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Nonlinear analysis of hollow slender reinforced concrete columns under eccentric loading

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Abstract

In this paper the behavior of slender reinforced concrete columns with longitudinal hole under axial compression load and uniaxial bending was investigated. The specimens of the research includes the analysis of eight slender columns of dimensions (150×150×1300 mm). the nonlinear finite element analysis has been carried out using ANSYS computer program (version 16.1) to simulate the behavior of reinforced concrete slender columns with longitudinal hole. Two parameters are considered (longitudinal steel ratio of the column longitudinal bars and grade of longitudinal steel reinforcement(fy)). The results showed that when the steel ratio is increased in hollow reinforced concrete slender columns, the ultimate load is appreciable increased. Four different values of steel ratios (1.6%,2.3%,3.2% and 4.2%) were used in the numerical analysis, the ultimate load is increased by(0.00%,7.14%, 17.59% and 35.51%) respectively. Also, the increase in the steel ratio resulted in decreasing the tensile steel stresses specially at the tension face of the slender column which finally leads to increase the load carrying capacity. The finite element solution revealed that the effect of using different values of yield stress was insignificant at early stages of loading and almost all the numerical columns had the same values of deflections and stresses at the same load level up to a tensile stress value in steel about 300 MPa. At stages close to ultimate load, deflections and tensile stress values were different for the considered numerical columns. , it was noted that, the selected four grades of steel (350, 450, 550 and 650) MPa led to increase the ultimate load by about (0.00%,19.98%, 31.97%, 41.12%) respectively.

Keywords: columns, slender column, long column, hollowsection, eccentricity.

الخلاصة

تناول هذا البحث سلوك الاعمدة الخرسانية المسلحة النحيفة والمجوفة تحت تأثير حمل انضغاط محوري و عزم احادي المحور. عينات البحث تتضمن فحص ثمانية اعمدة بأبعاد (150*150*1300ملم). استعمل التحليل العددي اللا خطي بالاستعانة بطريقة العناصر المحددة بواسطة برنامج الحاسوب (ANSYS 16.1) ليحاكي سلوك الاعمدة النحيفة الخرسانية المسلحة والمجوفة. تم دراسة متغيرين هما نسبة حديد التسليح الطولي و اجهاد الخضوع لحديد التسليح الطولي. وجد بان زيادة نسبة حديد التسليح في الاعمدة الخرسانية المسلحة النحيفة والمجوفة بالمقادير (1,6%و 2,3%و 3,2% و4,2%) تزيد الحمل الاقصى بالنسب (0,0%، 7,1%، 17,6%، 35,5%). وكذلك وجد بان زيادة نسبه حديد التسلح الطولي ادت الى نقصان في اجهادات حديد الشد في جانب الشد في الاعمدة النحيفة وبالتالي ادى الى زيادة الحمل الاقصى للعمود. كما وافصح التحليل العددي بان تاثير اجهاد الخضوع للحديد الطولي غير مؤثر في المراحل المبكرة للتحميل من حيث قيم الانفعالات والاجهادات المتولدة في العمود الى ان يبلغ اجهاد الشد (300 ميكا باسكال). وعند اقتراب الحمل المسلط من الحمل الاقصى عندها يبدأ اختلاف قيم الانفعالات والاجهادات. لوحظ بان الانواع الاربعة من اجهادات الخضوع للحديد (350،450، 550، 650 ميكا باسكال) ادت الى زيادة الحمل الاقصى بحوالي (0.0%، 20% ، 32% ، 41,5%) بالتتابع.

1- Introduction

In order to maximize structural efficiency in term of strength/mass and stiffness/mass ratios and to reduce contribution of the column to seismic response and high carrying demand on foundation, it is desirable to use hollow cross section for columns [1]. In location where the cost of concrete is relatively high, or in situations where the weight of concrete members is to be kept at a minimum, it may be economical to use hollow reinforced concrete columns [2].Also, transverse openings and longitudinal holes are often provided in reinforced concrete columns to allow access for services such as pipes for plumbing and electric wiring [3]. Many researches are primarily aimed to model the load- deflection behavior of the reinforced concrete columns. **Xie et al.** [4]**,** presented a three-dimensional finite element simulation of high strength concrete tied short columns with a rectangular cross-section under eccentric load. The model assumed that concrete behaves elastically as long as the stress lies within an initial yield surface. **Claeson and Gylltoft** [5], carried out an experimental study for the behavior of reinforced concrete short columns and the results of a nonlinear finite element analysis were presented. Twelve full-scale columns with square sections were tested under eccentric monotonic loading. The effect of parameters such as concrete compressive strength, spacing of ties. **Foster et al.** [6], presented an axisymmetric finite element model to analyze confined reinforced concrete short columns. A numerical example of three 400mm diameter circular reinforced concrete columns under axial concentric compression was also presented. **Al-Janabi** [7], carried out a finite element analysis using a three-dimensional nonlinear finite element model to analyze short reinforced concrete columns were subjected to eccentric compressive loads. The finite element solutions revealed that when using higher concrete compressive strength the load capacity increased. **Dowell and Dunham** [8] presented a nonlinear finite element model to study the axial load behavior of short concrete columns confined by conventional transverse reinforcement. The finite element methodology presented in their work to determine the confined concrete strength at each integration point from the existing confining stresses and then the current stress in the principal direction was found from the stress-strain curve. **Mohammed** [9] presented nonlinear finite element models for the analysis of confined short concrete columns. The three-dimensional 20-node brick element has been used to represent the confined concrete core, while the outer confining material has been modeled using the two-dimensional 8-node shell element. The models were used to investigate the overall structural behavior and load carrying capacity of concrete columns confined with steel tube and fiber reinforced polymer (FRP) with or without ordinary steel reinforcement.

