International Journal of the Physical Sciences Vol. 5(15), pp. 2310-2316, 18 November, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

The importance and development of national geodetic networks in map production: A Turkish case study

Ekrem Tuşat

Selcuk University, Çumra Vocational College, 42500 Çumra-Konya/Turkey.
E-mail: etusat@selcuk.edu.tr, etusat@gmail.com.

Accepted 15 November, 2010

Maps are a fundamental requirement for all kinds of infrastructure and engineering projects. Maps are produced by various institutions and organizations for different purposes. The important issue is that these maps from different sources are combined, archived, and stored in way that facilitates the economic use of a country's resources and promotes effective data exchange. For the combining and storing of maps produced by different institutions it is necessary to have accurate knowledge of the datum, coordinate system, projection and accuracy of the map, which is directly related to the datum, scope and accuracy of the national geodetic networks are used in map production. There have been considerable innovations in measurement technologies parallel to the general technological developments that have changed and improved national geodetic networks utilized in map production. This paper will investigate the role of the national geodetic networks in large scale map production in Turkey, taking into account changes in these networks and the geodesic structure and the development of national geodetic networks.

Key words: National geodetic networks, large scale map, the Turkish national fundamental GPS network, continuously operating reference stations-Turkey, global positioning system.

INTRODUCTION

Maps and the information they contain are vital for the planning and development of all kinds of engineering and infrastructure projects, and services. Today, incredible developments especially in computing, satellite and digital techniques have had an impact on the production of geographical information.

It is necessary that the spatial information, that constitutes the basis of Geo-graphical Information Systems (GIS), must be determined with high accuracy and qualification, and that this information be obtained from the National Fundamental Geodetic Networks (Kahveci and Yildiz, 2001). The basic problems encountered in the production, storage and later use of maps and map information are as follows:

Unknown horizontal and vertical datum.
Unknown projection.
Unknown accuracy (Fadaie, 2001).

In Turkey maps have been produced by many different institutions and organizations such as the General Directorate of Land Registry and Cadastre, Municipalities, General Directorate of Highways, Turkish State Railways and General Directorate of State Hydraulic Works. Each institution or organization has produced information intended to meet its own needs and thus, is a duplication of information and a lack of standardization. Indeed, these issues have been addressed in Article 1 of "Guideline on Large Scale Map and Map Information Production", which took effect as of 2005; the purpose of this guideline is to;

(a) Ensure a nationwide standardization in the production of large scale (1/5000 and larger) spatial (geographical) information and maps, monitor production by a single authority and prevent unnecessary repetition of services.
(b) Achieve the attainment by digital, graphic and photographic means of large scale spatial data and its positioning in maps, with three dimensional cartesian coordinates (X, Y, Z or geodetic coordinates in GRS80 elipsoid (latitude, longitude, elipsoid height) based on the Turkish Fundamental National GPS Network coordinate

system and the Helmert orthometric heights (H) based on Turkish National Vertical Control Network –1999. The data obtained using terrestrial, satellite and space, inertial and photogrammetric techniques is to be compiled in national data exchange format so that it can form a basis for geographical information systems and their visualize-tion through information technologies and cartographic techniques (Guideline on Large Scale Map and Map Information Production, 2005).

Since many maps did not connect to national geodetic networks, therefore, development plans and cadastral maps that cover the same map area are in different systems which results in problems for the user such as matching and transformation of the two systems and finding the same benchmark. After the connection to national geodetic networks was made obligatory, the period of grace for the use of locally produced datum has expired and all maps now have to be based on a national datum. However, since old maps still exist there is the problem of matching them to the newly produced maps (Tuşat, 2003).

NATIONAL GEODETIC NETWORKS

One of the most important goals of geodesy is the determination of three-dimensional positioning on earth. The positionings in question are defined on the basis of a certain coordinate system. As measurement systems improve and the higher accuracies that are obtained increase, significant changes and difficulties emerge in the definition of the coordinate systems. For example, the positioning of satellites from which measurements are taken must be defined in known coordinate systems.

