State of the problem of numerical modeling of optimal design of load bearing structures of linear pipeline systems

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Abstract. The features of the design and construction of oil and gas facilities are indicated. Metal flyovers were selected from the general list of capital construction projects in the industry for further study. Special requirements of regulatory documents for flyovers are considered. An example of reducing the cost of design and construction by creating unified design solutions is given, the disadvantages of this approach are identified. The problem of optimal design of flyovers as spatial metal structures is indicated. Brief results of monitoring of scientific papers describing modern optimization methods are presented.

1. Introduction

The oil and gas complex is the basis of energy supply in Russia and one of its most important national economic sectors, since the products manufactured by this complex are raw materials for the functioning of a number of other industries, and the output of their final products depends on this.

Design and construction of oil and gas industry facilities has a special specificity, which differs from industrial construction as a whole in a number of features, of which the following can be distinguished:

– significant volumes of construction and its duration;
– the dispersion of oil and gas field facilities on a large territory of the country's regions, which requires the construction of high-tech oil and gas pipelines and technological facilities for their maintenance;
– inaccessibility of areas of oil and gas fields;
– construction in severe climatic conditions of the Far North;
– fire and explosion hazard of work at the facilities.

All of the above features lead to a significant increase in the cost of production and transportation of oil and gas in comparison with foreign practice.

An important component of oil and gas production in Russia is the construction of oil and gas pipelines. One of the constituent parts of the pipeline system is flyovers (Figure 1) of various types, made primarily of metal structures. When designing space-planning and structural solutions of these capital construction projects, it is also necessary to pay attention to the industry features: permafrost conditions and increased requirements for the safety of facilities [1, 2].

An additional difficulty in creating design models of flyovers creates the need to take into account the special requirements of regulatory documents [3, 4]. We list some of these requirements:

- calculation of building structures of free-standing supports and flyovers should be performed as flat structures. If it is necessary to make more accurate calculations and take into account additional factors,
the calculation of building structures of free-standing supports and flyovers should be performed as the calculation of spatial systems, taking into account their joint work with pipelines;
- when laying pipelines on a flyover, the longitudinal horizontal load from the friction forces in the movable supporting parts of the pipes is perceived by the span and anchor supports and is not transferred to the intermediate supports;
- normative vertical load from pipelines on supports and flyovers should be taken as the sum of vertical loads from all pipelines.

Figure 1. Image of a flyover

One of the measures aimed at reducing the costs of design and construction is the creation of standard unified projects of buildings and structures for the arrangement of oil and gas fields. An effective solution to such a problem can be realized with the help of a mathematical optimization apparatus, introduced in the design of the load-bearing elements of these structures.

An example of the unification of design decisions is the creation of CSDS (Company Standard Design System) developed by NIPI, which are part of Rosneft, PJSC. This system makes it possible to accumulate optimal technical and economic design solutions for key technological facilities and unified requirements for the purchase of equipment and materials for the arrangement of oil and gas fields in a common database, which is used in design production. At the same time, it should be noted that optimization of construction projects is not widely used in real design yet. Such software systems as: LIRA-CAD, SCAD, MicroFE, which are used in the practice of modern Russian design, allow solving verification calculation, as well as perform constructive calculations in accordance with regulatory requirements, but they are not provided optimization modules.

World-class software systems (MSC Nastran, ANSYS and ABAQUS), in addition to the developed FE analysis apparatus, contain optimization modules. However, the main obstacle to the effective introduction of this software for optimal design tasks is that programs do not have a verification module based on Russian regulatory documents, accordingly there are not have the ability to change sections according to grade. For this reason, the development of effective optimization algorithms and programs based on them is one of the urgent problems of the entire industry.

2. Approaches to modeling overpass optimization tasks
Let us consider a variant of an integrated approach to the optimal design of structures associated with oil and gas production using the example of flyovers as spatial metal structures.
The optimality criterion for these structures is the minimum weight or volume of the structure. Limitations are set in the form of regulatory requirements in accordance with SP 16.13330.2017 Steel Structures. The state parameters of structures (internal forces, nodal displacements, stress, etc.) are determined by solving the problem of statistical analysis.

In general, the research of many Russian and foreign scientists is devoted to questions of the optimal design of building structures. We will name only a few authors who have made a significant contribution to this direction: N.P. Abovsky, N.V. Banichuk, A.I. Vinogradov, T.L. Dmitrieva, V.A. Kiselev, V.A. Komarov, L.S. Lyakhovich, V.P. Malkov, D.A. Matsuliavičius, Yu.M. Pochtman, I.M. Rabinovich, Yu.A. Radzig, A.R. Rzhanitsyn, N.D. Sergeev, N.N. Skladnev, A.F. Smirnov, A.P. Fippippov, A.A. Chiras, L. Schmitt, J. Arora, N. Adele, Z. Vasyutinsky, D. Keller, M. Levy, Z. Moruz, F. Niordson, N. Olhoff, V. Prager, D. Rozhvan, D. Taylor, M. Turner, E. Hog, R. Shield and many others.

