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USABILITY OF CHOLESKY FACTORIZATION METHOD IN THE DETERMINATION OF HORIZONTAL DEFORMATIONS: A CASE STUDY, ERMENEK DAM

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1. Introduction

One of the important task of geodesy is to determine deformation formed on the Earth and buildings.

Deformation measurements obtained from different areas are analyzed with different methods. Generally, θ^2 Criteria, Relative Confidence Ellipse Method, Mierlo Method, **Cholesky Factorization Method** and S Transformation Method are used in the analysis.

The horizontal deformations on the Ermenek Dam have been theoretically and practically determined by using Cholesky Factorization Method.

In the computations, a program was prepared by MATLAB 7.6.0 Release 13.0 M-File for analysis with Cholesky Factorization Method.

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2. Deformation Analysis By Cholesky Factorization Method

In case object points and fixed points in the control network can be **geometrically separable** Cholesky Factorization Method is a method that can **be used effectively.**

By taking unknown fix points, a partical trace minimum adjustment is made.

$$\hat{d}_F = \hat{x}_{2F} + \hat{x}_{1F} \qquad Q_{d_F} = Q_{1FF} + Q_{2FF}$$

$$R_F = d_F^T Q_{d_F}^+ d_F \qquad m_{01}^2 = R_F/f_1 \qquad (f_1 = 2.n_f)$$

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Taking advantage of the sum of the squares of the adjustments that calculated separately, **free adjustment results for both periods variance value that is common to both periods**

$$m_{02}^2 = \frac{\mathbf{v}_1^T \mathbf{P}_1 \mathbf{v}_1 + \mathbf{v}_2^T \mathbf{P}_2 \mathbf{v}_2}{f_{01} + f_{02}}$$

Test value T_1 $\quad T_1 = \frac{m_{01}^2}{m_{02}^2}$

If $T_1 < F_{f_1,f_2,1-\alpha}$ **there is no deformation in the fixed points.**

If $T_1 > F_{f_1,f_2,1-\alpha}$ **it is said that at least one fixed point has moved**

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In the case of deformation, the highest absolute value in the vector is removed. These operations are repeated until test value is smaller than F-table value.

After the test of the fixed point, it is proceed to the testing of object points. For fixed points a pair of coordinate unknown and for object points two pairs of coordinate unknown are selected and the measurement of periods are adjusted together.

$$\begin{bmatrix} \underline{v}_1 \\ \underline{v}_2 \end{bmatrix} = \begin{bmatrix} \underline{A}_I & \underline{A}_1 & 0 \\ \underline{A}_I & 0 & \underline{A}_2 \end{bmatrix} \begin{bmatrix} \underline{x}_F \\ \underline{x}_1 \\ \underline{x}_2 \end{bmatrix} - \begin{bmatrix} \underline{l}_1 \\ \underline{l}_2 \end{bmatrix} \qquad \underline{Q} = \begin{bmatrix} \underline{Q}_{FF} & \underline{Q}_{F1} & \underline{Q}_{F2} \\ \underline{Q}_{1F} & \underline{Q}_{11} & \underline{Q}_{12} \\ \underline{Q}_{2F} & \underline{Q}_{21} & \underline{Q}_{22} \end{bmatrix}$$

$$\underline{d} = \underline{x}_2 - \underline{x}_1 \qquad \underline{Q}_d = \underline{Q}_{11} + \underline{Q}_{22} - \underline{Q}_{12} - \underline{Q}_{21}$$

$$m_{03}^2 = \frac{\underline{\mathbf{d}}^T \underline{Q}_d^+ \underline{\mathbf{d}}}{f_3} \qquad f_3 = 2n_B$$

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Test value T_2

$$T_2 = \frac{m_{03}^2}{m_{02}^2}$$

If $T_2 > F_{f_s,f_2,1-\alpha}$, object points have moved with s = 1-α statistics confidence.

If $T_2 < F_{f_s,f_2,1-\alpha}$, it should not be immediately decided that there is no deformation and further detail examination should be considered. Because deformations are roughly investigated up to here.

