Structural Behavior Investigation of Reinforced Concrete Tapered Solid and Hollow Section Columns under Axial Load

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Abstract

This study involves taking eight models of reinforced concrete tapered columns section where the dimensions of the base at the bottom (d_a=200 mm) and at other end (d_b=150 mm) and side depth of (d=200 mm) while the total length (1000 mm).The main variable were taken the longitudinal and ties reinforcing ratio and section type (solid or Hollow) and hollow ratio. All specimens were simple support under influence of axial load to see the effect of these variables on strength and behavior of columns. All columns were classified as short due to slenderness ratio equal to (15.78) less than (22) according to ACI code. Test results gives, the strength capacity of Specimens increased by about (25%) where increased the longitudinal reinforcing ratio to 50% and decreased in corresponding lateral displacement by about (30%), also the ties reinforcing gives same trend but by about (12%) increasing in susceptibility endurance and decrease in lateral displacement by 20% at the mid and quarter upper slim of columns and simple attribution. The hollow section of columns have (recess) effect on columns behavior by reduced ultimate load capacity about (22-37%) and increased in lateral displacement by about (18-35%) for same of applied load compare with solid section. Also the increasing hollow ratio (16 to 41%) led to reduce in load capacity about (13-16%) and increased lateral displacement about (10-14%) with kept other properties constant of specimens. Patterns of failure was exfoliated in the concrete and an increase cracks numbers of the upper slim parts of specimens.

Key words: ultimate load, Tapered, Hollow, Columns, Axial Load.

1. Introduction

Structures are generally designed on the basis of economy and safety. For common structures, economy often requires the use of standard members because these members are relatively inexpensive and easy to obtain. For many structures, however, using tapered members may both increase structural efficiency and be economical. For small projects, this may not translate into overall economy, but more complex, unique, or large structures may (and often do) take full advantage of the structural efficiency tapered members offer by reducing the amount of material required while strategically stiffening certain parts of a member, thereby increasing the overall performance of the structure [1,2]

There are a number of limit states, or conditions for which a structure can be deemed unusable and can be considered to have failed. Structures can fail when members or the entire structure reach yield or ultimate strength, exceed a specified maximum deflection, or when fracture of members or collapse occurs. Buckling of members, not commonly considered to be a separate limit state, presents a stability issue that resembles a limit state in that it limits the resistance that can be developed by the member. [5, 6]

2. Objective of Study:

The main object of this paper are studying the effect of:

- a- Different amount of lateral reinforcing (Ties) and longitudinal reinforcing ratio on ultimate strength capacity
- b- Varying cross section (tapered) on behavior of reinforced concrete columns. Column's
- c- The contributed of recess (hollow section) in reducing or increasing load capacity when comparison.
- d- Hollow ratio of recess on the strength capacity of reinforced concrete columns.

3. Slenderness Ratio:

The ACI's intent is to permit columns to be designed as short columns if the secondary moment effect does not reduce their strength by more than 5%. Therefore, the transition from the short column (material failure) to the long column (failure due to buckling) is defined by using the ratio of the effective length (kl_u) to the radius of gyration (r) . The height, l_u is the unsupported length of the column, and k is a factor that depends on end conditions of the column and whether it is braced or unbraced. For example, in the case of unbraced columns, if is less than or equal to 22, such a column is classified as a short column, in accordance with the ACI load criteria. Otherwise, it is defined as a long[7]. In this study for all specimens the l_u = ***900 mm***, k **=1** *for simple supported and* [$r = \sqrt{(I/A)}$]of critical dimension i.e. least base (150 x 200 mm), the slenderness ratio were equal to 15.58 is less than 22 therefore the columns were classified as a short column.

4. Experimental program:

Eight reinforced concrete Tapered (varying cross section) columns was conducted in the structural laboratory of the Civil Engineering Department. The specimens involve four are solid and others hollow section with different ratio. The main parameters which taken in this research were the longitudinal reinforcing, ties reinforcement and hollow ratio. It’s Expect in this research to state the influence of axial load on the ultimate strength capacity and behavior of Tapered (varying cross section) columns and comparison between experimental tests result of specimens and confirm the best specimens with section which result the nearest value to the reference specimens result. Finally studying the factors which effect on the behavior of reinforced concrete tapered columns under axial load which have directly relation with the (Ties and longitudinal reinforcement and hollow ratio). The behavior of specimens under axial load was studied, the load displacement curves were plotted, and comparison of these curves was studied. The properties and details of columns are shown in Table (1) and Figs.(1-4).

4.1 Moulds Fabrication:

Four moulds were made and used to cast of the specimens as shown in Fig.(1) .The mould of columns model is made from plywood of (18mm) thickness as a base and four sides made from wood strips of (38mm) thickness forming a mould frame to construct tapered columns section. The four sides of mould are made movable and fixed to the base by screws. The clear dimensions of mould are (length 1000 m) ,bottom base (200 x 200 mm) and Top base (150 x 200 mm) normal depth 200mm, as shown in Fig.(1). All solid or hollow specimens were cast at the same day. To construct recess used styrabor of dimension (50x50 mm) and (80 x80 mm) and putting in core of Tapered reinforced concrete columns as shown in Figs.(1-2).

4.2 Material properties

4.2.1 Cement

For all test specimens, Ordinary Portland cement (Type-I) (TASLUJA-BAZIAN) which is product of the United Cement Company for Cement Production (UCC) was used. They conform to the Iraqi specification No. 5/1984[10].

4.2.2 Fine aggregate:

AL-Ukhaidher natural sand of (4.75mm) maximum size was used throughout this work. Grading of the sand conforms to the Iraqi Standard Specification No 45/1984[11].

4.2.3 Coarse aggregate

Graded Crushed gravel of a maximum size of 10mm from AL-Nibaee fields is used throughout the work; the aggregates was washed and air dried. The grading of the aggregate conforms to the limits specified by the Iraqi Specification No. 45/1984[11].

4.2.4 Steel Reinforcement

Deformed bars of (10 and 8 mm) diameter were used as column reinforcement. Two reinforcement ratios (ρ) were used in each group of the tested columns (two group of Non-prismatic) section. Table (2) shows the results of tensile test of the steel bars which were proved to conform to the ASTM A615 [14] requirements. Table (2) show the reinforcement details of all specimens. The test arrangement for reinforcement bar are shown in Fig.(3) to determine the specification of its.

4.2.5 Water

Ordinary potable water was used for concrete mixing and curing. A water-cement ratio (w/c) of 0.45 was used.

