Automation Engineering Design of Structures and Facilities

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Abstract: *The basic features of design optimization problems of engineering structures and buildings. The requirements for mathematical models optimization. It is shown that the process of optimal structures and facilities designing is a process of feedback control, which can be represented as a hierarchy of decision making. The main organization and functioning of a software program and CAD principles are developed.*

Keywords: *optimization, system analysis, design automation, mathematical model, mathematical and software, mathematical programming.*

I. Introduction

In the formulation of optimization problems in the engineering structures and buildings design an ambiguous interpretation (understanding) of Systems Analysis (approach) can be found): on one hand **-** this is really an analysis of any existing system, on the other **-** the formation of the system parameters to achieve the goals. In reality, the two positions go hand-in-hand, because you cannot create a system ,that provides goals, without analyzing the contents and determining the actual processes , that lead to the desired result. Systems analysis provides the conditions for joint optimization both structural parts of the system (subsystems) and the system as a whole, as well as computer software. The ultimate goal of systems analysis in the design is an actual design of the system, its subsystems and components for optimum efficiency and economy. Despite the fact that there are no well-defined rules in systematic analysis , the basic features are adequately disclosed in [1].

II. Main design processes of engineering structures and facilities

Taking into account the specifics of the design process of engineering design and construction tasks , the main features of our approach can be displayed in the following :-

I. As an optimized projected engineering design or construction, we take determined appropriate performance of the functions, the complex elements, endowed with specified properties and having links to the abstract and the external environment systems [I-III].

In this complex in the research process we can attach to each element the desired properties without regard to actual performance, to identify the possible contribution of these properties in the studied process and, therefore, justify the requirements for the prospective deal with this item. In practical optimization problems it is assumed that the properties of elements and their functional and technical specifications are known and therefore the functioning of the processes is considered in the field of permissible (taking into account the accepted limit) solutions of the systems. Both in first and second, as well as in the case of the software (development of algorithmic systems) evaluation of the complex is considered with taking into account the totality of known processes and phenomena and the relationship between them. All this highlights such features of the model of designed engineering structures and buildings that contribute to the elucidation of the functioning of this complex in order to select the least weight or cost.

The most significant is that in all cases, the system includes the concept of a whole consisting of interrelated, interacting and interdependent parts. The properties of these parts depend on the system as a whole, and the properties of the system – on the properties of its parts.

II. The place for specific design and engineering projected construction should be determined in the overall structure of the other systems. The systems approach requires a reasonable allocation of the designed system in general systems structure to maintain the normalizing parameters, dividing it into subsystems.

The design or construction is considered as an independent object of study and optimization, but with the necessary information exchange with the adjacent and external systems, and within it, between the subsystems.

The chosen general structure of systems should clearly delineate the boundaries of the system and contribute to selection (structuring) of its subsystems, which in size are available for research and homogeneous in the description. This provides links to the organization on each successive level, the descent of the system to the individual elements from the top - down with the subsequent transfer of the resulting aggregated data to the top (bottom-up).

Both the overall structure of compensation systems and subsystems of structures and facilities must have inherent properties of integrity: the changes that have arisen in any of their parts, impact on other parts, and on their entirety.

III. Engineering design or construction are presented in the form of the model. Complex systems designing, that the engineering designs and constructions are, requires knowledge of the quantitative and qualitative patterns of the system and its individual elements behavior , depending on the nature of the changes of multiple factors (parameters).

The model should be similar to the original, but differ from it. Its distinctive features are manifested in the fact that it is subjected to such transformations in the right direction, which is not possible in the direct study of the original.

Ultimately, the choice of method is determined by taking into account many considerations, the latter role of which belongs to the convenience of the treatment algorithm, the duration of the account, etc. It is also clear that the tasks require informal activities, opportunities to intervene in the process of counting and to obtain interim results for the implementation of a dialog mode.

IV. To assess the quality of designed structures and buildings solutions .a set of indicators is selected. As a rule, the purpose of system analysis is,that for all possible characteristics of external relations ,to achieve the best possible (optimal) solutions of designed structures and buildings according to their structural, economic and other indicators. However, the optimum and optimality is not an absolute concept, they require a precise definition of optimality criteria, i.e. the main features on which the effectiveness of different solutions are compared. Solution, the best in one setting and one criterion, may be far worse in other circumstances and other criteria. Optimizing on one criterion (sub optimization), mostly for technical systems is aimed at reducing the cost (in this study the objective function is the weight of the structure).

V. The analysis of the model structures and buildings should be transferred to the real systems. To transfer the solutions to the real object requires confidence in the adequacy of the solution. The adequacy is estimated by the analogy of a real object and the model properties according their main characteristics. Adequacy is achieved if the model fully reflects the stress-deformed state (VAT) of actual projected structures and facilities.

