RESEARCH ON THE TOPOLOGY OF EARTH DAM BY USING GNSS TECHNOLOGY

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Abstract: *Monitoring and assessment of the operational safety of hydrotechnical constructions made of earth and local materials requires geodetic measurements at specified intervals. Among these hydrotechnical constructions are the earth dams which have many negative events. A high percent of accidents in Romania occur at small earth dams. Monitoring the topology of earth dams is done by classical geodetic methods. But, in recent times, new technologies have emerged to track the topology of earth dams, of which GNSS technology stands out. Research conducted with GNSS technology, to monitor the geometric parameters of a dam in the Moldova area, has highlighted the reliability of the method by the accuracy of the results and reduced working time. Fild research conducted at the Podisu Dam in Iasi county, in conjunction with documentary studies on the evolution over time of the topology of the earth dam showed important changes with an influence on the stability of the construction. Interpretation of the data obtained by measurements showed a change in the geometric shape in the horizontal plane and in cross sections. The method of measurements performed using two GNSS receivers was used in the research.*

Keywords*:* *geometric parameters, RTK method, stability, topographic measurements*.

1. Introduction

Proper management of dams contributes to the stability of the structure over time, to the prevention of damage and the correct protection of the environment. The most common negative situations in the exploitation of the earth dams are those associated with the absence of annual maintenance works. Also, the absence of rehabilitation and modernization works contributes to the emergence of risk factors in the stability of the earth dam. Early detection of damages and anomalies is a very important step in assessing the integrity of the earth structure and in risk management [1], [2], [3]. Damage to the earth dams occurs in the process of their exploitation and is determined by a complex of factors. A statistical report compiled by [4] shows that the most common damage to the earth dams is caused by the following actions and operating situations: low capacity of large water discharges– 30%, the phenomenon of suffusion – 23%, landslides – 10%, other causes – 37%. Most of the earth dams in Romania are located in the Prut – Barlad river basin. At these dams, were registered most of the degradations of their structure and installations [15]. Studies and research conducted at national [2], [3] [5] and international level [6], [7], [8], highlights the occurrence of structural damage at earth dams caused by the action of natural and anthropogenic factors on the site. It follows that the process of monitoring geometric parameters at earth dams aims to obtain topological data necessary to verify the stability of earth dams. Topological data must be retrieved at specified intervals and used quickly in specialized calculation programs [9], [2].

Geometric parameters of the dam surface are usually determined by classical topo-geodetic methods. They are used for characteristic lengths, dimensions, settlements (precision levelling), horizontal movements etc. Determination of geometric parameters, such as horizontal and vertical displacements for inaccessible points located on slopes is done by microtriangulation [10].

Using a modern method, such as GNSS technology (Global Navigation Satellite System), allowed the testing of the capacity of spatial geodetic networks to meet the precision requirements in the monitoring the horizontal and vertical geometric parameters of civil and hydrotechnical constructions [11], [12] [8].

Various studies are used to carry out technical projects for hydrotechnical constructions, such as topographic, geotechnical, hydrological, hydraulic, climatic, hydrogeological, etc. Of all these studies, the topographic documentation, based on topographic measurements is of particular importance [13].

2. Materials and Methods

The study area is represented by the Bahluet river basin where several earth dams are located. From these, the "Podisu earth dam" was selected with location on the Sheep Valley River, a tributary stream of the river Bahluet. The research objective is located on the territory of Băltati commune in Iasi County (Fig.1).

