RESEARCH ON THE CURRENT STATUS OF THE GEODESIC BASE FOR MONITORING DISPLACEMENTS AT DAMS

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Abstract

Monitoring displacements at storage dams requires the presence of a geodetic network of a certain complexity. Dams in Romania were built over long periods of time, and most of them have an operating life of over 50-70 years. The geodetic network for monitoring displacements at these dams was executed according to the topographic plans existing at the time of design. At the current stage, the movement tracking system at a dam is carried out using the microtriangulation method. This system must be updated and optimized for the use of modern data acquisition equipment, for their rapid processing and transmission to decision-makers. Research conducted on a series of dams in eastern Romania has highlighted a series of problems that create a risk in the classic monitoring of dam displacements. A main problem at a series of dams is the updating of topographic plans, the geodetic tracking network and the equipment provided. Satellite techniques for taking over geodetic data are effective for monitoring displacements in "real time". Real-time monitoring of parameters at a dam allows for rapid intervention in assessing a risk and adopting safety measures. To this end, the current geodetic networks of dams must be analyzed and modernized by attaching modern equipment and software that can take over real-time displacements.

Keywords: displacements, geodetic network, GNSS, real time, robotic total stations

Monitoring the structural and functional parameters of dams aims to ensure operational safety, which effectively protects both the natural and human environment. One area of dam monitoring is the movement and deformation of structural elements (Popovici A., 2002). Movements in a dam vary depending on the nature of the material from which it is made, the forces acting upon it, and its structural condition over time. Horizontal and vertical displacements can occur in the body of the dam at the crest and on the slopes, settlements in the foundation, and at the abutments in the flanks, etc. Displacements in dams are monitored using a geodetic network designed and implemented during construction (Popovici A., 2002). The geodetic network deteriorates over time, being affected by physical and technical aging.

Romania has about 240 large-type dams, which have a service life of over 50–70 years. The geodetic network for monitoring movements at these dams was implemented according to the topographic plans available at the time of their design. The network was equipped with the equipment available at that time. Dams in Romania are classified into four categories of importance (A, B, C, D), where those in categories A and B are equipped with a "Structural Behaviour Monitoring (SBM)" service.

SBM manually collects geodetic data from the field through topographic measurements at intervals of time. Current climate change has disrupted the distribution of rainfall across Romania, a situation that has led to the occurrence of rapid floods with high flow rates. Classical geodetic networks are largely reactive, meaning they provide results after a longer period imposed by measurements and data processing.

The new climatic conditions also require the presence of a modern preventive geodetic network, which, along with the rapid acquisition and processing of data, can facilitate immediate decision-making. Research on the use of modern geodetic networks at dams is currently developing both nationally (Agapie – Mereuta I. *et al*, 2021, Negrilă A. and Onose D., 2013) and internationally (Corssetti M. *et al*, 2016, Maltese, A., *et al*, 2021, Wang T., *et al*, 2010, Zhang Y., *et al*, 2018).

There must be coordination between the two geodetic networks (classical and modern) in order to obtain viable measurement data. Some of the classical geodetic networks in their current state present a series of foundational and layout issues that hinder their proper functioning.

The paper presents the results of research on the analysis of the structural condition of the geodetic network used to monitor displacements at two dams located in the eastern part of Romania.

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At the same time, the paper argues for the need to modernize geodetic networks at dams through the introduction of modern equipment and technologies for real-time acquisition of topographic data.

MATERIAL AND METHOD

The research was carried out on geodetic networks implemented at two existing dams in the eastern region of Romania. In the study, a dam of category B importance, namely the Parcovaci Dam, and one of category A, namely the Stanca - Costesti Dam, were selected. The Parcovaci Dam is located on the Bahlui River, is of homogeneous type, and is made of earth. The dam's height is 25 m, and the crest length is 290 m. The dam is equipped with a geodetic network for monitoring the movements of the earth mass and concrete elements (*figure 1*).

