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PARTIALLY CONFINEMENT OF CORNER REINFORCED CONCRETE COLUMNS WITH SPECIAL TECHNIQUE

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ABSTRACT

This paper presents an experimental and analytical program to examine the different causes of confinement of corner reinforced concrete columns. The effect of number of outer stirrups, confinement area, partially penetrative dowels and fully penetrative dowels on the behavior of reinforced concrete corner reinforced concrete columns was studied. Experimental and analytical programs of two groups were performed. Horizontal displacement and strains were measured at different stages of loading. The load strains curves were plotted and discussed. The relation between each variable and the capacity of the column were plotted. The specimens were modeled using finite element analysis. The analysis was based on the non-linear iterative secant stiffness formulation. The final results showed that the partially penetrative dowels used in confinement were more effective than fully penetrative dowels. The rarefaction in the concrete particles in case of fully penetrative dowels caused reduction in failure load in comparison with the expected failure load.

KEYWORDS: Confinement, Partially Confinement, Corner Reinforced Concrete Columns, Fully Penetrative Dowels, partially Penetrative Dowels.

الإحاطة الجزئية للأعمدة الخرسانية المسلحة الركنية

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الملخص

هذا البحث يقدم دراسة نظرية وعملية لاختبار الإحاطة الجزئية للأعمدة الخرسانية المسلحة الركنية كحل فعال لتدعيم الأعمدة الركنية في المباني القائمة. تم دراسة النقاط التالية على سلوك الأعمدة الخرسانية المسلحة الركنية: تأثير المساحة المحاطة، و عدد الكانات الخارجية ، و نسبة تسليح العمود و كذلك الجوايط ذات الاختراق الجزئي و الجوايط ذات الاختراق الكلي للخرسانة. تم عمل برنامج عملي و دراسة تحليلة لمجموعتين من الأعمدة. تم قياس الإزاحات الأفقية و كذلك الإنفعالات في مراحل مختلفة من عمر التحميل للأعمدة. تم رسم منحنيات الحمل مع الانفعال للعينات و كذلك تم تحديد علاقة كل متغير بقيمة الحمل الأقصى للعينة. النتائج النهائية تشير إلى أن العينات المقواه باستخدام الجوايط ذات الاختراق الجزئي أكثر فاعلية من العينات المقواه باستخدام الجوايط ذات الاختراق الكلي، حيث أن الاختراق الكلي لقطاع العمود تسبب في فصل بين جزيئات الخرسانة نتج عنه تخفيض في الحمل الحقيقي عن الحمل المتوقع.

الكلمات المفتاحية : الإحاطة الجزئية ، الأعمدة الركنية، جوايط ذات اختراق كلي، جوايط ذات اختراق جزئي.

1. INTRODUCTION

Reinforced concrete elements are designed to satisfy safety, serviceability and economy. A wide number of existing buildings over the world is in need to strengthening or retrofitting due to factors such as additional load, functional change, and/or design errors. Strengthening of reinforced concrete columns is important in the repair and retrofit of concrete structures since the failure of a column has serious consequences for structural stability. The purpose of this study is to propose new techniques to confine reinforced concrete corner columns.

The confined concrete is defined as the concrete, which is restrained in the directions at right angles to the applied stress. R.Park and T.Paulay (1975). In practice, concrete may be confined by transverse steel (ties), commonly in the form of closely spaced steel spirals or ties.

In case of edge and corner reinforced concrete columns, it is difficult to create a closed outsider transverse steel (ties), so the suggested technique is to create a confinement area by drilling partially penetrative dowels and fully penetrative dowels with epoxy resin.

The effectively confined area of concrete may even further be reduced due to the arching action of concrete between the ties along the longitudinal axis of the member as shown in **Figure (1)**. The minimum area of effectively confined concrete is midway between tie levels and will control the strength of the column, Sheikh, S.A. and Uzumeri, (1980).

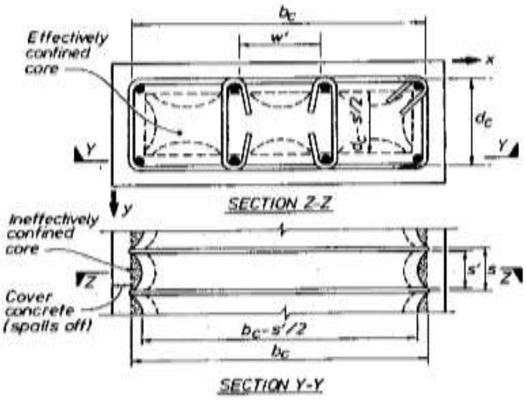


Figure (1) Effectively confinement core for rectangular columns.

