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METHOD OF TRACKING DEFORMATIONS FOR HYDROTECHNIC DAMS STRUCTURES

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Abstract

This study was conducted in order to assess the usefulness and accuracy of dams deformations. Comparisons of observed movements during consecutive years show the stability of the dams. The observations are done trough levelling, a procedure that delivers altimetry data. Levelling is conducted trough points, marks and brands, of known coordinates, both in altimetric and planimetric systems.. Measurements were conducted in two consecutive years. The results will be processed using Gauss Markov model. The data analysis will be done using statistical tests. The multitude of phenomena affecting dams lead to movements and deformations that must be under permanent monitoring. Land surveyors have the tools and knowledge for such performance monitoring.

***Key words**: deformations, dams, land measurements, levelling network.*

INTRODUCTION

Dams, dikes, embankments and other control structures for floods are subject to external loads causing the deformation and the permeability of the structure itself. Any clue of an abnormal behavior may endanger the safety of the structure. In order to facilitate the monitoring of such structures, they should always be equipped with the appropriate tools and/or points that can be traced in accordance with the type of structure, size and site conditions.

Monitoring trips/ deformation space - 3D: the problem of determining the position of points in a single system of reference for the three coordinates, was and is one of the main concerns of geodesy. Tridimensional geodesy eliminates this separation, keeping unity of the reference system to solve the problem of space positioning of geodetic points. The result of the processing consists in determinig the three dimensional spatial position of the geodesic network of points, in a unitary system.

Figure 1. Dam Gura Apelor

Gura Apelor Dam is an artificial dam built between 1975 and 1986 on the Râul Mare valley, about 40 km from Haţeg at the entrance of National Park Retezat from Retezat Mountains (Southern Carpathians, Romania) (http://www.hidroconstructia.com/rom/raul_mare_retezat.html).

Design features

Dam construction began in 1975. Its size are impressive: 168 m high, 225 million cubic meters of water in the reservoir, the dimensions of the entire dam outpace three times those of Keops (date Hidroconstrucția) pyramid.

Râul Mare Retezat hydropower has the role of producing both electricity, regulate stream flow and mitigate flood waves. (Figure1).

Displacement: Movement of a point placed on a construction subjected to strains.

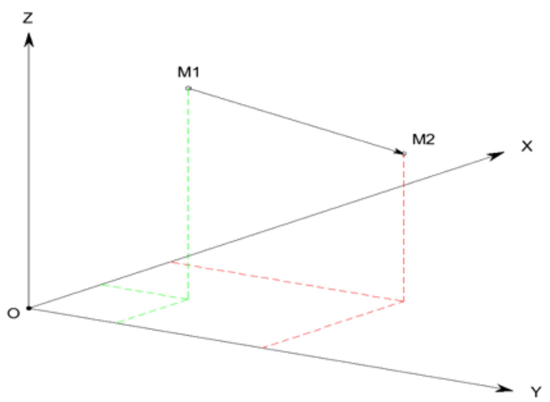


Figure 2. Displacement

Deformation: changing the relative distance between points located on a building subjected to strains .

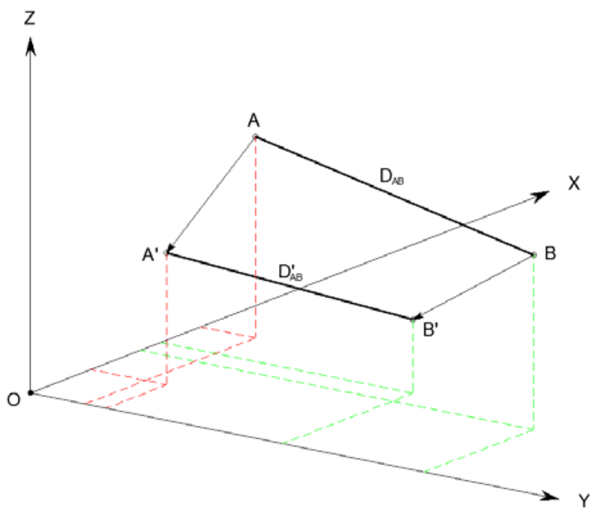


Figure 3. Deformation

MATERIALS AND METHODS

The multitude of phenomena that influence the appearance of construction displacements and deformations, as well as constructions response to the influence of these phenomena require the need for performance monitoring in time of the objective. Observations are done at different ages in time. Processing of these observations is hampered by practical difficulties the ages of measurement is subject to practical difficulties. Determinaiting building subsidence is usually done by precision geometric levelling of marks embedded in the building, that moves with it, to the fixed reference points outside the building and which make up the supporting network of points. (Figure 4) Depending on the type, shape and size of the examined object levelling network can take the form of closed polygons or traverses approximately parallel to each other. The levelling network of points is made up by marks placed on the observed object and by the control marks (placed outside the construction). Marks shape and material is chosen according to local conditions, the shape and material of the surveyed construction.

