Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. IV, 2015
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

ASPECTS REGARDING THE OBSERVATIONS OF VERTICAL DISPLACEMENTS OF ROCKFILL (RIPRAP) DAMS

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Abstract

The paper refers to the monitoring of vertical displacements of rockfill (riprap) dams, displacements caused by the process of material compaction of dams. In order to monitor the vertical displacement, on the weir crest and berms situated on the downstream-side were placed tracking markers. To determine the vertical displacements was used a DNA 03 level and DNA levelling invar staff. Measurements processing was done rigorously through the method of conditional measurements and indirect measurements. The case study was conducted on the Belis Fantanele dam using the measurement periods of May to October 2013, respectively from March to November 2014. The maximum recorded value of compaction is 312 mm on the RN10 landmark located on the dam weir crest.

Key words: *compaction, geometric levelling, rigorous processing.*

INTRODUCTION

In the case of hydrotechnical planning, an important component is the upstream dams that form the lake basin which constitutes the driving force (Li and Wang, 2011).
Dam stability is very important considering that if it succumbs, great materials and sometimes life losses occurs downstream (Kalkan et al., 2010).
Considering this fact, dam stability is monitored through topographic measurements regarding their vertical and horizontal movements (Manea, 2013; Onose et al., 2014).
In the case of concrete arch dams, horizontal displacements predominates, and in the case of rockfill dams, vertical displacement predominates (Ortelecan et al., 2014; Sails et al., 2014).

MATERIALS AND METHODS

To determine the vertical displacements on the weir crest and downstream face, tracking landmarks are placed to observe vertical displacements.
Considering the small values of displacements, to record these displacements is used high precision geometric levelling and the measurement processing is performed by rigorous methods using functional models from conditioned measurements and from indirect measurements (Dima, 2005; Onose et al., 2009).
For a levelling traverse with known height points at the ends, a correction equation can be written as presented:

$$a_1v_1 + a_2v_2 + \cdots + a_nv_n + w_1 = 0; \qquad (1)$$

where:
a_i – correction coefficients;
v_i – measured elements corrections;

w_1 – non-closure on height datum;
p_i – ponderous different levels of measurement.

$$w_1 = [v_{ij}]_A^B - (H_B - H_A) \tag{2}$$

where:
H_A – landmark height datum for surveying;
H_B – landmark height datum for closure.

$$p_i = \frac{1}{\Delta h_{ij}} \tag{3}$$

where:
Δh_{ij} – measured level differences.

Solving the correction equation is made in the condition of minimum: [pvv]→ minim, thus reaching the normal equation of correlation presented as:

$$\left[\frac{aa}{p}\right] k_1 + w_1 = 0 \tag{4}$$

where:
k_1 – undetermined coefficient of Lagrange (correlated).

$$\left[\frac{aa}{p}\right] = \frac{a_1 a_1}{\frac{1}{p_1}} + \frac{a_2 a_2}{\frac{1}{p_2}} + \cdots + \frac{a_n a_n}{\frac{1}{p_n}} = \Delta h_{A,1} + \Delta h_{1,2} + \cdots + \Delta h_{n-1,B} = [\Delta h_{ij}]_A^B \tag{5}$$

Considering the relationship (4) and (5), we can write:

$$k_1 = -\frac{w_1}{[\Delta h_{ij}]_A^B} \tag{6}$$

The corrections v_i are calculated using the equation:

$$v_{ij} = \frac{1}{p_{ij}} a_i k_1 \tag{7}$$

From relationship (6) and (7) results:

$$v_{A,1} = -\Delta h_{A,1} \frac{w_1}{[\Delta h_{ij}]_A^B}$$
$$v_{1,2} = -\Delta h_{1,2} \frac{w_1}{[\Delta h_{ij}]_A^B} \tag{8}$$
....
$$v_{n-1,B} = -\Delta h_{n-1,B} \frac{w_1}{[\Delta h_{ij}]_A^B}$$

The standard deviation of the observations in the traverse of geometric leveling is calculated using the equation:

$$m_0 = \pm\sqrt{\frac{[pvv]}{r}} \tag{9}$$

where:
r – number of geometric conditions.

Non-closure tolerance on the traverse leveling is calculated using the equation:
$T_h = 0.5mm\sqrt{n}$
where:
T_h – non-closure tolerance on height datum;
0.5 mm – admissible non-closure on the distance between surveying stations and levelling staffs;
n – number of distances between surveying stations and levelling staffs.

The most probable value of measured level differences will be equal to the measured level differences plus correction determined by the relationship (8).

$$(\Delta h_{A,1}) = \Delta h_{A,1} + v_{A,1}$$
$$(\Delta h_{1,2}) = \Delta h_{1,2} + v_{1,2} \tag{10}$$
....
$$(\Delta h_{n-1,B}) = \Delta h_{n-1,B} + v_{n-1,B}$$

where:
(Δh_{ij}) – the most probable value of the level difference;
Δh_{ij} – the measured level differences.