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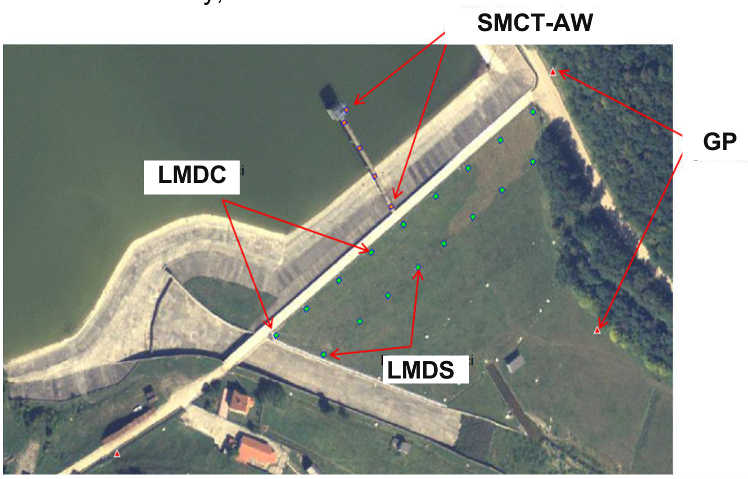

Figure 1 **Components of the geodetic network for displacement monitoring at Parcovaci Dam: GP – geodetic pillars; LMDC – level marks on the dam crest; LMDS – leveling marks on the downstream slope; SMCT-AW – settlement marks on the control tower and access walkway (Agapie-Mereuta I., 2025)**

a

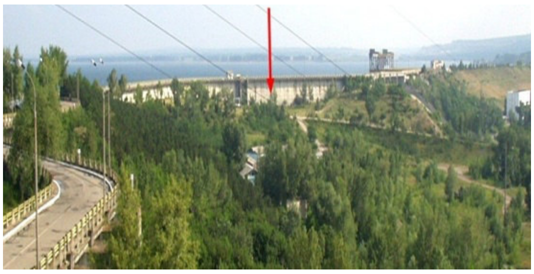

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Figure 2 **General view of the Stanca-Costesti Dam with the areas for placing the geodetic network: a – earth dam; b – concrete gravity dam (photo by the author, 2024)**

The Stanca-Costesti Dam is located on the Prut River and has a mixed structure, being constructed with both concrete and earth components. The dam has a height of 48 meters and a crest length of 1500 meters. The dam is equipped with a complex geodetic network for monitoring movements in the earth component and the concrete elements (Hidroconstructia, 2000).

The research method consisted of the following stages:

- analysis of the design documentation regarding the type and technical equipment of the geodetic network for monitoring displacements and deformations at the dam;
- analysis of the technical documentation regarding the modifications and rehabilitations carried out on the geodetic network for monitoring displacements;
- analysis of the technical documentation regarding the manner of performing measurements, processing the results, and interpreting them;
- field analysis of the structural and functional condition of the geodetic network for monitoring displacements after a long period of operation;
- performing topographic measurements on certain parts of the data acquisition circuits from the geodetic network for monitoring displacements;
- analyzing and developing a concept for modernizing the geodetic network for displacement

monitoring by introducing modern technologies and equipment that work together with the traditional ones.

During the field research, photos and videos were taken from the location of the studied geodetic network. A series of images were also captured with the help of a drone.

RESULTS AND DISCUSSIONS

Dams in Romania of categories A and B, about 181 in total, are equipped with geodetic networks to monitor displacements. Dams in categories C and D do not have geodetic networks for movement monitoring (Agapie - Mereuta I., 2025). Displacements monitoring is provided for in the dam operation regulations and carried out by the UCC department.

Horizontal and vertical displacements in the structural components of dams are of the following types:

a - partial or relative displacements, which result from the comparative analysis of the data from the latest measurement with those from the previous measurement;

b - total or absolute displacements, which result from the analysis of measurement series taken over time and their reference to the initial measurement (the "zero" measurement).

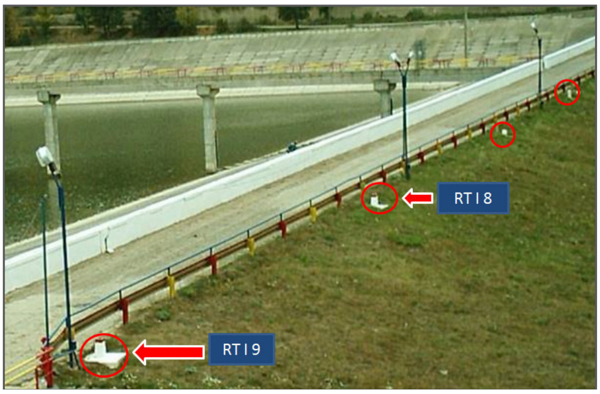
Displacement measurements are carried out at least once in the case of normal operating conditions. In special situations caused by extreme natural and anthropogenic phenomena (floods, earthquakes, accidents, exceeding critical settlement values, etc.), measurements will be performed immediately. Processed measurement data are entered into calculation programs to check the safety condition of the dam at various stages of operation (Chirilă C., and Căsăndrescu I.A., 2015, Agapie -Mereuță I., 2020).