4.3 Properties of Concrete and Mixing

To produce concrete, the mixing proportion [cement: sand: coarse aggregate] was (1 : 1.475 : 2.95) by weight and the water–cement ratio was (0.45).This mix was based on several trials in order to obtain the most suitable mix to produce a strength ranging from (24 to 30 MPa) of cylinder compressive strength. The trial mix was uniform and of good workability. The mix contents for (1 m3) of concrete are given in Table (3). The average compressive strength of cylinder (150 x 300 mm) of concrete fc` of these mixer of 28 days are about 28 MPa.

4.4 Experimental Test Procedure:

Eight R.C. column specimens were tested using a hydraulically increasing universal testing machine (MFL system) of capacity (3000kN) under monotonic loads up to ultimate load at the structural laboratory as shown in Fig.(4). The tested columns were simply supported at two ends and loaded with concentrated loads axial load. After finish curing time (28 day), the columns are cleaning then painted with white color. When the dry surface of columns and become ready to test, the specimen is placed in position.

After the specimen is placed in position, a concentrated load (axial) was applied at the center of the specimen. The load was increased gradually at increments of (10 kN). At each load increment, the center displacement's at a distance of about (500mm) from the columns ends and at top end at distance about (250 mm) as shown in Fig.(4) were measured using dial gauges of (0.01mm) accuracy fixed on special holders beneath the specimen. The test was continued till failure. Failure mode and crack patterns were noticed and recorded. Fig.(4) show the test arrangement

Table 1: Experiential Details of specimens

Specimen symbol	Column length mm	Top base mm	Bottom base mm	*Long. Reinforcing mm	Ties reinforcing mm	Section Type	Hollow Ratio %
C1	1000	150 x 200	200 x 200	4 Ø 10	Ø8 /100	Solid	---
C2	1000	150 x 200	200 x 200	4 Ø 10	Ø8 /120	Solid	---
C3	1000	150 x 200	200 x 200	6 Ø 10	Ø8 /100	Solid	---
C4	1000	150 x 200	200 x 200	6 Ø 10	Ø8 /120	Solid	---
C5	1000	150 x 200	200 x 200	4 Ø 10	Ø8 /100	Hollow	16
C6	1000	150 x 200	200 x 200	4 Ø 10	Ø8 /100	Hollow	41
C7	1000	150 x 200	200 x 200	6 Ø 10	Ø8 /100	Hollow	16
C8	1000	150 x 200	200 x 200	6 Ø 10	Ø8 /100	Hollow	41

*Long. : Longitudinal.

Fig.1 Moulds Fabrication and Reinforcement Layout .

Table 2. Properties of steel reinforcement

Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	f_y (MPa)	f_u (MPa)	Elongation (%)
8	8.22	50.24	380	475	5
10	10.21	79	420	525	5.3

