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ОСНОВНІ ПІДХОДИ ДО ПРИЗНАЧЕННЯ ПРОСТОРОВИХ І ХАРАКТЕРИСТИК ЖОРСТКОСТІ ПОКРИТТЯ СИСТЕМИ МАРХІ ПРИ РЕГУЛЮВАННІ ПАРАМЕТРІВ ЙОГО НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ

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Анотація. У статті розглянуто можливості перекриття прямокутних в плані великопрольотних покриттів з нестандартним співвідношенням сторін за допомогою структурної системи МАРХІ. Наведено основні відомості з типізації основних конструктивних елементів системи МАРХІ для стержнів і вузлових вставок-конекторів. Запропоновано підходи до регулювання основних параметрів напружено-деформованого стану (НДС) проектованої системи, реалізація яких дозволяє використовувати для перекриття нестандартних прольотів типові конструктивні елементи даної системи. Запропоновано аналітичні залежності для призначення основних параметрів (відносна висота покриття *h/l*, відносний вигин покриття *f/l*) і розглянуті основні закономірності зміни параметрів НДС проектованого покриття залежно від зміни параметрів проектування.

Ключові слова: великопрогонові структурні покриття, система МАРХІ, напружено-деформований стан, типізація, уніфікація.

ОСНОВНЫЕ ПОДХОДЫ К НАЗНАЧЕНИЮ ПРОСТРАНСТВЕННЫХ И ЖЕСТКОСТНЫХ ХАРАКТЕРИСТИК ПОКРЫТИЯ СИСТЕМЫ МАРХИ ПРИ РЕГУЛИРОВАНИИ ПАРАМЕТРОВ ЕГО НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ

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Аннотация. В статье рассмотрены возможности перекрытия прямоугольных в плане большепролетных покрытий с нестандартным соотношением сторон с помощью структурной системы МАРХИ. Приведены основные сведения типизации основных конструктивных элементов системы МАРХИ для стержней и узловых вставок-коннекторов. Предложены подходы для регулирования основных параметров напряженно-деформированного состояния (НДС) проектируемой системы, реализация которых позволяет использовать для перекрытия нестандартных пролетов типовые конструктивные элементы рассматриваемой системы. Предложены аналитические зависимости для назначения основных параметров (относительная высота покрытия *h/l*, относительный выгиб покрытия *f/l*) и рассмотрены основные

закономерности изменения параметров НДС проектируемого покрытия в зависимости от изменения параметров проектирования.

Ключевые слова: большепролетные структурные покрытия, система МАРХИ, напряженно-деформированное состояние, типизация, унификация.

THE MAIN APPROACHES TO THE APPOINTMENT OF SPATIAL AND STIFFNESS CHARACTERISTICS OF THE MARCHI SYSTEM ROOFS WHEN REGULATING THE PARAMETERS OF ITS STRESS-STRAIN STATE

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Abstract. The article discusses the possibilities of covering rectangular large-span roofs with non-standard side ratio with the help of the MARCHI structural system. The basic information about the typification of the main structural members of the MARCHI for rods and joint-connectors are given. The approaches for regulating the basic parameters of the stress-strain state (SSS) of the designed system are offered. Their realization allows to use typical structural elements of the system to cover the non-standard spans. Analytical dependences for appointment of basic parameters (relative height of roof *h/l*, relative bump of roof *f/l*) are suggested and the basic dependances of changing SSS parameters of the being designed roof depending on the design parameter change are considered.

Keywords: large-span structural root, system of MARCHI, stress-strain state, typification, unification.

Introduction

MARCHI system is a completely new method of design and construction, based on closed interconnection of analysis, manufacture, transportation and erection of structure elements and formation of volumetric and spatial structural covering of buildings and structures. This system corresponds to qualitative analysis of functional, technological, architectural, constructional, technical and economic tasks.

Unlike earlier existing methods of construction which are based on typification of large structural members (column, beam, truss, etc.) or of the entire building, the MARCHI system considers as an object of typification a rod and a nodal member , optimized according to their masses and bearing capacities. They do not follow any exact architectural and structural form, what ensures the possibility of their accumulation at the warehouse of a manufacturing plant with further assembling to form any necessary structure [1, 4, 8, 15, 16].

