IOSUD - Universitatea Politehnica Timişoara

Şcoala Doctorală de Studii Inginereşti

RESEARCH AND RESULTS REGARDING GEOSPATIAL METHODS AND MODELS USED FOR CONSTRUCTION MONITORING OVER TIME

Doctoral Thesis – Summary

for the attainment of the Doctor of Philosophy title at
Politehnica University of Timișoara
in the doctoral field of Civil Engineering and Installations

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The doctoral thesis is structured into eight chapters, each examining various aspects of long-term structural monitoring. These encompass the theoretical foundation of the research topic, an analysis of the factors influencing structural behavior, advanced methods for deformation tracking, case studies involving the monitoring of heritage structures and critical infrastructure, as well as the author's personal contributions towards optimizing monitoring processes.

Chapter 1: Introduction

This chapter presents the rationale behind the chosen research topic, outlining the proposed objectives, the structure of the dissertation, as well as a general overview of long-term structural monitoring. Within this context, emphasis is placed on integrating sustainable development principles and employing modern information management solutions for construction projects, such as Building Information Modeling (BIM).

The first chapter centers on ensuring the safety of building use, underscoring the importance of durability and the protection of human life. It highlights the necessity of a rigorous assessment of a building's technical condition, which includes the analysis of structural components, the detection of deformations and deteriorations, and consideration of external factors such as seismic demands, climatic variations, and dynamic loads generated by occupancy and use.

Structural analysis is essential for the early identification of potential issues, enabling timely interventions through maintenance, reinforcement, or repairs, thus preventing major risks. Dynamic loads—most notably seismic forces and vibrations—have a significant long-term impact on structural behavior, and detailed monitoring of these aspects plays a crucial role in safeguarding the building's stability.

Modern technological advancements, including sensors for monitoring vibrations and deformations, facilitate the collection of accurate real-time data. These data support rapid and effective decision-making. Continuous and periodic monitoring, coupled with the analysis of material behavior, helps prevent structural deficiencies and extends the service life of buildings.

Additionally, this chapter introduces the notion of BIM (Building Information Modeling). BIM is presented as an innovative technology that centralizes the geometric, physical, and functional data of a construction project into a three-dimensional digital model. This methodology fosters interdisciplinary collaboration and enables the analysis of structural, energy, and durability performance throughout the building's entire lifecycle. By employing BIM, one can achieve significant benefits, such as reducing errors, saving time, and optimizing costs.

Key ideas of the chapter:

- **Continuous Monitoring**: Early identification of structural issues is crucial for preventing deficiencies and maintaining safety.
- **Modern Technologies**: Advanced monitoring systems provide precise data for effective interventions.
- **Structural Deformations**: These must be constantly analyzed to prevent significant damage and extend the operational lifespan of structures.
- **Monitoring Planning**: A well-structured system ensures the durability and safety of constructions.
- **Energy Efficiency and Sustainability**: Reducing resource consumption and using durable materials are essential for responsible operation.

This chapter highlights the necessity of an integrated and multidisciplinary approach to ensuring the safety and durability of constructions, advocating for the adoption of modern technologies and innovative solutions.

Chapter 2: Physical actions on constructions

This chapter analyzes the key factors that must be monitored to evaluate structural deformations and displacements. A comprehensive understanding and appropriate management of these phenomena are essential for maintaining the long-term integrity and safety of constructions. Through rigorous monitoring and the implementation of efficient technical solutions, design and engineering specialists can prevent structural damage, ensure optimal building performance, and safeguard both users and the environment.

Structural stability is a central concern in civil engineering, requiring the management of forces and physical influences that may compromise the structural integrity of buildings. These actions, whether static or variable, are rigorously analyzed to ensure long-term durability and safety.

- **Static actions**: These represent permanent forces, such as self-weight and constant loads, which must be evenly distributed on foundations to avoid settlements and cracks. These require precise analysis during the design phase.
- **Dynamic actions**: These include vibrations, traffic, industrial movements, and wind. They can lead to material fatigue or cracks, necessitating solutions such as vibration dampers and flexible structures.

- **Seismic actions**: Earthquakes require the use of flexible structures, such as steel and reinforced concrete frames, along with measures like expansion joints. Local seismic risk analysis is vital.
- **Climatic actions**: Rain, wind, snow and temperature variations demand protective measures, such as thermal and waterproof insulation to prevent material deterioration and structural overload.
- **Thermal actions**: Material expansion caused by temperature fluctuations can be managed through expansion joints and the use of materials resistant to extreme temperatures.
- **Wear actions**: Loads applied during daily use gradually degrade materials. Regular maintenance and periodic inspections are essential to maintain building performance.
- **Hydrological actions**: Groundwater pressure, infiltration and flooding can affect foundations, requiring solutions such as efficient drainage and waterproofing.

Managing physical actions on constructions is crucial for stability and safety. Engineers must apply advanced design solutions and modern monitoring technologies, alongside periodic maintenance, to extend the lifespan of buildings and protect users and the environment.

This chapter also presents essential principles in construction design, focusing on aspects such as structural calculation, the selection of high-quality materials, seismic-resistant design, resistance to climatic factors, the integration of maintenance measures and road management. Structural calculations assess permanent, variable and exceptional loads per international standards to ensure long-term safety. The use of certified high-quality materials contributes to construction durability, while seismic-resistant designs employ modern technologies to protect structures in seismically active areas. Climatic factors are addressed through effective insulation and drainage techniques. Incorporating maintenance measures from the design phase reduces costs and the frequency of subsequent interventions. Road maintenance is addressed through innovative solutions, durable materials and integrated management to optimize resources via preventive and predictive planning. These principles ensure the robustness and sustainability of buildings and infrastructure.

