Operational Procedures of Agencies Contributing to the ISC

Seismic Monitoring at the Turkish National Seismic Network (TNSN)

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Excerpt from the Summary of the Bulletin of the International Seismological Centre:

Alver, F., Ö. Kılıçarslan, K. Kuterdem, M. Türkoğlu and M.D. Şentürk (2019), Seismic Monitoring at the Turkish National Seismic Network (TNSN), *Summ. Bull. Internatl. Seismol. Cent.*, July - December 2017, *53*(II), pp. 41–58, https://doi.org/10.31905/D9GRP8RD.

5.2 Seismic Monitoring at the Turkish National Seismic Network (TNSN)

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Turkey ranks third in the world in terms of earthquake-related casualties and eighth with regard to the total number of people affected. Every year, the country experiences at least one 5+ magnitude earthquake – which renders the proper management and coordination of disasters absolutely crucial (*Türkoglu et al.*, 2014). The Disaster and Emergency Management Authority (AFAD) introduced a novel disaster management model which prioritizes Turkey's transition from crisis management to risk management – which came to be known as the Integrated Disaster Management System. AFAD currently has 81 provincial branches across Turkey in addition to 11 search and rescue units. Notwithstanding its position as the sole authority for disasters and emergencies, AFAD cooperates with a range of government institutions and non-governmental organisations depending on the nature and severity of individual cases. AFAD was established on 17th December 2009 by Law no. 5902. In 2018, with presidential legislation, AFAD was affiliated to the Ministry of Interior. It is a governmental organisation and some of the duties are as follows:

1. Provide emergency relief and coordination when a disaster occurs,
2. take effective measures before, during and after a disaster in order to reduce hazards,
3. make emergency settlements and shelters by establishing and providing communication and action with the related ministries, public organisations and institutions related to any kind of disaster issues,
4. establish nationwide seismic networks to observe and study earthquake activity to diminish casualties and damage,
5. prepare hazard maps and identify new safer areas for housing by making policies for safer building and cities by applying the seismic building code of Turkey,
6. coordinate and support research and studies about earthquakes in Turkey by institutes or NGOs.

AFAD is the sole governmental responsible organisation for monitoring and communicating earthquake related information to the public in Turkey.

Turkey is among the countries most affected from disasters on a global scale due to its tectonic, seismic, topographic and climactic structure. Although disasters such as floods, avalanches, landslides and fires are common in our country, earthquakes take first place when evaluated in terms of their devastating effects. Therefore, the Earthquake Department (ED), that was established in 1955 under the Ministry of Public Works, was also designed as a department under AFAD as a unique governmental organization in 2009.

The Earthquake Department has identified its objectives as:

1. The development of a national seismological network (strong and weak ground motion seismic observation networks) in terms of quality and quantity to meet the country's needs,
2. reduce the error tolerance in seismic hazard assessments by closer observation of seismic activity,
3. provide better quality data to groundwork engineering seismology and earthquake engineering studies into reducing damage from earthquakes,
4. play an active role in disaster risk management, regularly obtaining seismic data which are the main data in local, regional and national seismic hazard and risk maps,
5. to inform disaster managers and response teams quickly and reliably when an earthquake occurs.

5.2.1 Regional Seismicity

Turkey is one of the world's most earthquake prone countries, as it is located in an active seismic zone on the Alpine-Himalayan earthquake belt. Most of the population and industrial complexes are in active earthquake zones. The importance and urgency of the works related to the pre-disaster mitigation of earthquakes were emphasized after the 17 August 1999 Marmara Earthquake and 12 November 1999 Düzce Earthquake which killed nearly 18,000 people.

Turkey has frequently suffered from major damaging earthquakes in the 20th and 21st centuries. Furthermore, in the past century 120 moderate and large earthquakes, some of them causing considerable surface faulting, happened all over the main tectonic provinces of Turkey. Of these earthquakes the Erzincan quake (Ms=7.9) was the biggest Turkish earthquake, happened on 26 December 1939, produced 360 km surface faulting from Erzincan through Erbaa to Amasya along the North Anatolian fault (*Ambraseys*, 1970; *Ketin*, 1976). This earthquake caused 32,962 deaths and was accompanied by a 7.5 m right lateral coseismic slip near the middle part of the rupture. Eight large earthquakes ($Ms \geq 7.0$) occurred on the North Anatolian fault zone in the period from 1939 to 1999.

The Earthquake activity of Turkey and its surrounding regions is observed, evaluated, archived and published to the public via the website of the Earthquake Department (`https://deprem.afad.gov.tr`). An earthquake occurring anywhere in our country which has a magnitude greater than 1.0 can be recorded and evaluated. The number of earthquakes (2005–2018) processed by the Turkish National Seismic Network (TNSN) is shown in Figure 5.5. Figure 5.6 shows the distribution of seismicity from 2009 to 2019.

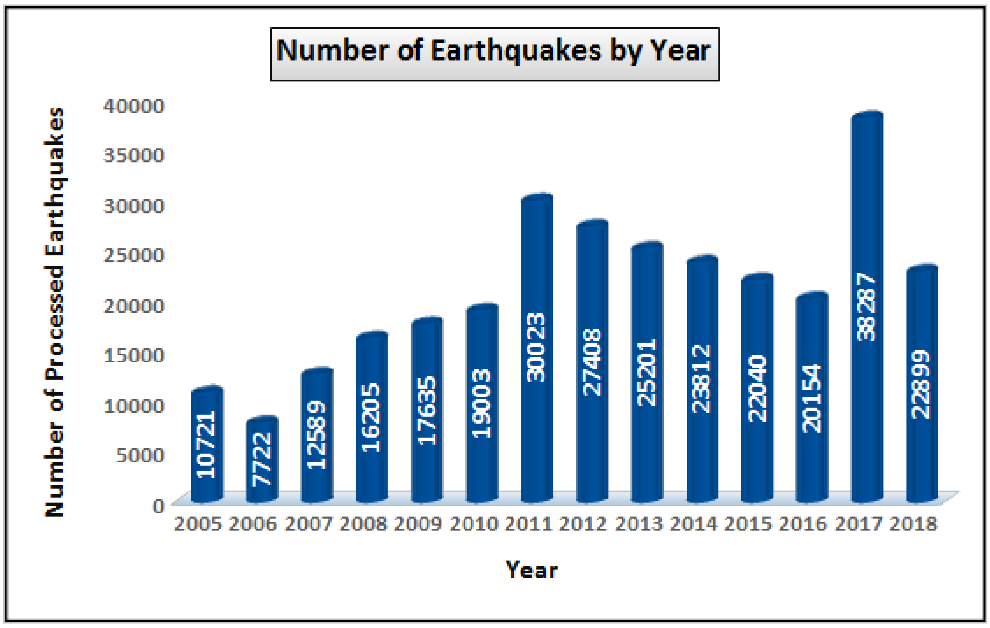

Figure 5.5: *Number of earthquakes by year since 2005 determined by the TNSN of AFAD. The increase in number of earthquakes in 2017 indicates the aftershock activity of Gökova Gulf (Mw=6.5 20.07.2017 UTC 22:31:09), Karaburun (Mw=6.2 12.06.2017 UTC 12:28:37) and Adıyaman Samsat (Mw=5.5 02.03.2017 UTC 11:07:25) earthquakes.*

