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Full Length Research Paper

GPS network adjustment regarding active fault lines in Bursa Metropolitan Area, Turkey

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Turkey is located on one of the world's seismically most active regions. In such a region, a geodetic network evaluation may not satisfy standards ordered by national regulations. In such a way, effects of active fault lines should be taken into consideration apart from possible reasons, such as outliers, shortcomings of functional and stochastic models, in a computational procedure. This study deals with the evaluation of the Bursa Metropolitan Area (BMA) basic GPS network. The precisions of the network observations were quite better than the tolerances of the Turkish regulation. However, the adjustment was resulted in the model test failure. Investigations showed that the problem was caused by the effects of the active faults on the region. To solve the problem, an approach regarding the fault lines was applied.

Key words: Geodesy, geodetic networks, adjustment, active faults.

INTRODUCTION

Bursa Metroplolitan Area (BMA) is a heavy industrial area located in the Southern Marmara Region of Turkey (Figure 1). The first photogrammetric base maps of BMA which covers 1300 km2 were produced in 1994. The population and the urban area of Bursa rapidly grew through the elapsed fifteen years. Therefore, a new project came to order for producing the actual base maps of the area. The first step of this project was to establish a basic geodetic GPS network to which the ground control points required for the photogrammetric compilation and other geodetic operations. For this purpose, a basic GPS network with 73 site points was set up over an area of 4000 km^2 (Figure 1). This network was observed and processed with respect to regulation on large scale map productions being in force in Turkey. However, there are plenty of active faults in Turkey. One of them is the famous North Anatolian Fault (NAF). The NAF splits to two branches in Marmara Region; one branch goes through Marmara Sea, and the other one runs towards the Bursa basin. The aforementioned situation necessitated a further approach for processing the basic network regarding the active fault structure in the project area.

OBSERVATION AND ADJUSTMENT PROCEDURE WITH RESPECT TO THE REGULATION IN TURKEY

According to the regulation a basic GPS network is to tie the Turkish National Fundamental GPS Network (TUTGA-Turkish acronym). TUTGA is referenced to ITRF96 at 1998.0 epoch. After the 1999 major earthquakes, Golcuk Mw=7.4 and Duzce Mw=7.2, the reference epoch 1998.0 was replaced with 2005.0 for Marmara Region where the earthquakes occurred. The maximum baseline between the site points must be smaller than 20 km (Deniz et al., 2008).

Network observations have to be carried out in static mode with a minimum duration of 2 h, a cut off angle of 10° and a maximum sample rate of 15 s. The baseline

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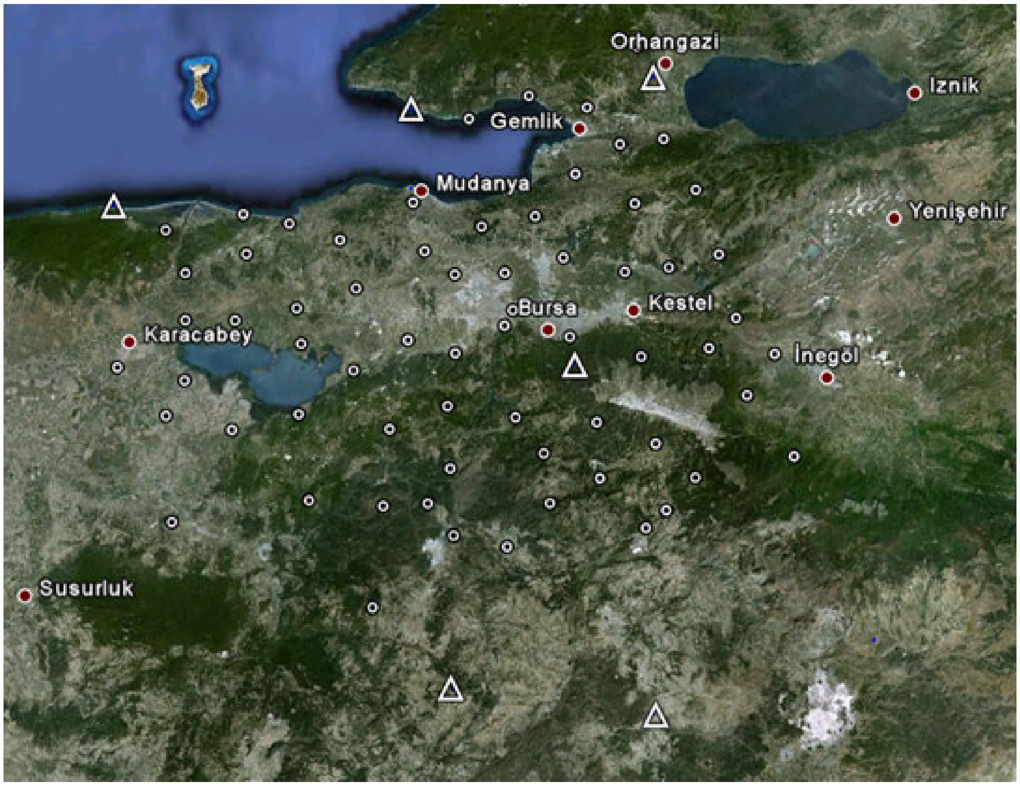