National geodetic networks are not the objective in geodetic studies but rather they are tools. Therefore, the definition, purpose, scope and service fields of geodetic networks must be determined very carefully. National fundamental geodetic networks are a set that is com-posed of points that are marked on the ground at certain and appropriate intervals to include all of a country's territory and their positions in relation to each other and their components of absolute gravity in each one are determined together with their accuracy rates (Gürkan, 1985).

The goals of national geodetic networks, on the other hand, can be defined as assisting directly or indirectly with all kinds of plans and projects especially for military, economic and social purposes intended for the deve-lopment of the country. National fundamental geodetic networks have in the past, involved; horizontal control (Geodetic) networks, vertical control networks and gravity networks.

Today, there is a single network that fulfils the tasks that were carried out by the three networks given above. Therefore, national fundamental geodetic networks are expected to possess three dimensional, the required epoch, high precision coordinate and gravity values on a global coordinate system and fulfill the function of imple-menting project information in practice. The development of the description of positioning made by Manning and steed (2001) is shown in Figure 1. As seen in the figure, expectations from geodetic networks have increased over time in parallel to the development of the description of positioning over time.

Given that significant changes have occurred in positioning information as a result of tectonic plate move-ments and earthquakes, the importance of determining the concept of epoch, that is the velocity factor in addition to the coordinate, increases twofold. Moreover, geodesy has been influenced by the process of globalization espe-cially as a result of the activities of space geodesy and has made it necessary for national geodetic networks to be defined on a three-dimensional, terrestrial and global coordinate system.

The Turkish national geodetic network (TNGN)

Studies about the fundamental geodetic networks in Turkey began in 1932 with benchmarking, horizontal angle, vertical angle, base and astronomic measure-ments within the scope of the 1st Order Horizontal Control Network. This network consisted of 27 large tri-angulations, a geodetic polygon, and covers the whole of the country. These triangulations consist of triangles that have sides of 25 to 35 km. The HAYFORD 1910 ellipsoid was used in the evaluation of the TNGN (General Command of Mapping, 1988). The datum of the National Geodetic Network is ED50 (European Datum, 1950). This datum was realized by connecting to 8 geodetic control stations of the European network from Greece and Bulgaria (Çelik et al., 2004).

The guideline numbered 19711 that took effect after it was published in the Official Gazette dated 31st January 1988 and titled of "Guideline on the Production of Large Scale Maps" required that all kinds of geodetic work have to be based on the Turkish National Geodetic Network. However, deformations have occurred in this network over time for physical and geometric reasons (General Command of Mapping, 1988; Turgut, 1991), and a need has arisen for a new fundamental network Figure 2.

The Turkish national fundamental GPS network (TNFGN)

It has been concluded that as a result of regional and local horizontal positioning deformations in the national fundamental horizontal control network points, height deformations have occurred at points in the North Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ), Aegean Region and Eastern Anatolia Region and they have ceased to meet practical utility

