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# Impact of Holes on the Buckling of RHS Steel Column

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## Abstract

This study presented an experimental and theoretical study on the effect of hole on the behavior of rectangular hollow steel columns subjected to axial compression load. Specimens were tested to investigated the ultimate capacity and the load- axial displacement behavior of steel columns. In this paper finite element analysis is done by using general purpose ANSYS 12.0 to investigate the behavior of rectangular hollow steel column with hole. In the experimental work, rectangular hollow steel columns with rounded corners were used in the constriction of the specimens which have dimensions of cross section (50*80)mm and height of (250 and 500)mm with thickness of (1.25,4 and 6)mm with hole ((α*80)*80)mm when α is equal to (0.2,0.4,0.6 and 0.8). Twenty four columns under compression load were tested in order to investigate the effect of hole on the ultimate load of rectangular hollow steel column. The experimental results indicated that the typical failure mode for all the tested hollow specimen was the local buckling. The tested results indicated that the increasing of hole dimension leads to reduction in ultimate loads of tested column to 75%. The results show the reducing of load by 94.7% due to decreasing the thickness of column while the hole size is constant (0.2*80*80). The buckling load decreases by 84.62% when hole position changes from $L_o$=0.25L to 0.75L. Holes can be made in the middle of column with dimension up to 0.4 of column's length. The AISC (2005) presents the values closest to the experimental results for the nominal yielding compressive strength. The effect for increasing of slendeness ratio and thickness to area ratio(t/A) leading to decreacing the critical stresses and the failure of column with large size of hole and (t/A) ratio less than 0.74% was due to lacal buckling while the global buckling failure was abserve for column with small size of hole and (t/A) ratio above than 0.74%. The compersion between the experimental and theoretical results showed a reasonable agreement and the difference was in the range (1.28-14.88)%.

**Keywords:** Ultimate strength, Experimental test, Numerical analysis, RHS Steel Columns, Holes.

## الخلاصة:

في هذا البحث تم اجراء دراسة عملية ونظرية لتأثير الفتحات في تصرف الاعمدة الفولاذية المستطيلة المجوفة المعرضة لأحمال ضغط محورية. تم فحص عينات لدراسة التحمل الاقصى وتصرف حمل-أزاحات محورية للأعمدة الفولاذية. في هذا البحث تم استخدام نظرية العناصر المحددة المتمثلة ببرنامج ANSYS 12.0 لتحليل تصرف الاعمدة المستطيلة المجوفة مع فتحات. في الجزء العملي استعملت اربعة وعشرون نموذج من الاعمدة الفولاذية المستطيلة المجوفة بزوايا مدورة الذي له ابعاد مقطع (50*80) ملم وارتفاع (250,500) ملم و بسمك (1.25,4 and 6) ملم مع ابعاد حفرة ((α*80)*80) ملم بحيث ان α مساوية الى (0.2,0.4,0.6 and 0.8) . تم فحص اربعة وعشرون من الاعمدة الفولاذية تحت حمل انضغاط من اجل التحقيق في تأثير الحفرة في المقاومة القصوى للأعمدة المستطيلة المجوفة. أظهرت النتائج العملية أن طريقة الفشل النموذجية لجميع العينات المجوفة المختبرة كانت التواء المحلي. وأظهرت النتائج التي تم اختبارها أن زيادة ابعاد الحفرة يؤدي إلى الحد من الحمل الاقصى للعمود يصل إلى 75%. وأظهرت النتائج تقليل الحمل بنسبة 94.7% بسبب انخفاض سمك العمود بينما يكون حجم الثقب ثابتا. ينخفض الحمل التواء بنسبة 84.62% عندما يتغير موقع الحفرة من 0.25L إلى 0.75L. يمكن إجراء الحفرة في منتصف العمود مع بعد يصل إلى 0.4 من طول العمود. و AISC(2005) يعرض القيم الأقرب إلى النتائج العملية لمقاومة خضوع الانضغاط. أدى تأثير زيادة نسبة الانحناء ونسبة السمك إلى مساحة (t / A) مما أدى إلى خفض مقومة الانضغاط الحرجة وفشل العمود مع حجم كبير من الحفرة و (t / A) نسبة أقل من 0.74% ويرجع ذلك إلى الانبعاج المحلي في حين أن فشل الإبزيم العالمي كان معتمدا للعمود مع حجم صغير من الحفرة و (t / A) نسبة فوق 0.74%. وأظهرت النتائج وجود اتفاق معقول بين النتائج العملية والنظرية وكان الفرق يتراوح بين%(1.28-14.88).

**الكلمات المفتاحية**:– المقاومة القصوى، الاختبار التجريبي، التحليل العددي، الاعمدة الفولاذية المستطيلة المجوفة، فتحات.

## 1. Introduction

Holes in steel structures may be existed for many cases, such as for ducts through columns is necessary to essential service like water supply, sewage, air-conditioning, electricity telephone, and network in pipe can lead to loss of strength and possible structural failure. Until now little work has been done on holes in columns, and hence, the present study aims to examine the amount of strength lost owing to the presence of holes in columns.

Holes within a steel tube column effect on ultimate strength and behavior of buckling rectangular hollow section (RHS) column is a radial keeping consideration in their design. RHS columns are frequently used in pylon, most, thermopile and column lighting.

The columns of steel effected at a declined rigid wall with no friction was investigated numerically by (Han and Park, 1990). They tested different angles and found, the empiricist flier expression for the critical angle, the axial collapse, bending collapse and a transition zone were the response of failure.

The response of buckling and post buckling on composite cylindrical tubes subjected to axial compression and internal pressure loads using ABAQUS was studied by (Tafreshi, 2002). The research studied the influence of size and tendency of holes on buckling capacity. The effect of the holes on the behavior of deformation on the simply supported steel tubes with rectangular holes of different sizes positioned at their mid-length subjected to axial compression was studied by (Vartdal *et.al.*, 2005; Tafreshi and Colin, 2006), investigated the response of composite cylindrical tubes subjected to combined load , by numerical study using nonlinear finite element analysis, in which the post buckling analysis of cylinders with geometric imperfection is carried out to effect of lake capacity on critical buckling load. The impact of holes on the global, distortional and local buckling properties of thin-walled structural members have been studied by using shell finite element eign-buckling analysis to calculate the critical elastic buckling loads of C-Section columns and beams. The existence of stiffened holes decreased the flexural, flexural-torsional and lateral torsional buckling loads of the thin-walled columns and beams are investigated, with the largest decrease occurring for column flexural-torsional buckling. (Cristopher and Cheng, 2010).

