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Experimental investigation on reinforced concrete interior beam–column joints rehabilitated by ferrocement jackets

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ABSTRACT

In this study, a method for rehabilitating reinforced concrete interior beam–column joints using ferrocement jackets with embedded diagonal reinforcements is proposed. It improves seismic performance of substandard beam–column joints and repairs deteriorated concrete cover without increasing the dimensions of the joints. Ferrocement, comprising mortar and wire mesh, was applied to replace concrete cover to enhance shear strength of the joints. Diagonal reinforcements were installed to reduce the forces transferred to the joint core. Four 2/3 scale interior beam–column joints, including one control specimen and three strengthened specimens, were prepared and tested under quasi-static cyclic loading. Three types of mortars were considered for each strengthened specimen. Test results have indicated that the proposed rehabilitation method can improve seismic performance of interior beam–column joints using ferrocement with high strength mortar. Strength of mortar is the vital factor affecting the performance of strengthened specimens. Anchor bolts installed at the interface between ferrocement and concrete substrate improve bonding and overall performance. Finally, a method for predicting the shear strength of joints rehabilitated by ferrocement jackets with embedded diagonal reinforcements is proposed.

1. Introduction

In reinforced concrete structures, beam–column joints are critical members for transferring forces and moments between beams and columns. Due to the moments reversal across beam–column joints when subjected to seismic action, higher joint shear forces are formed in the joint cores. As a result, beam–column joints are designed to have sufficient strength to maintain the stability and integrity of the structures. However, buildings in areas of low to moderate seismic risk, such as those in Hong Kong and Singapore [1,2], were traditionally designed without seismic provisions, i.e. designed to gravity load and wind load only. Such beam–column joints become vulnerable members in moment resisting structures and display poor performance under seismic action according to post-earthquake investigations [3,4] and experimental study [5]. Furthermore, substandard beam–column joints are common in old buildings of which are now facing the problem of aging or approaching the end of their design life span. This increases the probability of failure of beam–column joints and ultimately collapse of structures under seismic action [6]. Therefore, it is necessary to rehabilitate existing substandard beam–column joints for enhancing their seismic performance and extending their design life span.

Several rehabilitation methods for beam–column joints, including concrete jacketing, steel jacketing and fiber reinforced polymer (FRP) wrapping, etc., have been proposed. Concrete jacketing is effective for upgrading beam–column joints due to compatibility with the original structure [5,7,8]. However, it requires labor-intensive procedures to construct, increases the member sizes and reduces the usable floor areas. Besides, dynamic properties of strengthened members may be altered [9]. Steel jacketing [10], FRP wrapping [11–17] and a combined method using both steel jacketing and FRP wrapping [18] have the advantage of high strength and eliminate some limitations of concrete jacketing. However, they have poor fire resistance due to strength degradation of resin under moderate temperature. Proper insulation is required [19]. Further, FRP wrapping is subjected to limitations on construction (e.g. obstructed by beams and slabs) causing difficulties in providing sufficient anchorage [9]. All in all, the above are unattractive to building structures by reasons of complicated to construct, increased member sizes and/or poor resistance to fire.

With due consideration on simplicity and constructability, a rehabilitation method for beam–column joints using ferrocement jackets with embedded diagonal reinforcements is proposed. Ferrocement was applied to replace the concrete cover in the joint region to enhance shear strength. It is defined as "a type of thin

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wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh" [20]. The use of uniform and close dispersed wire mesh in both directions equips ferrocement with homogenous and isotropic properties. As a thin-walled structure within thickness compatible to the concrete cover, ferrocement does not increase the member sizes. It can be easily applied without formwork and to any shape [21,22]. Furthermore, geometry and mass of existing structures are unmodified, dynamic characteristics of the structures are unchanged.

Tests on reinforced concrete columns and beams strengthened by ferrocement have shown significant enhancement in strength [22–24]. In addition, diagonal reinforcements were embedded in beam–column joint to reduce the force transferred to the joint core. Among others, Tsonos et al. [25] and Chalioris et al. [26] have demonstrated that joints with crossed and inclined reinforcements exhibit improved seismic performance.

To assess the effectiveness of the proposed rehabilitation method, four 2/3 scale beam–column joints, including one control specimen and three strengthened specimens, were tested under quasi-static cyclic loading. Three types of mortars, including cement–sand mortar, cementitious mortar and epoxy-based mortar, were used for strengthening. Seismic performances in terms of ultimate loading capacity, ductility, energy dissipation, stiffness and joint shear strength were evaluated. Finally, a method is proposed for predicting the shear strength of joints strengthened by the proposed rehabilitation method.

