Effect of Concrete Strength and Aspect Ratio on Strength and Ductility of Concrete Columns

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Abstract**—**This paper presents the effect of concrete compressive strength and rectangularity ratio on strength and ductility of normal and high strength reinforced concrete columns confined with transverse steel under axial compressive loading. Nineteen normal strength concrete rectangular columns with different variables tested in this research were used to study the effect of concrete compressive strength and rectangularity ratio on strength and ductility of columns. The paper also presents a nonlinear finite element analysis for these specimens and another twenty high strength concrete square columns tested by other researchers using ANSYS 15 finite element software. The results indicate that the axial force – axial strain relationship obtained from the analytical model using ANSYS are in good agreement with the experimental data. The comparison shows that the ANSYS is capable of modeling and predicting the actual nonlinear behavior of confined normal and high-strength concrete columns under concentric loading. The maximum applied load and the maximum strain have also been confirmed to be satisfactory. Depending on this agreement between the experimental and analytical results, a parametric numerical study was conducted by ANSYS 15 to clarify and evaluate the effect of each variable on strength and ductility of the columns.

Keywords**—**ANSYS, concrete compressive strength effect, ductility, rectangularity ratio, strength.

I. INTRODUCTION

THE current design of reinforced concrete structures is concerned with the behavior of ultimate strength and ductility under severe loading condition in view of the safety of structures and economy. One of the most important structural elements which play a significant role is the column. Columns are basically the main structural elements used to resist both vertical and lateral loads. The importance of ductility and associated energy absorption capacity of a structure in resisting earthquakes has long been recognized. The need for ductility was emphasized in recent years in light of the damages sustained by ductile buildings subjected to severe earthquakes. Compression failure in reinforced concrete members is a brittle failure. It is evident that special design and detailing techniques must be employed to improve the ductility of a column, which is a compression member. Previous studies [1], [4] have demonstrated that confinement of column concrete improves both of strength and ductility very significantly. In spite of a lot of studies that studied the stress-strain relationship and ductility of confined concrete columns [1], [4], [7], more experimental investigation especially for rectangular columns are needed. The overall objective of this paper is to establish the effect of concrete compressive strength and rectangularity ratio on strength and ductility of normal and high strength reinforced concrete columns through experimental and analytical research. The columns investigated can be classified as short columns, not affected by secondary stresses.

II. EXPERIMENTAL PROGRAM

A comprehensive experimental program was conducted to investigate the behavior of concrete columns confined with rectilinear reinforcement. The test program included a total of nineteen rectangular columns subjected to monotonically increasing concentric compression. Test specimens were designed to investigate the influence of main parameters of confinement. The parameters investigated are including cross-sectional shape, concrete strength, volumetric ratio, the spacing of transverse reinforcement, longitudinal reinforcement distribution, transverse reinforcement arrangement, and yield strength of transverse reinforcement. The columns specimens were casted horizontally in four sets while each set had a different batch of concrete with different compressive strength. The columns were confined with four different reinforcement configurations. Column geometry and tie configurations are as shown in Fig. 1 and the properties of tested specimens are as shown in Table I.

A. *Evaluation of Tested Columns*

To evaluate the effect of the various parameters on the behavior of the tested column specimens, two measures are strength and ductility of the tested specimen will be used.

B. *Evaluation of Column Strength*

The column strength under concentric loading was recorded during testing. Experimental observations indicated that cover spalling had occurred prior to the attainment of the load capacity; therefore, the maximum load was resisted by the concrete core [4], [7], including the contribution of longitudinal reinforcement. Table II contains recorded strengths of rectangular columns. According to the previous researches [2], 0.85 f'_c will be used to represent the in-place strength of unconfined concrete in columns. Strength enhancement due to confinement was measured by effective confinement index (Ks), by comparing strengths of Core (f'_{cc}), and unconfined concrete (f'_{co}). (Ks) was computed by (1). The core capacity was established by subtracting the contribution of longitudinal reinforcement from the recorded column

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capacity. The ratios of confined to unconfined concrete strengths are listed in Table III. It is indicating up to 42% increase in concrete strength due to confinement.

$$Ks = f'_{cc} \ / \ f'_{co} \tag{1}$$

C. Evaluation of Column Deformability

Column deformability reflects the ability of columns to deform without a significant loss of strength. Deformability of columns tested in this study program was investigated by the ductility. The ductility of columns was evaluated in terms of the axial strain ductility ratio which is the ratio between the axial strains of confined core at a certain level of loading on the descending part of the axial strain of the confined core at the ultimate strength [3]. In this study, the used strain ductility ratio is u_{85d} and can be computed as:

$$u_{85d} = \in_{85d} \ / \in_{cc} \tag{2}$$

u_{85d} = Axial strain ductility ratio corresponding to $\in_{85d}$; $\in_{85d}$= Axial strain corresponding to the 85% of the ultimate compressive load on the descending part; $\in_{cc}$= Axial strain corresponding to the ultimate compressive load.

