A Finite Element Study of the Behaviour of Cold— Formed Thin— Opened Walled Steel Column

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Abstract— Numerical modelling of the behaviour of cold–formed thin–walled steel column with opening is presented in present paper. ANSYS software was utilized to simulate the behaviour of cold-formed steel column under static load. Two groups of steel column were analyzed. The first group has box section while the other has channel section. Materials and geometric nonlinearity were adopted in this study. An experimental data were used for this reason. A reasonable agreement by means of load and axial displacement between experimental and ANSYS results was obtained.Furthermore, the effects of column length, location of opening, and stiffener location on behaviour of cold formed steel columns are investigated. It is found that, stiffeners have significant effect when they are used at ends of the column rather than they exit around the opening. Increasing length of the column clearly increases the axial displacement and slightly decreases the load capacity.

Index term— cold-formed, thin-walled, steel column, finite element analysis, opening of web, stiffener

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1 INTRUDACTION

Cold-formed steel member are less weight and thinner than hot–rolled sections. They can be used to produce and forming of almost any shape and section to any desired geometry and length [1]. Openings in webs of cold formed steel columns used to facilitate sanitary, electrical, and mechanical works. These openings should have size, shape and location, as far as possible; have no effect on the structural strength requirements. The main disadvantage of opening in cold-formed steel sections is the local buckling due to high width of open to thickness ratios. Recent codes of practice and standards have suggested simplified methods and processes for the design of steel members with perforation [2, 3]. However, numerical and experimental researches have been published to investigate the effect of openings on the load capacity of cold-formed steel (CFS) members subjected to monotonic axial load [4-6]. An extensive parametric study have helped to enhance the understanding the behaviour and buckling of wide range of opening web sections under different combinations of axial compressive load and bending moment [7-8].

2 NUMERICAL SIMULATION AND ANALYSIS

The aims of current paper are to build a numerical model to investigate the effect of thelength ofcolumn, opening location, and stiffener using on the behaviour of steel columns with cold formed sections thin walled CFS. Two groups are will be analyzed of ten small-scale steel columns having box and channel section. The numerical model validity will be verified with experimental which obtained by Al-jalad and Al-thairy [9].

2.1Specimens Description and Test Procedure

Twenty small-scale specimens of cold-formed thin-walled steel column which tested by Al-Jallad and Al-Thairy [9] have been analyzed in the present study. Ten of them have a box section while the other have a channel sections. Figure 1 and 2 and table 2 illustrate the dimensions, web opening locations and description of specimens. The material properties of the steel columns and the tensile test results are shown in Table 1. All specimens were subjected to an increasing monotonic static load up to failure, which is specified by the reloading of the test machine gages [9].

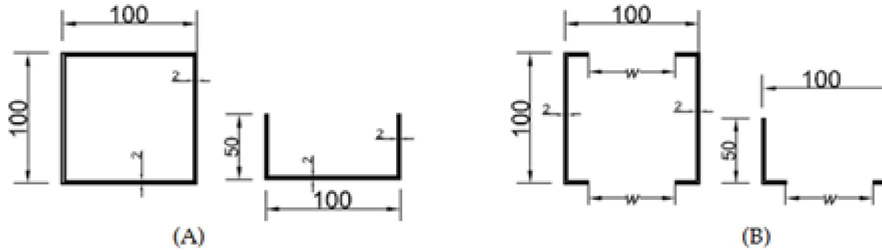

Figure 1: Cross sectional dimensions of the steel column sections (A); and typical sections at opening location (B) [9

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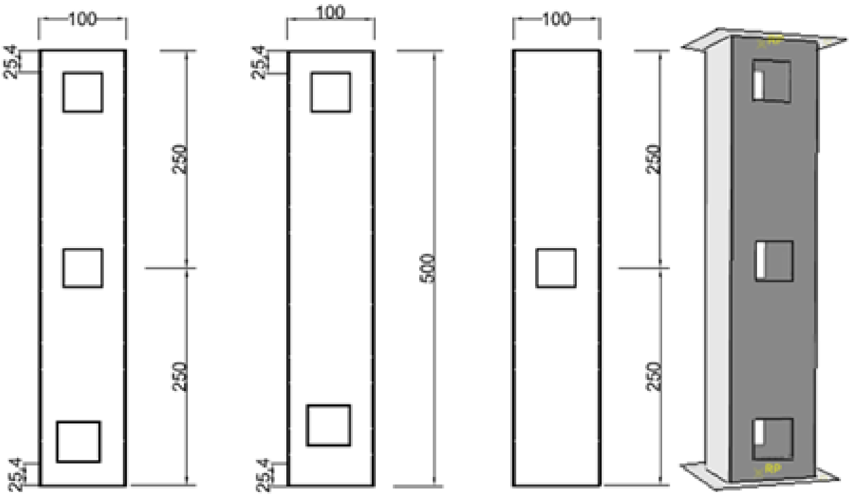


Figure 2: Typical distribution of web openings along the steel columns length for all opening shapes [9].

