Thin-Walled Structures 104 (2016) 44–53

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Strength and stiffness of cold-formed steel purlins with sleeved and overlapped bolted connections

Alomir H. Favero Neto [a,*], Luiz C.M. Vieira Jr. [b], Maximiliano Malite [c]

[a] Institute for Technological Research (IPT), Av. Prof. Almeida Prado, 532 - Sao Paulo, Brazil
[b] University of Campinas - Campinas, Brazil
[c] University of Sao Paulo - Sao Carlos School of Engineering, Sao Carlos, Brazil

ARTICLE INFO

Article history:
Received 29 August 2015
Received in revised form
16 January 2016
Accepted 23 February 2016
Available online 10 March 2016

2015 MSC:
00-01
99-00

Keywords:
Thin-walled member
Cold-formed steel purlin
Overlaped connection
Sleeved connection

ABSTRACT

This paper aims to analyze the strength and stiffness of semi-continuous cold-formed steel purlins subjected to flexure. A series of nine cold-formed steel Z sections with sleeved and overlapped bolted connections were tested in bending. Results show that strength is often limited by a plastic mechanism failure, which reduces the web rigidity and induces an early development of local buckling in the compressed flange. In addition to the experiments, this paper presents a numerical and analytical study of the strength and stiffness of semi-continuous purlins, as well as, an analytical method to predict vertical displacement.

1. Introduction

Long runs of cold-formed steel purlins are widely used in framing systems. There are two common methods of connecting two adjacent purlins: (i) by overlapping and bolting two members, an overlapped connection, and (ii) by bolting a short cold-formed steel member similar to the purlin that holds and connects both purlins, a sleeved connection. The continuity is advantageous since it redistributes the maximum moments from the mid-span to the supports and also reduces displacements.

In a traditional design method the connection is assumed to guarantee full continuity. The strength and stability check of the connection zone are determined by superposing the component sections (double purlin or sleeve and purlin).

Several research groups have investigated the continuity assumption and a succinct literature review is outlined in the following section. The literature review is subdivided according to the connection type.

1.1. Sleeved connections

Moore [20] documented a series of purlin tests on commonly used sleeved connections. The tests were carried out by the UK Building Research Establishment in response to the collapse of several cold-formed steel roofs during snowstorms in the winter of 1981–1982. Moore [20] shows that strength of the sleeved purlin is higher (12–58%) than a continuous purlins and the failure happens at the end of the connection. Moore [20] also noted that for sleeved connections the relationship between moment and rotation is non-linear. This characteristic is attributed to slip between purlin and sleeve, local yielding at the bolt hole, and distortion of the flange. Gutierrez et al. [14] analyzing different sleeved connections observed that strength and stiffness can be lower than the one of continuous purlins.

Bryan [6] determined an analytical equation for the rotational stiffness of sleeved connections based on a series of bolted lap shear tests. Tan et al. [26] adapted Bryans equations for different bolt diameters. Together, equations from Bryan [6] and Tan et al. [26] are a simplification of the behavior described by Moore [20] since both equations lead to a linear moment–rotation relationship. Wang et al. [28] proposed a model that takes in account the non-linearity of the moment–rotation relationship based on the results of lap shear test of single bolted connection and, more

* Corresponding author.
E-mail addresses: alomir@ipt.br (A.H. Favero Neto), vieira@fec.unicamp.br (L.C.M. Vieira Jr.), mamalite@sc.usp.br (M. Malite).

http://dx.doi.org/10.1016/j.tws.2016.02.017

recently, Gutierrez et al. [15] conducted a numerical study to propose a simplified method to characterize the stiffness and strength of purlin joints with sleeve connections.

1.2. Overlapped connections

Murray and Elhouar [21] concluded from 24 experiments of purlins with overlapped connections that the three traditional design assumptions are valid: (i) full continuity, (ii) lap strength is equal to the sum of individual strength of each purlin, and (iii) fully restrained bending (longitudinal stresses are determined by conventional flexure theory and lateral-torsional buckling is disregarded). These conclusions are the base for the design method proposed in the AISI Design Guide D111 [2]. Ghosn and Sinno [13] observed that failure is caused predominantly by bending and concluded that shear interaction can be disregarded. Epstein et al. [10] concluded that the traditional design assumption of restrained bending may overestimate the strength, and that the inertia of each section of the purlin (lapped and not lapped) shall be carefully analyzed.

