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European and United States approaches for steel storage pallet rack design
Part 1: Discussions and general comparisons

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ABSTRACT

A very common application of cold-formed thin-walled steel members regards the industrial storage systems for goods and products, such as pallet racks, which are the core of the present paper. Owing to the increasing needs associated with globalization as well as the importance of the logistics, nowadays, rack manufactures must be highly competitive in the most industrialized countries: as a consequence, it is frequently required that engineers design in accordance with standards of the country where the storage rack will be in service. Due to peculiarities associated with the requirements of each code, different values of the rack load carrying capacity are expected and their quantification should be of great interest for commercial reasons: this is an important open question for designers and manufactures that up to now is without any practical response.

A two-part paper has been written to summarize the main results of a comparative study on pallet rack design provisions currently adopted in Europe and the United States. *Part 1* describes the key features of both codes, discussing similarities and differences associated with the admitted design procedures with reference to the member verification procedures and to the alternative analysis approaches. Furthermore, practical comparisons related to isolated members under compression and bending are proposed to allow a direct appraisal of structural performance.

The companion paper (*part 2: Practical applications*) reports on an exhaustive analysis with regards to the contents herein introduced and applied to the design of 216 medium-rise semi-continuous pallet racks that are unbraced in the longitudinal direction.

1. Introduction

Among the different industrial solutions to store goods and products, steel storage pallet racks represent one of the most commonly used solutions [1], which are often made by cold-formed thin-walled members. As shown in Fig. 1, they consist of a regular sequence of upright frames connected to each other by pairs of pallet beams carrying the stored units. From a structural point of view, racks are generally braced only in the transverse (cross-aisle) direction, owing to the impossibility to locate longitudinal (down-aisle) bracing systems without reducing the storage capabilities. Stability in the down-aisle direction is hence provided solely by the degree of flexural continuity associated with beam-to-column joints and base–plate connections, which have to be modeled as semi-rigid joints.

An increasing number of cases where design, fabrication and erection of rack structures are separated by large distances has been observed in recent years, as a result of rapid globalization and of the modest costs associated with the transportation of these very light-weight structures. Owners require the use of widely accepted steel design codes regardless of the location where the structure is going to be built; as a consequence, structural engineers are now faced with the challenge of being competent with design specifications, which could present substantial differences between one another. Attention is herein focused only on the pallet rack design for static loads: in Europe (EU), the reference is the EN15512 specification, *"Steel static storage systems-Adjustable pallet racking systems-Principles for structural design"*[2]. This code, which is in the process of being updated in the next few years, is the evolution of the recommendations FEM 10.2.08 [3], published by the technical committee Working Group 2 of the "Federation Europeenne de la Manutention" (FEM). In the United States (US), the design of industrial steel storage racks is carried out according to the Rack Manufacturers Institute (RMI) specification "*Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks*" [4], which is tied closely to the AISI specification [5] for the cold-formed steel design (*North American specification for the design of cold-formed steel structural member*).

In the framework of a recent study on the analysis approaches for traditional steel frames constructed using hot-rolled members

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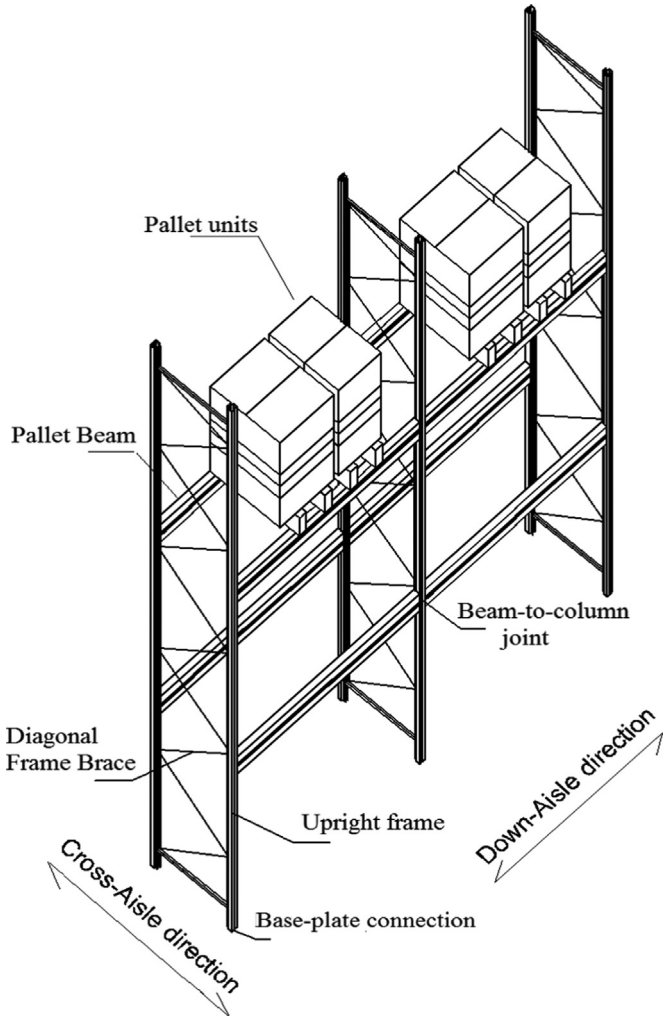