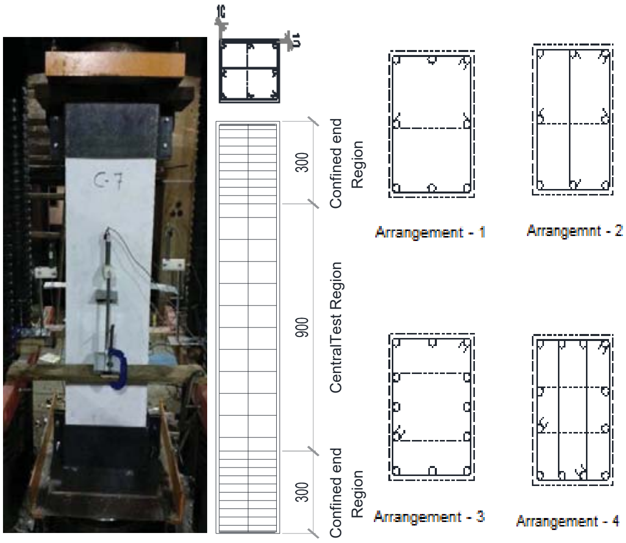

Fig. 1 Cross-sectional arrangements and section geometry of tested columns

III. FINITE ELEMENTS AND NUMERICAL ANALYSIS

In this study, ANSYS R15.0 [8] was used, which is capable of modeling the nonlinear behavior of reinforced concrete columns. Tested specimens in this investigation and other specimens tested by other researchers are used for predicting the nonlinear behavior of well confined concrete columns with various compressive strength and various lateral reinforcement, under concentric load.

TABLE I
PROPERTIES OF TESTED SPECIMENS

Columns Label	Arrangement	Section dimension	Longitudinal reinforcement		f'_c	$f_{y.long}$	$f_{y.ties}$	Ties diam.	s
			NO	Diam. mm	MPa	MPa	MPa	mm	mm
C-1	4	200x400	12	12	41.5	501	331	8	80
C-2	1	200x400	4, 4	10, 18	41.5	534,361	331	8	80
C-3	3	200x400	4, 4	10, 18	41.5	534,361	331	8	80
C-4	3	200x400	12	12	41.5	501	291	6	45
C-5	2	200x400	12	12	41.5	501	331	8	80
C-6	3	200x400	12	12	39.5	501	331	8	60
C-7	3	200x400	12	12	39.5	501	331	8	80
C-8	2	200x400	4, 4	10, 18	39.5	534,361	534	10	100
C-9	4	200x400	12	12	39.5	501	331	8	120
C-10	3	200x400	10	12	39.5	501	534	10	125
C-11	1	200x300	4, 4	10, 18	47.5	534,361	331	8	80
C-12	2	200x300	4, 4	10, 18	43.5	534,361	534	10	100
C-13	3	200x300	12	12	43.5	501	534	10	125
C-14	3	200x300	4, 4	10, 18	43.5	534,361	331	8	100
C-15	3	200x300	12	12	47.5	501	331	8	80
C-16	4	200x300	12	12	43.5	501	331	8	80
C-17	3	200x300	12	12	47.5	501	331	8	50
C-18	3	200x300	10	12	43.5	501	331	8	80
C-19	2	200x300	12	12	43.5	501	331	8	110

