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Finite element modelling of blind bolted composite joints

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ABSTRACT

This paper aims to develop a detailed three-dimensional finite element model to study the behaviour of blind bolted endplate composite joints that connect composite beams to a concrete filled steel tubular column. All connection components such as steel beam, profiled sheeting, shear stud, endplate, blind bolt, concrete infill, concrete slab, hollow steel column and reinforcing bars were separately modelled using shell, solid and truss elements. The obtained predictions of the moment–rotation curve and failure mode were compared with experimental results and a very good agreement was established. In addition, an analytical model for predicting the moment–rotation response of composite joints up to failure was also presented based on the component method. Finally, extensive parametric studies were carried out to investigate the influences of shear studs and reinforcement ratio, blind bolt types and diameters, column sections and thickness ratios on the joint performance.

1. Introduction

Due to their excellent seismic performance such as high strength, high ductility and large energy absorption capability, concrete-filled steel tubular (CFST) structures have been increasingly used in multi-storey buildings. In these framed building structures, the bolted endplate joints have been favourably used in construction practice to connect composite beams to a CFST column because of the simplicity and economy of their fabrication and assembly. These joints may be either flush or extended endplate types depending mainly on their strength and stiffness requirements. A typical bolted endplate joint consists of the endplate welded to the end of the steel beam. This assembly is then connected to either open section columns using standard bolts or CFST and hollow section columns using the blind bolts which can be installed from the outer side of the steel tube.

The behaviour of bolted endplate composite joints has been extensively investigated via experimental tests [1–11], finite element (FE) simulations [10–12] and analytical approaches [5,7,13,14]. However, these studies were limited to conventional composite joints in which the standard bolts were used to connect the steel beams to the open section column. The studies on the behaviour of the composite joints connecting the steel beams to CFST columns using the blind bolting technique were still limited. Loh et al. [15] carried out a series of tests on flush endplate composite joints with Hollo-bolt to study the effects of partial shear connection and reinforcement ratio on composite joints. They concluded that the degree of shear connection has a significant effect on the behaviour and rotational capacity of composite joints. The behaviour of composite joints with oneside Ajax bolts subjected to low-probability, high-consequence loading was examined experimentally by Mirza et al. [16] and numerically by Mirza and Uy [17]. Numerical studies on the semi-rigid behaviour of blind bolted composite joints were recently conducted by Ataei et al. [18] to develop moment–rotation models that can be used in advanced analysis and design of composite framed structures.

Although experimental and numerical studies involving blind bolted composite joints have been carried out [15–18], no effort has been devoted to investigating the influences of column sections and different types of blind bolts. Therefore, the main objective of this paper is to develop a reliable FE model to further investigate the effects of column sections and different types of blind bolts on the joint behaviour. All joint components and the interaction between them were taken into account in the modelling to achieve reliable results. Since the geometry of the tightened Hollo-bolt is quite different with that of the standard bolt and oneside Ajax bolt, the Hollo-bolt was carefully modelled as close to its real shape as possible. To avoid numerical convergence difficulties caused in large deformation and complex contact problems, the explicit solver provided by the general commercial code ABAQUS was used. The bolt pretension was also included using the initial temperature approach. The validity of the developed FE model was also verified.

2. Description of composite joints

Four cruciform beam-to-column joints tested by Loh et al. [15] were considered in this study. The joints, which were designed to simulate the internal regions of a typical composite frame, consist of two composite beams connected to a CFST column using eight Hollo-bolts and two flush endplates. The detailed layout and geometric dimension of the specimens were shown in Fig. 1 and Table 1. All specimens are similar with respect to the steel beam, concrete slab, blind bolts,

