S Transformation and θ^2 Criterium Approach at Determination of Horizontal Deformations

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Key words: Deformation analysis, S Transformation, θ^2 Criterium

SUMMARY

The determination of deformations occurring at engineering structures like dam, bridge, building, etc. is extremely important in terms of reducing the severity of serious disasters, preventing life and good losses and safety of buildings. In this respect, the engineering structures are measured at definite intervals with terrestrial or satellite techniques and these measurements are evaluated with statistical methods.

In this study, the measurements made with terrestrial methods in a micro-geodesic network formed from 5 references and 20 object points at Dicle Dam were evaluated with S transformation and θ^2 criteria.

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1. INTRODUCTION

The last and the most important parts of the deformation research are the stages of data evaluation and discussion of results. Sometimes, the cost due to wrong decision becomes too large to be paid; therefore more attention should be spent. Until today, the analysis problem of deformation measurements has been investigated by many scientists. Aeschlimann (1971), Baumann (1972), Kuntz (1977), Milev (1973), Van Mierlo (1975), Niemeier (1975, 1977), Pelzer (1971, 1976), Chen (1983), Chrzanowski-Chen and Secord (1986) can be listed as the studies especially performed in the last 35 years.

There were developed many methods for deformation analysis. The applied analysis method presents differences with respect to the used model. In this study, S transformation and θ^2 criteria were used in the analyses of the geometrical changes of Dicle Dam.

2. DEFORMATION ANALYSIS WITH S TRANSFORMATION

The period measurements in the analysis of the deformation measurements are adjusted separately by free adjustment method. The outlier measurements are determined. The homogeneity test is performed for period variance. Before the localization process of the deformation, first of all, it is investigated whether there is deformation or not in the whole of the network by making global congruency test.

If the network geometries observed at times t_1 and t_2 vary (multivariant network), the global congruency test covers only the network sections formed by conjugate points. In other words, the networks measured at times t_1 and t_2 are positioned according to the conjugate points. S transformation matrix is used for this process.

The S transformation matrix is calculated with;

$$S = I - G\,(B^T G\,)^{-1} B^T \qquad (\,B = E\,.\,G\,) \tag{1}$$

equation (Kuang, 1996). I is the unit matrix in Equation (1). And G is the matrix of eigenvectors corresponding to d (defect) number of eigenvalues (λ=0) of matrix N which is the normal equation coefficients matrix. In a p pointed direction network having defect number of d = 4; on the verge of x_{io}, y_{io} (i = 1,…,p) are the approximate coordinate values, for G matrix;

$$G^T=\begin{bmatrix} 1 & 0 & 1 & 0 & \ldots\ldots\ldots & 1 & 0 \\ 0 & 1 & 0 & 1 & \ldots\ldots\ldots & 0 & 1 \\ -y_{10} & x_{10} & -y_{20} & x_{20} & \ldots\ldots\ldots & -y_{po} & x_{po} \\ x_{10} & y_{10} & x_{20} & y_{20} & \ldots\ldots\ldots & y_{po} & x_{po} \end{bmatrix} \begin{array}{l} \text{Translation of X axis} \\ \text{Translation of Y axis} \\ \text{Rotation} \\ \text{Scale} \end{array} \tag{2}$$

can be written. In triangulateration or trilateration networks, since the scale of the network is known, the last row of the G^T matrix disappears.

The E matrix named as datum selector matrix in Equation (1) is a diagonal matrix including value "1" corresponding to point coordinates assigning datum on its diagonal and value "0" for the other values of the matrix. The adjustment results in any *i* datum is transformed into *j* datum with S transformation by using equations (3),(4),(5) (Demirel, 1987).

$$S_j = I - G(B_j^T G)^{-1} B_j^T \tag{3}$$

$$x_j = S_j . x_i \tag{4}$$

$$Q_{xx}^j = S_j . Q_{xx}^i . S_j^T \tag{5}$$

In a network measured in time t_n, let's suppose that the conjugate (datum) points defined as "e" are determined by free adjustment having their coordinates in the first line and the coordinates of other points defined as "b" and the other unknowns at the second line. According to this, the x_i parameter vector related to i datum and the weight coefficients matrix is;

$$x_i = \begin{bmatrix} x_e^i \\ x_b^i \end{bmatrix} \tag{6}$$

$$Q_{xx}^i = \begin{bmatrix} Q_{ee}^i & Q_{eb}^i \\ Q_{be}^i & Q_{bb}^i \end{bmatrix} \tag{7}$$

divided into sections and then there is passed from *i* datum to *j* datum providing the positioning of network with respect to conjugate points by using Equations (3), (4) and (5). In j datum, the $(Q_{ee}^j)_1$ ve $(Q_{ee}^j)_2$ weight coefficients matrix is calculated together with $(x_e^j)_1$ ve $(x_e^j)_2$ coordinate unknowns.