Toward the end of the chapter, structural deformations and displacements are addressed, classified to understand and manage their impact on construction integrity and safety. Axial deformations (tension, compression), transverse deformations (bending, torsion), elastic and plastic deformations, buckling and shearing are analyzed, as well as differential, seismic, vibration-induced, thermal and landslide displacements. These phenomena are critical for preventing damage and collapse, requiring precise analyses and tailored solutions, such as reinforcement, seismic isolation or the use of expansion joints, to ensure construction durability and functionality.

Chapter 3: Methods for monitoring construction deformations over time

This chapter provides a concise overview of methods and tools used to determine linear and three-dimensional displacements of structures. It addresses advanced monitoring techniques and specialized equipment that enable precise measurement and evaluation of structural behavior over time, ensuring efficient deformation monitoring and contributing to the safety and stability of constructions.

Geodetic Methods for Measuring Vertical Displacements and Deformations

The chapter presents geodetic methods used for monitoring vertical displacements and deformations in constructions, emphasizing modern technologies and their precision.

High-Precision Geometric Leveling, also known as direct leveling, is the reference method for determining elevation differences between points due to its horizontal sights and high accuracy. It is used for exact vertical displacement measurements, with applications ranging from scaled experiments to monitoring large structures such as dams and bridges. Geometric leveling is reliable, versatile, and stable over the long term, making it ideal for tracking settlements and deformations over time.

High-Precision Trigonometric Leveling offers a practical alternative, especially in inaccessible areas or over long distances. Based on angle and distance measurements, this method is effective for tall or hard-to-reach constructions, though it is more vulnerable to atmospheric errors. However, by integrating total stations and GNSS technology, it ensures high precision and extended applicability.

Modern technologies such as GNSS, LIDAR, and drones have revolutionized structural deformation monitoring. GNSS enables precise real-time measurements of horizontal and vertical displacements, proving useful in monitoring large structures. LIDAR, through laser scanning, provides detailed 3D models of constructions and enables accurate analysis of deformations and deterioration. Drone imaging supplies rapid, detailed data about terrain and constructions. Equipped with cameras, multispectral sensors, or LIDAR, drones effectively monitor inaccessible areas, and image processing generates digital models and detailed maps useful for structural analysis.

These methods, each with its specific advantages, contribute to precise and efficient construction monitoring, supporting their long-term safety and durability. For effective real-time monitoring and shorter reaction times in critical situations, real-time structural monitoring is essential.

Real-time deformation monitoring is an advanced technology used for the continuous and precise measurement of changes in position, shape, or size of structures during operation. By employing high-precision sensors and transmitting data to a central system, this process allows instant detection of structural changes, ensuring stability and safety.

Monitoring systems include sensors such as inclinometers for tilt measurement, extensometers for detecting settlements and displacements, piezometers for monitoring soil water pressure, and sensors for cracks and vibrations. Data collected is transmitted via cables or wirelessly, analyzed using specialized software, and may trigger automatic alarms if critical safety thresholds are exceeded.

The primary advantage of real-time monitoring is prompt intervention upon detection of structural issues, preventing major damages or disasters. This system is indispensable for monitoring strategic structures such as dams, bridges, and telecommunications towers, where even minor deformations can indicate significant risks.

The equipment used, including extensometers, inclinometers, crack sensors, and accelerometers, contributes to accurate structural and geotechnical condition evaluation. Additionally, these tools support proactive measures for ensuring safety and optimizing construction maintenance.

Continuous monitoring offers essential benefits such as preventing damages, enhancing safety, reducing repair costs, and optimizing maintenance planning based on real-time data. It plays a crucial role in projects where structural integrity and public safety are priorities, ensuring infrastructure durability and disaster prevention.

Chapter 4: Studies and research for long-term monitoring of art works on the Caransebeș bypass

This chapter provides a detailed analysis of the research conducted within a project aimed at monitoring bridges and overpasses. It includes an in-depth examination of the methodologies applied and the data collected for evaluating the structural behavior of these constructions, highlighting the importance of continuous monitoring to ensure their safety and durability.

The necessity of long-term monitoring for the objective

The construction, operational since December 2011, encountered significant stability issues that led to temporary closures and numerous repair interventions between 2012 and 2013. Among these was the reconstruction of the Valea Mică viaduct, located at km 7+375. In the context of repeated repairs and high traffic intensity, a topographic study was initiated to monitor the long-term behavior of the structure, based on a dedicated technical project.

The identified issues, including cracks, settlements, and displacements, were detailed in reception reports. For instance, the bridge at km 7+375 required expert evaluations of its stability, while the embankments of the Sebeș, Potoc, and Valea Mare viaducts were rebuilt and reinforced due to significant settlements. The Valea Mică viaduct, constructed using TERRE ARMEE technology, exhibited failures in prefabricated panels and torsions in the upper beams, necessitating its reconstruction and the initiation of strict monitoring protocols.

To implement the monitoring program, it was essential to develop a technical project for the supervision of the objectives included in this program. Preparing the technical monitoring project involved creating a detailed plan for the long-term observation of the structure's behavior to ensure the stability and safety of the works. This project includes:

No.	Stage	Description
1	Defining Monitoring Objectives	Establishing key parameters to be tracked, such as settlements, horizontal displacements, and structural cracks.
2	Selecting Monitoring Methods	Choosing appropriate technologies and methods for measurements, such as topographic equipment, displacement sensors, and photogrammetry techniques.
3	Planning Equipment Placement	Identifying critical points of the structure (abutments, pillars, embankments) where monitoring equipment will be installed to obtain relevant data.
4	Measurement Frequency	Determining an appropriate frequency for data collection based on the structure's needs and identified risks.
5	Data Analysis and Interpretation	Developing procedures for collecting and interpreting monitoring data, including the use of analytical models or software for structural behavior evaluation.
6	Reporting Results	Defining the format and frequency of monitoring reports, which will include periodic evaluations of the structure's condition and recommendations for potential interventions.

