EXPERIMENTAL INVESTIGATION FOR IMPROVING THE PERFORMANCE OF THIN-WALLED TUBULAR STEEL COLUMNS USING CFRP STRIPS

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ABSTRACT

The use of carbon fiber reinforced plastic (CFRP) strips to enhance the behavior of local stability for thin-walled tubular steel columns has been investigated experimentally. Tubular steel columns specimens are made from welding thin plates at their edges. The type of strengthen carbon fiber is a unidirectional woven fiber mat of mid strength which is a product of Sika coded as SikaWrap -230C. The CFRP is fixed using a resin Sikadure-330. The study is focusing on the local stability of such members. Many pattern of wrapping are suggested herein. Recommendations have been drawn for the best pattern chosen to obtain the most efficient and economic strengthen pattern.

الخلاصة

تم تحري السلوك ألمختبري لاستعمال شرائح ألياف تسليح الكربون البوليمري (CFRP) لتحسين أداء الاستقرارية الموقعية للأعمدة الحديدية المجوفة . تم تصنيع نماذج الأعمدة الحديدية المجوفة من لحم صفائح نحيفة الجدران في الحافات الخارجية. نوع التقوية تمت باستعمال حصيره ألياف كربون منسوجة باتجاه واحد من النوع متوسط المقاومة إنتاج شركة سيكا ذو الرمز (Sika Wrap -230C). تم تثبيت ألياف الكربون باستعمال راتنج نوع (Sikadure-330). ركزت الدراسة على الاستقرارية الموقعية لمثل هذه الأعضاء. تم اقتراح أنماط عديدة للتقوية. تم استخلاص توصيات لأفضل نمط من ناحية الكفاءة والاقتصاد.

Keywords: Thin-walled; CFRP; Tubular Steel; Axial Load.

INTRODUCTION

Carbon fiber reinforced plastic (CFRP) composite materials have been increasingly employed in the construction industry, mainly in applications dealing with structural strengthening and repair [1]. Fiber reinforced composites offer a range of properties that include less dense, high-strength and high-stiffness, fibers embedded in an epoxy adhesive matrix. The mechanical properties of reinforced fibers rely on the fiber characteristics, such as their size, the percentage of fiber reinforcement, and the orientations of fibers. Most existing applications involve concrete-FRP composite members or FRP-repaired concrete. Nonetheless, a relatively small and innovative body of work is developing focusing on steel-FRP composite structural systems [2].
One of the greatest limitations to the behavior of conventional steel tubular beams composed of thin sections is the susceptibility of the steel component to local buckling. This local instability is more likely to occur in thin than in thick sections, and the effect of local stresses within the steel can result in a reduction of strength.

Employing non-ferrous materials in the form of carbon fiber-reinforced polymer (CFRP) sheets, as external reinforcement, in thin-walled tubular sections can provide substantial weight savings. The nature of fiber-reinforced polymers (FRP) - the attributes that make them superior - has been, and currently remains a subject area of extensive study for those concerned in using FRP materials for rehabilitation of existing structural components that are structurally inadequate. In recent years, there have been a number of studies related to strengthening of steel structures with CFRP, particularly in the field of thin-walled steel structures. Recent research on the strengthening of circular hollow sections (CHS) with FRP by Teng and Hu [3] and Hong et al. [4] in axial compression, Haedir et al. [5, 6] in bending, Doi et al. [7] in bending and compression, Jiao and Zhao [8] in tension, and Zhao et al. [9] and Xiao et al. [10] on concrete filled CHS, have shown significant benefits in strength and stiffness of steel members with externally bonded CFRP. Experiments on steel RHS strengthened with CFRP under transverse end bearing force were described by Zhao et al. [11]. In the present study nine square hollow steel short columns reinforced by CFRP sheets were tested under axial load to investigate the best distribution of CFRP. Each specimen made from four parts of steel grade 250 and connected together by seam welding with dimensions (2.5x200x400) mm. The specimens strengthen by carbon fiber is a unidirectional woven fiber mat of mid strength which is a product of Sika coded as SikaWrap -230C. The CFRP is fixed using a resin Sikadure-330.

EXPERIMENTAL SETUP AND TEST SPECIMENS

The section dimensions of the specimens produced by seam-welded along length of four parts of steel with 2.5 mm thickness, 200mm width and 400mm height of 320 MPa yield steel. The measured uni-axial tensile material properties are listed in **Table 1.** **Fig.1** shows the Measured uni-axial tension stress–strain material curve of the steel sheets which used to fabricate the tuber steel columns.

