The Effects of Geodetic Configuration of the Network in Deformation Analysis

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Key words: Network configuration, deformation analysis, optimization, confidence ellipses

SUMMARY

The optimization and design of monitoring scheme should precede the field observation and analysis procedures. Optimized monitoring schemes ensure the detection of predicted deformations according to a selected tolerance criterion. In this study, the effects of configuration of Gerede micro geodetic network in deformation analysis were researched. In this network, at first the deformation analysis has been carried out with respect to the results obtained through the direction and distance measurements made in 1983, and 1985. Then, measurement plans in two epochs were optimized. According to the optimized measurement plan deformation analysis has been carried out. Finally, deformation analysis results, which were obtained after optimization of measurement plan were compared and interpreted with the results that were obtained before optimization of measurement plans.

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1. INTRODUCTION

The aim of deformation analysis is the detection; localization and modelling of point movements in multiply measured networks. Such an analysis provides valuable information about the deformations of physical and man-made objects on the earth surface. In the deformation studies, geodetic observations are repeated at different epochs of time. The observations of each epoch are adjusted independently. From coordinate differences between the epochs, the parameters of the deformation model are estimated and conclusions on the object deformations are drawn.

The word “optimization” has recently come into use in geodesy to indicate designing networks based on well-specified quantitative considerations and techniques; it suggests planning for the best solution. Since design of deformation networks has major significance to determine deformation, the geodetic networks must have optimal design. An optimized monitoring scheme ensure the most economic field campaign, and it helps in identifying, eliminating, or minimizing the effects of the gross and systematic errors existing in the observation data prior to the estimation of the deformation parameters in order to avoid misinterpreting measuring errors as deformation phenomena.

In this study, the effects of configuration of Gerede micro geodetic network in deformation analysis were researched. The subject area is located on a fault line near Gerede around The North Anatolian Fault Zone (NAFZ) in Turkey. The network established for the detection of possible crustal movements in the area covering 4.2 km^2 consists of 8 points. In this network, at first the deformation analysis has been carried out with respect to the results obtained through the direction and distance measurements made in 1983, and 1985. The deformation analysis method applied in this study is called “deformation analysis with relative confidence ellipses”. Horizontal movements on the deformation points were determined regarding 95% statistical confidences. Then, the measurement plans in two epochs were optimized. In this optimization problem, some measurements were out of from the measurements plan. This procedure was repeated until a satisfactory network configuration was found. According to the optimized measurement plans, deformation analysis has been carried out. Finally, deformation analysis results, which were obtained after optimization of monitoring schemes, were compared and interpreted with the results that were obtained before optimization of measurement plans.

2. OPTIMIZATION OF GEODETIC NETWORK

The proper and optimal design and subsequent assessment of geodetic network is an integral part of most surveying engineering projects. Optimization and design are carried out before the measurements are actually made. The purpose of an optimal design is to solve for both the network configuration and observations accuracy in order to meet the desired criteria. Optimization means minimizing or maximizing an objective function which represents the criteria adopted to define the "quality of a network". Generally the quality of a control network is characterized by its precision, reliability,strength, and economy (Seemkooei 2001).

Different optimization problems are usually classified into different orders; Grafarend (1974) identifies four orders of design:

- Zero-order design (ZOD): design of a referance system
- First-order design (FOD): design of the network configuration
- Second-order design (SOD): selection of the weights for the network observations
- Third-order design (TOD): addition of observations to improve an existing network.

There are two methods that can be used to solve the design problem, namely, analytical method and trial and error method. In the trial and error method, a solution to the design problem is postulated upon which the design criteria are computed. If either of these criteria were not satisfied, a new solution is required and the criteria functions are recomputed. The procedure is repeated until a satisfactory network is found. In contrast, the analytical method offers specific algorithms for the solution of particular design problems, which do not require human intervention. The term analytical design is used to describe a method that solves a particular design problem by a unique series of mathematical steps (Kuang 1991).

