4.10.1. GENERAL OVERVIEW REPORT FOR MONITORING GEODYNAMIC ACTIVITIES IN TURKEY

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4.10.1.1. General geodynamic structure of Turkey

When general geodynamics of Turkey is examined, it is seen that it has very complex structure. Turkey is the country affected by several different faults such as Black Sea plate, Eurasian plate, Aegean plate, African Plate, Arab Plate and Anatolian Plate. See Fig. 4.10.1.1. Due to this structure almost 92% of the country is under the risk of earthquake. Earthquake is the action that creates sudden movements in the country. However the country is under the influence of continues crustal movements by time; it is about 2 cm per a year.

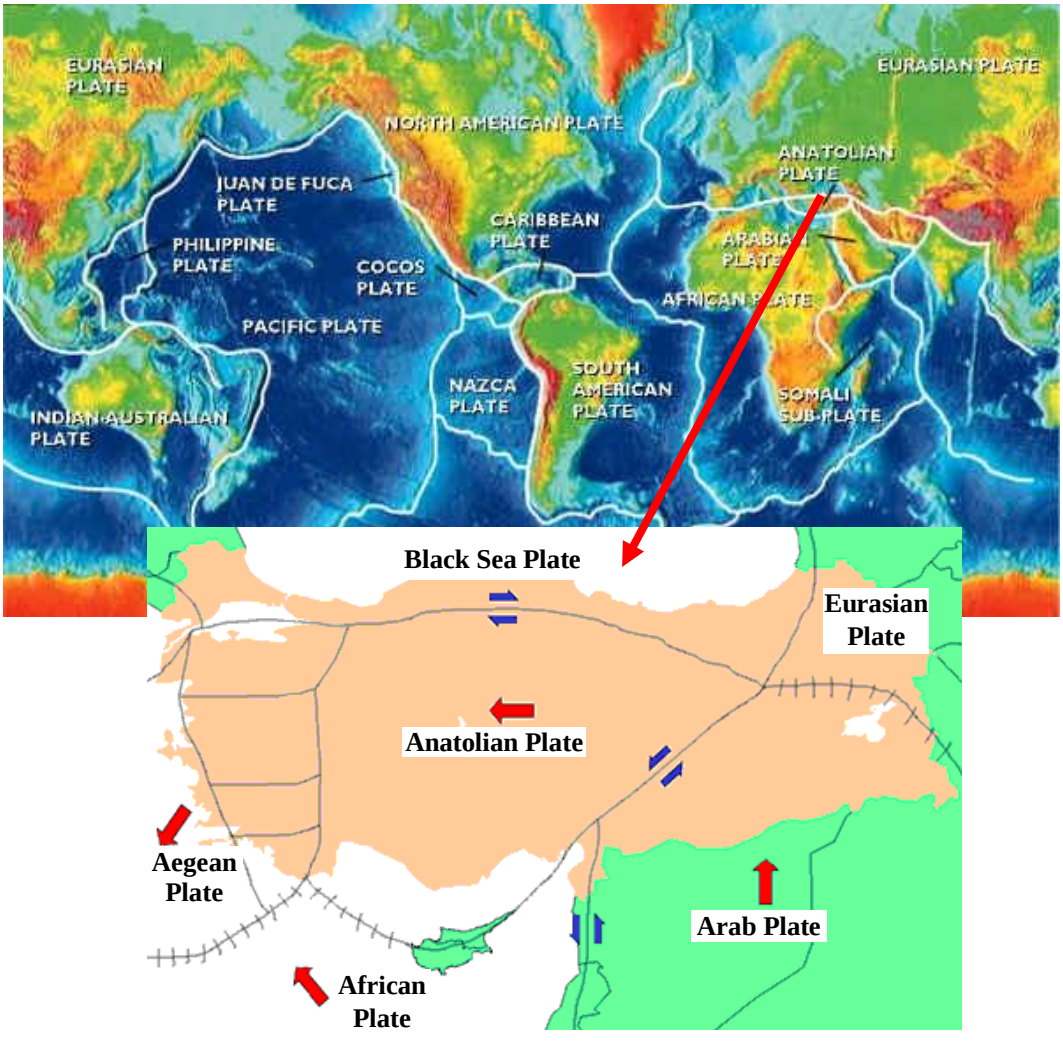


Fig. 4.10.1.1. General Tectonic Structure of Turkey

4.10.1.2. High magnitude earthquakes in Turkey

The following table shows the high magnitudes (over than 5) earthquakes and their damages on to human life. As is mentioned, almost all part of Turkey is under the risk of earthquake. When locations in this table are investigated it is seen that earthquakes occurred in every part of the country. The table covers earthquakes from 1902 to 2005. Seismic activities and earthquakes in Turkey are continuously monitored by governmental institution called as Kandilli Observatory and Earthquake Research Institute. Its web site address for online se seismic activity monitoring is *http://www.koeri.boun.edu.tr/sismo/map/en/index.html*.

