ANALYSIS OF TOTAL CRUSTAL DEFORMATION BY THE COMPARISON OF TERRESTRIAL AND GPS MEASUREMENTS IN THE MARMARA REGION

by

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ABSTRACT

ANALYSIS OF TOTAL CRUSTAL DEFORMATION BY THE COMPARISON OF TERRESTRIAL AND GPS MEASUREMENTS IN THE MARMARA REGION

In order to monitor crustal movements along one of the branches of North Anatolian Fault Zone (NAFZ), Geodesy Department of Kandilli Observatory and Earthquake Research Institute (KOERI) established microgeodetic networks around the eastern Marmara Region. General Command of Mapping (GCM) - Istanbul Technical University (ITU) net as part of the networks was measured from 1941 to 2007 five times with both space methods and conventional methods.

The terrestrial network implemented by GCM as constitution of nine pillars scattered around south and north of Iznik Mekece fault. The net was measured by trilateration and triangulation methods by GCM and ITU. After KOERI Geodesy Department joined GCM-ITU net in Marmara Microgeodetic Project, the net was also monitored by GPS Campaigns.

This study is based on the use of repeated observations over the network and on the analysis of the results obtained from different epochs by means of displacements. Thus, first all epoch of observations were computed and then the amount of displacements were analyzed judging by the fault movement and the accuracy values for each observation method. In addition to this, in order to check the coherence of results, GPS campaign data have been processed in detail.

ÖZET

MARMARA BÖLGESİ'NDE YERSEL VE GPS ÖLÇÜMLERİNİN KARŞILAŞTIRILMASI YARDIMIYLA YERKABUĞU HAREKETLERİNİN ANALİZİ

Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Jeodezi Ana Bilim Dalı, Kuzey Anadolu Fay Hattı (KAFH) üzerindeki yerkabuğu hareketlerini incelemek amacıyla Marmara Bölgesinde mikrojeodezik ağlar kurmuştur. Harita Genel Komutanlığı (HGK)-İstanbul Teknik Üniversitesi (ITU) ağı bu ağın bir parçası olarak 1941 yılından 2007 yılına dek hem geleneksel metotlar hem de uzay teknikleri kullanılarak beş kez ölçülmüştür.

İznik-Mekece fayının kuzeyi ve güneyine dağılmış, ilk hali dokuz pilyeden oluşan ağ, yersel gözlem amacıyla HGK tarafından inşa edilmiştir. Harita Genel Komutanlığı ve İstanbul Teknik Üniversitesi, bu ağ üzerinde doğrultu ve kenar ölçümleri gerçekleştirmiştir. Ayrıca ağ, Kandilli Rasathanesi ve Deprem Araştırma Ensititüsü (KRDAE) Jeodezi Ana Bilim Dalı tarafından mikrojeodezik ağlara katıldıktan sonra GPS ölçümleri ile de gözlenmiştir.

Bu çalışma ağ üzerinde tekrarlanmış ölçümlerin kullanılarak elde edilen sonuçların yer değiştirme değerlerini zamana bağlı olarak analiz etmeyi amaçlamaktadır. Buna göre, öncelikle her yıla ait gözlemin değerlendirilmesi yapılmış, daha sonra yer değiştirme miktarları fayın hareketi ve her yöntemin kendine has doğruluk kıstasları göz önüne alınarak incelenmiştir. Sonuçların tutarlılığını kontrol etmek amacıyla GPS kampanyaları verileri ayrıca detaylı bir biçimde değerlendirilmiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

w	Weight
v	Residuals
n	Number of triangles gathered from directions
w	Error of each triangle closure
X_0, Y_0	Translation parameters
k	Scale factor
α	Rotation
NAF	North Anatolian Fault
KOERI	Kandilli Observatory and Earthquake Institute
GPS	Global Positioning System
GCM	General Command of Mapping
EDM	Electronic Distance Measurements
EAF	East Anatolian Fault
NNAF	Northern Strand
SNAF	Southern Fault
SSNAF	Southern South North Anatolian Fault
MARNET	Telemetric Seismic Earthquake Network of Marmara Region
IZINET	Seismic Earthquake Network of Iznik-Mekece Fault
NAFZ	North Anatolian Fault Zone
C&GS	Coast and Geodetic Survey
EDMI	Microwave Electronic Distance Measurement Instruments

TGO	Trimble Geomatics Office
WGS84	World Geodetic System 84
BRF	Bogazici Research Fund
GIPSY	GPS Inferred Positioning System
OASIS	Orbit Analysis and Simulation Software
ED-50	European Datum 1950
TUBITAK	The Scientific and Technical Research Council of Turkey
MRC	Marmara Research Center
EMSRI	Earth and Marine Sciences Research Institute
MAGNET	Marmara Continuous Global Positioning System Network
SOPAC	Scripps Orbit and Permanent Array Center

1. INTRODUCTION

Geodetic techniques for monitoring displacements and deformation parameters are recognized as a favorable method in many studies focused on crustal movements. With the help of increasing knowledge on crustal deformation, the issue on understanding the behavior of interior Earth as well as the surface of it. Besides the space geodesy associated with terrestrial applications provides a useful tool to monitor deformations.

Surveys for monitoring crustal deformation along NAF were carried on by KOERI Geodesy Department since 1989. The network in study area as a part of these applications has been measured five times by geodetic techniques since 1941.

Due to the improvements on modern technology, each survey condition had differences from the others. Therefore the triangulation and trilateration applications evolved into GPS campaigns in time.

The GCM-ITU net was first established by te General Command of Mapping. Part of the network was included by the first, second and the third degree national triangulation net. The first measurement obtained from the net is from 1941 which had poor geometry and low accuracy. These observations could have been performed again after twenty-two years later in same conditions.

This observation is pursued by another giant gap of time without performing any other measurement. However, the new application brought forth by the modern technology such as EDM measurements were performed by ITU research team. Afterwards, KOERI research resurveyed the network around Marmara Region and was measured by the Global

Positioning Techniques in two epochs.

Terrestrial and GPS methods were analyzed. The idea of analyzing both individually and together two methods of application leads to the study sections detecting deformation divided into two categories:

1. The comparison of single adjusted values of different epochs of measurements
2. Processing GPS campaigns and focusing on deformation analysis derived from processing results.

The study steps are consisted of:

- A single free network adjustment per epoch
- A single constrained adjustment according to reference stations.
- The estimation of horizontal displacements
- Comparison of displacements and their analysis.

2. THE EASTERN MARMARA REGION

2.1. Anatolian Plate

The Eastern Mediterranean, Asia Minor, Middle East, and northeast Africa is a zone of complex tectonics associated with the interaction of four of the Earth's major lithospheric plates, Arabia, Nubia, Somalia, and Eurasia (Reilinger et al., 2006)

During the middle Miocene, Arabia was separated from Africa along the left-lateral Dead Sea fault zone (Le Pichon et al. 1988). In the middle to late Miocene time interval, the northern border of Arabia entered into collision with the southern margin of Eurasia (Perinçek et al., 1979), forming the Bitlis Thrust Zone (Yurur et al. 1998). Meanwhile, the African plate is subducting under the Anatolian and Aegean plates by creating Hellenic Arc (Le Pichon et al. 1988).

Therefore, along the Hellenic Trench, northeastern part of Africa moves approximately 10mm/yr towards North while northern Arabian Plate has been slowly moving northwest with a velocity of 18-25mm/yr relative to Eurasia (McClusky et al. 2000)

Anatolian plate, being under the influence of these large plates, moves westwards. The collision between Eurasia and Arabian plate has been recognized as the main force for this movement. (Şengör et al 2005). However, recently it is also suggested that the increasing rate of motion toward the Hellenic and Cyprus trenches has been responsible for the westward motion of Anatolia. (Reilinger et al., 2006).

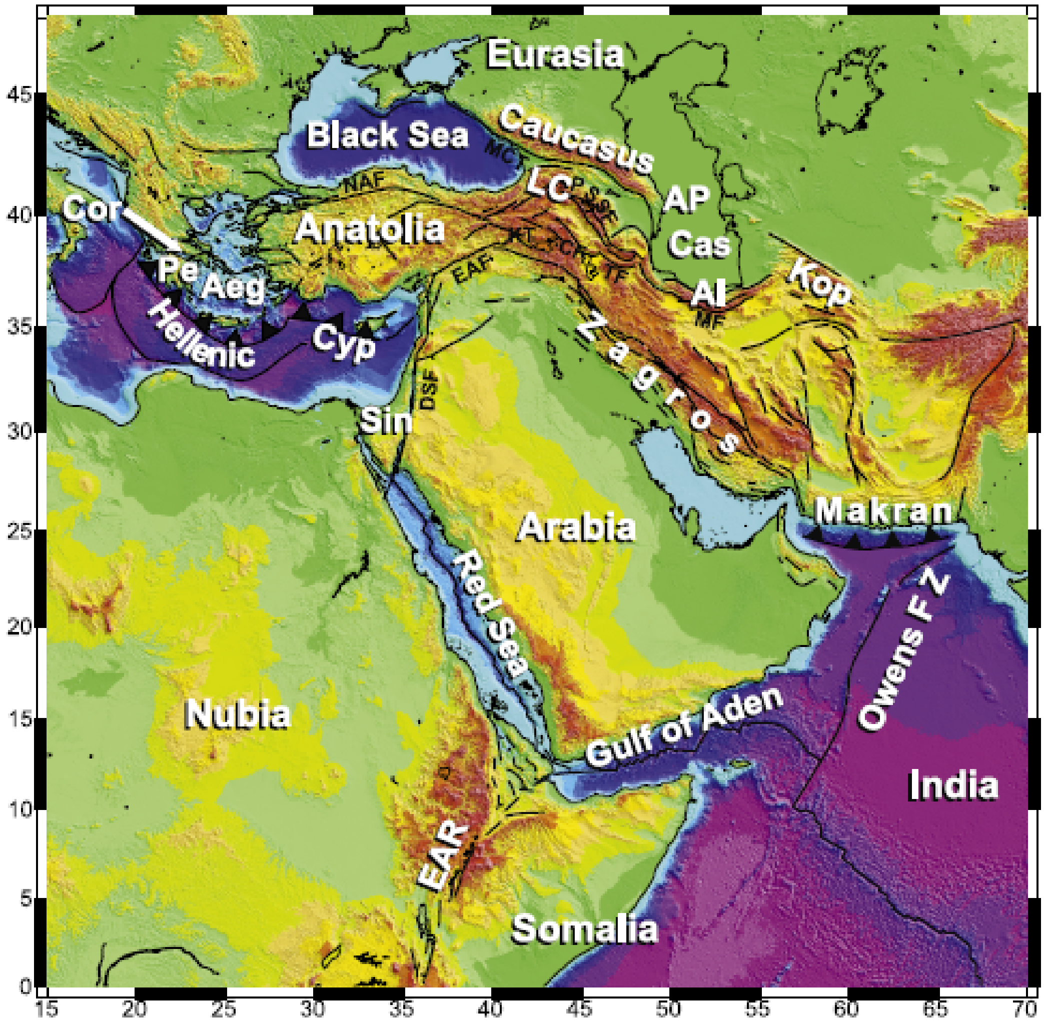

Figure 2.1. Earth's major lithospheric plates in Eastern Mediterranean (Reilinger et al., 2006)

Anatolian plate is rotating counter-clockwise, relative to Eurasia which results in a slip velocity of 24 mm/yr in the North Anatolian Fault (McClusky et al., 2000).

Three primary fault formations impact Anatolian Plate: North Anatolian Fault (NAF), East Anatolian Fault (EAF), and Aegean extension regime.

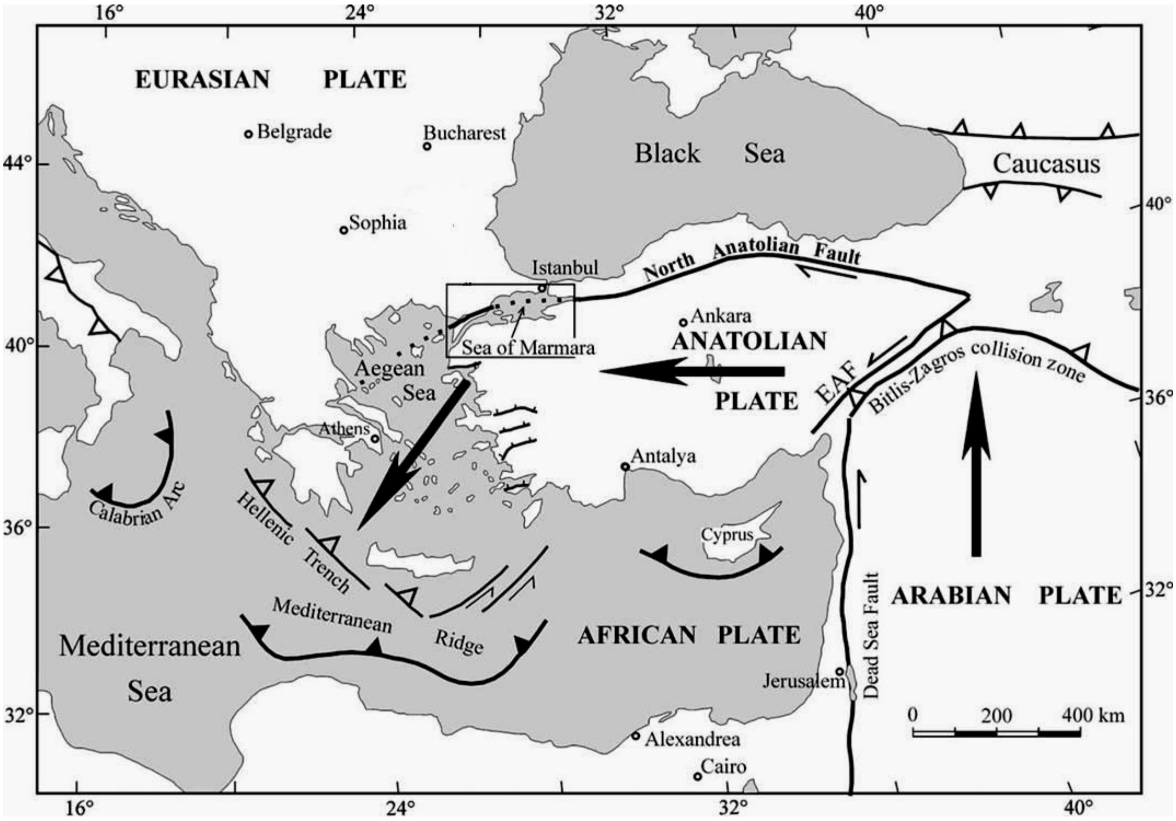

Figure 2.2. Active tectonic map of Eastern Mediterranean. The movements are relative to Eurasia (McClusky et al, 2002)

North Anatolian Fault is a dextral fault system which lies 1500 km along whole northern Anatolia. The sinistral EAF so close to NAF lies at the westward direction with the velocity of 11±2 mm/yr according to the GPS derives slip rate estimates.

Aegean Region with the 30 mm/yr NS-SW extension (McClusky et al, 2000) is a very active continental extension in the world.

The fact that motions in Central Anatolia relative to Eurasia are 15-20 mm/yr while in Western Anatolia and Aegean Sea they are 30-40mm/yr could suggest that Western Anatolia decouples from Central Anatolia and the Isparta Angle by the Fethiye-Burdur fault zone and Eskişehir Fault (Barka et al, 1997)

2.2. North Anatolian Fault Zone and Marmara Region

North Anatolian Fault Zone as the largest fault system of Anatolia is a natural junction between the Caucasus System and Aegean extension regime. This right lateral strike slip fault begins from Karliova, elongates through whole northern Anatolia until the vicinity of Mudurnu where it splits into two main fault strands. First one of these strands is called Northern Strand (NNAF) and it modifies the tectonic boundary of northern zone which covers Gulf of Izmit and Marmara Sea through Gulf of Saros. August 17 Izmit and November 12 Duzce earthquakes in 1999 occurred in that part of the NAFZ.

Southern fault (SNAF) kept his way from Mudurnu to south of Marmara Sea. Farther west, the south segment (SSNAF) again divides into two parts that form the pull-apart basins including Marmara Sea and define three major strands.(Straub 1998, Okay et al. 1999) The first one beginning from Geyve follows the path hosting Lake of Iznik, Mudanya, Bandırma and arrives at the Gulf of Gemlik and is defined as a middle strand.

The southern part separates from the middle strand while creating two faults in the direction of NE-SW and goes along Bursa, Manyas Lake and Gulf of Edremit. Up to Bursa the fault structure is normal faulting, after that the motion transforms into a right lateral strike slip. From the Gulf of Edremit, the fault goes into Aegen Sea.

The GCM-ITU network in our study was established around Iznik region, thus pillars of network scattered through northand the south of the middle strand.

2.3. Research Area around the Lake Of Iznik

Because of 1967 Mudurnu earthquake, North Anatolian Fault Zone bifurcated into Izmit-Sapanca Fault Zone and Iznik Mekece Fault. The belt which is surrounded by these two fault form a middle strand which begins from Mudurnu Valley in SW direction and goes through Geyve, Iznik, Gemlik and Bandırma.

While the morphologic features along the eastern middle strand indicate a clear right lateral strike-slip movement, the fault expressions by the south of Iznik Lake going through Gemlik bay are strike-slip with some amount of vertical component of north-side down. (Ucarkus G. et al, 2003)

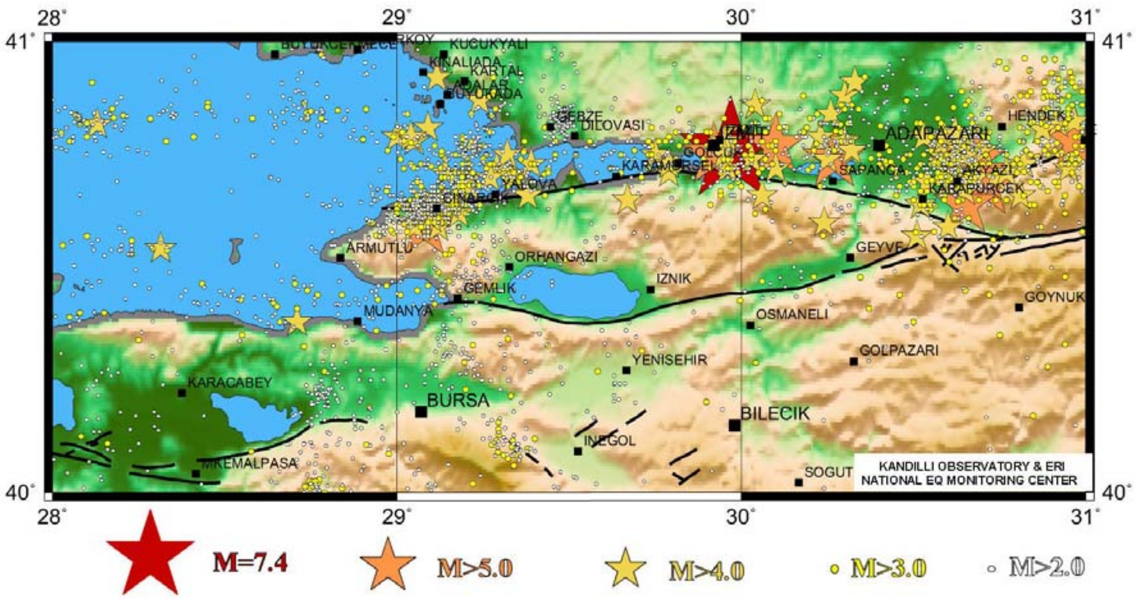

Figure 2.3 . Iznik Mekece Fault and the recorded earthquake events on and around the fault. (Gurkan et al., 2005)

Some linear fault traces are clear along the Iznik-Mekece fault (Honkura et al. 1999).

The fault that is located around west of Geyve, goes along approximately 15 km up to Sakarya River as an right lateral fault (Barka 1993) and then bounds the Geyve basin and then leaps over to the right side continuous through Mekece and Iznik Lake in W-SW direction. The Geyve-Pamukova basin has been considered as a pull-apart basin.

The fault between Cerkesli and Iznik can be traced all along the south edge of the Iznik Lake. However it hemisects in the vicinity of Sölöz and forms the southern strand which starts to skew to SW.

Apart from this, the main fault segment follows the line from western part of Iznik to Gulf of Gemlik direction and forms the Gencali fault.

Although the fault related morphology is clear, this basin is not as active as the northern strand. In addition to this, the GPS derived velocity of this strand was determined 1-2mm/yr (Ucarkus et al. 2003) which is relatively slower than the other branches of NAF. Therefore the earthquake activity of this section was not reported as much as the others.

Ambraseys and Finkel (1991) reported two past events in this section. First one occured west of Iznik Lake in AC 128 and the other one is around Geyve-Pamukova area in 1419. As a result, both historical earthquakes and trenches result may indicate the reoccurance interval large earthquakes around of 2000 years or more for Gemlik-Geyve section of middle strand (Barka 1997).

The time interval of 1900-1976, there had been only two medium-magnitude earthquakes reported. With the help of MARNET and IZINET projects, also the micro level activities are recorded from 1974.(Honkura et al. 2000)

2.4. Previous Research

In order to trace seismic events and find out the tectonic structure, many research has been conducted on the middle strand although the records indicate a much more static structure. Furthermore, Stein et al (1997) documented the high failure stress accumulation in the middle strand while modeling the stress distribution around the area.

With these results in mind, the middle strand has been studied using the trenching method (Ikeda 1989, 1991 and Barka 1993). However the conclusions of the research were not consistent with each other.

For monitoring crustal deformation, Goedesy Department of Kandilli Observatory and Earthquake Research Institute established microgeodetic networks around the western part of NAF and initiated the study on them using conventional geodetic methods in 1989.

