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A comparative numerical study on the innovative I-beam to thin-walled hybrid fabricated column connection

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ABSTRACT

Hybrid fabricated columns (HFCs) consisting of mild-steel thin plates connected to ultra-high strength thin-walled tubes at corners have exhibited superior performance compared to the equivalent conventional tubular columns. The higher load-bearing capacity, energy absorption, and post-buckling strength of these columns provide designers with new possibilities in the construction of high-rise buildings. Although several studies have been conducted on these columns, the connection between I-beams and this type of column is challenging. In this paper, using 3-D finite element modelling a numerical study is conducted to compare the behaviour of recently patented bolted modular M-HFC connection between I-beams and HFCs with the welded non-modular type of this connection (called as W-HFC). The performance of the W-HFC connection is also compared with four different types of common conventional connections currently in use in the industry. Moreover, a topology optimisation has been performed on the M-HFC connection in order to reduce the overall weight of the connection components while keeping the moment- rotation characteristics of the connection as close as possible to the originally proposed connection.

1. Introduction

The concept of fabricated sections composed of thin plates and tubes welded together to form a closed section was first studied by Aoki [1]. 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 each individual member's capacities. Based on investigations by different researchers on the behaviour of these fabricated columns with various configurations (Fig. 1), including square hybrid fabricated columns (HFCs) consisting of mild-steel plates and very high strength tubes [2–7], and square hybrid columns consisting of corrugated plates with or without corner tubes [8–10], their load-bearing capacity, post-buckling strength, ductility, and energy absorption compared to those of equivalent conventional sections are significantly improved. This makes HFCs suitable for the construction of moment frame structures.

One major challenge limiting the widespread commercial use of HFCs in construction is the lack of suitable robust connections between beams and these columns. In order to tackle this issue, the authors recently proposed an innovative **m**odular type of connection, named the **M**-HFC connection (Fig. 2), that can be used with this type of column, and its mechanical performance under static loading was experimentally and numerically analysed [11,12].

The results of the experimental tests conducted on the M-HFC connection have demonstrated that this patented connection can deliver a high moment capacity and also more ductility compared to the requirements of the different codes of practice [13,14]. The modular nature of the connection also allows for faster and more reliable construction, while eliminating the need to perform extensive on-site welding. Furthermore, it has been designed to be re-usable after the occurrence of extreme events that could lead to the demolition of the structure.

Although the superior behaviour of the proposed M-HFC connection was demonstrated in the recent study conducted by the authors [11,12], a study on possible variations of the proposed connection is still required. Hence, in order to explore the mechanical performance of the non-modular type of the proposed connection, welds replace some of the bolts in the M-HFC connection. The performance of the proposed connection should also be compared with conventional connections currently in use in industry. Moreover, the connection topology should be optimised in a way that whilst showing a high performance, it is more economical to manufacture and use in the construction.

In this paper, the moment-rotation curve is used to compare the

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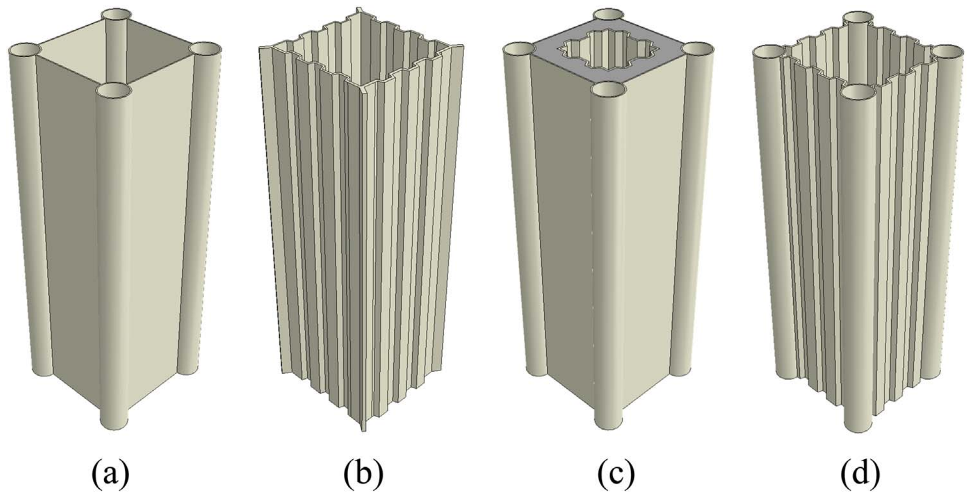

Fig. 1. Various types of HFCs (a) Flat face with corner tubes (b) Corrugated face without corner tubes (c) Concrete-filled double skin sections with corner tubes (d) Corrugated face with corner tubes.