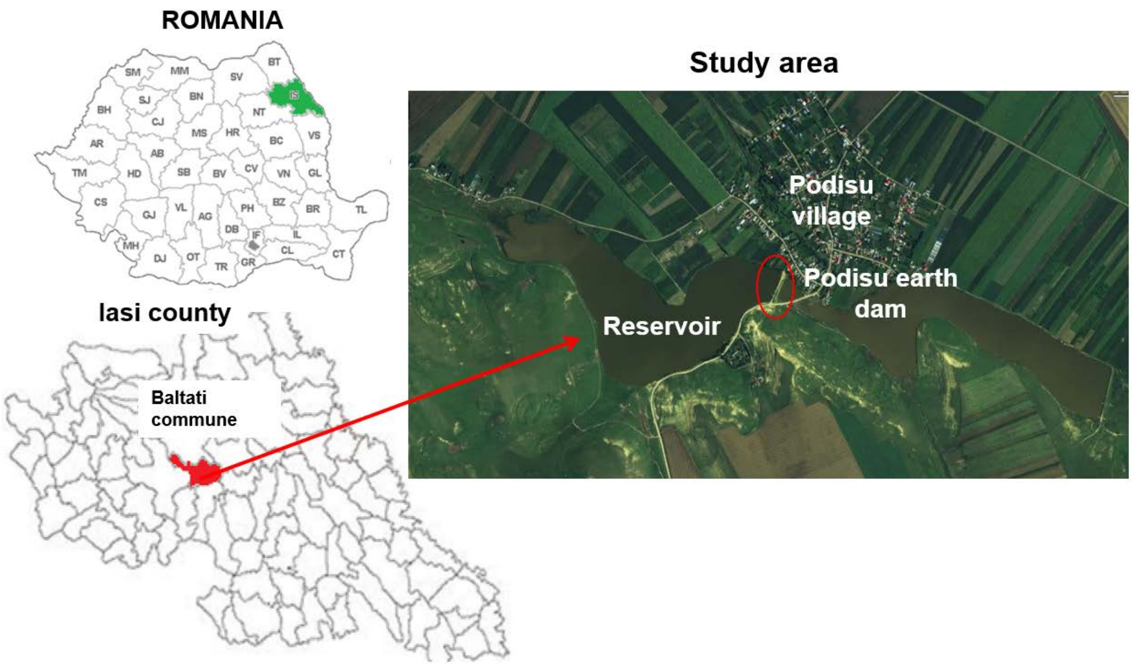


Figure 1 – The location on the orthophotoplan of the Podisu accumulation from Iasi county, Baltati commune

The Podisu accumulation falls from a cartographic point of view on three geodesic trapezoids at a scale of 1:5000, with the nomenclatures: L-35-31-A-a-3-IV, L-35-31-A-a-4-III, L-35-31-A-c-1-II (Fig.2).

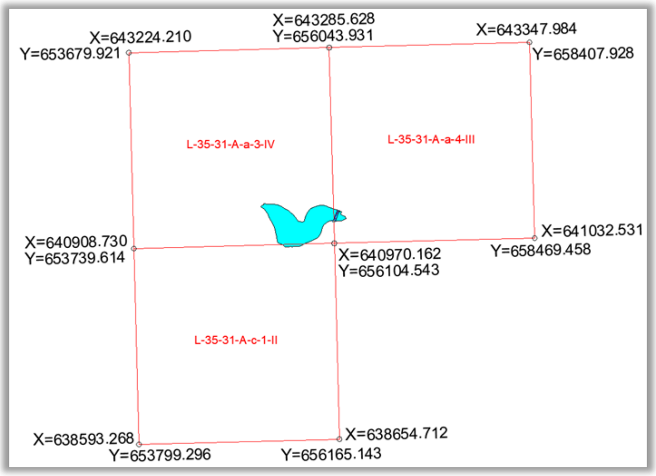


Figure 2 – Framing on geodetic trapezoids the study area

Podisu accumulation (Fig. 3) was designed and built between 1961-1962 with the main function of fish farming and secondary flood control on the Sheep Valley River. According to the technical expertise carried out in 2006 [14] in order to assess the operational safety of the hydrotechnical arrangement, it falls into the normal category C of importance.

Figure 3 – General view of the Podisu dam (source: author)

The methodology for researching topological changes at the earth dam contains the following steps:

- Recognition of the study area.
- Ensuring the conditions for carrying out the measurements – GNSS equipments, measurement method, observation planning, specific measurement processing software.
- Carrying out measurements using the GNSS RTK method.
- Data processing from geodetic and technical measurements.
- Preparation of topographic documentation: situation plans, transversal profiles, longitudinal profiles, characteristic sections at the earth dam etc.
- Preparation of the topological database of the dam.

