Engineering Structures 171 (2018) 658–672

Contents lists available at ScienceDirect

Engineering Structures

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

Stability and moment-rotation behavior of cold-formed steel purlins with sleeved bolted connection

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ARTICLE INFO

Keywords:
Cold-formed steel purlin
Sleeved connections
Semi-rigid connections

ABSTRACT

Long runs of cold-formed steel Z-section purlins are often segmented due to assemblage and transportation issues. The segments are commonly connected by bolts to a short cold-formed steel member similar to the purlin; this short member is typically called a sleeve; from a structural point of view, it does not guarantee a state of full continuity to the purlin. This study reports a series of 15 experiments on cold-formed steel Z-sections purlins with sleeved bolted connections tested in bending. These experiments vary cross-section height, thickness and length of sleeve, and span. This parametric experimental study seeks to better understand the flexural-buckling strength, collapse mechanism, and moment-rotation behavior of purlin-sleeve systems. Since the design of purlins with sleeved bolted connections is often limited by the serviceability limit state, in this case excessive displacement, special attention is given to accurately determining and understanding the moment-rotation behavior of purlin-sleeve systems. Based on the experimental results, an expression is proposed to predict nonlinear moment-rotation behavior; the proposed expression is compared to expressions previously proposed in the literature. The proposed moment-rotation expression, when used in a simple rotation spring-beam model, leads to accurate prediction of displacement and bending moment in the purlin-sleeve system at any load stage.

1. Introduction

The increasing demand of long-span purlins have raised the need of structural steel manufacturers to search for more efficient roof systems. The lighter multi-span purlin systems can be achieved by promoting the correct continuity of the purlins, resulting in a better redistribution of the bending moment and reduction of displacements. Bolted connection is a common solution to promote continuity between purlin members. These systems are usually connected by overlapping a short segment or through a separate element, a sleeve. Both types of connections are attained by bolting together the web of juxtaposed purlins or purlin-sleeve. Due to long-span purlins, storage and transportation is detrimental in determining costs and logistics of erection. Since, sleeved systems do not require an additional length to overlap to the following purlin segment it is easier to store and transport. Furthermore, according to the erectors, the sleeve connections are easier and faster to assemble compared to overlapped connections.

Moore [1] published the first study about purlins with sleeved bolted connections. This paper details an experimental study on cold-formed steel Zed, Zeta and sigma section purlins with sleeved bolted connections. The main result showed the connections have highly nonlinear moment-rotation behavior. As the purlins design is often limited by the serviceability limit state, it is necessary to investigate the connections' rigidity; especially since rotational stiffness is responsible for a significant parcel of the purlins systems' flexibility. Although only three sleeve samples were tested, Moore [1] proposed a simplified beam purlin model with the connection flexibility based on elastic-plastic rotational springs. Based on the maximum rotation of the connection and experimental moment corresponding to this rotation, the secant stiffness was calculated. In this method the maximum rotation adopted was 0.05 rad.

In a similar manner, Tan et al. [2], Yang and Liu [3] and Favero et al. [4] adopted the beam spring model to represent other configurations of sleeve purlin systems. For moment connections, the rotational spring stiffness was estimated based on the mechanism proposed by Bryan and Zadanfarrokh [5] and Bryan [6]. This mechanism depends on the bearing deformation of the bolt hole, where a bearing stiffness expression was determined through lap shear test on bolted steel plates. The bearing deformation expression proposed by Bryan [6] is related to the profile thickness. It consists of a simplification of the