Location	Date	Magnitude	Death	Injured
ÇANKIRI	09.03.1902	5.6	4	-
MALAZGİRT	24.04.1903	6.7	2626	-
MÜREFTE	09.08.1912	7.3	216	466
AFYON-BOLVADİN	04.10.1914	5.1	400	-
ÇAYKARA	13.05.1924	5.3	50	-
PASİNLER	13.09.1924	6.9	310	-
AFYON-DİNAR	07.08.1925	5.9	3	-
MİLAS	08.02.1926	4.7	2	-
FİNİKE	18.03.1926	6.9	27	-
KARS	22.10.1926	5.7	355	-
İZMİR-TORBALI	31.03.1928	7.0	50	-
SİVAS-SUŞEHRİ	18.05.1929	6.1	64	-
HAKKARİ SINIRI	06.05.1930	7.2	2514	-
DENİZLİ-ÇİVRİL	19.07.1933	5.7	20	-
BİNGÖL	15.12.1934	4.9	12	-
ERDEK	04.01.1935	6.7	5	30
DİGOR	01.05.1935	6.2	200	-
KIRŞEHİR	19.04.1938	6.6	149	-
İZMİR-DİKİLİ	22.09.1939	7.1	60	-
TERCAN	21.11.1939	5.9	43	-
ERZİNCAN	26.12.1939	7.9	32962	-
NİĞDE	10.01.1940	5.0	58	-
KAYSERİ-DEVELİ	20.02.1940	6.7	37	20
YOZGAT	13.04.1940	5.6	20	-
MUĞLA	23.05.1941	6.0	2	-
VAN-ERCİŞ	10.09.1941	5.9	194	-
ERZİNCAN	12.11.1941	5.9	15	-
MUĞLA	13.12.1941	5.7	-	-
BİGADİÇ-SINDIRGI	15.11.1942	6.1	7	-
OSMANCIK	21.11.1942	5.5	7	-
ÇORUM	11.12.1942	5.9	25	-
NİKSAR-ERBAA	20.12.1942	7.0	3000	-
ADAPAZARI-HENDEK	20.06.1943	6.6	336	-
TOSYA-LADİK	26.11.1943	7.2	2824	-
BOLU-GEREDE	01.02.1944	7.2	3959	-
DÜZCE	10.02.1944	5.4	-	-
MUDURNU	05.04.1944	5.6	30	-
GEDİZ-UŞAK	25.06.1944	6.2	21	-
AYVALIK-EDREMİT	06.10.1944	7.0	27	-
ADANA-CEYHAN	20.03.1945	6.0	10	-
VAN	20.11.1945	5.8	-	-
KADINHAN-ILGIN	21.02.1946	5.6	2	-

VARTO-HINIS	**31.05.1946**	**5.7**	**839**	**349**
İZMİR-KARABURUN	**23.07.1949**	**7.0**	**1**	**7**
KARLIOVA	**17.08.1949**	**7.0**	**450**	**-**
KIĞI	**04.02.1950**	**4.6**	**20**	**-**
İSKENDERUN	**08.04.1951**	**5.7**	**6**	**10**
KURŞUNLU	**13.08.1951**	**6.9**	**52**	**208**
HASANKALE	**03.01.1952**	**5.8**	**133**	**-**
YENİCE-GÖNEN	**18.03.1953**	**7.4**	**265**	**366**
KURŞUNLU	**07.09.1953**	**6.4**	**2**	**-**
AYDIN-SÖKE	**16.07.1955**	**7.0**	**23**	**-**
ESKİŞEHİR	**20.02.1956**	**6.4**	**2**	**-**
FETHİYE	**25.04.1957**	**7.1**	**67**	**-**
BOLU-ABANT	**26.05.1957**	**7.1**	**52**	**100**
BAŞKÖY	**07.07.1957**	**5.1**	**-**	**-**
KÖYCEĞİZ	**25.04.1959**	**5.7**	**-**	**-**
HINIS	**25.10.1959**	**5.0**	**18**	**-**
MARMARİS	**23.05.1961**	**6.5**	**-**	**9**
IĞDIR	**04.09.1962**	**5.3**	**1**	**22**
DENİZLİ	**11.03.1963**	**5.5**	**-**	**-**
ÇINARCIK-YALOVA	**18.09.1963**	**6.3**	**1**	**26**
DENİZLİ	**22.11.1963**	**5.1**	**-**	**-**
MALATYA	**14.06.1964**	**6.0**	**8**	**36**
MANYAS	**06.10.1964**	**7.0**	**23**	**130**
DENİZLİ-HONAZ	**13.06.1965**	**5.7**	**14**	**217**
KARLIOVA	**31.08.1965**	**5.6**	**-**	**-**
VARTO	**07.03.1966**	**5.6**	**14**	**75**
VARTO	**19.08.1966**	**6.9**	**2394**	**1489**
ADANA-BAHÇE	**07.04.1967**	**5.3**	**-**	**-**
ADAPAZARI	**22.07.1967**	**7.2**	**89**	**235**
PÜLÜMÜR	**26.07.1967**	**6.2**	**97**	**268**
AKYAZI	**30.07.1967**	**6.0**	**2**	**40**
BİNGÖL-ELAZIĞ	**24.09.1968**	**5.1**	**2**	**40**
BARTIN	**03.09.1968**	**6.5**	**29**	**231**
FETHİYE	**14.01.1969**	**6.2**	**-**	**-**
GÖNEN	**03.03.1969**	**5.7**	**1**	**-**
DEMİRCİ	**23.03.1969**	**6.1**	**-**	**-**
ALAŞEHİR	**28.03.1969**	**6.6**	**41**	**186**
KARABURUN	**06.04.1969**	**5.6**	**-**	**3**
GEDİZ	**28.03.1970**	**7.2**	**1086**	**1260**
ÇAVDARHİSAR	**19.04.1970**	**5.9**	**-**	**2**
DEMİRCİ	**23.04.1970**	**5.7**	**-**	**43**
BURDUR	**12.05.1971**	**6.2**	**57**	**150**
BİNGÖL	**22.05.1971**	**6.7**	**878**	**700**
EZİNE	**26.04.1972**	**5.0**	**-**	**-**
VAN	**16.07.1972**	**5.2**	**1**	**-**
İZMİR	**01.02.1974**	**5.2**	**2**	**22**
KARS-SUSUZ	**25.03.1975**	**5.1**	**2**	**26**
LİCE	**06.09.1975**	**6.9**	**2385**	**3339**
DOĞU BEYAZIT	**02.04.1976**	**4.8**	**5**	**13**
ARDAHAN	**30.04.1976**	**5.0**	**4**	**-**
DENİZLİ	**19.08.1976**	**4.9**	**4**	**28**
ÇALDIRAN-MURADİYE	**24.11.1976**	**7.2**	**3840**	**497**
LİCE	**25.03.1977**	**4.8**	**8**	**17**

