Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2021) 4177-4184

ECCOMAS Proceedia

COMPDYN 2021
8th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Streamed from Athens, Greece, 28 - 30 June 2021

COMPONENT MODELLING OF CONNECTIONS BETWEEN CIRCULAR-HOLLOW-SECTIONS AND THROUGH-ALL MEMBERS

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Abstract

The recent use of the 3D Laser Cutting Technology in the field of civil engineering has led to the development of novel typologies of steel beam-to-column connections made by welding circular hollow section columns (CHS) to through-all members. The main feature of these joints is that they are able to provide higher flexural strength, stiffness and energy dissipation capacity compared to the corresponding joints with elements simply welded to the external surface of the hollow section. Currently, there are no codified rules for such a type of structural details and, consequently, the design of these joints implies the development of complex FE models. Aiming at filling the knowledge gap regarding the structural flexural behaviour of CHS through I-beam joints, a research activity is currently ongoing at the STRENGTH laboratory of the University of Salerno with the objective to provide simple analytical tools for the design and modelling of such connections through the component method, both under monotonic and cyclic loading conditions.

This paper deals with the preliminary study of the behaviour of one of the elementary components characterising the response of beam-to-column joints composed by CHS columns and I-beams, which is the "plate transversally welded to the column in tension/compression". This component is meant to model the local behaviour exhibited by the CHS tube at the upper/lower beam flange level. This component is very important because it governs the deformability of the connection and may limit the resistance of the joint due to the local failure of the CHS tube. In the performed work, monotonic and cyclic tests on specimens representative of realistic geometric configurations of beam-to-column joints have been carried out. Subsequently, a finite element (FE) model, representative of the analysed connection, has been developed and validated against the experimental results.

Keywords: component method, laser cutting technology (LCT), experimental activity, FEM.

ISSN:2623-3347
Peer-review under responsibility of the organizing committee of COMPDYN 2021.
doi: 10.7712/120121.8776.18825

1 INTRODUCTION

In the last decades, the 3D-Laser Cutting Technology (3D-LCT) has proved to be very useful in many applicative fields since it allows to manufacture a mass production with high accuracy. The only exception regards the field of civil engineering because of the relevant cost of large-scale structural components. Nevertheless, the 3D-LCT is a good solution when very complex geometrical components have to be manufactured; an example of such a case is represented by steel beam-to-column connections between circular hollow section (CHS) columns and double-tee beams. In fact, until now, except for the study of the behaviour of tubular profiles ([1]-[4]), some different solutions for coupling the aforementioned profiles have been conceived: i) the beam is simply welded to the external surface of the column [5]; ii) plates, welded to the flanges of the double-tee profile, intersect the column [6]; iii) the beam is welded to collar plates externally welded or bolted to the column [7]; iv) the connection is filled with concrete, while the beam is welded to the external surface of the column [8]. The first solution is very easy to manufacture, but the obtained connection provides low stiffness and resistance such that it can be adopted only in the case of pinned or semi-continuous frames [9]. The second and the third solution, instead, are good alternatives but the need of conceiving complex special elements [10] represents a relevant drawback. The fourth approach, instead, induces the slowdown of the construction process due to the pouring of concrete on-site [11].

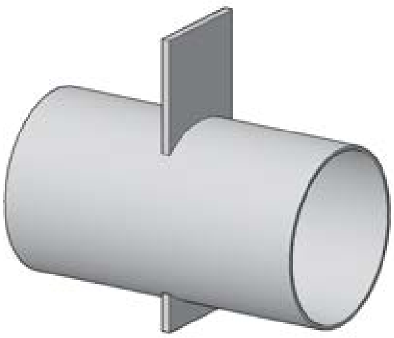
The briefly above summarised existing solutions well clarify the possibilities offered by the beam-to-column connection between CHS columns and through-all beams obtained by adopting the 3D-LCT. In fact, the cut of the tubular profile according to the shape of the double-tee section guarantees the beam to cross the CHS before welding both the members, increasing, in such a way, both the stiffness and the resistance of the joint without appealing to additional plates or concrete. Because of these benefits, a relevant interest in the technological aspects [10] and mechanical behaviour exhibited by the aforementioned beam-to-column connection recently arose. In particular, at the University of Salerno, experimental, numerical and theoretical activities have been carried out in order to study the resistance and the stiffness of the analysed joint. As results of the first step of the study, formulations to predict the flexural strength and initial stiffness of CHS columns to through-all I-beam connections have been proposed ([12]-[14]). These equations have been analytically derived starting from the behaviour of the easiest components in which the connection could be simplistically divided: the hollow section subjected to the transverse tension/compression of the flanges of the double-tee profile and the beam web and column under shear actions. Because of the complexity of the obtained theoretical formulations, it has been necessary to derive simplified equations whose coefficients have been calibrated against the overall response of the numerically simulated connections. Basing on such statements, it is clear that, even though the proposed equations allow to have a reliable prediction of the flexural strength and initial stiffness of the studied connection nevertheless, they do not allow to really account for the local behaviour of the single nodal components. This is the reason why one of the steps of the research activity consists of studying singularly all the components of the CHS to through-all double-tee connections aiming at assembling all the components to foresee the behaviour of the whole joint.

