*Proc. 1st International Conference on Structural Engineering Research (iCSER 2017)*
*20-22 Nov 2017, Sydney, Australia*
*ISBN: 978-0-6480147-6-8*

# Structural Performance of Novel Concrete in Beam-Column Joints

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***Abstract***

*Beam-column joints are critical regions in reinforced concrete structures which require proper design approach to lead to ductile behaviour instead of a brittle one and increase resilience and energy absorption capacity of structures particularly during earthquakes. For this purpose, the amount of steel reinforcement in this region has usually high density, particularly the number of stirrups as transverse reinforcement are increased to provide the desired ductility required by different design codes. However, the use of large amounts of reinforcement is associated with difficulties regarding concrete pouring and vibration of fresh concrete. The lack of full concrete penetration into the joint region causes porosity and formation of voids and honey comb in concrete at this critical region. To address this problem extensive studies have been conducted to evaluate and improve structural performance of beam-column connections. This paper is part of an ongoing research in this area through experimental testing of a novel concrete in beam-column joint specimens and a conventional concrete for comparison. To evaluate the behaviour of these beam-column joints, failure mode, crack at the failure, load-deflection behaviour and ultimate load capacity of the subassemblies were investigated according to the data obtained from the experiments. The novel concrete tested in this research showed better performance in terms of failure mode, crack propagation and ultimate load capacity.*

***Keywords:*** Beam-column joints, Novel concrete, Crack pattern, Ultimate load capacity

## 1. INTRODUCTION

Beam–column connection, as a major structural sub-assemblage in reinforced concrete (RC) moment-resisting frame structures, plays a very crucial role during severe loading events such as earthquakes. Furthermore, the well-known design philosophy of strong-column weak-beam only works properly if this component of RC structures performs as intended without brittle failure (Eslamihassanabadi (2013)). To evaluate the performance of beam–column connections during earthquakes, most previous researchers have used cyclic loading tests, focusing on energy dissipation capacity of different types of joints (Durrani and Wight 1985, Joshi, Murty et al. 2005, Nie, Bai et al. 2008), Corinaldesi, Letelier et al. (2011), (Letelier and Moriconi 2014, Ruiz-Pinilla, Pallares et al. 2014, Metelli, Messali et al. 2015). Joshi, Murty et al. (2005) investigated four full-scale beam–column joints under cyclic loading in order to identify a suitable technique for connecting precast beam and column components. Durrani and Wight (1985) reported the results of an experimental investigation on the performance of a beam–column joint under earthquake-type loading. Nie, Bai et al. (2008) tested six beam–column joints for proposing a new connection system for concrete filled steel tube composite column and RC beams.

There are numerous studies available on retrofitting the beam-column joints by use of different methods such as FRP composites (Geng, Chajes et al. 1998, El-Amoury and Ghobarah 2002, Mukherjee and Joshi 2005), Eslamihassanabadi (2013), which emphasized the importance of appropriate performance of this structural component. This paper investigates the use of a type of new concrete in these RC joints and compares it to conventional concrete under same cyclic loading and test set up.

# 2. EXPERIMENTAL WORK

## 2.1. Materials

Two types of reinforced concrete (RC) beam-column joins were tested. First series were made of conventional concrete (CC) and the second series were made of a new concrete (ARC). CC was supplied by Concrite Pty Ltd, NSW Australia. It had 28-day compressive strength of 40 MPa and comprised 350 kg/m$^3$ cement, 150 kg/m$^3$ fly ash, 960 kg/m$^3$ coarse and 661 kg/m$^3$ fine aggregates and 2.3 litre/m$^3$ water reducing admixtures (Pozz 80 from BASF the Chemical Company). The cement and fly ash used in CC were shrinkage limited Portland cement and low calcium fly ash (type F). The coarse aggregates had maximum size of 10 mm and were sourced from Dunmore Quarry, NSW, Australia and fine aggregates included 600 kg/m$^3$ of Nepean river sand and 150 kg/m$^3$ of Kurnell sand. The slump of the concrete was 140 mm and it had the density and air content of 2,360 kg/m$^3$ and 1.0 % respectively.