PALU	**26.03.1977**	**5.2**	**8**	**26**
İZMİR	**16.12.1977**	**5.3**	**-**	**-**
FOÇA	**14.06.1979**	**5.9**	**-**	**-**
MUŞ-BULANIK	**27.03.1982**	**5.2**	**-**	**-**
BİGA	**05.07.1983**	**4.9**	**3**	**-**
ERZURUM	**30.10.1983**	**6.8**	**1155**	**1142**
ERZURUM-BALKAYA	**18.09.1984**	**5.9**	**3**	**35**
MALATYA-SÜRGÜ	**06.06.1986**	**5.6**	**1**	**20**
KARS-AKYAKA	**07.12.1988**	**6.9**	**4**	**11**
ERZİNCAN	**13.03.1992**	**6.8**	**653**	**3850**
DİNAR	**01.10.1995**	**6.0**	**96**	**240**
ÇORUM-AMASYA	**14.08.1996**	**5.4**	**-**	**6**
ADANA-CEYHAN	**27.06.1998**	**6.3**	**145**	**1041**
KOCAELİ	**17.08.1999**	**7.4**	**17127**	**43953**
KOCAELİ	**13.09.1999**	**5.8**	**-**	**-**
MARMARA DENİZİ	**20.09.1999**	**5.0**	**-**	**-**
MARMARİS-MUĞLA	**05.10.1999**	**5.2**	**-**	**-**
BOLU-DÜZCE	**12.11.1999**	**7.2**	**845**	**4948**
BOLU-YIĞILCA	**14.2.2000**	**5.1**	**-**	**-**
DENİZLİ-HONAZ	**21.4.2000**	**5.0**	**-**	**-**
ÇANKIRI-ORTA	**6.6.2000**	**6.1**	**2**	**1766**
SAKARYA-HENDEK	**23.8.2000**	**5.8**	**-**	**9**
AFYON-SULTANDAĞI	**15.12.2000**	**5.8**	**6**	**547**
TUNCELİ-PÜLÜMÜR	**27.1.2003**	**6.2**	**1**	**7**
İZMİR-URLA	**10.4.2003**	**5.6**	**-**	**-**
BİNGÖL	**1.5.2003**	**6.4**	**176**	**520**
ERZURUM-ÇAT	**25.3.2004**	**5.1**	**9**	**20**
AĞRI-DOĞUBEYAZIT	**2.7.2004**	**5.1**	**18**	**32**
MUĞLA-GÖKOVA KÖRFEZİ	**3-4.8.2004**	**5.0 - 5.4. - 5.0**	**-**	**-**
ELAZIĞ-SİVRİCE	**11.8.2004**	**5.5**	**-**	**12**
HAKKARİ	**25.1.2005**	**5.5**	**2**	**5**
BİNGÖL-KARLIOVA	**12.3.2005**	**5.7**	**-**	**16**
BİNGÖL-KARLIOVA	**14.3.2005**	**5.9**	**-**	**-**

4.10.1.3. Projects carried out for monitoring tectonic activities in Turkey

- ## Micro geodetic networks

Most of the micro geodetic networks have been established for monitoring geodynamic activities on North Anatolian Fault (NAF). Fig. 4.10.1.2. shows the İsmetpaşa, Gerede, Taşkesti and Akyazı - Dokurcun micro geodetic networks on NAF.

İsmetpaşa micro geodetic network was established in 1969. Size of the network is about 1x1 km^2. First measurements was also carried out in 1969 in İsmetpaşa. Yearly average of horizontal movements is 15 mm. Total number of geodetic control stations is 6 in the network.

