REGULATION OF SPACE GRID STRUCTURE STRESS-STRAIN STATE

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Abstract. By analysing publications and research, it is found that space grid structures, which are spatial rod lattice systems, are characterised by their effective static behaviour. The stress-strain state of construction structures, in particular slabs, can be significantly dependent on a number of factors: the shape of the base cell, the way it rests on the supports (walls, columns), the method of arrangement of support posts, and the thickness of the slab. As a conclusion from the research analysis, it can be stated that the research of one of these factors (force regulators), which affects the material capacity of the structure, is relevant. Finite element models of space grid structures are described, which differ in the arrangement of columns on which the structure is supported. The arrangement of columns is taken in three ways: columns are located at the corners of the slab; columns are located along two parallel sides of the slab; columns are displaced inside the slab 4.5 m on both sides. That is, the method of localization of the columns is the regulator of forces in the slab elements. The variants of column arrangement can be used to determine the most efficient model in terms of static behaviour. Consequently, this most efficient model will also be the least material-intensive, i.e. it will have the lowest possible weight. The most rational (efficient) model from the considered variants was determined. The efficiency was determined by the criterion of more rational stress-strain state. Selection of element cross-sections according to the first and second groups of limit states was carried out. The weight of each model was counted and the model characterised by the lowest material capacity was determined. According to the criterion of material capacity, the most efficient model of the space grid structure is the model No. 3, supported by 4 columns displaced inside the slab by 4.5 m.

Keywords: space grid, forces, force regulators, column arrangement, capacity, efficiency.

Introduction

Space grid structures characterised by a planar solution or a curved surface have a number of advantages. These advantages are primarily caused by the principle of space grid structures. The basic, or formative, spatial element is a system of inclined, vertical and horizontal rods. These rods are arranged within the base element in an orderly manner. The order of these rods is ordered and resembles crystals of natural origin, such as graphite and diamond. There are five Platonic solids (polyhedrons): a tetrahedron, a cube or hexahedron, an octahedron, a dodecahedron, and an icosahedron [1]. Using Platonic solids, it is possible to model a basic element that forms the entire structure of a slab. The slab is formed by multiplying such a basic element along the two axes of the XOY plane. Fig.1 shows space grid structures with square mesh belt.

In the practice of world-class construction, many unique and original structures of public and industrial purposes have been built. In 1898-1908, Alexander Graham Bell created lightweight but strong grid structures based on the tetrahedron. The famous futurist Buckminster Fuller created the octet truss in 1961. Today, along with the traditional geometric forms of gridded spatial coverings, futuristic forms are being implemented in various landmark buildings, such as Stansted Airport and the Bank of China Tower, the space structure of Heydar Aliyev Cultural Centre in Baku [2].

The futuristic structures are made of intertwined posts that form a pattern of geometric shapes. The behaviour of plastic limit states of external lattices and two-layer hinged lattices has been the subject of many substantial analytical and experimental researches since the early 1950s. These pioneering contributions were made by Hayman (1952, 1953), Stevens (1961, 1968), Hongladaramp et al. (1968), Wah (1969), Grigoryan (1971, 1972, 1973a), and Sack and Hecky (1971), among others. More definitional visions have also been reported by Grigoryan (1973b), Marsh (1975, 1977), Sapple and Collins (1981), Park and Walker (1984), Schmidt (2000a), Kaveh and Talatahari (2009), Goizadeh et al. (2012), and Maalek and Abadi (2012), among others. A highly organised review of space structures with a special accent on analytical methodologies, including plastic boundary analysis, was given by Kheristchian (2000).While the field of space structures has seen significant progress in both the technological and computational aspects of such systems, the same cannot be said about the relevant design methods in general. An excellent review of innovations in space structures can be found in the wide-ranging bibliography of Schmidt (2000b) [3].