Within this framework, this paper deals with the study of the component consisting of the "plate transversally welded to the column in tension/compression". Such a topic is not a novelty since Voth [15] has already investigated it, also proposing a formulation for the strength prediction. Nevertheless, his approach consisted of calibration against experimental and numerical results of regression coefficients of an existing formula ([16], [17]) for tubes with plates externally welded to the column, without adapting the theoretical approach to the specificities exhibited by the connection with through plate.

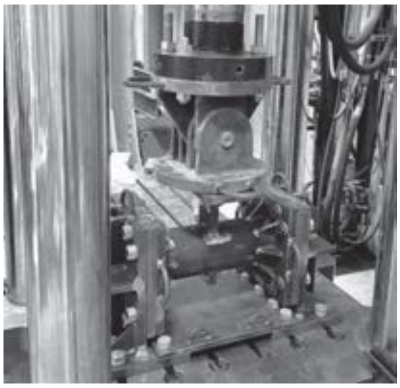
The present study is a preliminary work for characterizing the behaviour of the nodal component between CHS profiles and through-all plates under tension/compression forces and it is composed of experimental and numerical activities. The experimental campaign consisted of performing three monotonic and three cyclic tests on CHS to through-all plates specimens differing for the geometric properties of the connected elements. Afterwards, numerical models of the tested specimens have been modelled thanks to finite element software and have been validated against the experimental results. As future developments, the validated numerical models will be exploited to perform parametric analyses to investigateg a wide range of geometrical properties of the studied CHS to through-all plate connections, aiming at proposing design equations meant to predict the strength and stiffness of the analysed component.

2 EXPERIMENTAL ACTIVITY

Aiming at studying the component highlighted in the introduction, three monotonic and three cyclic tests have been performed on specimens having as members circular hollow section profiles and through-all plates (Figure 1).



a) 3D view of the studied connection



b) Experimental set-up (Specimen 1)

Figure 1: Analysed connection and experimental set-up

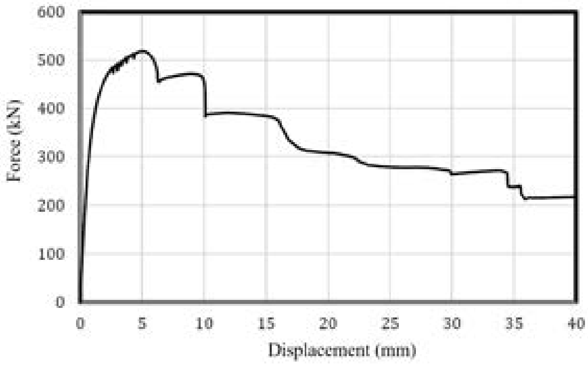
The examined specimens differ for the geometric properties of the connected profiles: the first connection is characterised by a tubular member with a diameter equal to 168 mm, thickness 6 mm, length 450 mm and by a 100 mm width, 30 mm thick and 350 mm length through-all plate; the second specimen is characterised by a CHS with a diameter equal to 219.1 mm, thickness 5 mm, length 500 mm and by a through-all plate with a width of 150 mm, the thickness of 20 mm and length of 350 mm; the third specimen has a tubular member with a diameter equal to 273 mm, thickness 6 mm, length 500 mm and a 160 mm width, 20 mm thick through-all plate with length equal to 400 mm. The plates have been properly selected in order to be ideally representative of the flanges of double-tee profiles (IPE200, IPE300 and IPE330 for the three specimens, respectively) of a CHS to through-all -beam connection.

