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Experimental study of beam to concrete-filled elliptical steel tubular column connections

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A B S T R A C T

This paper investigated the rotation behavior of simply bolted I-beam to concrete-filled elliptical steel tubular (CFEST) column connections experimentally. Ten different joint assemblies were tested to failure, with a constant axial compressive load applied to the column and upwards concentrated loads at the beam ends. All of the steel tubes were hot-finished and had a cross-sectional aspect ratio of 2. The orientation of the column and the arrangement of the stiffening plates were taken into consideration. Moment versus rotation relationships and failure modes were compared for each joint, highlighting the benefits of using core concrete and stiffeners in these connections.

1. Introduction

Concrete-filled steel tubular columns (CFST) are widely used in frame structures owing to their superior structural performance. The CFST column is an optimum combination of different materials, steel and concrete. With the confinement effect provided by the steel tube, the core concrete will obtain higher strength, while in turn, the concrete may eliminate or delay the commencement of local buckling in the steel tube. Additionally, the outer steel tube could be the formwork when casting concrete, which is more economic compared with reinforced concrete and enables rapid construction.

The most common cross-sectional shapes of CFST columns until now have been circular, square and rectangular. Only recently did a new range of elliptical hollow sections (EHSs) become available in the manufacturing industry and subsequently be introduced into building structures. The sectional sizes of EHSs range from $120 \times 60 \times 3.2$ mm up to $500 \times 250 \times 16$ mm in Grade S355J2H and the minimum yield strength is 355 MPa [1]. The EHS not only has a varied and interesting appearance which fulfils the esthetic purpose in design, but also provides potential structural efficiency. With two different principal axes, it has better bending capacity compared with a circular hollow section (CHS) of the same area or weight [2]; its closed shape offers high torsional stiffness [3] and high resistance to lateral torsional buckling [4].

With the merits mentioned above, EHS has been applied in several cases, e.g. Heathrow Airport in London and Society Bridge in Scotland. However, there is a lack of appropriate design rules to ensure the safety and economy of utilizing EHS in construction, which hinders its widespread application. Currently, existing research has focused on the behavior of hollow EHSs [5,6] and concrete-filled EHSs [7–10]. However, these investigations did not involve the interaction between members in a connection.

The first experiment on welded EHS tubular joints dates back to 2003; Bortolotti et al. [11] and Pietrapertosa and Jaspart [12] tested the brace-to-chord N- and X-joints where the brace was welded on the wide side of the EHS chord. Choo et al. [13] then furthered the study based on experimental results of welded EHS X-connections covering a wider range of variables through numerical analysis. It is concluded that with appropriate EHS orientation, axially loaded EHS connections can achieve higher capacities than equivalent CHS connections with the same brace and chord sectional areas. Willibald et al. [14] investigated the behavior of gusset–plate connections to EHSs where the branch/through plate was arranged in either the longitudinal or transverse direction of the EHS steel tube; and was connected on the wide/narrow side of the EHS. It is found that the yield strength of the through plate connection is approximately twice that of the branch plate connection or more. Connections with composite tubular columns have also been studied based on varied connection types and loading conditions. Elremaily and Azizinamimi [15] conducted laboratory tests on through beam connections under monotonic loading with the beam web attached to the web cleat plate

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through both fabrication bolts and fillet welds. Wang et al. [16,17] investigated the static and hysteretic behavior of flush end plate joints to CFST columns using high strength blind bolts. Cheng et al. [18] reported static behavior of CFST connections with square columns stiffened with internal diaphragms. Han and Li [19] tested connections with a reinforced concrete (RC) slab reinforced by an external ring, under seismic loading; Song and Han [20] provided a numerical investigation on the post-fire behavior of such CFST connections. However, the fabrication of these connection types is always complicated and time-consuming. And it is even more difficult to repeat the investigations for connections with EHSs due to the complexity of geometry. Lam and Dai [21] conducted a numerical study using an ABAQUS solver on four types of easy-to-construct beam to elliptical column connections. The effect of some important parameters on the structural behavior of the connections was observed.

This paper follows on from the above numerical study and starts to explore the behavior of simply bolted I-beam to concrete-filled elliptical column connections experimentally, employing either fin plates or a through plate. The aim is to eventually find out solutions to these kinds of connections for design. Several joint configurations, with or without concrete core/stiffening plates in the columns, were taken into consideration. A total of 10 specimens were tested to failure with the columns bending in the major or minor axis direction. The moment versus rotation relationships and failure modes of 10 specimens were addressed and analysed; the effect of core concrete and stiffening plates on bending behavior of simply bolted beam to elliptical column connections was highlighted.

