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NUMERICAL STUDY OF BACK-TO-BACK LIPPED CHANNEL PROFILES FOR A PRELIMINARY PUSHOVER ANALYSIS

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Abstract

This paper presents a numerical analysis of the 2C300 × 3 back-to-back lipped channel subjected to four-point bending, with results compared to those from EN 1993-1-3 [1]. The analysis is based on the studies of the 2C240 × 2 profile, validated by experimental test results [2]. The aim is to determine the section's maximum load bearing capacity, to calibrate plastic mechanism models and support pushover analysis. The study also includes preliminary pushover analyses of frame structures, based on [3], considering two types of beam-column connections. The finite element analysis was used to determine the plastic moment resistance of the plastic hinges in these models.

Keywords*: cold-formed structures, numerical analysis, plastic mechanism, pushover analysis, plastic hinges.*

1. Introduction

Thin-walled cold-formed steel (TWCFS) members have become increasingly prevalent in the construction industry due to their advantageous properties, including lightweight design, high strength-to-weight ratios, and versatility in various applications. These members are used in a wide range of structural applications, from secondary load-carrying elements to primary structural components in low- to midrise buildings [4]. Among TWCFS members, built-up back-to-back channel sections are gaining traction as effective solutions for bending and compression loads in building structures [5].

Despite the existence of established design codes, such as EN 1993-1-3 [6], which provide guidelines for designing steel structures, the capacity calculations for built-up cross-sections often yield conservative estimates compared to numerical analyses and experimental results [5]. For instance, according to Eurocode 3 [6]], the calculations for a TWCFS structure should be conducted within the elastic range, meaning that pushover analysis is not considered for evaluating seismic action on the structure. However, several studies [7, 8, 9] have demonstrated the ability of these cross-sections to form plastic mechanisms, which can lead to energy dissipation. This discrepancy highlights the need for further investigation into the structural behaviour of these members under pure bending or combined loading conditions, such as compression and bending.

This research investigates the behaviour of back-to-back lipped channels under pure bending using finite element analysis to determine the deformation shape of the specimens and the ultimate load. These results will then be used for a preliminary pushover analysis of 2D multi-story frame structures.

2. Subject of investigation

The study focused on a beam with a back-to-back lipped channel cross-section subjected to four-point bending, as shown on the left side in Fig. 1. This loading configuration induces a region of pure bending in the central span of the beam.

On the right side of Fig. 1 the height of the lipped channel cross-section is illustrated. The inner radius is 3 mm, the thickness is 3 mm, the flange width is 86 mm, and the lip length is 33 mm. The material used is S350G+Z, with a yield strength of 350 N/mm². The material curve employed for the FE analysis is a quad-linear material model according to prEN 1993-1-14 [10].

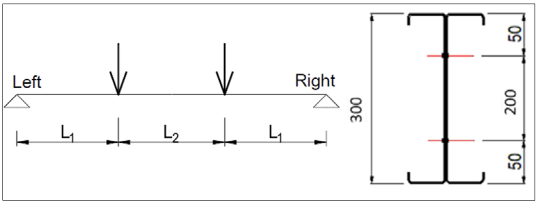

Fig. 1. *Static scheme of the experimental test and the cross- section properties .*

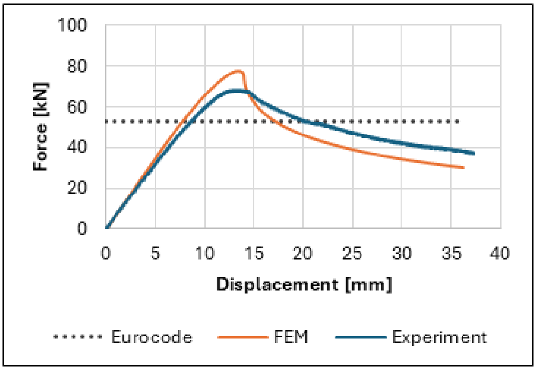

Fig. 2. *Load-displacement curve from the ASCCS2025 conference presentation.*

3. Methodology

3.1. Previous FE analyses

The methodology of the numerical analysis for the back-to-back lipped channel with a 2C300x3 cross section under bending is based on previous research conducted by the authors, which will be presented briefly in the following. The earlier study [11] investigated the behaviour of back-to-back lipped channel section beams under four-point bending to understand their failure modes, ultimate capacities, and load-displacement behaviour. The research aimed to explore the structural response of these thin-walled cold-formed steel elements, presenting a numerical investigation of the specimens, which is validated by experimental tests conducted in the Polytechnic University of Timisoara. The Finite Element Analysis (FEA) was performed using Ansys Mechanical APDL, focusing on three model types: T1 (which treated back-to-back lipped channels as a single I-section with webs in contact), T2 (where the back-to-back channels were modelled with separate webs) and T3 (which considered separate webs with displacements applied via a steel plate). The models used SHELL281 elements and were validated against experimental test results. Three material models were implemented: a two-stage Ramberg-Osgood model, a quad-linear model, and a true stress-strain model based on tensile tests. A mesh density study confirmed that the models were not sensitive to mesh sizes smaller than 15 mm.