A network of geometric levelling consists of levelling landmarks. Between these land marks measurements are done to determine the differences in level and length of routes subjected to observations.

In such a network, to perform adjustment calculations one must know or determine:

-measure level differences (Δh_{ij}) by geometric levelling method;

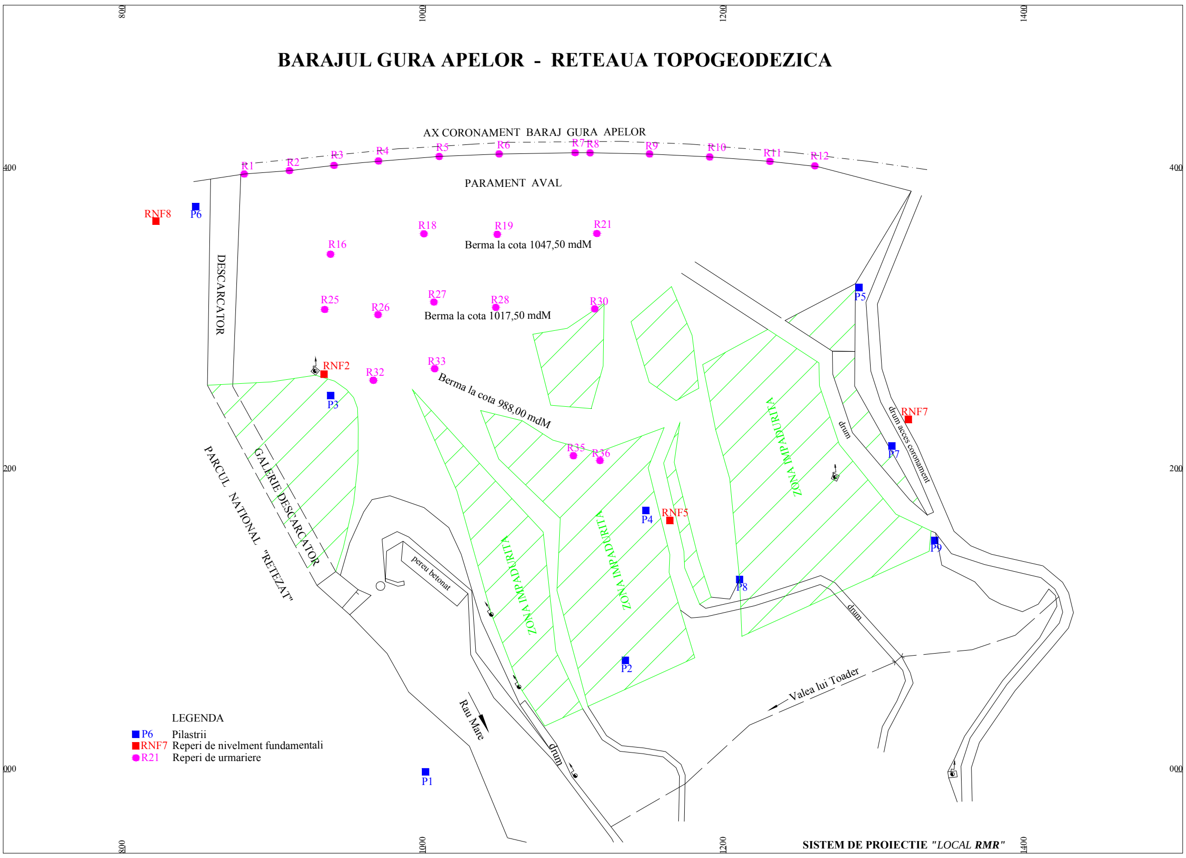


Figure 4. Dam Gura Apelor - Geodetic network

-the lengths of the paths followed to determine the level differences necessary for determining weights of the measurements, with the relationship:

$$P_{ij} = \frac{1}{L_{ij[km]}} \quad (1)$$

-the altitude (H_i) of one or more height marks of the levelling network of points considered;

With these elements, through a rigorous process, are to be determined:

a) absolute values (most likely) of altitudes of all the new network points, depending of the original known elements, in the adopted reference system;

b) the most likely values (compensated) of the level differences, on the routes on which they were measured;

c) The accuracy with which these values are determined by the processing method.