The measurements in the research area aimed at achieving a topographic survey by using two GNSS receivers (base-rover) (fig. 4). The measurement method was the relative kinematic positioning in real time (RTK – Real Time Kinematic). Positioning accuracy, in RTK mode, provided by the receivers used (Trimble R8S) was 0.015 m vertically and 0.008 m horizontally.

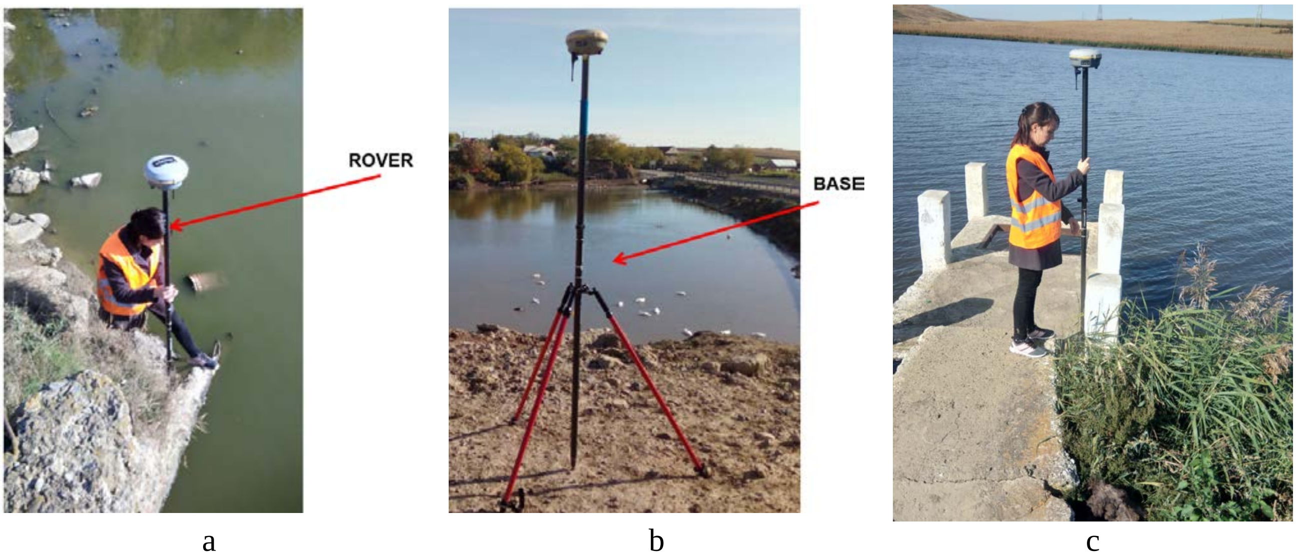


Figure 4 – Measuring equipment in the research area: a – rover; b – base; c – measuring the elevations in the area of the discharger (source: author)

The principle of the relative positioning method is to find the coordinates of a new point in relation to the coordinates of a know fixed point (base). This is done by determining the vector size between the two points defined by relative coordinates (ΔX, ΔY, ΔZ) in the WGS 84 reference system.

3. Results and Discussion

The special events recorded in 1976, the flood with a probability of exceeding over 1%, led to the discharge of all dams in the waterfall in this area. Material dislocations occurred in the body of the dams due to exceeding the crest of the dams with a water layer of about 1.00 – 1.50 m [14], [15].

Studies conducted after 1990 show that the most common accidents are found in earth dams of C and D categories. One of the causes is their private administration by companies or individuals [14] (Fig. 5). The Water Basin Adminstrations have only the role of control and issuance of operating permits. The current administrators sometimes do not respect the correct way of operation, but also of monitoring the structural parameters at the earth dams, according to the technical regulations in România.