In comparative analysis, seven FE models were compared with experimental results and Eurocode 3 [6]] calculations.

The most accurate numerical analysis was presented in the ASCCS2025 conference in Hong Kong (see Fig. 2), which was a T2 model with true stress-strain material curve. Imperfection was not included in the models, nor was the effect of the slip of the wooden blocks that were present in the experimental tests to prevent the lateral displacement of the webs.

Due to the lack of experimental tests performed for 2C300x3 back-to-back lipped channels, the numerical investigation of these specimens presented in this study supplements the above mentioned research [11].

3.2. Numerical study of 2C300x3 back-to-back lipped channel

To investigate the behaviour of 2C300 back-to-back lipped channels a numerical analysis was performed using the finite element method in the Ansys Mechanical APDL software [12]. A suitable discrete model of the back-to-back lipped channel was developed using the SHELL281 finite element type, and taking into consideration all the insights from the paper and presentation mentioned in the previous chapter. Only one configuration was analysed, where the webs of the back-to-back lipped channels were considered separate, and displacements were applied directly to the upper flanges. Due to the lack of coupon tests, the quad-linear material model was used.

The primary elements of the numerical models are shown in **Fig. 3**, which are similar to those in the previously mentioned study **[11]**. The support conditions were applied to the pilot nodes (PN) of the contact pairs (CP) at the beam's end. Displacements of (Uy = –70 mm) mm were applied to the upper flanges of the lipped channels in strips with a length of Ls = 100 mm. Coupled nodes were defined along the web of the lipped channels within the loading zones, and a constraint (Ux = 0) was implemented to prevent lateral displacement of the beam webs. For the experimental tests, wooden blocks were used to prevent this lateral displacement.

Based on the mesh density study from **[13]**, the FE model is not sensitive to mesh size as long as it is 15 mm or smaller. In the case of the numerical analysis of 2C300x3 back-to-back lipped channels a 10 mm size mesh was used on most of the areas and 2 mm mesh for the rounding corners.

4. Results of finite element analysis

The deformation patterns of the 2C300x3 profiles are shown in **Fig. 4.** The ANSYS simulation indicates both localized stress concentrations and overall structural behaviour under applied loads. The figure highlights the areas of maximum equivalent stress (SEQV), particularly at the deformation midpoint where significant bending occurs. The deformation shape provides useful information for developing the plastic mechanism algorithm in further research.

The load-deformation curve compared with the maximum load capacity line according to the calculations from the Eurocode 3 **[6]** is shown in **Fig. 5.** The difference between the ultimate loads obtained using the numerical method and the Eurocode calculation is 30.6% (see **Table 1**). The loads are obtained as the average of the reaction forces from the supports, allowing for comparison with the plastic mechanism curve in further research.

5. The preliminary pushover analyses

Since plastic deformation in cold-formed steel structures typically occurs in the main structural elements (beams and columns) rather than in the components of the connections, the presented numerical results can be used for a preliminary pushover analysis of multi-story frame structures, using the configurations and cross-sections from the paper published by Zsolt Nagy et al. in 2017 **[3]** The paper discusses the column-beam connection of a spatial structure (see **Fig. 6**). In this chapter, the pushover study focuses on a single isolated current 2D frame of this spatial structure. The columns have hot-rolled tube sections, while the beams consist of cold-formed 2C300 back-to-back lipped channels.

