MEASUREMENTS OF THE VERTICAL DEFORMATIONS AT THE INCLINOMETERS IN THE RIGHT SLOPE OF THE CĂTĂMĂRĂŞTI RESERVOIR DAM, SITUATED ON SITNA RIVER, BOTOŞANI COUNTY – A CASE STUDY

STUDIU DE CAZ – MĂSURĂTORILE DEFORMAŢIILOR VERTICALE LA ÎNCLINOMETRELE DIN VERSANTUL DREPT AL BARAJULUI ACUMULĂRII CĂTĂMĂRĂŞTI, PE RÂUL SITNA, JUDEŢUL BOTOŞANI

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Abstract*: In the framework of the investment „Safety re-inforcement of Cătămărăşti reservoir, located on the Sitna river in Botosani county" a stabilization platform was built on the location of the old surface outlet, equipped with 8 inclinometers wells to monitor the evolution of the vertical deformations and stability in the right embankment. The vertical deformations were monitored after the final acceptance of the safety works carrying out 4 series of measurements on the inclinometer wells. The measurements were performed with P/N 50302510 Inclinometer Slope Indicator and used as guiding mark the upper elevation of the well pipes. The measurements data were processed using the maximum values of displacements (on the two orthogonal directions A0-A180 and B0-B180). The paper presents the comparative results of 4 series of measurements.*
Key words*: inclinometer, surface outlet, embankment, vertical deformations*

Rezumat*: La executarea lucrărilor de investiţii „Punere în siguranţă a acumulării Cătămărăşti, amplasată pe râul Sitna, în judeţul Botoşani" a fost realizată o platformă de stabilizare, pe amplasamentul vechiului descărcător, prevazută cu 8 foraje înclinometrice cu rol de urmărire a evoluţiei deformaţiilor pe verticală şi de monitorizare a stabilităţii umărului drept al barajului. Deformaţiile pe verticală au fost monitorizate dupa recepţia lucrărilor de investiţii prin 4 serii de măsurători pe cele 8 înclinometre. Măsurătorile înclinometrice au fost efectuate cu Înclinometru Slope Indicator, P/N 50302510 şi au avut ca reper de referinţă a datelor, cota superioară tubulatură. Prelucrarea datelor măsurătorilor s-a făcut sub forma valorilor maxime ale deplasării (pe cele doua directii ortogonale A0-A180 si B0-B180). Rezultatele obţinute în cadrul celor patru serii de măsurători, au constituit obiectul studiului de caz.*
Cuvinte cheie*: înclinometru, descărcător, versant, deformaţii pe verticală*

INTRODUCTION

Cătămărăşti reservoir, located on the Sitna river in Botoşani county and administered by Water Management System Botoşani was commissioned in 1979.

The reservoir was aimed to satisfy the following functions: water supply for Botoşani city (industry), irrigation, fishing, flood protection downstream and

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providing a salubrious flow of 0,030 m³/s. The dam was made of clay and silty materials and it has a double trapezoidal section with a front sealing length of 540 m (Romanian Comitee of Large Dams, 2000). The outlets of this reservoir are a surface outlet with a WES curve profile weir and a two wires bottom outlet with a nominal diameter of 1400 mm.

During the construction of the surface outlet located in the right embankment, a landslide of the embankment occurred and it led to the deterioration of tiles in the foundation plate channel. This phenomenon was caused by the fact that during the earthfill construction, the area adjacent to the surface outlet was not systematized, the drain collector was not executed and also pipes weren't installed in the foundation plate channel and in the right embankment (Synthesis Report on Constructions Behavior Monitoring, 2010 p 14 -17).

During the exploitation of the reservoir, landslides of the right embankment were observed in the immediate vicinity of the surface outlet, which resulted in deformations of the weir, materializing in displacements and cracking of the concrete tiles, especially in dam axis area.

Starting the year 1992, the landslides of the right embankment continued to adversely affect the surface outlet, imposing an increased constructions behavior monitoring, according to *Design Rules 087-2003*. After the year 2000, the studies for the stability of Cătămărăşti reservoir were resumed (Stematiuet al., 2010). These studies have established the need for safety re-inforcement of the reservoir, the optimal solution being the construction of a new surface outlet located in central part of the dam body, after the demolition of the old surface outlet and groundwater draining the right embankment of the dam.

In the framework of the investment „Safety re-inforcement of Cătămărăşti reservoir, located on the Sitna river, in Botoşani county" a stabilization platform was built on the location of the old surface outlet. It was equipped with eight boreholes inclinometer. (The acquisition of equipment for behavior monitoring of the dam and the right embakment for safety re-inforcement of Cătămărăşti reservoir-The National Institute for Research and Development in Environmental Protection, 2009). The location of the inclinometers in relation to the dam and its right embankment is shown in Figure 1.

