Engineering Structures 59 (2014) 284–297

Contents lists available at ScienceDirect

Engineering Structures

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

Rotational stiffness of cold-formed steel roof purlin–sheeting connections

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ARTICLE INFO

Article history:
Received 24 April 2013
Revised 8 October 2013
Accepted 14 October 2013
Available online 4 December 2013

Keywords:
Cold-formed steel
Purlin
Roof sheeting
Rotational stiffness
Connections
Analytical method
Experimental studies

ABSTRACT

Cold-formed steel (CFS) sections are commonly used in modern roof construction. Most purlin members are of thin-walled open cross section. They are usually subjected to roof loading at the top flange in either an upward or a downward direction. The load application points, where the sheeting/purlin connections are located, are often eccentric to the shear centre, and thus inevitably generate a torsional moment that will induce twisting and/or warping deformations in addition to bending deflection. This type of complexity associated with the loading conditions will be exacerbated by the occurrence of single- or mixed-mode buckling (e.g. overall, distortional and local buckling) due to compression flanges tending to move sideways. The connections between purlin and roof sheeting provide a restraining effect on purlin members by preventing such lateral and twisting movements, and thus have a beneficial effect on their load-carrying capacity. In design practice, this effect should be taken into account from a design-efficiency perspective. To this end, a key step is to quantify the rotational restraint stiffness by using an engineering-orientated model. This paper firstly reports a series of torsional restraint tests (*F*-tests) for both sigma and zed sections. Two loading directions were examined by adjusting the purlin fixing direction. The rotational angles between the connected flange and sheeting were recorded at each loading step, from which the moment–rotation curves were produced and presented for each test case. A linear relationship has been observed for the moment–rotation relationship from all test specimens. Secondly, a hand calculation model for calculating the rotational stiffness at each connection was developed. In that model, the rotation was deemed to be primarily caused by the localised deformation of the roof sheeting and the distortional deformation of the purlin flange. The rotation caused by the separation of connection was found to be negligible. The model was validated by the experimental test results and an example was presented to demonstrate the application of the model proposed. The rotational stiffness calculated by this model can be used to evaluate the input parameters required for numerical modelling of purlin–sheeting interaction.

1. Introduction

Cold-formed steel (CFS) sections have a wide range of applications in modern construction, such as being used as purlins or as side rails in light-weight buildings [1]. For building structural systems, a purlin is a type of secondary element acting as an intermediate member in the load path to transfer load from the roof sheeting to the primary frame structure. Common types of purlin sections include channel, zed and sigma shapes. In design practice, this group of sections is normally classified as slender because the sections are unlikely to reach their full cross-sectional resistance governed by the yield stress of constituent material [2]. Furthermore, the open and thin-walled cross sections may lead to a high susceptibility to various types of buckling failure, e.g. local, distortional and lateral torsional buckling. Roof sheeting, which is normally attached to purlins using self-drilling screws, can enhance a purlin's load resistance by supplying it with a certain degree of lateral and rotational restraining effect. Therefore, it is common and economical to treat these two members as an interactive system during the design process [3].

Research into the performance of purlin–sheet systems can date back to the 1960s, including some key research studies mentioned

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[1] On leave.

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http://dx.doi.org/10.1016/j.engstruct.2013.10.024

Nomenclature

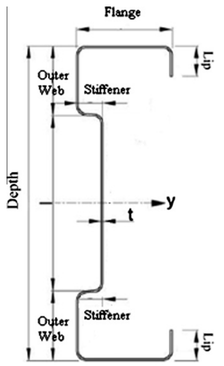
a	the distance between the screw and the line of contact between purlin and sheeting
b	the remaining flange width after subtracting a, i.e. $C - a$
b_T	the breadth of the single trough of roof sheeting
C	the flange width
C_d	the rotational stiffness
D	the bending stiffness of roof sheeting per unit run, $Et_s^3/12(1 - \upsilon^2)$
I_s, I_p	the second moment of areas of sheeting and purlin
θ_s	the rotation angle of the cantilever sheet at the screw connection
θ_l	the rotation angle associated with the localised deformation of the sheet at the screw connection
θ_k	the rotation angle due to the separation between the roof sheet and the purlin flange at the screw connection
θ_p	the rotation angle due to the purlin flange bending

below. Lucas et al. [4,5] initially presented a full, and later a simplified, finite element (FE) model to study the interactional behaviour and its effect on the load-carrying capacity of purlin–sheet systems. The full FE model was comprehensive and accounted for both gravity and uplift loading conditions; however, not all modelling information was presented in detail and hence the model is difficult to reproduce. Vieira et al. [6,7] developed an FE model for the purlin–sheeting system, allowing for the material and geometric nonlinearity effects, to investigate the ultimate load and the longitudinal stress in channel shaped purlins. Li et al. [8] has presented an analytical method for predicting the flexural behaviour of zed purlins under uplift load when they are partially restrained by roof sheets. The model adopts the classic asymmetrical beam theory by considering both bending and twisting effects. Research by Sokol [9] focused on the lateral torsional buckling of purlins restrained by sheeting, and developed a semi-analytical method taking into account the effects of anti-sag bars and the moment gradient. All these studies concur that roof sheeting provides both lateral and rotational restraint to purlins. While the lateral restraint is usually considered to be fully effective, the rotational restraint can be variable but plays a vital role in determining the flexural behaviour of purlins [10], e.g. a higher rotational stiffness can lead to a reduced buckling length in the compression zone, a reduced tensile stress in the free flange, and therefore a higher loading resistance [11].

There is a consensus that the effect of rotational restraint of purlin–sheeting systems is associated with a variety of factors such as the shape and thickness of the sheeting, the geometry of the purlin, the number of screws per unit length, and the type of screw and its applied location. Ye et al. [12,13] investigated the effect of the magnitude and location of rotational restraints on buckling

Table 1
Nominal cross section dimensions for sigma sections.

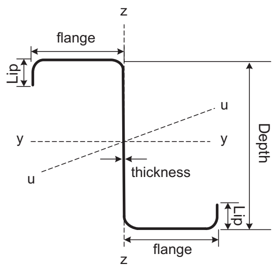
Section code	Depth (mm)	Flange (mm)	Lips (mm)	Outer-web (mm)	Stiffener (mm)	Thickness (mm)
Σ20012	200	62.5	20	45	16	1.2
Σ20016	200	62.5	20	45	16	1.6
Σ20025	200	62.5	20	45	16	2.5
Σ24015	240	62.5	20	45	16	1.5
Σ24023	240	62.5	20	45	16	2.3
Σ24030	240	62.5	20	45	16	3.0
Σ30018	300	75.0	20	60	16	1.8
Σ30025	300	75.0	20	60	16	2.5
Σ30030	300	75.0	20	60	16	3.0



y–y is geometric axes of cross section.

Table 2
Nominal cross section dimensions for zed sections.

Section code	Depth (mm)	Flange (mm)	Lips (mm)	Thickness (mm)
Z14614	145	62.5	20	1.4
Z14618	145	62.5	20	1.8
Z20618	200	65	20	1.8
Z30720	300	75	20	2.0



y–y is geometric axes *u–u* is principal axes of cross section