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Enhancement of seismic performance of beam-column joint connections using high performance fiber reinforced cementitious composites

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HIGHLIGHTS

- Six half-scale exterior beam-column connections are tested under cyclic loads.
- The effective parameters of the test are a) stirrup details in joint, b) pattern and type of concrete materials.
- The absence of stirrup at column in joint zone caused shear failure of NC connection.
- Substitution of NC with HPFRCC in the joint zone enhanced shear and flexural capacity.
- Flexural failure was observed at failure stage of HPFRCC beam-column joint.

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ABSTRACT

In this paper, six half-scale exterior beam-column joint connections are casted and tested under cyclic loads to investigate and evaluate the possibility of using high performance fiber reinforced cementitious composites (HPFRCC) to remove the necessity of confining (transverse) reinforcements and solve the construction problems in beam-column joints under seismic loads. Fiber reinforced cementitious materials used in this study comprises 2% volume fraction of hybrid fiber, hooked end steel fiber and hybrid macro synthetic fibers. The basic mechanical properties of HPFRCC are determined by uniaxial tension and compression tests. The hysteretic behavior, ductility, stiffness, energy dissipation, damping characteristics and cracking patterns of HPFRCC beam-column joint connections are evaluated and compared with those of normal concrete with and without special seismic requirements in joints. The test results revealed that HPFRCC connections considerably enhanced shear and flexural capacity as well as deformation and damage tolerance behavior at post-cracking stage compared to those of normal concrete at ultimate stages. Moreover, the failure mode of HPFRCC specimens changed from shear mode to flexural mode compared to the failure mode of concretes without required seismic details.
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1. Introduction

In RC structures, loads are transferred from beams to columns by beam-column joint connections. These connections undergo compression, tension and shear forces which make the connections the most vulnerable part of moment resisting structures under seismic loads. The bearing capacity of connections under these loads depends on beam-truss mechanism which develops by combined action of longitudinal and transverse reinforcements [1]. It is generally expected that these connections show significant bearing capacity under seismic loads and inelastic deformations with no strength reduction. But non-seismic detailed connections fail under cyclic seismic loads and shear strength is reduced due to concrete crushing and lack of concrete-reinforcement bonding. In fact, it seems that brittle behavior of concrete cannot restrain the formation of shear cracks and cause premature slippage of beam reinforcements from the connection during flexural yielding of reinforcements [2].

Joint committee [3] proposed some requirements for confinement, shear strength, development length of reinforcing bars in beam and column in connection region and weak beam/strong column concept to obtain proper connection behavior in frames and maintain the deformations in the elastic range [4].

It should be noted that satisfying the minimum requirements of ACI code cannot prevent the formation of wide diagonal cracks in connections under large displacements. Therefore, these criteria will not basically provide life safety and prevention of structural failure. Satisfying the standard requirements such as minimum

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and maximum spacing value for transverse reinforcements in connections based on requirements of critical region, and simultaneously use of longitudinal reinforcements in beam and column can often induce high congestion of reinforcing bars and construction problems.

Furthermore, it is required to construct structural members using new materials with appropriate capacity under seismic loads and deformations in connection regions regarding the performance-based design of structures. The use of connections with proper capacity results in reduction of plastic hinge rotations, decrease in structural damages and increase in structural performance level. Using HPFRCCs in beam-column joint connections is one of the alternatives to achieve this objective.

Fiber reinforced cementitious composites can be defined as composite materials having two main components including fiber and mortar. The fiber and mortar make a strong composite by proper bonding. High performance fiber reinforced cementitious composites (HPFRCCs) are special types of fiber reinforced cementitious composites with strain hardening behavior as their main characteristics based on tensile stress-strain curve.

A materials can be assumed as a high performance material, should the stress-strain curves shows strain hardening behavior after the initial crack stage. Otherwise, the stress-strain curves for normal fiber reinforced cementitious composite shows strain softening behavior immediately after the first crack (See Fig. 1) [5]. The absence of coarse aggregates and proper distribution of large amount of fibers causes strain hardening properties with multiple micro cracks and high capacity of strain within 1% to 5%, and also an increase in ductility of structure [6]. The higher strain capacity of these materials makes them efficient to be used in plastic hinge of beam-column joint connections under large inelastic deformations and reduces the amount of required transverse reinforcements. Additionally, the brittle properties of normal concretes such as crushing, spalling and bonding failure can be enhanced. The tensile strain properties of HPFRCCs can improve the post cracking behavior and also enhance the interfacial bonding of concrete and reinforcements [7]. The mostly used fibers in these materials include steel fiber and synthetic fibers (PVA, PP, PE, Spectra, Kevlar, etc.) [8].