2. Experimental study

2.1. Specimen types and details

Of all the specimens, five different joint assemblies (named after Type-A, -B, -C, -D, and -E) have been considered, as illustrated in Fig. 1. Each type of assembly comprised one specimen with a hollow EHS column and another specimen with an EHS column filled with concrete, to explore the enhancement of concrete infill on the structural behavior of these joints. All EHS columns were manufactured from Grade S355 steel with a minimum yield strength of 355 MPa. Due to the different axes of the EHS tube, two configurations of joint can be obtained as shown by Type-B and Type-D joints. As it is difficult to arrange stiffeners in both major and minor axis directions, only one stiffener plate is adopted for each joint, as seen in Type-A and Type-E connections. For minor axis connection Type-C, a through plate, functioning as both fin plate and stiffener, is adopted to ensure the continuous stiffness of the joint. The five joint assemblies are described as follows:

Type-A: Major axis connection with stiffener

Two fin plates (220 × 110 × 10 mm) in the major axis direction and a stiffener plate (220 × 140 × 10 mm) in the minor axis direction.

Type-B: Major axis connection without stiffener

Two fin plates (220 × 110 × 10 mm) in the major axis direction and no stiffener plate.

Type-C: Minor axis through plate connection

A whole plate (220 × 320 × 10 mm) through the column function as both fin plate and stiffener plate in the minor axis direction.

Type-D: Minor axis connection without stiffener

Two fin plates (220 × 110 × 10 mm) in the minor axis direction and no stiffener plate.

Type-E: Minor axis connection with stiffener

Two fin plates (220 × 110 × 10 mm) in the minor axis direction and a stiffener plate (220 × 140 × 10 mm) in the major axis direction.

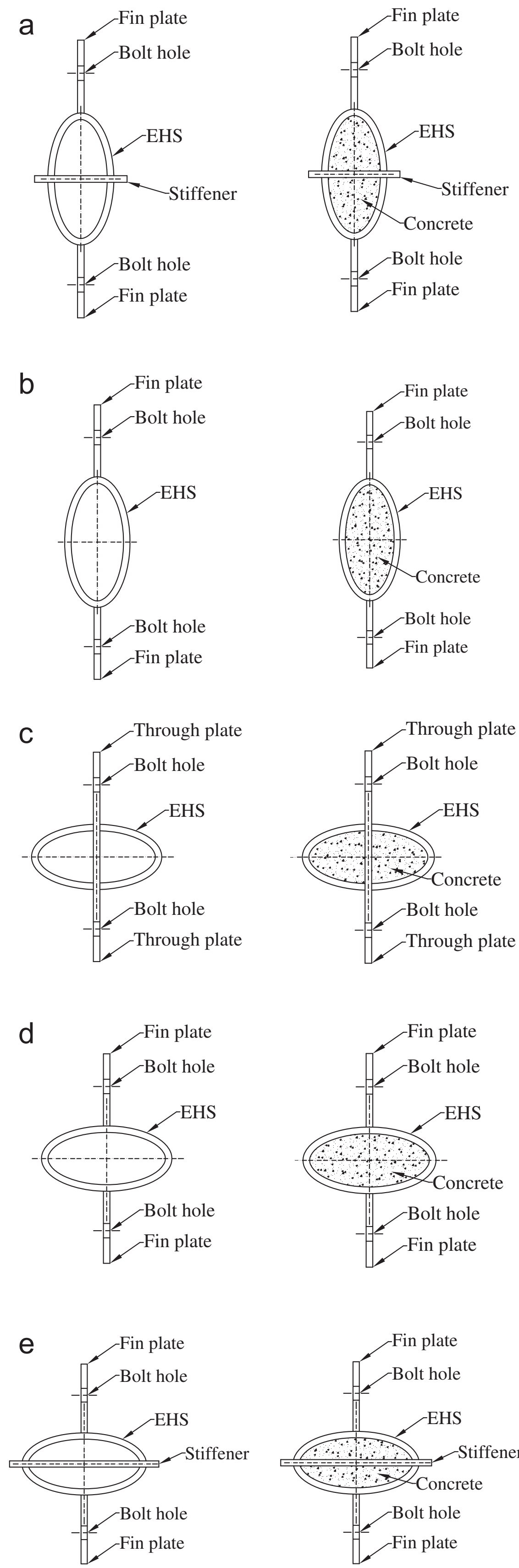

Fig. 1. Joint assemblies (cross-sectional view): (a) Type-A: major axis connection with stiffener; (b) Type-B: major axis connection without stiffener; (c) Type-C: minor axis through plate connection; (d) Type-D: minor axis connection without stiffener and (e) Type-E: minor axis connection with stiffener.