As seen in Figure (1), concrete is confined by arching action between transverse steel (ties). Larger tie spacing (S) will result in less confined area and hence lower load-carrying capacity of concrete, whereas smaller tie spacing provides a better confinement, Mander et al (1988).

Mander et al. (1988) derived a model for confinement of concrete from experimental values of 17 steel spiral reinforced concrete cylinders with varying ratios of reinforcement. The following relation for strength of confined concrete was proposed:

$$f'_{cc} = f'_{co} \left(-1.254 + 2.254\sqrt{1 + \frac{7.94 f'_l}{f'_{co}}} - 2\frac{f'_l}{f'_{co}}\right) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

f'_{co} = unconfined concrete compressive strength.

f'_l = effective lateral confining pressure = k_e x lateral pressure.

k_e = ratio between effectively confined concrete area and core concrete area.

The longitudinal strain in the confined concrete was proposed as:

$$\varepsilon_{cc} = \varepsilon_{co}\left[1 + 5\left(\frac{f'_{cc}}{f'_{co}} - 1\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

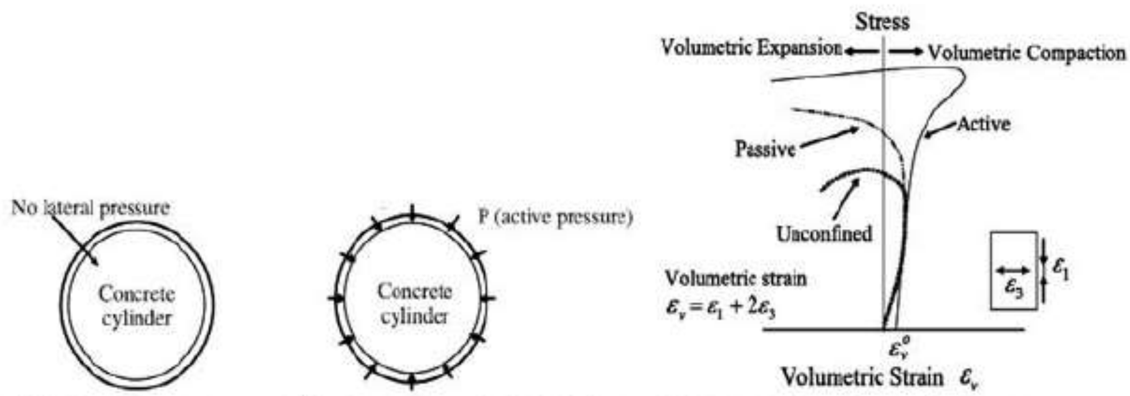
Where:

ε_{co} = the longitudinal strain of the confined concrete at failure.

Larger effective confining pressure would result in higher strength and correspondingly higher strain value. Ductility of the concrete as indicated by the post peak part of the curve will also increase.

Every possible structural confining method that exists will fall under one of two fundamental confining approaches; either passive or active confinement. **Figure (2)** shows schematics of cross sections of passively and actively confined concrete cylinders, respectively.The behavior of confined concrete section is affected by several factors: amount and size of transverse steel (ties), spacing of transverse steel (ties), distribution of longitudinal reinforcement, properties of transverse steel and axial load rating. These factors are discussed below. Abdelrazik and Amr (2016) performed an experimental program consisting of four groups and a reference group to study the relation between each variable and the capacity of the column. The final results showed that the increase in the spacing between external stirrups caused the decrease of the capacity of columns strengthened with CFRP (passive & active). The capacity of columns strengthened with CFRP for active external stirrups was higher than passive external stirrups by about 11.5%.
Youssef et al. [2007] performed tests on 87 large scale specimens (16 inch by 32 inch) and 30 standard sized specimens (6 inch by 12 inch) with CFRP and GFRP jackets. Based on 63 specimens for circular columns, Youssef et al. calibrated an equation for confinement as follows:

$$f'cc = f'co + [1+2.109 \left(\frac{f'_l}{f'_{co}}\right)^{0.783} \quad \ldots\ldots\ldots\ldots \quad (3)$$



(a) Passive confinement before loading (b) Active confinement before loading. (c) Stress vs. volumetric strain of concretes.