In constructing the geodetic network for dams, the classic triangulation network of Romania (the "state" network) was used. This network consists of points with known coordinates across the territory of Romania. The points are classified into four orders of importance (I, II, III, IV), and the dam network relies on these points and supplements them with new points of order V.

Classical geodetic networks for measuring displacements at dams use planimetric geodetic networks and altimetric geodetic networks. The system for monitoring displacements at a dam is currently carried out using the microtriangulation method and the high-precision geometric levelling method (Luca M., et al., 2013). Field research conducted at the two selected dams highlighted a series of problems that need to be addressed to achieve the most efficient measurement activity possible.

The Parcovaci Dam is equipped with a geodetic network for monitoring movements, consisting of six geodetic pillars and 17 levelling benchmarks with a vertical axis embedded in the dam body (*figure 1*). On the access walkway to the intake tower, four settlement marks are installed, and on the deck of the operating tower, there is one settlement mark (*figure 3*) (Agapie-Mereuta I., 2025).

The research conducted at the Parcovaci Dam highlighted the extent of aging of the geodetic network for monitoring displacements. The components of the network are in good working condition but show a certain degree of physical as well as moral wear.



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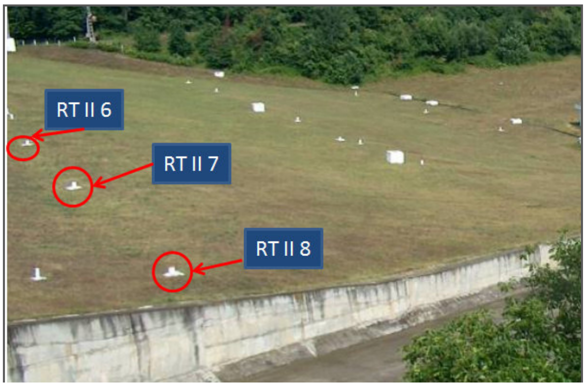

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Figure 3 **Visualization of the placement of the geodetic network at the Parcovaci Dam: a – benchmarks on the dam crest; benchmarks on the slope.**

The geodetic network for monitoring displacements at the Stanca-Costesti Dam (the Romanian sector) has a complex structure, in accordance with the verification requirements for a Category A dam (*figure 2*).

The research analyzed 15 points from the primary network, 19 points from the support network, and 203 mobile study benchmarks (*figure 4*). The analyzed mobile benchmarks are distributed as follows: 82 altimetric study benchmarks embedded in the concrete dam crest; 4 altimetric study benchmarks embedded in the emergency intake; 85 mobile planimetric and altimetric study benchmarks embedded in the concrete dam; 12 planimetric and altimetric study benchmarks embedded in the spillway; 10 mobile planimetric and altimetric study benchmarks embedded in the sluice gate. In the earth dam, 10 mobile planimetric and altimetric study benchmarks are embedded.

The monitoring of displacements and deformations at the Stanca - Costesti Dam is carried out for the following structures: the concrete dam, the earth dam, the spillway, the right shoulder consolidation dam, the sluice gate, and the spillway. The purpose of the monitoring is to determine the spatial coordinates X, Y, Z of the points of the support network, the auxiliary network, and the study benchmarks, to process them, and to calculate the longitudinal L and transverse T deviations for the study benchmarks. Geodetic measurements are carried out periodically, specifically on an annual basis.

In the first stage, the situation plans with the location of the designed and executed geodetic network were analyzed. An initial conclusion indicates the need to update the situation plans to reflect the reality on the ground. Furthermore, the situation plans need to be digitized to comply with current displacement monitoring techniques and to create a modern GIS-based database.

