Behavior and Stress Analysis around Openings for Reinforced Concrete Columns

Dr. Nabeel Hasan Ali Al-Salim

***Abstract*—**This research is devoted to investigate the behavior and ultimate strength of reinforced concrete short columns with different shapes of transverse openings. The experimental part includes investigation of the ultimate strength of tested columns. Variables considered in the test program include different shapes of openings with the same opening ratio of 0.133. In the numerical part, the columns have been analyzed using nonlinear finite element model. The finite element analysis has been carried out to analyze the tested columns to determine the stresses at the longitudinal bars and the stresses in concrete at the sections of openings. An increase in the ultimate strength of about 2.06% is noticed when the single opening having 20mm diameter is replaced by two symmetrical openings of 10mm diameter each. Also, a decrease in the ultimate strength of about 2.88% and 5.97% is noticed when the single circular opening of 20 mm diameter is replaced by 20x20 mm square opening or 20x40 mm rectangular opening respectively.

***Keywords*—** Nonlinear Finite Element Analysis, Openings, RC Columns, Stress Analysis.

I. Introduction

TRANSVERSE openings are often provided in reinforced concrete columns to allow access for services, such as pipes for plumbing and electrical wiring. The provision of such openings may result in the lost of strength, stiffness and ductility and, hence, significant structural damage may be sustained, if the provision of the openings is not considered adequately during the design or construction stages. The ACI building Code ACI 318M-2011 in section 6.3.4 stated that "*Conduits and pipes, with their fittings, embedded within a column shall not displace more than 4 percent of the area of cross section on which strength is calculated or which is required for fire protection*". Experimentally investigating of the influence of presence transverse openings in columns to examine the strength reduction due to the presence of such openings is carried out in present study under concentric loaded columns. Also, The finite element analysis has been carried out to analyze the tested columns to determine the stresses at the longitudinal bars and the stresses in concrete at the sections of openings.

Dr. Nabeel Hasan Ali . Al-Salim, lecturer, College of Engineering, Civil Engineering Department, University of Babylon, Hilla, Iraq (corresponding author's Phone: +9647831730125; e-mail: dr_nabeelalsalim@yahoo.com.

II. Experimental Program

Specimens Description

Tested columns having an overall length of 900 mm with a square cross section of 150 mm by 150 mm and all the transverse openings are lying in mid height of columns. Opening ratio is defined as the projection area of the opening at the opening diameter level (i.e. at mid height of column) divided by the area of the column cross section. The reinforcement provided in all columns of this study are 4Φ10mm longitudinal reinforcement, so that the steel ratio (ρ) is about 1.4% which lies within the ACI 318M-11 Code limits (1% - 8%). The transverse tie reinforcement is consisted of Φ6mm@100mm for stirrups. The overall length of all tested columns was 900mm; test length is the middle part with a 700mm length. The remaining parts of column (100mm length for each part) are located inside the steel caps to apply the required load at ends. This configuration is to prevent aforetime failure at the ends, which make the general failure of the column at the test region. In addition, the embedded ends stabilize the specimen during the testing and to simulate the general case of the column in any actual structures.

III. Specimen Identification

General

In order to identify the test specimens with the different columns numbers, sizes of the openings the following designation system is used.

- **Column group number:** The first group of characters is used to specify the column number. C2 refers to the tested columns of this group .
- **Shape of the opening:** the second group of characters is used to specify the shape of the opening. Φ10 refers to that the opening is consisted of two circular openings of 10mm diameter with 10mm clear distance in between, S20 refers to square opening of 20mm sides length and R20-40 refers to rectangular opening of 20-40mm sides length. All shapes of openings have the same opening ratio13.33%.
- **Eccentricities:** The third group of characters is used to specify the eccentricity magnitude of the loading. E0 refers to there is no eccentricity in loading.

Table 1 illustrates the specimen identification system and description based on specimen pattern described above.

IV. EXPERIMENTAL REAULTS

Ultimate Strength Results

The experimental results for the ultimate strength of all tested columns are given in Table 2. These columns were subjected to axial compressive load only with different opening numbers and shapes (two circular openings of 10mm diameter, one circular opening of 20mm diameter, 20x20 mm square opening and 20x40 mm rectangular opening). All of them have the same opening ratio of 0.13. For these columns, an increase in the ultimate strength of about 2.06% is noticed when the single opening having 20mm diameter is replaced by two symmetrical openings of 10mm diameter each. This increase is due to the decrease in the opening volume from 15000π mm^3 to 7500π mm^3 which leads to redistribution in stress at critical cross section of the column. Also, a decrease in the ultimate strength is noticed when the single circular opening of 20 mm diameter is replaced by 20x20 mm square opening or 20x40 mm rectangular opening. The percentage decrease in the capacities is 2.88% and 5.97% respectively. This decrease is due to the increase in the opening volume from 47124 mm^3 for circular opening to 60000 mm^3 and 120000 mm^3 for square and rectangular opening respectively.