In deformation analysis,the optimal design of network and optimization of measurement plan play crucial role. Objectives of the optimization of a deformation network are:

- To meet a predetermined accuracy goal
- To establish a self-checking and reliable mathematical model
- To yield sufficient sensivity in respect to certain a priori known functions of the parameters
- To design an observation plan which is feasible under pratical and financial constraints.

In this study, the first measurement plan was optimazed according to aim function. As the aim function, it was researched the geometry that respond both the mathematical-statistical test and the first deformation values in deformation points. Therefore, the test statistic was

$$T = \frac{\underline{d}_i^{\,T} \underline{Q}_{di}^{-1} \underline{d}_i}{2\sigma_0^2} \qquad (1)$$

selected as the aim function. The measurement plan that has minor impact on test statistic was researched. During this procedure, the geometry of the control network was not changed. In this procedure, firstly the measurement that had the least effect on test statistic was out of the measurement plan. After detecting the first redundant measurement, the second redundant measurement was researched. This procedure continued iteratively until a satisfactory network configuration- respond to the first deformation greatness in deformation points- was obtained. In the end, according to the last measurement plan, deformation analysis was done.

3. DEFORMATION ANALYSIS

Any object, natural or man-made, undergoes changes in space and time. Deformation refers to the changes a deformable body undergoes in it is shape, dimension, and position. Since the results of deformation surveys are directly relevant to the safety of human life and engineering surveying, recently deformation analysis has become more important.

In general, the deformation analysis is managed in three steps in geodetic networks. In the first step, the measurements that were carried out in t_1 and t_2 measurement epochs are adjusted separately, according to free adjustment method; outliers and systematic errors are detected and eliminated in this step. In the second step, global test procedure is carried out and by this test it is ensured that if the network point, which were assumed as stabile, stayed actually stabile in $\Delta t = t_2 - t_1$ time interval or not. In here, in the global test, after the free adjustment calculations of the networks separately, the combined free adjustment is applied both epoch measurements. During the combined free adjustment computation, the position of the assumed stabile points, are given as one single group of points for both epochs, on the other hand the positions of deformation points in t_1 instant are assumed as if one group of points and the positions in the t_2 instant are assumed as another group of points. In addition to this, in combined free adjustment, the partial-trace minimum solution is applied for the stabile points ($tr(Q_{stabile,\ stabile}) = min$). After determining a group of stabile points as the results of global test, the deformation points are handled one by one and it is inspected that if their positions are changed or not (Ayan 1982; Ayan et al. 1991, Erol 2003).

In this study "The Relative Confidence Ellipses Method" was applied. All the observations in the two periods were adjusted together as free nets by taking as datum points, which were assumed to be stable with respect to each other. For this process the datum point coordinate unknowns were taken as a one-valued set, but the other points were considered as a two-valued set, each value corresponding to each period.

The difference vector between the coordinates estimated from the combined adjustment of the points P_i was written as

$$\underline{d}_i = \begin{bmatrix} d_{yi} \\ d_{xi} \end{bmatrix} = \begin{bmatrix} Y_{2i} - Y_{1i} \\ X_{2i} - X_{1i} \end{bmatrix} \tag{2}$$

and with the cofactor matrix $\underline{Q}d_i$, the test statistic was

$$T = \frac{\underline{d}_i^T \underline{Q}_{di}^{-1} \underline{d}_i}{2\sigma_0^2}, F_{2,f;\alpha} \qquad ; f = n - u + d_i \tag{3}$$

Where, σ_0^2 was the estimated unit variance of the combined adjustment, f was the degree of freedom of this adjustment, $F_{1-\alpha;2,f}$ freedom 2 and f in level of significance α. If $T>F_{2, f; \alpha}$, the zero hypothesis H_o : E ($\underline{d}_i$) = $\underline{0}$ was rejected.

Deformation vectors were computed from

$$d_{si} = \sqrt{dx_i^{\ 2} + dy_i^{\ 2}} \tag{4}$$

and their directions were computed from

$$\alpha_i = \text{arctg}\left(\frac{dy_i}{dx_i}\right) \tag{5}$$

Confidence ellipses can be drawn geometrically using the results of the zero-hypothesis $\underline{d}_i$ = 0 (with

$\underline{d} = \sqrt{dx^2 + dy^2}$ as magnitude of the difference vector): first drawing the displacement vector and then the confidence ellipse at its top. If the displacement vector is not completely lying in the confidence ellipse, the hypothesis “the point has not moved” is rejected.

