BUILDING STRUCTURES, BUILDINGS AND CONSTRUCTIONS

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INCREASING EFFICIENCY OF A CONNECTION OF UNIFIED ELEMENTS OF AN ARCH OF LIGHTWEIGHT BUILDINGS

Statement of the problem. When designing lightweight arch buildings using the principle of an "open" standardizing, which provides the erection of load-carrying arches of any outline from a set of unified elements, the major question to be addressed is the development of an effective connection of unified elements providing their connection at arbitrary angles.
Results. Numerical studies were made of a connection of thin-walled cold-bent open-section profiles on self-drilling, based on which an optimum disposition of self-drilling screws providing the greatest durability and rigidity of connection was defined. The experimental studies were made of models of connections of unified elements with a proposed disposition of self-drilling screws. Also, numerical and experimental studies of a new way of strengthening thin-walled elements connection were provided.
Conclusions. The data obtained in numerical and experimental studies allow us to draw conclusions about perspectivity and expediency of the proposed ways of increasing efficiency of unified elements connection of a lightweight arch building.

Keywords: arch building, "open" standardizing, connection, unified elements, increasing efficiency.

Introduction

Developing a typical node of connection of the arch elements is a major issue in the design of arch buildings according to the "open" standardizing principle. When applied to the arch construction, this method ensures the erection of structures of an arbitrary span and shape.

Previously the paper [1] identified the results of numerical and experimental research of a valid operation of the connection node of unified elements of an arch building with the construction solution discussed in the papers [2, 3]. The research revealed sufficient strength and viability of the structure of the suggested node (Fig. 1).

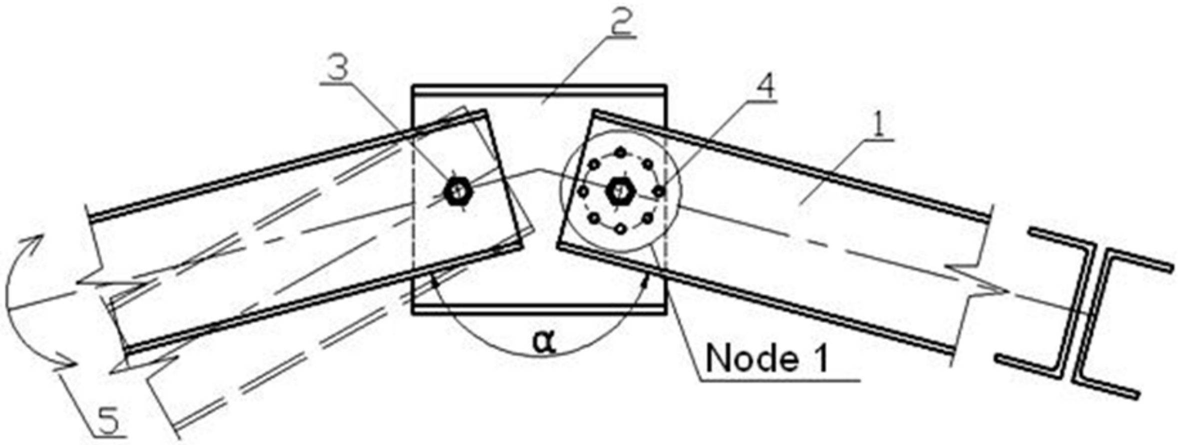

Fig. 1. Typical connection node of unified elements of the arch:
1 — unified element; 2 — gusset plane; 3 — central bolt;
4 — self-drilling and self-cutting screws;
5 — turn of the element during the installation of the required shape of the arch axis

The present paper discusses ways to enhance the efficiency of the above node connection while choosing a viable scheme of positioning self-drilling self-cutting screws and applying construction solutions to improve the bearing capacity of the node.

1. Identifying a rational scheme of positioning self-drilling and self-cutting screws in the connection node of the unified arch elements

In order to identify a rational positioning of self-drilling and self-cutting screws to provide the greatest strength of the connection node of the unified elements, 4 major variants of positioning screws next to the central bolt (Fig. 2) were examined in PC ANSYS.

