MONITORING THE STABILITY OF EARTHDAMS USING LOCAL GEODETIC NETWORKS

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***Abstract**: Monitoring the behavior of earth dams over time requires that they be permanently equipped with their own tools and control points. Monitoring is performed according to the importance category of the objective, control parameters, but also the specific conditions of the location. The paper presents a modern way of tracking structural deformations in the case of earth dams, owned by private owners, in order to assess their operational safety. The article presents three earth dams of different categories of importance (B, C and D), to analyze how to monitor each objective. The main study area is represented by the Piscicola Podișu accumulation located on the Valea Oii river in Iași county. For the location of the earth dam, measurements were made for the creation and monitoring of the local geodetic network. The network consists of reference points (S1, S2), station points (B1, B2, B3, B4) and control points (P1-P11) located on the studied dam. The way of working involved several stages. In the first stage, the site recognition and the monitoring requirements of the dam stability parameters were performed. In the second stage, the conditions for carrying out the measurements for drawing up the situation plan and designing the geodetic monitoring network were analyzed. In the third stage, measurements were performed for the design of a local GNSS geodetic network. The purpose of this paper is to design and analyze GNSS measurements in the monitoring of earth dams with modern technologies.*

***Keywords**: deformations, GNSS, monitoring, situation plan, geodetic network.*

1. Introduction

Earth dams are massive structures that retain large amounts of water in the reservoir. They are an important part of modern civilian infrastructure that contributes to water supply, irrigation, electricity and pisciculture. Their structural stability is very important because a possible failure of a dam will lead to a sudden release of a large amounts of water, resulting material and human damage downstream. Therefore, it is important to monitor their deformations in order to avoid such unfortunate events [9].

Tracking of earth dams involves monitoring stability parameters (geometric and topological) by fast procedures, to ensure increased reliability and efficiency. The GNSS satellite system is widely used in real-time deformation monitoring, being an efficient way to track movements with high accuracy [4,5].

The technique of measuring and processing data has evolved a lot in recent years, reaching today the real-time monitoring deformations of the constructions in the in-situ tracking by geodetic methods [8].

The type, number and distribution of monitoring equipment depend on the specific characteristics and problems of the location of the earth dams. Geodetic monitoring involves the determination of the vertical and horizontal displacements of the target points located on the dam in relation to the reference points located in stable areas [6].

Many factors can affect the movement of a dam, including the level of water in the reservoir (hydrostatic pressure) and seasonally varying ambient temperature (termal expansion). Previous studies indicate that the accuracy achievable using the GNSS system is adequate to monitor the movements of a dam [7].

2. Material and research method

The research material is represented by earth dams of different categories of importance (B, C and D), to analyze how to monitor each objective.

Parcovaci earth dam is located in the upper basin of the Bahlui river, on the territory of Deleni commune, at 10 km from Harlau town, Iași county. The access to the dam is made from the communal road DC 150 Harlau – Parcovaci, road branching from E58 (Fig. 1). In accordance with STAS 4273/1961, Parcovaci dam is included in class II of importance and special category (B).

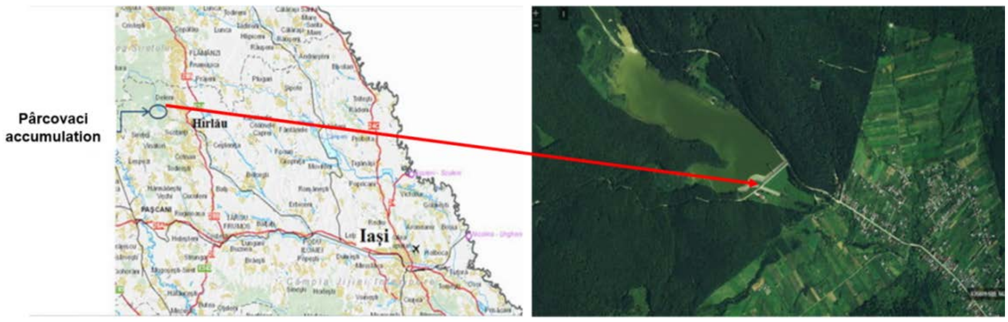


Fig. 1. Location of Parcovaci dam, Deleni commune, Iași county

Sarca dam is located on the Sheep Valley River, on the territory of Băltati commune, at 2 km from the confluence with the Bahluiet River, Iași county. The access to the dam is made from a communal road that branches from the E58 road (Fig 2). In accordance with STAS 4068/1987, Sarca dam is included into category C of normal importance.

