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Experimental investigation of CFT column to steel beam connections under cyclic loading

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A B S T R A C T

Four half-scale interior connections with steel beams and concrete filled tubular (CFT) columns were tested, under cyclic displacement controlled load. Square and circular steel tubular columns were considered with two different types of connections. (i) Shop welded, flat and curved extended end-plates bolted to the CFT column with steel rods passing through the column and (ii) a through beam connection type, where the beam passes through the joint and is connected with an additional bolted bracket without using any welding between the beam and the column. The experiments demonstrated that all the subassemblies performed in a ductile manner to large displacements with no apparent signs of local distress in the tube wall. Rods passing through the columns in both cases were effective. Both circular and rectangular end-plate connections showed similar performance. Also, the through beam connections behaved very well.

1. Introduction

Buildings with composite steel-concrete framing are increasing around the world, as they combine the advantages of high erection speed and the ductility of the steel structures, with the high compressive strength of the concrete. The concrete-filled steel tube column has been advantageous in that the steel tube provides confinement, thus increasing the stiffness and strength of the concrete, while the concrete reduces the possibility of the local and global buckling of the tube wall. Besides this, the steel tube column eliminates the column formwork during construction.

A wide range of beam-CFT column connections have been studied over the past several decades. A convenient connection involves attaching the steel beam directly to the skin of the steel tube for simple connections [1,2]. However, Alostaz and Schneider [3,4] have shown that welding the beam directly to the steel tube should not be used in moment-resisting frames. Severe tube wall distortions can prohibit the development of the plastic bending capacity of the beam, and cause very large stresses and strains on the flange weld and tube wall. In contrast, bolted connections or combinations of “field bolted-shop welded” connections have performed well [5], as they avoided problems related to the brittle weld failure observed in the 1994 Northridge and 1995 Kobe earthquakes [6,7]. In moment end-plate (MEP) connections all welding can be performed in the factory, where it is possible to obtain higher quality control, rather than in the field where the welding can be time consuming and costly. MEP connections are easy to erect and cost approximately the same as other moment connections.

Prion and McLellan [8] proposed a connection, which consisted of beam end-plates attached to the CFT column, using through-column bolts which showed good behavior. Chung et al. [9] and Wu et al. [10,11] also demonstrated that good performance is possible but this requires appropriate design and detailing of the bolted connections. Chung et al. [9] and Wu et al. [10] also tested the bolted beam to rectangular CFT column connections with stiffened extended end-plates. The stiffened extended end-plate subassemblies exhibited superior seismic resistance in stiffness, strength, ductility and energy dissipation than assemblies with smaller stiffeners. Li et al. [12] tested full-scale exterior steel beam end-plate connections to circular CFT columns with high-strength steel rods through the column. The end-plates were flat and six steel plates were used, to separate the end-plate and circular column on each side. The specimens showed good ductility and energy-dissipation capability for this shape of column too.

An alternative way to connect the beam to the column uses the penetration of the beam flange, web or entire cross-section through the steel tube. These can be referred to as “through beam” connections. Fukumoto and Morita [13], Elremaily and Azizinamini [14] and Cheng and Chung [15] investigated the connection details and shear strength in the panel zone of the through beam CFT column connections. In these connections the beam is welded to the column tube. In an

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alternative connection, the beam end may have a welded anchorage which is embedded in the CFT column [3,16]. Atorod et al. [17] discussed the performance of various details to connect steel beams to circular CFT columns, and describe the connection details for passing the beam through the column. All researchers showed that the through beam connections may be suitable for high seismic areas.

One reason for the brittle fractures in welded beam-to-column connections observed during the 1994 Northridge earthquake, is that high weld stresses developed at the column face, due to the plastification of the beams framing into the column. A remedial measure, based on limited experimental investigations has been proposed in FEMA 267 [18] with the intention of moving the location of the plastic hinge away from the face of the column. This movement of the plastic hinge away from the column face is carried out by either increasing the capacity of the beam at the column face by the addition of cover plates, haunches or ribs onto the beam flanges, or by reducing the strength of the beam at a distance away from the face of the column by reducing the beam flange material (reduced beam section).

A number of new connection typologies shift the plastic hinge away from the column flange by reinforcing the connection with cover plates [19], or using the cover-plate-haunch [20,21], or by weakening the beam flange near the connection, such as the "Dog-bone" approach [12,22].

It may be seen from the discussion above, that there is a need for CFT-steel beam connections that are practical, easy to assemble and provide good performance where the region of yielding is moved away from the area of significant welding, to avoid the limiting possibility of premature weld fracture, and site welding should be avoided so that construction quality and speed can be high. The scope of this study is to address the need stated above, by seeking answers to the following questions:

i) Can extended end-plate connections with rods passing through the column, in which yielding is moved away from the column face, be effective for circular CFT columns with curved end-plates, as they have been shown to be for connections with flat end-plates to rectangular CFT columns?
ii) For through beam connections, can site welding be avoided for connections to both circular and rectangular CFT column, and the location of the yielding be moved away from the column face?