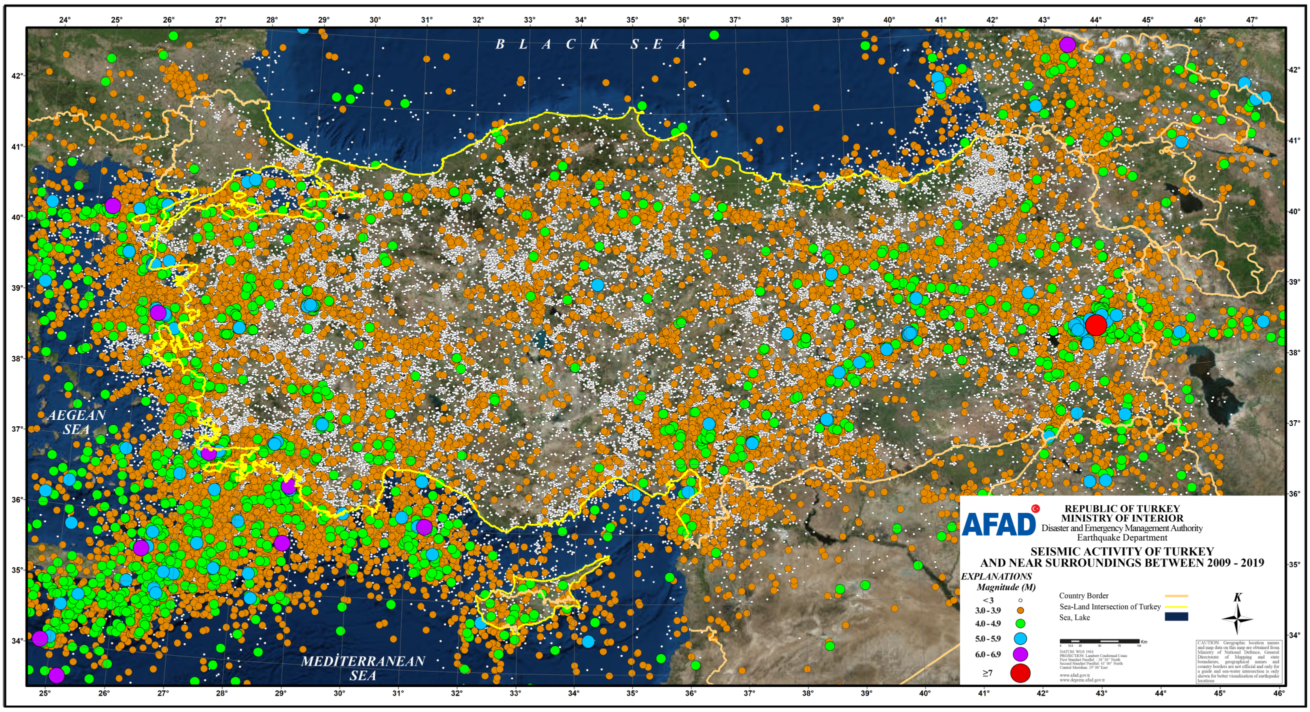

Figure 5.6: *Earthquake activity in Turkey between 2009-2019. Circles are colour coded by magnitude M, where white is $M < 3$, orange 3.0 - 3.9, green 4.0 - 4.9, blue 5.0 - 5.6, purple 6.0 - 6.9 and red $M \leq 7$.*

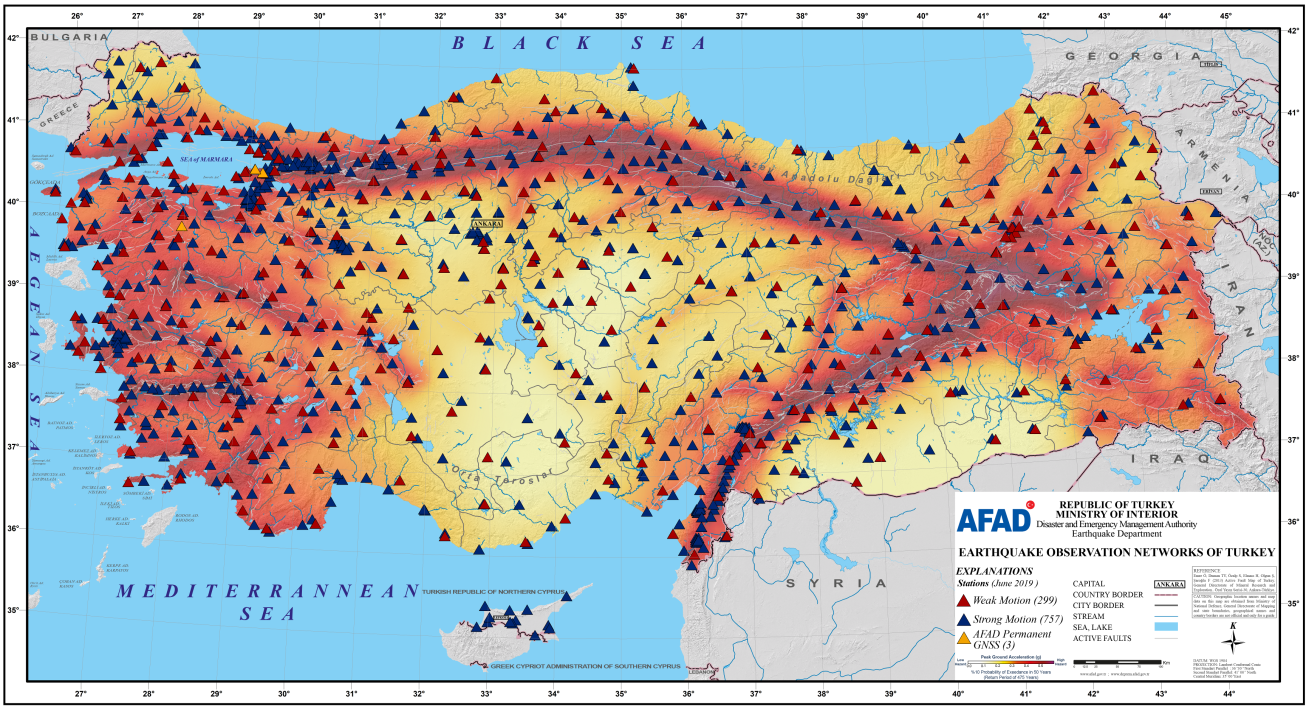

__Figure 5.7:__ Earthquake Hazard Map of Turkey and Turkey National Seismic Network. Red triangles are weak motion stations (299), blue triangles are strong motion stations (757) and yellow triangles are AFAD permanent GNSS stations (3), (June 2019).

5.2.2 History of the Turkey National Seismic Network

TNSN mainly consists of four different seismological observation systems, namely: weak motion, strong ground motion, deep borehole and Global Navigation Satellite System (GNSS) networks.

Weak-Motion Network

AFAD Earthquake Department has been striving in depth on earthquake mitigation activities such as the establishment of seismic observation networks, development of earthquake resistant building codes and the preparation of seismic maps etc. since its inception date in 1955.