The global congruency test of the conjugate points is calculated with;

$$H_o : E(x_e^j)_1 = E(x_e^j)_2 \tag{8}$$

$$d_e = (x_e^j)_2 - (x_e^j)_1 \tag{9}$$

$$(Q_{dd})_e = (Q_{ee}^j)_1 + (Q_{ee}^j)_2 \tag{10}$$

$$R_e = d_e^T (Q_{dd})_e^+ . d_e \tag{11}$$

and test value F is calculated with the following equation,

$$F = \frac{R_e}{m^2 . h_e} \tag{12}$$

where, $h_e = u_e - d$ is degrees of freedom of R_e.
$F \rangle F_{h_e, f, 1-\alpha}$ is judged to be a deformation at the section formed by the conjugate points of the network. The common variance m^2 that will be valid for 1st and 2nd periods in Equation (12) is calculated with the following equation (İnal and Ceylan, 2003).

$$\mathrm{m}^2 = \frac{f_1 . m_1^2 + f_2 . m_2^2}{f_1 + f_2} \tag{13}$$

Where;
m_1^2 : variance of 1st period
m_2^2 : variance of 2nd period
f_1 : the number of redundant observations of 1st period or degrees of freedom of 1st period
f_2 : the number of redundant observations of 2nd period or degrees of freedom of 2nd period

3.1 The Investigation of Significant Point Movements by Using S Transformation

If there is decided to be any deformation in the network at the end of the global congruency test, the investigation about moving points begins. Thinking each conjugate point is displaced, the x_e^i sub-vector including the conjugate point coordinates of parameters' vector (6) related to the period defined with free adjustment in *i* datum is divided into two sub-vectors namely x_h^i sub-vector including the coordinates of a point that is supposed to be moving and x_s^i sub-vector including the other conjugate (assumed to be constant) point coordinates. Since the parameters related to unconjugate points and the other unknowns are collected in x_b^i vector, the (6) vector and (7) weight coefficients matrix become;

$$x_i = \begin{bmatrix} x_s^i \\ x_h^i \\ x_b^i \end{bmatrix} \quad ; \qquad Q_{xx}^i = \begin{bmatrix} Q_{ss}^i & Q_{sh}^i & Q_{sb}^i \\ Q_{hs}^i & Q_{hh}^i & Q_{hb}^i \\ Q_{bs}^i & Q_{bh}^i & Q_{bb}^i \end{bmatrix} \tag{14}$$

Now the network measured in time t_n is positioned with respect to the constant accepted points whose coordinates exist x_s. When this datum is denoted with k, the S_k transformation matrix should be determined from Equation (3) appropriate to (14) differentiation;

$$G = \begin{bmatrix} G_s \\ G_h \\ G_b \end{bmatrix} \quad ; \qquad B_k = E_k.G = \begin{bmatrix} G_s \\ 0 \\ 0 \end{bmatrix} \tag{15}$$

and for each period;

$$x_k = S_k.x_i \tag{16}$$

$$Q_{xx}^k = S_k.Q_{xx}^i.S_k^i \tag{17}$$

transformations should be made. The d_s coordinate differences of the points accepted to be constant and their weight coefficients matrix $(Q_{dd})_s$ is calculated with;

$$d_s = (x_s^k)_2 - (x_s^k)_1 \tag{18}$$

$$(Q_{dd})_s = (Q_{ss}^k)_1 + (Q_{ss}^k)_2 \tag{19}$$

equations. R_s value is determined for each point of the x_e sub-vector.

$$R_s = d_s^T.(Q_{dd})_s^+.d_s \tag{20}$$

If it is decided to be any deformation at any location of the network as a result of the global congruency test, the movement at $(R_s)_{min}$ point is found to be significant and included in the x_b vector.

$$F = \frac{(R_s)_{\min}}{m^2.h_s} \tag{21}$$

If the test magnitude calculated with the above equation is found to be greater than $F_{h_s,f,1-\alpha}$ limit value, the (14)-(21) calculations will be repeated for the remaining conjugate points. The investigation about of the other moving points will remain continued (Demirel, 1987).