Table 1
The dimensions and the measured uni-axial tension material properties of the steel sheets which used to fabricate the tuber steel columns

Specimen	Thickness *t (mm)*	Width *w (mm)*	Length *l* (mm)	Yield Stress f_y *(MPa)*	Ultimate Stress *fu* *(MPa)*	Failure Strain ε_f
1 to 9	2.5	200	400	320	400	0.10714

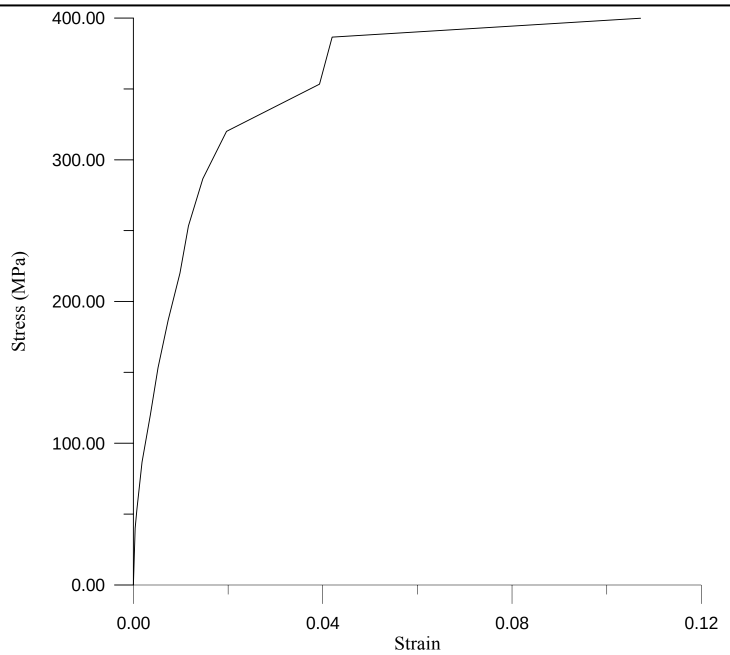


Fig. 1 The measured uni-axial tension stress – strain material curve

The tuber steel columns strengthen with different patterns of woven carbon fiber type SikaWrap-230C by epoxy type Sikadur-330 the material properties are tabulated in **Table 2**.

Table 2
The material properties of Sika Wrap-230c carbon fiber and Sikadur-330 epoxy

Material	Fabric design thickness (mm)	Fiber density g/cm³	Areal weight g/m	Tensile strength (Mpa)	E-Modulus (Mpa)
SikaWrap - 230C	0.131	1.76	230	4300	238000
Sikadur-330	--	--	--	30	4500

The test program include tested nine strut column; non strengthen steel column (NSS), column strengthen with transverse CFRP followed by longitudinal CFRP around all column (FSS1) (Full Strengthen Steel Column), column strengthen with longitudinal CFRP followed by transverse CFRP around all column (FSS2). The column (PSS3) (Partial Strengthen Steel Column) in which the CFRP applied in longitudinal pattern with (2.5cm) strip width at each corner and with (5cm) strip width in transverse pattern at ends and mid height. The same distribution of CFRP was applied for column (PSS4) but with increased a longitudinal strip with (5cm) width at the middle of each face, the column (PSS5) has the same distribution of CFRP of column (PSS3) but with addition crossing (5cm) strip at each face. The same amount of CFRP of column (PSS3) was applied for column (PSS6) but with strip width (2.5cm), The same idea was applied between column (PSS4) and column (PSS7), finally in column (PSS8) a strip with width (2.5cm) was applied with inclination of (45˚). **Fig.2** shows the distribution of CFRP of each tested specimen.