Gerede micro geodetic network was established and first measurement campaign was carried out in 1981. Total number of geodetic control stations is 11. Size of the network is about 4x4 km^2. No significant movement has been recorded for this network.

Taşkesti micro geodetic network was established in 1981 as Gerede network. Size of the network is about 10x10 km^2. First design has been done with 12 control stations and then extended with additional 4 control stations in 1984. No significant movements have been recorded in its first design. After extending the network 3.8 mm yearly average significant movements have been recorded.

Akyazı-Dokurcun micro geodetic network was established in 1976. Total number of geodetic control stations is 11. Size of the network is about 10x40 km^2. First design has been done with 4 control stations and then extended to 11 control stations. No significant movement has been recorded for this network.

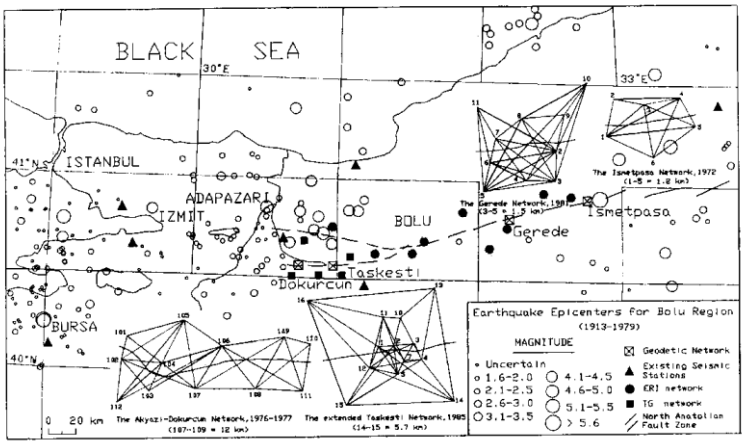


Fig. 4.10.1.2. İsmetpaşa, Gerde, Akyazı-Dokurcun Micro Geodetic Networks

İznik micro geodetic network was established in 1990. Total number of geodetic control stations is 5. Sapanca micro geodetic network was established in 1991 with 6 geodetic control stations. Akyazı micro geodetic network was established in 1992. Total number of geodetic control station is 10. See Fig. 4.10.1.3.

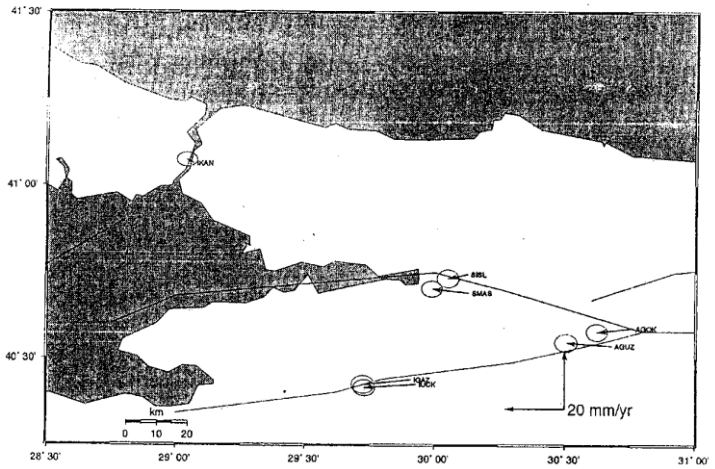


Fig. 4.10.1.3. İznik, Sapanca, Akyazı Micro Geodetic Networks

All micro geodetic networks above have been surveyed using conventional techniques. However after year 2000s they have been surveyed using GPS techniques. GPS technology has also changed the surveying strategy. Based on this strategy some of the micro geodetic networks have been combined within GPS campaigns.

- **Regional geodetic networks based on satellite techniques**

a) Satellite Laser Ranging - SLR

In order to determine plate taconites in East-Mediterranean region WEGENAR-MEDLAS (Working Group of European Geo-Scientists for the Establishment of Network for Earthquake Research – Mediterranean Laser Ranging) project has been began in Turkey in 1986. Following 5 mobile SLR stations have been established within this project: Diyarbakır, Melengiçlik (Konya), Yığılca (Bolu) Yozgat and Ankara. First four stations were established in 1987 and the last one in 1989. Based on SLR surveys Eurasian, Anatolian and Arab plates' velocities have been determined.

b) Project in East and West Anatolia

The specific name of this project is "Faults in Turkey and Determination of Regional Deformations". That project was the remaining part of the WEGENAR-MEDLAS project. The regional geodetic network was designed with 33 GPS and 4 SLR stations. The project goals were as follows.