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a b c d

Figure 4 **Components of the geodetic network for measuring displacements at the Stanca-Costesti Dam investigated: a – pillar on the crest; b – station point on the spillway; c, d – benchmarks on the berms and earth slope (author photo, 2025).**

Field research highlighted the following situations:

- the components of the geodetic network for monitoring displacements are degraded to various degrees depending on the construction material and the period of operation; at the time of the research, this equipment had been in use for over 50 years (the construction of the dam began in 1973 and was completed in 1978);

- the concrete infrastructure of the pillars, benchmarks, and markers is deteriorated due to the action of climatic factors, as well as anthropogenic factors; the metal components already exhibit advanced degrees of rust (*figure 4*);

- On the earth component of the dam, vegetation has developed consisting of trees, shrubs, and bushes, which in the current stage obstructs the line of sight between stations and benchmarks (*figure 5*);

- conducting cycles of verification measurements of the circuits highlighted limited visibility between network points, especially on berms 1 and 2, and on the downstream slope; this situation is caused by uncontrolled vegetation growth (figures 5 and 6);

Figure 5 **Pillar with visibility blocked by vegetation on the downstream slope of the earth dam (author photo, 2025).**

- uncontrolled vegetation growth, particularly of trees, has created visibility problems during measurements on the crest;

- field research highlighted possible deteriorations on some pillars, benchmarks, and marks, a situation that caused difficulty in making microtriangulation observations with the required accuracy (*figure 4*);

Figure 6 **Pier with visibility blocked by vegetation on berm 2 of the downstream slope of the earth dam (photo author, 2025)**.

- the analysis conducted in the field indicated that, compared to the time of commissioning the geodetic network, approximately 40–50% of the sightlines between points are no longer visible in the field; in (*figure 7*), routes with visibility are shown with a solid line, and routes without visibility with a dashed line.

Within geodetic networks for monitoring movements at dams, maintaining direct visibility between benchmarks is essential for obtaining adequate measurement accuracy.

Figure 7 **Checking the sight lines on the dam crest and the downstream slope of the dam.**

Disturbing or even blocking the visibility paths of the geodetic network with various obstacles affects the functional state of the monitoring network. The most common obstacles at earth dams are uncontrolled vegetation growth, construction of buildings along the line of sight, and the placement of local structures and installations (electric poles, signs, panels, etc.). Such situations, present at the analyzed dams, can compromise the integrity of geodetic observations. Similar situations also arise from the lack of periodic maintenance and annual repair work necessary to maintain optimal conditions for monitoring displacements.

The traditional system for collecting topographic data currently includes a series of modern optical equipment for acquiring coordinates in the field. This system has the great advantage of obtaining very precise data. However, it has the disadvantage of requiring special viewing conditions, more time for data processing, and transmission to the beneficiary.

The modern GNSS system uses satellites to collect data, which it processes quickly in a relatively short time / or "in real time" and transmits to the recipient for decision-making. The disadvantage of this system is the relatively lower accuracy of the data obtained compared to the classical system.

Increasing the efficiency of the dam displacement monitoring system must be achieved at the current stage, considering the high frequency of climatic risk factors in recent times. At the same time, geodetic systems for monitoring dam displacements must be modernized through the use of state-of-the-art technologies and equipment.

Monitoring the behaviour of dams over time is mandatory according to regulations in the field, with the aim of early detection of potential stability problems.

In economically advanced countries, in recent years there has been a shift to using satellite technologies for topographic measurements, as well as the use of scanners and drones, etc. The most commonly used techniques are GNSS networks (Global Navigation Satellite Systems), LiDAR scanning technologies (TLS/ALS), and InSAR technology. These technologies have also begun to be used in Romania, starting with GNSS (Vele D. and Stoian I., 2014, Agape-Mereuta I. *et al.,* 2021, Chirilă C., et al., 2013, Luca M., and Agape-Mereuta I., 2022), and laser scanning (Negrilă A. and Onose D., 2013).

Dams of special importance should be monitored with a GNSS system, using ”robotic total stations” that continuously collect field data, process it, and transmit it in real time to the dam operation department.

A robotic total station (RTS) can continuously measure horizontal and vertical angles as well as distances using reflective prisms mounted on the structure. This allows the calculation of the spatial coordinates of the monitored points. Through automatic target recognition (ATR) technology, the instrument detects and tracks the target prisms without human intervention. The data is transmitted in real time to a control computer, where it is automatically processed, and displacements are calculated and analyzed almost instantly.

CONCLUSIONS

1. The current method of monitoring movements at dams is carried out using classical geodetic methods, namely the micro-triangulation method and the high-precision geometric leveling method. These methods have the advantage of high accuracy, but a significant disadvantage due to the long time required for data acquisition and processing.

2. The current state of geodetic networks for monitoring movements shows an advanced degree of wear at some dams and is equipped with technology outdated by current standards. Some of the geodetic points in the primary and support networks, as well as the altimetric and planimetric reference benchmarks, need to be rehabilitated structurally and also re-calibrated regarding their spatial coordinates.