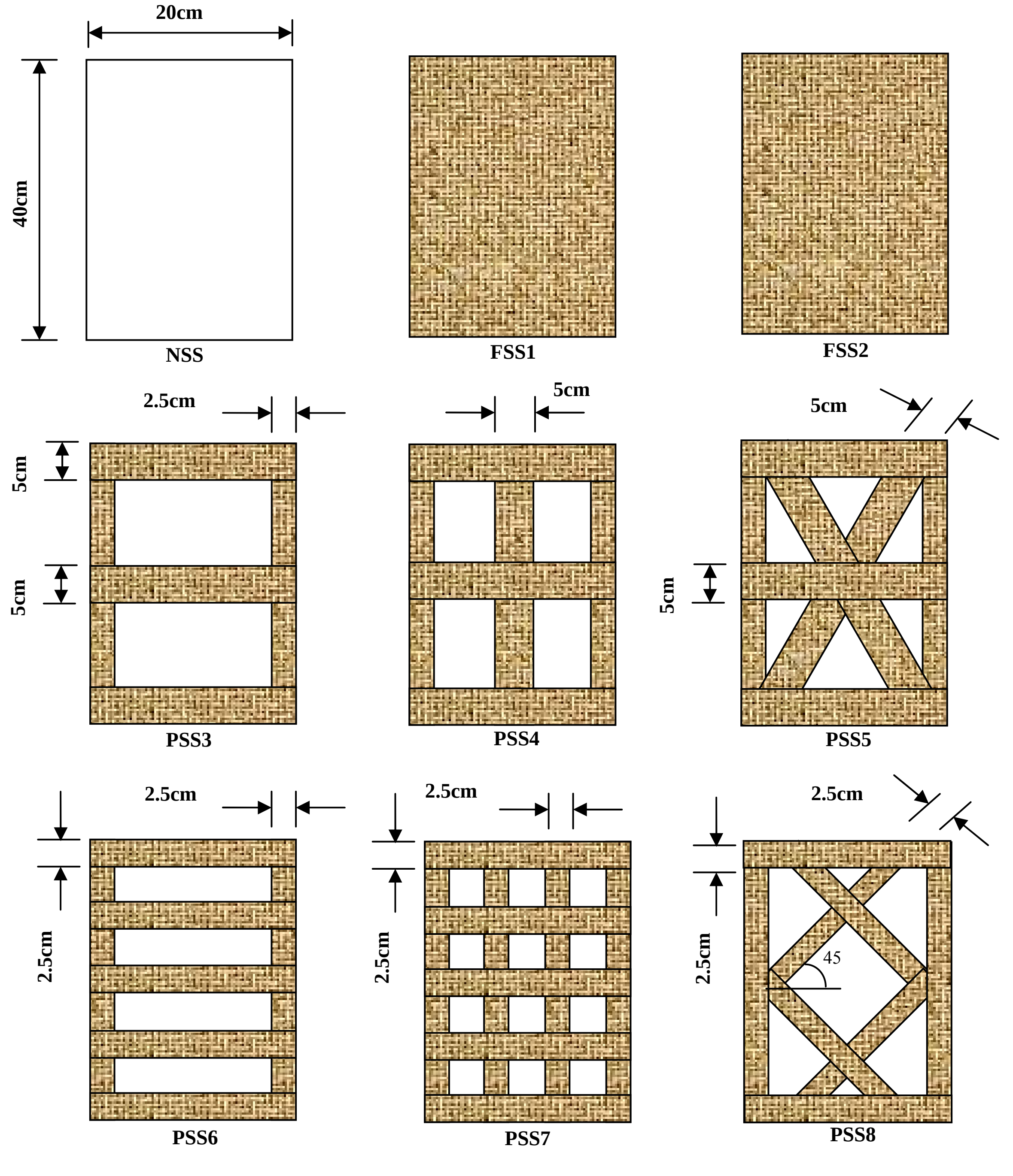


Fig. 2 The Distribution Pattern of CFRP of the tested specimens

EXPERIMENTAL RESULTS

The results of the tested specimens that obtained from applying an axial compressive load by using an universal testing machine as shown in **Fig.3**, shows that the application of CFRP to the tubular steel columns increase the stiffness, the ultimate axial compressive load and decreases the local buckling at the ends of the column. The obtained results were tabulated in **Table 3**. The axial compressive load to axial displacement curve for the tested columns are shown in **Fig.12**, also the curves of each column are shown in **Fig.4** and **Fig.5, Fig.6, Fig.7, Fig.8, Fig.9, Fig.10 and Fig.11**. From these figures it's clear that the best distribution of CFRP was for column PSS7. Where this pattern gives a behavior better than the behavior of columns FSS1 and FSS2 that have a full application of CFRP on the columns.

Fig. 3 The universal testing machine

Table 3 : The experimental results of the tested columns

Specimen	A_{CFRP} (cm^2)	A_{CFRP}/A_{column}	P_u (kN)	$\frac{Pu - Po}{Po} \times 100$

NSS	0	0	160	0%
FSS1	6400	2	182.5	14%
FSS2	6400	2	182.5	14%
PSS3	1600	0.5	165	3%
PSS4	2400	0.75	172.5	7.8%
PSS5	3720	1.16	185	15.6%
PSS6	1600	0.5	182.5	14%
PSS7	2400	0.75	**190**	**18.75%**
PSS8	1950	0.61	187.5	17.8%

Where:

P_u : ultimate axial load (kN).

P_o : ultimate axial load of non strengthen steel column (160 kN).