In an earthquake council meeting organised in Istanbul in 2004 it was decided to establish an advanced Turkish National Seismic Network for monitoring, recording, evaluating, archiving and announcing earthquakes across the country. The development of the network in terms of weak and strong motion instrumentation has accelerated following the 2004 meeting. As of May 2019 the earthquake activity of Turkey has been observed 7 days/24 hours with 299 weak motion stations and 757 strong motion stations (accelerometers). In addition to those networks, AFAD has started to enhance the national seismic network by adding permanent GNSS stations. By 2019 a total of 3 permanent GNSS stations have been installed by AFAD (Fig. 5.7 and Fig. 5.8).

The TNSN has 299 broadband (BB) seismic stations, all of which are installed on bedrock of varying qualities. The seismometer data is transmitted via GPRS, DSL or satellite depending on availability. Except for some 30 s CMG-6TD instruments, most of the BB instruments are 120 s CMG-3T (Fig. 5.9).

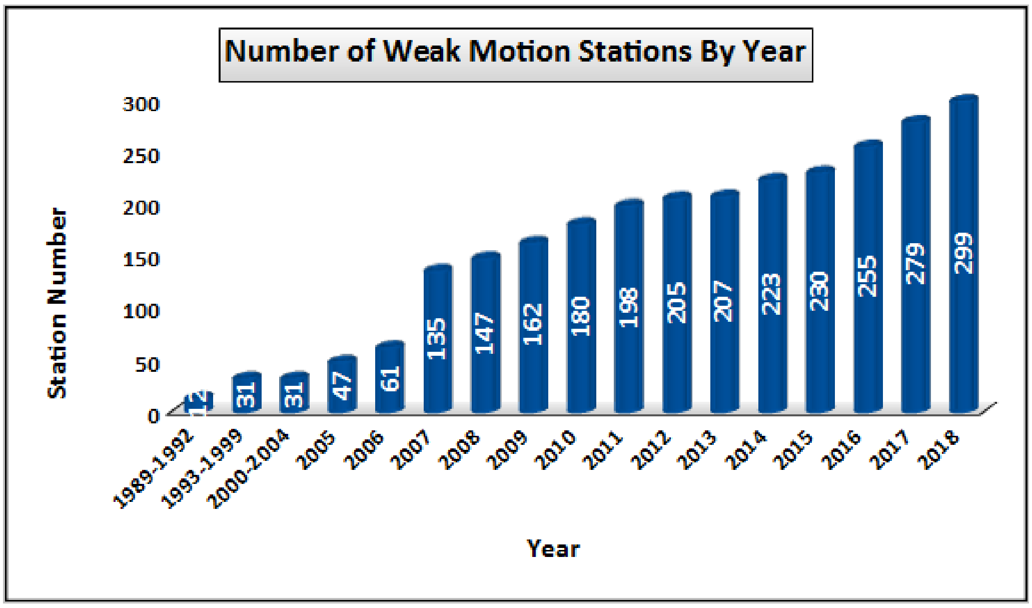

Figure 5.8: *Number of seismometers in the TNSN between 1989-2018.*

Figure 5.9: *Station installation in the field (seismometer).*

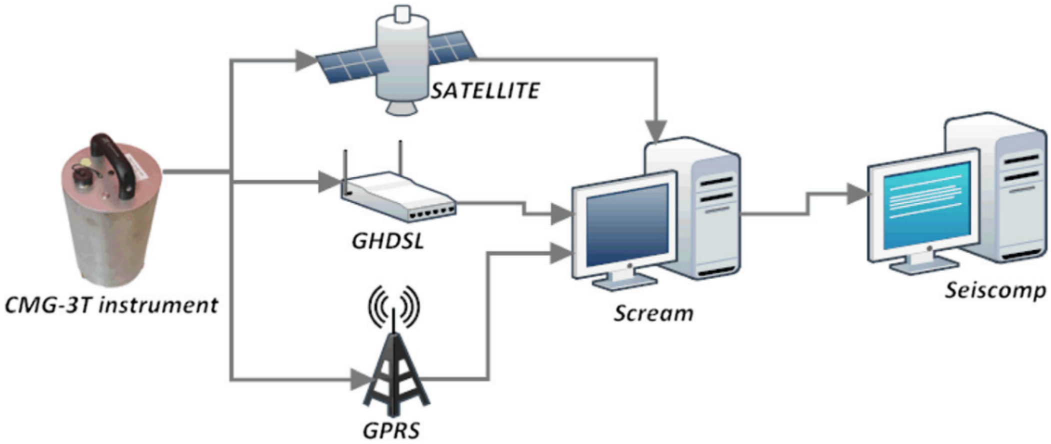

Figure 5.10: *Operation scheme of the TNSN (*Kılıç et.al.*, 2016a).*

The network is still being expanded. Data from various other small size local networks operated by universities (14 stations by Atatürk University, 5 by Cumhuriyet University, 4 by Süleyman Demirel University, 4 by Anadolu University) also contribute to the TNSN.

The real-time data from the TNSN is collected by the Güralp program SCREAM (`http://www.guralp.com`) and saved in 15-min GCF formatted segments and transferred in real time to a SEISCOMP system (Geofon-Gitews Development Group 2009) for automatic processing. The data is stored as daily files in MiniSeed format in the SEISCOMP data structure (SDS). A simple depiction of network operation and data transmission for a typical station is given in Figure 5.10. (*Kılıç et al.*, 2016a).

Strong-Motion Network

The first National Strong Motion Network of Turkey (TR-KYH) was established in 1973 under the Ministry of Public Works and has been operated by the Earthquake Department of AFAD since 2009.

The TR-KYH maintains the national network, a data center and a strong-motion data analysis and research center in support of this responsibility. The accelerometers are mainly installed on the North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone (EAFZ) and Aegean Graben System where large earthquakes occurred in the past. The TR-KYH consists of 757 strong motion observation stations (Fig. 5.11). The data management center of TR-KYH is located in Ankara. Currently there are 5 different types of digital accelerometers (GSR-16, GSR-18, GURALP, SARA, GMSplus) in the network. The instruments are mainly installed at government buildings such as meteorology stations or local ministerial offices for safety, ease of maintenance and data transmission opportunities. The total number of stations will increase to 1000 by 2023.

Accelerometers are installed both free-field in specially constructed enclosures (Fig. 5.12) and inside governmental buildings. Data is transferred to the central office continuously or by trigger mode applications (Dial-up, Internet, ADSL, GPRS/EDGE etc.) and is then submitted to users from the main network after being processed.

The access to strong motion data is free via AFAD Earthquake Department website (`http://kyhdata.deprem.gov.tr/2K/kyhdata_v4.php`).

