Performance Evaluation of Retrofitted Exterior Beam Column Joint Under Cyclic Loading

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Abstract. This research paper presents an experimental study on the cyclic behavior of retrofitted exterior beam-column joint using textile reinforced concrete. Exterior beam-column joint specimens were cast and tested under reverse cyclic loading upto a certain drift and then damaged specimens were retrofitted using textile reinforced concrete (TRC). The cover concrete in the cracked regions were removed and TRC has been used at top and bottom of the joint instead of replacing the core concrete. Repaired joints were tested under quasi static loading till it reaches the failure stage. Parameters such as damage tolerance, hysteretic curve, dissipate energy were used to examine the performance of the retrofitting schemes. It shows that the use of TRC as the external strengthening measures works upto a certain extent compared to the conventional joint interms of energy dissipation and stiffness retention.

Keywords: Textile reinforced concrete · Beam-column joint · Cyclic loading · Joint shear

1 Introduction

The recent earthquake in Nepal and other sub continental regions where number of destroyed structures with fatal moments shows the importance of earthquake resistant design and its safety against the natural disaster. The post seismic assessment of building in Nepal after 2015AD earthquake revealed that the failures of RC structures were mainly due to the brittle shear failure of beam-column joints in terms of shear demand, moment capacity ratio of beam-column joints and ductility which in turn causes early joint failure prior to the formation of plastic hinges. Many strengthening and retrofitting methods such as Fiber Reinforced Polymer (FRP) wrapping and RC jacketing, steel plate jacketing are existing. Similarly the use of high performance fiber reinforced cementitious composites such as Engineered Cementitious Composite (ECC), Textile Fiber Reinforced Concrete (TRC) and the use of Steel Fiber Reinforced Concrete (SFRC) are also in practice in restoring the deficient beam –column joint. There are two ways of strengthening such as removal of damaged cover concrete and replaced with fresh concrete and in other case removal of joint core concrete and replaced with fresh concrete

J. A. Fonseca de Oliveira Correia et al. (Eds.): ASMA 2021, STIN 26, pp. 180–187, 2023.
https://doi.org/10.1007/978-3-031-05509-6_15

followed external strengthening measures using FRP wrapping and RC jacketing etc. The use of SFRC as a joint core have shows various advantages such as improved joint shear resistance without compromising the energy dissipation and damping capacity (Mohammad 2007; Chidambaram et al. 2015). The discrete steel fiber acts as a bridge in transferring the stress across the crack which significantly improve the post peak strain and strength retention capacity (Holschemacher et al. 2010). SFRC acts as secondary shear reinforcement in resisting the shear force (Ganesan et al. 2007). The removal of core concrete and replacement of same with fresh concrete is laborious and needs external support which is not a cost effective solution. The use of textile improves the tensile stress and strain capacity of Textile Reinforced Composite (TRC) and can be moldable into any shape (Curbach et al. 1999). The performance of TRC varies with respect to the textile and mortar strength. In last decades the application of TRC has ben studied extensively for prefabricated works and strengthening of existing RC and Masonry structures (Triantafillou et al. 2006; Bournas et al. 2007; Tzoura et al. 2016). The high strength continuous fiber in mesh configuration with cementitious matrix makes its better resistance to fire and suitable for RC and masonry structure strengthening work in parallel to the widely used FRP (Al-Salloum et al. 2011; Awani et al. 2017). In TRC the textiles are the main reinforcement and the perforation between the fibers offers better interlocking between the matrix and substrate. Many experimental studies have been carried out on retrofitting the external beam-column joints using concrete jacketing, steel jacketing and fiber reinforced polymer wrapping. But very limited studies have been conducted on the shear behaviour of beam-column joints using TRC with high strain grid material. In this study a TRC with glass textile with an additional geo-grid layer has been used in retrofitting a damaged exterior joint. A detailed assessment of seismic performance of beam-column joints with the proposed retrofitting techniques are experimentally investigated in this study.

2 Experimental Program

This experimental study investigates the influence of TRC retrofitting technique in beam-column joint to enhance its joint shear capacity and ductile behaviour.

