Research of multiple metal rods joining node in spatial construction, using one welding connection

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Abstract. Elements in the nodes of spatial bar structures can be assembled either with bolted connections or with welding. For welded nodal connections, each element should be attached separately. This complicates the process of manufacturing the structure and increases the labour input while assembling this structure. The so-called "tub welding node" does not have such flaws as several bars are joined by a single weld formed during a single pass of the welding machine. The weld of such a node is in a complex stress and strain state. It means that a relatively small weld should constantly take heavy loads. To assess the stress and strain state of the welding node, the researchers conducted numerical studies in the SolidWorks software system. The calculation model of the structural node was based on the results of a particular existing structure examination. These empirical numerical studies revealed that stresses are evenly distributed in the body of the weld, but its surface stresses exceed the stresses inside the weld. There are some areas on the weld surface that exceed the yield strength of steel. Still, the size of these areas is negligible.

1. Introduction
Spatial bar structures are characterized by the existence of complex nodes. These nodes complexity arises from the need to combine many bar elements in a single node. For major spatial structures, the number of joint elements can reach 12 [1-7]. Elements in the nodes of spatial bar structures can be assembled either with bolted connections or with welding. For welded nodal connections, each element should be attached separately. This complicates the process of manufacturing the structure and increases the labour input while assembling this structure. The researchers from the Central Research Institute of Building Constructions named after V.A. Kucherenko developed a structural node which made it possible to join a large number of bar elements in a single weld [1]. This node is now known as a "tub welding node". Welding of multiple elements is carried out simultaneously in one pass of a welding machine. This is a great advantage of this type of welding over previously known methods. Another advantage of a "tub welding node" is that it requires no expenses for such secondary elements of interface nodes as gusset plates, gaskets, joint connectors, and other specially manufactured elements. These secondary elements are used for attaching the bars. In this case, the bars are not attached to each other, but to the secondary elements. These elements are not required if a "tub welding node" is used. In tub welding nodes, the bars are attached to each other without the use of additional connecting parts. The node gets its name from the technology of performing the welding process. It is made by simultaneous welding of all nodal elements in one pass. The node has found industrial application in spatial structures made of circular pipes. Pipe ends are flattened before welding to tightly join the bars ends to each other. During the welding process, a space of about 3 cm
wide is formed between the ends of the pipes. This space is filled with melting metal. This creates a compact node with the weight not exceeding 2-2.5% of the entire structure weight [8]. To give the bars a different direction, e.g. a tilt in the vertical plane, the ends of the bars are cut at the desired angle.

This technology has found its application in a number of implemented projects. Spatial bar structures with tub welding nodes are used, for example, in the roofing of the music and drama theater in Astrakhan, the airport terminal in Brest and the market building in Togliatti which is the object of this research [8].

2. Materials and methods
When examining the technical condition of the market building in Togliatti, the authors found it necessary to analyze the strength of the nodal connections of the market spatial roofing. The roofing of the building is a pyramid with a base of 54x54 m and a height of 27.4 m. The top of the pyramid is located on only one of the diagonals of the base. The top divides the diagonal of the base into segments of 26.4 and 49.7 m. Therefore, only two sides of the pyramid are isosceles triangles (see Figure 1). The faces of the pyramid join at the level of the bottom flanges. The pyramid rests on 20 columnar foundations. To avoid the formation of temperature stresses in the roof elements, the supporting parts of the pyramid on two sides can be shifted in any direction. On the other two sides they can be shifted only in the plane of the face (see Fig. 1). The faces of the pyramid are made of structural slabs. Structural slabs are space-framed constructions. These slabs have two grids of flanges joined by inclined braces. The flanges are made of pipes with a diameter of 114 mm with a wall thickness of 4-12 mm. The inclined braces are made of pipes with a diameter of 83 mm with a wall thickness of 4-6 mm. The faces rest on the edges of the pyramid. The edges of the pyramid are welded metal beams of a closed composite cross-section.

The authors made a calculation model of the pyramid based on the measuring works. The calculation model was made of bar-shaped finite elements. Static calculation of the model was made in "Lira" software package. The calculation was based on the building actual loading. As a result of the calculation, forces were obtained in all elements of the model. The calculated forces were used as an external load when calculating nodal connections.

The study of the strength of the nodal connection was performed for the most loaded node of the calculation model. There were six elements of the flange grid and three elements of the frame girder in the node selected for research (see Figure 2). For numerical studies of nodal connections of spatial structures, researchers use various software systems, for example, Ansys, Nastran, Revit, Bentley,
STAAD, etc [8-12]. The authors chose SolidWorks settlement complex for their research. To study the strength of the node, the researchers made its virtual model. The geometry of the node model was built in the SolidWorks computer program. The geometry of the weld was adopted as an ideal cylindrical shape (see Figure 3, 4). The diameter of the cylinder was taken from the actual measured value registered when examining the structure.

**Figure 2.** Nodal connections: a-actual; b-calculation model.

**Figure 3.** Virtual model of the node.
3. Results and discussion

The node was studied while using the SolidWorks Simulation computer program. Stresses distribution in the calculated model and its strain diagrams were also obtained while using SolidWorks Simulation.

To assess the stress and strain state of the weld, the authors marked areas with maximum stresses in the weld (see Figure 4). Figure 4 shows that there are small areas in the weld with stresses exceeding the yield stress of the material. The yield stress of the material is exceeded in 2.16 times. Areas with excess of the yield stress have a local character. The size of these sections does not exceed 1/523 of the weld pass volume. The described characteristics are based on the ratio of the number of finite elements with extreme stresses (2 pcs) to the total number of finite elements in the weld model (1046 pcs).

![Figure 4. Areas with maximum stresses in the weld.](image)

Figures 5, 6 shows the cross section of the calculation model made of the weld. The figure shows that the stress in the weld exceeds the stress in the bar elements. It also shows that the inner part of the weld and its surface differ considerably on the stress level. Extreme stresses are concentrated on the surface of the weld. Inside the weld, the stress level is less than the yield stress of steel. At an average, the stress state of the weld is evaluated as acceptable. The nature of the stress distribution in the weld indicates the effectiveness of this type of connection. Having a small geometry, the tub welding node can take heavy loads. While the material consumption for the formation of the weld is low, the stresses in it are relatively small. This makes it possible to conclude that the tub welding node is an effective type of connection for spatial bar structures.
4. Conclusions
The results of numerical studies of the node are as follows:
• The "tub welding node" is a reliable joint connection.
• The stresses are evenly distributed in the body of the weld.
• At the same time, the stresses on the weld surface exceed the stresses inside the weld. There are some areas on the weld surface that exceed the yield stress of steel. The size of these sections is negligible and does not exceed 1/523 of the weld pass volume.
• The "tub welding node" is an effective joint connection for spatial bar structures, as this welding node can take heavy loads at low material consumption.

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