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The behavior of ultra-high-strength reinforced concrete columns under axial and cyclic lateral loads

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KEYWORDS

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Abstract In general Ultra High Strength Concrete (UHSC) is a new class of concrete that has been developed in recent decades. UHSC is characterized by extraordinary mechanical and durability properties. The UHSC-Matrix is very brittle material behavior. In this research an experimental program consists of twelve square UHSC columns is being carried out to study the behavior of UHSC columns subjected to constant axial load combined with cyclic lateral loading in order to simulate the case of seismic action. The main parameters of this program were: longitudinal reinforcement ratio, percentage of steel fiber, stirrups ratio, axial load level and concrete compressive strength. In this experimental program each specimen represents a column extending on both sides from the beam-column connection to the location of the point of inflection. Particular attention is paid to the effect of each variable on the strength enhancement, stiffness degradation, energy dissipation capacity, curvature ductility and displacement ductility of the tested columns. Valuable conclusions were obtained from the research results. By increasing the concrete compressive strength the column capacity increases accompanied by a decreasing in the ductility aspects, increasing the longitudinal steel ratio from 2% to (3.6% and 4.5%) leading to an increase in the column capacity and ductility aspect of the tested columns. Using steel fiber between (1.33–2.67)% is recommended in UHSC columns in seismic zones. The Egyptian concrete code of practice limits for the columns stirrups is suitable in seismic zones for columns subjected to a low axial load level.

Introduction

In the past several years an advance in the science of concrete materials have led to the improvement and development in the concrete technology. Sustainable use of supplementary materials and revolutionary developments in super plasticizing

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admixtures have facilitated in the mechanical properties and durability of concrete. For example researches are using silica fume and high range water reducing admixtures to produce high density concrete. In addition to high strength, the concrete should exhibit greater durability characteristics. This means that the concrete should be high strength and high performance. One of the materials developed in recent years is Ultra-High Strength Concrete (UHSC) also known as reactive powder concrete (RPC). This material possesses a compressive strength greater than 21,750 psi (150 MPa) [1].

In the case of reinforced concrete columns, it is necessary to allow for relatively large ductility without shear failure or significant strength degradation. It is well established that high ductility could be achieved in reinforced concrete members by furnishing a large amount of lateral confinement steel. When properly detailed, lateral steel would provide higher ductility, prevent premature buckling of main reinforcement, and avert shear failure [2]. It was investigated recently that the longitudinal steel has a small beneficial effect on the flexural ductility [3]. The amount of lateral steel required in structures where strength (and not ductility) is the primary design criterion is considerably less than that required in earthquake-prone areas. Using fibers for improving ductility and avoiding brittle behavior is a general way that has been widely investigated in the last few decades. Also it was found that the fiber plays a critical role in the ductile behavior of a structure until flexural failure [4] and it is addition in the H.S.C at any of the tested fiber contents did not increase the ultimate load of the column [5]. The axial load level has a beneficial influence on the moment resisting capacity and initial stiffness. However it also accelerates strength and stiffness degradation. The main objective of this research is to investigate the different parameters that affect the behavior of UHSC columns under axial and cyclic lateral loads.

Research significance

This paper presents the results of an experimental program which is being carried out to investigate the different parameters that affect the behavior of reinforced (UHSC) columns under axial and cyclic lateral loads, including steel fibers; the experimental program consists of twelve square UHSC columns. The main parameters were: longitudinal reinforcement ratio, percentage of steel fiber, axial load level, stirrups ratio and compressive strength. The test data are used to give proposed regulations for designing of UHSC columns located in seismic zones.

Table 2 Reference columns configurations [6].

Specimen	Main reinforcement	% ρ	F_{cu} (MPa)	% steel fiber	ρ_v	Axial load P
CR1	4∅12	2	100	0	$S = 7.5/15$	0.2 P_0
CR2	4∅12	2	50	0	$S = 7.5/15$	0.2 P_0
CR3	4∅12	2	25	0	$S = 7.5/15$	0.2 P_0

Research program

The experimental program consists of twelve square UHSC columns have a total height of 2300 mm and a cross section of 150 × 150 mm. A clear cover of 15 mm thickness was provided to all specimens. Tables 1 and 2 show the configurations of experimental program of the tested specimens. The test variables include longitudinal reinforcement ratio, percentage of steel fiber, axial load level, stirrups ratio and compressive strength. The effect of the last parameter (compressive strength) was studied by using the results of three similar reference columns from a previous research [6] and were having a different compressive strength The beam stub, which was heavily reinforced, provided a point of application of lateral load and strengthening of the joint region so that any hinging will occur in the column rather than the joint and it locates at the midpoint of the column so that used instrumentation were at the two portions of column. Fig. 1 shows the concrete dimensions and steel reinforcement details of specimen C1.

Materials properties

The materials used in this study were coarse aggregate which was local crushed dolomite from natural resources with nominal maximum size of 5 mm, the fine aggregate was natural siliceous sand with grain size ranging from 0.15 to 0.5 mm, CEMI 42.5N of the Suez Company – Suez factory, Quartz powder used as a filler form with Blain fineness of 470 m^2/kg, and a specific gravity of 2.63, Clean drinking fresh water free from impurities, and chemical admixture. All concrete ingredients comply with the requirements of the Egyptian standard specifications. Silica fume was used as addition for the cement to produce workable concrete with high cubic compressive

Table 1 Columns configurations.

Specimen	Main reinforcement	% ρ	F_{cu} (MPa)	% steel fiber	ρ_v	Axial load P
C1	4∅12	2	141	0	$S = 7.5/15$	0.2 P_0
C2	4∅16	3.6	141	0	$S = 7.5/15$	0.2 P_0
C3	4∅18	4.5	141	0	$S = 7.5/15$	0.2 P_0
C4	4∅12	2	141	1.33	$S = 7.5/15$	0.2 P_0
C5	4∅12	2	141	2.67	$S = 7.5/15$	0.2 P_0
C6	4∅12	2	141	0	$S = 10/20$	0.2 P_0
C7	4∅12	2	141	0	$S = 5/10$	0.2 P_0
C8	4∅12	2	141	0	$S = 7.5/15$	0
C9	4∅12	2	141	0	$S = 7.5/15$	0.35 P_0

The nominal column axial load capacity $P_0 = 0.67\ F_{cu}\ (A_g - A_{st}) + F_y * A_{st}$.
S: spacing of the transverse reinforcement.

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