The choice of a calculation scheme was based on a l-section gusset plate of with the wall 3 mm thick tightly gripped from one side and a fragment of the unified element from paired thin-walled channel bar with the section of 100×50×1.5 mm. On the central bolt and self-drilling and self-cutting screws with the diameter of 6.3 mm one end of the rectangular fragment was rigidly joined to the plate like a console. A vertical load of 2000 kg was applied to the other end of the unified element that caused a bending moment in the connection node which is equivalent to the effort that occurs in the construction proper as this connection is in operation. The axis of the central bolt was 540 mm away from the load application point. All the elements of the calculation schemes were modeled using volumetric finite elements (tetrahedra) with 80000 to 86000 of them depending on the variant of the calculation scheme.

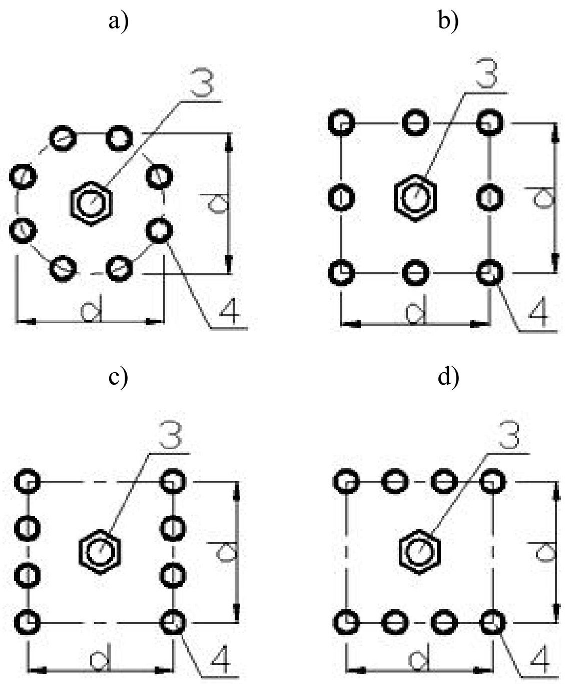

Fig. 2. Variants of positioning self-drilling and self-cutting screws (node 1, Fig. 1):
a) in a circle; b) in a square; c) vertically; d) horizontally;
3 — central bolt; 4 — self-drilling and self-cutting screws

Under other identical conditions only the location scheme of self-drilling and self-cutting screws according to Fig. 2 was subject to change. The criteria that were crucial to the positioning of self-drilling and self-cutting screws and ensuring the greatest strength of the connection node of the unified elements were vertical and horizontal movements of the control point, vertical movement of the other end of the unified element and maximum relative plastic deformations in the hole of the screws (Table 1).

As seen from Table 1, the most rigid of all is the horizontal positioning. The relative plastic deformations in this positioning are minimum which is indicative of the most even distribution of efforts between self-drilling screws compared to the other options. Fig. 3 shows the distribution of relative plastic deformations in the holes of self-drilling screws depending on how they are positioned when the specified load is applied.

Table 1

The comparison of the parameters that describe the strength of the connection node for different schemes of positioning self-drilling screws

Scheme of positioning self-drilling screws	Movement of the control point, mm		Vertical movement of the other end of the unified element, mm	Maximum relative plastic deformation in the holes of self-drilling screws
	vertical	horizontal		
In a circle	0.17419	0.20442	4.7043	0.18407
In a square	0.067611	0.10642	3.1953	0.17252
Vertically	0.063572	0.12686	3.2957	0.31979
Horizontally	0.05663	0.056799	3.0267	0.13545

