Journal of Constructional Steel Research 146 (2018) 16–32

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Fabrication of laser cut I-beam-to-CHS-column steel joints with minimized welding

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ARTICLE INFO

Article history:
Received 2 November 2017
Received in revised form 20 February 2018
Accepted 27 February 2018
Available online xxxx

Keywords:
Laser cutting technology
Tubular structures
CHS joints
Hollow section joints
Tolerances
Joint fabrication
Passing through joints
Fillet weld
Partial penetration weld
Full penetration weld

ABSTRACT

The available connection methods of I-beam-to-CHS-columns are complex and costly. They commonly need local stiffeners and gusset plates to allow an efficient load transfer between the beam and the column, resulting in excessive welding quantities, since directly welding the beams to the column surface increases the vulnerability of the joint to the local distortions. These problems prevent the widespread use of CHS profiles as columns in the construction sector, although they have excellent structural and architectural properties. Researchers worldwide have been investigating the possibilities to simplify the fabrication and increase the structural performance of such joints. This article proposes "LASTEICON" solution to achieve this objective: joints with "passing through" beams, obtained by using laser cutting technology (LCT). Thanks to LCT, welding quantity and fabrication time of such tubular connections can be reduced significantly, obtaining better precision with higher quality in the joint assembly, and improving the workplace safety with less manual work and more computer-programmed automation. For the development of this new joint type, the first step was to investigate the fabrication details including the tolerances required for the slots, laser cutting parameters, and welding aspects. This paper presents the whole fabrication process applied to the joints assembled with different column and beam sizes and welding types, quantifying the time and resources spent during the process. Furthermore, a detailed description of laser cutting procedure has been provided, to show its potential in the steel construction sector.

1. Introduction

Cost of steel fabrication process usually accounts for 30–40% of the global project budget, in which the fabrication of joints takes the largest portion [1]. This rate becomes higher with increasing joint complexity. Among different steel joint typologies, circular hollow section (CHS) connection is one of the most complicated. In multi-storey building construction practice, I beams are connected to CHS columns either by direct welding or adopting local stiffeners and gusset plates to allow the load transfer between beam and column (Fig. 1). The first solution causes vulnerability of severe local distortion on the CHS profile and premature flange fractures, while the second one, resulting in excessive welding quantity, causes both economic and practical difficulties during the construction and spoils the aesthetics of the design. On the other hand, CHS profiles have excellent properties with high compression, tension and bending resistance in all directions, thanks to their inherent shape and geometrical properties, which could make them an excellent choice as columns in multi-storey buildings. Research shows that structures produced using tubular sections have lighter overall weights in the order of 40% [2], and they require a smaller volume of fire protection material than their equivalent H section [3]. Indeed composite CHS columns can be designed to have a fire resistance up to 120 min, without using extra fire protection [4]. Several design guides and articles have been published regarding the application of structural hollow sections and their connections [4–11]. However, their use in the building construction is not well promoted because of the complex detailing requirements of their joints.

When steel hollow sections are involved, the complexity of joints is a worldwide problem [3,14–21]. For instance, in Japan, several researchers indicated the necessity of developing new connection types, since the traditional external-diaphragm connections require a large amount of welding, and the existing through-diaphragm connections are fabricated by cutting the CHS profile into pieces, and then welding the pieces together with steel circular plates [22–25]. Schneider and Alostaz [26] experimentally investigated various details of I-beam-to-CHS-column connections in which they showed that a direct connection of the beam to the tubular column wall causes premature flange fracture and severe local distortion on the CHS wall. Passing through concept has been studied by some researchers [27–31], with promising outcomes, although they have not mentioned the issues related to the fabrication

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https://doi.org/10.1016/j.jcsr.2018.02.039
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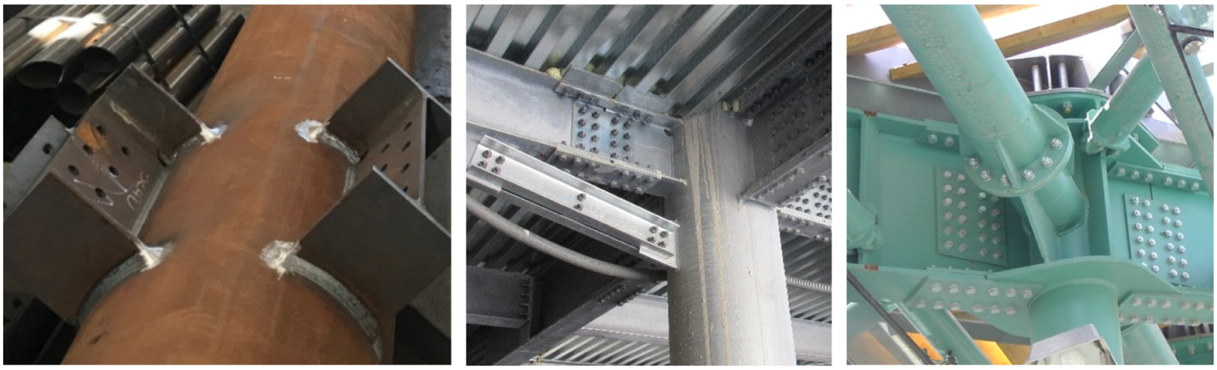

a. Mirandola school project joints by OCAM – directly welded joints b. External diaphragm joint [12,13]

