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OPTIMIZATION OF INTEGRATION PARAMETERS OF SUSPENSION SHELL STRUCTURES

The problem of search the optimum physical and geometrical constructive parameters of suspended structure are considered. The problem is formulated as one-criterion, multi-parametric, non-linear, of non-evident aspect. A local search is based on concept of the Hook-Jeevs method. A global search is executed using the method of test points. An example of parametric optimization of one-bay suspended combined structure witch vertical suspensions is presented.

Keywords: suspended structure, the Hook-Jeevs method, the method of test points.

The design of building structures is based on the results of calculation by various methods of building mechanics, followed by verification of their operational properties. In this approach, the quality of design solutions is largely determined by qualification of designer.

Building srtuctures, and especially suspension spatial coverage, are the complex multiparameter systems, for which is quite difficult to select the “good” original layout settings.

In general, the task of optimizing the design parameters is formulated as follows: it is required to find optimal values of parameters of given constructive form of suspension system that meets the extreme values the target function. As an objective function we will use the mass of construction [1]:

$$G = \sum_{i=1}^{n_e} A_i \cdot l_i \cdot \gamma_i \cdot \alpha_i \cdot \beta_i \cdot \varphi_i \quad , \tag{1}$$

where G is the mass of construction; $A_i \cdot l_i \cdot \gamma_i$ are the cross-section, the length and the volume weight of the i^{th} element, respectively; $\alpha_i \cdot \beta_i \cdot \varphi_i$ are the constructive factor, the cost factor and the factor of the use of higher-strength steel, respectively; n_e— is the number of elements.

At that the following restrictions are imposed on design:

– at the strength of elements:

$$\phi_i = \sigma_i - R_i \leq 0; \; i = 1.2, \ldots, \; n_e; \tag{2}$$

– at the rigidity (deformability) of design:

$$\delta_j = f_j - [f_j] < 0; \; j = 1.2, \ldots, n_u; \tag{3}$$

– at minimum allowable values of optimization parameters:

$$\chi_k = P_k - P_k^{\min} \geq k = 1.2, \ldots, n, \tag{4}$$

where σ_i, R_i are the stress and limit stress of i^{th} element; $f_j, [f_j]$ are the value and limit value of j^{th} controlled movement; n_u is the number of controlled movements; $P_k, P_k^{\min}$ is the k^{th} optimization parameter and its minimum allowable value; n is the number of optimization parameters (dimension optimization problem).

Thus, the problem of parametric optimization of suspension constructions belongs to the class of one-criterion problems of conditional optimization [1, 2]. Given that the correlation between the target function and the optimization parameters is non-linear and of implicit form, as well as that suspension systems are characterized by a variable calculated scheme [6], the its application for the solution with the use of optimization methods based on the use of derivatives is not appropriate [1, 2, 3]. On this basis, for finding extremum of objective function apply computational scheme, based on implementing the idea of Hook-Jeeves method [2, 3].

Search is an iterative process (transfer from one point to another in space of the search), which consists of exploring search (the choice of direction of the next step of search), and test steps for the model (search in selected direction). Physically points in the search space are the constructive specified form with certain geometrical and physical parameters of the field of permissible values.

At exploring search each position (optimization parameter), in turn, changes by adding or subtracting the search step with further test of improvement of objective function. If this test is done, the new value of researched optimization parameter is remembered. As a result of study of all the parameters n the new point is found in the direction of which the search should be continued. In case when the direction of further search (the new base point) cannot be determined the reduction of search step is made. Search is considered finished if as a result of research with minimum allowable step it fails to find a new base point.

Note that the geometrical parameters (span, step of structures, etc.) tend to differ greatly in absolute size from the physical parameters (height of section, axial and flexural stiffness, etc.), and that the optimization parameters can have different dimensions. In the present work to bring the parameter to a generalized scaling by dividing the current values on the corresponding value of the base point is used.

When searching per sample a step in the direction e chosen at researching is executed. To accelerate the convergence adjustment of step of search, which depends on the cosine of angle between the last two lines of the search introduces. This new point of search is calculated with the following equation:

$$\overline{X_{i+1}} = \overline{X_i} + \Delta_{i+1} \cdot \overline{W_{i+1}}; \tag{5}$$

$$\Delta_{i+1} = \Delta_i \cdot K_i; \tag{6}$$

$$K_i = a^{\cos\varphi_i - \cos\varphi_0}; \tag{7}$$

$$\cos\varphi_i = \frac{\overline{A_{i-1}A_i} \cdot \overline{A_{i-2} \cdot A_{i-1}}}{\left|\overline{A_{i-1}A_i}\right| \cdot \left|\overline{A_{i-2} \cdot A_{i-1}}\right|}, \tag{8}$$

where $\overline{X_{i+1}}, \overline{X_i}$ are the vectors of coordinates of the new and current base points of the search; A_i, A_{i-1}, A_{i-2} are the basic points of the search for *i*-m, *i*-1-m, *i*-2-th step of the search; Δ_{i+1}, Δ_i are the length of $i+1^{th}$ and the i^{th} search step, $\overline{W_{i+1}}$ is the vector of i $+1^{th}$ search direction; φ_i is the angle between i^{th} and i-1^{th} lines of search ($\overline{W_i}$ и $\overline{W_{i-1}}$); K_i is i^{th} factor of adjustment of length of search step; a, φ_0 are the search parameters.

