PRACTICAL IMPLEMENTATION OF THE MIHAJLOVIČ METHOD IN THE "MANTOVO" DAM

Veton HAMZA[1]

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SUMMARY

In complex engineering objects such as dams, bridges, viaducts and other objects, deformations occur on them over time as a result of the external factors and the size of the objects themselves. In order to avoid potential disasters, these objects in certain time periods are supervised for potential deformations. There are a range of different methods of deformation analysis through which displacement of objects is determined. In this research a practical application of the *Method of Mihajlovič* is applied for determination of horizontal deformations of the *"Mantovo"* dam with the aim of analyzing the conducted results. In practical implementation two epochs of measurements are used, the first epoch from the year 1978 and the second epoch from the year 2008. From the conducted calculations it is confirmed that this methodology has its disadvantages in determination of the stable points that also affect the determination of the points that are located in the dam itself. This issue is overcome by setting more stable points when developing the network, these points should not be dislocated over time, but of course in natural environments this is difficult to achieve. The inability of determining the stable points is a major drawback that limits the practical implementation of this methodology.

Key words: geodetic network, deformations, stable points, epochs of measurements, deformation analyses.

1. DESCRIPTION OF THE DAM

The *"Mantovo"* dam was built in the late seventies of the last century. It is located in the southeastern part of the Republic of Macedonia, precisely in the Kiva Lakavica River. This accumulation has a capacity of 490 million m^3 water and is mostly used for agricultural needs in the region. It is an embankment dam, and has the following characteristics (Samarov, 2010):

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[1] **Ass.MSc.Veton HAMZA**, veton.hamza@unt.edu.mk,veton_hamza@hotmail.com,
University Mother Teresa- Skopje, Geodesy and Geoinformatics Department,
Adress: Negotino - Gostivar. FYROM, Tel +389 72 755 215

- the construction height (49.0 m)
- the slope of downstream side (1:2)
- the slope of upstream side (1:1.75)
- the length of dam's crest (138 m)
- the maximal width of the base (161.38 m).

The view of the dam on the accumulated side is shown in Fig.1 while the view on the side where geodetic points are placed is shown in Fig.2.

Fig.1. The view on the accumulation

Fig.2. Downstream side of dam

2. PREVIOUS MEASUREMENTS FOR AUSCULTATION OF THE DAM

During the construction of the dam a geodetic network was developed that was used for construction needs and then for performing auscultation. For determination of the altitude deformations a high network is used that consists of five benchmarks placed far from the dam that actually are the basic benchmarks, while also a part of the high geodetic network are the 15 geodetic points placed in the dam itself (Fig.5).

The horizontal network is composed of 26 geodetic points, which include 20 points arranged in three rows with a mutual distance of 22 m and 6 basic points that make up the basic part of the geodetic network from which the measurements were conducted (Fig.3). The points of the basic network are placed in the concrete pillars that also have devices for forced centering (Fig.4). For determination of the horizontal deformations, horizontal angles from the stations *I*,*II*,*III*,*IV*,*V* and *VI* to the points that are located on the dam are measured. The measurements are conducted in four series with the theodolite *Wild T3* with the precision of *1"*. The measured angles are controlled if they have rough errors with the *"Data Snooping"* method (Baarda, 1986).

The first epoch of measurement is done after the construction of the dam in the year 1978 and within this period the local coordinative system is also defined, and based on the measurements the approximate coordinates are determined. After the first epoch a couple epochs of measurements for osculation of the dam are done. In this research as the second epoch of measurements are the conducted measurements in the year 2008.

