THE STRUCTURAL AND DESIGN SPECIFICS OF SPACE GRID SYSTEMS

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***Abstract**: The aim of the study is to identify the main trends in the development of space grid structures. To resolve this purpose was conducted review of the known structural concepts, nodal connections and specifics of the space grid structures, also conclusions have been about feasibility improvement of the considered structural concepts to develop the new kinds, without the drawbacks of analogues. Analysis of papers of foreign and domestic scientists that devoted to theoretical, numerical and experimental studies of stress-strain state, the influence of different factors on it, geometrical optimization and designing of space grid structures was conducted to achieve the objectives. The space grid structures, in particular the flat double-layer grid and most frequent nodes were studied. A full review of the history of development of space grid structures was conducted and there are present some important moments in paper. It was found that the rapid development of structural designs was caused by scientific and technical progress, in particular improvement of the physical and mechanical properties of materials, the development of calculation methods; the development of software systems for simulating the behaviour of the structure under load, which significantly increases the calculation accuracy and reduce the complexity of design. It is also found that the main parameters that have influence on effectiveness of structural designs are geometric dimensions of its modular elements, the ratio of its depth to the span. The world experience develop of connection components was studied. General classification of nodal connections is presented. The main advantages and disadvantages of existing space grid structures are highlighted; it allows finding possible ways to improve them. The main direction of improve of spatial grid structures consist in develop new kinds of node connections, it was found as the result of the theoretical research. Considering the results, a few ways to improvements nodes were proposed.*

***Key words**: rod, node, welding, bolt, module, span, structure, lattice.*

1. Introduction

In the construction of large-span buildings and structures for various purposes often is a problem of the complexity of work and waste of material due to its inefficient use. This situation in the construction has developed through outdated industry, properties and technical and economic indicators of the existing designs that are a morally and physically outdated over time. These factors have a direct impact on the overall cost and duration of construction of the object, so there was a need to improve and find new load-bearing structures, in particular space frames that would have led to significant savings in materials and reduce the complexity of technological processes of manufacturing and installation.

That was the cause of the ideas develop of concept of new space systems that will be able to combine not only advantages of existing space frames but would have their own original characteristics and their unique benefits and specifics. For his must be carefully and thoroughly study the world experience of studies of space grid structures.

2. Design, construction and investigate the space grid structures

Design issues of space grid structures from time to time attracted the attention of scientists all over the world. Previously analysis of the history of the development of the structures has shown that the appearance and development of each new structural form due to the desire to find the most cost-effective structural concept. Significant number of works of foreign and domestic scientists devoted to this issue, and the study of structural designs. Most of the work related to the rational designing and finding of relevant geometric parameters [1]. In [2] studied constructive solutions and schemes, methods of calculation and installation methods, as well as study the effect of the size of the structural elements and their shapes on the stress-strain state and the mass of the structure. Research and further development of constructive solutions to the space grid structures and methods of their calculation have performed by M. N. Kirsanov V. I. Trofimov, R. I. Hisamov, V. N. Shimanovsky, A. V. Shimanovsky, J. Chilton, J. M. Gerrits, Z. S. Makowski, G. S. Ramaswamy and others.

The main geometric parameters of structural designs are height H and the size of the module M. Height it is the distance between the top and bottom chord, and the module it is the distance between the two joints in the top chord. Despite the fact that these parameters seem to be quite simple, properly chosen values can significantly influence the cost of the structure. In turn, the height and size of the module is influenced by several parameters: the mesh type, the distance between supports, the form of the roof, as well as the nodal system. In fact, the height and size of the module are interconnected. The parameter that connects them is the angle α between the rod of the module and its horizontal projection. This angle should be between 30°...60°, but advisory in nature is equal to the angle of 45°.

Common ratio of height H to the size of the module M does not exist and, as a rule, is determined by practical experience. It is believed that the structural height of the structure is relatively small as compared with conventional structures. However, one must consider the fact that a small structural height with respect to the structures span creates the need for smaller size modules, which will promote the growth of their quantity, and hence the number of nodes, the total weight of the structure and cost structure. Structural optimization is the best way to determine the optimal ratio of height to span. In [3], using the principles of structural optimization, the optimal ratio spans search was carried out in the range of 24 to 72 m and a height of the space grid structures. Seven types of gratings were investigated. The size and height of the modules were taken as a variable, and the total value was taken as the objective function, which is the sum of the cost of the elements, joints, roofing and enclosing materials. This approach made it possible to argue about the validity of the data. It has been found that the optimum design parameters for the different systems are different, and the module size generally increases with span. In addition, empirical formula was obtained to determine the optimal ratio of the span and height. Based on these expressions, diagrams of dependence between the span L and height H of the space grid structures were built [3]. Also for comparison of the results showing further research in this area, which are discussed in [4].

