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PREDICTING INITIAL STIFFNESS IN WELDED T-JOINTS FEATURING CHS CHORDS AND LONGITUDINAL THROUGH-PLATE CONNECTIONS

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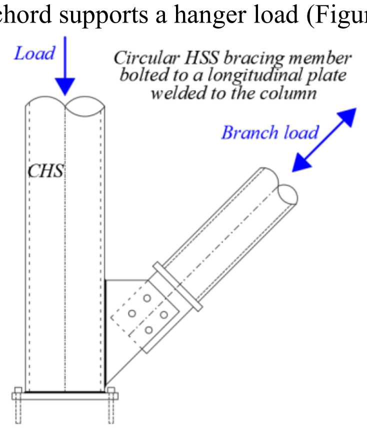
Abstract- In steel braced frames, connecting longitudinal plates to Circular Hollow Sections (CHS) can lead to low joint stiffness due to deformation of the tube face, often requiring thicker members. To improve this, passing-through plate connections offer increased stiffness but lack predictive stiffness models in current codes and research. This study addresses that gap by developing stiffness formulations for CHS T-joints with axially loaded passing-through plates. Using validated finite element models and parametric analysis of 65 configurations, the proposed equations—based on simplified mechanical models—accurately predict initial stiffness of the connection, having a mean prediction ratio of 1.01 and the coefficient of variation equal to that of 7%.

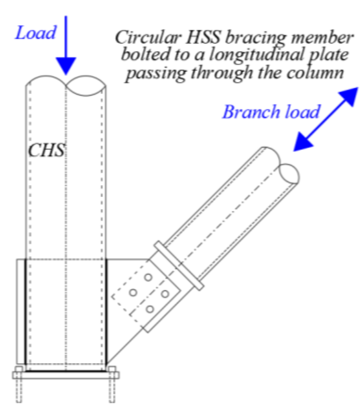
Keywords- Passing-through longitudinal plate, Circular hollow section profile, Regression analysis, Finite element modelling, Abaqus

1 Introduction

Hollow structural section (HSS) members are increasingly favored over open steel sections due to their aesthetically appealing exposed steelwork. Despite a higher cost per ton, their superior compression resistance often results in lighter, more economical compression elements [1]. HSS members also typically reduce painting and transportation costs due to their smaller surface area and lighter weight, while easing installation [2]. Longitudinal plates subjected to axial loads are commonly welded to HSS members in low-rise steel braced frames where wind governs lateral loading [3]. These plates are usually shop-welded to the column and field-bolted to the brace (Figure 1a), though an alternative involves passing the plate through the HSS and welding it on both sides (Figure 1b). A similar detail is seen in CHS trusses, where a plate welded to a chord supports a hanger load (Figure 1c and 1d).



a) Longitudinal Externally Welded



b) Longitudinal Passing Through

c) Longitudinal Externally Welded (K-Joint)

d) Longitudinal Passing Through (T-joint)

Figure 1: Example of a Plate to CHS Connection

Attaching longitudinal plates to CHS members, a practice adapted from I-sections, is common in braced frames for connecting multiple braces at various angles. While extensive research exists on gusset plates welded to I-sections, studies on CHS connections remain limited. In I-sections, axial loads transfer directly through the flange to the web, providing inherent stiffness. In contrast, CHS members distribute axial loads circumferentially via an arching mechanism, inducing out-of-plane bending and making the connection more flexible. This often results in excessive face deformation, with a 1% CHS diameter limit used as a serviceability criterion [4]. Hence, assessing the initial stiffness of such connections is critical. However, Eurocode 3 Part 1.8 [5] only addresses externally welded plates, lacking guidance on through-plate connections and stiffness predictions.

To address the lack of stiffness prediction methods for longitudinal plate-to-CHS joints—particularly for passing-through configurations overlooked by Eurocode 3 Part 1.8—this study proposes analytical equations to estimate initial connection stiffness. Building upon foundational research by Washio et al. [6], Akiyama et al. [7], and analytical work by Togo [8] and Wardenier [9], this study focuses exclusively on passing-through plate connections under axial tension. Passing-through plates are estimated to exhibit 3 to 5 times greater stiffness compared to externally welded plates. Finite element (FE) models were developed and validated using experimental data from Voth [10], which included tests on passing-through plate joints. A parametric analysis comprising sixty-five simulations was then performed on the validated models, forming the basis for the proposed stiffness prediction equations.