V. FINITE ELEMENT ANALYSIS

A. Ultimate Load

Table 3 shows the ultimate load of all modeled columns obtained from the finite element method and compared with the experimental results.

B. Load versus Deflection Curves

The experimental and finite element load versus deflection curves for all columns are presented in Figures 1 to 4. Generally, one can observe from these curves that the finite element results show good agreement with the experimental one throughout the entire range of behavior.

C. Finite element stress results in main reinforcement

The finite element stress in longitudinal steel bars versus applied load curves for some of columns are presented in Figures 5 and 6. The stresses were recorded at the middle zone of the columns. It can be seen from the figures that the compression steel bars of all columns which are under pure compression reaches its yield stress (f_y) which is equal to 549.5 MPa.

D. Finite element stress results at sections of openings

The finite element concrete stress in x-direction versus depth curves for all columns with openings are presented in Figures 7 to 10. The stress is defined in (MPa) and the depth is defined in (mm) (the depth lie along y-coordinate from y=0 mm to y=150 mm). For all columns with pure compression, the stresses were recorded at nodes resulting from intersection of planes x = 400 mm and z = 0 mm. One can noticed from figures that the stress at the section of openings locations at failure load transferred suddenly to the longitudinal bars levels.

VI. CONCLUSION

Based on experimental results and the finite element analysis the following conclusions can be drawn:

1. It can be noticed from tested columns which have the same opening ratio of 13.33%, that the experimental ultimate strength is increased by about 2.06% when a single circular opening having 20mm diameter is replaced by two symmetrical openings of 10 mm diameter each. Also, the experimental results showed that the ultimate strength is decreased when the circular opening of 20 mm diameter is replaced by 20x20 mm square or 20x40 mm rectangular one. This decrease in the ultimate load of experimental results was 2.88% and 5.97% respectively.
2. The finite element results are in good agreement with the experimental results. The ratios of finite element to experimental ultimate strength ranged between 1.001 and 1.009 for all tested columns.
3. According to the finite element results it can be noticed that the compressive steel bars of all columns under concentric loading reaches its yield stress at load failure.
4. The finite element results show that the stress at the section of openings locations at failure load transferred suddenly to the longitudinal bars levels.

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TABLE I
DESCRIPTION OF TESTED COLUMNS.

C2Φ10E0	Column having two symmetrical circular opening of 10 mm diameter subjected to axial compressive load
C2Φ20E0	Column having a circular opening of 20 mm diameter subjected to axial compressive load
C2S20E0	Column having 20x20 mm square opening subjected to axial compressive load
C2R20-40E0	Column having 20x40 mm rectangular opening subjected to axial compressive load

TABLE II
ULTIMATE STRENGTH CAPACITY OF ALL TESTED COLUMNS.

Column identification	Opening ratio %	Eccentricity mm	Experimental ultimate load kN	Difference in ultimate strength %
C2Φ10E0	13.33	0	1030.44	+2.06
C2Φ20E0	13.33	0	1009.67	Ref. column
C2S20E0	13.33	0	980.58	-2.88
C2R20-40E0	13.33	0	949.43	-5.97

TABLE III
EXPERIMENTAL AND FINITE ELEMENT ULTIMATE LOAD RESULTS FOR COLUMNS.

Column identification	Experimental ultimate Load kN	Finite element ultimate Load kN	% defference in ultimate Load	P_{FEM} / P_{Exp}
C2Φ10E0	1030.44	1040.00	0.92	1.009
C2Φ20E0	1009.67	1015.30	0.55	1.006
C2S20E0	980.58	984.21	0.37	1.004
C2R20-40E0	949.43	950.59	0.12	1.001

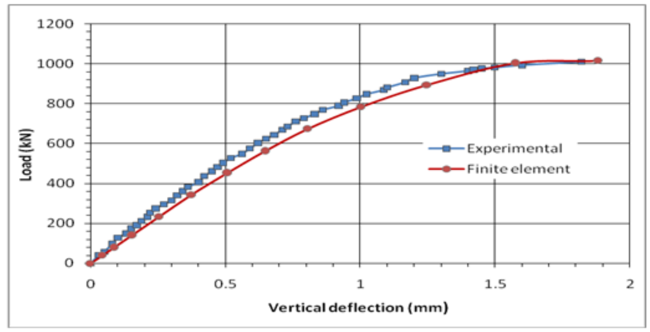

Fig. 1: Column C2Φ10E0, experimental and finite element load versus vertical deflection curves.

