Numerical studies on prototype CHS and open sections welded joints for steel truss girders with the use of laser cutting technology

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October 2017

Abstract

In the era of technology, construction industry has changed very little in the past few years and, when compared to others, it is performing poorly in areas like project delivery, life cycle performance and sustainability. In order to achieve more efficient and optimized solutions in steel structural construction, innovative design connections on truss girders pretend to be developed making use of laser cutting advanced technology. These connections consist of performing laser cutting slots in the chord's faces so that brace members can pass through and be welded on both top and bottom faces.

The structural performance of these connections was assessed based on the results provided by a finite element numerical analysis in two different types of truss girders specimens. Several innovative geometries were studied considering the powerful capabilities of laser cutting and different parameters were tested to prove the viability of this technology. Results showed that these joints are able to minimize deformations and stresses' concentration as well as to reduce the design dimensions with no losses in performance.

Although the main focus is on the outstanding structural and architectural properties of hollow structural section profiles, the additional study of open section joints showed the extendibility potential of this technology in other applications.

Keywords: laser cutting, hollow structural sections, connections, truss girders, steel detailing, numerical modelling

1. Introduction

Focusing on shaping the future of construction, the importance of innovating and adopting formal processes, with rigor and consistency, getting knowledge from other industries and having a less conservative company culture are aspects that construction industry must establish to keep up with the labour productivity improvement of other industries (BUEHLER 2017). The possibility of creating standardized and prefabricated components with automatic and efficient processes in a smart life-cycle assessment pretends to transform the construction industry. However, the drivers of change are several and demanding (technique, economy, sustainability, society, politics, regulation, etc).

This work comes hand to hand with this purpose by adopting laser cutting technology (LCT), used already in other industries (e.g. automobile industry), to improve the quality and performance of steel structures, with emphasis on hollow structural sections' (HSS) connections. The use of HSS in steel construction is much smaller when compared to the use of open structural sections. In fact, structures composed by hollow sections have much more complex detailing, more fabrication and erection requirements and more steelwork in terms of connections, resulting in higher global costs.

Therefore, taking advantage of the developed laser cutting technology, an innovative project called LASTEICON – Laser Technology for Innovative Connections in Steel Construction appeared to solve this issue and to be the key turning point in the market position of HSS. The major intention is to promote these sections as an industry standard approach making use of the advantages of laser cutting to design simpler innovative joint solutions with reduced fabrication costs as well as welding and stiffener plates (CASTIGLIONI, et al. 2015), with emphasis on I-beam-to-CHS-column connections (Figure 1.1).

Regarding LASTEICON targets, this work will focus on the application of laser technology in welded truss girders' joints to prove the extendibility of this concept.

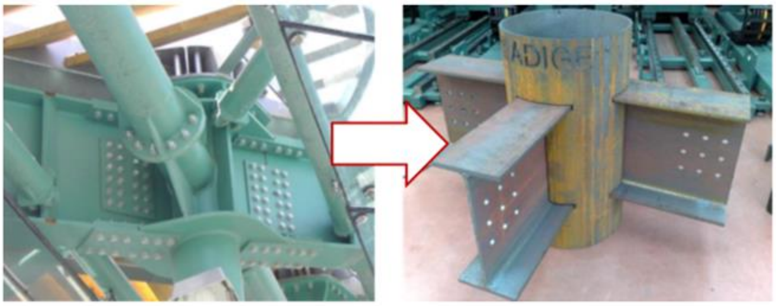


Figure 1.1: LASTEICON I-beam-to-CHS-column joint specimen (FELDMAN 2016).

2. Laser cutting technology

Laser cutting technology presents a huge potential in terms of steel structures development once it allows reducing fabrication costs in approximately 9% (according LASTEICON partners). In fact, a big share of the costs in this industry are related to the fabrication process (about 30-40% of the overall project budget) mainly due to joints design complexity, wasted material and shop man-hours. An automated process followed by a clean and precise cut with considerable time savings represent some of the advantages of this technology, which compensate the big initial investment in this type of machines.