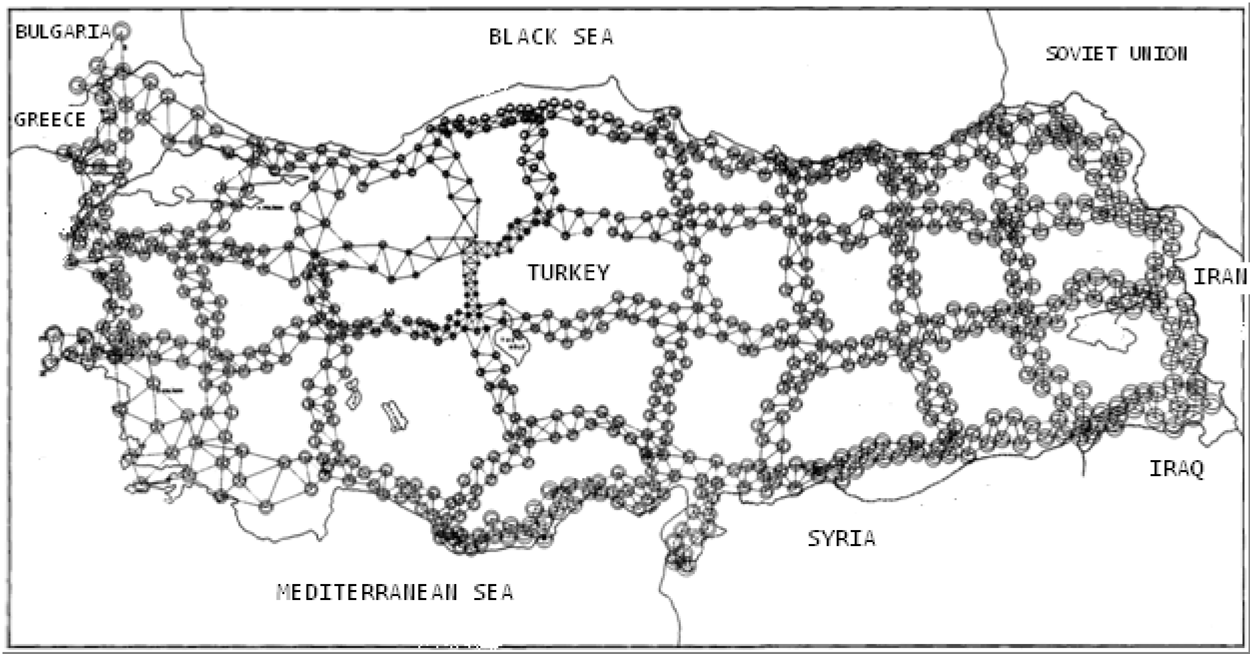

Figure 1. Developmental stages of the description of positioning.

Coordinate

↓

Coordinate + Datum

↓

Coordinate + Datum + Epoch

↓

Coordinate + Datum + Epoch + Accuracy

Figure 2. Turkish national geodetic network and point errors (General Command of Mapping, 1988).

needs. The use in geodesy of the Global Positioning System (GPS) based on satellite geodesy since the end of the 1980s has attained a precision level of 0.1-0.01 ppm with GPS, rendering the regional and local deformations in the current national fundamental horizontal control network more prominent and thus the need to form a new geodetic fundamental network and consequently the TNFGN was established Figure 3.

The TNFGN is a network that consists of 594 highly homogenously distributed points, on the International Terrestrial Reference Frame (ITRF) coordinate system. This has three-dimensional coordinates (X, Y, Z) and velocities of these coordinates (Vx, Vy, Vz), their heights in appropriate height systems (H) and geoid height (N) are known with an accuracy level of 1-3 cm, the point interval is 25 - 50 km but can be 15 km in areas where the geoid exhibits variation (Ayhan et al., 2002). The TNFGN consists of the following five fundamental components:

(a) A GPS network whose 1998.0 epoch-coordinates are known in International Terrestrial Reference Frame.
(b) TNFGN-99 Velocity Zone.
(c) Coordinate transformation between TNFGN-99 and

