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ECONOMIC AND CONSTRUCTIVE OPTIMIZATION OF THE NODAL CONNECTIONS OF ELEMENTS FROM CLOSED PROFILES

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The deformation and strength characteristics of different variants of the nodal connection of the dome coating structures made of round and rectangular pipes are presented. According to the considered variants of nodal joints, their bearing capacity is analyzed and their material consumption and labor costs for manufacturing are estimated. Numerical studies of the stress-strain state of structures is performed in the "IDEA Statica" program. The design of a reliable and cost-effective connection node using a rolling angle is developed.

Introduction. Application of closed cross-section structures (round or rectangular tubes) reduces the consumption of metals, maintains the fast pace of structures erection, gives advantages during the application of different coatings, and increases illumination [1-5].

With all these advantages, the tubular profile structures are not immune to accidents that can be caused by the destruction of nodes [6].

The object of the research is a mounting node of a dome with a diameter of 36 meters and a height of 8 meters (Fig. 1).

The research purpose is the development of the proposed structural solution of the mounting node connection in a tube dome and the study of its stress-strained state (SSS).

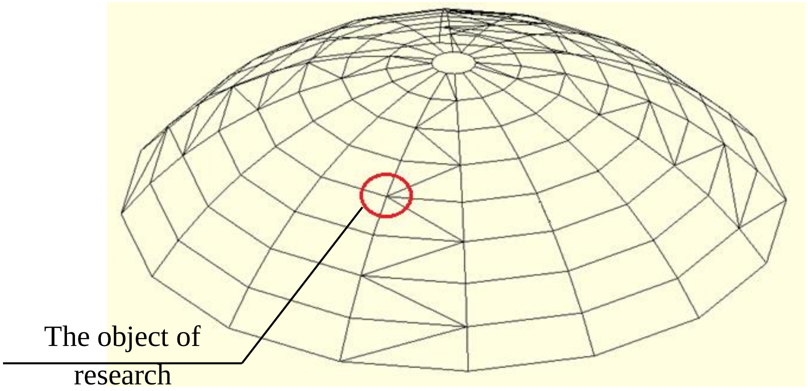

Fig. 1. Construction of the dome

Methods. In order to achieve this purpose, a numerical method was used. A solid-state three-dimensional model of the node was constructed using the IDEA StatiCa 10 software package. This software package is based on the component method, the essence of which is that a node is considered as a set of related elements – components. The calculation model for the node under study, consisting of elastic bonds and rod elements that perceive longitudinal, transverse, bending and torsional deformations, is built according to certain rules.

As a result of the calculation, forces and stresses are found in each component, which can then be used for the necessary tests of the node (for strength, stability, etc.) in accordance with the required design standards.

The design of the node made of round tubes. According to the theory of strength of materials, the round cross-section of a tube is the most advantageous because it provides maximum rigidity with minimum materials.

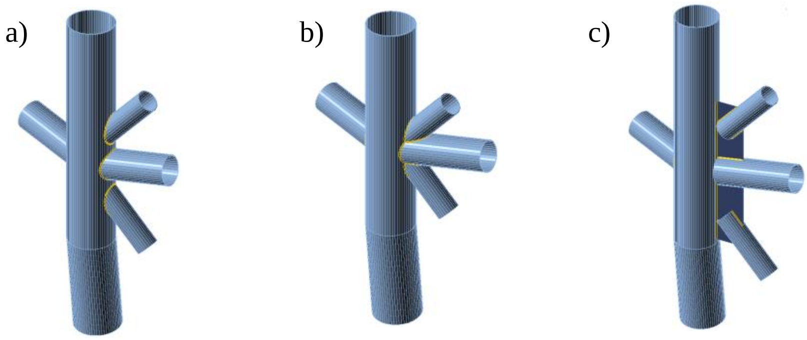

Fig. 2. Design versions of the node made of round tubes

The original design selected for the node comprised round tubes, with girders and bracings welded to the rib of the dome (Fig. 2a). Girders and bracings transmit a significant part of the longitudinal forces to the rib of the dome (in the same structure). It is evident that there is a significant inequality in the distribution of stresses in the place of their mounting to the rib of the dome. The bearing capacity of such a node is 313.8%, that means, the forces arising in the elements after the static calculation of the dome can be increased by 3.14 times before the node collapses.

In order to conveniently compare the reliability and the economic efficiency of the node designs, we will introduce the following coefficients K1 (the ratio of the node's load-bearing capacity to the material consumption) and K2 (the ratio of the node's load-bearing capacity to the labor cost of its manufacture).

