STUDIES ON THE REAL-TIME MONITORING OF GURA APELOR DAM

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Abstract: *This thesis presents a modern monitoring model of the geodetic parameters specific to dams made of earth and rock. The monitoring of dam components movements in the horizontal plane is currently carried out by the micro-triangulation method. The optimization of the monitoring process geometrical parameters for water accumulations dams requires the use of modern equipment and technologies. They allow a faster retrieval of data and its immediate processing with high-performance analysis programs. This reduces the time between measuring the formation and making the intervention decision. The studies and researches carried out have indicated the development and application of a real-time monitoring system of the geometrical parameters at Gura Apelor dam. The proposed monitoring system uses a set of modern equipment including Leica Nova TM50 total stations, 360° prisms and GNSS antennas. The monitoring equipment is supplied with sensors for atmospheric information for the correction of measurements.*

Keywords*: deformations, geodetic equipment, GNSS, tracking network, total robotic stations*

1. Introduction

Dams are designed and executed for a long period of operation. Monitoring their behaviour over time guarantees their structural and functional safety while exploitation. A number of physical monitored dam parameters is represented by the reaction of the "dam-foundation" system to the actions generated by the embedding medium. In the case of dams made of fillings (earth, rock) the displacements of various components and especially the subsidence in various sections of the construction is very important. Also, the parameters of the water infiltration through the dam body (the position of the infiltration curve, the pressure of the water in the pores, the infiltration from the slopes, etc.) that have a direct connection with the subsidence phenomenon are carefully monitored [1].

The current state of research indicates an increase in the degree of behaviour tracking automation of the hydrotechnical constructions, which implies an adequate endowment with specialized equipment and software. The technique and technology of measuring and processing data has developed a lot in recent years, reaching as far as real-time monitoring of land and building movements and deformations [1], [2], [3].

Research in the field of dam surveillance has highlighted the problem of streamlining the monitoring process by using the current technologies used to track dam deformation. The total robotic stations and the GNSS (Global Navigation Satellite System) system provide efficient solutions for measuring three-dimensional displacements. Also, remote sensing and terrestrial laser scanning allow the measurements to be extended to hard-to-reach areas [2], [4].

Accuracy is a key requirement in any monitoring process. A poorly designed monitoring system can lead to false conclusions and misinterpretations. In order to obtain good accuracy, the design of the monitoring system must be based on: a good understanding of the physical process leading to deformation, the sources of errors in the measurements monitoring and their reduction, sufficient redundancy of measurements and equipment suitable for harsh environmental conditions [5].

At national level, the monitoring of dams is carried out by known classical methods, which ensure a high accuracy of measurements [6]. The classical methods involve going through some stages that cannot be avoided, such as: moving the specialists to the objective that have be monitored, making manual measurements and processing them. This involves a certain amount of time necessary for the preparation of technical documentation and drawing up conclusions on the measurements results. At international level, modern monitoring methods are used that ensure speed in the process of data collection and processing [3] [4] [5] [7]. The major advantage is the possibility to take urgent measures in extreme cases, such as the remediation of some malfunctions or the rapid warning and evacuation of the population, thus avoiding catastrophes.

Technology has advanced so much in recent years that real-time monitoring of land and construction deformations has been achieved. This is due to the emergence of specially designed systems for automatic monitoring, which coordinate the tracking activity, take over the measurements and transmit all data to the analysis and decision centres [6].

This paper analyses the application of a real-time monitoring system to the Gura Apelor dam. The movements monitoring in the horizontal plane of the dam is currently carried out by micro-triangulation. The modernization of the dam's real-time monitoring process can be achieved by using a set of modern equipment that includes Leica Nova TM50 total stations, 360° prisms and GNSS antennas. The research also aims to highlight the potential of modern technologies to track the real-time movements behaviour of earth and rock dams.