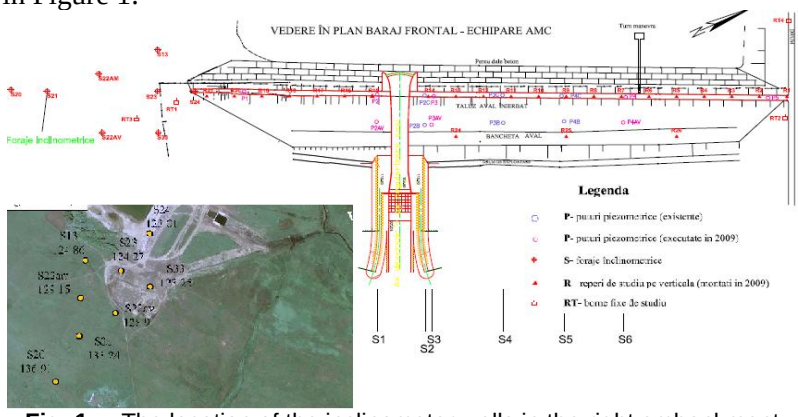

Fig. 1. – The location of the inclinometer wells in the right embankment

The inclinometer wells are aimed to track the evolution of the vertical deformations and monitor the seepage through the dam body and right embankment. They are located on the right embankment, except to the identified as S2.4, which is placed in the dam body.

MATERIAL AND METHOD

Inclinometers reference measurements were carried out in the time frame 08-11.09.2009. The measurements, reported as deviations from a vertical line drawn through the column pipe are the projections of the pipe on the two orthogonal vertical planes: ridge-valley direction, respectively upstream-downstream direction. The conclusions of the report prepared by The National Institute for Research and Development in Environmental Protection shows that the maximum deviation from vertical columns of inclinometers are between 43-410 mm on the ridge-valley direction and 30-540 mm on the upstream-downstream direction. (The acquisition of equipment for behavior monitoring of the dam and the right embakment for safety re-inforcement of Cătămărăşti reservoir-The National Institute for Research and Development in Environmental Protection, 2009).

After the final acceptance of the safety works a contract between the Technical University of Civil Engineering Bucureşti as performer and Water Basinal Administration Prut-Bârlad as beneficiary was signed. Under this contract, 4 series of inclinometers and piezometer measurements on the inclinometer wells were carried out, in the following days: 07/12/2010, 12/20/2010, 10/08/2011, and 11/25/2012. Four measurement reports were drawn.

The inclinometer wells were arranged on approximately parallel lines with the upstream-downstream direction and the monitoring direction A0-A180 for each well is approximately transverse. The data were processed using the maximum values of displacements (on the two orthogonal directions A0-A180 and B0-B180). The measurements used as guiding mark the upper elevation of the well pipes, which is 30 to 70 inches higher than the land surface. *The measurements were performed with P/N 50302510 Inclinometer Slope Indicator (*accuracy class 0.01 mm to 500 mm, double pendulum*).* The measurements were carried out from 0.5 m to 0.5 m and they were read in the two orthogonal directions A and B.

RESULTS AND DISCUSSIONS

Inclinometric monitoring − stage I: 07/12/2010

The results of the measurements compared to the values registered in the year 2009 show the emergence of earth displacements of right embankment subjected to monitoring. The values of the size and direction of the resultant vector are given in Table 1.

Compared to baseline readings on the inclinometer tubes, tube length differences fall within the 0.57 ... 1.5 m, except S2.4 inclinometer tube, where the difference was of 10.0 m. The inclinometer tube S2.4 could only be measured to a depth of 4.5 m (as to 15.0 m depth initially reported). The tube appeared to have been damaged below the depth of 4.5 m, hydrostatic level was recorded bellow this land rate (Technical Report - Inclinometric and Piezometric Monitoring for Cătămărăşti reservoir. Technical University of Construction Bucureşti July 2010, p.5).

Table 1

Size and direction of the resultant vector

Inclinometer well	Displacement size (mm)	Displacement direction
S2.0	231	Downstream to upstream
S2.1	1623	Downstream to upstream
S2.2 upstream	245	Upstream to downstream
S2.2 downstream	485	Upstream to downstream
S2.3	380	Upstream to downstream
S1.3	106	Downstream to upstream
S3.3	60	Downstream to upstream
S2.4	1023	Upstream to downstream

Inclinometric monitoring − phase II: 12/20/2010

The results of the measurements compared to the new reference values from Technical Report - Inclinometric and Piezometric Monitoring for Cătămărăşti reservoir-July 2010 regarding the size and direction of the resultant vector are given in Table 2.