2. Experimental program

2.1. The specimens

Four 2/3 scale beam–column joints, named as C1, S1, S2 and S3, were prepared. Specimen C1 was the control specimen while the other three specimens were strengthened by ferrocement jackets with embedded diagonal reinforcements. The specimens represent beam–column joints with smaller-size transverse beams (Fig. 1). For simplicity, slabs are not modeled. Nevertheless, tests on idealized plane beam–column joints can help us to understand effectiveness of the proposed rehabilitation method.

Dimensions and reinforcement details of specimens are shown in Fig. 2. Ends of columns and beams are points of contra-flexure. The columns are 2385 mm high with a cross section of 300 mm by 300 mm. Overall lengths of the beams are 2700 mm with a cross section of 300 mm by 400 mm. Main reinforcements in the columns are 12T16 (or 2.7% longitudinal reinforcement ratio). Same reinforcements (4T16) are provided as top and bottom longitudinal reinforcements (or 1.35% longitudinal reinforcement ratio) in the beams. Transverse reinforcements in both columns and beams are R8 ties at 150 mm spacing and are reduced to 100 mm spacing at 400 mm from the ends. The transverse reinforcement ratios are 0.22% for both beams and columns. All specimens were designed without transverse reinforcements in the joints.

Fig. 1. Interior beam–column joint with smaller-size transverse beam.

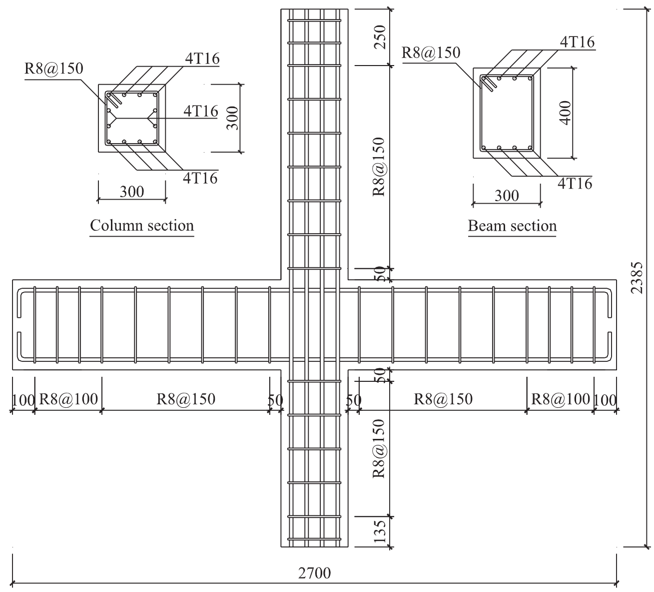

Fig. 2. Dimensions and reinforcement details of specimens.

Specimens were casted using ready-mixed concrete. Measured cubic concrete strengths estimated on the day of testing are given in Table 1. Measured yield strength and ultimate strength of longitudinal reinforcements are 540 MPa and 642 MPa respectively. Measured yield strength and ultimate strength of transverse reinforcements are 410 MPa and 521 MPa respectively.

Three types of mortars were used in the ferrocement, including cement–sand mortar, cementitious mortar and epoxy-based mortar. Measured cubic strength of each mortar is given in Table 1. Weight proportion of the cement–sand mortar was 1 part of cement to 2.5 parts of sand and with 15% of cement replaced by PFA. The other two types of mortar were commercial products available in the market. Welded square mesh had averaged wire diameter of 1.45 mm and spacing at 13.23 mm in both directions. Measured ultimate strength of single wire is 350 MPa in both directions. Ultra high strength steel bars were used as diagonal reinforcements with measured yield strength at 800 MPa.

2.2. Rehabilitation scheme

The proposed rehabilitation method aims to increase shear resistance by ferrocement and to diverge part of the forces transferred into joint core by diagonal reinforcements. Fig. 3 shows the proposed rehabilitation method. Concrete cover within the joint region and the plastic hinge zones was removed and surface

Table 1
Compressive strength of concrete and mortar.

Specimen	C1	S1	S2	S3
Concrete (MPa)	46.1	47.4	47.5	49.3
Mortar (MPa)	N/A	34.0	34.7	71.6
Types of mortar for ferrocement	N/A	Cement–sand	Cementitious	Epoxy-based