Figure (2) Schematics of the cross section of confined concrete before loading and stress versus volumetric strain curves of unconfined, passively, and actively confined concrete. (Shin and Andrawes 2010).

2. EXPERIMENTAL PROGRAM

2.1 Specimen Details

The experimental program was carried out at Faculty of Engineering laboratory - Al Azhar Universty. The experimental work was carried out on two groups consisting of ten columns. All columns had a cross section 120 mm x 150 mm and total length 1200 mm (including top and bottom cap to prevent local failure). All specimens in the first group has 4Y8 longitudinal bars and Y6@200 mm stirrups and the first control column has the same reinforcement as shown in **Figure (3)**. In the second group all specimens has 6Y8 longitudinal bars and Y6@200 mm stirrups and the second control column has the same reinforcementas shown in **Figure (4)**.The details of strengthening of all specimens are shown in **Table (1)**.

Figure (3) Details of specimen in group 1.

Figure (4) Details of specimen in group 2.

Table 1-The details of strengthening of all specimens.

Groups/Specimen	Specimen No.	Shape of Confinement	No. of outter stirrups
Group 1 with longitudinal bars 4Y8	C 1-0 Control Column	----	----
	C 1-1	Partially penetrative dowels	6 steel strips with 20 mm width and 2 mm thickness
	C 1-2	Fully penetrative dowels	6 steel strips with 20 mm width and 2 mm thickness
	C 1-3	Partially penetrative dowels	8 steel strips with 20 mm width and 2 mm thickness
	C 1-4	Fully penetrative dowels	8 steel strips with 20 mm width and 2 mm thickness
Group 2 with longitudinal bars 6Y8	C 2-0 Control Column	----	----
	C 2-1	Partially penetrative dowels	6 steel strips with 20 mm width and 2 mm thickness
	C 2-2	Fully penetrative dowels	6 steel strips with 20 mm width and 2 mm thickness
	C 2-3	Partially penetrative dowels	8 steel strips with 20 mm width and 2 mm thickness
	C 2-4	Fully penetrative dowels	8 steel strips with 20 mm width and 2 mm thickness

2.2 MATERIAL PROPERTIES AND MIX DESIGN

The aimed concrete characteristic strength was 35 MPa. The water / cement ratio used was 0.47, water quantity was 200 kg/m3 and cement quantity was 425 kg/m3. Volume of coarse aggregates was 0.7 m3 and volume of fine aggregates was 0.35 m3. Six standard cubes with dimensions 150x150x150 mm were taken from the concrete at regular intervals during casting of the columns. These control cubes were casted, compacted and cured simultaneously with each tested specimen. They were tested at the time of the columns testing. Results of the cubes testing are presented in **Table (2)**.

Table 2 Results of standard cubes.

Cube No.	*Cube 1*	*Cube 2*	*Cube 3*	*Cube 4*	*Cube 5*	**Cube 6**
Strength (MPa)	**38.0**	**38.8**	**39.5**	**37.5**	**38.2**	**38.1**

One type of steel was used in this program, normal mild steel with yield strength 240MPa. Steel forms coated with oil were used. The reinforcement was placed in its positions in the forms.

Casting took place immediately after mixing. A mechanical vibrator was used in placing the concrete around the reinforcement together with the hand tamping to ensure full compaction. Columns were left in the forms for 48 hours after which the sides of the forms were stripped away. The specimens were submerged in water for the following week. Then they were left in the ordinary atmosphere with average temperature of 24°C for at least 28 days before strengthening.

2.3 APPLICATION OF STRENTHENING

After 28 days of concrete casting, strengthening was applied according to the following steps:

1. Preparation of concrete surface using a hammer and blower to remove the weak parts on the concrete cover.
2. Washing concrete surface with water.
3. Drilling number of holes in the specimen according to number of outer stirrups. In case of partially penetrative dowels, the dowels were made from two sides as shown in **Figure (5)**, but in case of fully penetrative dowels, the dowels were made from one side as shown in **Figure (6)**.
4. In case of fully penetrative dowels some damages occurred in the other side due to drilling, so this damage was repaired with a grout.
5. One angels 20*20*2 were fixed in the allowed corners with epoxy resin.
6. The outer steel stirrups were fixed with thread bar with diameter 8 mm filled in the previous holes and fixed with a nut and epoxy resin.
7. The outer steel stirrups were welded with the angles as shown in **Figure (7)**.