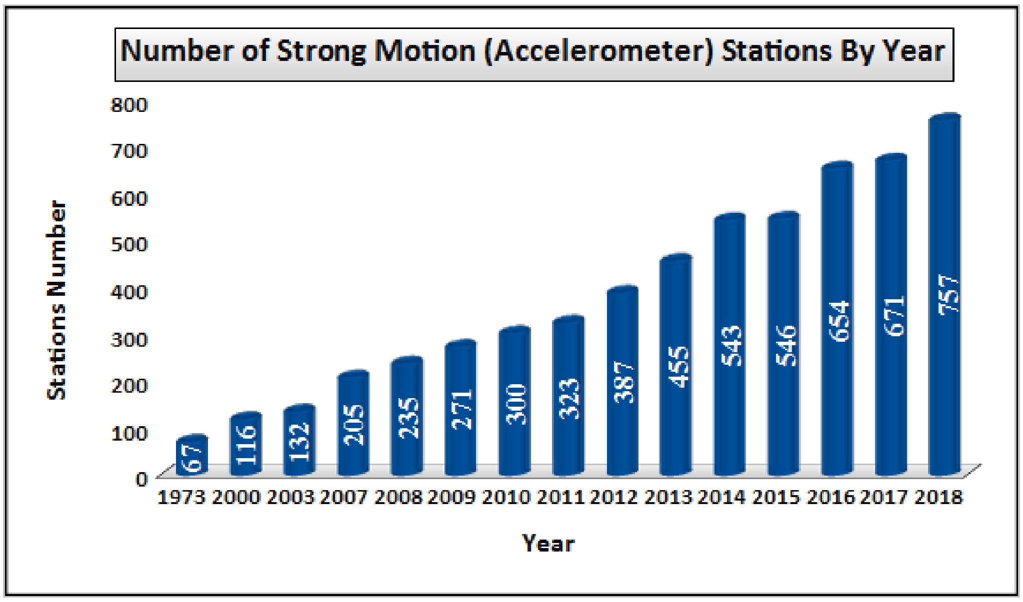

Figure 5.11: *Development of the number of accelerometers between 1973–2018.*

Figure 5.12: *Example of a strong motion station.*

Site Investigation for Stations

For the site selection of stations several conditions such as active tectonic faults of the area, the density of buildings for different geological structures, energy lines, communication, security, environmental noise, transportation etc. are considered.

In order to determine the station site characterisation, the non-invasive site exploration procedure MASW (Multi-channel analysis of surface waves) was conducted to determine the P- and S-wave velocity profiles. The soil column lithology at each strong-motion site was defined by drilling boreholes and carrying out geotechnical laboratory tests on the disturbed and undisturbed samples taken out from

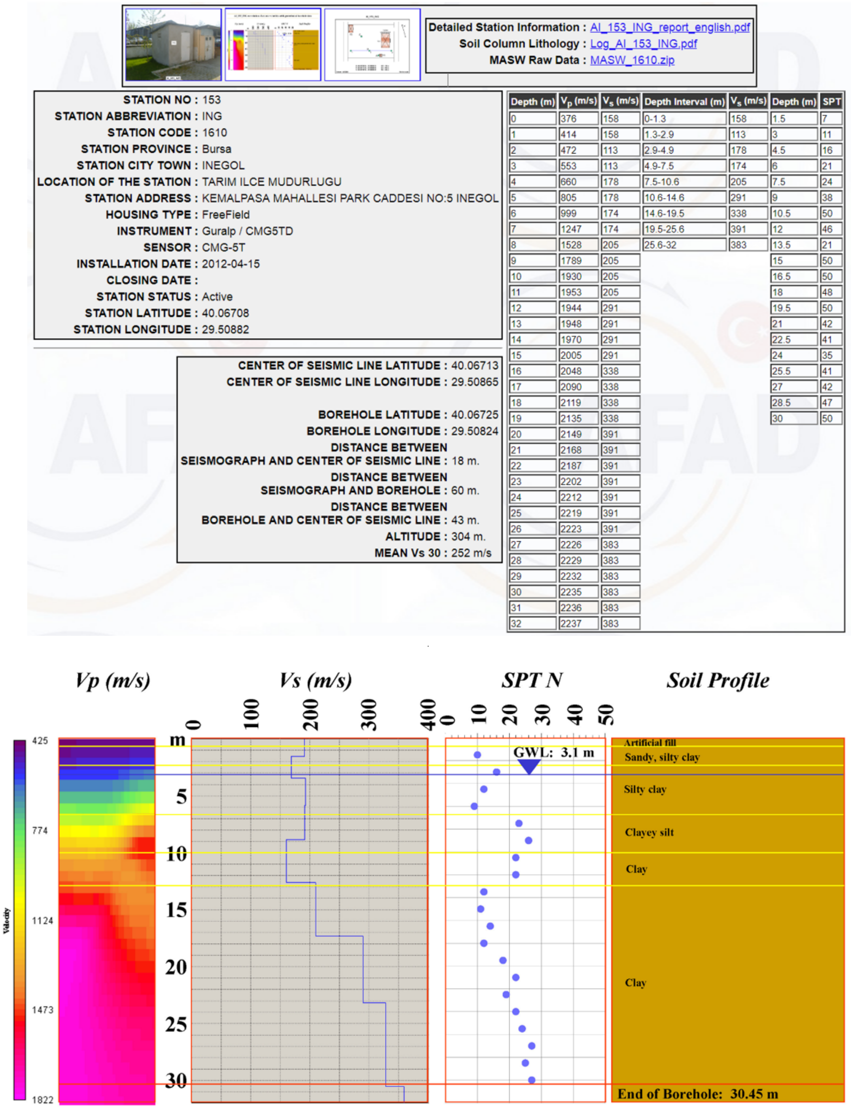

Figure 5.13: Example for site information profiles for stations.

these boreholes. In total, for 153 Strong Motion Station locations site characterisation was determined by both geotechnical and seismic methods (Fig. 5.13).

Borehole Seismic Network

The first Borehole Seismometer project in Turkey (GONAF) was set up in 2011 by AFAD and GFZ (German Research Centre for Geosciences) and station installation has been completed (*Prevedel et al.*, 2015). Analysis of data that is obtained from this project is continuing. In the GONAF Project, there are seven stations where four borehole sensors are installed at different depths (75, 150, 225 and 298 m). These stations are located in Istanbul (Tuzla, Büyükada and Sivriada) and Yalova (Kurtköy, Esenköy, Bozburun and Teşvikiye).

With the experience and knowledge gained in this project, AFAD developed the Borehole Seismometer Network Project and installed borehole seismometers at 100 m depth in İzmir, Çanakkale and Kahramanmaraş in 2016 and in Afyonkarahisar, İzmir, Denizli and Balıkesir in 2017 (Fig. 5.14). It is planned

Figure 5.14: *Borehole station installation.*

to install 36 borehole stations in Turkey (Fig. 5.15) at 160 km interval and 9 abroad. Negotiations are continuing with some countries in Eastern Europe and the Caucasian countries.

The main objectives of the project are:

- To understand the behaviour of faults before, during and after an earthquake,
- to evaluate teleseismic events recorded by Turkish stations,
- to improve the accuracy of earthquake parameters.