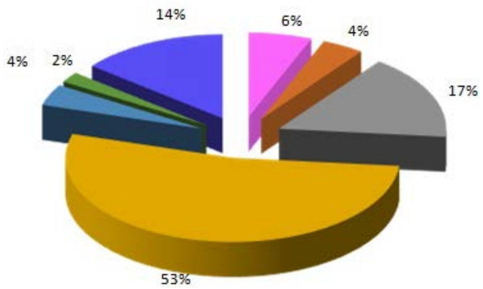


Figure 5 – Distribution of dams in Moldova (C and D category) on administrators: ABA Prut - Barlad – 6%; ABA Siret – 4 %; Companies – 53%: PFA – 17%; UAT – 14%; monasteries – 4%; Hydroelectric Company – 2% [15]

The research carried out followed the evolution in time of the topology of the Podisu earth dam. This was done by processing the documentary data and those taken from the field and introducing them in a comparative analysis over time. The data known from the documentation required the choice of only three characteristic sections of the dam: in the central axis and in the drain section. The purpose of tracking the topological parameters of the earth dam is to verify its stability over time to various actions at the site (floods, earthquakes, landslides and so on).

The cross section of the dam is trapezoidal and trafficable crest (Fig. 6). The earth dam is of the homogeneous type, with a length of 167,27 m, a crest width of 4,5 m and a heigh of 4,00 m. The slope of the upstream slope is 1:1 and the downstream slope is 1:2. The upstream slope is protected with a layer of stone and the downstream slope with grass [14], [3]. The Podisu earth dam has been completely destroyed by the flood since 1970. The earth dam was rebuilt in 1977 using local materials to restore the dam body.

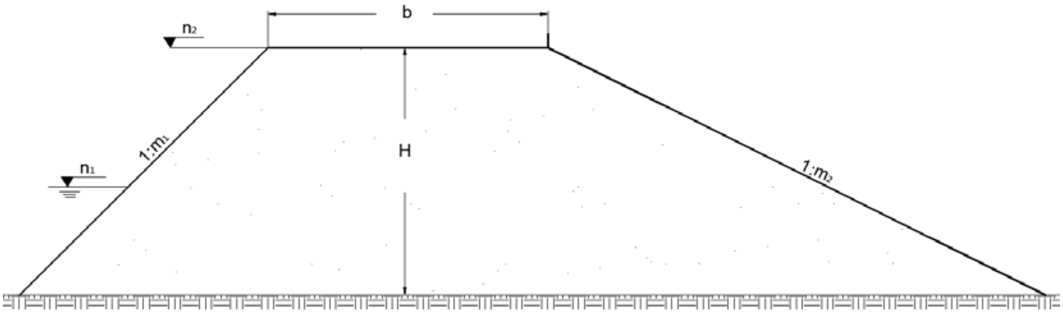


Figure 6 – Characteristics of the designed cross section of the Podisu earth dam: b – the crest width; H – the height of the dam; m_1 = 1 – the slope of the upstream slope; m_2 = 2 – the slope of the downstream slope; n_1 - minimum level of operation; n_2 - maximum level of operation;.

