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High strength and reactive powder concrete columns subjected to impact: Experimental investigation

Luan Huynh [a], Stephen Foster [b], Hamid Valipour [b,*], Robert Randall [c]

[a] Aurecon Australia, Neutral Bay, Sydney, NSW 2089, Australia
[b] Centre for Infrastructure Engineering and Safety (CIES), School of Civil and Environmental Engineering, The University of New South Wales (UNSW), Sydney, Australia
[c] School of Mechanical Engineering, The University of New South Wales (UNSW), Sydney, Australia

HIGHLIGHTS

- Impact drop test on HSC and RPC columns are carried out and results are reported.
- Influence of axial force on failure mode & impact resistance of columns is studied.
- Energy absorption ability of HSC and RPC columns subjected to impact is studied.
- Failure mode of HSC and RPC columns under impact load is discussed.

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ABSTRACT

Reinforced concrete structures during their construction stage and service life may experience severe loading scenario such as impact loads. In the literature, there are numerous experimental and numerical studies investigating the performance of RC slabs and beams subjected to impact loading but that of RC columns are scarce, especially for high strength and very high strength concrete columns. This experimental study investigates the performance of sixteen RC columns of three different types, i.e. high strength concrete, high strength concrete core with reactive powder concrete shell and reactive powder RC under low- to medium-velocity impacts. The effect of axial force, loading eccentricity and the use of steel fibre reactive powder concrete, as a replacement for conventional concrete, on the impact performance of columns are considered. The experimental results showed that axial force and its eccentricity had significant influence on both the impact resistance and the failure mode of the columns subjected to impact. Also, it was observed that application of reactive powder concrete can enhance the impact performance of the columns.

1. Introduction

Bridge piers, columns of multistorey car parks and lower storey columns of buildings are the structural components most vulnerable to vehicle collision (impact loads). The economic cost and loss of human life following severe damage in the building columns and bridge piers can be significant. Accordingly, protection and impact damage mitigation of reinforced concrete (RC) columns against low- to medium-impact loading scenarios such as vehicle collisions is an important design consideration.

Over the past three decades, extensive experimental and numerical studies have been devoted to behaviour of RC members subjected to high strain rate loadings (e.g. impact of vehicle collision, dropping mass and blast). In the numerical studies, some of the researchers have focused on development of appropriate constitutive laws that can adequately capture the strain-rate dependency of concrete and steel behaviour [1–3], whereas other researchers have employed nonlinear finite element (FE) models to capture the local and global response of RC members subjected to impact loads [4,5]. For example, explicit nonlinear continuum-based FE models have been used to capture the response of columns subjected to transverse vehicle impact [6,7], assess the progressive collapse response of the RC frames following severe damage and loss of a column due to impact of blast [8,9], and determine the failure mode and impact resistance of RC slabs and panels [2,4,10]. In addition to continuum-based FE models,

* Corresponding author at: School of Civil and Environmental Engineering, The University of New South Wales, Kensington, Sydney, NSW 2052, Australia. Tel.: +61 2 9385 6191.
E-mail address: H.Valipour@unsw.edu.au (H. Valipour).

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1D frame FE models have been developed and used to efficiently capture the global behaviour of beams subjected to impact/impulse loads [11].

The experimental studies undertaken by different research groups cover various aspects of RC behaviour subject to impact loading at material as well as structure level [12–14]. At material level, the effect of strain rate on the strength, stiffness and toughness of concrete and reinforcing steel has been extensively studied [15–19] and also behaviour of different types of concrete (e.g. light-weight, high strength and steel fibre reinforced concrete) under impact loading have been investigated [12,13,20–27]. At structure level, dynamic response, failure mode and damage mitigation of RC beams, slabs and panels subjected to impact of blast and dropping mass have been extensively studied [28–30]. However, less attention has paid to behaviour of RC columns subjected to transverse impacts [31,32]. Particularly, influence of magnitude and eccentricity of axial load on the impact behaviour of RC columns/beam-columns have not been thoroughly investigated [33].

