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# ВРАХУВАННЯ НАПРУЖЕНОГО СТАНУ ВУЗЛІВ У РОЗРАХУНКАХ НАДІЙНОСТІ ВИСЯЧИХ СТРИЖНЕВИХ ПОКРИТТІВ

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**Анотація.** Відсутність необхідних для оцінки надійності покриттів в цілому досліджень надійності їх вузлів обумовлює актуальність задачі оцінки напружено-деформованого стану та надійності зварних вузлів покриттів і вироблення рекомендацій щодо таких конструкцій на основі отриманих даних. У зв'язку з цим у статті проаналізовано проблеми надійності великопрольотних висячих покриттів і описані принципові підходи до врахування надійності вузлів в розрахунках надійності висячих стрижневих покриттів. За розрахункові прийняті опорні вузли кріплення гнучко-жорсткої нитки до зовнішнього і внутрішнього контуру, проміжні вузли верхнього і нижнього поясів несучої нитки, вузли кріплення вертикальних і горизонтальних в'язей до несучих ниток покриття. В аналізі прийняті логіко-імовірнісні методи оцінки надійності вузлів і методи, основані на математичній статистиці. Проведений структурний аналіз надійності вузлів висячих покриттів показав, що вони в основному описуються послідовними схемами з включенням паралельних з'єднань залежних елементів, відповідних багатоелементним з'єднанням, підібраних з запасом. Врахування кореляції між елементами структурних схем вузлів внаслідок спільності зусиль і міцності сталі дозволяє скоротити число врахованих у схемі елементів і підвищити підсумкову оцінку надійності.

**Ключові слова:** вузли висячого покриття, гнучко-жорсткі нитки, показники надійності, напружено-деформований стан, логіко-імовірнісні методи.

# УЧЕТ НАПРЯЖЕННОГО СОСТОЯНИЯ УЗЛОВ В РАСЧЕТАХ НАДЕЖНОСТИ ВИСЯЧИХ СТЕРЖНЕВЫХ ПОКРЫТИЙ

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**Аннотация.** Отсутствие необходимых для оценки надежности покрытий в целом исследований надежности их узлов обусловливает актуальность задачи оценки напряженно-деформированного состояния и надежности сварных узлов покрытий и выработки рекомендаций относительно таких конструкций на основе полученных данных. В связи с этим в статье проанализированы проблемы надежности большепролетных висячих покрытий и описаны принципиальные подходы к учету надежности узлов в расчетах надежности висячих стержневых покрытий. В качестве расчетных приняты опорные узлы крепления изгибно-жесткой нити к внешнему и внутреннему контуру, промежуточные узлы верхнего и нижнего поясов несущей нити, узлы крепления вертикальных и горизонтальных связей к несущим нитям покрытия. В анализе приняты логико-вероятностные методы оценки надежности узлов и методы, основанные на математической статистике. Проведенный структурный анализ надежности узлов висячих покрытий показал, что они в основном описываются последовательными схемами с включением параллельных соединений зависимых элементов, соответствующих многоэлементным соединениям, подобранным с запасом. Учет корреляции между элементами структурных схем узлов вследствие общности усилий и прочности стали позволяет сократить число учитываемых в схеме элементов и повысить результирующую оценку надежности.

**Ключевые слова:** узлы висячего покрытия, изгибно-жесткие нити, показатели надежности, напряженно-деформированное состояние, логико-вероятностные методы.

# STRESS-STRAIN STATE OF THE JOINTS IN RELIABILITY COMPUTATION OF SUSPENSION ROD ROOFS

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**Abstract.** Due to the lack of investigations of reliability estimating of suspension roofs in common with their joints, that lead to urgency of estimation of stressed-strained state and reliability of welded joints of roofs and creating recommendations concerning such structures on the basis of obtained data. Due to this the reliability of large-span suspension roofs was investigated and a novel fundamental approach is proposed for the determination of joints' reliability in the design phase of suspension rod roofs. The supporting joints of rigid threads to the external and internal contour, intermediate joints of the top and lower chords of supporting threads, joints of vertical and horizontal links to the supporting thread of the roof were used as design data. To estimate the joints' reliability the logic and probabilistic methods were used for this analysis conjointly with the methods based on mathematical statistics. The structural design of the reliability of suspension roof joints are mainly described by sequential schemes, including parallel connections of dependent elements, corresponding to multi-element connections. The correlation between the elements of structural schematic joint drawings, due to the generality of strength of the steel, allows to reduce the quantity of elements and increase the final reliability level of joints.

**Keywords:** suspension roof joints, rigid threads, reliability indices, stressed-strained state, logic and probabilistic methods.

## Introduction

The problem of reliability of structures is a constituent part of a science of building elements uniting problems of design, designing work, production, erection and operation of building and constructional structures.

Reliability of metal structures of buildings and constructions representing themselves statistically determined and non-determined systems of components was investigated by many researchers. The major problems and samples were considered by S. F. Pichugin [1] and G. Shpete [2].

In the engineering theory, reliability evaluation of complex systems is usually reduced to examination and analysis of two principal kinds of joints:

a) series connection, failure-free work probability of which at independent components is determined as

$$P_m = \prod_{i=1}^{m} P_i , \qquad (1)$$

where $P_i$ is probability of failure-free work of $i$-component;

b) parallel connection

$$P_m = 1 - \prod_{i=1}^{m} (1 - P_i) . \qquad (2)$$

Series connection in probabilistic meaning can be used for description of statistically determined system, e. g. trusses.

But a practical evaluation of real structures reliability cannot be reduced to application of simple equation (1) in consequence of availability of correlation between resistance conditions of components.

Activities of statistically non-determined systems is definitely associated with parallel connection, but evaluation of their reliability cannot be done according to (1) because of redistribution of forces in the system after failure of separate components which are dependent. Thus, reliability evaluation of statistically non-determined structures requires thorough and careful analysis of character of their activities and failure under load and discount of distinguishing features of failures of the components and the system on the whole.