As part of the monitoring program, the included structures were the SEBEȘ bridge at km 4+725, the POTOC bridge at km 5+512, the VALEA MARE bridge at km 7+107, as well as the armored earth passage VALEA MICĂ, located at km 7+375.

Regarding the selected monitoring methods, we opted for geodetic techniques, involving cyclic measurements of linear nature (high-precision geometric leveling) and angular nature (trigonometric leveling). These were based on a network of fixed points placed outside the construction (embankment). To establish the support network, fixed benchmarks were installed in areas outside the direct influence of the construction, thereby ensuring a stable reference base for measurements.

In the research process, we also included detailed planning of the measurement campaigns. A monitoring schedule over a two-year period was proposed, during which seven measurement cycles were planned, structured as follows:

- 3 measurement campaigns were conducted in the first 6 months of the project;
- 2 measurement campaigns were carried out in the following 6 months, thus completing the first year of monitoring;
- 2 measurement campaigns took place in the second year of the project, with a frequency of one campaign every 6 months.

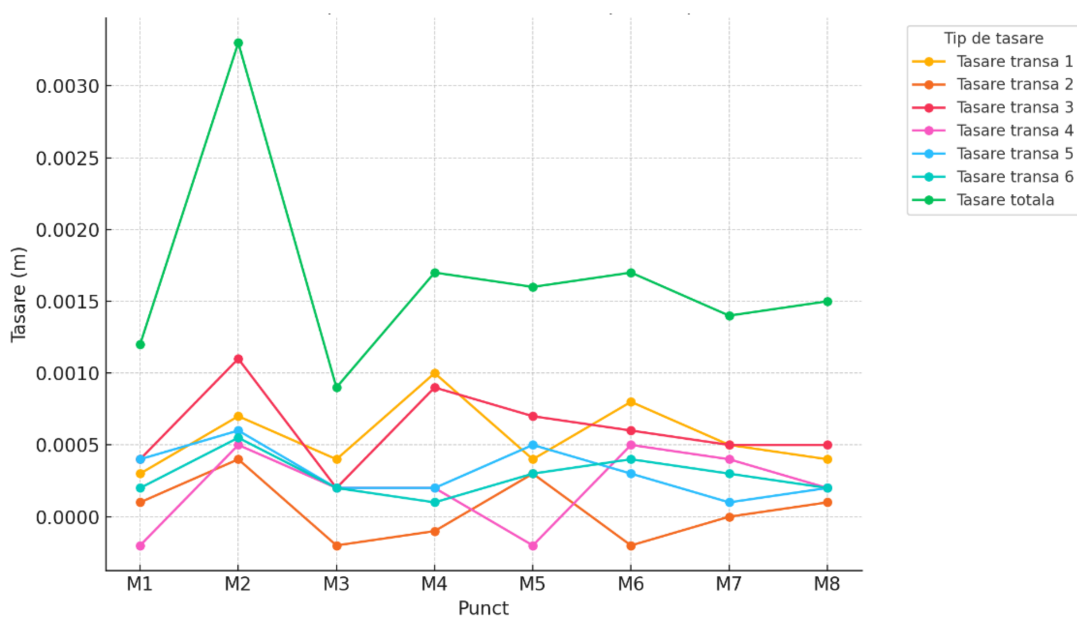

Fig. 2. The evolution of point and trench stakeout methods

A structural analysis of a bridge was also performed, based on images captured by drones, representing a modern technique that combines traditional inspection methods with advanced image processing and digital reconstruction technologies. This methodology enables the rapid, safe, and detailed evaluation of structural conditions, providing essential information for maintenance, rehabilitation, or extension planning.

Analyzing the obtained data, it was observed that the Sebeș Bridge exhibits good stability, with the measured differences falling within the acceptable tolerances for safe use.

Based on the processed field measurements, the following conclusions regarding the Valea Mică Passage can be drawn:

The maximum vertical deformations at the marks placed on the parapet beam are 7.0 mm (mark M9), while at the base of the passage, they are 3.2 mm.

The settlement difference between the parapet beam and the base of the passage (approximately 4 mm) could result from the distribution of traffic-induced loads.

The horizontal deformations of the armored earth passage are negligible, with the maximum measured value being 2 mm.

Analyzing both horizontal and vertical deformations, it is assessed that there are no stability issues.

No recommendations are necessary for identifying solutions to improve the structural stability.

In conclusion, structural analysis of a bridge based on drone-captured images is an essential tool for civil engineers, providing detailed and precise information. This method allows for an accurate assessment of the current state of the structure, facilitates the planning of rehabilitation work, and helps prevent potential critical failures, contributing to the safety and durability of infrastructure.

Chapter 5: Applied models for monitoring floor displacements and structural elements in an industrial building

This chapter details the methodology for long-term monitoring of a production hall (TMD FRICTION, located in Caransebeș, Vârful Gugu Street, no. 1, Caraș Severin County) situated in an area with geotechnical risks concerning the stability of the foundation soil. It describes the models applied for evaluating the displacements of the floor and structural resistance elements, offering a systematic analysis of structural behavior over time to ensure the safety and optimal operation of the building under geotechnical risk conditions.

The study was requested by the beneficiary following the observation of cracks in the floor of the hall and the locker rooms, which could potentially impact production activity. To identify the causes, a technical expertise on the concrete floor was conducted, supplemented by geotechnical and vibration studies. Topographic monitoring of the vertical displacements of the floor and structural elements was also required to evaluate the long-term stability of the hall.

