Performance of BFRP and GFRP Hollow Circular Steel columns subjected to axial compression loads.

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Abstract

Recent research has been focused on rehabilitation and strengthening of deteriorated steel structures and bridges using Fiber Reinforced Polymer (FRP) materials. This paper deals with the behavior of FRP confinement of hollow steel sections subjected to axial compression loads. The load carrying capacity and buckling failure patterns of hallow steel sections strengthened by different FRP were studied experimentally. Numbers of circular hallow steel sections of same diameter with different L/D ratio test specimens were fabricated. Three different L/D ratio test specimens were used as control specimens. The different number of layers in FRP such as basalt (BFRP) and glass (GFRP) fabrics in different orientations has been fabricated. The effects of strengthened elements were observed under axial compression load. The load vz slenderness ratio, stress strain relationship, the ultimate load vz orientation and number of ply wrapping by different FRP were deeply analyzed and are plotted, tabulated and discussed. Besides local and overall buckling modes, failure patterns and rupturing of fiber of strengthened and non strengthened specimens were also observed. It is concluded that BFRP fabric wrapped by double layers in the circumferential direction elements withstand more axial compressive load than other strengthened and non strengthened elements.

Keywords: circular hallow steel section, axial compression, FRP, local and overall buckling, strengthening.

1. INTRODUCTION

Steel concentrated structures are popular almost all over the world [1]. Circular hollow steel (CHS) tubes are progressively more used both in building and bridge structures due to their well-organized geometry. During their service life, these members are subjected to loading of various types such as axial loading, bending and torsion [2]. Rehabilitation of such structure is frequently required. Owing to the loss of cross- section from corrosion [3], current techniques for strengthening steel structures have some negative aspects including requiring heavy equipment for installation, their fatigue performance, in addition to the need for continuing maintenance due to persistent corrosion attack. Hence inventive and cost effective methods are necessary for strengthening and rehabilitation of steel structures due to the demand to increase the specified load and/or deterioration as a result of corrosion [4]. External bonding of advanced composite materials is one such method to strengthen steel structure efficiently [5].

Fiber Reinforced Polymer (FRP) is a popular material to be used as external confinement of concrete members for both strengthening and retrofitting purposes [6]. By applying FRP material in concrete members, no significant increase in weight of structure will occur, while FRP material significantly enhances the concrete structure's performance especially in terms of strength and ductility. The most common material used is Glass Fiber Reinforced Polymer (GFRP) and Basalt Fiber Reinforced Polymer (BFRP) [7]. The strength improvement is found to be depending on factors such as cross-sectional shape, slenderness ratio, diameter to thickness ratio or thickness of steel tube and local buckling behavior of steel tubes [8].An extensive review of research in the general field of steel structures strengthened with CFRP is carried out in [9]. The investigations on steel hollow sections were all performed on compact sections [10].The section slenderness affects both the strength and energy absorption, with a general trend of slender sections gaining greater increase in strength than compact sections with the addition of CFRP, and compact sections gaining greater increase in energy absorption than slender columns[11].

The research regarding the application of GFRP and BFRP to strengthen compression members, specifically on columns is limited. So this research is focused to use the GFRP and BFRP to strengthen hollow steel pipe and study the performance of GFRP and BFRP strengthened circular hollow sections in connection with the different fiber lay-outs.

2. Material Properties

2. 1 Materials

2.1.1 Glass fiber

Nitowrap EP (GF) is a glass fiber composite wrapping system where Nitowrap GF is used in conjunction with an epoxy sealer cum primer; Nitowrap 30 and a high build epoxy saturant Nitowrap 410. The system is protected by a polyurethane top coat of Nitowrap 512 in case of atmospherically exposed structures. Nitowrap EP (GP) is fabric type and can be tailored into desired shape. The physical and mechanical properties of the glass fibers are listed in Table 1.

Table 1 Properties of Nitowrap EP (GF) Glass fiber unidirectional fabric specification

Fiber orientation	weight $\left({}^{g}/{}_{m^2}\right)$	Density $\left({}^{g}/{}_{cc}\right)$	Thickness mm	Width mm	Tensile Strength $\left({}^{N}/{}_{mm^2}\right)$	Tensile Modulus $\left({}^{N}/{}_{mm^2}\right)$
Unidirectional	920	2.6	0.90	1000	3400	73,000

2.1.2 Description of Basalt fiber

The basalt fiber properties are obtained from the M/S Zhe jiang, GBF Basalt fibre Co. Ltd. China. Basalt unidirectional fabric specifications are mentioned in the Table 2. The physical and mechanical properties of the different Basalt fibers are listed in Table 2.