Reliability analysis of statistically non-determined system is usually done by the following methods and techniques: a method of states, a probabilistic method of limiting equilibrium, a Monte-Carlo method, a Markovian model of reliability analysis [1]. Analytical and computational methods used in the technical reliability theory to the computation of complex systems, which can be used for reliability analysis of statically indeterminate systems are shown in the Fig. 1.

Reliability of metal structures of buildings and construction representing statically determined or undefinable systems of elements was studied by numerous scientists. Separate problems and example were considered by a number of researchers. Good recent results this issue are described by Kala [3]. In the determination of reliability parametres of unique structures Guo et al. [4], Kwon and Frangopol [5] and Wu et al. [6] have recieved good results.

Useful scientific experience in the field of structural reliability assessments have received Luo et al. [7] and Xiao et al. [8]; in the field of probabilistic interval reliability of structural systems are Qiu et al. [9].

The problem of reliability especially concerns unique large-span structures. Among these are suspension shell which have increased level of responsibility on application denial from which can bring to severe economic results and social consequences.

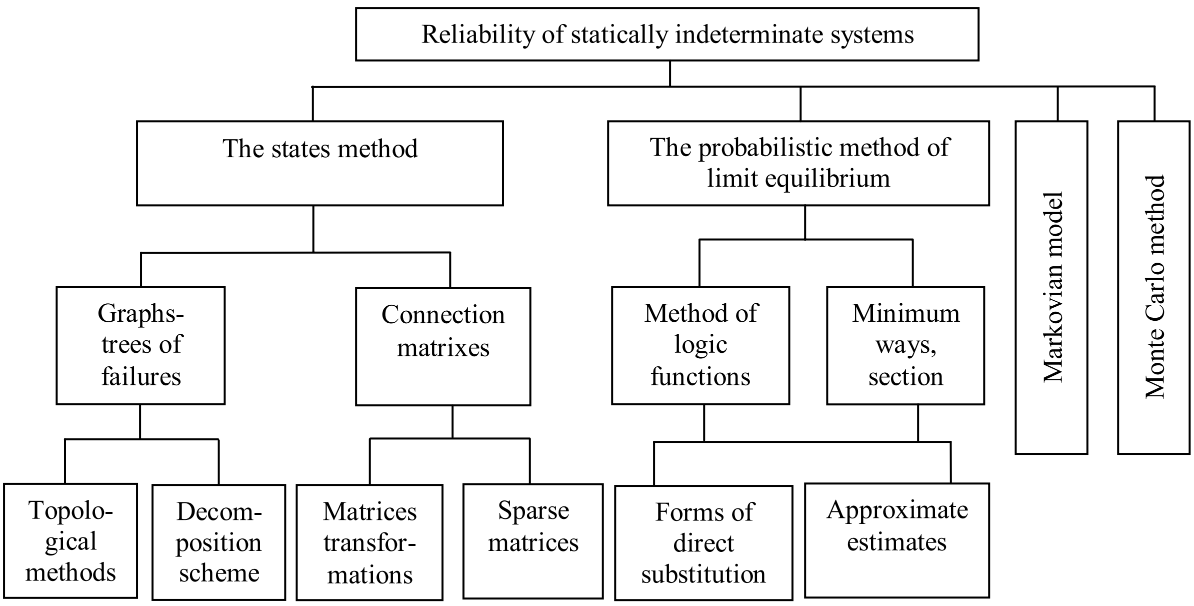



**Figure 1.** Methods for assessing the reliability of statically indeterminate systems.

During their designing there are problems exceeding the limits of existing regulatory documents. Novelty of technical conceptions demand from a structural engineer profound specific knowledge, an experience of designing work of such kind of structures is required. Requirements of reliability, technological and economic efficiency have to be realized in full volume, in this connection, environmental and social factors should be considered.

Nowadays, one of the most dynamic developing kinds of space, large-span structures interesting in architectural and structural relations are the stationary, suspension roofs (Fig. 2).

Large-span roofs have a higher level of responsibility as their failures can lead to serious economic and social consequences. In this context, the design of these unique structures should be based on an integrated approach of rational choice of design solutions. These decisions are related to functionality, architectural design, manufacturing and installation techniques, operating conditions. The requirements of reliability, manufacturability and cost-effectiveness into account environmental and social factors should be fully implemented.

The bases the shells design were founded in the XIXth century. The intensive progress of the shells design has been started since the 1930s. Great contribution to the theory of design of large-span spatial shells was done by a number of researchers. Today closely pursuing this issue V. F. Mushchanov, Y. N. Pryadko [10] and I. N. Rudneva [11].

The last 15 years in particular, the advent of powerful computers and the development of sophisticated nonlinear CAD software (ADINA [12], ABAQUS [13] and others) have enabled engineers to utilize suspension roofs in complicated large scale structures, some of which can be classified among unique examples of engineering excellence [14].

Probabilistic assessment of reliability is one of the most important tasks in roofs researches in the objects with high responsibility. The main property that determines the reliability of these structures is the dependability of their work: ability to save the pre-defined operational quality during the lifetime. Quantitative characteristic of this property is the probability of failure-free operation.

Among the works of the reliability assessment of the large-span suspension roofs and cable-stayed structures can be distinguished works of V. F. Mushchanov [10] and A. A. Sventikov [15] and P. G. Yeremeyev [16].

The joints occupy the significant part in composition of structures. Application of numerical simulation permits to investigate the impact of structural schematic drawing to the joints operation and accumulate of necessary base of statistic materials on stressed-strained state of such kind of joints. At the same time, contemporary status of computer