Vibration measurements were performed, and to ensure optimal operation, it was recommended to adjust the operating frequency of machinery to avoid resonance ranges. This adjustment helps reduce vibrations and extend the lifespan of critical equipment components, promoting system stability and efficiency.

Monitoring industrial floors using topographic methods is essential for detecting displacements and maintaining structural safety. High-precision geometric leveling is frequently used to measure vertical variations over large areas, providing accurate data on millimetric deformations. Measurement accuracy is crucial, with acceptable errors varying depending on the type of construction and terrain. For rapid deformations, high accuracy is necessary for prompt evaluation. Periodic observations may allow more relaxed requirements, but sensitive or large-scale constructions demand extremely precise measurements.

Following the analysis of existing cracks and data from geotechnical and vibration studies, a structured monitoring process was implemented, consisting of five measurement stages over one year. This approach enabled detailed and continuous evaluation of potential structural degradations.

To monitor vertical displacements in the hall's floor, the mid-level geometric leveling method was used with a LEICA DNA 03 digital level and GPCL2 invar stadia, recognized for their high precision (0.3 mm/km) and measurement resolution (0.01 mm). This equipment allows real-time display of levels and data recording for subsequent processing.

The process included systematic measurements, data processing to calculate displacements, and verification of benchmark stability, followed by documentation preparation. To ensure accuracy, two leveling runs were conducted: a primary and a secondary one, to eliminate errors that may arise due to the large surface area of the hall.

Findings from Field Measurements and Data Processing

Settlement marks placed on structural resistance elements showed changes throughout the measurement cycles. The maximum settlement was recorded at Mark L11, with a value of **9.2 mm**.

Settlements determined for bolts embedded in the floor exhibited comparable magnitudes to those obtained for settlement marks placed on columns.

These results indicate consistency in settlement phenomena across the various monitored points of the structure.

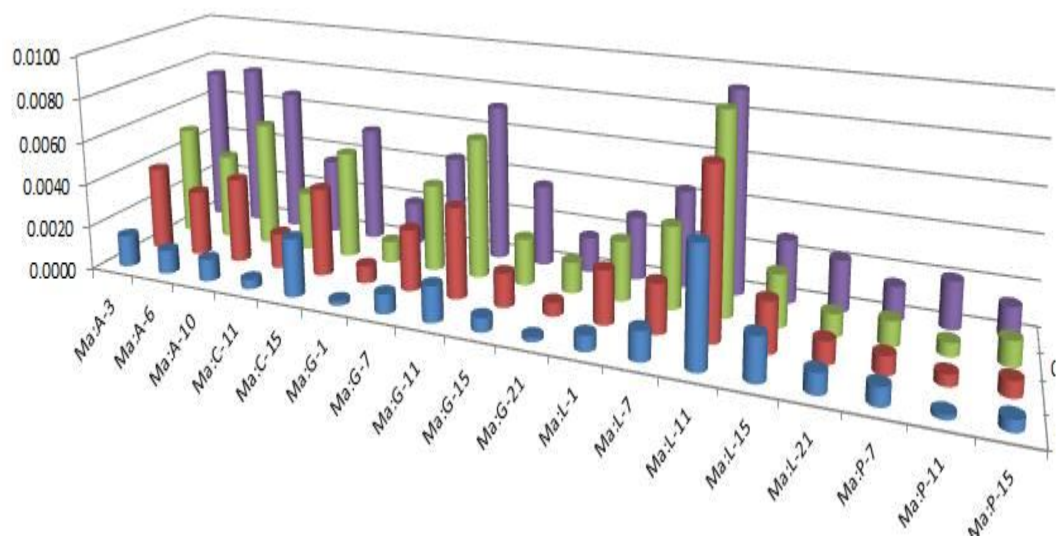

Fig. 3. Graphical representation of settlements

Based on the obtained data, a technical expertise report was prepared proposing floor consolidation using injection techniques. This solution involves performing injections in areas adjacent to joints and near foundations to increase load-bearing capacity and ensure structural stability.

After completing the consolidation phase, three additional cycles of topographic measurements were conducted, with the primary objective of monitoring and evaluating the evolution of settlements under the new structural and geotechnical conditions generated by the performed works.

Following the additional measurements, the findings were:

- Settlement marks placed on the structural resistance elements (columns) showed changes during the measurement cycles, with the maximum settlement recorded at Mark A10 at 2.6 mm.
- For bolts embedded in the ground floor, the settlement situation was similar in magnitude to the values determined at the column marks. The maximum value was recorded at Bolt Bl 1, measuring 1.6 mm.
- All benchmarks monitored in the consolidated areas exhibited insignificant displacements.

Considering the evolution of floor deformations and the resistance structure over time, it is assessed that the settlements have stabilized following the implementation of consolidation solutions through soil injection. This allows for the development of a comprehensive consolidation project for the floors and foundations of the building.

Chapter 6: High-precision topographic analysis for gate systems at the Iron Gates I Lock

This chapter presents the study conducted as part of the lock modernization project. It highlights the advantages of using laser scanning technology, which enables the acquisition of significant volumes of precise data even under challenging working conditions. Laser scanning technology has demonstrated high efficiency in collecting essential topographic details for the rehabilitation of the lock, thereby optimizing the modernization process and improving data accuracy.

In 2006, the rehabilitation process of the Romanian lock on the left bank began, but it was interrupted for a period and resumed approximately two years ago.

The scope of the work involves the replacement of the metal structure, the rehabilitation of embedded components in the gate recess associated with the segment gate, the rehabilitation of the protective screen within the gate recess, along with its associated embedded components, and the rehabilitation of the protective frame. The gate recess is located in the downstream cofferdam area at the Intermediate Head.

