

Accounting for the flexibility of nodes in the design of steel mesh dome

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Abstract. This paper presents the results of a study of the stress-strain state of a geodesic dome covering the planetarium designed in the city of Nizhny Novgorod. Four design schemes were created in the SCAD with different types of node modeling. A comparative analysis of the effect of the strain capacity of the “BrGTU” type unit on the stress-strain state of the dome cover has been carried out. The results are obtained on the change in the displacements of the structure nodes and internal forces in the dome bars, with rigid and hinged mates. The option of increasing the diameter of high-strength bolts to reduce the overall deformability of the system is considered. On the basis of the obtained results, it was concluded that it is necessary to take into account the strain capacity of the semirigid connections when designing mesh steel domes.

1 Introduction

Geodesic domes have received great development in the second half of the twentieth century. They are still one of the best solutions for curved deck of various types of buildings and structures [1, 38, 39]. Currently, there is a considerable amount of research devoted to solving problems of optimization of metal structures [2 - 6], but there are relatively few works devoted to optimal design, taking into account the actual work of the nodes of the joints. This is since in the current Russian codes and standards the issue of knot deformability is not considered, the connection is usually perceived as either a hinge or a rigid fixing. Such an understanding of the actual behavior of the node leads to errors in the calculation [4]. Therefore, at all stages of design, it is necessary to take into account the factor of nodal compliance, its value may change the redistribution of forces in the structural elements [7, 8].

A considerable number of researchers worked on the study of the actual behavior of the nodal joints of metal structures [9–37, 39]. There are studies devoted to the study of the influence of nodal compliance in structural structures of the covering [23–28, 30–34, 36, 37]. O.I. Efimov deliberately used strain capacity, which allowed him to achieve a decrease in metal consumption almost by 30% [23, 24]. Dragan V.I. and A. Shurin experimentally confirmed the accuracy of accounting for compliance in the calculation for the design of the combined covering, which consists of a structural slab and steel arches of FEM [25–28]. The

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study of the work of the elements of spatial frame systems was conducted by N.N. Trekin. In this study, the nonlinearity and the possible flexibility of the nodes were considered [29]. Simulation of structural structures using computer-aided design (CAD) considered in [30–35]. In [30] compliance is modeled in CAD in three different ways, one of which is the method of O. Yu. Deriglazova and I.S. Injutova [31]. In [32–34], Tur V.I. and Tur A.V. to test the correctness of the model of a newly developed structural node in the Nastran software package experimented with a connector in a test console. In these studies, effective design solutions for coverings were described, but there was paid not enough attention to the description of methods for constructing calculation models [35].

The purpose of this work is to take into account the impact of considering the compliance of the nodal connections in the structural design to the stress-strain state of the geodesic dome of the planetarium covering using SCAD.

We define the main tasks:

- To create a finite element model of a geodesic dome cover in SCAD;
- To analyze the stress-strain state of the elements of the main supporting structures of the covering;
- To compare the solutions of the structural design, taking into account the compliance and the classical studied covering model. To take into account the impact of nodular compliance factor on the dome SSS.

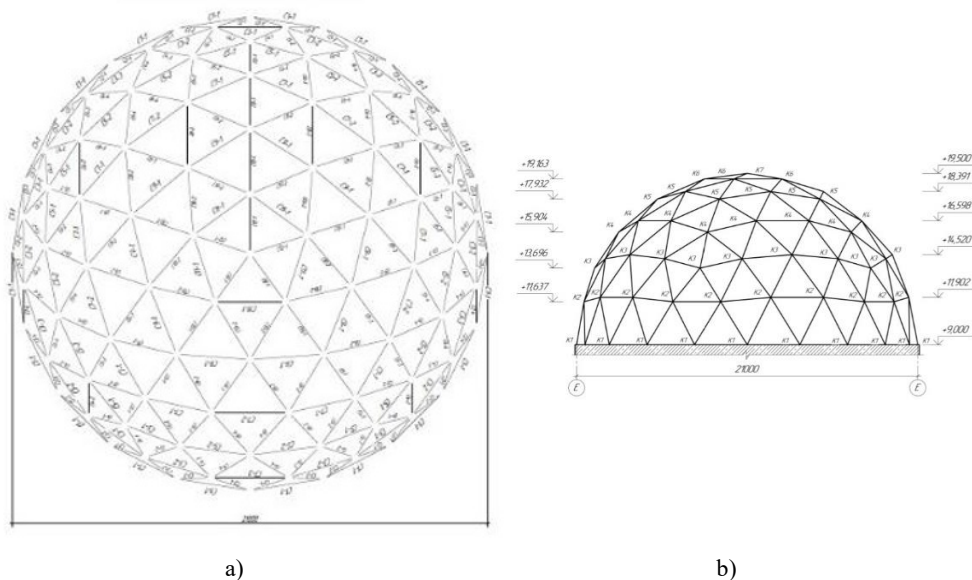


Fig. 1. a) plan the location of the structural elements of the covering; b) front view.

