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Analytical Study of the Behavior of Steel Beam-Columns with Different Shapes of Web Opening at Different Location

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Abstract: **Openings in webs of steel beams or steel beam column are commonly used to reduce the material volume without affecting the structural strength or serviceability requirements. Most of previous research focused on the behavior of beam with web opening but only few concentrated on beam column with web opening. This paper highlights the behavior of steel beam column with different shapes of web opening at different locations. A finite element software ANSYS 19 was used for modeling beam column element with web opening. The results obtained from this study have shown that, load capacity of beam column with circular web opening is bigger than that of beam columns with square or rectangular web opening. The behavior of the steel beam columns became weaker and the vertical deflection at failure stage is increased when the area of web opening has been increased. Whenever web opening is located near to location of applied load that is lead to increase deflection.**

Keywords: **Steel Beam-Column, Web Opening, Load Capacity, ANSYS.**

I. INTRODUCTION

Openings in webs of steel beam are commonly used to facilitate electrical, mechanical, and sanitary works in addition to access inspection equipments, ventilation ducts, air condition ducts, communication systems, fire protection systems. Another important reason for using web openings in steel beam is to reduce the material volume without affecting the structural strength or serviceability requirements.

The steel columns were studied in much previous research by using experimental investigations and analytical solutions. Herein, some of these researches are presented. *Shanmugam and Dhanalakshmi [1]* have presented a numerical study using the finite element package ABAQUS to develop a design equation to determine the ultimate load capacity of perforated channel short columns containing single or multiple openings of square and circular shapes. The suggested equations use web plate slenderness and opening area ratio as the main variables. The accuracy of the suggested design equation is validated against number of experimental and finite element results available in published literature. *Salhab and Wang [2]* have suggested a method to calculate the equivalent web thickness of thin-walled channel sections with perforated webs to be used in the design of solid sections. The suggested method was based on a regression analysis of a numerous of finite element simulation results of elastic local buckling resistance of perforated plates under axial compressive load. It has been shown that the equivalent thickness is significantly related to the plate width to thickness ratio, the total width of perforation at the critical section and the width of the perforation zone. *Sweedan and El-Sawy [3]* have also used the finite element method to investigate the critical axial elastic local web buckling load of cellular beam–column elements. The effect of the plate length and width, and the perforations diameter, and spacing on the elastic buckling load of perforated web plate has also been investigated. The results of the parametric study have helped to enhance the understanding of the elastic local buckling behaviour of web plates of cellular beam–column elements under compression. *Sadjad A. Al-Jallad and Haitham Al Thairy [4]* studied experimentally the effects of web opening on the behavior and failure of steel columns with cold formed thin-walled sections (CFS) subjected to axial compressive load. The study had shown that for most of the tested columns, increasing the numbers of web openings results in decreasing the column axial strength compared to the reference steel column. The maximum percentage of the reduction in the columns axial compressive strength caused by the presence of web opening was found to be about 30% and 45% of the reference columns strength for columns with box and channel shape sections, respectively. It was also found that the reduction in the axial compressive strength of the column specimens caused by the presence of web openings is lower for the circular shape openings compared to that for rectangular and/or square shape web openings. *Muhammad Abed Attiya [5]* studied numerically the behavior of cold–formed thin–walled steel column with opening by using ANSYS software. To simulate the behavior of cold-formed steel column under static load, two groups of steel column were analyzed which was studied experimentally by *Sadjad A. Al-Jallad and Haitham Al Thairy [4]*. He found that the results which was obtained from ANSYS were in a good agreement with the results of experimental tests. Using the stiffener at the ends of steel column increased failure load by about (12%) and (7%) for box and channel sections respectively. 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%. *Hanan Hussien El-Tobgy et al. [6]* studied experimentally and numerically the structural behavior of castellated beam-column steel elements. An experimental investigation was performed on twelve short and long castellated beams, columns and beam-column elements. They found that the castellation has no effect on the linear buckling load for elements subjected to pure axial loading. Otherwise, the castellation ratio has significantly affected the linear buckling moment of the pure bending elements. Additionally, the castellation process increases the major axis inertia of the section but does not affect the minor axis inertia. Pure bending strength is mainly governed by the major axis inertia, particularly for beams restrained against lateral-torsional buckling. On the other hand, pure axial capacity is governed by the section area and minor axis inertia. Accordingly, castellation process significantly enhances pure bending strength, but does not enhance the pure axial strength. However, for beam-columns, the strength enhancement ratio depends on the eccentricity ratios (e/d).