Depending on the nature of the variables involved in the model, this can be:

-functional model (Gauss-Markov) does not contains random elements and describes a pure relationship between sizes, defined by the formula:

$$v = Ax - l \quad (2)$$

-statistical mode (stochastic) that contains random variables that characterize the possibility of displacements and deformations, being expressed by the equation:

$$\Sigma_{ll} = \sigma_0^2 Q_{ll} \quad (3)$$

Based on these variables, complex relationships are established between random values, ie at a given value of the argument corresponds a set of possible values of the function.

Remarks:

v - the measurement corrections vector;

A - matrix coefficients;

x - parameter vector (unknowns vector);

l - vector of free terms;

C_m - variance covariance matrix of measurements;

σ_0^2 - factor variance share or unit variance;

$Q_{xx} = N^{-1}$ - this block is extracted from the general matrix of cofactors:

By processing these levelling observations geometric corrections are to be determined for compensated values whose sizes are not yet known.

$H_i = H_i^{\mathbf{0}} + x_i \quad , i = \mathbf{1}, \mathbf{2}, ..., n$, (4)

and for differences in level measured:

$\Delta h_{ij} = \boldsymbol{H}_{ij}^{\mathbf{0}} + v_{ij}$ (5)

After writing the system of linear equations of corrections, the system is normalized and solving of the normal system of equations follows. A process which delivers corrections for new points altitudes and corrections for level differences.

$$N = A^T PA \quad (6)$$

$$x = -N^{-1} A^T Pl \quad (7)$$

Notations:

N - normal matrix system of equations;

A - matrix correction coefficients system of equations;

P - weights matrix

x - vector of the unknown elements

l - free terms matrix

These values added to the provisional elements will provide the most likely values (adjustments) for the two type of elements: relations (4) and (5).

Finally, the elements of accuracy should be computed.

The standard deviation of unit weight can be determined by the relation:

$$s_{\mathbf{0}} = \sqrt{\frac{[\mathrm{pvv}]}{\mathrm{n} - \mathrm{h}}} \quad (8)$$

where n is the number of level differences measured in the network and h is the number of new points in the network (unknown).

The standard deviation of a single level difference is:

$$s_i = \frac{s_0}{\sqrt{\mathrm{P_i}}}, \ \mathrm{i} = 1,2,\ldots,\mathrm{n} \quad (9)$$

The standard deviation of the unknown quantities (quantities determined indirectly)

$$\left(s_{\mathrm{x}}\right)_{\mathrm{j}} = s_0 \cdot \sqrt{\mathrm{q_{jj}}}, \ \mathrm{j} = 1,2,\ldots,\mathrm{h} \quad (10)$$

A global network standard deviation of the unknown quantities can be determined. This is an indication of the determination accuracy of the altitude of the network points:

$$s_t = \frac{1}{\mathrm{h}} \sum_{\mathrm{j}=1}^{\mathrm{h}} \left(s_{\mathrm{x}}\right)_{\mathrm{j}} \quad (11)$$

At Gura Apelor Dam due to geological and structural conditions two field stages were conducted. (Figures 5- 8)

Figure 5. Stage –september 2015

Because we do not know and cannot always determine the limits of the territory affected by a construction (especially for large buildings), there is no guarantee that all reference bench marks of will be found out of the reach of deformations (Figure 6).

Figure 6. The area action deformations

In addition, the action of various factors such as geological, weather, etc. can lead to the disruption of stability of some of the control points. The remoteness of the control points of as opposed to the construction may not be specified with precision but must take into account the geological conditions in the area. So, for processing 8 bench marks were chosen. Geometric levelling measurements were made with the level Leica 250M and the altitude system used is the Black Sea 1975 (Figure 7).