Structural members possess a number of advantages due to their large spatial stiffness. Structural coverings can be used for covering significant spans at different supporting contours or column grids. Comparatively short building height used at this allows to achieve impressive architectural solution as well as economy in building volume and enclosure walls. The regularity of configuration of the structure allows assembling covering for different spans and of various shapes of the same standard elements, and multiply connections of the system increase its reliability at sudden local failures [2, 11–13].

As for disadvantages of structural systems they include increased labour input at their manufacture and assembly, what is a consequence of the departure from the principle of material concentration. This drawback, to a certain degree, is compensated by homogeneity of operations at manufacturing and assembling and this creates conditions for line production of standard structural members [2, 14].

Cross – cored space structures (frame) (CCSS) of the MARCHI system possess good shape forming possibilities. Being assembled of separate tubular rods and connecting polyhedron members by one – bolt joints, CCSS of the MARCHI system are regular structures at the base of which there are regular polyhedrons. Their most important characteristics are densely filled space and uniform length of a modular rod within the designed structure (Fig. 1). These properties are in particular characteristic of regular Platon bodies such as tetrahedron and polyhedron and a number of Archimedean bodies – Archimedean polyhedrons, obtained by dividing ribs of Platon bodies into equal number of segments [1].

The unified assortment of the MARCHI system was created on the basis of optimization according to the weight of the limited number of rod and connecting block members, the choice of which is based on three main aspects:

1. Determination of gradation of bearing capacities of rod and connecting block members of the assortment, used for assembly of practically unlimited quantity of erection schemes of spatial structures.
2. Determination of the rational number of dimention type of rod and connecting block members in a large range of bearing capacity from 1 to 1000 kN.
3. Standardization of the main geometric sizes of rod and connecting block members and their connections, as well as usage of structural materials of high strength, ensuring optimal economy of erection grade of the system [1].

The MARCHI system has rather a wide range of application in construction. This system allows to cover structures for any destination with spans to 100 m. They may be both elite large scale structures such as museums, exhibition halls, covered (roofed) stadiums for football team training and warehouses, trade and special industrial buildings, coverings of powerhouse halls of large hydropower stations (Fig. 2) [10]. At present the system is widespread in Russian Federation (Bureyskaya Hydropower Station in the Far East, 86 structures built before Moscow Olympiad of 1980) [1].

The object of research is s structural load carrying construction of a large span covering of the entertainment center in Donetsk. Dimensions of the covered part of the building are 68.4×42.0 m (Fig. 3). The column spacing is different in longitudinal and transverse directions. The mark of the lower part of the covering +12.2 m [3].

The structural slab of the MARCHI system is used as a covering. The supporting members of the structural slab are tubes connected in blocks with bolts by special members called connectors. The pyramid having a rectangular base of 3.0×3.6 m (what corresponds to column spacing along and across the building) and edges of 3.6 m is taken as an elementary cell of the structure of the basic variant. The height of the structural covering is 2.73 m and the angle of an edge tilt α = 49.4° (Fig. 4) [3].

The MARCHI system possesses a lot of good qualities and is a reliable and economically advantageous covering variant. However, there is a certain number of problems which designers can face with at choosing the MARCHI system as a covering.

1) Using the MARCHI system with nonstandard spans leads to geometric change of an elementary cell and correspondently of irregular column spacing.

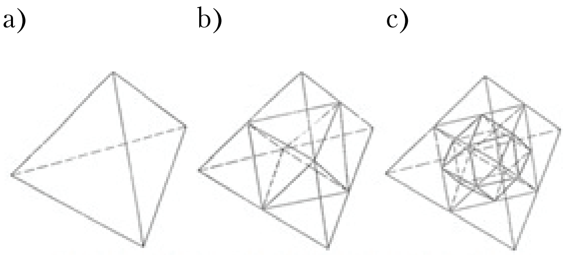

Figure 1. Platonad Archimedian bodies: a) tethraedron; b), c) polyhedron.

Figure 2. Turbine room span – Bureyskaya Hydropower Station (size covered 150.0×28.5 m).