For measurements, the radiation method, the rectangular coordinate method, and laser scanning were used, adapted to meet the required precision standards. The selected equipment included the Leica TS15 total station for topographic measurements and the API Imager PRO 5010 laser scanner, ensuring precise and detailed data collection. The main challenge was identifying scanning positions to meet the required precision, considering the difficulties of accessing the interior of the gate and the instability of the scanning equipment on the crane. The solution was to perform scans from five different positions, three outside the gate and two inside, aligned with the guide rails.

Fig. 4. Scan performed inside the valve

The large number of points acquired, 283,952,960, allowed for the generation of a three-dimensional (3D) model. The use of the 3D model obtained through laser scanning provides significant advantages in the analysis of object deformations, particularly due to the high density of the acquired points and the precision of this technique. The resulting model represents a highly detailed virtual replica of the studied object, offering a solid foundation for evaluating and monitoring deformations at various stages of operation.

In conclusion, the 3D model obtained through laser scanning is an advanced and efficient tool for structural deformation analysis, enabling precise and rapid monitoring that contributes to extending the lifespan of structures. Compared to traditional methods, laser scanning reduces data collection and interpretation time, saving resources and minimizing operational downtime. For complex or hard-to-access structures, such as gates, terrestrial scanning based on LiDAR technology is essential. However, several technical challenges must be addressed, including the positioning of scanning stations, georeferencing point clouds, and ensuring high data density and precision. Limitations such as reduced visibility or material reflection can affect data quality. With proper planning and the use of appropriate equipment, terrestrial scanning can deliver highly precise results for the analysis and monitoring of complex structures.

Chapter 7: Spatial analysis model for long-term monitoring of an innovative road structure

This chapter presents a best-practice model used for long-term monitoring of several road sectors. By combining conventional topographic methods with modern measurement techniques such as photogrammetry and terrestrial laser scanning, high data precision and a comprehensive overview of the entire studied area were ensured.

As part of this study, the behavior of roads in the village of Ohaba-Forgaci and the Ohaba-Forgaci – Boldur road segment was monitored. The analysis focused on road sectors within the village limits of Ohaba-Forgaci, Timiș County, and a road segment between Ohaba-Forgaci and Boldur. This analysis was necessary following the modernization of these roads, which was carried out by implementing a macadam-type road structure that includes a binder to enhance the road's consolidation and resistance. The macadam structure is increasingly used in high-traffic areas, such as those where heavy agricultural machinery operates, characteristic of northern regions.

To execute this project, a variety of modern topographic measurement methods and technologies were used, ensuring a detailed and accurate evaluation of the roads' behavior over the long term. The implemented technologies included:

- **Mid-level geometric leveling** – for precise measurements of elevation differences;
- **Trigonometric leveling** – used to determine altitudes by measuring vertical angles;
- **GNSS technology** – for accurate localization and coordinate measurement;
- **Terrestrial laser scanning** – an advanced method of collecting three-dimensional data, ensuring detailed terrain mapping;
- **Digital photogrammetry** – used to reconstruct three-dimensional objects and surfaces based on digital images.

During the study, both traditional methods and modern topographic measurement techniques were applied. In the initial phase, classical topographic methods, such as total station measurements and geometric leveling, were used to establish control point positions and create an initial road model. These data were essential for establishing a baseline for subsequent measurements and detecting structural changes that might occur over time.

A significant step in the monitoring process was the use of digital photogrammetry, which enables the acquisition of detailed aerial images of the studied road segments. Photogrammetry provides an overview of the roads, proving useful for the visual assessment of deformations, cracks or other irregularities that may occur during road use. It also allows for periodic image acquisition, facilitating the detection of changes over time.

To further enhance measurement precision, terrestrial laser scanning was employed. This advanced technology captures a vast number of data points in a short time, with a density of up to one million points per second. Laser scanning enabled the creation of 3D models of the roads, offering a detailed analysis of their surface and structure. This technology is crucial for detecting minor changes that may foreshadow more significant deformations in the long term.

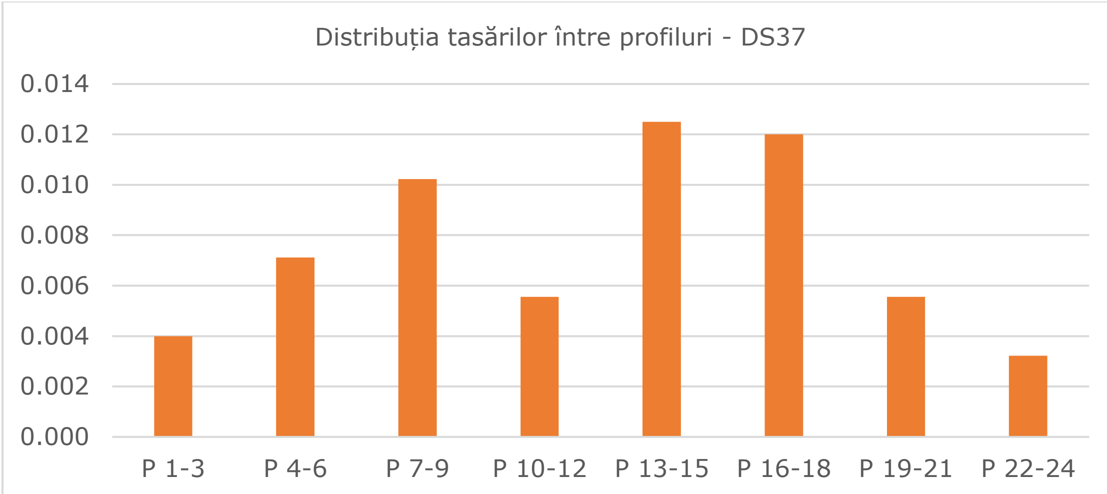

Fig. 5. The settlement distribution diagram for one of the segments at Ohaba-Forgaci

One of the main advantages of this study was the use of an integrated approach, where data obtained through one method was validated and correlated with data from other methods. This approach increased the reliability of results and reduced the risk of errors. Consequently, we achieved rigorous and detailed monitoring of road structures, providing an accurate evaluation of the condition of the roads in the studied areas.

