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Monitoring the vertical and horizontal displacements of the Poiana Mărului dam

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Abstract
This study presents the main steps that are needed in order to realise the monitoring of hydrotechnical constructions. The subject of this study is the Poiana Marului dam, situated on the BistraMarului River.
The geometric levelling and also the microtriangulation and microtrilateration topographical measurements on the dam were made in two stages, at a six months interval. All these measurements represent the only external verification that emphasize, with a high accuracy level, the vertical and horizontal displacements that occur in the structure of the dam.

Keywords:
Dam, Geometric Levelling, Altitude, Displacements

1. Introduction

The monitoring of the constructions' behavior over time occurred due to the need to obtain information about the real state of a structure, to observe its evolution and to detect the occurrence of new degradations.
The monitoring of the hydrotechnical constructions' behavior takes place throughout the life of the hydrotechnical construction and has as a main role the maintenance of their safety and functionality in order to avoid the potential danger that these constructions represent for the settlements downstream (human but also significant material losses) .

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Due to the succession of rainy years and also to the sudden warming of spring in the Banat Mountains, exceptional amounts of rainfall overlapped the melting season, resulting in floods with catastrophic effects on most of the rivers in Caraş-Severin County. In order to reduce the damaging effects of the water, there were carried out works of regularization and embankment of the riverbeds. Thus, a complex fitting out program was developed to ensure the protection of the localities and economic objectives along the main watercourses in the county. [1]
Located on the BistraMărului River, a tributary of the Bistra River, the Poiana Mărului Dam (Fig.1) is part of the Bistra-Poiana Mărului-Ruieni-Poiana Ruscă hydropower plant, being put into operation for the first time in 1992. [2]

Fig. 1 The location of the Poiana Marului dam

This fitting out includes the Poiana Mărului and Poiana Ruscă dams, and the Ruieni and Râul Alb hydroelectric plants, as well as the secondary adduction Bistra - Lac Poiana Mărului (16.902m), which ensures the accumulation of water flows (1.66 m³/s) from adjacent basins (the 5 secondary water captures: Bistra, Lupului, Bucova, Marga and Niermeş). Thus, a surface accumulation of 125 ha was obtained at the normal retention level (620 mdM) with a total volume of 96.2 mil m³. [2]
The dam of Poiana Mărului is a dam built from rockfills with clay core. The elevation of the dam crowning is of 625 m, with a maximum height of 125 m, a base width of 448 m, its total length being 408 m. The narrow area of the quays

bounded by the downstream river elbow and the change of orientation of the right slope and, upstream, the widening of the valley imposed the location of the dam. [2]
The Poiana Mărului dam is located about 25 km away from the town OţelulRoşu and captures the waters of a 204 km² basin. The access to this objective is achieved through the county road DJ 683 Zăvoi - Măru - Poiana Mărului, which connects the town of OţelulRoşu with the tourist resort Poiana Mărului. [2]
Periodic monitoring of the constructions is carried out continuously assessing the safety status of the hydrotechnical objective by conducting geometric mean levelling measurements for observing possible vertical displacements, as well as microtriangulation measurements to determine the horizontal displacements undergone. These methods allow detection of safety deficiencies and the intervention by structural and/or non-structural measures to prevent the development of atypical phenomena or behaviors.

2. Methodology

2.1. Performing the measurements necessary to determine vertical and plane displacements

2.1.1. Performing geometric mean levelling measurements

The altimetric monitoring network for the constructions of the hydroelectric power plant Poiana Marului is made up of 8 fundamental bench marks: RNSTC1 and RNSTC2, located near the dam keeper`s house, RN605S and RN605D, on berm 605, RN585S, on berm 585, RN565D, on berm 565, RN545S and RN545D located on berm 545m and 48 monitoring bench marks, located on the downstream berms of the dam, on the crowning respectively (***Fig. 2***). Out of these, the fundamental bench marks RN585S and RN545D were not identified in the field because either they were destroyed, covered or inaccessible.

