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Ultra-light gauge steel storage rack frames. Part 1: Experimental investigations

A.N. Trouncer *, K.J.R. Rasmussen

School of Civil Engineering, University of Sydney, NSW 2006, Australia

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ABSTRACT

This paper presents an experimental investigation into locally unstable ultra-light-gauge steel storage rack frames that are prone to flexural-torsional buckling. The aim of the research was to understand how local instabilities and interactive buckling affect the strength of ultra-light gauge frames and to create reliable data through a controlled experimental investigation. A total of twelve full scale tests were conducted in the Civil Engineering Structures Laboratory at the University of Sydney. Prior to testing, the geometric imperfections of each member were measured, as were the material properties of the cold-rolled sections and the virgin steel from which the sections were formed. The cross-sectional deformations, ultimate loads and observations regarding failure modes were accurately captured and documented. The tests were also successful in capturing the post-ultimate response of the frames as well as the rotational stiffness of the beam-to-upright connections. Results from nominally identical tests were in good agreement. The tests provide comprehensive data for assessing the effects of interactive buckling and the extent to which cross-sectional deformations amplify the second-order deformations in locally unstable storage rack frames.

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1. Introduction

Thin-walled cold-formed steel sections are increasingly being used as structural members in light-gauge steel structures due to their high strength-to-weight ratio and efficient use of material. However, due to their reduced wall thickness, thin-walled cold-formed steel sections are prone to local and distortional buckling as well as overall buckling. It is well understood that these cross-sectional deformations reduce the rigidity of the section, and hence amplify sway deflections and cause a redistribution of the internal forces in the structural frame. Unless accounted for, the internal bending moments are underestimated and the structural design may become inadequate. This paper forms the first part of a research program undertaken at the University of Sydney investigating the effects of additional second order moments in unbraced steel frames caused by cross-sectional buckling and the extent to which these need to be accounted for in design. The aim of this paper is to present the results from the full scale tests on ultra-light gauge steel storage racks conducted. Based on the results provided, further investigations into the effects of these additional second order moments are described in a companion paper [1].

Although promising research has been completed in extending the scope of geometric and material nonlinear (GMNIA or "advanced") analysis to the direct design of steel frames consisting of non-compact sections, there is an information gap in relation to large-scale physical testing of steel frames consisting of non-compact members. While a significant amount of research has been conducted for steel frames comprised of cold-formed compact sections [2–5], and the idealization of joints using advanced analysis [5–8], only a few researchers [9–11] have completed large scale tests of steel frames consisting of non-compact members. If methodologies for the design by advanced analysis are to extend to include non-compact members, it is imperative that additional accurate full scale testing is completed on steel frames consisting of non-compact members, in order to provide data for model verification purposes. A secondary aim of the paper is to make such experimental data on the behaviour and failure modes of locally unstable steel frames available.

A total of 12 full scale tests were completed in the Civil Engineering Structures Laboratory at the University of Sydney. While the overall system failure was recorded, emphasis was also placed on capturing the local instabilities in the uprights during loading. Hence, deformations in the uprights during testing were captured, and observations regarding local failure modes were documented. The relative joint rotation between the pallet beam and upright was also measured. In addition, the geometric imperfections of each member were measured before testing, as were the material properties of sections and the virgin steel from which the sections were formed. The experimental set-up, the observed failure

* Corresponding author.

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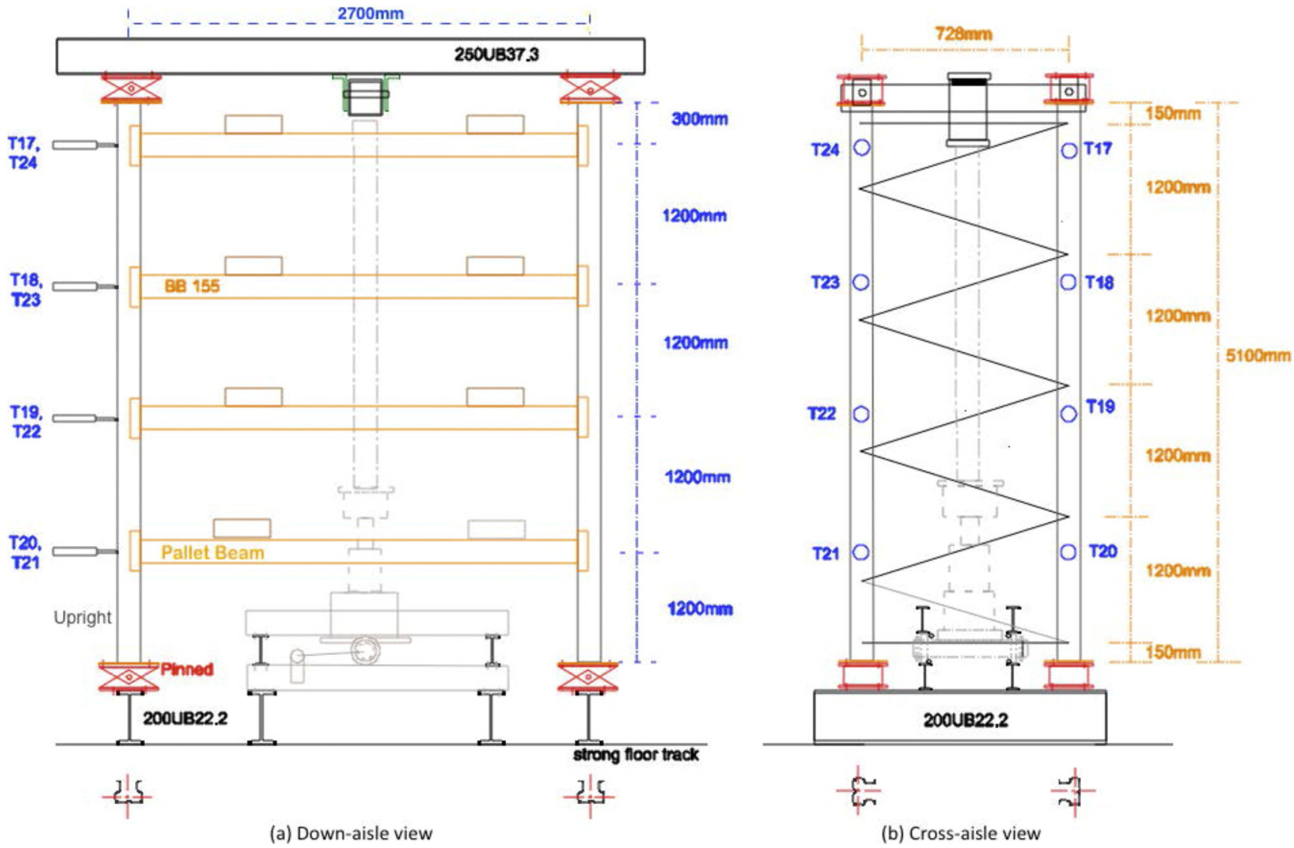

