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Structural Behaviour of Beam to Concrete-filled Elliptical Steel Tubular Column Connections

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ABSTRACT

Elliptical hollow sections (EHSs) have been utilized in construction recently because of their visual appearance as well as the potential structural efficiency owing to the presence of the two principle axes. However, little information currently exists for the design of beam to elliptical column connections, which is an essential part of a building structure. Thus, to ensure the safe and economic application of EHSs, a new research project has been initiated. Rotation behaviour of simply bolted beam to concrete-filled elliptical steel column connections was investigated experimentally. Various joint types were considered and the benefits of adopting core concrete and stiffeners were highlighted. This paper covers the experimental studies and simulation of the connections using the ABAQUS standard solver. Comparisons of failure modes and moment vs. rotation relationships of the connections between numerical and experimental results were given. Good agreement has been obtained and the developed finite element model was therefore adopted to conduct a preliminary parametric study to explore the effect of critical parameters on the structural behaviour of beam to concrete-filled elliptical column connections.

1. Introduction

Concrete-Filled Steel Tubular (CFST) columns are well-known for their superior structural properties due to the mutual complementation of the steel tube and the concrete core. The most common cross-sectional shapes of CFST columns are circular, square and rectangular. A new range of elliptical hollow sections (EHSs) has been made available recently by the manufacturing industry, which adds diversity to the sectional shape and fulfils the aesthetics demand by designers. However, limited information exists to enable safe and economic design of EHS components/connections in structures, which might limit its widespread application. Efforts have been made on investigating the structural behaviour of elliptical columns [1,2], beams [3], welded truss EHS connections [4,5]. Zhao and Packer [1] experimentally investigated both unfilled and concrete-filled EHS stub columns filled with normal concrete and self-consolidating concrete. According to the obtained results, they derived the yield slenderness limit which is used to identify occurrence of local buckling of steel hollow sections subjected to axial compressive force for carbon steel EHS based on the equivalent rectangular hollow sections (RHS). They also extended the above concept and method to predict the load carrying capacity of concrete-filled EHS stub columns and good prediction was generated by using procedures in Eurocode 4. Dai and Lam [2] investigated the axial compressive behaviour of short concrete-filled EHS columns by using ABAQUS finite element analyzing (FEA) software and an improved confined concrete stress-strain model was proposed for concrete-filled EHS stub columns. Typical failure modes, static bearing capacities and load versus end shortening relationships of the composite stub columns obtained by the finite element analysis were verified against experimental observations. The comparison and analysis indicated the FEA method was reliable in prediction the basic structural behaviour of concrete-filled EHS stub columns under compression. Static strength of axially loaded EHS X-joints with brace members welded to the narrow sides of the EHSs has been studied experimentally and numerically by Shen

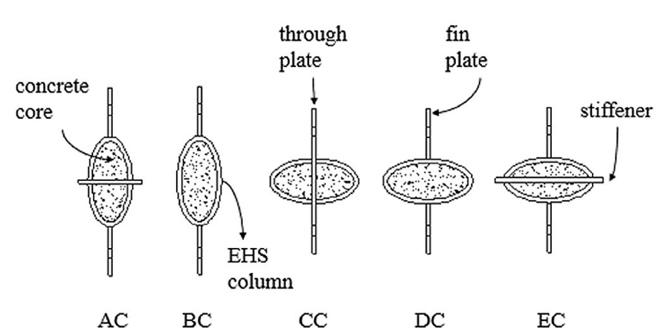

Fig. 1. Joint types.

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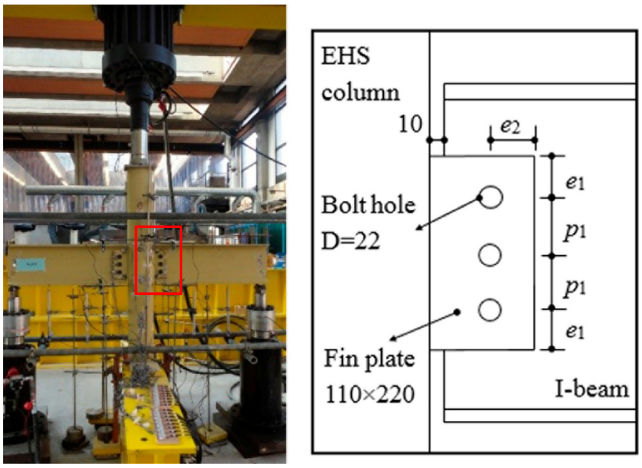

Fig. 2. Test arrangements & Planed connection dimensions ($e_1 = 50$, $e_2 = 50$, $p_1 = 60$; mm).