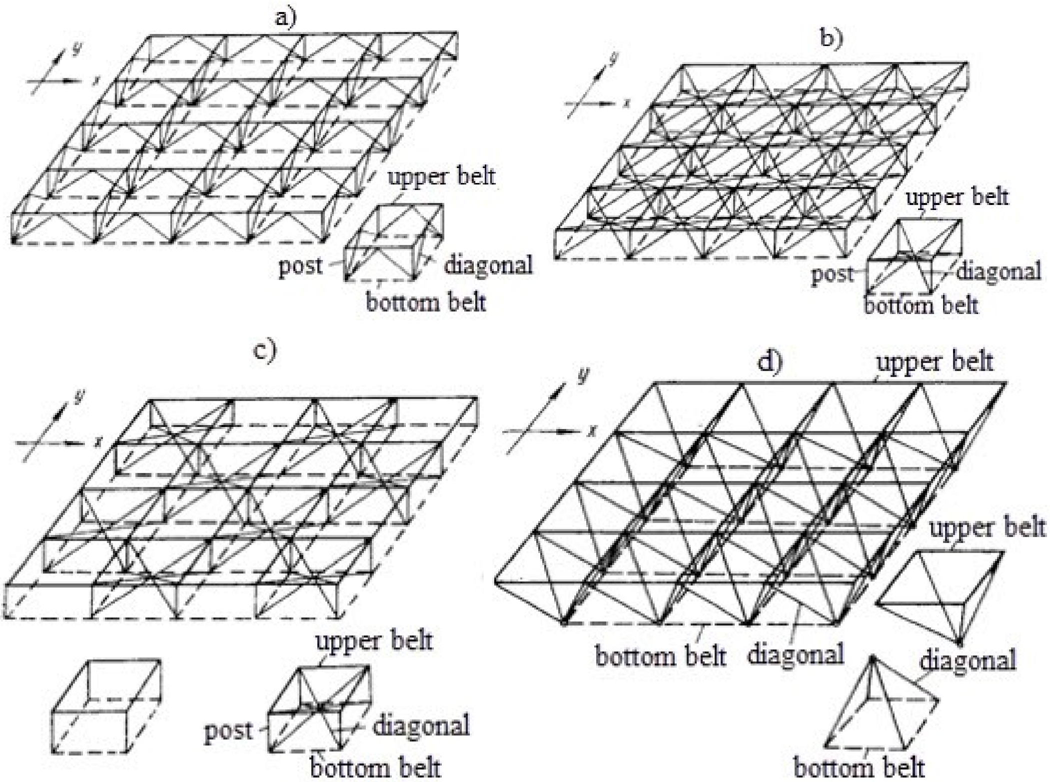

Fig. 1. **Space grid structures with square mesh belt:** a – type of vertical cross trusses in two directions; b, c – with the location of braces outside the plane of the trusses; d – type of inclined cross trusses in two directions

A new design philosophy for grid structures is presented in [3]. A newly developed observation-based design process is described in [3], which aims to rationally and efficiently select structural elements rather than researching their usefulness through iterative processes. The results of the foregoing studies point to two important design considerations: the successful plastic limit state design (LSD) of such structures can be achieved provided that the ductility of the tensile elements can be maintained and the deflection of the compressed elements can be delayed by proper sizing and detailing, until the deformation of pre-selected groups of tensile elements, and provided that the out-of-plane displacements of the structure at the onset of failure can be accurately estimated [3].

In [4] group search optimisation and its improved algorithm are proposed for the optimisation design of the spatial mesh structure. In [4], it is indicated that the finite element model of the spatial mesh structure is first built using the ANSYS platform. Then, group search optimisation (GSO) and quick group search optimisation (QGSO) are compiled using the parameterised ADPL ANSYS programming language, and the spatial mesh optimisation analysis is performed. Finally, the results of the optimisation and the ANSYS optimisation are compared [4].

An overview of examples of destruction of long-span spatial mesh structures is given in [5].The mechanism of anti-progressive collapse of large-span single-layer spatial grid structures is comprehensively investigated, both field tests of experimental models of basic units of single-layer spatial grid structures and numerical modelling of processes are presented [6].

The paper considers spatial floor systems built on the basis of a rational combination of concrete and steel properties [7]. The distinctive features are a rational combination of concrete and steel properties and a simplified construction technology. A multi-criteria numerical analysis of spatial lattice structures with a span of 18 m was carried out using the finite element method (FEM) to find the optimal parameters of cross-sections and arrangement of the structure rods. To do this, 48 different finite element models of spatial mesh structures were created in a graphical algorithmic editor Sapfir 2018 Generator and the resulting stresses, displacements and potential strain energy were analysed. Due to the energy approach of Vasilkov-Shmuckler, the optimal variant has been determined. The results of analysis were used in construction and designing of a building in Kharkiv [7].

The paper [8] describes experimental studies of the design of a spatial frame assembled from GFRP pultruded elements of a circular hollow profile (CHS). The results of static tests are presented. It is concluded that the structural behavior can be well described by FE modeling considering realistic initial imperfections such as out-of-rectitude, eccentricity of members, and additional eccentric compressive forces [8].

A novel connector for an all-composite space truss structure with the ability to adapt to changes in surface curvature was proposed. The proposed connectors were used to assemble a spatial truss assembly, which was then subjected to static loading until failure. Detailed finite element modeling was performed for the space truss to understand the stress concentration in the connection area and the effect of bolt prestressing force [9].

Flager in [10] proposes a new two-level hierarchical method for optimizing the shape and size of truss elements. The method uses a unique combination of algorithms organized hierarchically: a fully constrained design (FCD) method for discrete size optimization is nested within SEQOPT, a gradient-based optimization method that deals with continuous shape variables.

The relationship between the nature of the static behavior and the spatial grid structure is given in [10]. Form-finding and optimization for free form grid structures supported by branching columns based on an updated force density method are given in [11].

In paper [12] it is indicated that the existing optimization algorithms are also applicable to only one grid structure or branched columns, but the interaction between grid structures and branched columns should be sufficiently considered in the design process. This study [12] presents a shape-finding and intelligent optimization algorithm for grid structures with branched columns. The study of the spatial lattice structure for progressive collapse is given in [13].

The authors modelled a 3D finite element model of a two-layer grid of the spatial structure and investigated several collapse scenarios. The studies were performed using an implicit method that corresponds to the alternative paths method defined in GSA. In addition, an explicit method was used to model the entire process of structural collapse [13].

