10th International Conference on Fracture Mechanics of Concrete and Concrete Structures
FraMCoS-X
G. Pijaudier-Cabot, P. Grassl and C. La Borderie (Eds)
https://doi.org/10.21012/FC10.233111

LOCAL AXIAL COMPRESSIVE BEHAVIOURS OF ECC RING-BEAM CONNECTIONS

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Key words: Local compression; Axial compressive load; Engineered Cementitious Composite (ECC); Ring beams.

Abstract: Ring-beam is a kind of through-beam connections where the steel tube is interrupted by a strengthening ring-beam while the reinforced concrete beams are continuous in the joint zone. The ring-beam is used to enlarge the connection zone in order to compensate for the possible decrease of the axial load-carrying capacity. However, due to brittleness of concrete, the durability problem arising from concrete cracking is a big challenge for this kind of connection. Engineered cementitious composite (ECC) is a class of high performance cementitious composites with pseudo strain hardening behaviour and excellent crack control. Substitution of concrete with ECC in the ring-beam region can efficiently avoid the cracking. Meanwhile, due to super high ductility of ECC materials, ECC outside the compression zone can provide persistent constraints on core regions, which effectively improves the axial carrying capacity and ductility of the connection. In this paper, six ECC ring-beams including three concrete ring-beams and three ECC ring-beams with various reinforcement ratio and height were tested under local axial compressive force. According to the test result, ECC ring-beams show good integrity throughout the test with no matrix spalling. The ring-beams made by ECC exhibited better axial load-carrying capacity, ductility and energy dissipation than concrete specimens, which is more obvious for specimens with on bars. Therefore, the application of ECC in the ring-beam is an effect method to improve the local axial compressive behaviour of this kind of connection.

INTRODUCTION

Recently, concrete-filled steel tubular (CFST) columns have been employed in a wide variety of structural applications because of the excellent seismic behaviour, high load carrying capacity, and good ductility performance [1-4]. The connection between CFST column and beam is the most vital component of a CFST frame structure, which is crucial for the safety of the whole structure. In prior researches on various types of connections for CFST columns, it has been shown that most studies have concentrated on investigating the connection between CFST columns and steel beams [5-7]. Limited research can be found with respect to the connection between the CFST columns and concrete beams. A big challenge for this kind of connection is the difficulty to arrange the longitudinal steel bars in the beam and the transferring of moments and shear forces at the beam end. A new type of reinforced concrete ring beam connection (Fig.1) was proposed and tested by Chen et al. [8-9]. The steel tube is interrupted by a reinforced concrete ring beam while the reinforced concrete beams are continuous in the joint zone. The ring beam is used to enlarge the connection zone in order to compensate for the possible decrease of the axial load carrying capacity. Test results showed that this kind of through-beam connections had better seismic performance than the through-column connections. However, due to brittleness of concrete, the durability problem arising from concrete cracking is a big problem. Normally, enhancing the reinforcement ratio is a common method to reduce the crack width, whereas it is inevitable to increase the complexity of fabrication because of the dense steel bars in the connection region. Meanwhile, by reason of the interruption of steel tube, improving the local axial compressive behavior of the ring beam is significant. It is essential to come up with a new connection to solve the concrete cracking problem as well as improve the local compressive behavior of ring beams.

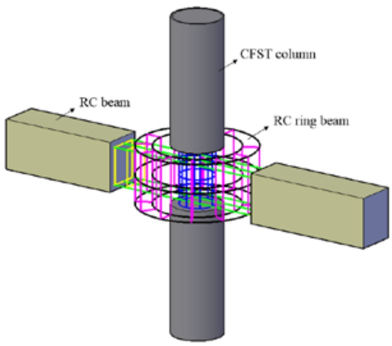


Figure 1: Schematic diagrams of reinforced concrete ring beam connection.

Engineered cementitious composite (ECC) is a class of high performance cementitious composites with pseudo strain hardening behaviour and excellent crack control. Its ultimate tensile strain can reach over 6% while the crack width is controlled to below 80 µm [10-13]. Therefore, substitution of concrete with ECC in the connection and the ring beam region may efficiently avoid the cracking. Moreover, due to super high ductility of ECC materials, ECC outside the compression zone can provide persistent constraints on core regions, which effectively improves the axial carrying capacity of the connection.

