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SOME FACTORS AFFECTING THE AXIAL STATIC BEHAVIOR OF HIGH STRENGTH SHORT REINFORCED CONCRETE COLUMNS-THEORETICAL APPROACH

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In this study, non-linear three dimensional finite element model was utilized to study the confinement of high strength reinforced concrete short columns under axial static loading. The accuracy of the model was verified experimentally in Japan. The parameters affecting the degree of confinement of columns are: grade and quality of used concrete, grade and quality of used main longitudinal reinforcement, presence of longitudinal reinforcement, type of acting load (static or repeated loading), and rate of loading, eccentricity of applied compressive load, slenderness ratio, end condition, concrete cover, shape and size of cross-section, presence of lateral loading, presence of shear stress on columns, confinement of concrete and its factor of efficiency, type and strength of confinement material, volumetric ratio of confining steel and confining reinforced configuration. The current research is focusing on the effect of following parameters upon the static behavior of axial short columns: shape of cross-section either circular, rectangular and square, end boundary condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free), volumetric ratio of confinement ρ_s *as: 0, 1.023%, 1.6225%, and 2.70%, and grade of concrete either,* f_{cu} = 300, 600, 900 kg/cm^2*. The obtained theoretical results are; the axial stress* (f_{cc})*–axial strain* (ε_{cc}) *relationship, the lateral stress* (f_{cl})*–axial strain* (ε_{cc}) *relationship, the axial stress* (f_{cc})*–lateral strain* (ε_{cl}) *relationship, the axial stress* (f_{cc})*–lateral stress* (f_{cl}) *relationship and the axial stain* (ε_{cc}) *–lateral strain* (ε_{cl}) *relationship.*

From the results of the study, it was declared how the previous included parameters are affecting the axial static behavior of confined high strength R.C short columns.

For different volumetric ratios, the strength ratios (f_{cc}/f_{cu}, f_{cl}/f_{cc}, f_{cl}/f_{cu}) *increases with increase of volumetric ratio* (ρ_s) *and the highest strength for circular columns than rectangular columns than that for square columns. Also, the strength ratios decrease with increase grade of concrete* (f_{cu})*.*

For different end condition, the highest strength ratios for square columns at (fixed-fixed) end condition than for circular columns than for square columns both at (hinged-hinged) end condition.

KEYWORDS: *High strength short column; Confinement, Axial static behavior, Longitudinal and lateral reinforcement, Non linear3D finite element, ABAQUS.*

NOTATION

Ag:	gross cross section area of column
b,d :	width and depth of reinforced concrete column rectangular or square section
D:	diameter of reinforced concrete column of circular section
f_{cu}:	specified concrete compressive strength based on standard cylinder test (grade of concrete)
f_{cc}:	maximum compressive strength of core concrete
f_{cl}:	maximum effective (lateral) confining stress
L:	Column length,
ρ_s%:	volumetric ratio of transverse reinforcement
µ%:	longitudinal reinforcement ratio
ε_{cc}:	strain at maximum strength of concrete
ε_{cl}:	lateral strain at (lateral) confining stress

INTRODUCTION

High–strength concrete may offer the most cost-efficient solution for many structural design problems while providing higher strengths and improve durability. The use of HSC is particularly advantageous in compression member. For this reason, the use of HSC in columns and core walls of buildings among other applications is increasing allowing for more rapid construction by attaining higher strength at an earlier age, reducing anchorage length requirement; and higher durability. Also HSC permits early form removal, increasing the speed of construction, lower deflections due to increased modulus of elasticity, lower creep, and greater resistance to physical and chemical deterioration constitute other advantages related to improved performance ***(Salim et al., 1999).*** The use of HSC in columns leads to smaller cross sections, higher load carrying capacity, less reinforcing steel requirements, and less frame work.

The behavior of reinforced concrete columns is generally affected by some main factors as:

1. Grade and quality of concrete and main reinforcement ***Salim (1994),***
2. Type of acting load (static and repeated loading): ***Salim et al. (1994),***
3. Rate of loading: ***Salim (1994).***
4. Eccentricity of applied compressive load and its deformability: ***Natalie (1996), Stephen (2001).***
5. Confinement of concrete columns,
6. Volumetric ratio of transverse reinforcement: ***Salim et al. (1999).***
7. Strength of confinement steel: ***Polat (1992), (Sugano et al., 1990).***
8. Confining reinforcement spacing: ***Salim et al. (1999), (J. Xia et al. 1996).***
9. Confinement reinforcement configuration: ***Li Bing et al. (2001).***
10. Presence of lateral loading and it's direction: ***Watanabe et al. (1987).***

11. Presence of shear stress: ***Abdel-Fattah et al. (1989).***
12. Type of confinement material: ***Mander et al. (1988).***
13. Shape and size of cross-section: ***Salim et al. (1994)*** and
14. Slenderness ratio as well as different end condition: ***CEEN 219 (2002)***

PARAMETERS OF THE STUDY

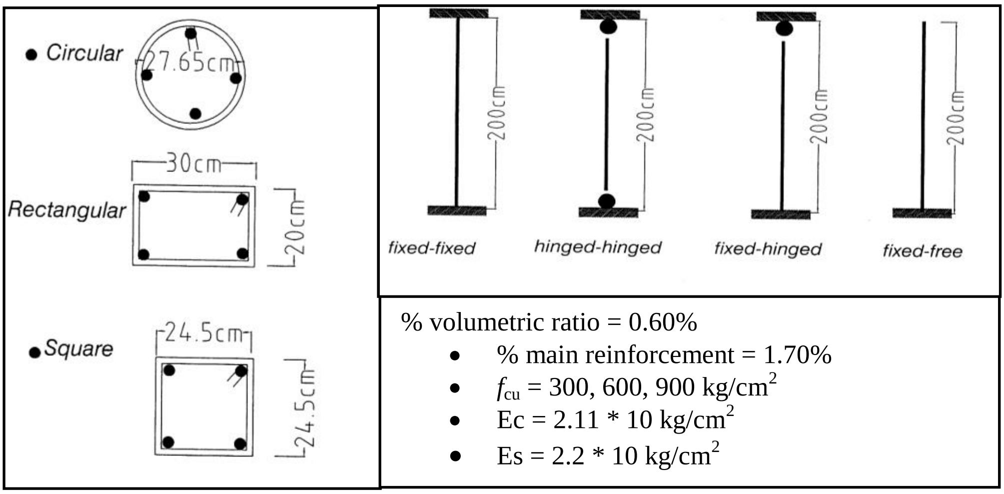
The current research is focusing on studying the effect of following parameters upon the static behavior of axial short columns:

- Shape of cross-section either of circular, rectangular and square,
- End boundary condition either fixed-fixed, hinged-hinged, fixed-hinged and fixed-free,
- Volumetric ratio (ρ_s) of confinement as: 0, 1.023%, 1.6225%, and 2.70%, and
- Grade of concrete either, f_{cu} = 300, 600, 900 kg/cm^2). See **Figs. (1) and (2)**

The properties of the studied 72 columns are summarized in **Tables (1), (2) and (3)** taking all above referred parameters**.**

THEORETICAL APPROACH FOR AXIALLY LOADED R.C COLUMNS:

The modifications were based on an analytical model carried out by ***(Khairy Hassan, 1999)***. In the current study, we used finite element software called ABAQUS. To fulfill the purpose of the above mentioned study 72 R.C short columns were analyzed using the ABAQUS model.



% volumetric ratio = 0.60%

- % main reinforcement = 1.70%
- f_{cu} = 300, 600, 900 kg/cm^2
- Ec = 2.11 * 10 kg/cm^2
- Es = 2.2 * 10 kg/cm^2

Fig.1: End boundary condition

THE OBTAINED THEORETICAL RESULTS

The obtained theoretical results one can evaluate the following relationship for all studied parameters; The axial stress (f_{cc})–axial strain (ε_{cc}) relationship, The lateral stress (f_{cl})– axial strain (ε_{cc}) relationship, The axial stress (f_{cc})–lateral strain (ε_{cl}) relationship, The axial stress (f_{cc})–later stress (f_{cl}) relationship and The axial stain

(ε_{cc})–lateral strain (ε_{cl}) relationship. **Tables (1), (2) and (3)** summarizes the obtained theoretical results of both maximum stresses and strains for the studied columns.

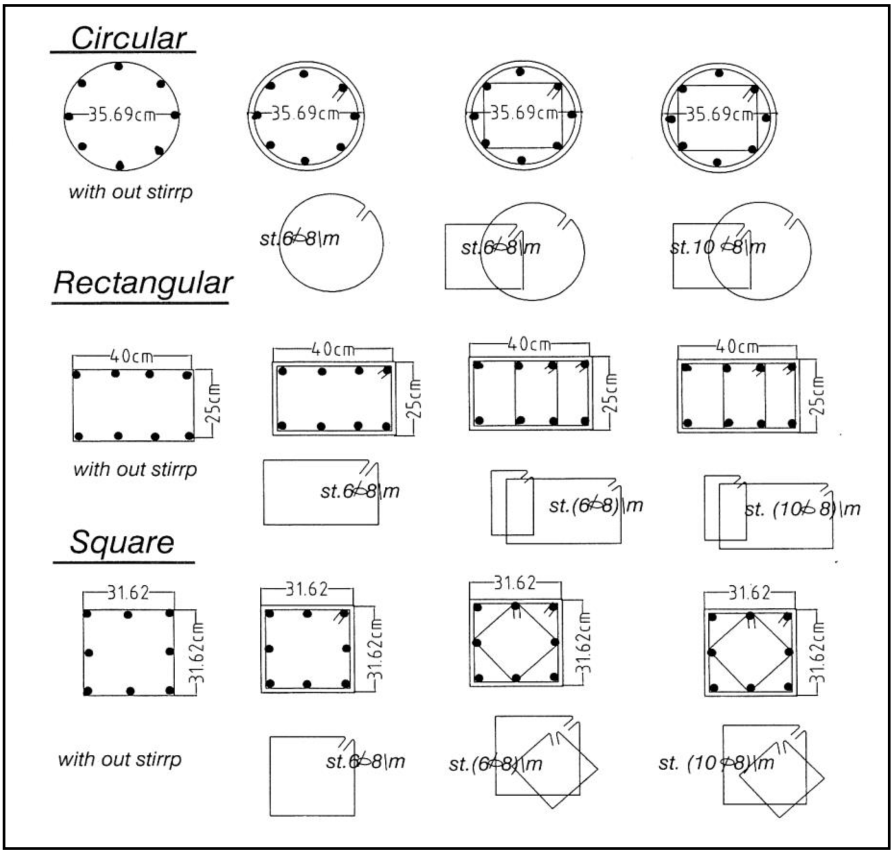


Fig.(2): Confining reinforcement configuration.

1. Axial stress (f_{cc}) – axial strain (ε_{cc}) relationship

Figures (3), (4) and (5), show samples of the obtained axial stress (f_{cc})–axial strain (ε_{cc}) relationships for circular, rectangular and square sections with constant volumetric ratio (ρ_s = 0.6%) using different grades of concrete (f_{cu}=300, 600, 900 Kg/cm^2) for the different end conditions of columns (fixed–fixed, hinged–hinged, fixed– hinged and fixed–free).

Table (1): Properties of Studied R.C Columns for Rectangular Section.

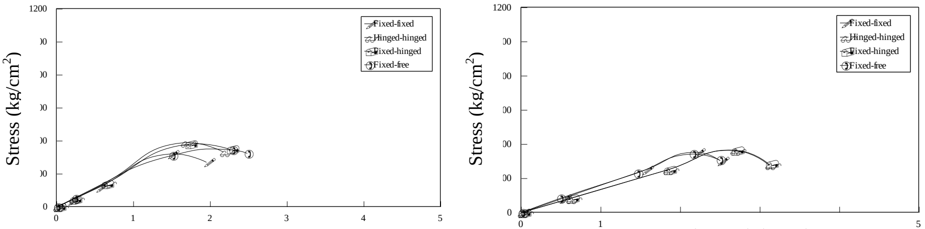
Column No. designation	End condition	Shape of cross section	Height of column (L)cm	Cross-section dimensions		Grade of used concrete f_{cu} kg/cm^2	Longitudinal reinforcement			Transverse reinforcement	
				(b x t) or D (cm)	Ag Cm^2		No. of bars	Area of Reinf. Cm^2	% of Reinf. (μ)	No. of Ties and Diameter of bars (mm)	Volumetric ratio (ρs) %
C1	Fixed-free	Rectangular section	L = 200 cm.	25 x 40	1000	300	8ϕ16	16.08	1.61	-	0
C2	Fixed-free			25 x 40	1000	300	8ϕ16	16.08	1.61	6ϕ 8	1.023
C3	Fixed-free			25 x 40	1000	300	8ϕ16	16.08	1.61	2 x 6 ϕ 8	1.625
C4	Fixed-free			25 x 40	1000	300	8ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C5	Fixed-free			25 x 40	1000	600	8ϕ16	16.08	1.61	-	0
C6	Fixed-free			25 x 40	1000	600	8ϕ16	16.08	1.61	6ϕ 8	1.023
C7	Fixed-free			25 x 40	1000	600	8ϕ16	16.08	1.61	2 x 6 ϕ 8	1.6225
C8	Fixed-free			25 x 40	1000	600	8ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C9	Fixed-free			25 x 40	1000	900	8ϕ16	16.08	1.61	-	0
C10	Fixed-free			25 x 40	1000	900	8ϕ16	16.08	1.61	6ϕ 8	1.023
C11	Fixed-free			25 x 40	1000	900	8ϕ16	16.08	1.61	2 x 6 ϕ 8	1.6225
C12	Fixed-free			25 x 40	1000	900	8ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C13	Fixed-fixed			20 x 30	600	300	4ϕ18	10.17	1.7	6ϕ8	0.6
C14	Hinged-hinged			20 x 30	600	300	4ϕ18	10.17	1.7	6ϕ8	0.6
C15	Fixed-hinged			20 x 30	600	300	4ϕ18	10.17	1.7	6ϕ8	0.6
C16	Fixed-free			20 x 30	600	300	4ϕ18	10.17	1.7	6ϕ8	0.6
C17	Fixed-fixed			20 x 30	600	600	4ϕ18	10.17	1.7	6ϕ8	0.6
C18	Hinged-hinged			20 x 30	600	600	4ϕ18	10.17	1.7	6ϕ8	0.6
C19	Fixed-hinged			20 x 30	600	600	4ϕ18	10.17	1.7	6ϕ8	0.6
C20	Fixed-free			20 x 30	600	600	4ϕ18	10.17	1.7	6ϕ8	0.6
C21	Fixed-fixed			20 x 30	600	900	4ϕ18	10.17	1.7	6ϕ8	0.6
C22	Hinged-hinged			20 x 30	600	900	4ϕ18	10.17	1.7	6ϕ8	0.6
C23	Fixed-hinged			20 x 30	600	900	4ϕ18	10.17	1.7	6ϕ8	0.6
C24	Fixed-free			20 x 30	600	900	4ϕ18	10.17	1.7	6ϕ8	

Table (2): Properties of Studied R.C Columns for Circular Section.