In conclusion, the combination of traditional methods and modern technologies allowed for a precise and detailed analysis of the roads in the village of Ohaba-Forgaci and the Ohaba-Forgaci – Boldur segment. By implementing terrestrial laser scanning, digital photogrammetry, and other advanced techniques, we obtained high-precision data essential for long-term monitoring of road structural conditions. These methods will significantly contribute to assessing road behavior and preventing potential major deformations that could arise in the future.

Chapter 8: Conclusions, original contributions, and future research directions

This chapter presents the conclusions derived from the research conducted as part of the monitoring processes for the analyzed objectives, highlighting the author's original contributions. Additionally, it details how the research results have been utilized, emphasizing their impact on improving monitoring methods and their practical applicability.

Monitoring the behavior of constructions is essential for mitigating risks associated with limit states, which can affect both functionality and safety. These risks include the inability to meet operational requirements and the emergence of hazards that threaten the safety of people and property. Therefore, it is crucial to monitor deformations and structural displacements early, as they may indicate a loss of stability.

Modern geodetic technologies are essential for tracking the evolution of constructions, with applications including the measurement of settlements, horizontal displacements, and inclinations. These technologies, particularly automated systems, enable precise evaluation of construction behavior and the early detection of instability phenomena.

Settlement or horizontal displacement is not always an alarm signal; however, when measured values exceed predicted thresholds, a detailed analysis becomes necessary. A settlement monitoring program is crucial for ensuring the long-term optimal and safe operation of a construction. Without adequate monitoring, risks may arise that could compromise the building's lifespan and the safety of its users.

BIBLIOGRAPHY

[1] Adrian Alionescu, Ioan Sorin Herban, Clara-Beatrice Vîlceanu, Cosmin Constantin Mușat - Mathematic Interpolation Methods - Support for an Efficient 3D Modeling of Landslides in the Context of Displacements Monitoring, AIP Conference Proceedings 1648, 670002 (2015); DOI: 10.1063/1.4912897, pp. 67002-1-67002-4

[2] Adrian Alionescu, Sorin Herban, Carmen Grecea, Clara–Beatrice Vîlceanu - Comparative study of TLS and digital photogrammetry for 3D modeling of the Martyr's cross monument, Proceedings of IGIT 2015, International Conference, Integrated geo-spatial information technology and its application to resource and environmental management towards GEOSS, ISBN 978-963-334-211-4, pp. 94-99, Publisher: Nyugat-magyarországi Egyetem Kiadó, Sopron

[3] Arsene, C. (2005). Comportarea în timp a construcțiilor situate în zonele de exploatare a zăcămintelor de sare. Urmărirea comportării în timp prin metode geodezice, Zilele Academice Timișene, Universitatea „Politehnica” din Timișoara, pp. 509-514.

[4] Brebu F.M. (2011) – Contribuții privind evaluarea topo–geodezică a deplasărilor și deformațiilor construcțiilor, Teză de Doctorat, Editura Politehnica, Timișoara.

[5] Brebu F.M., Bălă A.C. (2011) – Monitoring of special construction using 3D laser scanning, Buletinul Științific al Universității „Politehnica" din Timișoara, Seria Hidrotehnica, ISSN 1224-6042, vol. 2, pp. 71-75

[6] Clara-Beatrice Vîlceanu, Sorin Herban, Adrian Alionescu, Cosmin Mușat - Processing of environmental data using Digital Terrain Models for the western part of Romania, Proceedings of “15th International Multidisciplinary Scientific GeoConference SGEM 2015”, ISSN 1314-2704, Vol. II, Geodesy & Mine Surveying, Cartography & GIS, DOI:10.5593/sgem2015B22, pp. 1043-1051

[7] Coșarcă C. (2009) - Sisteme de măsurare în industrie, Editura Conpress, București, ISBN 978-973-100-077-0.

[8] Coșarcă C., Sărăcin A., Dragomir P.I., Docan D.C., Clinci T.S. (2014) - Măsurători geodezice inginerești, Editura Conpress, București, ISBN 978-973-100-326-9, pp. 183.

[9] Cristescu N. (1978) – Topografie inginerească, Editura Didactică și Pedagogică, București.

[10] Florea, Alunecări de teren și taluze. Editura Tehnică, București - 1979

[11] Grecea C., Rusu G., Mușat C., Moscovici A.-M. (2013) - Challenges in Implementing the Systematic Land Registration in Romania, 1st European Conference of Geodesy and Geomatics Engineering (GENG ‘13), Recent Advances in Geodesy and Geomatics Engineering, Antalya, Turcia, ISBN 978-960-474-335-3; ISSN: 2227-4359, pp. 98-106.

[12] Grecea C., Sturza M., Mușat C. (2009) – Complemente de măsurători terestre, Vol. 1, Ediție Revizuită, Editura Politehnica, Timișoara.

[13] Haida V., Marin M., Mirea M. (2004) – Mecanica pământurilor, Editura Orizonturi Universitare, Timișoara.

[14] Herban I.S. (2006) - Contribuții la aplicarea metodelor topografice la studiul și urmărirea deplasărilor construcțiilor și ale terenului, Teză de Doctorat, Editura Politehnica, Timișoara.

