DETERMINATION OF VELOCITY FIELD AND STRAIN ACCUMULATION OF DENSIFICATION NETWORK IN MARMARA REGION

by
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ABSTRACT

DETERMINATION OF VELOCITY FIELD AND STRAIN CCUMULATION OF DENSIFICATION NETWORK IN MARMARA REGION

For the implementation of constructing continuously operating reference stations and determination of transformation parameters, Turkey has started a new project: Turkish Continuously Operating Reference Stations (CORS-TR). Network-120, Network-90, and Network-60 were created as CORS test networks. These networks were composed of 115 check points which were established by institutions such as Geodesy Department of Kandilli Observatory and Earthquake Research Institute of Boğaziçi University, Istanbul Metropolitan Municipality, General Command of Mapping (GCM), General Directorate of Land Registry and Cadastre, and TUBITAK Marmara Research Center (MRC) in Kırklareli, Tekirdağ, Bursa, Bilecik, and Adapazarı. Before the 1999 earthquake, positions of 115 check points which are tied to Turkish National Fundamental GPS Network (TNFGN) were determined by different time and institutions.

Between July 15 and October 30, 2006; corporations such as TOPCON, TRIMBLE, and LEICA made observations. They evaluated CORS test networks. TOPCON and TRIMBLE measured all of CORS test networks, but LEICA measured only Network-60. Positions of main points of test networks were calculated and points were tied to International GNSS Service (IGS).

The purpose of this study is to provide analysis of datum of 1999 observations and unity of datum, to analyze evaluation and computation of coordinates of 2006 observations, and to examine unity of datum in 2006 observations. It will also describe the determination

of velocity field, strain accumulation on test field by modeling difference vectors between the coordinates of check points and the comparisons with other studies. The difference vector between the coordinates of check points in 1999 and 2006 (observed and computed by different companies) were derived.

ÖZET

MARMARA BÖLGESİ'NDEKİ SIKLAŞTIRMA AĞINDA HIZ ALANI VE GERİLİM BİRİKİMİNİN BELİRLENMESİ

Kırklareli, Tekirdağ, Bursa, Bilecik, Adapazarı'nda İstanbul Büyükşehir Belediyesi, Harita Genel Komutanlığı, Tapu ve Kadastro Genel Müdürlüğü, TUBITAK Marmara Araştırma Merkezi gibi kuruluşların tesis ettiği ve 1999 depremlerinden önce konumları Türkiye Ulusal Temel GPS Ağı'na bağlı olarak farklı zamanlarda ve ağlarla belirlenen 115 kontrol noktasıyla Ağ-120, Ağ-90 ve Ağ-60 olarak üç ağ oluşturulmuştur. 115 noktadan oluşmaktadırlar.

15 Temmuz–30 Ekim 2006 tarihleri arasında TOPCON, TRIMBLE ve LEICA gibi şirketler bu noktaları ölçmüş ve değerlendirmişlerdir. TOPCON ve TRIMBLE üç test ağını, LEICA sadece Ağ-60'ı ölçmüştür. Test ağının ana noktalarının koordinatları IGS'e bağlı olarak hesaplanmıştır.

Bu çalışmada, 1999 koordinatlarının datumlarının incelenmesi ve datum birliğinin sağlanması, 2006 ölçmelerinin değerlendirmelerin ve koordinat hesabının incelenmesi ve tüm koordinatların datum birliğinin olup olmadığının irdelenmesi, kontrol noktalarındaki fark vektörlerinin modellenerek test alanında hız alanının, test alanında gerilim birikiminin belirlenmesi ve diğer çalışmalarla karşılaştırılması amaçlanmıştır. 1999 ve 2006 yıllarındaki koordinatların farkları bulunmaktadır.

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ε	Strain tensor
$e_{xx}, e_{xy}, e_{yy}, e_{yz}, e_{xz}, e_{zz}$	Strain tensor parameters
Δ	Dilatancy
γ_1	Principal shear strain
γ_2	Engineering shear strain
γ	Total shear strain
E_1	Maximum principal strain
E_2	Minimum principal strain
β	Direction of maximum principal strain arc
E_{SHEAR}	Maximum shear strain
E_{INTER}	Maximum normal strain

GPS	Global Positioning System
CORS-TR	Continuously Operating Reference Stations
TNFGN	Turkish National Fundamental GPS Network
IGTN	Istanbul GPS Triangulation Network
MERLIS	Marmara Earthquake Region Information System
KOERI	Kandilli Observatory and Earthquake Research Institute of Boğaziçi University
GCM	General Command of Mapping
MRC	Marmara Research Center
IKU	Istanbul Kultur University
GDLRC	General Directorate of Land Registry and Cadastre
TLSMPR	Turkish Large Scale Map and Mapping Production Regulation
IGS	International GNSS Service

ITRF	International Terrestrial Reference Frame
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 84

1. INTRODUCTION

Strain analysis is a mathematical tool for the kinematic analysis of repeated geodetic measurements. Japanese seismologists, Terada and Miyabe, published first strain analysis of the repeated geodetic measurements in 1929. Later, a new method developed in 1966. It was the determination of strain by measuring directions directly without determining the coordinates of station and deformation. A similar method aimed at the determination of strain by changes in successive mean ranging data in 1976.

Since 1980, there were developments in electronic distance measurements, adjustment and methods of deformation analysis. These developments indicated that the strain analysis should be done after the deformation analysis. In other words, strains have to be calculated from the adjusted coordinates of measurements or deformation vectors (Deniz, 1997)

In recent years, Global Positioning System (GPS) measurements have been used to obtain the information of the strain accumulation along fault lines because of its high precision. The process of GPS measurements has been mostly studied subject in geodesy and geodynamics.

The aim of this study is to determine the velocity field and strain accumulation of densification network in Marmara Region. The coordinates of Turkish National Fundamental GPS Network (TNFGN), Istanbul GPS Triangulation Network (IGTN) and Marmara Earthquake Region Information System (MERLIS) stations which were installed previously in Marmara region were used in this study. The coordinates of the same stations which were computed from Continuously Operating Reference Stations (CORS-TR) test networks were also used. Here, the evaluation of data obtained in different networks at different times and computation of strain from this data will be done. Whether or not data derived from networks which were constructed for engineering purpose could be used for dynamic purposes will be studied. Standards for engineering purposes were used in these networks. Therefore, the process of this study will be different from a study of geodynamic network.

2. TEST NETWORKS

Test networks, which were used in this study, were constructed for Continuously Operating Reference Stations (CORS-TR) project. They were called Network-120, Network-90, and Network-60 with respect to the length of baseline. Their lengths of baseline were 120km, 90km and 60km respectively. These networks composed of 115 check points from Turkish National Fundamental GPS Network (TNFGN), Marmara Earthquake Region Information System (MERLIS) and Istanbul GPS Triangulation Network (IGTN). They were established by institutions such as Geodesy Department of Kandilli Observatory and Earthquake Research Institute of Boğaziçi University (KOERI), Istanbul Metropolitan Municipality, General Command of Mapping (GCM), General Directorate of Land Registry and Cadastre (GDLRC), and TUBITAK Marmara Research Center (MRC) in Kırklareli, Tekirdağ, Bursa, Bilecik, and Adapazarı. They were measured by GPS techniques after the 1999 earthquake at different times by different institutions. They were tied to TNFGN. Corporations such as TOPCON, TRIMBLE, and LEICA also measured test networks between July 15 and October 30, 2006. They were tied to International GNSS Service (IGS) network. In this study, the differences between the coordinates of test networks at epoch 2000.45 and 2006.60 were evaluated. Velocity field and strain accumulation in Marmara Region were determined.

2.1. Continuously Operating Reference Stations (CORS-TR)

Istanbul Kultur University (IKU) is working on a crucial project for Turkey called "The Establishment of National CORS System and Determination of Datum Transformation Parameters" jointly with General Command of Mapping (GCM) and General Directorate of Land Registry and Cadastre (GDLRC). Hereafter, this project will be called CORS-TR Project. It is an ongoing project of IKU.

The main goals of this project that will establish CORS-TR stations functioning 24/7 hours / day and, thus, enable the determination of datum transformation parameters are:

- Providing real-time cm-level precise geodetic positioning throughout Turkey continuously (i.e. 24 hours / day, 7 days / week), in faster, more economical and reliable ways for collecting geographic data, including terrestrial mapping and cadastre.

- Providing dm- and m-level positioning for navigation and vehicle tracking in and transportation activities.

- Determining datum transformation models and computations for transferring cadastral and topographic maps and data from ED50 datum to ITRFyy datum.

- Modeling the ionosphere and troposphere in the region of Turkey, and contributing to atmospheric studies and weather predictions, and providing enhanced capability and tool for various scientific research, such as in the fields of signal and communication,

- Providing mm-level accuracy for tracking plate tectonics, measuring deformations.

Network-60, Network-90, Network-120 were created as CORS-TR test networks. These networks contain stations of each TNFGN, MERLIS and IGTN networks. Coordinates and locations of CORS-TR stations were given in Table 2.1. and Figure 2.1. respectively. They were tied to 8 IGS stations (ANKR, TUBI, DRAG, NOT1, SOFI, BUCU and MATE). GPS measurements and adjustments were done by corporations such as TOPCON, TRIMBLE, and LEICA. The GPS data collected from these networks were processed by using GEONAP and Bernese softwares. They were adjusted by using GEONET software (CORS-TR Benchmark Test Report, 2006).

Table 2.1. Coordinates of CORS-TR stations

STATION ID	2006.60 ITRF COORDINATES	
	UTM NORTH (m)	UTM EAST (m)
AHMT	4558630,042	716009,252
AKCO	4546739,847	749931,778
GATE	4521744,188	704310,062
IGAZ	4480434,508	746648,863
IKAN	4547867,522	673391,618
KUTE	4484073,850	693918,193
MAER	4535938,873	580774,470
SELP	4545408,792	614738,130
SISL	4514449,319	257709,571
SRYR	4551063,843	672248,407
YUVA	4589200,526	571920,203
8	4544461,491	729455,273
10	4553524,013	742036,122
91	4528492,687	703295,114
106	4504664,598	695778,546
123	4513180,139	748400,478
129	4540930,034	723587,155
159	4522983,778	745238,507
169	4529741,087	719358,319
221	4527510,697	249006,532
222	4535789,953	251226,474
272	4513440,626	271408,696
356	4480273,610	250645,288
1009	4573042,973	611961,057
1014	4564348,553	625422,924
1015	4564919,202	615900,342
1021	4560644,246	598502,550
1025	4585339,043	615469,141
1030	4546449,163	594320,492
1032	4568711,839	586879,542
1033	4579700,018	599700,930
1039	4543623,114	647782,709
1043	4571522,700	647169,298
1046	4555861,501	657507,053

1047	4547418,186	654015,716
1051	4558793,496	666528,135
1057	4567889,215	632774,490
1059	4569025,600	670922,348
1060	4563780,892	673054,805
1069	4550626,498	695392,414
1070	4549821,261	709655,604
1073	4542814,100	678310,828
1076	4556505,901	674024,874
1082	4554060,775	733418,071
1083	4549251,521	729396,144
1088	4561844,985	720079,951
1092	4538650,732	629486,733
1096	4533201,241	694515,026
1100	4517398,137	705998,706