TABLE II
EXPERIMENTAL STRENGTH AND CONFINEMENT INDEX (KS) FOR COLUMNS

Columns Label	**Arrangement**	f'_c	P_{Test}	P_{CC}	$f'_{cc}\ (exp)$	$f'_{co} = 0.85f'_c$	**Ks**
		Mpa	KN	KN	**Mpa**	**Mpa**	**mm**
C-1	4	41.5	3602	2931	45.8	32.28	1.30
C-2	1	41.5	3670	3141	49.1	35.28	1.39
C-3	3	41.5	3557	3028	47.3	35.28	1.34
C-4	3	41.5	3480	2808	43.2	35.28	1.22
C-5	2	41.5	3463	2792	43.6	35.28	1.24
C-6	3	39.5	3359	2688	42.0	33.58	1.25
C-7	3	39.5	3232	2561	40.0	33.58	1.19
C-8	2	39.5	3218	2689	42.7	33.58	1.27
C-9	4	39.5	3408	2737	42.8	33.58	1.27
C-10	3	39.5	3318	2758	43.9	33.58	1.31
C-11	1	47.5	2857	2327	49.7	40.38	1.23
C-12	2	43.5	2733	2204	47.1	36.98	1.27
C-13	3	43.5	2999	2328	49.8	36.98	1.35
C-14	3	43.5	2777	2248	48.0	36.98	1.30
C-15	3	47.5	3258	2587	55.3	40.38	1.37
C-16	4	43.5	3120	2449	52.3	36.98	1.42
C-17	3	47.5	3183	2512	53.7	40.38	1.33
C-18	3	43.5	3014	2454	52.5	36.98	1.42
C-19	2	43.5	3037	2366	50.6	36.98	1.37

TABLE III
AXIAL STRAIN DUCTILITY RATIO FOR THE COLUMN

Columns Label	**Arrangement**	f'_c, **Mpa**	ε_{85}	$\varepsilon_{\chi\chi}$	u_{85d}
C-1	4	41.5	N/A	N/A	N/A
C-2	1	41.5	0.00386	0.00226	1.71
C-3	3	41.5	0.00153	.001253	1.22
C-4	3	41.5	0.00397	0.00240	1.58
C-5	2	41.5	0.00510	0.0033	1.55
C-6	3	39.5	0.00378	0.0031	1.22
C-7	3	39.5	0.00479	0.00325	1.48
C-8	2	39.5	0.00469	0.00303	1.55
C-9	4	39.5	0.00530	0.00286	1.62
C-10	3	39.5	0.00517	0.00266	1.67
C-11	1	47.5	0.00391	0.00283	1.29
C-12	2	43.5	0.00407	0.00311	1.31
C-13	3	43.5	0.00323	0.00275	1.18
C-14	3	43.5	0.00396	0.00307	1.21
C-15	3	47.5	0.00430	0.00341	1.26
C-16	4	43.5	0.00404	0.00286	1.59
C-17	3	47.5	0.00508	0.00329	1.54
C-18	3	43.5	0.00420	0.00300	1.40
C-19	2	43.5	0.003475	0.00266	1.31

A. Geometry Modeling

In this study, nineteen normal strength concrete columns with dimensions of the section 250x250 mm were tested experimentally with properties shown in Table I and twenty high strength concrete columns tested experimentally by [2] with properties shown in Table IV, were analyzed by ANSYS R.15.0 program. Where the main variables considered are concrete strength ranging from 39.5 MPa to 124 MPa, and different confinement characteristics.

B. ANSYS Finite Element Model

The FEA study included the modeling of reinforced concrete columns, along with the dimensions and properties corresponding to the actual experimental data. The element type and material properties will be displayed in the following details to reflect the actual mechanical and physical properties of the column specimens.

TABLE IV
PROPERTIES OF COLUMNS TESTED BY [3]

Columns Label	**Arrangement**	Longitudinal Reinf.		f'_c	*fy.long*	*fy.ties*	Ties diam.	s	ρ ties
		NO.	Diam. Mm	Mpa	Mpa	Mpa	mm	mm	%
CS-1	1	4	16	124	450	400	11.3	55	3.33
CS-2*	2	8	16	124	450	570	6.5	55	2.16
CS-3	3	12	16	124	450	570	6.5	55	2.16
CS-4	2	8	16	124	450	1000	7.5	55	2.17
CS-5	3	12	16	124	450	1000	7.5	120	1.32
CS-8	2	8	16	124	450	400	11.3	85	3.24
CS-9	3	12	16	124	450	400	11.3	120	3.06
CS-11	1	4	16	81	450	400	11.3	40	4.59
CS-12	1	4	16	81	450	400	11.3	55	3.33
CS-13*	2	8	16	92	450	570	6.5	55	2.16
CS-14	3	12	16	92	450	570	6.5	55	2.16
CS-15	2	8	16	81	450	1000	7.5	55	2.17
CS-16	3	12	16	81	450	1000	7.5	85	1.87
CS-18	3	12	16	81	450	400	6.5	85	1.4
CS-19	2	8	16	92	450	400	11.3	85	3.24
CS-20	3	12	16	92	450	400	11.3	85	4.32
CS-22	2	8	16	60	450	1000	7.5	85	1.4
CS-23	3	12	16	60	450	1000	7.5	120	1.32
CS-24	2	8	16	60	450	400	11.3	85	3.24
CS-25	3	12	16	60	450	400	11.3	120	3.06