3. DEFORMATION ANALYSIS WITH θ^2 CRITERIA

In the deformation analysis performed with this method, again the period measurements are adjusted separately by free adjustment method. The outlier measurements are determined. The homogeneity test is performed for period variance. If the network geometries in the first and second periods differ from each other, the network is located with respect to common points.

A most appropriate variance value can be calculated with Equation (13) by associating the variances of separately and independently balanced L_1 and L_2 measurements. The Global congruency test is applied by using (8)-(12) equations as in the deformation analysis with S-transformation. If there is found deformation in the network with this test, the investigation of reference and object points begins.

3.1 Testing Reference Points

The difference vector d and the weight coefficients matrix Q_d are conveniently divided into sections. That is to say, the matrix is sectioned for reference and object points.

$$d = x_2 - x_1 = \begin{bmatrix} \underline{d}_S \\ \cdots\cdots \\ \underline{d}_O \end{bmatrix} \text{ and } Q_d^{\ +} = (Q_1 + Q_2)^+ = P_d = \begin{bmatrix} \underline{P}_{SS} & \vdots & \underline{P}_{SO} \\ \cdots\cdots & \cdots\vdots\cdots & \cdots\cdots \\ \underline{P}_{OS} & \vdots & \underline{P}_{OO} \end{bmatrix}$$

$$\theta^2 = \frac{d^T P_d d}{h} \tag{22}$$

the expression in the numerator of Equation (22) can be stated as;

$$\underline{d}^T \underline{Q}_d^{\ +} \underline{d} = d_S^{\ T} P_{SS} d_S + 2 d_S^{\ T} P_{SO} d_O + d_O^{\ T} P_{OO} d_O$$

From here, with the following transformation,

$$\begin{aligned} \underline{\bar{d}}_O &= d_O + P_{OO}^{\ -1} P_{OS} d_S \\ \underline{\bar{P}}_{SS} &= P_{SS} - P_{SO} P_{OO}^{\ -1} P_{OS} \end{aligned} \tag{23}$$

the discrepancy sections of the reference and object points can be separated as in the following.

$$\underline{d}^T \underline{Q}_d^{\ +} \underline{d} = \underbrace{\underline{d}_S^{\ T} \underline{\bar{P}}_{SS} \underline{d}_S}_{discrepancy\ for\ reference\ points} + \underbrace{\underline{\bar{d}}^T \underline{P}_{OO} \underline{\bar{d}}_O}_{discrepancy\ for\ object\ points}$$

The P_{ss} matrix calculated with Equation (23) belonging to reference points can be also calculated by making partial trace minimum solution.

The average discrepancy of reference points is calculated with the following Equation (24);

$$\theta_S^{\,2} = \frac{d_S^{\,T} P_{SS} d_S}{h_S} \tag{24}$$

the h_s value in Equation (24) is the number of members in d_s vector. The F_s test magnitude is calculated with Equation (25) for the points that are assumed to be fixed.

$$\hat{F}_S = \frac{\theta_S^{\,2}}{m^2} \tag{25}$$

The $F_{h_S,f,1-\alpha}$ value is taken from the F distribution table. If $\hat{F}_S > F_{h_S,f,1-\alpha}$ occurs, it is concluded that there is deformation at reference point area with 1- α confidence level. Otherwise, the positions of all the network points are accepted.

Some other tests are required to be performed in order to determine at which points the deformations actually occurred. The difference vector is sectioned by assigning each considered point as moving and other points as fixed points. Here d_B represents the coordinate differences of the point assumed to be moving, and d_F shows the coordinate differences of the other points accepted as fixed.