Figure 7. Progress measurements - Leica Sprinter 250M

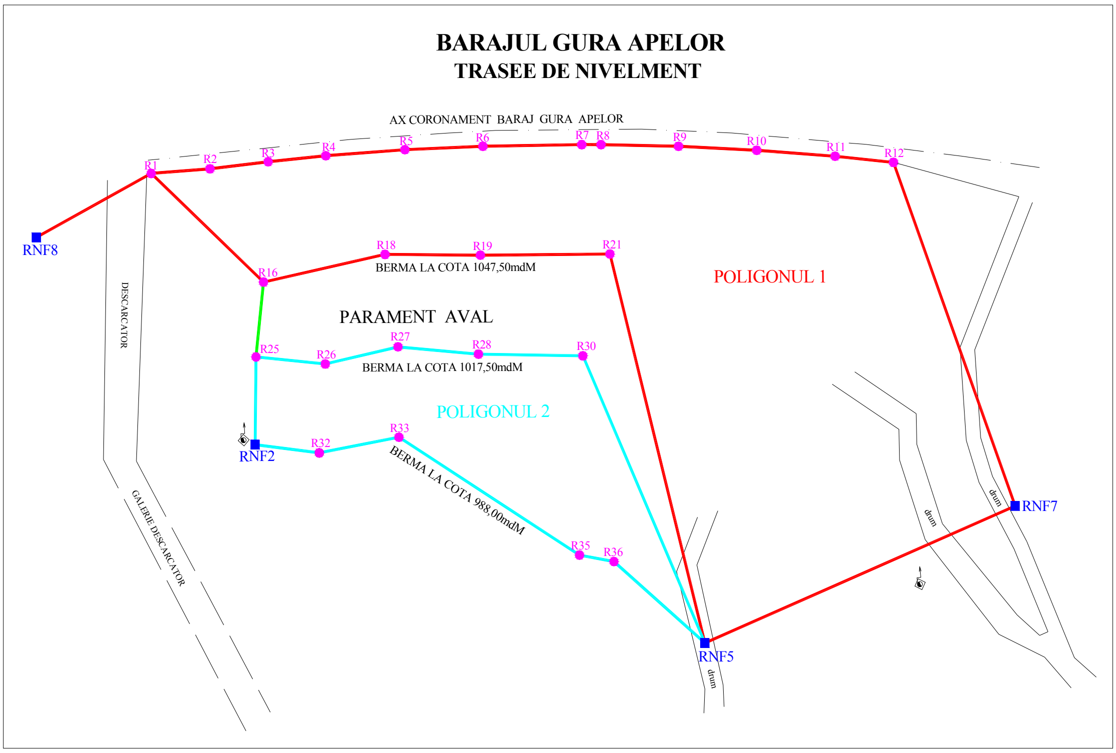


Figure 8. Geometry of the geodetic network with the same configuration at two different measurement periods

RESULTS AND DISCUSSIONS

By adding adjustments to the provisional values (Table 1) the most probable values of the parameters will be determined.
The normal system is compatible determined, so the values of the unknown elements can be uniquely determined. The results of the matrix calculus is presented below:
Compensation of the geometric levelling network through indirect measurement method was described in the processing algorithm. As a result of processing the corrections (vi) for measurements and (xj) parameters are determined.

$$x = \begin{pmatrix} -0.0004 \\ -0.0018 \\ -0.0026 \\ -0.0029 \\ -0.0036 \\ -0.0042 \\ -0.0044 \\ -0.0046 \end{pmatrix} \qquad v = \begin{pmatrix} -0.0004 \\ -0.0015 \\ -0.0007 \\ -0.0004 \\ -0.0007 \\ -0.0006 \\ -0.0002 \\ -0.0002 \\ -0.0022 \end{pmatrix}$$

Table 1. Selection field book

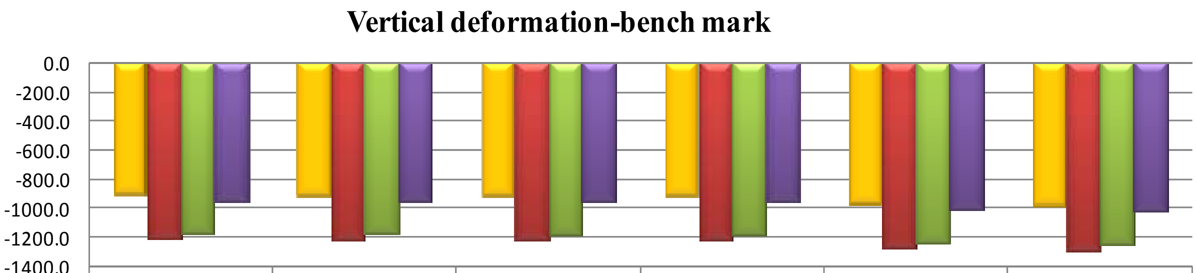
PtNo	Height [m]	Distance [m]	StaffType	Meas_Type	IsReferNo	Elevation [m]	D.Elv [m]	Cut [m]	Delta-Height-dH [m]	Denumire reper in teren
GA1	1.305313	10.541687	Upright	B	1	1000	1078.4695	1078.4694		RNF8
GA2	1.223997	10.88689	Upright	F	1	0				
GA2	1.223953	10.887767	Upright	F	1	0				
GA1	1.305303	10.541407	Upright	B	1	0				
GA2			Upright	BFFB-mean	1	1000.0813	1078.5508	1078.5506	0.081333	
....										
GA19			Upright	BFFB-mean	1	973.55319	1052.0227	1052.0208	-1.28689	RND
GA19	0.30843	15.924212	Upright	B	1	973.55319				
GA20	2.651934	14.889211	Upright	F	1	0				
GA20	2.651931	14.890286	Upright	F	1	0				
GA19	0.308443	15.925622	Upright	B	1	0				
GA20			Upright	BFFB-mean	1	971.20969	1049.6792	1049.6772	-2.3435	
GA20	0.347603	9.756473	Upright	B	1	971.20969				
GA21	1.984819	9.900331	Upright	F	1	0				
GA21	1.984796	9.900642	Upright	F	1	0				
GA20	0.347602	9.757562	Upright	B	1	0				
GA21			Upright	BFFB-mean	1	969.57249	1048.042	1048.0399	-1.63721	
....										
GA27			Upright	BFFB-mean	1	965.72147	1044.191	1044.1883	0.239767	R18
....										
GA39			Upright	BFFB-mean	1	967.05407	1045.5236	1045.5197	-2.07299	R21