TABLE 1

MECHANICAL PROPERTIES OF THE STEEL MATERIAL FROM THE UNIAXIAL TENSILE TEST[9].

Steel coupon Thickness t (mm)	Steel coupon width w (mm)	Steel coupon length L (mm)	*fy* (N/mm2)	E(N/mm2)	Fu(N/mm2)	ε_u
2	15	200	420	201×103	534	0.107

Where fy, E, Fu and εu are the yielding stress, the modulus of elasticity, the ultimate tensile stress and ultimate tensile strain of the steel material respectively.

TABLE 2

DIMENSIONS AND PROPERTIES OF THE STEEL COLUMN SPECIMENS WITH WEB OPENING DETAILS[9]

columns designations	Cross section shape	Cross section dimensions (W×H×t)(mm)	Opening shapes	Opening dimensions (w×h) or d (mm)	(opening width/section width) (w/W)	Number of web openings
CP	HRS*	100×100×2	Reference	NA	NA	NA
C1	HRS	100×100×2	Square	44.3×44.3	0.443	1
C2	HRS	100×100×2	Square	44.3×44.3	0.443	2
C3	HRS	100×100×2	Square	44.3×44.3	0.443	3
C4	HRS	100×100×2	Rectangular	65×30.2	0.65	1
C5	HRS	100×100×2	Rectangular	65×30.2	0.65	2
C6	HRS	100×100×2	Rectangular	65×30.2	0.65	3
C7	HRS	100×100×2	Circular	50	0.5	1
C8	HRS	100×100×2	Circular	50	0.5	2
C9	HRS	100×100×2	Circular	50	0.5	3
UP	C**	100×50×2	Reference	NA	NA	NA
U1	C	100×50×2	Square	44.3×44.3	0.443	1
U2	C	100×50×2	Square	44.3×44.3	0.443	2
U3	C	100×50×2	Square	44.3×44.3	0.443	3

U4	C	100×50×2	Rectangular	65×30.2	0.65	1
U5	C	100×50×2	Rectangular	65×30.2	0.65	2
U6	C	100×50×2	Rectangular	65×30.2	0.65	3
U7	C	100×50×2	Circular	50	0.5	1
U8	C	100×50×2	Circular	50	0.5	2
U9	C	100×50×2	Circular	50	0.5	3

** Hollow rectangular or box section*

*** Channel section*

2.2 Finite Element Modeling of Specimen

A Finite Element Analysis (FEA) is commonly used now to analyze of different structural problems. For present problem, ANSYS 15 (ANSYS 2014) software is used to simulate the behaviour of the cold-formed steel column under axial compression. Shell elements are often used to model thin webs members such as cold–formed thin–walled sections. So, SHELL181, from Ansys element library, was also adopted. This element have four nodes with three degrees of freedom per node. So it capable to solve three-dimensional problems. It is also suitable for linear, large strain, and/ or large rotation problems [10]. A mesh is generated by defining nodes and connecting them to define the elements. Finite element model details with mesh size and boundary conditions are explained in Figure 3.

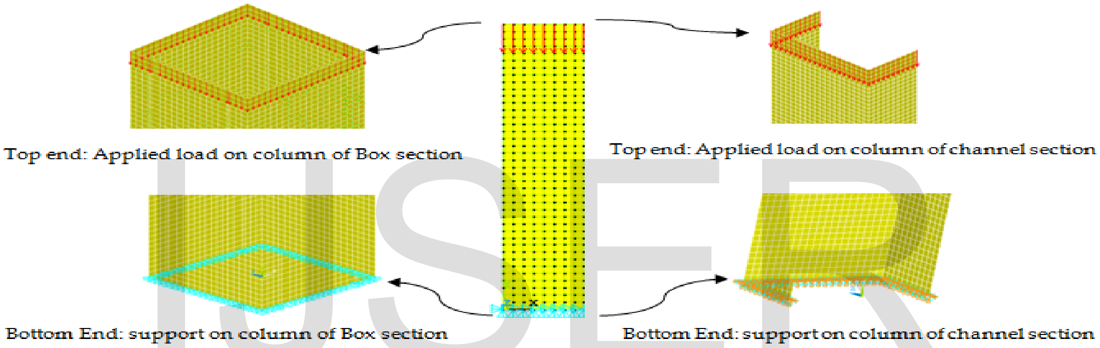


Figure 3: Detailed with mesh size and boundary conditions for box and channel section [10]

2.3Verification Analysis

An appropriate numerical model is established to precisely simulate the behavior of cold–formed thin–walled steel column. It is based on the finite-element package ANSYS 15. Two-section type of specimen (box and channel section) with different applications such as number and shape of web opening on the axial compressive strength of steel columns are investigated. The numerical predictions are compared with the available test data.

