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Velocity dynamics in Türkiye's nationwide cadastral network

Türkiye geneli kadastral ağlarda hız dinamiklerinin incelenmesi

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Abstract

Turkey, situated within a tectonically active region, is subject to frequent seismic events that induce crustal deformation of varying magnitudes. These deformations differentially affect geodetic infrastructure across distinct zones, leading to measurable variations in the velocity fields of geodetic benchmarks. This study investigates continuous velocity changes observed at geodetic sites across Turkey, resulting from cumulative deformation between the establishment of the geodetic network and the present day. Velocity components (Vx, Vy, Vz) for C1 and C2 benchmarks were obtained from the Map Data Bank (HBB) and compared with contemporary velocities predicted using the Turkish National Reference Frame (TUREF) published by the General Directorate of Mapping (HGM). Cartesian velocities of 482 C1 and C2 sites distributed across Turkey were analyzed, and component-based velocity difference maps were generated. Maximum velocity discrepancies were determined as 25 mm/year (X-component), 39 mm/year (Y-component), and 37 mm/year (Z-component). These inconsistencies highlight the potential for decimeter-level errors in the coordinates during long-term epoch transformations, which may propagate into cadastral infrastructure distortions.

Keywords: Velocity accuracy, Interpolation, GNSS velocity, Epoch translation, C1-C2 sites

Öz

Tektonik olarak aktif bir bölgede yer alan Türkiye, çok sayıda depreme maruz kalmakta ve bunun sonucunda farklı büyüklüklerde deformasyona uğramaktadır. Bu deformasyonlar jeodezik altyapıyı farklı bölgelerde ve farklı büyüklüklerde etkileyerek jeodezik noktaların hızlarında değişimlere neden olmaktadır. Bu çalışma kapsamında jeodezik altyapının kurulduğu süreçle günümüz arasında meydana gelen birikmiş deformasyonlar sonucunda Türkiye genelinde jeodezik noktalarda meydana gelen hız değişimleri incelenmiştir. Bu amaçla Harita Bilgi Bankası'ndan C1 ve C2 noktalarına ait Vx, Vy ve Vz hızları temin edilmiş ve bu noktaların Harita Genel Müdürlüğü (HGM) tarafından yayınlanan Ulusal Jeodezik Hız Alanı (TUREF) kullanılarak kestirilen güncel hızları arasındaki farklar incelenmiştir. Türkiye geneline dağılmış 482 adet C1 ve C2 noktasına ait kartezyen hız verileri incelenerek her bir nokta için bileşen bazında fark haritaları üretilmiştir. X, Y ve Z bileşenleri için hız farkları sırasıyla maksimum 25, 39, 37 mm/yıl olarak elde edilmiştir. Bu farklar uzun dönemde yapılacak epok taşımalarının koordinatlarda desimetre seviyesinde hatalara neden olabileceğini ve kadastral altyapıda bozulmalara neden olabileceğine işaret etmektedir.

Anahtar kelimeler: Hız doğruluğu, Enterpolasyon, GNSS hızı, Epok taşıma, C1-C2 noktaları

1 Introduction

Turkey, due to its unique tectonic setting, lies within one of the most actively deforming segments of the Alpine-Himalayan Orogenic Belt—one of the world's three major seismic zones in terms of seismicity. The neotectonic evolution of Turkey and adjacent regions is closely linked to continental convergence driven by the collision between the African-Arabian and Eurasian plates, as well as subsequent geological processes arising from this interaction [1,2]. The Anatolian Plate, subjected to the northward motion of the Arabian Plate toward the Eurasian Plate, undergoes westward displacement. The movement of Western Anatolia, constituting the western segment of the Anatolian Plate, is characterized by SW-directed motion resulting from the subduction of the African Plate beneath the Eurasian Plate along the Hellenic Arc [3-5] (Figure 1). The Anatolian Plate, situated between the tectonically stable Eurasian Plate to the north and the southward-advancing African and Arabian Plates, hosts numerous active faults resulting from compressional forces and kinematic loading induced by these two southern plates. In addition to these primary active fault structures, secondary fault systems and fault zones divide Anatolia into smaller blocks, contributing to the neotectonic evolution of the Anatolian block. This dynamic process has given the region with a structurally complex and rapidly deforming geological character. The Anatolian Plate, traversed by active fault zones, has historically hosted and continues to host numerous large, destructive earthquakes.

The deformation resulting from the collision of the Eurasian and Arabian plates along the Bitlis-Suture Zone led