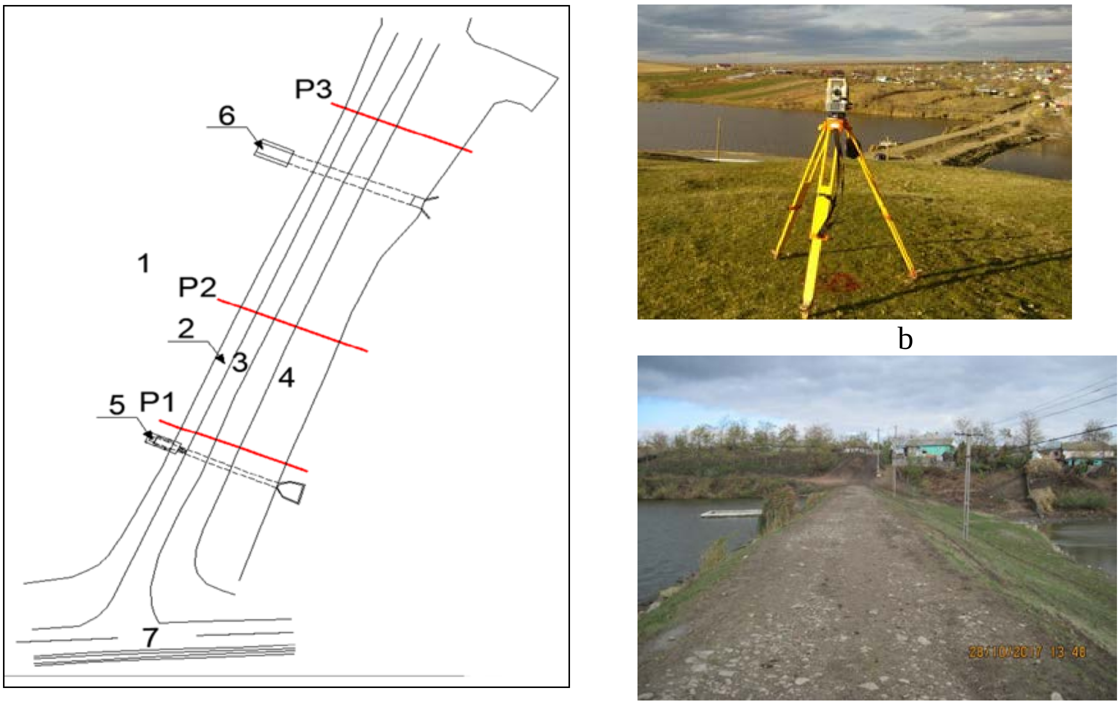
The dam was verified by technical expertise works in 2006 and 2018 [14]. Between 2020 and 2021, geodetic measurements were carried out on the dam as part of a complex research program. Geodetic measurements used GNSS technology. By processing the data from the measurements, the situation plan, transversal profiles and the longitudinal profile of the dam were obtained. The geometric data obtained were used in a comparative analysis of the evolution in time of the dam shape and the characteristic geometric parameters of the dam.

In 2006, according to the expertise made by [14], three transversal profiles were determined corresponding to the characteristic sections of the dam: area of the C1 discharger (profile $P_{t,1}$), the central area of the dam (master section – profile $P_{t,2}$) and the marginal area near the C2 discharger (profile $P_{t,3}$). The measurements regarding the topology of the dam, carried out in 2021 were performed on these threee characteristic profiles, but also on a series of intermediate profiles considered at the dam. GNSS technology was used to make the measurements, which allows fast measurements. The situation plan (Fig 7) made after processing the measurements indicate the components of the earth dam and the location of the three main characteristic sections studied.

By processing the results of geodetic measurements (Table 1) and after the graphic representation, the cross-section profile in characteristic sections and the longitudinal profile of the dam were obtained. Characteristic sections for cross-sections ($P_{t,i}$) were placed on the dam body from right to left.

Table 1 – Processed coordinates for control points on the crest in July 2021 (partial data)

Point	Processed coordinates		
	X (m)	**Y** (m)	**Z** (m)
$P_{t,1}$	641266.300	656107.800	87.946
$P_{t,2}$	641294.900	656119.751	87.928
$P_{t,3}$	641323.800	656131.968	87.859



b

a c

Figure 7 – Location of cross-section profiles (year 2021): a – situation plan of the dam, 1 – storage lake; 2, 4 – downstream and upstream slope; 3 – crest; 5 – C1 discharger; 6 – C2 discharger; 7 – road; $P_{t,1}$, $P_{t,2}$ $P_{t,3}$ – the cross profile; b – general view of the hydrotechnical accumulation; c – the crest of the dam (source: author).

For the comparative analysis, three charactersitics profiles were selected for which a series of data were found in the analyzed documentary studies [14]. The studied profiles were noted and have the positions : $P_{t,1}$ – small and medium water discharger area; $P_{t,2}$ – The central axis of the dam; $P_{t,3}$ – high water discharger area (Fig. 7).

The analysis was performed by analytical comparison of the values of geodetic measurements at various time intervals. The profiles of the cross sections of the dam were also analyzed through graphs ($P_{t,1}$, $P_{t,2}$ și $P_{t,3}$) considered to be characteristic.