The results accessible in the following are set in terms of load-axial displacement relationships. An inspection of the finite element results shows an excellent agreement between the numerical and experimental results. This agreement continue up to experimental failure load. Then the theoretical load increase pregnancy continues until the failure, which is larger than the experimental values. This may be due to that the experimental tests are pausing when reloading in the test machine as it is indicated by Al-Jallad and Al-Thairy. At this level load recorded by test machine assumed as failure load by authors [9]. While, numerical failure load is assumed if one of the following was occurred:

- An instability in the structure which recorded either by high displacement in one or more nodes or high strain in some elements,
- The stresses exceed the ultimate limit,
- Convergence could not be obtained.

These conditions show failure load higher than those obtained from experimental tests. Table 3 shows failure load and axial displacement for experimental and numerical tests for specimens C4, C5, C6, U4, U5, and U6.

TABLE 3

FAILURE LOAD AND ITS AXIAL DISPLACEMENT FOR EXPERIMENTAL AND NUMERICAL TESTS.

Specimen Description	Experimental results [9]		Numerical result		Ratio of axial displacement at experimental failure load*
	Failure	Axial	Failure	Axial	

	load	displacement	load	displacement	
C4	165	2.48	277	8.19	0.94
C5	163	2.49	257	8.38	0.97
C6	160	2.3	161.5	10.39	1.12
U4	76	1.9	116	12.34	1.09
U5	71	1.8	96.5	5.55	1.01
U6	70	1.9	94.375	5.56	0.94

* *(Numerical axial displacement divided by experimental axial displacement) at the experimental failure load.*

The experimental and numerical Load-axial displacement curves obtained for the tested steel columns are shown in Figures 4-13 below.Experimental failure load will be adopted in the ANSYS to show the amplitude of convergence between experimental and theoretical behaviour.

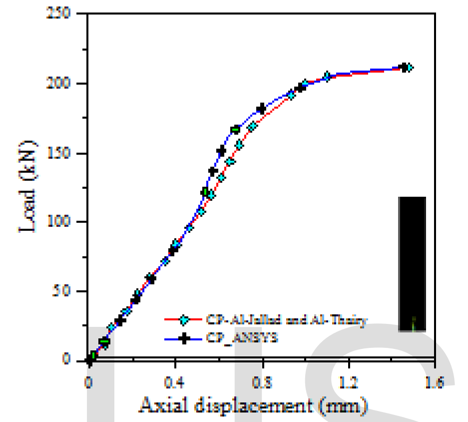


Figure 4: Numerical and experimental Load-axial displacement curves for specimen CP.

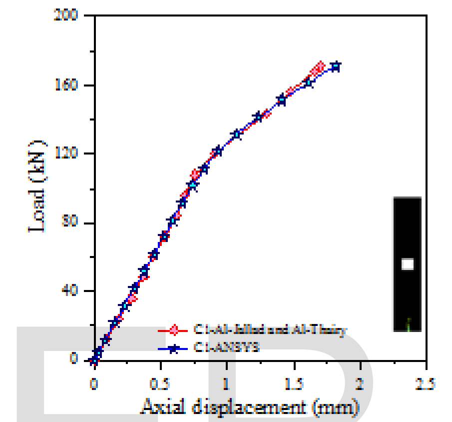


Figure 5: Numerical and experimental Load-axial displacement curves for specimen C1.

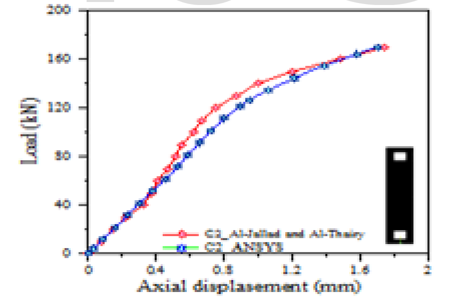


Figure 6: Numerical and experimental Load-axial displacement curves for specimen C2

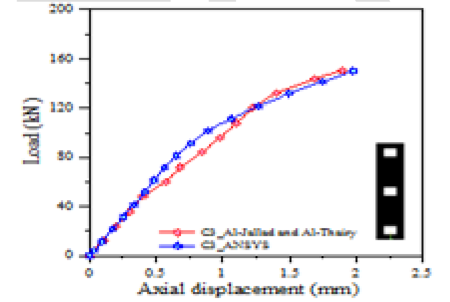


Figure 7: Numerical and experimental Load-axial displacement curves for specimen C3

