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An innovative I-beam to hybrid fabricated column connection: Experimental investigation

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ABSTRACT

Hybrid fabricated columns (HFCs) have been investigated by researchers during the past two decades. Many researchers have reported higher load-bearing capacity, post-buckling strength and better energy absorption as the main advantages of this type of column compared to other structural sections. This provides an opportunity for the construction industry and designers to utilise these superior properties in building more reliable structures. However, no matter how capable and reliable a column is, it still needs a robust connection to make the use of this column in construction viable. Since the topic of connections between these columns and I-beams has been untouched, the authors decided to study this knowledge gap. In this research, a new generation of modular connections is proposed by the authors, referred to hereafter as M-HFC. The performance of this connection has been tested experimentally. In addition, a three-dimensional finite element model has been developed to simulate the behaviour of the connection. The results show that this connection is a fully resistant and semi-rigid connection according to the standard classifications, which makes it a good choice for use in moment frames.

1. Introduction

Today's construction industry demands structural members with very high capacity. Cold-formed sections, such as rectangular or circular hollow sections, which are currently available in the market, have limitations on the member dimensions [1–5]. On the other hand, fabricated sections appear to have the capacity of meeting these higher demands. Considering the closed profile of the fabricated members, additional stresses resulting from special loading cases such as torsion, warping and biaxial moments are less of an issue, while these stresses can lead to the reduced load-bearing capacity of open sections [6]. The concept of hybrid sections composed of thin plates and tubes welded together to form a closed section was first studied by Aoki [7]. In this research, stub columns with triangular cross-sections were fabricated by welding three plates to three tubes at each apex and tested under uniform and eccentric compressive loading. It was found that the capacity of the stub columns was far greater than the sum of the individual member's capacities. Numerous researchers have worked on this concept and have made considerable developments in terms of finding the behaviour of the new configuration of fabricated columns under different loading conditions, materials, and temperatures using experimental and numerical methods [8–16].

Based on the previous research, the greater load-bearing capacity, post-buckling strength, ductility, and energy dissipation of hybrid fabricated columns make them suitable for use in moment-resisting frames. However, although they possess the aforementioned advantages, the development of suitable beam-to-fabricated column connections is challenging.

The difficulty of access to the internal space of the hollow columns can result in reluctance in using bolted connections for hollow columns. However, different methods, including blind bolting systems such as Flowdrill, Hollobolt, and ONESIDE, have been developed in order to resolve this issue [17–27]. On the other hand, while the majority of conventional steel frames are constructed using welded connections, on-site welding errors, and labour costs make using bolted connections more appealing.

In addition to research on beam to I-shaped column end-plate connections, particular studies have focused on this type of connection between I-beam to rectangular hollow sections. For example, Ghobarah et al. investigated this connection with high-strength bolts and blind bolts [28]. Later, they proposed a design procedure together with an analytical moment-rotation relationship for extended end-plate connections to hollow rectangular sections [29]. A design guide for bolted end-plate

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connections for hollow rectangular sections [30] and a finite element (FE) model for the design of bolted hollow structural sections joints [31] have been proposed by Wheeler et al. Achieving a full-resistance connection by attaching the connection directly to the rectangular column face usually needs local strengthening of the face. One of the methods used is locally thickening the face using a special procedure invented in Japan [32]. However, without stiffening of the hollow section column face, deformation of the flexible column face may be the governing failure mode, irrespective of the type of fastener used [20].

Moment-frame connections with traditional welded or bolted connection were extensively used from the 1960s to the early 1990s due to the belief that they can show enough ductility. After the Northridge, California earthquake (January 17, 1994) this belief came under scrutiny as a result of the brittle fracture observed in nearly 150 buildings [33]. A 5-year investigation was initiated by FEMA[1] to discover the causes and find the required solutions. Design recommendations and state-of-the-art reports were published in 2000 [34]. In spite of the extent of studies that have been carried out, which have led to several new connection details being proposed for the connection of I-beams to wide flange columns since the 1994 Northridge earthquake, research on the connection of I-beams to box columns has been limited [35]. Since box columns have not been a common choice for construction (particularly in the US) the pre-qualified connections for these columns are very limited [36]. Therefore, the lack of a suitable connection that can be used in practice has encouraged researchers to propose different types of connection between I-beams and rectangular tubular columns using structural components such as plates, angles, and tees. Efforts to improve the connections have not been limited to the structural scale, and many researchers have investigated the material scale behaviour of different grades of steel in order to gain a better understanding of their characteristics under different loading conditions [37–40]. Hitherto, the challenging problem of connecting beams to hybrid fabricated columns consisting of mild-steel plates and ultra-high strength (UHS) corner tubes has not been investigated. In this paper, an innovative type of connection is proposed for connecting I-beams to hybrid fabricated columns. The connection behaviour is investigated through experimental and numerical studies in order to extract moment-rotation curves for the connection, which can be used to find out how the connection behaves under quasi-static monotonic loading compared to the requirements specified by the relevant codes and standards for moment resisting frame connections.

