INVESTIGATION OF CRUSTAL MOVEMENTS ALONG TUZLA FAULT-İZMİR

By

Aslı Sabuncu

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ABSTRACT

INVESTIGATION OF CRUSTAL MOVEMENTS ALONG TUZLA FAULT - İZMİR

Earthquakes are the most dangerous natural catastrophe which have affected adversely the humanity both spiritually and morally for centuries. Turkey is home to several devastating and disastrous earthquakes for many years. Earthquakes occur due to the deformation along the crust. For years, studies of monitoring crustal deformation have been conducted by geoscientists with different backgrounds. Geodetic surveying techniques have been used in this area since the beginning of 1900s. Nowadays, deformation and displacement parameters monitored by geodetic techniques are recognized as a favorable method in many studies focusing on crustal movements.

The Aegean Region including Western part of Turkey, mainland of Greece, the Hellenic Arc is the most active domain and deforming part in terms of seismological and geodynamical which is placed in the Alpine Himalayan Belt. This region mainly is under pure shear stress caused by an internally deforming counter-clockwise rotation of the Anatolian Plate relative to the Eurasian Plate. İzmir, historically named as Smyrna, is a touristic and commercial center not only for Aegean Region but also for Turkey. It is the third, largest city and it has the second biggest port of Turkey.

The objective of this study is to monitor crustal deformation along Tuzla Fault and its vicinity by geodetic techniques. Tuzla Fault, located between Menderes Town and Doğanbey Cape, has NE-SW lineament trending. It has a significant importance in terms of its seismicity, as the earthquakes which occur near or along this fault which is extremely close to the third largest city, Izmir. Reconnaissance for the sites was performed. Then, a geodetic network was established in August 2009 and followed by observations of the first GPS campaign and leveling measurement within the same year. In the subsequent year, second GPS campaign and leveling measurement were carried out.

Two different geodetic techniques are used for the determining the crustal movement along the Tuzla Fault. The result of the measurements will guide in determining the movements of the subjected fault. With the increase of the crustal movement monitoring for this region, this type of study should continue and observation interval should be densified.

ÖZET

TUZLA FAYI (İZMİR) BOYUNCA KABUK HAREKETLERİNİN İNCELENMESİ

Depremler yüzyıllardır insanoğlunu hem maddi hem de manevi şekilde etkileyen doğal afetlerdir. Türkiye, yıllardır yıkıcı ve tahrip edici depremlerin yuvası haline gelmiştir. Depremler, Yerkabuğunda meydana gelen deformasyonlardır. Kabuk deformasyonlarını belirleme çalışmaları yıllardır farklı disiplinlerdeki bilim adamları tarafından yürütülmektedir. Jeodezik ölçme tekniklerinin bu alandaki çalışmaları 1900'lerin başına rastlamaktadır. Günümüzde, deformasyon ve yer değiştirme parametrelerinin jeodezik tekniklerle izlenmesi, kabuk hareketleri çalışmalarında kullanılan en güncel yöntem olarak görülmektedir.

Türkiye'nin batısı, Yunanistan ve Helenik Yayı içine alan Ege Bölgesi Alp Himalaya deprem kuşağının sismolojik ve jeodinamik bakımdan en aktif ve en fazla deformasyona uğrayan bölümüdür. Bu bölge, temel olarak, Anadolu levhasının Avrasya levhasına göre saat yönünün tersine olan bağıl hareketi nedeniyle deformasyona uğramaktadır. İzmir tarihsel adıyla Smyrna ticaret merkezi olup sadece Ege bölgesinin değil aynı zamanda Türkiye'nin en büyük ve gelişmiş üçüncü şehri ve ikinci liman şehridir.

Bu çalışmanın amacı, Tuzla Fayı ve yakın çevresinin jeodezik yöntemlerle kabuk deformasyonlarının belirlenmesidir. Tuzla Fayı KD-GB eğilimli bir fay olup, Menderes İlçesi ve Doğanbey Burnu arasında yer almaktadır. Tuzla Fayı'nda bu çalışmaların yapılmasının sebebi o faya rastlayan depremler ve Türkiye'nin 3. büyük ve kalabalık şehrine yakın olmasıdır. Bölgede ilk olarak istikşaf çalışması yapılmış olup, jeodezik ağ 2009 yılının Ağustos ayında kurulmuştur. Bunu takiben ilk GPS gözlemleri ve hassas nivelman ölçmeleri de bu ayda yapılmıştır. Ertesi yıl 2. GPS kampanyası ve 2. hassas nivelman ölçmeleri başarı ile tamamlanmıştır.

İki ayrı jeodezik teknikle Tuzla Fayı'ndaki kabuk hareketlerinin belirleme çalışması yapılmıştır. Ölçmelerin sonuçları faydaki hareketliliği belirlemek için rehber niteliğindedir. Kabuk hareketlerinin gözlenmesi çalışmalarının giderek önem kazanmasıyla bu bölgedeki çalışmalar daha fazla yapılmalı ve ölçmeler sıklaştırılmalıdır.

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LIST OF SYMBOLS / ABBREVIATIONS

USGS	United States Geological Survey
SLR	Satallite Laser Ranging
VLBI	Very Long Baseline Interforemetry
GPS	Global Positioning System
GDMRE	General Directorate of Mineral Research and Exploration
IESEMP	İzmir Earthquake Scenerio Earthquake Master Plan
KOERI	Kandilli Obsevatory and Earthquake Research Institute
NEMC	National Earthquake Monitoring Center
CCD	Charged Couple Device
PCMCIA	Mean of the normal distribution
TLSMMIPR	Turkish Large Scale Map and Map Information Production Regulation
GIS	Geographic Information Systems
C/A	Coarse Acquisition
PRN	Pseudo Random Noise
TGO	Trimble Geomatic Office
ASKE	Askeriye
CTAL	Çatalca
ESEN	Esenli
GEMR	Gaziemir
GORC	Görece
HZUR	Huzur Sitesi

DBEY	Doğanbey
KOKR	Kokar
KPLC	Kaplıca
PTKV	Petek Vadisi
SFRH	Seferihisar
TRAZ	Tırazlı
TURG	Turgutlu
URKM	Urkmez
YACI	Yağcılar
YKOY	Yeniköy
$w(mm) \leq 12\sqrt{S}$ km	The tolerance error in closure levelingfor 2nd order leveling
$l_1 + v_1 = A_1 x_1 \;\; \sum_{x1} = \sigma_{01}^2 Q_{l1}$	Coordinate unknowns of displacement vectors
$H_o = E(\underline{x}_1) = (\underline{x}_2)$	The null hypothesis
$f_1(n_1 - u_1 + d_f)$	Degree of freedom
$\Omega_1 = v_1^T P_1 v_1$	Test of null hypothesis
$s_{o1}^2 = \Omega_1 / f_1$	Test of null hypothesis
$T_G = ((\Omega_{G-} \Omega_0)/r)/(\Omega_0/f_0)$	T_G Test value
$T_{H=} d^t Q_d^+ d / r s_o^2$	T_H Test value

1. INTRODUCTION

Earthquakes are the most dangerous natural catastrophe which affected adversely the human beings both spiritually and morally for all centuries. Turkey is located between one of the most seismically active region in the world. Additionally, Turkey is home to devastating and disastrous earthquakes for many years. Earthquakes occur due to the deformation along the crust.

Plate tectonics is a recent scientific thought and it can contribute many scientific branches with the purpose of developing themselves and also can respond many unanswered questions. It illustrates large scale movements of Earth’s lithosphere. The lithosphere, which is the earth’s crust and upper mantle, is broken into sections called plates. Plates move around on top of the mantle like rafts. The plate is categorized into two types: Ocean plate is below the oceans which is about 5-10 km and continental plate is below the continents for 35-70 km. Moreover, the phenomenon of plate tectonics include “continental drift”.

The continental drift theory was about the relative positions of continents change during geologic time. This was put forwarded by Abraham Ortelius in 1596 initially however Alfred Wegener was fully developed the hypothesis of continental drift in 1912 and expanded in his 1915 book “The Origin of Continents and Oceans”. Wegener believed that 200 million years ago, all the continents were unite and named “Pangea – all Earth” which refers to “Supercontinent” (Erickson J., 2001).

On the earth surface, there are nine large plates and numbers of smaller plates. These large plates are The North American, South American, Eurasian, African, Indian, Antarctic, The Pacific, Nazca and Australian (Figure 1.1).

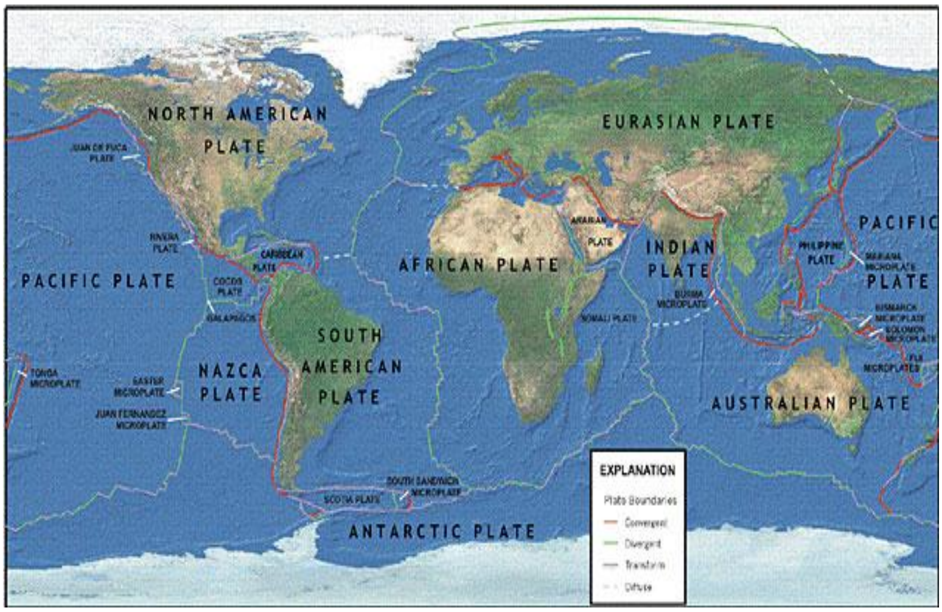

Figure 1.1. The major plates of the Earth (USGS)

(http://earthquake.usgs.gov/learning/topics/Plate_tectonics/Plates.php)

These plates usually move at a velocity within a range of 1 to 15 cm per year. There are three main types of tectonic plate boundaries. These are divergent boundaries, convergent boundaries and transform boundaries. New oceanic crust takes place meanwhile two or more than two plates pull away each other in the divergent boundaries. If the plates continue to move, more crusts are formed and ocean basins are expanded and the new ridge system are generated. The well known example of this type of boundaries is the Mid-Atlantic Ridge which moves 2,5 centimeters per year (cm/yr) (Kious J. & Tilling I.R.,1996).

The further type of plate boundary is convergent boundaries. At this type, one plate dives in to another one. That is to say, two plates converge each other then, one plate is overriding another, thereby imposing the other into the mantle beneath it. There are 3 types of convergent boundaries: Oceanic-oceanic, oceanic-continental, continental-continental. The well known examples are Japan and the Aleutian Island, the western coast of South America where the oceanic Nazca Plate is being subducted under the South American Plate continent and the Himalayas and the Tibetan Plateau.

The final tectonic plate boundaries is transform boundaries. The base of this concept is, the plate can not slide or past each other easily. San Andrea Faults in the North America and North Anatolian Fault in Turkey are the renowned example of this type.

Crustal deformation monitoring is the most important issue that different geoscience dicipline of scientists have been working on it for many years.

With the great attention on crustal deformation by destructive earthquakes, the issue on understanding the behavior of interior Earth as well as the surface of it. Geodetic surveying techniques had been used in this area since at the beginning of 1900. With the advent of high technology, the conventional surveying techniques were abandoned. Today, the movement of tectonic plates can be directly measured by a variety of space geodetic techniques, including Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS).

Each site of the Earth's crust is exposed to deformation hence the most outstanding sources of the perpetually and temporarily displacements of these points are plate tectonics, ocean, atmospheric, hydrological loading, tidal effects and local geological processes. Deformation measurements are intented to determine the distortion of structures' positions and shapes as well as monitor the earths' crustal deformation. The measurements are done by different geodetic types and evaluated which are done at different time interval or periods. In attempt to get accurate and precise results, more than one measurement should be surveyed.

In this thesis, Turkey's third biggest and crowded city, Izmir, is preferential domain in order to determine the large scale deformation study with space geodetic technique, GPS, and conventional geodetic technique, precise leveling. Besides GPS technique, conventional geodetic techniques such as precise leveling selected for determinig small vertical deformations along the fault line.

The second chapter of this study explains the whole region in terms of seismicity, tectonics from different and past scientific studies aspect with important explanations. Besides, significant faults in the region and their locations are explained and denoted with maps in the study area. Tuzla Fault and its feature will be introduced in terms of all details. Additionally, historical and instrumental period of earthquake information are placed in this chapter.

The third chapter of this study gives the details of different types of geodetic methods used in the study area in order to monitor crustal deformation. These techniques are precise leveling and GPS. In this chapter, both surveying techniques are delivered in great detail. Furthermore, GAMIT/GLOBK scientific software and how its process steps evaluated data are also studied. Finally, the result of geodetic techniques are analyzed.

The last chapter states the results of this study with the comparison between two different methods and the conclusion.

2. SEISMICITY AND TECTONICS OF THE AEGEAN REGION

2.1. Tectonic Settings of Turkey and Aegean Region

Earth is a good laboratory for geoscientists in order to study various kind of tectonic phenomena then examine the results. The Earth has many features of its complex structure such as huge rift valleys, marvellous mountains, deep ocean basins as well as they are the consequences of the earthquakes.

There is a boundary between African and Eurasian Plates which illustrate in the west by the Hellenic Arc and in the east the Cyprus Arc and a diffuse fault system of Eastern Anatolian Fault Zone (Yilmaz, Y. 2000, Ergun, M., and Oral, E. Z., 2000, Kocyigit, A., 2000, Utku, M., 2000, Taymaz, T., 2001). The African Plate is subducting under two most significant plates- Anatolian and Aegean- by creating Hellenic Arc (Le Pichon *et al.,* 1988). Additionally, the Anatolian Plate has a relative motion of 22-25 mm/yr with respect to Eurasian Plate. Northern part of the Africa near the Hellenic Trench moves about 10 mm/yr towards north meanwhile northern Arabia Plate has been moving with 18-25 mm/yr velocity rate with respect to Eurasia (Mc Clusky *et al*., 2000).

The Aegean region and its surrounding area including Western part of Turkey, Aegean Sea, mainland Greece and part of the Northern Eastern Mediterranean is extremely seismic and active part of the Alpine-Himalayan Orogenic belt system (Mc Kenzie 1972, 1978, Mercier *et al.,* 1977, Jackson *et al.,* 1982, Armijo *et al.,* 1996).