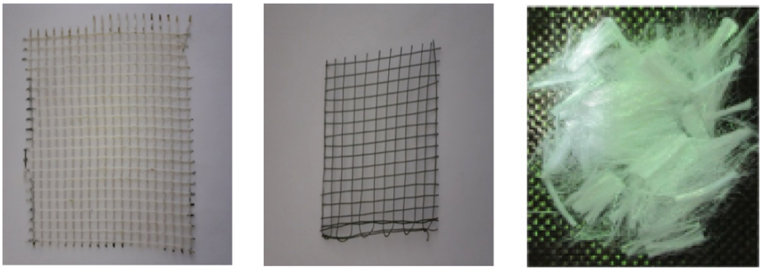
2.1 Materials and Testing Program

Table 1 provides the mix ratio of different concrete composites used in retrofitting the exterior beam-column joints. Ordinary Portland Cement (OPC) as cementitious material, coarse aggregate with maximum size of 20 mm and locally available river sand as fine aggregate are used in conventional concrete preparation before retrofitting with keeping water-cement ratio as 0.45 in accordance with 0.5% super-plasticizer to provide better workability. For the retrofitting purpose of fully yielded joint specimen, textile reinforced concrete (TRC) is used. In which glass textile and geo-grid layer as reinforcing materials and fiber reinforced cementitious composites (FRCC) using poly propylene fiber is used. Cylindrical specimens of standard size 100 mm × 200 mm are prepared and tested in 1000 kN compression testing machine (CTM) to determine the compressive strength.

The compressive strength of ECC is 15 MPa which is because of the use of untreated recycled sand in the mix preparation instead of normal river sand. Figure 1 show the materials used in TRC preparation.

Table 1. Concrete mix proportion

Specimen details	Cement	Sand	Coarse agg.	Fly ash	Silica fumes	Water binder ratio	Super plasticizer (%)	Vol. of PP fibers (%)	Comp. strength MPa
Conventional concrete	1	1.35	2.21	–	–	0.45	0.5	–	27
ECC for TRC	1	1.5	–	1	–	0.35	0.5	0.5	15

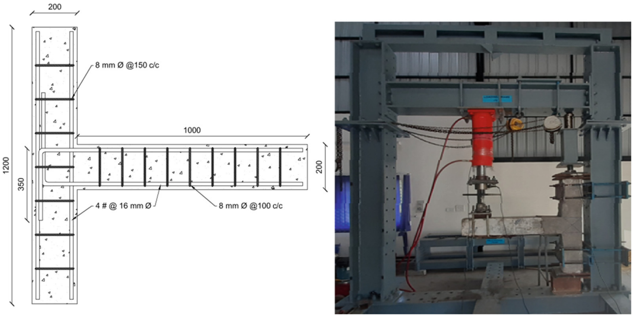


Textile fiber Steel mesh Polypropylene fiber

Fig. 1. Materials used in (TRC) preparation.

2.2 Beam-Column Joint Specimen and Test Setup

Two exterior beam–column joint specimens are used in this study and tested under quasi static loading to study the hysteretic behavior of the retrofitting scheme used. The complete details of beam–column joint specimens are given in Table 2. The reinforcing details of specimen designed as per IS 456:2000 codal provisions are shown in Fig. 2. The same specimens after testing are retrofitted using TRM layers. Figure 2 shows the beam–column joint test setup used in the study, in which a constant axial load of 25 kN was applied using screw jack. The cyclic loading was applied under displacement control with amplitude of loading increases from 10 mm till complete failure occurs.



(a) (b)

Fig. 2. Typical reinforcement details of joint specimen and test setup.

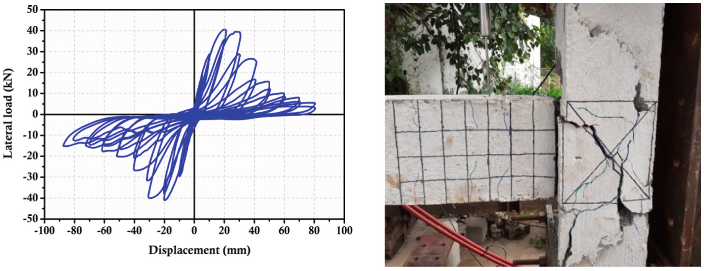
Table 2. Details of exterior beam-column joints

Codal provision followed	Samples ID	Column reinforcement		Beam reinforcement	
		Longitudinal	Transverse	Longitudinal	Transverse
IS456:2000	J1-C	#4–16 mm dia bar.	8 mm @150 mm c/c	#4–16 mm dia bar.	8 mm @100 mm c/c
	J1-D				
	J1-R				