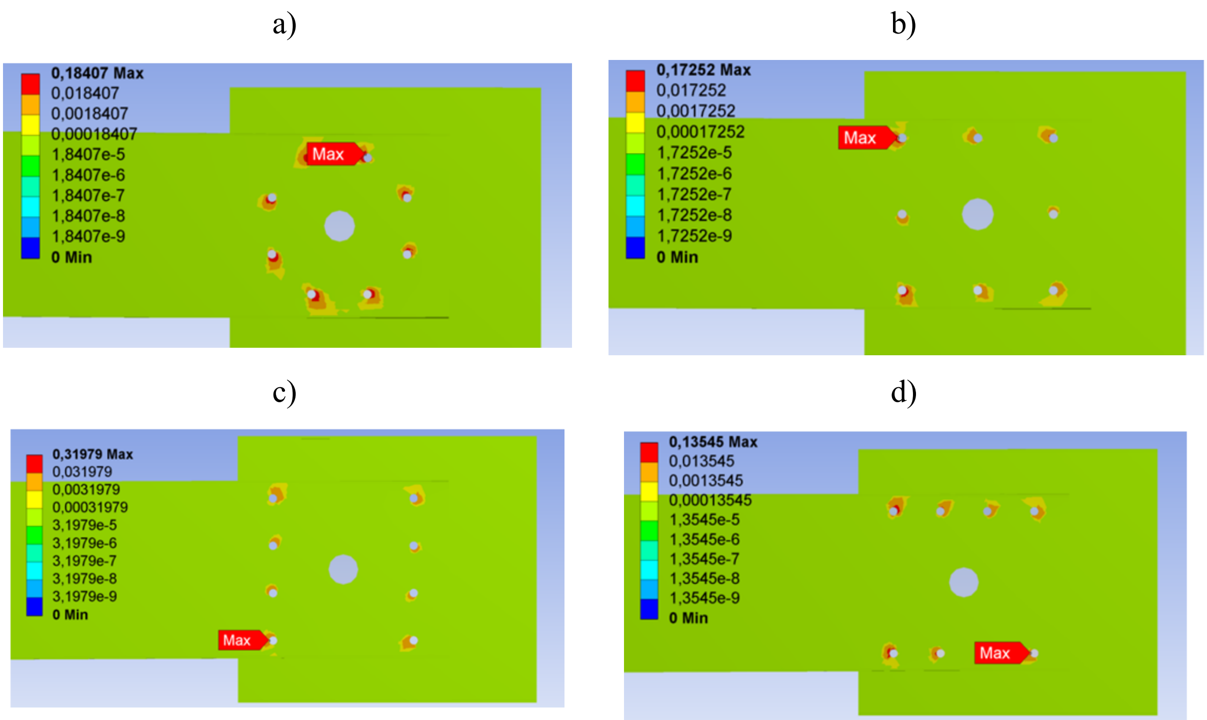

Fig. 3. Distribution of relative plastic deformations in the holes of self-drilling screws when they positioned in a circle (a), in a square (b), vertically (c) and horizontally (d)

2. Experimental research of the node connection of the unified arch elements with the vertical positioning of self-drilling screws

In order to assess the current bearing capacity of the suggested structure of the typical node and positioning of self-drilling screws natural tests of the node connection of the typical node of thin-walled elements were carried out**.** A geometric scheme of the experimental sample is given in Fig. 4.