Parra-Montesinos et al. (2005) tested two full-scale middle beam-column connections. The beam-column joint and beam in plastic hinge regions were substituted with HPFRCC materials [4]. The shear reinforcements in joint regions were removed and the spacing of stirrups was increased in plastic hinge regions of beam in the test specimens. The test results revealed that these connections can show appropriate behavior under high shear loads and damages. Moreover, other findings show that the connection region reinforcements can be removed and the required shear strength can be obtained. The proper confinement of longitudinal reinforcements in beams during the loading is achieved in other observations [4].

Hemmati et al. (2013) investigated the influence of using HPFRCC materials in concrete beams and frames. The test results show an increase in bearing capacity and ultimate deformations of HPFRCC beams and frames [9]. Also, increase in length and rotational capacity of plastic hinges in HPFRCC beams and frames is observed compared to those of the corresponding normal concrete specimens. Zhang et al. (2015) used Polypropylene-Engineered cementitious composites (PP-ECC) to avoid congestion of reinforcing bars and reduce the large value of transverse reinforcements in exterior beam-column joint connections in rigid frame railway bridges. The test results show that PP-ECC contributes in substitution of transverse reinforcements in beam-column joint connections in rigid frame railway bridges [10]

Chidambaram et al. (2015) investigated the behavior of exterior beam-column joint connections with different cementitious composites using hybrid steel fibers and polypropylene fibers under cyclic loads. The test results show that the use of HPFRCC materials can increase stiffness, bearing capacity and energy dissipation compared to those of normal concrete specimens [11]. Fang et al. (2013) and Said et al. (2016) studied the influence of using ECC on behavior of exterior RC beam-column joint connection under inverse cyclic loads. ECC connection significantly enhanced the flexural and shear capacity, and also damage tolerance and deformation behavior in failure and ultimate stages compared to those of normal concrete specimens [12,13]. Saghafi et al. (2016) experimentally investigated the use of HPFRCCs for retrofitting beam-column joint connections in rigid frame railway bridges. The test results revealed that the behavior of exterior beam-column joint connections retrofitted with HPFRCC panels increased ductility by 93% and lateral strength by 45% compared to those of normal concrete connections [14].

Different experimental studies have been conducted to investigate the influence of FRCs on cyclic performance of beam-column joint connections [15–19]. However, only few experimental studies have been implemented to investigate the influence of HPFRCCs with individual and hybrid fibers on behavior of external beam-column joint connections under cyclic loads. The most of the conducted studies have been focused on the influence of HPFRCCs on internal beam-column joint connections [4,20–22].

At the present study, six half-scale exterior beam-column joint connections with and without seismic details are casted using hybrid steel and macro synthetic fibers with different patterns of concreting. The specimens are tested under cyclic loads to investigate the cracking patterns, hysteretic behavior, ductility, stiffness, energy dissipation and damping. This experimental study has been

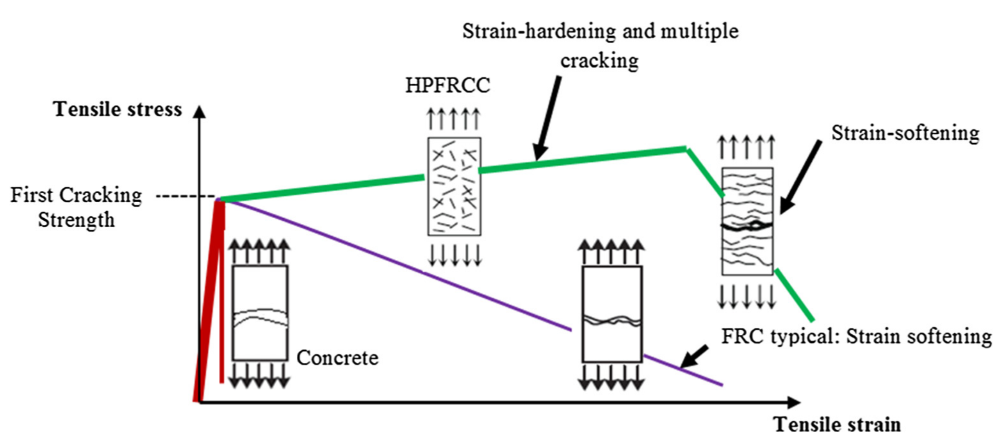

Fig. 1. Comparison of tensile behavior of normal concrete, FRC and HPFRCC.

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