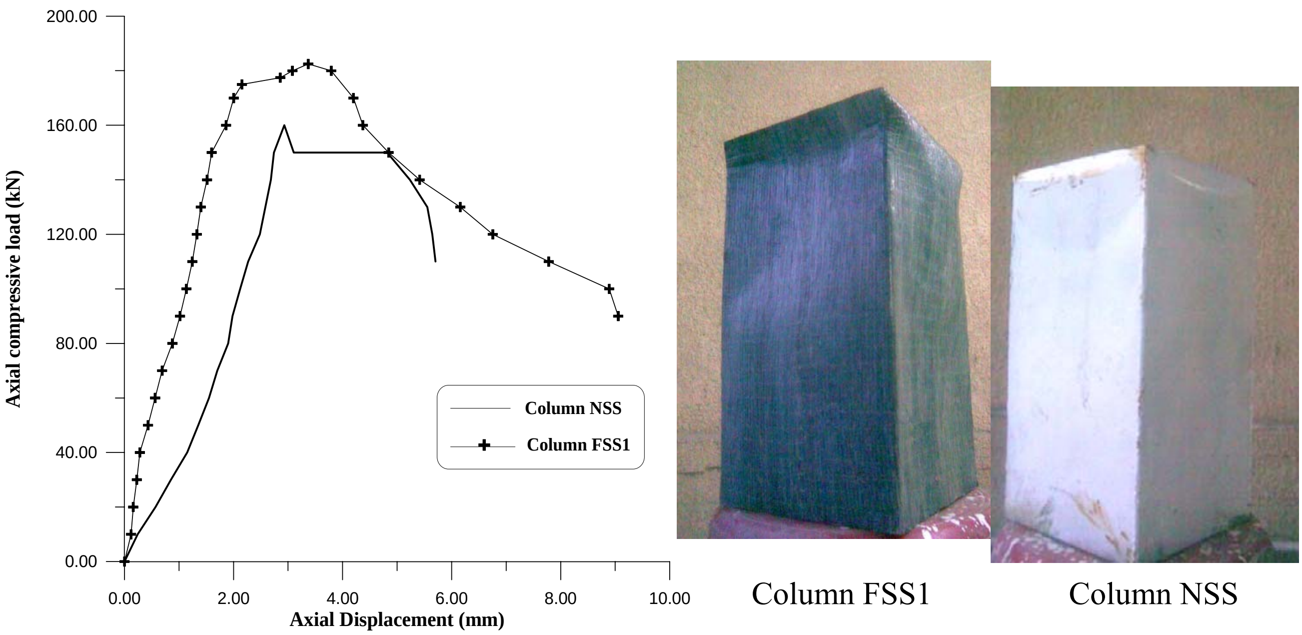
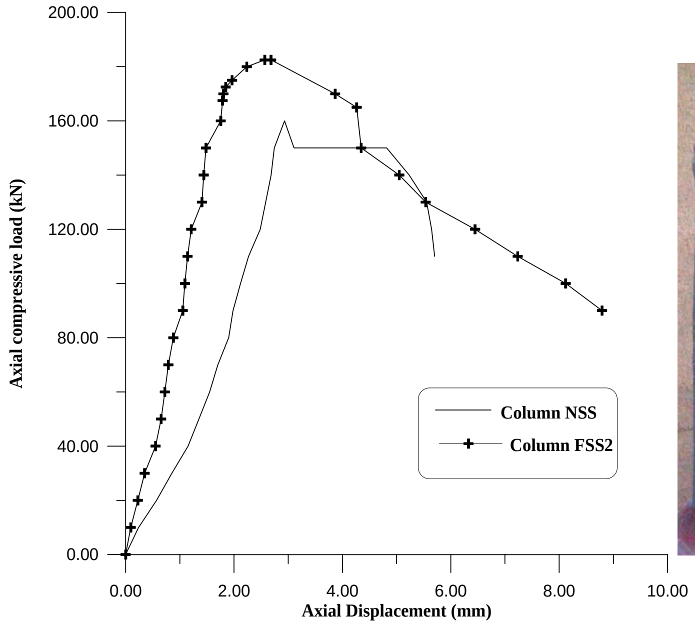
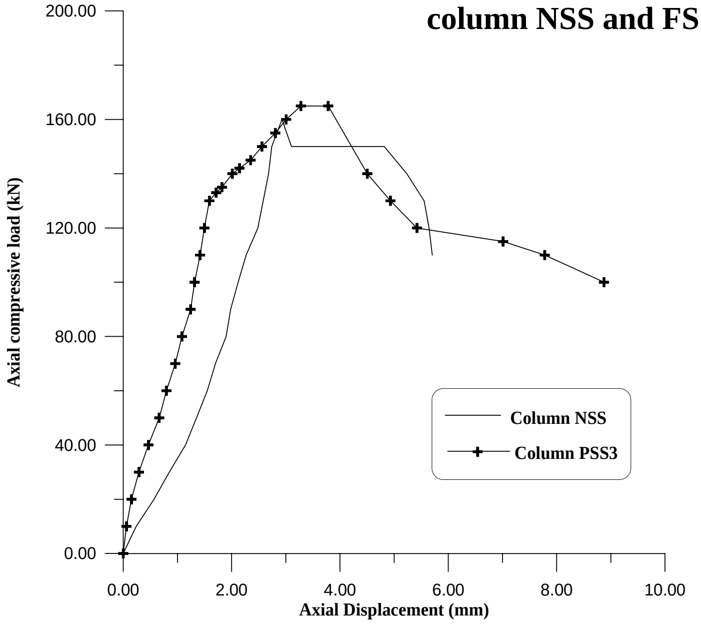