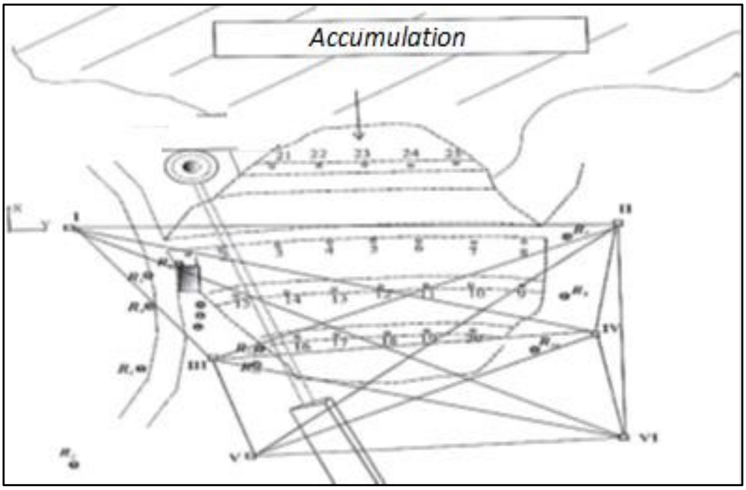


Fig.3.Geodetic network in the "Mantovo" dam

Fig.4.Points of the basic network

Fig.5.Geodetic points

3. METHODS FOR OSCULTATION

Nowadays different models for determining the deformation on the objects are used; among the safest methods are the method of *Pelzer, Caspary, Delft, Karlsruhe* etc. With the *Pelzer* method when equalizing the network the next conditions are required: $v^T pv=min$ and $x^T x=min$ (Mihajlovič and Aleksič, 1994). This method has a lot of similarities with the method of *Caspary* which also foresees the same conditions when equalizing the network (Caspary, 2000*)*.

The method of Mihajlovič differs from these methods because it foresees the use of conventional datum of the geodetic network, while with other methods the datum is optimal according to the S-transformations (Baarda, 1981). This methodology in practical application tends to give uncertain results, and in the Republic of Macedonia it is not used for the osculation of the dams and other complex objects. In the research this methodology of osculation on the *"Mantovo"* dam is applied, while the main goal is the analysis of the conducted results.

4. THE METHOD OF MIHAJLOVIČ

The method of Mihajlovič is classified in the group of conventional methods of deformation analyses, which unlike other methods requires the fulfillment of the next condition ($v^T pv=min.$) during the equalization of the geodetic network. This method is based on the stability of the coordinate system, if the points that define the coordinate system are not dislocated in the period between the two epochs, then the difference of the coordinates from the second and the first epoch will represent the deformations of the points. If the points that define the coordinate system are dislocated then the unstable points will undergo a displacement caused by the outside factors and instability of the coordinate system.

This methodology is based on two statistical tests, one of which refers to the difference of lengths and the second to the difference of the azimuth angles. In the beginning all of the azimuth angles and lengths of the sides are calculated using the formula that includes all combinations (Mihajlovič and Aleksič, 1994):

$$r = \frac{n(n-1)}{2} \quad \text{....(1)}$$

where:

r -number of sides of the network
n -number of points of the network

After defining the number of the sides, afterwards it is determined in which sides the differences of lengths obtained from first and the second epoch have a value around zero, and this is done with the next hypothesis (Mihajlovič and Aleksič 1994):

$$H_o = M[\Delta S_i] = 0 \quad \text{....(2)}$$

$$H_A = M[\Delta S_i] \neq 0 \quad \text{....(3)}$$

This hypothesis is checked through the statistical test (Mihajlovič and Aleksič, 1994):

$$t_i = \frac{\Delta S_i}{\sigma_{\Delta Si}} = \frac{\Delta S_i}{\sigma\sqrt{Q_{\Delta Si}}} \quad \text{....(4)}$$

In case of:

1. $t_i < t_{\alpha/2}$ the statistical test has a normal central dispersion and the first hypothesis is accepted (Form. 2).
2. $t_i > t_{\alpha/2}$ the statistical test has a normal eccentric dispersion and the alternative hypothesis is accepted (Form. 3).

