MONITORING THE TEMPORARY STABILITY OF THE PODIȘU DAM FROM IASI COUNTY BY ADVANCED TOPOGRAPHIC MEASUREMENTS

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Abstract

The paper presents elements of analysis of the temporal stability of earth dams by using topographic methods. Structural deformations and displacements are determined and processed by data obtained from advanced topographic studies on the geometry of the dam construction. The studies and researches were carried out for the Podișu earth dam located on the Valea Oii river, Bahlui river basin, Iași county. Special hydrological events recorded in recent years in the Bahlui river basin and especially on the Valea Oii river, have influenced the stability of the earth dams in cascade in this area. Monitoring the structural condition of dams and obtaining stability analysis data were made by topographic surveys in 2006, 2017, 2019. To carry out in accordance with the legislation in force the monitoring of the behavior of constructions, they must be equipped with settlement tracking landmarks but also fixed landmarks. This situation is not fulfilled at most class C and D earth dams. In the absence of tracking marks, in 2019 four landmarks were instaled at the Podișu dam and a local tracking network was created. With the help of topographic measurements, the constructive elements of the earth dam were reconstructed and the analysis base of the stability model was restored (situation plan, longitudinal and transversal profiles, constructive details etc.).

Key words: database, deformations, topographic plan, profiles, settlement landmarks

In the last 20 years have produced a number of climate changes in the world, with direct influence on the hydrological cycle. These changes are present in Romania and influence the distribution of annual rainfall and flows in river basins. The high value of the changes creates an important hydroclimatic risk in the evolution of flows and levels on rivers. Hydrological changes influence the behaviour of the river, but also dam construction and existing constructions in the river bad and bank (Luca M. *et al*, 2016).

The safety of hydrotechnical structures is a very important element that must enter the concerns of designers and society in general. In the case of their distruction due to hydrological hazards, other activities from the area, the settlements and human lives may be strongly affected. Braking dams accidents do not occur suddenly but almost always there are signs of danger that would allow preliminary measures to limit or even avoid disasters (Boboc V., Mitroi R., 2016).

From the research carried out until this moment, achieving hydrotechnical objectives involves the use of detalied technical and economic documentation. Various studies are used when making the technical project: topographic studies, geotechnical studies, hydrological studies, hydraulic studies, hydrogeological studies etc. Of all these studies, the topographic documentation, based on topographic measurements, is of particular importance (Luca M. *et al*, 2017).

The methods and technology of data measurement and processing have evolved a lot in recent years, reaching today the real-time monitoring of the deformtions of the constructions subjected to the on-site tracking process by geodetic metods (Onu C., 2011).

Spatial geodetic networks, determined by GNSS technology, have the dominant role in local geodetic network creation nowadays. In the case of the monitoring of some hydrotechnical constructions, these networks are designed so that their geometrical configuration would allow the determination of the coordinates of control points which are located on the construction with high accuracy (Chirilă C., Căsăndrescu I.A., 2015).

The quality of the horizontal coordinates of the points in a local geodetic network is influenced by many factors such as: equipment used for measurement/observation, network geometry, measurement strategy as well as data processing methods (Julianto E.N. *et al*,2018).

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MATERIAL AND METHOD

The research material is represented by the Podisu earth dam located on the Valea Oii river. From an administrative territorial point of view, the studied massif is located on the territory of Baltati commune in Iasi county. The access to the earth dam is made through an exploatation road that branches from DC 116 in Podisu locality (*figure 1*).