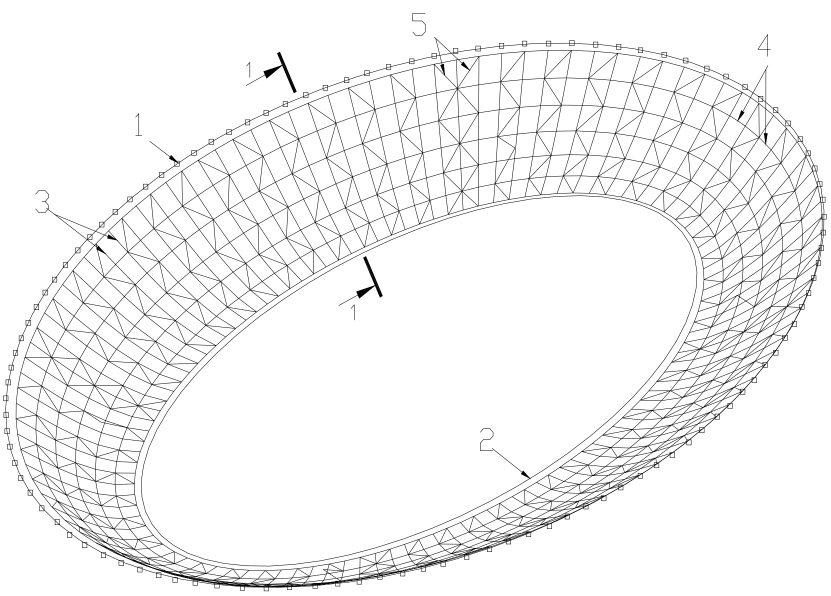



**Figure 2.** Structural schematic drawing of spatial and rod roof: 1, 2 – external and internal contours, 3, 4, 5 – radial, annular and diagonal components.

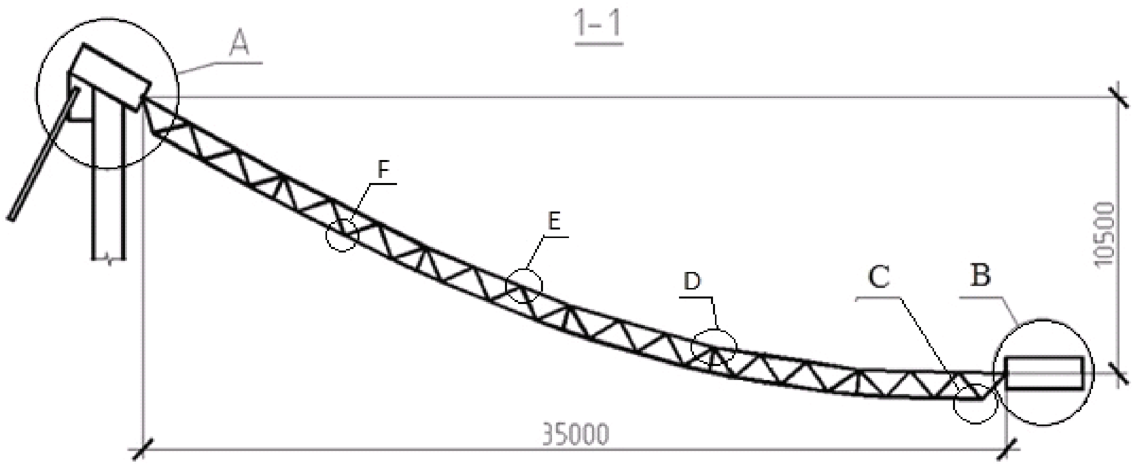



**Figure 3.** Structural schematic drawing of space and bar roof. Open-cut mine 1–1.

engineering development opens possibilities for determination of reliability estimation of joints of suspension roofs, bearing in mind parameters of stressed-strained state and correlation links between functions of bearing capacity of joints elements.

N. Chowdhury [17] and M. Skorupa [18] dealt with investigations of stressed-strained status of steel structures joints. However, lot of questions remain in the investigation of stress-strain state (SSS) of suspension roofs joints.

Nowadays, practically there are no investigations to estimate reliability of roofs on the whole and reliability of their joints, that stipulate of urgency of estimation problem of stressed-strained state and reliability of welded joints of roofs and working-out of recommendations concerning such structures on the basis of obtained data.

The hot topic of provision of required level of reliability at design work of large-span roofs, in particular of suspension and rod shells, in many aspect determining the efficiency of large-span roofs construction, was considered by V. F. Mushchanov and Y. N. Pryadko and received its approval in [10] in which the method of design and design work of rigid threads with through section based on determination of numerical exponents of reliability has been made. Block-scheme of this method is shown on Fig. 4. The values designations of the block-scheme are shown in Table 1.

The proposed method provides the sequence of solution of problem series: determination rational geometric parameters of a structure; obtaining of appropriate rigidity characteristics of basic supporting elements; determination of a track of elements destruction for typical roof diagram with the following evaluation of stressed and strained state of an object; determination of numerical safety indices of a structure (determination of the lower and upper safety limits).

The above-described method also has shortcomings. This method does not take into account issues of joints working in a shell in determining the reliability of the roof. This issue provides new areas of research. The first step in this direction were made already. Some issues have been considered in [19], where the fundamental approaches to providing the reliability of suspension roofs joints by numerical methods were determined. However, the authors reviewed only the common approaches for typical joints of suspension roofs. In this article authors apply same approaches for the joints of suspension roof, designed by the described above method. Models of joints was designed in modern CAD.

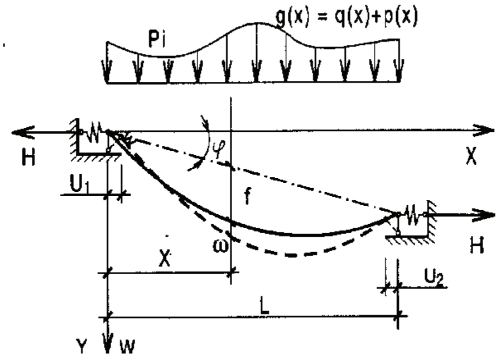
Thus, the main objective at the given stage is to study the fundamental approaches to determination of joints reliability of suspension roofs by numerical methods, using microsimulation in modern CAD.

