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An investigation on the behavior of a new connection for precast structures under reverse cyclic loading

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ABSTRACT

This paper aims to develop a new precast beam-column connection with U-shaped bars and ECC materials, which eliminates the need for formworks, welding and bolting. In this paper, an experimental study of five precast and two monolithic connections, including exterior and interior connections under reverse cyclic loading, will be carried out. All specimens were evaluated by their failure mode, hysteresis characteristics, stiffness degradation, ductility and energy dissipation under reverse cyclic loading. The proposed connection using high strength concrete exhibited more satisfactory seismic behavior than the cast-in-place construction in terms of hysteretic behavior, stiffness degradation and energy dissipation, while their load-carrying capacity and ductility were slightly lower. When ECC material is incorporated, these precast connections showed improved load-carrying capacity and ultimate displacement compared with the precast connections using concrete. Their seismic performance is comparable to (even better at certain aspects) the conventional cast-in-place connections and is therefore recommended for the applications in the high seismic region.

1. Introduction

In recent years, precast concrete structures have been extensively investigated and employed in a wide variety of structural applications. It can significantly reduce the need for site formwork and hence speed up the building process with high construction quality. Despite above advantages, some framed structures incorporating precast concrete elements have been reported to perform poorly in earthquakes [1–3]. It is common knowledge that the seismic performance of precast structures is closely related to the behavior of its connections which are considered to be the weakest link in the system. It is therefore necessary to come up with a practical connection design for precast structures that has desirable seismic performance comparable to cast-in-place concrete structures.

In prior researches on various types of connections for precast concrete structures [4–7], it has been shown that ensuring stress transmission between the top and bottom columns as well as between the left and right beams is the key to successfully design connections in precast structures. For the linking of columns, mechanical connection [8] and sleeve connection [9] two mostly reported common practices. Adoption of mechanical connection omits the process of casting concrete, but the costly mechanical components and demanding precision during installation limit their application in a broader range. Sleeve connections, conventionally used in precast columns, have exhibited excellent capacity of transferring stress between the bars in top/bottom columns [10,11] and are convenient to construct with. As a result, they are more favored in a variety of precast structures.

For the linking of beams, the reinforcing bars in both beams are either straight spliced to each other, or anchored in the form of 90-degree hook or U-shape in the joint region. Parastesh et al. [12] studied the connection with straight spliced beam bars (as shown in Fig. 1a), which exhibited higher ductility and energy dissipation than monolithic specimens. However, adequate space needs to be reserved for the straight spliced bars in order to prevent bond slip of the bars. Compared with straight spliced bars, shorter hooked bars or U-shape bars are more convenient for transportation and require less casting area in the beam ends. This kind of connection appeals to cases where casting space in beam end is insufficient. Shariatmadar et al. [13] tested connections with U-shaped bars reaching out from precast beam (as shown in Fig. 1b), which significantly reduced the casting area in the beam end. However, as also reported by [13], when the U-shaped bars in beams are spliced directly to each other in the joint, the insufficient overlapping length inevitably led to insufficient bond stress transmission and bond slip was resulted.

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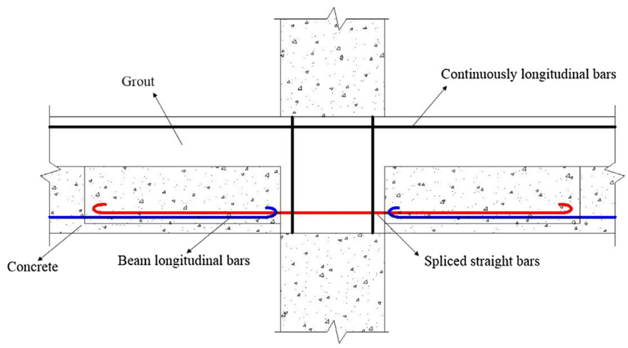
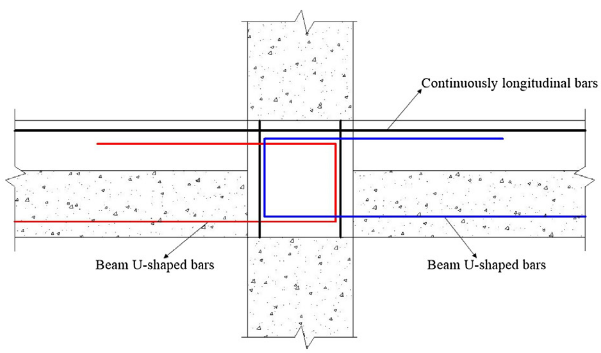
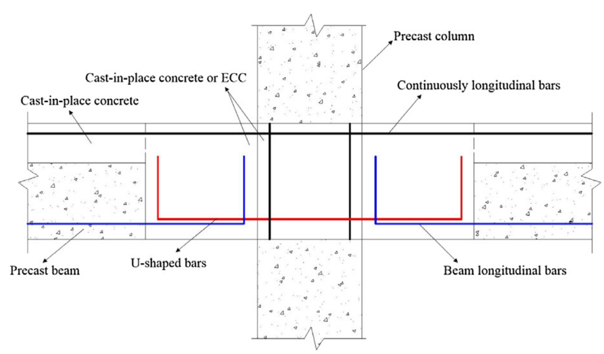


(a) Connection with beam bars straight spliced



(b) Connection with beam bars in U-shape form



(c) Connection proposed in this study.