In terms of cutting quality and productivity, this technology can create optimal cut surfaces through a complex process of fusion and oxidation cutting followed by chemical degradation and vaporization. Moreover, when evaluating the main phenomena which characterise the different cutting processes of steel elements, like surface roughness, heat affected zone, surface striation and residual stresses, minimal laser cutting effects are observed (MADIĆ, et al. 2017). Finally, regarding the economical and sustainable aspects inherent to construction industry, the benefits of this technology are appreciated and comprise all the life cycle of building projects, as shown Figure 2.1.

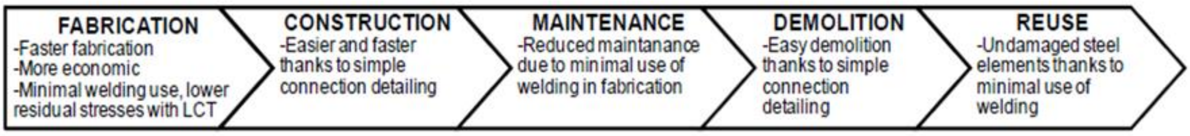


Figure 2.1: Scheme of the benefits of LASTEICON during the life cycle of a building project (CASTIGLIONI, et al. 2015).

On the other hand, HSS adoption in steel construction provides structures, notably truss girders, with excellent mechanical and shape properties, which are not so much explored and developed when compared to open sections, due to higher costs and design complexity.

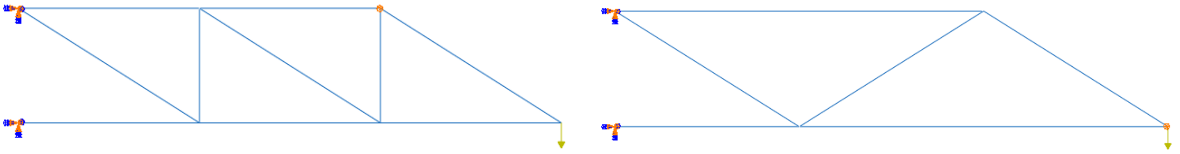
In that way, regarding the study of complex and innovative joints, performed efficiently by means of laser cutting, this work pretends to design new HSS and open section joints' solutions that in terms of strength, deformation, stresses and rotational stiffness, might improve the static performance of the structure. Additionally, to more accurately assess the joints' behaviour, a comparative study with conventional joints is also going to be performed.

The design of these connections will be accomplished by making use of the 3D modelling capacities from SolidWorks software, whereas the study of joint's structural behaviour will be based on the results provided by a numerical analysis executed on (Abaqus v.6.13 2013) FEM software. The compatibility between these two programmes was accomplished through an associative interface.

3. Methodology

3.1. Models geometry

The analysed connections correspond to respectively N and K-joint typologies, which geometries were taken from the two truss girders specimens presented in Figure 3.1, corresponding to a Pratt (Type I) and a Warren (Type II) truss girder specimen, respectively.



a) Truss type I

b) Truss type II

Figure 3.1: Truss girder specimens analysed.

The action load is applied on the extremity node and boundary conditions are set as fully constrained on the left side nodes, as shown in Figure 3.1. Additionally, an external support was placed near the load to prevent lateral buckling from happening.

The design of LASTEICON innovative connections consists of creating laser cutting slots in chords' faces so that brace members can pass through and be doubly welded on the top and bottom faces of the chord. With this concept, alternative solutions can be created, as shown in Figure 3.2, for the studied N-joints (CHS truss type I).