4. NUMERICAL APPLICATION

A significant part of Turkey is subjected to frequent and damaging earthquakes. Turkey is located on the relatively small Anatolian plate and, which is squeezed between three other major tectonic plates- the north–moving African and Arabian plates located to the south, and the south–moving Eurasian plate located to the north. The combination of these plate movements is forcing the Anatolian plate to move west into the Aegean Sea. This movement produces fault structures at the boundary between the plates, most significantly The North Anatolian Fault Zone (NAFZ). The NAFZ stretches 1500 km across Turkey and has been the source of eight earthquakes of magnitude seven or greater in the last century.

In this study, the effects of configuration of Gerede micro geodetic network on deformation analysis were researched. The subject area is located on a fault line near Gerede around The North Anatolian Fault Zone (NAFZ) in Turkey. The network established for the detection of possible crustal movements in the area covering 4.2 km^2 consists of 8 points. There are 23 distances and 48 directions measurement in Gerede micro geodetic network. The measurements were carried out between 1983 and 1985.

Before starting to optimize the first measurement plan it was necessary to decide that: which measurements’ influences are stronger in the network, distances or directions? For this reason firstly two epoch measurements were adjusted through the free adjustment procedure according to the first measurement plan. In the end, the adjusted coordinates have been obtained. In this study, from now on these free adjusted coordinates that were carried off according to the first measurement plan are called: “adjusted coordinates group one (ACG1)”.

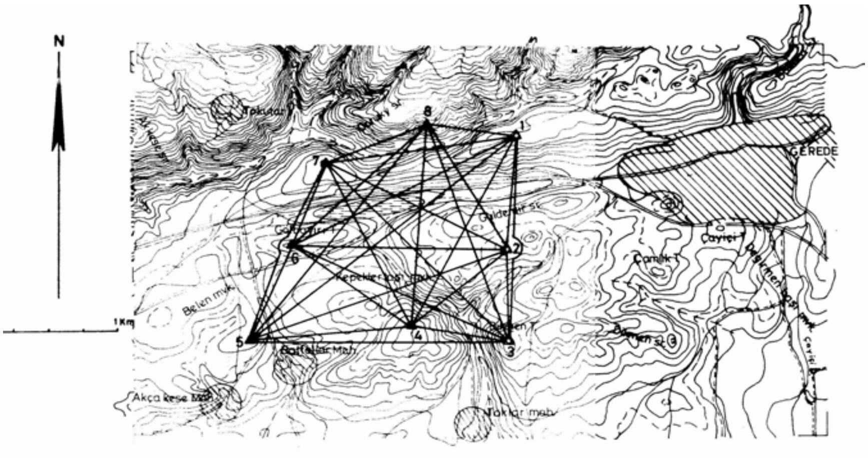

Figure 1: Configuration of the micro geodetic network in Gerede

After these computations, alternately distance measurements were out of from the first measurement plan. According to the new measurement plans, control network was adjusted. The adjusted coordinates, which were obtained according to the new measurement plans are called from now on: “adjusted coordinates group two (ACG2)”. The computations that were explained above for distance measurements were done again for direction measurements. This time the distance measurements stayed steady, and changes were done in direction measurements in the first measurement plan. In the end adjusted coordinates were obtained. These coordinates are called: “adjusted coordinates group three (ACG3)”.

Finally, the differences both ACG1-ACG2 and ACG1-ACG3 were researched. Differences both ACG1-ACG2 and ACG1-ACG3 are given in Table 1, Table 2, Table 3 and Table4.