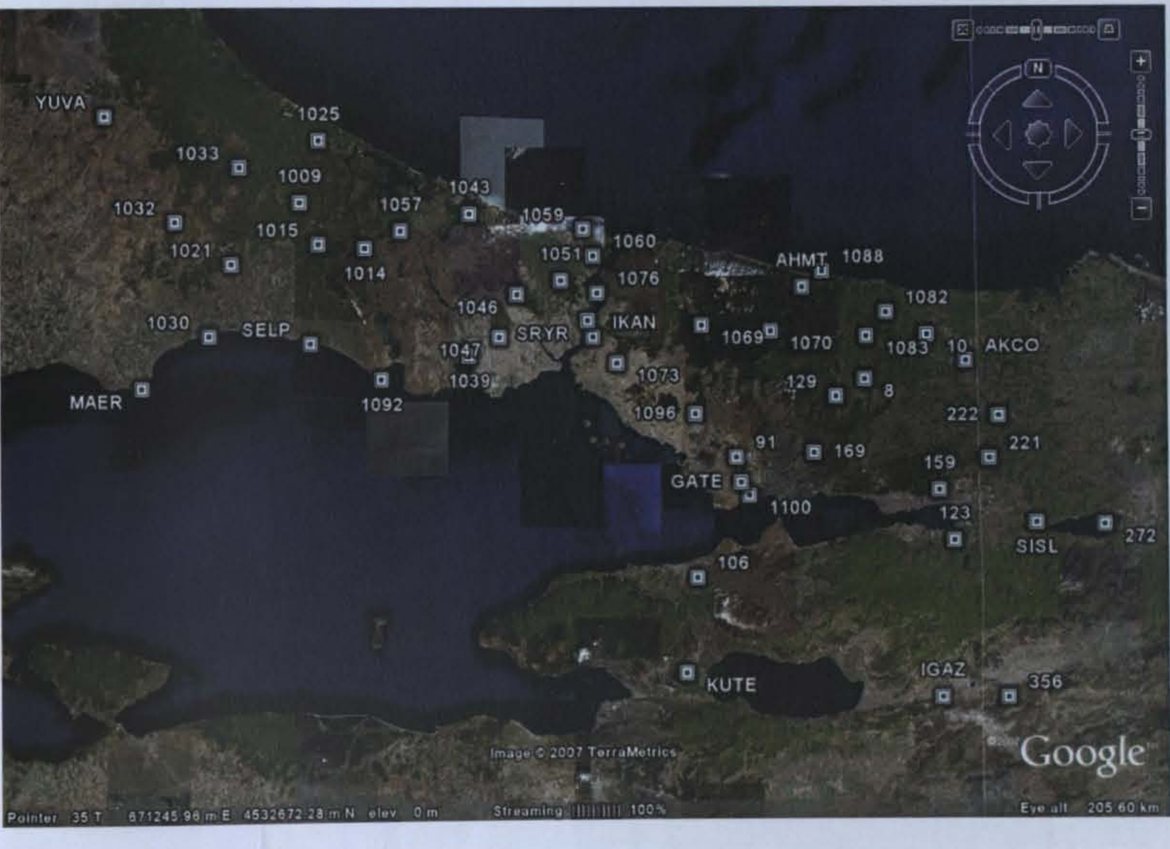

Figure 2.1. CORS-TR stations

2.2. Turkish National Fundamental GPS Network (TNFGN)

Turkish National Fundamental GPS Network (TNFGN) consists of 594 GPS stations which were distributed all over Turkey homogeneously. 3D coordinates, their associated velocities and ellipsoidal heights have been computed in ITRF 96 for each station. It had been established between the years 1997-1999. It was tied to 8 IGS stations operating continuously in all sessions (ONSA, MADR, WTZR, MATE, ANKR, ZWEN, KIT3, NICO, and BAHR). It has been conducted by General Command of Mapping (GCM). The basic goal of this network stations is to give adequate information for all GPS based survey activities and monitoring deformation throughout Turkey as well. Positional accuracy of the stations is about 1-3 cm whereas the relative accuracies are in the range of 0.01 ppm. The relation between TNFGN and Turkish Conventional Horizontal and Vertical Control Networks has been determined. Considering the on-going tectonic feature of the region, second period surveys of the great majority of the points have been completed in 2003, 2004 and 2005 and velocities have been estimated. Also appropriate models for coordinate transformation from ED-50 system into the WGS84 have defined within the context of TNFGN. GPS observations were evaluated by using Bernese and GLOBK softwares. The evaluation of GPS observations and annual solutions were done by Bernese software. The computations of station coordinates and velocities by combining these results were done by GLOBK software. The positions of TNFGN stations that were used in this study were given in Table 2.2. and Figure 2.2. (TNFGN Report, 2001).

Table 2.2. Coordinates of TNFGN stations used in test network

STATION ID	1998,0 ITRF COORDINATES	
	UTM NORTH (m)	UTM EAST (m)
AHMT	4558630,094	716008,827
AKCO	4546739,703	749931,176
GATE	4521746,689	704305,124
IGAZ	4480434,548	746649,243
IKAN	4547867,530	673391,263
KUTE	4484074,008	693918,400
MAER	4535938,772	580774,239
SELP	4545408,708	614737,896
SISL	4514449,303	257707,658
SRYR	4551063,839	672248,058
YUVA	4589200,446	571919,968

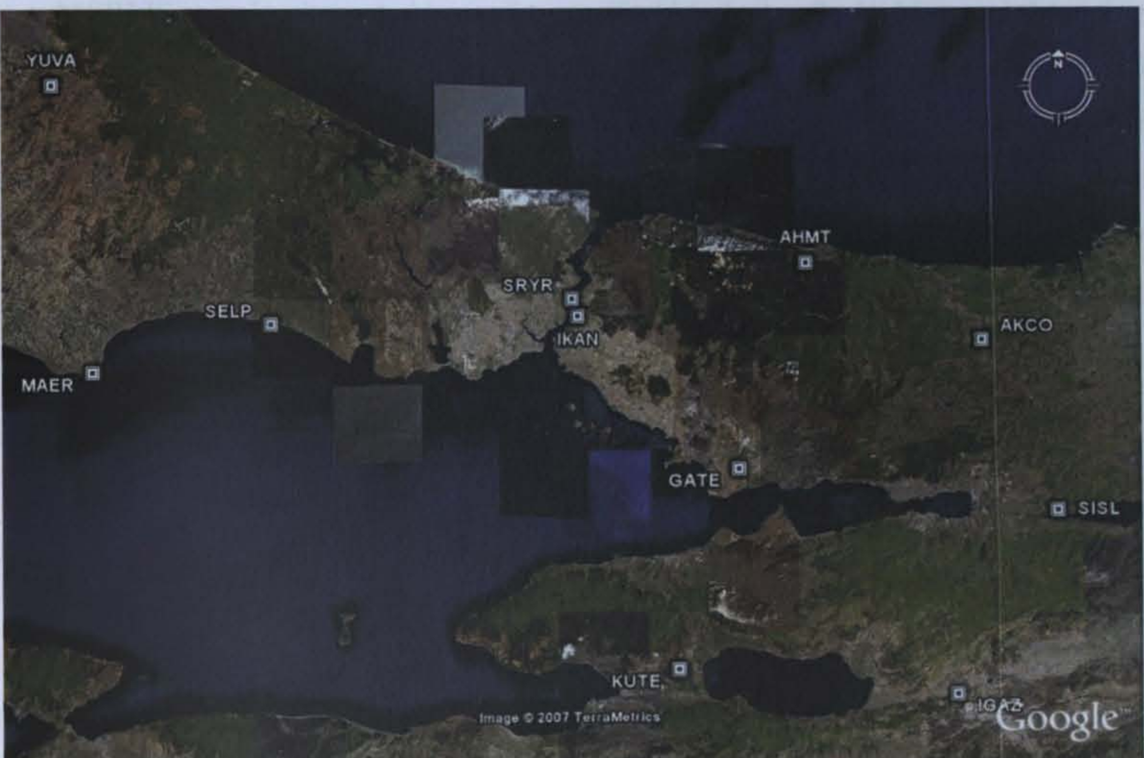

Figure 2.2. TNFGN stations used in Test network

2.3. Marmara Earthquake Region Information System (MERLIS)

After August 17, 1999 Earthquake, crustal movements occurred in Marmara Region which is an intense residential and industrial area. Therefore, building a land information system was required for reformation and development of Marmara Earthquake Region. This system was called "Marmara Earthquake Region Information System" (MERLIS). This project was conducted by General Directorate of Land Registry and Cadastre. Information of land registry and cadastre were renovated and adapted to new technologies of the day. These applications provide rapid and easy access to the information in digital environment for other public bodies and institutions. GPS control points were tied to TNFGN for the purpose of renovation.

MERLIS was implemented according to Turkish Large Scale Map and Mapping Production Regulation (TLSMPR). Therefore, all baselines were shorter than 20km. Leica SkiPro software was used for the evaluation and adjustment of GPS observations. The accuracy of the fundamental network stations was agreeable to the regulation. The positions of MERLIS stations were given in Table 2.3. and Figure 2.3. successively (MERLIS Report,2006).

Table 2.3. Coordinates of MERLIS stations

STATION ID	2000.45 ITRF COORDINATES	
	UTM NORTH (m)	UTM EAST (m)
8	4544461,413	729455,080
10	4553523,932	742035,941
91	4528492,630	703294,955
106	4504664,531	695778,459
123	4513180,085	748400,335
129	4540929,948	723586,964
159	4522933,701	745238,326

169	4529741,025	719358,145
221	4527510,567	249006,344
222	4535789,850	251226,263
272	4513440,462	271408,541
356	4480273,548	250645,307
AKCO	4546739,741	749931,577
GATE	4521744,034	704309,905
IGAZ	4480434,379	746648,883
KUTE	4484073,717	693918,193
SISL	4514449,178	257709,402

