Journal of Constructional Steel Research 65 (2009) 1644–1663

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

journal homepage: www.elsevier.com/locate/jcsr

Hysteretic behaviour of flush end plate joints to concrete-filled steel tubular columns

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ARTICLE INFO

Article history:
Received 11 November 2008
Accepted 31 December 2008

Keywords:
Concrete-filled steel tubes
Semi-rigid connections
Flush end plates
Blind bolts
Hysteretic behaviour

ABSTRACT

The results of an experimental research study involving the testing of four bolted moment-resisting connections under simulated seismic loading conditions are presented. Each test specimen modeled the interior joint of a moment-resisting frame consisting of H-shaped steel beams and circular or square concrete-filled steel tube (CFST) columns using high-strength blind bolts. In order to investigate the seismic behaviour of the blind bolted flush end plate joints to CFST columns, the hysteretic performance, failure modes, stiffness degradation and energy dissipation of the connection type are evaluated in detail. The test parameters varied included the column section type and the thickness of the end plate. The experimental results indicate that both the blind bolted connections with circular and square sections exhibited excellent hysteretic behaviour in terms of their moment–rotation response, strain distributions and energy dissipation. Under cyclic loading, all tested specimens displayed large rotation ductility capacities, and the failure modes were similar to those under monotonic loads. The effects of cyclic loading on the behaviour of the composite joint were obvious, especially on load bearing and stiffness of the connections. The joint type exhibited excellent seismic performance, so that it can be effectively utilized in moment-resisting composite frame structures.

1. Introduction

Concrete-filled steel tubes (CFST) have several structural and constructional benefits [1]. The steel tube provides confinement and thus increases the stiffness and strength of the concrete, and eliminates the use of formwork during construction. Meanwhile, the concrete reduces the possibility of local buckling of the tube wall. These advantages have been recognized and have led to CFST sections becoming efficient and economical as either column or bracing members in some tall buildings.

However, a practical difficulty arises for designers who attempt to employ on-site bolting in connections detailed to have a high degree of fixity to be used in moment-resisting frames [2]. A recently introduced system involves blind fasteners which are developed to be used in applications where access for installation is from one side of the connection only, as in the case of connecting the end plate of a beam to a tube column. In the context of structural engineering, the commercially available blind bolts include the Huck-high-strength blind bolt [3], Flowdrill [4], Lindapter Hollo-bolt [5], and the Ajax oneside bolt [6]. Each type of fastener differs in the bolt components, resistance mechanism and method of installation. Owing to the many advantages associated with hollow section steel members (HSS) including aesthetic appearance and economy in terms of material costs, the blind bolts were thus used in connections to HSS columns. Korol et al. [7] have studied the static behaviour and failure modes of the extended end plate connections to HSS columns with blind bolts under monotonic loads. Mourad et al. [8] have investigated the experimental behaviour of the blind bolted extended end plate connections for HSS columns under cyclic loading, and analyzed the effect of the joint flexibility on the response of the type of frame.

Presently, little effort has been devoted to studying steel beams connected to concrete-filled steel tubular (CFST) columns by the blind bolting technique. Tizani and Ridley-Ellis [9] reported the test results of the performance of three types of blind bolts compared with the standard dowel bolt when used in the T-stub bolted connections to concrete-filled steel tubular columns under tensile loading. Goldsworthy and Gardner [10,11] carried out a series

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doi:10.1016/j.jcsr.2008.12.008

