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Research Article

Enhancing of Self - Compacting Reinforced Concrete Columns Using Central Reinforcement

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Abstract

To enhance self-compacting reinforced concrete (SCRC) columns using central reinforcement, 13 SCRC columns are tested and analyzed. The experimental program consists of a control specimen without central reinforcement and the other 12 specimens using a central steel reinforcement bar. Variables that have been taken into account are the diameter of central reinforcement bar, a bundle of four central reinforcement bars, and the tie ratio. All specimens are subjected to axial compressive loads. Deflection values are registered after each increase in loading, also modes of failure are observed and recorded by visual inspection. The experimental results are verified for some specimens by performing a nonlinear finite element analysis using a dynamic nonlinear automatic gradual (ADINA) program. The experimental and the numerical analysis showed a good agreement regarding both ultimate load and deflection. Accordingly, results suggest that the use of central reinforcement significantly increases both ultimate load carrying capacity and ductility.

Keywords: *Self – Compacting; reinforced concrete columns; Central reinforcing element; ductility.*

1. Introduction

During the past decade, it has been realized that the use of fiber reinforced polymer (FRP) composites successfully promotes the external confinement of reinforced concrete columns. The study carried out by R. Benzaid et al. on circular and square plain concrete (PC) and reinforced concrete (RC) columns strengthened with carbon fiber reinforced polymer (CFRP) sheets, demonstrates that the ultimate strength, and ductility of CFRP confined concrete increase as the number of confining layers increases. S. Eshchi and V. Zanjanizadeh have conducted an experimental research program on the use of glass fiber reinforced polymer (GFRP) for retrofitting small – scale slender RC columns. Accordingly, test results suggest that GFRP warps significantly increase the flexural strength and ductility of slender rectangular reinforced concrete columns.

Y. Tanaka et al, presented an alternative method that exhibits similar effects as those revealed by external fiber reinforced polymer warps. This method consists of applying central reinforcement to the reinforced concrete columns. This central reinforcement is more effective in preventing the brittle nature of the concrete core after the external shear cracks have occurred, resulting in reinforced concrete column shortening. As the results of experimental study carried out by Y. Tanaka et al to study the formation process of plastic hinges at the end portions of reinforced concrete columns. After bending and shear cracks at the end portions of a member at the first stage of yielding, for further horizontal displacement of the member, plastic hinges at the end portions are formed by bending and shear cracks. The final stage is reached when shear failure at the end portions of the member is caused.

The presence of central reinforcement requires high flowability, which is achieved by using self – compacting concrete (SCC) for casting heavily reinforced concrete members such as column and beam column joints. SCC is a new generation high performance concrete, which is highly flowable and can spread in place under its own weight and achieve good consolidation in the absence of vibration without having the defects due to segregation and bleeding. SCC possesses uniform high density and very low permeability, endowing itself with excellent resistance to aggressive environments and disintegrating agencies, and benefiting the durability of concrete buildings and structures . A part from easier concrete placement, it has been found that SCC can have a better bond with reinforcing bars. The experimental campaign conducted by Khayat et al. on highly confined RC subject to concentric compression, also confirms the influence of the cement – based composites on the

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structural performances. More precisely, for a given cross – section, the load average axial strain diagrams appear more ductile in the case of columns made of self – compacting (SC) concrete than in normal concrete (NC) columns.

2. Experimental program

In order to investigate the performance of self-compacting reinforced concrete (SCRC) columns with central reinforcement, 12 column specimens equipped with central reinforcement are designed and casting as well as one specimen without central reinforcement. All specimens are tested under axial compression loads. To find the effect of central reinforcement on the performance of SCRC columns, the following variables are taken into account : the diameter of central reinforcement; a bundle of four bars; and tie ratio.

2.1 Test Specimens

Each column is a square with 150 x 150 mm cross section and 750 mm high. Test specimens are reinforced with main reinforcement of four longitudinal bars of 12 mm diameter and ties of 4 mm diameter . Composition of the specimens are shown in Fig. (1) and specifications of the specimens are listed in table (1).

Table 1: Specification of the specimens.