Table 2

Size and direction of the resultant vector

Inclinometer well	Displacement size (mm)	A0-A180 Vector (mm)	B0-B180 Vector (mm)
S2.0	1.51	1.23	0.94
S2.1	4.31	3.28	3.44
S2.2 upstream	6.24	6.14	− 2.50
S2.2 downstream	9.28	9.28	− 2.34
S2.3	8.71	8.47	2.88
S1.3	5.58	2.60	− 4.94
S3.3	14.5	14.37	5.21
S2.4	1.95	− 1.74	− 0.88

Inclinometric monitoring − stage III: 11/08/2011

The results of the measurements compared to the reference values from Technical Report - Inclinometric and Piezometric Monitoring for Cătămărăşti reservoir-July 2010 regarding the size and direction of the resultant vector are given in Table 3.

Compared to the measurement data from the year 2009, there is a general lowering of the surface area being monitored. This is supported by the fact that almost all tubes "remained suspended" - the land showed displacement and the tubes were left "stuck/embedded at the bottom" (Technical Report - Inclinometric and Piezometric Monitoring for Cătămărăşti reservoir. Technical University of Construction Bucureşti November 2011).

The displacements recorded (absolute maximum value) and the direction of displacement vector are at this measurement phase consistent with the position of the wells on the right embankment of the dam and its overall slope.

Table 3

Size and direction of the resultant vector

Inclinometer well	Displacement size (mm)	A0-A180 Vector (mm)	B0-B180 Vector (mm)	Absolute displacement daily rate (mm/day)
S2.0	7.16	7.15	-2.04	0.0193
S2.1	4.31	12.40	-6.26	0.0277
S2.2 upstream	9.71	8.52	5.98	0.0118
S2.2 downstream	27.31	26.83	-7.56	0.0959
S2.3	29.11	29.05	-2.73	0.0699
S1.3	31.25	30.94	-4.42	0.0889
S3.3	38.73	38.53	7.99	0.0829
S2.4	2.90	-2.90	-0.88	0.0193

Inclinometric monitoring − stage IV: 11/25/2012

The results of the measurements compared to the reference values from Technical Report - Inclinometric and Piezometric Monitoring for Cătămărăşti reservoir-July 2010 regarding the size and direction of the resultant vector are given in Table 4:

Table 4

Size and direction of the resultant vector

Inclinometer well	Displacement size (mm)	A0-A180 Vector (mm)	B0-B180 Vector (mm)	Absolute displacement daily rate (mm/day)
S2.0	15.70	15.60	-2.53	0.0206
S2.1	14.58	12.24	13.49	0.0052
S2.2 upstream	17.41	10.79	13.66	0.0186
S2.2 downstream	28.39	28.34	-3.43	0.0516
S2.3	50.47	50.42	-2.89	0.0026
S1.3	35.54	35.50	-2.58	0.0103
S3.3	50.05	49.97	11.52	0.0273
S2.4	2.00	-2.00	-1.02	-0.0022

Compared to measurements data recorded in the year 2011 the general lowering of the surface of the monitored embankment was emphasized, as all the tubes "were left hanging." Earth displacements in the embankment were registered in the horizontal direction (in plane) to the depths between 8.0 m and 11.0 m. The land surface showed curve cracks, a few centimeters wide, parallel with the inclinometers position lines.

The size of the displacements rates shows that earth movements falls in the category of "**extremely slow landslides**". The direction of displacement is transverse to Cătămărăşti reservoir, upstream to downstream, according to the slope of the embankment. The size of the displacement vector of the earth increases from upstream to downstream. The highest values of displacement are presented for the monitoring line in the vicinity of dam.

Compared to the displacements recorded in October 2011, it appears that, at the end of November 2012, after a period of one year between the stages of monitoring, the values of vertical deformations were doubled. In the monitoring stage in November 2012, the value of the depth at which the land may be considered stable, shows that the right embankment is characterized by an instability phenomenon with landslides that were classified as "**shallow slides to deep slides**".

CONCLUSIONS

1. The displacement curves must be verified with the field situation, with reference to the possible cracks in the embankment, especially in the downstream side, cracks that need adhesion in order to avoid rain water infiltration and activation of new earth displacements.

2. We recommend further measurements to be completed with topographic monitoring of inclinometers in the embankment and the surrounding areas.

3. Combining physical surveying methods lead to better construction behavior monitoring, to a deeper understanding of the phenomenon that occur in both the dam body and the surrounding land. It is thus possible to determine the interdependence between environmental factors and changes in shape and absolute position of the structure.

4. The equipment used for the measurements plays a crucial role. This should be of a superior accuracy class and checked the metrologically before collecting field data.

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