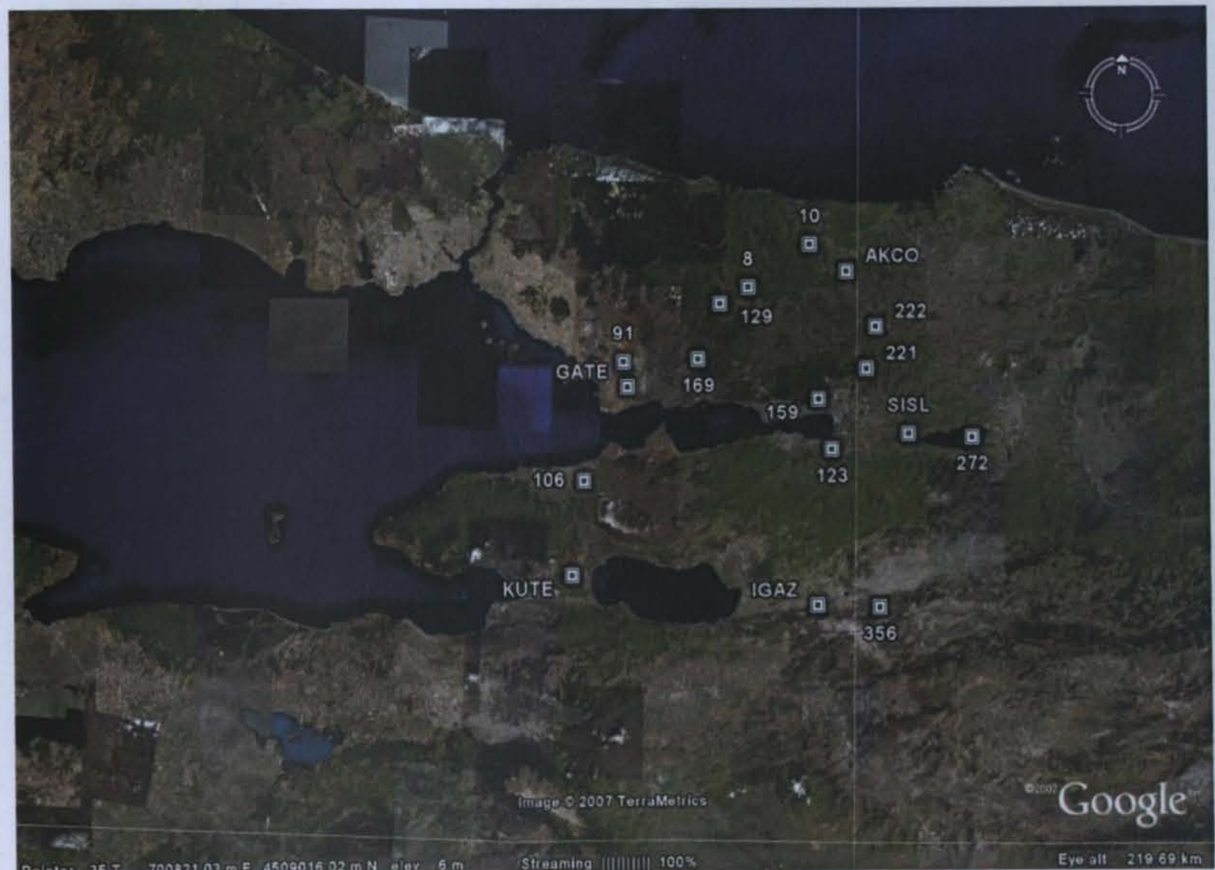

Figure 2.3. MERLIS stations

2.4. Istanbul GPS Triangulation Network (IGTN)

Istanbul GPS Triangulation Network Project was conducted by Mapping Department of Istanbul Metropolitan Municipality. Following studies were accomplished in IGTN project:

- 650 triangulation points which will be the basis of the production of 1/1000 and 1/5000 scale digital photogrammetric map, were measured by GPS, adjusted and the results were analyzed,
- Transformation parameters which provide transformation from the ITRF coordinates of triangulation points that be measured to local coordinate system of triangulation points were determined,
- The local geoid was computed.

GPS measurements were done by EMİ Map Data Processing Corporation. A fundamental network was constructed. This network was composed of 58 points. Evaluation and adjustment of this network were done by Geodesy and Photogrammetry Engineering Department of Istanbul Technical University. Five of TNFGN points were chosen as control points for adjustment. The positions of IGTN stations were given in Table 2.4. and Figure 2.4.

Bernese and Leica SkiPro softwares were used for the evaluation and adjustment of GPS observations. The scale agreement of this network with TNFGN was 1, 4 ppm. The results of constrained adjustment tied to TNFGN were evaluated. According to these results, the root mean square errors of the coordinates of the fundamental network stations were mostly below ±1 cm and maximum at ±1, 3 cm in horizontal. The accuracies of the ellipsoidal heights were ± (1-2) cm and maximum at 2,8 cm (IGTN Report,1999).

Table 2.4. Coordinates of IGTN stations

STATION ID	2005,0 ITRF COORDINATES	
	UTM NORTH (m)	UTM EAST (m)
1009	4573042,951	611961,004
1014	4564348,502	625422,909
1015	4564919,154	615900,300
1021	4560644,186	598502,515
1025	4585338,992	615469,107
1030	4546449,114	594320,444
1032	4568711,791	586879,480
1033	4579699,984	599700,880
1039	4543623,084	647782,670
1043	4571522,667	647169,253
1046	4555861,467	657507,016
1047	4547418,148	654015,680
1051	4558793,457	666528,098
1057	4567889,158	632774,454
1059	4569025,564	670922,306
1060	4563780,865	673054,769
1069	4550626,456	695392,380
1070	4549821,221	709655,562
1073	4542814,065	678310,785
1076	4556505,867	674024,834
1082	4554060,729	733418,026
1083	4549251,475	729396,101
1088	4561844,929	720079,899
1092	4538650,679	629486,717
1096	4533201,193	694514,975
1100	4517398,087	705998,672

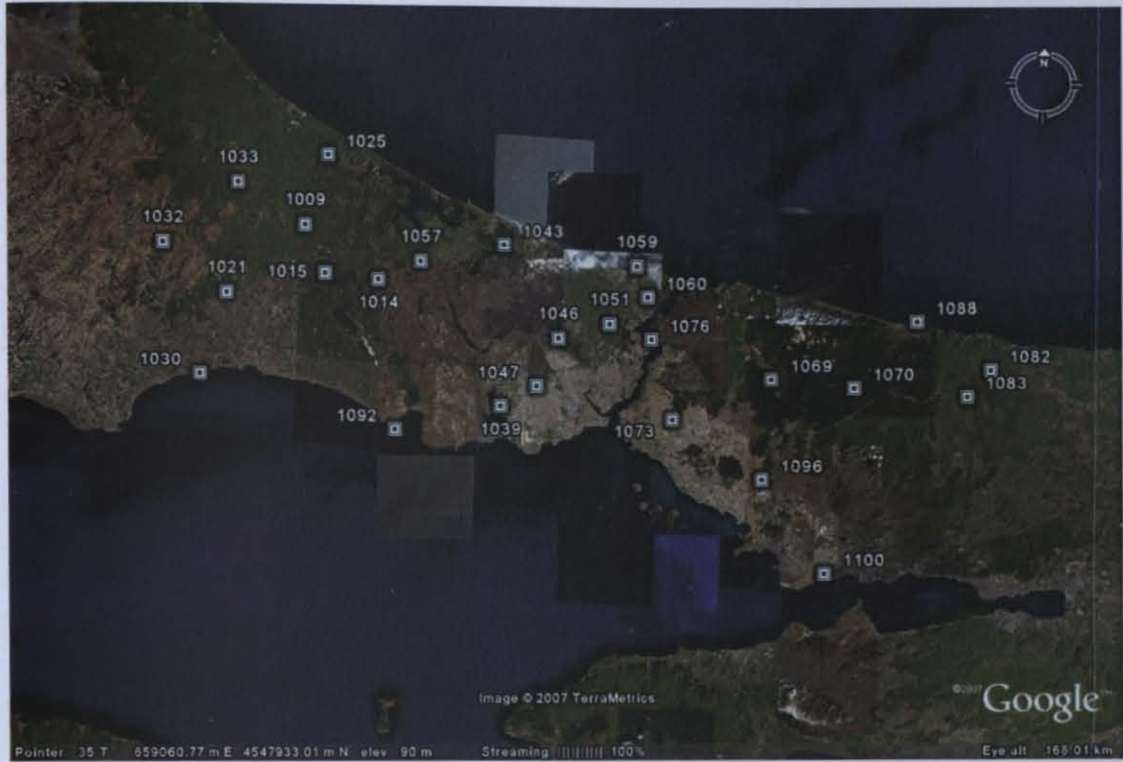

Figure 2.4. IGTN stations

3. EVALUATION OF DATA

3.1. Examination of datum

All test networks were measured by GPS technique. The positions that are obtained directly from the GPS measurements were based on the ITRF datum. The positions (latitude/longitude) were conversed to UTM grid coordinate values. In order to examine datum of test networks, all positions had to be in the same epoch and UTM grid zone. Coordinates at epoch 2000.45 on 27 UTM zone of some of TNFGN and IGTN stations were taken from IGTN reports. Hereafter, all the coordinates were transformed into 27 UTM zone of 6 degrees longitude in width. Transformations were done by using J-Trans software. Therefore, TNFGN, MERLIS and IGTN networks were obtained at epoch 2000.45 on 27 UTM zone. Coordinates of CORS-TR were also obtained at epoch 2006.60 in 27 UTM zone. Displacement vectors were calculated from 2000.45 and 2006.60 epochs. The displacement vectors were given in Table 3.1. and Figure 3.1.

Table 3.1. Coordinates of stations and displacement vectors

STATION ID	2000.45 COORDINATES		2006.60 COORDINATES		DISPLACEMENT (m)	
	UTM NORTH (m)	UTM EAST (m)	UTM NORTH (m)	UTM EAST (m)	NORTH (m)	EAST (m)
AHMT	4558629,9657	716009,0616	4558630,0420	716009,2520	0,0763	0,1904
AKCO	4544921,0451	749831,6047	4544921,1511	749831,8056	0,1060	0,2009
GATE	4519935,3364	704228,1811	4519935,4903	704228,3381	0,1539	0,1570
IGAZ	4478642,2053	746550,2237	4478642,3342	746550,2037	0,1289	-0,0200
IKAN	4547867,4598	673391,4453	4547867,5220	673391,6180	0,0622	0,1727
KUTE	4482280,0875	693840,6258	4482280,2205	693840,6258	0,1330	0,0000
MAER	4535938,7897	580774,3147	4535938,8730	580774,4700	0,0833	0,1553
SELP	4545408,7113	614737,9823	4545408,7920	614738,1300	0,0807	0,1477
SISL	4513406,5434	764510,8057	4513406,6955	764510,9646	0,1521	0,1589
SRYR	4551063,7725	672248,2343	4551063,8430	672248,4070	0,0705	0,1727