The method of choosing the optimal constructive solution of steel covering trusses at the stage of variant design, taking into account constructive, technological, economic and operational requirements, is given in [14]. Paper [15] presents the results of a parametric study of various factors affecting the bending behaviour of two-layer mesh spatial structures, taking into account such factors as: different locations of supports, a concrete slab on the upper belt of the structure, and an experimental study on a full-scale grid. Based on the study, it was concluded that the upper concrete slab increases not only the strength of the upper chordal compressed elements, but also increases the strength and stiffness of the system with a failure safety system.

Space grid structures have gained considerable popularity due to their high efficiency. These structures stand out from others not only because of their original shape, but also because of their extremely high load-bearing capacity. Space grid structures allow large spans to be covered without intermediate supports [16]. These structures are distinguished from others not only by the originality of their shape, but also by their extremely high efficiency parameters under load. The scope of their application is wide − buildings for public use, entertainment and exhibition halls, sports arenas. The practice of designing space grid structures indicates that tube-shaped profiles are particularly interesting for space grid structure design. Such profiles are characterised by an optimal rod cross-section, which effectively accepts axial loads and responds to them with axial tensile and compressive forces [1; 17]. Space grid structures have a lot of advantages, including universality, relatively low weight, multicoupling, and the ability to manufacture plate elements on the threading technological lines [1]. The rational distribution of axial forces in all groups of slab bars (upper belt, braces, lower belt) determines the most efficient and effective cross-section of the bar elements and, as a result, the optimal weight of the slab. Space grid structures are quite sensitive structures, the stress-strain state of which depends on many factors: boundary conditions (the method of arrangement of the columns or leaning on walls [18]), the shape of the base element of the crystal [19], the height of the slab, the creation of prestressing in the elements of the bottom belt. The method of arrangement of the columns significantly affects the stress-strain state of the rods of the space grid structure [18].

Variational research, which uses numerical methods, allows by search to find a design with optimal parameters among possible variants. The search for the most efficient variant of the structure according to the criterion of least weight (material capacity criterion) is a task that is solved at the initial stages of design. To optimise the structural solution of a space grid structure, it is necessary to take into account not only the criterion of material capacity, but also the labour costs of manufacturing, transportation and installation of the structure. The complex of these parameters influences the final cost of the structure. An important feature of space grid structures is the possibility to design the cross-sections of the elements in such a way that the space grid structure can use its bearing capacity to the maximum. This saves steel and reduces the cost of the structure.

Materials and methods

The numerical method of analysis of construction structures (finite element method) is one of the methods of structural mechanics. The method is implemented in the Lira-SAPR software. It is a representation of a construction structure as a design model consisting of a certain number of finite elements and the nodes by which the elements are connected to each other. It is implied that under load the behaviour of such elements is predictable. And it depends, among other things, significantly on the boundary conditions of the finite element model. There is a relationship between the stress state in the finite elements and the displacements of the connected nodes. All elements of the space grid structure are divided into structural groups: top girder bars, bottom girder bars, lattice bars, columns. All rod elements are made of C 235 construction steel, from hot-rolled pipe profiles. Characteristics of the steel grade used: R_y = 230 MPa = 23.0 kN·cm^{-2}, R_{yn} = 235 MPa = 23.5 kN·cm^{-2}. Modulus of elasticity of steel is $E = 2.06 \cdot 10^4$ kN·cm^{-2}, γ = 78.5 kN·m^{-3}, μ = 0.3.

Methodology of designing groups of structural elements of a space grid structure according to design codes [20]. The methodology is implemented in the module “Steel structures” in software Lira-SAPR. The design code allows to estimate the degree of using the cross-sectional area for the profiles of the rod elements specified by the designer in the first design approximation. The design methodology also allows to select cross-sectional profiles for all groups of structural elements according to the forces obtained from the results of static analysis of the elements of the finite element scheme. The cross sections are selected in accordance with the requirements of the first and second groups of limit states according to the norms [20].

Main part

The structure to be studied is a space grid structure with dimensions of 30.0×30.0 m in the upper belt plan and 27.0×27.0 m in the lower belt plan (Fig. 2). The grids of the upper and lower belts have an orthogonal grid. The mesh size is 3.0×3.0 m. The height of the structure (slab thickness) is 3.0 m.

The quantity of columns and the way they are arranged in the plan will be accepted as parameters that can be called “force regulators” in the rod elements of the structure (Fig. 3).

The distance between the columns and the number of columns for each model is shown in Table 1.

Table 1

Distance between columns and number of columns

Model No.	Distance between columns, m	Number of columns
1	27.0	4
2	6.0 and 3.0	12
3	18.0	4

The geometry of the slab and its loading are constant parameters that do not change in all models. A variable parameter is the number of supports and their location. The strength condition for tensile rods and the strength condition for compressive rods are used as constraints.