Specimen	**Main reinforcement**	**Central reinforcement**	**Tie Ratio (%)**
H	4 Ø 12	-	0.2
$H_1^/$	4 Ø 12	1 Ø 12	0.3
$H_2^/$	4 Ø 12	4 Ø 12	0.3
$H_3^/$	4 Ø 12	1 Ø 16	0.3
$H_4^/$	4 Ø 12	4 Ø 16	0.3
$H_5^/$	4 Ø 12	1 Ø 18	0.3
$H_6^/$	4 Ø 12	4 Ø 18	0.3
H_1	4 Ø 12	1 Ø 12	0.4
H_2	4 Ø 12	4 Ø 12	0.4
H_3	4 Ø 12	1 Ø 16	0.4
H_4	4 Ø 12	4 Ø 16	0.4
H_5	4 Ø 12	1 Ø 18	0.4
H_6	4 Ø 12	4 Ø 18	0.4

2.2 Materials Properties

2.2.1 Cement

In this study, Ordinary Portland Cement (OPC) is used in all test specimens, the properties for cement based on the Egyptian Code of Practice are given in table (2).

Table 2: Properties of cement.

Tests	**Results**	**ECP 203 – 2007** **Specification limits**
Initial setting time	86 minutes	Not less than 45 min.
Final setting time	3 hours and 20 minutes	Not more than 10 hr
3 days compressive strength	19.2 N / mm^2	Not less than 18 N / mm^2
7 days compressive strength	28.9 N / mm^2	Not less than 27 N / mm^2

2.2.2 Aggregates

Both of the natural sand and the coarse aggregate of natural crushed possesses a nominal maximum size of 20 mm are used in the reinforced concrete columns. The specific gravity of both coarse aggregate and fine aggregate is found to be 2.62. The sieve analysis is performed on the particles and the results are presented in Table (3).

Table 3 : Particle size distributions.

Sieve size (mm)	37.5	20	14	10	5	2.36	1.18	0.6	0.33	0.15	0.08
% passing (dolomite)	100	96.2	81.5	45	15	-	-	-	-	-	-
% passing (sand)	-	-	-	-	98.6	95.6	86.4	63.6	26	2.2	0.58

2.2.3 Admixtures

2.2.3.1 Chemical admixtures

A chemical admixture Viscocrete 5930 is used to Enhance the flowability of concrete for ease of casting and increase its viscosity to avoid segregation and bleeding. This chemical admixture is a brownish liquid and weighs approximately 1.10 ± 0.01 Kg / l. Viscocrete has been added at a dose estimated by 2 % of the cementations materials for the mix of concrete.

2.2.3.2 Mineral admixtures

A mineral admixture silica fume is used to Enhance the density of concrete for durability and bond characteristics. Silica fume is a light gray powder has a specific gravity of 2.1 and a fixed dose to be 15 % of cement as a replacement of cement.

2.2.4 Reinforcement

Two types of reinforcing steel are used, the first is high grade deformed steel bars of 12, 16, and 18 mm for main reinforcement and the second is a normal mild steel bars of 4 mm for shear reinforcement. Each specimens has four 12 mm reinforcing bars close to the corner of square column. While the central reinforcement varies in diameter from 12, 16 to 18 mm with four specimens each. The ultimate stress of 4, 12, 16, and 18 mm bars is 409, 525, 545, and 570 N / mm^2 respectively. Reinforcement details of specimens are shown in Fig. (2).

Figure 1. The test specimens

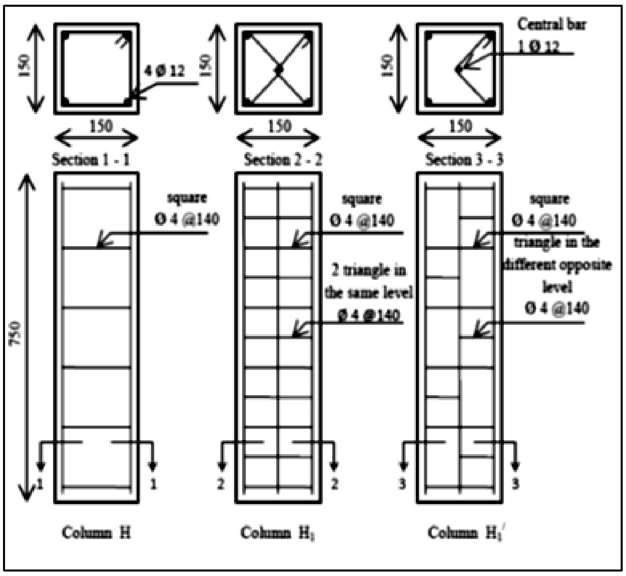


Figure 2. The reinforcement detailing.