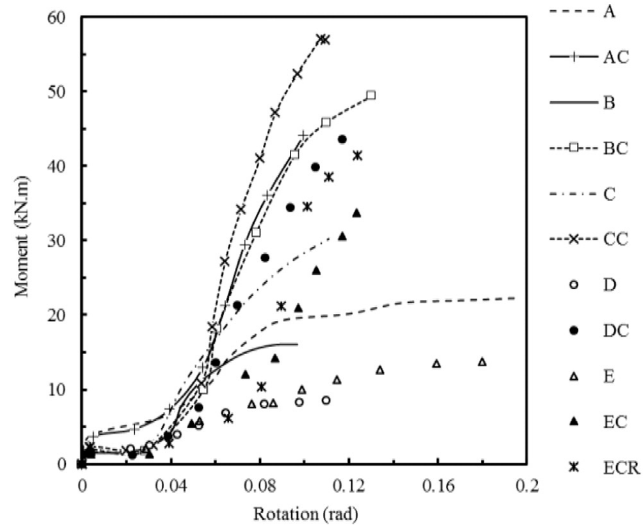

Fig. 3. Summarized moment vs. rotation relationships.

et al. [4]. In their study, both brace member compression tests and tension tests were performed. They found that this type of EHS X-joint could be related to relevant circular hollow section X-joints. Despite the above mentioned attempts of investigation on EHS and those not specified provided herein, large gaps still exist in research. Beam to concrete-filled elliptical column connections, which are essential in framed structures, remain unfamiliar to designers. The fabrication of such connections could be complicated and cumbersome owing to the curved face of the column. Fin plate connections have been widely adopted owing to the merits of easier erection, rapid construction and lower cost. Jones [6] studied the behaviour of single-sided fin plate to steel tubular columns loaded by tensile and shear force. Parameters including column cross-section shape (CHS and RHS), column and fin plate thickness, concrete infill, elevated temperatures and lever arm were considered. In this study, failure modes including fracture of the fin plate and tearing out of the tube around the welds were observed, deformation limit of 3% of the tube width for hollow tubes in CIDECT Guide was re-evaluated and proved to be inadequate to extract the ultimate strength of the connections. In addition, concrete infill was observed to significantly increase the capacity of connections over empty ones and specimens with CHS were found to have greater strength than similarly proportioned RHS ones. However, this study only focus on isolated fin plate with column connections regardless of bolts that linking beams to the connections and also the moment behaviour of the connections was not explored especially when large beam rotation occurred. A series of double-sided fin plate beam-column connections considering different joint assemblies was investigated by Lam & Dai [7] through a numerical modeling technique, aiming to investigate their moment-rotation behaviour. Connections with and without concrete core and stiffener plates were studied. The studied joint types are illustrated in Fig. 1, from type-AC to DC. An experimental study [8] was carried out to verify the obtained preliminary findings and also to provide better understanding of the structural behaviour of these joints, including an additional joint type-EC (Fig. 1, EC) which considered an embedded stiffener plate in the major axis direction of the EHS column. Corresponding connections with EHS columns, i.e. without concrete infill, were also tested to highlight the benefit of using the concrete infill. This paper herein presents the experimental program and details of a finite element (FE) model for the simulation of the experiments on concrete-filled joints. Preliminary parametric numerical results based on the verified FE model are given to highlight the effect of critical parameters on the structural behaviour of beam to concrete-filled elliptical column connections.

2. Description of experimental program

2.1. Test arrangements

Details of the experiments can be found in the previous paper [8], so only a brief summary is given in this section. A total of ten specimens (of which five are connections with a concrete core in the column and the other five are corresponding to hollow connections) were tested to failure with the column under a constant downward compressive force and the beams subjected to upward concentrated forces at the beam ends, replacing the slab-floor load that would occur in a real structure. Three hydraulic actuators were employed to exert these forces. Test arrangement and a typical beam to elliptical column specimen is shown in Fig. 2 in which some dimensions of the connection are also illustrated.

Table 1
Mean measured dimensions of EHS columns (mm).

Specimen ID	$2a \times 2b \times t$ (mm × mm × mm)	L (mm)
Joint-A	198.43 × 99.52 × 5.05	1500
Joint-AC	198.60 × 101.89 × 4.97	1499
Joint-B	200.01 × 101.51 × 4.92	1487
Joint-BC	198.47 × 101.57 × 5.01	1498
Joint-C	198.50 × 100.50 × 4.88	1498
Joint-CC	198.21 × 101.42 × 5.02	1498
Joint-D	197.78 × 102.03 × 4.54	1497
Joint-DC	198.50 × 101.62 × 5.05	1500
Joint-E	197.82 × 102.10 × 4.75	1495
Joint-EC	198.11 × 101.58 × 5.17	1495

Table 2
Failure moment and corresponding rotation.

Specimen ID	Failure moment (kN·m)	Rotation (rad)	M_{filled}/M_{hollow}
Joint-A	22.3	0.20	/
Joint-AC	43.8	0.11	1.96
Joint-B	16.0	0.10	/
Joint-BC	49.6	0.12	3.10
Joint-C	30.0	0.11	/
Joint-CC	57.2	0.11	1.91
Joint-D	8.4	0.12	/
Joint-DC	43.6	0.11	5.19
Joint-E	13.3	0.18	/
Joint-EC	33.8	0.13	2.54
Joint-ECR	41.4	0.13	3.11

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