List of notation

B	Width of square steel tube
b_f	Width of steel beam flange
CFST	Concrete-filled steel tube
D	Exterior diameter of circular steel tube
t	Thickness of steel tube
t_f	Thickness of steel beam flange
t_p	Thickness of end plate
t_w	Thickness of steel beam web
E_e	Total dissipated energy ability coefficient
f_{cu}	Compressive cube strength
f_y	Yield strength of steel material
H	Column length
h_b	Beam height
n	Axial load level, $n = N/N_u$
N_0	Axial load applied to the column
N_u	Axial compressive capacity of the column
M	Moment of the beam-to-column connection
M_u	Ultimate moment capacity of the beam-to-column connection
M_{bp}	Design plastic moment resistance of the beam
P	Load of the beam end
P_{y1}	Yielding load of the beam end
P_{y2}	Yielding load of the column wall
$P_{\max}$	Ultimate loading capacity of the beam end
P_u	Failure load of the beam end, $P_u = 0.85\ P_{\max}$
P_j^1	Maximum load of the beam end under the 1st loading cycle when number of cycles $\Delta/\Delta_y = j$
P_j^i	Maximum load of the beam end under the ith loading cycle when number of cycles $\Delta/\Delta_y = j$
P_j	Maximum load of the beam end under the jth loading cycle when number of cycles $\Delta/\Delta_y = j$
$P_{\max}$	Maximum load of the beam end in the whole test
u_j^i	Displacement of the beam end under the ith loading cycle when number of cycles $\Delta/\Delta_y = j$
K_j	Ringed rigidity of joint
K_{ie}	Initial stiffness of connection, defined as the scant flexural stiffness corresponding to 20% M_u in moment–rotation curves
K_{se}	Service-level stiffness of connection, defined as scant flexural stiffness corresponding to 60% M_u in moment–rotation curves
θ_r	Connection rotation
θ_y	Elastic yielding angular displacement
θ_u	Elastic–plastic angular displacement
$[\theta_e]$	Elastic layer angular displacement
$[\theta_p]$	Elastic–plastic layer angular displacement
μ	Displacement ductility coefficient
μ_θ	Angular displacement ductility coefficient
W	Dissipated energy in each cycle
W_{total}	Total dissipated energy
ξ_e	Equivalent damping coefficient
E_e	Factor of dissipated energy
Δ	Displacement of the beam end
Δ_{y1}	Displacement of the beam end according to P_{y1}
Δ_{y2}	Displacement of the beam end according to P_{y2}
$\Delta_{\max}$	Displacement of the beam end according to $P_{\max}$
Δ_u	Displacement of the beam end according to P_u
Δ/Δ_y	Number of cycles
λ_i	Strength degradation coefficient at the same loads
λ_j	Strength degradation coefficient at the total loads

of cyclic tension experiments on a T-type element consisting of an end plate and a fan-shaped horizontal web-plate, which are attached to the CFST column by blind bolts. They investigated the use of extensions to blind bolts and the stiffness of a T-type element. France et al. [12,13] conducted a series of joint tests under monotonic loading to investigate the moment capacity and rotational stiffness of end plate connections to concrete-filled tubular columns with flow drill connectors. In order to investigate the effects of shear connection and reinforcement ratio in composite joints, Loh et al. [15] reported an experimental study on connections using blind bolting of flush end plates to CFST columns with square sections. Wang et al. [16,17] conducted an experimental program involving four sub-assemblages of cruciform beam-to-column joints of circular or square concrete filled steel tube columns and H-shaped steel beams using Hollo-bolts subjected to monotonic loading. Table 1 presents the details of some of these existing experiments of blind bolted joints to CFST columns.

Scant attention has been paid to considering the seismic behaviour of blind bolted connections to CFST columns. Wang et al. [16,17] studied a type of connection for CFST columns, which was constructed using an approach of a flush end plate to circular or square concrete-filled hollow columns with blind bolts. Specially, a novel curved flush end plate joint to circular concrete-filled hollow columns with blind bolts was reported in Ref. [16,17]. In order to investigate the seismic behaviour of this type of blind bolted flush end plate joint, the hysteretic performance, failure modes, stiffness degradation and energy dissipation of the type of connection was evaluated in detail in this paper. The test parameters varied were the column section type and the thickness of the end plate. The test results indicate that the joint type exhibits excellent seismic performance, so it can be effectively used in the moment resistance of composite frame structures.

2. Experimental design

2.1. Design of specimens

The test specimens were constructed in a cruciform shape to simulate the internal region of a frame. Four cruciform beam-to-column connections were tested under symmetrical loading. Table 2 summarises the details of the specimens. Fig. 1 provides the design details of the beam-to-column connections. The columns for specimen CJD1 and CJD2 are concrete-filled square steel tubes with a cross-section $200 \times 200 \times 8$ mm; the columns for specimens CJD3 and CJD4 are concrete-filled circular steel tubes with cross-section 219×8 mm. Meanwhile, the beams are commercial H-shaped steel sections of a cross-section HN$300 \times 150 \times 6.5 \times 9$ mm for all test specimens. In order to shift the plastic zone away from the column face, triangular plates were attached to the flange of the beam by complete penetration butt welds. Moreover, the end of the beam flange was further strengthened by welded triangular plates, which were welded to the end plate in Fig. 1. Yield stress and elongation percentage of the material of triangular plates used in reinforcing the beam ends are the same as those of the steel beams, seen in Table 3.

The flush end plate type connections were adopted by using Hollo-bolt blind bolts [18] to connect the steel beams to CFST columns. The blind bolts were drawn into contact with the body and the legs were expanded and clamped against the side of the hole, when they were tightened (illustrated in Fig. 2). More details of the bolts can be found in [18]. The Hollo-bolts used in the tests was Grade 8.8 M16, which was a nominal ultimate and yield stress of 800 N/mm^2 and 640 N/mm^2 respectively. These bolts were tightened to 190 Nm torque following the British Tubes and Pipes Specification [19]. In the experimental program, the column section type and the thickness of the end plate were the parameters varied. The experimental setup photo is shown in Fig. 3.