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SEISMOPROGNOSIS OBSERVATIONS IN THE TERRITORY OF AZERBAIJAN

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RETROSPECTIVE ANALYSIS OF VERTICAL MOVEMENTS AND MAJOR EARTHQUAKES IN THE CAUCASUS (1925–2023)

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Abstract

This study presents a retrospective analysis of vertical crustal movements in the Caucasus for the period 1925–2023, based on geodetic leveling, GNSS observations, and satellite interferometry (InSAR). Spatial–temporal patterns of surface uplift and subsidence, reflecting the development of orogenic processes in the region, were identified through mapping. It is established that the central part of the Caucasus has been characterized by stable uplift (up to 10–12 mm/year) throughout the entire period, whereas peripheral zones demonstrate subsidence of varying intensity. A comparative analysis of seismicity revealed a correlation between anomalous vertical deformations and the foci of strong earthquakes, confirming their possible role as indicators of seismic hazard. Particular attention is given to the correlation of vertical tectonic movement phases with major seismic events of the 20th–21st centuries, including earthquakes in Armenia, Dagestan, Georgia, as well as adjacent areas of Turkey and Iran. The results emphasize the need for integrated monitoring using modern geodetic and remote sensing techniques to assess seismic risk in the Caucasus.

Keywords: Caucasus, vertical crustal movements, orogenic processes, geodetic leveling, GNSS, InSAR, seismicity, seismic hazard, geodynamics, tectonic deformation.

QAFQAZIN ŞAQULİ HƏRƏKƏTLƏRİNİN VƏ İRİ ZƏLZƏLƏLƏRİN RETROSPEKTİV TƏHLİLİ (1925–2023)

Yetirmişli G.C., Kazımova S.E.

Xülasə

Təqdim olunan işdə 1925–2023-cü illər dövrü üzrə Qafqazda Yer qabığının şaquli hərəkətlərinin geodezik nivelirləmə, GNSS müşahidələri və peyk interferometriyası (InSAR) məlumatları əsasında retrospektiv təhlili aparılmışdır. Tərtib edilmiş xəritələr əsasında regionda orogen proseslərin inkişafını əks etdirən yer səthinin qalxma və çökməsinin məkan-zaman qanunauyğunluqları müəyyən edilmişdir. Müəyyən olunmuşdur ki, Qafqazın mərkəzi hissəsi bütün dövr ərzində davamlı qalxma ilə (ildə 10–12 mm-ə qədər) səciyyələnir, periferiya zonaları isə müxtəlif intensivlikli çökmə nümayiş etdirir. Seysmikliyin müqayisəli təhlili anomal şaquli deformasiyaların güclü zəlzələlərin ocaqları ilə əlaqəsini aşkar etmişdir ki, bu da onların seysmik təhlükənin mümkün indikatorları kimi rolunu təsdiqləyir. Xüsusi diqqət XX–XXI əsrlərdə baş vermiş iri seysmik hadisələr, o cümlədən Dağıstan, Azərbaycan və Gürcüstanda, eləcə də Türkiyə və İranın qonşu ərazilərində baş vermiş zəlzələlər ilə şaquli tektonik hərəkətlərin fazalarının müqayisəsinə yönəldilmişdir. Alınmış nəticələr Qafqazda seysmik riskin qiymətləndirilməsi üçün müasir geodezik və məsafədən zondlama metodlarından istifadə etməklə kompleks monitorinqin vacibliyini vurğulayır.

Açar sözlər: Qafqaz, Yer qabığının şaquli hərəkətləri, orogen proseslər, geodezik nivelirləmə, GNSS, InSAR, seysmiklik, seysmik təhlükə, geodinamika, tektonik deformasiyalar.

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РЕТРОСПЕКТИВНЫЙ АНАЛИЗ ВЕРТИКАЛЬНЫХ ДВИЖЕНИЙ И КРУПНЫХ ЗЕМЛЕТРЯСЕНИЙ КАВКАЗА (1925–2023 ГГ.)

Етирмишли Г.Дж., Кязимова С.Э.

Аннотация

В работе представлен ретроспективный анализ вертикальных движений земной коры Кавказа за период 1925–2023 гг. по данным геодезического нивелирования, GNSS-наблюдений и спутниковой интерферометрии (InSAR). На основе построенных карт выделены пространственно-временные закономерности поднятия и опускания земной поверхности, отражающие развитие орогенических процессов в регионе. Установлено, что центральная часть Кавказа на протяжении всего периода характеризуется устойчивым поднятием (до 10–12 мм/год), в то время как периферийные зоны демонстрируют опускание различной интенсивности. Сравнительный анализ сейсмичности выявил связь аномальных вертикальных деформаций с очагами сильных землетрясений, что подтверждает их возможную роль в качестве индикаторов сейсмической опасности. Особое внимание уделено сопоставлению фаз вертикальных тектонических движений с крупными сейсмическими событиями XX–XXI вв., включая землетрясения в Дагестане, Азербайджане, Грузии, а также на сопредельных территориях Турции и Ирана. Полученные результаты подчеркивают необходимость комплексного мониторинга с использованием современных геодезических и дистанционных методов для оценки сейсмического риска на Кавказе.

Ключевые слова: Кавказ, вертикальные движения земной коры, орогенические процессы, геодезическое нивелирование, GNSS, InSAR, сейсмичность, сейсмическая опасность, геодинамика, тектонические деформации.

Introduction

The study of vertical movements of the Earth's surface using geodetic methods has a long history. The greatest attention has been paid to seismically active regions, where the effort to understand the mechanisms of destructive earthquakes is combined with the goal of ensuring safety. Since the 1970s–1980s, particular interest has been focused on the relationship between crustal deformations and seismic activity, including the search for short-term precursors of strong earthquakes [31, 32]. In this context, geodynamic observatories have been established in several regions to provide regular monitoring of deformations, which has allowed the identification of characteristic changes in the behavior of the Earth's surface before, during, and after earthquakes.

The most studied deformations are vertical movements preceding major seismic events. In the 1960s–1970s, large-scale uplifts of the Earth's surface covering hundreds of square kilometers were recorded, which were interpreted as precursors to strong earthquakes. Such anomalies were observed prior to the 1964 Niigata earthquake in Japan (M = 7.4) [30]. Similar cases have also been documented in Costa Rica (1991) [30], Alaska (1964), Chile (1960), and other regions.

Cases of anomalous uplift have also been recorded in Southern California. In this region, the persistent uplift of mountain structures (1–2 mm/year) is associated with compression along the San Andreas Fault zone and is confirmed by GPS and InSAR data [30].

With the introduction of InSAR, remote monitoring of vertical deformations has become possible. The combination of InSAR and GNSS allows for increased accuracy in displacement measurements and is widely used in Europe and other regions.

Thus, crustal uplift serves as an important indicator of tectonic processes and a potential precursor of strong earthquakes. High-precision geometric leveling, which forms the basis of height reference systems in various countries, has been actively used to determine vertical movements of the Earth's crust.

Vertical Movements of the Caucasus Crust Based on Leveling, GNSS, and InSAR Data (1925–2023)

To date, it can be stated that the geotectonic evolution of the Caucasus remains insufficiently studied. There is no consensus on the course of geological processes in this region. Vertical movements of the Earth's crust in the Caucasus have been documented on several maps based on repeated precise leveling data. Works [8, 30] provide detailed descriptions and maps of vertical movements for the period 1925–1992.

The first map, the "Map of Contemporary Vertical Movements in Eastern Europe" was compiled using leveling data from 1925–1950. In 1968, a survey of new leveling lines spanning 3,200 km and covering 266 benchmarks was conducted, which for the first time recorded intense uplift of the Greater Caucasus using geodetic data. The second map, the *"*Map of Contemporary Crustal Vertical Movements*"* covers several European countries and the USSR. The Caucasus data in both versions of this map are consistent and are based on leveling data from 1951–1975. The third map, the *"*Map of Vertical Movements of the Caspian Region Surface*"* was constructed using leveling results from 1975–1992. The average interval between survey cycles was approximately 30 years. The accuracy of vertical movement estimates ranged from 0.2 to 2.6 mm/year [7].

Observations of vertical and horizontal surface movements in the Caucasus using InSAR began around the early 2000s, following the availability of satellite data with sufficient spatial and temporal resolution. Considering GNSS station data from the Institute of Geology and Geophysics of the Ministry of Education of Azerbaijan for the period 1998–2014, as well as data [28, 29] from GNSS stations of the Republican Center of the Seismological Service [7] and maps based on InSAR observations [6], a map of vertical movements in the Caucasus for the period 1998–2023 was compiled.

The maps of vertical movements of the Caucasus for different periods – 1925–1950, 1951–1975, 1975–1992, and 1998–2023 – are presented below. These maps, shown as color gradients, depict the rate of vertical displacement in millimeters per year (mm/year), where blue indicates subsidence and red indicates uplift. As shown in Fig.18, uplift is evident in the Greater Caucasus during the periods 1925–1950, 1975–1992, and 1998–2023.

During 1951–1975, uplift was observed in the Lesser Caucasus. It should be noted that, across all studied geophysical fields, the Eastern Caucasus differs from the Western Caucasus. In 1925–1950, the central part of the Caucasus, particularly along the Main Caucasus Ridge, exhibited significant uplift at rates of 5–10 mm/year, reaching peaks of up to 12 mm/year in active zones concentrated within a 100–150 km wide north–south strip. Peripheral areas, especially near the Black Sea, showed subsidence at rates of -1 to -3 mm/year, reaching -5 mm/year in coastal zones, reflecting the initial phase of compressional tectonic activity caused by plate collision.

Subsequently, during 1951–1975, the intensity of central uplift decreased to 3–7 mm/year, with peaks up to 8 mm/year, while subsiding zones expanded near the Caspian and Black Seas, where rates reached -1 to -5 mm/year, with maxima up to -6 mm/year in sedimentary basins, possibly due to sedimentary loading or changes in the tectonic regime.

In 1975–1992, uplift in the central region intensified again to 5–10 mm/year, with local maxima of 12–15 mm/year along the Main Caucasus Ridge, whereas subsidence was confined to the southwestern and northeastern corners of the region, with rates of -1 to -3 mm/year, reaching -4 mm/year along the coasts, possibly related to seismic activity or renewed crustal deformation.

In the modern period, 1993–2023, the data show the most pronounced movements: extensive central uplift at rates of 6–8 mm/year, with peaks up to 10 mm/year in a 50–100 km wide band, and scattered subsidence at rates of -1 to -5 mm/year, reaching -7 mm/year in sedimentary basins near the Caspian Sea, indicating ongoing compression and orogenesis.

Relationship between Vertical Movements and Major Earthquakes in the Caucasus: A Retrospective Analysis (1925–2023)

Based on the above, maps of vertical movements in the Caucasus were compiled for the periods 1925–1950, 1951–1975, 1975–1992, and 1998–2023 [7, 30] (Fig. 1). Seismicity data were taken from [3, 17–27].

The persistent uplift along the Main Caucasus Ridge reflects compressional tectonics resulting from plate collisions, while variations in the intensity and spatial distribution of movements may be related to seismic activity and changes in the tectonic regime. From 1925 to 2023, the amplitude and spatial variability of movements increased, which may be attributed to accelerated tectonic processes or improved measurement accuracy.

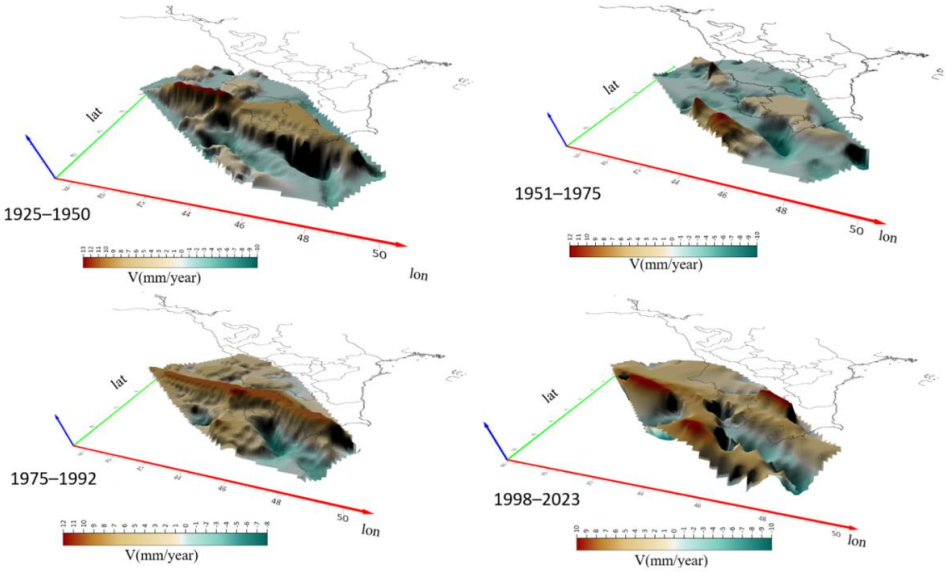


Figure 1. Maps of vertical movements in the Caucasus for the periods 1925–1950, 1951–1975, 1975–1992 [8, 30], and 1998–2023

The Absheron Peninsula also exhibits subsidence, which can be explained by hydrocarbon extraction in the region. The maps demonstrate a consistent trend of central uplift associated with orogenesis, and peripheral subsidence reflecting the interaction of tectonic and isostatic factors.

An interesting observation indicating a real connection between anomalous uplift of the Earth's surface in various regions of the world and strong earthquakes is that these earthquakes often occur within or near zones of anomalous uplift, particularly in areas with high gradients of transition from subsidence to uplift. At the same time, there are areas of anomalous uplift that have not yet experienced earthquakes (or where earthquakes have not yet occurred). One such area is the Stavropol Uplift, isolated from the Greater Caucasus uplift and located on a tectonic platform. Notably, a strong earthquake with a magnitude of approximately 6.0 occurred in this region in 1921. These circumstances suggest that the area should be considered seismically hazardous.

During the considered time interval, catastrophic earthquakes were repeatedly recorded across the Caucasus. To establish a possible relationship between major seismic events and phases of vertical tectonic movements in the region, diagrams were constructed showing the correlation between the Caucasus topography, the magnitude of vertical displacements, and the distribution of earthquakes across different time periods. Profiles were made across the Caucasus along the southwest–northeast direction (Fig. 2).

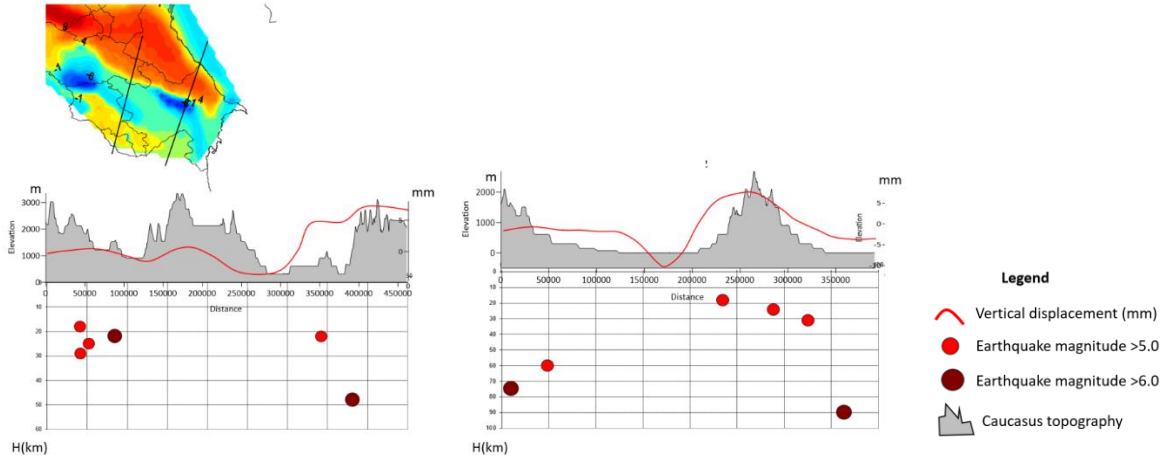


Figure 2. Diagrams showing the relationship between the Caucasus topography, vertical displacements, and the distribution of earthquakes for the period 1925–1950

It is assumed that increased rates of modern horizontal and vertical movements in seismically active regions reflect the interseismic phase of the seismic cycle, during which accumulated elastic stresses are redistributed and partially released. Conversely, a slowdown of these movements may indicate the accumulation of deformation energy and, consequently, an increased seismic hazard. The spatial distribution of major earthquake hypocenters generally supports this interpretation: their epicenters, with few exceptions, are located near the boundaries of preceding tectonic uplifts.

In the first profile (1925–1950) along the Nakhchivan–Dagestan direction, a minor uplift of 1 mm/yr is observed in the Lesser Caucasus and an uplift of up to 7 mm/yr in the Greater Caucasus, which is consistent with the regional topography (Fig. 3). During this period, six earthquakes with magnitudes of M = 5.5–6.6 were recorded. The strongest events include the earthquake on 22 February 1934 with M = 5.8, on 29 June 1948 with M = 6.4 (depth 48 km), and on 27 April 1931 with M = 6.6 (depth 15 km). The earthquake on 27 April in the Syunik region (Armenia) caused a very large number of casualties (2,890 people) and injuries, with extensive damage to buildings and infrastructure near the epicenter. This was the 8th most destructive earthquake ever recorded in Armenia and the 5th most destructive earthquake in the world in 1931. Additionally, the Zagatala earthquakes on 2 September 1936 (M = 5.3, I_0 = 6) and 29 June 1948 (M = 6.1, I_0 = 7) were significant events.

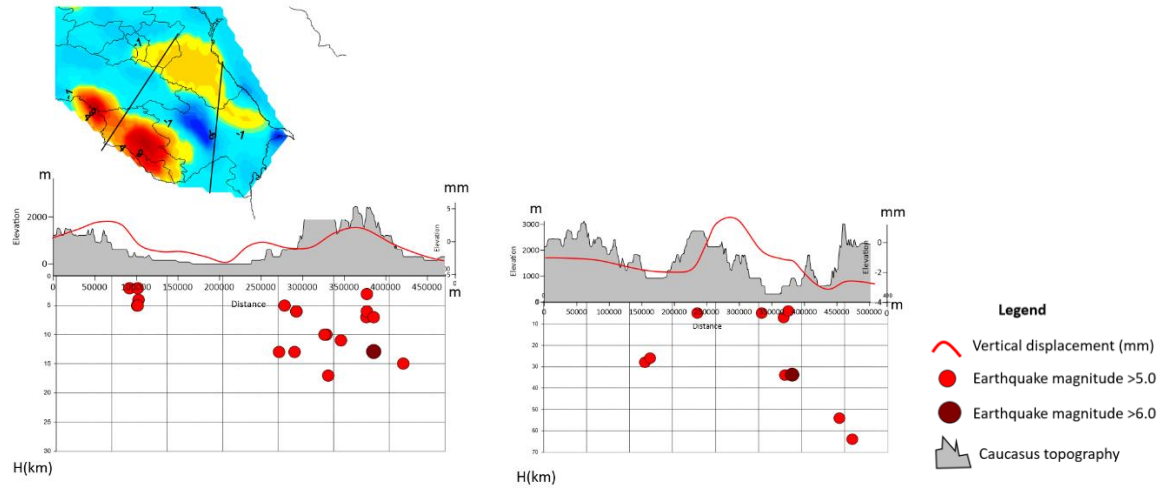


Figure 3. Diagrams showing the relationship between the Caucasus topography, vertical displacements, and the distribution of earthquakes for the period 1951–1975

In the second profile along the Iran–Caspian Sea direction, subsidence of the Kurin Basin of up to 10 mm/yr and uplift of the Greater Caucasus up to 6 mm/yr are observed. This uplift was accompanied by earthquakes with magnitudes of M = 5.5–6.9. On 19 February 1924 at 06:59 GMT, a strong earthquake of magnitude 6.0 occurred in northern Iran in the Ardabil region, with the epicenter 21 km from Jalilabad. On 9 April 1935, a major Caspian earthquake with M = 6.6 (depth 90 km) occurred. Furthermore, on 9 October 1931, 5 July 1931, and 30 August 1948, three earthquakes with M = 5.5–5.6 took place in the Shamakhi and Guba districts.