This research was devoted to study the effect of two important material parameters on the nonlinear finite element analysis of reinforced concrete slender columns with longitudinal holes under eccentric loading. The parameters considered in this study were the longitudinal steel ratio, steel reinforcement yield strength. Columns were analyzed by ANSYS (16.1) software program. These parameters are explained below:-

1- Influence of longitudinal steel ratio of column longitudinal bars (ρ)was studied using different diameters of bars (area of steel). Four bar diameters and steel ratios were considered (10, 12 , 14 and

16)mm bar size which results in steel ratio of (1.6%,2.3%,3.2% and 4.2%) respectively.

2- Influence of grade of longitudinal steel reinforcement(fy). Four grades of steel were used (350,450,550 and 650) MP.

2- Materials and methods

2-1 Properties of referenced slender columns (geometric aspects)

In order to obtain accurate results for the effect of each of the mentioned parameters on the structural behavior and load carrying capacity of the slender columns, columns must be considered with specified values for the selected parameters. The effect of using different value for one parameter was made possible by keeping the values of the remaining parameters constant. For this purpose, the guide slender column section shown in Fig.(1). Table (1) represents reference column characteristic (geometric aspects).

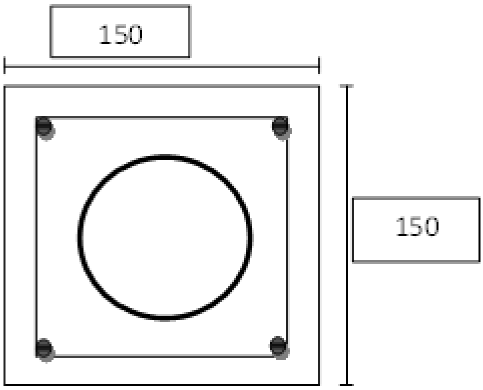


Fig (1) Cross section of the reference column

Table (1) Reference columns characteristic (geometric aspects)

Geometric properties	
Type of column	slender

Effective length of column (Le)	1300 mm
Dimension of cross section columns	150*150 mm
diameter of hole (D)	50.8 mm
Hole location	center of column
Longitudinal bars location	4 longtudinal bars at column corner
Ties	ϕ 6 @ 100 mmc/c
Clear cover	20 mm

All numerical columns including the reference column were analyzed by (ANSYS 16.1 Computer Program). Fig. (2) represents modeling and meshing of the analyzed columns.

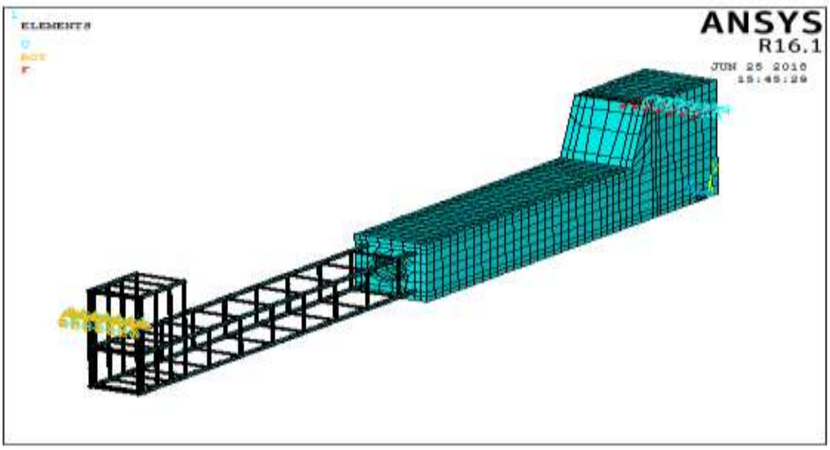


Fig (2) Modeling and meshing of the analyzed columns.

3-Results and discussion

3-1 Influence of longitudinal steel ratio on the behavior of slender column

This section deals with the effect of using different values of steel ratios of the numerical column longitudinal reinforcement on the load carrying capacity, mid-height lateral deflection and shortening of columns. Effect of steel ratio on tensile and compressive stresses in a main steel bars was also discussed. Four ratios for the column reinforcement were considered (1.6%, 2.3% , 3.2%, 4.2%).

Table (2) presents material properties for columns (CF1, CF2, CF3 and CF4) used in the finite element analysis.

To investigate the effect of steel ratio, columns with high eccentricity value must be considered. Therefore, columns were analyzed under150 mm load eccentricity. The values of all other parameters were kept constants. Four values of steel reinforcement ratio were considered 1.6%, 2.3%, 3.2%, 9%, and 4.2%, (diameters of 10, 12, 14 and 16mm bars) respectively. The analyzed four columns had the same geometric properties of the reference column.

Table (2) Material properties for numerical columns (CF1, CF2, CF3 and CF4)

Material properties	
Concrete	
grade of concrete	30 MPa
Poisons' ratio	0.3
Modulus of elasticity	25743 MPa
ft	3.4 MPa
Steel reinforcement	
fy	350 MPa
Modulus of elasticity of steel reinforcement	200000 MPa
Hardening parameter of steel reinforcement	0%

Table (3) presents the numerical ultimate loads and max. lateral deflection at mid height and column shortening for columns (CF1, CF2, CF3 and CF4).