Listed and taken to the execution, the main provisions of the systems approach are characterized by a basic framework of the method, but the efficiency of its use depends entirely on the way of their implementation. In order to systematize and generalize the information about the main symptoms of systemic analysis that contribute to the representation of disparate data in an orderly manner with a smaller number of significant variables, you must:

- systemize relationship between the systems ,designed to maintain the normalized parameters;
- analyze multiple baselines, to find a form of generalization ,suitable for determining the VAT system conditions classification;
- identify the classification structure or structures, contributing to a focused selection of competing options;
- determine the principles of decomposition of systems ,based on the analysis of their aggregate as a whole;
- formulate a basic framework for constructing a mathematical model of the design or construction;
- classify optimization problems ,arising in practice, research and design.

The purpose of the design process is to develop technical documentation, required for the production of design objects and based on both priori (the original) and posteriori (additional) information, obtained in the design .Thus, the design is the process of creating a prototype of an object, indispensable for the object manufacture. Design is essentially a process of feedback control (Fig. 1). Terms of Reference (TOR) produce inputs or outputs, which are compared with the results of the design, and if they do not match, the design cycle repeats itself as long as the error (deviation from the set of technical requirements) is not within limits.

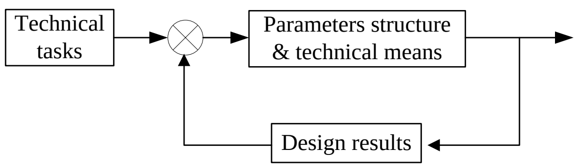

Fig. 1. The scheme design

The design process is system design, i.e. a set of interacting with each other designers and means, required for the hardware. In essence, the system design can be considered as a complex man-machine multi-loop, multi-dimensional control systems with feedback, requiring the collection, transmission, processing and using information to achieve the design objectives. They should be subject to one or another criterion of optimization, for example, the criterion of minimum length or maximum performance on a limited budget, or the fastest designed system payback criterion, etc. To reduce design time it is necessary to increase the speed of transmission of useful signals, and to prevent interference, i.e. signals, not carrying useful information. The incorrect or inaccurate intermediate results, or an unfortunate choice of the structure of the system design, when the signals, necessary for making decisions on any low level , get to the upper levels, where they can be not only useless but harmful, may give such interference. On this basis, we can conclude that a systematic approach, principles and methods of control theory are of great interest for the rational organization of the design.

"Computer-Aided Design" (CAD) was used in all cases where a computer was used for calculations, related to the design. Currently Apr for engineering structures and buildings is associated with the new stage of development - the creation of computer-aided design (CAD), primarily designed to meet the challenges of scientific research and conceptual, partly technical, design. CAD can be considered as a system of feedback control. Therefore, we can give the following definition, emphasizing the "management" aspect of CAD. CAD is a man-machine or an automated process control system design of engineering structures and buildings and technical documentation, required for the manufacture of the designed object. Common to all CAD systems is that they are, as already was indicated above, regardless of the design object, may themselves be regarded as the automated process control system for the production of technical documentation. Therefore, the development of a general theory of automated control systems is at the same time the development of theoretical foundations of any CAD objects.

III. Steps to create automated design of optimal structures and facilities

Thus, the essence of computer-aided design of optimal engineering structures and buildings comprises:

1. The development of the optimized mathematical model of the object (the projected design and construction) and the external environment on the a priori available information and the results of the identification of existing facilities or physical models.

2. Structural synthesis on the basis of analysis of the design projected features and construction, determination of the necessary information flows, taking into account the possibility of decomposition of the system and distribution management functions to appropriate levels.

3. Structural synthesis of algorithmic (automated) optimization of engineering structures and buildings system.

4. Definition of the computer interaction modes.

5. Analysis of the results of computer simulation.

6. Clarifying and making amendments to the TOR.

7. Documentation.

Let's call computer-aided design of engineering structures and buildings, carrying out the first five of the above points, a system of automated synthesis.

Certainly the development of CAD engineering structures and buildings must be guided by standard operating system.

One of the most important bases to create CAD software application for optimization of engineering structures and buildings is the method of computational mathematics. However, the "adaptation" of these methods to a form that is possible and convenient for implementation of the computing means, is a complex and laborious process that represents the life cycle of a software product. The most important step in this process is the development of algorithmic software [2].

Once you made up the algorithm of solutions of a problem, the programming process, i.e. coding algorithm in terms of selected high-level language, or directly in terms of machine instructions starts.

Created (designed) software package (RFP) for the optimization of engineering structures and buildings should have the following features:

- be built in a modular (sub systems) principle;
- have some flexibility in the ratio of hardware and software operating environment;
- availability for poorly prepared in the field of computer science professionals;
- have friendly means of advanced problem-oriented dialogue;
- allow interface with tool support systems: databases, graphics systems, databases;
- allow modification and expansion.