2 Experimental investigation

The object of the study is the covering of planetarium, designed for the Nizhny Novgorod region. The covering is a mesh geodesic dome which is - a hemispherical architectural structure, assembled from rods forming geodesic structure. The shape of the dome is formed by a connection of rods: rods of different lengths converge at each node, which generally form polyhedron close in shape to a segment hemisphere. The location of all elements of the dome are shown in Figures 1. Thrust perceived lower support ring, which relies on reinforced concrete columns. The roof of the dome consists of pneumatic

membrane-cushions of three layers of ETFE film, enclosed in aluminum profiles and supported by the load carrying structure of the dome. The spatial FE model in the SCAD software package was adopted as a model of covering.

Construction materials:

- rods - hot-deformed steel pipes of various diameters.
- steel spheres with a diameter of 140 mm with wall thicknesses of 19, 22 and 26 mm from steel C345 and high-strength bolts of various diameters from steel 40X.
- the dome attachment points with a supporting reinforced concrete ring are made on "BrGTU" connectors with a support plate, which is fixed with anchor bolts to the reinforced concrete ring.

Types of finite elements: belt elements - type 5 of the FE, lace - type 5. The rods are fastened together by a hinge (turning relative to UY). In places where the dome is installed on the support ring, there are connections along the X, Y, Z directions. The finite element model is presented in Figure 2.

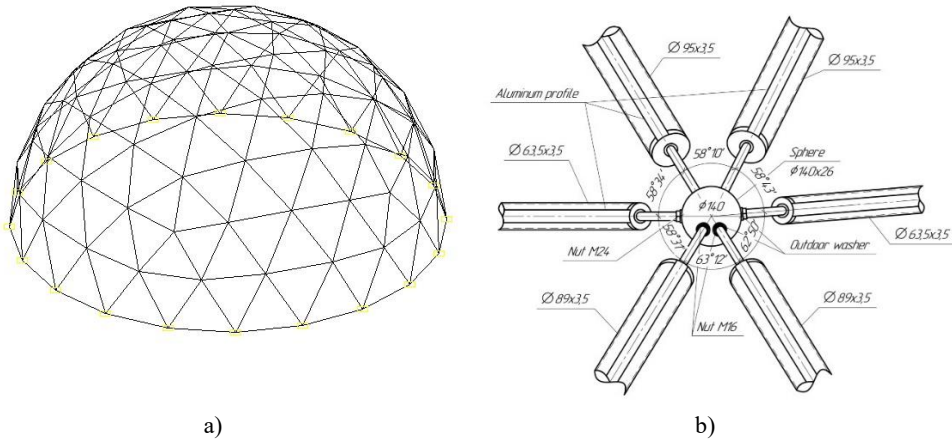


Fig. 2. a) the FE model of star-room coverage in SCAD; b) "BrGTU" type node.

The strain capacity of the "BrGTU" type units will be provided in several ways, several variants of the structural design have been developed for this. To bring the scheme closer to the actual construction, rigid inserts were introduced at the ends of the pipe-rods - they have both geometric and physical characteristics of high-strength bolts of corresponding diameters. The fastening of the bolts was specified in two ways, the first is the hinge fastening at the central nodal point, the second is rigid fastening at the central nodal point, this is due to the enough thickness of the sphere in which high-strength bolts are installed in the actual knot.

Design options:

- The hinge scheme (with hinges at the ends of the rods);
- The scheme with rigid inserts that have the characteristics of high-strength bolts with hinges at the ends;
- The scheme with rigid inserts that have the characteristics of high-strength bolts that are rigidly mated in the central node;
- The scheme with rigid inserts that have the characteristics of high-strength bolts with increased diameter, which are rigidly fixed in the central node.

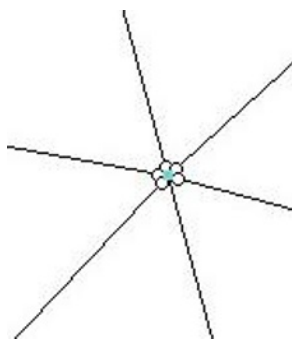


Fig. 3. Type 1

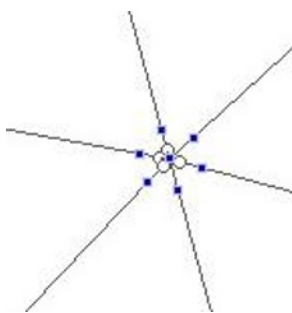


Fig. 4. Type 2 and 4

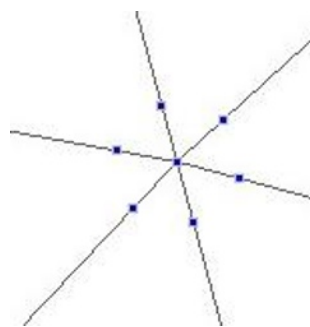


Fig. 5. Type 3

The covering weight is given to the elements of the upper belt of the dome. The loads acting on the elements are set considering the cargo area. The static analysis of the geodesic dome is made using the finite element method (FEM) using the SCAD Office. Together with the own weight of the dome and roof, snow and wind loads were applied. According to the results of the static analysis in the software package SCAD Office obtained values of the given stresses and deviations of the system in the form of displacements.