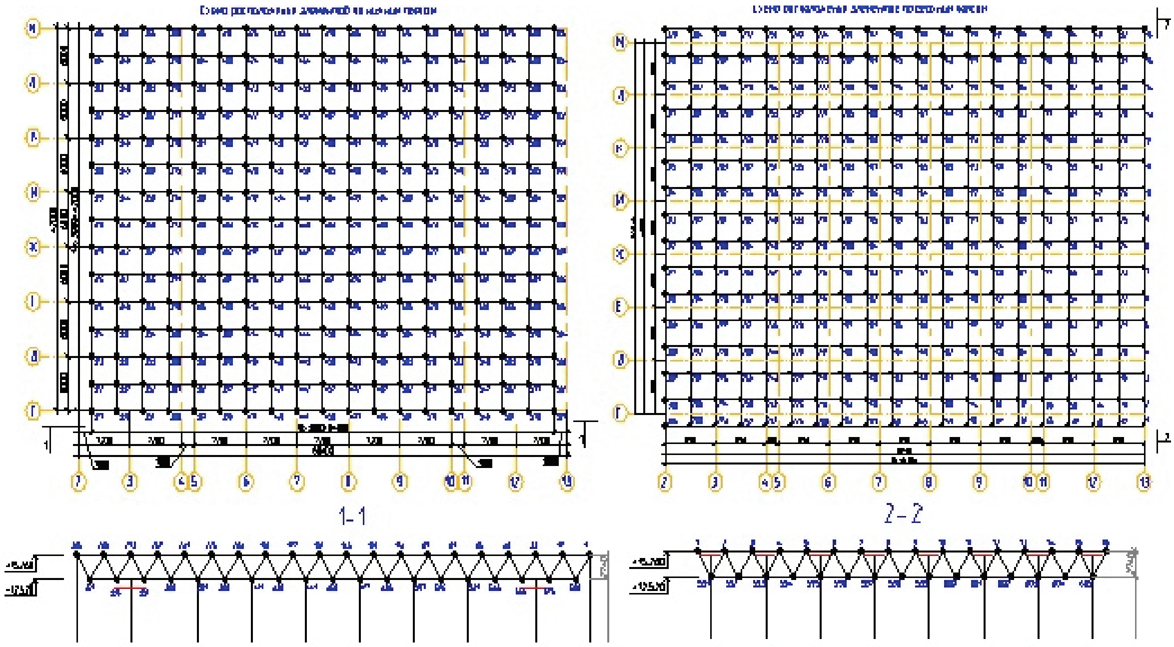

Figure 3. Being investigated structural system.

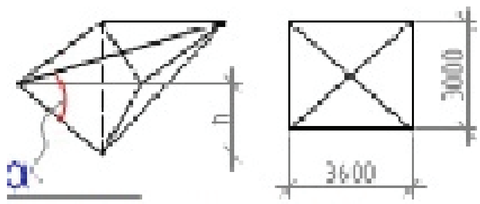

Figure 4. Elementary cell of a structural slab.

2) Due to unconventional ratio of structure plan dimentions (for a particular case discussed further, 68.4×42.0 ≈ 1.6:1.0) large efforts arise in blocks.

Some possible ways of effort control in covering members are the following:

1) changing local geometric parameters (in this particular case it is the change of the height of an elementary cell);
2) changing the general geometry of the covering by prelimenery upward bend (transition from flat geometry to curvilinear one).

The main part

The aim of the given research is finding such geometric parameters of the cell, which could satisfy maximum bearing capacity of high strength 40X «select» bolt which is 100 t. Both analytical and numerical analyses of SSS of structures are used for this purpose.

The analytical method of analysis is based on the approximate method of covering slab design and is carried out according to the methodology suggested by A. G. Truschev [5, 9].

Numerical researches were fulfilled using programme complex «SCAD», which is a calculating complex for strength analysis of structures by finite element method [7]. The single environment of designed scheme synthesis and analysis of results ensures unlimited possibilities for modeling designed schemes from the most simple to the most complicated ones.

In the course of analysis the basic changeable parameter was the ratio of the covering height to the span (h / l), depending on which the change of efforts in main bearing covering members were analyzed. The results of research are given in Tables 1, 2.

$$N_{\Pi} = \pm 2{,}1 M_{max} \cdot \alpha / h; \quad N_{p} = \pm 1{,}4 \cdot V \alpha_1 / \sin\alpha .$$

Notations used in figures 5 and 6:

N min p – maximum compression efforts in braces, obtained by the numerical method;

N п – efforts in braces obtained by the analytical method;

[N] – limit loads corresponding to bolt load – carrying capacity.