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Elements of d vector must be converted into another uncorrelated vector. For that reason full weight matrix $\mathbf{P}_d$ of d vector;

$$\underline{P}_d = \underline{Q}_d^{-1}$$

and C is calculated to represent an upper triangular matrix as follow,

$$\underline{P}_d = \underline{C}^T \underline{C}$$

The quadratic form of vector was obtained by replacing the C matrix instead of P_d matrix;

$$q = \underline{d}^T \underline{P}_d \underline{d} = \underline{d}^T \underline{C}^T \underline{C}\, \underline{d}$$

This representation is shortened as so:

$$\underline{C}\, \underline{d} = \underline{r}$$

For each object point,

$$q = \underline{r}^T \underline{r} = r_{x1}^2 + r_{y1}^2 + \ldots + r_{xn}^2 + r_{yn}^2$$

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Test value **T,**

$$T = \frac{q_i}{2\, m_{02}^2}$$

If $T < F_{2,f_2,1-\bar{\alpha}}$ **,point has not moved.**

If $T > F_{2,f_2,1-\bar{\alpha}}$ **,point has moved.**

According to test result, if a point has not moved, the point is attached to class of fixed points and each step of anaylsis is repeated from the start.

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3. Applications

The Ermenek Dam is located on the Göksu river in Ermenek(Karaman, Turkey) in 2002. The dam is a thin concrete arch body –filling type. The volume of arch body is 272 000 m^3. and the height of the arch from the stream bed is 210.00 m. Ermenek dam is 21thdam in the world and 6th dam in Europe and first dam in Turkey in terms of body height.

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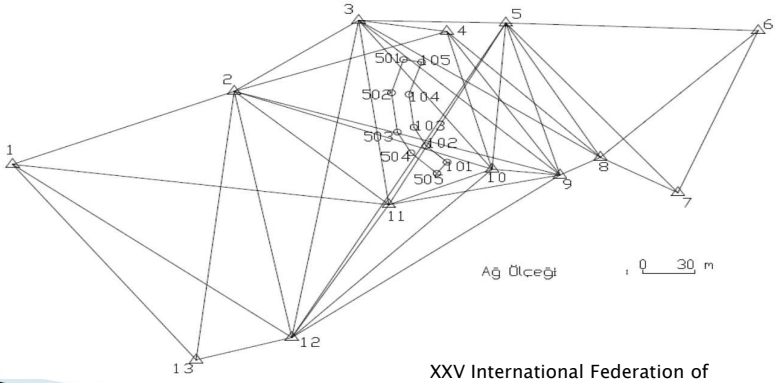
In order to determine movement on the crest of the Ermenek Dam, **13 reference** and **10 object points** were used. **Reference points** are numbered **as 1,2, .., 13**. **Object points** are numbered **as 101,102,103,104,105 (downstream side) and 501,502,503, 504.505(upstream side).**



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In geodetic network, **4 series direction observations** and **ranging data** were measured. In network, **166 direction observations**, **128 ranging data** were measured. Deformation research, using **the ranging data + direction observations** and **the only direction observations**, were made separately and the results were compared.

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3.1. Evaluation of period measurements

In this study, since the network can be geometrically divided, points 1-13 were taken as fixed-points and points 101-105 and points 501-505 placed on the crests as object points. **Evaluation was made** by using **only direction observations** and **direction observations + ranging data** separately and the effect of changes in the measurement plans on the analysis result were investigated .