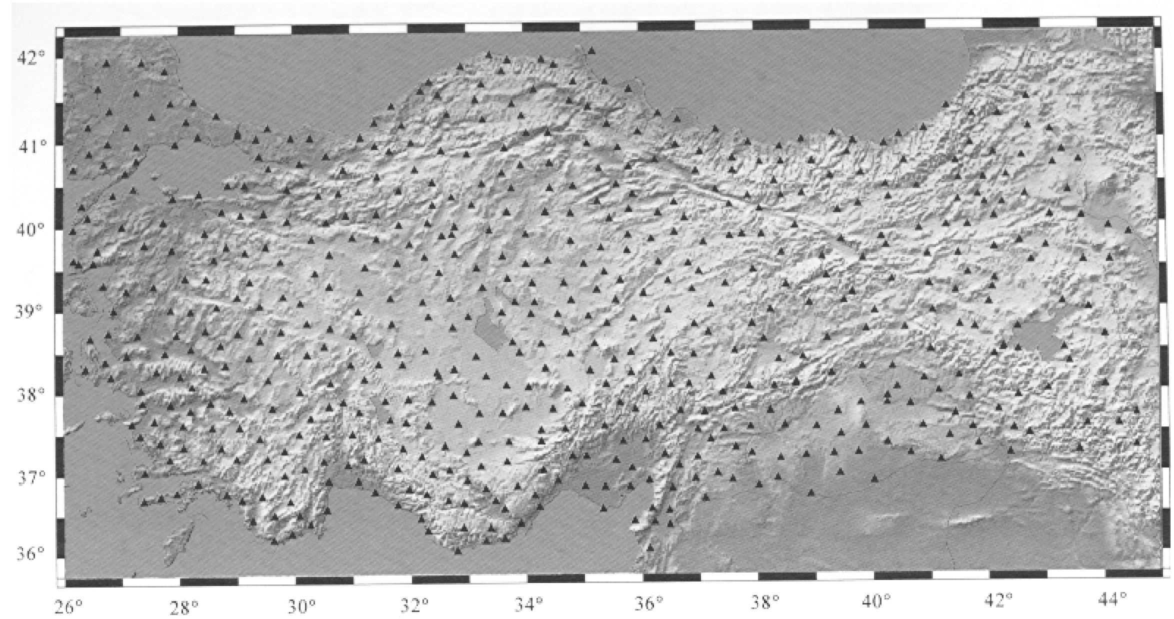

Figure 3. The Turkish national fundamental GPS network (www.hgk.mil.tr).

ED50.
(d) The Turkish National Vertical Control Network-1999 (TNVCN-99) with a known Helmert Orthometric Height at every point.
(e) Turkey Geoid 1999 (TG-1999).

Here, the number 99 means the epoch values that were initially announced; in particular, the TNFGN velocity zone and geoid of Turkey are updated over time and efforts continue to improve them.

Continuously operating reference stations-Turkey (CORS-TR)

Changes have occurred in fundamental geodetic networks in parallel to the developments in GNSS technology, and the concept of epoch has become one of the essential concepts in map production with the introduction of ITRF. With this change in the networks, the concepts of static and dynamic networks have emerged, and instead of static fundamental geodetic networks that are composed only of points and coordinates, GNSS stations that broadcast observations and data for 24 h, together with the concept and applications of a dynamic network that consists of data control centres have begun to be used. In parallel to these developments on a global level, the establishment of CORS-TR (CORS-TR, 2010) has been completed and has begun to be used in map production Figure 4.

CORS-TR is a research and application project that operates on network principle and is intended to establish realtime kinematic (RTK) GPS stations and determine cellular transformation parameters. It is used in collecting positioning data in a rapid, economic and more reliable manner, realtime monitoring of plate movements in the earth's crust, earthquake modeling, atmosphere and ionosphere modeling and long-term climate forecasts. The CORS-TR network consists of 146 permanent stations in Turkey and the Turkish Republic of Northern Cyprus. All the stations operate on a 7-day-24-h-basis and connect to the servers through ADSL or alternatively EDGE. The system can be utilized in the form of RTK or static applications.

This infrastructure can be used by all of RTK-operating dual-frequency GPS/GNSS receivers and all kinds of single-frequency GPS/GNSS receivers that can receive RTCM correction. As the corrections are broadcast via GPRS/EDGE, the NTRIP protocol must be supported in the receiver and/or control unit in order to connect to the system; also, there must be a built-in GPRS modem in the receiver and/or control unit (it could also be a connect card in the form of CF card) or the system can be accessed by a mobile phone via Bluetooth or cable. All GSM operators can connect to the system (CORS-TR 2010). (Thus, a user with a GNSS receiver that is compatible with the system can obtain coordinates, real-time and continuously, ITRF96 datum at a 2005.0 epoch.

