PLASTIC STRENGTH OF EXTERNALLY WELDED CHS-TRANSVERSE PLATE T-JOINTS

[a]Ali Ajwad* and [b]Massimo Latour

a: DICIV, University of Salerno, Fisciano, Salerno, Italy. aajwad@unisa.it
b: DICIV, University of Salerno, Fisciano, Salerno, Italy. mlatour@unisa.it
* Corresponding author

Abstract- Utilizing tube-like hollow sections (HSS) as columns in Moment Resisting Frames (MRFs) offers beneficial resolutions for overall structural performance. Nonetheless, the adoption of HSS columns is limited by the intricacy in engineering connections between columns and Double Tee Beams. One of most common approach for such types of joints is welding the beam externally to the chord using either fillet or full penetration butt welds. As per the EC3:1.8 guidelines, a so-called component method approach can be used for such types of joints to predict their plastic strength. The component method approach simplifies the joint design by breaking down the joint into its fundamental components, allowing for a detailed examination of each component's behaviour and interaction, thus ensuring precise evaluation of joint performance and reliability. In this study, the emphasis lies on delineating the strength attributes of welded joints in a T-shape, connecting Circular HSS chords and externally welded transverse plates. The component's mechanical response seeks to mimic connection dynamics between beam flange and chord in connections connecting CHS chords and welded IPE profiles. More precisely, this critical element has been isolated and thoroughly examined using results from theoretical approaches and numerical simulations, culminating in identification for the most suitable analytical design equation.

Keywords- Component Method, Parametric Analysis, Finite Element Modelling (FEM), Circular Hollow Sections, externally welded double-tee beams, resistance.

1 Introduction

Usage of Circular Hollow Sections (CHS) in modern structures, particularly for Moment Resisting Frames (MRFs), has seen a significant increase in recent years. The inherent geometric properties of CHS, such as their uniform strength characteristics and aesthetic appeal, make them highly suitable for use in high-load bearing applications [1]. This growing trend is supported by advancements in manufacturing and material science, which have improved the quality and availability of CHS for structural applications. The adoption of CHS in MRFs is further driven by their ability to dissipate energy efficiently during seismic events, making them a preferred choice in earthquake-prone areas [2-4]. Despite their increasing use in MRFs, CHS are predominantly utilized in portal frames rather than perimeter frames. Portal frames benefit significantly from the structural efficiency and simplicity of CHS, especially in industrial buildings and warehouses where large, clear spans are required. The preference for CHS in portal frames over perimeter frames can be attributed to the specific load distribution and architectural requirements that differ significantly between these two types of structures. Understanding the behaviour of joints in perimeter frames becomes crucial as the application of CHS expands beyond traditional portal frames. The joints in perimeter frames often undergo more complex stress distributions due to the variability in loading conditions and the architectural constraints associated with these structures. Currently in Eurocode 3 part 1.8 [5], there are well established guidelines available to design soldered and fastened joints with double Tee sections, however, in the case of CHS as column, it still uses a basic method from studies done in 1982 by Wardenier [6]. The procedure operates under assumption that the primary influence on flexural response stems from the chord face failure mode which can be considered the weakest component of the joint. This localized failure mode is conceptualized by modeling resistance of corresponding T-joints with branch plates multiplied with the beam depth (h_1) as depicted in Fig. 1. Building upon this, Wardenier, De Winkel, and Van Der Vegte [7-14] conducted numerous experimental campaigns and numerical studies and influenced CIDECT (International Committee for the Development and Study of Tubular Structures) to incorporate their findings into the organization's design guidelines [15].