- **Determination of location of seismic activities along the North Anatolian Fault and East Anatolian Fault**
- **Determination of deformation on Anatolian plate because of Arab, African and Eurasian plates**
- **Determining relative movements of Arab, African and Eurasian plates.**

c) Project in West Black Sea

That project also was the remaining part of the WEGENAR-MEDLAS project. The specific name of the project is "Research on Crustal Movements along the North Anatolian Fault". The regional geodetic network was established in 1989. Total number of GPS station is 30 in this network. Some of the Taşkesti micro geodetic network stations were also integrated to this network.

d) Project in Aegean Region

In 1989 a regional geodetic network has been established with 30 station to understand the seismic activities in Aegean region due to plates intersecting at Aegean region. The other project in Aegean region is "West Anatolian Project". That project was also carried out to understand the complex tectonic structure of Aegean region. 38 geodetic control stations were established for this project.

e) Project in Marmara Region

One of the largest projects in Marmara was "Marmara Region Tectonic and Its Interaction with Underground-water, Geothermic and Seismology." Based on this project there are several sub projects. One of the sub projects was "Surveying Kinematics Field of Earth's Surface Using satellite Techniques" The goal of this sub project was to determine the tectonic model of the region and to compare surface kinematics with underground-water circulation and micro earthquake distribution. The regional geodetic network was established in 1990 and was designed with 52 geodetic control stations.

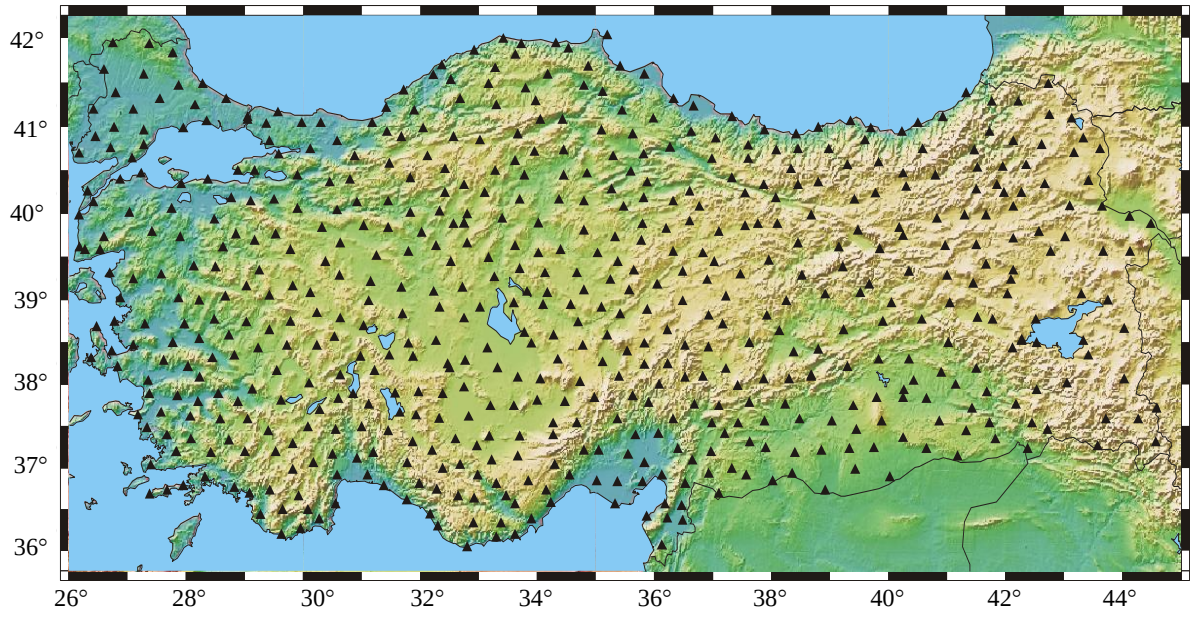
4.10.1.4. National geodetic infrastructure of Turkey

First national geodetic network establishment was began in Turkey in the beginning of 1900s. Designing strategy of that network was accepted as a fixed frame. That means coordinates of control stations of that network was stable even though their locations physically changed due to crustal movements. Datum of that network was determined connecting the European network with 8 common control stations. Thereafter it was adjusted in 1954 based on European Datum 1950. However that network lost its consistency by time due to the physical location changes at its control stations. Today this network does not compensate almost any needs of the country. Therefore a new network was established that can sense the crustal movements in the country. This network was designed with a totally different philosophy than the previous network. It was designed 4D. The technical structural specs of this network are given below.

- ## Turkish fundamental GPS network 1999A – TUTGA-99A

Turkish National Fundamental GPS Network (TUTGA) has been established in between 1997 and 1999 (Fig. 4.10.1.4) and some of the stations have been re-surveyed due to the earthquakes happened in 1999. The total number stations are 596 and for each station 3D Coordinates and their associated velocities have been computed in ITRF96 (Reference Epoch: 1998.0) that means 4D. Positional accuracy of the stations is about 1-3 cm whereas the relative accuracies are in the range of 0.01 ppm. Also, the network has been connected to the Turkish Conventional Horizontal and Vertical Control Networks through some points and time-dependent coordinates of all the stations are being computed in the context of the maintenance of the network with periodic GPS observations. Considering the on-going tectonic feature of the region, second period surveys of the great majority of the points have been completed in 2001, 2002 and 2003 and velocities have been estimated. Also appropriate models for coordinate transformation from ED50 system into the ITRF96 have defined in the context of TUTGA. Detailed information about TUTGA can be obtained in www.hgk.mil.tr.

