loading of long columns between 13% to 23%. Tao et al. (2007) investigated about the concrete filled steel tubular stub columns and beams, been exposed to and damaged by the standard ISO-834 fire and subsequently CFRP repaired. After that, they tested the retrofitting of the elements using CFRP. They observed that retrofitting of columns is more effective than beams, which increase the bearing capacity and stiffness of the column. Sundarraja et al. (Sundarraja et al., 2012; Sundarraja and Sivasankar, 2013) retrofitted hollow steel short columns by wrapping CFRP sheets in the transverse and longitudinal. They observed that in

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the transverse, method increased the bearing capacity and axial stiffness of the columns. Additionally, their experiment indicated that axial deformations of the local buckling thrust were delayed. Gao et al. (2013) strengthened hollow steel tubes with CFRP sheets. The results of their studies indicated that adding the number of layers can increase the strength and stiffness of the tubes. Abdollahi chakand et al. (2013) implemented twisting moment to a box-shaped steel beams strengthened with CFRP sheets under different angles. They found that the angle of CFRP sheets can increase the capacity of twisting moment. This was more effective at the angle of 45 degrees. Zhao et al. (2006; 2009) investigated the retrofitting of lightweight box-shaped steel beams with CFRP. They found that there is a positive correlation between the number of layers of CFRP, the amount of loads, the mode, and the final shape of the failure. Bambach and Elchalakani (2007) put box-shaped steel sections retrofitted with CFRP, under axial compression. They found that CFRP material can increase the loading under pressure. Feng et al. (2013) tested a number of steel sections filled with mortar after retrofitting with FRP. The results showed that, after retrofitting the failure became localized and resistance to buckling increased. For samples with fewer slender, destruction at the end and the local buckling was observed, and for samples with more slender, bearing capacity and ductility increased. Kalavagunta et al. (2013) investigated the axial loading of the flanged channel columns retrofitted with CFRP. Because of sudden separation of CFRP layers, a significant reduction in capacity and failure was observed; however, the use of CFRP increased the loading capacity. Additionally, they found that the surface preparation and temperature are two important factors to achieve good adhesion between the steel and fiber. Haedir and Zhao (2011) evaluated the impact of retrofitting with CFRP in short columns. They showed that, using a combination of longitudinal and transverse CFRP can increase the capacity and using more CFRP is effective in delaying buckling.

This study examines the use of CFRP sheets for strengthening and retrofitting of SHS steel short and slender columns. Modeling and analysis performed employing ANSYS is. Different support conditions, the coverage rate, and number of layers of CFRP sheets were implemented to examine the critical load of columns.

2. Material characteristics

The sizes of sections and the properties of the steel used in this study are given in Table 1. The yield strength mean value, found by coupon tests, is 240.06 N/mm2 and the ultimate tensile strength mean value is 375.10 N/mm2. The CFRP sheets used in this research SikaWraps-230C reinforced with unidirectional carbon fiber. Properties of CFRP sheets are shown in Table 2. Epoxy used in this study is suggested by the supplier of CFRP product. The epoxy is commonly used for the SikaWraps-230C, which is called Sikadurs-330 (Table 3).

Table 1: Dimensions and material properties of SHS steel

Dimensions (h × b × t) (mm)	Length L (mm)	E-modulus (N/mm2) Mean value	Stress (N/mm2) Yielding (Fy)	Stress (N/mm2) Ultimate (Fu)
90 × 90 × 2.5	500	200000	240.06	375.10
40 × 40 × 2.5	3000	200000	240.06	375.10

Table 2: Properties of fibers

CFRP Sheet: SikaWraps-230C				
Fabric design Thickness (mm)	Modulus of elasticity (N/mm2)	Ultimate tensile strength (N/mm2)	Ultimate tensile elongation (%)	Thickness (Impregnated with Sikadurs-330) (mm)
0.131	238000	4300	1.8	1

Table 3: Properties of adhesive

Adhesive: Sikadurs-330			
Tensile strength	Modulus of elasticity (N/mm2) Tensile	Modulus of elasticity (N/mm2) Flexural	Elongation at break (%)
30	4500	3800	0.9

3. Methods

3.1. Simulations

Recently, the application of accurate scientific software in modeling and simulation of scientific problems has been increased. One of the most powerful analytical tools which are widely used in mechanical and civil engineering is ANSYS. The solution of problems in the software is based on the finite element method (FEM) which is a numerical method based. In this study, materials considered in the form of three-dimensional models so the SOLID elements. Additionally, for models that have irregular mesh, the SOLID187 can be used [25]. The study was also SOLID187 elements that yielded the satisfactory results. Fig. 1 presents more details of this methodology.