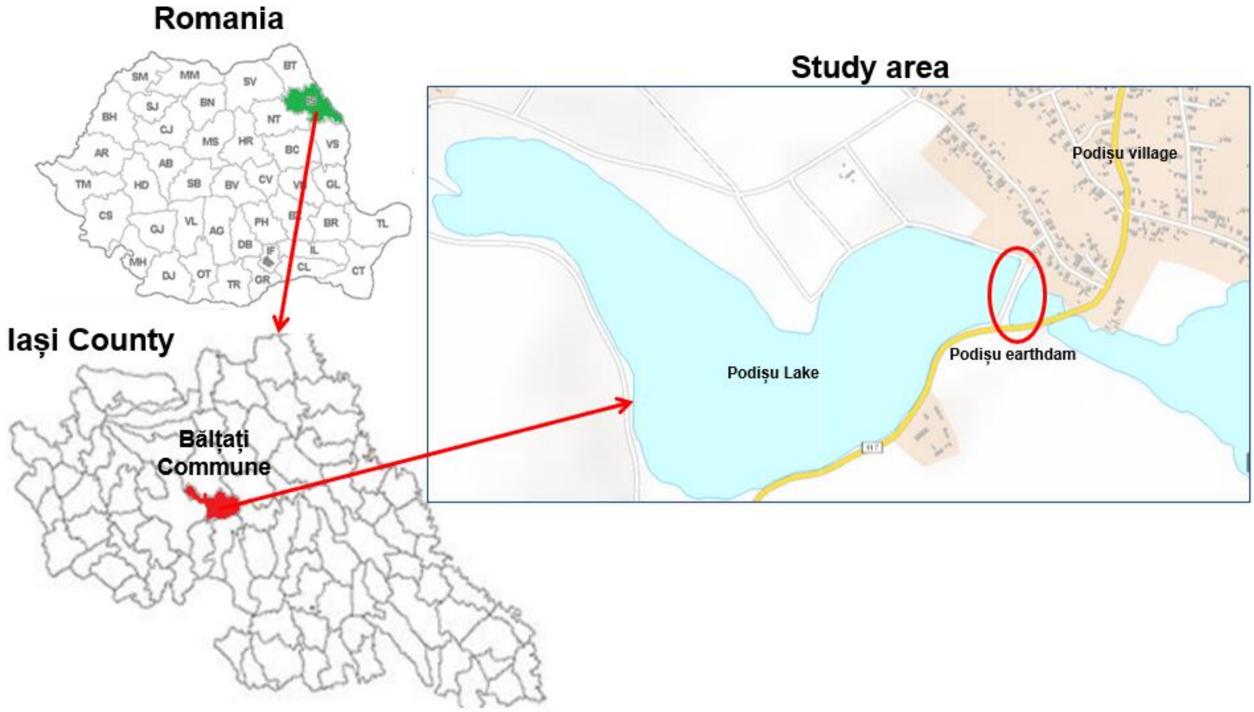

Figure 1 **Representing the study area by framing it on the map of Romania, Iasi county, Podisu locality**

The Podișu reservoir was built between 1961-1962 with an area of 15.63 ha. The accumulation was designed to contribute to flood mitigation on the Valea Oii river and to ensure the flow of servitude downstream to the accumulation Ichim.

The research methodology consists of the following stages:

- Researching the history of the studied objective.
- Analysis of the main technical characteristics of the Podișu earth dam.
- Prezentation of structural aspects.
- Prezentation of the current surveillance system for the studied area.
- Analysis of topographic measurements performed for the dam by comparing the cross-sectional profiles performed in 2006 and 2016.
- Recognizing the objective and performing topographic measurements in order to prepare the situation plan in 2019.
- Design of a local geodetic network for tracking the movements of the earthdam.

The Podișu accumulation is in category C of normal importance and also fulfills the role of a fish pond. The important phenomena that need to be followed are the external stresses and displacements (relative and absolute) that occur during the exploitation period of the earth dam.

RESULTS AND DISCUSSIONS

The Podișu reservoir was built between 1961-1962 with the main role in flood mitigation on the Valea Oii river, ensuring the flow of servitude downstream. Special events recorded in 1976 when the flood, with a probability of exceeding over 1%, caussed all the cascading dams in this area to be discharged, due to the overtopping of dams. The accumulations located on the Valea Oii river are: Boureni, Bejeneasa, Filiaşi, Podişu, Ichim and Sârca.

All dams were rebuilt between 1977-1978. Concidering this event and to avoid breaking them, adequate monitoring is very important, to follow external stresses and displacements.

Earth dam Podişu (*figure 2*) is located in the southwest of Podişu village. The Podişu dam is a homogeneous type of earth dam made of local materials with a trapeziodal shape and a circulated crest.

Figure 2 **Overview of the Podișu earthdam**
(photo: Agapie I., 2019)

From a geological point of view, the area of lake Podișu consists of Sarmatian deposits over which are deposited quaternary formations consisting of deluvial and alluvial deposits. Deluvial deposits are represented by clays, sandy clays, dusty-sandy clays and have a maximum thickness of 8-9 m on the left side and over 10 m on the right side (Sbiera I.B., 2006).