- ## Turkish National Vertical Control Network - TUDKA99



4.10.1.4. Distribution of TUTGA stations

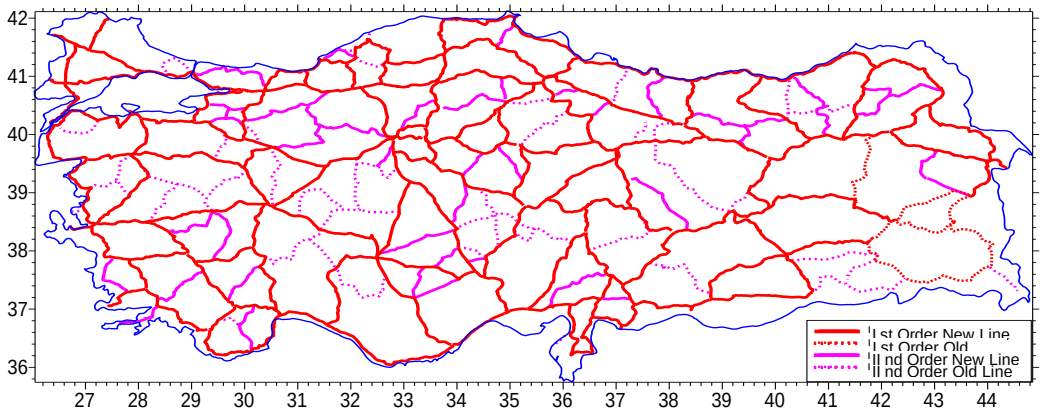


Fig. 4.10.1.5. Turkish national vertical control network-1999 (TNVCN-99)

Turkish National Vertical Control Network (TUDKA-99) was established with the adjustment of 243 lines of 25680 points with total length of 29316 km. This network includes 151 first and 41 second order lines measured between 1970 and 1993, and 7 first and 44 second order lines measured before 1970 (Fig. 4.10.1.5.). Vertical datum for TUDKA-99 is defined with arithmetic mean of instantaneous sea level measurements recorded at Antalya tide gauge between 1936 and 1971. In the adjustment, geopotential numbers were used as observations and geopotential numbers, Helmert orthometric heights and Molodensky normal heights at all points were calculated. Gravity values in modified Potsdam datum were used in calculating geopotential numbers. The adjustment results in precision of point heights varying from 0.3 cm to 9 cm depending on the distance from the datum point. Differences between TUDKA 99 Helmert orthometric heights and currently used Normal orthometric heights were found to be between –14 cm and +36.9 cm and mean value of it was found as +9.5 cm with standard deviation of ±8.4 cm. Correction value between two height systems at any point given with position can be calculated.

Right after 17 August 1999 İzmit earthquake, in November 1999, in order to determine the vertical displacements in TUDKA-99, levelling line of 110 km re-measured in the region; Hersek – Karamürsel – Gölcük – İzmit – Adapazarı - Arifiye and Doğançay (Fig. 4.10.1.6.).

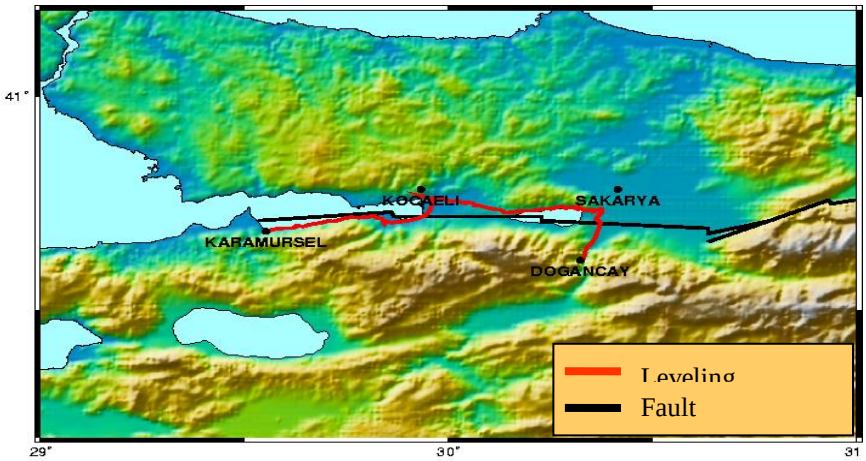


Fig. 4.10.1.6. Re-measured levelling lines in November 1999

The comparison of geometric levelling heights before and after İzmit earthquake relative to 5_DN_38 benchmark located in west of Hersek results in vertical displacements is varying between -52 cm and +8 cm. It became necessary to re-measure levelling lines in wider region considering the huge amount of vertical deformation due to İzmit and Düzce earthquakes.

In order to determine the vertical displacements in a wider area due to 17 August İzmit and 12 November Düzce earthquakes, 14 first and second order levelling lines of 1300 km re-measured in the region; Bursa - İstanbul – İzmit – Adapazarı - Zonguldak and Bolu during May-September 2000 and 2002 (Fig. 4.10.1.7.). Relative gravity measurements were also carried out at vertical control points.

