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"Effect of Stirrups Shape and Branches on The Behaviour of Rectangular RC Columns"

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ABSTRACT :*The behavior of RC columns was well-studied on the last third of 20th century through many experimental and theoretical research all over the world. The previous researchers considered the general behavior of RC columns under various loading types, different reinforcement details and types, several concrete grades, different cross section and shape, and spiral stirrups effect, the effect of stirrups shape and branches on the behavior of rectangular RC column is not studied yet, for this purpose total 14 specimens were prepared and tested experimentally under axial load to study the parameters that correlated to stirrups number, shape, and branches. The tested specimens divided into 4 main groups which the first 3 groups contain 9 specimens with cross section area 150*200 mm and different stirrups number and shape. The last group contains 5 specimens with cross section area 150*300 mm and different stirrups shape and branches the behavior of all tested specimens likes ultimate load, longitudinal and lateral steel strain, axial and radial deformation were discussed. To verify the experimental results, the tested specimens were analyzed numerically using a nonlinear finite element program (ANSYS19) and the obtained results were compared to those obtained experimentally. The ultimate loads, deformations and strains were also recorded and compared.*

KEYWORDS *columns confinement, axial loaded, stirrups effect, stirrups branches, stirrups shape, stirrups number, volumetric ratio,*

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I. INTRODUCTION

It is known that the centrally loaded rectangular RC columns would be subjected to stress in both the axial and transverse directions. This stress effect is mainly resisted by column stirrups.

In fact, many codes such as "ECP [1] and "ACI [2] do not explicitly account for this effect and there are no formulas were recognized and listed except for circular spiral columns however, the effects of different parameters such as stirrups shape , and branches.

Different experimental and analytical models of concrete confined by rectilinear ties have been proposed to predict stress-strain curve of confined concrete columns but a few models predict only strength and corresponding strain. Several variables have been considered in these models. However, the amount of lateral reinforcement received the most attention. Some of the other variables appear in experimental and analytical models that have effect in confinement such as plain concrete strength, the yield stress of the longitudinal steel, distribution of longitudinal steel, stirrups configuration, stirrups spacing and cross section area.

One of the most common methods to determine / quantify the effect of confinement on concrete is The effective confinement pressure method which proposed to determine the strength and the ductility of the confined concrete "Cusson and Paultre [3] ". Which explained by "Sheikh and Uzumeril [4].

II. STUDY PARAMETERS

The experimental program is studying effect of stirrups number, shape, and branches of the behavior of rectangular RC columns under axial load. A total of fourteen columns tested experimentally. All Fourteen specimens have a height of 2100 mm with effective height 1800 mm and column head height 150 mm in each side, 150 mm width, and length of 200 mm and 300 mm. Concrete cover 1 mm from each side divided into four groups:

• Three groups (A, B, C) of nine specimens were 150 mm*200 mm having rectangular cross section shapes. Each group has a different stirrups shape with column head, were prepared as follows:

• Group (A) marked as (1R), (2R), (3R), having stirrups distance equal to 90 mm, 70 mm, and 50 mm which represent 60% to 30% column width (b) respectively with the same stirrups shape and longitudinal RFT bars.

. Group (B) marked as (7R), (8R), and (9R), having stirrups distance equal to 90 mm, 70 mm, and 50 mm which represent 60% to 30% column width (b) respectively with the same stirrups shape and longitudinal RFT bars.

• Group (C) marked (7R) as, (8R), and (9R), having stirrups distance equal to 90 mm, 70 mm, and 50 mm which represent 60% to 30% column width (b) respectively with the same stirrups shape and longitudinal RFT bars.

• A group of five specimens were 150 mm*300 mm having rectangular cross section shapes with column head were prepared as follows:

. Three rectangular specimens marked (10R), (11R), and (12R) having stirrups distance equal to 90 mm with 4, 6, and 8 stirrup branches respectively and having the same stirrups shape and longitudinal RFT bars.

• Two rectangular specimens marked (13R)), and (14R) having stirrups distance equal to 90 mm with 6 and 8 stirrup branches respectively and having the same stirrups shape and longitudinal RFT bars.

III. EXPERIMENTAL PROGRAM

A Description of Specimens

As mentioned in Table (1), the experimental program consists of fourteen columns divided into four groups (A, B, C, and D). The first three groups (A, B, and C) with cross section 150*200 mm as shown in Figs. (1), (3), (4), and (5), and column head cross section 250*300. Group (D) with cross section 150*300 mm as shown in Figs. (2), (6), (7), (8), (9), and (10), and column head cross section 250*400 mm.