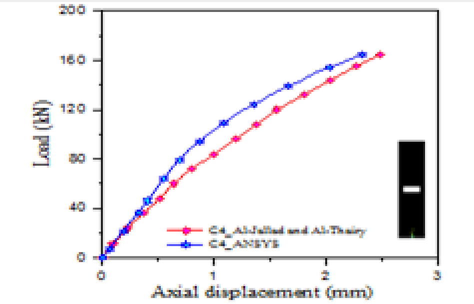


Figure 8: Numerical and experimental Load-axial displacement curves for specimen C4

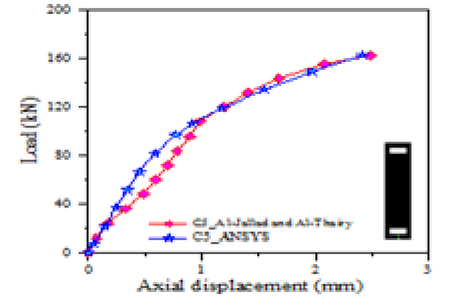


Figure 9: Numerical and experimental Load-axial displacement curves for specimen C5.

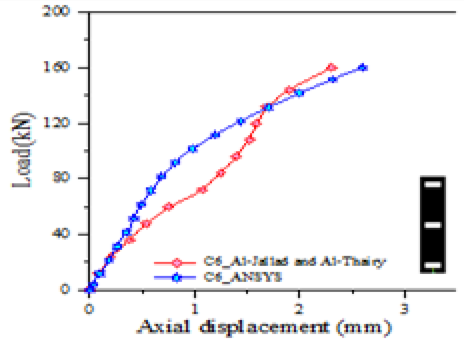


Figure 10: Numerical and experimental Load-axial displacement curves for specimen C6.

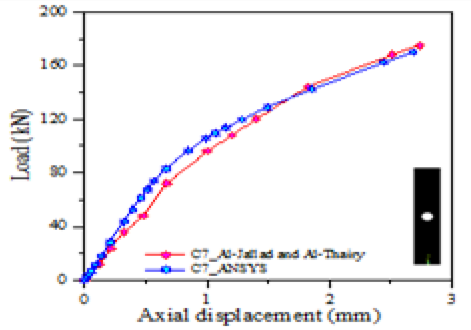


Figure 11: Numerical and experimental Load-axial displacement curves for specimen C7.

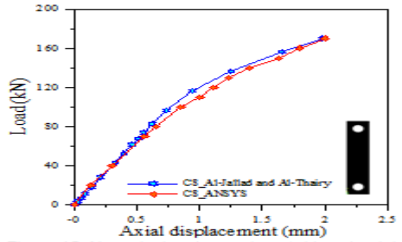


Figure 12: Numerical and experimental Load-axial displacement curves for specimen C8.

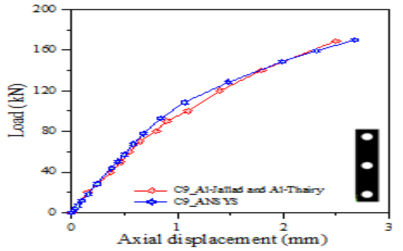


Figure 13: Numerical and experimental Load-axial displacement curves for specimen C9.

For the channel specimens, Figures 14-23 appear a good agreement between finite-element solution and experimental data for load-axial displacement as those obtained in box section.

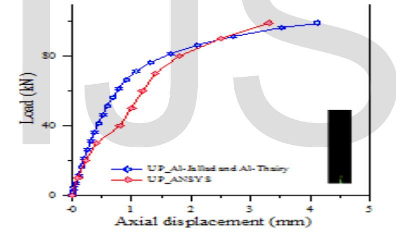


Figure 14: Numerical and experimental Load-axial displacement curves for specimen UP.

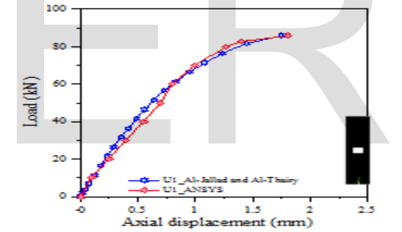


Figure 15: Numerical and experimental Load-axial displacement curves for specimen U1.