2. Proposed connection

2.1. Description

Conventional connections may not be a suitable choice to transfer the loads from an I-beam to the hybrid fabricated column effectively. Therefore, it is necessary to design a new connection from scratch, based on the characteristics of the hybrid fabricated column (Fig. 1).

This new connection should be capable of taking most advantage of the significantly higher capacities of the corner tubes in hybrid fabricated columns. Obviously, the connection should demonstrate enough ductility and moment capacity in such a way that a weak member-strong connection relation exists. A new connection has been recently proposed for this type of column by the authors and has been investigated numerically [42]. The proposed connection is modular to make construction quicker, easier, and safer. The modular connection reduces the necessity

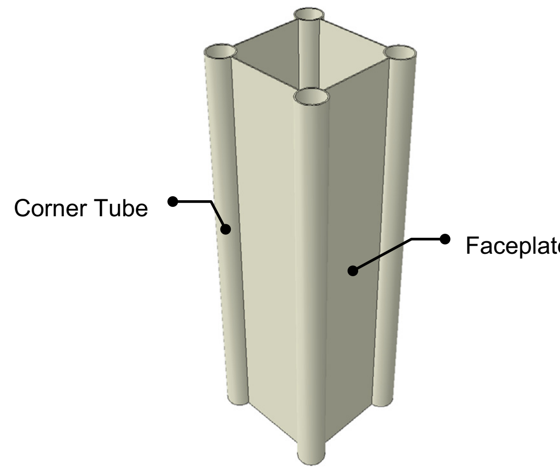

Fig. 1. Hybrid fabricated column.

of on-site welding, increases safety, and provides the building with better construction tolerances, which makes the jobs of different trades easier and improves the overall quality of the structure. It will also provide the possibility of retrofitting the building by replacing only the damaged parts or erecting temporary moment frames. The connection parts are also re-usable in new constructions if a structure built with these connections were demolished. This connection is also flexible enough to cover a wide range of column and beam sizes with minimum modifications in the components or by changing the distance between the top and bottom segments. Although the connection has fascinating characteristics, it nevertheless requires more investigation in areas such as geometrical optimisation and ease of production of connection parts. Fig. 2 shows a representation of the proposed connection. Each part of the proposed connection is separately displayed in Fig. 3.

2.2. Connection parts

The proposed connection comprises fifteen components. These components form two solid segments through the assembly of parts 1,3-1,3-4,4-1,4-4 at the top and parts 2,3-2,3-3,4-2,4-3 at the bottom, as shown in Fig. 2. These two segments are distanced from each other depending on the size of the beam that is to be used with this connection in the structure. Four parts of this connection (3-1 to 3-4 as shown in Fig. 3(c)) are welded to the column tubes and transfer the load from the connection to the column. These parts are strong bases for the corner parts (4-1 to 4-4 as shown in Fig. 3(d)) of top and bottom segments. The slot in the middle of this part (Fig. 3(d)) works as a guide for easier assembly of the parts and in interaction with the previously-mentioned part prevents the lateral movement of the top corner part under loading. After the installation of the top and bottom corner parts, the inclined surface in the middle slot of the top corner part engages with the similar but negative surface on the bottom corner part and acts as a wedge lock. This guarantees the continual interaction of these two parts. The design of the top corner part has been made with the bilateral connection capability of the connection in mind. The design provides engineers with the possibility of using this connection on every column in the structure and attaching up to four beams to the same connection simply by adding a few more components. These two corner parts are attached together using bolts that resist the upward movement of the connection if any upward force is transferred to the connection.

In both segments, an interconnecting member (parts No. 1 and 2) joins the two adjacent top corner parts. These middle parts

[1] U.S. Federal Emergency Management Agency.