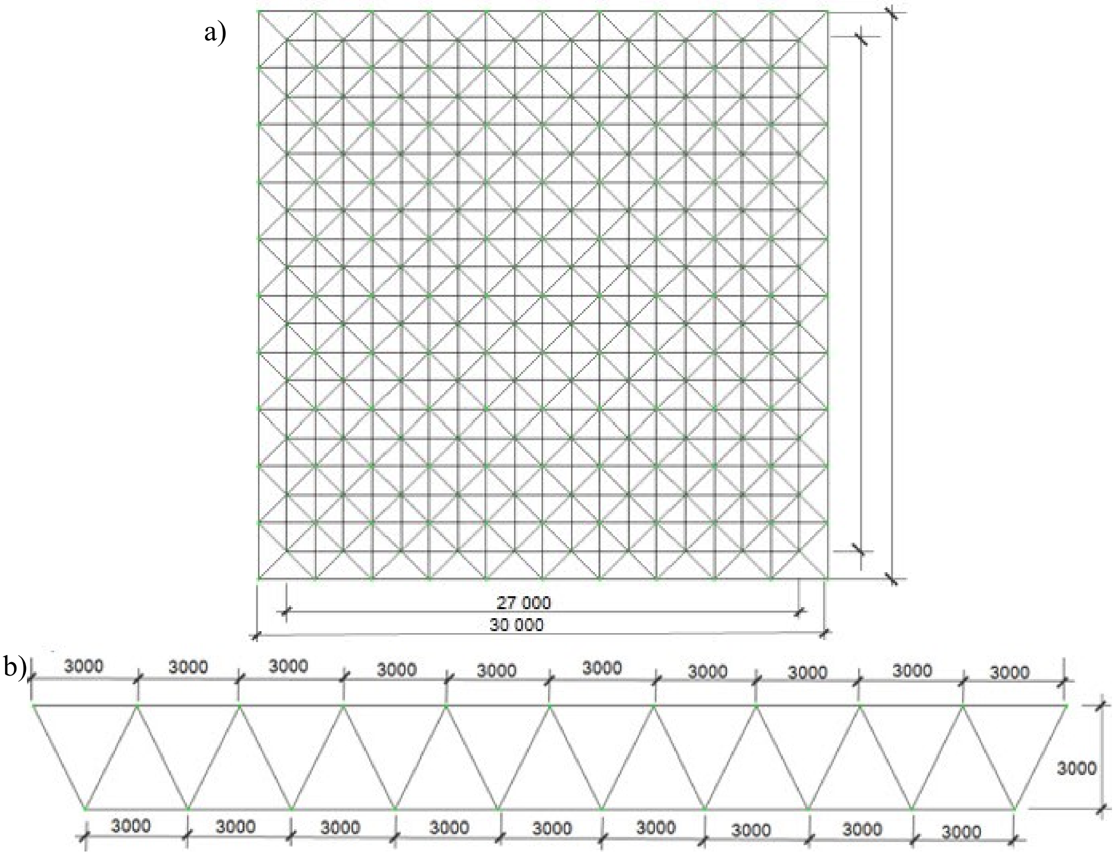

Fig. 2. **Geometric model of space grid structures:** a − view in the XOY plane; b − view in the XOZ plane

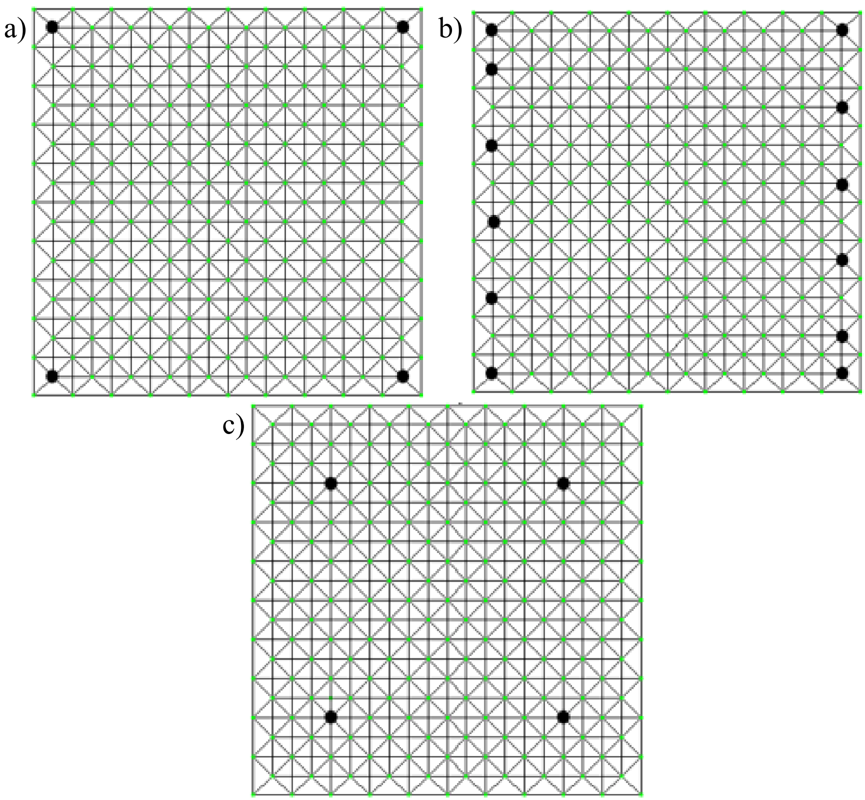

Fig. 3 **Column arrangement variants:** a − model No. 1 (at four corners of the lower belt); b − model No. 2 (on both sides of the lower belt); c − model No. 3 (for four columns offset inside the cover slab by 4.5 m)

Fig. 4 shows the researched spatial models of the slab.

