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Experimental Investigation of Crumb Rubber Concrete Columns under Seismic Loading

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ABSTRACT

Crumb rubber concrete (CRC) is a class of concrete that incorporates crumb rubber from used tyres as a partial replacement for the natural aggregates in conventional concrete. Previous research at the material level has shown that the rubber can improve the ductility, damping ratio, and energy dissipation properties of concrete, which are the most important parameters in concrete structures that are subjected to earthquake loads. However, CRC can have lower compressive strength when compared with conventional concrete. This paper describes experimental work conducted to explore the possible use of CRC for structural columns. Three reinforced concrete columns having 240 mm diameter and 1500 mm shear span were tested under axial compression load and incrementally increasing reversed cyclic loading. One column was constructed out of CRC and the other two were constructed out of conventional concrete but subjected to different axial loads. A snap-back test was conducted to evaluate the damping properties of each column. The results indicated that the use of CRC increased the hysteretic damping ratio and energy dissipation of the columns by 13% and 150% respectively. However, CRC decreased the viscous damping ratio compared to a conventional concrete column. The CRC column was able to sustain a lateral load and ultimate drift of about 98.6% and 91.5%, respectively, of those sustained by the conventional column. This investigation demonstrates that CRC provides an environmentally-friendly alternative to conventional concrete in structural applications.

1. Introduction

Used tyres that are currently dumped to landfill are a significant problem throughout the world. Scrap tyres are among the largest and most problematic sources of waste of modern societies, due to their durability and the huge volumes of discarded tyres every year [1,2]. Recycling of used rubber conserves valuable natural resources and reduces the amount of rubber entering landfill [3]. One application where recycled tyres can be used is in concrete. Crumb rubber concrete (CRC) is similar to conventional concrete but uses crumbed scrap tyre rubber as a partial substitution for mineral aggregates.

Well designed and detailed reinforced concrete (RC) structures under the prevailing capacity design codes suffer from severe damage at predesigned locations (i.e. plastic hinges). More energy-dissipative materials and systems are highly desirable to reduce this damage [4–6]. Experimental studies on rubberised concrete materials have shown that using rubber in concrete as a partial replacement of mineral aggregates enhances its ductility, toughness, impact resistance, energy dissipation, and damping ratio [7–9]. However, it reduces its compressive strength, tensile strength, and modulus of elasticity compared to conventional concrete [10–14]. Zheng et al. [15] used ground rubber with particle sizes of 2.62 mm and rubber-chips with particle sizes in the range of 15–40 mm including steel belt wires. They observed a continuous increase in damping ratio (ζ) with rubber content increase up to 30% coarse aggregate replacement. In addition, using bigger rubber particles showed higher ζ than that shown with smaller rubber particles. On the other hand, Skripkiūnas et al. [16] observed a continuous decrease in ζ with rubber content increasing up to 30% sand replacement. The rubber particle size in their study [16] was 1–3 mm. Resende et al. [17] used rubber particles of 2.4 mm size and found that there was no increase in ζ. However, a significant increase in ζ was observed when they used rubber and steel fibre together [17].

Limited studies have been carried out on larger scale structural elements that were constructed from CRC. The results of these studies are inconsistent with no consensus on the effects of using CRC on the structural performance of structural elements [18–22]. Son et al. [18] investigated the efficiency of using CRC to improve the deformability and energy absorption capacity of RC columns under pure axial loading. They tested six column specimens having dimensions of 200 mm × 300 mm × 1600 mm. The variables in their investigation were the concrete compressive strength (24 and 28 MPa), the rubber particle sizes (0.6 and 1.0 mm), and rubber content (2.7% and 5.4% by total aggregate volume). Their test results showed that the curvature ductility of the column specimens improved by 45% to 90% depending on the rubber size and content. Gansesan et al. [19] investigated the behaviour six exterior reinforced beam-column joint specimens under monotonic,