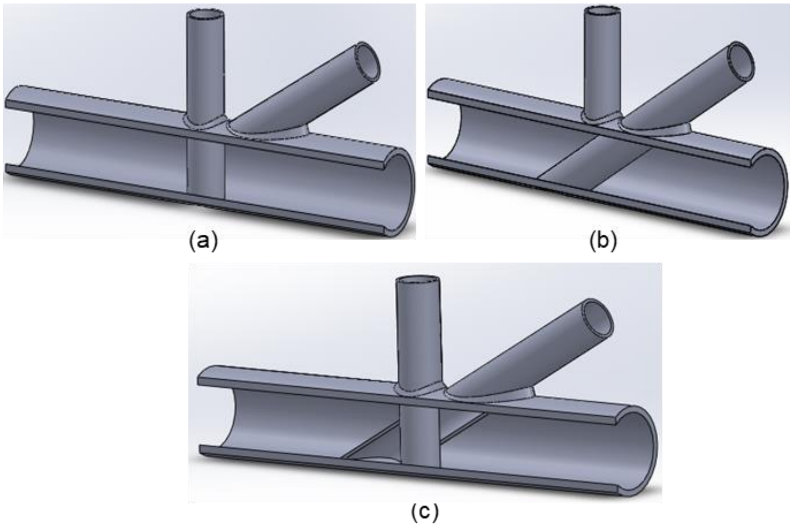

(a) (b) (c)

Figure 3.2: Design model of innovative CHS N-joints. (a) New_1 joint; (b) New_2 joint; (c) New_3 joint.

Joint "New_3" has the characteristic that both brace members are simultaneously embedded inside the chord, which is accomplished by cutting half of each brace section and assembling them, avoiding contact. It is important to remember that for fabrication processing, all these cut-edge details will be automatized by 3D CAD software and they will be cut by proper LCT machines.

The same procedure was applied for the other N and K-joints of truss specimen type I and II as well as for open section profiles. Figure 3.3 shows the design geometry of a conventional and innovative open section N-joint composed by an HEA chord profile and a set of two angle section profiles for each brace member. In this case, the angle profiles pass through the chord's upper flange and are welded along with the web of the HEA profile. In all the presented connections, special attention was given to guarantee the non-existence of eccentricities, consequently avoiding secondary moments.

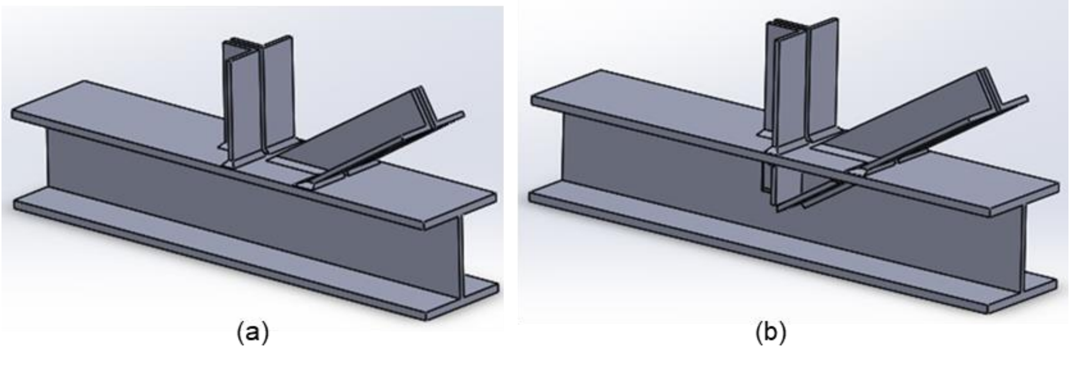

(a) (b)

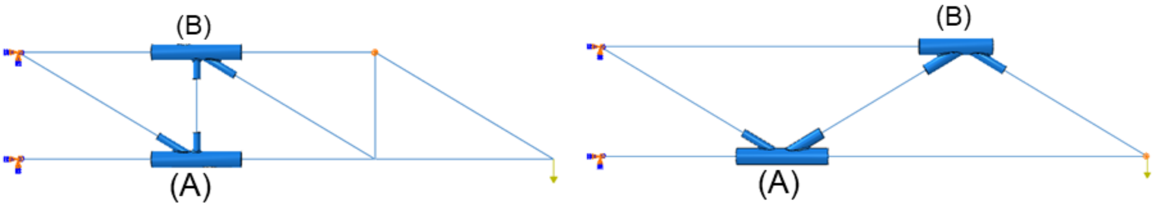
Figure 3.3: Design model of innovative Open Section N-joints. (a) Traditional joint; (b) New joint.