The Aegean region forms parts of a major seismic belt - that starts at the Indian Ocean and extends up to the Atlantic Ocean - and is bounded by the African, the Eurasian and the Anatolian Plates. Due to the collision of these three plates at the Aegean region, the majority of the seismic activity of the eastern Mediterranean area occurs in the Greek territory (Jackson and McKenzie, 1988).

In addition, the Aegean region is placed in the convergent boundary between two important plates which are African and Eurasian. During the last 92 Ma the African Plate has activity and rotated counter clockwise with respect to Eurasian Plate (Muller *et al.,* 1993). Thus the Aegean region is dominated by pure shear stress and the deformation is relative to the Eurasia with counter-clockwise rotating Anatolian Plate. Aegean region with 30 mm/yr NE-SW extension is very active continental extension in the world (Mc Clusky *et al.,* 2000). The figure 2.1 shows the velocity rate of main plates around the Aegean region.

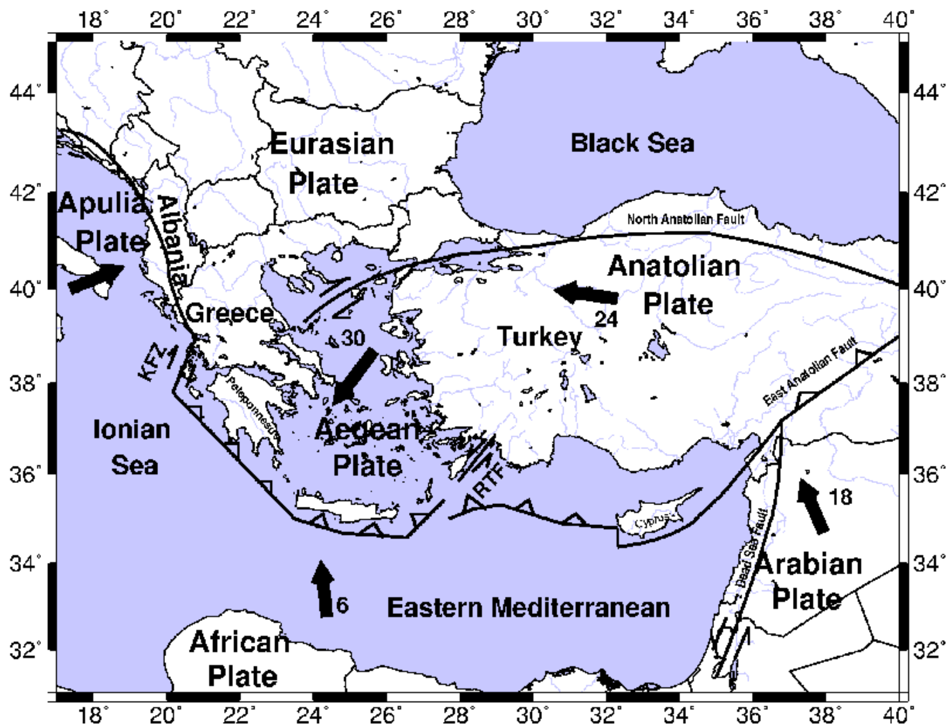

Figure 2.1. The velocity map of Turkey modified from Mc Clusky *et al.,* 2000

According to Thatcher, W and Nyst, M (2004) the present day Aegean deformation is due to the relative motions of four minor plates and straining severe isolated zones internal to them. These microplates are the South Aegean, Anatolia, Central Greece and the Sea of Marmara.

The Aegean region is dominated by the two major motions.

1) The westward escape of the Anatolian Plate, bounded by the North Anatolian Fault and East Anatolian Fault intersecting at the Karliova depression of the East Anatolian with a rate of 20-25 mm/yr. The westward motions changes the direction in the West Anatolia with a rather abrupt counter-clockwise rotation, towards southwest over the Hellenic Trench.
2) The N-S extension of the Western Anatolia and the Aegean with rate about 30-60 mm/yr. As a result of these motions a group of E-W trending grabens have been developing. These grabens are bounded by E-W trending normal fault zones which, extend about 100-150 km. These fault zones are generally segmented and each segment is no longer than 8-10 km (Yilmaz, Y., 2000).

Reilinger *et al.*, (2006) performed a study which is about the plate interactions of Arabia- Africa- Eurasia Zone. The figure 2.2 shows the interactions of Arabia-Africa–Eurasia Zone with Caucasus Block, Aegean Plate and Anatolian Plate. Moreover, the figure 2.2 also indicates the extentional plate boundaries by double lines, thrust faults by the lines with triangles and strike slip boundaries by the plain lines. White arrows denote the GPS-derived plate velocities relative to the Eurasia in mm per year.

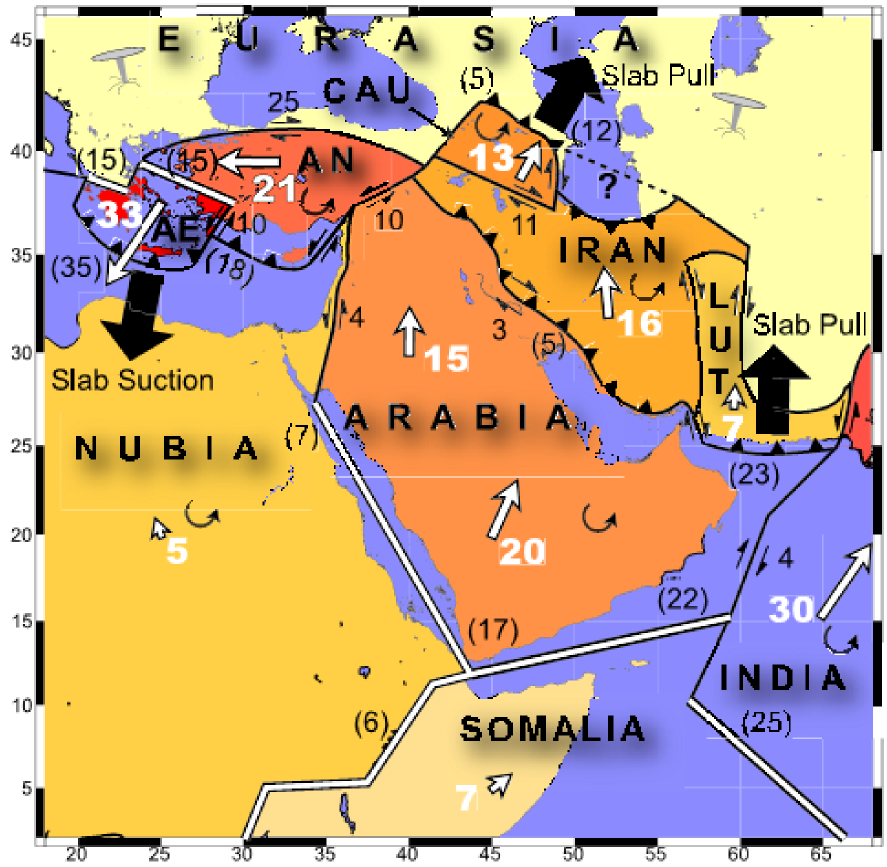

Figure 2.2. Arabian- African- Eurasian Plate interaction (Reilinger *et al.*,2006)

The tectonics of Izmir and its vicinity are very complex in geological sense and should be investigated in detail to understand long and short term geodynamic activities (K. Halicioglu., H.Ozener., 2008).

2.2. Study Area

Izmir is highly populated touristic and commercial center not only for Aegean region but also for Turkey. One of the oldest settling area of the Mediterranean region was Izmir which was the ancient Greek city and has been located strategically significant and a central point near the Aegean coast (Figure 2.3). Izmir is located between the Gulf of Kusadasi at the south and Madra Mountains at the north. The city is also placed with 37° 45’ and 39 ° 15’ North Latitude and 26° 15’and 28° 20’ East Longitude with approximately 12012 km^2 domain. The population has been reached approximately 2,7 millions.

Figure 2.3. The view of Izmir from Google Earth

2.3. Seismicity

Tectonic forces move and deform parts of the earth's crust, particularly along plate margins. Stress refers to a force per unit area. Where stress can be measured, it is expressed as the force per unit area at a particular point. Strain is the change in size (volume) or shape, or both, while an object is undergoing stress (Plummer., Mc Geary., Carlson., 2001). When the stress exceeds the strength of the rocks, the rupture happens and the energy released in the form of earthquake.

2.3.1. Seismicity of the Study Region

Seismicity is a significant concept that means the distribution of the earthquakes in terms of the geographically and historically. The region including with active faults is located in the borders of 1. degree earthquake risk zone. Ozmen *et al.*, (1997) prepared a seismicity map. This map consists of data from instrumental time to the present and indicates Turkey's total risk activity (Figure 2.4). Additionally, the table shows the high risk domains in terms of population, area, industry centers and dams of allocations of percentage (Table 2.1). The region seismicity map is in figure 2.6.

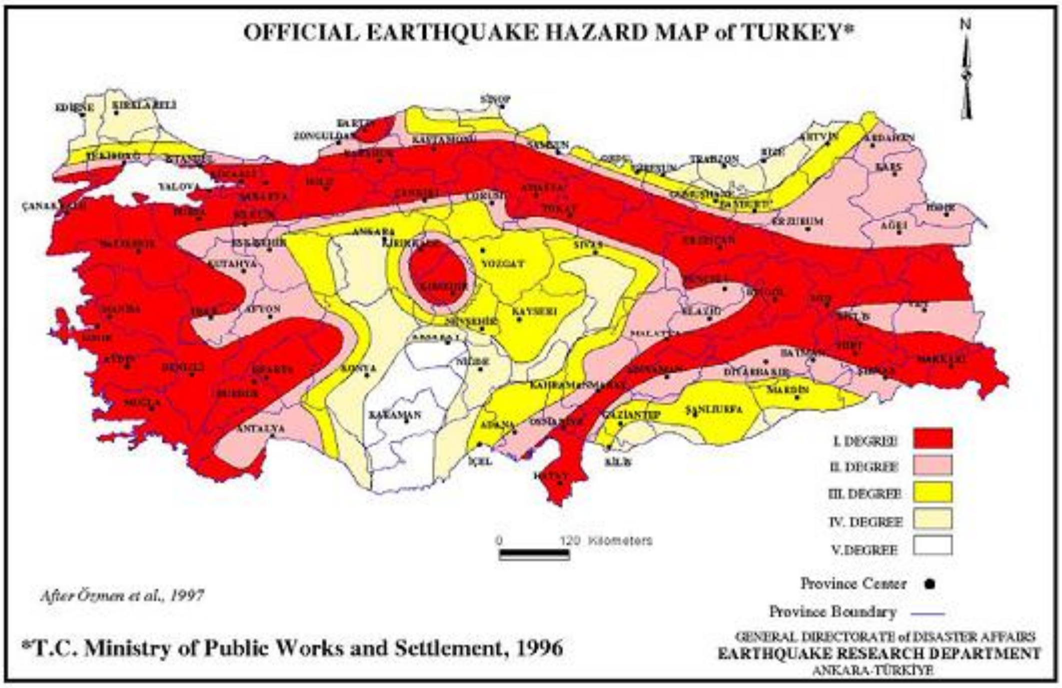

Figure 2.4. Turkey Earthquake hazard map (Ozmen *et al.*, 1997)

Table 2.1. Seismic risk zones in terms of population, area and industry centers and dams distribution in percentages (Ozmen *et al.*, 1997)

Earthquake Zone	**Population (%)**	**Surface Area (%)**	**Major Industry Centers (%)**	**Dams (%)**
Zone I	22	14.8	24.7	10.4
Zone II	39	28.4	48.8	20.8
Zone III	24	28.8	12.0	33.3
Zone IV	20	19.4	12.6	27.1
Zone V	5	8.6	1.7	8.4

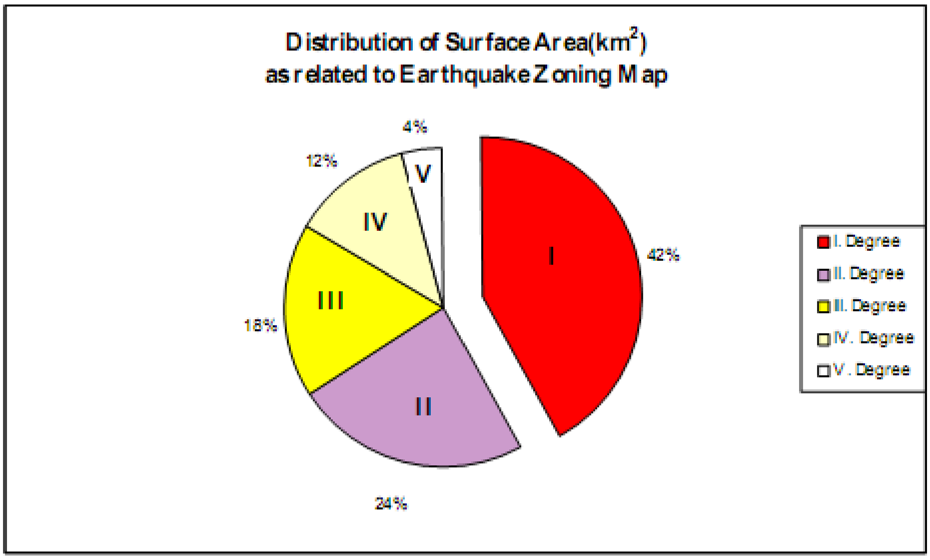

Figure 2.5. Distribution of surface area as related to earthquake zoning map (Ozmen *et al.*, 1997)

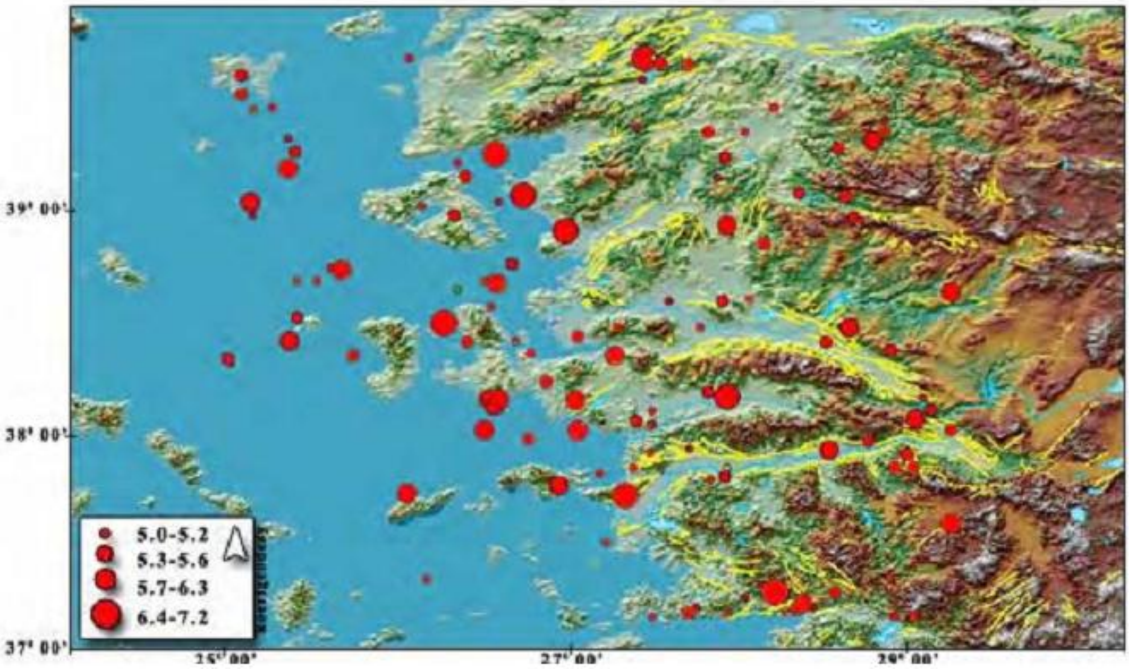

Figure 2.6. The seismicity map of Aegean region between 1900-2009 (Ozener H., 2010)

Table 2.2 and table 2.3 indicate the earthquakes which happened near the vicinity of the study area Izmir in historical and instrumental period.