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to the formation of the left-lateral strike-slip East Anatolian Fault Zone (EAFZ) and the right-lateral strike-slip North Anatolian Fault Zone (NAFZ). The ongoing convergence between the Eurasian and Arabian plates following their collision has driven the development of four distinct neotectonic provinces in Turkey: The East Anatolian contractional province, the North Anatolian province, the Central Anatolian "Ova" province, and the Western Anatolian Extensional Province (WAEP) [6-8]. The NAFZ, one of the most significant tectonic elements of the Anatolian Plate and a transform fault system with an E-W orientation and right-lateral strike-slip motion that separates the Eurasian and Anatolian plates, extends from the north of Lake Van in the east. It progresses westward from Karlıova through Erzincan, Suşehri, Reşadiye, Erbaa, Havza, Ladik, Kargı, Ilgaz, Kurşunlu, and north of Çerkeş, continuing through İsmetpaşa, Gerede, Bolu, and Lake Abant, then traverses Lake Sapanca and the Gulf of İzmit, passing beneath the Sea of Marmara, and extends to the southern part of Thrace [9,10]. An examination of historical and instrumental earthquake records reveals that numerous destructive earthquakes with surface ruptures have occurred along the NAFZ, with magnitudes ranging between 6.3 and 7.4 (Mw), including notable events such as the 1992 Erzincan, 1999 Düzce, and 1999 Gölcük earthquakes [11-14]. EAFZ, the second major fault zone of the Anatolian Plate, intersects with the NAFZ near Karlıova in the north and extends from Gölbaşı through Kahramanmaraş and the Amik Plain to the Mediterranean Sea. This fault zone, which exhibits a complex left-lateral strike-slip motion in a NE-SW orientation, has also experienced numerous destructive earthquakes, the most recent being the 2023 Maraş earthquakes (Pazarcık Mw: 7.7 and Ekinözü Mw: 7.6) [15-19]. Following the NAFZ and EAFZ, the WAEP stands out as one of the most significant seismic source regions in the platelet. Deforming at an average rate of approximately 20 mm/year, it is among the fastest deforming continental regions in the world. This region typically releases accumulated energy through numerous low-to-mid magnitude swarm-type seismic activities, yet, similar to other regions of the Anatolian Plate, it has also experienced numerous destructive earthquakes with magnitudes exceeding M:6 (1919-Balıkesir, 1955-Söke, 1970-Kütahya, 1995-Dinar), [12, 20]. Although Central Anatolia is considered a relatively quiet region in seismically active Turkey, it contains faults of varying orientations and characteristics due to the extensional regime from the west and the escape tectonics driven by the compressional forces from the east acting on the Anatolian Plate. The main tectonic structures in the Central Anatolian region include the left-lateral Central Anatolian Fault Zone, the Tuz Gölü Fault Zone with a right-lateral and normal fault component, the İnönü–Eskişehir Fault System, the Konya Block Fault Zone, and the Akşehir Fault Zone [21-24]. Numerous earthquakes with magnitudes exceeding M:5 have occurred in the crust forming the central part of the Anatolian Plate during the instrumental period, the most recent of which is the 2023 Obruk earthquake (Mw: 5.3) (1921-Altınekin, 1938 Kırşehir, 1968-Cihanbeyli, 2007-Bala, 2016-Çiçekdağı, 2020-Obruk) [12, 20].

In addition to the complex and multiple damage they inflict on natural and artificial features through ground shaking, earthquakes—particularly those with M≥6 and shallow focal depths—can generate surface ruptures ranging in length from centimeters to kilometers [25]. A surface rupture, defined as the deformation that can occur on the Earth's surface as a result of a moderate to large earthquake ($M \geq 6$) originating from a fault, is directly related to the earthquake's magnitude, focal depth, fault geometry, rupture process and propagation, as well as the intrinsic properties of the units affected by the fault and located near the surface [26]. Furthermore, the displacement (slip) between blocks on either side of a fault zone varies depending on the earthquake's magnitude. These surface ruptures and displacements, which cause significant crustal deformation, have produced substantial horizontal and vertical displacements in events occurred earlier:

- The 1939 Erzincan earthquake (Mw 7.8) generated ~360 km of surface rupture with ~7.5 m of slip
- The 1999 Gölcük earthquake resulted in ~130 km of rupture with ~5 m displacement
- The 2002 Çay earthquake created ~26 km of rupture with up to 30 m vertical displacement [27-29], (Figure 2).

Among the most significant seismic disasters recently experienced in Turkey, the 2023 Kahramanmaraş earthquakes (Mw 7.7 Pazarcık and Mw 7.6 Ekinözü) produced surface ruptures spanning 80-270 km across different segments, with observed displacements exceeding 7 meters [18, 30-34]. The surface ruptures and displacements, which are more prominently observed during large shallow earthquakes, cause significant positional changes in reference points especially near the epicenter where displacements are measured, leading to substantial damage to geodetic infrastructure. Determining the horizontal and vertical displacements caused by seismic events is crucial for maintaining the accuracy of position-based studies post-earthquake. In this context, preserving the currency of geodetic infrastructure against such deformations is of critical importance

As detailed in the preceding section, historical records indicate that Turkey experienced over 200 destructive earthquakes prior to 1900. During the instrumental period, numerous earthquakes exceeding magnitude 7.0—occurring in various regions and at different times—have caused significant casualties, surface ruptures, and consequently major infrastructure damage and economic losses [35]. In seismically active Turkey, earthquakes frequently generate vertical and horizontal crustal movements reaching several meters in magnitude. Such displacements can now be accurately modeled using data obtained from GNSS observations, facilitated by advancements in Satellite Technologies [36-42]. Intraplate tectonic movements and their resultant earthquakes not only cause socio-economic damage but also directly impact the country's geodetic infrastructure by inducing annual centimeter- to meter-scale displacements of surface points [43].