Table 2 Properties of Basalt fiber fabric specification

Structure weaving	weight $\left({}^{g}/{}_{m^2}\right)$	Density $\left({}^{g}/{}_{cc}\right)$	Thickness mm	Width mm	Warp density $\left({}^{N}/{}_{mm2}\right)$	Tensile Modulus $\left({}^{N}/{}_{mm^2}\right)$
Unidirectional	1050	2.85	0.60	1270		

2.4 Circular Steel Hollow Tubes

The Circular hollow steel tubes confirming to IS 1239:1983 are used in this study. The steel tubes were chosen with three different lengths (100mm and 200mm) of thickness (2 mm) so as to have different L/D ratio for the same diameter. All CHS sections were nominally internal and external diameter of 72.2 mm and 76.2 mm respectively. The average yield strength obtained from tensile coupon test was 307.5 MPa.

3. Load carrying capacity by Analytical Method

To study the structural behavior of load carrying capacity of different FRP confined specimens with different orientations and layers, the non confined by FRP specimens load carrying capacity is analytically calculated by Rankine formula [5]. All the necessary parameters are calculated and the ultimate load carrying capacity is estimated and is tabulated in Table 3, for different non strengthened specimens (NSS).

Table 3 Load carrying capacity of NSS by Rankine method

Sl. No	Specimen Destination	L_{eff} mm	D mm	d mm	Sectional Area mm^2	Rankines Constant 'a'	Radius of Gyration γmin = $\sqrt{{}^{I}/{}_{A}}$	Slenderness Ratio $\lambda = {}^{leff}/{}_{\gamma min}$	Ultimate Stress $\sigma_c = {}^{N}/{}_{mm^2}$	Moment of Inertia I mm^2	Rankines Load $P_R = \frac{\sigma_c \times A}{1 + a\left({}^{leff}/{}_{\gamma min}\right)^2}$
1	NSS 100	100	76.20	72.20	456.976	0.000133	26.243	3.810	320	320920	148.825
2	NSS 200	200	76.20	72.20	465.976	0.000133	26.243	7.621	320	320920	147.969
3	NSS 300	300	76.20	72.20	465.976	0.000133	26.243	11.431	320	320920	146.566

4. Experimental Investigation

To investigate the behavior of BFRP and GFRP strengthened Hollow Circular Steel Columns under pure axial compression, a series of tests were executed to consider the influence of slenderness ratio and type of fiber on the axial compressive strength of HCS columns. The slenderness ratios of the steel cross – section considered in this study were 3.81, 7.62 and 11.43. All three types of fibers wrapped completely in the outer surface of the specimen and overlap in one side width. The effects of varying the number of fiber layers were also examined. The experimental series consist of testing 4 sets of hollow circular steel tube specimens starting from NSS (non strengthened specimen), BFRP (Basalt fiber reinforced polymer) wrapped and GFRP (Glass fiber reinforced polymer) specimens. The two types of fibers were wrapped in longitudinal and circumferential directions in single and double layers (Fig.1, Fig.2).

Fig. 1 Specimens wrapped circumferentially

Fig. 2 Specimens wrapped longitudinally

4.1. Specimen preparation

The 100 mm and 200 mm long circular hollow tubular specimens were cut from 6.0 m long hollow steel tubes. The surface of the steel specimens were first roughened by sand blasting and then scrubbed by sand paper to remove the corroded particles in steel and to get better bonding between steel specimen and fibers. Afterwards the sand blasted surface of the steel substrate was cleaned by acetone to eradicate all contamination before wrapping with the fibers. Prior to the specimen strengthened by different type of fibers, one thin coat of Nitowrap 30 primer was applied. Then the basalt, glass and carbon fibers were wrapped to the external surface of the hollow steel specimens with different wrapping schemes, such as longitudinal and circumferential directions in single and double layers. During wrapping of fiber fabrics the resin and hardener Nitowrap 410 are correctly proportioned as per the specifications of the manufacturer s direction and thoroughly mixed together and applied as per the manufacturer s direction. The excess epoxy and air gap were removed using a ribbed roller moving in the direction of the fiber. Careful attention was given to the effectiveness of the bonding between the steel substrate and fiber.