The parameter φ_0 defines the angle of circular cone at the top of the search (base point). The surface of the cone is the location of such areas $\overline{W_i}$ for which the step length does not change. In rejecting the vector of direction inside or outside the length of the search step, respectively, increases or decreases.

The proposed algorithm of search provides finding only a local extremum of objective function. To obtain a global solution the method of test points is used [2, 3]. In this method, the local search starts from multiple test points, which can be defined both by random, and a specific algorithm. In this way, a number of local minima are found from which sampling of the least is made. The last is taken as a global.

Evaluating the objective function is performed in three phases: identification of deflected mode of construction, check it under the terms of the strength and rigidity and computation of the objective function itself. In this paper, the calculation of suspension spatial coating is carried out by the finite element algorithm of calculations, and taking into account the geometric nonlinearity [4]. The sagging of the flexible fiber under its own weight, as well as turning of the estimated structural diagram of "compressed" flexible rods is taken into account.

Investigate the suspension spatial coverage using cross bearing yarns, doubly-inclined suspension and system of cross rigidity beams and longitudinal beams (Fig.).

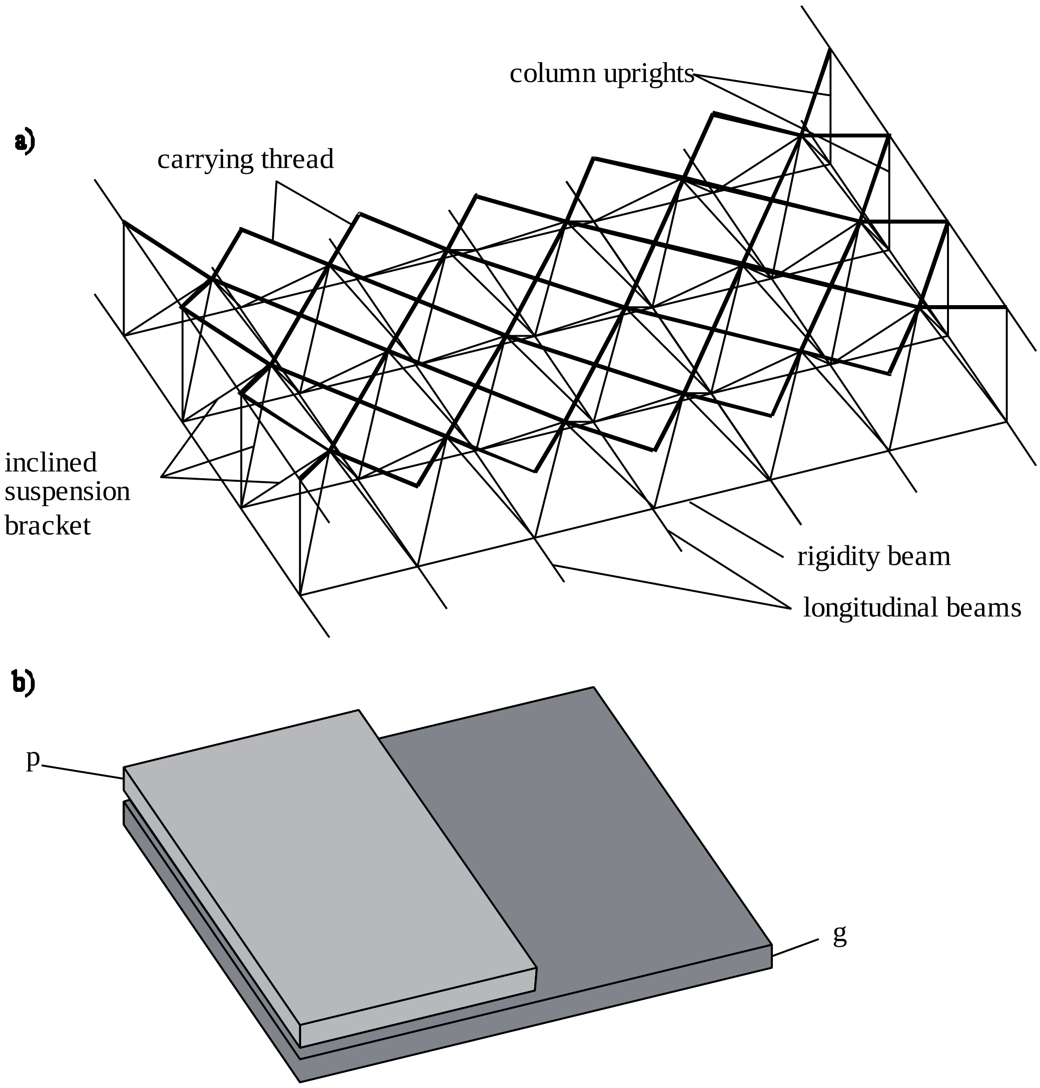

Fig. Spatial suspension scheme: a — design scheme, b — scheme of load

As the original design with the following topology parameters is used: span — 72 m, the number of steps and columns of longitudinal bars — 6 (i. e., orthogonal beams system in the plan is a 6x6 grid), the ratio of step column to step of longitudinal bars — 1 (i. e., the grid is square with the side 12 m), each node of the connection of transverse and longitudinal beams was connected to four adjacent nodes of bearing ropes of doubly-inclined pendants; bearing filaments form a cylindrical surface of parabolic shape. In studies the following schemes of loading with temporary load were used: scheme with application of a half of the passage with uniform distribution of load (asymmetrical distributed scheme); scheme with uniformly distribution of load loaded on the whole area of the coating (symmetrical distribution scheme); scheme with load in central node with concentrated force (symmetric centered scheme).

As an optimization parameters the following parameters of a suspension covering were taken:

- sag of carrying threads (of a cylindrical surface formed by the carrying threads);
- a minimum clearance between the carrying threads and orthogonal system of beams z_0;
- height of cross section of carrying threads (axial rigidity $EA_{нн}$);
- height of cross section of inclining suspension bracket (axial rigidity $EA_{нп}$);
- height of cross section of transverse beams of rigidity (flexural rigidity $EJ_{бж}$);
- height of cross section longitudinal bars of orthogonal beam system (flexural rigidity $EJ_{пб}$);
- height of the cross sectional of column uprights (axial rigidity $EA_{нс}$);
- height of cross section of columns (axial rigidity $EA_{к}$).

