Behaviour of thin-walled cold-formed steel members in eccentric compression

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Abstract

Thin-walled cold-formed steel (TWCFS) structures are usually made of members of class 4 cross-sections. Since these sections are prematurely prone to local or distortional buckling and due to the fact they do not have a real post-elastic capacity, the failure at ultimate stage of those members, either in compression or bending, always occurs by forming a local plastic mechanism. The present paper investigates the evolution of the plastic mechanisms and the possibility to use them to characterise the ultimate strength of short thin-walled cold-formed steel members subjected to eccentric compression about minor axis, particularly for members with lipped channel cross-section. Five different types of plastic mechanisms for members in compression with different eccentricities are identified and examined. The research is based on previous studies and some new investigations of the authors.

Keywords: thin-walled cold-formed steel members, plastic mechanism, eccentric compression, minor axis

1. Introduction

Thin-walled cold-formed steel (TWCFS) structures are usually made of members of class 4 cross-sections. Since these sections are prematurely prone to local or distortional buckling and due to the fact they do not have a real post-elastic capacity, the failure at ultimate stage of those members, either in compression or bending, always occurs by forming a local plastic mechanism. This fact suggests the possibility to use the local plastic mechanism analysis to characterise the ultimate strength of such members, since an approximate upper-bound estimation of the load-carrying capacity of those members is the intersection point of the rigid-plastic curve and imperfect elastic one [1]. The load-carrying capacity of such members subjected to simple states of loading (pure bending or pure axial compression) is relatively well determined on the basis of the theory of thin-walled structures [1]. However, determination of the load-carrying capacity of TWCFS members subjected to combined load, particularly eccentric compression, is still an open question and the code specifications for that case should be improved. This improvement may be supported by developing adequate theoretical models of local plastic mechanisms. A first attempt at the identification of plastic mechanisms of short TWCFS members subjected to eccentric compression has been published by Ungureanu et al. [4].

The yield line theory (YLA) applied to thin-walled steel structures allows one to perform an analysis of structural behaviour in the vicinity of ultimate load and in the post-failure stage. The plastic mechanism approach is based on two basic methods, namely the *energy method (work method)* and the *equilibrium strip method.*

Experiments carried out by many researchers on beams or columns built from plate strips, subjected to uniform compression show that in such members some simple plastic mechanisms can be distinguished, which have been termed as basic mechanisms. A database for plastic mechanisms for thin-walled cold-formed steel members in compression and bending has been presented in details by Ungureanu et al. [3].

The aim of the present study is to identify different plastic mechanisms of failure in TWCFS members subjected to eccentric compression about minor axis, at different eccentricities, of lipped channel section columns.

2. Plastic mechanisms in eccentric compression

The dimensions of the cross-section investigated in the present work are $a \times b \times c \times t$ = 150×60×20×2 mm with and an internal radius r = 3 mm. A column length of 450 mm was investigated, made of structural steel of yield stress f_y = 355 N/mm^2. Positive and negative eccentricities along the symmetry axis are investigated (see Figure 1). Buckling loads and modes were determined for the large range of eccentricities, from e = -60 mm to e = +100 mm. For positive eccentricities (e = 10, 30, 60, 100 mm) and e = -5 mm, distortional buckling takes place. For the negative eccentricity, e = -10 mm a local-distortional buckling mode was observed, while for eccentricities e = -30 mm and e = -60 mm the local buckling takes place.

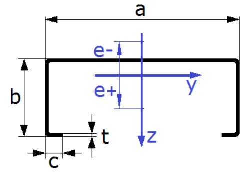
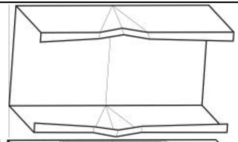
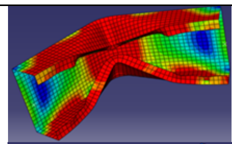
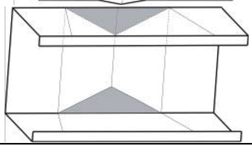
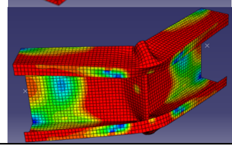


Figure 1: Subject of investigation

On the basis of FE numerical experiments, five plastic mechanisms of failure were identified [5]. In Table 1 two of them are presented. For small and medium negative eccentricities a modified pitched-roof mechanism has been identified [5]. It consists of local pitched-roof mechanism in the web and two local mechanisms in the flanges. Thus, the total energy of plastic deformation is a sum of bending strain energy and membrane strain energy in tension fields (shadowed in Figure 2).