Absolute height datum marks will be calculated based on the most probable value of level differences shown in equation (9). Absolute height datums are calculated using the equation:

$$H_1 = H_A + (\Delta h_{A,1})$$
$$H_2 = H_1 + (\Delta h_{1,2}) \tag{11}$$
....
$$H_B = H_{n-1} + (\Delta h_{n-1,B})$$

Depending on the absolute height datums of markers determined in the current era (period) of measurement and absolute height datums determined on the base measurement will determine the compaction of landmarks in the current era (period) with the relations:

$$T_i^j = H_i^j - H_i^0 \tag{12}$$

where:
T_i^j – compaction of landmark i at era j;

H_i^j – absolute height datum of landmark i at era j;
H_i^0 – absolute height datum of landmark i at base era (period).

In the case of indirect measurements, each measured quantity will have a corresponding correction equation.
The correction equation system is written as matrix:

$$AX + l = V \quad (13)$$

where:
A –unknowns coefficient matrix;
X – column vector of unknown corrections;
l – column vector of free terms;
V – column vector of measured elements corrections.

Unknown corrections matrix is calculated using the equation:

$$X = (A^T PA)^{-1} A^T Pl \quad (14)$$

where:
A^T – transposed matrix A;
P – ponderous matrix;

The standard deviation of ponderous unit is calculated using the equation:

$$m_0 = \pm\sqrt{\frac{V^T PV}{n-k}} \quad (15)$$

where:
V^T – transposed column vector of measured elements corrections;
n – number of equations;
k – number of unknowns.

The most probable value of the absolute height datums are calculated using the relationship:

$$(H_i) = H_i + x_i \quad (16)$$

where:
(H_i) – the most probable value of absolute height datums;
H_i – provisional value of absolute height datums;
x_i – corection of provisional height datums.

$$(\Delta h_{i,j}) = \Delta h_{i,j} + v_{i,j} \quad (17)$$

where:
$(\Delta h_{i,j})$ – the most probable value of level differences;
$\Delta h_{i,j}$ – measured value of level differences;
$v_{i,j}$ – corections of measured elements.

To check the compensated level differences, the relationship applies:

$$[\,(\Delta h_{i,j})\,]_A^B \quad (18)$$

The landmark compaction is calculated with the same relationship as in the case of conditional measurements (relationship 12).

RESULTS AND DISCUSSIONS

The case study was conducted on the Fantanele Belis dam, Cluj County, constructed in 1974 with height of 92 m.
Fantanele dam is part of the Somes River hydropower planning scheme on the Fantanele – CHE Floresti II dam sector and the first hydrotechnical construction of the Somes Mic River management plan.
Fantanele dam is located on the Somes Cald River, downstream from Belis, upstream of the confluence of Somesului Cald River with Batrana on the left side and Valea Rea on the right side.
Fantanele hydrotechnical planning include:
- Fantanele reservoir lake and the slopes;
- Fantanele rockfill (riprap) dam.

Fantanele dam is a rockfill (riprap) dam with concrete mask placed on the upstream, with the mask preventing water infiltration into the dam body. Dam height is 92 m and weir crest height is 996 m. Normal retention level is 991 m.
Altimetric monitoring network for the vertical displacements is formed of 16 tracking markers, located on the dam weir crest and 8 tracking markers located on the dam berms. Initial leveling landmarks located near the weir crest on the two sides have been destroyed, and now fixed points are considered, landmarks located on pilasters I, PII and PIII.
Measurements made at Fantanele dam consist of:
- Measurements for the determination of dam stress factors (water level in the lake, air temperature and atmospheric precipitations in site).

- Measurements made to determine the dam displacements using topogeodezical landmarks placed on weir crest, upstream mask and downstream berms;
- Measurements to determine infiltration through the dam and foundation conducted at drainage wells, outlet drainage spillways and downstream toe of the dam;
- Measurements for determining the piezometric levels in hydrogeological drilling;
- Measurements to determine the specific pressures and strains in the upstream cut-off of the dam;
- Measurements to determine deformations in the rock foundation of the upstream cut-off.

