Journal of Constructional Steel Research 140 (2018) 92–107

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Monotonic and cyclic tests on beam-column joints of industrial pallet racks

Federico Gusella [a], Giovanni Lavacchini [b], Maurizio Orlando [a,*]

[a] Dept. Civil and Environmental Engineering, University of Florence, Via di S. Marta, 3, I-50139 Florence, Italy
[b] Studio Lavacchini, Viale IV Novembre, 46/3, I-50032 Borgo San Lorenzo (FI), Italy

ARTICLE INFO

Article history:
Received 5 September 2017
Accepted 15 October 2017
Available online xxxx

Keywords:
Cold-formed steel
Pallet racks
Beam-column connections
Cyclic tests
Hysteresis loop
Energy dissipation

ABSTRACT

Pallet racks are characterized by boltless beam-column connections and the extensive use of thin-walled cold-formed steel members. Due to the great number of beam-end connector types and member geometries, a reliable evaluation of their structural behavior, especially under seismic loads, requires a thorough modeling of beam-column joints, whose moment-rotation curves can be reliably assessed only through experimental tests. In this paper, the authors present results of monotonic and cyclic tests on four different types of industrial rack joints. Tested joints differ from one another in the type of beam-connector, which is obtained by folding the beam end or is welded to the beam-end section with different welding layouts. Moreover, joints differ in the number of tabs and the relative thickness of the upright and the beam-end connector. Experimental results from cyclic tests allows for moment-rotation curves of joints to be accurately identified, confirming that they are significantly different from traditional steel framed buildings due to pinching in hysteresis loops. Obtained curves can be used for reliable modeling of joints in seismic analyses of steel pallet racks. As producers of steel rack structures are interested in reducing the total welding length of beam-end connectors for time efficiency and cost saving, the influence of the welding layout of beam-end connectors on the structural response and failure mode of joints has also been investigated. Finally, some joints have also been equipped with additional bolts to evaluate their influence on the bearing capacity, initial elastic stiffness and dissipated energy per cycle.

1. Introduction

Steel storage pallet racks are characterized by boltless beam-column connections and the extensive use of thin-walled cold-formed steel (CFS) members, so they are easily assembled and the owner can change their layout according to his needs. Uprights are equipped with a regular distribution of holes, where tabs of beam-end connectors are inserted, so beams can be easily disconnected if a new corridor or free space is required. In the down-aisle (longitudinal) direction, owing to the impracticability of using bracings to allow pallets to be loaded or unloaded, beams not only sustain pallets, but also provide adequate stiffness against the down-aisle buckling through these semi-rigid connections at their ends.

The structural response of steel rack connections is difficult to be evaluated analytically, because of the great number of beam-end connector types and different profiles used for beams and uprights. For these reasons, design standard codes for steel storage racks [1,2] require specific experimental tests to evaluate the strength, stiffness and dissipative capacity of rack beam-column joints. In the performance-based seismic design of steel storage pallet racks, beam-column joints play a key role and many researches [3] have highlighted the need to take into account their inelastic response. Experimental tests on beam-column connections to investigate on their structural behavior have been performed by many researchers. For example the connection flexibility of boltless rack connections was investigate in [4]; the stiffness of joints in bolted connected CFS trusses was evaluated in [5], respectively by means of full-scale tests under monotonic load. Tests on different types of commercially available beam-end connectors, under a monotonic increasing load, were performed in [6], where the effect of the upright's features on the moment-curvature relationship was analyzed. Moreover, monotonic experimental tests were conducted in [7] to investigate the flexural behavior of connections under hogging loading in a single cantilever test setup. Several groups of beam-upright connections with different constructional details, such as the upright's profile, the thickness or the number of tabs in the beam-end connector, were investigated. These tests highlighted that the failure mode of connections mainly depends on the relative thickness between the upright and the beam-end connector.

* Corresponding author.
E-mail addresses: federico.gusella@unifi.it (F. Gusella), giovanni.lavacchini@gmail.com (G. Lavacchini), maurizio.orlando@unifi.it (M. Orlando).

https://doi.org/10.1016/j.jcsr.2017.10.021
0143-974X/

Experimental tests aimed to investigate the behavior of beam-column joints under cyclic reversal loading were discussed in [8], where constant amplitude cyclic tests were performed highlighting that very ductile rack connections can cause large swaying of uprights during earthquakes, thus leading to significant second-order effects. Other experimental findings on beam-column connections under cyclic loads were presented in [9]. In these cyclic tests the loading history included series of three cycles of equal maximum displacement and the maximum displacement of the series was increased until the connection failed; obtained results showed a pinching in the moment-rotation hysteresis curve, highlighting the different response of rack connection respect to traditional steel joints. In [10] the authors analyzed a specific type of connector, in which tabs work in tension and compression [11]. This connection type was tested in different configurations, changing its structural details and the authors observed that the envelope of the cyclic moment-rotation curve was comparable with the monotonic one.

The structural response of bolted moment connections, formed by CFS members, was investigated in [12], where the authors observed, after an initial high moment-rotational stiffness of the connection, a significant amount of looseness, which is negligible in the ultimate limit state design of the whole structure.