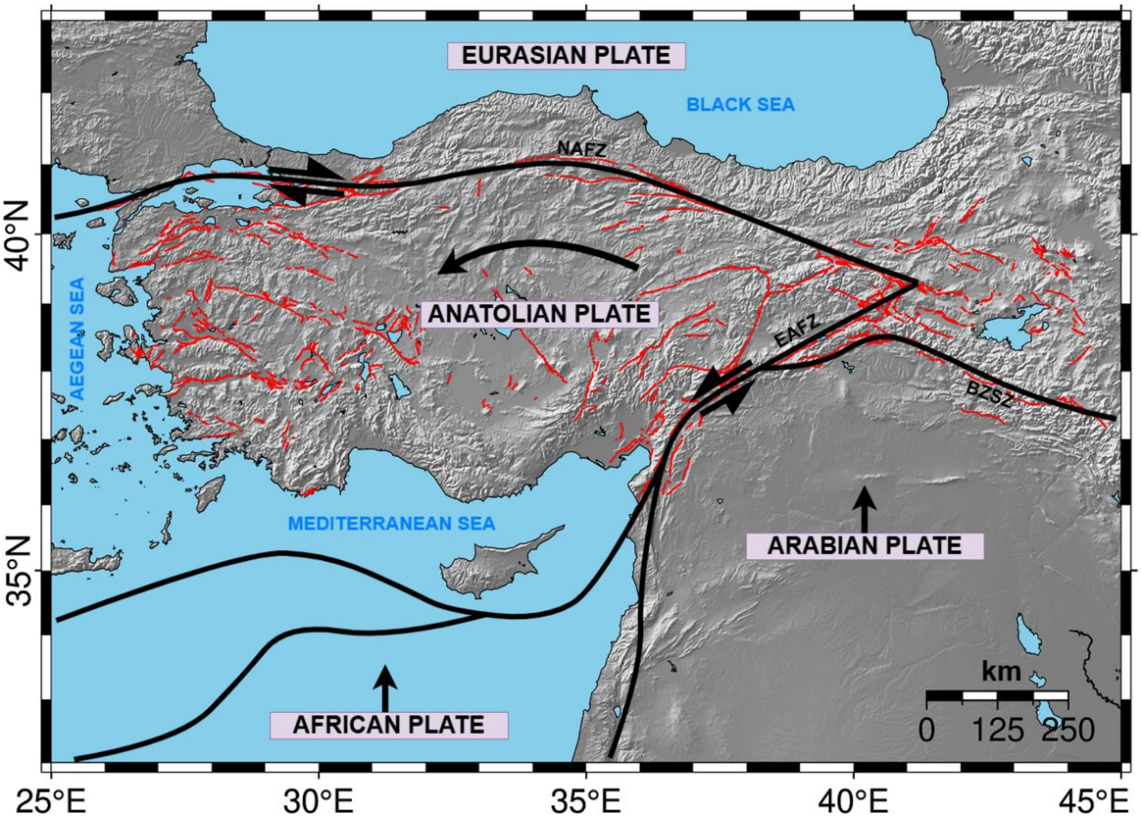


Figure 1. The major tectonic structures within the Anatolian Plate are shown in the Figure (red lines represent faults sourced from Emre et al. [11], while light gray lines denote faults obtained from Zelenin et al. [44], Şafak Yaşar [45] Thick black arrows indicate the motion directions of major plates, whereas thick black lines represent principal plate boundaries (NAFZ: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, BZTS: Bitlis-Zagros Thrust Belt, DSFZ: Dead Sea Fault Zone, HA: Hellenic Arc, CA: Cyprus Arc).

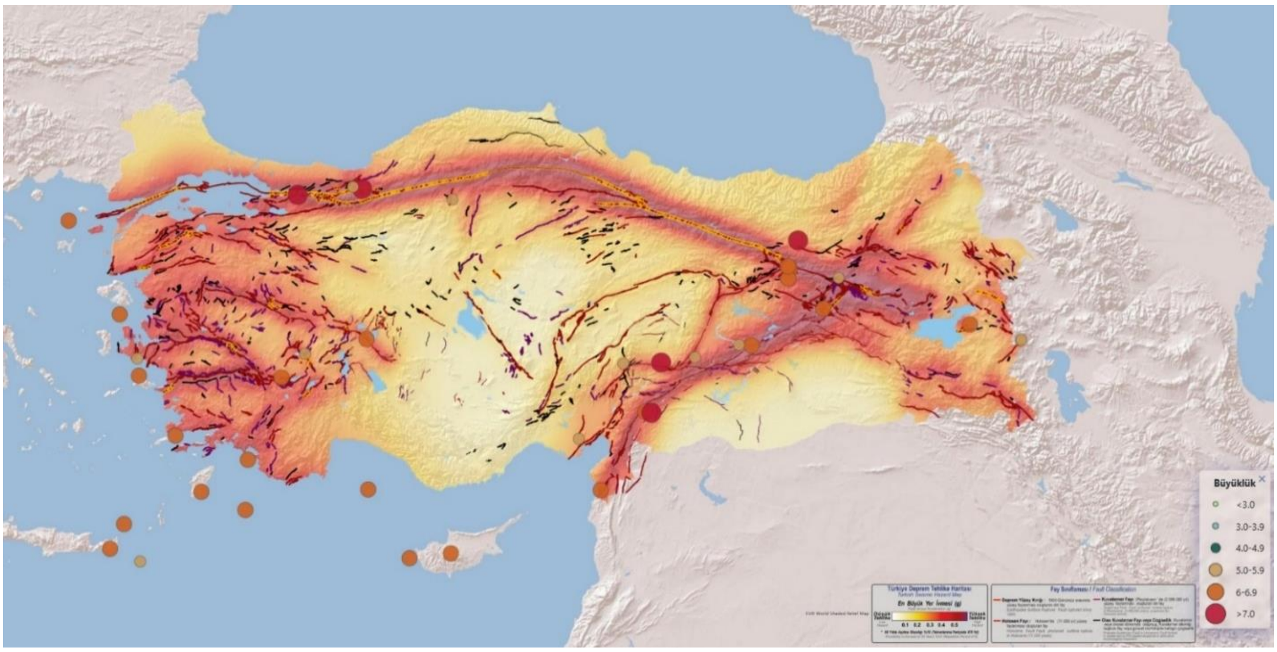


Figure 2. The representation of M≥6 earthquakes that occurred in Turkey and its surrounding region on the Earthquake Hazard Map (AFAD).

Due to the fact that almost the entire country, consisting of seven different geographic regions, is under a high-risk earthquake threat and the impact of major earthquakes that have occurred in these regions in the past, changes in the coordinates and velocities of the points in the Turkish National Fundamental GPS Network (TNFGN-TUTGA) have led to the influence on the velocities of C1 and C2 class points used in cadastral studies in the country. The changes in position and velocity occurring at TNFGN and Turkish National Permanent GPS Network-Active (TNPGN-Active, TUSAGA-Active) points as a result of earthquakes lead to discrepancies in the coordinates and velocities of points in geodetic networks. These changes cause shifts in property boundaries, loss of accuracy in digital maps, and ultimately disrupt the relationship between the land and the map [46-48]. The velocities of the C1 and C2 points in our country have been calculated using the interpolation method, based on velocities obtained in previous years. The velocities used in the interpolation method are calculated by making necessary estimates with the TNFGN and TNPGN-Active data prepared and provided by the General Directorate of Mapping (HGM). The velocities obtained by the HGM have varied over time due to tectonic movements or insufficient measurement data. For these reasons, it is crucial to continuously update the geodetic infrastructure in our country, which is largely seismically active, as it is vital for the accuracy of spatial-based positioning studies.

