ANNOTATION

to the dissertation for the degree of Doctor of Philosophy
(PhD) 6D071100 – Geodesy

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GEOMONITORING OF DEFORMATION PROCESSES OF SPORTS STRUCTURES BASED ON HIGH-PRECISION GEODETIC MEASUREMENTS

Assessment of the current state of the scientific and technical problem. The task of geodetic monitoring is one of the most widespread and responsible tasks in the practice of geodetic works. In the twentieth century, the basic principles of geodetic monitoring, technological observation schemes, and mathematical models for determining accuracy, observation intervals, and data processing were developed. At present, methods and technologies of geodetic monitoring have undergone significant changes. These changes are associated with the diversity of geometric parameters of constructed structures (length, height, diameter, etc.) and the possibilities of construction (the absence of restrictions related to environmental conditions, the type of foundation under the structure, and the construction of objects in seismic zones).

From this point of view, it is obvious that modern structures are subjected to more complex loads, which leads to more complicated deformation processes. Among modern engineering structures, the construction technology of which has undergone significant changes, sports facilities occupy a special place. The operation of sports structures is associated with the presence of specific loads, such as the impact of a large number of spectators (stadiums, velodromes) or loads directly from competitions (bobsleigh tracks, racetracks).

Under these conditions, existing approaches to the design and implementation of geodetic monitoring of sports structures do not ensure the required accuracy, detail, and efficiency of the works. The implementation of geodetic monitoring of sports structures requires the development and improvement of existing mathematical models for accuracy assessment, observation techniques, and models for analyzing measurement results.

The classical approach to the organization and implementation of geodetic monitoring of engineering structures is presented in the works of Yu.P. Gulyaev, A.K. Zaitsev, D.Sh. Mikhelev, E.B. Klyushin, V.V. Simonyan, and G.A. Shekhovtsev.

The problems of geodetic monitoring of engineering structures are addressed in the works of a number of domestic scientists, who consider the issues of monitoring organization, deformation analysis, and the application of modern technologies in the conditions of the Republic of Kazakhstan.

The works of foreign scientists are primarily aimed at improving monitoring technologies. In particular, the developments of the scientific schools of Stuttgart (D. Wujanz, F. Neitzel, W. Busch), Milan (F. Fregonese, M. Scaioni, G. Alba), Nottingham (X. Meng), and Bratislava (A. Kopáčik, P. Kyrinovič, I. Lipták, J. Erdélyi) should be noted.

Relevance of the research topic. Geodetic monitoring of sports structures is a specific monitoring task associated with observations of structures subjected to various static and dynamic loads. Previously proposed methods and models for determining observation accuracy, monitoring techniques and technologies, and mathematical models for processing monitoring results were based on a completely different state of the construction industry and geodetic production. Under these conditions, there arises a need to use improved models for calculating observation accuracy, new technologies, and models for measurement analysis that reflect modern conditions of design and construction of sports structures.

Modern advances in the field of structural analysis, including sports structures, have made it possible to reconsider the problem of accuracy and observation interval determination in a fundamentally new way. Existing mathematical models for determining accuracy are based on accepted standard values that only approximately characterize the deformation process of engineering structures. In most cases, the standardization of geodetic monitoring accuracy is carried out using guideline indicators developed for typical structures, to which sports facilities do not belong.

A significant drawback is the consideration of an engineering structure as a static object in which displacements occur according to the same laws and different parts of the building are considered homogeneous. Under such an approach, monitoring locations (installation sites of deformation signs and marks) are assigned either based on the observer's experience or intuitively, without any scientific justification. In this regard, a scientifically substantiated integrated model for calculating expected displacements based on the interaction of the structure–foundation–environment system is required. Thus, the development of a mathematical model for determining the accuracy of geodetic monitoring of displacements as a function of deformations obtained using simplified structural mechanics models is relevant.

The complex geometry and the need to control various deformation parameters of sports structures (spatial displacements, monitoring of surfaces, shells, individual nodes, monitoring of crack development, etc.) limit the use of traditional monitoring methods such as geometric leveling or angular-linear measurements. At the same time, regulatory literature considers and recommends methods and technologies that are either outdated or have changed significantly over the past twenty years. Therefore, the most important task is the development of a methodology and technology for geodetic monitoring of sports structures using modern measurement methods. Among such methods, terrestrial laser scanning has particular advantages, as it makes it possible to obtain a spatial model of a sports structure for its comprehensive investigation and analysis.

At present, the analysis of monitoring results is mainly performed and presented in the form of displacement graphs and calculations of individual deformation parameters such as tilt, deflection, torsion, etc. However, the spatial model of a structure obtained from laser scanning results makes it possible to perform a more comprehensive and detailed analysis of structural deformation. In this case, the task of developing new models and methodologies for analyzing monitoring results becomes particularly relevant. The redundancy of terrestrial laser scanning data makes it possible to use more complex mathematical models for displacement modeling, examples of which are spline functions and their modifications in the form of B-splines and non-uniform rational B-splines (NURBS).

Based on the above, it can be concluded that the topic of the dissertation research is relevant and is aimed at improving models for determining observation accuracy, developing new technologies, methodologies, and models for analyzing the results of geodetic monitoring of sports structures.

Purpose of the research. To improve the methodology and technology of geodetic monitoring of deformation processes of sports structures based on high-precision geodetic measurements.