Table (3) Ultimate loads and max. deflections of numerical columns (CF1,CF2,CF3 and CF4)

Numerical column designatio	longitudinal steel ratio (ρ)	Numerical ultimate load	% increase in ultimate load	Max. lateral mid-height deflectio	Max. column longitudinal shortening

n		p_u(kN)		n (mm)	(mm)
CF1	1.6%	58.15	---------	9.79	1.77
CF2	2.3%	62.3	7.14%	8.34	1.6
CF3	3.2%	68.38	17.59%	7.46	1.45
CF4	4.2%	78.8	35.51%	7.13	1.33

Figs. (3) and (4) exhibit the effect of vertical load on lateral mid height deflection and longitudinal shortening of the considered numerical columns (CF1,CF2, CF3 and CF4) respectively. Fig. (5) shows the finite element tensile stresses in steel bars at mid height versus the applied load for numerical columns (CF1,CF2,CF3 and CF4) where the steel ratio (ρ) of columns were (1.6%, 2.3%, 3.2% and 4.2%) respectively.Fig. (6), illustrates the finite element compressive stresses in steel bars at mid height versus the applied load for numerical columns (CF1,CF2,CF3 and CF4) where the area steel ratio (ρ) of columns were (1.6%, 2.3%, 3.2% and 4.2%) respectively. Figs. (7), (8), (9) and (10), show comparison between numerical tensile and compressive stresses in steel bars at mid height for each considered column versus the applied load (columns CF1,CF2,CF3 and CF4) where the steel ratio ρ of columns reinforcement were (1.6%, 2.3%, 3.2% and 4.2%) respectively.

Four numerical column specimens were characterized by the formation of cracks at the tension face followed by yielding of tension reinforcement and shifting of the neutral axis towards the compression side.

Cracking at tension face appeared at small value of loading because of the large value of eccentricity which led to increase the value of bending moment. The first crack appeared at (0.15 - 0.2) of P_u. Therefore, the moment had dominated effect rather than the axial load.

Appearing of the first crack at small value of applied load led to decrease the value of cracked moment of inertia (I_{cr}). Therefore, the column failed at small value of applied load.

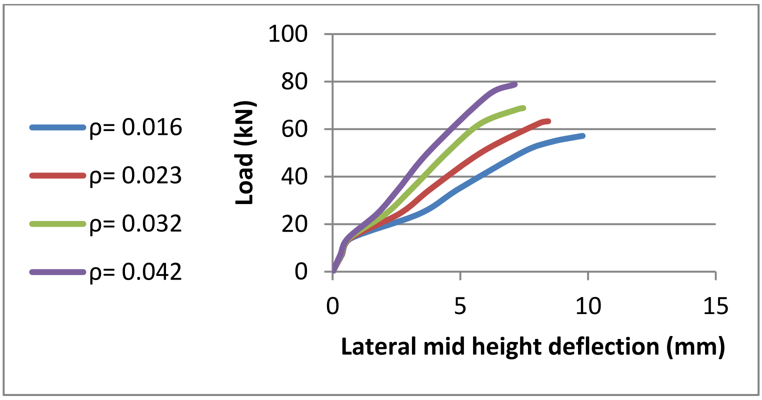


Fig. (3) Effect of vertical load on lateral mid height deflection of numerical columns (CF1,CF2, CF3 and CF4)

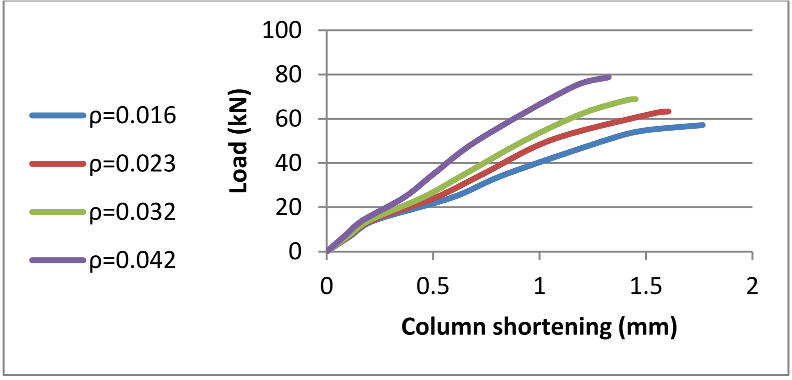


Fig. (4) Effect of vertical load on column shortening for numerical columns (CF1,CF2, CF3 and CF4)

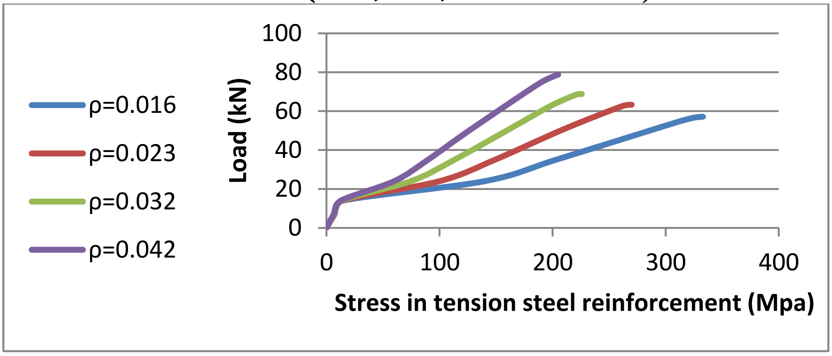


Fig. (5) Finite element tensile stresses in steel bars at mid height versus applied load for numerical columns (CF1,CF2, CF3 and CF4)

