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European alternatives to design perforated thin-walled cold-formed beam–columns for steel storage systems

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SUMMARY

Rack systems to store goods and products are one of the most important applications for thin-walled cold-formed steel members. Adjustable pallet racks are used widely worldwide and are characterized by regular systems of perforations along the uprights (i.e. vertical members) to connect easily pallet beams and diagonal members forming the skeleton frame. Design rules are based on the well-established approaches for the more traditional solid members, suitably extended to account for the presence of regular perforations via component tests accurately described in rack specifications.

This paper focuses on the performance of isolated uprights under axial load and gradient moment. In particular, three European alternatives to design beam–column rack members have been discussed and applied: the first and the second are traditionally used for thin-walled cold-formed steel members while the latter, the so-called *general method* of Eurocode 3 part 1-1, allows to take directly into account the key features associated with upright response. The geometry of the cross-sections and of their perforation system, the member slenderness and the load condition has been assumed as parameters of this study. Research outcomes demonstrate that the predicted performances can result significantly different, reflecting directly on the weight and the cost of the whole storage system. Furthermore, numerical analyses and design calculations show that standard codes need urgent revisions, leading in few cases to design beam–columns from the unsafe side.

1. Introduction

Industrial steel storage pallet racks are quite similar to the framed steelworks traditionally used for civil and commercial buildings [1]: some differences are due to the presence of boltless beam-to-column connections with a moderate degree of flexural continuity and to the very extensive use of thin-walled cold-formed members, typically interested by local and distortional buckling phenomena as well as by their mutual interaction [2]. Several types of storage systems are offered nowadays from manufacturers, such as adjustable pallet racks, which are the most commonly used (Fig. 1), drive-in and drive-through racks, push back racks, gravity flow racks and rack supported platforms. Serviceability responses and failure conditions are often complex to predict under both monotonic and seismic loads: in general, high engineering competences are required to guarantee significant load carrying capacities with structural systems of extremely limited weight, and, as a consequence, of very modest costs in order to be competitive on the market.

Theory of thin-walled cold-formed members with open solid cross-section was well-established several decades ago [3–5] and now steel specifications propose very refined design approaches able to account for local, distortional and overall buckling phenomena as well as for their mutual interactions. Verification criteria adopted in Europe to design cold-formed beam–columns with a non-symmetric class 4 cross-section [6] impose the evaluation of five effective cross-sections: one for the axial load and four associated with flexure, being necessary to consider the cases of both positive and negative moments about each principal axis. The width of the effective compressed zones of the cross-section is significantly influenced [7,8] by the interaction between axial load and bending moments, which is ignored when evaluating the resisting cross-section properties. Moreover, with reference to storage racks, the uprights, i.e. the vertical beam–column members of the skeleton frames, have generally an open mono-symmetric cross-section (Fig. 2), characterized by the presence of regular perforations to erect quickly the structures and/or to adapt the clear height of the load levels to the pallet sizes, which could change over time. Important theoretical and experimental studies have been focused on perforated plates and members. In particular, Szabo and Dubina [9] discussed accurately the existing cold-formed calculation methods to evaluate the strength and proposed an approach for members with square and circular holes. The same type of perforations was considered also in other studies on

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Fig. 1. Typical adjustable pallet rack.

isolated plates [10–12], angles [13] and channels [14]. As to the uprights for adjustable pallet racks, recently Eccher et al. [15] proposed an isoparametric spline finite strip method for the geometric nonlinear analysis of perforated folded-plate structures. Moreover, important researches are currently in progress [16,17] to contribute to the development of appropriate design approaches able to account directly for the presence of perforations in columns and beam–columns. Furthermore, as clearly summarized in ref. [18], the existing rules to design racks are therefore empirical and their validity is only in the range of the investigated parameters. In particular, from a practical point of view, due to the great differences not only in the cross-section upright geometries (Fig. 2) but also in their perforation types (Fig. 3), i.e. circular, elliptic and diamond holes, slots and cut-outs, a design assisted by testing procedure is required by the most recent rack specifications [19–21]. The European code for cold-formed steel structures [22] proposes a very refined approach which cannot be used for uprights, owing to the complex cross-section shapes and to the presence of regular perforations. Effective cross-section properties of uprights to be used for all the verification checks must hence be based on component tests, which are accurately described in the Appendix A of EN 15512 standard [19] for rack design in European areas. In particular, the stub column test allows to evaluate the effective area accounting for perforations, cold manufacturing processes, local and distortional buckling phenomena and their natural interactions. The typical specimen is composed by a stub upright, at each end of which a thick steel plate is welded (Fig. 4). The characteristic failure load (R_k) is based on the statistical re-elaboration of the experimental results related to a set of tests on nominally equal specimens under axial load: the effective area, A_{eff}, however limited to be not greater than the gross one, is evaluated as:

$$A_{eff} = \frac{R_k}{f_y} \tag{1}$$

where f_y is the yielding strength of the base material before the cold working processes.

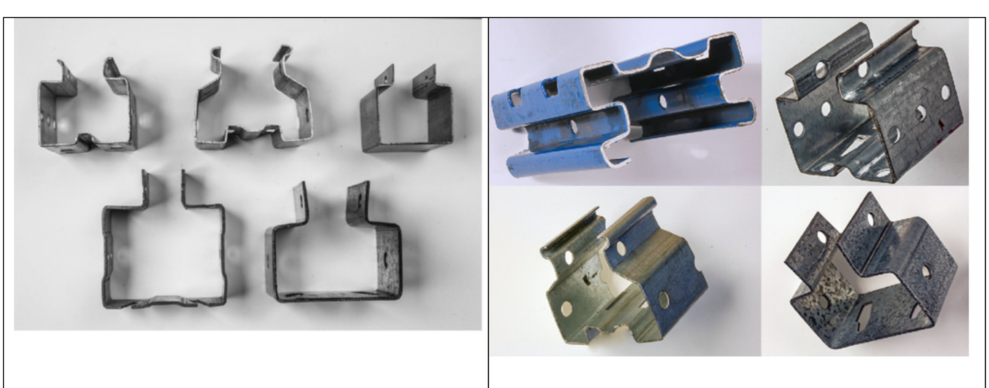

Fig. 2. Typical mono-symmetric cross-section employed as rack uprights (courtesy of Miss. Alessandra Pellegatto).