2. Materials and Methods

The research material consists of the Gura Apelor Dam [8]. It is located on the upper course of the river Râul Mare at 660 m downstream from the confluence of the rivers Ses and Lăpuşnic (Figure 1). The dam is made of rock and has a central clay core. The characteristics of Gura Apelor Dam are as follows (Figure 2) [8]:

- maximum height above the foundation: 168 m;
- length at the top: 460 m;
- width at the top: 12m;
- total volume of fillings: 10.285.000 m3;
- volume of water in the storage lake: 225.000.000 m3;
- inclination of upstream slope: 1:2.25 below elevation 980 mdM, 1:2 between elevation 980 and 1020 mdM and 1:1.75 between elevation 1020 and 1078.5 mdM;
- inclination of downstream slope: 1:2.25 below elevation 980 mdM, 1:75 between elevation 958.5 and 988.5 mdM and 1:1.5 between elevation 988.5 and 1078.5 mdM;

The high-water discharger is in the form of a side spillway located on the right slope, which continues with a fast tunnel and finished by a spring board. The spillway has a capacity of 1500 m3/s. The bottom outlet is made of pressure tunnel with a diameter of 2,40 m and can discharge a flow rate of 120 m^3/s. The regularized discharges in the storage are used in the

Retezat Hydropower Station, with an installed power of 335 MW and a power output of 605 GWh/year.

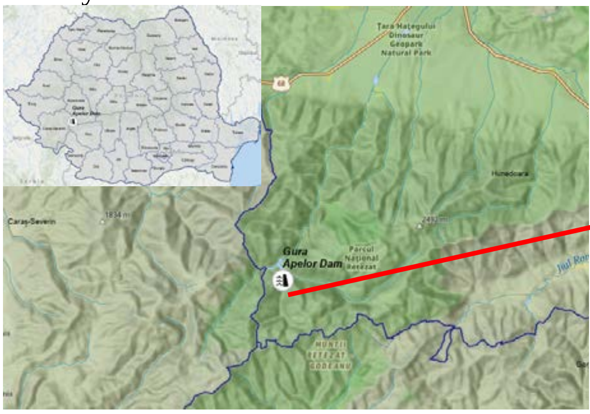

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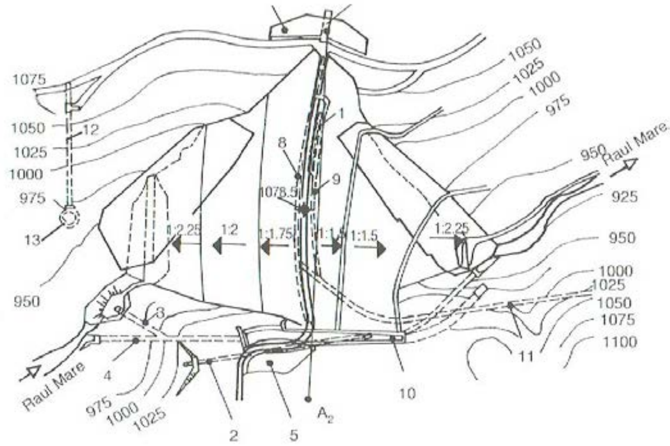
Figure 1– Gura Apelor Dam: a - study area location on the map of Romania and the map of Retezat National Park; b - downstream view of the dam.

Also, the downstream hydropower stations rise the total installed power of the Râul Mare River up to 483 MW with a power output of 830 GWh/year. In addition to this there are the power stations on the Strei River with an installed power of 81,1 MW and a power output of 170 GWh/year [8].



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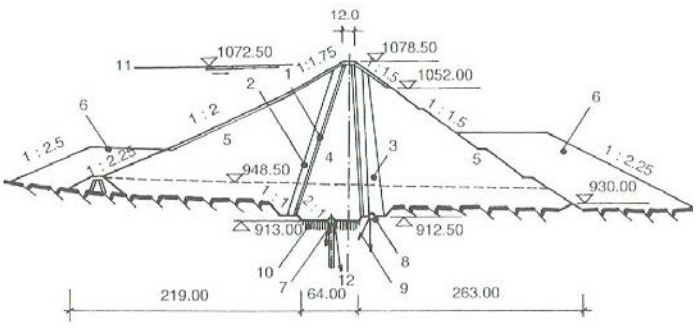

