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Performance of Stiffened Slender Built up Steel I-Columns

M. E. Abou-Hashem El Dib, M. K. Swailem, M. M. Metwally, A. I. El Awady

***Abstract*—**The present work illustrates a parametric study for the effect of stiffeners on the performance of slender built up steel I-columns. To achieve the desired analysis, finite element technique is used to develop nonlinear three-dimensional models representing the investigated columns. The finite element program (ANSYS 13.0) is used as a calculation tool for the necessary nonlinear analysis. A validation of the obtained numerical results is achieved. The considered parameters in the study are the column slenderness ratio and the horizontal stiffener's dimensions as well as the number of stiffeners. The dimensions of the stiffeners considered in the analysis are the stiffener width and the stiffener thickness. Numerical results signify a considerable effect of stiffeners on the performance and failure load of slender built up steel I-columns.

***Keywords*—**Steel I-columns, local buckling, slender, stiffener, thin walled section.

I. Introduction

SLENDER steel columns (3 plates' elements) are used in a diversity of structural steel projects, due to their high strength to weight ratios. All plates composing columns may be subjected to compressive stresses which may cause local buckling in both flange(s) and web. This may occur also due to initial and geometrical imperfections during the fabrication process. In addition, global buckling of member may also happen. Many studies have been made during the past few decades on the slender steel columns with and without stiffeners to give better understanding for their behavior and their ultimate capacity. M. Anbarasu et al. [1] presented numerical investigations of intermediate length cold-formed steel compression members with and without stiffeners compressed between pin ends. Hong-Xia Shen. [2] illustrated numerical study for webbed rectangular section beam-columns. He was concluded that the developed finite element model can simulate the local-overall interaction buckling behaviors of the eccentrically loaded welded box-section compression members. Salem et al. [3] presented analytical study about the capacity of axially loaded thin-walled tapered I-columns with doubly symmetric sections. Another experimental research work was submitted by Elhussieny et al. [4] for testing five slender steel I-columns with different slenderness ratios with and without horizontal stiffeners. Analytical and numerical study was presented by Salem et al. [5] to investigate the behavior of bi-axially loaded slender I-section columns. Alinia et al. [6] also presented numerical study for slender webs in I-column girders having stocky flanges under the action of combined lateral and axial loads. Most of these research works considered the effect of using stiffeners on the column behavior without deliberation of the dimensions of stiffeners. In this paper, a parametric study is done to investigate the performance of stiffened-columns having different slenderness ratios. Also, the effect of using horizontal stiffeners with different numbers and dimensions on the load carrying capacity of the investigated columns is introduced. Several buckling modes for steel slender sections have been studied.

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II. Problem Modeling

A finite element technique is used to perform the required analysis. A model using a non-linear finite element program ANSYS V.13 [7] is developed to simulate a hinged-hinged support steel slender column. From the library of elements available in ANSYS, the shell element 181 is selected to use, because it gives good accuracy in the buckling problems. It is used for modeling flange, web plates and stiffeners. Solid 186 elements are used also to model end bearing plates. The mesh density is selected so that the elements aspect ratio is nearly equal to one. The column boundary conditions at supports are simulated to represent hinges where the DOFs to be constrained are Ux and Uz at two sides and the load is applied from upper and lower plates in opposite directions. Geometric imperfections are applied to the analyzed column by solving the model as eigenvalue buckling solution in finite element program. Two cases are considered for material non-linearity, the perfect linear elastic and the multi linear elastic-plastic. The steel elastic modulus is considered to be $2.0x10^5$ MPa and Poisson's ratio is assumed equal to 0.3. The columns are assumed free to buckle about the minor axis.

To validate the numerical results of the developed model, a comparison of these results against an experimental previous work results is achieved. The previous experimental work used in validation was conducted on five slender steel I-columns [4]. A good adaptation of the present work results and the previous experimental results is achieved as illustrated in Table I.

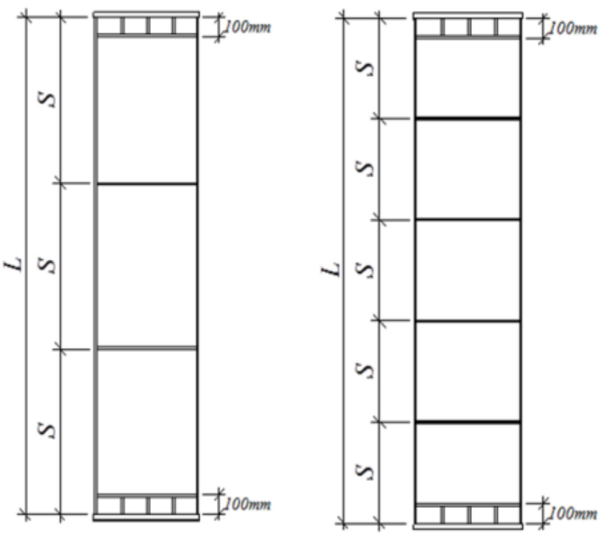
TABLE I
FINITE ELEMENT VS EXPERIMENTAL PREVIOUS RESULTS [4]

SP-No	Stiff.	d_w/t_w	$b_f/2t_f$	V_{exp}(KN)	$V_{F.E}$ (KN)	$V_{F.E}/V_{exp}$
C-0-1-A	no	150	20.4	505	508	1.006
C-0-1-B	no	150	20.4	560	564	1.007
C-0-2	no	150	20.4	362	374.5	1.034
C-1-2	2 stiff	150	20.4	415	419	1.01
C-2-2	4 stiff	150	20.4	457	454	0.993

b_f= width of flange, d_w= depth of web, t_f= thickness of flange, t_w= thickness of web, V_{exp}= experimental failure load, $V_{F.E}$=finite element failure load, $b_f/2t_f$= half flange width to thickness ratio, d_w/t_w= web depth to thickness ratio.