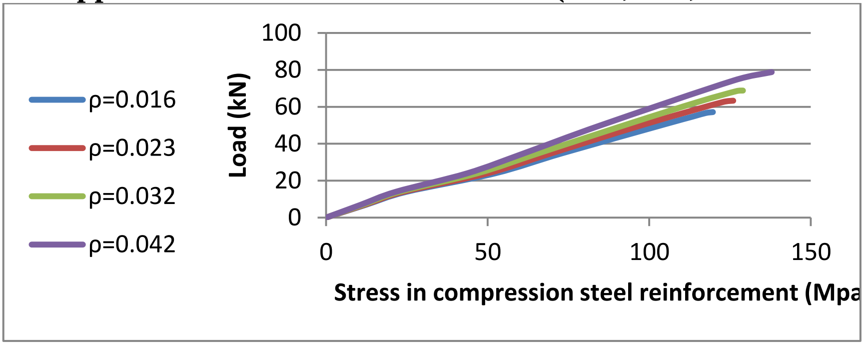


Fig. (6) Finite element compressive stress in steel bars at mid height versus applied load for numerical column (CF1,CF2, CF3 and CF4)

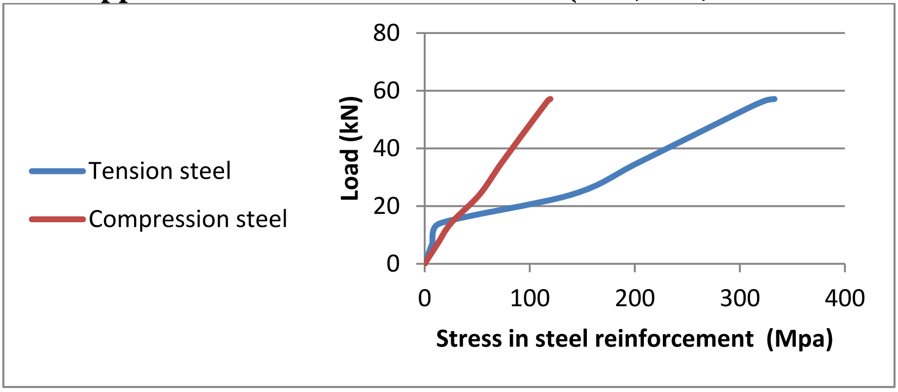


Fig. (7) Finite element stresses in steel bars at mid height versus load for numerical column CF1 (ρ=1.6%)

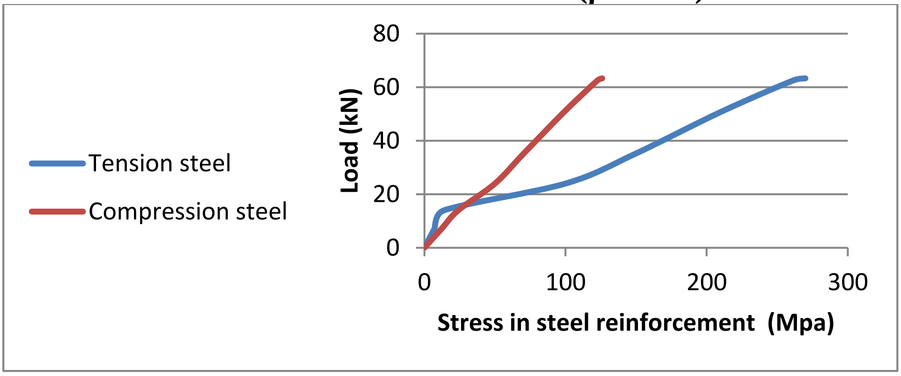


Fig. (8) Finite element stresses in steel bars at mid height versus load for numerical column CF2 (ρ=2.3%)

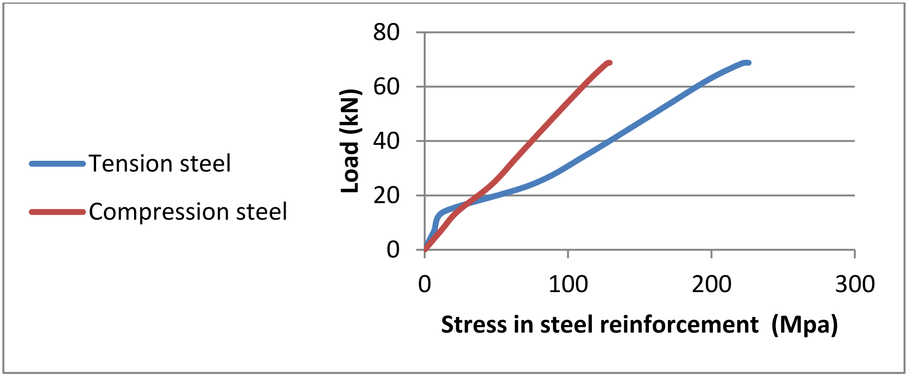


Fig. (9) Finite element stresses in steel bars at mid height versus load for numerical column CF3 (ρ=3.2%)