The main results obtained regarding the topology of the Podisu earth dam are the following:

- The cross section of the dam has changed as a geometric shape compared to the one designed in 1963, but also as dimensions, according to the topological data determined in 2006 and 2021, respectively.
- The trapezoidal shape in the central section of the dam has been transformed into a mixed-trapezoidal shape by the appearance of a berm on the downstream slope (Fig. 8). The berm continues on the downstream with varying widths and different downstream slopes.
- The width of the berm varies along the length of the dam from 3.63 m in $P_{t,1}$ profile up to 3,80 m and respectively 4.07 m in $P_{t,2}$ and $P_{t,3}$ profiles.
- The width of the crest is variable in time along the length of the dam, situation confirmed by studies and measurements performed. The width variation is also present from one profile to another. The research highlighted the following aspects:
- 1. For the $P_{t,1}$ profile width value changed from 4.50 m in 1963 to 4.35 m in 2006 and then to 4.31 m in 2021 (Fig. 8).

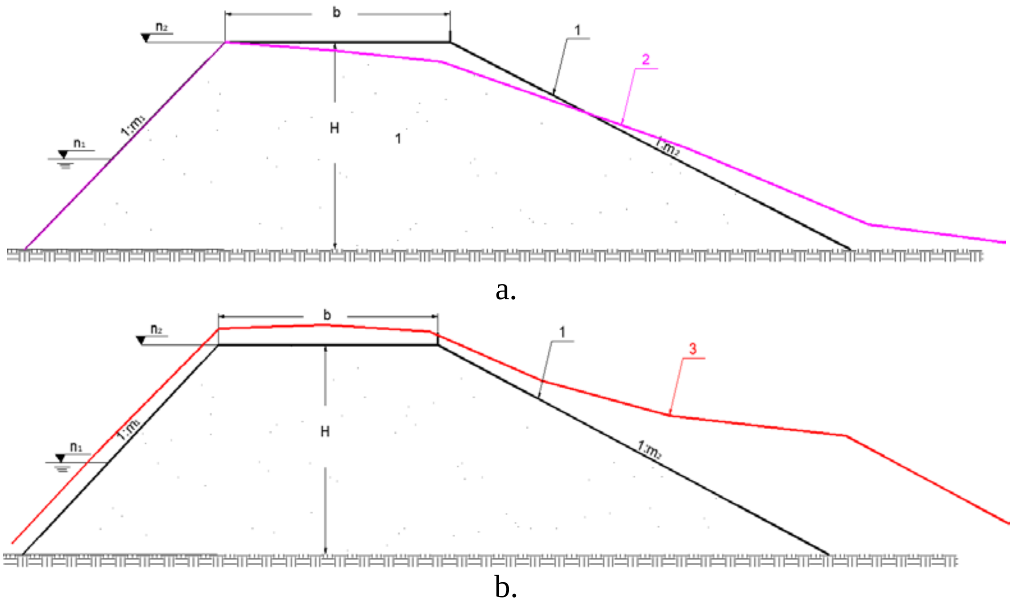


Figure 8 – The cross section profile $P_{t,1}$: a – The cross section profile designed and executed, 1 - in 1963, 2 – cross section profile measured in 2006; b, 3 - cross section profile measured in 2021.

2. For the $P_{t,2}$ profile width value changed from 4.50 m in 1963 to 4.01 m in 2006 and then to 4.02 m in 2021 (Fig. 9).

3. For the $P_{t,3}$ profile width value changed from 4.50 m in 1963 to 3.82 m in 2006 and then to 4.46 m in 2021 (Fig. 10).

- The research carried out on the topology of the upstream slope of the earth dam revealed the following:

  1. The upstream slope has remained the same 1:1 slope from the execution until now.
  2. The shape of the upstream slope, verified by measurements in 2006, is the same as originally designed.
  3. However, in 2021 there will be a slight change in the slope from 1:1 to 1: 0.9 in the $P_{t,3}$ profile.
  4. From the analysis of the data in the figures 8b, 9b, 10b, the consolidation of the upstream slope is highlighted by its uplift (placement of stones with a growing role and ensuring the stability of the slope, but also protection against the action of water).