III. PARAMETRIC STUDY

This study is carried out to investigate the effect of horizontal stiffeners on the failure load of columns shown in Fig. 1. The effect of existence of horizontal stiffeners, their number along the column length and their dimensions are considered in the study. The analysis is performed for different column slenderness ratios (L/r). The presented parametric study, is done for a column having web-depth (d_w= 570 mm), web thickness (t_w= 3.8 mm), flange width (b_f = 150 mm) and flange thickness (t_f= 3.8 mm). The studied parameters and their range of variation are illustrated in Table II. The column sections are chosen to be a slender section with d_w/t_w =150 and $b_f/2t_f$ = 19.74. Figs. 2-4 show the buckling modes of columns with L/r = 62.5, 100 and 150 respectively. The buckling happened in short columns with L/r=62.5 is local buckling but a global buckling is occurred in long columns with L/r=100 and 150.



(a) Specimens with two Stiffeners

(b) Specimens with four Stiffeners

Fig. 1 Studied columns

IV. RESULTS AND DISCUSSIONS

The results of analysis are shown in Figs. 5-41. The effect of the horizontal stiffener's thickness (t_s), stiffener's number (NS) and stiffener's width (b_s) as well as the column slenderness ratio (L/r) on the column failure load ratio (P_F/P_S) are illustrated in the following sections respectively, where: P_F is failure load of stiffened column and P_S is failure load of un-stiffened column.

Fig. 2 Example of local buckling in stiffened slender plate column with L/r =62.5

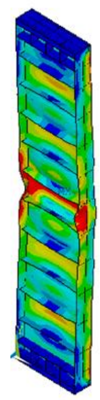


Fig. 3 Example of global buckling in stiffened slender plate column with L/r =100

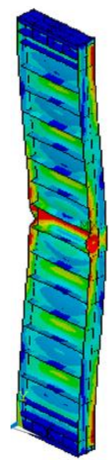


Fig. 4 Example of global buckling in stiffened slender plate column with L/r =150

A. Effect of Horizontal Stiffener's Thickness (t_s)

Figs. 5-7 show charts of the horizontal stiffener's thickness (t_s) versus the column failure load ratio (P_F/P_S) for different number of horizontal stiffeners (NS) and different aspect ratios (S/d_w). The column slenderness ratio is (L/r = 62.5) for the three charts. Figs. 8-11 and 12-15 illustrate the same effect but for slenderness ratios equal to (L/r =100) and (L/r =150) respectively. It is clear from these curves that, as the thickness of the horizontal stiffener increases, the column failure load increases. The charts show that the load capacity of the stiffened column is more than the load capacity of the un-stiffened ones reaching a ratio of 38% for the case of short column with (L/r = 62.5 & S/d_w = 0.416), 33% for the case of long column with (L/r =100 & S/d_w = 0.416) and 22% for the case of long column with (L/r =150 & S/d_w = 0.416). It is to be noted that the slenderness ratio is the same for these three cases.

TABLE II
CONSIDERED PARAMETERS

No.	Parameters	Status	Values	Notes
1	Column slenderness ratio (L/r)	variable	62.5, 100, 150	L= 1660, 2660 & 3990 mm
2	Horizontal stiffener's thickness (t_s)	variable	3, 4, 5,6 mm	-
3	Horizontal stiffener's width (b_s)	variable	55,65,75 mm	-
4	Number of horizontal stiffeners(NS)	variable	Case 1 NS=0	No Hl. stiffener
			Case 2 NS =2	Two stiffeners at one third of column height
			Case 3 NS=4	Four stiffeners at one fifth of column height
			Case 4 NS=6	six stiffeners at one seventh of column height
			Case 5 NS=10	ten stiffeners at 1/11 of column height for L/r=100
			Case 6 NS=16	sixteen stiffeners at 1/17 of column height for L/r=150

L= column length, r= radius of gyration.

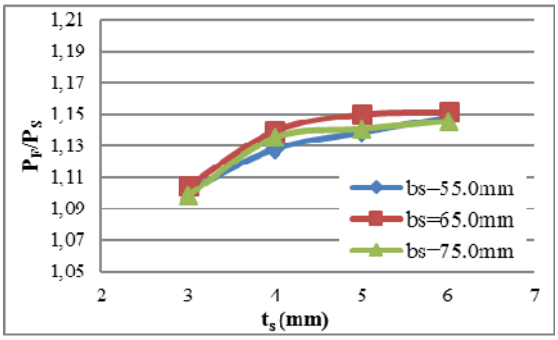


Fig. 5 Stiffener Thickness Vs Column Failure Load Ratio (L/r =62.5, NS=2 & S/d_w = 0.97)

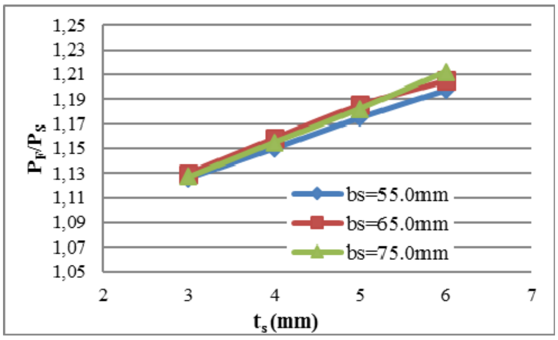


Fig. 6 Stiffener Thickness Vs Column Failure Load Ratio (L/r =62.5, NS=4 & S/d_w= 0.58)