2.3 Mix Proportions

The same SCC mix is adopted for all specimens, where mix proportions are presented in table (4). Quantity of the cementations materials is 450 Kg / m^3 with a water / cementations ratio (W / C) = 0.45. Concrete compressive strength of the SCC mix after 28 days is estimated by about 36 N / mm^2.

2.4 Test Specimens Preparation

Cement, dolomite, sand, and silica fume are mixed dryly until the mixture is thoroughly mixed. Dose of viscocrete is added to the mixing water and then to the dry mixture until get a homogenous mixture. Tests are done for fresh SCC of slump flow, T50 (the time of flow to reach a diameter of 500 mm) , and V-funnel as described in EFNARC as shown in Fig. (3) and Fig. (4), respectively. Results which have been obtained for the properties of fresh SCC are listed in table (5). After these tests SCC are cast into the wooden forms, which had been prepared with the steel reinforcement along with six standard cubes of size 150 x 150 x 150 mm. forms have been removed after 24 hours of casting then specimens are covered by burlap wetted by water for 28 day curing period.

Figure 3. The slump – flow test.

Figure 4. The V- funnel test.

2.5 Test Setup and Procedures

Specimens are tested under axial load until failure occurs using a hydraulic testing machine of capacity

2500 KN as shown in Fig. (5). Linear variable displacement transducers (LVDT 's) have been developed at the top and bottom of the specimen to measure the vertical displacement.

Table 4: Details of concrete mix.

Particulars	**Quantity (Kg / m^3)**
Cement	382.5
Water	202.5
Dolomite	833
Sand	833
Silica fume	67.5

Table 5 : The fresh properties of SCC.

Tests	**Fresh properties**	**Typical range of values**	
		Min.	**Max.**
Slump – flow (mm)	700	650	800
The spread diameter T_{50} (sec.)	3.1	2	5
V – funnel (sec.)	7.3	6	12

Figure 5. Test setup

3. Analytical study

The numerical analysis is carried using finite element analysis program ADINA for some concrete columns, which have been tested experimentally. Model of concrete and reinforcement, as well as mesh geometry used for concrete and reinforcement are illustrated in Fig. (6).

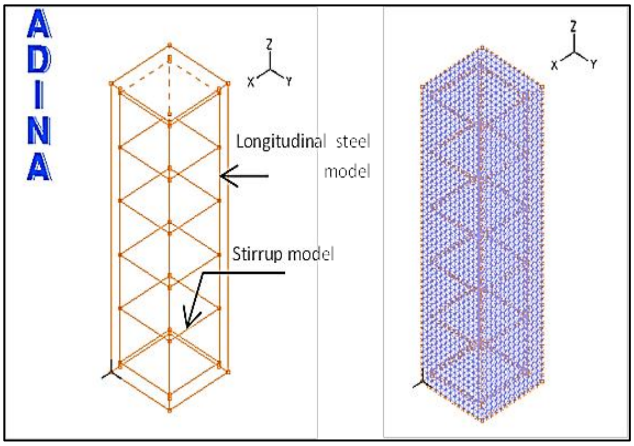


Figure 6. a) The concrete and reinforcement model; b) The mesh geometry for the concrete and reinforcement.

3.1 Material Properties

The stress-strain curve for concrete is represented in Fig. (7), where uniaxial cut – off tensile stress is considered to be 10 % of the uniaxial maximum compressive stress, the uniaxial compressive strain is assumed to be 0.003 and the Poisson's ratio equal to 0.2. The steel reinforcement is modeled by a multilinear stress-strain curve.