Table 2.2. Disastrous earthquakes in İzmir and its proximity in historical period

Date	Location	Latitude	Longitude	Intensity	Magnitude
17 A.D.	Izmir -Sardies	38.40	27.50	X	7.0
176	Sakiz, Sisam island	38.60	26.65	VII	5.8
177	Sakiz, Sisam island	38.60	26.65	VII	5.8
178	Izmir	38.30	27.10	VIII	6.5
688	Izmir	38.41	27.20	IX	6.5
1039	Izmir	38.40	27.30	VIII	6.8
20 Mar 1389	Izmir- Foca	38.40	26.30	VIII	6.7
20 May 1654	Izmir	38.50	27.10	VIII	6.4
2 Jun 1664	Izmir	38.41	27.20	VII	5.8
14Feb 1680	Izmir	38.40	27.20	VII	6.2
10 Jul 1688	Izmir	38.40	26.90	X	6.8
13Jan.1690	Izmir	38.60	27.40	VII	6.4
Sep.Oct.1723	Izmir	38.40	27.00	VIII	6.4
4 Apr. 1739	Izmir	38.50	26.90	IX	6.8
24 Nov.1772	Izmir	38.80	26.70	VIII	6.4
3-5 Jul 1778	Izmir	38.40	26.80	IX	6.4
3 Nov. 1862	Izmir	38.50	27.90	X	6.9
29 Jul 1880	Izmir	38.60	27.10	IX	6.7
15 Oct 1883	Izmir-Cesme	38.30	26.20	IX	6.8

Table 2.3. Disastrous earthquakes in İzmir and its proximity in instrumental period

Date	Location	Latitude	Longitude	Depth	Intensity	Magnitude
19 Jan 1909	Izmir-Foca	38.00	26.50	60	IX	6.0
31 Mar 1928	Izmir	38.18	27.80	10	VIII	6.5
22 Sep 1939	Izmir	39.07	26.94	10	IX	6.6
23 Jul 1949	Karaburun	38.57	26.29	10	X	6.6
02 May1953	Karaburun	38.48	26.57	40	VIII	5.0
16 Jul 1955	Izmir	37.65	27.26	40	VIII	6.8
19 Jun 1966	Karaburun	38.55	27.35	9	VIII	4.8
06 Apr 1969	Izmir	38.47	26.41	16	VIII	5.9
01 Feb 1974	Izmir	38.55	27.22	24	VIII	5.3
16 Dec 1977	Izmir	38.41	27.19	24	VIII	5.5
14 Jun 1979	Karaburun	38.79	26.57	15	VIII	5.7
06 Nov 1992	Seferihisar	38.16	26.99	17	VIII	5.7
28 Jan 1994	Manisa	38.69	27.49	5	VIII	5.2
24 May1994	Aegean sea	38.66	26.54	17	VIII	5.6
10 Apr 2003	Urla	38.26	26.83	16	VIII	5.6
17-24 Oct 2005	Seferihisar	38.17	26.66	10		5.7-5.9-5.9

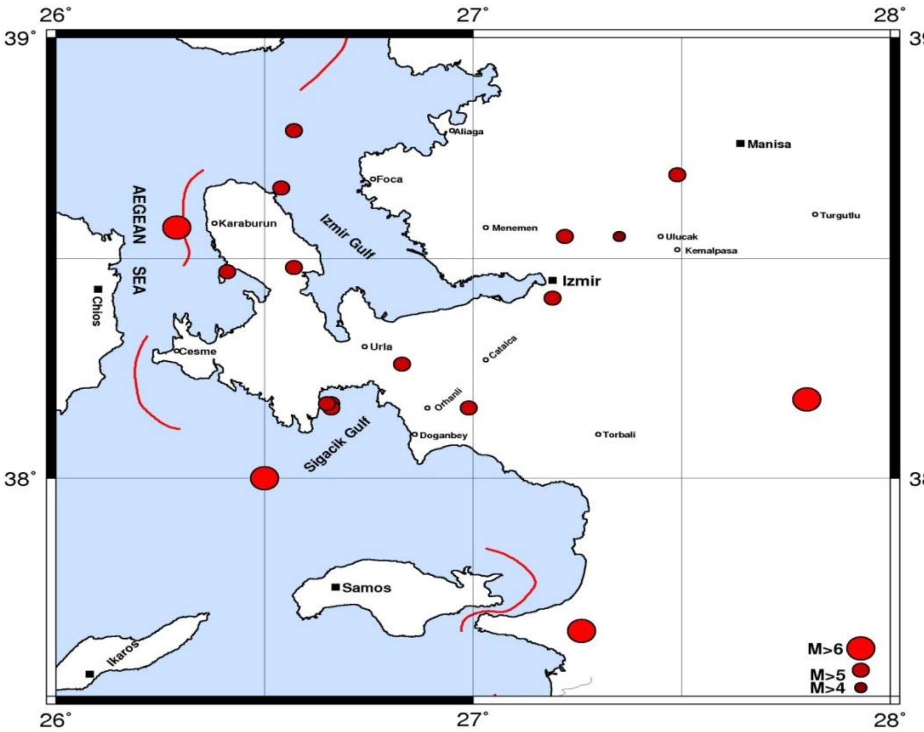

Figure 2.7. Seismicity of İzmir and its surrounding between 1909-2010

2.4. Significant Faults in Aegean Region

Izmir and its vicinity are placed in tectonic regime dominated Western Anatolia. Izmir has been witnessed dense earthquake activities since its historical period. Moreover, the report on active faults and seismicity in Izmir and its vicinity (Emre *et al.*, 2005) by General Directorate of Mineral Research and Exploration (GDMRE) explains 13 active faults approximately 50 km radius area which has a central part of Izmir. These faults are Izmir Fault, Guzelhisar Fault, Gulbahce Fault, Menemen Fault, Seferihisar Fault, Yeni Foca Fault, Bornova Fault, Gumuldur Fault, Gediz Graben Fault Zone, Dagkizilca Fault, Manisa Fault, Kemalpasa Fault, Tuzla Fault (Figure 2.8).

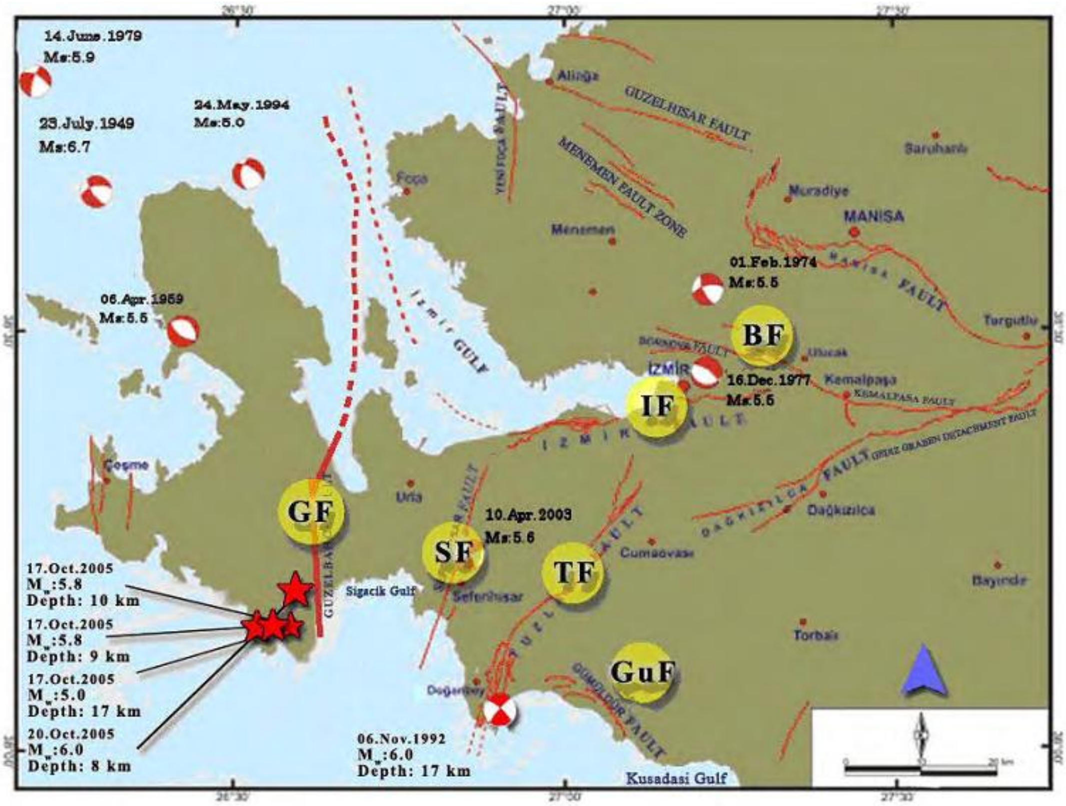

Figure 2.8. Important faults of Izmir and its vicinity
(taken from Halicioglu and Ozener 2008)

The fault lying in the east of Izmir Gulf is named Izmir Fault. It is a morphological boundary of that gulf with a lineament of E-W (Emre and Barka, 2000). Izmir Fault is 35 km long dip-slip normal fault which is lying between Guzelbahce and Pinarbasi. The western part of this fault has bifurcated into two segments. Each part of the two is about 15 km long. According to GDMRE report, Izmir Fault had brought about big earthquakes due to Holocene period with surface ruptures. In addition, geological data indicate that this fault appeared after Miyocene.

Guzelhisar Fault is lying between the province Aliaga and Osmanlica northest part of Izmir. It is N70W trending and about 25 km long. According to Emre *et al.,* (2006) and Saroglu *et al.,* (1985) researh studies, Guzelhisar Fault forms right-lateral strike-slip character. Moreover geomorphologic proof of Guzelhisar Fault indicates that it was active Quaternary period.

Menemen Fault zone resembles the fault cluster which is lying between Dumanlidag volcano complex and Gediz lowland. The Menemen Fault zone has 4 segments which are 15 km long with NW-SE direction and the fault zone width is about 5 km. The longest fault which is in the middle of the fault zone is about 12 km long. According to GDMRE data, these faults are called possibly active faults due to the lack of information and the uncertainty of the Quaternary activity.

Gulbahce Fault is separating the Gulf of Izmir and Karaburun Peninsula in terms of its structural and morphological characteristic. According to IESEMP, this fault is named Karaburun Fault (Erdogan 1990, IESEMP 2000, GDMRE 2002). However, in order to avoid any misunderstanding in given name, this fault is denoted Gulbahce. According to Ocakoglu *et al.,* (2005) this fault is 70 km long with undersea parts. The fault has two segments, 30 km long in the south part and 40 km long in the north part. In addition, Ocakoglu *et al.,* (2005) research study indicates that Gulbahce Fault has strike-slip behaviour. Moreover, some oblique components can be seen in the north part of this fault. According to GDMRE, 17 October 2005 Sigacik, Izmir (M_w=5,6 and M_w=5,9) earthquakes preassessment report, these earthquakes offset locations are densified near the southern part of this fault. Figure 2.9 shows the focal mechanism solution of 17-21 October 2005 Sigacik Gulf-Seferihisar (Izmir) earthquakes. Additionally, figure 2.10 indicates the seismic activity of Seferihisar Sigacik Earthquakes between 17-29 October 2005.

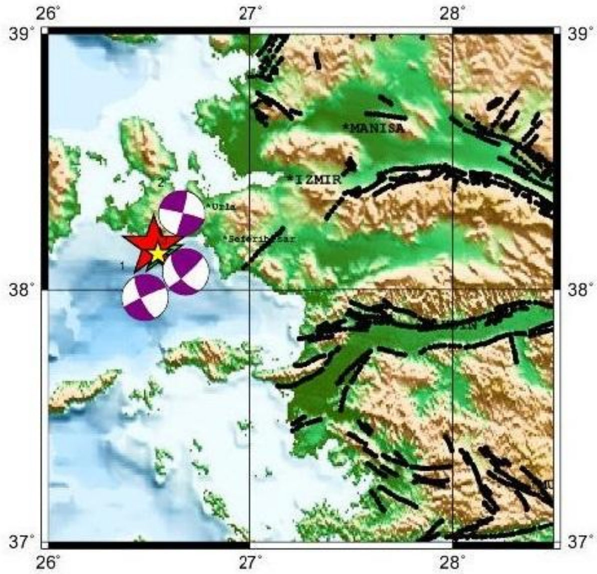

Figure 2.9. Focal mechanism solution of 17-21 October 2005 Sigacik Gulf – Seferihisar (Izmir) earthquakes (KOERI-National Earthquake Monitoring Center (NEMC))

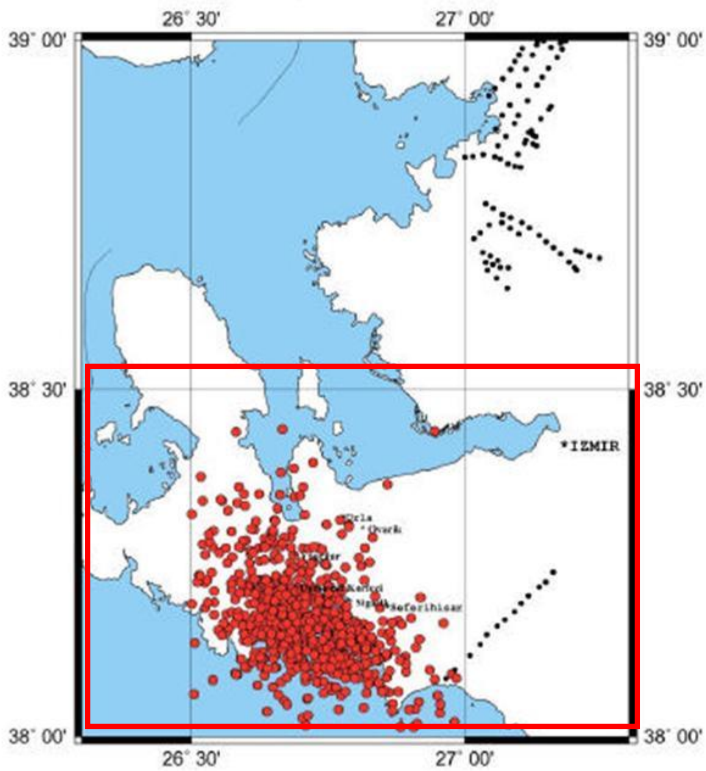

Figure 2.10. The seismic activity of Seferihisar Sigacik Earthquakes between 17-29 October 2005 (KOERI-NEMC)

Seferihisar Fault is lying between the Gulf of Sigacik and Guzelbahce with a lineament trending of N20E in southwest of Izmir. According to Ocakoglu *et al.,* (2004, 2005) submarine data indicate that this fault is continuous to south direction in the Aegean Sea. This fault is 23 km long and within the undersea segment it has reached 30 km long (Emre *et al.,* 2005). According to İnci *et al.,* (2003), fault zone interprets right-lateral strike-slip behaviour. Geomorhological data indicates that Seferihisar Fault was an active fault during Holocene era (Ocakoglu *et al.,* 2005). In addition, the epicenter location and aftershocks distribution of 10 April 2003 Seferihisar Earthquake (M_w=5,7) coincide with the vicinity of Seferhisar Fault Zone (Figure 2.11). Tan and Taymaz (2003) investigation result of the focal mechanism solutions of 10 April 2003 Seferihisar Earthquake, denoted a NE-SW right-lateral trend for the fault trace.