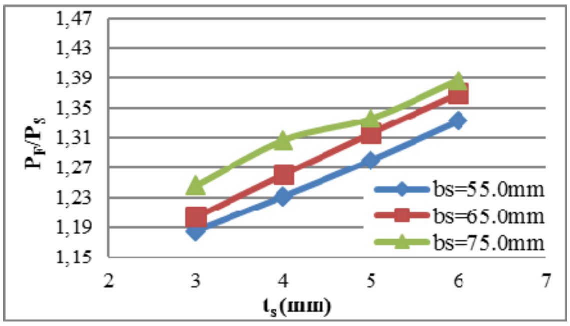


Fig. 7 Stiffener Thickness Vs Column Failure Load Ratio (L/r =62.5, NS= 6 & S/d_w = 0.416)

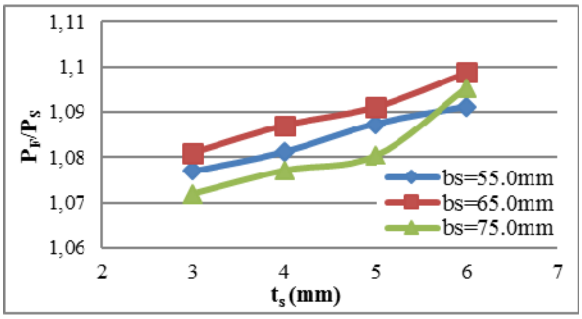


Fig. 8 Stiffener Thickness Vs Column Failure Load Ratio (L/r =100, NS=2 & S/d_w = 1.56)

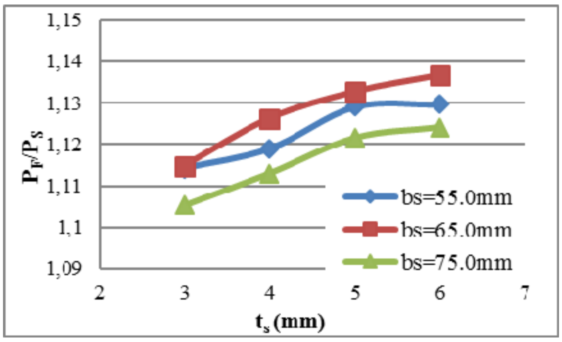


Fig. 9 Stiffener Thickness Vs Column Failure Load Ratio (L/r =100, NS=4 & S/d_w = 0.93)

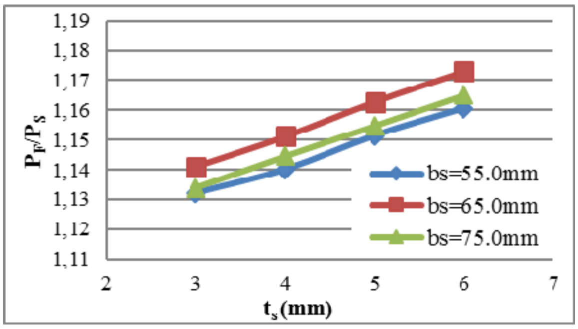


Fig. 10 Stiffener Thickness Vs Column Failure Load Ratio (L/r =100, NS=6 & S/d_w = 0.67)

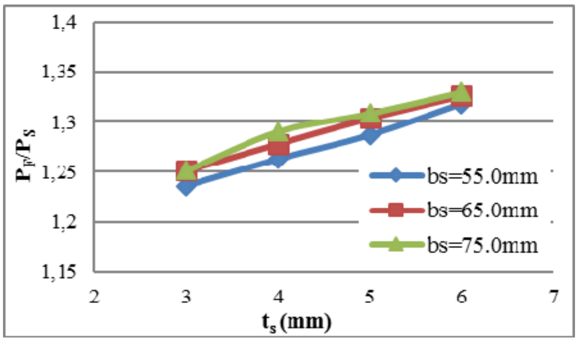


Fig. 11 Stiffener Thickness Vs Column Failure Load Ratio (L/r =100, NS=10 & S/d_w = 0.416)

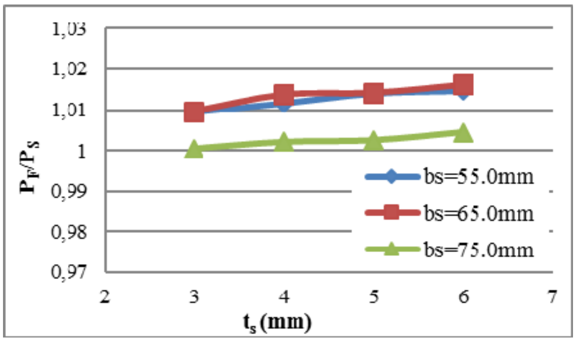


Fig. 12 Stiffener Thickness Vs Column Failure Load Ratio (L/r =150, NS=2 & S/d_w = 2.33)

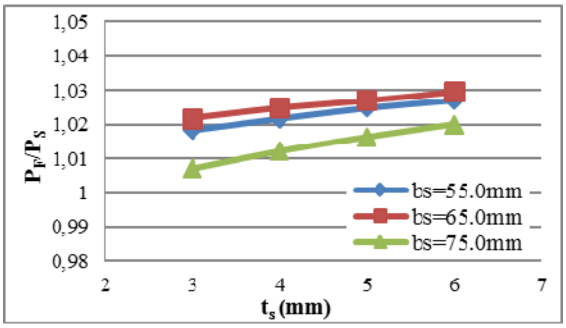


Fig. 13 Stiffener Thickness Vs Column Failure Load Ratio (L/r =150, NS=4 & S/d_w = 1.4)

