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Improved design rules for fixed ended cold-formed steel columns subject to flexural–torsional buckling

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ABSTRACT

This paper has presented the details of an investigation into the flexural and flexural–fl buckling behaviour of cold-formed structural steel columns with pinned and fixed ends. Current design rules for the member capacities of cold-formed steel columns are based on the same non-dimensional strength curve for both fixed and pinned-ended columns. This research has reviewed the accuracy of the current design rules in AS/NZS 4600 and the North American Specification in determining the member capacities of cold-formed steel columns using the results from detailed finite element analyses and an experimental study of lipped channel columns. It was found that the current Australian and American design rules accurately predicted the member capacities of pin ended lipped channel columns undergoing flexural and flexural torsional buckling. However, for fixed ended columns with warping fixity undergoing flexural–torsional buckling, it was found that the current design rules significantly underestimated the column capacities as they disregard the beneficial effect of warping fixity. This paper has therefore proposed improved design rules and verified their accuracy using finite element analysis and test results of cold-formed lipped channel columns made of three cross-sections and five different steel grades and thicknesses.

1. Introduction

Cold-formed steel members are becoming increasingly popular within the construction industry due to their superior strength to weight ratio and ease of fabrication as opposed to hot-rolled steel members. They are often subject to axial compression loads in a range of applications (see Fig. 1). These thin-walled members can be subject to various types of buckling modes, namely local buckling, distortional buckling, flexural buckling and flexural–torsional buckling. Hence extensive research efforts have gone into the many investigations addressing the buckling behaviour of cold-formed steel columns.

Popovic et al. [1] performed tests on fixed and pinned ended angle columns. Their test specimens failed in flexural and flexural–torsional modes. They showed that the design capacity curve proposed in AS/NZS 4600 [2] is conservative for shorter specimens. Popovic et al. [1] reported that the reason for this is most likely the post-buckling reserve of the section in the torsional mode. Young [3,4] conducted experimental studies of angle columns and concluded that AS/NZS 4600 [2] design rule is conservative. Hence he proposed a new design rule for concentrically loaded compression members of fixed ended cold-formed steel plain angle sections. This was adopted in Silvestre et al. [5] to estimate the global column strength, which gave more accurate ultimate strengths for fixed-ended and pin-ended columns. Shifferaw and Schafer [6] found that plain and lipped angles with fixed end conditions exhibited post-buckling strength with respect to global torsional or flexural–torsional buckling modes due to the presence of warping fixity, which is ignored in all the current design rules.

Rasmussen and Hancock's [7] research into the flexural of cold-formed steel channels showed that AS/NZS 4600 [2] conservatively predicted the member strengths of fixed ended columns at intermediate and long lengths. Recently, Bandula Heva and Mahendran [8] carried out a series of compression tests of cold-formed steel channel members subjected to flexural–torsional buckling, and showed that AS/NZS 4600 [2] design rules conservatively predicted the strength of tested specimens. These findings therefore warrant further investigations into the behaviour of fixed ended lipped channel steel columns subject to flexural and flexural–torsional buckling.

The overall aim of this research is to investigate the accuracy of current design rules in determining the strengths of concentrically loaded cold-formed steel columns with fixed ends subject to flexural and flexural–torsional buckling. Experimental results for this study were obtained from Bandula Heva and Mahendran [8]. In their study suitable test specimens were selected based on the standard sections, thicknesses and grades that are commonly used

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in structural and architectural applications and available literature. The dimensions and lengths of lipped channel section columns were selected based on a number of preliminary analyses using a finite strip analysis programme CUFSM [9] so that flexural–torsional buckling governed the member behaviour. In this study, finite element models were developed using a finite element analysis programme ABAQUS [10] to simulate the behaviour of long lipped channel section columns using suitable loading and boundary conditions. The developed finite element models were validated by comparing their results with Bandula Heva and Mahendran's [8] test results. The validated model was then used in a detailed numerical study into the axial compression strengths of lipped channel columns. Five different steel grades and thicknesses were considered in this numerical study to investigate the effect of using low and high grade steels. Three different section dimensions were also considered in this study with varying column lengths. The results obtained from this study were compared with the predicted ultimate loads from the current cold-formed Australian and American steel standards, based on which the accuracy of current design rules for pinned and fixed ended cold-formed steel compression members undergoing flexural and flexural–torsional buckling was investigated. This paper presents the details of this research study and the results.

