DEFORMATION ANALYSIS IN CASE OF CONCRETE DAMS

Alexandra DREGHICI, Lect.PhD.Eng., "1 Decembrie 1918" University of Alba Iulia, Romania, alexandra.popa@hotmail.com

***Abstract**: Rigorous methods of displacement and deformation analysis need a relatively large volume of computations. In many cases, including concrete dams, the detection of displacements and deformations in a short time may help preventing any negative effects on monitored objectives and the environment. Therefore, we must understand, determine, and monitor the factors that may cause building deformations and, if case, take the corresponding measures in order to prevent any negative effects on the observed building. Mainly because of their role, concrete dams are included into the most important class of buildings that need to be monitored. In the paperwork, I chose as a case study the Tau Dam, included into Şugag-Tău Hydropower Complex, built on the Sebes Valley, Alba County, Romania.*

***Keywords:** Deformation analysis, monitoring geodetic network, global congruency test, spatial localization*

1. Introduction

The whole activity of monitoring and deformation analysis should begin with the design of the observation plan. The main steps that should be achieved are [4]:

- establishing the number, spatial distribution and materialization for the points of the monitoring geodetic network, according to their type;
- establishing the position accuracy for the monitored objective;
- establishing the measuring methods and instruments in order to achieve the required accuracy;
- establishing the period between the measurement epochs;
- planning the observations in order to determine displacements and deformations;
- establishing the data processing methods;
- preparing the documentation, based on the results.

In case of concrete dams, in order to ensure their protection and safety, we must consider the importance of the water use (indispensable element for life and society, material for productive activities, source of energy, strategic resources of water mean of transportation and many others).

The protection, enhancement, and sustainable development of this resource represent actions of general interest.

Beside the functional role, the concrete dams produce important effects on the environment. The insufficient knowledge of some elements may lead to severe catastrophes. In order to avoid these unwanted consequences, by the time of the dam construction, there must be installed some devices for behavior monitoring of the concrete dam [4].

2. Monitoring Methods and Deformation Analysis

Any monitoring project implies the existence of points with known coordinates, determined in a reference system. All these points make up the monitoring geodetic network. The processing depends on the network type, it’s destination, the distances between the points etc [4].

Usually, a geodetic monitoring network is a free network in order to increase the inside precision. In a free geodetic network, the initial data volume consists of provisional values of the unknowns, geodetic observations and the corresponding covariance matrix. Without additional conditions, the geodetic network can not be classified in a coordinate system. In this case, the rank defect is equal to the number of freedom degrees in the considered geodetic network [2], [3].

The functional model contains no random elements and describes a pure relationship between values. A point position will result after data processing at different measurement epochs. For geodetic measurements adjustment in order to determine any displacement and deformation, generally we are using a computational functional model (1) [2], [3]:

$$\begin{bmatrix} \mathbf{v_1} \\ \mathbf{v_2} \\ \mathbf{...} \\ \mathbf{v_k} \end{bmatrix} = \begin{bmatrix} \mathbf{A_{11}} & \mathbf{0} & \mathbf{...} & \mathbf{0} \\ \mathbf{0} & \mathbf{A_{22}} & \mathbf{...} & \mathbf{0} \\ \mathbf{...} & \mathbf{...} & & \mathbf{...} \\ \mathbf{0} & \mathbf{0} & \mathbf{...} & \mathbf{A_{kk}} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{x_1} \\ \mathbf{x_2} \\ \mathbf{...} \\ \mathbf{x_k} \end{bmatrix} - \begin{bmatrix} \mathbf{l_1} \\ \mathbf{l_2} \\ \mathbf{...} \\ \mathbf{l_k} \end{bmatrix} \tag{1}$$

The stochastic model contains random variables that characterize the possibility of displacement and deformation evolution. Because the geodetic measurements are affected by errors, they must be treated as random variables. The simplified stochastic model is given by relation (2) [2], [3]:

$$\mathbf{C_{mm}} = \sigma_0^2 \mathbf{Q_{mm}} = \sigma_0^2 \begin{bmatrix} \mathbf{Q_{11}} & 0 & \dots & 0 \\ 0 & \mathbf{Q_{22}} & \dots & 0 \\ \dots & \dots & & \dots \\ 0 & 0 & \dots & \mathbf{Q_{kk}} \end{bmatrix} \tag{2}$$

Deformation analysis consists on geodetic network adjustment at different measurement epochs, computing coordinate differences for the geodetic network point, and statistical testing in order to determine if the coordinate differences are significant.

For displacement and deformation analysis using the Pelzer method, there are some basic principles that need to be considered [2], [3], [4]:

- the geometry of the monitoring geodetic network at every measurement epoch *i* is given by the coordinate values $\mathbf{x_i}$ and the corresponding covariance matrixes $(\mathbf{C_{xx}})_i$;
- the coordinates are obtained after geodetic measurements processing, similar to the free geodetic networks;
- for each measurement epoch, we keep the same provisional coordinates for all of the monitoring geodetic network points;
- the statistical analysis of the displacements significance is based on the information obtained after the adjustments at each measurement epoch;
- chaining the configuration of the monitoring geodetic network may be possible, by changing in time the number of geodetic network points, or modifying the measurement plan;

- for the beginning of the deformation analysis, there is the global congruency test, in order to verify whether there are points with significant displacements or not;
- if the test shows that there are points with significant displacements, there is the localization phase.