Figure 1. The basic GPS network in BMA. The triangles represent TUTGA points while the dotted circles represent the other basic network points (The satellite image obtained from google earth).

components obtained must satisfy precision limits $\sigma_{\Delta X}, \sigma_{\Delta Y}, \sigma_{\Delta Z} \leq \pm(10mm + 1ppm)$ (Deniz et al., 2008). The network adjustment is to perform in two steps. In the first step, the network is adjusted by the method of free network adjustment. Then, a similarity transformation is applied between the coordinates of TUTGA points known and obtained from the adjustment. The scale factor resulted in the transformation must satisfy 1-λ ≤ ± 3 ppm (Deniz et al., 2008).

If the above-mentioned scale condition is satisfied a final adjustment is conducted by the method of constraint adjustment with respect to the TUTGA points. The coordinates adjusted must satisfy the precision conditions σ_φ, $\sigma_\lambda \leq \pm$ 3 cm, $\sigma_h \leq \pm$ 5 cm (Deniz et al., 2008).

BMA BASIC GPS NETWORK AND ITS ADJUSTMENT

In accordance with the regulation, the six TUTGA points located in the project area were included in the basic network, and the other site points were set up regarding a point gap < 20 km. The observation plan displayed by Figure 2 was carried out between 1st - 5th July, 2009, using 4 Leica AT502 and 5 Trimble 41249 receivers. A total number of the baselines observed were 201. Minimum and maximum precision values for the baseline components were obtained 0.2 and 1.1 cm, respectively (Table 1). These values match the limit values given above (Mescioglu Eng. and Consult. Co., 2009).

NETWORK ADJUSTMENT WITH RESPECT TO THE REGULATION

In the first step of the computational procedure, the baseline vectors obtained were adjusted by the free network method with respect to the six TUTGA points (for more information about the free network adjustment, (see Mittermayer, 1972; Papo and Perlmutter, 1981; Blaha, 1982). After the adjustment, the maximum value of accuracy was found 3.8 mm for the horizontal components and 7.3 mm for the vertical component of the adjusted coordinates. These values are quite good in comparison to the limit values. However, F-test value of the adjustment is 1.73, and is bigger than the F-test limit value of 0.96 for the degree of freedom of 384. This means the model test for the adjustment is failed (Table 2).