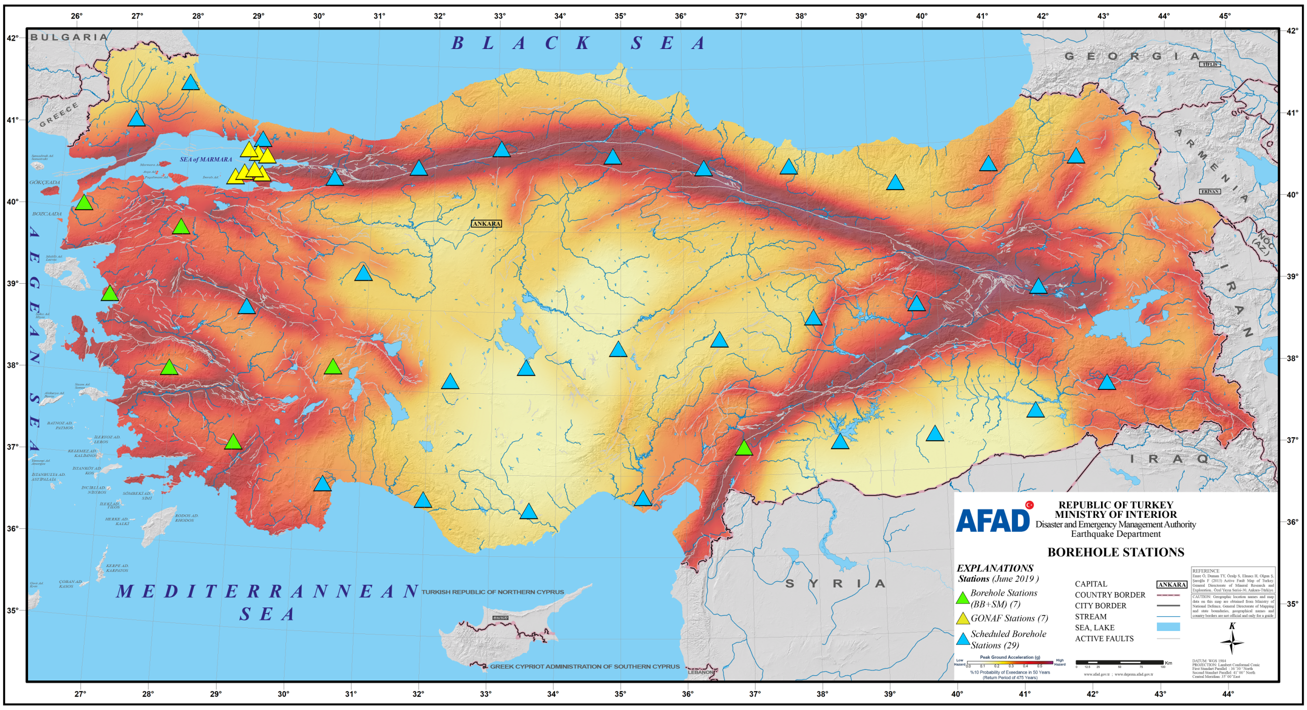

Figure 5.15: *Map of the Borehole Seismic Network. Green triangles are borehole stations (BB+SM) (7), yellow triangles are GONAF stations (7) and blue triangles are scheduled borehole stations (29), (June 2019). White colours are 0.0 g peak ground acceleration/low seismic hazard and red colours are 0.6 g peak ground acceleration/high seismic hazard (10% probability of exceedance in 50 years, return period of 475 years).*

GNSS Network

We are implementing real-time high-rate monitoring at co-located GNSS/seismic stations for rapid determination of earthquake magnitudes and rupture characterization. Coupled GNSS and seismometer data provides broadband (with true DC) displacement waveforms, which have huge potential for earthquake early warning as well as reliable filtering of accelerometer data.

The number of permanent GNSS stations, operated by public and private sectors, in Turkey already exceeds 200 and continues to grow each day. While not as sensitive as broadband seismometers, the non-inertial observation mechanism of GNSS enables obtaining measurements very close to the earthquake source without saturation, which makes it ideal for earthquake early warning systems. We are operating three permanent GNSS stations by our own capacity, as Figures 5.7 and 5.16 indicate. For earthquake monitoring and analysis we have real-time access to 158 nation-wide continuous Turkish National Permanent GNSS Network (CORS-TR) stations that are operated by other public institutions for mapping purposes.

We built a central GNSS analysis center which operates in real time and is capable of transferring data from remote GNSS stations, analysing raw GNSS data with both PPP (Precise Point Positioning) and Relative Kinematic modes, producing filtered instant coordinate time series and storing them in a database, and finally analysing coordinate time series for modelling the earthquake mechanism with coseismic offsets.

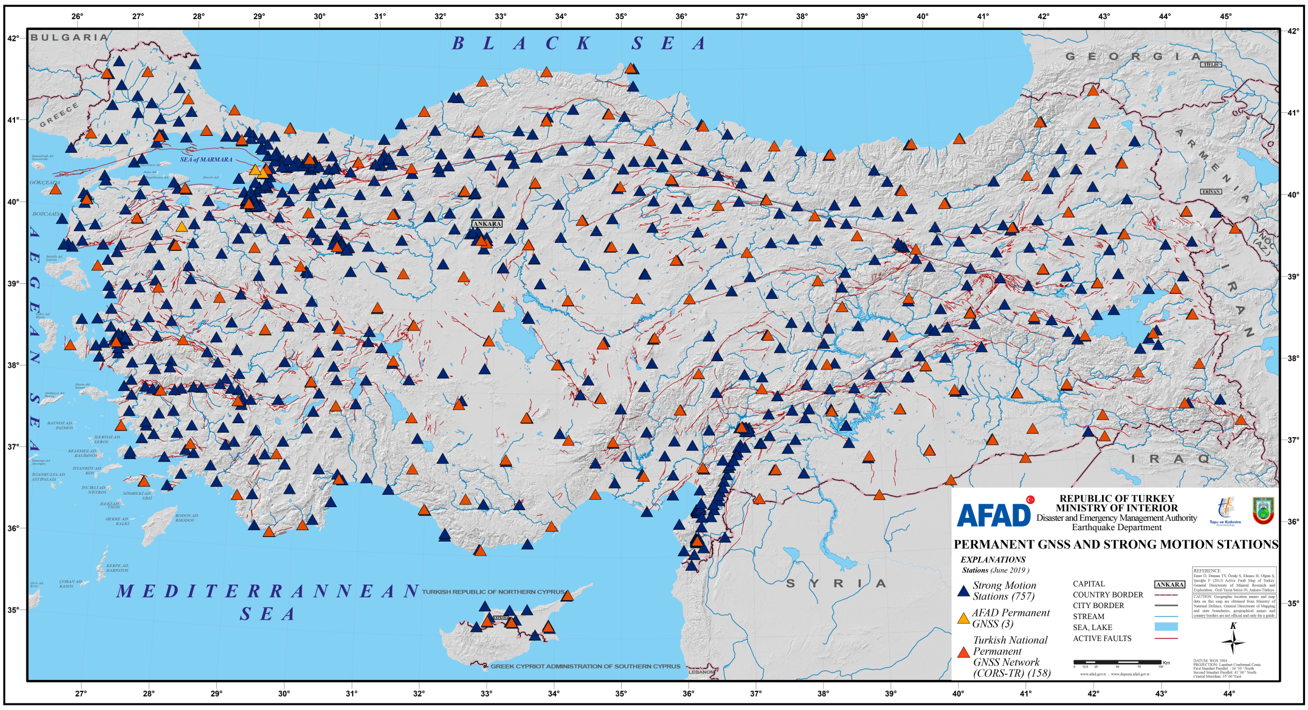

Figure 5.16: *Permanent GNSS Network and Strong Motion Stations. Blue triangles are strong motion stations (757), orange triangles are stations of the Turkish National Permanent GNSS Network (CORS-TR) (158) and yellow triangles are AFAD permanent GNSS stations (3), (June 2019).*

5.2.3 Data Processing

Weak-Motion and Borehole Data Processing

The waveform data are routinely processed manually for event location and magnitude determination using a programme called Earthquake Analysis (EA) that was developed at AFAD (*Yanık*, 2015). The data of the borehole network is integrated into EA in a similar way as the weak motion stations.