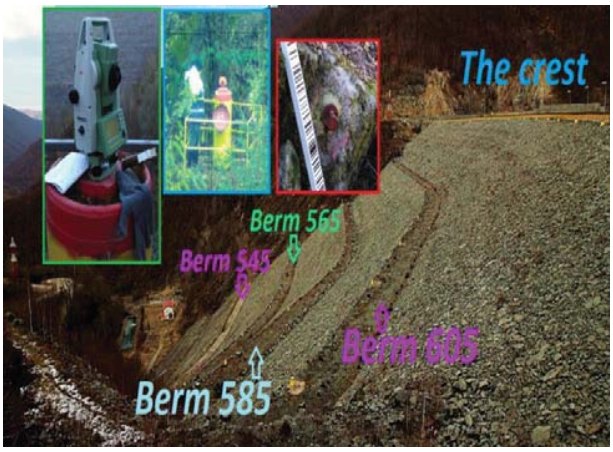

Fig. 2 The crest and the 4 berms

For the levelling measurements, the Leica digital level 250M, 3 m fibre glass barcode staff were used, the precision being ± 0.7 mm/double km of levelling.
To detect the vertical displacements, the geometric levelling with two horizons, was chosen as a method of measurement.
The measurements were made by the same operator, with the same instrument and staff set. The readings on the staffs were performed so that the settling error of the instrument and of the staffs was eliminated (Back-Front-Front-Back method). The degradation error of the staffs' soles was also eliminated, beginning and ending the traverse with the same staff, and the spans had lengths of less than 25 m. No measurements were made when the mirage phenomenon occurred, when the lighting conditions were low or the humidity level was high

2.1.2. Realizing themictrotriangulation measurements

The microtriangulation network consists of six pilasters B1, B6N, B7 and B8 left bank; two pilasters B4, B5 - right bank and 39 monitoring marks (***Fig. 3***).
The type of pilasters is cylindrical, with Wild type force centering devices, not protected by thermal insulation.
The access to the pilasters and berm marks was properly done, except for pillars B1, B6N and B7. At these pilasters the access was difficult because of the absence of the road, the access to them could only be made through the swamp or on steep slopes.
The monitoringplanimetric network is distributed as follows:

- 12 marks numbered from R37 to R47 are located on the crowning, on the downstream side.
- 10 marks numbered from R27 to R36 on the berm at elevation 605,
- 6 marks denoted from R10 to R15 on the berm at elevation 585,
- 6 marks denoted from R16 to R21 on the berm at elevation 565,
- 5 marks denoted from R22 to R26 on the berm at elevation 545.

Fig. 3 Pilasters and monitoring markers

For the microtriangulation stage, the measurements were performed with the TS 06 Plus total station produced by Leica, which provides a 1" precision in determinig the directions.
The measurement method used for microtriangulation was the method of the series, from each stationed pilaster being made 4 series of measurements.
As in the case of the geometric levelling, the measurements were performed by the same operator, with the same device and under optimum temperature, lighting and humidity conditions.

2.2. Processing of measurements to determine vertical and planimetric displacements

In order to determine the fundamental fixed bench marks, the network they are forming was compensated as being free, and at the end the global congruence test was applied, together with the statistical Fischer test, to determine the existence of the displacements, and the Student test for locating the eventual displacements.
In order to determine the elevations of the bench marks set on the crowning, a traverse levelling closed on the starting point was made, considering the bench mark RN 605D, on the berm 605, as being fixed. To determine the elevations of the monitoringbench marks located on the berms 605 and 585, the fundamental bench marks RN605S and RN605D were considered as being fixed, for the berm 565 - the bench mark RN565D, and for berm 545 – the bench mark 545S.
The compensation of the levelling network was achieved by the conditional measurements method, proceeding identically for both periods (October 2016 and April 2017).
The compensation of the microtriangulation network was done in block, using the leasts square method. Prior to the compensation, stable pilasters were identified by applying the statistical tests used in the geometric levelling.
The constraint of the microtriangulation network was made on pilasters B4, B6N, B7 and B8.

3. Results

Table 1 shows the values of the vertical displacements in relation to period 0, but also between the two measurement periods.