The newly developed concrete (ARC), was prepared in the laboratory. It consisted of a durable binder under commercial name of Renderoc-G (Salek, Samali et al. (2015)) from Parchem, Australia, and the same coarse aggregate and same admixtures as used in CC. Its 28-day compressive strength was 31 MPa, the ratio of course to fine aggregate was 0.5, and water to binder ratio was 0.4. It had a slump of 140 mm and density and air content of 2,150 kg/m$^3$ and 0.8 % respectively.

## 2.2. Test procedure

The geometry and reinforcement arrangement in the specimens and schematic test set up are presented in Figure 1a and 1b, respectively. The specimens were tested in a 2D testing rig as shown in Figure 1a,1b and 1c. The top and bottom supports of the column were hinged using pins.

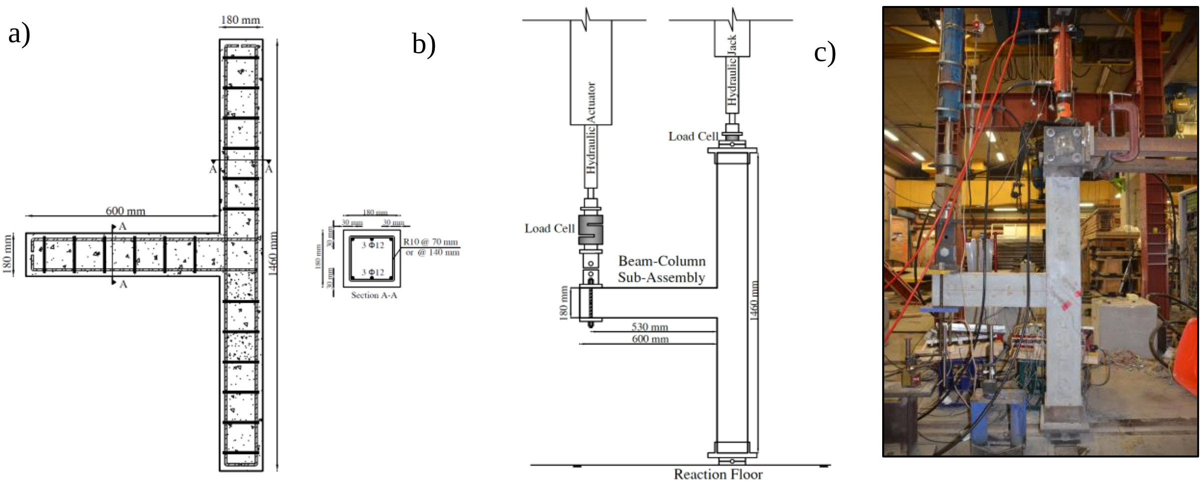


**Figure 1. a) Specimens details and reinforcement for beam-column joints used in the experiments b) Schematic test set-up for beam-column joints and c) Actual test set-up for beam-column joints**

The load at the tip of the beam, increased with the increments of 0.25kN/s in all cycles till failure (Figure 2). Failure modes, crack patterns at the failure and ultimate load capacity of these subassemblies were evaluated and compared to the CC.

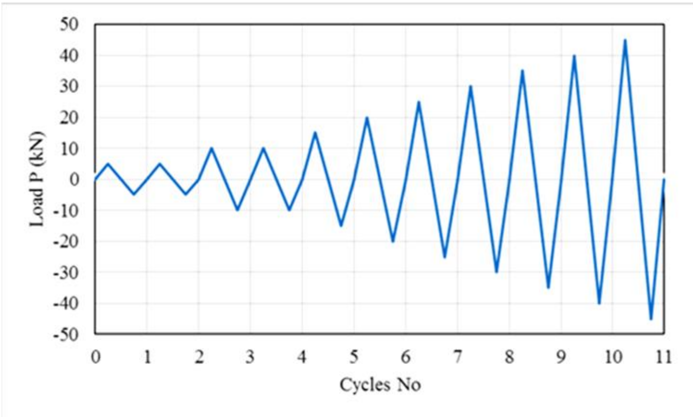


**Figure 2. Load pattern in cyclic test of beam-column joints**

The first series of specimens were cast with CC and the second and third series were made of ARC. The spacing between the transverse reinforcing bars at the joint in the CC-70mm and ARC-70 mm specimens was 70 mm, and in the third series of specimens, this spacing was 140 mm.