As a result of measurements in May 2013 and their processing were obtained:

- Maximum displacements from the base measurement era (period) are:
  - -307.5 mm (compaction) at landmark RN10 – on weir crest (Figure 1b)
  - -41.6 mm (compaction) at landmark B6 – on berms (Figure 1d)
- Maximum displacements from the previous measurement era (period) are:
  - -3.2 mm (compaction) at landmark RN14 – on weir crest (Figure 1a)
  - -1.7 mm (compaction) at landmark B3 – on berms (Figure 1c)

As a result of measurements in October 2013 and their processing were obtained:

- Maximum displacements from the base measurement era (period) are:
  - -308.3 mm (compaction) at landmark RN10 – on weir crest (Figure 2a)
  - -41.8 mm (compaction) at landmark B3 – on berms (Figure 2c)
- Maximum displacements from the previous measurement era (period) are:
  - +2.5 mm (swelling) at landmark RN14 – on weir crest (Figure 2b)
  - -2.8 mm (compaction) at landmark B6 – on berms (Figure 2d)

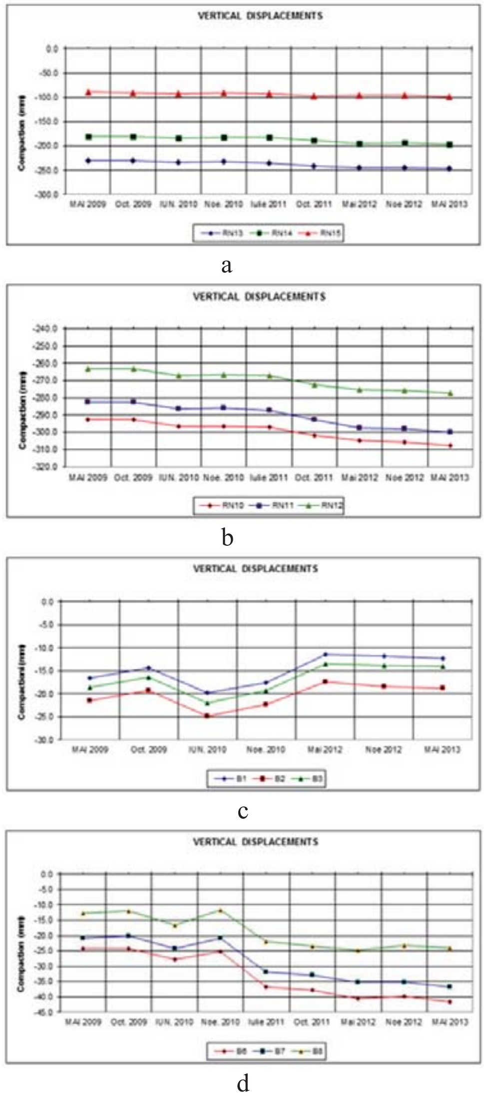


Figure 1. Vertical displacements (May 2013)

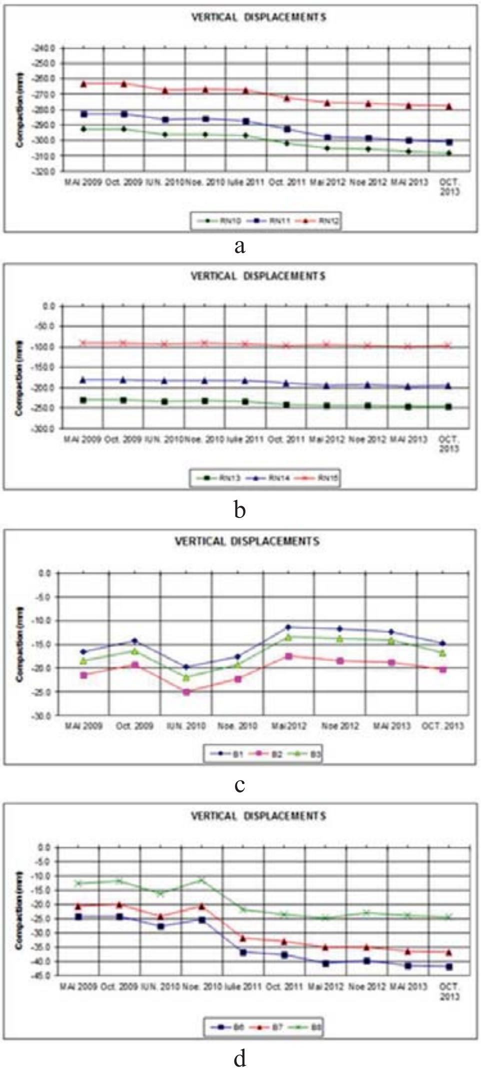


Figure 2. Vertical displacements (October 2013)