YUVA	4589200,4569	571920,0501	4589200,5260	571920,2030	0,0691	0,1529
8	4542643,6284	729363,2981	4542643,7064	729363,4911	0,0780	0,1930
10	4551702,5224	741939,1269	4551702,6034	741939,3078	0,0810	0,1809
91	4526681,2330	703213,6371	4526681,2899	703213,7960	0,0569	0,1589
106	4502862,6652	695700,1477	4502862,7322	695700,2346	0,0670	0,0869
123	4511374,8130	748300,9752	4511374,8670	748301,1181	0,0540	0,1429
129	4539113,5760	723497,5294	4539113,6620	723497,7203	0,0860	0,1909
159	4521174,5075	745140,2310	4521174,5845	745140,4119	0,0770	0,1809
169	4527929,1286	719270,4019	4527929,1906	719270,5758	0,0620	0,1739
221	4525838,1926	754937,8958	4525838,3351	754938,0743	0,1425	0,1785
222	4534247,0760	756584,6923	4534247,1932	756584,8957	0,1172	0,2034
272	4513335,9567	778244,4418	4513336,1309	778244,5852	0,1742	0,1434
356	4478839,4843	759791,7704	4478839,5449	759791,7472	0,0606	-0,0232
1009	4573042,9155	611960,8810	4573042,9730	611961,0570	0,0575	0,1760
1014	4564348,4665	625422,7841	4564348,5530	625422,9240	0,0865	0,1399
1015	4564919,1198	615900,1765	4564919,2020	615900,3420	0,0822	0,1655
1021	4560644,1557	598502,3869	4560644,2460	598502,5500	0,0903	0,1631
1025	4585338,9555	615468,9838	4585339,0430	615469,1410	0,0875	0,1572
1030	4546449,0771	594320,3187	4546449,1630	594320,4920	0,0859	0,1733
1032	4568711,7575	586879,3524	4568711,8390	586879,5420	0,0815	0,1896
1033	4579699,9469	599700,7572	4579700,0180	599700,9300	0,0711	0,1728
1039	4543623,0522	647782,5407	4543623,1140	647782,7090	0,0618	0,1683
1043	4571522,6329	647169,1242	4571522,7000	647169,2980	0,0671	0,1738
1046	4555861,4332	657506,8844	4555861,5010	657507,0530	0,0678	0,1686
1047	4547418,1158	654015,5479	4547418,1860	654015,7160	0,0702	0,1681
1051	4558793,4240	666527,9618	4558793,4960	666528,1350	0,0720	0,1732
1057	4567889,1230	632774,3269	4567889,2150	632774,4900	0,0920	0,1631
1059	4569025,5329	670922,1698	4569025,6000	670922,3480	0,0671	0,1782
1060	4563780,8334	673054,6312	4563780,8920	673054,8050	0,0586	0,1738
1069	4550626,4246	695392,2452	4550626,4980	695392,4140	0,0734	0,1688
1070	4549821,1872	709655,4251	4549821,2610	709655,6040	0,0738	0,1789
1073	4542814,0288	678310,6545	4542814,1000	678310,8280	0,0712	0,1735
1076	4556505,8328	674024,7009	4556505,9010	674024,8740	0,0682	0,1731
1082	4554060,6932	733417,8868	4554060,7750	733418,0710	0,0818	0,1842
1083	4549251,4406	729395,9647	4549251,5210	729396,1440	0,0804	0,1793
1088	4561844,8930	720079,7593	4561844,9850	720079,9510	0,0920	0,1917
1092	4538650,6465	629486,5908	4538650,7320	629486,7330	0,0855	0,1422
1096	4533201,1617	694514,8406	4533201,2410	694515,0260	0,0793	0,1854
1100	4517398,0544	705998,5364	4517398,1370	705998,7060	0,0826	0,1696

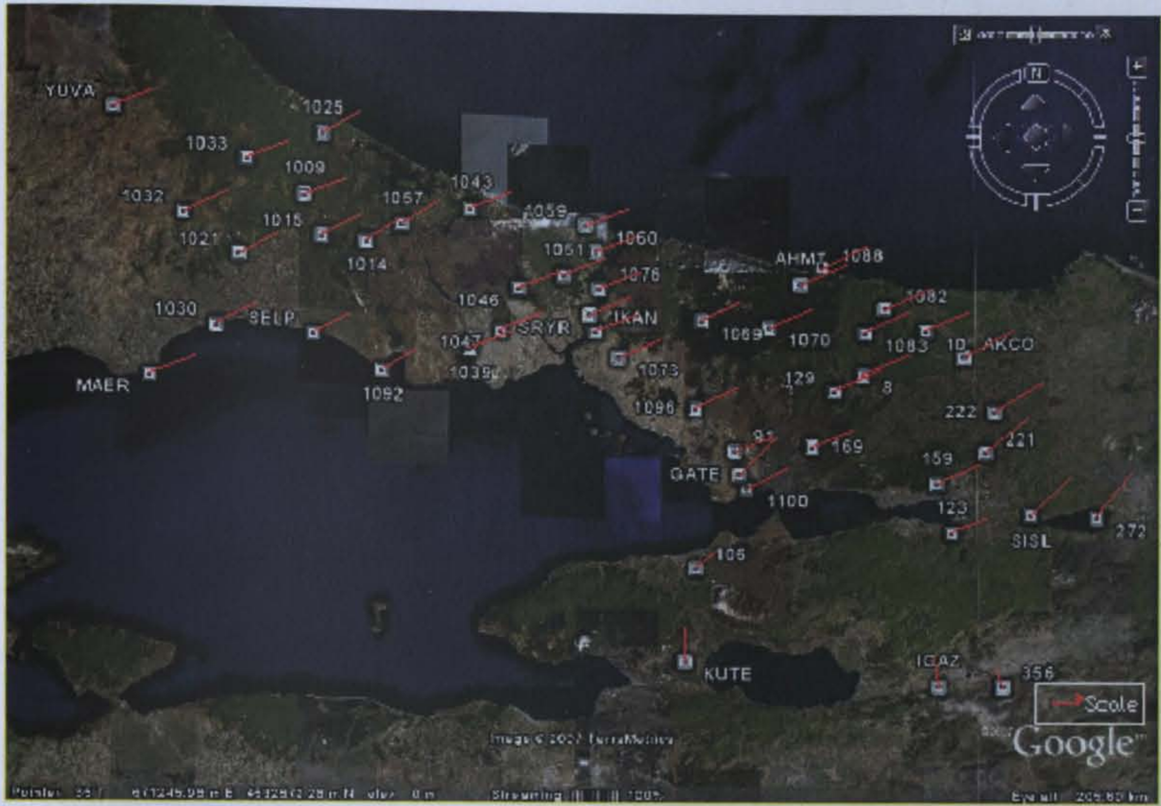

Figure 3.1. Displacement vectors between 2006.60 and 2000.45 epochs

For the purpose of the investigation of datum, two epochs had to be analyzed. TNFGN, MERLIS and IGTN networks were tied to TNFGN which was tied to IGS network using ONSA, MADR, WTZR, MATE, ANKR, ZWEN, KIT3, NICO and BAHR points. CORS-TR network was also tied to IGS network using ANKR, TUBI, DRAG, NOT1, SOFI, BUCU and MATE points. IGS stations of TNFGN were in ITRF96 datum (Table 3.2.), whereas IGS stations of CORS-TR were in ITRF2000 datum (Table 3.3.). By comparing the coordinates in ITRF96 and ITRF2000 of IGS stations which made up datum of two networks, whether or not there were any significant scale changes and rotation were examined. The transformation parameters would enable to obtain the datum parameters, so transformation parameters between ITRF96 and ITRF2000 (rotations, translations and a scale factor) of each network were computed by using Adjust Software (Table 3.4.). The parameters of each network were compared with each other.

Table 3.2. Coordinates of IGS stations of TNFGN

STATION ID	ITRF96 COORDINATES AT EPOCH 1997.0		
	X(m)	Y (m)	Z (m)
ANKR	4121948,602	2652187,958	4069023,671
WTZR	4075580,697	931853,669	4801568,044
MATE	4641949,718	1393045,282	4133287,333
ONSA	3370658,674	711877,032	5349786,866
KIT3	1944945,365	4556652,206	4004325,969
ZWEN	2886325,555	2155998,407	5245816,135
NICO	4359415,854	2874116,991	3650777,707
BAHR	3633909,068	4425275,486	2799861,265

Table 3.3. Coordinates of IGS stations of CORS-TR (CORS-TR Report,2006)

STATION ID	ITRF-2000 COORDINATES AT EPOCH 1997.0		
	X (m)	Y (m)	Z (m)
ANKR	4121948,524	2652187,904	4069023,758
TUBI	4211317,316	2377865,929	4144663,268
DRAG	4432980,620	3149432,112	3322110,468
NOT1	4934546,203	1321265,036	3806456,124
SOFI	4319372,078	1868687,819	4292063,947
BUCU	4093760,836	2007793,835	4445129,965
MATE	4641949,526	1393045,455	4133287,465

Table 3.4. Transformation parameters

	TNFGN	CORS-TR
Scale	1.000000001 ± 0.0000000006	1.000000190 ± 0.0000000270
Rotation about X	-0°00'00.00046" ± 0.00014"	-0°00'00.01077" ± 0.01260"
Rotation about Y	0°00'00.00027" ± 0.00021"	0°00'00.00089" ± 0.02874"
Rotation about Z	-0°00'00.00003" ± 0.00015"	-0°00'00.00371" ± 0.00597"
X translation	0.015 ± 0.006	-0.639 ± 0.613
Y translation	0.019 ± 0.004	-0.322 ± 0.255
Z translation	-0.022 ± 0.005	-1.008 ± 0.725

The coordinates in ITRF96 of stations which made up TNFGN datum were compatible with the coordinates in ITRF2000 of the same stations. However, it indicated that there was a significant translation between the coordinates in ITRF96 and ITRF2000 of stations which made up CORS-TR datum. It could be said that the differences between TNFGN datum and CORS-TR datum involved the datum translations. Therefore, it was necessary to consider these translations in the computation of strain parameters with displacements.

4. DETERMINATION OF STRAIN ACCUMULATION

4.1. Mathematical Models

4.1.1. Definitions

Strain is used in physics, mechanic and other related sciences. The basic definition of strain is explained as follows:

Assume that a force is applied to an L length bar throughout its axis (Figure 4.1.). This force causes the extension of the bar. Thus, the length l of the bar extends to L+ΔL.

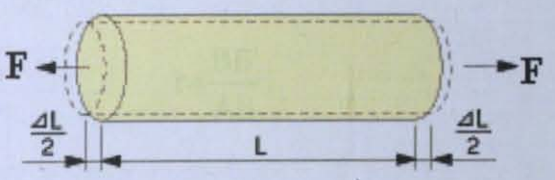

Figure 4.1. A force is applied to the bar

The ratio of ΔL to L, that is ΔL/L, is called strain.

$$\varepsilon = \frac{\text{Extension}}{\text{Original length}} = \frac{\Delta L}{L} \quad (4.1))$$

The unit of strain is strain s. (Microstrain μs=1ppm)

The deformation of the bar is extension and the applied force is a tensile force, so this is called tensile strain (Figure 4.2.(a)). If a compressive force is applied, then it is called compressive strain (Figure 4.2.(b)). Tensile and compressive strains are called normal strains.

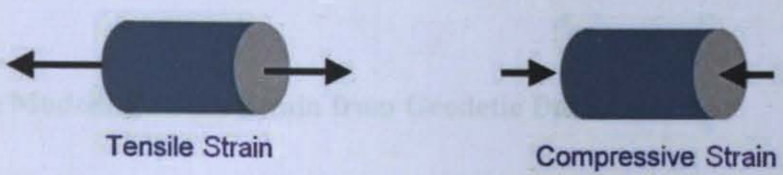

Figure 4.2. (a) Tensile strain (b) Compressive strain

Assume that a force is applied to a rectangular object which is attached to the wall on one side. This force causes the deformation of the object. The value of deformation r; in radian is defined as

$$r = \frac{BB'}{AB} \tag{4.2)}$$

It is called shear strain (Figure 4.3.) (Salmon,1931).