Earthquake Analysis Program (EA)

The EA system uses a relational database and has graphical features to quickly access and process the data. Under the current version of EA, Ml is calculated by reading the maximum amplitude on Wood Anderson simulated traces. Several other magnitudes (M_W from spectra, MS, MB, Ms, Mwp) can also be calculated within EA. The EA database can also accommodate other externally provided event parameters, such as fault plane solutions. AFAD also uses SEISAN (*Havskov and Ottemöller*, 1999; *Ottemöller et al.*, 2013) for manual processing of larger events (M$>$ 3.5) to calculate fault plane and moment tensor solutions (*Kılıç et al.*, 2016a).

Outstanding features of Earthquake Analysis (EA) software are:

- Windows based,
- user-friendly,
- easy to install,

- reads popular formats (gcf, sac, seisan, miniseed, suds) directly,
- rapid phase picking,
- computes magnitude automatically,
- based on a relational database.

EA has been developed with Microsoft's Visual Basic 6.0. Several users can simultaneously work with EA on data analysis if EA uses a SQL server. When using a SQL Server, sending e-mails and SMS as well as publishing information on our web pages is performed automatically (Fig. 5.17).

User information is recorded together with the analysed events making it possible to determine user errors (incorrect pickings, solutions with high RMS value etc.). EA matches events and wave forms according to time, station code and components.

EA can query catalogue information from its own database, the Seisan SFILE directory, Seiscomp3 and the USGS PDE catalogue. Data from Seiscomp3 is received via an ARC Link connection. By entering a specific time and the record length, waveforms can be displayed from the current time (UTC) to 5, 10 or 15 minutes backwards (Fig. 5.18). This process makes it easy to analyse the data in real time.

Different tools such as filters, move, resize etc. can be applied to one or more selected waveforms. Waveforms can be sorted according to station, agency and network code or P phase in ascending or descending order. Stations can be sorted according to distance from a selected station. All Butterworth filters such as LP, HP, BP can be applied.

EA can generate residual, Wadati and travel time graphs in order to check the accuracy of the phase readings. It is possible to use multiple crustal models for hypocentre determination. EA uses two different programs, either Hypo2000 (*Klein*, 2002) or Hypocenter (*Lienert and Havskov*, 1995).

We realized two significant projects with data obtained from the TNSN which are: "Development, Pro-

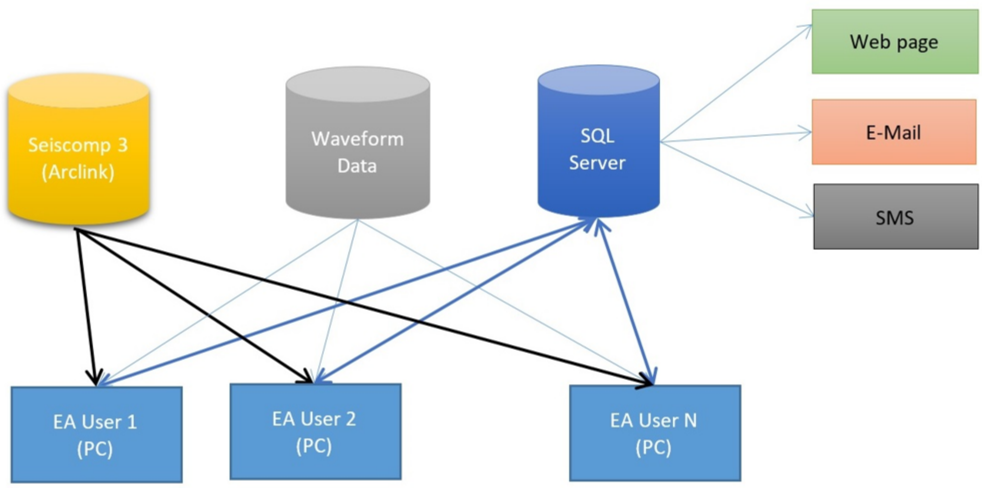

Figure 5.17: *General operational principles of EA Software.*

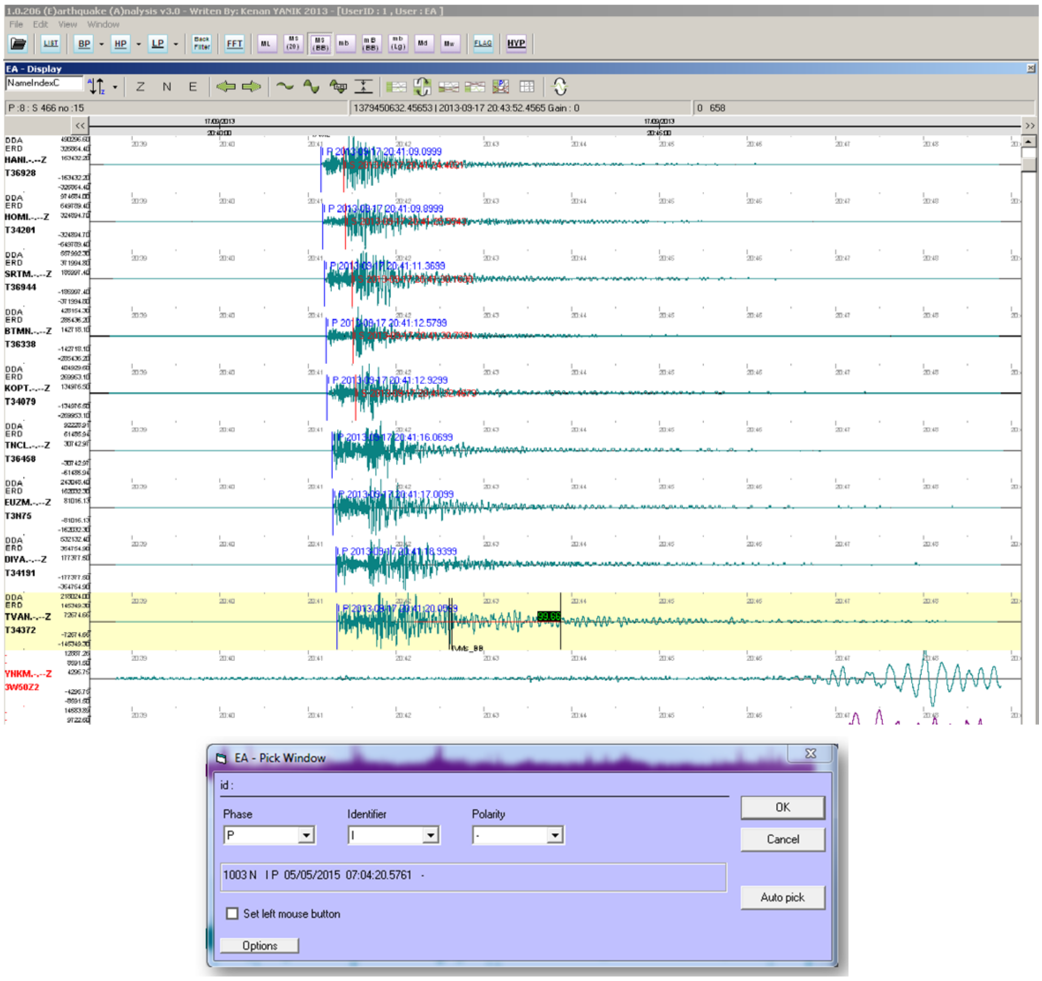

Figure 5.18: *EA waveform and picking window.*

gramming and Calibrating M_W, Ms and Ml Magnitude Scales for the Benefit of National Seismological Network of Turkey" and "The Ambient Noise Analysis of Turkish National Seismic Network".