The pushover analysis evaluates a structure's energy dissipation under seismic loads using plas-

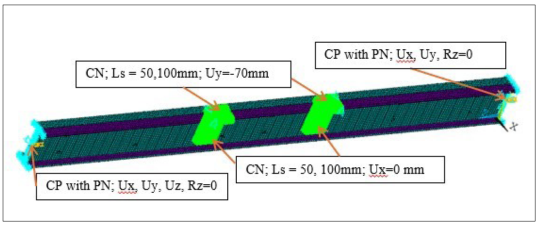

Fig. 3. *The main elements of the FE models.*

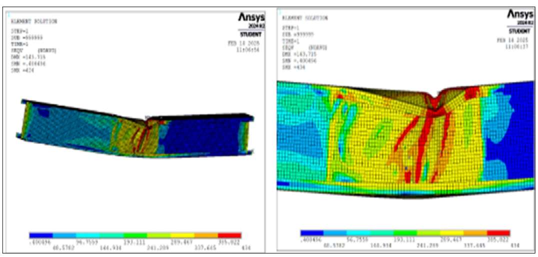

Fig. 4. *Deformed shape of the specimen.*

Table 1. *Comparison of ultimate loads*

	FEA [kN]	Eurokód 3 [kN]
Ultimate load	103.74	72
Difference	30.6%	

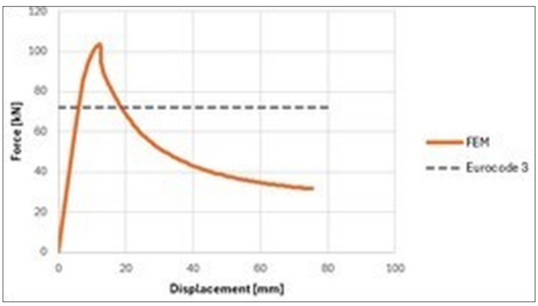

Fig. 5. *Load-deformation curve compared with calculations acc. to Eurocode 3.* **[6]**

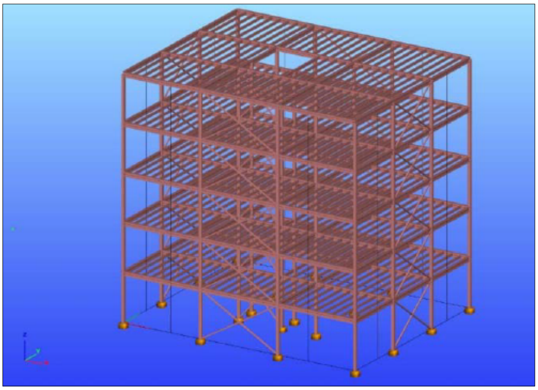

Fig. 6. *The reference structure.* [3]

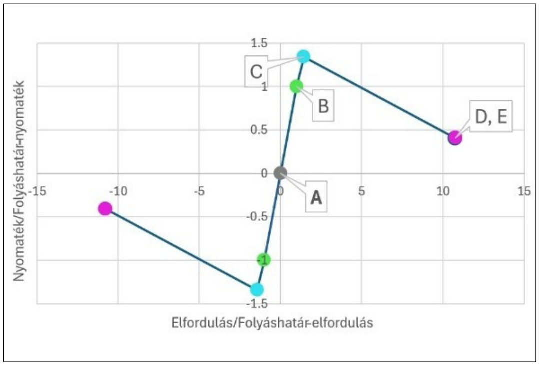

Fig. 7. *Normalized moment-rotation curve for plastic hinges of the beams.*

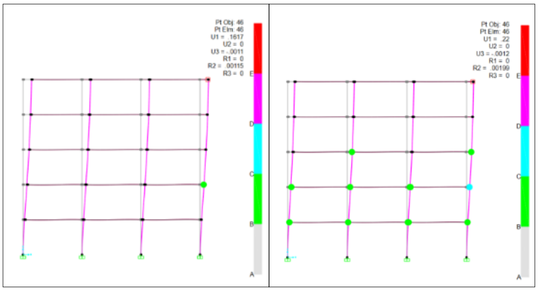

Fig. 8. *Pushover analysis of a frame structure with 4 stories and rigid connections.*

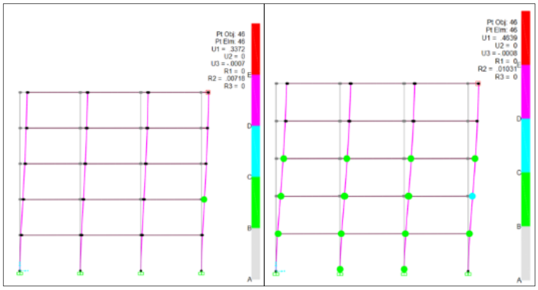

Fig. 9. *Pushover analysis of a frame structure with 4 stories and semi-rigid connections.*

tic hinges, which are defined by moment-rotation curves. It is a static nonlinear analysis, used to determine how far a building can progress into the inelastic range before reaching the verge of total or partial collapse. In the case of cold-formed steel structures, these plastic hinges behave more like local plastic mechanisms within the structural elements.