The constructive characteristics of the Podișu earth dam are highlighted in *table 1*.

Table 1
Technical data of the Podișu earth dam

Podișu dam (cadastral cod: XIII.1.15.32.12.7)		
Dam length	104 m	
Average crest heigh	87.45 m	
Maximum height	3.9 m	
Crest width	4.5 m	
Slope	Upstream	1:1 (rough stone wall prtection)
	Downstream	1:2 (grass protection)

In order to transit large and medium waters, the dam is provided with two overflows spillway C1 and C2 located at the ends of the dam.

Spillway C1 (*figure 3*) built of reinforced concrete has a rectangular section of 2.00 x 3.70 m. Its heigh is 3.5 m and the length of the water access front is 1.0 m. Spillway C1 is provided with wooden valves to control the water level in the lake and flows discharged downstream. Spillway C1 is also provided with a window equipped with metal grilles.

a.

b.

Figure 3 **Photo representing the spillway C1: a – upstream; b – downstream bottom discharge**
(photo: Agapie I., 2019)

Pipe conduit has a legth of 19.50 m and is constructed of reinforced concrete. The pipe shaft is at 82.70 m elevation. Spillway C1 flows into the energy disspation channel made of reinforced concrete.

Spillway C2 (*figure 4*) is made of reinforced concrete, has a rectangular section measuring 3.8 x 5.0 m and a height of 3.5 m. For free access to water the spillway has a window equipped with metal grilles. Also, the presence of wooden valves can be noticed, with the help of which the water level in the lake and the flow discharges downstream can be controlled. The length of the water access front is 2.0 m.

Spillway C2 outlet, of reinforced concrete has a length of 22.0 m and a square section measuring 2.0 x 2.0 m. The pipe shaft is at 83.30 m elevation. Also, in the case of spillway C2, outlet flows into the energy disipating channel.

a.

b.

Figure 4 **Photo representing the spillway C2: a – upstream; b – downstream bottom discharge**
(photo: Agapie I., 2019)

The Podisu accumulation monitoring system includes visual observations, which take place periodically on the accumulation lake and the earth dam. Thus, it is possible to follow the state of degradation of the banks, their sliding tendencies as well as the tracking of infiltrations in the area of the upstream and downstream slopes. The monitoring of the earth dam takes into account the processes of erosion of the slopes, the appearance of cracks or fissures in the body of the dam, the condition of the slopes in the embedded area of the dam, possible displacements or settlements of the dam and adjacent slopes. The strength of the spillway, the appearance of cracks, the state of integrity of the concrete, the damage of the joints are also checked.

According to the last technical inspection carried out in 2016 (Tănăsescu, 2016), the concrete surfaces of the spillways C1 and C2 were in satisfactory condition with no significant cracks or exfoliations. During the visual inspection of the earth dam, the state of protection of the upstream and downstream slopes was examined. Their condition is satisfactory, without the presence of wetting or infiltration. The analysis shows that the discharge of bottom drain at the spillway C1 requires repair work.

Also, based on the visual observations made during the technical expertise from 2006 and 2016, no landslides of the slopes adjacent to the dam and the lake basin were observed.

The Podisu earth dam is not provided with infiltration monitoring equipment and does not have a drainage system installed. The water level in the accumulation lake is determined following the observations made by the operating personnel at the hydrometric sight drawn on the wall of the spillway C1. The earth dam has no landmarks for tracking settlements or movements. The relative follow of the evolution of these phenomena can be highlighted with the help of the situation plans and the transversal profiles drawn up in 2006, 2016 and 2019.

During the 2006 expertise, following the topographic measurements, the situation plan presented in *figure 5* was drawn up. The cross-sectional profile 1 will be analyzed by comparing it with the results obtained for the same profile following the topographic measurements from 2016.

