Development of nodal solutions for fixing cable ties in spatial rod structures

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Abstract. The article presents the results of analysis of the stress-strain state of the developed new nodal solutions for fixing cable ties in collapsible spatially strained structures, since the existing nodal solutions are not intended for connecting cable ties. During operation under extreme conditions for the structure (sudden gusts of wind, dynamic effects), it is necessary to ensure the reliability of the nodal connections of the cable ties with the struts. It is also important to maintain the speed of building structures. The mentioned ideas influence on additional moments that worsen the work of the temporary structures node. Stress-strain state analysis of the original and newly developed node was performed on the basis of both computer modeling and natural experiment, the results were compared. In the course of the conducted research, the most stressed zones in the created nodes were identified, as well as the reasons for the destruction of newly created nodes.

Keywords: construction, node, cable ties, numerical and experimental studies, structures, buildings.

1 Introduction

When conducting major public events (sports, entertainment, etc.), during reconstruction of buildings and structures, construction of temporary buildings, bridges, pillars, etc. the most important problem in organizing temporary structures is the choice of the load-bearing system [1-4]. For this purpose, mobile spatial rod structures should be used. This is due to the speed of installation and disassembly, the possibility of repeated use, the creation of complex spatial forms and a large load-bearing capacity [5-8].

The most widely used systems are modular scaffolding. The peculiarity of these systems is that we can create completely different types of structures and use them as scaffolding, stands, stages, podiums, platforms [9-12].

The versatility of the rod elements and special parts ensures quick installation and disassembly, as well as the ability to install on uneven, difficult areas. The structures are easily and quickly adapted to the terrain, which is a special advantage [13-17].

During operation under extreme conditions for the structure (sudden gusts of wind, dynamic effects), it is necessary to ensure the reliability of the nodal connections of the cable ties with the struts. It is also important to maintain the speed of building structures. To do this, we analyzed the stress-strain state of the node of the most commonly used system of modular assembly of scaffolding, Layher Allround [18-20].
2 Materials and methods

2.1 Object of research

The main drawback of Layher systems is the eccentricities at the connection nodes of the vertical struts with the post and the presence of a gap in the nodes that reduces the rigidity of the structure. One way to increase rigidity is to install prestressed cable ties.

It is important to develop a method for attaching prestressed cable ties that exclude the appearance of a gap, instead of vertical struts.

The scheme of fixing pre-tensioned cable ties will be analyzed on the basis of the existing structure erected during the FINA aquatics competition in 2015 in the city of Kazan.

The structure consists of a wall that divided the Kazan Arena into 2 zones. This wall consists of a Layher system inside and is covered with competition banners on the outside. In order to improve the stiffness in the design scheme, the diagonal struts were replaced with prestressed ropes (figures 1-2).

![Figure 1. General view of the dividing wall at the FINA 2015 competition in Kazan.](image1)

![Figure 2. Mosaic of efforts N.](image2)

The rigidity of the structure was increased by the introduction of cable ties. Then it was important to study the load carrying capacity of the node when using flexible connections in the laboratory.
2.2 Numerical studies
Numerical and experimental studies of the nodal connection. The studied node is designed to connect it with the cable tension of prefabricated forms of temporary structures. Considering the operation of only cable ties, the node experiences tensile forces and torque effects. There is no compressive force, since the cable does not work in this phase.

The following boundary angles are identified, under which diagonal cables can be attached:
- 11,01°, in crossbar with a length of 2.57 m and post length of 0.5 m;
- 69,95°, in crossbar with a length of 0.73 m and post length of 2 m.

A model was also studied, in which the angle of connection of diagonal ropes was equal to the angle obtained during the experimental calculation, described below. This angle was obtained in a cell with a crossbar length equal to 1.84 m and a post length calculated from the axis of the rope connection nodes equal to 2.72 m. With these parameters, the angle is 47.43°.

In following models, we accepted the post and bolt head of crossbar fixed rigidly, because this corresponds to the operation of the node in the system.

In the advanced node (figure 3): 4 rods should be made of the same material as the flange to ensure the best weldability. In order to ensure the integrity of the rods with flanges, when making the assembly, holes should be drilled in one of the flanges diameters of which are greater than the diameters of the rods by 1 mm, these holes are inserted into the rods and these rods are welded to the lower flange from the inside and to the upper flange from the outside.

![Figure 3. Model of the source node and the advanced node.](image)

2.3 Experimental studies
An experiment was conducted in the laboratory as part of testing the operation of cable ties. The purpose of the experiment was to identify the limiting loads that lead to the appearance of fluidity in the node under consideration. To perform this task, strain gauges were installed at the predicted places of maximum stress (figure 5). The geometric characteristics of the node that affect the limit loads are shown in the diagrams (figure 4).
3 Results and discussion
The source node showed a fairly high result. Its strengthening was facilitated by the presence of a crossbar, the head of which perceived part of the bending moment and transmitted it to the post due to the design of the crossbar tip (figures 6-7).
When the diagonal was located at an angle of 11.01°, the fluidity limit was reached at 24 kN, at 69.95° – 7 kN, at 47, 43° – 10 kN.
The results of laboratory studies have shown that the studied numerical model of the initial node corresponds to the experimental one with a small error.

Figure 6. Graph of the dependence of stress in the flange on the force applied to the structure.
During the experiment, the structure was loaded to the maximum values. The maximum force obtained in puffs when loading the central rack with a force of 3250 kg, exactly 1150 kgf/cm². With this effort the maximum stress (tension) at the node was equal to 278 MPa.

In the first variant of loading the advanced node, fluidity is achieved in the weld of the rods at a load of 59 kN. This rigidity was provided by the fact that the 2 flanges are connected rigidly by rods that ensure their joint operation.

![Figure 7. Model of an advanced node with a specified flow zone for different loads.](image)

With the second option of fixing, the bearing capacity of the node is very high, since the limit loads of the metal are much higher than for bending. The stresses reach their limits when the load in the cables is equal to 90 kN.

**4 Conclusions**

The main problem of "Layher" system nodes has always been connected with the gaps that occur in the nodes and the eccentricity that occurs due to the way the diagonals and crossbars are fixed to the flange. It was also necessary to increase the carrying capacity of the node.

The gap problem was solved by replacing vertical diagonal elements with cable ties and changing the way these ties were attached to the node. The increase in the bearing capacity of the node was achieved by improving the method of fixing the diagonal elements, which allowed reducing the eccentricity that occurs in the node, thereby increasing its bearing capacity.

In subsequent studies, it is necessary to consider the combination of loads in different directions, to find the most unfavorable and advantageous positions for fixing the ties during such loads.

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