## 2.3. Results and discussion

### 2.3.1. Failure mode and cracking

The crack patterns of the three types of specimens at failure are presented in Figure 3. It was observed that at the latest cycle of loading, specimen CC-70 mm was not capable of completing the cycle and the crack widening occurred between beam and column rapidly and the cracks in joint grew dramatically toward the columns and the sample failed by yielding and then, the reinforcing bar in joint section ruptured. Many cracks were observable in joint and column for this specimen.

The specimens ARC-70 mm and ARC-140 mm could complete the last cycle at 40 kN but they could not proceed further to the next cycle. In both samples, the cracks widened in section between beam and column and the cracks in the joint area grew intensely, particularly, the ones in the column. These two specimens also failed by yielding of the reinforcing bars in joint section followed by their rupture.

CC-70 mm ARC-70 mm ARC- 140 mm

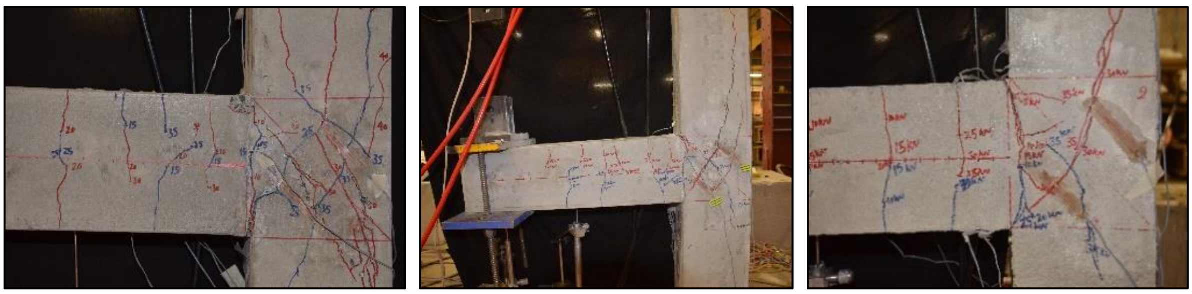

**Figure 3. Crack pattern in joint specimens at failure**

### 2.3.2. Load-deflection and ultimate load

Load versus beam tip displacement curves for beam-column subassemblies are shown in Figures 4 to 6. Regardless of the spacing of the transverse bars, ARC specimens showed stiffer behaviour under cyclic load tests as they have closer hysteresis loops in comparison with CC specimens. This is shown in both Figures 4 and 5.

Between the two ARC samples with 70 mm and 140 mm spacing in stirrups, the ARC 70 mm showed stiffer behaviour and had closed hysteresis loops. However, comparing the behaviour of CC-70 mm and ARC-140 mm (Figure 5) reveals that ARC 140 was still stiffer than CC-70 mm. In terms of peak load, specimen ARC-70 mm reached 46.5 kN at the end of 40 kN load cycle while the specimen CC-70 mm could not complete this loop and the ultimate load in this sample was 39.9 kN.

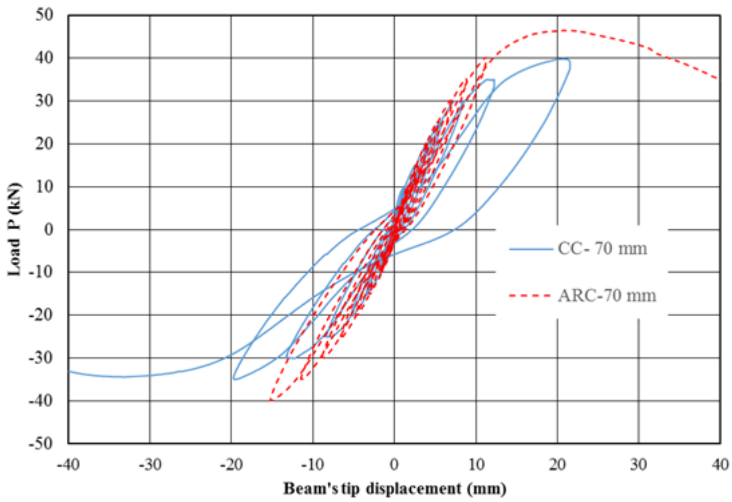


**Figure 4. Load versus beam's tip displacement in cyclic load test of beam-column joints for CC versus ARC with 70 mm spacing (CC-70 mm) in the stirrups**