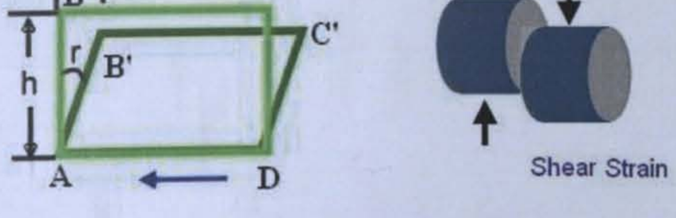

Figure 4.3. (a) Shear force (b) Shear strain

Strain accumulation indicates the amount of strain between two epochs. Strain rate (the velocity of strain accumulation) is defined as the annual vector or amount of strain.

In this study, total strain accumulation between epoch 2000.45 and epoch 2006.60 of the test network were examined.

4.1.2. The Modeling of The Strain from Geodetic Data

The physical definition of strain was done according to an object whose form, size and physical properties were known. It was required some approximations for the strain determination models for earth.

Repeated measurements of geodetic network or geodynamic traverse stations which have been built on locations that will characterize the area and movements were used to obtain strain from geodetic data. Assume that

i. The area was characterized by geodetic network or geodynamic traverse stations,
ii. Strains between repeated measurements were linear and homogeneous.

A lot of model that withstand two principal approaches were developed.

I. Methods based on infinitesimal strain approximation
II. Finite element methods

Three dimensional strain tensor in a coordinate system are defined as

$$\varepsilon = \begin{vmatrix} e_{xx} & e_{xy} & e_{xz} \\ e_{xy} & e_{yy} & e_{yz} \\ e_{xz} & e_{yz} & e_{zz} \end{vmatrix} \tag{4.3}$$

where

$$e_{xx} = \frac{\partial X'}{\partial X},\ e_{yy} = \frac{\partial Y'}{\partial Y},\ e_{zz} = \frac{\partial Z'}{\partial Z} \tag{4.4}$$

$$e_{xy} = \frac{1}{2}\left(\frac{\partial X'}{\partial Y} + \frac{\partial Y'}{\partial X}\right),\ e_{xz} = \frac{1}{2}\left(\frac{\partial X'}{\partial Z} + \frac{\partial Z'}{\partial X}\right),\ e_{yz} = \frac{1}{2}\left(\frac{\partial Y'}{\partial Z} + \frac{\partial Z'}{\partial Y}\right) \tag{4.5}$$

where X, Y, Z are original coordinates

X', Y', Z' are deformed coordinates

The determination of the accuracy of horizontal positioning is more accurate than the accuracy of the vertical positioning, so only horizontal strain parameters are calculated.

Consequently, two dimension strain tensor is calculated by two models:

$$\varepsilon = \begin{vmatrix} e_{xx} & e_{xy} \\ e_{xy} & e_{yy} \end{vmatrix} \tag{4.6}$$

4.1.2.1. Computation of Strain Parameters with Finite Element Method. Observations at two epochs are used for least square adjustment separately. Linear extension of a baseline in a network becomes;

$$\varepsilon = \frac{S' - S}{\Delta t.S} \tag{4.7}$$

where S is original length

S' is deformed length

If time interval between two epochs, Δt is given, strain rate ε is found. However; if Δt isn't taken into account, ε will become strain accumulation.

Linear extension of the baseline which has t azimuth is

$$\varepsilon = e_{xx}\cos^2 t + e_{xy}\sin 2t + e_{yy}\sin^2 t \tag{4.8}$$

By using this general equation, parameters of strain tensor are calculated. Therefore, the network has to be constructed of triangles and strain tensor has to be calculated for each triangle (Figure 4.4.) (Denli, 1998).

Triangles in the network are taken as "unit particle" of finite element method. By combining unit particles, continuous parameters in the network (solution area are found. For each baseline of a triangle, three general equations are created. Thus, e_{xx}, e_{xy}, e_{yy} are found. These parameters of strain tensor are the strain parameters of the point of equilibration of each triangle.

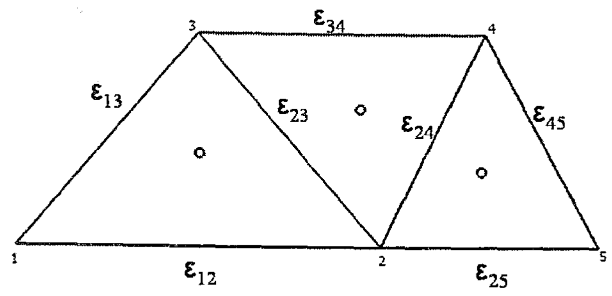

Figure 4.4. Triangulation for the strain tensor (organization of unit particles)

Strain parameters which are calculated with this method are independent from datum parameters. Calculated strain parameters for the points of equilibration of triangles imply scale differences in the network. It is required to provide the continuity for the network among the parameters which are calculated for points of equilibration.

4.1.2.2. Computation of strain parameters with infinitesimal strain method. Assume that P point is connected to surrounding points by the repeated observations (Figure 4.5.). dx and dy coordinate differences or deformation vector for each point are derived. The general deformation equation is

$$\begin{aligned} dx_i &= x_i e_{xx} + y_i e_{xy} + t_x \\ dy_i &= x_i e_{yx} + y_i e_{yy} + t_y \end{aligned} \tag{4.9}$$

where t_x, t_y are translation unknowns. In matrix form:

$$\begin{vmatrix} dx \\ dy \end{vmatrix} = \begin{vmatrix} 1 & 0 & x & y & 0 & 0 \\ 0 & 1 & 0 & 0 & x & y \end{vmatrix} \begin{vmatrix} t_x \\ t_y \\ e_{xx} \\ e_{xy} \\ e_{yx} \\ e_{yy} \end{vmatrix} \tag{4.10}$$

where

$$\begin{aligned} x &= X_i - X_P \\ y &= Y_i - Y_P \quad \text{i=1,....n} \end{aligned} \tag{4.11}$$

Equations are constructed for each point connected with P point by observations and for the P point itself. Thus, 6 unknown (2 translations and 4 strain parameters) are calculated. These parameters of strain tensor are the strain parameters of any particular point (P).

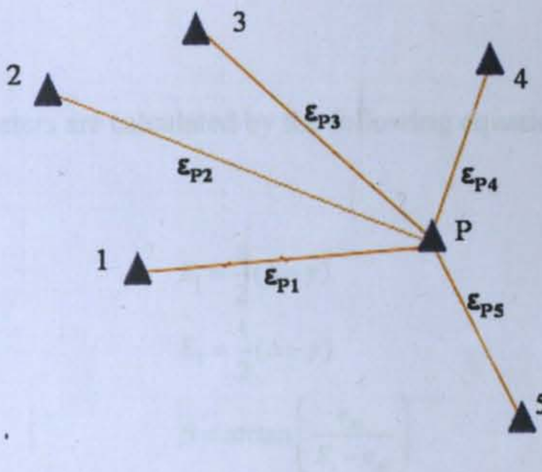

Figure 4.5. Point P and its surrounding points

In this method, it is assumed that translation parameters in the computation of strain could eliminate translations which result in the differences between datum. However, it is

$$\begin{vmatrix} dx \\ dy \end{vmatrix} = \begin{vmatrix} 1 & 0 & x & y & 0 & 0 \\ 0 & 1 & 0 & 0 & x & y \end{vmatrix} \begin{vmatrix} t_x \\ t_y \\ e_{xx} \\ e_{xy} \\ e_{yx} \\ e_{yy} \end{vmatrix} \tag{4.10}$$

where

$$\begin{aligned} x &= X_i - X_P \\ y &= Y_i - Y_P \quad \text{i=1,....n} \end{aligned} \tag{4.11}$$

Equations are constructed for each point connected with P point by observations and for the P point itself. Thus, 6 unknown (2 translations and 4 strain parameters) are calculated. These parameters of strain tensor are the strain parameters of any particular point (P).

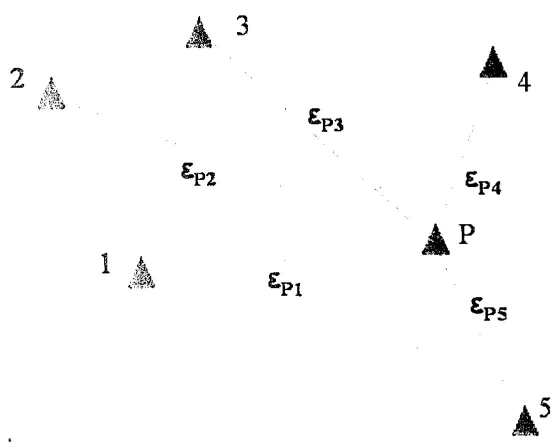

Figure 4.5. Point P and its surrounding points

In this method, it is assumed that translation parameters in the computation of strain could eliminate translations which result in the differences between datum. However, it is required to examine whether or not there is a correlation between translation components and translation parameters.

Subsequently, strain parameters shown below could be calculated from the parameters of strain tensor.

$$\Delta = e_{xx} + e_{yy} \qquad (4.12)$$
$$\gamma_1 = e_{xx} - e_{yy} \qquad (4.13)$$
$$\gamma_2 = 2e_{xy} \qquad (4.14)$$
$$\gamma = \sqrt{\gamma_1^2 + \gamma_2^2} \qquad (4.15)$$

where Δ is dilatancy

γ_1 is principal shear strain

γ_2 is engineering shear strain

γ is total shear strain

Principal strain parameters are calculated by the following equations.

$$E_1 = \frac{1}{2}(\Delta + \gamma) \qquad (4.16)$$
$$E_2 = \frac{1}{2}(\Delta - \gamma) \qquad (4.17)$$
$$\beta = \arctan\left(\frac{e_{xy}}{E_1 - e_{xy}}\right) \qquad (4.18)$$

where E_1 is maximum principal strain

E_2 is minimum principal strain

β is direction of maximum principal strain arc

Maximum shear strain

$$E_{SHEAR} = 0,5(E_1 - E_2) \tag{4.19}$$

Maximum normal strain

$$E_{INTER} = 0,5(E_1 + E_2) \tag{4.20}$$

The graphical representation of principal strain parameters are shown in Figure 4.6 (Salmon,1931).

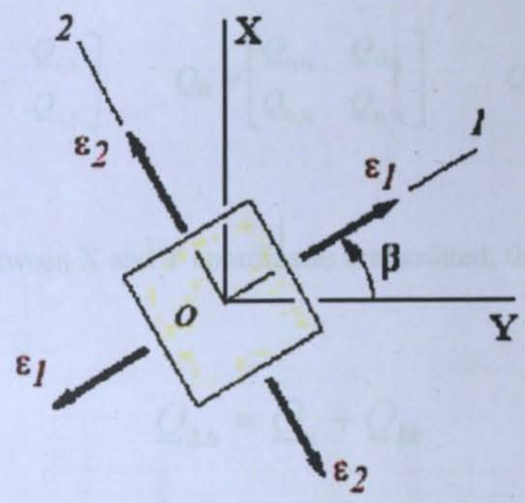

Figure 4.6. Principal strain parameters (In mechanical engineering)

Strain parameters which are calculated from baseline or coordinates differences between two epochs give strain accumulation. If these values are divided by time interval between two epochs Δt, strain rate is obtained.

