Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (42) No. (1) January, 2020

Performance of Moderate Concrete Column Reinforced with Steel Equal Angle Section under Concentric Load

Dr. Hala Metawei[1], Dr. Dalia Arafa[2], Dr. Alaa F. Elkashif[3]
[1]Associate Professor, Housing and Building National Research Center, Cairo, Egypt
[2]Researcher, Housing and Building National Research Center, Cairo, Egypt
[3] Researcher, Housing and Building National Research Center, Cairo, Egypt

ملخص البحث

يهدف البحث لدراسة سلوك الأعمدة القصيرة الخرسانية متوسطة المقاومة المسلحة بالزوايا متساوية الأبعاد بالنسبة للأعمدة المسلحة بأسياخ الحديد المتعارف عليها كذلك دراسة تأثير تقليل المسافة بين الكانات علي قوة تحمل العمود والممطولية. تم اختبار عدد ستة أعمده مربعه بأبعاد 250 *250 مم وطول 750 مم تحت تأثير حمل ضغط محوري. تم تقسيم عينات الاختبار الي مجموعتين، المجموعة الأولي المسافة بين الكانات 100 مم والمجموعة الثانية المسافة بين الكانات 50مم، كل مجموعه تحتوي علي ثلاثة أعمده العمود الأول مسلح بعدد ستة أسياخ قطر 18 مم والعينة الثانية مسلحه بعدد أربعة زوايا بأبعاد (50*50*5) مم والعينة الثالثة مسلحه بعدد أربعة زوايا بأبعاد (60*60*4) مم كحديد طولي. تم استنتاج تصرف الأعمدة بقوة تحمل الأعمدة، الإزاحة الطولية، طريقة الانهيار، التشكل والممطولية. أظهرت النتائج أن استخدام الزوايا المتساوية الأبعاد كحديد طولي للأعمدة الخرسانية متوسطة المقاومة المحملة بأحمال ضغط محورية أبدت تصرف مقبول في المقاومة والممطولية وأثبتت النتائج تفوقها عن الأعمدة المسلحة بأسياخ حديد. أدت نقص المسافة بين الكانات ألي زيادة حمل المقاومة والممطولية.

ABSTRACT

The aim of this paper is to study the behavior of concrete short columns reinforced using steel equal angle composite compression members relative to column reinforced by conventional steel bars. As well, to study the effect of confinement by decreasing stirrups spacing on strength and ductility. Six column quarter scales with 250 x 250 mm cross-section with height of 750 mm were tested under concentric compressive load. The experiment is performed for two series of columns, the first series had stirrups spacing 50 mm, the second series had stirrups spacing 100 mm. Each series had three column The first column reinforced with six diameter 18 mm traditional reinforcement bars used in Egypt, the second column reinforced with four equal steel angles with dimension (50 x 50 x 5) mm, and the third column reinforced with four equal steel angles with dimension (60 x 60 x 4) mm as main reinforcement. Behavior of the specimens was investigated in terms of load carrying capacity, axial displacement, failure modes, strain, and ductility. Results indicated that using steel equal angle as longitudinal reinforcement for moderate concrete columns subjected to concentric compression offers acceptable strength and ductility behavior. The columns reinforced with steel equal angle had higher performance than the columns reinforced with steel bars. The mechanism of failure was explained. Gains in strength and ductility were recorded for columns concrete cores of well-confined columns.

Keywords: Column, Strength, Ductility, Steel Angle, Conventional Steel

INTRODUCTION

Moderate strength-concrete has been applied to a wide variety of the practical engineering, such as building engineering, high rise buildings often use composite column for high strength, ductility, and stiffness. The advantage of higher fire resistant of encased composite columns let them preferred in construction. There is no research carried out of moderate strength concrete columns with steel equal angle sections. The use of steel equal angle sections instead of conventional steel in columns increase the confinement of concrete core and the ductility, because of the complexity of earthquake action, in the seismic analysis and design we need to increase the ductility of columns by different ways including increase stirrups percentage.

Columns with good configuration of longitudinal and lateral reinforcement have good ductility and strength gain.