$$d_S = \begin{bmatrix} \underline{d}_F \\ \cdots\cdots \\ \underline{d}_B \end{bmatrix} \quad \text{and} \quad \underline{\overline{P}}_{SS} = \begin{bmatrix} \underline{P}_{FF} & \vdots & \underline{P}_{FB} \\ \cdots\cdots & \cdots\vdots\cdots & \cdots\cdots \\ \underline{P}_{BF} & \vdots & \underline{P}_{BB} \end{bmatrix} \tag{26}$$

appropriate to (23) transfromation,

$$\begin{aligned} \underline{\overline{d}}_B &= d_B + P_{BB}^{\;-1} P_{BF} d_F \\ \underline{\overline{P}}_{FF} &= P_{FF} - P_{FB} P_{BB}^{\;-1} P_{BF} \end{aligned} \tag{27}$$

is calculated. The quadratic expression in the numerator of $\theta_S^{\,2}$ in Equation (24);

$$\underline{d}_S^{\,T} \underline{P}_{SS} \underline{d_S} = d_F^{\,T} P_{FF} d_F + d_B^{\,T} P_{BB} d_B \tag{28}$$

can be written as the summation of the two terms given in Equation (28). The second term of Equation (28) at the right is formed from the discrepancy the examined point, and the first term is formed from the discrepancy of the other points of the network. The average discrepancy ratios of all the points existing in d_s vector can be calculated by using equations (26)-(28). If the number of points in d_s vector is k then for each point;

$$\theta_J^{\ 2} = \left(\frac{d_B^{\ T} P_{BB} d_B}{2} \right)_J \ (j = 1,2,......., k) \qquad (29)$$

the average discrepancy value can be calculated using the above formula (Equation 29). The value "2" in the denominator is the number of components existing in vector d_B. The maximum among $\theta_J^{\ 2}$ values is found by $\theta^2_{\max} = \max(\theta^2{}_j, j = 1,2.....,k)$. It is accepted to have deformation with s = 1 – α confidence level at the point where the average discrepancy is maximum.

If one of the reference points had deformation, the other network points should be examined whether they had any significant deformation or not. Therefore the discrepancy for k-1 number of points in Equation (29) is calculated by;

$$\theta^2{}_{kalan} = \left(\frac{d_F^{\ T} \overline{P}_{FF} d_F}{h_S - 2} \right) \qquad (30)$$

the global congruency test was applied for k-1 number of points.

$$P\left(\theta^2{}_{kalan} / m^2 > F_{h_S - 2, f, 1-\alpha} : H_0 \right) = \alpha \qquad (31)$$

can be written. If some other points are accepted to have deformation at the end of this test, the deformed point will be taken out of the d_F vector. This process was continued until the $\theta^2{}_{kalan} / m^2$ ratio becomes less than the limit value taken from the F distribution table. In this manner, the process ends in order to determine the displaced points. The points except the displaced ones were set as the actual fixed points.

3.2 Testing Object Points

After setting the fixed reference points, the determination process for object point deformations starts. The displaced reference points were subjected to the procedure as they were object points. The difference vector d and matrix P_d are divided into sections properly.

$$d = \begin{bmatrix} \underline{d}_F \\ \cdots\cdots \\ \underline{d}_O \end{bmatrix} \quad \text{and} \quad \underline{P}_d = \begin{bmatrix} \underline{P}_{FF} & \vdots & \underline{P}_{FO} \\ \cdots\cdots & \cdots\vdots\cdots & \cdots\cdots \\ \underline{P}_{OF} & \vdots & \underline{P}_{OO} \end{bmatrix} \tag{32}$$

The displacement component vector of object points with respect to the control points whose positions are proved to be fixed is obtained by;

$$\overline{\underline{d}}_O = d_O + P_{OO}^{-1} P_{OF} d_F \tag{33}$$

Where, $\underline{P}_{00}$ is the weight coefficients matrix related to $\overline{\underline{d}}_O$ vector.

The average discrepancy of the object points should be calculated as in the following;

$$\theta_O^{\,2} = \frac{\overline{\underline{d}}_O^{\,T} P_{OO} \overline{\underline{d}}_O}{h_O} \tag{34}$$

h_0 is the number of components existing in $\overline{\underline{d}}_o$ vector. Then, as fulfilled in the fixed point investigation, if there exists any deformation, the analysis should continue with the global congruency test and localization of deformation processes. All in all; the deformed points were determined and the displacement magnitudes related to these points were the components of $\overline{\underline{d}}_o$ vector (Pelzer, 1976).