(Shariati and Kbarpour, 2012), examined the influence of elliptical holes with various orientations, on the behavior of buckling and ultimate strength of stainless steel circular tubes subjected to combined loading.

In this paper, ultimate strength and behavior of buckling on steel RHS under axial compression loading was studied numerically and experimentally. A numerical analysis using the ANSYS 12.0 finite element software were carried out in order to study the effect of slenderness ratio, size and location of holes on buckling capacity and ultimate strength of RHS column. Four different hole dimension orientations were analyzed, representing 0.2h, 0.4h, 0.6h and 0.8h were h is the high of column cross section (b*h)and b is width of cross section. Three different thicknesses of column cross-section orientations were analyzed, representing, 1.25mm, 4mm and 6mm. Also, holes located at various location. Additionally, in section 4, for some specimens, practical buckling test was performed and the results of practical tests were compared to numerical results. A very good correlation between practical and numerical simulations was observed.

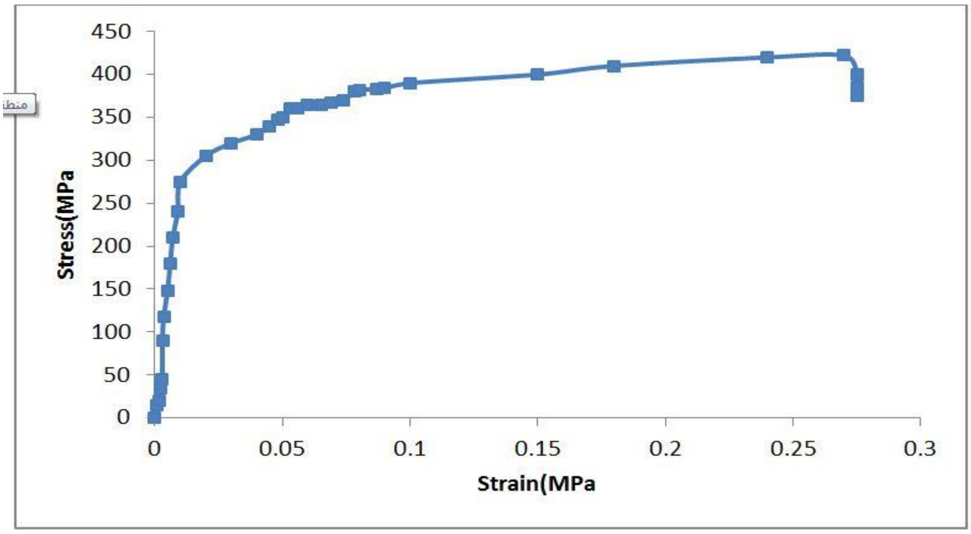
## 2. Experimental work

### 2.1. RHS geometry and mechanical properties

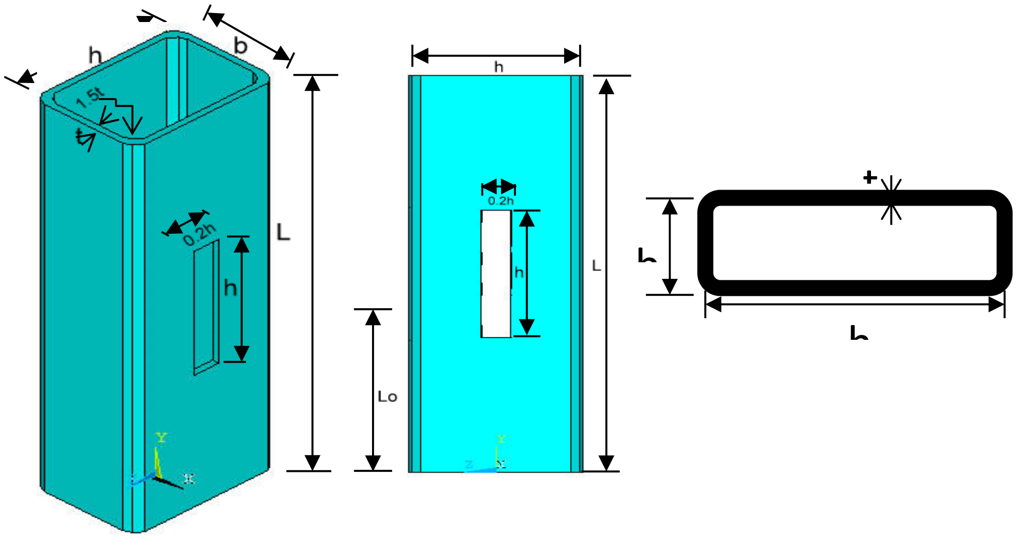
For this study, used a specific instrument to calculating the yield stress (Fy) shown in Figure (1). The specimen was put between the two legs of the instrument, the legs pull the specimen each one pulls in the opposite direction until the specimen reaches its ultimate state then get the yield stress Fy=362MPa, Fu=422MPa and Es=200GPa ,these properties shown in Figure (2).

The steel tube dimension of cross-section (b*h)mm and height (L)mm with thickness (t)mm and radius of rounded (1.5t)mm as shown in Figure (3). According to this Figure the hole dimension (αh*h)mm. Specimens were nominated as C1.

**Figure (1): The instrument which is used for the yield stress**




**Figure(2): Stress-strain curve of steel specimen C1**



**Figure(3): Geometry of column with hole**

## 2.2. Preparation Specimens

The rectangular hollow sections (RHS) were cut from the original 6m steel C-channel section and then attached double channel section by welding to perpetrate the (RHS). To ensure that the specimen member acts as a unite, AISC requires that the slenderness of an individual component be no greater than three-fourth of the slenderness of the (RHS), that is:

$$\frac{Ka}{ri} \leq \frac{3}{4}\left(\frac{KL}{r}\right) RHS \qquad (1)$$

**Where:**

a= Distance between connectors , (Lacing connection) (mm).

ri= Minimum radius of gyration of the attached components.(mm).

The rectangular hole installed inside the web of rectangular hollow section toward (h) direction at center with difference size and places. The dimensions of the rectangular section RHS are illustrated in Table (1) and Figure.(3).

**Where:**

L= Overall high of the column.

b= Overall width of the cross-section.

h= Overall depth of the cross-section.

t= Thickness of the cross-section.

α= Constant for varying of width of hole.

The inside and the surface of the RHS were brushed to remove any rust and loose debris. The deposit of grease and oil, if any, were cleaned any too.

