Computational Materials Science 96 (2015) 416–424

Contents lists available at ScienceDirect

Computational Materials Science

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

Parametric studies on buckling of thin walled channel beams

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ARTICLE INFO

Article history:
Received 10 March 2014
Received in revised form 7 July 2014
Accepted 30 July 2014
Available online 28 August 2014

Keywords:
Buckling
Thin-walled beams
Finite element analysis

ABSTRACT

The lateral buckling analysis of cold-formed thin walled beams subjected to pure bending moments has been performed. The critical buckling loads are estimated based an optimization criteria. The estimated critical buckling stresses are compared with the published results, they show excellent agreement. The effect of the beam length, radius and thickness of the flanges and the length of the extended open flanges, on the critical buckling stresses have been studied for several combinations of the geometric parameters of the beam. Among the three beams, the critical buckling moments for the beam with the extended open flanges are found to be the maximum. However, considering the material and manufacturing costs, beams with rounded cross section are efficient in resisting the buckling loads.

1. Introduction

Thin-walled structures are extensively used in the automobile and aerospace industry, due to their excellent stiffness, strength to weight ratios and stability. Closed thin-wall beams are good at resisting the torsional loads, compared to the dropped sections [1,2]. Buckling is one of the main problems of thin-walled beams, which is being observed since mid-20th century [3,4]. Rondal [5] reviewed the progress in the field of cold-formed steel members and summarized the major research in [6].

With the development of the technology; analytical, numerical and experimental studies of global, distortional and local buckling analysis of cold-formed thin-walled beams is accelerated across the world. Blandzi and Magnucki [7] have reviewed the buckling and optimal design of cold-formed thin-walled beams for selected problems. Sudhir et al. [8] have studied the buckling behavior of thin-wall stiffened composite panels [9,10]. Camotim and Basaglia [11] have analyzed the local and global buckling behavior of thin-walled steel members and structural systems based on the Generalized Beam Theory (GBT). They compared their results with the shell finite element method (FEM). GBT based distortion buckling analysis of thin-walled channel columns and beams with arbitrary sloping single-lip edge stiffeners and pinned/free-to-warp or fixed/warping-free end sections is presented in [12]. The progress in the Direct Strength Method (DSM) compared to the Effective Width Method (EWM) for cold-formed steel member design is reported in [13,14].

Mahendran and Murray [4] have performed the elastic buckling analysis of ideal thin-walled structures under combined loading using a finite strip method (FSM), where the presence of the shear loading is accounted by modifying the commonly used displacement functions when the shear is absent. Ovesy et al. [15] have developed three different versions of the FSM for predicting the geometrically non-linear response of box sections with simply supported ends when subjected to uniform end shortening in their plane. Young [16] proposed the bifurcation analysis of thin-walled plain channel members subjected to compression loads, using an elastic non-linear FSM to determine the flexural and torsional tangent rigidities of a section undergoing local buckling. Paczos [17] compared the experimental investigations on thin-walled beams having double-box flanges with the results from the FSM. Therefore, FEM, GBT and FSM are found to be the major tools available for the analysis of thin-walled structures [7].

The buckling in the short thin walled sections is local, whereas in the long members the buckling is a combination of the lateral and torsional loads. For intermediate length members, the two modes interact to produce a lateral–distortional buckle, characterized by simultaneous distortion and lateral deflection of the cross-section [18]. Dinis and Camotim [19] have estimated the local/distortional mode interaction concerning the post-buckling behavior in a cold-formed steel lipped channel beams subjected to uniform major axis bending, using the shell finite element analysis in ABAQUS. Pignataro et al. [3] have worked on the effect of the local overall interaction on the post-buckling analysis of simply

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http://dx.doi.org/10.1016/j.commatsci.2014.07.058
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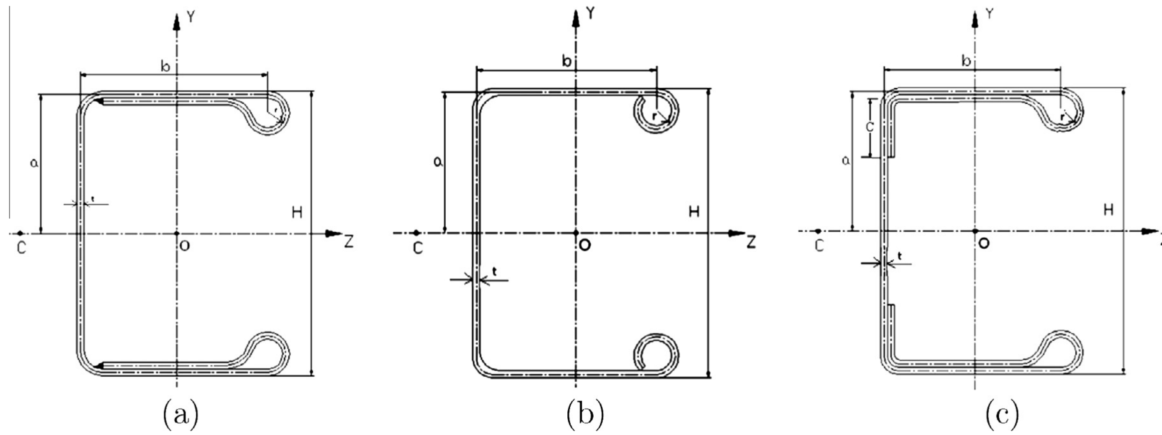