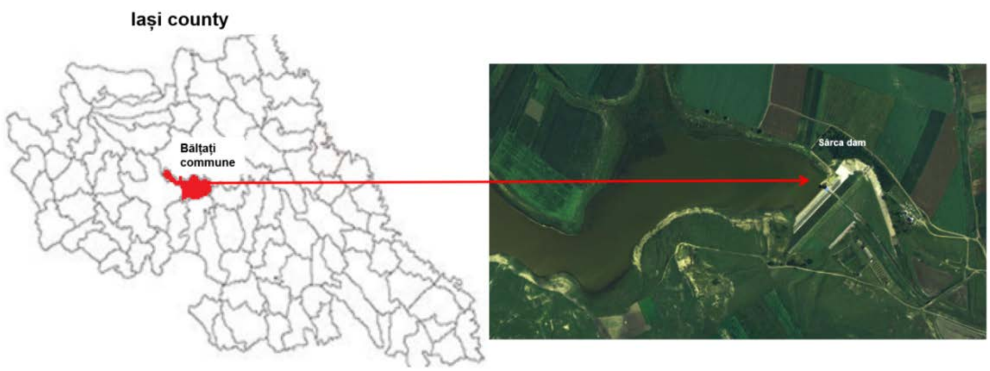


Fig. 2. Location of Sarca dam, Sheep Valley River, Baltati commune, Iași county

The Podisu earth dams located on the Valea Oii river, on the territory of Baltati commune, in Iași county. The access to the dam is made through an exploitation road that branches from DC 116 in Podisu locality (Fig.3). In accordance with STAS 4273/1983, Podisu dam is included in category D of importance and is owned by the private owner SC. PISCICOLA PODISU SRL.

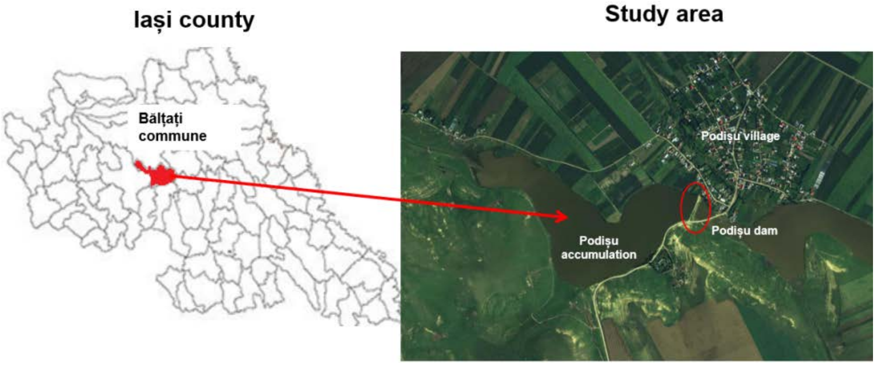


Fig. 3. Location of Podisu dam, Sheep Valley River, Baltati commune, Iași county

The research methodology presents the way of geodetic monitoring the displacements for the earth dams (of category B and C) which is in the Romanian Waters National Administration. For the Podisu earth dam (category D), in the absence of a displacement tracking system, the implementation of a modern monitoring method was considered. Thus, a local geodetic network was created in analogy with the networks used to track the dams of higher importance. The GNSS satellite technology, used in the monitoring process, is modern and different from the classical measurements, specific for tracking the behavior of category B and C dams.