Akyazi network (bifurcation region of western part of NAFZ), Iznik network (around southern branch) and Sapanca network (northern part of branches) have a total of 27 points connected to each other in their respective networks (Ozener et al, 2003) Since 1994, GPS campaigns have been organized to monitor the deformation. As a result, mean velocity of Iznik-Mekece segment of NAFZ was found as 18 mm/yr for the period 1994-1998, before the Izmit earthquake.

As shown in Figure 2.4. The GCM network was added to these groups of microgeodetic network in 2004.

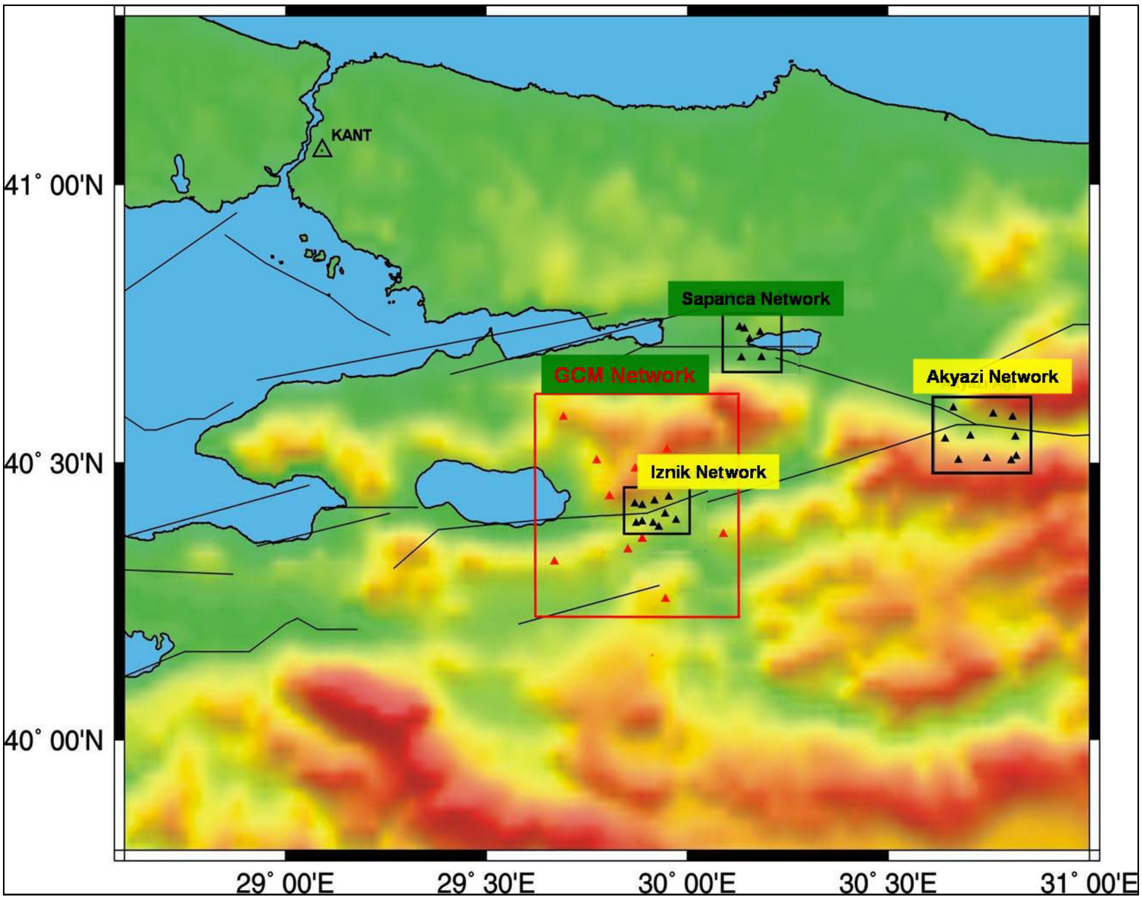

Figure 2.4. The location of KOERI Geodesy Department networks of Marmara Project

3. INVESTIGATING DISPLACEMENTS FROM 1941 TO 2007 ON GCM-ITU NETWORK

3.1. The GCM-ITU Network and Observation Methods

General Command of Mapping and ITU network had been first established around Iznik as a composition of six stations. Unfortunately, only one of them survived up to now. The first measurements using conventional techniques from the network date back to 1941. The geometry differs vastly from the present condition of the net which contains five stations ranging from10 to 30 km. These observations were followed by the 1963 application, adding new pillars into the configuration.. One of them was a first degree bench mark including the National Triangulation Network. Therefore a ten-station network with a more eligible geometry was obtained.

Judging by the application of modern technology, the observation of the 1981 was the breaking point for the network. The measurements were performed by a team of researchers from Istanbul Technical University Geodesy and Photogrammetry Engineering Department. They did not only accomplish several series of angle and baseline measurements but also rearranged the network. While the method was being changed, the network geometry was also improved by the installation of three new stations located with regard to the structure. On the other hand, some of the stations which had been formed for earlier measurements did not manage to prevail for 1981 observation. However a twenty three year period of neglect followed here after until Kandilli Observatory and Earthquake Research Institute decided to joint the GCM-ITU network into their NAFZ research based microgeodetic networks monitored. Consequently, the network has begun to be observed by GPS methods since 2004 .

Figure 3.1. The constellation of GCM_ITU network. The green marks display the terrestrial stations which could not prevail for GPS campaigns.

Nevertheless, the composition of the network had totally changed because of the damage that occurred during the twenty-year gap. Thus, the number of stations diminished. Although all observations carried out in 1941, 1963 and 1981 terrestrial observation and GPS campaign organized in 2004 and 2007 were used in evaluation process, it is necessary to eliminate some of the older stations in order to protect the network geometry and have more consistent results (Figure3.1.).

Reference frame for the displacement solution tied to control stations is referred to as datum definition in the study. In order to determine crustal movement in region a datum definition is designed to reveal the internal deformation. Therefore, the control stations are designated as to obtain the maximum number of displacement relative to one side of fault. Furthermore the parameters of translation, rotation of datum and the scale factor is taken into account in selection of control stations.

3.2. Terrestrial Surveys

3.2.1. 1941 and 1963 Surveys

3.2.1.1. The Adjustment Methods. Prior to the development of electronic distance measuring equipment and the global positioning system, triangulation was the preferred method for extending horizontal control over long distances (Ghilani and Wolf, 2006).

In 1941 and 1963, the GCM-ITU network was monitored by triangulation method. Nevertheless both measurements were not adequate for network adjustment. Furthermore they also failed individually to form proper geometry. Therefore, it is decided to unite both measurements and adjust them as a single observation (Figure 3.2). The data gathered from directions measurements and their standard error can be seen in Appendix A.

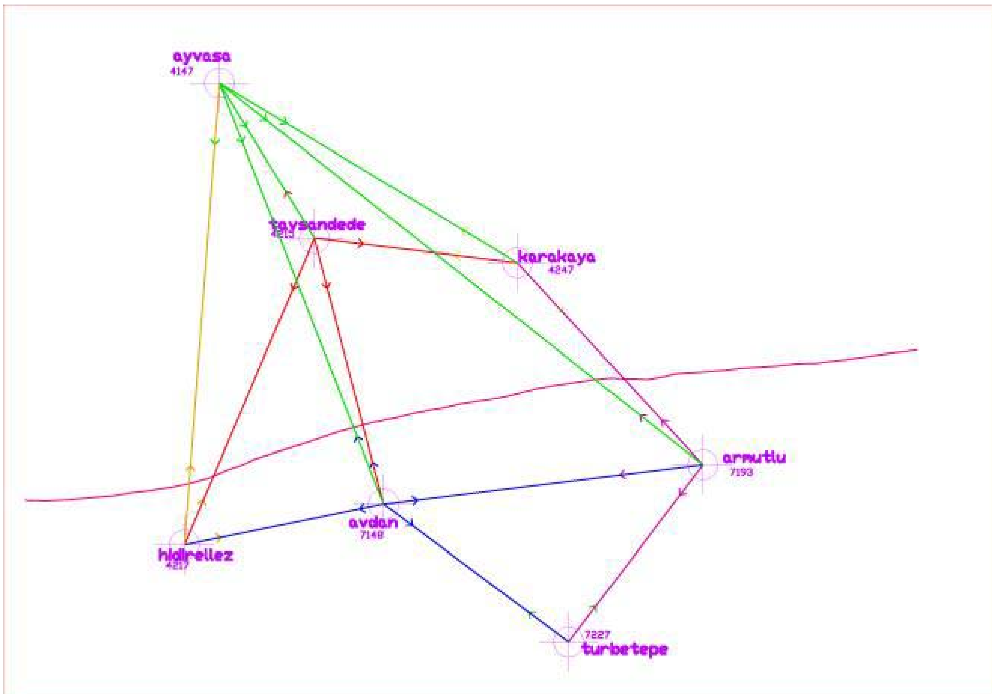

Figure 3.2. Canavas of 1941&1963 surveys

In order to improve the accuracy of results and to be able to check the data over possible errors, geodesists must apply redundant observations. Nonetheless, redundant measurements result in inconsistent set of equations. Adjustment methods help us to solve these equations employing least squares method. This method is based on the idea that “the sum of the squares of the errors times their respective weights is minimized” (Ghilani and Wolf, 2006). Where,

w:weights
v:residuals

$$\sum wv^2 \rightarrow \text{minimum} \tag{3.1}$$

Adjustments may be required to supply a sufficient number of stable points in order to achieve a more determined solution. This solution can be applied by fixing the coordinates of control stations by setting their Vx and Vy corrections to zero, so their coefficients were removed from the coefficients matrix A. This approach is also tied to the notion of having relative deformation and forming datum according to control points.

The concept of the adjustment method that it is used for united 1941-1963 observations based on the idea of fixing 4217 Hidirellez, 7227 Turbetepe and 7193 Armutlu stations located below the Iznik-Mekece fault line in order to determine the motions correctly the station above the fault. Coordinates of the control station were based on the ED-50 system.

3.2.1.2. Results of Constrained Adjustment. An adjustment program prepared in FORTRAN was applied for whole adjustment process. The detailed result of adjustments can be seen in Appendix A.

Total Network Points: 7
Control Points: 3

Number of Direction Measurements: 24

Table 3.1. Control points of whole epochs of constrained adjustment

Points	Y (m)	X (m)
Hıdırellez/4217	471439.520	4468758.726
Armutlu/7193	503345.740	4473679.220
Türbetepe/7227	495078.996	4462788.052

Table 3.2. Constrained adjustment results of 1941&1963 epoch

Points	Y(m)	X(m)
4215	479437.6	4487595.830
4247	491922.9	4486099.439
7148	483701.0	4471259.467
4147	473590.6	4497140.073

Table 3.3. Mean errors from constrained adjustment of 1941&1963 epoch

Points	My(cm)	Mx(cm)	Mp(cm)
4215	40.3678	65.7207	77.1283
4247	83.6878	79.1553	115.1921
7148	32.2961	14.9835	35.6026
4147	62.2436	67.5314	91.8409

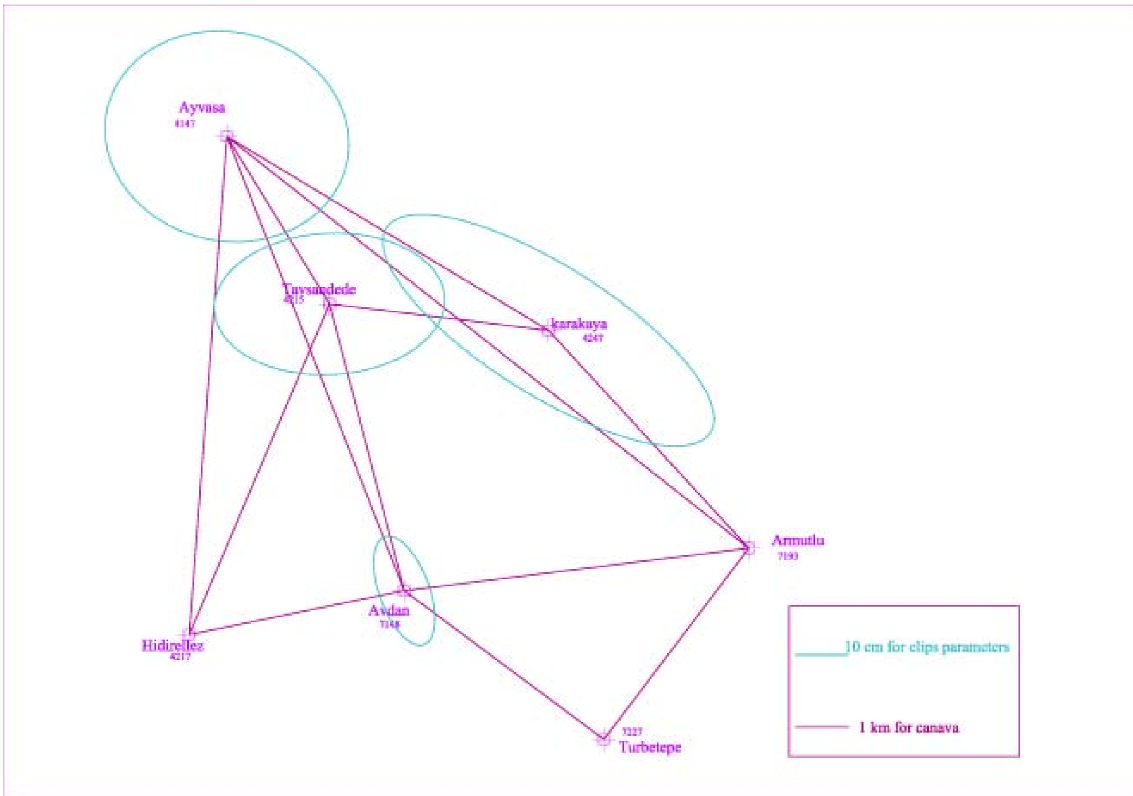

Figure 3.3. Parameters of error ellipses of 1941&1963 epoch

As shown in the tables above the insufficient geometry of networks have a misleading influence on results. Consequently, the accuracy value of each point turned out higher than expected.

3.2.2. 1981 Survey

3.2.2.1. The Adjustment Methods. In 1981, both trilateration and triangulation methods were applied. Baselines were measured by one of the first generation EDM systems: the tellurometer. (Figure 3.4.)

Figure 3.4. EDM (Tellurometer CA 1000)

.Tellurometers used microwaves rather than light waves to measure distances. The unit was the result of the search for an instrument that was lightweight and portable, required a small amount of power, and was accurate over several kilometers, the drawback being that atmospheric conditions affect microwaves more than light waves. Thus, microwave electronic distance measurement instruments (EDMI) were never as precise as lightwave instruments such as Geodimeters.

Horizontal distances were produced from the raw slope distances by using the reduction to sea level formulas (Figure 3.5.)

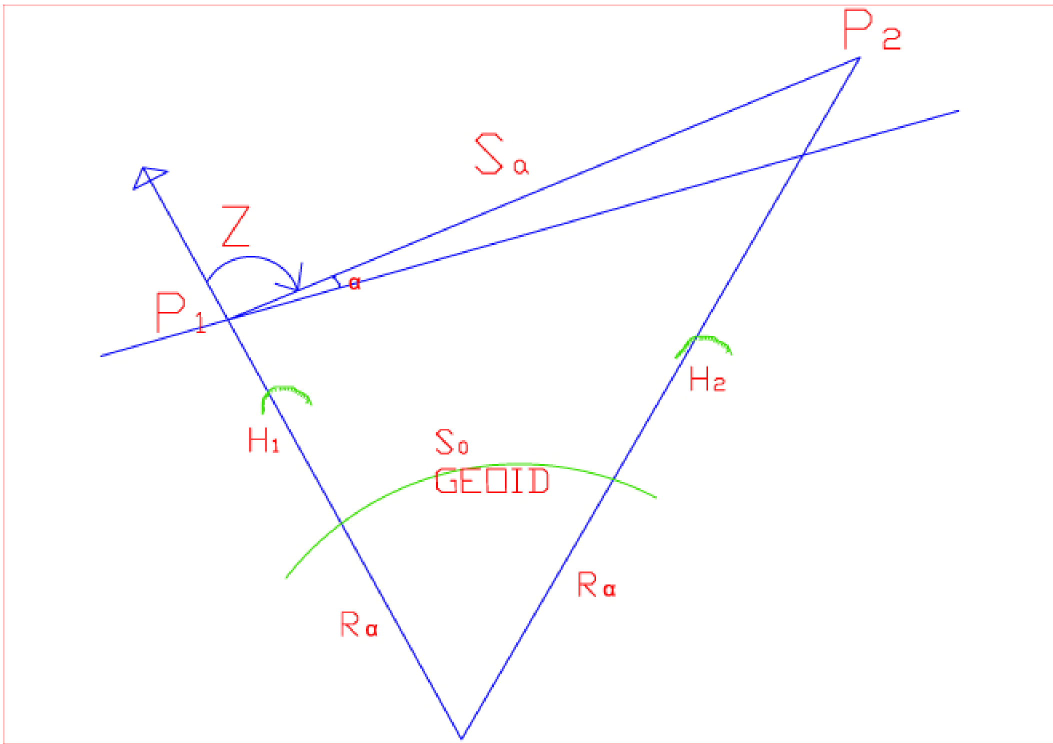

Figure 3.5. Differences of slope and horizontal distances

In the adjustment, the standard errors of mean for the direction measurements are evaluated by Ferrero Equation 3.2. and accepted its square as unit variance.

$$S_0 = \left[\frac{S_a - (H_2 - H_1^2)}{(1+\frac{H_1}{R_\alpha})(1+\frac{H_2}{R_\alpha})} \right]^{1/2} + \frac{S_E^3}{24R_\alpha^2} \qquad (3.2)$$

n : the number of triangles gathered from directions

w: the error of each triangle closure

$$m_r = \pm\sqrt{\frac{[ww]}{6n}} \tag{3.3}$$

For distance measurements, standard deviations were evaluated from equation 3.3 and divided into the unit variance (Equation 3.4) to have the final results.

$$m_s = a \pm b \text{ ppm} \tag{3.4}$$

$$P = \frac{m_r^{\,2}}{m_s^{\,2}}\left(\frac{mgon}{cm}\right)^2 \tag{3.5}$$

To sum up, the constrained adjustment method is also applied for these observations and the same control stations accepted as fixed coordinates. (Figure 3.6.) Changes in the coordinates of 4215 Tavsandede Tepe, 202 Aygiran and 226 Hacidag stations were examined relative to these control stations.

Apart from these, the number of redundant observations was adequate in 1981 survey to apply free network adjustment in order to check outliers. A free network adjustment means no constraints were involved in the adjustment process so the inertial multiplication of unknowns after the adjustment must be minimum.

$$x^T x = \min \tag{3.6}$$

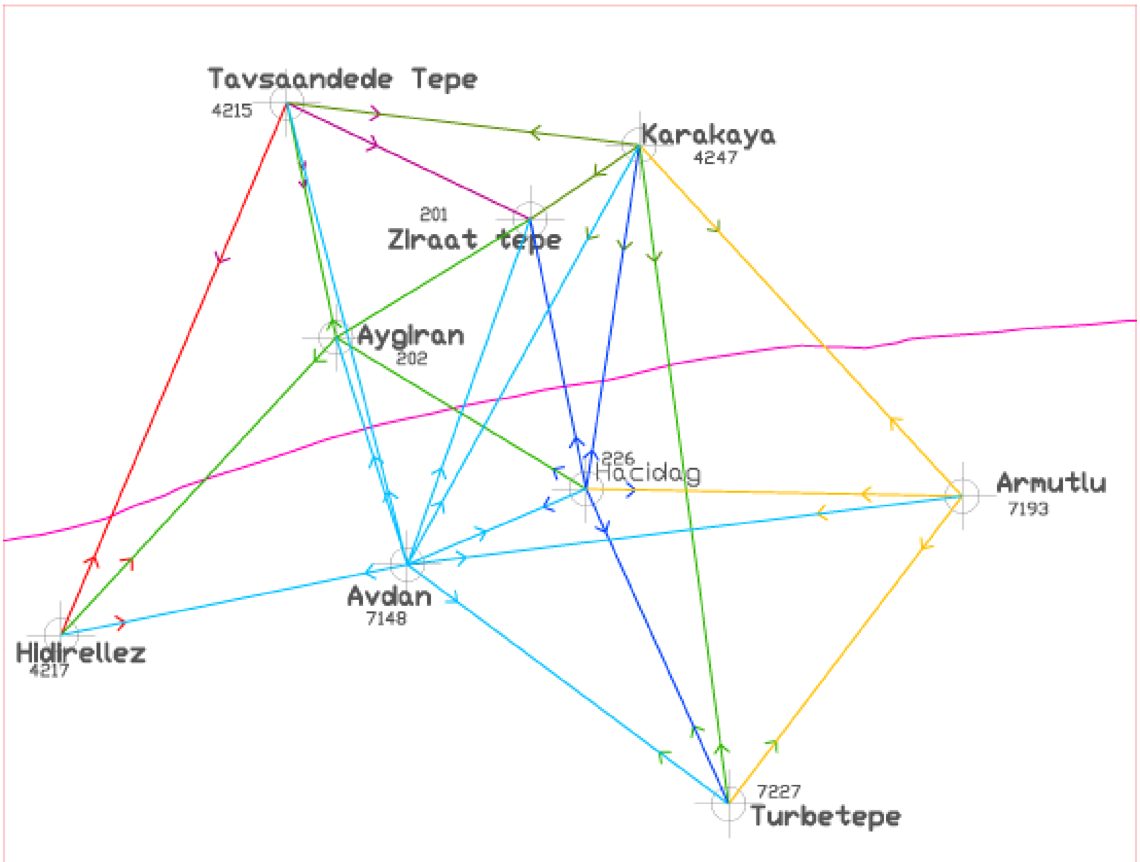

Figure 3.6. Canavas of the epoch 1981

Free network adjustment makes it possible to detect outliers in observation by applying statistical tests. In our study, the Pope test which applies a posteriori variances was used upon observations in order to check outliers and determine the confidence regions.