*: columns CS-2 and CS-13 had double layers of cross ties

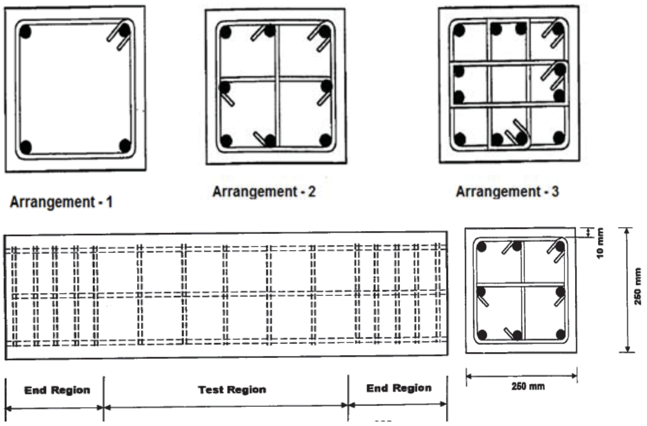

Fig. 2 Cross-sectional arrangements and section geometry of columns [2]

- Concrete Element Type

Eight-node solid element, Solid65, was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. The element is capable of predicting plastic deformation, cracking and crushing in three orthogonal directions.

- Steel Reinforcement Type

Link180 element was used to model the steel reinforcement. Two nodes are required for this element; each node has three degrees of freedom, translations in the nodal x, y, and z directions. The element is also capable of modeling plastic deformation.

- Concrete and Reinforcement Properties

Concrete is a brittle material and has different behavior in compression and tension. The stress-strain curve relationship for concrete is described by multi- linear isotropic curve, linear elastic up to about 30% of the maximum compressive strength (f'_c). The stress–strain curve for each column model is constructed using points connected by straight lines to represent the multilinear isotropic stress -strain curve for the concrete. Elastic modulus is the initial tangent slope of the stress-strain curve of the concrete, Poisson's ratio assumed to be 0.2.

An elastic modulus equal to 200,000 Mpa and Poisson's ratio of 0.3 were used for the longitudinal and transversal reinforcement while the steel reinforcement was assumed to be linear isotropic elastic materials.

C. Element Meshing

After recording all the input data of material and geometrical properties, the column models were divided into small cubical or rectangular elements, as shown in Fig. 3. For column specimens reinforced with longitudinal and transversal reinforcement, elements were created according to the location of reinforcing bars either the longitudinal or lateral reinforcement, as well as the column specimen cross – sectional perimeter. By using merge items in ANSYS, SOLID65 and Link180 elements can be interconnected one to another forming a single solid column model which is capable of simulating the actual behavior of reinforced concrete column.

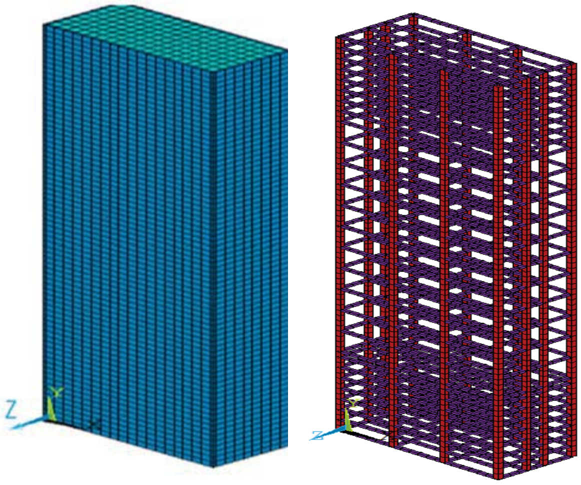

Fig. 3 3D of concrete column mesh and 3D view in reinforcement

D. Loads and Boundary Conditions

Displacement boundary conditions are needed to constrain the model to get a unique solution. To ensure that the model acts the same way as the experimental columns specimens, boundary conditions need to be applied where the supports and loadings exist. For all columns models the displacement of all nodes at the bottom base of the column in y direction was held (Uy = 0). To simulate the effect of the steel plate with 10 mm thickness and 300 mm height around the columns faces at the bottom and top of the column, the displacement of nodes at the columns faces which are parallel to X. direction was held in direction Z (Uz = 0) and the displacement of nodes at the columns faces which are parallel to Z. direction was held in direction X (Ux = 0) up to 300 mm height from the bottom and top faces of the column. To apply the axial load on the top of the column specimens, an axial pressure was implemented over the entire top surface of the column model.