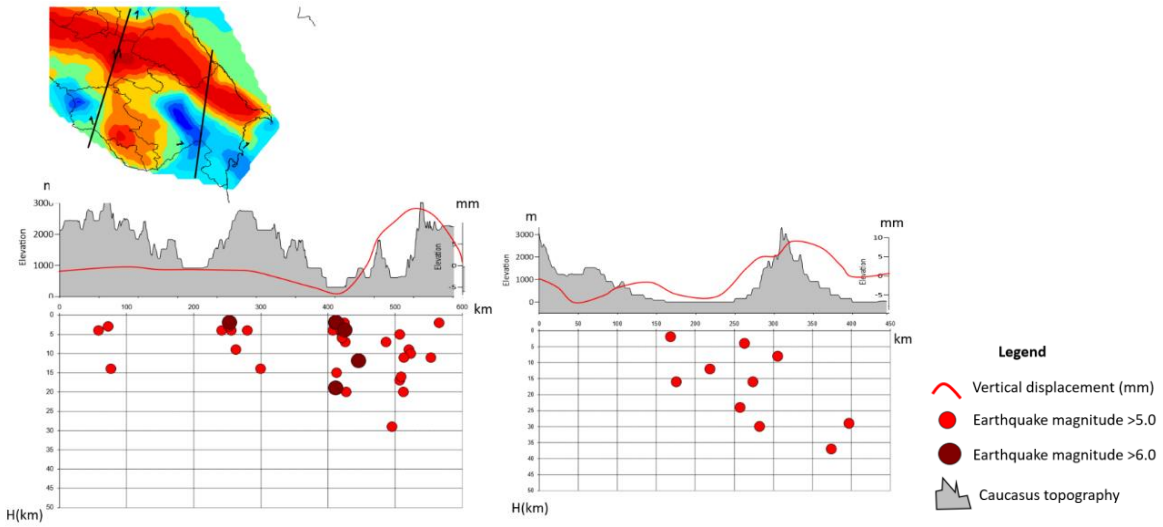


Figure 4. Diagrams showing the relationship between the Caucasus topography, vertical displacements, and the distribution of earthquakes for the period 1976–1992

As noted above, the second period (1951–1975) is characterized by active vertical uplift of the Lesser Caucasus. Along the Armenia–Dagestan profile, an elevation of up to 5 mm/yr is observed, followed by subsidence of the Kura Basin up to 2 mm/yr and uplift of the Greater Caucasus up to 3 mm/yr. This period is marked by high seismic activity at depths ranging from 2 to 16 km. In Armenia, earthquakes with M = 5.5 at depths of 2–5 km were recorded in 1962 and 1968. On the territory of the Greater Caucasus, 13 earthquakes with magnitudes of M = 5.5–6.7 were registered. The most significant event was the earthquake on 14 May 1970 in Dagestan, with a magnitude of M = 6.7 and an intensity of 9. The epicenter was located 30 km northwest of Makhachkala. The earthquake destroyed 22 settlements, killed 31 people, and left about 45,000 homeless. This event became the largest seismic event in the Caucasus in the 20th century after the 1902 Shamakhi earthquake.

Along the second profile, Iran–Makhachkala, the southern slope of the Greater Caucasus shows an uplift of 2 mm/yr, while the Tersk-Caspian depression subsides by 2 mm/yr. During this period, 8 earthquakes with magnitudes of M = 5.2–6.6 occurred along this profile, the strongest being the Caspian earthquake on 19 September 1961, with M = 6.6 and a depth of 64 km.

Along the profile-oriented Armenia–Grozny (1976–1992), tectonic movements are observed as subsidence of the Kura Basin at a rate of up to 5 mm/yr and uplift within the Greater Caucasus reaching 9 mm/yr (Fig. 4).

This region is characterized by heightened seismic activity, with three focal zones identified, showing a gradual increase in focal depths toward the northeast. The most active zone is associated with the Main Caucasus thrust.

During the analyzed period along this profile, seven earthquakes with magnitudes M = 6.0–6.9 and more than 25 earthquakes with magnitudes M = 5.6–5.9 were recorded. Among them, the most significant events include: on 24 November 1976, an earthquake with a magnitude of M = 6.9 occurred on the border of Iran and Turkey, with a focal depth of approximately 10 km. Within the

Greater Caucasus, on 29 April 1991, the destructive Racha earthquake occurred with Mw = 7.0, accompanied by two aftershocks exceeding Mw = 6.0. In the western part of this event's focal zone, strong earthquakes with magnitudes M = 6.0–6.4 had previously occurred in 1905, 1963, and 2009 [11]. Particular attention is given to the catastrophic Spitak earthquake on 7 December 1988 (Mw = 6.8), which claimed over 25,000 lives. It should be noted that from 1964 to 1983, the epicentral region experienced increased seismic activity, predominantly in a sub-meridional direction. The strongest earthquake during this period occurred in 1978 with M = 5.3. Maximum seismotectonic deformation values were recorded between 1977 and 1983, during which seven seismic events with magnitudes M = 4.5–5.3 were registered. The focal zone of the 1988 Spitak earthquake, reaching an intensity of up to 10 at the epicenter and located in northwestern Armenia, is associated with major fault systems: Abul-Samsar, Pambak-Sevan, and Transcaucasian [1]. This area remains one of the most seismically active zones in the Caucasus. On 15 June 1991, near the city of Bakuriani (Georgia), a significant earthquake occurred, destroying eight villages with a magnitude of M = 6.3. The tremors were felt along the Black Sea coast. Along the Iran–Caspian Sea profile, vertical movements of the southern slope of the Greater Caucasus reached up to 10 mm/yr. Eleven earthquakes with magnitudes M = 5–5.5 were recorded, mainly in the Shamakhi region. The most significant earthquake occurred on 29 November 1981 (M = 5.5), and on 15 October 1993 at 22:37 northwest of Ismailli, an earthquake with M = 5 occurred.

The fourth period was characterized by uplift in both the Lesser and Greater Caucasus (Fig. 5).

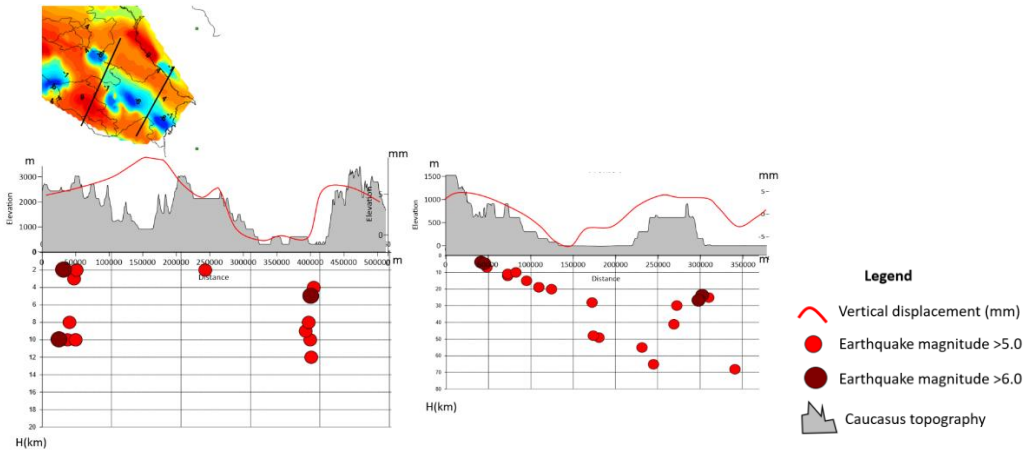


Figure 5. Diagrams showing the relationship between the Caucasus topography, vertical displacements, and the distribution of earthquakes for the period 1998–2023

During the period 1998–2023, along the first profile, the rate of vertical uplift in the Lesser Caucasus reached up to 8 mm/yr, and in the Greater Caucasus – up to 6 mm/yr. One of the most significant seismic events in the region was the earthquake on 11 August 2012, which occurred at 15:53 local time, 60 km northeast of Tabriz. The main shock had a magnitude of M = 6.4, with the epicenter located in Ahar Shahrestan, approximately 20 km southwest of the city of the same name, and a hypocenter depth of 9.9 km. Eleven minutes later, an aftershock of M = 6.3 occurred, with its epicenter 12 km southwest of the main shock.

Earlier, on 23 October 2011, a destructive earthquake of Ms=7.3 occurred in Van Province, southeastern Turkey, near the Iranian border, causing 604 fatalities and injuring 2,068 people. At the Georgia–Armenia border in the Javakheti Highlands near Lake Paravani, two earthquakes were recorded: on 9 February 1997 (MLH = 4.5, I_0 = 5–6) and 14 January 1999 (MS = 4.3, I_0 = 6–7). The region had also experienced previous seismic activity, including an event on 29 June 1967 with intensity 6.

On 27 November 1997, at 17:34 in the Sagarejo District of eastern Georgia, the Hashmi earthquake occurred (MW = 5.3, I_0 = 7). In Tbilisi, on 25 April 2002, one of the strongest post-1900 earthquakes struck (KR = 12.2, Imax = 7–8), characterized by a shallow focus (h = 5 km) and predominantly southeast-oriented extensional stresses. The Oni earthquakes on 6 February 2006 (04:08) and 7 September 2009 (22:41), occurring in the Racha area along the middle Rioni River on the southern slope of the Greater Caucasus, reached M = 6.2 and were associated with the northern branch of the focal zone of the 29 April 1991 Racha earthquake (M = 7.0, I_0 = 7–8).

On 7 June 2017, at 18:25, a M = 5.1 earthquake occurred in the Kura Depression, Georgia. Along the Armenia–Turkey border in July 2004, several seismic events occurred: 1 July (M = 4.8, h = 25 km, I_0 = 6–7) and 30 July (M = 4.2, h = 10 km, I_0 = 6). The epicentral area is bounded by ridges and mountain massifs, including the Tsakhkunatsky Ridge, Mount Aragats (4000 m), Arailer (2500 m), Gegham Ridge, Greater and Lesser Ararat (5165 m and 3925 m), and the Agryadak Ridge. Earthquake foci in the Iğdır–Doğubayazıt region are related to the Ararat deep fault, as well as the Spitak–Ararat and Sevan–Ararat faults. On 5 February 2021, an earthquake of M = 5.5 occurred in Armenia.

In the Chechen Republic, increased seismic activity was also observed. On 11 October 2008, at 09:06, the Kurchaloy earthquake occurred (Mw = 5.8, I_0 = 7–8), felt over a wide area including neighboring regions of Russia, Georgia, and northern parts of Armenia and Azerbaijan. On 12 December 2020, the Chernogorsk earthquake (Mw = 4.8, I_0 = 5–6) was recorded in Chechnya.

In Azerbaijan, seismic activity increased, particularly in the northwest. Notable events include: 8 February 2004 – Shaki earthquake (MPVA = 5.1, h = 8–14 km), 7 May 2012 – two Zaqatala earthquakes (M = 5.6 and 5.7; Mw = 5.6 and 5.3, I_0 = 7), 14 October 2012 – Balakan earthquake (M = 5.6), and 29 June 2014 – M = 5.3 event in the Zagatala and Balakan area. Subsequent shocks occurred on 29 September and 4 October (M = 5.5 and 5.0) in the Vandam structure. On the border with Dagestan, earthquakes were recorded on 3 May 2017 (M = 5.2) and 5 June 2018 (M = 5.5).

Along the second profile, vertical uplift of both the Lesser and Greater Caucasus reached 5 mm/yr. Along the southwest-northeast-oriented profile, the increasing focal depth of earthquakes indicates the subduction of the Kura Depression beneath the Greater Caucasus. In central Azerbaijan, in Agdash, a Mw = 5.4 earthquake with intensity I_0 = 7 occurred on 4 June 1999.

On 21 March 2000, a M = 4.3 earthquake (I_0 = 6) was recorded near Lake Sarysu (Saatly District), felt in several cities. On 4 September 2015, a M = 5.9 earthquake (I_0 = 7, depth = 16 km) occurred in Oghuz District, accompanied by two foreshocks and 92 aftershocks. On 1 August 2016, a M = 5.6 earthquake occurred in Imishli District, and on 11 May 2017 in Saatly – M = 5.4. On 15 November 2017, at the junction of the Lesser Caucasus and Kura Depression, a notable earthquake of M = 5.7 also occurred [17].

In the Talysh Zone, the strongest earthquake occurred on 9 July 1998 in the Lerik District (Mw = 6.0, I_0 = 7). It was accompanied by intense aftershock activity – within the first five hours, 67 aftershocks were recorded, and the overall aftershock field extended along the Talysh Fault. A secondary event in the same area occurred on 11 July 2007, with a magnitude of Mw = 5.2 and intensity I_0 = 6. In 2024, seismic activity resumed in the region: on 11 May, an earthquake of M = 5.3 occurred in Lankaran, followed by another event of M = 5.0 on 28 June.

The Caspian Zone also exhibits high seismicity. Among the most powerful events were two earthquakes on 25 November 2000, occurring one minute apart (Mw = 6.8 and 6.5), with a maximum intensity of I_0 = 8 in the epicentral area. They were felt almost throughout the country, generating 165 aftershocks, 36 of which were felt in Baku. On 10 January 2014, a M = 5.0 offshore earthquake occurred in the northern sector of the Azerbaijani Caspian, followed on 10 February by the stronger

Hadjigabul earthquake (M = 5.7) [20]. In 2023, additional earthquakes with magnitudes of M = 5.6 were recorded in the central Caspian Sea on 4 July and 7 December.

In Ismayilli District, a M = 5.3 (Mw = 5.1) earthquake occurred on 7 October 2012 with intensity I_0 = 5–6. Seismic activity resumed on 5 February 2019, with a foreshock of M = 4.4 followed by the main shock of M = 5.2 [19]. In Shamakhi District, a notable earthquake of ML = 5.1 occurred on 20 November 2021. Two moderate earthquakes in 2007 should also be noted: 23 August in Aghsu District (M = 4.0) and 19 September in Terter District (M = 4.5), both with maximum intensity I_0 = 5.

Discussion of Results

Thus, vertical movements indicate the ongoing tectonic growth of the Caucasus Mountains, reflecting the region's active neotectonic evolution. A spatial correlation has been established between zones of intense vertical uplift and areas of strong seismic activity. Epicenters of major earthquakes are generally located along boundaries between uplift and subsidence zones, particularly within the Main Caucasian Thrust. This supports the concept of deformation accumulation during the interseismic phase, followed by its release as earthquakes.

A key factor controlling both historical and contemporary tectonic movements in the Caucasus is the progressive motion of the Arabian lithospheric plate, driven by Alpine orogeny [5,16]. However, the energy sources and primary causes of this process remain subjects of scientific debate, as no unified, widely accepted concept satisfactorily explains its nature. In addition to the Arabian Plate motion, several studies note a counteracting, though less intense, convergence of the southern sector of the East European Platform. The combination of these processes generates meridional compression and sub-latitudinal extension of the crust, as confirmed by GNSS observations.

The northern protrusion of the Arabian Plate interacts with stable, consolidated areas of the oceanic lithosphere, resulting in redistribution of deformation: part of the strain is directed westward along the East Anatolian Fault, and part toward the northeast, toward the Lesser Caucasus. In this context, the system of strike-slip faults of the Lesser Caucasus arc, located in direct contact with the southern flank of the Greater Caucasus, plays a key role. Within this zone, the catastrophic Spitak earthquake of 1988 occurred.

Analysis of the morphostructural organization, kinematics of contemporary movements, and seismicity distribution in the Caucasus reveals characteristic geodynamic patterns associated with the interaction of rigid lithospheric blocks. Similar structural-geodynamic relationships are observed in other continental-type orogenic zones. In this context, it is instructive to compare the Caucasus region with the Pamir and Southern Tien Shan, where analogous morphostructural and tectonic features are recorded. A tectonic analogy emerges between two major geodynamic systems: Lesser Caucasus – intermontane depressions – Greater Caucasus and Pamir – intermontane depressions – Southern Tien Shan. Both structures demonstrate comparable morphotectonic configurations, including contrasting blocks in terms of geomechanical properties, separated by zones of active deformation represented by intermontane basins [1, 2].

The linear morphostructural organization of the Greater Caucasus and Southern Tien Shan is controlled by the predominance of rigid, mechanically consolidated lithospheric blocks that exhibit relatively plastic resistance to tectonic stresses. In contrast, the arcuate configuration of the Lesser Caucasus and the Pamir indicates the presence of more compliant and weakly consolidated blocks capable of significant intralithospheric deformation. This morphological distinction reflects fundamental contrasts in lithospheric mechanical behavior in response to compressive forces generated by tectonic plate collisions. In both cases, the central portion (intermontane depressions) constitutes a zone of active seismotectonic loading, concentrating contemporary vertical movements and deformations.

Despite alternative interpretations, a number of geophysical and geodynamic data support the hypothesis of a hidden subduction zone between the Lesser and Greater Caucasus [4, 9, 12]. First, seismic activity in the region demonstrates the presence of a dipping slab, manifested as a cluster of earthquake foci localized at depths up to 60 km with a distinct spatial orientation corresponding to the mid-segment of the subduction complex. Second, geodetic data and the pattern of contemporary vertical crustal movements [13, 14, 15] provide additional evidence. Specifically, geodetic and geophysical observations indicate prolonged subsidence of intermontane depressions such as the Kura and Rioni basins. These depressions exhibit persistently negative rates of vertical movement, consistent with a typical geodynamic subduction model, where a regional uplift is expected above the subducting plate due to mechanical underthrusting and material accumulation in the zone ahead of the subduction front.

Analysis of vertical movements in the southeastern Greater Caucasus shows gradual uplift and thrusting. Geophysical studies reveal a zone of reduced rock density between the Transcaucasian plate and the margin of the Scythian Platform, characterized by increased deformability [10, 18, 28]. This facilitates the underthrusting of the Transcaucasian crust beneath the northern block and is considered one of the factors contributing to the tectonic uplift of the Greater Caucasus. GNSS observations indicate a decrease in the absolute rates of contemporary vertical crustal movements from south to north.

Conclusions:

1. A retrospective analysis of vertical movements in the Caucasus for the period 1925–2023 reveals a stable pattern: the central parts of the Greater and Lesser Caucasus are characterized by continuous uplift, whereas peripheral zones and intermontane depressions, such as the Kura Basin, experience subsidence. These processes reflect the combined influence of tectonic and isostatic factors, as well as local anthropogenic impacts, for example, hydrocarbon extraction on the Absheron Peninsula.
2. Throughout the 20th and early 21st centuries, the central part of the Greater Caucasus has demonstrated sustained and intense uplift (up to 10–15 mm/year), whereas peripheral areas, particularly the Caspian and Black Sea coastal regions, are subsiding at rates of up to -7 mm/year. This reflects ongoing orogenesis and active tectonic plate collision.
3. Direct comparison of vertical displacement maps with epicenters of major earthquakes shows that most strong seismic events occur near the boundaries of anomalous uplift zones or in areas with a high gradient of transition from subsidence to uplift. This confirms the existence of a relationship between vertical tectonic activity and seismic processes.
4. Profile analyses along the Nakhchivan–Dagestan and Iran–Caspian Sea directions indicate that periods of accelerated vertical uplift coincide with interseismic phases of elastic stress redistribution, whereas a slowdown in vertical movements points to the accumulation of deformation energy and an increased likelihood of strong earthquakes.
5. Regional differences in the amplitude of vertical displacements reflect morphostructural and tectonic characteristics: the linear uplift of the Greater Caucasus is associated with rigid lithospheric blocks, while the arcuate structures of the Lesser Caucasus exhibit more plastic crustal behavior.
6. Seismic activity from 1925–2023, including catastrophic events (Spitak 1988, Racha 1991), confirms the high seismic hazard of certain zones in the Caucasus, such as the central part of the Greater Caucasus, the Kura Basin, the Talysh zone, and the Caspian region.

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MICROSEISMIC VIBRATION MEASUREMENTS WITH *Vp/Vs* ASSESSMENT AT THE CHARTAK RESERVOIR DAM

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Abstract

This paper presents the results of a study of microseismical vibrations and the possibility of estimating the *Vp/Vs* ratio, as well as the physical parameters of dam conditions, using the Chartak Reservoir as an example. The Nakamura method was used to obtain the ratios of the spectra of the horizontal components of microseismical vibrations to the spectrum of their vertical components (H/V ratios). Determining the *H/V* ratio and *Kg* revealed that the seismic instability coefficient *Kg* at the dam crest does not exceed 17.8. It was also found that an inclined seismic impact increases the amplitude amplification factor of the Chartak Reservoir dam vibrations.

Key words: dam, microseismical vibrations, longitudinal and transverse waves, shear modulus, compression modulus.

ÇARTAK SU ANBARI BƏNDİNDƏ VP/VS NİSBƏTİNİN QİYMƏTLƏNDİRİLMƏSİ İLƏ MİKROSEYSMİK VİBRASİYA ÖLÇMƏLƏRİ

Hamidov L.A.

Annotasiya

Bu məqalədə Çartak Su Anbarı nümunəsində mikroseysmik titrəyişlərin tədqiqinin nəticələri, həmçinin Vp/Vs nisbətinin və bəndin vəziyyətinin fiziki parametrlərinin qiymətləndirilməsi imkanları təqdim olunur. Mikroseysmik titrəyişlərin üfüqi komponentlərinin spektrlərinin onların şaquli komponentlərinin spektrinə nisbətlərinin (H/V nisbətləri) əldə edilməsi üçün Nakamura üsulundan istifadə edilmişdir. H/V nisbətinin və Kg parametrinin müəyyən edilməsi nəticəsində məlum olmuşdur ki, bəndin krestində seysmik qeyri-sabitlik əmsalı Kg 17,8-dən artıq deyil. Həmçinin müəyyən edilmişdir ki, maili seysmik təsir Çartak Su Anbarı bəndinin titrəyişlərinin amplituda güclənmə əmsalını artırır.

МИКРОСЕЙСМИЧЕСКИЕ ВИБРАЦИОННЫЕ ИЗМЕРЕНИЯ С ОЦЕНКОЙ ОТНОШЕНИЯ VP/VS НА ПЛОТИНЕ ЧАРТАКСКОГО ВОДОХРАНИЛИЩА

Хамидов Л.А.

Аннотация

В работе представлены результаты изучение микросейсмических колебаний и возможности оценки *Vp/Vs*, а также физических параметров состояния плотин на примере Чартакского водохранилища. Для получения отношений спектров горизонтальных компонент микросейсмических колебаний к спектру их вертикальной компоненты (*H/V* отношений)

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использован метод Накамуры. Определение соотношения *H/V* и *Kg* показало, что, коэффициент сейсмической неустойчивости *Kg* на гребне плотины не превышает значения 17,8. Выявлено, что наклонное сейсмическое воздействие увеличивает коэффициент усиления амплитуды колебаний плотины Чартакского водохранилища.