3.2.2.2. Results of Constrained Adjustment.

Table 3.4. Constrained adjustment results of 1981 epoch

Points	Y(m)	X(m)
Tavsandede Tepe/4215	479437.590	4487596.270
Karakaya/4247	491921.773	4486099.844
Avdan/7148	483701.080	4471259.386
Zirat tepe/201	488055.590	4483477.665
Aygıran/202	481183.916	4479288.022
Hacidag/226	490035.818	4473934.716

Table 3.5. Mean errors from constrained adjustment of 1981 epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	11.2162	8.7576	14.2302
Karakaya/4247	8.9111	7.7529	11.8117
Avdan/7148	6.3001	6.1001	8.7694
Zirat tepe/201	8.5794	7.0205	11.0857
Aygıran/202	7.9159	6.1136	10.0019
Hacidag/226	5.825	4.9814	7.6645

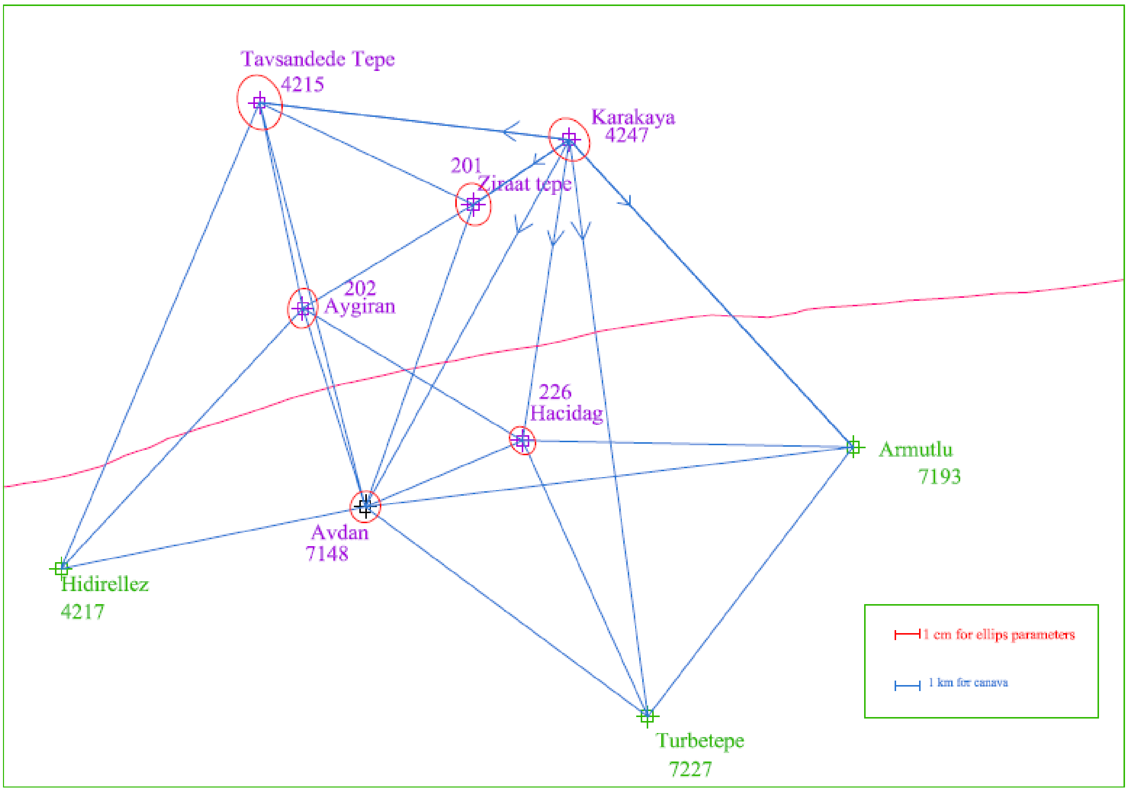

Figure 3.7. Parameters of error ellipses of 1981 epoch

3.2.2.3. Results and Outlier Detection of Free Network Adjustment

Table 3.6. Free network adjustment results of 1981 network

Points	**Y(m)**	**X(m)**
Hıdırellez/4217	471439.671	4468758.760
Armutlu/7193	503345.666	4473679.230
Türbetepe/7227	495078.945	4462788.070
Tavsandede Tepe/4215	479437.629	4487596.160
Karakaya/4247	491921.737	4486099.760
Avdan/7148	483701.102	4471259.390
Zirat tepe/201	488055.574	4483477.590
Aygıran/202	481183.952	4479287.970
Hacidag/226	490035.794	4473934.710

Table 3.7. Mean errors from free network adjustment of 1981 epoch

Points	My(cm)	Mx(cm)	Mp(cm)
4217/ Hidirellez	25.5259	13.9666	29.0970
7193/ Armutlu	25.5851	6.4010	26.3737
7227/ Turbetepe	13.3957	21.9754	25.7364
4215/ Tavsandede Tepe	12.4876	17.4961	21.4954
4247/ Karakaya	8.3688	15.2229	17.3716
7148 /Avdan	6.5627	8.6381	10.8484
201 /Zirat Tepe	4.0807	11.2645	11.9809
202 /Aygiran	9.4573	5.6626	11.0229
226/ Hacidag	5.4829	4.6992	7.2211

The total Redundancies :32

The number of observation :55

The degree of freedom :32

Standardized correction for Pope Test: 3.106

Taking into consider that the mp_{max} = ±14 cm, for constrained adjustment no outlier was detected, thus it can be said that the adjustment completed successfully.

3.3. GPS Measurements and Their Analysis

3.3.1. The Adjustment Methods

The GPS measurements were carried out in 2004 and 2007 using campaign method. The details about GCM-ITU GPS campaigns can be found in section 4. In this part, we just demonstrate the network geometry and processing methods.

When KOERI Geodesy Department initiated the GPS measurements, half of the stations were lost. Therefore, the department added other GPS stations, Gazkesmez from Iznik Network to achieve a better geometry. (Figure 3.8.)

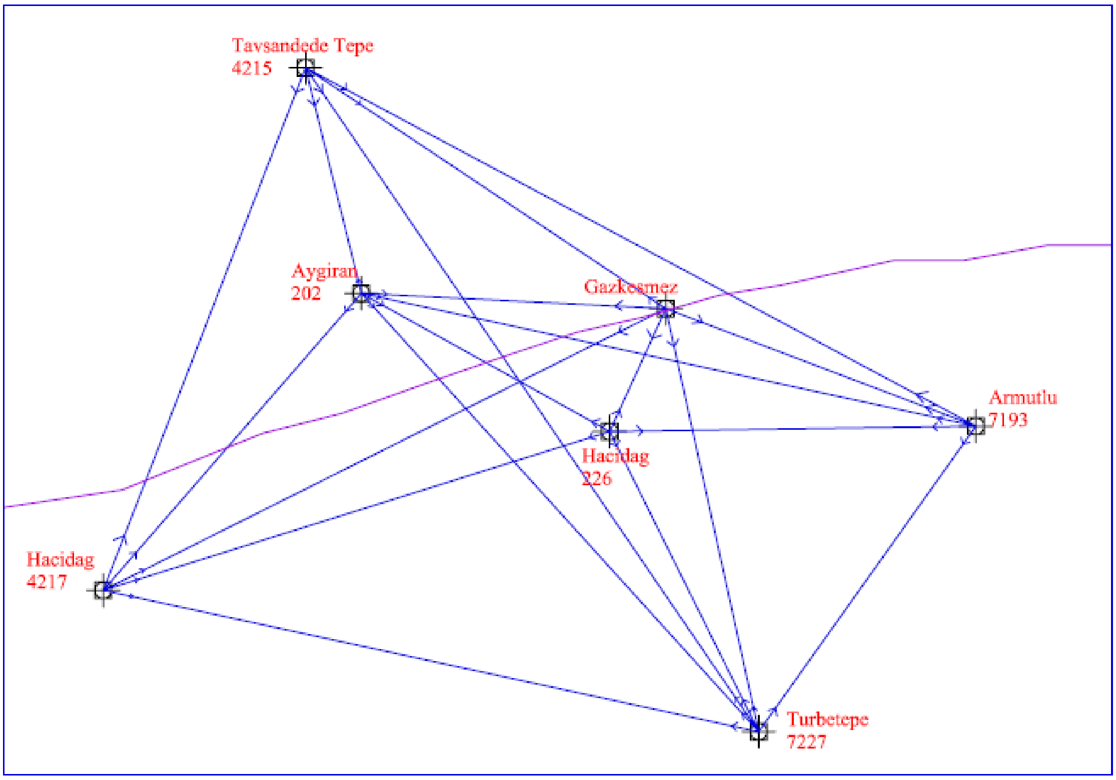

Figure 3.8. Canavas of GPS campaigns

Trimble Geomatics Office Software is employed to process GPS data using precise orbits gathered from GNSS web site. TGO is sort of commercial software optimized for GPS surveying accuracies (a few parts per million relative positioning accuracy). TGO can process all types of GPS and conventional survey data. Constrained adjustment used only one control point, which is held fixed in the survey network and is employed to evaluate GPS measurements.

Comparing the terrestrial data to the GPS outcomes, baseline components are separated from coordinate results and designating as raw data (Appendix A) and then processed individually as terrestrial trilateration measurements by constrained adjustment with stable stations in ED-50 datum. Therefore as usual in TGO processing using WGS-84 coordinates for coordinate outputs was not involved in our GPS data processing which would have been caused datum problem.

Apart from the individual adjustment to increase the degree of freedom and the accuracy we united both measurements and processed them as a single trilateration network. The detailed results can be read from Appendix A.

3.3.2. Results of Constrained Adjustment

Table 3.8. Constrained adjustment results of 2004 campaign

Points	**Y(m)**	**X(m)**
Tavsandede Tepe/4215	479437.5594	4487596.105
Aygiran/202	481184.0067	4479288.026
Hacidag/226	490035.9748	4473934.772

Table 3.9. Mean errors from constrained adjustment of 2004 campaign

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	9.6422	7.0494	11.9443
Aygiran/202	8.2030	9.3438	12.4337
Hacidag/226	5.3514	7.1474	8.9287

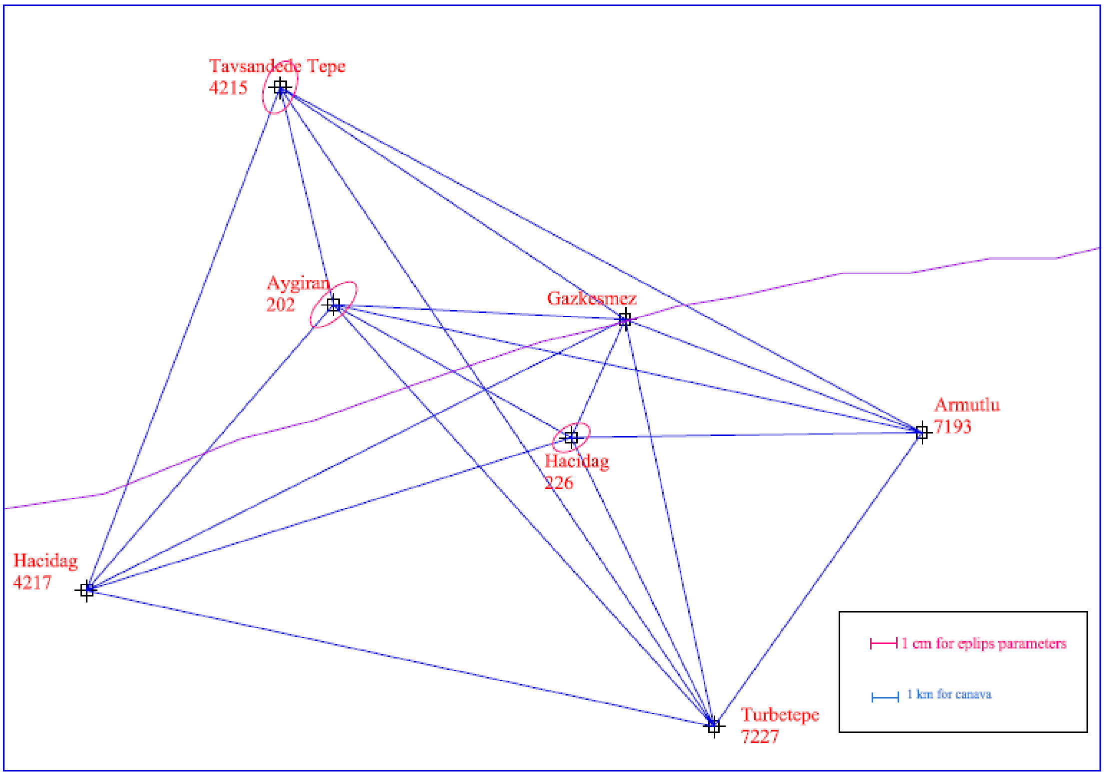

Figure 3.9. Error ellipses of 2004 campaign adjustment

Table 3.10. Constrained adjustment results of 2007 campaign

Points	Y(m)	X(m)
Tavsandede Tepe/4215	479437.5784	4487596.1210
Aygiran/202	481183.9653	4479288.0390
Hacidag/226	490035.9446	4473934.7430

Table 3.11. Mean Errors From Constrained Adjustment Of 2007 Campaign

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	6.8860	4.5080	8.2304
Aygiran/202	4.2278	4.3596	6.0730
Hacidag/226	3.8808	5.1484	6.4472

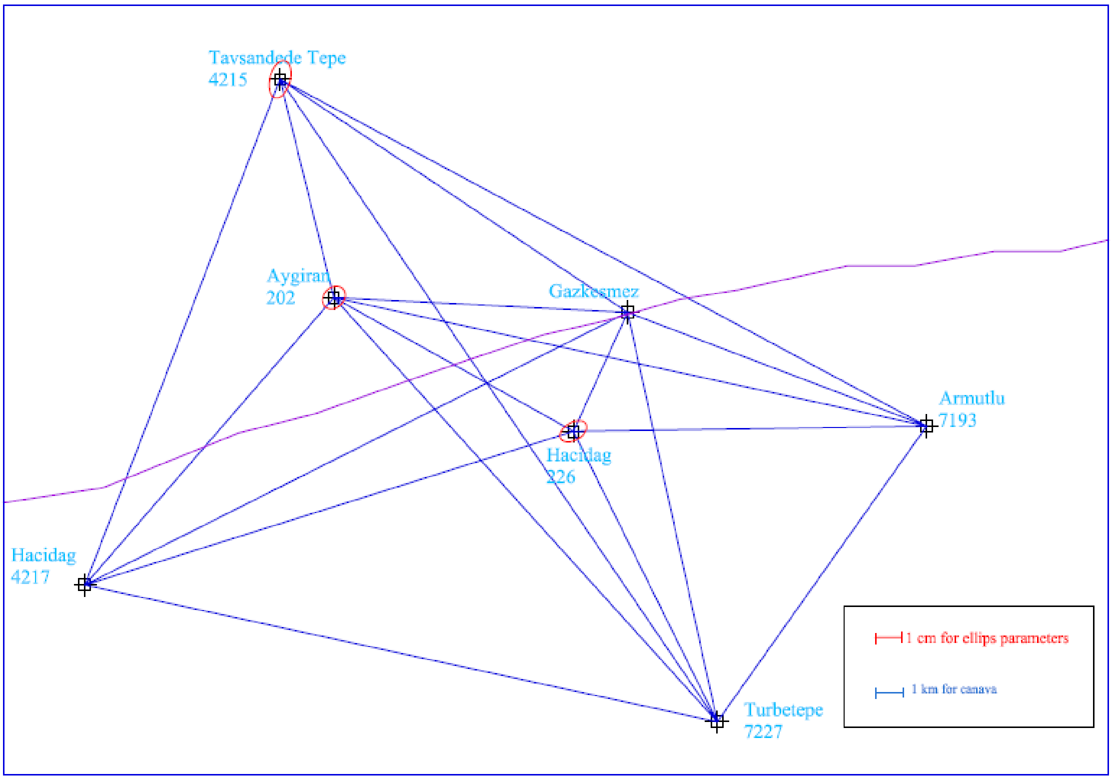

Figure 3.10. Error ellipses of 2007 campaign adjustment

Taking into account the results displayed in the tables in this section, it can be concluded that the mean errors of unconstrained station are relatively small than of terrestrial observations.

3.3.3. Results and Outlier Detection of Free Network Adjustment

Table 3.12. Free network adjustment results of united 2004&2007 campaign

Points	Y(m)	X(m)
Hıdırellez/4217	471439.4281	4468758.695
Armutlu/7193	503345.7115	4473679.272
Türbetepe/7227	495079.0682	4462787.961
Tavsandede Tepe/4215	479437.5392	4487596.011
Aygiran/202	481183.9555	4479287.919
Hacidag/226	490035.9115	4473934.622

Table 3.13. Mean errors from free network adjustment Of 2004&2007 campaign

Points	My(cm)	Mx(cm)	Mp(cm)
Hıdırellez/4217	1.6418	1.7984	2.4351
Armutlu/7193	1.4185	2.1985	2.6164
Türbetepe/7227	1.8483	1.6255	2.4614
Tavsandede Tepe/4215	2.0814	1.3446	2.4780
Aygiran/202	1.7353	1.6772	2.4134
Hacidag/226	1.5680	2.2139	2.7130

The total redundancies :20

The number of observation :29

The degree of freedom :29

Standardized correction for Pope Test :2.864

3.4. Investigation of Displacements Between Observations

Coordinate changes based on computation of differences on the displacement vector for northing and easting values of each unconstrained stations were investigated in detail.

According to Table 3.13, the coordinate differences between 1941&1963 epoch and 1981 for the station 4215/Tavsandede Tepe is not significant, due to the fact that the error of mean for each coordinate is bigger than the previous data collection. On the other hand, analyzing the changes from 1981 to 2004 and from 2004 to 2007 judging by this comparison, the outputs can be considered acceptable for 1981-2004 period but not for 2004-2007. MATLAB software was used for statistical figures of outcomes in analyzing.

Table 3.14. Movements on the north of the fault for station Tavsandede Tepe/4215

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
1941&1963	479437. 552 ± 40.4 (+) 0.038	4487595.830 ± 65.7 (+) 0.440
1981	479437.590 ± 11.2 (-) 0.031	4487596.270 ± 8.8 (-) 0.165
2004	479437.559 ± 9.6 (+) 0.019	4487596.105 ± 7.0 (+) 0.016
2007	479437.578 ± 6.9	4487596.121 ± 4.5

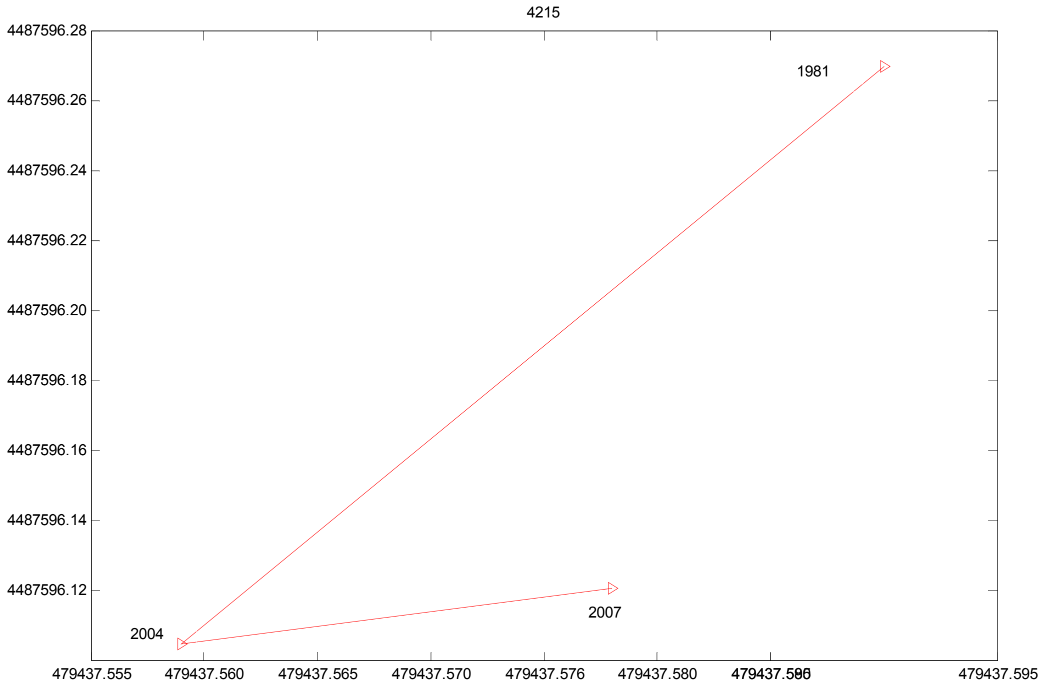

Figure 3.11. Displacement of the station 4215/Tavşandede Tepe for the period of 1981-2007.

Comparing the movements of each epoch individually for the station 202, it is observed that the mean errors as displayed in Table 3.14 are higher than the displacement values.