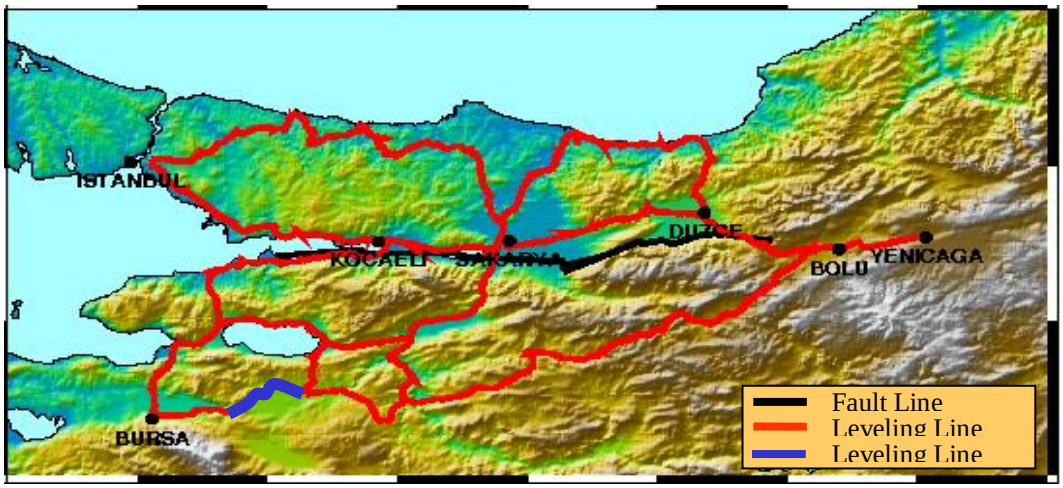


Fig. 4.10.1.7. TUDKA-99 lines re-measured in 2000 and 2002

- **Turkish national permanent GPS network - TUSAGA**

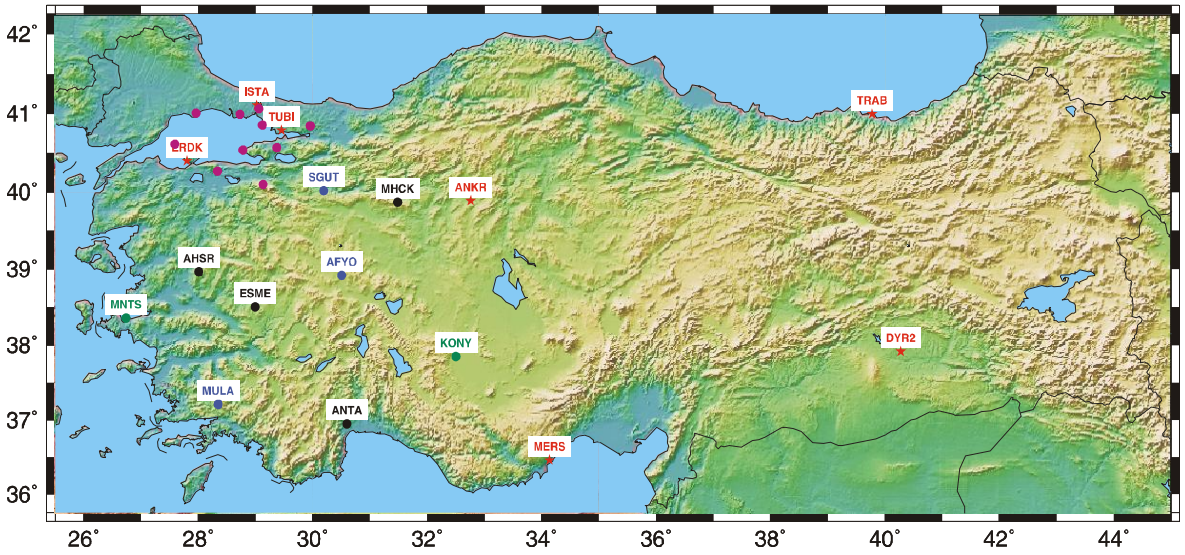


Fig. 4.10.1.8. Current distribution of TUSAGA stations

The Turkish national permanent GPS network (TUSAGA) is still in establishment phase with its 16 operational stations of which data can be used (Fig. 4.10.1.8.). In addition to the currently working Ankara station since 1991 under IGS network, Dicle, Gebze, Erdemli, Erdek, Trabzon and İstabul stations were included into the network during the years, 1997, 1998, 1999, 2000 and 2001. Other than that of those stations, the data from 11 stations around Marmara Sea, established under a private project with TÜBİTAK Marmara Research Centre, can be utilized by scientific community. The time-series analyses of TUSAGA stations are performed at General Command of Mapping on monthly bases. Spectral analyses for the determination of periodical components in the series are performed as well as the work for the co-seismic and post-seismic displacements due to the Marmara earthquakes. TUSAGA is aimed to consist of about 16 stations in the planning phase of the Network, however, the earthquake prone character of Turkey dictates to increase the number of sites of about 25-76 in future. Besides their usage as master stations for a wide range of surveying activities, TUSAGA stations are going to be utilized as geodetic control and for monitoring the crustal movements in geodynamical activities within their continuous data collection and analyses cycle.

Today, except the national mapping agencies several local governments, universities and private companies are planning to establish their own CORS networks for compensating their institutional needs and also for business purposes.