Tabel 1 Vertical displacements

	POIANA MARULUI DAM					Oct. 2016 - Apr. 2017 [mm]
	Differences between the current and main stage[mm]					
NAME OF CONSTR.	**NO. OF MARKER**	**ELEVATION 0 [m]**	**Oct. 2016**	**Apr. 2017**	**Obs.**	
BERM 545	RN545 D	546.4640	-	-	not found	
	RN545S	539.1974	0	0	stable	
	RN1-22	545.7570	-108.0	-107.5		**0.4**
	RN1-23	545.5310	-181.5	-181.1		**0.4**
	RN1-24	545.4890	-110.0	-109.5		**0.5**
	RN1-25	545.6560	-131.2	-130.1		**1.2**
	RN1-26	545.7970	-40.4	-38.6		**1.8**
	FH1	545.8150	-	-	not found	
	FH3	546.7980	-	-	not found	
BERM 565	RN565 D	565.9916	0	0	fix	
	RN2-16	565.1620	-48.6	-49.8		**-1.2**
	RN2-17	565.2430	-163.2	-165.7		**-2.4**
	RN2-18	565.0240	-161.2	-165.0		**-3.7**
	RN2-19	565.2550	-176.2	-180.1		**-3.9**
	RN2-20	565.1280	-117.6	-120.8		**-3.2**
	RN2-21	565.5320	-66.5	-68.2		**-1.7**
BERM 585	RN585S	590.8540	-	-	not found	
	RN3-10	585.8720	-200.6	-207.4		**-6.7**
	RN3-11	585.4550	-197.8	-202.9		**-5.2**
	RN3-12	585.4700	-196.8	-201.3		**-4.5**
	RN3-13	585.4390	-276.9	-281.1		**-4.2**
	RN3-14	585.6090	-233.3	-238.3		**-4.9**
	RN3-15	585.8000	-206.8	-213.8		**-7.0**
	FH11	587.6700	-	-	not found	
	FH2	586.6440	-	-	not found	
BERM 605	RN605S	604.7008	0	0	fix	
	RN4-36	605.8790	-128.8	-130.5		**-1.7**
	RN4-35	605.1640	-242.4	-246.1		**-3.7**
	RN4-34	604.9140	-299.0	-303.9		**-4.9**
	RN4-33	604.8970	-309.0	-314.4		**-5.4**
	RN4-32	604.9880	-366.7	-372.3		**-5.6**
	RN4-31	604.7460	-366.7	-372.0		**-5.3**
	RN4-30	604.8000	-348.6	-353.8		**-5.1**
	RN4-29	604.9720	-344.1	-348.0		**-3.9**
	RN4-28	604.9230	-240.0	-242.0		**-1.9**
	RN4-27	605.2390	-86.4	-84.8		**1.6**
	RN605 D	607.4350	0	0	fix	
	FH12	605.2730	-	-	not found	
	FH13	605.4460	-	-	not found	
DAM CROWNING	RN5-37	625.2540	-169.2	-177.0		**-7.7**
	RN5-38	625.7090	-260.5	-267.2		**-6.6**
	RN5-39	625.9890	-276.7	-284.5		**-7.8**
	RN5-40	625.9090	-279.6	-286.6		**-7.0**
	RN5-41	625.9790	-258.5	-265.5		**-7.0**
	RN5-42	626.0190	-372.3	-382.2		**-10.0**
	RN5-43	625.9810	-355.7	-364.2		**-8.5**
	RN5-44	625.7910	-338.6	-347.8		**-9.2**
	RN5-45	625.6640	-284.7	-292.9		**-8.2**
	RN5-46	625.4500	-214.9	-221.9		**-7.0**
	RN5-47	625.2720	-105.2	-112.3		**-7.1**
	RN5-48	625.1750	-17.1	-23.7		**-6.7**

The vertical displacements of the last 5 periods are represented graphically (***Fig. 4***).