Table 3.15. Movements on the north of the fault for station Aygiran/202

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
1941&1963	-	-
1981	481183.916 ± 7.9 (+) 0.091	4479288.022 ± 6.1 (+) 0.004
2004	481184.007 ± 8.2 (-) 0.032	4479288.026 ± 9.3 (+) 0.013
2007	481183.965 ± 6.9	4479288.039 ± 4.4

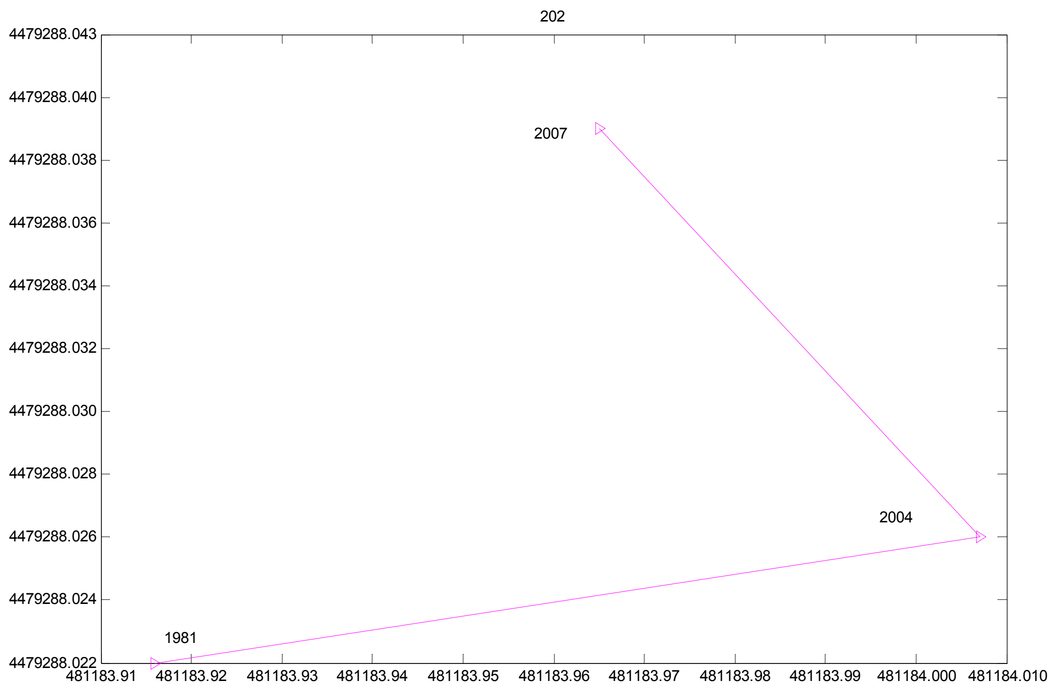

Figure 3.12. Displacement of the station 202/Aygiran for the period 1981-2007.

The case of station 226 is more complicated, because only the difference on easting between the epochs of 1981-2004 is significant.

Table 3.16. Movements on the south of the fault for station Hacıdag/226

Campaigns' Years	**Easting (m±cm)**	**Northing (m±cm)**
	(±) Differences	**(±) Differences**
1941&1963		
1981	490035.818 ± 5.8	4473934.716 ± 5.0
	(+) 0.221	(+) 0.065
2004	490035.975 ± 5.3	4473934.772 ± 7.1
	(-) 0.030	(-) 0.029
2007	490035.945 ± 3.9	4473934.743 ± 6.4

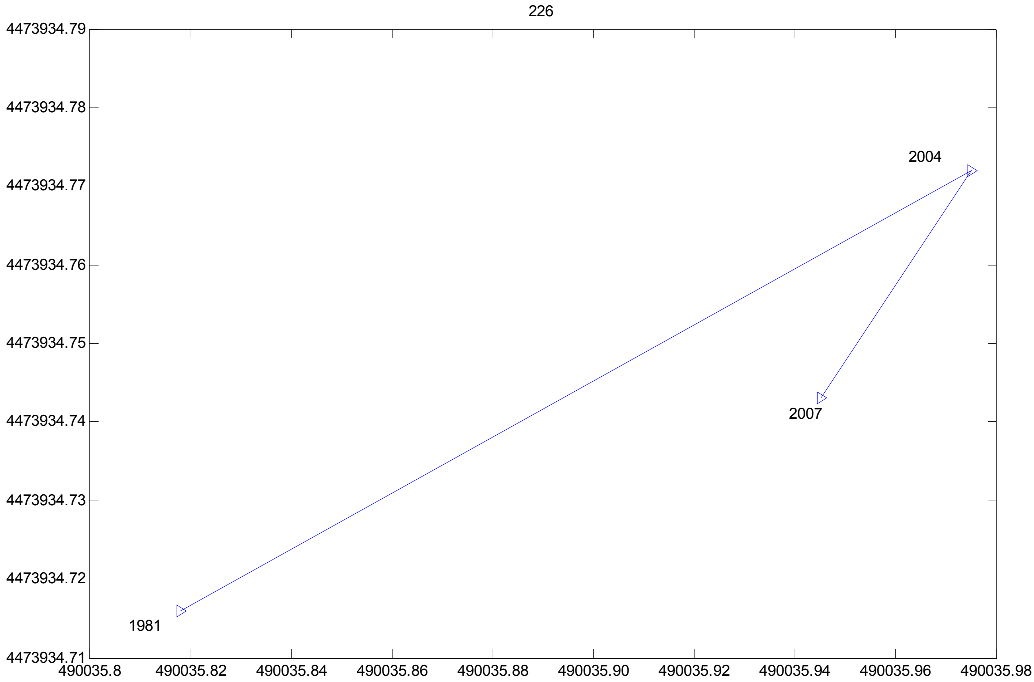

Figure 3.13. Displacement of the station 226/Hacidag for the period of 1981-2007.

While analyzing the adjusted coordinates of GPS observations and their mean square errors, it has been concluded that, because of the datum difference from terrestrial ones, the GPS data does not fit the requirements of constrained adjustment. Consequently, for detecting rotation, scaling and translation factors, the Two Dimensional Helmert Transformation is applied to coordinates gathered from free network adjustment of united 2004 and 2007 GPS data.

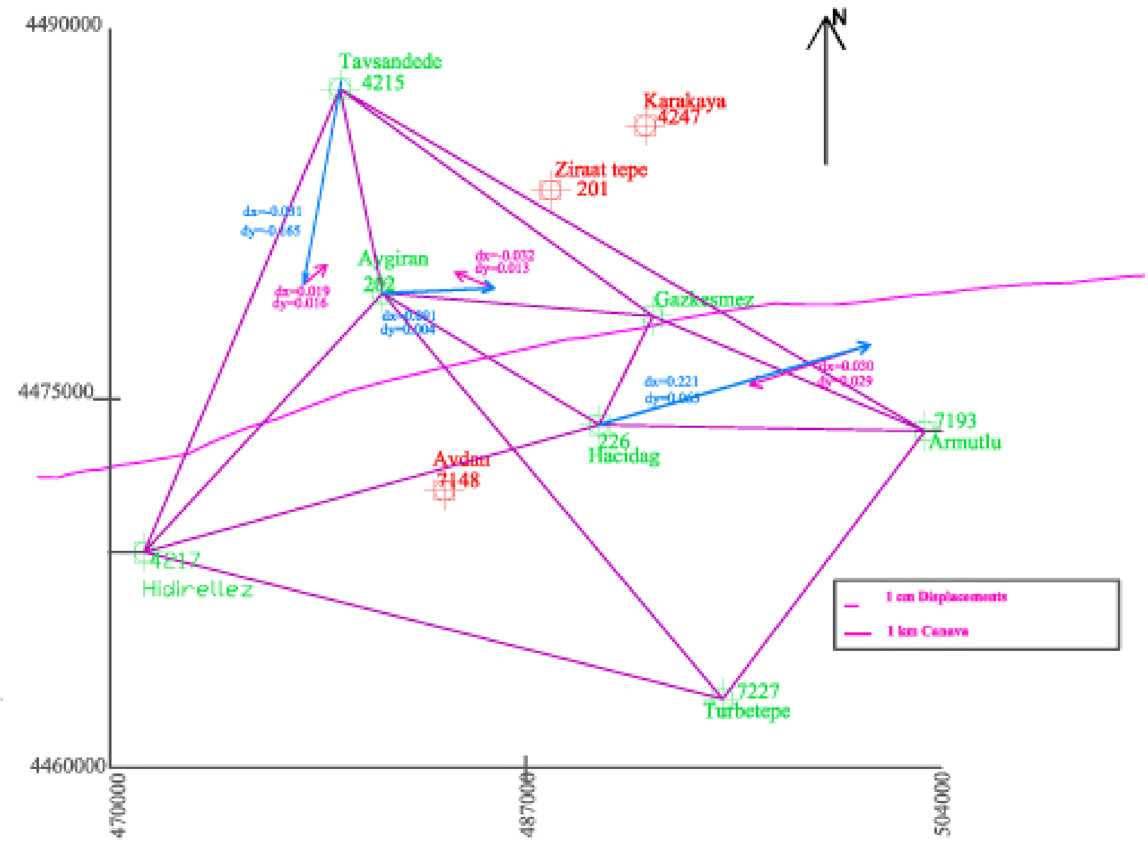

Figure 3.14. The amount of displacement between 1981 and 2007 on the study area. The blue lines represent the changes from 1981 to 2004 and pink ones shows the displacement in the time interval of 2004-2007.

3.4.1 The Detection of Transformation Parameters

Where X_0, Y_0 represents two translation parameters with a scale factor k and rotation α, the 2D-Helmert Transformation Formula between (U,V) and (X,Y) coordinate system is,

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} X_0 \\ Y_0 \end{bmatrix} + k \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{bmatrix} U \\ V \end{bmatrix} \tag{3.7}$$

From transformation the scale factor was evaluated -10.814 ppm which was highest value upon others Table3.16, so it may lead to insufficient outcomes..

Table 3.17. 2D-Helmert transformation parameters for 2004&2007 epoch

No	Parameter	Value	R.M.S.	Dim
1	Shift dX	0.0250	0.0427	m
2	Shift dY	0.0450	0.0427	m
3	Rotation about Z	0.600	0.6192	["]
4	Scale	-10.814	3.0018	[ppm]

3.4.2 The Analysis of Transformed Coordinates

Because of the new transformed coordinates, the analysis based on detecting changes in coordinates between epochs was reproduced. Table 3.17. Displacements were investigated between the 1981 constrained adjustment outputs of 4215, 202 and 202 benchmarks and the transformed coordinates of them from free network adjustment results of 2004 and 2007 united epochs.

Table 3.18. Movements on the north of the fault station Tavsandede Tepe/4215 After 2D Helmert Transformation

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
1981	479437.590 ± 11.2 (+) 0.183	4487596.270 ± 8.8 (-) 0.391
2004&2007	479437.734 ± 2.0	4487595.879 ± 1.3

Table 3.19. Movements on the north of the fault station Aygıran/202 After 2D Helmert Transformation

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
1981	481183.916 ± 7.9 (+) 0.191	4479288.022 ± 6.1 (-) 0.150
2004&2007	481184.107 ±1.7	4479287.872 ± 1.7

Table 3.20. Movements on the south of the fault station Hacıdag/226 After 2D Helmert Transformation

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
1981	490035.818 ± 5.8 (+) 0.134	4473934.716 ± 5.0 (-) 0.109
2004&2007	490035.952 ± 2.2	4473934.607 ± 2.7

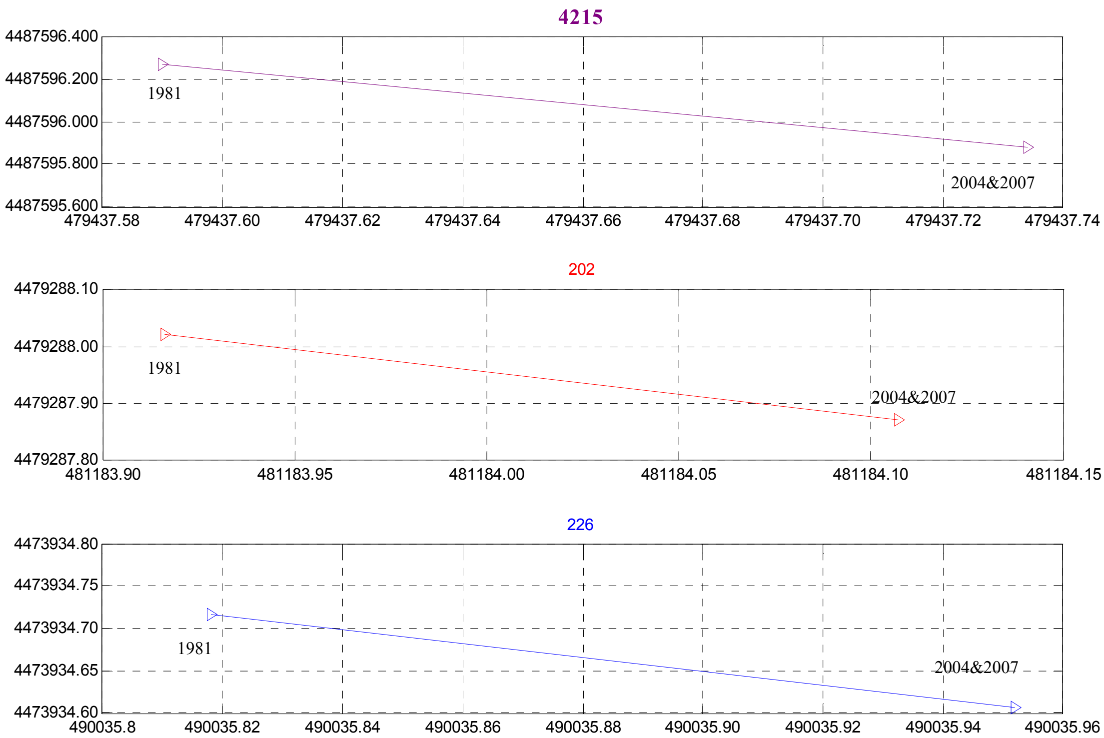

Figure 3.15. The graphic of displacement between 1981 and 2004&2007 for the stations of 4215, 202 and 226 along northing and easting direction.

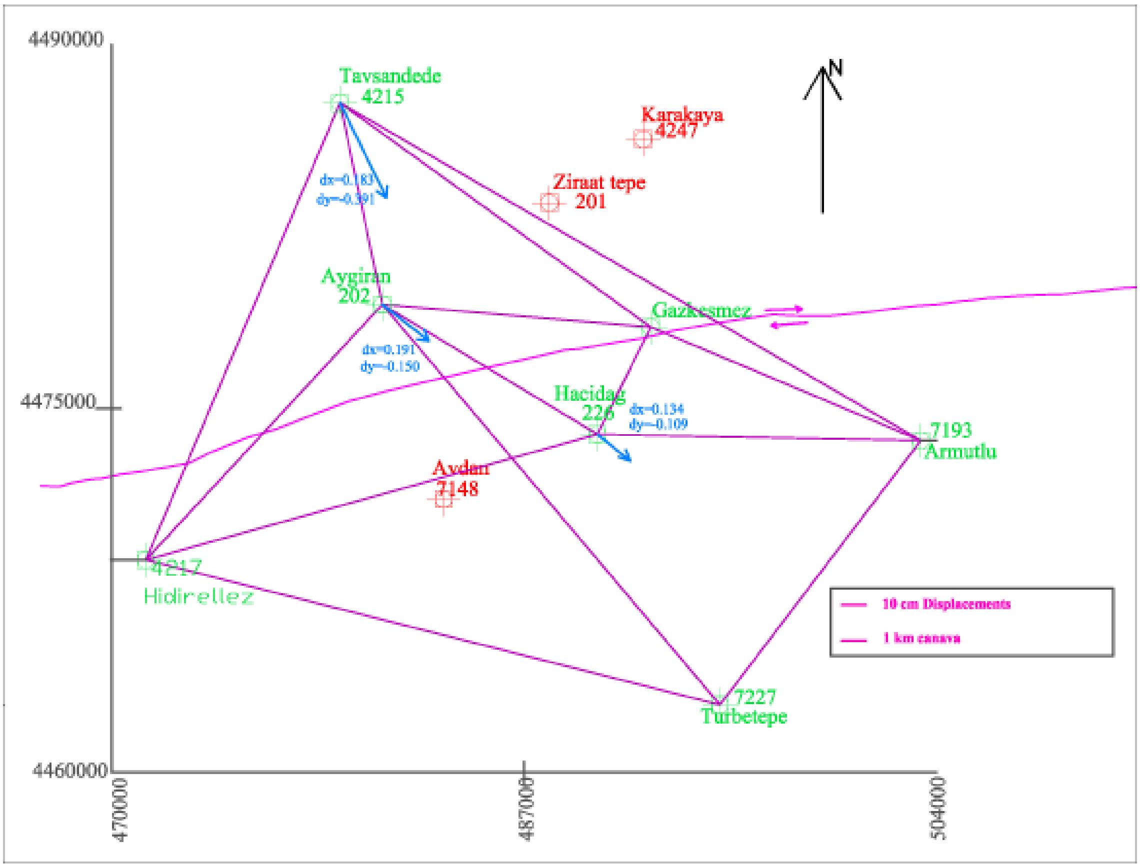

Figure 3.16. The amount of displacement between 1981 and 2004&2007 on the study area.

As displayed in Figure 3.12. and Figure 3.13., 4215 and 202 stations located north of the fault move to southeast consistent with the fault movement.

3.4.3. Comparison of GPS Baseline Vectors between Traditional and GPS Measurements

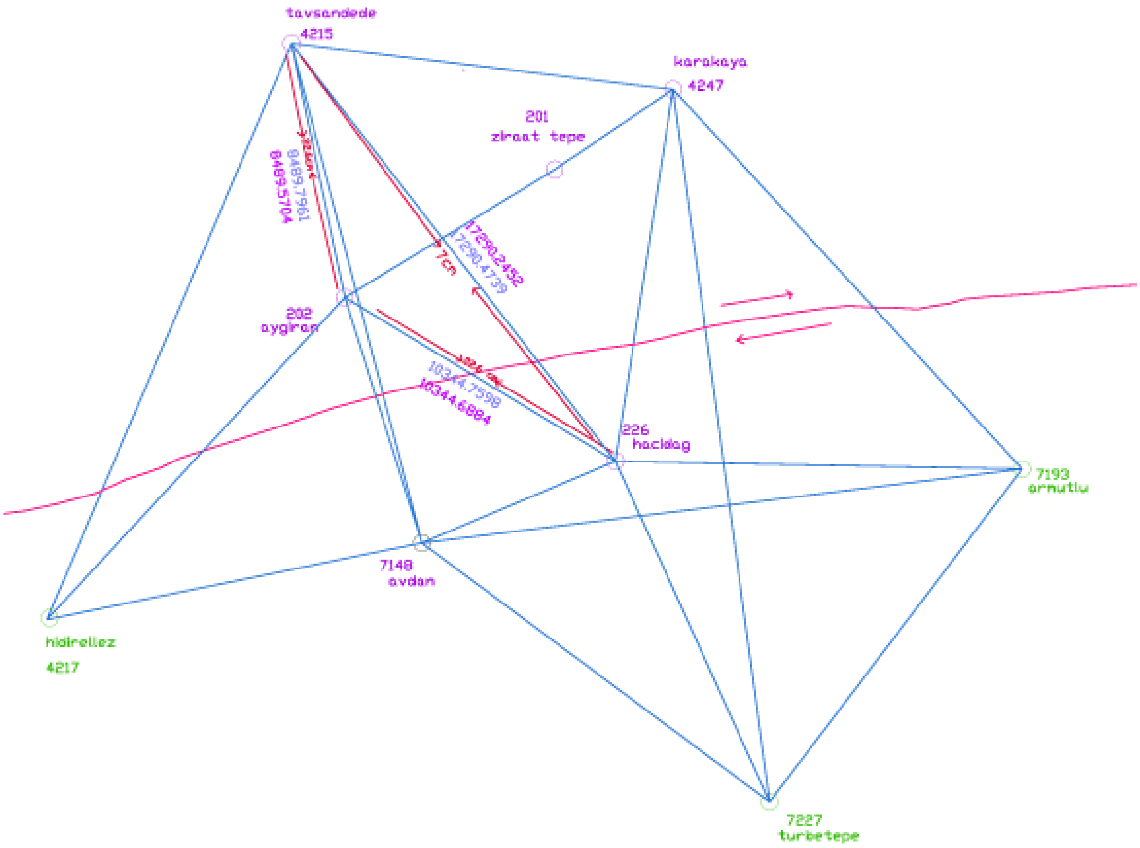

Figure 3.17. The changes on the displacement values between 4215, 202 and 226 stations.

The baseline was produced from transformed coordinates of united 2004&2007 GPS coordinates and adjusted baselines of constrained adjustment for 1981 epoch. Movements on stations caused contraction on baselines which was similar to the revealed displacement results.

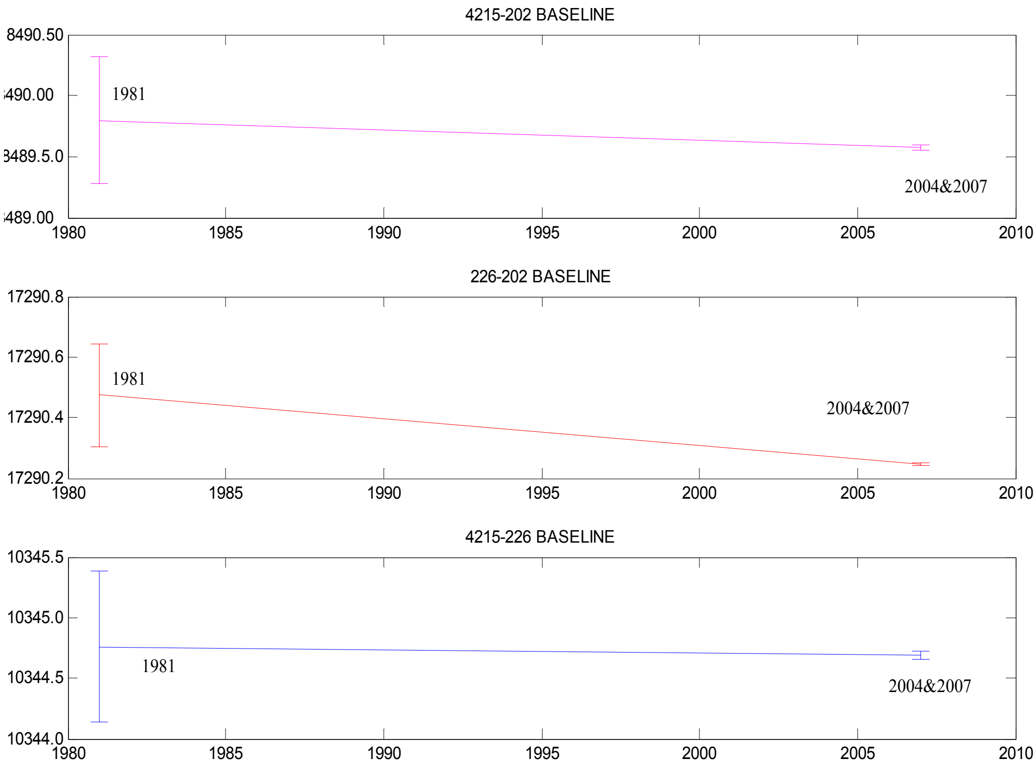

Figure 3.18. The graphic of the changes on displacements between 1981 and 2004&2007 years for the stations of 4215, 202 and 226.