Seferihisar Fault can be assessed as a transfer fault of Gediz Graben System and also is considered similar to Tuzla Fault because of the link between Seferihisar Fault and Izmir Fault with E-W trending.

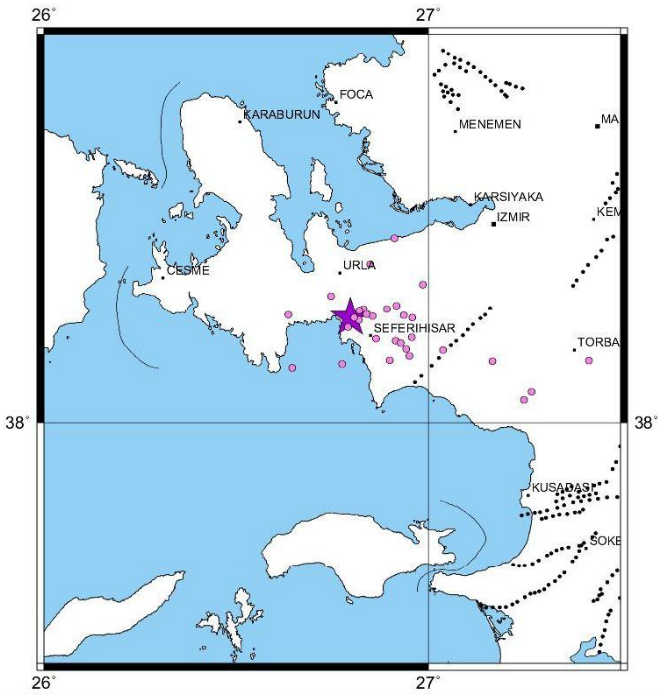

Figure 2.11. The distribution of aftershocks after 10 April 2003 Seferihisar Earthquake (KOERI- NEMC)

Yeni Foca Fault is lying between the eastern part of Nemrut port and Gerenkoy in the south. This is 20 km long N-S lineament trending possibly active fault. According to Altunkaynak and Yilmaz (2000) exploration, Yeni Foca Fault is interpreting left-lateral strike-slip fault.

Bornova Fault cluster is NW-SE lineament trending which is lying northwest of the Gulf of Izmir and south part of Karsiyaka and Kemalpasa. It is an active fault however there is not sufficient data about fault activity.

The fault, called Gumuldur is lying between the province Gumuldur and Ozdere in the southwest of Izmir. It is about 15 km long with a lineament trending of N55W normal fault. According to Genc *et al.*, (2001), this fault is named as Ortakoy Fault. Tuzla Fault is lying along the northwest of this fault. Gumuldur Fault is a potentially active fault due to the edge of the Gulf of Kusadasi and its effect on the morphology of Quaternary.

Gediz Graben Fault Zone is significant fault clusters which are normal fault with E-W trending of this region. The fault clusters consist of 3 main faults. These faults are Dagkizilca, Kemalpasa and Manisa. Dagkizilca Fault is bound to Gediz Graben Fault System. It is a right-lateral strike-slip tranfer fault with N70E trending and 27 km long. It is lying between south of Kemalpasa and Torbali. Kemalpasa is an active fault which is lying between Bagyurdu and Ulucak in the western part of Gediz Graben (Emre and Barka 2000). It is 24 km long with a lineament N75E. Manisa Fault is a normal fault which is located in the northwest branch of Gediz Graben. It is 40 km long with N65W lineament trending which is lying between Manisa and Turgutlu near Muradiye.

Tuzla Fault is lying between Gaziemir and Doganbey in the southwest of Izmir with NE-SW lineament direction (Emre and Barka 2000). Tuzla Fault has various names in literature such as Cumaovasi, Cumali Reverse Fault and Orhanli Fault (Saroglu *et al.*, 1987, 1992; Esder 1988; Genc *et al.*, 2001). The fault length is 42 km on the ground between Gaziemir and Doganbey. According to Ocakoglu *et al.*, (2004, 2005) with GDMRE Sismik-1 Research Vessel in the Doganbey Cape, Tuzla Fault is still continuous SW direction and goes beyond 50 km long under the Aegean Sea.

Tuzla Fault has 3 segments. These are Catalca, Orhanli, Cumali. Catalca segment is the northeast part of Tuzla Fault and 15 km long N35E lineament trending. Catalca segment is right-lateral strike-slip fault corresponding the Quaternary geomorphological data. Orhanli segment has N50E lineament trending with 16 km long fault which is located in the southeast of the Tuzla Fault. The last part of Tuzla Fault is Cumali segment. Cumali segment comes into being fault zone which is parallel to each other NNE-SSW direction in the southwest part of Tuzla Fault. Cumali Fault is lying between Doganbey Cape and Cumali Thermal Springs with 15 km long. This segment also goes beyond 25 km with submarine (Ocakoglu *et al.*, 2005).

Table 2.4. Earthquakes occured in the study area (KOERI-NEMC)

Day/Month	**Year**	**Latitude**	**Longitude**	**Depth**	**Ms**
06 November	1992	38.16	26.99	17	6,0
28 January	1994	38.69	27.49	5	5,2
24 May	1994	38.66	26.54	17	5,0
10 April	2003	38.26	26.83	16	5,6
17 April	2003	38.24	26.86	6	4,8
04 August	2004	37.09	27.65	18	5.4
04 August	2004	37.13	27.74	2	5.0
04 August	2004	37.26	27.90	13	5.0
10 January	2005	37.01	27.81	17	5.4
17 October	2005	38.15	26.54	10	5,8
17 October	2005	38.15	26.53	9	5,8
17 October	2005	38.15	26.58	17	5,0
20 October	2005	38.18	26.59	8	6,0

Tuzla Fault is well recognized by recent earthquakes M_w= 6.0 which was occured on Doganbey promontory. Though the morphology at Doganbey promontory is seen left lateral, the focal mechanism solutions indicate that Tuzla Fault character is right lateral (Tan and Taymaz, 2001). Moreover, geological observations reveal a right lateral offset of 200-700 m at young river beds of Holocene age along Tuzla Fault which the latest earthquake M_w=6.0 indicates the focal mechanism solution that right-lateral (Emre and Barka 2000, Ocakoglu 2004). The table 2.4 denotes the earthquakes happened in the study area.

3. OBSERVATIONS ALONG TUZLA FAULT BY GEODETIC TECHNIQUES

Monitoring crustal deformation technique is one of the most important part of crustal deformation analysis, studied by different branches of scientists for years. Geodetic surveying techniques have been used since the beginning of 1900. Deformation measurements and their data processing are the most significant component of surveying engineering measurements. Monitoring deformation has a wide area from tectonic movements, plate interactions, volcanic movements to large engineering structures such as skyscrappers, bridges and viaducts.

Geodesy has a significant role not only in monitoring and determining both deformations and displacements, but also in detecting the movements' direction and velocity in 3D.

In order to monitor the deformation along the Tuzla Fault, Izmir, KOERI Geodesy Department have used two different geodetic surveying techniques. These geodetic methods are precise geometric leveling and Global Positioning System.

3.1. Leveling

Leveling is a well-known and old method for determination of height differences between two points on the Earth's surface. Three principal methods are used determining differences in elevation, namely, barometric, trigonometric, spirit levelling.

Barometric Leveling: Barometrric leveling makes use of the phenomenon that difference elevation between two points proportional to the difference in atmospheric pressures at these points. The method is, therefore, relatively inaccurate and is little used in surveying work on except reconnaissance or exploratory surveys.

Trigonometric or indirect leveling: It is this process of leveling in which the elevations of points are computed from the vertical angle and horizontal distances measured in the field. In a modified form called stadia leveling commonly used in mapping both the difference in elevation and horizontal distance between the points are directly computed from the measured vertical angles and staff readings.

Direct levelling (spirit leveling): It is the branch of leveling in which the vertical distance with respect to a horizontal line may be used to determine the relative differences in elevation between two adjacent points. A horizontal plane of sight tangent to level surface at any points is readily established by means of a spirit level or a level vial. In spirit leveling, a spirit level and a telescope are combined and vertical distances are measured by observing on graduated rods placed on the points. It is the most precise method of determining elevations and the most commonly used by engineers. Precise leveling is the one of the direct leveling methods (Dr. B.C. Punmia, Ashok Kumar Jain, Ashok Kr. Jain, 2005)

3.1.1. Precise Leveling

Precise levelling is a particularly accurate method of direct levelling which uses highly accurate levels and with a more rigorous observing procedure than general engineering levelling. It aims to achieve high orders of accuracy such as 1 mm per 1 km. In general, there is no outstanding gap between precise and ordinary leveling. Precise leveling is generally used for the following objectives:

- First and second degree level network surveying
- Establishing benchmarks with high precision
- High and complicated engineering structures such as bridge, dams, skyscrapers
- Monitoring deformation and vertical movement near or alongside important structures, fault zones and engineering structures.

In this kind of leveling, the instrument accuracy is very high and the telescope magnification is between 40-50. In precise leveling, generally single-piece 3 m long invar staff is used. Invar staffs graduations are usually by 1 cm or 0,5 cm.

In precise leveling, in order to obtain high accuracy, below issues should be taken into account.

- Precise leveling must be done as double-run.
- Instruments should be established not to swing when the measurements occur.
- Staffs should be stayed on the staff metal base.
- The distance between instrument and staffs are equal and smaller than 35m to minimize errors of reading, sights should be kept short.
- In order to avoid effects of refractions, level instruments should be established as long as possible.
- In order to avoid staff starting point errors, the measurement should start and finish with the same staff.
- In order to avoid systematic errors effects, double-run measurements should be on the same route.
- Measurements should be done very early in the morning, late in the evening or cloudy weather. Leveling applications should not be done in the middle of the day and sunny days.
- Staffs should be supported with staff sustainers.
- With the contribution of tilting level, tabular level should be adjusted carefully at each staff reading.
- Staff metal base and bottom of the staff should be clean.
- In the staff readings, procedure is very important. First read back left (bl1) then forward left (fl1), then again forward right (fr2) and finish back right (br2) (Turkish Large Scale Map and Map Information Production Regulation (TLSMMIPR), 2005)

3.1.2. Errors in Leveling

In general, surveying applications do not accept errors which effect the results adversely. However, errors can not only be totally eliminated but also they can be included in acceptable tolerances. There are two types of errors which are effected leveling applications. These are;

- Systematic errors
- Incidental errors

The sphericity effect, symetric refraction, asymetric refraction, residual slope error, paralax error, level and staff which are not stable, inclined staff error are called as the systematic errors. Besides, the incidental errors are staff division average error, staff reading error, leveling average error, leveling line has different slope due to average refraction error and the target point distance are not equal.

3.1.3. Leveling Instrument in Terms of Accuracy

In leveling method, accuracy means 1 km double run in the leveling line which is measured standard deviation from the measurement differences.

The accuracy depends on the following significant attributes:

- Instrument
- Leveling staff plate
- Measurement methods
- Elimination of systematic errors in the measure time
- Enviromental effects such as atmospheric, underground *etc*.

Leveling instruments are categorized into 4 groups in terms of their accuracy:

1. Low accuracy leveling instrument (construction leveling instrument)
2. Middle accuracy leveling instrument

3. High accuracy leveling instrument
4. Very high accuracy leveling instrument

1. **Low accuracy leveling instrument**: Generally this type of instrument is used in construction domains, determination of elevation in the construction points, short connection leveling and basic cross section calculation. This type of instrument accuracy is very low ±10-20 mm. The telescope magnification is between 15-20 and sensitivity of bubble is 30″-60″.

2. **Middle accuracy leveling instrument:** Middle accuracy instrument generally used for the following area such as construction cases, new leveling benchmark construction between close area. The accuracy of this instrument is ± 5-10 mm and the telescope magnification is between 20-25 and lastly sensitivity of bubble is between 20″- 30″.

3. **High accuracy leveling instrument:** The high accuracy leveling instrument is used in the following purposes.
   - III. degree leveling measurement
   - Surface leveling
   - Volume calculation by cross section

   The accuracy is between ± 1-2 mm, telescope magnification is 25-30 and the sensitivity of bubble 10″- 30″.

4. **Very high accuracy leveling instrument:** This type of instrument is generally used for I. and II. order leveling network measurement. In addition, deformation measurement in bridges, dams and high construction is used, too. The accuracy is very high and ≤ 0,5 mm. The telescope magnification is between 35-50 and the sensitivity of bubble is 5″-10″.

3.1.4. Digital Level

Digital level is the most important instrument for the surveying engineering that can be regarded as a fusion of a digital camera and automatic level. Leica company produced the first digital level calling WILD NA 2000 in 1990. This level made the process by special bar-coded invar staff image with digital image processing or correlation method. Digital level structure can be regarded as the combination of digital camera and automatic level. (Figure 3.1).