In this study, six ring beam connections including three concrete ring beam connections and three ECC ringbeam connections with various reinforcement ratio and height were tested under local axial compressive force. The local compressive behaviour between concrete connections with ring beams and ECC connections with ring beams are compared in terms of failure modes, equivalent stress-strain curves, peak load and energy dissipation.

1. EXPERIMENTAL PROGRAM

1.1 Test specimens and design parameters

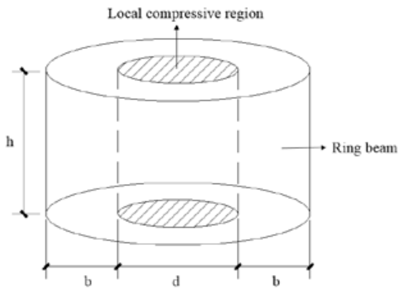


Figure 2: The schematic diagrams of connection specimen with a ring beam.

Fig. 2 shows the schematic diagrams of connection specimen with a ring beams, including the local compressive region and the ring beam. Six ring beam connections including three concrete ring beam connections and three ECC ring beam connections were tested, designed to study the effect of matrix material on the local compression behaviour of connection specimen. While all specimen had a consistent local compressive region with the diameter of 200mm, and ring bars and stirrups were arranged in the ring beam. Table 1 summarizes the test parameters of the specimens, where the first character of the natation, “E” or “C”, denotes the use of ECC or concrete for the matrix, and the next three characters "A" and "B" represents the height-to-width ratio and reinforcement ratio, respectively.

Table 1: Details of specimens

Specimens	Matrix tpye	b (mm)	h (mm)	ρ
C-A2B0	Con	120	240	0%
E-A2B0	ECC	120	240	0%
C-A1B1	Con	120	120	2%
E-A1B1	ECC	120	120	2%
C-A2B1	Con	120	240	2%
E-A2B1	ECC	120	240	2%

1.2 Material properties

All connection specimens tested in this study were casting using concrete or ECC with specified design strength of 30MPa. The normal concrete mixture includes cement, river sand and granite stone. The ECC composite contained Polyvinyl Alcohol (PVA) fibers, Portland cement, fly ash, fine silica sand, super-plasticizer and water. Cubic specimens (150mm×150mm×150mm) made with concrete and ECC have been reserved and tested, and the averaged compressive strength are 33.9MPa and 32.9MPa, respectively.

1.3 Test setup

All connection specimens were tested using a testing machine with a maximum compressive loading capacity of 10,000kN, as shown in Fig.3, and a force sensor with a capacity of 10,000 kN was used to record the applied load. To simulate the local load transferred from the circular column, two steel plates with a diameter of 200mm were installed on the top and bottom of the connection specimens. Four LVDTs were placed on the bottom loading plate to measure the axial displacement in the core region. Testing data were all recorded automatically by a data logger.

Figure 3: Test setup.

2. TEST RESULTS AND DISCUSSION

2.1 Cracking patterns and failure modes

(a)

(b)

(c)

(d)

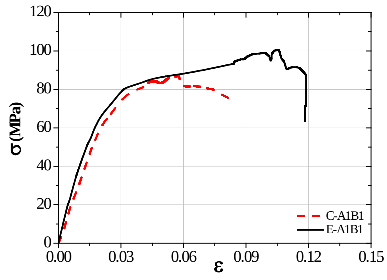
(e)

(f)

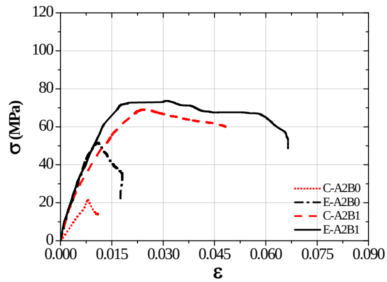
Figure 4: Crack patterns and failure modes for concrete and ECC ring beam connections (a) C-A2B0; (b) E-A2CB0; (c) C-A1B2; (d) E-A1B1; (e) C-A2C1; (f) E-A2B1.