- ## Turkish national sea level monitoring network (TUDES)

National Mapping Agency (NMA) operates seven tide gauge stations namely Antalya-II, Bodrum-II, Erdek, Mentes, Amasra, İğneada and Trabzon-II located at Mediterranean, Marmara, Agean and Black sea coasts under the frame of Turkish Sea Level Monitoring Network (TUDES). In 1998 and 1999 in order to fulfil the GLOSS standards, NMA modernised the existing analogous floating type tide gauges in stilling wells with the digital and automatic tide gauges that consist of a measurement and data collection unit with a self-calibrating acoustic ranging sea level sensor and meteorological sensors. The digital and automatic tide gauges, being state of art, are capable of real time monitoring of sea level and meteorological parameters. The data are collected at the data centre in Ankara via telephone lines and are checked for quality regularly. Distribution of the existing digital and automatic tide gauges and the planned ones are given in Fig. 4.10.1.9.

Fig. 4.10.1.9. Locations of the existing and planned digital tide gauge stations

of TUSELN

There are 4-6 benchmarks at Local levelling networks of tide gauges which are connected to the Turkish vertical control network by at least two levelling benchmarks. One of the benchmarks of the local levelling network is chosen as TG-GPS benchmark on which episodic GPS measurements are carried out to detect the absolute vertical land movements. The periodical first order precise levelling measurements are performed at 1-2 year intervals between tide gauge zero and the primary tide gauge benchmark and other levelling benchmarks including TG-GPS in order to provide sea level data continuity on a common datum and to monitor the relative land movements.

TUDES has the capability to provide reliable data for the investigation of local relative sea level changes and determination of vertical crustal movements at Turkish coasts having complex tectonic structures. On the other hand, TUDES contributes to studies for the improvement of national geodetic vertical datum of Turkey. Its dependable real time sea level and meteorological data have given opportunity to examine sea-air interactions for climate change studies in Turkey. TUDES offers dependable and accurate relative sea level observations for calibration of satellite altimeters and, also provides the exploration of sea level measurements for navigation purposes. Moreover, TUDES provides sea level statistics for some engineering purposes such as harbour design and coastal area planning in Turkey.

- ## Determination of velocity field of Turkey and displacements after Marmara earthquakes

Anatolia, which takes place among major plates Africa, Arabia and Eurasia is an ideal place to study both inter-plate tectonic and the deformation. GPS studies in Turkey which date back to late 1980's, have revealed the current northward motion of Arabia with respect to Eurasia and eastward escape of Anatolian Plate due to compression along East Anatolian Fault where the two plates collide. This rigid body rotation gives an upper bound of 24 mm/yr along North Anatolian Fault with an Euler pole near Sina, Egypt as well as compression in Marmara region which was implication of the catastrophic earthquake sequence (17 Aug 1999 M_w=7.4 İzmit and 12 Nov 1999 M_w=7.2 Düzce Earthquakes) in 1999. Fig. 4.10.1.10 shows a recent velocity field of Anatolia in a Eurasia-fixed frame. Survey-type GPS observation campaigns initiated just after the earthquakes enabled the precise determination of co-seismic displacements reaching up to a few meters. While the post-seismic phenomena is still under investigation by survey-type campaigns and a continuous network, current results have not proved any significant change in the inter-seismic velocity field after the earthquakes possibly due to the on-going post-seismic signals.

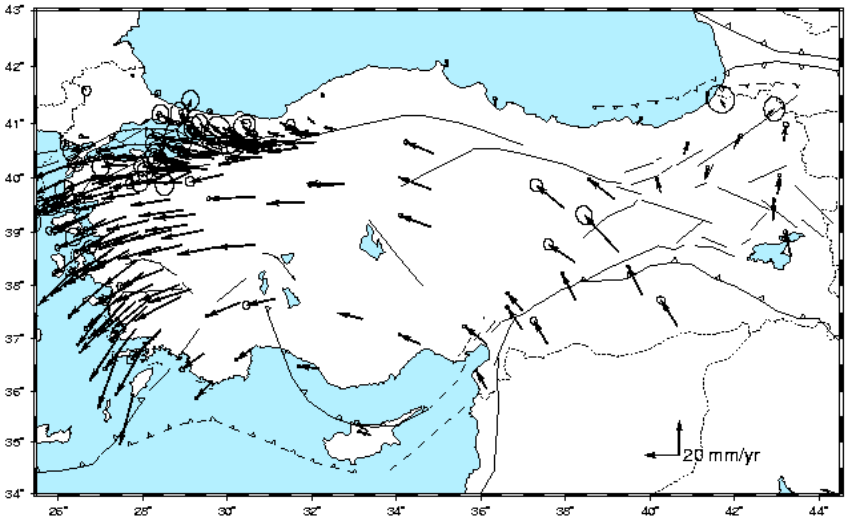


Fig. 4.10.1.10. Horizontal Velocity Map of Turkey acquired from inter-seismic data before the earthquakes (Eurasia Fixed)

4.10.1.5. Conclusion

The above information was composed from several sources indicated on reference part of this report. Therefore the information given in this report are not fully belongs to the author. This report was prepared only for informing CERGOP community about national geodynamics activities in the country from past to date.

4.10.1.6. Acknowledgment

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4.10.1.7. References

This report was prepared mainly based on the following references:

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