Ibrahim, et al[9] tested 12 square high strength concrete column with dimension 210 mm sides and 600 mm height reinforced with either steel bars or steel equal angle sections, the lateral tie spacing varied from 50 to 400 mm. They studied the influences of the type of longitudinal reinforcement and the spacing of lateral ties under axial compression. They demonstrated that using of steel equal angle sections instead of steel bars as longitudinal reinforcement in high strength column specimens led to significant improvement in the axial load carrying capacity and ductility due to the higher confinement of the concrete provided by the steel equal angle section, and as the spacing of stirrups decreases the ductility increases and strength of the column. Syed Wasim N Razvi, M. G. Shaikh[2] examined three column specimens, one confined with 6 mm stirrups, the second confined with welded wire mesh in addition to 6mm stirrups, and the third confined with only welded wire mesh. The load carrying capacity and energy absorption curve of short reinforced concrete column confined with ferro mesh jacket in addition to stirrups higher than the column confined using 6 mm stirrups only. Keun-Hyeok, et al[10] presents a relatively simple V-shaped tie arrangement approach as an alternative to the conventional crossties for seismic design of reinforced concrete (RC) columns. The mechanical contribution of the V-tie was characterized regarding the confining core concrete and preventing the premature buckling of the longitudinal reinforcement. They tested fourteen columns to failure under concentric axial load to investigate the performance and shortcomings of the proposed V-tie approach. Test results showed that a 90-degree hook of crossties was gradually opened beyond the ultimate strength of columns. In contrast, no V-ties were extracted from core concrete during the period of tests, even for high-strength concrete columns under a compressive strength of 105 MPa. As a result, higher ductility ratios were observed in V-tie columns than in crosstie columns. In summary, the V-ties possess significant potential to provide supplementary transverse reinforcement of RC columns.

Chaitanya, Rao, and Reddy[3] tested four specimens, two are conventional and two columns are having equal angles as main reinforcement. They found from experimental and analytical results that short columns under axial loading fails due to crushing, but, due to replacement of rounded bars with angles, crushing of short column was controlled in steel replaced columns, strength of the steel replaced column was improved by an average of 20% on replacing of main reinforcement with angle sections, and Deflection in steel replaced concrete columns was decreased by 2.38 times when compared to that of conventional reinforced concrete columns. Lui Bing et al [6] tested thirty reinforced concrete columns, either 240 mm diameter circular or 240 mm square and 720 mm high, containing different confining reinforcement configurations, yield strengths of transverse reinforcement, and concrete compressive strengths, under concentric loads to failure at different strain rates. They found that when the concrete compressive strength reached 75 MPa, the compressive strength enhancement due to dynamic loading appeared to become insensitive to the curing condition. Also, the strength enhancement due to dynamic loading became less with increase in concrete compressive strength. For the test units confined by Grade 430 steel, a high strain rate resulted in an almost 11% increase in the concrete core compressive strength, a slight increase in the modulus of elasticity, and an increase in the slope of the descending branch of the stress-strain curve. The effect of strain rate on the strain corresponding to the peak stress was much smaller or nearly insignificant. For the test units confined by high yield steel (fyh = 1318 MPa), an increase in the rate of strain may not result in an increase in the concrete core compressive strength, but it does increase the modulus of elasticity and the slope of the descending branch of the stress-strain curve. A large decrease in the strain at the peak stress was observed; The test results confirmed that high strain rates appear to have a less weighty effect on the stress-strain relationship of high-strength concrete than on low- and moderate strength concrete. There was no obvious effect of cross-sectional shape on the behavior of the test units in this study.

Tobbi et al.[8] reports the experimental investigation of the compressive performance of concrete columns reinforced longitudinally with FRP or steel bars and with FRP as transverse reinforcement. They tested Twenty concrete columns measuring 350 x 350 x 1400 mm under concentric compressive load. The parametric study included variables such as transverse reinforcement configuration, material type and spacing, longitudinal reinforcement ratio, and confining volumetric stiffness. Results showed that FRP bars have contribution as longitudinal reinforcement for concrete columns subjected to concentric compression and that the combination of FRP transverse reinforcement and steel longitudinal bars offers acceptable strength and ductility behavior.

RESEARCH SIGNIFICANCE

This study aims to clarify the difference of using steel equal angles versus traditional reinforcement in moderate strength concrete columns and to investigate the benefit of reducing stirrups spacing with steel equal angle relative to load carrying capacity, and ductility of the columns.

