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Experimental investigation of built-up cold-formed steel section battened columns

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ABSTRACT

This paper presents an experimental investigation on behaviour and design of built-up cold-formed steel section battened columns. The built-up columns were pin-ended and consisted of two cold-formed steel channels placed back-to-back at varied spacing of intersection. The two channels were connected using batten plates, with varying longitudinal spacing. The cold-formed steel channel sections were manufactured by brake-pressing flat strips having a plate thickness of 2 mm. The built-up cold-formed steel section battened columns had different slenderness and geometries but had the same nominal length of 2200 mm. The column strengths, load–axial shortening, load–lateral displacement and load–axial strain relationships were measured in the tests. In addition, the failure modes and deformed shapes at failure were observed in the tests and reported in this paper. Overall, the built-up column tests provided valuable experimental data regarding the column behaviour that compensated the lack of information on this form of construction as well as used to develop nonlinear 3-D finite element models. The column strengths measured experimentally were compared against design strengths calculated using the North American Specification, Australian/New Zealand Standard and European Code for cold-formed steel columns. Generally, it is shown that the specifications were unconservative for the built-up cold-formed steel section battened columns failing mainly by local buckling, while the specifications were conservative for the built-up columns failing mainly by elastic flexural buckling.

1. Introduction

Cold-formed steel structures have many advantages comprising superior strength-to-self-weight ratio, ease of construction, and economic design. Recently, developed manufacture techniques and increased strength of materials gave the edge to cold-formed steel over traditional hot rolled steel in the construction of a wide range of structures. A summary of the major research developments in cold-formed steel structures is given by Yu [1] and Hancock [2]. Although, extensive experimental investigations were conducted and reported in the literature on cold-formed steel single columns having symmetrical or asymmetrical cross-sections, tests on built-up cold-formed steel section columns are rarely found in the literature, leading to the current investigation.

The behaviour of built-up battened carbon steel columns was investigated by Johnston [3]. The columns had batten plates attached to the column components via bolted connections. Overall, the study investigated the contribution of end tie plates (end batten plates) to the buckling strength and distribution of direct or moment applied loads to the component elements of the battened columns. Toossi [4] studied the out-of-plane buckling of battened columns, under axial and/or moments. A general relationship between the applied loads and the section properties of the column was proposed in the study. Temple and Elmahdy [5] carried out experimental and theoretical investigations on the behaviour of battened columns made of standard carbon steel channel sections. It was concluded that the local buckling length (longitudinal distance between end connectors of two adjacent batten plates) as well as nondimensional slenderness ratio of whole cross-section are the main factors affecting the column strength and behaviour. The number of connectors in built-up double-angle battened columns was investigated by Zahn and Haaijer [6]. The investigation highlighted the design of built-up battened double-angle columns. Temple and Elmahdy [7,8] discussed the buckling mode of built-up carbon steel columns. In the study [7], the authors proposed a brief derivation of an equivalent slenderness ratio equation and its applicability. While the study [8] showed that nondimensional slenderness ratio of main column components between connection points had a significant effect on the column strength and buckling behaviour. Dung et al. [9] and Jui-Ling [10] carried out tests on built-up hot-rolled columns. Nondimensional slenderness ratio of the built-up columns was investigated. The authors proposed formulas for the calculation of column slenderness ratios based on available formulas in current