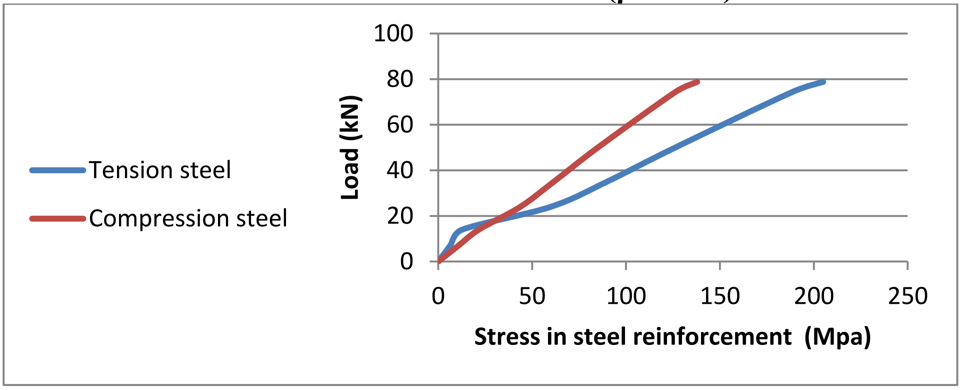
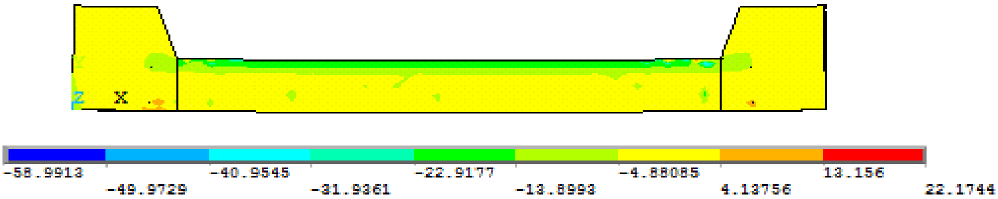
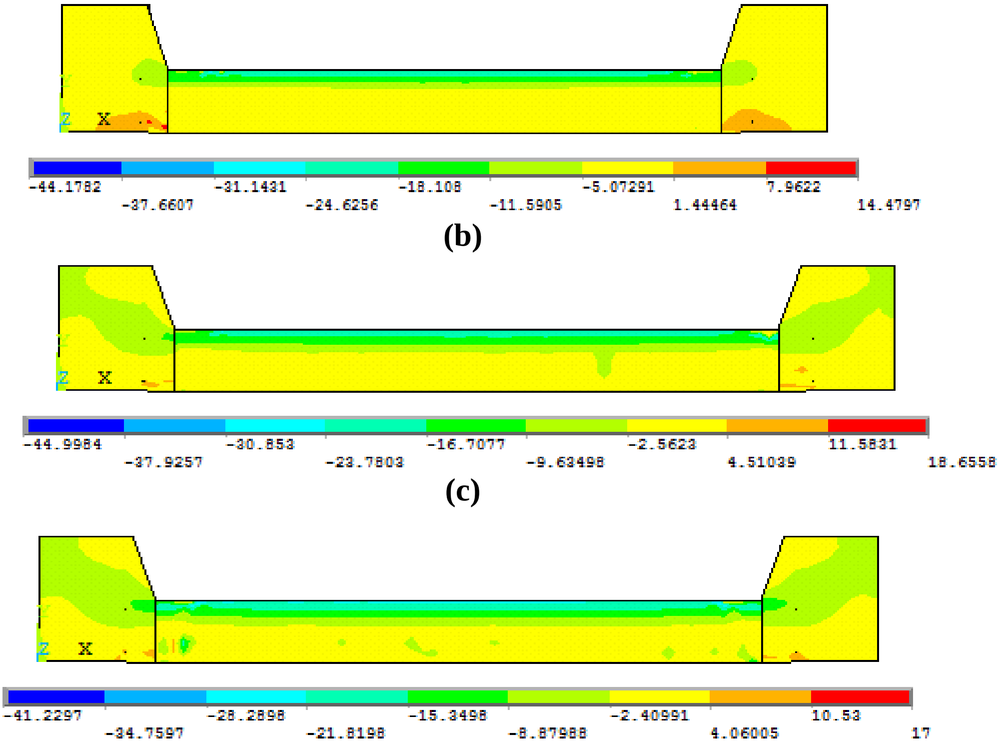


Fig. (10) Finite element stresses in steel bars at mid height versus load for numerical column CF4 (ρ=4.2%)

Figs. (11) exhibits stress distribution in longitudinal x- direction of numerical columns (CF1,CF2,CF3 and CF4) at ultimate load level respectively. Figs. (12) shows crack pattern of numerical column (CF1) obtained at ultimate load stage.



(a)



(b)

(c)

(d)

Fig. (11) Stress distribution in longitudinal direction of numerical columns at ultimate load level
(a) CF1, (b) CF2, (c) CF3 (d) CF4

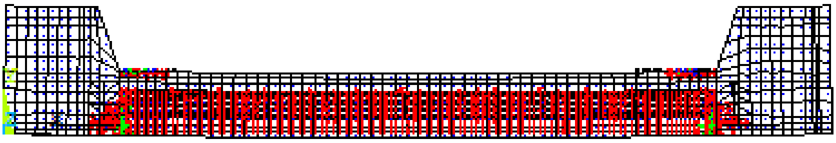


Fig. (12) Crack pattern of numerical column CF1 at ultimate load level.

3-2 Influence of grade of steel bars on the behavior of numerical slender columns

This section deals with the effect of yielding stress value of the numerical columns longitudinal reinforcement on the load capacity, mid-height deflection and shortening of the columns. Also the effect of yielding stress on the tensile and compressive stresses in the main steel reinforcement is discussed. Four types of yielding stress values for the columns reinforcement were considered (350, 450, 550 and 650) MPa. Table (4) represents material properties for numerical columns (CF5, CF5, CF7 and CF8) used in the finite element analysis. To investigate effect yielding stress of longitudinal steel bars, the column must be loaded a high load eccentricity value in order to obtain large tensile stresses at steel located close to tension face. The four selected columns have been analyzed under150 mm load eccentricity. The values of all other parameters were kept constants. The selected values of yielding stress in steel reinforcement were (350, 450, 550 and 650)MPa. The analyzed columns had the same geometric properties of the reference column. Table (4) shows material properties used for analyzing columns (CF5,CF6,CF7 and CF8).