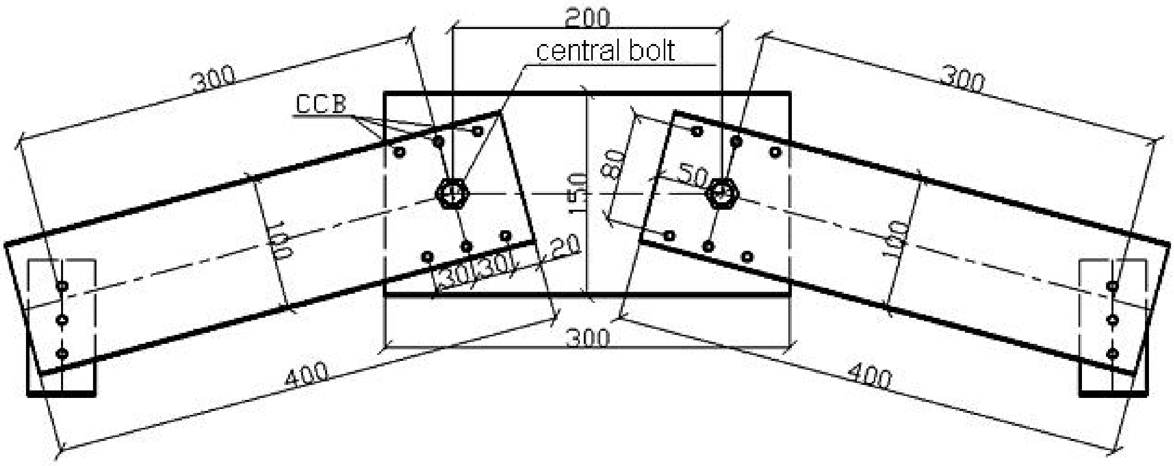

Fig. 4. Geometric scheme of the experimental sample of the typical connection node of the unified arch elements

The experimental sample was tested in a hydraulic press УГ 20/2 (Fig. 5). A number of self-drilling screws in the joint was chosen on the assumption of the even distribution of a bending moment between pairs of self-cutting screws regardless of the effect of the cutting force. Based on the bearing capacity of a self-drilling screw on the condition that it smashes a thin-walled element accepted in [4], the theoretical destructive force for the joint was 1500 kg. During the natural test the failure of the sample occurred at the load of 1930 kg due to the loss of stability of the gusset plate wall that caused the test sample to twist.

The parameter that was central to how the node connection operated under load was chosen to be a change in the revolving angle of the unified element that was tracked by a clock indicator (Fig. 5).

The graph of change in the revolving angle of the element depending on the load applied is in Fig. 6.

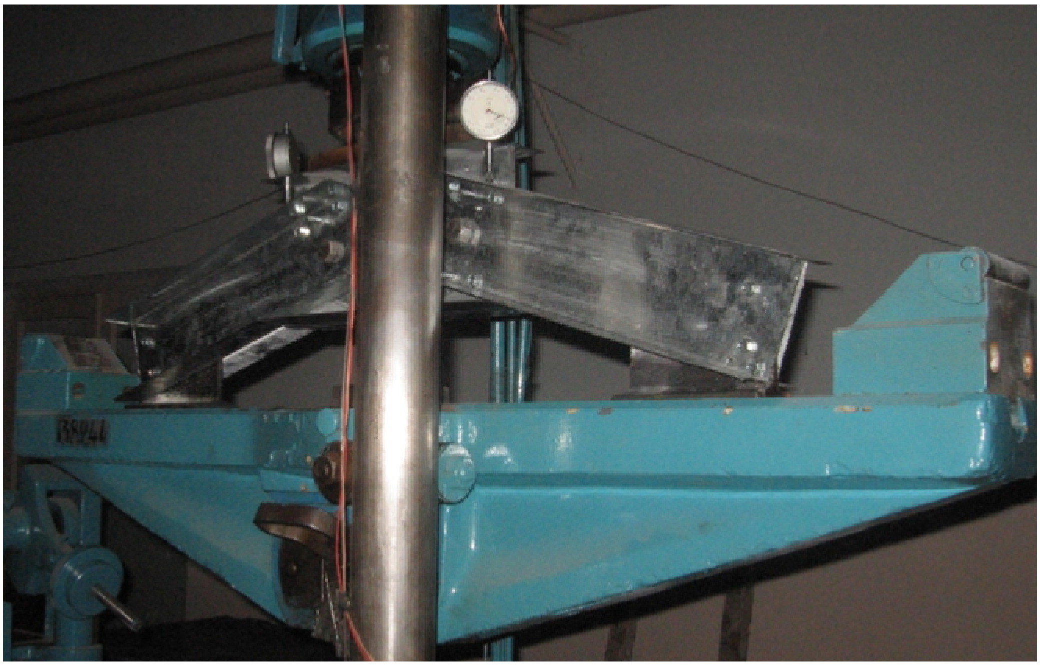

Fig. 5. Testing of the experimental sample
of the joint of the unified elements on a hydraulic press УГ 20/2