3.5. The Interpretation of Outcomes

Taking everything into account, the following results were obtained from the analysis:

- Although the adjusted coordinates of the data have been computed, the triangulation network data obtained from united 1941&1963 observations are not sufficient to reach reliable conclusions.
- The triangulation and triletaretion network of 1981 epoch was adjusted both free network and constrained approach. From the further computation, the accuracy of position values were obtained between 7cm and 29 cm.

- While 2004 and 2007 campaign results were being analyzed with each other, the results were found to be insignificant relative to the results from the comparison of terrestrial and GPS methods.
- Therefore the united 2004&2007 campaigns were adjusted with free network approach in order to have a more reliable comparison.
- The free network outputs and the terrestrial adjusted data of 1981 were analyzed to get the displacements. Based on the directions of displacement vectors shown in Figure 3.14, relative motion has been found on the both sides of the fault.
- The north of the fault the movement of 4215 and 202 stations is in the direction of southeast.
- Contrarily, the station 226 moves within the same direction, even though the location of the point is different from the others.
- Because of the datum problem and the amount of error in terrestrial measurements, it is not possible to reach reliable conclusion.
- Consequently, the more detailed detection of GPS campaigns will be helpful to make more reliable interpretations. Thus, the next section is designated to investigation of displacements between 2004 and 2007 campaigns.

4. INVESTIGATION OF DISPLACEMENTS BETWEEN 2004 AND 2007 GPS CAMPAIGNS

4.1. The Method of Campaigns

GCM-ITU Network started to observe again in 2004 using GPS method by KOERI Geodesy Department as a research project supported by Research Fund of Bogazici University (Gurkan et al., 2005) in order to carry on research in connection with the crustal deformation around the lake of Iznik. Because of the devastating effects of time, only six of the stations could survive. Four of them were situated south of the Iznik-Mekece Fault and the others were on the north. Therefore Gazkesmez station (Figure 4.1.) was added to densify the northern part which finalizes the geometry of the network (Figure 4.2).

Figure 4.1. Gazkesmez station

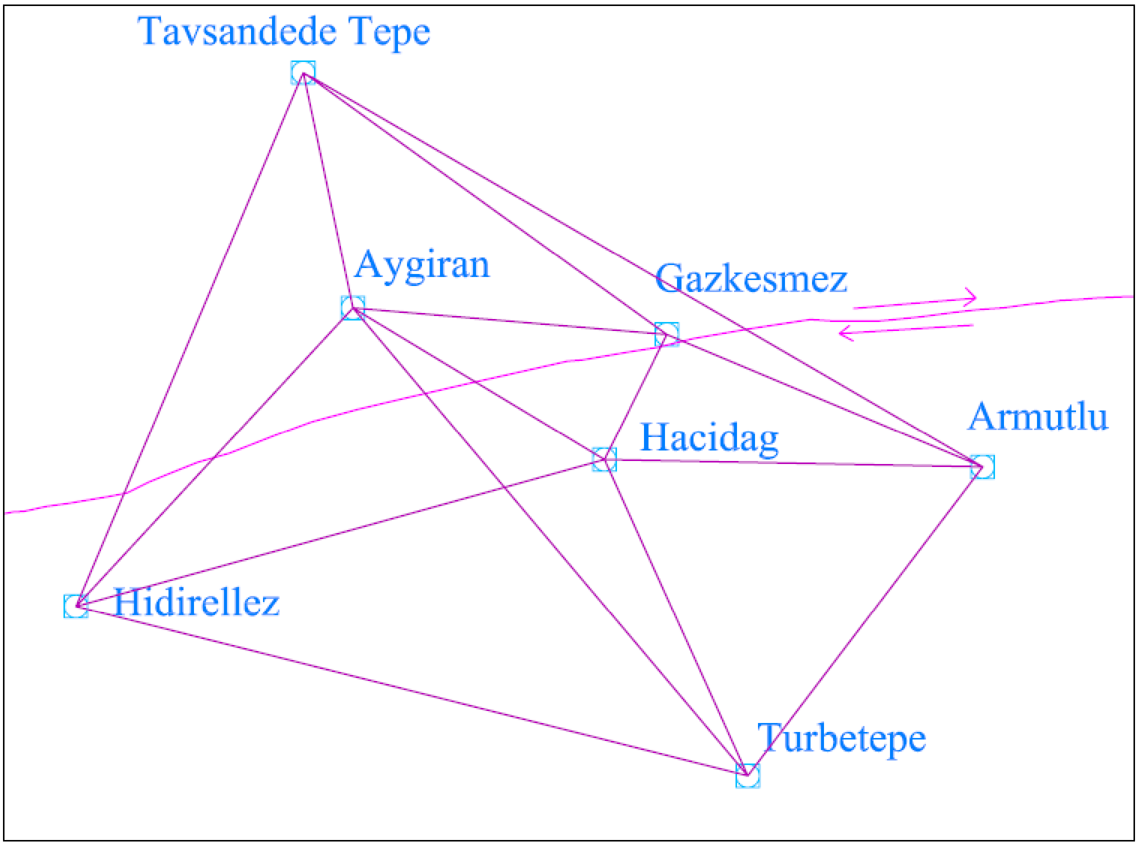

Figure 4.2. The Geometry of GCM-ITU Network in GPS Campaigns

After three years 2007 GPS Campaign was organized on May on the same network constellation. The method of static GPS measurement was performed in this study. Therefore the campaigns had been planned to monitor the network at least eight hours., but some environmental obstacles occurred during the survey.

The occupation time of the first campaign changes from five to eight hours within two days. On the other hand the 2007 campaign was accomplished by seven-hour-long, simultaneous sessions in one day. Both campaigns were conducted using Trimble 4000 SSI and SSE receivers (Figure 4.3.)

Figure 4.3. Trimble 4000 SSI receiver

The 4000SSI is a dual frequency GPS receiver employed in geodetic studies, photogrammetic applications and crustal movement monitoring. Accuracy of the receiver depends on the number of satellites visible, duration of observations, baseline length and atmospheric and surrounding conditions. Assuming that tracking at least five satellites in static surveying and processing data with precise ephemerides one may approach the accuracy of the receiver (Trimble) :

Horizontal: ±5 mm + 0.5 ppm

Vertical: ±5 mm + 1 ppm

Three types of antenna were used in observations: Choke Ring Antenna, Permanent L1/L2 Antenna, Compact L1/L2 Antenna. The choke ring antennas consist of a number of conductive concentric cylinders around a center which prevents multipath effects. The dual frequency antennas have lower power consumption. The ground plane features also reduced multipath .The antennas from the study area can be seen in Figure 4.4. These information about the Trimble products summarized from the manufacturer web site.

Figure 4.4. The GPS antenna on the Hidirellez Station

4.2. GPS Data Processing

Trimble Geomatics Office Software (TGO) and GIPSY/OASIS II (GPS Inferred Positioning System / Orbit Analysis and Simulation Software) software were used in GPS processing. The analysis strategy was similar to the previous section in order to compare the outcomes. For adjustment, constrained adjustment option in TGO was employed. In addition to this, precise coordinates of stable stations were gathered using precise point positioning method in GIPSY. These two processes also helped us to check the results.

This section focuses on the processing strategy and software firstly; then the displacements and the analysis of results of processing are displayed accordingly.

4.2.1. GIPSY/OASIS II Software and Precise Point Positioning

NASA Jet Propulsion Laboratory (JPL) developed the GIPSY/OASIS II software package. The GIPSY analysis designated to reduce phase and pseudo-range data simultaneously. It uses undifferenced data which provides several advantages, such as estimating individual site coordinates and satellite parameters.

Precise Point Positioning (PPP) is a mode which utilizes JPL precise orbits and clock information (such as .eci, .shad, tpeo.nml, .tdpc files) to achieve precise coordinate determination using single receiver. The precision of outcomes are less then 1cm.

In this study coordinates of stable stations were produced by PPP analysis in GIPSY package by following these steps:

- Data input
- Functional Model
- Parameter Estimation
- Creating solution file

Before the analysis, raw binary GPS data in .DAT format gathered from Trimble receivers were translated to RINEX (Receiver INdependent EXchange) format files using TEQC program developed by UNAVCO. TEQC can perform an initial data quality check which identifies the time gaps and abnormalities on file.

“Ninja” is a data input module of GIPSY which reads the RINEX file and runs TurboEdit. It is another routine which eliminates outliers, detects cycle slips and creates qm (quick measurement) file. For removing satellites which are not in an *.eci (Earth-Centered Inertial) file from qm file we applied “weed” module.

The functional model, on the other hand, is produced by “qregres”. It also creates the design matrix of estimation and models solid earth tides, ocean loading and earth orientation.

The third step of processing part is parameter estimation including filtering, smoothing, mapping, reediting data and computing residuals. All parameters are estimated by Square Root Information Filter (SRIF). It is a modified version of Kalman Filter. (Zumberge, 1997) . SRIF is very helpful to split large matrices into small ones by using Household Transformation.

The parameter estimation modules are: pre-prefilter, pre-filter, filter, smapper, postfit, postbreak.

The main GIPSY output file is smcov.nio. Despite the fact that this is a binary file, it can not be read and interpreted for final solutions. As a result, we use “stacov” program which converts it into text file with fixed station coordinates and add their sigmas. Stacov files in PPP are the results of fiducial free solution. In order to put them into a known reference frame such as ITRF 2000, we apply “apit” command. In addition to this, “statistics” command makes it possible to produce baseline components from stacov file.

4.2.1.1. The Outcomes Of Precise Point Positioning Mode of GIPSY. The 2004 Campaign data was processed in GIPSY/OASIS II by using PPP mode in order to estimate the precise coordinates of fixed stations. The Cartesian coordinates of 2004 GPS campaign in ITRF 2000 (International Terrestrial Reference Frame). are displayed in Table 4.1. These coordinates were transformed into WGS-84 system.

Table 4.1. The Cartesian coordinates of 2004 GPS campaigns in ITRF.

Stations	X	Y	Z
HDAG	4218054,11784947±0,0061	2423746,09613411±0.0043	4112312,56110020±0,0058
HDRZ	4230144,97982434±0,0048	2409251,38229920±0.0035	4108258,84105681±0,0042
IGAZ	4214159,77797239±0,0055	2424031,34409934±0.0043	4115367,53657500±0.0049
ARAN	4219392,27424194±0,0053	2414296,41856107±0.0046	4116308,10569394±0.0046
ARML	4211373,13323874±0.0046	2435259,49740078±0.0047	4111952,25903298±0.0048
TAVD	4215571,59979911±0.0066	2410073,95078919±0.0058	4122605,99736702±0.0059
TURB	4221775,92301870±0.0061	2431718,94233952±0.0050	4103809,57333948±0.0049

Irregular formats derived from transformation between .DAT files to RINEX ones and most importantly the atmospheric errors coupling with the inadequate ephemerides information, cause loss of data in 2007 campaign in GIPSY processing. Some of the stations can not be processed at all. Moreover the results gained from the processed ones were not accurate enough to analyze. Therefore, TGO software had to be employed in order to neglect data transformation issues.

4.2.2. Trimble Geomatics Office Software

After having precise coordinates of stable stations as the same of the section two, the raw data was processed in TGO software using fully constrained adjustment option.

Trimble Geomatics Office is a multipurpose software for surveying applications. In this study, the baseline processing module and network adjustment module were used for evaluation of the data. The program has an user friendly interface as it is shown in Figure 4.5.

In processing, the first step is opening a project to organize the data. To select the options for an individual project, the datum and units must be determined on properties window. The raw data was imported into the software by .DAT format obtained from Trimble receivers. In addition to this, precise ephemeredes files (.sp3) were downloaded from IGS (International GPS Service) site on line and inserted into the processing project. The baselines were processed using these precise ephemerides informations in Wave Baseline Processor. In this module it is also possible to identify which ionospheric and tropospheric models would be applied to.

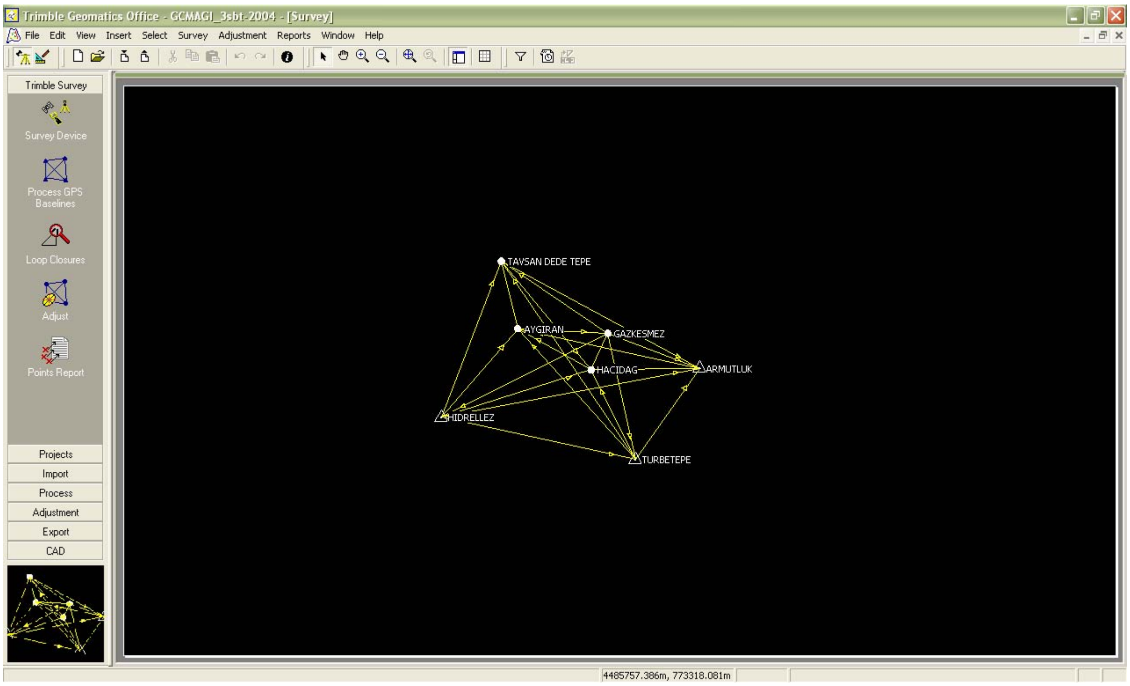

Figure 4.5. The TGO Software

For adjustment in TGO, the network adjustment module was used. This module can be used in

- Detect blunders and large errors
- Model random errors
- Configuring adjustment settings
- Evaluate constrained adjustment
- Report adjusted coordinates and statistical parameters.

After processing the baselines of both 2004 GPS Campaign and 2007 Campaign, these data were computed in TGO network module by fixing the coordinates of Turbetepe, Hidirellez and Armutlu stations. (Figure 4.6.)

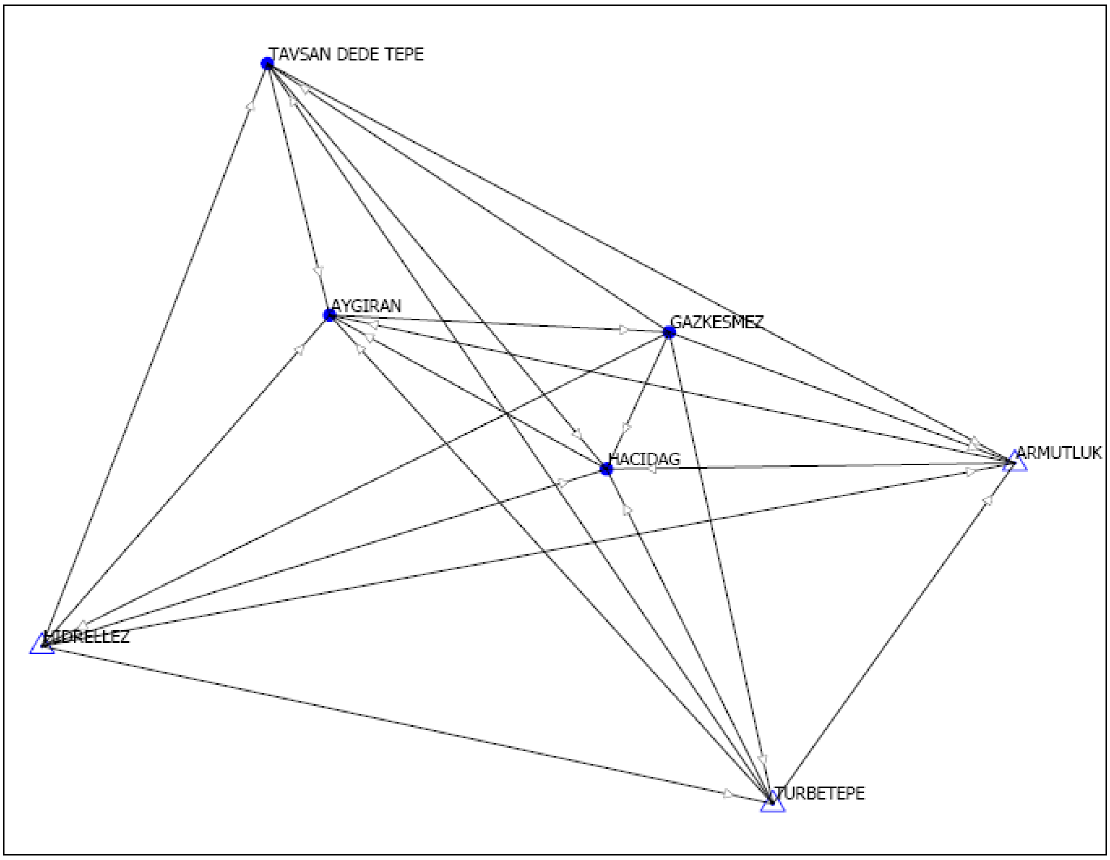

Figure 4.6. The canavas of GPS Campaigns

For adjustment computation, the fully constrained adjustment was performed, so the network was tied to the control points in the network. The software repeats this adjustment until the global statistics are acceptable, literally until the Chi-Square test passes. TGO software performs the Chi-Square test by computing the level of significance for network. In this study the level of significance was estimated as 95%, thus errors were evaluated using 1.96σ (Figure 4.7.). In addition to this any outlier was detected during the adjustment which passes the critical Tau value 3.02.

Table 4.2. Adjusted Geodetic Coordinates of 2004 Campaign

Point	**Latitude**	**N error**	**Longitude**	**E error**	**Height**	**h error**	**Fix**
ARMUTLU	40°23'45.34115"N	0.000m	30°02'20.34353"E	0.000m	596.853m	0.000m	*
AYGIRAN	40°26'46.43147"N	0.001m	29°46'40.01591"E	0.001m	755.683m	0.015m	
TAVSAN DEDE TEPE	40°31'15.62380"N	0.002m	29°45'24.93883"E	0.002m	727.893m	0.023m	
TURBETEPE	40°17'52.21756"N	0.000m	29°56'30.11303"E	0.000m	843.205m	0.000m	*
HACIDAG	40°23'53.43052"N	0.001m	29°52'55.94932"E	0.001m	859.827m	0.010m	
HIDRELLEZ	40°21'04.08186"N	0.000m	29°39'48.21410"E	0.000m	745.654m	0.000m	*
GAZKESMEZ	40°26'16.79852"N	0.001m	29°54'28.76152"E	0.001m	378.520m	0.012m	

Error ellipses figures are obtained from TGO and the scaled network directed to North. The bar scales covered the ellipse and arrow indicate the magnitude of the errors. The direction of the semi-major axis represents the direction of the largest error.