Fig. 4 The axial compressive load to axial displacement curve of column NSS and FSS1



Column FSS2 Column NSS

Fig. 5 The axial compressive load to axial displacement curve of column NSS and FSS2



Column PSS3 Column NSS

Fig. 6 The axial compressive load to axial displacement curve of column NSS and PSS3

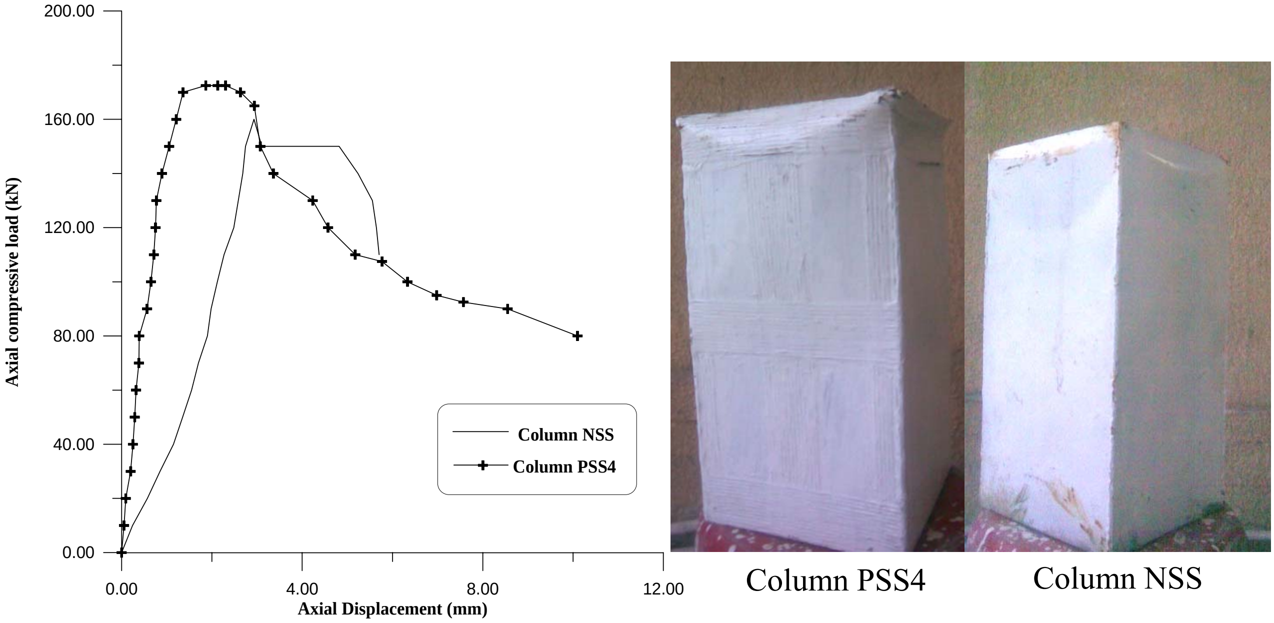


Fig. 7 The axial compressive load to axial displacement curve of column NSS and PSS4

