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Calculating the global buckling resistance of thin-walled steel members with uniform and non-uniform elevated temperatures under axial compression

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ABSTRACT

This paper develops a method, based on the Direct Strength Method (DSM) global buckling curve, to calculate the global buckling ultimate strength of cold-formed thin-walled (CF-TW) steel members under uniform and non-uniform elevated temperatures. The assessment is carried out by checking the DSM curve-based results with numerical simulation results using the general finite element software ABAQUS. The numerical model has been validated against a series of ambient temperature and fire tests on panels made of two different lipped channel sections tested to their ultimate load carrying capacities at ambient temperature or to their fire resistance at different load levels. The validated numerical model has been used to generate a database of numerical results of load carry capacity of CF-TW members with different uniform and non-uniform temperature distributions in the cross-sections under different boundary and loading conditions and with different dimensions. It is concluded that the DSM global buckling column curve is directly applicable for uniform temperature but a simple modification is required for non-uniform temperature distributions.

1. Introduction

Cold-formed thin-walled (CF-TW) steel members have a high strength to weight ratio and are easy to construct. They are widely used as load bearing members in low-rise housing construction, commercial buildings and in many other structural applications, for which both ambient and elevated temperature ultimate strength are important considerations, as they have low fire resistance because of rapid temperature rise due to high thermal conductivity of steel and high section factor. Thin-walled steel members are usually part of a wall construction and protected by gypsum board from both sides with fire exposure from one side (Fig. 1), which results in non-uniform temperature distributions in the cross-section of the CF-TW member.

For ambient temperature design calculations, the traditional approach is the effective width method. There is now a growing movement to replace the effective width method by the Direct Strength Method (DSM) [1,2], because the latter offers advantages in dealing with sections with multiple stiffeners and the calculations are much simpler than using the effective width method. For fire resistance calculations, the DSM is particularly advantageous over the effective width method because the non-uniform temperature distribution in the cross-section effectively turns the CF-TW cross-section with uniform mechanical properties at ambient temperature, into one with non-uniform mechanical properties in fire condition for which application of the effective width method would be extremely tedious.

DSM is an extension of the use of column curves for global buckling to local and distortional buckling (Fig. 2). The simplicity of this method is that by determining the elastic buckling loads (which can be easily performed using computer programs, Fig. 3) and the squash load, the column strength can be directly determined, without complex calculations of the effective widths.

The global buckling curve forms the basis of the other DSM buckling curves. Furthermore, at present, there is no design method that may be used to deal with columns with non-uniform temperature distributions. As the first of a series of papers to assess the applicability of DSM to thin-walled members with non-uniform temperature distributions, this paper will concentrate on the applicability of DSM-based global buckling curve to thin-walled members.

2. Finite element modelling validation against experimental study

The assessment of DSM will be based on a database of global buckling results using the general finite element software ABAQUS. To ensure accuracy of these results, the ABAQUS simulation method has been validated against a series of experimental studies by Feng and Wang [5].

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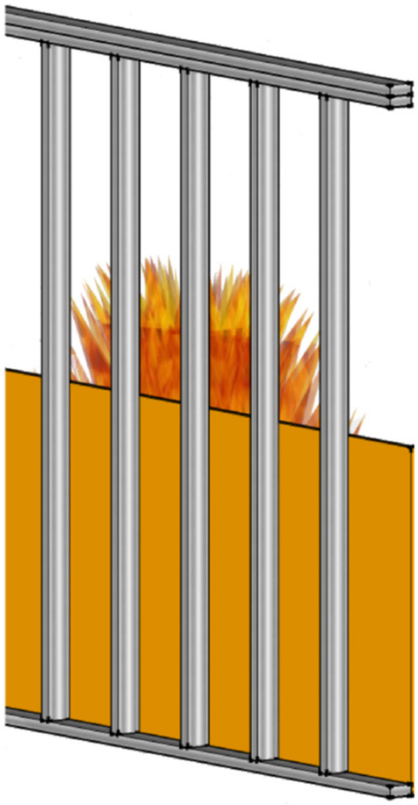

Fig. 1. Wall construction under fire attack.