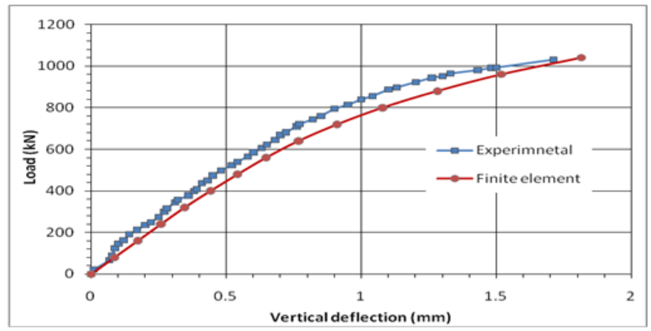

Fig. 2: Column C2Φ20E0, experimental and finite element load versus vertical deflection curves.

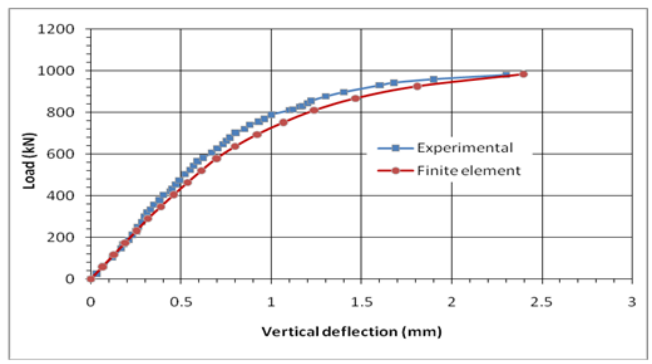

Fig. 3: Column C2S20E0, experimental and finite element load versus vertical deflection curves.

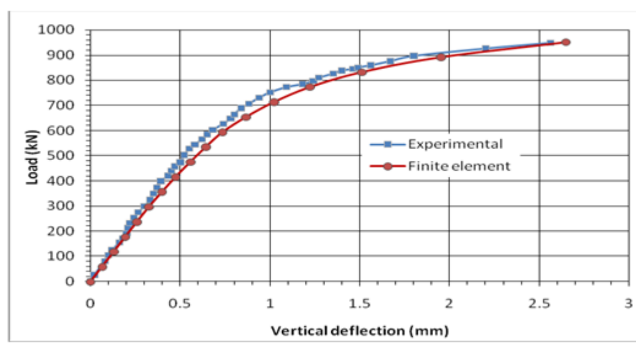

Fig. 4: Column C2R20-40E0, experimental and finite element load versus vertical deflection curves.

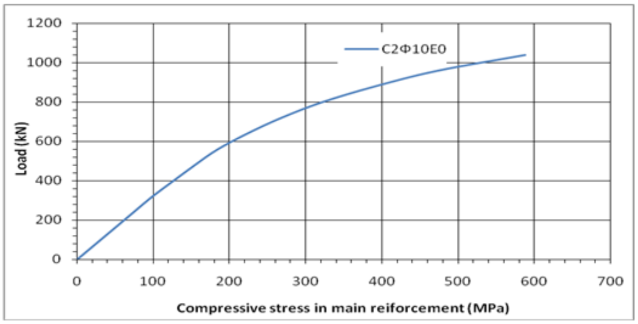

Fig. 5: Column C2Φ10E0, finite element stress in longitudinal steel bar versus load.

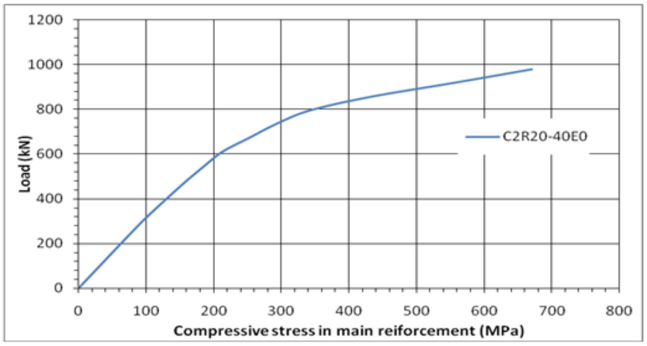

Fig. 6: Column C2Φ20E0, finite element stress in longitudinal steel bar versus load.