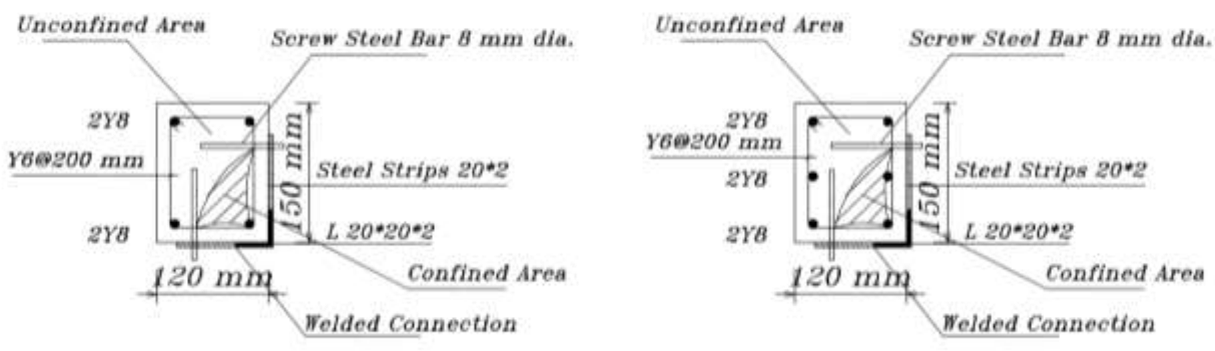


Figure 5: Partially Penetrative Dowels in Group 1 and Group 2

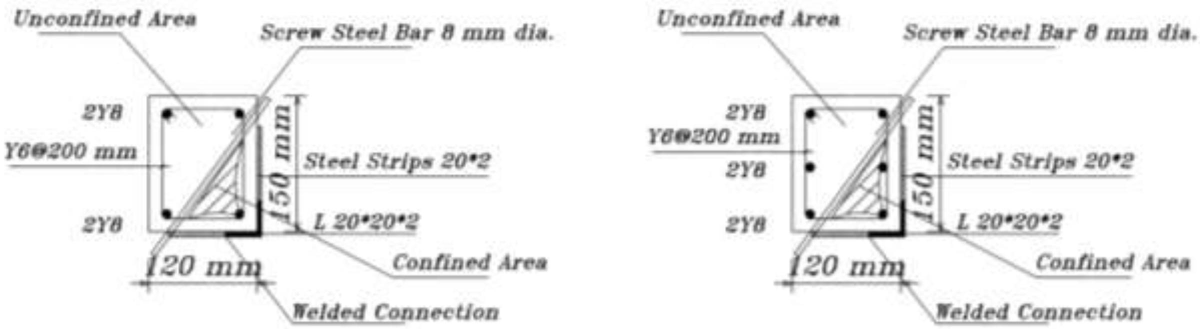


Figure 6: Fully Penetrative Dowels in Group 1 and Group 2

Figure 7: Welded Connections between Angels and Steel Stirrups

2.4 Test Setup

The structural-testing machine in the Reinforced Concrete Laboratory at the Civil Engineering Department of Al-Azhar University was used to test. Horizontal displacement at mid-point of columns was measured using LVDT, while strains of inner longitudinal reinforcement and strains of external stirrups were also observed. The vertical loads were measured at different stages of loading. The test setup is shown in **Figure (8)**.

Figure 8: Test Setup

3. RESULTS AND DISCUSSION

3.1 Failure Loads

The failure loads of the tested columns were compared with estimated failure loads due to the assumption of estimated failure load of unconfined area and failure load of confined area according to Mander et al .(1988) .

For Group 1 the experimental failure loads were bigger than the estimated failure loads with average ratio 3% and the experimental failure loads are shown in **Figure (9)**.

For Group 2 the experimental failure loads are bigger than the estimated failure loads with average ratio 5% and the experimental failure loads are shown in **Figure (10)**.