Column No. designation	End condition	Shape of cross section	Height of column (L)cm	Cross-section dimensions		Grade of used concrete f_{cu} kg/cm^2	Longitudinal reinforcement			Transverse reinforcement	
				(b x t) or D (cm)	Ag Cm^2		No. of bars	Area of Reinf. Cm^2	% of Reinf. (μ)	No. of Ties and Diameter of bars (mm)	Volumetric ratio (ρs) %
C25	Fixed-free	CIRCULAR SECTION	L = 200 cm.	35.69	1000	300	8ϕ16	16.08	1.61	-	0
C26	Fixed-free			35.69	1000	300	8ϕ16	16.08	1.61	6 ϕ 8	1.023
C27	Fixed-free			35.69	1000	300	8ϕ16	16.08	1.61	2 (6 ϕ 8)	1.6225
C28	Fixed-free			35.69	1000	300	8ϕ16	16.08	1.61	2(10 ϕ 8)	2.7
C29	Fixed-free			35.69	1000	600	8ϕ16	16.08	1.61	-	0
C30	Fixed-free			35.69	1000	600	8ϕ16	16.08	1.61	6 ϕ 8	1.023
C31	Fixed-free			35.69	1000	600	8ϕ16	16.08	1.61	2 (6 ϕ 8)	1.6225
C32	Fixed-free			35.69	1000	600	8ϕ16	16.08	1.61	2(10 ϕ 8)	2.7
C33	Fixed-free			35.69	1000	900	8ϕ16	16.08	1.61	-	0
C34	Fixed-free			35.69	1000	900	8ϕ16	16.08	1.61	6 ϕ 8	1.023
C35	Fixed-free			35.69	1000	900	8ϕ16	16.08	1.61	2 (6 ϕ 8)	1.6225
C36	Fixed-free			35.69	1000	900	8ϕ16	16.08	1.61	2(10 ϕ 8)	2.7
C37	Fixed-fixed			27.65	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C38	Hinged-hinged			27.65	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C39	Fixed-hinged			27.65	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C40	Fixed-free			27.65	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C41	Fixed-fixed			27.65	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C42	Hinged-hinged			27.65	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C43	Fixed-hinged			27.65	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C44	Fixed-free			27.65	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C45	Fixed-fixed			27.65	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C46	Hinged-hinged			27.65	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C47	Fixed-hinged			27.65	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C48	Fixed-free			27.65	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6

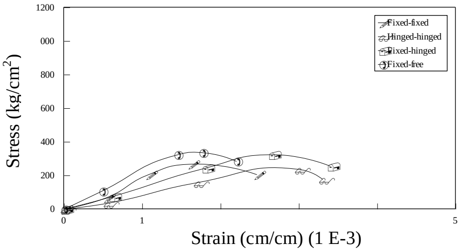
Table (3): Properties of Studied R.C Columns for Square Section.

Column No. designation	End condition	Shape of cross section	Height of column (L)cm	Cross-section dimensions		Grade of used concrete f_{cu} kg/cm^2	Longitudinal reinforcement			Transverse reinforcement	
				(b x t) or D (cm)	Ag Cm^2		No. of bars	Area of Reinf. Cm^2	% of Reinf. (μ)	No. of Ties and Diameter of bars (mm)	Volumetric ratio (ρs) %
C49	Fixed-free	Square SECTION	L = 200 cm.	31.62x31.62	1000	300	4ϕ16	16.08	1.61	-	0
C50	Fixed-free			31.62x31.62	1000	300	4ϕ16	16.08	1.61	6 ϕ 8	1.023
C51	Fixed-free			31.62x31.62	1000	300	4ϕ16	16.08	1.61	2 x 6 ϕ 8	1.6225
C52	Fixed-free			31.62x31.62	1000	300	4ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C53	Fixed-free			31.62x31.62	1000	600	4ϕ16	16.08	1.61	-	0
C54	Fixed-free			31.62x31.62	1000	600	4ϕ16	16.08	1.61	6 ϕ 8	1.023
C55	Fixed-free			31.62x31.62	1000	600	4ϕ16	16.08	1.61	2 x 6 ϕ 8	1.6225
C56	Fixed-free			31.62x31.62	1000	600	4ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C57	Fixed-free			31.62x31.62	1000	900	8ϕ16	16.08	1.61	-	0
C58	Fixed-free			31.62x31.62	1000	900	8ϕ16	16.08	1.61	6 ϕ 8	1.023
C59	Fixed-free			31.62x31.62	1000	900	8ϕ16	16.08	1.61	2 x 6 ϕ 8	1.6225
C60	Fixed-free			31.62x31.62	1000	900	8ϕ16	16.08	1.61	2x10 ϕ 8	2.7
C61	Fixed-fixed			24.5x 24.5	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C62	Hinged-hinged			24.5x 24.5	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C63	Fixed-hinged			24.5x 24.5	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C64	Fixed-free			24.5x 24.5	600	300	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C65	Fixed-fixed			24.5x 24.5	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C66	Hinged-hinged			24.5x 24.5	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C67	Fixed-hinged			24.5x 24.5	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C68	Fixed-free			24.5x 24.5	600	600	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C69	Fixed-fixed			24.5x 24.5	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C70	Hinged-hinged			24.5x 24.5	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C71	Fixed-hinged			24.5x 24.5	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6
C72	Fixed-free			24.5x 24.5	600	900	4ϕ18	10.17	1.7	6 ϕ 8	0.6



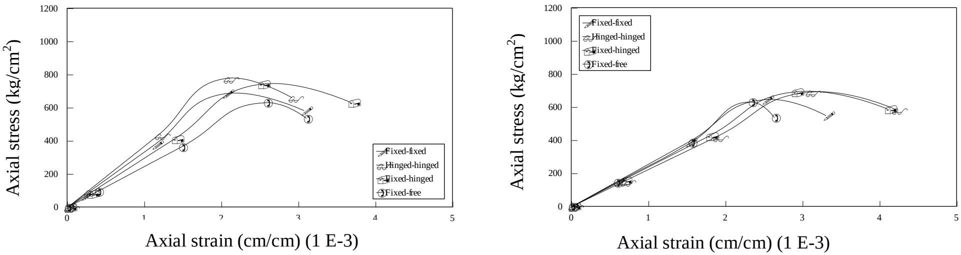
For circular columns

For rectangular columns



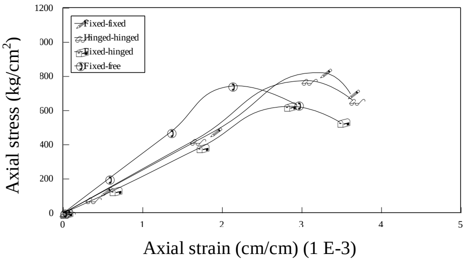
For square columns

Fig. 3: Axial (stress-strain) diagram at different end condition (fixed-fixed, hinged-hinged, fixed-hinged, fixed-free) for different shapes (circular-rectangular -square) at grade of concrete f_{cu} = 300 kg/cm^2 and ρ_s = 0.6%.



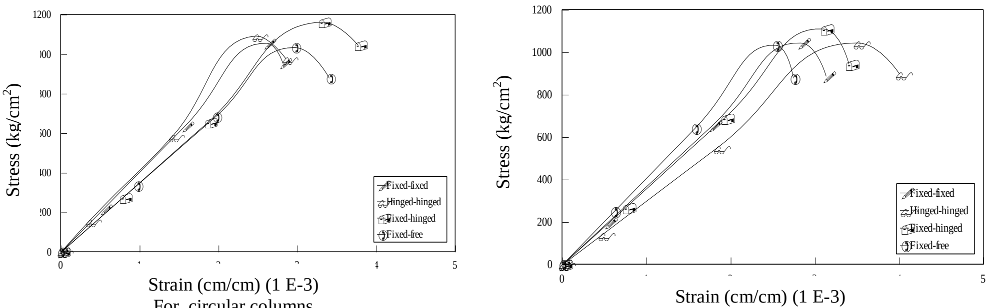
For circular columns

For rectangular columns



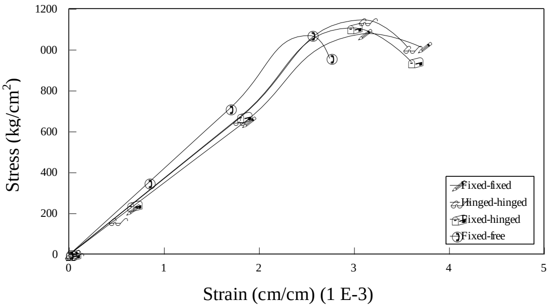
For square columns

Fig. 4: Axial (stress-strain) diagram at different end condition (fixed-fixed, hinged-hinged, fixed-hinged, fixed-free) for different shapes (circular-rectangular -square) at grade of concrete f_{cu} = 600 kg/cm^2 and ρs = 0.6%.



For circular columns

For rectangular columns

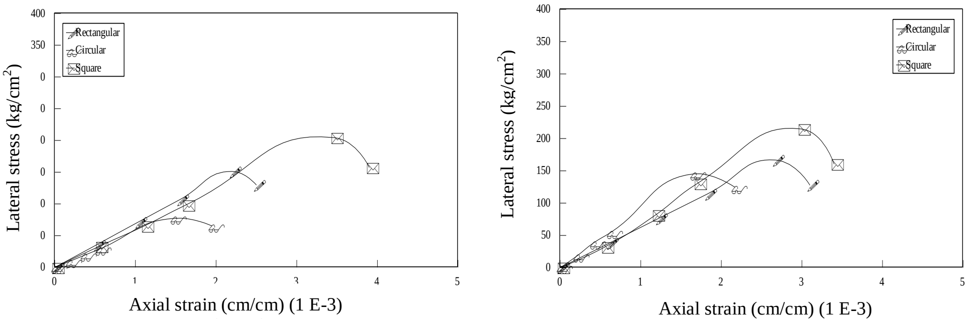


For square columns

Fig.5: Axial (stress-strain) diagram at different end condition (fixed-fixed, hinged-hinged, fixed-hinged, fixed-free) for different shapes (circular-rectangular -square) at grade of concrete f_{cu} = 900 kg/cm^2 and ρ_s = 0.6%.

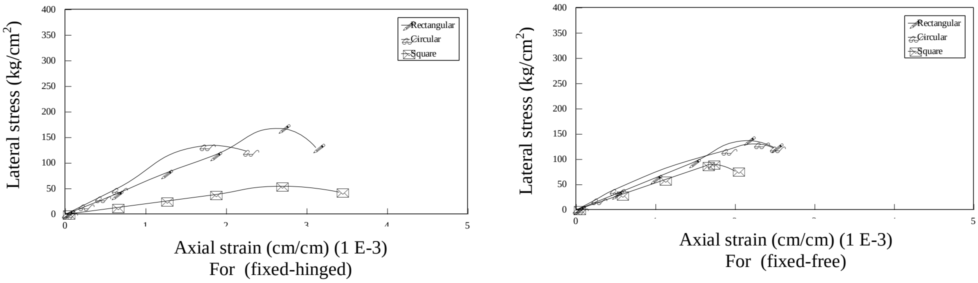
2. Lateral stress (f_{cl})–axial strain (ε_{cc}) relationship:

Figures (6) (7) and (8) show samples of the obtained lateral stress (f_{cl})–axial strain (ε_{cc}) relationships for circular, rectangular and square sections with constant volumetric ratio (ρ_s=0.6%) using different grades of concrete (f_{cu} = 300, 600, 900 kg/cm^2) for the different end condition of columns (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free).