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Figure 2 – Characteristics of Gura Apelor Dam: a – plane view, b – cross-section; 1 – drainage gallery (elevation 996 m ASL); 2 – half-bottom outlet; 3 – bottom outlet; 4 – diversion gallery; 5 – right slope protection; 6 – left slope protection; 7 – grouting gallery (elevation 1078.5 m ASL; 8 – grouting gallery; 9 – collecting gallery; 10 – spillway; 11 – discharging gallery; 12 – headrace gallery; 13 – water intake;

1 – filter I; 2 – filter II; 3 – sorted ballast; 4 – clay; 5 – rockfill; 6 – downstream loading shell (on left slope); 7 – grouting gallery; 8 – collecting gallery of seepage water by core; 9 – draining drillings; 10 – strengthening drillings; 11 – NRL; 12 – crest axis;

The research methodology contained the following steps:

- Study of the rock dam design documentation and the monitoring system based on the available data.

- Analysis of the current dam movements monitoring system (type measurements, equipment, endowment with measurement points, data retrieval and interpretation, etc.).
- Analysis of modern equipment and technologies for monitoring the massive land discharges that can be applied to the investigated objective.
- Design of a modern system for movements monitoring at the Gura Apelor rock dam for real-time data retrieval and immediate processing of data.

3. Results and Discussion

The geometric parameters monitoring for dams made of earth fillings and rockfill is carried out at the present stage by the classical method of micro-triangulation. Micro-triangulation is used to determine the vector of the horizontal displacement of the control points fixed on the construction under study, in relation to a reference system, consisting of points fixed in non-deformable terrains and outside the area of the construction influence. The network consists of the following categories of points: control points, station points, reference points and orientation points. The control points, also called markings, are fixed on the construction to be observed. The station points from which repeated observations are made towards the points on the construction are materialized with reinforced concrete pilasters, with a deep foundation, having at the top, special pieces of device centring and clamping. The reference points are located in stable terrains and at distances of 200-300 m from the observed construction. Orientation points are located at greater distances in terrains with a high degree of stability.

The monitoring of the geometrical parameters of the Gura Apelor dam is carried out by the classical method of micro-triangulation, using a network of pilasters, considered fixed and a network of tracking landmarks (figure 3).

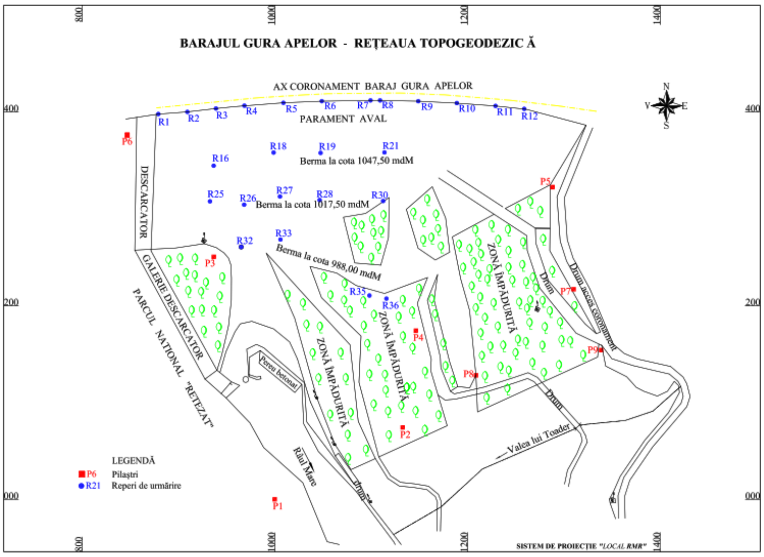
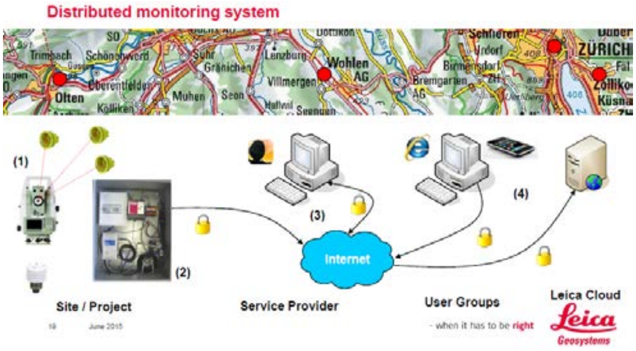


