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Behaviour and strength of hollow flange channel sections under torsion and bending

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ABSTRACT

Hollow flange channel section is a cold-formed high-strength and thin-walled steel section with a unique shape including two rectangular hollow flanges and a slender web. Due to its mono-symmetric characteristics, it will also be subjected to torsion when subjected to transverse loads in practical applications. Past research on steel beams subject to torsion has concentrated on open sections while very few steel design standards give suitable design rules for torsion design. Since the hollow flange channel section is different from conventional open sections, its torsional behaviour remains unknown to researchers. Therefore the elastic behaviour of hollow flange channel sections subject to uniform and non-uniform torsion, and combined torsion and bending was investigated using the solutions of appropriate differential equilibrium equations. The section torsion shear flow, warping normal stress distribution, and section constants including torsion constant and warping constant were obtained. The results were compared with those from finite element analyses that verified the accuracy of analytical solutions. Parametric studies were undertaken for simply supported beams subject to a uniformly distributed torque and a uniformly distributed transverse load applied away from the shear centre. This paper presents the details of this research into the elastic behaviour and strength of hollow flange channel sections subject to torsion and bending and the results.

1. Introduction

Hollow flange channel (HFC) section is a cold-formed high-strength and thin-walled steel section produced using a patented dual electric resistance welding and automated continuous roll-forming process. It has a unique mono-symmetric channel shape comprising two rectangular hollow flanges and a slender web (see Fig. 1). It can be used as flexural members in residential, commercial and industrial buildings. Many experimental and numerical investigations have been undertaken in the past on HFC flexural members at Queensland University of Technology. These investigations were aimed at determining the member moment capacities when they were subjected to lateral distortional and lateral torsional buckling [1–6], the section moment capacities [7,8] and finally the shear capacities [9–13]. They focused on hollow flange channel sections subject to bending action only, which means that they were subjected to transverse loads applied at the shear centre and that member torsion is precluded.

Due to its mono-symmetric characteristics, hollow flange channel section beams will also be subjected to torsion since the transverse loads are applied away from the shear centre. However, torsion is often ignored because it is commonly thought to occur rarely, and when it occurs, it is considered unimportant. Further, difficulties in predicting the effects of torsion discourage designers from considering torsion. Past research on torsion in steel members has concentrated on open sections, typically cold-formed steel channel sections [14,15] and hot-rolled steel I-sections [16–18]. At the same time very few cold-formed steel design standards provide suitable design rules for steel members subject to torsion. Trahair and Pi [19], Pi and Trahir [20,21] and Trahair and Bradford [22] proposed some design methods for steel members subject to torsion. But their design methods and related equations are mainly based on the analysis of hot-rolled I-section members.

Hollow flange channel section has a unique shape including two closed rectangular flanges and a slender web, and thus is quite different from conventional open sections. Its torsional behaviour remains unknown to researchers and designers until now. Therefore in this research the elastic behaviour and strength of hollow flange channel sections subject to uniform torsion, non-uniform torsion and combined torsion and bending were investigated using differential equilibrium equations. The results were then

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Fig. 1. Hollow flange channel sections and applications.

compared with finite element analysis results. Parametric analyses were undertaken for simply supported beams subject to both uniformly distributed torques, and uniformly distributed transverse loads applied away from the shear centre. This paper presents the details of this research into the elastic behaviour and strength of hollow flange channel section beams subject to torsional and bending actions.

2. Hollow flange channel sections subject to torsion

The section is in a state of uniform torsion when both the rate of change of the angle of twist and the longitudinal warping deflections are constant along the member. The torque acting at any cross-section is only resisted by the shear stresses distributed around the cross-section. Otherwise, it is in a state of non-uniform torsion where the torque is resisted by additional warping shear stresses in conjunction with the shear stresses due to uniform torsion. Whether a member is in a state of uniform torsion or non-uniform torsion depends on the loading arrangement and the warping restraints. In most practical cases non-uniform torsion is encountered. To understand the torsional behaviour of hollow flange channel sections, uniform torsion is investigated first, followed by the analysis of non-uniform torsion.

2.1. Uniform torsion

Hollow flange channel section has a unique shape including two closed rectangular flanges and a slender web. The uniform shear flow, which is the product of shear stress and wall thickness, could be assumed as q in both closed flanges (see Fig. 2(a)) while the shear flow in the web could be assumed to be zero. To determine the shear flow, the section is cut at points “B” and “C” to make it an imaginary open section (see Fig. 2(b)). There would be relative longitudinal displacements at the cut edge due to the actions of torque and shear flow. These relative longitudinal displacements can be written as Eqs. (1) and (2), respectively.

$$u_H = -\theta'(z)\Omega_1 = -2ab\theta'(z) \tag{1}$$

$$u_q = q\oint\frac{ds}{Gt} = \frac{2q}{Gt}(a+b) \tag{2}$$

where $\theta'(z)$ is the rate of change of the twist angle, Ω_1 is twice the area enclosed by one rectangular flange, G is the shear modulus of

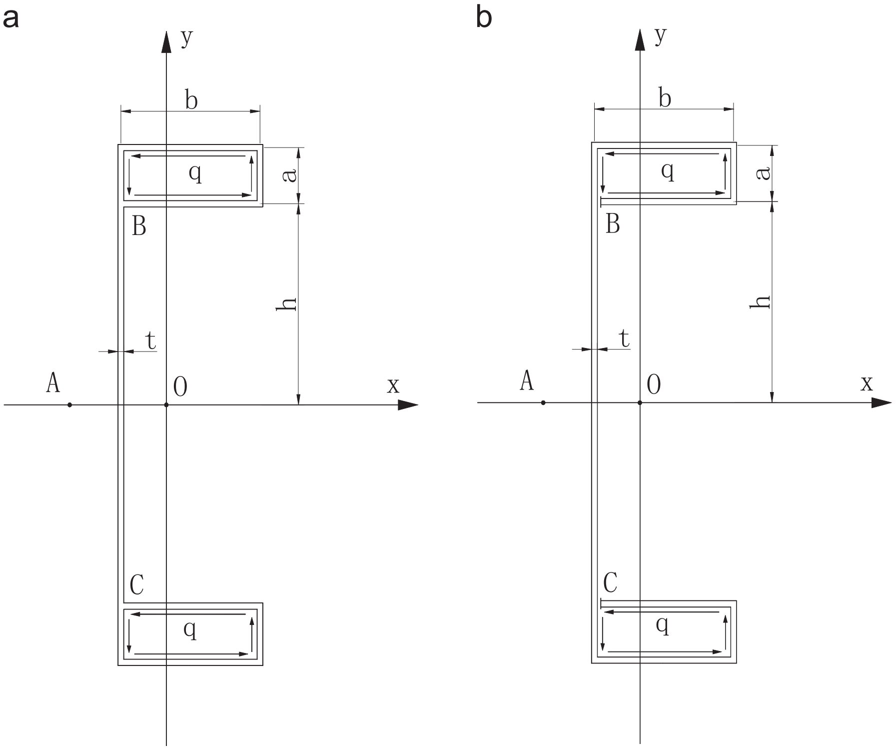

Fig. 2. Shear flow in hollow flange channel sections. (a) Shear flow distribution. (b) Imaginary open section.