4.2. Instrumentation

The hollow steel columns were tested in compression machine of capacity 2000 KN. The experimental set up is shown in Fig.4. Before the application of load, each member was positioned on the support and also centered to make sure that the two supporting ends were parallel to each other and at right angles to the loading axis. The load was applied to the column specimen by hydraulic jack monitored by using 1000 KN capacity load cell. The two ends of the resistance to vertical load are allowed rotation at their ends, so as to keep in pinned or hinged support at both ends. At the beginning, 10% of the estimated load (15KN) was applied slowly, so that the columns settle properly on their support. Then the load was removed after checking the proper functioning of the instrumentation, the axial load was applied gradually and slowly and the column was tested to failure by applying the concentric compressive load and the observations such as ultimate loadings, the deformation of fibers were carefully recorded and tabulated which also include the stress, strain and percentage of change in length of the specimens. The load at which the fiber starts rupturing and the nature of failure were also noted for each column. The experimental setup is shown in Fig .4.

Fig .4. Experimental setup

4.3. Details of the test specimens.

Totally thirty nine specimens were fabricated. In that non strengthened specimen are three numbers, strengthened with FRP in different layers and different orientation are made on twelve specimens of different fibers. In order to identify the test specimens with different slenderness ratios, and different strengthening schemes with FRP, the following system of designation is used (Table 4).

Table 4 Designation of strengthened test specimens

SL NO	Specimen strengthened with BFRP	specimen strengthened with GFRP
1.	BFSL 100	GFSL100
2.	BFSL 200	GFSL 200
3.	BDDL 100	GFDL100
4.	BDDL 200	GFDL 200
5.	BFSC 100	GFSC100
6.	BFSC 200	GFSC 200
7.	BFDC100	GFDC 100
8.	BFDC 200	GFDC 200
	Non strengthened specimens	
9.	NSS 100	NSS 200

The number at the end (100 and 200) represents the length of circular steel tubes. The first two letters such as BF and GF represent the fibers of basalt and glass respectively. The third letters S and D represent number of layers like single or double. The last letter followed by the number L and C represents the orientation of wrapping of fibers in longitudinal and circumferential directions respectively. Finally NSS represents non strengthened sections.

5. Results and discussion.

5.1. Failure modes

In order to make a clear investigation on the behavior of load and overall bucking of three different FRP strengthened, hollow steel tube columns of slenderness ratios 3.81 (100 mm in length) and 7.62 (200 mm in length) are considered in this study. Each group consists of four categories, which are single layer and double layers of FRP fabric, wrapped in longitudinal and circumferential directions. The columns were symmetrically loaded until failure so that the influence of fiber on the compressive behavior of CHS can be analyzed with graphs. Furthermore the columns were still loaded even after failure to understand the failure pattern. All the specimens exhibited a distinctive bucking failure (i.e.) elephant foot buckling, (Fig. 6(a)) which is proved to be the common failure mode in hollow steel tubes in the past researches. Ring buckling also developed along the circumference of the specimens (Fig. 6(b)). Increase in load leads to the rupture of the fiber and then crushing of fiber in any of the single layer wrapped specimen (Fig. 6 (c)) because of good bond between the steel and fiber.

(a)

