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Buckling of parallel purlins in standing seam or screw-fastened roofs

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ABSTRACT

Purlins are usually connected to roof sheeting by sliding-clips, while wall sheeting is often screw-fastened to girts. This paper investigates the buckling of such two types of parallel purlin/girt systems inter-connected by multiple lines of sag rods. One single purlin braced by one sag rod at any place along the span is first analyzed, and its buckling deformation at any cross-section is seen as a flexibility coefficient which is then used to study the buckling of the purlin braced by multiple sag rods along span. A flexibility matrix is constructed, whose eigenvalues are the base of critical equations. In the case where the sag rods are placed with equal spaces along span, the eigenvalues are expressed in explicit forms, of which each represents one buckling mode. Threshold stiffness of the sag rods are presented for multiple sag rod bracings for these two types of sheet-to-purlin connection. Based on the findings of this paper, the differences of buckling behaviors between these two types of purlin systems have been revealed. The effect of local deformation of the web at the sag rod connecting points on the sag rod stiffness is also included. Parallel purlin systems are then investigated in a compact matrix form. After carrying out matrix operations and slight approximations, a key parameter is found to be used to reflect the effect of the number of purlins and zig-zag layout of sag rods in adjacent bays on the effective sag rod stiffness.

1. Introduction

Cold-formed thin-walled Z- or C-shaped purlins, as secondary members in a roof or wall sheeting system, may buckle lateral-torsionally under wind suction, or more exactly, buckle lateral-distortionally. The upper tensile flange is connected to the sheeting either by screws (Fig. 1a) or by sliding clips (Fig. 1b). For screwed connection, the cross section rotates about the line formed by the screws on the upper flange, as shown in Fig. 2b, and for sliding clip connection, lateral displacement of the upper flange is allowed, as shown in Fig. 2d. The rotation of the cross sections is restrained by sheeting in these two types of connections, such restraints are provided by the twisting moment formed by the tensile force in the screw and the compression at the contact point between the purlin and the sheeting, and in the case of sliding clips, is provided by the two screws fixing the clips to purlins. So, purlins are assumed to be restrained by a uniformly distributed torsional spring along the span. Web-flange lateral distortion is a kind of local deformation occurring along the whole span, due to the high width-to thickness ratio of the purlin web, as investigated recently by Basaglia et al. [1], Yuan et al. [2]. Eurocode [3] has incorporated the effect of web-flange lateral distortion in its design approach of screw-connected purlin. In this paper, the effect of such deformation will be incorporated through a reduced rotational stiffness along spring.

Under wind suction, the bottom/compression flange is free of lateral restraint, so sag rods are usually necessary to prevent the purlin from lateral-torsional buckling. The effective stiffness of the sag rod, as revealed by Polyzois [4], Sun et al. [5], Zhang & Tong [6–8], and Tong & Tang [9], is much less than its original axial stiffness due to the local deformation of the purlin web. With the torsional restraints and the finite effective stiffness of the sag rod taken into consideration, the lateral buckling of one-single-purlin braced by one sag rod at the midspan and a parallel purlin system braced by one line of sag rods have been investigated by Tong & Tang [9].

In 1990, Tong [10] investigated the stiffness requirements on platform beams which provide lateral support to very tall columns in an industrial hall. For an axial compression column braced by equally spaced platform beams, the stiffness requirement on the beams is found to be related to the number of bracings n_b along tall columns, and a coefficient to reflect this effect was given in closed form by

$$\Gamma_{\mathrm{Tong},1990} = (n_b + 1)^3\left(1 + \cos\frac{\pi}{n_b + 1}\right) \tag{1}$$

In 1991, Tong [11] investigated the stiffness requirement in a parallel compression column system. In such a system, Tong [11] found that the stiffness requirement should be magnified by a coefficient related to the number of columns, n_c, which is given in closed form by:

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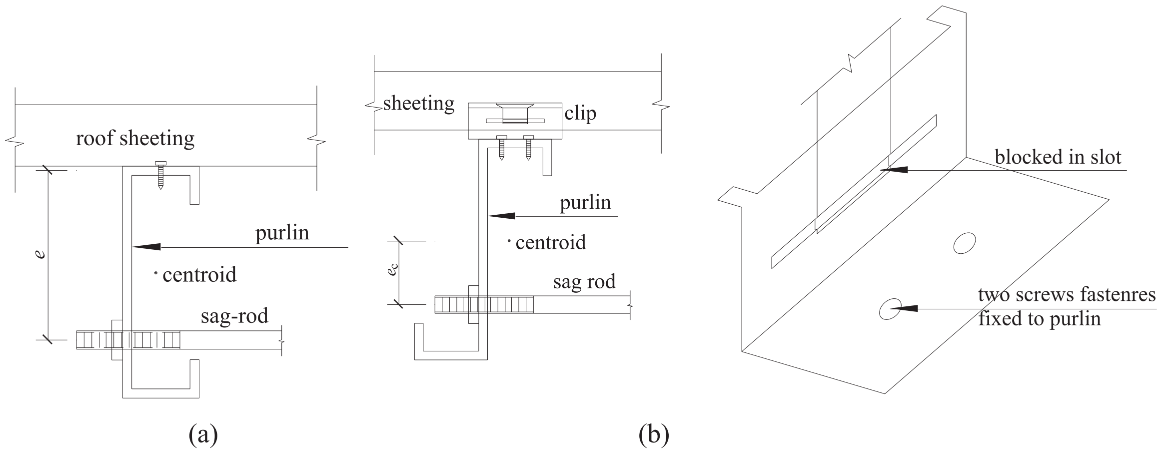

Fig. 1. Two types of purlin-to-sheeting connections: (a) screwed connections and (b) sliding clip connections.