Development, Programming and Calibrating M_W, Ms and Ml Magnitude Scales for the Benefit of National Seismological Network of Turkey

The project's aim is the calibration of Ml scale and implementation of standard Ml, M_W, MS magnitude computations into the Earthquake Analysis (EA) system.

Algorithms to compute Ml, Ms, MS, Mb, MB and M_W magnitudes are implemented into EA as new subroutines. The modules have been compared and verified against SEISAN. The new program module in EA computes M_W by a spectrum method. The attenuation parameters (Qo, alpha and kappa) are evaluated by two approaches (QLg inversion and by an iterative optimization technique). M_W magnitudes computed by the new codes comply with the values obtained from Dreger Moment Tensor Inversion (SEISAN) (*Dreger et al.*, 2000) as well as those reported by other international agencies. AFAD Earthquake Department is now capable of reporting seven different magnitudes for local and regional earthquakes (*Özyazıcıoğlu et al.*, 2013).

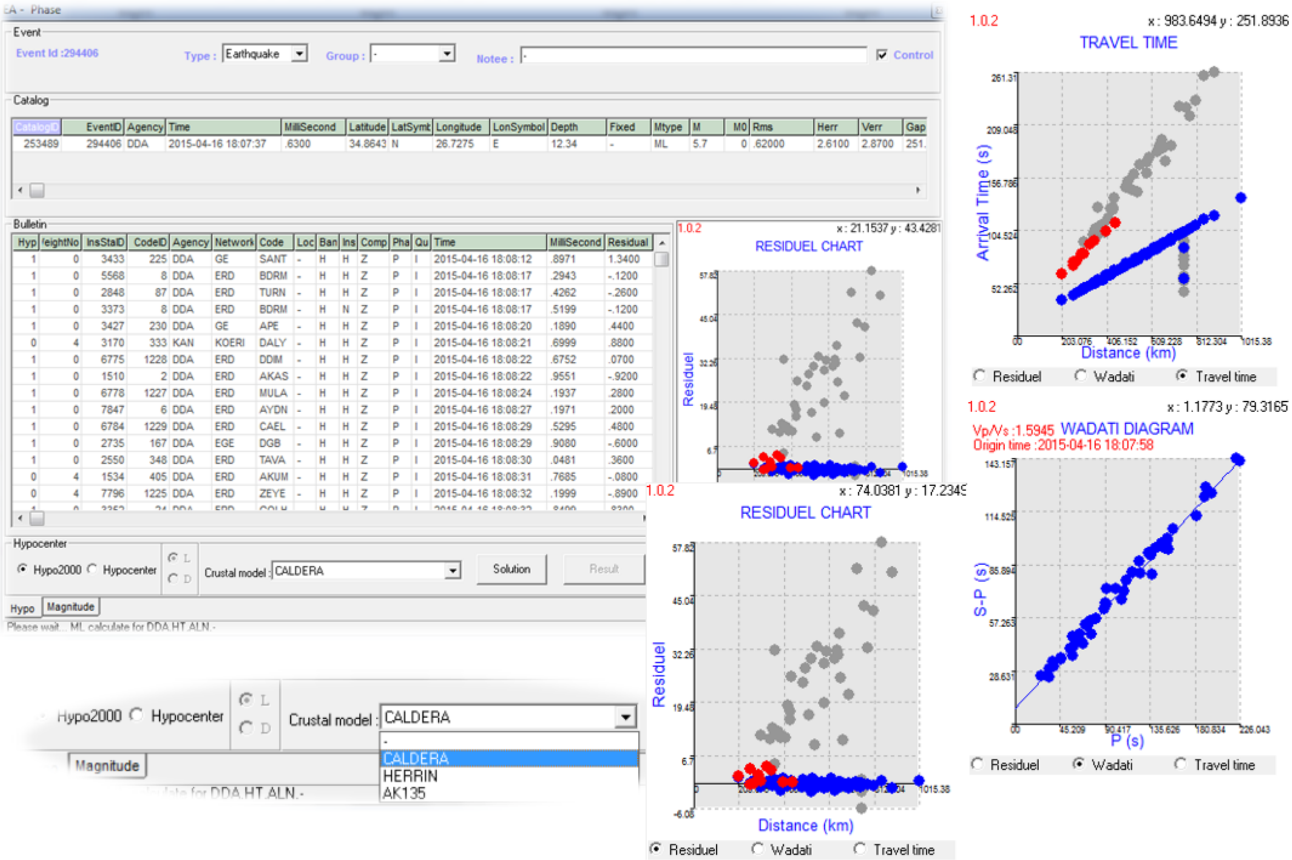

Figure 5.19: *Phase and hypocenter solution windows and Wadati diagram, travel time curve and residuals plots in EA.*

The Ambient Noise Analysis of the Turkish National Seismic Network

Ambient noise analysis is a routine evaluation of performance of seismic networks. With almost 300 broad band seismometer stations, the Turkish National Seismic Network is among the most notable in the world. This network is relatively young and is still expanding. Nevertheless, prior to the project, no efforts are reported to target evaluating the recording quality of this network or an overall noise analysis for Turkey (*Özyazıcıoğlu et al.*, 2015).

The project's aim is the determination of recording quality of Turkish National Seismic Network by extensive noise analyses and development of a noise model for Turkey. In this project diurnal, monthly and annual noise levels for each station were obtained and presented in PDF (Probability Density Function) plots and spectrograms. Ambient noise distribution and noise models for Turkey have been developed with additional stations. For the TNSN, annual, monthly and daily probabilistic density functions and spectrograms were generated and background noise levels were determined. Possible sources (i.e. near sea, volcanically active, weak bed rock etc.) were discussed and recommendations were made to eliminate noise. As a result, a considerable number of instruments have been found to be malfunctioning due to buggy firmware; when firmware updates were applied noise levels in these stations came to normal levels. Furthermore, nearly 50 stations are found to have been used with incorrectly defined response functions.

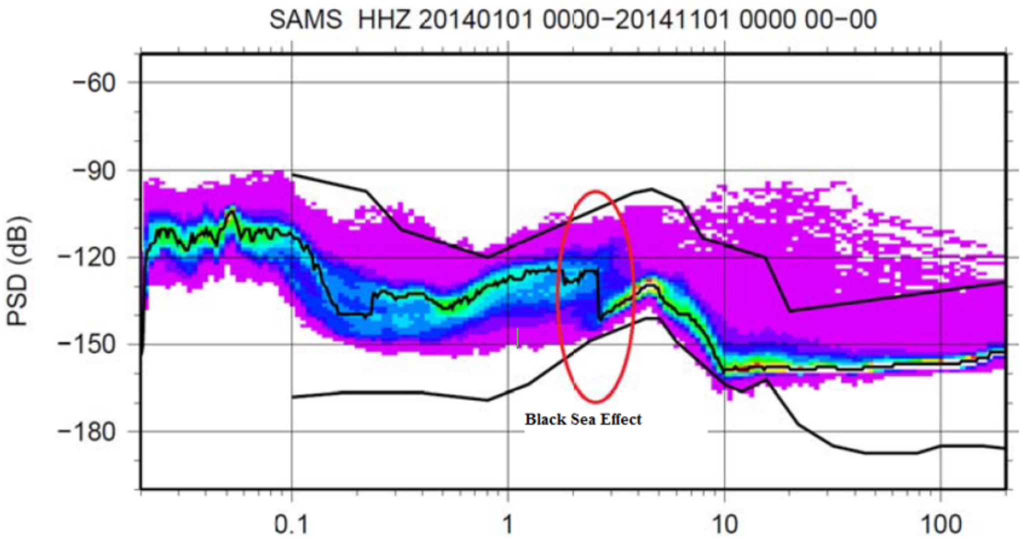

Figure 5.20: *PSD plot of noise related to the Black Sea (SAMS Station Black Sea Shore) (Kılıç et al., (2016b).*