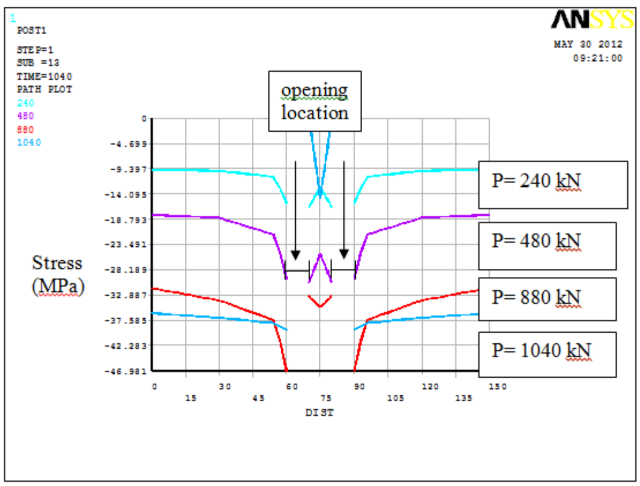

Fig. 7: Finite element stress in x-direction at section of opening for column C2Φ10E0.

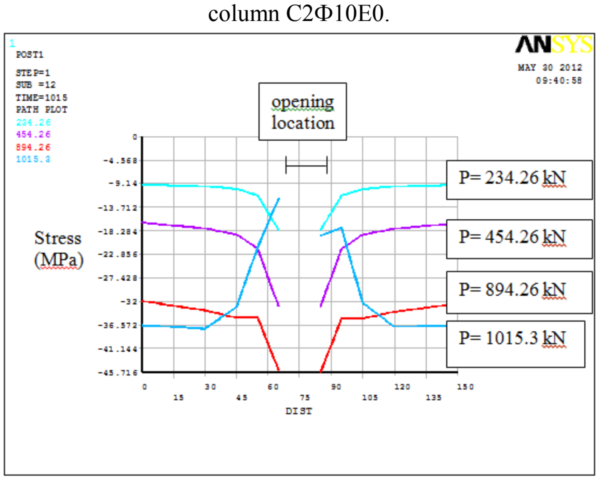

Fig. 8: Finite element stress in x-direction at section of opening for column C2Φ20E0.

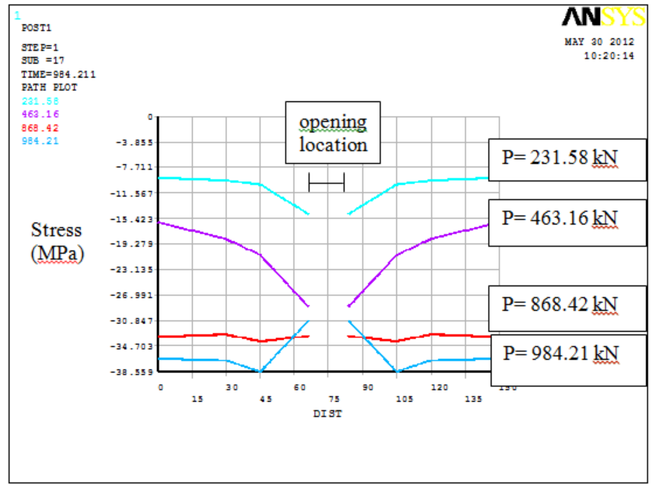

Fig. 9: Finite element stress in x-direction at section of opening for column C2S20E0.

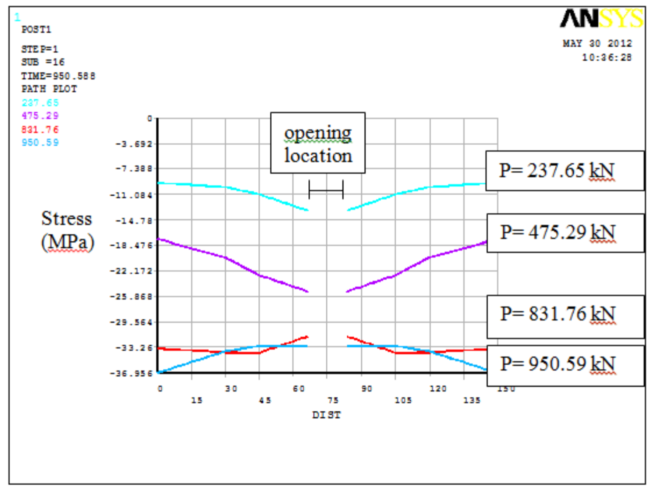

Fig. 10: Finite element stress in x-direction at section of opening for column C2R20-40E0.