[15] Herban S., Grecea C., Rusu G., Alionescu A. (2014) - Evaluation of structure deformation using geodetic methods, 2nd European Conference of Geodesy & Geomatics Engineering (GENG '14), Advances in Environmental Development, Geomatics Engineering and Tourism, Brașov, România, ISBN: 978-960-474-385-8; ISSN: 2227-4359; pp. 157-162.

[16] Herban, S. - Aplicarea metodei elementelor finite în cazul măsurării și urmăririi deformațiilor construcțiilor și terenului, Simpozion Internațional GeoCAD, Alba Iulia, 2005

[17] Herban, S. - Aplicarea metodelor topografice la studiul și urmărirea deplasărilor și deformațiilor construcțiilor, Referat Doctorat, 2000

[18] Herban, S. Modele de determinare a deplasărilor și deformațiilor construcțiilor, Zilele Academice Timișene - 2004

[19] Herban, S. Procedee și metode topografice de urmărire a tasării construcțiilor - Zilele Academice Timișene - 2001

[20] Iacobescu O., Barnoaiea I. (2014) - Topografie – Note de curs pentru învățământul la distanță, Partea I, Universitatea „Ștefan cel Mare” Suceava, Facultatea de Silvicultură.

[21] Legea nr. 10/1995 privind calitatea în construcții - Normativ privind urmărirea comportării în timp a construcțiilor, indicativ P 130-2023

[22] Manea G., Călin A. (2005) - Caracteristicile fotogrametriei digitale în raport cu cea analogică și cu cea analitică, Simpozionul Științific Internațional de Cadastru GeoCAD Alba-Iulia, RevCAD Journal of Geodesy and Cadastre, nr. 5, pp. 301-310.

[23] Mușat C.C. (2006) – Contribuții privind stabilirea tasărilor și deformațiilor construcțiilor utilizând metode și tehnici topo-geodezice moderne, Teză de Doctorat, Editura Politehnica, Timișoara.

[24] Neamțu M., Onose D., Neuner J. (1988) – Măsurarea topografică a deplasărilor și deformațiilor construcțiilor, Institutul de Construcții București.

[25] Neamțu, M. - Determinarea deplasărilor orizontale ale construcțiilor prin metode geodezice - Referat Doctorat, 1971

[26] Normativ I.N.C.E.R.C. - Normativ pentru determinarea tasărilor construcțiilor civile și industriale prin metode topografice C 61-64

[27] Normativul privind proiectarea clădirilor de locuințe (revizuire NP 016-96), indicativ NP 057-02 din 24.09.2002

[28] Nuttens T., De Wulf A., Bral L., De Wit B., Carlier L., De Ryck M., Stal C., Constales D., De Backer H. (2010) – High Resolution Terrestrial Laser Scanning for Tunnel Deformation Measurements, FIG Congress 2010: Facing the Challenges – Building the Capacity, Sydney, Australia, pp. 2.

[29] Ortelecan, M., Pop, N. (2005). Metode topografice de urmărire a comportării construcțiilor și terenurilor înconjurătoare, Editura AcademicPres, Cluj-Napoca, ISBN 973-7950-99-2.

[30] Ordin 847/02.06.2014 - Procedura privind activitățile de control efectuate pentru aplicarea prevederilor legale privind urmărirea curentă și specială a comportării în exploatarea construcțiilor - indicativ PCU 004, Ministerul Dezvoltării Regionale și Administrației Publice, București, 2014

[31] Palamariu, M., Popa, A. (2008). Urmărirea comportării terenurilor și construcțiilor, Seria Didactică, Universitatea „1 Decembrie 1918” Alba Iulia.

[32] Perfecționarea metodelor de lucru și a tehnologiilor în topografia inginerească. București, 1979

[33] Paul Zdrenghea, Vîlceanu Clara-Beatrice, Sorin Herban, Adrian Alionescu - Using the laser scanning for conservation of Cultural Heritage buildings, International Conference on Numerical Analysis And Applied Mathematics 2022, ICNAAM-2022, Volume 3094, DOI: 10.1063/5.0213285

[34] Radu Teșilă, Georgiana Rusu, Beatrice Vîlceanu, Adrian Alionescu - Targeting Displacements' Monitoring of Constructions through Mathematical Methods, AIP Conference Proceedings 1738, 350010 (2016); DOI: 10.1063/1.4952133, pp. 350010-1 - 350010-4