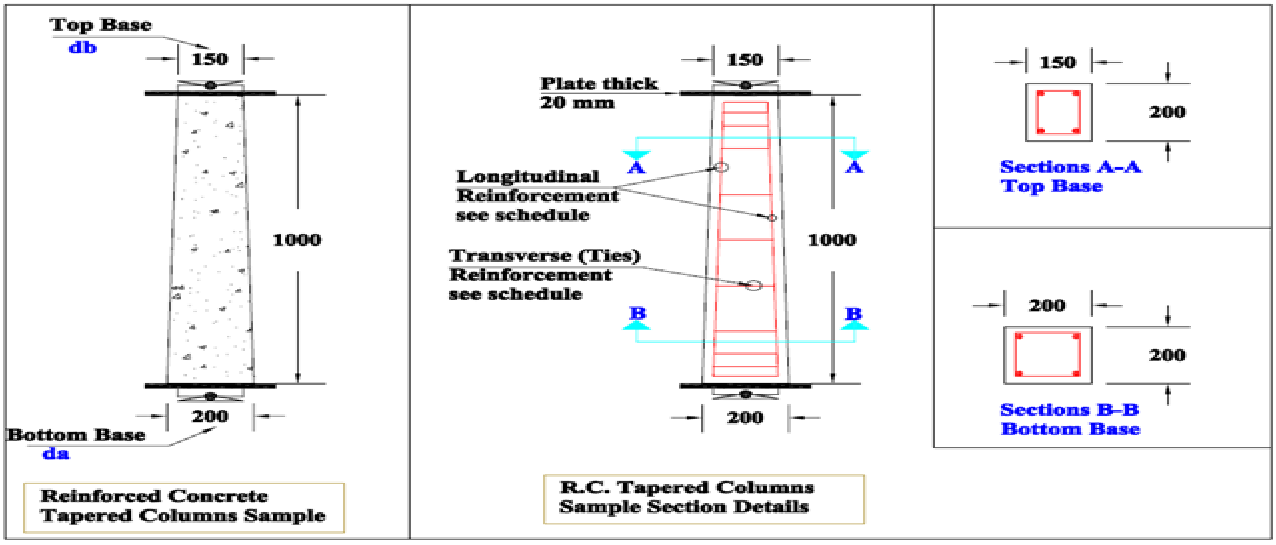


Fig.2 Tapered Columns Dimension and Details (Solid and Hollow

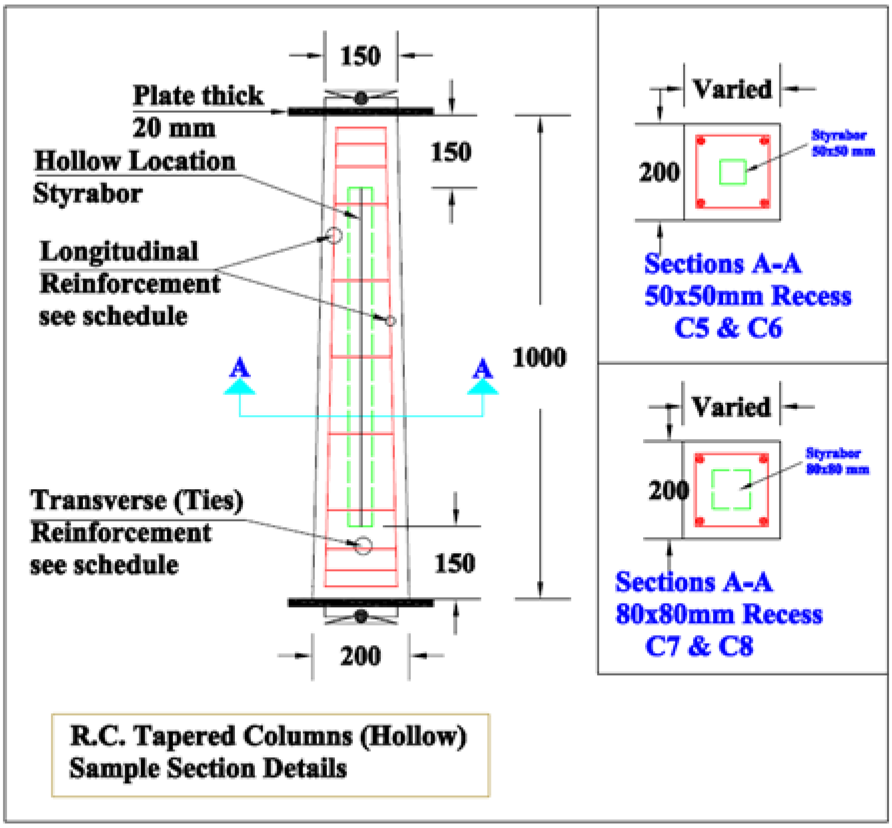


Fig.2 continued

Fig.3 Tensile Steel Testing Machine

Table 3. Mix proportions for (1 m^3) of concrete

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water/Cement Ratio	Water (kg/m^3)
400	590	1180	0.45	180

(A) Arrangement of R.C. Column.

(B) Position of dial-gauges.

Fig.4 Loading, Boundary Conditions and Instruments Layouts.

5. Test Results:

Test results for each case, including displacement and cracking are highlighted. Load versus lateral displacement was recorded at point of (central and quarter of column length) at distances about (500 and 250 mm) from the edges of the column. Crack patterns with first crack load and propagation of cracks are also studied. Ultimate load capacity with failure modes is recorded. The first crack was found to develop around the sides of the loading area of (150 x 200 mm^2) on the top end of columns when the dimension of top end less bottom edge of the column. These cracks were formed by about (8.33 – 11.5%) of the ultimate failure load, Tables (4 and 5). In the case of columns with non-prismatic section cracks appear near thin ends at top of the column near one or more of the corners at about (29 – 37%) of the ultimate failure load, as shown in Tables(4&5). The ultimate load, maximum central displacement were recorded and given in Tables (4&5). As the load is increased after formation of the first crack, more cracks begin to appear and, propagated diagonally towards the corners and towards the edge of the column. At large loads, these cracks extended with the formation of new cracks at different orientations. Meanwhile, cracks start to appear around the edge of the applied load at all sides with different intensity.

Failure was distinguished by the successive displacement at the quarter point of the column at higher load levels through crushing or spalling of concrete and collapse of columns at weak end, then, yielding of the tensile reinforcing steel. All columns were tested up to failure. The crack pattern of each reinforced concrete column was marked by paint. This procedure allows the cracks to be visible at failure as shown in Fig.(5).