4. NUMERICAL APPLICATION

In this study, a deformation research was carried out by the help of the measurements obtained at Dicle Dam in three periods (February 1998, April 1999 and April 2001). There were 5 reference and 20 object points in the network formed for the purpose of observing deformations. The foundation of number 302 object point was made but not included to the measurements (Figure 1). 58 directions and 49 distances were measured in the network. The distances between reference points are measured for three series, the distances from reference points to object points are measured for 2 series with Wild T2, and the distances are measured with Leica TC-1700 (m_s =±(2mm+2.ppm.S) for four times. The weights of directions and distances are calculated by using the relation that gives the measuring accuracy of the EDM and the standart deviation of one series direction measurement which is calculated as a result of station adjustments at the reference points.

The deformation research was performed with S-transformation and θ^2 criteria. First of all, the period measurements were separately free adjusted and the outlier measurements were determined with pope method. 3-4 distance and 5-3 direction observation were found outlier during the adjustment of 2nd period measurements. The deformation research was performed for February 1998 – April 1999 and February 1998 – April 2001 period of times. The coordinate differences obtained due to free adjustment of the network during the periods are given in Table 1 and Figures 2, 3 and 4. In addition, the homogenity test was applied for the period variances. Before all else, applying the Global congruency test in the deformation test, it was tested whether any deformation exists among the whole network or not. Due to having deformation in the network, the reference points numbered as 1, 2, 3, 4 and 5 and supposed to be fixed were examined whether they had any deformation or not, and the possibility of deformation at fixed points was determined at the end of the test. Therefore localization was applied on fixed points, and the deformed reference points were considered as the object points, and the deformed points with 95 % possibility were determined by repeating the test procedure (Table 2).