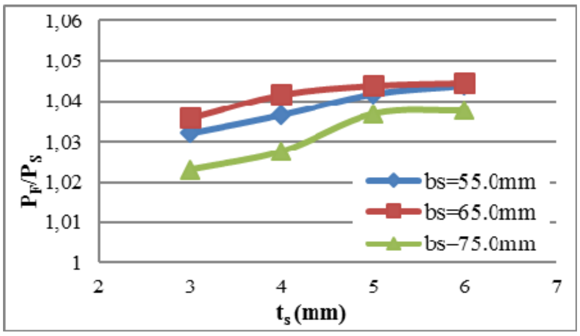


Fig. 14 Stiffener Thickness Vs Column Failure Load Ratio (L/r =150, NS=6 & S/d_w = 1.0)

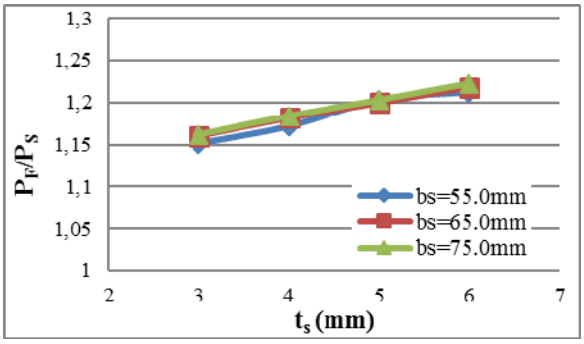


Fig. 15 Stiffener Thickness Vs Column Failure Load Ratio (L/r =150, NS=16 & S/d_w = 0.416)

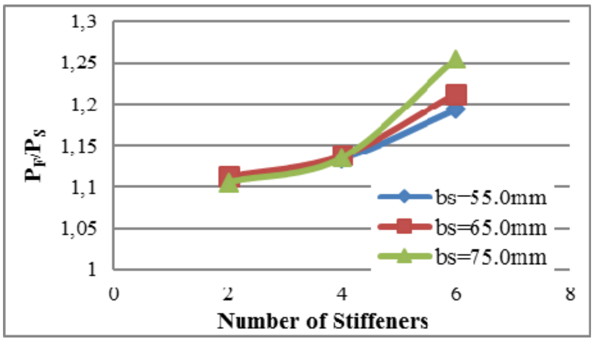


Fig. 16 Number of Stiffeners Vs Column Failure Load Ratio (L/r =62.5 & ts=3.0 mm)

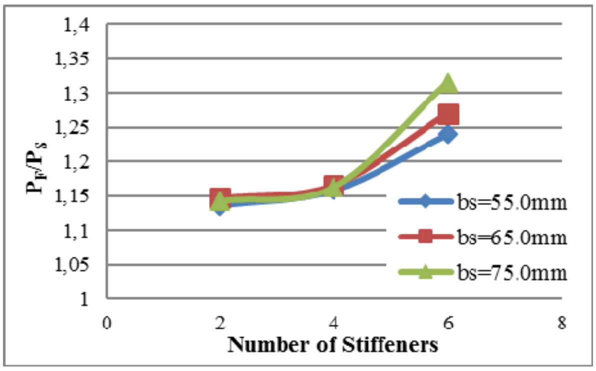


Fig. 17 Number of Stiffeners Vs Column Failure Load Ratio (L/r =62.5 & ts=4.0 mm)

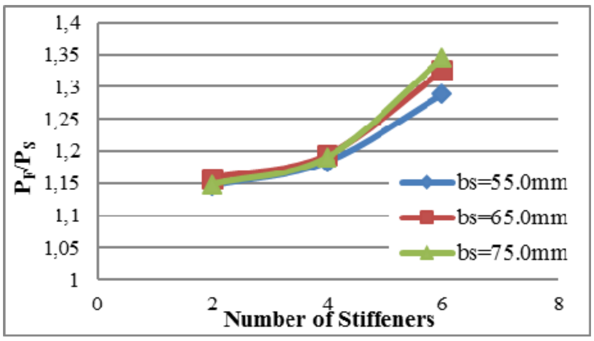


Fig. 18 Number of Stiffeners Vs Column Failure Load Ratio (L/r =62.5 & ts=5.0 mm)

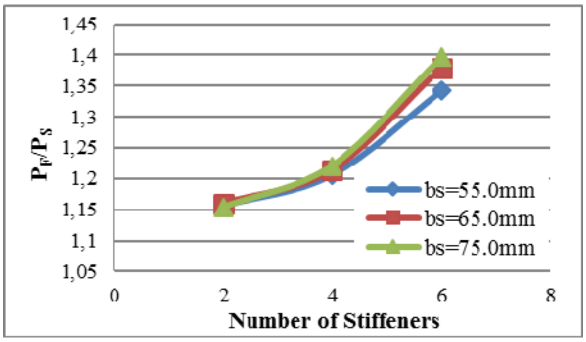


Fig. 19 Number of Stiffeners Vs Column Failure Load Ratio (L/r=62.5 & ts=6.0 mm)

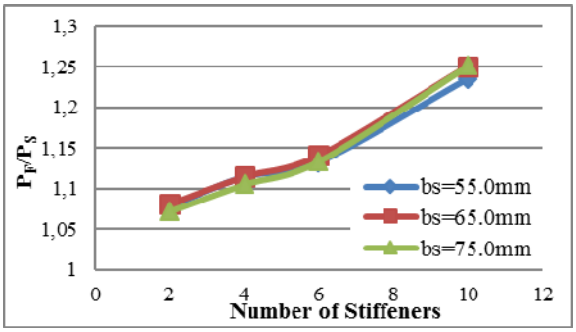


Fig. 20 Number of Stiffeners Vs Column Failure Load Ratio (L/r=100 & ts=3.0 mm)