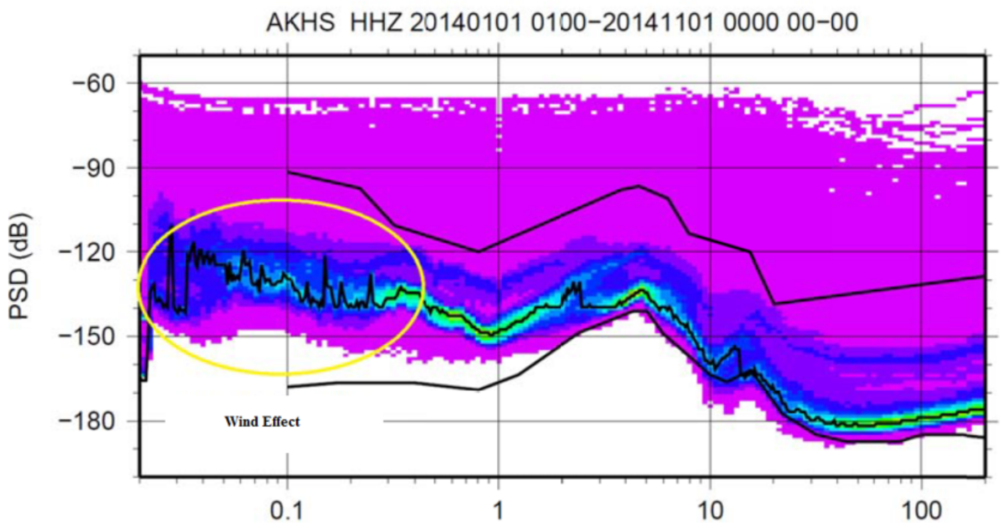

Figure 5.21: *Low-Period noise generated by a nearby post vibrating by the wind (AKHS Station, Manisa, Akhisar) (Kılıç et al., 2016b).*

Another interesting result of our research is the systematic display of high noise up to some characteristic period in stations close to the sea or large size inland lakes. It is seen that these characteristic periods of high noise are related to the size of the sea or lake (proportional to the surface area or volume of water).

Examples of power spectrum density (PSD) plots are given in Figures 5.20 and 5.21. (*Özyazıcıoğlu et al.*, 2015).

Strong-Motion Data Processing

Acceleration records in the database are composed of three types of data. These are: raw waveforms in ASCII format, processed data and RRSM (Rapid Raw Strong Motion Database, `http://www.orfeus-eu.org/rrsm/`) including PGA (Peak Ground Acceleration), PGV (Peak Ground Velocity), PSA (Peak Spectral Acceleration) and instrumental intensity for the purpose of providing input for ShakeMap (Wald et al. 2006). Unprocessed data obtained from different types of instruments are manually analysed and converted to ASCII format by the expert seismologist in the first 24h after the event origin time.

RRSM data, in other words, automatic peak-motion parametric data, that is used as input to ShakeMap is automatically obtained from the SeisComp3 scwfparam module (`http://www.seiscomp3.org/doc/seattle/current/apps/scwfparam.html`) (*Cauzzi et al.*, 2013) once a new earthquake origin is available. AFAD ShakeMaps are automatically generated using the measured ground motions recorded by the strong motion network. For earthquakes greater than 4.5, ShakeMap is revised with the AFAD magnitude, epicentre and fault parameters manually.

The processed data was obtained within the project "Compilation of The Turkish National Strong Motion Network Database According to International Standard" (*Akkar*, 2009). With this project, Turkish national strong-ground motion station site information was provided and accelerometric data was processed. These outputs have been disseminated via an internet-based interface. Information from a total of 17 national and international seismic agencies was used to obtain geophysical parameters of the earthquakes during the compilation of the strong-motion database. When the seismic agency information was insufficient, the relevant reports and technical papers were used to determine the required earthquake parameters. Raw accelerometric data was processed uniformly with a consistent methodology through the windows-based software called USDP (Utility Software for Data Processing) that was developed during the course of the project (*Akkar and Bommer*, 2006). In the framework of processing, 3000 events and 4600 raw accelerometric data between 1976 and 2008 were processed uniformly. Elastic spectral parameters of all records were also determined for researchers by using the same filter method.

5.2.4 Turkey Earthquake Data Center System (TDVM)

One of the major problems for geoscientists is the lack of access to data. With AFAD-TDVM, researchers will have access to the data they need from a single center. Thus, the number of researchers using reliable seismological data will increase and more contributions to solve seismological problems will be achieved.

AFAD-TDVM is coordinated by AFAD Earthquake Department for the purpose of providing data access to the TNSN from a single center. In this way, it is ensured that researchers in both our country and other countries have access to the data quickly and reliably.

Through the AFAD-TDVM, all users have access to data via high speed and performance systems without any discrimination such as person, university or institution. The most important point regarding the performance of this system is data transmission and forming appropriate transmission paths for national and international partners.

AFAD-Earthquake data center consist of 1059 stations (weak, strong motion, borehole and GNSS). All seismological data is sent to AFAD-TDVM via the internet.

At the moment only seismic data (Waveform, Catalogues, Bulletin, Station Information etc.) is stored within the system. Offline data will be included after related projects finish and restrictions on the use of those expired. We collect station information in dataless format, which allows us to revise all information in case of any instrument change. Seismic data is available via `tdvm.afad.gov.tr`. AFAD Earthquake Department shares earthquake data and bulletin catalogues with the ISC (agency code DDA), EMSC and ORFEUS. AFAD Earthquake Department also exchanges real time earthquake data with several countries (Azerbaijan, Geogia, Bulgaria, Romania, Albania, Uzbekistan, Bosnia and Herzegovina and Hungary) under mutual protocols.

The web page is designed to be user friendly. When the user makes a query, all data will be accessible within a minute. The data is sent to the user's e-mail as mini-seed, full-seed or dataless (SEED File).

Data providers for Turkey Earthquake Data Center are: AFAD Earthquake Department, Antalya Metropolitan Municipality, Atatürk University, Natural Movement Research Foundation, Düzce Municipality, Kocaeli Metropolitan Municipality, Osmangazi Municipality, Süleyman Demirel University, Gazi University, Anadolu University, General Directorate of Hydraulic Works, Cumhuriyet University, Dokuz Eylül University, İskenderun Municipality, Kocaeli Metropolitan Municipality, Sakarya University, TÜBİTAK-Marmara Research Centre Geo and Marine Sciences Institute, Boğaziçi University Kandilli Observatory And Earthquake Research Institute, General Directorate of Mineral Research and Exploration, General Directorate of Turkish State Railways.

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