In order to ensure the plates could pass through the CHSs, the tubular members have been cut with a tolerance of 2 mm around the imprint of the shape of the plates, while the welds consist of single-sided full-penetration butt welds chamfered with an angle equal to 30° adopting the Metal Inert Gas (MIG) welding technique, as suggested by EN 4063-131 provision [18].

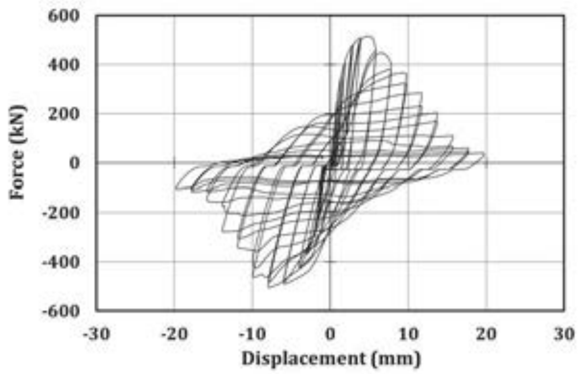
The basic material properties of the steel members, characterised by a S275JR steel grade, have been defined by tension coupon tests obtained by the base metal of the specimens.

The testing rig has been conceived in such a way to apply the force at the upper end of the plate employing a vertical actuator (load capacity of 2000 kN in tension and 3000 kN in compression) which is fixed to a rigid steel reaction frame constrained at its base to the strong laboratory floor.

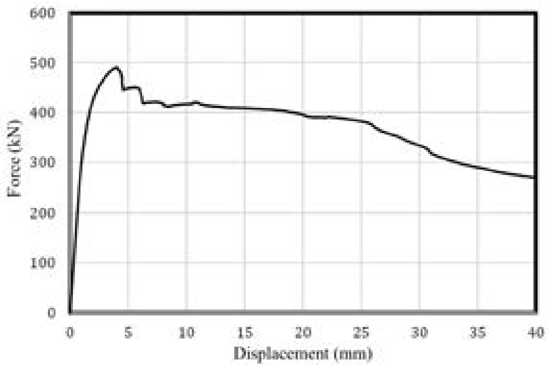
In the test layout, the CHS has been placed horizontally, and its ends have been restrained thanks to steel supports conceived to fix all the degrees of freedom and bolted to the rigid floor of the ITALSIGMA machine (Figure 1). The monotonic and cyclic tests consisted of applying displacements at a rate of 0.5 mm/min until 10 mm displacement, 1 mm/min between a displacement of 10 mm and 20 mm, and 2 mm/min for displacements higher than 20 mm. The specimens have been equipped with 5 LVDTs to monitor not only the vertical displacements but also the horizontal displacements of the supports in order to prove they behave as fixed supports.



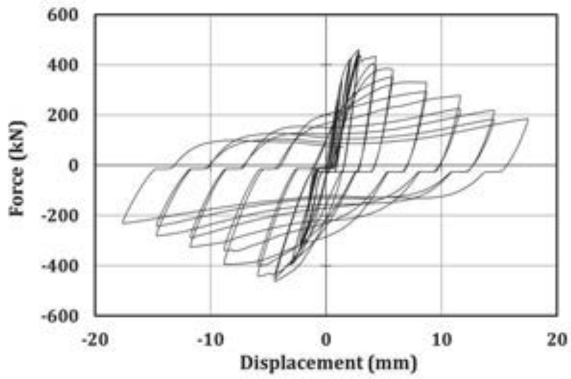
a) Force-displacement monotonic curve (test 1)



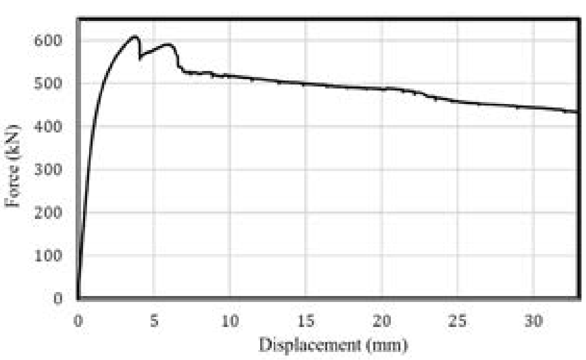
b) Force-displacement cyclic curve (test 1)



