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Load-carrying capacity and energy absorption of thin-walled profiles with edge stiffeners

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Abstract

The paper presents results of the study into plastic mechanisms (collapse behaviour) of short stub thin-walled profiles with edge stiffeners under compression. The aim of the study was to investigate an applicability of such profiles as energy absorbers. Solutions of other researchers and the author are presented. The new plastic mechanism solution for hat-section column is derived.

Keywords: Thin-walled profiles; Cold-formed sections; Local buckling; Plastic mechanism; Energy absorption

1. Introduction

Cold-formed steel profiles are usually considered to be non-ductile and low-dissipative structures because of the predominant part played by local stability. However, recent research results [1] indicate that they can fail in plastic manner, i.e. in the stage of failure they form local or even global plastic mechanisms. That happens, when due to the local buckling of a stub column, its behaviour in the post-buckling range displays large local elasto-plastic and plastic deformation of the section walls. Subsequently yield lines occur and the plastic mechanism of failure is being formed.

Such failure behaviour is typical for stub thin-walled cold-formed profiles and has been confirmed by many researchers both in the experimental and numerical way [2].

The methods used up till now for the post-buckling and load-carrying capacity analysis of thin walled profiles under compression or bending can be classified in the following groups:

(1) Purely analytical methods based on the concept of effective width or the interactive buckling approach. Solutions obtained within the second approach are mainly based on the asymptotic Koiter's theory [3].
(2) Numerical methods, namely the finite element method (FEM) and the finite strip method (FSM). Linear and non-linear general beam theory (GBT) should be also mentioned within this group.
(3) Analytical-numerical or semi-empirical methods. The example of the first category is the direct strength method (DSM) introduced by Schaffer, while the representative of the second one is ECBL plastic-elastic method proposed by Dubina and Ungureanu [4,5], which uses the rigid-plastic theory and consists in the introduction of a reduction factor, that takes into account the interaction of local rigid-plastic failure mode with the global elastic buckling. This method requires an analysis of local plastic mechanisms.

Finally, the upper-bound estimation (UBELC) of the load-carrying capacity consisting in the determination of the intersection point of a post-buckling path (evaluated using either analytical method or FEM/FSM) and a rigid-plastic failure curve obtained from the plastic mechanism analysis should be incorporated into the last group of analytical-numerical methods [6].

The aim of the present study is the analysis of plastic mechanisms of failure in stub thin-walled open section profiles with edge stiffeners subject to compression or bending with particular attention focused on special plastic mechanism for a certain class of analysed sections. The results of this analysis can be applied to the determination

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of the load-carrying capacity of a profile using one of the methods categorized in the third group mentioned above (ECBL or UBELC). The results can also be used for the parametric study into the applicability of relatively short stub columns as energy absorbers.

2. Problem formulation

The subjects of the analysis were two profiles, namely the channel section (Fig. 1a) and the top hat-open section (Fig. 1b) under compression.

Some special problems occur in the buckling and post-buckling analysis of profiles of mono-symmetric sections with edge stiffeners, where a sudden change from symmetric to anti-symmetric buckling mode is possible.

The present study is focused mainly on the analysis of the new plastic mechanism model in top hat section, which has been verified both in the experimental way and with the numerical FE simulation [8].

Simultaneously, the discussion concerning the results of the analysis of plastic mechanisms in lipped channel section is conducted within the study. This analysis is based on FE simulation performed by the author and the results published by other researchers [2,5].

3. Plastic mechanisms in open section profiles with edge stiffeners

A proper identification of a geometry of the plastic mechanism of a thin-walled member is crucial for a correct evaluation of the post-buckling rigid-plastic curve (*failure curve*), which subsequently results in a proper estimation of the load-carrying capacity of the member and the energy absorption in the process of plastic failure.

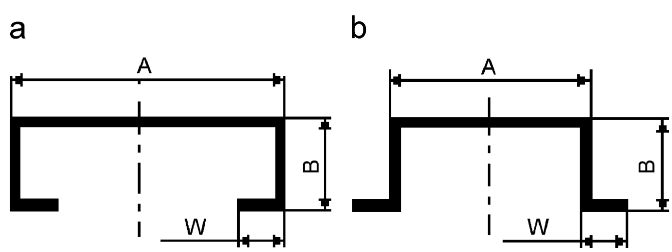

Fig. 1. Open section profiles with edge stiffeners.

3.1. Plain and lipped channel section

The first models of plastic mechanisms in channel section under compression were elaborated by Murray and Khoo [9] and also Rassmussen. They have identified both *true mechanisms* (Fig. 2a) and *quasi-mechanisms* [6] Fig. 2c.

In the works mentioned above two different approaches were applied for the solution of the plastic mechanism problem: the static *yield strip method* [2,5] and the kinematical, energy method, which consists in the formulation (on the base of principle of virtual velocities) of the energy dissipated at yield lines (*yield line method*) [6,7]. The first method is more effective in the case of quasi-mechanisms in profiles under compression, the second one—in the analysis of both true and quasi-mechanisms, particularly in profiles under bending, but also under compression. The advantage of the latter is that it enables to estimate an amount of the dissipated energy in the process of failure directly.

The problem of the plastic mechanism in lipped channel section under compression was preliminarily elaborated by Rassmussen and then, in details, by Dubina et al. [2,5]. They applied the yield strip method and treated the mechanism as combined of two local mechanisms: quasi-mechanisms (either roof-shaped—Fig. 2c, or flip-disc—Fig. 2d) in webs or flanges and the true mechanism (Fig. 2a) in lips. In [5] the ranges of dimensions ratios are discussed, for which one of the quasi-mechanisms in webs and flanges is formed.

3.2. Top hat section

The FE simulation indicated three different plastic mechanisms in short top hat sections under compression, shown in Fig. 3. They are different from those mentioned in the above paragraph.

The analysis performed within the present work is focused on the V-shaped plastic mechanism shown in Fig. 3b, typical of the certain class of top hat sections, namely specified by $b/a \geqslant 0.67$ (dimensions a,b,w are indicated in Fig. 1 in capital letters, t is referred to as the

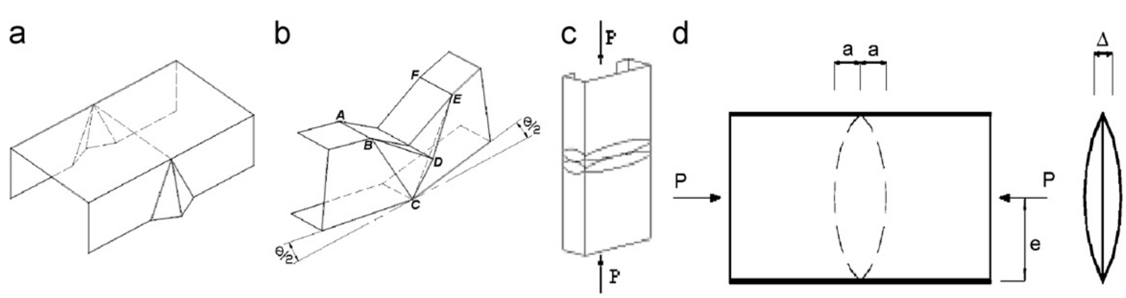

Fig. 2. Plastic mechanisms in channel section profiles: (a) without lips (under compression or bending in the flange plane [9], (b) without lips (under bending in web plane) [6], (c) roof-shaped mechanism-lipped channel under compression [2,5], (d) flip disc mechanism-lipped channel under compression [2,5].