Thin–Walled Structures 109 (2016) 344–351

Contents lists available at ScienceDirect

Thin–Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Effective width method for distortional buckling design of cold-formed lipped channel sections

Yao Xingyou[a,b,*], Guo Yanli[a], Li Yuanqi[b]

[a] Nanchang Institute of Technology, Nanchang, China
[b] Tongji University, Shanghai, China

ARTICLE INFO

Keywords:
Cold-formed steel
Partially stiffened elements
The energy method
Distortional buckling
Effective width method

ABSTRACT

The aim of this paper is to improve the effective width method for distortional buckling strength of cold-formed steel lipped channel members using the energy method and the large deflection theory based on nonlinear post-buckling strength analysis of the partially stiffened element. The accuracy of the proposed method was verified using the finite element method. Comparison on post-distortional buckling strength is conducted between the energy method and the effective width method in the Chinese code *Technical code of cold-formed thin-walled steel structures* (GB50018-2002). The compared results show that the energy method is very efficient and the effective width method formula in Chinese code can be used to calculate the post-distortional buckling strength. Then, The half-wave length, elastic buckling stress of distortional buckling and the corresponding stability coefficient of partially stiffened elements are developed based on the energy method. With comparison on the calculated results of elastic buckling stress using the proposed method and the Finite Strip Method, suitability and good precision of the developed method are illuminated. Finally, a uniform formula for the stability coefficient of partially stiffened elements considering both local and distortional buckling effect is established. Comparison with experimental results and calculated results predicted with North America specification indicates that the proposed method is reasonable and has a high accuracy and reliability for the distortional buckling load carrying capacities of cold-formed lipped channel members.

1. Introduction

Cold-formed lipped channel sections have been widely used in residential and commercial construction. These channel members may buckle in one or several buckling modes including local buckling, distortional buckling, and overall buckling based on different boundary conditions, the dimension of sections, and the effective length. Local buckling involves deformation of the cross section with only rotation occurring at interior fold lines of the section. Distortional buckling involves deformation of the cross section with rotation and translation occurring at interior fold lines. Overall buckling involves translation and rotation of the entire cross section. Meanwhile, The local buckling mode occurs with repeated waves at a short length, while overall buckling occurs in one half-wave over the length of the member. Distortional buckling occurs at a wave length intermediate to the two other modes.

North American specification for the design of cold-formed steel structural members (AISI-S100 2010) [1] and Australian/New Zealand standard cold-formed steel structures(AS/NZS4006 2005) [2] both apply an effective width method to determine the design strength of channel members. The effective width method introduced by von Karman et al. [3] and modified by Winter [4]. First an over stability strength is used to account for overall buckling. Then, to include interaction between overall buckling and the other modes, the gross section is reduced to an effective section by element reduction via effective width formula. This element by element effective width reduction accounts for local buckling, and partly distortional buckling. Subsequent experiments indicated that these specifications do not always provide consistent and conservative predictions. The two key shortcomings identified were lack of a consistent treatment for the interaction of elements in local buckling, and inadequate provisions to handle distortional buckling.

Direct strength method about the distortional buckling is introduced in the North American [1] and the Australia Specification [2] for cold-formed steel structural members based on several study results [5–8]. These design method requires calculation of the elastic distortional buckling stress, which may be completed using finite strip analysis, or using a closed-form solution which have given in these two specifications. Meanwhile Silvestre and Camotim [9] have supplied an alternative closed-form solution for elastic distortional buckling

* Corresponding author at: Nanchang Institute of Technology, Nanchang, China.
E-mail address: yaoxingyoujd@163.com (Y. Xingyou).

http://dx.doi.org/10.1016/j.tws.2016.10.010
Received 8 October 2016; Received in revised form 9 October 2016; Accepted 9 October 2016
0263-8231/

based on generalized beam theory. These design methods are very effective for calculating the distortional buckling strength but a little complicate for design.