EXPERIMENTAL PROGRAM

SPECIMEN DETAILS AND DESIGN

The experimental program studied the influence of using two sizes of steel angles (SEA sections) as longitudinal reinforcement versus longitudinal steel bars, and the effect of decreasing lateral reinforcement (ties) spacing on the behavior of square columns under axial concentric compression load. A total of six specimens with cross sectional dimensions 250 x 250 mm and 750 mm height (reinforcement detail and concrete dimensions) are shown in Figure (1) and Table (1), were casted and tested under concentric axial compression. The experiment is performed for two series of columns, the first series had stirrups spacing 50 mm, the second series had stirrups spacing 100 mm, the stirrups diameter was 10 mm with yielding strength 240 MPa. Each series had three columns; the first column reinforced with six 18 mm diameter longitudinal reinforcement with nominal yield tensile strength 550 MP. as confirmed by laboratory test, the second column reinforced with four equal steel angles with dimension (50 x 50 x 5) mm, and the third column reinforced with four equal steel angles with dimension (60 x 60 x 4) mm as longitudinal reinforcement, the nominal yield strength of angels was 450 MPa; as confirmed by laboratory test. The test results were compared to the Egyptian Code of Practice EPC [1], and American Code ACI318-14[19]. The used formulas according to the Egyptian code of practice EPC [1] were:

$$P_U = 0.35 f_{CU}(A_C - A_{SC}) + 0.67\, f_y\, A_{SC} \qquad \textit{For steel bars} \qquad (1)$$

$$P_U = 0.35 f_{CU}(A_C - A_{SC}) + 0.67\, f_y\, A_{SC} + 0.67\, f_{yss}\, A_{SS} \qquad \textit{For steel Angle} \qquad (2)$$

Where

fcu: Concrete cube compressive strength
Ac: Area of Column Cross Section
Asc: Area of Steel Bars in Column
fy: Yield Strength of Steel Bars
fyss: Yield Strength of Steel Section
Ass: Area of Steel Section

ACI 318-14 formula is

$$P_n = 0.8(0.85 f_c'\left(A_g - A_{St}\right) + 0.67\, f_y\, A_{St}) \qquad \textit{For steel bars and angles} \qquad (3)$$

Table1: TESTED SPECIMENS DETAIL

Series No.	**Specimen Labels**	**Longitudinal Reinforcement**					**Lateral Reinforcement**	
		Rft. Type	**No.**	**Bar Diameter (mm)**	**SEA Section Dimension (mm)**	**µ %**	**Diameter (mm)**	**Spacing (mm)**
1	CR-S50	Steel bars	6	18	---	2.4	10	50
	C-A50-S50	SEA Sections	4	---	50x50x5	3.0	10	50
	C-A60-S50	SEA Sections	4	---	60x60x4	3.0	10	50
2	CR-S100	Steel bars	6	18	---	2.4	10	100
	C-A50-S100	SEA Sections	4	---	50x50x5	3.0	10	100
	C-A60-S100	SEA Sections	4	---	60x60x4	3.0	10	100

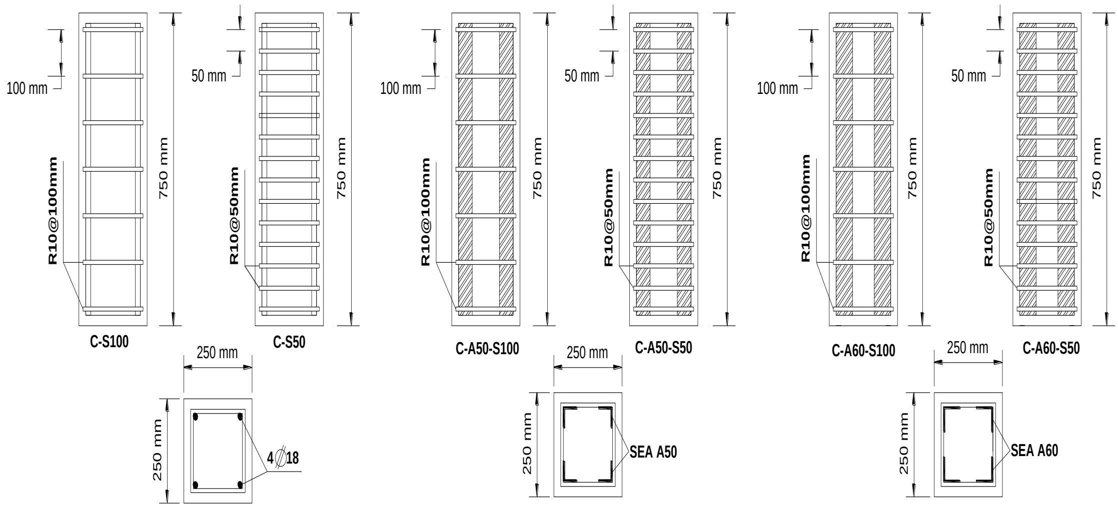


Figure 1. Concrete Dimensions and Reinforcement Details of Specimens (All dimensions are in (mm)