Table 1. Specimens details

. GR	Sp.No.	Dim. mm	Col. Height (mm)	Eff. Col. Heig-ht (mm)	Longitudinal R.F.T			Transverse R.F.T		
					Diame-ter	As cm^2	As Ratio	Di-am-eter	S mm	Volumet-ric Ratio
A	**1R**	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	90	0.4187 %
	2R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	70	0.538 %
	3R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	50	0.7536 %
B	**4R**	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	90	0.5117 %
	5R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	70	0.6579 %
	6R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	50	0.9211 %
C	**7R**	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	90	0.5768 %
	8R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	70	0.7416 %
	9R	150*200	210	180	12 Ø 6	3.39	1.13 %	Ø 4	50	1.0383 %
D	**10R**	150*300	210	180	16 Ø 6	4.52	1.00%	Ø 4	90	0.3969 %
	11R	150*300	210	180	16 Ø 6	4.52	1.00 %	Ø 4	90	0.5954%
	12R	150*300	210	180	16 Ø 6	4.52	1.00%	Ø 4	90	0.6823 %
	13R	150*300	210	180	16 Ø 6	4.52	1.00 %	Ø 4	90	0.4776 %
	14R	150*300	210	180	16 Ø 6	4.52	1.00%	Ø 4	90	0.5644 %

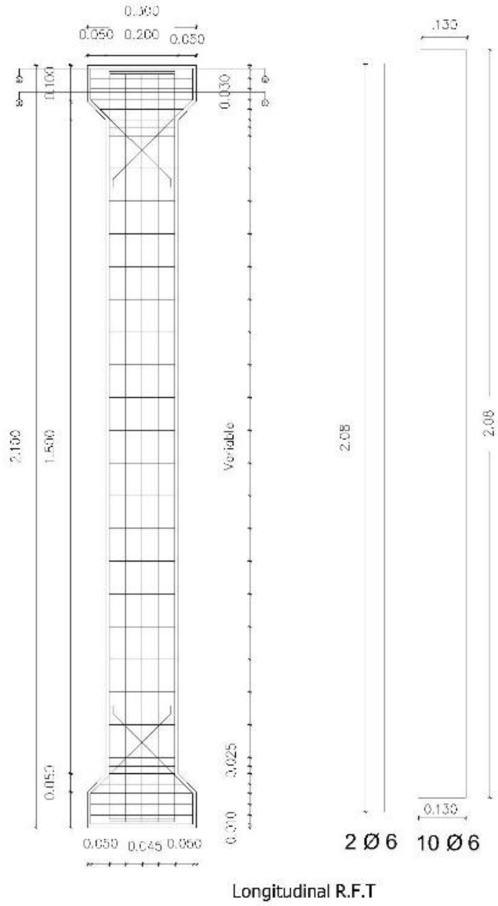


Fig. 1. Columns longitudinal reinforcement details for groups (A, B, and C)

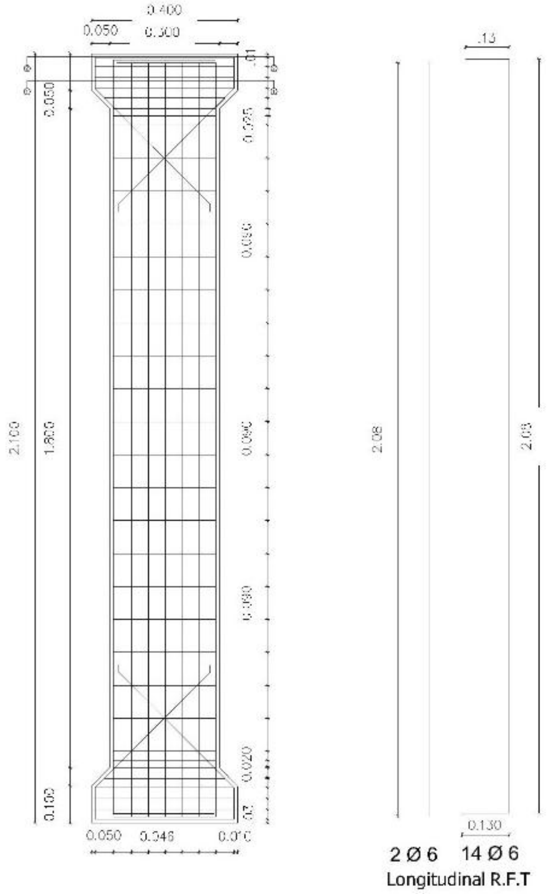


Fig. 2. Columns longitudinal reinforcement details for group (D)

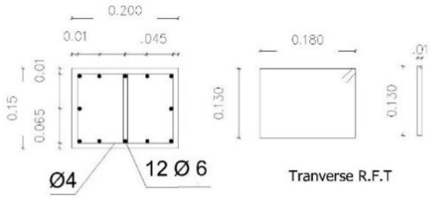


Fig. 3. Stirrups reinforcement details for group (A)

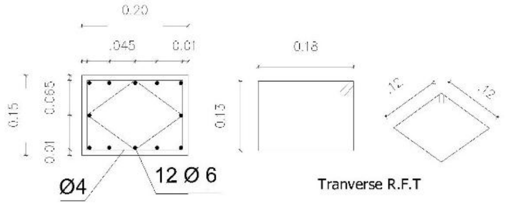


Fig. 4. Stirrups reinforcement details for group (B)

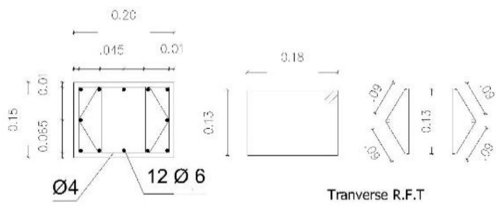


Fig. 5. Stirrups reinforcement details for group (C)