II. NUMERICAL STUDY

The aim of this paper is to study numerically the behavior of non-compact steel beam-column elements having different shapes and locations of web opening. The analysis of beam-columns was done using ANSYS 19 *[7]* Workbench, a finite element software for mathematical modelling and analysis. All specimens are a simply supported beam column with a length (L) equal 2400 mm using built up section with two flange plates with width (b_f) and thickness (t_f) equal to 100 mm and 6 mm, respectively. The bearing stiffeners are provided at both ends of specimens with heights 370 mm, width 150 mm and thickness 8 mm. The steel beam column specimens having non-compact web with height (d) equal to 320 mm and thickness (t_w) equal to 3 mm. The web opening has height (h_0) and width (a_0) with different shapes as square, rectangular and circular. Three locations of the opening were considered, at (D/L) equal to 0.25, 0.40 and 0.50 from the beam column span where (D) is the distance between the centerline of web opening and end support. The studied beam columns names defined with symbols are divided into letters and numbers according to opening shape and ratio D/L. For example, IS-0.15 means beam column with square web opening with ratio D/L=0.15. Fig. (1) and Table I present the specimens cross sections and configuration. The finite nonlinear Shell element 181 is used to model all of beam column's flanges, web and end bearing stiffeners because that has four nodes, and each node has six degrees of freedom. Steel is defined by isotropic linear properties with modulus of elasticity E equal to 204.7 GPa and Poison's ratio υ equals to 0.3. in addition, the multilinear isotropic hardening rule with von Mises yield criterion is defines as yield strength f_y and strain ε_y equal to 245 MPa and 0.001197, respectively and ultimate strength f_u and strain ε_u equal to 387 MPa and 0.07057, respectively where the tangential modulus of elasticity equal to 0.01E as shown in Fig. (2). All specimens are subjected to vertical concentrated load (P) at mid span and horizontal concentrated axial load (H) at end support equal 0.5P.

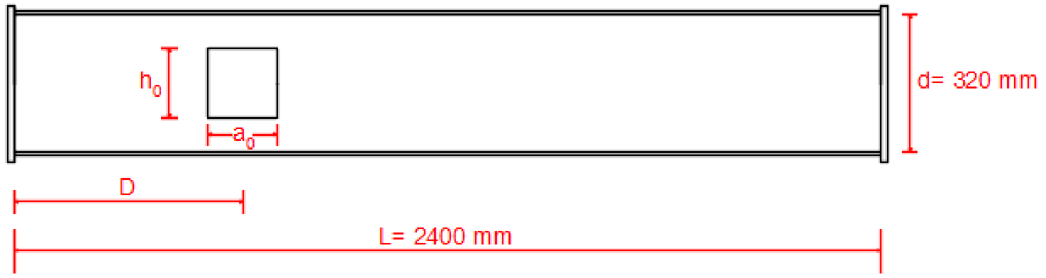

Fig. (1) The beam column configuration

TABLE I: SUMMARY OF VARIABLE PARAMETERS FOR THE STUDIED BEAM COLUMNS

Specimens	Opening height (h_o) (mm)	Opening width (a_o) (mm)	Opening shape	Opening distance (D) (mm)	h_o/d	D/L
I-P	----	----	No opening	----	----	----
IS-0.25	160	160	Square	600	0.50	0.25
IS-0.40				960		0.40
IS-0.50				1200		0.50
IR-0.25		320	Rectangular	600		0.25
IR-0.40				960		0.40
IR-0.50				1200		0.50
IC-0.25		160	Circular	600		0.25
IC-0.40				960		0.40
IC-0.50				1200		0.50