With regard to the t-test values of the observations the baseline vectors in Table 3 were found as outliers. Considering these outliers might be the reason of the failure of the model test, the adjustment was reiterated, removing one baseline with the largest t-test value each

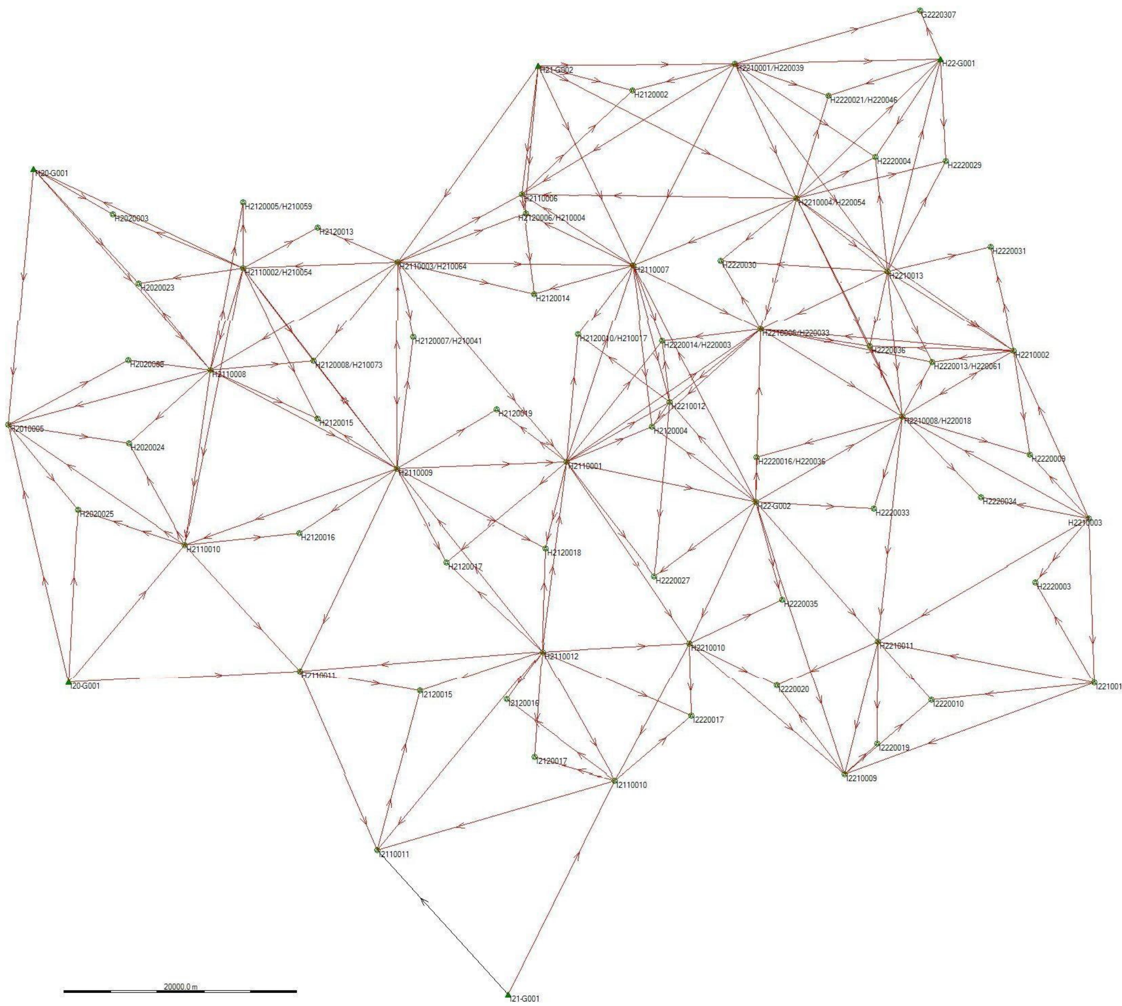

Figure 2. A scheme of the BMA basic geodetic GPS network.

Table 1. Basic network observation details.

Total number of site points	73
Number of TUTGA points	6
Observation duration	2 h
Sample rate	5 s
Cut off angle	10 degree
Minimum precision value	0.2 cm
Maximum precision value	1.1 cm

Table 2. Free adjustment summary.

