Determination of bearing capacity of steel thin-walled cold-formed structures using the example of centrally compressed struts

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Abstract. Until 2017, there were no regulatory documents in Russia that allowed calculations of light steel thin-walled structures (LSTWSs), which hampered their use in construction. The paper compares various methods of calculating LSTWSs in compliance with Russian, European and American standards, and describes their features. The direct method of finding the strength of steel thin-walled profiles, developed by American scientists B. Schafer and T. Pekoz, is described. The method is based on the determination of the bearing capacity of a section according to the results of calculating critical forces for three forms of buckling. Using the CUFSM program developed by B. Schafer on the basis of the finite strip method, a centrally compressed strut from LSTWS was calculated; critical forces of three forms of buckling were determined, and profile bearing capacity was determined as the minimum value of three.

1 Introduction

Improving the methods for calculating light steel thin-walled structures (LSTWSs) makes it possible to take advantage of their positive properties, such as efficiency, energy efficiency, environmental friendliness, the speed of construction by means of small-scale mechanization, etc. The above-mentioned properties fully meet the requirements of modern sustainable development. In 2016, in Russia, for the calculation of structures from LSTWSs, a set of rules SP 260.1325800.2016 “Thin-walled steel structures made of cold-formed galvanized profiles and corrugated sheets” was adopted, based on Eurocode 3 standards [1 - 3]. According to the regulatory documents, LSTWS is assigned to the 4th class of sections in which local stability loss occurs when the stresses reach the yield strength of steel (ultimate load method). In this regard, the calculation is carried out according to the characteristics of the effective section, i.e. buckled sites are not taken into account. Determining the characteristics of an effective cross section is rather cumbersome and time consuming. The calculation according to European standards is carried out by

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dividing the section into separate sections (shelf, wall, bending), that is, their interaction is not taken into account, which leads to underestimated load-bearing capacity.

2 Materials and methods

An alternative calculation method is the Direct Strength Method (DSM) [4], developed by American scientists B. Schafer and T. Pekoz. As is known in thin-walled rods, three forms of stability loss are distinguished:

- local;
- with distortion of the section (deplanation);
- general (bending, torsional, bending-torsional).

The method of direct determination of strength is based on finding critical forces for these three forms of buckling, and on their basis determining the bearing capacity of a section. In this case, the calculation is based on the characteristics of the full cross section, and the interaction of elements is taken into account.

To determine the critical efforts for buckling, B. Schafer developed the CUFSM program [5] based on the finite-band method. The cross section of the profile is divided into longitudinal strips. Due to the lack of length partitioning, it may be more rational to choose interpolating functions for determining displacements compared to the finite element method. This greatly reduces the resources needed for computing. The result of the calculation in the CUFSM program is a graph showing the ratio of the critical stress buckling to the force corresponding to the yield strength of steel and the corresponding half-wavelength. The minimum value of the coefficient of local buckling is determined within the half-wavelength of less than or equal to the maximum cross-sectional size. The total buckling is calculated taking into account the half-wave length, which depends on the method of fixing the element. Deplanation buckling corresponds to a half-wave length several times larger than the maximum cross-sectional size and lies between the local form of stability loss and the general one.

Below there is an example of calculating a strut with a length of 3000 mm unfastened at a length of 1500 mm (Fig. 1) from a profile LS 175x55x15-1 (according to TU 1121-010-46216359-2015 Cold-formed profiles from galvanized steel and details of their joints / Lazar LLC)

Fig. 1. Calculation diagram

Figures 2-8 show a method for determining critical forces resulting from buckling in the CUFSM program.

Fig. 2. Creating a section in CUFSM.

Fig. 3. Setting the yield strength of steel.

Fig. 4. Geometrical characteristics of the section.

Fig. 5. Setting boundary conditions.

Fig. 6. Critical force of local buckling.

Fig. 7. Critical strength of buckling with sectional distortion.

Fig. 8. The critical strength of overall buckling.

The bearing capacity of the profile is defined as the minimum value of three:

P_{ne} is overall buckling;

P_{nl} is local buckling;

P_{nd} is buckling with sectional distortion.

Determination of bearing capacity overall buckling

If $\lambda_c \leq 1.5$

$$P_{ne} = (0.658^{\lambda_c^2}) P_y \quad (1)$$

where

$$P_y = A_{gr} f_y \quad (2)$$

$$\lambda_c = \sqrt{P_y / P_{cre}} \quad (3)$$

here P_{cre} is minimum value of critical force of bending, torsional or bending-torsional forms of buckling.