For (fixed-fixed)

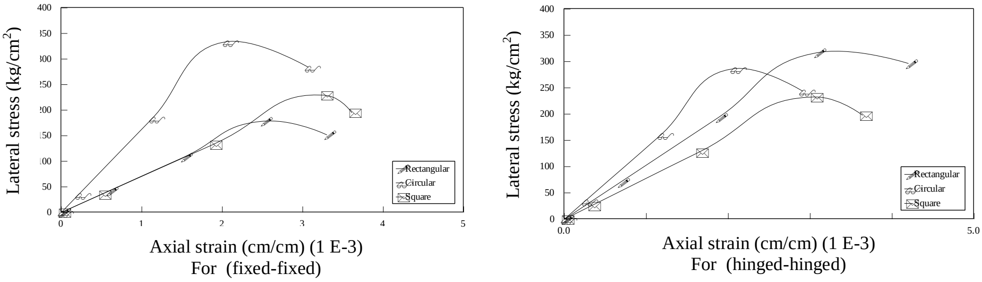
For (hinged-hinged)



For (fixed-hinged)

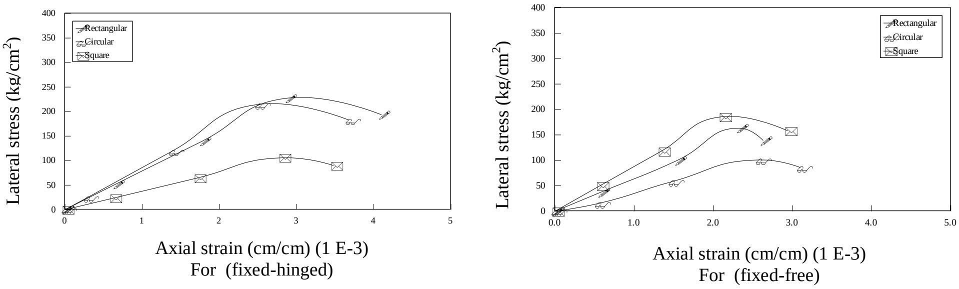
For (fixed-free)

Fig. 6: (Lateral stress–axial strain)) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu}=300 kg/cm^2 and ρ_s=0.6%.



For (fixed-fixed)

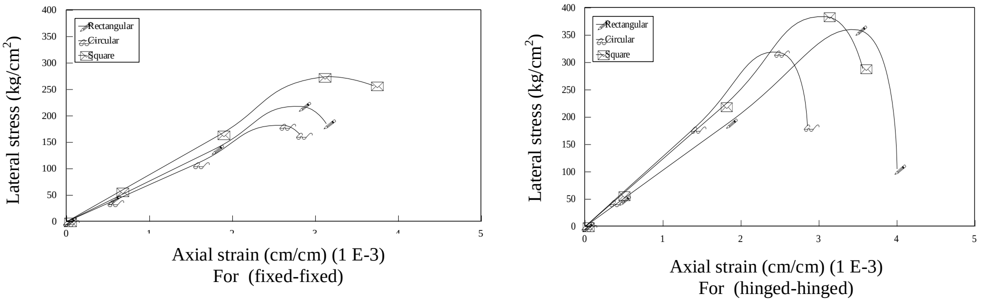
For (hinged-hinged)



For (fixed-hinged)

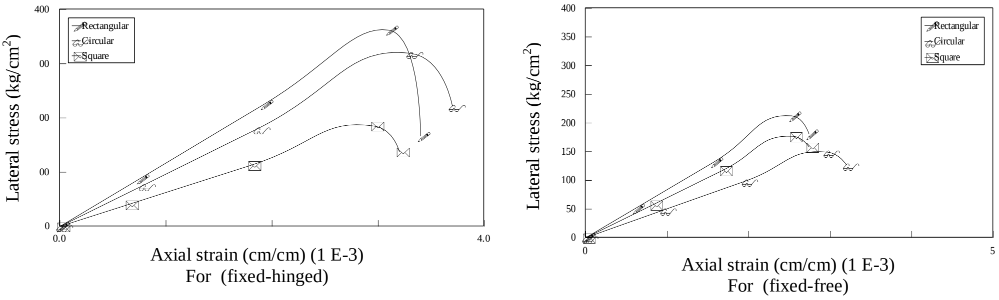
For (fixed-free)

Fig. 7: (Lateral stress–axial strain)) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu}=600 kg/cm^2 and ρ_s=0.6%.



For (fixed-fixed)

For (hinged-hinged)



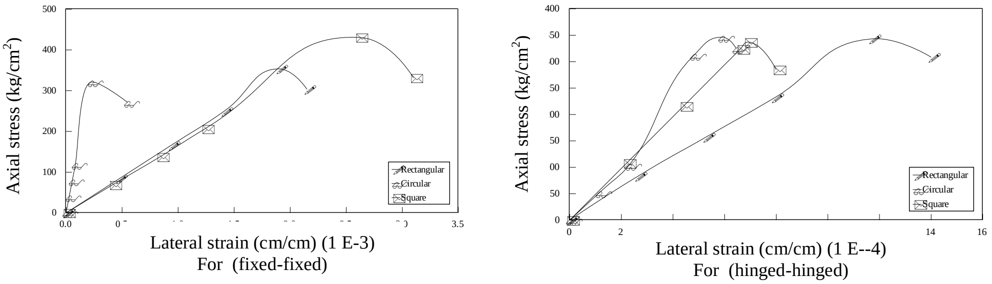
Axial strain (cm/cm) (1 E-3)
For (fixed-hinged)

Axial strain (cm/cm) (1 E-3)
For (fixed-free)

Fig. 8: (Lateral stress–axial strain)) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu}=900 kg/cm^2 and ρ_s=0.6%.

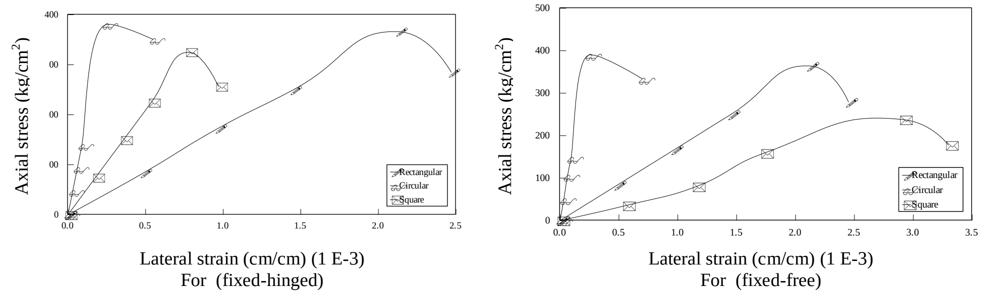
3. Axial stress (f_{cc})–lateral strain (ε_{cl}) relationship:

Figures (9), (10) and (11) show samples of the obtained axial stress (f_{cc})–lateral strain (ε_{cl}), relationships for circular, rectangular and square sections with constant volumetric ratio (ρ_s=0.6%) using different grades of concrete (f_{cu} = 300, 600, 900 kg/cm^2) for the different end condition of columns (fixed–fixed, hinged–hinged, fixed–hinged and fixed–free).



Lateral strain (cm/cm) (1 E-3)
For (fixed-fixed)

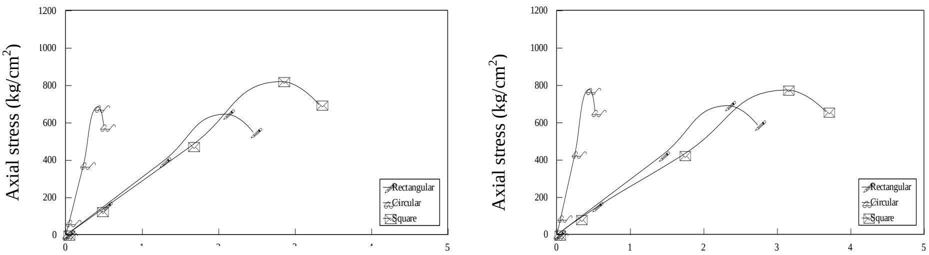
Lateral strain (cm/cm) (1 E--4)
For (hinged-hinged)



Lateral strain (cm/cm) (1 E-3)
For (fixed-hinged)

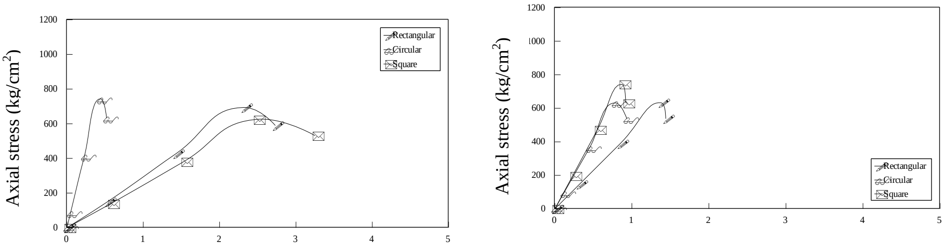
Lateral strain (cm/cm) (1 E-3)
For (fixed-free)

Fig.9: (Axial stress–lateral strain) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 300 kg/cm^2 and ρ_s = 0.6%.



Lateral strain (cm/cm) (1 E-3)
For (fixed-fixed)

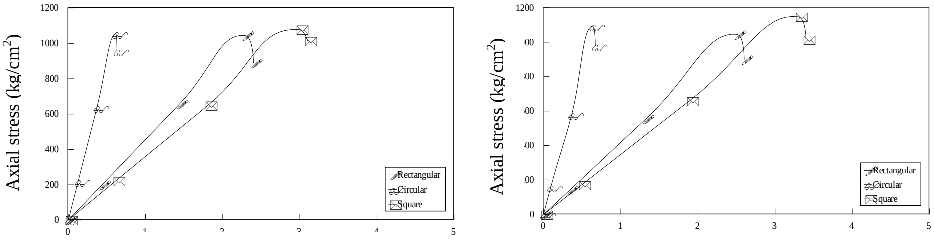
Lateral strain (cm/cm) (1 E-3)
For (hinged-hinged)



Lateral strain (cm/cm) (1 E-3)
For (fixed-hinged)

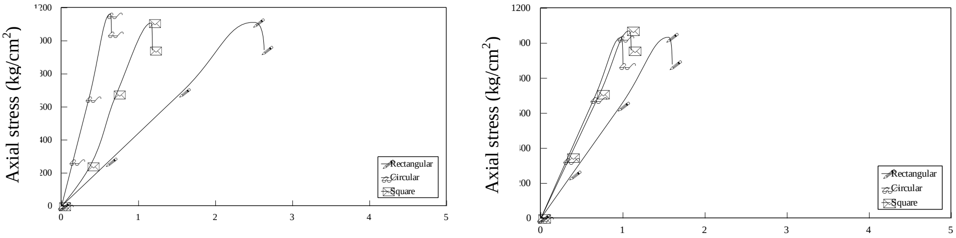
Lateral strain (cm/cm) (1 E-3)
For (fixed-free)

Fig.10: (Axial stress–lateral strain) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 600 kg/cm^2 and ρ_s = 0.6%.



Lateral strain (cm/cm) (1 E-3)
For (fixed-fixed)

Lateral strain (cm/cm) (1 E-3)
For (fixed-hanged)



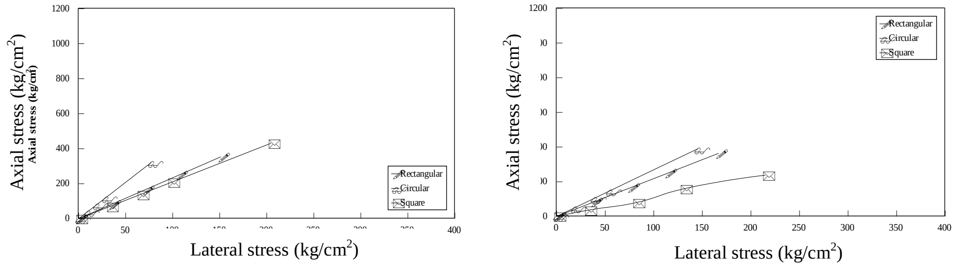
Lateral strain (cm/cm) (1 E-3)
For (fixed-hinged)

Lateral strain (cm/cm) (1 E-3)
For (fixed-free)

Fig. 11: (Axial stress–lateral strain) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 900 kg/cm^2 and ρ_s = 0.6%.

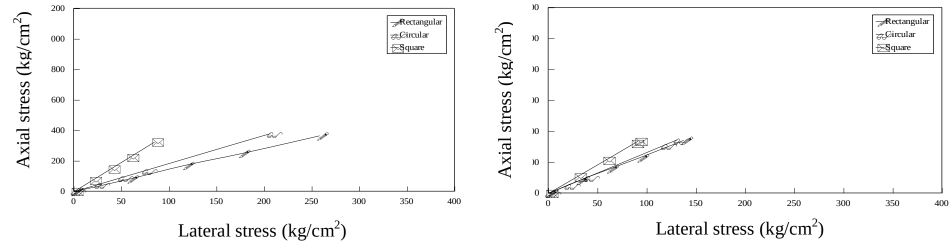
4. Axial stress (f_{cc})–lateral stress (f_{cl}) relationship:

Figures (12), (13) and (14) show samples of the obtained axial stress (f_{cc})–lateral stress (f_{cl}) relationships for circular, rectangular and square section with constant volumetric ratio ($\rho_s = 0.6\%$) using different grades of concrete (f_{cu} = 300, 600, 900 kg/cm^2) for the different end condition of columns (fixed–fixed, hinged–hinged, fixed–hinged and fixed–free).



For (fixed-fixed)

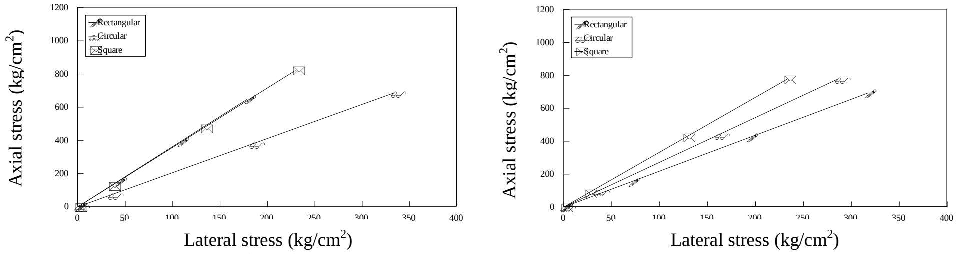
For (hinged-hinged)



For (fixed-hinged)

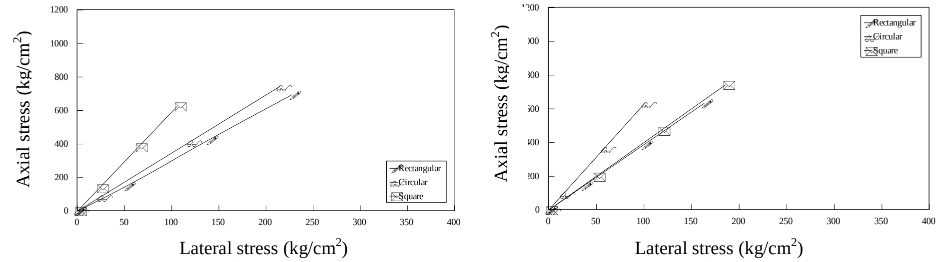
For (fixed-free)

Fig.12: (Axial stress-lateral stress) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 300 kg/cm^2 and $\rho_s = 0.6\%$.