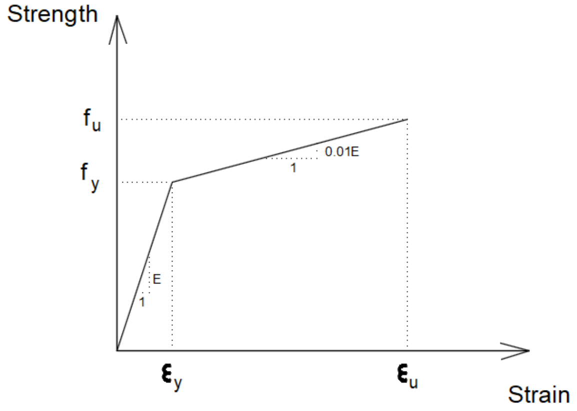

Fig. (2) Stress-strain curve for analyzed models

III. RESULTS AND DISCUSSION

The results of numerical analysis such as load capacity and deflection of beam columns with different shapes of web opening at different locations are shown in Table II. It is obvious from table that the percentage of reduction in load capacity of beam columns with circular web opening are equal 4.9%, 9.6% and 13.2% for specimens IC-0.25, IC-0.40 and IC-0.50, respectively compared to reference specimen I-P. The same observation for beam columns with square web opening, the percentage of reduction in load capacity are equal 9.11%, 15.9% and 21% for specimens IS-0.25, IS-0.40 and IS-0.50, respectively. While the percentage of reduction increased in beam column with rectangular web opening which equal 15.8%, 25.2% and 31.5% for specimens IR-0.25, IR-0.40 and IR-0.50, respectively. This behavior can be explained by the effect of the stress developed at the opening edges. These stresses have less effect in the case of circular opening because of distribution almost equally stresses around the circular opening edges while for square and rectangular shapes opening, the stresses are localized at the opening corners which may increase the possibility of local buckling. The more reduction in load capacity of specimens with rectangular opening than the square opening due to the unequal stress concentrations at corners in the rectangular case rather than the square case. Furthermore, the losses in load capacity are increased as near web opening to the location of applied load.

Fig. (3), (4) and (5) show the vertical load-deflection relationship of the beam columns with different shapes of web opening at different locations. It can be observed that a small difference in the deflection of specimens IS and IC, because area of square opening is approximately equal to area of circular opening. While deflection of specimen IR is bigger than that of IS and IC because area of rectangular opening is more than that of square or circular opening which lead to decrease moment of inertia about major axis I_x for cross section. It can be concluded that the behavior of the steel beam columns became weaker and the vertical deflection at failure stage is increased when the area of web opening has been increased. This is an expected behavior since increasing the area of web opening reduced the members stiffness owing to decreasing of the cross-sectional area at opening location. Additionally, it can be noticed that whenever web opening is located near to location of applied load that is lead to increase deflection.

TABLE II: ULTIMATE LOAD CAPACITY AND DEFLECTION OF SPECIMENS

Specimens	Load capacity		Deflection (mm)
	Ultimate vertical load (P) KN	Ultimate horizontal load (H) KN	
I-P	71.3	35.6	4.49
IC-0.25	67.8	33.9	3.71
IS-0.25	64.8	32.4	3.99
IR-0.25	60.0	30.0	4.49
IC-0.40	64.6	32.3	3.80
IS-0.40	59.9	30.0	3.25
IR-0.40	53.5	26.7	4.33
IC-0.50	61.9	31.0	3.90
IS-0.50	56.3	28.2	3.76
IR-0.50	48.8	24.4	3.63