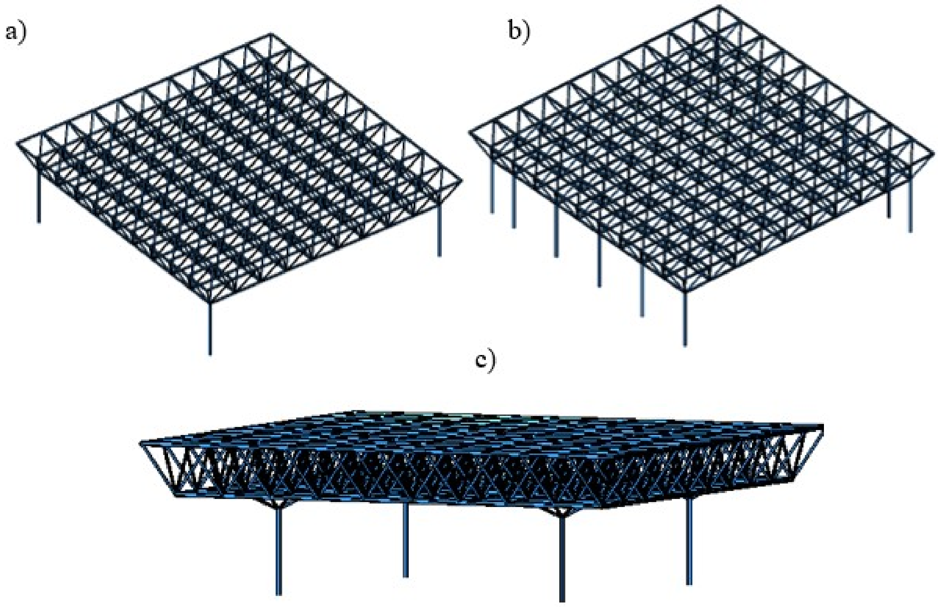

Fig. 4. **Spatial models under research:** a – model No. 1; b – model No. 2; c– model No. 3

The strength condition for tensile bars and the stability condition for compressed bars are accepted as constraints. Limits on the limit deflection, which depends on the ultimate flexibility of the structure, are also adopted. All elements are hinged. Electrically welded straight-seam pipes are adopted for all elements. The nature of the slab support determines the behaviour of the structure. For example, when supported by four columns located in the corners of the structure, the structure works in both directions (in the XOZ and YOZ planes). The equality of the stress-strain state parameters is also due to the square shape of the space grid structure in the plan. The more the shape of the slab in the plan is close to a rectangle, i.e. the greater the difference in the ratio of the sides, the more uneven the redistribution of axial forces in the rods of its belts in two mutually perpendicular directions will be.

For the numerical experiment, three types of finite element schemes were modelled. The schemes were composed of a core space grid structure and columns. All the rods had a pipe-shaped cross-section and were approximated by the rods of a spatial truss. Before the first iterative analysis, the following pipe profiles were adopted: 245×32 mm for the rods of the upper and lower belts, 168×25 mm for the rods of the lattice. The columns are accepted with a cross-section of 273×40 mm.

Wind loads were not taken into account for the structure since internal forces from wind action are approximately 1% and their effect on the stress-strain state of the space grid structure is not significant. Three loads are accepted: 1) own weight of the structure (automatically computed in the Lira SAPR software); 2) roof weight -1.36 kN·m^{-2}; 3) snow load for the second climatic region of Ukraine -1.87 kN·m^{-2}[21].

Results and discussion

Table 2 shows the maximum axial forces in all rod design groups. Table 3 shows the maximum forces in the columns.

Table 2

Maximum forces N in the structure belts

Model No.	**Upper belt**		**Lower belt**		**Bracing**	
	Compression	**Tension**	**Compression**	**Tension**	**Compression**	**Tension**
1	-99.3	2.14	0	130.7	-68.6	58.46
2	-62.04	2.32	-2.68	70.97	-27.12	21.05
3	-17.47	14.3	-7.9	44.74	-26.12	13.15
	Support braces for columns				-93.9	0

Table 3

Maximum forces in the columns

Model No. 1			Model No. 2			Model No. 3		
***N*, tones**	**M_y, t·m**	**M_z, t·m**	***N*, tones**	**M_y, t·m**	**M_z, t·m**	***N*, tones**	**M_y, t·m**	**M_z, t·m**
-92.6	± 2.87	± 2.87	-38.1	± 1.49	± 0.2	-91.1	± 0.43	± 0.43

Fig. 5 shows the graphs of vertical deflections in the middle section of the lower belt. Fig. 6 shows the maximum values of vertical deflections for the three models under research.