**Table(1): RHS (Rectangular Hollow Section) Dimensions.**

| Section | L(mm) | b(mm) | h(mm) | t(mm) | α |
|---|---|---|---|---|---|
| RHS | 250 | 50 | 80 | 6 | 0.2 |
| | | | | 4 | 0.4 |
| | 500 | | | 1.25 | 0.6 |
| | | | | | 0.8 |

## 2.3 Instrument and Test Procedure

A 2000 KN capacity hydraulic compressive testing machine was used it for the compression tests of all specimens. The axial deformation corresponding to the applied compression load was measured at every regular interval of 10 kN by a dial gage of accuracy 0.01 mm pace rate of about 4 kN/sec was fed to the machine for testing the specimens. The axial load was allowed up to ultimate load was observed and readings were tabulated up to falling of the load after the specimen reaches its peak load. The test specimen are shown in Figure (4)

**Figure(4): The instrument and test setup**

The steel column was loaded gradually until the first buckling was observed. In the column (C1) visible buckling are first observed around the base of column this behavior called local buckling.  show the specimens were tested under tensile forces machine as shown in Figure (5).

a b

**Figure(5): The test setup machine and some specimens**

**a: without hole(α=0, t=1.25mm, L=250mm). b: with hole(α=0.2h, t=1.25mm, L=250mm).**

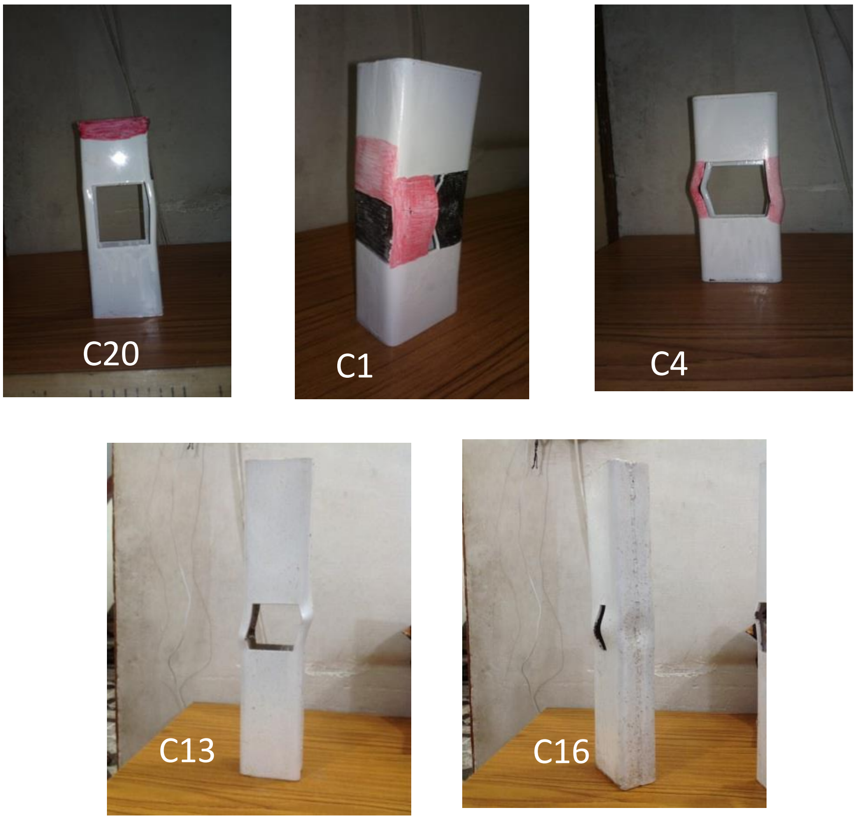
## 2.4 Specimens Description and Experimental Results

To study the effect of holes and discover the best behavior of local buckling for rectangular hollow section, twenty four stub columns under compression were tested. The specimens can be classified into three categories by thickness, each of them which classify into four categories by size of hole. Note that the gross area of rectangular hollow section was constant for all specimens. The geometry and experimental results for all specimens is presented in Table (2).

**Table(2): Test results for rectangular hollow sections**

| Specimens | L(mm) | t(mm) | α | $P_{Exp.}$(kN) | Deformation(mm) |
|---|---|---|---|---|---|
| C1 | 250 | 6 | 0.2 | 456.6 | 2.35 |
| C2 | 250 | 6 | 0.4 | 397 | 2.04 |
| C3 | 250 | 6 | 0.6 | 349 | 1.79 |
| C4 | 250 | 6 | 0.8 | 286.4 | 1.47 |
| C5 | 500 | 6 | 0.2 | 444 | 2.15 |
| C6 | 500 | 6 | 0.4 | 395.2 | 2.02 |
| C7 | 500 | 6 | 0.6 | 372.42 | 1.87 |
| C8 | 500 | 6 | 0.8 | 287 | 1.5 |
| C9 | 250 | 4 | 0.2 | 290.7 | 1.58 |
| C10 | 250 | 4 | 0.4 | 257 | 1.32 |
| C11 | 250 | 4 | 0.6 | 212 | 1.15 |
| C12 | 250 | 4 | 0.8 | 177.8 | 0.92 |
| C13 | 500 | 4 | 0.2 | 259 | 1.35 |
| C14 | 500 | 4 | 0.4 | 240.87 | 1.27 |
| C15 | 500 | 4 | 0.6 | 211.97 | 1.12 |
| C16 | 500 | 4 | 0.8 | 184 | 0.98 |
| C17 | 250 | 1.25 | 0.2 | 24.14 | 0.57 |
| C18 | 250 | 1.25 | 0.4 | 19.7 | 0.48 |
| C19 | 250 | 1.25 | 0.6 | 13.8 | 0.42 |
| C20 | 250 | 1.25 | 0.8 | 6.92 | 0.35 |
| C21 | 500 | 1.25 | 0.2 | 24.89 | 0.67 |
| C22 | 500 | 1.25 | 0.4 | 19.32 | 0.46 |
| C23 | 500 | 1.25 | 0.6 | 15.65 | 0.43 |
| C24 | 500 | 1.25 | 0.8 | 7.23 | 0.4 |

The deformed shape of rectangular hollow section (RHS)of steel columns with hole were illustrated in Figure (6).