Figure 3 – The topo-geodetic network of Gura Apelor dam

The most well-known systems for spatial deformation monitoring are: Leica GeoMoS System, GOCA System, Trimble 4D Control and SOUTH SMOS. In the figures below you can see the principle schemes of the Leica GeoMoS systems (Figure 4.a) and Trimble 4D Control (Figure 4.b).

The Leica GeoMoS system comprises three applications: Monitor, Analyzer and Adjustment. Online application called Monitor is responsible for controlling the sensors, collecting the data, and processing the received data, functioning as a system for managing the events produced (retrieval, processing and transmission of information in real time). The offline application, Analyser is responsible for viewing, analysing and post-processing the data. Adjustment application allows the user both simulation possibilities in the tracking network and the possibility to make decisions based on statistical optimization and data validation.



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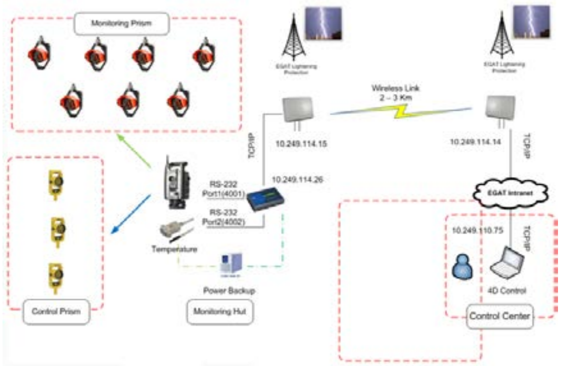

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Figure 4 – Principle scheme of spatial monitoring systems: a – Leica GeoMoS system [9]; b – Trimble 4D Control system [10].

The research aimed to design a real-time monitoring system for the Gura Apelor dam. The fixed network (figure 5) consists of nine pilasters, numbered from P1 to P9, placed on the two slopes of the valley, downstream of the dam. Three pilasters (P1, P3 and P6) are placed on the right slope, and six pilasters (P2, P4, P5, P7, P8 and P9) are placed on the left slope. The tracking network consists of 24 markers, numbered from R1 to R36. At the level of the top are the numbered landmarks from R1 to R12. On the downstream parament of the dam, arranged on three levels, on beers arranged at the elevation of 1045.78 mdM there are four landmarks numbered from R16 to R21. At the 1017.50 mdM elevation there are four landmarks numbered from R25 to R28 and at the elevation of 988.00 mdM there are four landmarks numbered from R32 to R36. Some of the pilasters and tracers are no longer used for measurements due to vegetation that obstructs visibility between points [11].

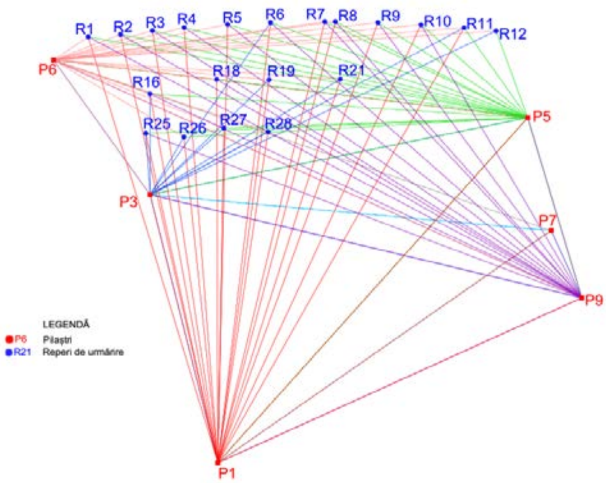

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Figure 5- Micro-triangulation network: a - Visa outline for the micro-triangulation network; b - leica nova TM50 total station located on pilaster