Displacement and deformation analysis in this case is divided into two main phases:

- the global congruency test – establishes whether, between the two considered measurement epochs, there are points that suffered significant displacements;
- localization problem – if there are points with significant displacements, they will be identified.

The global congruency test must be formulated according to the verifying model of the linear hypothesis. The null hypothesis (3) establishes whether ther are points with significant displacements in the monitoring geodetic network, between the two measurement epochs [3]:

$$H_0: \quad M(\mathbf{x_0}) = M(\mathbf{x_k}) \tag{3}$$

The localization of the significantly displaced points: the difference vector **d** and the cofactor matrix of the coordinate differences (4) are divided into [3]:

$$\mathbf{d} = \begin{bmatrix} \mathbf{d}_F \\ \mathbf{d}_M \end{bmatrix} \text{ and } \mathbf{Q_{dd}} = \mathbf{P_{dd}} = \begin{bmatrix} \mathbf{P}_{FF} & \mathbf{P}_{FM} \\ \mathbf{P}_{MF} & \mathbf{P}_{MM} \end{bmatrix} \tag{4}$$

If the monitoring geodetic network includes a number of *p* points, than we will have *p* discordances (5):

$$R_i = \left(\left(\bar{\mathbf{d}}_F \right)^{\mathbf{T}} \mathbf{P}_{MM} \bar{\mathbf{d}}_M \right)_i \text{ , for } i = \overline{1, p} \tag{5}$$

The point with the maximum discordance $R_{\max}$ is considered to be a mobile point.

The computations are repeated until there are no more points that suffered significant displacements, according to the global congruency test. After all the computations, we will have all the stable points and the mobile points between the two measurement epochs.

3. Case study

For the case study, I chose the Tau Dam, one of the largest dams built on the Sebes River, Alba County, Romania – 78m height, 187m length.

The lake ensures the water supply for many towns in the area and the Hydropower Complex corresponding to the Tau Dam ensures the electricity supply in case of any deficiencies of other hydropower complexes [4] – Fig. 1.

Considering these aspects, one can conclude about the importance of the Tau Dam monitoring in particular and concrete dams monitoring in general (Law 466/2001 concerning the dams safety) [4].

Fig. 1. Tau Dam, Alba County, Romania

For the behavior monitoring of the dam, there must be made geodetic measurements every 6 months (in spring and in autumn) correlated with physical measurements [1].

In 1984, when the dam was built, there were placed on the dam canopy also 34 leveling benchmarks and 3 outside of the dam, representing the altimetric monitoring geodetic network. The 34 leveling benchmarks are placed both on the upstream and downstream of the canopy [4] – Fig. 2.

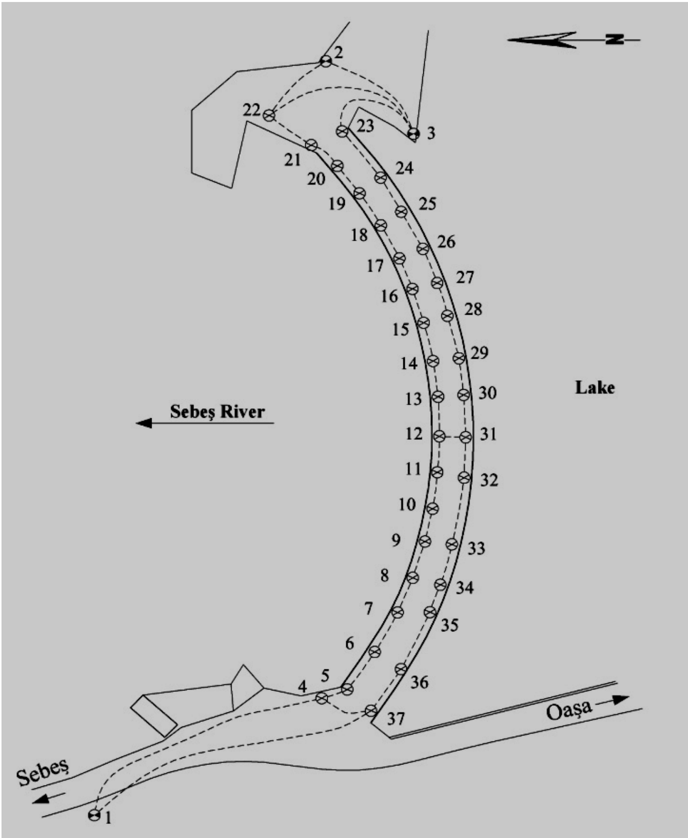

Fig. 2. The altimetric monitoring geodetic network

The geodetic measurements and processing were made using the polygon method, starting and ending with the 3 leveling benchmarks placed outside of the dam canopy, at each measurement epoch [4].

