PREDICTING THE INITIAL STIFFNESS OF EXTERNALLY WELDED CHS-TRANSVERSE PLATE JOINTS AT VERTICAL AND HORIZONTAL CONNECTIONS

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Abstract- This study performs an analytical examination of how transverse T-type plate-to-circular hollow section (CHS) connections behave when subjected to tension or compression forces from the branch plate. At present, EC 3: 1.8 focuses only on resistance prediction of tubular joints and does not address stiffness prediction. Consequently, in practical applications, tubular joints are frequently modelled using simplistic assumptions of either pinned or fully restrained conditions, resulting in inaccurate predictions due to the omission of stiffness considerations. This paper addresses the identified gap in Eurocode 3 Part 1.8 by proposing two equations, using Clapeyron theorem, for initial stiffness prediction of transverse plate-to-CHS joints using the Clapeyron theorem. The proposed equations aim to provide guidelines for stiffness prediction, which is currently absent in the code. Numerical comparisons were conducted with results from another study, analyzing 40 cases. The findings demonstrated that both equations accurately predicted stiffness, with mean values close to 1 and 1.03 and coefficients of variation (CoV) of 12% and 15%, respectively.

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

1 Introduction

Circular Hollow Section (CHS) members are increasingly preferred as a substitute for steel open section members due to their visually appealing exposed steelwork. The enhanced compression resistance of CHS steel members often results in lighter and more cost-effective elements compared to open section members, despite the higher cost [1]. Moreover, CHS members generally have reduced painting costs due to their smaller surface area, lower transportation costs due to their lighter weight, and simpler installation procedures due to their reduced weight compared to open sections [2]. In the context of a CHS-plate joint, the joint exhibits high deformability as compared to traditional connections with open sections. This flexibility can result in excessive distortion or plastic deformation of the CHS connecting face, particularly at the interface with the transversally attached branch plate. As per the guidelines outlined by IIW (1989) [3], a face deformation limit of 1% of the main member (Circular Hollow Section) diameter is traditionally used as a serviceability deformation threshold. Therefore, accurately determining the initial stiffness provided by this type of connection is crucial for ensuring that the deformation remains within acceptable limits during serviceability. Despite the fact, Current design guidelines concerning circular hollow sections which are Eurocode 3 part 1.8 [4], AISC 316-16 [5] and CIDECT [6] have a notable limitation. They primarily address the assessment of resistance for externally welded plates but do not include provisions for predicting stiffness in these configurations. Building upon this limitation, the present study aims to bridge identified knowledge gaps by introducing analytical formulations using the Clapeyron theorem for stiffness determination. These formulations will be validated through comparison with numerical results obtained in a previous study [7]. The focus is on enhancing the understanding and prediction of stiffness in circular hollow section (CHS) connections, complementing the existing guidelines in Eurocode 3 Part 1.8 [4].

2 Parametric Study

In order to check the accuracy of the derived equation, numerical data of 40 selected cases (Table 1) obtained from [7] was utilized in this study which were validated using experimental data available in literature. The selected cases depended upon non-dimensional parameters τ, β, γ and (Figure 1), where;

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

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 [8].

Table 1 – Parametric analysis Cases [5]

Case	k(kN/mm)	β	γ	τ	Case	k(kN/mm)	β	γ	τ
1	292	0.62	16.14	3.33	**21**	487	0.61	15.28	3.13
2	299	0.62	16.14	3.75	**22**	553	0.65	15.28	3.13
3	308	0.62	16.14	4.17	**23**	630	0.70	15.28	3.13
4	323	0.62	16.14	5.00	**24**	714	0.74	15.28	3.13
5	335	0.62	16.14	5.83	**25**	430	0.44	20.32	2.50
6	577	0.65	15.28	3.13	**26**	469	0.47	20.32	2.50
7	603	0.65	15.28	3.75	**27**	514	0.49	20.32	2.50
8	621	0.65	15.28	4.06	**28**	558	0.52	20.32	2.50
9	628	0.65	15.28	4.38	**29**	606	0.54	20.32	2.50
10	653	0.65	15.28	5.00	**30**	191	0.55	21.91	5.00
11	485	0.49	20.32	2.00	**31**	227	0.55	19.92	5.00
12	511	0.49	20.32	2.50	**32**	265	0.55	18.26	5.00
13	534	0.49	20.32	3.00	**33**	307	0.55	16.85	5.00
14	552	0.49	20.32	3.50	**34**	353	0.55	15.65	5.00
15	241	0.54	16.14	4.17	**35**	342	0.62	22.75	4.00
16	261	0.57	16.14	4.17	**36**	395	0.62	21.00	4.00
17	284	0.59	16.14	4.17	**37**	449	0.62	19.50	4.00
18	336	0.65	16.14	4.17	**38**	506	0.62	18.20	4.00
19	366	0.67	16.14	4.17	**39**	304	0.45	22.23	3.00
20	442	0.57	15.28	3.13	**40**	342	0.45	20.92	3.00