6. Behavior of Specimens and Parametric of Study:

The study involves of the effect of different parameters on the behavior of reinforced concrete tapered columns (linearly varying cross section) along length. The longitudinal and ties reinforcing ratio and hollow ratio as main variables was carried out. Displacement at all stages of loading of the reinforced concrete column were also discussed. Figures below shows the effect of these parameters (variables) on ultimate load of all specimens. From Figs.(7 to 10) show the load varying lateral displacement curve at quarter end near small base dimension, it can notice that when increasing ties or longitudinal reinforcing ratio led to increase on ultimate load and decrease the corresponding lateral displacement by about (22-35%) and (15-20%) respectively also the ductility of specimens increased by about (8-13%) for solid section. While for hollow core specimens these recess gives decreased in strength capacity of columns in rang by about (25-38%) and increased in displacement by about (11- 18%) with kept other property of specimens without change, also recess led to decreased in ductility ratio by about (20-29%) comparison with others solid specimens. But it can show the increased longitudinal reinforcing give more enhancement in strength capacity of specimens contains hollow recess.

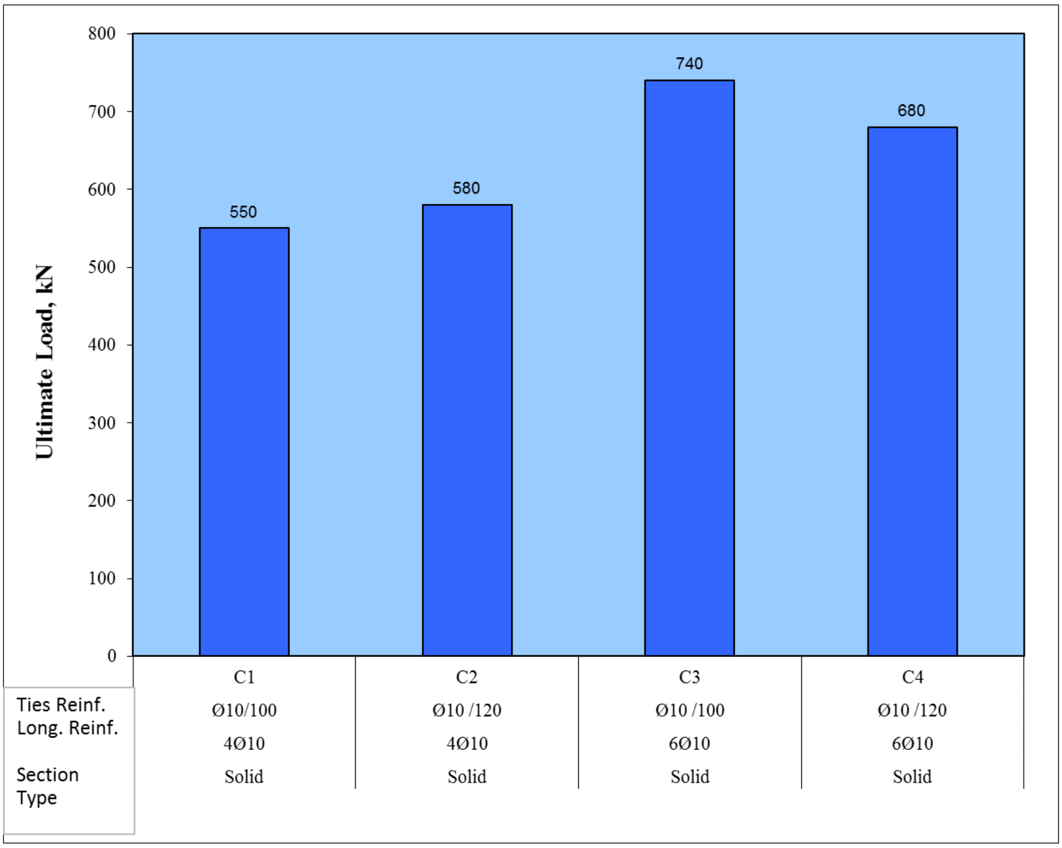
Table. 4 First Crack and ultimate Loads Test Results

Column No.	Long. reinforcing	Section Type	Hollow ratio %	ultimate Load (Pu) kN	Difference Load %	Max. Quarter Disp. (mm)	Difference Quarter Disp. %
C1	4 Ø 10	Solid	---	550	---	2	---
C5	4 Ø 10	Hollow	16	426	-22.5	2.4	+20
C6	4 Ø 10	Hollow	41	370	-33	2.48	+24
C3	6 Ø 10	Solid	---	740	---	2.5	---
C7	6 Ø 10	Hollow	16	555	-25	2.66	+10
C8	6 Ø 10	Hollow	41	466	-37	2.76	+10.4

Table. 5 Comparison of First Crack and ultimate Loads for Solid & Hollow Section.