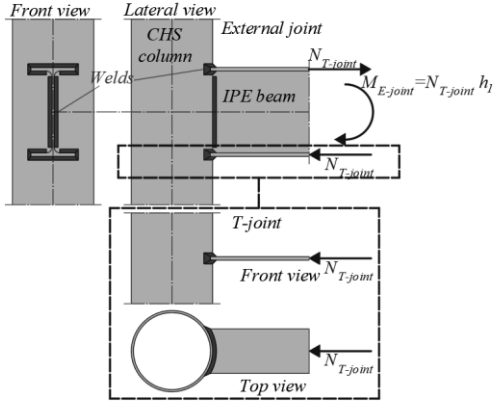


Figure 1: Approach of EC3 part 1.8 [5] approach for CHS-IPE Joints

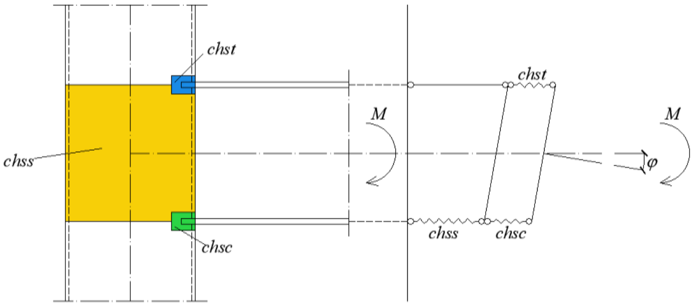


Figure 2: Components Identification

However, recent research conducted by Voth and Packer [16, 17] has shown that the equations suggested by CIDECT and EC3: 1-8 for predicting plastic resistance for T-joints are too conservative. This makes us question if these equations are suitable for beam-to-column connections. Precisely, the findings point out that both standards overlook the impact of plate thickness and fail to distinguish between tension and compression resistance, leading to overly conservative estimates. In this context, a study was conducted at the University of Salerno which involved experimentation, validation of numerical models against the same, conducting a parametric analysis using the validated models and comparing the results of the same with the current available analytical formulations which include EC3 [5], CIDECT [15] and Voth [17]. The present manuscript offers the analytical portion of this research which covers the validity of the available formulation to predict the CHS-Plate component of the joint. In actual, as per the EC3: Part 1.8 component method approach [5], three components can be identified when it comes to CHS-externally welded IPE joint (Fig. 2) which are explained in table 1 below.

Table 1 – Components

Component	Type	Equivalency
chsc	Local Deformability	Plate-CHS T-Joint in compression
chst	Local Deformability	Plate-CHS T-Joint in Tension
chss	Shear Strength of Tube	Panel in Shear under beam action

This research will focus specifically on the resistance of chst/chsc components to evaluate the predictive accuracy of available formulations. The third component 'chss' will be used in the next part of this research where the whole joint will be studied in entirety.

2 Analytical Formulations

The T-joints involving Welded branch plates and CHS chords resist chord failure using Togo's ring model theory [18]. The ring model provides a framework for analyzing a CHS exposed to actions transmitted axially by a plate that is externally welded at 90^0. This helps like a simplified representation for a more complex issue, where the development of yield lines in three dimensions would typically govern failure under load as shown in Figure 3.

The equations currently used in estimating the resistance for T-joints under compression or tension (similar to those in connections between circular hollow section columns and double-tee beams) are shown as Equations 1, 2 and 3, and come from references [5], [15], and [16].

$$F_{pl,EC3} = (4 + 20\beta^2) f_{y0} t_0^2 \tag{1}$$

$$F_{pl,CIDECT} = 2.2(1 + 6.8\beta^2)\gamma^{0.2} f_{y0} t_0^2 \tag{2}$$

$$F_{pl,Voth} = k_1(1 + k_2\beta^2)(1 + 0.6\eta)\gamma^{k_3} f_{y0} t_0^2 \tag{3}$$