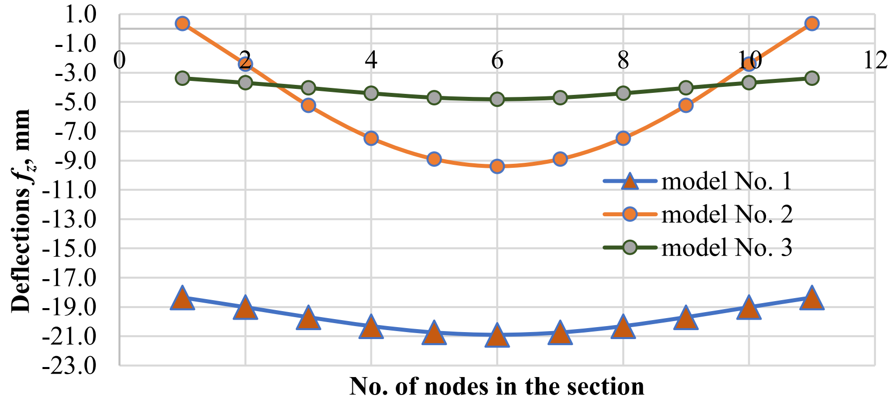

Fig. 5. **Graphs of vertical deflections in the nodes of the structure in its cross section 1-1**

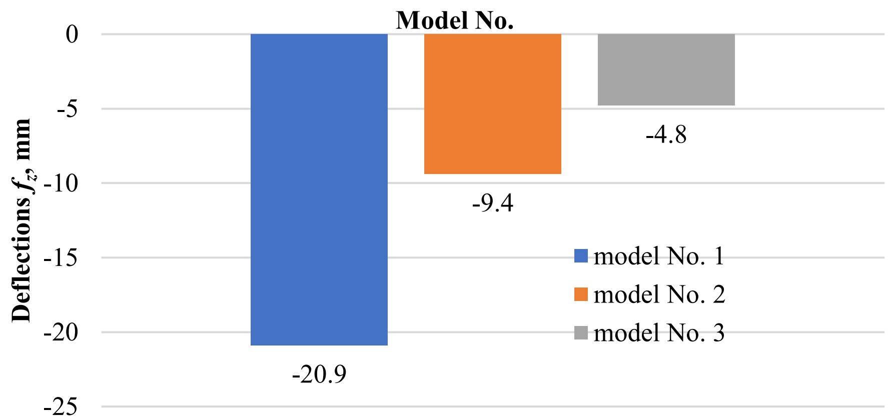

Fig. 6. **Maximum vertical displacements of the nodes of the design models**

The maximum permissible deflections are determined according to [22] using the formula:

$$f = \frac{l}{250} = \frac{27000}{250} = 108 \text{ mm} \tag{1}$$

As it can be seen from Fig. 6, the deformability of all models is within acceptable limits. Table 4 shows the% use of the cross-section bearing capacity by different groups of rod elements for the three models of the space grid structure under research after the first iterative static analysis.

Table 4 shows that all of the core elements are understressed.

Table 4

Load-bearing capacity of the section for slab core groups after the first iterative analysis

Name of the construct	**Load-bearing capacity of the cross-section, %.**		
	Model No. 1	**Model No. 2**	**Model No. 3**
Upper belt	11.4	7.2	2
Lower belt	15	8.1	5.1
Bracing	15	5.9	5.7
Columns	26	10	15.7

Using the module for designing metal structures in Lira-SAPR, optimum new cross-sections of rods of all design groups were selected in accordance with the requirements for the strength, stability and stiffness. The design results are shown in Table 5.

Table 5

New cross-sections of space grid structure elements

Model No.	Cross-section (pipe profile) adopted in the first iteration	Cross-section matched by Lira-SAPR software based on the results of static analysis		
		No. of cross-section type in the Lira-SAPR software	Steel	Pipe profile, mm
Upper belt				
1	242×32	46	S 235	95×8.5
2	242×32	52	S 235	6×7
3	242×32	24	S 235	38×3
Lower belt				
1	242×32	24	S 235	95×7.5
2	242×32	24	S 235	95×5
3	242×32	12	S 235	50×8
3	203×50	41	S 235	83×10
Bracing				
1	168×25	69	S 235	68×9
2	168×25	89	S 235	63.5×3.5
3	168×25	39	S 235	57×3.5
Columns				
1	273×40	47	S 235	273×8
2	273×40	55	S 235	194×5
3	273×40	13	S 235	203×7.5

Table 6 shows the new element cross-sections and the estimated weights of the upper, lower belts, braces and columns for all space grid structure models.

Table 6

Counting the weight of the upper belt elements (according to GOST 8732-78)

Model No.	No. of cross-section type	Steel	Pipe profile	Weight of one meter in length profile, tons	Length of rods of the belt, m	Weight, tons
1	46	S235	95×8.5	0.018125	540	9.79
2	52	S235	76×7	0.0119066	540	6.43
3	24	S235	38×3	0.0025884	540	1.40

Table 7

Counting the weight of the lower belt elements (according to GOST 8732-78)

Model No.	No. of cross-section type	Steel	Pipe profile	Weight of one meter in length profile, tons	Length of rods of the belt, m	Weight, tons
1	24	S235	95×7.5	0.0161775	540	8.74
2	24	S235	95×5	0.0110932	540	5.99
3	12	S235	50×8	0.00828288	540	4.47
	Weight of column support bracing in model No. 3					
3	41	S235	83×10	0.0179956	37.6	0.68

Table 8

Counting the weight of the bracing elements (according to GOST 8732-78)