Column No.	Long. reinforcing	Ties Ø8 / space mm	Hollow ratio %	First Crack Load (Pcr) (kN)	ultimate Load (Pu) kN	Max. Central Disp.(mm)	Max. Quarter Disp. (mm)	Pcr/ Pu %
C1	4 Ø 10	100	---	170	550	1.15	2	30.9
C2	4 Ø 10	120	---	192	510	0.75	1.35	37.6
C3	6 Ø 10	100	---	230	740	1.2	2.5	31
C4	6 Ø 10	120	---	210	680	1	1.4	30.8
C5	4 Ø 10	100	16	164	426	1.36	2.4	38.5
C6	4 Ø 10	100	41	155	370	1.53	2.48	41.1
C7	6 Ø 10	100	16	183	555	1.5	2.6	32.9
C8	6 Ø 10	100	41	145	466	1.64	2.76	31.11

Fig.5 Crack Patterns of Tested Columns (Solid and Hollow section).



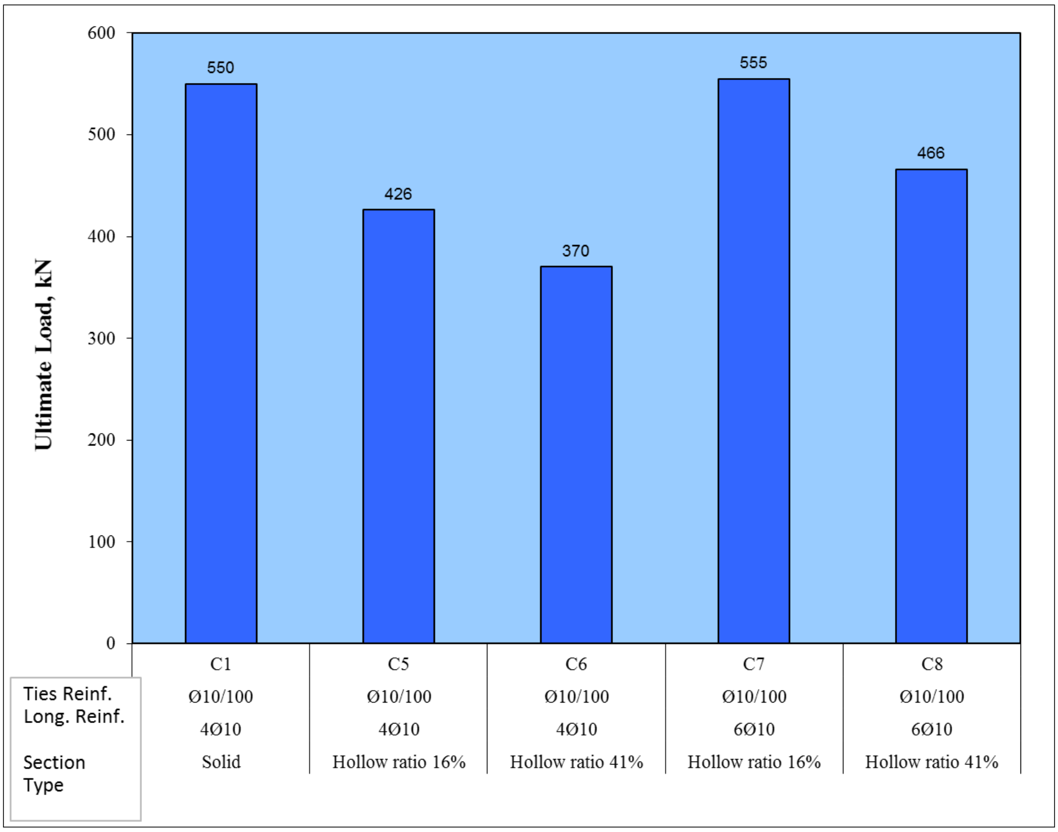
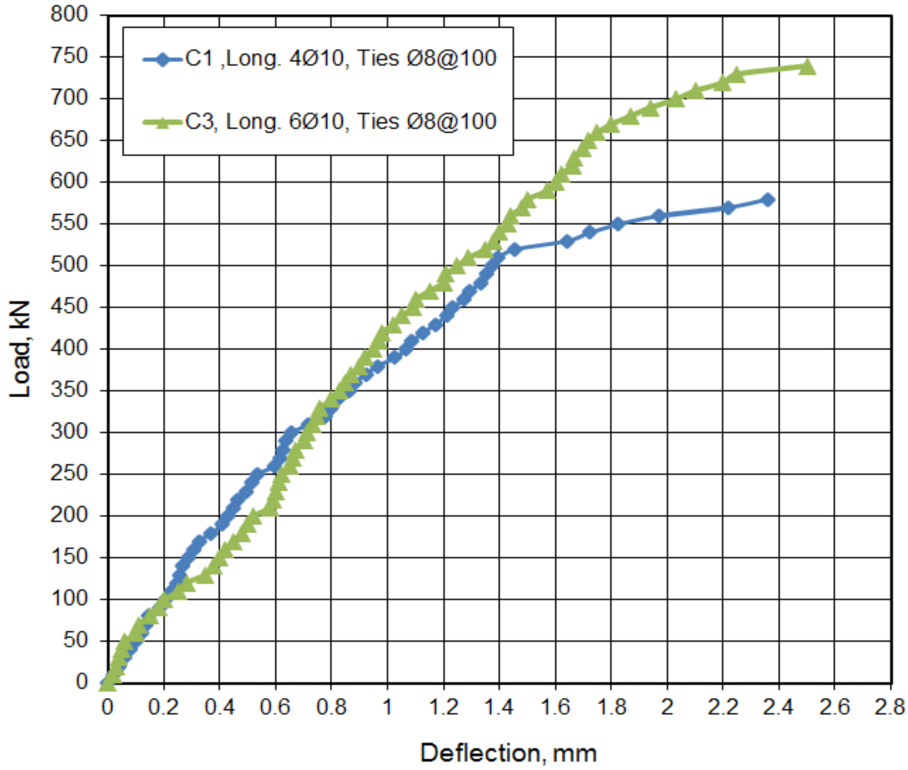
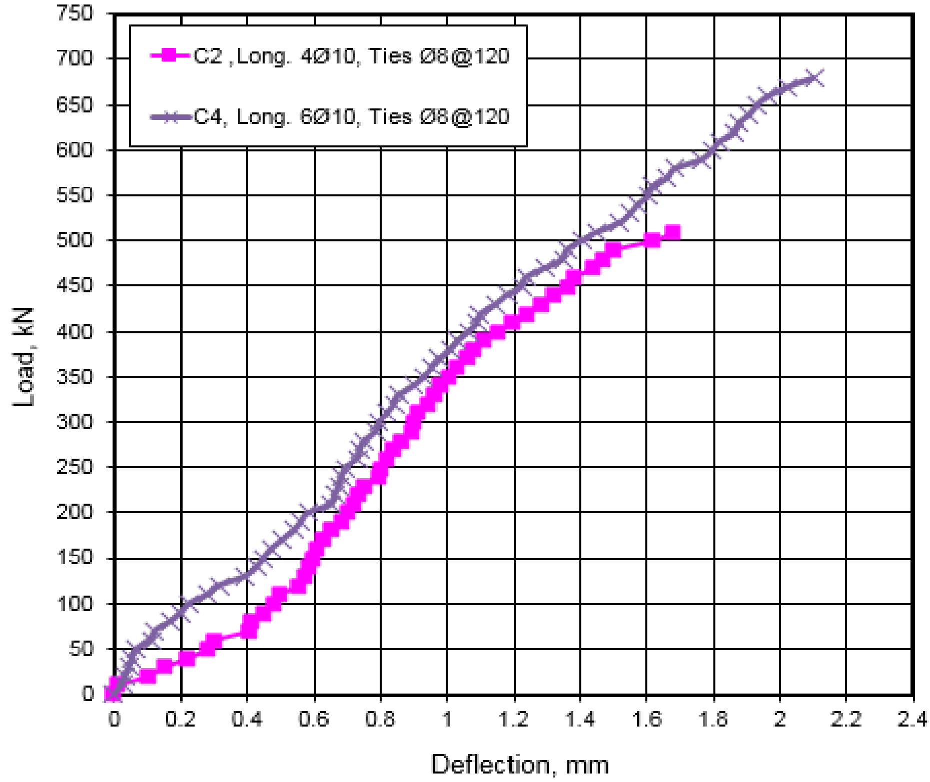