Table 1. Determination of reference points exposed to deformations

Measurement Plan	T_1	F-table	Result	Reference points, exposed to deformation
Direction	9.19	$F_{26,220,0.95}$=1.54	+	1,2,5,10,11,12,13
Direction + range	15.32	$F_{24,469,0.95}$=1.52	+	1,2,4,5,7,10,11,12,13

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Table.2 Global test for object Point

Measurement Plan	T_2	F-table	Results
Direction	70.59	$F_{34,220,0.95}$=1.48	+
Direction+range	94.53	$F_{38,469,0.95}$=1.43	+

Table.3 Determination of object points exposed to deformation

Analyses according to directions observations								Analyses according to directions observations+ ranging data							
NN	**T**	**F-table**	**Results**	**NN**	**T**	**F-table**	**Results**	**NN**	**T**	**F-table**	**Results**	**NN**	**T**	**F-table**	**Results**
1	20.57	3.04	+	**101**	88.26	3.04	+	**1**	19.66	3.02	+	**101**	81.19	3.02	+
2	45.14	3.04	+	**102**	55.63	3.04	+	**2**	68.18	3.02	+	**102**	65.04	3.02	+
				103	59.41	3.04	+	**4**	24.27	3.02	+	**103**	76.83	3.02	+
5	28.64	3.04	+	**104**	**0.001**	**3.04**	-	**5**	61.02	3.02	+	**104**	34.96	3.02	+
				105	6.77	3.04	+	**7**	**0.93**	**3.02**	-	**105**	4.79	3.02	+
10	14.211	3.04	+	**501**	19.84	3.04	+	**10**	23.45	3.02	+	**501**	30.45	3.02	+
11	76.68	3.04	+	**502**	**0.002**	**3.04**	-	**11**	163.31	3.02	+	**502**	167.12	3.02	+
12	29.84	3.04	+	**503**	138.83	3.04	+	**12**	92.07	3.02	+	**503**	194.70	3.02	+
13	**1.97**	**3.04**	-	**504**	126.08	3.04	+	**13**	22.37	3.02	+	**504**	169.65	3.02	+
				505	129.45	3.04	+					**505**	187.09	3.02	+

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3.2. Introduction of the Program

In this study, a program performing the deformation analysis with Cholesky Factorization Method was prepared in the programming language MATLAB 7.6.0. Using the ranging data and directions observations measured in Ermenek Dam, the results have been interpreted. Before running the program a data file **"measures.doc"** was created by using Microsoft Office Excell to calculate the measurement, in this program primarily a file has been prepared in the format of the data to be received in as "measurement.doc". In this file there are measurements of **the ranging data**, **directions observations** from the first and second periods, and **approximated points coordinates** which will be used in calculations **(Figure 4)**.

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The codes which were necessary for the program to get data from this file were assigned. Then, the program takes this data sequentially and adjusts the first and the second period measurements with free adjustment and determines outlier measurements with Pope method. After then the partial trace minimum adjustment has been performed according to the fixed points (Figure 5).

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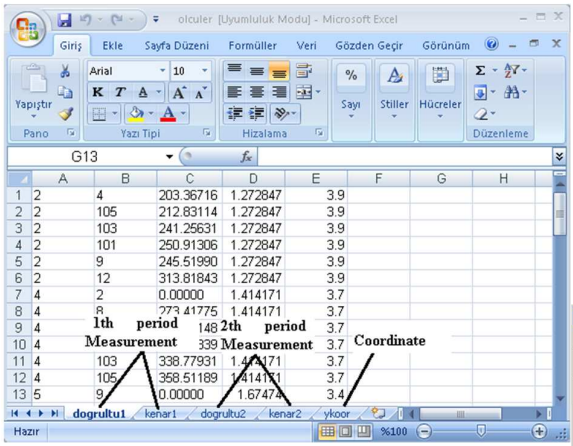

Figure 4. The screenshoot of data in Excell file data

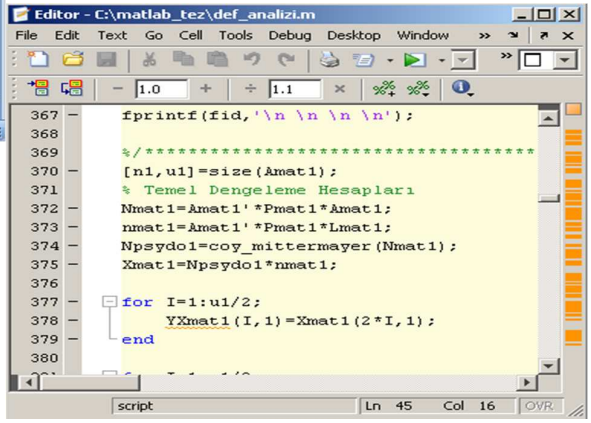

Figure 5. Screenshot of the code written in the basic adjustment operations

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After completing the adjustment processes, a global test is first run for fixed points and the localization process for fixed points is carried out. Following the deformation analysis based on fixed point, mass adjustment was done for object points which were converted into fixed point due to their movement. Later, global test run for whether there is a deformation in the moving network points and object points and localization of deformed points is performed (Figure 6).