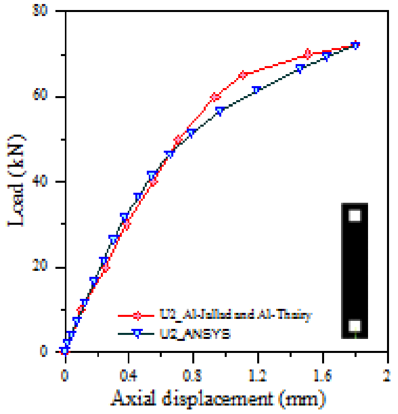


Figure 16: Numerical and experimental Load-axial displacement curves for specimen U2.

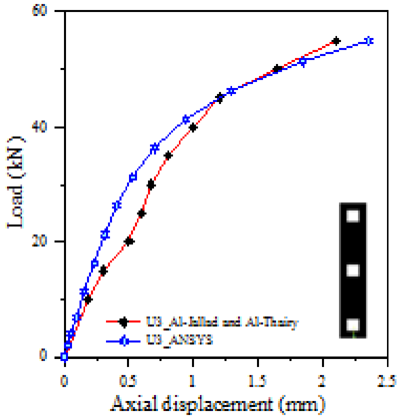


Figure 17: Numerical and experimental Load-axial displacement curves for specimen U3.

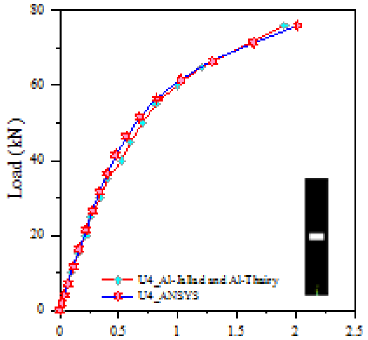


Figure 18: Numerical and experimental Load-axial displacement curves for specimen U4

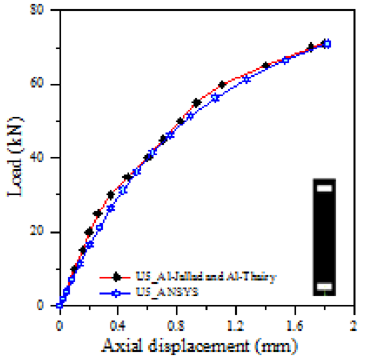


Figure 19: Numerical and experimental Load-axial displacement curves for specimen U5.

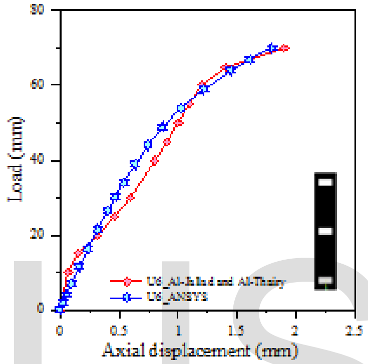


Figure 20: Numerical and experimental Load-axial displacement curves for specimen U6

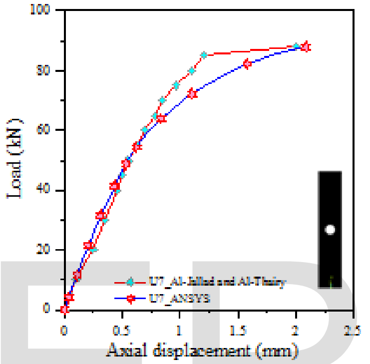


Figure 21: Numerical and experimental Load-axial displacement curves for specimen U7

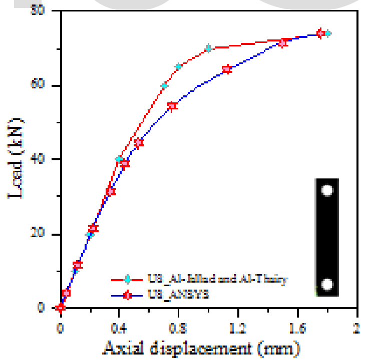


Figure 22: Numerical and experimental Load-axial displacement curves for specimen U8.

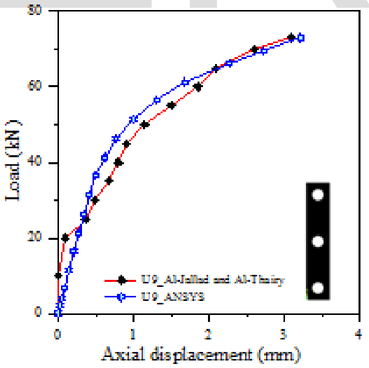


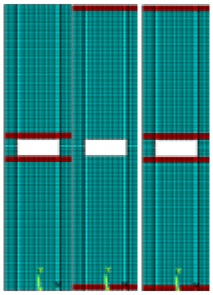
Figure 23: Numerical and experimental Load-axial displacement curves for specimen U9

3 PARAMETRIC STUDY

As an application of present model and as a complementing of its competence in simulate various conditions, a study of the effects of some parameters such as stiffener effects, opening locations and the length of column on the behaviour of cold-formed thin-walled columns was accomplished here. Specimens (C4, C5, C6, U4, U5 and U6) have been selected for this reason.