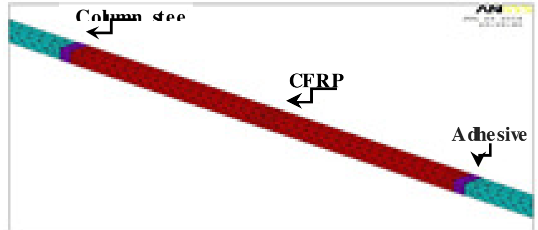

Fig.1: Detail on columns located adhesive and CFRP

Table 4: Comparison of critical load of columns in both laboratory and numerical analysis

Model Name	No. of layers CFRP	Experimental Critical Load (KN)	Numerical Critical Load (KN)	Error (%)
CC1	0	560	563	0.54
FW-T1	1	657	660	0.46

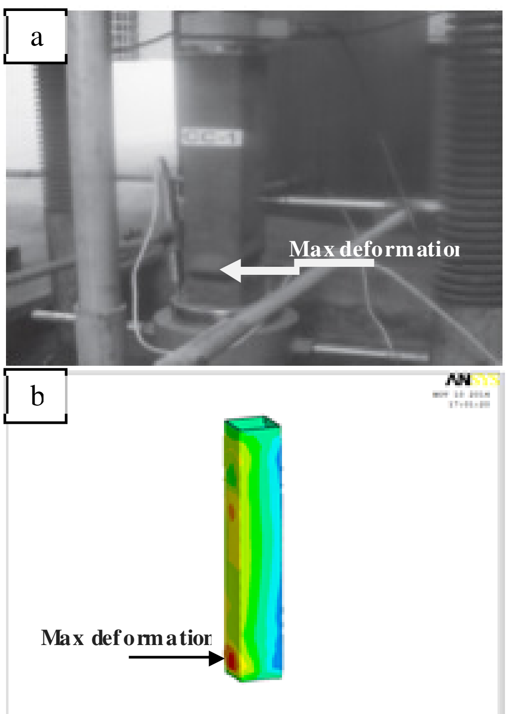

Fig.2: Model CC1 column after buckling (a: Experimental, b: Numerical).

3.2. Validity of software results

It is necessary to validate the calculation of software. In this research study, the software results have been validated and calibrated by the experimental result of Sundarraja and Sivasankar [15]. As you can see in table 4, the experimental results and the simulations using ANSYS are very similar. Figs. 2 and 3 shows the failure modes sample of the columns simulated using ANSYS and experimental. It is obvious that, these modes are very similar.

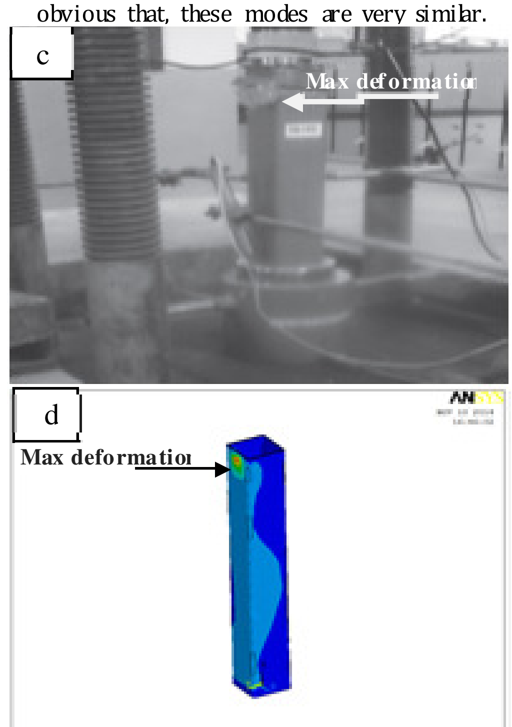

Fig.3: Model FW-T1 column after buckling (c: Experimental, d: Numerical).

4. Results and Discussions

4.1. Critical load of columns with one layer of CFRP

Table5 shows the characteristic of samples modeled in software and the results. Column length of all samples equal and number of CFRP layers different is considered. Coverage percent varies depending on the length of the column and the center CFRP wrapping position are in the center column. As it shows, the percentage increase in the critical load of columns is increased by 0.57% to 38.89%. This is varied for coverage rates of 25% and 100%. Additionally, the maximum percentage increases in the critical load of columns of coverage; 100% have been achieved. Table6 shows the simulation results for samples with one and two layers of CFRP. Column length for all samples and the number of CFRP layers and are the same. The percent coverage varies depending on the length of the column and the center CFRP wrapping position is in the center column. The maximum rate for critical load of columns happened in coverage 100%.