4.1.2.3. The precisions of strain parameters computed with Finite Element Method. Three strain parameters are computed from the changes in the baseline values of a triangle for each side. The processing for computing precision of computed strain parameters is given below.

The cofactor matrix of the baseline calculated from coordinates of i and j points becomes (Demirel, 2003)

$$Q_{\Delta\Delta} = \begin{bmatrix} Q_{\Delta X \Delta X} & Q_{\Delta X \Delta Y} \\ Q_{\Delta X \Delta Y} & Q_{\Delta Y \Delta Y} \end{bmatrix} = Q_{ii} + Q_{kk} - Q_{ik} - Q_{ik}^T \tag{4.21}$$

$$Q_{ii} = \begin{bmatrix} Q_{x_i x_i} & Q_{x_i y_i} \\ Q_{x_i y_i} & Q_{y_i y_i} \end{bmatrix} \qquad Q_{kk} = \begin{bmatrix} Q_{x_k x_k} & Q_{xky_k} \\ Q_{x_k y_k} & Q_{y_k y_k} \end{bmatrix} \qquad Q_{ik} = \begin{bmatrix} Q_{x_i x_k} & Q_{x_i y_k} \\ Q_{y_i x_k} & Q_{y_i y_k} \end{bmatrix} \tag{4.22}$$

If the correlation between X and Y coordinates are omitted, the cofactor matrix becomes

$$Q_{\Delta\Delta} = Q_{ii} + Q_{kk} \tag{4.23}$$

The cofactor matrix for baseline differences between computed baselines in two epochs is

$$Q_{\Delta S \Delta S} = 2Q_{\Delta\Delta} = 2Q_{ii} + 2Q_{kk} \tag{4.24}$$

If the positioning accuracy of points is taken equal and close o each other, the cofactor matrix is simplified as

$$Q_{\Delta S\Delta S} = 4Q_{xx} \tag{4.25}$$

The mean covariance matrix of adjusted results of TNFGN, IGTN and MERLIS networks is

$$C_{xx} = \begin{bmatrix} m_x^2 & - \\ - & m_y^2 \end{bmatrix} = \begin{bmatrix} (1,5cm)^2 & - \\ - & (1,5cm)^2 \end{bmatrix} \tag{4.26}$$

Considering the equation which is given above

$$C_{\Delta S\Delta S} = 4\begin{bmatrix} m_x^2 & - \\ - & m_y^2 \end{bmatrix} = 4\begin{bmatrix} (1,5cm)^2 & - \\ - & (1,5cm)^2 \end{bmatrix} \tag{4.27}$$

and $m_{\Delta S\Delta S} = \pm 4,24cm$ are obtained.

If average baseline of test network is taken as 25km, expected error ratios of strain parameters is

$$m_\varepsilon = \frac{m_{\Delta S\Delta S}}{S_{av}} = \pm 1,7\,ppm \tag{4.28}$$

4.2. Determination of Strain in a Network with Global Test

Strain parameters of a particular point can be calculated by finite element model and infinitesimal strain method. It is also possible to compute the strain parameters of a whole 3D network. For this purpose, the differences between two epochs were used. An approximate coordinates were chosen from an epoch. Free network adjustment was carried out. A global test which indicates significant deformation between two epochs was applied (Brunner,1979).

The general equation of the vector of deformations can be written as

$$d = Bu \tag{4.29}$$

where B is the matrix of coefficients

$$B = \begin{vmatrix} x & 0 & 0 & y & z & 0 & 0 & z & -y \\ 0 & y & 0 & x & 0 & z & -z & 0 & x \\ 0 & 0 & z & 0 & x & y & y & -x & 0 \end{vmatrix} \tag{4.30}$$

u is the vector of unknown elements (extensions, shearing strain and rotations)

$$u^T = \begin{vmatrix} \varepsilon_{11} & \varepsilon_{22} & \varepsilon_{33} & \frac{1}{2}\gamma_{12} & \frac{1}{2}\gamma_{23} & \frac{1}{2}\gamma_{13} & \omega_{11} & \omega_{22} & \omega_{33} \end{vmatrix} \tag{4.31}$$

The linear equations for the adjustment are constructed as

$$d + v_d = Bu \tag{4.32}$$

The solution of the adjustment is given by

$$u = (B^T B)^{-1} B^T d \tag{4.33}$$

The cofactor matrix is calculated by

$$Q_u = (B^T B)^{-1} \tag{4.34}$$

Root mean square error of unit measurement is calculated by

$$m_0 = \pm\sqrt{\frac{v^T v}{n-u}} \tag{4.35}$$

The precisions of unknowns are computed by

$$m_i = m_0 \sqrt{Q_{ii}} \tag{4.36}$$

As the first step of the evaluation, TNFGN, MERLIS and IGTN networks were used in the subsequent least square adjustment for the computation of the strain tensor and test for the significance of deformation.

$$\begin{vmatrix} dx_i \\ dy_i \\ dz_i \end{vmatrix} = \begin{vmatrix} x & 0 & 0 & y & z & 0 & 0 & z & -y \\ 0 & y & 0 & x & 0 & z & -z & 0 & x \\ 0 & 0 & z & 0 & x & y & y & -x & 0 \end{vmatrix} \begin{vmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \frac{1}{2}\gamma_{12} \\ \frac{1}{2}\gamma_{23} \\ \frac{1}{2}\gamma_{13} \\ \omega_{11} \\ \omega_{22} \\ \omega_{33} \end{vmatrix} \tag{4.37}$$

$$\begin{aligned} x &= X_i - X_0 \\ y &= Y_i - Y_0 \\ z &= Z_i - Z_0 \end{aligned} \tag{4.38}$$

X_i, Y_i, Z_i Coordinates of the network points

$X_0,\ Y_0,\ Z_0$ Coordinates of the approximate point

$$X_0 = 4210km$$
$$Y_0 = 2340km$$
$$Z_0 = 4170km$$

The cofactor matrix Q

0,00069486	7,9303E-05	3,63273E-05	0,0002509	0,000309446	8,0891E-05	-5,153E-05	0,000261801	-0,0001085
7,9303E-05	0,00040338	4,5041E-06	0,000383	3,83671E-05	0,0003468	-0,0003432	3,24598E-05	0,00033894
3,6327E-05	4,5041E-06	0,000102794	1,425E-05	4,47296E-05	2,2631E-05	1,511E-05	-8,9751E-06	-6,164E-06
0,0002509	0,000383	1,42499E-05	0,00042468	0,000121385	0,00033123	-0,0003197	0,000102696	0,00028528
0,00030945	3,8367E-05	4,47296E-05	0,00012138	0,000193641	4,9812E-05	-1,425E-05	0,000110925	-5,251E-05
8,0891E-05	0,0003468	2,26314E-05	0,00033123	4,98122E-05	0,00031683	-0,0003006	2,37705E-05	0,00028619
-5,153E-05	-0,0003432	1,51105E-05	-0,0003197	-1,42529E-05	-0,0003006	0,00031075	-3,0431E-05	-0,0002912
0,0002618	3,246E-05	-8,9751E-06	0,0001027	0,000110925	2,3771E-05	-3,043E-05	0,000146748	-4,442E-05
-0,0001085	0,00033894	-6,1643E-06	0,00028528	-5,25091E-05	0,00028619	-0,0002912	-4,4424E-05	0,00034558

The vector of unknown elements u and the precisions

$$\begin{vmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \frac{1}{2}\gamma_{12} \\ \frac{1}{2}\gamma_{23} \\ \frac{1}{2}\gamma_{13} \\ \omega_{11} \\ \omega_{22} \\ \omega_{33} \end{vmatrix} = \begin{vmatrix} 0{,}00816372 \pm 0.0025 \\ -0{,}0103271 \pm 0.00190 \\ -0{,}0005358 \pm 0.00095 \\ -0{,}007684 \pm 0.00190 \\ 0{,}00416803 \pm 0.0013 \\ -0{,}0086032 \pm 0.0017 \\ 0{,}00915879 \pm 0.0017 \\ 0{,}00339968 \pm 0.0011 \\ -0{,}0117071 \pm 0.0017 \end{vmatrix}$$

$v^T v = 1{,}219117568$

The results indicate that there is a deformation of the network and the network rotated around the x, y and z axes. They also show that extension along z axis ε_{33} is not significant because precision of ε_{33} is bigger than its value.

4.3. Strain Analysis Program and a Numerical Example

4.3.1. Computation of Strain Accumulation with Finite Element Method

In this study, TNFGN, MERLIS, IGTN and CORS-TR networks were used to compute the strain accumulation. Coordinates of TNFGN, MERLIS and IGTN networks were on epoch 2000.45 whereas coordinates of CORS-TR were on epoch 2006.60. Because of the discrepancy of datum of each epoch, strain parameters were computed with Finite Element Model. In order to calculate principal strain parameters, a program which was written in FORTRAN language for mechanical engineers was used.

For construction of triangles NETCAD software was used, later triangles were simplified (Figure 4.7.). A numerical example of the computation of strain parameters with finite element method was given below:

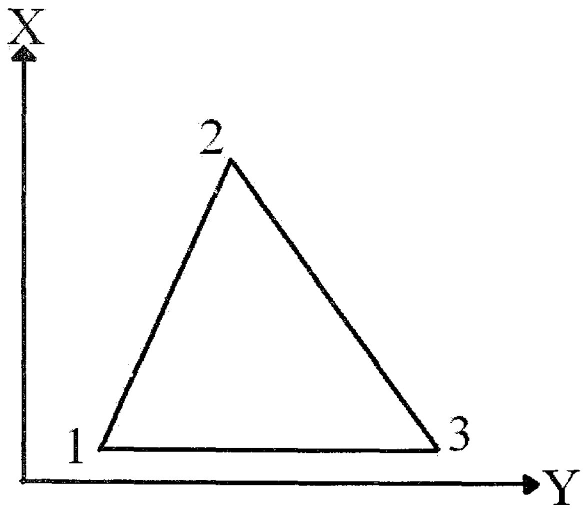

Figure 4.7. Unit particle of the network

An example of the computation of strain parameters for a triangle was given below related to Figure 4.7.