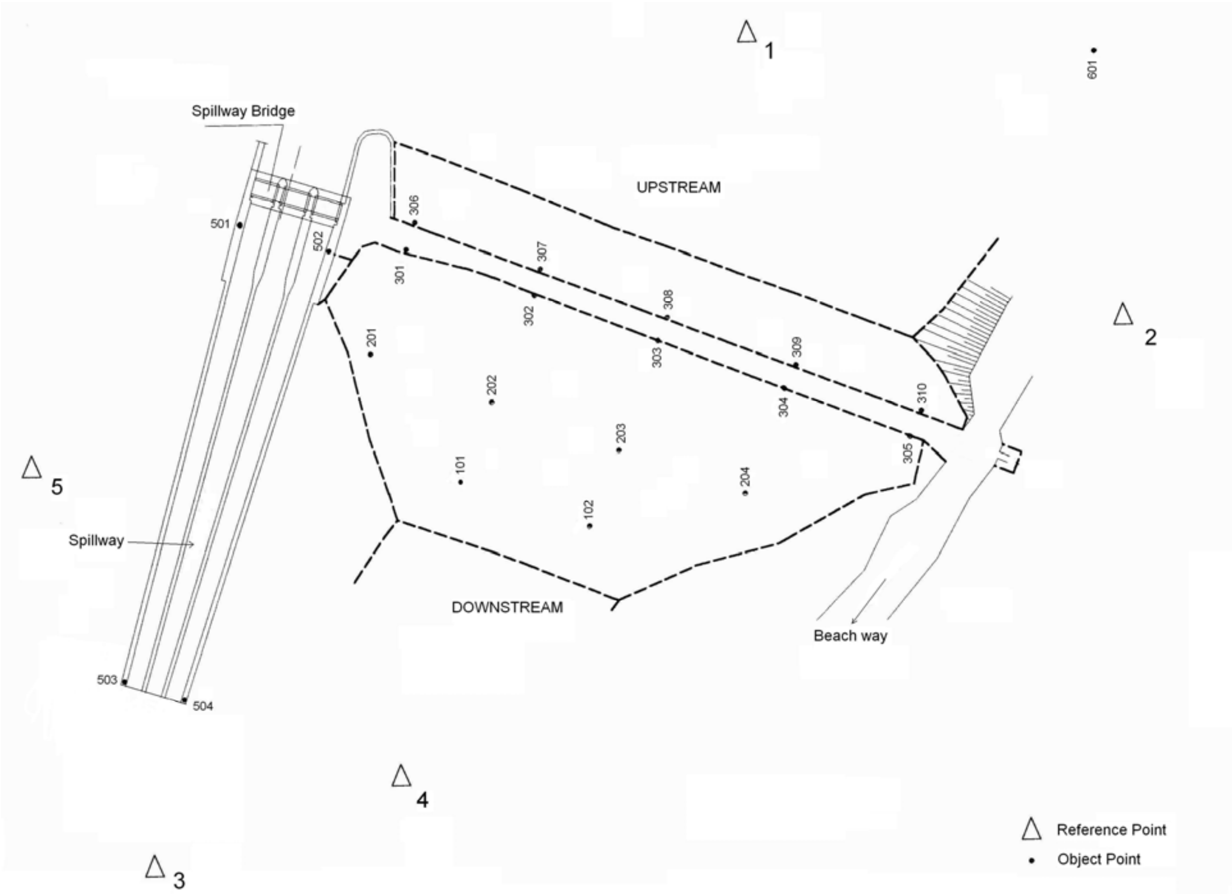

Figure 1: Dicle Dam-monitoring Network (Micro geodetic network with reference and object points)

Table 1: Coordinate difference according to free adjustment results between two period

Point Number	February 1998-April 1999			February 1998-April2001			Legend
	dx(mm)	dy(mm)	ds(mm)	dx(mm)	dy(mm)	ds(mm)	
1	-10.1	8.9	13.5	-16.8	12.5	20.9	Reference Points
2	-13.8	3.8	14.3	-10.8	6.4	12.6	
3	-14.1	-4.5	14.8	0.8	1.2	1.4	
4	1.8	-21.6	21.7	25.3	-40.4	47.7	
5	-9.1	-0.1	9.1	-5.6	10.8	12.2	
101	-55.6	-15.8	57.8	-70.0	-19.9	72.8	Upstream's Slope 2.line
102	-57.7	-11.0	-58.7	-75.1	-10.4	75.8	
201	-43.1	2.4	43.2	-62.4	3.1	62.5	Upstream's Slope 1.line
202	-80.9	-17.8	82.8	-130.5	-37.7	135.8	
203	-73.1	-26.4	77.7	-131.6	-44.3	138.9	
204	-38.7	-24.0	45.5	-63.0	-35.6	72.4	
301	37.1	145.9	150.5	40.6	208.4	212.3	Crest Upstream side
303	64.1	1.5	64.1	82.1	-8.1	82.5	
304	68.7	-6.4	69.0	105.2	-16.1	106.4	
305	61.7	-25.9	66.9	117.8	-21.1	119.7	
306	40.2	68.0	79.0	25.3	117.1	119.8	Crest Upstream side
307	68.4	-27.2	73.6	56.5	-45.4	72.5	
308	41.3	-5.8	41.7	9.3	-21.9	53.9	
309	53.1	-4.5	53.3	78.4	-17.6	80.4	
310	53.2	-46.8	70.9	30.1	-71.7	77.8	
501	-12.8	2.4	13.0	-8.8	6.9	11.2	Spillway bridge and ski-jump bucket
502	-11.4	4.9	12.4	-15.0	5.6	16.0	
503	-14.0	-1.6	14.1	-6.8	7.0	9.8	
504	-9.3	-3.2	9.8	-1.2	3.3	3.5	
601	-15.9	4.9	16.6	-13.6	8.0	15.8	Power Entrance

The d_s values in Table 1 are calculated with the following equation;

