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SPECIFIC FEATURES OF GEODETIC WORKS DURING THE CONSTRUCTION OF HYDROELECTRIC POWER PLANTS

The aim of this study is to determine the features of geodetic support during the construction of hydroelectric power stations (HPPs) using modern equipment. The study evaluates geodetic tasks across the design, construction, and exploitation stages of HPPs in Ukraine. It demonstrates that devices such as electronic total stations and terrestrial laser scanners reduce the time required to collect spatial data. Key characteristics of HPP geodetic support are established, including high-precision measurements, continuous monitoring, and specialized networks. These solutions form a theoretical basis for practical geodetic works at water management facilities.

***Keywords**: hydraulic structures; geodesy; geodetic support of construction; electronic total station; terrestrial laser scanner.*

Fig.: 3. References: 11.

Relevance of the research. Modern infrastructure development relies on automated geodetic systems that generate unprecedented volumes of high-precision spatial data. This shift requires adapting classical error theory and statistics to process massive metrological datasets and ensure structural safety through continuous instrument verification. This study examines modern criteria for evaluating measurement accuracy and mathematical algorithms designed to minimize random and systematic errors.

Problem statement. Geodetic methodology evolves alongside data technologies. Robotic surveying has redefined accuracy and the human role, highlighting the gap between error-prone raw data and reliable processed models. Bridging this gap requires a robust algorithmic framework for evaluating accuracy (using mean square and relative errors) and a strict classification of instruments based on precision and calibration standards.

Analysis of recent research and publications. To form a comprehensive understanding of the regulatory framework and methodological foundations for performing geodetic works during the construction of hydraulic structures, sources [1, 2, 6] were analyzed. Modern trends regarding spatial data collection, processing, and their integration with geographic information systems (GIS) and artificial intelligence (AI) are discussed in the works of [3, 4].

The issues concerning the overall reliability and operational safety of large-scale hydraulic facilities in Ukraine are highlighted in the study [5]. Practical aspects of implementing advanced methods, specifically terrestrial laser scanning (TLS) for creating digital 3D models of hydropower plants (HPP), as well as the specificities of designing mini-hydropower plants, are described in papers [7, 10].

Special attention is given to high-precision methods for monitoring deformations and vertical displacements of dams using satellite technologies (GNSS), satellite radar, and InSAR, which are investigated in detail in scientific researches [8, 9, 11].

Isolation of previously unexplored parts of the general problem. Analysis of previous studies has shown that geodetic research on hydraulic structures has been conducted extensively, but primarily focusing on the monitoring of deformations and settlements during the exploitation phase. This remains a critical component for ensuring the safety of existing facilities. In general, various theoretical models for high-precision measurements and satellite-based monitoring (GNSS) of existing dams have been proposed.

However, a key limitation is that the specific features of geodetic support during the active construction stage of hydropower plants (HPP), especially with the application of contemporary high-precision instruments, have not been fully disclosed in the context of Ukraine. While traditional methods are well-documented, the methodological integration of robotic total stations and terrestrial laser scanning for the installation of hydro-units and geometry control of complex structures remains insufficiently explored. Moreover, there is a lack of comprehensive comparative analysis regarding the efficiency of these modern tools specifically for hydraulic engineering tasks under the challenging environmental conditions of Ukrainian water management systems.

Research objectives. The purpose of this study is to determine the specific features of geodetic support during the construction of hydroelectric power plants (HPP) and the application of modern geodetic equipment in these activities.

Object of the research: The object of the study is geodetic works during construction.

Subject of the research: The subject of the study is geodetic support at specific stages of hydroelectric power plant construction.

Assumptions and Limitations: The concept of "hydroelectric power plants" (HPP) encompasses both tidal power plants (TPP) and pumped-storage hydropower plants (PSHP). This scope determines the following assumptions and limitations:

Special attention should be given to the issues of developing the geodetic control network (geodetic basis) within the construction site territory.

A hydroelectric power plant (HPP) is accepted as the primary object of construction.

The statement of basic materials. To develop a design for a structure, initial data regarding the region and construction conditions are required, while economic indicators are also taken into account. For this purpose, comprehensive engineering surveys are conducted; regarding HPP construction, surveys are carried out to justify its placement scheme. Engineering-geodetic surveys play an equally important role, involving the collection and analysis of materials from previously performed geodetic and topographic works at the construction site, creating new or densifying existing geodetic networks, and providing topographic materials to design organizations and teams performing other types of surveys. When developing an HPP layout scheme, engineering-geodetic surveys are performed to determine the volumes of planned reservoirs and flooding patterns.