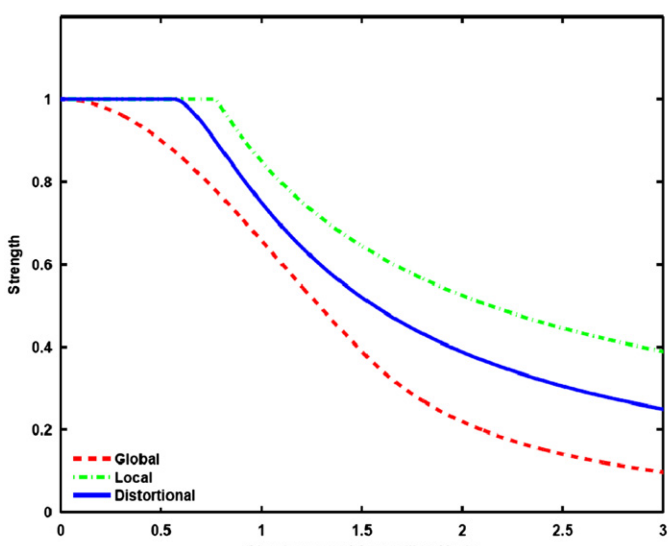

Fig. 2. Local, distortional and global buckling column curves.

2.1. *Full-scale tests of cold-formed thin-walled steel structural panels at ambient temperature and exposed to fire*

A series of eight panel tests were performed by Feng and Wang [5] and Feng [6]. Two of the eight tests were at ambient temperature and the other six tests were under fire exposure to the panel from one side only.

Fig. 4 shows a fire test in progress. The test panel was contained in a self-contained loading rig and exposed to fire attack from one side. The overall size of the panels was 2000 mm × 2200 mm, which

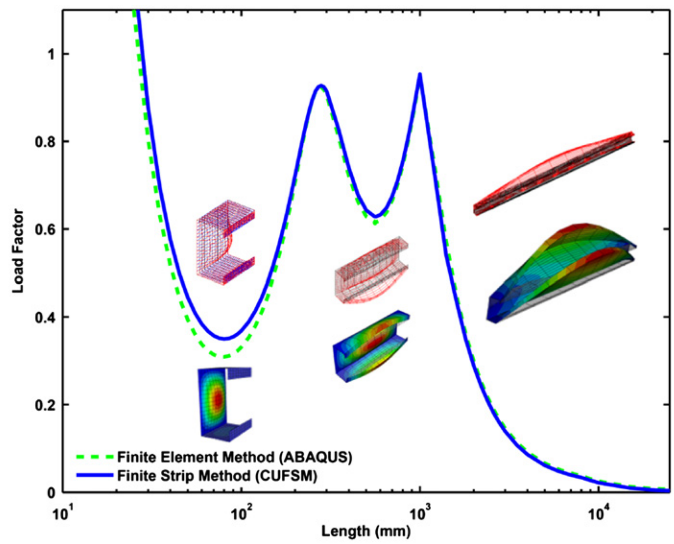

Fig. 3. Examples of elastic buckling curve by using ABAQUS [3] and CUFSM [4].

Fig. 4. A fire test in progress [6].

consisted of three vertical lipped channel studs (100 × 56 × 15 × 2 or 100 × 54 × 15 × 1.2), four flat bar lateral bracings, two horizontal channel trances, one layer of 12.5 mm thick fireline gypsum board on each side and Isowool 1000 as an interior insulation. Screws spaced at 300 m were used to fix the gypsum boards horizontally to steel studs. Fig. 5 shows the lipped channel stud dimensions.

Fig. 6 shows overall dimensions of the panels and Figs. 7 and 8 show the displacement transducer and thermocouple locations.

For the ambient temperature tests, the specimen was inserted between two channel sections, one at the top and one at the bottom. The top was bolted to a moving beam to facilitate load application and the bottom was fixed to a supporting beam. The support channels allowed the specimen to rotate out of plane but prevented the in-plane rotation. For the fire tests, the test specimen was exposed to fire from one side from the 2 m × 2 m aperture from a furnace next to the panel.