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Load capacity of cold-formed column members of lipped channel cross-section with perforations subjected to compression loading – Part I: FE simulation and test results

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ABSTRACT

An investigation was carried out into the influence of perforations of various shapes on the buckling behaviour of cold-formed column members of lipped channel cross-section. A finite element analysis using ANSYS, an experimental investigation, and design code predictions using the AISI Specification, British Standards (BS) and EU Standards, are employed to determine the buckling load capacity. An experimental investigation of the buckling behaviour of flat and fixed ended columns is presented, and the findings from this are used to validate finite element results, and compare with design code predictions. The numerical results of load vs. displacement behaviour are shown to be in good agreement with those reported from the tests. It is shown that the ultimate failure load of the lipped channels under compression varies greatly with the presence of perforations.

1. Introduction

Cold-formed steel members have become competitive building products in modern building construction due to their inherent favourable characteristics over conventional hot-rolled steel members. Due to cold work, the material properties of the formed sections show significant changes compared to those of the steel strip, plate, or bar before forming. The change in the mechanical properties due to cold work is caused mainly by strain hardening and strain aging. Cold-formed members show high yield strength around bends compared to flat portions of cross-section [1]. The increase in the strength values can be used in the design process in some applications as a significant advantage.

Cold-formed steel members have been mainly applied to light steel structures including frame systems, thin-walled steel trusses, grids, and reticulated shell structures. A multiplicity of widely different products, with a variety of shapes, sizes, and applications are produced using different cold forming process. Unlike hot-rolled steel members, there are certain unique characteristics related to cold-formed steel members which were found to be largely dependent on the forming process [2].

The thinness of the cold-formed steel members provides advantages over conventional hot-rolled members such as high strength-to-weight ratio, high structural efficiency, and the variety of materials which can be formed. Cold-formed members are typically manufactured with perforations to facilitate various services in building construction. These perforations are varied with respect to their position, size, shape, number of perforations, and orientation as shown in Fig. 1. The limitations of existing design code procedures for cold-formed steel members with perforations affect the design flexibility and decrease the reliability of cold-formed products in the modern construction industry [3–8]. Recent research projects have been presented to incorporate the effect of perforations for determining the ultimate capacity of perforated channel sections [9].

A large number of investigations have been carried out by numerous researchers on cold-formed steel members and structures. The Direct strength method, finite element method, generalised beam theory, and the finite strip method have been used in investigations related to cold-formed steel structures [10–12]. At the present time, cold-formed steel applications are extremely widespread. However, the complications induced by the inherent characteristics of such structures which arise due to the slenderness of members and cross-sections, promote failure at different loading conditions, and such effects must be taken into account in design.

Compared with conventional structural column members, cold-formed steel, thin-walled, open cross-section column members

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Nomenclature

H	web height
B	flange length
D	lip height
R	fillet radius
t	thickness of section
L	length of section
$h_{perforation}$	perforation width
$l_{perforation}$	perforation length
$ø_{perforation}$	perforation diameter
a	perforation position
C	centroid
SC	shear centre
FEA	finite element analysis
FE	finite element
P_{exp}	experimental buckling load
P_{FEA}	FEA buckling load
P_{cre}	buckling load – AISI
P'_c	buckling resistance under axial load – BS 5950
$N_{b,Rd}$	buckling resistance of a compression member – Eurocode3
$\overline{X}$	mean
S	standard deviation
COV	coefficient of variation
E	modulus of elasticity (N/mm^2)
σ_y	average yield strength (N/mm^2)

have at least three competing buckling modes namely: local, distortional, and Euler (flexural or torsional-flexural) buckling as illustrated in Fig. 2. Effects of material non-linearity, residual stresses, imperfections, etc., give potential for the interaction of buckling modes, and also must be considered. In the case of local buckling, any interaction that exists between elements e.g., the web and the flange, is typically ignored and each element is treated independently [13–16]. Distortional buckling has the ability to control the final failure mechanism, and hence, needs special attention. Further, compared with local buckling, distortional buckling has lower post-buckling capacity and higher imperfection sensitivity [17–19]. Although, there seems to be a consensus on this classification of buckling modes, there is no consensus on the exact meaning of the modes themselves [20].