Similarly, the European Datum 1950 (ED-50) and the Turkey National Horizontal Control Network (TUYKA), which have been in use since the 1950s, have undergone deformation due to tectonic movements and can no longer provide high positioning accuracy due to being a static network. Therefore, with advancements in satellite technology, the Turkey National Fundamental GNSS Network (TNFGN-99; TUTGA-99) was established through studies conducted between 1997 and 1999. However, subsequent earthquakes caused large-scale displacements at TNFGN points, leading to an update of the network, which was redefined as TNFGN-99A. Later, in 2015, new measurements were conducted, and the TNFGN network was completely renewed, now serving as one of the fundamental platforms for positioning applications in its current form [49,50]. Today, the TNFGN and TNPGN-Active networks, which are key components of the country's geodetic infrastructure, play a critical role in monitoring plate and crustal movements by serving as the primary source through real-time data obtained using GNSS technology, which includes time information (X, Y, Z, t). In addition, the velocities of C1 and C2 degree points, which are used in cadastral studies and form the foundation of the geodetic network from past to present, are directly related to the accuracy of the TNFGN and TNPGN-Active velocities, which have changed in parallel with the development of the country's geodetic infrastructure. These velocities are calculated through interpolation. In addition to the impact of earthquakes on the velocities of C1 and C2 degree points from past to present, the differences in the establishment years of these points can also cause significant discrepancies in velocities. This is because the velocities prior to the TNPGN-Active system were calculated based on the surrounding existing TNFGN points, which may lead to notable differences between the velocities. Due to the velocity estimation of TNFGN points based on the existing campaign data at the time of establishment of C1 and C2 points, velocity differences may arise between points located in close proximity to each other. Additionally, uncertainties regarding which points to use for interpolation in the velocity estimation process can also create issues in the calculation of velocities. All of these factors are considered to have a significant impact on the reliability of cadastral studies and the accuracy of geodetic measurements, potentially leading to a series of negative consequences. Therefore, it is crucial to regularly update geodetic networks and cadastral data, as well as to continuously monitor the effects of earthquakes, for ensuring positioning accuracy.

Therefore, the aim of this study is to analyze the differences between the velocities calculated in different periods for cadastral points established at various times in Turkey, which have been subjected to coseismic and postseismic effects from past to present. By examining these velocity changes using TNFGN and TNPGN-Active data, the study seeks to quantitatively reveal potential issues in velocity calculations and the impact of tectonic deformations and time on geodetic networks. In this context, the velocities obtained from interpolations at the time of establishment of selected C1 and C2 points in different regions, uniformly distributed across Turkey, have been compared with the new velocity values calculated from the current velocities of TNFGN and TNPGN-Active points. These velocities were calculated using the interpolation method and then compared. In this calculation process, the TNFGN and TNPGN-Active data provided by the HGM were used. Differences between the velocities estimated for cadastral points, based on the time of their establishment and the increasing number of campaigns, especially for TNFGN points, have been observed in the TNFGN and TNPGN-Active data provided by the HGM. Additionally, time-dependent changes in velocities due to earthquakes have also been observed. The changes caused by earthquakes occurring along active tectonic belts in our country in the coordinates and velocities of the points vary depending on the magnitude of the earthquake. Sometimes, the effects last for 1-2 months, while in other cases, they can persist for as long as 5-15 years [51, 52]. Therefore, during this period, updating the postseismic velocities and coordinates of the points, especially those located in the area where the earthquake occurred, is crucial for reducing the effects of the earthquake and for location and property-based studies related to post-earthquake reconstruction.

2 Material and method

In order to examine the velocity changes that have occurred between past years and the present at C1 and C2 points, which are homogeneously distributed across Turkey, the differences between the Vx, Vy, and Vz velocities obtained at the point level from the HBB and the GNSS point velocities provided by the HGM have been analyzed. For this purpose, the coordinate information and GNSS velocities of the C1 and C2 points were obtained from the online services of the relevant institutions, and using these data, the TUREF Datum and ITRF-96 velocities of the points for velocity estimation were obtained through interpolation. A total of 482 points were analyzed, and the ITRF-96 velocities (Vx, Vy, Vz) in the TUREF Datum were determined using the latitude and longitude information, and the results were listed in a table. Additionally, to determine the accuracy of the calculated velocities, the points were queried on a 1/25,000 scale map using sheet numbers from the Map Data Bank website. The point numbers, types, latitude and longitude information, velocities calculated using the interpolation method, production and reference years, and other related details for the points within each sheet boundary have been listed and organized into a table. In this application process, with particular attention given to the fact that the reference years of the points are from 2005 onwards, the information obtained from the two velocity fields was used to compare all components of the points' TUREF velocities (Vx, Vy, Vz). Difference maps were created for each component, and the difference values between the obtained velocities were assessed on a regional scale.

2.1 Study area and dataset

This study, aimed at numerically presenting the velocity changes occurring during the development and transformation process of geodetic infrastructure at cadastral points, was conducted on a national scale in Turkey. For this purpose, a total of 1,360 1/25.000 scale sheets across Turkey were examined using the General Directorate of Land Registry and Cadastre (TKGM) and HBB portal. In the portal, which aims to compile and present all types of map-related information from various sources under a single platform, detailed information on geodetic points is provided by the Ministry of Environment, Urbanization and Climate Change and the General Directorate of Land Registry and Cadastre – Department of Mapping. Based on the data obtained from these sheets, 12,380 potential points were identified across the country that could represent the velocity characteristics of each region. In the data analysis process, it was assumed that there would be no significant differences between the velocities calculated at points that are close to each other. Therefore, only the sheets within the “a” section of the area divided into 1/25,000 scale sheets were considered. Then, considering the need for homogeneous representation of different blocks on the Anatolian Plate, as well as ensuring the data's current and reliable nature, a total of 482 C1-C2 points with a reference year of 2005 and established as pillars were evaluated within the scope of the study (Figure 3).