Table 4.1. Coordinates of points in the example

POINT NUMBER	I.EPOCH		II. EPOCH	
	NORTH	EAST	NORTH	EAST
1	4478839,4843	759791,7704	4478839,5449	759791,7472
2	4513335,9567	778244,4418	4513336,1309	778244,5852
3	4511374,8130	748300,9752	4511374,8670	748301,1181

Table 4.2. Coordinate differences of points

	ΔX	ΔY	ΔX	ΔY
1-2	34496,4724	18452,6714	34496,586	18452,8380
1-3	32535,3287	-11490,7952	32535,3221	-11490,6291
2-3	-1961,1437	-29943,4666	-1961,2639	-29943,4671

Lengths of baselines

Baseline differences

$$\left.\begin{array}{ll} S_{12}=39121{,}70356 & S'_{12}=39121{,}88231 \\ S_{13}=34504{,}86905 & S'_{13}=34504{,}80751 \\ S_{23}=30007{,}62031 & S'_{23}=30007{,}62866 \end{array}\right\} \begin{array}{l} \Delta S_{12}=0{,}178754\text{m} \\ \Delta S_{13}=-0{,}061542\text{m} \\ \Delta S_{23}=0{,}008354\text{m} \end{array}$$

Strain tensor parameters

$e_{12} = 4{,}569177304\mu s$ $\quad e_{13} = -1{,}783574368\mu s$ $\quad e_{23} = 0{,}27839595\mu s$

$e_{12} = 4{,}5692$ $\quad e_{13} = -1{,}7836$ $\quad e_{23} = 0{,}2784$

$\alpha_{12} = 31^g{,}2700$ $\quad \alpha_{13} = 178^g{,}3865$ $\quad \alpha_{23} = 295^g{,}8364$

Using the equation 4.8 following results were obtained

$$A = \begin{vmatrix} 0{,}2225 & 0{,}8318 & 0{,}7775 \\ 0{,}1109 & -0{,}6280 & 0{,}8891 \\ 0{,}9957 & 0{,}1304 & 0{,}0043 \end{vmatrix}$$

$$l = \begin{vmatrix} 4{,}5692 \\ -1{,}7836 \\ 0{,}2784 \end{vmatrix}$$

$$x = (A^T A)^{-1} A^T l \tag{4.39}$$

$$x = \begin{vmatrix} e_{yy} \\ e_{xy} \\ e_{xx} \end{vmatrix} = \begin{vmatrix} -0,31 \\ 4,47 \\ 1,19 \end{vmatrix}$$

$$E_1 = 4,97\mu s$$
$$E_2 = -4,09\mu s$$
$$\beta = 92^g,87$$
$$E_{SHEAR} = 4,53\mu s$$
$$E_{INTER} = 0,44\mu s$$

Strain parameters were computed for the same triangle by using the program (Figure 4.8.):

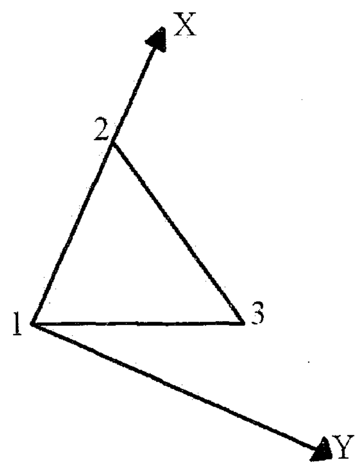

Figure 4.8. Perspective of the program to calculate strain parameters

The output of the program was given below.

Stress-Strain Changes Within the Triangle of Observation Points: 1 2 3

Young Modulus: .75000D-05 Strain E is given in [10**-6]

Poisson Ratio .30000D-05 Stress is given in [MPA]

Shear Modulus: .37500D-05

Change between Observation Time: 2 and 1

Point of Equilibration: X= 4501183.418 Y= 762112.396

Angles in triangle: PHI1= 52.88 PHI2= 135.43

	PNT. 1 - 2	PNT. 1 - 3	PNT. 2 - 3
D.Diff./Distance:	-4.56908431	1.78344309	-.27842342
Angle to North:	68.73	121.61	204.16

STRAIN

Angle of the Principle strain axes to North: PSI= 86.56

Princ. Strain Comp.: E1= 4.08990 E2= -4.96685 E3= .00000

Strain Tensor: EXX=-4.56908 EYY= 3.69214 EXY= 1.85586

EINTER= -.43847 ESHEAR= 4.52837

STRESS

Stress Components: S1= .00000 S2= .00000 S3= .00000

SINTER= .00000 SSHEAR= .00000

PHI (1)-PSI= .00 CHI= 217.83

SNORM= .00000 STAU= .00000

AME STRESS= .00000 AME PHI= -17.65

4.3.2. Computation of Strain for Each Triangle

Principal strain parameters computed for each triangle in test network were given in Table 4.1.

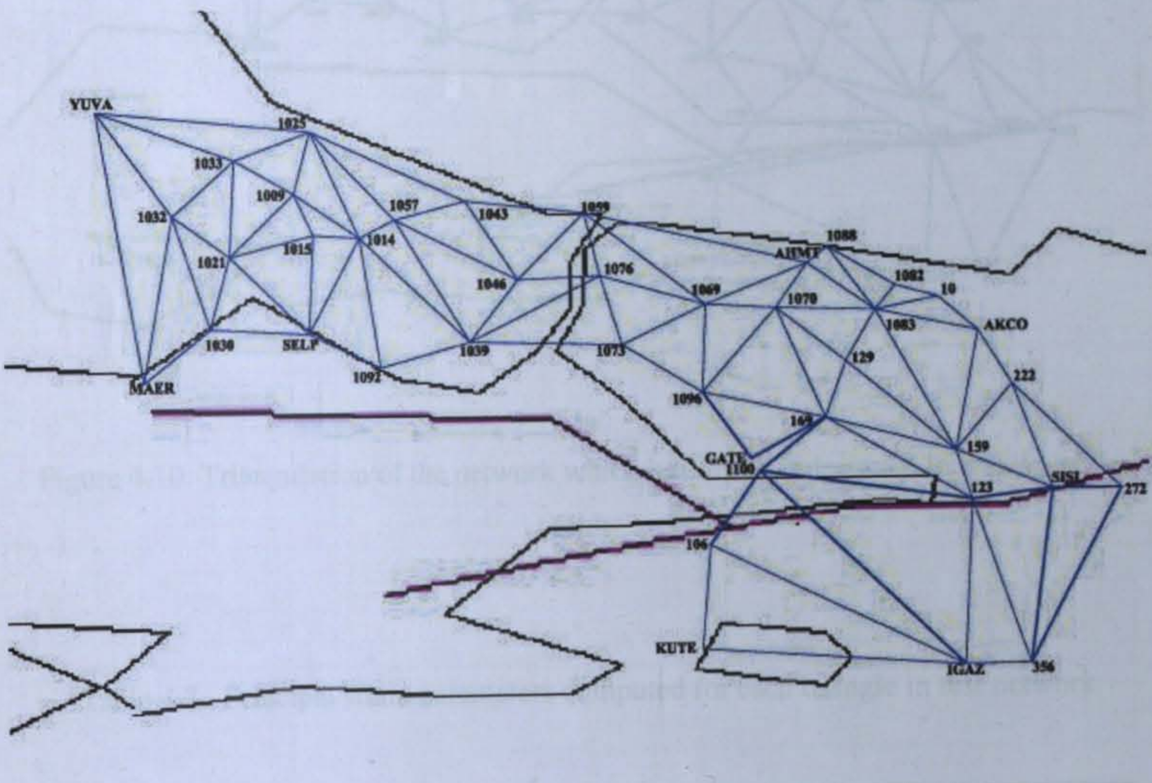

Figure 4.9. Triangulation of the network

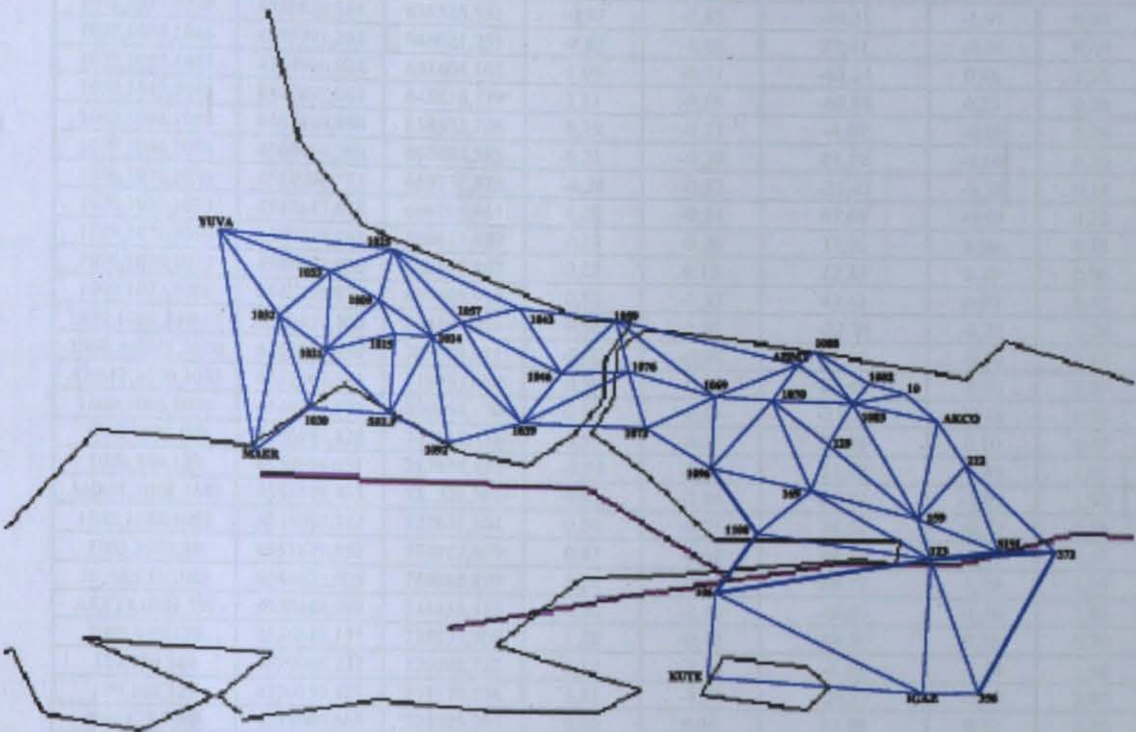

Figure 4.10. Triangulation of the network which have been redesigned in respect of the fault

Table 4.3. Principal strain parameters computed for each triangle in test network

TRIANGLE CORNER POINTS	COORDINATES OF POINT OF EQUILIBRATION		PRINCIPAL STRAIN COMPONENTS		ANGLE OF THE PRINCIPAL STRAIN β (grad)	E_{INTER} (μs)	E_{SHEAR} (μs)
	NORTH (m)	EAST (m)	E_1 (μs)	E_2 (μs)			
YUVA,MAER,1032	4564617,001	579857,906	0,25	-3,18	-0,40	-1,46	1,72
MAER,1032,1030	4550366,541	587324,662	0,45	-0,95	-44,81	-0,25	0,70
1032,1030,1021	4558601,663	593234,019	2,37	-0,13	69,52	1,12	1,25
YUVA,1032,1033	4579204,054	586166,72	1,33	-0,73	-76,22	0,30	1,03
1032,1033,1021	4569685,287	595027,499	1,97	0,89	66,87	1,43	0,54
1033,1021,1009	4571129,006	603388,008	1,10	-0,71	-17,26	0,19	0,91
YUVA,1033,1025	4584746,453	595696,597	0,57	-1,84	49,63	-0,63	1,21
1033,1025,1009	4579360,606	609043,541	0,61	-2,51	9,28	-0,95	1,56
1025,1009,1014	4574243,446	617617,55	3,41	-1,86	-98,06	0,78	2,64
1030,SELP,1021	4550833,981	602520,229	1,32	-0,43	13,99	0,45	0,87
SELP,1021,1015	4556990,662	609713,515	0,22	-0,24	-11,56	-0,01	0,23
1021,1009,1015	4566202,064	608787,815	3,10	-0,02	-68,16	1,54	1,56
1009,1015,1014	4567436,834	617761,281	2,97	2,63	-0,52	2,80	0,17
1015,1014,SELP	4558225,433	618686,981	2,83	-0,25	12,67	1,29	1,54
SELP,1092,1014	4549469,275	623215,786	0,47	-0,12	15,62	0,17	0,29
1092,1014,1039	4548874,055	634230,639	0,34	-1,57	29,92	-0,62	0,96
1025,1014,1057	4572525,515	624555,365	0,28	-2,85	0,85	-1,29	1,57