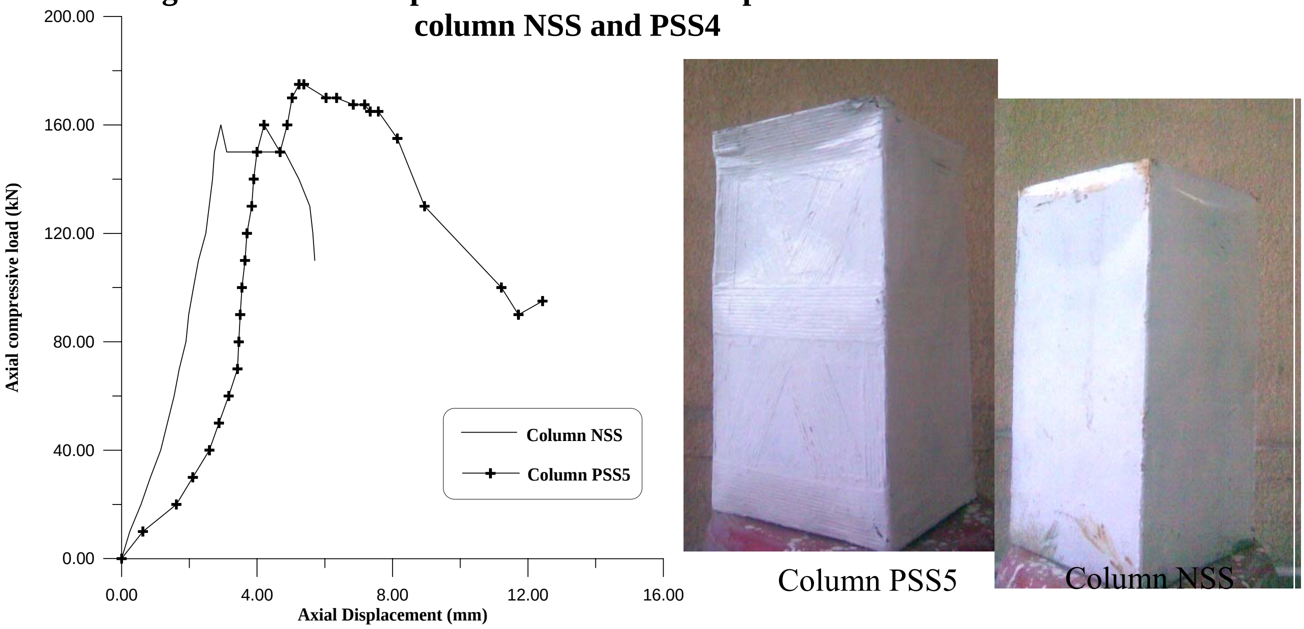


Fig. 8 The axial compressive load to axial displacement curve of column NSS and PSS5

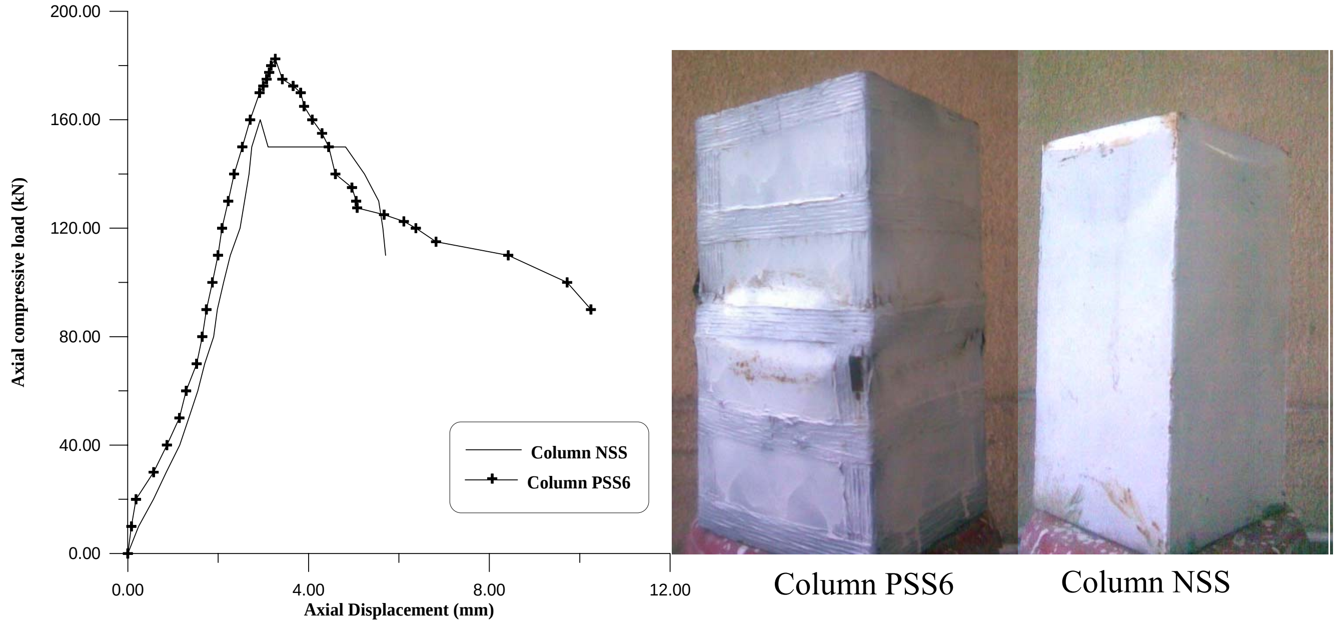


Fig. 9 The axial compressive load to axial displacement curve of column NSS and PSS6