Ключевые слова: плотина, микросейсмические колебания, продольные и поперечные волны, модуль сдвига, модуль сжатия.

Introduction

The physical parameters of a medium-sized reservoir dam are assessed by recording microseismical vibrations within its body (*Khamidov*, 2020; *Rodrigues, Paula and oth.*, 2021; *Yusupov, Mamarozikov, and oth.*, 2025). Studying changes in the natural vibrations of dams and embankments of similar reservoirs in Uzbekistan allows us to study physical changes in their structural structure. It is known that microseismical monitoring is implemented using two main methods: passive microseismical and interferometric, based on the analysis of seismic noise in the environment (*Yusupov, Mamarozikov, and oth.*, 2025; *Khamidov, Artikov, and oth.* 2022) Although interferometry is not always available in practice, it can relate the rigidity modulus and specific gravity of an object. Passive microseismical monitoring also provides valuable information about the structure of dams. Passive microseismical surveys allow reservoir owners to monitor seismic activity within their territories and in adjacent areas (*Rodrigues, Paula and oth.*, 2021; *Yusupov, Mamarozikov, and oth.*, 2025). This is valuable for analyzing historical seismic data, identifying potentially induced seismicity, and for regional monitoring of subsurface geology and hydrogeology.

Due to the significant impact of water level changes in this regularly used reservoir, areas of hydrostatic pressure may form within the rock-fill dam. Uneven kinematic displacements within the dam body, in turn, depend on the conditions under which its physical and mechanical parameters change under the influence of natural seismic forces. In this case, the physical parameters of the dam can be determined from changes in longitudinal (*Vp*) and shear (*Vs*) seismic waves.

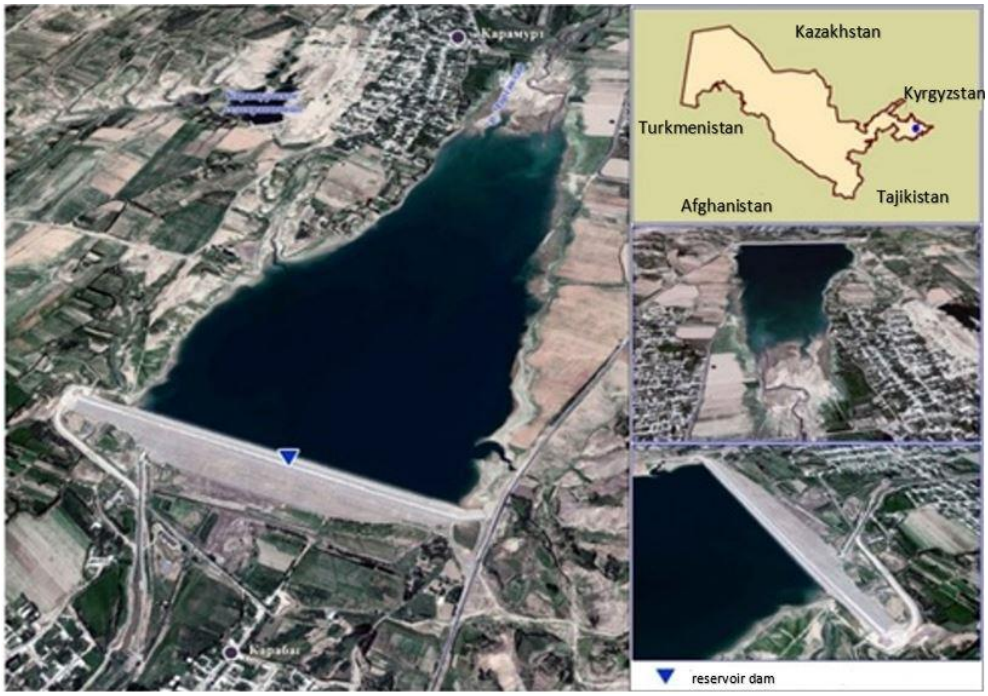


Figure. 1. Location of the Chartak reservoir according to (Website of the MWR RUz, 14.10.2025)

In recent years, in order to increase the efficiency of seismic research in the Chartak reservoir zone, local seismic monitoring of micro-vibrations has been organized in order to assess the natural frequencies of both the dam and the coastal slopes.

The aim of the research is to study microseismical vibrations and the possibility of assessing *Vp/Vs*, as well as physical parameters of the state of dams using the Chartak reservoir as an example.

Currently, the concept of "microseismical observations" encompasses a whole range of technologies based on the analysis of waves of various origins and types (emission, man-made signals, surface waves, etc.). It is important that the recorded wave field can be processed in parallel using different methods, based on different components of microseisms, to obtain fundamentally different information about the environment. The method of analyzing the state of an earth dam allows one to take into account the design features of the structure, piecewise heterogeneous physical and mechanical characteristics of the soils of both the structure and its foundation (*Yusupov, Mamarozikov, and oth.*, 2025; *Khamidov, Artikov, and oth.* 2022).

The Chartak Reservoir is located in the Namangan Region of the Republic of Uzbekistan, 20 km northwest of Namangan. Phase I was commissioned in 1971, and Phase VI in 2013. The Chartaksay River is the source of water supply. The dam is 1,448 meters long and 37 meters high. It is located in the zone of 8-point earthquake intensity (Fig. 1) (*Website of the MWR RUz*, 14.10.2025).

Tectonically, the Chartak Reservoir is located within a belt of anticlinal uplifts of Neogene-Quaternary, and possibly earlier, age, marking a zone of major disturbances in the Paleozoic basement. This zone can be identified with a major fault zone, exhibiting all the characteristics of a marginal fault [6], or a so-called flexural-fault zone (*Sadykov, Nurmatov and oth.*; 2021; *Rebetsky, Ibragimova and oth.*, 2020). The dam site is located north of the most intense disturbances in the southern part of the zone (the Namangan anticline) and west of the most complexly constructed and actively developing eastern part of this zone.

Research methodology

To obtain analytical information, expeditionary studies were conducted to determine the seismic and natural frequencies of vibrations of the Chartak Reservoir dam and shore slopes. The H/V ratio represents the transfer function of the soil cross-section across the entire thickness of the relatively cohesive geological material of the engineering foundation, representing an analogue of the amplitude-frequency characteristic (*Khamidov, Ibragimov and oth.*, 2020; *Nakamura*, 1989).

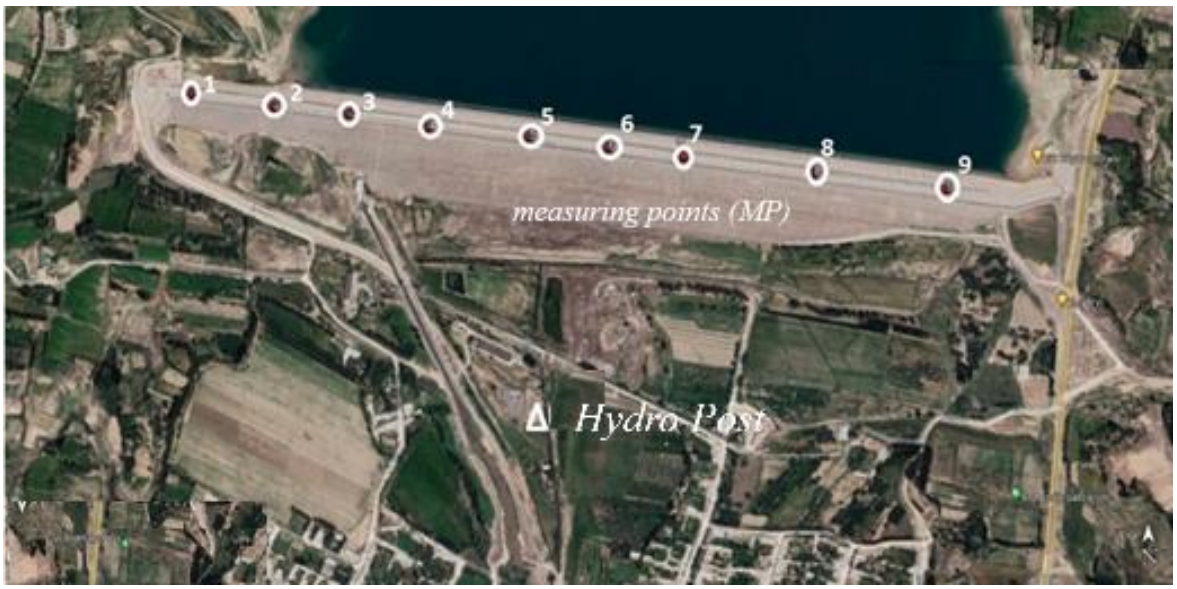


Figure. 2. Location of registration points in the dam body Chartak Reservoir

Observations are performed by a single three-component station without loss of quality of the resulting data. This allows for the rapid and detailed resolution of the tasks set during engineering and seismological studies.

The measurements were limited to recording microseisms at 40-minute intervals with a step size of 25 to 100 meters along the crest and berms of the Chartak Reservoir dam. The locations of ten microseismical recording points within the Chartak Reservoir dam are shown in Figure 2.

Table 1.

Recording point coordinates and calculated parameters obtained from microseismical measurements

№ MP	Chartak				
	Coordinates		f_0	HVSR	*Kg*
	N	E			
1	41,17664	71,80263	0,68	4,48	29,5
2	41,17646	71,80412	0,71	3,49	17,2
3	41,17635	71,80550	1,01	3,43	11,6
4	41,17617	71,80694	1,13	4,48	17,8
5	41,17604	71,80879	1,11	3,36	10,2
6	41,17589	71,81025	1,09	5,04	23,3
7	41,17576	71,81162	0,93	4,62	23,0
8	41,17554	71,81402	0,92	3,71	15,0
9	41,17532	71,81644	1,09	4,71	20,4
Hydro Post 10 1 km from the dam	41,16937	71,80931	0,89	4,25	20,3

The following software environment was used to process the records: GEOPSY, (*H/V* Nakamura's ratio), Waves. (*Nakamura*, 1989). Three-component digital seismometers (velocimeters) with a built-in recorder CMG-6TDE manufactured by Guralp, UK, were used to record microseisms.

By processing microseismical records, the spectral amplitudes of the two horizontal components (*N-S* and *E-W*) and the vertical component are calculated. The results are presented as the ratio of the horizontal component (*H*) to the vertical component (*V*) as a function of frequency (*f*):

$$[H/V](f) = \left[\frac{S_{NS}^2(f) + S_{EW}^2(f)}{2S_V^2(f)}\right]^{1/2} \quad (1)$$

Next, the dominant frequencies (or periods) and relative amplitude levels of oscillations are determined using the *H/V(f)* curve (1).

Estimates of natural oscillations from multi-profile seism metric surveys in dams were determined by calculating the relative change in oscillation intensity from $\delta_i = A_{ma\,(i)}/A_{ma}$, where *i* is the sequential number of the measurement points. Calculations of the thickness of the layer from coarse-grained to fine-grained rocks were performed in reservoirs using the following empirical equations: $h = 156 \cdot f_0 - 1{,}08$, where *h* is the thickness of the fill rock layer, *fo* is the resonant frequency of each part of the debris massif. To determine the velocity of transverse waves *Vs*, the expression $T = 4h/Vs$ was used; where *T* is the resonant period for each type of rock mass, *h* is the thickness of each part of the rock, and *Vs* is the velocity of transverse waves. To eliminate random impulse noise, the spectra were calculated using preliminary filtering (*Khamidov, Artikov, and oth.* 2022; *Khamidov, Ibragimov and oth.*, 2020).

Research results

During the first measurement cycle, a dam body natural frequency profile was compiled with precise data on the recording points. Changes in the natural frequencies at certain recording points can be used to assess the degree of water load on the dam body or changes in the dam body's condition.

Table 1 presents the calculated parameters obtained from microseismical measurements, including Fo (the soil resonance frequency), the HVSR transmission coefficient, and *Kg* (the seismic instability coefficient) based on the coordinates of the measurement points.

Table 2 shows the values of shear (*Vs*) and longitudinal (*Vp*) waves and the volume density (ρ) calculated and determined by microseismical surveys at the specified points of the Chartak Reservoir dam.

Figure 3 below shows the points (MP measurement points according to Figure 2) where instrumental seismometric measurements were conducted in the Chartak Reservoir dam body.

Table 2.

Changes in physical parameters along the Chartak Reservoir dam body

H (m)	V_p	V_s	ρ (kg/m^3)	μ	λ	υ	E	Vp/Vs
	m/s			(GPa)	(GPa)		(GPa)	
3,5	253	151	1500	0,03	0,03	0,22	0,08	1,68
7	315	195	1814	0,07	0,04	0,19	0,16	1,62
49	397	257	2571	0,17	0,07	0,14	0,39	1,54
3	302	145	1490	0,03	0,07	0,35	0,08	2,08
6	315	185	1841	0,06	0,06	0,24	0,16	1,70
49	470	278	2586	0,20	0,17	0,23	0,49	1,69
5	242	150	1538	0,03	0,02	0,19	0,08	1,61
11	301	180	1844	0,06	0,05	0,22	0,15	1,67
45	408	243	2512	0,15	0,12	0,23	0,36	1,68
3	491	150	1587	0,04	0,31	0,45	0,10	3,27
14	624	300	1831	0,16	0,38	0,35	0,44	2,08
44	1132	517	2420	0,65	1,81	0,37	1,77	2,19
3	344	147	1522	0,03	0,11	0,39	0,09	2,34
6	413	219	1851	0,09	0,14	0,30	0,23	1,89
46	503	305	2565	0,24	0,17	0,21	0,58	1,65
4	244	142	1545	0,03	0,03	0,24	0,08	1,72
7	495	148	1953	0,04	0,39	0,45	0,12	3,34
50	525	293	2565	0,22	0,27	0,27	0,56	1,79
3	246	150	1542	0,03	0,02	0,20	0,08	1,64
8	400	170	1943	0,06	0,20	0,39	0,16	2,35
50	500	300	2501	0,23	0,18	0,22	0,55	1,67
3	243	150	1530	0,03	0,02	0,19	0,08	1,62
8	494	187	1903	0,07	0,33	0,42	0,19	2,64
50	507	307	2500	0,24	0,17	0,21	0,57	1,65
6	245	144	1574	0,03	0,03	0,24	0,08	1,70
9	500	215	1967	0,09	0,31	0,39	0,25	2,33
50	759	384	2516	0,37	0,71	0,33	0,99	1,98

Fig. 3 shows the frequency distribution of microseismical signals at recording points in the dam body.

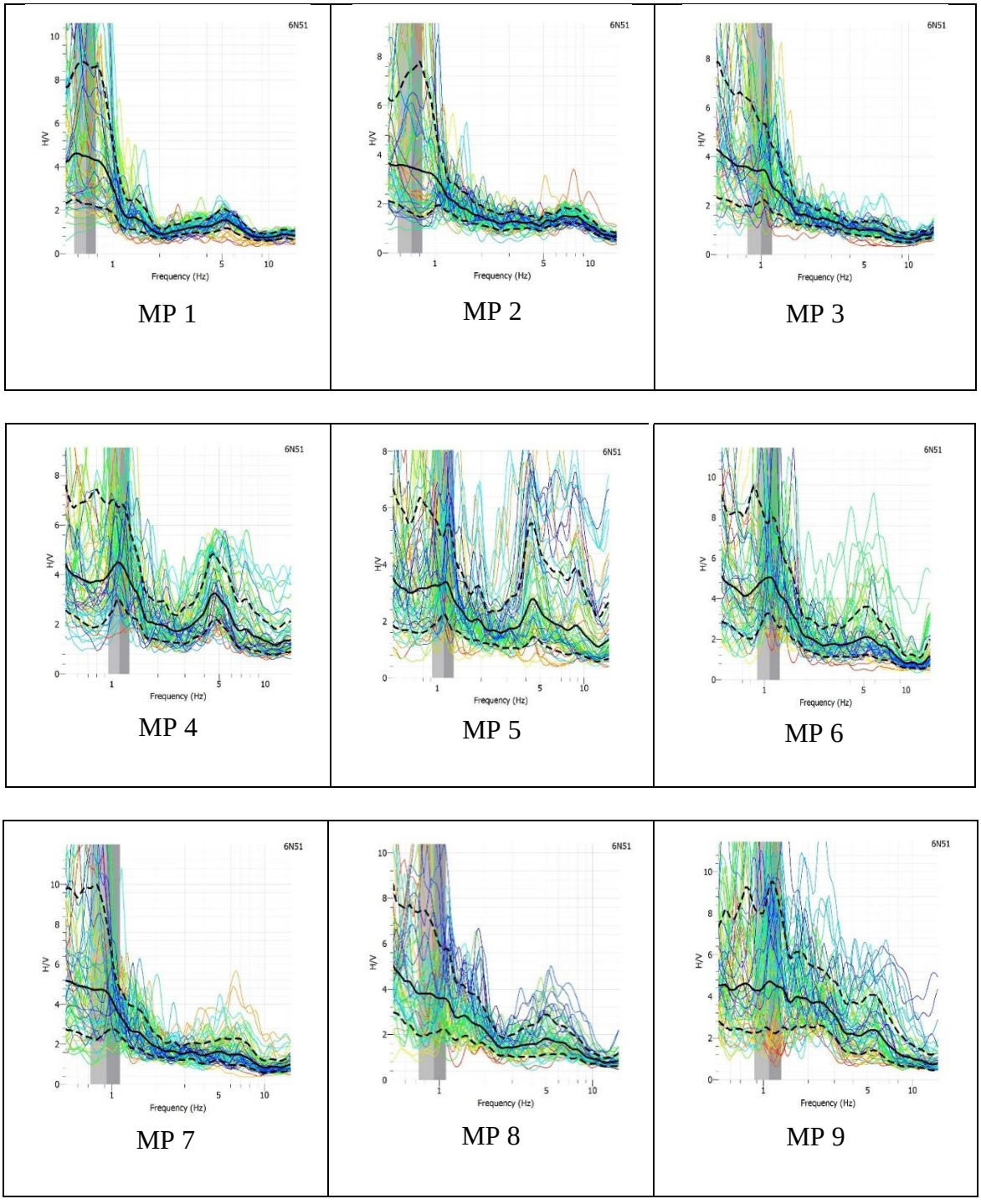


Figure. 3. Frequency distribution of microseismic signals at 1 recording point according to Fig. 2

Fig. 4 shows the changes in the depth of transverse (*Vs*) and longitudinal (*Vp*) waves and the bulk density (ρ) determined on the body of the Chartak reservoir dam.

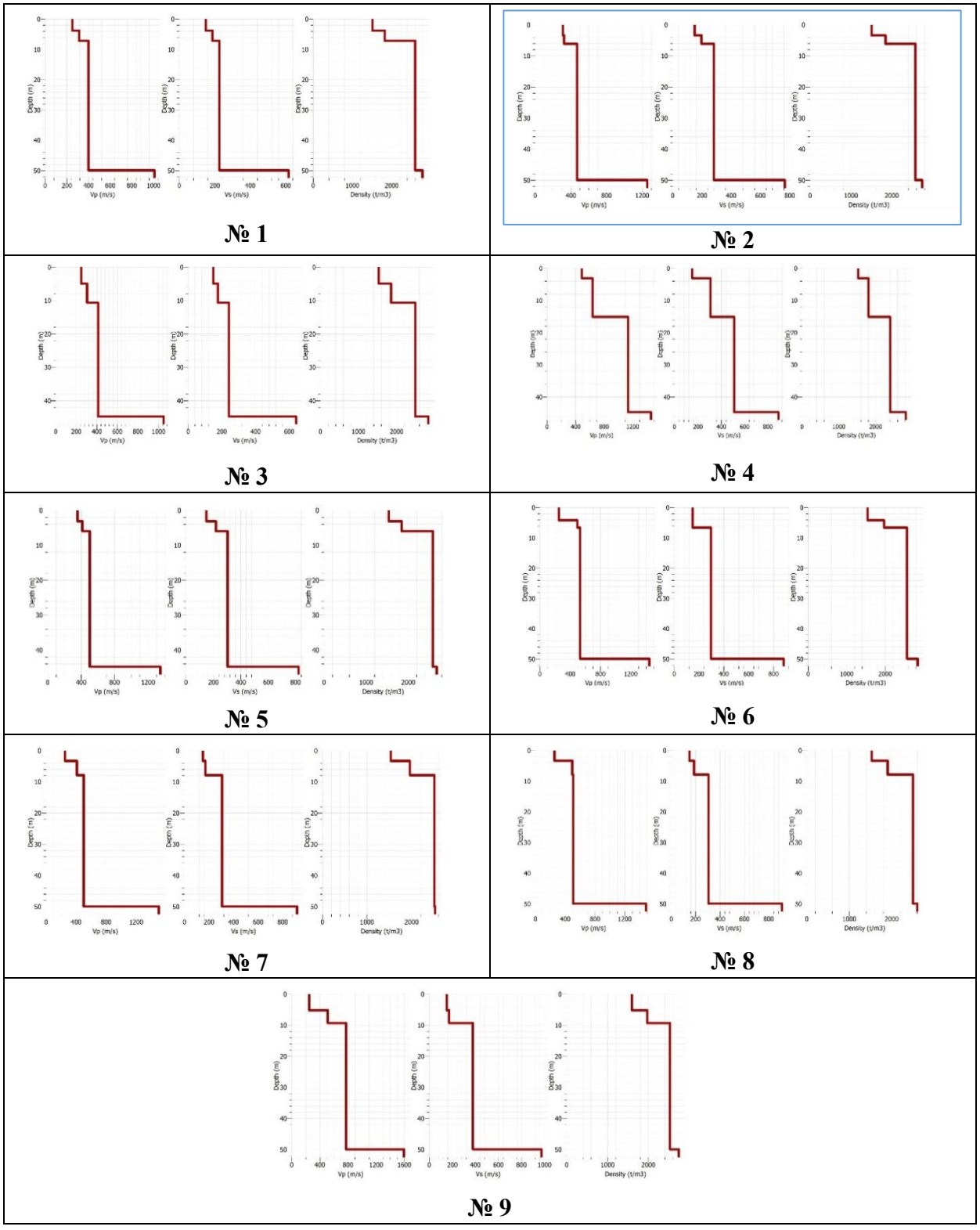


Figure. 4. Graph of changes in the depth of transverse (Vs) and longitudinal (Vp) waves and bulk density (ρ), determined on the body of the Chartak reservoir dam

The calculations were based on microseismical recordings at nine measuring points (MP) on the Chartak Reservoir dam and one point 1 km away from the dam. Figure 4 below shows a graph of

the variation in shear (*Vs*) and longitudinal (*Vp*) wave depth and bulk density determined for the Chartak Reservoir dam body.

