New nodal connection of thin-walled cold formed profiles with a trapezoidal wall using separate welded bushings

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Abstract. The article suggests a new constructive solution of the node made of thin-walled cold-formed profiles with a part of concave flat wall with the use of separate welded bushings for bolt arrangement. To assess the load-carrying capacity of the proposed node numerical and experimental study of a prototype model, consisting of thin-walled cold-formed profiles connected by a gusset plate with a bolt, using separate welded bushings was fulfilled. By results of researches character of pressure distribution in places of bolts installation is revealed and actual carrying capacity of new node is defined. The significance of the obtained research results for the construction industry lies in the fact that the new design solution of the node with the use of separate welded bushings makes it possible to eliminate the gap between the gusset plate and trapezoidal wall of the profile, thus performing the bolt fastening in this place and improving the actual work of the node. It should be noted that the proposed solution of connection with the use of separate welded bushings allows increasing the carrying capacity of the node, taking into account the installation of bolts in the concave part of the profile wall.

Keywords: stress-strain state, load-carrying capacity, cold-formed profiles, welded bushings, trapezoidal wall, bolted nodal joint.

1 Introduction

Throughout the whole development stage of metal structures the main task was to improve the supporting structures - to ensure strength and deformability along with reducing their weight and reducing the labor intensity of manufacturing and installation. One of the ways to achieve these goals is to use thin-walled cold-formed profiles in structures [1]. In recent years these profiles are actively introduced in the manufacture of trusses [2-7], frame structures [8-9], used in small bridge structures [10] at low-rise [11], multi-storey [12] construction. The reason for such an active use of thin-walled cold-formed profiles is explained by several factors such as: the publication of a new set of normative rules "SP 260.1325800.2016. Thin-walled steel structures made of cold-formed galvanized profiles and corrugated sheets. Design rules", adjustment of the technological line for the production of profiles, which entailed a linear increase in the number of manufacturers' plants, foreign experience of application, as well as scientific works to develop calculation methods [13-14].

However, the practical experience of application of thin-walled cold-formed profiles in supporting structures shows that the used nodal connections are not rational. It is expressed in not grounded steel consumption in constructions, at the expense of massive connections on sheet gussets, labor intensity of their performance. The most disturbing thing is that the actual work of some nodal joints made of thin-walled cold-formed profiles is questionable. In this regard, it is necessary to carry out additional research, which, unambiguously, should be supported experimentally, identify existing disadvantages and develop technical solutions.

The following works are devoted to studies of nodal joints made of thin-walled cold-formed profiles [15-19]. Both profiles with a part of concave flat wall [20-22] and nodal joints made of paired elements connected by a sheet gusset using bolts [23-25] are very interesting. Flexibility of manufacturing and shape of the contour of thin-walled cold-bent profiles make it possible to find those constructive solutions that provide the necessary strength and deformation characteristics, together with the simplicity of their assembly and minimization of steel consumption, ultimately, allowing to produce truly lightweight thin-walled structures at the output.
2 Materials and methods

2.1 Object of research

In work [23] we consider a prototype of connection of thin-walled cold-formed profiles with trapezoidal wall, where the bolt connection can be made only in two vertical rows in the contact zone with the gusset plate, noting the uneven distribution of stresses on the height and the length of the profile. Taking into account the actual work of the node it is proposed to strengthen the gusset plate with sheet steel for the possibility of placing additional rows of bolts in the concave part of the thin-walled wall profile [23].

In this paper a new version of the node connection is considered, where continuous separate bushings welded to the gusset plate are used instead of sheet steel. For an estimation of bearing capacity of the offered node the experimental prototype is developed (see Figure 1).

The prototype is an assembly of two thin-walled cold-formed profiles with dimensions of 120x20x4 mm made of C350 class steel, connected by a 120x120x16 mm sheet gusset plate made of C245 class steel, by means of welded continuous separate bushings ø 40 mm, tightened by M16 bolt of strength class 5.8, the elements are united by steel plates with dimensions of 150x150x16 mm.

