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ANALYTICAL AND NUMERICAL STUDY ON THE BEHAVIOR OF STEEL FLUSH END PLATE (FEP) CONNECTIONS

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Abstract

This study evaluates the behavior of the steel flush end plate (FEP) beam-to-column external joint, presented in reference [1]. The investigations involve both analytical and numerical approaches to assess the performance of this typical connection. The analytical method, described in reference [2], represents the Component Method and the numerical analyses involved two finite element method-based software, Consteel and IDEA StatiCa. These two software tools adopt two distinct methodologies - one utilizing the Component Method, while the other implements the Component-Based Finite Element Method. A comparative analysis of the results was performed to evaluate the reliability of the analytical and numerical methods and to analyse the differences between these procedures. The results of the investigations indicate that the end plate is the weakest component of the examined connection. Therefore, a numerical parametric study was conducted to analyse the influence of the end-plate thickness on the overall behavior of the steel flush end-plate beam-to-column external joint.

Keywords: *steel structures, flush end-plate (FEP) connections, component method, component-based finite element method (CBFEM), semi-rigid joint.*

1. Introduction

Connections are critical components of steel or composite structures, significantly influencing their overall behaviour in terms of internal stress distribution and deformations. This paper presents the results of a preliminary study on the behaviour of a beam-to-column external steel connection, isolated from the tested specimens presented in reference **[1].** Through analytical and numerical methods, this study provides a comprehensive evaluation of how variations in end plate thickness affect the initial stiffness and load bearing capacity of the examined connection.

The analytical evaluation of the steel joints with different end plate thicknesses was carried out using the Component Method, in accordance with the SR EN 1993-1-8:2005 **[2]** standard. Furthermore, the numerical analysis of these joints was performed using Consteel and Idea StatiCa software, which apply different methods: the Component Method and Component-Based Finite Element Method (CBFEM).

The specimens presented in **[1]** were designed to represent typical flush end plate connections within a structural frame with a span of 8.00 m. One test was conducted on an internal joint (T1), while two tests were performed on external joints (T2, T3). In all three cases, the joints were made of steel columns and composite beams with a 10 cm thick and one meter wide reinforced concrete slab. The slab was connected to the steel beam using a single row of 11 pcs. shear studs, welded to the upper flange of the beam and spaced at 10 cm intervals. The column sections consisted of HEB240 profiles, while the beams were made of IPE270 profiles. At the load point, located at the free end of the IPE cantilever, 10 mm thick stiffening plates were added.

The end plate, with a thickness of 10 mm, was welded to the IPE270 beam and fastened to the column with four M16 bolts. The HEB240 and IPE270 profiles were fabricated from S275 steel grade, while the bolts were of class 10.9.

The tested specimens are illustrated in **Figure 1.** and the results obtained for the initial stiffness ($S_{j.ini}$) and moment resistance ($M_{j.Rd}$) of the external composite connections are presented in **Table 1.**

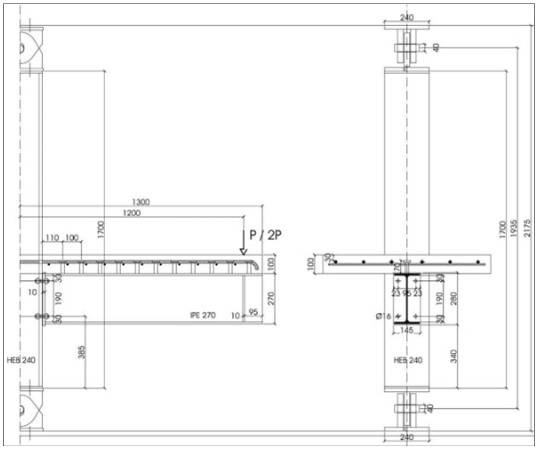

Fig. 1. *The T2 and T3 specimens, tested as part of the experimental program* [1]

Table 1. *Results from reference* [1] *for the composite joint*

Connection	$S_{j.ini}$ [kNm/rad]	$M_{j.Rd}$ [kNm]
T2	13700	147.4
T3	15800	163.1

2. Analytical Evaluation

The analytical investigation was conducted using the Component Method, where each component is identified as a spring with a nonlinear force-deformation curve, as mentioned by J. Jaspart [3]. Therefore, each component is considered as a semi-rigid component. The method requires the following steps:

- identifying the active components within the joint;
- determining the stiffness and/or the capacity of each individual component, including key parameters such as initial stiffness, design bending resistance and shear resistance;
- identifying the weakest component which determines the final capacity of the joint.

Analytical results indicate that, in the case of the examined flush end plate connection composed entirely of steel parts, the end plate is the weakest component of the joint. The results demonstrate a significant increase in moment resistance and initial stiffness as the thickness increases. However, beyond a thickness of 16 mm, this effect diminishes, as the column flange becomes the most sensitive component.

Table 2 presents the analytically determined initial stiffness ($S_{j.ini}$) and moment resistance ($M_{j.Rd}$) of the assessed joint with varying end plate thicknesses, showing the percentage differences ($S_{j.ini}^{10}$+) in initial stiffness between the joint with a 10 mm thick end plate and those with greater thicknesses.

Table 2. *Analytical results of the investigated joint*

Connection	$S_{j.ini}$ [kNm/rad]	$M_{j.Rd}$ [kNm]	$S_{j.ini}^{10}$+ (%)
A-p10mm	10034.49	34.28	0
A-p12mm	11466.35	39.54	14.26
A-p14mm	12312.10	45.77	22.70
A-p16mm	12796.50	52.94	27.53
A-p18mm	13064.54	57.64	30.19
A-p20mm	13201.75	57.82	31.56

3. Numerical Analysis

In reference [1], the weld size between the beam and the end plate was not specified. Therefore, 3 mm weld was used throughout the evaluations to match the end plate dimensions. Furthermore, it should be noted that the mechanical properties obtained through tensile testing of the steel components were not provided in reference [1]. As a result, the numerical analyses were conducted using theoretical mechanical properties, specifically a yield strength of 275 N/mm² and a Young's modulus of 210 GPa.