For (fixed-fixed)

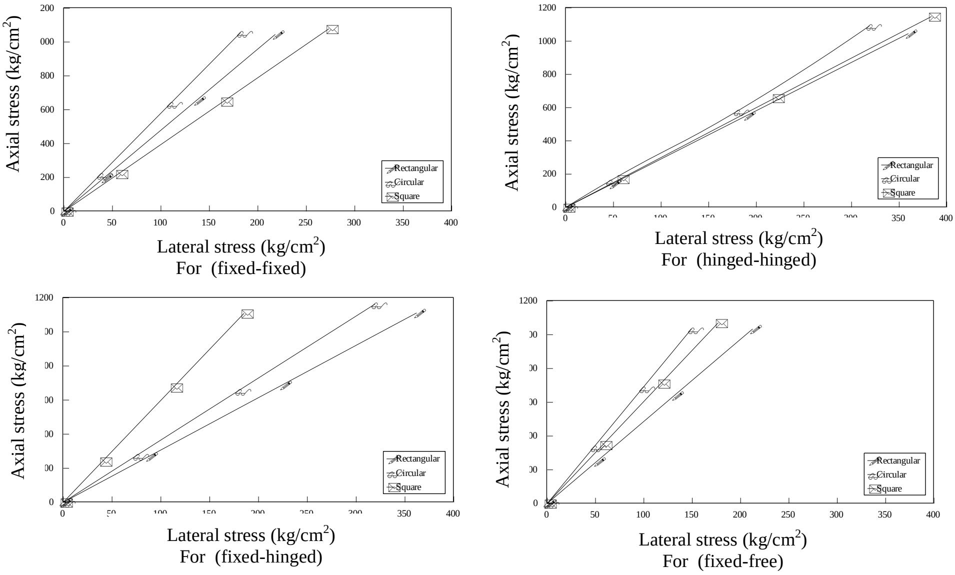
For (hinged-hinged)



For (fixed-hinged)

For (fixed-free)

Fig.13: (Axial stress-lateral stress) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 600 kg/cm^2 and $\rho_s = 0.6\%$.



For (fixed-fixed)

For (hinged-hinged)

For (fixed-hinged)

For (fixed-free)

Fig.14: (Axial stress-lateral stress) diagram at different end condition (fixed–fixed, hinged–hinged, fixed–hinged, fixed–free) for different shapes (circular–rectangular–square) at grade of concrete f_{cu} = 900 kg/cm^2 and ρ_s = 0.6%.

DISCUSSION OF THE THEORETICAL RESULTS

Here this research is only focusing on the effect of following parameters upon the theoretical static behavior of axial short columns in terms of the induced stresses and strains of such as columns:

1. Volumetric ratio of stirrups.
2. End condition.
3. Shape of cross-section; either of circular, rectangular or square.
4. Grade of concrete.

Tables (4), (5) and (6) summarizes the obtained theoretical both maximum stresses and strains for the studied columns. To declare how the included parameters influence the various calculated values represented by the maximum induced axial stresses and strains it is beneficial to be taken as ratios based on the reference grades of concrete. The effect of the third and fourth parameters is interrelated with both first and second parameters as follows:

1- Effect of Volumetric Ratio on Maximum Stresses and Strains

Figures (15), (16) and **(17)** shows how the ratios of (f_{cc}/f_{cu}), (f_{cl}/f_{cc}), (f_{cl}/f_{cu}) and ($\varepsilon_{cl}/\varepsilon_{cc}$) are affected by the above mentioned parameters, volumetric ratio (ρ_s%), grade of concrete and shape of cross-sections for constant end condition. Examination of all figures shows that:

- For a constant grade of concrete and constant end condition the induced maximum axial stresses (f_{cc}) increases with increases of (ρ_s%).

- The effect of volumetric ratio (ρ_s%) with the induced maximum axial stress (f_{cc}) for section of constant end conditions (fixed-free) for different shapes of cross-sections for different used grades of concrete (300, 600, 900 kg/cm^2) reflects that the induced maximum axial stress (f_{cc}) with the increase of the volumetric ratio (ρ_s%) and the rate of increase depend on both grade of concrete and shape of cross-sections.
- The effect of volumetric ratio (ρ_s%) up on the induced lateral stress (f_{cl}) for sections having different shapes of cross-sections for constant end condition (fixed-free) reflects the fact that these induced lateral stress also are affected by the all volumetric ratio (ρ_s%) concrete grade and shape of cross-section.
- Also, it is shown how the ratios of (f_{cc}/f_{cu}), ($f_{cl}/.f_{cc}$), (f_{cl}/f_{cu}) and ($\varepsilon_{cl}/\varepsilon_{cc}$) are affected by the above mentioned parameters, volumetric ratio (ρ_s%), grade of concrete and shape of cross-sections for constant end condition.

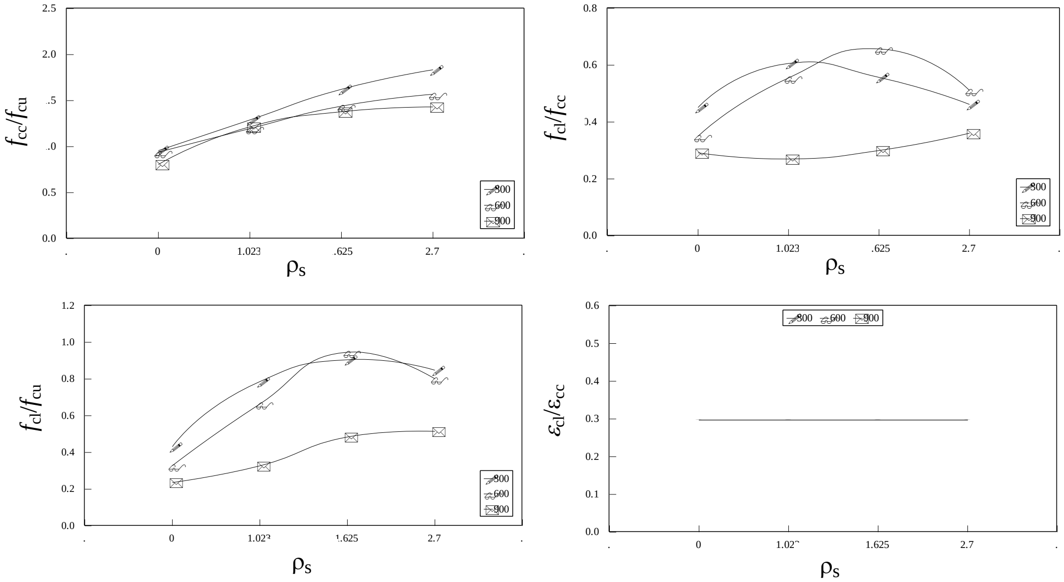


Fig.15: Effect of volumetric ratio ($\rho_{s\%}$) on the ratios of the induced maximum stress and strains for axial R.C columns for different shapes of cross-section with constant end condition (fixed-free) for circular columns

Table (4): The Obtained Theoretical Maximum Stresses and Maximum Strains for Studied Columns For Rectangular Sections.

Column No. designation	End condition	Shape of cross section	Grade of concrete f_{cu} kg/cm^2	Percent Reinf. μ_s(%)	Volumetric ratio ρ_s(%)	f_{cc} (kg/cm^2)	f_{cl} (kg/cm^2)	ε_{cc} x 10^{-5} (cm/cm)	ε_{cl} x10^{-5} (cm/cm)	ε_{cf}x10^{-5} (cm/cm)
C1	Fixed-free	**Rectangular Section**	300	1.61	0	242.5	69.16	31.0	9.39	41.0
C2	Fixed-free		300	1.61	1.023	344.78	104.77	52.8	15.70	163.0
C3	Fixed-free		300	1.61	1.6225	413.61	201.35	69.0	20.5	213.0
C4	Fixed-free		300	1.61	2.70	462.27	299.19	72.6	21.6	310.0
C5	Fixed-free		600	1.61	0	547.12	158.20	106.0	31.5	122.0
C6	Fixed-free		600	1.61	1.023	704.62	287.94	131.0	39.0	221.0
C7	Fixed-free		600	1.61	1.6225	831.44	405.08	163.0	48.4	261.0
C8	Fixed-free		600	1.61	2.70	871.74	565.43	188.0	55.8	262.0
C9	Fixed-free		900	1.61	0	706.44	201.89	154.0	45.7	164.0
C10	Fixed-free		900	1.61	1.023	967.92	277.17	158.0	46.9	200.0
C11	Fixed-free		900	1.61	1.6225	1157.22	378.48	252.0	74.3	312.0
C12	Fixed-free		900	1.61	2.70	1219.59	570.126	265.0	78.0	320.0
C13	Fixed-fixed		300	1.70	0.6	353.55	151.17	220.0	190.0	250.0
C14	Hinged-hinged		300	1.70	0.6	364.00	166.72	267.0	211.7	310.0
C15	Fixed-hinged		300	1.70	0.6	366.14	167.68	268.0	213.0	311.0
C16	Fixed-free		300	1.70	0.6	343.20	137.34	216.0	117.0	240.0
C17	Fixed-fixed		600	1.70	0.6	647.28	178.44	251.0	209.0	330.0
C18	Hinged-hinged		600	1.70	0.6	691.97	316.79	308.0	232.0	420.0
C19	Fixed-hinged		600	1.70	0.6	694.02	227.6	289.0	232.0	410.0
C20	Fixed-free		600	1.70	0.6	633.03	163.33	233.0	138.0	263.0
C21	Fixed-fixed		900	1.70	0.6	1044.96	217.98	283.0	229.0	313.0
C22	Hinged-hinged		900	1.70	0.6	1045.27	251.76	350.0	251.0	400.0
C23	Fixed-hinged		900	1.70	0.6	1111.33	253.48	310.0	252.0	340.0
C24	Fixed-free		900	1.70	0.6	1034.18	212.47	253.0	156.0	274.0

Table (5): The Obtained Theoretical Maximum Stresses and Maximum Strains for Studied Columns For Circular Sections.

Column No. designation	End condition	Shape of cross section	Grade of concrete f_{cu} kg/cm^2	Percent Reinf. μ_s(%)	Volumetric ratio ρ_s(%)	f_{cc} (kg/cm^2)	f_{cl} (kg/cm^2)	ε_{cc} x 10^{-5} (cm/cm)	ε_{cl} x10^{-5} (cm/cm)	ε_{cf}x10^{-5} (cm/cm)
C25	Fixed-free	Circular Section	300	1.61	0	287.0	129.31	21.3	6.33	31.2
C26	Fixed-free		300	1.61	1.023	359.31	235.81	98.0	9.33	175.0
C27	Fixed-free		300	1.61	1.6225	486.95	271.41	64.4	13.8	127.0
C28	Fixed-free		300	1.61	2.70	550.406	254.31	52.0	15.5	236.0
C29	Fixed-free		600	1.61	0	563.47	256.16	80.6	18.5	92.7
C30	Fixed-free		600	1.61	1.023	717.5	398.41	70.1	20.8	220.0
C31	Fixed-free		600	1.61	1.6225	864.6	567.76	97.0	28.8	176.0
C32	Fixed-free		600	1.61	2.70	940.8	480.53	116.0	34.4	211.0
C33	Fixed-free		900	1.61	0	724.8	212.36	89.0	26.4	110.0
C34	Fixed-free		900	1.61	1.023	1093.36	294.14	102.0	30.3	161.0
C35	Fixed-free		900	1.61	1.6225	1240.95	436.0	152.0	45.0	199.0
C36	Fixed-free		900	1.61	2.70	1287.31	463.33	162.0	48.1	212.0
C37	Fixed-free		300	1.70	0.6	321.56	77.31	148.0	22.6	195.0
C38	Hinged-hinged		300	1.70	0.6	390.0	145.34	166.0	24.7	217.0
C39	Fixed-hinged		300	1.70	0.6	380.55	133.98	171.0	24.7	225.0
C40	Fixed-free		300	1.70	0.6	346.45	130.,65	228.0	59.0	248.0
C41	Fixed-free		600	1.70	0.6	686.7	333.86	205.0	42.1	307.0
C42	Hinged-hinged		600	1.70	0.6	779.42	286.44	207.0	44.2	291.0
C43	Fixed-hinged		600	1.70	0.6	743.94	214.77	251.0	44.1	368.0
C44	Fixed-free		600	1.70	0.6	632.28	100.85	258.0	78.5	310.0
C45	Fixed-free		900	1.70	0.6	1056.3	182.27	261.0	61.6	281.0
C46	Hinged-hinged		900	1.70	0.6	1092.91	223,125	247.0	63.7	285.0
C47	Fixed-hinged		900	1.70	0.6	1163.48	222.87	330.0	63.6	370.0
C48	Fixed-free		900	1.70	0.6	1034.65	149.33	296.0	98.0	320.0

Table (6): The Obtained Theoretical Maximum Stresses and Maximum Strains for Studied Columns For Square Sections.