The statistical test shows that the lengths in which the value of the statistical test is colored with red (the last column t_i) the first hypothesis applies (Tab.1), when solving practical cases the statistical test for lengths can also be performed through the next test (Mihajlovič and Aleksič, 1994):

$$|\Delta S_i| \leq 3\sigma_{\Delta Si} \quad \text{....(5)}$$

This condition is attained by the lengths shown in column ΔS_i marked with red color, as it can be seen from Table.1 this condition fulfills a large number of sides. From the Table1 it can be seen that we have two groups of points in which the difference of the azimuth angles are gathered around a particular value. One group consists of points *I,II, III* and *VI*, while in the other group we have the points *II,IV* and *V.* All these points can be declared as conditionally stable points. From these results it cannot be decided to which group of points should the test for azimuth angles apply, that is why the test is applied for both groups of points. Whether conditionally stable points are really stable will be confirmed through the difference of the azimuth angles, and the following hypothesis (Mihajlovič and Aleksič 1994):

$$H_o = M[\Delta\varphi_i] = 0 \qquad \text{....(6)}$$

$$H_A = M[\Delta\varphi_i] \neq 0 \qquad \text{....(7)}$$

This hypothesis is checked through the statistical test (Mihajlovič and Aleksič, 1994):

$$t_i = \frac{|\Delta\varphi_i|}{\sigma_{\Delta\varphi i}} = \frac{\varphi_i - \overline{\varphi}}{\sigma\sqrt{Q_{\Delta\varphi i}}} \qquad \text{....(8)}$$

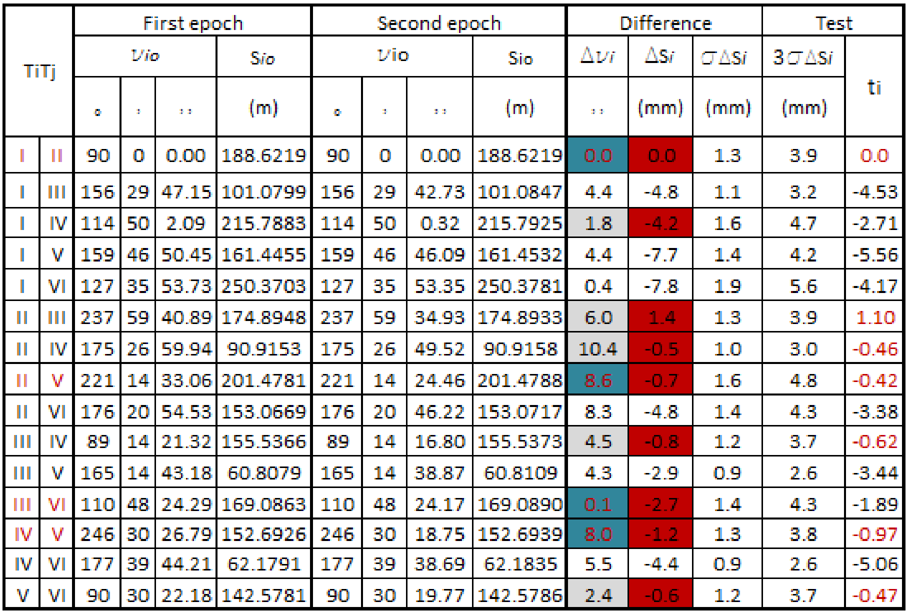
In case of:

1. $t_i < t_{\alpha/2}$ the statistical test has a normal central dispersion and the first hypothesis is accepted (Form. 6).
2. $t_i > t_{\alpha/2}$ the statistical test has a normal eccentric dispersion and the alternative hypothesis is accepted (Form. 7).

From the obtained values it is defined that the statistical test of azimuths applies to both groups of points, whereas the dilemma that appears is which group of points should be pronounced as stable. This issue is not easy to solve. The stable points impact the determination of the deformations of the points that are located in the dam itself, which is why the inability to define the stable points results in the impossibility of determining the deformations on the other geodetic points located on the dam.

The solution to this matter is to have stable points and their number should be higher than the number of the points that are declared as conditionally stable points (Mihajlovič and Aleksič, 1994). This means that when projecting the network, points need to be set in such a way in which we will be certain that they will not shift over time, which regarding the natural conditions is almost impossible.

Table1.The difference of the azimuth angles and the lengths between the second and the first epoch.



