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Experimental behaviour of steel reduced beam section to concrete-filled circular hollow section column connections

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Abstract

In this paper, five specimens of connections of reduced beam section (RBS) steel beam to concrete-filled steel tubular (CFST) circular hollow section (CHS) column using an external ring were tested. The experiments considered the hysteretic behaviour under combined constant axial load and cyclic lateral load. For comparison, three specimens of a weak-column without an RBS configuration steel beam to CFST column connection were tested under the same conditions. The axial load level of the CFST column, width of connection stiffening ring and RBS configuration were considered as the experimental parameters of their seismic behaviour. It was found that the lateral load (P) versus lateral deformation (Δ) hysteresis curves exhibited no obvious strength deterioration and stiffness degradation. The energy dissipation of the RBS connections is significantly improved when compared with weak-column connections. The concrete filled CHS columns failed as a weak-column connection and their energy dissipation capacity was reduced. It can be concluded that the RBS connections exhibit good seismic performance.

Keywords: Concrete; Connections; Ductility; Energy dissipation; Reduced beam section (RBS); Seismic behaviour; Steel; Steel beam

1. Introduction

In a real building structure, connections play a key role for a structure in determining whether or not a structure will reach its theoretical ultimate load, because plastic hinges are usually formed at the location of two or more members.

A conventional type of moment-resisting connection, which consists of a concrete-filled steel tubular (CFST) column and a steel beam, shown in Fig. 1, is widely used in tall buildings and has been investigated by a large number of researchers (e.g. Alostaz and Schneider [1]; Azizinamini and Schneider [2]; Schneider and Alostaz [3]). However, in practice in China, it was found that the ring width of this type of connection designed according to the regulations of the Japanese Code AIJ [4] or the Chinese Code DBJ13-51-2003 [5] is too large to be adopted, because it is difficult to incorporate the large ring plate, particularly for CFST columns with a sectional size exceeding 500 mm. A reasonable width of the outside ring of this type of connection is of concern to engineers. Thus, a smaller dimension of the connection is desirable and advantageous for construction [6].

The reduced beam section (RBS) moment connection for structural steel was based on the recommended configuration of the AISC *Seismic Provisions for Structural Steel Buildings* [7]. In a reduced beam section (RBS) moment connection, portions of the beam flanges are selectively trimmed in the region adjacent to the beam-to-column connection. In an RBS connection, yielding and hinge formation are intended to occur primarily within the reduced section of the beam, and thereby limit the moment and inelastic deformation demands developed at the face of the column [8]. A review of the research literature indicates that a large number of RBS connections have been tested under a variety of conditions by different investigators at institutions throughout the world, such as Chambers et al. [9], Chen et al. [10], Chen and Chao [11], Jin et al. [12], etc.

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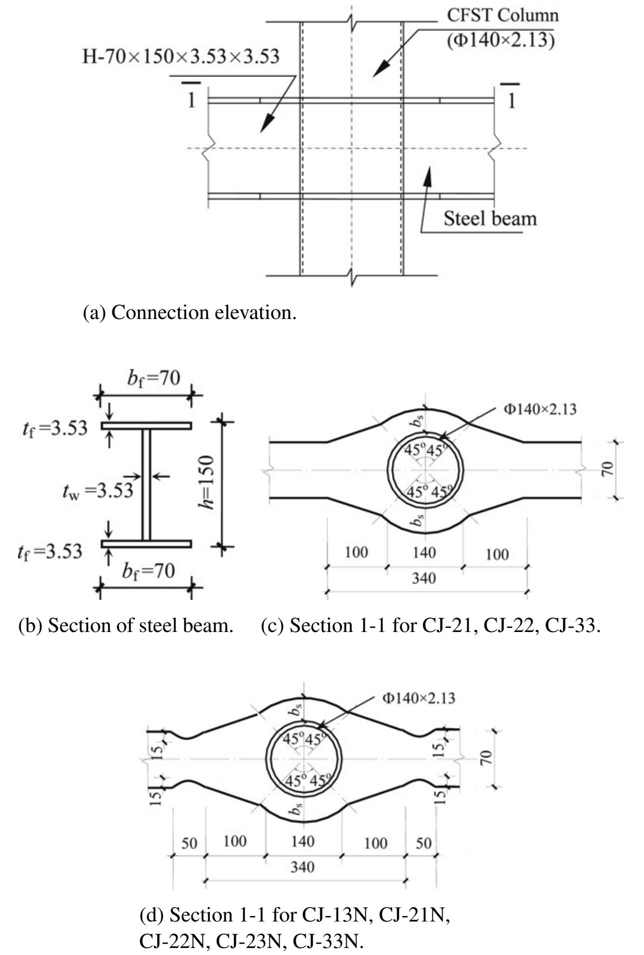
Notations