[35] Rusu G. (2016) – Contribuții privind urmărirea în timp a deplasărilor și deformațiilor construcțiilor prin metode topo-geodezice, Seria 18, Nr. 2, Editura Politehnica, Timișoara, ISSN: 2393-4816, ISBN: 978-606-35-0048-0
[36] Rusu G., Mușat C.C. (2012) - Modern concepts of 3D modeling in geodetic works, RevCAD Journal of Geodesy and Cadastre, vol. 13, pp. 137-146.
[37] Rusu G., Mușat C., Costescu I. (2015) - Considerații privind urmărirea în timp a comportării construcțiilor utilizând metode topo-geodezice moderne, Zilele Academice Timișene, ediția a XIV-a, Simpozion "Drumul și mediul înconjurător", Timișoara, Editura Solness Timișoara, ISSN 2247-3807, pp. 181-189.
[38] S.I. Herban, C.-B. Vîlceanu, A. Alionescu, C. Grecea - Studying the movement of buildings and developing models to determine real settlements, Journal of Environmental Protection and Ecology (JEPE), Vol. 15, No. 2 (2014), pp. 789-797, ISSN 1311-5065
[39] STAS 2745 - 69 - Urmărirea tasării construcțiilor prin metode topografice
[40] Sternberg H. (2006) - Deformation measurements at historical buildings with terrestrial laser scanners, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI, Part 5, Dresden, pp. 303-308.
[41] Sturza M., Novac G., David V., Herban I.S., Baciu A. (2007) – Complemente de măsurători terestre, Vol. 2, ISBN: 978-973-625-377-5, Editura Politehnica, Timișoara.
[42] Udrea F. (2011) - Managementul riscurilor de mediu, Universitatea Spiru Haret București, Editura Uffman, ISBN 978-606-8222-68-4.
[43] Ursea, V. - Topografie aplicată în construcții. Editura Didactică și Pedagogică, București, 1974
[44] Vîlceanu C.B. (2014) - Utilizarea tehnologiilor geodezice moderne pentru monitorizarea, prelucrarea și analiza unor alunecări de teren și construcții din pământ armat, Teză de Doctorat, Editura Politehnica Timișoara, ISSN: 1842-581X, ISBN: 978-606-554-754-4.
[45] Vîlceanu C.B., Bălă A.C. (2013) - Crearea modelului digital al terenului utilizând tehnologia de scanare laser terestră pentru alunecarea de teren – drum de acces între localitatea Orșova și platoul Topleț, culmea Dranic, județul Mehedinți, Revista Română de Inginerie Civilă, Vol. 4, Nr. 2, Editura Matrix Rom, pp. 131-141.
[46] https://ecosynergy.ro/blog-impactul-cladirilor-asupra-mediului-solutii-eficiente-pentru-reducerea-efectului-negativ/
[47] https://en.wikipedia.org/wiki/Error_analysis_for_the_Global_Positioning_System
[48] https://gamasfaltari.ro/avantajele-asfaltului-modificat-cu-polimeri/
[49] https://galkanepi.com.br/leica-tcrp1205-r300-geooprema-A4302211
[50] https://geooprema.com/wp-content/uploads/2020/04/Leica-TCRP1205-R300-1.jpg
[51] https://infraser.ro/drumuri/importanta-intretinerii-preventive-a-drumurilor-economii-pe-termen-lung/
[52] https://link.springer.com/article/10.1007/s12524-022-01494-y
[53] https://masuratori-terestre.blogspot.com/p/nivelmentul.html
[54] https://pdfcookie.com/documents/nivelment-geometric-nj2614p3nrl4
[55] https://rompos.ro/index.php/informatii-tehnice/utilizare-si-aplicatii
[56] https://sisirl.com/survey-equipment-product/leica-gmp111-0-mini-prism/
[57] https://sisirl.com/wp-content/uploads/2018/01/GMP111-0-Mini-Prism.png
[58] https://skygrid.ro/image/cache/catalog/NEW/Mira_leica_GPCL2_11-1000x1000-1000x1000.jpeg
[59] https://static.machinetools.com/uploads/1917172/galaxyD-view1-zoom-600px.png

[60] https://www.3dlasermapping.com/zeb1-indoor-mapping
[61] https://www.anpm.ro/dezvoltare-durabila
[62] https://www.environmental-expert.com/products/api-model-imager-pro-c-high-speed-laser-scanning-276301
[63] https://www.geosense.com/product-category/extensometers/
[64] https://www.geosense.com/product-category/inclinometers/
[65] https://www.geosense.com/product-category/piezometers/
[66] https://www.geosense.com/product-category/tilt-sensors/
[67] https://www.geosense.com/products/geologger-cr-series/
[68] https://www.geosense.com/wp-content/uploads/2021/04/DigitalTapeExtensometerManualV1.0.pdf
[69] https://www.geosense.com/wp-content/uploads/2021/05/MEMS-Tilt-Meter-Beam-Application-Guide-V1.2.pdf
[70] https://www.giscad.ro/aparat/trimble-dini/
[71] https://www.giscad.ro/wp-content/uploads/2022/03/Dini_studio_back_right_3151-removebg-preview.png
[72] https://www.indiamart.com/proddetail/dji-phantom-4-pro-v2-0-drone-camera-23546097555.html
[73] https://www.mdlpa.ro/userfiles/cod_proiectare_seismica.pdf
[74] https://www.mpifma.ro/tehnologia-bim-ce-este-si-avantaje/
[75] https://www.planradar.com/ro/ce-este-bim/
[76] https://www.researchgate.net/figure/Real-time-kinematic-RTK-GNSS-El-Mowafy-2000_fig1_49662751
[77] https://www.sciencedirect.com/science/article/abs/pii/S0263224121012665
[78] https://www.sccssurvey.co.uk/aerial-photography-target-aerial-photography-target.html
[79] https://www.sccssurvey.co.uk/media/catalog/product/cache/eb4d4766e44c6b2bf836cfeffa662e43/d/_/d_13-lp500-1.jpg
[80] https://www.terre-armee.com/reinforced-earth/retaining-walls/
[81] https://www.tokopedia.com/adigtc/trimble-dini-level-accuracy-0-3-0-7-digital-level-automatic-leveling?extParam=whid%3D15029366
[82] https://www.tualcom.com/what-is-gnss/
[83] https://ro.scribd.com/doc/35584776/Deformabilitatea-metalelor-%C5%9Fi-aliajelor
[84] https://ro.scribd.com/document/614574054/Building-Information-Modeling-CDE-BIM
[85] http://masuratori-terestre.blogspot.ro/p/nivela.html
[86] https://ecosynergy.ro/blog-impactul-cladirilor-asupra-mediului-solutii-eficiente-pentru-reducerea-efectului-negativ/
[87] https://www.anpm.ro/dezvoltare-durabila
[88] https://www.geosense.com/wp-content/uploads/2021/05/MEMS-Tilt-Meter-Beam-Application-Guide-V1.2.pdf
[89] https://www.planradar.com/ro/ce-este-bim/
[90] https://www.mpifma.ro/tehnologia-bim-ce-este-si-avantaje/