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After completing all the calculations and analysis, the program saves data from adjustments for first and second periods, global and localization test of fixed points, mass data adjustments, global test of object points and localization of deformation at the object points in a “txt” file called as “results.txt”. (Figure 7).

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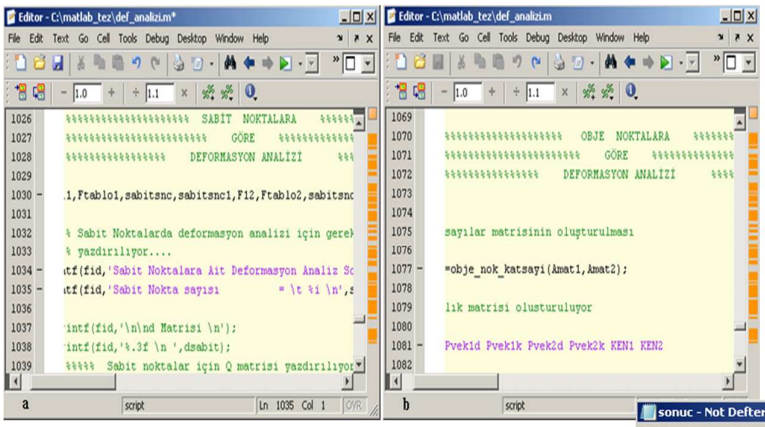

Figure 6. a) Deformation analysis according to Reference points, b) Deformation analysis according to Object points

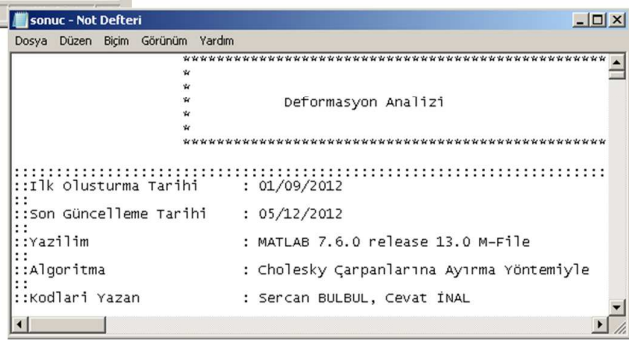

Figure 7. Screenshot of the results file

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4. Conlusions

- Different methods of analysis are used in the evaluation of deformation measurements.
- In this study, Cholesky Factorization Method which is one of the static evaluation methods used in the analysis of deformation is examined theoretically and directions observations and ranging data obtained from the Ermenek Dam for two periods in December 2010 and in June 2012 were separately evaluated according to directions observations and direction observations + ranging data separately and the results were compared.
- If reference points and object points on the network are initially known, Cholesky Factorization Method can easily be applied.
- It is a suitable method for programming. Movement analysis can be made with uncorrelated difference vector.

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- When the measurements carried out on the Ermenek Dam were evaluated, with 95% statistical confidence, any deformation **was not observed** on **reference points 4, 5, 6, 7, 8, 9, 13** and **object points 104, 502 in the evaluation done according to direction observations** and on **reference points 3, 6, 7, 8, 9 in the evaluation according to direction observation + ranging data**.
- At the points exposed to deformation, **movements were less than 6mm**. and it doesn't effect the result of movement analysis in the measurement plan.
- Using the MATLAB 7.6.0 Relase 13.0 M-File, a program developed by us and planned to make more professional in the future was used in calculations.

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Thank you for your patience

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