Column No. designation	End condition	Shape of cross section	Grade of concrete fcu kg/cm^2	Percent Reinf. μ_s(%)	Volumetric ratio ρ_s(%)	f_{cc} (kg/cm^2)	f_{cl} (kg/cm^2)	ε_{cc} x 10^{-5} (cm/cm)	ε_{cl} x10^{-5} (cm/cm)	ε_{cf}x10^{-5} (cm/cm)
C49	Fixed-free	**Square Section**	300	1.61	0	240.0	66.86	60.3	17.9	71.0
C50	Fixed-free		300	1.61	1.023	332.95	148.28	31.4	29.1	112.0
C51	Fixed-free		300	1.61	1.6225	401.36	229.49	128.0	38.1	275.0
C52	Fixed-free		300	1.61	2.70	448.125	240.61	134.0	39.8	350.0
C53	Fixed-free		600	1.61	0	492.05	151.19	183.0	54.30	203.0
C54	Fixed-free		600	1.61	1.023	670.803	180.53	220.0	71.20	320.0
C55	Fixed-free		600	1.61	1.6225	815.628	375.61	310.0	92.0	372.0
C56	Fixed-free		600	1.61	2.70	820.272	346.8	343.0	102.0	410.0
C57	Fixed-free		900	1.61	0	693.95	196.05	187.0	85.3	195.0
C58	Fixed-free		900	1.61	1.023	949.74	289.11	290.0	83.20	310.0
C59	Fixed-free		900	1.61	1.6225	1135.68	392.67	409.0	121.5	437.0
C60	Fixed-free		900	1.61	2.70	1162.13	442.06	450.0	133.0	480.0
C61	Fixed-fixed		300	1.7	0.6	430.95	204.,46	346.0	261.0	367.0
C62	Hinged-hinged		300	1.7	0.6	237.97	214.89	299.0	291.0	340.0
C63	Fixed-hinged		300	1.7	0.6	325.08	54.98	265.0	78.0	341.0
C64	Fixed-free		300	1.7	0.6	337.15	90.72	169.0	68.9	200.0
C65	Fixed-fixed		600	1.7	0.6	821.63	229.53	326.0	281.0	361.0
C66	Hinged-hinged		600	1.7	0.6	775.87	232.67	304.0	311.0	364.0
C67	Fixed-hinged		600	1.7	0.6	625.17	105.83	281.0	248.0	348.0
C68	Fixed-free		600	1.7	0.6	743.2	185.82	211.0	87.0	294.0
C69	Fixed-fixed		900	1.7	0.6	1078.35	273.28	307.0	299.0	370.0
C70	Hinged-hinged		900	1.7	0.6	1147.78	268.19	309.0	303.0	356.0
C71	Fixed-hinged		900	1.7	0.6	1108.66	129.61	296.0	117.0	320.0
C72	Fixed-free		900	1.7	0.6	1070.7	176.89	254.0	108.0	274.0

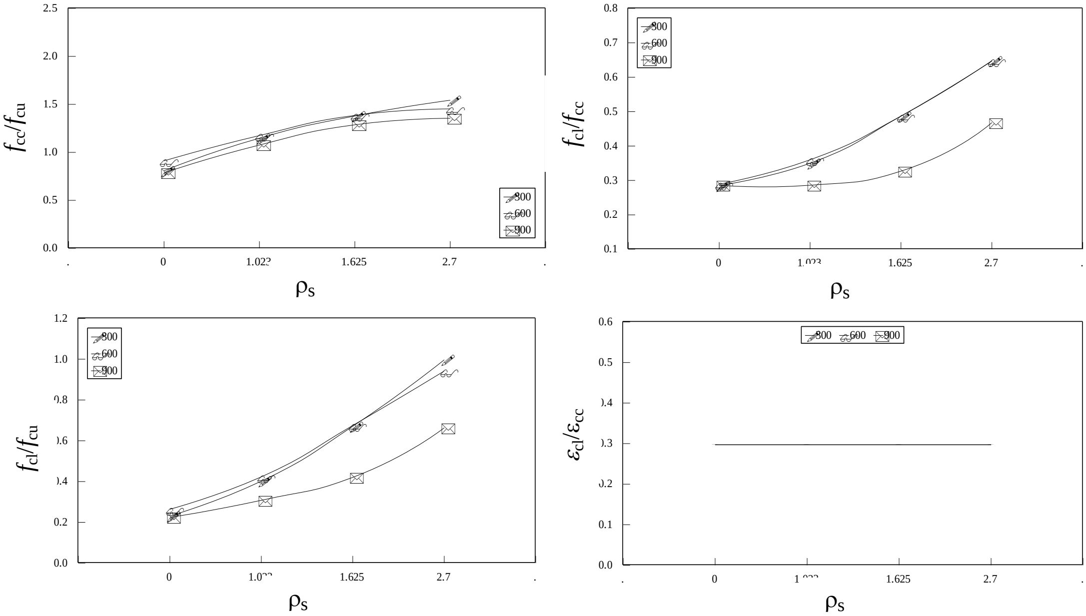


Fig.16: Effect of volumetric ratio (ρ_s%) on the ratios of the induced maximum stress and strains for axial R.C columns for different shapes of cross-section with constant end condition (fixed-free) for rectangular columns.

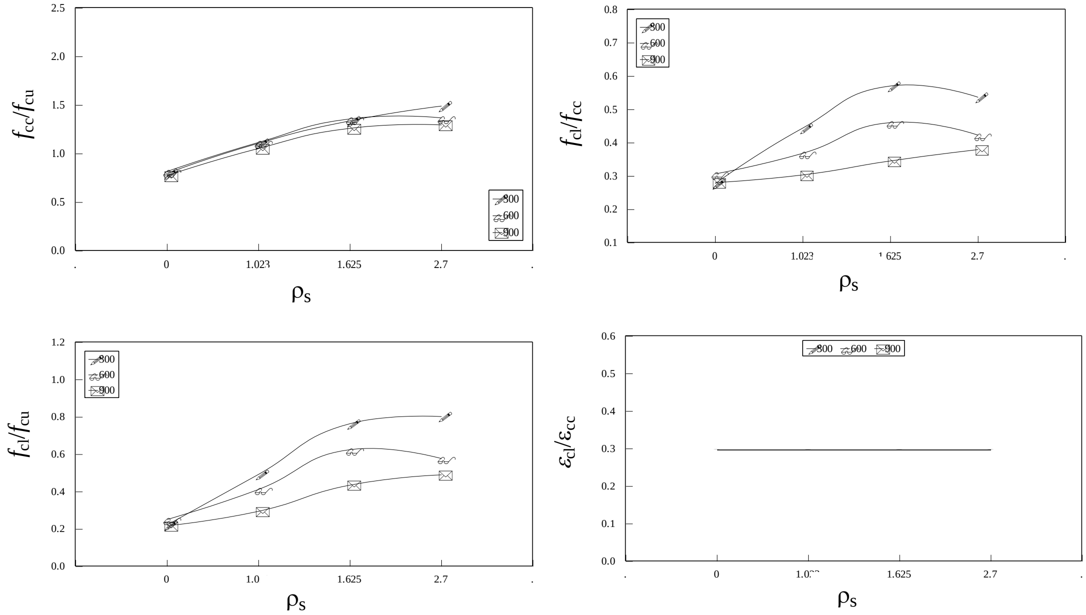


Fig.17: Effect of volumetric ratio (ρ_s%) on the ratios of the induced maximum stress and strains for axial R.C columns for different shapes of cross-section with constant end condition (fixed-free) for square columns.

2. Effect of Boundary Condition on the Induced Maximum Stresses and Strains

Figures (18) (19) and **(20)** show how the end boundary condition affects the induced axial stresses, lateral stresses and lateral strains for axial columns for different grades of concrete with constant volumetric ratio (ρ_s = 0.6%). Such effect is shown in **Figs. (21), (22) and (23).**

Examination of previous figures led to the following observation:

- The highest ratio of (f_{cc}/f_{cu}), for (f_{cu} = 300 and 600 kg/cm^2) was obtained at (hinged-hinged) end condition however for (f_{cu}=900 kg/cm^2) it was obtained at (fixed-hinged) end condition.
- The highest ratio of the maximum value (f_{cl}/f_{cc}) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 600 kg/cm^2).
- The highest ratio of the maximum value (f_{cl}/f_{cu}) was obtained at (fixed-fixed) end condition, for grade of concrete (f_{cu} = 600 kg/cm^2).
- The highest ratio of the maximum value ($\varepsilon_{cl}/\varepsilon_{cc}$) was obtained at (fixed-free) end condition, for grade of concrete (f_{cu} = 900 kg/cm^2).

Finally the following can be summarized:

The highest ratio of the maximum value (f_{cc}/f_{cu}) was obtained at (fixed-hinged) end condition, for grade of concrete (f_{cu}) = 900 kg/cm^2. The highest ratio of the maximum value (f_{cl}/f_{cc}) was obtained at both (fixed-hinged) and (hinged-hinged) end condition for grade of concrete (f_{cu} = 300, 600 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cu}) was obtained at (fixed-hinged) end condition for grades of concrete (f_{cu} = 300 kg/cm^2).The highest ratio of the maximum value ($\varepsilon_{cl}/\varepsilon_{cc}$) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 300 kg/cm^2).

The highest ratio of the maximum value (f_{cc}/f_{cu}) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cc}) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cu}) was obtained at (hinged-hinged) end condition, for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value ($\varepsilon_{cl}/\varepsilon_{cc}$) was obtained at (hinged-hinged) end condition for grade of concrete (f_{cu}) = 900 kg/cm^2.

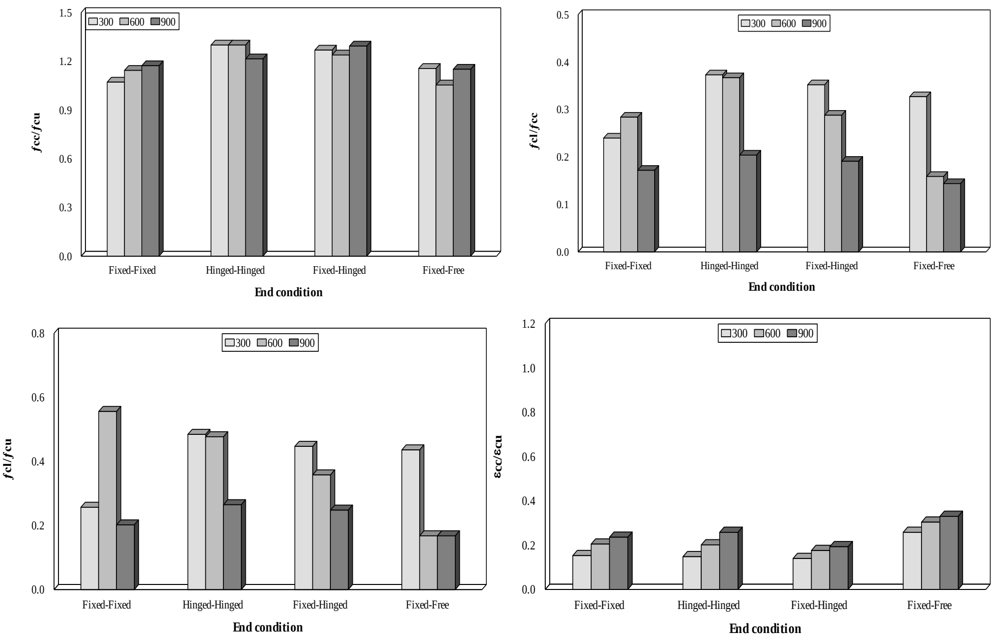


Fig.18: Effect of end boundary condition on the induced ratios of the maximum stress and strains for axial R.C columns for different Grades of concrete with constant volumetric ratio (ρ_s=0.6%) for circular columns.

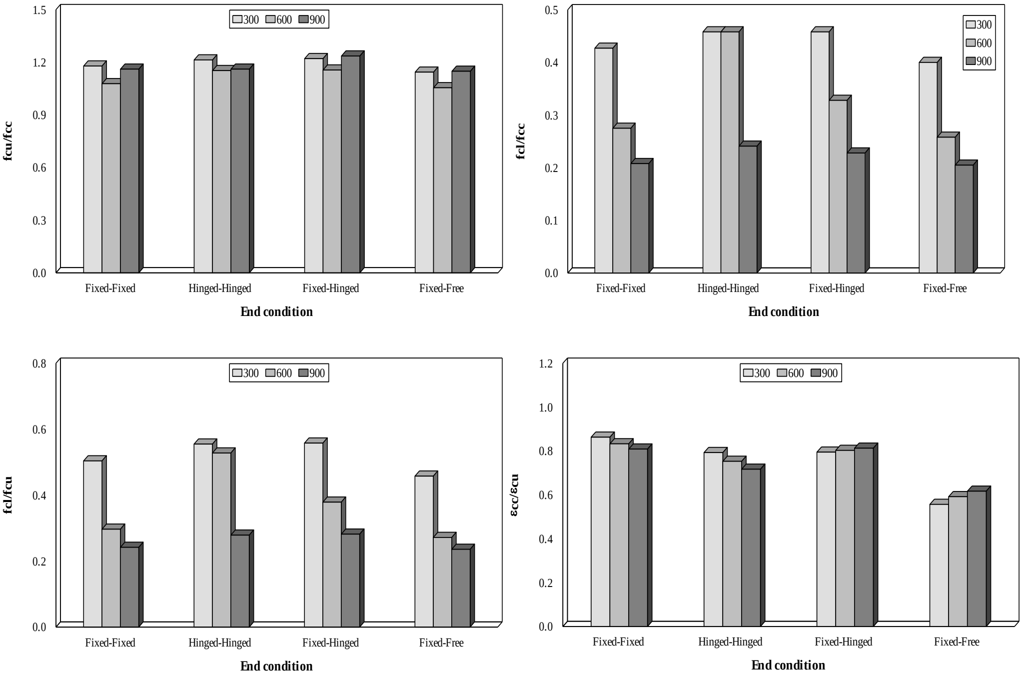


Fig.19: Effect of end boundary condition on the induced ratios of the maximum stress and strains for axial R.C columns for different Grades of concrete with constant volumetric ratio (ρ_s=0.6%) for rectangular columns.