- The research carried out on the condition of the heigh of the dam highlighted the following:

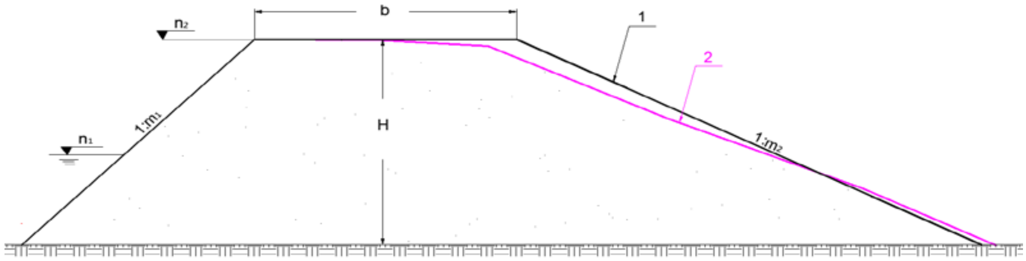
1. Dam heigh according to $P_{t,1}$ profile data indicates a change in value from 4.00 m (projected value) to 3.62 m in 2006 (settlement phenomenon, but also wind erosion). In 2021 has been measured a heigh of 4.35 m, value obtained by filling and consolidating the dam (Fig. 8).

2. Dam height according to $P_{t,2}$ profile data indicates a change from 4,0 m to 3.87 m in 2006 (settlement phenomenon) and an average of 4,32 m in 2021 through filling and consolidation works (Fig. 9).

3. Dam height according to $P_{t,3}$ profile data indicates a change from 4,0 m designed to 3.78 m in 2006 (settlement phenomenon) and an average of 4,43 m in 2021 through filling and consolidation works (Fig. 10).

- The research carried out on the topology of the downstream slope of Podisu earth dam (Fig. 11.b) highlighted the following:

- 1. The downstream slope of the dam was designed with a slope of 1:2. Measurements carried out in 2006 showed a change in the slope through settlement processes. This situation is highlighted in $P_{t,1}$ and $P_{t,2}$ profiles.
- 2. In 2021 a berm was also found in the $P_{t,3}$ profile.
- 3. In 2021 the downstream slope was modified by embankment filling works and the berm was thus strengthened.



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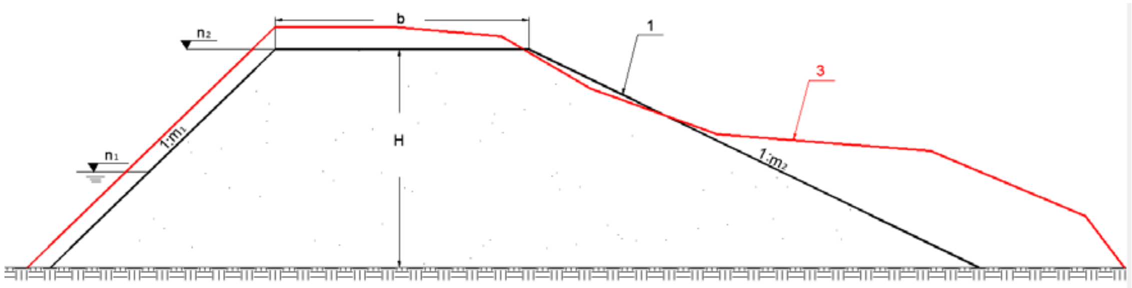
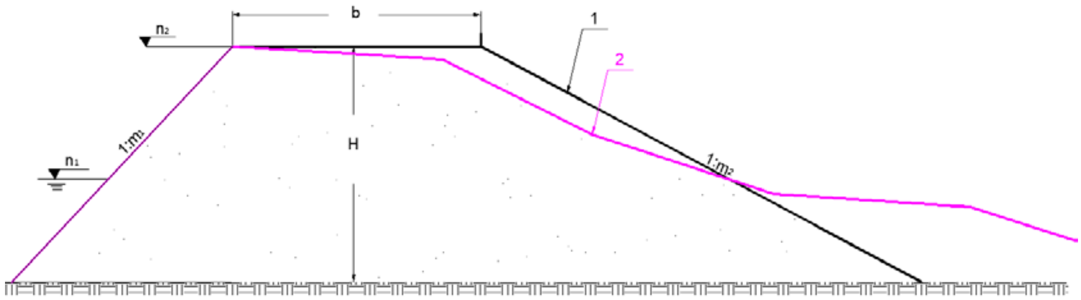
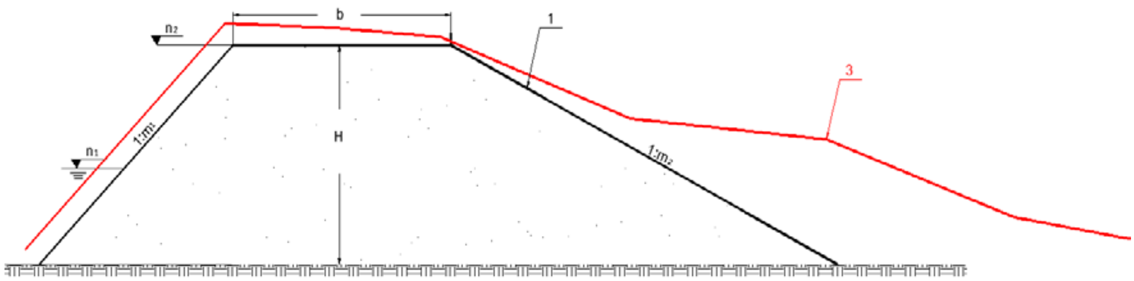