4. Results and disscusion

4.1 Load Carrying Capacity

All specimens of square column are tested under axial load with the numerical analysis for some selected specimens using the finite element program. Results of loading carrying capacities of specimens are summarized in table (6). The test results demonstrated that the ultimate load for specimen H_5 with a single 18 mm central bar 24.7 % greater than the control specimen H with no central bar. The specimen H_6 with a bundle of 4 central bars reinforcement exhibited ultimate load 62.5 % greater than the control specimen H without central reinforcement. Also, table (6) displays the comparison between the ultimate load values of both experimental results and numerical analysis, with a ratio of numerical values to experimental values averaging 1.061 and a coefficient of variation (c.o.v) equal to 4.46 %. consequently, numerical results show a good agreement when compared to those obtained from the experimental work.

Table 6 : The loading capacity values.

Specimen	**Ultimate Load (KN)**		
	Experimental (a)	**Analytical (b)**	**b / a**
H (control)	970	1000	1.031
$H_1^/$	1014	1100	1.085
$H_2^/$	1286	1300	1.011
$H_3^/$	1052	-	-
$H_4^/$	1359	-	-
$H_5^/$	1119	-	-
$H_6^/$	1497	-	-
H_1	1035	1170	1.13
H_2	1300	1360	1.046
H_3	1083	-	-
H_4	1419	-	-
H_5	1210	-	-
H_6	1577	-	-
mean			1.061
c.o.v %			4.46

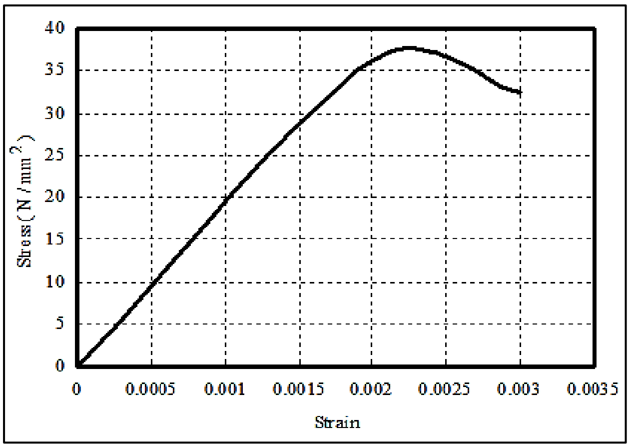
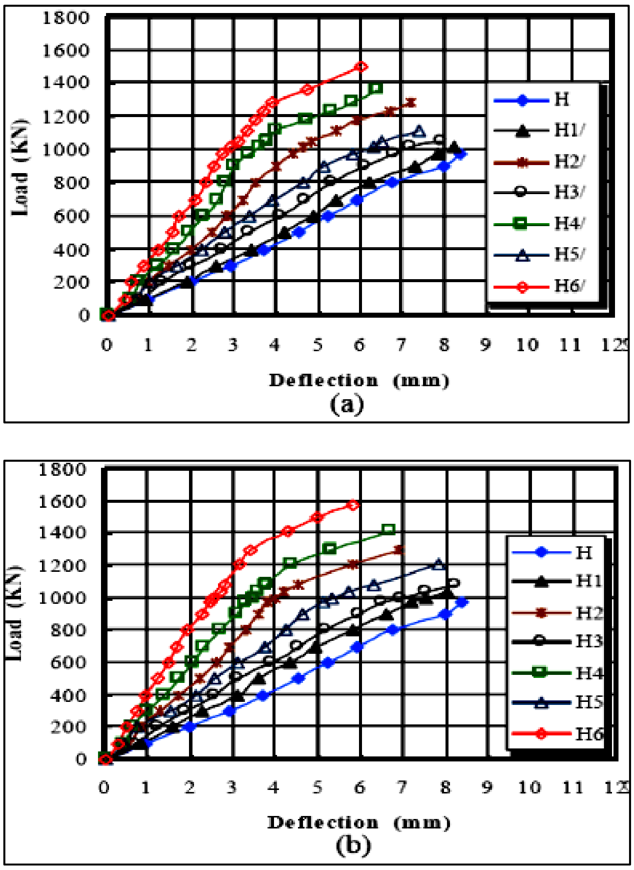


Figure 7. A typical stress-strain relation for concrete.