2. Experimental program

2.1. Test specimens and configuration

The experimental program is composed of half-scale models of interior steel beam CFT column subassemblies. All specimens were designed as per AISC 2011 [23] and constructed. All connections, panel zones, and columns were designed in such a way, that all yielding would occur only in the beams, satisfying the strong-column weak-beam concept. As per the strength estimation, under over strength beam action, the rods, panel zone, columns, and end-plate lift-off were expected to reach 94%, 65%, 68%, and 85% of their capacities respectively. Based on AISC 341–2010 [24] "seismic provisions for structural steel buildings", the width-thickness ratio for concrete filled square and circular columns, b/t and D/t respectively, should be within the limiting width-thickness ratios such as $(1.4\sqrt{(E/F_y)}$ and $0.076\ E/F_y)$ respectively. The width–thickness ratios b/t and D/t provided for all specimens were 34 and 27 respectively, satisfying the AISC 341–2010 [24] specification. Here D is the outer diameter of the circular CFT section, b is the inner width of the rectangular section, t is the thickness of the CFT section, while E and F_y are modulus of the elasticity of the column and yield strength of the steel tube respectively.

Inflection points were assumed at the beam and column mid-points as shown in Fig. 1. A constant axial load, equivalent to 11% of the compressive strength of the joint panel zone (based on the actual material strength and geometric properties of steel and concrete) was applied on top of the column, to represent the load from the upper storeys. Vertical cyclic displacements were applied at the beam mid-points, so that the P-delta effects expected in the actual situation, where the column top moves were not considered.

In this paper, two types of steel beam-CFT column connections were studied. The basic components of the test specimens and the type of connection are given in Table 1. It may be seen that the columns of Specimen No. 1 and Specimen No. 3 had square cross-sections, while Specimen No. 2 and Specimen No. 4 had circular cross-sections. Specimen No. 1 and Specimen No. 2 used extended end-plate connections, while Specimen No. 3 and Specimen No. 4 used the through beam connection type. Also connection details are illustrated in Figs. 2 and 4.

2.1.1. Extended end-plate connection (Specimens No. 1 and 2)

Specimen No. 1, shown in Fig. 2a, is composed of a concrete filled tubular column with a 220 × 220 mm square cross-section. Since the required dimensions are not available commercially, the column was made by combining two equal L-shaped Grade 300 ($F_{ymin} = 300$ MPa) steel plates into a steel box tube. Full penetration butt welds with backing bars were made at the two corners. This column is connected to a Grade 300 universal steel beam UB 203 × 133 × 7.8 × 5.8 with two flat stiffened extended end-plates welded between the beam and end-plate with fillet welds. These end-plates were fastened to the square tubes by threaded rods passing through the column, as shown in Fig. 3a.

Specimen No. 2, illustrated in Fig. 2b, has a Grade 250 circular tube and two curved end-plates at the beam end. These curved plates (16 mm thickness) were cut from a circular tube having its internal diameter equal to the external diameter of the CFT column. There are 4 rods above and below the flange plate respectively, and in total 8 rods in the east and west end-plates. The Ø22 mm diameter rods were ordered and tested to ensure that F_{ymin} was 400 MPa.

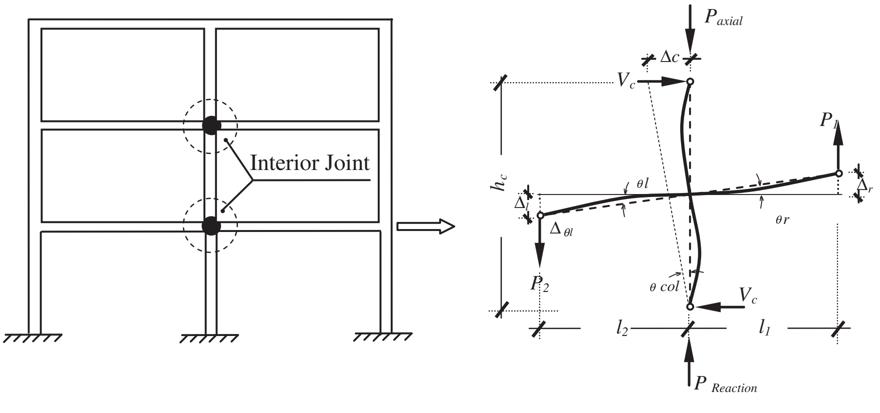

Fig. 1. Interior joint in the frame.