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Determining the transverse shear stiffness of steel storage rack upright frames

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ABSTRACT

The stability of steel storage racks in the cross-aisle direction is typically ensured by cold-formed steel bolted upright frames. Sensitive to second-order effects, accurately determining the shear stiffness of these frames is essential for seismic design and for ensuring the stability of the rack, especially for high-bay racks and racks supporting the building enclosure, where the outer rack frames must withstand cross-aisle horizontal actions due to wind loading. The main international racking specifications adopt different approaches to determining the shear stiffness of cold-formed steel storage rack upright frames. The Rack Manufacturers Institute (RMI) specification conservatively uses Timoshenko and Gere's theory. The European Specification EN 15512 recommends testing, however it is not clear whether the shear stiffness obtained using the recommended test procedure is correct. The newly revised Australian Standard AS 4084 adopted the European approach but also introduced an alternative test method for determining the combined bending and shear stiffness of upright frames in the transverse direction. This paper reviews and analyses the factors influencing the shear deformation of cold-formed steel bolted upright frames and introduces the alternative test set-up adopted in the revised Australian Standard. 36 upright frames have been tested using the two test methods, and experimental results are presented, discussed and compared with finite element analysis results. Recommendations on how to use the test outcomes in design are also provided. Based on these recommendations, the paper shows that the two test methods are not equivalent and yield different results for the transverse shear stiffness of upright frames.

1. Introduction

Steel storage racks are common structures used in industry to store goods on pallets. They act as freestanding structures in their own right and are designed as lightly as possible, yet able to carry heavy loads. Typically made of cold-formed steel profiles, their stability is often solely ensured by the base plate to floor connections and the pallet beam to upright connections in the down-aisle direction [1,2] (Fig. 1). In the cross-aisle direction, stability is ensured by upright frames consisting of uprights connected by bracing members as shown in Figs. 1 and 2. The bracing members are typically bolted to the upright flanges and made from cold-formed lipped Cee-sections. There may be one or two bracing members connected to the upright at the same bracing point, as shown in Fig. 2. Circular hollow section (CHS) bracing members are also used in practice but are less common than the Cee-sections.

Sensitive to second-order effects, accurately determining the shear stiffness of these upright frames is essential for seismic design and for ensuring the stability of the rack, especially for high-bay racks and racks supporting the building enclosure, where the outer rack frames must withstand cross-aisle horizontal actions due to wind loading. For static design, the shear stiffness value mainly affects the serviceability limit state rather than the ultimate limit state, yet accurately determining the transverse shear stiffness is also required to determine the cross-aisle elastic buckling load P_{cr} of the upright frame as developed hereafter. For seismic design, the shear stiffness of the upright frame influences the natural frequency of the rack and hence the earthquake force in the cross-aisle direction. Underestimating the shear stiffness would lead to unsafe design earthquake forces.

The Rack Manufacturers Institute, RMI [3], and the former Australian Standard, AS 4084 [4], calculate the transverse shear stiffness S_D of upright frames based on Timoshenko and Gere's [5] shear formulae, in which the upright frame shear deformation is assumed to be only due to the axial deformation of the bracing members. The shear stiffness is then used to estimate the elastic buckling load P_{cr}. For instance, for

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