2 Parametric Study

In order to check the accuracy of the derived equation, numerical data of 65 selected cases (Table 1) obtained from [11-12] was utilized in this study which were validated using experimental data available in literature with a mean of 0.99. The selected cases depended upon non-dimensional parameters τ, β, γ and η (Figure 2), where;

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

To connect plates to chords, zero thickness tie contacts were used as a simplified approach. This simplification was intended to reduce the computational time required for the analysis without comprising the accuracy of the models outcomes as already shown in [13-14].

Table 1 Parametric analysis Cases

Case	k(kN/mm)	β	η	γ	τ	Case	k(kN/mm)	β	η	γ	τ
1	204	0.05	0.52	16.14	1.67	**34**	895	0.10	1.23	13.58	2.78
2	227	0.08	0.52	16.14	2.50	**35**	998	0.10	1.43	13.58	2.78
3	255	0.10	0.52	16.14	3.33	**36**	263	0.06	0.62	20.32	2.50
4	308	0.13	0.52	16.14	4.17	**37**	287	0.06	0.74	20.32	2.50
5	349	0.15	0.52	16.14	5.00	**38**	312	0.06	0.86	20.32	2.50
6	329	0.05	0.91	15.65	1.43	**39**	338	0.06	0.98	20.32	2.50
7	365	0.07	0.91	15.65	2.14	**40**	365	0.06	1.11	20.32	2.50
8	408	0.09	0.91	15.65	2.86	**41**	349	0.10	1.37	18.26	3.50
9	489	0.11	0.91	15.65	3.57	**42**	630	0.11	1.37	15.65	3.50
10	552	0.14	0.91	15.65	4.29	**43**	1023	0.13	1.37	13.69	3.50
11	532	0.04	1.51	15.28	1.25	**44**	1608	0.14	1.37	12.17	3.50
12	585	0.06	1.51	15.28	1.88	**45**	2560	0.16	1.37	10.96	3.50
13	645	0.08	1.51	15.28	2.50	**46**	288	0.10	1.23	20.38	4.00

14	765	0.10	1.51	15.28	3.13	**47**	475	0.11	1.23	17.46	4.00
15	854	0.12	1.51	15.28	3.75	**48**	753	0.13	1.23	15.28	4.00
16	390	0.04	1.48	20.32	1.50	**49**	1188	0.15	1.23	13.58	4.00
17	413	0.05	1.48	20.32	2.00	**50**	1858	0.16	1.23	12.23	4.00
18	455	0.06	1.48	20.32	2.50	**51**	285	0.08	1.10	19.50	3.00
19	480	0.07	1.48	20.32	3.00	**52**	454	0.09	1.10	17.06	3.00
20	510	0.09	1.48	20.32	3.50	**53**	673	0.10	1.10	15.17	3.00
21	376	0.10	0.52	13.84	2.86	**54**	967	0.11	1.10	13.65	3.00
22	469	0.10	0.77	13.84	2.86	**55**	354	0.08	1.47	19.50	3.00
23	562	0.10	1.03	13.84	2.86	**56**	563	0.09	1.47	17.06	3.00
24	645	0.10	1.29	13.84	2.86	**57**	830	0.10	1.47	15.17	3.00
25	748	0.10	1.55	13.84	2.86	**58**	1186	0.11	1.47	13.65	3.00
26	390	0.09	0.46	13.69	2.50	**59**	422	0.09	1.41	19.76	3.50
27	478	0.09	0.68	13.69	2.50	**60**	588	0.10	1.41	17.78	3.50
28	568	0.09	0.91	13.69	2.50	**61**	448	0.10	1.41	19.76	4.00
29	657	0.09	1.14	13.69	2.50	**62**	631	0.11	1.41	17.78	4.00
30	746	0.09	1.37	13.69	2.50	**63**	373	0.08	1.48	22.58	3.50
31	578	0.10	0.61	13.58	2.78	**64**	289	0.09	1.48	20.32	3.50
32	684	0.10	0.82	13.58	2.78	**65**	399	0.10	0.98	20.32	4.00
33	790	0.10	1.02	13.58	2.78						