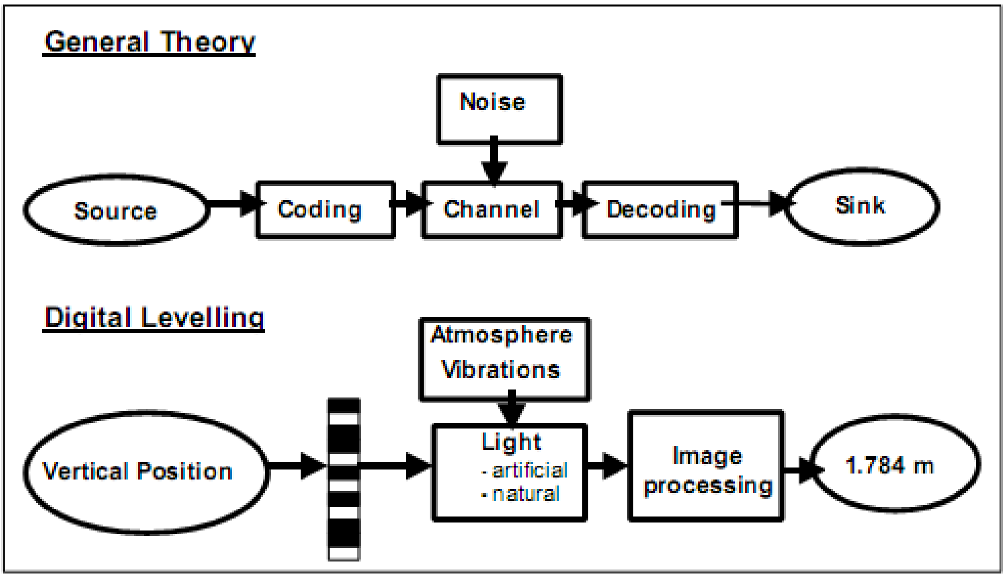

Figure 3.1. The information transfer of digital leveling (Ingensand,1999)

It has a telescope with upright image and a compensator to stabilise the line of sight. Additionally a position sensor coupled with the focus lens supplies a rough distance information. This refers to the Leica instruments only, the others operate without information of the focus-position. A tilt-sensor observes the compensator position and a beam-splitter guides part of the light to the CCD-sensor (Figure 3.2).

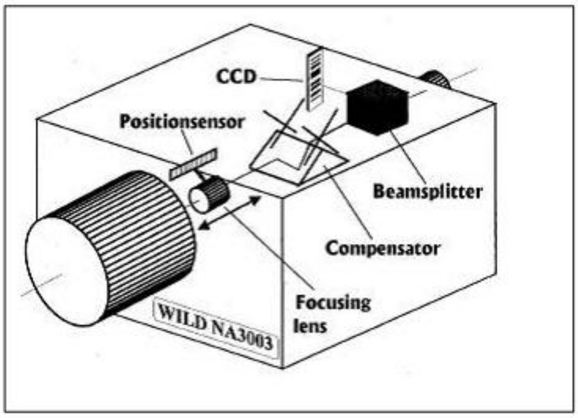

Figure 3.2. Basic optical design of today's digital level (Ingensand,1999)

The processor system is based on a microprocessor. The detector-diode array converts the bar-code image into an analog video signal of 256 intensity values.

3.1.4.1. Signal Analysis and Image Processing Methods of Digital Levels

The determination of the position by image processing is a combination of a radiometric processing and the detection of the egdes *ie*; black-white transition of the code elements (H. Ingensand, 1999) (Figure 3.3). Table 3.1 shows the latest digital level specification.

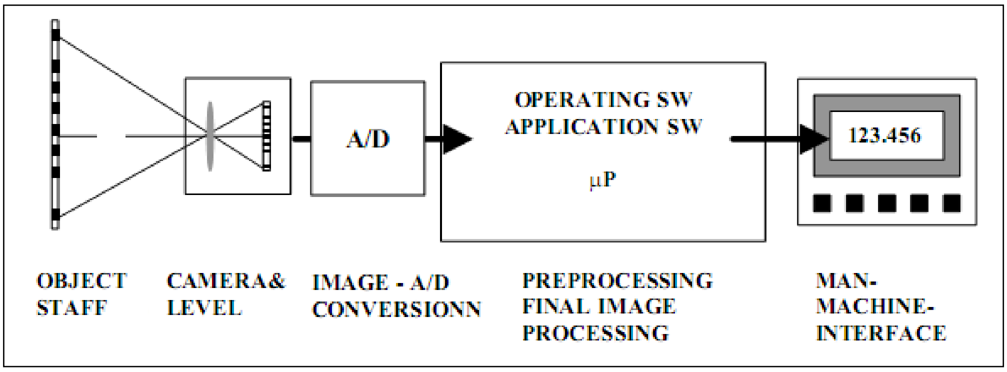

Figure 3.3. Data capture and processing (Ingensand,1999)

Table 3.1. Specification of digital levels

Instrument Feature	TOPCON DL101	TOPCON DL102	WILD NA3003	SOKKIA SDL30	LEICA DNA3	TRIMBLE DINI	ZEISS DINI10
Accuracy mm/km double run	0,4 mm invar staff	0,4 mm invar staff	0,4 mm invar staff	1,0 mm (0,7 mm ETHZ Fibreglass Staff)	0.3 mm with invar staff	0,3 mm with invar staff and 0.7 mm with invar staff	0,3 mm invar staff
Distance (resolution)	1cm	1cm	1cm	0.1 %*D	1 cm	25 mm	1cm
Measurement time	4sn	4sn	4sn	> 3sn	3 sn	3sn	4sn
Range	2-60 m invar staff	2-60 m invar staff	1,5-60 m invar staff	1,6-100 m standard staff	1.8-110 m	1.5-100 m. with invar staff	1,5-100 m invar staff
Data storage capacity	2400	2400	500	-	6000 meas.or 1650sta.	Up to 30000 with internal memory	2000
Field of view	no info	no info	2'	1' 20″	No info	2.2	minimum 30 cm
Weight including batary	2,8 kg	2,8 kg	2,5 kg	2,4 kg	2,8 kg	3,5 kg	3,0 kg
Operation time battery	10 hours	10 hours	8 hours	> 7 hours	12 hours	3 days	1 day
Display	2 lines	2 lines	2 lines	2 lines	8 lines	No info	4 lines
Compensator - Type -Accuracy -Working Range	Pendulum 0,3″ +- 15'	Pendulum 0,3″ +- 15'	Pendulum 0,3″ +- 15'	Pendulum ---- > +- 15'	Pendulum 0,3″ +- 10'	Pendulum 0,2″ , 0,5″ +- 15'	Pendulum 0,2″ +- 15'

3.1.5. Instruments Used in This Study

In this study, the precise leveling was made with high precision leveling instruments which are currently used by namely Topcon DL-101C with 3 m aluminium invar staff. Additionally, the invar staff was mono with barcode array. 2 staff sustainers and 2 staff metal base that were used in precise leveling both in 2009 and 2010.

The level instrument is capable of storing data by using PCMCIA standard memory card. The internal memory store up to 8000 levelled points. Data recording directly either internal memory or PCMCIA card is selectable. The accuracy of the instrument for 1 km double run 0,4 mm with invar staff. The instrument which was used in the study area shown in the Figure 3.4.

Figure 3.4. Topcon DL-101C

Besides, in 2009 the second leveling instrument was used in precise leveling which was called GeoMax ZDL 700 (Figure 3.5). However its feature written in its catalogue show that the accuracy is 0,7 mm per double run, the instrument could not give this accuracy. This staff was made of aluminium, the weather was always rough windy thus the instruments were too weak to stand vertical and stable. When all things taken into consideration GeoMax ZDL 700 was not suitable for precise leveling.

Figure 3.5. GeoMax ZDL 700

3.1.6. Leveling Network

In the study area, the precise leveling network with 3 benchmarks was established by the project team for the precise leveling study in 2009. Since these benchmarks are located along the roads, most of them are proned to disturbance due to expansion of roads or other infrastuctral developments. In order to overcome these obstacles, standard benchmarks were planted at a spacing of 0,5-2 km at secured places. The survey team used stainless steel pin to epoxied into the rock. These benchmarks are located along the fault zone. The new benchmarks are named Kaplica (KPLC), Huzur Sitesi (HZUR) and Doganbey (DBEY). The route between KPLC – HZUR is approximately 2800 m and between HZUR- DBEY is approximately 4700 m. The length of two benchmarks were too long thus the survey team planted three different level control points for both 2009 and 2010. Besides, the level control points which planted in 2009 and in 2010 are different. All benchmarks coordinates are shown in the Table 3.2.

KPLC benchmark is located along the road of Urkmez and Karakoc Thermal Spring within 2 km Karakoc Thermal Spring junction. The Kaplica benchmark was established on the rock near the road.

HZUR benchmark is located on Urkmez - Seferihisar road near 1 km Karakoc Thermal Spring junction. The benchmark was established on the rock near Huzur Sitesi turnout.

DBEY benchmark is located on Urkmez – Seferihisar road. The benchmark was established on the rock where is located near the road in the wood 300 m within Doganbey turnout. The figure 3.6 shows the leveling benchmarks.

Table 3.2. Coordinates of leveling benchmarks

Station	Station ID	Longitude(N) WGS84	Latitude (E) WGS84
Kaplica	KPLC	26° 54’ 27″	38° 05’ 07″
Huzur Sitesi	HZUR	26° 54’ 01″	38° 04’ 04″
Doganbey	DBEY	26° 52’ 18″	38° 04’ 37″

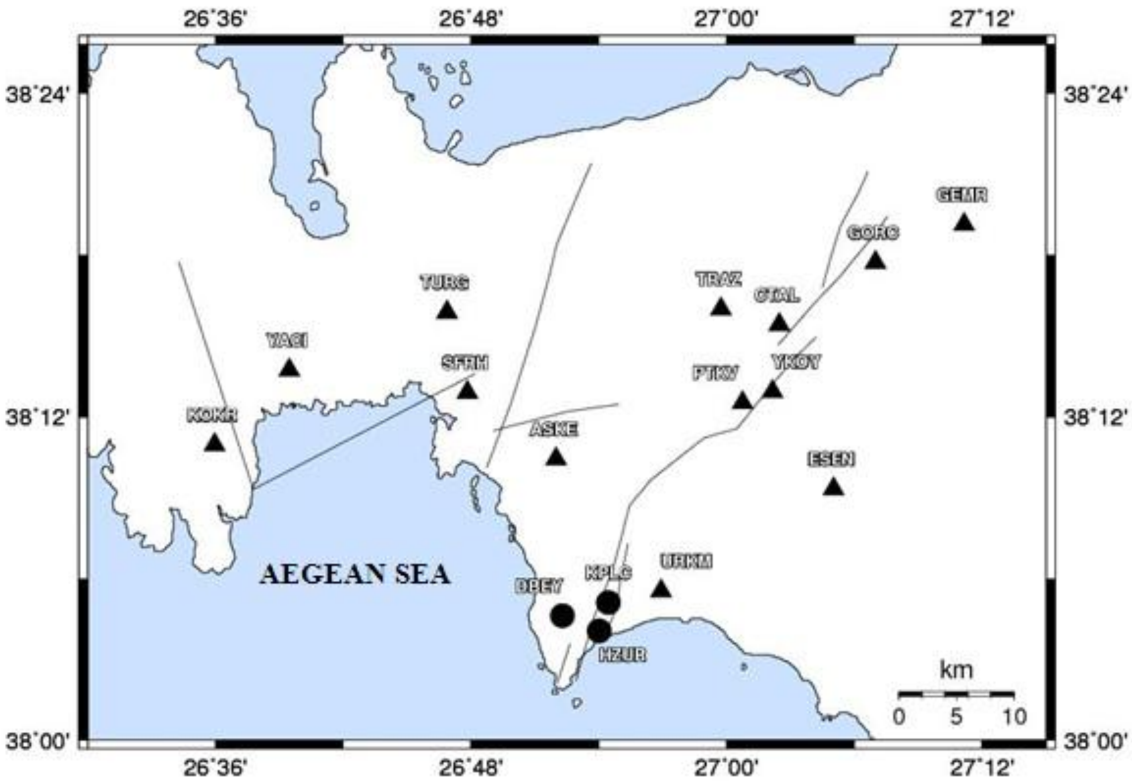

Figure 3.6. Working area with GPS points (triangles) and leveling benchmarks (circle)

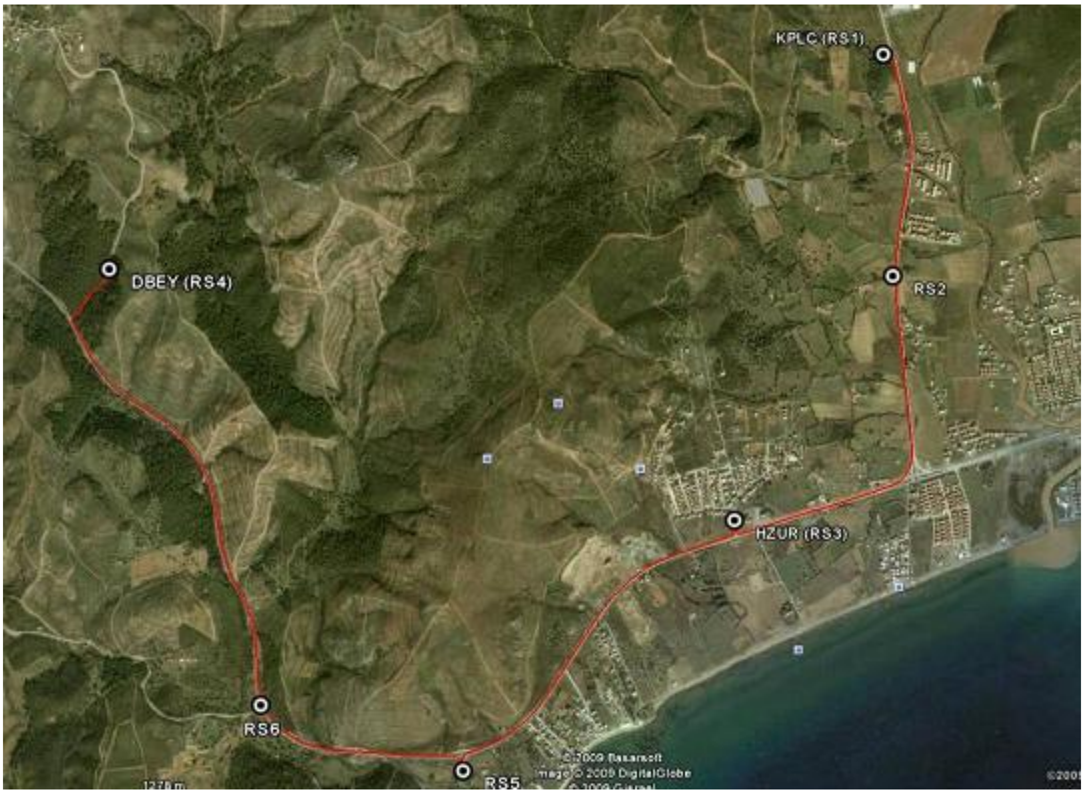

Figure 3.7. The leveling network route in 2009

3.1.7. Results of Leveling

For this type of leveling, 4 readings were taken that consists of two backsight and two foresight readings. The tolerance value is relied on the Turkish Large Scale Map and Map Information Production Regulation (TLSMMIPR) 2005.

The tolerance error in closure leveling for the second order leveling is

$$w(mm) \leq 12\sqrt{S(km)} \quad (1)$$

w (mm) : Error in closure leveling
S (km) : The length of leveling route

Putting all given and known parameters in the formula, the result was
$w\ (mm) \leq 12\sqrt{14,999227}$

w (mm) ≤ 46,474 mm. and the survey result was 19,97 mm for 2009.