3 Results and Discussion

3.1 Hysteresis Behaviour

The hysteresis behaviour of all tested beam–column joint specimens before and after retrofitting are shown in Fig. 3 and 4. The hysteresis behaviour of specimen J1-C shows brittle failure since there is a sudden drop in load carrying capacity after attaining the peak load with higher rate of degradation. The pinching in the loop shows the importance of ductile detailing in seismic resistance. The difference between the post peak load at 30 mm and 40 mm displacement is 50% which shows the brittle inelastic strength retention behavior of joint specimen without critical detain in the hinge region. This brittle response was occurred as a result of early diagonal cracks at the joint region. Initially flexural cracks were noticed in the beam hinge region, after peak load the diagonal cracks were started to grow faster and led the concrete cover to spall as shown in Fig. 3b. The spalling of cover concrete significantly affected the rebar anchorage and bond stress at joint region and affected the joint shear resistance.

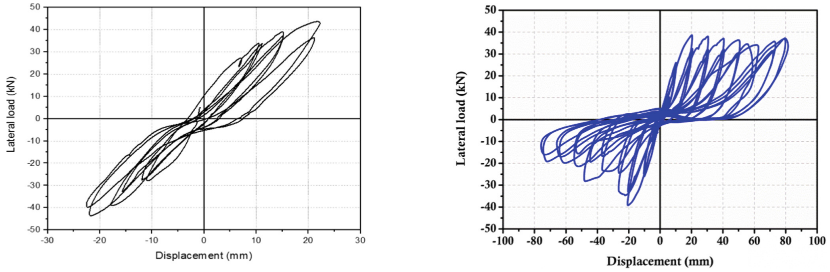


(a) Hysteresis curve

(b) Spalling of joint cover concrete

Fig. 3. Hysteresis behavior and failure pattern of J1-C.

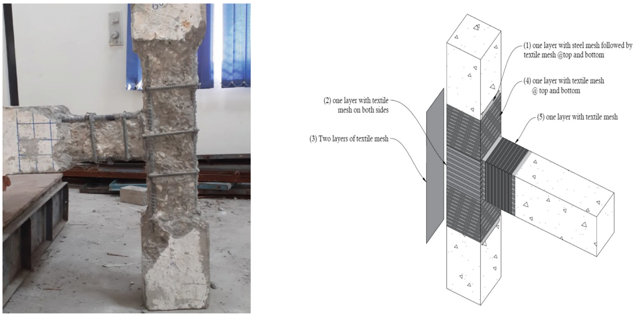
Another joint specimen of same configuration J1-D was tested up to 20 mm displacement. Figure 4 (a) shows the hysteresis curve of J1-D. The specimen J1-D experienced flexural cracks in the beam hinge region, diagonal cracks in the joint region and joint interface crack at 20 mm displacement. The test was stopped at 20 mm displacement and the damaged sample was retrofitted. In retrofitting the joint cover concrete was removed thoroughly over the entire joint and beam hinge region. The loose particles were removed and a coat of polymer based cement slurry was applied over the exposed concrete as shown in Fig. 5(a). Over the slurry coat a layer of ECC was plastered followed by glass textile - steel wire mesh – glass textile sandwich layer was used in retrofitting work as depicted in Fig. 5(b). In this scheme the interface crack was filled with cement slurry instead of epoxy or polymer modified mortar. The retrofitted sample was kept in curing for 28 days and tested under cyclic loading till complete failure occurs. Figure 4(b) shows the hysteresis behavior of the joint specimen J1-R. Hysteresis curve shows diverse behavior in positive push and negative pull. The peak load of J1-R is little lesser than J1-C but the inelastic behavior of joint specimen shows the efficacy of the TRM layer in resisting the applied force. The peak load is constant till 80 mm displacement in J1-R whereas the load drop is sudden in J1-C. The pinching width of J2-R is high compared to J1-C. But the negative loop show degradation in load after peak but the rate of degradation is lesser than J1-C. At 40 mm displacement the strength retention capacity of J1-R is 75% which is 15% higher than J1-C. The difference in the positive and negative loop is because of the early layer failure during pull.



(a) J1-D

(b) J1-R

Fig. 4. Hysteresis behavior of joint specimens.



(a) Removal of cover concrete (b) TRC layer

Fig. 5. Retrofitting techniques used in beam-column joint specimens after cyclic test.