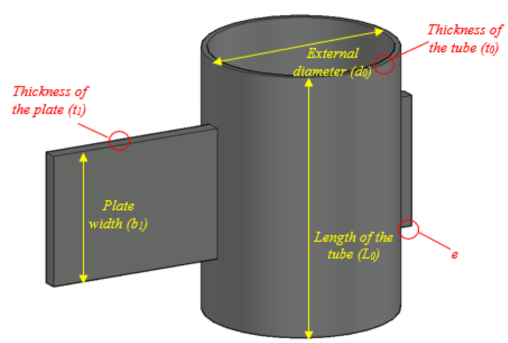


Figure 2: Geometric Factors Affecting Mechanical Performance of connection

3 Equation Derivation

To establish a formulation for computing the stiffness in the passing-through plate configuration, the initial step involves identifying a closed-form solution for the 2D scheme as outlined in Figure 3. In this scheme, guided supports are strategically placed at the plate-to-column attachments, and an external roller is positioned at the midpoint of the examined arch. Wherein the negligible contributions of axial and shear deformability were disregarded to simplify the equation.

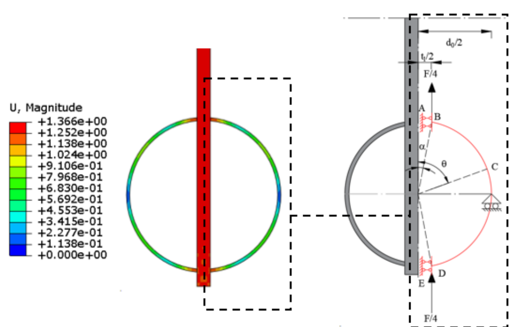


Figure 3: Simplified scheme to assess the stiffness of the passing through component

The derived Equations are as follows;

$$k_{passing} = \frac{1}{16} E d_o \eta^{0.63} \gamma^{-2.96} \tau^{0.14} \frac{(0.7\beta^2 + 1.5\beta - 1)^2}{(0.003 - 0.02\beta + 0.06\beta^2 - 0.1\beta^3)} \tag{1}$$

$$k_{passing.,sim.} = 60 E d_o \beta^{0.3} \eta^{0.63} \gamma^{-2.96} \tau^{0.14} \tag{2}$$

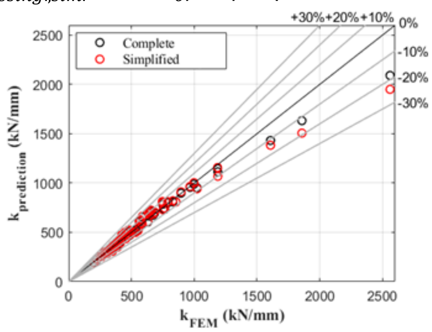


Figure 4: Stiffness formulations vs FE models

4 Conclusion

This study addressed the lack of stiffness prediction methods for passing-through plate-to-CHS connections in Eurocode 3 Part 1.8. A validated finite element model—calibrated against experimental results—was used to conduct a parametric analysis of 65 T-joint configurations with passing-through plates. Based on this, both a closed-form analytical expression and a simplified design formula were proposed. The simplified formula demonstrated strong agreement with FE results (Figure 4), achieving a mean prediction ratio of 1.01 and a coefficient of variation (CoV) of 0.08, confirming its accuracy and reliability. However, the applicability of the proposed equation is currently limited to the parameter ranges considered in the parametric analysis—specifically, β ranging from 0.04 to 0.16, γ between 10.96 and 22.58, τ from 1.25 to 5, and η between 0.46 and 1.55. These ranges correspond to CHS profiles that are readily available in the market, ensuring the proposed formula remains practically relevant for typical design applications.

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