At a first perspective, the innovative designed connections should represent a more resistant solution in terms of strength and rotational stiffness, as the embedded members will work as internal reinforcement. Thus, stresses can be distributed along both chord's faces and consequently, deformations shall be reduced.

Finally, if the previous phenomena are observed, LASTEICON innovative joints can be pre-designed with smaller section dimensions, guaranteeing the identical structural performance of traditional solutions with larger dimensions.

3.2. Numerical modelling

To prove the extendibility of laser cutting technology on new joints applications, previous finite element method (FEM) analyses must be made to assure their potential. From the numerical investigation performed by (RADIĆ, MARKULAK and MIKOLIN 2010), several FEM models approach were tested in the context of truss girders. Among them, an acceptable and efficient modelling approach, consisting in a combination of beam with 3D shell elements, achieved results mostly identical to a complete 3D shell model (which is a heavier solution in terms of complexity and calculations). Therefore, the correspondent model was adopted and two of the truss specimens' beam nodes were replaced by 3D solid joints ((A) and (B)). The result is presented on Figure 3.4, for both truss types I and II.



a) CHS substructure type I

b) CHS substructure type II

Figure 3.4: 3D model approach, composed by beam and solid elements (CHS profiles).

During the process of modelling the connections, several parameters were assumed after previous numerical validation tests. Some of the most relevant were the interaction constraint adopted to create the link between beam members and solid joints as well as the mesh refinement for the most complex geometries.

3.3. Type of analyses

In order to efficiently evaluate joints' performance above the yield limit of steel, where a kinematic strain hardening behaviour was adopted, a design procedure was first carried out to determine the final dimensions of truss specimens. This study was also used to verify whether global ductility behaviour was being considered.

Once the models are simulated, local joints' parameters like chord's face deformation, nodes' rotation, lateral displacements and angular distortion will be calculated and studied to prove the potential of laser technology.

Finally, in order to optimize the previous solutions, a parametric analysis was performed to evaluate the influence of the chord's thicknesses in the behaviour of the studied connections. By doing so, it will be possible to compare if the benefits of LASTEICON joints allow reducing profile dimensions and guarantying an efficient structural performance.

4. Results and discussion

4.1. Numerical analysis

As explained in section 3, this study started by the pre-design of truss specimens considering only beam elements. Figure 4.1 shows the load–displacement analysis performed on CHS truss type II where it is possible to see the tests executed with different profile dimensions in order to avoid premature collapse (buckling phenomenon). This analysis was extended to the remaining truss girders specimens.

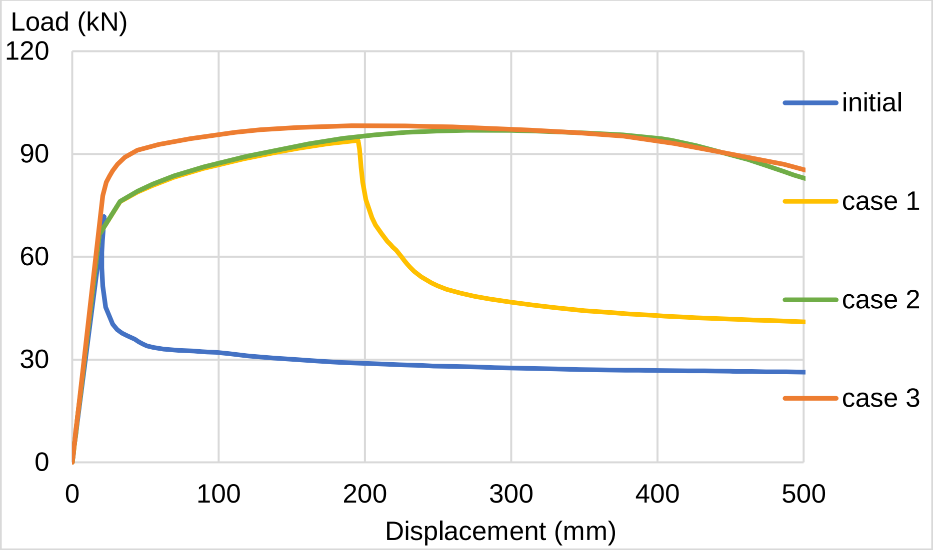


Figure 4.1: Load – displacement analysis on CHS substructure type II.