MATERIAL PROPERTIES

The specimens were casted using moderate strength concrete. The targeted concrete strength was 45 MPa. Three Concrete cubes 150x150x150 mm in dimension from each patch were tested in compression after 28 days, to evaluate the compressive strength of concrete mix according to Egyptian Code requirements [1]. The average concrete strength was 42 MPa, Table (2) shows concrete Mixture design. Three samples of steel bar 18 mm diameter were tested according to ASTM A370-15[13] and an average yield strength of 550 MPa was obtained. Two types of steel angles SEA sections were used. Samples with specific dimensions from each type were tested in tension according to ASTM A370-07b[11] and an average yield strength of 450 MPa was recorded. The steel equal angle sections were fetched from iron steel factory in Helwan. Steel angles sections tensile test details are shown in Figure (2) and tensile properties are illustrated in Table (3). All material and specimens tests were carried at Housing Building National Research Centre

Table 2: CONCRETE MIXTURE DESIGN

Cement Kg/m^3	Coarse aggregate (dolomite) kg/m^3	Fine aggregate (Sand) kg/m^3	Water Liter/m^3	Super Plasticizer mL/m^3
400	1000	720	198	1000

Table 3: STEEL SECTIONS TENSILE PROPERTIES

SEA Section	Leg width (mm)	Thickness (mm)	Angle Area (mm^2)	Yield Tensile Strength (MPa)
A50	50	5	480	450
A60	60	4	464	450

Figure 2. SEA Sections Tensile Tests

PREPARATION OF SPECIMENS

The concrete was casted in a thick plywood forms, the plywood sections were placed together with screws. The steel cage was prepared by tack welding the SEA sections with the 10 mm diameter stirrups in specimens C-A50-S50, C-A50-S100, C-A60-S50 and C-A60-S100. A clear concrete cover of 25 mm was insured at top, bottom and from the four sides of the columns before concrete casting. Columns reinforcement and casting details are shown in Figure (3).

Figure 3. Specimens preparation details

INSTRUMENTATION AND TESTING PROCEDURE

Six Column specimens were instrumented externally by two linear variable differential transducers (LVDTs) located at opposite corners at a distance of 470 mm to capture the axial deformations and measure strain of the specimen as shown in Figure (4). The head of the specimen was secured against local failure under compression load by bonding unidirectional carbon fiber fabric with width 100 mm at top and bottom head of each column. The testing of the specimens was carried out using a 3500 KN compression testing machine at the Housing and Building National Research Center Laboratory. All instrumentations were connected to a data logger to record the data.

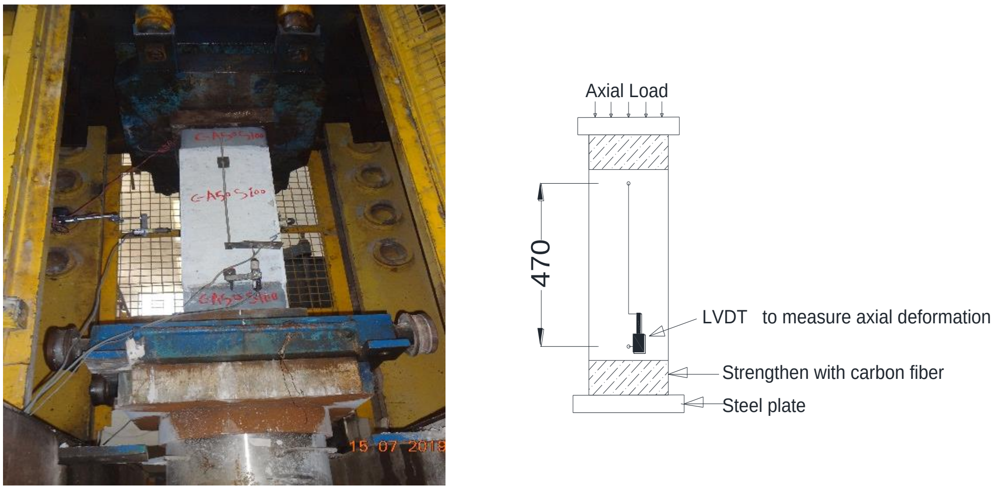


Figure 4. Test Setup

EXPERIMENTAL RESULTS AND DISCUSSIONS

Based on the experimental results the behavior of tested columns discussed in terms of crack propagation, load-deflection curves, and ductility.