Based on the feasibility study, a structural design is developed, which considers the designs of hydraulic and energy structures, includes scientific research to verify design proposals, and finally establishes the parameters of the hydroelectric node. Like all complex objects, HPP design is carried out in two stages:

In the first stage, a technical design is prepared, which serves as a guide for the organization and execution of construction works;

In the second stage, working documentation is developed for the detailed design of all elements of the hydraulic node structures with specified dimensions and levels; also, construction execution plans (CEP) and geodetic execution plans (GEP) are created.

As a rule, the construction of hydroelectric power plants is carried out in several stages. The essence is that the primary structures (the HPP building, water intakes) are fully constructed first, and then the installation of the main equipment is performed sequentially.

For example, one can consider the construction process of the Dniester HPP (Fig. 1, a), which began in 1973. The article notes that the first two units were commissioned in 1981, and the final unit was commissioned in 1983. While historical projects like the Dniester HPP primarily relied on traditional geodetic methods, contemporary reconstruction and new construction projects necessitate the integration of advanced high-precision tools.

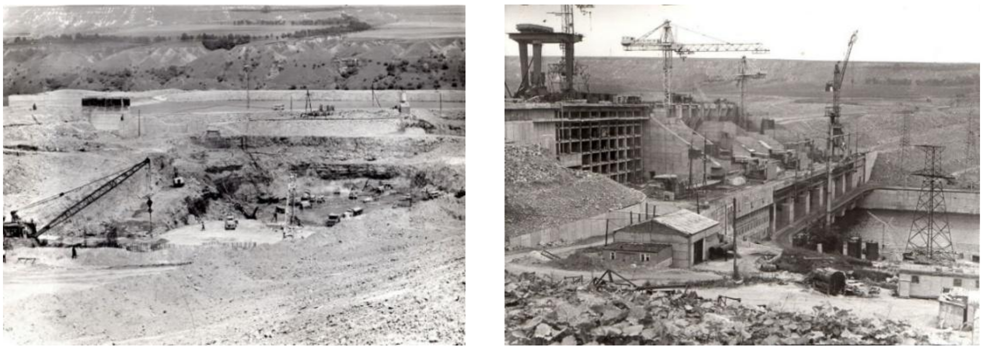

Fig. 1. Example of HPP construction:
a – start of construction of the Dniester complex hydroelectric node;
b – completion of construction of the main hydraulic structures of the Dniester HPP

HPP construction is traditionally divided into three periods:

– Preparatory: Infrastructure, resource routes, and flow diversion structures.
– Main: Construction of primary hydraulic structures and unit commissioning.
– Final: Completion and handover for operation.

Post-construction geodetic works track geometric changes using satellite technologies. In Ukraine, this is governed by DBN V.1.3-2:2010, requiring Geodetic Execution Plans (GEP) and scientific support for complex structures.

The geodetic framework comprises the State Geodetic Network (SGN) and densification networks. For hydroelectric power plants (HPPs), triangulation using electronic total stations or GNSS receivers is employed, depending on the circumstances, to determine the planimetric position with high accuracy.

Typically, one of the sides of the triangulation coincides with the main axis of the hydroelectric complex, which can be taken as the abscissa axis. Network points are marked with special geodetic markers equipped with devices for rapid forced centering of instruments and sighting targets (Fig. 2).

Fig. 2. Appearance of a geodetic pillar for forced centering of instruments

Density networks under conditions of limited visibility are established using the method of theodolite traverses. The elevation control system, which establishes the elevation of the river channel and supports topographic surveys, involves the creation of first- and second-class leveling networks along stable, non-flooded sections of river valleys. The choice of methodology depends on the conditions: Class II leveling is used for slopes less than 0.00003, and for wide rivers, it is necessary to lay out traverses on both banks. Densification networks (Classes III–IV) use depth or rock benchmarks, positioned to allow for the transmission of elevations over distances of 2–3 stations.

Monitoring of HPP structures is carried out in two stages:

1. Establishing deep benchmarks on both riverbanks.
2. Embedding deformation marks in foundations referenced to the first stage. Such networks are critical for the safety of high-responsibility facilities like HPPs.

A more appropriate approach to using contemporary geodetic instruments at construction sites can be characterized as follows: the instrument used must ensure high precision while significantly saving human labor and time. Potential representatives of such geodetic instruments include, for example, the electronic total station and the terrestrial laser scanner (Fig. 3).

а *б*

Fig. 3. Geodetic instruments relevant to the subject of the study:
a – Faro Focus 3D 120 terrestrial laser scanner; b – Leica Nova MS60 total station

The Leica Nova MS60 ensures highly efficient geodetic support for HPP construction, particularly in:

– Earthworks and monitoring: Surveying stockpiles, analyzing design surfaces, and real-time monitoring of dams, ice, and snow.

– Complex structures: Dimensional control of the hydroelectric node, as-built surveys, and structural health analysis.