Table 1: Adjusted coordinate differences when 1-3 distance measurement is out of from the first measurement plan

Compt. 13	**1983**		**1985**	
	ACG1-ACG2		**ACG1-ACG2**	
PN.	dy(mm)	dx(mm)	dy(mm)	dx(mm)
1	-0.01	-0.04	-0.01	-0.13
2	-0.01	0.00	-0.03	0.00
3	0.00	0.03	-0.01	0.11
4	0.00	0.01	0.01	0.04
5	0.00	0.00	0.02	0.02
6	0.00	0.01	0.02	0.01
7	0.01	0.00	0.01	0.00
8	0.00	-0.01	-0.01	-0.04

Table 2: Adjusted coordinate differences when 4-5 distance measurement is out of from the first measurement plan

Compt. 45	**1983**		**1985**	
	ACG1-ACG2		**ACG1-ACG2**	
PN.	dy(mm)	dx(mm)	dy(mm)	dx(mm)
1	-0.14	-0.07	0.00	-0.01
2	-0.17	-0.02	-0.02	0.00
3	-0.18	-0.06	-0.02	0.00
4	-0.54	0.02	-0.04	0.00
5	0.75	0.43	0.07	0.02
6	0.21	-0.13	0.01	-0.01
7	0.10	-0.08	0.00	0.00
8	-0.02	-0.08	0.00	0.00

Table 3: Adjusted coordinate differences when 1-3 direction measurement is out of from the first measurement plan.

Compt. 13	1983		1985	
	ACG1-ACG3		ACG1-ACG3	
PN.	dy(mm)	dx(mm)	dy(mm)	dx(mm)
1	-0.04	-0.10	-0.12	-0.29
2	-0.01	0.02	-0.01	0.07
3	0.14	0.02	0.44	0.07
4	-0.02	0.00	-0.06	0.01
5	-0.04	0.03	-0.13	0.10
6	-0.02	0.02	-0.05	0.05
7	-0.01	0.00	-0.05	0.00
8	0.00	0.00	-0.01	0.00

Table 4: Adjusted coordinate differences when 4-5 direction measurement is out of from the first measurement plan.

Compt. 45	1983		1985	
	ACG1-ACG3		ACG1-ACG3	
PN.	dy(mm)	dx(mm)	dy(mm)	dx(mm)
1	0.11	-0.02	-0.52	0.21
2	-0.03	0.00	0.15	0.08
3	-0.17	0.03	0.85	-0.02
4	-0.40	0.33	1.69	-1.30
5	0.12	-0.74	-1.17	3.07
6	0.12	0.18	-0.15	-1.07
7	0.12	0.15	-0.37	-0.65
8	0.14	0.08	-0.49	-0.32

In the light of differences both ACG1-ACG2 and ACG1-ACG2 it was concluded that the effects of direction measurements were stronger than the effects of distance measurements in the control network. Hence, it was decided that direction measurements had to be remained in the observation plan. In the end, by getting out distance measurements from the first measurement plan, the first measurements plan was optimized.

Before starting to optimize the measurement plan, the test statistic

$$T = \frac{\underline{d}_i^{\,T} \underline{Q}_{di}^{-1} \underline{d}_i}{2\sigma_0^2} \tag{6}$$

was selected as the aim function and the measurement plan that had minor impact on test statistic was researched. For this aim, alternately distance measurements were out of from the first measurement plan. According to new measurement plans free adjustment and analysis procedures were done. In the end of analyses, test statistic values were obtained. These test statistic values were compared with the first statistic values that were obtained according to the first measurement plan. Finally it was decided that 1-3, 1-4, 2-3, 4-5, 4-6, and 5-7 distance measurements had lower effect in test statistic value. The results are given in Table 5, Table 6, Table 7, Table 8, Table 9 and Table 10.

Table 5: Test statistic values when 1-3 distance measurement is out of from the first measurement plan.

Compt. 13	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	56.026
3	30.844	30.863
4	14.666	14.179
5	13.848	14.137
6	9.534	9.513

Table 6: Test statistic values when 1-4 distance measurement is out of from the first measurement plan.

Compt. 14	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	55.672
3	30.844	29.304
4	14.666	14.622
5	13.848	13.909
6	9.534	9.236

Table 7: Test statistic values when 2-3 distance measurement is out from the first measurement plan

Compt. 23	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	54.247
3	30.844	27.095
4	14.666	15.242
5	13.848	13.924
6	9.534	9.593

Table 8: Test statistic values when 5-7 distance measurement is out from the first measurement plan.