Implications of using high-strength (HSC) and reactive powder concrete (RPC) on the energy-absorption and impact resistance of RC beams, slabs and panels have been studied by different researchers [29,34–36]. From the available experimental data and numerical analyses, it can be concluded that using HSC and RPC can improve the impact resistance and alter the failure mode and pattern of cracks and scabbing in beams and slabs [10,36], but there is little experimental data on structural performance, impact resistance and failure mode of HSC and RPC columns subjected to transverse impact loads.

This paper presents an experimental study of high strength concrete (HSC), reactive powder concrete (RPC) and high strength concrete core (HSC): reactive powder concrete shell (RPC) columns and beams subjected to multiple impacts. The test program was designed to investigate the potential use of RPC as a replacement for HSC for critical columns, with an expectation that impact resistance and energy absorption ability of columns to be significantly enhanced. The columns were tested horizontally using a drop weight impact arrangement and the dynamic response, impact resistance, failure mode and energy dissipation of all specimens under multiple impacts were recorded and the results are discussed. The failure mode (brittle/ductile and flexure/shear) of the beam–columns due to axial load and its eccentricity is also studied.

2. Experimental program

The experimental program consisted of three parts, i.e. static, pilot and main impact tests. The static tests were aimed at determining the static strength and stiffness and energy dissipation of the specimens. The main objective of the pilot tests was to explore the essential steps in conducting an impact test including signal processing, impact force calculation and accelerometer calibration. The main impact tests were carried out to investigate the impact behaviour and failure mode of HSC specimens, specimens with a HSC core and RPC shell and RPC specimens.

The main variables in the experimental program are:

- Composition of concrete (i.e. HSC, RPC & HSC core with RPC shell) columns.
- Magnitude and eccentricity of axial force in the columns.

The details of the experimental program including specimen geometries, test set-up, instrumentation and test procedures are provided in the following sections.

2.1. Test specimens

In total, sixteen specimens (thirteen beam–columns and three beams) were tested and are classified into 6 series with respect to testing conditions (see Table 1). The pilot test series included two columns with HSC core and RPC shell. Test series 1, 4 and 5 consisted of three columns, one HSC, one RPC and one specimen with HSC

Table 1
Specimen type.

Series	Specimen	Description	Comments
Pilot test	PL1B	HSC:RPC	Impact test with concentric axial load
	PL2B	HSC:RPC	
1	1A	HSC	Static test with concentric axial load
	1B	HSC:RPC	
	1C	RPC	
2	2A	HSC	Impact test without axial load
	2B	HSC:RPC	
	2C	RPC	
3	3A	HSC	Impact test with concentric axial load[a]
	3C	RPC	
4	4A	HSC	Impact test with axial load applied at eccentricity $e = +62.5$ mm (above the neutral axis)[a]
	4B	HSC:RPC	
	4C	RPC	
5	5A	HSC	Impact test with axial load applied at eccentricity $e = -62.5$ mm (below the neutral axis)[a]
	5B	HSC:RPC	
	5C	RPC	

[a] The axial force in the column is 440 kN.

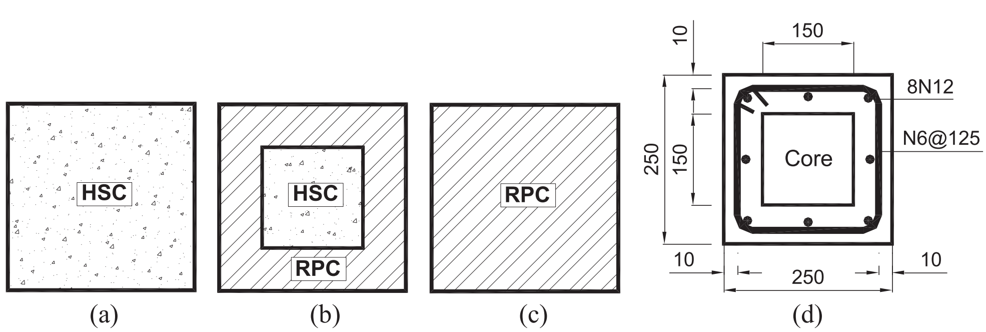

Fig. 1. Schematic cross section of the tested columns (a) HSC, (b) composite (HSC core-RPC shell), (c) RPC and (d) geometrical outline and reinforcing details of the specimens.