E. Discussion

In this study and as noted in [5], it was found that if the crushing capability of the concrete is turned on, the finite element column models fail prematurely. The crushing of concrete started to develop in elements located outside the transverse reinforcement which is unconfined. Subsequently, adjacent concrete elements crushed within several load steps as well, significantly reducing the local stiffness. Finally, the solution diverged. Therefore, in this study, the crushing capability was turned off for the unconfined elements. For the reinforced concrete columns, the considered column area is the confined area up to the center line of transverse reinforcement, it is matching with the assumption that the peak load of the columns and maximum strength during experimental tests were carried by the confined area after spalling of concrete cover. The final load applied from finite element analysis, is the last load before the solution diverged. During this study, verification is carried out in order to check the validity and accuracy of the finite element procedure. The accuracy was determined by ensuring that axial force- axial strains relationship, maximum stress, maximum strain and maximum load is reasonably predicted compared with experimental results.

The axial force-axial strain curves obtained from ANSYS solution (Py and εy) are compared with experimental results, as shown in Fig. 4, its shows that the predictions are in close agreement with experimental curves. This indicates that the actual behavior of confined column specimens with transverse steel under concentric compressive loading can be accurately predicted by the FEA approach. The accuracy of the proposed procedure is also confirmed through the close value of compressive stress and compressive strain at maximum load, which is the final load from the finite element models of the last applied load before the solution diverged, compared with experimental results as shown in Tables V and VI. These values show the accuracy of the proposed procedure in predicting the actual nonlinear behavior of columns.

IV. EFFECTS OF TEST PARAMETERS ON BEHAVIOR OF CONCRETE COLUMNS

A. Concrete Compressive Strength

From the experimental program results, Rectangular columns C-18 and C-15 with the same arrangement of longitudinal and lateral reinforcement had 43.5 and 47.5 MPa concrete strength respectively. The results indicate that 43.5 Mpa concrete benefited more from the same confinement reinforcement and developed higher strength enhancement. Furthermore, the 43.5 Mpa concrete clearly showed better ductility characteristics than the companion concrete with 47.5 Mpa as shown in Tables III and IV and in Fig. 5.

From the finite element analysis done by ANSYS program and considering the same properties for the actual specimens CS-24 and CS-19 tested by [1], with different values for compressive concrete strength, Table VII indicates that lower strength concrete benefited more than higher strength from the same confinement reinforcement.

TABLE V
COMPARISON BETWEEN EXPERIMENTAL AND FEA LOADS, STRESS AND STRAIN FOR THE RECTANGULAR COLUMNS OF PRESENT STUDY

Columns Label	Experimental Results		FEA Results		FEA / Experimental	
	Max. Load (KN)	Max. Comp. strain (mm/mm)	Max. Load (KN)	Max. Comp. strain (mm/mm)	Max. Load (KN)	Max. Comp. strain (mm/mm)
C-1	3602	N/A	3791	0.00301	1.05	N/A
C-2	3670	0.00226	3399	0.00241	0.93	1.07
C-4	3480	0.00240	3504	0.00263	1.01	1.10
C-5	3463	0.00330	3767	0.00299	1.09	0.91
C-6	3359	0.00310	3602	0.00300	1.07	0.97
C-7	3232	0.00325	3439	0.00308	1.06	0.95
C-8	3218	0.00303	3471	0.00275	1.08	0.91
C-9	3408	0.00286	3551	0.00295	1.04	1.03
C-10	3318	0.00266	3277	0.00263	0.99	0.99
C-11	2857	0.00283	2875	0.00306	1.01	1.08
C-12	2733	0.00311	2609	0.00291	0.95	0.93
C-13	2999	0.00275	2938	0.00291	0.98	1.06
C-14	2777	0.00307	2737	0.00278	0.99	0.90
C-15	3258	0.00341	3242	0.00345	1.00	1.01
C-16	3120	0.00286	2936	0.00307	0.94	1.07
C-17	3183	0.00329	3263	0.00336	1.03	1.02
C-18	3014	0.00300	2815	0.00326	0.93	1.09
C-19	3037	0.00266	2938	0.00291	0.97	1.09