$$N=\begin{pmatrix} 18.7027 & -3.6797 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ -3.6797 & 10.9340 & -7.2543 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & -7.2543 & 22.7454 & -15.4910 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -15.4910 & 23.4482 & -7.9572 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & -7.9572 & 16.7533 & -8.7961 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & -8.7961 & 38.5244 & -29.7283 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & -29.7283 & 59.4383 & -29.7100 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & -29.7100 & 32.2267 \end{pmatrix}$$

Field measurements were carried out during the period September - November 2016, after which the data has been processed at the office. These were made in accordance with:

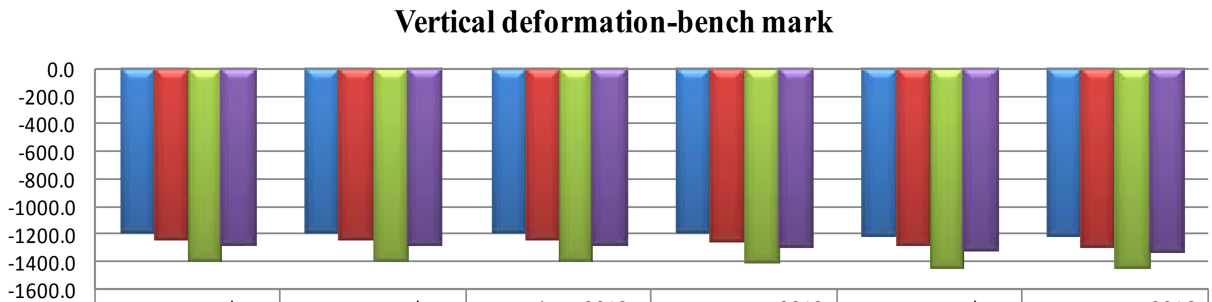
- STAS 10439/76-Marking and flagging points for construction supervision.
- STAS 2745/90- Surveying construction compression trough topographic methods.

The values obtained can be found as a comparative study towards 2010-2016 in stages (Figures 9 - 13). Altimetric tracking network consists of 4 fundamental height marks placed downstream of the dam: the RNF2-990.10mdM, RNF5-1021.12mdM, RNF7, and RNF8 located at the canopy level and 27 bench mark (Figure 4).



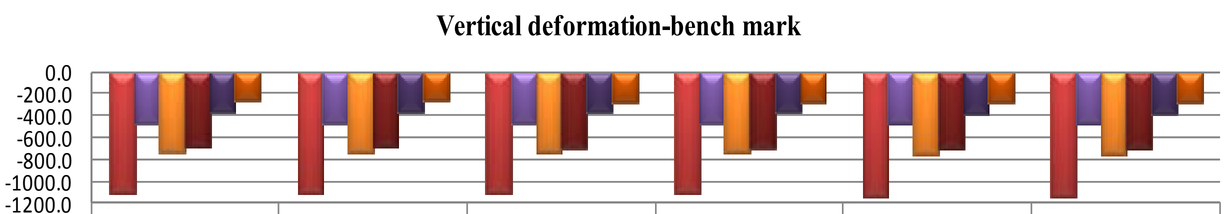
	stage september 2010 [mm]	stage september 2011 [mm]	stage june 2012 [mm]	stage august 2012 [mm]	stage september 2015 [mm]	stage august 2016 [mm]
R16	-915.0	-924.5	-927.1	-926.3	-982.1	-996.4
R18	-1205.8	-1211.4	-1217.0	-1217.9	-1275.8	-1290.5
R19	-1169.3	-1172.1	-1180.2	-1180.2	-1236.7	-1252.5
R21	-953.4	-950.8	-960.2	-959.0	-1010.8	-1024.6