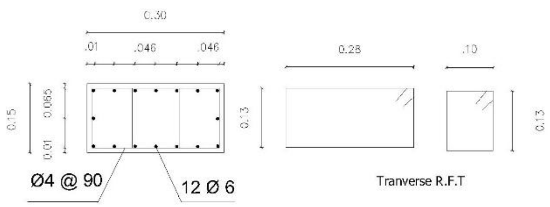


Fig. 6. Stirrups reinforcement details for specimen (10R)

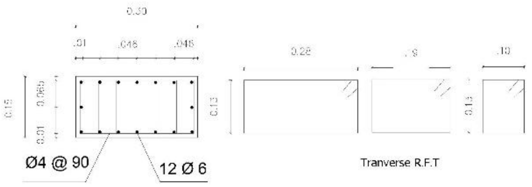


Fig. 7. Stirrups reinforcement details for specimen (10R)

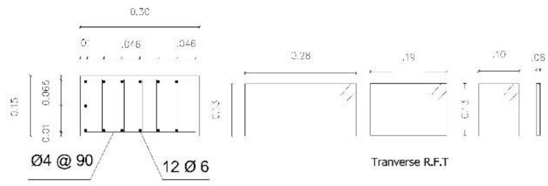


Fig. 8. Stirrups reinforcement details for specimen (12R)

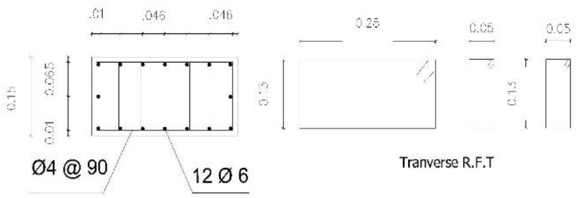


Fig. 9. Stirrups reinforcement details for specimen (13R)

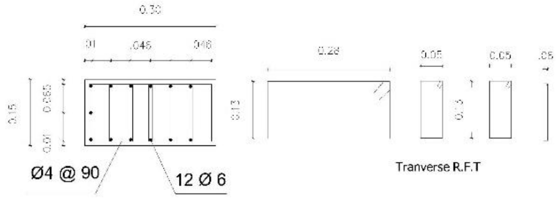


Fig. 10. Stirrups reinforcement details for specimen (14R)

BMaterial Properties

The steel, cement, and aggregate used in this paper are the same used for traditional concrete. Siliceous sand was used as the fine aggregate have 4.75mm maximum particle size. Coarse aggregate was crushed dolomite of 12.5 mm maximum particle size. The ratio between fine aggregate to coarse aggregate was 1:2. Moreover, the water cement ratio was 0.40. The average of six cubes (150*150*150mm) compressive strength at 28day was 32Mpa.

The yield strength of steel reinforcement for vertical bars and the stirrups bars are 240MPa and 360MPa respectively.

CTest Setup

Fig. (11) show the test setup used for experimentation a very rigid steel frame consisting of I-sections was used as base to support a column specimen. The load was applied vertically using a hydraulic jack with 250 KN capacities in the middle of column head. All columns specimens were painted white with lime to enable tracing of the crack propagation easily during testing’s. The jack was connected to S.I.B. 360 to keep it in a vertical position. A load cell was directly located underneath the jack to measure the load equal increments. The loading was applied in increments of 40 KN. The bulking is measured by using two instruments at the mid height of columns.

D Load cell

The load was imposed consistently and measured by a load cell. A load cell with capacity of 250 tons is used which is connected to a digital display unit.

3.4.2 Mechanical dials gauges

Three dials gauges were used to measure the buckling and settlement for each increment. The first point located in mid height length direction of column to get the profile shape of the deformed length direction of column. The second point located in mid height width direction of column to get the profile shape of the deformed width direction of column. The third point located at the top of column to get column settlement value.

E Electrical strain gauges

For all fourteen columns, there are two types of electrical resistance stain (ERS) gauges (TML type FLA - 6 - 11 with 5 mm length, 120.3 Ω resistance and gauge factor 2.12 %) & (PL-60-11-1L with 20 mm length, 120.3 ±0.5Ω resistance, gauges factor 2.07±1%) were used to measure the surface strains in (the stirrups, longitudinal steel) and concrete respectively. For type (TML type FLA - 6 – 11) located at the start of first stirrup from mid height column for every type of stirrups & mid height for longitudinal steel

For type (PL-60-11-1L) located at mid height of column for width and length direction strain was measured by using digital strain meter (TC- 31K type S238C).

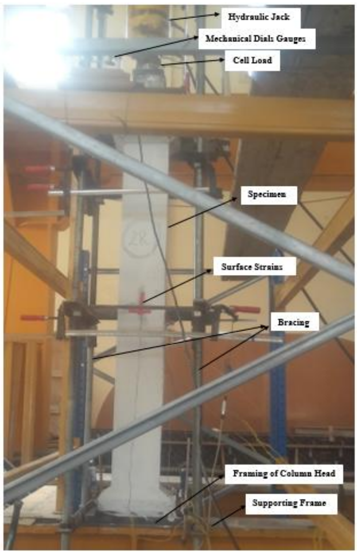


Fig. 11.Test setup

IV. TEST RESULT

This section presents all data for each specimens as shown in Table (2), radial deformation and axial shortening, lateral and longitudinal steel strain.