$$ds = \sqrt{dx^2 + dy^2} \tag{35}$$

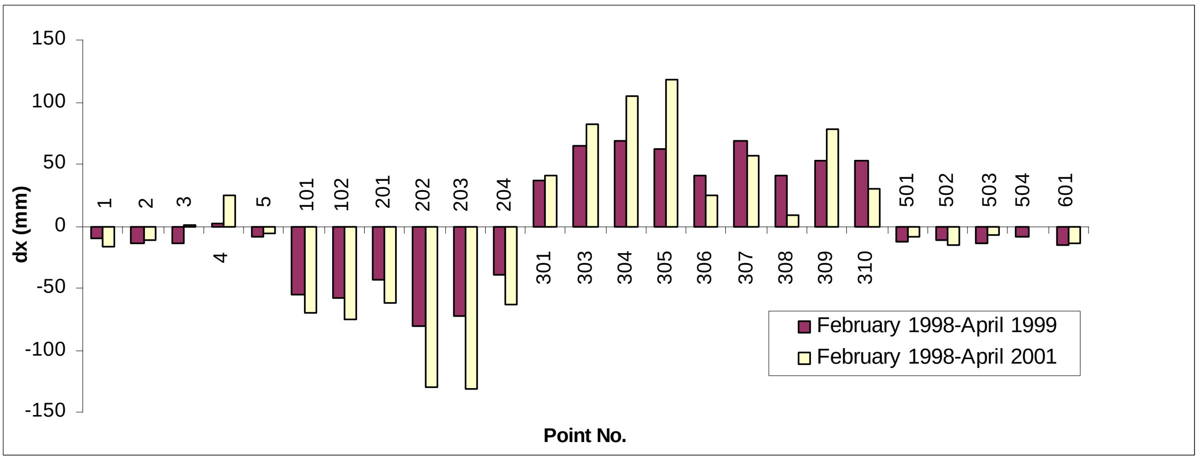

Figure 2: Coordinate difference according to free adjustment in the x axis

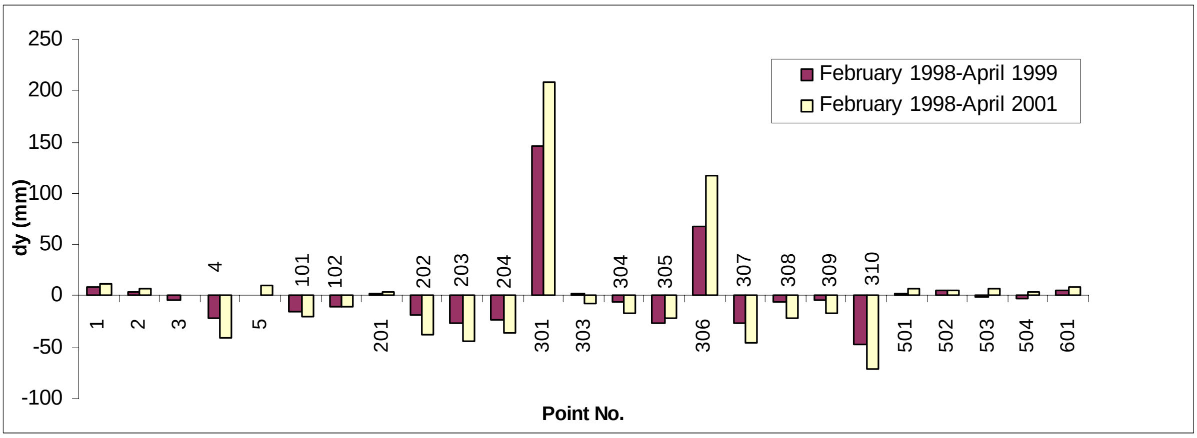

Figure 3: Coordinate difference according to free adjustment in the y axis

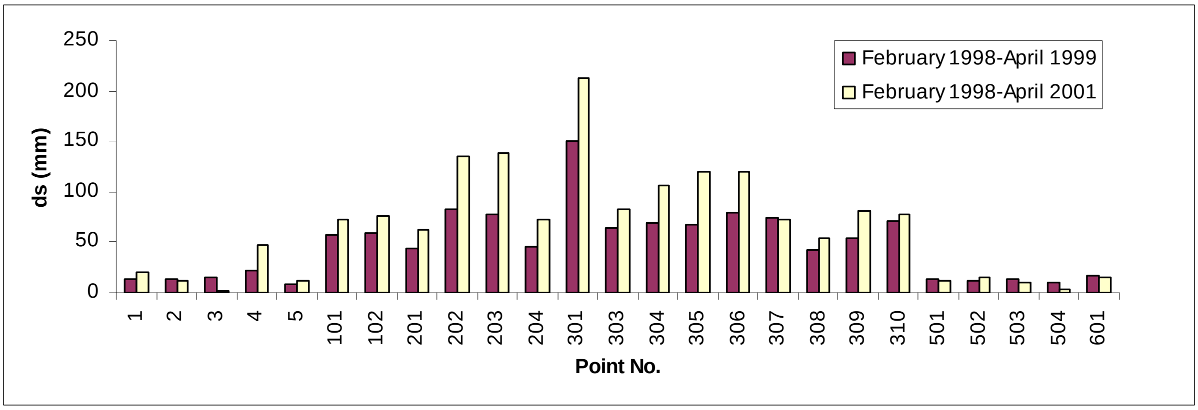

Figure 4: ds value calculated equation (35) according to free adjustment

Table 2: Results of deformation analysis

Point Number	February 1998-April 1999			February 1998-April 2001		
	S transformation	θ^2 Criterium	Localization sequence	S transformation	θ^2 Criterium	Localization sequence
1	√	√	-	√	√	-
2	√	√	-	√	√	-
3	√	√	-	√	√	-
4	x	x	10	x	x	9
5	√	√	-	√	√	-
101	x	x	13	x	x	13
102	x	x	14	x	x	15
201	x	x	15	x	x	14
202	x	x	11	x	x	4
203	x	x	12	x	x	5
204	x	x	16	x	x	16
301	x	x	3	x	x	1
303	x	x	8	x	x	8
304	x	x	7	x	x	7
305	x	x	9	x	x	6
306	x	x	6	x	x	10
307	x	x	4	x	x	11
308	x	x	5	x	x	12
309	x	x	2	x	x	3
310	x	x	1	x	x	2
501	√	√	-	√	√	-
502	√	√	-	x	x	17
503	√	√	-	√	√	-
504	√	√	-	√	√	-
601	√	√	-	√	√	-

√ There is not deformation. **x There is deformation.**

5. CONCLUSION

The analysis of horizontal geometrical variations in Dicle Dam was performed with S-transformation and θ^2 criteria. The period measurements were separately adjusted by free adjustment method and the outlier measurements were determined by pope method for the analysis fulfilled with both of the methods. The homogenity test was applied to the period variances that they were found in harmony, and the common variance value was calculated. Before all else, the Global congruency test was performed whether there exists any deformation or not at the whole of the network. Afterwards, the deformation existence was tested at fixed points, and the deformed reference points were determined by making localization. In the last step, the deformed reference points were included to the object points, and the deformation investigation was carried out for object points. Consequently, completely the same results were obtained with both S-transformation and θ^2 criteria methods.

REFERENCES

Aeschlimann, H., 1971. Zur Genauigkeit Geodätischer Verschiebungsmessungen Diss. ETH Zürich