Consteel and Idea StatiCa software were used to numerically evaluate the flush end plate external joint. Consteel adopts the Component Method, while Idea StatiCa utilizes the Component Based Finite Element Method (CBFEM) for the evaluation of steel connections.

As previously mentioned, the Component Method considers each joint component as a spring.

In contrast, CBFEM integrates the advantages of the Component Method and the Finite Element Method by decomposing the joint into its individual components. It then applies nonlinear material analysis to evaluate each component independently, as well as the joint as a whole, considering component interactions that ultimately determine the overall capacity of the joint, as described by Lubomír Šabatka [4].

A numerical analysis was performed to compare both methods and to validate the analytical results. The results obtained from Consteel and the analytical method showed strong agreement, with differences in initial stiffness and moment resistance remaining below 10%.

The finite element model of the examined flush end plate connection is shown in Figure 2 and the results of the analysis are presented in Table 3 and 4. Additionally, a parametric study was performed by increasing the thickness of the end plate.

4. Discussions and Results

In the ArcelorMittal design guide [5] for multi-storey buildings, it is specified that flush end plate connections with relatively thin end plates (10 mm in S275 steel grade) are generally assumed to be pinned. However, the developed numerical models demonstrated that the investigated configuration exhibits semi-rigid behaviour. Figures 3 and 4 illustrate the differences in bending moment distributions for a frame structure with a span of 8 m. The first illustrates the effect of the tested joint on the bending moment distribution within the structure, while the second uses pinned connection as a reference to compare the effect of different joint types on the structural behaviour.

Furthermore, the analytical and numerical evaluations provide valuable insights into how the choice of calculation method can lead to variations in the results. For the examined joint, tested in reference [1], featuring a 10 mm thick end

Table 3. *Numerical results of the investigated joint in Consteel*

Connection	$S_{j.ini}$ [kNm/rad]	$M_{j.Rd}$ [kNm]
NC-p10mm	9216.41	34
NC-p12mm	10929.6	39.14
NC-p14mm	12026.5	45.22
NC-p16mm	12700.32	52.23
NC-p18mm	13102.63	52.07
NC-p20mm	13333.14	52.07

Table 4. *Numerical results of the investigated joint in Idea StatiCa*

Connection	$S_{j.ini}$ [kNm/rad]	$M_{j.Rd}$ [kNm]
NI-p10mm	9319.441	31.022
NI-p12mm	11359.719	38.301
NI-p14mm	11818.897	45.233
NI-p16mm	12629.169	52.165
NI-p18mm	13351.153	53.032
NI-p20mm	13860.144	53.205

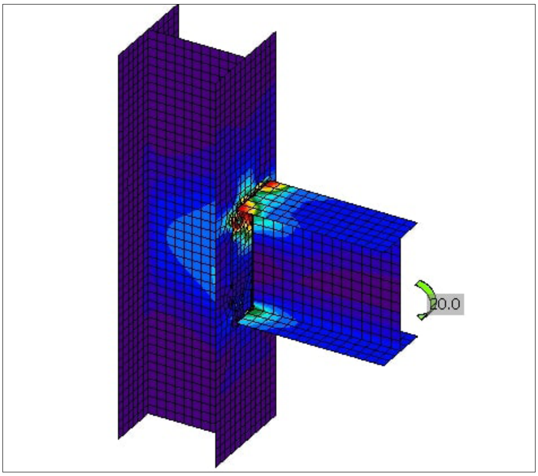

Fig. 2. *Finite element model of the investigated joint.*

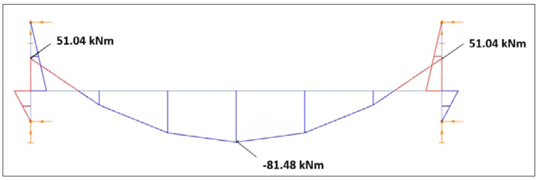

Fig. 3. *Bending moment diagram for the studied joints.*

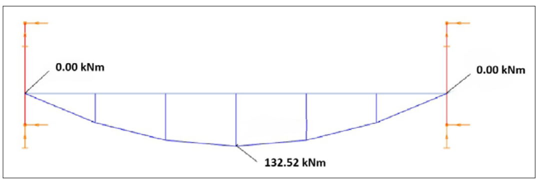

Fig. 4. *Bending moment diagram for pinned connections.*

plate, the results show a high degree of similarity, with differences below 10%. Both the analytical evaluation and Consteel software utilize the Component Method, leading to comparable moment resistance and initial stiffness values. Although Idea StatiCa employs CBFEM, its results do not differ significantly from those obtained using Component Method.

Based on the results of the analytical and numerical analyses, it has been demonstrated that the end plate is the weakest element of the examined connection. The results indicate a significant increase in moment resistance and initial stiffness as the end plate thickness increases. However, beyond a thickness of 16 mm this effect becomes less pronounced, as the column flange then becomes the most critical component of the connection.

5. Conclusion

The evaluation of the connection was made using analytical and numerical methods, revealing its semi-rigid behaviour and its ability to transfer bending moments. The results indicate that the Component Method and CBFEM procedure yield comparable moment resistance and stiffness values, with differences remaining within an acceptable range for the examined joint.

Further aims of the study include an experimental program involving the testing of two types of connections: joints connecting exclusively steel parts and joints connecting steel columns and composite beams.

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