Interpretation of seismic data obtained from the reservoir dam using *P*- and *S*-wave velocities and rock density resulted in the determination of the velocity ratio *K*, shear modulusμ, elastic constant λ, Poisson's ratio ν,Young's modulus E and bulk density. The figures and calculation results clearly demonstrate differences in the spectral and amplitude components of microseismical vibrations. The natural vibrations of the dam body at various points consist of an ensemble of frequencies (vibration modes) that depend on the physical state of the structure.

The obtained experimental data were processed using standard methods, including: spectral calculation and analysis of natural microseisms; construction of *H/V* ratio spectra; modeling of one-dimensional vertical soil sections in the shear wave velocity format and obtaining geotechnical parameters of the thickness of layered soils. Data processing was carried out using the Geopsy program (www.geopsy.org) (*Software EU: GEOPSY, appeal October* 2025).

These parameters have the following characteristics: the velocity ratio $K = Vp/Vs$ is used to determine the ratio of the velocities of longitudinal and shear waves. The average value of the *K* coefficient for strong earthquakes is taken to be 1.73. Since the wave parameters of microseismic vibrations are small, this coefficient can be significant. The shear modulus was determined using the following formula: $\mu = V_S^2 \cdot \rho$, where ρ (g/cm3) is the density of the fill rock. The distribution of the compressive modulus across the dam body is predominantly high at the base (river flow zone), and when analyzing the data obtained for the dam, it was noted that the shear modulus increases threefold (0.23–0.64 GPa) toward the central part of the dam.

Conclusion

Microseismical vibration measurements and *Vp/Vs* ratio assessments at the Chartak Reservoir dam revealed that oblique seismic action increases the amplitude amplification factor of the Chartak Reservoir dam's vibrations. The maximum relative up-down displacement in these dams decreased with increasing V_P wave incidence angle, while the relative displacement increased with increasing V_S wave incidence angle. This suggests that the maximum principal stresses at the dam's nodal points initially increased and then decreased with increasing V_P -wave incidence angle and gradually decreased with increasing V_S wave incidence angle. A frequency profile was compiled for the Chartak Reservoir dam's support points. An assessment of the seismic instability coefficient of the Chartak Reservoir dam, based on in-situ measurements of vibration frequencies and the H/V ratio and *Kg*, revealed that the seismic instability coefficient *Kg* at the dam crest does not exceed 17.8. No man-made conditions affecting the seismic instability coefficient *Kg* at the Chartak Reservoir dam crest were identified.

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GPS-BASED MONITORING OF HORIZONTAL CRUSTAL MOVEMENTS AND SEISMIC ACTIVITY IN AZERBAIJAN IN 2025

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Annotation

The territory of Azerbaijan is characterized by high seismic activity and complex geodynamic features. In 2025, horizontal movements of the Earth's crust were assessed using data from 22 GPS stations. The analysis revealed that the average velocities were 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11.0 mm/yr in the Kura depression, 13.52 mm/yr in the Talysh region, and 5.34 mm/yr on the Absheron Peninsula. Maximum velocities were observed in Lankaran (13.83 mm/yr), Lerik (13.55 mm/yr), Jalilabad (13.21 mm/yr), and Saatli (13.35 mm/yr).

During the same period, focal mechanisms of 72 earthquakes ($ml \geq 3.0$) were analyzed, showing the predominance of compressional and right-lateral strike-slip motions. Most earthquakes occurred at depths of 3–74 km, reflecting local geodynamic activity, particularly in the Talysh zone with higher seismic velocities and earthquake intensity. In total, 22 earthquakes occurred in the Caspian Sea sector, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran area, and 3 in the Lesser Caucasus.

Integrated seismic and GPS data indicate that the average horizontal crustal movement across Azerbaijan is approximately 8.04 mm/yr toward the northeast. Results show that increased velocities in the Talysh, Kura depression, and Greater Caucasus zones correspond to enhanced geodynamic stress and seismic activity, while buffer structures in the Absheron Peninsula and southern slopes of the Greater Caucasus reduce horizontal displacement. This provide a detailed characterization of Azerbaijan's geodynamic and seismic environment and form a scientific basis for assessing potential seismic hazards.

Keywords: Azerbaijan, seismic activity, geodynamic zones, GPS measurements, horizontal velocity, earthquake focal mechanism, Lode-Nadai coefficient

2025-Cİ İLDƏ AZƏRBAYCAN ƏRAZİSİNDƏ GPS VASİTƏSİLƏ YER QABIĞININ ÜFÜQİ HƏRƏKƏTLƏRİ VƏ SEYSMİK AKTİVLİYİN MONİTORİNQİ

Kazımov İ.E., Kazımova S.E.

Annotasiya

Azərbaycan ərazisi yüksək seysmik aktivliyə malik və mürəkkəb geodinamik xüsusiyyətlər göstərən regiondur. 2025-ci ildə aparılmış tədqiqat çərçivəsində 22 GPS stansiyasının məlumatları əsasında Yer qabığının horizontal hərəkətləri qiymətləndirilmişdir. Əldə olunan nəticələr göstərir ki, Böyük Qafqazda orta sürət 6,13 mm/il, Kiçik Qafqazda 8,00 mm/il, Kür çökəkliyində 11,0 mm/il, Talış bölgəsində 13,52 mm/il, Abşeron yarımadasında isə 5,34 mm/il təşkil edir. Maksimal sürətlər Lənkəran (13,83 mm/il), Lerik (13,55 mm/il), Cəlilabad (13,21 mm/il) və Saatlı (13,35 mm/il) stansiyalarında müşahidə olunmuşdur.

Eyni dövrdə 72 zəlzələnin ($ml \geq 3.0$) ocaq mexanizmləri təhlil edilmiş və sıxılma, sağ tərəfli qırılıb-qalxma tipli hərəkətlərin üstünlük təşkil etdiyi müəyyən edilmişdir. Zəlzələlərin əksəriyyəti

[1] Republican Seismic Survey Center of Azerbaijan National Academy of Sciences

3–74 km dərinlikdə baş vermiş və lokal geodinamik aktivliyi, xüsusilə Talış zonasında yüksək seysmik sürət və zəlzələ intensivliyi ilə uzlaşmışdır. Xəzər dənizi sektorunda 22, Kür çökəkliyində 13, Böyük Qafqazda 22, Lənkəran ərazisində 9 və Kiçik Qafqazda 3 zəlzələ qeydə alınmışdır.

İnteqrasiya olunmuş seysmoloji və GPS məlumatlar əsasında Azərbaycan ərazisi üzrə orta üfüqi hərəkət sürəti təxminən 8,04 mm/il və şimal-şərq istiqamətində müəyyən edilmişdir. Nəticələr göstərir ki, Talış, Kür çökəkliyi və Böyük Qafqaz zonalarında sürətlərin artması ilə geodinamik gərginliklər və seysmik aktivlik artır, Abşeron yarımadası və Böyük Qafqazın cənub yamacında isə "buffer" strukturlar hərəkətin ötürülməsini azaldır. Bu nəticələr regionun geodinamik və seysmik mənzərəsini dəqiqliklə ortaya qoyur və potensial seysmik təhlükənin qiymətləndirilməsi üçün elmi əsas yaradır.

Açar sözlər: Azərbaycan, seysmik aktivlik, geodinamik zonalar, GPS müşahidələri, horizontal sürət, zəlzələnin ocaq mexanizmi, Lode-Nadai əmsalı

МОНИТОРИНГ ГОРИЗОНТАЛЬНЫХ ДВИЖЕНИЙ ЗЕМНОЙ КОРЫ И СЕЙСМИЧЕСКОЙ АКТИВНОСТИ НА ТЕРРИТОРИИ АЗЕРБАЙДЖАНА С ИСПОЛЬЗОВАНИЕМ GPS В 2025 ГОДУ

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Аннотация

Территория Азербайджана относится к регионам с высокой сейсмической активностью и сложным геодинамическим строением. В рамках исследований, проведённых в 2025 году, на основе данных 22 GPS-станций была оценена величина горизонтальных движений земной коры. Полученные результаты показывают, что средние скорости составляют: в пределах Большого Кавказа – 6,13 мм/год, Малого Кавказа – 8,00 мм/год, Куринской впадины – 11,0 мм/год, Талышского региона – 13,52 мм/год, Абшеронского полуострова – 5,34 мм/год. Максимальные значения скоростей зафиксированы на станциях Ленкорань (13,83 мм/год), Лерик (13,55 мм/год), Джалилабад (13,21 мм/год) и Саатлы (13,35 мм/год). В тот же период был выполнен анализ механизмов очагов 72 землетрясений ($ml \geq 3,0$), по результатам которого установлено преобладание режимов сжатия и правосторонних сдвигово-взбросовых движений. Большинство землетрясений произошло на глубинах 3–74 км и отражает локальную геодинамическую активность, в частности согласованность высоких скоростей деформаций и интенсивной сейсмичности в Талышской зоне. В секторе Каспийского моря зарегистрировано 22 землетрясения, в Куринской впадине – 13, в Большом Кавказе – 22, в Ленкоранском регионе – 9 и в Малом Кавказе – 3 события. На основе интеграции сейсмологических и GPS-данных средняя скорость горизонтальных движений по территории Азербайджана оценивается примерно в 8,04 мм/год и ориентирована в северо-восточном направлении. Полученные результаты свидетельствуют о том, что в зонах Талыша, Кураинской впадины и Большого Кавказа увеличение скоростей сопровождается ростом геодинамических напряжений и сейсмической активности, тогда как на Абшеронском полуострове и южном склоне Большого Кавказа наличие «буферных» структур приводит к ослаблению передачи деформаций.

Ключевые слова: Территория Азербайджана, сейсмическая активность, геодинамические зоны, GPS-наблюдения, горизонтальные скорости, механизм очага землетрясения, коэффициент Лоде-Надаи.

Introduction

The territory of Azerbaijan is one of the geodynamically complex regions with high seismic activity. The interaction of the Eurasian, Arabian, and Iranian plates has resulted in the formation of tectonic blocks and fault systems of varying scales. The velocities and directions of movement of these blocks are key indicators that control crustal deformation processes, earthquake intensity, and propagation characteristics. In particular, the Greater Caucasus, Lesser Caucasus, Talysh zone, Kura Depression, and Absheron Peninsula are distinguished by their distinct geodynamic and seismic characteristics [3, 4, 5, 20].

In recent decades, GPS observations have enabled precise monitoring of crustal movements across Azerbaijan. Measurements conducted in 2025 at 22 GPS stations allowed for the assessment of horizontal displacement rates and directions in different parts of the region, taking into account errors related to station topography, ionospheric effects, and signal modulation. The aim of these studies was not only to determine velocities but also to produce accurate geodynamic mapping of the country and identify areas of potential seismic hazard [6, 14, 15].

Analysis for 2025 indicates that horizontal velocities average 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11 mm/yr in the Kura Depression, 13.52 mm/yr in the Talysh zone, and 5.34 mm/yr on the Absheron Peninsula. Maximum velocities were observed in the Talysh region (Lankaran, Lerik, Jalilabad) and at the Saatly station, confirming the high seismogeodynamic activity of these zones. The mean velocity in the northeast direction was 8.04 mm/yr, with increasing trends observed on the Absheron Peninsula, Kura Depression, and Greater Caucasus.

Additionally, the focal mechanisms of 72 earthquakes ($ml \geq 3.0$) that occurred in Azerbaijan in 2025 were studied, and their geodynamic characteristics were analyzed. The majority of these earthquakes originated in granite and basalt layers of the crust, with dominating compressional and right-lateral reverse faulting. The Caspian Sea, Talysh, and Kura Depression regions exhibited high seismic activity, and GPS observations confirmed correlations between earthquake foci. Based on earthquake distribution and mechanisms, the regional distribution of the Lode-Nadai stress ratio and compression-tension axes was determined, highlighting the complexity of geodynamic and seismic conditions across Azerbaijan and the distinct characteristics of different zones.

Integrated seismological and geodynamic analyses allow for the localization of stress fields resulting from plate collisions, as well as the evaluation of block movement directions and velocity dynamics. These data provide a crucial scientific basis for assessing seismogeodynamic activity, predicting risks, and evaluating earthquake occurrence probabilities in the region.

Thus, this study systematically presents the results of GPS and seismological observations conducted in Azerbaijan in 2025, including horizontal movements of crustal blocks, regional distribution of velocities, and earthquake focal mechanisms. The research contributes both to understanding regional geodynamic processes and to assessing potential seismic risks.

Geodynamics of Azerbaijan in 2025

To determine the velocities and directions of horizontal movements of individual tectonic blocks of the Earth's crust in Azerbaijan, 22 GPS stations were connected to the network, and the positions of globally tracked satellites were refined via the internet. Over the past 13 years, a comprehensive data archive has been accumulated. In 2025, the collected data were analyzed using the GAMIT/GLOBK (v5.76) software package at the University of Massachusetts to evaluate both the quality of the station conditions and the reliability of the measurements (Fig. 1).

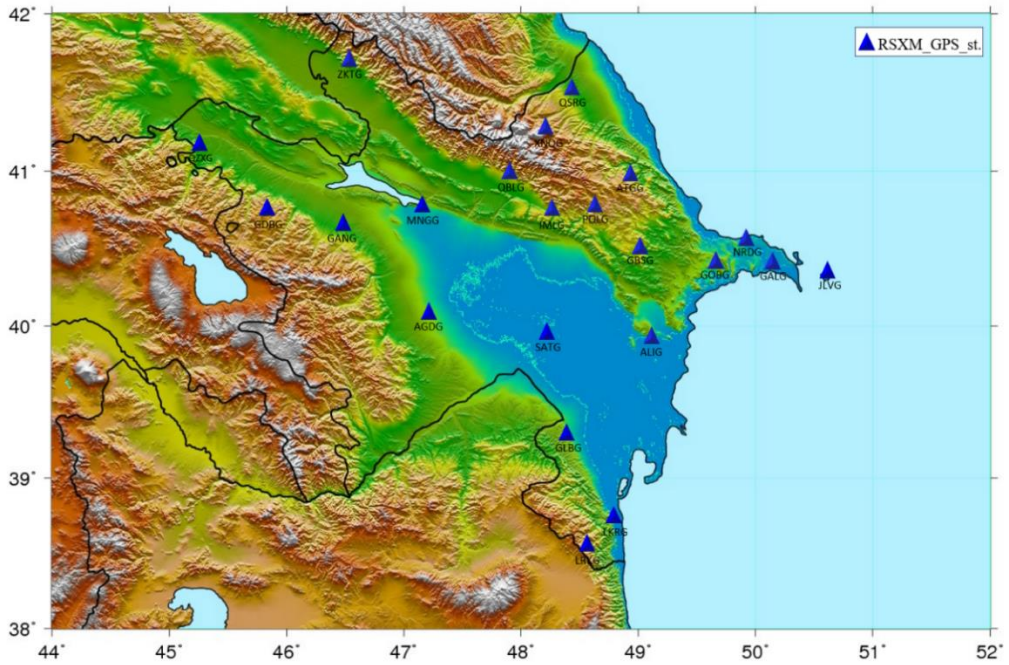


Figure 1. Network map of 22 GPS stations

During the analysis, the modulation errors of GPS signals due to local topography and deviations caused by the ionosphere were calculated on a daily basis for each station. Based on the obtained results, the horizontal displacements and their directions in 2025 were determined (Fig. 1), and velocities were computed individually for each station. In 2025, the average horizontal velocities were found to be 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11 mm/yr in the Kura Depression, 13.52 mm/yr in the Talysh region, and 5.34 mm/yr on the Absheron Peninsula.

The highest velocities were observed at the Lankaran (13.83 mm/yr), Lerik (13.55 mm/yr), and Jalilabad (13.21 mm/yr) stations in the Talysh region, as well as at the Saatly station (13.35 mm/yr). At these stations, the velocities remained consistently high compared to previous years, confirming the intense seismogeodynamic activity in the Talysh zone.

Overall, the 2025 data indicate average northeast-directed horizontal movements of approximately 8.04 mm/yr across Azerbaijan. The table below presents a comparative analysis of average velocities by region, showing an increasing trend, particularly on the Absheron Peninsula, Kura Depression, and Greater Caucasus zones.

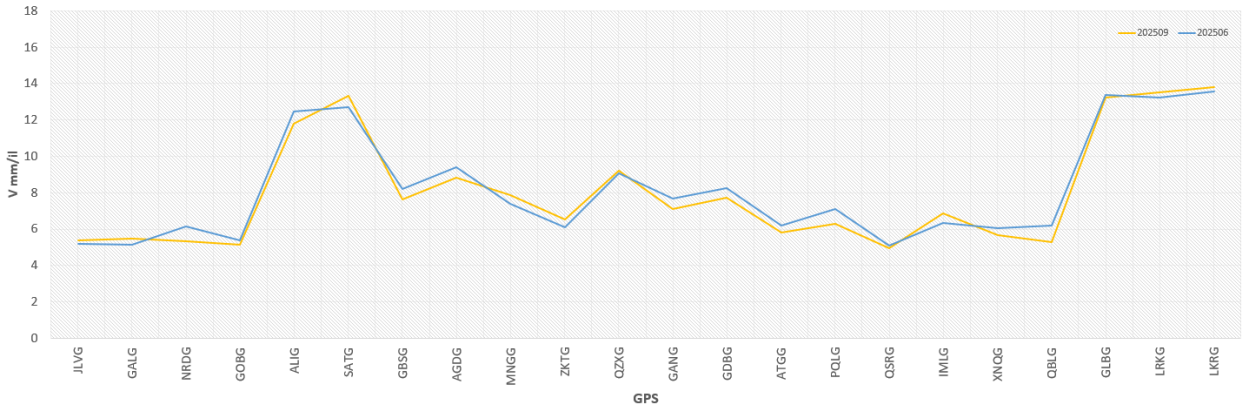


Figure 2. Comparative graph of velocities calculated from GPS stations in 2025

Figure 2 shows the horizontal displacement velocities for the 22 GPS stations. Overall, the lines are closely grouped, indicating the stability of the results. Some variations are observed, but they remain within the range of 0.3–0.8 mm/yr. The minimum velocities (~5 mm/yr) were recorded at the JLVG, NRDG, GOBG, QSRG, and QBLG stations. The maximum velocities (13–14 mm/yr) were observed at the SATG, GLBG, LRKG, and LKRG stations. Thus, over nine months, velocities across the 22 stations ranged from 5 to 14 mm/yr.

The most notable changes were observed at the ALIG and SATG stations. Comparison of six-month data (12.46–12.7 mm/yr) with nine-month data (11.8–13.35 mm/yr) indicates that the velocity at the ALIG station decreased by approximately 0.66 mm/yr, while at the SATG station it increased by approximately 0.65 mm/yr. These trends remained consistent over both periods.

Stations located on the Absheron Peninsula (JLVG, GALG, NRDG, GOBG) showed relatively low velocities, ranging from 5 to 6 mm/yr. In contrast, the southern stations of Azerbaijan (GLBG, LRKG, LKRG) recorded the highest velocities (13–14 mm/yr). The nine-month data indicate that the horizontal movement vectors remained largely stable across almost all stations, with variations within ±0.1–0.2 mm/yr. Only the ALIG station experienced a slight decrease (~0.66 mm/yr), while the SATG station showed a slight increase (~0.65 mm/yr), likely reflecting local geodynamic processes.

Overall, the horizontal velocities of the Earth's crust in Azerbaijan remained predominantly stable throughout 2025. Distribution maps of horizontal velocities and vectors for GPS stations in 2025 were constructed (Figs. 2 and 3).