The first version of the node has the coefficients K1=1.24 and K2=51.9.

If we bring the bracings closer to the girders, we can increase the load bearing capacity of the node (Fig. 2b). In this case, part of the shear load in the bracings will be transmitted to the girders with a lesser extent involving the rib of the dome in the work. However, the manufacture of such connections is much more complicated because it requires more complicated work with the tubes ends. In addition, there are difficulties with the welding process. The bearing capacity of the second version of the node design is 481.0 %, the coefficients K1=1.96 and K2=65.7 [7].

Additionally, one of the other versions of the node design is to connect the girders and the bracings to the rib of the dome using gusset plate (Fig. 2c). The structural failure happens at the point where the end of the tensile bracings contacts the flange (or at the point where the gusset plate adjoins the rib of the dome) due to sudden change of cross section. The load-bearing capacity of the node is 235.2%, the coefficients K1=0.87 and K2=35.2 [7,8].

The main values of deformation and strength characteristics and material consumptions of the nodes made of round tubes described above are presented in the Table 1 and in the Figs. 3–6.

Table 1

Deformation and strength characteristics of the nodes made of round tubes

Characteristics	Unit of measurement	1 version	2 version	3 version
Maximum stress at the node	MPa	227.60	171.20	248.90
Maximum stress in the rib body	MPa	227.60	171.20	248.90
Maximum stress in the girder body	MPa	89.90	132.70	210.00
Maximum stresses in the bracing body	MPa	102.80	155.50	244.80
Maximum stress in welds	MPa	192.30	122.70	218.40
Bearing capacity	%	313.8	481.0	235.2
Material consumption	kg	252.86	240.22	270.76
Coefficient K1	-	1.24	1.95	0.87
Coefficient K2	-	51.9	65.7	35.2