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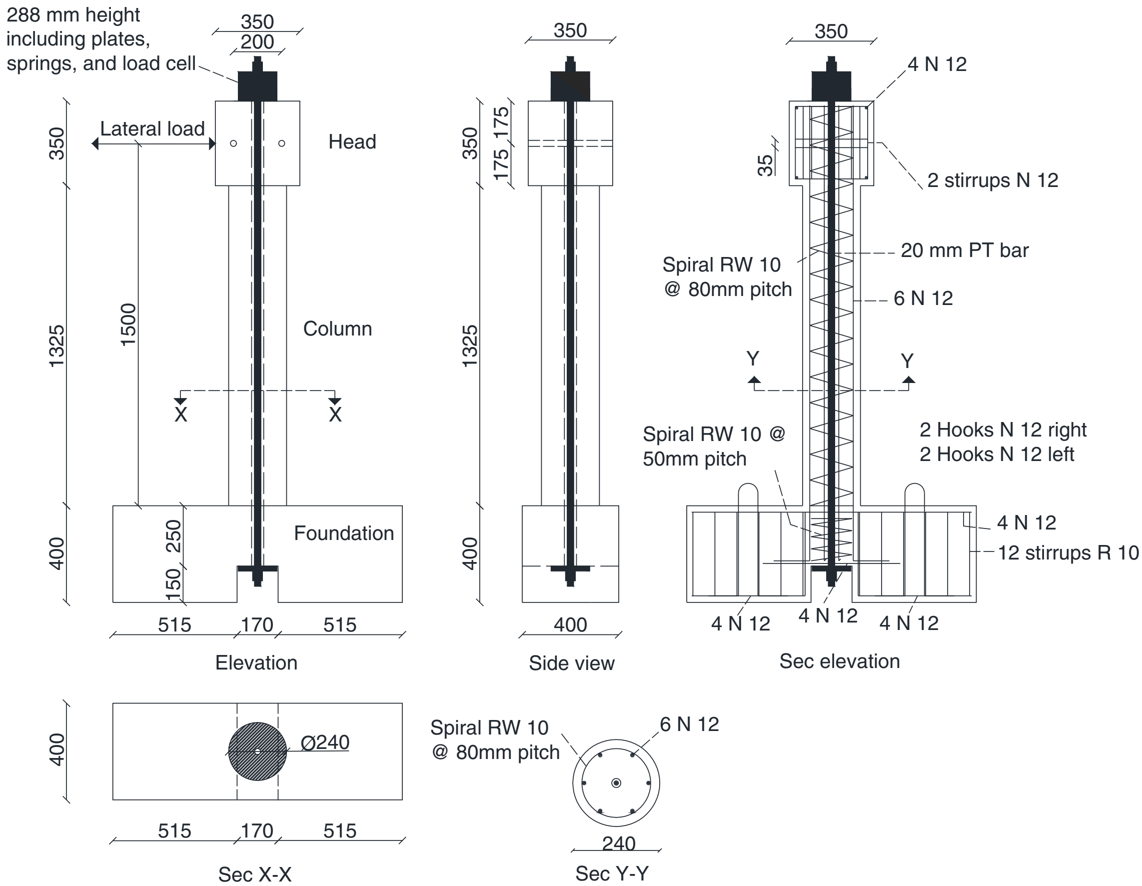

Fig. 1. Column dimensions and reinforcement details.

repeated, and reversed cyclic loading. Three specimens were constructed out of conventional concrete and the other three were constructed out of CRC. They replaced 15% of the concrete fine aggregates volume by shredded rubber with a maximum size of 4.75 mm. Their results indicated that the addition of shredded rubber significantly enhanced the beam-column joint behaviour in terms of energy dissipation, ultimate deflection, ductility, crack pattern and width. However, reductions of approximately 13.7% were observed in the load carrying capacities of the CRC specimens. Xue and Shinozuka [20] tested two small-scale columns having dimensions of 40 mm × 40 mm × 500 mm on a shaking table. One column was constructed out of conventional concrete and the other one was constructed out of CRC. The CRC mixture included replaced 15% of the fine aggregates volume replaced by rubber with particle size of 6 mm. Their tests showed that the CRC increased the damping ratio by 62% and decreased the peak seismic response acceleration by 27% compared to conventional concrete. Bowland [21] investigated the damping properties of two large-scale footbridges 9145 mm × 2135 mm using an electro-dynamic shaker. One bridge was constructed using conventional concrete, while the other one was constructed using CRC by replacing 15% of sand volume with rubber of 0.25 mm particle size. This investigation showed that the crumb rubber did not significantly affect the damping of the bridge and the crumb rubber sometimes reduced the viscous damping. Al-Tayeb et al. [22] have tested three types of concrete namely, conventional concrete, CRC, and hybrid concrete (CRC top and conventional concrete bottom) under impact and static three-point bending loadings. They replaced the concrete sand volume by 5, 10, and 20% crumb rubber with 1.0 mm particle size. The impact bending loads increased with the increase in rubber content, especially for the hybrid concrete. However, the static bending load decreased with increasing rubber content.

The inconsistencies in the effect of crumb rubber on the static and dynamic properties of reinforced concrete structures indicate the need for further research. Very few studies have been undertaken to date on the behaviour of reinforce concrete structural elements constructed out of CRC. These points provided the motivation to investigate the performance of CRC as a construction material in reinforced columns under lateral cyclic loading simulating seismic loads. In this study, three reinforced concrete columns having 240 mm diameter and 1500 mm shear span were tested under axial compression load and incrementally increasing reversed cyclic loading. One column was constructed out of CRC and the other two were constructed out of conventional concrete having different axial load. A snap-back test was conducted to evaluate the damping properties of each column before the cyclic testing. The contribution of this research is to fill a gap in the literature by investigating the seismic behaviour of concrete columns constructed out of CRC. This study explores the potential use of CRC in structural columns to provide an environmentally-friendly alternative to conventional concrete.

Table 1
Properties of reinforcing steel and PT bar.

Bar code	Diameter (mm)	E (GPa)	f_y (MPa)	ε_y	f_u (MPa)	ε_u
N12	12.0	200	550	0.00275	698	0.11600
RW10	10.5	200	612	0.00306	641	0.02680
PT	20.0	200	901	–	1102	–

2. Experimental programme

Three circular reinforced concrete columns with a diameter of 240 mm and shear span of 1500 mm were cast and tested under axial compression load and incrementally increasing reversed cyclic loading.