**Figure(6): Photographs show the buckling and local buckling for RHS with hole**

### 2.4.1 The effect of hole size

The load deformation curves and corresponding with the nominal yielding compressive strength according AISC specifications were presented in Figures (7,8 and 9). The basic requirement for compression members are covered in Chapter E of the AISC specifications. The nominal compressive strength is:

$$Pn = Fy * Ag \qquad \textbf{(AISC Equation E3-1)}$$

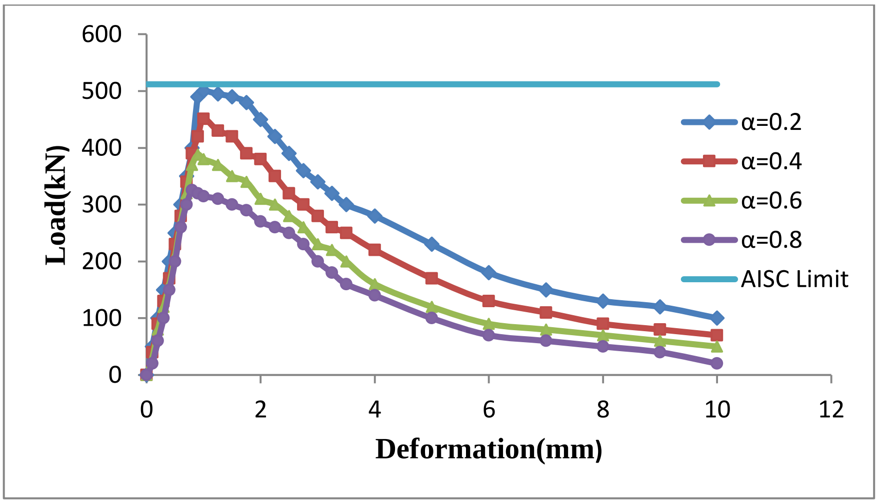



**Figure (7): Load-Deformation curves for RHS column with variable hole size (L=250mm and t=6mm)**

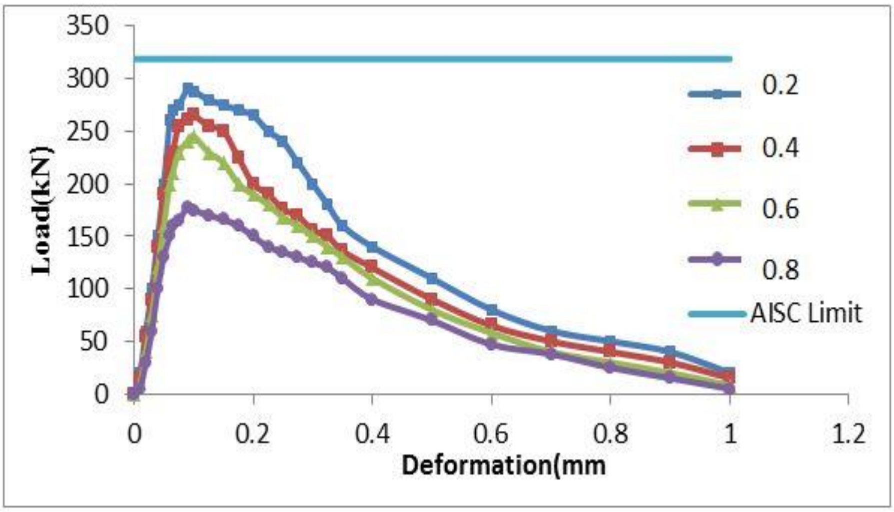



**Figure (8): Load-Deformation curves for RHS column with variable hole size (L=250mm and t=4mm)**

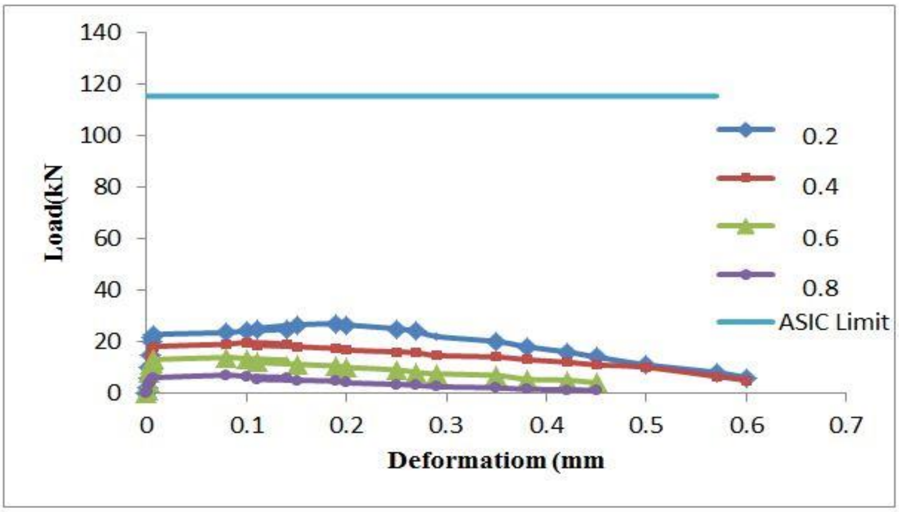



**Figure (9): Load-Deformation curves for RHS column with variable hole size (L=250mm and t=1.25mm)**

Figure (10) presents summary of the buckling capacity of RHS column versus deformation, for rectangular hole with various length of column. The properties of hole and thickness of column are constant .The results show when the hole position is constant, an increase in length of column, decreases the global buckling load by 2.76%.

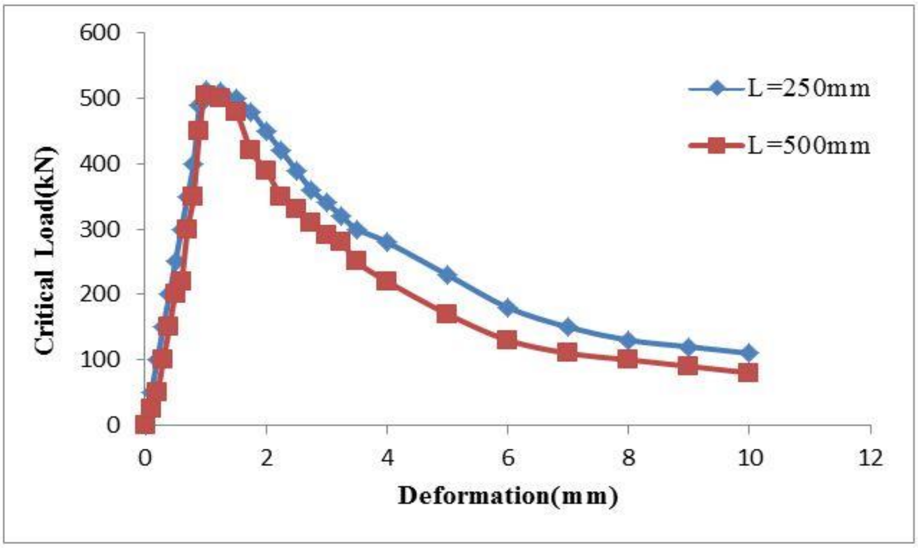



**Figure (10): Load-Deformation curves for RHS column with constant hole size**

**From the precedes results, the following remarks are records:**

- It can be seen that the typical failure mode for all the tested hollow specimen was the local buckling.
- The tested results indicated that the increasing of hole dimension leads to reduction in ultimate loads of tested column to 75%.
- The results show the reducing of load by 94.7% due to decreasing the thickness of column while the hole size is constant (0.2*80*80).
- Also it can be seen a good convergence with the AISC limits for the nominal yielding compressive strength when thickness of column decreasing.