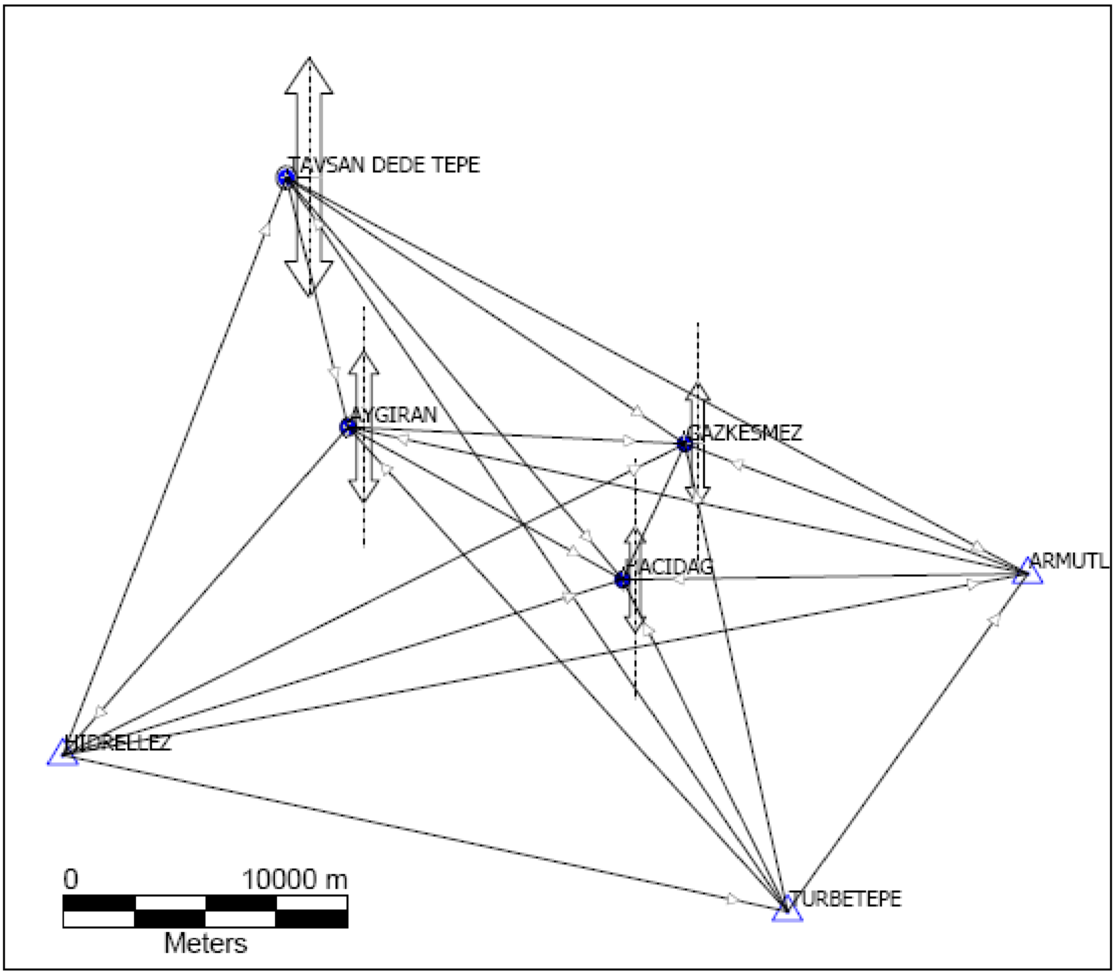

Figure 4.7 Error ellipses from the adjustment of 2004 GPS campaign

In the processing part of 2007 campaign, there was an outlier detected and eliminated, with respect to critical Tau value which equals to 3.18. Furthermore error ellipses were evaluated and drawn using 1.96σ confidence interval. (Figure 4.8.)

Table 4.3. Adjusted geodetic coordinates of 2007 campaign

Point	**Latitude**	**N error**	**Longitude**	**E error**	**Height**	**h error**	**Fix**
AYGIRAN	40°26'46.43192"N	0.003m	29°46'40.01626"E	0.002m	755.707m	0.032m	
ARMUTLU	40°23'45.34115"N	0.000m	30°02'20.34353"E	0.000m	596.853m	0.000m	*
HACIDAG	40°23'53.43059"N	0.003m	29°52'55.94936"E	0.002m	859.844m	0.024m	
GAZKESMEZ	40°26'16.79858"N	0.002m	29°54'28.76161"E	0.002m	378.544m	0.028m	
TAVSAN DEDETEPE	40°31'15.62426"N	0.003m	29°45'24.93968"E	0.003m	727.929m	0.051m	
TURBETEPE	40°17'52.21756"N	0.000m	29°56'30.11303"E	0.000m	843.205m	0.000m	*
HIDIRELLEZ	40°21'04.08186"N	0.000m	29°39'48.21410"E	0.000m	745.654m	0.000m	*

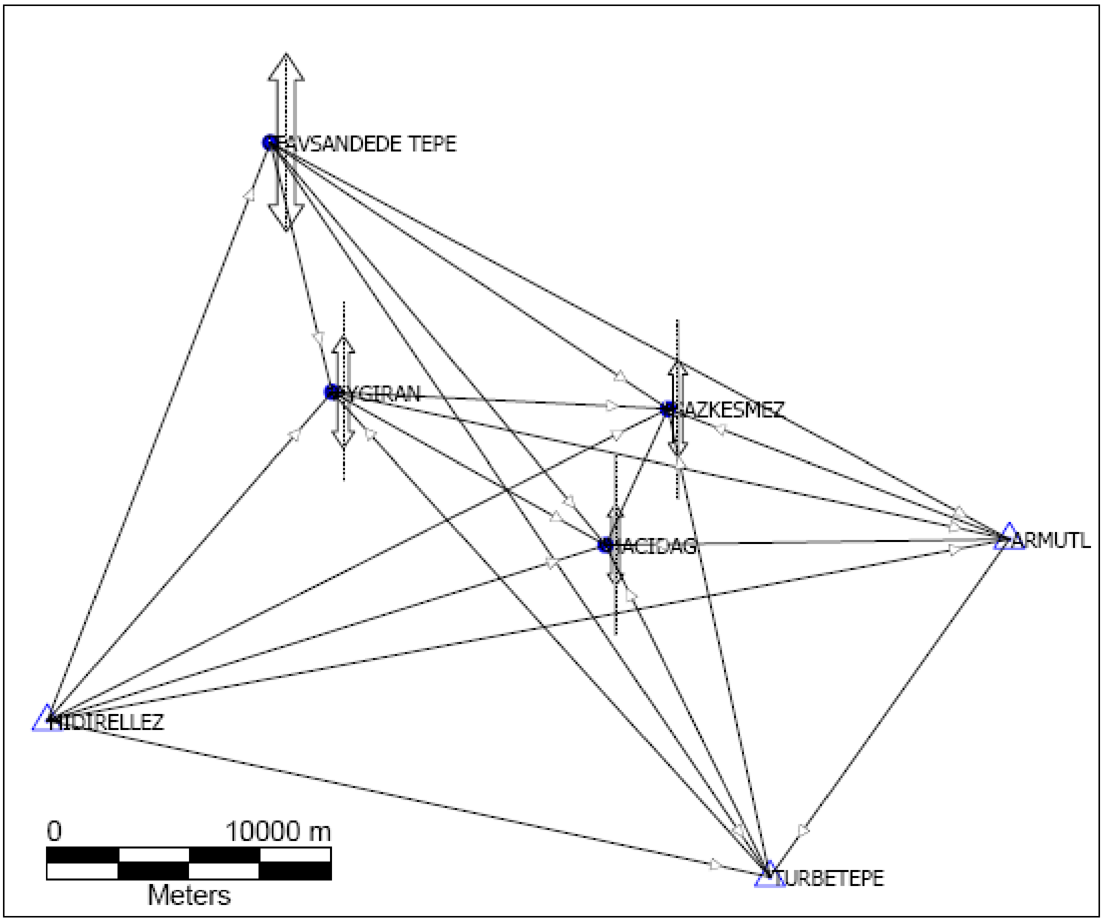

Figure 4.8 Error ellipses from the adjustment of 2007 GPS campaign

4.3. The Displacements Between 2004 and 2007 GPS Campaigns

Coordinate changes on northing and easting values for each tied coordinates were investigated according to their significance and direction.

According to Table 4.4., the computed displacements between two campaigns for station Tavsandede Tepe for both easting and northing direction are lower than their standard mean errors of each adjusted coordinates, thus they can be interpreted as accurate enough.

Table 4.4. Movements on the north of the fault for station Tavsandede Tepe

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
2004	733546.421 ± 0.2 (+) 0.019	4489238.701 ±0.2 (+) 0.015
2007	733546.440 ± 0.3	4489238.716 ± 0.3

Comparing the coordinate changes in three years of stations Aygiran and Gazkesmez, it can be claimed that the results are significant since the mean errors are small.(Table 4.5., Table 4.6.)

Table 4.5. Movements on the north of the fault for station Aygiran

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
2004	735574.802 ± 0.1 (+) 0.007	4480992.582±0.1 (+) 0.014
2007	735574.809 ± 0.2	4480992.596 ± 0.3

Table 4.6. Movements on the north of the fault for station Gazkesmez

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
2004	746648.845 ± 0.1 (+) 0.001	4480434.506±0.1 (+) 0.003
2007	746648.847 ± 0.2	4480434.508 ± 0.2

For Hacidag station, the coordinate differences are distinctly lower than the other stations. This may be due to the location of the site which is the same with the stable points considering Iznik-Mekece fault.

Table 4.7. Movements on the south of the fault for station Hacıdag

Campaigns' Years	**Easting (m±cm)** **(±) Differences**	**Northing (m±cm)** **(±) Differences**
2004	744606.175 ± 0.1 (+) 0.001	4475941.422±0.1 (+) 0.003
2007	744606.176 ± 0.2	4475941.425 ± 0.3

As displayed on Figure 4.9., all movements are directed to northeast in consonance with the movements of Iznik-Mekece fault. The value of changes in coordinates on northing and easting directions could be perceived from Figure 4.10.The biggest changes are found in Tavsandede Tepe site which is the furthest one with respect to the fault. Accordingly, the minimum movement is found in Hacidag which is the nearest station to the fault.

Therefore, it is claimed that the whole stations moved together in spite of the fact that the network is split in by the fault.

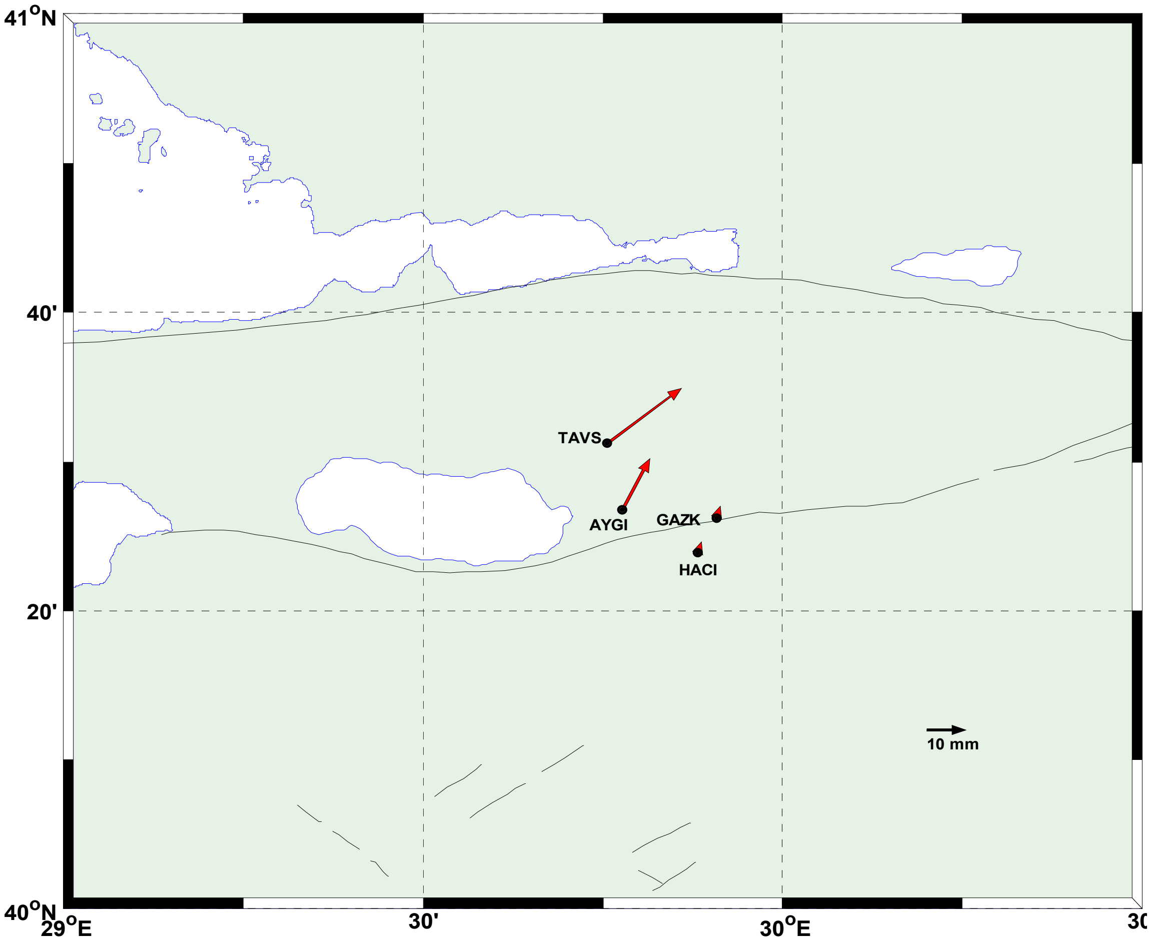

Figure 4.9 The magnitude and the direction of displacements on the study area between 2004 and 2007 relative to Hidirellez, Turbetepe and Armutlu sites.

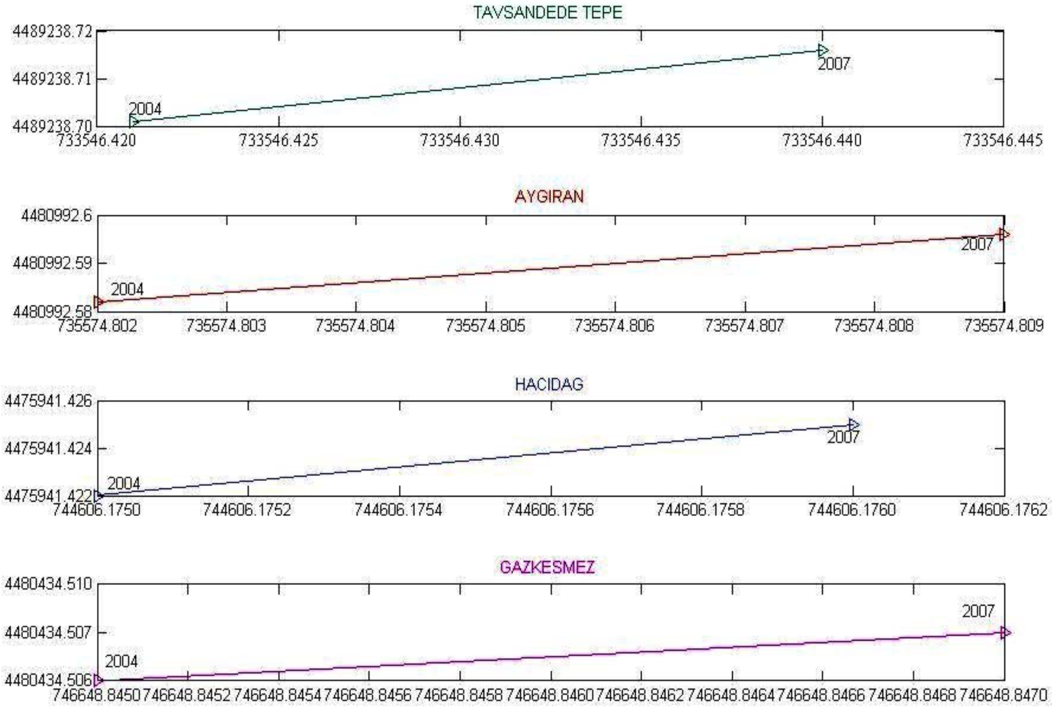

Figure 4.10. The graphic of displacement between 2004 and 2007 GPS Campaigns for the stations of Tavsandede Tepe, Aygiran , Hacidag and Gazkesmez along northing and easting direction.

In order to investigate other effects on GCM network rather than the Iznik-Mekece fault and to extend the research area, three stations were articulated into the study from MAGNET (Marmara Continuous Global Positioning System Network).

4.4. Analyzing Crustal Movements on the Extended Network

4.4.1. The New Network Geometry

While extending the network area, two main goals were taken into consideration:

- The location of new sites (around Marmara region)
- The available data of campaign days

Therefore, MAGNET network conducted by TUBITAK-MRC-EMSRI (The Scientific and Technical Research Council of Turkey-Marmara Research Center-Earth and Marine Sciences Research Institute) was determined as the most appropriate network. The network was established before the Izmit earthquake in 1999 for crustal deformation associated with strain accumulation along the western NAF system.(Ergintav., S., 2007). It consists of 18 sites scattered along Marmara Region (Figure 4.11.)

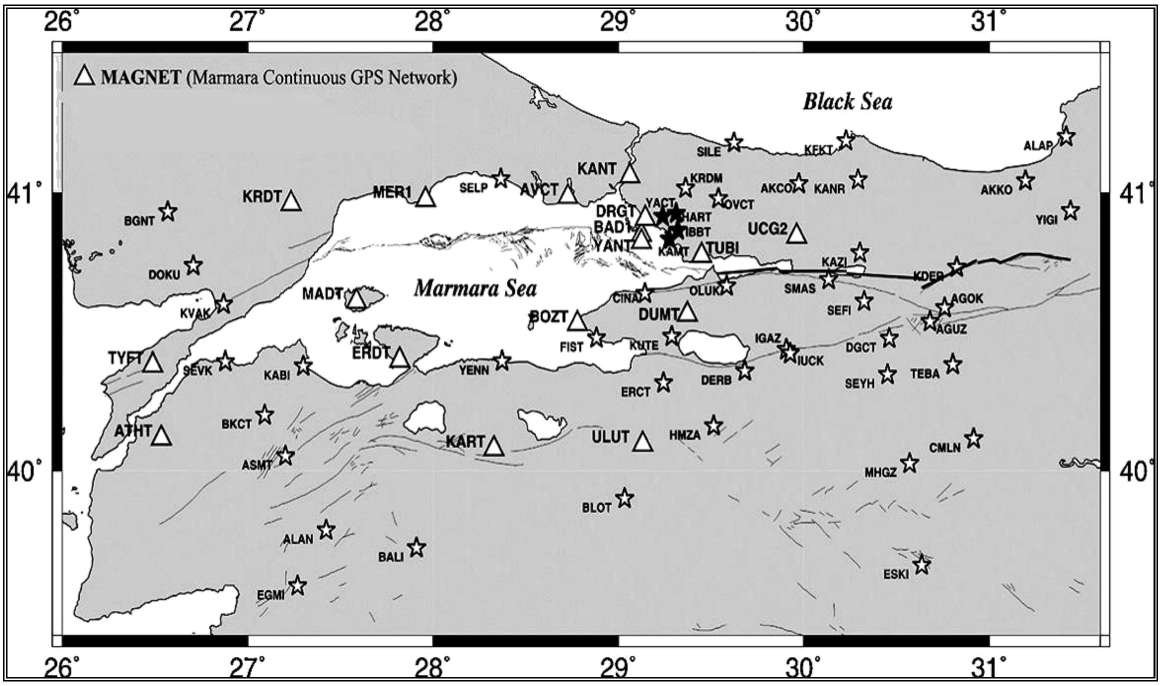

Figure 4.11. MAGNET Network (Ergintav 2007)

In this part, deformations are estimated with the contribution of three MAGNET stations. BAD1 (Buyukada), TUBI (Tubitak) and ULUT (Uludag). The final network geometry of extended GCM network is displayed in Figure 4.12

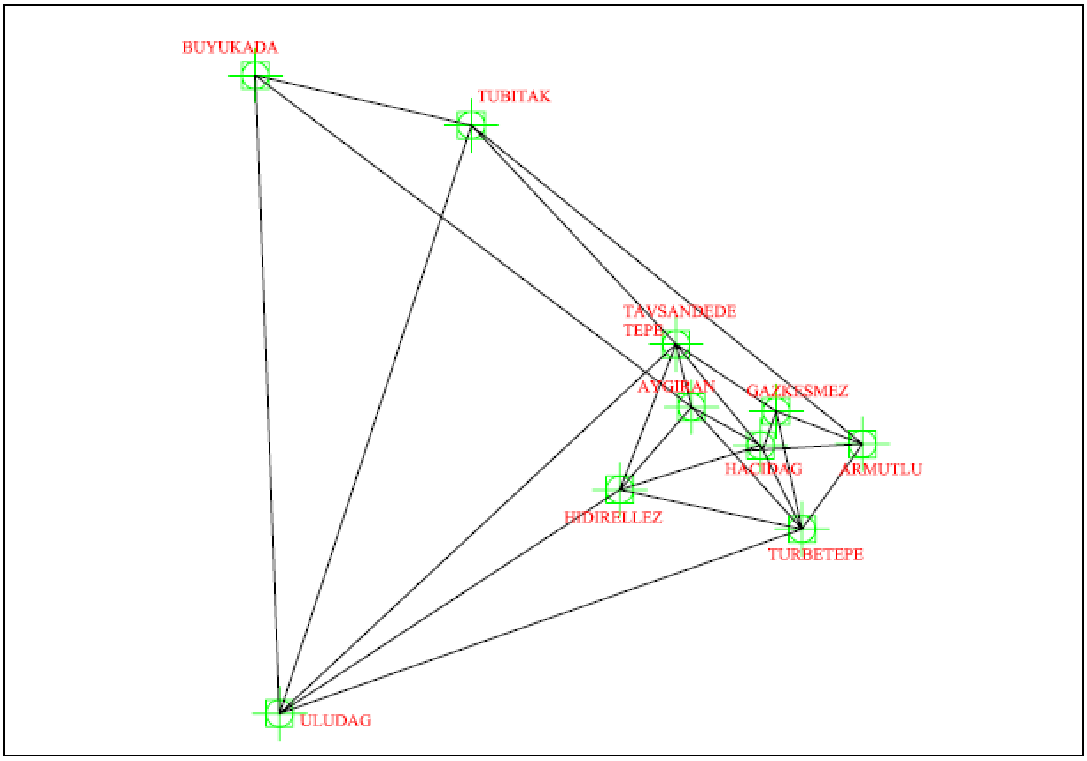

Figure 4.12. The extended GCM Network by three MAGNET Station

4.4.2. Methods of Processing

TGO software was also employed for GPS processing step of the extended network. Although the method of the process was the same, the adjustment model differs from previous one.