The first two parameters are the geometric and the rest are physical. In order to make conclusions about behavior of suspension coverings with a triangular lattice received absolute results were equated to the known relative coefficients [5]:

$$f_0 = L / f\,;\; z_0 = (f + z) / f\,;$$

$$n_0 = \frac{EJ_{бж}}{EA_{нн} \cdot L^2}\,;\quad n_2 = \frac{EA_{п}}{EA_{нн}}\,;$$

$$n_3 = \frac{EJ_{пб}}{EJ_{бж}}\,;\quad n_4 = \frac{EA_{нс}}{EA_{к}}\,. \tag{9}$$

When optimizing the layout parameters as the initial values five different structural systems, defined in accordance with the recommendations were taken [5].

According to the results of studies the following ranges of optimal layout parameters of studied suspension coverings have been found: f_0 — 8.5÷9.5; z_0 — 1.07÷1.1; n_0 — 1.5 · 10^{-4}÷2.5· 10^{-4}; n_2 — 0.25÷0.35; n_3— 0.75÷0.9; n_4— 1.2÷1.3.

These optimal spatial suspension structures are close sufficiently to the various schemes of load, which confirms previous conclusions about high spatial rigidity of studied coatings. Change in the intensity of the temporal load is governed by the change in the relative sag and clearing between the carrying threads and girder system. This fact, in our view, can be attributed to a significant influence of load capacity of carrying threads on deflected mode of suspension structure. The calculations revealed that at decreasing of discharge of material to arbitrary element of design stresses in the element are increasing, and at increasing growth of stresses in the adjacent neighboring cells takes place. In connection with it a paradox occurs: as material discharge construction may stop satisfying operational requirements. At the same time in the process of search following situation may arise: some optimization parameters cannot be either increased or decreased. This phenomenon can be attributed to the acceptance of the load in suspension spatial coatings is performed on some chains of interconnected structural elements, determined by topological features of design and layout of loading [6]. It can be said mostly of groups of ancillary flexible elements: carrying threads and inclined suspension bracket.

Compared with the plane suspension structures with a triangular lattice studied tea spatial coverages have less values of the relative sag f_0 and the relative clearance z_0, which indicates a higher impact on the deflected mode of coverings of beam system. Compared with the spatial suspension coating, formed from flat diameters, constructions with cross flexible rods has more high coefficients of stiffness of structural elements $n_0 \div n_4$, due to greater localization of the kinematic movements in the given structures and, consequently, the topological localization of design scheme.

Based on the above the following conclusions can be drawn:

1. The proposed algorithm for parametric optimization is very effective at choice of the arrangement parameters of suspension coats, and conducted studies revealed the fields of the areas of the most economical engineering solutions of given structures.

2. Spatial suspension covering using cross suspension elements have a high operating reliability.

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