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MONITORING OF THE DEPOSIT DISPLACEMENTS AND THE SETTLEMENT BEHAVIOR IN SIMIONEŞTI VILLAGE LOCATION, CORDUN COMMUNE, NEAMŢ COUNTY

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Abstract: *Monitoring the displacements and settlements of tailings deposits is necessary due to stability problems that may arise over time. The paper deals with the monitoring by means of topographical measurements of two tailings deposits located on a site in Simioneşti village, Cordun commune in Neamţ county. Topographic measurements are used to monitor the movement of landmarks located on these deposits and the settlement behavior of the deposit, so that any stability problems can be detected in time.*
Keywords: *deposit stability monitoring, surveying of settlement and displacement*

1. General information

Monitoring the movements and settlements of tailings deposits is necessary due to problems that may arise over time.

Problems and hazards associated with tailings deposits include the following [1, 2]:

- slope instability;
- the generation of acidic waters and the discharge of toxic substances, leading to the contamination of surface and underground waters downstream;
- dust pollution and erosion;
- land degradation.

In view of these environmental hazards, rehabilitation measures aim to [1, 2]:

- improving the stability of landfills;
- ensuring stability against erosion;
- minimizing the degree of infiltration;
- reducing the effects generated by acidic waters and reducing the flow of exfiltrates.

The present paper deals with the monitoring by means of topographical measurements of two tailings deposits located on a site in Simioneşti village, Cordun commune in Neamţ county.

An aerial view of the studied site from Simioneşti village is presented below. The two deposits taken into the study are represented with a red outline. On the site, there are still two areas in preparation where other deposits will be created in the future.

2. Preparing and carrying out topographic measurements

Landmarks were placed on the tailings deposits to track the behavior over time, materialized through Feno landmarks, one marker in the corner areas of the deposits, and one marker in the center of the deposits. We note that the upper part of the deposits is a flat and almost horizontal surface, covered with topsoil and grass, so that there is good visibility between the monitoring landmarks.

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Figure 1. The location of the studied deposits, in Simionești village, Cordun commune (source: Google Earth)

Also, to ensure a unique and stable reference system from one stage to another of measurements, a topographic support base was placed outside the area of influence of the deposits, consisting of two points that were determined by GNSS measurements [3], marked on plan with GPS-1 and GPS-2. Their coordinates were transcalculated in the Stereografic 1970 projection system with the TransDatRO application [4], and the elevations in the Black Sea 1975 altimetric system. The Stonex S9 GNSS receiver was used with the TransDatRO application implemented.

At each stage of measurements it started from the two stable points. The initial stage of measurements was carried out in October 2016 (also called "zero measurement"), denoted T_0. Subsequently, each year during the month of October, a measurement session was carried out, respectively in 2017 stage T_1, in 2018 stage T_2, in 2019 stage T_3, in 2020 stage T_4, in 2021 stage T_5 and in 2022 stage T_6.

Equipment used: A Leica TCR 407 power total station was used for the topographic measurements and the construction of the polygonal network.

In each measurement session, a closed polygonal network [5] was carried out on the two stable landmarks, GPS-1 and GPS-2, at the same time determining the coordinates and elevations of the 10 monitoring landmarks.

The processing of conventional measurements was carried out using spreadsheet programs [6], and the drawing up of the situation plan and other graphic representations was done using computer-aided design programs [6].

3. Calculation of displacement and settlement elements and preparation of the situation plan

To exemplify the calculations performed at each measurement stage, we will calculate the displacement and settlement elements for the October 2022 (T_6) measurement, relative to the October 2016 (T_0) zero measurement.

The plane coordinates and elevations of the landmark points from the T_0 measurement stage carried out in 2016, used for reference, are presented in table 1.

The plane coordinates and elevations of the landmark points from the T_6 measurement stage carried out in 2022 are presented in table 2.

Following the comparison of the plan (2D) and altimetric (H) coordinates of the monitoring landmarks from the 2022 stage compared to the 2016 stage, the displacements in the directions of the East and North coordinate axes (ΔE and ΔN) as well as the vertical displacements (settlements ΔH) are presented in table 3.