Fig. 1. Typical steel storage pallet rack.

[6], it has been demonstrated that non-negligible differences can be observed with reference to the frame performances predicted according to the EU [7] and the US [8] permissible design alternatives. As a consequence, owing to the extensive use of cold-formed members for logistic applications, the Authors decided to analyze also the design approaches for steel storage pallet racks, which differ from the more traditional steel frames due to the use of thin-walled components and for the significant influence of second-order effects.

Research results are summarized in a two-part paper, which has been focused on bi-symmetric cross-section uprights, being the important effects associated with non-coincidence between the centroid and the cross-section shear center already investigated in previous research [9–11]. Despite the fact that usually upright cross-sections present one axis of symmetry (Fig. 2a), an increasing number of solutions recently proposed for the industrial storage market is characterized by the use of boxed closed cross-section (Fig. 2b), which present, in several cases, two axes of symmetry. In this *part 1*, key features of both the EU and the US design codes are introduced and discussed, focusing attention on the evaluation of the effective geometric properties and on the verification design procedures for columns and beam–columns. Furthermore, the permitted approaches for structural analysis are discussed highlighting the similarities and differences. Attention is mainly paid to the upright design for two reasons:

1. The difference due to the choice of the method of analysis according to both the considered codes reflects mainly on the design of these vertical elements. No alternatives are available for the design of the other key rack components (i.e., pallet beams, upright lacing and joints).
2. The importance of these vertical members with reference to the total weight of the industrial storage systems.

The companion paper (*part 2: Practical applications*) [12] reports the evaluation of the load carrying capacity according to the considered design alternatives, basing the proposed research outcomes of a set of 216 racks differing in configuration, geometry of the components and degree of rotational stiffness of beam-to-column joints and base–plate connections.

2. Effective cross-section properties

The theory of thin-walled cold-formed members was well-established several decades ago [13–15] and now steel specifications [5,16] propose very refined design approaches able to account for local, distortional and overall buckling phenomena as well as for their mutual interactions. Theoretical design procedures have been completely defined only for few types of cross-section, such as channel, angle and hat cross-sections, which are the most commonly used in framing, metal buildings and lightweight housing systems [17]. These cross-sections are often different from the ones typically used in the structural systems to store goods and products. In several cases, open mono-symmetric perforated cross-sections (Fig. 2a) are used but also hollow square/rectangular cross-sections are employed, the closure of which is sometimes obtained by overlapping and clamping to each other the lateral edges of the strip coils (Fig.2b).

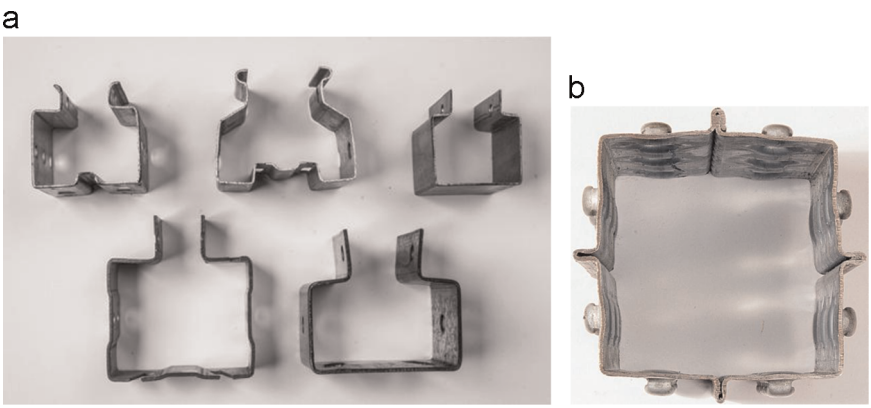

Fig. 2. Typical mono-symmetric (a) and bi-symmetric (b) cross-section uprights used in pallet racks system.