Fig. 1. Schematic diagrams for the connecting method of beam bars.

To avoid the bond slip of beam bars, improvements are made by two ways in current study. In first way, precast beams are designed with 90-degree hooked longitudinal reinforcements bare in the vicinity of the joint to shorten the straight splicing length. To further reduce casting area, additional U-shaped bars are used in the joint zone to replace the additional straight spliced bars (schematic diagram shown in Fig. 1c). Meanwhile, the overlap between the hooked beam bars and additional U-shaped bars can ensure the stress transfer efficiency in the joint area and prevent bond deterioration. The second way is by introducing ductile materials in the joint zone as well as the beam end. Engineered Cementitious Composite (ECC) is a class of high performance cementitious composites, characterized by super-high tensile ductility up to several percent strain capacity [14,15]. ECC exhibits strain-hardening behavior in tension accompanied by the formation of multiple fine cracks and the maximum crack width can be controlled to below 80 μm [16,17]. When subjected to compression, the strength of ECC is close to normal concrete but the ultimate strain is almost twice [18,19]. The shear characteristics of ECC materials is similar to that in tension

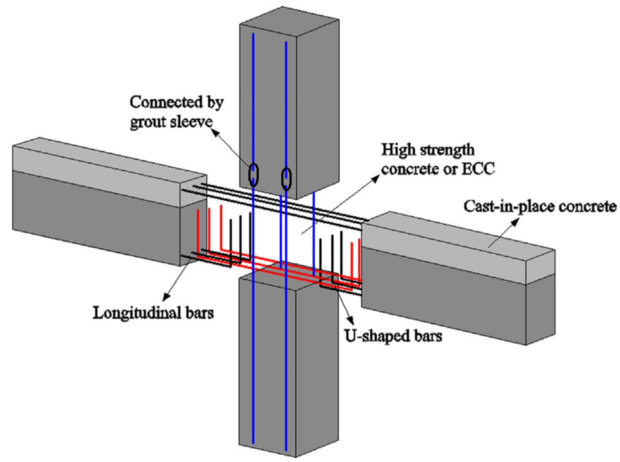


Fig. 2. Schematic diagram of the precast joint.

[20]. Moreover, experiments on the steel reinforced ECC elements proved that ECC can deform compatibly with steel reinforcement and avoid bond splitting cracks [21]. Choi et al. [22] reported precast connections containing ECC materials, which showed satisfactory seismic performance, and 15% higher strength than monolithic ones. Overall, the excellent mechanical properties of ECC provide an alternative way to solve the bond deterioration problem and thus improve the seismic performance of structures [23–26].

Based on above discussions, a new type of precast connection shown in Fig. 2 is proposed in this study where the columns are connected by sleeve connections. U-shaped bars in the joint are designed to connect with the hooked bars in beam ends and super-ductile ECC materials are introduced in the cast-in-place area. To evaluate the performance of proposed connection, a comprehensive experimental program will be carried out in present study, where its strength, stiffness, ductility and energy dissipation characteristics will be assessed. The influences of different parameters, including joint types, cast-in-place materials, axial compression ratio on the column, are to be discussed.

2. Experimental program

2.1. Design and details of specimens

In order to evaluate the seismic behavior of the precast connections proposed in this study, two monolithic connections (JMMO and JSMO) and five precast beam-to-column connections (JMC3, JME3, JSC2, JSC4 and JSE2) were prepared with different joint types, cast-in-place materials in the connection zone and varying axial load on the column, as listed in Table 1. The exterior and interior joints are scaled down from the prototype of a 2-story RC building with scale of 2:3, of which the seismic precautionary intensity is 7°, and the designed PGA (peak ground acceleration) is 0.1 g. Fig. 3 shows the plan view of the

Table 1
Summary of the specimen information.

Specimen	Type	Axial compressive ratio	Materials in cast-in-place region
JMMO	Interior, monolithic	0.3	Concrete
JMC3	Interior, precast	0.3	Concrete
JME3	Interior, precast	0.3	ECC
JSMO	Exterior, monolithic	0.2	Concrete
JSC2	Exterior, precast	0.2	Concrete
JSC4	Exterior, precast	0.4	Concrete
JSE2	Exterior, precast	0.2	ECC