TABLE VI
COMPARISON BETWEEN EXPERIMENTAL AND FEA LOADS, STRESS AND STRAIN FOR THE SQUARE COLUMNS TESTED BY [2]

Columns Label	Experimental Results		FEA Results		FEA / Experimental	
	Max. Load (KN)	Max. Comp. strain (mm/mm)	Max. Load (KN)	Max. Comp. strain (mm/mm)	Max. Load (KN)	Max. Comp. strain (mm/mm)
C-1	6040	0.0032	5979	0.00291	0.99	0.91
C-2	6597	0.0040	6974	0.00389	1.06	0.97
C-3	7218	0.0033	6950	0.00344	0.96	1.04
C-4	6631	0.0040	7005	0.00360	1.06	0.90
C-5	6849	0.0030	6885	0.00312	1.01	1.04
C-9	7177	0.0037	7292	0.00360	1.02	0.98
C-11	4856	0.0033	4935	0.00349	1.02	1.06
C-12	4366	0.0033	4400	0.00362	1.01	1.10
C-13	4874	0.0067	5261	0.00712	1.08	1.06
C-14	5561	0.0030	5614	0.00287	1.01	0.96
C-15	5296	0.0035	5282	0.00370	1.00	1.06
C-16	5578	0.0033	5178	0.00335	0.93	1.01
C-18	4713	0.0028	5170	0.00293	1.10	1.04
C-19	5536	0.0048	5548	0.00464	1.00	0.97
C-20	5911	0.0070	6461	0.00642	1.09	0.92
C-22	3977	0.0035	3855	0.00333	0.97	0.95
C-23	4437	0.0038	4291	0.00338	0.97	0.88
C-24	4076	0.0035	4058	0.00355	1.00	1.01
C-25	4246	0.0043	4351	0.00411	1.02	0.96

TABLE VII
EFFECT OF CONCRETE STRENGTH ON CONFINED CONCRETE COMPRESSIVE STRENGTH

Columns Label	f'_c	$f_{y.long}$	concrete core dimension (mm)	$P_{F.A.A}$	$P_{C\ test}$	f'_{cc}	f'_{co}	C f'_c	$\frac{f'_{cc}}{f'_{co}}$
	MPa	MPa		KN	KN	Mpa	Mpa	Mpa	
CS- C30	30	450	218.7	2474	1754	36.7	25.50	11.2	1.44
CS- C40	40	450	218.7	3067	2347	49.1	34.00	15.1	1.44
CS- C50	50	450	218.7	3584	2864	59.9	42.50	17.4	1.41
CS- 24	60	450	218.7	4119	3399	71.1	51.00	20.1	1.39
CS- C70	70	450	218.7	4635	3915	81.8	59.50	22.35	1.38
CS- C80	80	450	218.7	5070	4350	90.9	68.00	22.95	1.34
CS- 19	92	450	218.7	5548	4828	100.9	78.20	22.75	1.29
CS-C100	100	450	218.7	5859	5139	107.4	85.00	22.45	1.26
CS-C110	110	450	218.7	6285	5565	116.3	93.50	22.85	1.24