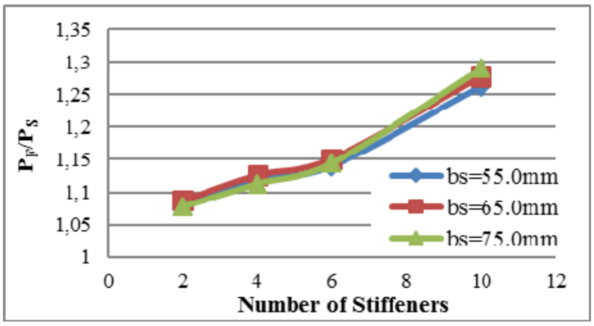


Fig. 21 Number of Stiffeners Vs Column Failure Load Ratio (L/r=100 & ts=4.0 mm)

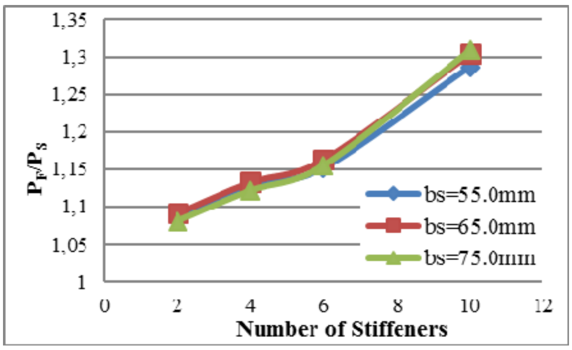


Fig. 22 Number of Stiffeners Vs Column Failure Load Ratio (L/r=100 & t_s=5.0 mm)

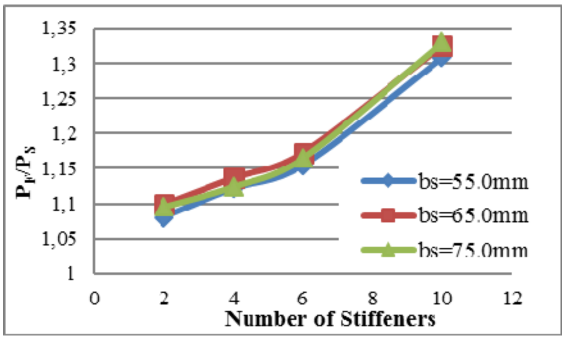


Fig. 23 Number of Stiffeners Vs Column Failure Load Ratio (L/r=100 & t_s=6.0 mm)

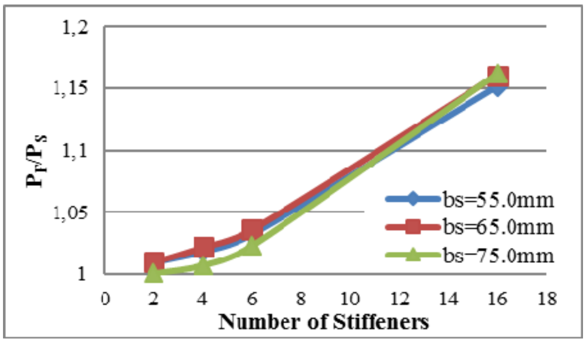


Fig. 24 Number of Stiffeners Vs Column Failure Load Ratio (L/r=150 & t_s=3.0 mm)

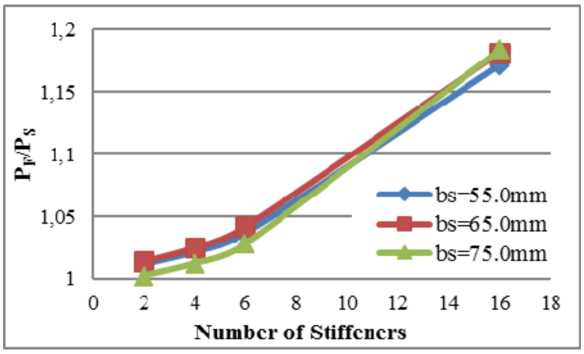


Fig. 25 Number of Stiffeners Vs Column Failure Load Ratio (L/r=150 & t_s=4.0 mm)

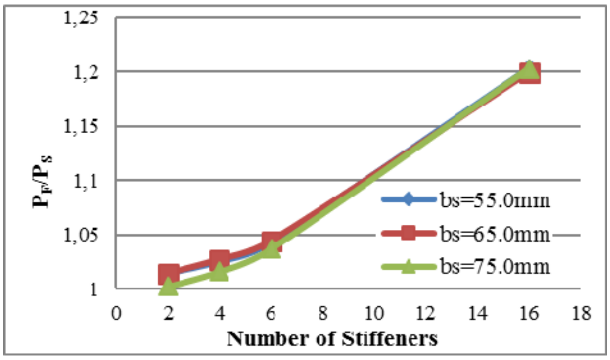


Fig. 26 Number of Stiffeners Vs Column Failure Load Ratio (L/r=150 & t_s=5.0 mm)

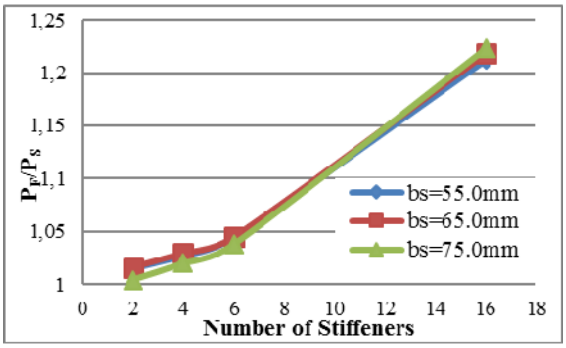


Fig. 27 Number of Stiffeners Vs Column Failure Load Ratio (L/r=150 & t_s=6.0 mm)

A. Effect of Horizontal Stiffener's Number (NS)

Figs. 16-19 present the horizontal stiffener's number (NS) versus the column failure load ratio (P_F/P_S) for column slenderness ratio (L/r=62.5) and different stiffener's thicknesses. Figs. 20-23 and 24-27 illustrate the same effect but for slenderness ratios equal to (L/r=100) and (L/r=150) respectively. It is clear from these curves that, as the number of the horizontal stiffener increases, the column failure load increases. The charts show that the load capacity of the stiffened columns is more than the load capacity of the un-stiffened ones reaching a ratio of 38% for short column with (L/r=62.5& ts=6.0 mm), 33% for long column with (L/r=100 & ts=6.0mm) and 22% for long column with (L/r=150 & ts=6.0mm). It is to be noted that the aspect ratio is the same for these three cases (S/d_w = 0.416). This concludes that the effect of horizontal stiffeners on the short columns is more than on the long columns.

