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Structural behaviour of cold-formed thin-walled short steel channel columns at elevated temperatures. Part 2: Design calculations and numerical analysis

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Abstract

The companion paper has presented results of elevated temperature tests on 52 cold-formed thin-walled channels under compressive load. This paper presents the results of theoretical studies using a number of different calculation tools, these including simple design calculations based on modifying a few current design methods and a commercial finite element package ABAQUS. The design methods considered in this paper include the British standard BS5950 Part 5, Eurocode 3 Part 1.3 and the American Specification AISI. Modifications of the current design equations are made to enable them to include distortional buckling, the effects of service holes and elevated temperatures. To enable BS5950 Part 5 and Eurocode 3 Part 1.3 to predict the ultimate strength of thin-walled columns with a service hole, the AISI (1996) design method is introduced. To extend the capacity of these design methods to deal with distortional buckling failure mode, the method of Young, Kwon and Hancock for calculating distortional buckling capacity is introduced in these codes. Finally, the ambient temperature design methods are modified to take into account changes in the strength and stiffness of steel at elevated temperatures. From extensive comparisons between the results of tests, code predictions and numerical analyses, it may be concluded that by adopting the aforementioned modifications, the current code design methods can be easily modified to consider these advanced modes of behaviour.

For finite element analyses, both geometrical and material non-linearities are taken into account. The high temperature stress–strain relationships of steel are determined according to Eurocode 3, Part 1.2 or Outinen et al.

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1. Introduction

Cold-formed thin-walled steel structural members can fail in a variety of buckling modes including local, distortional and global buckling at ambient temperature or high temperatures. Due to highly non-linear stress–strain relationships of cold-formed steel at high temperatures in fire, these types of buckling behaviour become more complicated. However, there are very few theoretical studies, with validation by experimental results, of cold-formed thin-walled steel columns at elevated temperatures.

In Ref. [2], transient-state fire tests on rectangular hollow sections under concentric and eccentric compression loading are reported. They proposed a simple calculation method for local buckling based on Eurocode 3 Part 1.3 [4]. In this method, the effective width at elevated temperatures may be determined with the same formulae as at normal temperature, but the yield strength and the modulus of elasticity of steel at elevated temperatures should be reduced. The yield strength of steel is determined according to the 0.2% plastic strain at elevated temperatures. Randy [12] carried out a more detailed theoretical study and reached the same conclusion. Wang and Davies [15] performed a theoretical study using the design equations in Eurocode 3 Part 1.3 [4] to calculate the fire resistance of thin-walled cold-formed members. They found that the ambient temperature approach was suitable for adoption under fire conditions, however, design calculations should take into account reductions in the strength and stiffness of steel at elevated temperatures, the additional bending moments due to thermal bowing and shift in the neutral axis of the column cross-section. They made many assumptions about the effects of non-uniform temperature and stress distributions on the cross-sectional properties of thin-walled members and further research studies would be necessary to improve these assumptions. Lawson [8] presented a design method for cold-formed thin-walled steel structures. This method is based on the limiting temperature method for hot-rolled steel structures in BS 5950 Part 8 (BSI 1990).

This paper has three objectives. Firstly, it will introduce modifications to three current design methods to enable them to predict the elevated temperature tests on short thin-walled steel columns in the companion paper. Secondly, it will check the accuracy of these modifications and other design methods. Finally, it will evaluate the capabilities of a commercial software, ABAQUS [1], so as to make preparation for more extensive parametric studies in the future to deal with more complicated situations such as non-uniform temperature and non-uniform stress distributions.

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