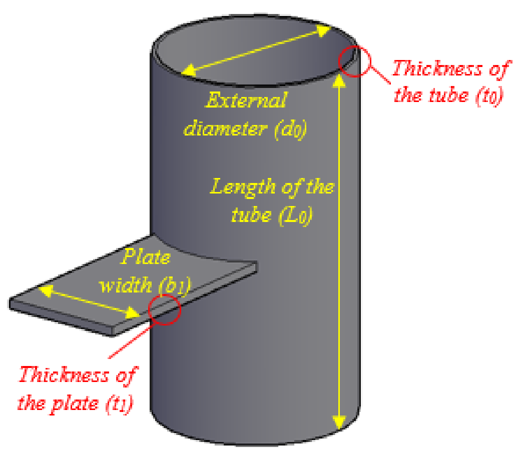

Figure 1: Geometric Factors Affecting Mechanical Performance of Specimen

3 Equation Derivation

The proposed method for stiffness prediction is built upon an analytical approach for the two-dimensional configuration depicted in Fig. 2. Finite element (FE) models indicate that, under low load levels, bottom semi of CHS chord experiences minimal deformation. Therefore, for simplification purposes, only a quarter of the tube is modeled, aligning with the reference configuration shown in Figure 1. Point A is fully restrained, and a guided support is placed at point B, where the plate connects to the tube. Because the system is hyperstatic, the principle of virtual work is used for calculating the reactions upon these supports.

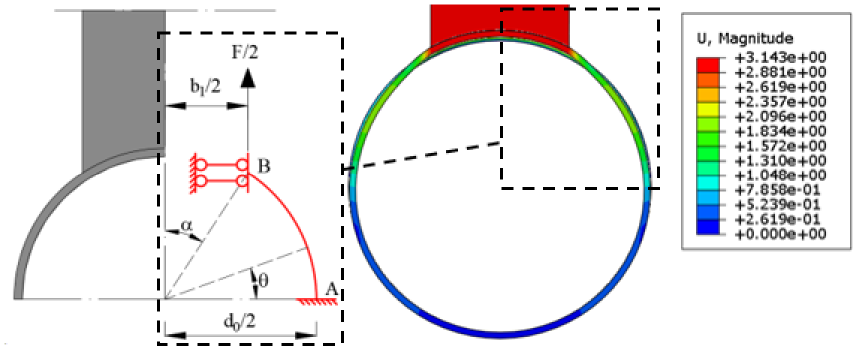

Figure 2: Simplified Procedure for Assessing Component Stiffness

After determining the reactions, the vertical displacement of node B (δ_B) in the tube is calculated using Clapeyron's theorem (Equation 1).

$$1 \cdot \delta_B = \int_0^{\frac{\pi}{2}-\alpha} M^s\,\chi^s\;dz + \int_0^{\frac{\pi}{2}-\alpha} T^s\,\gamma^s\;dz + \int_0^{\frac{\pi}{2}-\alpha} N^s\,\varepsilon^s\;dz \tag{1}$$

Comparisons and calculations showed that shear and axial deformability terms in Equation 1 only affect the displacement of node B (δ_B) by about 1%. To make things simpler, these terms are ignored. Using the integral from Equation 1, we can find the stiffness by dividing the force (F) by the displacement (δ_B), resulting in an easy-to-use equation.

$$k_{\mathrm{j}} = 226.5 \cdot \frac{E b_{eff} t_o^3}{d_o^3} \frac{0.03\beta^2 + 0.16\beta + 0.13}{(1 - 0.637\beta - 0.106\beta^3)^5(0.26\beta^2 - 0.55\beta + 1.06)} \tag{2}$$