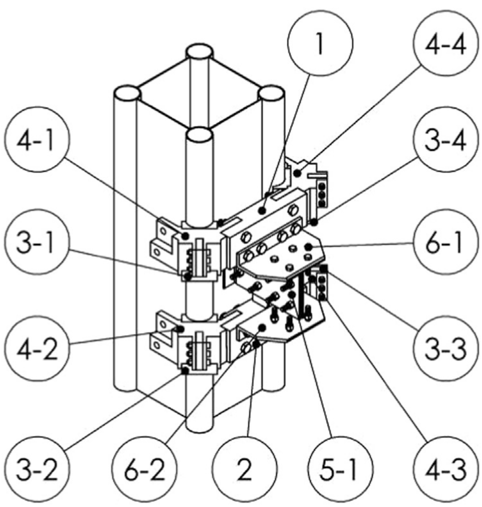

Fig. 2. M-HFC connection.

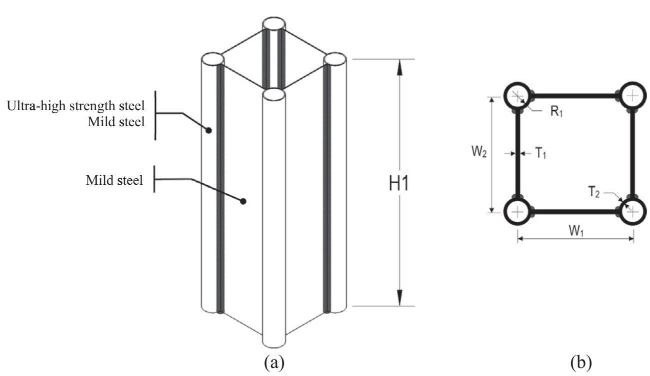

Fig. 3. (a) Hybrid fabricated column and (b) Column cross-section.

Table 1
Dimensions of the hybrid fabricated column cross-section.

Symbol	Value mm	Symbol	Value mm
W_1	286	T_1	3
W_2	286	T_2	3.2
H1	1000	R_1	34.85

performance of various connections. The moment-rotation curve of a connection is a direct indicator of its actual behaviour and is used to classify the connections. For instance, according to Eurocode 3: Part 1–8 [13] connections are classified based on their initial rotational stiffness as rigid, semi-rigid, and nominally pinned. Also, based on the strength criterion and comparing the design moment resistance of the connection with connected members, they are classified as full strength, partial strength and nominally pinned.

In practice, connections behave as semi-rigid and the relative deformation of their components should be taken into account. To this end, many experimental efforts have been dedicated to explore the moment-rotation relationship of several types of connections [15]. Several non-experimental methods have also been developed to predict the moment-rotation curves of end-plate connections, including the T-stub model, yield line model, and finite element (FE) analysis. The T-stub model was the outcome of early efforts to find semi-analytical methods for analysing end-plate connections [16,17]. Methods based on refined yield-line analysis have also been suggested and are widely accepted and employed by design procedures for end-plate connections [13]. Shi et al. performed several experiments and developed a new analytical model based on component-based method to evaluate the moment–rotation relationship for stiffened and extended steel beam–-column end-plate connections [18]. The FE models and softwares have also gained more popularity over time and played a major role in determining the behaviour of different connections and producing their moment-rotation curves [19–29].

Many researchers have investigated the connections between I-beams and rectangular hollow sections. These studies are ranging from methods of stiffening the face of the column (such as welded plates around or through the column or flow drill) to the use of end-plate connections with different types of bolts, and new connections such as through plates or through bolts connections [30–46]. Reverse channel connection is also another type of connection between I- beams and hollow or concrete-filled columns in which the flanges of the channel section are shop-welded to the column while an end-plate is welded to the beam, and the beam-end-plate assembly is bolted to the reverse channel. A limited number of research studies, such as those conducted by Wang and Xue [47], Heistermann et al. [48], and Al-Hendi and Celikag [49,50], have studied the fundamental behaviour of reverse channel connection using experimental tests, FE analysis, and analytical investigations.

ConXL is another connection which was proposed in 2005 [51]. The purpose of this connection has been to omit on-site welding, which increases weld quality and introduces more industrialisation to