The failure mode in all specimens occurs in the unconfined zone as shown in **Figure (11)**.

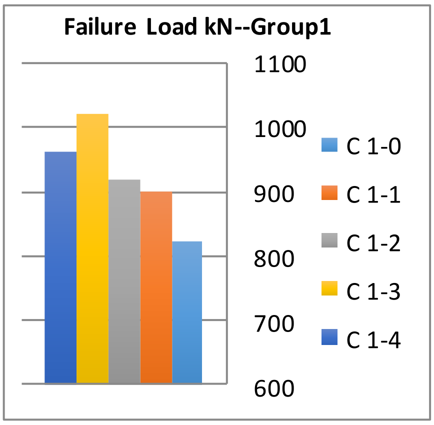


Figure 9: Failure Loads for Group (1)

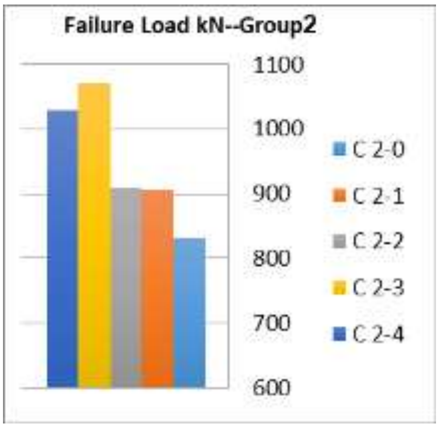
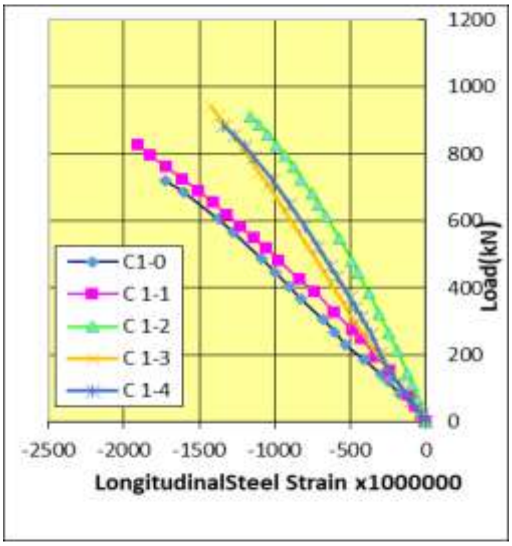


Figure 10: Failure Loads for Group (2)

Figure 11: Failure Modes of Different Specimen

3.2 Steel Strains

The longitudinal steel strains and outer stirrups strain were obtained from the electrical strain gauges. **Figures (12)** and **(13)** show the load and longitudinal steel strain curves through the load history for group 1 and group 2 respectively. **Figures (14)** and **(15)** show the load and outer stirrups strain curves through the load history for group 1 and group2 respectively.



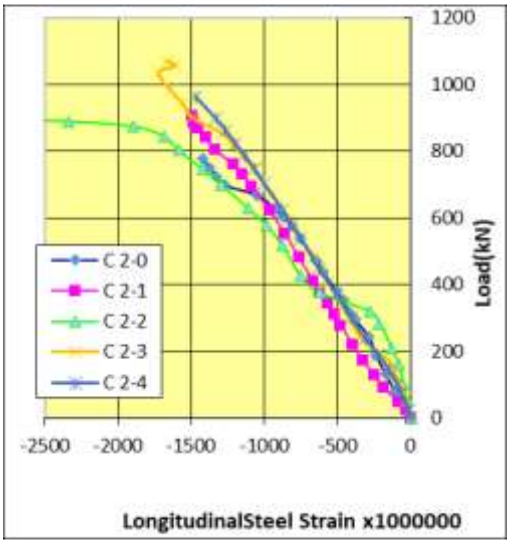
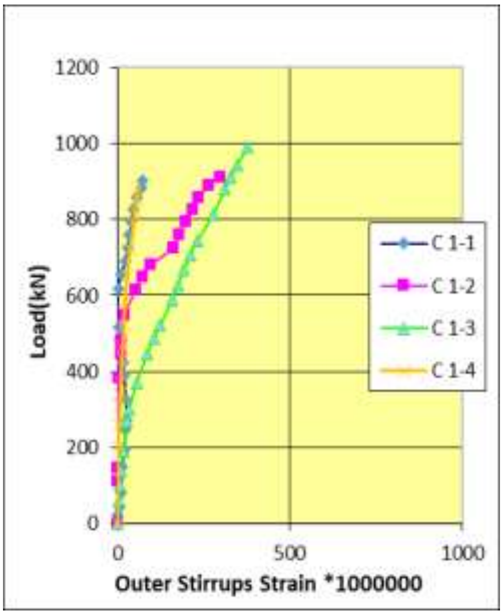