Loughlan [10] details appropriate finite element modelling strategies and procedures for the determination of the coupled local-distortional interactive response of thin-walled lipped channel sections which describe the complete loading history of the compression members from the onset of local buckling through post-local buckling behaviour leading to local-distortional interaction including material yielding and yield propagation to ultimate conditions and then to elastoplastic unloading. The results from the finite element models are shown to agree favourably with the ultimate loads and failure mechanisms from experimental tests. While the design method for post-local buckling and coupled buckling was not given.

Chinese code *Technical code of cold-formed thin-walled steel structures*(GB50018-2002) [11] also use the effective width method to calculate the strength of these cold-formed lipped channel sections, in which the interaction of elements in local buckling are considered and the distortional buckling are handled via a lower reduced plate buckling coefficient, but experiments indicated that these specifications do not always provide consistent predictions. Meanwhile, Chinese researchers [12–20] have provided some design method for distortional buckling too, but these design method is very complicated.

A simple and efficient design method for distortional buckling strength based on effective width method in Chinese code should be conducted for design in engineering. The paper presents a proposed design method for distortional buckling strength of cold-formed lipped channel steel members based on nonlinear post-buckling strength analysis of the partially stiffened element (Fig. 1) using the energy method and the large deflection theory. Then the half-wave length, the elastic buckling stress of distortional buckling and the corresponding plate stability coefficient of the partially stiffened element are developed. Finally, a uniform formula for the plate stability coefficient of the partially stiffened element considering both local and distortional buckling effect is established. The innovative effective width method will be incorporated in Chinese specification GB50018.

2. Distortional buckling for cold-formed lipped channel section

2.1. Postbuckling strength of the partially stiffened element

2.1.1. Energy solution

The distortional buckling analytical model for the partially stiffened element of the lipped channel member is shown in Fig. 2 and the deflected shape function and the initial deflected shape function are as follows:

$$w = fy\cos(\pi x/\lambda) \tag{1}$$

$$w_0 = \beta y\cos(\pi x/\lambda) \tag{2}$$

where f and β are coefficient , λ is the buckling half-wave length.

The basic assumptions [19] for this simplified analytical model include that the lip is as a elastic bearing beam and has no restrained action for the partially stiffened element, the shear stress around the partially stiffened element equal zero, and the transverse stress of the two longitudinal edges also equal zero. The boundary conditions of stress can be obtained based on the basic assumption as shown in Eqs. (3).

$$\tau_{xy}|x = \pm\lambda/2 = -\partial^2F/\partial x\partial y|x = \pm\lambda/2 = 0 \tag{3a}$$

$$\tau_{xy}|y = 0 = -\partial^2F/\partial x\partial y|y = 0 = 0 \tag{3b}$$

$$\tau_{xy}|y = b = -\partial^2F/\partial x\partial y|y = b = 0 \tag{3c}$$

$$\sigma_y|y = 0 = -\partial F^2/\partial x^2|y = 0 = 0 \tag{3d}$$

$$\sigma_y|y = b = -\partial F^2/\partial x^2|y = b = 0 \tag{3e}$$

Where τ_{xy} is the shear stress around the partially stiffened element, σ_y is the transverse stress of the longitudinal edge, F is the stress function, and b is the width of the partially stiffened element.

The following differential equations of large deflection buckling for a partially stiffened plate considering the initial deflection are introduced:

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2\partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{t}{D}\left[\frac{\partial^2 F}{\partial y^2}\frac{\partial^2(w+w_0)}{\partial x^2} + \frac{\partial^2 F}{\partial x^2}\frac{\partial^2(w+w_0)}{\partial y^2} - 2\frac{\partial^2 F}{\partial x\partial y}\frac{\partial^2(w+w_0)}{\partial x\partial y}\right] \tag{4}$$

$$\frac{\partial^4 F}{\partial x^4} + 2\frac{\partial^4 F}{\partial x^2\partial y^2} + \frac{\partial^4 F}{\partial y^4} = E\left\{\left[\frac{\partial^2(w+w_0)}{\partial x\partial y}\right]^2 - \frac{\partial^2(w+w_0)}{\partial x^2}\frac{\partial^2(w+w_0)}{\partial y^2} - \left[\left(\frac{\partial^2 w_0}{\partial x\partial y}\right)^2 - \frac{\partial^2 w_0}{\partial x^2}\frac{\partial^2 w_0}{\partial y^2}\right]\right\} \tag{5}$$

Where D, E, t, w,w_0 are the flexural rigidity of unit plate, the modulus of elasticity of steel, the thickness, the lateral deflected shape function, and the initial deflected shape function of the partially stiffened element, respectively.