3. Results and discussions

3.1. Results –Parcovaci earth dam

The Parcovaci accumulation has as main utility the water supply of Harlau locality and ensures the protection against floods of the localities located downstream (Harlau, Scobinti, Ceplenita, Cotnari).

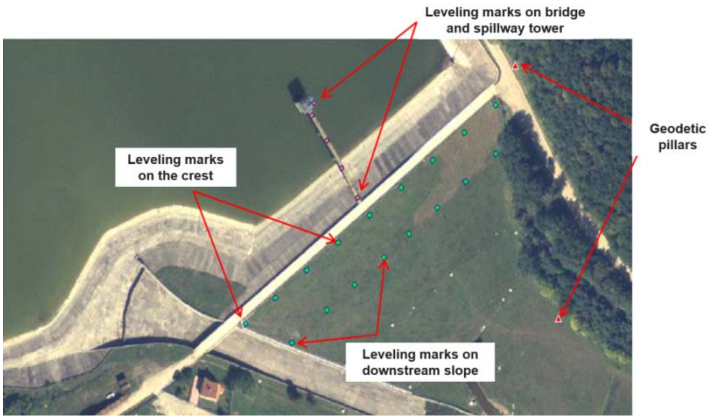


Fig. 4. Location on the orthophotoplan of the levelling landmarks and geodetic pillars for the Parcovaci dam [3]

It is presented below a number of selective elements from the study reflected on this earth dam.

In order to follow the evolution of the vertical deformations (settlements), the Parcovaci dam is equipped with 17 level landmarks with a vertical axis located on the body of the earth dam, 4 marks on access bridge, a mark on the intake tower and 6 geodetic pillars located outside the area of influence of the dam.

Levelling marks positioned on the dam body are distributed as follows:

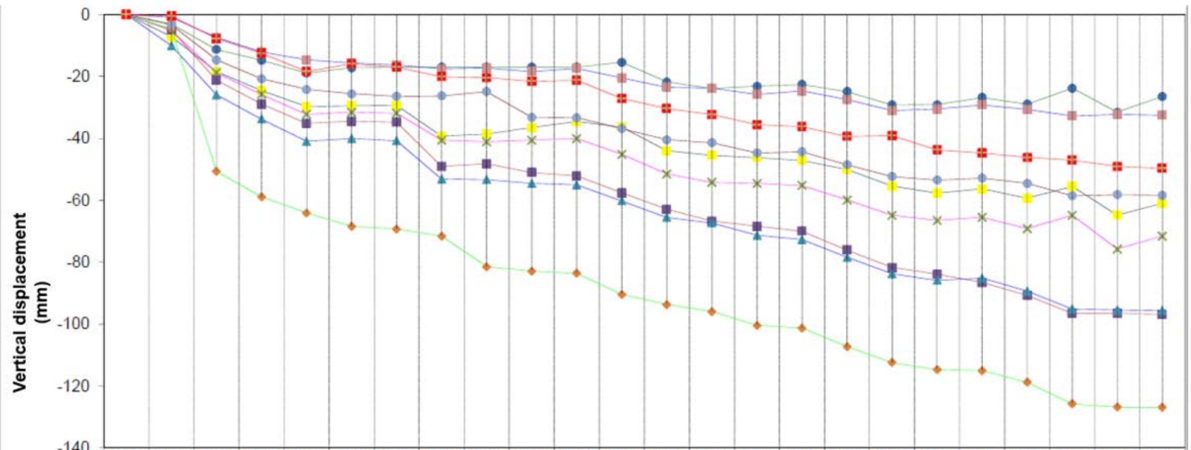
- 9 leveling landmarks located on the dam crest (Fig. 5.a);
- 8 leveling landmarks located on the downstream slope (Fig. 5.b);

a.

b.