FAILURE MODES AND CRACK PROPAGATION

Figure (5) shows the mode of failure and crack pattern for tested columns. Cracks started in the concrete cover at 70-90% of ultimate strength of the column as given in Table (4). The concrete cover began to spall from the core concrete immediately before the ultimate strength of columns. All columns achieve compression failure (concrete crushing) as they were axially loaded, the concrete and steel experienced some stresses, and failure starting without any lateral deformations. For all specimens the failure occurred at the top of the column, for specimen A60-S100 the failure accompanied with buckling of the angles as illustrated in Figure (5). For specimen C-A60-S50 failure occurred at the bottom of the column with cutting of the bottom carbon fiber.

AXIAL LOAD- DEFORMATION RELATIONSHIP

The maximum load, which is defined as the load at which the specimens could not carry any additional load, was recorded and the corresponding deformations as shown in Figure (6) and Table (4), shows cracking load, experimental maximum load, theoretical capacity according to Egyptian Code of Practice EPC [1] and American Code ACI318-14[19]. The Egyptian Code is very conservative when predicting the column capacity, on the other side the ACI318-14 code theoretical capacity is higher than experimental capacity for specimen CR-S100. From the Table we classify that the load carried by steel angle columns is more than conventional steel column. Relative to CR- S100, there is an increase in load reaches to 19.5% for C-A50-S100, and 12.1 % for C-A60-S100. While for specimens confined with 50 mm spacing stirrups, there is an increase in maximum load for specimen C-A60-S50 by 19.6%, and slight improvement for C-A50-S50 compared with CR- S50.

BEHAVIOR OF COLUMN SPECIMEN WITH DIFFERENT STIRRUPS SPACING

Using mild steel stirrups 10 mm and welding (for steel equal angle) to provide better confinement, withhold the main reinforcement in position and good behavior of the column. decreasing spacing increases, the confined concrete along column, as increasing the confinement efficiency and failure load. Figure 6 (c), (d) and (e) shows the effect of decreasing stirrups spacing. In addition, the stirrups spacing controlled the buckling of the reinforcement and delayed unstable crack propagation. The reduction in tie spacing from 100 to 50 mm for specimen reinforced with steel bars, the maximum load increased by 26.7%, for specimen C-A50-S50 the maximum load increased by 10%, and for specimen reinforced with equal steel angle A60-S50 the maximum load increased by 36.2 %. From curves 6 (a) and (b) it is clear that the column with stirrups spacing 100 mm the column with conventional steel bars is more stiffer than column with equal steel angles but verse versa while the spacing of stirrups were 50 mm this clarify the advantage of confinement for steel angle.

DUCTILITY OF MODERATE CONCRETE COLUMNS

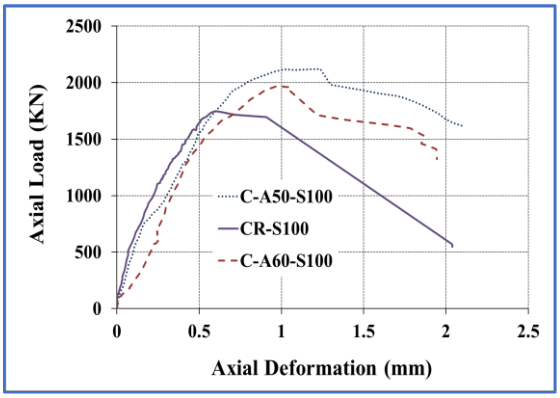
The ductility is important to investigate the behavior of the specimens under load, the ductility was calculated as a ratio of the axial deformation at 80% of the maximum load at descending part of the axial load-axial deformation curves $\Delta_{80\%}$ to the axial deformation at yield load Δ_y, as shown in Equation (4) [25]. Decreasing stirrups spacing increase ductility of specimen by 23.85% and 21.30% for specimen CR-50 and C-A60-S50 and make a slight improvement in ductility for specimen C-A50-S100.