Radial deformation measured by strain gauges. There is one position for strain gauge put directly on concrete column surface at the mid height of columns in perpendicular direction on load axis and the axial shortening measured by strain gauges put directly on concrete column surface at the mid height of columns in parallel direction on load axis.

The longitudinal steel strains measured by strain gauge put directly on the mid longitudinal steel bar at the mid height of columns in perpendicular direction on load axis.

The lateral steel strains measured by strain gauge put directly on the mid steel bar for each stirrup type at the mid height of columns in perpendicular direction on load axis. Specimens have two stirrups type, so there is strain gauge for each specimen on this group.

The failure of tested column was accompanied by cracking, and crushing of concrete and eventual buckling of verticals bars between ties as shown in Fig. (4-1).

Table 2. Test result for all specimens

GR.	Spec.	P_{cr} (kN)	P_{max} (kN)	$\varepsilon_{lateral\ steel}$ at P_{max}				$\varepsilon_{long.\ steel}$ at P_{max}	$\varepsilon_{concrete}$ at P_{max}	
				$\varepsilon_{strain(1)}$	$\varepsilon_{strain(2)}$	$\varepsilon_{strain(3)}$	$\varepsilon_{strain(4)}$	ε_{strain}%	ε_{axial}%	ε_{radial}%
A	1R	560	650	0.0600	0.0600			-0.1000	-0.1200	0.650
	2R	560	675	0.0550	0.0435			-0.1100	-0.1267	0.550
	3R	600	690	0.0587	0.0500			-0.1150	-0.1320	0.600
B	4R	560	640	0.0600	0.0650			-0.950	-0.900	0.750
	5R	560	655	0.0720	0.0620			-0.1000	-0.0954	0.0650
	6R	560	670	0.0700	0.0800			-0.1074	-0.0850	0.0750
C	7R	560	648	0.0700	0.0800			-0.1050	-0.0950	0.0800
	8R	560	671	0.0750	0.0750			-0.1150	-0.1100	0.0900
	9R	600	688	0.0800	0.0750			-0.1207	-0.1141	0.1000
D	10R	920	1050	0.0750	0.1000			-0.1200	-0.1700	0.1100
	11R	920	1080	0.0730	0.0970	-0.1000		-0.1836	-0.1155	0.1836
	12R	920	1095	0.0759	0.1086	0.0870	0.1131	-0.1414	-0.2222	0.1200
	13R	920	1078	0.0850	0.1000	0.0980		-0.980	-0.1850	0.1200
	14R	960	1105	0.0873	0.1065	0.0896	0.1097	-0.1357	-0.2222	0.1200

Group (A) **Group (B)** **Group (C)** **Group (D)**

Fig. 12.Failure shape

V. NUMERICAL ANALYSIS

A Introduction

In the theoretical part of this research the finite element analysis program ANSYS 19 was used. A finite element method (FEM) is a process which finite degrees of freedom can be approximated to be an assemblage of element each with a specified number of unknowns. In recent years, the use of finite element analysis has increased due to progressing knowledge and capabilities of computer software and hardware. It has now become the choice method to analyze concrete structural components. The use of computer software to model these elements is much faster, and extremely cost-effective. Finite element model was developed to simulate fourteen specimens, from linear through nonlinear response and up to failure, using the software package. Comparisons were done with respect to load-strain relationship, load-deformation relationship, and cracks patterns at failure. The basic aim of using this program was to construct and verify models for the experimentally tested columns.

B Non-Linear Behavior in ANSYS Program

Non-linearity of structural system is due to geometric non-linearity and or material non-linearity. The geometric non-linearity has to be considered if the structure deforms largely, lead to change its geometric configuration. The material non-linearity is related to non-linear stress-strain relationship of the structural material used. Non-linear stress-strain relationship of the structural material causes the structure stiffness to change during the stage of the analysis. ANSYS program has two different approaches to treat the material behavior, the linear elastic behavior and the non-linear plastic behavior. For the linear approach, the program is based on Hook's law and the stress is linear proportional to the strain according to the secant slope. The non-linear plastic behavior of material, which is characterized by non-recoverable strain, begins when stress exceeds certain stress level depend on the material type. In reinforced concrete structures, ANSYS program uses Makin elasticity option to represent the high tensile steel and Drucker-Prager plasticity option to represent the concrete non-linear behavior.

C Materials Properties

The material properties of the analyzed models as obtained experimentally are modeled for concrete and reinforcement steel.

- Concrete

Development of a model for the behavior of concrete is a challenging task. Concrete is a quasi-brittle material and has different behavior in compression and tension. The tensile strength of concrete is typically 8-15% of the compressive strength. In compression, the stress-strain curve for concrete is linearly elastic up to about 80 percent of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength. After it reaches the maximum compressive strength σcu, the curve descends into a softening region, and eventually crushing failure occurs at an ultimate strain εcu . In tension, the stress-strain curve for concrete is approximately linearly elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually to zero " Bangash [5].