Fig. 5. Location of the landmarks: a – on the crest; b – on the downstream slope [1, 3]

Between 14.10.1994 – 30.10.2017, 23 series of observations were made on the dam body. The observations were made on the landmarks located on the crest and on the downstream slope. In 2017 the "10" series was performed on the three landmarks located on the bridge and one landmark on the intake tower. The measurements were performed by classical topographic observations using the optical level as an instrument. The odds of the landmarks were determinate by the method of high-precision geometric levelling. In fig.6, the values expressed in millimeters for the marks located on the dam crest and the evolution graph of the recorded deformations are detailed [1].



	Seria "0" Mai 1994	Seria "1" Iun. 1995	Seria "2" Mai 1997	Seria "3" Iun. 1998	Seria "4" Oct. 1999	Seria "5" Nov. 2000	Seria "6" Nov. 2001	Seria "7" Nov. 2002	Seria "8" Nov. 2003	Seria "9" Nov. 2004	Seria "10" Nov. 2005	Seria "11" Nov. 2005	Seria "12" Iun. 2006	Seria "13" Iun. 2007	Seria "14" Iun. 2008	Seria "15" Mai 2009	Seria "16" Mai 2010	Seria "17" Mai 2011	Seria "18" Iun. 2012	Seria "19" Iun. 2013	Seria "20" Iun. 2014	Seria "21" Sept. 2015	Seria "22" Mai. 2016	Seria "23" Nov. 2017
RT I 1	0	-3.1	-11.3	-14.8	-18.9	-17.2	-17	-17	-17	-17	-17	-15.5	-21.8	-23.9	-23.2	-22.6	-24.9	-29.2	-29.1	-26.8	-29.0	-23.8	-31.6	-26.5
RT I 2	0	-7.2	-18.5	-24.6	-29.8	-29.5	-29.4	-39.3	-38.6	-36.5	-34.5	-36.3	-44.0	-45.5	-46.3	-47.1	-50.1	-55.5	-57.7	-56.3	-59.4	-55.5	-64.8	-61
RT I 3	0	-5.1	-18.8	-25.8	-32.3	-31.6	-31.9	-40.6	-41.1	-40.6	-40.1	-45.2	-51.5	-54.3	-54.6	-55.3	-59.9	-64.8	-66.5	-65.5	-69.2	-64.9	-75.8	-71.6
RT I 4	0	-5	-21.2	-28.9	-35.2	-34.5	-34.8	-49.1	-48.2	-51.1	-52.1	-57.6	-62.9	-66.8	-68.5	-70.0	-76.1	-81.7	-83.9	-86.6	-90.8	-96.6	-96.6	-96.9
RT I 5	0	-10.1	-26	-33.8	-41	-40.1	-40.8	-53.2	-53.4	-54.6	-55.1	-60.2	-65.6	-67.3	-71.3	-72.8	-78.4	-83.8	-85.9	-85.2	-89.4	-95.2	-95.5	-95.7
RT I 6	0	-4.6	-50.7	-58.9	-64.1	-68.4	-69.3	-71.6	-81.5	-82.9	-83.6	-90.4	-93.7	-96.0	-100.	-101.	-107.	-112.	-114.	-115.	-118.	-125.	-127	-127
RT I 7	0	-3.3	-14.7	-20.8	-24.2	-25.6	-26.4	-26.3	-24.9	-33.2	-33.4	-36.8	-40.5	-41.4	-44.7	-44.4	-48.5	-52.4	-53.5	-52.8	-54.6	-58.6	-58.2	-58.4
RT I 8	0	-0.9	-7.4	-12.1	-14.7	-15.7	-16.3	-17.6	-17.3	-18.4	-17.4	-20.5	-23.5	-23.8	-25.8	-24.7	-27.5	-31.0	-30.5	-29.2	-30.7	-32.8	-32.3	-32.5
RT I 9	0	-0.5	-7.8	-12.5	-18.4	-15.9	-17	-20.1	-20.4	-21.6	-21.2	-27.1	-30.4	-32.3	-35.6	-36.2	-39.4	-39.1	-43.7	-44.7	-46.2	-47.0	-49.1	-49.7

Series of measurements regarding the evolution in time of the vertical deformations

Fig.6. Diagram of the evolution of the vertical deformations for the landmarks located on the dam crest [1]

The displacements were within the limits of the permissible variation for this type of dam.

