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Column tests of cold-formed steel non-symmetric lipped angle sections

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Abstract

The geometry of angle sections is simple, but the behaviour and design calculations of angle sections can be quite complicated. Furthermore, lipped angle sections with unequal flange widths form a *non-symmetric* section and the behaviour of the section is even more complicated than a singly-symmetric angle section with equal flange widths. A test program on cold-formed steel non-symmetric lipped angle columns is presented. The non-symmetric angle sections were brake-pressed from high strength structural steel sheets having nominal yield stresses of 450 and 550 MPa with plate thicknesses of 1.0, 1.5 and 1.9 mm. The material properties of the column specimens were obtained by tensile coupon tests. The behaviour and strengths of cold-formed steel non-symmetric lipped angle columns were investigated. The test strengths are compared with the design strengths calculated using the North American Specification for the design of cold-formed steel structural members. In addition, the current design rules in the North American Specification for cold-formed steel non-symmetric lipped angle columns are assessed using reliability analysis. It is shown that the design strengths are generally quite conservative.

Keywords: Angle; Buckling; Cold-formed steel; Columns; Experimental investigation; Steel structures; Structural design; Thin-walled structures

1. Introduction

Plain and lipped angle sections with equal flange (leg) widths are singly-symmetric sections, while angle sections with unequal flange widths are non-symmetric sections. Although the geometry and loading of single angle section steel beams are usually comparatively simple, their behaviour may be extremely complicated, and the accurate prediction of their strengths very difficult [1,2]. This is also true for angle columns, especially for angle sections with unequal flange widths. Single angles, tees and double angles are widely used as chord and web members in trusses [3]. The buckling stress of cold-formed steel angle columns can be enhanced by the use of edge stiffeners that provide a continuous support along the longitudinal edge of the flanges. The edge stiffeners can be easily brake-pressed or roll-formed on the free edge of an unstiffened plate. The use of simple lips in the flanges of angle sections act as edge stiffeners of the sections. Hence, cold-formed steel angle sections having edge stiffeners can lead to an economic design as a result of higher buckling stress of the sections.

The primary advantages of cold-formed steel are light weight, high strength and stiffness, uniform quality, ease of prefabrication and mass production, economy in transportation and handling, fast and easy erection and installation [4]. The objective of this paper is to present a test program on cold-formed steel *non-symmetric* lipped angle columns. Three series of tests were performed on thin-walled angle sections having the nominal plate thicknesses of 1.0, 1.5 and 1.9 mm. The experimental ultimate loads of the fixed-ended columns are compared with the design strengths calculated using the North American Specification (NAS) [5] for the design of cold-formed steel structural members. In calculating the design strengths, elastic buckling stress was obtained by solving a cubic equation. This is due to the sections not having any symmetry either about an axis or about a point.

2. Test specimens

The column tests were conducted on cold-formed steel non-symmetric lipped angle sections. The test specimens were brake-pressed from high strength zinc-coated grades G450 and

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Nomenclature

A	full unreduced cross-section area
A_e	effective area
B_{f1}	overall width of long flange (long leg)
B_{f2}	overall width of short flange (short leg)
B_l	overall width of lip
E	Young's modulus
F_e	elastic buckling stress
F_m	mean value of fabrication factor
F_n	critical (nominal) buckling stress
F_y	yield stress is taken as 0.2% proof stress ($\sigma_{0.2}$)
G	shear modulus
I_x, I_y	moment of inertia of full unreduced section about the principal x-axis and y-axis
I_w	torsional warping constant
J	Saint-Venant torsion constant
L	length of column specimen
l_e	column effective length
l_{ex}, l_{ey}	column effective length for buckling about the principal x-axis and y-axis
l_t	column effective length for torsional buckling
M_m	mean value of material factor
P_{Exp}	experimental ultimate load (test strength)
P_m	mean value of tested-to-predicted load ratios
P_n	nominal axial strength calculated using North American Specification (unfactored design strength)
P_s	section capacity
r_{o1}	polar radius of gyration of cross-section about the shear centre
r_i	inside corner radius of specimen
r_x, r_y	radii of gyration of cross-section about the principal x-axis and y-axis
t	plate thickness of specimen
t^*	base metal plate thickness of specimen
V_F	coefficient of variation of fabrication factor
V_M	coefficient of variation of material factor
V_P	coefficient of variation of tested-to-predicted load ratios
x, y	principal coordinates
x_o, y_o	distances from the shear centre to centroid along the principal x-axis and y-axis
β	reliability index (safety index)
δ_1, δ_2	measured initial overall geometric imperfections at mid-length
ε_f	elongation (tensile strain) after fracture based on gauge length of 50 mm
ϕ_c	resistance (capacity) factor
λ_c	non-dimensional slenderness
$\sigma_{0.2}$	static 0.2% tensile proof stress
σ_{ex}, σ_{ey}	elastic buckling stresses for flexural buckling about the principal x-axis and y-axis
σ_t	elastic buckling stress for torsional buckling
σ_u	static ultimate tensile strength