Figure 12: Load-Steel Strain Curves for Group (1) **Figure 13: Load-Steel Strain Curves for Group (2)**

3.3 Discussion of Results

The experimental results showed the efficiency of the partial confinement of the specimen. The increase in column capacities ranged from 10% to 25% in Group (1), and from 10% to 29% in Group (2). It was observed that the specimen with partial dowel penetration showed higher increase in column capacities than specimen with full dowel penetration.

This phenomenon is caused by the complete separation between the confined and the unconfined areas in the column cross section formed by the dowels. The higher the number of fully penetrated dowels is, the weaker the column becomes. The strains of the outer stirrups remained almost linear up to failure in the tested specimen and all specimen suffered a compression failure in concrete, keeping the natural failure mode of columns, in spite of the capacity increase.



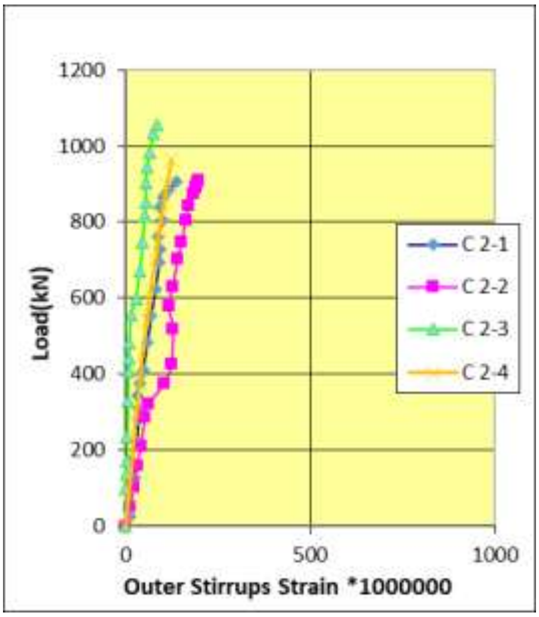


Figure 14: Load-Outer St. Strain Curves-Group (1) **Figure 15: Load- Outer St. Strain Curves-Group (2)**

4. ANALYTICAL MODELS

The specimens were modeled using finite element analysis. The used software was ABAQUS 6.12. The analysis was based on the non-linear iterative secant stiffness formulation. For compressive and tensile behavior, Concrete Damaged Plasticity model was used to describe

the yield criterion of concrete as compressive behavior and tension behavior as shown in **Figures (16)** and **(17)**. The stress strain curve of reinforcement was plotted as bilinear behavior. Cohesive Behavior model was used to describe the contact between concrete and outer stirrups (steel strips) with specified stiffness coefficients.
It merged the following described constitutive models for concrete, reinforcement and Epoxy. Concrete Damaged Plasticity model was used to describe the yield criterion of concrete.