A_s	Steel cross-sectional area
A_c	Concrete cross-sectional area
b_f	Overall width of I-beam
D	Sectional dimension of steel tube
E	Dissipated energy ability
E_c	Concrete modulus of elasticity
E_s	Steel modulus of elasticity
f_{cu}	Concrete cube strength
f_{sy}	Yield strength of steel
f_u	Ultimate strength of steel
h	Overall height of I-beam
h_e	Equivalent damping coefficient
H	Height of column of the connection
k	Beam to column linear stiffness ratio
K_j	Lateral rigidity of connection
L	Length of beam of connection
n	Axial load level ($n = N_0/N_u$)
N_0	Axial load of CFST column
N_u	Ultimate compressive resistance of CFST column
P	Lateral load of connection
P_u	Estimated ultimate lateral load capacity of connection
P_{ue}	Ultimate lateral load capacity of connection by experiment
P_y	Yield lateral load capacity of connection
SCC	Self-Consolidating Concrete
t_f	Flange thickness of I-beam
t_s	Wall thickness of the steel tube
t_w	Web thickness of I-beam
α	Steel ratio ($\alpha = A_s/A_c$)
ε_y	Yield strain
ν_s	Poisson's ratio of steel
ν_c	Poisson's ratio of concrete
Δ	Lateral displacement of connection
Δ_y	Yield displacement of connection
Δ_u	Lateral displacement when lateral load of connection falls to 85% of P_{ue}
μ	Displacement ductility coefficient

A significant amount of testing on RBS connections was also conducted under the FEMA/SAC program [13]. Most RBS connection test specimens of structural steel have been tested pseudo-statically, using a loading protocol in which applied displacements are progressively increased, such as the loading protocol specified in ATC-24 [14]. However, few RBS beam to CFST column connections have been tested under pseudo-static loading.

This paper provides new test data pertaining to the behaviour of steel RBS beam to CFST column connections using an external ring. Each connection was modeled as an internal joint from a planar frame. The eight connection specimens with circular cross-sections were tested under a constant axial load and a cyclically increasing flexural load. Five RBS connections to CFST columns were tested and three normal connections



(a) Connection elevation.
(b) Section of steel beam. (c) Section 1-1 for CJ-21, CJ-22, CJ-33.
(d) Section 1-1 for CJ-13N, CJ-21N, CJ-22N, CJ-23N, CJ-33N.

Fig. 1. Connection configuration (Unit: mm).

with weak-column specimens were considered for comparison. The test parameters included the width of ring, the axial load level and the configuration of the RBS. There were three types of connection specimens used to compare their mechanical performance for different ring widths. It was shown that the energy dissipation capacity of RBS connections are much improved, when compared with the weak-column connections. The axial load level of the column has an effect on the strength and seismic behaviour of the connections. With an increase in the axial load level of the column, the lateral ultimate strength of the connections reduces, and the displacement ductility and the capacity of energy dissipation also reduce. It can be concluded that the RBS to CFST column connection has reasonable seismic performance. The work in this paper provides a basis for further development of a theoretical model, which will be described in another paper, and will help to establish an approach to calculate the strength and overall behaviour of these types of connections.

2. Experimental program

2.1. General

Eight connection specimens of steel beam to CFST column using an external ring with circular cross-section, were tested