The structural behavior of rack connections were also investigated by finite element numerical models; in [13] results of experimental tests on rack beam-end connections using both a cantilever and a double cantilever test setup were compared with those obtained through non-linear finite element analyses, obtained results were found to match well with the full scale frame tests. Effects of the number of tabs were investigated in [14] by means of numerical models, managing to capture the tearing of the column web produced by tabs. In [15] an experimental research program aiming to evaluate the semi-rigid behavior of some typical bolted connections, used in cold-formed steel plane truss joints, was carried out and a numerical analysis of this type of connections, taking into account their semi-rigid behavior, was developed in order to demonstrate the improvement of load capacity in comparison with the classical pinned connection assumption.

The influence of the modeling of beam-column joints on the overall structural response of pallet racks was investigated in the numerical studies developed in [16], where frame models with semi-rigid joints are suggested, and in [17], where the importance of taking into account the cyclic behavior of connections to perform more reliable dynamic nonlinear analyses was underlined.

In this paper, with the aim to increase the knowledge on the structural behavior of beam-end connectors of pallet racks, the authors present and compare results of experimental tests on different types of joints under both monotonic and cyclic loading. The novelty of research is mainly represented by the investigation of the welding layout between the beam-end section and the connector and its influence on the structural response and failure mechanism of tested joints. In fact, producers of steel pallet racks are interested in minimizing the total length of welding for time efficiency and cost saving. Moreover, the authors study the opportunity of increasing the carrying capacity and ductility of joints through additional bolts, as they could allow for the overall seismic response of pallet racks to be increased. Nevertheless, not to lose main advantages of dry joints, bolts could be only added in a limited number of joints and in some specific positions inside the structure, to be investigated in the future.

2. Experimental program

2.1. Connection types

The behavior of four different types of beam-column connections, in the following named *A*, *B*, *C* and *D*, have been investigated experimentally. In all tested connections, the beam has a hollow rectangular cross section (height/base/thickness = 130/50/2 mm), while the upright has a perforated open section (height/base/thickness = 100/130/2.5 mm), whose ultimate capacity has been investigate through experimental tests in [18,19] under compression and bending with the assessment of its strength domains.

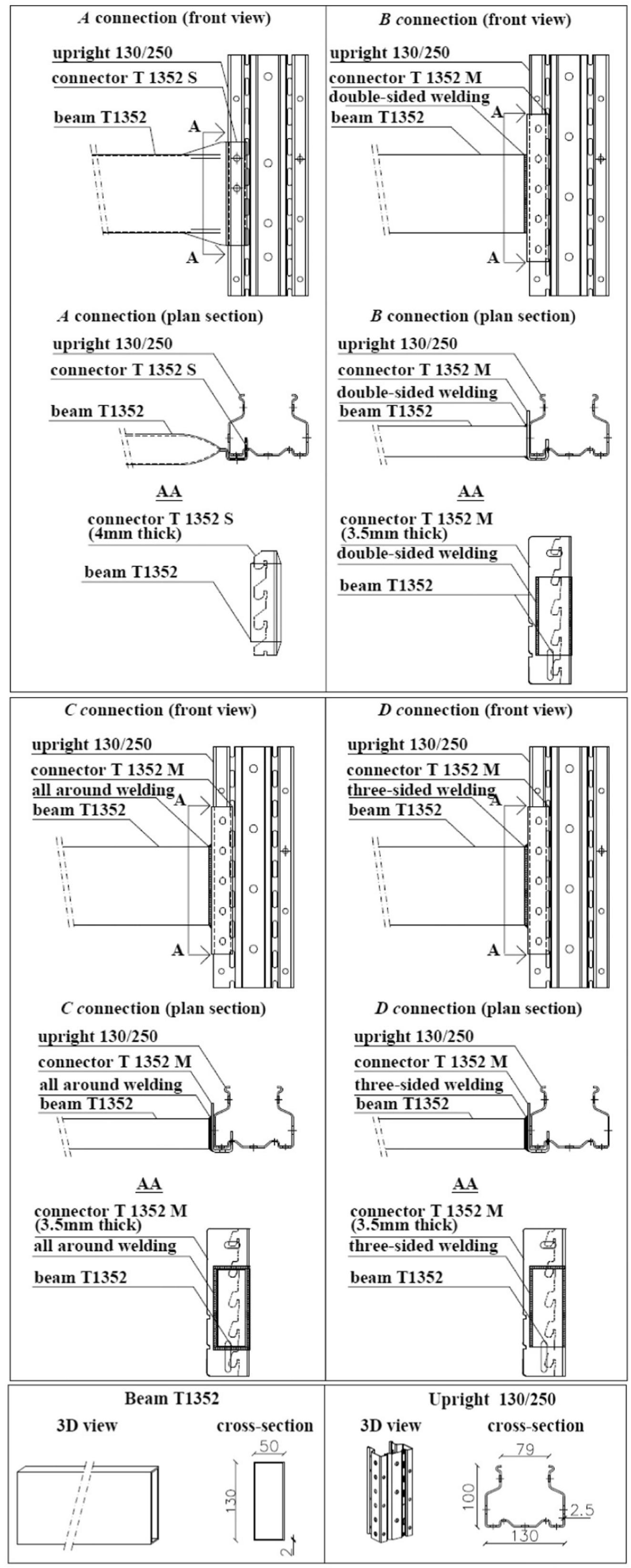

Fig. 1. Geometry and components of tested connections.