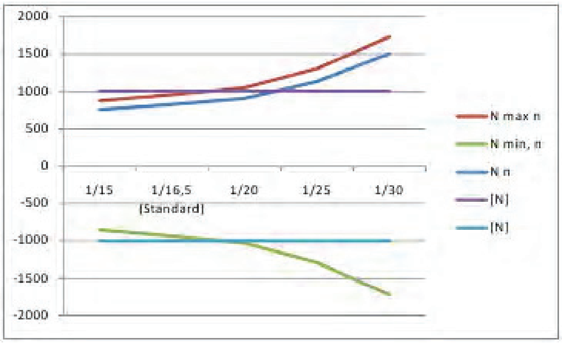

Figure 5. Efforts in chords (numerical and analytical analysis) depending on *h /l*.

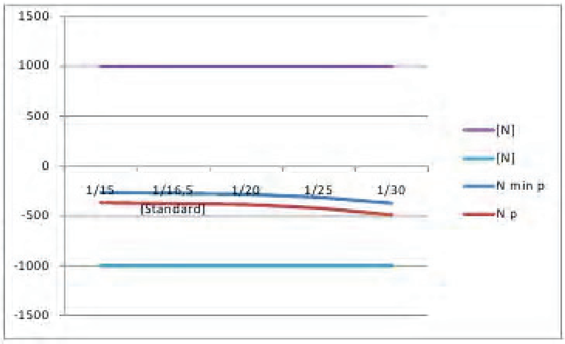

Figure 6. Maximum efforts in braces (numerical and analytical analysis) depending on *h / l*.

Table 1. Parameters and results of analytical analysis

№ Lines	Parameters	ratio *h/l*				
		1/15	1/16,5 (Standard)	1/20	1/25	1/30
1	2	3	4	5	6	7
1	Coefficients: Ψ a_{kop} $a_{\partial л}$	49 47,5 21	49 47,5 21	49 47,5 21	49 47,5 21	49 47,5 21
2	V (кН)	54,1	54,1	54,1	54,1	54,1
3	$M_{кор}$ (kNm) $M_{\partial л}$ (kNm) M_{max} (kNm)	358,6 158,4 358,6	358,6 158,4 358,6	358,6 158,4 358,6	358,6 158,4 358,6	358,6 158,4 358,6
4	h (m)	3	2,74	2,5	2	1,5
5	$l_{кор}$ (m)	42	42	42	42	42
6	$l_{\partial л}$ (m)	68,4	68,4	68,4	68,4	68,4
7	P (kN/m)	2,628	2,628	2,628	2,628	2,628
8	$a_{кор}$ (m)	3,6	3,6	3,6	3,6	3,6
9	$A_{\partial л}$ (m)	3	3	3	3	3
10	$a_{1,кор}$ (m)	7,2	7,2	7,2	7,2	7,2
11	$a_{1,\partial л}$ (m)	3	3	3	3	3
12	$Sin\alpha$	0,85	0,83	0,81	0,74	0,64
13	$\boldsymbol{N_n}$	±753,06	±824,5	±903,7	±1129,6	±1506,1
14	$\boldsymbol{N_p}$	–366,6	–375,4	–384,7	–421,1	–486,9

Table 2. Parameters and results of the numerical analysis

№ Lines	Parameters	Ratio *h / l*				
		1/15	1/16,5 (Standard)	1/20	1/25	1/30
1	$N_{max\ п}$, kN (element 247)	871,27	953,05	1043,6	1302,1	1733,27
2	$N_{min\ п}$, kN (element 861)	–854,5	–937,27	–1028,75	–1289,19	–1722,19
3	W_{max}, mm (joint 143)	93,3	107,9	125,8	186,4	318,5
4	$N_{min,\ p}$ kN (element 1237)	–265,41	–273,36	–282,89	–313,53	–372,56

The second method of effort control, as it was mentioned above, is the method of a preliminary upward bend. The aim of the investigation of this method is to study the influence of the slab sag on the SSS of the structure [17].

To analyze the influence of the preliminary curvature on the given (adopted) structure two ways of fixing a structural slab were chosen:

1. The structure is fixed by a hinge joint along the contour (outline).
2. The structural slab rests on elastic and compliant supports, rigid characteristics of which correspond to the considered variant of the design solution of the covering structure (the analysis is performed with account of support compliance Fig. 3).

All calculations by this method were also performed with the help of the programme complex «SCAD». The results of investigation are given in Tables 3, 4, 5 and in Figures 7 and 8.