Fig.6 Comparison of Ultimate load of Solid and Hollow Tapered Columns.

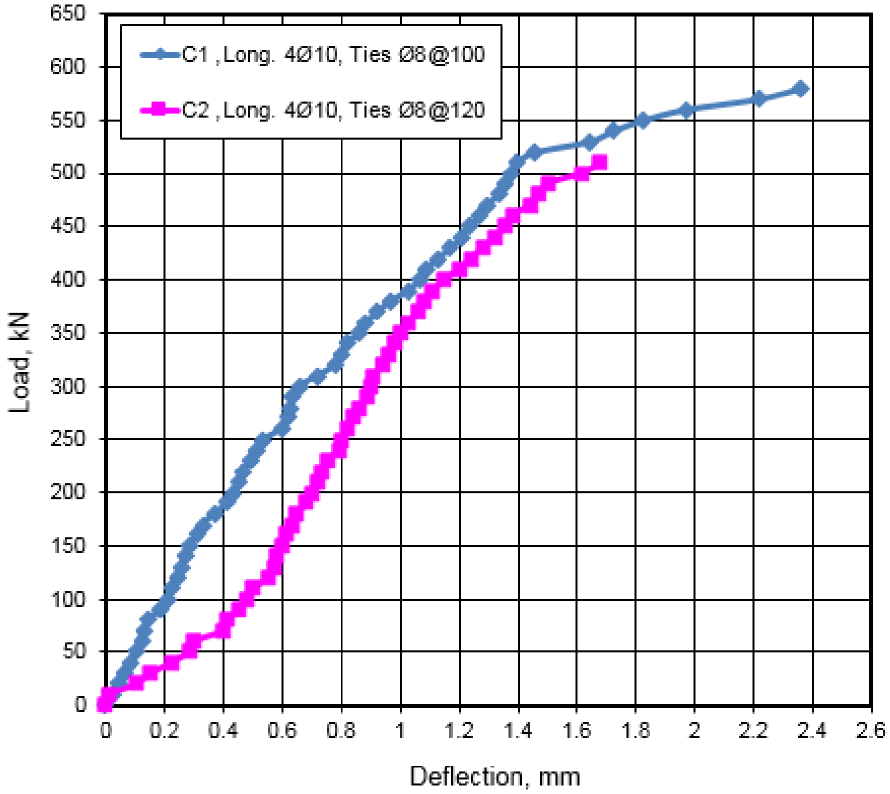


(1) Effect of Longitudinal Reinforcing

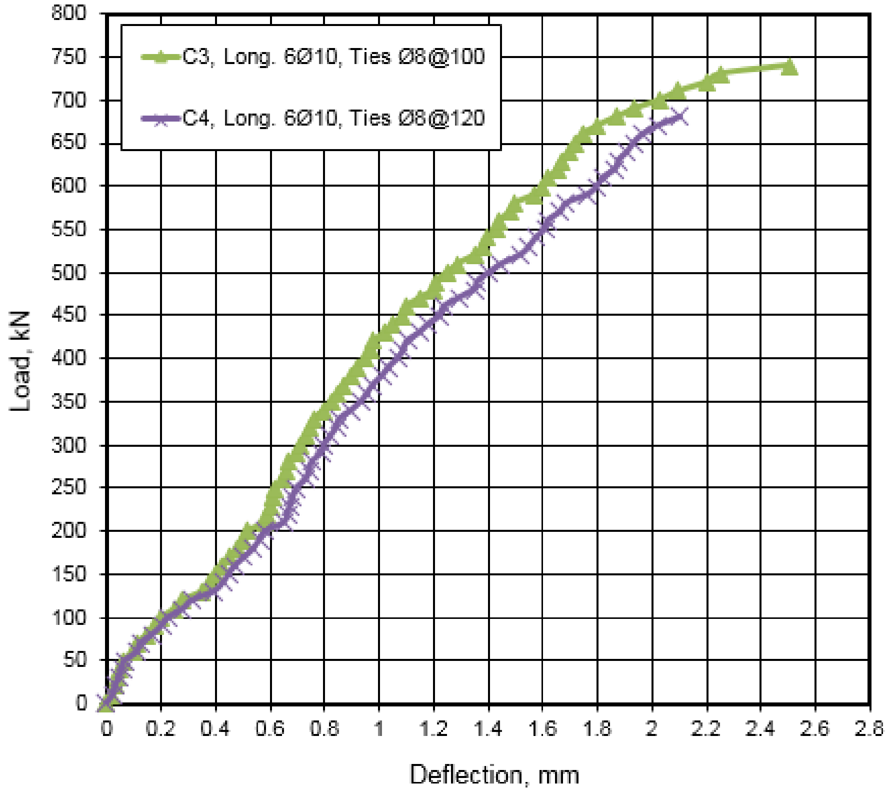


(2) Effect of Longitudinal Reinforcing

Fig.7 Lateral displacement of Quarter Thin End of Solid Tapered Column

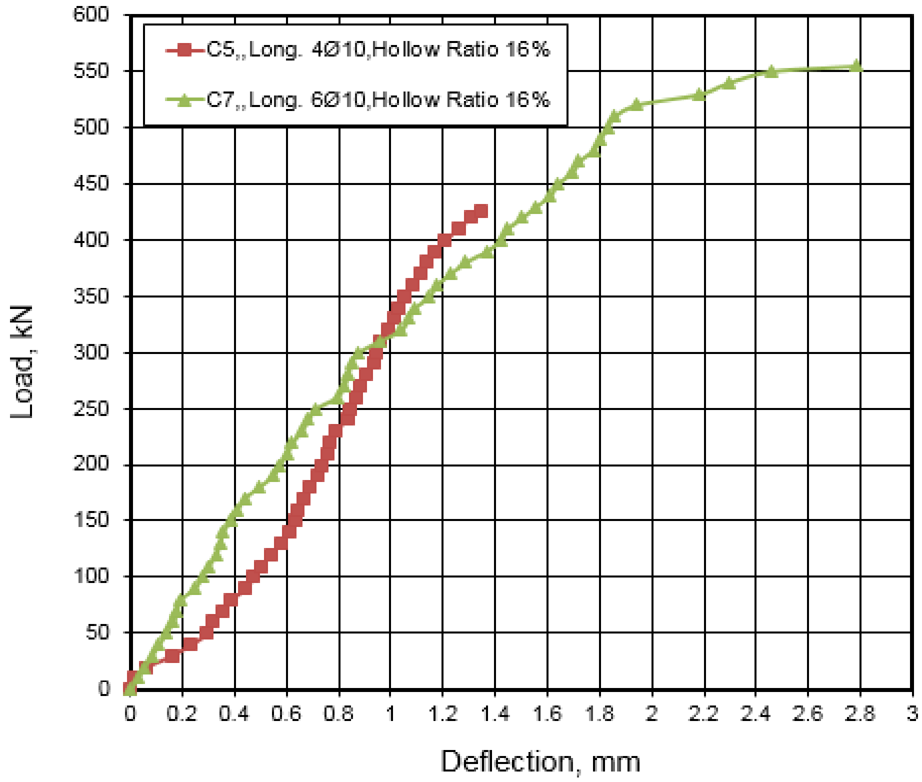


(3) Effect of Ties Reinforcing

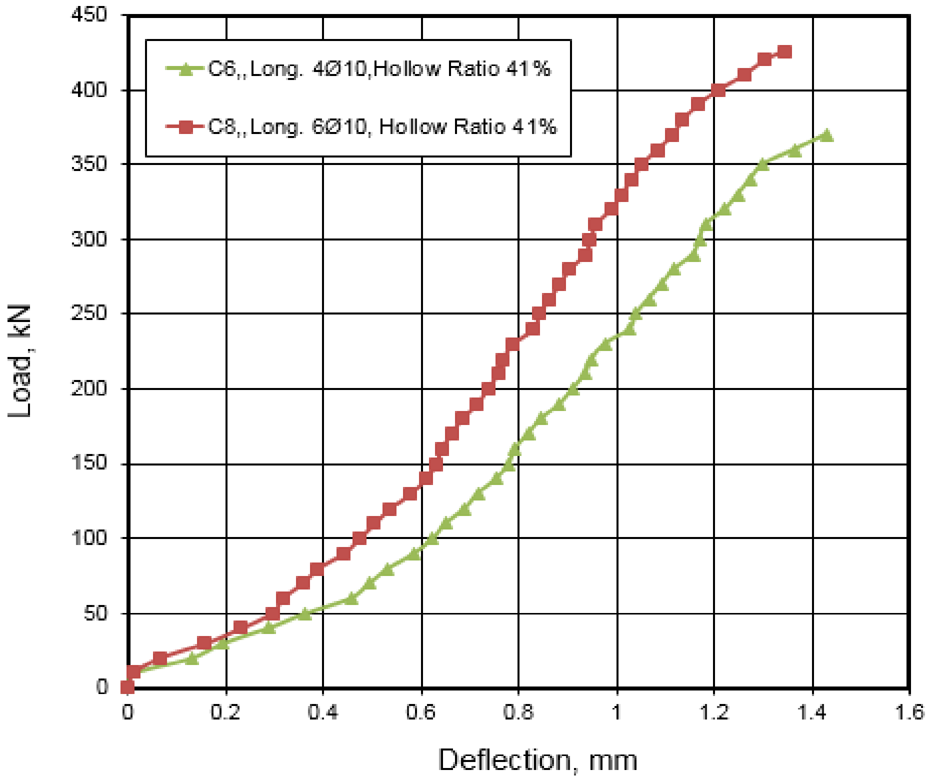


(4) Effect of Ties Reinforcing

Fig.7 Continue

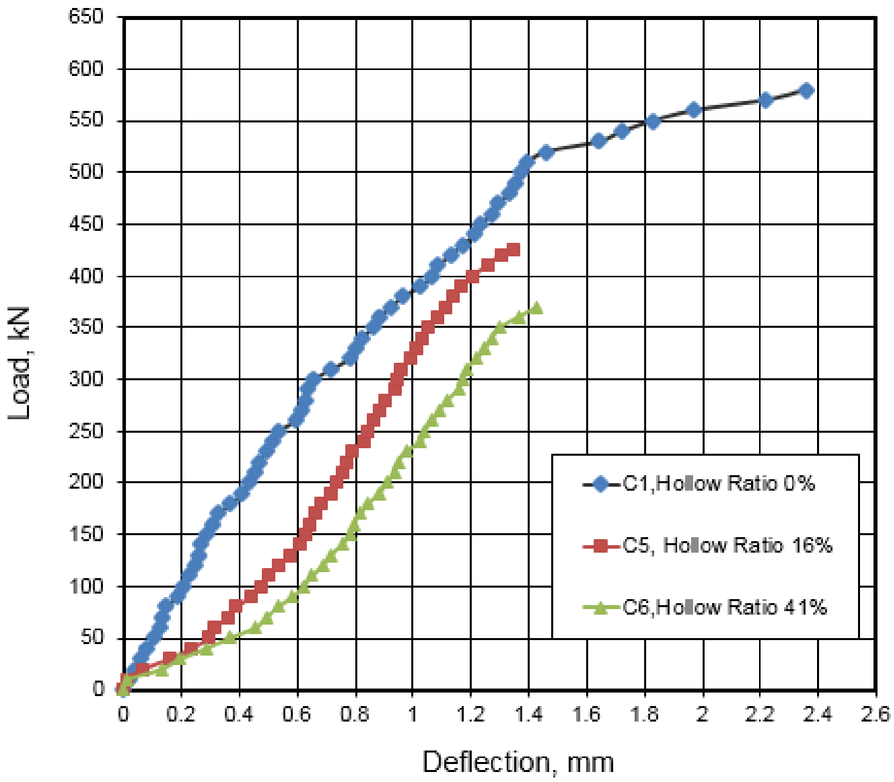


