Possibilities of Architectural and Structural Forming of Spatial Forms from Rod Arches

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Abstract. The process of forming new technological methods of construction of buildings and structures, a high degree of industrialization of construction and unification of elements, lead to the study of various principles of forming the spatial structure of the object from flat scans. The authors consider a new transformable architectural and structural system consisting of rod spatial arches, the main elements of the developed system are rods and hinges that connect them at the ends. The latter are made as an analog of bionic mobile communication. Analysis of the transformation of a rod spatial element into an arch of various shapes is performed by the following methods: traverses, jacks, pneumatic structures and automatic methods. As a result, you can use rod arches to create buildings and structures of various shapes. In the end, the versatility of such spaces allows buildings and structures based on rod spatial arches to be multifunctional. Specifically for the arches of the NPI series, the authors developed a hinge Assembly designed to connect the rods of a fast-erecting light spatial structure of a regular structure. Research has shown that on the basis of the resulting arched strezhnevoy system, it is possible to form spaces close to the cylindrical and spherical shape. The variability of forms based on a single set of structures, low-labor-intensive installation process using the principles of self-construction, create prerequisites for new research in the field of improving this type of transformable architectural and structural systems. These issues provide a wide range of tools for solving architectural, structural and technological factors of shaping, which contributes to the development of creative activity.

1. Introduction

In an era of dynamic development, society values simplicity and convenience. Therefore, modern architecture should not only be functional and aesthetic, but also convenient, practical and economical. Architectural and structural systems (ASS) are a set of load-bearing structures characterized by the spatial distribution of forces in the elements. They also differ not only in their variety (from rigid shells to fabric pneumatic coatings), but also in a wide range of materials (wood, metal, reinforced concrete, polymers). [1-3] The South Russian state Polytechnic University (NPI) is developing a new transformable ASS, consisting of rod spatial arches, and received the serial name NPI.

The field of research related to the search for dynamic means of shaping in architecture and construction covers the transformation of core kinematic systems and technical means that allow physical change of their parameters [4,5]. The main elements of the developed system are rods and hinges that connect them at the ends. The latter are made as an analog of a bionic mobile connection.
2. Transformable architectural and structural system of the NPI series

Initially, the structure is a linear spatial element – a multi-rod beam consisting of two belts and struts. The upper and lower belts are linear flat rod structures based on a triangulation grid that forms hexagonal and rhombic geometric shapes, respectively (see figure 1). When reducing the length of the rods in one of the directions of triangulation of the lower belt and due to the hinge joints of the rods and the constant length of the other rods of the system, the beam moves to the design position - it bends up with a bulge. According to recent research, such structures are able to pass the reverse cycle-dismantling, also using the ability of the lower belt rods to change their length. Due to various combinations of such deformations, the ASS has a wide range of forming capabilities [6-9].

An arch of the NPI series can be formed from two semi-arches, and represent a three-hinged kinematic system, or from a single arch, being a two-hinge system.

Research has shown that on the basis of the resulting arched rod system, it is possible to form spaces close to the cylindrical and spherical shape. Additional spatial rigidity of the frames is provided by the connections between them.

![Figure 1. Scheme of the rod spatial arch of the "NPI" series: 1 – rods of the upper belt; 2-rod of variable length of the lower belt; 3-struts connecting the upper and lower belts; 4-nodes connecting rods.](image)

3. Methods for transforming a rod spatial element into an arch

Using the known methods of changing the rod elements (hydraulic, mechanical), it is possible to transform the rod spatial element into an arch of various shapes using the following methods:

1. Traverses (see figure 2 a). This method is one of the simplest, but expensive. The traverse slings are lowered to a different height, calculated in advance for a certain bend in the arch, and are attached to the nodes of the upper belt of the structure. Under the influence of its own weight, when lifting, the rod arch of the NPI series changes its geometry from a straight rod beam to a spatial arch, after which the structure is installed in the design position, and the nodes are fixed.

2. Lifting Jacks (see figure 2 b). To lift the structure, a system of jacks is used, driven by a Central pump, to act on the spatial rod structures simultaneously at several points. Each Jack is given its own pre-calculated lifting height, so that the rod beam takes the form of an arch. After that, as in the previous method, the support nodes and the connection points of the lower belt rods are fixed, the jacks are lowered and moved to the next structure.
3. Pneumatic structures (see figure 2 c). Systems of the NPI series are assembled on top of pneumatic structures, and under the influence of pressure from the injected air, the geometry of the mounted system changes from the rod beam to the arch. After that, the hinge joints of the lower belt rods, as well as the support nodes, are securely fixed. The pneumatic structure is deflated and moved to a new location.

4. Automatic method (see figure 2 d). NPI series structures are assembled directly on the construction site from supplied rods of various lengths. One of the ends of the resulting beam is fixed to the support, the second is in a free position. The lower belt of this design consists of rods of variable length. After completing all the preparatory work, the rods are set in motion. When they are reduced, the spatial system turns into an arched structure moving to the second support. As with all the methods discussed above, the connection nodes are fixed.

![Figure 2](image-url)

**Figure 2.** Schemes for mounting structures in separate arches: a – traverses, b – lifting jack,
Arches of the NPI series allow searching for various variants of spatial planning solutions on a rational basis, creating "universal" buildings of multi-purpose functional purpose through the use of large-span and transformable structures; diversify architectural forms and compositional means.

With the help of rod arches, you can create buildings and structures of various shapes, the shape of which somehow corresponds to the organized internal space. Each of them can be considered as a three-dimensional structure of the pavilion type. Such buildings and structures are characterized by a single form of organized internal space. The necessary internal divisions in buildings and structures are carried out at the expense of mobile structural means that are not associated with the main load-bearing and self-supporting structures. In the end the versatility of such spaces allows buildings and structures based on rod spatial arches to be multifunctional.

The external shape of buildings and structures is a compact composite solution. Its individual sections are spatial arched structures consisting of two types of rods (variable and constant length) connected at nodal points. All this structural division of the shape of buildings and structures has a specific tectonic meaning, expressing the desire for dynamism and lightness. This characteristic is emphasized by the spatial rhythms of the faces from the center to the support.

Arched rod systems allow you to form objects that are close to domed, cylindrical, transverse, closed and flat forms. Thanks to them, you can significantly diversify the space-planning solutions of buildings and structures. In each case, you can find a harmonious combination of different types of buildings with the proposed forms [10,11].

4. A hinge joint for an arch of the NPI series

The authors of the article developed a hinge joint for an arch of the NPI series (see figure 3), designed to connect the rods of a fast-erecting light spatial structure of a regular structure. The node consists of pressure disks with slots connected by a Central tie bolt, between which rods with spherical tips are located radially in the plan. In disks on surfaces facing each other, the edges of the holes for spherical tips are beveled. Between the slots, the disks are connected by fixing bolts, which are tightened after mounting the structure [12-14].

![Figure 3. The rod hinged joint of a spatial of a regular structure.](image)
5. Conclusions
The ability to create spatial formations of various forms and functions allows you to compose several objects that have a single structural fabric, and form an ensemble on this basis. Small spatial systems can form recreation areas, solve problems of small architecture, serve as temporary public buildings, while large ones can become the compositional core of an urban ensemble or perform important social functions of a public center. The variability of geometric parameters of buildings and their forms based on a single set of structures, low-labor-intensive installation process using the principles of self-lifting, create prerequisites for new research in the field of improving this type of transformed ASS.

6. References
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