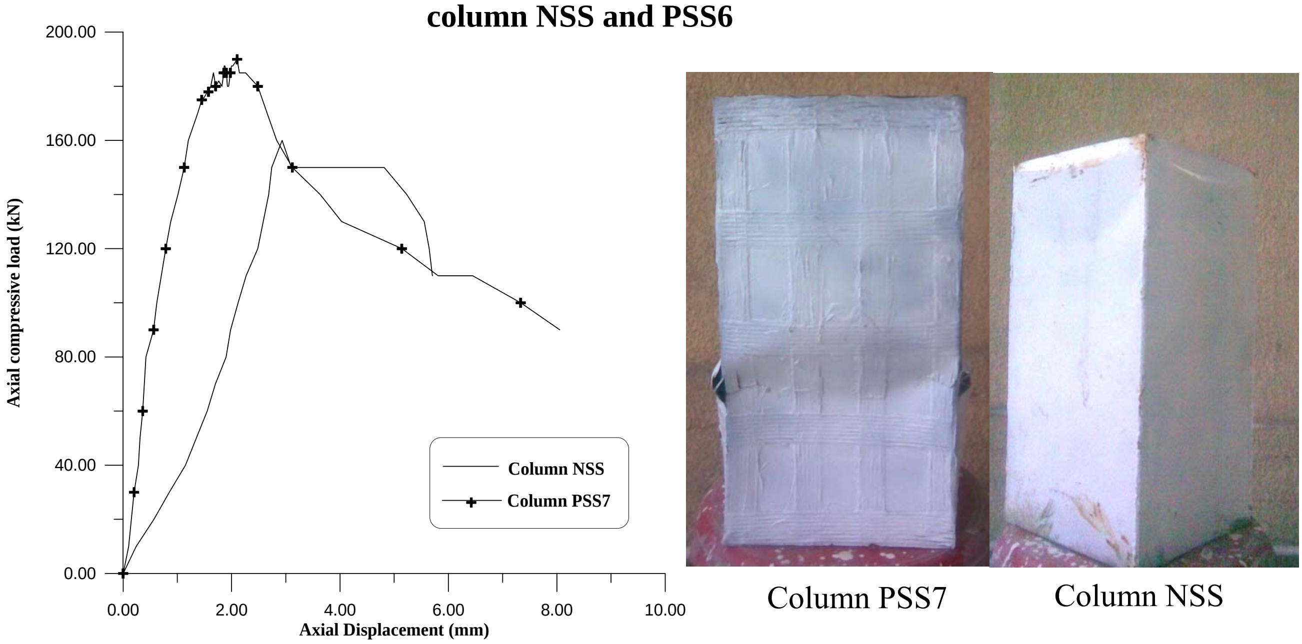


Fig. 10 The axial compressive load to axial displacement curve of column NSS and PSS7

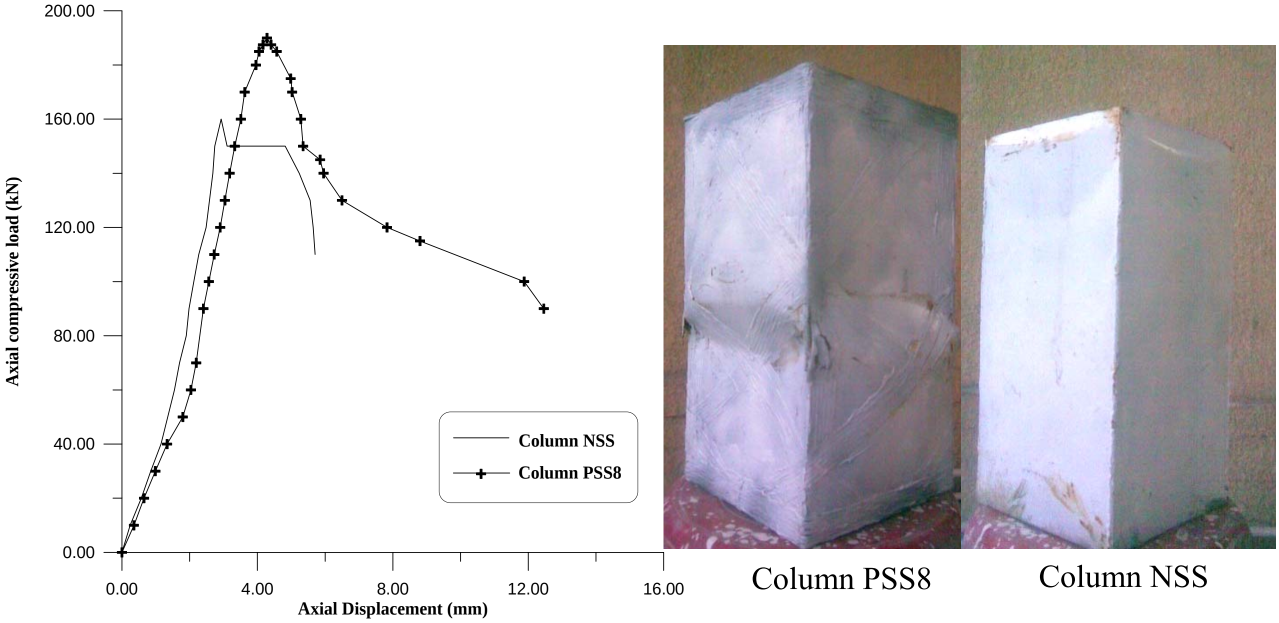


Fig. 11 The axial compressive load to axial displacement curve of column NSS and PSS8