Kind of adjustment	Free network
Point number	73
Unknown number	219
Number of observations	603
Degree of freedom	384
Max. horizontal accuracy	3.8 mm
Max. vertical accuracy	7.3 mm
F-test value	1.73
F-test limit value	0.96
Model test	1.73>0.96 failed

time. However, the model test always failed for each each adjustment leading to new outliers.

NETWORK ADJUSTMENT REGARDING ACTIVE FAULTS

Under the light of the above results, the computation procedure was stopped because there had to be a different problem from outlying observations. One of the possible problems blinking first could be effects of active faults on the reference TUTGA points. For that reason, GPS coordinates of active faults produced by General Directorate of Mineral Research and Exploration were achieved for the Bursa region and these data was

Figure 3. Active faults around the Bursa basin. The solid white lines display the active faults (the satellite image obtained from google earth).

Table 3. Outlier baselines of the first adjustment.

Baselines	Baselines
I2110010-I2120017	H2210010-I2110010
H2210001-H2210013	H2110012-H2210010
H2110009-H2120015	H2110012-H2210010
H2110010-H2110011	H2110012-H2110011
H2110003-H2110009	H2210011-I2210009
H2110003-H2110001	I20-G001-H2110010
H2110001-H2210010	H2110009-H2110010
H2210008-H2210002	H2110009-H2110010
H22-G002-H2210008	H211009-H2110001

Table 4. Free adjustment summary regarding the fault lines.

Type of adjustment	Free network
Point number	73
Unknown number	219
Number of observations	603
Degree of freedom	384
Max. horizontal accuracy	6.6 mm
Max. vertical accuracy	13.9 mm
F-test value	0.27
F-test limit value	0.96
Model test	0.27<0.96 accepted

mapped together with the Bursa geodetic network (Figure 3). As seen from the figure, the south branch of the NAF in Marmara Region passes through the Bursa basin, and cuts the network to north and south halves.

To solve the problem, it was decided to use the TUTGA points on only one half as the reference points. The decision was to use the TUTGA points on the North side due to two reasons: (1) the North side of the region is geologically more stable and (2) the South side has a more complex fault structure and the TUTGA points scattered in this complex structure was able to experience inhomogeneous dislocations. Eventually, the free adjustment step was repeated choosing the three TUTGA points in the North side as the reference points. This adjustment was resulted in the maximum horizontal accuracy of 6.6 mm and the maximum vertical accuracy of 13.9 mm. F-test value was degraded to 0.27; and thus the model test was accepted (Table 4). In the adjustment, none of the observations was detected as outlier. Figure 4 shows t-test value distributions of the observations utilized for the outlier detection.

In brief, the strategy regarding the fault lines enabled a successful free network. Hence, the other steps ordered in the regulation were able to be carried out for the network. In the second step, a coordinate transformation between the known and the adjustment - obtained