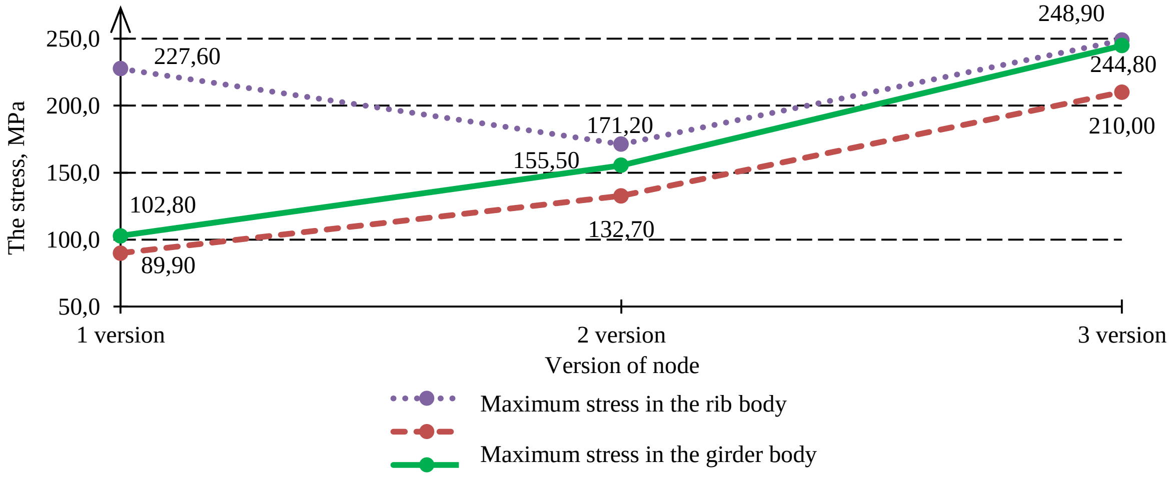

Fig. 3. Max stresses in nodes elements to design version

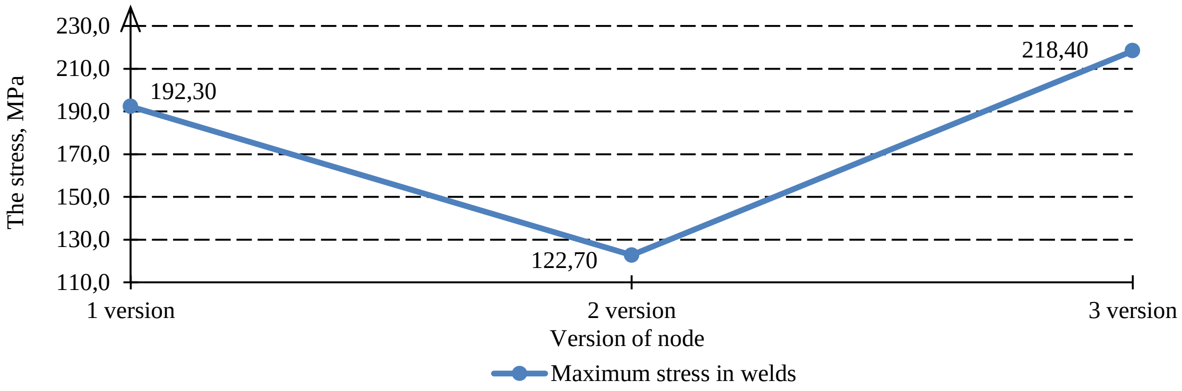

Fig. 4. Max stresses in nodes welds to design version

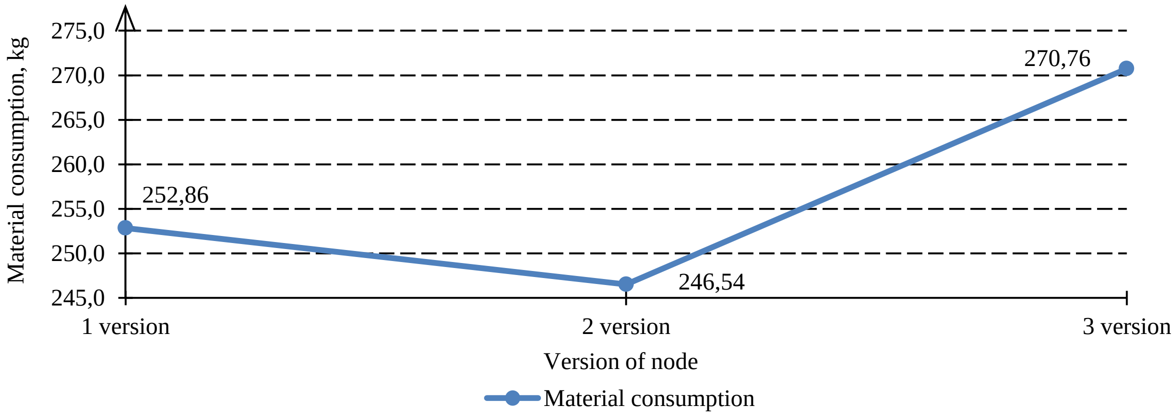

Fig. 5. Load-bearing capacity in nodes to design version

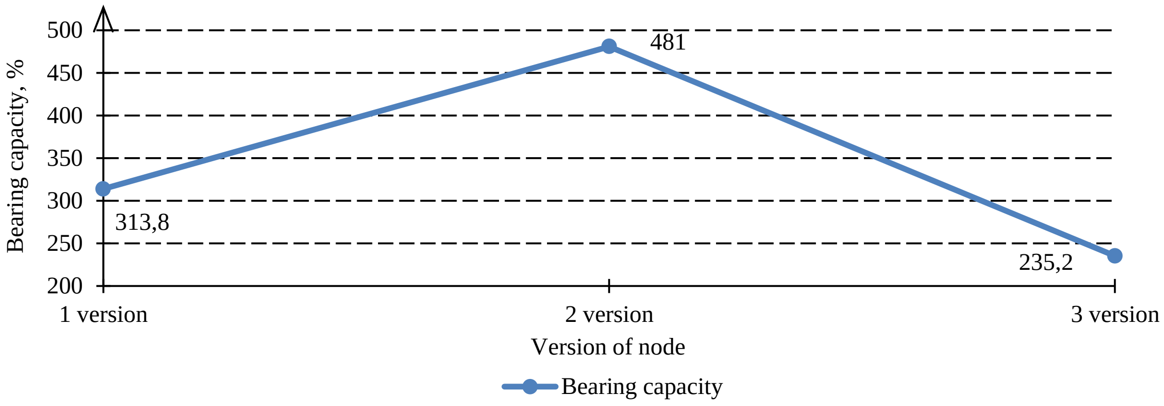

Fig. 6. Material consumption in nodes to design version

The design of the node made of rectangular tubes. The total mass of the dome made of round tubes is 32.98 tons. We can reduce the structure weight by using bent-welded rectangular tubes with a smaller surface area. In this case, total mass of the dome will be 30.49 tons.