Ho and Chung [16–18] and Chung and Ho [7] investigated a series of 26 overlapped-connection tests and observed failure at the edge of the lapped length due to the interaction between bending and shear. They also proposed an equation to determine the rotational stiffness; this equation is based on experimental data of single-bolted lap shear tests. Zhang and Tong [29] major contribution is the study of overlapped connections with self-drilling screws at the flanges. The additional screws on the flange do not change the strength of the connection arrangement. Dubina and Ungureanu [9] recommend that instead of evaluating the ultimate capacity of an overlapped connection by an interaction between bending and shear, it should be evaluated based on the interaction bending and web crippling.

In order to further explore this topic the authors defined a series of nine bending tests of cold-formed steel Z sections with sleeved and overlapped bolted connections. The experiments are discussed in the next section.

2. Cold-formed steel Z purlins experiments

2.1. Design

The typical moment diagram of a continuous purlin is depicted in Fig. 1(a). The uniform load represents dead, live, snow, and wind load. While the moment diagram varies depending on the connection stiffness, the inflection point is positioned at about a quarter of the purlin span from the support. At the region between inflection points, the moment diagram (parabola) can be approximated by a linear diagram, Fig. 1(b). This linear approximation leads to the typical test setup used to study connection arrangements. The test setup is known as inverted purlin connection test and consists of a simply supported beam with a concentrated load at midspan, Fig. 1(c).

Two different Z sections (Z1 and Z2) were tested; the sections have similar shape dimensions but different thickness. The nominal cross-section height is 270 mm and the ratio between cross-section height and span length (length of 6000 mm) is 44, which lies in the typical range of 25–50. Each cross-section was tested with a sleeved connection and an overlapped connection; these tests are also compared to a continuous specimen test. Information about cross-section dimensions, test set-up, and test results are summarized in Table 1.

The Z sections were tested in pairs and interconnected by the web to prevent the section from buckling laterally; the lateral bracing schedule is depicted in Fig. 2(b). The load was applied under displacement control with a hydraulic actuator. More details on the loading apparatus and interconnection arrangement can be found in Favero Neto and Malite [12].

In Table 1, the number notes are described as follows:

1. The specimen nomenclature follows the abbreviations: Z for lipped zed section, 1 for nominal thickness of 1.75 mm and 2 for nominal thickness of 2.70 mm, C for continuous specimen, L for sleeved connection, and T for overlapped connection, 5 for connection length of 1036 mm, 11 for connection length of 2200 mm, and P for the second test of the same configuration.
2. *Overall average cross-section dimension, where h is the depth*, $b1$ is the compression flange width, $b2$ is the tension flange width, *D is the lip size*, and t is the nominal thickness without the zinc coating.
3. D stands for distortional buckling, D+L stands for distortional buckling followed by local buckling, D of sleeve stands for distortional buckling of the sleeve only

2.2. Instrumentation

Five position transducers placed *equidistantly* from each other measured the vertical displacement in the connection region and two other position transducers measured eventual support settlement or local deformation at the support region, Fig. 2(a). At the center of the overlap, eight strain gages were placed, two on each exposed side of the flange (not in contact with the other section), while for sleeved connections only four strain gages *were* placed at

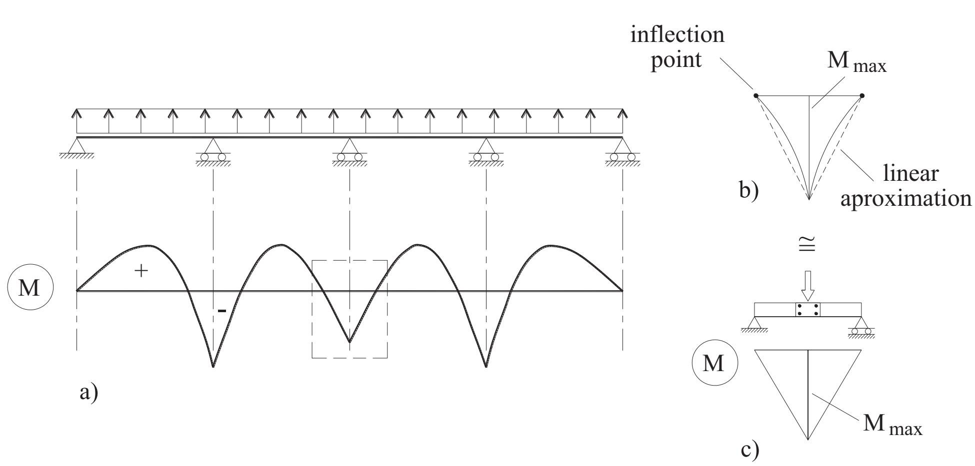

Fig. 1. Idealization of test setup. (a) Moment diagram of a continuous purlin. (b) Linear approximation of moment diagram. (c) Test setup.