Object of the research. The International Ski Jumping Complex "Sunkar".

Subject of the research. Deformation processes of sports structure constructions.

Research objectives. In accordance with the stated purpose, the following objectives were formulated and solved in the dissertation:

– to perform an analysis of existing methods and technologies of geodetic monitoring of sports structures, including methods for determining the accuracy of geodetic observations and methods for analyzing the results of monitoring deformation processes;

– to investigate and substantiate the application of structural mechanics methods, including finite element modeling, for estimating calculated displacements of sports structures and for developing a model for determining the required accuracy of geodetic monitoring, using the example of the "Sunkar" ski jumping complex;

– to develop a methodology for the rational placement of deformation marks on sports structure constructions based on the results of stress–strain state modeling;

– to develop and substantiate a methodology for analyzing spatial displacements of sports structures based on geodetic monitoring data using spline function theory.

Research methods. The research methods made it possible to fully solve the stated objectives. For the development of the mathematical model for calculating the accuracy of geodetic monitoring, basic principles and methods of structural mechanics, as well as the theoretical and computational algorithm of the finite element method, were used. The development of the methodology for placing deformation marks was carried out based on the results of displacement and stress calculations of the sports structure using the finite element method. For the models of analysis and interpretation of geodetic monitoring results, methods of computational mathematics were used, namely the theory and applications of spline functions.

Scientific statements submitted for defense

1. A mathematical model for calculating the accuracy of geodetic monitoring based on finite element modeling, allowing the calculation of observation accuracy using limiting calculated displacements, and a methodology for optimal placement of deformation marks in zones of stress concentration.

2. A methodology for studying spatial displacements of sports structures using spline function theory, ensuring the analysis of spatially inhomogeneous geodetic data and identification of regularities in displacement variations.

Scientific novelty of the dissertation

1. A comprehensive scientific and methodological basis for geodetic monitoring of sports structures has been developed, including a mathematical model for determining the required measurement accuracy based on finite element modeling, as well as a methodology for the rational placement of deformation marks in zones of expected maximum displacements and stress concentration, which makes it possible to reasonably assign accuracy and determine the monitoring scheme without preliminary hypotheses about the nature of deformations.

2. A methodology for analyzing spatial displacements of sports structures using spline function theory has been proposed, making it possible to perform approximation and interpretation of spatially inhomogeneous geodetic observations, identify regularities in structural deformation, and substantiate design solutions for protective measures.

Practical significance of the dissertation

– A technology for geodetic monitoring of sports structures using terrestrial laser scanning has been developed, which includes a technological scheme for performing the works and can be used for geodetic monitoring of other types of structures;

– Methodological recommendations for improving the regulatory framework in the field of geodetic monitoring of engineering structures have been developed;

– A computational algorithm for modeling complex curvilinear objects using computational geometry methods, namely spline functions, has been proposed. In practice, the computational algorithm has been implemented in the MATLAB programming language.

The results of the dissertation research were introduced into the educational process of the Kazakh National Research Technical University named after K.I. Satpayev and were also used in the implementation of engineering projects.

Validity and reliability. The validity and reliability of the scientific statements, conclusions, and recommendations are confirmed by the use of methods of geodetic measurement theory and structural mechanics, the application of finite element modeling and modern numerical methods for deformation analysis, as well as by comparison of modeling results with data from high-precision geodetic observations at the “Sunkar” ski jumping complex. The obtained results are substantiated and confirmed by publications in scientific journals and approbation at international scientific conferences.

Personal contribution of the author. The personal contribution of the author consists in the analysis of modern methods of geodetic monitoring of sports structures and the identification of limitations of regulatory approaches to accuracy determination. A mathematical model for assigning monitoring accuracy based on structural mechanics and finite element modeling was developed. Deformation modeling of the ski jumps of the “Sunkar” complex was carried out and the placement of deformation marks was substantiated. A monitoring technology for sports structures using terrestrial laser scanning was proposed.

Publications and approbation of the dissertation. Based on the dissertation research, seven publications were published, including: two articles in peer-reviewed journals (Scopus database; Civil Engineering Journal (Q1) and Journal of Geodesy and Geodynamics (Q2)); one article in journals recommended by the Committee for Quality Assurance in Education and the Ministry of Science and

Higher Education of the Republic of Kazakhstan; and four articles in the proceedings of international conferences, forums, and congresses, two of which are indexed in the Scopus database.

Main results of the dissertation research

1. A mathematical model for calculating displacements of sports structures using structural mechanics methods, in particular the finite element method, was investigated using the example of the “Sunkar” ski jumping complex.

2. A mathematical model for calculating the accuracy of geodetic monitoring of sports structures based on the principles of structural mechanics was developed.

3. A methodology for the rational placement of deformation marks on sports structure constructions based on the results of stress–strain state modeling was developed and substantiated using the example of the “Sunkar” ski jumping complex.

4. A technology for geodetic monitoring of sports structures based on terrestrial laser scanning has been developed.

5. A methodology for analyzing spatial displacements of sports structures based on geodetic monitoring data using spline function theory was developed and substantiated.

Structure and scope of the dissertation. The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. The dissertation is presented on 115 typed pages and contains 17 tables, 68 figures, and a list of 94 references.