(a) CR-S100 **(b) CR-S50**

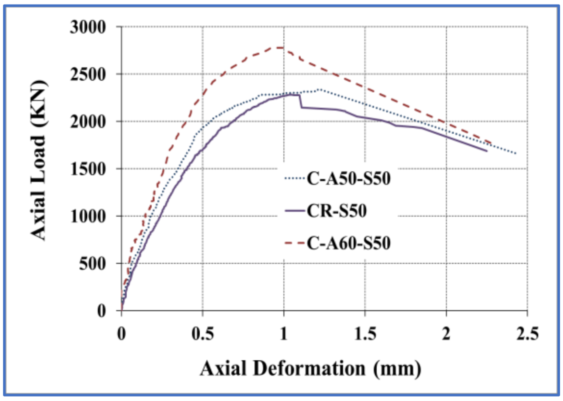
(c) C-A50-S100 **(d) C-A50-S50**

(e) C-A60-S100 **(f) C-A60-S50**

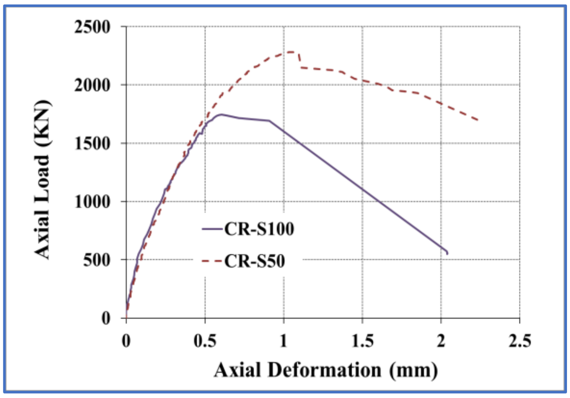
Figure 5. Column specimens at failure



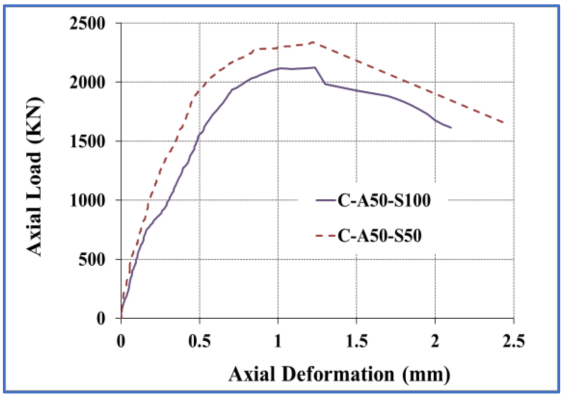
(a)



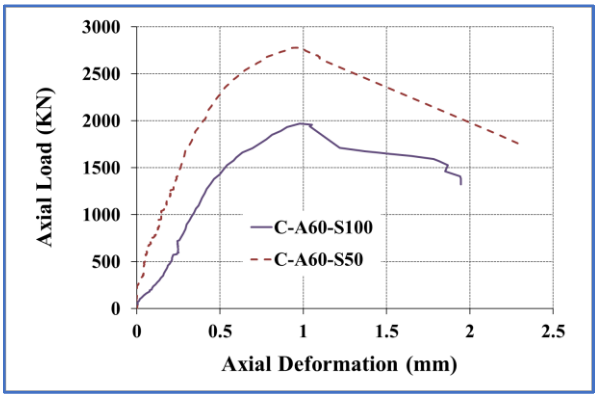
(b)



(c)



(d)



(e)

Figure 6. Load-axial Deformation Relationship

Where:

Ductility = $\Delta_{80\%}/\Delta_y$ (4)

ε = Deformation / LVDT length (470 mm)

$\varepsilon_{80\%}$ = strain at descending part at 80% of maximum load

ε_{max} = strain at maximum load

Table (5) shows the Ductility and Strain measured from the column specimens. The axial strains were calculated as the ratio of the average deformation for two LVDTs at the two opposite column faces to the gauge length (470 mm) of the test zone.