* The research was supported by ROMANIAN - POLISH JOINT RESEARCH PROJECT “Load-capacity of thin-walled steel members“ (2016 - 2018) under the agreement on scientific cooperation between the Romanian Academy and the Polish Academy of Sciences.

Table 1: Failure mechanisms of 150×60×20×2 mm lipped channel for positive (5÷20 mm) and negative (-5÷-60 mm) eccentricities

Eccentricity *e* [mm]	Buckling mode	Failure mode (mechanism)	Mechanism model	FE pattern
5 ÷ 20	Distortional	CF1		
-5 ÷ -60	Local-distortional Local	Pitched-roof		

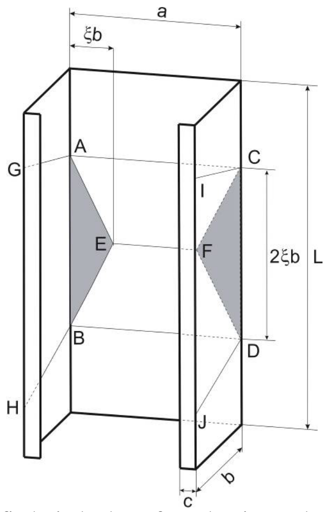


Figure 2: Modified pitched-roof mechanism - theoretical model

3. Load-deformation relations - comparative analysis

In order to investigate the applicability of the mechanisms presented in the above paragraph, comparative numerical calculations have been carried out. The results of FE calculations performed with ABAQUS code were compared with post-failure curves obtained from the yield line analysis (YLA), using the energy method and/or the equilibrium strip method. For some selected cases the FE results and post-failure curves are compared with pre- and post-buckling paths derived from the analytical-numerical method (ANM) based on the asymptotic approach [2]. In those cases, an upper-bound estimation of the load-carrying capacity was performed as the intersection point of the post-buckling path and post-failure curve.

The following methodology has been applied in the analysis of the five mechanisms: (1) using the ANM method, the displacement fields and the sectional force fields are expanded into a power series in the buckling mode amplitudes. The non-linear problem is solved by Byskov and Hutchinson's asymptotic method. The post-buckling path is evaluated using the concept of the reduction of effective stiffness, based on the effective width approach. The upper-bound load capacity estimation is performed as the intersection point of the post-buckling path and post-failure curve; (2) using the energy method related to YLA or the equilibrium strip method and the procedures described in details in [5].

Figure 3 shows FE load-shortening diagrams for medium negative eccentricities, compared with YLA analysis, together with pre- and post-buckling paths derived from analytical-numerical (ANM) algorithm (for eccentricity e = -60 mm only). The agreement of FE and YLA post-failure curves is good.

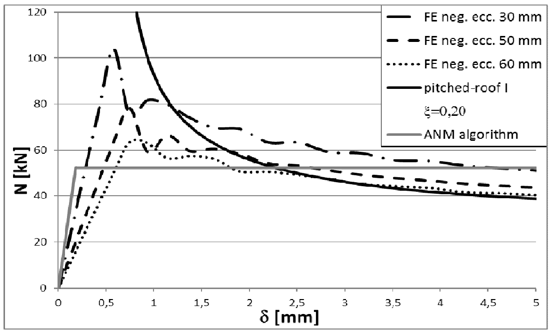


Figure 3: Load - shortening diagram for medium negative eccentricity; comparison of FE results and YLA analysis

4. Final conclusions

The results confirm the possibility to use the local plastic mechanism analysis to characterise the ultimate strength of short columns under eccentric compression, although the plastic mechanisms models should be improved, particularly for the smallest and the largest negative eccentricities. Even if the plastic mechanisms are identified for compression and bending separately, in the case of eccentric compression, this is far from a linear superposition of basic mechanisms. Generally, for certain eccentricity, an appropriate model of plastic mechanism should be calibrated on the basis of FE simulation results and, simultaneously, experimental results. Thus, further research into experimental verification of obtained theoretical results is in progress.

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