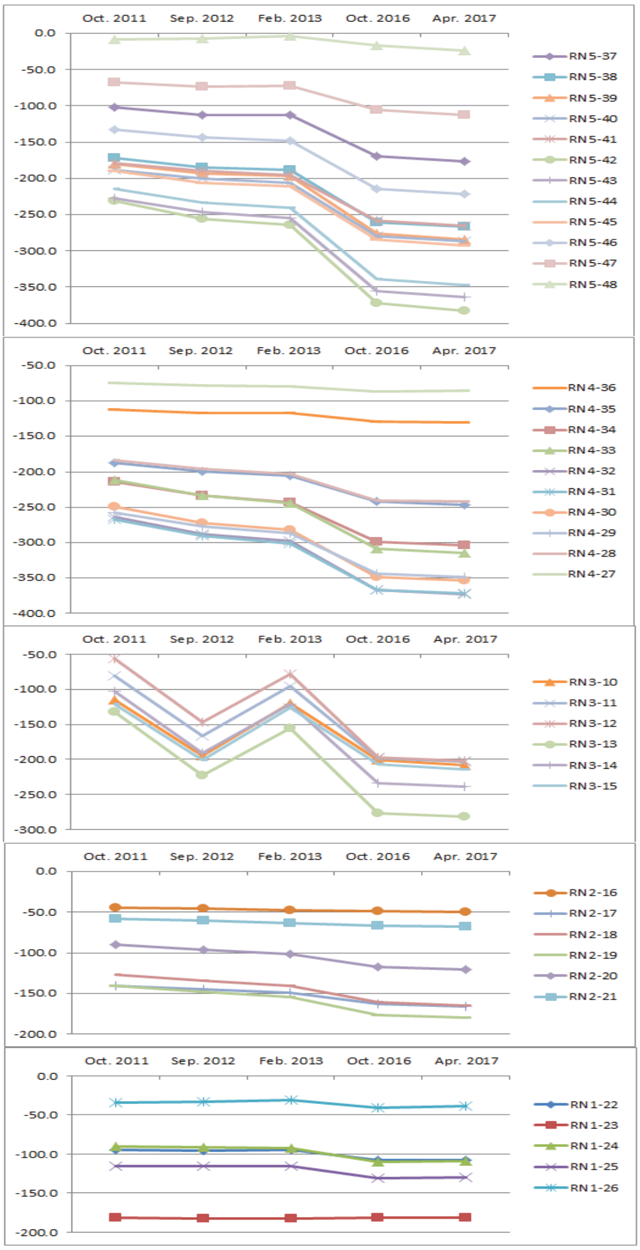

Fig. 4 Vertical displacements in realtion to period 0 of the last 5 measurement periods

Table 2 shows the horizontal displacements in relation to the period 0 of the 2 periods but also the planimetric displacements between the two periods(November 2016 and April 2017).

Axis X is oriented to the right bank and the Y axis upstream, so the positive displacements will be upstream and towards the right bank.