IV. The scheme for obtaining the optimal solution

Let's consider the integrated scheme for optimal solutions. To create a calculation model, taking full account of all the properties of a real object (the deformed system) is fundamentally impossible. The art of choosing the computational model is to identify the basic properties of a real object. After selecting a design model, a mathematical model for describing the strain and stress states, the dynamic processes, etc., connecting the incoming parameters should be composed. Availability and preliminary analysis of a mathematical model, describing the state of a deformable system, allows giving the task of the problem optimization and finding an effective mathematical tool optimization. To estimate the received solution (project) it is necessary to define an optimality criterion (the criterion of excellence, quality criteria, the criterion of efficiency, etc.). The objective function $C(x)$ is a mathematical account of the criterion of optimality. Using of the criterion of optimality ,limitations of the mathematical model describing the state, the mathematical apparatus of optimization (optimization techniques) allows you to find the optimal solution, which describes the projected structure (object model).

V. A mathematical model of optimization of cylindrical shells by weight

The problem of optimizing the design put a mathematical programming problem: it is necessary to determine the vector X (x_1, x_2, ...,x_n) of x_i $(i=1,\overline{n})$ optimized parameters, giving the objective function F (x) extreme (for definiteness, we take min), subject to restrictions on the parameters $a_i \le x_i \le b_i$, $(i=1,\overline{n})$; and functional limitations f_j (x)≤ 0 $(j=1,\overline{m})$ [3]. This problem can be written as

$$\left.\begin{aligned} &F(X)\to \min \\ &f_i(X)\le 0 \ (j=1,\overline{m}) \\ &a_i \le x \le b_i \ \ (i=1,\overline{n}) \end{aligned}\right\} \qquad (1)$$

For example, let's consider the problem of optimization of cylindrical shells by weight. We assume the objective function as

$$F(x)=\int_\alpha\int_\beta h(\alpha,\beta)Rd\alpha d\beta \qquad (2)$$

For open shell type codes are given:

a) the boundary conditions;

b) the length of the overlap- a;

c) the width of the overlap;

d) the material of the shell:

E modulus of allowable elasticity; σ - allowable stress; γ - gravity; ν - Poisson's ratio; [U] - allowable transfer (if required limitations on the stress; implementation of strength and stiffness);

e) - a system of external loads;

e) - other restrictions (such as design, technological, etc., if you want to meet them.).

Optimize able parameters are parameters that determine the variation of shell thickness, angle of the shell, which determines the degree of its steepness.

VI. The results of computer simulation

At present we have developed the engineering constructions optimization software on the base of global search [3]. It is realized in visual program system Delphi 7.

Task 1. Optimizing of cylinder shell ,of rectangular shape, the whole shape hinge supported, under uniform average load of q intensity.

The shell thickness is constant $h = const$.

The physical parameters of shell material: $E = 2 \cdot 10^6 \, кг/см^2; [\sigma] = 2000 \, кг/см^2; \nu = 0{,}5$ The shell geometrical parameters:

a=150sb=100sm

Load q=1 kg\sm^2.

Optimized parameters h, β_0.

Parameters restrictions :

$$\frac{\pi}{10} \le \beta_0 \le \pi;$$
$$0{,}1см \le h \le 3см$$

Minimized function is the cross–section aria

$$S = R \cdot h \cdot \beta_0$$

Construction restrictions:

$$\sigma_i \le [\sigma],$$

Where σ_1-stress intensity is calculated according to:

$$\sigma_i = \sqrt{(\sigma_{11} - \sigma_{12})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + 6\tau_{23}^2} \quad (3)$$

Stress values σ_{11}, σ_{22}, σ_{33}, σ_{23},τ_{23} were determined after solution of equations (3), solved according to Ritz method. AS co-ordinate functions were selected beam functions, which in case of shell hinge support, look like:

$$U_{nm} = \cos\frac{n\pi\alpha}{\alpha_0}\sin\frac{m\pi\beta}{\beta_0};$$
$$V_{nm} = \sin\frac{n\pi\alpha}{\alpha_0}\cos\frac{m\pi\beta}{\beta_0}; \quad (4)$$
$$W_{nm} = \sin\frac{n\pi\alpha}{\alpha_0}\cos\frac{m\pi\beta}{\beta_0}$$

The optimizing was performed with the help of global search algorithm to within ε≈2%.

Calculation results are given in Table 1.

Table 1

Local min	S sm^3	h sm	β_0 rad	σ_i kg\sm^2	Steps
1	125,0179	0,956369	2,467197	1990	52
2	126,6418	1,125607	1,662033	1977	28
3	114,072	0,8343	2,6613	1989	39
4	165,1633	1,53425	1,320312	1993	42

Figure 2 shows curves σ_i (α,β), corresponding to received minimums.