## Methodology

To achieve the above the roof by described method (Fig. 4) was designed. To perform the structural analysis the following dimensions of the roof approved: a = 186 m; b = 136 m; $a_1$ = 123 m; $b_1$ = 85 m. The main load-supporting elements of the designed roof are external contour, supported by columns or walls

**1. Engineering analysis of the roof**

**1.1. Analysis of the bent and rigid thread**




Equation of thread equilibrium

$$EI\frac{dw}{dx^4} - H\frac{d^2(f+\omega)}{dx^2} + q(x) = 0$$

Forces in thread components

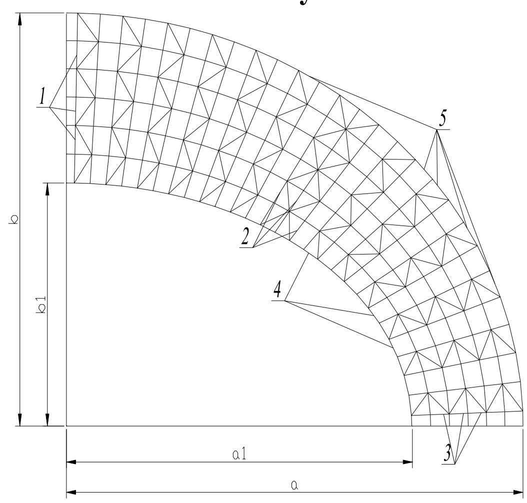
$$N_{ВП} \approx N \cdot \frac{a_{НП}}{h} + \frac{M}{h} \cdot \alpha \cdot k$$

$$N_{НП} \approx N \cdot \frac{a_{ВП}}{h} + \frac{M}{h} \cdot \alpha$$

Improved values of forces

$$N_{UB}^{y} = k'_{\sigma}k''_{\sigma}N_{UB} \qquad N_{UB}^{y} = k'_{\sigma}k''_{\sigma}N_{UB}$$

**1.2. Structural analysis of the roof**




1. Assignment of geometry parameters of the shell;
2. Snow load S requirement of $\overline{D}_1, \overline{D}_4, \overline{W}, \overline{U}$;
3. $\overline{D}_1, \overline{D}_4, \overline{W}, \overline{U}$ determination;
4. Determination of N and M forces from dependences of $\overline{D_1} = f(\overline{M}, \overline{W})$, $\overline{D_1} = f(\overline{N}, \overline{W})$ $\overline{D_1} = f(\overline{M}, \overline{U})$, $\overline{D_1} = f(\overline{N}, \overline{U})$

**2. Numerical analysis of the shell in the software SCAD**
(determination of trace to failure)

**3. Probabilistic design of the roof**

**3.1. Lower limit of reliability**

– Series connection (a brittle model);
– Random quantities: $\tilde{A}$, $\tilde{\sigma}_y$;
– Calculation of the reliability indices based on using the unique Monte Carlo method;
– Identification of the law of distribution of the random quantity density and determination of its boundaries.

**3.2. Higher limit of reliability**

– Parallel connection (a plastic model);
– Random quantities: $\tilde{A}$, $\tilde{S}$, $\tilde{M}, \tilde{N}$, $\tilde{\sigma}_y$,

$$\tilde{\sigma}(\tilde{M}, \tilde{N}, \tilde{A}) = \overline{\sigma}_N \cdot (1 + \nu_N - \nu_A) + \overline{\sigma}_M \cdot (1 + \nu_M - \nu_A);$$

– Safety characteristics of Rzhanitsyn

$$\gamma = (\overline{\sigma_y} - \overline{\sigma}) / \sqrt{\hat{\sigma}_y + \hat{\sigma}};$$

– Calculation of the reliability indices of the roofing
1-Psis=(1-Pspan)×(1-Pext.con.)×(1-Pint.con. )

**Figure 4.** Block-scheme of the determination technique numerical indices of reliability of suspension roof.

**Table 1.** The values designations of the block-scheme in Fig. 4

| | |
|---|---|
| h | – height of the threads section; |
| $a_{ub}$, $a_{lb}$ | – distance from the center of gravity of the composite section to the center of the cross section of the upper and lower thread chords respectively; |
| $\alpha$, k, k′, k″ | – correction coefficients; |
| $\overline{D}_1, \overline{D}_4, \overline{W}, \overline{U}$ | – dimensionless spatial and stiffness parameters; |
| $\widetilde{A}, \widetilde{S}, \widetilde{M}, \widetilde{N}, \widetilde{\sigma}_y$ | – random values of supporting contour section, snow load, forces and stresses in the elements respectively; |
| $\nu_N$, $\nu_M$, $\nu_A$ | – random values of the area section of supporting contour, of the snow load, of the forces and stresses in the elements respectively; |
| $P_{syst}$, $P_{span}$, $P_{ext.con}$, $P_{int.con}$ | – probabilities of failure of roof system, load-supporting threads, internal and external contours respectively. |

of the stadium; internal unsupported contour, supported by thrust; rigid threads with the form of trusses (Fig. 2). The roofs contours designed by welded box-section from steel sheet. All the other elements of the supporting structures made by box-shaped profile. As a design load were taken a constant load of its own structures weight and temporary snow load 160 kg/m$^2$ for Donetsk (Ukraine) [20]. This choice is due to the fact that the authors of this method are living in Donetsk. After completing all the necessary computations and definitions of the all physical characteristics of structural elements the design scheme in AutoCad 2014 for the macro-analysis was created. As it is seen in Figure 2 the external contour is fixed along the length. At same time the internal contour is not fixed and supported only by the thrust. The obtained scheme was successfully transported in Abaqus/CAE 6.13-1 for performing the macroanalysis and determining the forces and deformations in the rods. At the same time the three-dimensional model of the supporting joint «A» of the roof for microanalysis in SolidWorks 2014 has been performed and also transported in Abaqus/CAE (Fig. 5).