Same procedure was made for 2010. The length was 14,646544 km. Putting all given and known parameters in the formula, the result was

w (mm) ≤ 12√14,646544

w (mm) ≤ 45,9249 mm and the survey result was 4.57 mm for 2010.

In 2009, the survey team identified three control points on the route. The survey team made precise leveling as double run in both 2009 and 2010. Table 3.3 shows the summary set of precise leveling in 2009. In case of KPLC points height being 100,00 m. for both 2009 and 2010, the results are shown in table 3.5.

Table 3.3. Summary set of 2009 leveling

Benchmarks	**1st run ΔH**	**2nd run ΔH**	**Mean ΔH**	**Height (m)**
Kaplica				100,0000
	-0,68492	0,68488	-0,68490	
Cesme				99,3151
	8,94442	-8,94615	8,94528	
Huzur sitesi				108,26038
	1,60695	-1,60126	1,60410	
Poligon				109,86448
	20,5736	-20,5687	20,57115	
Refuj				130,43563
	68,36527	-68,3542	68,35973	
Doganbey				198,79536

Table 3.4. Summary set of 2010 leveling

Benchmarks	**1st run ΔH**	**2nd run ΔH**	**Mean ΔH**	**Height(m)**
Kaplica				100,0000
	-0,69078	0,69231	-0,69155	
Cesme				99,30845
	8,94548	-8,94511	8,94530	
Huzur sitesi				108,25375
	0,67413	-0,67285	0,67349	
Viraj				108,92724
	3,30533	-3,30575	3,30554	
Fener				112,23278
	86,55560	-86,55463	86,55512	
Doganbey				198,78790

Table 3.5. Heights of benchmarks for 2009 and 2010

Benchmarks	**Height (m) 2009**	**Height (m) 2010**	**Height differences(m)**
KPLC	100,00000	100,00000	0,00000
HZUR	108,26038	108,25375	-0,00663
DBEY	198,79536	198,78789	-0,00747

When comparing the leveling results for 2009 and 2010, the summary of sets indicate that there is a collapse at HZUR and DBEY benchmarks.

Additionally, standard deviation of all data collected during the survey calculated for double run precise leveling measurements in 2009 and 2010. The table 3.6 indicates the results of accuracy criteria for the precise leveling as double run.

Table 3.6. Accuracy criteria of precise leveling

Campaign Year	**2009**	**2010**
n (number of f-b)	5	5
Pdd	106,117551	4,533
S_0^2	10,611	0,4531
$S_{0\ (mm)}$	3,2575	0,6732
$S_{AH\ (mm)}$	6,3077	1,2891

The first precise leveling observation was performed in August 2009 (Figure 3.7) and the second precise leveling observation was performed in May 2010 (Figure 3.8). The interval of two observations were 9 months. Both observations were conducted using TOPCON DL101 precise level. When looking at the results for both year, between KPLC and HZUR sites and between KPLC and DBEY sites the vertical displacement were large and collapse was observed. The value of the collapse for KPLC and HZUR is 6.6 mm and for KPLC and DBEY is 7.4 mm for 9 months.

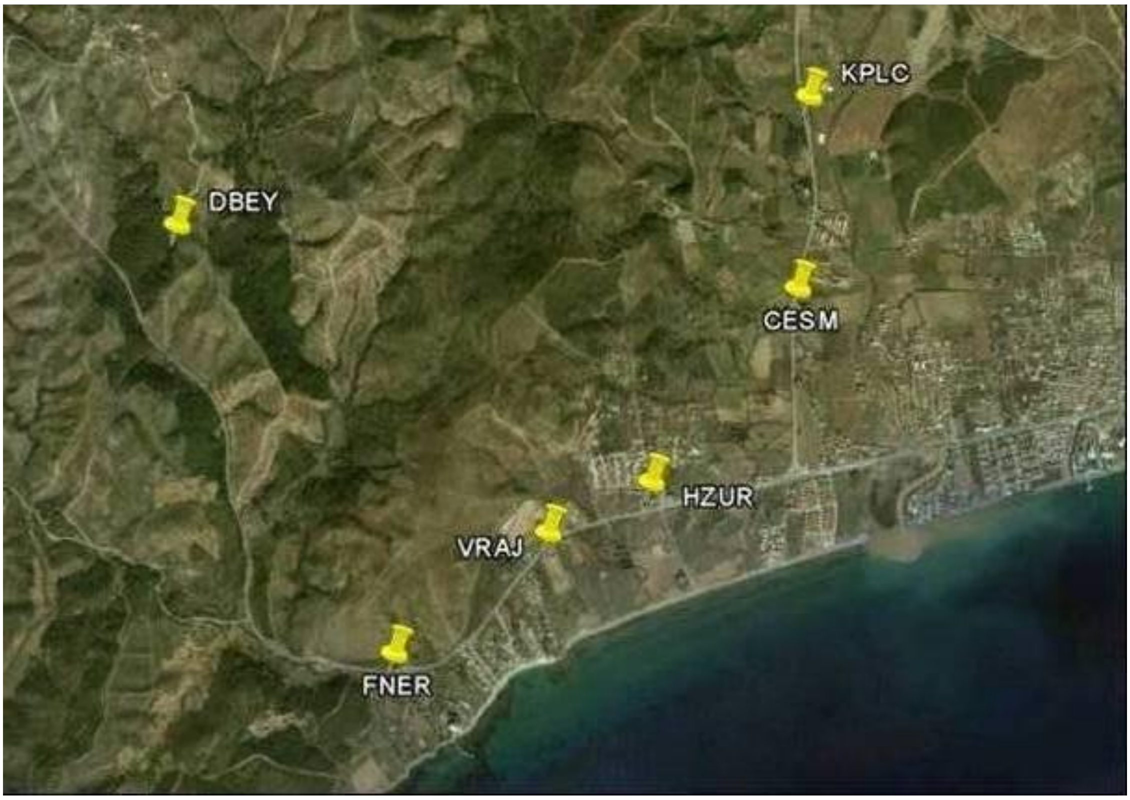

Figure 3.8. The leveling network route in 2010

3.2. GPS (Global Positioning System)

The Global Positioning System (GPS) is a satellite-based positioning system which determining positioning on land, on sea and in space with very high accuracy. The GPS satellites provide all-weather, worldwide 24-hour position and time information. GPS served the purpose of the military and national security in the United States initially.

GPS includes 3 segments which are space, control and user. The space segment is consisting of the orbiting GPS satellites and space vehicles. These vehicles are located 20200 km above the Earth's surface and there are at least 24 satellites with 6 orbital planes. The control segment includes a worldwide network of tracking stations, with a master control station in the United States at Colorado Springs, Colorado. The main objective of this segment is to track the GPS satellites to determine and predict satellite locations, system integrity, behaviour of satellite atomic clocks, atmospheric data, the satellite almanac and other considerations. The last segment is the user segment which consists of both users: civilians and military. The aim of user segment is to determine the users position anywhere on the Earth. A user can receive the GPS signals with a GPS receiver connected to a GPS antenna.

GPS measurement is used for numerous surveying and mapping applications. These applications mainly are:

- Crustal deformation studies
- Cadastral surveys
- Control surveys
- Topographic map generation such as contour maps, cross sections and profiles
- Base map for Geographic Information Systems (GIS)

GPS has a great deal of advantages over conventional surveying techniques.

- No line of sight between station is required
- Faster than conventional method
- Highly accurate
- Providing results in a unified world coordinate system
- Gives three-dimensional coordinates

High-precision GPS has been used since the mid-1980s for measuring relative tectonic plate motions, isostatic adjustment, motions along and across faults, and volcanic motions. From these measurements, researchers have calculated strain rates, mantle viscosity, locking depths of faults, and more. GPS can also be used to map and to navigate back to sample locations, to measure glacier velocities, and to monitor landslides (UNAVCO campaign GPS GNSS handbook).

GPS is a beneficial way to determine the deformation all around the world with high accuracy and precision. GPS has many advantages for detection of deformation such as;

- Easy usage
- Not depend on the weather condition
- Can work both day and night
- Provide high accuracy
- Points should not see each other.

The main reason for the growth in crustal deformation monitoring with GPS, the technique puts an inexpensive, precise geodetic tool in the hands of scores of university and other research groups. Unlike other space geodetic techniques, such as Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) requiring large facilities and expensive budgets, GPS measurements can be collected by small groups with logical and small budgets.

Nowadays, GPS applications in geodynamics and study on crustal monitoring has become very successful. The main needs for the analysis of crustal deformation are continuous and accurate information of relative position. This type of information is necessary in order to process the crustal deformation and make long term earthquake estimation in these regions.

3.2.1. Fundamentals of GPS Positioning

Positioning with GPS is relied on triangulation method from GPS satellites. Each of 24 GPS satellites transmit the unique code. The receiver generates the same codes at the same time as the satellites; by measuring the offset between the code generated and the code received, the receiver can determine the time the signal took to travel and therefore calculate the rough distance to each satellite (UNAVCO campaign GPS GNSS Handbook). The radio signals transmitted by the GPS satellites. Every GPS satellites has 2 radio signals with point positioning aims which 1575,42 Mhz referred to L1 (Link 1) and 1227,60 Mhz referred to L2 (Link 2).

GPS has two different frequencies due to two significant aims. Firstly, if there is a connection problem with L1 frequency, L2 frequency can be replaced with L1 frequency. Secondly with the help of even frequency attributes, to make a correction ionosphere. Pseudo Random Noise (PRN) code and navigation message are modulated on L1 carrier phase frequency. These PRN codes are Coarse/Acquisition (C/A) code and Precise (P) code. Only one PRN code which is the P code and navigation message is modulated on L2 carrier phase frequency. C/A code is 1 Mhz PRN code (figure 3.9). The main objective of selection C/A code period is to lock on the satellite in a short time. P code is modulated on both L1 and L2 frequencies.

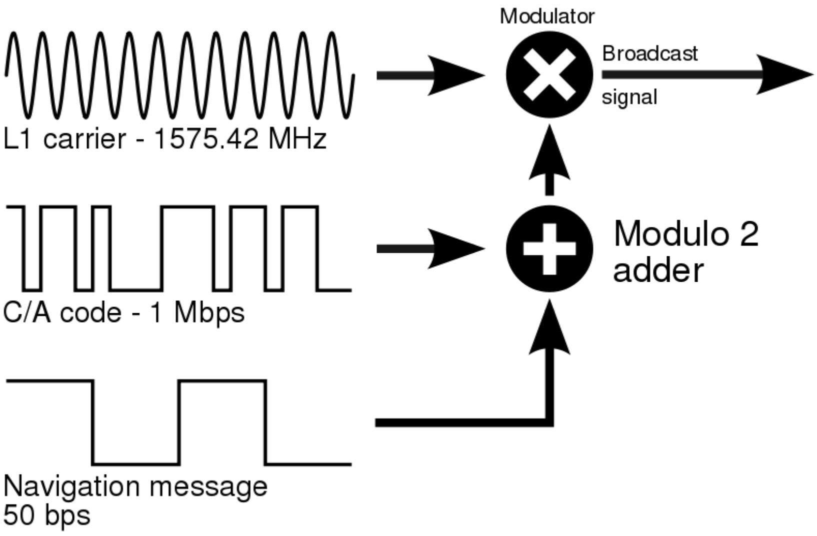

Figure 3.9. Visualization of the carrier frequency and the codes
(UNAVCO campaign GPS GNSS Handbook)

3.2.2. GPS Surveying Methods

Several methods are used to collect high precision GPS data. The specific method used relied on several factors which are survey aims, desired precision, available equipments and logistics of fields. The following table 3.7 shows the features of the most common GPS survey methods.

Table 3.7. Most common GPS survey methods

Survey style	Accuracy	Occupation time	Applications
Continous	< 0.5 cm	Months or more	Crustal Deformation, Geophysics, Reference stations
Static	0.5- 2.5 cm	Hours to day	Crustal Deformation, Geodetic Control, Very Long Baseline Surveys, Geophysics
Rapid Static	1-3 cm	Minutes	Short baseline surveys, Glaciology
Kinematic	1-5 cm	Seconds	Short baselines, Closely spaced points, Vehicle positioning, Feature surveys, GIS, Mapping and Navigation (RTK only)

Static surveys are regional, sub-cm precision GNSS surveys with portable equipment and are the standard campaign data collection method for crustal deformation surveys. They typically involve occupying each point for several days to get the highest possible accuracy. Collect at least 6 hours of simultaneous data per day for processing and repeat benchmark occupations if possible (UNAVCO Campaign GPS_GNSS Handbook).

3.2.3. GPS Error Sources

Although, GPS is the most advance, accurate and precise global position and navigation system, it has also some drawbacks like other systems. GPS errors are listed as follows:

- Satellite ephemeris errors
- Satellite clock errors
- Ionospheric effect
- Tropospheric effect
- Multipath effect
- Antenna phase center error

- Ambiguity and cycle slips
- Selective avability

3.2.4. GPS Instruments

In this study, GPS is the second technique in order to monitor crustal movement. GPS campaigns were carried out by high precision GPS systems include various separate instruments in 2009 and 2010.

These are:

- Receiver such as Trimble 4000 SSI and Trimble 4000 SSE, Trimble 5700
- Power such as 40 A Power, 12 A Power, Solar panel
- Antenna such as Permanent L1/L2, Compact L1/L2, Choke ring
- Tripod
- Tribrah
- Car cable
- Antenna cable
- Compass, tape line and monumentation records with file.

The equipment used for GPS surveys is designed for use in most weather conditions and is fairly rugged. However, as with all electronics the equipment should be handled with care. The most important hardware in GPS surveying are receiver and antenna system. These systems, their features and capacities affect all procedure directly from surveying optimization to all data processing. Receiver is the most significant instrument for GPS surveying. In general, all complicated receivers record satellite signals, make signal processing, transform for real time applications and calculate the necessary information for navigation. The 4000 SSI and 4000 SSE is a dual frequency GPS receiver employed in geodetic studies, photogrammetric applications and crustal movement monitoring. The Trimble 5700 GPS receiver is not only an advanced, but also easy-to-use, surveying instrument that is rugged and versatile enough for any job. 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.

Horizontal = ± 5mm + 0,5ppm

Vertical= ± 5mm +1ppm

GPS antenna is the further significant component and instrument of GPS surveying. The antenna task is to receive signals from satellite and sort out the multipath effect from the signal. The energy which are broadcasting from the satellites in electromagnetic waves, is transformed into electric current which is processed by electronic circuit in the receiver. Figure 3.10 shows the GPS equipments at PTKV point in 2010.

Figure 3.10. The equipments are at PTKV point

3.2.5. GPS Softwares

In GPS data processing, two types of software are used; commercial and scientific. Commercial software is used for practical engineering applications. Table 3.8 shows the commercial GPS softwares and their companies.

Table 3.8. Commercial GPS softwares and companies

Company Name	**Software Name**
Topcon	Topcon Tools
Trimble Navigation	TGO
Ashtech	AOS
Leica	GeoOffice

Scientific software is generally used for determination of crustal movement, establishment of fundamental GPS country network and develop reference systems (Table 3.9).