Compt. 57	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	56.016
3	30.844	31.448
4	14.666	15.179
5	13.848	11.484
6	9.534	10.119

Table 9: Test statistic values when 4-5 distance measurement is out of from the first measurement plan

Compt. 45	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	56.208
3	30.844	31.365
4	14.666	15.021
5	13.848	15.074
6	9.534	8.071

Table 10: Test statistic values when 4-6 distance measurement is out of from the first measurement plan.

Compt. 46	First Situation	Second Situation
Critical Value	4.82	4.83
P.N	Test Statistic	Test Statistic
2	56.004	55.856
3	30.844	29.464
4	14.666	14.489
5	13.848	12.964
6	9.534	8.904

In respect of these results, it was tried to be out more than one distance from the first measurement plan at the same time. For this aim, firstly three distances; 1-3, 1-4, and 5-7 were out of from the first measurement plan and deformation analysis was done according to new measurement plan. The results of the new measurement plan in test statistic are given in Table 11. According to Table 11, it is said that the influences of these three measurements in test statistic is insignificant. Thus, these three measurements can be omitted from the first measurement plan.

After this computation, four distances; 1-3, 1-4, 2-3, and 5-7 were out of from the first measurement plan. In addition to these computations the effects of five distances in test statistic were researched. For this aim, five distances; 1-3, 1-4, 2-3, 5-7, and 4-5 were out of from the first measurement plan. Finally, all of these computations were done for 1-3, 1-4, 2-3, 4-5, 5-7, and 4-6 distance measurements. By this computation, the effects of these six measurements in test statistic values in deformation points were researched. In the end, deformation analysis was done according to the last measurement plan. The effects of these changes in test statistic in deformation points are given in Table 12, Table 13 and Table 14.

Table 11: Test statistic values when 1-3, 1-4 and 5-7 distance measurements are out of from the first measurement plan

Compt. 13/14/57	First Situation	Second Situation
Critical Value	4.82	4.84
P.N	**Test Statistic**	**Test Statistic**
2	56.004	56.835
3	30.844	30.515
4	14.666	14.938
5	13.848	11.996
6	9.534	9.796

Table 12: Test statistic values when 1-3, 1-5-7 and 2-3 distance measurements are out of from the first measurement plan

Compt. 13/14/57/23	First Situation	Second Situation
Critical Value	4.82	4.84
P.N	**Test Statistic**	**Test Statistic**
2	56.004	58.508
3	30.844	26.513
4	14.666	16.280
5	13.848	12.575
6	9.534	10.475

Table 13: Test statistic values when 1-3, 1-4, 5-7, 2-3, and 4-5 distances are out of from the first measurement plan.

Compt. 13/14/57/23/45	First Situation	Second Situation
Critical Value	4.82	4.85
P.N	**Test Statistic**	**Test Statistic**
2	56.004	58.027
3	30.844	26.301
4	14.666	15.868
5	13.848	12.859
6	9.534	7.434

Table 14: Test statistic values when 1-3, 1-4, 5-7, 2-3, 4-5, and 4-6 distances are out of from the first measurement plan.

Compt. 13/14/57/23/45/46	First Situation	Second Situation
Critical Value	4.82	4.85
P.N	**Test Statistic**	**Test Statistic**
2	56.004	57.825
3	30.844	24.940
4	14.666	16.015
5	13.848	12.234
6	9.534	6.657

In the end all of these calculations, it was concluded that when1-3, 1-4, and 5-7 distance measurements were out of from the first measurement plan, there were not important changes in test statistics in deformation points. In this way, the most satisfactory network configuration, which responds to first deformation values in deformation points, was obtained. The measurement plans both the first one and the last one are given in Table 15 and Table 16. These two tables indicate that the last measurement plan has 13% less distance measurements than the first measurement plan.

Table 15: The first distance measurement plan in 1983.