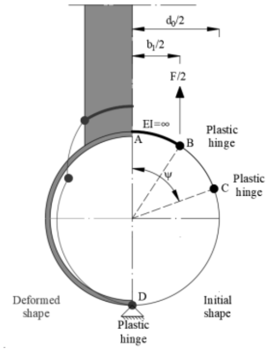


Figure 3: 'chst' Ring Model

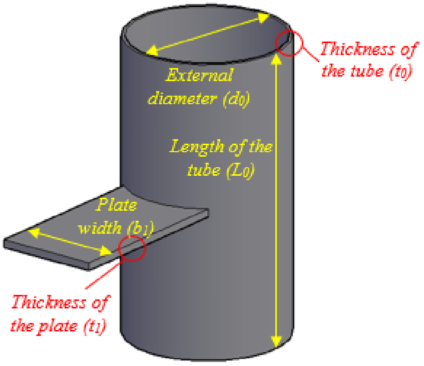


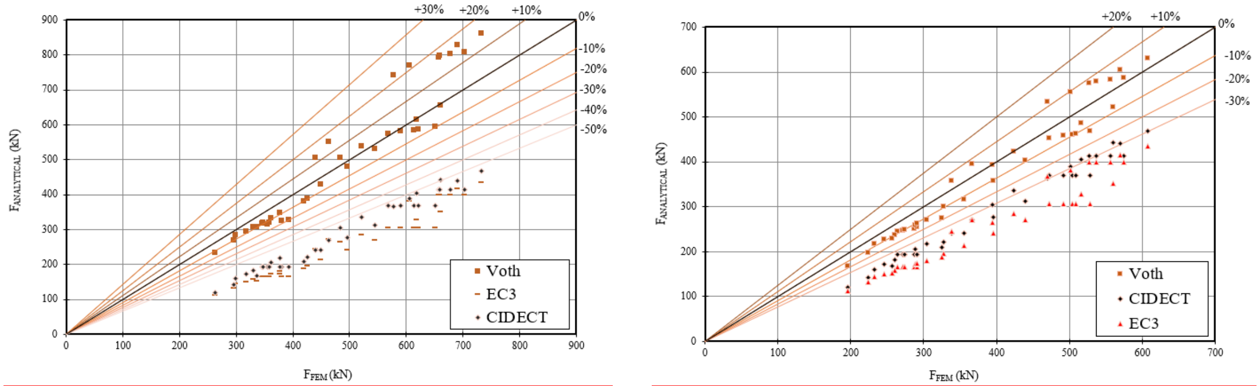
Figure 4: Strength influencing Geometric parameters

It's important to note that EC3 part 1.8 and CIDECT use the same equations for tension and compression. However, Voth adjusted the coefficients based on a large set of test results. In Eq. 3, for T-joints in tension, the coefficients k_1, k_2 and k_3 are 2.3, 2.5, and 0.55, respectively, whereas, $k_1 = 2.6$, $k_2 = 3$ and $k_3 = 0.35$ for compression behaviour. The other parameters involved in the equations are β, γ and η which are non-dimensional and depend on the geometry of the connections involved as depicted in figure 4 and shown below;

$$\beta = \frac{b_1}{d_o}, \gamma = \frac{d_o}{2t_o}, \tau = \frac{t_1}{t_o}$$

3 Parametric Analysis

For checking the accurateness level for equations 1-3, FE data from [19] was utilized. A simplified approach was adopted for the welds, employing zero-thickness Tie contacts to connect plates and chords. Mentioned generalization was intended at streamlining method of modelling, reducing computational period without losing in accuracy as already shown in [20]. The analysis involved a total of 40 cases with varying β, η, γ and τ (Table 2). Figures 5a and 5b compare the tension and compression strength from Forty Finite Element simulations for T-joints with predicted values by Eqs. 1-3.



a) *chst Component*

b) *chsc Component*

Figure 5: FE Models vs Analytical formulations

Table 2 – Parametric analysis Cases [19]

Cases	***k* (kN/mm)**	***β***	***γ***	***τ***	***η***
1-40	292-653	0.44-0.74	15.28-22.75	2-5.83	0.05-0.18

Assessment reveals that Voth's method correctly forecasts how strong the component is. In contrast, EC3-1.8 and CIDECT are cautious and forecast component's plastic resistance to be about 50% less in tension and 40% less in compression than it actually is. The difference stems from the assumption made by EC3 and CIDECT that the component's strength will be unvarying in both compression and tension, whereas in reality, that is not the case. The strength in tension component is relatively higher as compared to compression due to different buckling phenomenon. Furthermore, both overlook significant influence by the parameter 'η' on T-joint strength.

4 Conclusion

This paper focuses on investigating two components of CHS-externally welded double tee profiles which are effectively CHS-plate connection with either plate in tension and compression. There are equations present in design guidelines from EC3 and CIDECT to predict the plastic strength of these connections however, studies have shown that the equations tend to underpredict the actual strength exhibited by the same. Numerical data from [19] was taken to check the accuracy level of the equations from EC3 [5], CIDECT [15] and Voth [16] and the findings clearly show that Eurocode 3 Part 1.8 and CIDECT rules underestimate how strong the connections are. On the other hand, Voth's equations are very accurate. This highlights how important it is to consider plate thickness when making predictions.

Acknowledgement

The authors would like to express their gratitude to Prof. Dr. Gianvittorio Rizzano and Dr. Eng. Sabatino Di Benedetto for their invaluable guidance throughout the research.

References

[1]. Di Benedetto, S., Latour, M., Rizzano, G., Stiffness Prediction of Connections between CHS Tubes and Externally Welded I-Beams: FE Analyses and Analytical Study, *Materials*, 13, 3030; doi:10.3390/ma13133030, 2020.

[2]. Landolfo, R., Zandonini, R., Steel and Steel-Concrete composite structures in seismic area: advances in research and design, The research project RP3 of the ReLUIS-DPC 2014-18, 489 p, ISBN: 978-88-89972-74-8, 2018.