Fig. 1. Schematics of the cross sections and dimensions of the cold-formed channel beams considered in the present work. Beam with (a) dropped flanges, (b) rounded flanges and (c) extended open flanges.

supported channels subjected to uniformly compressive loads. Young [20] investigated the local buckling and shift of effective centroid of slender sections. The experimental local buckling loads are compared with the numerical results from the linear FSM analysis. Urbaniak and Kubiak [21] worked on the local dynamic buckling of simply supported C-shaped thin-walled girder segments subjected to bending. They considered various types of pulse loading like, triangular, trapezoidal and rectangular loads, with a duration corresponding to the fundamental period of vibration [22].

Bradford [18] estimated the lateral distortional buckling analysis of steel I-section members. Seo et al. [23] have presented a numerical method based on the formulation of the total potential energy, for predicting the elastic lateral distortional buckling moment of a mono-symmetric Lite Steel beam (LSB) sections with web openings. Yu and Schafer [24] have simulated the local and distortional buckling of cold-formed steel beams based on the non-linear FEM and validated the results with the experiment. They also verified that the moment gradient effect on distortional buckling failures are conservatively accounted for in the Direct Strength Method (DSM). Further, they proposed an empirical equation to design and predict the increase in the elastic distortional buckling moment due to moment gradient. Ma and Hughes [25] have worked on the lateral distortional buckling of mono-symmetric I-Beams with distributed vertical load.

Chu et al. [26] have estimated the effect of warping stress on the lateral-torsion buckling of cold-formed Zed-Purlins with partially lateral restraint from metal sheeting. Erkmen and Attard [27] worked on the lateral–torsional buckling analysis of thin-walled beams based on a geometrically nonlinear formulation and considering the effects of shear and pre-buckling deformation effects. To illustrate the effects of pre-buckling deformations as well as the shear deformations on the buckling load predictions, they compared the results based on fully nonlinear analysis and linearized buckling analysis with the experiment. Pluzsik and Kollár [2] have developed a mathematical model for restrained warping on closed orthotropic thin-walled beams subjected to torsional loads, by considering the shear deformation.

Kolakowski [28] have performed the static and dynamic interactive buckling analysis of thin-walled channel with imperfections subjected to uniform compression, considering the shear lag phenomenon and distortional deformations. Optimization studies on Z-shaped, S-shaped and Clothoid anti-symmetrical open cross sections of cold-formed thin-walled beams are performed by Lewinski [29]. Nilsen et al. [30] have estimated the performance of lightweight thin-walled steel sections through mathematical models for local buckling, distortional buckling, global buckling and shear buckling. Pistek [31] compared the FEM, the reduction coefficients method (RCM) and the gradually increased loading method (GILM) for limit load capacity calculation of thin walled aircraft structures, considering all possible forms of buckling and failures on the non-linear behavior of the structure under gradually increased loading.

Mohri et al. [32] have investigated the lateral buckling of simply supported thin-walled beam column elements with bi-symmetric I sections under combined axial and bending loads, based on a non-linear stability mode. Lee [33] have worked on the lateral buckling analysis of thin-walled laminated composite beams with mono-symmetric sections. They considered a general geometrically non-linear model for thin-walled laminated composites with arbitrary open cross-section and general laminate stacking sequences using systematic variational formulation based on the classical lamination theory. The inelastic lateral buckling of Steel members is estimated in [34].

Pastor and Roure [35] have performed an experimental study of open thin-walled section beams subjected to pure bending, to study the post-collapse behavior of U-sections and Ω-sections. They validated the experimental results with the numerical calculations (FEM) [36]. Trahair [37] explained how to use the method of design by buckling analysis (DBA) to design beam–columns and frames as well as beams and columns. Magnucki and Blandzi [38] have considered the variational design of open cross-section thin-walled beams in pure bending by subjecting them to couples, under stability constraints. Rabczuk et al. [39–44] and Zhuang et al. [45–49] have proposed the meshfree techniques to study the stability phenomenon.

Magnucki [50] performed the elastic buckling analysis of five different flanges of cold-formed thin-walled beams. In [50] the authors estimated the critical buckling stresses for each section and compared their results with the experiment. The shapes of the cross sections subjected to the constraints on strength, global and local buckling conditions and the geometric conditions, are optimized in [51]. Further, Magnucki et al. [52] studied the geometric properties of cold-formed thin-walled channel beams with open or dropped flanges, considering two C-sections including the

Table 1
Mechanical properties of thin walled beam considered in the numerical examples.

Material	Young's modulus E (GPa)	Shear modulus G (GPa)	Density $(\mathrm{kg/m^3})$	Poisson's ratio
Aluminium alloy (6061-T6)	69	26	2700	0.3