Table 4: EXPERIMENTAL TEST RESULTS

Specimen	Crack Load (kN)	Maximum axial Load (kN)	Axial deformation at Pmax (mm)	Theoretical capacity (kN)		$(P_{experimental}/P_{theoretical})$	
				ECP	ACI	ECP	ACI
CR-S100	1627	1744	0.60	1458	1843	1.19	0.94
C-A50-S100	1722	2122	1.23	1469	1847	1.44	1.14
C-A60-S100	1608	1969	0.98	1451	1833	1.35	1.07
CR-S50	1893	2282	1.04	1458	1843	1.56	1.2
C-A50-S50	1710	2338	1.22	1469	1847	1.59	1.26
C-A60-S50	1953	2779	0.97	1451	1833	1.91	1.51

Table 5: DUCTILITY AND STRAINS VALUES

Series No.	Specimen	Post-Ultimate Strain at 80% of P_{max} $\varepsilon_{80\%}$	εy	Ductility $(\Delta_{80\%}/\Delta_y)$	ε_{max}
Series 1	CR-S100	0.00255	0.00123	2.07	0.00127
	C-A50-S100	0.0042	0.00017	2.50	0.00265
	C-A60-S100	0.00372	0.0017	2.18	0.00249
Series 2	CR-S50	0.00425	0.00159	2.60	0.00234
	C-A50-S50	0.0044	0.0017	2.63	0.0032
	C-A60-S50	0.00372	0.00138	2.70	0.00212

CONCLUSION

This research program has participated to understand the axial behavior of column with moderate concrete strength using equal steel angle as reinforcement versus conventional steel. The study focuses on the spacing of stirrups and reinforcing using steel angle. The experimental results were compared considering the axial compression design provisions provided by the ECP Egyptian code of practice and ACI Building Code (ACI Committee 318 -14). The results demonstrate that; the steel equal angle was intended to improve load-carrying capacities of the columns with moderate concrete strength, localized cracks so that overall flexural and shear strength could be improved with an increase in ductile deformation capacity.

1. It is clear from results that the load carried by steel angle columns is more than conventional steel column. Relative to CR- S100, there is an increase in load reaches to 19.5% for C-A50-S100, and 12.1 % for C-A60-S100. On the other side for specimens confined with 50 mm spacing stirrups, there is an increase in maximum load for specimen C-A60-S50 by 19.6%, and slight improvement for C-A50-S50 compared with CR- S50.
2. The ECP is very conservative in evaluated the column capacity, on the other side the ACI 318-14 code theoretical capacity was near the experimental capacity for specimen CR-S100 and CA60-S100.
3. The reduction in stirrups spacing from 100 to 50 mm in specimen reinforced with steel bars, the maximum load increased by 26.7%, for specimen C-A50-S50 the maximum load increased by 10%, and for specimen reinforced with equal steel angle C-A60-S50 the maximum load increased by 36.2 %.

4. Relative to CR-S100, using steel equal angle A50 leads to ductility amplification with 20.7 % for Specimen C-A50-S100 and using steel equal angle A60 leads to ductility rise by 5.3 % for Specimen C-A60-S100.
5. Relative to CR-S50, using steel equal angle A50 and A60 leads to slight improvement in ductility, this because of confinement of stirrups.
6. When the thickness of the angle reduces, the ultimate strength reduced when the spacing was high (100 mm), while when the spacing decreased to 50 mm the confinement improved and the ultimate strength increased as in specimens C-A60-S100 and C-A60-S50.
7. It is recommended to increase the thickness of the angle with high stirrups spacing to avoid buckling of steel angles.