Model No.	No. of cross-section type	Steel	Pipe profile	Weight of one meter in length profile, tons	Length of the bracing elements, m	Weight, tons
1	69	S235	68×9	0.0130899	540	7.07
2	89	S235	63.5×3.5	0.0051768	540	2.80
3	39	S235	57×3.5	0.00461598	540	2.49

Table 9

Counting the weight of columns (according to GOST 8732-78)

Model No.	No. of cross-sectio n type	Steel	Pipe profile	Weight of one meter i n length profile, tons	Weight of one column, tons	Quantit y of column s in the model, pcs	Total weight of columns in the model, tons
1	47	S235	273×8	0.052261	0.313566	4	**1.25**
2	55	S235	194×5	0.023296	0.139776	12	**1.68**
3	13	S235	203×7.5	0.047577	0.190308	4	**0.77**

The total weight of the space grid structure and columns is calculated in Table 10.

Table 10

Counting the total weight of the structure

Model No.	Weight of the upper belt, tons	Weight of the lower belt, tons	Weight of the bracing, tons	Weight of the structura l plate, t	Weight of the columns, tons	Total weight, tons	Weight of the space grid structure in the total weight of the model, tons
1	9.79	8.74	7.07	**25.60**	1.25	**26.85**	4.67
2	6.43	5.99	2.8	**15.22**	1.68	**16.90**	9.92
3	1.40	5.15	2.49	**9.04**	0.77	**9.80**	7.76

Figs. 7–8 show a diagram of the total weight of the models, including the weight of the columns.

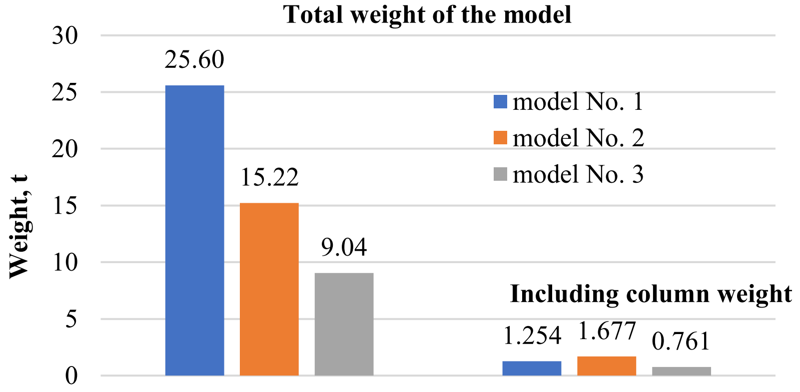

Fig. 7. **Total weight of the model and weight of columns in the model**

From Fig. 7 it can be seen that the weight of the structure according to the first model (when supported by four columns in the corners) is 68.2% more than when the columns on two sides are supported by two rows of columns.

But, obviously, if we displace the four columns from the corners by 4.5 m inside the slab and install braces between the column rod and the plane of the bottom belt, the weight of such structure can be reduced by 183% (2.8 times).

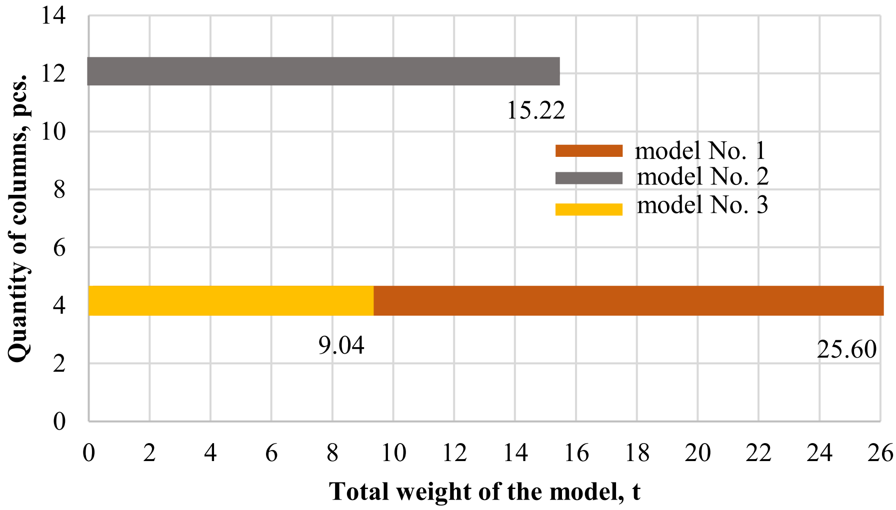

Fig. 8. **Changing the weight of the structure depending on the quantity of of columns according to the options for their arrangement:** model No 1 – 4 columns; model No 2 – 12 columns; model No 3 – 4 columns with displacement

The accuracy of the modeling results is determined by the correct construction of the finite element scheme, as well as by the analysis of the static operation of unified groups of rods (upper belt, lower belt, lattice elements). Thus, the elements of the upper belt behave in compression, the elements of the lower belt behave in tension, and the inclined elements of the lattice are subjected to an alternating axial force. In absolute value, the force *N* in the rods of the upper and lower belts has approximately the same value, which corresponds to the rules for the correct behavior of a spatial grid plate under a uniformly distributed load.