For this case study, we used 4 measurement epochs and the deformation analysis of the Tau Dam respected the main steps [2], [3]:

- geodetic observation adjustment – individual, for each measurement epoch;
- verifying the existence of significantly displaced points – applying the global congruency test;
- identifying the significantly displaced points, if case – the spatial localization problem.

For the geodetic observation adjustment, we consider the monitoring geodetic network to be free, and we computed the adjustment using the functional-stochastic model [2], [3].

After the adjustment, we obtained the altitudes for each leveling benchmark, at each measurement epoch, and also the precision indicators.

After the adjustment begins the proper deformation analysis, by applying the global congruency test in order to verify if there are points that suffered significant displacements between the analyzed measurement epochs. The acceptance of the null hypothesis means that there are no points that suffered significant displacements at the considered measurement epoch, while the rejection of the null hypothesis means that there are significantly displaced points in the monitoring geodetic network [2], [3].

After applying the global congruency test in case of the chosen concrete dam, we determined two significantly displaced benchmarks, in different periods.

Therefore, we ran over the next step, the spatial localization of these points. This step is based on the maximum discrepancy method. For each point there was calculated a discrepancy and the point with the maximum discrepancy is considered to have suffered a significant displacement [2], [3] .

The spatial localization showed that the levelling benchmarks 4 and 37 suffered significant displacements. For these points, there were calculated also the displacement and the displacement velocities – Table 1 [4].

Table 1. Significantly displaced leveling benchmarks

Measurement Epochs	**Point**	**Displacement** [mm]	**Displacement Velocity** [mm/year]
E0 – E1	4	-1.3	-1.2
E1 – E2	37	-1.1	-1.1
E2 – E3	37	3.1	2.9

For each leveling benchmark with significant displacement, there were drawn graphics of the deformation vector, such the one in Fig. 3, for leveling benchmark 37 [4]:

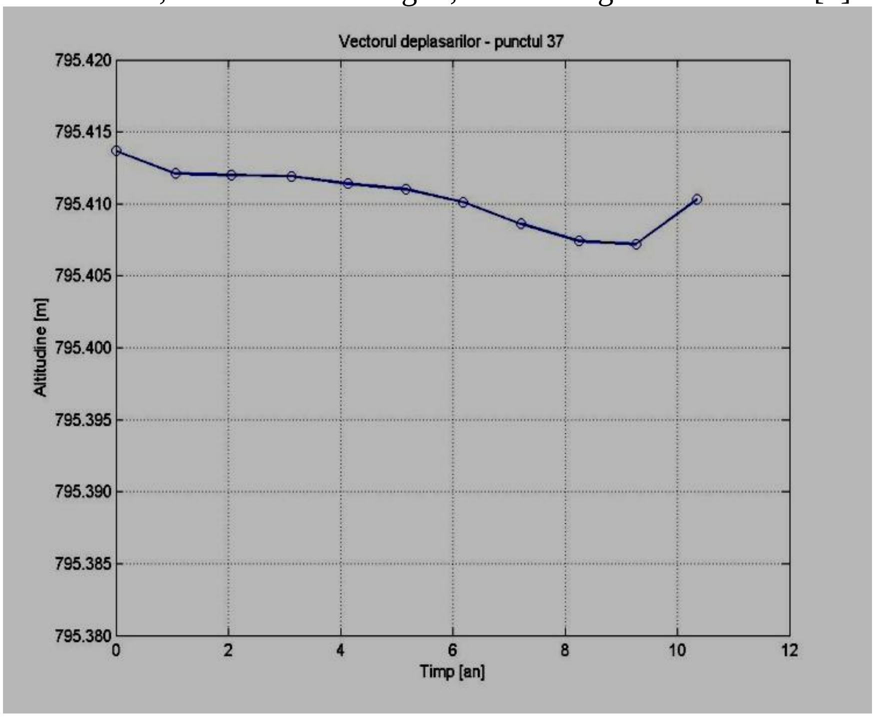

Fig. 3. Graphic representation of the deformation vector for benchmark no. 37

4. Conclusion

Measurement processing in order to determine displacements and deformations presents a high level of complexity and a huge amount of computations. The deformation analysis must be done according to mathematical statistics principles. This way, we will determine not only simple coordinate differences, but we will analyze the coordinate differences statistically [2], [3], [4].

Concerning the case study, I can say that after all the computations for the concrete dam on the Sebes River behavior monitoring, we identified 2 leveling benchmarks with significant displacements. For the future behavior forecast, we analyzed not only the leveling benchmarks identified with significant displacements, but all the leveling benchmarks of the monitoring geodetic network [4].

An important aspect is represented by drawing up behavior models for the monitored objective (concrete dam), which may supply information concerning displacements and deformations suffered by the monitored objective, the analysis of previous situations and behavior trend prediction [1], [2], [5].

5. References

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