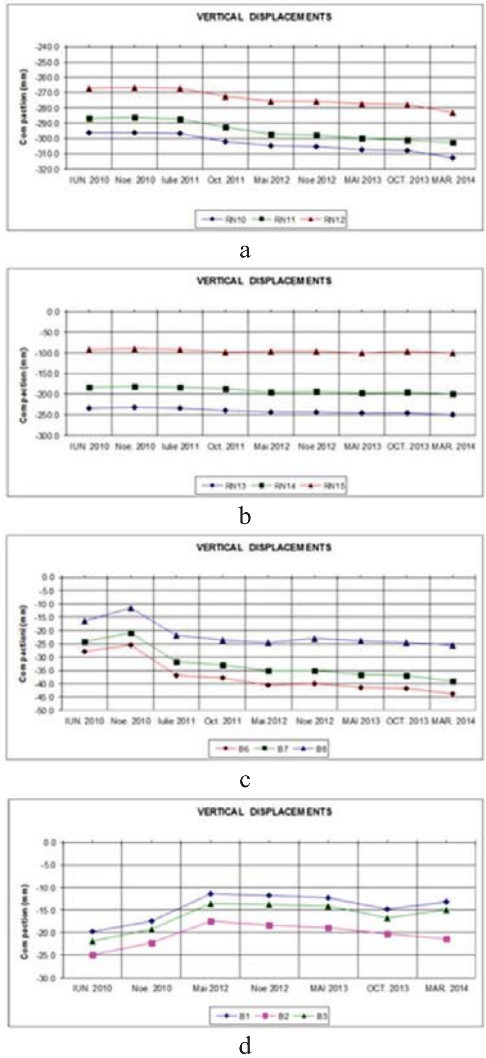


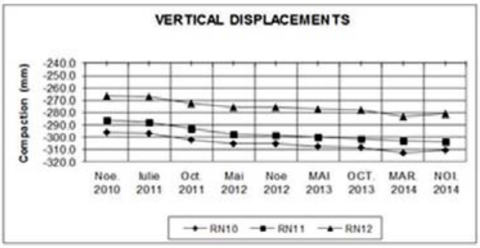
Figure 3. Vertical displacements (March 2014)

As a result of measurements in March 2014 and their processing were obtained:

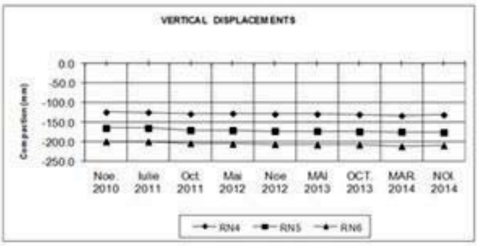
- Maximum displacements from the base measurement era (period) are:
  - -312.6 mm (compaction) at landmark RN10 – on weir crest (Figure 3a)
  - -44.0 mm (compaction) at landmark B6 – on berms (Figure 3c)
- Maximum displacements from the previous measurement era (period) are:
  - +5.4 mm (compaction) at landmark RN14 – on weir crest (Figure 3b)
  - +1.8 mm (swelling) at landmark B3 – on berms (Figure 3d)

As a result of measurements in November 2014 and their processing were obtained:

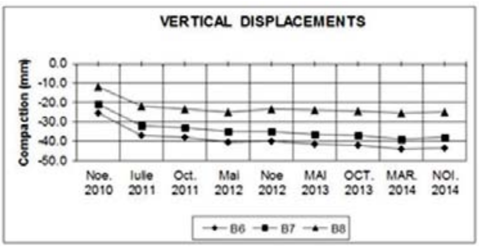
- Maximum displacements from the base measurement era (period) are:
  - -310.6 mm (compaction) at landmark RN10 – on weir crest (Figure 4a)
  - -43.5 mm (compaction) at landmark B6 – on berms (Figure 4c)
- Maximum displacements from the previous measurement era (period) are:
  - +2.0mm (swelling) at landmark RN6 – on weir crest (Figure 4b)
  - +2.5 mm (swelling) at landmark B 2– on berms (Figure 4d)



a



b



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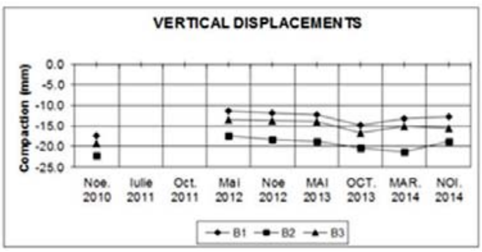

d

Figure 4. Vertical displacements (November 2014)

CONCLUSIONS

Considering the situation on the ground, projects which establish how to monitor construction behaviour, construction industry norms in order to achieve real results which ensures reliable interpretation of the complex phenomenon of construction displacement in time, the topographic activity to determine landmark points displacements, respectively building constructions in good condition and efficiency, the following are required:

- Ensuring an adequate visibility from the downstream pilasters of the dam to the landmarks on the dam berms.
- Rebuilding fundamental landmarks of RNS and RND levelling.
- Marking the landmarks for a proper identification.
- Ensure a minimum protection at the PD pilaster by installing a railing around it, thus avoiding the danger of falling from height. This pillar is located on the side wall of the water overflow.

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