In this study, the ultimate cubic compressive strength of the concrete (fcu) was 25.0MPa. According to the Egyptian Code of Practice (ECP 2017) the corresponding elastic modulus =22000.0 MPa.

Moreover, the tensile strength = 3.0 MPa. Poisson's ratio for concrete equals 0.2.

The shear transfer coefficient, βt, represents conditions of the crack face. The value of βt ranges from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer) (ANSYS 19). The value of βt for open cracks used in many studies of reinforced concrete structures varied between 0.05 and 0.25 " Bangash 1989 [5]; Hemmaty 1998 [6] ". The shear transfer coefficient used in this study was equal to 0.2 for open cracks and 0.9 for closed cracks.

Equation (5.1) suggested by " Dasayi and Krishnan [7] " presents the uniaxial compressive stress-strain relationship for concrete.

- Failure criteria for concrete

The model is capable of predicting failure for concrete materials. Both cracking and crushing failure modes are accounted for. The two input strength parameters, ultimate uniaxial tensile and compressive strengths, are needed to define a failure surface for the concrete. Consequently, a criterion for failure of the concrete due to a multiaxial stress state can be calculated " William and Warnke 1975 [8] ".

D Geometry and Finite Mesh

The specimens consist of fourteen columns. A nine columns of 15*20 and 180 mm clear height connected with a column head of 250*350 and 150 mm height. A four columns of 150*300 and clear height 1800 mm connected with a column head of 300*400 and 1500 mm height., as shown in Fig. (12)

After construction of model with volumes, areas, lines and key points, a finite element analysis requires meshing of the model. The model is then divided into a number of small elements, and after loading,

E Loads and Boundary Conditions

To ensure that the model acts in the same way as the experimental specimen, boundary conditions are needed to be applied where the supports and loads exist. The supports were modeled as a fixed support at the end nodes of the top and bottom steel plates. The nodes on the plate were given constraints in all degrees of freedom, applied as constant values of zero. The force, applied at the loading steel plate, is applied across the entire centerline of the plate. The force applied at each node on the plate is 1/20 of the applied forces. Fig. (13) shows the loading and boundary conditions of the specimens.

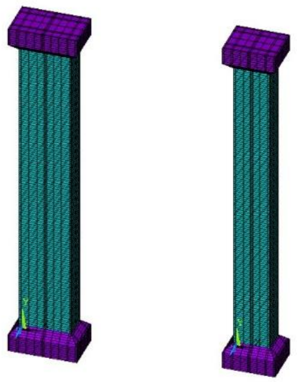


Fig. 12.Finite element mesh

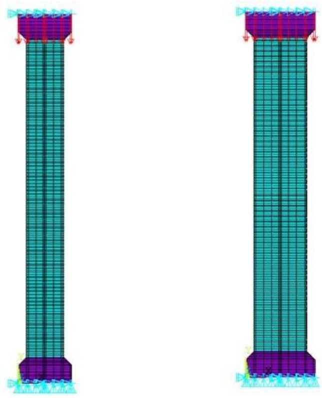


Fig. 13.Loads and boundary conditions for groups (A, B, and C)

F Results and Discussion

The goal of the comparison of the FE model and the experimental column is to verify the experimental results as shown in Table (3). In addition to ensure that, the elements, material properties, real constants and convergence criteria are adequate to model the columns in accordance to the following comparisons:

- Failure load and crack pattern as shown in Figure (14).
- Longitudinal steel strain. as shown in Figure (15).
- Lateral steel strain. as shown in Figure (16).
- Axial deformation. as shown in Figure (17).
- Radial deformation. as shown in Figure (18).

Table 3. EXP and ANSYS test result for all specimen

GR.	Spec.	P_{cr} (kN)	P_{max} (kN)	$\varepsilon_{lateral\ steel}$ at P_{max}				$\varepsilon_{long.\ steel}$ at P_{max}	$\varepsilon_{concrete}$ at P_{max}	
				$\varepsilon_{strain(1)}$	$\varepsilon_{strain(2)}$	$\varepsilon_{strain(3)}$	$\varepsilon_{strain(4)}$	ε_{strain}%	ε_{axial}%	ε_{radial}%
1R	EXP	560	650	0.0600	0.0600			-0.1000	-0.1200	0.650
	ANS	600	670	0.1400	0.1100			-0.1800	-0.1900	0.1700
2R	EXP	560	675	0.0550	0.0435			-0.1100	-0.1267	0.550
	ANS	600	700	0.1010	0.0800			-0.1100	-0.1267	0.550
3R	EXP	600	690	0.0587	0.0500			-0.1150	-0.1320	0.600
	ANS	640	720	0.0950	0.0750			-0.1910	-0.2200	0.1120
4R	EXP	560	640	0.0600	0.0650			-0.950	-0.900	0.750
	ANS	600	650	0.1330	0.1400			-0.1500	-0.1800	0.1500
5R	EXP	560	655	0.0720	0.0620			-0.1000	-0.0954	0.0650
	ANS	600	680	0.1000	0.1130			-0.1540	-0.1960	0.1100
6R	EXP	560	670	0.0700	0.0800			-0.1074	-0.0850	0.0750
	ANS	600	700	0.0930	0.1050			-0.1650	-0.2045	0.1040
7R	EXP	560	648	0.0700	0.0800			-0.1050	-0.0950	0.0800
	ANS	600	660	0.1370	0.1550			-0.1550	-0.1840	0.1550
8R	EXP	560	671	0.0750	0.0750			-0.1150	-0.1100	0.0900
	ANS	600	690	0.1300	0.1400			-0.1620	-0.1980	0.1500
9R	EXP	600	688	0.0800	0.0750			-0.1207	-0.1141	0.1000
	ANS	600	710	0.1300	0.1350			-0.1650	-0.2180	0.1460
10 R	EXP	920	1050	0.0750	0.1000			-0.1200	-0.1700	0.1100
	ANS	1000	1100	0.1000	0.1500			-0.1700	-0.2200	0.1800
11 R	EXP	920	1080	0.0730	0.0970	-0.1000		-0.1836	-0.1155	0.1836
	ANS	1000	1140	0.0950	0.1300	0.1400		-0.1800	-0.2300	0.1700
12 R	EXP	920	1095	0.0759	0.1086	0.0870	0.1131	-0.1414	-0.2222	0.1200
	ANS	1100	1160	0.1000	0.1500	0.1300	0.2000	-0.1950	-0.2800	0.1850
13	EXP	920	1078	0.0850	0.1000	0.0980		-0.980	-0.1850	0.1200