Figure 9. -Vertical deformation-bench mark 1047.50m level bank



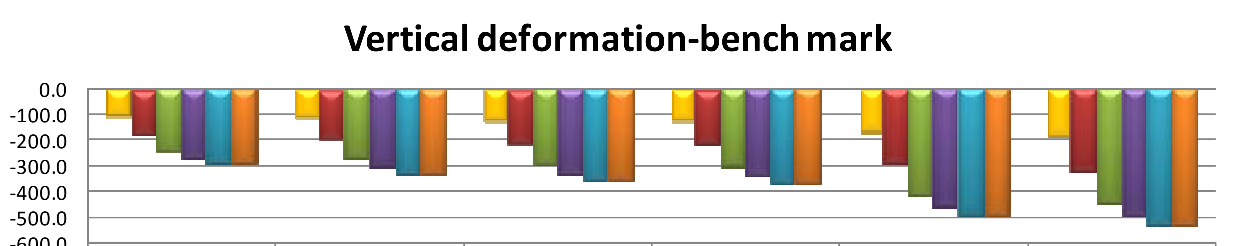
	stage september 2010 [mm]	stage september 2011 [mm]	stage june 2012 [mm]	stage august 2012 [mm]	stage september 2015 [mm]	stage august 2016 [mm]
R25	-1182.2	-1186.2	-1185.3	-1187.8	-1211.1	-1219.3
R26	-1237.0	-1244.4	-1243.6	-1248.0	-1281.4	-1292.4
R27	-1386.7	-1394.4	-1394.6	-1398.5	-1436.9	-1448.2
R28	-1271.9	-1276.9	-1280.8	-1285.1	-1321.0	-1331.2

Figure 10. -Vertical deformation-benchmark 1017.50m level bank



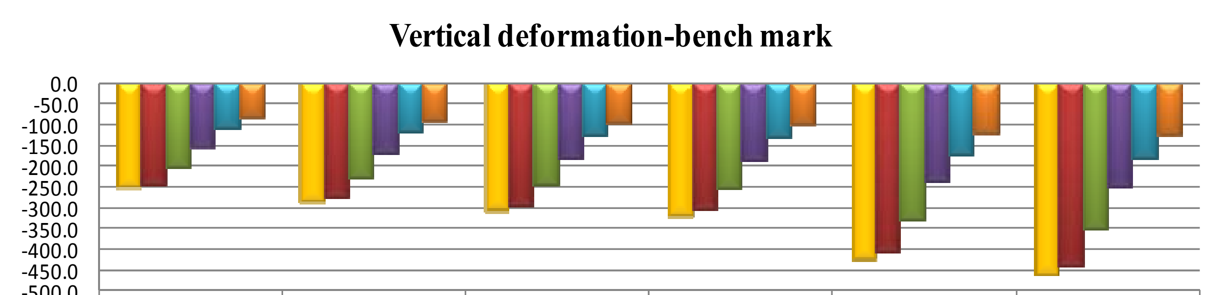
	stage september 2010 [mm]	stage september 2011 [mm]	stage june 2012 [mm]	stage august 2012 [mm]	stage september 2015 [mm]	stage august 2016 [mm]
R30	-1095.6	-1099.6	-1101.7	-1108.0	-1128.5	-1133
R32	-463.5	-466.8	-467.8	-467.4	-477.2	-479.7
R33	-736.5	-738.9	-742.6	-742.0	-755.0	-758.2
R34	-696.4	-699.0	-701.6	-703.7	-712.9	-715.6
R35	-371.7	-373.4	-374.8	-376.4	-385.8	-389.8
R36	-274.4	-274.0	-276.7	-278.6	-283.9	-286.3

Figure 11. -Vertical deformation-benchmark 988.0 m level bank



	stage sep 2010 [mm]	stage september 2011 [mm]	stage june 2012 [mm]	stage august 2012 [mm]	stage september 2015 [mm]	stage august 2016 [mm]
R1	-109.5	-118.4	-130.1	-131.1	-169.1	-179
R2	-176.4	-193.9	-211.5	-215.4	-292.9	-314
R3	-243.2	-270.6	-294.8	-303.0	-411.4	-443.8
R4	-271.8	-304.2	-328.1	-339.1	-458.7	-495.2
R5	-292.3	-329.9	-355.3	-367.4	-493.0	-532.9
R6	-288.9	-327.9	-353.6	-367.5	-492.2	-533.9

