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Review

State-of-the-art review on the design and performance of steel pallet rack connections

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ABSTRACT

Steel pallet racks (SPRs) are used in the industrial buildings, warehouses and superstores for storing a multitude of different kinds of goods. Because of changing needs over the years, it is often desirable that such installations be readily demountable and capable of reassembly. Therefore, the beam-to-column connections (BCCs) used in SPRs are boltless in nature. SPR BCCs govern the stability of the frame in the down-aisle direction. The design of SPR BCCs is one of the problems for designers that cannot be handled routinely within the existing design specifications available for bolted and welded connections. Moreover, the studies on the considerations necessary for the design and performance of SPR BCCs solely are rarely available. It is therefore, essential to bring to light the factors that play significant role to improve the design and performance of SPR BCCs. A critical review of the research performed over the last few decades into the global stability of SPR structures in the down-aisle direction only is presented in this paper. The information about the design methodologies and testing procedures defined in the literature and design codes as well as the factors governing the performance of boltless connections are identified. The major failure modes are highlighted. The characteristics of the main elements constituting SPRs are also succinctly discussed. Based on the findings, the limitations of current study are highlighted and future research areas are identified.

Contents

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1. Introduction

1.1. General

Industrial warehouses traditionally store the goods outside the retail area in a limited and congested space, whereas supermarkets have to store goods in close proximity to provide the consumer an easy and unblocked access to the goods. Storage racking system is conventionally used in industrial warehouses and supermarkets for the storage of palletized goods. Steel storage racks are regular, 3D multi-storey, multi-bay structures [1]. The primary categories of steel storage racks are pallet racks, drive-thru and drive-in racks [2]. The sub-types of commercially available steel storage rack structures are push back racks, cantilever racks, narrow aisle racks, gravity flow racks and double deep pallet racks. The drive-in and drive-thru rack systems utilize the use of rails throughout the depth of the rack in order to place the pallets [3]. In drive-thru racks, the pallets are placed on first-in-first-out principal. In drive-in racks, the pallets are placed as first-in-last-out principal. Pallet racks are most common kind of storage systems. Steel pallet racks (SPRs) are used when less space is available compared to the high volume of storage items [4].

The effective use of SPRs demands flexibility in the material constituting these racks to permit the handy adjustment and re-assembling of rack elements upon requirement [5,6]. Cold formed steel is therefore preferred for the manufacturing of these peculiar structures [7–10]. However, AS4084 [11] recommends the use of hot rolled steel when the rack has to support heavy loads. These structures can be efficiently modified and extended due to the inherent flexibility and adaptability of their connections [12,13].

In SPRs, most commonly, two perforated lipped channel sections are spaced apart by bolting or welding struts to make a truss frame [5]. However, in some cases, more traditional hot-rolled profiles are used as well as tubular hollow sections. The struts work as cross-bracing and prevent sway in this direction, which is termed as the 'cross-aisle direction'. This direction is usually braced using rails or diagonal bracing to avoid the difficulty in supporting the columns against bending about the weak axes. Bolted connections between the cross-aisle bracing and columns are usually used in Australia and Europe, while manufacturers in the United States frequently use welded connections [14]. The longer direction with different story heights between two pallets is called the 'down-aisle direction'. This direction is left unbraced for quick and unblocked access to the stored goods. The resistance to sway instability in the down aisle direction is provided collectively by the BCCs and base connections [15–21]. Because of lack of bracings in the down-aisle direction, structural analysis is carried out by adopting a semi-continuous sway frame model, i.e. unbraced frame with semi-rigid joints [22–24]. A pallet rack with its constituting components is shown in Fig. 1.

1.2. Pallet rack components

1.2.1. Column

The columns used in SPRs are usually thin walled steel sections contain arrays of perforations along the length, enabling beams to be clipped by connectors at variable heights and the bracings to be bolted to form the frames [25]. Initially, the simple lipped channel sections were used as columns in storage racks. Though, the simple lipped channel sections were not costly to manufacture and provided good structural efficiency, however it was observed that the connections between bracing members and these sections provide less than the required efficiency. In those days, welding arrangement was used between hot-rolled members which was not available for cold-formed sections manufacturers and thus, bolted connections were used. This approach introduced the involvement of spacers in storage rack columns and the lipped flange was avoided. Accordingly, modern sections having extra length of bends were invented, and typical presented by Prabha et al. [26] is shown in Fig. 2(a). These sections enabled a reliable bolted connection arrangement to bracing members.

The thickness of these columns varies between 1.5 mm and 3 mm, which is comparatively negligible to the sufficiently greater height of the column. Due to the high slenderness, the column becomes vulnerable against the flexural or flexural-torsional buckling globally along its whole length [27–29]. Moreover, local buckling may occur, where the section involves plate flexure alone without transverse deformation of the overall column, or distortional buckling [30–32], where the cross-sectional shape changes along the length of the member without transverse deformation. Further, the high slenderness of columns leads to the involvement of the non-linear effects of interaction between the applied axial load, P, and the resulting lateral displacement, δ, for the stability design of