The shape of the cross-section of rectangular tubes and its flat face make it possible to obtain very effective structural nodes with low values of design coefficients. The relatively small surface of the tubes significantly reduces the application cost fire-retardant, corrosion preventive and other coatings. Rectangular tubes are easier to fix securely, and due to their compactness, less space is required for their storage [9].

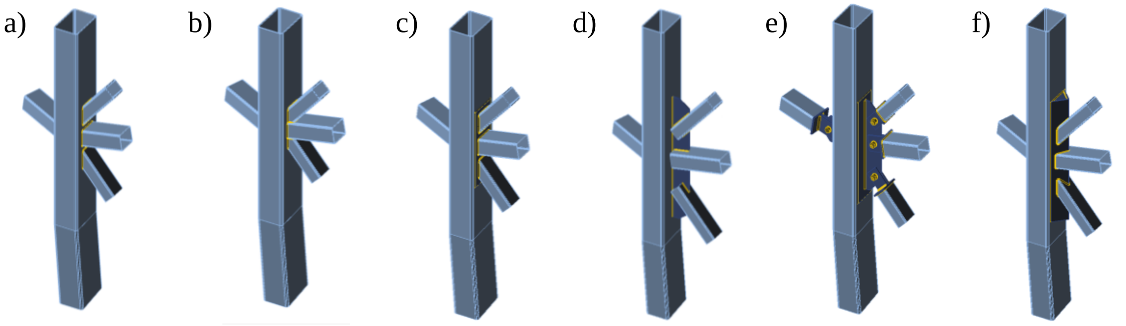

Fig. 7. Design versions of the node made of bent-welded rectangular tubes

When studying the deformation and strength characteristics of nodes made of rectangular tube, we originally chose a node with the bracings and the girders welded directly to the rib of the dome (Fig. 7a). The load-bearing capacity of the node is 105.6%, the coefficients K1=0.42 and K2=19.3 [7].

If we bring the bracings closer to the girders, we can increase the load bearing capacity of the node (Fig. 7b). The bearing capacity of the second version of the node design is 118.8 %, the coefficients K1=0.48 and K2=19.6.

One of the ways to increase the load-bearing capacity of the node made of rectangular tubes is to strengthen the rib with a battening plate (Fig. 7c). The battening plate accepts transverse forces from the bracings and the girders and distributes them along the walls of the rib evenly. This increases the rigidity of the connection. The load-bearing capacity is 182.3 %, the coefficients K1=0.70 and K2=31.7.

If we connect the bracings and the girders to the rib through a gusset plate (Fig. 7d), the bearing capacity of the node will be less than in the previous version and will equal 132.8 %, the coefficients K1=0.51 and K2=22.5 [7,8].

An alternative to the proposed welded connection is a bolted connection (Fig. 7e). The main advantage of this type of connection is the simplicity of installation, which eliminates the time-consuming process of welding and replaces it with the elementary operation of installing bolts. With this design of the connection, destruction will likely occur because of the loss of the bearing capacity of the bolt under the action of the shear force. The bearing capacity of the bolted version of the node is 81.5 %, the coefficients K1=0.46 and K2=17.1.

We proposed a new version of the nodal connection as an effective design solution (Fig. 7f). In this version the girders, the bracings, and the rib are wielded together with the aid of rolled equal-flange angle bar. One of the advantages of the proposed connection is more free access to heel area of the node, which gives possibility to produce high-quality welding with minimal labor. The load-bearing capacity of the designed version of the node is 198.7 %, the coefficients K1=0.71 and K2=28.1.

The main values of the deformation and strength characteristics and material consumption of the nodes made of rectangular tubes are presented in Table 2 and in Figs. 8–11.