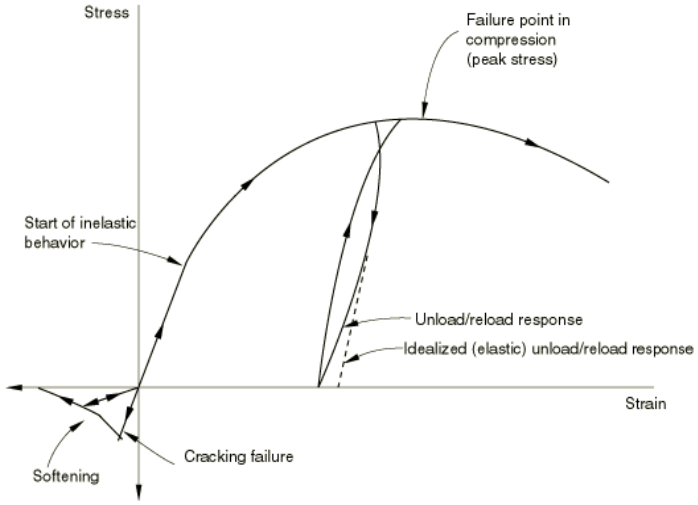


Figure 16: Axial behavior of plain concrete

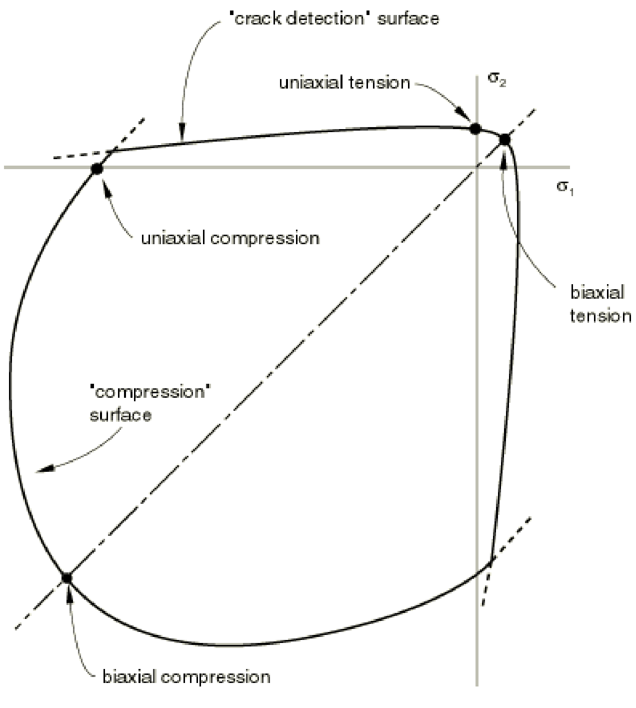


Figure 17: Concrete failure surfaces in plane stress.

The stress strain curve of reinforcement was plotted as shown in Figure (18). Cohesive Behavior model was used to describe the contact between concrete and outter stirrups (steel strips) with specified stiffness coefficients.

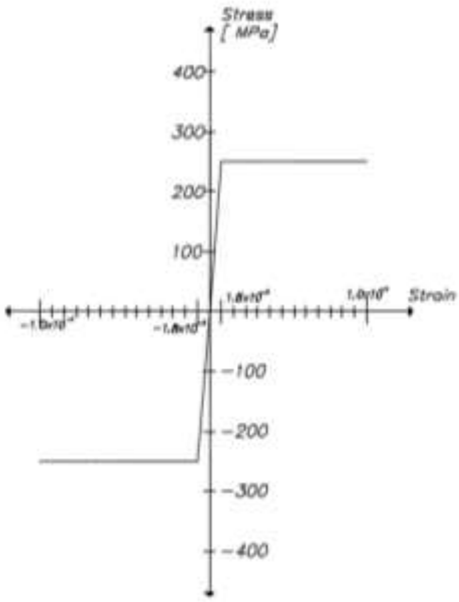


Figure 18: Idealized stress strain curve of reinforcement

The deformed shapes of the Columns C 1-0 is shown in **Figure (19)**. The simulation of column C 1-1 is shown in **Figure (20)**. The experimental and theoretical failure loads are compared in **Table (3)**. The failure was considered in the theoretical results when the stress in concrete began to decrease after that the strain in concrete began to reach 0.003. The difference between experimental and theoretical results was less than 8%.