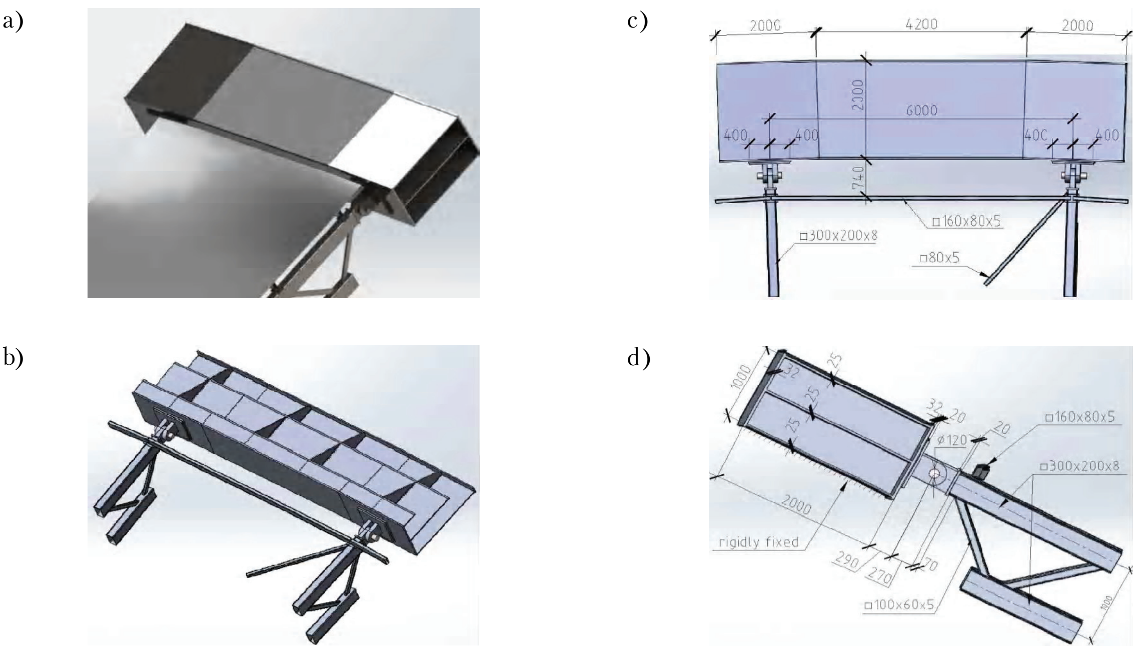



**Figure 5.** Tree-dimensional model of the supporting joint «A»: a) general view; b) cut view; c) top view; d) side view.

Further, the critical external load and also the internal forces in the places of clipping elements to models of joints were applied, giving rise to critical stresses in the elements and appear irreversible deformation. It is necessary to obtain the deformability of the model and identify the most vulnerable places. Furthermore, the displacements with all fastenings to the three-dimensional model were applied for the determination of the stress and strain state (Fig. 2, 6). All connections of elements of joints are made by welding. The exception is only in connection between the pin and truss in joint «A». In this case, the contact interaction is slipping without friction. Models were divided by grid with size of mesh 30 mm to perform the microanalysis. The simulation results are shown at paragraph 3 in Fig. 7.

Let us consider the fundamental approaches to regard of reliability of the main joints of system of the roof determining its structural form. We can relate to them the following: supporting joints of rigid thread to external contour «A» (Fig. 3, 7) and internal contour «B» (Fig. 3), joint of the connection the suporting brace with the lower chord of the truss «C» (Fig. 3), interstitial joints of upper and lower chords of supporting thread «D», «E», «F» (Fig. 3). In this case, it is necessary to note that denial not each joint may bring to fall of the entire roof. We assume that the destruction is the time when stress in the elements of the joint exceeds the yield strength of steel $\sigma_{Ti}$. On the basis of it, let us appoint the types of connections of joints in the roof (sequential or parallel connection). Sequential connections of joint in a roof have supporting joints «A» and «B». Parallel connections of joint in a roof have intermediate joints «C», «D», «E», «F».

In accordance with accepted in logic and probabilistic simulations notations [1], the conditions of trouble-free operation of elements let us denote by X, failure conditions by X'. The joint operation on whole let us describe by the function of introduced logical variables – the function of Boolean algebra (FBA) $y$ ($X_1$, $X_2$, ..., $X_n$) called as the condition of the system capacity (a joint).

The shortest way of successful functioning (SWSF) describing probability of trouble-free operation of minimum set of elements necessary for trouble-free of the system is expressed in the form of conjunction (logical multiplication) of elements:

$$P_i = \Lambda_{i \epsilon (K_{pl})} X_i \,, \tag{3}$$

where $K_{pl}$ – is a set of elements entering into the given way.

Starting from the above-mentioned, the condition of the system capacity (a joint) is described in the form of disjunction (logical adding) of all «d» having in the system the shortest ways of successful functioning (SWSF):

$$y(X_1, X_2, ..., X_n) = V_{i=1}^{d} P_i = V_{i=1}^{d} [\Lambda_{i \epsilon (K_{pl})} X_i]. \tag{4}$$