3.2.Results –Sarca earth dam

The main functions of the Sarca accumulation are: attenuation of flood waves, irrigation and fish framing. Sarca earth dam is a massif of homogeneous type made of local material. It is presented below a number of selective elements from the study reflected on this earth dam.

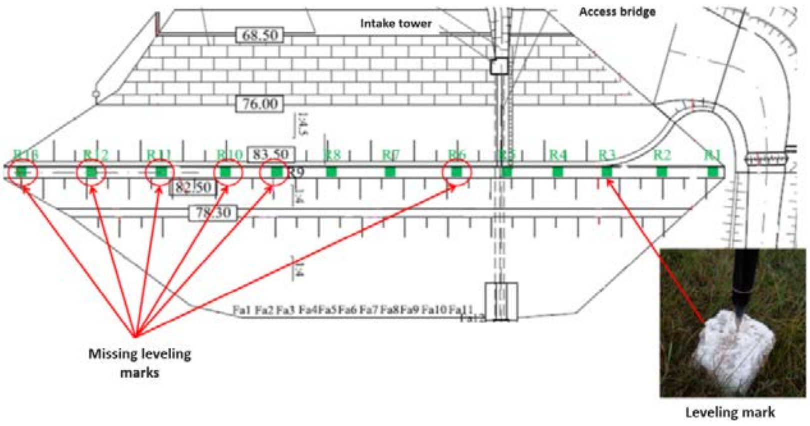


Fig.7. Diagram of the vertical deformations for the landmarks located on the dam crest [3]

The monitoring of the dam is carried out through annual observations on the levelling marks on the dam crest (Fig. 7). The geodetic monitoring network of the dam consist of 13 levelling marks located on the crest and two pilasters fixed in stable areas [3].

The program of geodetic measurements of the Sarca dam consists of levelling observations performed by the classical method with optical level. The results of the measurements performed in 2015 and 2017 are centralized in Table 1. The quotas are calculated in relation to cycle 0 of the measurements carried out in 2004.

Table 1. Settlement sheet for the Sarca dam [2]

Leveling marks	Quota (m)			Effective settlement (mm)	Settlement compared to previous reading (mm)
	First measurement 21.10.2004(m)	16.12.2015(m)	31.10.2017(m)		
R1	82.506	82.3922	82.3920	-113.8	-0.2
R2	82.442	82.4257	82.4256	-16.0	-0.1
R3	82.313	82.2902	82.2902	-22.7	0.0
R4	82.454	82.1909	82.1908	-263.3	-0.1
R5	82.410	82.0883	82.0881	-322.1	-0.2
R6	82.499	missing	missing	-	-
R7	82.456	81.9868	81.9867	-469.4	-0.1
R8	82.422	81.9527	81.9526	-469.5	-0.1
R9	82.373	82.0051	missing	-	-
R10	82.419	82.1442	missing	-	-
R11	82.401	82.1576	missing	-	-
R12	82.456	82.2016	missing	-	-
R13	82.806	82.7936	missing	-	-

In the field (Fig. 7) the slightly degraded condition of the existing marks and the absence or advanced degradation for 6 of 13 levelling marks were noted. From reading until 2017 there is a minimum settlement of 1.60 cm for landmark R3 and a maximum settlement of 46.9 cm for landmarks R7 and R8.