Table 5: Critical load of short columns with one and two layers of CFRP and different coverage precedent

Model Name	No. of layers CFRP	CFRP coverage (%)	Length (mm)	Critical load (N)	Increase load (%)
C0-0-500	0	0	500	214090	0.00
C1-50-500	1	50	500	221430	3.43
C2-50-500	2	50	500	221430	3.43
C1-100-500	1	100	500	265540	24.03
C2-100-500	2	100	500	297340	38.89

Table 6: Critical load of slender columns with one and two layers of CFRP and different coverage precedent

Model Name	No. of layers CFRP	CFRP coverage (%)	Length (mm)	Critical load (N)	Increase load (%)
C0-0-3000	0	0	3000	33750	0.00
C1-50-3000	1	50	3000	36628	8.53
C2-50-3000	2	50	3000	39357	16.61
C1-100-3000	1	100	3000	39164	16.04
C2-100-3000	2	100	3000	42848	26.96

4.2. Compares critical load of columns with different coverage precedent

Figures four and five compare the percentages of increased critical loading columns that is, strengthening and retrofitting with one and two layers of CFRP and coverage range of 50% and 100%. It can be seen in the figures that, for coverage 50%, effective number of CFRP layers of short columns is equal, but for slender columns are not equal. The reason being equal and not depends on the type of failure mode (figs. 6 and 7). According to Fig. 6a and b, it can be seen when the coverage incomplete failure mode occurs in location no CFRP and retrofitting part of the column more pressure and the tension is less. In fig6c and d, that the cover is 100%, because CFRP materials are under greater tension, therefore more effective are in the critical load of columns. In addition, Fig. 5 showed that when coverage percent CFRP layers is less 100%, CFRP increased the compressive load capacity of SHS steel slender columns. According to Fig7a and b, it can be seen that, for SHS steel slender columns the type of failure mode is buckling and failure mode occurs in location CFRP, therefore CFRP is effective in the critical load of columns, even coverage percent less 100%.

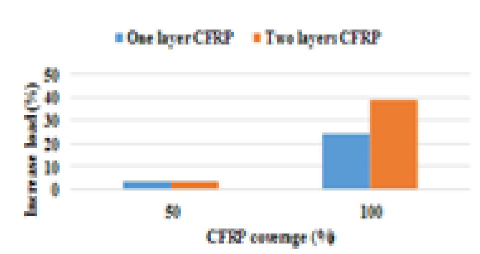

Fig.4: Compare Critical load of short columns

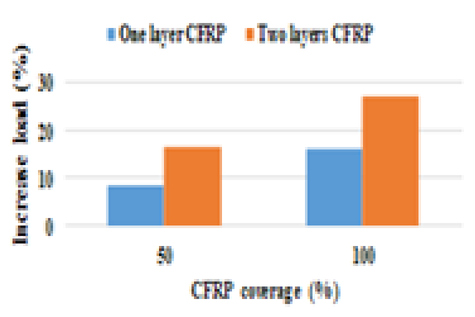

Fig5: Compare Critical load of slender columns.