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https://doi.org/10.1016/j.engstruct.2018.05.095
Received 29 September 2017; Received in revised form 9 May 2018; Accepted 27 May 2018
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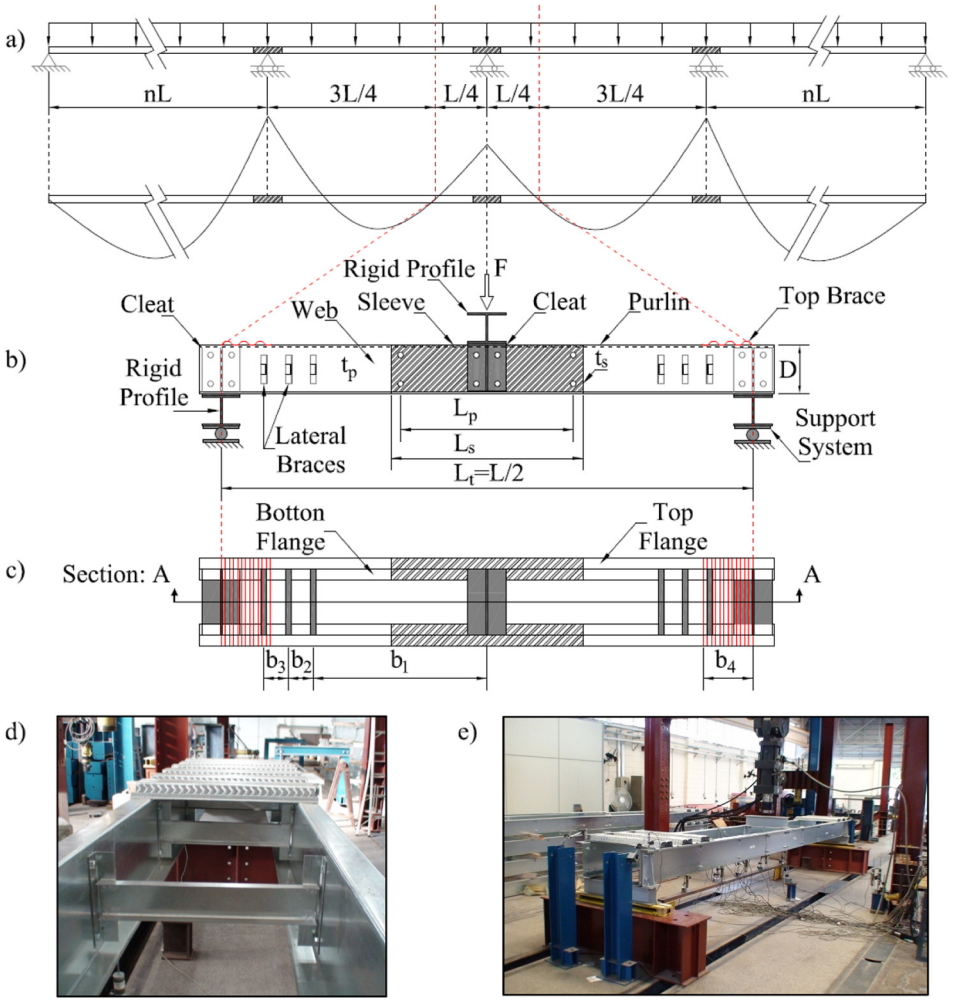

Fig. 1. Idealization of test setup: (a) Continuous beam with uniformly distributed load and moment, diagram of a continuous purlin (Adapted from Fávero et al. [4]), (b) Side view of the equivalent simply, supported beam and representation of the variables to be investigated parametrically (section A-A of Fig. 1c), (c) Top view of overall experimental setup and position of lateral bracing (Table 1), (d) Photography of the, lateral bracing system, and (e) Photography of experimental setup.

nonlinear moment-rotation behavior of the connection, as this strategy results in a linear approximation.

Aiming to introduce the nonlinear flexibility, Ho and Chung [7] proposed a nonlinear normalized bearing deformation curve based on lap shear tests. Then, this curve was used to predict the deformation characteristics of the lapped connection due to bearing deformation. To consider all the components of the connection flexibility in two rotational springs with rigid-plastic and elastic-plastic behaviors, Gutierrez et al. [8,9] approximated the moment-rotation curve by an exponential expression, as a function of the sleeve length-section depth ratio. In the semi-rigid model proposed to Z profile purlins with slotted sleeve connections, this expression led to a linear approximation of the connection stiffness. For most connections, the stiffness changes continuously as the moment increases. Thus, it is important to characterize the nonlinear moment-rotation behavior of the connection. In this direction, Ye et al. [10] proposed a nonlinear empirical expression governed by the sleeve length and the bending moment applied at the joint. Instead of rotational stiffness, this expression quantified the connection flexibility in terms of flexural rigidity variations in modified Z purlin system. Using a similar strategy, Liu et al. [11] developed a flexural rigidity expression to Z-shape purlins with vertical slotted holes in overlapped connections. This expression is related to the ratio between overlapped length and profile height, and overlapped length and profile thickness. The flexural rigidity expression is independent of the applied loading; Liu et al. [11], however, limited its applicability to an applied loading lower than 60% of the ultimate load.

The Design Guide D111-09 [12] shows recommendations and examples for continuous purlin designs, where the hypothesis of continuous beam to multi-span overlapped purlins is adopted. Safety requirements are needed when the design parameters are selected for developing full strength and stiffness. When compared to continuous purlins, Liu et al. [13] and the other above mentioned authors showed the semi-rigid and nonlinear response of the sleeve bolted connection. Therefore, many connection configurations depend on reliable moment-rotation or bearing stiffness curves; which describes the connection behavior at any load stage. These curves are generally obtained by individual or best-fit curve from multiple experimental or numerical analysis. Additionally, the lack of design codes and structural behavior research of sleeve bolted connections make these applications difficult and not viable.

This paper aims to better understand the flexural-buckling strength, the collapse mechanism, and the moment-rotation behavior of purlin-sleeve systems through a parametric experimental study. Based on the experimental results, an empirical expression is proposed to predict

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