TiTj		First epoch				Second epoch				Difference			Test	
		ν_{io}			S_{io}	ν_{io}			S_{io}	$\Delta\nu_i$	ΔS_i	$\sigma_{\Delta S_i}$	$3\sigma_{\Delta S_i}$	ti
		°	′	″	(m)	°	′	″	(m)	″	(mm)	(mm)	(mm)	
I	II	90	0	0.00	188.6219	90	0	0.00	188.6219	0.0	0.0	1.3	3.9	0.0
I	III	156	29	47.15	101.0799	156	29	42.73	101.0847	4.4	-4.8	1.1	3.2	-4.53
I	IV	114	50	2.09	215.7883	114	50	0.32	215.7925	1.8	-4.2	1.6	4.7	-2.71
I	V	159	46	50.45	161.4455	159	46	46.09	161.4532	4.4	-7.7	1.4	4.2	-5.56
I	VI	127	35	53.73	250.3703	127	35	53.35	250.3781	0.4	-7.8	1.9	5.6	-4.17
II	III	237	59	40.89	174.8948	237	59	34.93	174.8933	6.0	1.4	1.3	3.9	1.10
II	IV	175	26	59.94	90.9153	175	26	49.52	90.9158	10.4	-0.5	1.0	3.0	-0.46
II	V	221	14	33.06	201.4781	221	14	24.46	201.4788	8.6	-0.7	1.6	4.8	-0.42
II	VI	176	20	54.53	153.0669	176	20	46.22	153.0717	8.3	-4.8	1.4	4.3	-3.38
III	IV	89	14	21.32	155.5366	89	14	16.80	155.5373	4.5	-0.8	1.2	3.7	-0.62
III	V	165	14	43.18	60.8079	165	14	38.87	60.8109	4.3	-2.9	0.9	2.6	-3.44
III	VI	110	48	24.29	169.0863	110	48	24.17	169.0890	0.1	-2.7	1.4	4.3	-1.89
IV	V	246	30	26.79	152.6926	246	30	18.75	152.6939	8.0	-1.2	1.3	3.8	-0.97
IV	VI	177	39	44.21	62.1791	177	39	38.69	62.1835	5.5	-4.4	0.9	2.6	-5.06
V	VI	90	30	22.18	142.5781	90	30	19.77	142.5786	2.4	-0.6	1.2	3.7	-0.47

5. CONCLUSION

The method of Mihajovič in contrast to other conventional methods of deformation analyses has shorter calculations for determining the stability of the geodetic points. The same is based on the stability of the coordinate system while the dislocation of the coordinate system is a result of the points through which the same is defined (Mihajlovič and Aleksič, 1994).

From practical application of this method in the *"Mantovo"* dam it is concluded that with the same it cannot be defined which points remained stable in the period between the two epochs of measurements, while the method of Pelzer gives certain results when using the same measurements (Ajro, 2014).

In our case the differences of the azimuth angles are gathered around two values, the first group, same as the second group, meets the requirements in order to be declared as stable points based on the statistical test of this methodology. Knowing that the calculation of deformations of other points depends on the stable points, the same are not calculated because it cannot be confirmed which of the points are stable. This issue is overcome if, when projecting, the network stable points are placed in such way that we will be certain that they will remain stable and will not shift. Taking into account the natural conditions the stability of the points cannot be guaranteed. The number of the stable points for which we are certain that they are not displaced should be higher than the number of the points for which we have a dilemma whether they are stable.

Knowing that the number of the points that need to be declared as stable (conditionally stable) is not always the same complicates the solution of the issue even more. If this issue is solved, then as stable points are declared those points in which the difference of the azimuths angles will be gathered more around a particular value within the measuring accuracy. This solution is debatable for the sole fact that the network already exists and placing new points would induce a series of additional measurements, analyses and costs.

The inability of defining the stable points and the deformation of the dam in practical application is a major disadvantage of this methodology that limits its implementation even though the calculations are shorter compared to others conventional methods of deformation analyses.

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