3.1 Stiffener Effects

As mentioned earlier, one of the main problems in the cold-formed thin-walled column is the local buckling. To avoid such problem, stiffening at the weakness regions may be used. In order to explain the influence of stiffener, effect of stiffening the column ends and /or around opening on the behavior of the steel column is studied. For this purpose plates of 4 mm thick and 10 mm width are used as a stiffener as shown in Figure 24. Figures 25 and 26 show load deflection curve of steel column with various location of stiffener for the chosen specimens (C4 and U4). The analysis results for box and channel sections explain that existing stiffener at ends has more effect on ultimate load capacity than when it is placed around the opening. Nevertheless, high reducing in axial displacement value are recorded for the same load.



a-Near opening
Ends of the column

b-at ends of the column

c-Near opening and at

Figure (24) stiffener location of specimens C4 and U4.

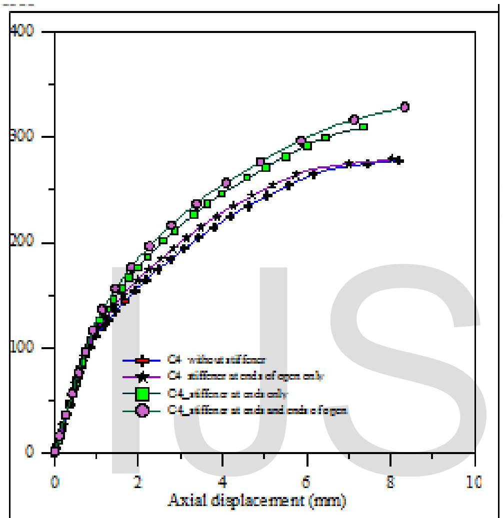


Figure (25) Effect of stiffener location on load-axial displacement curves for specimens C4.

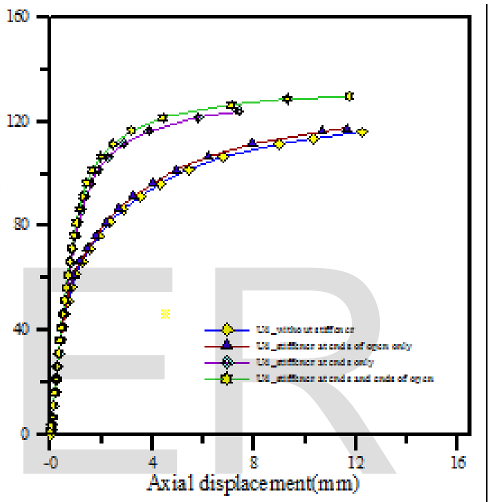


Figure (26) Effect of stiffener location on load-axial displacement curves for specimens U4.

The effect of using stiffener on specimen C6 which containing three rectangular opening is also studied. Table 4 shows the increment in the failure as result of using stiffener at various locations for specimens C4, U4, C6 and U6. It is found that using stiffener (on specimen C6) around the central or at the bottom opening has a least effect on failure load with increments approximately of (6 %) and (5.7 %) (Corresponding to specimen has no stiffener) for both mentioned stiffening cases respectively. Whereas, the stiffening of outer openings and ends of column increases the failure load by about 32.2 %. Moreover, stiffening of ends and around all openings enhanced failure load by about (40.2 %). The same behavior can be seen for U-shaped section column, except that the increment in the failure load is relatively smaller compared with the box column.

TABLE 4

THE FAILURE LOAD AS RESULT OF USING STIFFENER AT VARIOUS LOCATIONS FOR SPECIMENS C4, U4, C6 AND U6.

columns designations	No. of opening	Location of stiffener	Failure load (kN)	percentage of failure load increment*
C4	One	---------	277.62	---------
		At ends of column	309.96	12%
		Around the opening	278.88	0.45%
		At ends and around the opening	328.5	18.6%
U4	One	---------	116	---------
		At ends of column	124	6.7%

		Around the opening	117.5	1.3%
		At ends and around the opening	129.75	11.85%
C6	three	---------	261.5	---------
		Around the center opening	277.8	6%
		around the lower opening	276.3	5.7%
		Around the upper opening only	299.9	14.7%
		around both external openings	301.34	15.2%
		At ends of column	309.5	18.4%
		at the ends and around the center opening	317	21.2%
		around all openings	337	28.9%
		at the ends and around external opening	346	32.3%
		at the ends and around all openings	366.75	40.2%
U6	Three	---------	94.75	---------
		Around the center opening	101.75	7.3%
		around the lower opening	98.75	4.3%
		Around the upper opening only	105.62	11.4%
		around both external openings	111.5	17.6%
		At ends of column	113.75	20%
		at the ends and around the center opening	116.62	23%
		around all openings	124.62	31.5%
		at the ends and around external opening	130.5	37.7%
		at the ends and around all openings	141.5	49.3%