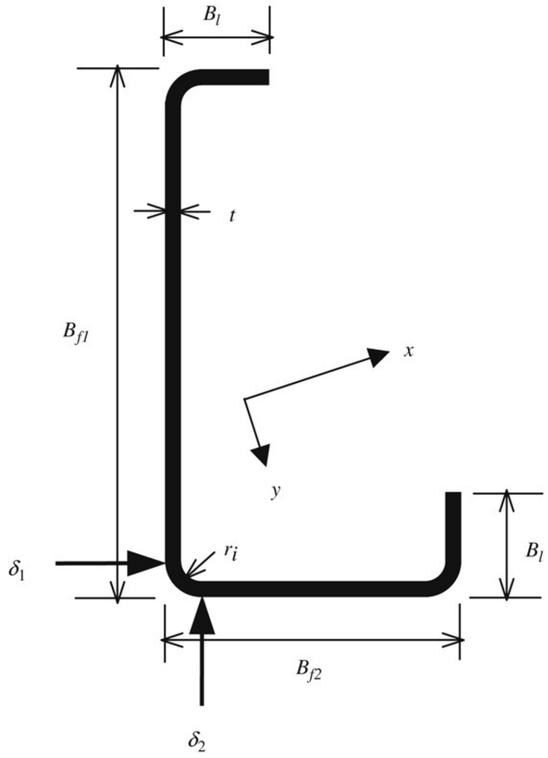

Fig. 1. Definition of symbols.

G550 structural steel sheets having nominal yield stresses of 450 and 550 MPa respectively. These structural steel sheets conformed to the Australian Standard AS 1397 [6]. Each specimen was cut to a specified length of 250, 625, 1000, 1500, 2000, 2500 and 3000 mm. Both ends of the specimens were welded to 25 mm thick steel end plates to ensure full contact between the specimens and end bearings. Three test series of non-symmetric lipped angle columns were compressed between fixed ends. The test specimens having a nominal lip width of 16 mm, a nominal long flange (long leg) width of 80 mm and a nominal short flange (short leg) width of 50 mm. The nominal plate thicknesses were 1.0, 1.5 and 1.9 mm. The three series are labeled U1.0, U1.5 and U1.9 according to their nominal thickness. The measured inside corner radius was 3.0 mm for Series U1.0, and 3.5 mm for Series U1.5 and U1.9 specimens.

The measured cross-section dimensions and column length for each test specimen are shown in Tables 1–3, using the nomenclature defined in Fig. 1. The cross-section constants of the test specimens based on the measured dimensions are shown in Table 4 that include the full unreduced cross-section area (A), moment of inertia of full unreduced section about the principal x-axis (I_x) and y-axis (I_y), torsional warping constant (I_w), Saint-Venant torsion constant (J) and the distances from shear centre to centroid along the principal x-axis (x_o) and y-axis (y_o).

The base metal thickness (t^*) was measured by removing the zinc coating by acid etching. The thickness of the zinc coating on each side of the section was measured as 21, 36 and 31 μm for Series U1.0, U1.5 and U1.9 respectively.