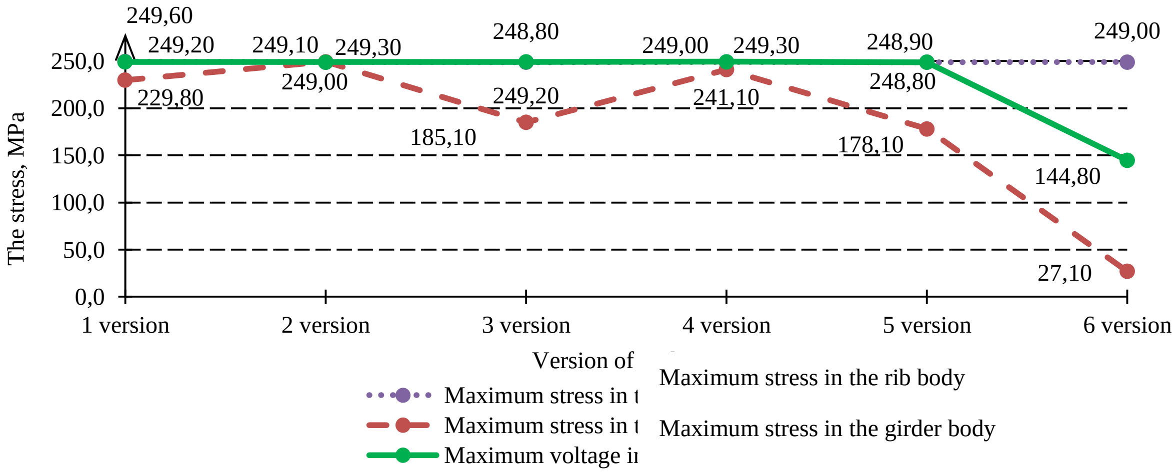

Fig. 8. Max stresses in nodes elements to design version

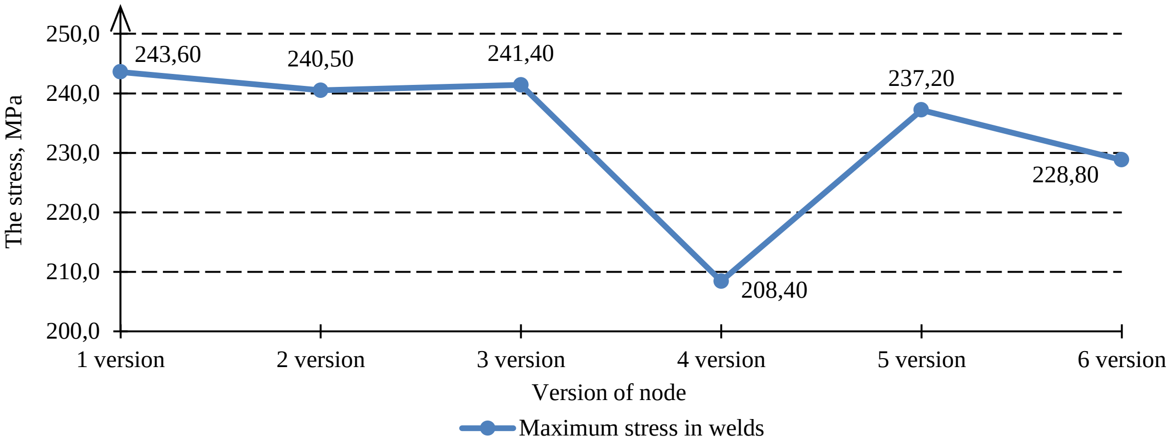

Fig. 9. Max stresses in nodes welds to design version

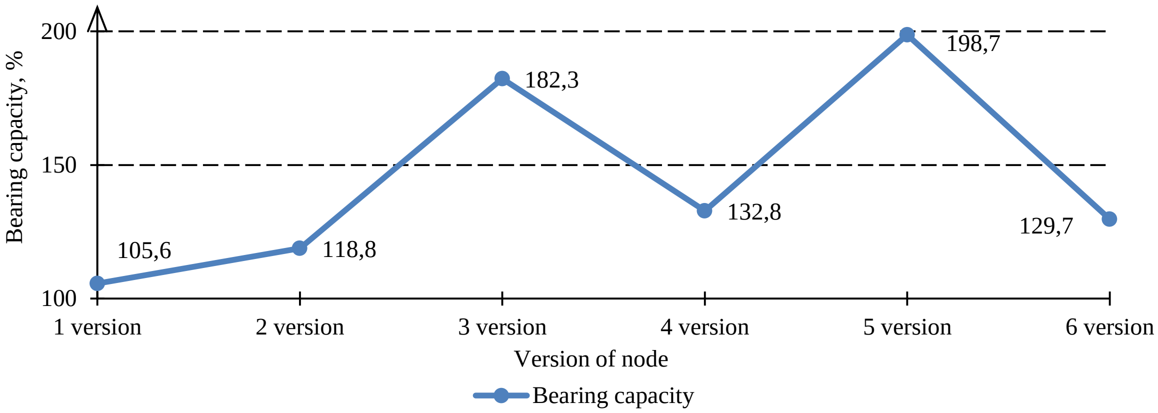

Fig. 10. Load-bearing capacity in nodes to design version

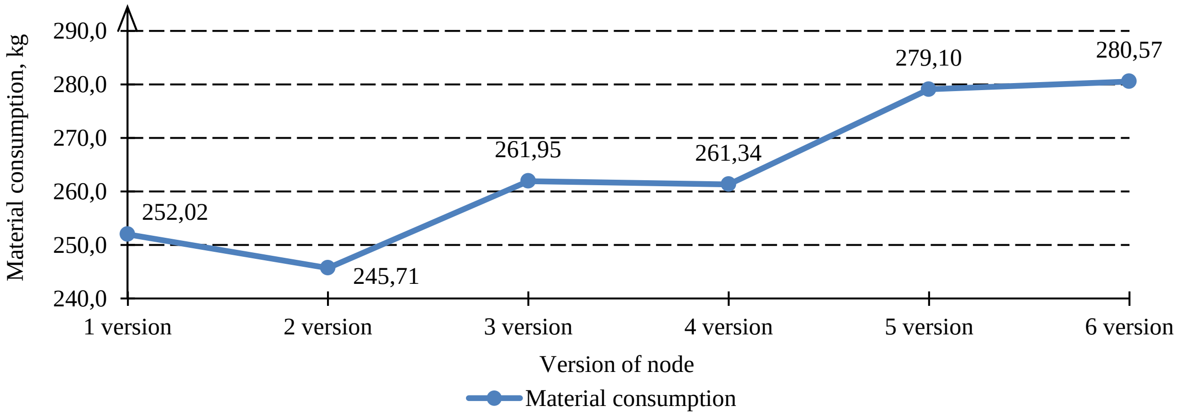

Fig. 11. Material consumption in nodes to design version

Table 2

Deformation and strength characteristics of the test unit made of bent-welded rectangular tubes

Characteristics	Unit of measurement	1 version	2 version	3 version
Maximum stress at the node	MPa	249.60	249.30	249.20
Maximum stress in the rib body	MPa	249.60	249.10	248.80
Maximum stress in the girder body	MPa	229.80	249.30	185.10
Maximum voltage in the bracing body	MPa	249.20	249.00	249.20
Maximum stress in welds	MPa	243.60	240.50	241.40
Bearing capacity	%	105.6	118.8	182.3
Material consumption	kg	252.02	252.02	261.95
Coefficient K1	-	0.42	0.48	0.70
Coefficient K2	-	19.3	19.6	31.7
Characteristics	Unit of measurement	4 version	5 version	6 version
Maximum stress at the node	MPa	249.30	249.00	248.90
Maximum stress in the rib body	MPa	249.00	249.00	248.80
Maximum stress in the girder body	MPa	241.10	27.10	178.10
Maximum voltage in the bracing body	MPa	249.30	144.80	248.90
Maximum stress in welds	MPa	208.40	228.80	237.20
Bearing capacity	%	132.8	129.7	198.7
Material consumption	kg	261.34	280.57	279.10
Coefficient K1	-	0.51	0.46	0.71
Coefficient K2	-	22.5	17.1	28.1

Conclusion. It is obvious that the deformation and strength characteristics of nodal connection depend on its design. In order to facilitate a comparative analysis of the designs and identify the most reliable and cost-effective option, the findings of the research are presented in Tables 1 and 2.