Fig.4 compares the final crack pattern and failure mode of connection specimens. Obvious differences are observed between concrete and ECC connections. By comparing the unreinforced ring beam connections (Fig.4 (a)(b)), suddenly splitting failure occurred for the concrete connection C-A2B0, with no crack observed on the surface of the ring beam before reaching the peak load. However, plenty of fine cracks formed on the surface of the unreinforced ECC ring beam. For the reinforced concrete connection specimens (Fig.4 (c)(e)), sudden splitting damage was avoided after cracking of concrete. Serious concrete spalling was found when the external load reduced to 85% of the ultimate load. In case of reinforced ECC connection specimens (Fig.4 (d)(f)), a large number of new cracks were generated on the surface of the ECC ring beam continuously. ECC connection specimens failed by the formation of a major crack on the side face. No spalling of matrix occurred due to the bridging effect of the fiber of ECC, and specimen kept its good integrity. At the ultimate state, only 10 cracks were observed on the concrete connections, while hundreds of fine cracks formed on ECC ring beams. This shows that substitution of concrete with ECC can effectively decrease the crack width. Also, many fine cracks effectively improve the energy dissipation capacity of the ring beam connection.

2.2 Equivalent Stress-Strain Curves



(a)



(b)

Figure 5: Equivalent stress-strain curves (a) Series A1; (b) Series A2.

Fig.5 shows the equivalent stress-strain curve of all connection specimens. It can be seen from Fig.4 that the peak stress of all connection specimens except C-A2B0 exceeds 30MPa, which is much higher than the compressive strength of the matrix. However, for the unreinforced concrete connection C-A2B0, the peak stress is only 21MPa, which has not yet reached the concrete compressive strength. In case of reinforced connection specimens C-A1B1, E-A1B1, C-A2B1 and E-A2B1, the equivalent stress-strain curves show a significant difference between the reinforced concrete connections and the reinforced ECC connections. During the early stage of loading, the stiffness of ECC connections is slightly higher than concrete connections even though the elastic modulus of ECC is lower than concrete. This phenomenon is more pronounced for the unreinforced concrete and ECC specimens. After entering the yield stage, the compressive performance of connection specimens with different matrix materials also shows obvious differences. Specifically, the stress of concrete ring beam connections decreases rapidly after reaching the peak load, while the descending portion of ECC connections is still relatively gentle. This is because the fiber bridging effect and good damage resistance of ECC materials which could delay the degradation of load carry capacity. The ultimate strain of E-A1B1 is 0.12, which is much larger than the concrete specimen C-A1B1. It can be deduced that the application of ECC in the connection region can effectively improve the deformation capacity of the ring beam connection. The same conclusion can be drawn when comparing E-A2B1 with C-A2B1.

2.3 Peak load

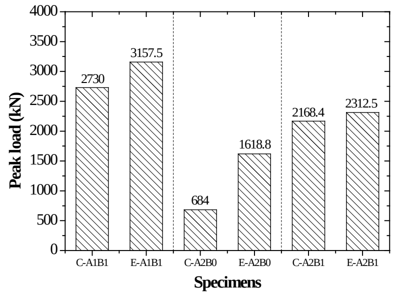


Figure 6: Peak load of concrete and ECC ring beam connections.

Fig.6 compares the peak load of all connection specimens. It is observed that the peak load of Specimen E-A2B0 is 2.5 times of that Specimen C-A2B0 even though ECC and concrete have the similar compressive strength. Due to the brittleness of concrete, cracks in the ring beam extended rapidly after initial cracking, leading to a sudden splitting failure for Specimen C-A2B0 even if concrete in the local region had not reached the compressive strength. However, the surrounding ECC ring beam provided a persistent constraint to the core region, thereby improving the ultimate bearing capacity of the ring beam connection. As is shown in Fig.6, the peak load of E-A1B1 is 15.7% higher than that of C-A1B1. While compared with C-A2B1, the peak load of E-A2B1 is 6.6% higher.

For concrete connection specimens, the concrete ring beam gradual loses its constraint effect because of concrete cracking. The majority of the constraint effect is derived from the steel ring bars in concrete ring beams. However, the surrounding ECC can still provide a stable hoop force after occurrence of fine cracks by reason of the fiber bridging effect. For ECC connections, the constraint effect can be shared by surrounding ECC ring beam and steel bars, thereby improving the ultimate bearing capacity.

2.4 Energy dissipation

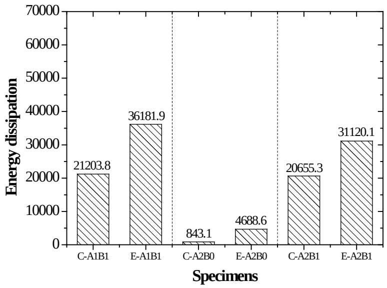


Figure 7: Energy dissipation of concrete and ECC ring beam connections.