4.2 Load Deflection behavior

The vertical deflections obtained are plotted versus the loads for specimens with tie ratio 0.3 and 0.4 % as shown in Figures (8 – a) and (8 – b), respectively. Through the study of load deflection curves of the test specimens, find that the greater the central reinforcement diameter and its number the higher the stiffness of the specimens and the lower the values of the vertical deflection. Deflection values decreased by about 4.9 % when using a single central reinforcement of 18 mm diameter in specimen H_5 compared to specimen H_3 with a single central reinforcement of 16 mm diameter. Replacement of a single central reinforcement of 18 mm diameter in specimen H_5 with a bundle of four 18 mm diameter in specimen H_6 leads to 25.6 % decrease in deflection values. The effect of the tie ratio is also evident through the relationship between load and deflection as shown in Figures (9 – a) and (9 – b), where the increasing the tie ratio leads to decrease in deflection values. Similar results are shown by the relationship between loads and deflection values in the numerical analysis as in Fig. (10). Figures. (11– a) and (11– b) show a comparison between deflection values of experimental results and numerical analysis of the specimens with tie ratio 0.3 and 0.4 % , respectively. It is found that the numerical results show a good agreement when compared to those obtained from the experimental work.



(a)

(b)

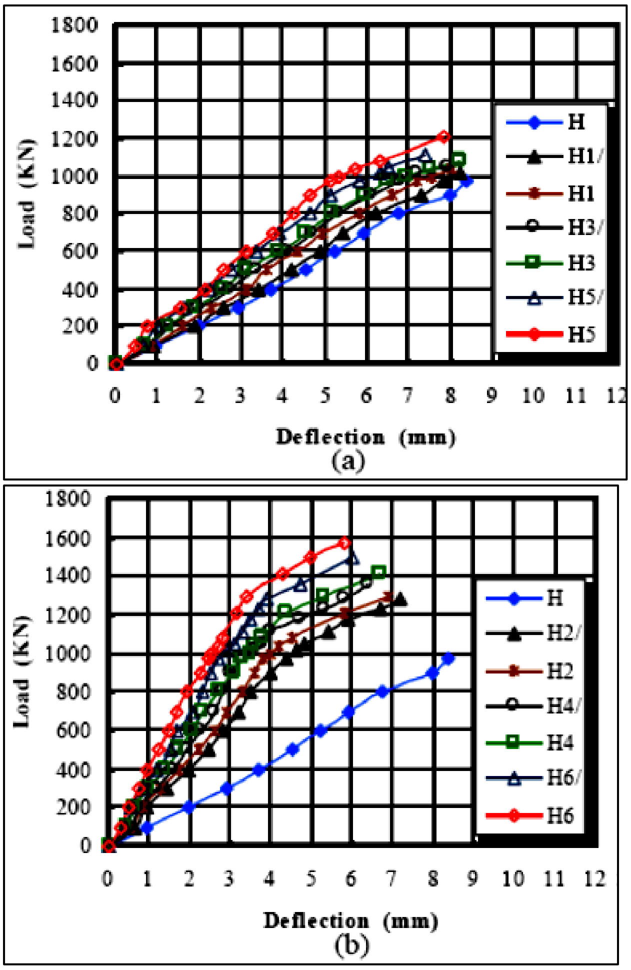
Figure 8. Load deflection curve for test specimen : a) control and with tie ratio 0.3 % ; b) control and with tie ratio 0.4 %.

4.3 Ductility and Energy Absorption

The ratio between the displacement at the ultimate load (Δ u) and the displacement at the yield load (Δ y) is known ductility factor (μ_Δ). Displacement at the yield load is obtained by the secant stiffness method [10]. The ductility factors for all test specimens are calculated and listed in table (7).Results indicate that ductility has been improved by about 22 % a single central reinforcement of 18 mm diameter and by about 36.4 % for a bundle of four central reinforcement of 18 mm diameter. The energy absorption which is the area under the load deflection curve increases with the increase in both the number and the diameter of central reinforcement and accordingly to overall the energy absorption improves.

Table 7: Ductility factor for the test specimens.