### 2.4.2 Effect of hole position

The effect of a change in hole position on the buckling load of RHS column with constant thickness and length of column create hole with constant size (b*0.4h) was studied. Then the changing the position of the hole from Lo=0.25L to 0.75L, the change in buckling load was plotted in Figure (11). The buckling load versus (Lo/L) ratio, by use data from Table 1. It can be seen from this Figure (11) that when hole position changes from Lo=0.25L to 0.75L, buckling load decreases by 84.62%.

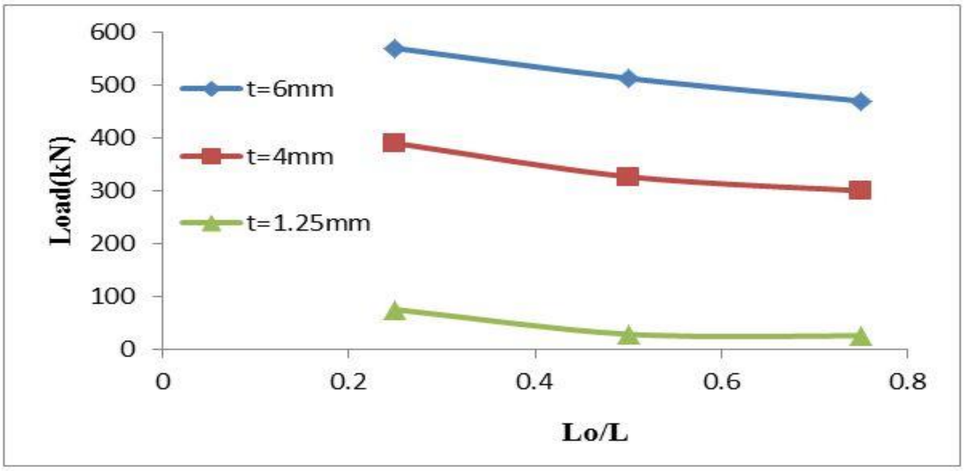



**Figure (11) Comparison of the buckling capacity of RHS column with variable rectangular location $L_o/L$ ratio, for C1**

### 2.4.3 Effect of hole's number

The buckling Load versus the number of holes with the size is constant which main is the length of hole is equal to h/2 =40mm is shown in Figure (12). It can be seen that for a hole size is half compare with the same geometry of RHS steel column with one hole. The results can be seen in Figure (13), the buckling load decreases by 88.74% when increasing the hole numbers with the size of holes is constant.

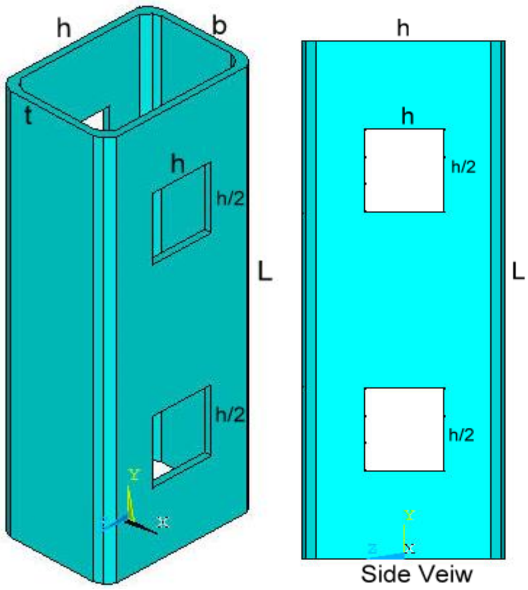



**Figure (12) Geometry of RHS column with versus number of hole, size of hole constant**

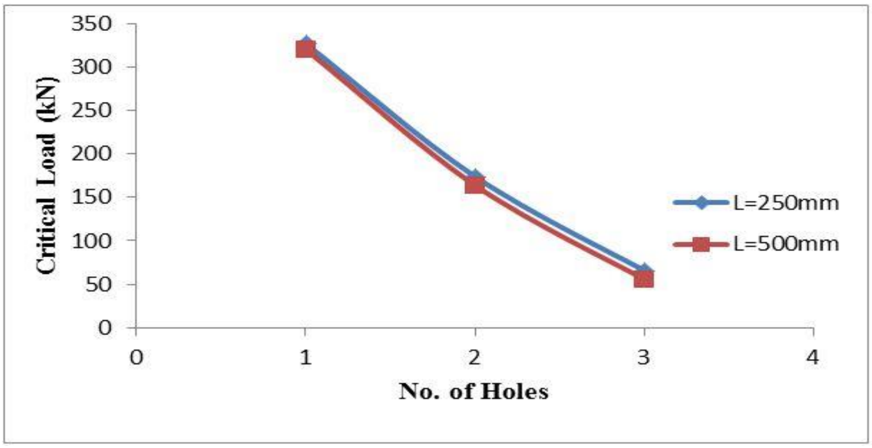



**Figure (13) Summary of the buckling capacity of RHS column with variable numbers of holes (b50-h80-t4)**

Figure (14), shows the effect of the increasing hole dimension ,position of hole , high of column and number of holes on the ultimate load of column results, when the cross-section of column remain constant.

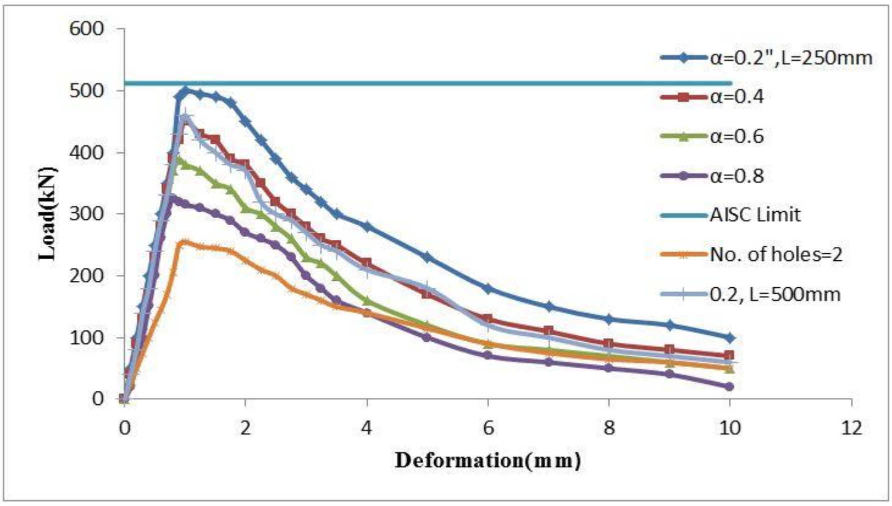



**Figure (14) Summary of the buckling capacity of RHS column with constant gross area and hole's dimension (b50-h80-t6)**

