Numerical Studies of the Nodal Connections of Metal Spatial Frames

V Alpatov

The Department of Construction Production Technology and Management, FSBEI of Higher Education "SamGTU" (ACEI), Samara region Molodogvardeyskaya Str. 194, Samara 443001, Russia

E-mail: avu75@mail.ru

Abstract. For structural structures, there is a problem of high labor intensity of manufacturing nodal connections. In the nodes of structural structures can be paired about eighteen rods. The joints of structures are usually divided into two types. The known structures with the nodes of the leaves, with knots of massive details, with the nodes on the bolts with knots on the welding and stuff. Structures perceive external loads with all their elements, so each node connection is in a complex stress state. The design of the nodal connection determines the reliability and efficiency of the structural design. The reliability of the node spatial structures can be analyzed at design time by using advanced computational systems.

Techniques for optimal design of massive nodes and for nodes of the subtle elements are very different. The search for the optimal solution of the structural design unit can be organized in the form of an iterative process. Typically, nodes that are made from a massive part are very rigid. Internal stresses are distributed in the shortest directions from the load application areas to the support. Therefore, you can find little loaded areas in massive nodes. The material in these areas can be removed. Get a more efficient design of the node. Nodes made of thin sheet elements have a large deformability. The rigidity of the node has to be provided using special techniques. The internal stresses are locally concentrated. Therefore, it is necessary to look for solutions for local tightening and hardening of the node, for example, by installing ribs or local thickening of sheet metal parts. Improvement of the design of the unit can be achieved by adding material to its weaknesses. It is established that the results of calculations performed using different calculation complexes have acceptable accuracy of calculations. The error between the stress calculations performed in different calculation complexes does not exceed 10%.

1. Introduction

Spatial lattice structures are often used as coverings of buildings. They are more stiff than trusses. They can be used to cover buildings with large spans.

For structural structures, there is a problem of high labor intensity of manufacturing nodal connections [1-7]. In the nodes of structural structures can be paired about eighteen rods [2, 5, 16-22].

The joints of structures are usually divided into two types. The known structures with the nodes of the leaves, with knots of massive details, with the nodes on the bolts with knots on the welding and stuff [1, 2, 16-25].
Structures perceive external loads with all their elements, so each node connection is in a complex stress state. The design of the nodal connection determines the reliability and efficiency of the structural design. The reliability of the node spatial structures can be analyzed at design time by using advanced computational systems. Such software as ANSYS, ABACUS, Autodesk Robot, SAP2000, STAAD, NASTRAN, Cosmos Works, LIRA, SCAD, etc. позволяют выполнить анализ напряженно-деформированного состояния узлового соединения структурной конструкции [25-27].

2. Materials and methods
Among the nodes of the structures we can distinguish two very different from each other are nodes that are executed based on the massive details (Mero, etc.) and nodes that are executed on the basis of thin metal sheets (Unistrat etc.) [2, 3, 5]. Studies [27-30] show that the stress-strain States of the two types of nodes are very different from each other. For massive nodes are characterized by low deformation and the presence of areas with a relatively low level of stress. For nodes on the sheet metal parts are characterized by low stiffness and the presence of areas with a high level of stress.

The rational design of structural units depends on the type of nodal connection. Techniques for optimal design of massive nodes and for nodes of the subtle elements are very different. The search for the optimal solution of the structural design unit can be organized in the form of an iterative process. At each step of design the geometrical parameters of the node are changed and the analysis of its stress-strain state is carried out by means of modern calculation complexes. Studies show that such an iterative process for different types of nodes is convenient to organize in different ways.

Typically, nodes that are made from a massive part are very rigid. Internal stresses are distributed in the shortest directions from the load application areas to the support. Therefore, you can find little loaded areas in massive nodes. The material in these areas can be removed. Get a more efficient design of the node. In the limit, the construction of such a node tends to degeneration. As a result of the solution of such optimization problem it turns out that the elements of the lattice structure should be attached to each other directly, that is, without the use of nodal parts. An example of such a solution is the node performed on the bath welding (Figure 1). In the specified node, the elements are connected to each other through only one weld.

