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Seismic behavior of bolted beam-to-column connections for concrete filled steel tube

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Abstract

Concrete-filled steel tubes (CFT) have the advantage of high strength, high stiffness and being constructed quickly. However, because the behavior of the beam-to-column connection for CFT is complicated and its design has not been sufficiently verified, their use has been limited.

In this paper, a new design of bolted beam-to-column connections for CFT is proposed. A mechanical model is established in order to derive theoretical equations for calculating the stiffness, the yielding shear strength and the ultimate shear strength of the panel zone. Also, a series of cyclic loading experiments have been conducted. The experimental results and theoretical results are very close, which demonstrates that the bolted connections have superior seismic resistance in stiffness, strength, ductility and energy dissipation mechanisms. From the laboratory studies, even though the story angular drift reaches 7% and the plastic angular displacement reaches 5%, the structure still stands. Those results indicate that the seismic resistance exceeds those specified in Taiwan and the US.

Keywords: Seismic behavior; Bolted beam-to-column connection; Concrete filled tube (CFT); Experimental study; Mechanical model; Panel zone

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1. Introduction

Steel–concrete composite structure combines the advantages of ductile steel frames with the high compressive strength of concrete components against control drift. Concrete-filled steel tube is one type of composite system and has many advantages over other types. The steel tube provides confinement and thus increases the stiffness and strength of the concrete. Meanwhile, the concrete reduces the possibility of local buckling of the tube wall. Besides this, the steel tube column eliminates the use of formwork during construction.

However, because the behavior of the beam-to-column connections for CFT is complicated and the design has not been sufficiently verified, their use has been limited [1–4]. In the Northridge Earthquake, US, 1994, the failure of beam-to-column connections was the common failure mode in steel structures [5,6]. Therefore, how to improve the design for the beam-to-column connections to avoid connection failure before the ductility of the beam, column and the panel zone is developed is the focus of recent research.

The beam-to-column connections of CFT can be classified broadly into two categories [7]. The most convenient connection is attaching the steel beam directly to the skin of the steel tube or through the diaphragm plate. From the experimental and analytical results of Alostaz and Schneider [8,9], welding the beam directly to the steel tube should not be used in moment-resisting frames. Severe tube wall distortions prohibited the development of the plastic bending capacity of the beam and caused very large stresses and strains on the flange weld and tube wall.

For the other connection category, the beam flange, the web or the entire cross-section are penetrated through the steel tube or the beam end is welded with anchorage which is embedded in the CFT column. In the research of Alostaz and Schneider [8,9], there were four methods. The first one was embedding weldable deformed bars. Experimental and analytical results showed that the deformed bars could transfer the beam flange force to the concrete core. For the second method, headed studs were attached to the inside walls at the beam flange, which could relieve severe distortion of the steel tube wall. Third, extending the web plate into the concrete core with attached headed studs was investigated but this connection did not have good moment-resisting behavior and thus was not suggested. For the fourth method, continuing the beam through the depth of the CFT column was considered to be the best rigid connection type. In the research of Schneider [10], the last connection type had the best seismic resistance behavior.

The related research showed that the second category of beam-to-column connections have better seismic resistance. However, the construction difficulty is the disadvantage of these connection types. In this research, the use of bolts is proposed in order to connect CFT columns and beams for improving the connection characteristics and performance. First, the end of the H-beam is welded with an end-plate; the end-plate is then connected to the square concrete-filled steel tube column with tie-rods. After the compressive strength of the concrete is fully developed, the tie-rods are pre-stressed. In addition, flange wing plates and upstanding ribs are welded to the end of the steel beam (Fig. 1). The use of flange wing plate can increase the distance of plastic hinges and the welding zone, and the reinforced upstanding rib can reduce the prying action.

After the columns have been erected in the field, the distance between two adjacent columns is slightly increased with a jack allowing enough space for the horizontal beam