**From the precedes results, the following remarks are records:**

- It can be seen that the increasing of hole's number has significant effect on the ultimate loads and deformation of tested columns, decreasing of load capacity by 88.74%, but length of column has limited effect on the ultimate loads and deformation of tested columns.
- The hole with dimension 0.4 of column's length and high (250mm) lead to reduction of ultimate load by 86.95% is the same reduction when the hole with dimension 0.2 of column's length and high (500mm).
- Holes can be made in the middle of column with dimension up to 0.4 of column's length.

## 3. Finite Element Idealization and Results

### 3.1 Geometry

In this study , the nonlinear element **Solid45**, which is an six-node element with six degrees of freedom per node, for the analysis of RHS. For applying boundary conditions in the axial loading simulation and ends supported were shown in Figure (15).

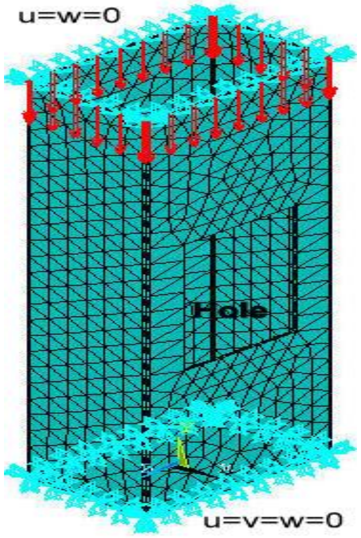



**Figure (15) Specimen under load**

### 3.2 Finite element results

The aim of this part is to make a comparison between the finite element models results and as experimental results to ensure that the element , material properties, real constant and convergence criteria are adequate to model the response of rectangular hollow cross section with hole. The comparison between the experimental results and the finite element results were findings in Table (3). There was a little difference between the two sets of data. The mean difference show about 10.66 % of experimental buckling load.

The load-end shortening curves and deformed shape of specimens in the buckling and local buckling states in numerical and experimental tests are compared in Figure (16). It can be seen that the peak load of both curves are approximate , while the initial stiffness of load end shortening curves is higher in finite element analysis (theoretical results) than in experimental results. This is may be due to the existence of trouble in the material which reduce the stiffness of the specimens in the experimental work, while the materials are assumed to be ideal in the finite elements analyses.

The analysis included two types of effects: effect of local buckling (column thickness) and effect of stresses.

**Table (3). Rapprochement of the experimental and numerical results**

| Specimens | $P_{theo}$(KN) | $P_{Exp.}$(kN) | Error% |
|---|---|---|---|
| C1 | 513 | 456.6 | 10.99 |
| C2 | 451 | 397 | 11.97 |
| C3 | 388 | 349 | 10. 05 |
| C4 | 325.4 | 286.4 | 11.98 |
| C5 | 504.2 | 444 | 11.94 |
| C6 | 444.2 | 395.2 | 11.03 |
| C7 | 423.2 | 372.42 | 11.99 |
| C8 | 319 | 287 | 10.03 |
| C9 | 326.6 | 290.7 | 10.99 |
| C10 | 285 | 257 | 9.82 |
| C11 | 243.34 | 212 | 12.87 |
| C12 | 202 | 177.8 | 11.98 |
| C13 | 320.6 | 259 | 12.85 |
| C14 | 279.4 | 240.87 | 13.79 |
| C15 | 238 | 211.97 | 10.94 |
| C16 | 197 | 184 | 6.24 |
| C17 | 28.4 | 24.14 | 15 |
| C18 | 22.12 | 19.7 | 10.94 |
| C19 | 15.72 | 13.8 | 12.21 |
| C20 | 8.13 | 6.92 | 14.88 |
| C21 | 27.97 | 24.89 | 11.01 |
| C22 | 21.84 | 19.32 | 11.54 |
| C23 | 15.65 | 15.45 | 1.28 |
| C24 | 8.03 | 7.23 | 9.96 |

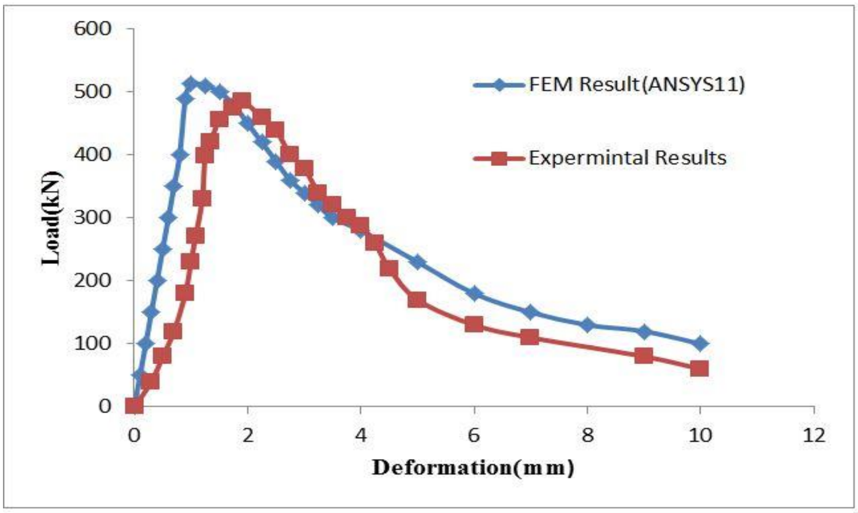



**Figure (16) Comparison of Experimental and numerical results for the specimen C1**

### 3.2.1 Effect of local buckling (column thickness)

In this section, the effect of thickness and slenderness ratio on the ultimate strength of rectangular hollow section was studied. For this purpose, holes with fixed size (b*0.2h) mm and L=250mm were formed in the mid-height position of column. Then, with changing the length of column from 250mm to 500mm, the variation in buckling load was studied. Table 4, presented the results of this analysis.