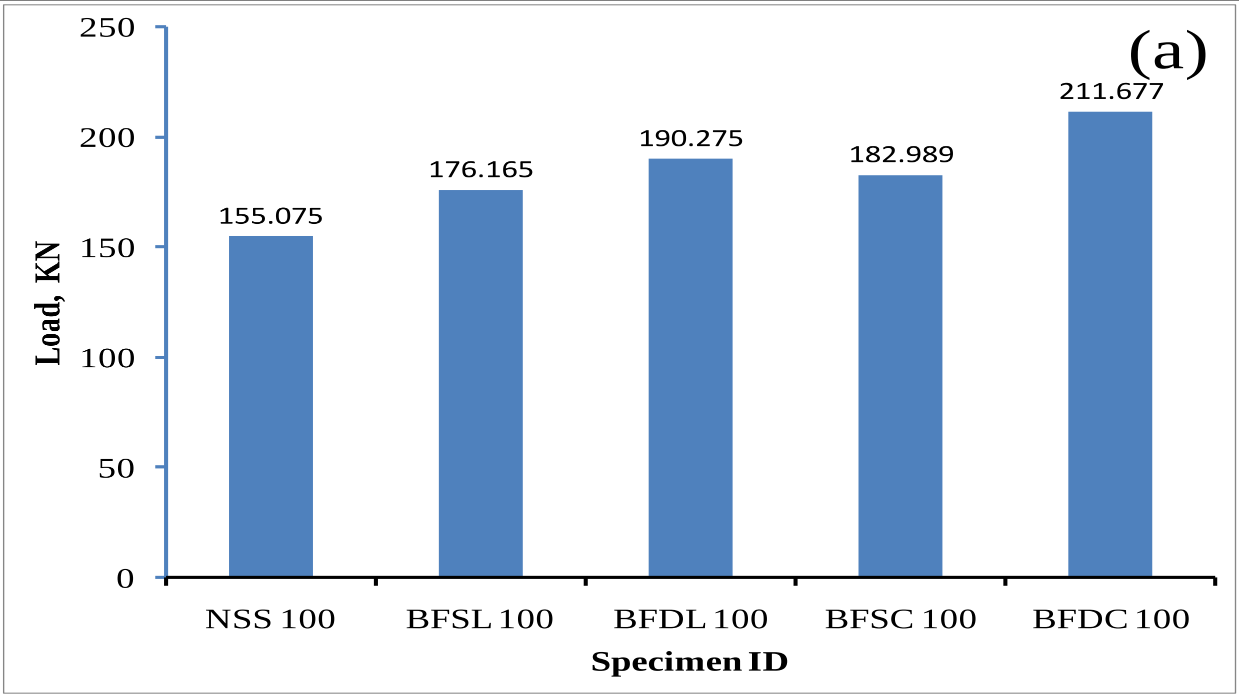
(b)

(c)

Fig. 5 Different mode on buckling failure (a) Elephant Foot Buckling (b) Failure Mode At Middle Section (c) Buckling Failure at Top and Bottom

5.2 The effect of load carrying capacity.

The analytical method due to Rankine is used to evaluate the ultimate compressive load capacity of the specimen pieces of circular hollow steel sections of length 100 mm and 200 mm respectively. The results are plotted for BFRP is shown in Fig. 6 (a-b) & GFRP is sown in 6(c-d). As expected the capacity decreases with increase in length of the specimen. As compared to the effect of slenderness ratio on ultimate compressive load, there is a 4% difference between the analytical and experimental values of the compressive load. There is a gradual decrease in compressive load as the slenderness ratio increases.