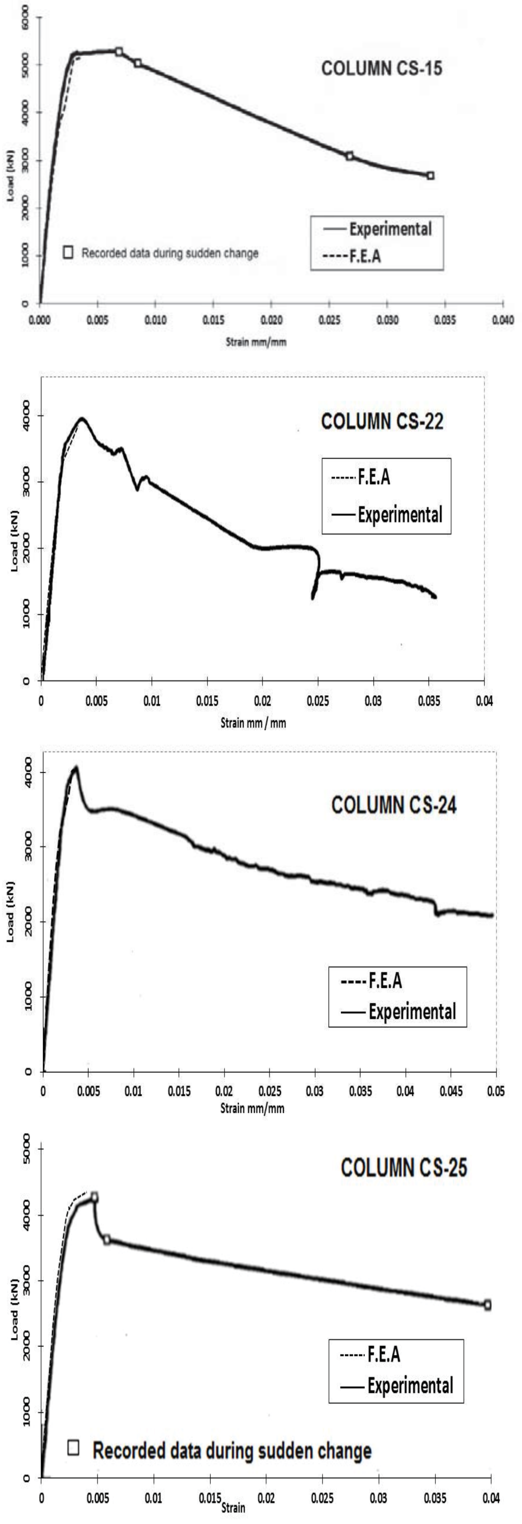

Fig. 4 Axial Force – Axial Strain Relationship for sample of - Columns Comparison between the Experimental and finite element analysis

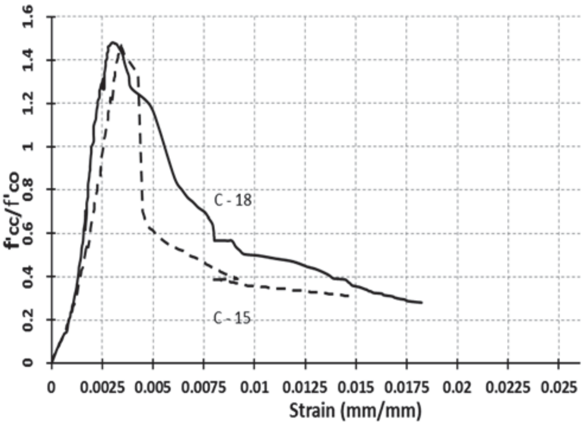

Fig. 5 Effect of concrete compressive strength

$\Delta f_c'$: The absolute gain in strength due to confinement can be computed as:

$$\Delta f_c' = f_{cc}' - f_{co}' \qquad (3)$$

Review of previous research indicated two conflicting views on strength enhancement in high strength concrete. While [1] concluded that the additional strength gain due to confinement was independent of concrete strength, Galeota et al. showed that the strength gain attained was lower in higher strength concretes [6]. The results of this study, as shown in Fig. 6, confirmed the findings of [1], i.e. the absolute gain in strength was independent of concrete strength in high strength concrete and was dependent on concrete strength in normal strength concrete.

The comparisons described above indicate a consistent decrease in deformability with increasing concrete strength. Therefore, if the same percentage of strength enhancement is desired, higher strength concrete columns are required to be confined more than those with lower strength concretes.

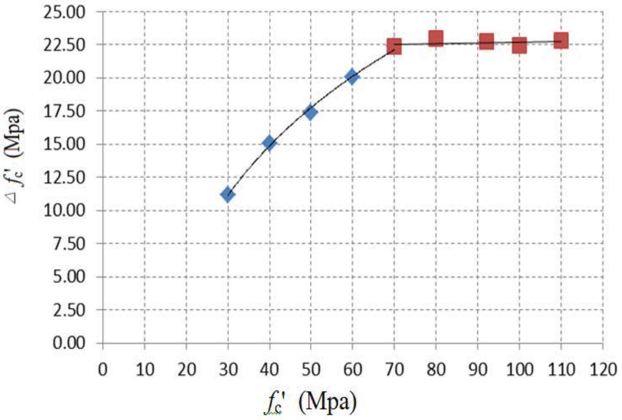

Fig. 6 Relation between the concrete strength and the absolute gain in strength

B. Aspect Ratio

From the experimental program results comparing between the pairs of rectangular columns C-6 and C-17 as shown in Tables III and IV, the results indicated that both strength and ductility of confined concrete for column C-17 with concrete section 200 x 300 mm showed a better enhancement in confined concrete compressive strength and ductility characteristics more than C-6 with concrete section 200 x 400 mm as shown in Fig. 7.