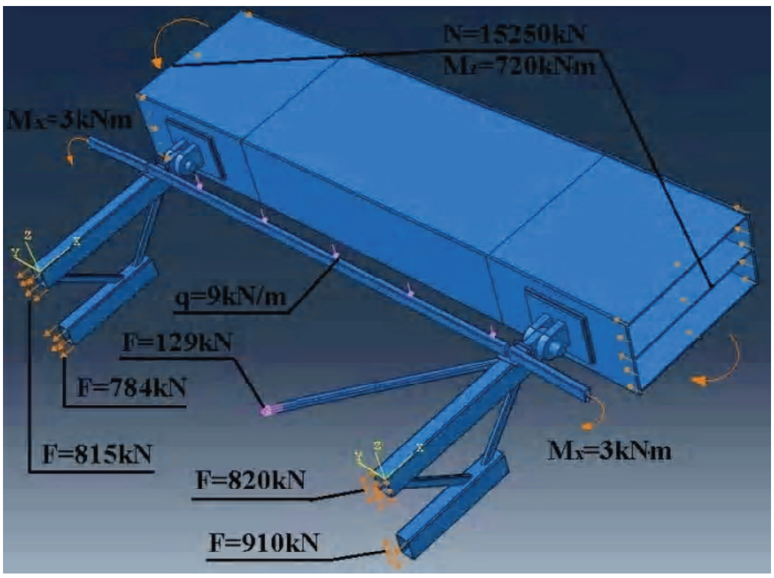



**Figure 6.** Tree-dimensional computational model of the supporting joint «A».

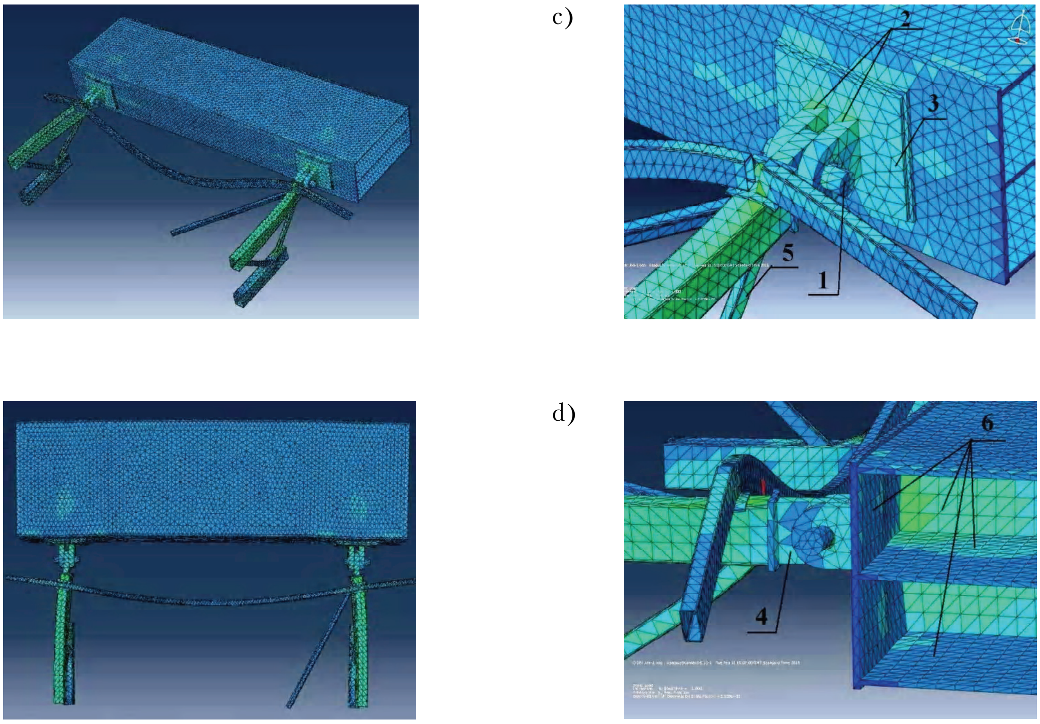



**Figure 7.** Deformed three-dimensional model in the supporting zone of the external contour: a) general view; b) view 1; c) view 2; d) view 3.

## Results and discussion

Lets start with supporting joint of suspension roof to the outer bearing outline «A» (Fig. 7).

Starting from the actual operation of such joint, its failure can occur in consequence of:

1 – a pin crushing;
2 – break of the fasteners between the thread and the contour;
3 – break of the mounting plate between the contour and truss;
4 – break of the fasteners between the upper chord element and the pin;
5 – the collapse of the supporting brace;
6 – loss of stability of the support contours elements.

Enumerated failures are represented in a form of elements in a total structural schematic drawing (Fig. 8). In this case, it would be unjustified the presentation of twin welds in the form of parallel connection because in the latest ones each element enables to carry out a function rested on a connection. In examined joint, one of two welds, obviously, cannot perceive double load and a twin weld is actually a single weld superimposed by two plots reflected in series connection.

In the compound 2, if the pin has a stop at the edges, redistribution of the stresses after a failure of one of the fastening elements will be possible. However, this dramatically increases load on the remaining elements, the nature of his work is changing and can be reflected by a parallel connection of the dependent elements. A similar situation in compound 6. If the one of the contour elements will lose a stability, the load will be distributed to other elements.

The condition of the system capacity reflecting the operation of a joint (Fig. 7) is described in the form:

$$y(X_1, X_2 ..., X_{11}) = X_1 \cdot (X_{21} \cdot VX_{22}) \times \\ \times X_3 \cdot X_4 \cdot X_5 \cdot (X_{61} \cdot VX_{62} VX_{63} VX_{64}). \qquad (5)$$

For conversion from logical function to probability one, the analysis of correlated bonds between the elements can be implemented. One can take approximately that all the forces in the joint are proportional to a load from the roof (main roof and snow one), thus in the condition of non-destruction of all the elements

$$Y_i = X_i = R_i - S_i = \sigma_{Ti} - \sigma_{qi} \geq 0, \qquad (6)$$

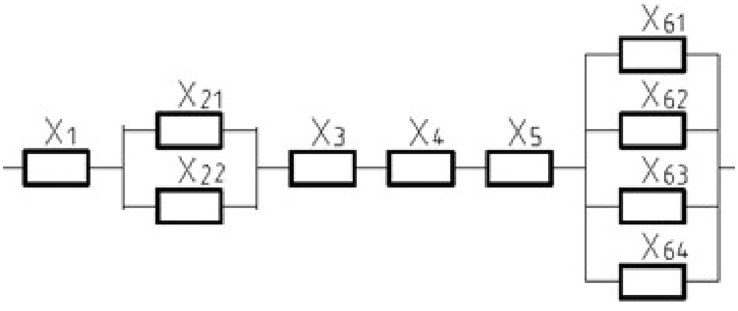



**Figure 8.** Reliability of a supporting joint of a suspension roof. Structural schematic drawing.

parameters $\sigma_{qi}$ are connected functionally. The second parameter $\sigma_{Ti}$ obviously coincides for details 1, 6 and welds 2–5. Thus, corresponding conditions of the trouble-free operation $X_1 - X_6$ have tight correlative connection with $r \approx 1$. In consequence of it, at conversion from FBA (5) to probabilistic form the pointed out groups of elements have to be presented by «the weakest units» with $P_{imin}$.

Probability properties of steel of details 1–6 and welds 2–5 are obviously should be taken independent, as such kind of an offer goes into reliability factor of the joint. In consequence of it, the correlations between the elements $X_i$ and $X_j$ in accordance with [11] are determined as:

$$r_{ij} = \frac{\hat{\sigma}_q^2}{\sqrt{\hat{\sigma}_T^2 + \hat{\sigma}_q^2}}. \quad (7)$$

Using total expression for standard ratio $\hat{\sigma}_T^2$ and $\hat{\sigma}_q^2$, with regard for variability and standardized deviations of designed value $\gamma_T$ and $\gamma_q$ for snow and fixed load [20] with regard to above-mentioned concepts about correlation connections, we get correlation coefficients $r_{ij} \leq 0.5$ between conditions of joint elements failure with independent strength of steel. At such comparatively weak correlation, the failure of elements can be considered independent.