Figure 12. -Vertical deformation-bench mark crest



	stage september 2010 [mm]	stage september 2011 [mm]	stage june 2012 [mm]	stage august 2012 [mm]	stage september 2015 [mm]	stage august 2016 [mm]
R7	-253.4	-286.1	-308.1	-319.4	-427.0	-461.5
R8	-242.0	-273.1	-294.3	-305.2	-407.1	-439.3
R9	-200.8	-225.2	-241.7	-249.9	-328.7	-352.2
R10	-152.3	-166.4	-178.8	-184.2	-235.0	-249.4
R11	-112.0	-120.5	-129.6	-132.5	-170.1	-179.9
R12	-86.5	-91.7	-97.2	-100.9	-121.9	-125.6

Figure 13. -Vertical deformation-bench mark crest

CONCLUSIONS

Measurements at the Gura Apelor Dam are aimed at determining the vertical displacements of the dam through topo-geodetic measurements on the level point network. The values of displacements are obtained trough differences between heights determined in the current measurent age and heights determined in the initial age of measurements.

It can be seen from the comparative tables attached (Figures 9 - 13) that there are no significant displacements both in relation to the initial phase, as well as in relation to the previous ones. The level differences were corrected and accuracy values were determined. (Table 2)

Table 2. Values deviations

nr.crt.	stage 2016	s_0 [mm]
1	Crest	1.03
2	1047.50 level bank	1.92
3	1017.50 level bank	0.57
4	988.00 level bank	0.64

At the level of the canopy, the upstream and downstream movements-are between 0-15 mm, for downstream, and left bank-shore movements are between 0-29 mm, to the right, in comparison with the 2015 results. These

values fit into the rules P130/1999- Technical Instructions for the execution of surveying works, execution and operation of hydropower.
No displacements job is complete without an analysis of the data. The result of processing is interpreted trough statistical tests.

Normality tests

Test interpretation:
H0: the variable from which the sample was extracted follows a Normal distribution.
Ha: The variable from which the sample was extracted does not follow a Normal distribution.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 61.54% (Figure 14).
Figures 15-17 show vertical movements of points placed on level banks.

Coronament-bench mark	
R1	-9.9
R2	-21.1
R3	-32.4
R4	-36.5
R5	-39.9
R6	-41.7
R7	-34.5
R8	-32.2
R9	-23.5
R10	-14.4
R11	-9.8
R12	-3.7