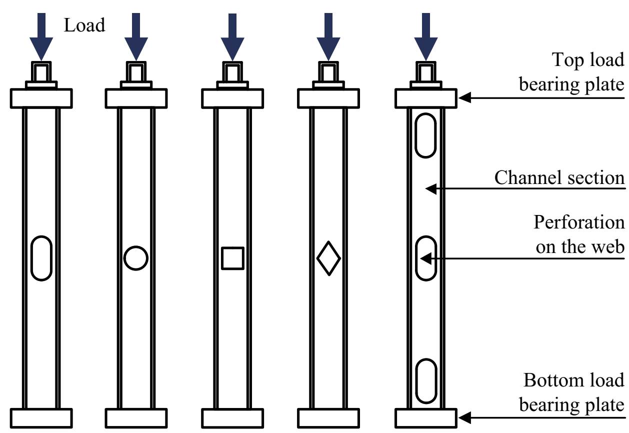

Fig. 1. Common perforation shapes used in cold-formed sections.

Cold-formed thin-walled steel structures are highly efficient in their use of material, but the advantages of thin-walled members are often limited due to the occurrence of various different buckling modes. The load capacity of cold-formed column members of lipped channel cross-section subjected to compression loading mainly depends on overall buckling if the slenderness ratio is high. Many cold-formed sections consist of open cross-sections with thin walls, and torsional–flexural buckling may or may not have a greater influence on failure than pure flexural

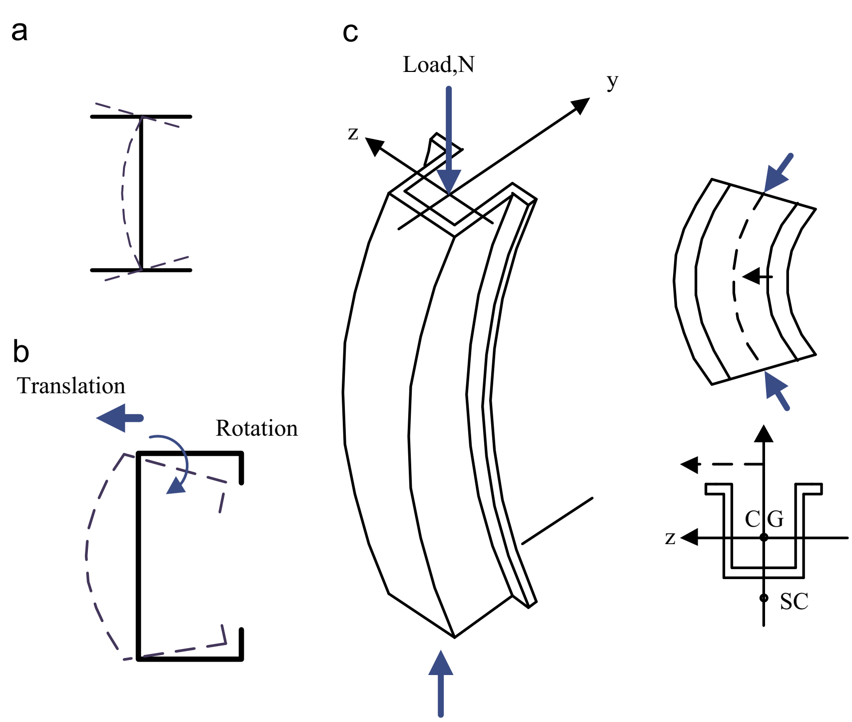

Fig. 2. Different buckling modes, (a) local, (b) distortional, and (c) flexural or torsional–flexural.