On the basis of above-mentioned facts, conversion from FBA (5) to the formula of probability of trouble-free operation (1) of the supporting joint «A» (Fig. 7), we get in the form of

$$P_A = P_1 \cdot (1 - Q_{21} \cdot Q_{22}) \cdot min(P_3, P_4, P_5) \times \times (1 - Q_{61} \cdot Q_{62} \cdot Q_{63} \cdot Q_{64}). \quad (8)$$

The similar analysis for the other most important joints of the roof can be made and the values of probability of trouble-free operation of joints «B», «C», «D», «E», «F» can be obtained: $P_B$, $P_C$, $P_D$, $P_E$, $P_F$.

With regard to accepted types of joints connections, probability of trouble-free operation of the system of joints takes the following form:

$$P_{sis\,y} = P_A \cdot P_B \cdot P_C \cdot P_D \cdot P_E \cdot P_F. \quad (9)$$

At the given stage of investigations the fundamental approaches to definition of reliability of joints of suspension roof were determined by numerical methods.

The further investigations assume on the basis of the method of Mushchanov–Priadko [10] to originate the method of design and designing work of suspension roofs, based on determination of numerical indices of reliability of designed structure with regard to joints operation in composition of a shell at determination of roof reliability. Prospective method offers calculation in 2 stages:

a) analysis of the systems reliability at the macro level considering the geometric characteristics of sections of the main structural elements;
b) analysis of the reliability of the system at the micro level, when the reliability analysis of the most strained structural elements is performed based on the analysis of the behavior of joints connections.

## Summury

1. Carried out structural design of reliability of joints of suspension roofs has shown that they are mainly described by sequential schemes including parallel connections of dependent elements corresponding to multi-elementary connections selected in store.
2. Correlation regard between the elements of structural schematic drawings of joints in consequence of generality of intensification and

strength of steel allows to reduce quantity of elements in the scheme and increase resulting estimation of reliability.

3. Reliability of joints of suspension roofs depends on the number of supporting elements entering into them: with increase of the number of elements, the reliability is decreased, low-element joints have greater reliability. The important factor is also homogeneity of strengths of elements: joints reliability results the least if reliability of the elements should be considered as independent one. Such kind of situation appears if the elements are produced from different types of steel by various producers, at comparison of fabricated and field joints, etc.
4. In consequence of its multi-elementary nature, the joints can be less reliable than elements themselves (rods of columns, span parts of suspension threads, etc) that should be considered at estimation of reliability of structures on the whole.
5. The proposed approach can be used for suspension and convex rod shells with similar design solutions of joints.
6. After performing the reliability analysis of the joints it is need to increase the supporting capacity of the construction in places with fixed critical stresses by increasing the welds cathetus, installation additional bolts, additional components, high strength steels and other.

## References

1. Пичугин, С. Ф. Надежность стальных конструкций производственных зданий [Text] / С. Ф. Пичугин. – Полтава : АСМИ, 2009. – 452 с.
2. Шпете, Г. Надежность несущих строительных конструкций [Text] / Г. Шпете. – М. : Стройиздат, 1994. – 288 с.
3. Kala, Z. Sensitivity Analysis of Stability Problems of Steel Structures Using Shell Finite Elements and Nonlinear Computation Methods [Text] / Z. Kala, J. Kala // WSEAS Transactions on Applied and Theoretical Mechanics. – 2009. – 4(3). – P. 105–114.
4. Time-dependent reliability of box-girder bridge considering creep, shrinkage, and corrosion [Text] / T. Guo, R. Sause, D. M. Frangopol, A. Li // Journal of Bridge Engineering. – 2011. – 16(1). – P. 29–43.
5. Kwon, K. Bridge fatigue reliability assessment using probability density functions of equivalent stress range based on field monitoring data [Text] / K. Kwon, D. M. Frangopol // International journal of fatigue. – 2010. – 32(8). – P. 1221–1232.
6. Wu, Z. Application of latin hypercube sampling technique to slope reliability analysis [Text] / Z. Wu, S. Wang, X. Ge // Rock and Soil Mechanics. – 2010. – 31(4). – P. 1047–1054.
7. Luo, Y. Structural reliability assessments based on probability and convex set mixed model [Text] / Y. Luo, Z. Kang, A. Li // Computers & Structures. – 2009. – 87(21–22). – P. 1408–1415.
8. Reliability sensitivity analysis for structural systems in interval probability form [Text] / N. Xiao, H. Huang, Z. Wang [et al.] // Structural and Multidisciplinary Optimization. – 2011. – 44(5). – P. 691–705.
9. Qiu, Z. Probabilistic interval reliability of structural systems [Text] / Z. Qiu, D. Yang, I. Elishakoff // International Journal of Solids and Structures. – 2008. – 45(10). – P. 2850–2860.