If $\lambda_c > 1.5$

$$P_{ne} = \left(\frac{0.877}{\lambda_c^2} \right) P_y \quad (4)$$

$$P_y = 101,05 \text{ kN (figure 3)}$$

$$P_{cr\theta} = 1,15P_y = 1,15 \cdot 101,05 = 116,21 \text{ кН (figure 8)}$$

$$\lambda_c = \sqrt{P_y/P_{cr\theta}} = \sqrt{\frac{101,05}{116,21}} = 0,932 \leq 1,5$$

$$P_{n\theta} = (0,658^{\lambda_c^2})P_y = (0,658^{0,932^2})101,05 = 70,25 \text{ кН}$$

Determination of bearing capacity for local buckling

$$\lambda_l = \sqrt{P_{n\theta}/P_{crl}} \quad (5)$$

При $\lambda_l \leq 0,776$

$$P_{nl} = P_{n\theta} \quad (6)$$

При $\lambda_l > 0,776$

$$P_{nl} = \left[1 - 0,15 \left(\frac{P_{crl}}{P_{n\theta}} \right)^{0,4} \right] \left(\frac{P_{crl}}{P_{n\theta}} \right)^{0,4} P_{n\theta} \quad (7)$$

$$P_{crl} = 0,23P_y = 0,11 \cdot 101,05 = 11,11 \text{ кН (figure 6)}$$

$$\lambda_l = \sqrt{P_{n\theta}/P_{crl}} = \sqrt{\frac{70,25}{11,11}} = 2,52 > 0,776$$

$$\begin{aligned} P_{nl} &= \left[1 - 0,15 \left(\frac{P_{crl}}{P_{n\theta}} \right)^{0,4} \right] \left(\frac{P_{crl}}{P_{n\theta}} \right)^{0,4} P_{n\theta} = \\ &= \left[1 - 0,15 \cdot \left(\frac{11,11}{70,25} \right)^{0,4} \right] \cdot \left(\frac{11,11}{70,25} \right)^{0,4} \cdot 70,25 = 31,19 \text{ кН} \end{aligned}$$

Determination of bearing capacity for buckling with sectional distortion

$$\lambda_d = \sqrt{P_y/P_{crd}} \quad (8)$$

При $\lambda_d \leq 0,561$

$$P_{nd} = P_y \quad (9)$$

При $\lambda_d > 0,561$

$$P_{nd} = \left[1 - 0,25 \left(\frac{P_{crd}}{P_y} \right)^{0,6} \right] \left(\frac{P_{crd}}{P_y} \right)^{0,6} P_y \quad (10)$$

$$P_{crd} = 0,296P_y = 0,296 \cdot 101,05 = 29,91 \text{ kN (figure 7)}$$

$$\lambda_d = \sqrt{P_y / P_{crd}} = \sqrt{\frac{101,05}{29,91}} = 1,84 > 0,561$$

$$\begin{aligned} P_{nd} &= \left[1 - 0,25 \left(\frac{P_{crd}}{P_y} \right)^{0,6} \right] \left(\frac{P_{crd}}{P_y} \right)^{0,6} P_y = \\ &= \left[1 - 0,25 \cdot \left(\frac{29,91}{101,05} \right)^{0,6} \right] \cdot \left(\frac{29,91}{101,05} \right)^{0,6} \cdot 101,05 \\ &= 42,81 \text{ kN} \end{aligned}$$

$$P_n = \min \begin{Bmatrix} P_{ns} \\ P_{nl} \\ P_{nd} \end{Bmatrix} = \min \begin{Bmatrix} 70,25 \\ 31,19 \\ 42,82 \end{Bmatrix} = 31,19 \text{ kN}$$

3 Conclusion

1. Thus, the load-bearing capacity of a centrally compressed strut of 3000 mm long unfastened on a length of 1500 mm from a 175x55x15-1 LS profile is 31.19 kN and is determined by the interaction of local and general buckling.
2. When calculating by Eurocode 3, the effective cross-sectional area was 1.02 cm². The bearing capacity, determined by the loss of stability in the bending-torsional form, was equal to 28.04 kN.
3. The difference of 10% is largely due to the interaction between the elements of the section (wall, shelves, bends) in the method of direct determination of strength.

References

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