PROBLEMS IN USING NATIONAL GEODETIC NETWORKS IN THE PRODUCTION OF LARGE SCALE MAPS

Datum problem

The horizontal control national geodetic network that had been used in Turkey and TNFGN and CORS-TR

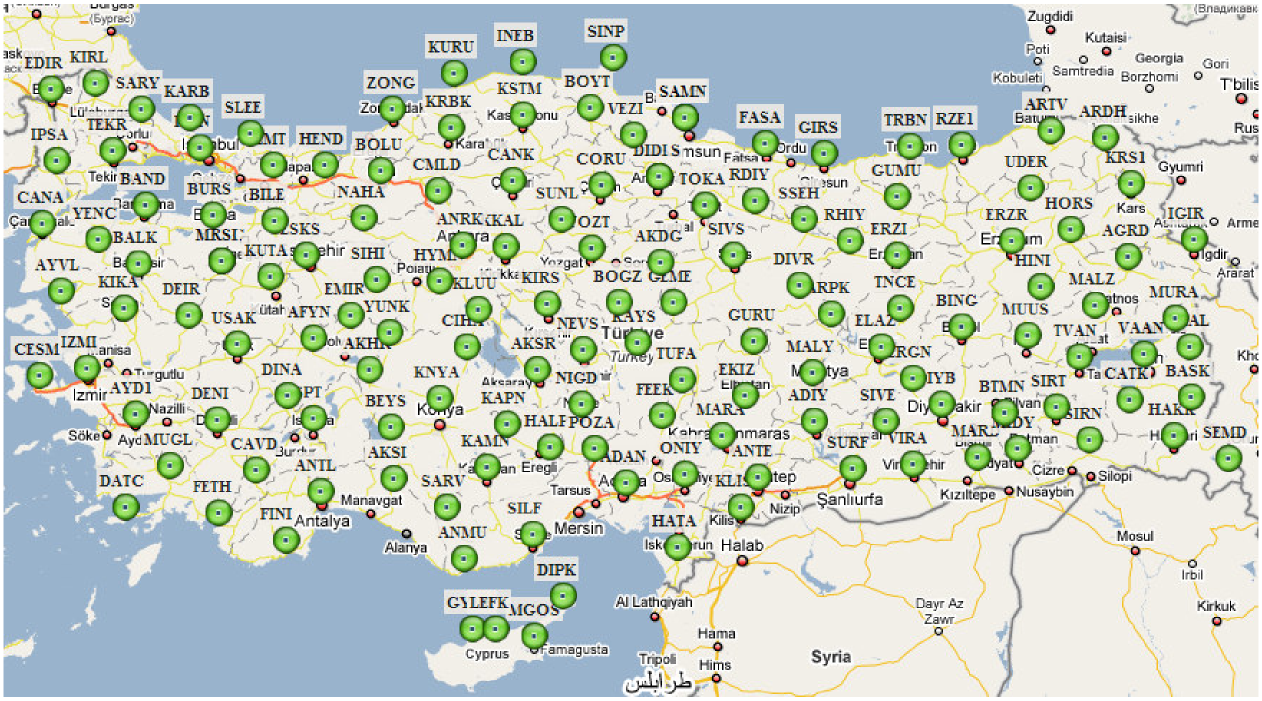

Figure 4. CORS-TR (http://cors-tr.iku.edu.tr).

Table 1. The geodetic infrastructure used in TNGN, TNFGN, CORS-TR and GPS.

	Datum	Ellipsoid	Coordinate System	Projection
TNGN	ED50	International Hayford	2B (φ,λ)+H	TM-UTM
TNFGN	ITRF96	GRS80	3B (φ,λ,h)+T	TM-UTM
CORS-TR	ITRF96	GRS80	3B (φ,λ,h)+T	TM-UTM
GPS	WGS84	WGS84	3B (φ,λ,h)	TM-UTM

Networks that are currently in use and the datum, ellipsoid, coordinate system and projection that are used by the GPS system are given in Table 1 for each network.

As can be seen in Table 1, the datum and ellipsoid of the systems, and their positioning and coordinate structures are different. The geodetic infrastructure of the horizontal control national geodetic network is the two dimensional (2D) ED50 system (European Datum, 1950); it consists of a system that combines the positioning of the international Hayford ellipsoid according to the Postdam-Helmertturm point and horizontal coordinates which are defined as the elipsoidal coordinates of the points in this system or UTM (in Universal Transversal Mercator Projection, Easting, Northing), which will be calculated from them and orthometric heights (H).