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Nomenclature

A_e	effective cross-section area
a_b	width of batten plates
B	overall cross-section width
B_1	channel back-to-back spacing
b	width of an individual channel
b_b	intermediate batten plate width
b_{b1}	end batten plate width
COV	coefficient of variation
D	overall cross-section depth
E_o	initial Young's modulus of cold-formed steel
F	elastic flexural buckling failure mode
F_e	least of the elastic flexural, torsional, and flexural torsional buckling stress
F_n	critical buckling stress
f_u	ultimate stress
K	buckling factor
L	local failure mode
L	column length
L_z	local buckling length
N_{cr}	critical buckling (Euler) load
$P_{AS/NZS}$	design strength calculated using the Australian and New Zealand Standard
P_{EC3}	design strength calculated using the European Code
P_{NAS}	design strength calculated using the North American Specification
P_{Test}	test strength
r	radius of gyration
r_i	internal radius
r_{y1}	minimum radius of gyration around the individual channel
t	thickness of channels
t_b	thickness of batten plates
σ_y	yield stress
σ_u	ultimate stress
$\sigma_{0.2}$	0.2% proof stress
λ_1	buckling factor
λ_c	critical slenderness
$\overline{\lambda}$	overall nondimensional slenderness
δ_1	lateral displacement at quarter-length
δ_2	lateral displacement at mid-length
ε_u	strain at fracture
χ	buckling factor
α	buckling factor
ϕ	buckling factor

codes of practice. The elastic critical load of built-up hot-rolled steel columns was the subject of an experimental investigation conducted by Hashemi and Jafari [11,12]. The studies proposed theoretical methods for predicting the elastic critical load and the column strength of the built-up columns. The stability of built-up thin-walled steel beams and columns was studied by Rondal and Niazi [13]. The study presented valuable experimental results on built-up elements composed of cold-formed channel profiles with battened plates or channel stitches. Eighteen tests were performed on columns with battened plates. The authors proposed design formulas for the calculation of equivalent nondimensional slenderness of built-up cold-formed steel battened columns. Georgieva et al. [14] examined the validation of the direct strength method to be used in the design of built-up cold-formed steel columns through experimental investigations. Generally, good agreement between experimental and numerical results was achieved. The study suggested that a similar design methodology, to that of single section columns, can be adopted for built-up cold-formed steel columns. The aforementioned investigations were mainly on built-up hot-rolled steel columns. On the other hand limited investigations were found in the literature on built-up cold-formed steel section battened columns leading to the current experimental investigation.

Behaviour of cold-formed steel sections is different from that of hot-rolled steel sections. Steels produced by hot rolling have usually sharp yielding plateau, with its yield stress is defined by the level at which the stress–strain curve becomes horizontal. On the other hand cold-formed steels have reduced or cold-worked gradual yielding plateau, with its stress–strain curve is rounded out at the “knee” and its yield stress is determined by either the offset method or the strain-underload method [15,16]. In addition cold-formed steel products are quite thin, which makes it very sensitive to initial local and overall geometric imperfections resulting from manufacturing and handling process. Current design codes of practice usually propose empirical formulas to account for initial geometric imperfections. Behaviour and design of built-up cold-formed steel section battened columns is more complicated, compared with that of single cold-formed steel columns. This is attributed to presence of local and overall buckling, connections among different components, interfaces among these components and distribution of loads bending moments in the column components. Therefore assessment of current design codes predictions against test results for built-up cold-formed steel section battened columns is addressed and highlighted in this study.

The main objective of this paper is to conduct new medium-scale tests on built-up cold-formed steel section battened columns. The tests would compensate the lack of experimental data on this form of construction and act as a data base for numerical models to be developed. The built-up cold-formed steel section battened columns investigated had different slenderness ratios and different geometries. The column strengths, failure modes, deformed shapes at failure, load–axial shortening, load–lateral displacement and load–axial strain relationships were measured in the tests and reported in this paper. The column strengths were assessed against the design strengths calculated using the North American Specification [17], Australian/New Zealand Standard [18] and European Code [19] for cold-formed steel columns, with detailed discussions and conclusions presented.

2. Experimental investigation

2.1. Test specimens

Five medium-scale tests were conducted in this study on built-up cold-formed steel section battened columns. The test specimens were denoted such that the cross-section shape and geometries can be identified from the label. Specimen B2B50-300 denotes a built-up section comprising two channels placed back-to-back (B2B) with a spacing between channels (B_1 = 50 mm). The 50 mm is the number following the letter B. The last number 300 mm is the buckling length (L_z) about the minor axis of a single channel. Table 1 summarizes the measured dimensions of built-up cold-formed steel section battened column test specimens. Also, Fig. 1 shows details and definition of symbols for the built-up cold-