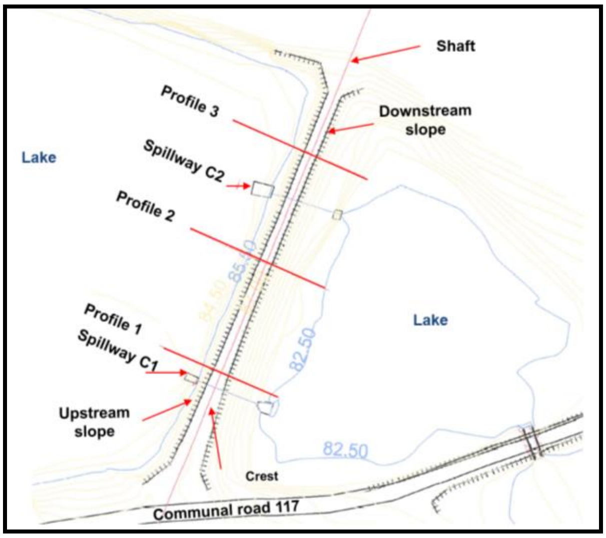

Figure 5 **Situation plan with the representation of the dam components and measured profiles**
(source: Sbiera I. B., 2006)

Figure 6 shows the two cross-sectional profiles performed in the expertises of 2006 and 2016. In order to draw up the transversal profiles, leveling measurements were performed for 9 points arranged along the line defining profile 1, at the distances mentioned in *figure 6.*

From the analysis of the two transversal profiles it can be observed an elevation of the dam crest by 27 cm in point 4 and by 40 cm in points 5 and 6, respectively. This is due to the works to raise the crest of the dam, the elevation measured in 2016 being 87.79 – 87.92 m compared to the average elevation of 87.45 m measured in 2006.

During the last technical expertise carried out in 2016, it was necessary to install the tracking landmarks on the dam crest and the fixed landmarks at the ends of the dam, with the periodic performance of topo-geodesic measurements.