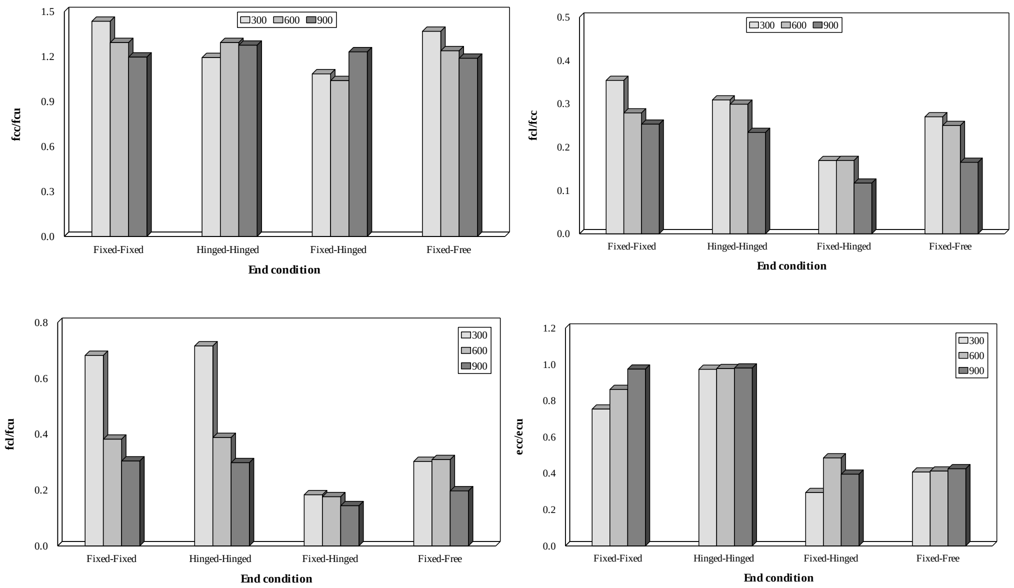


Fig.20: Effect of end boundary condition on the induced ratios of the maximum stress and strains for axial R.C columns for different Grades of concrete with constant volumetric ratio (ρ_s=0.6%) for square columns.

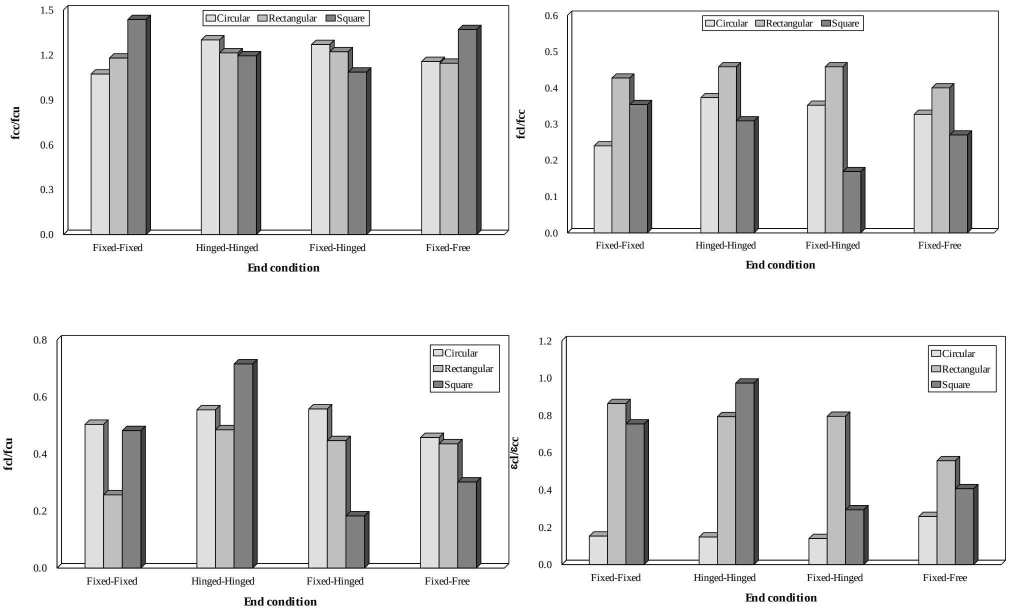


Fig.21: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C300.

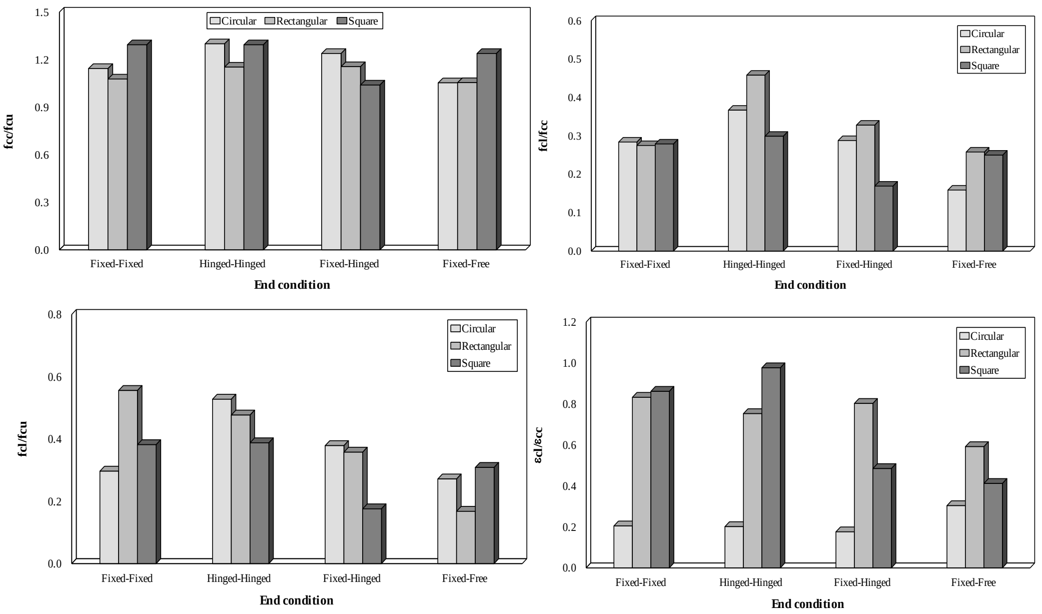


Fig.22: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C600.

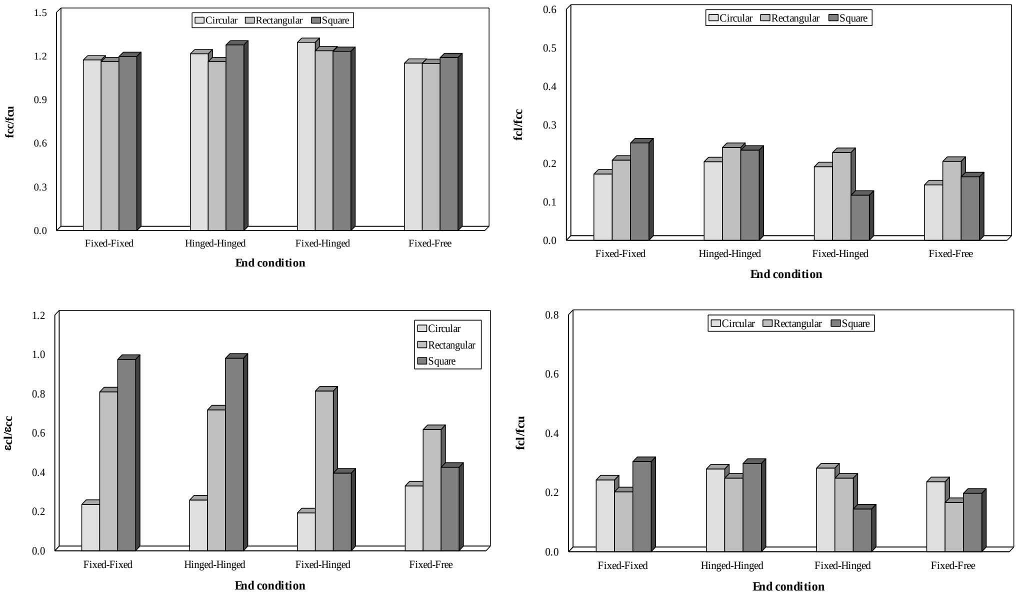


Fig.23: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C900.

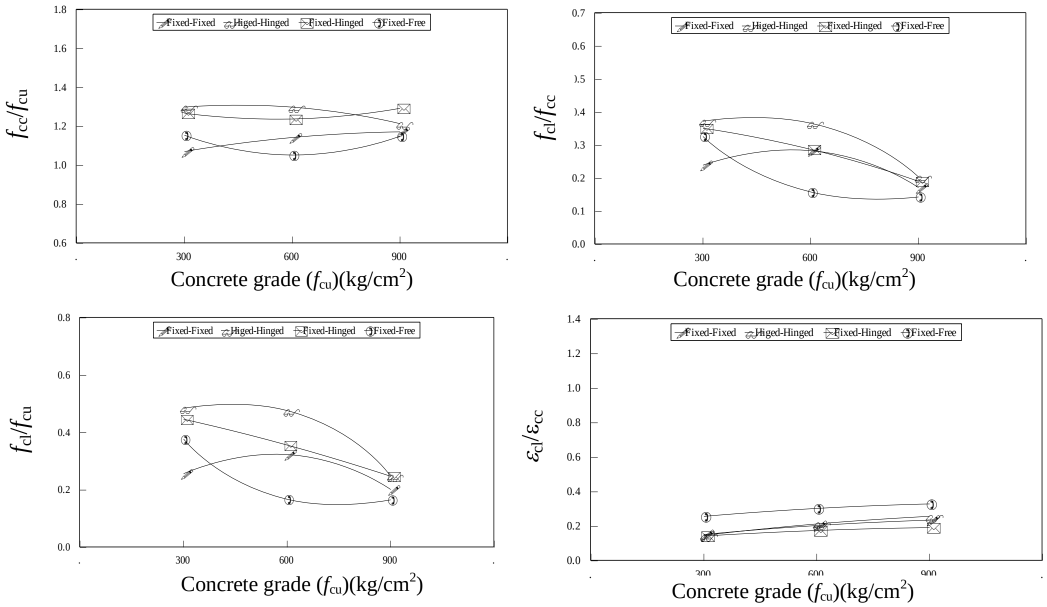


Fig.24: Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for circular columns.

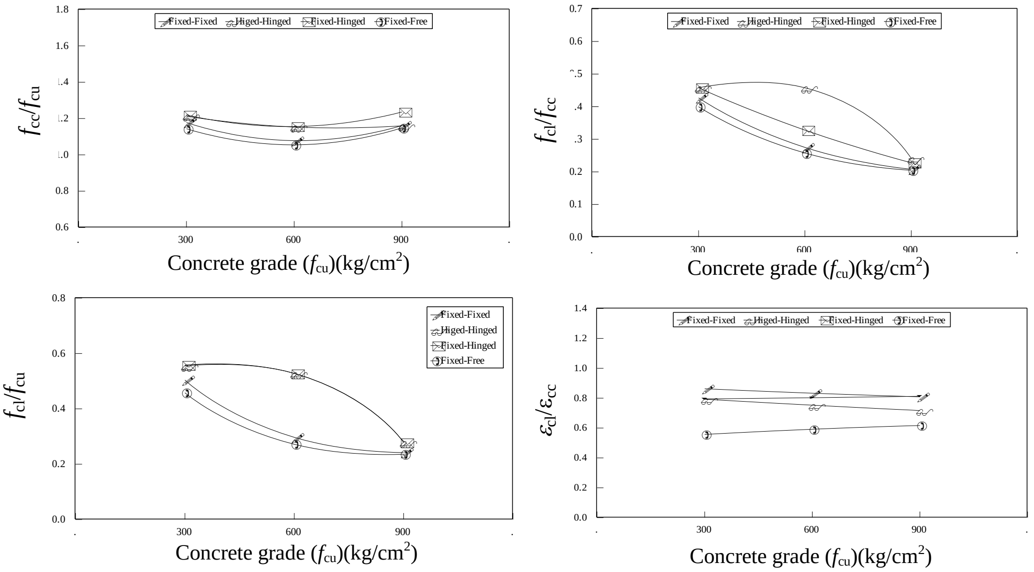


Fig.25: Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for rectangular columns.

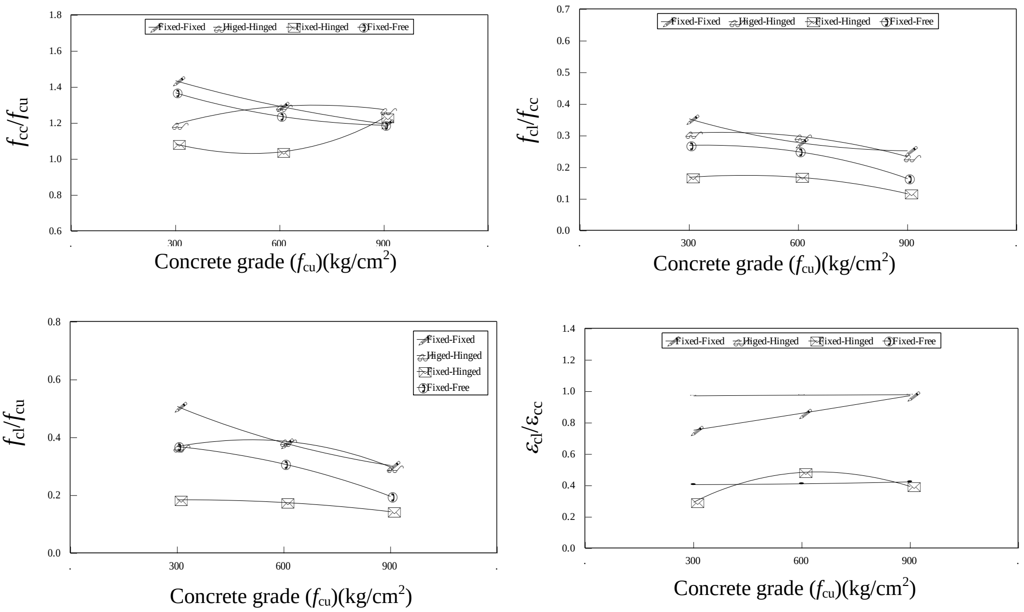


Fig.26: Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for square columns.