3.2 Energy Dissipation

The energy dissipation capacity of a component is also a significant parameter for the measurement of its post-yield response. The Cumulative Energy Dissipation (CED) is used to estimate the ductility of the joint specimens. The area of the hysteretic loop is used to estimate the energy dissipation. Higher energy dissipation in subsequent cycles shows ductile response and the lesser energy shows the brittle behavior. It is clearly evident from Fig. 6 that the retrofitted joint specimen (J1-R) with TRM layer has better ductile performance compared to joint specimen (J1-C) without confining reinforcement. The CED of both the joint specimens are follows same trend till 40 mm followed by increase in CED for retrofitted specimen. The specimen J1-R exhibits 50% higher CED than J1-C. This shows the better inelastic capacity of retrofitted specimen over control specimen.

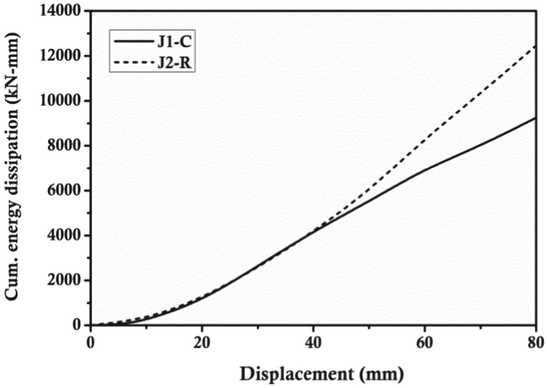
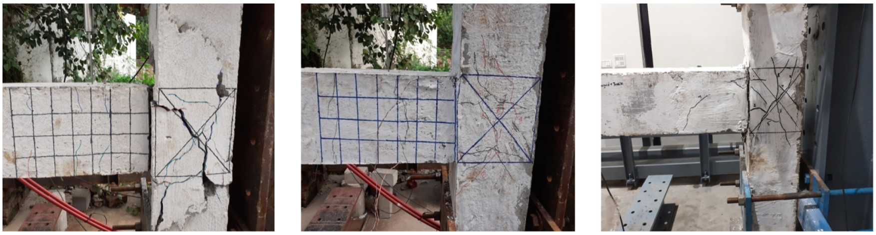


Fig. 6. Cumulative energy dissipation.

3.3 Crack and Failure Analysis

Figure 7 shows the failure pattern of the joint specimens. The crack pattern was marked on the surface during testing at each cycle as shown in Fig. 7.



(a) J1-C (b) J1-D (c) J1- R

Fig. 7. Crack pattern and failure mode.

Figure 7 shows distinguished failure pattern. The conventional specimen J1 shows typical shear failure with few flexural cracks in the hinge region. Initially flexural cracks were noticed in beam hinge portion followed by shear cracks at the joint. In specimen J1-C, shear crack formation at the joint that accelerates the slippage of embedded beam longitudinal reinforcement from the joint and spalling of cover concrete was noticed as shown in Fig. 7(a). The specimen J1-D was tested upto 20 mm displacement and experienced flexural cracks in beam hinge region followed by diagonal cracks in the joint. The specimen J1-R was retrofitted using TRM with fiber reinforced composites. The presence of fiber and continuous textile in multiple layers and its bridging effect delivers better synergetic action in resisting the initial and post yield crack growth. The specimen experienced diagonal shear cracks followed by the rupture of textile fibers at the joint region. The rupture of textile layers after peak shows sudden drop load during negative pull whereas the intact of textile layer at top exhibits better resistance to load in positive push. Thus the loop shows diverse behavior in push and pull loading. Finally the J1-R experienced delamination and interface cracks at joint.

4 Conclusions

This experimental study is mainly focused on the cyclic behaviour of external beam–column joints retrofitted with Textile Fiber Reinforced Concrete (TRC) without replacing the joint core concrete. Based on the parameters such as hysteresis characteristics, energy dissipation and crack pattern following are the main are conclusions drawn.

1. The brittle nature of conventional concrete without critical confinement fails to resist the lateral force and shows sudden drop in load with pinching effect. The retrofitted joint with TRC posse's better cyclic response compared to conventional interms of inelastic strength retention and displacement ductility. The pinching width observed in retrofitted specimen is better than control specimens.

2. The external TRC layer strengthening and absence of perfect bonding between the interface cracks fails to improve the energy dissipation capacity of retrofitted joint specimens in the initial stage. Thus, the specimen possesses similar trend as that of control up to 40 mm displacement followed by 50% increase at failure.
3. The crack pattern and failure mechanism of conventional joint specimen manifest the importance of confinement at the joint hinge region. The crack pattern of retrofitted specimen shows effectiveness of ECC in resisting the crack formation and its resistance to crack growth. The lesser tensile strengthen textile fails to resist the crack growth and thus finally exhibits interface failure at the joint region.

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