R	ANS	1040	1150	0.1290	0.1310	0.1430		-0.1900	-0.2350	0.1750
14	EXP	960	1105	0.0873	0.1065	0.0896	0.1097	-0.1357	-0.2222	0.1200
R	ANS	1080	1170	0.1250	0.1550	0.1350	0.2000	-0.1980	-0.2850	0.1870

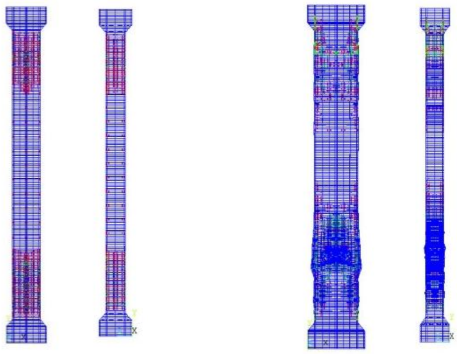
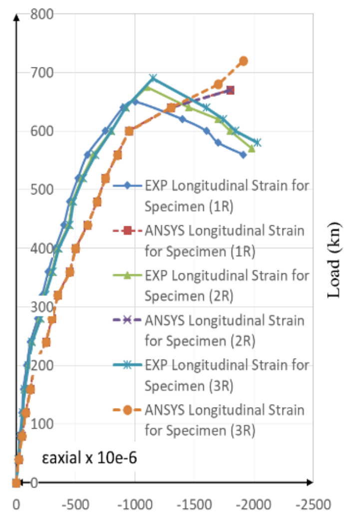
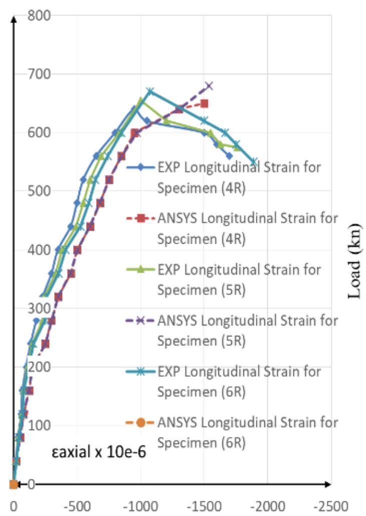


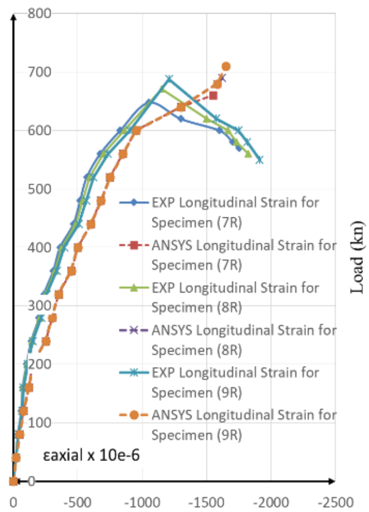
Fig. 14.ANSYS Failure shape



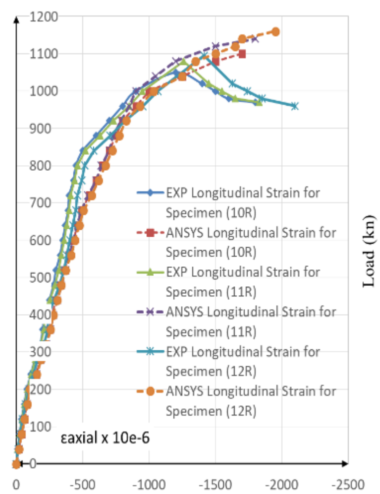
Group (A)