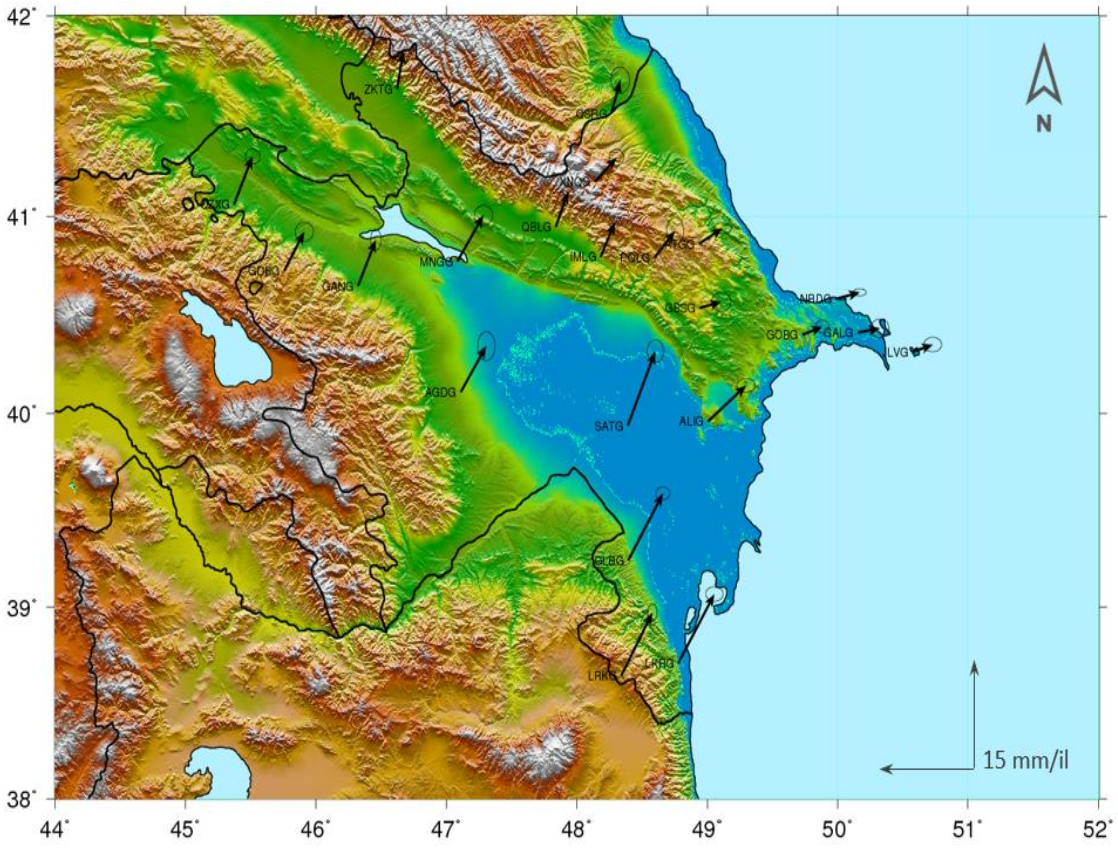


Figure 3. Map of azimuth directions of horizontal velocities obtained from GPS stations in 2025

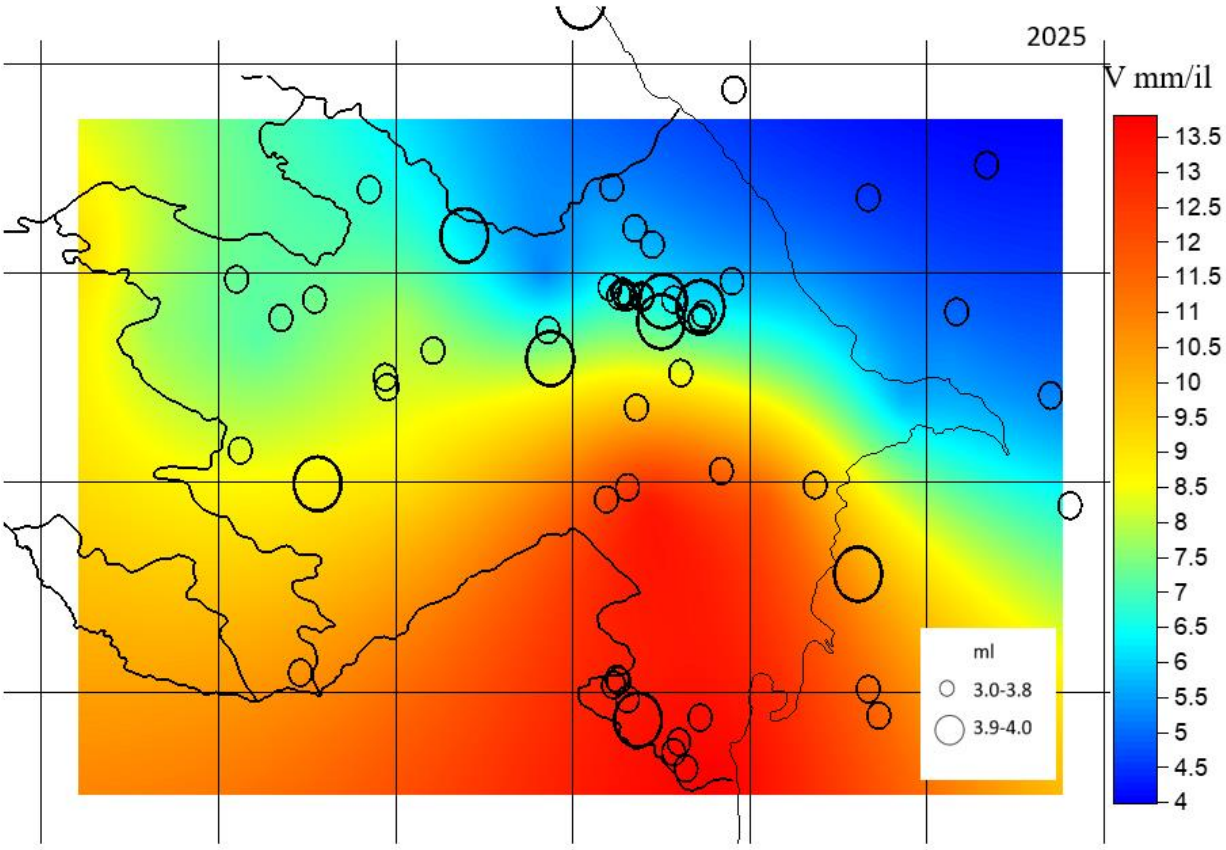


Figure 4. Distribution of horizontal velocities at GPS stations and earthquakes (ml > 3.0) in 2025

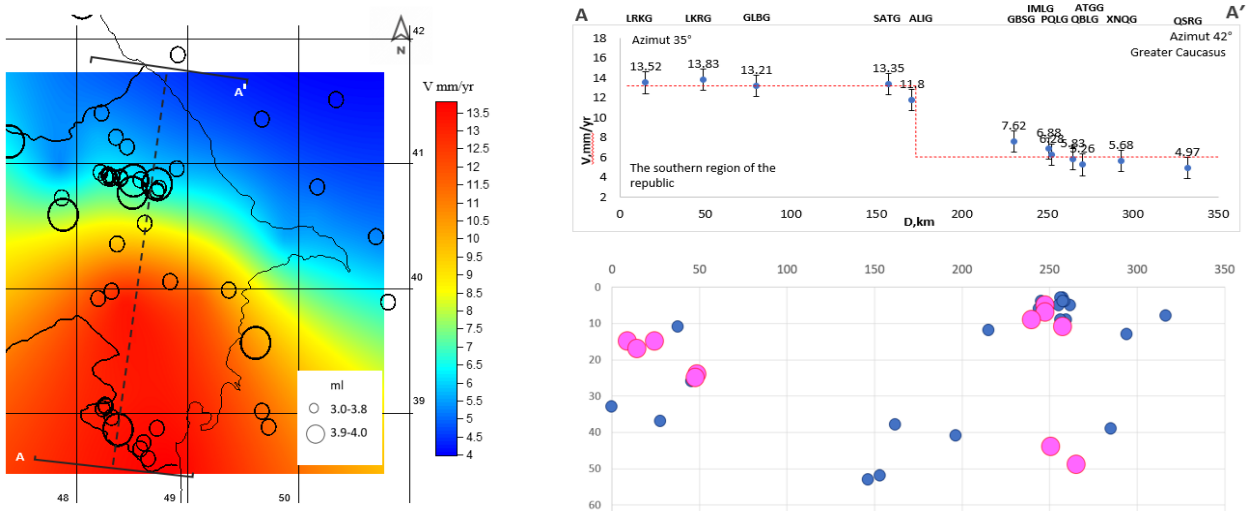


Figure 5. Horizontal velocity directions at GPS stations, histogram of horizontal displacements along the profile, and earthquake depth distribution in 2025

To monitor variations in horizontal velocities across different regions, a profile was constructed along the 1-1 SW–NE direction. The spatial distribution of GPS-derived velocity fields indicates that, overall, the territory of Azerbaijan is moving northeast relative to the Eurasian plate. Notably, a twofold decrease in velocities is observed between GPS stations located west of the Caspian Fault in the Kura depression and Talysh region, and those situated on the Absheron Peninsula east of the

Caspian Fault. This pattern highlights regional differences in crustal motion and confirms the influence of local tectonic structures on horizontal displacement rates.

The observed decrease in velocities between the Talysh region and the Greater Caucasus has several causes. Tectonically, the region between Talysh and the Greater Caucasus consists of small-scale blocks moving in different directions, compensating for deformation through internal slip and rotation. Approaching the Greater Caucasus, resistance to motion increases due to the presence of developed uplifted structures and anticlines that act as buffers, slowing horizontal displacement. In the central Kura depression and the southern slopes of the Greater Caucasus, major tectonic barriers such as the Adijay-Alyat uplift and the Arpa-Samur fault absorb part of the compressional energy, leading to reduced horizontal velocities. Additionally, the regional plate tectonics must be considered: in the Talysh region, the Iranian block approaches nearly perpendicular to the deformation front, while the influence of the Arabian plate in the Greater Caucasus is more oblique. Consequently, a portion of the motion in the Kura depression and the Greater Caucasus is accommodated by slip or block rotation rather than pure forward displacement, explaining the observed velocity decrease.

Sharp variations in mean horizontal velocities and azimuthal directions along the SW–NE profile indicate stress accumulation between these regions, which is reflected in seismic activity.

Results from GPS and seismological studies in 2025 complement each other, providing a comprehensive geodynamic picture of processes in different tectonic zones of Azerbaijan. Out of 70 recorded earthquakes, 68 occurred within Azerbaijan: 21 in the Caspian Sea, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran region, and 3 in the Lesser Caucasus. Seismological data indicate that most events were characterized by thrusting and strike-slip mechanisms, reflecting stress accumulation and release at the intersection of differently oriented tectonic faults. GPS observations corroborate these findings.

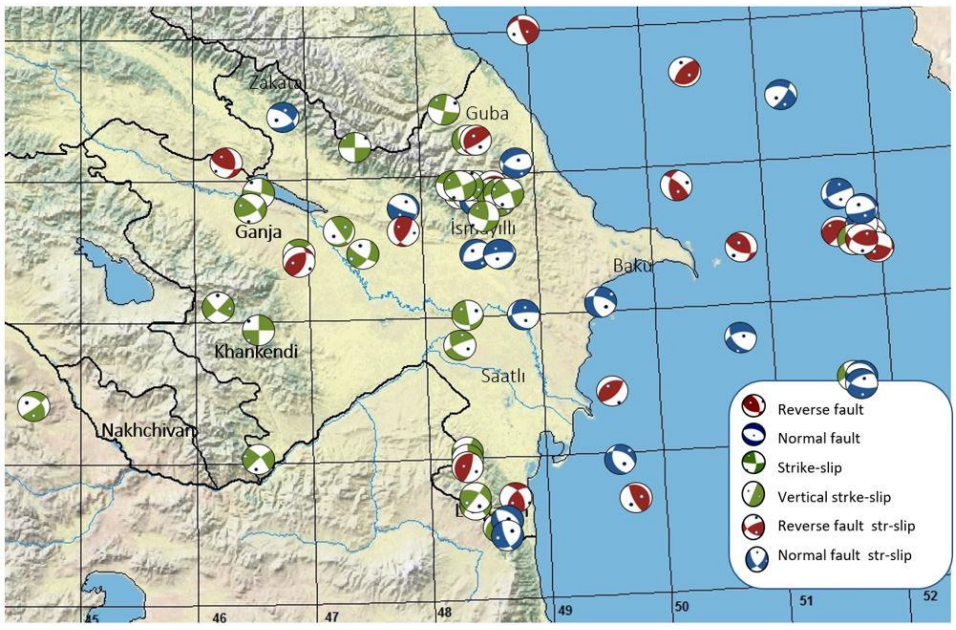


Figure 6. Focal mechanisms of earthquakes with ml ≥ 3.0 in 2025
(Fault map compiled by: Kengerli, Shikhalibeyli)[5]

1 – Dashgil-Mudrasa, 2 – Vandam, 3 – Gokchay, 4 – Siyazan, 5 – Zangi-Kozluchay, 6 – Germian, 7 – Adjichay-Alet, 8 – Western Caspian, 9 – Arpu-Samur, 10 – Gandjachay-Alazan, 11 – Gazakh-Signakh, 12 – Northern Adjinour, 13 – Iori, 14 – Kura, 15 – Mingachevir-Saatly, 16 – Bashlibel, 17 – Palmir-Absheron, 18 – Akhti-Nugedi-Kiliziali, 19 – Talysh, 20 – Yardimli, 21 – Front-Talysh, 22 – Central Caspian, 23 – Absheron-Near Balkan, 24 – Sangachal-Ogurchi, 25 – Chikishler, 26 – Yashma flexure, 26a – Gizilagach, 27 – Shakhov-Azizbeyov, 28 – Qarabogaz-Safidrud

The highest velocities (13–14 mm/yr) were observed at the Lankaran, Lerik, and Jalilabad stations in the Talysh zone, consistent with the region's high seismogeodynamic activity and higher earthquake occurrence. Earthquakes in the Kura depression (e.g., a magnitude ml=4.0 event in the Goychay district) were associated with right-lateral thrusting, consistent with GPS-derived average velocities of ~11 mm/yr. In the Greater Caucasus, earthquakes in the Ismayilli–Shamakhi area (ml=3.6–3.8) occurred in zones with slower GPS velocities (~6.21 mm/yr), but corresponded to areas of locally elevated stress accumulation.

Analysis of Earthquake Focal Mechanisms in the Caspian Sea and Greater Caucasus in 2025

Studying the focal mechanisms of strong earthquakes allows for the identification of characteristic tectonic motion types in different seismically active regions of the crust and enables the estimation of the maximum ground acceleration values associated with these motion types [18, 19]. Accordingly, in 2025, to investigate stress and deformation fields in the crust, the focal mechanisms and dynamic parameters of earthquakes were analyzed, along with their formation conditions, including compressional and extensional stress regions [17]. As a result, the focal mechanisms of 72 earthquakes with magnitudes ml ≥ 3.0 were determined and analyzed (Fig. 6).

Of the 72 recorded earthquakes, 70 occurred within the territory of Azerbaijan. Among these 70 earthquakes, 22 were in the Caspian Sea, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran region, and 3 in the Lesser Caucasus (Fig. 7).

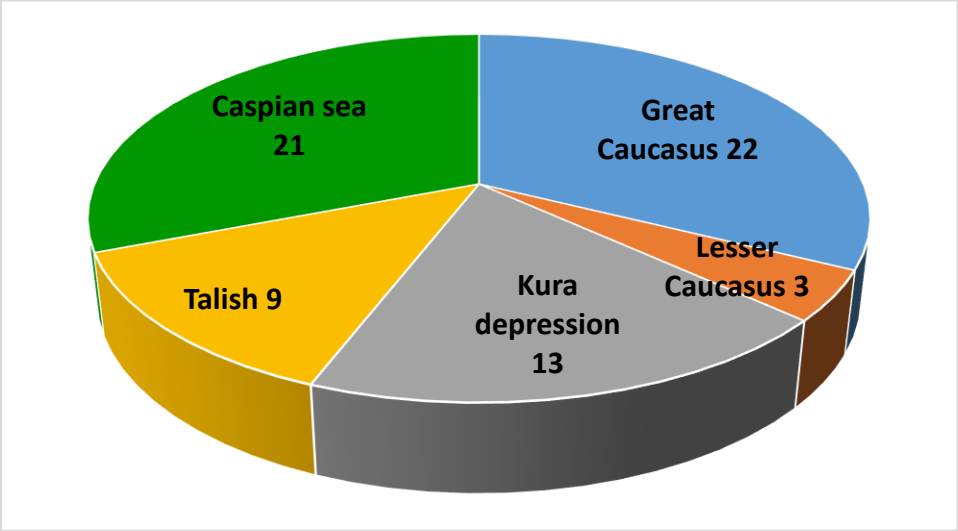


Figure 7. Histogram showing the distribution of focal mechanisms for 68 earthquakes (ml ≥ 3.0) recorded over the course of 2025

In 2025, the focal mechanisms of 22 earthquakes in the Caspian Sea were analyzed. The strongest earthquake of the year (ml= 4.0) occurred on March 7 at 08:22:58 local time in the Caspian Sea. The earthquake's depth was determined to be H = 45 km. The compression axis (P) (PL = 9) was oriented vertically, while the tension axis (T) (PL = 78) was oriented near-horizontal. For the first nodal plane, a steep dip angle (DP1 = 54°) was determined, and for the second nodal plane, a shallow dip angle (DP2 = 37°) was obtained. The displacement at the focus indicates that the movement was predominantly of a reverse-fault type.

On April 27, 2025, a magnitude ml= 3.6 earthquake occurred near the Absheron Peninsula at 18:13:14 local time. Its depth was H = 58 km. The compression axis (P) (PL = 13) was vertically oriented, while the tension axis (T) (PL = 46) was near-horizontal. Both nodal planes showed steep dip angles (DP1 = 70° and DP2 = 48°). The displacement at the focus was primarily reverse-fault, consistent with the Central Caspian fault system.

In 2025, 22 earthquakes occurred in the Greater Caucasus region. In the early months, the strongest earthquakes occurred in the Ismayilli (ml= 3.6) and Shamakhi (ML = 3.7) districts. On February 19, at 15:11:42 local time, an earthquake was recorded in Ismayilli. The epicentral intensity was 4, and nearby settlements—Lahij, Zarat, Julian, Burovdal, and Mudri villages—experienced intensity 3. The earthquake depth was H = 11 km. The orientations of the compression (P) and tension (T) axes were both near-vertical (PL = 4–7). For the first and second nodal planes, steep dip angles were determined (DP1 = 88° and DP2 = 82°). The focal displacement indicates a dominant right-lateral strike-slip movement, consistent with the Vəndam fault.

Another earthquake occurred in the Sheki district on April 21 (ml= 4.0), 5 km east of the Sheki station. The epicentral intensity was 4, with nearby settlements experiencing intensity 3. The earthquake occurred at 08:31:09 local time, with a depth of H = 17 km. The compression axis (P) (PL = 0–0) was oriented horizontally, and both nodal planes exhibited steep dip angles (DP1 = 90° and DP2 = 90°). The focal displacement was primarily strike-slip, consistent with the Dashgil-Mudrese fault.

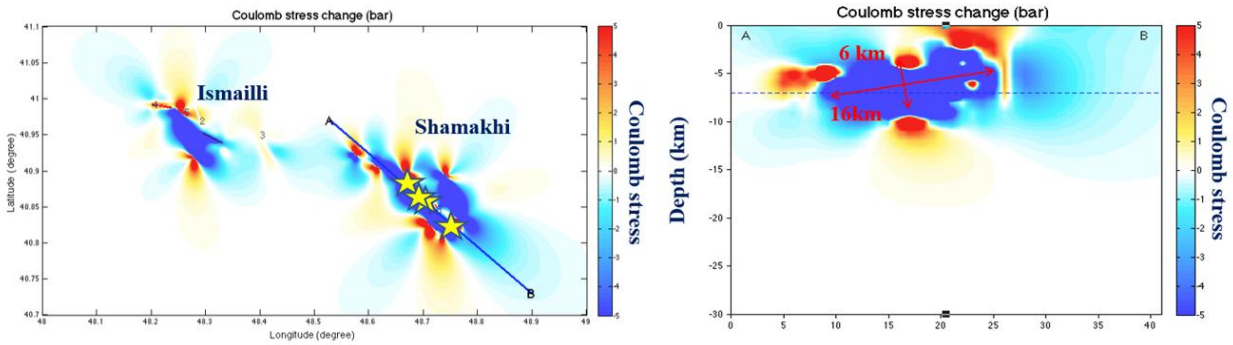


Figure 8. Distribution of Coulomb stresses and depth profiles for the earthquakes that occurred in Shamakhi district on June 5–6, 2025

The Shamakhi district also showed increased activity. The strongest earthquake occurred on June 5, 14 km northeast of the Pirqulu station, with a magnitude of ml= 3.7. The epicentral intensity was 4, with surrounding settlements in Shamakhi and Khizi experiencing 3–4 intensity. The earthquake occurred at 16:02:43 local time, with a depth of H = 7 km. The compression axis (P) (PL = 8–2) was near-horizontal, and the nodal planes had steep dip angles (DP1 = 86° and DP2 = 83°). The displacement at the focus was predominantly right-lateral, consistent with the Dashgil-Mudrese fault.

Additional earthquakes occurred on June 5–6: ML = 3.2 at 12:04:59 (05.06.2025), ml= 3.2 at 02:40:34 (06.06.2025), and ml= 3.6 at 06:18:36 (06.06.2025). The displacements at these foci exhibited the same characteristics as the main events, indicating consistent strike-slip motion. All events, including aftershocks, were shallow, occurring at depths of 2–10 km. Coulomb stress distribution for these earthquakes was mapped, with stress release indicated in blue [8]. Profiles show that four areas within the focal zones maintained residual stress, highlighting continued seismotectonic activity in these regions.