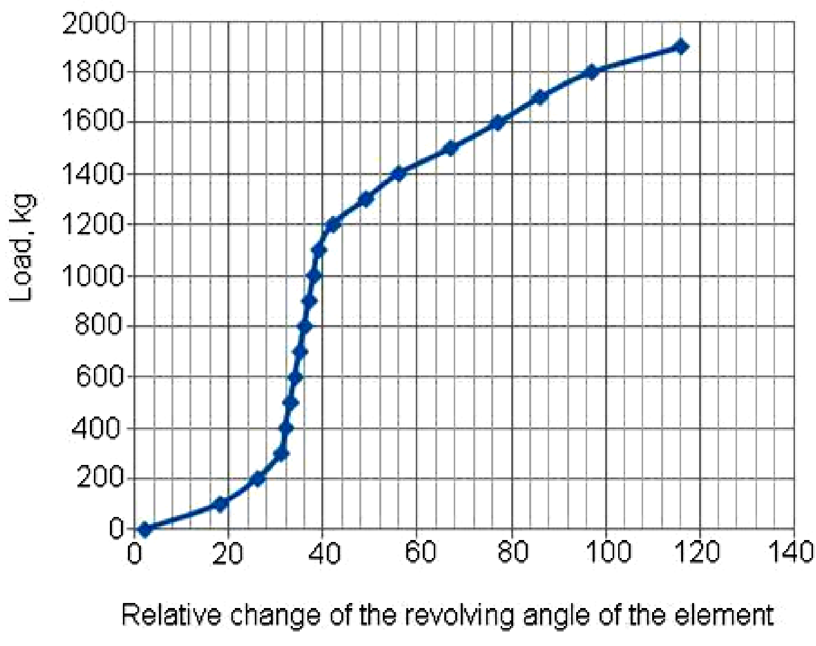

Fig. 6. Graph of change in the revolving angle of the element depending on the load applied

As seen in the graph, significant plastic deformations in the joint emerged at the load of 1200 kg, which is due to theoretical grounds for the calculation of this joint.

3. Developing construction solutions to improve the bearing capacity of the joints of thin-walled elements

Apart from using the rational scheme of the positioning of the self-drilling screws, the bearing capacity of the node connection of similar elements can be improved by employing the construction solutions to increase the thickness of the walls of the unified element in the place of the joint with the gusset plate. Fig. 7 shows one of the ways these construction solutions can be seen through [5].

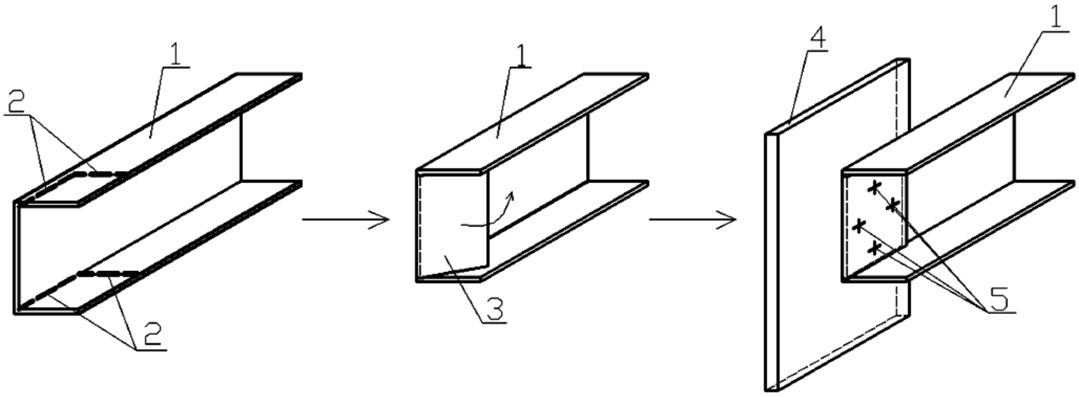

Fig. 7. A way to join open thin-walled elements in the bend type:
1 is a thin walled profile; 2 is a longitudinal and cross cuts; 3 is a bent area of the profile wall;
4 is the plate; 5 is a self-drilling screw

In order to assess the increase in the bearing capacity of the node connection of thin-walled elements using the above construction solutions computations were carried out on PC ANSYS. When vertical and longitudinal loads that caused efforts were applied in turns to the other end of the thin-walled channel bar that were similar to the bearing capacity of the wall of the hole of a self-drilling screw when it was smashed, vertical and horizontal motions of the control point as well as maximum relative plastic deformations of the walls of the holes of the self-drilling screw in the thin-walled element were identified (Table 2).