FP	LP	S(m)
1	2	818.6683
	3	1635.1580
	4	1801.8880
	6	2092.2530
	8	927.7109
2	3	816.4893
	4	1115.0270
	7	1618.1940
	8	1247.8000
3	4	761.7194
	6	1785.2480
	7	1934.8990
	8	1893.8360
4	5	1166.8740
	6	1065.8740
	7	1375.2980
	8	1657.2610
5	6	790.9407
	7	1448.2920
	8	2191.9950
6	7	657.3559
	8	1439.6920
7	8	866.2374

Table 16: The last distance measurement plan in 1983.

FP	LP	S(m)
1	2	818.6683
	6	2092.2530
	8	927.7109
2	3	816.4893
	4	1115.0270
	7	1618.1940
	8	1247.8000
3	4	761.7194
	6	1785.2480
	7	1934.8990
	8	1893.8360
4	5	1166.8740
	6	1065.8740
	7	1375.2980
	8	1657.2610
5	6	790.9407
	8	2191.9950
6	7	657.3559
	8	1439.6920
7	8	866.2374

In Table 17, the results of deformation analysis that were obtained from the first measurement plan are given. Moreover, in Table 18, the results of the last analysis, which were obtained from the last measurement plan, are given. When these two tables compare, it comes out that:

- The largeness of deformation vectors in deformation points 2, 3, 4,5, and 6 stays the same
- There are no significant changes between the ellipsis parameters.

Table 17: The results of the deformation analysis obtained from the first measurement plan

Point Number	dY(cm)	dX(cm)	A-Konf(cm)	B-Konf(cm)	θ (gon)	d(cm)	t(gon)
2	-0.840	0.732	0.407	0.319	68.94	1.114	-54.36
3	-0.766	0.297	0.511	0.275	67.24	0.821	-76.40
4	-0.436	0.427	0.437	0.302	98.88	0.611	-50.68
5	0.007	0.547	0.806	0.297	328.72	0.547	0.88
6	0.008	0.441	0.466	0.278	340.16	0.441	1.16

Table 18: The results of the deformation analysis obtained from the last measurement plan

Point Number	dY(cm)	dX(cm)	A-Konf(cm)	B-Konf(cm)	θ (gon)	d(cm)	t(gon)
2	-0.804	0.784	0.465	0.327	54.80	1.123	-50.82
3	-0.696	0.387	0.691	0.301	55.06	0.796	-67.73
4	-0.372	0.484	0.562	0.337	77.52	0.610	-41.73
5	0.043	0.622	0.987	0.359	334.61	0.624	4.44
6	0.036	0.452	0.506	0.282	342.76	0.453	5.00

Furthermore, the horizontal displacement vectors between two epochs are shown in Figure 2 and Figure 3 together with 95 % confidence ellipses. It is clear that all of the displacement vectors are only just falling outside the relative confidence ellipses and they are marginally significant both the results of the first analysis and the results of the last analysis.