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Table 1. „Zero" Measurement 2016 (t_0)

Landmark	Easting [m]	Northing [m]	Elevation H [m]
GPS-1	642136.593	609148.189	200.652
GPS-2	642113.052	609093.049	199.430
PM-1	642036.524	609050.114	199.826
PM-2	642155.842	609016.791	200.431
PM-3	642068.999	609053.181	200.169
PM-4	642097.398	609069.310	199.841
PM-5	642118.876	609064.154	199.742
PM-6	642029.405	609070.120	199.496
PM-7	642092.476	609034.051	199.953
PM-8	642098.306	608971.477	198.631
PM-9	642203.122	608950.758	198.610
PM-10	642231.561	609053.389	199.416

Table 2. Measurement 2022 (t_6)

Landmark	Easting [m]	Northing [m]	Elevation H [m]
GPS-1	642136.593	609148.189	200.652
GPS-2	642113.052	609093.049	199.430
PM-1	642036.533	609050.111	199.821
PM-2	642155.853	609016.802	200.417
PM-3	642069.006	609053.183	200.167
PM-4	642097.403	609069.310	199.837
PM-5	642118.881	609064.159	199.735
PM-6	642029.408	609070.113	199.494
PM-7	642092.480	609034.053	199.946
PM-8	642098.316	608971.480	198.624
PM-9	642203.145	608950.772	198.601
PM-10	642231.565	609053.414	199.360

Table 3. Differences 2022 stage compared to the 2016 stage

Landmark	ΔE (t_6-t_0) [m] (dif. Easting)	ΔN (t_6-t_0) [m] (dif. Northing)	ΔH (t_6-t_0) [m] (Settlement)
PM-1	0.009	-0.003	-0.005
PM-2	0.011	0.011	-0.014
PM-3	0.007	0.002	-0.002
PM-4	0.005	0.000	-0.004
PM-5	0.005	0.005	-0.007
PM-6	0.003	-0.007	-0.002
PM-7	0.004	0.002	-0.007
PM-8	0.010	0.003	-0.007
PM-9	0.023	0.014	-0.009
PM-10	0.004	0.025	-0.056

where:

t_0 represents the stage of measurements carried out in 2016;

t_6 represents the stage of measurements carried out in 2022;

ΔE, ΔN, ΔH represent the differences in coordinates and elevations between the stages of measurements.

Based on these differences in coordinates and elevations, the displacement vectors of the monitoring points were calculated in the horizontal plane, and the direction (azimuth) in which the displacement was made. Also, for the complete characterization of the displacements, the size of the spatial displacement vectors (3D) and their inclination with respect to the horizontal was calculated, as shown in the following table [5, 6]:

Table 4. Displacement vectors of landmarks

Landmark	Horizontal Displacement [m]	Displacement Azimuth [°]	Vertical Displacement [m]	3D Total Displacement [m]	Displacement Tilt [°]
PM-1	0.010	105.50	-0.005	0.011	-27.91
PM-2	0.015	44.08	-0.014	0.021	-43.09
PM-3	0.007	77.51	-0.002	0.008	-11.53
PM-4	0.005	93.97	-0.004	0.007	-37.11
PM-5	0.007	45.63	-0.007	0.010	-42.77
PM-6	0.007	156.98	-0.002	0.007	-13.90
PM-7	0.005	66.33	-0.007	0.009	-57.33
PM-8	0.011	75.31	-0.007	0.013	-34.61
PM-9	0.027	57.34	-0.009	0.028	-19.23
PM-10	0.025	9.00	-0.056	0.061	-65.98

The horizontal displacements of each landmark were figured on the situation plan according to the direction of displacement, with a red line, to scale. This resulted in the following situation plan, presented only partially:

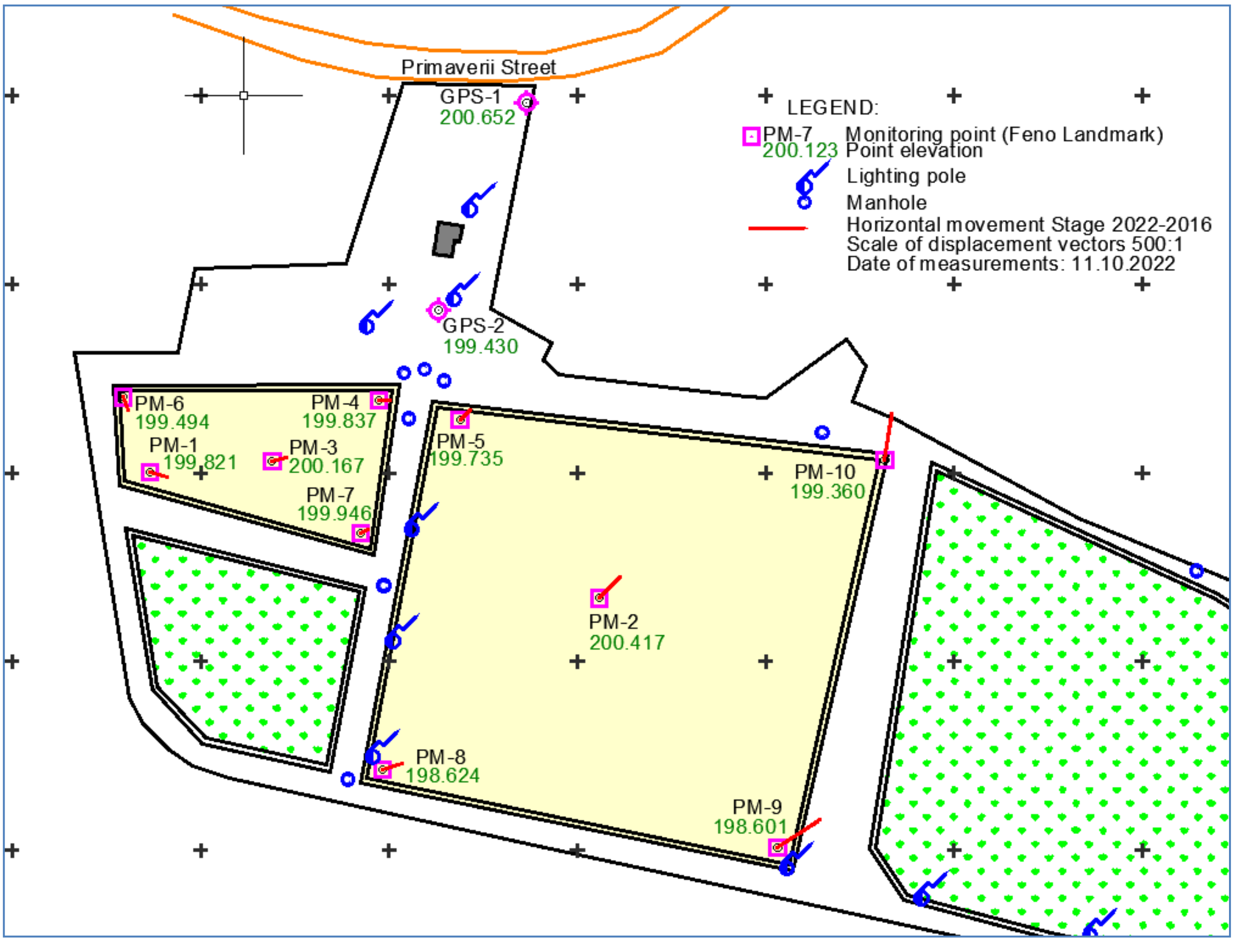

Figure 2. Situation plan with monitoring landmarks and measured displacements.

4. Landmark study of measured displacements in all stages

In order to better characterize the evolution over time of the movement of landmarks, we performed a study on each landmark separately, including all measurement stages. In this way one can see the "trajectory" traveled by the monitoring landmark over time. For example, two landmarks were chosen for each deposit that will be analyzed within the scope of this study.

On the first deposit we chose the landmarks PM-1 and PM-7. Their coordinates in all stages of measurement are presented in the following tables.

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Table 5. Landmark PM-1

PM-1	Easting [m]	Northing [m]	Elevation H [m]
T0	642036.524	609050.114	199.826
T1	642036.526	609050.107	199.827
T2	642036.528	609050.108	199.827
T3	642036.527	609050.108	199.824
T4	642036.532	609050.100	199.823
T5	642036.531	609050.097	199.823
T6	642036.533	609050.111	199.821

The graphical representation of the travel path is illustrated in the following figure, both as a planar representation and as an isometric representation.