B. Effect of Horizontal Stiffener's Width (b_s)

This section deals with the effect of the width of the horizontal stiffener (b_s) on the failure load of the slender steel I-Columns.

Figs. 28-30 show the horizontal stiffener's width (b_s) against the column failure load ratio (P_F/P_S) with different horizontal stiffener's thickness (t_s). These charts for (L/r=62.5) and for different number of horizontal stiffeners (NS) which gives different aspect ratios (s/d_w). Figs. 31-34 and 35-38 illustrate the same charts for (L/r=100) and (L/r=150) respectively. These charts illustrate that, the horizontal stiffeners' width (b_s=65 mm) gives the maximum failure loads for sections with big and medium aspect ratios. For the smallest aspect ratio S/d_w= 0.417 (big number of stiffeners), the maximum failure load occurs at (b_s=75 mm). In Fig. 38, for example, the increasing in failure load at bs= 65 mm reaches to 23% in case of (S/d_w=0.416 & ts=6 mm) but at bs=55 mm it reaches to 22%. In general, the stiffeners' width has a little effect on the column load capacity.

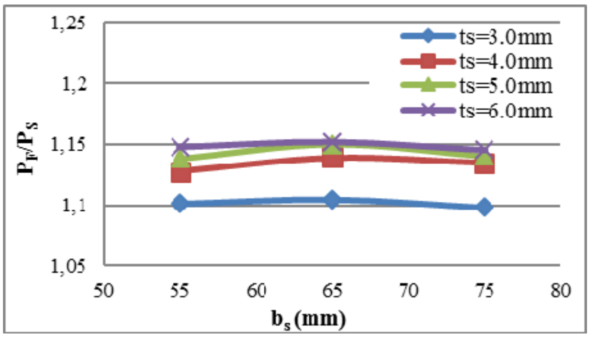


Fig. 28 Stiffener Width Vs Column Failure Load Ratio (L/r=62.5, NS=2 & S/d_w = 0.97)

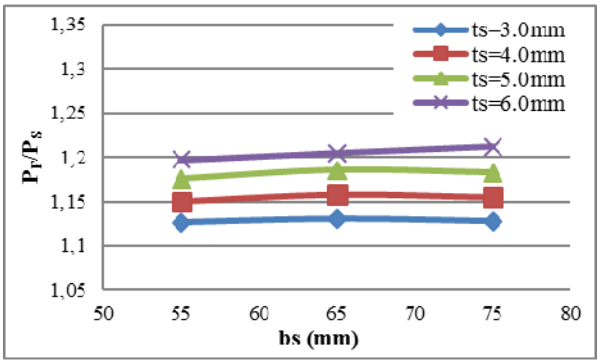


Fig. 29 Stiffener Width Vs Column Failure Load Ratio (L/r=62.5, NS=4 & S/d_w = 0.58)

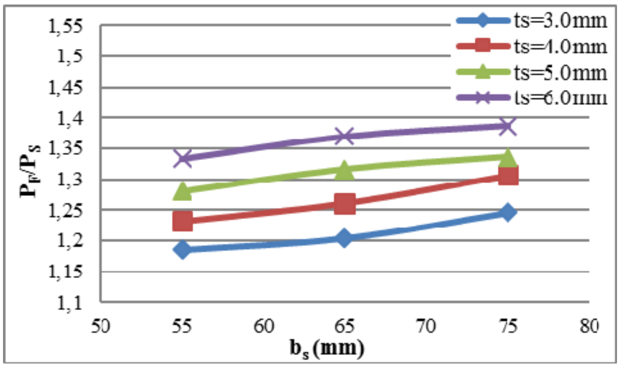


Fig. 30 Stiffener Width Vs Column Failure Load Ratio (L/r=62.5, NS=6 & S/d_w = 0.416)

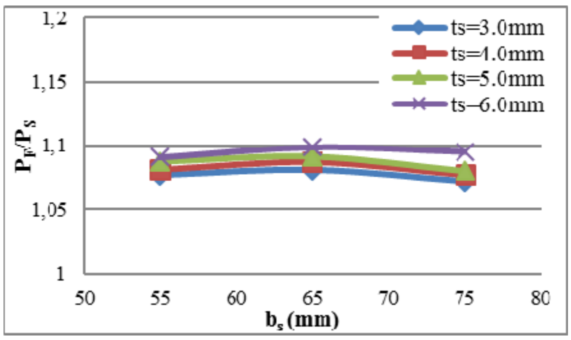


Fig. 31 Stiffener Width Vs Column Failure Load Ratio (L/r=100, NS=2 & S/d_w = 1.56)

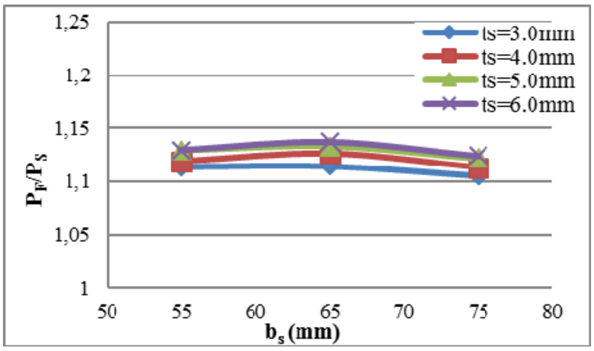


Fig. 32 Stiffener Width Vs Column Failure Load Ratio (L/r=100, NS=4 & S/d_w = 0.93)