Because of the fact that obtained raw data of continuous stations already exist, the idea of tying the network to them would result in more precise outcomes. Therefore, TUBI station was selected as the stable point and minimally constrained adjustment was applied to data.

The precise coordinates of TUBI stations were obtained from SOPAC (Scripps Orbit and Permanent Array Center) site (http://sopac.ucsd.edu/processing/coordinates/) on Internet in connection with the exact day of the observations.

Minimally constrained adjustment is the process of holding fixed, or "constraining" coordinates of one control point during the adjustment.. From this, it is possible to check the positions of other points, and determine how well our baselines fit together as an independent network. Therefore the software easily identifies the bad observations as outliers and estimates errors for each measurement.

For 2004 campaign days, one outlier was extracted (Tubitak and Gazkesmez baseline) and then removed based on the Tau value of 3.45. The adjusted coordinates in 1.96σ confidence interval are shown in the Table 4.8.

Table 4.8. Adjusted geodetic coordinates of extended network on 2004 campaign days

Point	**Latitude**	**N error**	**Longitude**	**E error**	**Height**	**h error**
AYGIRAN	40°26'46,43121"N	0,001m	29°46'40,01657"E	0,001m	755,432m	0,009m
TUBI	40°47'12,20957"N	0,000m	29°27'02,46033"E	0,000m	220,343m	0,000m
ARMUTLUK	40°23'45,34084"N	0,001m	30°02'20,34362"E	0,001m	596,719m	0,009m
TAVSAN DEDE TEPE	40°31'15,62340"N	0,002m	29°45'24,93962"E	0,001m	727,437m	0,011m
TURBETEPE	40°17'52,21741"N	0,001m	29°56'30,11314"E	0,001m	843,347m	0,010m
HACIDAG	40°23'53,43027"N	0,001m	29°52'55,94972"E	0,001m	859,700m	0,009m
HIDRELLEZ	40°21'04,08182"N	0,001m	29°39'48,21490"E	0,001m	745,676m	0,009m
GAZKESMEZ	40°26'16,79818"N	0,001m	29°54'28,76192"E	0,001m	378,282m	0,008m
ULUDAG	40°05'51,17410"N	0,001m	29°07'53,19898"E	0,001m	2088,938m	0,008m
BUYUKADA	40°51'07,62086"N	0,002m	29°07'04,42836"E	0,001m	238,364m	0,012m

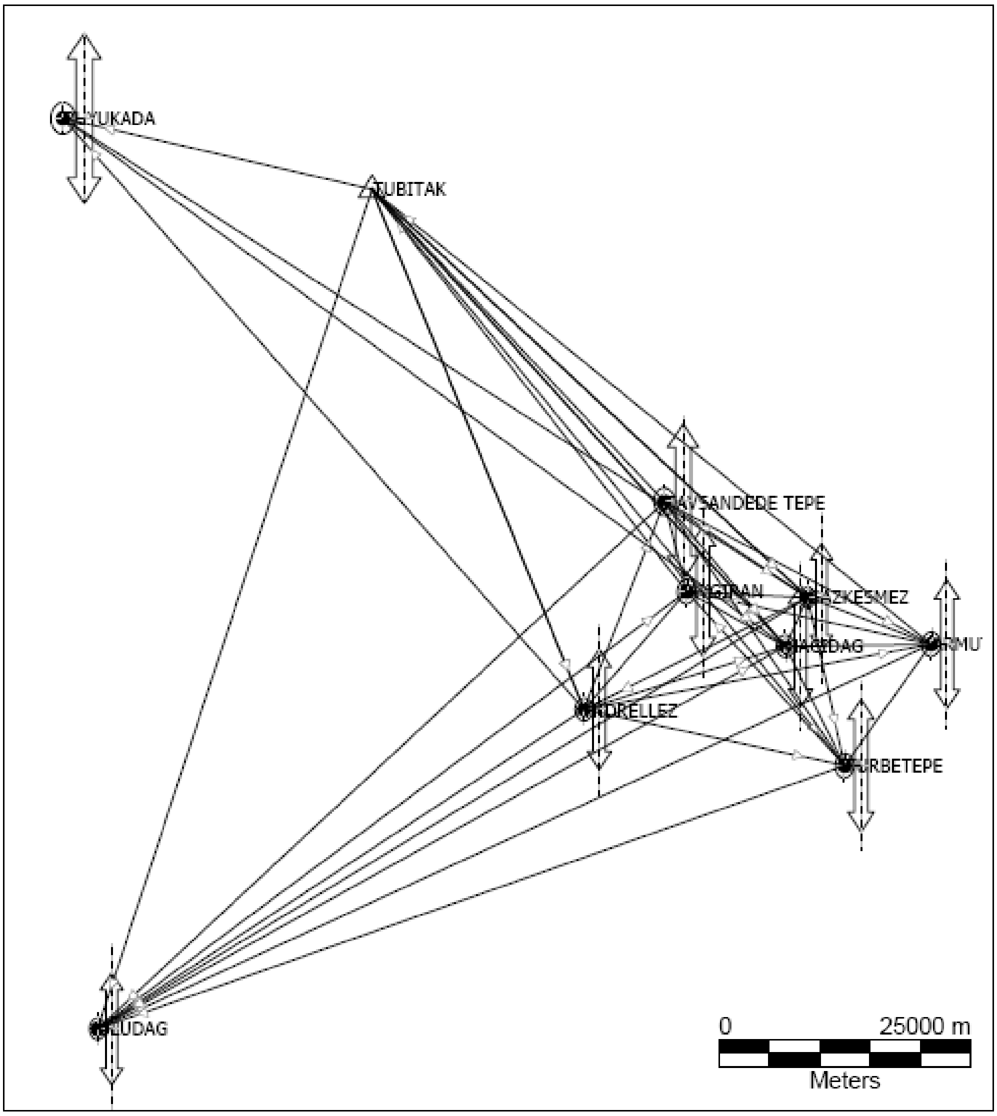

Figure 4.13 Error ellipses from the adjustment of extended network on 2004 campaign days.

While processing 2007 campaign the calculation was iterated until whole observations were able to pass the Chi-square test. The adjusted values are displayed in Table 4.9. which indicates that the errors are relatively smaller than the 2004 campaign. The reason of more precision might be related to duration of simultaneous observation which is more than three hours longer in 2007. For error ellipses the critical Tau value was determined as 3.47. (Figure 4.14.)

Table 4.9. Adjusted geodetic coordinates of extended network on 2007 campaign days

Point Name	Latitude	N error	Longitude	E error	Height	h error
BAD1	40°51'07,62213"N	0,001m	29°07'04,43112"E	0,001m	239,157m	0,006m
TUBI	40°47'12,21073"N	0,000m	29°27'02,46242"E	0,000m	220,348m	0,000m
ULUT	40°05'51,17578"N	0,001m	29°07'53,19855"E	0,001m	2088,935m	0,006m
ARAN	40°26'46,43260"N	0,001m	29°46'40,01627"E	0,001m	755,485m	0,008m
ARML	40°23'45,34188"N	0,001m	30°02'20,34284"E	0,001m	596,739m	0,008m
HACIDAG	40°23'53,43131"N	0,001m	29°52'55,94902"E	0,001m	859,745m	0,009m
GAZKESMEZ	40°26'16,79921"N	0,001m	29°54'28,76127"E	0,001m	378,327m	0,007m
TAVD	40°31'15,62476"N	0,001m	29°45'24,93987"E	0,001m	727,493m	0,008m
TURBETEPE	40°17'52,21829"N	0,001m	29°56'30,11229"E	0,001m	843,391m	0,008m
HDRZ	40°21'04,08288"N	0,001m	29°39'48,21427"E	0,001m	745,721m	0,008m

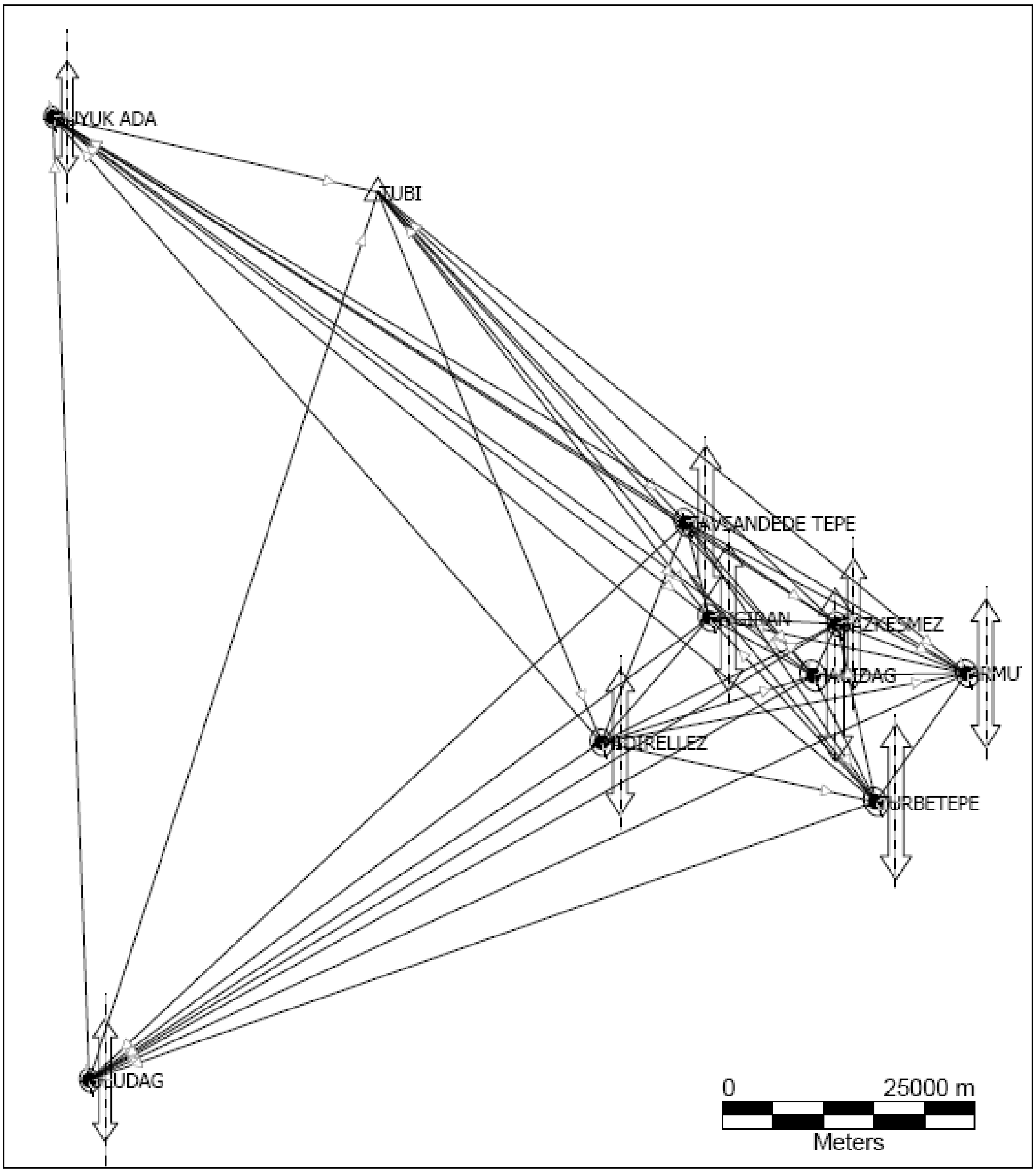

Figure 4.14. Error ellipses from the adjustment of extended network on 2007 campaign days.

4.4.3. Analyzing the Movements on the Network

The biggest mean standard error of both 2004 and 2007 adjustments is 2 mm, thus the displacements can be interpreted as accurate enough for statistically.(Table 4.10)

Table 4.10. The differences along Northing and Easting direction between 2004 and 2007 years for extended network

Site	Δn	Δe
BUYUKADA	0.041m	0.063m
TUBITAK	0.037m	0.048m
ULUDAG	0.051m	-0.012m
AYGIRAN	0.042m	-0.008m
ARMUTLU	0.032m	-0.020m
HACIDAG	0.031m	-0.018m
GAZKESMEZ	0.031m	-0.017m
TAVD. T.	0.042m	0.004m
TURBETEPE	0.027m	-0.021m
HIDIRELLEZ	0.032m	-0.016m

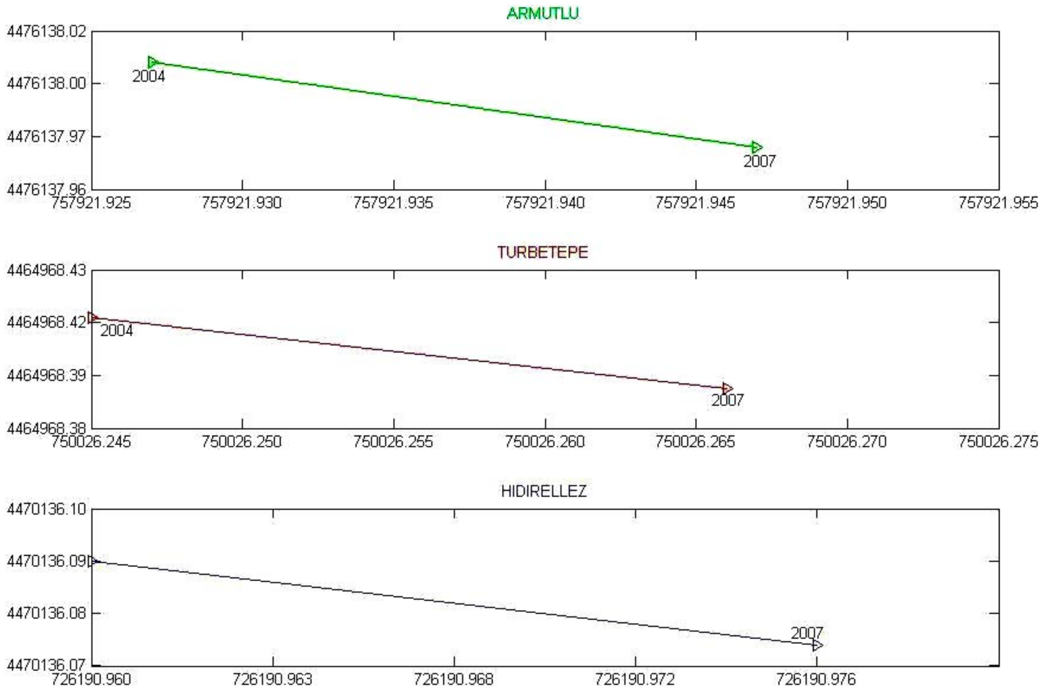

Figure 4.15.a. The graphic of displacement between 2004 and 2007 GPS Campaigns along extended network for the stations of Armutlu, Turbetepe and Hidirellez for northing and easting direction.

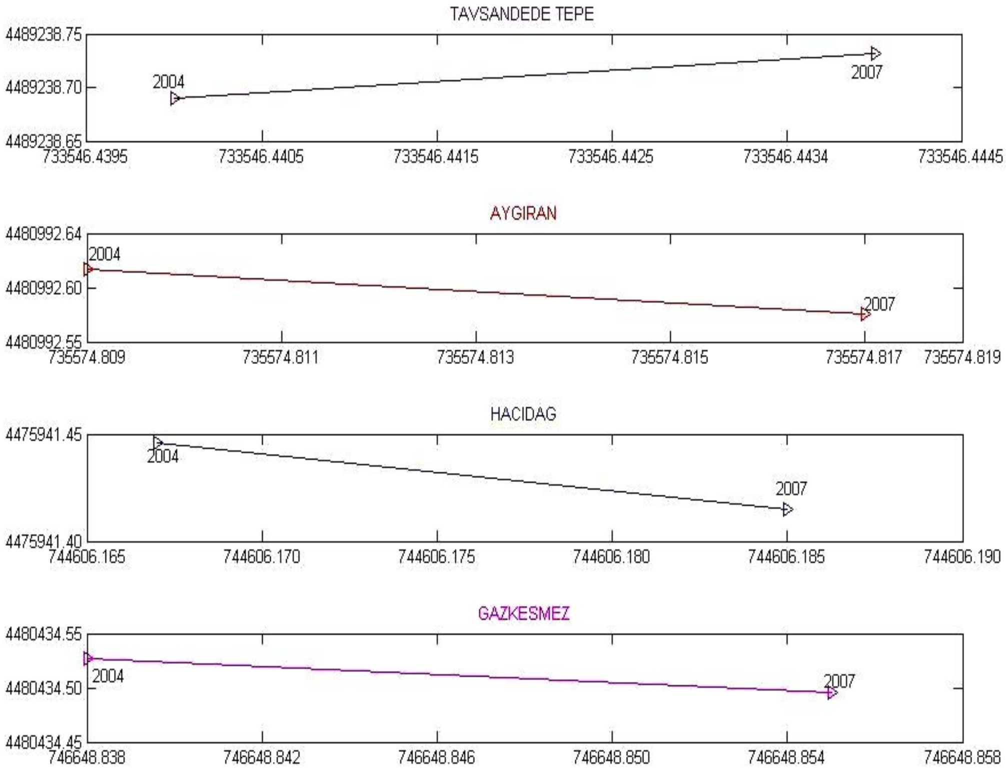

Figure 4.15.b. The graphic of displacement between 2004 and 2007 GPS Campaigns along extended network for the stations of Tavsandede Tepe, Aygiran, Hacidag and Gazkesmez for northing and easting direction.

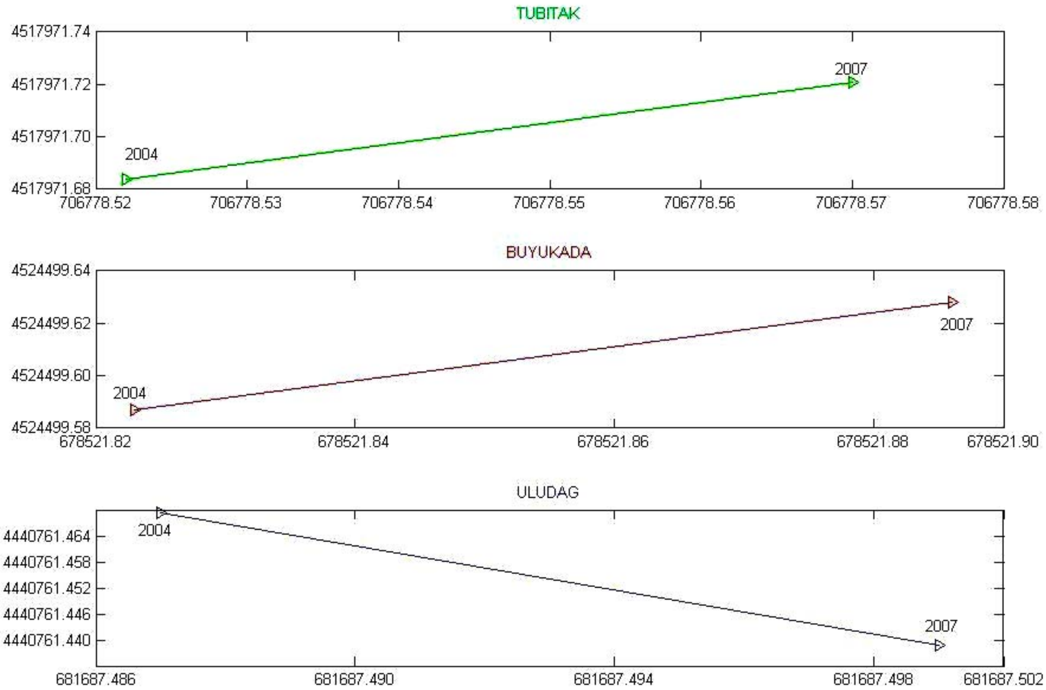

Figure 4.15.c. The graphic of displacement between 2004 and 2007 GPS Campaigns along extended network for the stations of Tubitak, Buyukada and Uludag for northing and easting direction.

As it shown in the Figure 4.16, the direction of displacement vectors which depends on the faults throughout the area changes. In summary,

- The movements on the GCM network relative to TUBI are similar to south east.
- The whole network keeps its integrity and all sites move together.
- On the other hand the Tavsandede Tepe station, which is the northeast one in the GCM network according to the Iznik Mekece Fault, slightly turns its way to the north.
- The values of displacements in three years on GCM-ITU network vary from 3.5 to 4.2. cm which is higher than the interior deformation analyzed before.

- The MAGNET stations moves depending on the yearly velocity rates of WGS-84 system consistent with prior studies.
- The northern strand of the NAF is the distinctive factor for the the changes in directions. Besides the Iznik-Mekece fault does not show any significant orientation on the GCM-ITU network.