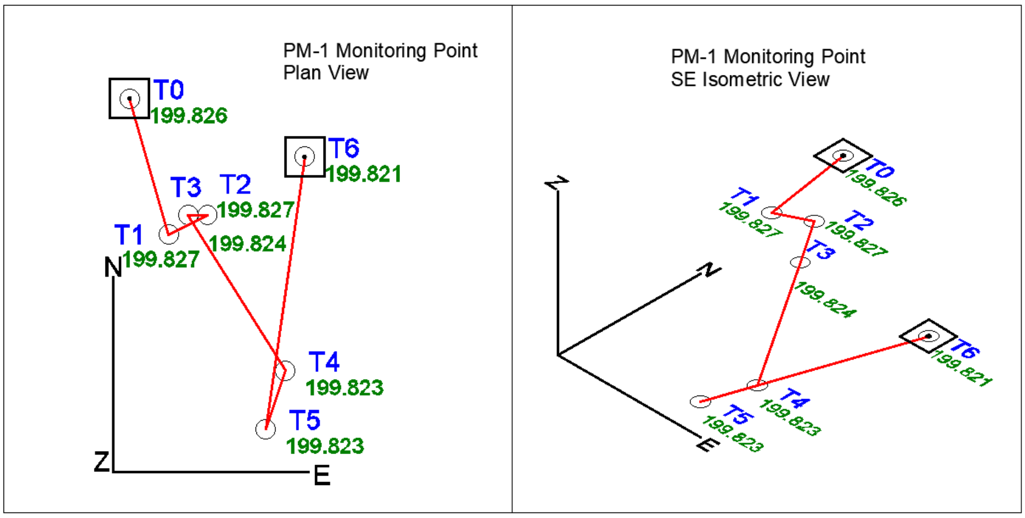

Figure 3. The movement trajectory of the PM-1 landmark over time

Table 6. Landmark PM-7

PM-7	Easting [m]	Northing [m]	Elevation H [m]
T0	642092.476	609034.051	199.953
T1	642092.481	609034.048	199.952
T2	642092.478	609034.051	199.952
T3	642092.481	609034.050	199.951
T4	642092.490	609034.047	199.950
T5	642092.483	609034.044	199.948
T6	642092.480	609034.053	199.946

Below there is the representation of the movement trajectory of the PM-7 landmark in the two variants.

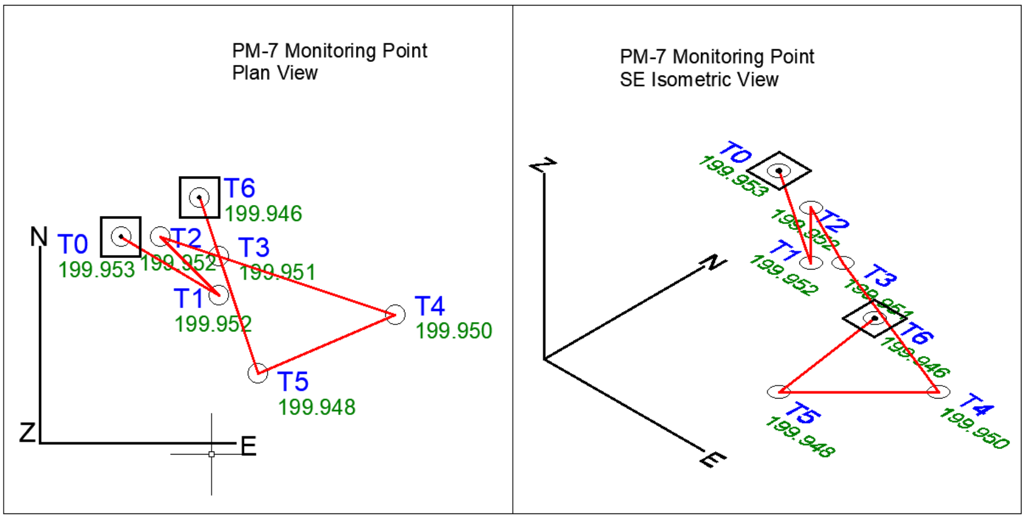

Figure 4. The movement trajectory of the PM-7 landmark over time

On the second deposit we chose the PM-2 and PM-8 landmarks. Their coordinates in all stages of measurement are presented in the following tables.

Table 7. Landmark PM-2

PM-2	Easting [m]	Northing [m]	Elevation H [m]
T0	642155.842	609016.791	200.431
T1	642155.849	609016.794	200.427
T2	642155.849	609016.793	200.427
T3	642155.849	609016.798	200.423
T4	642155.857	609016.796	200.421
T5	642155.866	609016.798	200.420
T6	642155.853	609016.802	200.417

The graphical representation of the travel path is illustrated in the following figure, both as a planar representation and as an isometric representation.