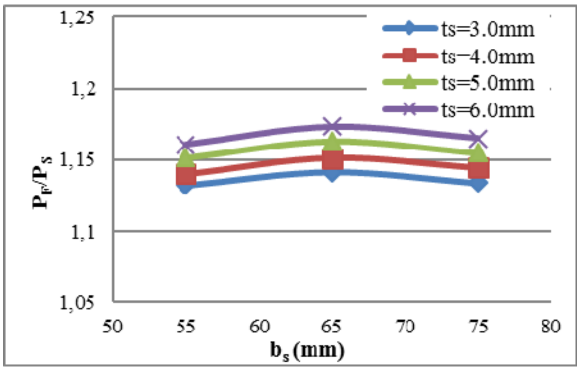


Fig. 33 Stiffener Width Vs Column Failure Load Ratio (L/r=100, NS=6 & S/d_w = 0.67)

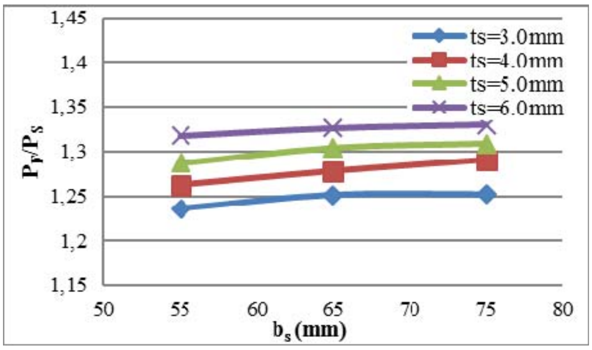


Fig. 34 Stiffener Width Vs Column Failure Load Ratio (L/r=100, NS=10 & S/d_w = 0.417)

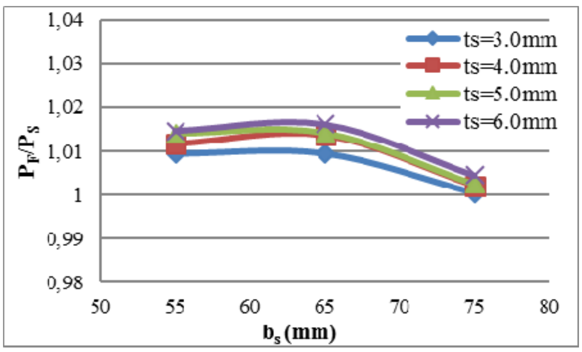


Fig. 35 Stiffener Width Vs Column Failure Load Ratio (L/r=150, NS=2 & S/d_w = 2.33)

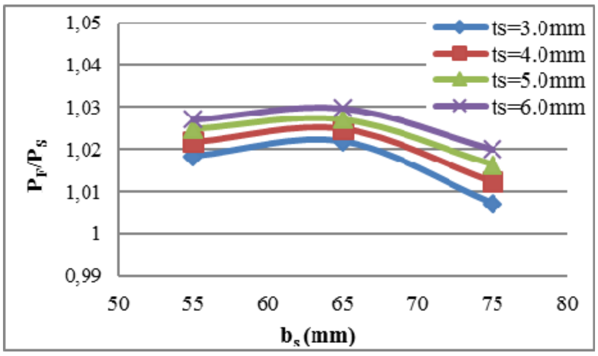


Fig. 36 Stiffener Width Vs Column Failure Load Ratio (L/r=150, NS=4 & S/d_w = 1.4)

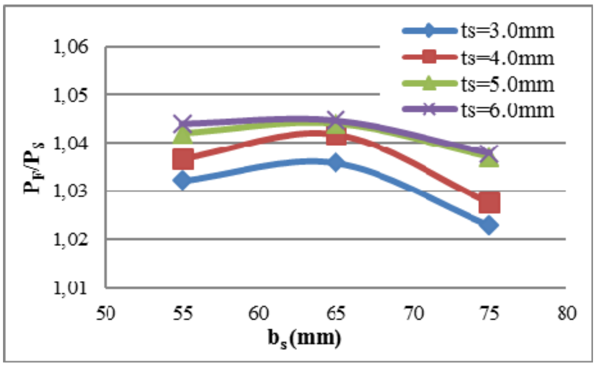


Fig. 37 Stiffener Width Vs Column Failure Load Ratio (L/r=150, NS=6 & S/d_w = 1.0)

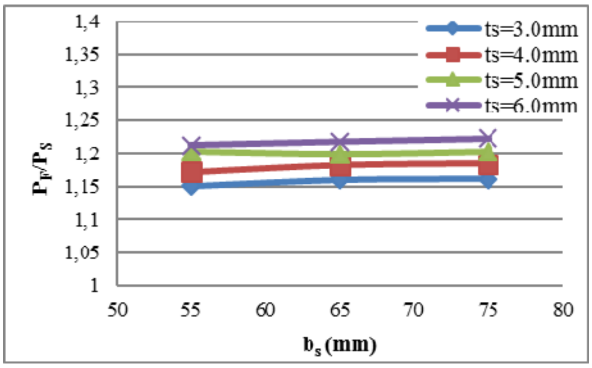


Fig. 38 Stiffener Width Vs Column Failure Load Ratio (L/r=150, NS=16 & S/d_w = 0.417)

C. Effect of Column Slenderness Ratio (L/r)

Figs. 39-41 show the effect of column slenderness ratio (L/r) on the column failure load ratio for (S/d_w=0.416) and for bs=55, 65 and 75 respectively. The charts indicate that, the column slenderness ratio (L/r=62.5) gives maximum column failure loads for bigger stiffener thicknesses (t_s). For the smallest stiffener thickness (t_s), the maximum column load capacity occurs for slenderness ratio (L/r=100). The minimum failure load occurs at (L/r=150). The increasing in failure load at (L/r= 62.5) reaches to 38% in case of (S/d_w=0.416 and b_s=75mm) but at (L/r= 150) it reaches to 22% for the same case.