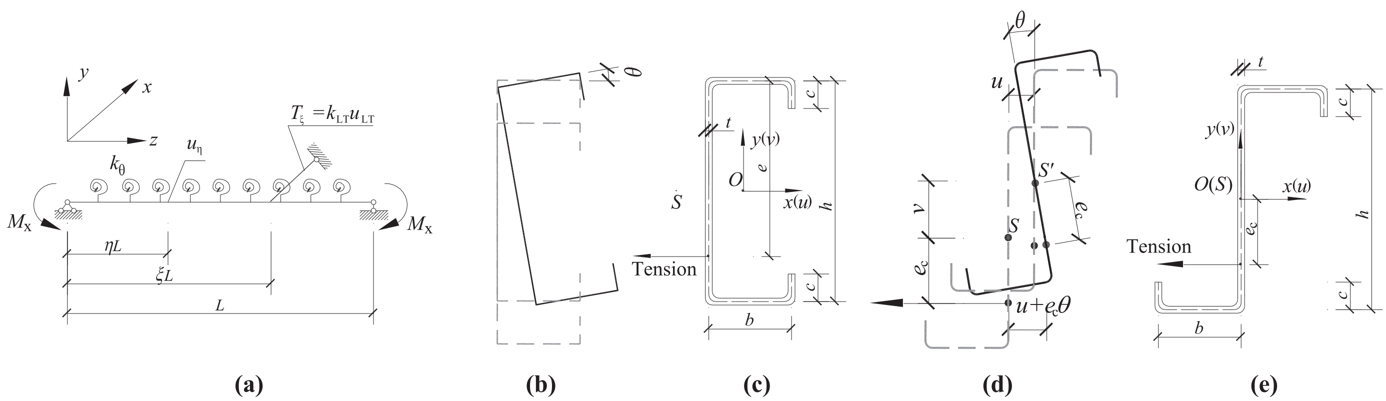

Fig. 2. Analysis model and notations: (a) the analysis model of one single purlin with one sag rod, (b) the displacement of a purlin screwed to the sheeting, (c) the notations of C-shaped sections, (d) the displacement of a purlin sliding-clip-connected to the sheeting, and (e) the notations of Z-shaped sections.

$$\Gamma_{\mathrm{Tong},1991} = \left(1 - \cos\frac{\pi}{2n_c + 1}\right)^{-1} \tag{2}$$

The coefficients in Eq. (1) and Eq. (2) are derived using the difference equations based on the stiffness matrix of a system.

In 2017, Tong & Tang [9] studied a parallel purlin system inter-braced by one line of sag rods, and found that the stiffness requirement of a parallel purlin system braced by one line of sag rods also agreed with Eq. (2). Also, in 2017, Ziemian & Ziemian [12] analyzed a parallel compression column system inter-connected by two key parts: anchor bracing and tie bracing. Whether the anchor bracing is rigid or flexible, a key factor in the stiffness requirement of the bracing is given by numerical analysis and fitting, which is very close to Eq. (2).

This paper studies parallel purlin systems in which they are connected to roof or wall sheeting by either screws or sliding clips, and presents a systematical way to solve the buckling of parallel purlin systems under wind suction. For these two types of purlin-to-sheeting connections, one single purlin braced by one sag rod at any place along the span is first analyzed, the results of which is then used to study the buckling of the purlin braced by multiple sag rods along span. Threshold stiffness of the sag rods are presented for multiple sag rod bracings along span. The effect of local deformation of the web at the sag rod connecting points on the sag rod stiffness is also introduced. The buckling of parallel purlin systems with multiple sag rods along span are then investigated.

2. One single-purlin system with one sag rod

The connection between girts and wall sheeting is often screw-fastened, as shown in Fig. 1a. On the other hand, roof sheeting is often connected to purlins by sliding clips in standing seam roof systems, as shown in Fig. 1b. Both types of connections will be studied.

2.1. Sliding clip connections

A purlin with one sag rod, simply supported at both ends, subjected to pure hogging moment, and restrained by uniformly distributed rotational springs provided by the roof sheeting at the top flange, is shown in Fig. 2a, and the total potential for buckling analysis is:

$$\Pi = \frac{1}{2}\int_0^L (EI_y u''^2 + EI_x v''^2 + EI_\omega \theta''^2 + 2EI_{xy} u'' v'' + k_\theta \theta^2 + GJ\theta'^2 - 2M_x u'\theta' + 2M_y v'\theta')\mathrm{d}z + \frac{1}{2}T_\xi u_{LT} \tag{3}$$

where E = Young's modulus of steel; G = shear modulus of steel; I_x, I_y, I_{xy}, I_ω, J = the moments of inertia with respect to y and x axis, the product of inertia, the warping inertia moment and free torsional constant, respectively; u, v = the displacements of the shear center in the x and y directions; θ = the rotation of the cross section about the shear center; M_x = the pure hogging moment with respect to x axis; L = the span length; T_ξ = the axial force in the sag rod (the sag rod is placed at the location $z = \xi L$, $0 < \xi < 1$); u_{LT} = the lateral displacement of the sag rod connecting point.k_θ = the reduced value of the uniformly distributed rotational spring, computed by

$$\frac{1}{k_\theta} = \frac{1}{k_{\theta,\mathrm{sheeting}}} + \frac{4(1-\nu^2)(h+2b)}{Et^2}$$

where $k_{\theta,\mathrm{sheeting}}$ = the rotational spring stiffness provided by the sheeting, t = the purlin thickness, ν = the Poisson ratio, h = the purlin

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