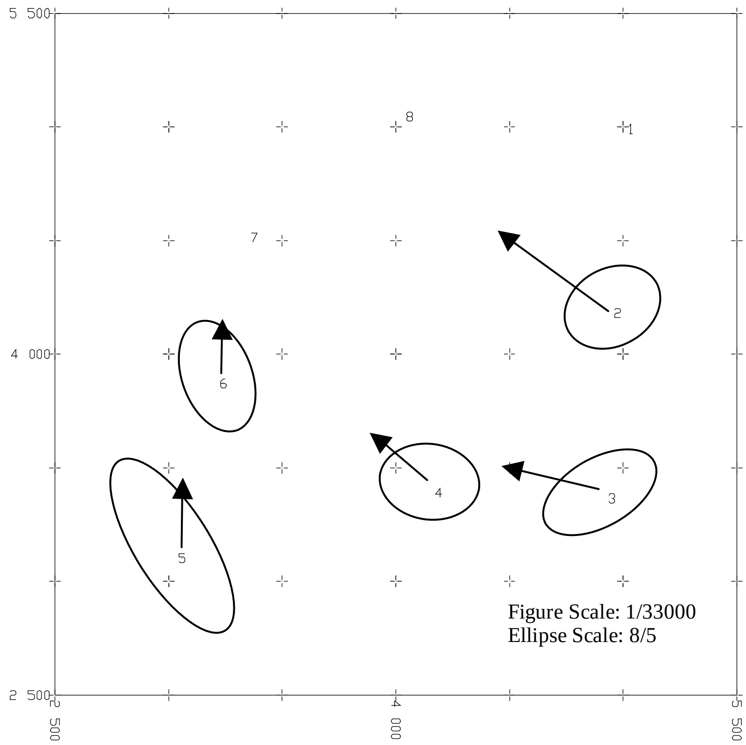

Figure 2: The horizontal displacement vectors between 1983 and 1985 together with 95% confidence ellipses according to the first analysis results that was done related to the first measurement plan.

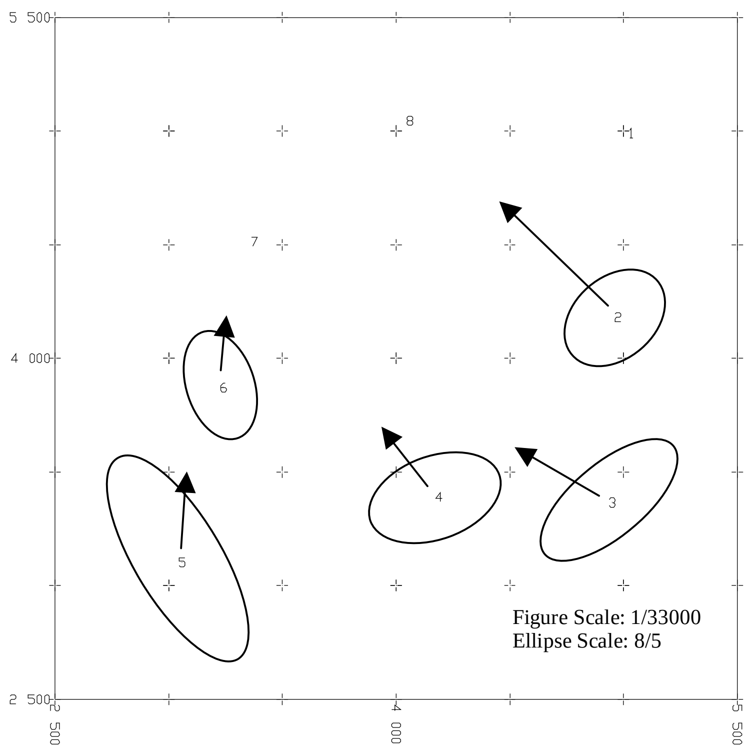

Figure 3: The horizontal displacement vectors between 1983 and 1985 together with 95% confidence ellipses according to the last analysis results that was done related to the last measurement plan.

5. CONCLUSIONS

In this study, the effects of geodetic configuration of the network in deformation analysis were researched. It was studied to get the most satisfactory network configuration that responds to the first deformation values in deformation points. In the last measurement plan, distance measurements were 13% decreased. Three distance measurements, 1-3, 1-4, and 5-7 were out of from the first measurement plan and the first measurement plan was simplified. In the end of the deformation analysis that was done according to the last measurement plan, the largest movement occurred with 1.12 cm in the point number 2. The minor movement occurred with 0.45 cm in the point number 6. Finally, it is obtained that the last analysis results are the same with the first analysis results.

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“International Symposium of Modern Technologies, Education and Professional Practice in the Globalizing World”, 06 – 08 November 2003, Sofia, Bulgaria

"Turkey National Geodesy Commission (TUJK) Geographic Information Systems and Geodetic Networks Workshop", Workshop of Turkey National Geodesy Commission, 24-26 September 2003, Selçuk University, Konya, Turkey
"Turkey National Geodesy Commission (TUJK) 2002 Year Scientific Workshop– Tectonic and Geodetic Networks", "Panel on the new Regulation on production of Maps and Map Information, 10-12 October, 2002, Earthquake Research Center of Boğaziçi University, İznik, Turkey

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