3. Effect of Shape of Cross Section

Figures (27), (28) and **(29)** declare the effect of shape of cross-section (circular–rectangular and square) on the induced maximum stresses and strains for different used volumetric ratios (ρ_s%) for the case of used constant grades with (fixed-free) end condition. **From the previous figures the following important remarks are given:**

For a given grade of concrete and constant cross-section shape with constant end condition, the induced maximum axial stresses (f_{cc}), the induced maximum lateral stresses (f_{cl}) well as the induced lateral strains (ε_{cl}) increases with the increase of volumetric ratio (ρ_s%). The rate of increase mainly depends on both the shape of cross-sections and grade of concrete. The rate of increase of the induced maximum axial and lateral stresses is higher for lower used grade of concrete (300) with the order circular, rectangular and square sections respectively.

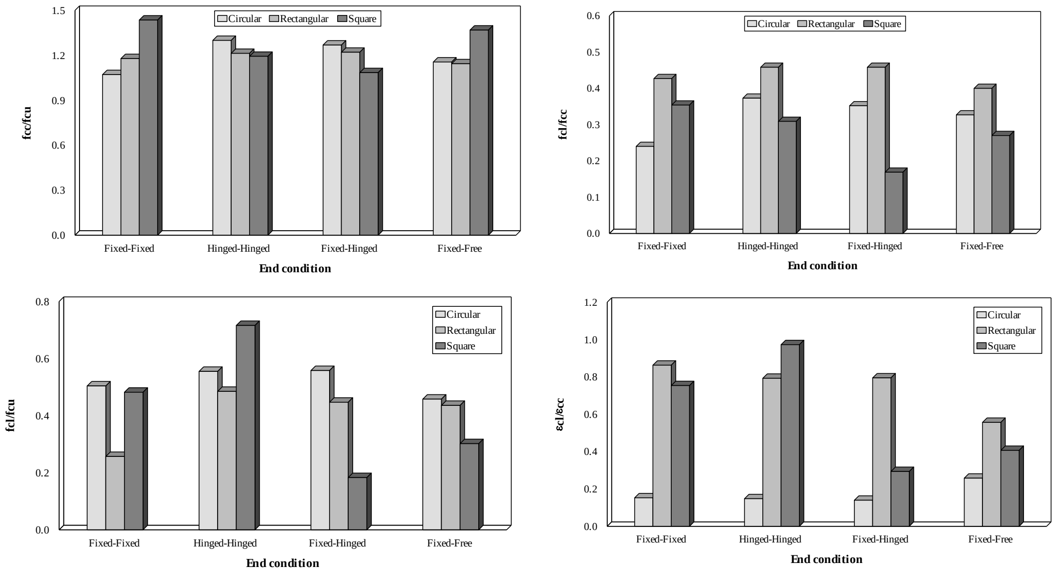


Fig.27: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C300.

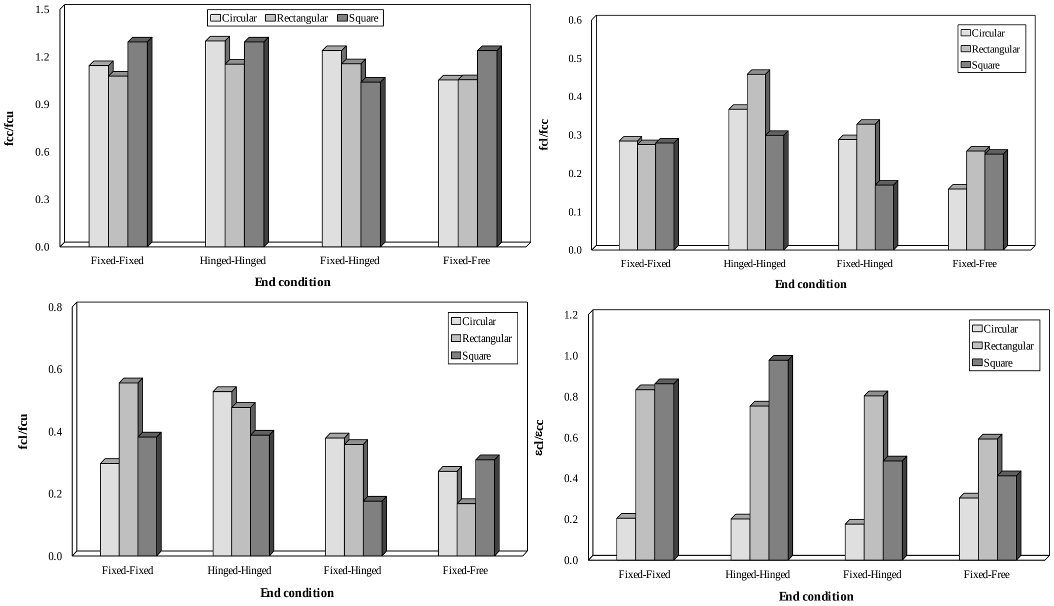


Fig.28: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C600.

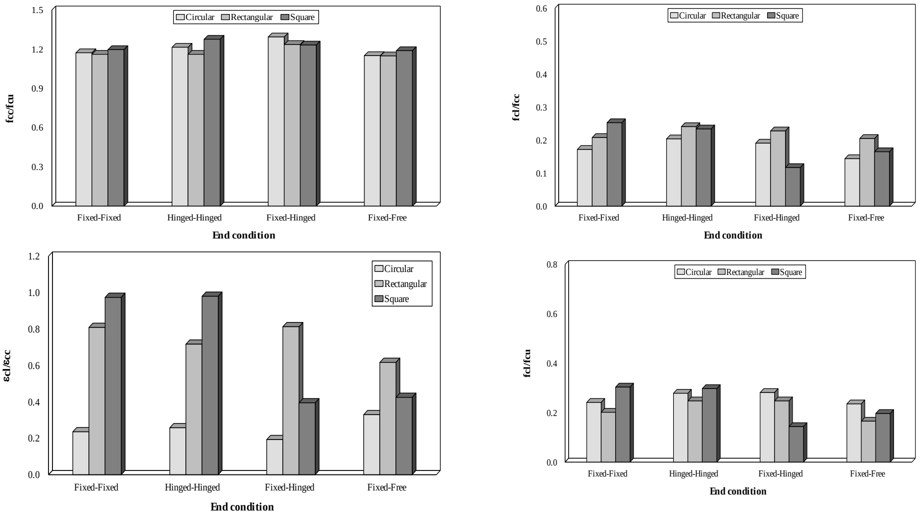


Fig.29: Effect of shape of cross-section on the ratios of the induced maximum stresses and strains for axial R.C columns for different and condition (fixed-fixed, hinge-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρs=0.6%) for concrete grade C900.

4. Effect of Grade of Concrete:

Figures (30), (31) and (32) indicate the effect of the concrete grade (f_{cu}) on the induced maximum axial stresses, lateral stresses and lateral strains for axial R.C columns at different volumetric ratios (ρ_s%) with different shapes of cross-sections for constant end conditions (fixed-free).

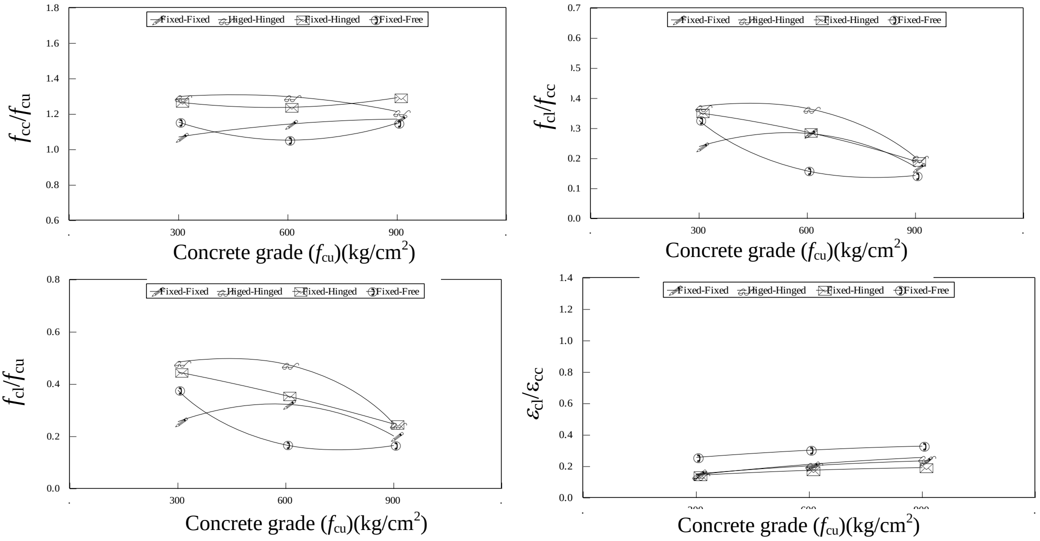


Fig.(30): Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for circular columns.

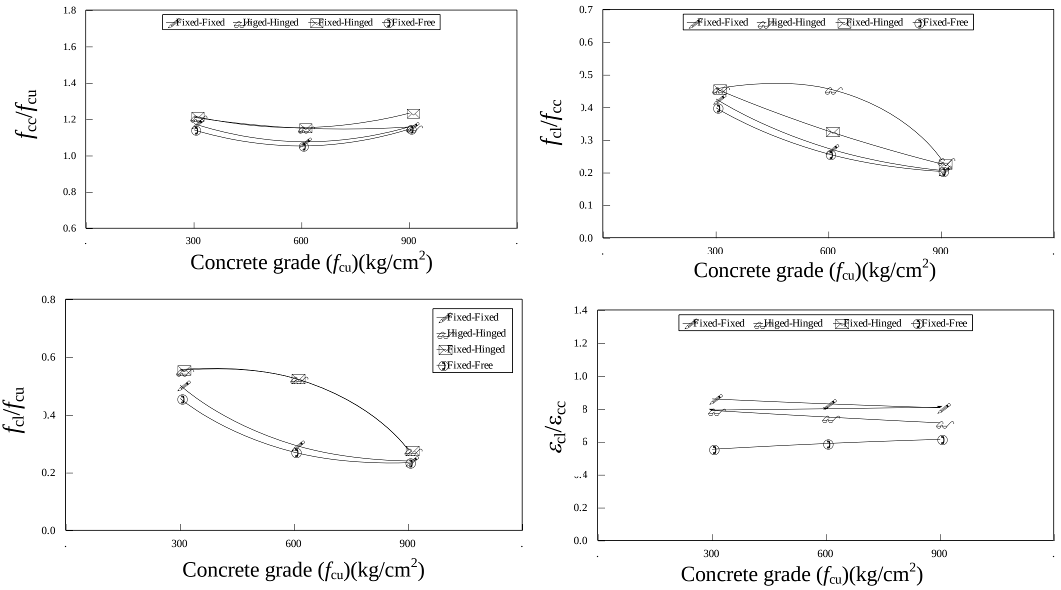


Fig.(31): Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for rectangular columns.

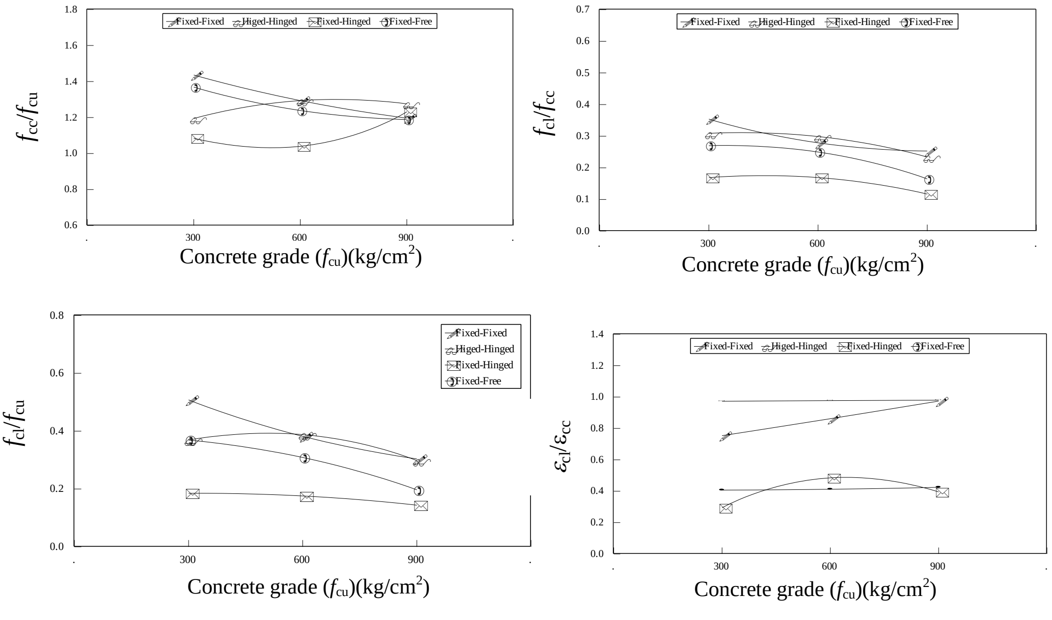


Fig.(32): Effect of concrete grade on the induced ratios of the maximum stress and strains for axial R.C columns for different end condition (fixed-fixed, hinged-hinged, fixed-hinged and fixed-free) with constant volumetric ratio (ρ_s=0.6%) for square columns.