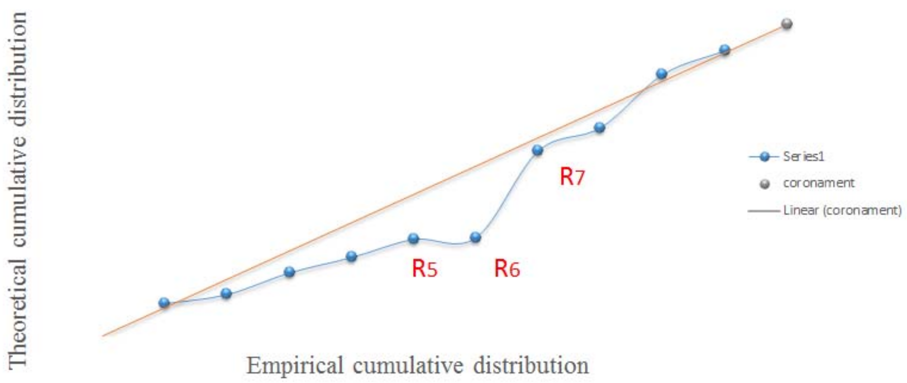


Figure 14. Deformation analysis stage (2015-2016)[mm]- Crest

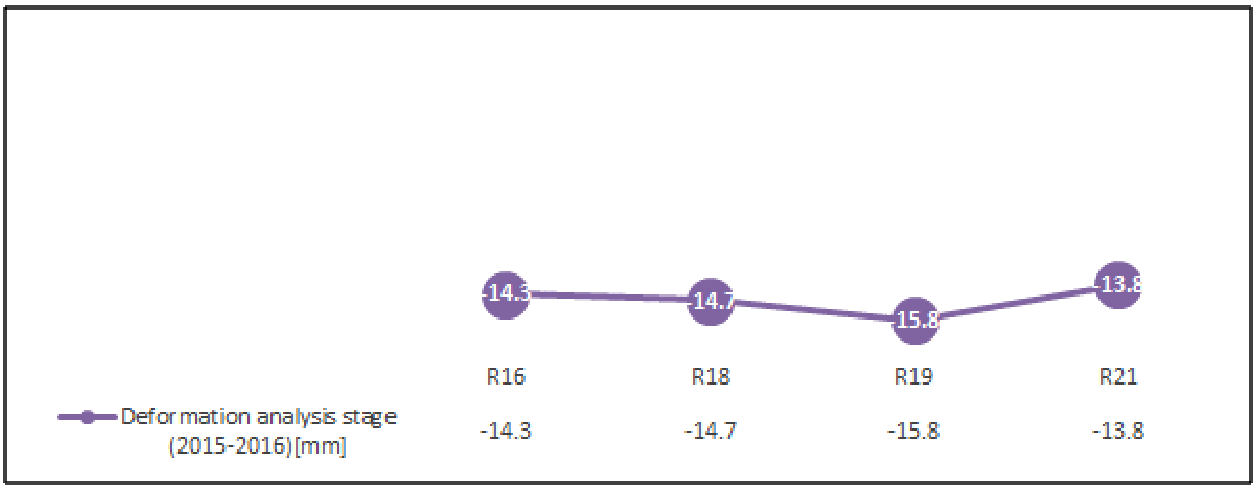


Figure 15. Bench mark 1047.50m level bank

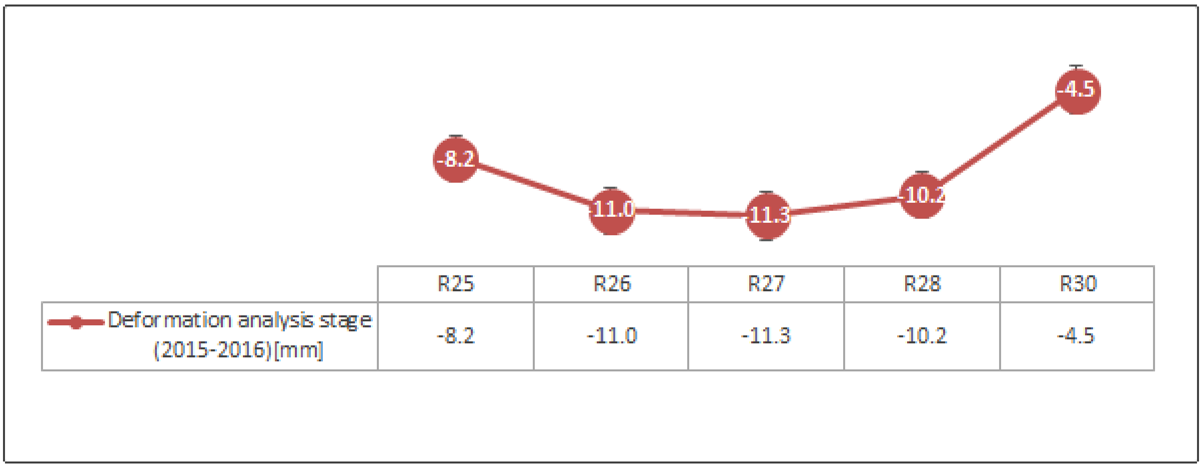


Figure 16. Bench mark 1017.50m level bank

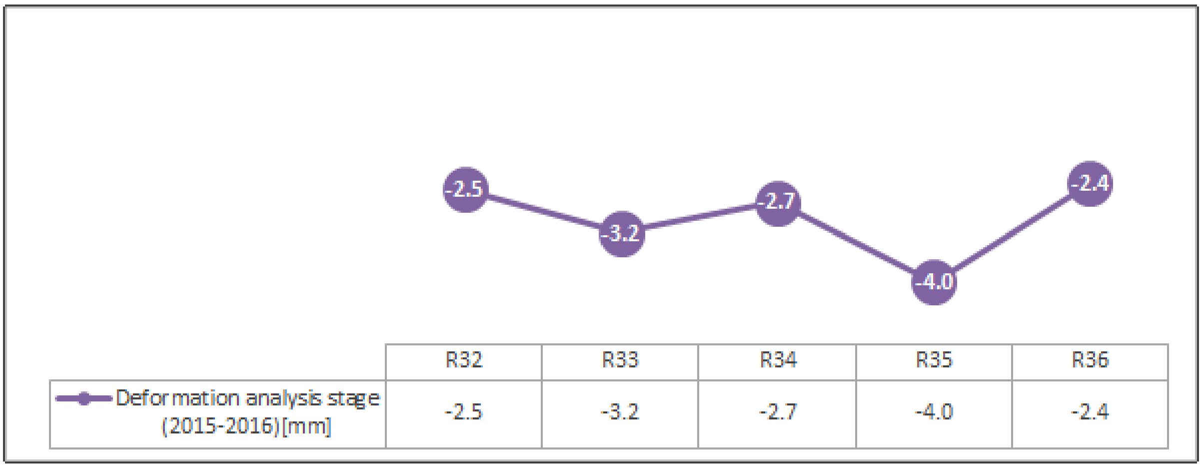


Figure 17. Bench mark 988.0m level bank

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date Hidroconstrucția