Let us consider in more detail some works affecting the problem of optimal design of spatial structures.

The general statement of the optimization problem was first proposed by L. Schmit [7]. In his work, he pointed out the admissibility of the application of structural analysis using the finite element model and the nonlinear programming method in the presence of various forms of constraints.

In 1991, Hazela and Berke presented optimization algorithms based on a neural dynamic model. When solving the optimization problem, scientists used neural networks that replaced the force-displacement ratio in a static analysis [9].

In 2002, an article was published that proposed a solution to the problem of optimal design of spatial structures by the method of practical nonlinear inelastic analysis [10].

The book [8] analyzes various problems associated with the design of steel structures of industrial facilities, including multi-tiered spatial core structures. Particular attention is paid to saving and calculating costs, which allows you to compare costs and significantly save on the design stages.

Alpatov’s article is devoted to the search for the optimal geometric shape of structures, as well as the optimal distribution of material in them with unchanged geometry. The article [12] describes the methodology for the optimal design of spatially-rod structures based on random search and directional search algorithms.

The ANSYS PC has been widely used in solving optimization problems. Examples of its use for solving optimal design problems with a description of the approximation method of a subtask and a first-order method are described in the verification report, performed by the scientific staff of CJSC SIC Stadio [13].

The work [15] is devoted to solving the problem of structural optimization of wireframe steel structures using a special genetic coding algorithm to establish a strategy for detecting an ideal group of elements and using the penalty method developed by the authors to take into account restrictions.

The application of the “harmony search” algorithm in optimizing the design of steel structures was considered in [17].

In 2015, a monograph was published by IRNITU researchers, which addressed the optimization problem in the form of a nonlinear mathematical programming problem and described the application of the author’s development: ROSK PC - a software package for calculating and optimizing building structures [18].

In the dissertation, Le Chan Minh Date described in detail the solution to the problem of optimizing spatial metal structures, with the possibility of varying both the parameters of the cross section and the coordinates of the nodes on a continuous and discrete range [21].

It should be noted that over the past two decades, special attention has been paid to the description of metaheuristic algorithms for solving the optimal design problem. The use of metaheuristics in the optimization of various kinds of engineering processes is an extremely popular and discussed topic in recent years. In general, metaheuristic algorithms for optimizing structural design were considered by scientists from three countries in the article [22] in 2016. Also, a book [25] is devoted to developments in the field of metaheuristics and their application in construction and design. This publication describes
in detail various metaheuristic algorithms and provides practical examples of demonstrating their real application in optimizing the design process.

We give a brief presentation of the works describing the use of metaheuristic algorithms. The use of optimization algorithms based on the method of colony of ants and harmonic search in the optimal design of spatial steel frames with a discrete change in the parameters of the sections according to the criterion of minimum weight with restrictions on strength and stability is given in [14]. In [16], the upper bound strategy for reducing the computational cost of the Big Bang – Big Crunch metaheuristic algorithm and its modifications used in the optimization of spatial steel structures is reflected. The development of a metaheuristic optimization algorithm based on eagle hunting at the junction of MATLAB and SAP2000 software systems (Figure 2) to reduce the metal consumption of steel spatial frames was discussed in [19].

![Spatial metal structure model in SAP2000](image1.png)

**Figure 2.** Spatial metal structure model in SAP2000

Optimization in the design of spatial steel structures under seismic loading based on the cuckoo metaheuristic algorithm was studied in [20]. Using the “Productive Design" approach and metaheuristic algorithms to solve the problem of optimizing eccentrically fixed frame structures (Figure 3) is given in [23].

![Eccentrically braced frame structure](image2.png)

**Figure 3.** Eccentrically braced frame structure
Optimal design of structures is presented in great detail in Arora's book “Introduction to Optimal Design” [24]. This publication illustrates various concepts and procedures with simple examples and demonstrates their applicability to engineering design tasks using Excel and MATLAB [11].

3. Conclusion

Based on the analysis of the sources cited, the following conclusions can be drawn.

Calculation and optimization of flyovers as typical unified parts of the piping system is an urgent and demanded task. At the same time, their modeling as spatial rod systems is proposed.

Despite a large number of studies in the field of optimization of spatial metal structures, none of these approaches can be used as universal for solving the problem of optimal design of technical flyovers for oil pipelines in accordance with Russian regulatory documents in design and construction.

The main areas of work on this issue will be:

1. Construction of a model for the problem of optimizing linear load-bearing structures of piping systems taking into account regulatory requirements.
2. Conducting a comparative analysis of the effectiveness of algorithms of different classes (gradient, metaheuristic, zero-order algorithms, etc.) in relation to solving conditional-extreme problems of optimization of flat and spatial rod structures.
3. Investigation of the possibility of embedding neural networks in the optimization process of spatial core systems of large dimension.

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