Table 3.9. Scientific GPS softwares and institutes

Software Name	**Supported centers**
Bernese	AIUB
GAMIT-GLOBK	MIT-SIO
GIPSY-OASIS II	JPL(NASA)
PAGE5	NOAA
GEONAP	University of Hannover
MURO.COSM	University of Texas-Van Martin System
DIPOP	University of New Brunswick

The main difference between commercial software and scientific software is that the applications used in scientific software are automated in commercial software. Scientific software is more complicated and less user friendly compared to commercial software. During data processing with scientific software, when a parameter is altered or errroneous process step is used, invalid results will be displayed (Yildiz F., Kahveci M., 2009). In this study, GAMIT/GLOBK scientific software was selected in order to process GPS data. Since GAMIT and GLOBK are a comprehensive suite of programs for analyzing GPS measurements primarily to study crustal deformation.

3.2.5.1. GAMIT – GLOBK

The codes for processing GPS observations were developed at MIT in the 1980's by Thomas Herring, Robert W. King, Simon C. McClusky.

GAMIT and GLOBK are comprehensive and complicated programs to analyze and process GPS measurements in order to determine crustal deformation primarily.

GAMIT is a collection of programs used for the analysis of GPS data by using the GPS broadcast carrier phase and pseudorange observables to estimate three-dimensional relative positions of ground stations and satellite orbits, atmospheric zenith delays, and earth orientation parameters. The software is designed to run under any UNIX operating system supporting X-Windows.

GLOBK is a Kalman filter whose primary purpose is to combine various geodetic solutions from the processing of primary data from space geodetic or terrestrial observations. It accepts as data or quasi-observations the estimates and associated covariance matrices for station coordinates, earth rotation parameters, orbital parameters, and source position generated from analyses of the primary observations. These primary solutions should be performed with loose a priori uncertainties assigned to the global parameters, so that constraints can be applied uniformly in the combined solution.

3.2.6. GPS Campaigns in 2009 and 2010

In 2009, KOERI Geodesy Department started to observe displacements along Tuzla Fault in Izmir by using GPS technique. The coordinates and names of GPS stations are given in the Table 3.10.

The tectonic significance and the GPS requirements were taken into account while selecting locations of stations. From the reconnaissance to the analysis of data collected, including observation, planning and measurement method, each step of GPS campaigns has basic importance in GPS geodynamics. GPS points possibly were established in optimum number and gradually in distance 1, 2, and 6 km away from active faults. GPS points were required not to be affected by surface movement such as landslide and transportation possibilities and the owners of the lands were also considered. GPS sites were placed into bedrock using high quality geodetic monuments. Selection of session lengths, receiver and antenna distribution are necessary in order to avoid the systematic biases (Ozener H; 2010).

Table 3.10. The coordinates of GPS stations

Station	**Station ID**	**Latitude^o (E) WGS - 84**	**Longitude^o(N) WGS - 84**
Askeriye	ASKE	38^o 10’ 27″	26^o 51’ 60″
Catalca	CTAL	38^o 15’ 26″	27^o 02’ 29″
Esenli	ESEN	38^o 09’ 21″	27^o 05’ 01″
Gaziemir	GEMR	38^o 19’ 08″	27^o 11’ 09″
Gorece	GORC	38^o 17’ 45″	27^o 06’ 60″
Huzur Sitesi	HZUR	38^o 04’ 04″	26^o 54’ 01″
Kokar	KOKR	38^o 10’ 59″	26^o 35’ 58″
Kaplica	KPLC	38^o 05’ 07″	26^o 54’ 27″
Petek Vadisi	PTKV	38^o 12’ 33″	27^o 00’ 45″
Seferihisar	SFRH	38^o 12’ 56″	26^o 47’ 50″
Tirazli	TRAZ	38^o 16’ 04″	26^o 59’ 34″
Turgutlu	TURG	38^o 15’ 54″	26^o 46’ 53″
Urkmez	URKM	38^o 05’ 33″	26^o 56’ 55″
Yagcilar	YACI	38^o 13’ 45″	26^o 39’ 28″
Yenikoy	YKOY	38^o 12’ 57″	27^o 02’ 10″

Static GPS observation was performed in this study. The sub-cm precision GPS survey is the standard data collection method for crustal deformation measurements. The first GPS campaign was accomplished in August 2009 and the second GPS campaign was performed in June 2010. 10-hour/day observation was performed at each station for two days. Both campaigns were conducted using by Trimble 4000 SSI, Trimble 4000 SSE and Trimble 5700 receivers. Three types of antenna were used in observations: Permanent L1/L2 Antenna,

Compact L1/L2 Antenna and Choke ring Antenna. Figure 3.11 shows the GPS equipment and site of SFRH point in 2009. Figure 3.12 shows the GPS equipment at TURG point in 2010.

Figure 3.11. A view from the GPS campaign at SFRH point

Center).

Figure 3.12. A view from the GPS campaign at TURG point

3.2.7. GPS Data Processing

The processing of the GPS data was performed with the GAMIT (King and Bock, 2004) / GLOBK (Herring, 2004) software package. Following steps were taken during the process:

- Each campaign was processed using the International Terrestrial Reference Frame ITRF_2005.
- Precise final orbits by the International GNSS Service (IGS) were obtained in SP3 (Standard Product 3) format from SOPAC (Scripps Orbit and Permanent Array Center).
- Earth Rotation Parameters (ERP) came from USNO_bull_b (United States Naval Observatory_bulletin_b).

- 16 stations from IGS global monitoring network were included in the process. These IGS stations were VILL, MADR, IRKT, ARTU, ZECK, METS, JOZE, BOR1, GRAZ, WTZR, ONSA, NYAL, ZIMM, GRAS, KOSG, BRUS.
- The 9-parameter Berne model was used for the effects of radiation and the pressure.
- Scherneck model was used for the solid earth tide and the ocean tide loading effects.
- Zenith Delay unknowns were computed based on the Saastamoinen a priori standard troposphere model with 2-h intervals.
- Iono-free LC (L3) linear combination of L1 and L2 carrier phases was used.
- The model, which depended on the height, was preferred for the phase centres of the antennas.
- Loosely constrained daily solutions obtained from GAMIT were included in the ITRF_2005 reference frame by a 7 parameters (3 offset–3 rotation–1 scale) transformation with 16 global IGS stations.

The ionospheric delay can be removed from the pseudorange data with a similar operation on the L1 and L2 pseudoranges. Ionosphere-free observations can be combined into single, double or triple differences and processed in the same manner as single frequency data.

In order to determine GPS points coordinate in ITRF system every GPS campaigns, 16 IGS stations from Europe are included to the calculation.

It is usually known that the atmospheric effects on the GPS signals are the most effective spatially correlated biases. GPS positioning results derived from the use of three different standard tropospheric models, namely the Saastamoinen model, Hopfield model and Simplified Hopfield model. The Saastamoinen and the Hopfield models tends to produce more reliable results than the use of the Simplified Hopfield model.

3.2.8. GPS Data Processing Results

Horizontal GPS velocities in the Eurasia-fixed reference frame and 1-sigma uncertainties plotted with 95% confidence ellipses are shown in Figure 3.13. RHO is the correlation coefficient between the E (east) and N (north) uncertainties. Table 3.11 shows the values which were taken during the two GPS campaigns in the study area.

Table 3.11. Velocities in the region determined by two GPS campaigns

Site	**Lon. (°)**	**Lat. (°)**	**E_{vel} (mm/year)**	**N_{vel} (mm/year)**	**E_{sig} (mm/year)**	**N_{sig} (mm/year)**	**RHO**
GEMR	27.186	38.319	-19.79	-7.90	2.08	2.34	0.013
GORC	27.117	38.296	-15.31	-5.33	1.90	2.11	-0.064
ESEN	27.084	38.156	-22.36	-13.28	1.76	1.88	-0.015
CTAL	27.041	38.257	-22.65	-15.19	2.60	3.16	-0.076
YKOY	27.036	38.216	-16.47	-12.50	2.02	2.22	-0.093
PTKV	27.012	38.209	-14.66	-15.50	2.20	2.45	-0.012
TRAZ	26.996	38.267	-20.09	-10.00	1.96	2.24	0.008
URKM	26.949	38.092	-18.00	-17.38	1.94	2.14	-0.032
KPLC	26.907	38.085	-20.61	-15.51	2.11	2.35	0.009
HUZR	26.900	38.068	-17.41	-20.49	1.94	2.13	0.016
ASKE	26.867	38.174	-26.72	-14.73	1.99	2.20	-0.044
SFRH	26.797	38.215	-15.09	-18.81	1.87	2.04	-0.016
TURG	26.781	38.265	-25.88	-12.84	1.85	2.01	0.006
YACI	26.658	38.229	-18.87	-13.79	1.96	2.22	0.029
KOKR	26.599	38.183	-17.56	-12.15	2.03	2.25	0.010

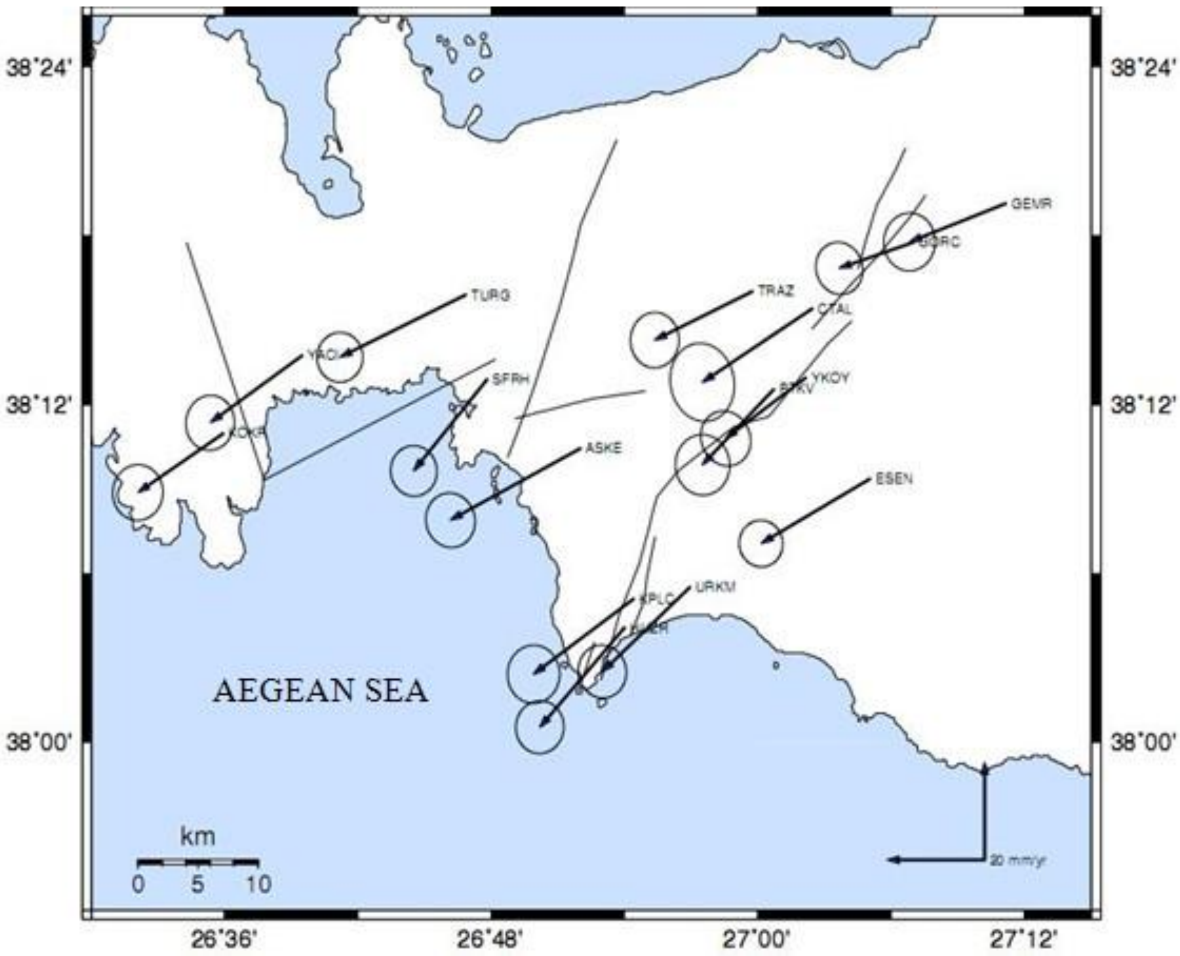

Figure 3.13. Horizontal GPS velocities relative to Eurasia - fixed reference frame (ellipses are at 95% confidence level)

4. DISCUSSION AND CONCLUSION

The purpose of this study is to determine the movements along Tuzla Fault. In this study, the deformations of Tuzla Fault was investigated using GPS and precise levelling data. Additionally, leveling results are analyzed by least squaress adjustment method and GPS results are compared with other studies in the same area.

A well designed local geodetic network with 16 new stations has been established before carrying out the measurement campaigns. The GPS campaigns were carried out at 15 stations. As DBEY site was planned only to be measured in precise leveling campaigns, so it was not included in GPS measurement. The deformation measurements of Tuzla Fault is carried out by two different measurement methods. The precise leveling campaigns are performed in August 2009, May 2010 and the GPS campaigns are carried out in August 2009, June 2010.

Furthermore, the least squares adjustment method which is used to analyze precise leveling results and former space geodetic study is mentioned in this section.

4.1. Analysing Leveling Result by Least Squares Adjustment

The domain or structure which is subject to deformation is generally presented, planted subsequent points. The point clusters are transformed to geodetic networks and these networks are generally treated as local networks.

The control networks are established in order to determine the deformation (Erol, 2008; Ayan, 1982; Ayan, 1981). The control networks are generally compromised with 3 different feature points. These are; deformation (subject) points, stable reference points and orientation points. Deformation points are selected from the area where the maximum and minimum deformations are anticipated. In order to determine the deformation in the area or structure, the geodetic control network measurements are repeated. Deformations are generally computed and determined via conventional spatial geodetic techniques in terms of static models by using at least two campaign analyses.

This aspect has 3 steps. These steps are;

- Global test
- Adjustment by least squares method
- Explication the deformation between two campaigns with geometric method for each measurement in every surveying campaign.

In this study, global test is used to determine the deformation by adjustment methods.

4.1.1. Global Test Application

In the first step, the measurements should be obtained from different campaigns at t_1 and t_2 time. These measurements should be adjusted with free adjustment methods seperately. Additionally, for both two different campaign adjustment, approximate coordinates should be taken identical. For both two campaign adjustment, some model tests should be applied and outliers should be eliminated.

In the second step, global congruency test should be performed in order to determine the network points which are stable between the interval of $\Delta t = t_2 - t_1$. Before the application of global congruency test, a set of adjustment and calculations should be performed in two analyses. These calculations are;

- A posteriori variance value which should be obtained from the adjustment for both two campaigns should be tested to null hypotesis ($H_0 = S_{01}^2 = S_{02}^2$)
- Should be tested by F test
- Should be proved by the two variance values' hope values should be equal to each other.