b.

Figure 9 – Cross section $P_{t,2}$ profile: a - The cross section profile designed and executed, 1 - in 1963, 2 – cross section profile measured in 2006; b, 3 - cross section profile measured in 2021.



a.



b.

Figure 10 – Cross section $P_{t,3}$ profile: a - The cross section profile designed and executed, 1 - in 1963, 2 – cross section profile measured in 2006; b, 3 - cross section profile measured in 2021.

a b

Figure 11 – The condition of the slopes at Podisu dam in 2021: a – upstream slope; b – downstream slope (source: author).

- The research carried out no the longitudinal profile of the Podisu earth dam revealed a change in its position in the vertical plane. The longitudinal profile shows a decrease in the elevation of the central area of the dam crest in 2006. This displacement has been remedied, so that the measurements from 2021 showed an approximation of the profile to the horizontal position.

The hydrotechnical arrangement containing the Podisu earth dam was chosen from a number of eight existing arrangements on the Sheep Valley River. The selection was given by existence of technical documentation containing a minimum of characteristic data of the hydrotechnical arrangement.

The results obtained through documentary and field research confirm the need for topographic studies to highlight the topology of the dam, over time, during the exploitation period. Changing the topology of the dam indicates the need for a stability calculation.

Checking the topology of the dam by classical geodetic measurements allows obtaining a correct image of the geometric parameters (millimetre accuracy). But this method of measurement has a disadvantage of a long time for retrieving and processing data by laborious calculations. GNSS technology, on the other hand, allows fast data retrieval in a much shorter time and at a relatively lower cost. The research showed the applicability of GNSS technology to perform rapid measurements in order to obtain data on the topology of the earth dams.

4. Conclusions

The RTK real-time measurement method determines the coordinates and displays them during the measurements. The measurement method allows a fast calculation of the coordinates and the accuracy of the horizontal and vertical determinations is 0.8-1.5 cm.

Research has shown that the Podisu earth dam has changed its topology over time, from 1963 to 2021, through flood degradation, wind erosion and filling earthworks to ensure stability.

The research carried out showed a change in the geometric parameters of the dam crest from 1963 to 2021, where the width has decreased from 3.82 to 4,35 in 2006, and then return to 4,50 m in 2021 through works to restor and consolidate the shape of the dam.

The upstream slope remained with the slope of 1:1 from 1963 to 2006. In 2021 there is an increase in it by filling it with stone in order to ensure the stability of the slope.

The downstream slope was mostly modified as shape and constructive parameters during the operation period (1963 - 2021). Its linear, continous shape has been transformed into a broken line with the appearance of a berm. The downstream slope was 1:2 in 1963 and then 1:2.4 in 2021.

The research confirms the viability of GNSS technology to perform rapid measurements for a preliminary assessment of the topology of category C and D dams in order to obtain the data necessary to analyze the stability of the dam.

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