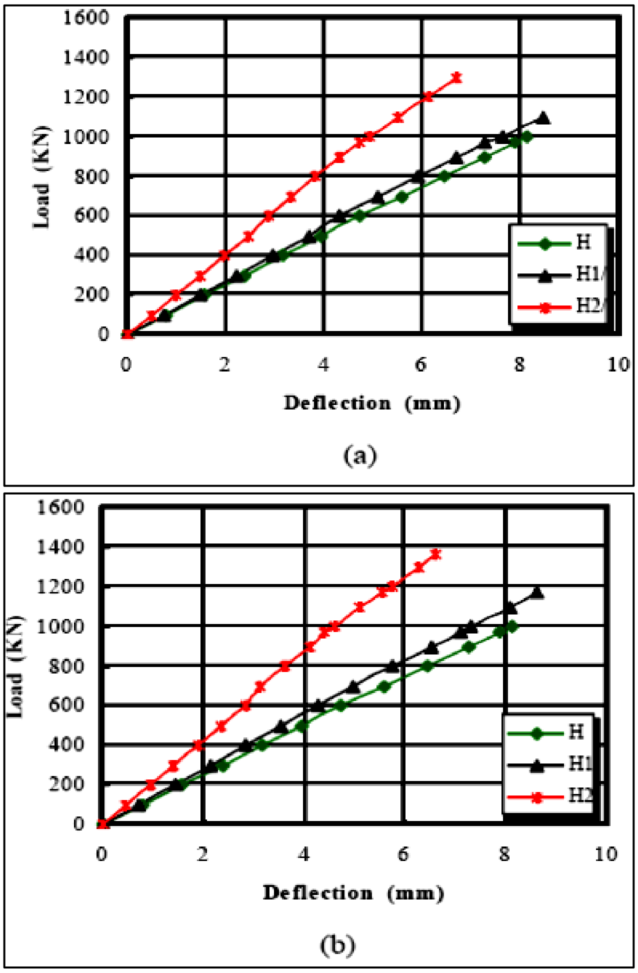
Specimen	**Displacement at yield load (mm)**	**Displacement at ultimate load (mm)**	**Ductility factor μ_Δ**
H (control)	7.1	8.37	1.18
$H_1^{/}$	6.8	8.2	1.21
$H_2^{/}$	4.9	7.2	1.47
$H_3^{/}$	6.1	7.9	1.29
$H_4^{/}$	4.2	6.4	1.52
$H_5^{/}$	5.3	7.4	1.4
$H_6^{/}$	3.8	6	1.58
H_1	6.4	8	1.25
H_2	4.6	6.9	1.5
H_3	6.1	8.2	1.34
H_4	4.3	6.7	1.56
H_5	5.4	7.8	1.44
H_6	3.6	5.8	1.61



(a)

(b)

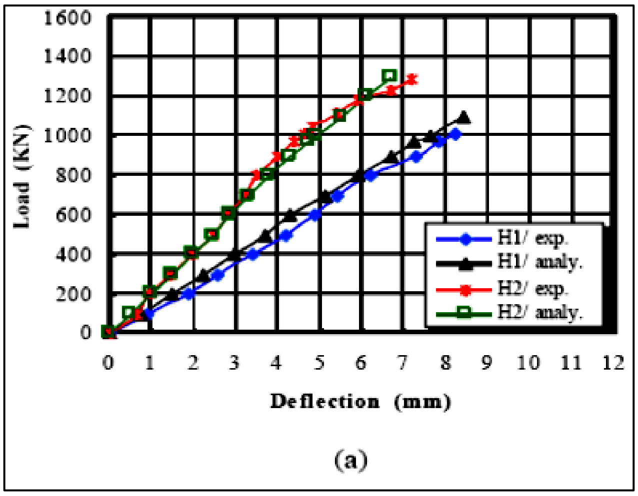
Figure 9. The effect of tie ratio on deflection values : a) control and specimens with a single central bar ; b) control and specimens with a bundle of central bars.



(a)

(b)

Figure 10. Load deflection curve for numerical results



(a)

4.4 Failure Mode of The Columns

Fig. (12) displays the location of maximum stress of concrete. The failure mode of the control SCRC column with no central reinforcement, the SCRC column with a single central reinforcement bar, and the SCRC column with a bundle of central reinforcement bars are presented in Fig. (13 – a) , Fig.