After the design dimensions on truss specimens were achieved, a global behaviour analysis was performed based on the comparison of load-displacement and load–rotation results from the final 3D models (Figure 3.4). In the end, no differences were obtained as all the models behaved similarly.

Hereinafter, the determination of local chord's face deformation as well as brace member longitudinal deformation parameters allowed observing some differences and the performance in the application of the innovative joints. As an example, Figure 4.2 presents the deformation on HEA chord due to vertical compression forces induced in the upper flanges, which cause distortion.

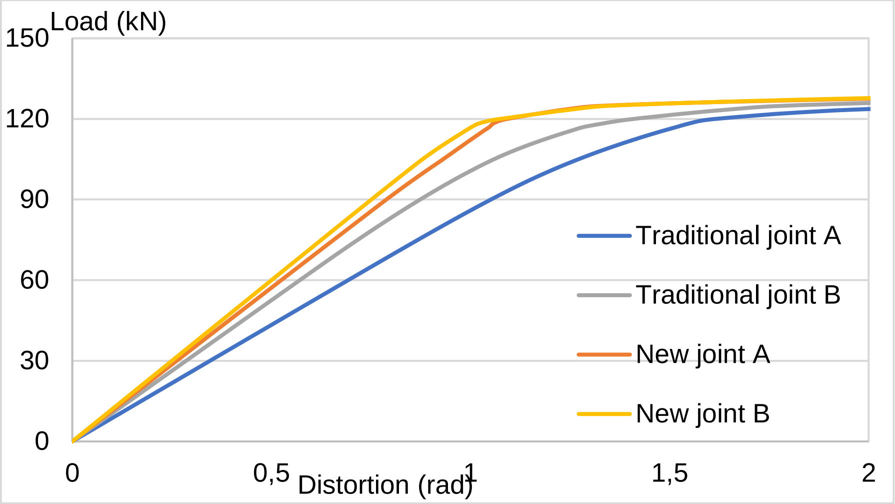


Figure 4.2: Vertical deformation of the chord's upper flange of OPEN section N-joints (A & B), truss type I.

The second exemplified analysis is the comparison of joints' behaviour between CHS truss type I and CHS truss type II, for connection (A), that can be seen in Figure 4.3.

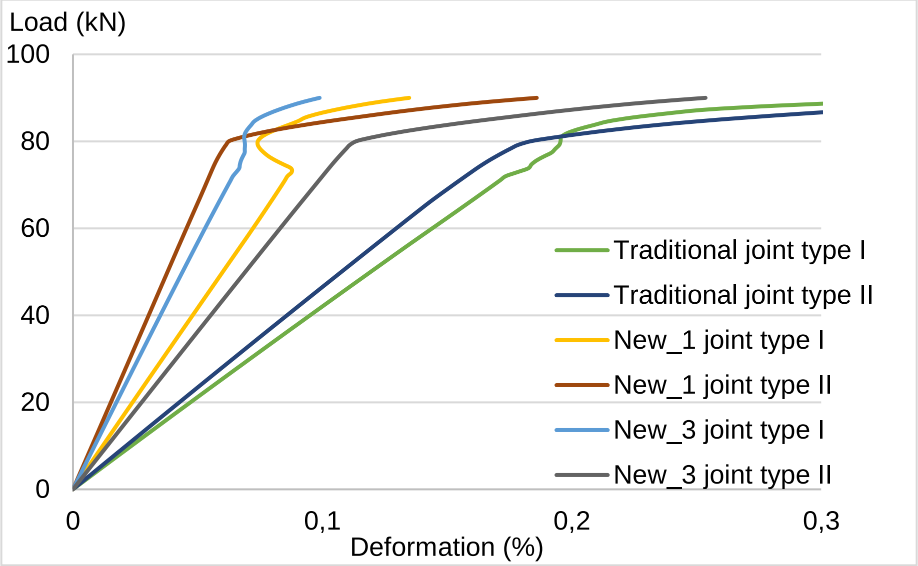


Figure 4.3: Lateral expansion of chord's face on CHS connection (**A)**, for trusses type I & II.

