Thin-Walled Structures 86 (2015) 47–55

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Numerical investigation of longitudinally stiffened web channels predominantly in shear

Cao Hung Pham, Gregory J. Hancock*

[a] School of Civil Engineering, The University of Sydney, NSW 2006, Australia

ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form
2 September 2014
Accepted 3 September 2014
Available online 28 October 2014

Keywords:
Thin-walled sections
Shear strength
High strength steel
Complex channel sections
Direct Strength Method
Finite element method

ABSTRACT

In practice, there is a wide variety of commercially available channel sections with complex shapes where the web is stiffened by adding longitudinal intermediate stiffeners. These stiffeners may improve the shear capacity of the channels. Recently, the Direct Strength Method (DSM) of design of cold-formed sections has been extended in the North American Specification for Cold-Formed Steel Structural Members (NAS S100:2012) to include shear based on research by the authors. The prequalified sections include flat webs and webs with small intermediate longitudinal stiffeners. To extend the range to larger intermediate stiffeners as occurs in practice, a series of predominantly shear tests of lipped channel sections with one web stiffener of different shapes and various sizes has been performed at the University of Sydney. Six different types of stiffened web channel sections were tested along with an additional reference plain section. All tests were conducted with straps screwed on the top flanges adjacent to the loading points. These straps provide torsion/distortion restraints which may enhance the shear capacities of the sections. The test failures were observed mainly in the combined bending and shear modes. Numerical simulations based on the Finite Element Method (FEM) using the software package ABAQUS/Standard are also performed to compare with and calibrate against the tests. The accurate results from the FEM models allow extension of the test data. Based on the reliable FEM models, a series of FEM modelling of predominantly shear tests for stiffened web channels has been performed without straps attached to the top flanges adjacent to loading points. The test and FEM results are subsequently plotted against the DSM interaction curves between bending and shear where the interaction is found to be significant. An extended range of DSM prequalified sections with longitudinally stiffened web channels in shear is proposed in this paper.

1. Introduction

Cold-formed steel structural members have been effectively and widely used around the world in such applications as wall studs, girts, steel housing frames, roof systems, etc. Among these types of structures, cold-formed purlins as intermediate members to transfer loads from the roof decks to main structural frames are manufactured by bending flat sheet to certain shapes at ambient temperature. Most commonly utilised purlin shapes are C- and Z-sections with attractive attributes such as high strength to self-weight ratio, ease of prefabrication and installation, versatility and high structural efficiency. With the continued advance of technology, cold-formed members are now being fabricated with higher yield stress materials up to 550 MPa. Also, the resulting reduction of thicknesses of high strength steel leads to the development of highly stiffened sections with more folds and stiffeners. As a result, the range of available purlin shapes and sizes is experiencing a significant expansion.

Currently, two basic design methods for cold-formed steel members are formally available in the Australian/New Zealand Standard for Cold-Formed Steel Structures (AS/NZS 4600:2005) [1] and the North American Specification for Cold-Formed Steel Structural Members [2]. They are the traditional Effective Width Method (EWM) and the newly developed Direct Strength Method of design (DSM) (Chapter 7 of AS/NZS 4600:2005, Appendix 1 NAS S100-2012). As sections become more complex with additional longitudinal web stiffeners and return lips as shown in Fig. 1, the computation of the effective widths becomes more complex. For the EWM, the calculation of effective widths of the numerous sub-elements leads to severe complications with decreased accuracy. In some special cases, no design approach is even available for such sections using the EWM. The DSM appears to be more beneficial and simpler by using the elastic buckling stresses of the whole section. There is no need to calculate cumbersome effective sections

* Correspondence to: School of Civil Engineering, Building J05, The University of Sydney, NSW 2006, Sydney, Australia.
Tel.: +61 2 9351 2129; fax: +61 2 9351 3343.
E-mail addresses: caohung.pham@sydney.edu.au (C.H. Pham), gregory.hancock@sydney.edu.au (G.J. Hancock).

http://dx.doi.org/10.1016/j.tws.2014.09.005
0263-8231/

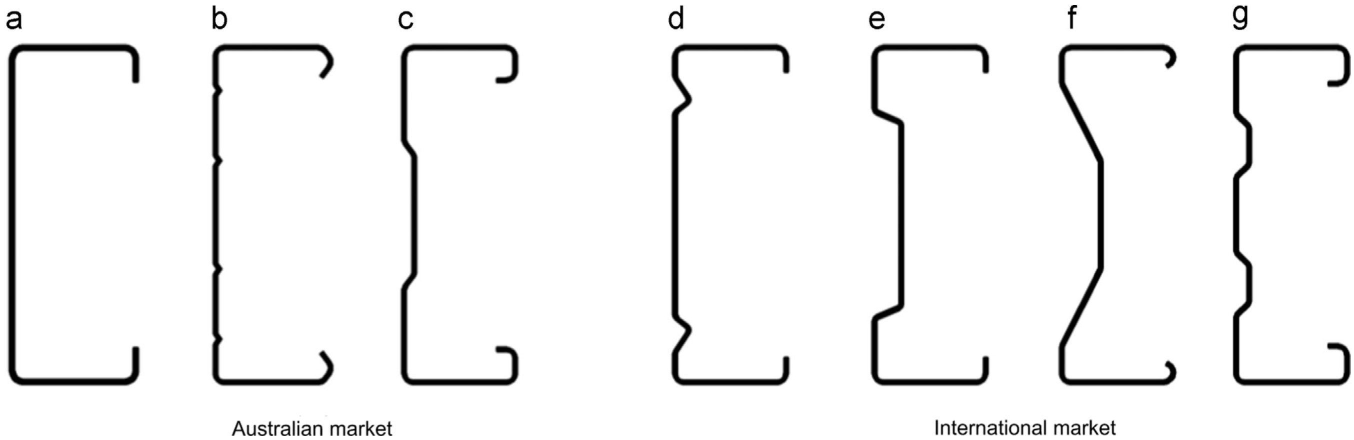

Fig. 1. Profile shapes of manufactured purlin profiles. (a). Standard C (b). BlueScope Lysaght (c). Fielders (d). Hadley (e). Albion (f). Kingspan and (g). HST.