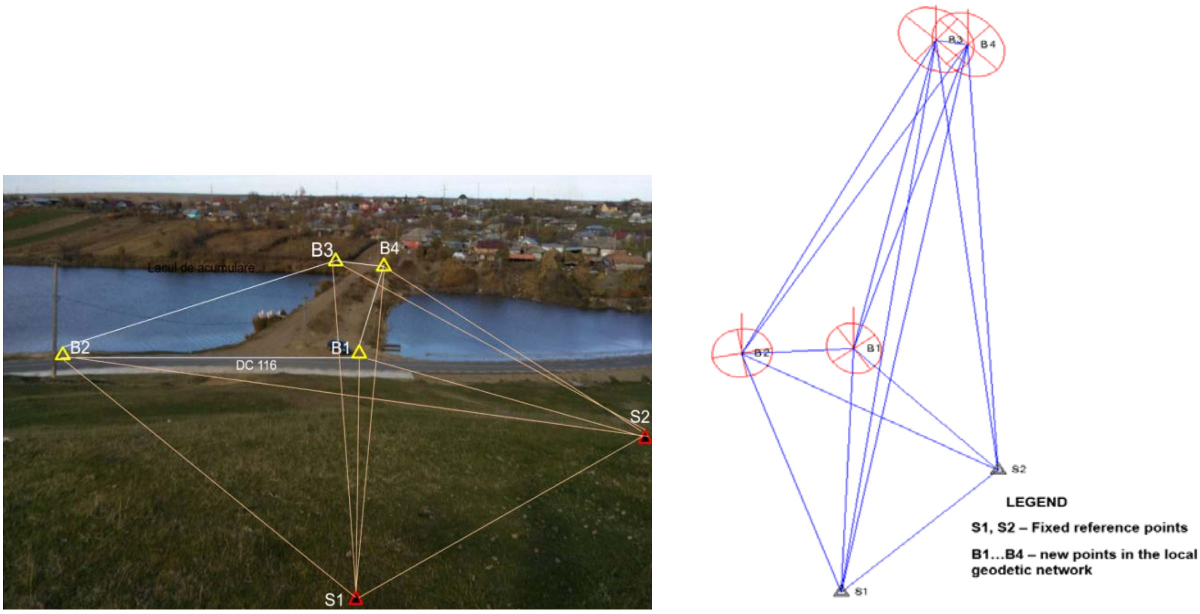
The settlement marks aim to indicate as accurately as possible the vertical components of the displacements of the studied construction. The maintenance of marks for construction monitoring is the responsibility of the executor, during the execution period and of the beneficiary during exploitation [10, 11].

3.3. Results – Podisu earth dam

The Podisu reservoir was built between 1961-1962 with the main role in flood protection on the Sheep Valley River and secondary fish framing. Podisu dam is a homogeneous type of earth mass made of local materials, with a trapezoidal section and a circulating crest. The accumulations located on the Sheep Valley River are: Boureni, Bejeneasa, FilIasi, Podisu, Ichim and Sarca.

The special hydrological events registered in the last years on the Sheep Valley River river, have influenced the stability of the earth dams which are located one after the other in this area. Most category C and D dams are not monitored by an appropriate UCC program. This fact is also influenced by the membership of the dams in a private management system [4].

Podisu earth dam is not equipped with movement tracking landmarks on which annual topographic measurements can be performed. To study the earth dam, in 2019, a local geodetic network was created consisting of: two reference points (S1, S2) and four station points (B1, B2, B3, B4) located in stable areas.



a. b.

Fig. 8. Podisu dam measuring technique: a -geodetic network for monitoring the Podisu earth dam; b - scheme with representation of GNSS vectors and ellipsis of errors in station points

The research methodology in order to create the local monitoring network of the Podisu earth dam consisted of:

- Site recognition.

- Selection and materialization of the points in the study area on which topographic measurements will be performed.
- Choosing the instruments and methods for performing the measurements.
- Performing topographic measurements by the fast static GNSS method.

In 2019 cycle 0 of measurements was performed. In the stage of data collection three receivers were used (two Trimble R8S and one Trimble R2). GNSS measurements were performed using the fast static method over a single day of observation.

In May 2021, the first cycle of measurements was performed. Four receivers (three Trimble R8S and one Trimble R2) were used in the field data collection stage. The processing of GNSS vectors, taken over in 2019 and 2021, was done automatically in the Trimble Business Centre program by including 69 and 36 GNSS vectors, respectively.