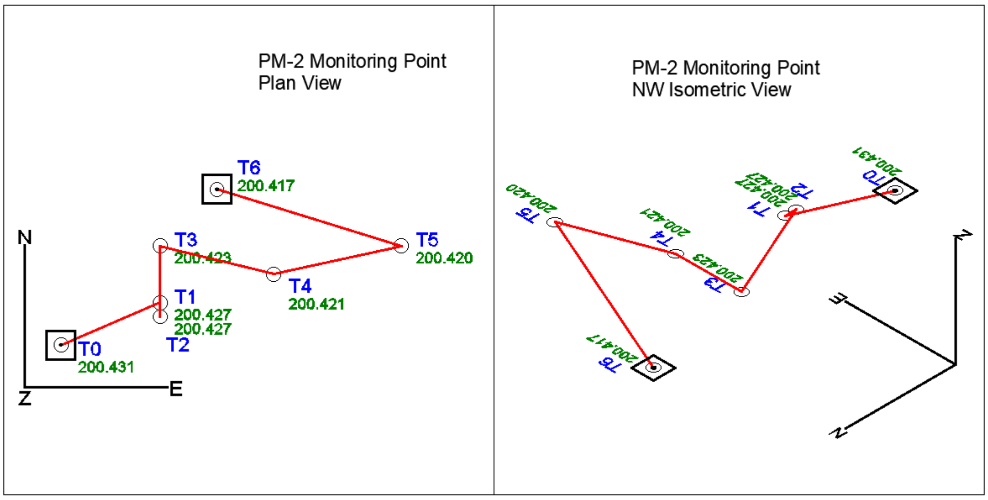

Figure 5. The movement trajectory of the PM-2 landmark over time

Table 8. Landmark PM-8

PM-8	Easting [m]	Northing [m]	Elevation H [m]
T0	642098.306	608971.477	198.631
T1	642098.314	608971.479	198.627
T2	642098.314	608971.479	198.629
T3	642098.316	608971.479	198.626
T4	642098.326	608971.476	198.624
T5	642098.332	608971.472	198.624
T6	642098.316	608971.480	198.624

Below there is the representation of the movement trajectory of the PM-8 landmark in the two variants.

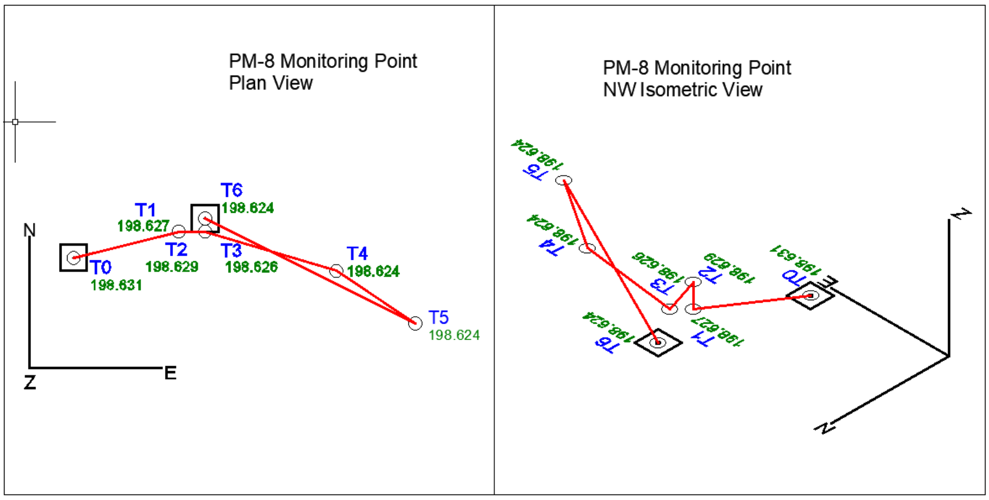

Fig. 6. The movement trajectory of the PM-8 landmark over time

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5. Conclusions

Following the results obtained through precision topographic measurements in the October 2022 stage and their comparison with the values obtained in the October 2016 measurement stage, a centimetric subsidence (settlement) is found, with values in the range of [0.2 – 5.6] cm for the landmarks materialized in the field. Horizontal displacements with values ranging between 0.5 cm and 2.7 cm were also found for the landmarks materialized in the field. It can be concluded that the landmarks are stable over time, and it is recommended to continue monitoring in annual measurement stages, in order to be able to detect potential stability problems in time.

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