**Table (4). Results of numerical analysis for RHS column with different column orientation and with different orientation hole.**

| Specimens | α | t(mm) | KL/r | L(mm) | $P_{theo}$(KN) |
|---|---|---|---|---|---|
| C1 | 0.2 | 6 | 6.4 | 170 | 513 |
| C2 | 0.4 | 6 | 5.68 | 170 | 451 |
| C3 | 0.6 | 6 | 6.783 | 170 | 388 |
| C4 | 0.8 | 6 | 7.61 | 170 | 325.4 |
| C5 | 0.2 | 6 | 15.77 | 420 | 504.2 |
| C6 | 0.4 | 6 | 14.77 | 420 | 444.2 |
| C7 | 0.6 | 6 | 16.76 | 420 | 423.2 |
| C8 | 0.8 | 6 | 17.7 | 420 | 319 |
| C9 | 0.2 | 4 | 6.87 | 170 | 326.6 |
| C10 | 0.4 | 4 | 7.063 | 170 | 285 |
| C11 | 0.6 | 4 | 7.354 | 170 | 243.34 |
| C12 | 0.8 | 4 | 7.83 | 170 | 202 |
| C13 | 0.2 | 4 | 16.97 | 420 | 320.6 |
| C14 | 0.4 | 4 | 17.45 | 420 | 279.4 |
| C15 | 0.6 | 4 | 18.2 | 420 | 238 |
| C16 | 0.8 | 4 | 19.355 | 420 | 197 |
| C17 | 0.2 | 1.25 | 8.22 | 170 | 28.4 |
| C18 | 0.4 | 1.25 | 8.32 | 170 | 22.12 |
| C19 | 0.6 | 1.25 | 8.43 | 170 | 15.72 |
| C20 | 0.8 | 1.25 | 7.69 | 170 | 8.13 |
| C21 | 0.2 | 1.25 | 20.31 | 420 | 27.97 |
| C22 | 0.4 | 1.25 | 20.53 | 420 | 21.84 |
| C23 | 0.6 | 1.25 | 20.81 | 420 | 15.45 |
| C24 | 0.8 | 1.25 | 18.98 | 420 | 8.03 |

To determine the effective are, the effective widths are used and that are is multiplied by the critical stress, determine without consideration of slenderness elements to obtain the nominal compressive strength. For cross-section with slender elements local buckling occurs (at isolated locations) and the overall yield strength $F_y$ will be reduced by the factor Q , and the flexure buckling critical strength will be:[AISC Manual section E7 chapter E part 16)

a) When $\frac{KL}{r} \leq 4.71\sqrt{\frac{E}{QFy}}$ $(or\ Fe \geq 0{,}44QFy)$

$$Fcr = \left[0.658^{\frac{QF_y}{F_e}}\right]QF_y$$

b) b) When $\frac{KL}{r} > 4.71\sqrt{\frac{E}{QFy}}$ $(or\ Fe < 0{,}44QFy)$

$$Fcr = 0.877F_e$$

**Where:**

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

Q=1.0 for members with compact and non-compact sections

$Q=Q_s*Q_a$ for members with slender-element sections.

$Q_s=1$ for members with slender-element sections, then $Q= Q_a$.

The reduction factor, $Q_a$, for slender stiffened elements is defined as follows:

$$Q_a = \frac{A_{eff}}{A} \quad \text{(E7-16)}$$

**Where:**

A=total cross-sectional are of member, ($mm^2$).

$A_{eff}$=summation of the effective areas of the cross section based on the reduced effective width $b_e$ (mm).

a) For uniformly compressed slender- elements, with $\frac{b}{t} \geq 1.49\sqrt{\frac{E}{f}}$, except flanges of square and rectangular sections of uniform thickness:

$$b_e = 1.29t\sqrt{\frac{E}{F_y}}\left[1 - \frac{0.34}{(b/t)}\sqrt{\frac{E}{F_y}}\right] \leq b \quad \text{(E7-17)}$$

b) For flange of square and rectangular slender-elements of uniform thickness, with $\frac{b}{t} \geq 1.4\sqrt{\frac{E}{f}}$:

$$b_e = 1.29t\sqrt{\frac{E}{F_y}}\left[1 - \frac{0.38}{(b/t)}\sqrt{\frac{E}{F_y}}\right] \leq b \quad \text{(E7-18)}$$

These requirements are represented graphically in Figure (17)

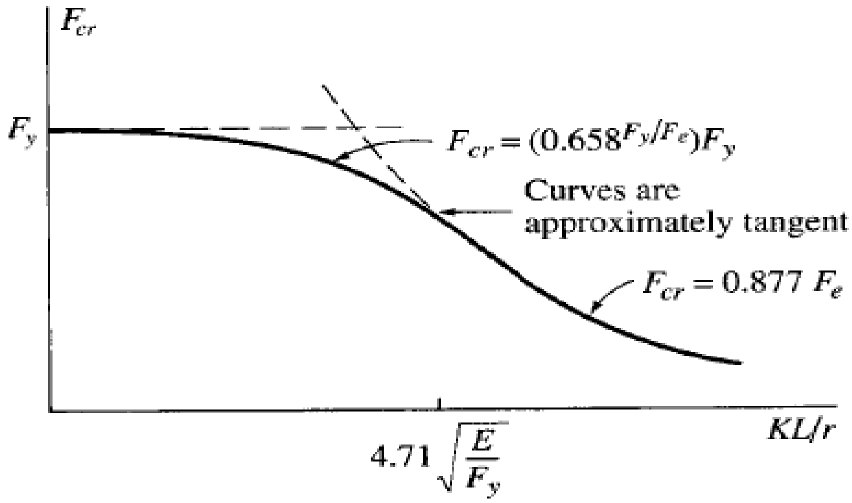



**Figure (17): Requirements of AISC equations for slenderness ratio**

The buckling load versus of RHS column orientation show in Figures.(18), we can comparison the changes in the buckling load with versus thickness and slenderness ratio KL/r . The results show that when the hole position is constant an increase in thickness of column, the local buckling and global buckling occur in the smaller thickness. when he increased the size of the openings, the ultimate load is reduced by 37.37% .