After obtaining the coordinates, Xsigma, Ysigma, Zsigma values, establishment years, and the campaign measurements (>3) available at the time of establishment for the selected points, the velocities (Vx, Vy, Vz) were calculated using interpolation. The reference epoch information was also acquired, and then the current velocities of the points were calculated. For this purpose, the velocity data for the years 1992-2021 were initially calculated based on the GNSS measurements of the TNFGN and TNPGN-Active points carried out by the HGM. These velocity data have been made available to users on the TUREF Velocity Field platform on the official website of the General Directorate of Mapping as of 2023 [53]. Following the earthquakes that occurred within the TUREF velocity field—where a total of 1,547 stations across Turkey and its surroundings were analyzed, including 723 single-epoch and 824 multi-epoch sites, with velocity components estimated using cross-validation and the Kriging algorithm—a need arose for an update [54]. As part of the TUREF project revision, previous GPS data from the inventory of the HGM were re-evaluated, time series were examined, and inconsistent data were removed [55]. In addition to the points permitted for use in velocity estimation in accordance with the regulations, this dataset also includes geodynamic and tide gauge GPS stations maintained by the HGM, as well as stations operated by various institutions and municipalities, to enhance spatial resolution. Within the project, all stations are classified into five statistically significant regions, and velocity data are provided through 6'x6' resolution grid files. Through this interface, which allows users to input the latitude and longitude coordinates of a specific point to estimate the TUREF Datum and ITRF-96 velocities (Vx, Vy, Vz), queries were conducted based on the latitude and longitude location data of the 482 points previously selected using the HBB online interface. As a result, the most up-to-date TUREF Datum and ITRF-96 velocity (Vx, Vy, Vz) information for these points was obtained, providing the current velocity data for the points.

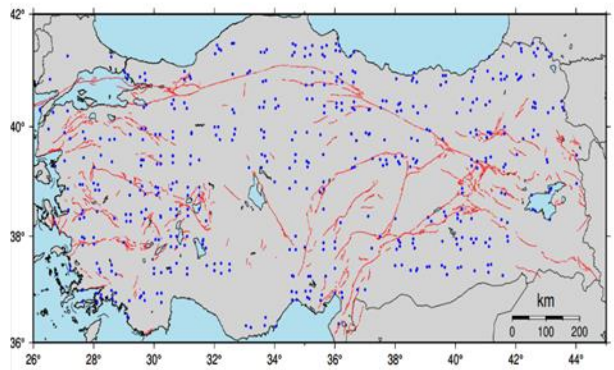


Figure 3. Locations of C1 and C2 degree points used in the study on the map of Turkey

3 Findings and discussion

The velocity data of the 482 points from previous periods filtered within the scope of the study were obtained through the HBB portal, and the current velocities of the relevant points were determined via the HGM velocity estimation portal. The velocities of the points are critical data that demonstrate how the positional changes in three-dimensional space have evolved over time. The velocity components of the points for which both past and current velocities were obtained were calculated in the X, Y, and Z directions, representing the east-west, north-south, and up-down movements of each point. The velocity data obtained separately from both systems were selected at the ITRF-96, 2005.00 epoch to ensure the consistency and comparability of the data sets. The differences between the velocities calculated from relatively limited data in the past and those calculated using the current network were then calculated on a component basis. The velocity differences in the X, Y, and Z components were evaluated separately, and these differences were visualized and interpreted using various methods. As a result of the calculations and analyses, the regional distribution of the velocity differences was also examined. This distribution also facilitates the comparison of geodetic movements in different geographic regions. Visual representations of the velocity differences in the XY direction, as well as histograms for the velocity differences obtained separately in the X, Y, and Z components, are provided in Figures 4 through Figure 9, respectively, based on the comparison of the past and current velocity data obtained from the HBB and HGM velocity estimation portal.

In Figure 4, which presents the vector sum of the velocity differences in the X and Y components, the maximum values of the horizontal velocity differences are observed in the Eastern and Southeastern Anatolia regions. It is observed that the velocity differences in the region of the Karlıova Triple Junction, a tectonically significant intersection, and the area of the EAFZ exceed 25 mm/year. In contrast, the points around the NAFZ in the Western Anatolia and Black Sea regions show velocity differences of approximately 10 mm/year. When evaluating the velocity differences in the X component shown in Figure 5, it is observed that these differences range from -11 mm/year in the south to 25 mm/year in the north. The largest velocity difference is found in the region of Batman Province. When examining the establishment years of these points, it is observed that they were established in 2006. Generally, when analyzing the velocity differences in the X component, it is seen that the differences are higher in the Southeast region compared to other regions.