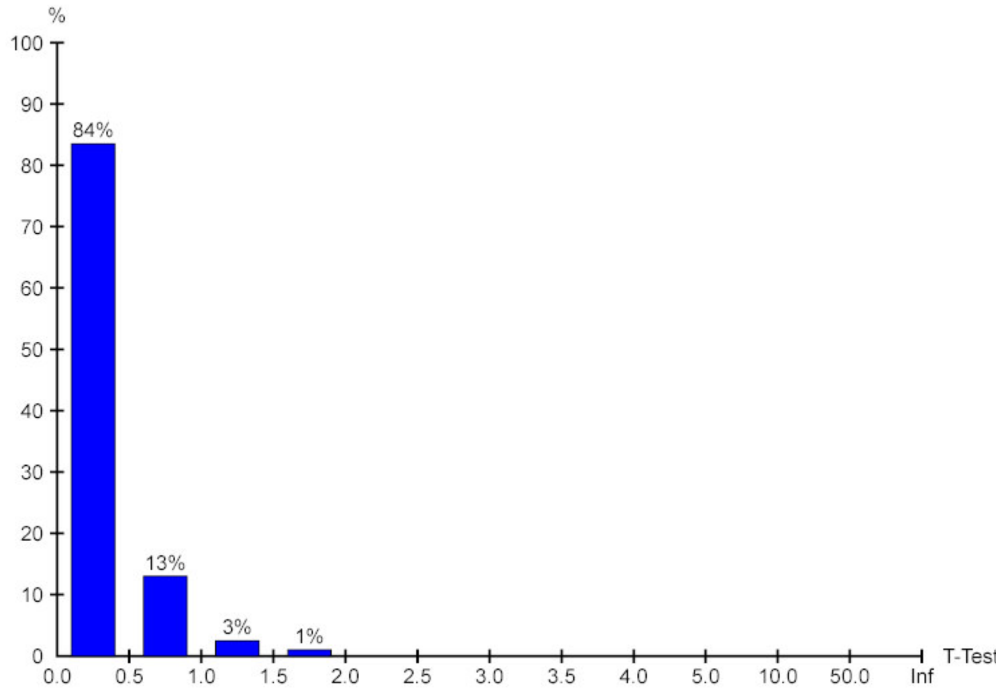

Figure 4. Distribution of the t-test values of the observations.

Table 5. Constraint adjustment summary regarding the fault lines.

Type of adjustment	Constraint
Point number	70
Unknown number	210
Number of observations	603
Degree of freedom	393
Max. horizontal accuracy	6.6 mm
Max. vertical accuracy	13.9 mm
F-test value	0.56
F-test limit value	0.96
Model test	0.56<0.96 accepted

coordinates of the TUTGA points utilized as the reference points was conducted for the scale control. This process was resulted in the scale factor of 0.0551 ± 0.1534 ppm. Since the scale factor obtained was quite smaller than the tolerance value 3 ppm the scale consistency was approved for the reference TUTGA points. The constraint adjustment step was therefore realized (for more information about the constraint network adjustment, see Kuang, 1996; Koch, 1997 and Ghilani and Wolf, 2006). For the datum definition of the network the same TUTGA points as in the free adjustment were utilized for this computation too. In this adjustment, the model test of the adjustment was accepted with the value 0.56. The max. horizontal accuracy was obtained 6.6 mm while the max. vertical accuracy was obtained 13.9 mm (Table 5). These entire criteria matched the standards in the regulation; however, the ten baselines were failed in the outlier detection (Figure 5). To eliminate the effect of the outliers the constraint adjustment was repeated iteratively, removing the outliers one by one starting from the one with the largest T-test value. After removing the 9th outlier, the adjustment yielded no outliers (Figure 6). The computation process of the BMA basic GPS network was therefore completed. In this adjustment, the model test value was degraded to 0.30. The max. horizontal and vertical accuracies were obtained 7.4 and 16.6 mm, respectively (Table 6).

CONCLUSIONS

A model test failure in a geodetic network adjustment can arise due to three reasons: (1) There may be outliers among observations, (2) the functional model may not reflect a complete relationship between unknowns and observations and/or (3) the stochastic model which represents the precision estimations of observations may not be realistic (Baarda, 1968; Kuang, 1996). However, while worked in a country like Turkey active faults must be absolutely taken into account. The situation experienced during the evaluation of the BMA GPS network is a very good sample for that requirement. In the Bursa sample, the model test was failed and many observations were detected as outlier in the first step adjustment. Afterwards the adjustment was repeated with