If displacement or shape shift occurs in the network at the end of global congruency test, deformation determining and localization methods would be applied as a third step (Erol, 2008). In order to determine geodetic network points' displacement vectors between campaigns, coordinate unknowns should be calculated from the formulas below.

$$l_1 + v_1 = A_1 x_1 \quad \sum_{x1} = \sigma_{01}^2 Q_{l1} \tag{2}$$

The coordinate unknowns differences should be tested as a zero value or not. Then H_o null hypothesis is establihed.

$$H_o = E(\underline{x}_1) = (\underline{x}_2);$$
$$H_o = \underline{x}_1 - \underline{x}_2; \tag{3}$$
$$H_o = d = \underline{x}_2 - \underline{x}_1 = 0$$

In order to be able to test data with null hypothesis, Ω_1 , s_{o1}^2 values should be calculated for each point by using the formulas below.

$$\Omega_1 = v_1^T P_1 v_1 \tag{4}$$
$$s_{o1}^2 = \Omega_1 / f_1$$

with the help of $f_1(n_1 - u_1 + d_f)$ degree of freedom, T_G test value is calculated for global test. T_G test value is calculated from

$$\Omega_0 = \Omega_1 + \Omega_2;$$
$$f_0 = f_1 + f_2; \tag{5}$$
$$r = f_G - f_0;$$
$$T_G = ((\Omega_G - \Omega_0)/r)/(\Omega_0/f_0)$$

Then T_G test value is compared with Fischer distribution (F_r) value and if $T_G > F_r$,fo, 1-α the network has been deformed from t1 to t2 and the null hypothesis is rejected. In this case, the next step is to locate the deformation.

4.1.2. Determining Deformation and Localization

In order to determine which points have significant and logical movement at the Δt time interval. This procedure should be calculated for each point seperately with the formulas below.

$$d = x_2 - x_1 \quad s_o^2 = \Omega_o / f_o \quad T_H = d^t Q_d^+ d / r s_o^2 \quad Q_d = Q_{x1} + Q_{x2} \tag{6}$$

T_H test value is compared with *threshold* value which is taken from Fischer distribution with fo and S=1-α =0.95 parameters. Then if $T_{F1} > F_r$,fo, 1-α , the movement in this region, at the point indicate that it is significant. The point which has the max test value is in charge of deformation at the end of global test application. Global test is repeated until there is no deformation at the point.

In this study, the adjustment was performed via global test for both 2009 and 2010 years.

First of all, global test is performed with 3 benchmarks. Then variance and covariance matrices are computed and variance-covariance matrices are denoted by Q_{dd}. After calculating variance - covariance matrices, the second step is to determine localization. Localization calculation should continue when there is no deformation in the network. Thus first localization is made for KPLC, HZUR, CESME and DBEY benhcmarks. The first localization results indicate that there is a deformation in the network and the point which had the max test value is in charge of deformation, at the end of global test application is HZUR point. In order to eliminate the deformation, HZUR point is subtracted from the localization process. After that, localization calculation continued. Former procedure and also calculations are repeated again for KPLC, CESME and DBEY benchmarks. At the end of the localization, still there was deformation and CESME point was in charge of the deformation so CESME point is subtracted from the calculation. In the last localization calculation, there is no deformation in the network. Additionally, deformation value is denoted by *dt*. The deformation value for KPLC benchmark is 0.000 mm., HZUR benchmark is 6.700 mm., CESME benchmark is 7.100 mm. and DBEY benchmark is 2.500 mm. Table 4.1 and table 4.4 indicate the adjustment report for 2009 and 2010. Table 4.2 and table 4.5 show the adjustment report for all benchmarks in 2009 and 2010. Table 4.3 and 4.6 show the adjusted heights and standard deviation for all benchmarks in 2009 and 2010 measurements.

Table 4.1. Adjustment report for 2009

Number of points	6
Number of Observations (n)	10
Number of Unknows (u)	6
Datum Defekt (d)	1
Degrees of Freedom (n-u+d)	5
vTpv	0.410
Apriori St.Dev (so)	0.602 cm
Apostteriori St.Dev (mo)	0.286 cm
Test value (T)	4.416
Table value (q)	7.146

Table 4.2. Adjustment report for all benchmarks in 2009

Points	Approximate Heights (m)	Adjusted Unknowns [dh (cm)]
KPLC	100.0000	-0.01
CESME	99.3151	-0.01
HZUR	108.2608	-0.01
REFUJ	109.8634	0.00
PLGN	130.4332	0.01
DBEY	198.7901	0.01

Table 4.3. Adjusted heights and standard deviation for all benchmarks in 2009

Points	Adjusted Heights (m)	Standard Deviation [mh (cm)]
KPLC	99.9999	0.22
CESME	99.3150	0.15
HZUR	108.2607	0.12
VRAJ	109.8634	0.12
FENER	130.4333	0.17
DBEY	198.7902	0.20

Table 4.4. Adjustment report for 2010

Number of points	6
Number of Observations (n)	10
Number of Unknows (u)	6
Datum Defekt (d)	1
Degrees of Freedom (n-u+d)	5
vTpv	0.036
Apriori St.Dev (so)	0.602 cm
Apostteriori St.Dev (mo)	0.085 cm
Test value (T)	50.208
Table value (q)	7.146

Table 4.5. Adjustment report for all benchmarks in 2010

Points	Approximate Heights (m)	Adjusted Unknowns [dh (cm)]
KPLC	100.0000	0.27
CESME	99.3151	-0.40
HZUR	108.2608	-0.44
VRAJ	108.9272	0.27
FENER	112.2328	0.26
DBEY	198.7901	0.04

Table 4.6. Adjusted heights and standard deviation for all benchmarks in 2010

Points	Adjusted Heights (m)	Standard Deviation [mh (cm)]
KPLC	100.0027	0.07
CESME	99.3111	0.05
HZUR	108.2564	0.04
VRAJ	108.9299	0.04
FENER	112.2354	0.06
DBEY	198.7905	0.07

Precise leveling route is approximately 7500 m. and double run method is used. The value of the vertical displacement for KPLC and HZUR is - 6.6 mm and for KPLC and DBEY is -7.4 mm for 9 months. The least squares adjustment method results indicate that there is a deformation in the leveling network. As comparing of two different methods for the leveling measurements, there is a consistency for the leveling results.

4.2. Previous GPS Study

According to Aktug and Kilicoglu (2006), velocity vectors in the area change between 20mm/yr to 30mm/yr (Figure 3.14). Velocity vectors are calculated with respect to Eurasia plate, in ITRF_2000 velocity field. Extension rate along Tuzla Fault is maximum in the region and confirms its active state.

In this study, velocity vectors, which have been computed by GPS measurements results, are between 21mm/yr to 25mm/yr (Table 4.7). The velocity vectors are calculated with respect to Eurasia plate, in ITRF_2005 velocity field. The obtained results in this study indicate that the same results obtained by Aktug and Kılıcoglu 2006

Table 4.7. Velocities in the region obtained from two GPS campaigns

(Aktug and Kilicoglu., 2006)

Site	Lon. (°)	Lat. (°)	E_{vel} (mm/year)	N_{vel} (mm/year)	Esig (mm/year)	N_{sig} (mm/year)	RHO
AKCP	27.863	38.485	-20,39	-15,74	0.13	0.15	0.10
AKGA	27.873	39.006	-22,73	-10,69	0.28	0.34	0.00
ARMT	26.712	38.393	-18,45	-20,12	0.46	0.58	0.13
AVCI	27.566	37.695	-20,52	-21,04	0.16	0.19	0.06
AYKA	26.700	39.311	-21,49	-11,79	0.19	0.22	0.15
BAYO	27.308	38.711	-20,95	-14,7	0.11	0.12	0.12
BIST	27.181	38.342	-20,03	-15,33	0.46	0.56	0.16
BLKV	26.601	38.440	-19,88	-18,96	0.66	0.79	0.16
CAKI	27.813	37.698	-21,5	-19,9	0.16	0.18	0.06
CALI	27.639	38.346	-20,39	-13,4	0.54	0.66	0.22
CEIL	26.385	38.311	-20,54	-21,14	0.11	0.12	0.13
CKOY	26.233	38.288	-20,36	-22,6	0.58	0.72	0.14
DBEY	26.830	38.137	-21,67	-26,83	0.78	0.92	0.11
DIKI	26.885	39.010	-21,37	-14,12	0.30	0.39	0.03
DOGA	27.181	37.627	-18,06	-22,83	0.16	0.18	0.06
GMDR	26.997	38.068	-21,93	-18,52	0.62	0.71	0.15
GOKT	27.165	38.597	-23,81	-13,28	0.17	0.20	0.04
HALP	27.675	38.677	-20,9	-12,57	0.14	0.16	0.07
KABU	26.470	38.671	-21,56	-18,63	0.37	0.43	0.07
KINI	27.316	39.024	-20,51	-12,49	0.42	0.47	0.04
KKLR	27.443	38.280	-19,54	-13,88	0.64	0.76	0.14
KMLP	27.357	38.388	-9,25	-17,16	2,78	3,17	0.12
KNRL	27.127	38.209	-24,78	-18,08	0.67	0.81	0.13
KOB1	27.112	39.244	-21,73	-12,02	1,20	0.80	0.17
MNSA	27.455	38.567	-20,03	-15,04	0.56	0.73	0.17
PAYM	26.926	38.317	-17,73	-11,4	0.72	0.81	0.06
SFRH	26.821	38.207	-22,12	-19,88	0.33	0.40	0.06
SOKE	27.486	37.818	-20,5	-18,81	0.39	0.40	0.06
TIRE	27.776	38.056	-21,88	-13,15	0.16	0.18	0.06
UADA	26.722	38.472	-16,69	-20,4	0.63	0.77	0.14
UCTP	27.613	38.263	-22,61	-15,99	0.35	0.44	0.01
YAMA	27.131	38.488	-23,81	-15,35	0.11	0.13	0.11
YENF	26.791	38.741	-22,99	-16,85	0.10	0.12	0.14
YKOY	27.073	38.798	-24,21	-10,24	0.84	0.95	0.12
YUNT	27.211	38.935	-18,22	-11,17	0.62	0.74	0.14
ZEYT	26.497	38.205	-22,03	-18,9	0.88	1,04	0.06

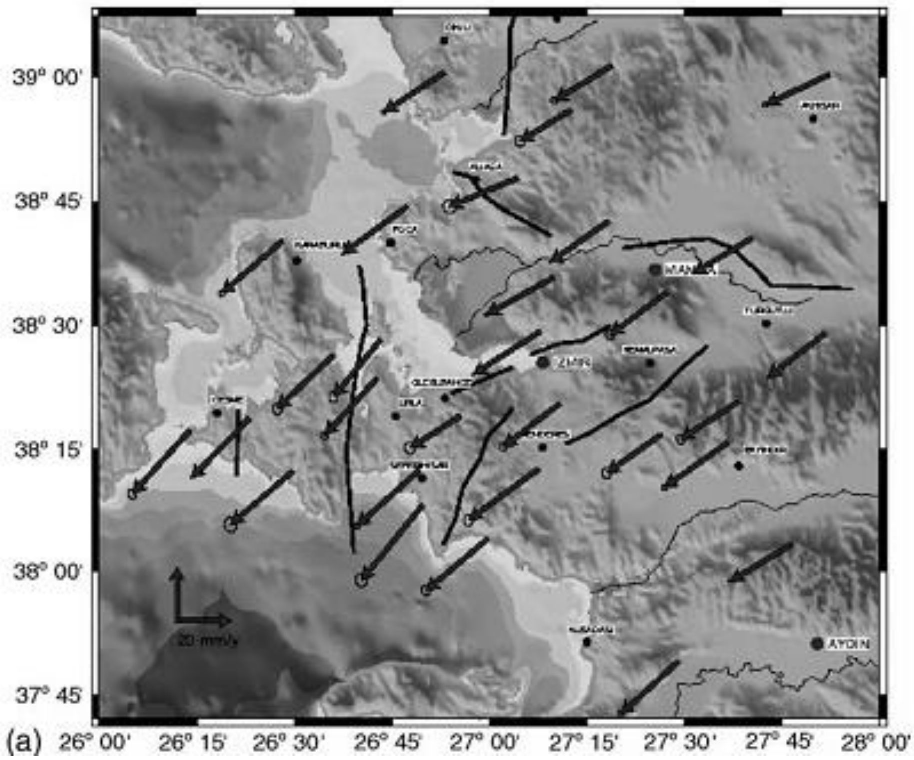

Figure 3.14. Horizontal velocity field relative to Eurasia-fixed frame (ellipses are at 95% confidence level) (taken from Aktug and Kilicoglu., 2006)

This study focused on the thought of dealing with a crustal deformation monitoring project by using different geodetic techniques. Moreover, this study tried to form interactions between different disciplines of geosciences and geodesy in terms of deformation monitoring projects. In other words, the project results can be expanded by measuring and collecting data using different geodetic techniques.

In conclusion, for further studies, campaign based GPS observations, precise leveling and other type of geodetic techniques are planned to perform in the following months in order to continue to monitor the deformations and strain analysis will be processed. There are various methods help to calculate strain rate by using GPS velocities. This study has been supported by TUBITAK-CAYDAG under grant no 108Y295 and Bogazici University-BAP Scientific Research Projects under grant no 5056.

APPENDIX A: Summary of GAMIT Files

File Name	Task of the files
A – file	ASCII version of the T-file (tabular ephemeris)
B –file	controls the batch mode of data processing
C – file	observed – computed (O-C's), partial derivatives
D – file	driver file of sessions and receivers
E – file	broadcast ephemeris, in RINEX navigation file or FICA Blk 9 format
G – file	orbital initial conditions and non-gravitational parameter values
H – file	adjustments and full variance-covariance matrix for input to GLOBK
I – file	receiver clock polynomial input
J – file	satellite clock polynomial coefficients
K – file	values of receiver clock offset during observation span, from pseudorange
L – file	station coordinates
M – file	controls merging of data (C-) files for solve and editing programs
N – file	data-weight overrides for solve created from autcln.sum.postfit
O – file	record of the analysis (reduced form of Q-file) for post-processinganalysis
P – file	record of a model run
Q –file	record of the analysis (solve run)
S – file	no longer used
T - file	tabular ephemeris
U - file	loading and meterological data for model
V- file	editing output of SCANRMS
W – file	meteorological data in RINEX met-file format
X – file	input observations
Y – file	satellite yaw parameters
Z – file	output meterological data

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AUTOBIOGRAPHY

Asli SABUNCU

Bogazici University, Turkey

Asli Sabuncu is currently working at Bogazici University as a research assistant in Kandilli Observatory and Earthquake Research Institute, the Department of Geodesy. She got her B.S. degree in Geodesy and Photogrammetry Engineering from Yildiz Technical University in 2005. Her research interests include geodesy, crustal deformation monitoring, precise levelling, surveying, GPS. She has co-authored 2 scientific papers in various conference proceedings. She is a member of American Geophysical Union.