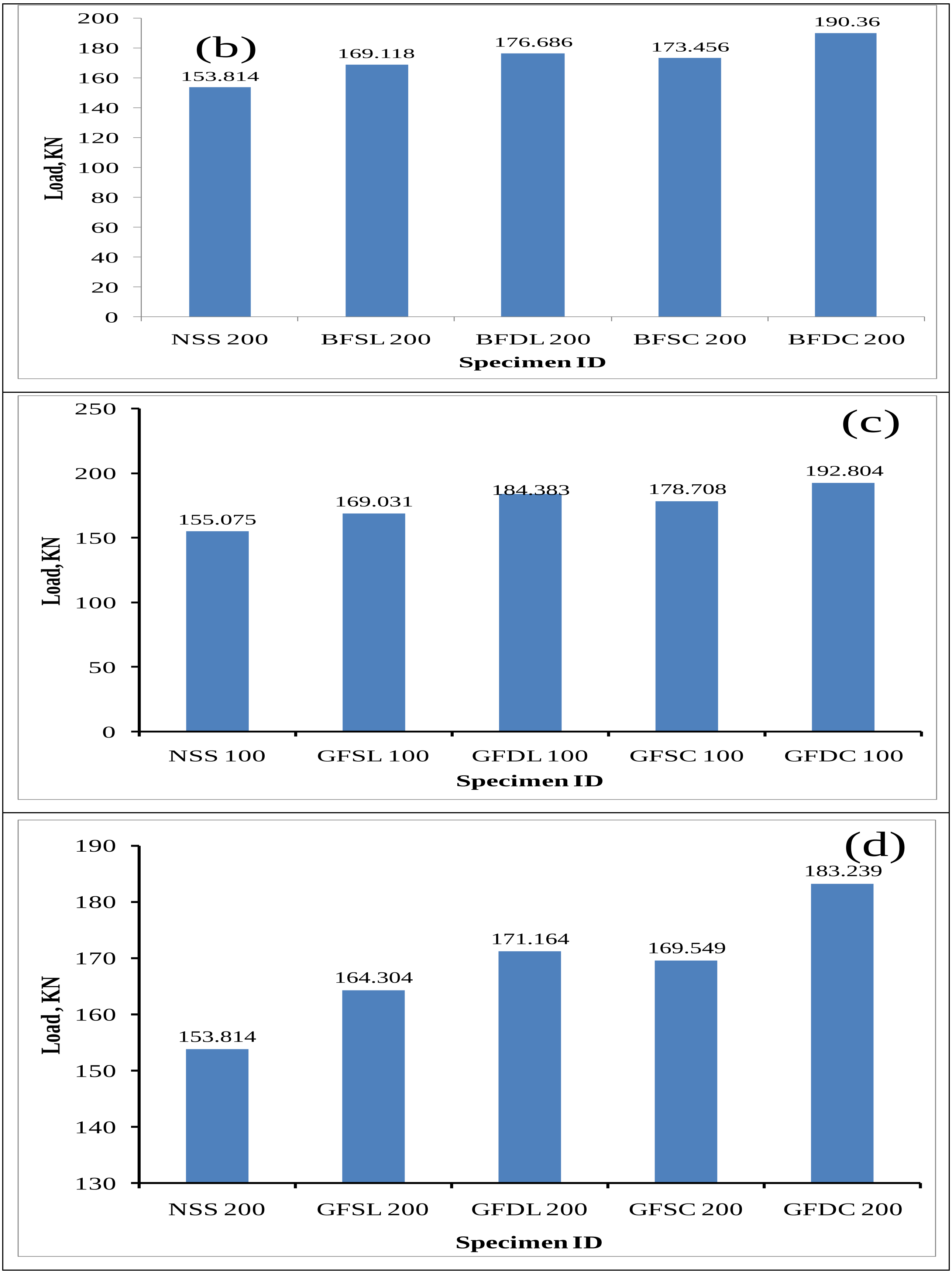


Fig. 6 The effect of load carrying capacity of BFRP (a) 100 mm (b) 200 mm & the effect of load carrying capacity of GFRP (c) 100 mm (d) 200 mm

The above graph compares the ultimate load carrying capacity of the specimen when different types of confinement of Basalt FRP are applied as shown in Fig. 6(a-b). The ultimate load carrying capacity is high for BFDC and decreases for BFDL, BFSC and BFSL in that order. When compared with NSS, BFDC shows an increase of 25.83% in load carrying capacity, BFDL shows 16.19% increase, BFSC shows 13.33% increase and BFSL shows an increase of 10.31%. When compared with BFSC, BFDC shows an increase of 12.51% and BFDL shows a 5.88% increase over BFSL. Between BFSC and BFSL it is obtained that BFSC has 3.20% more capacity than BFSL and similarly BFDC has 9.64% increases over BFDL. On the whole it is observed that as the length of the specimen increases its load carrying capacity decreases irrespective of the type of wrapping.

5.4. Effect of single layer and double layers of Basalt and Glass fiber on ultimate strength

The comparison of the load carrying capacity of unwrapped specimen (NSS) with GFRP and BFRP is shown in Fig. 7(a). The BFSL produces maximum increase in ultimate load capacity; say an increase of 10.31% compared to the GFRP. The comparison of the load carrying capacity of double longitudinal wrappings specimen (NSS) with GFRP and BFRP is shown in Fig. 7(b). It shows the different FRP materials in comparison with NSS. The following results are evident. The increase is 13% for GFDL and it is 16.19% to BFDL. The observation shows that BFDC is better than the other two. Also this graph studies the effect of single circumferential wrappings of the FRP materials on the ultimate load carrying capacity when compared with NSS. As observed from the study we have the following conclusions. BFRP gives the maximum increase in load capacity (13.3%). GFRP gives the least increase in load capacity (6.5%). The effect of double circumferential wrapping of the three FRP materials on NSS is depicted in this Fig. 7(b). It can be observed that BFRP produces the maximum increase in load carrying capacity (25.83%), GFRP produces 20.8% increase. It is confirmed that the BFDC gives good load capacity.