Also to prove the efficiency of the suggested solution, a series of the compression experiments of the joint of the two elements from sheet steel with the thickness of 2 mm on self-cutting screws with the diameter of 6.3 mm effort-free and bend strengthening. The samples were tested on a cutting machine (Fig. 8) with the destructive load for the effort-free joint being 1350 kg and 2700 kg for the bend strengthening in the assumption of the twice thick smashed metal.

Table 2

Comparison of the parameters that describe the rigidity of the connection node of thin-walled elements in different ways of joining them

Type of joining thin-walled elements	Load applied to the other end of the element	Motion of the control point, mm		Maximum relative plastic deformations in the holes of the self-drilling screws of the element
		vertical	horizontal	
Effort-free	Vertical	0.069952	0.081775	0.018206
	Longitudinal	0.00051862	0.056529	0.01557
Bend strengthening	Vertical	0.016953	0.020144	0.003015
	Longitudinal	0.0041794	0.020166	0.004025

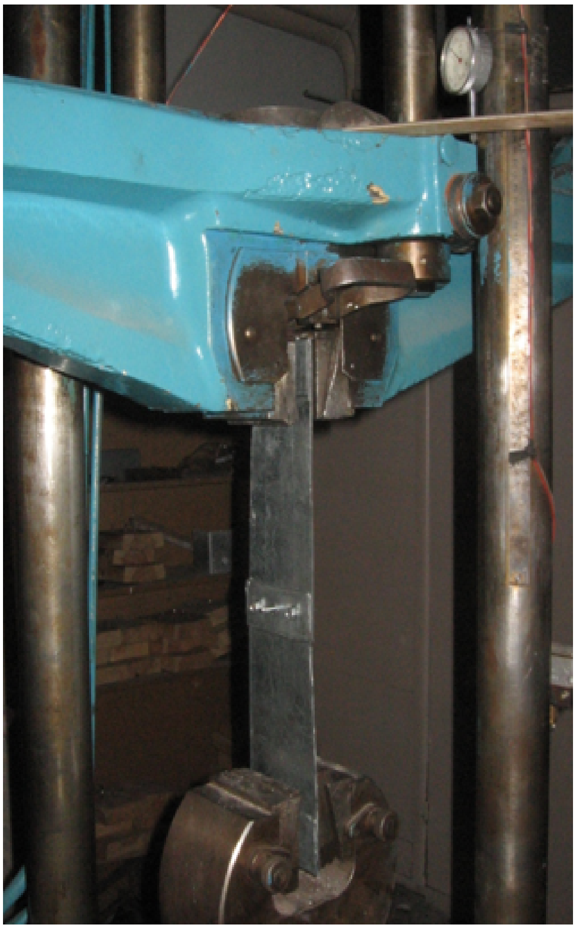

Fig. 8. Testing of the sample of the joint of the sheet metal samples on self-cutting screws during bend strengthening on a cutting machine

During the course of the experiment, the failure of the effort-free joint occurred under the load of 1900 kg due to the smash of the metal by the body of the self-drilling screw and joint strengthened by bending failed under the load of 3600 kg due to the cut of the self-drilling screw.

Conclusions

1. For the suggested construction solution for the connection node of the unified arch elements the optimal positioning of self-cutting self-drilling screws was identified that ensures the greatest strength of the node. The performed experimental research was consistent with the results obtained during the computer modeling and established the potential of the bearing capacity of the connection node of similar elements.
2. The construction solutions to improve the bearing capacity of the joint of thin-walled open section elements were developed and proved efficient numerically and experimentally.
3. The data analysis brought home a feasible and promising application of the above methods of improving the connection node of thin-walled arch elements of a lightweight building.

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