Fig. 1. Examples of conventional I-beam-to-CHS joints.

of the joint assembly. Wider use of tubular elements can be promoted in building construction if the designer's and steel fabricator's work are facilitated, and design and production costs are reduced. In this way, in exposed applications, the steel frame can become an attractive part of the building's visual display, reducing shadows and obscuring spaces. Simpler fabrication and better aesthetics with reduced overall costs will also increase the competitiveness of steel solutions. Simplifying the fabrication process would have important economic and sustainability benefits for the steel construction sector. This article presents how this objective can be achieved by introducing Laser Cutting Technology (LCT) to the fabrication of hollow section joints.

LCT is typically used for industrial manufacturing applications, and it also permits the fabrication of new joint typologies that are not possible with the current methods employed to assemble columns with several beams. Laser cutting machines can be used for round tubes from 10 up to 508 mm in diameter, with wall thickness up to 20 mm and lengths up to 14 m (Fig. 2) [2]. The initial investment on laser cutting machines may still be high; however, they reduce the overall costs and time spent for welding in the whole life-cycle of manufacturing. Cutting with laser has many advantages over conventional techniques; the operations are programmed and fully achieved by the machine, without any intervention of the operator. This eliminates human error on several processes of fabrication, which is an important financial saving and an increase of the quality level. The traditional fixed costs determined by punches, clamps, tools, templates and dies are entirely eliminated by CAD programming and the laser beam used as a universal cutting tool.

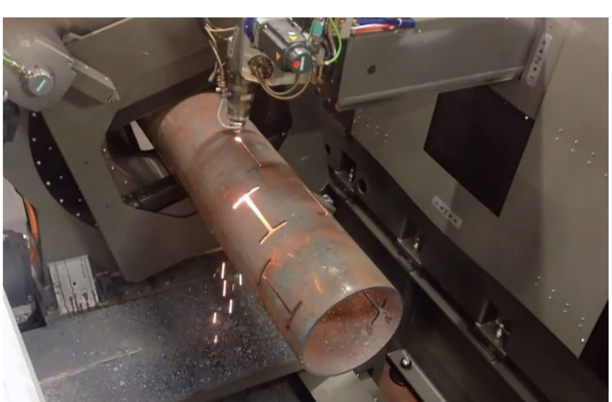

Fig. 2. Example of the laser cutting process on a CHS profile.

Moreover, the ease of interfacing a laser machine with CAD/CAM software tools allows cost-effective manufacturing of parts and quick changes in design [32]. This means generally shorter overall construction schedule. Less manual work and more automation also mean a safer work environment.

Also in terms of the environmental performance, the laser cutting technique surpasses the other cutting methods. Thanks to its high precision, welding becomes simpler in the fabrication of the joint assembly, releasing much lower amounts of slag. This improves considerably the workplace safety thanks to the reduced use of welding [32–34]. Besides, laser cutting operations release much less noise and pollution. Adopting LCT, special connections can be easily designed to join different types of structural elements, with pleasant aesthetic results as well as improving global structural integrity, without the need of costly prototypes being used for evaluation purposes. It ensures better uniformity of parts, less machine tooling time and most cost-effective management as well as excellent performance in terms of cutting quality [2]. Laser cutting can be up to thirty times faster than standard methods [2]. Steel profiles cut by LCT are also clean enough to go straight into fabrication without additional processes. Bursi et al. and Zanon et al. showed that material and high-cycle fatigue properties of the edges obtained by LCT satisfy the code requirements [35,36]. Moreover, the heat affected zone of laser cutting is much smaller, when compared to other methods [34]. This avoids material distortion and microcracks, that are unavoidable by other methods such as plasma or oxygen cutting. A reduced heat affected zone will improve the connection behaviour under seismic loading, reducing the risk of brittle fractures.

LCT can expand the freedom of architects and engineers when developing new projects. This possibility is being studied within a 42-month long research project LASTEICON [12,37], funded by Research Fund for Coal and Steel of the European Commission, where the authors of this paper are responsible for the coordination of the project composed of 9 European partners representing both academy and industry. Fig. 3 shows the different steps in which a prototype of 4-way laser-cut joint is assembled. In general, proposed joints are composed of steel profiles inserted through CHS columns, thanks to a fitted slot that is cut with a laser machine. This new joint type aims to have essential energy efficiency and sustainability benefits for steel buildings, by means of reduced detailing, welding, steel tonnage, workshop man-hours, and shorter construction schedules. This paper focuses exclusively on the fabrication process applied to the joints assembled with different column and beam sizes and welding types, which was the first step of the LASTEICON research project. The issues related to the tolerances and the laser cutting parameters are presented and discussed. Furthermore, time and resources spent during the assembly process are quantified.