Based on Eqs. (1)–(5) the stress function can be obtained as follows:

$$F(y) = F_1(y) - \frac{E}{2}(f + 2\beta)(\pi/\lambda)^2 f(\phi_s(y) + \phi_c(y))\cos(2\pi x/\lambda) \tag{6}$$

Where $\phi_s(y) = (\lambda/2\pi)^4$,
$\phi_c(y) = A_1 ch\frac{2\pi}{\lambda}y + A_2 sh\frac{2\pi}{\lambda}y + A_3\frac{y}{b}ch\frac{2\pi}{\lambda}y + A_4\frac{y}{b}sh\frac{2\pi}{\lambda}y$, the constants of integration A_1, A_2, A_3, and $A_4$are given as

$$\begin{cases} A_1 = -\left(\frac{\lambda}{2\pi}\right)^4 \\ A_2 = -\dfrac{\lambda^5\left(-2\pi bch\frac{2\pi b}{\lambda} + \lambda ch\frac{2\pi b}{\lambda}sh\frac{2\pi b}{\lambda} - \lambda sh\frac{2\pi b}{\lambda} - 2\pi b(sh\frac{2\pi b}{\lambda})^2 + 2\pi b(ch\frac{2\pi b}{\lambda})^2\right)}{16\pi^4\left(-4\pi^2b^2(sh\frac{2\pi b}{\lambda})^2 - \lambda^2(sh\frac{2\pi b}{\lambda})^2 + 4\pi^2b^2(ch\frac{2\pi b}{\lambda})^2\right)} \\ A_3 = \dfrac{\lambda^4 b\left(-2\pi bch\frac{2\pi b}{\lambda} + \lambda ch\frac{2\pi b}{\lambda}sh\frac{2\pi b}{\lambda} - \lambda sh\frac{2\pi b}{\lambda} - 2\pi b(sh\frac{2\pi b}{\lambda})^2 + 2\pi b(ch\frac{2\pi b}{\lambda})^2\right)}{8\pi^3\left(-4\pi^2b^2(sh\frac{2\pi b}{\lambda})^2 - \lambda^2(sh\frac{2\pi b}{\lambda})^2 + 4\pi^2b^2(ch\frac{2\pi b}{\lambda})^2\right)} \\ A_4 = \dfrac{\lambda^4 bsh\frac{2\pi b}{\lambda}\left(2\pi b - \lambda sh\frac{2\pi b}{\lambda}\right)}{8\pi^3\left(-4\pi^2b^2(sh\frac{2\pi b}{\lambda})^2 - \lambda^2(sh\frac{2\pi b}{\lambda})^2 + 4\pi^2b^2(ch\frac{2\pi b}{\lambda})^2\right)} \end{cases} \tag{7}$$

Since the solution of the stress function F only require the second order derivative of F_1(y), the second order derivative of F_1(y) is adequate and can be given as

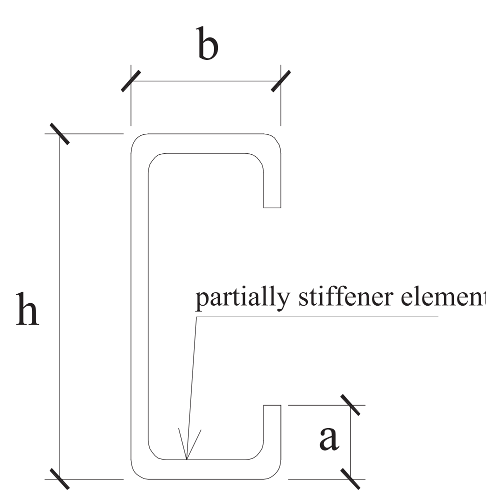

Fig. 1. Definitions for dimensions of lipped channel section.