** This ratio corresponding to specimen has no stiffener*

3.2Effect of Opening Location

To study the effect of opening location, specimen (C5 and U5, which has two openings) are chosen. The openings located at distance (25.4, 55, 110, 180, and 220 mm) from ends of column are investigated for both box and channel sections. In comparison with the failure load of the opening located at 24.5 mm from the end of column. It was found that, when the opening location had been far-off from ends, failure loads increased by about 4.56%, 9.3%, 8.44%, and 8.2% with opening located at 55, 110, 180, and 220 mm from ends of column, respectively. So it can be concluded that the changing of open location influence on the failure load only when the opening is exist at the middle of the first quarter of the column. It can be noted from Figures 27 and 28 that if the open deports larger than 110 mm, the failure load and corresponding axial displacement has not been increased.

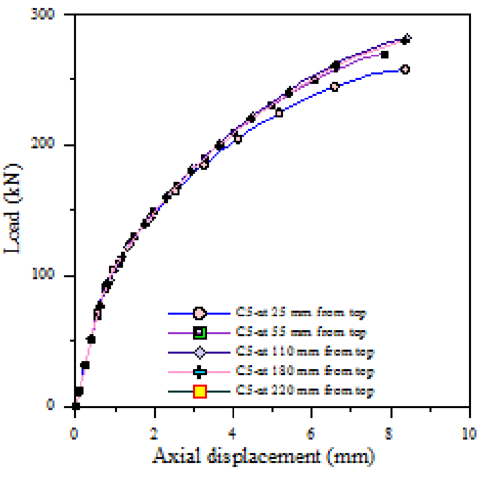


Figure (27) Effect of opening location onload-

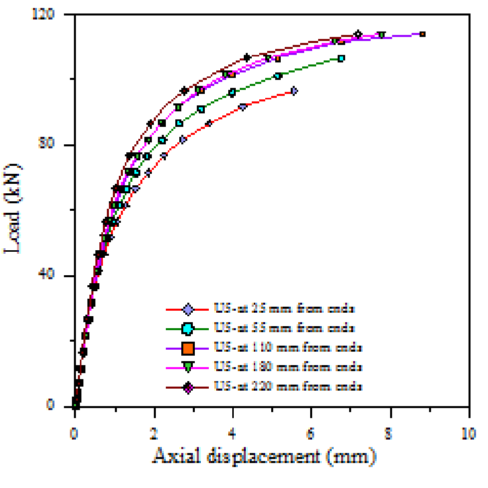


Figure (28) Effect of opening location onload-

The location effect of one opening in the web is also studied, (i.e. the opening distribution in the column is not symmetric), and thus C4 is selected as reference specimen. The openings are located at (25, 55, 110, 180, and 220 mm) from the top end of the column. Opening located greater than half column span does not considered. This is due to that the opening has the same effect if it is positioned at the same distance from any end. It is found that using one opening at different distances has slight effect on the behaviour of column as shown in Figure 29. When opening distance changed from 25.4 mm to 110 mm the failure load increases by approximately 6.5 %. After that there is no noticeable change on failure load can be noticed.

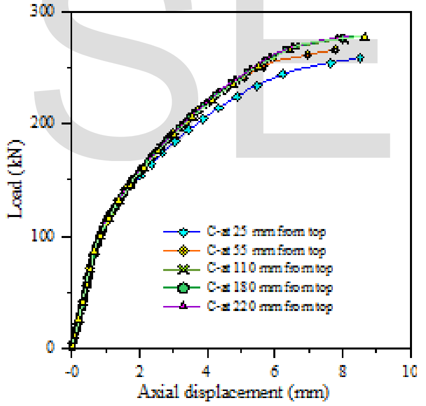


Figure (29) Effect of use one opening location for box section specimen

3.3 Column Length Effects

In order to investigate the influence of using different length of column on its the behaviour, the column length of box section column is changed from 500 mm to 1000 mm which increased by 125 mm in each step. However, for channel section the increment in the length is 50 mm in each step up to 700-mm. Columns length greater than those mentioned above has not been considered because that they suffer high buckling. Figures 30 and 31 show load-axial displacement curve for box and channel section with various length. Whereas Figures32 and 33 show effect of changing column length on its failure load and axial displacement respectively for specimens C6 and U6. For box section, it can be seen that the ultimate load capacity decreases up to 18% while the axial displacement increases up to 126 % when the length increases to 1000 mm. While increasing column length having channel section up to 700 mm leads to decrease the ultimate load capacity by 27.5 % and increase the axial displacement by 133 %.