(1) Effect of Longitudinal Reinforcing with Hollow Ratio 16%.

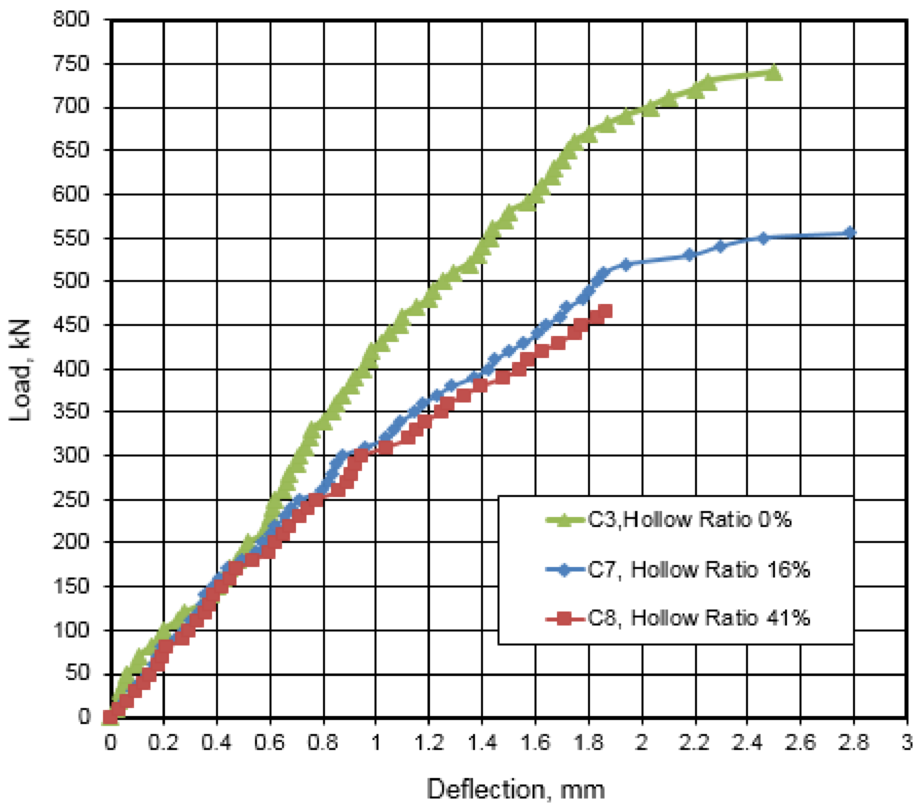


(2) Effect of Longitudinal Reinforcing with Hollow Ratio 41%.

Fig.8 Lateral displacement of Quarter Thin End of Hollow Tapered Columns with Different Longitudinal Reinforcing



(1) Effect of Hollow Ratio with Longitudinal Reinforcing 4Ø10mm.



(2) Effect of Hollow Ratio with Longitudinal Reinforcing 6Ø10mm.

Fig.9 Comparison of Lateral displacement of Quarter Thin End of Solid and Hollow Tapered Columns with Different Longitudinal Reinforcing