On the other hand, the GPS system is based on the datum of WGS84 (World Geodetic System, 1984) which is ellipsoid of this datum, and its coordinates can be obtained as three-dimensional (3D) ellipsoid-centred Cartesian (X, Y, Z), ellipsoidal (ϕ, λ, h) or (Easting, Northing) in the WGS84 system.

In the TNFGN and CORS-TR Networks, coordinates are defined by the ITRF96 coordinate system and 2005.0 epoch. The fundamental difference between the two is that TNFGN is a static network and involves points whose velocities and coordinates are known in the ITRF96 datum; CORS-TR, on the other hand, is a dynamic network that consists of points that make observations in the same datum and epoch 24 h and control centers which broadcast corrections.

Before 1988 it was not necessary to base maps of Turkey on the national network. Therefore, only local coordinate systems were formed in all areas where maps were made and a nationwide standardized coordinate and datum system could not be attained. With the "Large Scale Map Production Guideline" (LSMPG) in 1988, it became obligatory to base maps on the TNGN, and with the "Guideline for Large Scale Map and Map Information Production" published in 2005, it became compulsory for all geodetic studies to be based on TNFGN. With the introduction of TNFGN, Turkey replaced its old datum resulting in the problem matching maps and map information produced in Turkey before 2005 and those to be produced in future. In particular, there is a need to calculate the local transformation parameters for map studies conducted in large areas.

Height problem

Coordinates are obtained by connecting to the TNFGN or CORS-TR are GRS80 ellipsoid heights (h) in the ITRF datum. In practice, however, orthometric heights (H) are used hence, it is necessary to calculate orthometric heights from ellipsoid heights obtained from GPS.

One of the five major components of the TNFGN is the Turkish Geoid-1999 (TG-1999). It is stated that TG-99A has a precision of 10 cm and an accuracy of 15 cm (Kılıçoğlu, 2002). It is thought that TG-99A can be used directly in small and medium scale (1/25000 and smaller) maps, but it can be used directly or, after some improvement, in the production of 1/5000 and larger scale maps using GPS/Levelling geoid heights that are formed by 4 to 6 points (Ayhan et al., 2002). On the other hand, efforts continue to improve the Turkish Geoid. When a Turkish Geoid has accuracy in a few centimeters for the levels allover Turkey, these problems will be removed.

In the applications currently in use, this problem can be overcome through local geoid determination studies for large-scale map production. However, although the accuracies in these methods are sufficient for maps produced for cadastral purposes and those from which urban and regional plans will be drawn, it can be said that in studies such as domestic water supplies, irrigation, drainage and road projects where orthometric heights are far more important, heights would be better given in leveling.

Transformation problem

With the basing of networks that perform measurements via GPS on TNFGN, the XYZ cartesian coordinates of points in the ITRF system and their latitudes, longitudes and heights can be obtained according to the GRS80 ellipsoid. In order to transform these coordinates obtained through GPS measurements into the ED50 system, it is necessary to take GPS measurements for a sufficient numbers of points that are homogenously distributed in and around the area of study and whose coordinates are known in the ED50 system and then calculate the coordinates of these points in the ITRF system. With these coordinates that are known in both systems, the transformation parameters from the ITRF system to the ED50 system are calculated.

Although, ITRF coordinates are three-dimensional, they are not at the same accuracy level because ED50 coordinate system is in the form of 2B+H and the altitudes of the national geodetics in this network are determined through trigonometric leveling. Therefore, it would be more appropriate to handle the transformation from the ITRF datum to ED50 datum two-dimensionally. However, application of a three-dimensional transformation would be a better solution if the heights to be used in the transformation are known in sufficient accuracy, the area covered by the GPS network is not big and there are sufficient points with known heights. When operating in large areas, the relationships between the ED50 system and the ITRF should be handled separately for the horizontal position and the vertical position and a local geoid surface within the accuracy of centimeters should be determined for the area (Çelik, 2000).