Baumann, E.,1972. Die Anwendung Statistischer Methoden bei der Untersuchung Geodätischer Netze , DGK, Reihe C, No.175, München

Chen, Y.,Q.,1983.Analysis of Deformation sürveys- Generalized Method, Technical Report No.94, Dept. Of Surveying Engineering, University of New Brunswick.

Chrzanowski, A., Chen, Y. Q.,Secord, J.M.,1986. Geometrical Analysis of Deformation Surveys, Proceedings of the Deformation Measurements Workshop, MIT, Cambridge, Mass., pp.170-206.

Demirel, H.,1987. S transformasyonu ve Deformasyon Analizi, Türkiye 1. Harita Bilimsel ve Teknik Kurultayı, Ankara (In Tukish)

İnal, C., Ceylan, A.,2003. S Transformasyonu Uygulama Alanları, Selçuk teknik-online dergisi, Konya (In Turkish)

Kuang, S., 1986, Geodetic Network Analysis and Optimal Desing: Concepts and Applications, Ann Arbor Press, Onc. Chelsea, Michigan.

Kuntz, E.,Heck, B., Meier-Hirmer, B., 1977. Deformationsanalyse Mittels Relativer Fehlerellipsen AVN, Vol.84, p.78-87

Mierlo, J.,Van., 1975. Statistical Analysis of Geodetic Networks Designed for the Detection of Crustal Movements. In: Progress in Geodynamics-North-Holland Publ. Comp. Amsterdam/New York

Milev, G., 1973. Ausgleichung, Analyse und Interpretation von Deformationsmessungen, D.G.K., Reihe C. No.192.

Niemeier, W., 1975. Zur Generalisierung Gemessener Deformationen mit Statistischen Methoden FIG-Symp. Deformationsmessungen, Krakau.

Niemeier, W.,Buck, U., 1977. Beiträge zur Auswertung von Deformationsmessungen, XV FIG Congress of Surveyors, Stockholm.

Pelzer, H., 1971. Zur Analyse Geodätischer Deformationsmessungen, D.G.K., Reihe C, No.164, München

Pelzer, H., 1976. Ueber die Statistischen Eigenchaften der Ergebnisse von Deformationsmessungen VII Int. Kurs für Ingenieurmessungen hoher Präzision, Darmstadt.

BIOGRAPHICAL NOTES

Dr. Cevat Inal is a Professor at Selcuk University in Turkey. He has been academic staff at the university since 1983. His research interests focus on high precision surveying techniques, surveying applications, and engineering surveying applications, geodetic networks adjustment, high precision surveying instruments, deformation, and height determining studies.

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