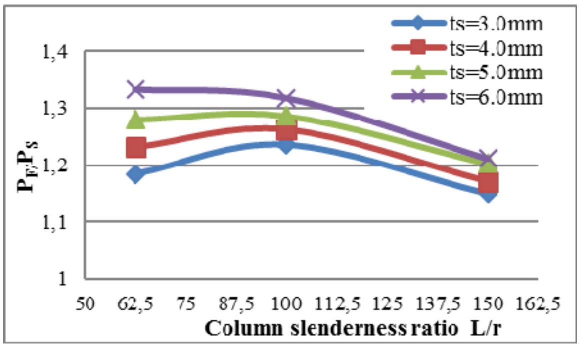


Fig. 39 Slenderness Ratio Vs Column Failure Load Ratio (S/d_w= 0.416 & b_s=55mm)

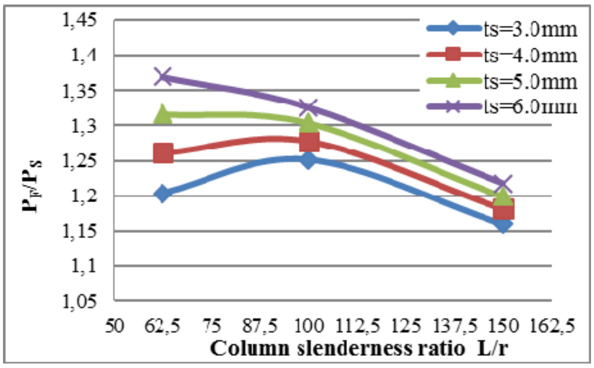


Fig. 40 Slenderness Ratio Vs Column Failure Load Ratio (S/d_w= 0.416 & b_s=65mm)

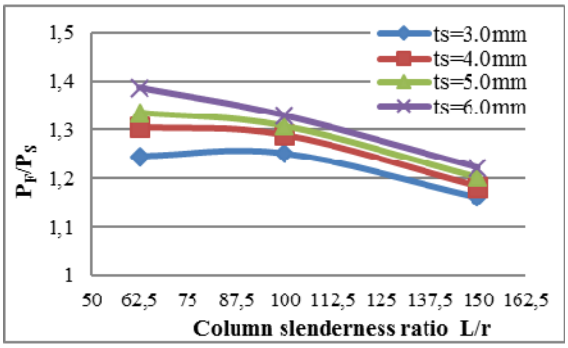


Fig. 41 Slenderness Ratio Vs Column Failure Load Ratio (S/d_w= 0.416 & b_s=75mm)

V. Conclusions

The main conclusions drawn from the present work are:

(1) The failure mode of the short columns with slenderness ratio (L/r=62.5) is local buckling. In long columns with slenderness ratio (L/r=100) and (L/r=150), the failure mode is global buckling.

(2) Increasing the thickness of the horizontal stiffeners leads to increasing the column failure load. For changing the thickness from 3 mm to 6mm, the column failure load increases with a ratio reaches to 17 %.

(3) Increasing the number of web horizontal stiffeners leads to increasing the column failure load with a ratio reaches to 25%.

(4) The width of stiffeners has insignificant effect on the column failure load.

(5) The effect of horizontal stiffeners on the short columns is more significant than on the long columns with the same aspect ratios. For the aspect ratio (S/L=0.416) the columns with slenderness ratios (L/r=62.5) and (L/r=100) have a close failure load, but the long columns with (L/r=150) give less failure loads.

(6) The load capacity of the stiffened columns is more than the load capacity of the un-stiffened ones reaching a ratio of 38% for short columns with (L/r=62.5) and 22% for long columns with (L/r =150) for the same aspect ratios.

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References

[1] M. Anbarasu and S. Sukumar."Finite Element-Based Investigation on Performance of Intermediate Length Thin-Walled Columns with Lateral Stiffeners" Arab J Sci Eng, (2014).
[2] Hong-Xia Shen. "Behavior of High-Strength Steel Welded Rectangular Section Beam–Columns with Slender Webs" Journal of Constructional Steel Research, vol. 59, pp. 27–45, (2003).
[3] A. H. Salem, M. ElAghoury, M. N. Fayed and I. M. ElAghoury. "Ultimate Capacity of Axially Loaded Thin-Walled Tapered Columns with Doubly Symmetric Sections" Thin-Walled Structures, vol. 47, pp. 931–941, (2009).
[4] O. M. ELhussieny, E.B. Matter, S. A. A. Mustafa and A.G. Alaaser, "Behavior of Slender Built up Steel I-Column", The Egyption International Journal of Engineering Sciences and Technology,(2014).
[5] A.H. Salem, M. El Aghoury, F.F. El Dib and M.T. Hanna. "Post Local Buckling Strength of Bi-axially Loaded Slender I-Section Columns" Thin Walled Structure, vol. 43, pp. 1003-1019, (2005).
[6] M.M. Alinia and A. Dibaie "Buckling and Failure Characteristics of Slender Web I-Column Girders under Interactive Compression and Shear", Comp. Meth. Civil Eng, vol. 3, pp. 15-34, (2012).
[7] ANSYS Release 13.0 Documentation. ANSYS Inc., (2010).