A comparison of the energy dissipation for connection specimens is shown in Fig.7. For the unreinforced connection, the energy dissipation is merely depend on cracking and inelastic deformation of the matrix, thereby resulting a lower energy dissipation in comparison with the steel reinforced connection. As few cracks is formed in C-A2B0, the energy dissipation of E-A2B0, for which a majority of energy are dissipated by fine cracks, is 5.6 times of that C-A2C0. Compared with specimens C-A1B1 and C-A2B1, the energy dissipation of specimens E-A1B1 and E-A2B1 are improved by 70.6% and 50.7%, respectively. This difference can be attributed to (1) multiple cracks along the ECC ring beams; (2) the full inelastic deformation of longitudinal ring bars because of the larger ultimate displacement of ECC ring beam connection; and (3) compatible deformation between ECC and steel bars, which avoids stress concentration along steel bars.

3. CONCLUSION

In the present study, the mechanical behaviour of ECC connections with ring beams under local compressive load were investigated and compared with concrete connections. According to the test result, concrete ring beam connections are characterized by a mass of large cracks and concrete spalling at the end of the test. However, hairline cracks form in ECC connections and ECC connections can preserve the integrity to the most extent. Substitution of concrete with ECC effectively decrease the crack width, which improves the normal service life of connections with ring beams. Additionally, compared with concrete ring beam connections, ECC connection specimens exhibit much higher load carry capacity and energy dissipation. The improvement is more significant for unreinforced connections. The application of ECC in the ring-beam is an effect method to improve the local axial compressive behaviour of this kind of connection.

REFFRENCES

[1] Chang X, Liang R Z, Zhou W, et al., 2013. Study on concrete-filled stainless steel–carbon steel tubular (CFSCT) stub columns under compression. *Thin-Walled Structures*, **63:**125-133.

[2] Roeder C W, Lehman D E, Bishop E., 2010. Strength and Stiffness of Circular Concrete-Filled Tubes. *Journal of Structural Engineering*, **136(12):**1545-1553.

[3] Chang X, Wei Y Y, Yun Y C., 2012. Analysis of steel-reinforced concrete-filled-steel tubular (SRCFST) columns under cyclic loading. *Construction and Building Materials*, **28(1):**88-95.

[4] Sakino K, Nakahara H, Morino S, et al., 2004. Behaviour of centrally loaded concrete-filled steel-tube short columns. *Journal of Structural Engineering*, **130(2):**180–188.

[5] Kang C H, Shin K J, Oh Y S, et al.,2001. Hysteresis behaviour of CFT column to H-beam connections with external T-stiffeners and penetrated elements. *Engineering Structures*, **23(9):**1194-1201.

[6] Beutel J, Perera N, Thambiratnam D., 2002. Cyclic behaviour of concrete filled steel tubular column to steel beam connections. *Engineering Structures*, **24(1):**29-38.

[7] Wang J, Zhang L, Jr B F S., 2013. Seismic response of extended end plate joints to concrete-filled steel tubular columns. *Engineering Structures*, **49(2):**876-892.

[8] Chen Q J, Cai J, Bradford M A, Liu X, Zuo Z.L, 2014. Seismic behaviour of a

through-beam connection between concrete-filled steel tubular columns and reinforced concrete beams, *Engineering Structures*, **80:**24-39.

[9] Chen Q J, Cai J, Bradford M A, Liu X, Wu Y, 2015. Axial compressive behaviour of through-beam connections between concrete-filled steel tubular columns and reinforced concrete beams, *Journal of Structural Engineering, ASCE,* 04015016.

[10] Li M, Li VC, 2011. High-early-strength ECC for rapid durable repair - material properties.

[11] Li VC, 2013. Erratum to: tailoring ECC for special attributes: a review. *International Journal of Concrete Structures and Materials,* **7(3):**251-251.

[12] Li VC, Wu H C, 1992. Conditions for pseudo strain-hardening in fiber reinforced brittle matrix composites. *Applied Mechanics Reviews,* **45(8):**390-398.

[13] Zhang J, Leung CKY, Gao Y., 2011. Simulation of crack propagation of fiber reinforced cementitious composite under direct tension. *Engineering Fracture Mechanics,* **78(12):**2439-2454.