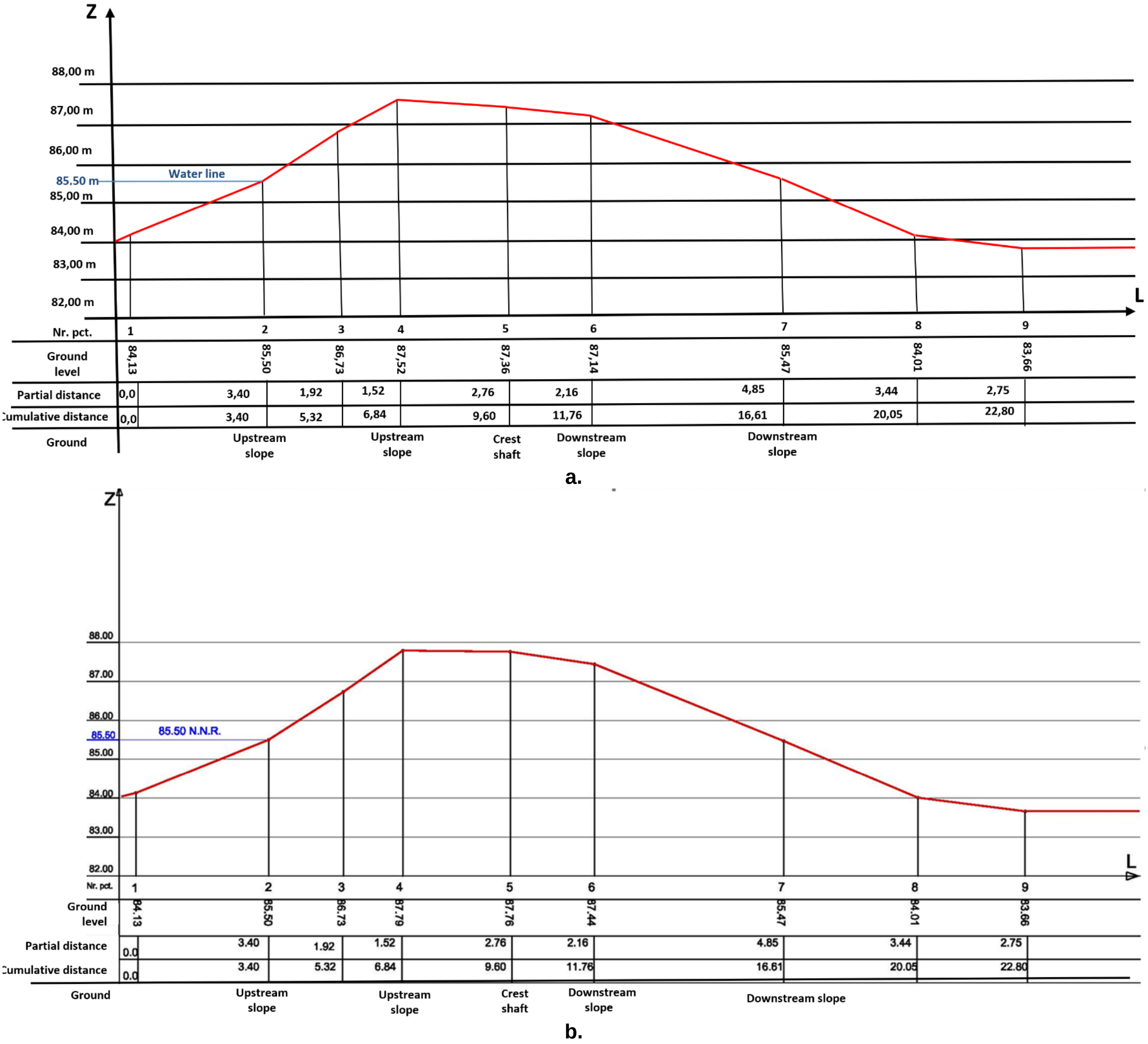

Figure 6 **Representation of the transversal profiles for the analyzed area: a – transversal profile according to the measurements from 2006; b - transversal profile according to the measurements from 2016**
(source: Sbiera I. B., 2006; Tănăsescu M., 2016)

In 2019, a topographic survey was carried out to verify the elevations of the upstream and downstream slopes and the crest. Thus, 10 transversal profiles were made. In *figure 7* the situation plan is represented for two profiles, one of which corresponds to the spillway C1. Compared to the last expertise performed in 2016, there is again an increase in elevations which indicates the realization of the consolidation works of the dam through increased height by about 40 cm.

To made the topographic plan, the geodetic measurements were performed using Trimble equipment. A Trimble R8S fixed receiver (*figure 7.c*) and a Trimble R8S mobile rover (*figure 7.b*) were used. The measurements were performed in real time, in RTK (Real Time Kinematic) mode having a horizontal and vertical positioning accuracy of 8 mm. This method of positioning in real time the coordinates of stationary points is called differential positioning (DGNSS). The situation plan was made in Stereo 70 projection, reference plan for elevation, Black Sea 1975.