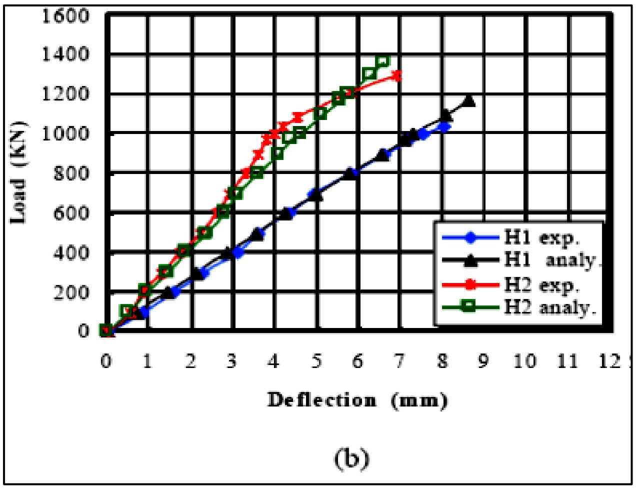


Figure 11. Comparison of load deflection curve for experimental and numerical specimens : a) specimens with tie ratio 0.3 % ; b) specimens with tie ratio 0.4 %.

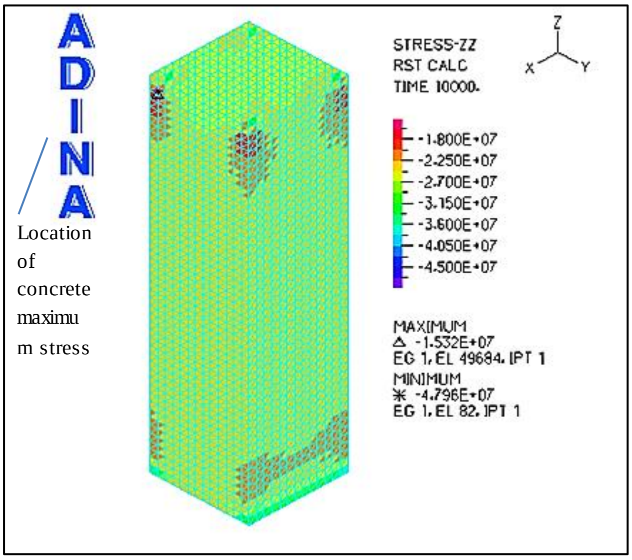


Figure 12. Location of concrete maximum stress.

Figure 13 (a)

Figure 13 (b)

(13 – b), and Fig. (13 – c), respectively. The results revealed that the use of central enhancement, whether a single bar or a bundle of bars in the SCRC columns reduces the extent and the number of longitudinal cracks and delays the crushing of concrete cover. By inspection the control specimen with no central reinforcement found that the cracks began to spread early and quickly during the axial loading process, hence leading to brittle failure. While in the case of specimens with a single central

Figure 13 (c)

reinforcement bar or a bundle of central reinforcement bars, cracks began later and spread at a slower rate during the axial loading process, leading consequently to more ductile failure and less damage to column.

5. Conclusions

In the light of the experimental study for SCRC columns with central reinforcement bar and the numerical analysis of some selected specimens using ADINA program and based on the presented results, the following main conclusions can be drawn :

- The ultimate load for SCRC columns with a central reinforcement bar of 18 mm diameter is 24.7 % greater than that of the control SCRC column without central reinforcement.
- The ultimate load for SCRC columns with a bundle of four central reinforcement bars of 18 mm diameter is 62.5 % greater than that of the control SCRC column without central reinforcement.
- The numerical results that are obtained using ADINA program showed a good agreement with those obtained experimentally for both ultimate load and deflection.
- the greater the diameter of central reinforcement bar and its number, the lower the values of vertical deflection.
- Using a bundle of four central reinforcement bars instead of a single central reinforcement bar of 18 mm diameter decreases the deflection values by 25.6 %.
- The use of central reinforcement enhances both the ductility and the energy absorption for the SCRC columns. The ductility is improved by 22 % when using a single central reinforcement bar of 18 mm diameter and by 36.4 % when replacing this single central reinforcement bar with a bundle of four central reinforcement bars with the same diameter.
- The cracks initiation are delayed when central reinforcement is used. The cracks number were less and slower to spread in SCRC columns with central reinforcement. Accordingly concrete columns with central reinforcement are more ductile and less possibility to crush the concrete cover.

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