2.2 Numerical and experimental studies

To ensure the strength of the weld of a continuous split bushing, a calculation must be made. The calculation of the weld is based on the minimum load-carrying capacity of the bolt. The load-carrying capacity of the bolt per shear:

\[ N = R_{bs} \cdot A_b \cdot n_s \cdot \gamma_h \cdot \gamma_c = 2000 \cdot 2,01 \cdot 2 \cdot 1 \cdot 0,9 = 7236 \text{ kg} \]  

Carrying capacity of the bolt for buckling:

\[ N = R_{bp} \cdot d_b \cdot \sum t \cdot \gamma_h \cdot \gamma_c = 6450 \cdot 1,6 \cdot 0,8 \cdot 1 \cdot 0,9 = 8256 \text{ kg} \]
Weld size equals the $k_T = 6 \text{ mm};$

Calculation of welded joints with angular seams for simultaneous action of transverse force and bending moment on the weld metal:

$$\sqrt{\left(\frac{Q}{n k_T \rho_{lw}}\right)^2 + \left(\frac{M}{n W_{lw}}\right)^2} \leq R_{wf} \cdot Y_{wf} \cdot Y_c;$$  \hspace{1cm} (3)

Stress at the fusion boundary is less than that of the weld metal.

Modeling of an experimental prototype was carried out by creation of separate models of details and their further assembling in the united node in software package "Solidworks" (see Figure 2).

Figure 2. Model of the experimental prototype.

Determination of the stress-strain state of the experimental prototype was performed in the module "Solidworks Simulation" taking into account the physical and geometric nonlinearity. The load on the prototype was applied through a steel plate as uniformly distributed on the area, the value of which was accepted equal to the minimum bearing capacity of the bolt on the shear. The creation of the finite element mesh was carried out on the basis of the node curvature (see Figure 3).

Figure 3. Finite element model.
An experimental study of the prototype was carried out in the national educational center "Strength". To determine the stress-strain state 5 strain gauges BE-120-10 AA were installed, which were connected to the strain station "Nationals Instruments NI cDAQ-9188", in turn connected to a personal computer, where data processing was carried out through the program "NI LabVIEW 2015". The loading was performed by the press «IR 5082». The load application speed and the load value were regulated with the "Testing M-auto" program. Movements of assembly elements were determined by the value of press rod movement (see Figure 4).

![Figure 4. Testing of an experimental prototype: 1 – Strain gauge location; 2 – Prototype loading.](image)

3 Results and discussion
As a result of nonlinear calculation of the prototype, its stress-strain state was determined (see Figure 5) and an epure of equivalent stress distribution over a thin-walled cold-formed profile was constructed based on the cross section 1-1 (see Figure 6).

![Figure 5. Stress-strain state of the prototype.](image)
Figure 6 Graph of distribution of equivalent stresses in a thin-walled profile in the cross-section 1-1 (see Figure 5).

Analyzing the stress distribution graph, we can say that the maximum stress in the profile in the bolt location area was $\sigma = 221.4 \frac{N}{mm^2}$, with vertical movement of prototype parts equal to $\delta = 1.05$ mm.

The application of the prototype load was done in stages. At the end of each step, the prototype was visually inspected for changes and defects. Destruction of the experimental prototype occurred as a result of shearing the bolt at load $N = 10.3$ t, which is 1.42 times higher than the calculated value.

It should be noted that the bolt is partially exposed to local curvature. Maximum vertical movement of the prototype elements is $\delta = 1.21$ mm, which is 1.15 times higher than the value obtained in the numerical study (see Figure 7).

![Figure 7. Destruction of the experimental prototype: 1 – bolt shaft; 2 – bolt head; 3 – washer.](image-url)

Strain gauges recorded changes of stresses throughout the experiment. On (see Figure 8) a graph of distribution of stresses on the cross-section 1-1 (see Figure 5) at rated load equal to $N = 7236$ kg is presented.
Figure 8. Stress distribution graph for profile height according to strain gauges.

Maximum stress according to the readings of strain gauges under the bolts is $\sigma = 236.8 \text{ N/mm}^2$, which is 1.06 times higher than the value in the numerical study.

4 Conclusions
The following conclusions can be drawn from numerical and experimental studies of the prototype:
1. Application of separate welded bushings allows receiving a new design of node with possibility of statement of bolts additional rows in the concave part of a profile wall and in a zone of its contact to a gusset plate.
2. The design of the connection node made of thin-walled cold-bent paired profiles with trapezoidal wall, with the proposed solution of installation of separate welded bushings, allows reducing steel consumption by 20-30 %, in contrast to the reinforcement of the node sheet steel.

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