Tabel 2 Horizontal displacements

FOLLOW UP OF THE BEHAVIOR OF THE HYDROTECHNICAL CONSTRUCTIONS								
PLANIMETRIC DISPLACEMENTS Poiana Mărului								
Type	**Name**	**PeriodNoiembrie 2016**		**PeriodAprilie 2017**		**Displacements 2016 -2017**		**Obs.**
		L-R-DR	**AV-AM**	**L-R**	**AV-AM**	**L-R**	**AV-AM**	
		2016 Δx [mm]	**2016 Δy [mm]**	**2017 Δx [mm]**	**2017 Δy [mm]**	**2016 - 2017 Δx [mm]**	**2016 - 2017 Δy [mm]**	
PILASTERS	B1	14.2	0.7	14.7	-4.9	**0.5**	**-5.6**	
	B2	0	0	0.9	-14.7	**0.9**	**-14.7**	
	B4	0	0	0	0	**0**	**0**	**fixed**
	B5	6.1	-3.4	-6	-3.3	**-12.1**	**0.1**	
	B6	-10	4	-9.3	0.3	**0.7**	**-3.7**	
	B6N	0	0	0	0	**0**	**0**	**fixed**
	B7	0	0	0	0	**0**	**0**	**fixed**
	B8	0	0	0	0	**0**	**0**	**fixed**
MONITORING MARKERS	R10	41.8	-49	40.2	-65.9	**-1.6**	**-16.9**	
	R11	40	-62.1	39.5	-78.5	**-0.5**	**-16.4**	
	R12	44.8	-48.5	38.2	-61.8	**-6.6**	**-13.3**	
	R13	21.2	-36.9	15	-48.4	**-6.2**	**-11.5**	
	R14	-66.5	-73.3	-74.1	-84	**-7.6**	**-10.7**	
	R15	-56.4	-57.5	-58.2	-64.1	**-1.8**	**-6.6**	
	R16	-59.6	-69.2	-68.2	-72.5	**-8.6**	**-3.3**	
	R17	-68.7	-85.9	-72.2	-87	**-3.5**	**-1.1**	
	R18	-45.8	-60.4	-52.4	-72.8	**-6.6**	**-12.4**	
	R19	23.8	-60.2	18.2	-68.2	**-5.6**	**-8**	
	R20	77.7	-62.7	78.6	-75.4	**0.9**	**-12.7**	
	R21	55.5	-62.6	55.2	-67.5	**-0.3**	**-4.9**	
	R22	-17.5	-77.2	-18	-77.5	**-0.5**	**-0.3**	
	R23	63	-67.4	52.4	-74.3	**-10.6**	**-6.9**	
	R24	-56.3	-53.5	-60.9	-65.4	**-4.6**	**-11.9**	
	R25	-17.4	-79.7	-28	-93	**-10.6**	**-13.3**	
	R26	-51.6	-80.3	-51.3	-85.4	**0.3**	**-5.1**	
	R27							**not found**
	R28	-78.6	-68.8	-86.7	-74.5	**-8.1**	**-5.7**	
	R29							**not found**
	R30	-30.4	-81.9	-37.6	-100.8	**-7.2**	**-18.9**	
	R31	-39.2	-60	-38.5	-76.6	**0.7**	**-16.6**	
	R32	56.2	-65.5	51.2	-84.2	**-5**	**-18.7**	
	R33	68.9	-49.8	71.9	-68.9	**3**	**-19.1**	
	R34	28.9	-50.5	34.1	-68.5	**5.2**	**-18**	
	R35	72.9	-44	73.2	-59.6	**0.3**	**-15.6**	
	R36	75.3	-61.8	75.8	-73	**0.5**	**-11.2**	
	R37	-50.8	-26.7	-65.1	-25.8	**-14.3**	**0.9**	
	R38	-51.1	-43	-58	-52.5	**-6.9**	**-9.5**	
	R39	-26.7	-69.9	-35.4	-71.9	**-8.7**	**-2**	
	R40	-13	-64.7	-21.1	-77.4	**-8.1**	**-12.7**	
	R41	-7.6	-73.1	-8.2	-87.5	**-0.6**	**-14.4**	
	R42	-1.6	-85.8	-7.5	-102.5	**-5.9**	**-16.7**	
	R43	46.8	-90.7	48.2	-92	**1.4**	**-1.3**	
	R44	27.1	-66.9	32.1	-51.5	**5**	**15.4**	
	R45	76.7	-72	77.8	-79.1	**1.1**	**-7.1**	
	R46	87.3	-67	90.4	-74.6	**3.1**	**-7.6**	
	R47	80	-77.2	83.5	-88.9	**3.5**	**-11.7**	
	R48	57.2	-70.9	56.6	-71.7	**-0.6**	**-0.8**	

4. Conclusions

The determination of the horizontal and vertical displacements of hydrotechnical constructions by topo-geodetic methods is the external verification of the stability and integrity of the structure and foundation ground. For this, the position of certain points fixed on the construction (monitoring bench marks, monitoring marks) is reported at a series of fixed points (fundamental bench marks, pilasters) located outside the area of influence of the factors acting on the constructions and on the lands on which they are located.

For periodic maintenance of the monitoring network, it is recommended:

- verification of the access to the pilasters, of the fundamental bench marks and monitoring marks;
- deforestation of vegetation that obstructs the sights;
- verification of the forced centering systems;
- verification of the integrity of the pilasters, monitoringbench marks, fundamental and monitoring marks.

The orientation of the axis of the local coordinate system for the microtriangulation network does not correspond to the existing meaning and signs convention in the domain of elasticity and strength of materials, construction statistics, hydraulics, because the X axis is not oriented on the downstream-upstream direction and the Y axis toward the left bank.

The maximum displacements determined within the altimetricmonitoring network between the two measurement periods are illustrated below:

1.8 mm (swelling) for bench mark RN1-26 (berm 545)
-3.9 mm (settling) for bench mark RN2-19 (berm 565)
-7.0 mm (settling) for bench mark RN3-15 (berm 585)
-5.6 mm (settling) for the bench mark RN4-32 (berm 605)
-10.0 mm (settling) for the bench mark RN5-42 (crowning)

Between the two stages in the planimetric monitoring network the following maximum displacements can be observed:

- Axis X: -14.3 mm for mark R37 (towards left bank);
- Axis Y: -19.1 mm for mark R33 (downstream).

Analyzing the displacements obtained both horizontally and vertically, within the two periods of the measurements, we can conclude that the dam of Poiana Marului did not suffer significant deformations, its permanent monitoring leading to exploitation in maximum safety conditions, without risk of accidents.

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