Notes to Tables 3, 4, 5. A dash in columns means entry of the previous parameters in the framework of allowable values. However, the note does not refer to the 6-th pressing out stage in the column «Fastening with account of support compliance» in table 3 because no calculations were performed.

Figures 7 and 8 show the diagrames of SSS dependence of the sag of the structural slab. The values for diagrames were taken (adopted) from the corresponding tables (3, 4, 5).

Conclusion

1. For the being considered plan of covering (*a*:*b*=*1.6*:*1.0*), at the load *Q=263 kg/m²* [6], which is characteristic of Donetsk, the limiting ratio *h/l*, at which it is possible to use standard blocks-connectors of the MARCHI system, is *h/l=1/17* what is a bit different from conventional recommendations on appointment *h/l* for structural coverings (1/15... 1/30).
2. The most sensitive to changes of *h/l* ratio are efforts (loads) in chords, which are changed proportionally to the covering height *h*. At decreasing covering height 2 times efforts in chords of the structure increase 100 %. Less

Table 3. Parameters of numerical analysis for 1/50

№ of pressing out stage	Controlled parameter	Method of support fastening	
		Fixed joint	Fastening with account of support compliance
0 (flat stage)	W_{max} (mm)	357,49	356,92
	N_{max} (kN)	171,42	159,65
	f_0/l	0	0
1	W_{max} (mm)	309,64	844,93
	N_{max} (kN)	151,36	290,75
	f_0/l	8,5	18,8
2	W_{max} (mm)	249,72	790,59
	N_{max} (kN)	151,27	270,94
	f_0/l	15,8	36,4
3	W_{max} (mm)	202,95	717,77
	N_{max} (kN)	133,66	243,44
	f_0/l	21,8	52,0
4	W_{max} (mm)	170,23	647,04
	N_{max} (kN)	118,57	216,52
	f_0/l	26,6	66,4
5	W_{max} (mm)	147,27	586,06
	N_{max} (kN)	106,48	193,18
	f_0/l	30,7	80,4
6	W_{max} (mm)	130,37	–
	N_{max} (kN)	96,90	–
	f_0/l	34,2	–

Table 4. Parameters of numerical analysis for 1/30

№ of pressing out stage	Controlled parameter	Method of support fastening	
		Fixed joint	Fastening with account of support compliance
0 (flat stage)	W_{max} (mm)	135,76	318,48
	N_{max} (kN)	95,39	175,55
	f_0/l	0	0
1	W_{max} (mm)	–	317,13
	N_{max} (kN)	–	174,99
	f_0/l	–	7,1
2	W_{max} (mm)	–	315,20
	N_{max} (kN)	–	173,85
	f_0/l	–	14,15
3	W_{max} (mm)	–	312,55
	N_{max} (kN)	–	172,43
	f_0/l	–	21,15

Table 5. Parameters of numerical analysis for 1/20

№ of pressing out stage	Controlled parameter	Method of support fastening	
		Fixed joint	Fastening with account of support compliance
0 (flat stage)	W_{max} (mm)	67,33	150,98
	N_{max} (kN)	63,11	116,68
	f_0/l	0	0
1	W_{max} (mm)	–	150,82
	N_{max} (kN)	–	116,61
	f_0/l	–	3,35