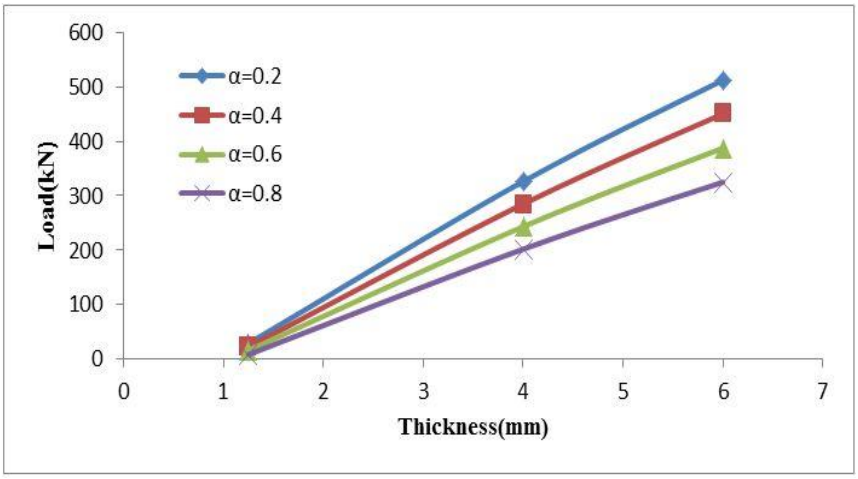



**Figure. (18): Comparison of the buckling capacity of RHS column with variable rectangular hole size (αh*hmm) for different thickness**

### 3.2.2 Critical stresses

The effect of hole size to rate area of cross-section for RHS and the effect of thickness to area ratio(t/A) on the critical stresses and ultimate load are considered in this part. The results of the analyze column were listed in Table(4). The stress-slenderness ratio(KL/r)curve for RHS column is shown in Figure (19).

**Table (4): The results of analyzed columns**

| Specimens | t/A (mm^-1) | $Fcr_{Exp}$(MPa) | Fcr $_{(theo)}$(MPa) |
|---|---|---|---|
| C1 | 0.3801 | 289.2253 | 324.9509 |
| C2 | 0.4327 | 286.2912 | 325.2326 |
| C3 | 0.5022 | 292.1235 | 324.7677 |
| C4 | 0.5984 | 285.6288 | 324.5238 |
| C5 | 0.3801 | 281.2441 | 319.3767 |
| C6 | 0.4327 | 284.9931 | 320.3288 |
| C7 | 0.5022 | 311.7268 | 322.0604 |
| C8 | 0.5984 | 286.2272 | 318.141 |
| C9 | 0.3976 | 288.9662 | 324.6521 |
| C10 | 0.4556 | 292.7107 | 324.6014 |
| C11 | 0.5333 | 282.6667 | 324.4533 |
| C12 | 0.6431 | 285.8521 | 316.1376 |
| C13 | 0.3976 | 257.4553 | 318.6879 |
| C14 | 0.4556 | 274.3394 | 318.2232 |
| C15 | 0.5333 | 282.6267 | 317.3333 |
| C16 | 0.6431 | 295.8199 | 316.7203 |
| C17 | 0.7431 | 143.5111 | 168.8366 |
| C18 | 0.9512 | 149.9125 | 168.3281 |
| C19 | 1.3439 | 148.3711 | 169.0141 |
| C20 | 2.5928 | 143.5387 | 168.6372 |
| C21 | 0.7431 | 147.9698 | 166.2802 |
| C22 | 0.9512 | 146.2598 | 166.1974 |
| C23 | 1.3439 | 147.8336 | 166.1112 |
| C24 | 2.5928 | 166.563 | 165.086464 |

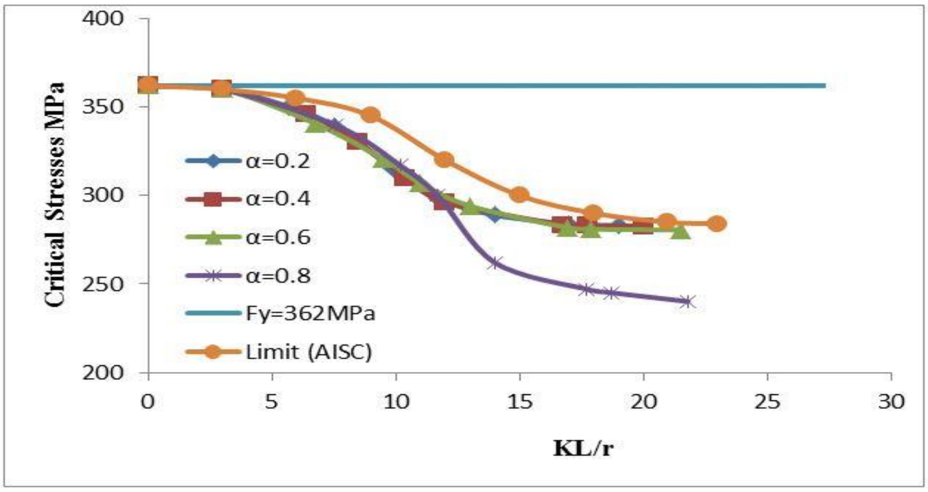



**Figure (19): Critical stresses-Slenderness ratio curve**

In general, for all analyzed column the results showed that the behavior of columns were the same failure by buckling before yielding, after that different behavior were observed. The results explain that the failure of column with thickness (1.25)mm was due to local buckling and clear about the hole. For RHS column the best behavior can be obtain with hole size equal to (0.4h*h)mm. The effect for increasing of slendeness ratio and thickness to area ratio(t/A) leading to decreacing the critical stresses and the failure of column with large size of hole and (t/A) ratio less than 0.74% was due to lacal while the global buckling failure was abserve for column with small size of hole and (t/A) ratio above than 0.74%.

## 5. Conclusions

From the results of RHS columns analysis, the following conclusions can be obtained:

- ❖ The typical failure mode for all the tested hollow specimen was the local buckling.
- ❖ The tested results indicated that the increasing of hole dimension leads to reduction in ultimate loads of tested column to 75%.
- ❖ The results show the reducing of load by 94.7% due to decreasing the thickness of column while the hole size is constant (0.2*80*80).
- ❖ Also it can be seen a good convergence with the AISC limits for the nominal yielding compressive strength when thickness of column decreasing.
- ❖ The increasing of hole's number has significant effect on the ultimate loads and deformation of tested columns, decreasing of load capacity by 88.74%, but length of column has limited effect on the ultimate loads and deformation of tested columns.
- ❖ The hole with dimension 0.4 of column's length and high (250mm) lead to reduction of ultimate load by 86.95% is the same reduction when the hole with dimension 0.2 of column's length and high (500mm).
- ❖ Holes can be made in the middle of column with dimension up to 0.4 of column's length.
- ❖ When the hole position is constant an increase in thickness of column, the local buckling and global buckling occur in the smaller thickness. when he increased the size of the openings, the ultimate load is reduced by 37.37% .
- ❖ The best behavior can be obtain with hole size equal to (0.4h*h)mm.
- ❖ The effect for increasing of slendeness ratio and thickness to area ratio(t/A) leading to decreacing the critical stresses and the failure of column with large size of hole and (t/A) ratio less than 0.74% was due to lacal while the global buckling failure was abserve for column with small size of hole and (t/A) ratio above than 0.74%.

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