– Hydro-unit installation: High instrument precision combined with GNSS integration significantly accelerates the development of detailed setting-out networks.

However, for rapid spatial data acquisition, Terrestrial Laser Scanning (TLS) is preferred. This method generates digital 3D models via point clouds. Practical experience with the Faro Focus 3D 120 at the Onokivska HPP confirmed the following advantages:

– Rapid large-scale topographic surveying and 3D modeling.

– Detection of geometric deviations and measurement of heavy machinery (lock gates, overhead cranes).

– Damage Assessment: TLS is indispensable for surveying destroyed infrastructure and calculating reconstruction volumes, which is critically relevant for Ukraine's current recovery efforts.

Conclusions. The characteristic features of geodetic works during the construction of hydroelectric power plants (HPP) have been established as follows:

1. Specific topographic requirements: Topographic materials must adhere to particular standards regarding scale and contour intervals (relief cross-sections).
2. High-precision measurements: The necessity for extreme accuracy, particularly during the installation and alignment of hydro-units.
3. Systematic geodetic control: Ongoing monitoring of the geometric parameters of hydraulic structures (HS).

4. Adverse environmental conditions: Execution of geodetic works in challenging settings, such as flooded areas, unstable or subsiding soils, and operations on ice during winter.

5. Durable geodetic monumentation: The installation of specialized, long-lasting geodetic markers and benchmarks designed to withstand harsh environmental factors.

6. GNSS integration: Equipping geodetic markers within the HPP territory with GNSS hardware for real-time monitoring of hydroelectric node displacements.

7. Scientific and technical support: The mandatory organization of specialized support for geodetic monitoring, given the complexity of the facility and its natural surroundings.

The scientific significance of this work lies in the formation of a theoretical framework for the practical implementation of geodetic operations during the construction of water management facilities.

In the course of the research, the following scientific results were achieved:

– An analysis of geodetic network development during both the construction and operational phases of an HPP was presented.

– Specific solutions were proposed for the utilization of modern geodetic equipment at various stages of HPP construction and maintenance.

Given the diversity of water management infrastructure, the object of this research has enabled a comprehensive representation of geodetic work technologies applicable to hydraulic structures of any purpose.

Statement on the Use of Generative AI and AI-Based Technologies in the Writing of This Article

While writing this article, the authors used the gemini.google.com service to translate the article's content into English. After using this service, the authors reviewed and edited the content as necessary and assume full responsibility for the content of this publication.

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ОСОБЛИВОСТІ ГЕОДЕЗИЧНИХ РОБІТ ПІД ЧАС БУДІВНИЦТВА ГІДРОЕЛЕКТРОСТАНЦІЙ

Метою дослідження є визначення та наукове обґрунтування особливостей геодезичного забезпечення на різних етапах будівництва та експлуатації гідроелектростанцій (ГЕС) в Україні із застосуванням сучасних технологій.

Методологічна основа роботи базується на комплексному аналізі класичних геодезичних вишукувань при будівництві ГЕС, нормативно-правової бази та аналізі геодезичного обладнання.

У роботі деталізовано структуру будівництва ГЕС та визначено специфічні вимоги до геодезичної основи, щодо чого було розглянуто методи тріангуляції та нівелювання як основу для створення високоточних планово-висотних мереж, також обґрунтовано застосування пунктів із примусовим центруванням приладів.

Для верифікації ефективності сучасного інструментарію проведено аналіз застосування електронного тахеометра Leica Nova MS60 та наземного лазерного сканера Faro Focus 3D 120, до того ж було аргументовано, що інтеграція GNSS-технологій у тахеометричні вимірювання дозволяє спростити процес польових робіт за рахунок оптимізації прив'язки приладу. Також, аналіз показав, що використання наземного лазерного сканування забезпечує створення 3D-моделей об'єктів, що є критично важливим для контролю геометрії складних вузлів та оцінки ступеня руйнувань інфраструктури в сучасних умовах за рахунок збору надлишкових даних.

На основі отриманих результатів сформовано теоретичну базу, яка дозволить розпочати виконання практичних геодезичних робіт на ГЕС, а також продемонстровано переваги автоматизованого збору даних для забезпечення моніторингу гідротехнічних споруд та для відновлення зруйнованих об'єктів енергетики.

Загалом, практична значущість дослідження полягає в удосконаленні методик геодезичного супроводу складних інженерних споруд, що дозволяє підвищити точність вимірювань, мінімізувати вплив помилок через людський фактор та забезпечити моніторинг деформаційних процесів у режимі реального часу.

Ключові слова: *гідротехнічні споруди, геодезичне забезпечення, гідроелектростанція, електронний тахеометр, наземне лазерне сканування, моніторинг.*

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