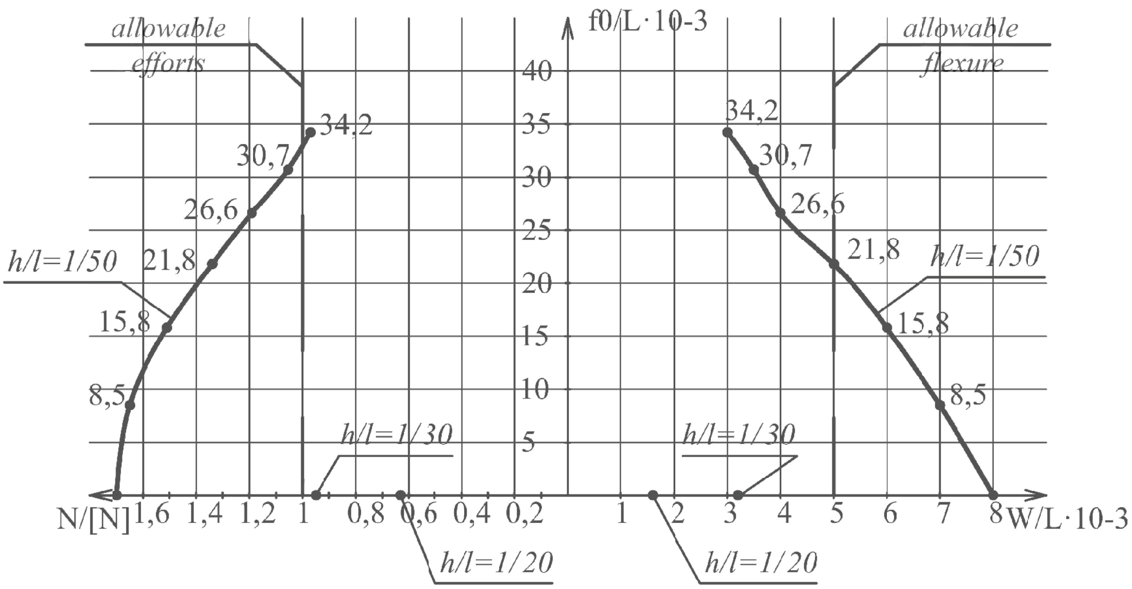

Figure 7. Dependeces of main parameters of SSS from covering (fixed fastening).

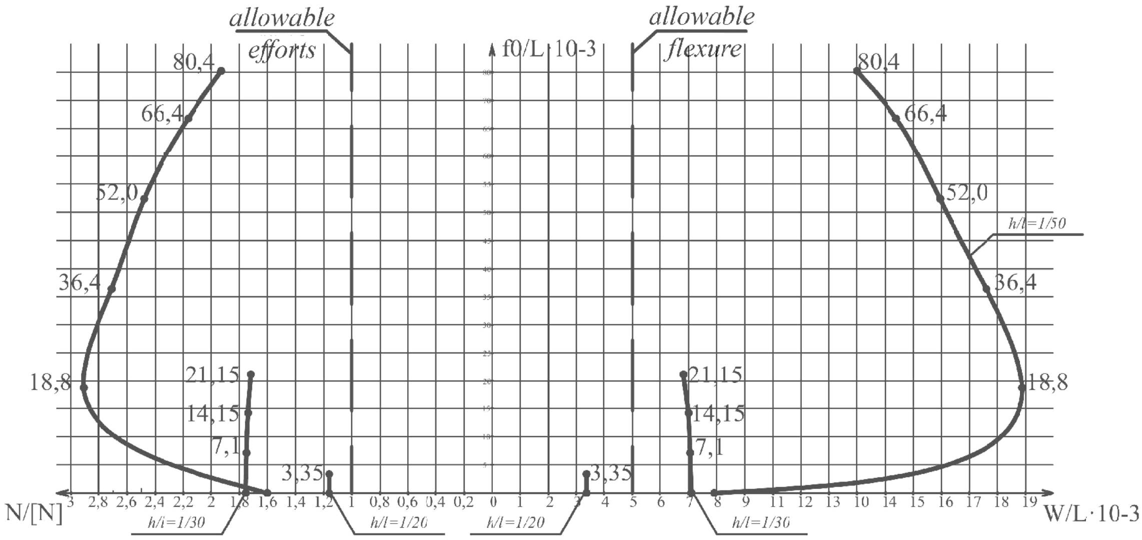

Figure 8. Dependences of the main parameters of SSS from covering (fastening with account of support compliance).

sensitive to changes of the geometry are the efforts in braces, where changes of geometric parameters 2 times cause 40 % change of efforts in braces.

3. When transfer from a flat scheme to a spatial one in the form of a gently sloping shell, the necessary value of the initial sag is $f/l=1/27$, at which the chance is created to use standard members of the MARCHI type for gently sloping shell that is stationary fixed along its contour.
4. Comparison of the results of analytical and numerical investigations show their satisfactory convergence within 15 %.

The results of research of the SSS of the structure obtained by means of a preliminary curvature demonstrated that the method of preliminary curvature is an efficient method of regulation of SSS parameters at the condition of the fixed rigid restraint of the structure. When designing the structural covering on elastic and compliable supports the method of preliminary curvature is the most effective at $h/l=1/50$. This ratio of the covering height to the span leads to the increased flexibility of the covering. This requires further specifying calculations for coverings of this type with the account of geometric nonlinearity.

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