[3]. Das, R., Kanyilmaz, A. and Degee, H., Laser Cut passing-through Open-to-CHS Beam-to-Column Connections. *ce/papers*, 4: 964-972, 2021, https://doi.org/10.1002/cepa.1385.

[4]. Varughese, L.M., & Johny, E., Analytical Study on Effect of Dimensions of Tapered Cover Plates and vertical stiffeners on Replaceable I-Beam to CHS Column Joint. *International journal of engineering research and technology*, 2018.

[5]. CEN [2005]: EN 1993-1-8 *Eurocode 3: Design of Steel Structures. Part 1-8: Design of Joints*, CEN, European Committee for Standardization, 2005.

[6]. Wardenier, J., Hollow section joints, Delft University Press, Delft, The Netherlands, 1982.

[7]. Wardenier, J., Kurobane, Y., Packer, J.A., Dutta, D., Yeomans, N., Design guide for circular hollow section (CHS) joint under predominantly static loading, Ed. By Comité International pour le Développement et l'Etude de la Construction Tubulaire (CIDECT), Verlag TÜV Rheinland GmbH, Köln, Germany, 1991.

[8]. Kamba, T., Tabuchi, M., Database for tubular column to beam connections in moment resisting frames, IIW doc. XV-893-95, Dep. Of Architecture, Faculty of Engineering, Kobe University, Japan, 1995.

[9]. van der Vegte, G.J., The Static Strength of Uniplanar and Multiplanar Tubular T- and X-Joints, Ph. D. Thesis, Delft University Press, Delft, The Netherlands, 1995.

[10]. de Winkel, G. D., and Wardenier, J., Parametric Study on the Static Strength of Axially Loaded Multiplanar Plate to Circular Column Connections, Proceedings ISOPE Fifth International Offshore and Polar Engineering Conference, Vol. IV, The Hague, The Netherlands, 1995.

[11]. de Winkel, G. D., and Wardenier, J., The Static Strength and Behaviour of Multiplanar I-beam to Tubular Column Connections loaded with In-plane Bending Moments, Proceedings of the Third International Workshop Connections in Steel Structures III, Trento, Italy, 1995.

[12]. de Winkel, G. D., and Wardenier, J., Parametric Study on the Static behavior of Uniplanar I-beam-to-tubular Column Connections Loaded with In-plane Bending Moments Combined with Pre-stressed Columns, Proceedings of the Seventh Int. Symposium on Tubular Structures VII, Miskolc, Hungary, 1996.

[13]. de Winkel, G. D., The Static Strength of I-beam to Circular Hollow Section Column Connections, Ph. D. Thesis, Delft University Press, Delft, The Netherlands, 1998.

[14]. Wardenier, J., A uniform effective width approach for the design of CHS overlap joints, Proceedings of the 5th International Conference on Advances in Steel Structures (ICASS), Singapore, Research Publishing Services, Vol. II, pp. 155-165, 2007.

[15]. Wardenier, J., Kurobane, Y., Packer, J.A., van der Vegte, G.J., Zhao, X.L., Design guide for circular hollow section (CHS) joints under predominantly static loading, 2nd Ed., CIDECT, Geneva, Switzerland, 2008.

[16]. Voth, A., Branch Plate-to-Circular Hollow Structural Section Connections, Ph. D. Thesis, Toronto, 2010.

[17]. Voth, A.; Packer, J.A., Branch Plate-to-Circular Hollow Structural Section Connections. I: Experimental Investigation and Finite-Element Modeling, J. Struct. Eng. 2012, 138, 995–1006.

[18]. Togo, T., Experimental study on mechanical behavior of tubular joints, D. Eng. Thesis, Osaka University, Osaka, Japan, 1967.

[19]. Ajwad, A., Di Benedetto, S., Latour, M., Rizzano, G., A component method approach for single-sided beam-to-column joints with CHS columns and welded double-tee beam, Thin-Walled Structures, 112055, ISSN 0263-8231, https://doi.org/10.1016/j.tws.2024.112055, 2024.

[20]. Sato, A., Elettore, G., Ajwad, A., Di Benedetto, S., Latour, M., Francavilla, A.B., and Rizzano, G., Stiffness of Welded T-joints Between SHS Profiles and Through Plates, STESSA 2024, pp. 350,361, Lecture Notes in Civil Engineering, vol 519. Springer, Cham. https://doi.org/10.1007/978-3-031-62884-9_31.