Epoch problem

In particular, with the introduction of TNFGN and the guideline that took effect in 2005, making it obligatory to base all large scale maps on this network. All large-scale maps have been produced in a 1998.0 epoch. However, while the reference epoch is 1998.0 for the initial broadcast TNFGN values and 2000.45 for the areas affected by the 1999 earthquake, it was re-broadcast in 2005.0 epoch after the point velocities were updated. Thus, although all maps are in ITRF96 datum, their epochs are variable (1998.0, 2000.45 or 2005.0).

CONCLUSION

Certain standards need to exist so that national resources can be used more effectively and productively, better quality maps and map information can be generated and this information can be used by individuals, institutions and organizations. With the obligation to be based on national geodetic networks, all nationwide maps should be produced in the same datum and coordinate system, in a known epoch, projection and accuracy. When the development of geodetic networks in Turkey, it can be seen that initial applications of local datum and coordinate systems are being undertaken. With the introduction of RLSMMIP in 1988, all geodetic studies were based on the National Geodetic Network, known as the ED50 network, thus the uniformity of datum and coordinate was ensured. However, a need arose for a new network as a result of the developments in GPS technology and geometric and physical deformations in ED50 network thus TNFGN was introduced. With the introduction of the Guideline on Large Scale Map and Map Information Production in 2005, it was stipulated that all types of map information produced in the country were be based on TNFGN and included in the ITRF datum.

With the development of the concept of dynamic network, CORS-TR was introduced and began to be used as the fundamental network in map production.

REFERENCES

Ayhan ME, Demir C, Lenk O, Kılıçoğlu A, Aktuğ B, Açıkgöz M, Fırat O, Şengün YS, Cingöz A,Gürdal MA, Kurt Aİ, Ocak M, Türkezer A, Yildiz H, Bayazıt N, Ata M, Çağlar Y, Özerkan A (2002). Turkish Fundamental GPS Network, General Command of Mapping, J. GCM, 16, Ankara.

Çelik RN (2000). GPS and National Geodetic Networks**,** Union of Chambers of Turkish Engineers and Architects Chamber of Survey and Cadastre Engineers Bulletin of Istanbul Branches - July, Istanbul, Turkey.

Çelik RN, Ayan T, Deniz R, Özlüdemir MT (2004). Geodetic Infrastructure of Turkey for GIS, GPS and Remote Sensing Applications, XXth ISPRS Congress, 12-23 July, İstanbul, Turkey.

CORS-TR (2010). Project of Establishment of International CORS System and Determination of Datum Transformation Parameters, http://cors-tr.iku.edu.tr/ (last visited date: 15-07-2010)

Fadaie K (2001). International Geomatics Standards Development Activities, Natural Resources Canada, Digital Earth 2001 Symposium, Fredericton, Canada.

General Command of Mapping (1988). The Points Error As An Adjustment in 1954 of Turkish First Order Horizontal Control Network, General Command of Mapping, Scientific Report Number: 1, 22 p, Ankara, Turkey.

Guideline on Large Scale Map and Map Information Production (2005). published in the Official Gazette dated 15th July 2005 numbered 25786 , http://www.hkmo.org.tr

Guideline on Large Scale Map Production (1988). Published in the Official Gazette dated 31st January, numbered 19711, Ankara, Turkey.

Gürkan O (1985). Requirement of National Geodetic Network and Sequence of Establishment, Boğaziçi University, Istanbul, Turkey.

Kahveci M, Yildiz F (2001). GNSS Theory-Practice, Nobel Press, p. 184, Ankara, Turkey.

Kılıçoğlu A (2002). The Updated Turkish Geoid (TG-99A), The workshop of Tectonic and Geodetic Networks, Turkey National Geodesy Commission Scientific Activities, Boğaziçi University, Iznik-Turkey (in Turkish).

Manning J, Steed J (2001). Positional Accuracy, A Spatial Data Foundation, International Symposium on Spatial Data Infrastructure (SDI), 19-20 November, University of Melbourne, Australia.

Turgut B (1991). Acceptability of Turkish National Geodetic Network in Large Scale Map Production. PhD dissertation, Selçuk University, Konya, Turkey.

Tuşat E (2003). Investigation on the Geodetic GPS Observation and Processing Standards Relevant To Large Scale Mapping. PhD dissertation, Selçuk University, Konya, Turkey.