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Besides the optimal geometric dimensions of the modular elements in the design of structural designs occupies an important place also efficient and reliable constructive solution of the nodal connections

3. Review of existing nodal connections and their research

As mentioned previously structural designs consist of rod members of different cross sections, which are joined at the nodes. Currently there are a large variety of solutions nodal connections but generally they can be divided into groups:

Group I – the nodal connections are made with mounting welding;

Group II – bolt connection or other modular elements are made without any welding. Such connection depend on how the bolts in, can be divided into two subgroups, where nodes bolts working in compression or tension bolts and bolts which resist the shear.

Group III – combined nodal connections. This group includes compounds in which welding is carried out in the factory, and the assembly with bolts on site.

In most cases, manufacturing the nodes requires the use of special connection parts - connectors [5], and they can be manufactured from cast, forged or welded spheres, hemispheres, polyhedrons, and other forms [6].

Welded node connections include Oktaplatte system, Segmo, SDC and many others. The node system Oktaplatte is the most known among this class of connections. The German company Manessman developed it, and its feature lies in that the node consists of two hemispherical hollow steel parts that in the joint with steel diaphragm made as a disc. The most famous example of the use of Oktaplatte system is a pavilion built for the World New York Exhibition in 1964-1965.

Bolt node connections include Sarton system, Premit, Triodetic, Mero, Space Deck, Envision, Unibat, Nodus, NS, Zachod, Berlin, Pyramitec, БрГТУ, System III, Pyramid Sphere System, Hemisperical Node System, Unistrut, Mostostal, Newbat, TRIDI 2000; ONDDI, Uzay, Montal, Spherobat, Axent, Wuppermann, Orbik and many others.

As can be seen from a review of the existing bolt nodal systems of structural designs, in different countries developed their own systems, which may be structurally differ from one another a connection way of rod elements, cross-sectional shape and form core elements of the connector. In the world practice of building space grid structures widespread nodal connection with axial bolts. The most popular among these systems as mentioned earlier is Mero system that was proposed by German designer M. Mengeringhausen. This system for connecting of rod shaped elements involves the use of the connector, which is a solid steel spherical polyhedron shape with arranged in it threaded holes. This connector allows you to connect up to 18 of rod shaped elements, which are equipment with axle bolt and sleeve. The node Mero system has a significant number of modifications and improvements [6].

4. Analysis of the results of research and the search for ways to improve the nodes

Considering the above and after a number of various nodal connection of space grid structures have been considered, it was established that the determining factor in the making of the cost of the erection of the structures is the complexity of the connection node. This statement has been made based on that in general, the load-bearing capacity of space grid structures is dependent on the bearing capacity of the node, and when the node is designed with a significant reserve of strength, it is accompanied by the overrun of steel. Hence, then the node is simpler in to manufacture and assembly, the less time-consuming, and therefore inherent safety factor will not cause large expenditure of steel. In addition, a small labour and material intensity positive effect on reducing the total cost of coverage.

As noted above depending on the way of assembly, the nodes are classified in bolted, welded and combined, but bolted nodes are used widely. Bolted nodes are used widely

because they have factory readiness and faster assembly procedure. However, it should be noted that the welded joints can be used quite effectively. For example, if the components made in lap joint [7] instead of butt joints, it is possible to reduce the accuracy requirements for the lengths of rods. Also, for welded assemblies, at light loads, as the rods of the lattice can be used steel rods of round or square cross-section (Fig. 1).