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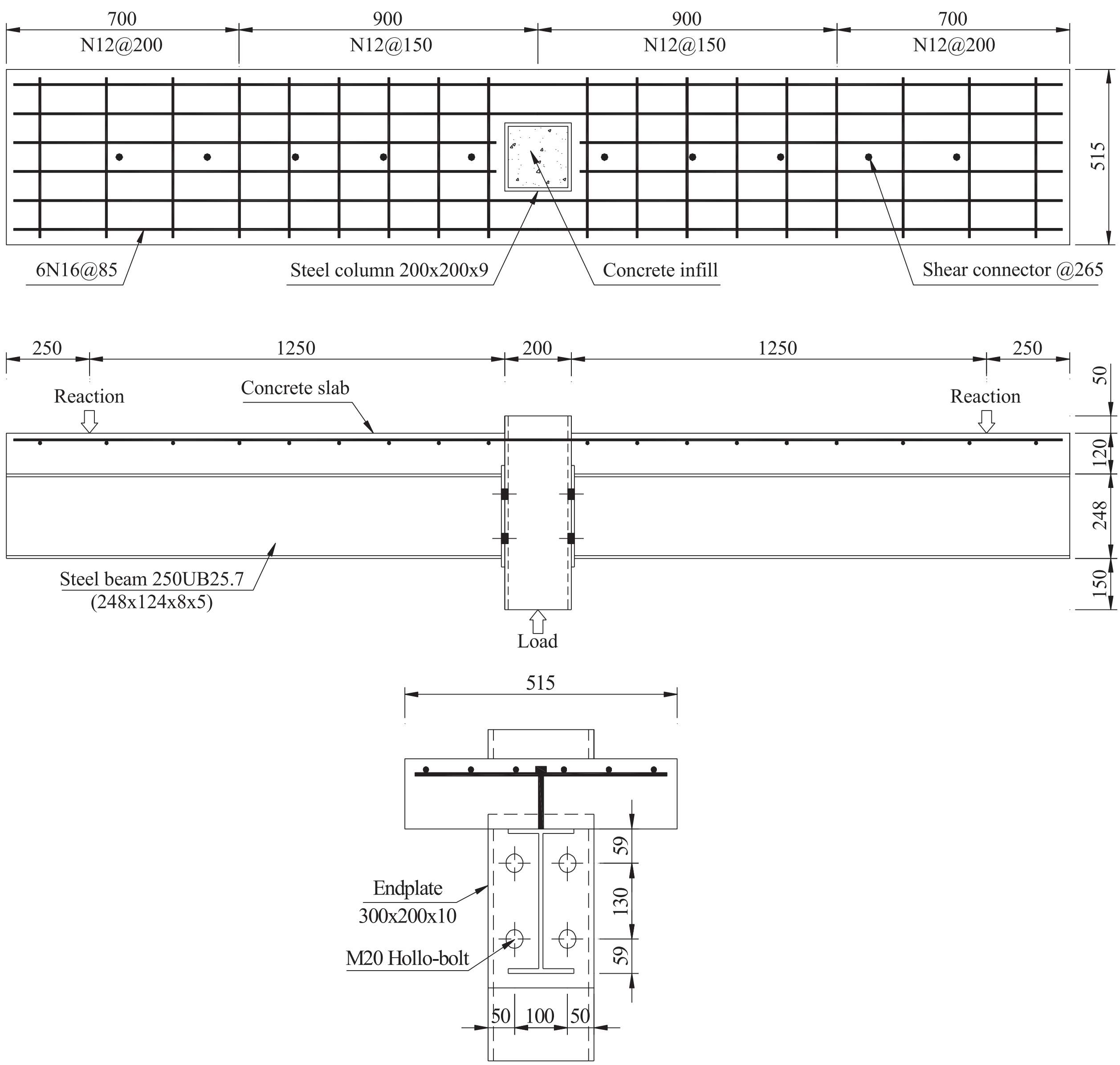

Fig. 1. Configuration details of specimen CJ1 tested by Loh et al. [15].

endplates and CFST columns. They were designed to vary the degree of shear connection and reinforcement ratio. The composite joints were inverted with the concrete slab facing down and the vertical load was applied to the CFST column. The specimens were loaded using a hydraulic actuator of 500 kN with an available stroke of 250 mm. The loading rate was set to 0.4 mm/min in the linear elastic range and subsequently increased to 1.0 mm/min in the nonlinear range towards the failure [15].

Table 1
Summary of specimens tested by Loh et al. [15].

Specimens	CJ1	CJ2	CJ3	CJ4
Reinforcing bars (ratio, %)	4ϕ16 (1.29)	4ϕ16 (1.29)	4ϕ16 (1.29)	2ϕ16 (0.65)
Number of stud	5	3	2	3
Spacing of stud (mm)	265	480	800	480
First stud from column face (mm)	100	140	300	140
Degree of shear connection (%)	110	66	44	133
Headed stud size	ϕ19 × 100 mm			
Concrete slab thickness	120 mm			
Hollo-bolt	M20 grade 8.8			
Bondek sheeting	3200 × 515 × 1 mm			
Steel column	200 × 200 × 9 mm			
Steel beam	250UB25.7 (248 × 124 × 8 × 5 mm)			
Flush endplate	300 × 200 × 10 mm			

3. Finite element model

Due to the symmetry of geometry and loading, only half of the joint was modelled. Unlike any other blind bolts, the geometries of the Hollo-bolt before and after tightening are completely different as shown in Fig. 2. This difference can provide more tensile resistances in the Hollo-bolted joints compared to other blind bolted joints if the tubular column was filled with concrete [19]. Therefore, the geometry of the Hollo-bolt was carefully modelled as in Fig. 2(c) to achieve an acceptable level of accuracy. An outline of the FE model of the CJ1 specimen was shown in Fig. 3.

There are two different solution strategies in ABAQUS: the implicit and the explicit solvers. The comparison between the implicit and explicit solvers has been carried out by Van der Vegte and Makino