Table (4) Material properties for numerical columns (CF5,CF6,CF7 and CF8)

Material properties		
Concrete		
Grade of concrete	50 MPa	
Poisons' ratio	0.3	
Modulus of elasticity	33234 MPa	
ft	4.38 MPa	
Steel reinforcement		
Modulus of elasticity of steel reinforcement	200000 MPa	
Hardening parameter of	0%	

steel reinforcement		

Table (5) represents numerical ultimate loads and lateral deflection at mid height and shortening for numerical columns (CF5,CF6,CF7 and CF8).

Table (5) Ultimate loads and max. deflections of numerical columns (CF5,CF6,CF7 and CF8)

Numerical column designation	Yielding stress of steel reinforcement (MPa)	Numerical ultimate load p_u(kN)	% increase in ultimate load	Max. lateral mid height deflection (mm)	Max. column longitudinal shortening (mm)
CF5	350	70.06	--------	10.82	1.85
CF6	450	84.06	19.98%	12.85	2.16
CF7	550	92.46	31.97%	14.09	2.45
CF8	650	98.93	41.12%	15.03	2.72

Fig. (13), (14) exhibit the effect of vertical load on lateral mid height deflection and shortening of numerical columns (CF5, CF6, CF7 and CF8) respectively. Fig. (15) represents the finite element tensile stresses in steel bars at mid height versus the applied load for numerical columns (CF5, CF6 ,CF7 and CF8), where the longitudinal yielding steel reinforcement of columns were (350, 450, 550 and 650) MPa respectively. Fig. (16) represents the finite element compressive stresses in steel bars at mid height versus the applied load for columns (CF5,CF6,CF7,CF8) where the longitudinal yielding steel reinforcement of columns were (350, 450, 550 and 650) MPa respectively.Figs. (17), (18), (19) and (20) represent comparison between numerical tensile and compressive stresses in steel bars at mid height for each considered column versus the applied load (columns CF5, CF6, CF7 and CF8) where the longitudinal yielding steel reinforcement of numerical columns were (350, 450, 550 and 650) MPa respectively.

Effect of yield stress value was investigated with 50 MPa concrete compressive strength. This value of compressive strength delayed the appearance of the first crack. According to the finite element results, only the steel bars of three columns (CF5,CF6 and CF7) (350, 450 and 550) MPa respectively reach yield stress. However, the tensile stress in column CF8 (650)MPa reaches to 610 MPa. It is worth noted that as the applied load increases, the tension stress remains constant at yield value at ultimate load.

The yield stress value had no effect on the first crack initiation, therefore, the first crack appeared at the same value of load (14.3 MPa).

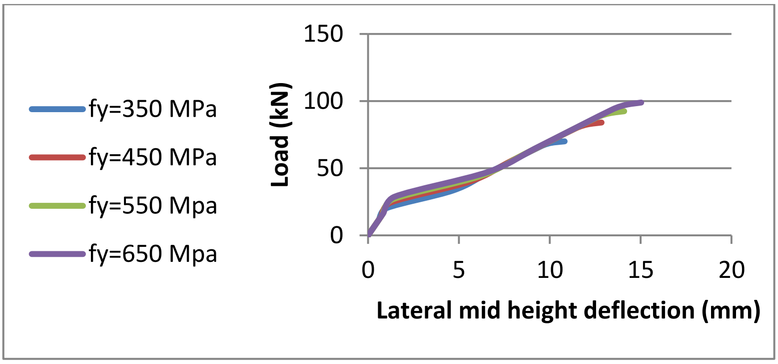


Fig. (13) Effect of vertical load on lateral mid height deflection for numerical columns (CF5,CF6, CF7 and CF8)

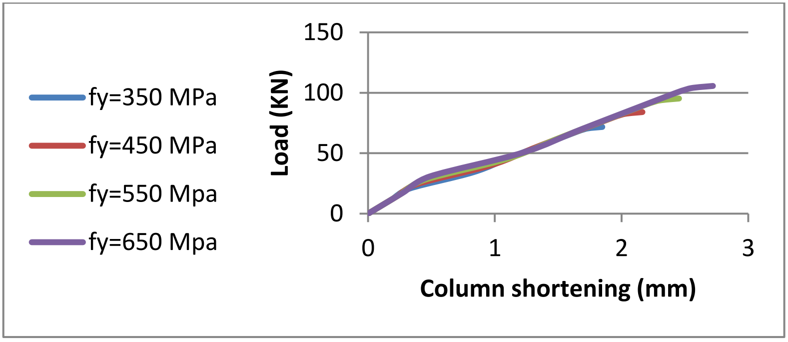


Fig. (14) Effect of vertical load on column shortening for numerical columns (CF5,CF6, CF7 and CF8)

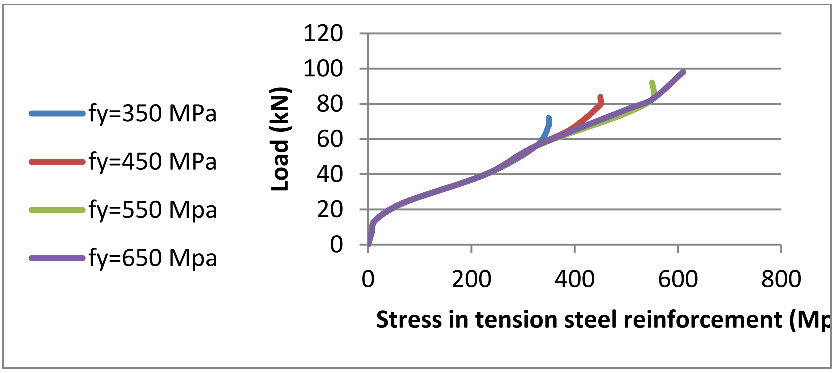


Fig. (15) Finite element tensile stresses in steel bars at mid height versus applied load for numerical columns (CF5,CF6, CF7 and CF8)

