Laterally braced thin-walled purlins in stability problems

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Abstract

In the paper numerical analysis of thin-walled purlins restrained by sheeting is carried out. Stability phenomenon is analysed for different purlins' lengths and for two types of cross-section, namely Z350 and Z250. Influence of sheeting bracing on load capacity of the purlins is examined taking into account different stiffness of trapezoidal sheet, configuration of anti-sag bars and different spacings of connectors. At this stage of the study the aim is to reach the most effective stability response, then to compare the numerical results with the analytical calculation based on European Standards. Special attention is focused on local and global buckling phenomena, which may cause unstable post-buckling behaviour. In the paper different ways of modelling the restrained purlins in general purpose finite element program ABAQUS is presented. The examples illustrate the importance of proper modelling of the laterally restrained purlins.

Keywords: thin-walled structures, stability analysis, buckling resistance, purlin restrained by sheeting

1. Introduction

Using in civil engineering practice thin-walled purlins restrained by sheeting can provide several benefits. Among them lightness due to its high strength in relation to weight and significant reduction of the costs, connected also with transport, erection and construction of foundation. It is well known that purlins and rails are co-working with trapezoidal sheeting. Thus, it is generally assumed that sheeting takes the load in its plane and the load normal to the sheeting is taken by the purlin. Therefore, the purlin may be regarded as laterally restrained by sheeting. The phenomena of thin-walled, cold-formed steel sections laterally restrained by sheeting is widely discussed in literature. The model of lateral-torsional buckling of partially restrained beams was developed in [4]. Author of [4] described the numerical computational procedure to obtain the critical buckling load. Advanced numerical study of the dependency between partial restraints and buckling behaviour of cold-formed zed-purlins was carried out in [6]. The influence of lateral restraints on the bending behaviour of the purlin was analysed in [5] too. Authors of [5] found out that the behaviour of purlins is different when the restraints are imposed at tensioned and compressed flanges. In design codes, this effect is reflected by recommending different procedures for sections subjected to gravity and uplift loading.

In the case of cold-formed steel members, boundary condition and initial geometric imperfections can significantly influence stability response, because these structures are often very susceptible to local and global instability. Method of introducing imperfections, is widely discussed in the literature in [1] and [2]. It is well known that the shapes and amplitude of imperfections strongly change the structural response.

2. Theoretical background

In the paper the influence of lateral restraints on stability behaviour is investigated in two independent ways: through a numerical experiment using the finite element method and by means of standard formulae.

2.1. *Assumptions for a simplified calculation:*

The lateral restraint realized by the trapezoidal sheeting generally takes the load in the plane of sheeting. Therefore, the purlin may be regarded as laterally restrained in the plane of the sheeting and partially rotationally restrained. The rotational restraint added to the purlin by the sheeting that is connected to purlin's top flange, should be modelled as rotational spring acting on the top flange of the purlin shown in Fig. 1.

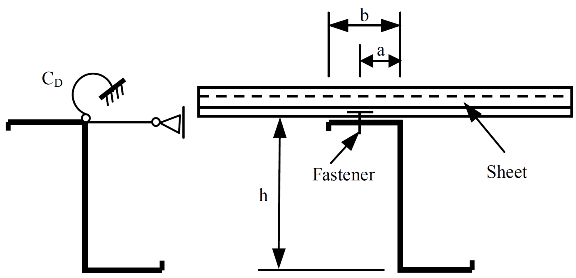

Figure 1: Laterally braced purlin with rotational spring restraint C_D from sheeting

The simplified formula for the total rotational spring stiffness C_D according to [EC 3] takes the form:

$$C_D = \frac{1}{(1/C_{D,A} + 1/C_{D,C})}$$

where:

$C_{D,A}$ – the rotational stiffness of the connection between the sheeting and purlin,

$C_{D,C}$ – the rotational stiffness corresponding to the flexural stiffness of the sheeting.