CONCLUSIONS

1. For a given grade of concrete and constant cross-section shape with constant end condition, the induced maximum axial stresses (f_{cc}), the induced maximum lateral stresses (f_{cl}), the induced lateral strains (ε_{cl}) increases with the increase of volumetric ratio (ρ_s%). The rate of increase mainly depends on both the shape of cross-sections and grade of concrete. The rate of increase of the induced maximum axial and lateral stresses is higher for lower used grade of concrete (300) with the order circular, rectangular and square sections respectively.
2. For columns confined with 0,1.023, 1.6225 and 2.7 % volumetric ratios, with fixed-free end condition, either grade of concrete 300, 600, 900 kg\cm2 for different cross sections (circular, rectangular and square), the strength ratio of (f_{cc}/f_{cu}) (f_{cl}/f_{cc}) (f_{cl}/f_{cu}) increases with increase of volumetric ratio (ρs). Strength ratio (f_{cc}/f_{cu}) increases with 78.85 % for circular columns, 75.28 % for rectangular columns and 73.75 % for square columns. This means that strength ratio of (f_{cc}/f_{cu}) increases for columns confined for circular column than rectangular columns with 1.05 % and rectangular than that for square columns with 1.02%. For lateral strength ratio (f_{cl}/f_{cc}) increases with 73.32% for circular columns with 68.45% for rectangular columns and with 51.97% for square columns. This means that strength ratio of (f_{cl}/f_{cc}) increases for columns confined for circular columns than that for rectangular columns with 1.07% and rectangular than square columns with 1.32%. For lateral strength ratio (f_{cl}/fcu) increases with 89.62% for circular columns. For rectangular columns, it increases with 89.16% and 87.0% for square columns. This means that strength ratio of (f_{cl}/f_{cu}) increases for columns confined for circular columns rather than rectangular columns with 1.01% and for rectangular columns rather than square columns with 1.02 %.
3. The grade of concrete, f_{cu}, definitely affects both the induced maximum axial and lateral stresses f_{cc}, f_{cl} which both increase f_{cu}, and maximum value was obtained at circular columns confined with 2.7 % volumetric ratio. The strength ratios (f_{cc}/f_{cu}) (f_{cl}/f_{cc}) (f_{cl}/f_{cu}) decrease with increase of grade of concrete f_{cu}. Strength ratio (f_{cc}/f_{cu}) increases 18.46, 9.98 and 8.31 for circular, rectangular and square columns respectively. Strength ratio (f_{cl}/f_{cc}) increases by 43.37, 37.68 and 43.49 % for circular, rectangular and square columns respectively. Strength ratio (f_{cl}/f_{cu}) decreases by 75.33, 59.94 and 64.79 % for circular, rectangular and square columns respectively.
4. Concerning effect of boundary condition on the induced maximum stresses and strains, the highest ratio of the maximum value (f_{cc}/f_{cu}) was obtained at (fixed-hinged) end condition, for grade of concrete (f_{cu}) = 900 kg/cm^2. The highest ratio of the maximum value (f_{cl}/f_{cc}) was obtained at both (fixed-hinged) and (hinged-hinged) end condition for grade of concrete (f_{cu} = 300, 600 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cu}) was obtained at (fixed-hinged) end condition for grades of concrete (f_{cu} = 300 kg/cm^2).The highest ratio of the maximum value ($\varepsilon_{cl}/\varepsilon_{cc}$) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value (f_{cc}/f_{cu}) was obtained at (fixed-fixed) end condition for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cc}) was obtained at (fixed-fixed) end

condition for grade of concrete (f_{cu} = 300 kg/cm^2). The highest ratio of the maximum value (f_{cl}/f_{cu}) was obtained at (hinged-hinged) end condition, for grade of concrete (f_{cu}=300 kg/cm^2). The highest ratio of the maximum value ($\varepsilon_{cl}/\varepsilon_{cc}$) was obtained at (hinged-hinged) end condition for grade of concrete (f_{cu}) = 900 kg/ cm^2

5. For columns confined with 0.60 % volumetric ratio with (fixed-fixed), (hinged-hinged), (fixed-hinged), (fixed-free) end condition, with grade of concrete 300, 600, and 900 kg\cm^2 for different cross section (circular, rectangular and square) it was found that: Highest strength ratio (f_{cc}/f_{cu}) was 1.436, 1.3 and 1.236 for square confined columns at(fixed- fixed) end condition, circular confined columns at (hinged-hinged) end condition and rectangular columns respectively. Highest lateral strength ratio (f_{cl}/f_{cc}) 0.486, 0.458 and 0.354 for circular confined columns at (fixed-fixed) end condition, rectangular confined columns with (hinged-hinged) end condition and square columns (fixed-fixed) end condition respectively. Highest lateral strength ratio (f_{cl}/f_{cu}) was 0.716), 0.558 and 0.556 for square confined columns at (hinged- hinged), rectangular with, (fixed-hinged) and circular columns with (fixed-fixed) end condition respectively Highest strains ratio ($\varepsilon_{cl}/\varepsilon_{cc}$) was 0.98, 0.863 and 0.33 for square confined columns at (hinged- hinged), rectangular confined columns (fixed-fixed) and circular columns at (fixed-free) end condition respectively.
6. The lateral strain ratio ($\varepsilon_{cl}/\varepsilon_{cc}$) is approximately the same value for different volumetric ratios of confinement (0, 1.023%, 1.6225%, 2.70%). This means the volumetric ratio of confinement has no effect on changing ($\varepsilon_{cl}/\varepsilon_{cc}$).
7. For columns confined with 0.60 % volumetric ratio with (fixed-fixed), (hinged-hinged), (fixed-hinged), (fixed-free), with grade of concrete 300,600,900 kg\cm^2 for different cross sections (circular, rectangular and square) it was found that the influence of concrete compressive strength (f_{cu}) on strength ratio (f_{cc}/f_{cu}) (f_{cl}/f_{cc}) (f_{cl}/f_{cu}) ($\varepsilon_{cl}/\varepsilon_{cc}$) is as follows: Highest strength ratio (f_{cc}/f_{cu}) was 1.436, 1.3 and 1.294 for grades of concrete 300 kg\cm^2 at fixed-fixed case, grade of 600 kg\cm^2 at hinged-hinged circular column and grade of 900 kg\cm^2 at fixed-hinged circular column respectively. This means that the lower strength f_{cu}, the more effective is the confinement represented by higher strength of strength ratio (f_{cc}/f_{cu}).

   Highest strength ratio (f_{cl}/f_{cc}) was 0.486, 0.458 and 0.241 for grade of concrete 600 at fixed-fixed circular column, 300 at hinged-hinged (fixed- hinged) of rectangular column and 900 at hinged-hinged rectangular column. Thus, the lower is the strength the more effective is the confinement strength ratio (f_{cl}/f_{cc}). Highest strength ratio (f_{cl}/f_{cu}) was 0.558, 0.556 and 0.282 for grade 300 at fixed-hinged rectangular column, 600 at (fixed- fixed) circular column and 900 at fixed-hinged rectangular column respectively. So that, confinement is more effective in lower grades of concrete than that in higher grades.

   Highest strains ratio ($\varepsilon cl/\varepsilon cc$) was 0.98, 0.977 and 0.973 for grade of concrete 900 at hinged-hinged square column, for grade of concrete 600 at (hinged-hinged) square column and grade of concrete 300 at hinged-hinged square column respectively. This means that confinement has slight effect on strain ratio ($\varepsilon_{cl}/\varepsilon_{cc}$).

8. For columns confined with 0.60 % volumetric ratio with (fixed-fixed), (hinged-hinged), (fixed-hinged), (fixed-free), with grades of concrete 300,600, 900 kg\cm^2 The effect of different cross sections is as follows:-
    - ***For circular*** column, the highest ratio of (f_{cc}/f_{cu}) was at (fixed- fixed), and the lowest ratio of (f_{cl}/f_{cc}) was at (fixed- free). The lowest ratio of (f_{cl}/f_{cu}) was at (hinged-hinged) and the highest ratio of ($\varepsilon_{cl}/\varepsilon_{cc}$) was at (hinged-hinged).
    - ***For Rectangular*** column, the highest ratio of increase of (f_{cc}/f_{cu}) was at (fixed-hinged) and the lowest ratio was at (fixed- hinged). The highest ratio of (f_{cl}/f_{cu}) was at (hinged-hinged) and the lowest ratio of ($\varepsilon_{cl}/\varepsilon_{cc}$) was at (hinged-hinged).
    - ***For square*** column, the highest ratio of (f_{cc}/f_{cu}) was at (fixed- hinged), the lowest ratio of (f_{cl}/f_{cc}) was at (fixed- free). The highest ratio of (f_{cl}/f_{cu}) was at (hinged-hinged) and the highest ratio of ($\varepsilon_{cl}/\varepsilon_{cc}$) was at (fixed-fixed).

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بعض العوامل التي تؤثر على السلوك الاستاتيكي للأعمدة الخرسانية المسلحة القصيرة ذات المقاومة العالية ـ دراسة نظرية

تم في هذا البحث عمل دراسة نظرية لبيان العوامل المؤثرة علي السلوك الأستاتيكي المحوري للأعمدة الخرسانية القصيرة ذات الخرسانة عالية المقاومة والتي لها قطاع دائري أو مستطيل أو مربع مع تغير نسبة حديد التسليح الطولي (μ%) ونسبة حديد التسليح العرضي (ρ_s%) (0, 1.023, 1.6225, and 2.70,) ورتبة الخرسانة (f_{cu}) (300, 600, 900 kg/cm^2) ونهاية الأعمدة (Fixed-fixed, Fixed-hinged, Hinged-hinged, Fixed-free) . ومن هذا المنطلق فان الهدف من هذا البحث هو محاولة تقديم إجابة نظرية من حيث أقصي إجهاد محوري و جانبي وأقصي انفعال محوري و جانبي يمكن أن تتحمله الأعمدة الخرسانية المسلحة المحزمة تحت تأثير الحمل المحوري .

لقد تم دراسة السلوك الأستاتيكي المحوري للأعمدة باستخدام نموذج مقترح ثلاثي الأبعاد يشمل استخدام نموذج تم التحقيق منة في اليابان عمليا وباستخدام برنامج الكمبيوتر **ABAQUS** تم التحليل الأستاتيكي للأعمدة و يحتوي هذا البحث علي شرح وافي للعوامل و العناصر المختلفة التي تم استخدامها في هذا البرنامج لحساب أقصي إجهادات (f_{cl}) ,(f_{cc}) وأقصي انفعالات (ε_{cl}) (ε_{cc}). تمت الدراسة على عدد (72 عمود) مأخوذاً في الاعتبار شكل القطاع الخرساني (دائري ومستطيل ومربع) ومساحة قطاع الخرسانة (Ag) ونسبة حديد التسليح الطولي (μ%) ، ونسبة حديد التسليح العرضي (ρ_s%) (0, 1.023, 1.6225 and 2.70) ورتبة الخرسانة (300,600,900 kg/cm^2)(f_{cu}) ونهاية الأعمدة (fixed- fixed, hinged-hinged, fixed-hinged and fixed-free) وذلك برسم العلاقات بين العوامل الآتية : الإجهاد المحوري (f_{cc}) ، الانفعال المحوري

(ε_{cc})والإجهاد الجانبي (f_{cl}) ، الانفعال المحوري (ε_{cc}) والإجهاد المحوري(f_{cc})، الانفعال الجانبي (ε_{cl})والإجهاد المحوري (f_{cc})، الإجهاد الجانبي(f_{cl}) الانفعال المحوري (ε_{cc}) والانفعال الجانبي (ε_{cl}) . السلوك الأستاتيكي للأعمدة الخرسانية المحزمة القصيرة تحت تأثير الأحمال المحورية تم تمثيله بالمتغيرات الآتية: أقصى إجهاد محوري للخرسانة إلى رتبة الخرسانة (f_{cc}/f_{cu}) ونسبة أقصي إجهاد جانبي للخرسانة إلى أقصي إجهاد محوري للخرسانة (f_{cl}/f_{cc}) ونسبة أقصي إجهاد جانبي للخرسانة إلى رتبة الخرسانة (f_{cl}/f_{cu}) ونسبة أقصي انفعال جانبي للخرسانة إلى أقصي انفعال محوري للخرسانة ($\varepsilon_{cl}/\varepsilon_{cc}$) .

أثبتت الدراسة أن هذه المتغيرات تتأثر بدرجة كبيرة بالعوامل التي شملتها الدراسة والسابق ذكرها وعلى سبيل المثال :

1- عند نسب التسليح العرضي المختلفة (ρ_s) فإن نسب الاجهادات المختلفة ($f_{cc}/f_{cu}, f_{cl}/f_{cc}, f_{cl}/f_{cu}$) تزيد مع زيادة نسب التحزيم للعمود الخرساني (ρ_s) ، وأعلى نسب مقاومة تتحقق عند القطاع الدائري ثم القطاع المستطيل ويليه القطاع المربع،وأيضاً نسبة المقاومة المختلفة تقل مع زيادة رتبة الخرسانة (f_{cu}).

2- عند نهايات الأعمدة المختلفة نسب الاجهادات ($f_{cc}/f_{cu}, f_{cl}/f_{cc}, f_{cl}/f_{cu}$) تحقق أقصى قيمة لقطاع العامود المربع عند نهاية (fixed-fixed) لرتبة الخرسانة (C300) ، ويليه القطاع للعمود الدائري ، ثم القطاع للعمود المستطيل ، وكلاهما عند نهاية (hinged-hinged) لرتبة الخرسانة (C900) .