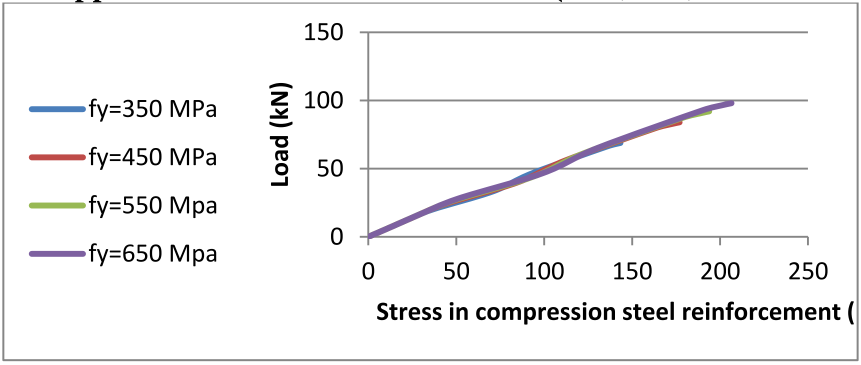


Fig. (16) Finite element compressive stresses in steel bars at mid height versus load for numerical columns (CF5,CF6, CF7 and CF8)

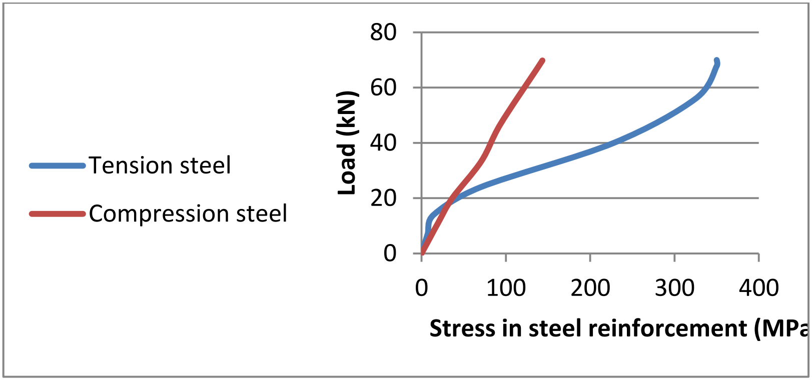


Fig. (17) Finite element stress in steel bars at mid height versus load for numerical column CF5 (fy = 350 MPa)

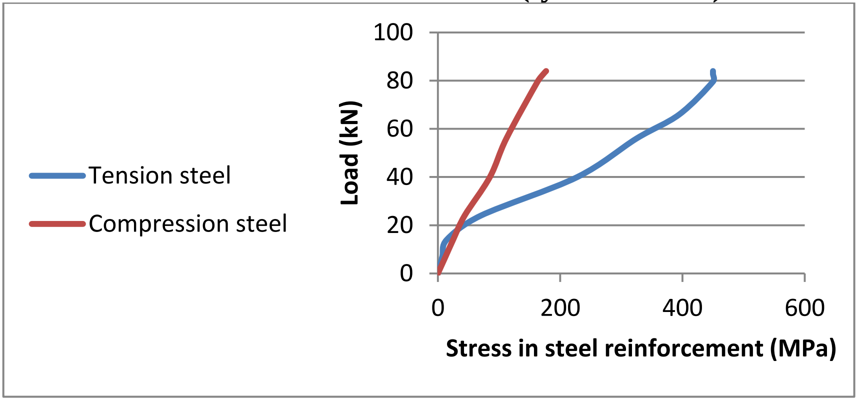


Fig. (18) Finite element stress in steel bars at mid height versus load for numerical column CF6 (fy = 450 MPa)

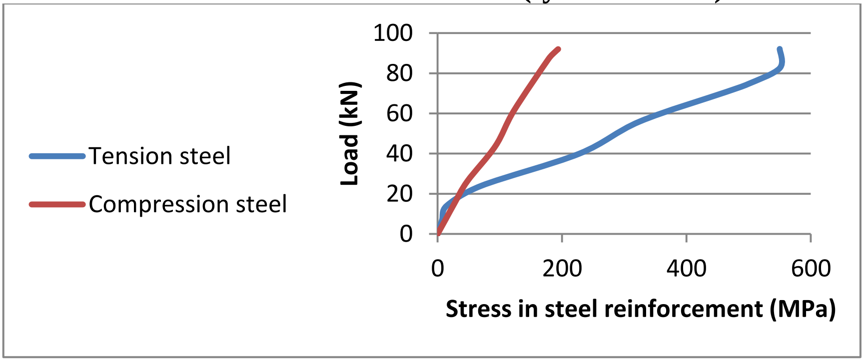


Fig. (19) Finite element stress in steel bars at mid height versus load for numerical column CF7 (fy = 550 MPa)