On July 12, 2025, an earthquake of magnitude ML = 3.8 occurred in the Ismayilli district, 10 km west of the Pirqulu station. The epicentral intensity was 4, with nearby settlements in Shamakhi district experiencing intensity 3–4. The earthquake occurred at 07:18:58 local time at a depth of H = 9 km. The compression axis (P) (PL = 4–23) was oriented near-horizontal, and the dip angles for the first and second nodal planes were steep (DP1 = 77° and DP2 = 72°). The focal displacement indicates a dominant left-lateral strike-slip motion, consistent with the Dashgil-Mudrese fault.

On August 21, 2025, an earthquake of ml = 3.6 occurred in Siyazan district, 10 km south of the Siyazan station. The event was not felt in settlements farther from the epicenter; nearby settlements

experienced intensity up to 3. The earthquake occurred at 17:17:58 local time at a depth of H = 49 km. The compression axis (P) (PL = 68) was oriented vertically, while the tension axis (T) (PL = 8) was near-horizontal. The first nodal plane showed a steep dip (DP1 = 57°) and the second a shallow dip (DP2 = 41°). The focal displacement was dominated by right-lateral reverse-fault motion, consistent with the Siyazan fault.

In the Kura depression, focal mechanisms were determined for 13 earthquakes over the past year. On March 26, 2025, a magnitude ml = 3.6 earthquake occurred in Samukh district, 46 km northwest of the Mingachevir station near the Mingachevir reservoir. The epicentral intensity reached 3 in nearby settlements. The earthquake occurred at 17:09:31 local time at a depth of H = 11 km. The compression axis (P) (PL = 5–7) was near-horizontal, and both nodal planes exhibited steep dips (DP1 = 89° and DP2 = 82°). The focal displacement indicates a dominant left-lateral strike-slip motion, consistent with the Gandja-Chay fault.

The strongest earthquake in the Kura depression occurred on August 9 in Goychay district (ml = 4.0) at 11:03:35 local time. Recorded 35 km southwest of Ismayilli station, the earthquake had an epicentral intensity of 4 in Goychay and 3 in surrounding settlements including Gabala, Ismayilli, and Agdash. The depth was H = 16 km. The compression axis (P) (PL = 16) was vertical, the tension axis (T) (PL = 60) near-horizontal; the first and second nodal planes had dip angles DP1 = 66° and DP2 = 36°, respectively. The focal displacement was dominated by right-lateral reverse-fault motion, consistent with the Khachinchay fault.

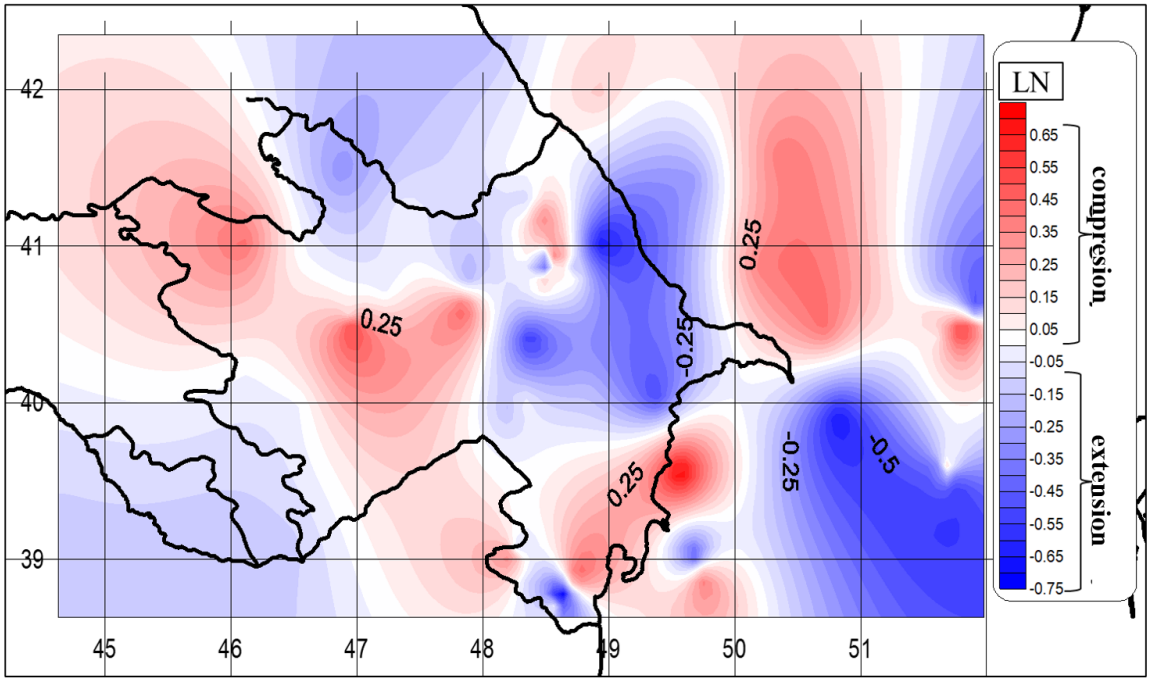


Figure 9. Distribution map of the Lode-Nadai ratio calculated based on the mechanisms of earthquakes that occurred in 2025

In the Lankaran region, focal mechanisms were determined for 9 earthquakes. The strongest event occurred on March 9 in Lerik district (ml = 4.0) at 07:49:54 local time, with a depth of H = 15 km. The P and T axes were near-horizontal (PL = 24–17), and the nodal planes exhibited steep dips (DP1 = 86° and DP2 = 61°). The focal displacement indicates right-lateral strike-slip motion, consistent with the Talish fault. On June 2, a second earthquake occurred at 07:51:15 local time at a depth of H = 15 km. The compression axis (P) (PL = 90) was horizontal, the tension axis (T) (PL = 0) near-vertical, and the nodal planes had dip angles DP1 = DP2 = 45°. The focal displacement was dominated by left-lateral strike-slip motion, consistent with the Pre-Talish fault.

In the Lesser Caucasus, 3 earthquakes were recorded, with focal mechanisms determined. The strongest was in Kalbajar district (ml = 3.7) on April 7 at 00:35:55 local time, 50 km southwest of the Agdam station. The earthquake occurred at H = 15 km, with P and T axes oriented horizontally (PL = 0–0). Both nodal planes showed steep dips (DP1 = DP2 = 90°). The focal displacement indicates dominant strike-slip motion, consistent with the Arpa-Samur fault.

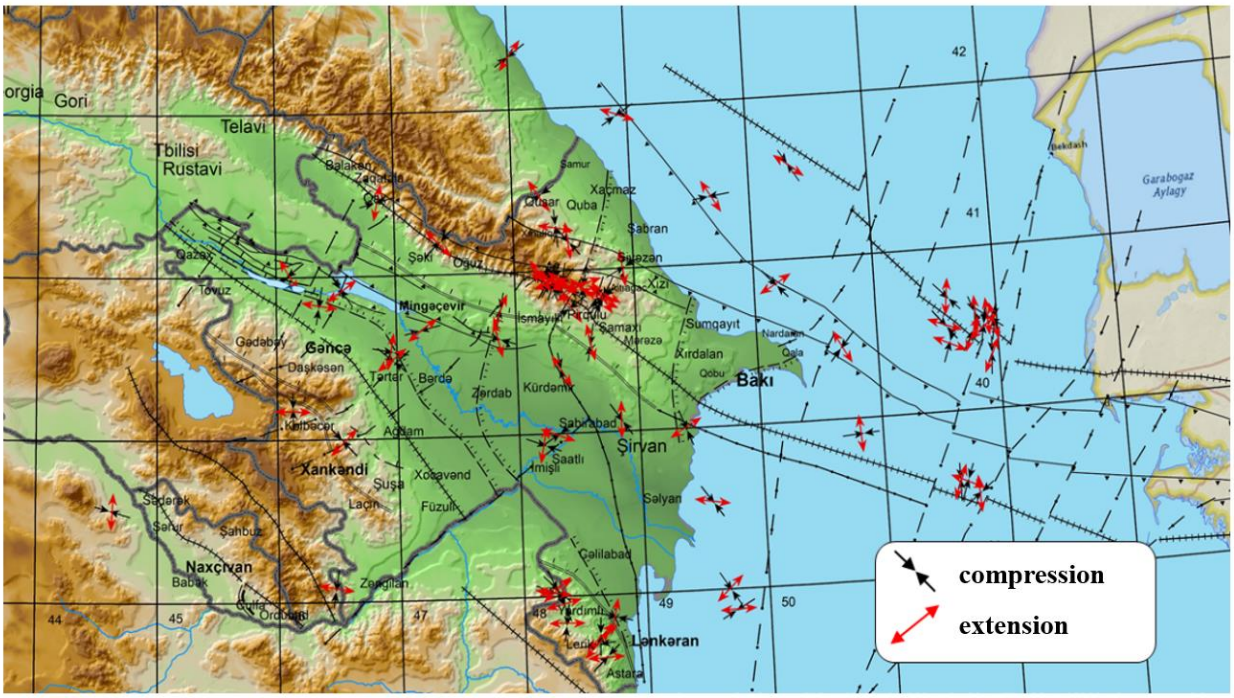


Figure 10. Distribution map of the compression-tension axes calculated based on the mechanisms of earthquakes in 2025

One of the strongest earthquakes of 2025 occurred in Dagestan. According to the Seismological Service Center, the earthquake's hypocenter was near Izberbash, at a depth of 14 km. Seismic waves were recorded at 00:33 Baku time, 28 km east of Izberbash and 51 km north-northwest of Derbent, with a magnitude of ml=5.3. The focal displacement was predominantly reverse-fault.

Based on the calculated focal mechanisms, a map of the Lode-Nadai stress ratio was constructed [1]. The map shows compressional stress dominating in the Lesser Caucasus, northeastern Talish, and the Central Caspian Sea, while extensional stress characterizes the Greater Caucasus, Lower Kura depression, Nakhchivan, Lankaran, and the southern Caspian region (Fig. 9). The geodynamics of crustal blocks in the eastern part of Azerbaijan is primarily influenced by the right-lateral faulting of the Western Caspian, with predominantly right-lateral reverse-fault motion observed in this area.

The orientation of the compression and tension axes shows that in several earthquakes in the Central Caspian and Greater Caucasus regions, they are directed NE–SW, whereas in the Talysh region, the tension axes are oriented NW–SE (Fig. 10).

Almost all earthquakes with magnitudes ml > 3.0 occurred at depths ranging from 3 to 74 km. The majority of seismic activity is observed within the granite and basalt layers of the crust. This suggests that the seismicity of the junction between the Scythian-Turanian platform and the Alpine orogen is associated with the intersection of tectonic faults of various orientations (seismogenic nodes) [9, 11, 12].

Uneven stress distribution over tectonic blocks is observed in areas of thin crust, brittle lithofacies, and specific petro-physical compositions. Such zones facilitate the accumulation of potential stress energy, and as stress increases, fractured structural zones form. For the Central

Caspian basin, the small angles of the tension axes indicate that thrust-faulting dominates in this region.

Results and discussion

Integrated analysis of seismological data (number, magnitude, depth, and distribution of earthquakes), geodynamic observations (GPS-measured velocities of lithospheric blocks, stress fields generated by plate convergence), focal mechanisms, orientation of compression/tension axes, and Lode-Nadai ratios has allowed for the synthesis of generalized results.

In 2025, 5216 local earthquakes were recorded, of which 71 had ml ≥ 3.0, and 19 were felt, corresponding to an approximate intensity of 5.4. Overall seismic activity is moderate but increased in zones of higher GPS-measured velocities (Ismayilli, Talysh, and the Caspian Sea). Correlation shows that increased velocities in the northwest of the republic and accumulated stress released in the Caspian Sea correspond to higher seismicity compared to 2024. This aligns with studies from 2023–2024 showing transitions from extension to compression and increased tectonic activity. Approximately 60% of earthquakes at depths ≤ 20 km reflect deformation in the sedimentary layers caused by plate motions. The primary causes of seismicity are collisions between the Arabian, Iranian, and Eurasian plates, resulting in compression, local extension, stress accumulation along faults, and energy release in brittle crustal layers. GPS data indicate that the mean horizontal velocity of continental movement in the northeast is ~8.1 mm/year.

Caspian Sea (Azerbaijan sector). A detailed analysis of the Caspian Sea reveals high seismicity in the central and northern parts under compression (28 events with ml ≥ 3, depths 20–74 km, focal depths for strong shocks 66–74 km). Strike-slip and thrust mechanisms dominate. Geodynamically, this is associated with the general compression of the Skif-Turan and South Caspian plates, activating faults such as Agrakhan-Krasnovodsk, Sangachal-Ogurchi, Shakhov-Azizbeyov, Mil-Chikishlyar, and Yashma-Byandov. In the central part, compression (axes-oriented NW–SE) and extension in the south promote lithospheric subsidence or rupture at depth. The strongest earthquake (ml 5.4, depth 74 km) occurred on 26 August 2025 off the Dagestan coast, associated with the Terek fault. Caspian Sea activity increased relative to 2024 due to enhanced compression in the transition from continental collision to oceanic deformation, increasing the risk of strong deep shocks. Low velocities on the Absheron Peninsula explain the weak seismicity—buffer zones absorb deformation without generating strong shocks.

Greater Caucasus (Shamakhi-Ismayilli, Balakan-Gabala, Quba-Qusar, Siyazan zones). The most active part of the Greater Caucasus recorded 22 events with ml ≥ 3.0, focal depths mainly 2–49 km (shallow 2–15 km). Seismicity is driven by compression from the Arabian plate (mean GPS velocity ~6.1 mm/year from 2024 to 2025) and primarily right-lateral strike-slip mechanisms with steep dip angles (DP 72–90). Block geodynamics enhance meridional migration of epicenters, activating the Western Caspian, Dashgil-Mudrasa, Vandam, and Siyazan faults. In some areas, extension (NW–SE) dominates, promoting brittle deformation in the thin crust and aftershocks (Ismayilli). Analysis of earthquakes from Shamakhi-Ismayilli revealed residual Coulomb stresses caused by uneven energy release due to local obstacles at the collision front, increasing the risk of sequential events in populated areas. Deep foci (up to 45 km) reflect stress accumulation in lower layers consistent with plate collision models. This aligns with the general pattern in the Caucasus, where compressional stresses from the Arabian Plate induce earthquakes along fold and thrust belts [2].

Kura Depression (Central and Lower Kura, Samukh, Goychay). Seismicity is weak (13 events with ml ≥ 3, depths 2–30 km). Strike-slip mechanisms dominate, related to compression in sedimentary basins, activating Gandjachay, Khachinchay, and Alazan-Ayrichay faults. Extension moderates activity through creep. Moderate activity results from the balance between plate

compression and basin extension, causing moderate shaking at fault intersections; the risk increases with faster movements, affecting hydraulic structures.

Talysh Zone (Lankaran, including the Iranian border). High seismicity is observed, though lower than in 2024 (nine events with ml ≥ 3 at 11–19 km depth in the granite layer). Geodynamics is driven by strong compression from the Iranian plate (reverse-slip mechanisms, max velocities ~13–14 mm/year), enhancing deformation in mountainous areas and activating Talysh and Near-Talysh faults. SW Talysh exhibits extension, NE compression. High velocities are directly related to seismicity: compression from the near-perpendicular approach of the Iranian plate strengthens fault activity, generating earthquakes at 11–19 km depth. Historical data show this zone as an intense deformation area with frequent moderate shocks. The reduction compared to 2024 (ml 5.3) may indicate partial stress release, but ongoing high ratios maintain risk.

Lesser Caucasus (including Samukh and Kalbajar). Low seismicity is observed (3 events with ml ≥ 3, depths 11–14 km), primarily from horizontal strike-slip and moderate-velocity (~8 mm/year) mixed deformation. Geodynamics relate to lateral movements in the plate junction activating Arpa-Samur, Lachin-Bashlibel, and Gandjachay faults. Minimal activity reflects relatively stable tectonics compared to the Greater Caucasus, with strike-slip faults predominating due to regional compression.

Nakhchivan Autonomous Republic. Minimal seismicity (33 shocks with 0.5–2.5 ml, no significant events) reflects stable geodynamics (~8 mm/year), isolated zones, and infrequent weak surface mechanisms due to the lack of active faults and buffering by surrounding plates.

Conclusions

In 2025, Azerbaijan continued to experience deformation under NE-directed compression due to the collision of the Arabian and Eurasian plates and the active role of the Iranian block. Compared to 2024, horizontal velocities increased in almost all major geotectonic zones. Overall, seismicity reflects the dynamics of plate collisions: compression dominates in the Caspian Sea and southern regions (Talysh), strike-slip faults predominate in the Greater Caucasus, and extension is moderate in the Kura and Nakhchivan regions. Variations in geodynamic conditions arise from uneven stress accumulation along faults and energy release in brittle crustal layers. Moderate-magnitude earthquakes (ml 3–5) were observed in 2025, with no catastrophic events.

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CONSTRUCTION WORK AND ASSESSMENT OF SEISMIC HAZARD LEVEL IN LIBERATED TERRITORIES (ON THE EXAMPLE OF JABRAYIL AND AGHDAM REGIONS)

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Annotation

Following the end of the Second Karabakh War, the Azerbaijani government promptly initiated the restoration of essential infrastructure and main communication lines in the liberated territories. Large-scale and rapid reconstruction efforts are successfully ongoing.

It is essential to carry out localized engineering-seismogeological investigations in the designated areas, including the construction sites in Jabrayil and Aghdam districts, which have been selected as research zones.

The construction site planned in the Jabrayil district is located in the Mil plain, covering an area along the Araz River.

The geomorphological structure of the area and the modern structural-denudational relief are products of the Late New Caspian stage and are still in the process of formation. In the territory of the Mil plain, modern relief forms – such as depressions, river valleys, river terraces, structural and erosional steps – have formed under the general background of recent tectonic movements and as a result of intensive erosion-denudation processes.

In the studied area, the development of relief-forming processes depends on the hypsometric elevation, the lithological composition of the rocks, the amount of atmospheric precipitation, and other factors.

Considering the relevance of the study, the engineering seismo-geological conditions of the area were assessed based on the data from 200 geological exploration boreholes in Jabrayil and 180 in Aghdam, as well as the results of seismic exploration using the Refraction Seismic Method (RSM) and Multichannel Analysis of Surface Waves (MASW), based on the seismic properties of the soils, their classification was determined.

Keywords: engineering-geological conditions, geophysical investigation, geological exploration, soils, physical-mechanical properties.

İŞĞALDAN AZAD OLUNMUŞ ƏRAZİLƏRDƏ TİKİNTİ İŞLƏRİNİN APARILMASI SEYSMİK TƏHLÜKƏ SƏVİYYƏSİNİN QİYMƏTLƏNDİRİLMƏSİ (CƏBRAYIL VƏ AĞDAM RAYONLARI TİMSALINDA)

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Xülasə

2-ci Qarabağ müharibəsinin başa çatdığı ilk günlərdən dövlətimiz tərəfindən işğaldan azad olunmuş ərazilərdə əsas kommunikasiyaların bərpası və zəruri infrastrukturların yaradılması işlərinə başlanılmışdır. Həyata keçirilən irimiqyaslı və sürətli bərpa quruculuq işləri uğurla davam etdirilir.

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Qeyd olunmuş ərazilərdə, o cümlədən tədqiqat ərazisi kimi seçilmiş Cəbrayıl və Ağdam rayonlarında həyata keçirilən tikinti sahələrində lokal olaraq mühəndisi-seysmogeoloji tədqiqatların yerinə yetirilməsi vacibdir.

Cəbrayıl rayonunda layihələndirilən tikinti sahəsi Mil düzənliyində Araz çayı boyu ərazini əhatə edir. Mil düzənliyi Kür-Araz ovalığının tərkib hissəsidir. Düzənlik qərbdə Qarabağ dağ silsiləsi ilə sərhədlənir, şimal-qərbdə Qarabağ düzənliyinə qovuşur, Şirvan düzənliyindən Kür çayı ilə, Muğan düzənliyindən isə Araz çayı vasitəsilə ayrılır.

Ərazinin geomorfoloji quruluşu, müasir struktur-denudasyon relyefin son Yeni Xəzər mərtəbəsinin məhsuludur və hal-hazırda formalaşmaqda davam edir. Mil düzünün ərazisində müasir relyef formaları-çökəkliklər çay dərələri, çay terrasları, struktur və erozion pillələr yeni tektonuk hərəkətlərin ümumi fonunda, intensiv eroziya-denudasiya prosesləri nəticəsində formalaşmışlar.

Tədqiq olunan ərazidə relyef əmələ gətirici proseslərin inkişafı ərazinin hipsometrik yüksəkliyindən, süxurların litoloji tərkibindən, atmosfer çöküntülərinin miqdarından və s.asılıdır.

İşin aktuallığını nəzərə alaraq Cəbrayıl rayonu ərazisində qazılmış 200 ədəd, Ağdam rayonu ərazisində isə 180 ədəd geoloji-kəşfiyyat quyularının məlumatları, Sınan dalğalar üsulu (SDÜ) və Səth Dalğalarının Çoxkanallı Analizi üsulundan (MASW) istifadə edilməklə yerinə yetirilmiş seysmik kəşfiyyat işlərinin nəticələrinin analizi əsasında ərazinin mühəndisi seysmo-geoloji şəraiti öyrənilmiş, qruntların seysmik xüsusiyyətlərinə görə hansı sinifə aid olması müəyyənləşdirilmişdir.