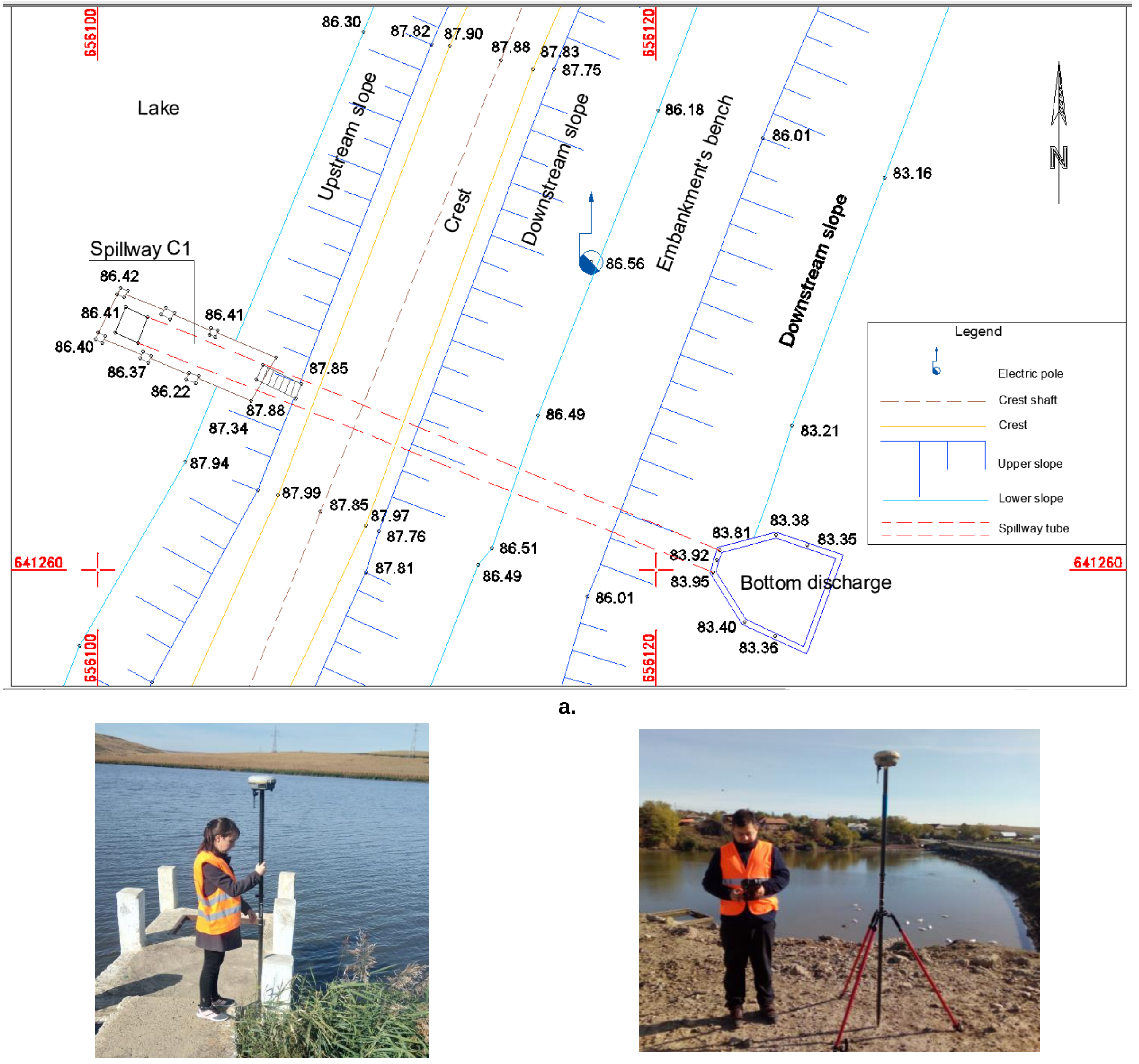

Figure 7 **Making the topographic study: a – situation plan in the area of the spillway C1; b – field measurements with the Trimble R8S mobile rover; c – Trimble R8S fixed receiver**

DGNSS positioning is most often used when positioning accuracy is desired. This method involves the use of at least two GNSS receivers: a reference receiver held in a fixed position, at a known coordinate point and another receiver, a rover, whose coordinates must be determined. The fixed receiver determines its own position based on the collected satellite measurements, which it compares to the known position. The difference between the two solutions allows the determination of the measurement errors and the necessary corrections. The corrections are transmitted by the reference station to the mobile receiver to determine its position (Diac M., 2020).

For periodic monitoring of horizontal and vertical movements of the earth dam, in 2019 a tracking network was created consisting of four control points marked with B1, B2, B3, B4, located at the ends od the dam and two reference points S1 and S2, positioned on the slope adjacent to the dam. The stages of the follow-up network were:

- Objective recognition, setting and marking of station points S1 and S2 (*figure 8.a*).

- Establishment and marking of points B1, B2, B3, B4 (*figure 8.b*).

- Determination of station point coordinates by the static GNSS positioning method.

- Performing static measurements and relative positioning of control points B1, B2, B3, B4.

a. b. c.

Figure 8 **Images representing the steps of creation of the geodetic network : a – marking and measuring station points; b – marking control points; c – scheme of the geodetic tracking network**

The static relative method was used to determine the coordinates of the control points. This method involves determining the coordinates of a new point in relation to the coordinates of a known fixed point, by determining the size of the vector between the two points (base-vector), in the reference system WGS 84. Relative static positioning involves simultaneous measurements on the same satellites. Observations recorded by the fixed receiver (S1, S2) are transmitted to mobile receivers (located in the points B1, B2, B3, B4). The observations from both receivers are combined to determine the relative position of the control points in relation to the station point. The accuracy of this positioning method is ± 5 mm ±1 ppm.