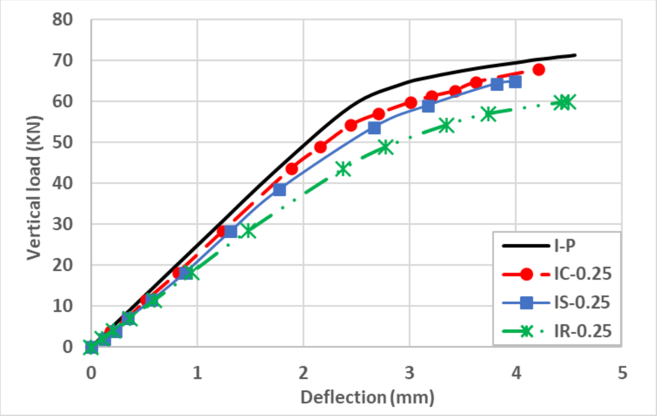

Fig. (3) Vertical load-deflection relationship of beam column with different shapes of web opening at location (D/L= 0.25)

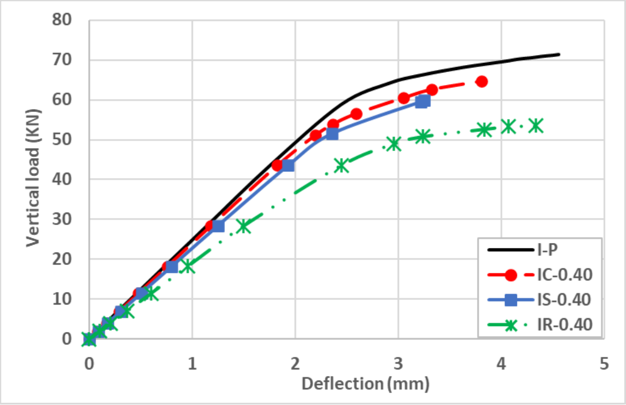

Fig. (4) Vertical load-deflection relationship of beam column with different shapes of web opening at location (D/L= 0.40)

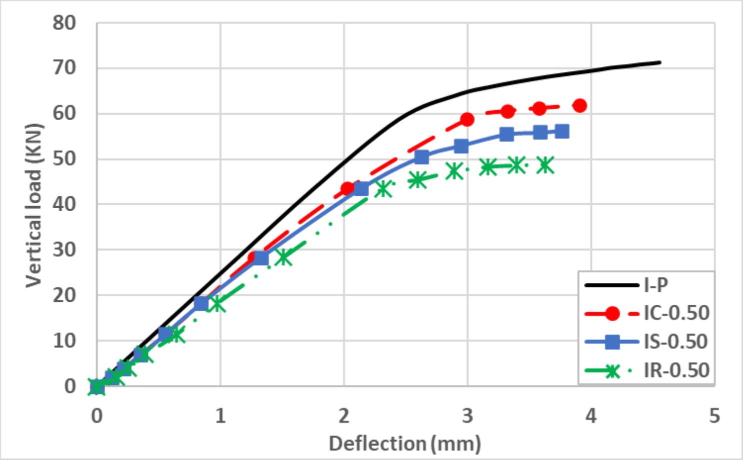

Fig. (5) Vertical load-deflection relationship of beam column with different shapes of web opening at location (D/L= 0.50)

The VON MISES stress for specimens I-P, IC-0.50, IS-0.50 and IR-0.50 are shown in Fig. (6), (7), (8) and (9), respectively.