Açar sözlər: mühəndis-geoloji şərait, geofiziki tədqiqat, geoloji kəşfiyyat, torpaqlar, fiziki-mexaniki xüsusiyyətlər

СТРОИТЕЛЬНЫЕ РАБОТЫ И ОЦЕНКА УРОВНЯ СЕЙСМИЧЕСКОЙ ОПАСНОСТИ НА ОСВОБОЖДЕННЫХ ТЕРРИТОРИЯХ (НА ПРИМЕРЕ ДЖАБРАИЛСКОГО И АГДАМСКОГО РАЙОНОВ)

Гаравалиев Э.С., Фаттахова Л.Т., Джалилова И.Н., Джамиева Р.Н.

Аннотация

С первых дней после завершения Второй Карабахской войны государством были начаты работы по восстановлению основных коммуникаций и созданию необходимой инфраструктуры на освобождённых от оккупации территориях. Масштабные и быстрые восстановительно-строительные работы продолжаются успешно.

На указанных территориях, в том числе на строительных участках в районах Джебраил и Агдам, выбранных в качестве объекта исследования, крайне важно проведение локальных инженерно-сейсмогеологических исследований.

Строительный участок, запроектированный в Джебраильском районе, охватывает территорию вдоль реки Араз на Милской равнине.

Геоморфологическое строение территории, современный структурно-денудационный рельеф являются результатом этапа Позднего Каспия и продолжают формироваться в настоящее время. На территории Милской равнины современные формы рельефа — впадины, русла рек, речные террасы, структурные и эрозионные ступени — сформировались на фоне новых тектонических движений в результате интенсивных эрозионно-денудационных процессов.

Развитие рельефообразующих процессов в исследуемой территории зависит от гипсометрической высоты местности, литологического состава пород, количества атмосферных осадков и других факторов.

С учётом актуальности проводимых работ были проанализированы данные 200 геологоразведочных скважин, пробуренных на территории Джебраильского района, и 180

скважин на территории Агдамского района. Также были использованы результаты сейсморазведки, выполненной с применением метода преломлённых волн (МПВ) и многоканального анализа поверхностных волн (МАПВ). На основе этих данных было изучено инженерно-сейсмогеологическое состояние территории и определено, к какому классу относятся грунты по их сейсмическим характеристикам.

Ключевые слова: инженерно-геологическое состояние, геофизические исследования, геологоразведка, грунты, физико-механические свойства.

Construction and installation work has begun in the territory of the Karabakh economic zone of the Republic of Azerbaijan. The study of seismic conditions in Karabakh before the occupation, the specification of the geological-tectonic structure, the resistance of state-important projects to ecological-seismic hazards, and the study of earthquakes occurring in the area were among the main scientific directions carried out by the Republican Seismic Survey Center (RSSC) of ANAS. Before the occupation, seismological stations operated in these areas, seismic activity maps were compiled, and changes in geophysical fields due to the influence of geodynamic stress were monitored. During the occupation, seismological stations located in the Jabrayil and Aghdam regions were destroyed by the Armenians, seismological and geophysical devices were looted, and seismic observations were not conducted in the area [6].

In the territory of our first research area, Jabrayil district, along with the Araz and Kura rivers, the Hakari River, the Ohchu River and other small rivers play a role in the formation of the relief in the area.

The ancient regional-scale deep fault zones existing in the area played a major role in the formation of the relief. Thus, the parent rock was broken and transported as a result of wind and precipitation.

Geotectonically, the Kura-Araz valley is a part of the depression, according to B.E.Khain, this Kura-Araz valley depression is considered a megasynclinorium with a complex structure that includes several structural units. The Mil plain is a component of the Kura-Araz intermontane megasynclinorium and, starting from the Meghri area, continues in the direction of the Araz River in the northeast direction and is bordered by the Lesser Caucasus frontal depression. This depression can be evaluated as a superimposition depression and, according to this feature, separates the southeastern part of the Lesser Caucasus tectonic zone from the Talysh fold zone.

The vast majority of the territory of Azerbaijan, as in previous years, is characterized by high seismic activity. Most of the earthquakes are associated with large deep faults that characterize structures of various tectonic regimes [7].

The geomorphological structure of the territory is a product of the latest New Caspian stage of the modern structural-denudation relief and is currently continuing to form. Modern relief forms in the territory of the Mil Plain - depressions, river valleys, river terraces, structural and erosion steps - were formed as a result of intensive erosion-denudation processes against the general background of new tectonic movements.

In the section from Horadiz settlement to Minjivan settlement, the Lesser Caucasus megaanticlinorium is subjected to burial in the Mil Plain area, and therefore the soils that form the Mil Plain differ from each other in composition. The tectonic structures subjected to burial in the Mil Plain are the Goycha-Karabakh and Somkhet-Aghdam anticlinoriums. In the Minjivan-Megri direction, the Zangezur anticlinorium passes from high mountains to medium mountains [5].

Depending on the composition of the rocks, their bedding conditions, and their location in the geosynclinal or platform area, rocks resist external and internal influences in different ways. Soft rocks are subject to disintegration more quickly.

Small faults and intensively fractured zones sharply reduce the resistance of rocks. Hard rocks, on the other hand, are subject to disintegration and fragmentation late, showing sharp resistance to external factors [11].

In the city of Jabrayil, it is planned to design 29 4-story and 4 5-story residential buildings for the construction of the "New Housing Complex". For this purpose, 200 geological exploration wells were drilled and the well data were analyzed by the RSSC (Figure 1, 2).

In the geological-lithological sections of the construction sites, gravel (crushed stone, clay interfill), clayey (containing gravel) soils of solid consistency are present, and their engineering-geological conditions are shown in the table (Table 1).

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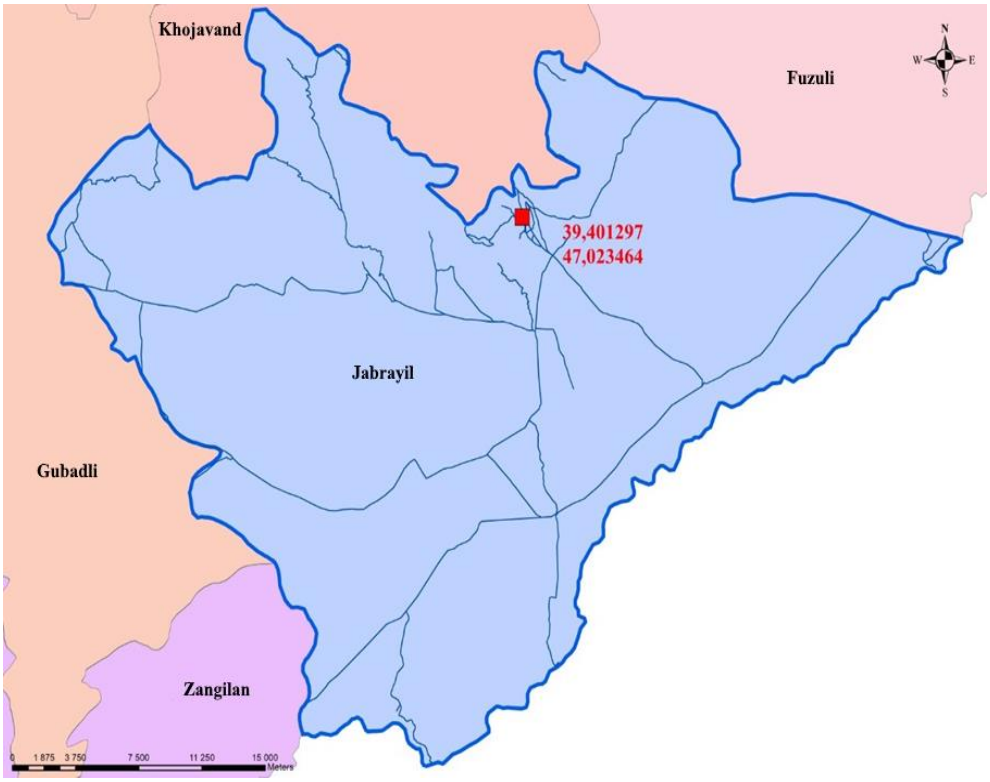


Figure 1. Research area being constructed in Jabrayil city

- research area

The main goal of the engineering-geological research conducted by the "Manzil" KM is to clarify the geological structure and hydrogeological conditions of the area, to determine the physical-mechanical properties of the soils underlying the subsoil, as well as their aggressive effect on the foundation, their resistance, and to investigate exogenous-geological processes.

The geological structure of the area includes alluvial-prolluvial (ap Q1) sediments of the Lower Quaternary Period, which are represented as clayey soils and gravelly soils. The geological-lithological section of these soils is shown (Fig. 2).

Table 1

Soils encountered in the project construction site in Jabrayil district

№	Soils	Well depth (m)	Number of wells (pieces)	Soil thickness (m)	Soil density ρ_d(q/sm^3)	Plasticity number I_p	Consistency I_L	Transverse wave speed V_i (m/s)	Groundwater level (m)
1.	Mountain gravel (crushed stone) of small size with clay interlayer	15,0	200	5,60-8,50	1,88	0,19	<0	700	No water detected
2.	Clay soil of a firm consistency with layers of mountain gravel and sand			0,50-9,20	1,46	0,11	<0	500	
3.	Clay soil, hard clay, with sand layers			1,0-4,0	1,44	0,12	0,32	470	

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vertical: 1:100

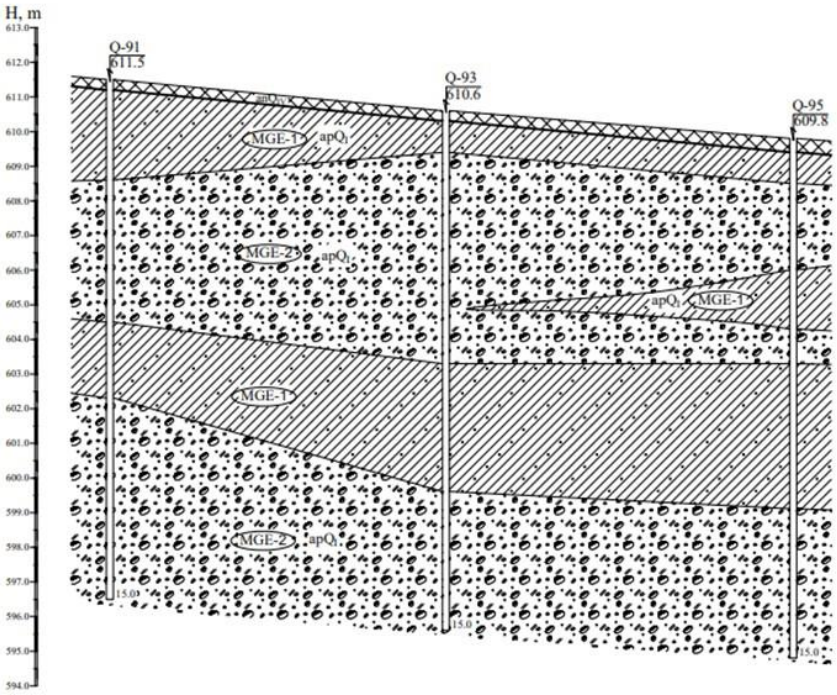


Figure 2. Geological-lithological cross-section of well sections in the construction area of the city of Jabrayil

- *loose sand*
- *clay*
- *mountain gravel*
- MGE - *Engineer-geological element*

Q – *well*

In the territory of Jabrayil city, using the PASI 16S24-U seismological apparatus, 1 (one) seismic profile line (profile length 48 m) consisting of 12 geophones with a distance of 4.0 m between them was conducted. To obtain data, 7 different points were used as energy sources along each profile, two of which were at the far edge points and the others were directly on the profile, using the hammer impact method.

In field conditions, the "Seismograph" seismological program was used, and the WINSISM program was used for processing and interpreting the received seismic data. [12,13].

The boundaries and thicknesses of the layers were determined using the Transient Wave Method (TWM) and Multichannel Analysis of Surface Waves (MASW). MASW also has the ability to identify the reflection of seismic waves typical of this area and other layers. This analysis was carried out to estimate the velocity of the incident wave using Poisson's ratio (Figure 3).

The purpose of the seismic exploration work was to determine the longitudinal Vp and transverse Vs waves in the rocks forming the section, to separate the layers into sections according to the differences in the propagation velocities of P and S waves in the profile, and to trace the section to depth in the field (Tables 2,3).

The gravelly soil forming the basis of the field section is more solid and stable as a foundation base.

Geophysical engineer – creates the opportunity to increase the accuracy of geological surveys and work in detail. Usually, the object of these studies are rocks characterized by their homogeneity, variable lithological composition, structure and physical properties. The effectiveness of these studies is achieved by obtaining the composition and structural characteristics of rock massifs in natural conditions of occurrence and the possibility of conducting numerous repeated observations without disturbing the geological environment [1,2]. This allows studying the intensity of geological processes occurring in the classification of natural and technical factors, and conducting geophysical regime observations. The complexity of geophysical methods and the method of observation are determined by the scale of the work and the nature of the problem being solved. When applying geophysical methods, it is possible not only to obtain information about the section, but also to increase the importance of hydrogeological surveys [8].

Table 2

Transverse wave propagation speed on profile1

Impact	S1, m/s	S2, m/s	S3, m/s	S4, m/s	S5, m/s	S6, m/s	S7, m/s	Average, m/s	Poisson's ratio, average	Yung modulus, GPa, average
V1	531	533	538	527	536	535	523	532	0.304	1.469
Depth 1	1.2	1.7	1.8	2.0	2.3	2.8	3.0	2.1		
V2	718	721	725	719	723	725	716	721	0.302	2.681
Depth 2	6.2	6.0	5.8	5.7	5.7	5.6	5.6	5.8		
V3	528	532	529	535	526	527	532	530	0.304	1.454
Depth 3	9.0	8.6	8.1	7.7	7.7	7.6	7.5	8.0		
V4	723	725	721	726	731	728	720	725	0.302	2.719
Depth 4	11.0	10.8	10.6	10.6	10.9	11.1	11.3	10.9		
V5	530	525	531	534	528	533	535	531	0.304	1.464
Depth 5	12.7	12.4	12.2	12.2	12.3	12.5	12.7	12.4		
V6	726	729	724	721	725	723	733	726	0.301	2.737

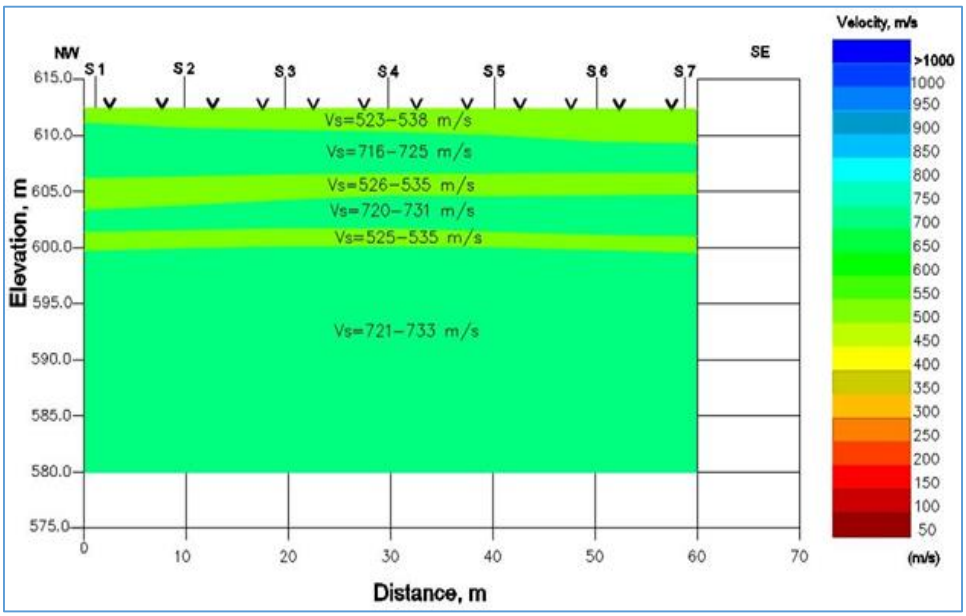


Figure 3. Cross-section of the research area along seismic profile 1

Table 3

Transverse wave propagation speed on profile 2

Impact	S1, m/s	S2, m/s	S3, m/s	S4, m/s	S5, m/s	S6, m/s	S7, m/s	Average, m/s	Poisson's ratio, average	Yung modulus, GPa, average
V1					529	533	535	532	0.304	1.458
Depth 1					1.0	1.3	1.5	1.3		
V2					720	725	724	723	0.302	2.696
Depth 2					1.9	2.1	2.5	2.2		
V3	533	537	535	529	528	534	532	533	0.304	1.480
Depth 3	2.7	2.9	3.0	3.0	3.2	3.2	3.3	3.0		
V4	728	725	731	736	723	721	729	728	0.301	2.753
Depth 4	6.0	5.8	5.7	5.5	5.9	6.2	6.6	6.0		
V5	534	539	525	533	538	523	528	531	0.303	1.486
Depth 5	11.2	11.0	10.9	10.9	10.7	10.6	10.4	10.8		
V6	732	729	731	727	722	728	734	729	0.301	2.788

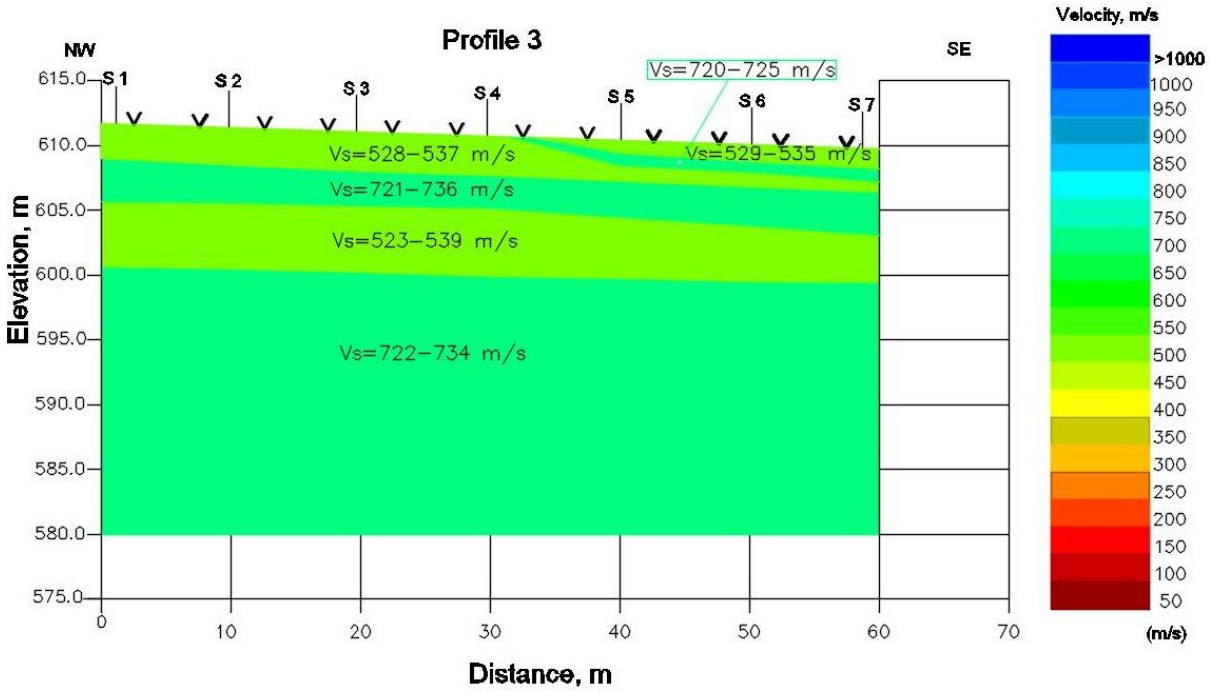


Figure 4. Seismic profile No. 2 cross-section of the study area

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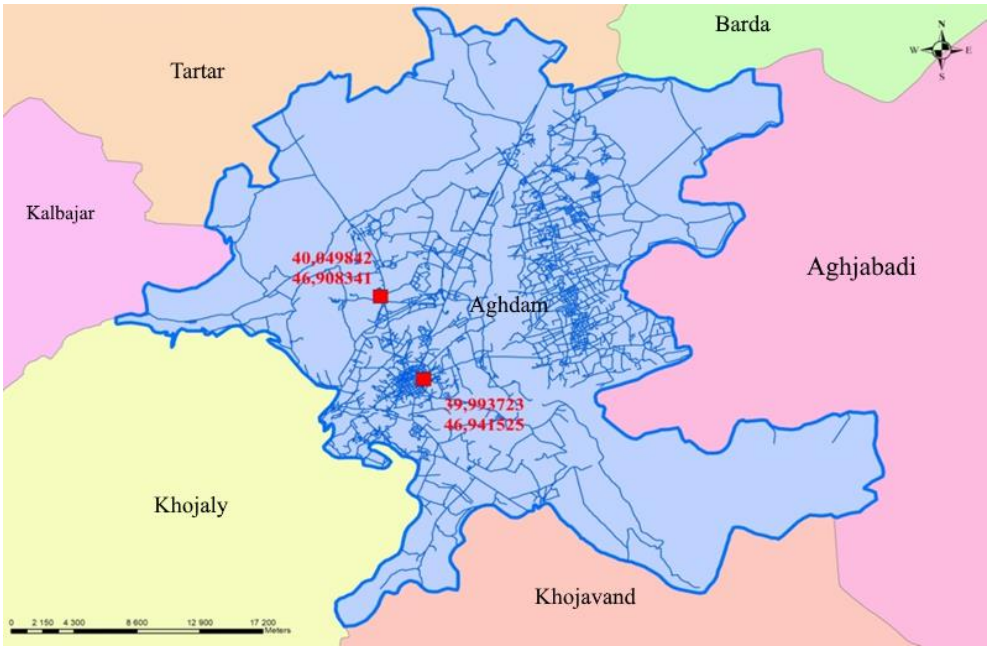


Figure 5. Research areas under construction in the territory of Agdam city.
-research areas

Thus, the soils participating in the geological-lithological cross-section in the Jabrayil region belong to class II according to their seismic properties [4].

