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Behavior of high strength concrete columns under eccentric loads

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KEYWORDS

High strength concrete HSC;
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Abstract In recent decades, high strength concrete (HSC) has been widely accepted by designers and contractors to be used in concrete structures, especially in high compressive stress elements. The research aims to study the behavior of high strength concrete columns under eccentric compression using experimental and analytical programs. The research is divided into two main parts; the first part is an experimental investigation for ten square columns tested at the Cairo University Concrete Research Laboratory. The main studied parameters were eccentricity of the applied load, column slenderness ratio; and ratios of longitudinal and transverse reinforcement. The second part is analytical analysis using nonlinear finite element program ANSYS11 on nineteen columns (ten tested square columns and nine rectangular section columns) to study the effect of the previous parameters on the column ultimate load, mid-height displacement, and column cracking patterns. The analyzed columns revealed a good agreement with the experimental results with an average difference of 16% and 17% for column ultimate load and mid-height displacement respectively. Results showed an excellent agreement for cracking patterns. Predictions of columns capacities using the interaction diagrams based on ACI 318-08 stress block parameters indicated a safe design procedure of HSC columns under eccentric compression, with ACI 318-08 being more conservative for moderate reinforced HSC columns.

Introduction

In recent years, high strength concrete columns have been widely used in many structures, especially, in high-rise buildings. ACI Committee 363 [1] defined high strength concrete as a concrete strength of 41 MPa. More recently, compressive strengths approaching 138 MPa have been used in cast-in-place buildings. Concrete compressive strength higher than 65 MPa is referred to as high-strength concrete in this study.

Experimental and analytical studies have been carried out to study the effect of some parameters on the behavior of HSC columns. Results obtained from previous researches on

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HSC column due to centric and eccentric loads [2–10] indicated the following behaviors.

a. Rectangular columns with tie spacing equal to lateral dimension of columns showed no confinement effect.
b. Spalling of concrete cover tends to occur at strength below 85% of the unconfined concrete strength in columns with higher concrete strength and closely spaced transverse reinforcement. Columns behavior with closely spaced transverse reinforcement improves significantly with the use of high-strength confinement steel.
c. The use of larger bar diameters for longitudinal reinforcement produces little beneficial effect on the ductility of column.
d. Increasing ratio of longitudinal reinforcement in high-strength concrete columns leads to an increase in column capacity but decreases its ductility.
e. Tie configuration is very effective in strength and ductility of HSC columns.
f. In general, when axial load increases, the flexural ductility of the column decreases.
g. As eccentricity increases, columns give more ductile behavior in under and post-peak stage.

Objectives

The main objective of this study is to investigate the behavior of column members with high-strength concrete through experimental and analytical research. The study included testing of ten square columns subjected to eccentric axial compression. The aim of experimental program is to evaluate the effect of some testing parameters on the strength of HSC columns. In addition, the test results will be used to develop a recommended design approach using nonlinear finite element analysis to simulate columns leading to a better understanding of its behavior. This approach depends on the interaction between axial load and corresponding moments based on ACI 318-08 [11] stress block parameters.

Moreover, it is aimed to use the conclusion of this research to extend the current ECP 203-07 [12] design code provisions for HSC columns.

Experimental program

An experimental program was carried out by Hani. A. Kottb [13] which consisted of ten square columns tested under eccentric loads by AMSELLER compression machine with 5000 KN capacity at the Cairo University Concrete Research Laboratory. A trial concrete mix design was made to get the target cubic compressive strength in range of 75 MPa, High-grade steel bars 10, 12, and 16 mm diameter were used for longitudinal reinforcement and mild steel bars 6 and 8 mm diameter were used for stirrups. The mechanical properties of the chosen steel bars obtained from tensile test of three samples, randomly selected from each batch, are shown in Table 1. Test program was divided into reference column and four groups representing the different studied parameters. These parameters are as follows:

a. Eccentricity of applied load (e)
b. Column slenderness ratio (H/t)
c. Longitudinal steel reinforcement ratio (μ)
d. Diameter of stirrups–transverse steel ratio (St)

Description of column groups is classified as follows:

Group A, studies the effect of load eccentricity, Group B, studies the effect of slenderness ratio (H/t), Group C, studies the effect of longitudinal reinforcement ratios (μ), while. Group D, studies the effect of different diameters of ties (St), Table 2 lists the details of these different groups.

Test specimens and test set up

All columns have cross sectional dimensions of 150×150 mm, but height varied from 1500 to 2250 mm. Longitudinal steel reinforcements were 4Φ12, 8Φ10, 6Φ12, and 4Φ16 mm to achieve steel percentage 2%, 2.7%, 3%, and 3.5%. Ties were Φ6 or Φ8 or Φ10 mm with constant spacing of 60 mm. Concrete external cover was 15 mm. All tested columns were loaded as pinned-end columns with eccentric load. Steel plate $250 \times 250 \times 20$ mm was placed between machine head and column end to reduce the effect of load concentration.

The concrete strains in both compression and tension sides were measured by 200 mm demec gauges, the demec gauges were placed at column mid-height, lower, and upper quarters of column height in both tension and compression sides. Prior to casting of columns, two electrical strain gauges having 10 mm length were attached to longitudinal and transverse steel at mid height and were connected to data logger indicator to observe strains of steel directly. Lateral deformations of columns due to applied load were measured using three LVDT, of 0.001 mm accuracy, placed at column mid-height and both of column quarters in tension side.

In order to avoid premature failure, column ends were confined internally by reducing spacing of ties from 60 to 30 mm, and externally by adding external steel end caps to a depth of 100 mm. Those caps were constructed using steel plates of 10 mm thickness. Steel cylinders were used to give target eccentricity in both upper and lower ends of tested columns.

All specimens were tested and loaded until failure. The load was applied gradually with initial increment of 40 KN until cracking load; hence, increment was reduced to 20 KN up to

Table 1 Mechanical properties of steel bars.

Steel diameter (mm)	Steel grade	Actual area (mm^2)	Yield strength (MPa)	Ultimate strength (MPa)	Elongation%
Φ6	Mid steel	28.4	340	489.4	20
Φ8		51.13	290	453.8	18.8
Φ10	High grade steel	77.31	650	728.3	6.0
Φ12		108.27	580	726.9	16.7
Φ16		200.0	540	728	18.75