Fig. 1. Test Setup - Frame orientation, bracing dimensions and transducer locations.

modes, the recorded ultimate strengths and the load-deflection responses of the frames.

2. Test frames

In order to accurately obtain imperfection data for the storage rack sections, it was first necessary to assemble the uprights in the upright frames prior to the imperfection measurement. To construct the upright frames, two nominally 5100 mm long storage rack sections were connected with eight 40 × 26 × 8 mm lipped channel bracing members using M8.8 zinc coated bolts. The first bracing member connected the members horizontally, 150 mm from the base, as shown in Fig. 1. A spacer ensured that the brace member was pressed flush against the flange of the upright at the first bolt hole. Eight other bracing members then ran diagonally up the frame, 600 mm vertically apart, crisscrossing until the final horizontal member was connected 150 mm from the top.

The uprights used in the frame tests were nominally 5100 mm long and 1.0 mm thick. Two types of cross-section were investigated, viz. the 90 mm wide rear-flange section (90RF1.0) and 90 mm standard upright section (90SD1.0). Both types of section were cold-rolled from G550 galvanised strip to Australian Standard AS1397 [12] with a guaranteed minimum proof stress of 550 MPa. Details of the nominal cross-section dimensions, measured thickness and measured material properties are provided in the references [13,14].

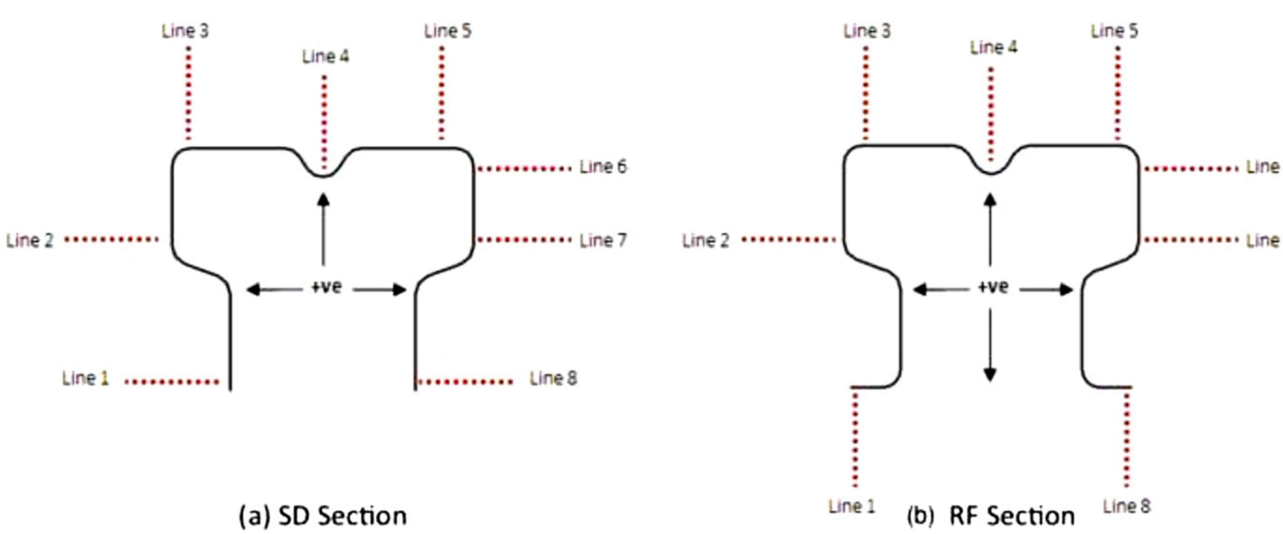

Fig. 2. Locations of laser lines for RF and SD sections.

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