3. Numerical examples

The study is carried out for purlins made from thin-walled profiles Z350 with 9m span and Z250 with 6m span in the elastic range using buckling procedure. To investigate influence

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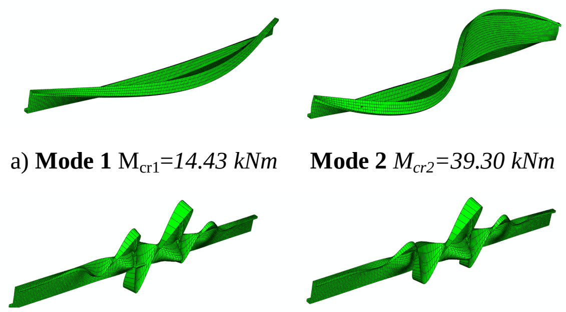
of restraints realized by sheeting on stability behaviour of a thin-walled purlin, different stiffness of trapezoidal sheet (TR-35 and TR-55), different spacings of anti-sag bars and connectors are considered. Moreover, forces in the connectors are calculated. Numerical examples were solved using the finite element program ABAQUS. In the numerical model four-node doubly curved shell elements with reduced integration S4R were employed.

The influence of the spacing of lateral bracing (L_0) on the interactive buckling phenomenon is shown in Fig. 2. It is shown that in the case in which no anti-sag bars are applied only global buckling appeared for two lowest buckling modes, whereas adding two bracings resulted only in local buckling mode. In this case the buckles develop in the middle region of the purlin, which is also the case for all other lengths. Note, that the local buckling loads are very close to each other.



a) **Mode 1** $M_{cr1}=14.43$ *kNm* **Mode 2** $M_{cr2}=39.30$ *kNm*

b) **Mode 1** $M_{cr1}=61.76$ *kNm* **Mode 2** $M_{cr2}=62.19$ *kNm*

Figure 2: Shapes of buckling mode for purlins: a) without bracings, b) with two bracings

The comparison of the critical moment M_{cr} obtained from FEM buckling analysis and critical moment calculated from analytical solution $M_{cr(eig.)}$ is presented in Tab. 1.

Table 1: Comparison of M_{cr} and $M_{cr(eig.)}$

	L **[m]**	L_o **[m]**	M_{cr} ***ABAQUS*** **[kNm]**	$M_{cr(eig.)}$ ***EC 3*** **[kNm]**
LP-Z250	6	6	14.42	14.51
		2	61.76	130.65
LP-Z350	9	9	13.59	15.153
		3	74.72	124.67

One can notice that the results obtained using analytical formulation provide higher values than in the case of FEM buckling analysis. The largest divergence appeared when the additional bracing was applied. It can be caused by taking in to account in the analytical formulation only the distance between the bracing, not its flexibility. Moreover, in this approach only global stability effect is considered, whereas in shell FEM model local and global buckling phenomena are allowed for.

In the paper a particular attention is paid to the influence of different spacings and different ways of modeling of the connectors. In Fig. 3 the deformation and stress distribution of the FEM model consisting of two purlins made from Z250 restrained by trapezoidal sheet TR-55 is shown. The sheet is fastened to the purlins by means of beam connectors that couple all DOFs of the connected nodes.

Several FEM models were created, in which the connectors were applied in every, every third, fifth and eighth fold of the trapezoidal sheet. It was found, that reducing number of connectors has a considerable influence on displacement of the cross-section in the mid-span, along the direction of roof slope. This displacement is about ten times greater in case when the connectors are applied in every fold compared to the model with connectors in every eighth fold. Influence on global deformation and displacements in other directions, for the monitored cross-section in the midspan, is negligible. Moreover changing boundary conditions and numerical model of connectors may influence the critical stresses too.

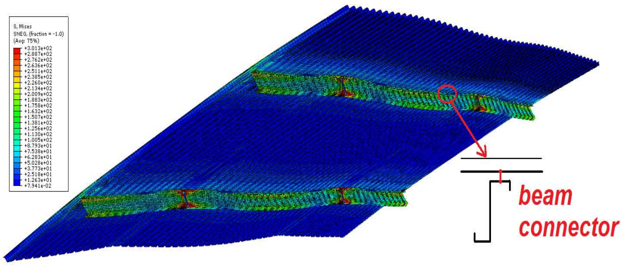


Figure 3: Deformation and effective stress distribution on roofing consisting of two zed-purlins and trapezoidal sheet

4. Conclusions

In the paper stability analysis of thin-walled purlins restrained by sheeting for different beam lengths and type of the cross-section was carried out. A particular attention was paid to the influence of a different stiffness of trapezoidal sheet, spacing of the anti-sag bars and connectors on load capacity of the purlin. It was presented that decreasing the spacing between the bracing results in increase of critical moment. It was shown that adding anti-sag bars not only increases critical moment but also causes the switching the buckling mode from global to local one. It was also found that number of the connector and spacing of purlins influence value of rotational spring stiffness C_D.

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