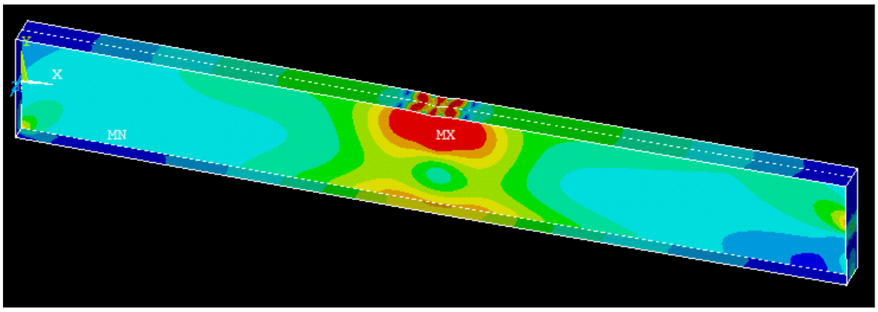

Fig. (6) VON MISES stress of specimen I-P

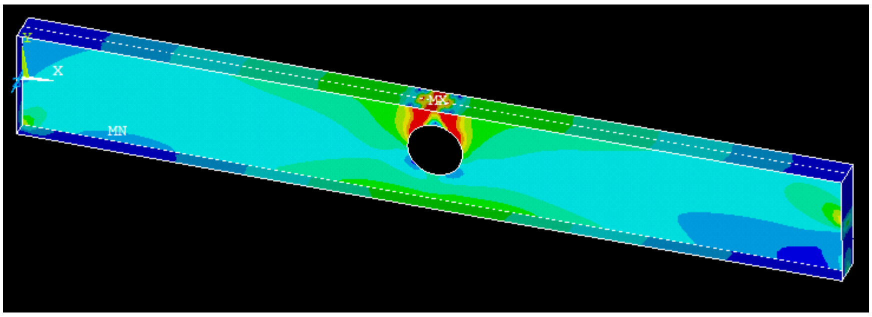

Fig. (7) VON MISES stress of specimen IC-0.50

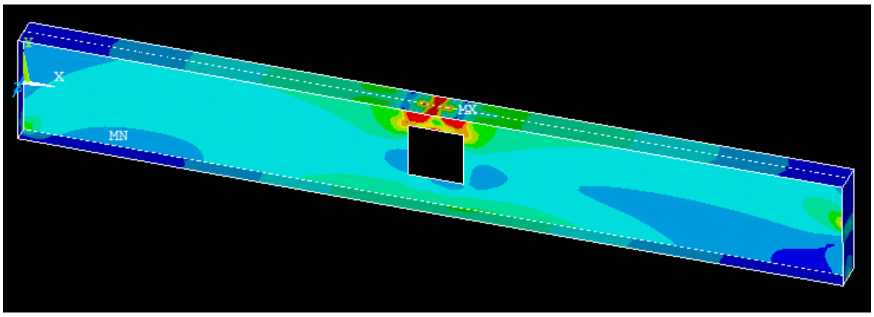

Fig. (8) VON MISES stress of specimen IS-0.50

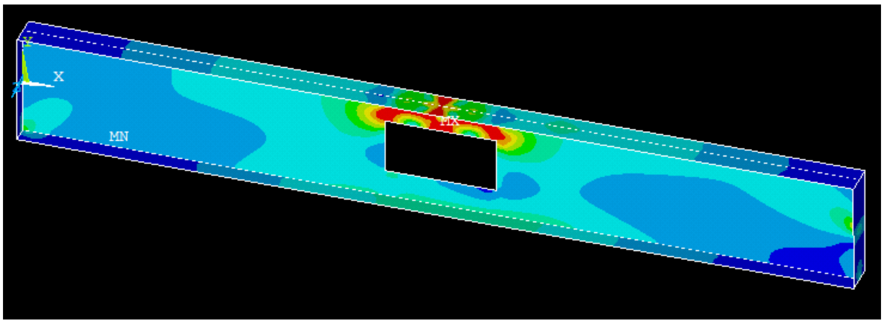

Fig. (9) VON MISES stress of specimen IR-0.50

IV. CONCLUSION

This paper investigates the behavior of beam column with different shapes of web opening at different location ratio and compared with reference beam column. Following conclusions can be derived from this study:

- Load capacity of beam column with circular web opening is bigger than that of beam columns with square or rectangular web opening.
- The more reduction in load capacity of specimens with rectangular opening than the square opening due to the unequal stress concentrations at corners in the rectangular case rather than the square case.
- The losses in load capacity are increased as near web opening to the location of applied load.
- The behavior of the steel beam columns became weaker and the vertical deflection at failure stage is increased when the area of web opening has been increased.
- Whenever web opening is located near to location of applied load that is lead to increase deflection.

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