From the finite element analysis done by ANSYS program and considering the same properties for the columns at Table VIII, as 35 Mpa, concrete compressive strength, 450 Mpa yield strength for longitudinal reinforcement, 360 Mpa yield strength transverse reinforcement, Spacing between ties in longitudinal direction (S) = 80 mm, with different aspect ratio, the results indicate that, the strength of confined concrete for square column showed better enhancement more than rectangular columns and the enhancement in confined strength decreases by increasing the ratio between the long direction and the short direction of rectangular columns.

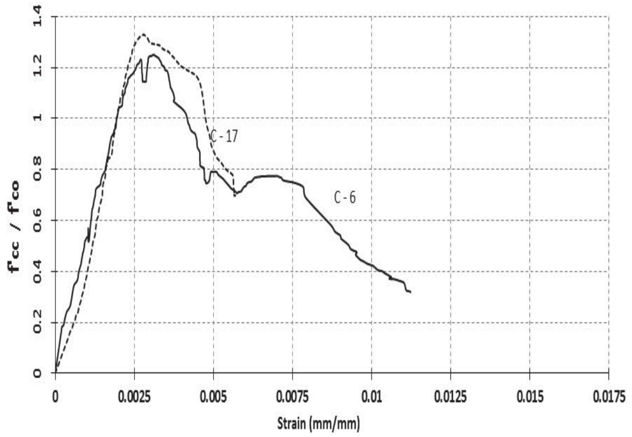

Fig. 7 Effect of section geometry

TABLE VIII
EFFECT OF SECTION GEOMETRY ON CONFINED CONCRETE COMPRESSIVE STRENGTH

Columns Label	Longitudinal Reinforcement		concrete core dimension (mm)	Area of Ties	$P_{C\ test}$	P_{CC}	f'_{cc}	f'_{co}	$\frac{f'_{cc}}{f'_{co}}$
	No.	Area mm^2		mm^2	KN	KN	Mpa	Mpa	
C-S.R1	6	154	240x240	78.5	2279	1863	41.5	29.75	1.393
C-S.R2	8	154	240x340	78.5	3201	2647	40	29.75	1.345
C-S.R3	10	154	240x440	78.5	4170	3477	39.8	29.75	1.338
C-S.R4	12	154	240x540	78.5	5142	4311	39.7	29.75	1.335
C-S.R5	14	154	240x640	78.5	6108	5137	39.6	29.75	1.331
C-S.R6	16	154	240x740	78.5	7078	5969	39.5	29.75	1.329
C-S.R7	18	154	240x840	78.5	8022	6775	39.4	29.75	1.323
C-S.R8	20	154	240x940	78.5	8935	7549	39	29.75	1.312

The results indicated that the strength of confined concrete for square column showed better enhancement more than rectangular columns and the enhancement in confined strength decreases by increasing the ratio between the long direction and the short direction of rectangular columns.

V.CONCLUSION

Based on experimental program and the finite element analysis and discussion above, the following conclusions can be drawn:

- ANSYS nonlinear finite element program is capable of modeling and predicting the actual behavior of confined normal and high strength reinforced concrete column subjected to axial loading.
- The results of numerical models were close to the experimental test results.
- A consistent decrease in deformability is observed with increasing concrete strength. Therefore, if the same percentage of strength enhancement is desired, higher strength concrete columns are required to be confined more than those with lower strength concretes.
- The absolute gain in strength was independent of concrete strength in high strength concrete and was dependent on concrete strength in normal strength concrete.
- The strength of confined concrete for square column showed better enhancement more than rectangular columns and the enhancement in confined strength decrease by increasing the ratio between the long direction and the short direction of rectangular columns.

NOTATIONS

f'_{cc}	:	Confined concrete compressive strength in the member.
f'_{co}	:	Unconfined concrete compressive strength in member
f'_{c}	:	Ultimate compressive strength concrete obtained from standard cylinder test
f_{test}	:	Maximum Stress carried by concrete core according to test results
$fy_{.long}$	:	Yield stress for the longitudinal reinforcement
$fy_{.ties}$	:	Yield stress for the transversal reinforcement
$P_{C.C}$	:	Maximum load carried by concrete core
$P_{F.A.A}$	:	Maximum axial load carried by column as observed in ANSYS model.
P_{Test}	:	Maximum axial load carried by column as observed in test
S	:	Spacing of transverse reinforcement in the longitudinal direction.
ρ	:	Volumetric ratio of transverse reinforcement, defined as the volume of transverse steel divided by the volume of concrete.

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