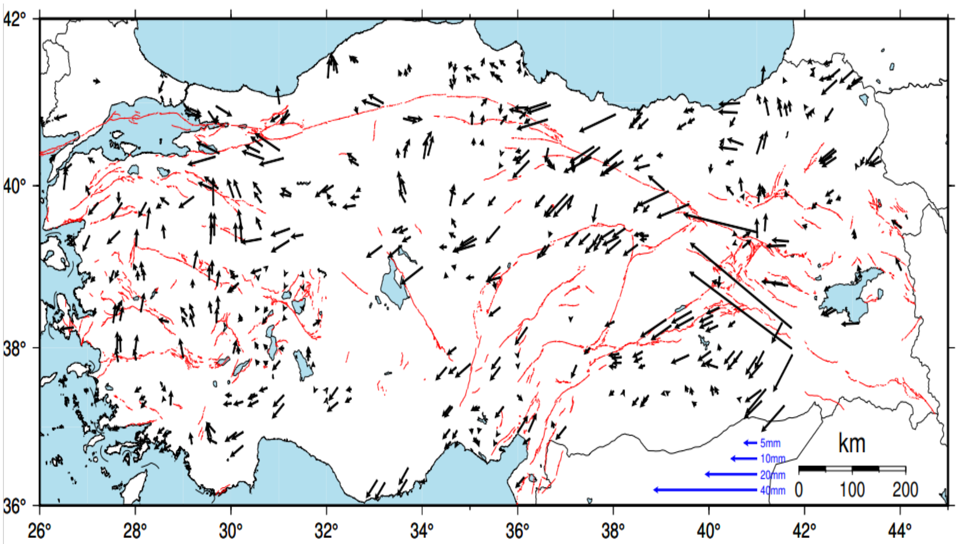


Figure 4. The graph of velocity differences in the XY horizontal component

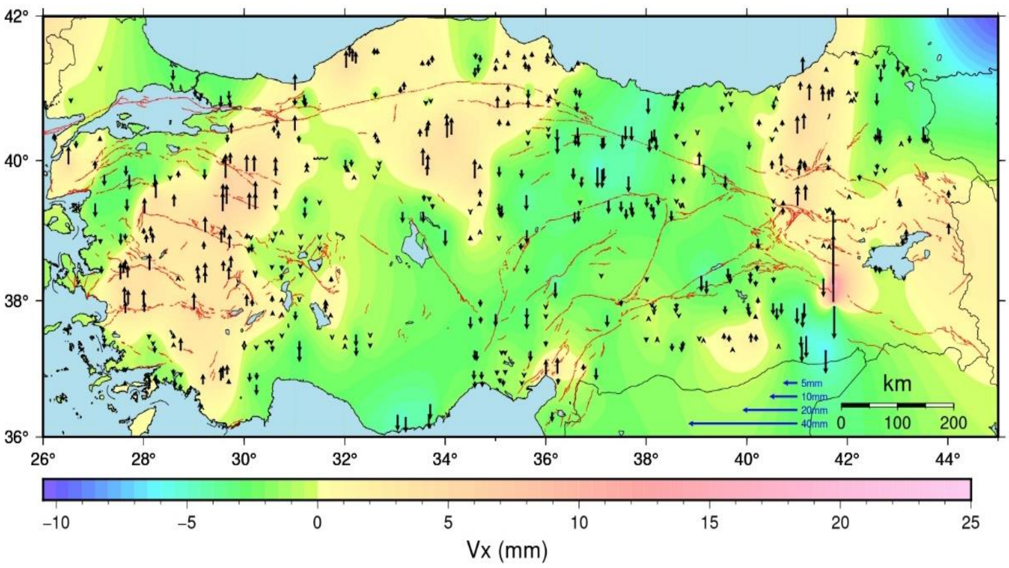


Figure 5. The graph of velocity differences in the X component

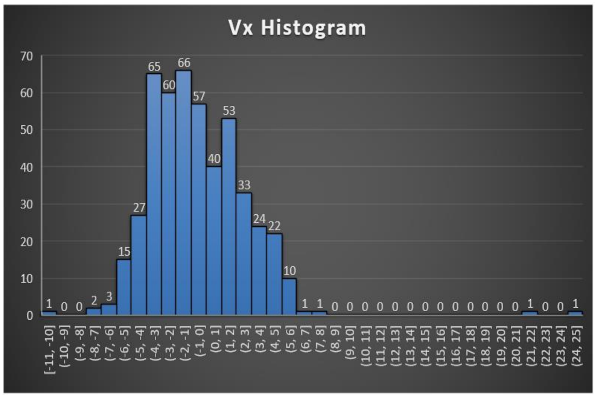


Figure 6. Vx Histogram Chart

In the histogram graph representing the distribution of the velocity differences in the X component of the points, it is observed that the majority of the points are concentrated around ±3 mm/year. When evaluating the velocity difference graph in the Y component provided in Figure 7, it is observed that the results for the Marmara, Black Sea, and Southeastern regions are higher compared to the other regions. It is observed that these velocity differences range from -39 mm/year in the west direction to 6 mm/year in the east direction. The largest velocity differences are found in the Marmara region, within Istanbul, where the establishment year is 2007; in the Black Sea region, within Çorum, with the establishment year being 2007; in the Southeastern region, within Siirt, where the establishment year is 2006; and in the Aegean region, in Muğla, where the establishment year is 2013. These regions exhibit higher differences compared to the other regions.

When evaluating the velocity difference graph in the Z component shown in Figure 8, it is observed that the largest velocity differences in the western region are found within Muğla province. The establishment year of these points is 2007. In the eastern regions, the largest velocity difference is observed in Mardin province, with the establishment year being 2020. When examining the velocity differences in the Z component, it is generally observed that the differences are higher, especially in the eastern and southeastern regions.

The differences between the velocities obtained from the HBB and the HGM have been examined on a component basis. For the X component, the velocity differences for 472 of the 482 points are between ±6 mm/year. Among these points, 216 have velocity differences ranging from ±2 mm/year. The velocity differences for other points in the X component range from ±7 to 25 mm/year. The maximum velocity difference is located within the borders of Siirt province and was established in 2006. When examining geodetic studies in this region, it is observed that the maximum velocity differences calculated by Aktuğ et al. [54] around Siirt are at their highest levels. This observation is similarly continued in the study published by Kurt et al. (2020). Since the C1-C2 velocities in Turkey are iteratively obtained from TNFGN points, it is considered that the TNFGN data calculated by Aktuğ (2011) is used at the point where the maximum velocity difference occurs. However, it is believed that these differences may have occurred due to the limited number of GNSS campaigns conducted at TNFGN points until the reference year of 2006. Similarly, the Kütahya-Bursa region, where the maximum differences for the X component are observed, is also identified as one of the regions with the highest differences in the study by Kurt et al. [55]. For the Y component, the velocity differences for 466 out of 482 points were observed to range from -9 mm/year to +3 mm/year. It was found that for 246 of these points, the differences were within ±2 mm/year. However, for the other points, the velocity differences for the Y component varied significantly between ±5 mm/year and 39 mm/year (Figure 9a).