REFERENCES

1. Egyptian Code of Practice for Design and Construction of Reinforced Concrete Structure, Housing and Building National Research Center, Giza, Egypt, ECP203-2007.
2. Syed Wasim N Razvi, M. G. Shaikh (2018), “Effect of confinement on behavior of short concrete column”, 2nd International Conference on Materials Manufacturing and Design Engineering, Science Direct, Elsevier pp. 563-570.
3. N. Chaitanya, V. Ranga Rao, M. Achyutha Kumar Reddy (2018), “performance of composite reinforced short column under axial loading”, International Journal of Engineering & Technology, 7 (3) (2018) pp.1376-1380.
4. Liu Jin, Min Du, Dong Li, Xiuli Du, Haibin Xu, “Effects of cross section size and transverse rebar on the behavior of short squared RC columns under axial compression,” Engineering Structures 142 (2017) pp..223–239.
5. M.F. Hassanein a, V.I. Patel, “Round-ended rectangular concrete-filled steel tubular short columns FE investigation under axial compression,” Journal of Constructional Steel Research 140 (2018) pp 222–236.
6. Li Bing, R. Park, and H. Tanaka, (2000) “Constitutive Behavior of High-Strength Concrete under Dynamic Loads,” ACI Structural Journal V. 97, No. 4. pp. 619-629
7. Hany Tobbi, Ahmed Sabry Farghaly, and Brahim Benmokrane “Concrete Columns Reinforced Longitudinally and Transversally with Glass Fiber-Reinforced Polymer Bars,” ACI Structural Journal V. 109, No. 4, 2012.pp. 551-558
8. Hany Tobbi, Ahmed Sabry Farghaly, and Brahim Benmokrane “Behavior of Concentrically Loaded Fiber-Reinforced Polymer Reinforced Concrete Columns with Varying Reinforcement Types and Ratios,” ACI Structural Journal V. 111, No. 2, 2014. pp.375-385
9. Ayoob A. Ibrahim, M. Neaz Sheikh, and Muhammad N. S. Hadi “Axial compressive behavior of steel equal angle section reinforced square high strength concrete column,” ACI Structural Journal V. 115, No. 5, 2018. pp.1413-1441
10. Keun-Hyeok Yang and Won-Woo Kim “Axial Compression Performance of Reinforced Concrete Short Columns with Supplementary V-Shaped Ties “ACI Structural Journal/November-December 2016 pp 1347-1356
11. ASTM A370-07b “Standard Test Methods and Definitions for Mechanical Testing of Steel Products”.
12. Sakai, K., and Sheikh, S. A., “What Do We Know about Confinement Reinforced Concrete Columns? A Critical Review of Previous Work and Code Provisions,” ACI Structural Journal, V. 86, No. 2, Mar.-Apr. 1989, pp. 192-207.

13. ASTM A370-15 Standard Test Methods and Definition for Mechanical Testing of Steel Products
14. Elwood, K. J.; Maffel, J.; Riederer, K. A.; and Telleen, A. K., "Improving Column Confinement—Part 1: Assessment of Design Provisions," Concrete International, V. 31, No. 11, Nov. 2009, pp. 32-39.
15. Hong, K. N.; Akiyama, M.; Yi, S. T.; and Suzuki, Y. M., "Stress-Strain Behaviour of High-Strength Concrete Columns Confined by Low Volumetric Ratio Rectangular Ties," Magazine of Concrete Research, V. 58, No.2,2006, pp.101- 115.
16. Razvi, S. R., and Saatcioglu, M., "Confinement Model for High Strength Concrete," Journal of Structural Engineering, ASCE, V. 125, No. 3, 1999, pp. 281-289.
17. Watson, S.; Zahn, F. A.; and Park, R., "Confining Reinforcement for Concrete Columns," Journal of Structural Engneering, ASCE, V. 120, No. 6, 1994, pp. 1798-1824.
18. Park, R., "Ductile Design Approach for Reinforced Concrete Frames," Earthquake Spectra, V. 2, No. 3, 1986, pp. 565-619
19. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.
20. Ozcebe, G., and Saatcioglu, M., "Confinement of Concrete Columns for Seismic Loading," ACI Structural Journal, V. 84, No. 4, July-Aug. 1987, pp. 308-315.
21. Mander, J. B.; Priestley, M. J. N.; and Park, R., "Observed Stress- Strain Behavior of Confined Concrete," Journal of Structural Engineering, ASCE, V. 114, No. 8, 1988, pp. 1827-1849.
22. Saatcioglu, M., and Razvi, S. R., "Strength and Ductility of Confined Concrete," Journal of Structural Engineering, ASCE, V. 118, No. 6, 1992, pp. 1590-1607
23. Fafitis, A., and Shah, S. P., "Predictions of Ultimate Behavior of Confined Columns Subjected to Large Deformations," ACI Structural Journal, V. 82, No. 4, July-Aug. 1985, pp. 423-433.
24. Lukkunaprasit, P., and Sittipunt, C., "Ductility Enhancement of Moderately Confined Concrete Tied Columns with Hook-Clips," ACI Structural Journal, V. 100, No. 4, July-Aug. 2003, pp. 422-429.
25. Feng, P.; Ye, L.; and Zhuang, J., "Review and New Proposals for Performance Indices of Flexural Members," Eighth International Symposium on Structural Engineering for Young Exports, Xi'an, China, 2004, pp.1-8.