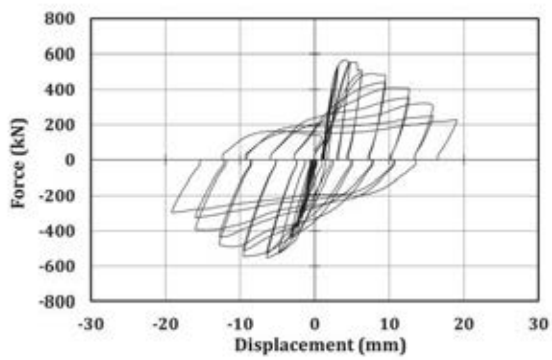
c) Force-displacement monotonic curve (test 2)



d) Force-displacement cyclic curve (test 2)



e) Force-displacement monotonic curve (test 3)



a) Force-displacement cyclic curve (test 3)

Figure 2: Experimental tests

In Figure 2 the force-displacement curves of the specimens are presented. The maximum forces withstood by the monotonically loaded connections are equal to 518 kN, 491 kN and 608 kN, respectively, for the three specimens, and in all the cases, the maximum strength capacity has been achieved for displacements lower than 5 mm. Instead, the maximum strength experienced by the connections subjected to the cyclic histories are equal to 521 kN, 466 kN and 570 kN, respectively, for the three specimens.

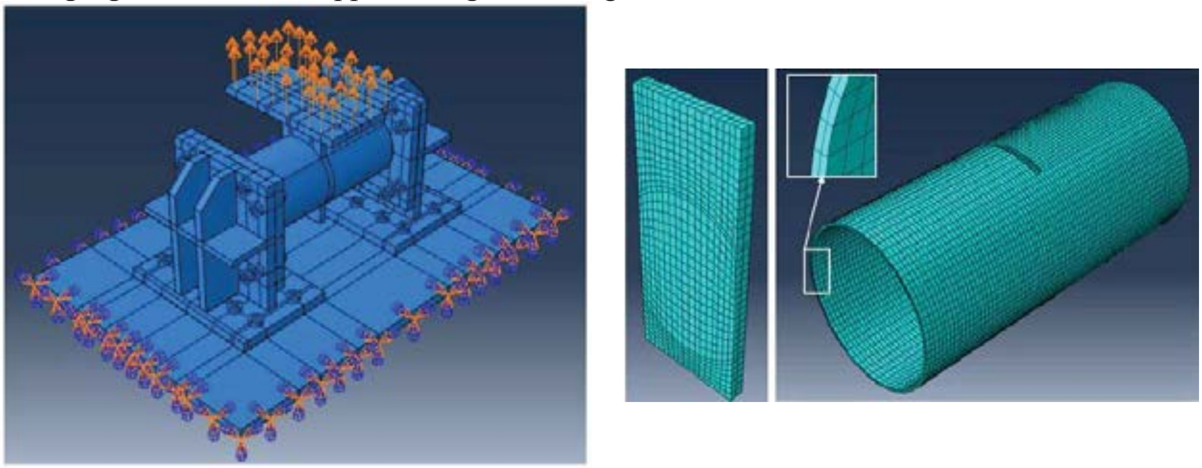
All the specimens collapsed because of the transverse crushing of the tube consistently with the deformed configuration analysed by [12].

3 NUMERICAL ACTIVITY

This paragraph is devoted to validating the numerical models of the tested specimens thanks to the finite element (FE) software Abaqus [19].

The geometric characteristics of the specimens have been properly modelled, except for the welds, which have been substituted by Tie contacts between the plate and the tubular profile. Instead, the definition of the mechanical properties has been based on the tension coupon tests; for the sake of clarity, the stress-strain laws have been modelled according to the quadrilinear relationship proposed by Faella [20] with Young's modulus of 210000 MPa and a Poisson's ratio equal to 0.30.

In the FE software, the specimens have been modelled together with the rigid floor of the testing rig and the fixed supports, as given in Figure 3a.



a) 3D view of the specimen *b) Mesh size*

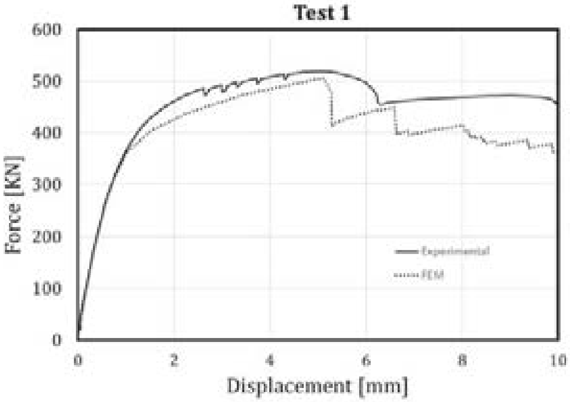
Figure 3: FE model

"Hard" contacts for normal behaviour and frictionless contacts for the tangential behaviour have been applied among the bolts and the plates to which they are connected with; Tie contacts have been employed to model not only the welds between the through-plate and the CHS profile, but also the welds among the plates of the fixed supports. In order to account for the damage evolution, in the numerical model, an equivalent plastic displacement at fracture equal to 4.8 mm has been considered according to the suggestions of [21], [22].