Task 2. Optimizing of cylinder shell, of rectangular shape, free-supported along edges under uniform load of q intensity.

The shell thickness is variable and is determined according to

$$h = h_0 + h_1 \cdot \sin\frac{\pi\beta}{\beta_0}.$$

Optimized parameters: h_0, h_1, β_0.

$$\frac{\pi}{10} \le \beta_0 \le \pi$$

$$0{,}5см \le h_0 \le 3см$$

$$-0{,}5см \le h_1 \le 0{,}5$$

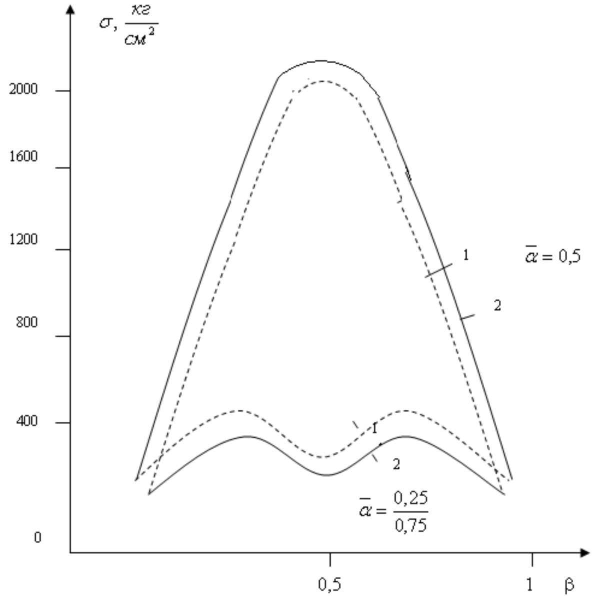

Fig. 2.

The rest parameters are the same as in task 1.

Optimization was performed with the help of global search algorithm to within ε≈2%.

Calculation results are shown in table 2.

Table 2

In. loc. min	S sm²	h_0 sm	h_1 sm	β_0 rad	$\sigma_{i\,max}$ kg\sm²	Steps
1	81,7348	0,38713	0,48340	1,9416	1998,7	57
2	97,8944	0,53173	0,38432	2,3025	1965	24
3	110,0278	1,2699	-0,4740	1,7447	1952	27
4	126,6314	1,0333	-0,1104	2,4939	1946	13
5	114,899	1,0548	-0,21962	2,2839	1936	23
6	106,003	1,0408	-0,0763	1,2513	1999,3	54

Figure 3 shows curves σ_i (α,β), related to 1-st and 4-th minimums

As we can see from tasks' 1 and 2 solutions results, the usage of cylinder shells of different thickness gives the opportunity to reduce a construction weight by about 14%. Tables 1 and 2 show the effectiveness of global search algorithm use in construction optimization, according to strength criterion.

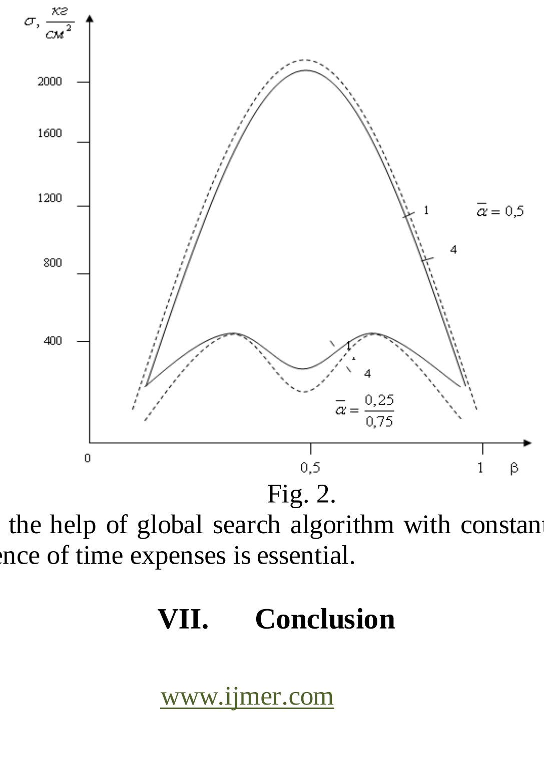

Fig. 2.

If the shell was optimized with the help of global search algorithm with constant step, 22-52 steps were necessary to determine one minimum. The difference of time expenses is essential.

VII. Conclusion

We have studied the specific of engineering construction design process and determined the essence and content of engineering constructions design automation. We have developed engineering constructions optimizing software, based on global search method and worked out the calculation of cylinder shells optimization according to their weight.

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