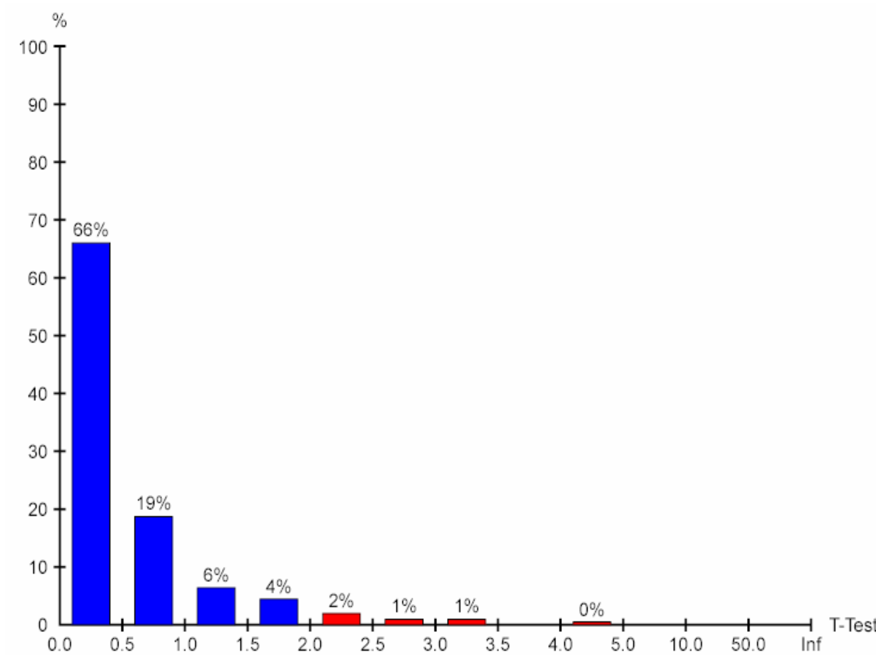

Figure 5. Distribution of the t-test values of the observations. The red bars shows the observations detected as outliers.

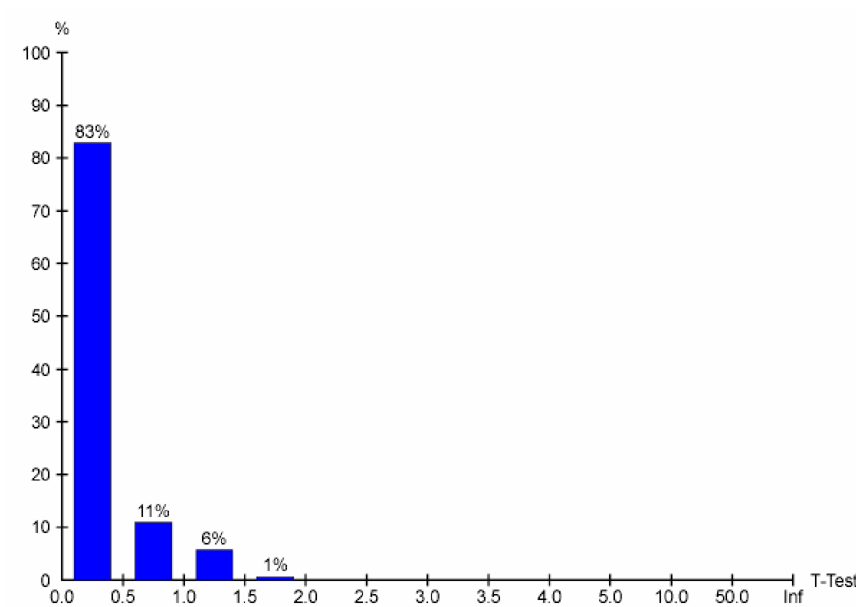

Figure 6. Distribution of the t-test values of the observations after outlier detection. The red bars shows the observations detected as outliers.

removing outliers one by one; however, each repeat was failed and produced new outliers. This was an unexpected case because the GPS observations were quite much and quite better than the tolerances in all respects (observation duration, number and precision) specified in Turkish National regulation on large scale map productions. The reason of the problem was determined as the dislocations of the TUTGA points due to the fault mechanism in the basin and the solution was produced through an approach regarding the active fault lines.

Table 6. Constraint adjustment summary regarding the fault lines after eliminating outliers.

Type of adjustment	Constraint
Point number	70
Unknown number	210
Number of observations	594
Degree of freedom	384
Max. horizontal accuracy	7.4 mm
Max. vertical accuracy	16.6 mm
F-test value	0.30
F-test limit value	0.96
Model test	0.30<0.96 accepted

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