The measurements performed resulted in a number of 20 vectors from 10 measurement sessions in relation to the reference station S1 and 10 measurement sessions in relation to the reference station S2.

The measurements were performed using three GNSS receivers at the same time, one Trimble R2 and two Trimble R8S. The observation time was 12 minutes.

Measurement processing was performed in the office with Trimble Business Center software, a application for processing and managing data taken with total station, GNSS receivers or UAV (Unmanned Aerial Vehicle).

The coordinates of the control points are presented in table 2.

Using the same measurement method, the coordinates of the control points can be determined annually or after the occurrence of special events (earthquakes, floods, etc.). The location of the control points, at the ends of the earth dam, allows their subsequent use for determining and following some points located on the crest of the dam or on its slopes. Thus, possible horizontal and vertical displacements that appear during the exploitation period of the dam can be followed. Decisions can also be made on consolidating the dam for its proper functioning.

Table 2

Coordinates of control points

Point	Relative static GNSS measurements		
	X (m)	Y (m)	Z (m)
B1	641235.174	656114.608	87.032
B2	641233.023	656073.577	88.785
B3	641362.707	656144.724	88.478
B4	641360.791	656156.363	88.407

The GNSS monitoring method assumes the first measurement as a reference (reference epoch). Future measurements will relate to the first measurement.

The application of GNSS measurement technology has the advantage of not requiring visibility between the points of the geodetic network but from each station a free horizon above the elevation of 15º is necessary. Thus, in order not to create visibility problems for satellites, points stationed with GNSS receivers should not be obstructed by dense vegetation, tall buildings, etc., which may interfere with the received satellite signal. Also, the geometric distribution and the number of satellites in the sky can limit the final accuracy of the measurements even if the individual phase observations from different satellites can be very accurate. This effect is also called dilution of precision (DOP) and its values are increased when parts of the sky are obstructed by artificial structures. All these sources of error must be eliminated in order to obtain millimeter accuracy using GNSS technology. A problem in tracking dams is the location of monitoring points adjacent to the dam walls, thus restricting the visibility of the satellite and the appearance of the multipath effect.

Multipath (*figure 9*) is a disturbance of the satellite signal resulting from the fact that the signal received by the GPS antenna includes both the direct component and the signals reflected from walls, water surfaces etc.

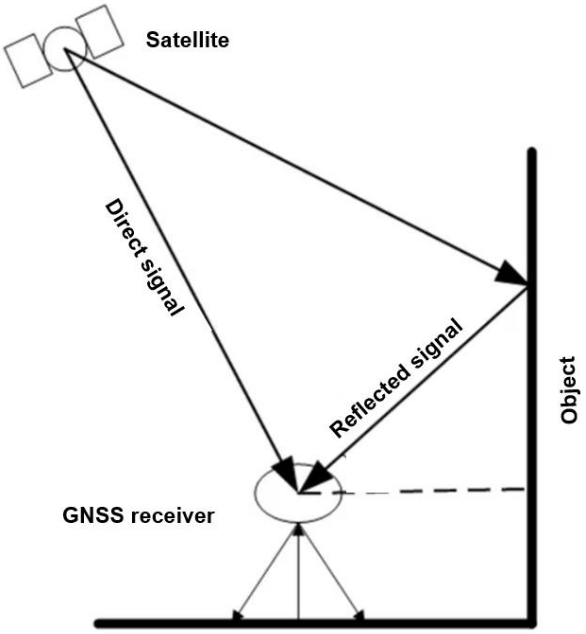

Figure 9 **Schematic representation of the multipath error in the process of performing measurements with GNSS technology** (source: Dai W. *et al*, 2017)

CONCLUSIONS

As part of the dam monitoring activity, for a good safety in their operation it is necessary to use modern tracking methods, which require the use of high-performance equipment and software to take and process data with high precision.

The local geodetic network created allows the performance of some measurement cycles and their comparison with the measurements from the reference epoch.

Making topographic surveys and drawing up situation plans and cross-sectional profiles allow the detection of trends of loss stability of slopes by traking the level differences recorded .

Making measurements using GNSS technology can highlight the evolution over time of a component element or the entire earth dam.

The relative static measurement method provides higher accuracy in determining the coordinates of the tracked points, compared to the differential RTK method.

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