1014,1057,1039	4558620,214	635326,551	-0,97	-2,85	-99,51	-1,91	0,94
1057,1039,1046	4555791,203	646021,251	-0,05	-1,03	87,41	-0,54	0,49
1025,1057,1043	4574916,904	631804,145	1,69	-0,77	-63,24	0,46	1,23
1057,1043,1046	4565091,063	645816,779	1,11	-0,65	-69,88	0,23	0,88
1043,1046,1059	4565469,866	658532,726	0,19	-0,37	-4,09	-0,09	0,28
1059,1046,1076	4560464,266	667484,585	0,21	-0,39	81,74	-0,09	0,30
1046,1076,1039	4551996,773	659771,375	-0,24	-0,52	-21,47	-0,38	0,14
1076,1039,1073	4547647,638	666705,965	0,20	-0,24	97,69	-0,02	0,22
1059,1076,1069	4558719,263	680113,039	0,37	-0,25	37,92	0,06	0,31
1076,1039,1073	4549982,095	682575,867	0,25	0,13	12,83	0,19	0,06
1069,1073,1096	4542213,872	689405,913	0,52	-0,33	43,61	0,09	0,42
1059,1069,AHMT	4559427,308	694107,826	0,56	-1,02	-22,71	-0,23	0,79
1069,AHMT,1070	4553025,859	707018,911	-0,03	-0,98	91,19	-0,50	0,47
AHMT,1070,1083	4552567,531	718353,484	0,75	-0,85	89,48	-0,05	0,80
1069,1096,1070	4544549,591	699854,170	0,54	-0,85	-21,56	-0,16	0,70
1096,1070,169	4536983,826	707813,556	0,57	-0,37	30,29	0,10	0,47
1070,169,129	4538954,631	717474,452	-0,04	-2,94	21,70	-1,49	1,45
AHMT,1088,1083	4556575,433	721828,262	0,87	-2,96	67,99	-1,05	1,92
1088,1083,1082	4555052,342	727631,204	0,10	-0,75	34,52	-0,32	0,43
1083,1082,10	4551671,552	734917,659	0,47	-0,68	94,74	-0,11	0,57
10,AKCO,1083	4548625,003	740388,899	3,14	-0,76	68,77	1,19	1,95
AKCO,1083,159	4538448,998	741455,933	-0,02	-2,10	-40,57	-1,06	1,04
1083,159,129	4536513,175	732677,908	1,28	-0,12	-99,59	0,58	0,70
129,159,169	4529405,737	729302,721	0,12	-2,48	-8,62	-1,18	1,30
159,169,123	4520159,483	737570,536	0,81	-4,98	-26,17	-2,08	2,90
169,123,1100	4518900,665	724523,305	0,96	0,46	53,04	0,71	0,25
AKCO,222,159	4533447,543	750518,843	0,70	-2,68	-8,25	-0,99	1,69
222,159,SISL	4522942,709	755411,91	3,18	-2,61	96,29	0,28	2,90
159,SISL,123	4515318,621	752650,671	2,81	-7,43	14,12	-2,31	5,12
[1]222,272,SISL	4520329,859	766446,647	2,75	-0,56	0,59	1,09	1,66
[1]272,SISL,356	4501860,661	767515,673	3,27	-4,60	-34,89	-0,66	3,94
[1]SISL,356,123	4501206,947	757534,517	4,48	-6,67	-62,99	-1,09	5,57
[1]356,123,IGAZ	4489618,834	751547,656	2,02	0,31	-24,13	1,17	0,85
[1]123,IGAZ,1100	4502471,691	733616,578	3,38	-1,22	-36,65	1,08	2,30
[1]IGAZ,1100,106	4499634,308	716082,969	3,03	-3,64	-2,86	-0,31	3,33
1096,169,1100	4526176,115	706594,593	0,85	0,29	92,14	0,57	0,28
KUTE,106,IGAZ	4487928,319	712030,332	4,14	-0,87	-34,53	1,63	2,50
1070,1083,129	4546062,068	720849,64	0,92	-0,17	-74,74	0,37	0,55
[2]272,356,123	4501183,418	762112,396	4,09	-4,97	-86,56	-0,44	4,53
[2]123,IGAZ,106	4497626,561	730183,782	3,86	-1,83	-38,58	1,02	2,85
[2]1100,123,106	4510545,178	716666,553	1,84	-2,10	33,36	-0,79	2,62

Translation movements between two sides of the fault were included in the strain parameters which computed from triangles intersected the fault. To observe the effect of translation movements, triangles were redesigned with respect to the fault and strain parameters were calculated using these triangles (Figure 4.11.)

[1] Triangles which intersected the fault

[2] Triangles which have been redesigned in respect of the fault

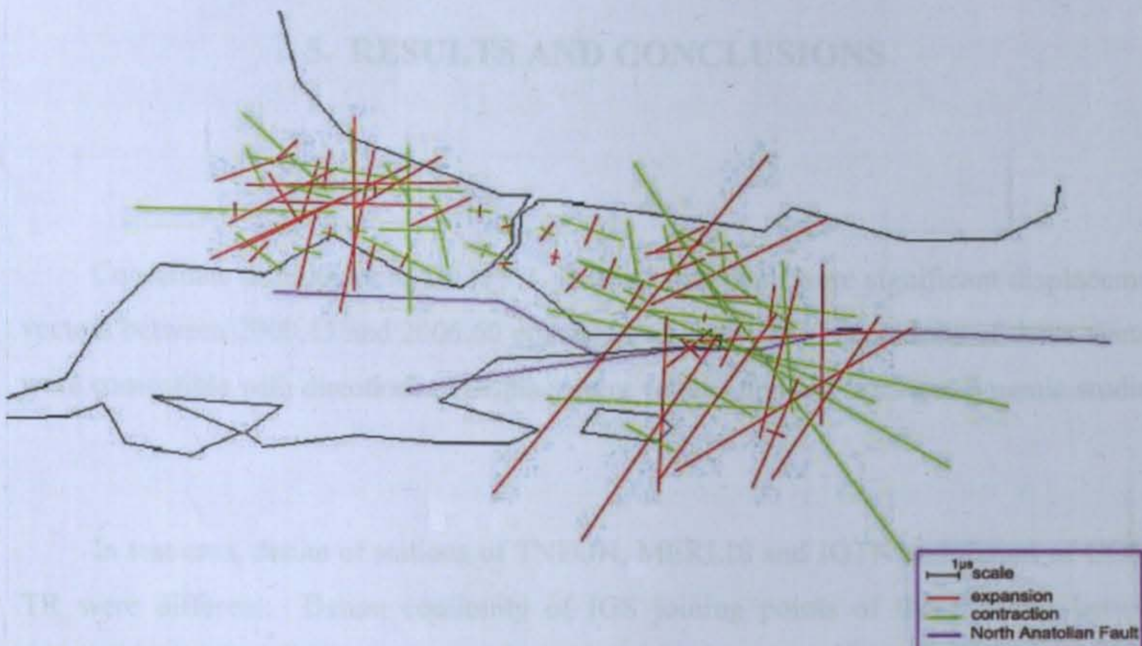

Figure 4.11. Principal strain parameters with North Anatolian Fault

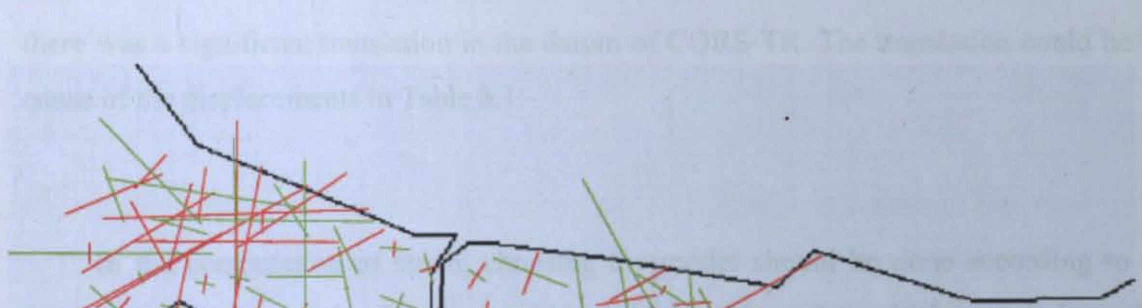

Figure 4.12. Principal strain parameters which calculated by using redesigned triangles with North Anatolian Fault

5. RESULTS AND CONCLUSIONS

Coordinate differences in Table 3.1. indicate that there were significant displacement vectors between 2000.45 and 2006.60 epochs of test networks. Directions of these vectors were compatible with directions of displacement vectors derived from geodynamic studies.

In test area, datum of stations of TNFGN, MERLIS and IGTN and datum of CORS-TR were different. Datum continuity of IGS joining points of these datum between 2000.45 and 2006.60 was examined with Helmert transformation. Coordinates of cardinal points of TNFGN, MERLIS and IGTN in ITRF96 and ITRF2000 were obtained and Helmert transformation was done. Coordinates of cardinal points of CORS-TR in ITRF96 and ITRF2000 were also obtained and Helmert transformation was done. In Table 3.4., there was a significant translation in the datum of CORS-TR. The translation could be the cause of the displacements in Table 3.1.

In the computation of strain, choosing the model should be done according to the state of datum of networks. Strains should be calculated from data which were independent to datum. Most suitable model for this study was the determination of strain with finite element model that relied on the deformations of baselines of network.

To apply this method, firstly triangles were constructed with Delaunay method. It was required to examine the triangulation. Some improper triangles were left out of triangulation.

Majority of strain parameters of test area obtained by evaluation of all of the three dimensional differences were significant. The results indicated that there was a significant deformation in the network.

Baseline ratios which were computed for triangle sides compared with $m_{\varepsilon}=\pm$ 1,7cm which was calculated in Section 4.1.2.3. The majority of ratios were bigger than 2 ppm. Therefore, it indicated that computed strain parameters were significant.

Strain parameters which were computed by the program in Table 4.1. indicated that

- Maximum principal strain parameter (E_1) was positive, in other words compression; minimum principal strain parameter (E_2) was negative, and this meant extraction.

- Maximum values were around Tekirdağ and Izmit, whereas minimum values were around Istanbul

- GATE, 1096 and 169 points had maximum strain accumulation of 6, 15 years between 2000, 45 and 2006, 60 epochs. SISL, 356 and 123 points near Iznik Lake had the closest value to the maximum.

Strain parameters calculated from triangles which intersected the fault were compared with strain parameters calculated from redesigned triangles in Table 4.1. The former strain parameters were bigger than the latter strain parameters. The results showed that triangles should be designed with respect to the fault.

In conclusion, it will be appropriate to examine these results in a multidisciplinary study.

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