In order to implement the real-time monitoring system of Gura Apelor dam, the following equipment was chosen: Leica Nova TM50 total stations, 360° prisms and GNSS antennas (figure 6, Table 1). The proposed total station provides continuous monitoring and is designed to withstand the harshest environmental conditions and ensure the operation of extreme temperatures (between - 20° and +50°). The measurement accuracy is 0.6 mm + 1ppm for distances and 0.5" (0.15 mgon) for angles. The targeting distance is from 1.50 m to 3500 m with prism and from 1.50 m to 1000 m without prism. Leica GRZ4 and Leica GRZ122 prisms at 360° can be detected automatically (ATR) from distances of up to 600 m.

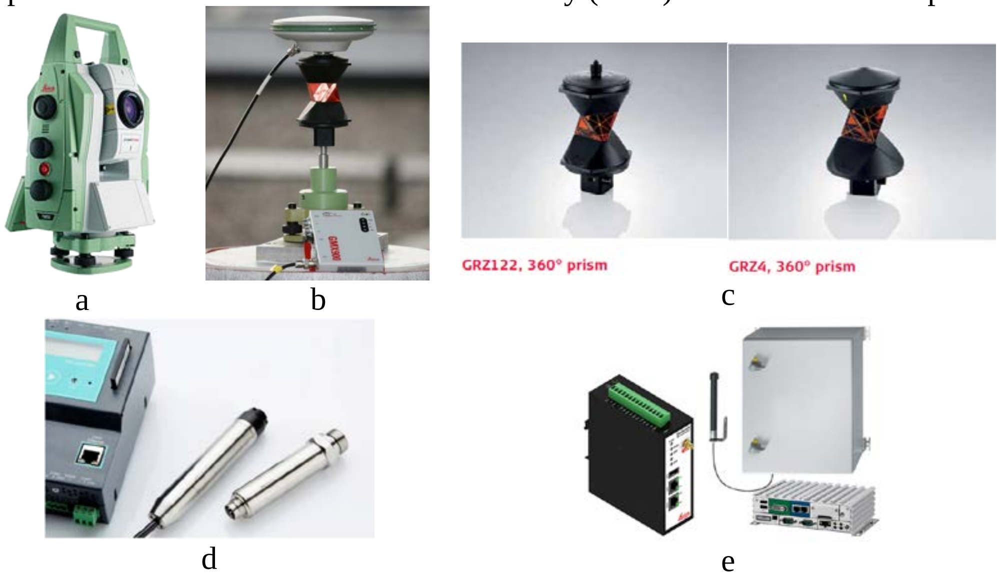

Figure 6 – Equipment of the new monitoring system: a – Leica Nova TM50 total station; b - Leica GRZ 122 prism, GS 07 antenna and GNSS receiver; c - Leica GRZ4 and GRZ122 prisms; d - temperature and pressure sensor; e - equipment for data transfer.

Table 1 - Equipment of the proposed monitoring system

Nr. crt.	**Number of equipment**	**Equipment type**
1	6	Leica Nova TM50 Total Station
2	10	Leica GS 07 Antenna
3	10	GNSS Leica GMX 902 Receiver
4	10	Leica GRZ4 360° prism
5	10	Leica GRZ122 360° prism
6	1	STS DTM temperature and pressure sensors
7	1	Leica Combox 20
8	1	Leica Monbox
9	1	Leica ComGate
10	1	Leica GeoMoS Monitor Software
11	1	Leica GeoMoS Analyser Software
12	1	Leica GeoMoS Now Software
13	-	Other accessories

The GNSS - GS07 intelligent antenna is capable of operating at outside temperatures between - 40° and + 65°. The accuracy of determination in RTK mode for HZ is 10 mm + 1ppm and for V it is 20 mm + 1ppm. The antenna provides in static and rapid static modes an accuracy of 3 mm + 0.5 ppm for HZ and 6 mm + 0.5 ppm for V. It is also proposed to use GNSS receivers - GMX 902, specially created for real-time monitoring applications [12]. The monitoring equipment shall be supplemented by temperature and pressure sensors to provide atmospheric information, which can be used to correct distance measurements from the total station.