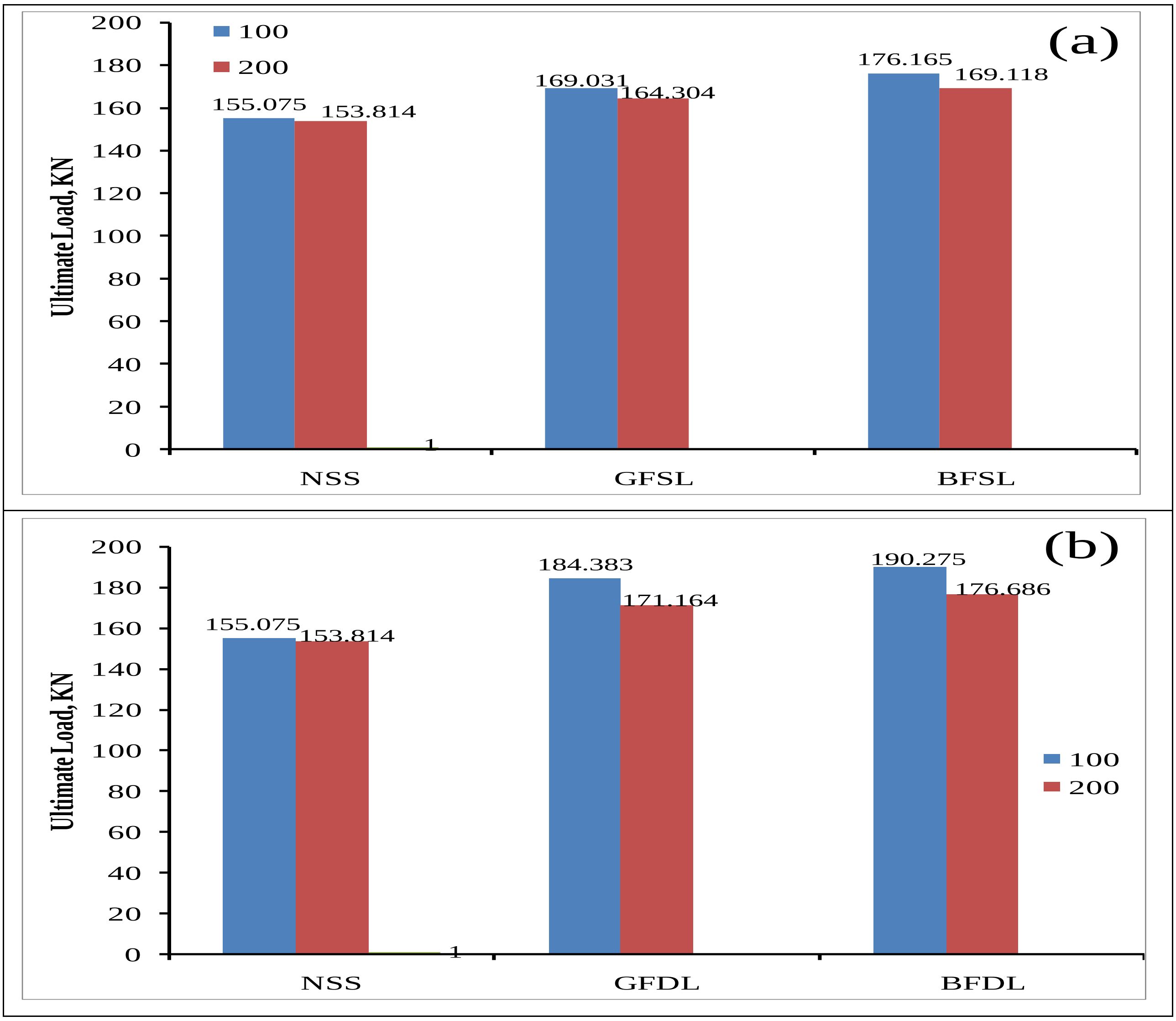


Fig. 6 Effect of ultimate load on different fibers

6. Conclusions

The following conclusions can be drawn from this experimental study.

1. There is a gradual decrease in ultimate compression load as the slenderness ratio of the specimen increase.
2. In general the load carrying capacity is increased by FRP wrapping.
3. Among the two different fibers included in this study BFRP increases the load carrying capacity when compared GFRP.
4. The load carrying capacity is more for circumferential double layer than the single layer.
5. In most cases buckling failure occurred at the bottom portion of the steel hollow sections similar to elephant foot buckling.
6. Ring buckling was also observed at the middle and top portion of the specimens at the ultimate load capacity.
7. Increasing load leads to rupture of the fiber and then crushing of fiber in all of the single layer wrapped specimens.

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