Modeling strain capacity of nodes should increase deformability of the mesh dome. The results of the displacements obtained will be closer to the real ones than in the simplified scheme; this must be taken into account when choosing the design of the covering.

3 Results and Discussion

Stress-strain states of several types of structural design were found. The results of changes in vertical and total deformations are presented in the images below:

The simulation took into account the interfacing of structural elements with each other using high-strength bolts. However, in SCAD PC there is no possibility to define an actual construction, which includes a thick-walled sphere, which is the middle of the connector and has its own strain capacity.

The vertical displacements increased by 15.4%, the total by 15.63 % relative to the initial scheme. At the same time, the internal forces did not change significantly, and decreased in relation to the initial scheme with hinged fastening of the rods. We can use the old method to determine the internal forces, it will give a small strength reserve. However, it is necessary to take into account the deformations that were obtained with other schemes in which the resulting displacements increased. The maximum displacements are obtained in the type 2 scheme. With an increase in the diameter of the bolts, the displacements of the nodes decreased. This is due to their high rigidity and can be applied with increased deformability of the dome, so as not to change the cross section of the lace rods. In the works of Tour V.I., Tour A.V. [30] used other models for specifying the nodes, but the results have a similar character.

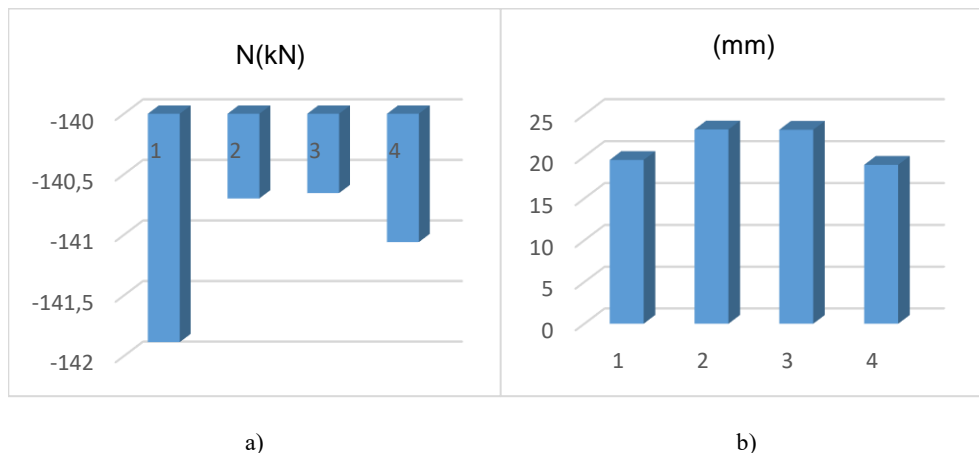


Fig. 6. Obtained histograms: a) internal forces; b) total displacement nodes in the corresponding schemes.

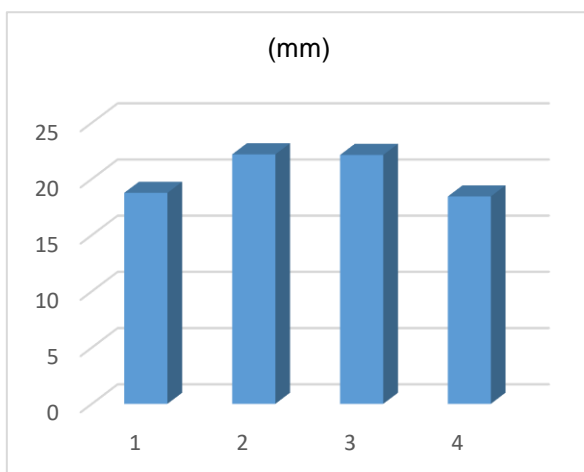


Fig. 7. The histogram of the obtained vertical displacements of the nodes in the corresponding schemes.

4 Conclusions

The results obtained in this paper allow us to draw the following conclusions:

1. The analysis of the stress-strain state of the dome models of the covering for loads and impacts with different types of modeling nodes was made. Numerical changes of displacements and internal forces in rods are determined;
2. After analyzing the data obtained, it can be concluded that the insertion of elements modeling the semirigid connection increase the overall deformability of the dome, which should be taken into account when designing.
3. With an increase in the diameter of high-strength bolts in the units of the "BrGTU" type, the deformability of the entire dome decreases.

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