Here, b_{eff} stands for an effective width that considers how the material deforms in three dimensions and 'E' is the modulus of elasticity for the CHS chord member equal to 210 kN/mm^2. It is determined using three non-dimensional parameters: β, γ and τ. This approach follows the method previously used by the authors in [6]. Therefore, b_{eff} can be expressed as follows;

$$\frac{b_{eff}}{d_o} = c_1 \beta^{c_2} \gamma^{c_3} \tau^{c_4} \tag{3}$$

Using the numerical data from Table 1, a regression analysis was performed to find the coefficients in Equation 3. The resulting values are as follows: $c_1 = 1.33 \text{ x } 10^{-3}$, $c_2 = -2.7$, $c_3 = 1.57$, $c_4 = -0.21$, namely:

$$k_j = \frac{3}{80} E d_o \beta^{-2.7} \gamma^{-1.43} \tau^{-0.2} \frac{0.03\beta^2 + 0.16\beta + 0.13}{(1 - 0.637\beta - 0.106\beta^3)^5(0.26\beta^2 - 0.55\beta + 1.06)} \tag{4}$$

Where;

$$\frac{0.03\beta^2 + 0.16\beta + 0.13}{(1 - 0.637\beta - 0.106\beta^3)^5(0.26\beta^2 - 0.55\beta + 1.06)} \cong 37.3\beta^{4.4} \tag{5}$$

Because Equation 4 is too complicated for practical use, a simpler version has been developed. This simplified form achieves an average error below 3% for angles α between 25° and 50° (refer to Figure 2).

$$k_{j,sim.} = 1.4 E d_o \beta^{1.7} \gamma^{-1.4} \tau^{-0.2} \tag{6}$$

The accuracy of both equations was checked (Eqs. 4 and 6) by comparing their predictions with the numerical results in Table 1. Figure 3 shows that Eq. 4 predicts the numerical results very closely, averaging 1 and 12% variability. The simplified equation (Eq. 6) is to some extent less accurate in comparison to the derived equation, with an average of 1.03 and variability of 15%. However, for practical purposes, Eq. 6 strikes a good balance between simplicity and accuracy.

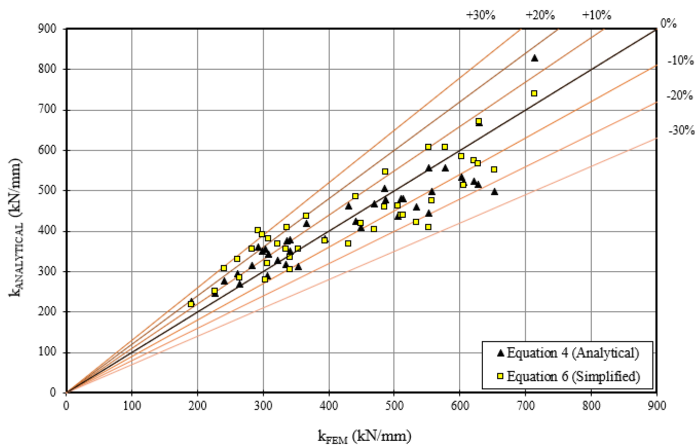

Figure 3: Stiffness formulations vs FE models

4 Conclusion

To address the absence of initial stiffness prediction formulations for CHS-to-transversally welded plate connections in Eurocode 3 Part 1.8 [4], a study was conducted to develop two equations for this purpose. Numerical data from 40 cases in a separate study [5] was used to validate these derived equations. The results demonstrated that both formulations achieved accuracy of good level when comparison is done to the numerical results. Specifically, analytical equation predicted initial stiffness with 1 as the mean value and 12% CoV, while the simplified equation yielded a mean value of 1.03 with 15% CoV. However, the equations are constrained by the defined limits of the parameters 'β', 'γ' and 'τ'. These limits are 0.44 to 0.74 for 'β', 15.28 to 22.75 for 'γ' and 2 to 5.83 for 'τ' respectively.

5 Recommendation for future research

This research can be further extended to the prediction of the initial stiffness of CHS-IPE joints in their entirety, where the CHS-Plate connection functions as an integral component.

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