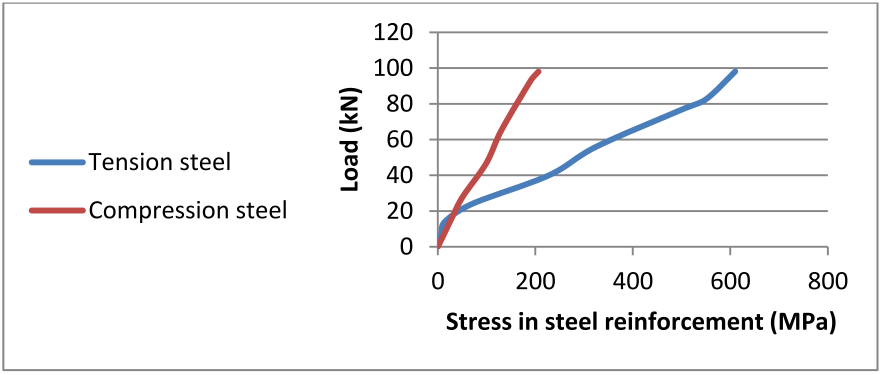
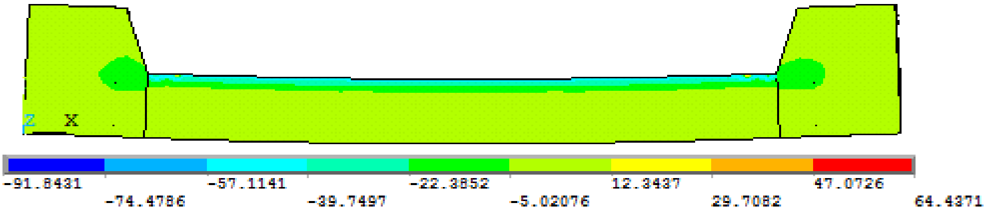
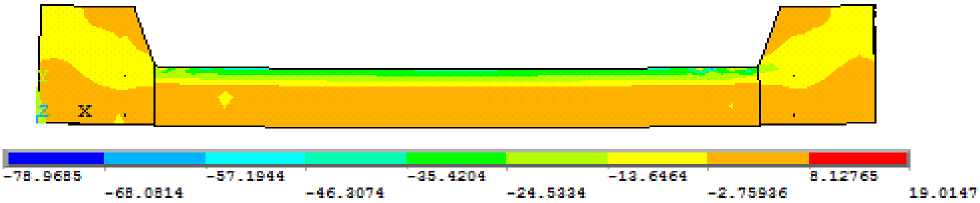


Fig. (20) Finite element stress in steel bars at mid height versus load for numerical column CF8 (fy = 650 MPa)

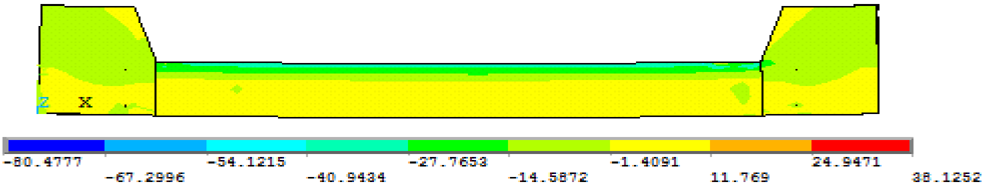
Figs. (21) represent stress distribution in longitudinal x- direction of numerical columns (CF1,CF2,CF3 and CF4) at ultimate load level respectively. Figs. (32) represent crack pattern of numerical columns (CF1,CF2,CF3 andCF4) obtained at ultimate load level respectively.



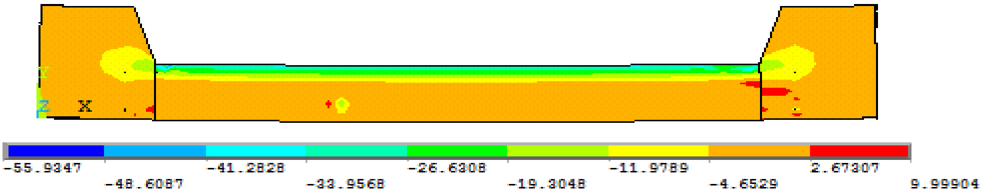
(a)



(b)



(c)



(d)

Fig. (21) Stress distribution in longitudinal x- direction of numerical columns at ultimate load level

(a) CF5 (b) CF6 (c) CF7 (d) CF8

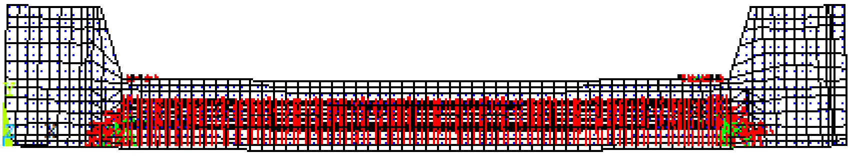


Fig. (22) Crack pattern of numerical column CF5 at ultimate load level.

4- Conclusions

1- The selected four values of steel ratios (1.6%,2.3%,3.2% and 4.2%) led to increase the ultimate load by (0.00%,7.14%, 17.59% and 35.51%) respectively.

2- Increasing the area of steel bars specially at tension face decreases the tensile stresses which leads to control the compression zone and finally increases the load carrying capacity of the slender column.

3- It was found that by increasing the ultimate load in a wide range with increasing the area steel in columns, the lateral mid height deflection and column shortening was decreased with increasing steel ratio.

4- The yield stress value had no effect on the early stages of loading, it was found that all columns had almost the same values and deflections and stress at the same load level up to a stress value in tension steel about 300 MPa. At stages close to ultimate load, deflections and tensile stress value were different for the considered numerical columns.

5- Finally, it can be concluded that, the selected four grades of steel (350, 450, 550 and 650) MPa led to increase the ultimate load by (0.00%,19.98%, 31.97%, 41.12%) respectively.

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