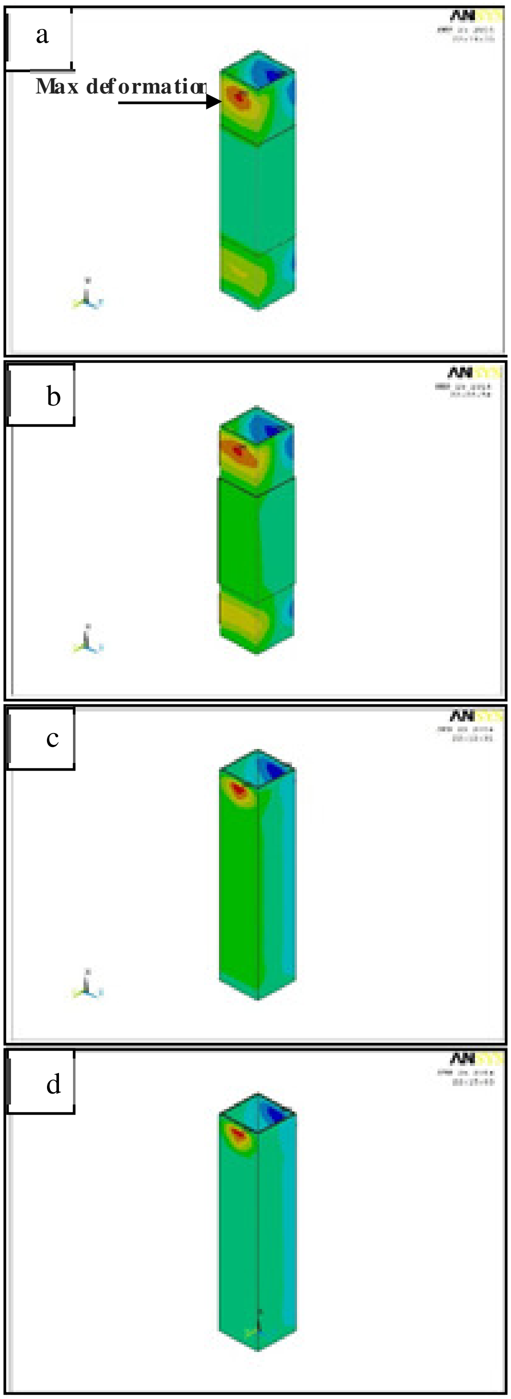

Fig.6: ANSYS modeling short columns (a: C1-50-500, b: C2-50-500, c: C1-100-500, d: C2-100-500).

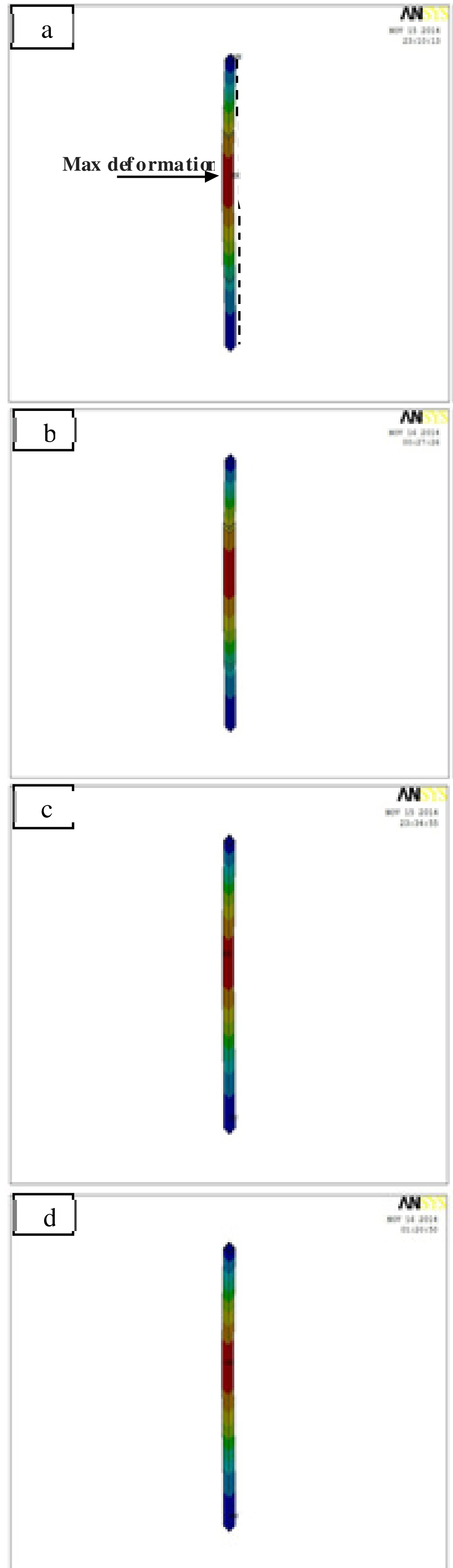

Fig7: ANSYS modeling slender columns (a: C1-50-3000, b: C2-50-3000, c: C1-100-3000, d: C2-100-3000).

5. Conclusion

Percentage around the hollow structural steel tubular columns to enhance the structural performance. Based on the obtained results, the failure modes, ultimate load carrying capacity, and CFRP wrapping position on hollow steel columns were discussed. Based on the analysis on 9 specimens wrapped with CFRP strips with different coverage percentage and with different layers, the following conclusions can be made:

- The analysis showed that fiber composites may be used for strengthening of axially loaded hollow steel columns.
- CFRP increases the critical load of the hollow steel columns.
- The coverage percentage of CFRP affects the rate of critical load.
- The number of CFRP used has a direct effect on increasing the maximum critical load.
- The position of CFRP has a direct effect on increasing the maximum critical load.
- For short columns retrofitted by one and two layers of CFRP, (with the coverage rate of 25% to 100%) the best coverage rate is 100%.
- For the short columns retrofitted by CFRP coverage percentage rate less 100%, CFRP is less effective.
- For the slender columns retrofitted by CFRP coverage percentage rate less 100%, CFRP is effective.

CFRP increases the critical loading of the hollow steel short columns more than slender columns.

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