## References

1. Pichugin, S. F. Durability of steel structures of industrial buildings. Poltava: ASMI, 2009. 452 p. (in Russian)
2. Shpete, G. Durability of supporting building structures. Moskow: Stroyizdat, 1994. 288 p. (in Russian)
3. Kala, Z.; Kala, J. Sensitivity Analysis of Stability Problems of Steel Structures Using Shell Finite Elements and Nonlinear Computation Methods. In: *WSEAS Transactions on Applied and Theoretical Mechanics,* 2009, 4(3), p. 105–114.
4. Guo, T.; Sause, R.; Frangopol, D. M.; Li, A. Time-dependent reliability of box-girder bridge considering creep, shrinkage, and corrosion. In: *Journal of Bridge Engineering,* 2011, 16(1), p. 29–43.
5. Kwon, K.; Frangopol, D. M. Bridge fatigue reliability assessment using probability density functions of equivalent stress range based on field monitoring data. In: *International journal of fatigue,* 2010, 32(8), p. 1221–1232.
6. Wu, Z.; Wang, S.; Ge, X. Application of latin hypercube sampling technique to slope reliability analysis. In: *Rock and Soil Mechanics,* 2010, 31(4), p. 1047–1054.
7. Luo, Y.; Kang, Z.; Li, A. Structural reliability assessments based on probability and convex set mixed model. In: *Computers & Structures,* 2009, 87(21–22), p. 1408–1415.
8. Xiao, N.; Huang, H.; Wang, Z.; Pang, Y.; He, L. Reliability sensitivity analysis for structural systems in interval probability form. In: *Structural and Multidisciplinary Optimization,* 2011, 44(5), p. 691–705.
9. Qiu, Z.; Yang, D.; Elishakoff, I. Probabilistic interval reliability of structural systems. In: *International Journal of Solids and Structures,* 2008, 45(10), p. 2850–2860.
10. Mushchanov, Volodymyr; Priadko, Iurii. Total algorithm of safety index of overhanging coating formed by rigid threads of through section. In: *Metal*

10. Мущанов, В. Ф. Общий алгоритм определения показателей надежности висячего покрытия, образованного жесткими нитями сквозного сечения [Text] / В. Ф. Мущанов, Ю. Н. Прядко // Металлические конструкции. – 2012. – Том 18, Номер 3. – С. 159–169.
11. Мущанов, В. Ф. Напряженно-деформированное состояние висячей системы, образованной системой изгибно-жестких нитей, при учете податливости опор [Text] / В. Ф. Мущанов, И. Н. Руднева, Ю. Н. Прядко // Металлические конструкции. – 2012. – Том 18, Номер 1. – С. 5–16.
12. ADINA. Theory and Modeling Guide [Text]. Volume II: ADINA Heat Transfer / ADINA R & D, Inc. – Watertown : ADINA R & D, Inc., 2012. – 83 p.
13. Programmer's manual for ANSYS [Text] : ANSYS Release 11.0. – Canonsburg : ANSYS Inc., 2007. – 294 p.
14. Littlefield, D. Great Modern Structures [Text]. 100 Years of Engineering Genius / D. Littlefield, W. Jones. – London : Carlton Books Ltd, 2012. – 288 p.
15. Свентиков, А. А. Анализ надежности висячих стержневых покрытий с учетом развития пластических деформаций [Text] / А. А. Свентиков // Актуальные проблемы исследований по теории сооружений : Сборник научных статей в двух частях. Часть 1 / ЦНИИС им. В. А. Кучеренко. – М. : ЦПП, 2009. – С. 12–21.
16. Еремеев, П. Г. Особенности проектирования уникальных большепролетных зданий и сооружений [Text] / П. Г. Еремеев // Современное промышленное и гражданское строительство. – 2006. – Том 2, Номер 1. – С. 5–15.
17. Static and fatigue testing thin riveted, bonded and hybrid carbon fiber double lap joints used in aircraft structures [Text] / N. Chowdhury, W. K. Chiu, J. Wang, P. Chang // Composite Structures. – 2015. – 121. – P. 315–323.
18. Observations and analyses of secondary bending for riveted lap joints [Text] / M. Skorupa, A. Korbel, A. Skorupa, T. Machniewicz // International Journal of Fatigue. – 2015. – 72. – P. 1–10.
19. Mushchanov, Volodymyr. Fundamental approaches towards joints operation at reliability designs of suspension roofs [Text] / Volodymyr Mushchanov, Iurii Priadko // Metal Constructions. – 2014. – Volume 20, Number 2. – P. 89–99.
20. ДБН В.1.2-2:2006. Державні будівельні норми. Система забезпечення надійності та безпеки будівельних об'єктів. Навантаження і впливи. Норми проектування [Text]. – Замість СНиП 2.01.07-85 ; надано чинності 2007–01–01. – К. : Мінбуд України, 2006. – 61 с.

*Constructions,* 2012, Volume 18, Number 3, p. 159–169. (in Russian)
11. Mushchanov, Volodymyr; Rudneva, Irina; Priadko Yurii. Intense-deformed condition of suspended system of bending-rigid fibers at the account of pliability of supports. In: *Metal Constructions,* 2012, Volume 18, Number 1, p. 5–16. (in Russian)
12. ADINA R & D, Inc. ADINA. Theory and Modeling Guide. Volume II: ADINA Heat Transfer. Watertown: ADINA R & D, Inc., 2012. 83 p.
13. Programmer's manual for ANSYS: ANSYS Release 11.0. Canonsburg: ANSYS Inc., 2007. 294 p.
14. Littlefield D, Jones W. Great Modern Structures. 100 Years of Engineering Genius. London: Carlton Books Ltd, 2012. 288 p.
15. Sventikov, A. A. Reliability analysis of of suspension rod coatings in view of development plastic strain. In: *Topical research problems on the theory of structures: Collection of scientific articles in two parts. Part 1.* Moscow: TsPP, 2009, p. 12–21. (in Russian)
16. Yeremeyev, P. G. Design peculiarities for the unique large-span buildings and structures. In: *Modern Industrial and Civil Construction,* 2006, Volume 2, Number 1, p. 5–15. (in Russian)
17. Chowdhury, N.; Chiu, W. K.; Wang, J.; Chang, P. Static and fatigue testing thin riveted, bonded and hybrid carbon fiber double lap joints used in aircraft structures. In: *Composite Structures,* 2015, 121, p. 315–323.
18. Skorupa, M.; Korbel, A.; Skorupa, A.; Machniewicz, T. Observations and analyses of secondary bending for riveted lap joints. In: *International Journal of Fatigue,* 2015, 72, p. 1–10.
19. Mushchanov, Volodymyr; Pryadko, Iurii. Fundamental approaches towards joints operation at reliability designs of suspension roofs. In: *Metal Constructions,* 2014, Volume 20, Number 2, p. 89–99.
20. DBN V.1.2-2:2006. National Structural Rules and Regulations. The system of reliability and safety provision of constructional projects. Loads and effects. Kyiv: Minbud of Ukraine, 2006. 61 p. (in Ukrainian)

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