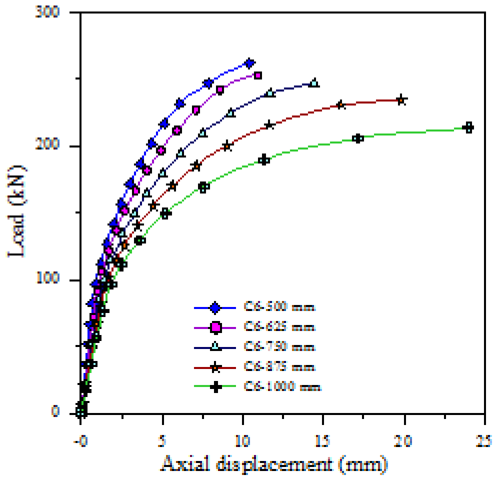


Figure (30) Effect of use various length of column on load-axial displacement curves for specimens C6.

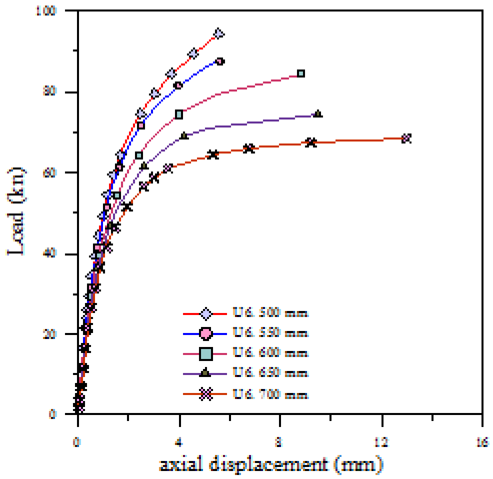
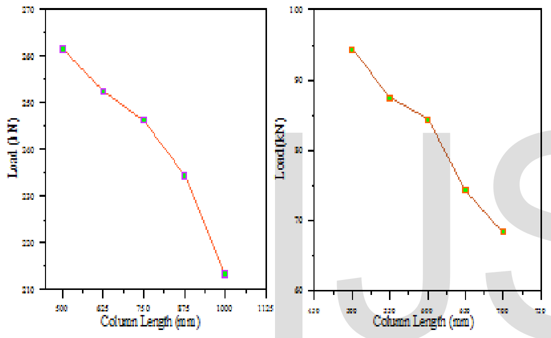


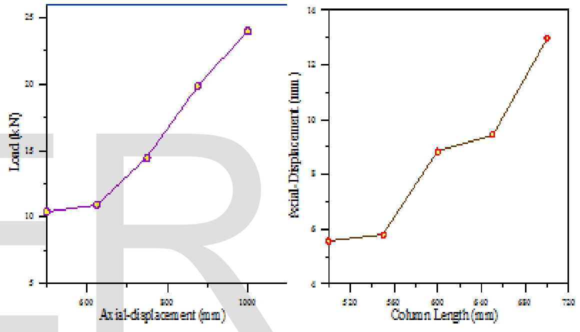
Figure (31) Effect of use various length of column on load-axial displacement curves for specimens U6.



Box-section

Channel-section

Figure (32) Effect of column length on failure load for box and channel section



Box-section

Channel-section

Figure (33) Effect of column length on axial displacement for box and channel section

4 CONCLUSIONS

1. The model accomplished by ANSYS software to analyze steel column with cold-form thin-opened walled section succeed to give a results in a good agreement with the experimental tests.
2. Using the stiffener at the ends of steel column increased failure load by about (12%) and (7%) for box and channel sections respectively. While when using stiffeneronlynear the opening, there is no effect on failure load for two sections. On the other hand stiffening the column ends and near the opening, failure load increases to (18.6%) and (11.2%) for box and channel section, respectively.
3. Stiffening of columns has three opening at the column ends and near all openings increases failure load to about 40% and 49.3% for box and channel section respectively. Whereas using stiffener about central opening alone or on bottom hole alone has no effect on the failure load.
4. Effect of opening location was clear when its position changed up to 40% of column length from the column end. The increment in failure load was about 9.3% and 17% for box and channel section respectively. Beyond this position, increment in failure was rarely kept constant.
5. Increasing column length has clear effect on axial-displacement and failure load. It is found that increasing the length of box section column to twice original one, increases the axial displacement by about 126% and decreases the failure load by approximately 18%. While for channel section, increase column length to 1.4 %, axial displacement increased by about 133% and failure load decreases by approximately 27.5%.

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