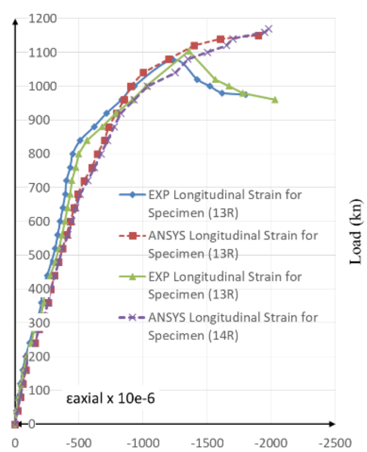
Group (B)



Group (C)

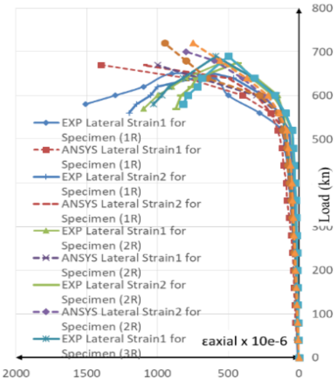


Specimens (10R, 11R, 12R)

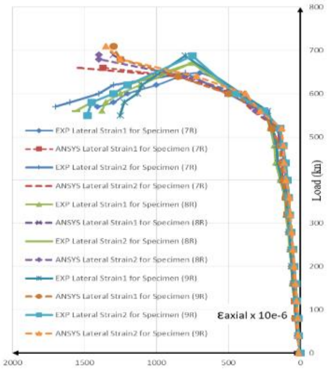


Specimens (13R, 14R)

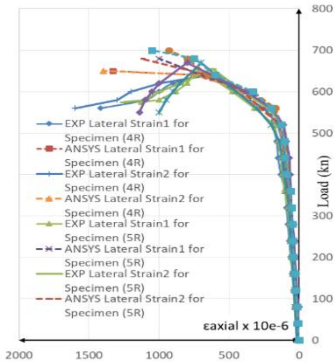
Fig. 15.Longitudinal load-strain curve



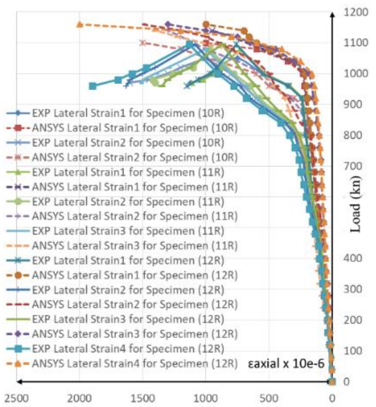
Group (A)



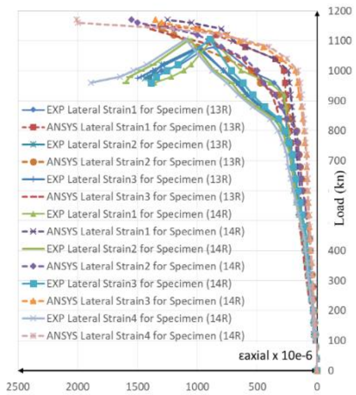
Group (B)



Group (C)

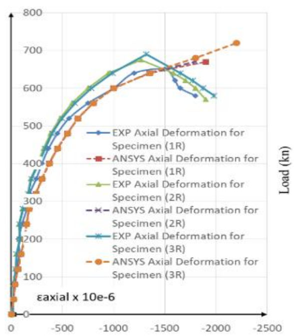


Specimens (10R, 11R, 12R)

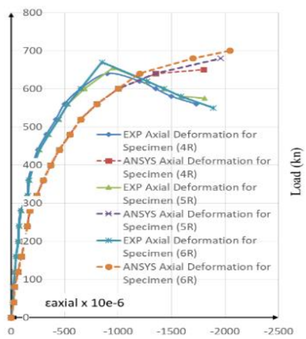


Specimens (13R, 14R)

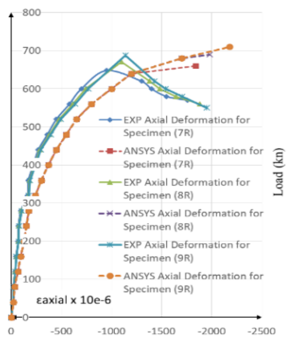
Fig. 15.Lateral load-strain curve



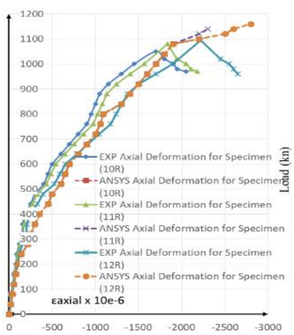
Group (A)



Group (B)

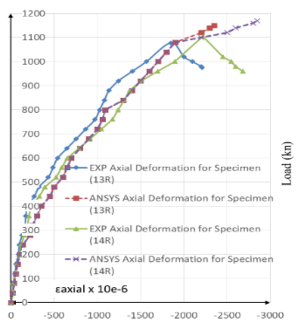


Group (C)

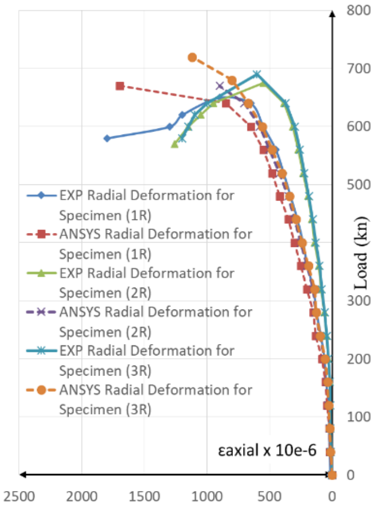


Specimens (10R, 11R, 12R)