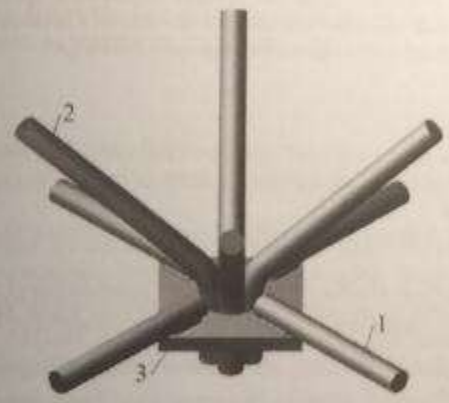

Fig. 1. Welded node of space grid structure: 1 – bottom chord; 2 – slanted rods; 3 – steel plate (by G. M. Gasii)

It has been proposed several ways to improve the space grid structures based on the information received, that caused a development of a concept new space rod system. The specifics of this system is in providing collaboration not only grid modular elements, but also plates, made with durable and efficient building materials, including translucent. Constructively these systems consist of top and bottom cords and space lattice. At the same time, top chord is made of rigid plates that in compression and transverse force, the bottom chord is made of flexible linear elements [8]. It should also be noted that this structure is modular, that is assembled from space structural modules are completely produced at factory [9]. These systems have three types of modules. It is support and span space modules and line modules from which make a flexible chord. This structural concept allows constructing cover with different forms and shapes, including a variety of shells [10]. Structural concept of such systems involves usage specially designed nodes for connection modules in the integral structure [11, 12].

The results of theoretical, numerical and experimental studies of this system enable us to assert about its efficiency and reliability, as well as resources saving, which is especially relevant in today's construction industry [13].

Conclusion

Considering the above, it was found that the nodal connections are members of structures that determine the cost of material consumption and complexity of installation work space grid structures. Nodes are classified on bolted, welded and combined. Bolted and combined nodes are most widely used. It should be noted that a significant number of existing nodes connections, including welding, involve the use of special steel connectors. Usage connectors, generally adds weight and complexity of assembly, and also requires the production of works with high accuracy. The analysis of theoretical and experimental studies has established that the most effective nodal connections are combined with gussets due to simplicity of manufacture, low weight and absence of axial bolts. However, these nodes have significant drawbacks. It is a large number of bolts and the complexity of using tubular rod elements and in the case of welding is a significant total length of the assembly weld. Therefore, as a result of the theoretical studies highlighted effective nodal connections, but it remains a certain number of problematic issues that require further research. Hence has been developed the concept of the new space grid system, the constructive solution that will save both material and human resources in the construction of coatings of different forms and shapes for large-span buildings.

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EXPERIMENTAL DETERMINATION OF THE CRACK WIDTHS IN RC ELEMENTS, SUBJECTED TO BENDING

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Abstract: *In this paper are described the experimental results for maximum and mean crack widths in reinforced concrete elements, subjected to bending. Twelve reinforced concrete beams are tested at 4-point bending test – 4 specimens with 3 beams in each one. The specimens differ in diameter of longitudinal reinforcement, reinforcement ratio, Ø/peff ratio and concrete cover.*

Key words: *experiment, crack width, cracks, RC elements, bending*

1. Introduction

Cracks form in reinforced concrete structures subjected to bending, shear, torsion, tension as a result of direct impact or imposed deformations [1, 2]. They worsen the adequate performance and durability of the structures. Crack width for elements subjected to bending have to be limited, in order to be ensured: durability of the structures (protection of the reinforcement), appearance of the elements and stiffness of the elements.

In various theories [3] is stipulated determining the crack width in order to avoid cracks with unacceptable widths and to ensure appropriate service of the structures. The study for cracks width is topical issue and different formulas for their determination are proposed. Cracks in the concrete are a natural result of its low tensile strength. Tensile stresses can occur in different situations, at a different time in the elements of structures or in separate parts thereof [4]. There are many formulas for determining the cracks width. The obtained experimental results are different and depend on the type of the test specimens, the manner of loading and used reinforcement. As a result, there isn't universally accepted theory for determining the cracks width.

Experimental research on cracks width in reinforced concrete elements subjected to bending will be presented in this paper.

2. Experimental setup and experimental results for crack widths

2.1. Experimental setup

For experimental research on the cracks width 12 reinforced concrete beams were prepared (fig. 1-a) – 4 specimens with 3 beams in each one – $A_{1,2,3}$, $B_{1,2,3}$, $C_{1,2,3}$ and $D_{1,2,3}$. The specimens differ in provided bottom longitudinal reinforcement, concrete cover and reinforcement ratio (table1). The concrete is grade C25/30, fine fraction of coarse aggregate (d_{max}=12 mm), consistency S3. All of beams have the same effective depth. The spans (300 cm) and cross section width (15 cm) for all of the elements are equal. Cross section height of specimens A and B is 27 cm, of specimens C and D is 30 cm, which provides bigger concrete cover for specimens C and D. Structural

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