![Figure 1. Elements welded together by a bath.](image1)

![Figure 2. A node is made on the leaf elements.](image2)

Nodes made of thin sheet elements have a large deformability. The rigidity of the node has to be provided using special techniques. The internal stresses are locally concentrated. Therefore, it is necessary to look for solutions for local tightening and hardening of the node, for example, by installing ribs or local thickening of sheet metal parts. In such nodes originally laid the principle of concentration of the material. Excess material in their design is virtually absent. To obtain a more effective design of the unit by extracting the material will not work. Improvement of the design of the unit can be achieved by adding material to its weaknesses.
The author has carried out studies of the stress States of these types of nodes. The objects of research were selected node “Markhi” (Figure 3), the node on the bath welding (Figure 1) and the author's development of the node made of sheet metal (Figure 2).

Figure 3. “Markhi” spatial design structure.

The purpose of research is to find ways to improve the design of the nodal connection by changing its geometric parameters. To achieve this goal, the following tasks were set and solved:
- Selection of tools for the analysis of stress-strain state of nodes;
- Construction of reliable geometric models of objects of research, allowing to take into account all their design features;
- Creation of computational models of objects of research with the most reliable description;
- Establishment of the actual stress-strain state of the nodes.

3. Results
As tools for research, the calculation complexes of LIRA, CosmosWorks, DesignSpace, SCAD were chosen. All of them work on the basis of the finite element method and are able to perform the analysis of the stress-strain state of solids. The choice of several computational complexes was justified by the desire to limit the influence of the individual complex features on the final result. The calculations performed in different programs allow to get rid of possible program errors of the complexes. The calculations performed in different programs allow to reduce the influence of features of the software implementation of the calculation systems on the final result of the calculation. Here we have in view of the differences in software systems used algorithms:
- математического описания конечных элементов;
- create finite element mesh;
- mathematical description of the boundary conditions and methods of contact details;
- mathematical description of loads;
- etc.

For the calculated complexes CosmosWorks DesignSpace and geometric models of the objects of study were constructed in the software package SolidWorks. For the LIRA and SCAD calculation complexes, geometric models of the objects of study were constructed by means of the calculation complexes themselves.

For the most reliable description of the models, individual features of the interface of each calculation complex were used. Models built by different complexes had some differences. Common to built computational models were:
- General geometry. The only exceptions were those parts of the geometry that could not be described by the chosen calculation complex. For example, some small details such as rounded edges and other;
- Physical and mechanical properties of materials of parts;
- The nature of the application of loads and their values;
- The nature of the external fixations of models;
- The nature of the methods of contact details of which the model consists.

In a massive body with internal voids formed by the intersection of bolt holes, the stresses are concentrated in the places of application of forces, and then by the shortest distances are transmitted to the support. The schematic representation of the described situation graphically resembles the crystal structure.

The surface areas of the solid part, located at the distance of the contact boundaries of the elements, are relatively under load.

Figure 4. The iteration process of changing the geometry of a node made of a massive part.

Figure 5. The iteration process of changing the geometry of a node made of thin sheets.

In these places, the material can be completely removed. If you do this, then the outer node, which is a polyhedron to turn first into a ball (Figure 4). If you continue to remove the material from the lightly loaded parts of the part, the ball will turn into a more complex shape (Figure 4). This complex figure of its geometric shape is similar to the structure of the crystal lattice.

In the process of iterative changes in the geometry of the node, made on the basis of a massive part, observed the degeneration of a massive body into an element similar to the crystal. By removing the "excess" material after each iteration, a lightweight node was obtained, increasingly moving away from the concept of a massive body.

For the node, made on sheet styles, was implemented iterative process to add material. As a result of the implementation of this algorithm, the node changed, moving to a more rigid structure by adding edges and local thickenings (Figure 5).

The model of the unit on the bath welding showed that it is impossible to add or remove material from the unit (Figure 6). The geometric shape of this node was optimal.
4. Conclusions:
On the basis of the research the following conclusions are made:

1. The calculation models of objects in four different analysis systems were constructed of the distribution pattern of stresses and shape deformation. Found much and malonarushennye surfaces of the parts.