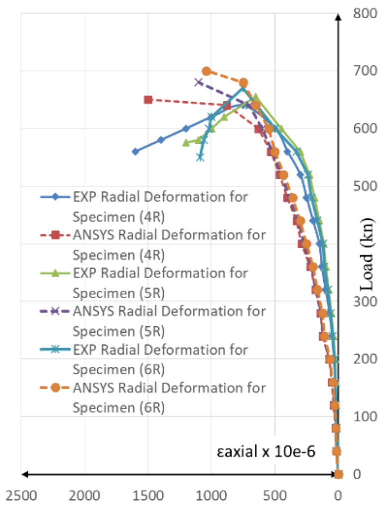
Fig. 16. Axial deformation curve



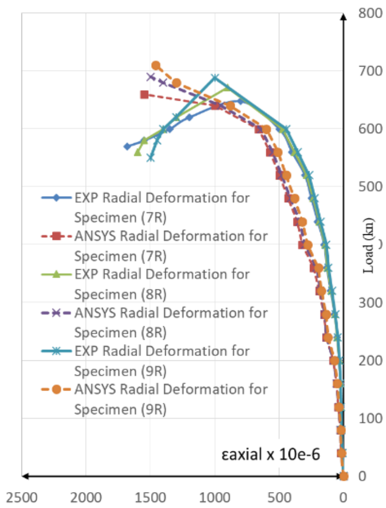
Specimens (13R, 14R)



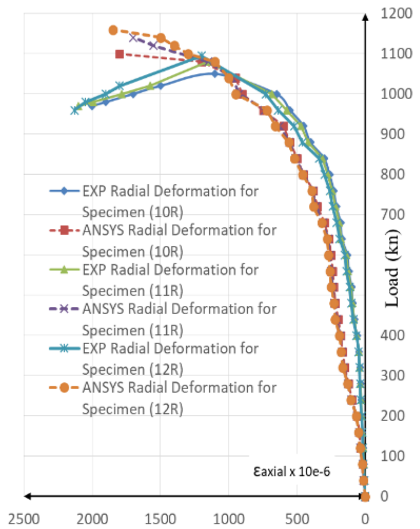
Group (A)



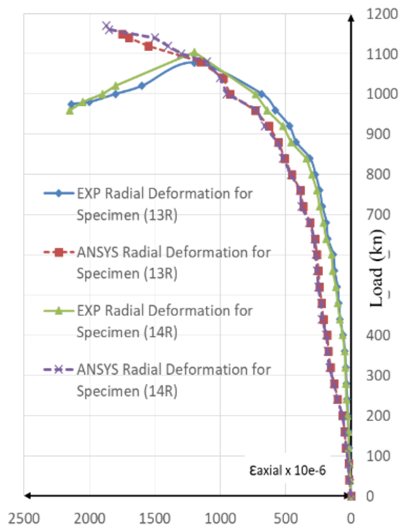
Group (D)



Group (C)



Specimens (10R, 11R, 12R)



Specimens (13R, 14R)

Fig. 16. Radial deformation curve

VI. CONCLUSIONS

Based on the analysis of the experimental and theoretical results of the tested RC columns with different stirrups shape, branches, and numbers. The following observations could be concluded:

1- The factors studied to get their effect on the behavior of axially loaded RC rectangular column are as follows:

- Stirrups Numbers.
- Stirrups branches.
- Stirrups shape.

2. Slightly inclined cracks were observed for all of the tested specimens during testings under concentric loading at about 85% of the failure load.

3. The non-linear numerical procedure introduced, successfully predicted the behavior and ultimate capacity of the tested rectangular RC columns.

4- Decreasing of stirrups distance from 90 mm to 50 mm also, the volumetric ratio % increase from 0.419% to 1.03% led to the following observations:

- The ultimate capacity of tested columns increased by about 6%.
- The axial deformation of tested columns increased by about 10%.
- The radial deformation of tested columns decreased by about 38%.
- The longitudinal steel strain of tested columns increased by about 9%.
- The lateral steel strain of tested columns decreased by about 34%.

5- Increasing of stirrups branches from 4 to 8 branch also, the volumetric ratio % increase from 0.396% to 0.682% led to the following observations:

- The ultimate capacity of tested columns increased by about 5%.
- The axial deformation of tested columns increased by about 10%.
- The radial deformation of tested columns decreased by about 8%.
- The longitudinal steel strain of tested columns increased by about 15%.
- The lateral steel strain of tested columns decreased by about 18%.

6- Changing of stirrups shape also, the volumetric ratio % increase about 0.21% led to the following observations:

- The ultimate capacity of tested columns increased by about 3%.
- The axial deformation of tested columns increased by about 5%.
- The radial deformation of tested columns decreased by about 31%.
- The longitudinal steel strain of tested columns increased by about 11%.
- The lateral steel strain of tested columns decreased by about 44%.

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