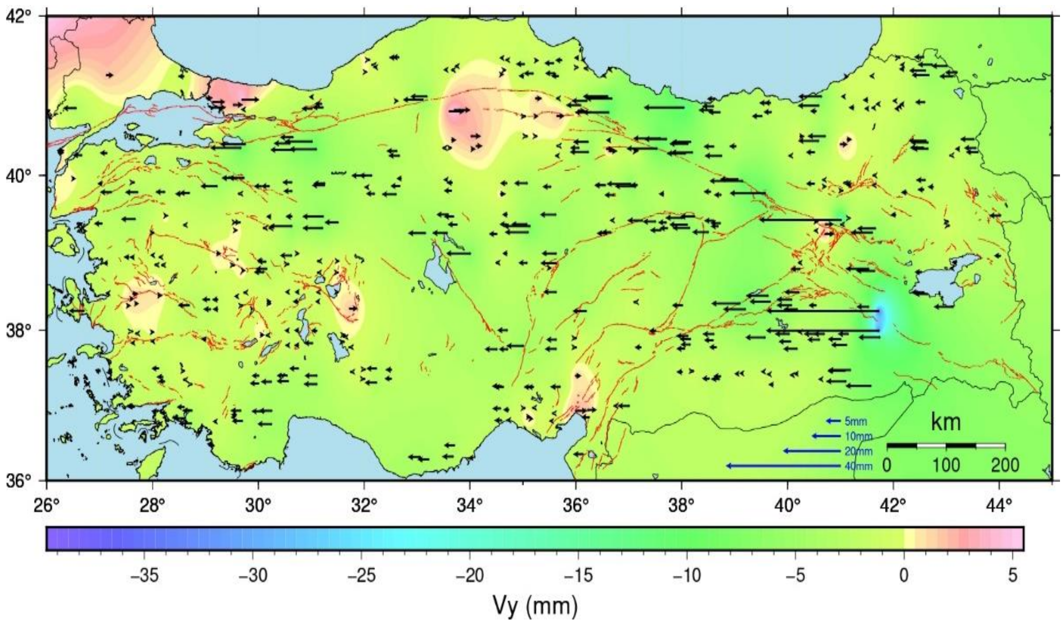


Figure 7. The graph of velocity differences in the Y component

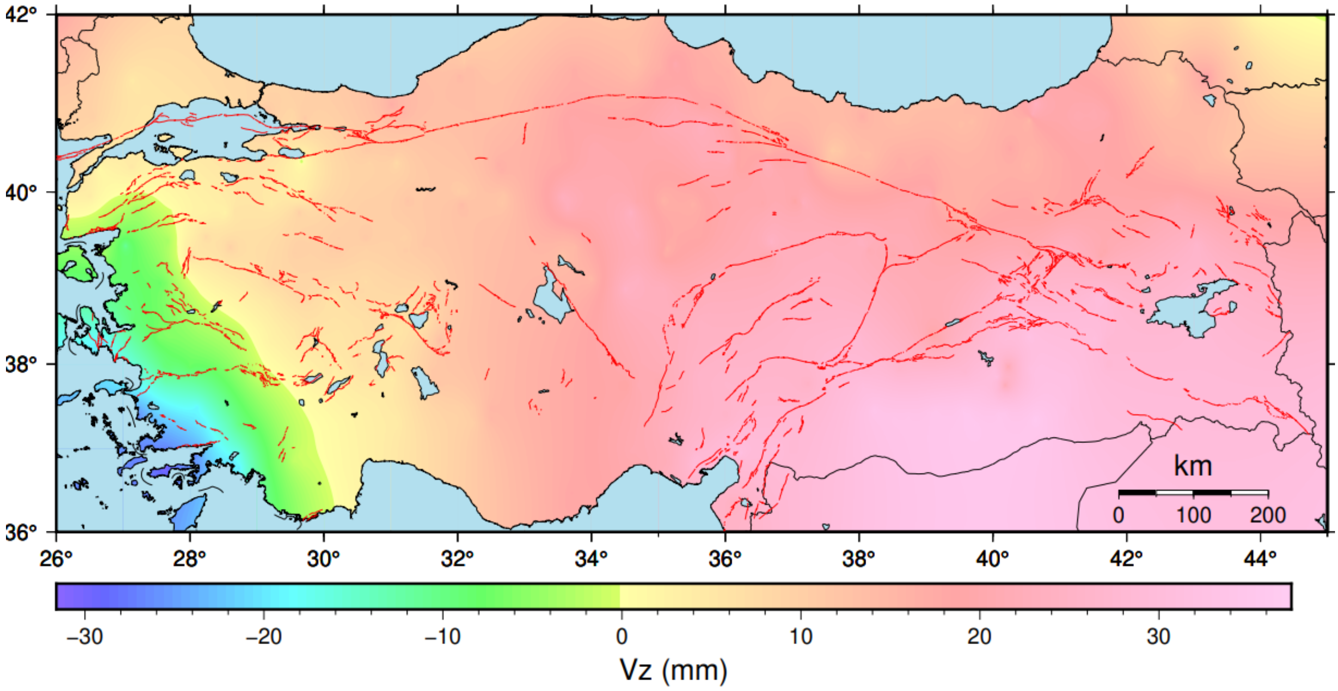
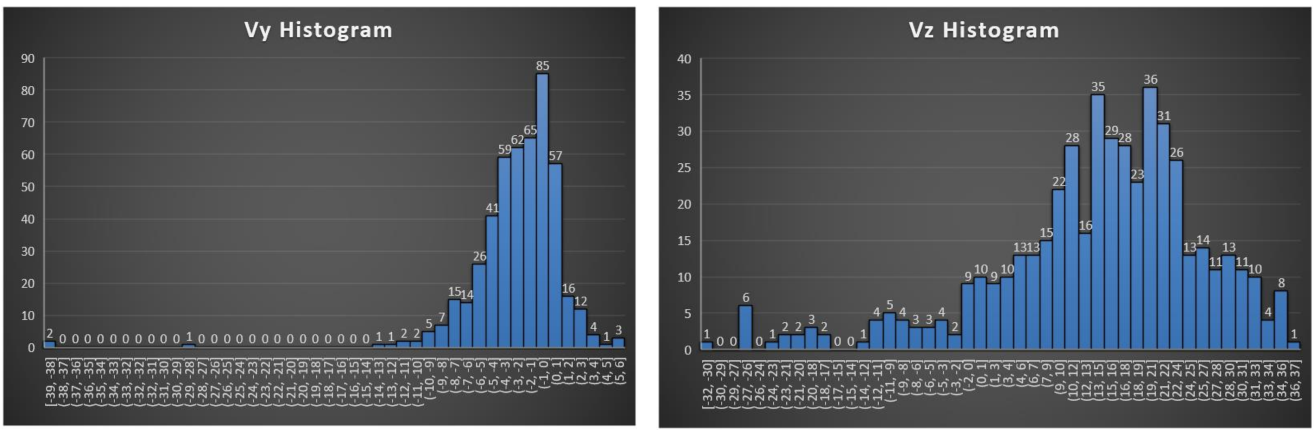