2. Experimental study

Bandula Heva and Mahendran [8] investigated the behaviour and strength of cold-formed steel lipped channel columns at both ambient and elevated temperatures. As part of their experimental study, they conducted six tests at ambient temperature to investigate the flexural–torsional buckling behaviour of fixed ended columns.

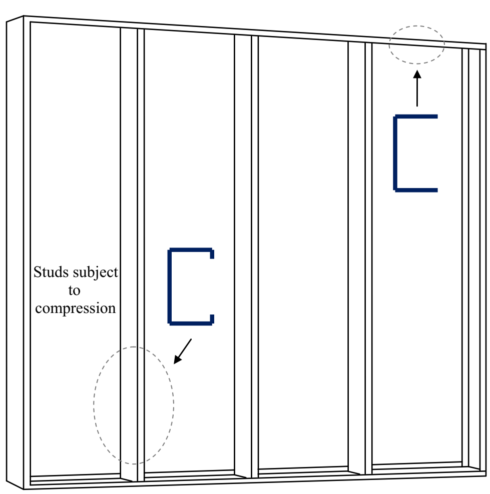

Fig. 1. Cold-formed steel columns used in steel frames.

2.1. Test specimens

The most common cold-formed steel column section of lipped channel was chosen for their tests. Test section dimensions and specimen lengths were selected based on preliminary numerical analyses and AS/NZS 4600 design rules so that flexural–torsional buckling governed the member behaviour. These analyses showed that the member lengths of 1600 mm or higher gave flexural–torsional buckling for the two selected lipped channel sections ($55 \times 35 \times 9$ and $75 \times 50 \times 15$) with fixed ends. Therefore two specimen lengths of about 1800 mm and 2800 mm were selected in their tests. Three grades and thicknesses, G550-0.95, G450-1.90 and G250-1.95, were selected to represent the cold-formed steel domain, each with nominal lengths of 1800 and 2800 mm. Table 1 gives the measured cross-sectional dimensions and lengths of six ambient temperature test specimens and the mechanical properties of steels.

Imperfections of all the specimens were measured along the specimens on all the surfaces except lips in the study of Bandula Heva and Mahendran [8]. Since the expected buckling mode was global buckling, only the global imperfection was measured. In most cases, the maximum imperfections were observed to be on the web. Table 1 shows the measured imperfections. The measured imperfections were significantly less than the tolerance value of L/1000 recommended by AS 4100 [11].

2.2. Test setup and procedure

A special test set-up was designed and built to test long columns of different heights inside a furnace, so that both ambient and elevated temperature tests can be done as required [8]. Hence the ambient temperature tests reported here were conducted inside the furnace while keeping the doors open as shown in Fig. 2. The loading arrangement consists of two loading shafts at the top and bottom and a hydraulic loading system as shown in Figs. 2 and 3. By using the nuts on each of the leveling bars in the special loading arrangement at the bottom, the base plate was leveled so that the guidance tube was vertical to allow the required application of load. The hydraulic jack was connected to a hydraulic pump through a pressure transducer. The pressure transducer was used to determine the applied axial load.

All the tests were carried out using fixed-end conditions. To achieve a fixed-end support, special end plates were made to fit the specimen ends (see Fig. 3). A groove of 12 mm deep and 10 mm width in the shape of specimen cross-section was made on a 15 mm thick circular steel plate. A rectangular hollow section (RHS) of 2 mm thick and 15 mm height was then welded to the plate. Geometric centre of the cross-section of the specimen was made to coincide with the centre of the plate. The specimen was placed within the grove, and 165 procreate coil grout mixed with water was then used to fill the grove and the end space up to the top of RHS. The specimen with these end plates was then placed between the two loading shafts and bolted to form fixed ends. Out

Table 1
Measured dimensions and mechanical properties of test specimens.

Lipped channels	f_y (MPa)	E (MPa)	Measured dimensions (mm)					Imperf
			Web	Flange	Lip	Thickness	Length	
G550 × 0.95 × 55 × 1800	615	205000	54.94	34.88	8.00	0.95	1740	L/2485
G550 × 0.95 × 55 × 2800	615	205000	54.82	34.78	7.82	0.95	2820	L/1446
G250 × 1.95 × 75 × 1800	271	188000	74.82	50.06	14.87	1.95	1740	L/2558
G250 × 1.95 × 75 × 2800	271	188000	74.97	49.88	14.69	1.95	2820	L/4086
G450 × 1.90 × 75 × 1800	515	206000	74.67	49.94	14.51	1.88	1740	L/2949
G450 × 1.90 × 75 × 2800	515	206000	74.27	49.78	14.92	1.88	2820	L/2073