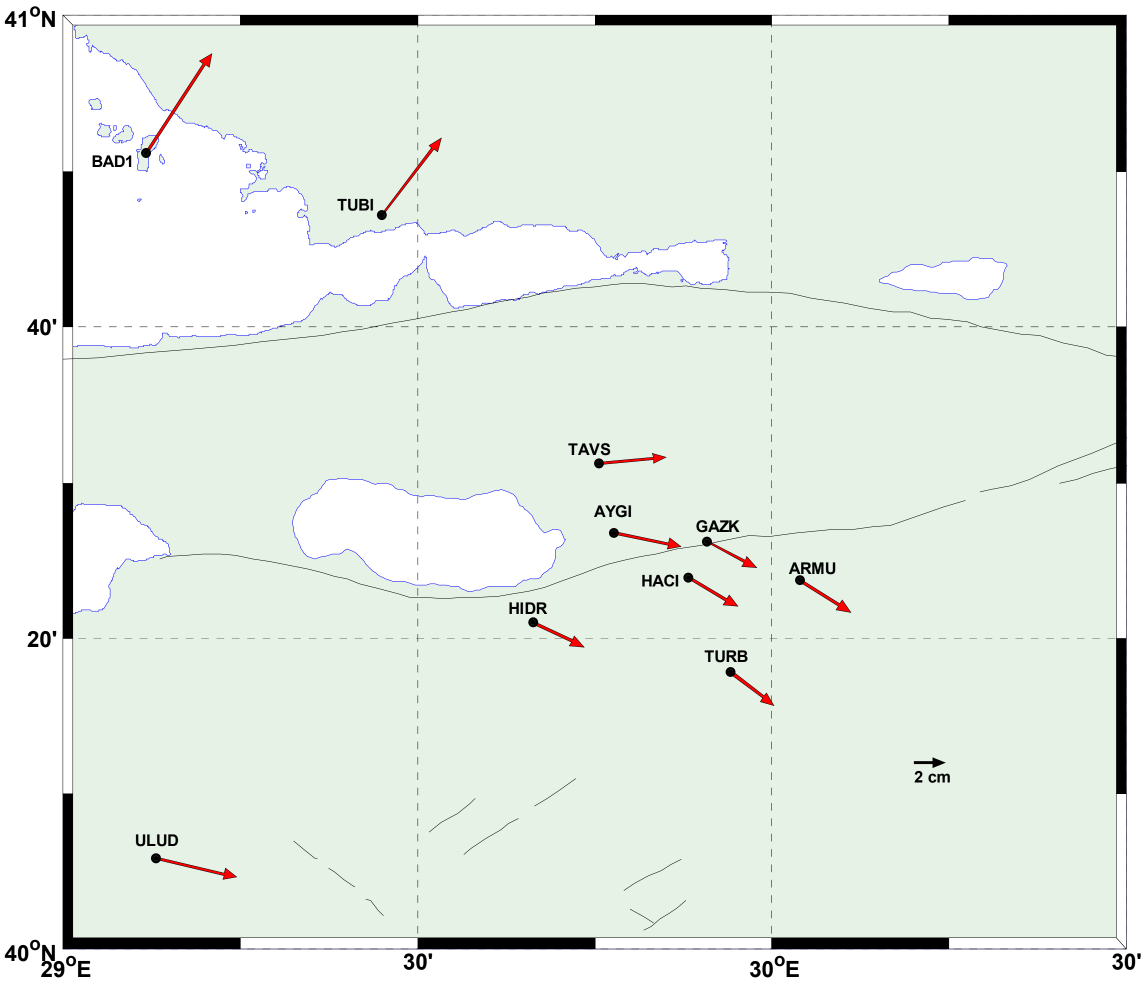

Figure 4.16 The magnitude and the direction of displacements on extended network between 2004 and 2007 years in WGS 84 system.

5. CONCLUSIONS

The aim of this study is to investigate the displacements of the GCM-ITU network located around the western branches of NAFZ along Lake of Iznik between 1963 and 2007 years using both terrestrial and space geodetic methods.

The steps of the study are as follows: first, the coordinates of the conventional observations and GPS displacements were computed by least square adjustment method. In order to calculate coordinates in the same datum for each observation, three sites were accepted as stable in processing: Hidirellez, Armurlu and Turbetepe. Afterwards, the results are compared to each other according to observation years in connection with the changes on the northing and easting with respect to error parameters.

Due to the inadequacy of the precision of conventional methods during these years, observations conducted on 1941 and 1963 did not provide significant results, in particular for deformation studies. Therefore they are not included in our displacement analysis.

On the other hand the terrestrial measurements gathered from 1981 had relatively small error, thus our analysis was based on the comparison of the outcomes from 1981 measurements and the outcomes from GPS measurements. To have more reliable solutions, the 2004 and 2007 campaigns were united and adjusted together. Therefore between 1981 data and 2004&2007 data, relative motion has been found on the both sides of the fault. While Tavsandede Tepe station and Aygiran station located the north of the fault moves southeast, Hacidag station moves to the same direction despite the fact that in the southern part of the fault. As a result, the sites located both northern and the southern part of the fault moves to the same direction. Therefore, it is to be inferred that the motion of the network depends on interior deformation. On the other hand the motion is gradually reduced if the site is located closer to the fault. In this case, the reason of this reduction is not only the influence of the fault but also constraints of stable stations

In order to check the significance of the first analysis, GPS data were processed and analyzed individually on both GCM-ITU network and extended network by adding continuous MAGNET sites. The data processed by commercial software (TGO) and displacements were analyzed taking into consideration the errors of the outcomes and the directions of the displacements.

The GPS analysis on the GCM-ITU network lead to similar results with the section three., the whole network moves together to one direction. In addition to this, the biggest change is detected on the furthest site from fault, Tavsandede Tepe and the smallest change is found on the nearest station, namely Hacidag. Apart from this, the direction of the motion differs from the prior section which can be the influence of large earthquakes that occurred in 1999 around the area.

In the extended network processing the network protects its integrity even if the larger area has much more exterior. However, the far sides of GCM-ITU network are directed slightly different. This may be due to the distinctive effect of northern strand of NAF. The sites located the north of the northern strand aimed to move northeast, although the others directed to south-east.

The whole set of analysis indicates that, the Iznik-Mekece Fault does not have distinctive effects on the GCM-ITU network bigger than its interior deformation.

APPENDIX : A OBSERVATION DATA AND ADJUSTED OUTCOMES

The observation tables are listed in this section. Tables are organized simultaneously with the observation year. Each observation is followed by their own adjustment result with error values.

Table A.1. The initial coordinates of the network stations

Points	Easting	Northing
4217	471439.520	4468758.726
7193	503345.740	4473679.220
7227	495078.996	4462788.052
4215	479437.636	4487596.219
4247	491921.691	4486099.800
7148	483701.080	4471259.320
201	488055.600	4483477.661
202	481183.938	4479287.999
226	490035.869	4473934.653

Table A.2. The observations of united 1941 1963 epoch

P1	P2	DIRECTIONS
4147	4247	0
	7148	41.78106
4247	4147	0
	4215	373.08445

P1	P2	DIRECTIONS
4147	4215	0
	7148	11.28239
	4217	39.80813
4147	7148	0
	7193	320.45500
4215	7148	0
	4217	41.814075
	4147	181.260393
	4247	323.845406
7227	7148	0
	7193	100.59062
7193	7227	91.31083
	7148	142.17988
	4247	202.64177
7148	4147	0
	4215	7.456862
	7193	115.906396
	7227	164.453146
	4217	310.901625

Table A.3. Constrained adjustment results of 1941&1963 epoch

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
4215	0.0743	479437.6	0.0075	4487595.830
4247	0.0532	491922.9	0.0259	4486099.439
7148	0.0839	483701.0	0.0392	4471259.467
4147	0.0503	473590.6	0.0622	4497140.073

Table A.4. Mean errors from constrained adjustment of 1941&1963 epoch

Points	My(cm)	Mx(cm)	Mp(cm)
4215	40.3678	65.7207	77.1283
4247	83.6878	79.1553	115.1921
7148	32.2961	14.9835	35.6026
4147	62.2436	67.5314	91.8409

Table A.5. Parameters of Error ellipses of 1941&1963 epoch

Points	A(cm)	B(cm)	FI(g)
4215	65.7683	40.2903	3.06
4247	9.1984	36.6730	147.78
7148	32.6251	14.2529	110.07
4147	70.0011	59.4525	166.76

Table A.6. The direction observations 1981 epoch

P1	P2	DIRECTIONS
7193	4247	0
	7227	288.67434
	7148	339.53810
	226	348.56361
7227	7148	0
	226	32.20823
	4247	50.68650
	7193	100.58895
4215	201	0
	7148	55.36822
	202	58.42954
	4217	97.18034
	4247	379.21383
4217	7148	0
	4215	338.36853
	202	360.34433
4247	201	0
	4215	45.53525
	7193	290.60023
	7227	329.37113
	226	347.73299
	7148	370.14393
201	202	0
	4215	63.2378
	4247	196.91548
	226	321.83036
	7148	356.65133
202	7148	0
	4217	66.87824
	4215	206.15233
	201	284.48529
	226	353.96823
226	7148	0

	202	60.06575
	201	112.41358
	4247	135.23075
	7193	226.66084
	7227	298.39017

Table A.7. The baseline observations 1981 epoch

P1	P2	BASELINES
7148	202	8413.949
	201	12970.814
	4247	16964.982
201	4247	4671.445
	4215	9551.558
	226	9746.207
	202	8048.085
202	4215	8489.639
	4217	14346.303
	226	10344.757
4215	7148	16883.877
	4247	12573.266
7193	7148	19793.109
	4247	16875.295
226	4247	12310.338
	7193	13312.280
	7148	6876.513

Table A.8. Constrained adjustment results of 1981 epoch

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
Tavsandede Tepe/4215	-4.5646	479437.590	5.0615	4487596.270
Karakaya/4247	8.208	491921.773	4.4432	4486099.844
Avdan/7148	-0.0027	483701.080	6.559	4471259.386
Zirat tepe/201	-0.9647	488055.590	0.413	4483477.665
Aygıran/202	-2.1809	481183.916	2.2639	4479288.022
Hacidag/226	-5.0583	490035.818	6.2935	4473934.716

Table A.9. Mean errors from constrained adjustment of 1981 epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	11.2162	8.7576	14.2302
Karakaya/4247	8.9111	7.7529	11.8117
Avdan/7148	6.3001	6.1001	8.7694
Zirat tepe/201	8.5794	7.0205	11.0857
Aygıran/202	7.9159	6.1136	10.0019
Hacidag/226	5.8250	4.9814	7.6645

Table A.10. Parameters of error ellipses of 1981 epoch

Points	A(cm)	B(cm)	FI(g)
Tavsandede Tepe/4215	11.2412	8.7254	106.75
Karakaya/4247	9.1599	7.4574	126.10
Avdan/7148	6.3915	6.0043	67.29

Table A.11. Adjusted baselines for 1981 epoch

P1	P2	s(m)	v(cm)	m	S(m)
7148	202	8413.949	0.2057	51.5596	8413.983024
7148	201	12970.814	20.3054	76.9365	12971.04913
7148	4247	16964.982	21.5369	99.6466	16965.22955
201	4247	4671.445	7.9236	31.7462	4671.530068
201	4215	9551.558	-0.2108	57.6245	9551.587663
201	226	9746.207	1.7977	58.8560	9746.239405
201	202	8048.085	5.9822	49.4854	8048.168634
202	4215	8489.639	11.6613	51.8050	8489.796132
202	4217	14346.303	0.1119	84.6619	14346.40456
202	226	10344.757	-2.4402	62.2358	10344.75978
4215	7148	16883.877	10.1500	99.1382	16884.04938
4215	4247	12573.266	24.8163	74.4775	12573.54790
7193	7148	19793.109	0.9798	115.9252	19793.13684
7193	4247	16875.295	9.584	99.0008	16875.39426
226	4247	12310.338	9.9512	73.1885	12310.44988
226	7193	13312.280	8.9382	78.9230	13312.37359
226	7148	6876.513	-2.4137	43.2295	6876.503735

Table A.12. Free network adjustment results of 1981 network

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
Hıdırellez/4217	15.1358	471439.671	3.5207	4468758.76
Armutlu/7193	-7.3997	503345.666	0.8597	4473679.23
Türbetepe/7227	-5.1249	495078.945	1.9957	4462788.07
Tavsandede Tepe/4215	-0.731	479437.629	-5.7175	4487596.16
Karakaya/4247	4.6113	491921.737	-3.5538	4486099.76
Avdan/7148	2.1925	483701.102	7.2699	4471259.39
Zirat tepe/201	-2.5555	488055.574	-6.7545	4483477.59
Aygıran/202	1.3473	481183.952	-2.993	4479287.97
Hacidag/226	-7.4758	490035.794	5.3726	4473934.71

Table A.13. Parameters Of Error Ellipses Of 1981 0bservatıons From Free Network Adjustment

Points	A(cm)	B(cm)	FI(g)
4217	283.359	66.117	70.53
7193	258.758	51.003	109.74
7227	251.439	54.906	166.82
4215	210.590	43.092	161.50
4247	168.500	42.248	29.21
7148	101.308	38.800	38.27
201	113.686	37.813	9.14
202	104.595	34.791	129.93
226	66.749	27.550	143.07

Table A.14. The observations of 2004 epoch (Slope distances and derived horizontal distances)

P1	P2	Sa	So
7193	202	22,863	22860.48165
4215	202	8,491	8,490
7227	202	21,574	21,571
226	202	10,347	10,345
226	202	10,347	10,345
4215	7193	27,667	27,664
7227	7193	13,677	13,673
4217	7193	32,287	32,283
7227	4215	29,331	29,327
4217	4215	20,467	20,465
4217	7227	24,385	24,382
4215	226	17,293	17,290
7227	226	12,236	12,234
4217	226	19,306	19,303
7193	226	13,316	13,312

Table A.15. Constrained adjustment results of 2004 campaign

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
Tavsandede Tepe/4215	0.8430	479437.5594	27.5149	4487596.105
Aygiran/202	6.8731	481184.0067	2.7010	4479288.026
Hacidag/226	10.5767	490035.9748	11.9185	4473934.772

Table A.16. Mean errors from constrained adjustment of 2004epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	9.6422	7.0494	11.9443
Aygiran/202	8.2030	9.3438	12.4337
Hacidag/226	5.3514	7.1474	8.9287

Table A.17. Parameters Of Error Ellipses Of 2004 Epoch

Points	A(cm)	B(cm)	FI(g)
Tavsandede Tepe/4215	10.3759	5.9166	70.31
Aygiran/202	11.4197	4.9178	43.97
Hacidag/226	7.7038	4.5136	30.46

Table A.18. Adjusted baselines of 2004 campaign

P1	P2	s(m)	v(cm)	S(M)	m
7193	202	22860.48165	-3.9165	22860.47083	7.7312
7193	226	13312.15095	6.3191	13312.21835	5.6752
4215	202	8489.62688	-1.1506	8489.655892	1.9989
4215	7193	27663.62259	4.4881	27663.70891	8.2789
4215	226	17290.34730	1.5431	17290.41428	6.0860
7227	202	21571.33261	10.0100	21571.27417	8.3677
7227	7193	13673.29863	-9.2433	13673.20726	7.8662
7227	4215	29327.35158	-5.7611	29327.35991	9.8509
7227	226	12234.38832	3.9423	12234.43640	4.4790
226	202	10344.73564	2.6422	10344.78925	5.3594
226	202	10344.73564	2.6422	10344.78925	5.3594
4217	7193	32283.34977	-4.3185	32283.40341	12.0869
4217	4215	20464.79615	3.2607	20464.98199	3.9131
4217	7227	24381.95573	22.0910	24381.83286	10.5041
4217	226	19303.23868	2.3164	19303.35681	6.9909

Table A.19. The observations of 2007 epoch (Slope distances and derived horizontal distances)

P1	P2	Sa	So
7193	202	22863.302	22860.46686
4215	202	8490.600	8489.61362
7227	202	21574.052	21571.31465
4217	202	14347.950	14346.34511
7193	226	13316.302	13312.25130
4215	226	17292.935	17290.36384
7227	226	12235.976	12234.40187
4217	226	19305.902	19303.24420
202	226	10346.568	10344.78585
7193	4215	27666.617	27663.61540
7227	4215	29330.970	29327.34555
7193	7227	13676.884	13673.25367
7193	4217	32286.914	32283.37107
4215	4217	20467.071	20464.82507
7227	4217	24384.990	24381.91915

Table A.20. Constrained adjustment results of 2007 campaign

Points	**Vy(cm)**	**Y(m)**	**Vx(cm)**	**X(m)**
Tavsandede Tepe/4215	2.7370	479437.5784	29.1356	4487596.121
Aygiran/202	2.7285	481183.9653	3.9478	4479288.039
Hacidag/226	7.5588	490035.9446	8.9907	4473934.743

Table A.21. Mean errors from constrained adjustment of 2007epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	6.8860	4.5080	8.2304
Aygiran/202	4.2278	4.3596	6.0730
Hacidag/226	3.8808	5.1484	6.4472

Table A.22. Parameters of error ellipses of 2007epoch

Points	A(cm)	B(cm)	FI(g)
Tavsandede Tepe/4215	7.2685	3.8612	75.33
Aygiran/202	4.7612	3.7699	45.73
Hacidag/226	5.5199	3.3312	29.88

Table A.23. Adjusted baselines of 2007 campaign

s(m)	v(cm)	S(m)	m
22860.4668	1.8923	22860.51406	6.1094
27663.6154	4.3855	27663.70069	5.9534
32283.371	-6.4415	32283.40341	8.6737
13312.2513	-0.7548	13312.24796	4.0322
8489.6136	-0.699	8489.647128	2.4276
17290.3638	0.4761	17290.42011	4.5580
20464.825	2.6077	20465.00431	3.6995
21571.3146	-4.5855	21571.31040	5.9885
12234.4018	1.1708	12234.42216	3.1336
29327.3455	-4.7923	29327.36351	7.2309
24381.9191	18.428	24381.83286	7.5379
14346.3451	0.4723	14346.45026	3.2819
19303.2442	-1.928	19303.31988	5.0064
10344.7858	0.7508	10344.82049	3.1930

Table A.24. Constrained adjustment results of 2004-2007 campaign

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
Tavsandede Tepe/4215	1.6652	479437.5677	28.1248	4487596.111
Aygiran/202	4.7279	481183.9853	2.9288	4479288.028
Hacidag/226	8.9275	490035.9583	10.5166	4473934.758

Table A.25. Mean errors from constrained adjustment of 2004&2007epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Tavsandede Tepe/4215	5.2272	3.5250	6.3047
Aygiran/202	3.5286	3.8219	5.2018
Hacidag/226	2.9175	3.8981	4.8690

Table A.26. Parameters of error ellipses of 2004-2007 constrained adjustment

Points	A(cm)	B(cm)	FI(g)
Tavsandede Tepe/4215	5.5403	3.0091	74.17
Aygiran/202	4.4146	2.7513	44.21
Hacidag/226	4.1908	2.4788	30.09

Table A.27. Adjusted baselines of 2004&2007 campaign

P1	P2	s(m)	v(cm)	S(M)	m
7193	202	22,860.48165	-1.78100	22860.49218	7.1818
7193	226	13,312.15095	7.94110	13312.23457	5.2346
4215	202	8,489.62688	-1.38710	8489.65353	3.7819
4215	7193	27,663.62259	4.08440	27663.70487	7.5852
4215	226	17,290.34730	1.61780	17290.41503	5.9231
7227	202	21,571.33261	-8.45380	21571.28973	7.0691
7227	7193	13,673.29863	-9.24330	13673.20726	6.0586
7227	4215	29,327.35158	-5.68370	29327.36068	8.3156
7227	226	12,234.38832	3.34490	12234.43043	4.7181
226	202	10,344.73564	3.91010	10344.80193	4.6309
226	202	10,344.73564	3.91010	10344.80193	4.6309
4217	7193	32,283.34977	-4.31850	32283.40341	9.3095
4217	4215	20,464.79615	4.14350	20464.99082	5.8815
4217	7227	24,381.95573	-22.09100	24381.83286	8.0904
4217	226	19,303.23868	0.35160	19303.33716	6.359
7193	202	22,860.46680	-0.29600	22860.49218	7.1818
7193	4215	27,663.61540	4.80340	27663.70487	7.5852
7193	4217	32,283.37100	-6.44150	32283.40341	9.3095
7193	226	13,312.25130	-2.09390	13312.23457	5.2346
4215	202	8,489.61360	-0.05910	8489.65353	3.7819
4215	226	17,290.36380	-0.03220	17290.41503	5.9231
4215	4217	20,464.82500	1.25850	20464.99082	5.8815
7227	202	21,571.31460	-6.65280	21571.28973	7.0691
7227	226	12,234.40180	1.99690	12234.43043	4.7181
7227	4215	29,327.34550	-5.07570	29327.36068	8.3156
7227	4217	24,381.91910	-18.42800	24381.83286	8.0904
4217	202	14,346.34510	1.08240	14346.45637	4.3655
4217	226	19,303.24420	-0.20040	19303.33716	6.359
202	226	10,344.78580	-1.10590	10344.80193	4.6309

Table A.28. Free network adjustment results of 2004-2007 campaign

Points	Vy(cm)	Y(m)	Vx(cm)	X(m)
Hıdırellez/4217	-9.1929	471439.4281	-3.1426	4468758.695
Armutlu/7193	-2.8537	503345.7115	5.2277	4473679.272
Türbetepe/7227	7.2214	495079.0682	-9.0661	4462787.961
Tavsandede Tepe/4215	-1.1779	479437.5392	18.1153	4487596.011
Aygiran/202	1.7503	481183.9555	-7.9967	4479287.919
Hacidag/226	4.2529	490035.9115	-3.1376	4473934.622

Table A.29. Mean errors from free network adjustment of 2004&2007epoch

Points	My(cm)	Mx(cm)	Mp(cm)
Hıdırellez/4217	1.6418	1.7984	2.4351
Armutlu/7193	1.4185	2.1985	2.6164
Türbetepe/7227	1.8483	1.6255	2.4614
Tavsandede Tepe/4215	2.0814	1.3446	2.4780
Aygiran/202	1.7353	1.6772	2.4134
Hacidag/226	1.5680	2.2139	2.7130

Table A.30. Parameters of error ellipses of 2004-2007 free network adjustment

Points	A(cm)	B(cm)	FI(g)
Hıdırellez/4217	1.9418	1.4693	160.85
Armutlu/7193	2.1990	1.4178	198.26
Türbetepe/7227	1.9549	1.4956	66.23
Tavsandede Tepe/4215	2.1148	1.2914	85.64
Aygiran/202	2.0487	1.2756	52.46
Hacidag/226	2.4446	1.1765	32.14

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