For the monitoring of Podisu earth dam, four control points on the dam crest marked from P1 to P4 were initially materialized. As the instability of the dam is mainly observed through changes in the downstream slope, the monitoring system was completed with seven checkpoints located on it. The final monitoring system of the dam contains 11 control points, on which systematic topographic observations will be made in order to monitor the stability [4].

The measurements were performed using the fast static GNSS method and four receivers. The fast static method involved the permanent placement of a receiver at points B1 and B2. The other two GNSS receivers made observations at each control point located on the dam. Thus, a number of 10 measurement sessions were performed. Each measurement session was set to make observations for 10 minutes. For the control points located on downstream slope, two cycles of observations were made in July and November 2021.

Table 2. GNSS measurement results – control points located on downstream slope

Pct.	**Period**	**Spatial rectangular coordinates**			**Estimated standard errors**		
		X(m)	**Y(m)**	**Z(m)**	**Sx(m)**	**Sy(m)**	**Sz(m)**
P5	Jul 2021	641345.675	656148.206	87.095	0.001	0.001	0.002
	Nov 2021	641345.684	656148.216	87.092	0.006	0.005	0.009
	Differences	-0.009	-0.01	0.003	-	-	-
P6	Jul 2021	641321.014	656137.564	86.443	0.001	0.001	0.002
	Nov 2021	641321.02	656137.569	86.424	0.006	0.005	0.008
	Differences	-0.006	-0.005	0.019	-	-	-
P7	Jul 2021	641292.847	656125.406	86.392	0.001	0.001	0.001
	Nov 2021	641292.856	656125.416	86.392	0.006	0.005	0.008
	Differences	-0.009	-0.01	0	-	-	-
P8	Jul 2021	641264.013	656113.214	86.987	0.001	0.001	0.001
	Nov 2021	641264.018	656113.225	86.961	0.006	0.005	0.008
	Differences	-0.005	-0.011	0.026	-	-	-
P9	Jul 2021	641261.033	656120.044	85.033	0.001	0.001	0.002
	Nov 2021	641261.046	656120.048	85.023	0.007	0.005	0.008
	Differences	-0.013	-0.004	0.01	-	-	-
P10	Jul 2021	641290.454	656131.466	84.969	0.001	0.001	0.002
	Nov 2021	641290.452	656131.466	84.952	0.006	0.005	0.007
	Differences	0.002	0	0.017	-	-	-
P11	Jul 2021	641318.724	656144.198	85.274	0.002	0.001	0.002
	Nov 2021	641318.727	656144.195	85.279	0.008	0.007	0.009
	Differences	-0.003	0.003	-0.005	-	-	-

Analyzing the results obtained, a maximum settlement at the P8 point of 2.60 cm can be observed in a two months interval time. Also, points P6 and P10 record a settlement of 1.90 cm and 1.70 cm respectively.

