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Assessment of the seismic behaviour of braced steel storage racking systems by means of full scale push over tests

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ABSTRACT

Pallet racking systems, made of thin-walled cold formed steel profiles, are commonly used to store valuable goods and products in the logistics industry. In service conditions, longitudinal (down-aisle) stability of the racks is provided by the flexural stiffness of the demountable beam-upright column connections and base joints. Rack designers usually prefer to avoid bracings for a full accessibility of shelves from both aisles. However, under seismic conditions, typical rack connections cannot often provide sufficient flexural performance in terms of stiffness and strength, which deems necessary to introduce spine (longitudinal) bracings in the down-aisle direction. Yet the racks can only be braced at one of their two longitudinal planes to allow pallet loading from the aisle, which results in an asymmetric horizontal bearing configuration. This combined with their perforated upright columns, and non-standard beam-upright and base connections make it even more difficult to estimate their complex global seismic performance. Therefore, full scale experimental investigations are strongly needed in order to understand and quantify the global performance of the braced storage racks, and improve their design for seismic actions.

This paper presents the experimental results of the Europe's largest full-scale push-over testing program that has been carried out on racking systems. In particular, experimental global capacity curves of 6 fully-loaded pallet racking specimens with spine bracings, provided by 5 different international rack producers, are presented, discussing the key factors influencing the racks' response, as well as the failure mechanisms of the different rack typologies. Furthermore, behaviour factor (q) values of each specimen are derived from re-analysis of test results. Vulnerability of braced racks to bracing connection failure is demonstrated, highlighting its causes. Design indications are provided in order to guarantee a globally homogenous ductility under seismic actions.

1. Introduction

Steel storage racks are commonly used to store valuable goods in logistics and commercial warehouses. Their structural components are often made of thin walled perforated profiles to ensure the versatility needed in storing goods. Due to the high competitiveness of logistics industry, they are designed as lightweight as possible to save on steel material costs. Despite the lightness of their structural systems, storage racks carry very high unit loads (in average 8–10 kN per pallet), by far higher than their self-weight, contrary to what happens in usual civil engineering structures.

Classical types of storage racks are well described by Pekoz et al. [1]. Structural system of pallet-racks (Fig. 1) [2] is mainly composed of uprights (vertical members) made of perforated thin walled elements, and pallet beams (horizontal members), made of built-up closed sections linking adjacent frames, lying in the horizontal direction parallel to the operating aisle. Diagonal elements (bracings) connect the uprights to each other in the cross-aisle (transversal) direction to form the upright frames, whereas the connections between the uprights and the pallet beam (beam-to-column joints) in down-aisle (longitudinal) direction are usually made of proprietary hook-in connectors welded to the pallet beam ends, and engaged into perforated holes in the uprights. Uprights are usually connected to the industrial floor by L shaped components that are connected on the upright base on one leg, and on the floor on the other.

Stability of upright frames in cross-aisle direction is always provided by diagonal elements. On the other hand, in down-aisle direction, rack designers usually prefer avoiding bracings to make the shelves accessible on both sides from two aisles, allowing an efficient loading and unloading of goods in service. However, in high seismic regions, this configuration is usually not adequate to resist strong horizontal loads because of insufficient flexural

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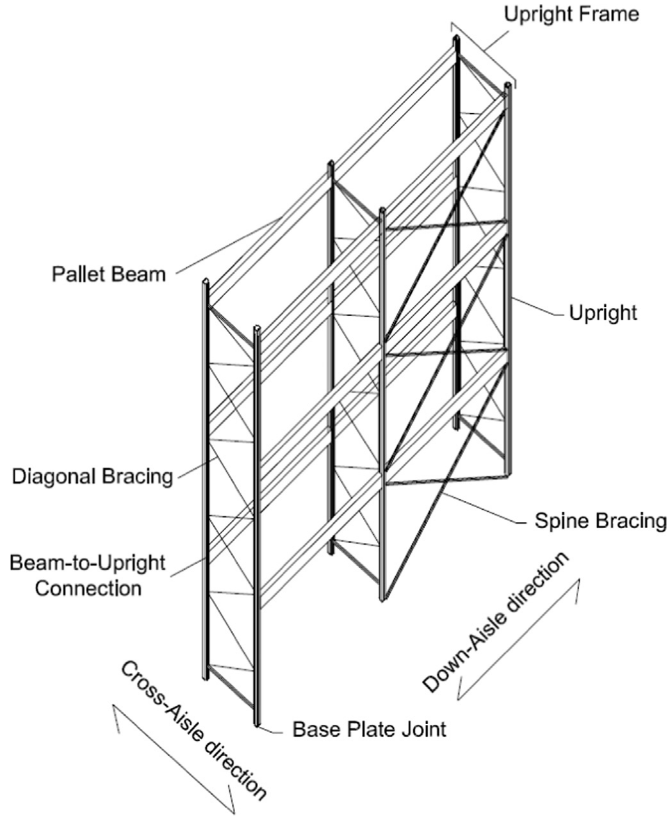

Fig. 1. Typical braced pallet rack configuration [2].

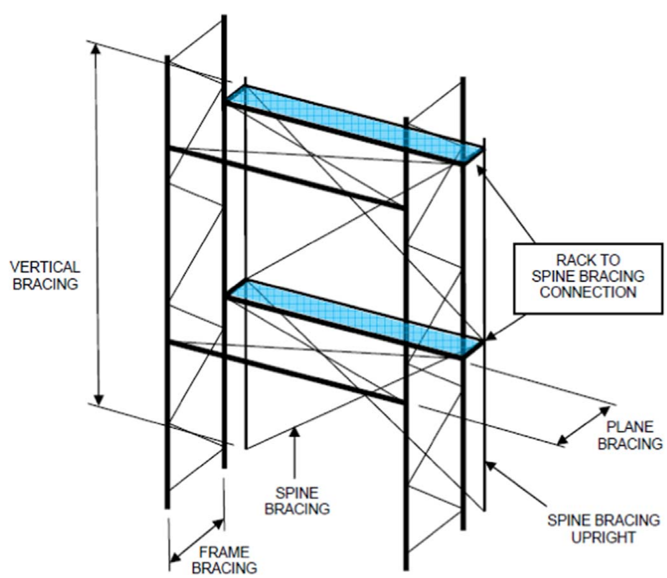

Fig. 2. Spine bracing layout [3].

stiffness of the racks' demountable beam-upright column connections. When high-seismicity is a concern, spine bracings are often used in down-aisle direction. The complex structural configuration of storage racks braced only in one side, in contrast to civil engineering structures in which bracings are placed regularly in all sides, result in a poorly understood seismic behaviour, and should be investigated carefully. In the literature, experimental tests which can reasonably estimate the seismic behaviour of this type of racks are not yet available. For this reason, under the co-ordination of the authors, a large research group including experts both from academy and rack industry has implemented a research project funded by Research Fund for Coal and Steel (RFCS), where full scale push-over tests have been performed on fully-loaded pallet racking specimens having spine bracings. This paper