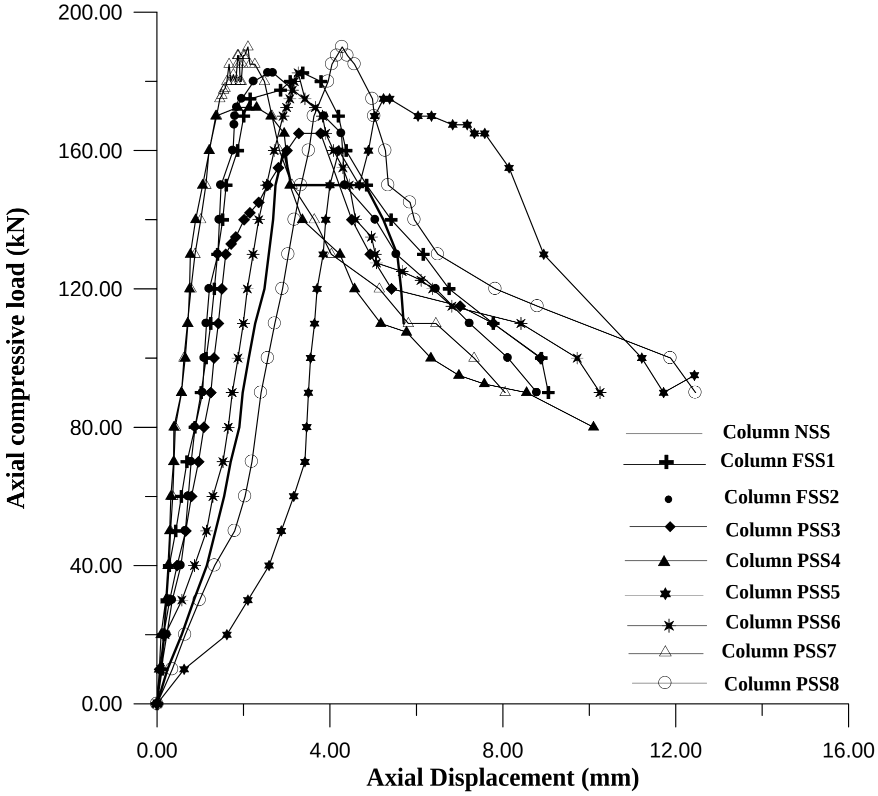


Fig. 12 The axial compressive load to axial displacement curve of the tested columns

Fig.13 shows that the column PSS7 represent the best distribution of CFRP which increases the ultimate load to about (18.75%). The columns FSS1, FSS2 and PSS6 give the same increasing in ultimate load but the column PSS6 represent most economic between them because it has 0.25 amount of CFRP of columns FSS1 and FSS2.

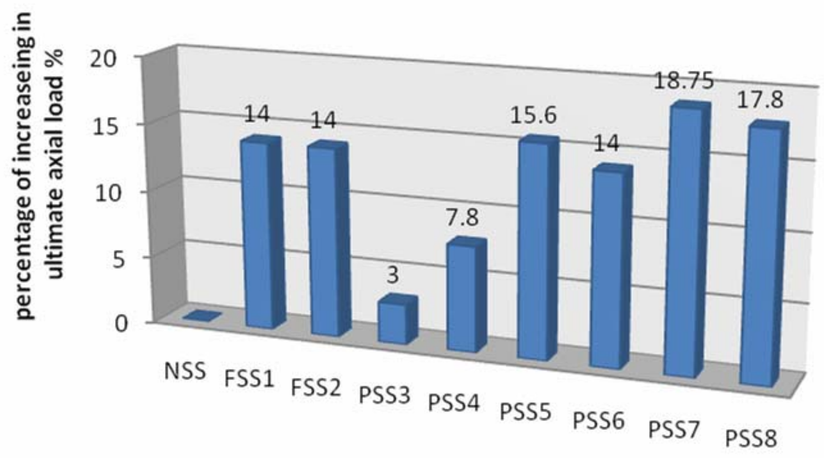


Fig.13 the percentage of increasing to ultimate axial load for the tested columns

CONCLUSION

1- The distribution pattern has a significant effect on the behavior of thin-walled tubular steel columns strength with CFRP, where the pattern of column PSS7 gives increasing in ultimate capacity more than the column FSS1 and FSS2.
2- The application of CFRP on thin-walled tubular steel columns increases the ductility and ultimate compressive load to about 18.75% .
3- The full strengthen by CFRP for the column is not economic and decreases the total efficiency of CFRP because of the column may be failure due to local buckling.
4- The distribution pattern must be proper with the case of bucking of column which the last depend on the aspect ratio of the column.
5- When distributed the CFRP in two directions one must put the vertical pattern and then the horizontal pattern to increase the stiffness.

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