4.2. Parametric analysis

The analyses performed on the previous section (3.1) have shown that no significant variation was obtained for the chord's deformation parameter on CHS joints. Furthermore, the similar behaviour from vertical brace members settled that chord's stiffness was overdesigned in comparison with brace members, which led to large deformations on the braces and almost insignificant ones on the chords.

Therefore, the thickness of this element was reduced to 4mm, instead of the initial 6,3mm.

For this case, the results have clearly shown the differences in the performance of each joint typology. Moreover, when comparing this model with the initial one, interesting results were obtained. For example, Figure 4.4 shows that “new_3 joint (4mm)” has an identical deformation to “traditional joint (6,3mm)”. Therefore, it is possible to reduce the designed dimensions making use of LASTEICON innovative connections.

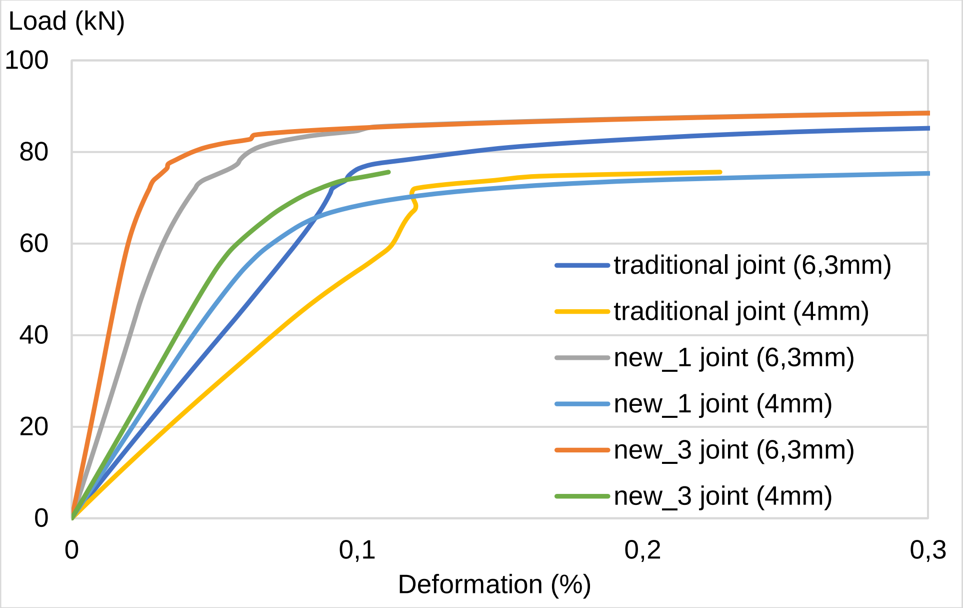


Figure 4.4: Vertical chord surface deformation on CHS N-joints (connection A) for both chord thicknesses, truss type I.

5. Conclusions

From the previous results provided by numerical model analyses, some conclusions were obtained and will be summarized below.

- Overall, joints’ structural performance was enhanced in comparison to conventional connections, which proves the viability to proceed with these new joints’ typologies through more advanced analyses, such as experimental tests;
- No differences were found when studying the influence of joint’s typologies in the global behaviour of the structure. More research should be done about different models’ approaches;
- The axial force applied on the chord, more specifically compression, has influence on joints’ deformation;
- The joint’s geometry of truss specimen type II presented some warnings when considered joint type “New_1” due to punching shear failure;
- LCT can improve structural performance of either CHS and OPEN section truss specimens;
- LASTEICON “New_3” joint represents an optimal solution as it allows reducing chord’s section dimensions with no increase on the deformation.

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