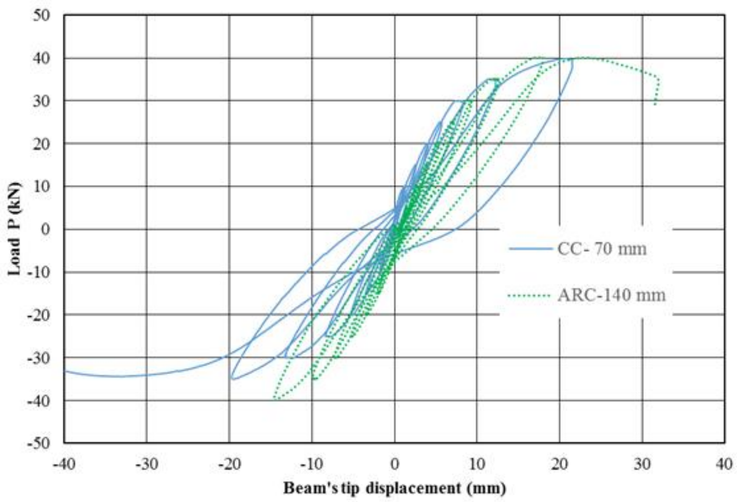


**Figure 5. Load versus beam's tip displacement in cyclic load test of beam-column joints for CC-70 mm and ARC with 140 mm spacing between the stirrups**

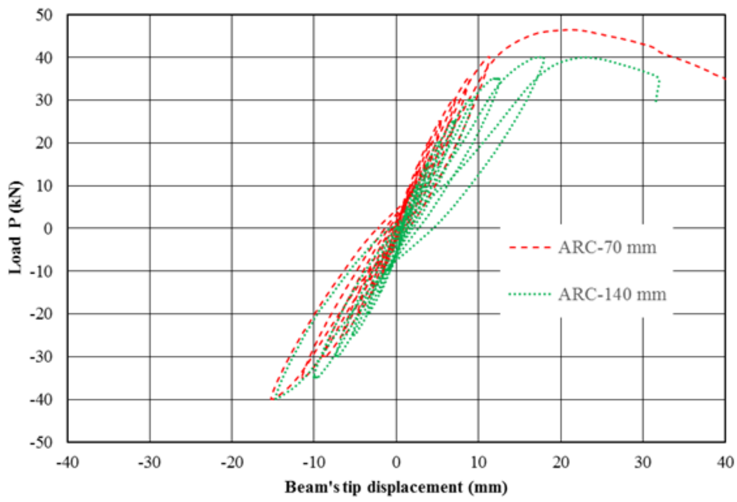


**Figure 6. Load versus beam's tip displacement in cyclic load test of beam-column joints for ARC with 70mm vs 140mm spacing between the stirrups**

In terms of the ultimate load, the load capacity of beam-column joint increased by 16 % when using ARC materials instead of conventional concrete in the same samples in terms of reinforcement arrangement. In addition, the peak load was not affected by increasing stirrups spacing twice when the ARC material was used. Larger stirrup spacing using ARC joints will save time and material without compromising the seismic capacity of the joint.

## 3. CONCLUSION

Two types of concrete were tested in RC beam-column joints with same arrangements of reinforcement and less transverse reinforcing bars. The tip of the beams was loaded cyclically and their structural performance including the crack location, load-deflection at the tip of the beam and the ultimate load capacity were investigated. Results revealed;

- The specimens ARC-70 mm and ARC-140 mm could complete more loading cycles compared to the CC-70 mm.
- ARC specimens showed stiffer behaviour under cyclic load test in comparison with CC specimens even after reduction of the transverse reinforcing bars at the joints by 50%.
- The ultimate load capacity of joints constructed with ARC material was higher than the same sample cast by conventional concrete.

However, more study is recommended in this regard before using this concrete in major structural applications.

## 4. ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Advanced Materials Charactrisation Facility [AMCF] at Western Sydney University, the Centre for Infrastructure Engineering [CIE] at Western Sydney University, Structures laboratory at University of Technology [UTS] and Parchem for Construction Co/Dulux group, Australia.

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