Static analysis was performed to determine the stress-strain state of the entire structure. The selection of sections of tensile elements was carried out according to the strength design. Selection of sections of compressed elements was carried out according to the strength and stability design. Limit flexibility of elements and vertical displacements of the whole structure are also taken into account in the design.

The adequacy of the design selection of the element group cross-sections is determined by the constraints and characteristics of the codes [20] assigned to the finite elements when specifying the stiffness and material parameters. The constraints are the strength condition for tensile rods, the stability condition for compressed rods, and the limitations according to the ultimate flexibility of the structure deflection, which is the maximum permissible. For the upper and lower belts, the types of structural groups were assigned – an element of the upper or lower belt of the structure; for the bracing elements, the truss grid element was typologically adopted, and for the columns – the column element. The reliability factor for responsibility is equal to 1.0. The coefficient of design length for columns in two planes is 0.6; the value of the limit flexibilities is taken in the range of 180–60α [20].

The design of steel structures was performed in the elastic stage of the material behavior.

Conclusions

1. The spatial grid structure, based on the crystal shape borrowed from natural crystals, is an effective roof structure that allows covering large spans (12÷36 m) without intermediate supports.
2. As a rule, the rods of the upper belt (orthogonal grid of rods in the XOY plane) behave mainly in compression, and the rods of the lower belt (orthogonal grid of rods in the XOY plane) behave mainly in tension. The spatial grid of the braces is subject to alternating effects – the inclined rods behave in both compression and tension. The space grid structure is a construction system that reacts quite strongly to changes in some parameters. Such parameters are a number of factors that

significantly affect the stress-strain state of a space grid structure. They are also called force regulators. As force regulators, we can use the way the columns are arranged to support the slab. All other parameters of the design model remain unchanged.

3. The most deformable and less rigid will be model No 1, supported on columns in 4 corners. Such a space grid structure behaves in two directions (in the XOZ and YOZ planes) and the deformations in these planes are equal and are about 21 mm. The deflections of the Z-axis for all three models do not exceed the maximum permissible deflection value of 10.3 cm. Model No 2 behaves as a plate supported on 2 sides (the plate rests on 6 columns on each side). Significant deflection occurs in the XOZ plane, but the vertical deflection is 2 times less. The most rigid system turned out to be the slab-model No. 3, as the deformability of such slab turned out to be minimal − 4.8 mm, which is about 1/3 of the maximum deflection of the slab in model No. 1. It can be concluded that the displacement of four columns by 4.5 m inside the slab along the X-axis and Y-axis, respectively, significantly changed the picture of the stress-strain state of the space grid structure.
4. The effectiveness of the structure based on model No. 2 was confirmed by further analysis of the axial force *N* in the rods. Thus, the compression force in the rods of model No. 3 decreased by a maximum of 466.7% (5.7 times) compared to the rods of model No. 1. The tensile forces in the lower belt decreased by a maximum of 192.1% (2.9 times) in model No. 3 compared to model No. 1.
5. The axial force *N* in the four columns for models No. 1 and No. 3 is almost the same. In model No. 3, the columns behave in central compression, since the bending moments in the rods in both planes are almost zero. The columns of models No. 1 and No. 2 behave in compression with bending, i.e. they are in a fundamentally different stress state.
6. The results of the strength check of the pre-accepted slab rod cross-sections have revealed that the space grid structure rods operate with significant understress. Thus, the bearing capacity of the cross-sections of the upper belt in model No. 1 was used by a maximum of 11.4%, in model No. 2 − by 7.2%, and in model No. 3 − only by 2%. The load-bearing capacity of the lower belt cross-sections in model No. 1 is used by a maximum of 15%, in model No. 2 − by 8.1%, and in model No. 3 − by 5.1%. The bearing capacity of the brace cross-sections in model No. 1 is used by a maximum of 15%, in model No. 2 − by 5.9%, and in model No. 3 − by 5.7%. In columns of model No. 1, the bearing capacity has been used by 26%, in model No. 2 − by 10%, in model No. 3 − by 15.7%.
7. The new cross-sections of the space grid structure rods selected according to the condition of the strength and rigidity allowed us to estimate the weight of each structural model of the space grid structure (Fig. 7).
8. Thus, according to the criterion of material capacity, the most efficient model of a space grid structure is a slab according to model No. 3, supported by 4 columns displaced inside the slab by 4.5 m.

Research perspectives

For a more detailed and optimal design, several analysis iterations should be conducted in order to ensure that the largest possible percentage of the structural rod groups in the structure has the fullest possible use of the cross-sectional area.

Also, for the purpose of a more accurate design, already in the second iteration, it is necessary to form groups of bars for several force *N* ranges. For them, we will assign a new corresponding pipe profile. Next, several iterative analyses should be carried out until the percentage of cross-sectional utilisation is significant (> 50%) for a larger number of rods in the design group. This will significantly reduce the weight of the slab, although it will increase the number of rod sizes in all rod structural groups.

Author contributions

Conceptualization and methodology, N.S.; investigation, N.S., S.H., V.L. and L.Ts.; writing − original draft preparation, H.Ts. and S.R.; writing − review and editing, H.Ts., S.H. All authors have read and agreed to the published version of the manuscript.

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