especially with intermediate stiffeners. The development of the DSM for compression and bending including the reliability of the method is well researched.

The recent development of the Direct Strength Method (DSM) of design of cold-formed sections in pure shear [3] has been extended in the North American Specification for Cold-Formed Steel Structural Members [2]. The DSM design rules for sections with and without Tension Field Action (TFA) were calibrated against a series of predominantly shear tests of both plain C- and SupaCee sections [3,4] performed at the University of Sydney. In the DSM for shear, the elastic buckling load in shear is required to be computed. Hancock and Pham [5,6] have employed the complex Semi-Analytical Finite Strip Method (SAFSM) of Plank and Wittrick [7] to compute the signature curves for channel sections in pure shear. The method assumes the ends of the half-wavelength under consideration are free to distort and the buckle is part of a very long length without restraint from end conditions. Further extended studies of this theory on complex sections with rectangular and triangular intermediate stiffeners in the web have been performed by Pham et al. [8,9]. In practice, sections may be restrained at their ends by transverse stiffeners leading to the change in shear buckling modes and the increase of the buckling loads by the end effects. To provide solutions, Pham and Hancock [10,11] have used the Spline Finite Strip Method (SFSM) developed for shear elastic buckling by Lau and Hancock [12]. Another more efficient alternative in computation is the new theory of the Semi-Analytical Finite Strip Method (SAFSM) using multiple series terms [13] recently developed to study the elastic buckling of channel sections with simply supported ends in shear.

The prequalified sections in the North American Specification for Cold-Formed Steel Structural Members [2] include flat webs and webs with small intermediate longitudinal stiffeners such as Fig. 1(a) and (b). Recent research by Pham et al. [14,15] has created a Finite Element Method (FEM) model using ABAQUS/Standard [16] to predict the strength of stiffened web sections subjected to pure shear. Based on the concept of this model, pure shear load may be simulated in isolation from bending even though the shear flow distribution is not in equilibrium longitudinally balanced by the moment gradient. The model validated with the shear tests in Pham and Hancock [3,4] was extended to compute shear strengths for the full range of section sizes in comparison with the shear strength curves proposed for the DSM. The numerical simulation results from Pham et al. [15] fit very well the shear strength curve where the TFA is included. They lie slightly below the TFA curve probably because the simply supported boundary condition of the model has less restraint to TFA than the actual tests used to calibrate the DSM equations.

In order to extend the range of complex sections to larger intermediate stiffeners as occurs in practice (see Fig. 1), an experimental programme was performed at the University of Sydney [17]. The main aim of this paper is to develop numerical analyses to simulate the test data on stiffened web channels (SWC) with various stiffener sizes subjected to predominantly shear. The test results and numerical simulations are compared with the DSM design rules for shear. As the shear strength is significantly improved by the large web stiffeners, the effect of bending becomes important. Failures in the combined bending and shear modes were observed both experimentally and numerically. The numerical investigation is based on the Finite Element Method (FEM) using ABAQUS/Standard [16]. The FEM modelling also allowed simulation of the SWC sections in shear without straps attached on the top flanges adjacent to the loading points. The test results and FEM results are subsequently plotted against the DSM interaction equations between bending and shear. The recommendations for an extended range of the prequalified sections are given in the paper for the stiffened web channels predominantly subjected to shear.

2. Experiments on stiffened web channel (SWC) in shear

2.1. Test rig design and test Specimens

The experimental programme [17] comprised a total of fourteen tests conducted in the J. W. Roderick Laboratory for Materials and Structures at the University of Sydney. All tests were performed in the 2000 kN capacity DARTEC testing machine, using a servo-controlled hydraulic ram. A diagram of the test set-up configuration is shown in Fig. 2. This is the same rig as used by Pham and Hancock [3,4].

At the loading point at mid-span, the DARTEC loading ram has a spherical head to ensure that the load is applied uniformly on the steel bearing plate of 20 mm thickness, and moved downwards at a constant stroke rate of 2 mm/min during testing. The load was transferred to two stiffened channel sections $250 \times 90 \times 6$CC (Cold-formed Channel) which were connected to the test beam specimens by two vertical rows of M12 high tensile bolts. The distance between these two vertical rows of bolts is 50 mm.

At the supports, the two test specimens were bolted through the webs by vertical rows of M12 high tensile bolts. These rows of bolts were connected through the webs of two stiffened channel sections $250 \times 90 \times 6$ CC. The load was subsequently transferred to steel load transfer plates of 20 mm thickness bolted through the flanges of the stiffened channel sections $250 \times 90 \times 6$ CC. These load bearing plates eventually rested on the half rounds of the