For a better understanding of the proposed monitoring system, a 3D model was created with the layout of the fixed and control points, as well as with some of the proposed equipment (Figure 7). The graphical information from the Autodesk environment, represented by points and lines (visas between points) was georeferenced in the Stereografic-1970 coordinate system, then exported in shape format, after having previously been put on thematic layers. The resulting files were imported into the ArcGIS Pro (Arcscene) and with the help of special functions in the symbology section, the specific symbols of each type of point were assigned.

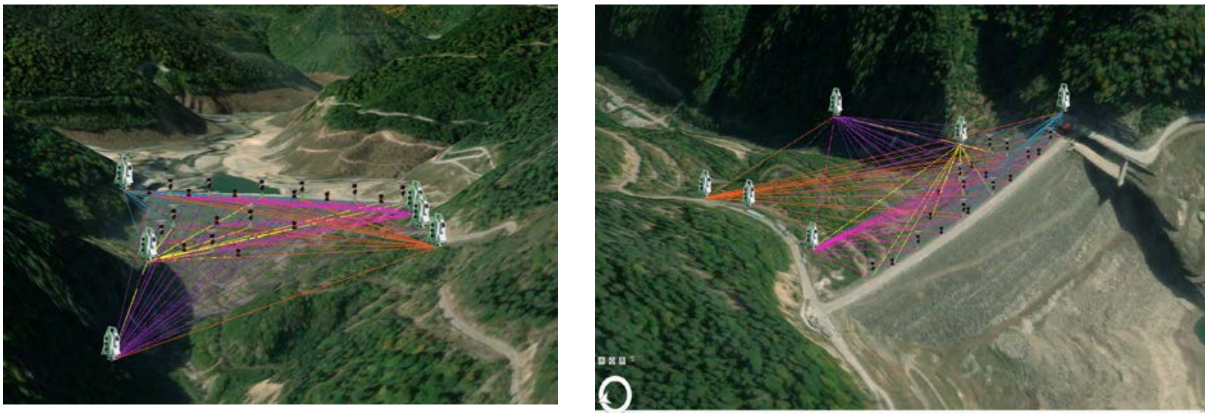

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Figure 7 - 3D model with the arrangement of the monitoring equipment:
a – downstream view; b – upstream view.

This system manages the measurement cycles by automatically transferring data between the field and the office. With the help of tools for rigorous data calculation and analysis, interested people can easily and quickly access the results. The raw data is stored in a SQL database, being easily exported for use in external applications. The final data shall be presented in the form of automatic graphs, images, maps, tables, charts and reports. You can also define sets of conditions for alarms based on certain thresholds and the software automatically sends alerts via SMS or e-mail when the set thresholds are exceeded.

The current movements tracking process for dams using classical methods requires periodic field visits to make measurements [13]. Implementing a real-time monitoring system is an investment that offers several benefits. There is a necessary initial investment, but in the long term, it is streamlined by reducing the costs of measurements, field trips, large volume of data, timely intervention, etc.

Once the system is installed and configured, the analysis of the recorded data is performed in real time and can be accessed at any time through specific applications. This allows the team to take on additional projects with the same workforce, while maintaining control of critical movements of the monitored infrastructure, increasing productivity. The analysed monitoring model can be used to monitor the movements of all types of dams and constructions.

4. Conclusions

The real time geometrical parameters monitoring systems offer the possibility of obtaining the necessary information in order to ensure the safety of the constructions for a normal exploitation and the evaluation of the conditions for the prevention of incidents, accidents and damages, the reduction of material damages, the avoidance of human life loss and the degradation of the environment.

Real-time monitoring can improve the procedure for assessing the operational safety of dams for water accumulations by reducing the time for data collection, but also for their rapid processing for the purpose of making immediate decisions.

Real-time monitoring systems allow urgent measures to be taken in extreme cases, such as the remediation of malfunctions or the rapid warning and evacuation of the population, in which case the catastrophes can be avoided.

Once the monitoring system is installed and configured, the analysis of the recorded data is carried out in real time and the database can be accessed at any time through specific applications.

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