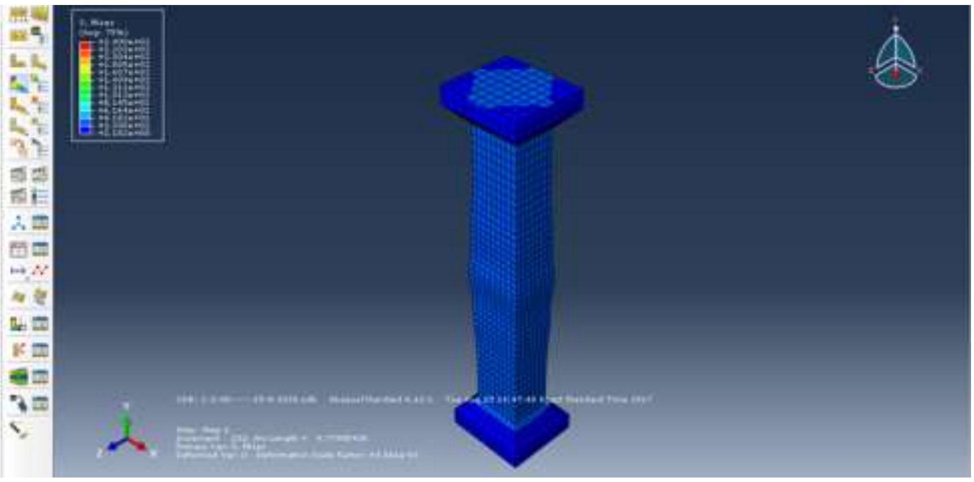


Figure 19: Deformed Shape of Column C1-0

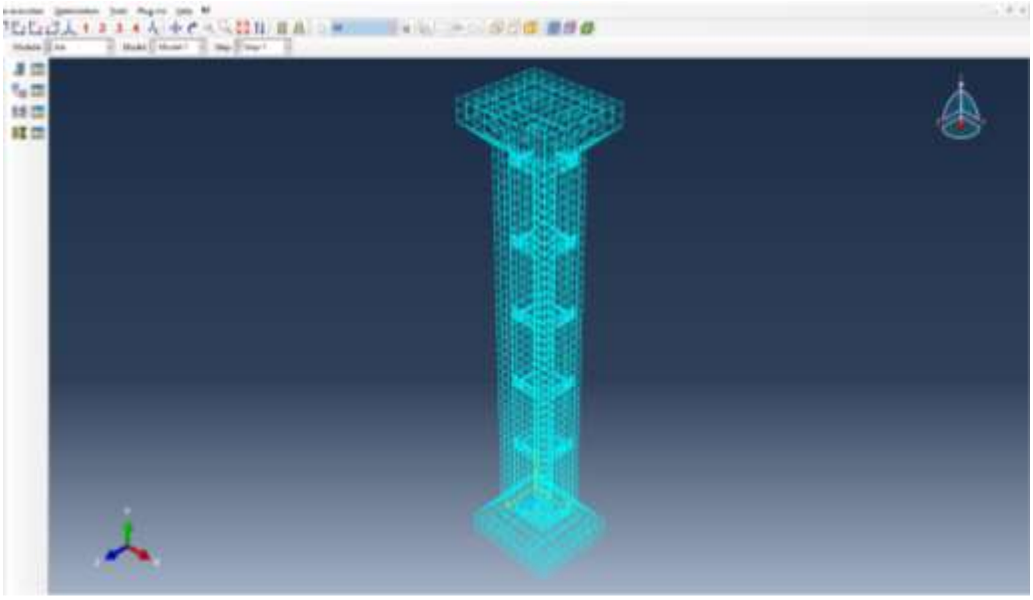


Figure 20: simulation of Column C1-1

Table 3: Comparison between Experimental and Theoretical Results

Specimens	Experimental Failure Loads (kN)	Theoretical Failure Loads (kN)
C 1-0	822	810
C 1-1	901	925
C 1-2	919	910
C 1-3	1021	1110
C 1-4	963	900
C 2-0	830	850
C 2-1	906	965
C 2-2	906	950
C 2-3	1069	1150
C 2-4	1025	940

5. SUMMARY AND CONCLUSIONS

The present study investigated the effect of the partial confinement of concrete columns using external stirrups with partial and full dowel penetration. This method should be useful in confining external and corner columns in existing buildings, where it is difficult to confine the whole column perimeter. The following summarizes the findings of this investigation:

1. A successful method for confining corner concrete columns partially to increase their capacities is introduced.
2. Partial confinement with fully penetrated dowels showed an increase of about 17% in column capacity, while specimen with partially penetrated dowels showed an increase of more than 29% in column capacity .
3. Full penetration of dowels forms a weak point in the column cross section by totally separating the confined and unconfined zones.
4. Finite element models showed good agreement with the experimental results in the capacities and strain result. The difference between the experimental and theoretical results ranged between 3% to 8%.

5. Based on the results of this study a full parametric study could be performed to pretend solid equations for the partial confinement.

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