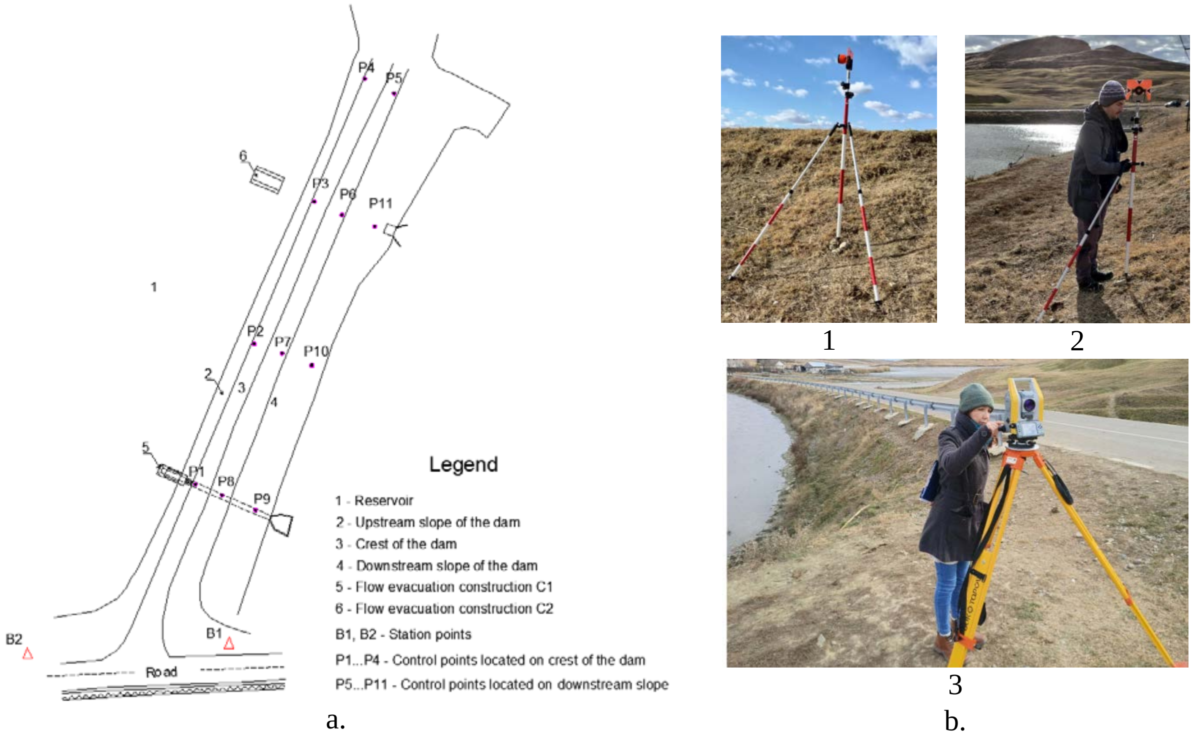


Fig. 9. The location of the station and control points: a - plan with the location of the points in the local tracking network; b1-3– images during measurements

In November 2021, the observations on the control points were made with the total station Trimble C5 (Fig.9). The measurements involved the consecutive location of the total station in points B1, B2 and targeting at the reflector located at each control point. Below are the comparative results for the control points located on the dam crest (Table 3).

Table3. Coordinate differences – dam crest points

Point		X(m)	Y(m)	Z(m)
P1	GNSS	641266.26	656107.808	87.931
	Total station	641266.262	656107.806	87.936
Differences		-0.002	0.002	-0.004
P2	GNSS	641294.898	656119.773	87.898
	Total station	641294.894	656119.779	87.907
Differences		0.004	-0.006	-0.008
P3	GNSS	641323.807	656131.963	87.841
	Total station	641323.808	656131.971	87.850
Differences		0.000	-0.008	-0.009
P4	GNSS	641348.790	656142.232	87.988
	Total station	641348.786	656142.241	87.982
Differences		0.004	-0.009	0.006

From the analysis of the data presented in table 3 it is found that the relatively fast static method using GNSS technology provides accurate measurements. The coordinate differences between the total station measurements and the GNSS observations are a maximum of 1 cm.

4. Conclusions

The monitoring of the earth dams is done by performing topographic measurements at certain time intervals depending on the meteorological changes or after special events.

GNSS technology and the fast static measurement method allow obtaining the coordinates of the monitored points with high accuracy.

The main advantages of GNSS measurements are:

1. Perform measurements continuously, regardless of time (day or night) and weather conditions.
2. Determination of the three-dimensional spatial position of the earth dam (determination of X, Y, Z coordinate of points located on the dam)
3. There is no need intervisibility between monitored points as in the case of measurements with the total station or optical level.
4. Possibility to transmit real-time measured coordinates for analysis and control.

Measurements performed with both GNSS technology and the total stations allow obtaining results with adequate accuracy to monitor the movements of an earth dam.

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