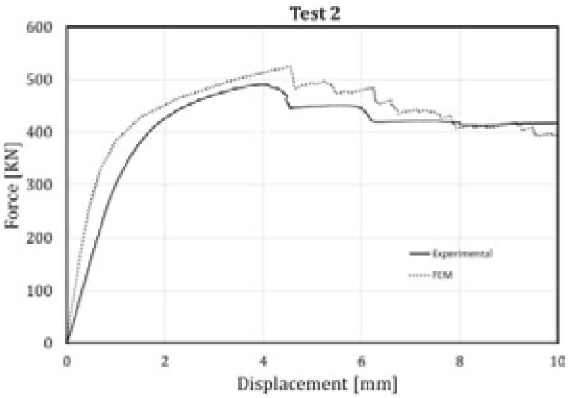
C3D8-type (8-node linear brick) elements with a size equal to 5 mm have been used to mesh the members (Figure 3b).

Referring to Eurocode 3 part 1.5 [23] and according to the construction tolerances provided by EN10034 [24], the imperfection related to the beam-plate attachment, which promotes the local buckling of the tubular profile, has been embedded in the numerical model.

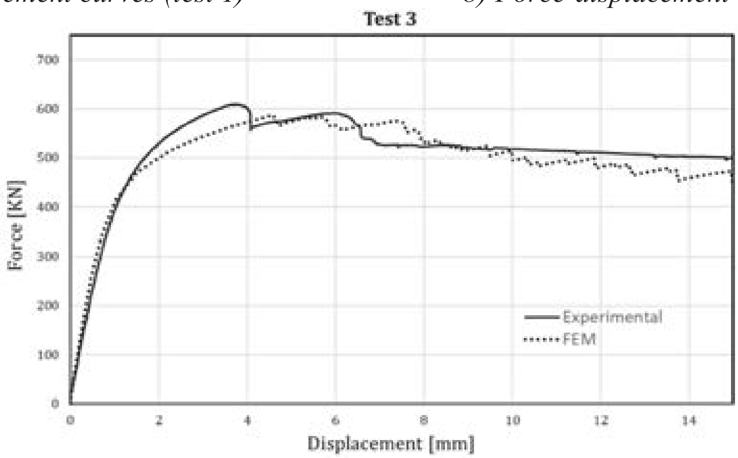
The numerical model has been validated against the experimental results by loading the end of the plate with the same monotonic displacement histories to which the real-scale specimens were subjected. At the end of the simulations, carried out by adopting a static solver, it has been possible to observe the consistency of the failure modes exhibited by the FE models with the experimental observations and also the good prediction of the force-dismplacement curves, as shown in Figure 4.



a) Force-displacement curves (test 1)



b) Force-displacement curves (test 2)



c) Force-displacement curves (test 3)

Figure 4: Experimental versus FE results

4 CONCLUSIONS

The present work is devoted to studying one of the components of CHS to through-all I-beam connections; in fact, the attention has been focused on the analysis of the plate transversally welded to the circular tubular profile in tension/compression since this component is supposed to behave as the flanges of the double-tee beam welded to the CHS member.

The research efforts consisted in performing experimental tests and numerical simulations. The main conclusions are:

1. the experimental activity has shown that the developed collapse mechanism exhibited by the analysed component is consistent with the supposed theoretical mechanism proposed by [12];

2. a numerical model of the tested specimens has been validated against the experimental results.

Starting from the validated numerical model, the future research efforts will be devoted to the study of a wider range of CHS to through-all plate connections characterized by different geometrical properties. The ultimate aim of the present research activity is to propose design formulations able to forsee the strength and stiffnes of the analysed component.

ACKNOWLEDGEMENTS

The authors want to express their gratitude to Dr. Eng. Francesco Perri and Eng. Ciro Esposito for the help provided during the experimental activity.

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