Our second research area, Aghdam district, borders Aghjabadi, Tartar, Barda, Kalbajar, Askeran and Khojavend as well as Fuzuli districts. The city of Aghdam, the center of the district, is located 362 km from Baku, 3 km from the bank of the Gargar River, in the southwest of the Garadagh plain.

Our other research area is the complexes in the “Yeni Yashayish Quarter” and “Chullu” village in Aghdam city (Figure 5).

Table 4

Soils encountered in construction sites designed in the Aghdam region.

№	Soils	Well depth (m)	Number of wells (pieces)	Soil thickness (m)	Soil density ρ_d(q/sm^3)	Plasticity number I_p	Consistency I_L	Transverse wave speed V_i (m/s)	Groundwater level (m)
1.	Mountain gravel (crushed stone) of small size with clay interlayer	12, 15	180	1,50-6,40	1,59	0,24	0,03	330	No water detected
2.	Clay soil of a firm consistency with layers of mountain gravel and sand			2,50-10,0	1,60	0,13	-0,53	350	
3.	Clay soil, hard clay, with sand layers			0,50-4,0	2,15	0,18	0,23	700	

Visual inspection of the geological and engineering-geological conditions of the construction sites in the research areas, drilling of engineering-geological wells, taking rock samples, conducting standard penetration tests (SPT), geological-lithological data of the results of field research were compiled in engineering-geological reports and a total of 180 well data were analyzed [3] and the physical-mechanical properties of the wells involved in the well sections are shown in Table 4.

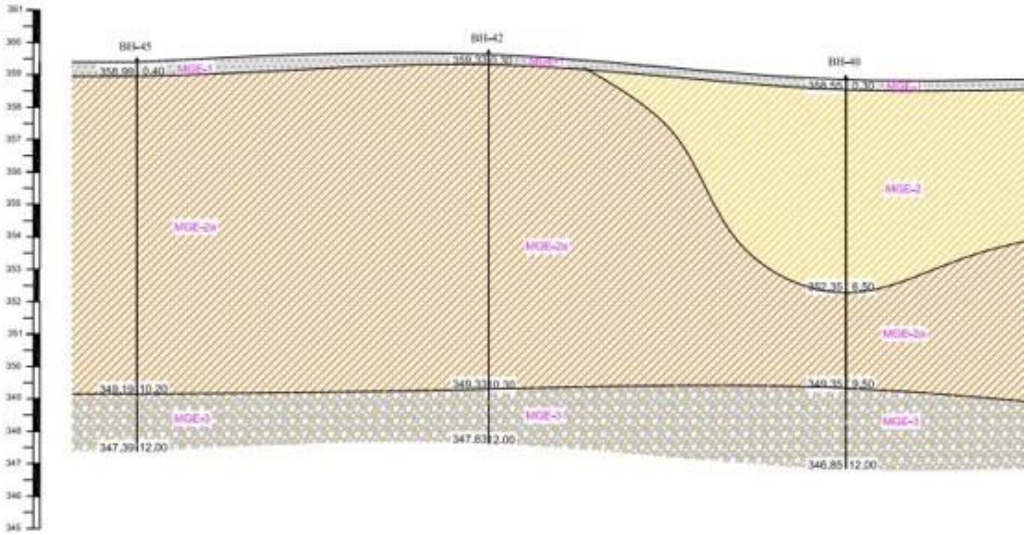


Figure 6. Geological-lithological cross-section of the construction site in the Chullu village of Aghdam region

- cast soil
- semi-solid clay containing clay particles and fragments
- solid clay containing clay particles and fragments
- gravel with a filler consisting of plastic sands

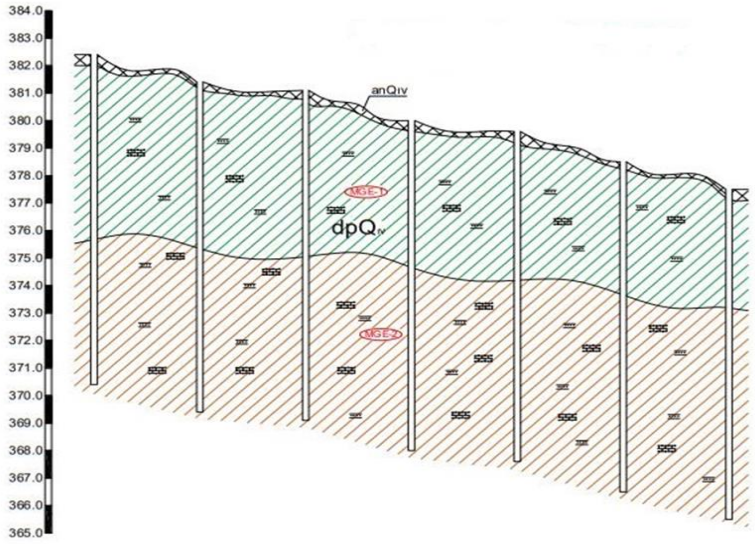


Figure 7. Well intersections in the "New Residential Quarter" in Aghdam city

- poured soil

- clay (semi-solid and solid)

The study areas in the territory of Aghdam city are represented by hard and semi-hard clay, gravel-gravel soils (Figure 6,7).

In accordance with the nature of the main issues that need to be solved during the implementation of various engineering activities in the geological environment, rock properties are used. These include density, porosity, moisture, plasticity, etc. of rocks. In engineering geology, it is necessary to study their physical and mechanical properties in order to classify rocks for various purposes or to evaluate rocks that form building materials and foundations [10].

Thus, in the geological-lithological sections of the designed construction sites in the Aghdam region, the soils are semi-solid and hard clays (porosity coefficient e>0.90) belonging to class III according to their seismic properties. The hard clays distributed in the study area have a weak swelling ability. In the lower layer, there are alluvial-prolluvial gravel-gravel soils belonging to class II according to their seismic properties. Groundwater was not found in the study areas.

When constructing buildings and structures, engineering survey works are carried out with the aim of increasing the durability, reliability and operability of buildings and structures, protecting people's health, obtaining (collecting) materials and information that provide an assessment of the condition of the foundations of buildings and structures, deformations and subsidences occurring in the constructed, reconstructed, repaired buildings and structures, as well as in buildings and structures in adjacent territories. Based on the results of engineering survey works, measures related to constant monitoring of the technical condition of adjacent and neighboring objects during construction should be provided for in the construction project [9].

The conduct of engineering and survey works carried out to obtain the necessary initial data for studying geological conditions and technogenic impacts for the efficient and safe use of land plots determines the requirements for the performance of such works, the mechanism for implementing state control over construction and urban planning activities during the execution of works, as well as engineering and survey works.

When assessing the seismic hazard in each construction site, it is of great importance to study the physical and mechanical properties of soils and indicators of other engineering and geophysical

factors. The prepared geological materials will play an important role in the correct direction of exploration work in the future and the correct selection of technological schemes.

Since Azerbaijan is located in a seismically active zone, it is imperative to take into account seismic hazard when carrying out urban planning, land use, emergency situations, insurance of people's lives and property, and especially when designing buildings under construction.

Correct assessment of engineering-geological conditions together with seismic hazard is always relevant and can allow for the identification of probable earthquakes to the greatest extent possible.

Results

1. Based on engineering-geological and geophysical data, it was determined that the clay and gravel soils involved in the construction site in the territory of Jabrayil city belong to class II in terms of seismic properties.
2. In the geological-lithological sections of the designed construction sites in the territory of Aghdam city, it was determined that the solid and semi-solid clay soils belong to class III in terms of seismic properties, and the gravel soils belong to class II.

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GRAVIMETRIC MAPPING AND ITS DECISIVE ROLE FOR ACHIEVEMENT OF CERTAIN GOALS

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Abstract

Analysis of gravity field changes during mapping, studying anomalous zones, gradient zones of stress changes, as well as the possible presence of individual fault sections that could be associated with the profiles of the projected area. Drawing up an isoanomal map and a map of vectors reflecting the deep dynamics and strength of the gravitational field of the area by gravimetric reconnaissance, characterizing the change in this geodynamic stress.

Key words: Gravity field, gradient zones, isolines, tectonic faults, anomalous areas.

QRAVİMETRİK XƏRİTƏALMA VƏ MÜƏYYƏN MƏQSƏDLƏRƏ ÇATMAQ ÜÇÜN ONUN HƏLLEDİCİ ROLU

E.M.Bağırov, A.T.İsmayılova

Annotasiya

Xəritədə ağırlıq sahələrinin dəyişməsinin təhlili, anomalıyaların, qradiyent zonalarının, həmçinin layihələndirilən sahənin profillərində əlaqələndirilə bilən ayrı-ayrı qırılma sahələrinin mümkün mövcudluğunun öyrənilməsi. Qravimetrik kəşfiyyat üsulu ilə ərazinin qravitasiya sahəsinin gərginliyini və dərinlik dinamikasını əks etdirən, bu geodinamik gərginliyin dəyişməsini səciyələndirən izoanomal xəritə və vektorlar xəritəsinin tərtib edilməsi.

Açar sözlər: Qravitasiya sahəsi, qradiyent zonaları, izoliniyalar, tektonik pozğunluqlar, anomal ərazilər.

ГРАВИМЕТРИЧЕСКОЕ КАРТИРОВАНИЕ И ЕГО РЕШАЮЩАЯ РОЛЬ ДЛЯ ДОСТИЖЕНИЯ ОПРЕДЕЛЕННЫХ ЦЕЛЕЙ

Э.М.Багиров, А.Т.Исмаилова

Аннотация

Анализ изменений поля силы тяжести при картировании, изучения аномальных зон, зон градиентов изменения напряженности, а также возможного наличия отдельных участков разломов, с которыми могли быть связанны на профилях расположенных проектируемой площади. Составление изоаномальной карты и карты векторов, отражающих глубинную динамику и напряженность гравитационного поля местности методом гравиметрической разведки, характеризующих изменение этого геодинамического напряжения.

Ключевые слова: Гравитационное поле, зоны градиентов, изолинии, тектонические нарушения, аномальные области.

Mapping is a tool for visualizing and analyzing material and information flows in the process of creating the value of the obtained data. Gravity maps are an extension of the field of geodynamics with a geographic or topographic basis on which the results of calculating gravity anomalies are displayed. At the points where gravity measurements were taken, the calculated values of the gravity

[1] Republican Seismic Survey Center of Azerbaijan National Academy of Sciences

anomaly based on the measurement results are plotted. Gravity anomaly maps show how much the actual gravitational field of the earth differs from the gravitational field of a homogeneous, featureless surface of the earth.

There are many ways of cartographic representation. In this article we will consider two methods of cartography, conducted research:

- Method of isolines and pseudo-isolines
- Method of signs of movement

The method of isolines and pseudo-isolines is intended to show continuous and gradually changing phenomena in space. The main tool is isolines and pseudo-isolines. More important are not individual isolines, but their pattern (height, depth, gradient zones, anomalous zones, etc.).

The method of movement signs is used to show spatial movements. With the help of movement signs, it is possible to show the path, the method, direction and speed of movement, the quality, power and structure of flows. The main graphic tools are vectors and tapes (the direction of gradient zones, the allocation of gravity, etc.).



Figure 1. CG-5 AutoGrav Gravimeter

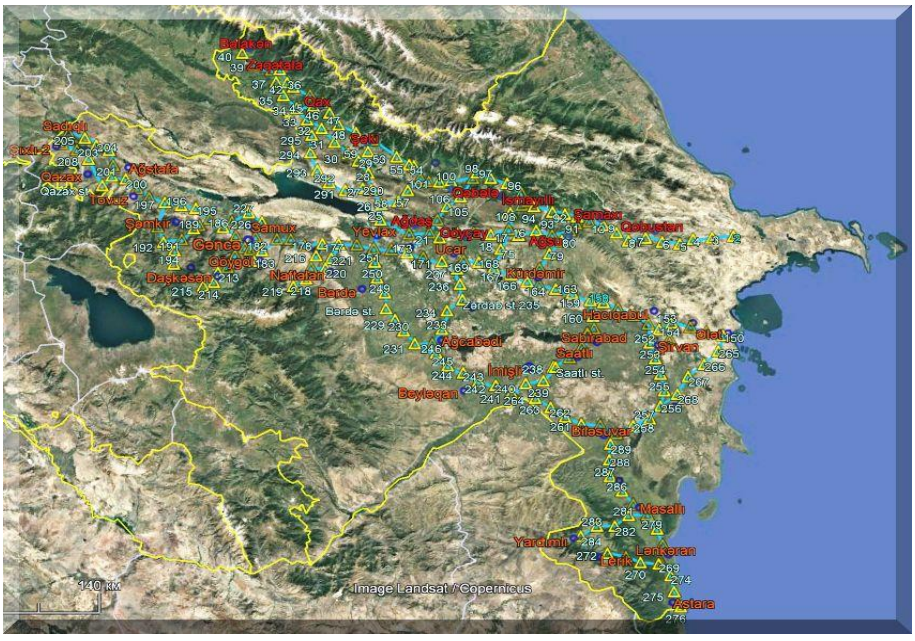


Figure 2. Layout of observation and support points of 4 existing geodynamic polygons

Processes occurring in the internal structure of the Earth and periodically repeating themselves create various deformations in the upper layers of the earth's crust, data on which are regularly processed and used in various research works.

Existing on four geodynamic polygons and in the territories included in the research area, it is necessary to study non-tidal variations both from the point of view of their solution and from the point of view of their optimal geographical conditions in the specified regions. The main goal is to study the structure of the concentrated crust due to non-tidal variations of the gravitational field in seismically active zones of these regions and, on this basis, to restore geodynamic conditions during the formation of structures using a complex of geophysical data in this area. Gravity is considered one of the leading methods for detecting deformations, shifts, gradient zones, and deep faults occurring in the internal structure of the earth. This allows us to evaluate geological processes occurring in deeper layers of the earth's crust and comprehensively analyze their direct connection with seismic activity. This is what gravity maps are for.

Canadian-made CG-5 AutoGrav gravimeters were used to study the effect of gravity on the earth's crust in existing geodynamic testing sites (Fig. 1). These devices allow us to identify the nature of changes in gravity in research areas intended to determine time measurements. The work carried out in 2024 fully covers measurements using high-precision gravimeters at long-term observation points at research sites (Fig. 2).

In order to create a single gravimetric map of the republic's territory (according to the Bouguer anomalies), a new Shirvan-Kazakh geodynamic polygon was created in accordance with the project, where research work was also completed. Thus, during its existence, work was completed on the remaining three polygons and a map of anomalies (Fig. 3.) and a vector map (Fig. 4.) were compiled depending on the Bouguer anomaly of the gravitational field.

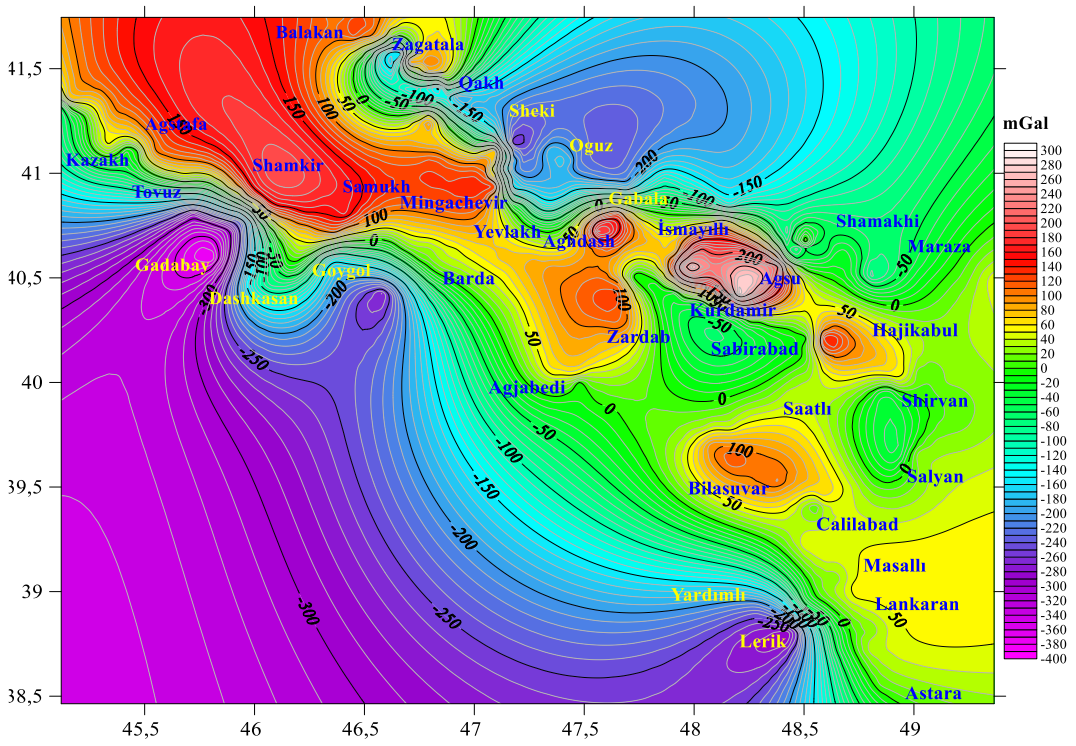


Figure 3. Map of gravity and anomalies along the Bouguer anomaly (2024)

The map of gravity and anomalies (Fig. 3) clearly shows the implementation of the first mapping method. Gradient zones, intense anomalous zones, minimum and maximum values of gravity, etc. are highlighted.

The map of vectorial movement signs (Fig. 4) shows the second mapping method. As shown, the direction of gravity movement and gradient zones.

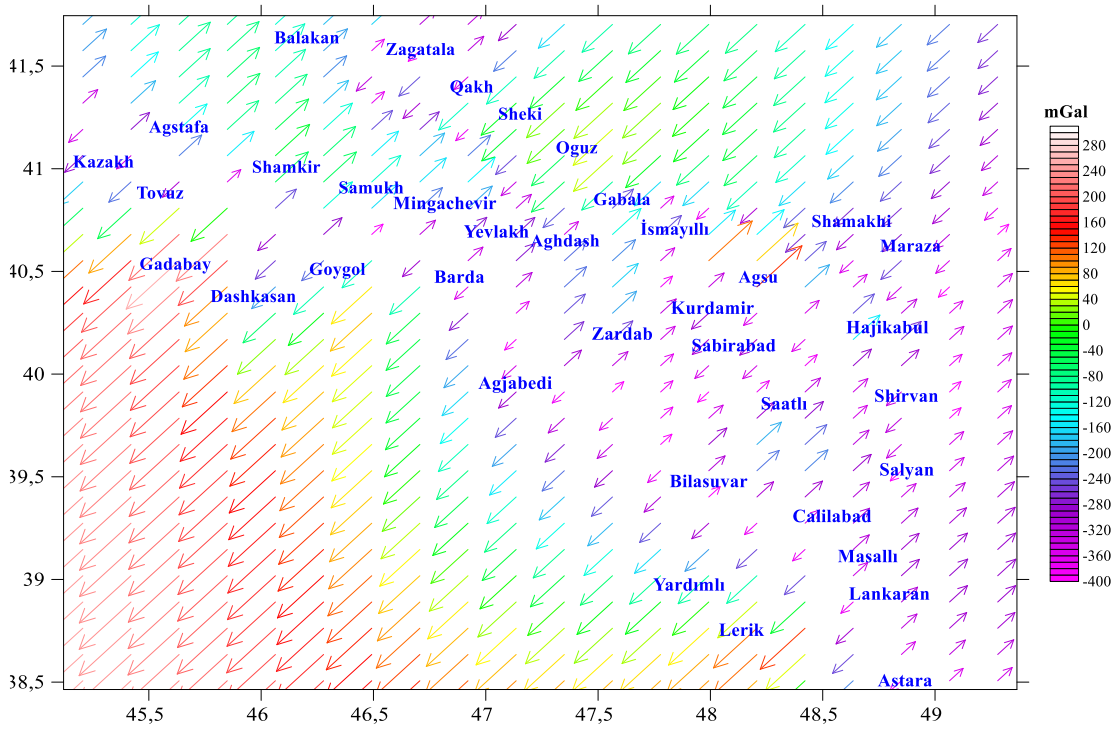


Figure 4. Map of spatial displacement signs

Conclusion

From the conducted studies, it can be concluded that with the help of these mapping methods, it is possible to clearly, accurately and visually demonstrate all the necessary studied gravity data.

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