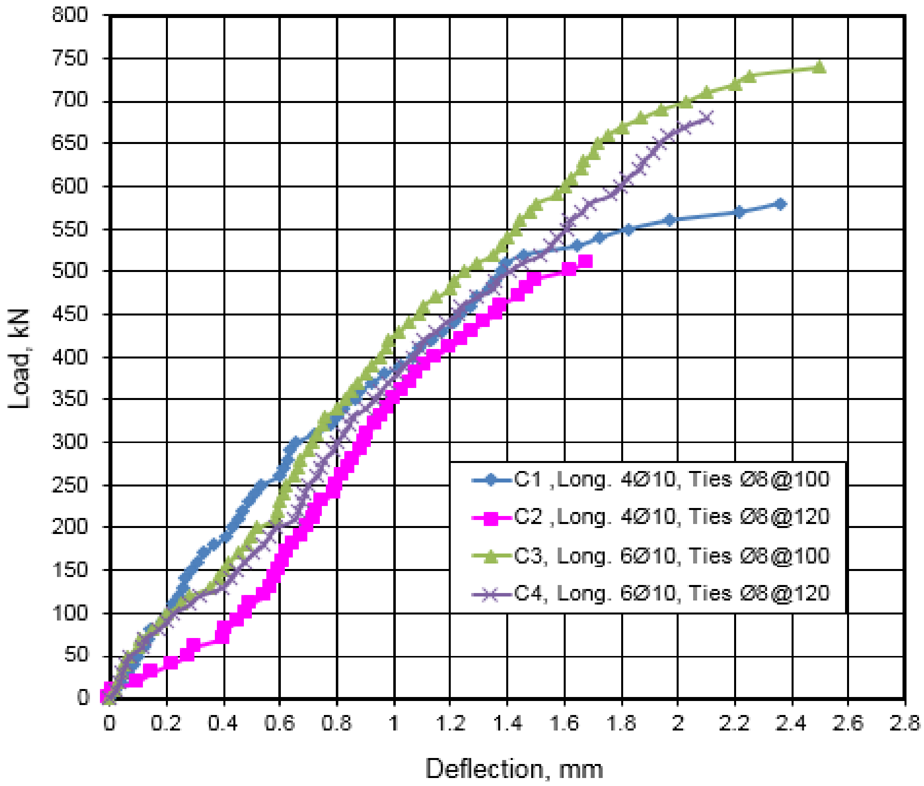


Fig.10 Lateral displacement of Quarter Thin End of Solid Tapered Columns

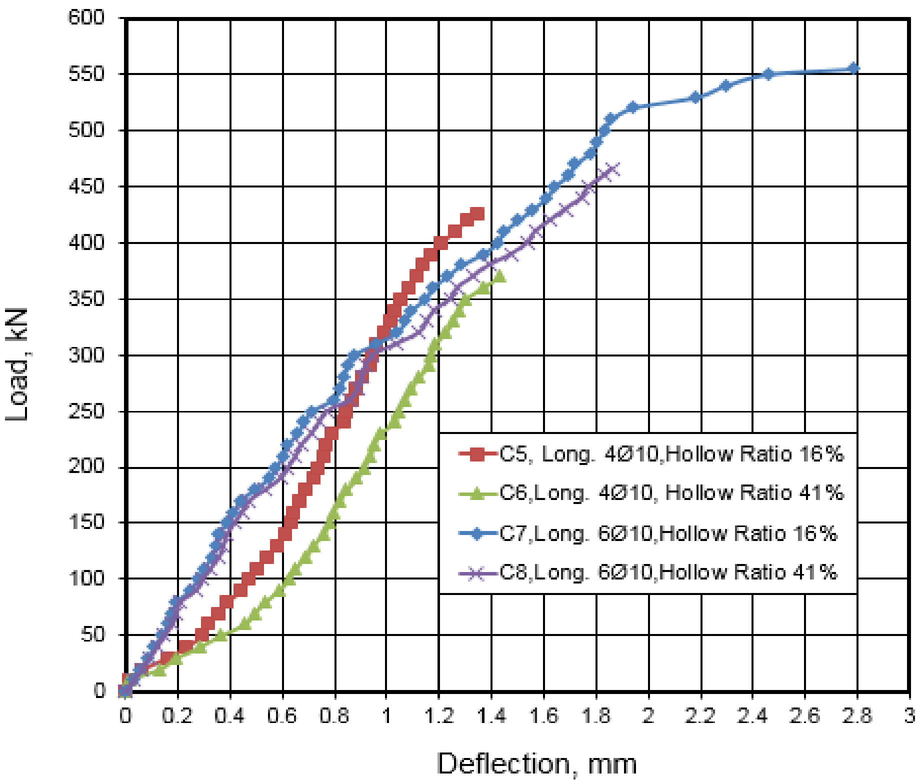


Fig.11 Lateral displacement of Quarter Thin End of Hollow Tapered Columns

7-Conclusion

Form the experimental result, we got the following conclusions:

1- It has been observed from the tests carried out that the cracks appear under axial load for reinforced concrete column is about (29 – 37%) of the ultimate failure load.

2- Some of concrete columns fails under crushing of concrete at thin ends of columns due to excessive loads or lack of support.

3- The lateral displacement at quarter thin ends greater than center of columns by about (42% to 55%) due to varying section (varying moment of inertia along length of columns) contributed an increased moment of inertia of columns section.

4- When increased longitudinal reinforcing ratio by about 50% led to decrease in lateral displacement and increased in load carrying capacity by about (25.6 % & 28.6%) respectively for same other property & applied load.

5- The ultimate load of column by about 11.3% with increasing the amount of ties reinforcing by about 20%.

6- Hollow recess effect on columns behavior by reduced ultimate load capacity about (22-37%) and increased in lateral displacement by about (18-35%) for same of applied load compare with solid section.

7- The increasing hollow ratio (16 to 41%) led to reduce in load capacity about (13-16%) and increased lateral displacement about (10-14%) with kept other properties constant of specimens. Patterns of failure was exfoliated in the concrete and an increase cracks numbers of the upper slim parts of specimens.

8- Ductility is increased in all cases axial load when increased long or ties reinforcing by about (20-36%).

10-The phenomenon of crushing concrete cover (Spalling) was shown due to excessive loads or lack of support under axial load.

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تحري السلوك الانشائي للاعمدة الخرسانية المتغيرة المقطع الصلدة والمجوفه تحت الحمل المحوري

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الخلاصة

تضمنت الدراسة فحص ثمانيه نماذج خرسانيه مسلحة من الاعمدة المتغيرة المقطع وبابعاد في القاعدة السفلى (عرضها 200 ملم) والعليا (150 ملم) والعمق العمودي (200 ملم) بينما الطول الكلي (1000 ملم). المتغيرات الرئيسية التي اخذت هي (نسبة الحديد الطولي والعرضي ونوع المقطع (صلد او مجوف) وكذلك نسبه التجويف. كل النماذج كانت بسيطة الاسناد تحت تاثير حمل محوري لملاحظه تاثير هذه المتغيرات على مقاومة وسلوك الاعمدة. جميع الاعمدة صنفت على انها قصيرة حيث ان نسبة النحافة تساوي (15.78) اقل من(22) حسب مواصفات الامريكية. نتائج الفحص بينت ان مقاومة تحمل النماذج تزداد تقريبا 25%عند زيادة نسبه حديد التسليح الطولي بمقدار 50% ونقصان في الازاحة الافقية المقابل تقريبا 30%, كذلك زياده نسبه حديد التسليح العرضي تعطي نفس نمط السلوك ولكن تقريبا 12% زيادة في قابلية التحميل ونقصان في الازاحة الجانبيه في منتصف والربع الاعلى النحيف للعمود واسناد بسيط بمقدار حوالي 20 %. للمقطع المجوف للاعمدة لها (فتحات تجاويف) تؤثر على السلوك الانشائي للاعمدة بواسطة نقصان في قابلية التحمل القصوى حوالي (22-37%) وزيادة في الازاحة الافقية المقابله تقريبا (18-35%) لنفس الحمل المسلط بالمقارنة مع المقاطع غير المجوفة. كذلك زيادة نسبة التجويف (16 الى 41%) تؤدي الى تقليل قابلية التحميل حوالي (13- 16%) وزيادة في الازاحة الافقية بمقدار (10-14%) مع بقاء باقي الخصائص الاخرى للنماذج ثابتة. كانت انماط الفشل تقشر في الخرسانة وزيادة عدد التشققات للجزء العلوي النحيف للنماذج.

الكلمات المفتاحية : الحمل الاقصى – متغير المقطع – مجوف – اعمدة – حمل محوري.