2. It is established that the results of calculations performed using different calculation complexes have acceptable accuracy of calculations. The error between the stress calculations performed in different calculation complexes does not exceed 10%.

3. The iterative process algorithm for finding the optimal geometry of a node is convenient to organize: for a massive part-by removing excess material; for nodes from thin sheets-by adding material.

4. In a node made on the basis of a massive part, there are areas with low stresses. If you remove low-loaded areas, the geometry of the node will take the form similar to the crystal.

5. In the node, made on sheet shapes, there is a large deformability, and the stresses are locally concentrated. If you add material to the node in the form of edges and local thickenings, the node will acquire a more rigid structure. The final shape of the node in a simplified graphical representation will be similar to the shape of the crystal.

6. In the node, made on the bath welding, the harmonious distribution of stresses between the elements. The geometric shape of such a node is similar to the shape of a crystal.

5. References
[1] Kholopov I et al 2012 The use of a spatial lattice of metallic structures in coatings machinery Vestnik VolgGASU 22 (Volgograd: VolgGASU) pp 225-232
[2] Trofimov V 1972 Structural structures. Research, calculation and design (Moscow: Stroyizdat) p 155
[3] Faybischenko V 1990 Metal cross-pivot spatial structures of coatings (Moscow: VNIINTPI)
[4] Perelmuter A and Yurchenko V 2012 Construction mechanics and design of structures 6 pp 18-25

[5] Hisamov R 1979 Determination of technical and economic indicators of structural coatings (Kazan: Kazan Civil Engineering Institute) p 80

[6] Kljachin A 1995 Spatial bar-shaped metal structures of regular structure (Ekaterinburg: Diamond) p 276

[7] Trushchev A 1983 Spatial metal structures (Moscow: Stroyizdat) p 215

[8] Begun G 1984 Recommendations for the design of structural structures (Moscow: Stroyizdat) p 298

[9] Alpatov V 2014 Procédia Engineering vol 91 pp 177-182

[10] Mushchanov A Romensky I 2013 The collection of reports of the Fifth International Scientific and Practical Conference (Moscow: MGSU) pp 111-115

[11] Gaylord Edwin et al 1997 Spatial metal structures (New York: The McGraw Hill Companies) p 1024

[12] Gorokhov E et al 2008 Constructions of stationary coatings over stands of stadiums (Makeyevka: DonNACEA) p 405

[13] Gorokhov E et al 2012 Calculation and design of spatial metal structures (Makeyevka: DonNACEA) p 561

[14] Schumacher M et al 2010 Architecture in Motion (Basel: Birkhauser Verlag AG) p 248

[15] Hutchinson R et al 2003 International Journal of Solids and Structures 40 pp 6969-6980

[16] John D Renton 2002 Regular Structures. Elastic Beams and Frames pp 15.1 -15.36

[17] Robert A Heller 2003 Mechanics of Structures. Encyclopedia of Physical Science and Technology pp 259-278

[18] Vasilchenko V 1990 Directory of the designer of metal structures p 312

[19] Dykhovichny Yu 1987 Large-span structures of the Olympiad-80 buildings in Moscow (Moscow: Stroyizdat) p 277

[20] Beranek W 2000 Krachtswerking deel 3: Varkwerken, standzekerheid (Delft: TU Delft) p 92

[21] Agafonkin V 2011 Proceedings of KazGASU 2 pp 76-80

[22] Birkilev V et al 1990 Design of metal structures (Moscow: Stroyizdat) p 432

[23] Mushchanov A et al 2016 Construction of unique buildings and structures 2 pp 18-29

[24] Alpatov V and Sakharov A 2018 IOP Conf. Ser.: Mater. Sci. Eng. 365 p 062022

[25] Alpatov V et al 2016 MATEC Web Conf. 86 p 02015

[26] Alpatov V 2016 MATEC Web Conf. 86 p 02020

[27] Alpatov V et al 2016 Urban planning and architecture 4 pp 14-22

[28] Alpatov V 2016 MATEC Web Conf. 86 p 02005

[29] Buzalo N et al 2014 Internet-journal NAUKOVENIE 2 pp 1-13

[30] Kljachin A 1991 Construction and architecture 7 pp 14-18