Based on the analysis performed, we can conclude that the use of bent-welded pipe structures reduces the overall weight of the structure and lower material consumption. Moreover, the new design of the node - made of bent-welded tubes with a rectangular cross-section with the aid of rolled equal-flange angle bar – is the most reliable and cost-effective. Therefore, it is necessary to strive not to increase the material capacity of the node, but to improve its design to increase the load-bearing capacity. The design node can find practical application in the structures of domes, trusses and shells.

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ЭКОНОМИЧЕСКАЯ И КОНСТРУКТИВНАЯ ОПТИМИЗАЦИЯ УЗЛОВ СОПРЯЖЕНИЯ ЭЛЕМЕНТОВ ИЗ ЗАМКНУТЫХ ПРОФИЛЕЙ

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Ключевые слова: трубчатый профиль, напряженно-деформированное состояние, несущая способность, элемент купола.

Представлены деформативно-прочностные характеристики различных вариантов узлов соединения конструкций купольного покрытия из труб круглого и прямоугольного сечения. По рассматриваемым вариантам узловых соединений анализируется их несущая способность и оценивается их материалоемкость и трудозатраты на изготовление. Численное моделирование напряженно-деформированного состояния конструкций выполняется в программе “IDEA Statica” Разработана конструкция надежного и экономически-эффективного узла соединения с использованием прокатного уголка.

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