Figure 8. The graph of velocity differences in the Z component

In particular, the maximum velocity difference is located within the boundaries of Siirt province and corresponds to a point established in 2006. The analysis of geodetic studies conducted in this region revealed that the maximum velocity differences reported by Aktuğ et al. [54] have increased notably. These findings were also confirmed in the study conducted by Kurt et al. [55]. For the Z component, the velocity differences for 438 out of 482 points were found to range between -1 mm/year and +35 mm/year. For 245 of these points, the velocity differences were found to range between ±10 mm/year and 23 mm/year. For the remaining points, the differences varied between ±32 mm/year and 37 mm/year. The maximum velocity differences in the Z component were identified in the eastern region around Siirt province and in the western region around Muğla province (Figure 9b). When the obtained findings are compared with a similar study in the literature by Balaban et al. [56], the velocity differences in the X component for Afyonkarahisar and its surroundings were calculated between -5 mm/year and +10 mm/year in this study, whereas in the other study, this region was represented with differences ranging from -15 mm/year to +10 mm/year. For the Y component, the maximum differences were approximately -10 mm/year in both studies, while for the Z component, the values were around +10 mm/year. Based on these findings, it can be stated that the velocity differences obtained for the X, Y, and Z components in points located around Afyonkarahisar are consistent between the two studies, indicating a general agreement in their results.



(a) (b)

Figure 9. (a) Vy histogram chart (b) Vz histogram chart

4 Conclusions

In this study, the component-basis differences in GNSS velocity data, which can vary over time due to tectonic activity or limitations in measurement frequency, were analyzed at geodetic control points of C1 and C2 classes across Turkey—an area affected by active tectonic movements. The data used were obtained from the HBB and HGM. Analyses conducted at 482 points with a homogeneous national distribution revealed maximum velocity differences of up to 25 mm/year in the X component, 39 mm/year in the Y component, and 37 mm/year in the Z component. These discrepancies were found to be particularly pronounced in the Eastern and Southeastern Anatolia regions, where high tectonic deformation is present, while lower differences were observed in the Western Anatolia and Black Sea regions. The main causes of the observed differences are thought to include limited GNSS campaign data during the establishment years of the points, interpolation limitations, and the temporal variability of tectonic motion. The findings highlight the potential for decimeter-level errors in long-term epoch transformations and underscore the necessity of periodically updating the geodetic infrastructure in tectonically active regions to reflect ongoing deformation.

Our country is located in a region characterized by active seismic zones. Over the past 30 years, there have been 25 earthquakes with magnitudes greater than M:6. Postseismic movements occurred along faults after these earthquakes often differ significantly from preseismic motions. As a result, using pre-earthquake velocities for establishing new geodetic points in the aftermath of an earthquake can lead to epoch translation errors. Moreover, several microplates (or tectonic blocks) with varying kinematic characteristics exist on the Anatolian Plate. Due to the differing velocities of these microplates, it is crucial to select reference points—such as those from TNFGN and TNPGN-Active—that lie on the same tectonic block when interpolating velocities for newly established points. This approach ensures more homogeneous velocity estimates and leads to more accurate results. However, velocity values from TNFGN and TNPGN-Active points with a limited number of GNSS campaigns and high standard deviations should not be used. The unreliability of these velocities may introduce significant computational errors, and such points should be excluded from analytical evaluations.

This study represents a significant step toward emphasizing the importance of updating Turkey's geodetic network and identifying earthquake-induced deformations within it. The time series and tectonic coherence of GPS stations distributed across Turkey have been examined in detail under the complex influences of earthquakes occurring both within the country and its surrounding regions. This research holds critical importance for ensuring the continuity of Turkey's geodetic infrastructure and for gaining a more comprehensive understanding of seismic effects. The analysis presented in this study marks a substantial advancement in both geodetic and seismic research. In earthquake-prone regions such as Turkey, accurately interpreting GPS data and reliably assessing seismic risks is of vital importance. This research contributes to improved preparedness against future earthquake hazards and enhances societal resilience. As a result, the effectiveness of infrastructure development, disaster management, and emergency response strategies can be significantly increased.

Conflict of interest

The author declares that there are no conflicts of interest.

Similarity rate (iThenticate): %12

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