The stiffness of beam-column connections is a key factor for a successful pushover analysis, as increasing connection stiffness enhances the capability for plastic hinge (or local plastic mechanism) formation. In this study, two main connection categories were investigated: fully rigid connections and semi-rigid connections. The stiffness of the semi-rigid connections was determined using IdeaStatica software [13] while the pushover analyses were performed in SAP2000 software [14].

The moment-rotation curve defined for the plastic hinges of the beam is shown in Fig. 7, while for the column, the plastic hinge was automatically defined by the software. The curve in Fig. 7 is expressed in terms of the ratio of moment to yield moment and rotation to yield rotation, with point B corresponding to a value of 1, representing yielding. Point C indicates the ultimate capacity for pushover analysis, while points D and E represent the residual strength and total failure, respectively. Since residual strength is not considered in this study, point D coincides with point E.

Pushover analyses were performed on 2D multi-story frame structures with different numbers of stories (1, 2, 3, and 4), subjected to lateral loads calculated using the lateral force method, according to P100/2013 [15].

For the tallest structure, the first yielding (point B) of a rigid column-beam connection occurs at step 22, with a top-right corner displacement of 151.7 mm (Fig. 8 left side). When one of the nodes reaches point C (ultimate capacity), the displacement increases to 220 mm at step 28 (Fig. 8, right side).

In the case of semi-rigid joints, yielding occurs much earlier, at step 2, with a displacement of 337.2 mm (Fig. 9 left side). The hinge curve reaches point C at step 3, with a displacement of 463.9 mm (Fig. 9 right side).

For the lowest structure (a single-story frame), when the connections are fully rigid, the maxi-

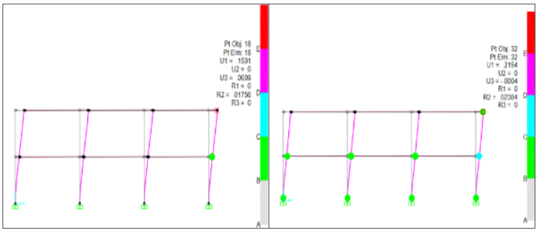

Fig. 10. *Pushover analysis of a frame structure with 2 stories and rigid connections.*

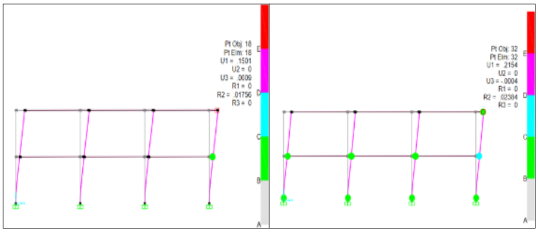

Fig. 11. *Pushover analysis of a frame structure with 1 story and semi-rigid connections..*

mum displacement at the first yielding point is 71 mm, occurring at step 10 (**Fig. 10** left side). At the ultimate capacity point, the displacement increases to 98.4 mm at step 13 (**Fig. 10** right side).

In the case of semi-rigid connections, the maximum displacement at the yielding point is 150 mm, occurring as early as step 1 (**Fig. 11** left side). At the ultimate capacity point, the displacement reaches 215.4 mm at step 3 (**Fig. 11** right side).

6. Summary and conclusions

Finite element analysis of 2C300 back-to-back lipped channels was performed to determine the ultimate capacity point of the load-deformation curve. The results were compared with Eurocode calculations, revealing a difference of more than 30% in the ultimate capacity loads. This load was then used to define the plastic hinge curve for a preliminary pushover analysis. Then pushover analyses were conducted on 2D frame structures with varying connection stiffness and story numbers. The displacement results indicate that using realistic joint stiffness (where connections are semi-rigid), the structures exhibit significantly larger flexibility than continuous joint approach. Therefore, neglecting the semi-rigid behaviour in the structural analysis can bring more optimistic results than real structural behaviour. On the other hand, structure-cladding interaction can compensate the reduced lateral frame stiffness due to semi-rigid joints, but needs proper structural models, to catch the cladding contribution to acquire adequate lateral stiffness of the structure under horizontal loads. Further investigations are focusing on modelling improvement, to identify solutions that enhance adequate structural rigidity, with the help of the stress-skin effect.

In future research, plastic hinges defined through analytical calculations will be used to explore the potential application of plastic mechanism algorithms in pushover analyses.

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