3. A large part of the dams require an update of the topographic plans in correlation with the changes in the site. Additionally, the topographic plans must be digitized for their inclusion in tracking programs that use the GIS method to monitor the dam's operation process.

4. The need to make decisions in a short time in response to natural actions affecting the dam necessitates the modernization of the geodetic network through the use of modern technologies and equipment for monitoring movements, such as GNSS, particularly those that acquire and process data in real time.

5. Dams of particular importance, such as the Stanca-Costesti dam located on a border river, must be equipped with geodetic networks to monitor movements in real time, in order to prevent disasters by quickly acquiring and processing high-risk data.

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REFERENCES

Agapie (Mereuță) I., **Luca M., 2020** - *Settlement monitoring of the earth dams by performance periodical topo-geodetic measurements*. J. PESD, vol. 14 nr. 1, pp. 99-109 edited by "Al. I. Cuza University of Iasi". doi.org/10.15551 /pesd2020141008.

Agapie (Mereuță) I., **2025** - *Contributions to monitoring the stability of earth masses through modern technologies.* Doctoral thesis. Technical University "Gh. Asachi" of Iasi, Romania. (in Romanian)

Agapie (Mereuță) I., **Luca M., Gherasim P.M., Dominte V., 2021** - *Design of GNSS networks for monitoring earth dams deformations.* Journal of Applied Life Sciences and Environment Vol. LIV, Issue 4 (188) / 2021: 354-369.https://doi.org/10.46909/journalalse-2021-031

Chirilă C., Popia C.A., Smadici A.V., **2013** - *Testing coordinates of network control points for monitoring horizontal displacements of hydrotechnical constructions.* RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 15, 51-60.

Chirilă C., Căsăndrescu I.A., 2015 - *Study on application of microtrilateration geodetic network for monitoring of hydrotechnical constructions*. RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 19, pg. 41-48.

Corsetti M., Aranno P.J.V.D, Giancola F., Marsella M., Scifoni S., Sonnessa A., 2016 - *Satellite techniques: new perspectives for the monitoring of dams*, Engineering Geology for Society and Territory, vol. 5, p. 989-993.

Hidroconstrucţia S.A., 2000 - The 50th Anniversary of S.C. Hidroconstrucţia S.*A., 1950 – 2000*. Edit. Hidroconstrucţia, Bucureşti.

Luca M., Agapie (Mereuta) I., 2022 - *Research on the topology of earth dam by using GNSS technology*. RevCAD, Journal of Geodesy and Cadastre, no. 32, „1 December" University of Alba Iulia, Aeternitas Publishing House Alba Iulia, p. 59-68.

Luca M., Dominte (Croitoru) V., Marcoie N., Agapie (Mereuță) I., **2023** - *Verification of topographic drawing parameters of water outlets at earth dams.* RevCAD, no. 35, „1 December" University of Alba Iulia, Aeternitas Publishing House Alba Iulia, p. 15-24.

Maltese, A., ***et al.*** **2021** - *Toward a Comprehensive Dam Monitoring: On-Site and Remote-Retrieved Forcing Factors and Resulting Displacements (GNSS and PS–InSAR).* Remote Sensing, 13(8): 1543. DOI: 10.3390/rs13081543.

Negrilă A., Onose D., 2013 - *Dam monitoring using terrestrial laser scanning*. Journal RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 15, pg. 149-158.

Popovici A., 2002 - Dams for water reservoirs. Edit. Tehnică, Bucureşti. (in Romanian)

Scaioni, M., ***et al.*** **2018** - *Geodetic and Remote-Sensing Sensors for Dam Deformation Monitoring*. Sensors, 18(11): 3682. DOI: 10.3390/s18113682.

Vele D., Stoian I., 2014 - *GNSS technology application for the monitoring of Fantanele dam, in county Cluj*. J. RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 17, pg. 169-176.

Wang T., Perissin D., Rocca F., Liao M.S., 2010 - *Three Gorges Dam stability monitoring with time-series InSAR image analysis*. Science China, Earth Sciences, p. 1-13.

Zhang Y., Yang S., Liu J., Qiu D., Xiaoyan Luo X., Jianhong Fang J., **2018** - *Evaluation and analysis of dam operating status using one clock-synchronized dual-antenna receiver*. Hindawi, Journal of Sensors, Volume 2018, Article ID 9135630, 12 pages. https://doi.org/10.1155/2018/9135630